Search for self-interacting dark matter in CMS
and
experience with CMS Phase-1 pixel detector upgrade

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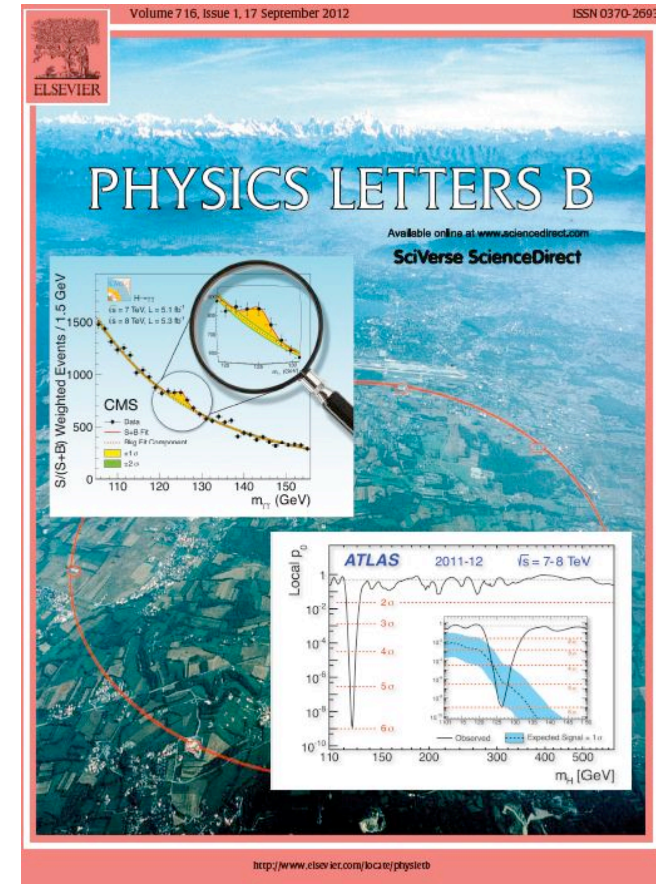
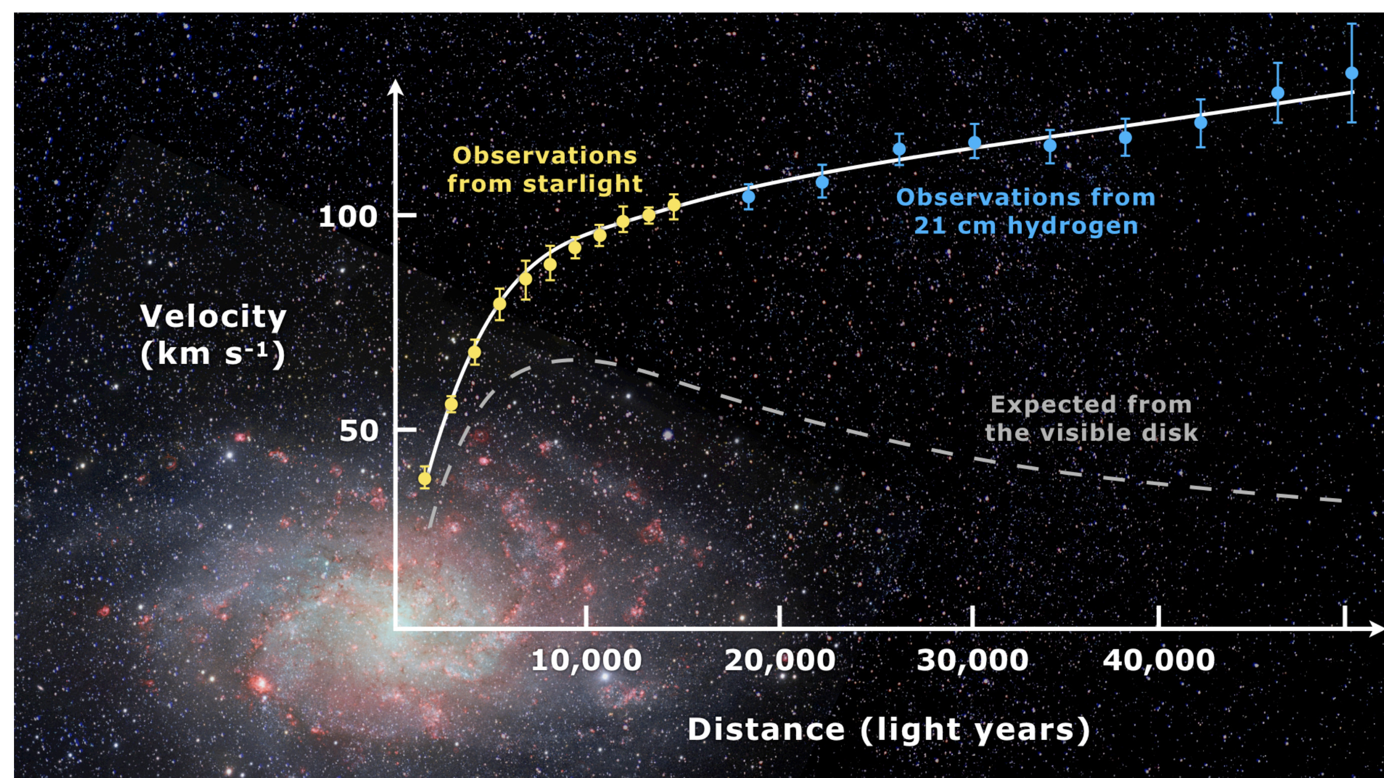
SLAC FPD seminar | June 16, 2020

- The Higgs boson was discovered; standard model more complete.
- Standard model is not the completion of physics,
  - Hierarchy problem
  - Neutrino mass
  - Dark matter
  - etc.



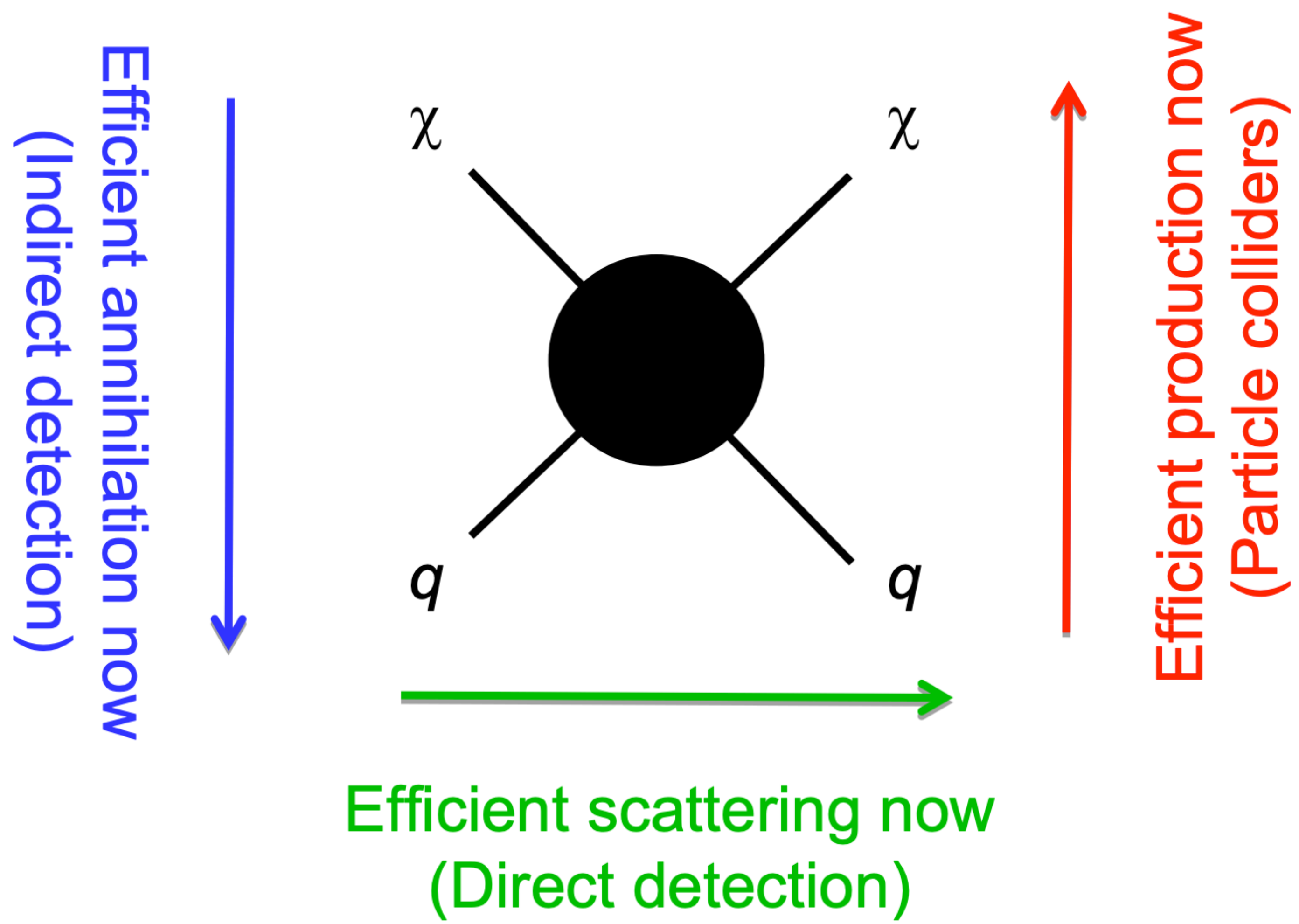
- One important piece missing — dark matter
- Dark matter known to exist from astrophysical observations,
  - Galaxy rotation curve
  - Gravitational lensing



https://en.wikipedia.org/wiki/Galaxy_rotation_curve

* Popular DM candidate: **WIMP** (weakly interacting massive particle)
* WIMP miracle: "weak" mass scale & coupling → correct abundance.

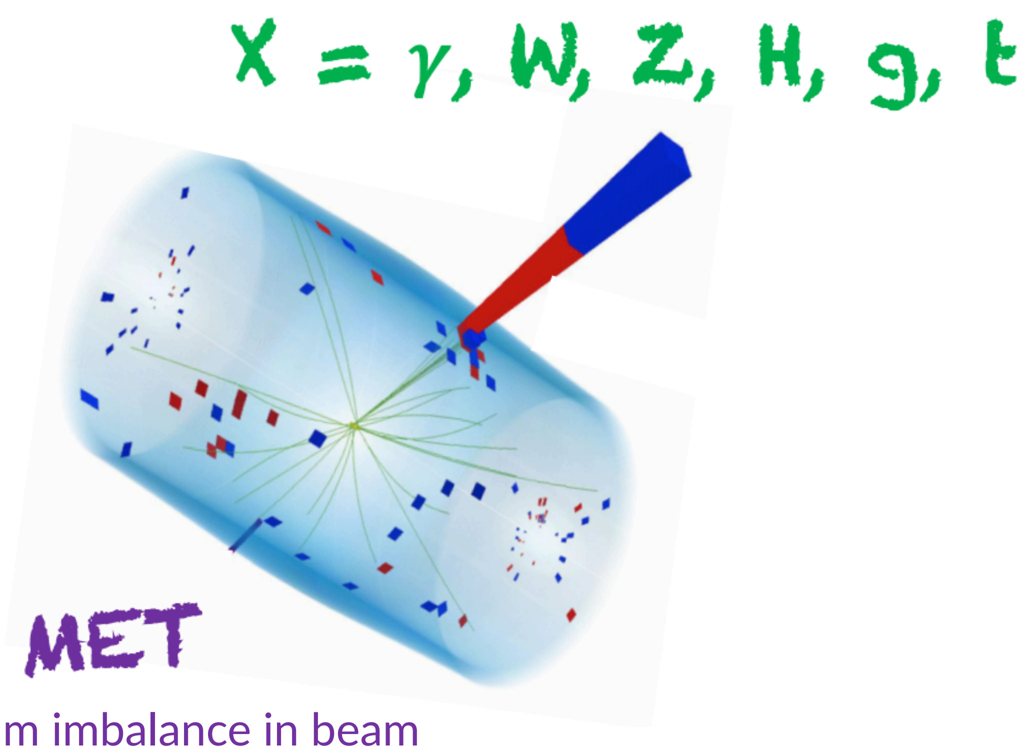
WIMP detection



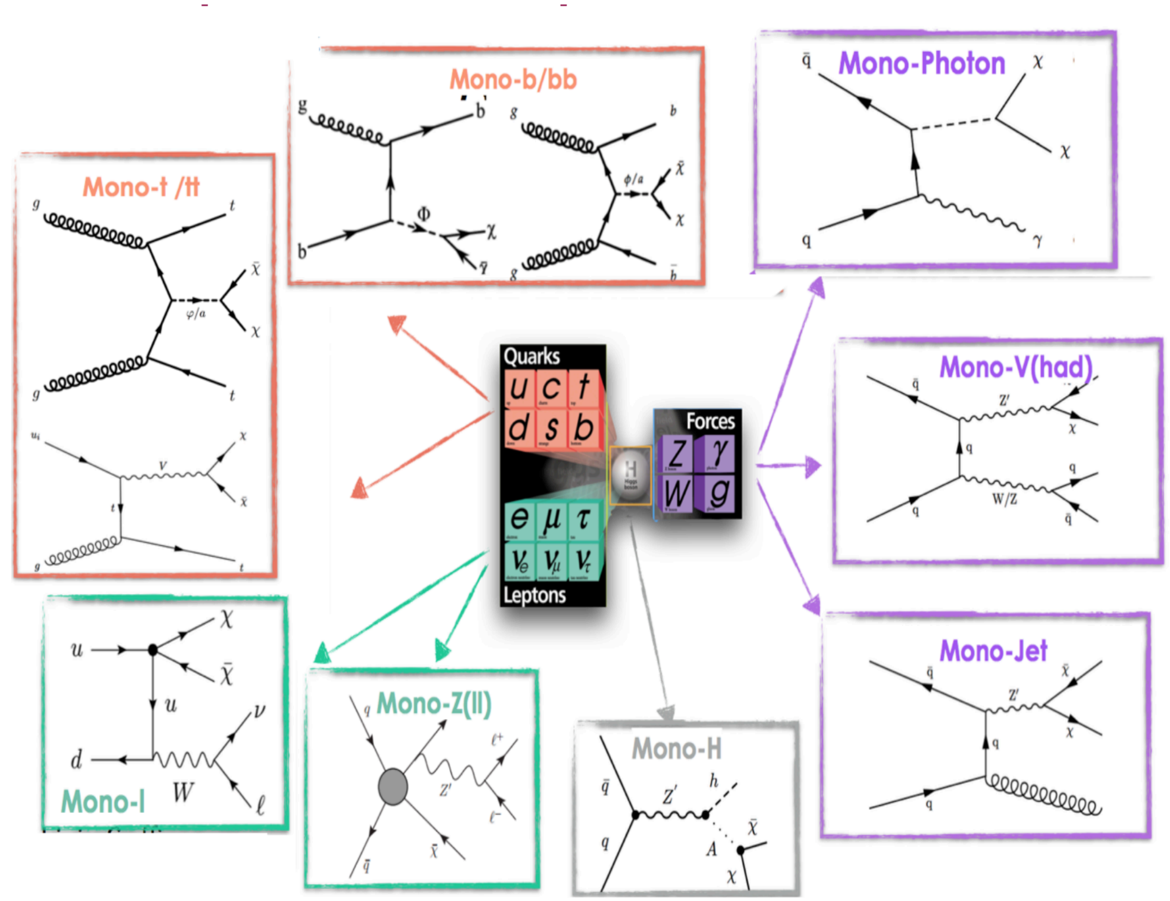
(Feng. 2009)

WIMP at collider

* Large missing E_T signature search at collider.
* Many searches performed, dark matter **not found** yet.



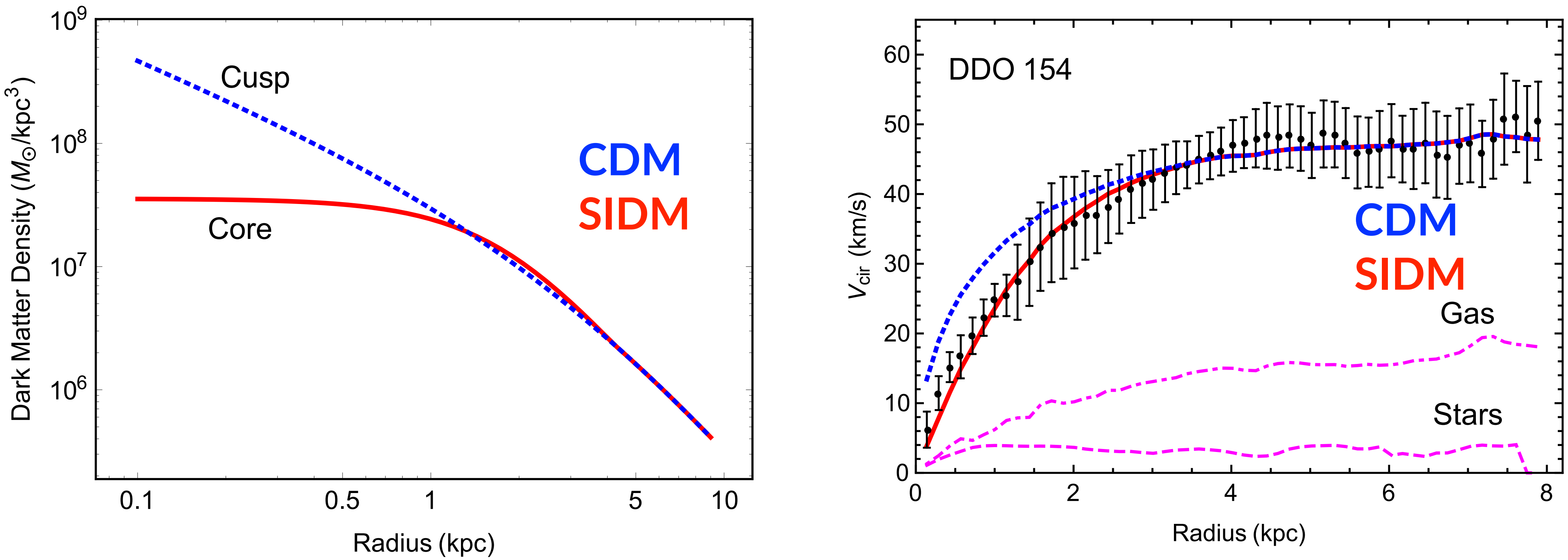
momentum imbalance in beam transverse plane due to non-interacting particles



(Sharma. LHCP2020)

SIDM

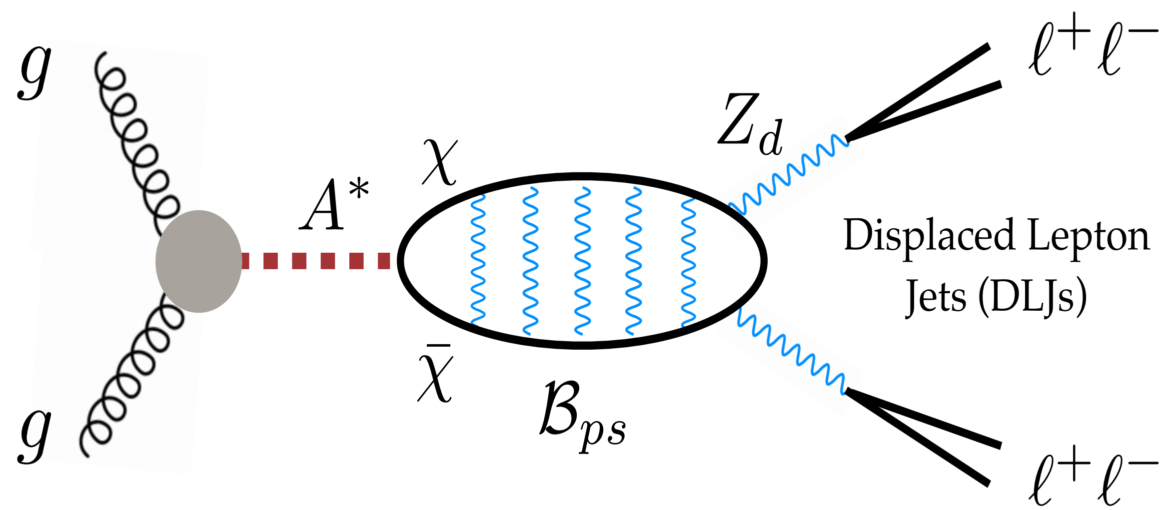
* Keep eyes open for other dark matter scenarios
* SIDM (self-interacting dark matter)
* Elastic scattering, need σ/m~1cm^2/g (~2*10^{-24}cm^2/GeV)
  * WIMP – σ/m~2*10^{-38}cm^2/GeV, effectively collision-less CDM.

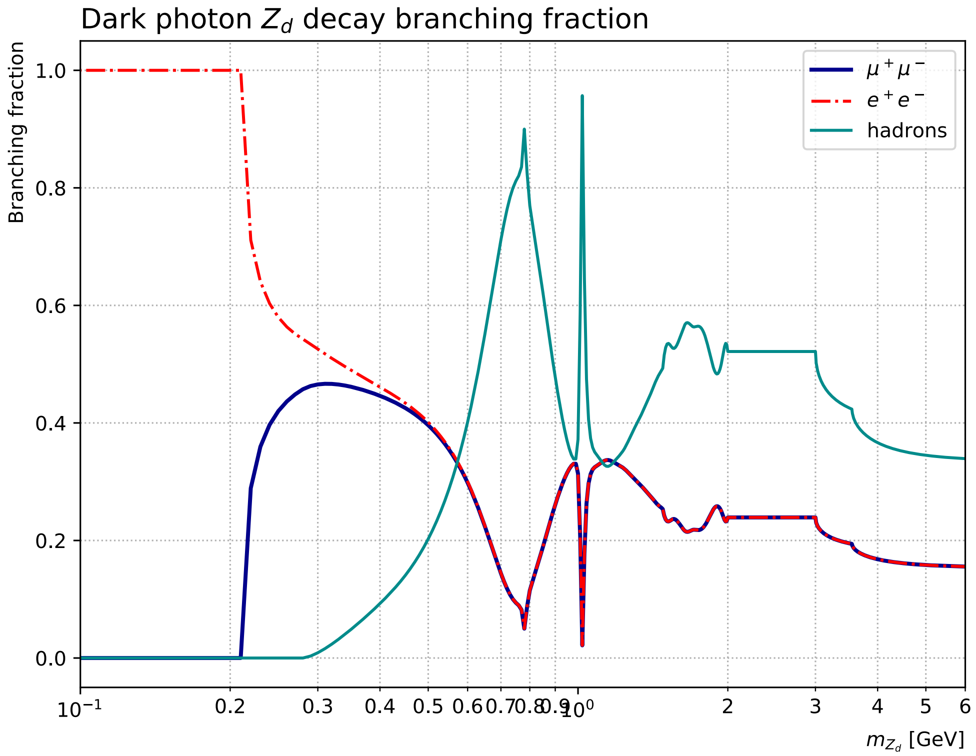


(S. Tulin, HB Yu, Phys.Rept. (730) 2018 1-57)

* Collisionless CDM-only simulations predict "cuspy" density profile, while observation prefers "core".
* Other issues: missing satellites problem, rotation curve diversity problem, etc.

* SIDM model at LHC





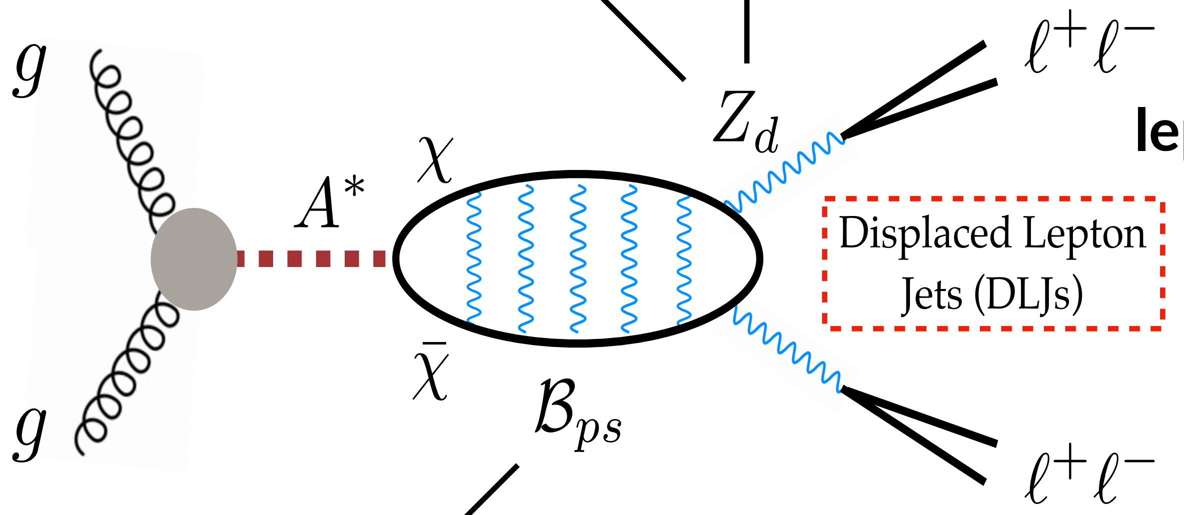
(Tsai, Xu, Yu, JHEP08(2019)131)

* SIDM particle (χ) couples to gluon (g) via a heavy pseudoscalar (A*).
* Dark photon (Z_d) mediates dark matter self-interaction, leads to SIDM bound state (B_{ps}).
* SIDM bound state annihilates into a pair of boosted Z_d.
* Z_d decays to a pair of standard model opposite charged leptons via kinetic mixing portal.
  * We focus on $Z_d \to \mu^+\mu^-$ / e^+e^-

SIDM model features

Dark photon is long-lived.

Dark photon is light (0.3-5GeV)

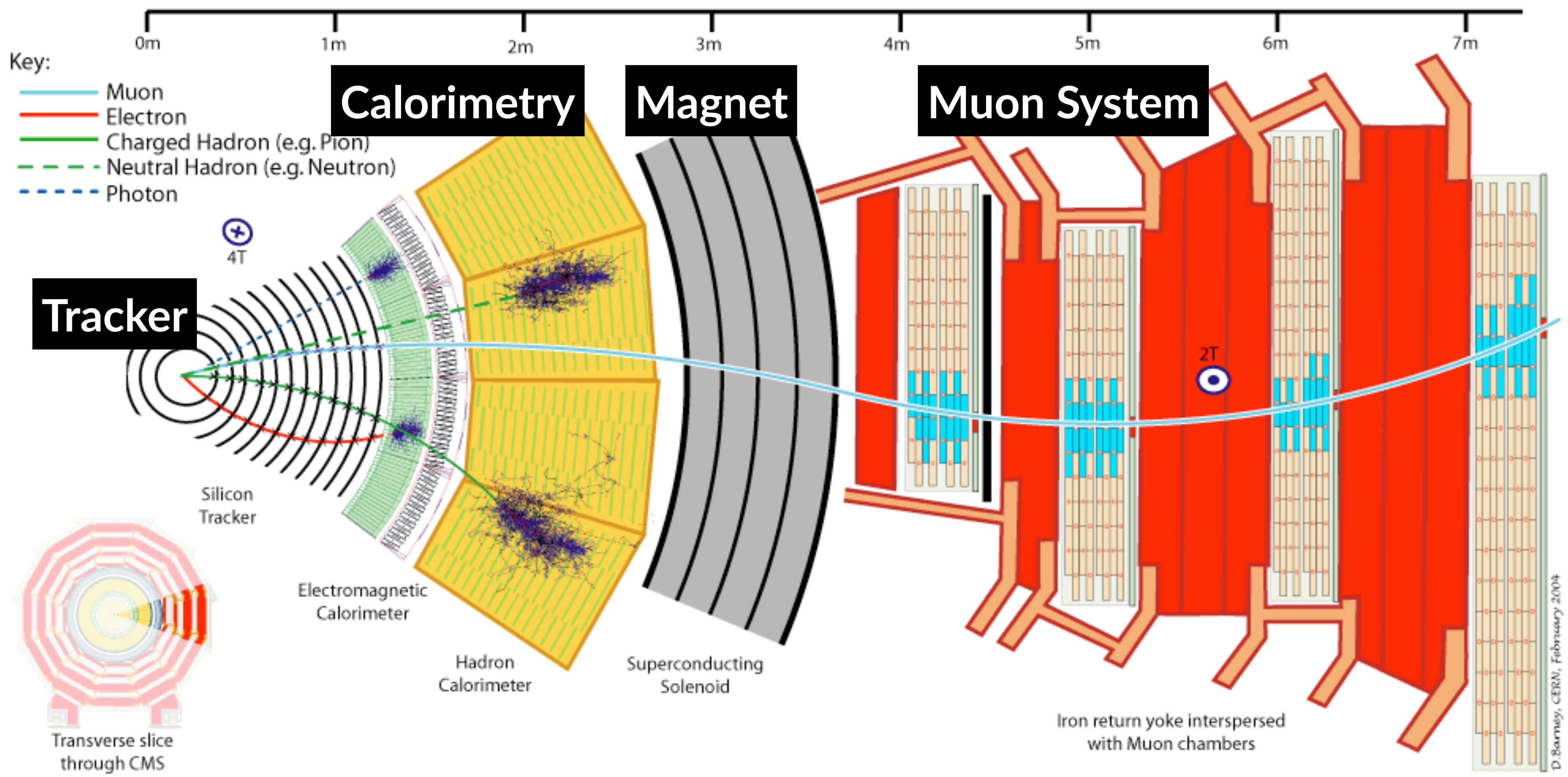


lepton pair is boosted

SIDM bound state is heavy (100-1000GeV)

(Tsai, Xu, Yu, JHEP08(2019)131)

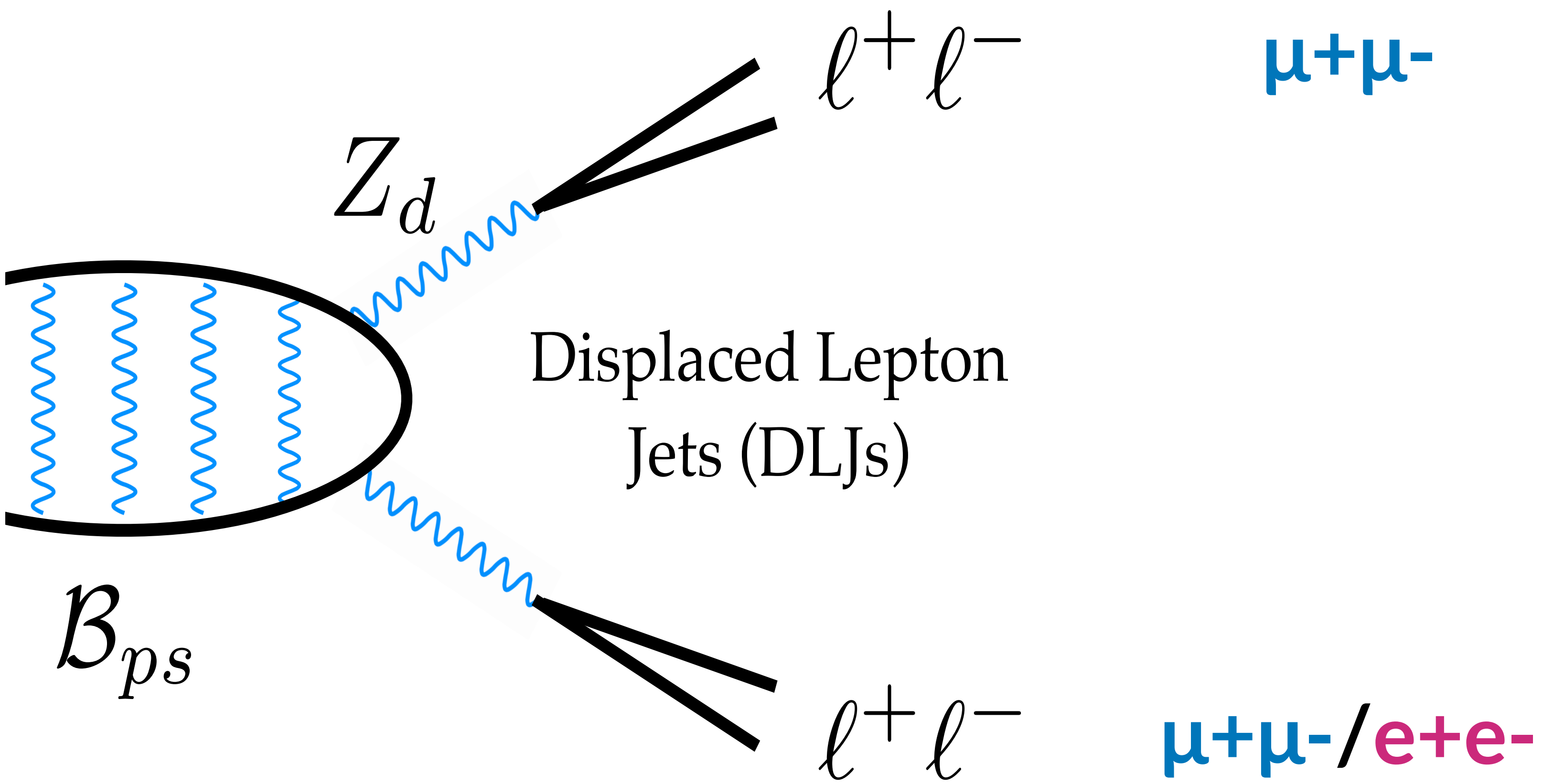
The CMS detector



- CMS (compact muon solenoid)
- Layer structured, general purpose detector for pp, heavy ion collisions.
- Installed at LHC, positioned at the opposite side of ATLAS.

