Physics Summary

Dirk Zerwas
IJCLab and DMLab

May 19, 2023
LCWS

- Preparations
- Top
- Higgs
- Beyond

Laboratoire de Physique des 2 infinis Irène Joliot-Curie

DARK MATTER LAB

ECFA Study: KEY4HEP

Aidan Robson,
Mary-Cruz Fouz,
Jenny List

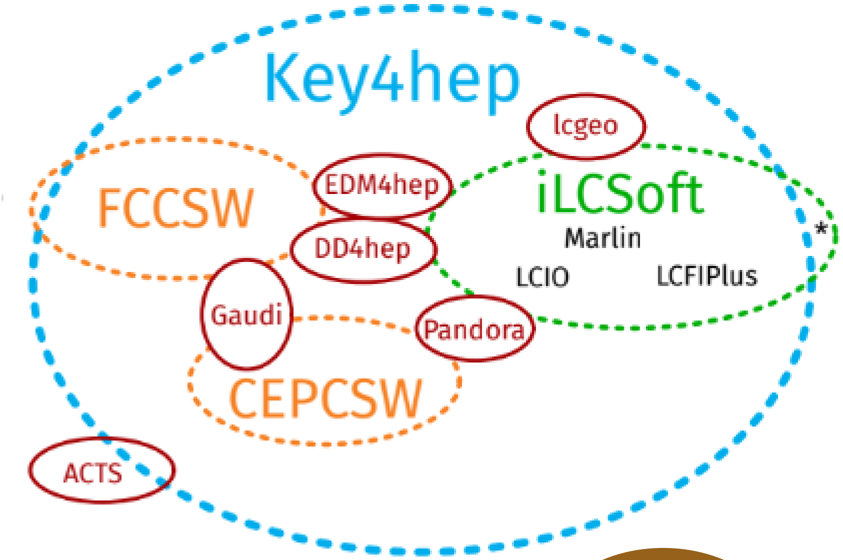
ECFA Working Groups Higgs Factories

- **Physics, Physics Analysis Tools, Detectors**
- **Meetings:**

https://indico.cern.ch/category/14055/

- **October 11-13, 2023 Paestum (south of Naples)**

https://agenda.infn.it/event/34841/



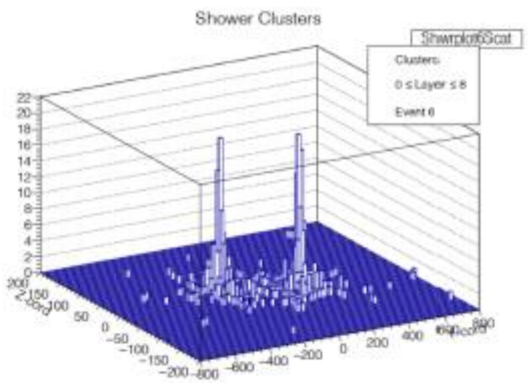
Happy to work with C^3

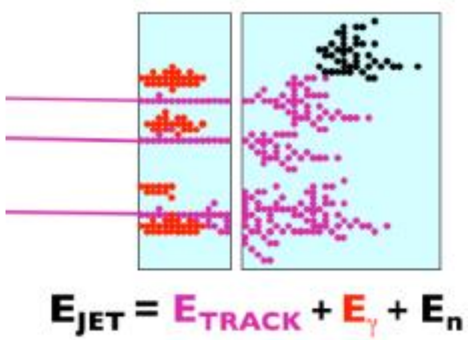
C^3

Muon Collider

Maximilian
Swiatlowski

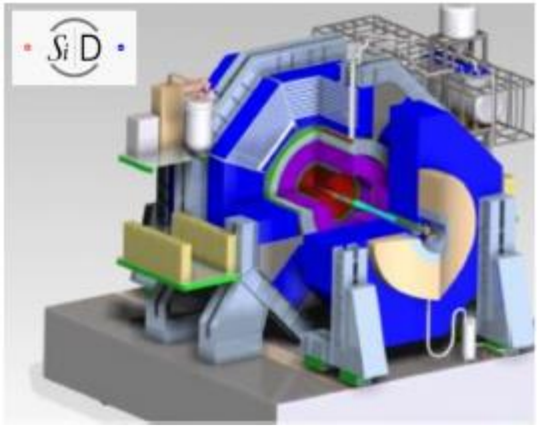
Started studies with ilcsoft will move to KEY4HEP





Many areas for fruitful collaboration:

- **High granular calorimetry**
- **ParticleFlow reconstruction**
- **...**

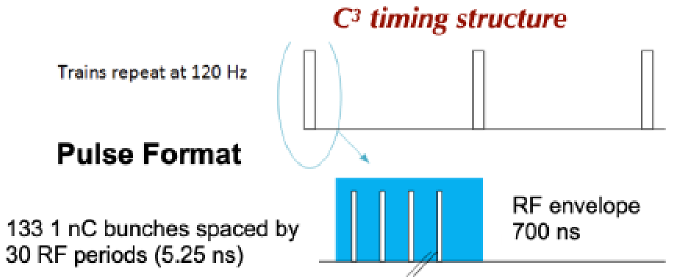


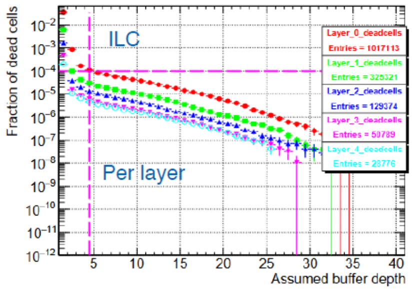
Beam induced Background of course different

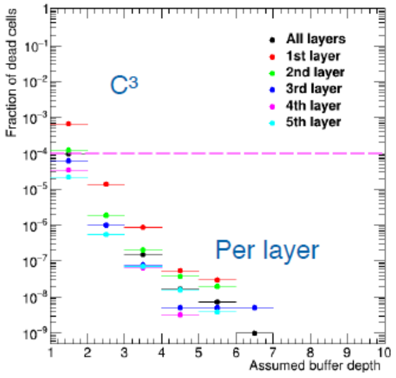
Beamstrahlung/Background C^3

Lindsey Gray Dimitris Ntounis Elias Mettner

Different effects:
- **Beamstrahlung**
- **Pair production of electrons/muons/hadrons**
- **Overlay due to bunch spacing**



