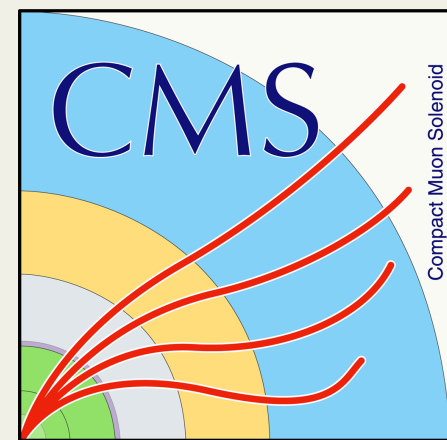


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# Search for New Physics with CMS in Events with Opposite-Sign Dileptons, Jets, and Missing Transverse Energy

Derek Barge

December 1, 2015



# Outline

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## 1. The Standard Model & Supersymmetry

## 2. The CMS Detector

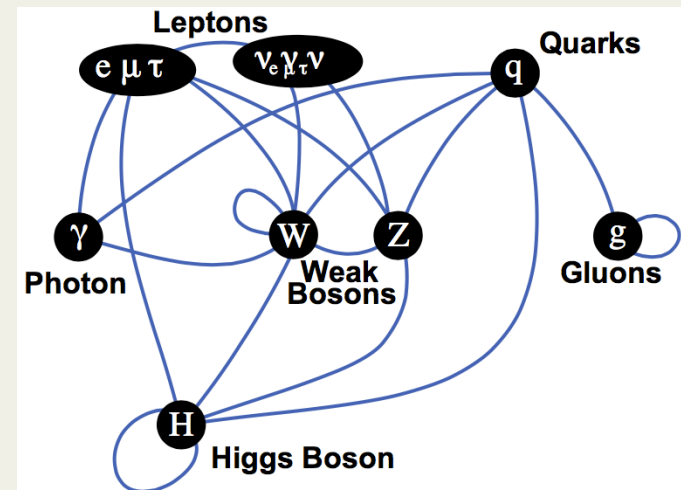
## 3. Analysis

# The Standard Model (SM)

- **Electroweak Model**
  - $SU(2) \times U(1)$  gauge theory
  - Unifies EM & weak forces
  - Symmetry spontaneously broken via the Higgs mechanism, giving the  $\gamma$ , massive  $W^\pm$ ,  $Z^0$  bosons
- **Quantum Chromodynamics**
  - $SU(3)$  gauge theory
  - Gluons bind quarks in colorless bound states of baryons, mesons
  - Asymptotic freedom

mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	2/3	2/3	2/3	0	0
spin →	1/2	1/2	1/2	1	0
	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> Higgs boson
<b>QUARKS</b>	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon	
	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	1/2	1/2	1/2	1	
	<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	<b>Z</b> Z boson	
<b>LEPTONS</b>	<b><math>\nu_e</math></b> electron neutrino	<b><math>\nu_\mu</math></b> muon neutrino	<b><math>\nu_\tau</math></b> tau neutrino	<b>W</b> W boson	<b>GAUGE BOSONS</b>
	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	$\pm 1$	
	1/2	1/2	1/2	1	
	<b><math>\nu_e</math></b> electron neutrino	<b><math>\nu_\mu</math></b> muon neutrino	<b><math>\nu_\tau</math></b> tau neutrino	<b>W</b> W boson	

Particles



Couplings

# Failures of the Standard Model

- Hierarchy Problem

- 1-loop Higgs mass correction is quadratically divergent:
- Unnatural fine tuning

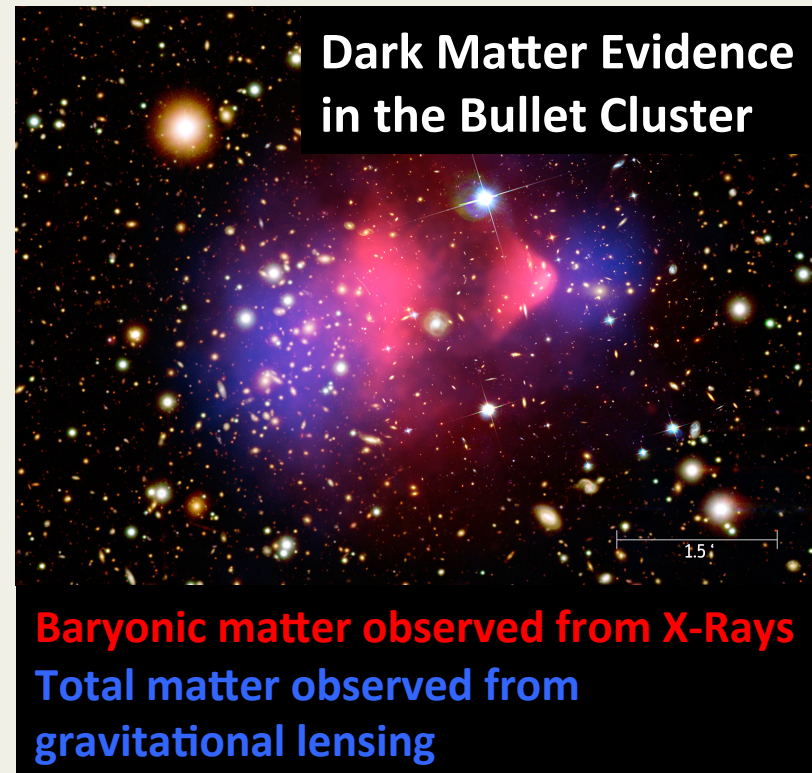
$$m_H^2 = m_{H_0}^2 - \frac{1}{8\pi^2} \lambda_f^2 \Lambda^2, \quad \Lambda \sim 10^{19} \text{ GeV}$$

- Astrophysical composition

- **Baryon asymmetry**
  - Matter, antimatter nearly equal in SM
    - CP violation is rare
  - Observe far more matter than antimatter
- **Dark Matter ~ 22% of total matter**
  - Strong Astrophysical evidence

- Neutrino Masses

- SM neutrino is **massless**
- Experiment:  $0 < m_\nu < 2 \text{ eV}$



# Supersymmetry (SUSY)

- Postulates a “Superpartner” for each SM particle
  - Spin quantum numbers differ by  $\frac{1}{2}$

Standard Model

Superpartner

Lepton ( $S=\frac{1}{2}$ )



Slepton ( $S=0$ )

Quark ( $S=\frac{1}{2}$ )



Squark ( $S=0$ )

Gauge Boson ( $S=1$ )



Gaugino ( $S=\frac{1}{2}$ )

Field Content of the MSSM					
Super-Multiplets	Boson Fields	Fermionic Partners	SU(3)	SU(2)	U(1)
gluon/gluino	$g$	$\tilde{g}$	8	1	0
gauge/	$W^\pm, W^0$	$\tilde{W}^\pm, \tilde{W}^0$	1	3	0
gaugino	$B$	$\tilde{B}$	1	1	0
slepton/	$(\tilde{\nu}, \tilde{e}^-)_L$	$(\nu, e^-)_L$	1	2	-1
lepton	$\tilde{e}^-_R$	$e^-_R$	1	1	-2
squark/	$(\tilde{u}_L, \tilde{d}_L)$	$(u, d)_L$	3	2	1/3
quark	$\tilde{u}_R$	$u_R$	3	1	4/3
	$\tilde{d}_R$	$d_R$	3	1	-2/3
Higgs/	$(H_d^0, H_d^-)$	$(\tilde{H}_d^0, \tilde{H}_d^-)$	1	2	-1
higgsino	$(H_u^+, H_u^0)$	$(\tilde{H}_u^+, \tilde{H}_u^0)$	1	2	1

- Dark Matter Candidate

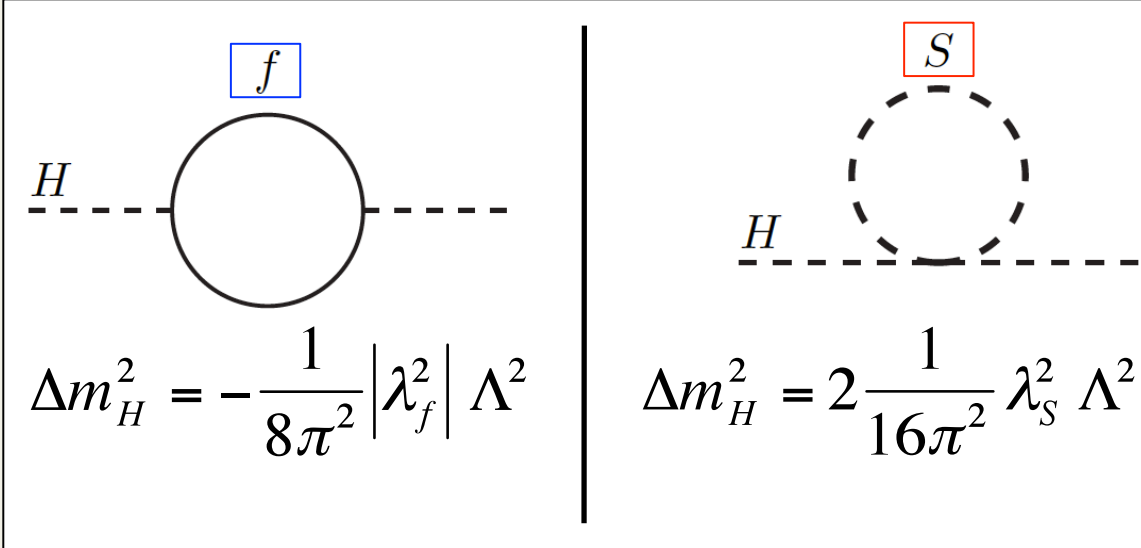
- Lightest SUSY Particle (LSP)
- Example: Neutralino
  - Mixture of Bino, Wino, Higgsino

- New **R-Parity** quantum number

- $(-1)^{3(B-L) + 2S}$ 
  - (Baryon, Lepton, Spin)
- Results in SUSY pair production
- Stable LSP could be dark matter

# Hierarchy Problem

- **SUSY naturally solves the Hierarchy Problem**
  - SM **fermions** have complimentary **sfermion** partners (bosons)



The diagram shows two Feynman diagrams side-by-side, separated by a vertical line. The left diagram shows a Higgs boson (dashed line labeled 'H') entering a fermion loop (solid circle labeled 'f' in a blue box) and exiting as a Higgs boson. Below it is the equation: 
$$\Delta m_H^2 = -\frac{1}{8\pi^2} |\lambda_f^2| \Lambda^2$$
. The right diagram shows a Higgs boson (dashed line labeled 'H') entering a sfermion loop (dashed circle labeled 'S' in a red box) and exiting as a Higgs boson. Below it is the equation: 
$$\Delta m_H^2 = 2\frac{1}{16\pi^2} \lambda_s^2 \Lambda^2$$

- **The divergent SM fermion loop correction to the Higgs mass is exactly cancelled by the sfermion correction in SUSY**
  - Couplings cancel exactly:  $\lambda_s = |\lambda_f^2|$  , also works at higher orders

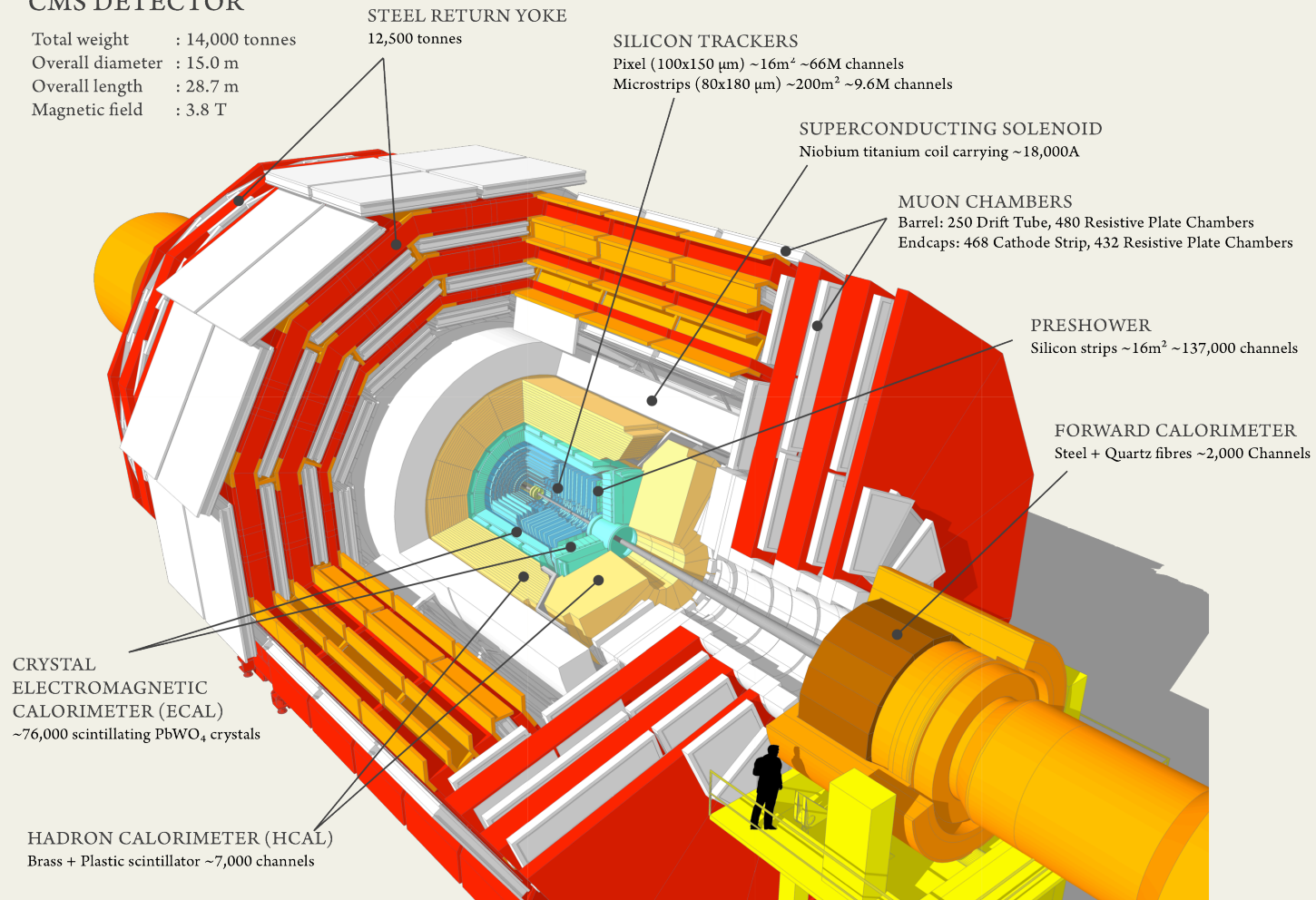
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# **The Detector**

# The Compact Muon Solenoid (CMS)

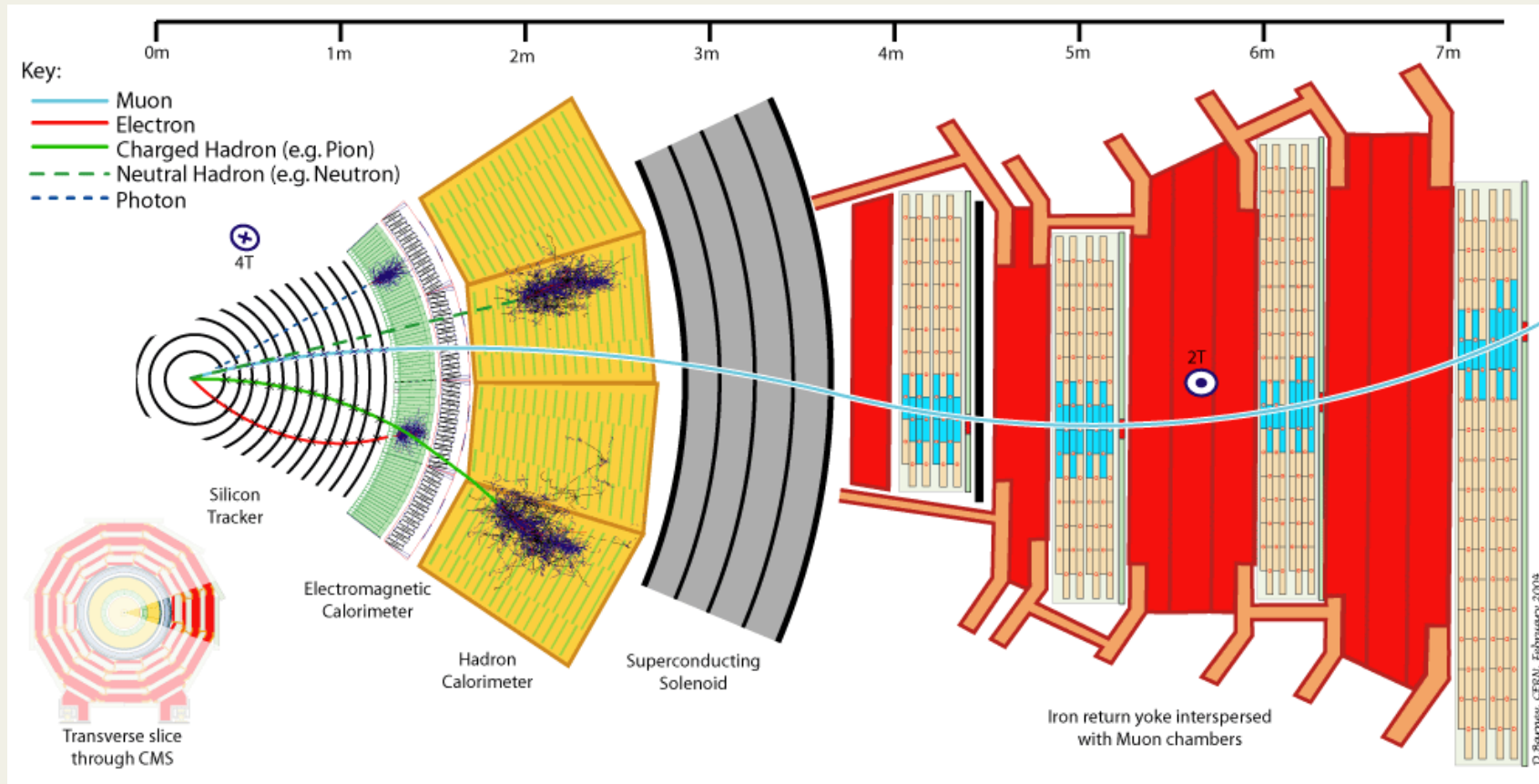
## CMS DETECTOR

Total weight : 14,000 tonnes  
Overall diameter : 15.0 m  
Overall length : 28.7 m  
Magnetic field : 3.8 T



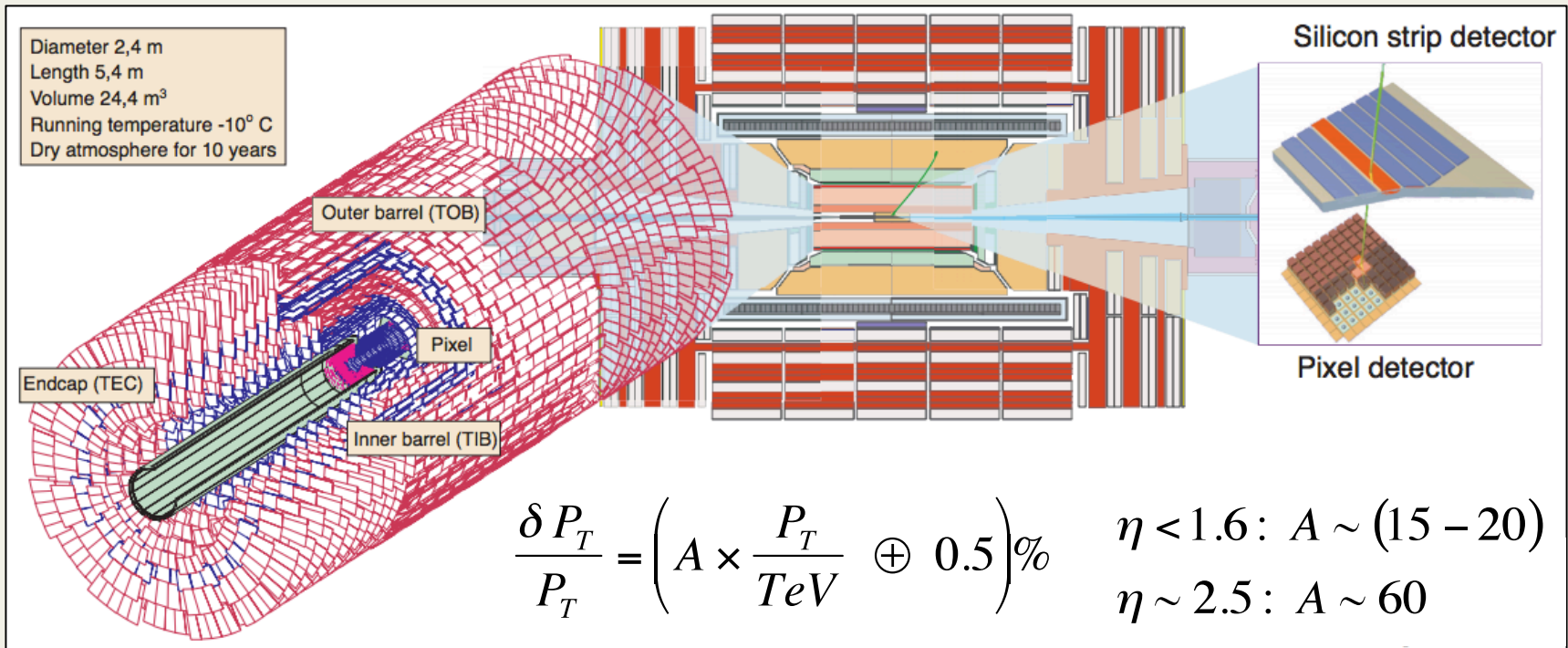
**CMS is a tool used to observe pp collision products**

# Detecting Particles

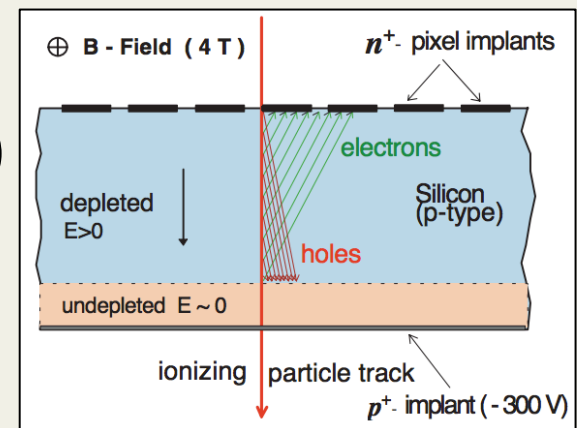


Muon Electron Charged & Neutral Hadrons Photon

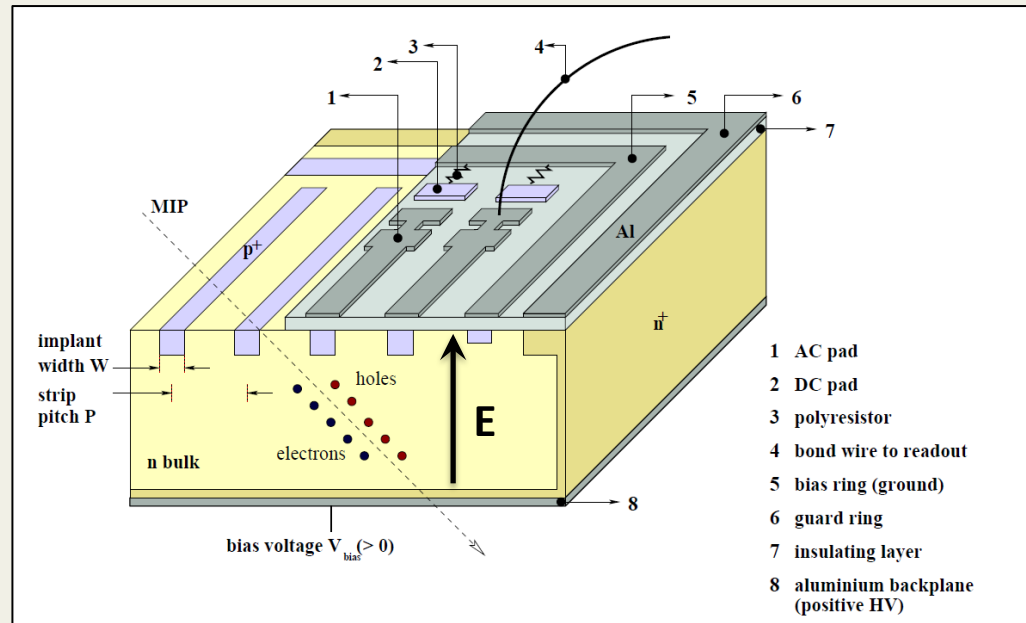
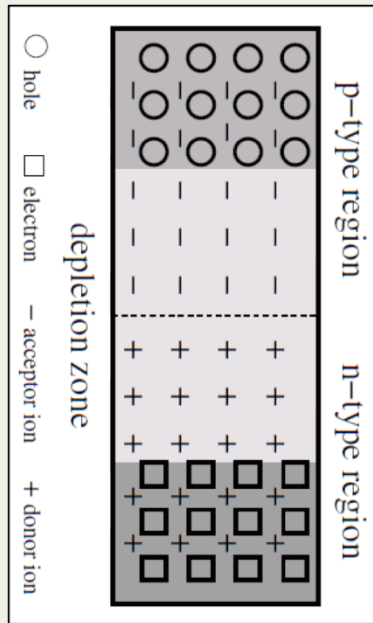
# Tracker



- **Measures charged particle:**
  - Momentum ( $\delta P_T/P_T \sim 1.5\% @ 100 \text{ GeV}$ )
  - Impact parameters
    - $d_0$  resolution  $< 35 \mu\text{m}$  above 10 GeV (pixels)



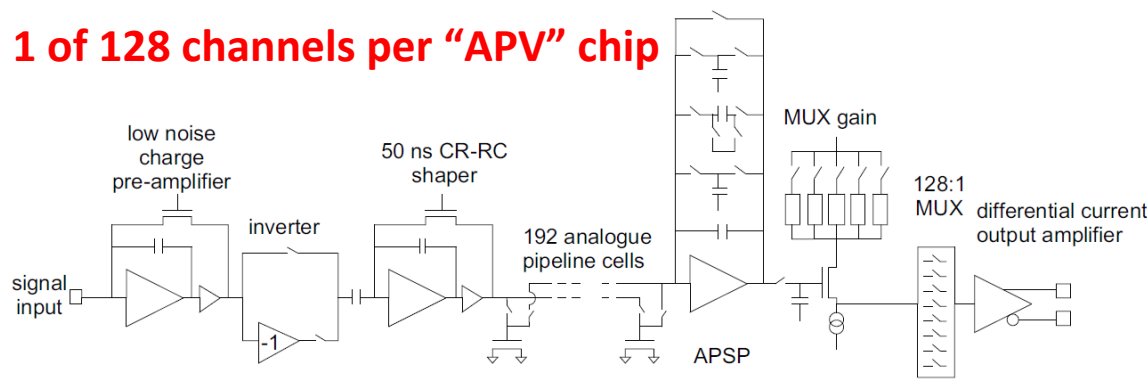
# CMS Tracker: Silicon Strip Detectors



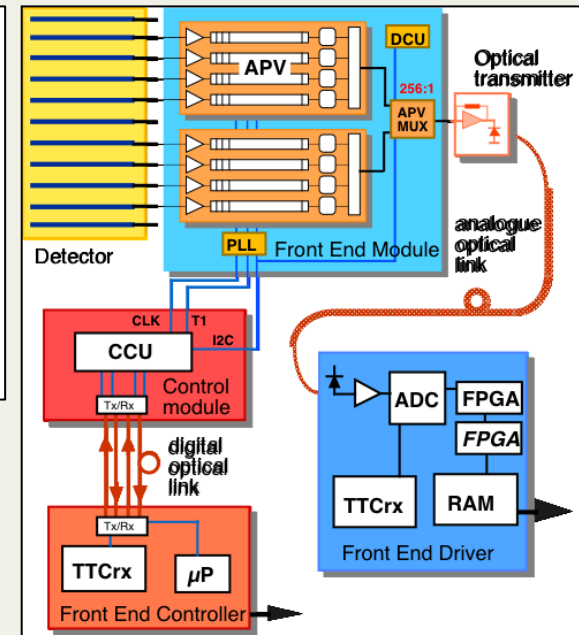
- Silicon doped with **P** (acceptor) & **N** (donor) atoms develops potential gradient. Electrons move to **P** side, holes move to **N** side until equilibrium is reached.
- Depletion zone has no free charge carriers once equilibrium is reached.
  - **Charged particles traversing depletion zone ionize electron-hole pairs that can be measured.**
  - External electric field widens depletion zone, moves holes to p+ side. Small “leakage current” flows.
  - CMS silicon strip detectors read out holes on p strips.
  - Fast response (~10 ns), good signal (1 MIP loses 260 eV /  $\mu\text{m}$ , takes ~ 3.6 eV to free e-h pair).