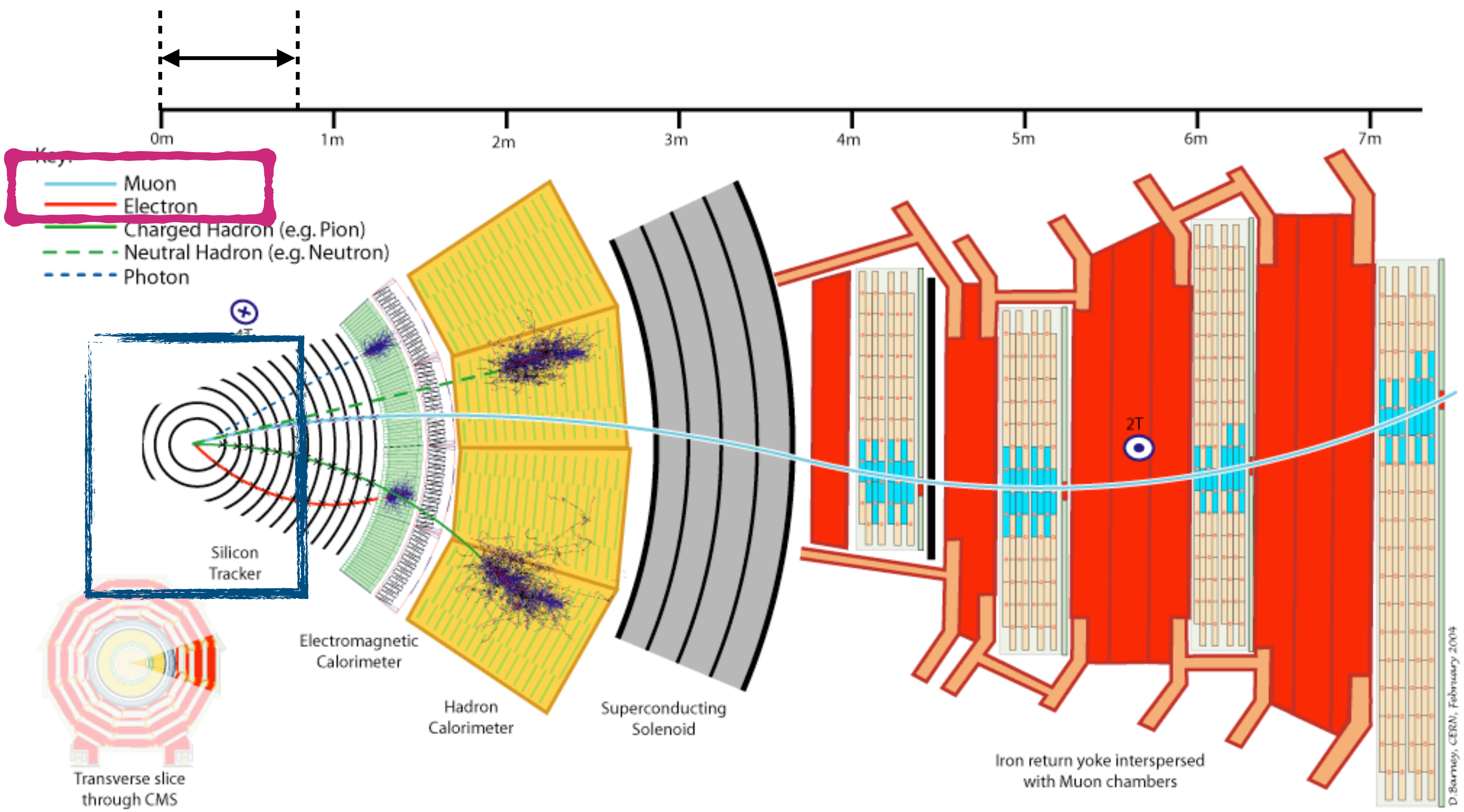
Trigger

* Triggers on **displaced muons**.
  * Trigger object reconstructed using only muon chamber information.
  * No beam spot constraint.
* Two muons, p_T>23 (25) GeV, |eta|<2 (2.4).
* Trigger only available for 2018 data.



2 search channels:
- channel 4μ
- channel 2μ2e

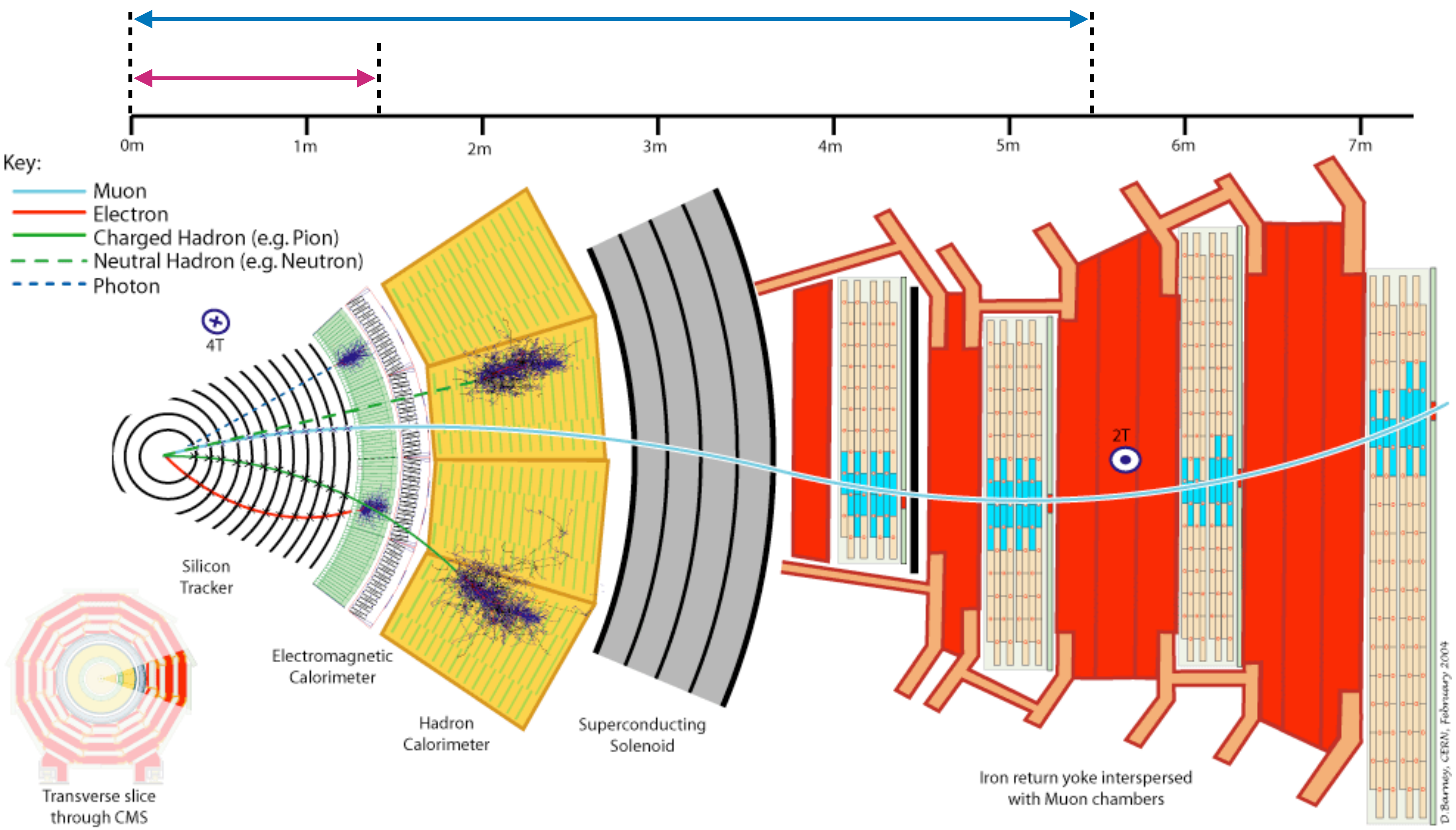
* Out-of-box objects: **PF** (particle flow) **candidates**: PFMu, PFElectron
  * Great efficiency & resolution for signal with *short* displacement
  * Limited by tracking of silicon tracker.



Signal reconstruction

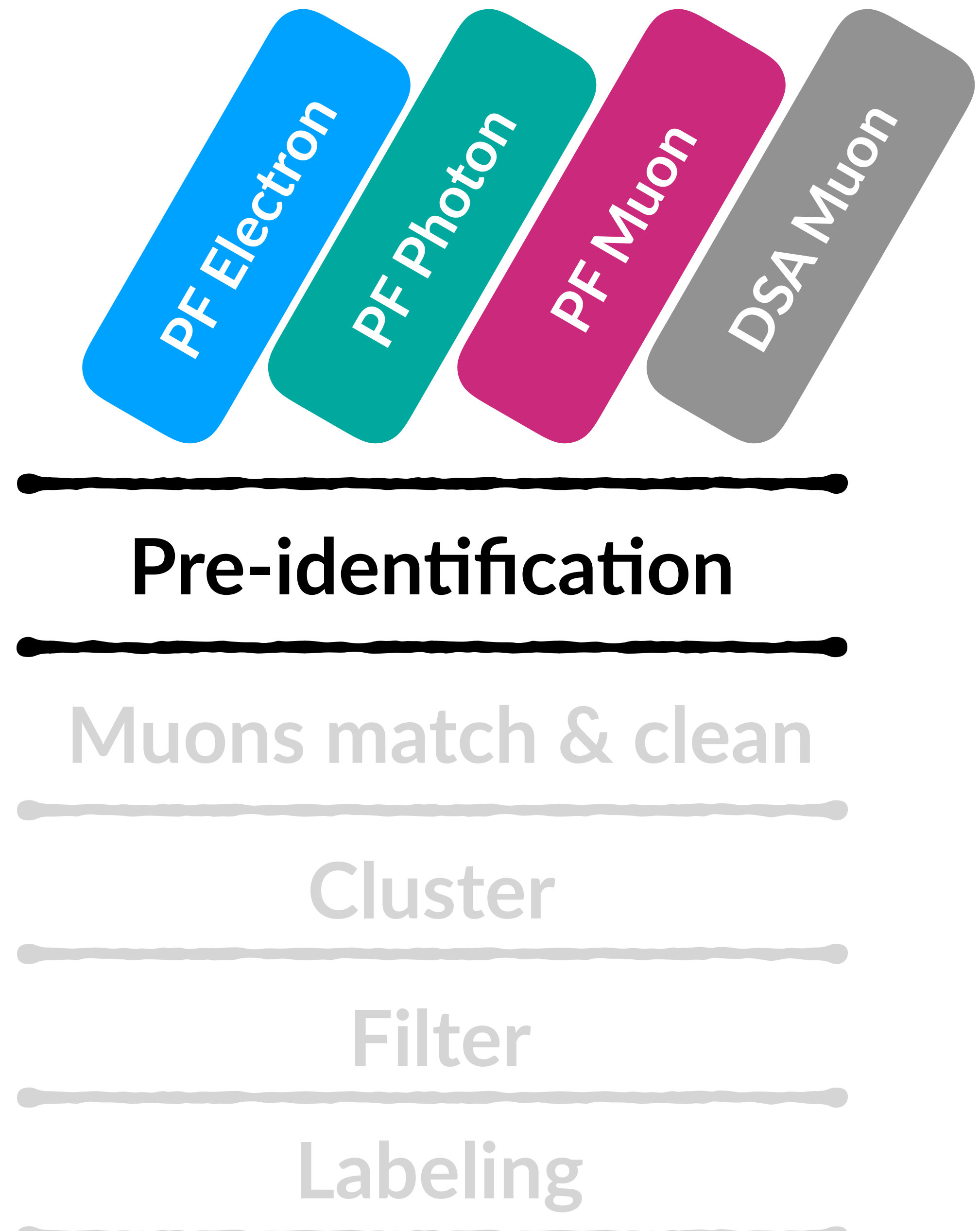
- Signal with *large* displacement
  - $Z_d \to \mu\mu$, displaced standalone muons (DSA)
    - Dedicated muon reconstruction, not part of PF.
  - $Z_d \to ee$, PF Photon
    - Displaced electrons whose track is not reconstructed would appear as a photon.

DSA: using muon chamber information only, no beam spot constraint.



* *Strategy*: cluster collimated leptons into "jets" — **lepton-jet**.
    * No fixed number of particles clustered.
    * Multiple types of particles possible.

- Use the standard set of identification criteria for **PF** Electron, Photon, Muon.
- Use "*loose*" working point for **high efficiency**.
- Customized DSA ID based on number of hits/muon stations, normalized χ^2 and p_T error/p_T.



* To be generic, cluster leptons into "jets" — **lepton-jet**.
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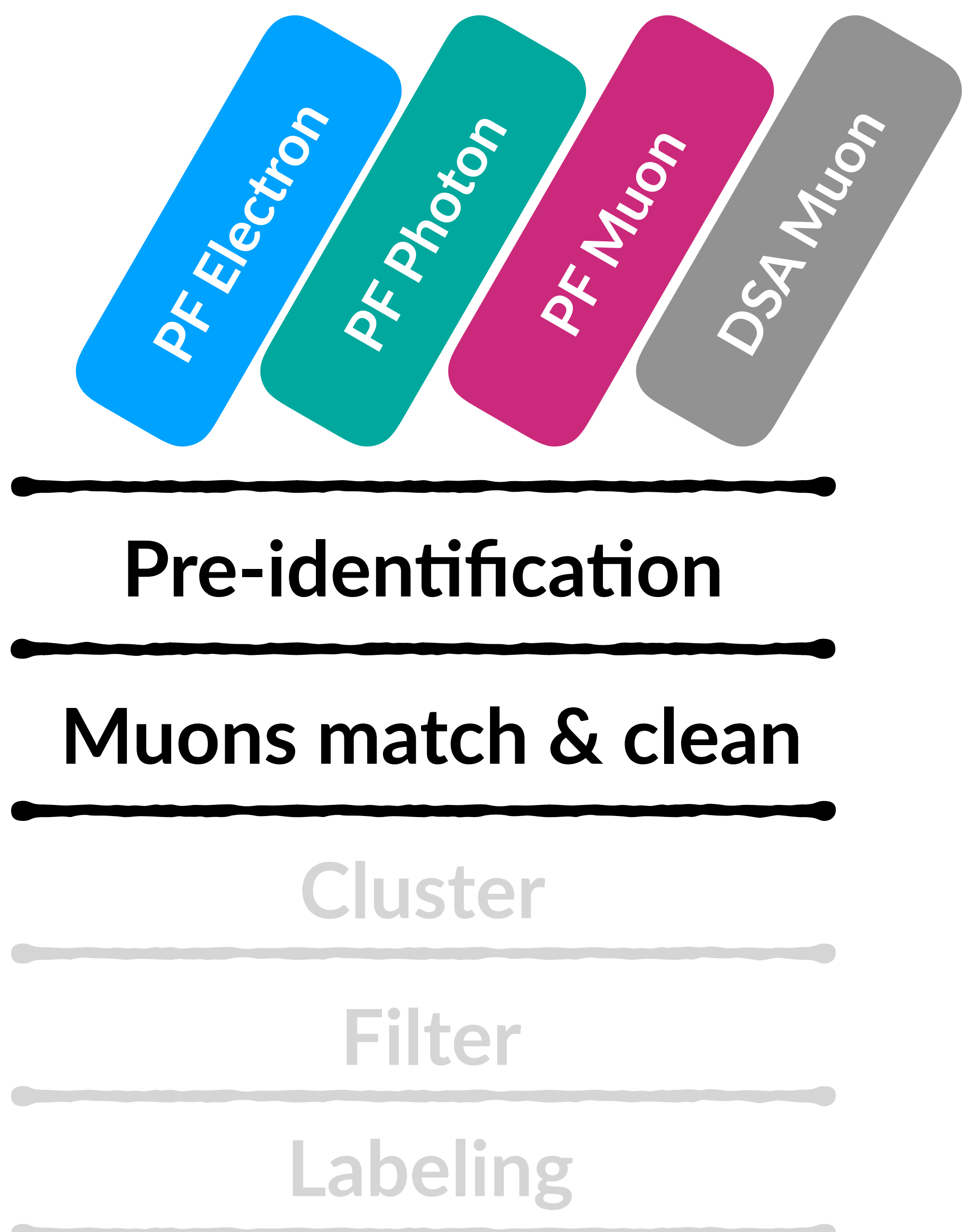

- A single muon may be reconstructed both as a PF Muon and a DSA muon.
- Match & clean to avoid duplicate counts.
- Based on distance + muon segment overlap.

Signal reconstruction

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  * No fixed number of particles clustered.
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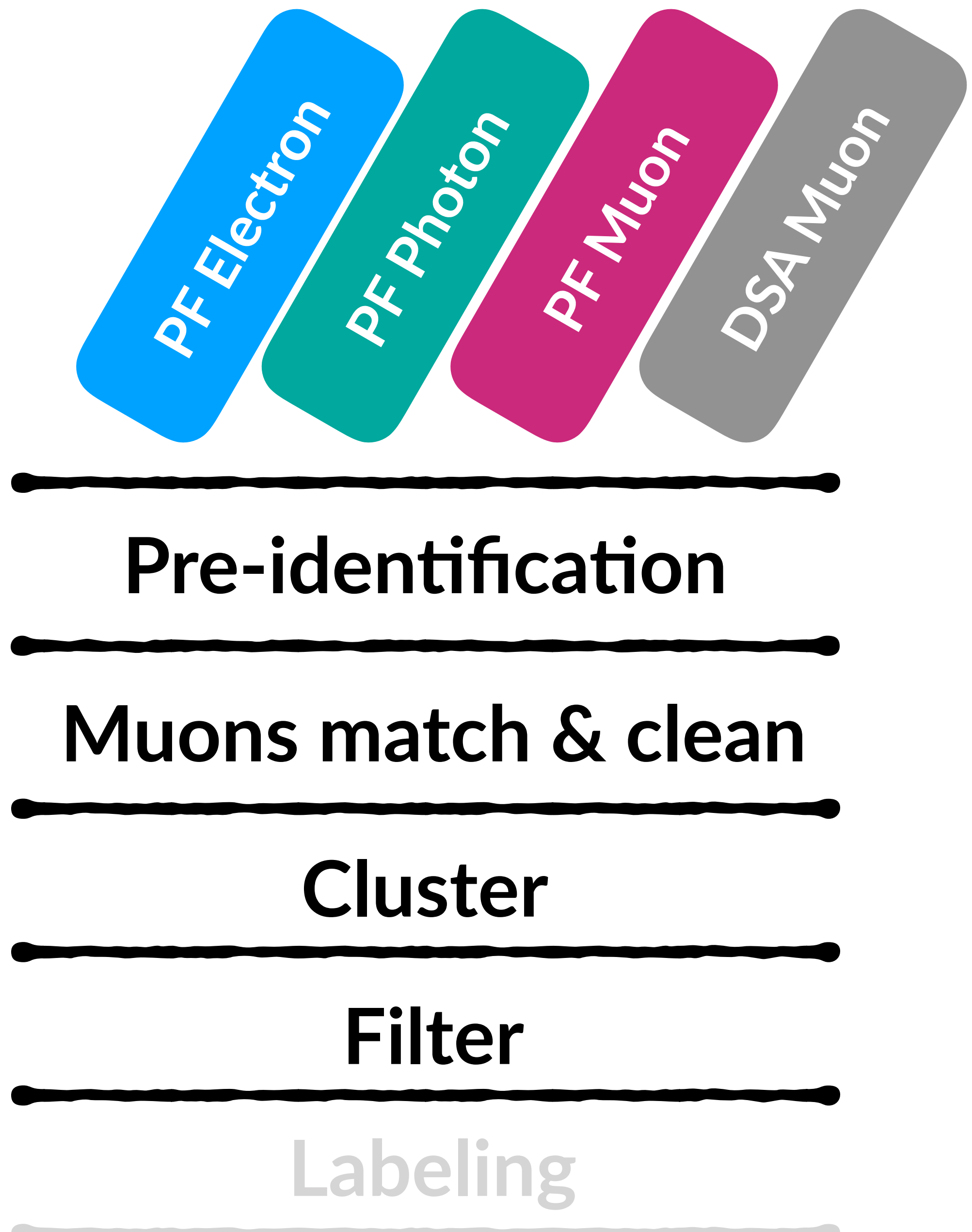
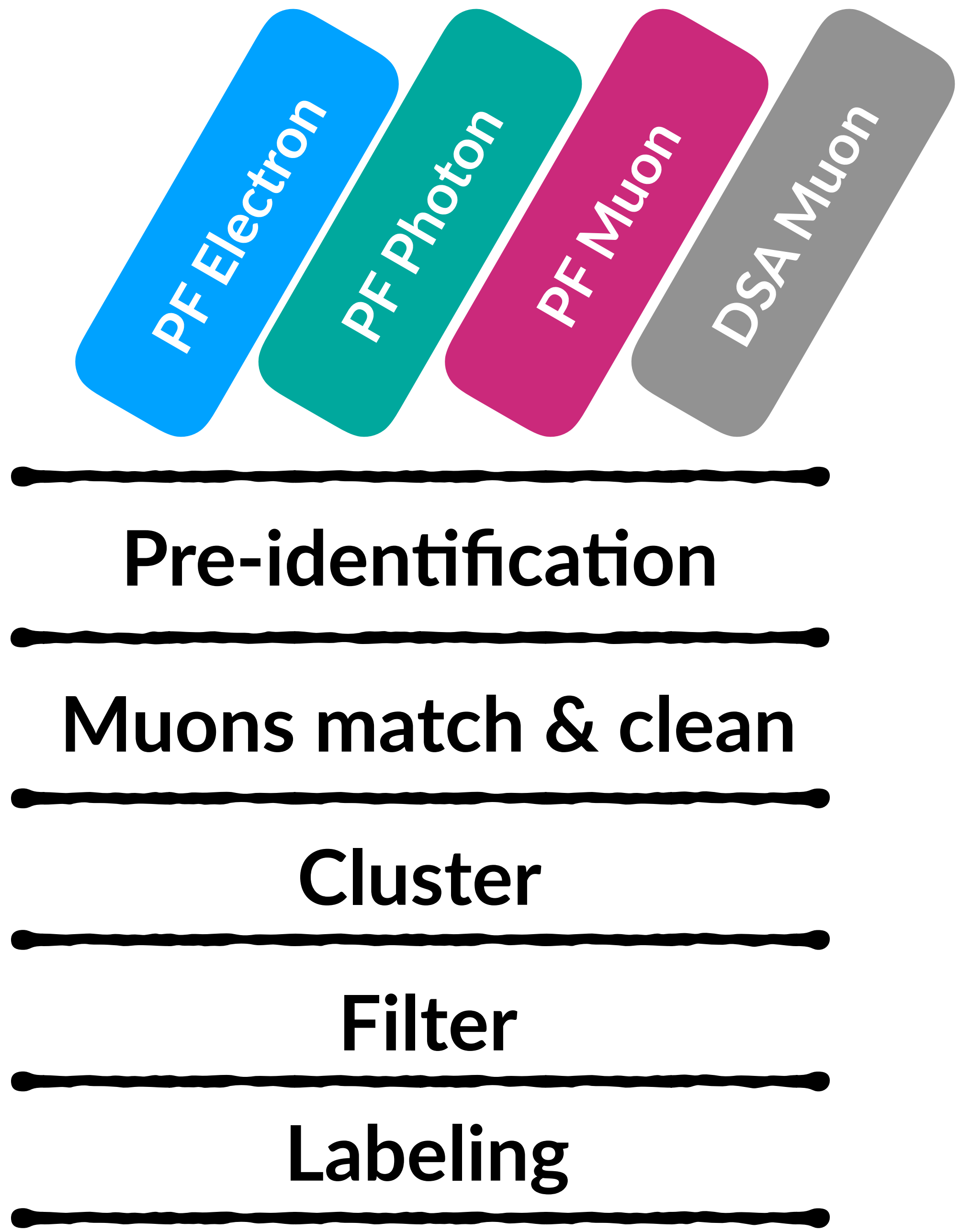


- Cluster with Anti-kt, ΔR=0.4
- Filter:
  - p_T>30GeV, |eta|<2.4.
  - Even muon multiplicity.
  - Sum of muon charge = 0.

* To be generic, cluster leptons into "jets" — **lepton-jet**.
  * No fixed number of particles clustered.
  * Multiple types of particles possible.

- Has any muon(PF/DSA Muon)?
  - Yes: ***Muon-type*** lepton-jet
  - No: ***Egm-type*** lepton-jet



Signal reconstruction

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  - No: ***Egm-type*** lepton-jet

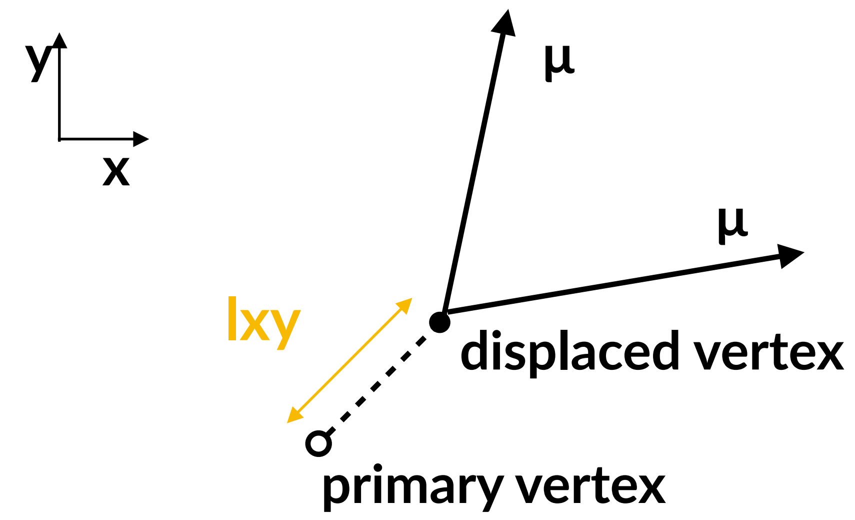
Final state: *Two **isolated** lepton-jets **back-to-back** in transverse plane.*

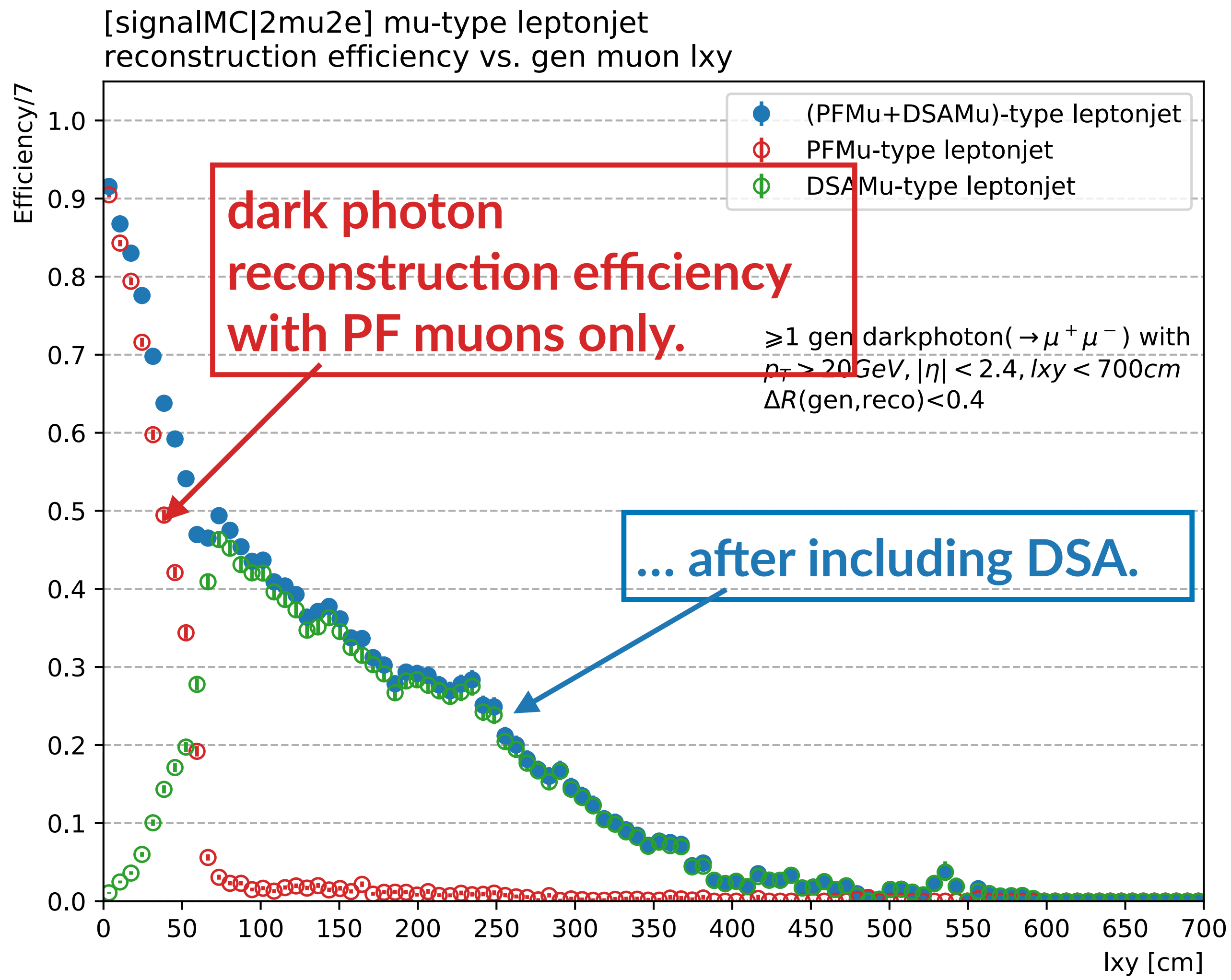
Channel 4mu:
- Two muon-type lepton-jets