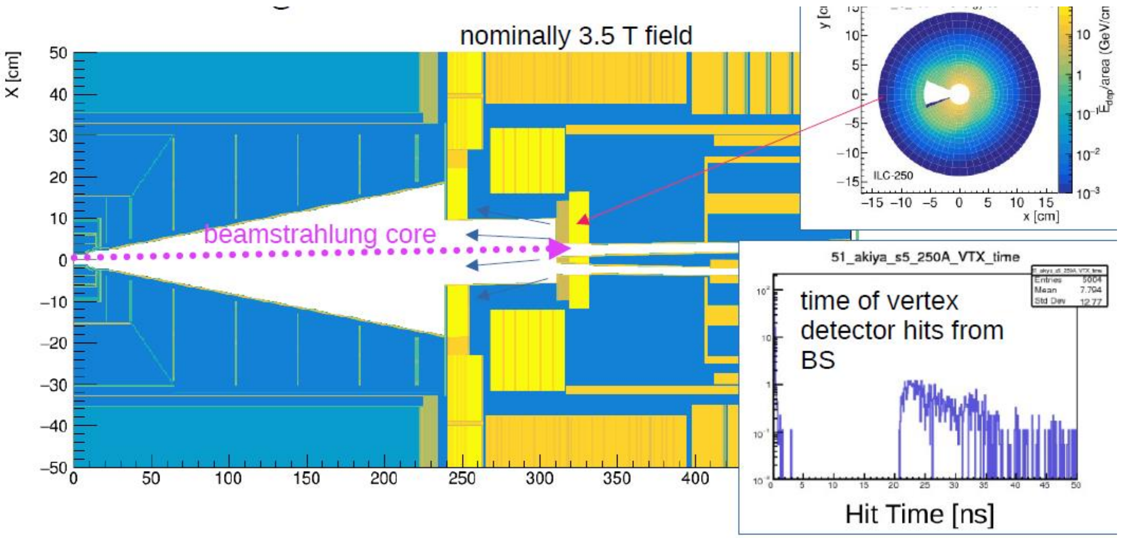




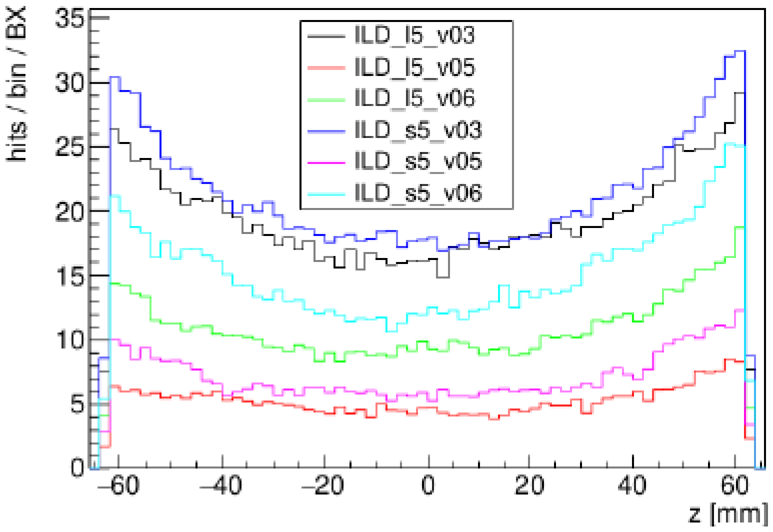
Expect and "observed" ILC/10

Beam Background ILD

Daniel Jeans



Anti-DID field reflects late hits into the outgoing beampipe



Black: no anti-DID
Red: anti-DID

Further work on ILD@FCC
6x hits in TPC…

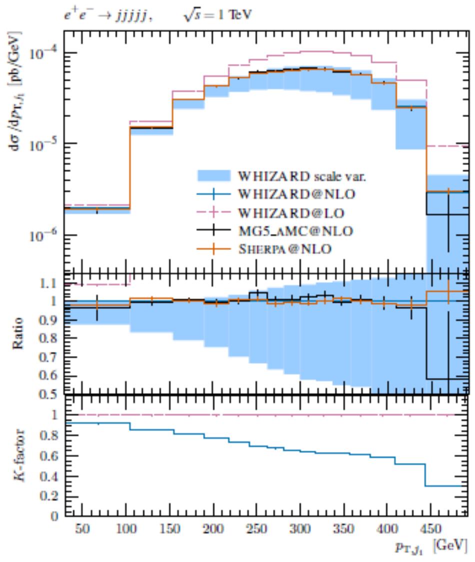
Juergen Reuter

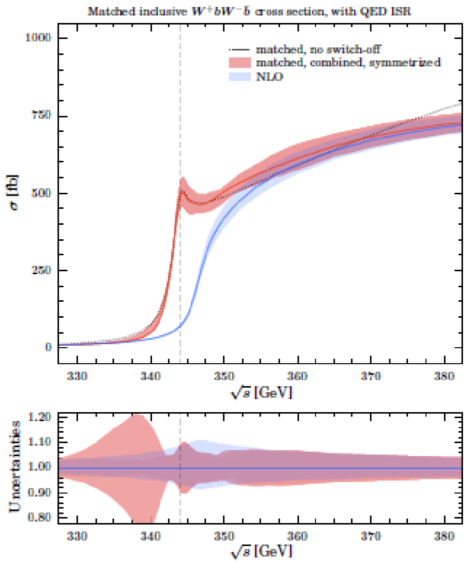
Whizard

“Workhorse” of the electron-positron studies

- NLO Automation (EW and QCD for ee)
- NLO differential fixed order
- Generic NLO-QCD Powheg like matching
- Top threshold: NLO-NLL QCD matched

ee @ 1 TeV, NLO QCD





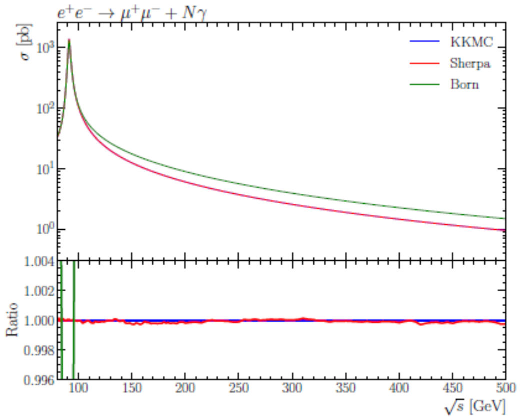
- Improvements user interface….
- Whizard on GPUs

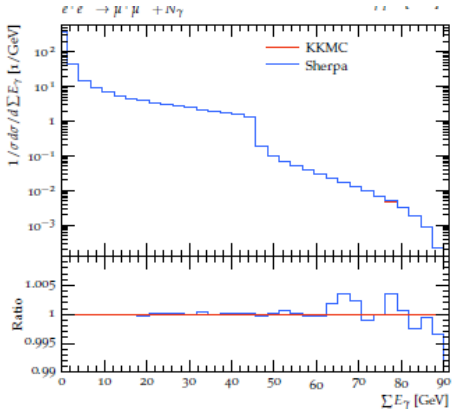
Sherpa

Alan Price

One of the main generators used at LHC

- Now working on lepton version
- YFS resummation compared to KKMC





- NLO and NNLO with GRIFFIN (muon pairs)

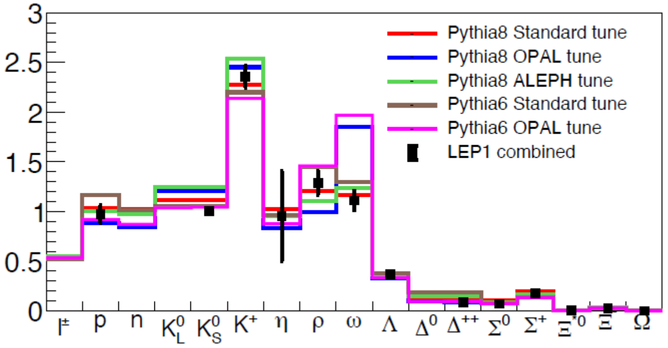
Born	YFS	YFS+Recola	YFS+GRIFFIN
2114.5 pb	1463.09 pb	1494.7(8) pb	1497.5(7) pb

- Validated against MADGRAPH
- To be released soon
- Includes Polarization

Zhijie Zhao

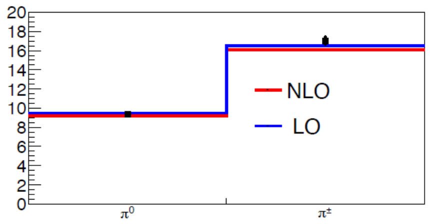
Tuning Pythia8

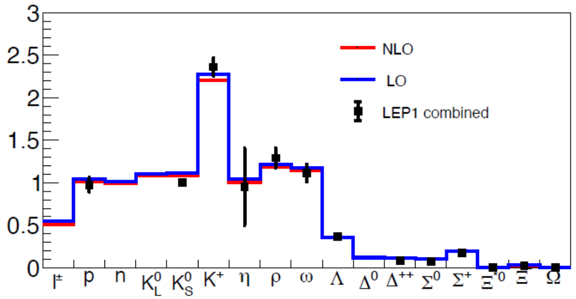
Goal: Move from Whizard1.95+Pythia6 to Whizard3+Pythia8



- **Tune to Z data: Pythia8 standard best**

- **Test NLO Powheg of Whizard:**

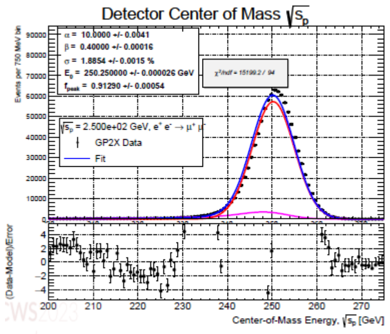




Modeling Center-of-Mass Energy Precision using Dimuons and Bhabhas at ILC

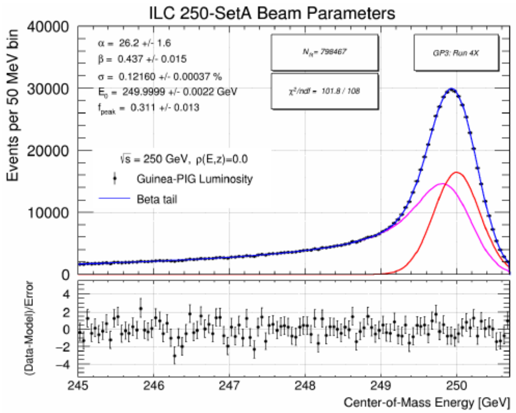
Brendon Madison

- **Combine GuineaPig with Generator**
- **Final state: Muon pairs, electron pairs**



Evaluating Detector and Physics Limitations on Center-of-Mass Energy Determination in e+e- Colliders Using Dileptons

Graham Wilson



$$\sigma/\sqrt{s} = 0.1216 \pm 0.0004\% \text{ (cf } 0.1217\% \text{ in TDR } (\ 0.190\% \oplus 0.152\%)/2)$$

Tracking detectors designed for ILC have the potential to measure beam energy related quantities with precision similar to the intrinsic energy spread using dimuon events (and also especially wide-angle Bhabha events).

