The 6th International Workshop on Future Tau Charm Facilities

FTCF, 2024, Guangzhou

THE CGEM INNER TRACKER OF BESIII

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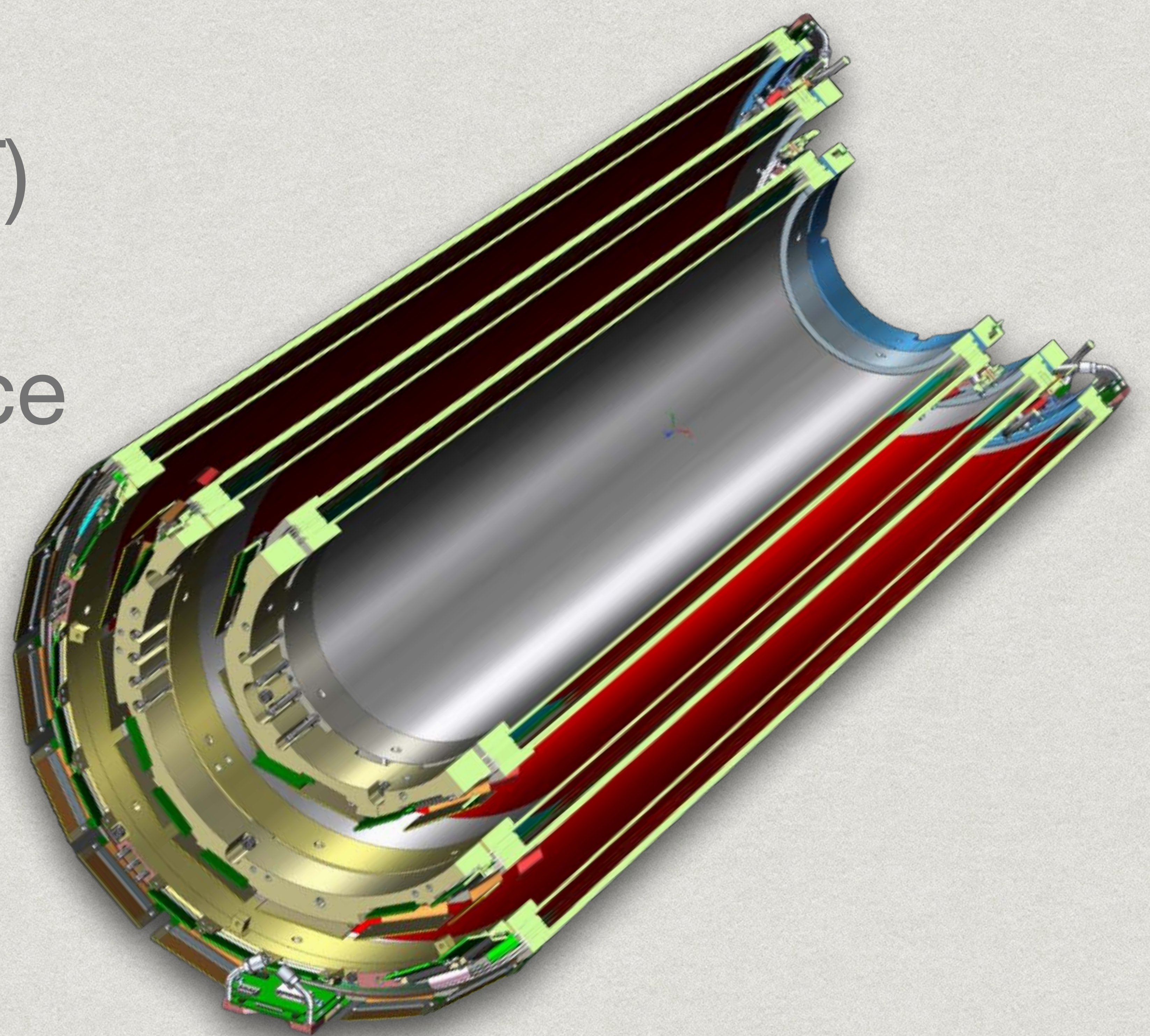
on behalf of the CGEM-IT group

Outline of the talk

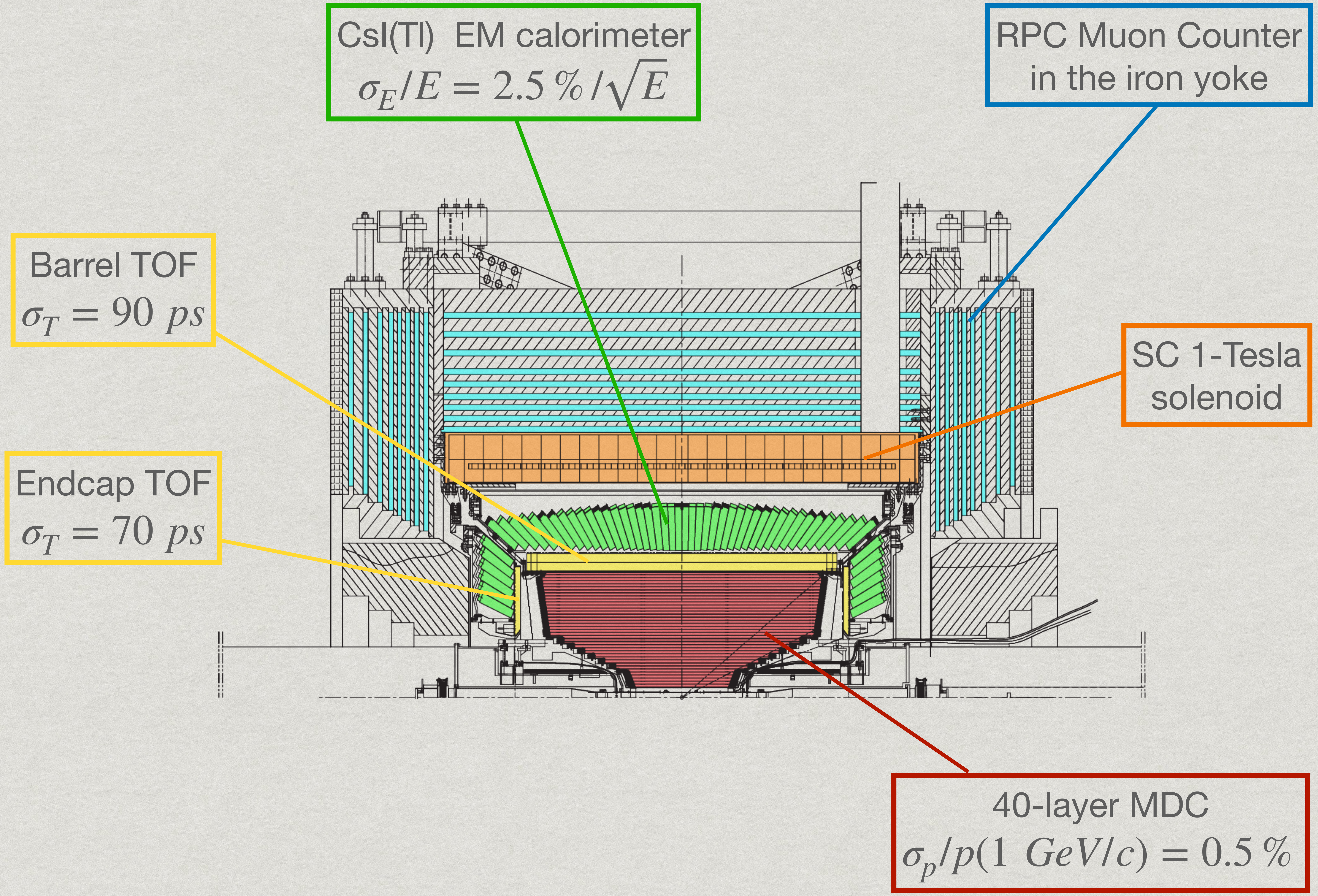
- The BESIII experiment and its upgrade program
- The Cylindrical GEM Inner Tracker (CGEM-IT)
- Simulation studies and expected performance
- Status of the project
- Summary and outlook



THE BESIII EXPERIMENT AND ITS UPGRADE PROGRAM

The BESIII experiment @ BEPCII

- $E_{CM} = 2 - 4.95 \; GeV$
- $\mathscr{L}_{peak} = 1.0 \times 10^{33} \; cm^{-2}s^{-1}$
- Center-of-mass energy spanning the τ-charm sector
- Region below 2 GeV directly accessible (via ISR)
- World's largest sample of
  - J/ψ —> 10 billions
  - $\psi(2S)$ —> 3 billions
  - $\psi(3770)$ —> 20 fb^{-1}
- About 22 fb^{-1} of data for Exotic Charmonium Spectroscopy



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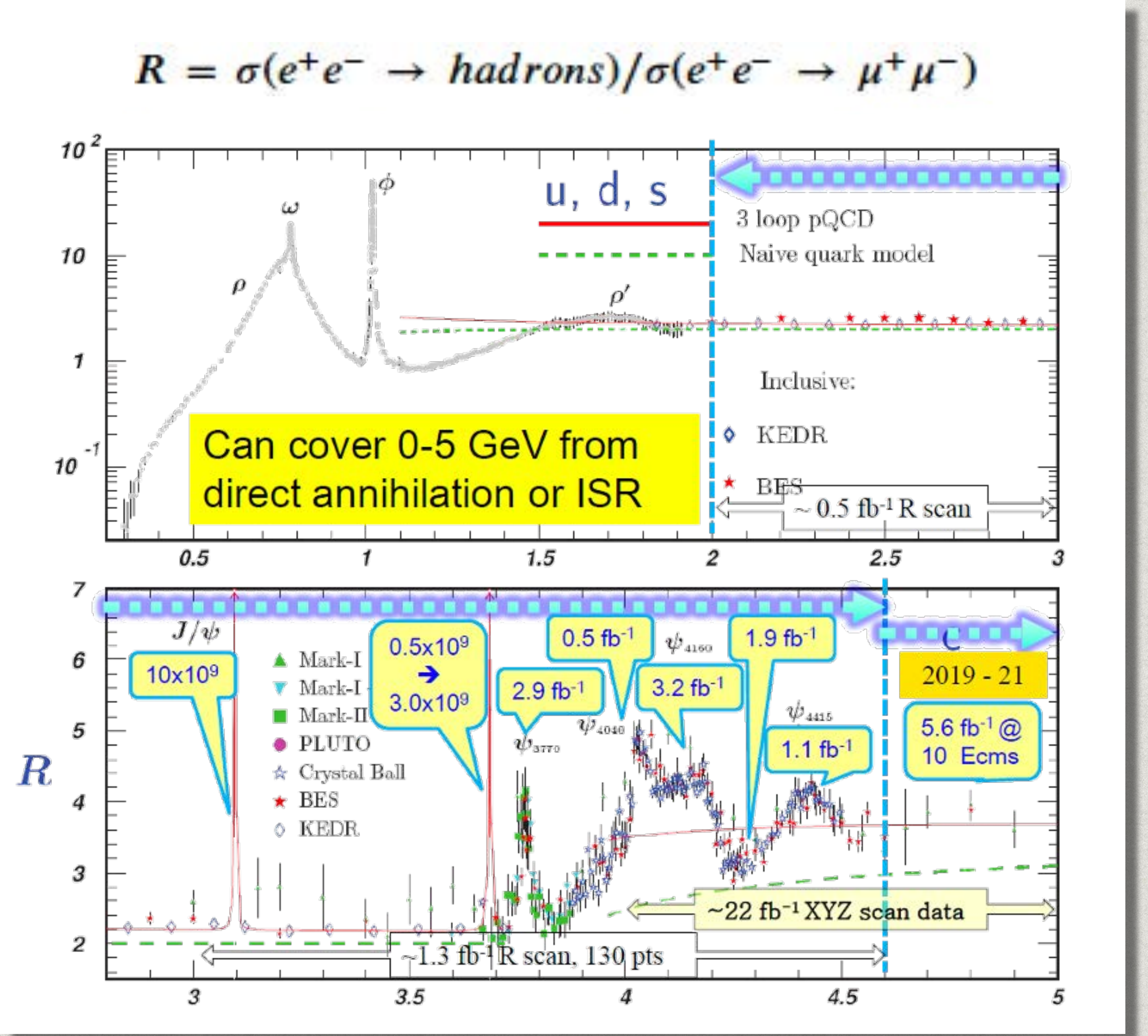
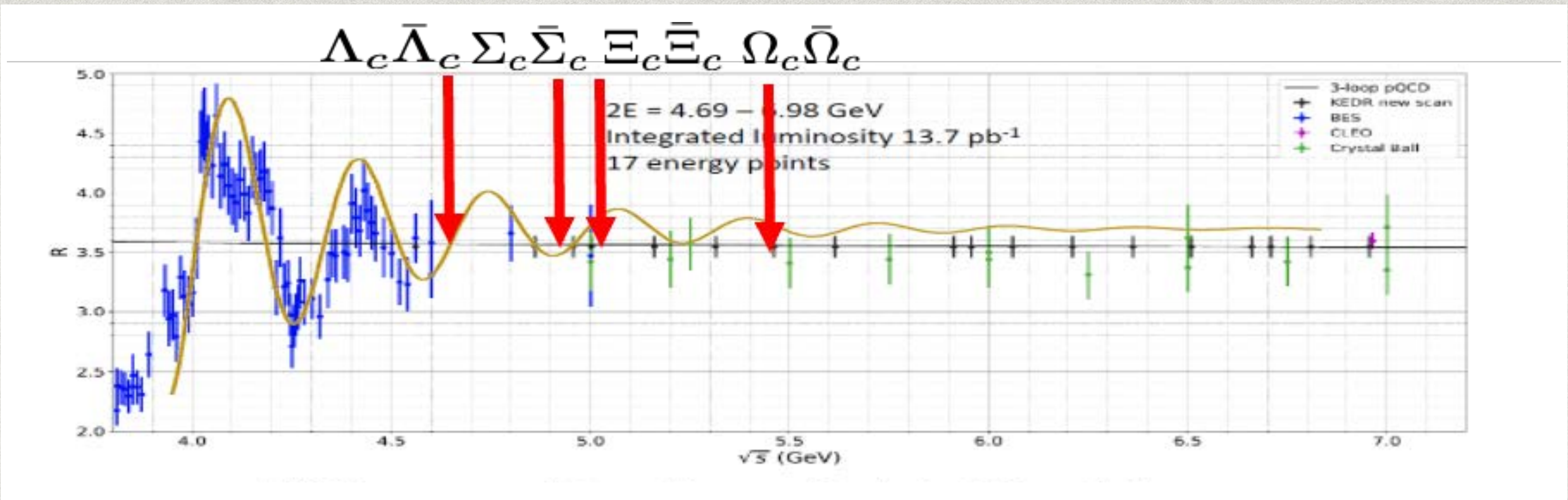


The BESIII upgrade program: physics



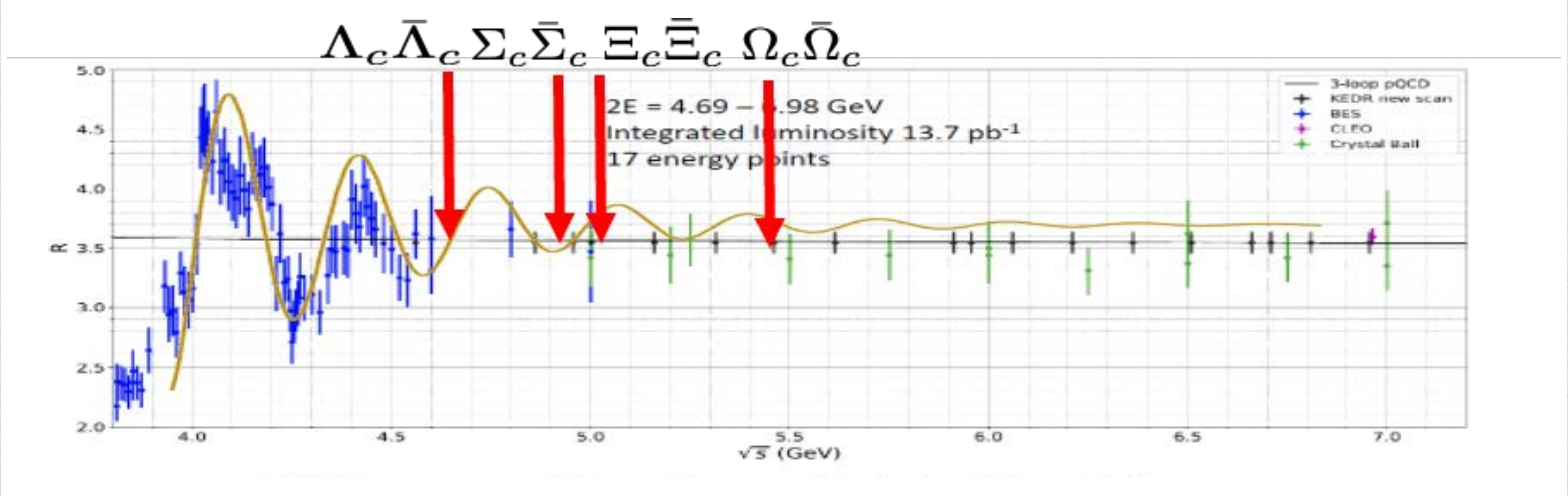
- $e^+e^- \to \Sigma_c\overline{\Lambda}_c^-\pi$
- $e^+e^- \to \Sigma_c\overline{\Sigma}_c$
- $e^+e^- \to \Lambda_c^+\overline{\Lambda}_c^-$ and $e^+e^- \to \Xi_c\overline{\Xi}_c$

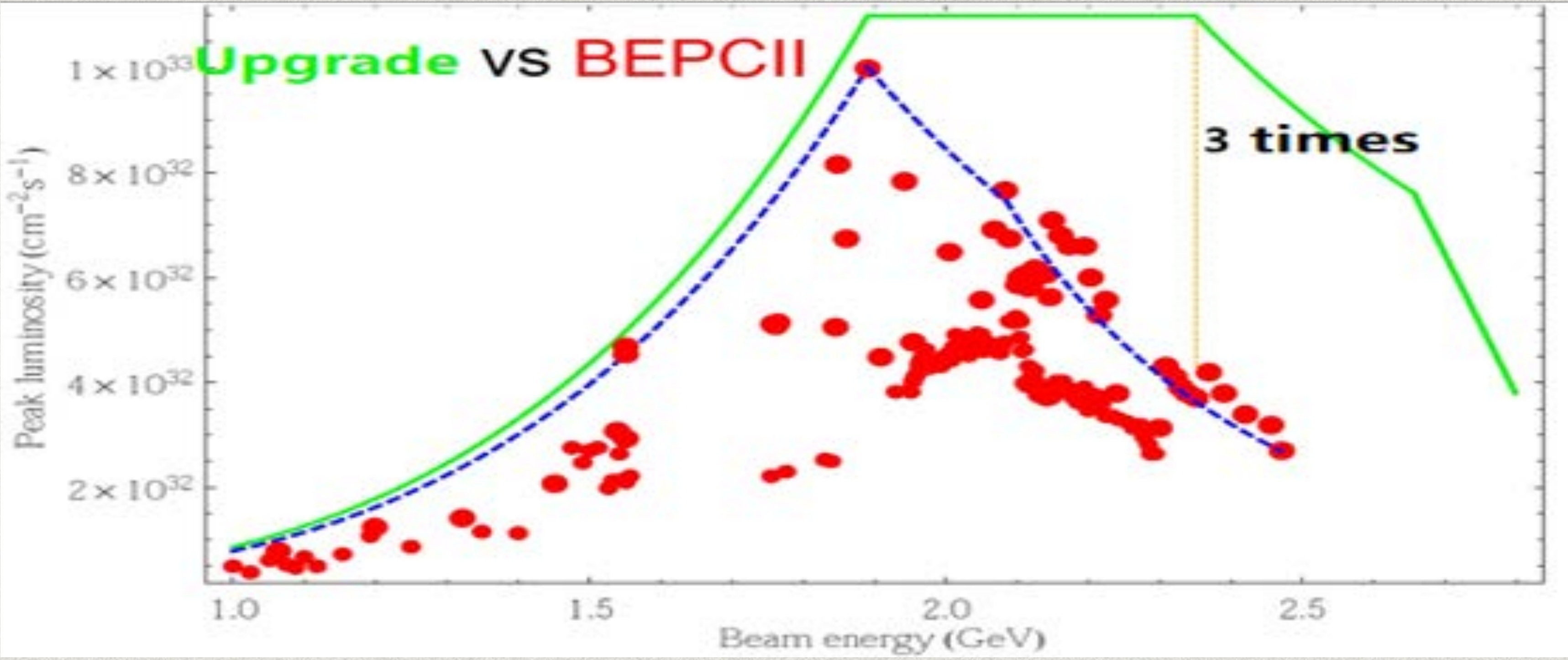
- Upgrade of the C.M. energy to 4.95 GeV, then up tp 5.6 GeV
- Measurements of the cross sections near threshold to provide insight of the vacuum productions of $c\overline{c}$ and $s\overline{s}$ pairs
- Study the EM structure of charmed baryons
- Studies of the absolute BFs of Σ_c and Ξ_c