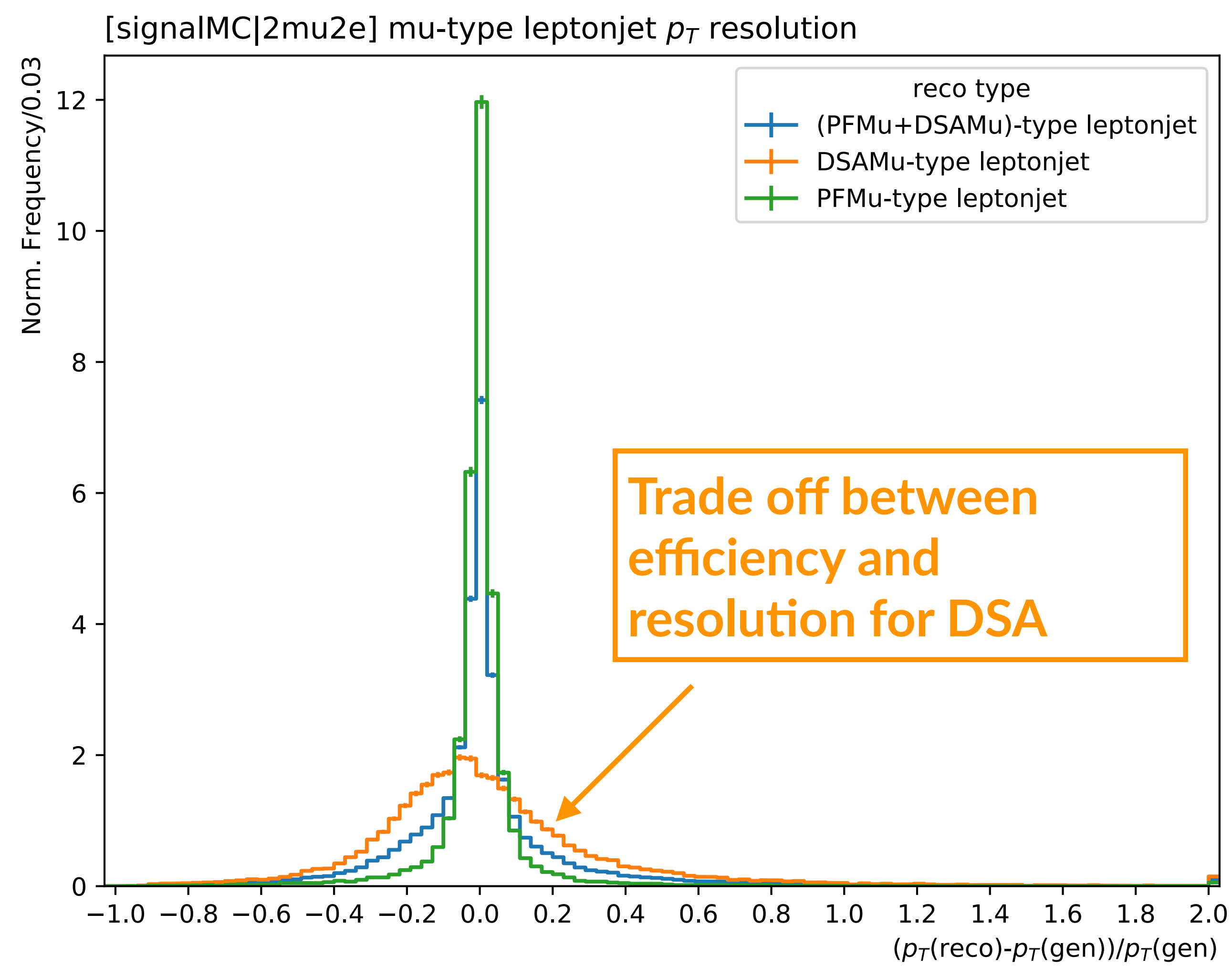
Channel 2mu2e:
- One muon-type lepton-jet
- One egm-type lepton-jet

Lepton-jet performance

* Muon-type lepton-jet $Z_d \rightarrow \mu^+\mu^-$
  * Efficiency vs. dark photon lxy
  * p_T resolution







Lepton-jet performance

- Egm-type lepton-jet $Z_d \rightarrow e^+e^-$
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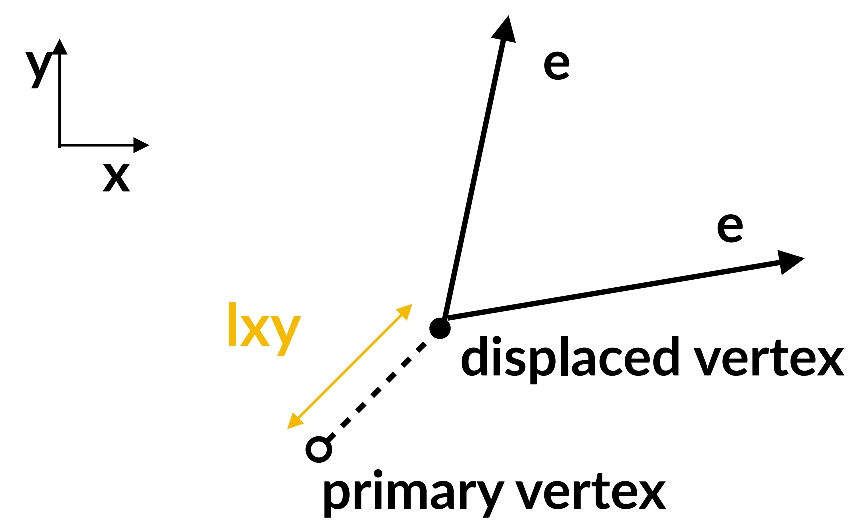
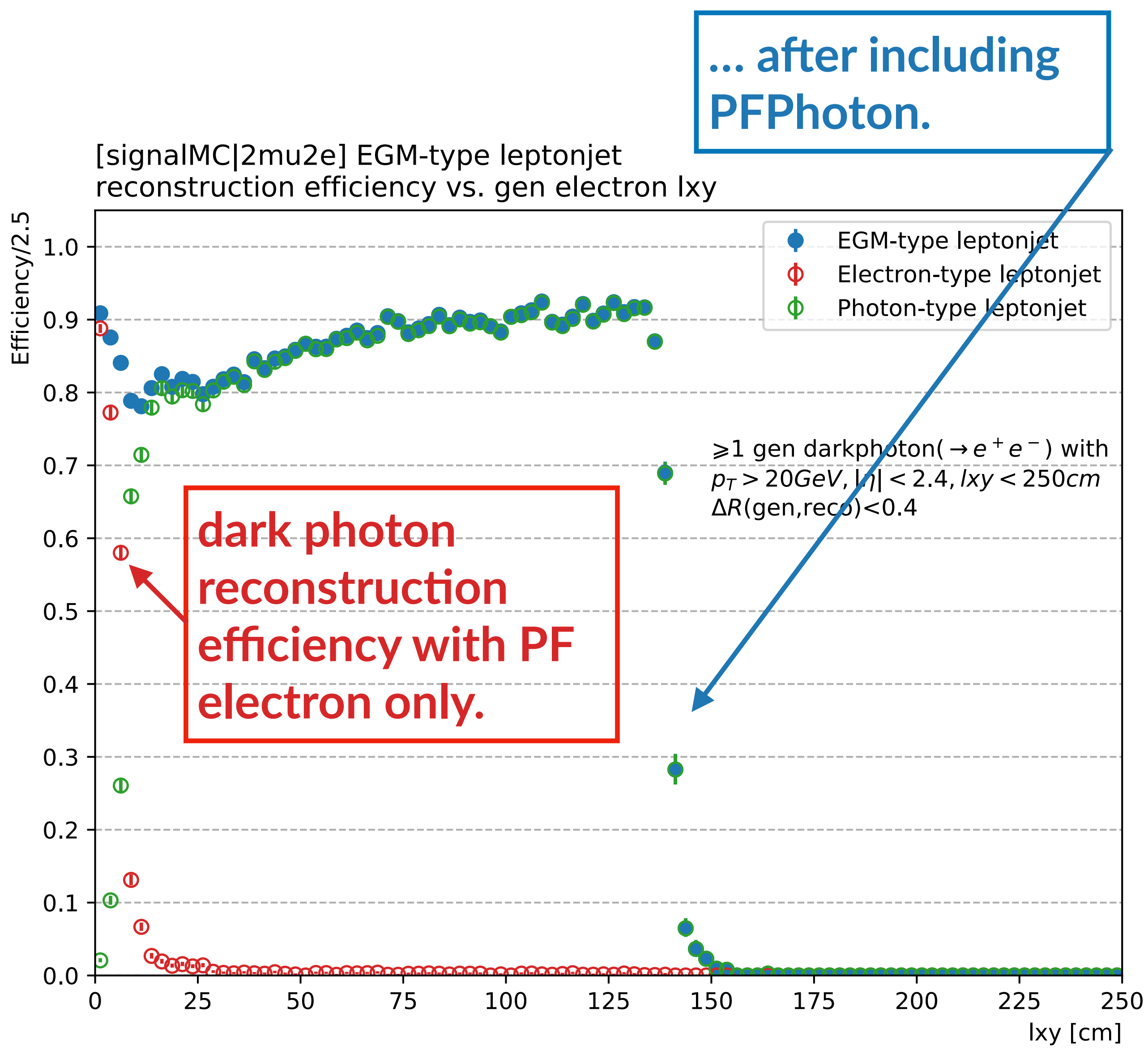
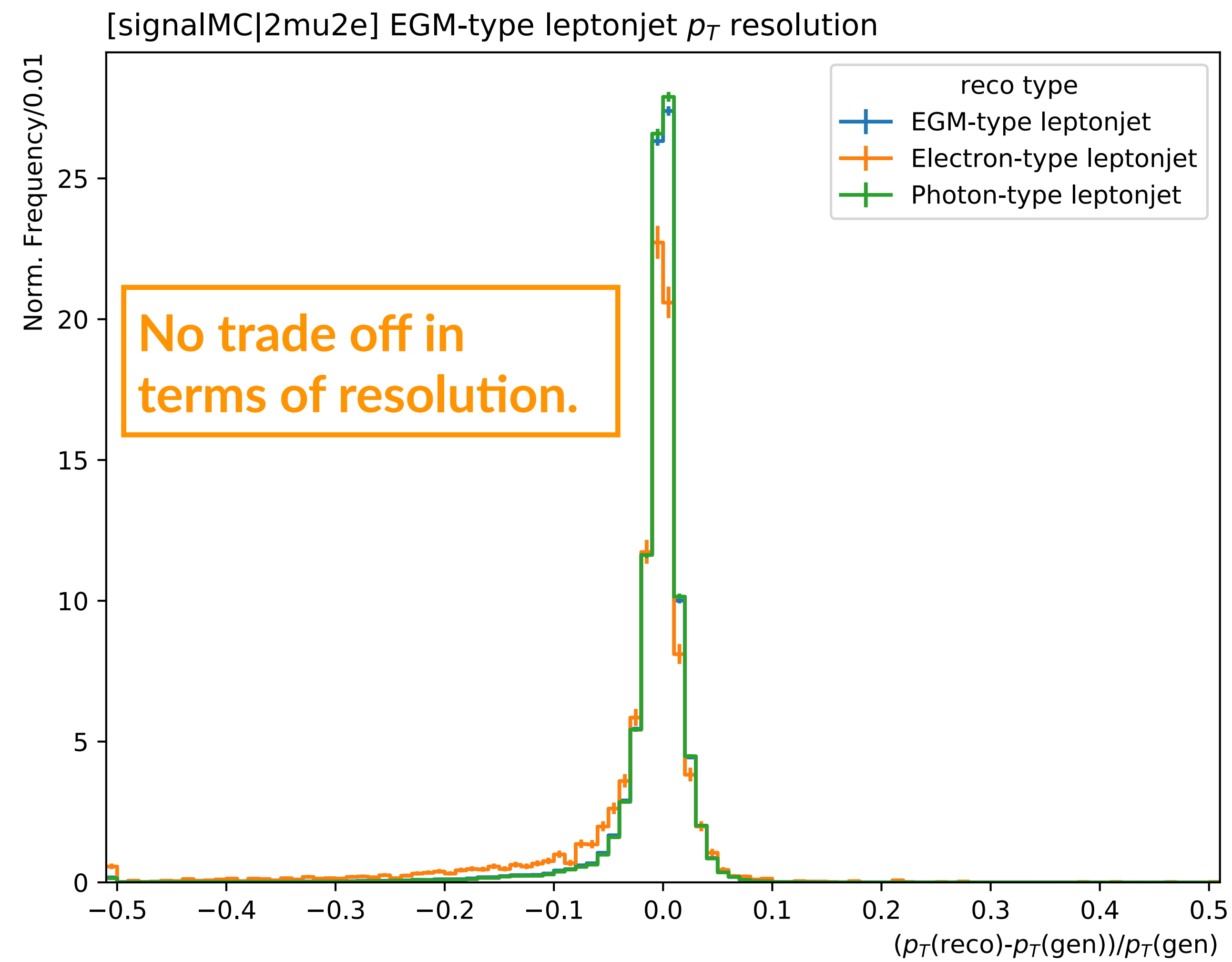


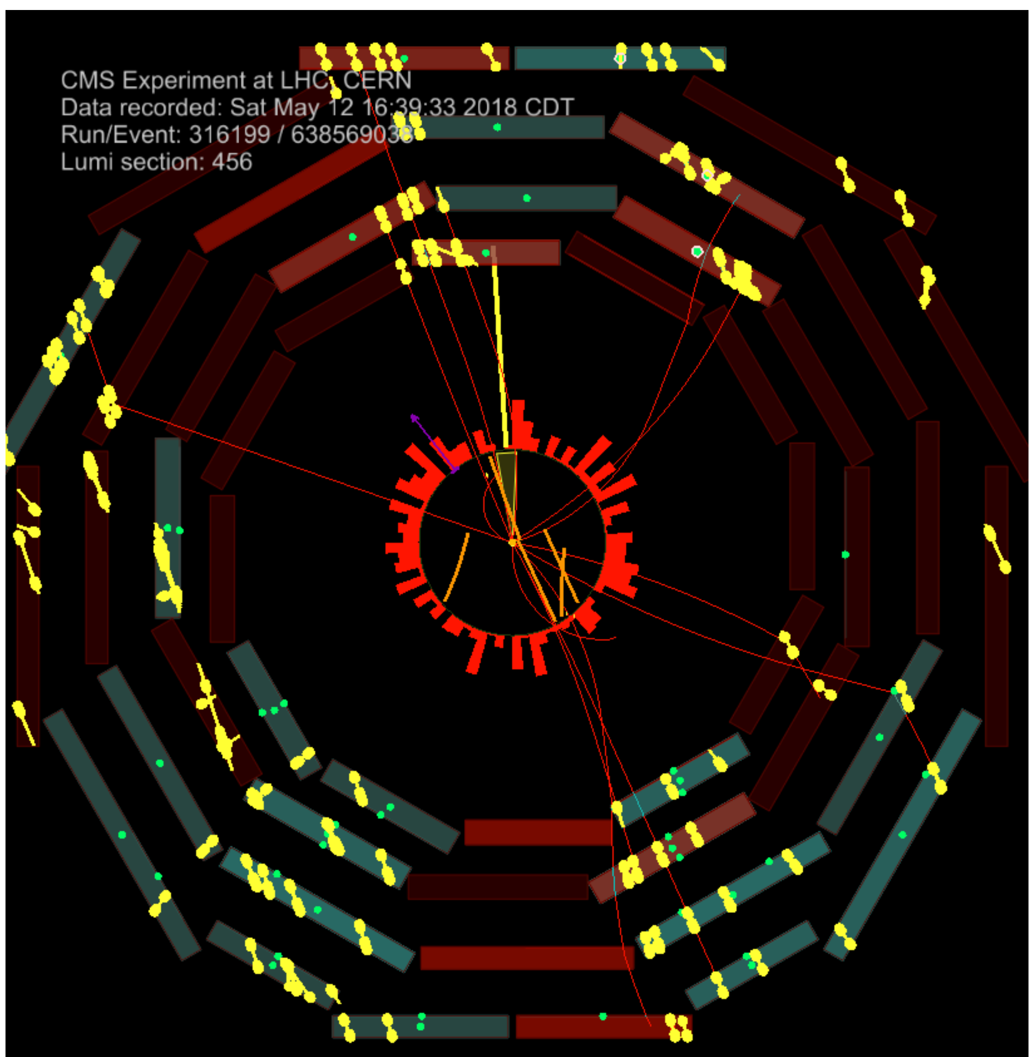


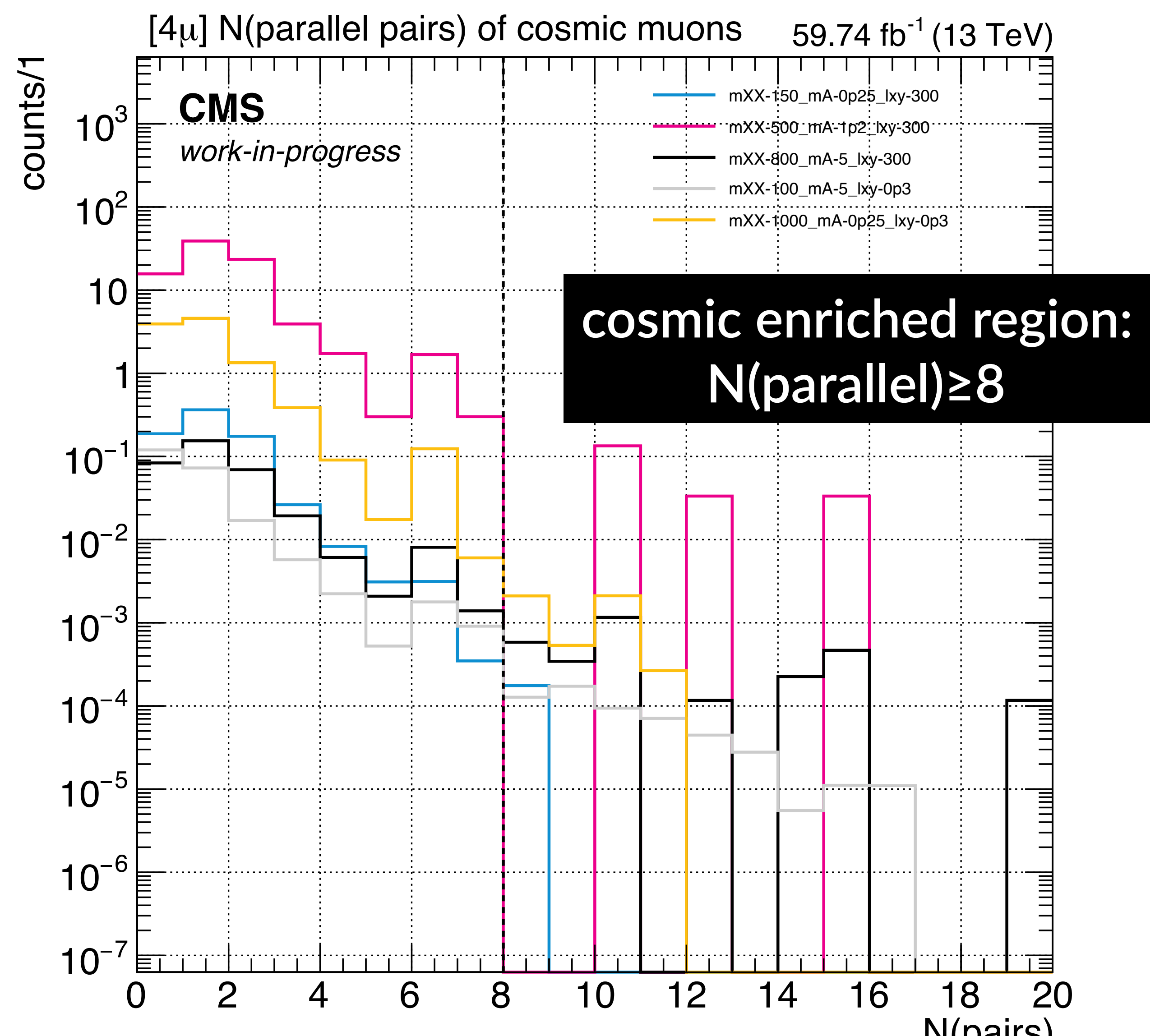


- Cosmic muon as a background
  - ***DSA*** may have cosmic contamination
  - Dedicated cuts to remove cosmic muons.

"parallel": |cos(α)|>0.99
α: 3D angle between 2 tracks

Cosmic shower:
large number of *parallel* muons.





Cosmics

Data: N(parallel)≥8
signal MC: N(parallel)<8

* Cosmic muon as a background
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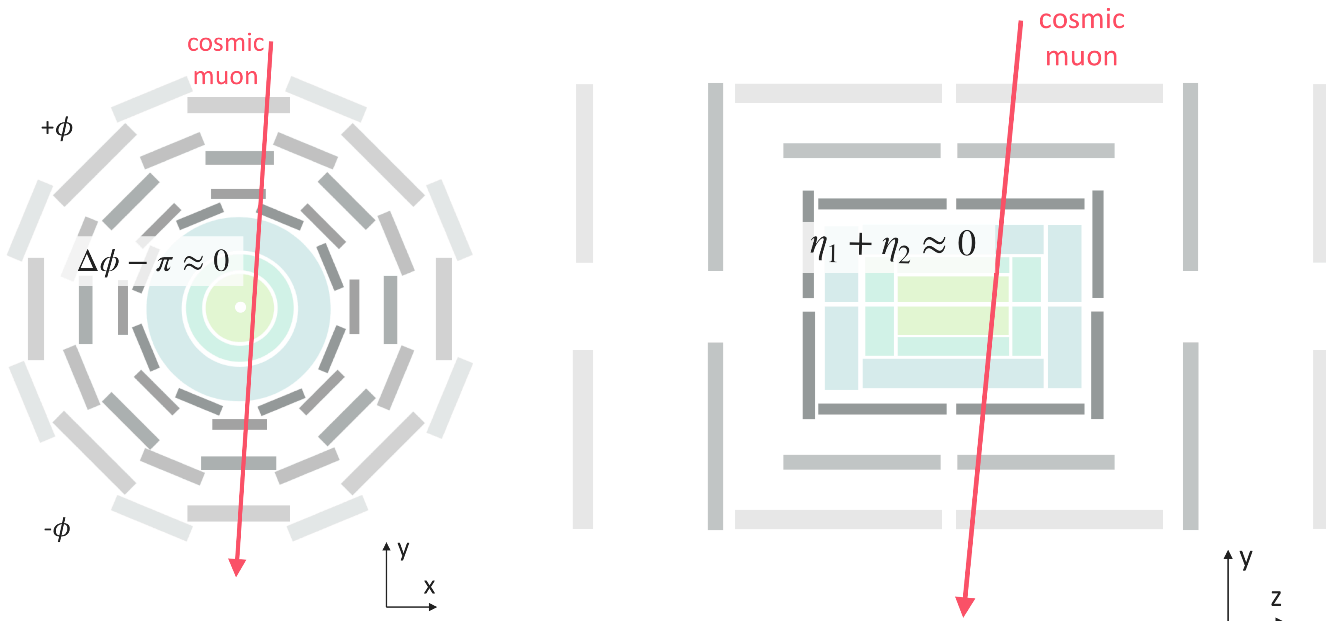
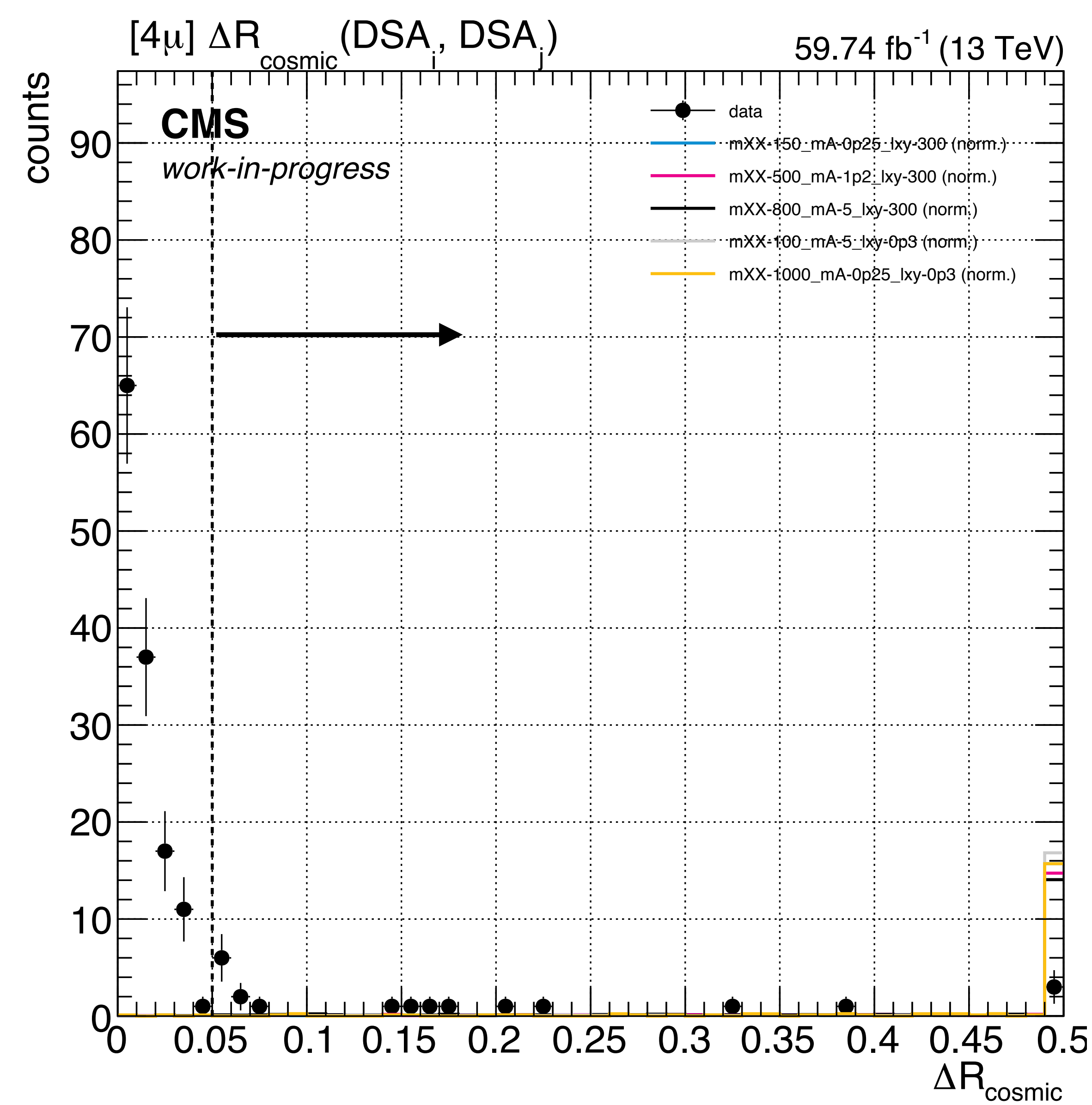
1. ΔR_{cosmic}>0.05



(c/o K. DiPetrillo)

$$\Delta R_{cosmic} = \sqrt{(\eta_1+\eta_2)^2 + (\pi - \Delta\phi)^2}$$

$$\Delta R_{cosmic} \rightarrow 0$$



Data: N(parallel)≥8
signal MC: N(parallel)<8

- Cosmic muon as a background
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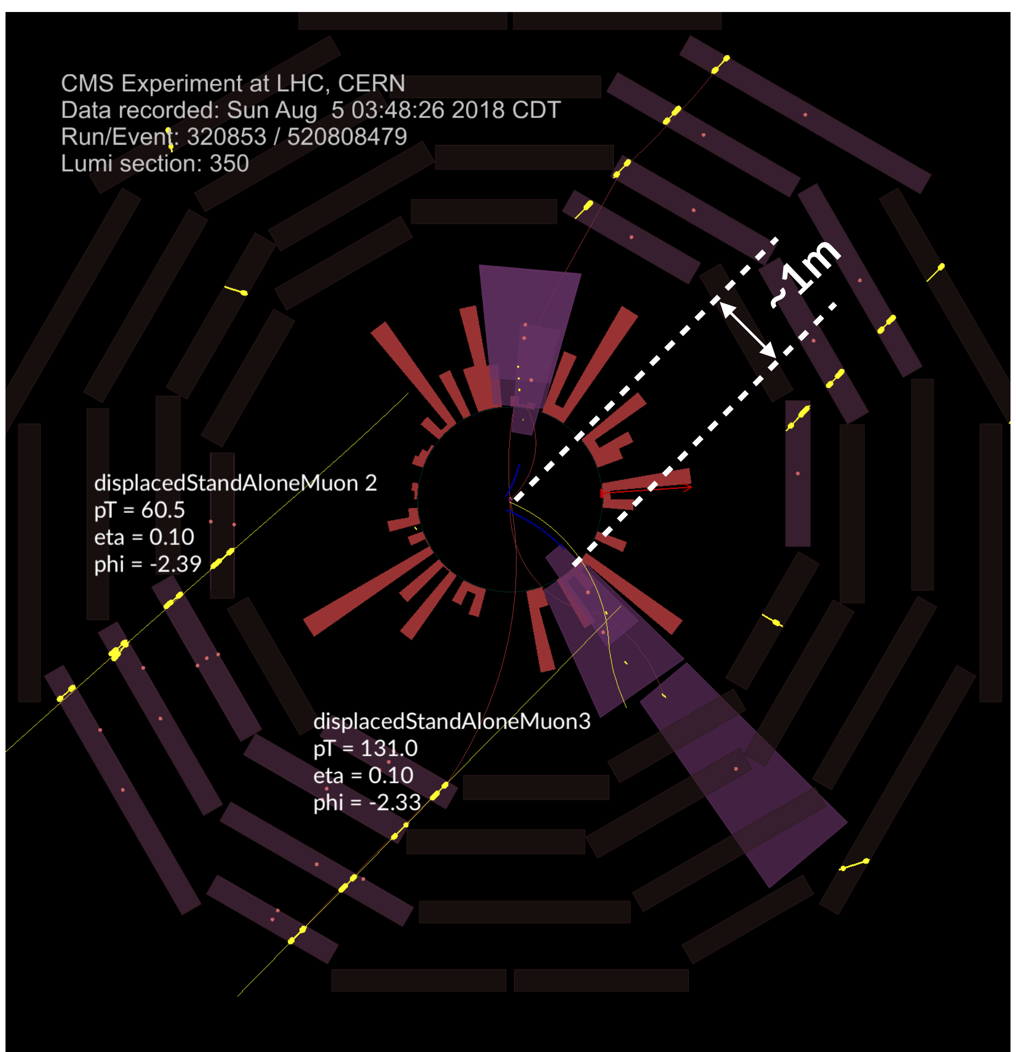
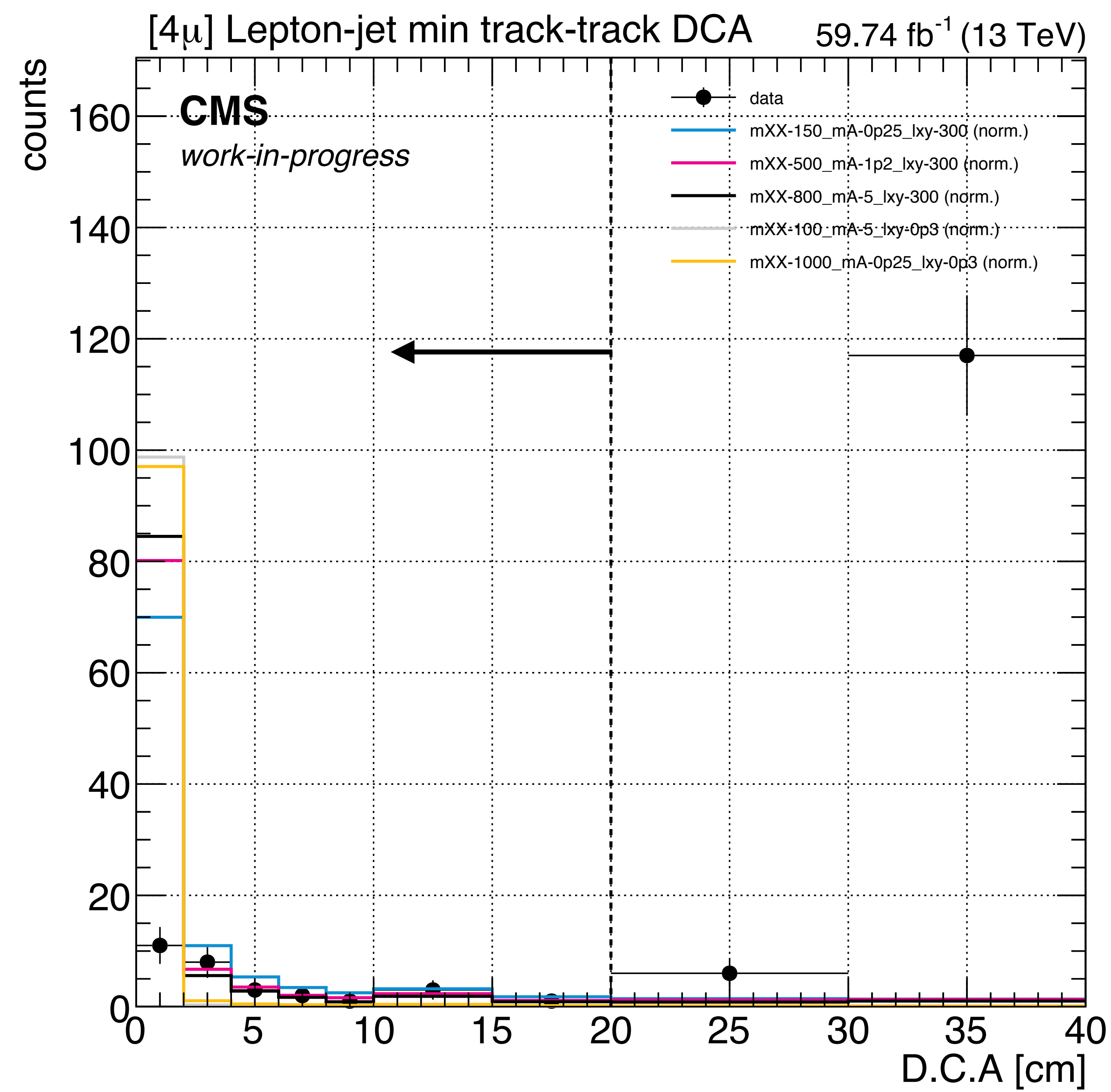
2. DCA (distance of closest approach) between two tracks<20cm

- Parallel cosmic muons can be clustered together, ΔR(η,φ)→0
- The DCA between the two can be large.