Benedikt Gocke

Top Quark ATLAS

Differential and total cross sections

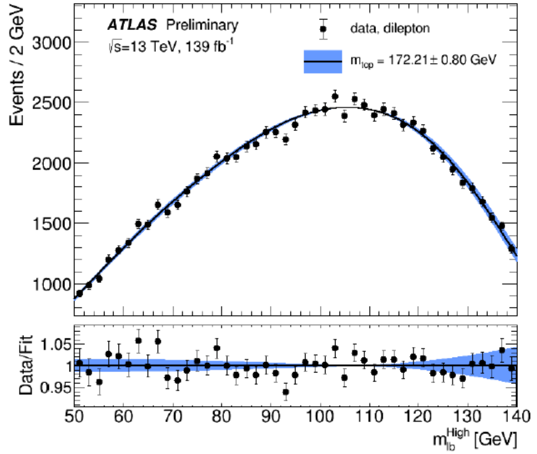
$$\sigma_{t\bar{t}} = 859 \pm 4\,(\text{stat}) \pm 22\,(\text{syst}) \pm 19\,(\text{lumi})\ \text{pb}$$

13.6 TeV

$$\sigma_{t\bar{t}t\bar{t}} = 22.5^{+6.6}_{-5.5}\text{fb}$$

$$\sigma_{tq\gamma} \times \mathcal{B}(t \to \ell\nu b) + \sigma_{t(\to\ell\nu b\gamma)q} = 303 \pm 9\,(\text{stat})^{+33}_{-32}\,(\text{syst})\ \text{fb}$$

Mass measurement



	m_{top} [GeV]
Result	172.21
Statistics	0.20
Method	0.05 ± 0.04
Matrix-element matching	0.40 ± 0.06
Parton shower and hadronisation	0.05 ± 0.05
Initial- and final-state QCD radiation	0.17 ± 0.02
Underlying event	0.02 ± 0.10
Colour reconnection	0.27 ± 0.07
Parton distribution function	0.03 ± 0.00
Single top modelling	0.01 ± 0.01
Background normalisation	0.03 ± 0.02
Jet energy scale	0.37 ± 0.02
b-jet energy scale	0.12 ± 0.02
Jet energy resolution	0.13 ± 0.02
Jet vertex tagging	0.01 ± 0.01
b-tagging	0.04 ± 0.01
Leptons	0.11 ± 0.02
Pile-up	0.06 ± 0.01
Recoil effect	0.39 ± 0.09
Total systematic uncertainty (without recoil)	0.67 ± 0.05
Total systematic uncertainty (with recoil)	0.77 ± 0.06
Total uncertainty (without recoil)	0.70 ± 0.05
Total uncertainty (with recoil)	0.80 ± 0.06

$$m_{top} = 172.21 \pm 0.20(\text{stat}) \pm 0.67(\text{syst}) \pm 0.39(\text{recoil})\ \text{GeV}$$

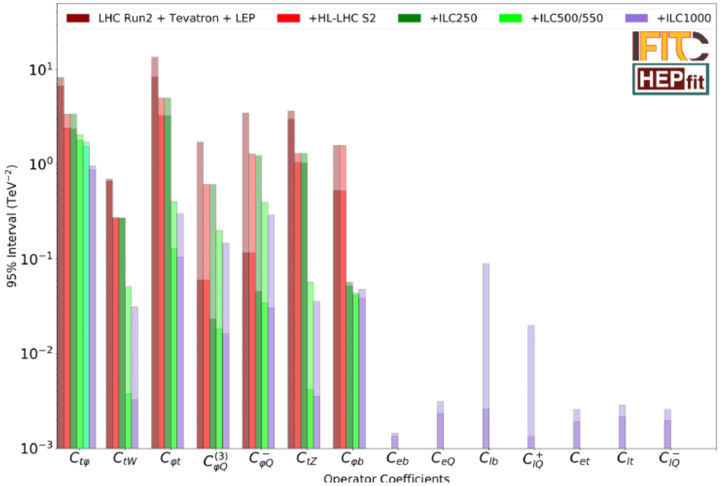
Charge Asymmetry (prediction 1%)

$$A_C^{t\bar{t}} = \frac{N(\Delta|y_{t\bar{t}}|>0) - N(\Delta|y_{t\bar{t}}|<0)}{N(\Delta|y_{t\bar{t}}|>0) + N(\Delta|y_{t\bar{t}}|<0)}$$

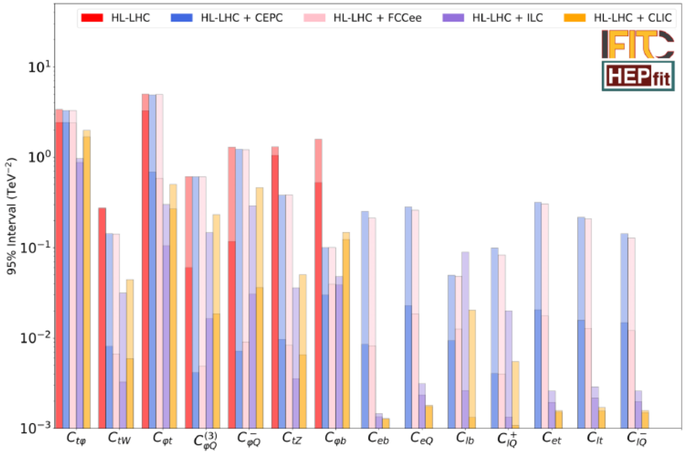
$$A_C^{t\bar{t}} = 0.0068 \pm 0.0015\,(\text{stat} + \text{syst})$$

SMEFT Top Quark

Fernando Cornet-Gomez



Estimate the precision on coupling operators



Excellent prospects for linear colliders

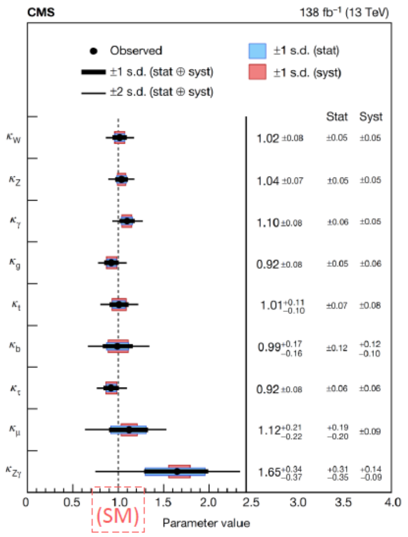
Best precision on top-yukawa at highest energy

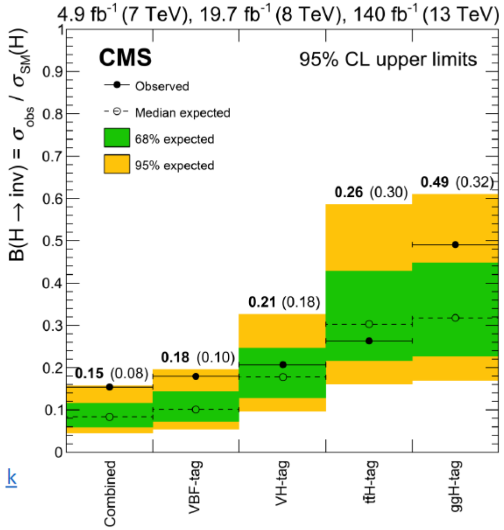
Values in % units		LHC	HL-LHC	ILC500	ILC550	ILC1000	CLIC
δy_t	Global fit	12.2	5.06	3.14	2.60	1.48	2.96
	Indiv. fit	10.2	3.70	2.82	2.34	1.41	2.52

Ulaşcan Sarıca

Higgs Boson with CMS

mH = 125.38 ± 0.14 GeV
Spin 0, Spin1 excluded 99.999% CL
Couplings: standard

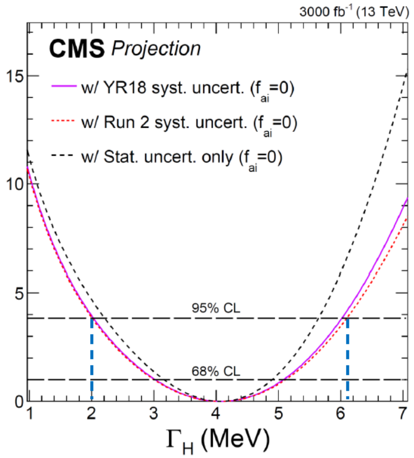




k

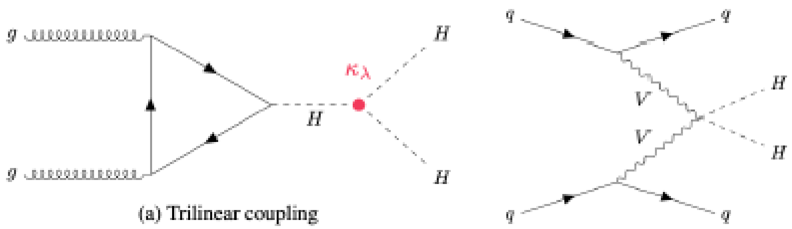
Width via off-shell method: $\Gamma_H = 3.2^{+2.4}_{-1.7}$ MeV,

Projection HL-LHC

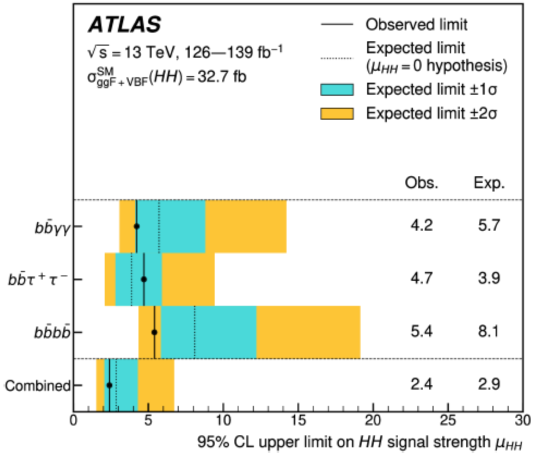


Probing EWSB with ATLAS

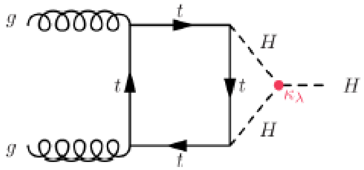
Shuzhou Zhang



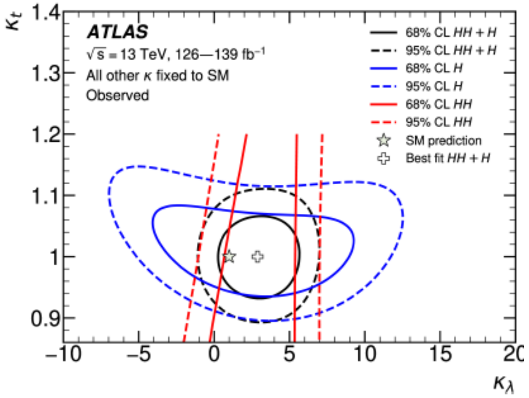
Sophisticated analyses with BDTs
Combined for three channels: 2.4