Competitive with BELLE2

more at arXiv:1912.05983v3

The BESIII upgrade program: machine



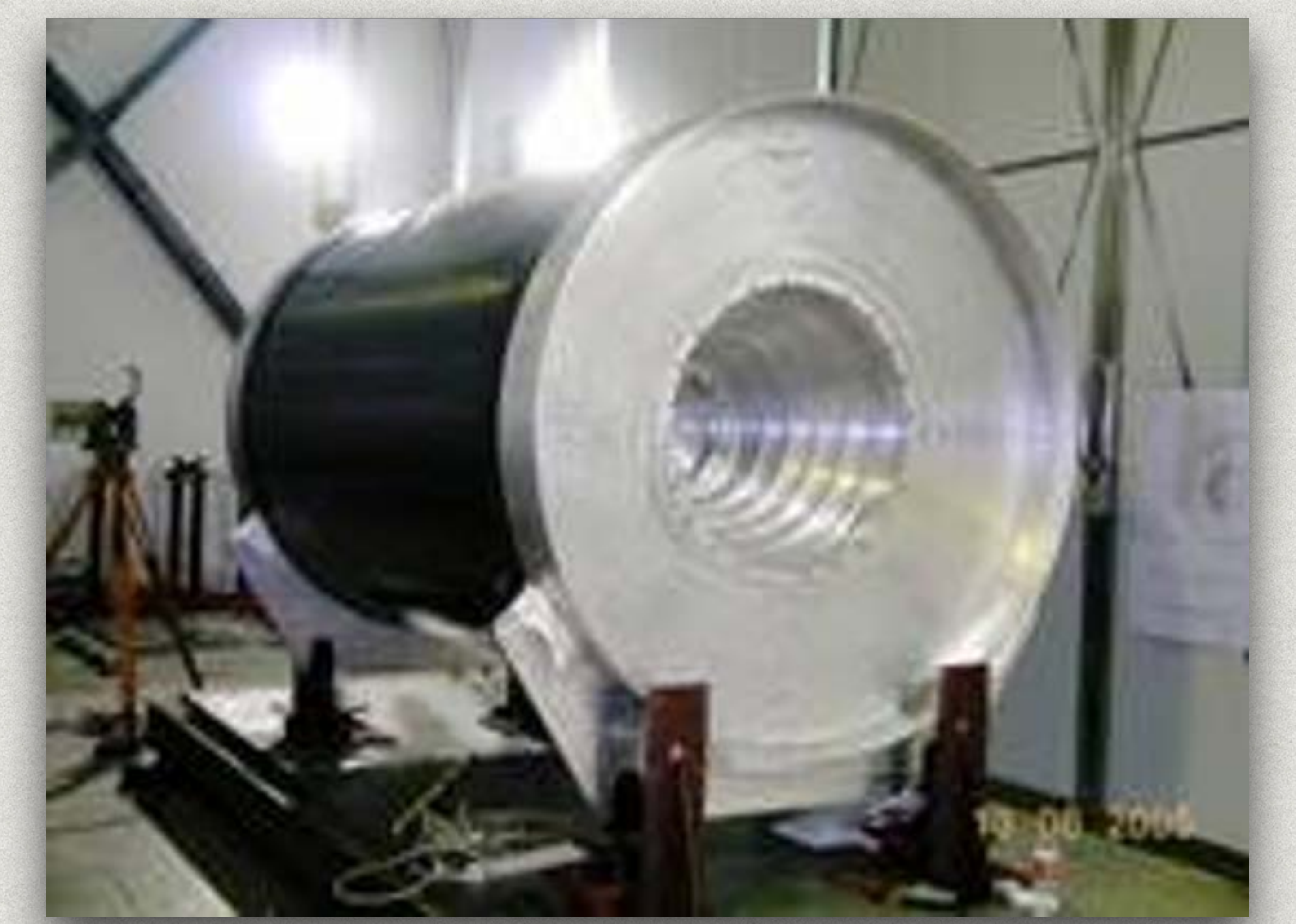


- BEPCII upgrade aims at increasing luminosity by a factor of 3 & increasing beam energy to 2.8 GeV
- Key technologies: double beam power & optics upgrade & new high gradient of magnets

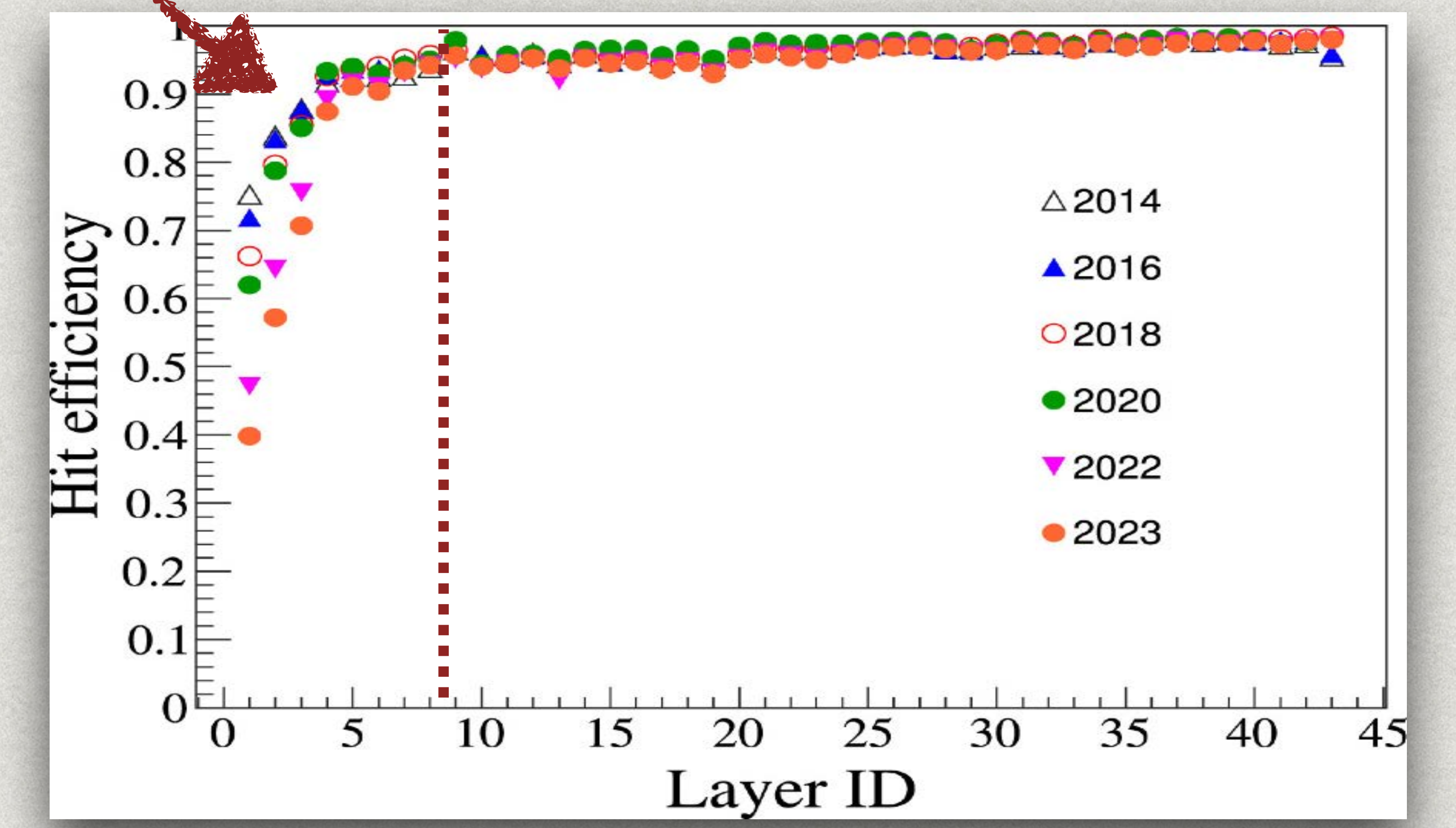
The BESIII upgrade program: detector

- MDC performs tracking, momentum and dE/dx measurement for charged particle identification

- Inner and Outer MDC are two separate chambers sharing the same gas volume



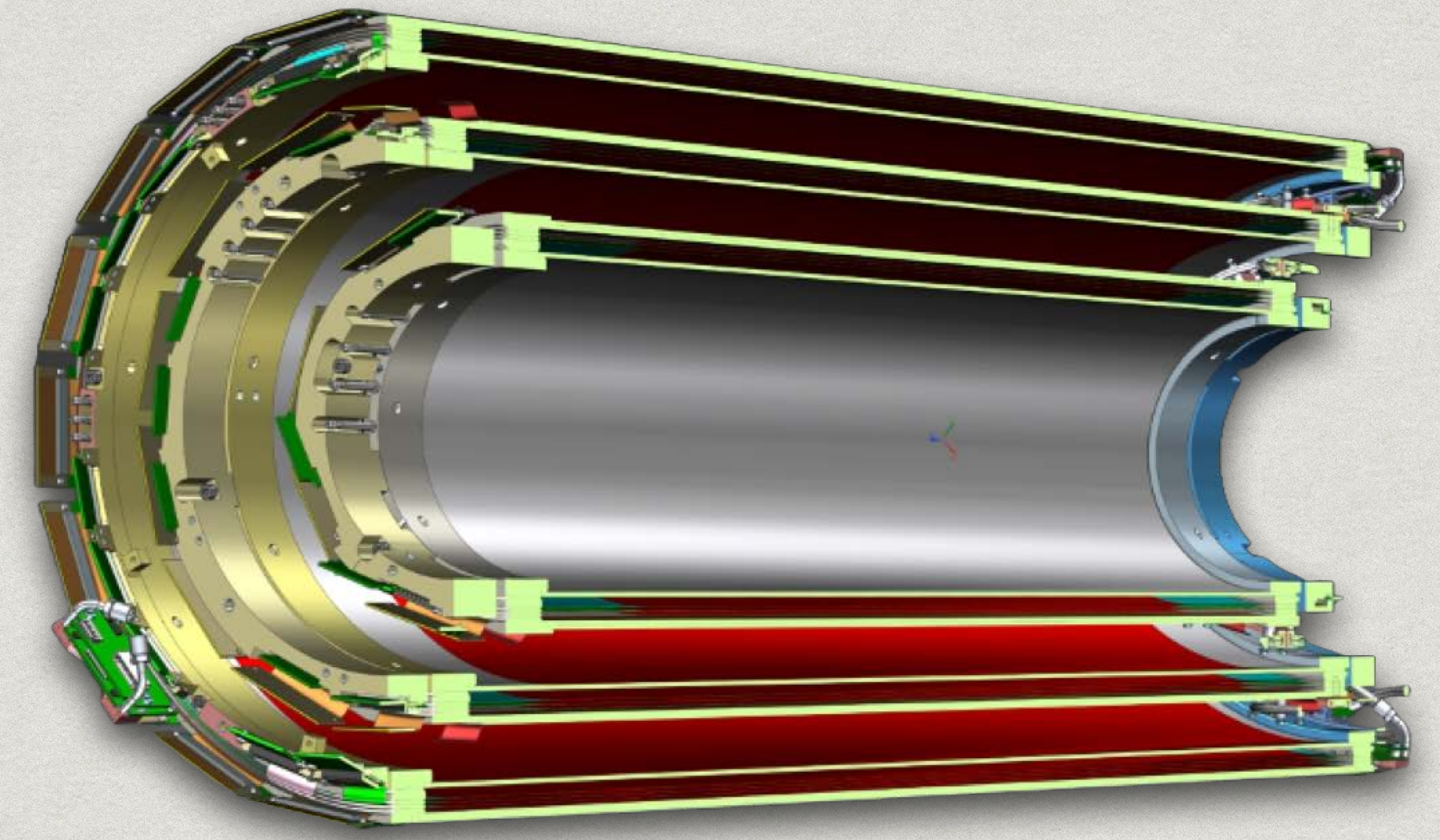
Inner Tracker



- The increasing of the luminosity is speeding up the aging of the Inner Tracker

NIM A Volume 1063, June 2024, 169276

The Cylindrical GEM Inner Tracker

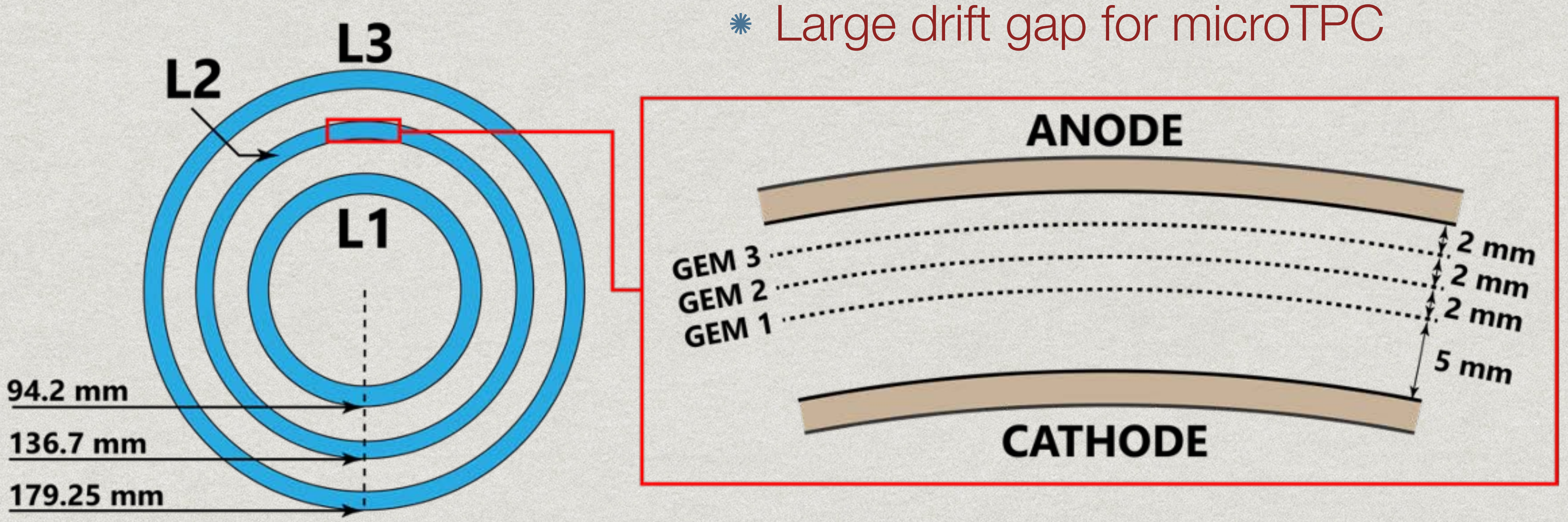


- 3 layers of cylindrical triple-GEM detectors to replace the inner MDC
- Improve rate capability, aging and secondary vertex reconstruction
- While retaining the current momentum and tracking performance ($\sigma_p/p \sim 0.5\,\%$ @ 1 GeV)
- Main System Requirements
  - Angular coverage: 93%
  - Low material budget (~0.5% of X_0 per layer —> 1.5% of X_0 in total)
  - High azimuthal spatial resolution —> 130-150 μm with charge and time readout
  - Substantial improvements in rad hard and secondary vertex reconstruction (~300 μm in z)

Detector design

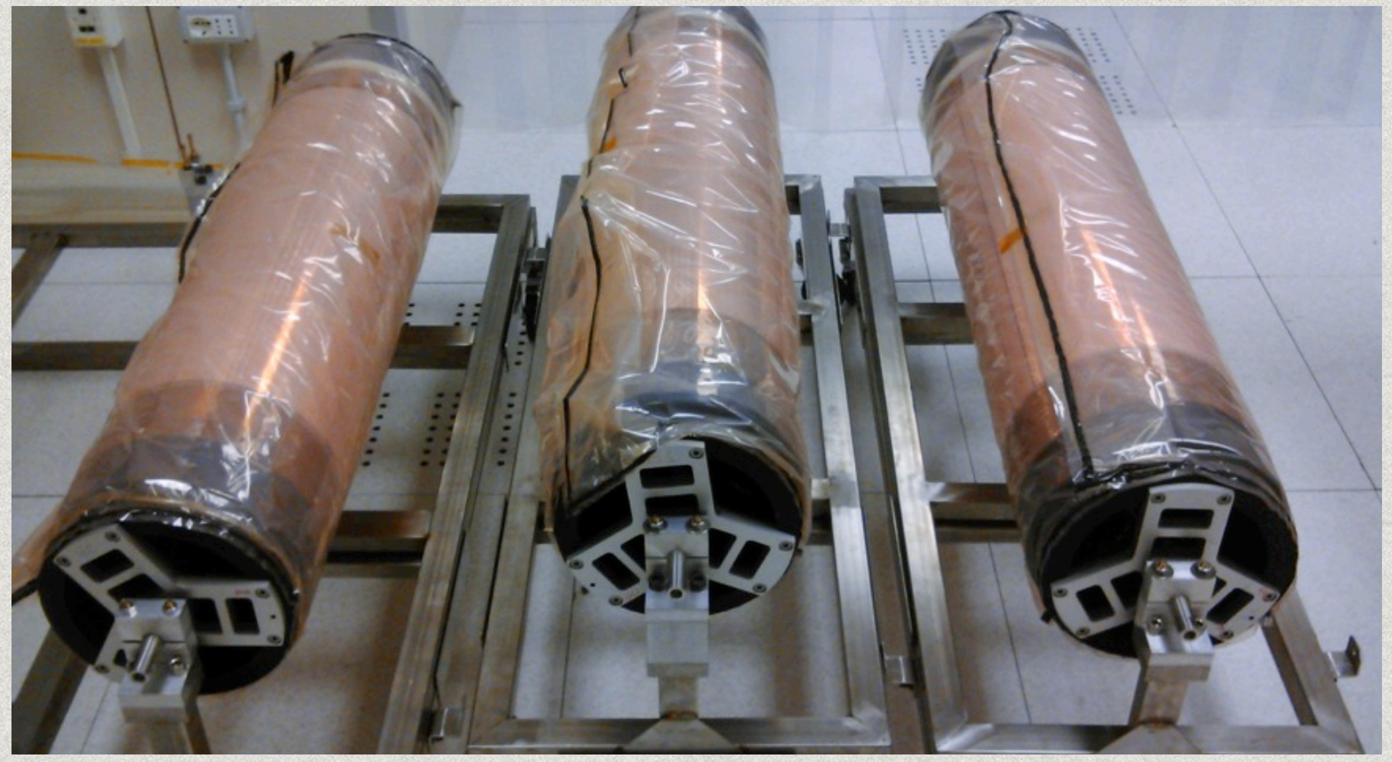
- Anode strip pitch 650 micron
- Gas mixture: Ar/Isobutane 90/10
- Large drift gap for microTPC