# CMS Tracker Modules: Readout

## 1 of 128 channels per "APV" chip



- Preamplifier
  - Charge sensitive, few ns rise time,  $\mu$ s width
- Inverter
  - Increases dynamic range
- Shaper
  - Designed to maximize S/N and sample at up to the peak LHC rate of 25 ns
- Analog Pipeline
  - 192 cells store charge measurement for up to 4  $\mu$ s awaiting trigger
- Designed for less than 3,000 electron noise equivalent (1 MIP signal is > 20,000 electrons)

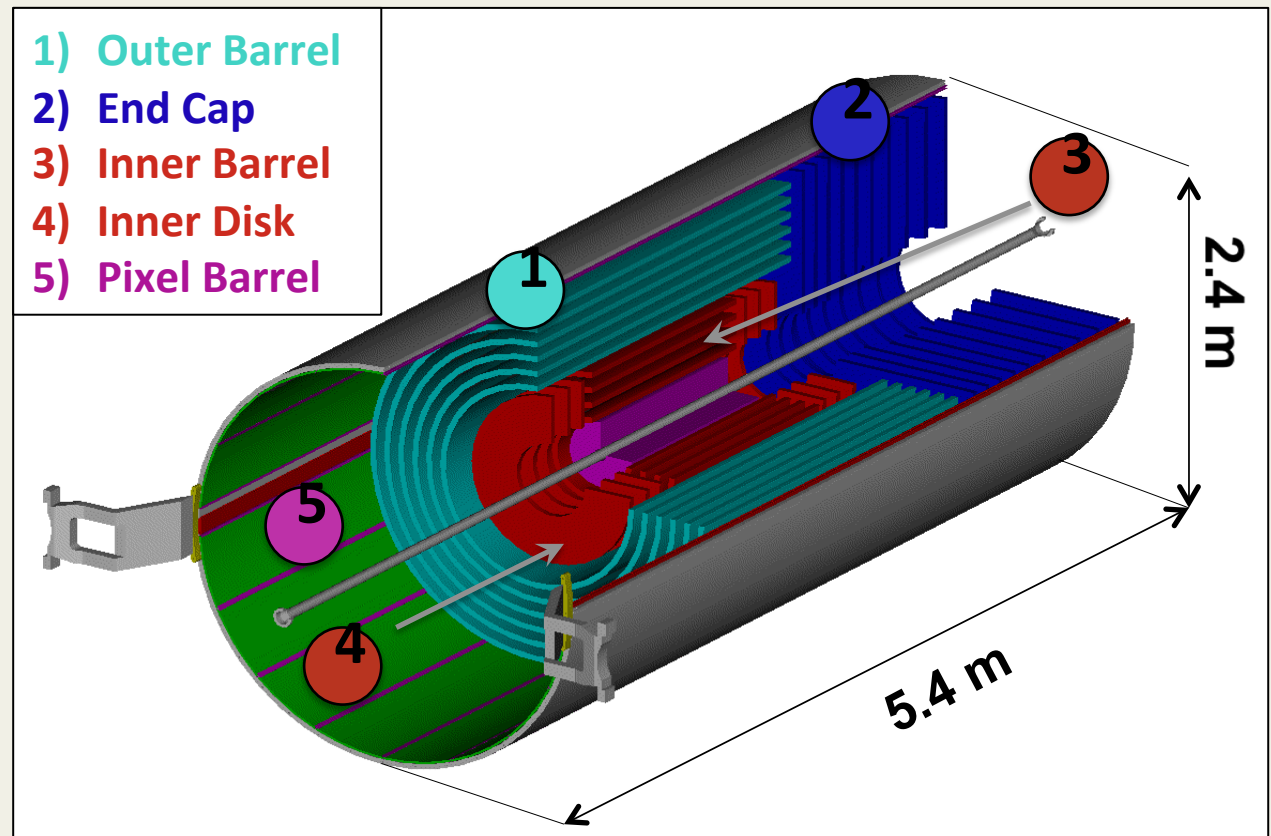


# Tracker

- **Strip Tracker**

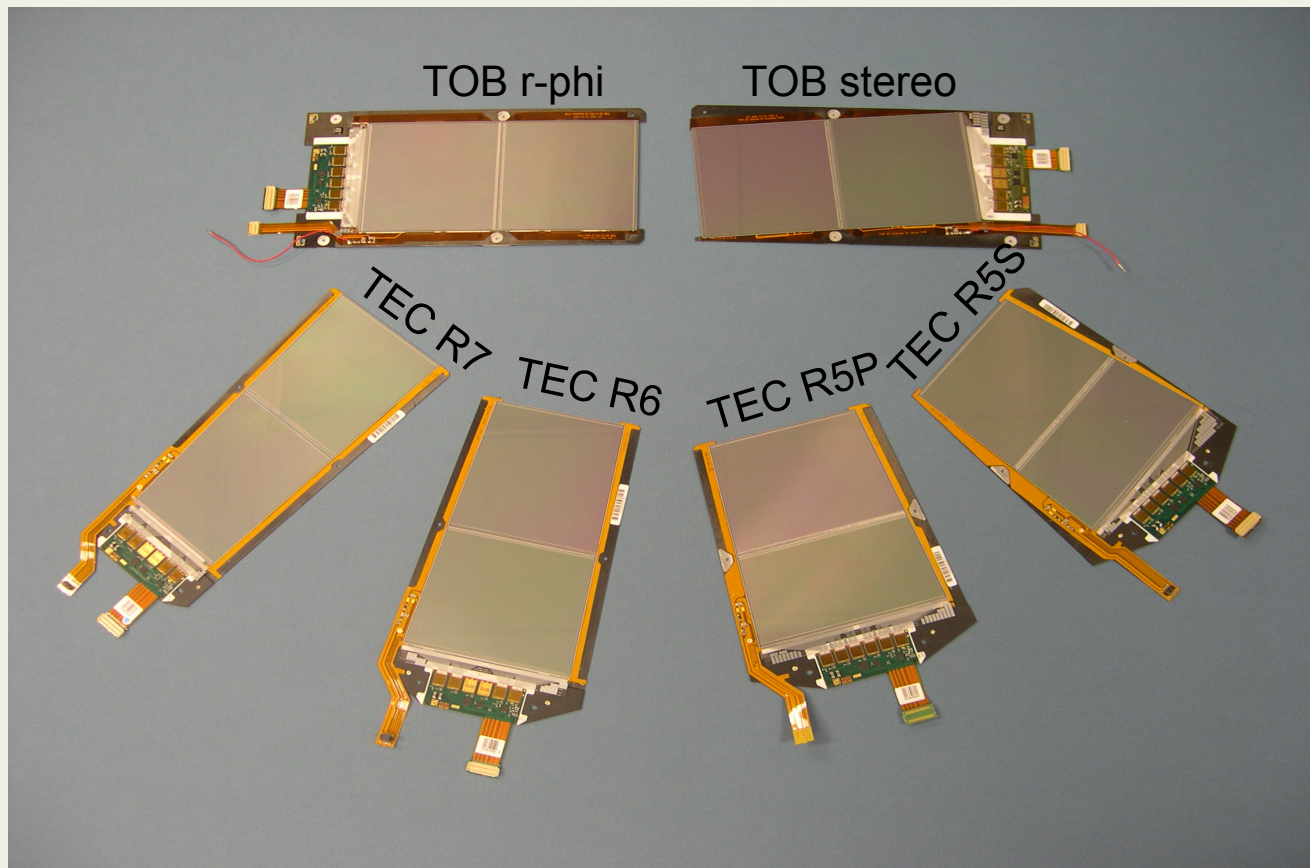
- 10 M strips
- 26 M wires
- 78 k chips
- All Silicon
  - 207 m<sup>2</sup>
  - 100 kg

The Outer Barrel and half of the outer 3 of the 7 End Cap rings were built in the U.S. (at UC Santa Barbara & Fermilab)

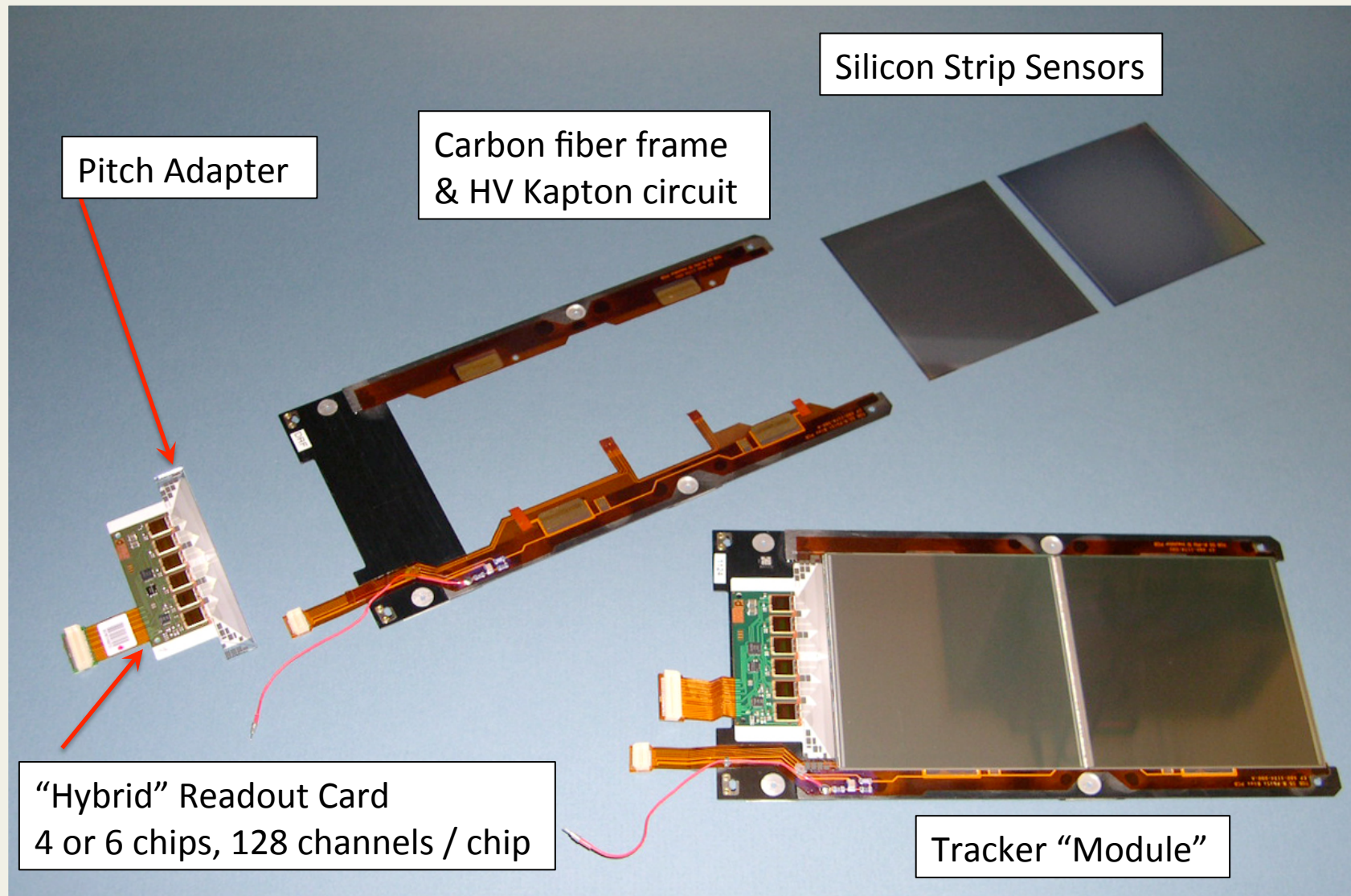


# CMS Tracker Modules

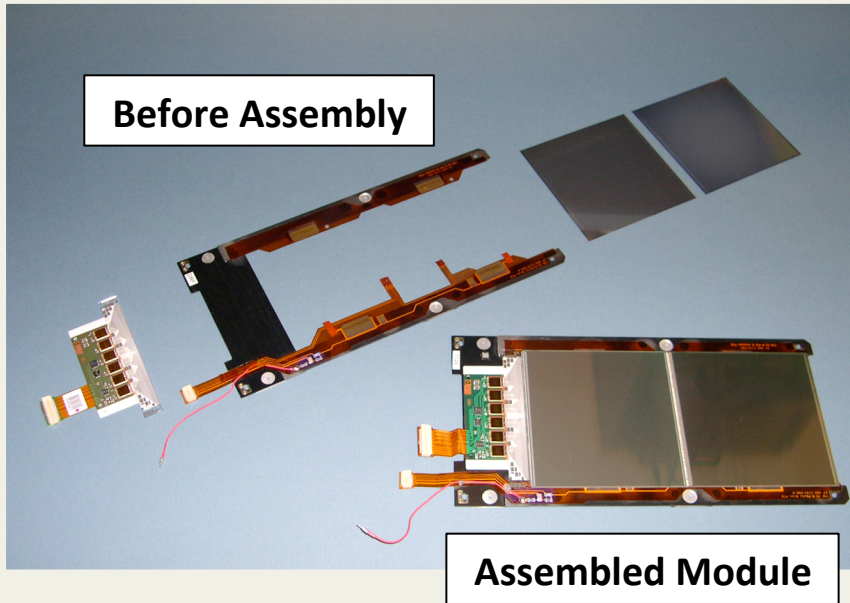
- US (UCSB/FNAL) responsible for the Tracker “Outer Barrel” & part of the “End Cap”. Assembly, wire-bonding, electrical testing, and integration of ~ **7,200** modules, **135 m<sup>2</sup>** of Si.



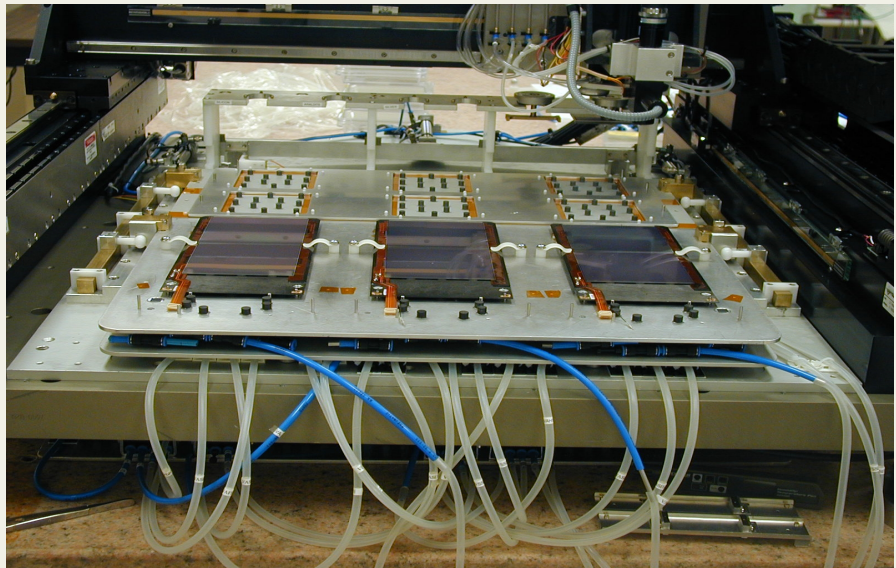
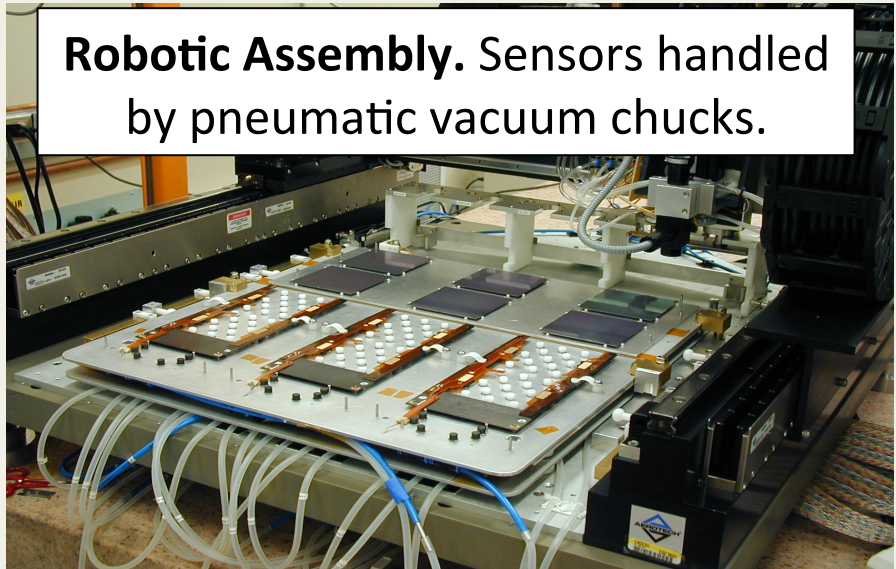
# CMS Tracker Modules



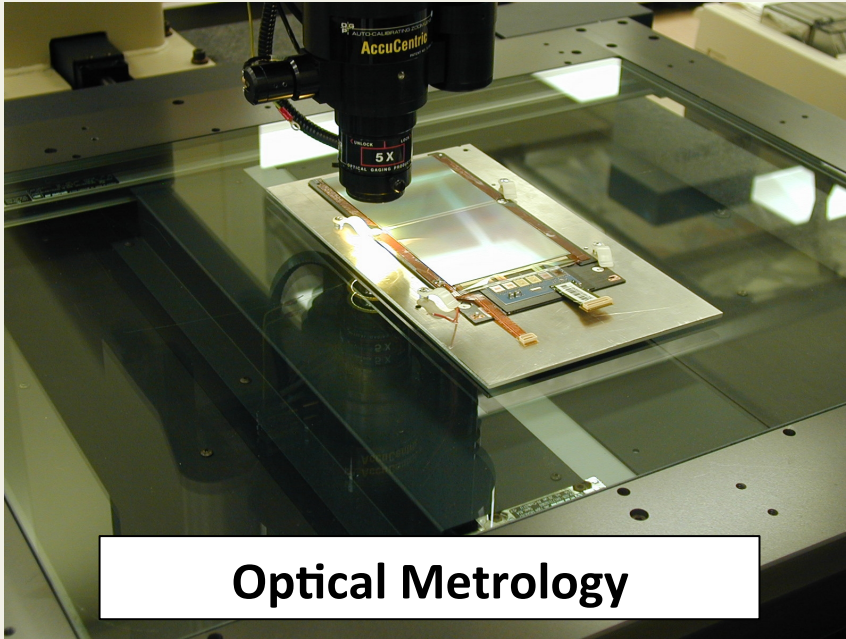
# CMS Tracker Modules: Mechanical Assembly



- 1) Mechanical Assembly
- 2) Wire-bonding
- 3) Electrical Testing
- 4) Integration & Installation



# CMS Tracker Modules: Mechanical Assembly



Optical Metrology

- 1) Mechanical Assembly
- 2) Wire-bonding
- 3) Electrical Testing
- 4) Integration & Installation

$$\Delta\theta_{RMS} = 4.3 \times 10^{-3} \text{ deg}$$

$$\Delta X_{RMS} = 8.1 \mu$$

(2,600 entries)

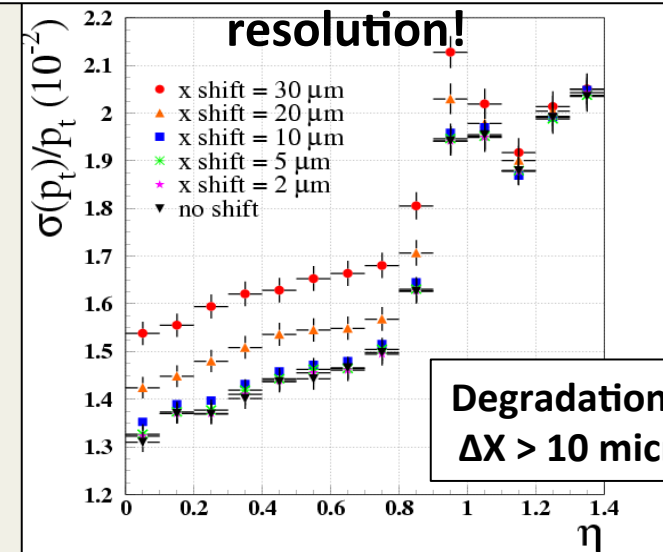
S2

S2

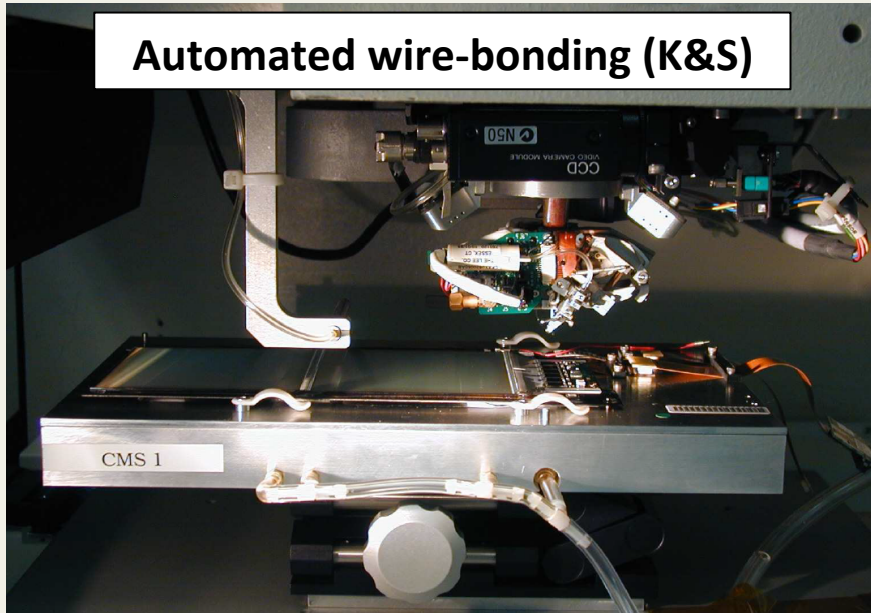
S1

S1

Alignment important for  $P_T$

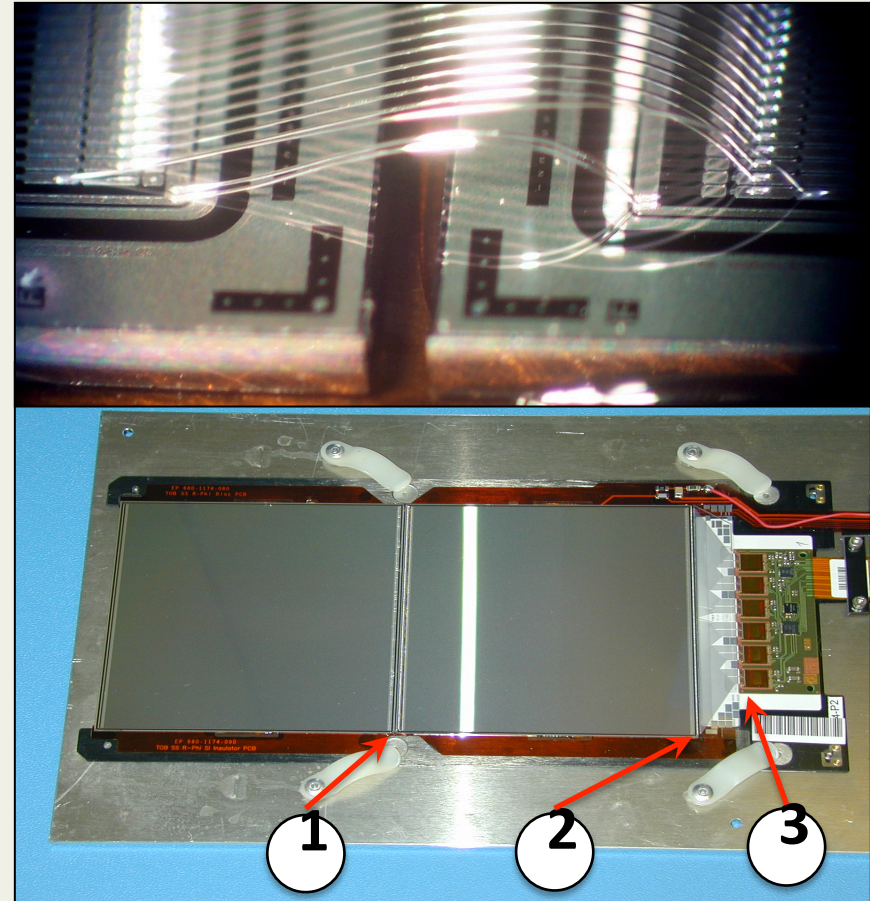


# CMS Tracker Modules: Wire-bonding



- 1) Mechanical Assembly
- 2) Wire-bonding**
- 3) Electrical Testing
- 4) Integration & Installation

Si Strip Tracker has **26 Million** wire-bonds (**13 Million US**)



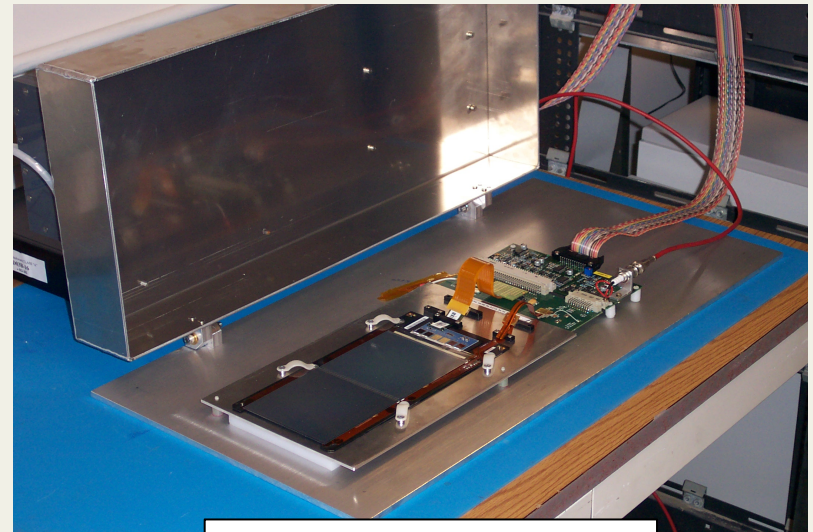
## Wire-bonds:

- 1) Sensor to Sensor
- 2) Sensor to Pitch Adapter
- 3) Pitch Adapter to Chip

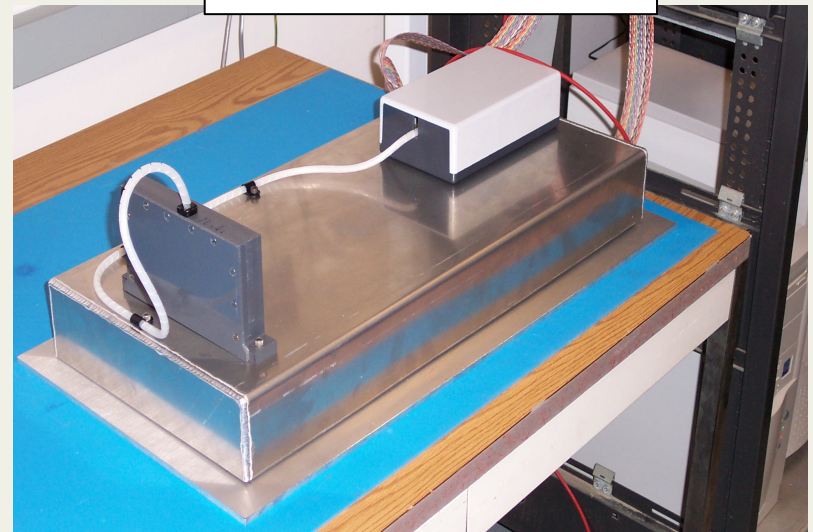
# CMS Tracker Modules: Testing

- Testing is critical for verifying design goals
- 10 years of continuous running once installed

- 1) Mechanical Assembly
- 2) Wire-bonding
- 3) Electrical Testing**
- 4) Integration & Installation

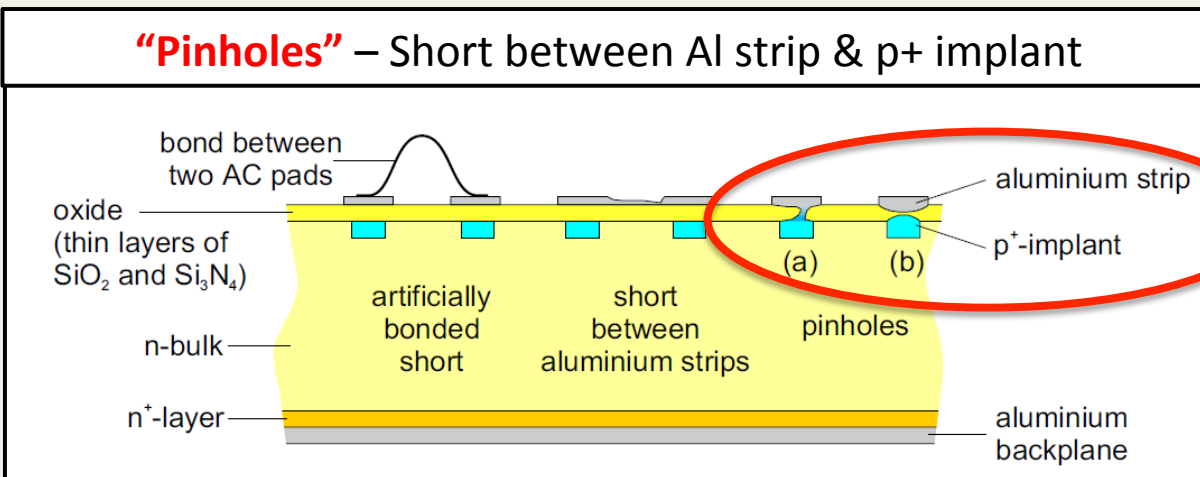
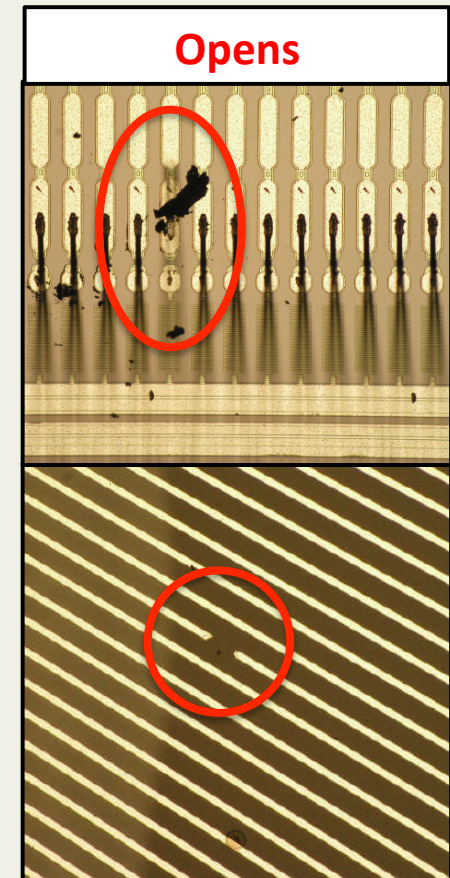
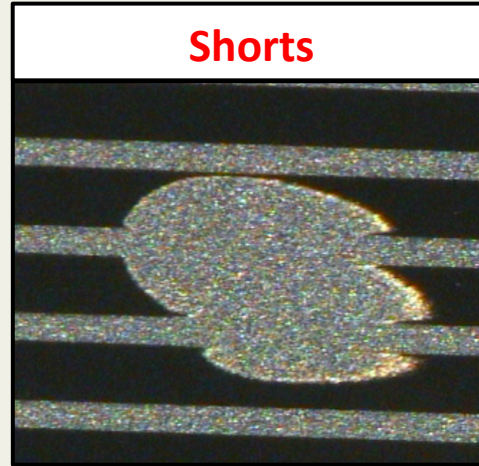
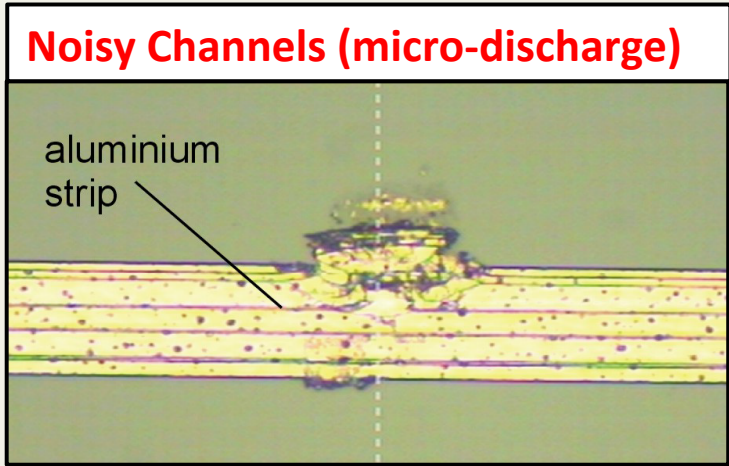