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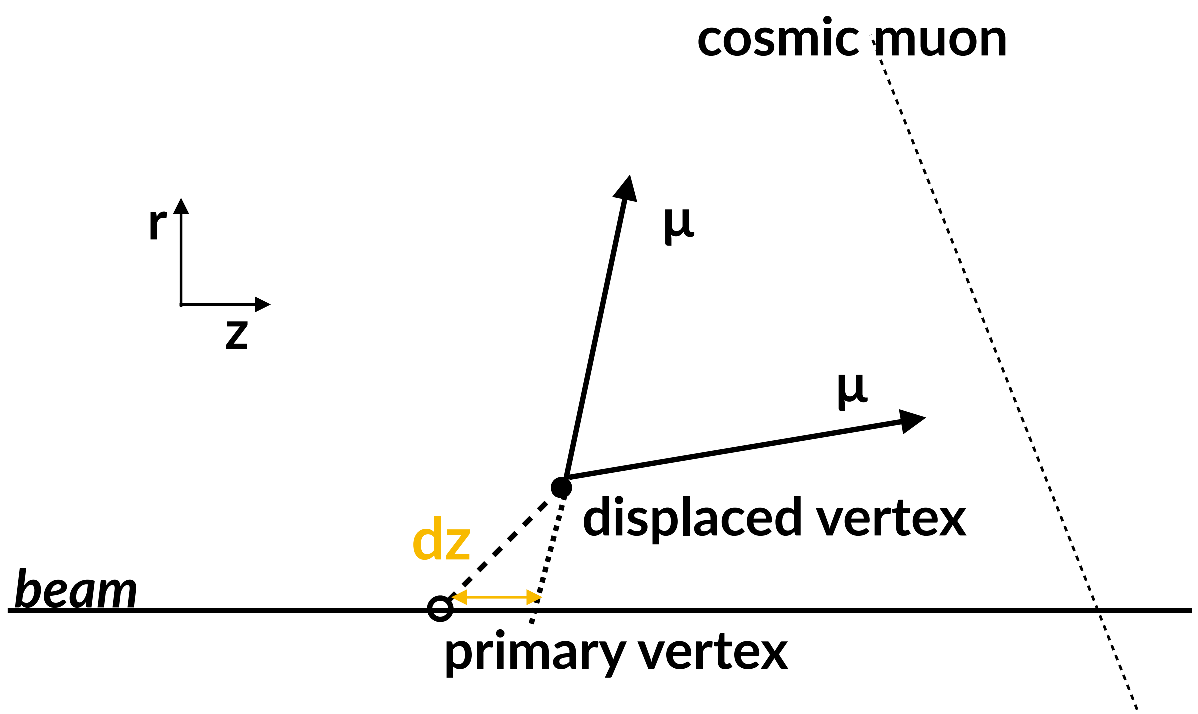
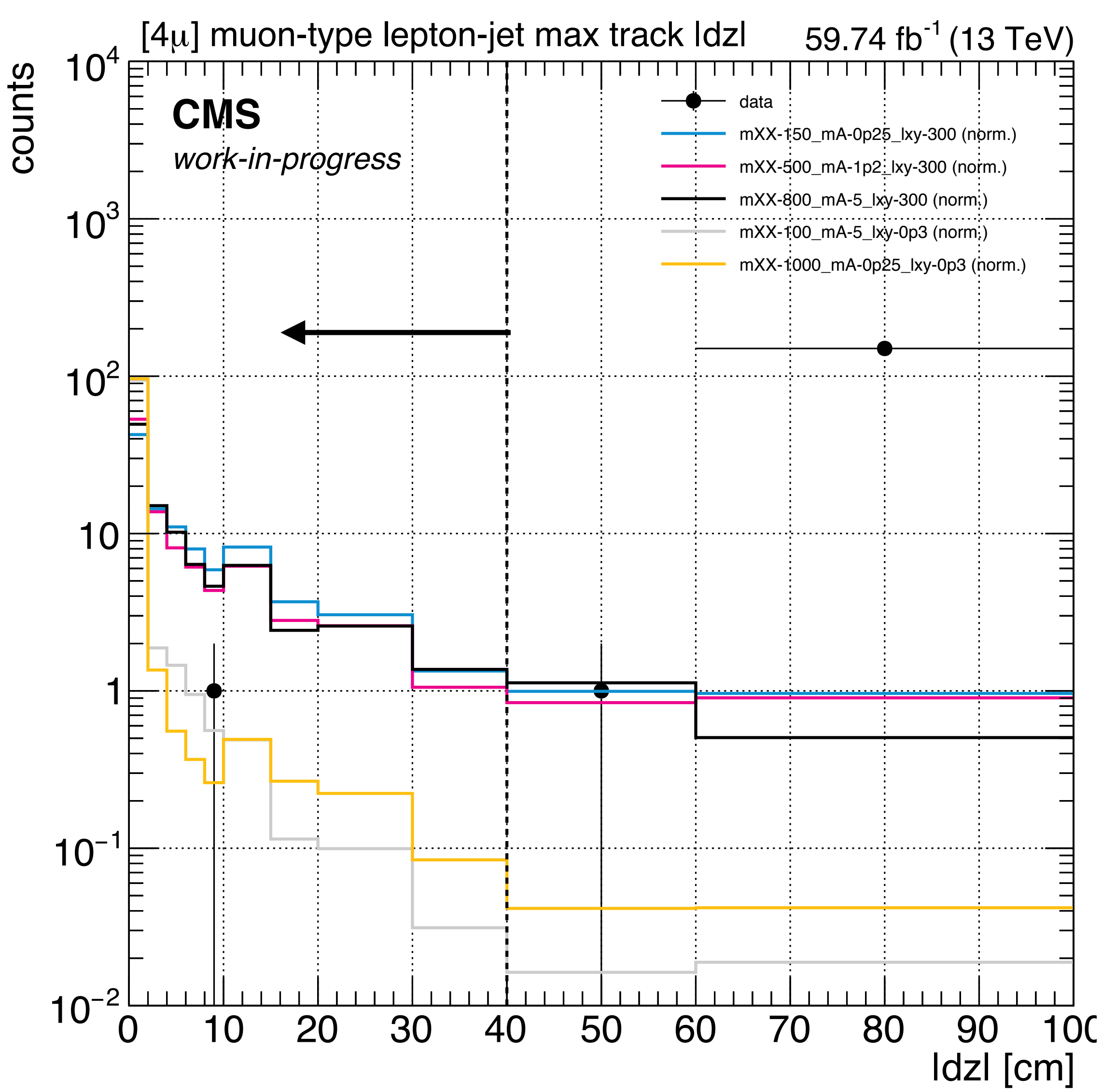


3. Max track |dz|<40cm

- Cosmic muons have large |dz|;
- Even though signal is displaced, due to large boost, |dz| is small.



Cosmics summary

* Cosmic muon as a background
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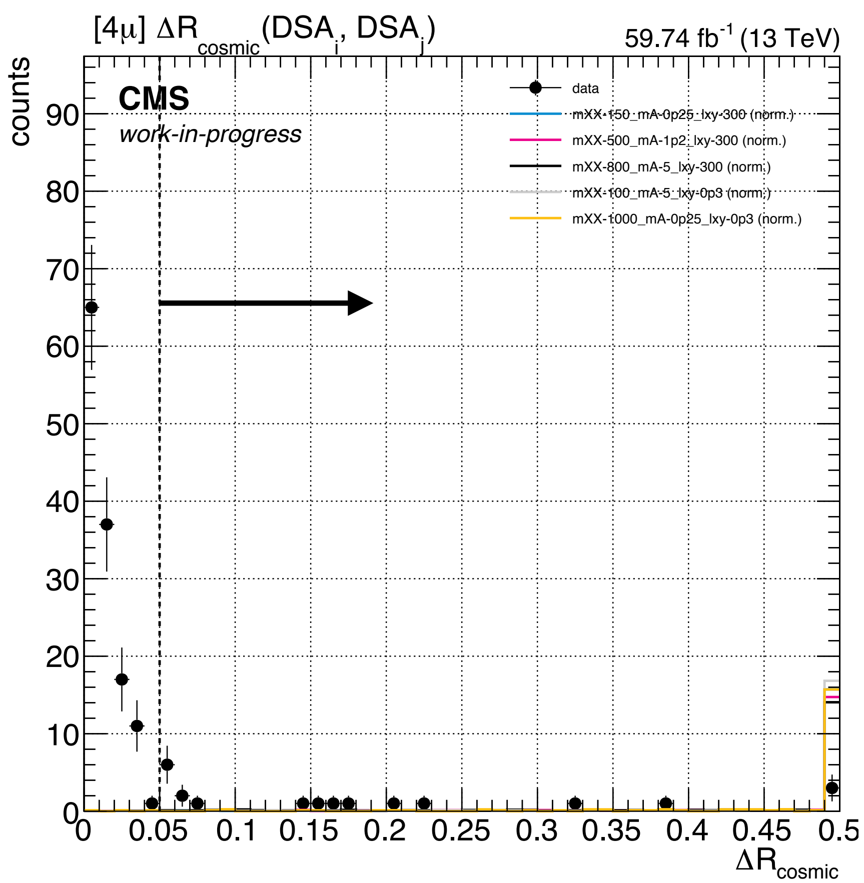
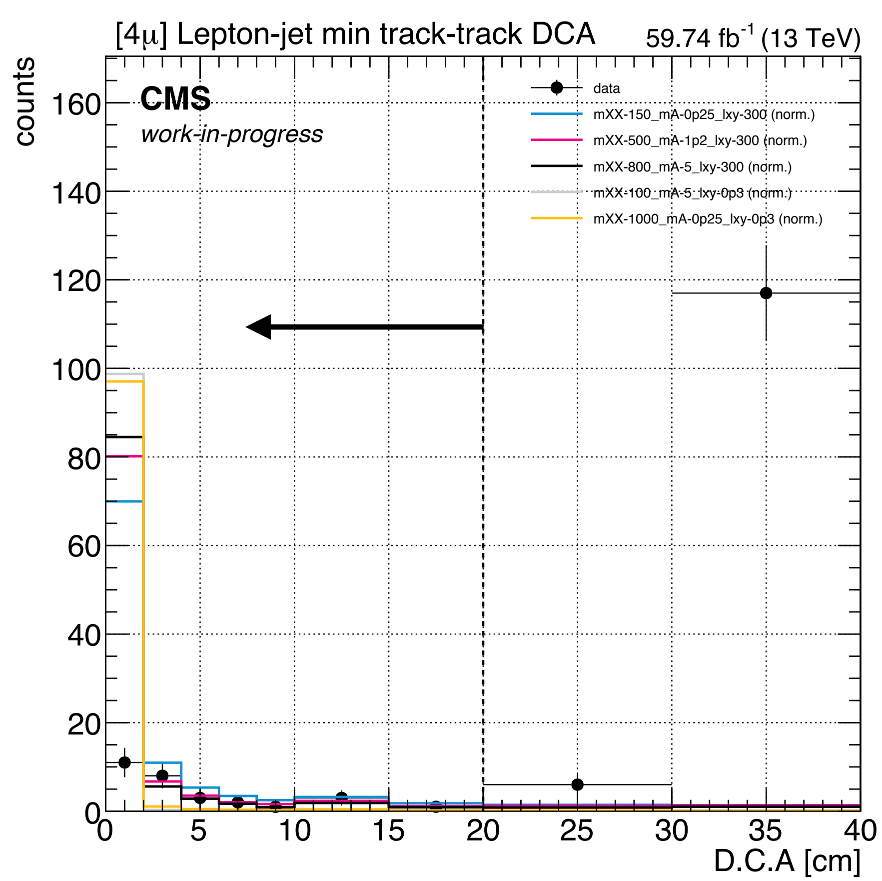
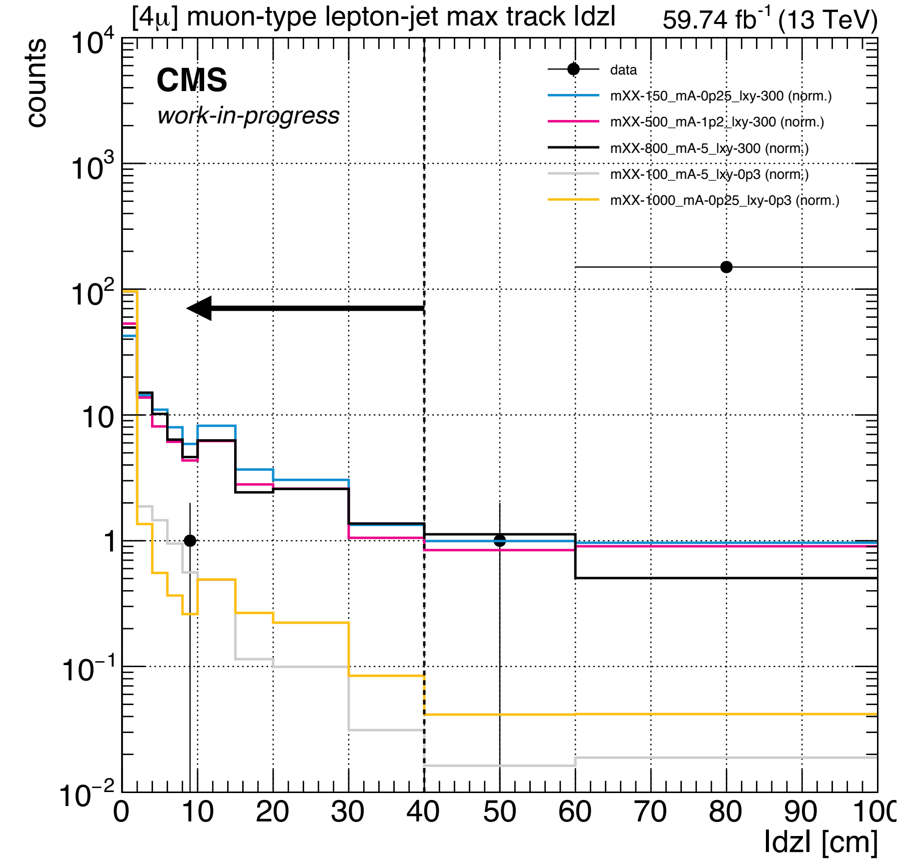


2. DCA<20cm



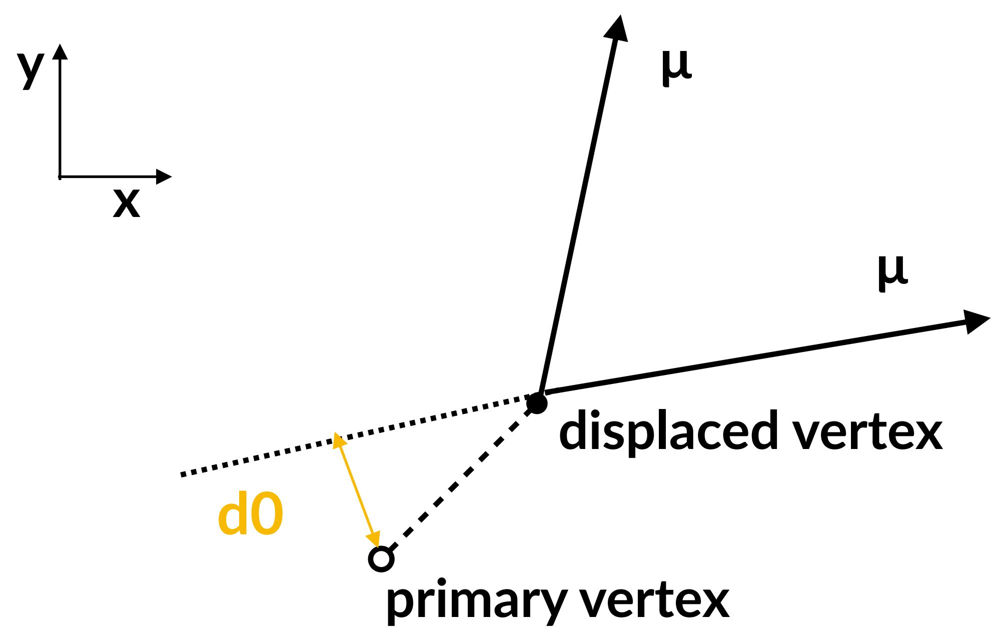
3. Max |dz|<40cm

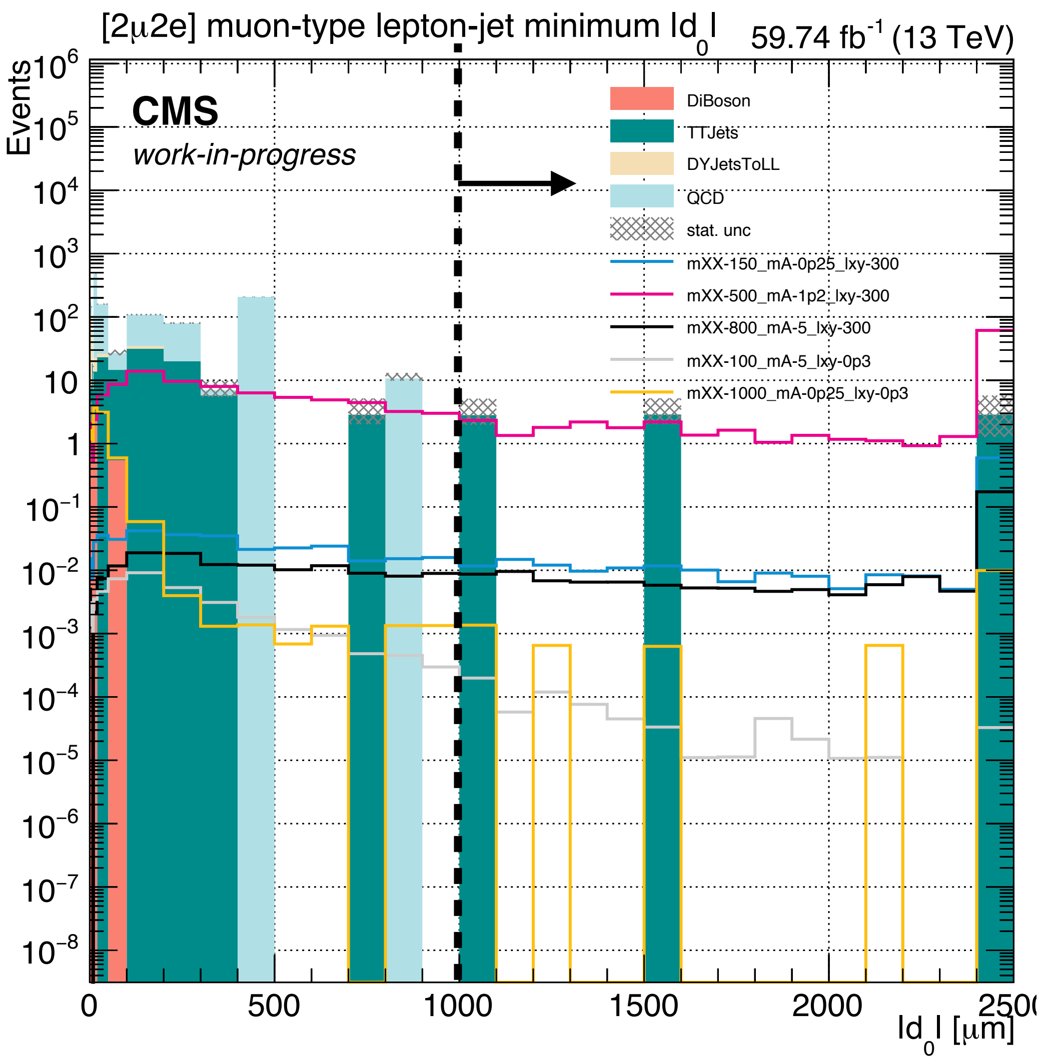


With above cuts applied,
no events in cosmic-enriched data sample survived.

Displacement cut

* Reduce prompt background: DYjets, ZZ
  * Displacement cut on track's |d0|

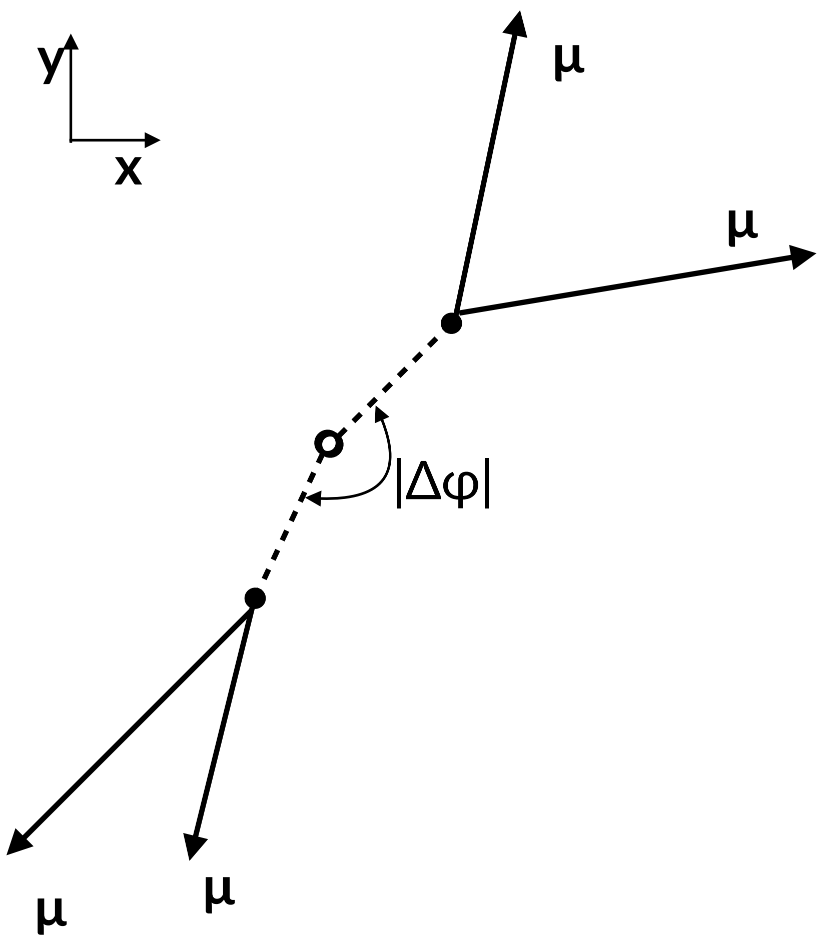


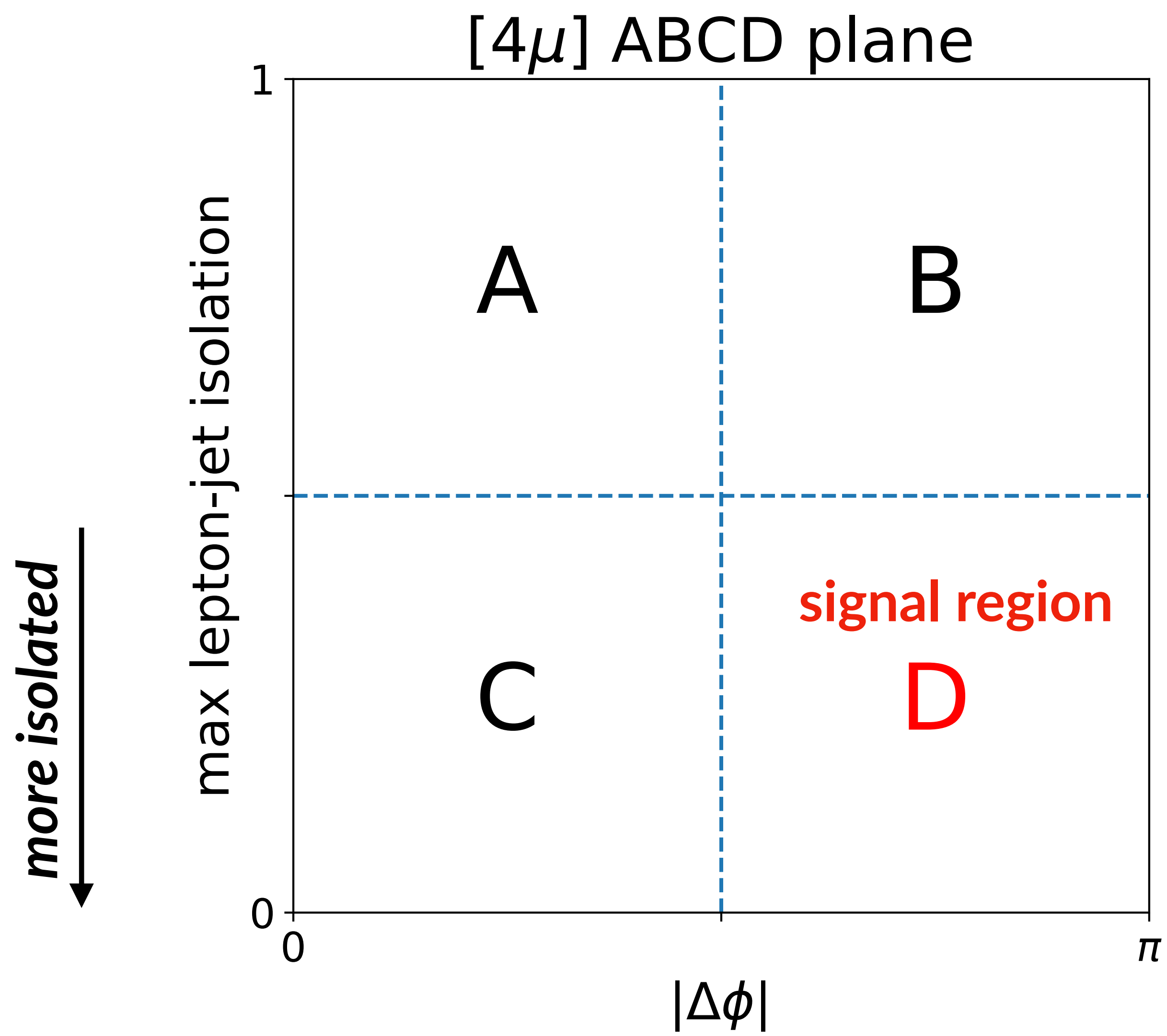


* Run out of background MC.
* Data-driven background estimation next.

ABCD background estimation

* QCD, TTJets
  * Non-prompt muons from heavy flavor decay
  * Estimate using ABCD method with
    1.Lepton-jet isolation
    2.|Δφ| between lepton-jet pair





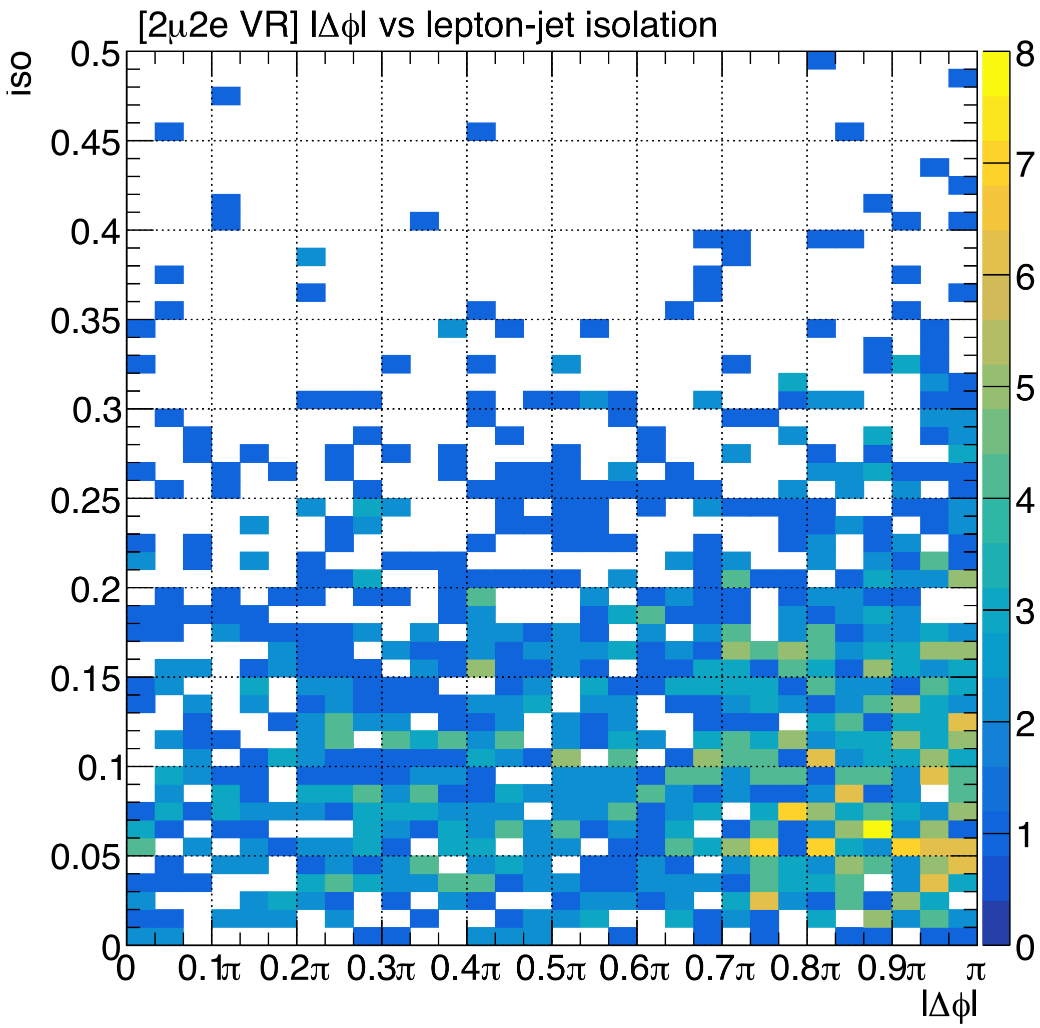
Estimate the yield of D with yield of region ABC by, given the two variables are uncorrelated.