Combine with single Higgs



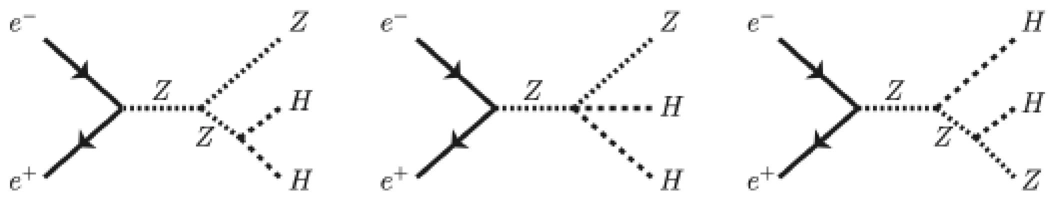
Definitely standard



HL-LHC:
Expected significance 3.4σ

Julie Munch Tordal

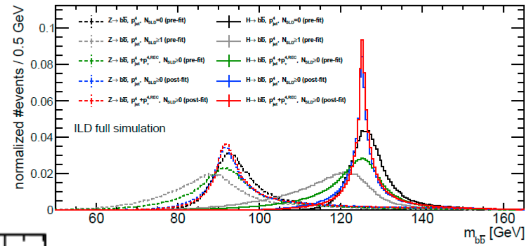
ILC Higgs Self-coupling

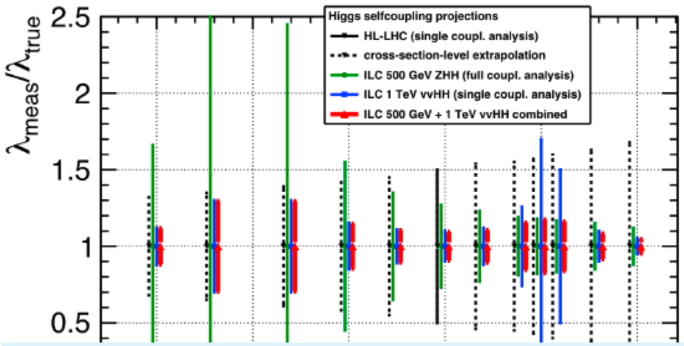


Revisit analysis:

- **Improved b tagging**
- **Kinematic fitting with better error parametrization**

	DBD	new
1-eff(c)	90%	95%
Rejection factor	10	20



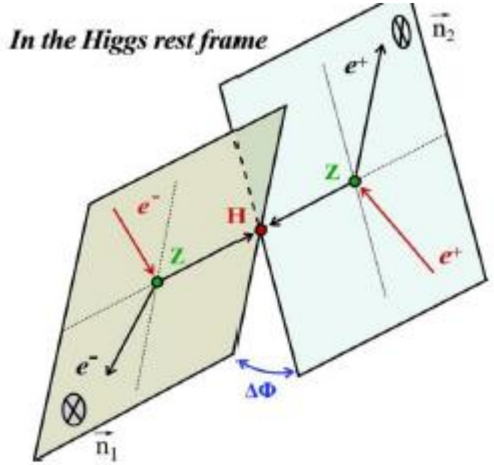


Combining ZHH and $\nu\nu HH$ ensures at least 10-15% precision for *any* value of λ

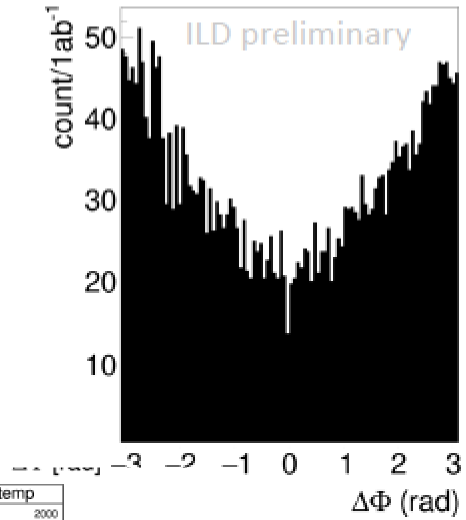
Clear case for high energy

ILC CP Higgs in Fusion

N. Vukasinovic

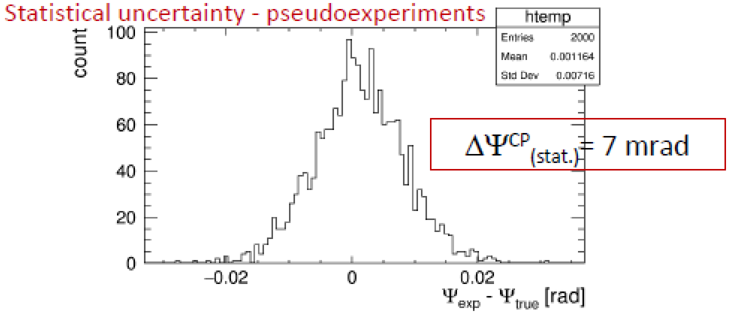


$$\Delta\Phi = \begin{cases} \arccos(\cos\Phi), & \sin\Phi \geq 0 \\ 2\pi - \arccos(\cos\Phi), & \sin\Phi \leq 0 \end{cases}$$



1TeV

- **ZZ fusion (2 electrons)**
- **Background eliminated**
- **68% efficiency**



Aleksander Zarnecki

ILC Light Higgs

Motivation: N2HDM Model = THDM+real singlet
CMS 95GeV di-photon and di-tau

$\mathrm{BR}^{bb}_{h_1}$	$\mathrm{BR}^{gg}_{h_1}$	$\mathrm{BR}^{cc}_{h_1}$	$\mathrm{BR}^{\tau\tau}_{h_1}$
$\Rightarrow$ 0.005	0.348	0.198	$\Rightarrow$ 0.412

Search for tau decays collinear approximation

Sample	Events expected after			Final
	Presel.	Z mass	h_1 + rec	eff.
Signal	1738.75	1168.28	702.356	5.267
$qqqq$	150.922	0	0	0
$qql\nu$	491142	2917.88	208.42	0.002
$qq\tau\nu$	70134.4	444.201	0	0
$qqll$	17053.6	678.604	44.2568	0.003
$qq\tau\tau$	13011.5	7503.45	3219.61	2.154
$qq\nu\nu$	34.3705	0	0	0
h_2	2552.55	895.052	22.1	0.02
Total	594079	12439.2	3494.39	
Significance		10.84		

With improved tau algorithm:

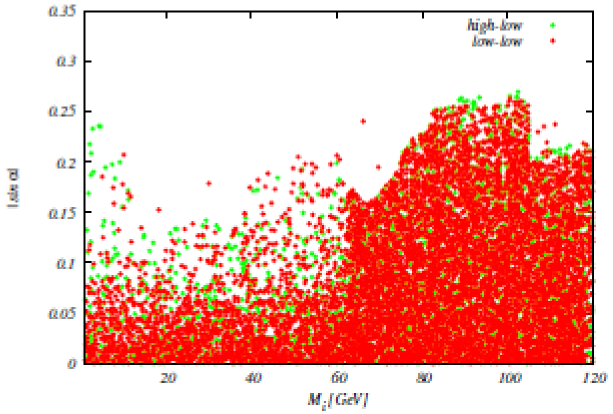
Decay channel	Tau tagging	Events expected		Signal significance
		Signal	Total bg.	
Hadronic	old	423.9	2733.3	7.544
	new	435.0	3042.9	7.376
Semi-leptonic	old	702.4	3494.4	10.84
	new	692.9	3475.1	10.73
Leptonic	old	260.0	1353.0	6.474
	new	276.0	1376.4	6.791

What if????

Models for Light Scalars

Tania Robens

An short overview on low mass scalars at future lepton colliders



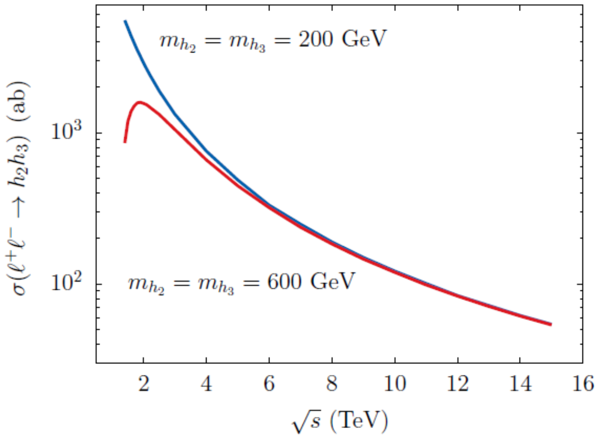
- **many new physics models predict one/ several scalars below 125 GeV**
- typical decays into $b\,\bar{b}$, $\tau^+\tau^-$
- cross sections could reach **up to** $50\,\mathrm{fb}$ **from** Zh **production**
- decays of $h_{125} \to s\,s$ **also within reach**
- important connection to EWSB/ EW phase transitions

Howard Haber

P-even, CP-violating Signals in Scalar-Mediated Processes

- **Are new sources of CP violation present in the Higgs sector?**
- **P-even CP violation can arise in extended Higgs sectors**
- **Need to measure simultaneously:**

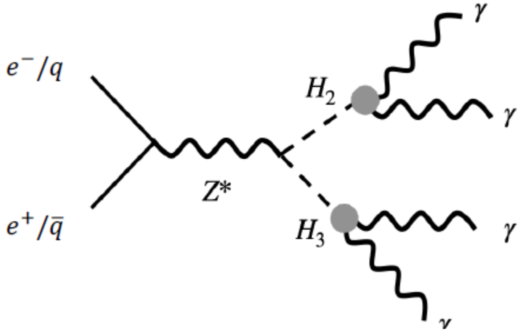
1. $h_2 H^+ H^-\,,\quad h_3 H^+ H^-\,,\quad Z h_2 h_3\,,$
2. $h_2 h_k h_k\,,\quad h_3 H^+ H^-\,,\quad Z h_2 h_3\,,\quad$ (for $k = 2$ or 3),
3. $h_3 h_k h_k\,,\,,\quad h_2 H^+ H^-\,,\quad Z h_2 h_3\,,\quad$ (for $k = 2$ or 3),
4. $h_2 h_k h_k\,,\quad h_3 h_\ell h_\ell\,,\quad Z h_2 h_3\,,\quad$ (for $k, \ell = 2$ or 3).