Module Test Station



# CMS Tracker Modules: Testing

- **Potential Faults**



# CMS Tracker Modules: Testing

- **Noise Test**

- **Noisy Channels**

- **Opens: Low noise**

- Less Capacitance
- Can distinguish near & far sensor opens

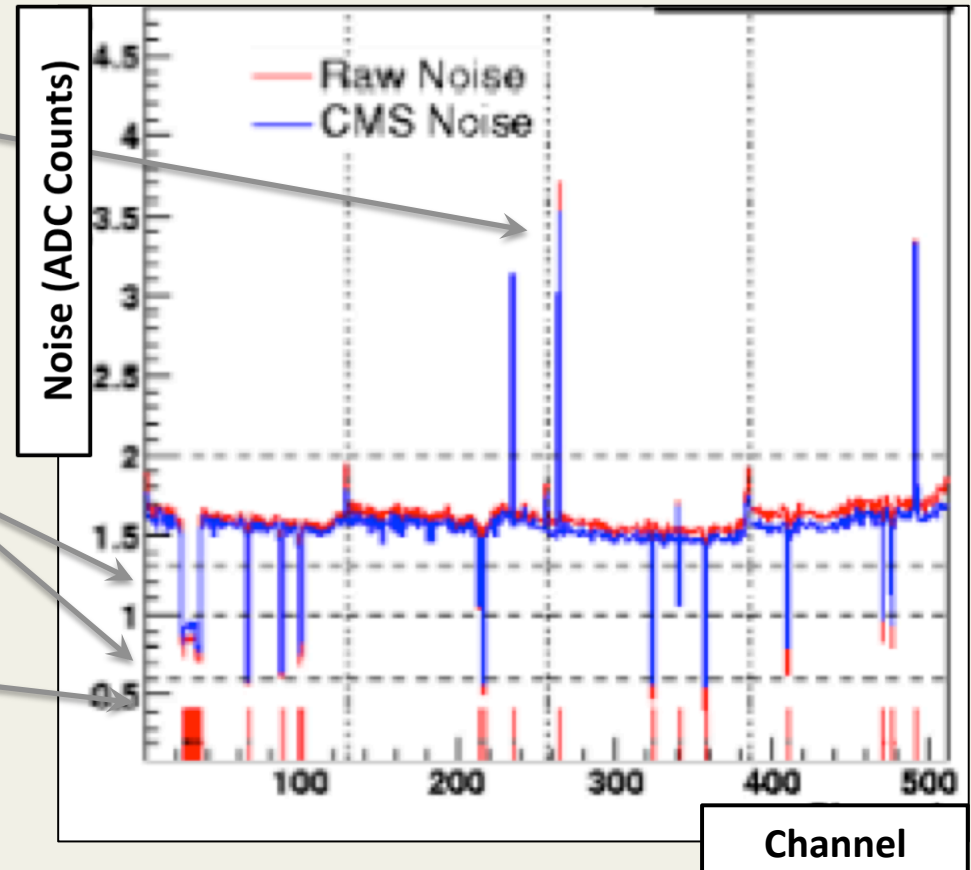
- **Pinholes**

- Very low noise

- **Shorts**

- high or low noise

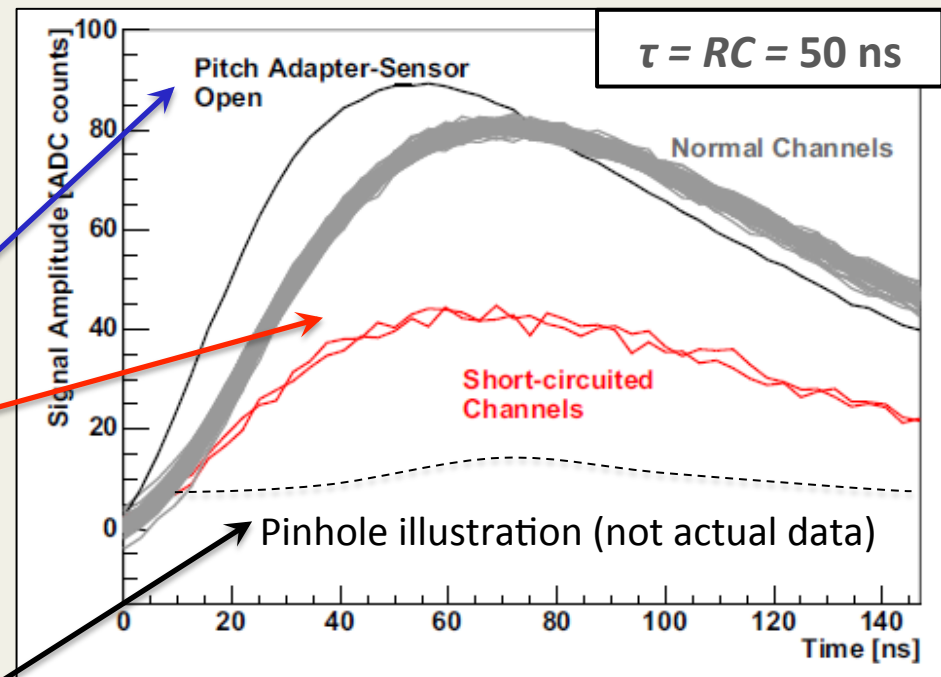
- Channels automatically flagged



# CMS Tracker Modules: Testing

- **Pulse Shape Test**

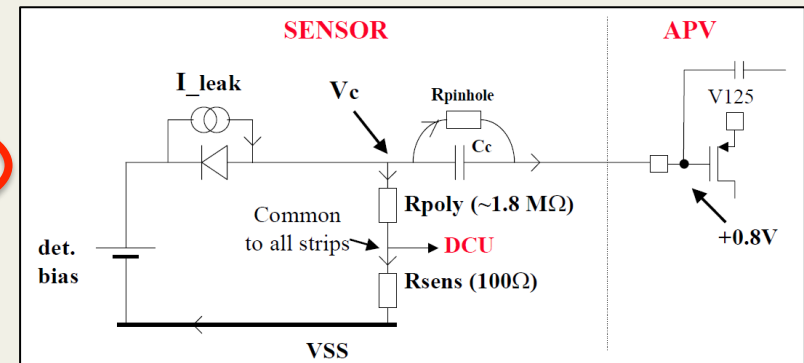
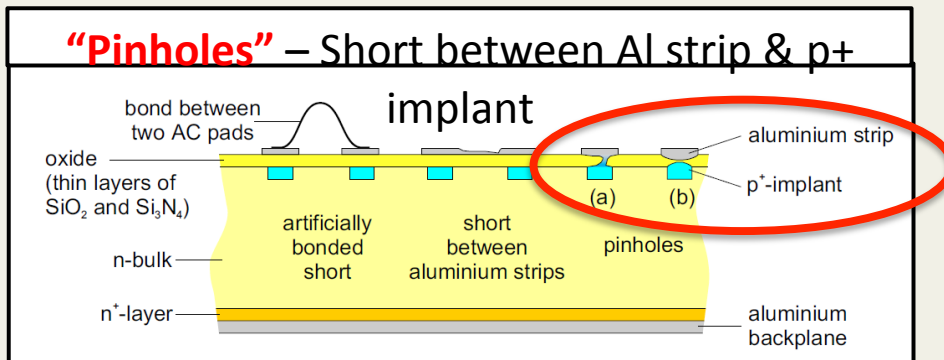
- Charge is injected per channel by an on-chip calibration circuit capable of supplying up to 25 fC ( $\sim 7$  MIP). The signal is shaped on-chip by a CR-RC shaper.
- Sensitive to the chip input capacitance and can detect **opens, shorts, & pinholes**.
- **Opens**: lower  $C$ , lower  $\tau$
- **Shorts**:  $C$  doubled, parallel  $R$  halved,  $\tau$  unchanged.  $Q$  shared between 2 channels, Amplitude is halved.
- Pinholes: Virtually no signal.



# CMS Tracker Modules: Testing

- **Pinhole Test (1)**

- Pinhole: Short across  $\text{SiO}_2$  insulator separating Al strip and p+ implant
  - Causes: photolithographic defect in the insulating layer, deep scratches

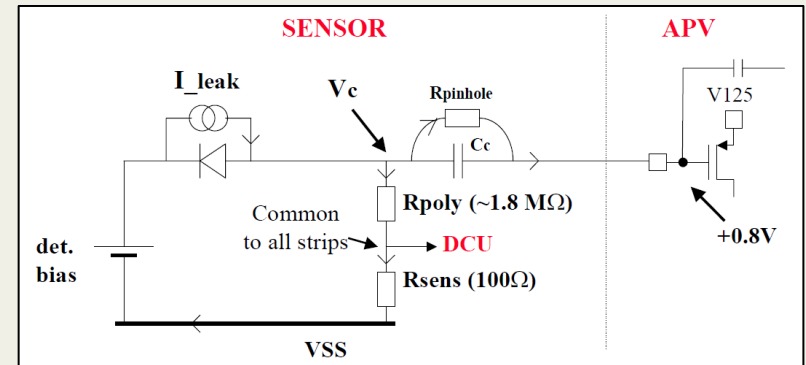


- Chip preamp input potential is “grounded” to  $V_C$ , which depends on  $I_{leak}$
- If  $V_C < 0.8 \text{ V}$  (small  $I_{leak}$ ), current flows from APV to sensor (**OK**, lose one channel)
- If  $V_C > 0.8 \text{ V}$  (large  $I_{leak}$ ), current flows from sensor to APV
  - **BAD:** Preamp output saturates, single inverter can starve the rest (128) and disable the chip.
  - Dangerous because  $I_{leak}$  grows linearly with radiation fluence
- If  $V_C = 0.8 \text{ V}$ , normal response

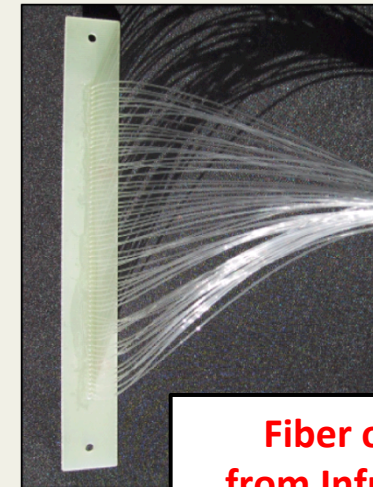
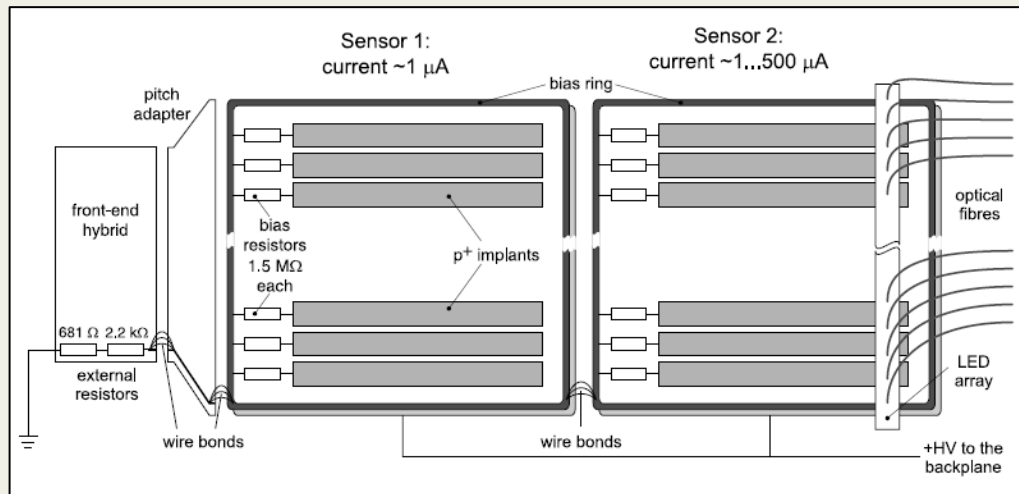
# CMS Tracker Modules: Testing

- **Pinhole Test (2)**

- Increase  $I_{leak}$  by illumination with infrared LED light
  - Penetration depth of infrared matches Si thickness



- Vary LED intensity (and therefore  $I_{leak}$ ), measure pulse height



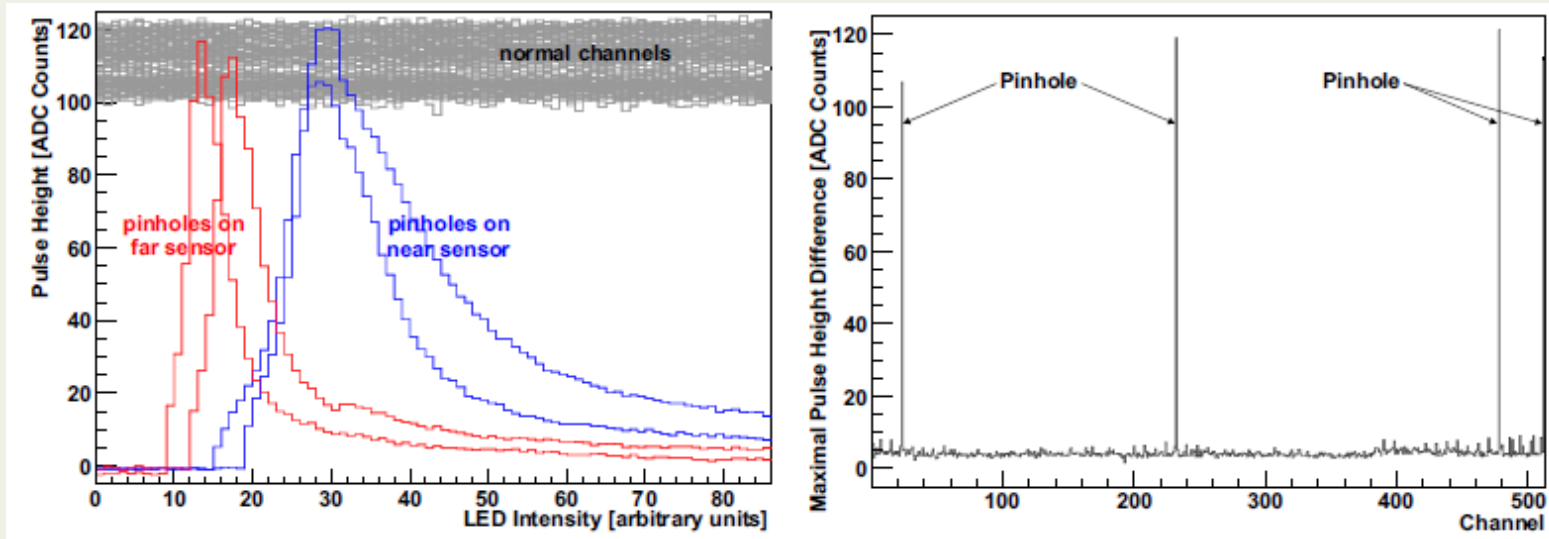
**Fiber outputs from Infrared LED**

# CMS Tracker Modules: Testing

- ***Pinhole Test (3)***

- Pulse Height is measured vs. LED intensity (and therefore the leakage current,  $I$ ) for each channel
- At some value of  $I$ , the pinhole behaves like a normal channel
- The max difference in pulse height is taken over the range of  $I$

- **Large values indicate pinholes**



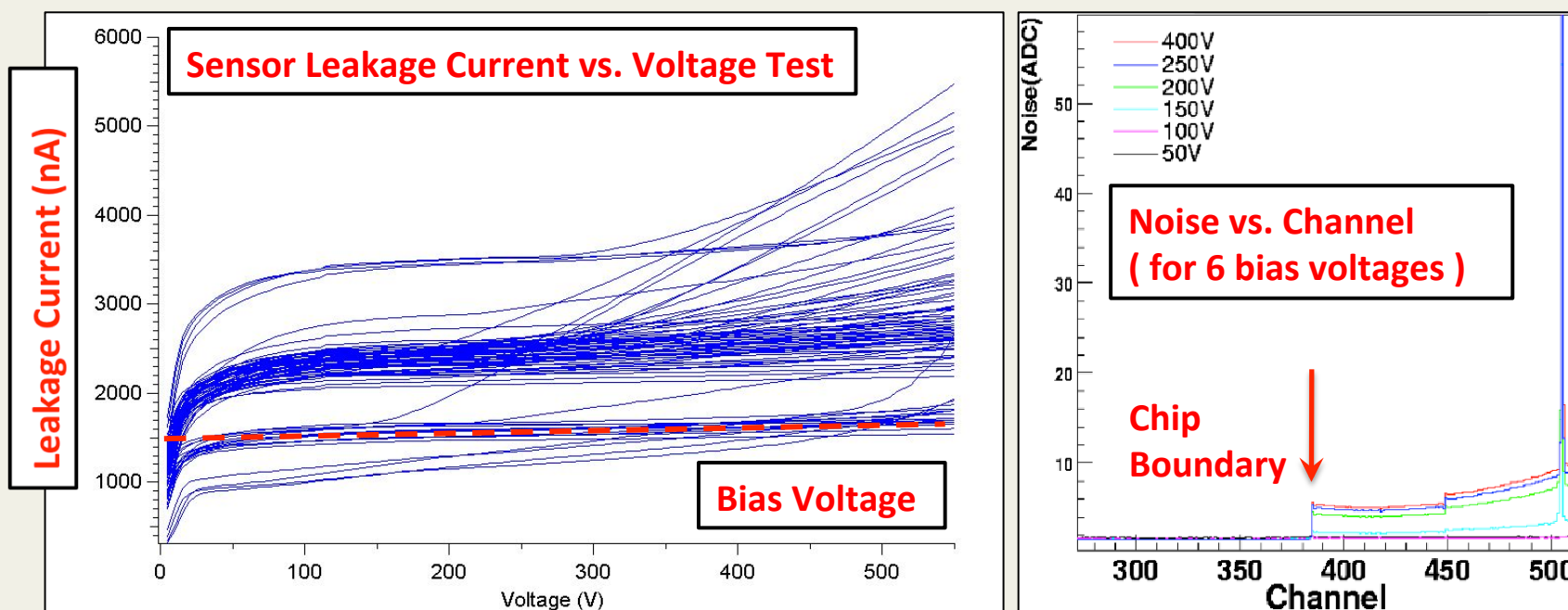
# Production or R&D?

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- **Several serious *problems* discovered & *solved* during production:**
  - *Common Mode Noise in silicon sensors*
    - *Order of more than 12,000 sensors switched to new vendor*
  - *Opens in hybrid readout connector*
    - *Integrate problem areas into kapton layers*
  - *Failure of power connection to chips on hybrid (poorly plated through vias)*
    - *Worked with vendor, added intermediate kapton layer*
  - *Failure of silver epoxy sensor to sensor bias connection*
    - *Make bias connection with wirebonds*
  - *Sensor damage due to spark discharge from HV bias bonds*
    - *Encapsulate wirebonds*
  - *Wirebonds broken due to vibration (shipping & handling)*
    - *Encapsulate wirebonds*
  - *Etc...*
- **Production of ~ 7,200 modules compressed to about a 1 year schedule**

# Common Mode Noise

- **Noisy channels from discharge in silicon sensor**
  - Associated with abnormal leakage current vs. bias voltage curve
  - Can disable entire chips. Problem appeared/worsened with time.



- Ultimately attributed to sensor corrosion (Al by  $H_3PO_4$ )
  - **Solution: Switch vendor for ~ 12,000 sensors during production**

# Results

- **Highly Automated Production**

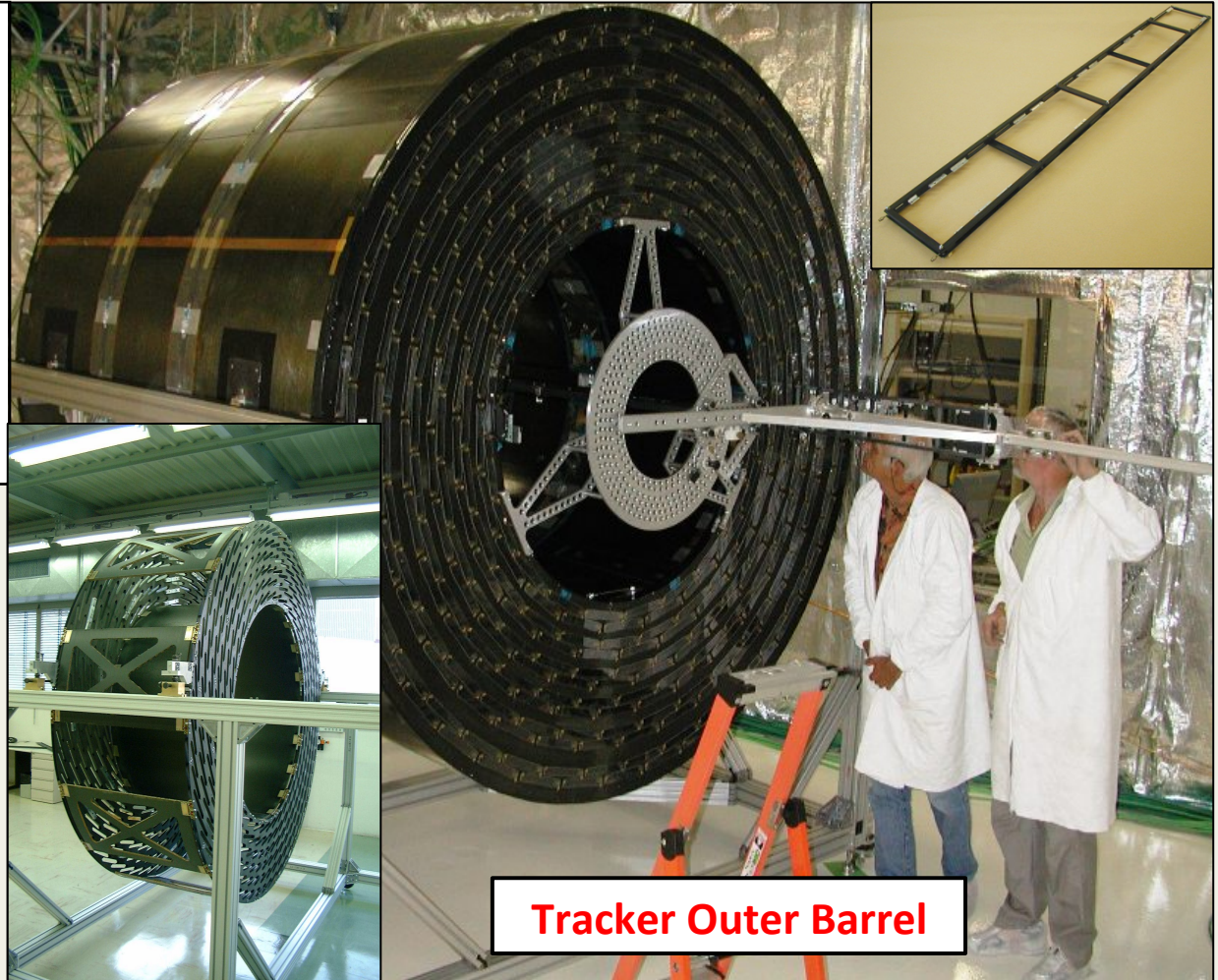
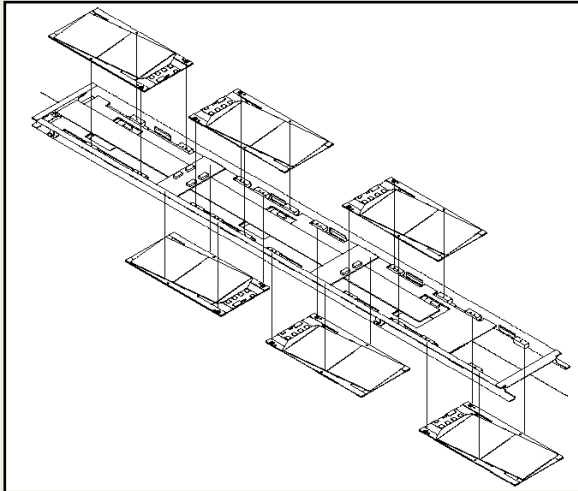
- Developed automated fault finding algorithm

Test Type	Noise	Pulse Height	Peak Time	Pinhole Difference	Pinhole Max
<b>Fault Type</b>					
Open	low	high	low		high
Short	high or low	low (~1/2)		low	low (~1/2)
Noisy	high				
Pinhole	very low	very low		very high	

- **Testing Statistics**

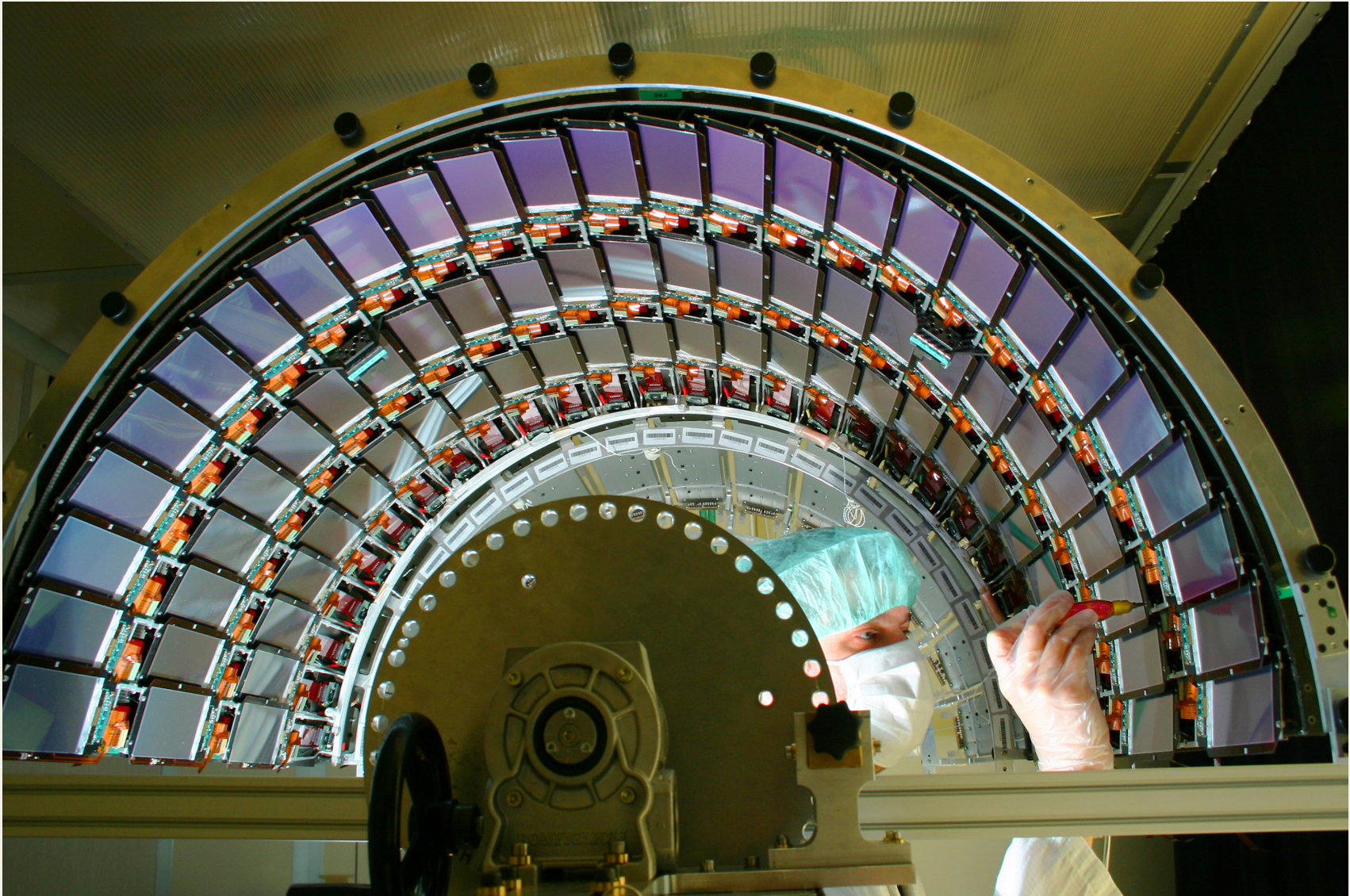
- 27 bad modules out of 7115 ( **0.3%** )
- 2,423 bad channels out of 3,900,408 ( **0.06%** )
- Design Goal: Less than **1%** bad channels

# CMS Tracker Integration



- 1) Mechanical Assembly
- 2) Wire-bonding
- 3) Electrical Testing
- 4) Integration & Installation**

# CMS Tracker Integration

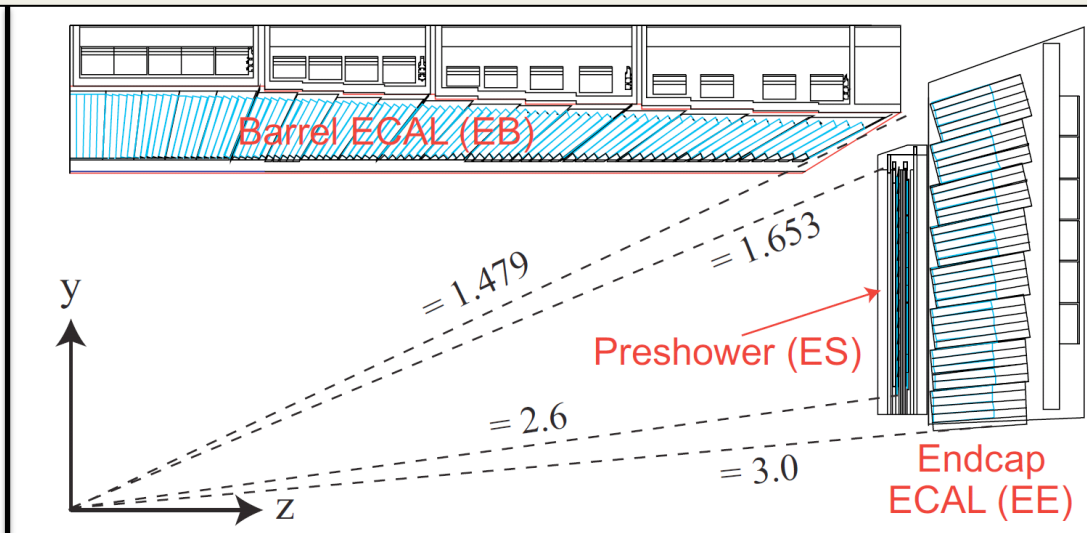
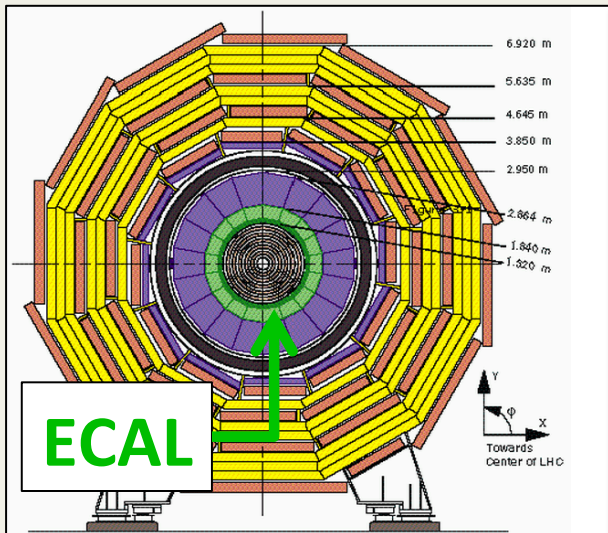