$$N_D^{pred} = \frac{N_B^{obs} \times N_C^{obs}}{N_A^{obs}}$$

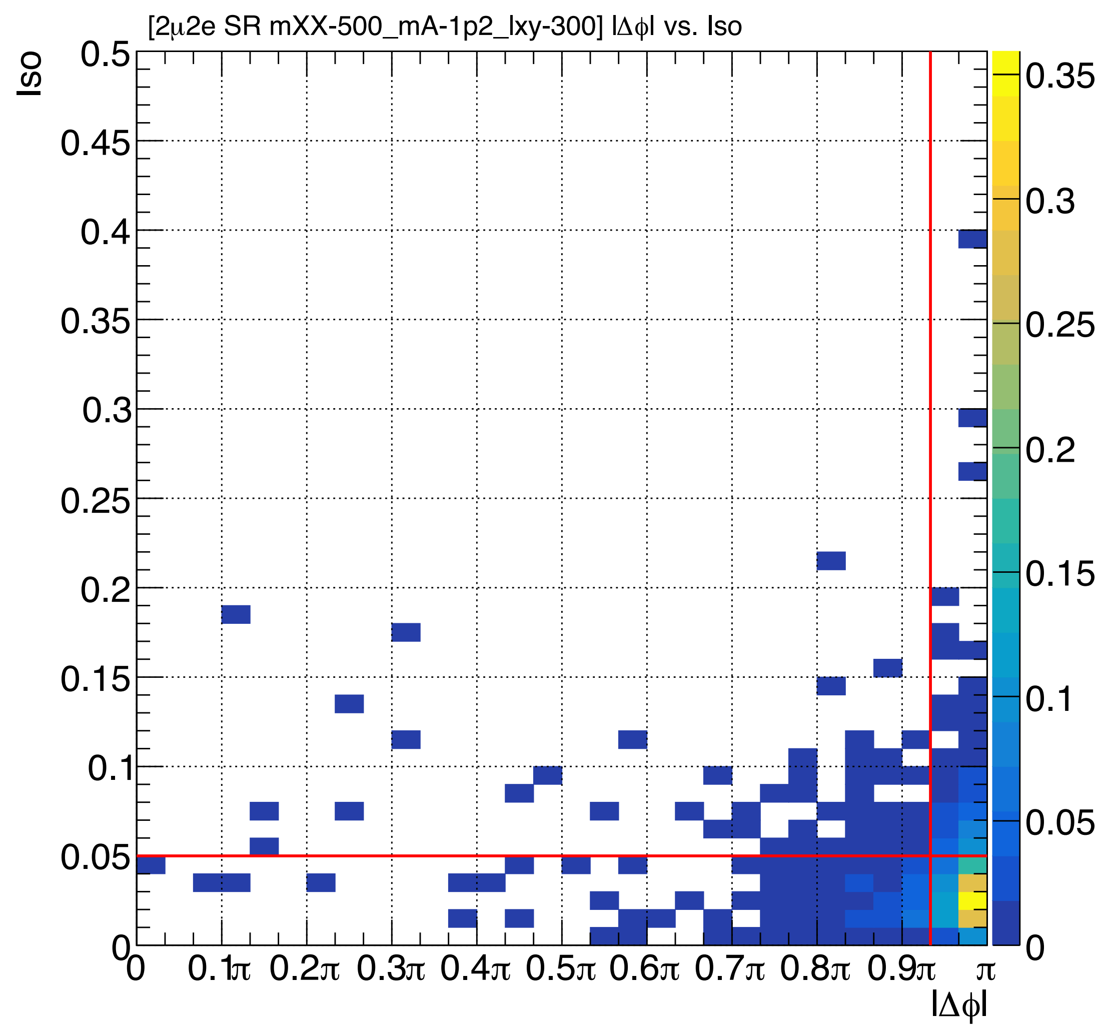
Validation

* MC not trustworthy; validate the method with *"proxy events"* in data.
  * A single muon as a proxy of a muon-type lepton-jet.
  * N(*b*-jet) > 0

validation region, data



signal region, signal mc



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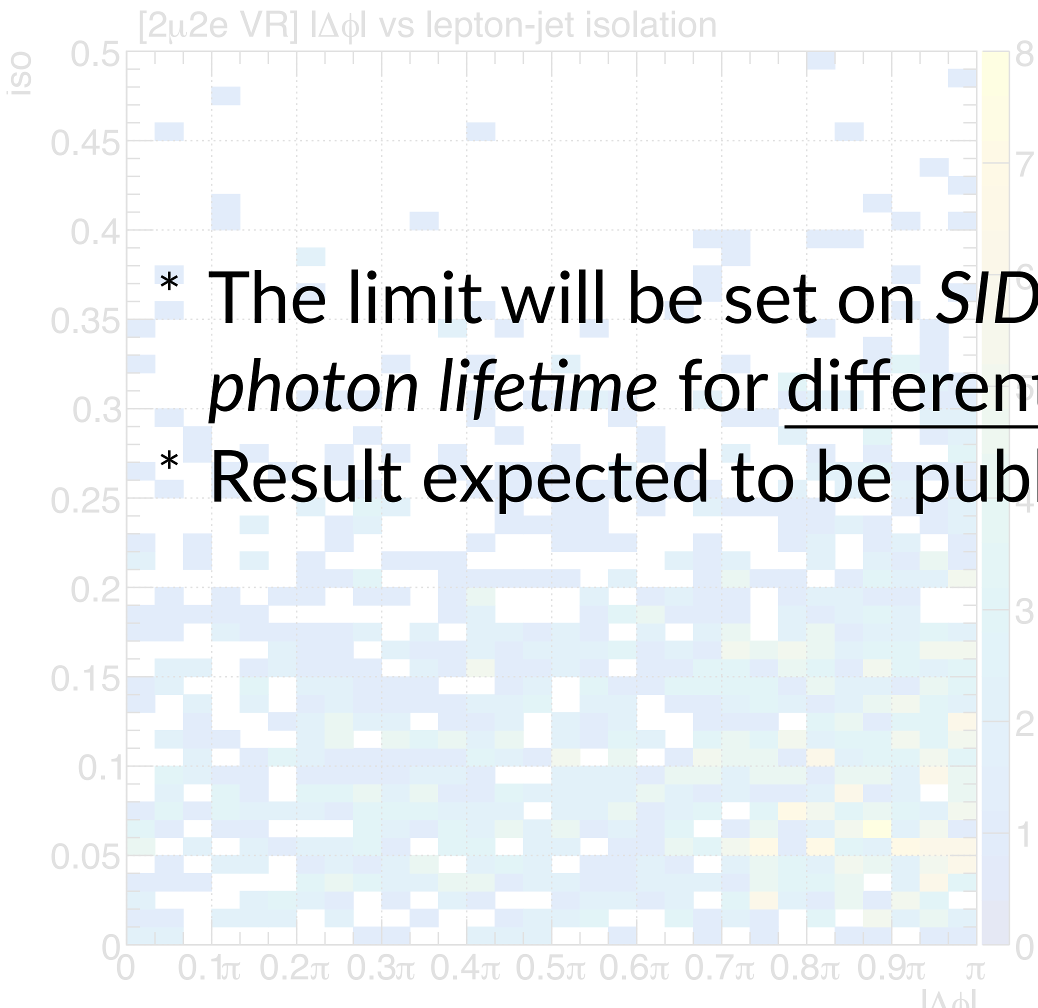
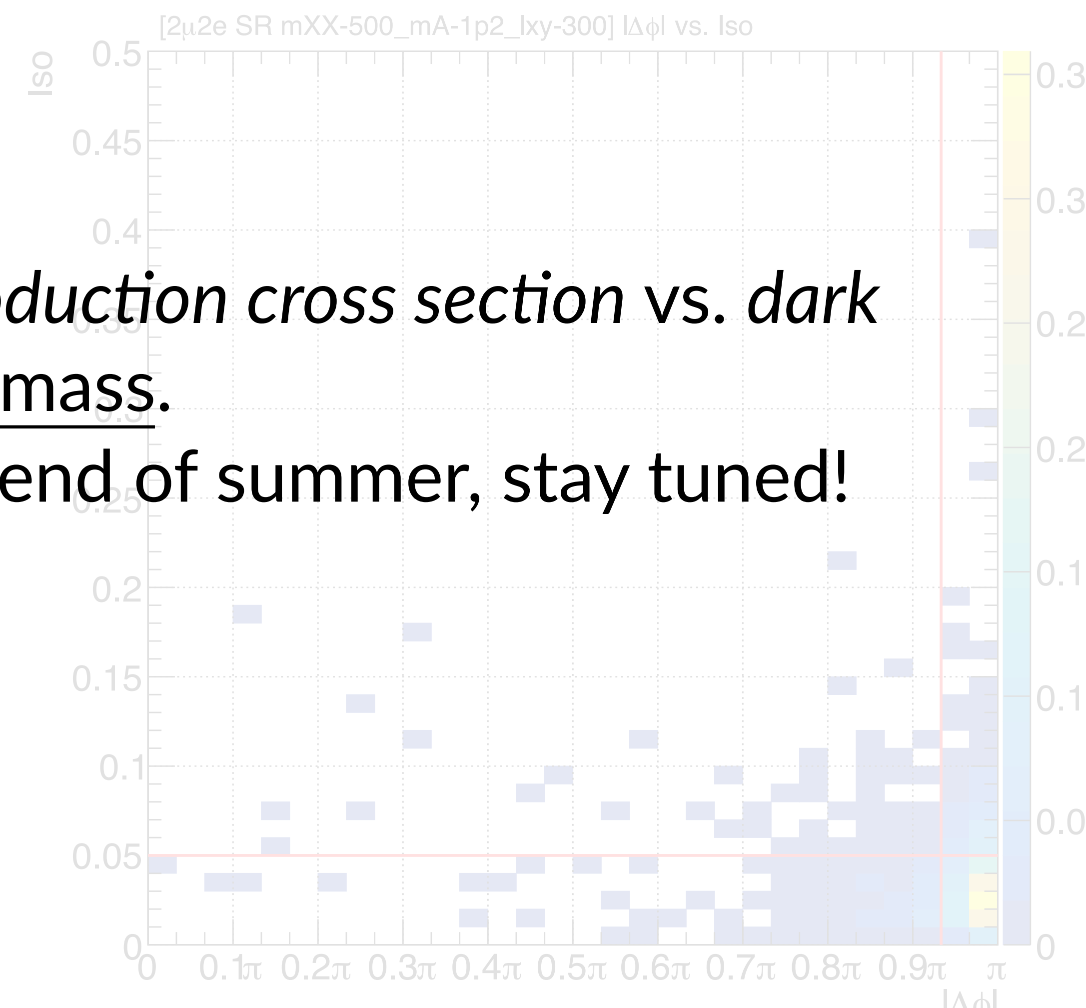
ABCD plane of validation region, data



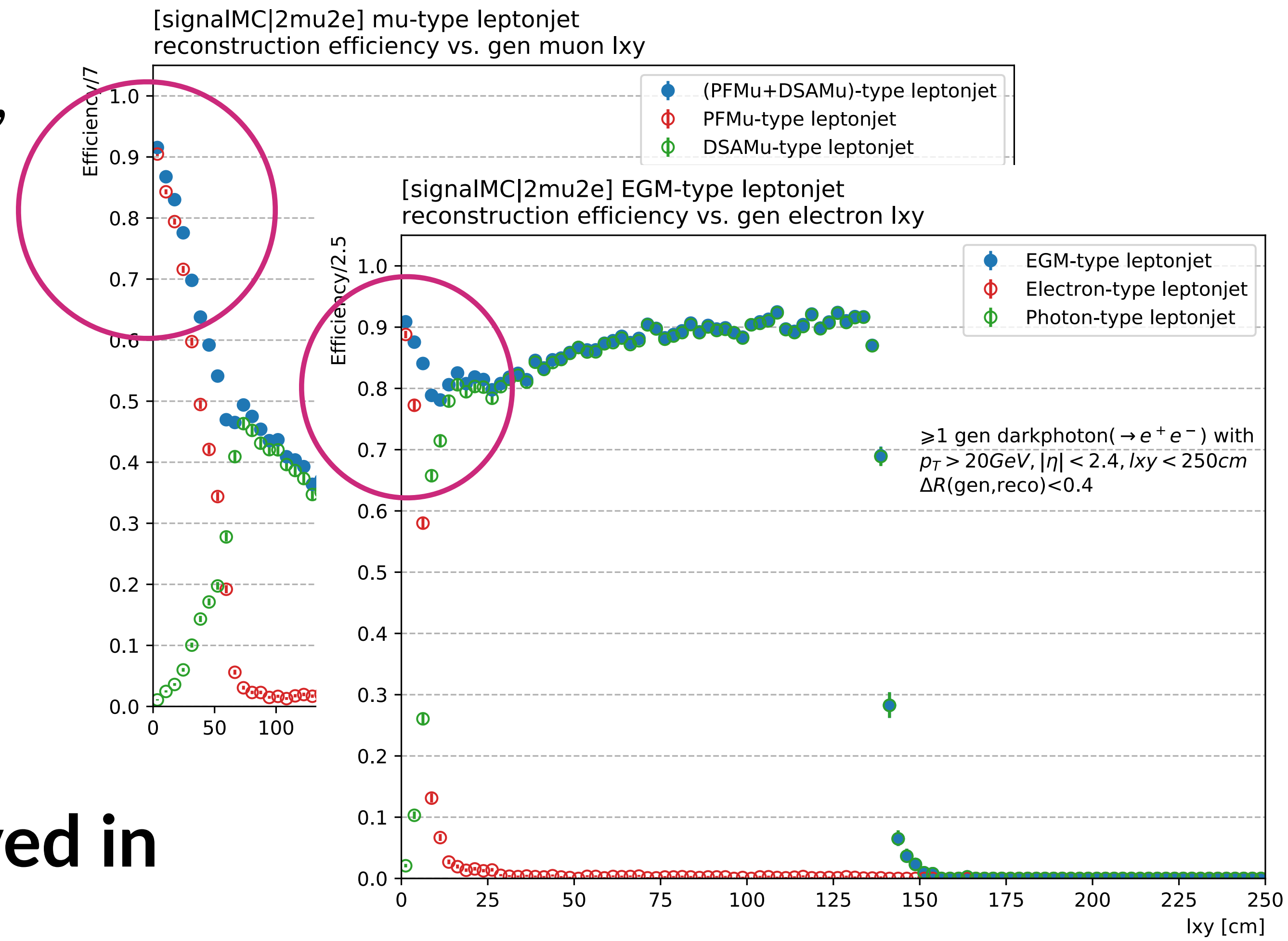
ABCD plane of signal region, signal mc



* The limit will be set on *SIDM production cross section* vs. *dark photon lifetime* for different DM mass.
* Result expected to be public by end of summer, stay tuned!

LLP call for a better tracker

* Long-lived particles → displaced tracks, vertices
* A better tracker is desired!

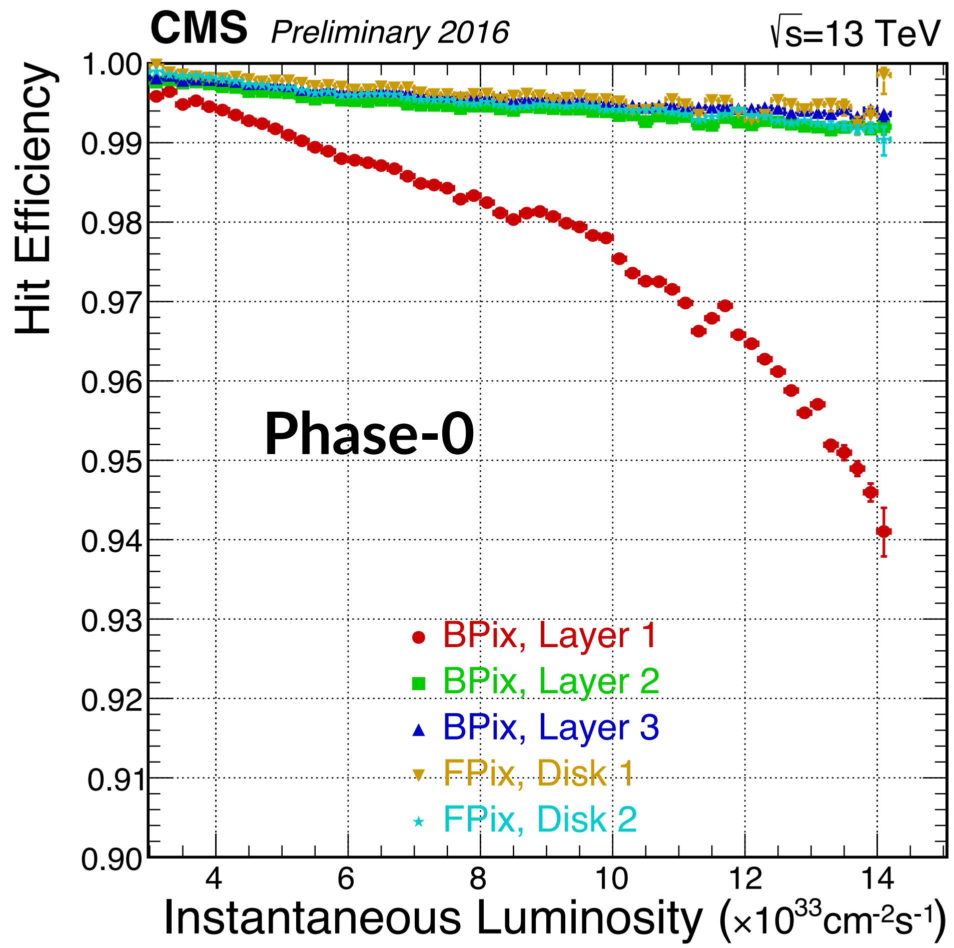


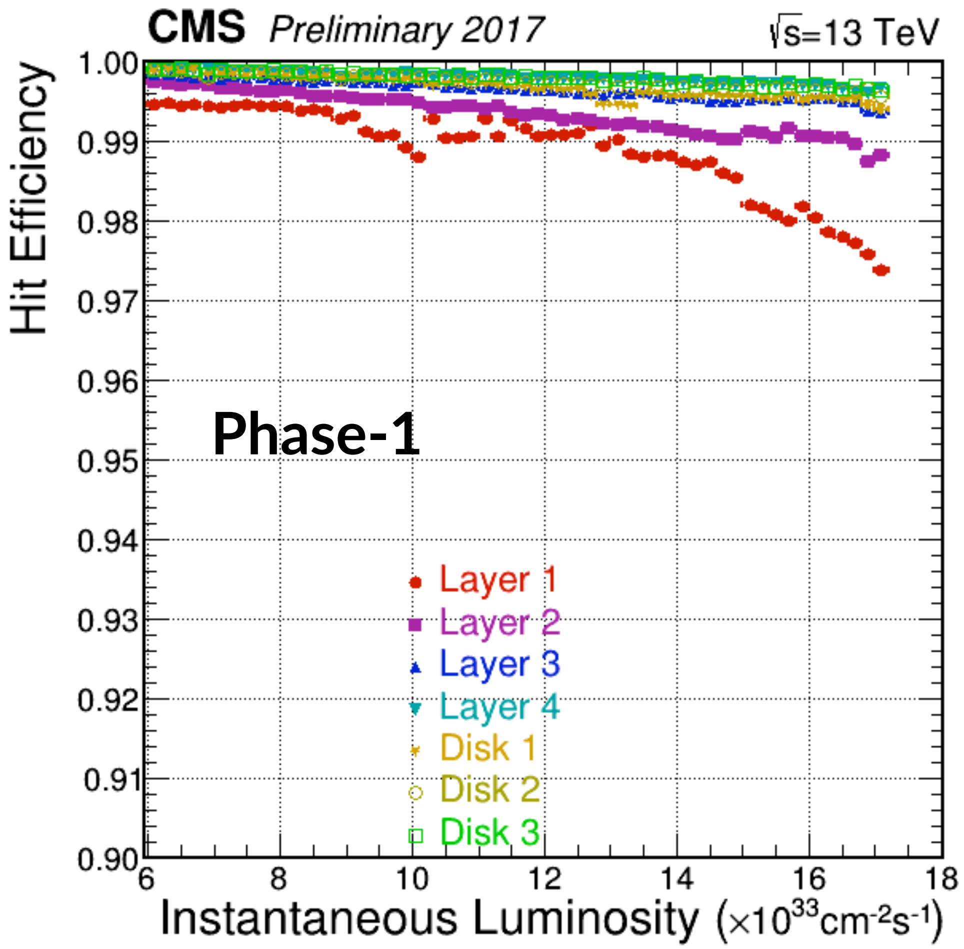
* **Tracking performance is vital, involved in almost all analysis.**
* **Upgrade the tracker for more collisions!**

Experience of CMS Phase-1 pixel detector upgrade

Motivation

* The pixel detector is the innermost sub-detector of CMS, vital for tracking and vertexing.
* The Phase-0 detector was operated from the beginning until 2016.
* The tracking performance of the Phase-0 pixel detector degrades with increased instantaneous luminosity.
  * The expected peak luminosity for 2017-2018 is ~ $2\times10^{34}cm^{-2}s^{-1}$.
* The upgraded, Phase-1 pixel detector is designed to outperform the previous one at high instantaneous luminosity.

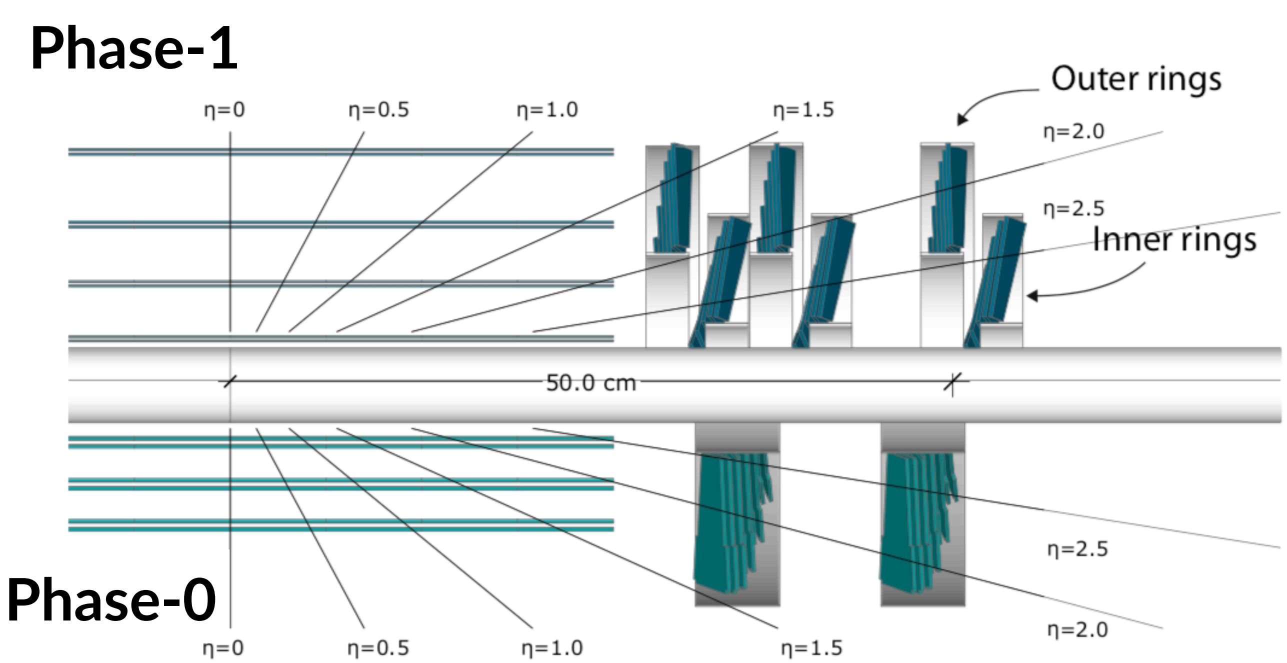


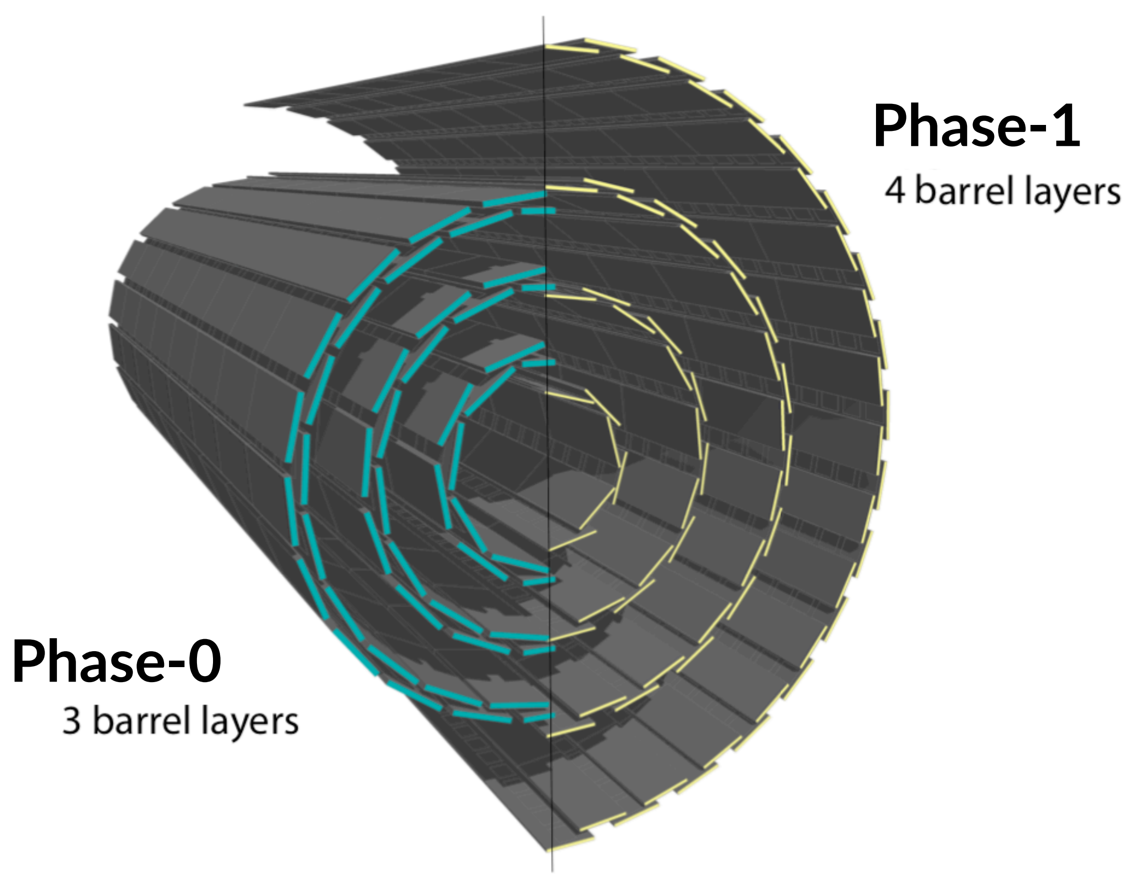


https://twiki.cern.ch/twiki/bin/view/CMSPublic/PixelOfflinePlots2016

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PixelOfflinePlotsAugust2017

* Phase-1 w.r.t. Phase-0
  * One extra layer(3→4) in barrel; One extra disk(2→3) for each endcap.
    * ~87.7% more pixels (**66M→124M**)
    * Layer1 closer to beam pipe (43mm→29mm)
  * Digital readout provides enough bandwidth.
  * New backend and readout system.
  * Two-phase CO_2 cooling to reduce material budget.
  * Pixel size ($100 \times 150 \mu m^2$) and type (n^+-in-n) remain the same.





(CMS-TDR-011)

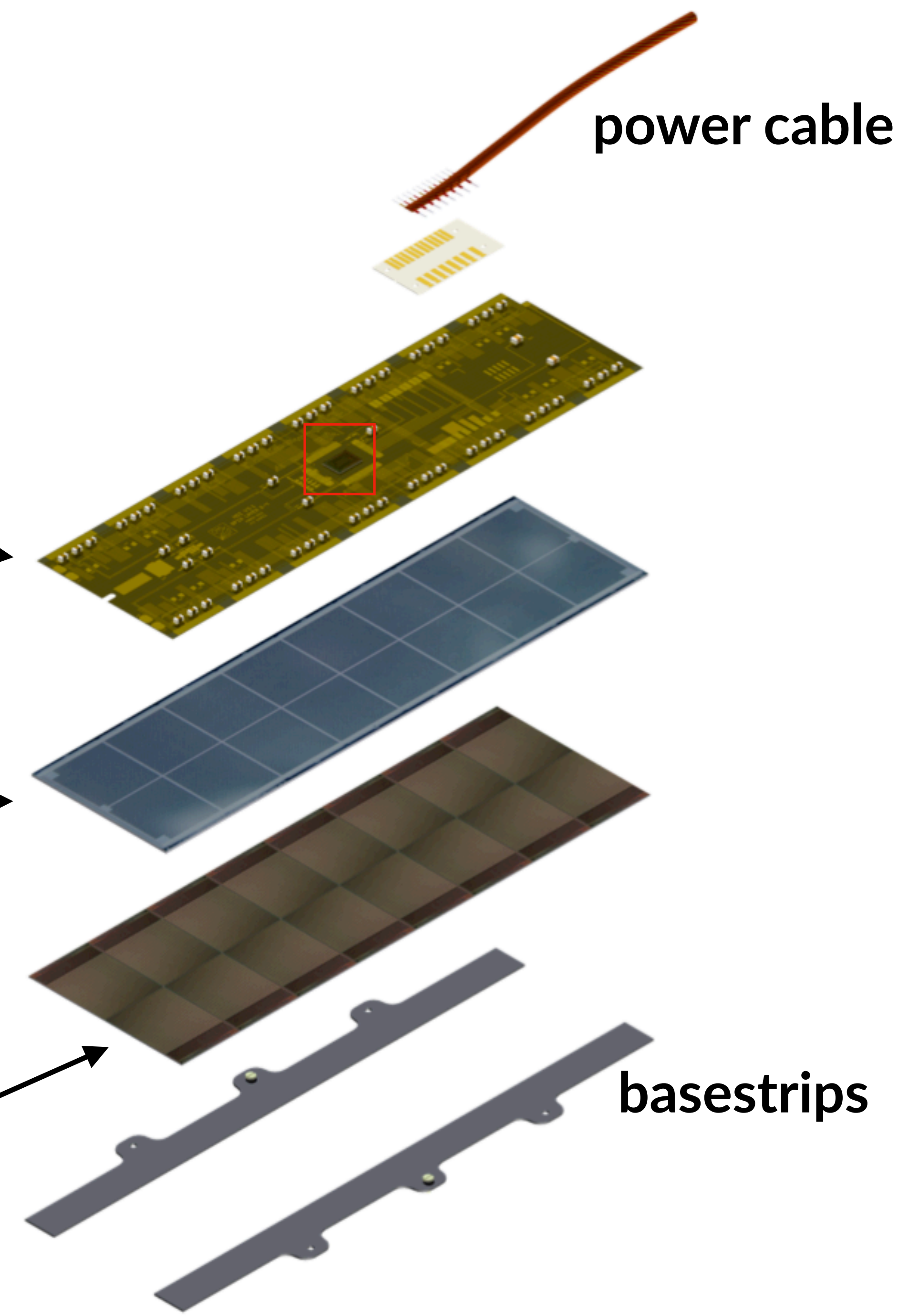
Pixel module

* Phase-1 pixel detector modules
  * 2 rows, 8 ROCs (Read out chip) each
  * Total active area: 16.2x24.8 mm^2

HDI (high density interconnect)
- Provides power and signal distribution.
- TBM (token bit manager): manage digital readout.

Sensor
- 285µm thick; bump-bonded to ROC
- 66560 pixels/module

ROC
- PSI46digv2 (BPix layer2-4, FPix), PROC600 (layer1)
- Double column drain architecture
- Expanded data and timestamp buffer size w.r.t phase-0.
- PROC600: designed to withstand high particle rate of 600 MHz/cm^2



Exploded view of a BPix layer2-4 module, layer1 and FPix modules have similar structure

(CMS-TDR-011)

- Standardized test and qualification procedure following the module production chain.
  - All 672 modules for FPix were tested at Fermilab.

Non-exhaustive list of tests:

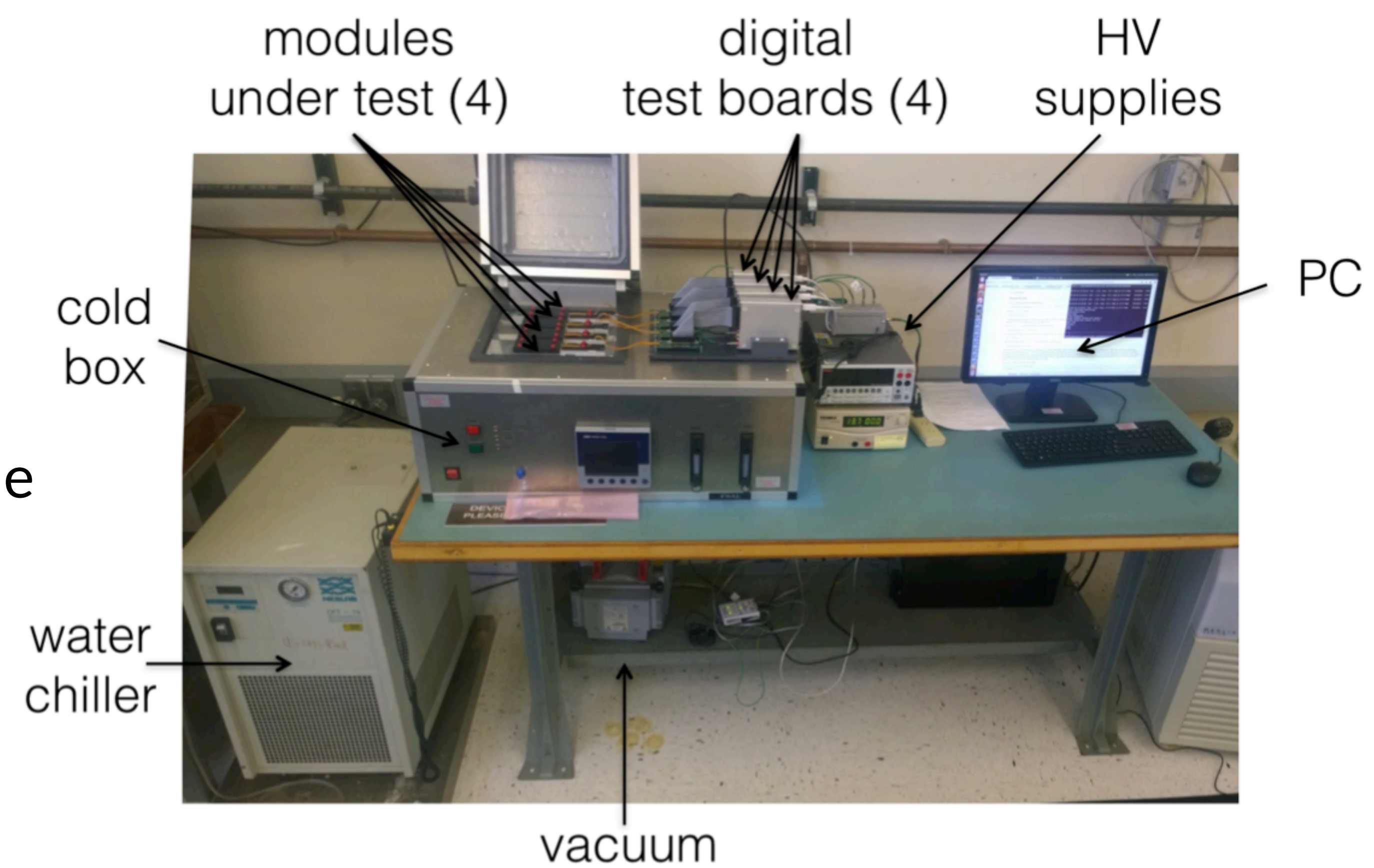
Pretest
- Make sure module is responsive and in operation state.