Designed to provide mechanical robustness with relatively low material budget

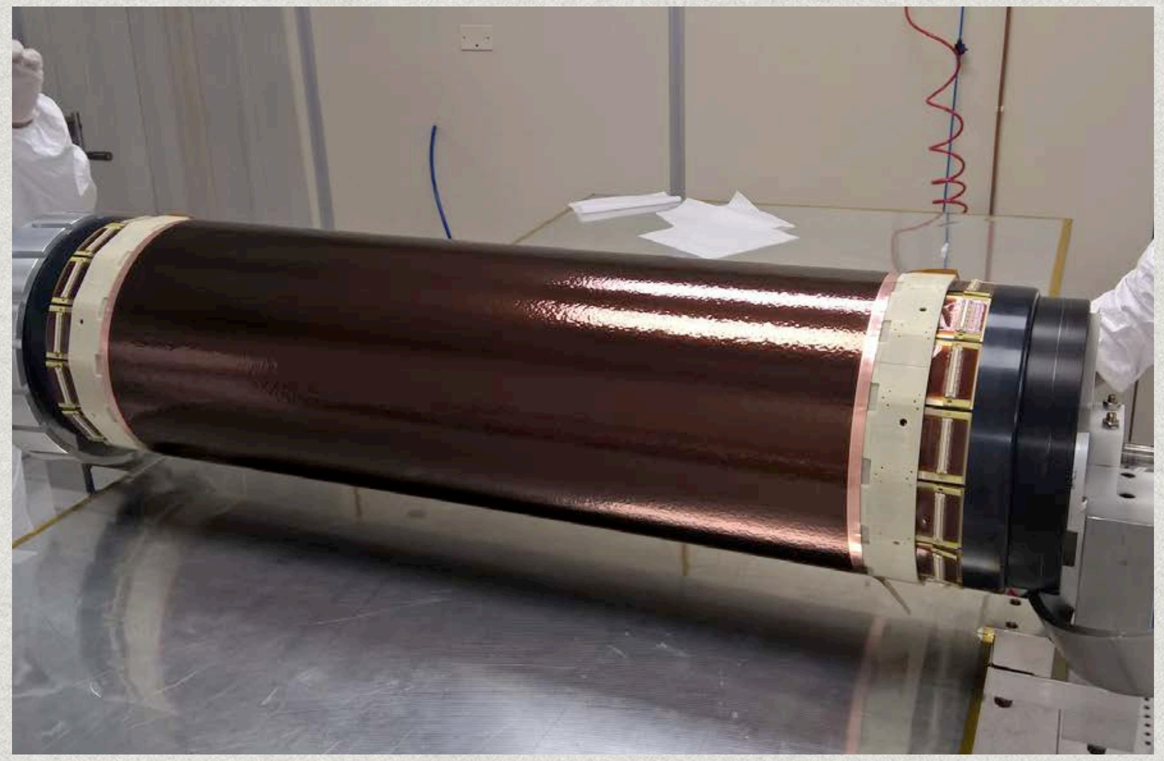


Cathode

3 GEMs



Anode



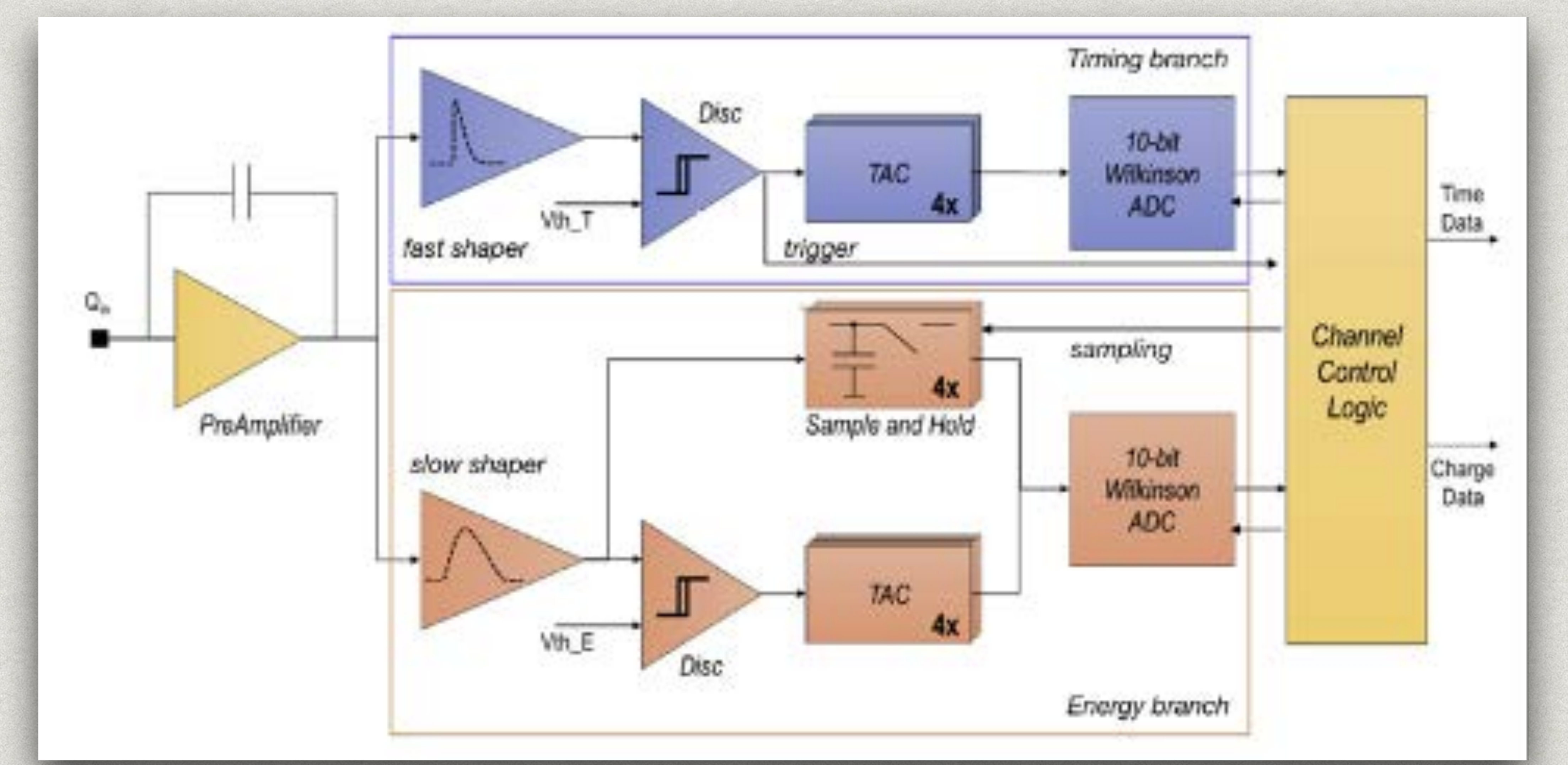
Space and time resolutions defined by optimization of the mechanical design, electronics and operating parameters

more at https://www.mdpi.com/2073-8994/14/5/905

Electronics design

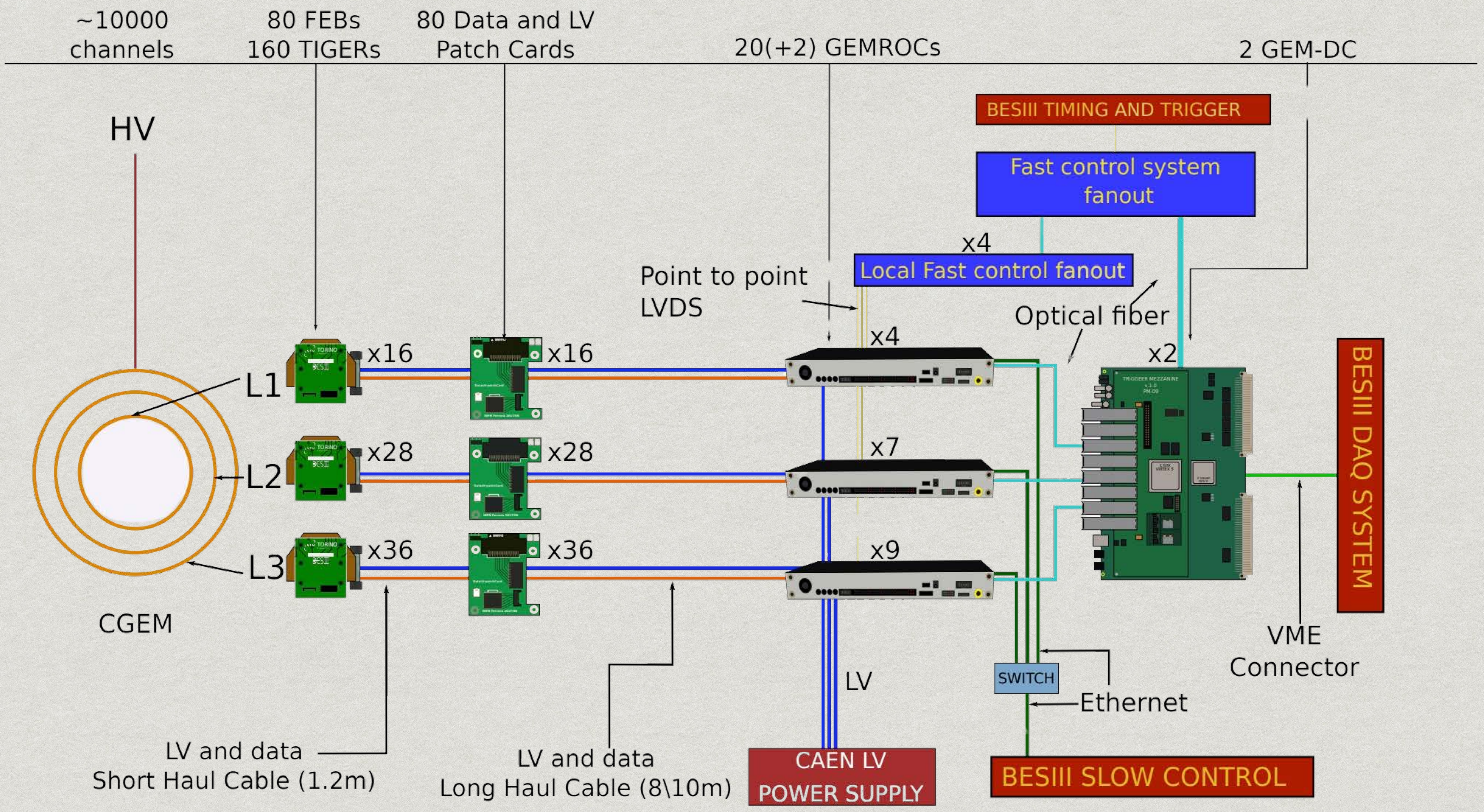
more at JINST 16 P08065

- 64 channels, up to 60 kHz/ch rates
- ENC noise below 2000 e^- rms for strip capacitance < 100pF   Max. strip C ~300 pF
- Analog charge measurement up to 50 fC
- Possibility to extend the dynamic range with Time-over-Threshold
- T and Q branch of every channel
- 12 mW/ch power
- SEU tolerant digital part



Tested also on microRWELL

CGEM-IT system implementation



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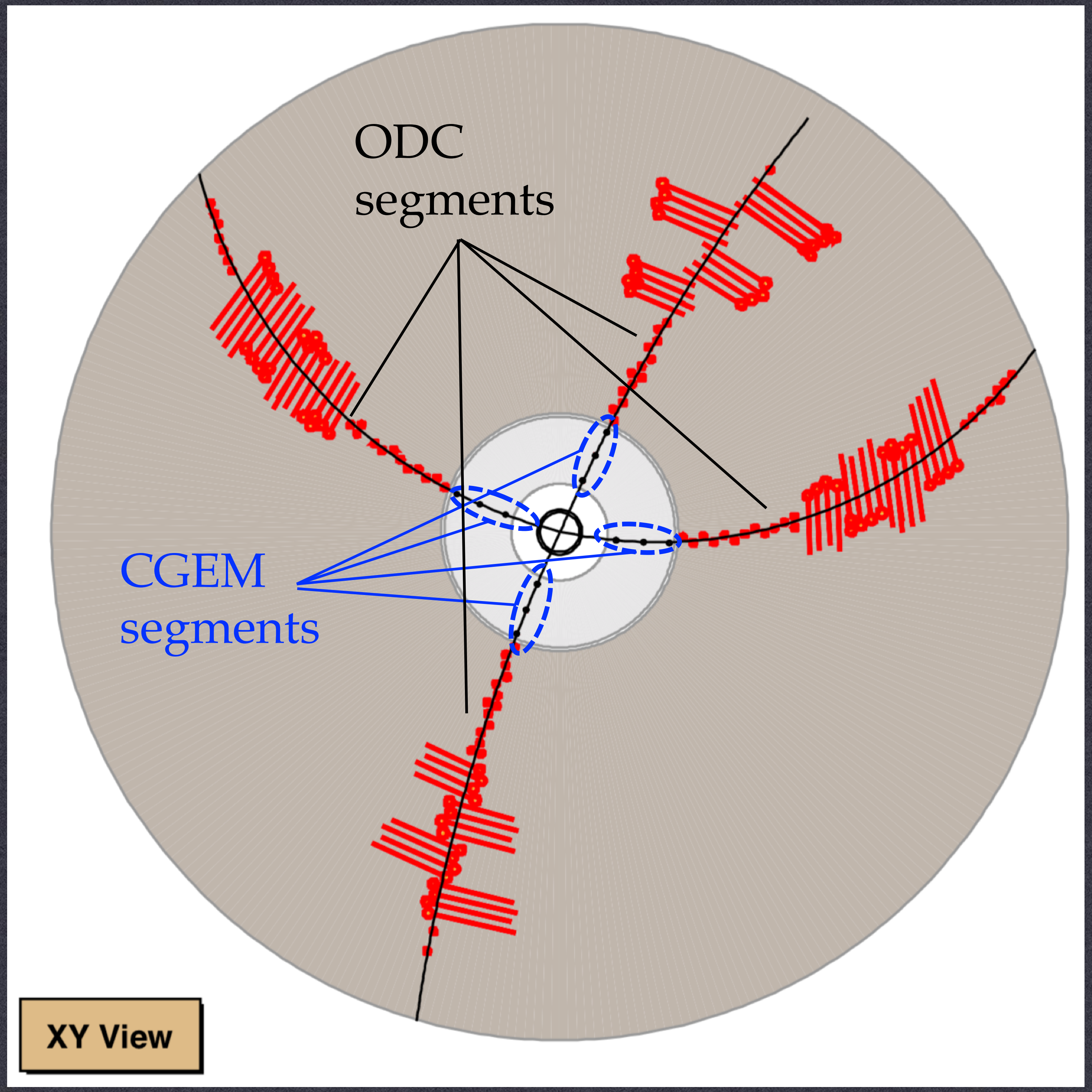
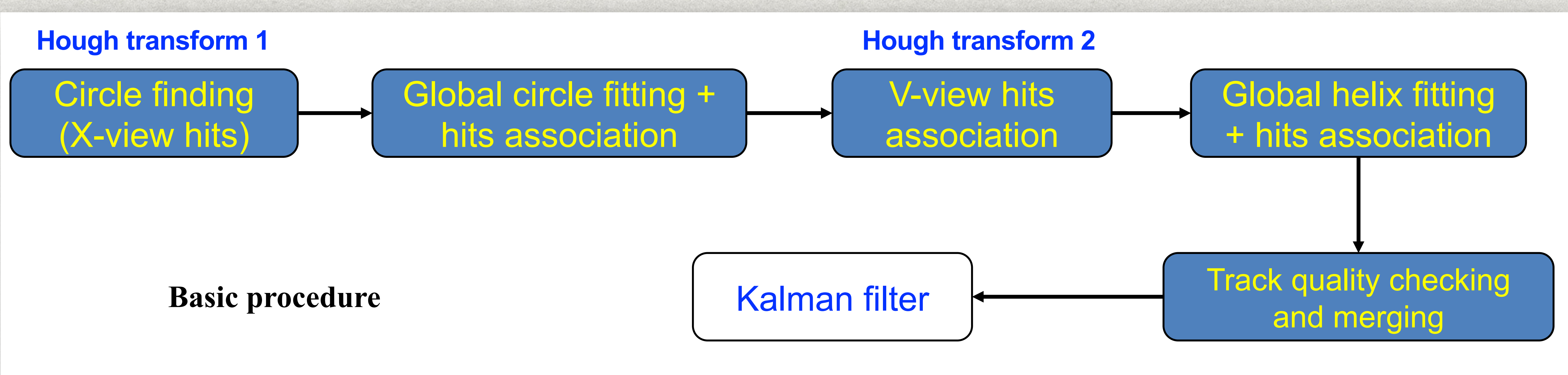
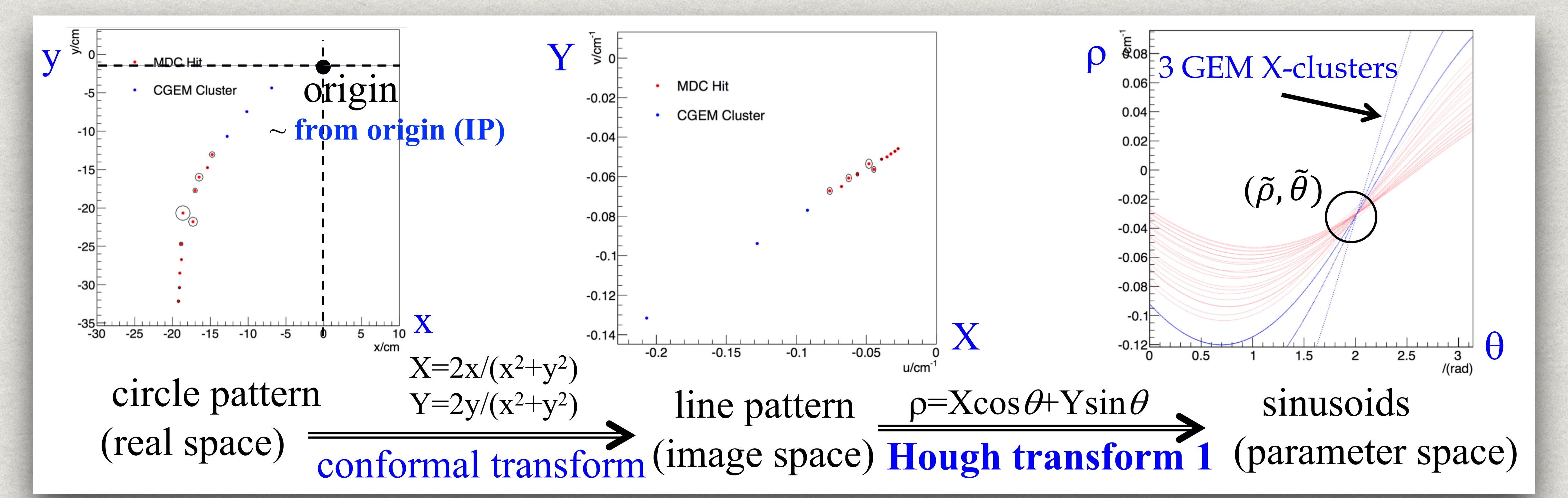
SIMULATION STUDIES AND EXPECTED PERFORMANCE



Track finding

- Global method with Hough Transform
- The procedure includes two steps:
  - Circle finding
  - V-view hits association
- Both steps use Hough transform to get track candidates and initial track parameters
- A global fitting with Least-Square method is done after each step