SLAC  
1 December 2015

Derek Michael Barge  
UC Santa Barbara | CMS Collaboration

30

# Electromagnetic Calorimeter (ECAL)

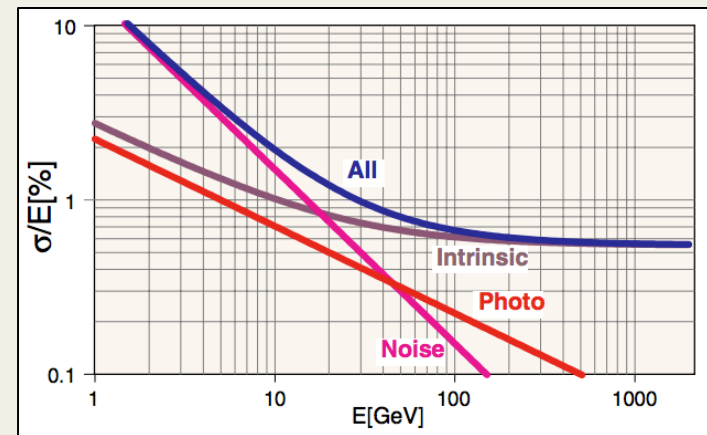


- **Measures energies & positions of electrons & photons**

- Lead tungstate absorber

- Depth of ~ 26 radiation lengths
    - Radiation length: ~ 1 cm
    - Moliere radius: ~ 2 cm

$$\left(\frac{\delta E}{E}\right)^2 = \left(\frac{2.8\%}{\sqrt{E/GeV}}\right)^2 + \left(\frac{12\%}{E/GeV}\right)^2 + (0.3\%)^2 \text{ (EB)}$$



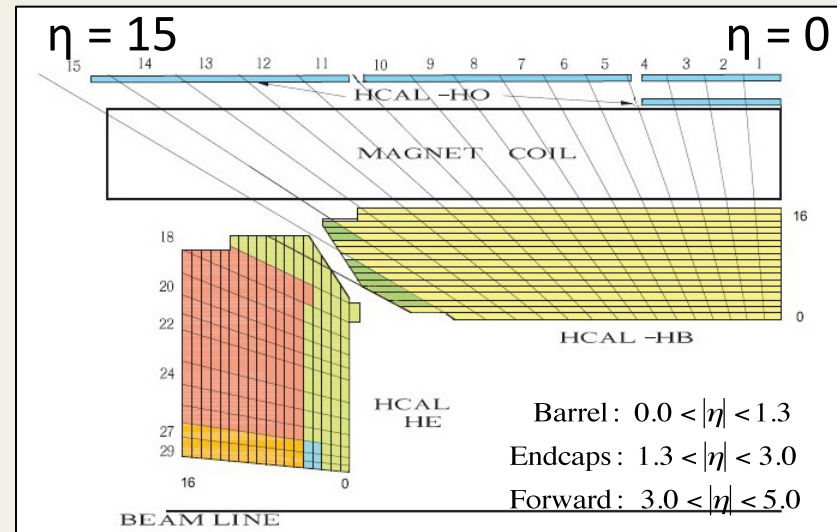
# Hadronic Calorimeter (HCAL)

- Measures energies and positions of hadronic jets

- Sampling calorimeter

- Scintillator interleaved with brass absorber

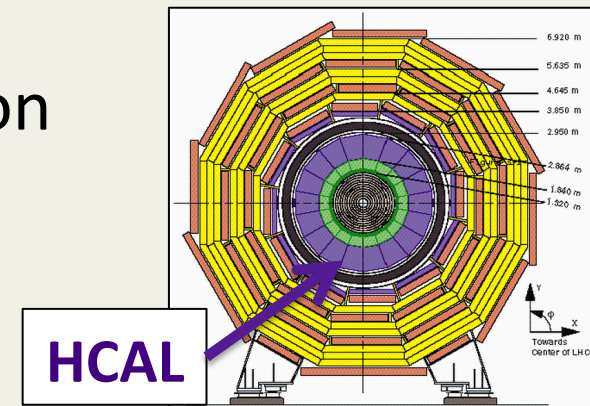
$$\left(\frac{\delta E}{E}\right)^2 = \left(\frac{a}{\sqrt{E/\text{GeV}}}\right)^2 + b^2 \quad \begin{array}{l} a \sim 90\% \\ b \sim 5\% \end{array}$$



- Missing Energy Transverse (MET)

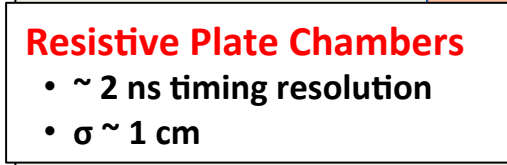
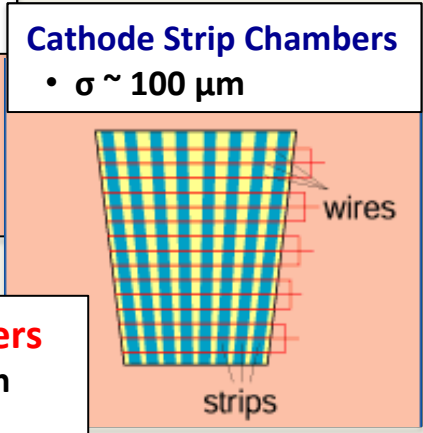
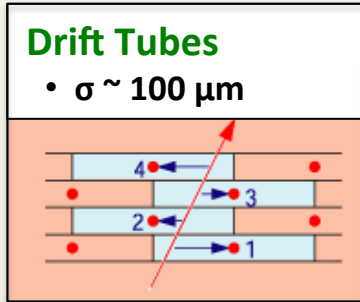
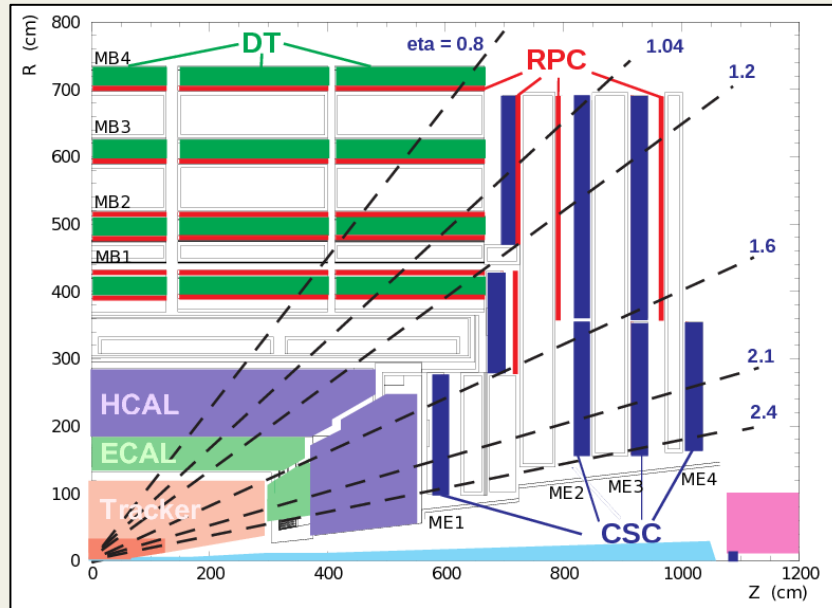
- Inferred from energy conservation

$$\cancel{E}_T = - \sum_{i=1}^{n \text{ Towers}} (E_T)_i (\cos \theta_i \hat{x} + \sin \theta_i \hat{y})$$



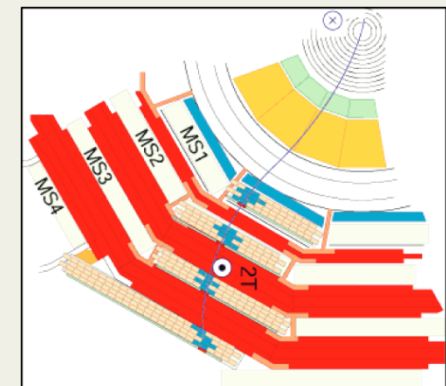
# Muon System

- Muon Id, triggering, and momentum measurement



- Momentum resolution (standalone)

$$\frac{\delta P_T}{P_T} \sim 8\% - 15\% (10 \text{ GeV}), 20\% - 40\% (1 \text{ TeV})$$



---

# **Analysis**

# Motivation (1)

---

- **This is a signature based search for new physics**
  - Interpreted in terms of SUSY, sensitive to non-SUSY too
- The Signature
  - 1. Two leptons of opposite charge ( by choice )**
  - 2. Missing Transverse Energy ( MET )**
    - Motivated by the (indirect) observation Dark Matter
  - 3. Hadronic Jet Activity**
    - Highest cross section from strong production
    - Metrics: **Jet Multiplicity** ,  $H_T$  ( Scalar sum of Jet  $P_T$  )

# Motivation (2)

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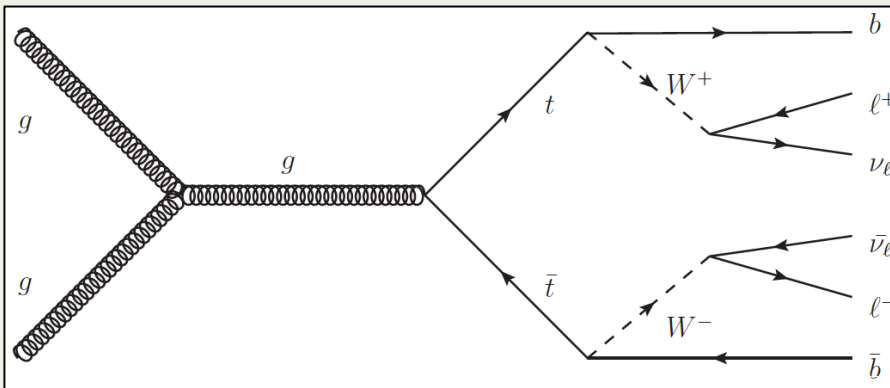
- **Why dileptons?**
  - “Clean” experimental signature
    - Prompt leptons tend to be isolated
    - Good resolution in momentum and energy
- **Which dileptons?**
  - Opposite Sign (OS) and not from a Z boson
  - Other choices: Same Sign, Opposite Sign with a Z
- **Counting experiments**
  - Define 2 dimensional signal regions in plane of ( **MET** , **H<sub>T</sub>** )
  - Estimate Background in each signal region
  - Excess could be a discovery
  - Otherwise set limits to constrain new physics models

# Motivation (3)

## Dilepton Final States

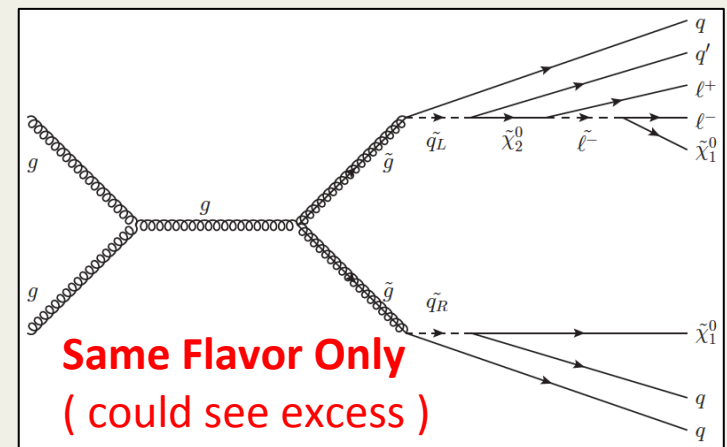
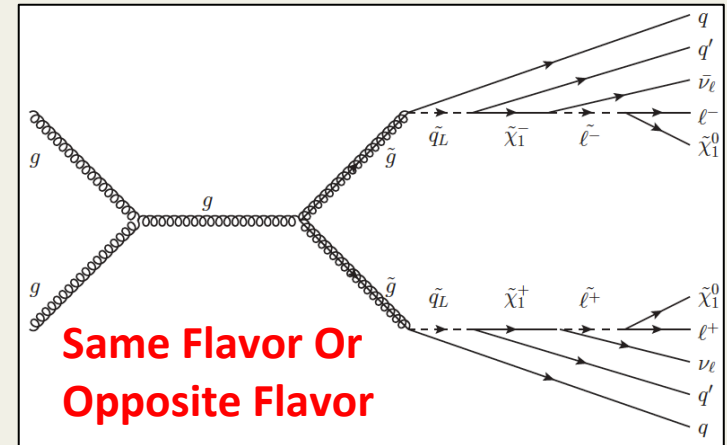
### Backgrounds

- Dominant background: top pairs



- Lesser backgrounds
  - Residual **Drell-Yan + Jets**
  - **WW , Top , Fake Leptons**

## Signal Examples (SUSY)



# Outline

---

1. Overview
- 2. Basic Selections**
3. Definition of Signal Regions
4. Background Estimation Methods
5. Results

# Basic Selections

---

- **Lepton Selections**

- Data collected on high  $P_T$  dilepton triggers

- $\epsilon(\mu\mu) \sim 90\%$  ,  $\epsilon(e\mu) \sim 95\%$  ,  $\epsilon(ee) \sim 100\%$  ,  $\sigma \sim 2\%$

- 2 leptons of opposite charge

- Well identified & isolated leptons;  $(P_T^{\text{MAX}}, P_T^{\text{MIN}}) > (20, 10)$  GeV

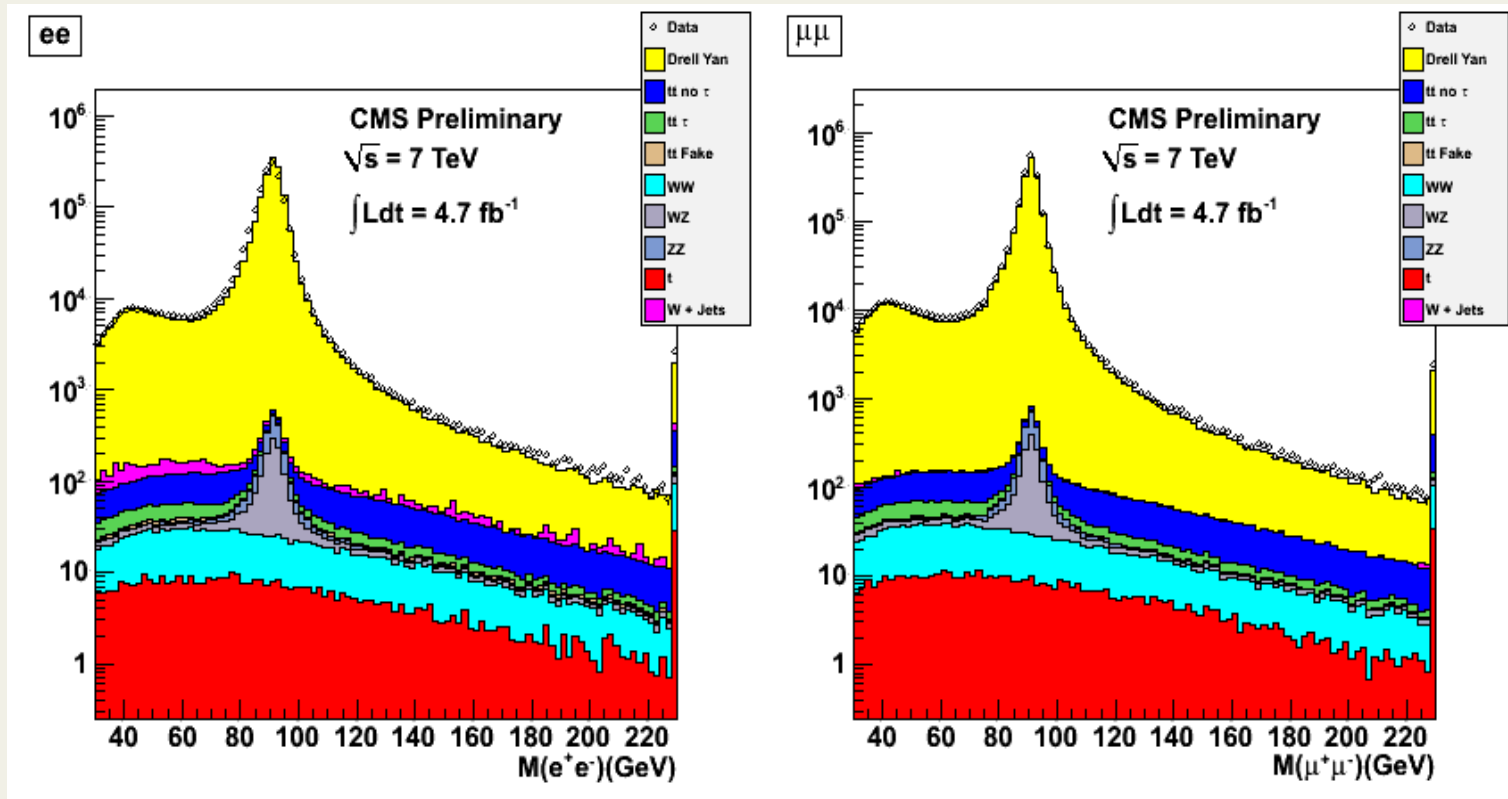
- Selection efficiency is (90 – 95)% above  $P_T \sim 20$  GeV

- **Data**

- Analysis with early data:  $5 \text{ fb}^{-1}$  of integrated luminosity, 7 TeV

- Statistical errors dominate. Emphasis on first results with reasonable data/MC agreement.

# Dilepton Invariant Mass



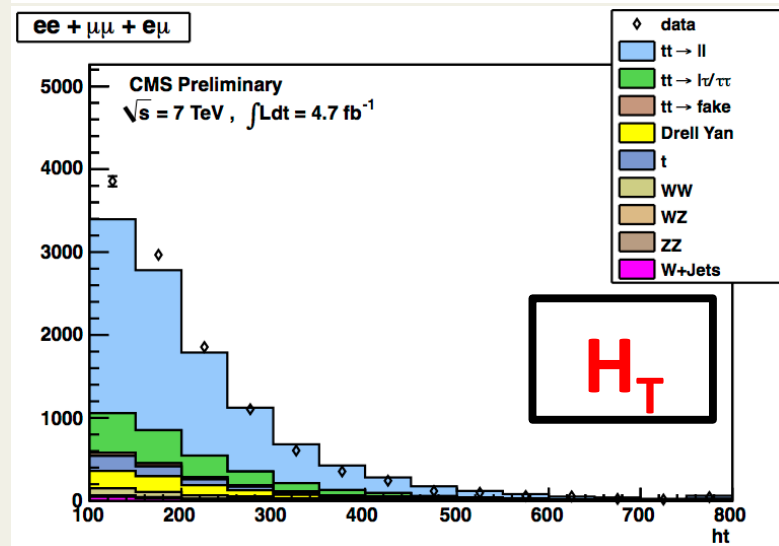
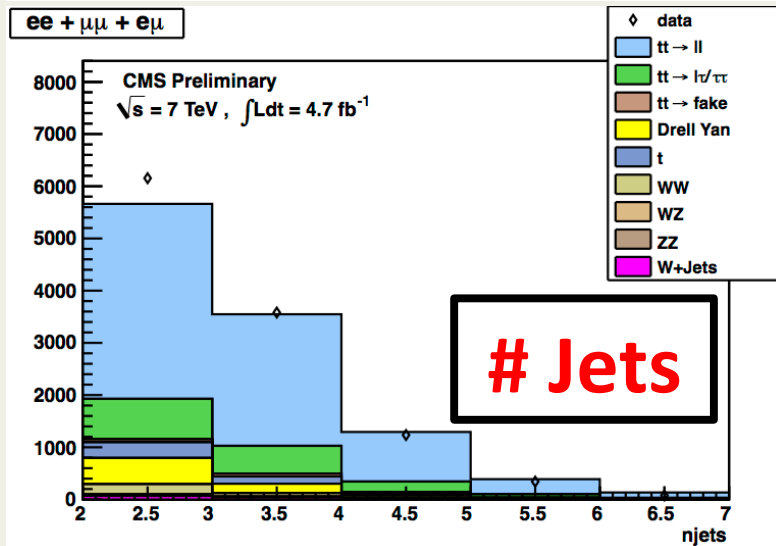
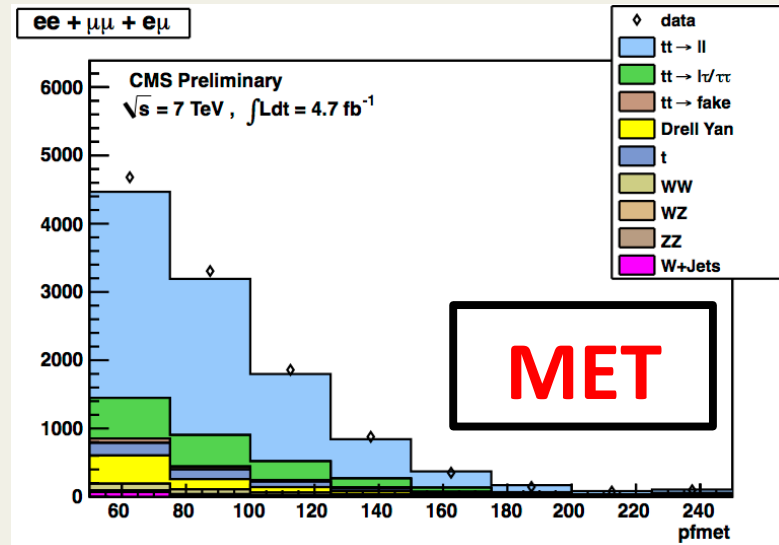
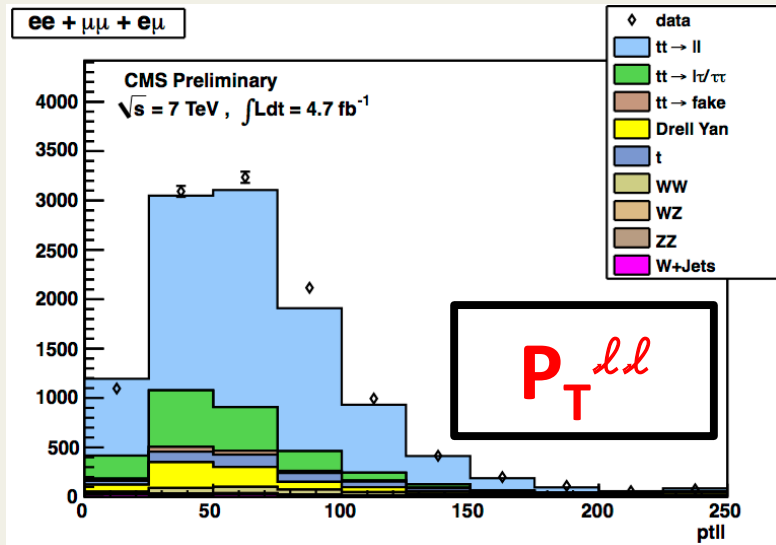
- **Data & Monte Carlo agree within  $\sim 5\%$  in Z Peak ( $76 \text{ GeV} < M_{ll} < 106 \text{ GeV}$ )**
  - Monte Carlo normalized to data & corrected for trigger  $\epsilon$
  - Level of agreement covered by uncertainties in luminosity ( $\sim 4.5\%$ ), lepton Id & Isolation ( $\sim 2\%$ ), and dilepton trigger efficiency ( $\sim 2\%$ )

# Cleaning the top Background

---

- A sample of opposite sign, isolated dileptons has been selected.
- Next, a **“Preselection”** is defined as:
  - **Basic Selections**
  - **Missing Transverse Energy > 50 GeV**
  - **2 Jets or more**
    - **30 GeV** Threshold on **Jet  $P_T$**
    - Separated by  **$\Delta R > 0.4$**  from nearest lepton
  - **$H_T > 100$  GeV (Scalar Sum of Jet  $P_T$ )**
  - **Z Veto: Discard events with  $76 \text{ GeV} < M_{ll} < 106 \text{ GeV}$**
- The **Preselection** is designed to further reject non-top backgrounds
  - Drell-Yan in particular; top is left as the principal irreducible background
  - Check data & Monte-Carlo agreement prior to counting experiments
  - Expect kinematics to be top-like

# Key Distributions after Preselection



# Preselection Yields

- **Selections: MET > 50 GeV , H<sub>T</sub> > 100 GeV , # Jets ≥ 2 , Z Veto , Dilepton Selection**

	ee	μμ	eμ	all
tt → dileptons	1465.8 ± 32.6	1872.4 ± 41.5	4262.2 ± 94.1	7600.4 ± 167.5
tt → tau(s)	302.8 ± 7.0	397.5 ± 9.1	888.6 ± 19.9	1588.9 ± 35.3
tt → other	50.2 ± 1.4	15 ± 0.6	90 ± 2.3	155.2 ± 3.7
Drell Yan	192.6 ± 11.3	236.6 ± 12.6	311.8 ± 14.7	740.9 ± 26
WW	55.0 ± 1.7	66.2 ± 1.9	150.7 ± 3.8	272.0 ± 6.5
WZ	13.4 ± 0.4	15.0 ± 0.4	24.6 ± 0.6	53.0 ± 1.3
ZZ	2.6 ± 0.1	3.3 ± 0.1	3.3 ± 0.1	9.1 ± 0.3
Single Top	94.6 ± 3.1	119.6 ± 3.7	278.1 ± 7.3	492.3 ± 12.1
W + jets	47.3 ± 10.6	9.8 ± 4.6	59.4 ± 11.5	116.6 ± 16.4
Total MC	2224.3 ± 51.5	2735.4 ± 61.8	6068.8 ± 135	11028.5 ± 244.3
Data	2333	2873	6184	11390

- **Data well predicted by Standard Model Monte-Carlo**

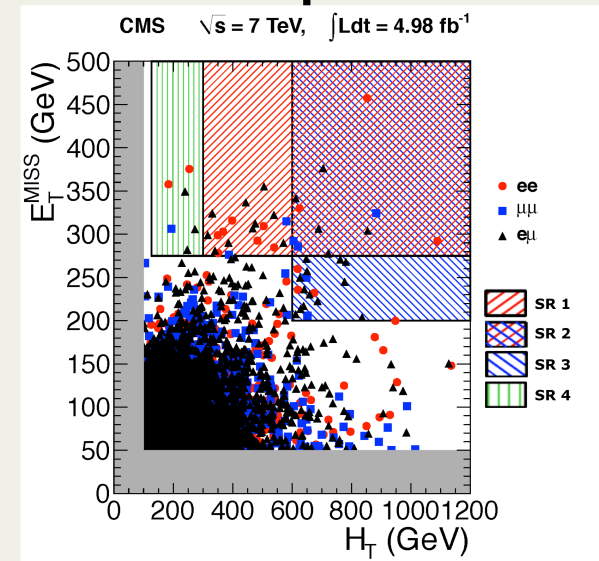
# Outline

---

1. Overview
2. Basic Selections
- 3. Definition of Signal Regions**
4. Background Estimation Methods
5. Results

# Signal Regions

- Define 4 signal regions in the MET vs.  $H_T$  Plane
  - Look for new physics at large MET and / or  $H_T$
- Signal Regions (“SR”) are disjoint in (MET,  $H_T$ )



MET	$H_T$
$275 \text{ GeV} < \text{MET}$	$300 \text{ GeV} < H_T < 600 \text{ GeV}$
$275 \text{ GeV} < \text{MET}$	$600 \text{ GeV} < H_T$
$200 \text{ GeV} < \text{MET} < 275 \text{ GeV}$	$600 \text{ GeV} < H_T$
$275 \text{ GeV} < \text{MET}$	$125 \text{ GeV} < H_T < 300 \text{ GeV}$



# Outline

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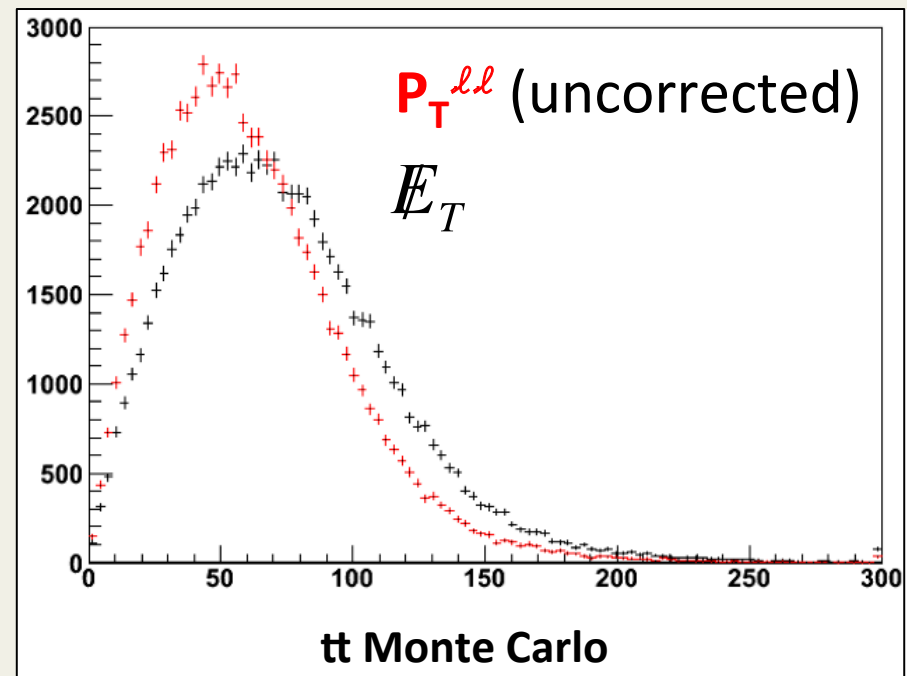
1. Overview
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# $p_T^{\ell\ell}$ Method: Introduction

- The " $p_T^{\ell\ell}$  method" predicts  $\cancel{E}_T$  in  $t\bar{t} \rightarrow \ell^+\ell^- + \cancel{E}_T + 2 \text{ Jets}$ 
  - $\cancel{E}_T$  arises from  $W \rightarrow \ell\nu \therefore p_T^\ell, p_T^\nu$  distributions are similar
  - $\cancel{E}_T^{\text{true}} = p_T^{\nu_1} + p_T^{\nu_2}$
  - $\mathbf{p}_T^{\ell\ell} = \mathbf{p}_T^{\ell_1} + \mathbf{p}_T^{\ell_2}$  and  $\cancel{E}_T$  distributions are similar
  - $\cancel{E}_T$  is harder because of  $W$  polarization

• **Predict  $\cancel{E}_T$  from  $\mathbf{p}_T^{\ell\ell}$  !**

- Correct for  $W$  polarization
- Call correction  $\mathbf{K}_C$ , derive from Monte - Carlo



# W polarization (1)

- Why does W polarization affect the momentum spectrum of the leptons & Neutrinos?

– Consider 2 cases:

**1. Neutrino has maximum E**

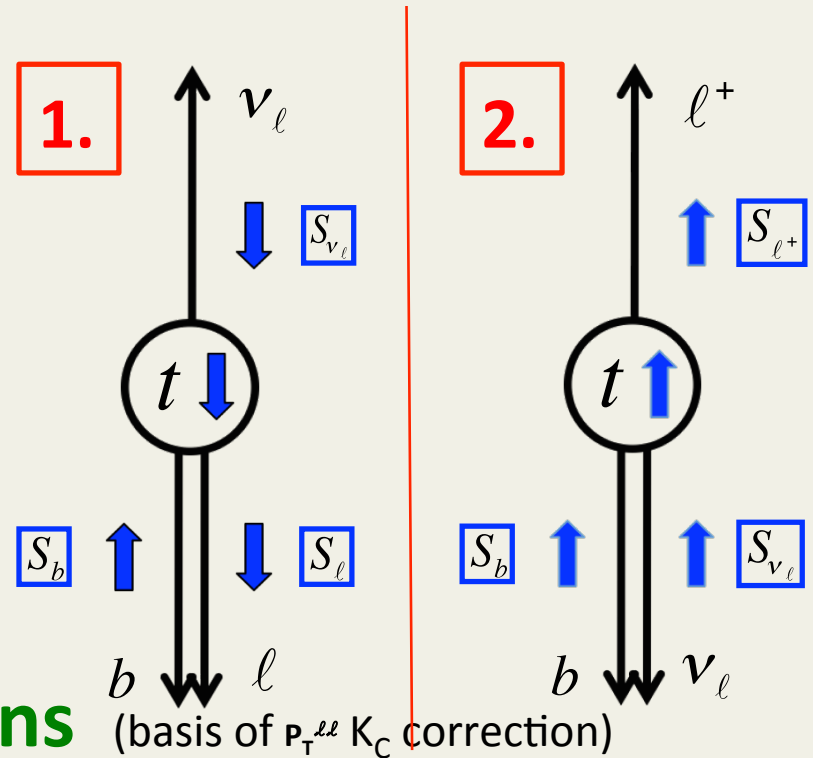
- Allowed by left-handed W

**2. Lepton has maximum E**

- Fails to conserve  $J_z$  due to right-handed W

- Momentum spectra:

**Hard neutrinos, soft leptons**



$$m_b \sim 0$$

# W polarization (2)

- The top differential decay rate is:

$$\frac{d\Gamma}{d \cos\theta^*} \propto 2f_0 \sin^2 \theta^* + f_- (1 - \cos\theta^*)^2 + f_+ (1 + \cos\theta^*)^2$$

$\cos\theta^*$  is the angle between the charged lepton and the top quark in the W rest frame.