PixelAlive
- Identify faulty pixels.

TrimmingTest
- Calibrate each PUC (pixel unit cell) to the same threshold in terms of the calibration pulse strength.

PHOptimization (pulse height)
- Set appropriate dynamic range for the ADC (analog digital converter) that digitize the recorded pulse height.

Bumpbonding test
- Flag the problematic bump bonds that connect the sensor to the ROC



One module testing setup at SiDet in Fermilab

Pixel module testing example

TrimmingTest — *calibrate each PUC (pixel unit cell) to the same threshold in terms of the calibration pulse strength.*

3 DAC registers: **VthrComp, Vtrim, trim bits**

Digital Analog Converter

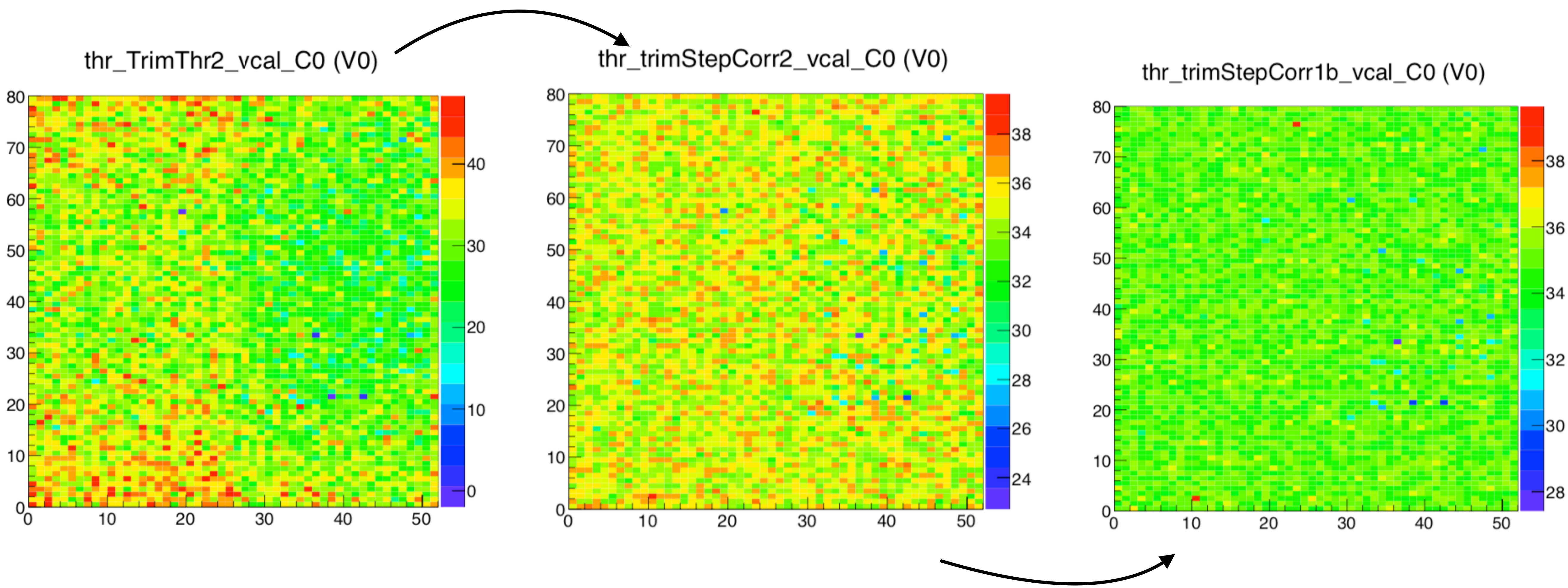
- **VthrComp** → **Baseline threshold for the comparator unit.**
- **Vtrim** → **Set ROC-wide scale for the effect of the trim bits. i.e. multiplicative factor applied to the trim bits.**
- **trim bits** → **4 bits for each pixel**

The optimization of each setting is performed sequentially per ROC.

TrimmingTest — *calibrate each PUC (pixel unit cell) to the same threshold in terms of the calibration pulse strength.*

3 DAC registers: **VthrComp, Vtrim, trim bits**

- 4 bits for each pixel, setting range: 0-15
- Binary search tree algorithm to search for the optimal bits for each pixel in 5 steps. *(only show 3)*



Overview of the pixel system with DAQ

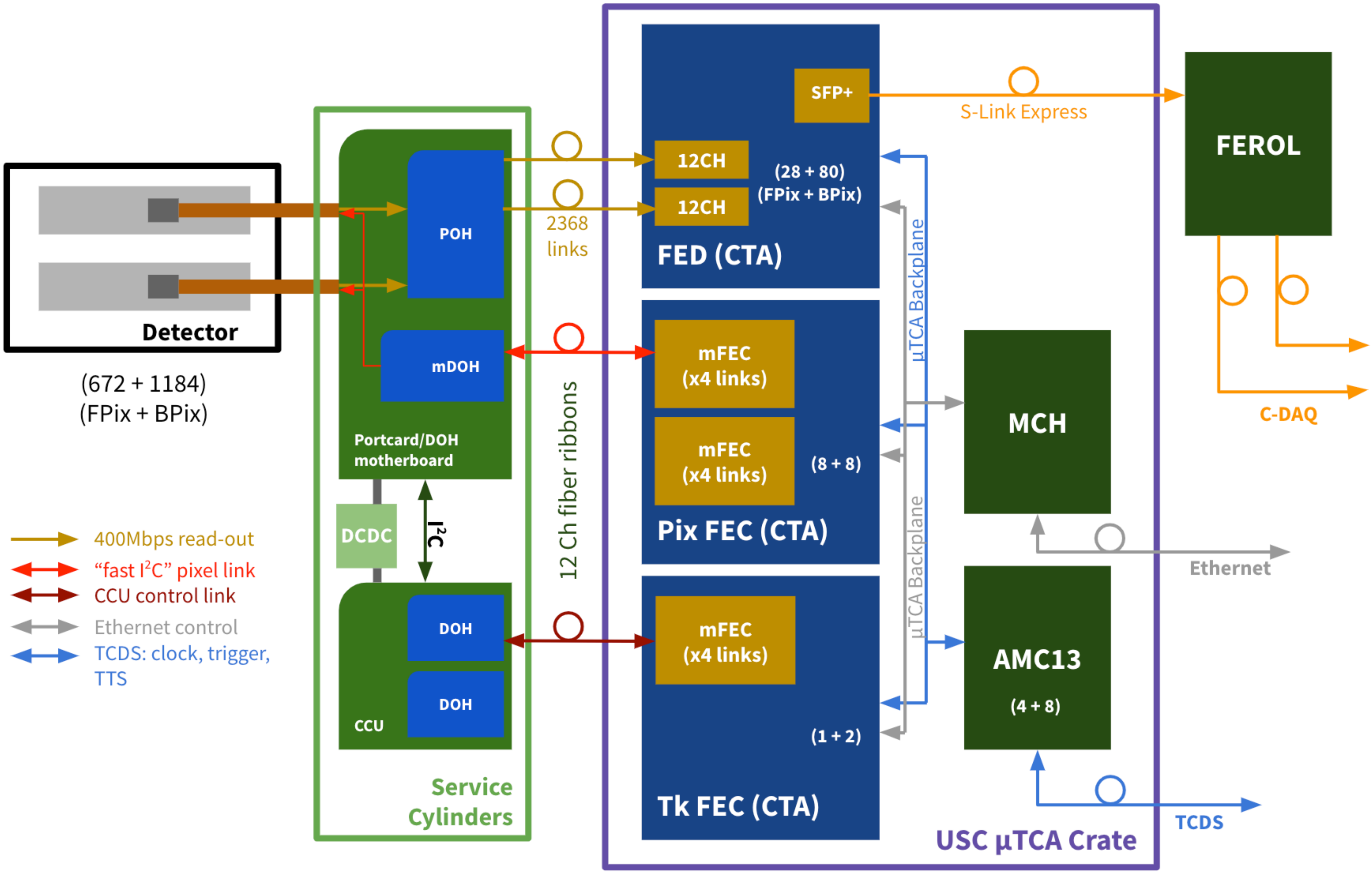
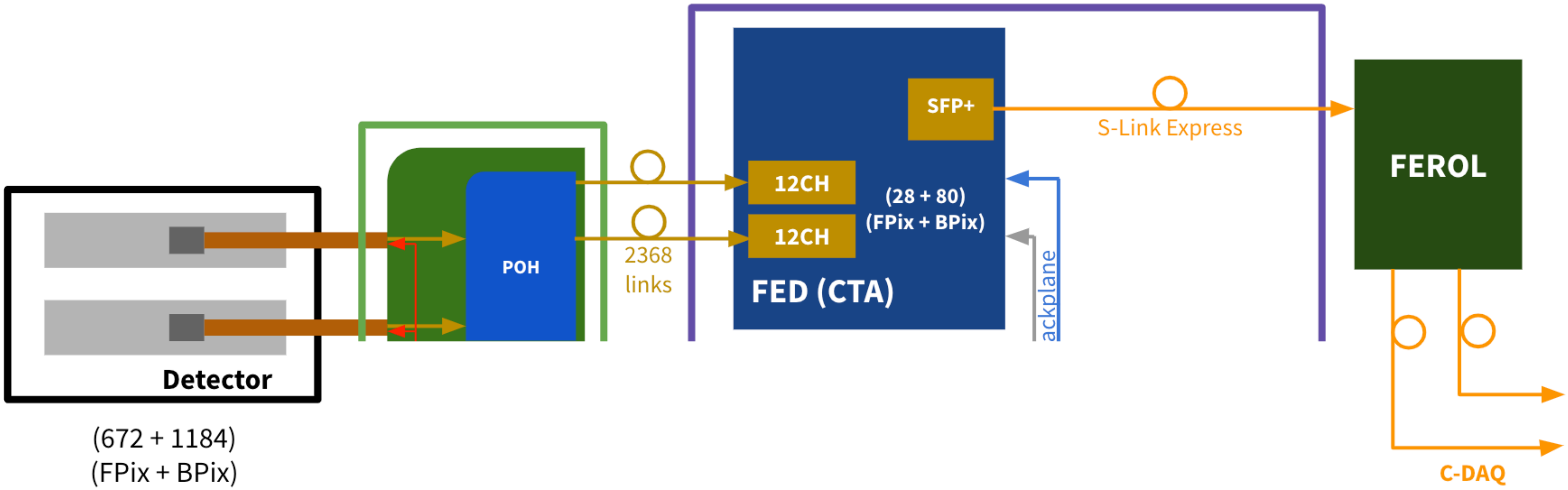


Figure: Complete overview of the µTCA DAQ system of Phase1 pixel detector

Data flow from module to cDAQ



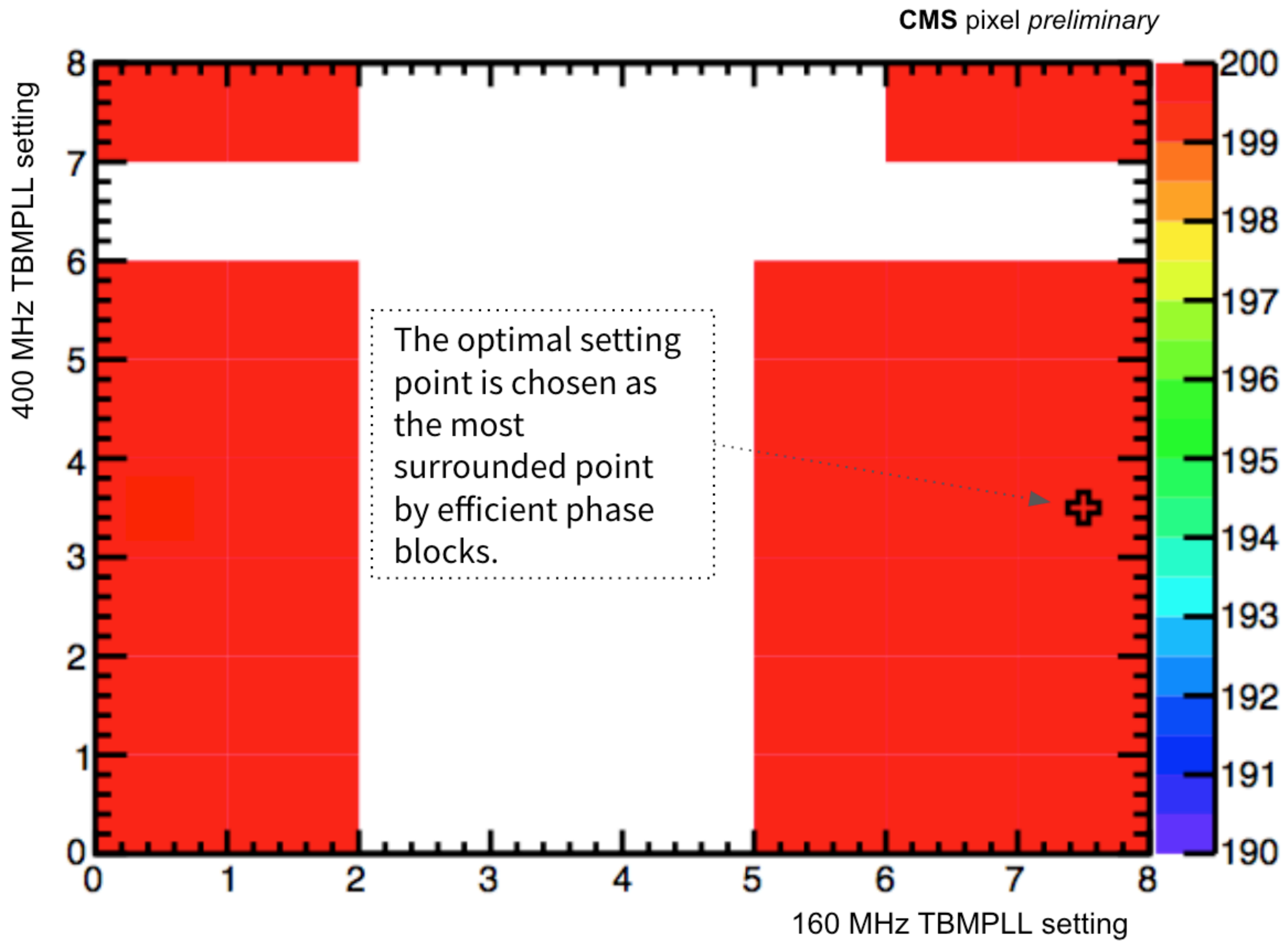
- POH (Pixel Opto-Hybrid)
  - Converts the electrical signal from the pixel modules to optical data.
  - Sends the data to the FED.

- FED (FrontEnd Driver)
  - Decodes the incoming data stream from detector frontend, assemble all 24 channels' data into event fragments.
  - Push the data to CMS central data acquisition.
  - 108 FEDs in total.

Detector checkout — communication

- Module register settings need to be calibrated to give optimal performance.
- Example: **TBM delay phase scan**

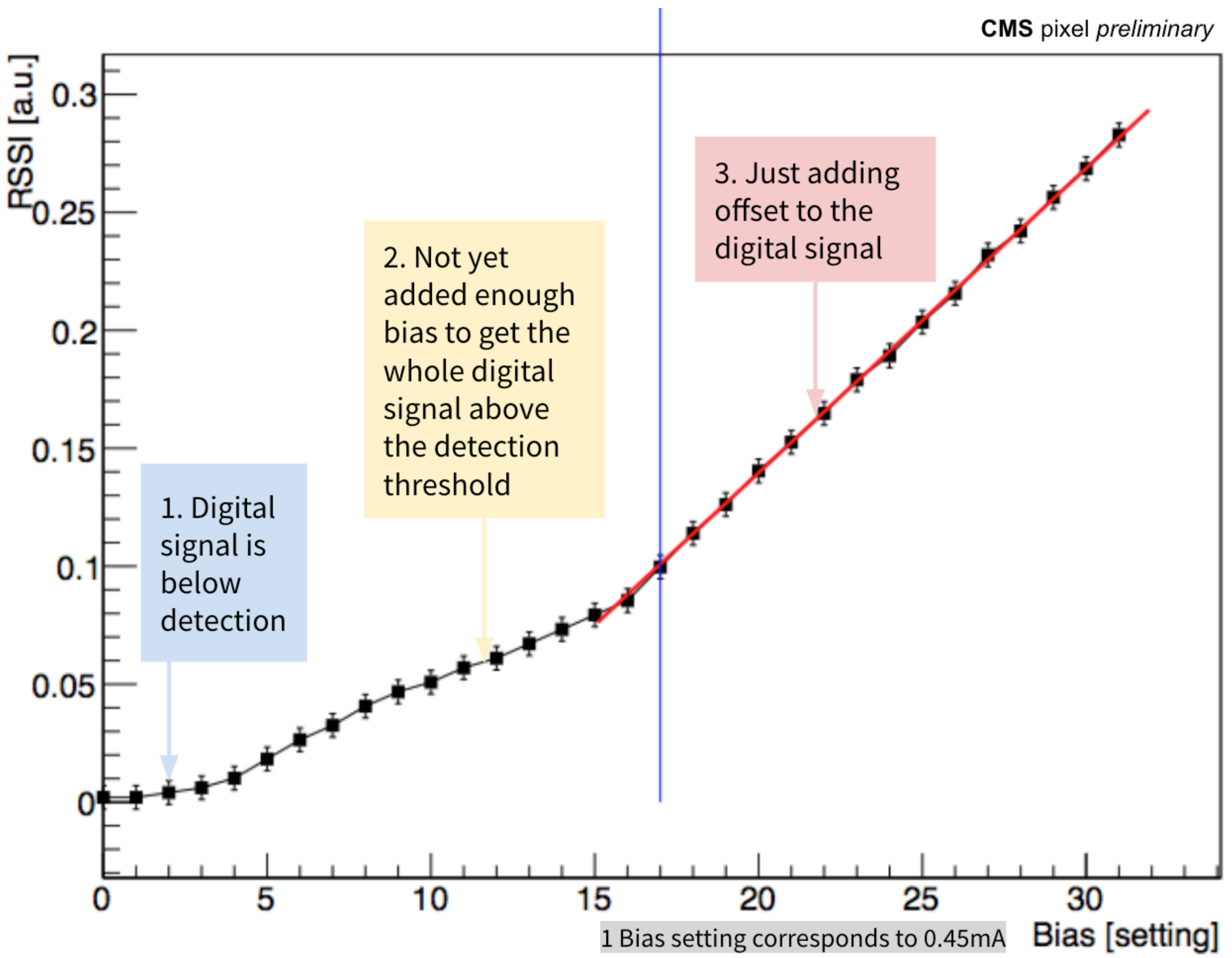
- TBM manage the 160Mbit/s ROC readout at 400MHz.
- The calibration scans over the two delay setting phase space.
- A score is given based on readout data stream structure.
- The optimal setting point is indicated as open cross on the right.



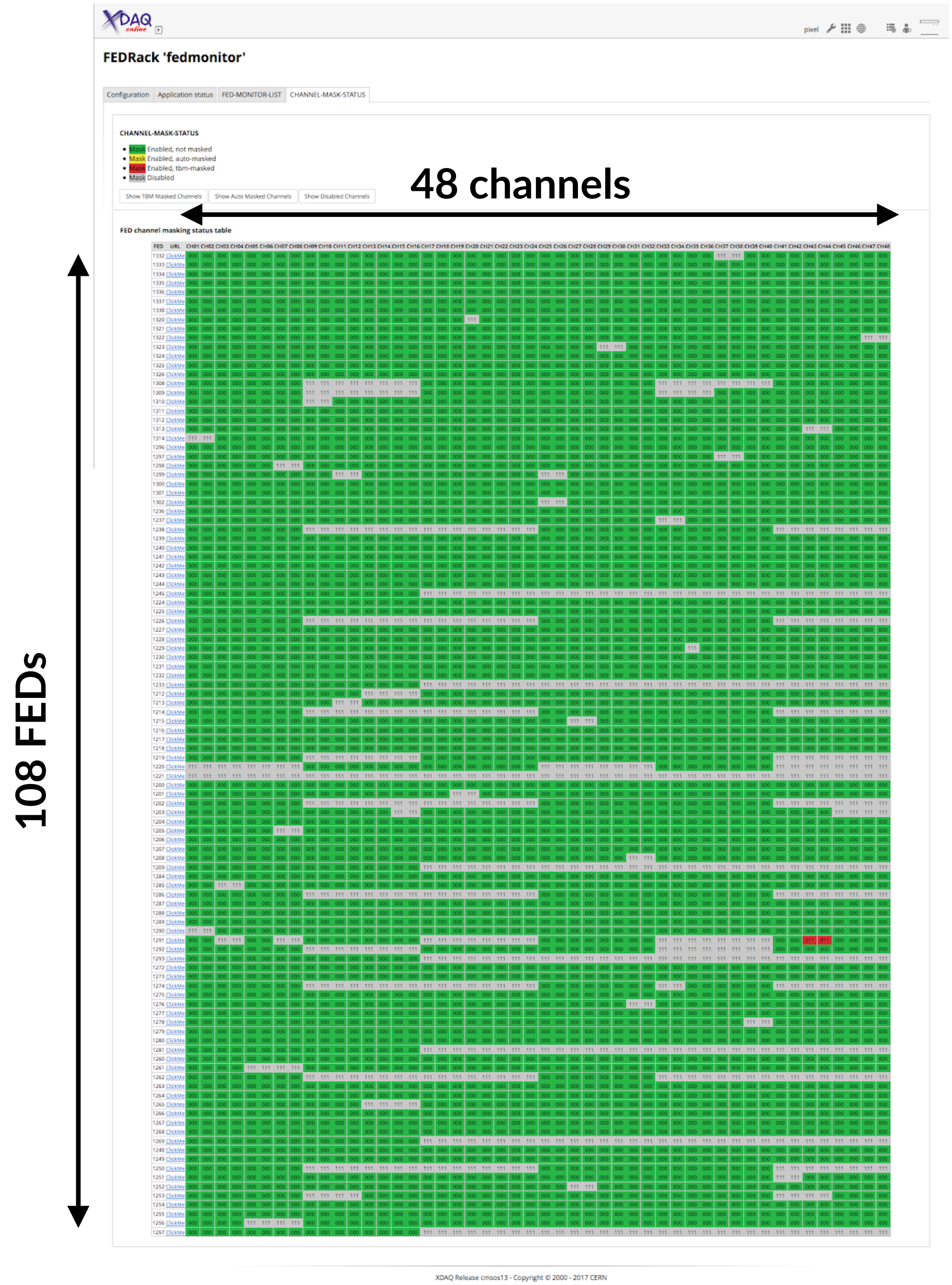
Detector checkout — communication

* Calibrations for auxiliary electronics are also required.
* Example: **POH bias setting calibration**

- POH bias controls the amount of light sent from the detector to the FED.
- As POH bias increases, more light is sent, and the RSSI (Received Signal Strength Indication) values on the FED also increase.
- The bias value of the laser diode is chosen right after the second slope change as indicated by the blue line.



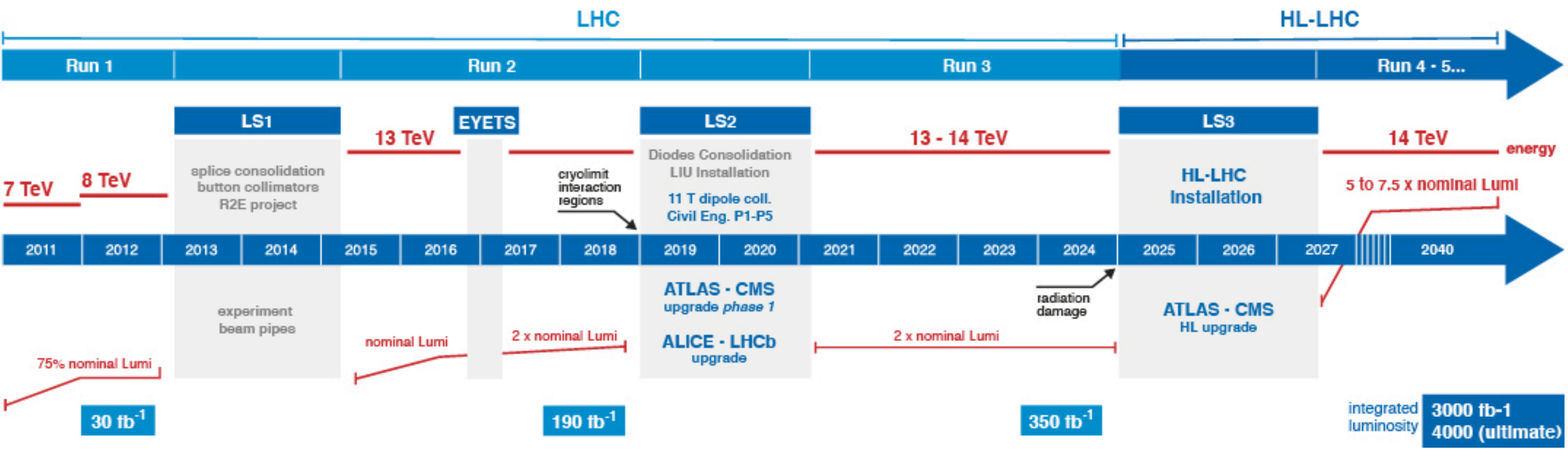
* Monitoring is important for high quality data delivery.
  * Spot problems early, facilitate debugging …
* DQM for high-level data (occupancy, cluster..) monitoring.
* Low-level data monitor
  * Example: **FEDMonitor**
    * (I am the developer.)



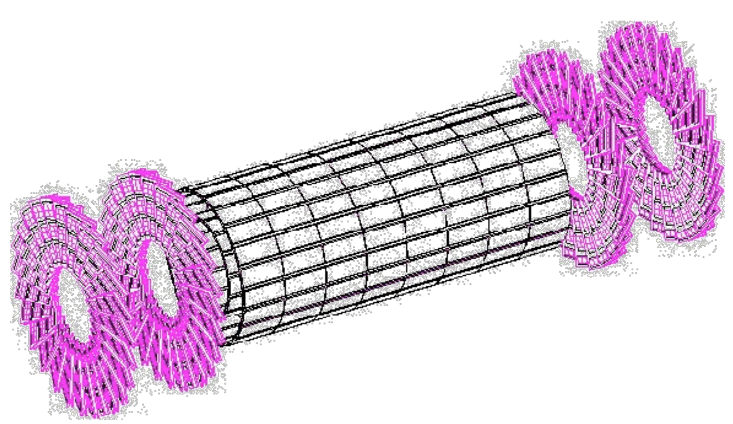
FEDMonitor

* Two XDAQ applications.
* Reading FED register values periodically.
* Display them in web browser.
* Provides detailed channel information.
* View status of all channels in one page!

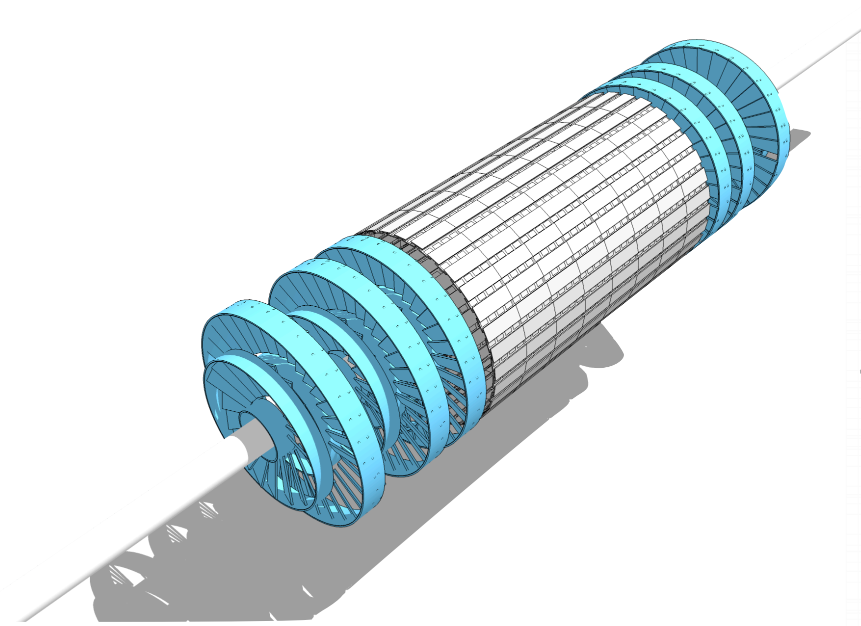
Pixel detector for HL-LHC



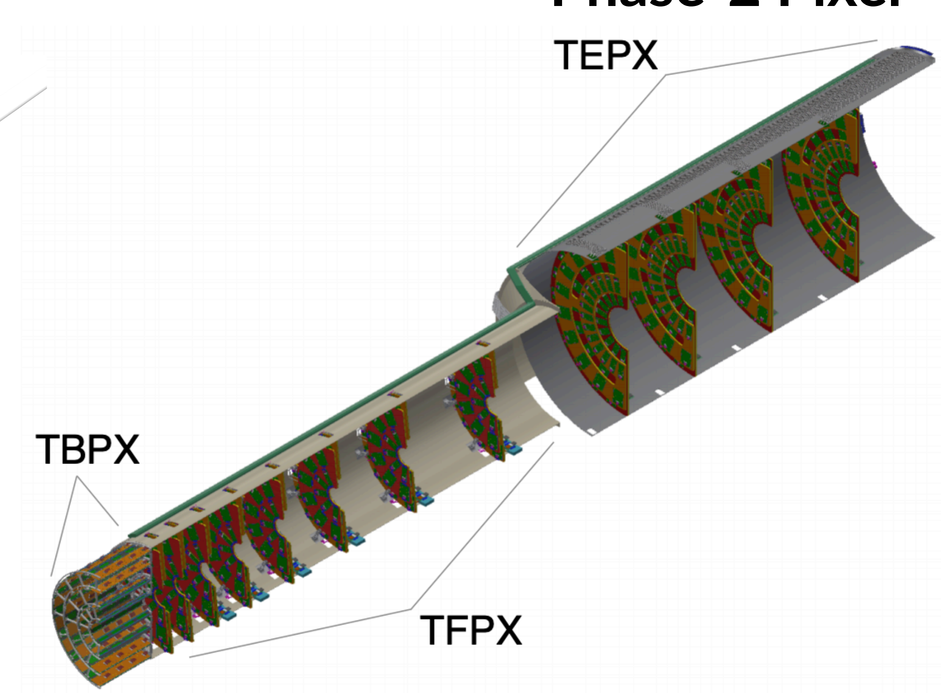
Phase-0 Pixel



Phase-1 Pixel



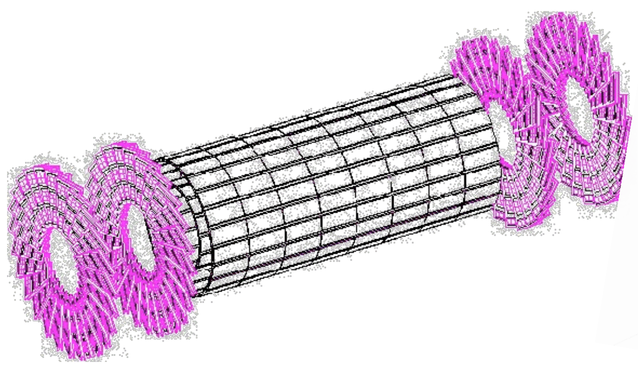
Phase-2 Pixel



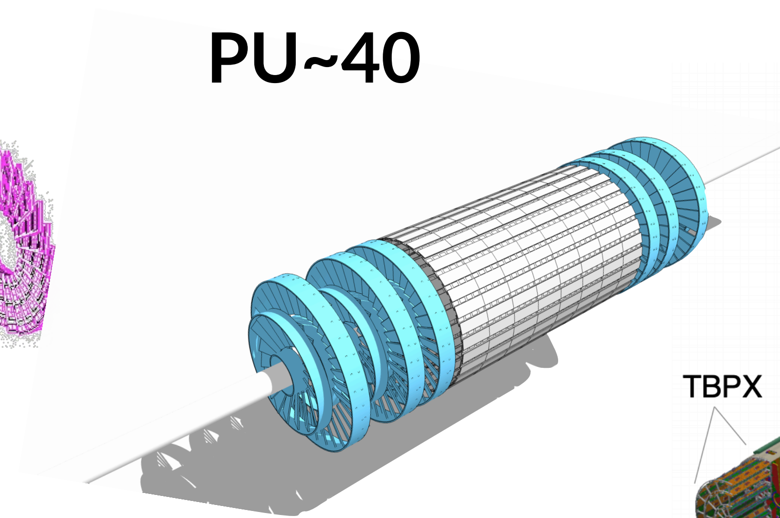
Pixel detector for HL-LHC

* Upgrade is needed to cope with the increasing luminosity.
* Upgrade activities ongoing
  * New layout
  * New sensor, ROC
  * etc.