- **Calls for high energy**

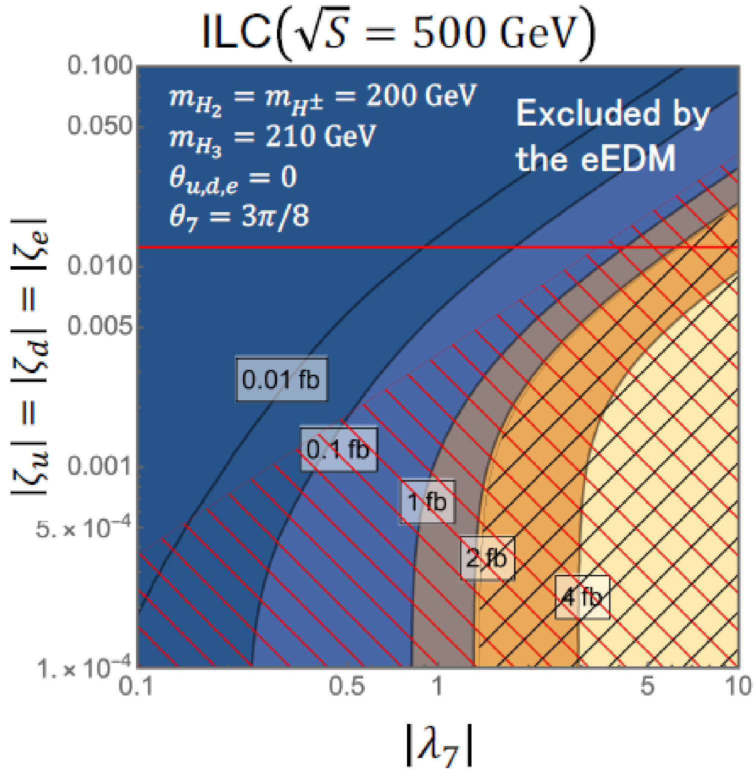
Kento Katayama

Multi-photon signatures THDM to determine CP



- **A2HDM**
- **Interesting signature**

$$\begin{pmatrix} \lambda_1 & \Re\lambda_6 & -\Im\lambda_6 \\ \Re\lambda_6 & -\frac{\mu^2}{v^2}+\frac{1}{2}(\lambda_3+\lambda_4+\Re\lambda_5) & -\frac{1}{2}\Im\lambda_5 \\ -\Im\lambda_6 & -\frac{1}{2}\Im\lambda_5 & -\frac{\mu^2}{v^2}+\frac{1}{2}(\lambda_3+\lambda_4-\Re\lambda_5) \end{pmatrix}$$



Yushi Mura

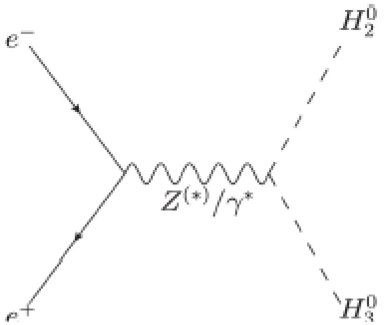
Electroweak Baryogenesis in aligned THDM

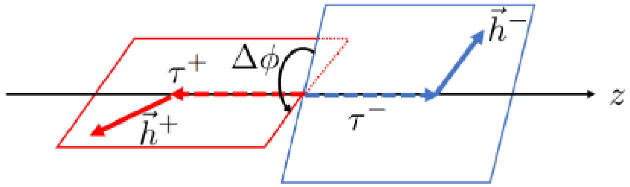
- **A2HDM**

$$\begin{pmatrix} \lambda_1 & \mathrm{Re}\lambda_6 & -\mathrm{Im}\lambda_6 \\ \mathrm{Re}\lambda_6 & \frac{M^2}{v^2}+\frac{\lambda_3+\lambda_4+\mathrm{Re}\lambda_5}{2} & -\frac{1}{2}\mathrm{Im}\lambda_5 \\ -\mathrm{Im}\lambda_6 & -\frac{1}{2}\mathrm{Im}\lambda_5 & \frac{M^2}{v^2}+\frac{\lambda_3+\lambda_4-\mathrm{Re}\lambda_5}{2} \end{pmatrix}$$

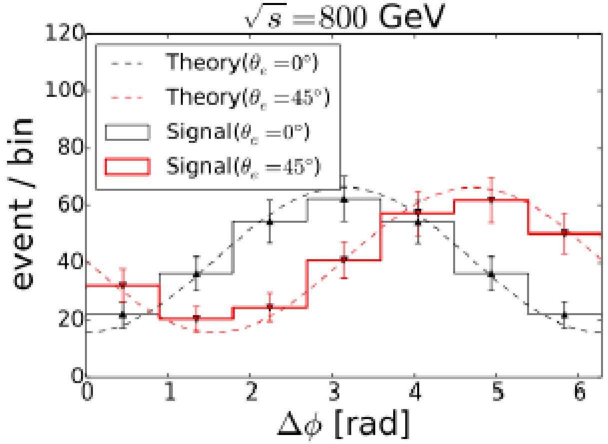
$$\lambda_6 = 0$$

$$H_{2,3} \to \tau^+\tau^- \to X^+\bar{\nu}X^-\nu$$





Jeans and Wilson, Phys. Rev. D 98 (2018) 013007



Test also CP in

- **Gravitational Waves**
- **EDM**
- **Flavour**

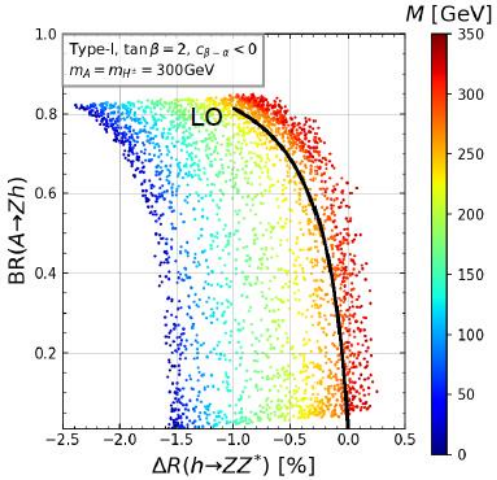
Calls for high energy

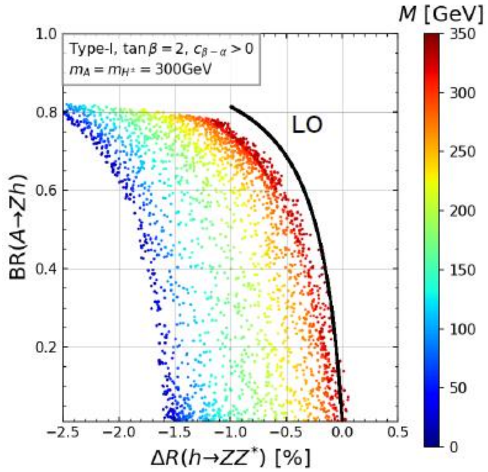
Radiative corrections impact on extended Higgs sectors

Masashi Aiko

125GeV Higgs		CP-even		CP-odd		Charged	
$h \to ff$	✔	$H \to ff$	✔	$A \to ff$	✔	$H^\pm \to ff'$	✔
$h \to VV^*$	✔	$H \to VV$	✔	$A \to Z\ h/H$	✔	$H^\pm \to W^\pm\ h/H$	✔
$h \to \gamma\gamma/Z\gamma/gg$	✔	$H \to hh$	✔	$A \to W^\pm H^\mp$	✔	$H^\pm \to W^\pm\ A$	✔
		$H \to AA/H^+H^-$	✔	$A \to VV$	✔	$H^\pm \to W^\pm\ Z/\gamma$	✔
		$H \to ZA/W^\pm H^\mp$	✔				

$A \to Zh$



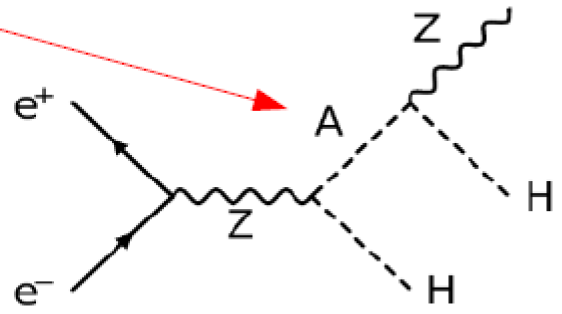


Calculations made available in H-COUP v3

Jan Klamka

Long lived Particles with ILD

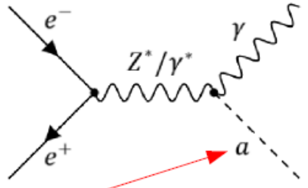
Long-lived, with $c\tau = 1\,\mathrm{m}$