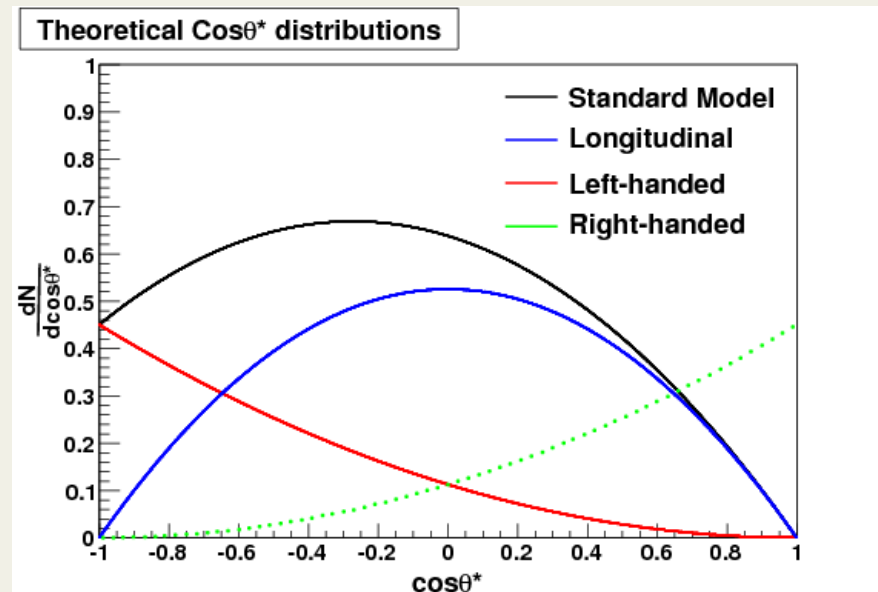
$f_0$ ,  $f_-$ , and  $f_+$  are the fractions of longitudinal, left handed, and right handed W bosons respectively.  $f_0 + f_- + f_+ = 1$ .

- In top decays:

–  $f_+ = 0$       W ( $S_z = +1$ )

–  $f_0 \sim 70\%$       W ( $S_z = 0$ )

–  $f_- \sim 30\%$       W ( $S_z = -1$ )

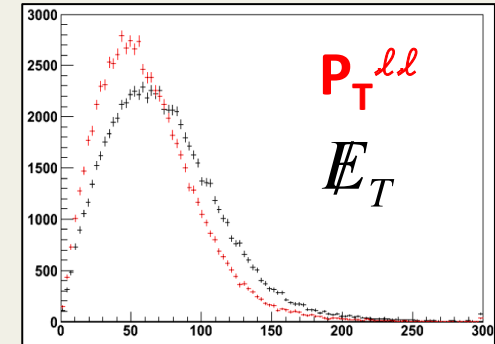


# $P_T^{ll}$ Method: Overview

Use  $P_T^{ll}$  to predict MET:

## 1. Correct for W Polarization

- Scale  $P_T^{ll}$  up by MC correction  $K_C$
- Explained Previously



## 2. Renormalize $P_T^{ll}$ distribution after MET Cut

- MET cut truncates MET distribution, reduces  $P_T^{ll}$  distribution
- Scale  $P_T^{ll}$  up by correction  $K$

## 3. Correct For Drell-Yan Contamination

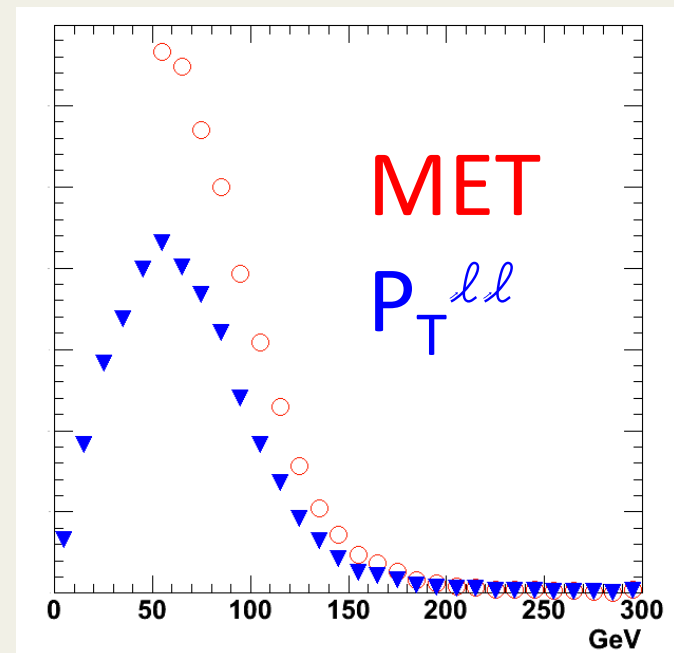
- Subtract residual Drell-Yan left over after MET Cut , Z Veto

$$N_{E_T}^{\text{Predicted}} = \left( N_{P_T^{ll}}^{\text{Observed}} - N_{\text{Drell-Yan}}^{\text{Predicted}} \right) \times K \times K_C$$

# $P_T^{ll}$ Method: Renormalization

- The  $P_T^{ll}$  method predicts  $\cancel{E}_T$  from  $p_T^{ll}$  in dileptonic top pairs
- Drell-Yan largely suppressed
  - $\cancel{E}_T > 50$  GeV. Increase to  $\cancel{E}_T > 75$  GeV for Same Flavor. Z Veto.
  - MET distribution is truncated below the cut.
  - $P_T^{ll}$  distribution stats reduced by MET cut. Distribution domain is unchanged.
- Scale up  $p_T^{ll}$  to predict  $\cancel{E}_T > X$ 
  - Call this renormalization factor  $K$

$$K = \frac{\int_0^\infty N(p_T^{ll}) dp_T^{ll}}{\int_{50 \text{ GeV}}^\infty N(p_T^{ll})_{\text{OF}} dp_T^{ll} + \int_{75 \text{ GeV}}^\infty N(p_T^{ll})_{\text{SF}} dp_T^{ll}}$$



# $P_T^{\ell\ell}$ Method: Summary of Correction Factors

- $K_C$  is derived from [Monte-Carlo](#)

- Corrects for W-polarization

- $1.0 < K_C < 1.7 \pm (13\% - 46\%) K_C$  ( will be used later )

\*  $K_C$  now includes systematic error due to 7.5 % Jet Energy Scale variation

Signal Region	K	$K_C^*$
SR1	$1.65 \pm 0.12$	$1.66 \pm 0.70$
SR2	$1.56 \pm 0.41$	$1.66 \pm 0.37$
SR3	$1.40 \pm 0.49$	$1.29 \pm 0.17$
SR4	$1.90 \pm 0.05$	$0.98 \pm 0.45$

- $K$  is measured in [data](#)

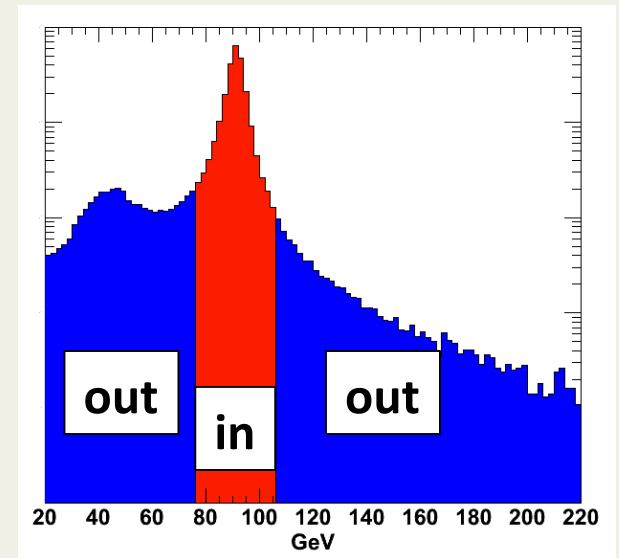
- Renormalizes  $N ( P_T^{\ell\ell} > X )$  so it predicts  $N ( MET > X )$

- $1.4 < K < 1.9 \pm (3\% - 35\%) K$  ( will be used later )

# Drell-Yan Background: Estimation Method

- **Need to estimate residual off-peak Drell-Yan background**
  - In-peak Drell-Yan removed; off-peak reduced by MET > 50 GeV
  - Method: Use data events in the Z-Peak apply MC correction to predict off-peak

Signal Region	Drell Yan
<b>SR1</b>	1.82 ± 1.96
<b>SR2</b>	0.91 ± 0.91
<b>SR3</b>	0.78 ± 0.78
<b>SR4</b>	0.39 ± 0.39



$$R_{out/in}^{MC} \equiv N_{\ell^- \ell^+ -out}^{Drell-Yan MC} / N_{\ell^- \ell^+ -in}^{Drell-Yan MC}$$

$$N_{Drell-Yan out}^{Data Est.} = R_{out/in}^{MC} \left( N_{Same Flavor-in}^{Data} - N_{e\mu-in}^{Data} \times \frac{1}{2} \left( k_{\mu\mu} + \frac{1}{k_{\mu\mu}} \right) \right), \quad k_{\mu\mu} = \sqrt{\frac{N_{\mu\mu-in}^{Data}}{N_{ee-in}^{Data}}} = 1.13 \pm 0.05$$

# Outline

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1. Overview
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- 5. Results**

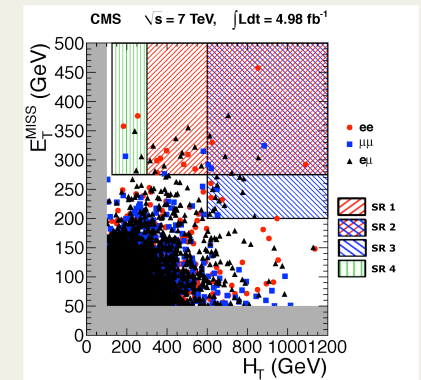
# $P_T^{\ell\ell}$ Method: Results (1)

- Background predictions from the  $P_T^{\ell\ell}$  Method

Signal Region	Observed ( $P_T^{\ell\ell} > X$ )	Drell-Yan	K	$K_C$	$P_T^{\ell\ell}$ Method Prediction	Data
SR1	6	1.82	$1.65 \pm 0.12$	$1.66 \pm 0.7$	<b><math>11.5 \pm 7.3 \pm 5.6</math> (sys)</b>	<b>19</b>
SR2	5	0.91	$1.56 \pm 0.41$	$1.66 \pm 0.4$	<b><math>10.6 \pm 5.8 \pm 3.8</math> (sys)</b>	<b>11</b>
SR3	7	0.78	$1.40 \pm 0.49$	$1.29 \pm 0.2$	<b><math>11.3 \pm 4.8 \pm 4.2</math> (sys)</b>	<b>18</b>
SR4	7	0.39	$1.90 \pm 0.05$	$0.98 \pm 0.4$	<b><math>12.3 \pm 4.9 \pm 5.7</math> (sys)</b>	<b>6</b>

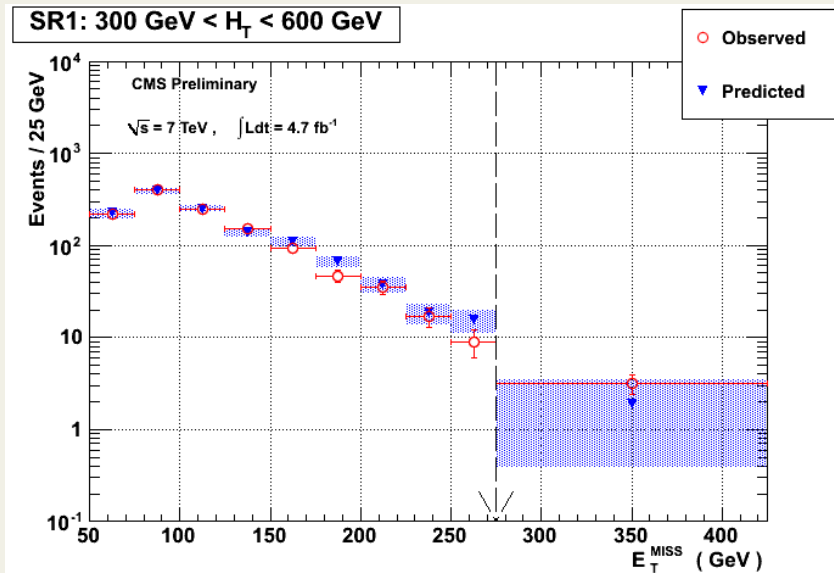
$$\left( N_{P_T^{\ell\ell}}^{\text{Observed}} - N_{\text{Drell-Yan}}^{\text{Predicted}} \right) \times K \times K_C = N_{E_T}^{\text{Predicted}}$$

- Syst. error contributions from  $K$ ,  $K_C$ ,  $R_{\text{out/in}}$
- No evidence of new physics observed**

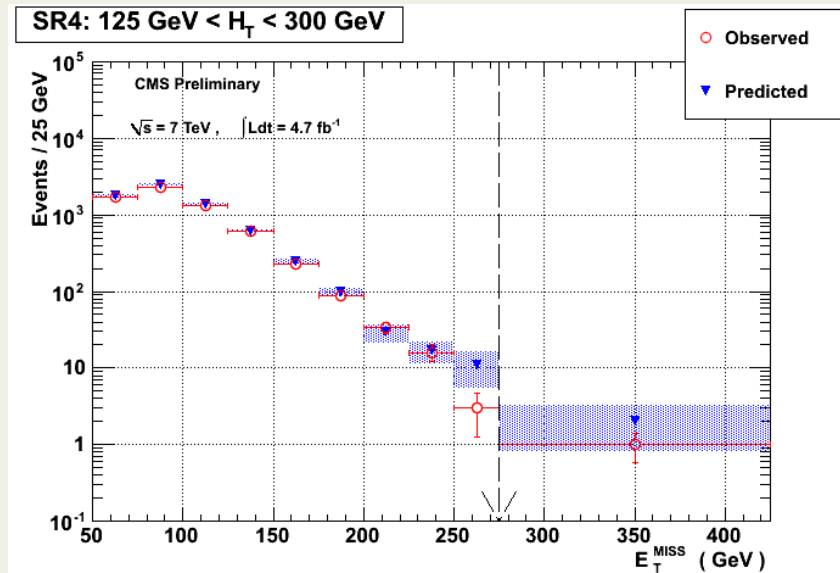


# $P_T^{ll}$ Method: Results (2)

- Prediction of MET shape from the  $P_T^{ll}$  Method



SR1:  $300 \text{ GeV} < H_T < 600 \text{ GeV}, 275 \text{ GeV} < \text{MET}$



SR4:  $125 \text{ GeV} < H_T < 600 \text{ GeV}, 275 \text{ GeV} < \text{MET}$

- Signal regions indicated by vertical dashed lines
- MET shape well predicted by data-driven  $P_T^{ll}$  Method

# Summary of Results

- $P_T^{ll}$  Method & Monte Carlo predictions have been found so far for 4 signal regions:

Signal Region	MET	HT
<b>SR1</b>	275 GeV < MET	300 GeV < $H_T$ < 600 GeV
<b>SR2</b>	275 GeV < MET	600 GeV < $H_T$
<b>SR3</b>	200 GeV < MET < 275 GeV	600 GeV < $H_T$
<b>SR4</b>	275 GeV < MET	125 GeV < $H_T$ < 300 GeV

- Data agrees with **Monte Carlo** and  $P_T^{ll}$  **Method** predictions

Signal Region	Observed	Monte Carlo	$P_T^{ll}$ Prediction
<b>SR1</b>	<b>19</b>	<b><math>18.9 \pm 1.1</math> (stat)</b>	<b><math>11.5 \pm 7.3</math> (stat) <math>\pm 5.6</math> (sys)</b>
<b>SR2</b>	<b>11</b>	<b><math>11.5 \pm 0.6</math> (stat)</b>	<b><math>10.6 \pm 5.8</math> (stat) <math>\pm 3.8</math> (sys)</b>
<b>SR3</b>	<b>18</b>	<b><math>19.1 \pm 0.8</math> (stat)</b>	<b><math>11.3 \pm 4.8</math> (stat) <math>\pm 4.2</math> (sys)</b>
<b>SR4</b>	<b>6</b>	<b><math>4.2 \pm 0.3</math> (stat)</b>	<b><math>12.3 \pm 4.9</math> (stat) <math>\pm 5.7</math> (sys)</b>

# Upper Limits

- No evidence for new physics observed

Signal Region	Observed	Predicted ( $P_T^{ll}$ Method)	Upper Limit
<b>SR1</b>	19	$11.5 \pm 7.3$ (stat) $\pm 5.6$ (sys)	<b>20</b>
<b>SR2</b>	11	$10.6 \pm 5.8$ (stat) $\pm 3.8$ (sys)	<b>11</b>
<b>SR3</b>	18	$11.3 \pm 4.8$ (stat) $\pm 4.2$ (sys)	<b>18</b>
<b>SR4</b>	6	$12.3 \pm 4.9$ (stat) $\pm 5.7$ (sys)	<b>6.5</b>

- Set **upper limit** on the non-Standard Model contribution to each signal region
  - 95% confidence level limit set using CLS statistic
  - Model-independent limits

# Exclusion Limits

- **Use flavor information for SMS, CMSSM limits**

- Perform **6 bin** shape analysis by separating **SR1** , **SR2** , **SR3** into same and opposite flavor bins
- Improves sensitivity to signal models with more same flavor than opposite flavor dileptons

Signal Region	SF	OF	Predicted ( $P_{\tau^{\ell\ell}}$ Method)
<b>SR1</b>	9	10	$5.7 \pm 5.1$ (stat) $\pm 2.8$ (sys)
<b>SR2</b>	6	5	$5.2 \pm 4.1$ (stat) $\pm 1.9$ (sys)
<b>SR3</b>	5	13	$5.6 \pm 3.4$ (stat) $\pm 2.1$ (sys)

- **Do shape analysis in 6 bins of signal region & flavor**

- The prediction for each flavor bin is **half** of the total
  - Same flavor and opposite flavor predictions are taken to be the same
- The statistical errors on the flavor predictions are  $2^{-1/2}$  of the total statistical error
- The systematic error on the flavor predictions are  $\frac{1}{2}$  the total systematic errors

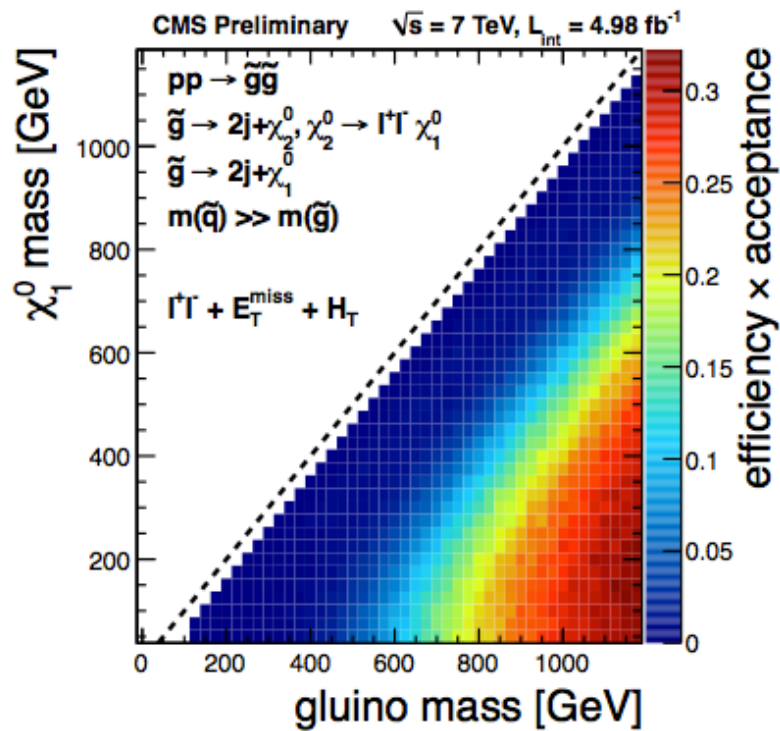
# Simplified Model Spectra

- **Simplified Model Spectra (SMS) try to express limits in a simple, more model-independent manner**
  - Small number of unambiguous physical parameters
    - Physical particle masses, Branching ratios
  - **Express limits (on  $\sigma \times \text{B.R.}$ ) in terms of physical particle masses**
  - Collapses some of the fine-structure to full SUSY mass spectra (CMSSM)
  - Results in same essential phenomenology as more complicated models
- **T1lh** is an **SMS** model in which pair produced gluinos decay into OS leptons and jets

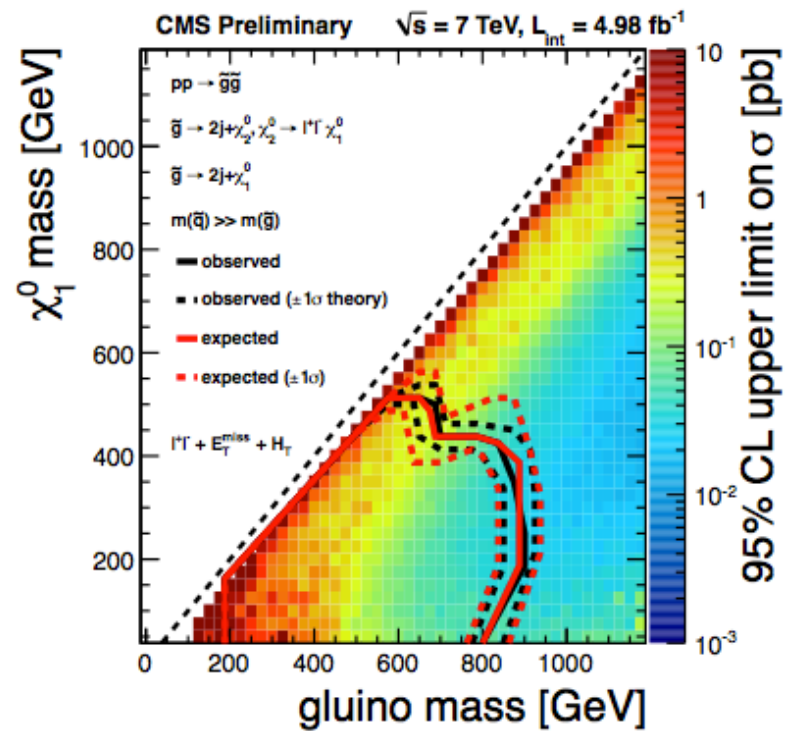
$$pp \rightarrow \tilde{g}\tilde{g} \rightarrow qq\chi_1^0 \quad qq\chi_2^0, \quad \chi_2^0 \rightarrow \ell^+\ell^-$$

# SMS Exclusion

- Exclusion contour for **SMS T1lh** model in  $(m_{\tilde{g}}, m_{\tilde{LSP}})$  plane
  - Set at 95% confidence level using CLS statistic



**Selection Efficiency  $\times$  Acceptance**



**Obs. / Exp. Exclusion Contours**

# Conclusion

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- Searched for new physics in the opposite-sign dilepton final state
  - **Signature of Missing Transverse Energy and Jets**
- **No evidence for new physics was observed**
- **Set upper limits on the non-Standard Model contribution to yields in the signal regions**
  - Most stringent limit in this channel at the time of publication
- Published in Phys. Lett. B 718, 815

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# Backup

# Data vs. Monte Carlo

**SR1**

	ee	mm	em	Total
MC	$4.0 \pm 0.5$	$4.8 \pm 0.7$	$10.1 \pm 0.7$	$18.9 \pm 1.1$
Data	7	2	10	19

**SR2**

	ee	mm	em	Total
MC	$2.2 \pm 0.2$	$2.9 \pm 0.2$	$6.3 \pm 0.5$	$11.5 \pm 0.6$
Data	3	3	5	11

**SR3**

	ee	mm	em	Total
MC	$3.5 \pm 0.2$	$5.0 \pm 0.5$	$10.6 \pm 0.5$	$19.1 \pm 0.8$
Data	3	2	13	18

**SR4**

	ee	mm	em	Total
MC	$1.0 \pm 0.1$	$1.1 \pm 0.2$	$2.2 \pm 0.2$	$4.2 \pm 0.3$
Data	2	1	3	6

**Data and MC agree well in all signal regions (errors stat. only)**

# W polarization

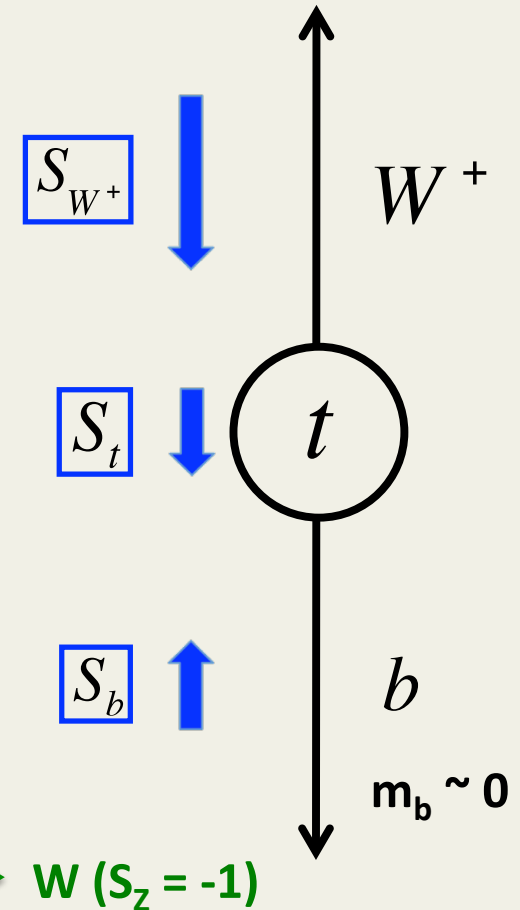
- The W has three polarization states

- W ( $S_z = 0$ ), W ( $S_z = -1$ ) are allowed

- W ( $S_z = 1$ ) is forbidden

- No configuration conserves  $J_z$

$S_t$	=	$S_W$	+	$S_b$
+1/2	=	0	+	+1/2
+1/2	=	+1	+	+1/2
+1/2	=	-1	+	+1/2
-1/2	=	0	+	+1/2
-1/2	=	+1	+	+1/2
-1/2	=	-1	+	+1/2



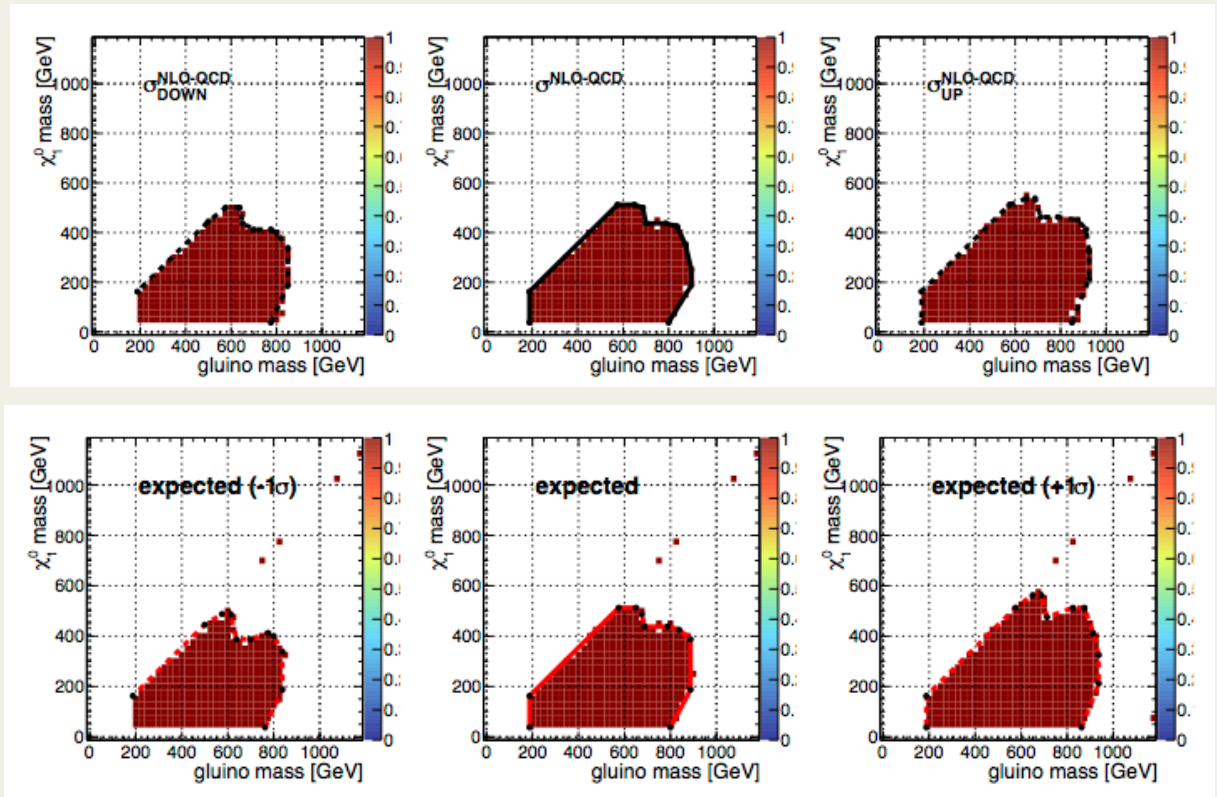
- W's from top are longitudinally or negatively polarized

# Systematic Errors

---

- **Luminosity, lepton, & trigger efficiencies**
  - Systematic errors taken as constant for all signal models
    - Luminosity uncertainty  $\sim 4.5\%$
    - Trigger efficiency uncertainty  $\sim 2.0\%$
    - Dilepton identification & isolation uncertainty  $\sim 2.0\%$
- **Hadronic Energy Scale**
  - Systematic errors determined from sensitivity of signal region yields to **7.5%** variation in the hadronic energy scale
  - Computed separately for each signal model
    - Varies from **20% – 50%**