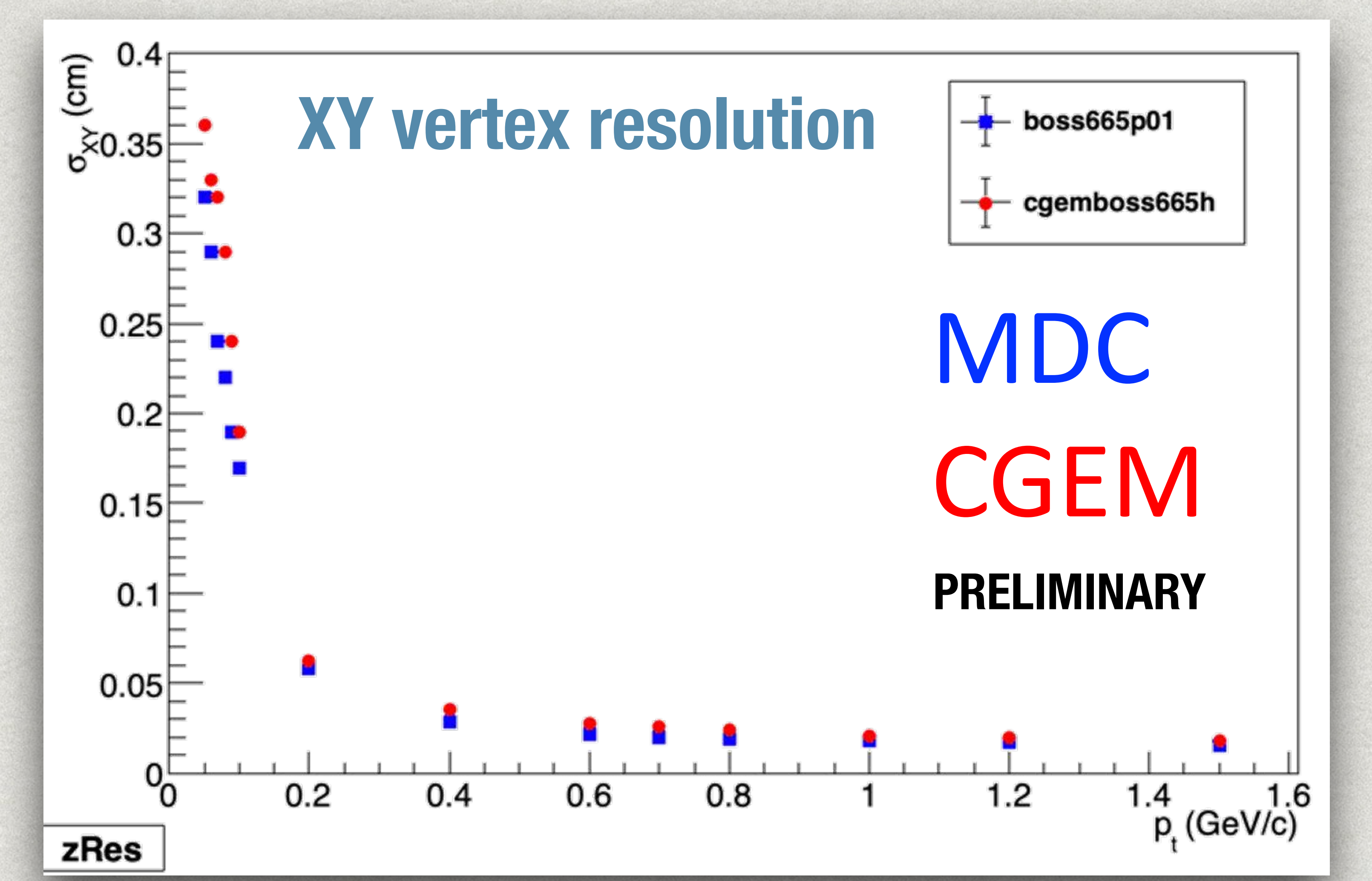


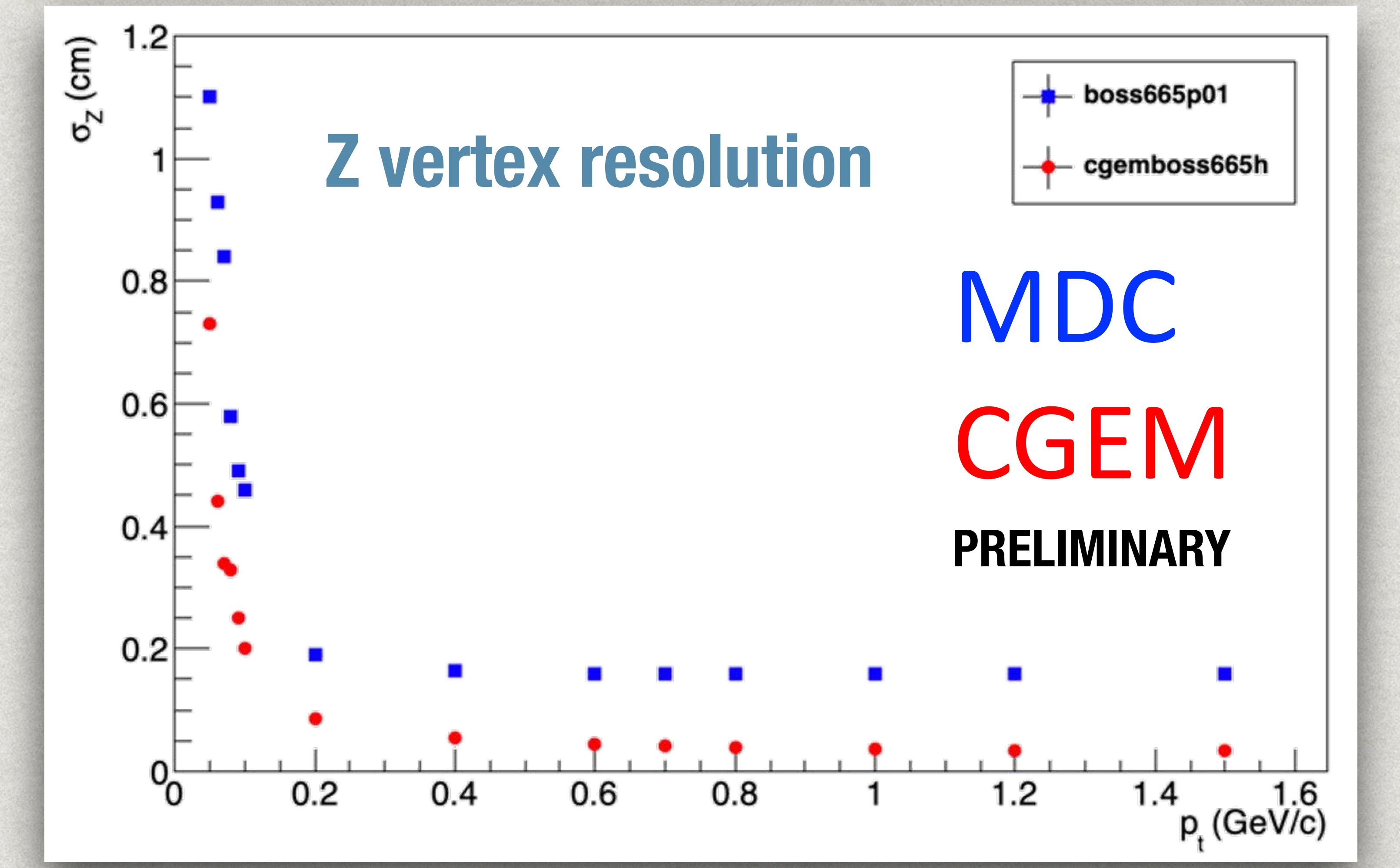


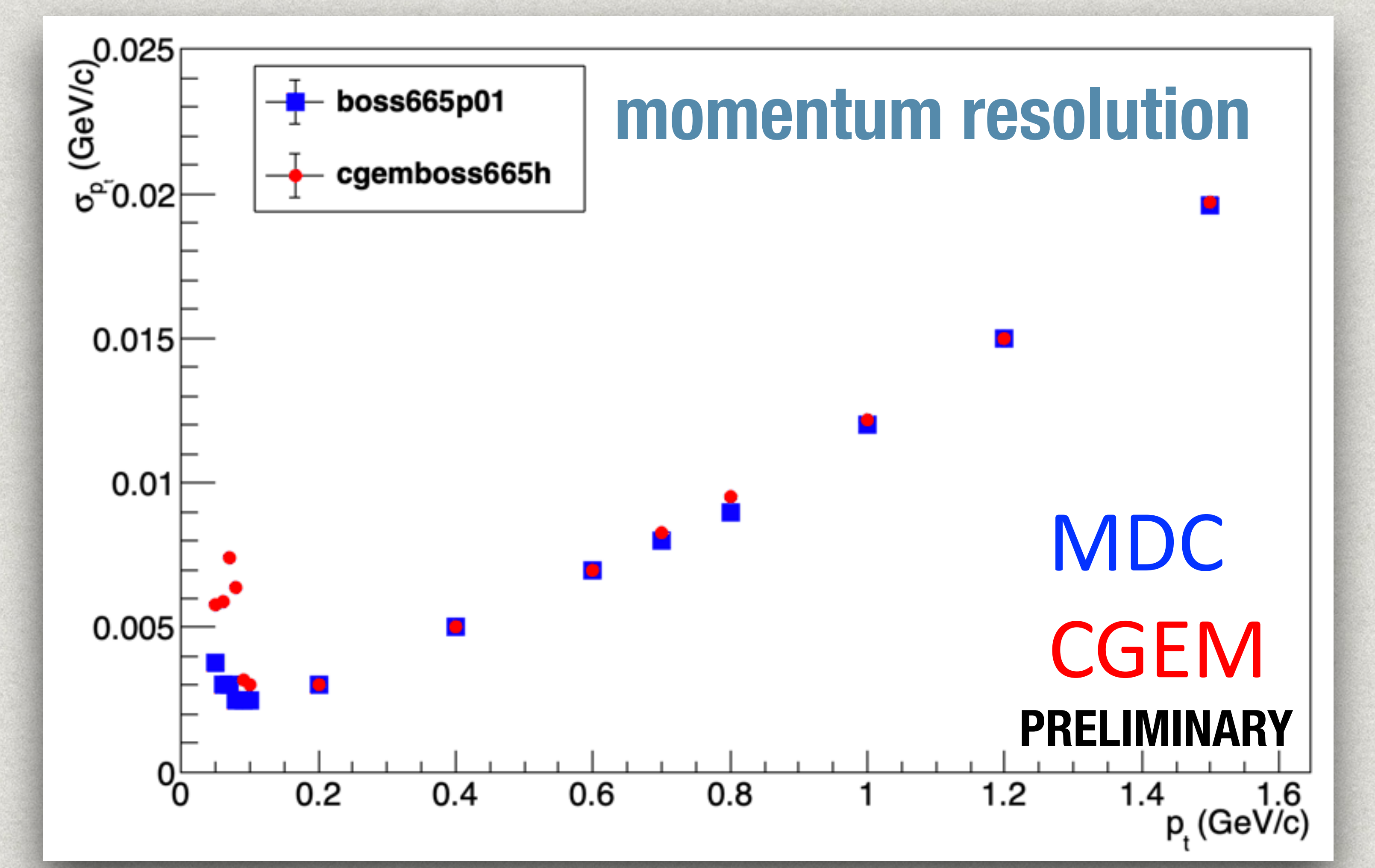
X-view hits: DC axial wire hits and CGEM X-clusters

V-view hits : DC stereo wire hits and CGEM V-clusters

Expected performance

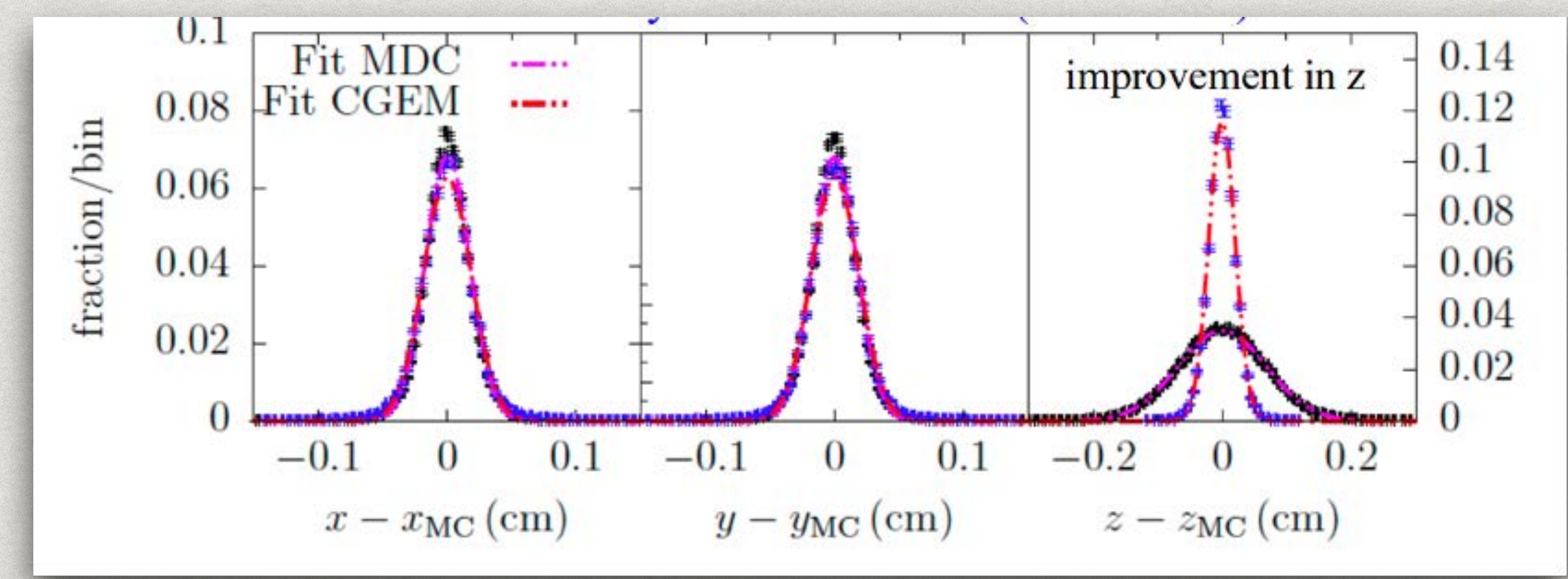






- No difference between different multiplicities
- CGEM XY resolutions slightly worse at low pt
- CGEM Z resolution much better
- Momentum resolution worse only at very low pt

Impact on vertex reconstruction



$\Sigma_c(2455)$ DECAY MODES

$\Lambda_c^+ \pi$ is the only strong decay allowed to a Σ_c having this mass.

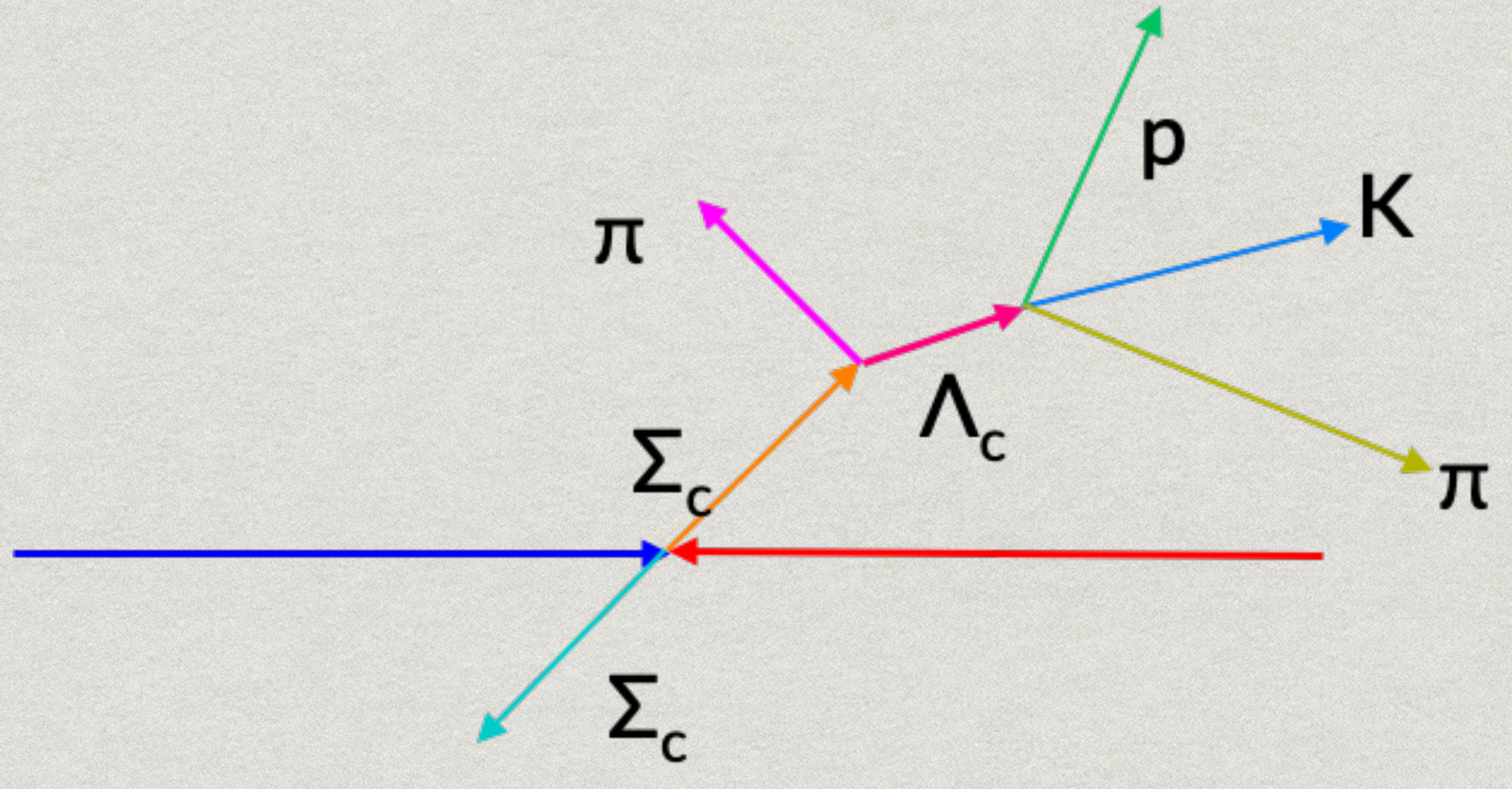
	Mode	Fraction (Γ_i/Γ)
Γ_1	$\Lambda_c^+ \pi$	$\approx$ 100 %

Ω_c^0 DECAY MODES

No absolute branching fractions have been measured. The following are branching *ratios* relative to $\Omega^- \pi^+$.