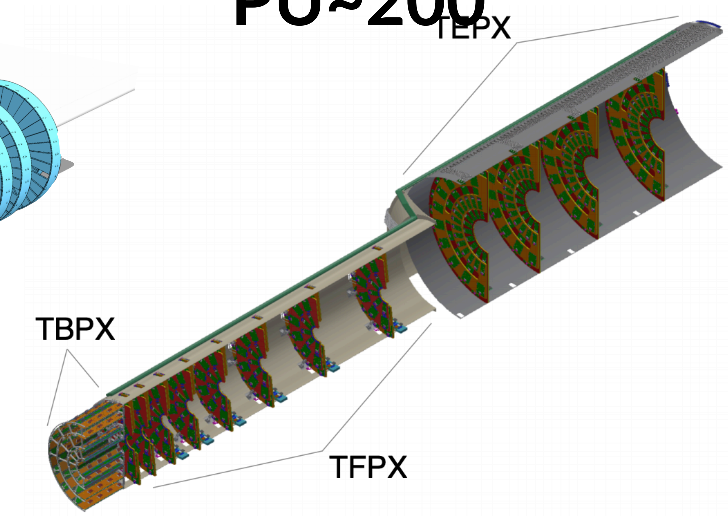
$L \sim 1\times10^{34} cm^{-2}s^{-1}$
PU~20



$L \sim 2\times10^{34} cm^{-2}s^{-1}$
PU~40



$L \sim 5\times10^{34} cm^{-2}s^{-1}$
PU~200

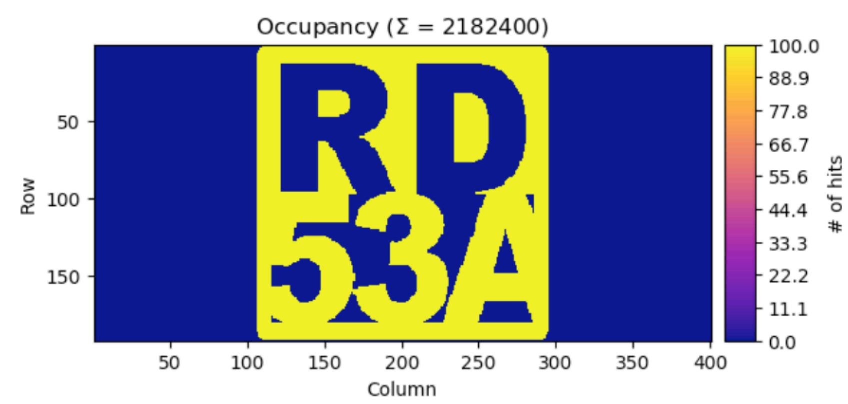


	Phase-0	Phase-1	Phase-2
Layout	3 layers + 4 disks	4 layers + 6 disks	**4 layers + 24 disks**
Inner radius	4 cm	3 cm	3 cm
Active Si area	1 m^2	1 m^2	5 m^2
Channels	66M	124M	**2000M**
Pixel size	100x150 μm^2	100x150 μm^2	**25x100/50x50 μm^2**
Radiation tolerance	100 Mrad	300 Mrad	**1000 Mrad**

Pixel detector for HL-LHC

New ROC ⇨ **RD53 collaboration (ATLAS and CMS)**

https://rd53.web.cern.ch/

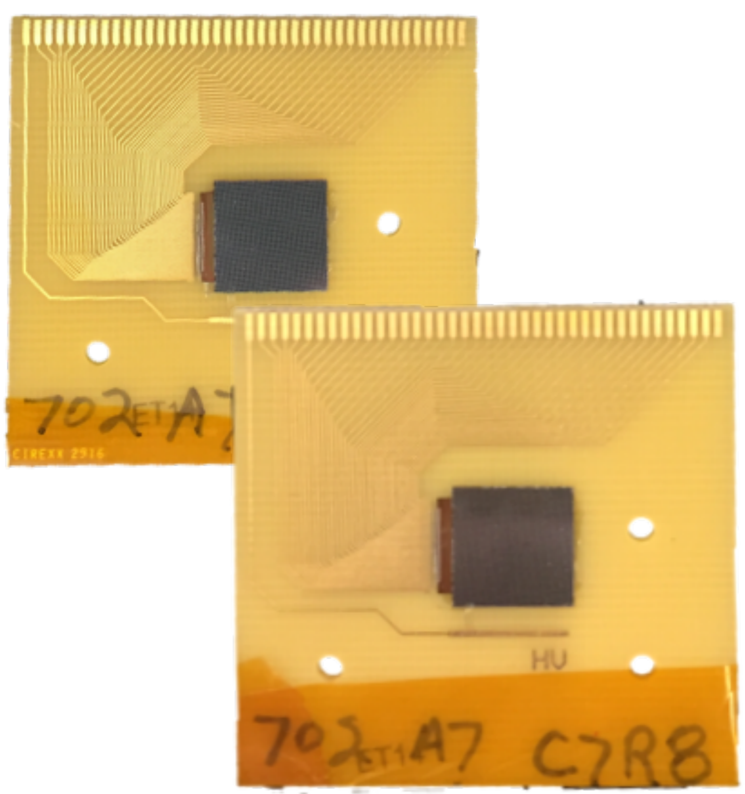


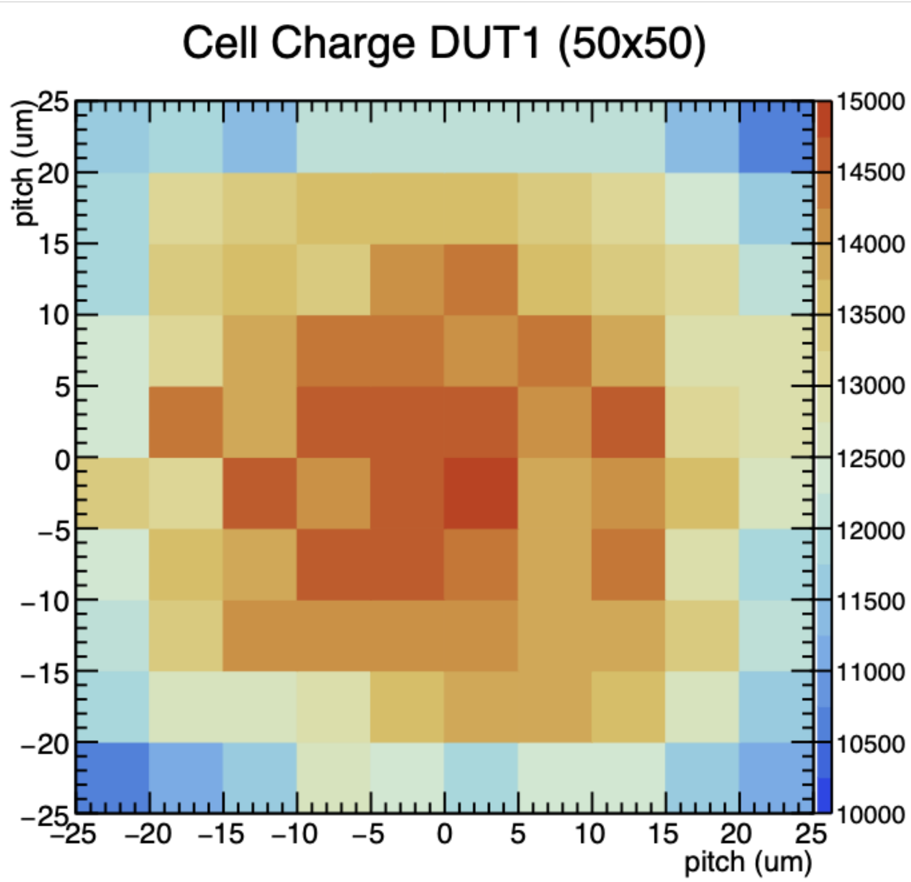
New sensor

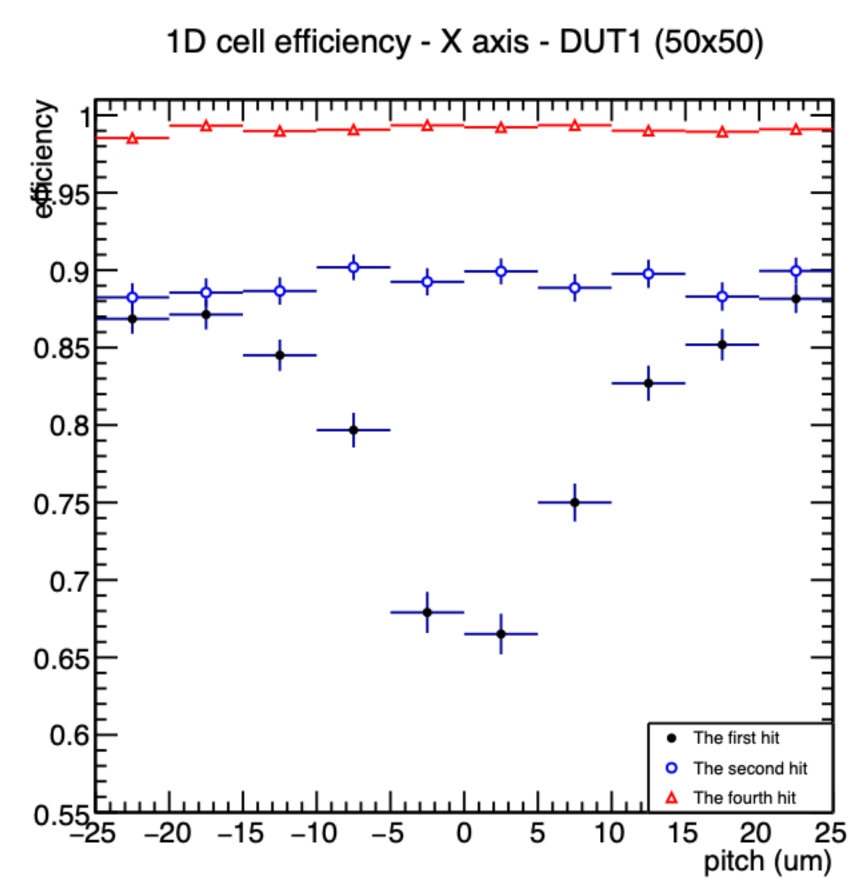
* Radiation hardness
* Hit efficiency
* Cell charge
* Residual resolution

⇨ **120GeV proton Testbeam@Fermilab**

Charge collected on a pixel as a function of track position, using only central hit, or 2/4 neighboring hits as well







Summary

- Self-interacting dark matter is a well motivated DM candidate worth searching for.
- Displaced lepton-jet is a striking signature, great experimental handle.
- I developed the analysis and it will produce the first limit on SIDM from collider data.

- Phase-1 pixel detector was installed in EYETS2016-2017, expected to be in operation until end of Run3 (~2024).
- Many tests performed during the production and system integration to ensure smooth commissioning. Valuable experience for NEXT pixel detector!
- HL-LHC is approaching, R&D program actively ongoing, getting ready for it!

Backup

Object ID: PF Electron, Photon

CMS electron cut-based ID
loose working point (average efficiency ~90%)

p_T>10GeV, |eta|<2.4

	superCluster $\|\eta\| \leq 1.479$	superCluster $\|\eta\| > 1.479$
$\sigma_{i\eta i\eta}(full5 \times 5) <$	0.0112	0.0425
$\|\Delta\eta_{seed}\| <$	0.00377	0.00674
$\|\Delta\phi_{in}\| <$	0.0884	0.169
H/E<	$0.05 + 1.16/E_{SC} + 0.0324\rho/E_{SC}$	$0.0441 + 2.54/E_{SC} + 0.183\rho/E_{SC}$
relIsoWithEA<	$0.112 + 0.506/p_T$	$0.108 + 0.963/p_T$
$\|\frac{1}{E} - \frac{1}{p}\| <$	0.193	0.111
expected missing inner hits≤	1	1
pass conversion veto	yes	yes

Table 1: Electron cut-based *loose* ID criteria (V2)

CMS Photon cut-based ID
loose working point (average efficiency ~90%)

p_T>20GeV, |eta|<2.4

	superCluster $\|\eta\| \leq 1.479$	superCluster $\|\eta\| > 1.479$
H/E<	0.04596	0.0590
$\sigma_{i\eta i\eta} <$	0.0106	0.0272
ρ-corrected PF charged hadron Iso<	1.694	2.089
ρ-corrected PF neutral hadron Iso<	$24.032 + 0.01512p_T + 0.00002259p_T^2$	$19.722 + 0.0117p_T + 0.000023p_T^2$
ρ-corrected PF photon Iso<	$2.876 + 0.004017p_T$	$4.162 + 0.0037p_T$

Table 2: Photon cut-based *loose* ID criteria (V2)

Object ID: PF Muon, DSA

CMS muon loose ID

pass PF Muon ID	yes

Table 3: Muon *loose* ID criteria

p_T>5GeV, |eta|<2.4

DSA ID

N(stations)≥	2
N(hits)≥	12
N(DT hits)>	18 when N(CSC hits)=0
$\sigma_{p_T}/p_T <$	1
χ^2/ndof<	4

Table 4: Displaced standalone (DSA) muon ID criteria

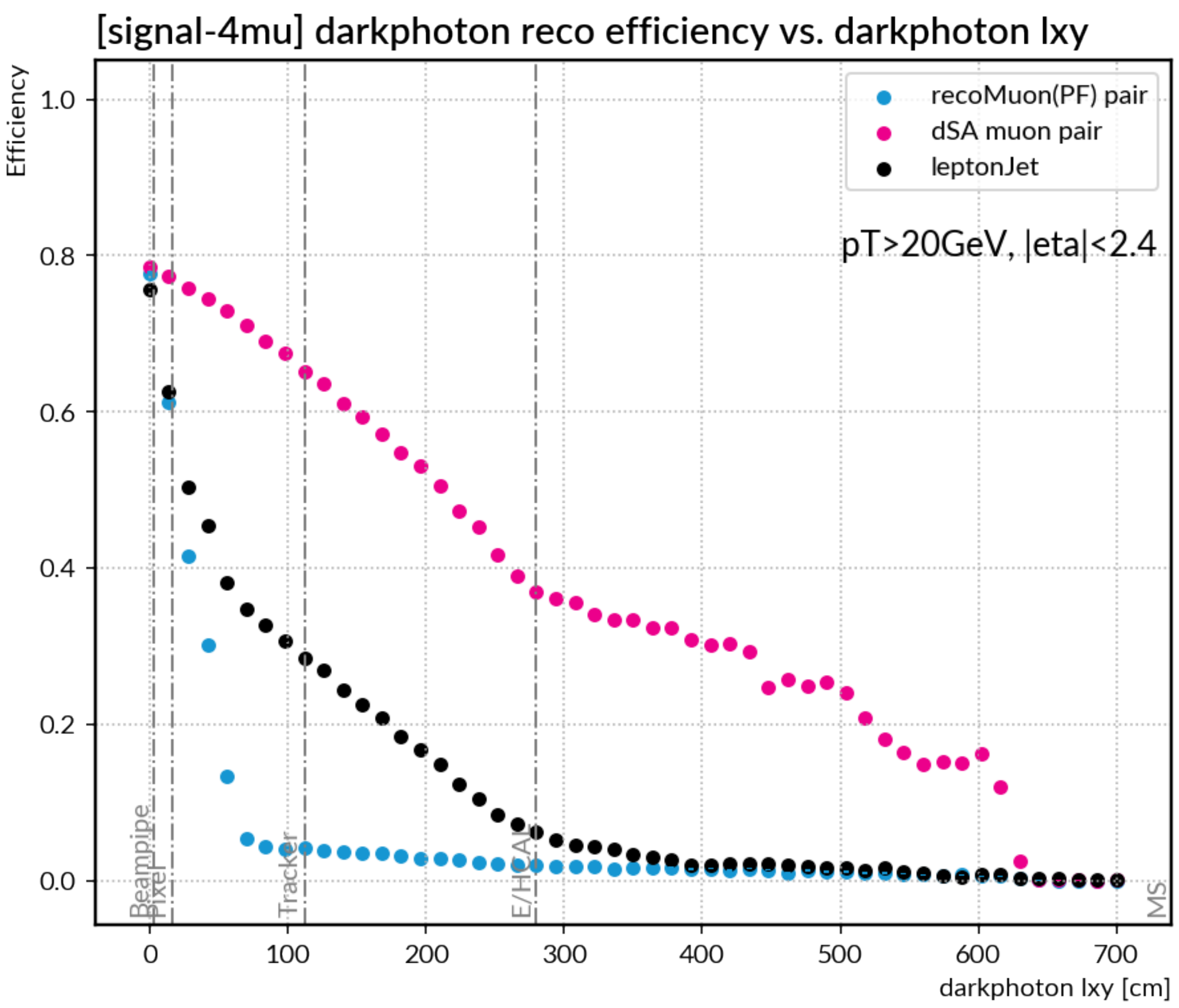
p_T>10GeV, |eta|<2.4

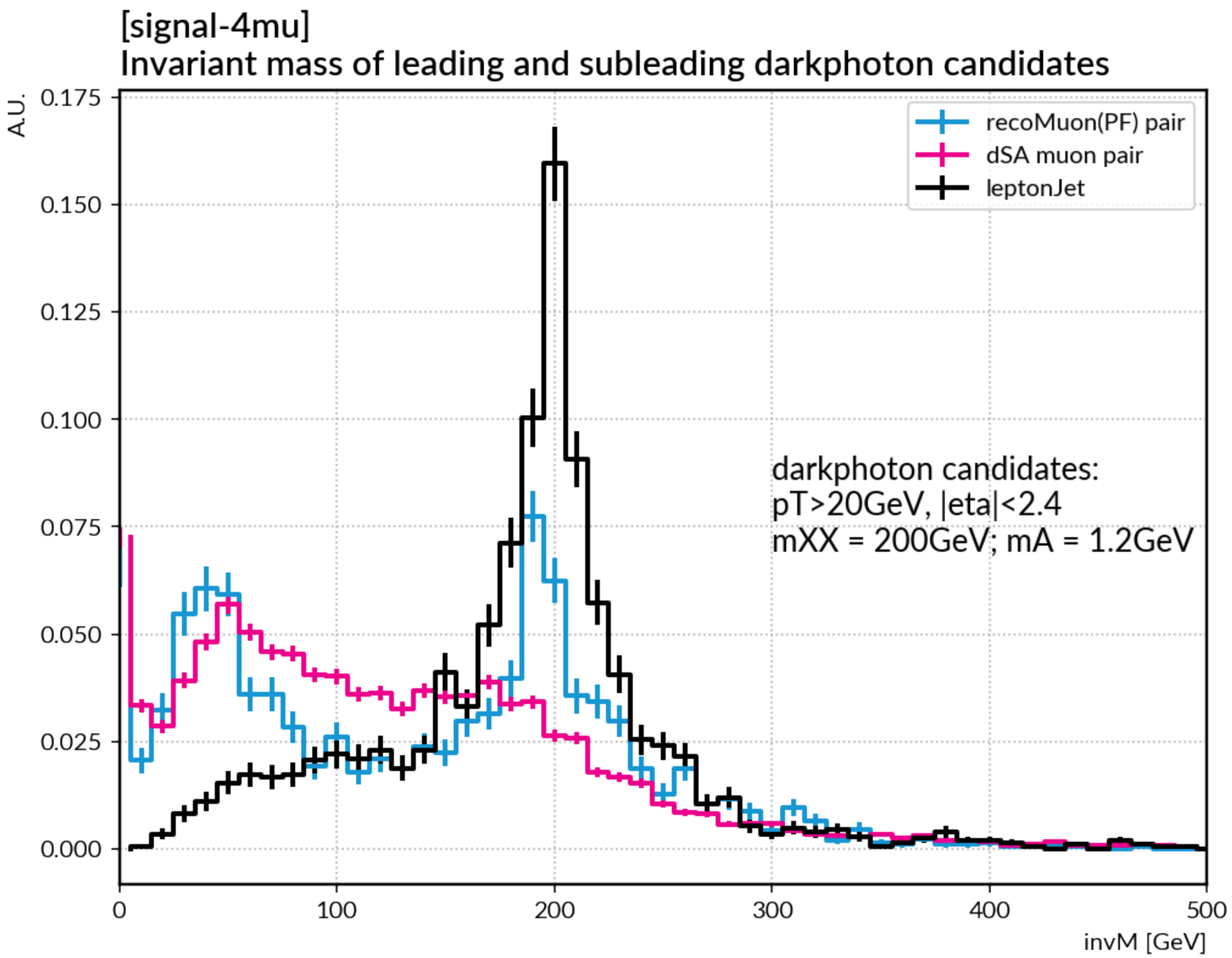
Lepton-jet performance comparison

To illustrate the benefit of lepton-jet reconstruction for dark photons, 3 methods are tested:

1. Dark photon as a pair of opposite charged PF muon pair
2. Dark photon as a pair of opposite charged DSA muon pair
3. Dark photon as a lepton-jet

Left shows the reconstruction efficiency as a function of dark photon lxy;
Right shows the invariant mass of two dark photon candidates.

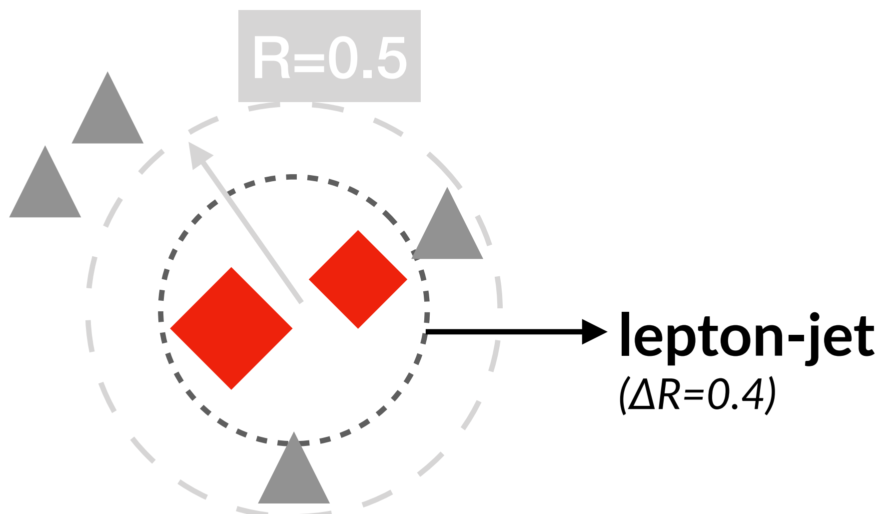




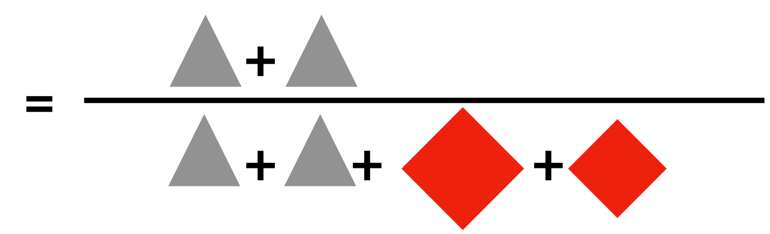
Lepton-jet isolation

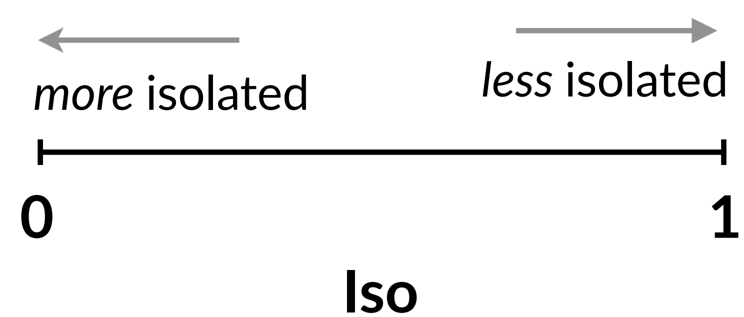
Idea:

- lepton-jet is expected to be isolated, with little activity around.
- define a **lepton-jet isolation** based on PFCandidates



$$\text{Iso} = \frac{\sum_{R=0.5} \text{energy}^{*} - \text{footprint}}{\text{numerator+lepton-jet}}$$

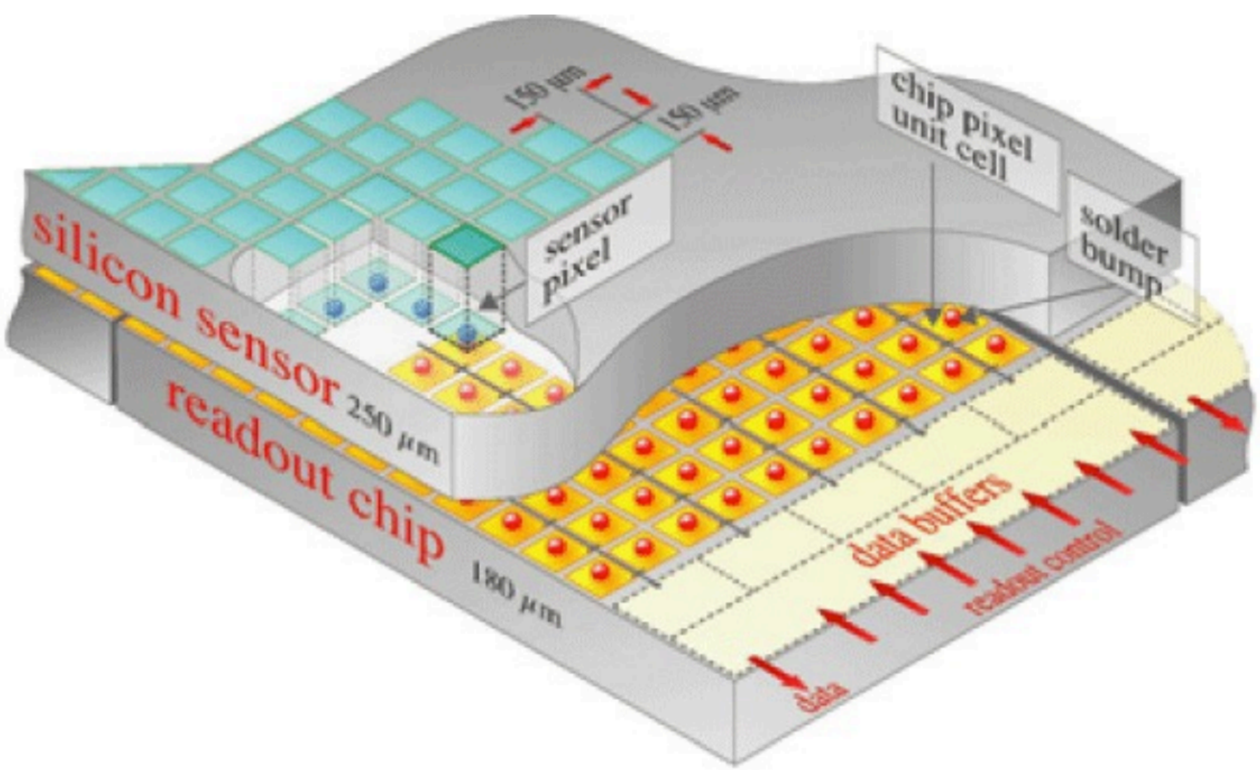


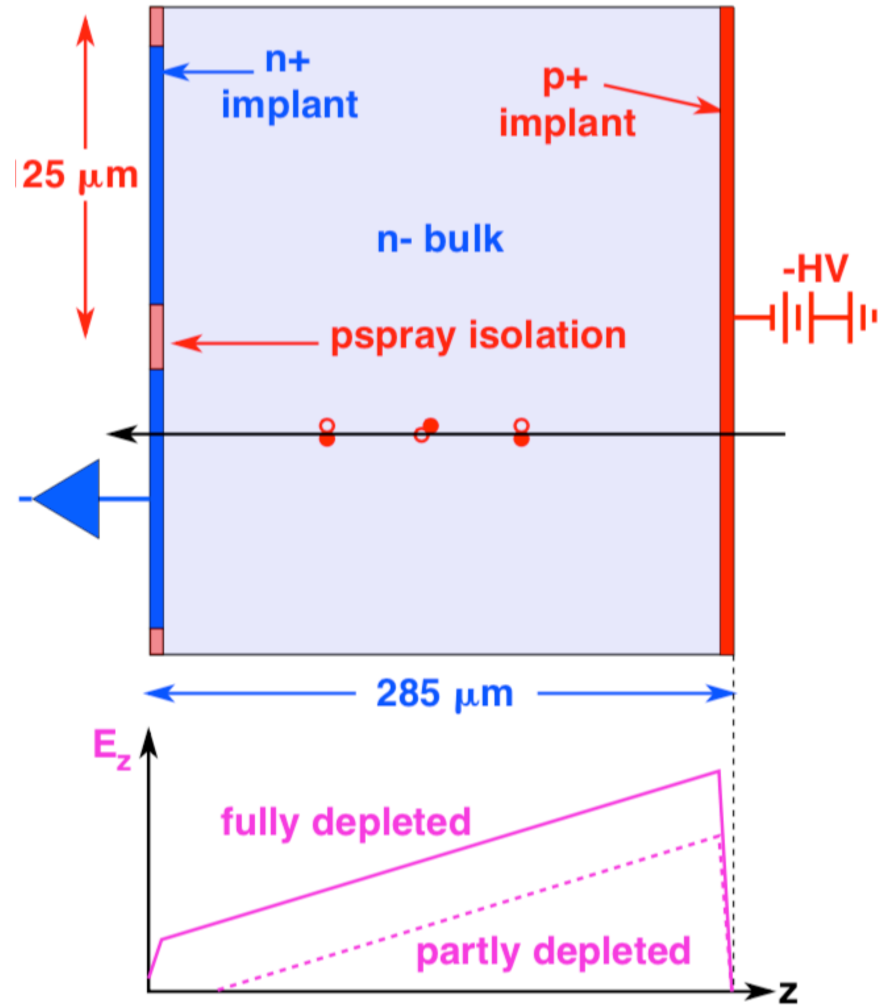


* only PFCands associated with primary vertex.

* μ-type candidates are excluded to avoid shape distortion seen for DSA-type lepton-jets. When a PFMu in cone but did not pass loose Id+Iso, it can be double counted. To be consistent, μ-type candidates are excluded for isolation.