# SMS Limits



- Top: Observed
- Bottom: Expected

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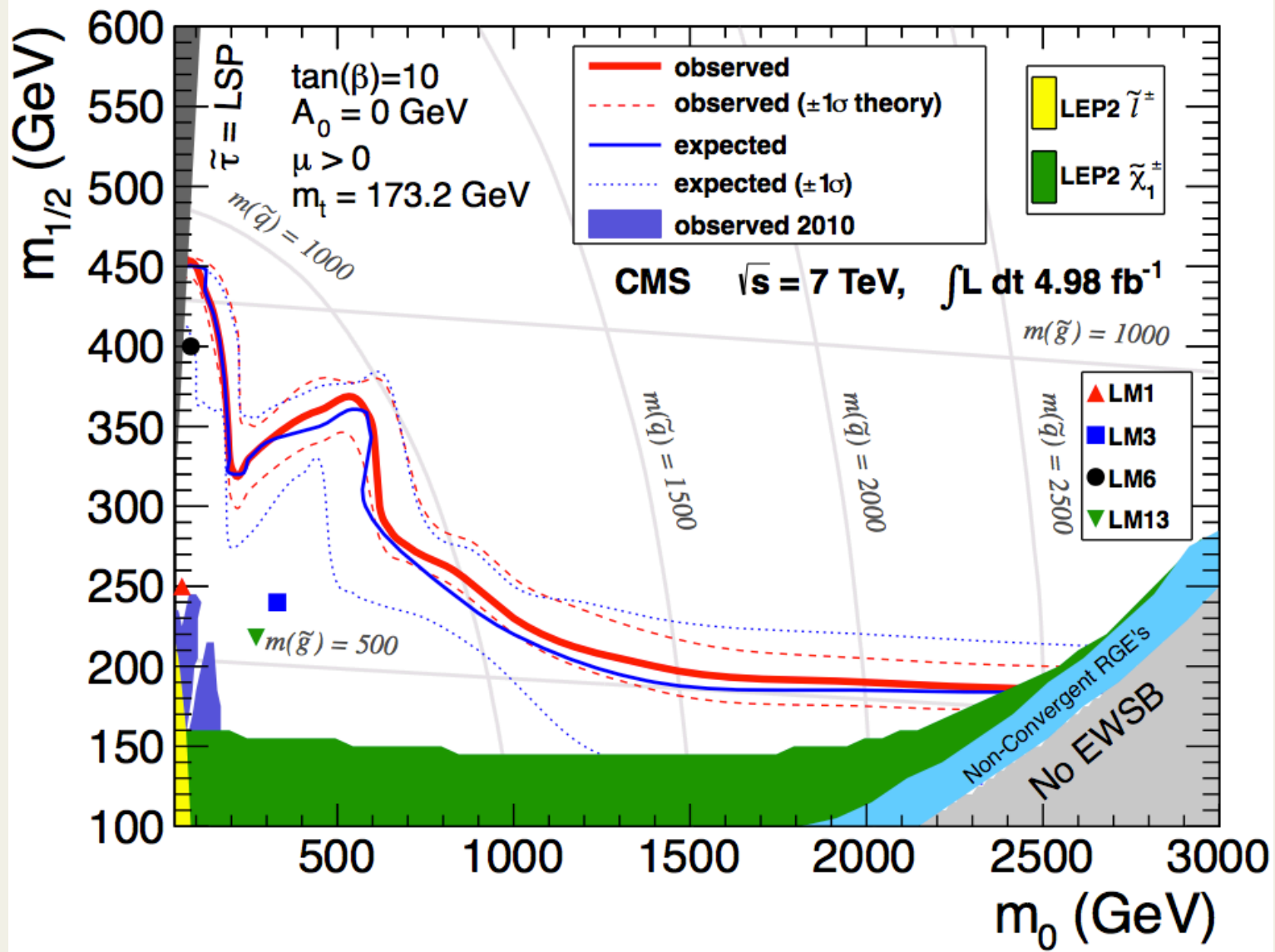
# **CMSSM Limits**

# CMSSM

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- **SUSY models can have many parameters**
  - The Minimal Supersymmetric Standard Model (MSSM) has 105 parameters, for example
    - Many can be eliminated by experimental constraints
  - **The Constrained MSSM (CMSSM) has 5 parameters**
    - The gluino and scalar masses are taken to unify at the GUT scale
    - $m_0$ ,  $m_{1/2}$  are the gaugino, scalar masses respectively ( GUT scale )
    - $A_0$  is 3-gaugino coupling at the GUT scale
    - $\mu$  is the Higgsino mass ( GUT scale )
    - $\tan \beta$  is the ratio of VEV 's of the Higgs doublets ( EWK scale )
- **The CMSSM is often used to interpret experimental results**
  - Limits on new physics expressed in  $(m_0, m_{1/2})$  plane

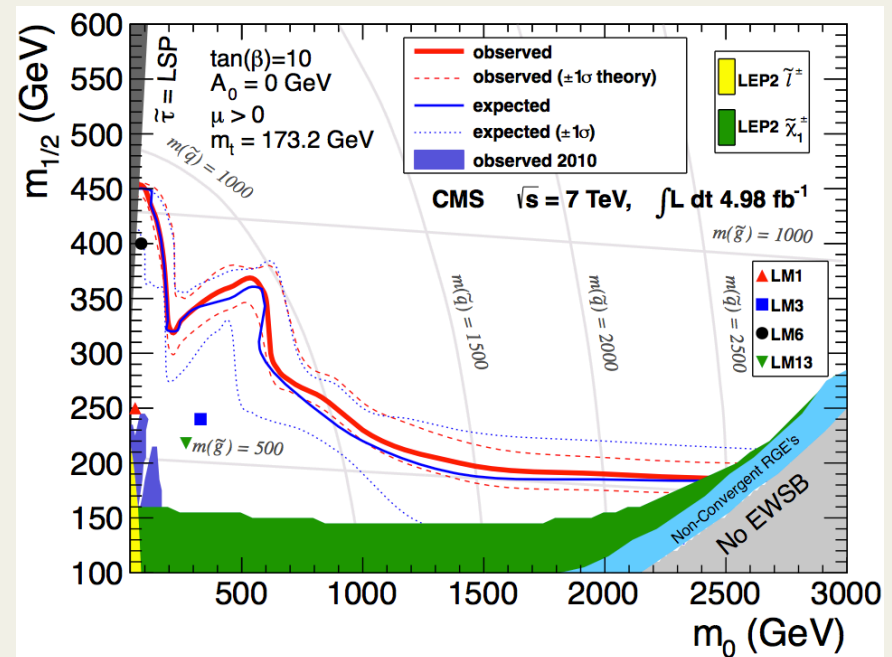
# CMSSM Exclusion



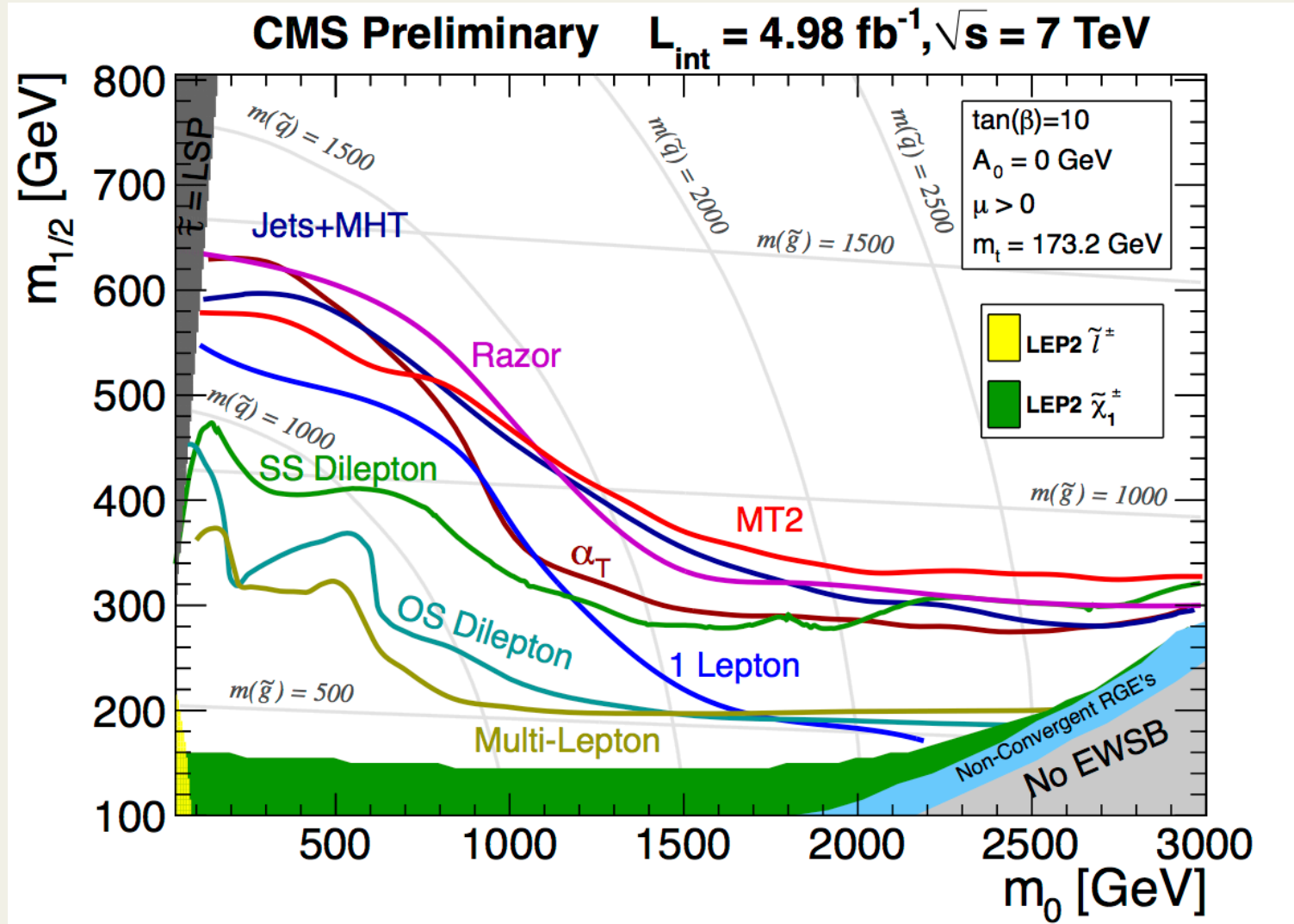
# CMSSM Exclusion: Discussion

- Acceptance Uncertainties

Signal Model	high $E_T^{\text{miss}}$	high $H_T$	tight	low $H_T$
LM1	22%	33%	40%	19%
LM3	26%	34%	42%	18%
LM6	11%	15%	19%	10%
LM13	26%	31%	40%	14%



# CMSSM Comparison



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# Outreach

# Efficiency Model (1)

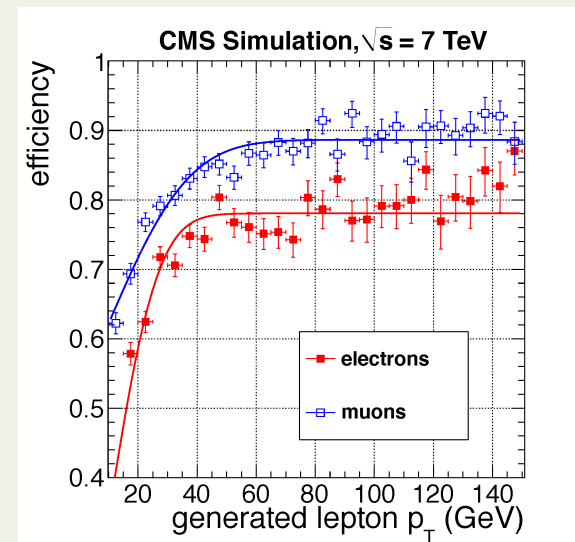
- **How can one tell if a new physics model is excluded or not?**
  - Yields for an arbitrary new physics model can be found at generator level for each signal region

- **The lepton selection efficiency is needed**

- “selection efficiency” = Id & isolation
- Signal selection efficiencies needed also
- Trigger  $\varepsilon$  (100% ee , 95% e $\mu$  , 90%  $\mu\mu$ )

- **Functions fit to the lepton efficiencies are provided:**

$$f(P_T) = \varepsilon_\infty \text{Erf}\left(\frac{P_T - C}{\sigma}\right) + \varepsilon_C \left[1 - \text{Erf}\left(\frac{P_T - C}{\sigma}\right)\right]$$



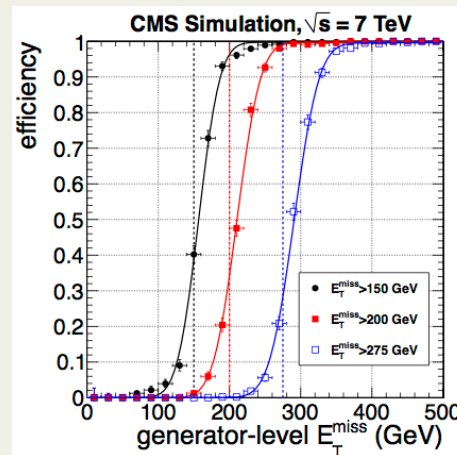
Param	Electrons	Muon
C	10 GeV	10 GeV
$\varepsilon(\infty)$	0.78	0.89
$\varepsilon(C)$	0.34	0.62
$\sigma$	18 GeV	30 GeV

# Efficiency Model (2)

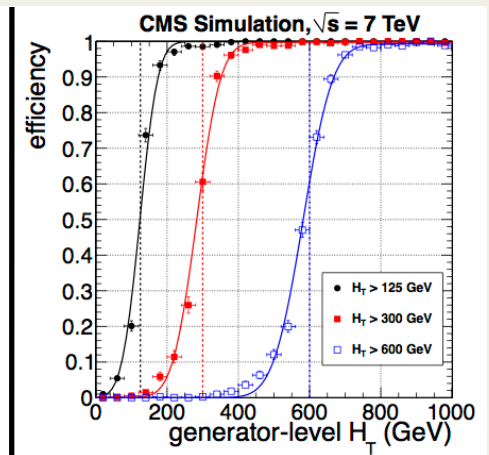
- How can one tell if a new physics model is excluded or not?
  - The signal region selection efficiencies are needed
  - Trigger efficiencies & lepton selection efficiencies given

- Functions fit to the signal selection efficiencies are provided:

$$f(x) = \frac{1}{2} \varepsilon_{\infty} \left[ \text{Erf} \left( \frac{x - C}{\sigma} \right) + 1 \right]$$



Param	MET > 200 GeV	MET > 275 GeV
$e(\infty)$	1	1
C	211 GeV	291 GeV
$\sigma$	33 GeV	39 GeV

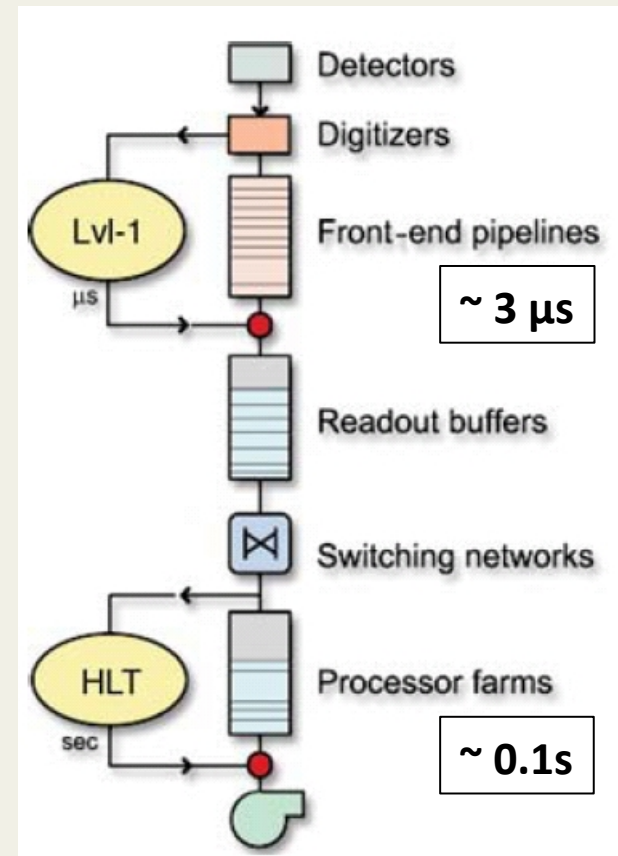


Param	HT > 300 GeV	HT > 600 GeV
$e(\infty)$	1	0.99
C	283 GeV	582 GeV
$\sigma$	75 GeV	93 GeV

- Efficiency model reproduces full reconstruction results to ~ 5%

# Trigger & Data Acquisition

- **Select & save “interesting” events**
  - Defined by trigger menu ( example: 2 muons with  $P_T > 20$  GeV )
- **The LHC collision rate is 40 MHz**
  - Can only store a few **100 events / s**
    - Event size is **~ 1 MB**
    - Two tier trigger chooses events
  - **Level 1 Trigger**
    - 100 kHz event bandwidth
    - Local to subsystems, fast custom hardware
  - **High Level Trigger** ( ~ a few 100 Hz )
    - Global trigger, synchronizes L1
    - Software distributed across ~1k processors



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# **Selections**

# Data & Triggers

- **Data**
  - **5 fb<sup>-1</sup>** of integrated luminosity collected on dilepton triggers
- **Triggers:** High  $P_T$  dilepton triggers (ee,  $\mu\mu$ , e $\mu$ )

Trigger	Efficiency	Pt Threshold of Leading Lepton	Pt Threshold of Trailing Lepton
ee	100%	17 GeV	8 GeV
e $\mu$	95%	17 GeV	8 GeV
$\mu\mu$	90%	7 GeV	7 GeV
		13 GeV	7 GeV , 8 GeV
		17 GeV	8 GeV

## Online selections:

Leading lepton  $P_T > 20$  GeV

Trailing lepton  $P_T > 10$  GeV

- **Good trigger efficiency: 5% inefficiency measured per-muon**
- **Uncertainty in trigger efficiency: 2%**

# Lepton Selections

## Electrons

- Impact Parameter
  - $d_0 < 400 \mu\text{m}$
  - $d_z < 1 \text{ cm}$
- **Isolation < 0.15**
  - Cone of  $\Delta R = 0.3$  ( 1 GeV subtraction EB )
- Identification
  - $\sigma_{\text{in-in}} < 0.01$  ( 0.03 Endcap )
  - $d\phi < 0.15$  ( 0.10 Endcap )
  - $d\eta < 0.007$  ( 0.009 Endcap )
  - $H/E < 0.1$  ( 0.075 Endcap )
- Conversion Rejection:
  - $|\text{dist}| < 0.02 \text{ cm}$
  - $|d(\cot\theta)| < 0.02$
  - Less than 2 missing expected inner hits
- Muon Veto
  - Veto if a muon is within a cone of  $\Delta R = 0.1$
- $|\eta_{\text{SC}}| < 1.444$  OR  $|\eta_{\text{SC}}| > 1.556$

## Muons

- Impact Parameter
  - $d_0 < 200 \mu\text{m}$
  - $d_z < 1 \text{ cm}$
- **Isolation < 0.15**
  - Cone of  $\Delta R = 0.3$
- Global Muon & Tracker Muon
- $\chi^2 / (\# \text{ degrees of freedom}) < 10$
- 11 or more tracker muon fit hits
- $\geq 1$  stand alone hits in global muon fit
- $\delta p_t / p_t < 0.1$

# Dilepton Selections

- **Dilepton Selection**

- 2 leptons of opposite charge
- Must pass a dilepton trigger
- Transverse Momentum
  - $P_T > 10 \text{ GeV}$  ( Both leptons )
  - $P_T > 20 \text{ GeV}$  ( Highest  $P_T$  lepton )
- Pseudo rapidity
  - $|\eta| < 2.5$  ( Electrons )
  - $|\eta| < 2.4$  ( Muons )
- Must pass lepton selections
  - Described on previous slide
  - Isolation  $< 0.15$  ( cone of  $\Delta R = 0.3$  )
  - $d_0 < 400 \mu\text{m}$  (  $200 \mu\text{m}$  ) electrons ( muons )

- Event Selections ( listed previously )

- Good vertices with more than 4 D.O.F.
- $d_0 < 2 \text{ cm}$  ,  $d_z < 24 \text{ cm}$  ( Vertex )

- **Dilepton Selection Efficiency**

- Electrons

- $20 \text{ GeV} < P_T$                       ~ 90 %
- $15 \text{ GeV} < P_T < 20 \text{ GeV}$         ~ 70 %
- $10 \text{ GeV} < P_T < 15 \text{ GeV}$         ~ 50 %

- Muons

- $20 \text{ GeV} < P_T$                       ~ 95 %
- $15 \text{ GeV} < P_T < 20 \text{ GeV}$         ~ 85 %
- $10 \text{ GeV} < P_T < 15 \text{ GeV}$         ~ 75 %

- Uncertainty on selection efficiency

- 2% ( Identification and Isolation )

# Tag & Probe

- $e$

		10 - 15 GeV	15 - 20 GeV	20 - 40 GeV	40 GeV -
ISO	MC	$0.8402 \pm 0.0037$	$0.8968 \pm 0.0017$	$0.9718 \pm 0.0002$	$0.9938 \pm 0.0001$
	DATA	$0.7801 \pm 0.0047$	$0.8796 \pm 0.0021$	$0.9701 \pm 0.0002$	$0.9926 \pm 0.0001$
	DATA/MC	$0.9284 \pm 0.0070$	$0.9809 \pm 0.0030$	$0.9982 \pm 0.0003$	$0.9987 \pm 0.0001$
ID	MC	$0.6756 \pm 0.0042$	$0.8064 \pm 0.0021$	$0.9040 \pm 0.0003$	$0.9232 \pm 0.0003$
	DATA	$0.6743 \pm 0.0050$	$0.8152 \pm 0.0024$	$0.9039 \pm 0.0004$	$0.9167 \pm 0.0003$
	DATA/MC	$0.9981 \pm 0.0096$	$1.0109 \pm 0.0040$	$0.9999 \pm 0.0005$	$0.9930 \pm 0.0004$
ID X ISO	MC	$0.5677 \pm 0.0043$	$0.7231 \pm 0.0023$	$0.8785 \pm 0.0004$	$0.9175 \pm 0.0003$
	DATA	$0.5260 \pm 0.0050$	$0.7171 \pm 0.0027$	$0.8768 \pm 0.0004$	$0.9099 \pm 0.0003$
	DATA/MC	$0.9266 \pm 0.0113$	$0.9916 \pm 0.0049$	$0.9981 \pm 0.0006$	$0.9917 \pm 0.0005$

- $\mu$

		10 - 15 GeV	15 - 20 GeV	20 - 40 GeV	40 GeV -
ISO	MC	$0.8124 \pm 0.0025$	$0.8773 \pm 0.0013$	$0.9634 \pm 0.0002$	$0.9931 \pm 0.0001$
	DATA	$0.7744 \pm 0.0028$	$0.8600 \pm 0.0015$	$0.9590 \pm 0.0002$	$0.9906 \pm 0.0001$
	DATA/MC	$0.9533 \pm 0.0045$	$0.9803 \pm 0.0023$	$0.9954 \pm 0.0003$	$0.9974 \pm 0.0001$
ID	MC	$0.9892 \pm 0.0007$	$0.9892 \pm 0.0004$	$0.9899 \pm 0.0001$	$0.9873 \pm 0.0001$
	DATA	$0.9867 \pm 0.0009$	$0.9869 \pm 0.0005$	$0.9868 \pm 0.0001$	$0.9837 \pm 0.0001$
	DATA/MC	$0.9975 \pm 0.0011$	$0.9977 \pm 0.0007$	$0.9969 \pm 0.0002$	$0.9964 \pm 0.0002$
ID X ISO	MC	$0.8036 \pm 0.0025$	$0.8678 \pm 0.0014$	$0.9537 \pm 0.0002$	$0.9805 \pm 0.0001$
	DATA	$0.7641 \pm 0.0028$	$0.8488 \pm 0.0016$	$0.9464 \pm 0.0002$	$0.9744 \pm 0.0002$
	DATA/MC	$0.9509 \pm 0.0046$	$0.9780 \pm 0.0024$	$0.9923 \pm 0.0003$	$0.9938 \pm 0.0002$

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**PtII**

# $P_T^{ll}$ Method: Calculation of $K_C$

- $K_C$  is a correction for **W Polarization** in **ttbar**  $\rightarrow ll$ 
  - Applied to  $N ( P_T^{ll} > X )$  to predict  $N ( MET > X )$

Signal Region	$K_C^*$
<b>SR1</b>	$1.66 \pm 0.12$
<b>SR2</b>	$1.66 \pm 0.13$
<b>SR3</b>	$1.29 \pm 0.07$
<b>SR4</b>	$0.98 \pm 0.12$

$$K_C \propto \frac{N_{E_T}^{MC} (E_T > X, H_T > Y)}{N_{P_T^{ll}}^{MC} (P_T^{ll} > X, H_T > Y)}$$

\* Errors here are statistical only

- $K_C$  is calculated from Monte-Carlo
  - Trust based in precision electroweak measurements
  - Depending on kinematics:  $1.0 < K_C < 1.7 \pm ( 6\% - 12\% ) K_C$

# $P_T^{ll}$ Method: Calculation of K

- The  $P_T^{ll}$  method predicts **MET** from  $P_T^{ll}$  in ttbar
  - If a selection on **MET** is applied, the  $P_T^{ll}$  distribution must be scaled up by a factor **K** to predict **MET**
    - **MET > 50 GeV (75 GeV) OF (SF)** to suppress Drell-Yan

- **K** agrees well between data & Monte-Carlo

Signal Region	K MC	K Data
SR1	$1.73 \pm 0.01$	$1.65 \pm 0.12$
SR2	$1.46 \pm 0.05$	$1.56 \pm 0.41$
SR3	$1.46 \pm 0.05$	$1.40 \pm 0.49$
SR4	$2.00 \pm 0.01$	$1.90 \pm 0.05$

- **K** measured in data will be used (  $1.4 < K < 1.9$  )

# $P_T^{\ell\ell}$ Method: Systematic Errors

- Systematic error  $P_T^{\ell\ell}$  background prediction

$$N_{E_T}^{\text{Predicted}} = \left( N_{P_T^{\ell\ell}}^{\text{Observed}} - N_{\text{Drell-Yan}}^{\text{Predicted}} \right) \times K \times K_C$$

$$\sigma_{\text{sys}}^2 = \left( \frac{\sigma_K^2}{K^2} + \frac{\sigma_{K_C}^2}{K_C^2} \right) \left( N_{E_T}^{\text{Predicted}} \right)^2 + K^2 \times K_C^2 \times \sigma_{R_{\text{out/in}}}^2 \times \left( N_{\text{SF-in}} - k_\epsilon \times N_{\text{OF-in}} \right)^2$$

- Example (SR1):

- K:  $(0.12 / 1.65)^2 (11.47)^2 = 0.70$
- $K_C$ :  $(0.70 / 1.66)^2 (11.47)^2 = 23.39$
- $R_{\text{out/in}}$ :  $(1.65)^2 (1.66)^2 (0.07)^2 (15 - 1.13 \times 1)^2 = 7.07$

Signal Region	Observed $P_{Tl} > X$	<u>Drell-Yan</u> Estimate	K	$K_C$	<u>P<sub>Tl</sub></u> Method Prediction
<b>SR1</b>	6	1.82	$1.65 \pm 0.12$	$1.66 \pm 0.7$	<b><math>11.47 \pm 7.27 \pm 5.58</math> (sys)</b>

# $P_T^{ll}$ Method: MET Resolution

---

- The  $P_T^{ll}$  resolution is much better than the MET resolution
- MET resolution effects can be modeled with a MET bias term and Gaussian term
- **It turns out to be a  $\sim 10\%$  effect in the  $P_T^{ll}$  background predictions**

# $P_T^{ll}$ Method: Signal Contamination

---

- **Signal contamination in the  $P_T^{ll}$  signal regions used to predict MET is inevitable.**
  - This leads to overestimation of MET
- **Overestimation can be large**
  - Factor of 1.7 (LM0) to 2.5 (LM1)
- **However, the excess can still be observable**
  - LM0:      Observed: 71      Predicted: 23
  - LM1:      Observed: 38      Predicted: 16
- **Upon observation of an excess, the game changes**
  - Examine all distributions to understand signal character

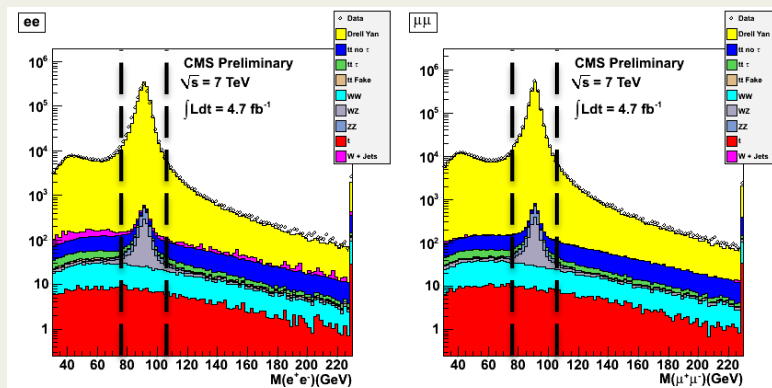
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**Drell-Yan**

# Z Peak Yields

- Yields for  $76 \text{ GeV} < M_{ll} < 106 \text{ GeV}$ 
  - Basic selections applied

Sample	N(ee)	N( $\mu\mu$ )	N( $\mu\mu$ ) / N(ee)
Data	1,402,167	1,787,957	1.28
MC	1,400,681	1,704,862	1.22
Data / MC	1.00	1.05	



**Z Peak yields in data & MC agree within  $\sim 5\%$  or better**

- Significant uncertainties in luminosity ( $\sim 4.5\%$ ), lepton Id & Isolation ( $\sim 2\%$ ), and dilepton trigger efficiency ( $\sim 2\%$ )

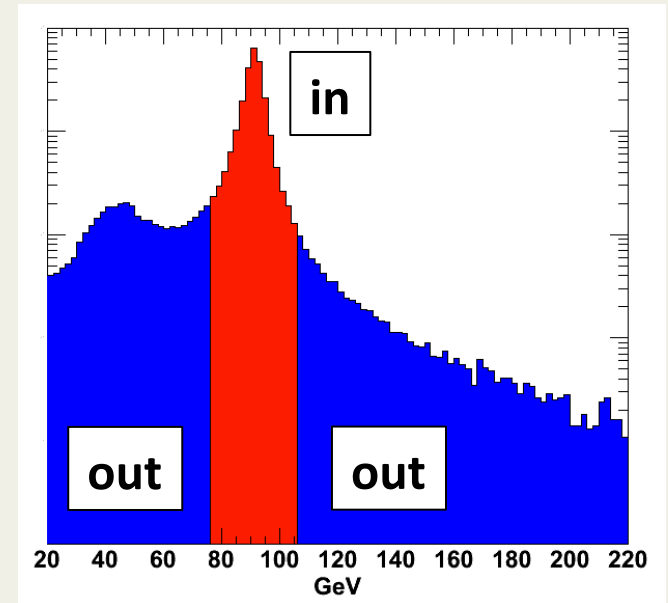
# Drell-Yan Background: Estimation Method

(1)