	Mode	Fraction (Γ_i/Γ)	Confidence level
	Cabibbo-favored ($S = -3$) decays — relative to $\Omega^- \pi^+$		
Γ_1	$\Omega^- \pi^+$	**DEFINED AS 1**	

- Expected impact on vertex reconstruction
- Better separation for complex topologies and improvements on secondary vertexes, both crucial for charmed baryon decays

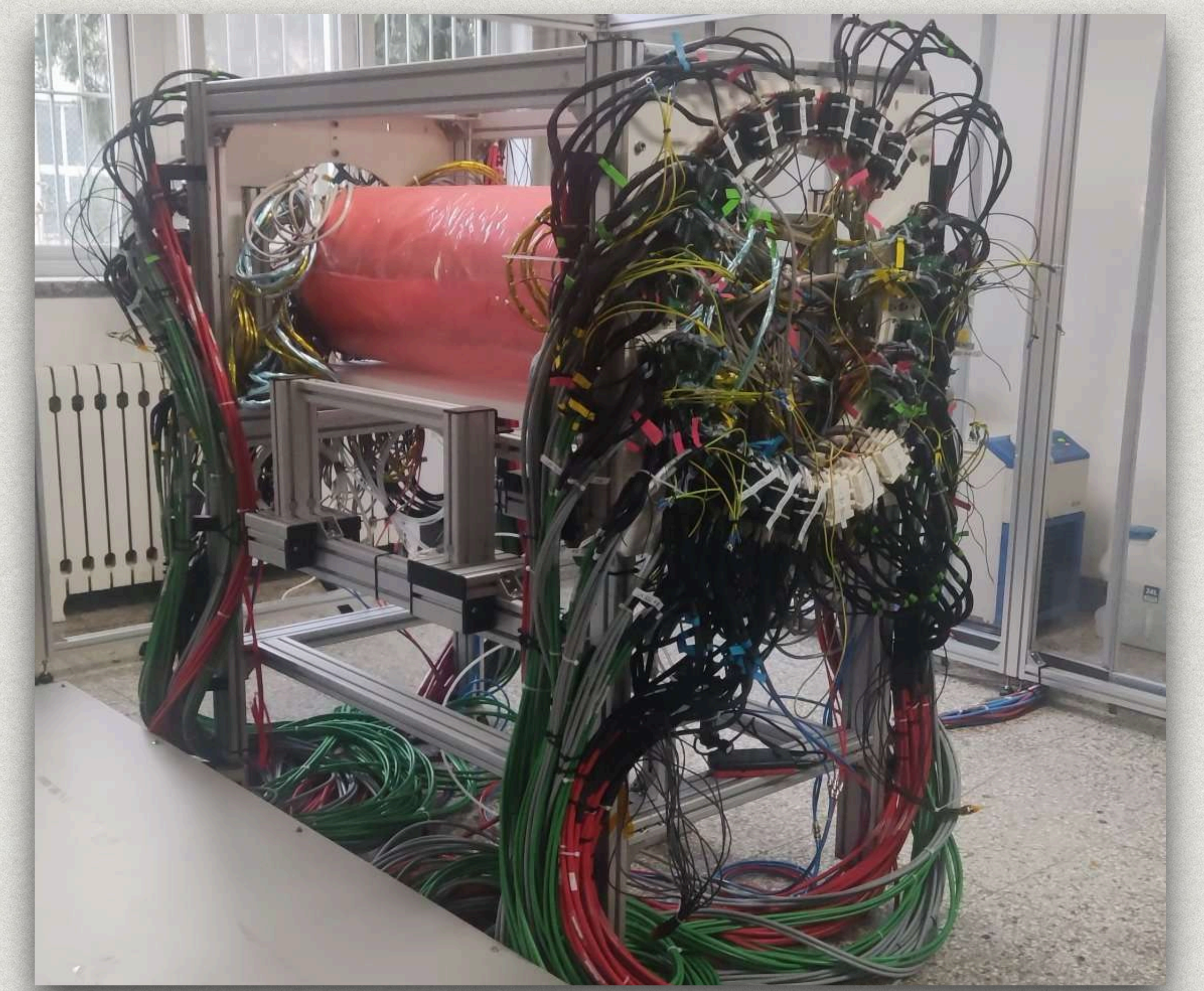


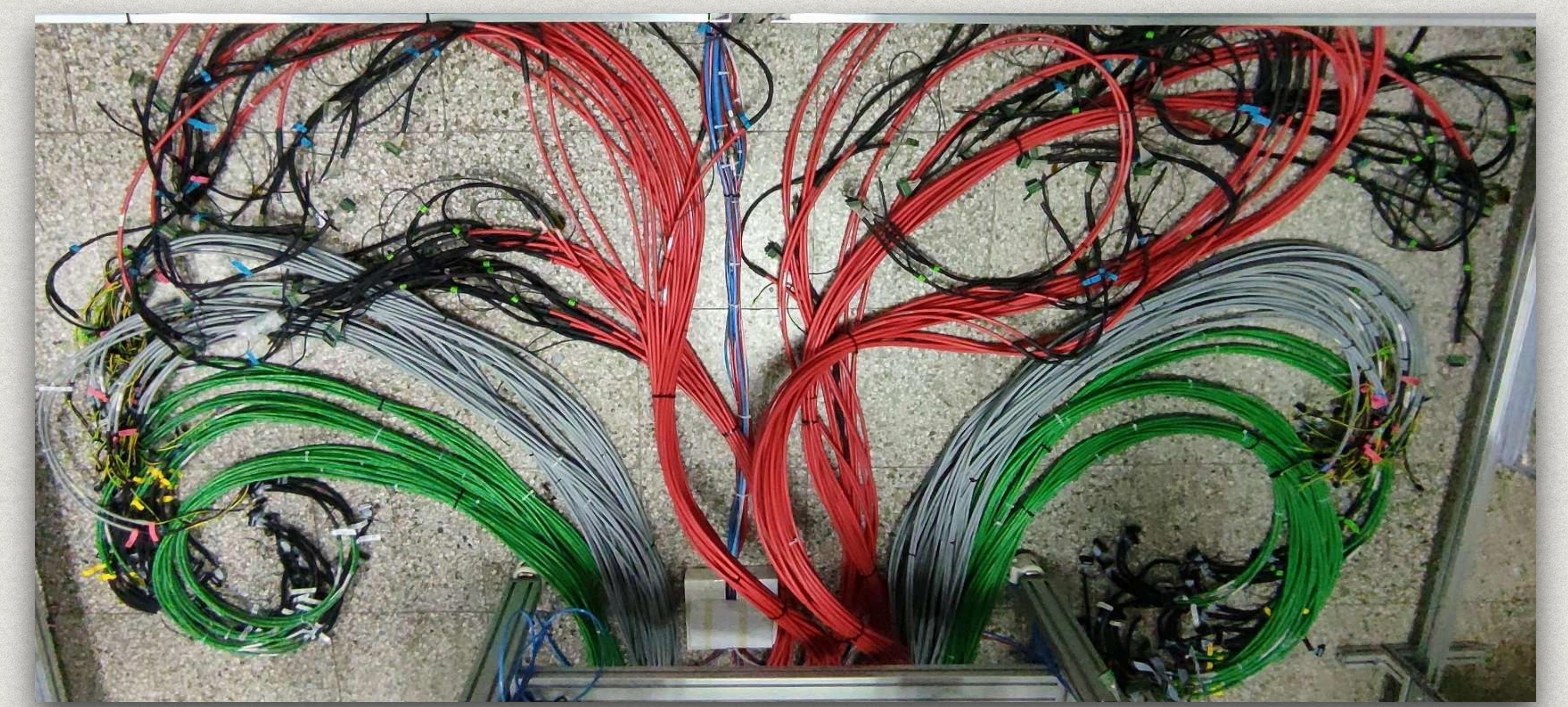
decay topology example

STATUS OF THE PROJECT

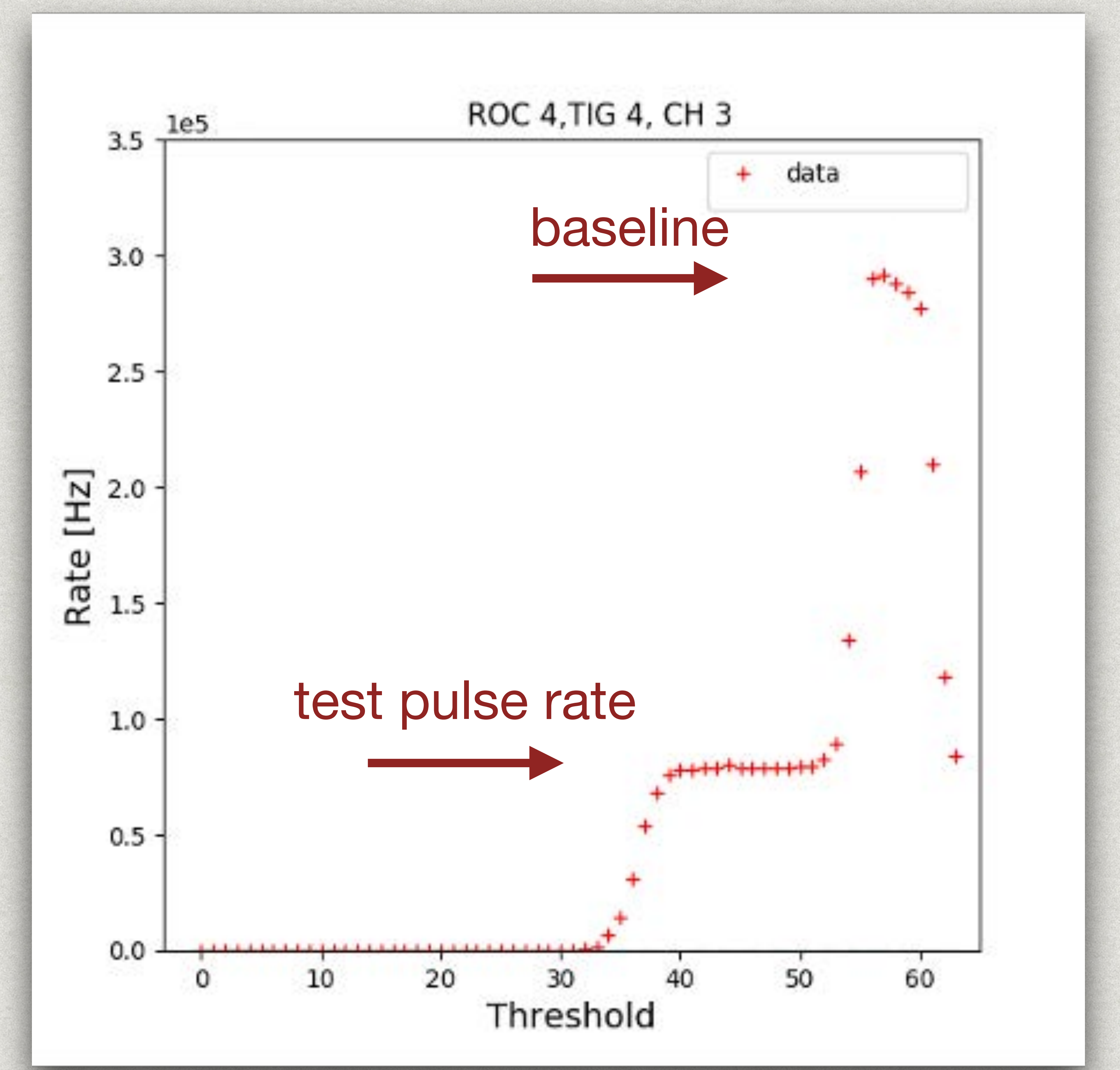
Detector staging

- Standalone commissioning with cosmics before installation
- Continuous running for operations and performance evaluation