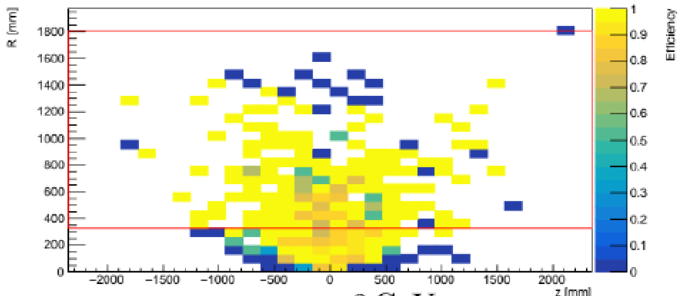
Z decay to muons

Δm	1 GeV	2 GeV	3 GeV	5 GeV
Tot. eff. (correct / decays within TPC acceptance)	3.9%	37%	52.2%	60.4%
Corectness (correct / all found)	96.4%	97.4%	98.8%	98.6%

Axion-like-particle and a photon



Long-lived, with $c\tau = 10\,\mathrm{mm}$



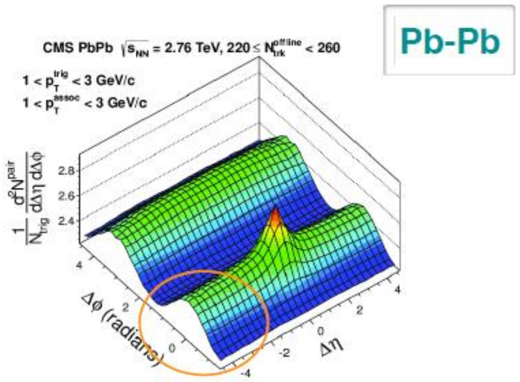
$m_a = 3\,\mathrm{GeV}$

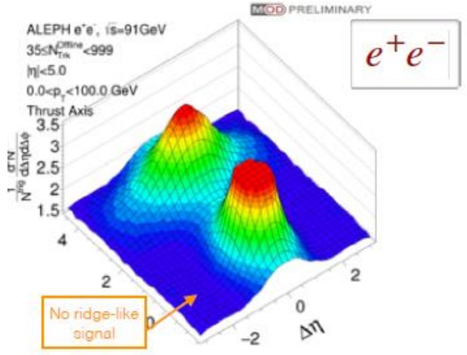
High efficiency

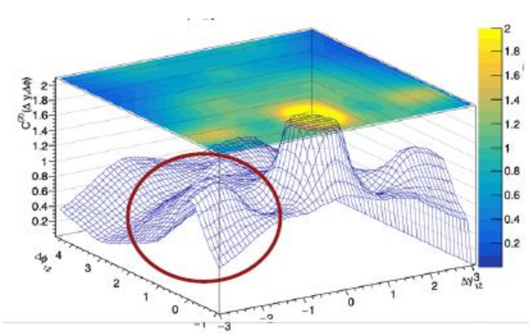
Search for hidden sectors

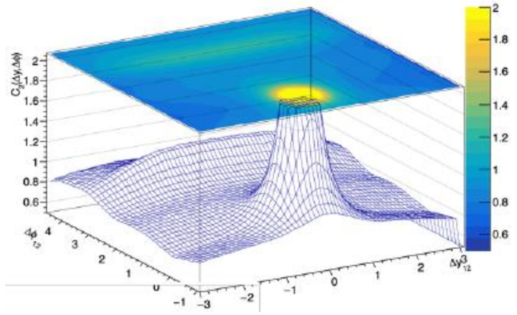
Emanuela Musumeci

$$C_2(\Delta y, \Delta\phi) = \frac{S(\Delta y, \Delta\phi)}{B(\Delta y, \Delta\phi)}$$







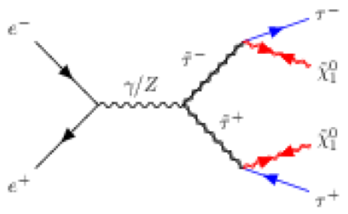


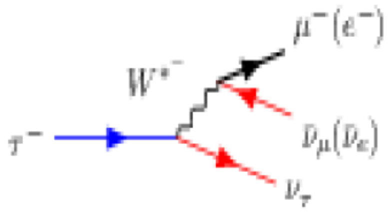
Thrust axis used

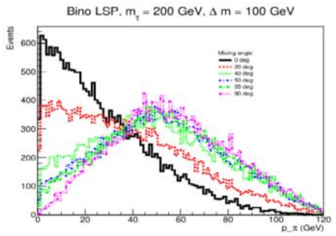
Teresa Nunez

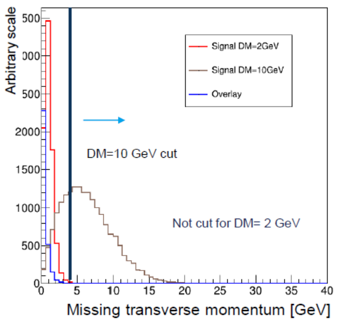
ILC Search for Staus

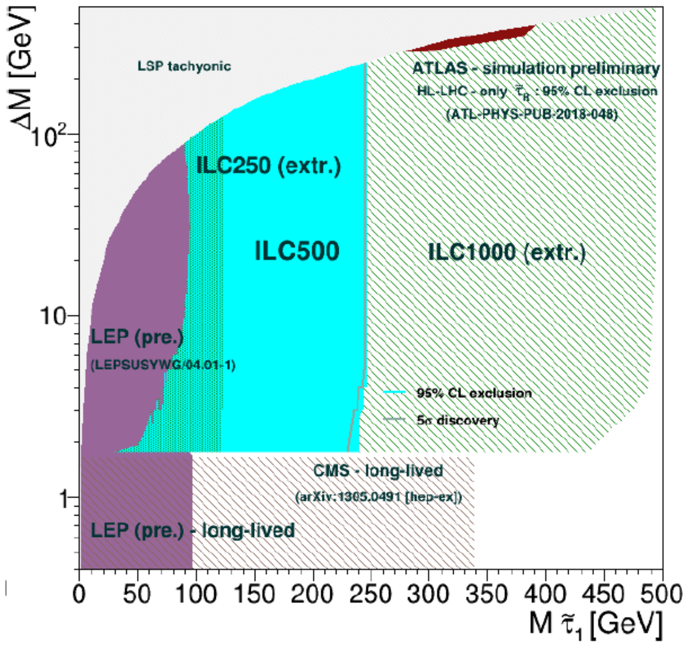
Supersymmetric partner of tau as NLSP





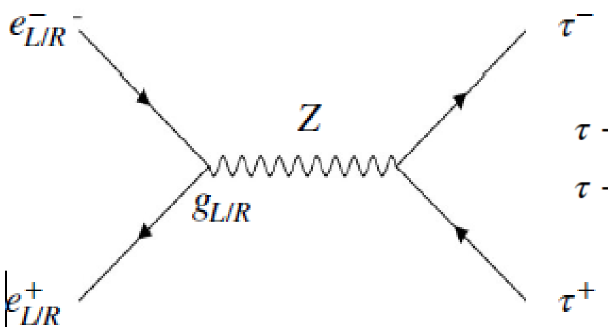






Keita Yumino

Tau Polarisation



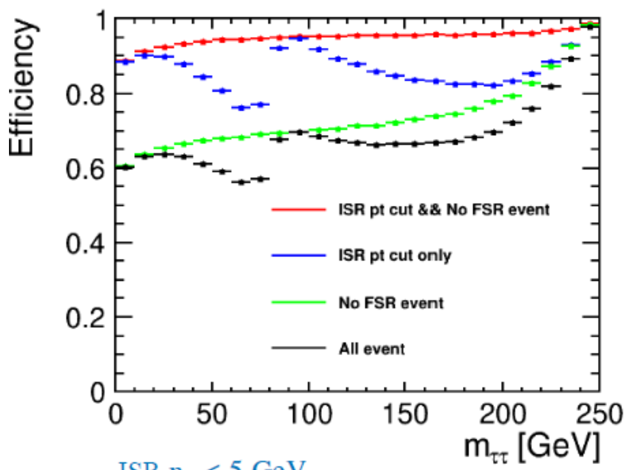
$\tau \to \pi\nu$ (BR ~ 10 %)

$\tau \to \rho\nu$ (BR ~ 26 %)

$$\frac{dP(\tau)}{d\cos\theta} = \frac{3}{8}A_\tau(1+\cos^2\theta) + \frac{3}{4}\left(\frac{A_e - P_e}{1 - A_e P_e}\right)\cos\theta$$