- The Drell-Yan background is largely removed
  - MET > 50 GeV ( 75 GeV ) Opposite Flavor ( Same Flavor )
  - Z resonance removed:  $76 \text{ GeV} < M_{\ell^+\ell^-} < 106 \text{ GeV}$  vetoed
- Need to estimate residual off-peak Drell-Yan
  - Use data events in the Z-Peak
  - Apply a correction factor from Monte-Carlo to predict off-peak Drell-Yan

$$R_{out/in}^{MC} \equiv N_{\ell^-\ell^+ - out}^{Drell-Yan MC} / N_{\ell^-\ell^+ - in}^{Drell-Yan MC}$$

$$N_{Drell\ Yan - out}^{Data\ Est.} = R_{out/in}^{MC} \times N_{Same\ Flavor - in}^{Data} + \dots$$



# Drell-Yan Background: Estimation Method

## (2)

- Estimate off-peak Drell-Yan from in-peak

$$N_{\text{Drell-Yan-out}}^{\text{Data Est.}} = R_{\text{out/in}}^{\text{MC}} \times N_{\text{Same Flavor-in}}^{\text{Data}} + \dots, \quad R_{\text{out/in}}^{\text{MC}} \equiv \frac{N_{\ell^-\ell^+-\text{out}}^{\text{Drell-Yan MC}}}{N_{\ell^-\ell^+-\text{in}}^{\text{Drell-Yan MC}}}$$

- **But there is ttbar in the data Z-Peak too**
  - Causes overestimation of Drell-Yan background
  - **ttbar contribution to the Z-Peak can be corrected for**
    - It is half of the opposite flavor yield in the Z-Peak, corrected for differences in electron & muon efficiencies

$$N_{\text{Drell-Yan-out}}^{\text{Data Est.}} = R_{\text{out/in}}^{\text{MC}} \left( N_{\text{Same Flavor-in}}^{\text{Data}} - N_{e\mu-\text{in}}^{\text{Data}} \times \frac{1}{2} \left( k_{\mu\mu} + \frac{1}{k_{\mu\mu}} \right) \right), \quad k_{\mu\mu} = \sqrt{\frac{N_{\mu\mu-\text{in}}^{\text{Data}}}{N_{ee-\text{in}}^{\text{Data}}}}$$

# Drell-Yan Background: Results (1)

- Calculation of Drell-Yan background estimates:

$$N_{Drell-Yan\ out}^{Data\ Est.} = R_{out/in}^{MC} \times \left( N_{ee-in}^{Data} + N_{\mu\mu-in}^{Data} - N_{e\mu-in}^{Data} \times \frac{1}{2} \left( k_{\mu\mu} + \frac{1}{k_{\mu\mu}} \right) \right)$$

$$R_{out/in}^{MC} = 0.13 \pm 0.07 \quad , \quad k_{\mu\mu} = 1.13 \pm 0.05 \quad \underbrace{\hspace{10em}}_{\sim 1}$$

- Data-driven Drell-Yan background estimation confirms Monte-Carlo prediction that Drell-Yan is negligible

Signal Region	ee	$\mu\mu$	$e\mu$	DY Estimate	Drell-Yan MC
<b>SR1</b>	2	0	0	$+0.26 \pm 0.26$	$2.0 \pm 0.9$
<b>SR2</b>	0	1	2	$-0.13 \pm 0.32$	$0.3 \pm 0.3$
<b>SR3</b>	1	0	1	$+0.00 \pm 0.20$	$0.7 \pm 0.5$
<b>SR4</b>	0	0	0	$+0.00 \pm 0.00$	$0.0 \pm 0.0$

# Drell-Yan Background: Results (2)

- The  $P_T^{\ell\ell}$  method (previously discussed) works for  $t\bar{t}$ 
  - Residual Drell-Yan inevitably contaminates the signal regions
  - This Drell-Yan contamination to  $P_T^{\ell\ell}$  can be corrected for

$$N_{E_T}^{\text{Predicted}} = \left( N_{P_T^{\ell\ell}}^{\text{Observed}} - N_{\text{Drell-Yan}}^{\text{Predicted}} \right) \times K \times K_C$$

Signal Region	Drell Yan
SR1	$1.82 \pm 1.96$
SR2	$0.91 \pm 0.91$
SR3	$0.78 \pm 0.78$
SR4	$0.39 \pm 0.39$

- Use Drell-Yan Estimation Method
  - Selection in  $P_T^{\ell\ell}$  used to predict MET
  - Replace MET cut with  $P_T^{\ell\ell}$  cut
- The **Drell-Yan estimate** will be subtracted from each SR
  - Improves the  $P_T^{\ell\ell}$  estimate of the  $t\bar{t}$  background

# Drell-Yan Background: Estimation Method

- The Drell-Yan background estimate from before:

$$N_{\ell^-\ell^+_{SF-out}}^{Data} = R_{out/in}^{MC} \times \left( N_{\ell^-\ell^+_{SF-in}}^{Data} - \frac{1}{2} k_{\ell^-\ell^+} \times N_{e\mu-in}^{Data} \right)$$

$$k_{\mu^-\mu^+} = \sqrt{\frac{N_{\mu\mu-in}^{Data}}{N_{ee-in}^{Data}}} = k_{e^-e^+}^{-1}$$

- Total Drell-Yan background is the sum of ee , μμ:**

$$N_{ee-out}^{Data} = R_{out/in}^{MC} \left( N_{ee-in}^{Data} - \frac{1}{2} N_{e\mu-in}^{Data} \times k_{ee} \right) \quad N_{\mu\mu-out}^{Data} = R_{out/in}^{MC} \left( N_{\mu\mu-in}^{Data} - \frac{1}{2} N_{e\mu-in}^{Data} \times k_{\mu\mu} \right)$$

$$N_{Drell\ Yan-out}^{Data\ Est.} = R_{out/in}^{MC} \times \left( N_{e^-e^+-in}^{Data} + N_{\mu^-\mu^+-in}^{Data} - \frac{1}{2} N_{e\mu-in}^{Data} \times \left( k_{\mu\mu} + \frac{1}{k_{\mu\mu}} \right) \right)$$

---

# Results

# Preselection Yields

- CMSSM Monte-Carlo predictions
  - Previously showed data & SM MC agreement in a dilepton tt sample
  - Selections: MET > 50 GeV, HT > 100 GeV, NJets > 1, Z Veto, Lepton
  - **Table shows comparison of CMSSM & Standard Model Monte-Carlo predictions with data for a few signal points:**

	ee	μμ	eμ	tot
<b>Total SM MC</b>	2224.3 ± 51.5	2735.4 ± 61.8	6068.8 ± 135	11028.5 ± 244.3
<b>Data</b>	2333	2873	6184	11390
<b>CMSSM LM1 MC</b>	271.8 ± 8.3	342.1 ± 9.7	165.6 ± 5.7	779.6 ± 19.6
<b>CMSSM LM3 MC</b>	106.9 ± 3.7	125.2 ± 4.1	180.7 ± 5.5	412.8 ± 10.7
<b>CMSSM LM6 MC</b>	19.5 ± 0.6	23.2 ± 0.7	26.2 ± 0.8	68.8 ± 1.7

- **LM1, LM3** already disfavored by Monte-Carlo
- **LM6** & other CMSSM points clearly not excludable

Note: Errors shown are statistical

# $P_T^{ll}$ Method: Dependence of $K_C$ on Jet Energy Scale

- Calibrated jet energies have significant systematics
- Systematics on  $K_C$  due to uncertainty in the Jet Energy Scale (JES)
  - **Uncertainty on  $K_C$  taken to be its response to  $\pm 7.5\%$  change in jet energy**

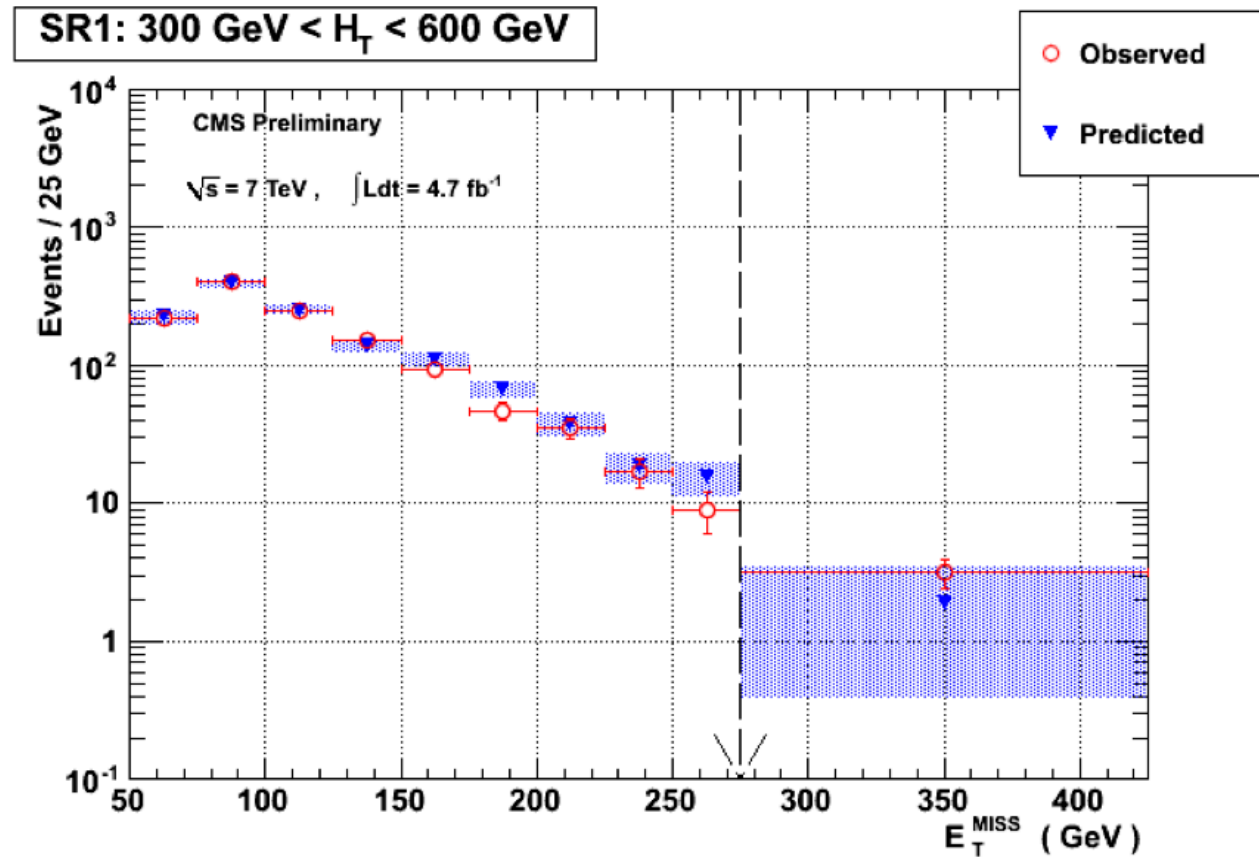
MADGRAPH	Nominal	JES Up 7.5%	JES Down 7.5%	Uncertainty
SR1	$1.66 \pm 0.12$	$2.78 \pm 0.20$	$1.01 \pm 0.08$	<b>68 %</b>
SR2	$1.66 \pm 0.13$	$2.09 \pm 0.13$	$1.23 \pm 0.12$	<b>35 %</b>
SR3	$1.29 \pm 0.07$	$1.49 \pm 0.06$	$1.16 \pm 0.07$	<b>15 %</b>
SR4	$0.98 \pm 0.12$	$1.40 \pm 0.18$	$0.72 \pm 0.09$	<b>43 %</b>

- **Uncertainty on  $K_C$  due to JES is about 15% to 70%**

# $P_T^{ll}$ Method: Results

- SR1

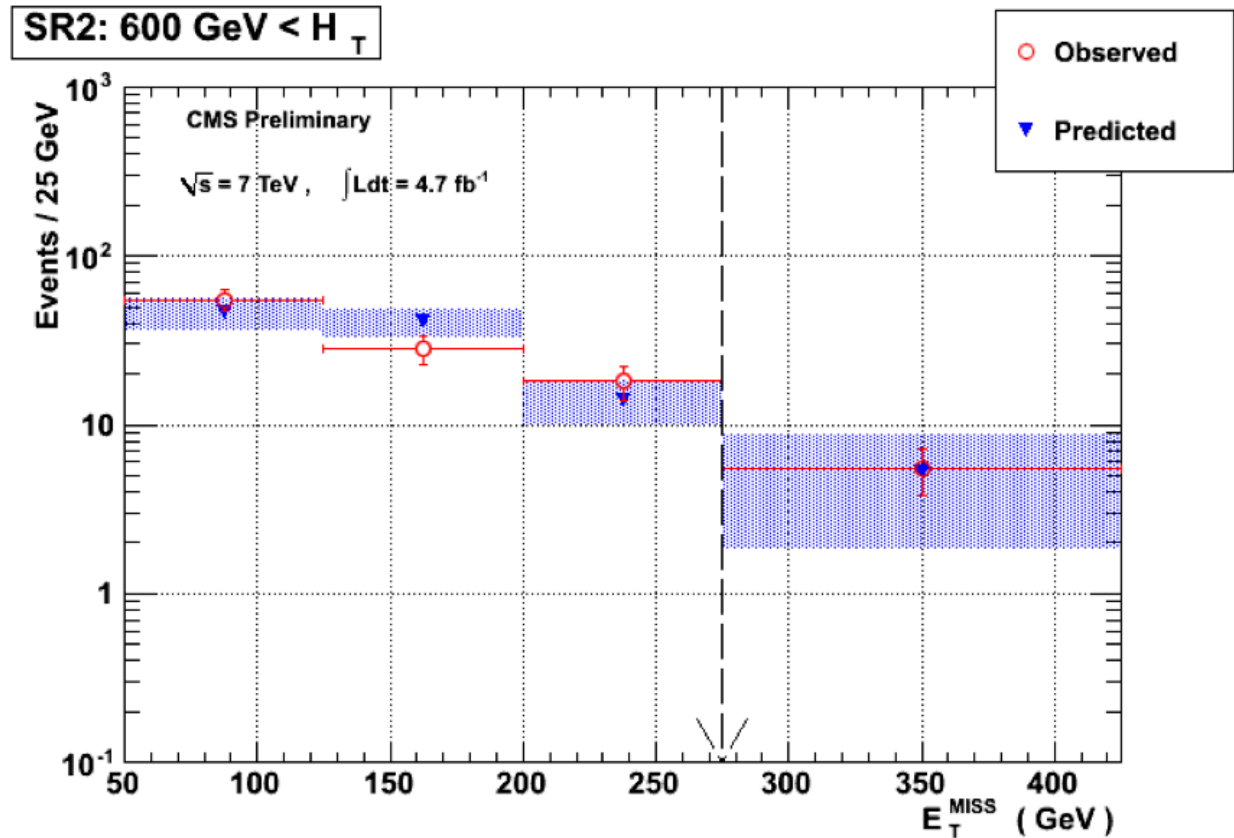
Figure 18.4: Results of the  $p_T(\ell\ell)$  method in the SR1 signal region. Distributions of  $p_T(\ell\ell)$  (Predicted) and  $E_T^{\text{miss}}$  (Observed) in data for the region  $300 \text{ GeV} < H_T < 600 \text{ GeV}$  are shown. The vertical dashed line indicates the requirement  $E_T^{\text{miss}} > 275 \text{ GeV}$ . The observed yield in this region is 19, which is consistent with the predicted yield of  $11.5 \pm 7.3 \pm 5.6$ .



# $P_T^{\ell\ell}$ Method: Results

- SR2

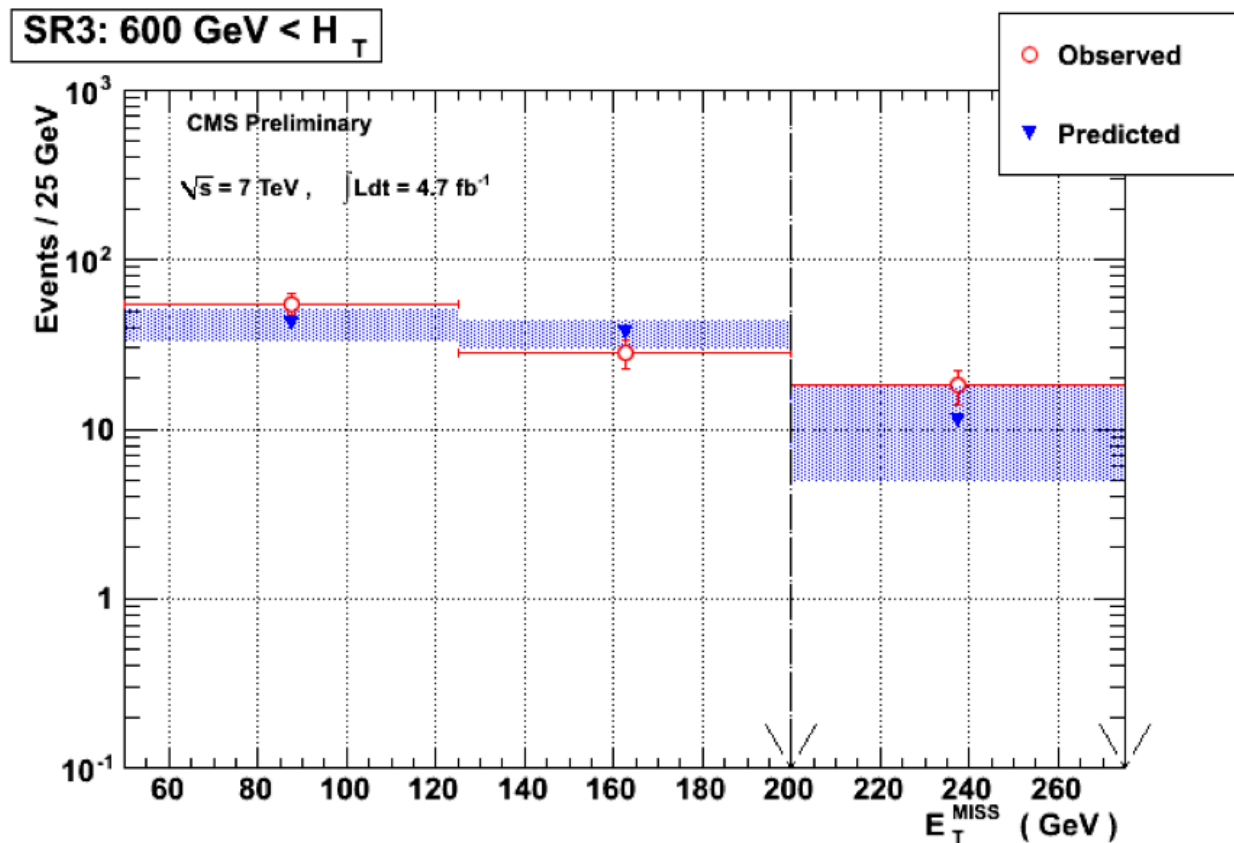
Figure 18.5: Results of the  $p_T(\ell\ell)$  method in the SR2 signal region. Distributions of  $p_T(\ell\ell)$  (Predicted) and  $E_T^{\text{miss}}$  (Observed) in data for the region  $H_T > 600$  GeV are shown. The vertical dashed line indicates the requirement  $E_T^{\text{miss}} > 275$  GeV. The observed yield in this region is 11, which is consistent with the predicted yield of  $10.6 \pm 5.8 \pm 3.8$ .



# $P_T^{\ell\ell}$ Method: Results

- **SR3**

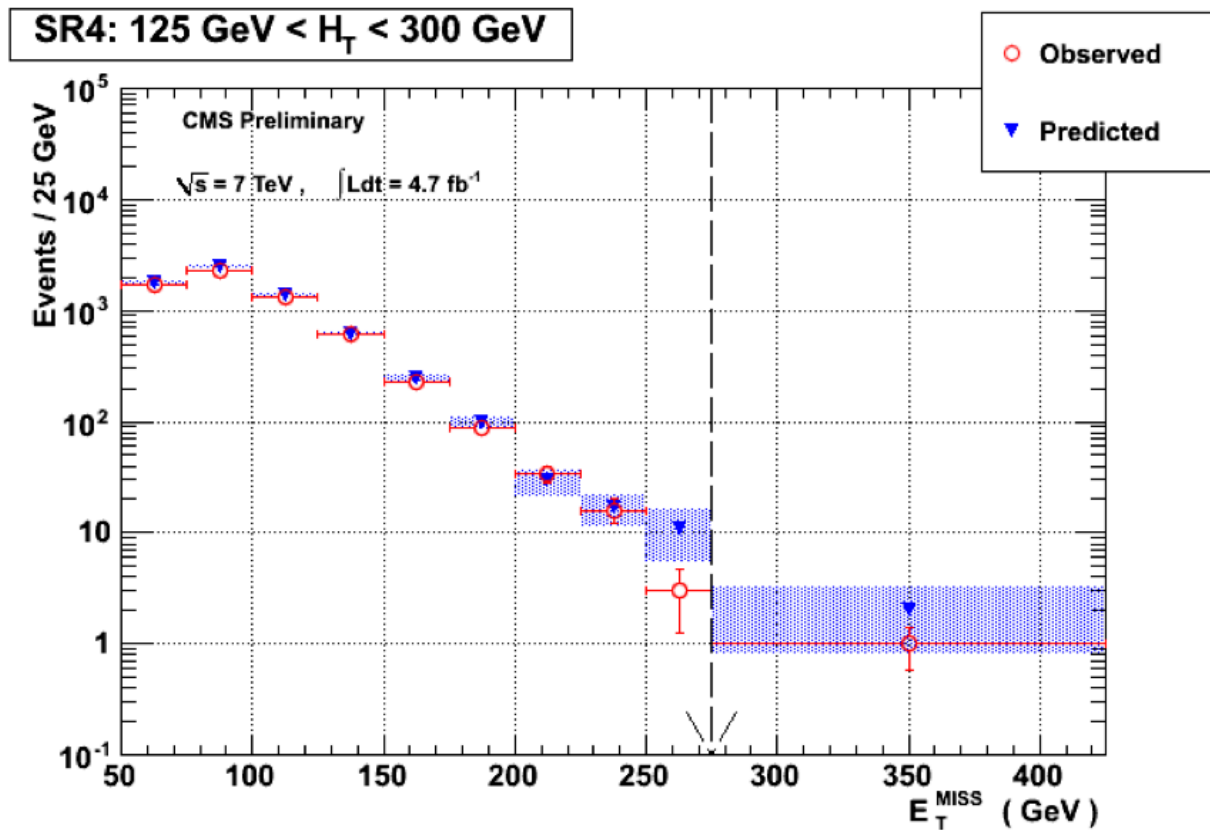
Figure 18.6: Results of the  $p_T(\ell\ell)$  method in the SR3 signal region. Distributions of  $p_T(\ell\ell)$  (Predicted) and  $E_T^{\text{miss}}$  (Observed) in data for the region  $H_T > 600$  GeV are shown. The vertical dashed lines indicate the requirement  $200 \text{ GeV} < E_T^{\text{miss}} < 275 \text{ GeV}$ . The observed yield in this region is 18, which is consistent with the predicted yield of  $11.3 \pm 4.8 \pm 4.2$ .



# $P_T^{\ell\ell}$ Method: Results

- SR4

Figure 18.7: Results of the  $p_T(\ell\ell)$  method in the SR4 signal region. Distributions of  $p_T(\ell\ell)$  (Predicted) and  $E_T^{\text{miss}}$  (Observed) in data for the region  $H_T > 300$  GeV are shown. The vertical dashed line indicates the requirement  $E_T^{\text{miss}} > 275$  GeV. The observed yield in this region is 6, which is consistent with the predicted yield of  $12.35 \pm 4.9 \pm 5.7$ .

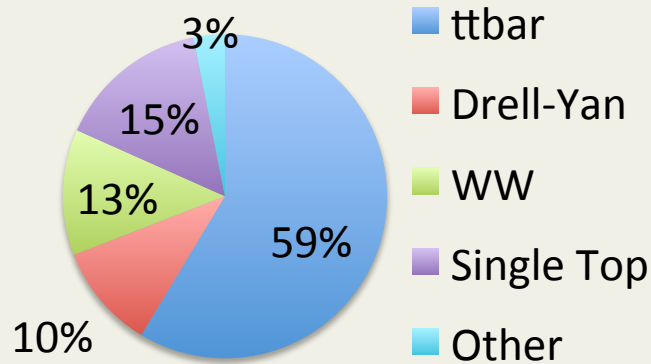


# Background Composition

## Signal Region 1

275 GeV < MET

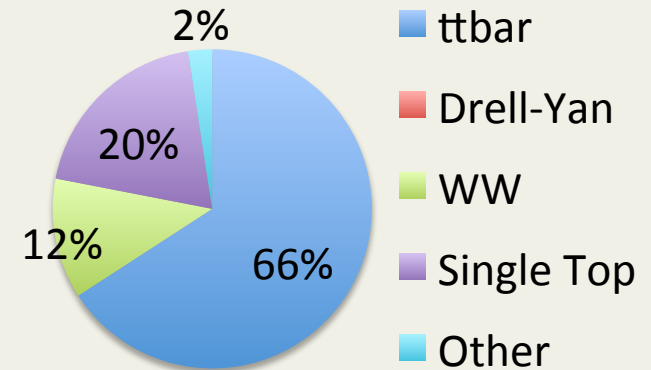
300 GeV <  $H_T$  < 600 GeV



## Signal Region 4

275 GeV < MET

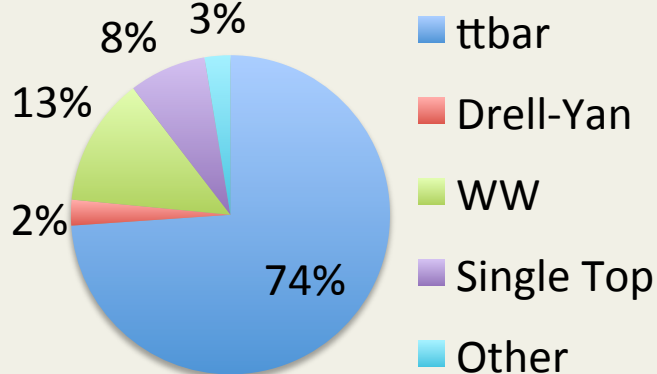
125 GeV <  $H_T$  < 300 GeV



## Signal Region 2

275 GeV < MET

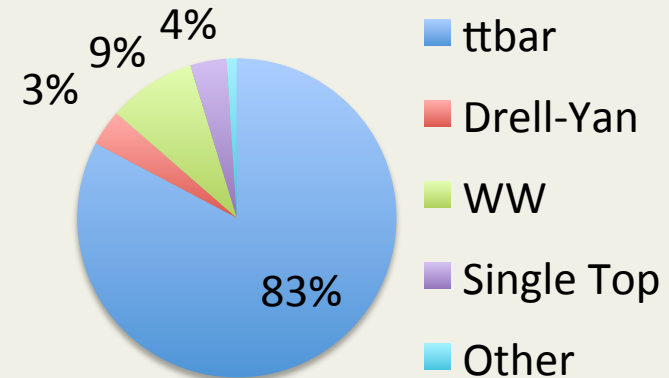
600 GeV <  $H_T$



## Signal Region 3

200 GeV < MET < 275 GeV

600 GeV <  $H_T$

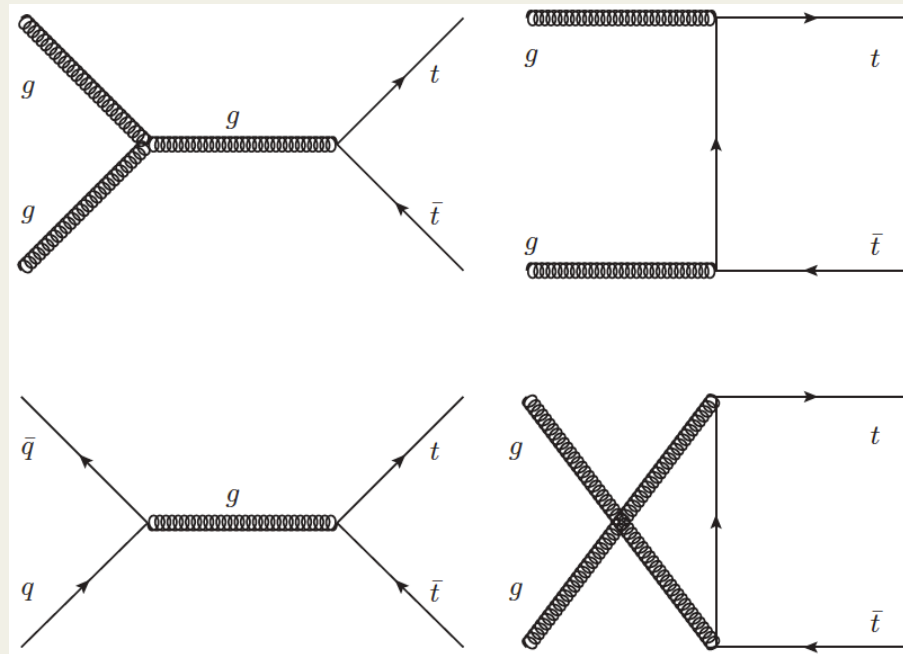


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# Top Physics

# The top quark

- **Why the top quark?**
  - Dominant background
- **Top pair production**
  - Mass: 173 GeV
  - Strong production @LHC
  - Cross section  $\sim 194$  pb



# The top quark

- **ttbar decay**

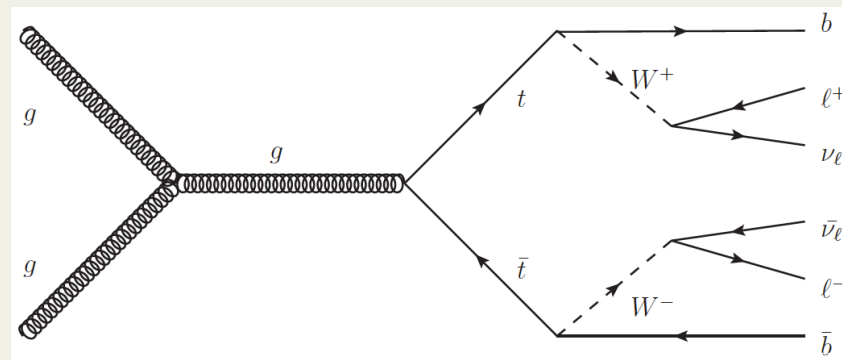
- ~ 100% Wb
  - 2 b-jets

- **Dileptonic decay**

- Branching Fraction ~ 1/81
- 2 neutrinos give MET

Top Pair Decay Channels

$c\bar{s}$	electron+jets	muon+jets	tau+jets	all-hadronic	
$u\bar{d}$					
$\tau^-$	$e\tau$	$\mu\tau$	$\tau\tau$	tau+jets	
$\mu^-$	$e\mu$	$\mu\mu$	$\tau\mu$	muon+jets	
$e^-$	$ee$	$e\mu$	$e\tau$	electron+jets	
$W$ decay	$e^+$	$\mu^+$	$\tau^+$	$u\bar{d}$	$c\bar{s}$



# W polarization

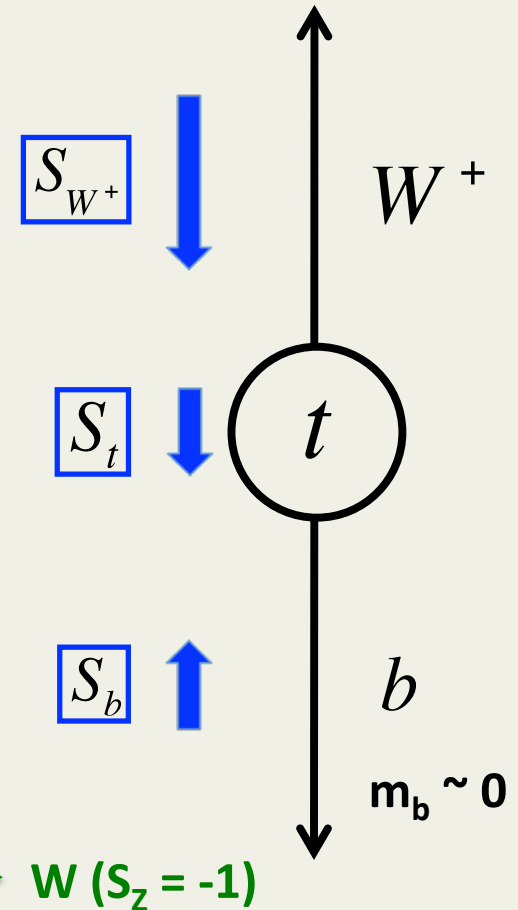
- The W has three polarization states

- W ( $S_z = 0$ ), W ( $S_z = -1$ ) are allowed

- W ( $S_z = 1$ ) is forbidden

- No configuration conserves  $J_z$

$S_t$	=	$S_W$	+	$S_b$
+1/2	=	0	+	+1/2
+1/2	=	+1	+	+1/2
+1/2	=	-1	+	+1/2
-1/2	=	0	+	+1/2
-1/2	=	+1	+	+1/2
-1/2	=	-1	+	+1/2



- W's from top are longitudinally or negatively polarized

# W polarization

- How does the polarization of W's from top affect the momentum spectrum of the lepton? Neutrino

– Consider 2 cases:

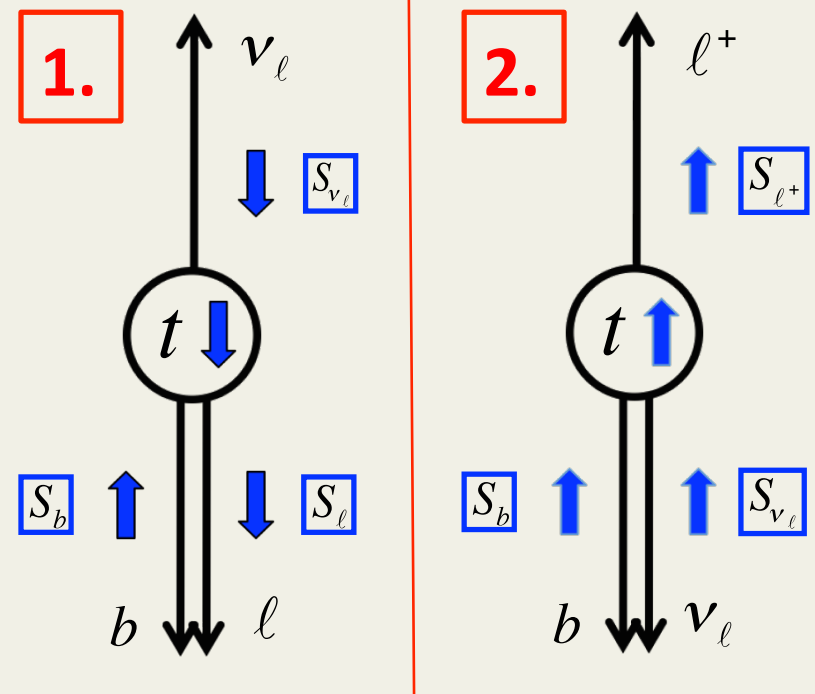
## 1. Neutrino has maximum E

- Allowed by left-handed W

## 2. Lepton has maximum E

- Fails to conserve  $J_z$  due to right-handed W

- Momentum spectra:



**Hard neutrinos, soft leptons** ( basis of  $P_T^{\ell\ell} K_C$  cor. )

# W polarization

- The top differential decay rate can be written as:

$$\frac{d\Gamma}{d \cos\theta^*} \propto 2f_0 \sin^2 \theta^* + f_- (1 - \cos\theta^*)^2 + f_+ (1 + \cos\theta^*)^2$$

$\cos\theta^*$  is the angle between the charged lepton and the top quark in the W rest frame.