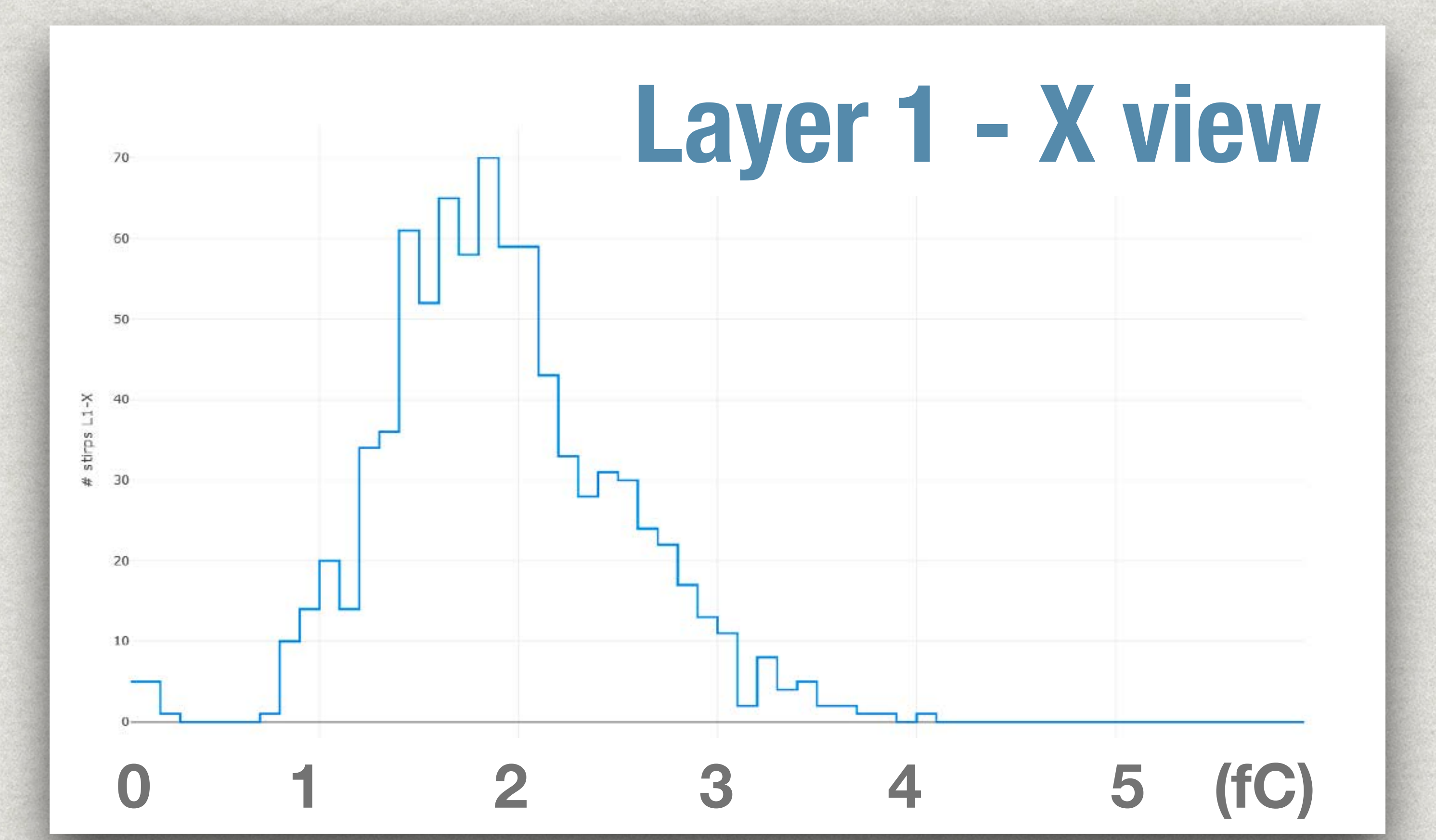
Channel by channel noise calibration

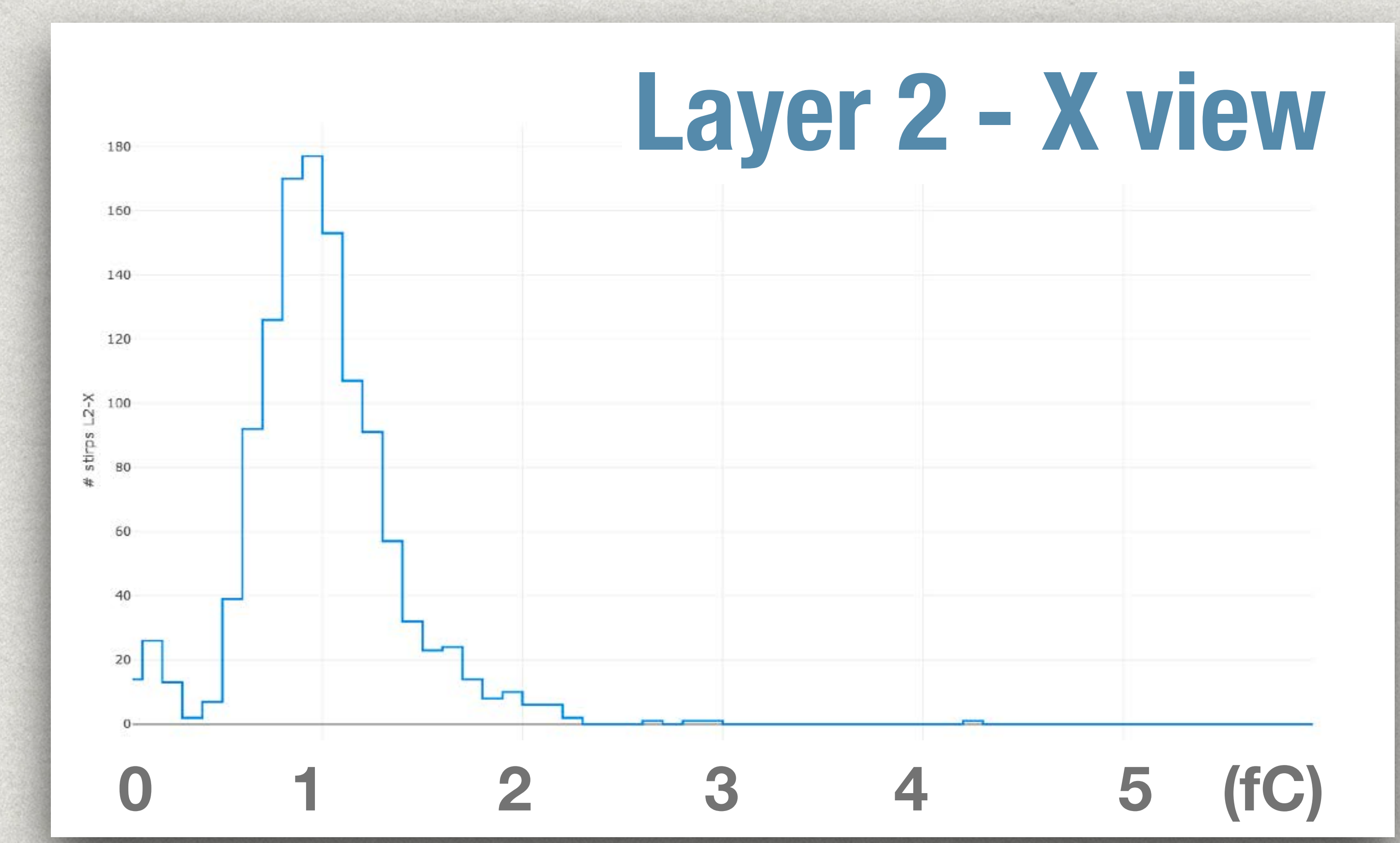


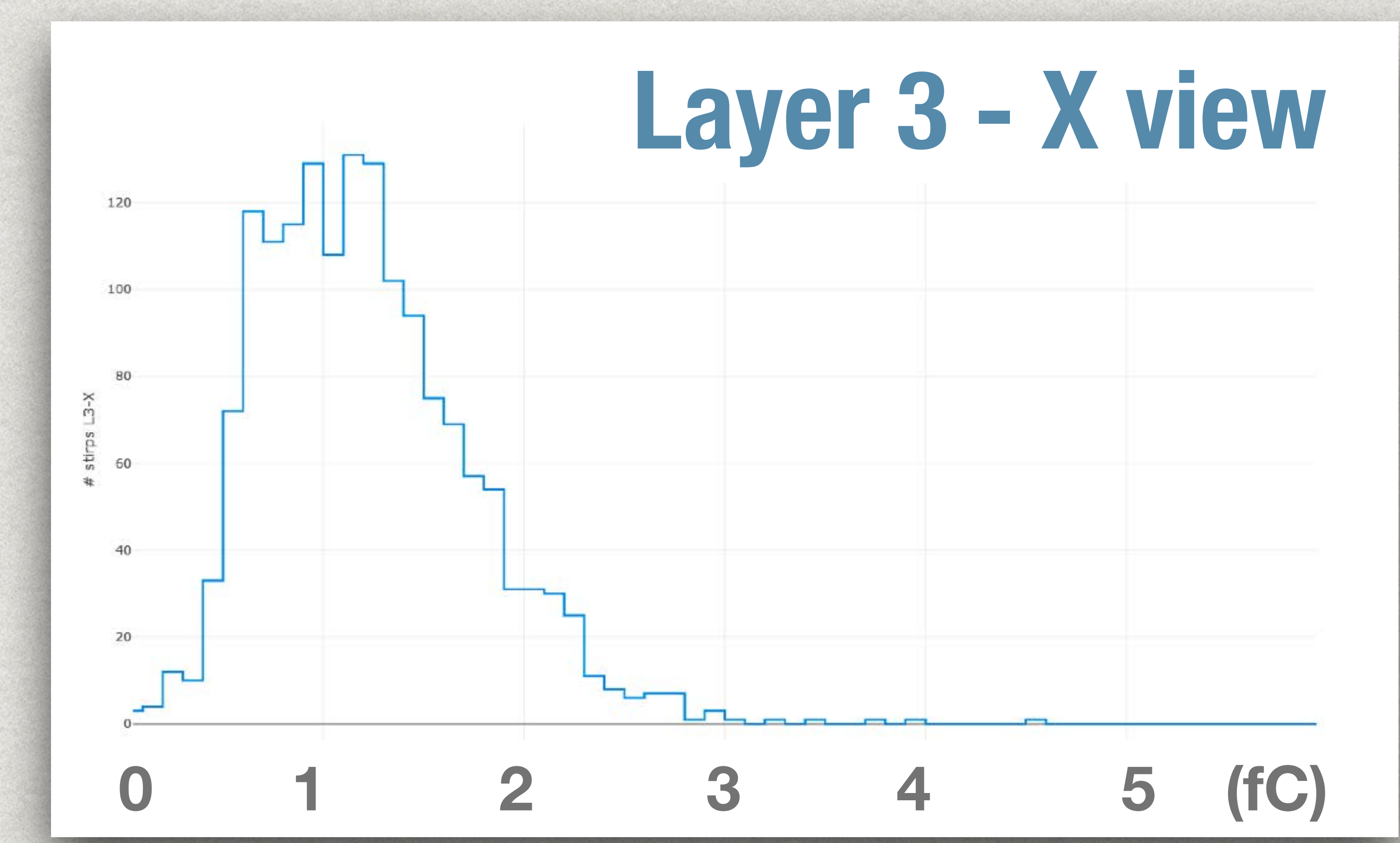
toward lower threshold →

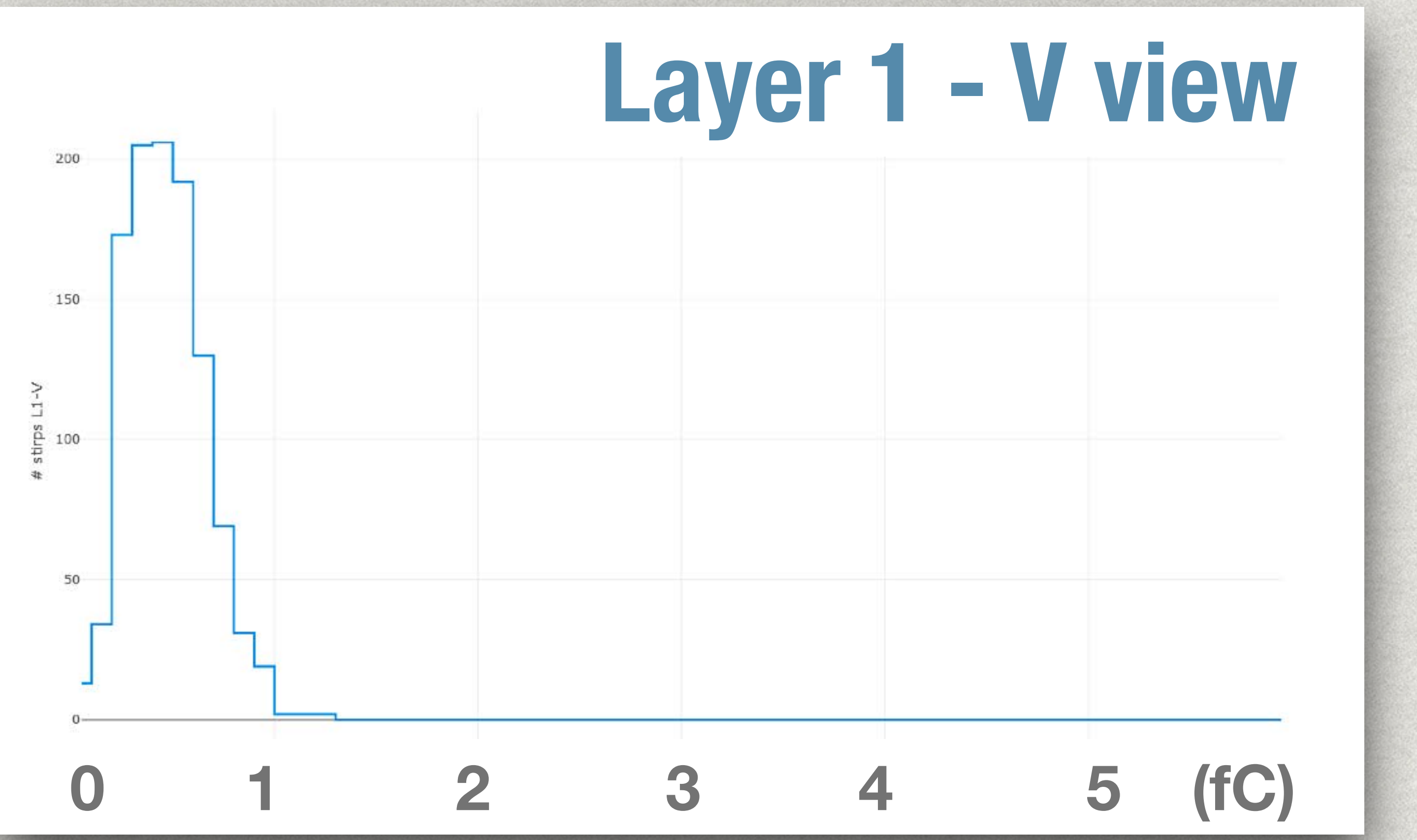
- Inject a fixed number of analog test pulse of known amplitude
- Fit the full shape to extract S-curve (from TP rise) and baseline
- Used to set the thresholds on both T and E channels