Measurement of tau polarization measures asymmetry

Impact parameter method efficiency



ISR $p_T < 5$ GeV

No FSR photon event

Promising new method of reconstruction

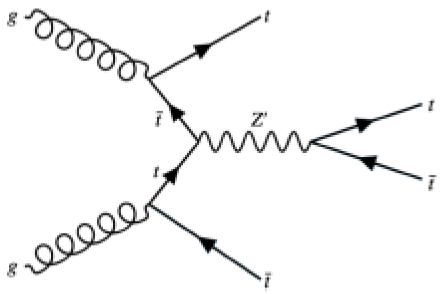
Ines Ochoa

ATLAS BSM

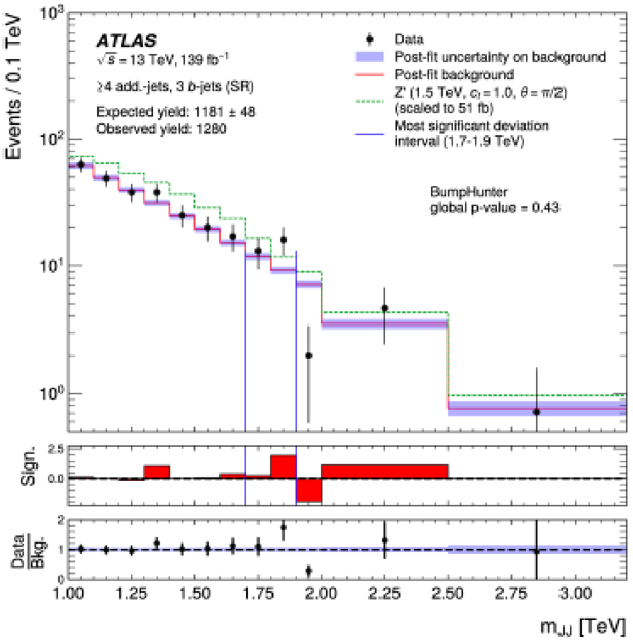
Extensive searches in a multitude of signatures

Presented here:

- Higgsino pairs
- top-philic resonances
- ALP
- Clockwork



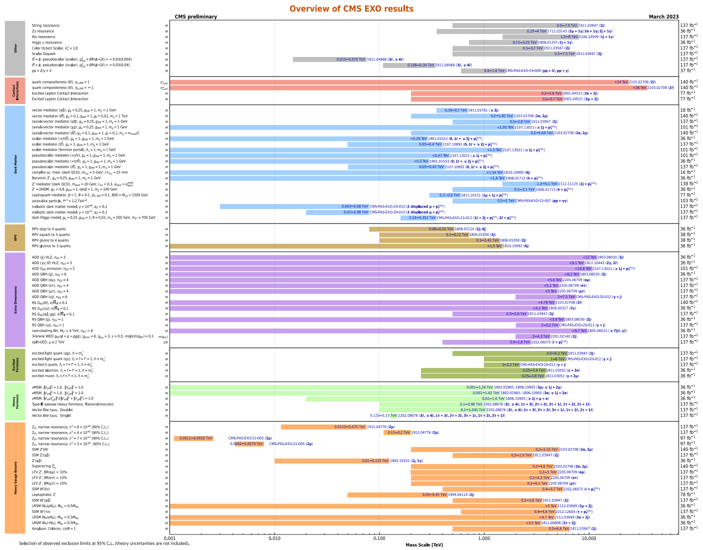
- Large radius jets
- No Ambulance in sight

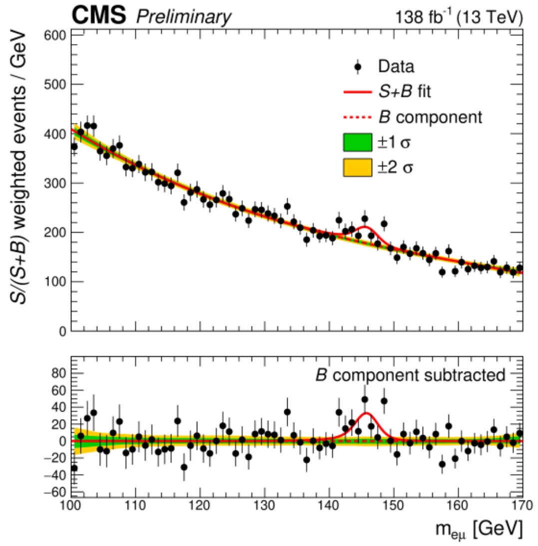


Sridhara Dasu

CMS BSM

Extensive searches in a multitude of signatures





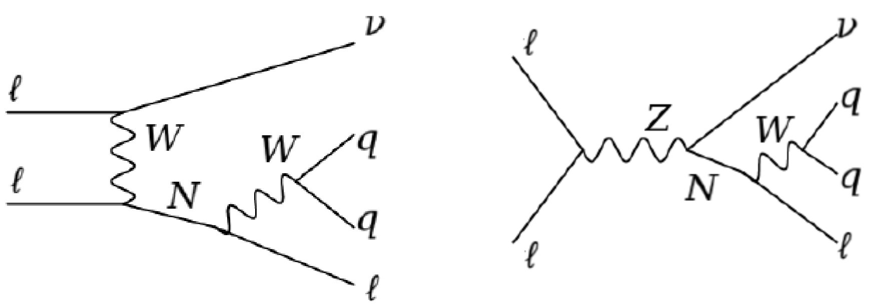
LFV: X→eμ

We shall see

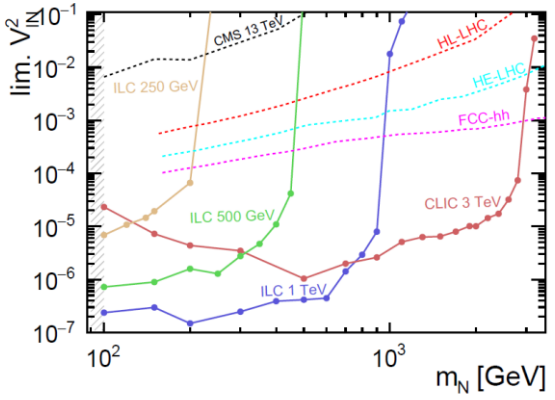
K. Mekala

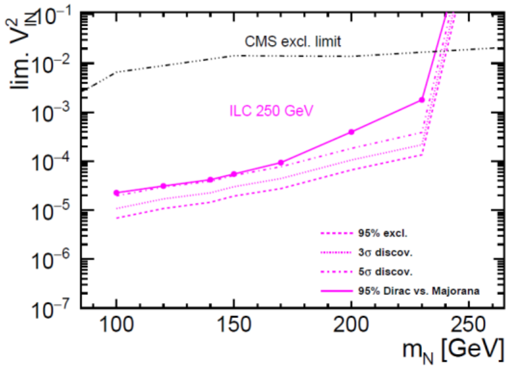
Heavy Neutrinos at ILC

Production and Decay:



BDT analysis:



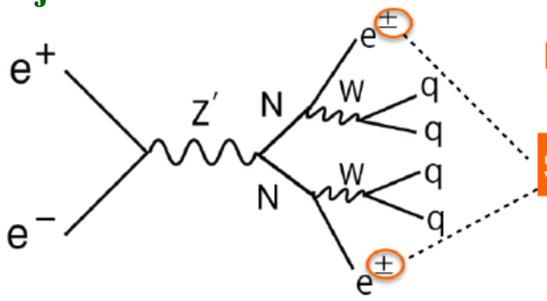


ILC can probe the nature of the heavy neutrino

Jurina Nakajima

RH neutrino pair-production at ILC

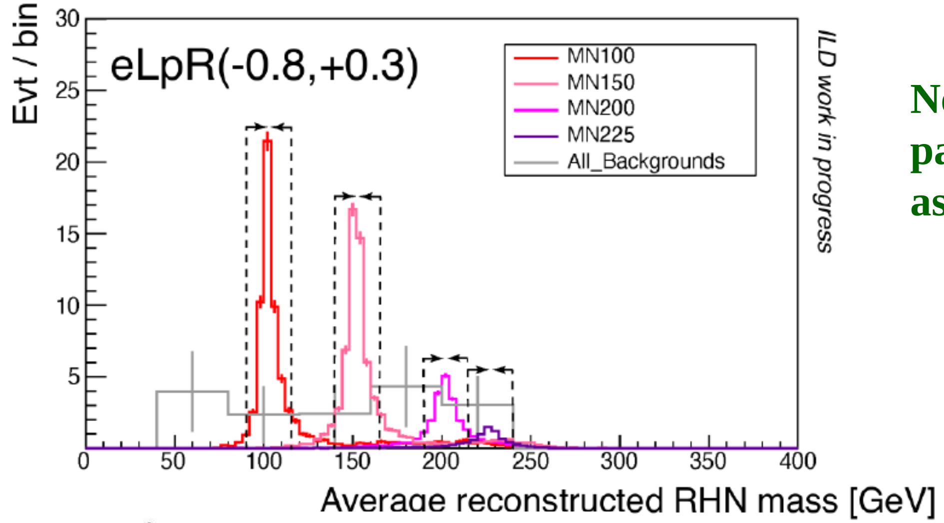
Majorana with additional Z'



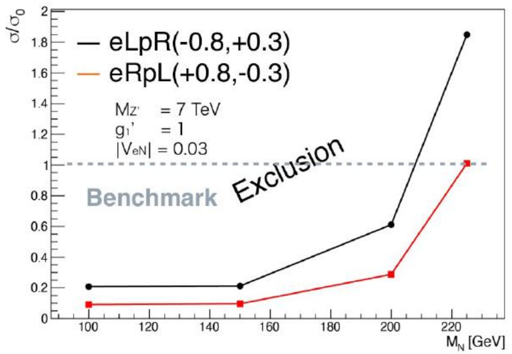
Lepton # violation is possible!