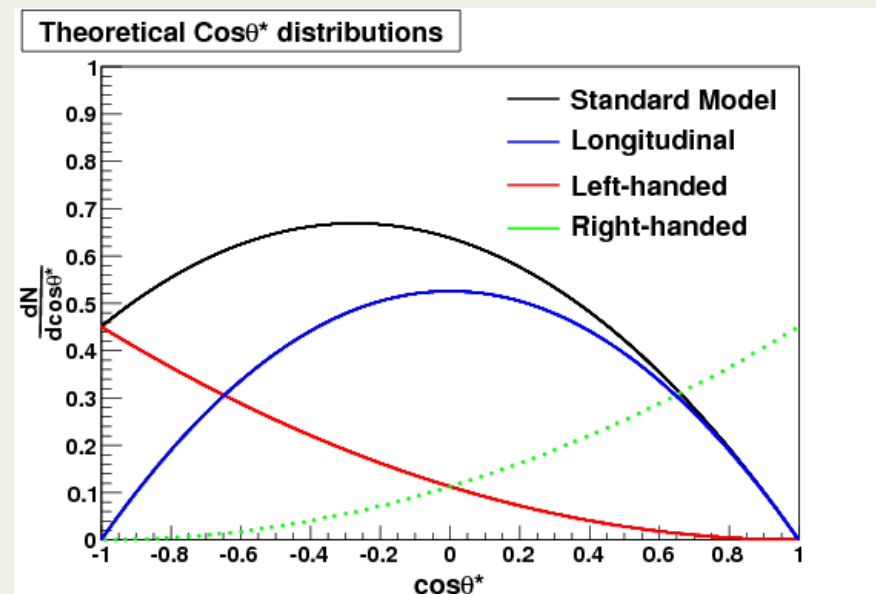
$f_0$ ,  $f_-$ , and  $f_+$  are the fractions of longitudinal, left-handed, and right-handed W bosons respectively.  $f_0 + f_- + f_+ = 1$ .

- In top decays:

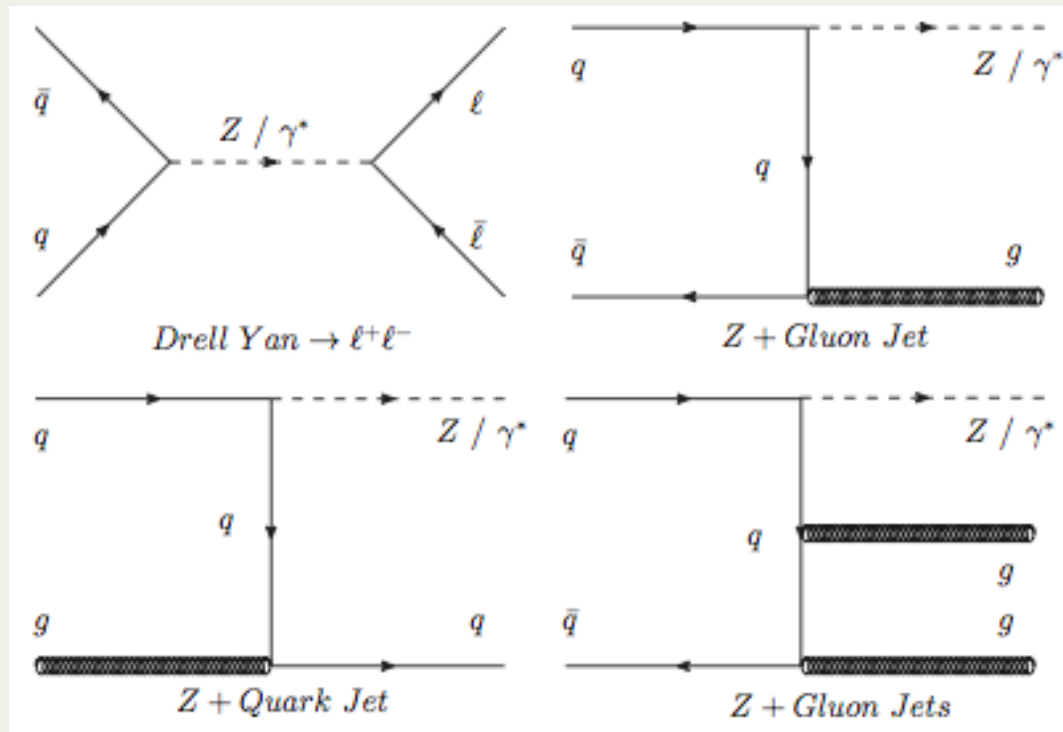
—  $f_+ = 0$       W ( $S_z = +1$ )

—  $f_0 \sim 70\%$       W ( $S_z = 0$ )

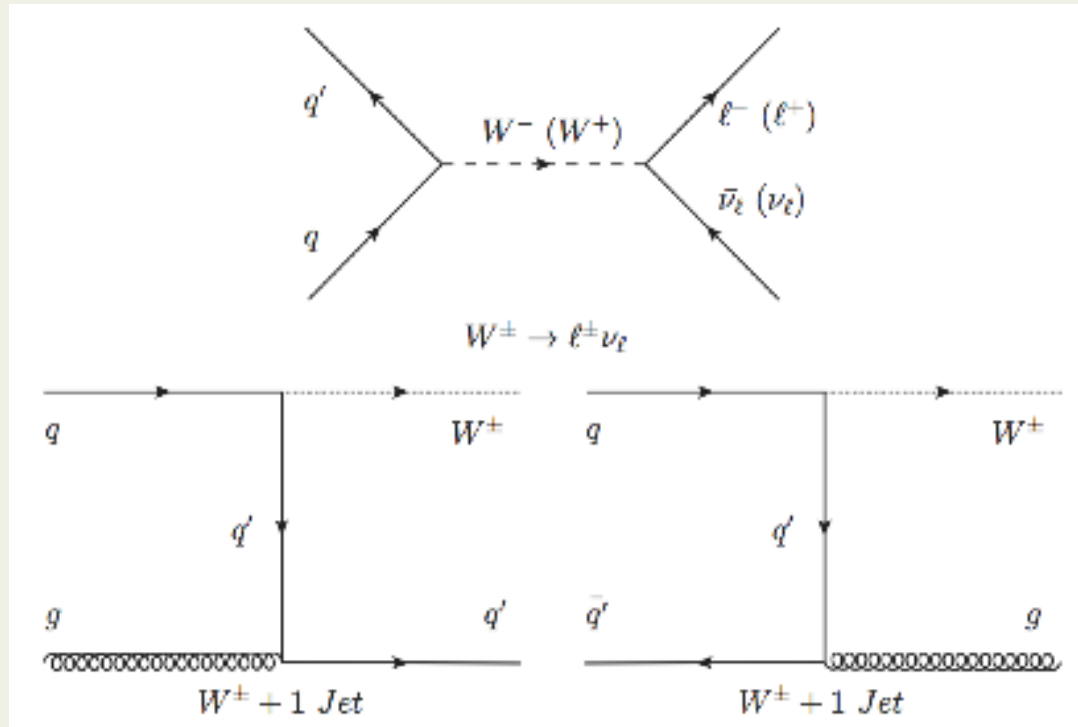
—  $f_- \sim 30\%$       W ( $S_z = -1$ )



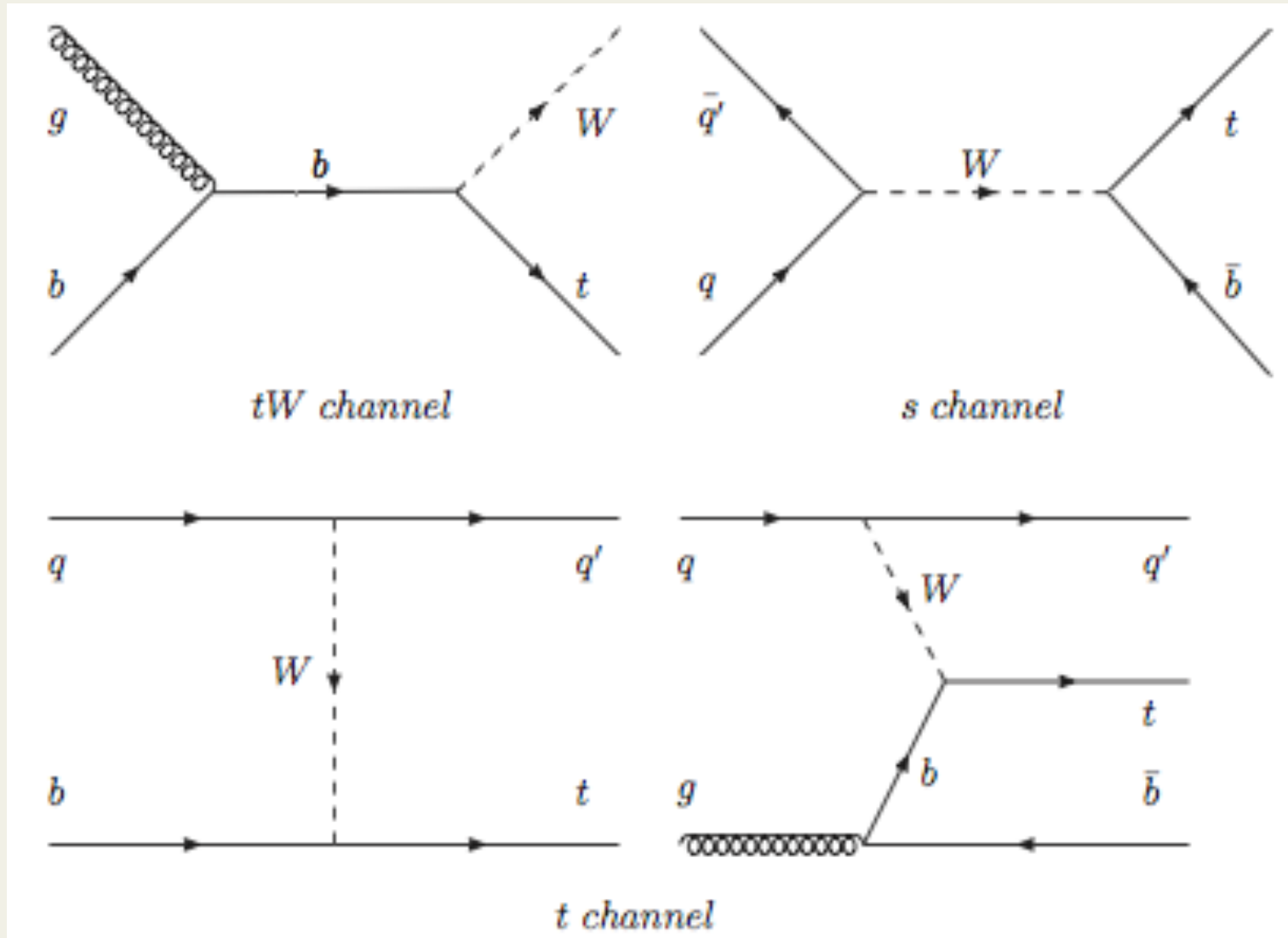
# Drell-Yan



# WW



# top



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# **Fake Leptons**

# Fake Leptons

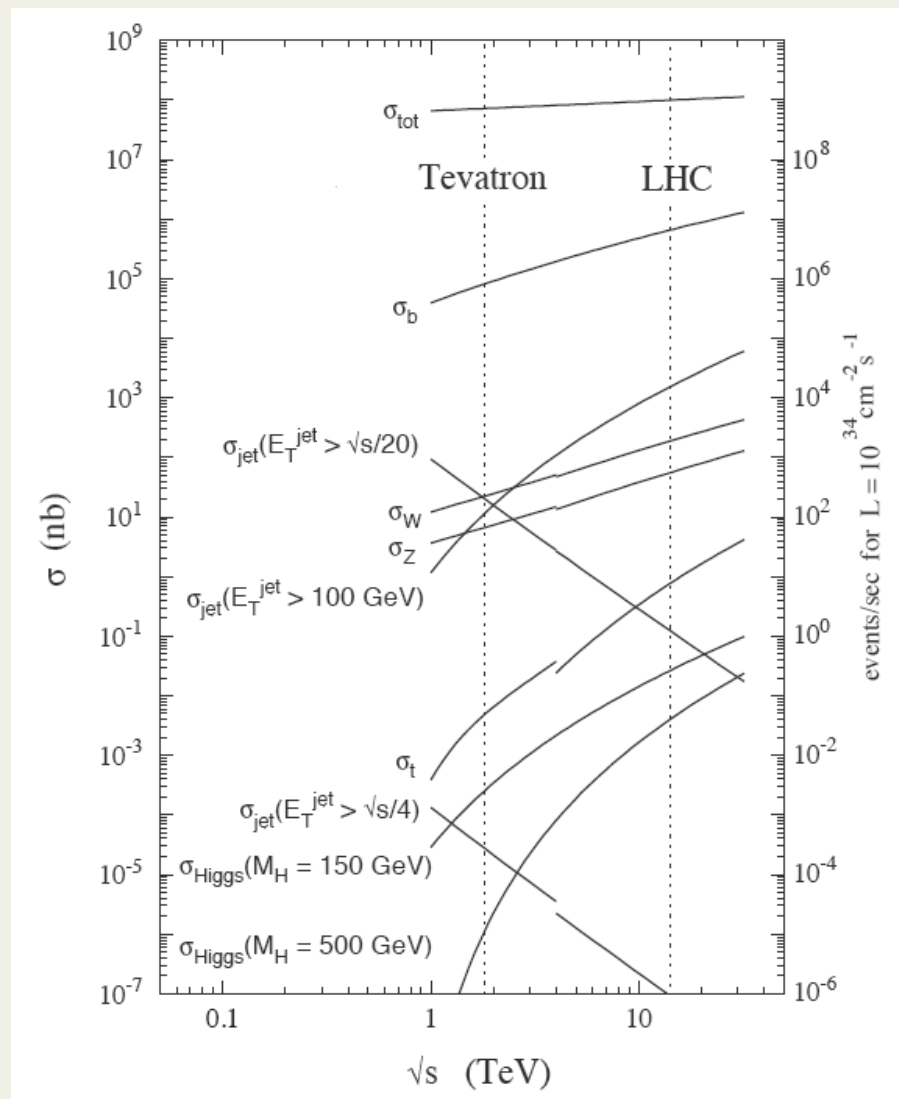
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Selection	$N_{Fakes}^{single}(D)$	$N_{Fakes}^{single}(D')$	$N_{Fakes}^{double}(D)$	$N_{Fakes}^{single}(D')$
High $H_T$	$2.6 \pm 1.0$	$1.5 \pm 0.8$	$0.1 \pm 0.1$	$0.0 \pm 0.0$
High $E_T^{miss}$	$2.9 \pm 1.2$	$1.5 \pm 0.8$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
SR1	$1.7 \pm 1.0$	$0.7 \pm 0.5$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
SR2	$1.2 \pm 0.7$	$0.8 \pm 0.6$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
SR3	$1.5 \pm 0.7$	$0.7 \pm 0.5$	$0.1 \pm 0.1$	$0.0 \pm 0.0$
SR4	$0.0 \pm 0.0$	$0.8 \pm 0.6$	$0.0 \pm 0.0$	$0.2 \pm 0.2$

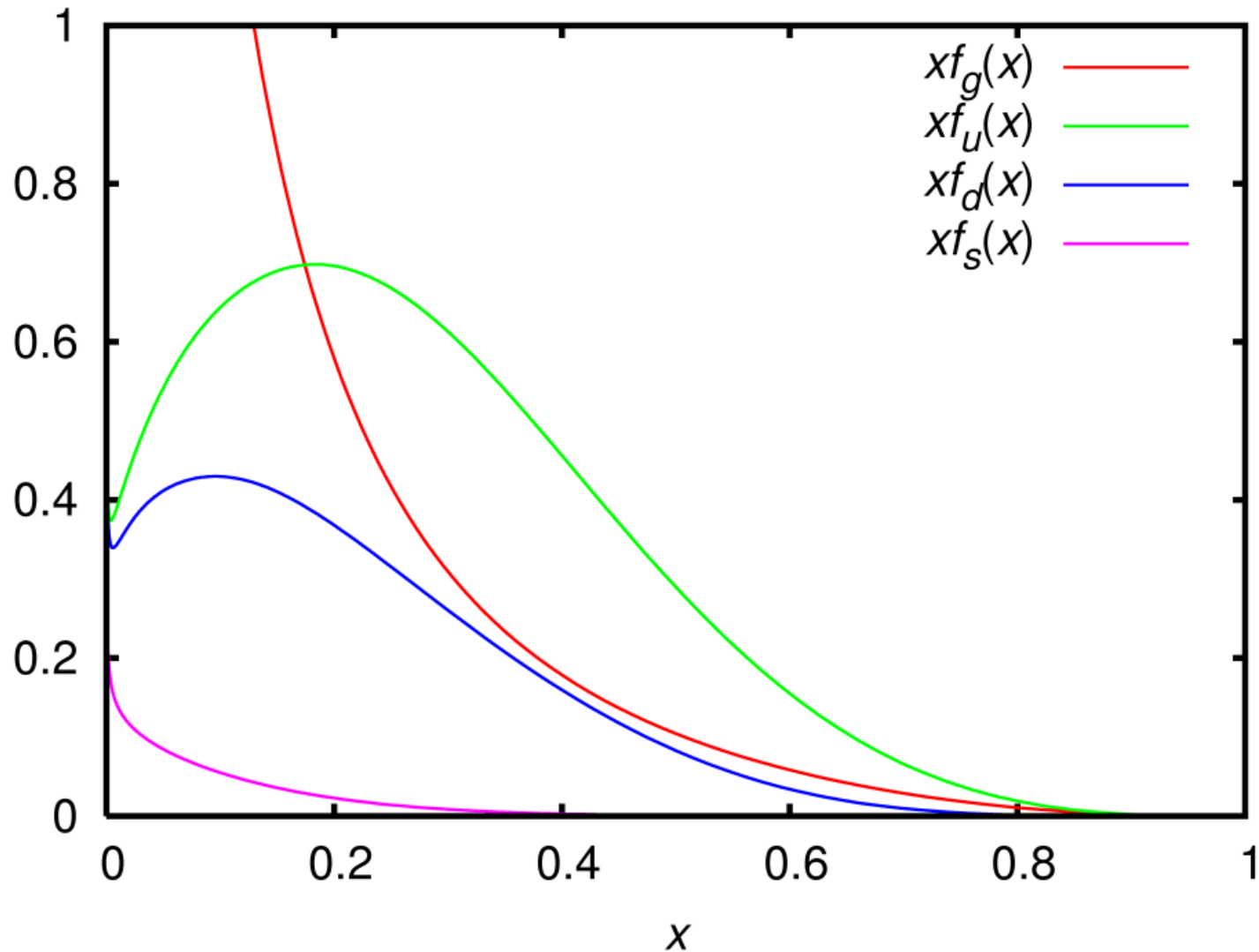
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# **Cross Sections & PDF 's**

# Cross Sections at the LHC



# Parton Distribution Functions

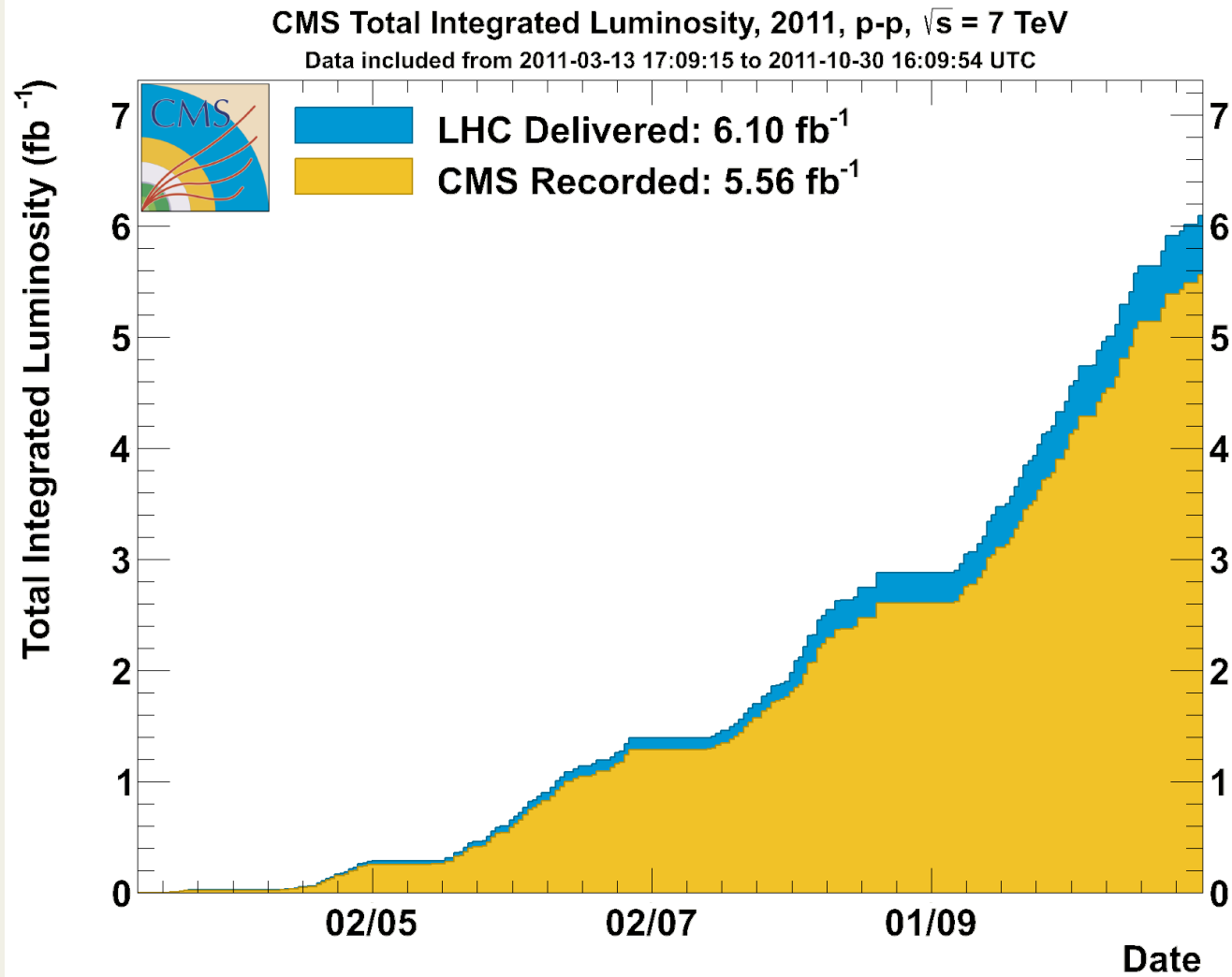


# Monte-Carlo

- Samples

Sample	$\sigma(pb)$	Generator	Comments	Name
$t\bar{t}$	157.5	Madgraph-Tauola	Inclusive (Fall 2011)	/TTJets_TuneZ2_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v2/AODSIM
$t\bar{t}$	157.5	Madgraph-Tauola	Inclusive (Summer 2011)	/TTJets_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$t\bar{t} \rightarrow t^+t^- \nu\bar{\nu} b\bar{b}$	16.5	Powheg-Pythia		/TTTo2L2Nu2B_7TeV-powheg-pythia6/Summer11-PU_S4_START42_V11-v1/AODSIM
$t$ ( $s$ -channel)	3.19	Powheg-Tauola		/T_TuneZ2_s-channel_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$\bar{t}$ ( $s$ -channel)	1.44	Powheg-Tauola		/Tbar_TuneZ2_s-channel_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$t$ ( $t$ -channel)	41.92	Powheg-Tauola		/T_TuneZ2_t-channel_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$\bar{t}$ ( $t$ -channel)	22.65	Powheg-Tauola		/Tbar_TuneZ2_t-channel_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$tW$	7.87	Powheg-Tauola		/T_TuneZ2_tW-channel-DR_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$\bar{t}W$	7.87	Powheg-Tauola		/Tbar_TuneZ2_tW-channel-DR_7TeV-powheg-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$Z/\gamma^* \rightarrow e^+e^-$	3319.61	Powheg-Pythia	$10 < M_{ee} < 20$	/DYToEE_M-10To20_CT10_TuneZ2_7TeV-powheg-pythia/Summer11-PU_S4_START42_V11-v1/AODSIM
$Z/\gamma^* \rightarrow e^+e^-$	1666	Powheg-Pythia	$20 < M_{ee} < 50$	/DYToEE_M-20_CT10_TuneZ2_7TeV-powheg-pythia/Summer11-PU_S4_START42_V11-v1/AODSIM
$Z/\gamma^* \rightarrow \mu^+\mu^-$	3319.61	Powheg-Pythia	$10 < M_{\mu\mu} < 20$	/DYToMuMu_M-10To20_CT10_TuneZ2_7TeV-powheg-pythia/Summer11-PU_S4_START42_V11-v1/AODSIM
$Z/\gamma^* \rightarrow \mu^+\mu^-$	1666	Powheg-Pythia	$20 < M_{\mu\mu} < 50$	/DYToMuMu_M-20_CT10_TuneZ2_7TeV-powheg-pythia/Summer11-PU_S4_START42_V11-v1/AODSIM
$Z/\gamma^* \rightarrow \tau^+\tau^-$	33319.61	Pythia 6-Tauola	$10 < M_{\tau\tau} < 20$	/DYToTauTau_M-10To20_TuneZ2_7TeV-pythia6-tauola/Summer11-PU_S3_START42_V11-v2/AODSIM
$Z/\gamma^* \rightarrow \tau^+\tau^-$	1666	Powheg-Pythia	$20 < M_{\tau\tau} < 50$	/DYToTauTau_M-20_CT10_TuneZ2_7TeV-powheg-pythia-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$Z/\gamma^* \rightarrow l^+l^-$	3048	Madgraph-Tauola	$50 < M_{ll}$	/DYJetsToLL_TuneZ2_M-50_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$W \rightarrow l\nu + \text{Jets}$	31314	Madgraph-Tauola		/WJetsToLNu_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$WW \rightarrow l^+l^- \nu\bar{\nu}$	4.783	Madgraph-Tauola		/WWJetsTo2L2Nu_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$WZ \rightarrow l\nu l^+l^-$	0.856	Madgraph-Tauola		/WZJetsTo3LNu_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$WZ \rightarrow l^+l^- q\bar{q}$	1.786	Madgraph-Tauola		/WZJetsTo2L2Q_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$ZZ \rightarrow l^+l^- l^+l^-$	0.076	Madgraph-Tauola		/ZZJetsTo4L_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$ZZ \rightarrow l^+l^- \nu\bar{\nu}$	0.3	Madgraph-Tauola		/ZZJetsTo2L2Nu_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
$ZZ \rightarrow l^+l^- q\bar{q}$	1.0	Madgraph-Tauola		/ZZJetsTo2L2Q_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
LM1	4.888	Pythia 6		/LM1_SUSY_sfsht_7TeV-pythia6/Summer11-PU_S4_START42_V11-v2
LM3	3.438	Pythia 6		/LM3_SUSY_sfsht_7TeV-pythia6/Summer11-PU_S4_START42_V11-v2
LM6	0.3104	Pythia 6		/LM6_SUSY_sfsht_7TeV-pythia6/Summer11-PU_S4_START42_V11-v2

# Luminosity



# LHC

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- LHC