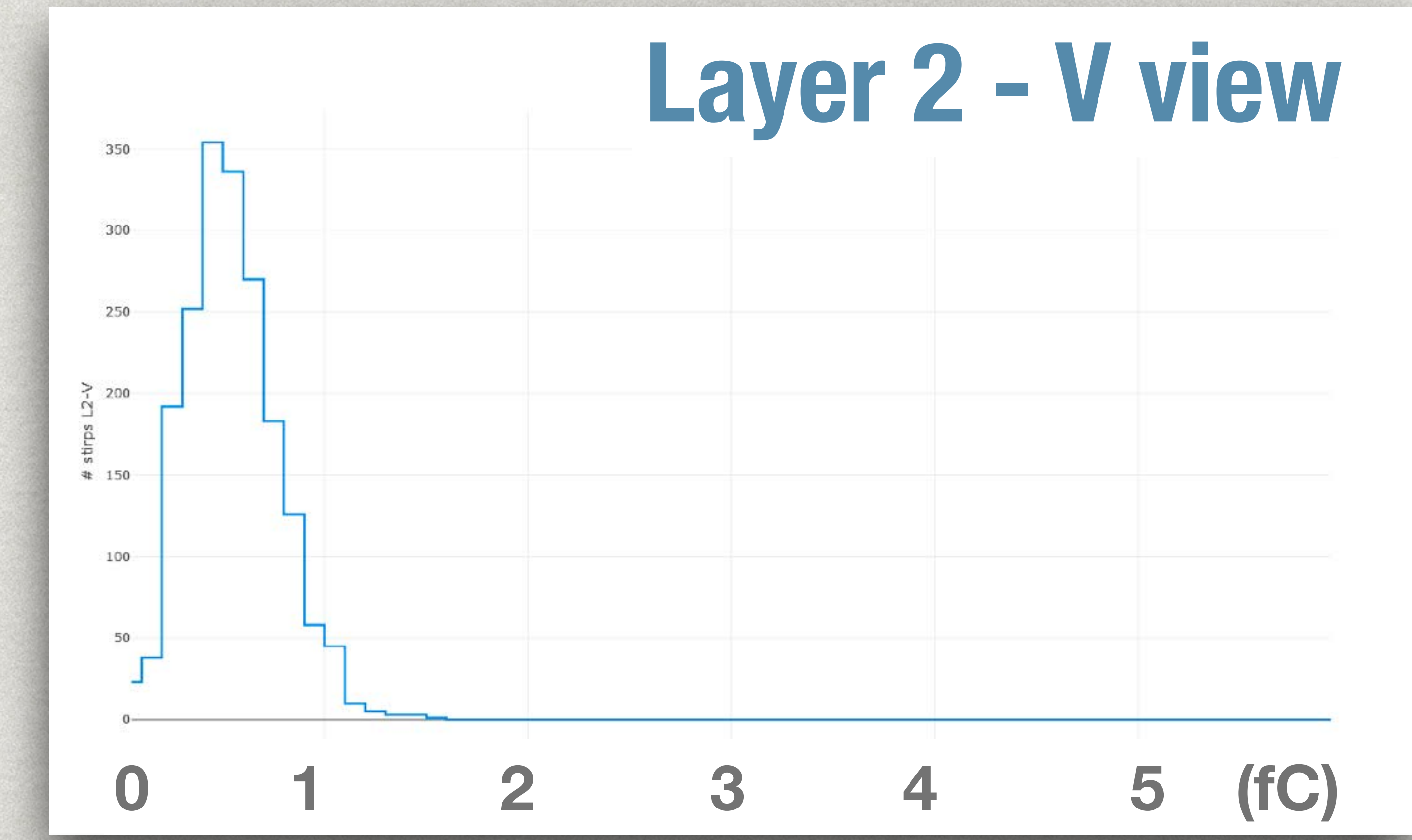
Noise distributions

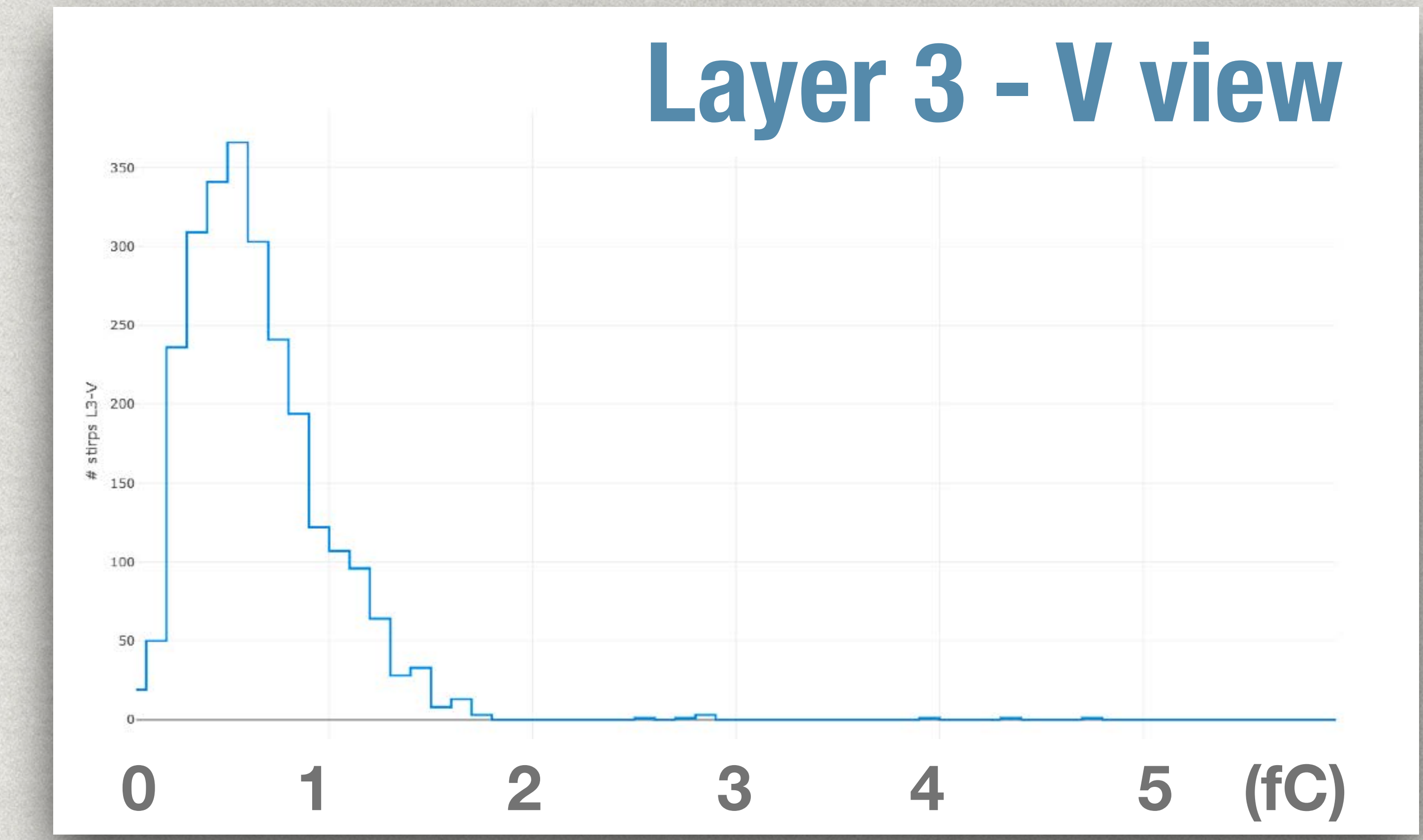






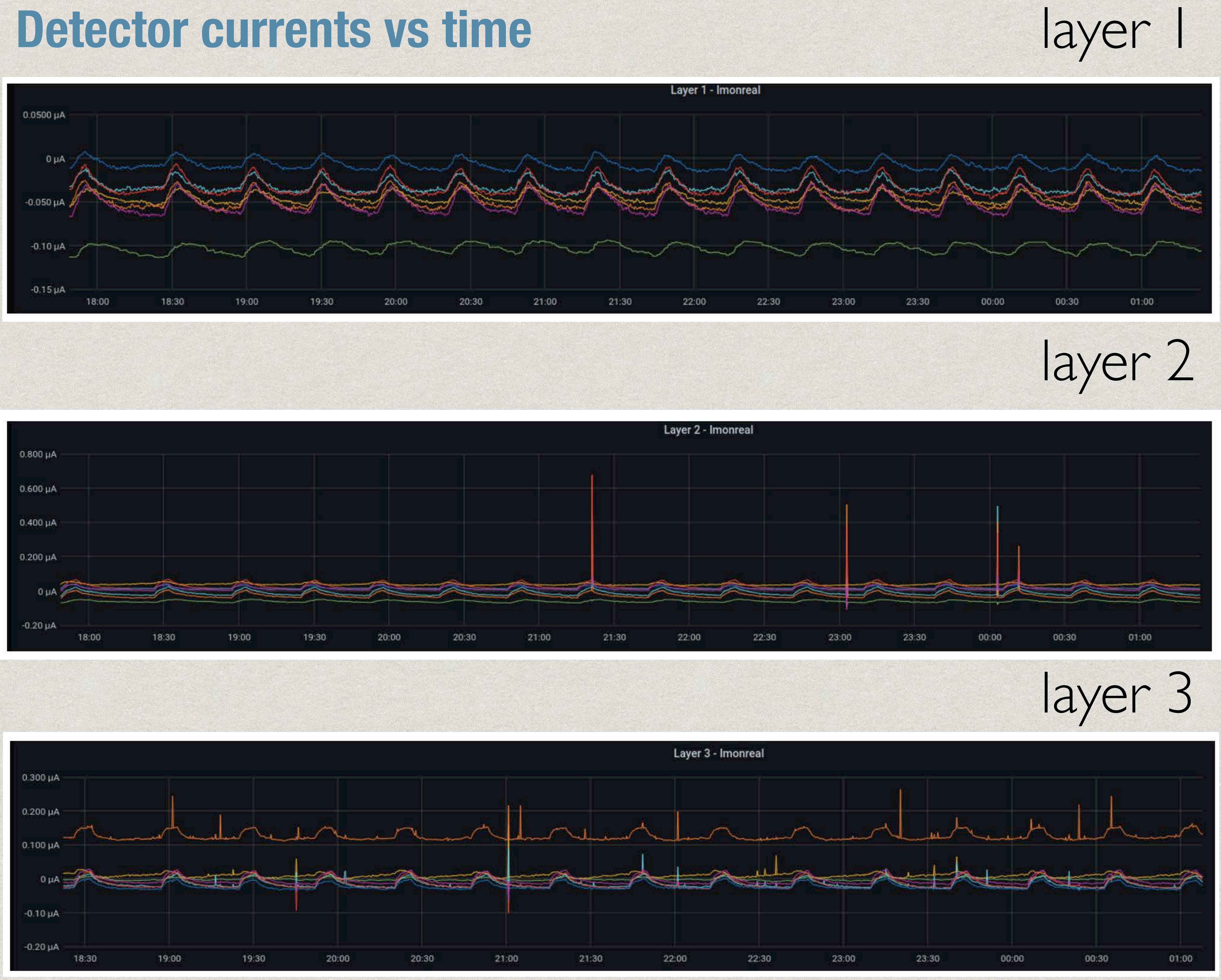




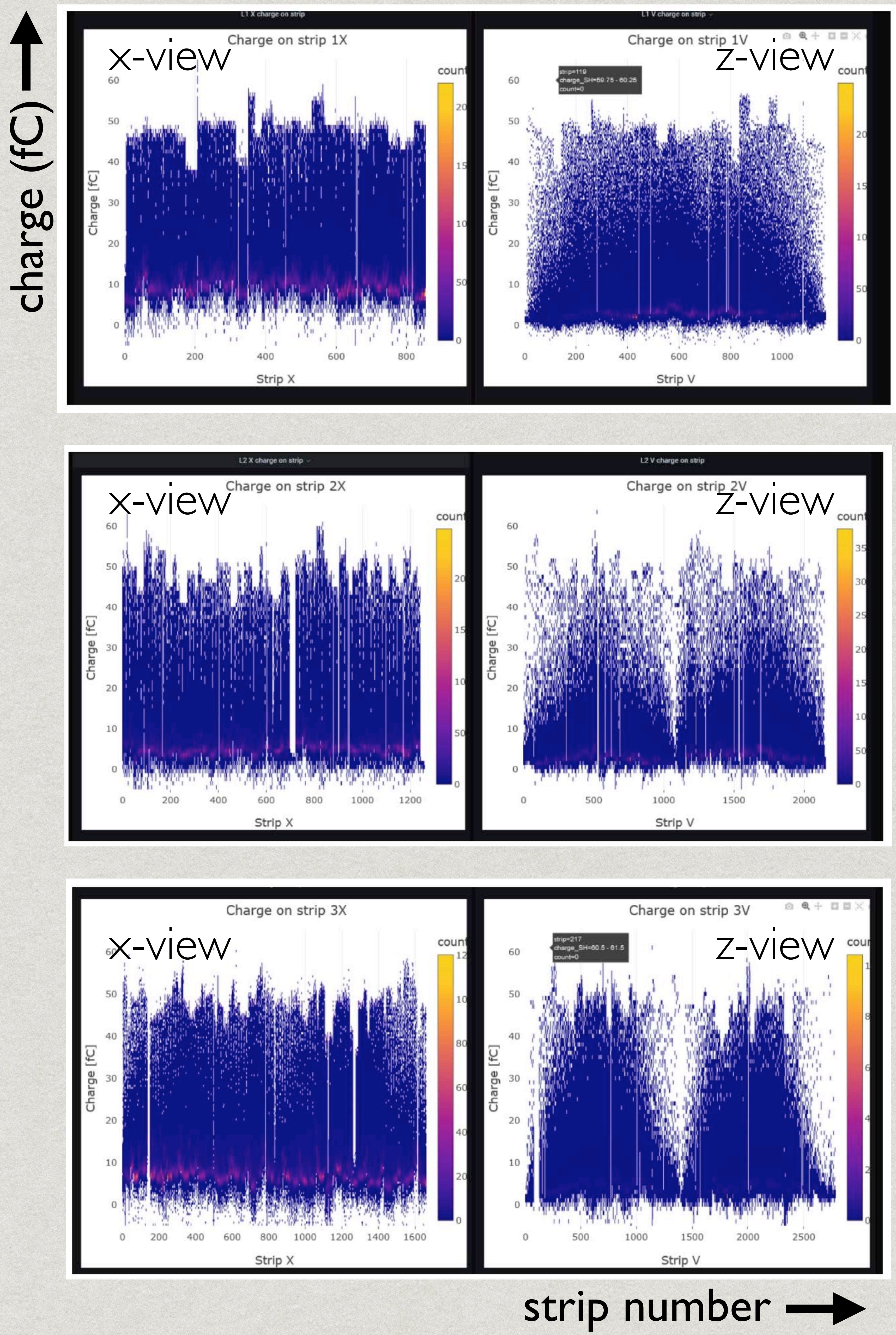


Detector operations

Detector currents vs time

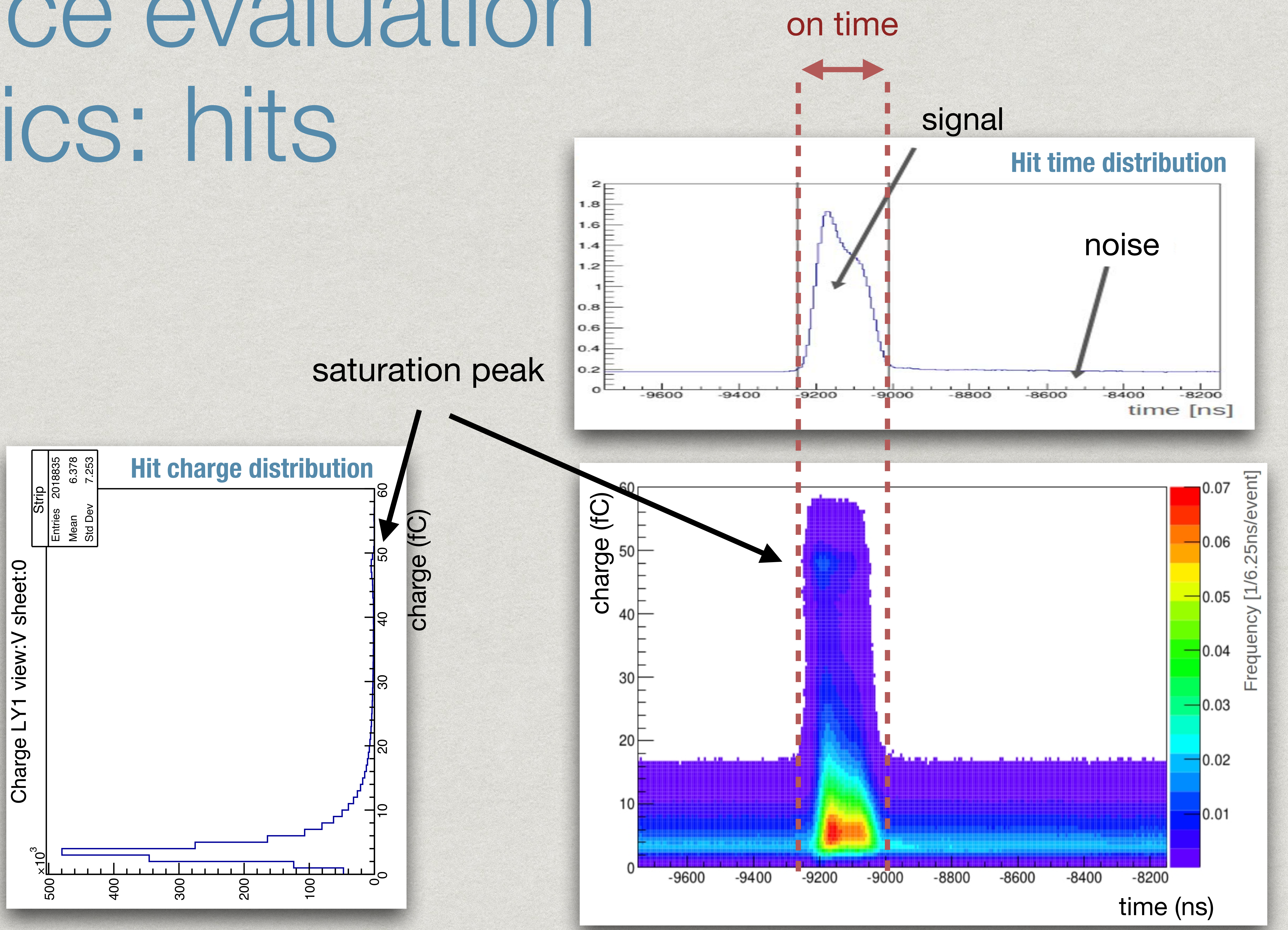


Charge per strip distribution

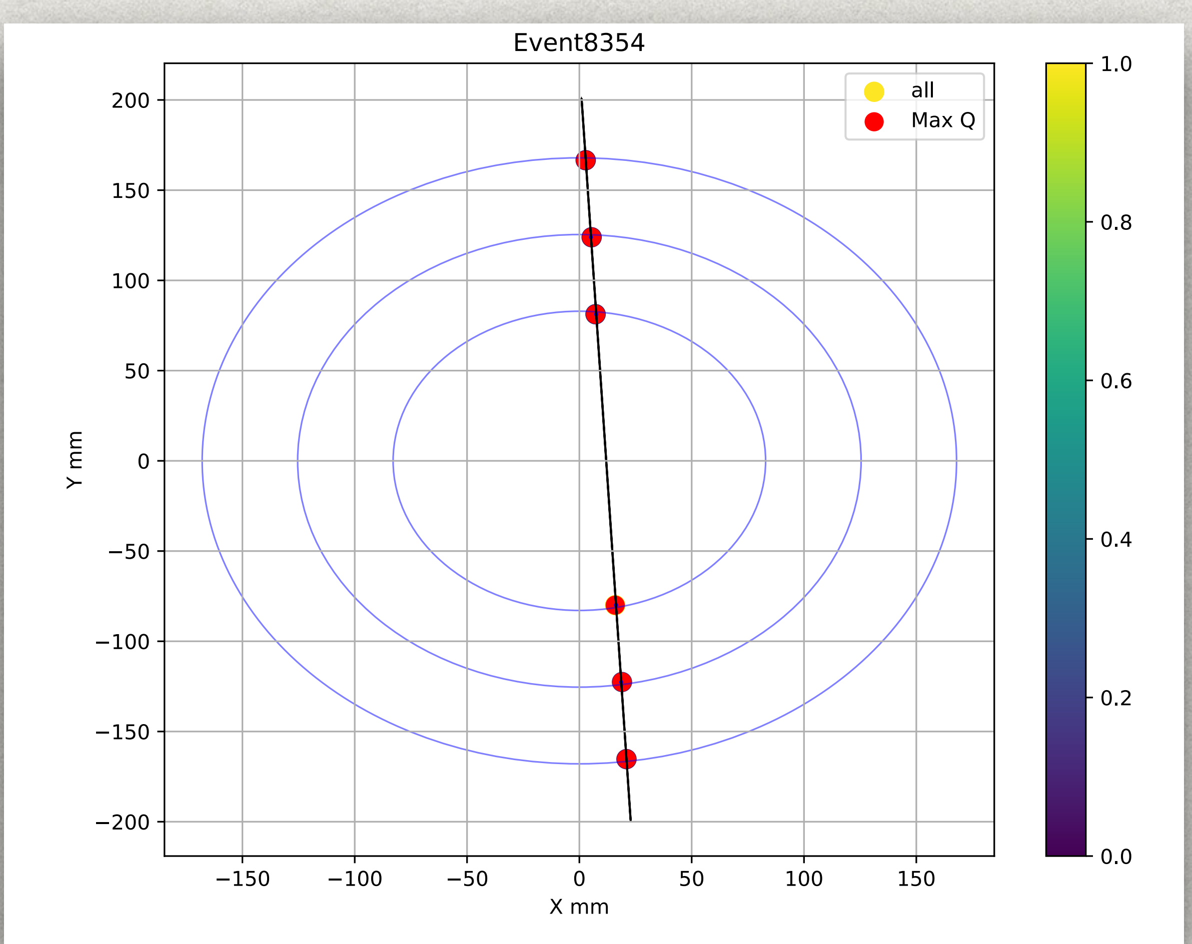


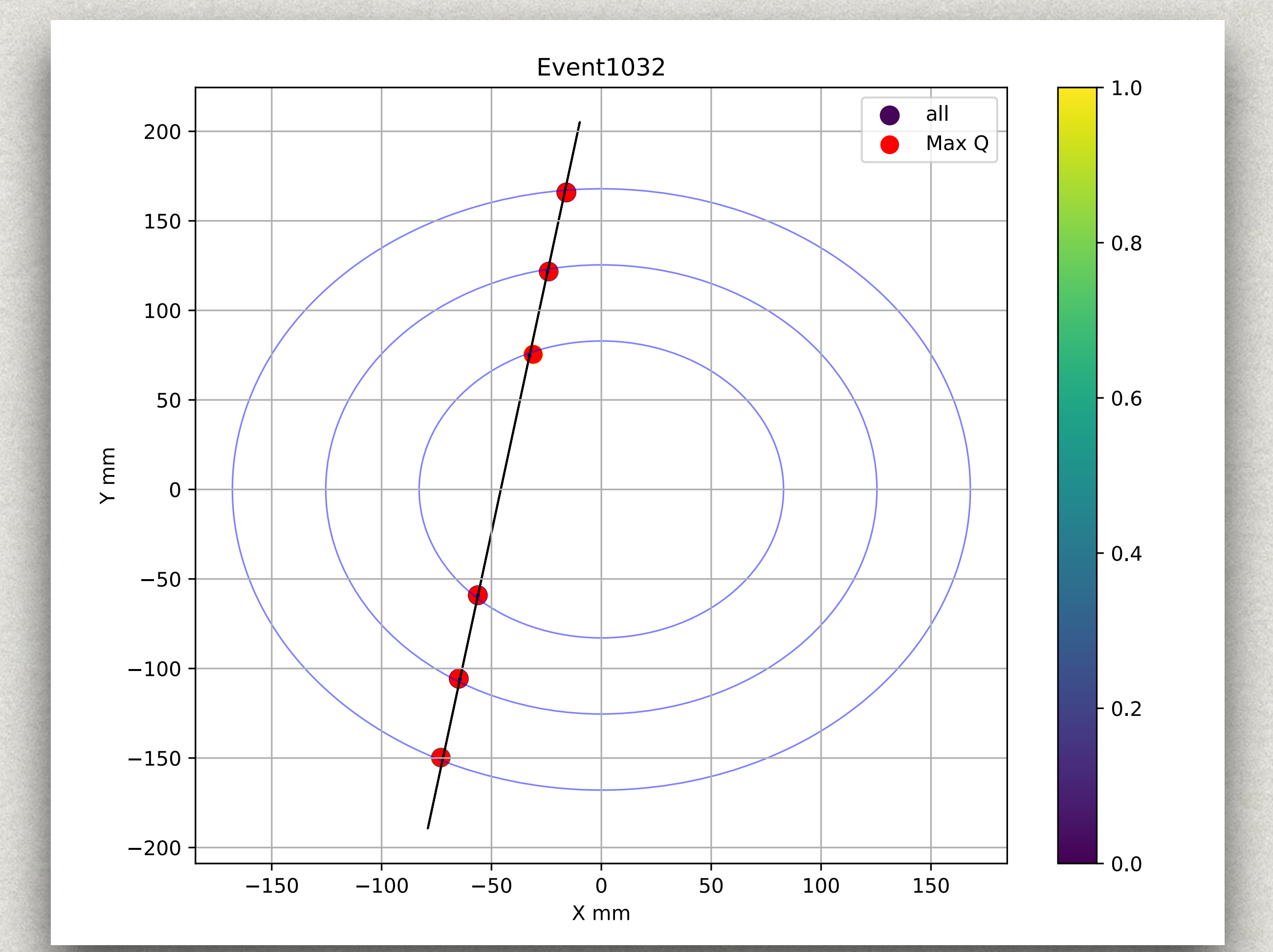
Performance evaluation with cosmics: hits

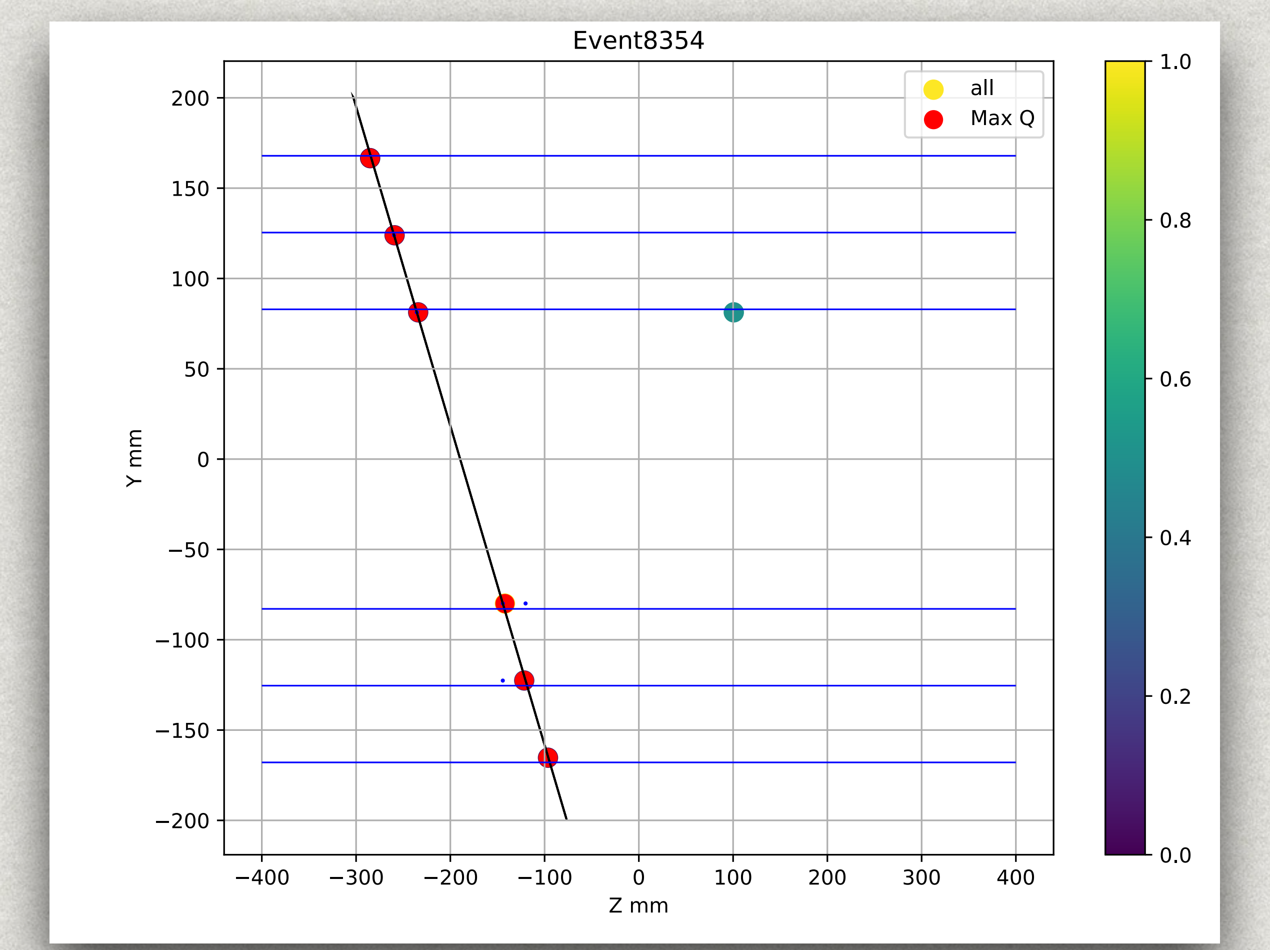
- Signal clearly visible in charge vs time distribution