Pixel sensor





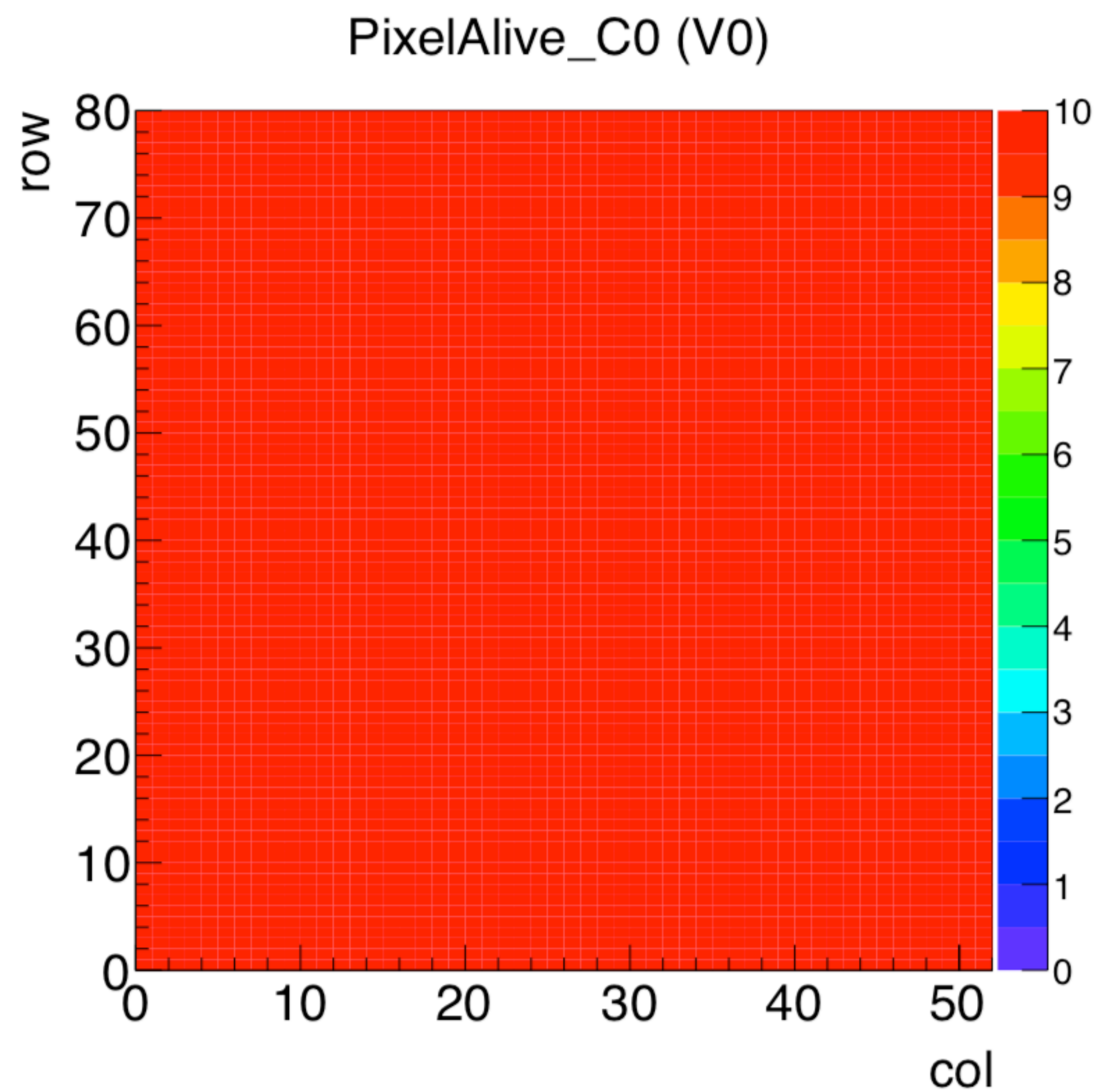
n+-in-n design:
hightly doped n+ implants in lightly doped n- substrates with p+ backplanes.

Pixel module testing example

PixelAlive — *identify faulty pixels.*

1. Alive test 2. Mask test 3. Address decoding test

- Inject 10 calibration pulses to each pixel.
- Measure the number of recorded signals.
- All pixels are masked except the one under test.



- ***Dead***: no recorded hits
- ***Problematic***: less than 100% efficiency
- ***Good***: same number of signals recorded as the number of the injected calibration pulses.

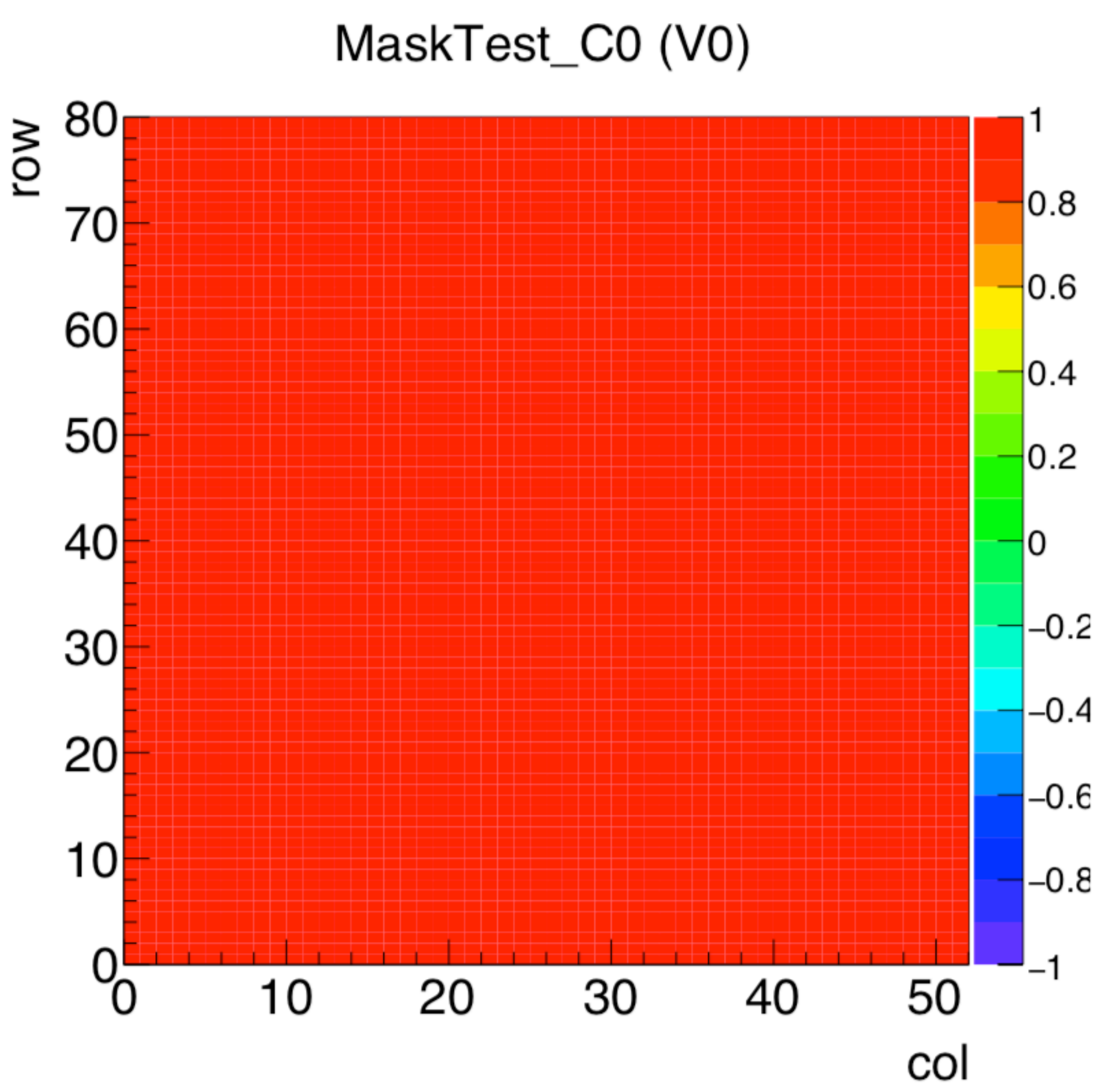
Pixel module testing example

PixelAlive — *identify faulty pixels.*

2. Mask test

- all pixels are masked.
- repeat the procedure as Alive test

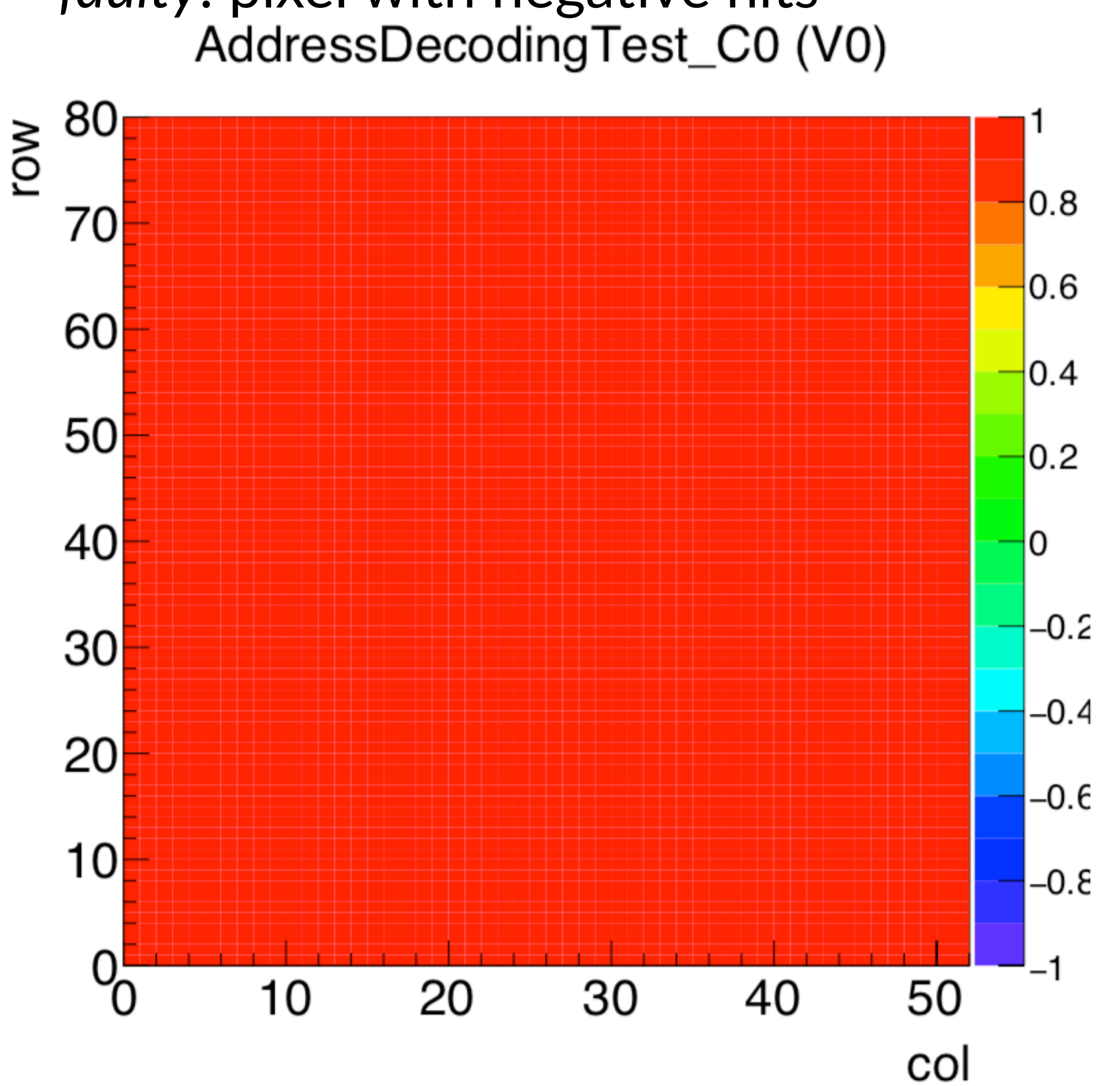
- *faulty*: non-zero efficiency



3. Address decoding test

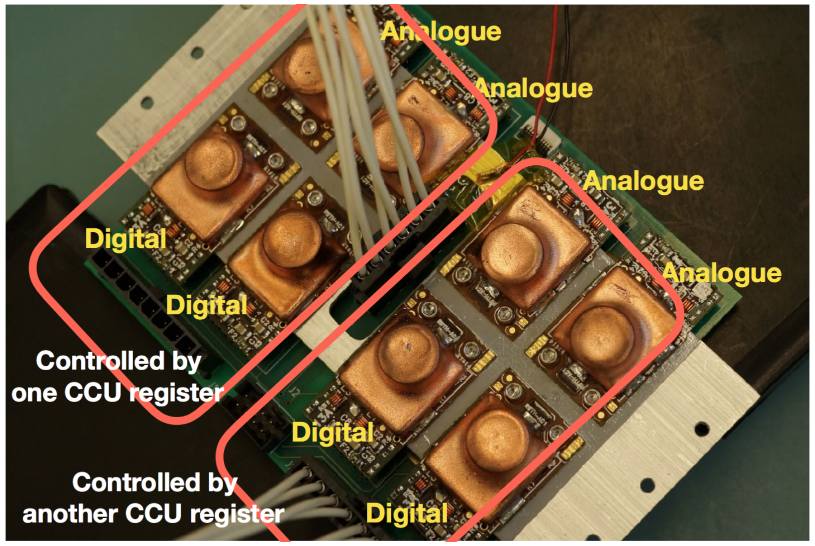
- same efficiency measurement for each pixel.
- Address out of order will result in negative pulse height.

- *faulty*: pixel with negative hits



binContent: 1: good pixel, 0: dead pixel, -1: faulty pixel

Detector service and frontend control



* DC-DC converter
  * custom ASIC converts high voltage power (11V) to low voltage for digital (3.6V) and analog (2.4V) parts of pixel modules.
  * No need to install extra power cables during limited EYETS16-17. (Extended Year End Technical Stop)

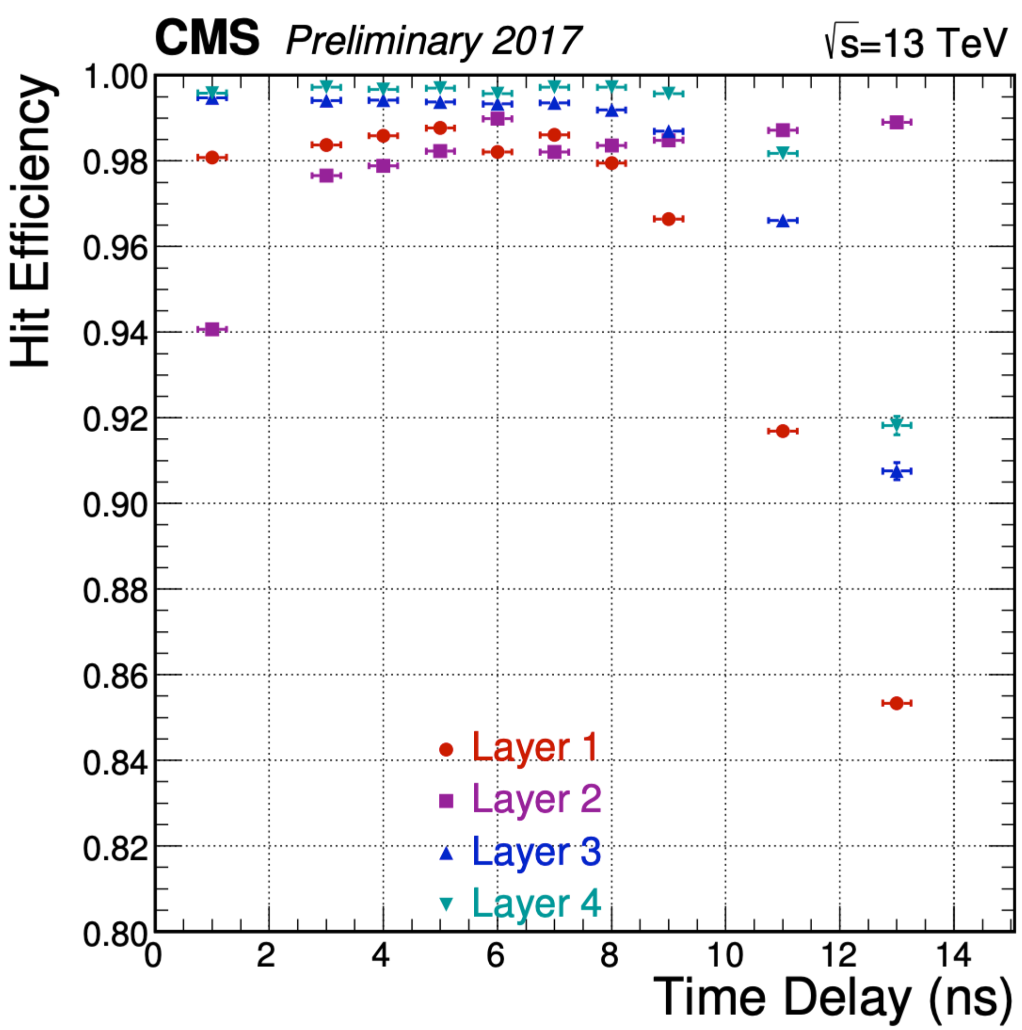
* TkFEC (Tracker FrontEnd Controller)
  * program auxiliary components in pixel supply electronics such as opto-hybrids and DC-DC converter.

* PxFEC (Pixel FrontEnd Controller)
  * distribute 40 MHz clock, trigger and fast signals to the pixel modules.
  * program registers of ROC and TBM

Detector commissioning

- **Detector timing**
  - Non-optimal timing setting would result in hit efficiency loss.
  - Clock phase programmable by chips on DOH motherboard, but in groups of modules.
    - E.g. modules in BPix layer1&2 can share a common programmable delay.

- BPix layer1 using PROC600, layer2-4 and FPix using PSI46digv2.
- Different phase at which PROC600 and PSI46digv2 chips associate timestamps to hits.
- Overlap of possible phase is ~7ns.



The goal is to delay the 25ns window as much as possible in order to allow for the readout of pixel hits that are registered late but are still produced in the bunch crossing.

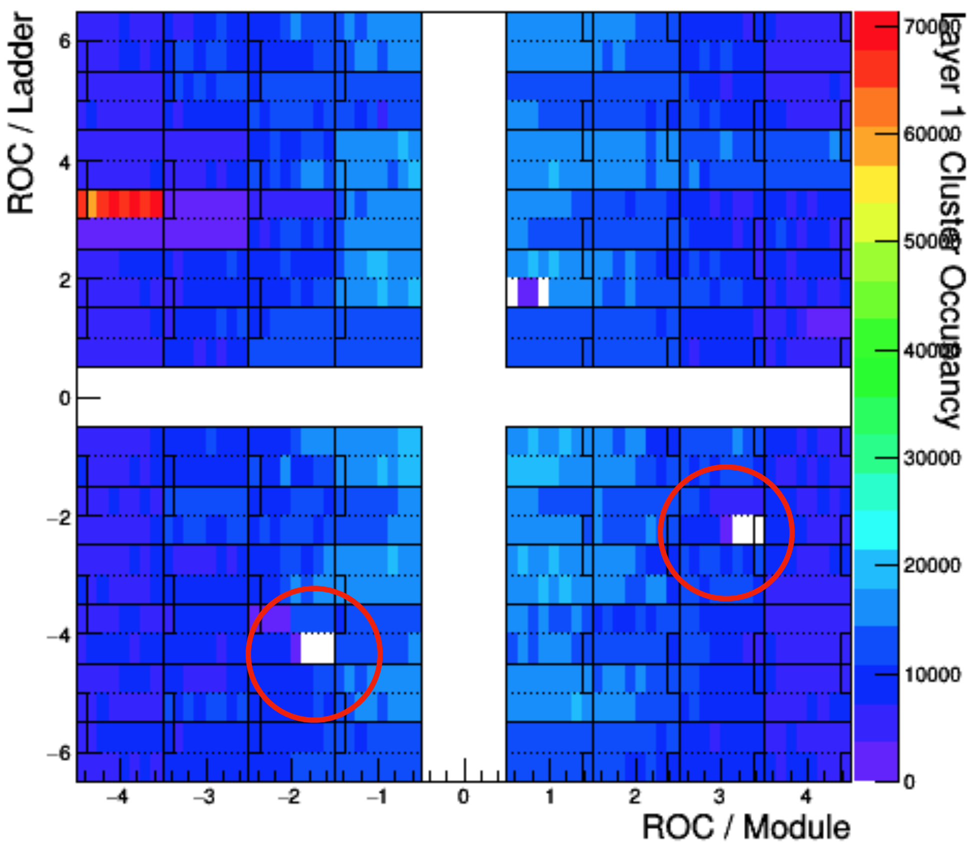
6ns is set for *layer 3&4* (and FPix), chosen 3ns earlier than the falling edge of the efficiency plateau.

Delay settings for *layer1&2* are adjusted such that the default 6ns delay optimizes for layer1, but also a good compromise for layer2.

* **SEU** (single event upset)
  * Change of state by one single ionizing particle striking a sensitive node in a micro electronic device, such as a transistor.

* **ROC**
  * No data send out from a single ROC.
  * *Fix by reprograming the ROC.*
* **TBM**
  * Stopping sending tokens, no data from relevant ROCs read out.
  * *Fix by turning on and off the DC-DC converter that power the module.*
* **Portcard**
  * No data read out from entire readout group.
  * *Fix by reprograming the portcard.*

TBMs affected by SEU appears as "holes" in cluster occupancy map.



Pixel acronyms

- CTA: CMS Tracker AMC
- AMC: Advanced Mezzanine Card
- LPC: Low-Pin-Count
- FMC: FPGA Mezzanine Card
- TTS: Trigger-Throttle Signal
- POH: Pixel-Opto-Hybrid
- DOH: Digital Opto Hybrid
- mDOH: modified DOH
- mFEC: FEC optical mezzanine
- CCU: Communication & Control Unit
- Rx-FMC: Receiver FMC
- TCDS: Trigger and Command Distribution System
- FEROL: Front-End Readout Optical Link
- TPLL: Tracker Phase-Locked Loop
- QPLL: Quartz Phase-Locked Loop
- FC7: FMC Carrier xilinx series 7
- MCH: MicroTCA Carrier Hub

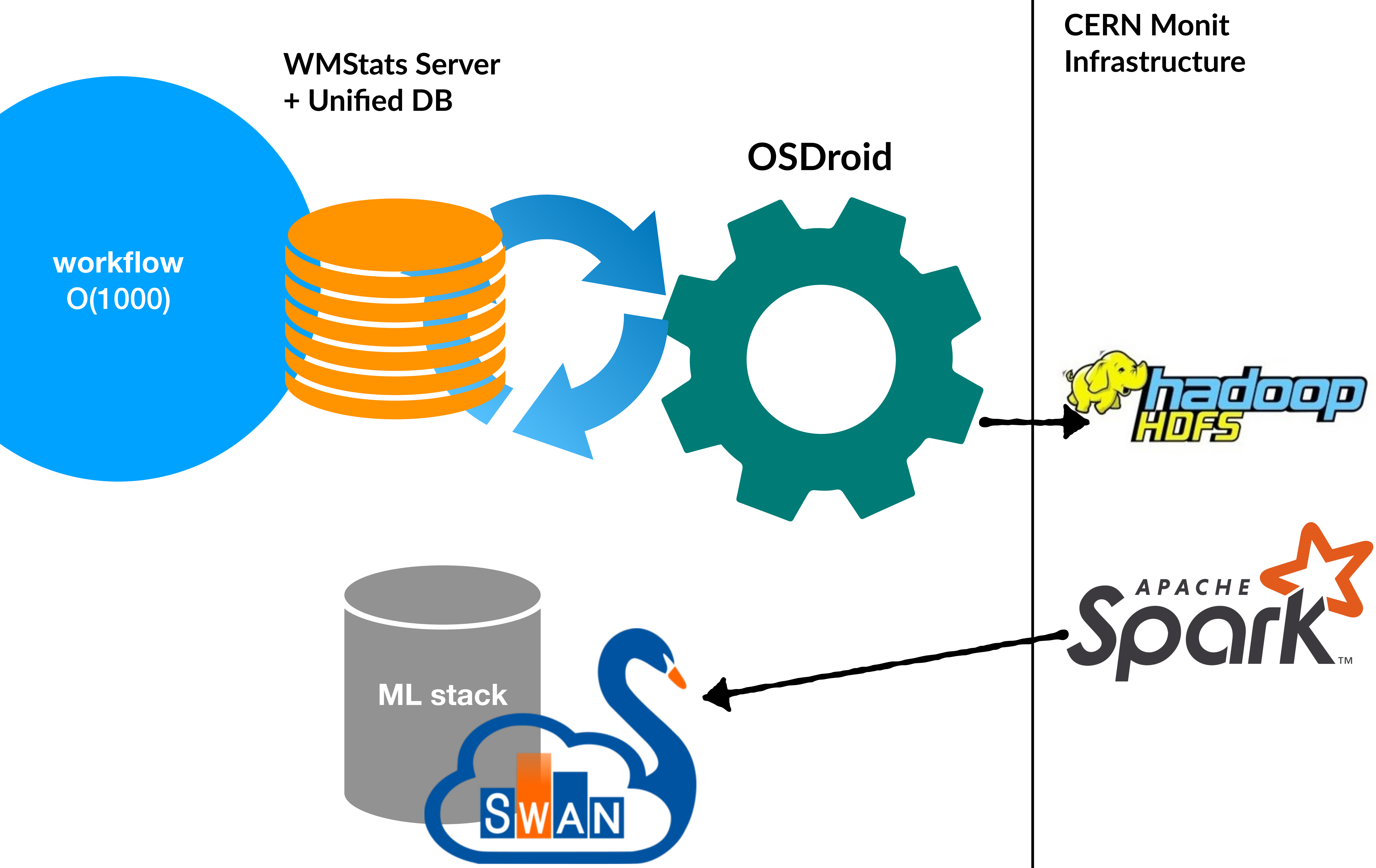
Machine learning for CMS computing operations support

- CMS offline processing: data reconstruction, MC generation
- Tasks are managed in ***"workflows"*** – to deliver for analyzers.
  - O(1000) in system.
- Operators watch over the system, spot problems and take actions.
  - Site problem, workflow misconfiguration

- Run 3 onwards, much more loads in the system expected.
- Machine learning for prediction and action-taking!

OSDroid **(Operation Support Droid)**

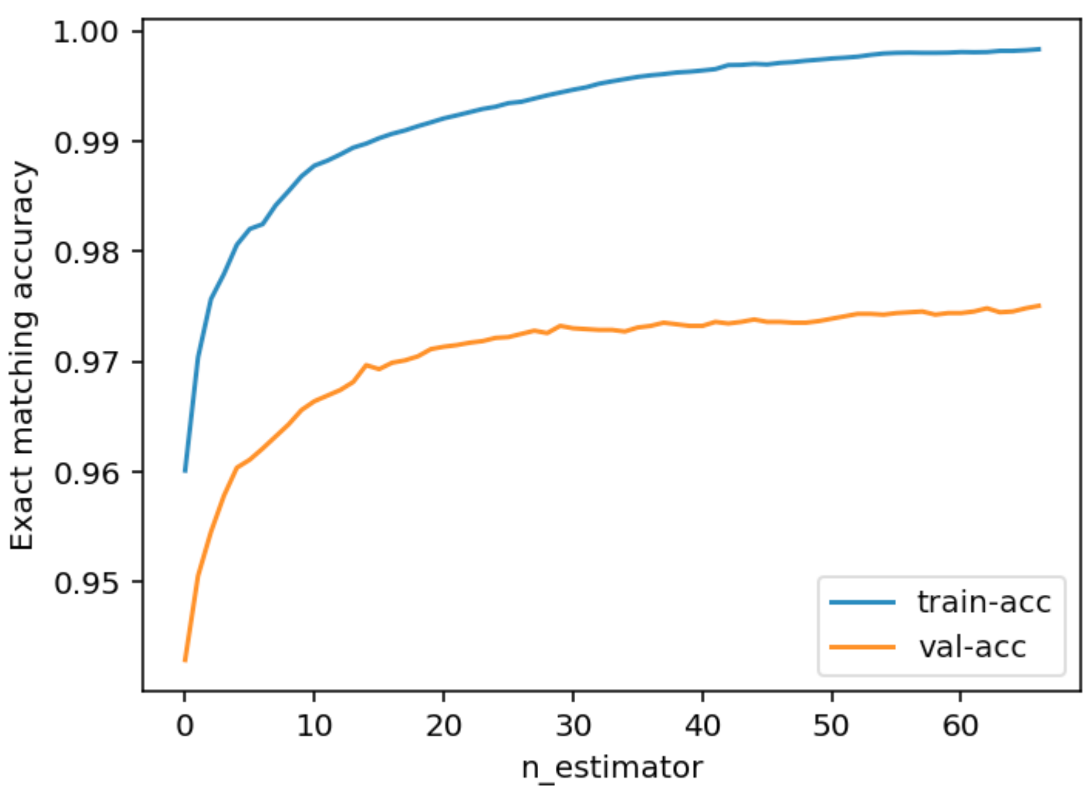
Data collection

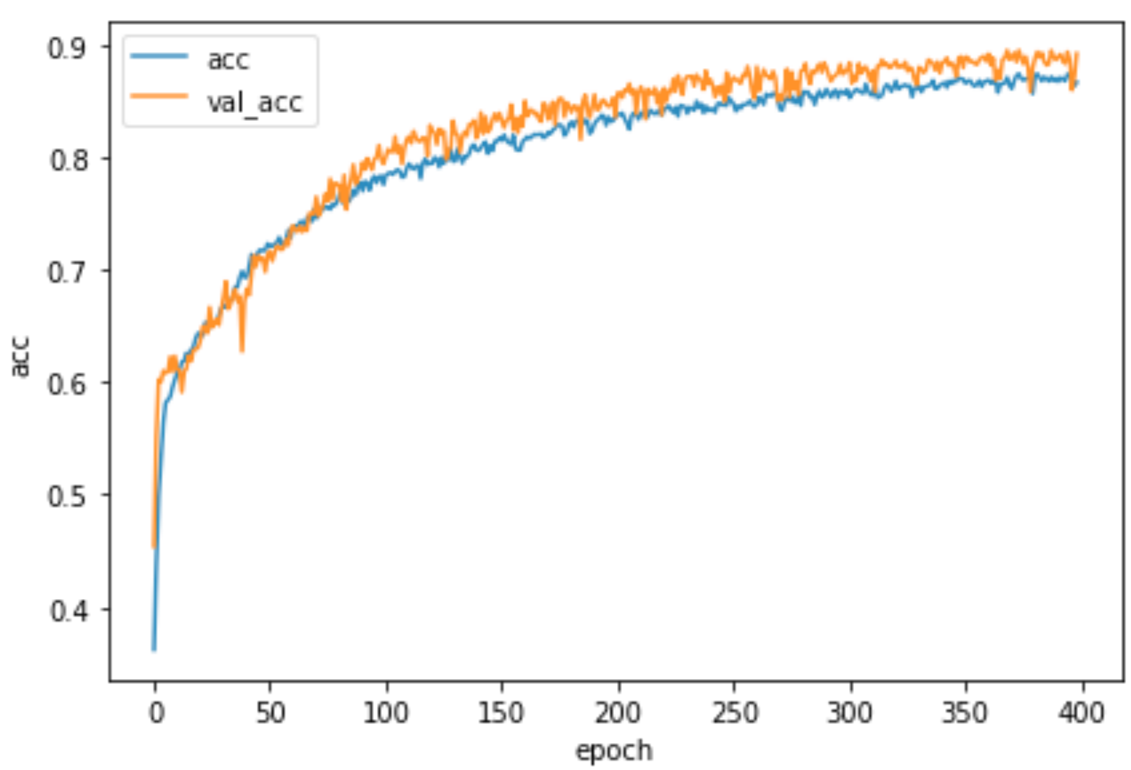


Model training

- BDT
- XGBoost
- Hyperparameter tuning: Bayesian optimization
- **Precision: 97.4% (test set)**

- DNN
- TensorFlow+Keras
- Dense DNN w/ drops and batch normalization
- Hyperparameter tuning: Bayesian optimization
- **Precision: 88.4% (test set)**





Model production

https://github.com/CMSCompOps/OSDroid

- View model predictions
- Send out alerts
- Post JIRA tickets

- Web application based on Flask
- jQuery+MySQL

Aim for Run3!