Same sign leptons possible

Very small SM BG!



Need good particle association



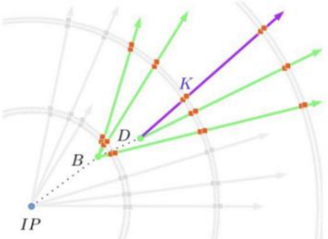
Exclusion guaranteed ☺

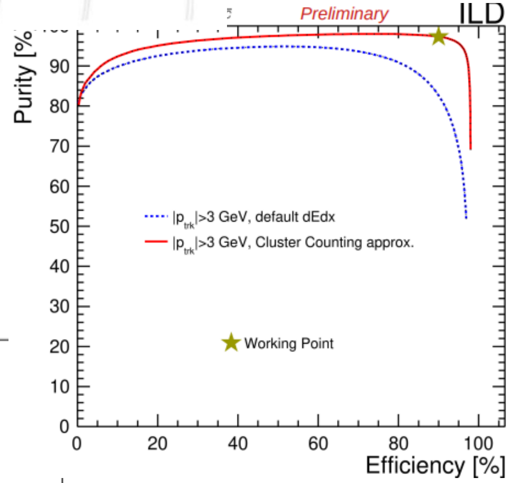
Needs high energy

Jesús P. Márquez

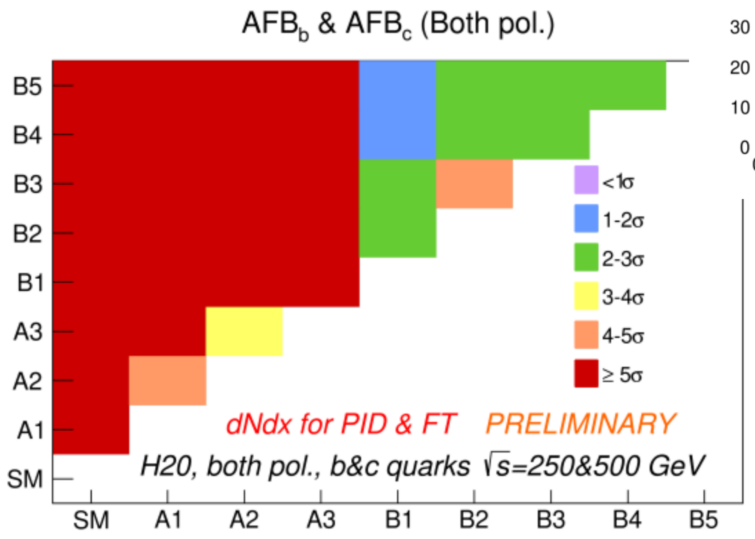
BSM physics at ILC250/500 with ILD

- **Hadronic fraction**
- **Forward-backward asymmetry**





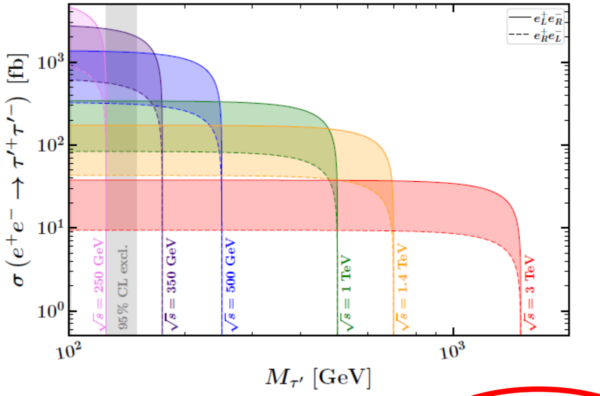
- **Improved TPC dEdx**



Good separation power against models

Prudhvi N. Bhattiprolu

Isosinglet vectorlike leptons

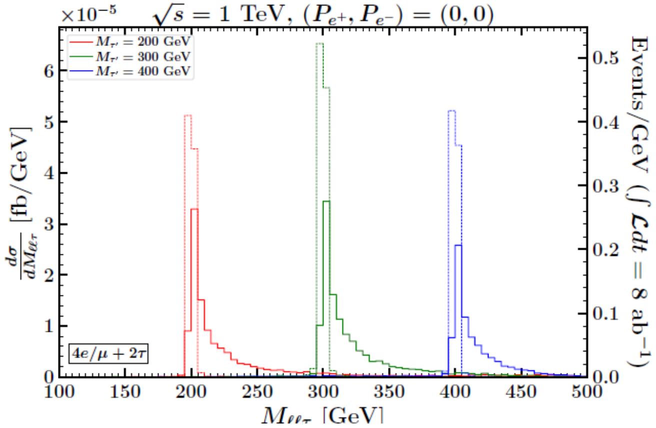


$e^+e^- \to \tau'^+\tau'^- \to ZZ\tau^+\tau^-, \quad hh\tau^+\tau^-, \quad Zh\tau^+\tau^-$

$ZW^\pm\tau^\mp + \not{E}, \quad hW^\pm\tau^\mp + \not{E},$

$W^\pm W^\mp + \not{E}$ **(largest!)**

Nice illustration of the use of in-person conference: better understanding of detector simulation!

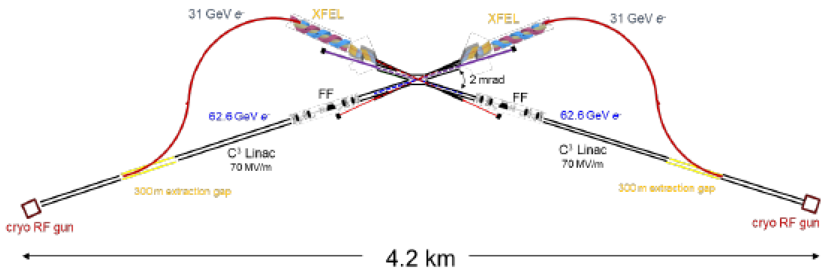


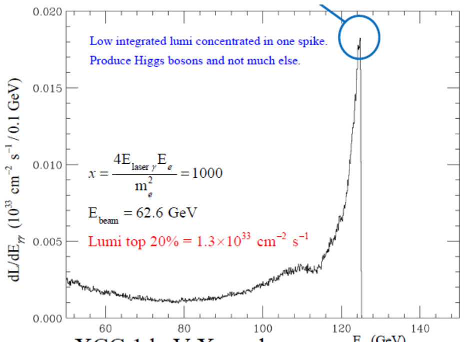
Includes Beamstrahlung and ISR

Tim Barklow

XCC: XFEL Compton γγ Collider Higgs Factory

XCC s-channel $\gamma\gamma \to H$ @ $\sqrt{s} = 125$ GeV



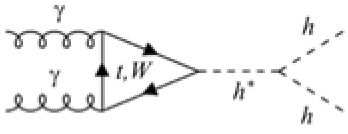


XCC 1 keV X-ray laser

Colliding Particles	ILC/C³ e^+e^-	XCC $\gamma\gamma$
Stage I:		
$\sqrt{s}$ (GeV)	250	125
Luminosity (fb^{-1})	2000	460
Beam Power (MW)	5.3 / 4.0	4.0
Run Time (yr)	10	10
# Single Higgs	0.5×10^6	1.3×10^6

Revisting the photon collider:

- XFELs+electron beams
- Lower CME
- Resonant production of Higgs
- One particle less to reconstruct
- Threshold for HH lower



LUXE

Adrian Irles

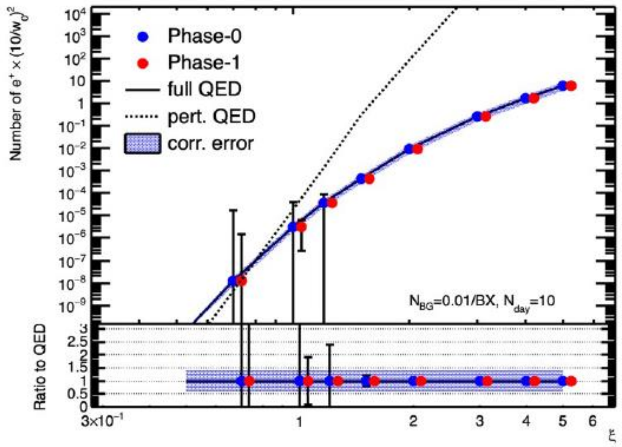
Experiment at XFEL:

- 30-350TW optical laser
- 16.5GeV XFEL electron b
- Effective Field 10^14V/m

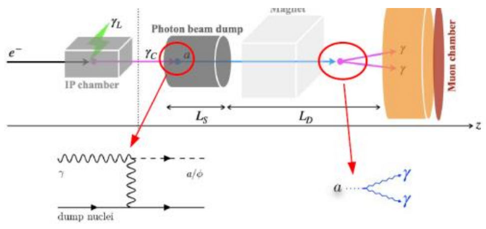
Field intensity parameter

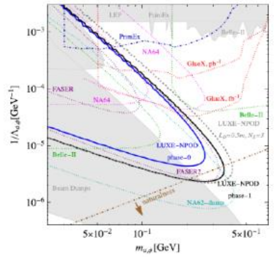
$$\xi = \sqrt{4\pi\alpha}\left(\frac{\varepsilon_L}{\omega_L m_e}\right) = \frac{m_e \varepsilon_L}{\omega_L \varepsilon_{cr}}$$

Deviation from pert.QED (passing Schwinger limit)



Optical Beam Dump experiment: new physics search





- Good for ILC
- Uses ILC technology
- Uses ILC detector developments