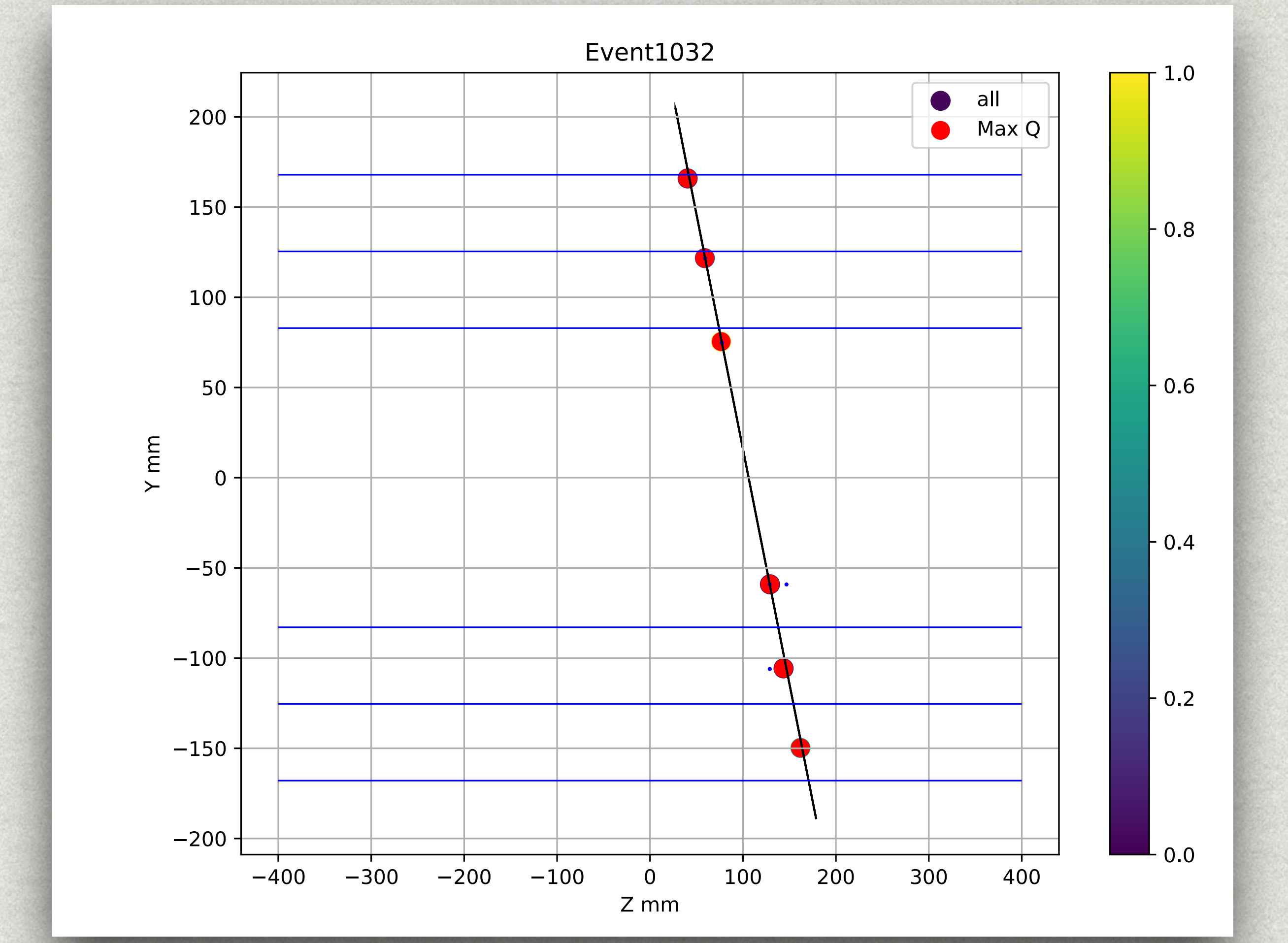


Performance evaluation with cosmics

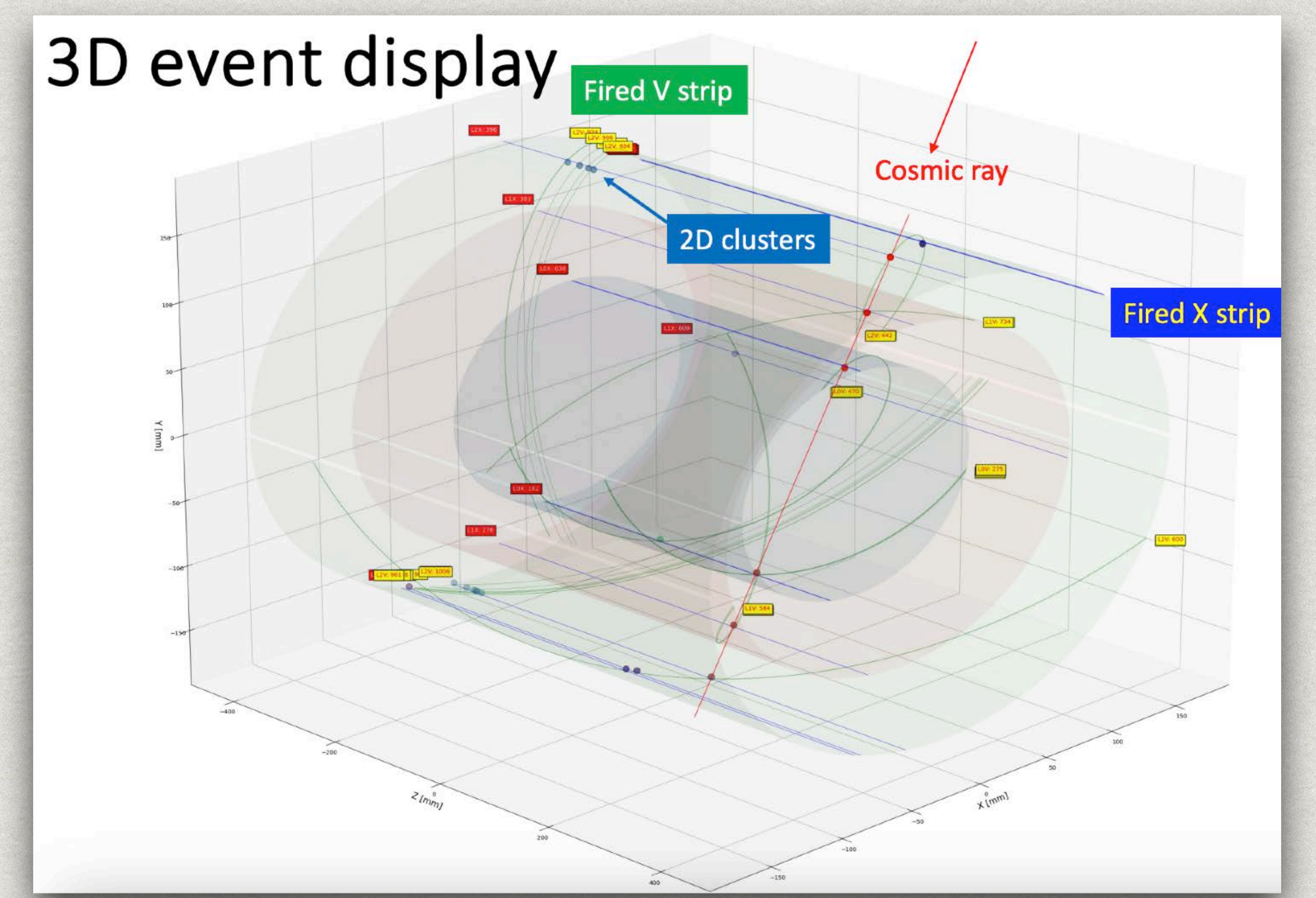




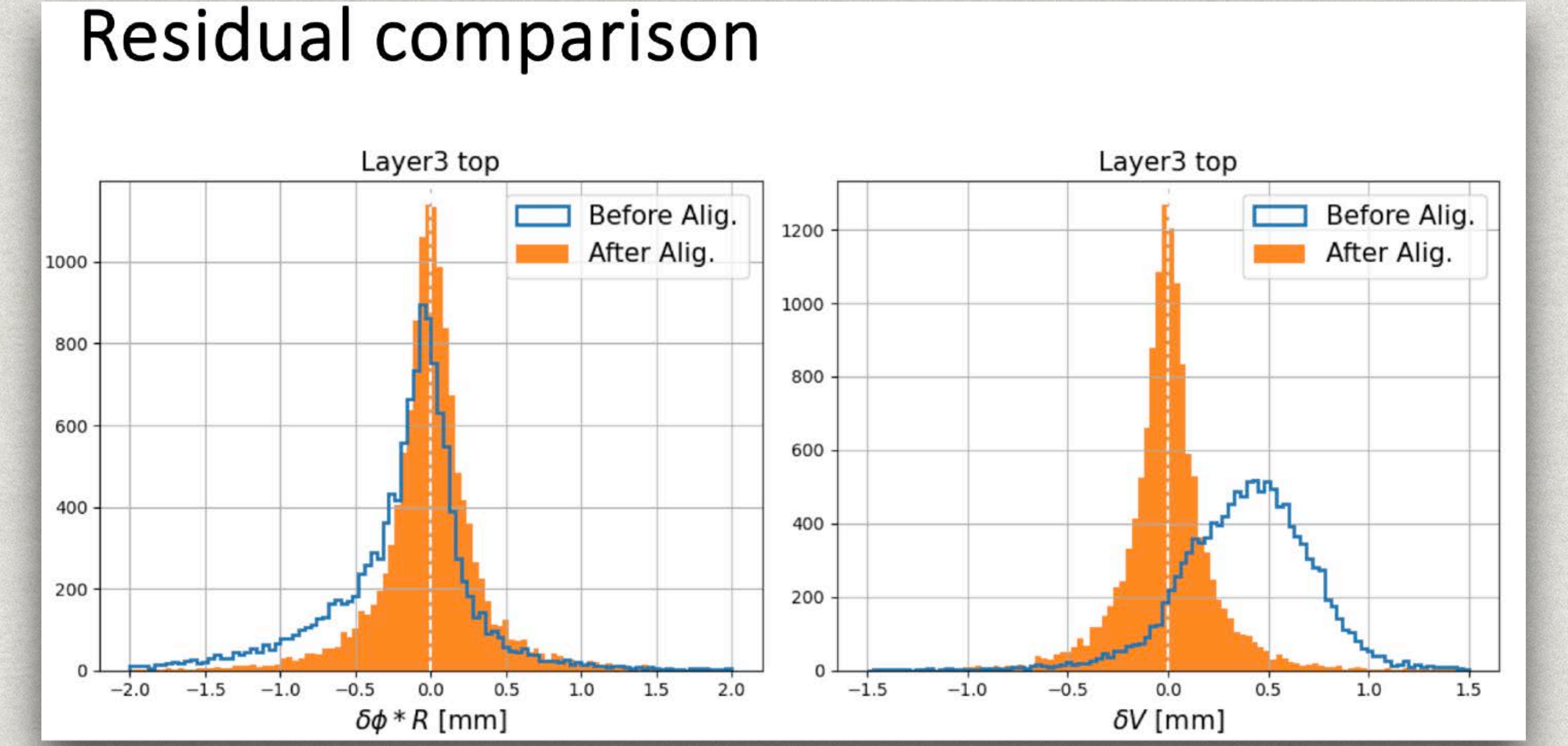


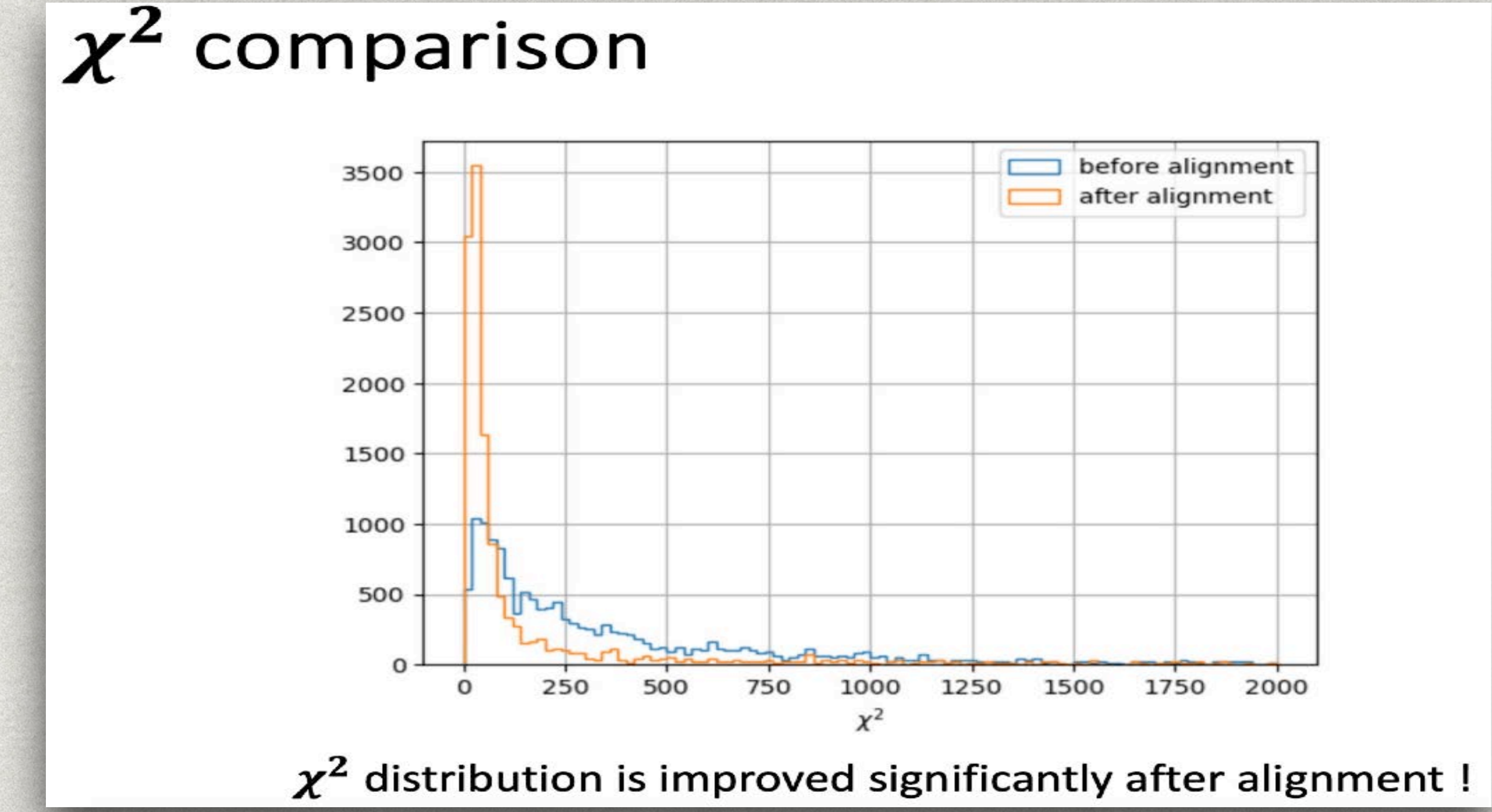


Alignment and residuals

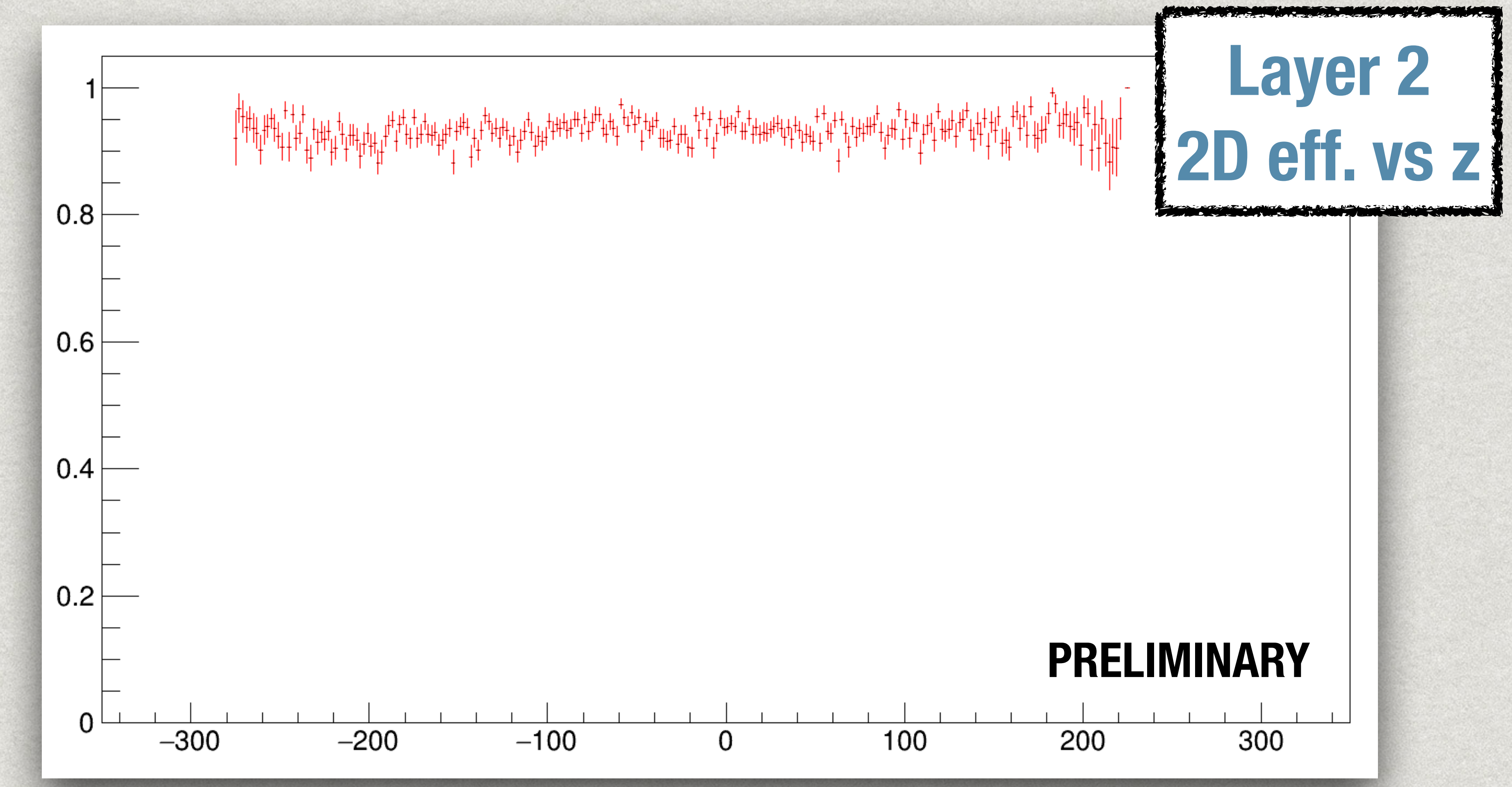


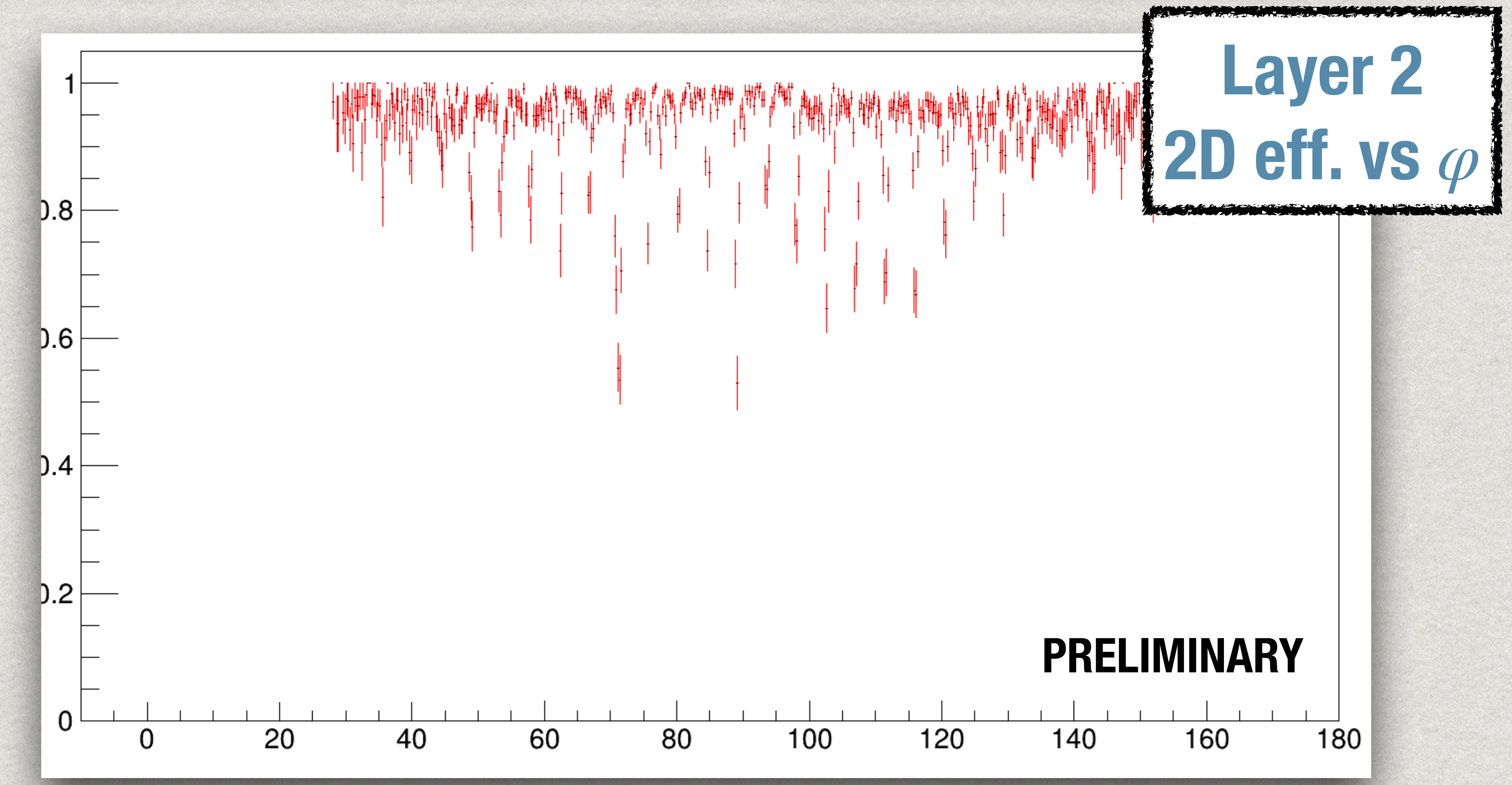
- Provides geometry corrections (rotation, offset, ...)
- Method: track fitting with these corrections as global parameters, which are obtained iteratively using the tool Millepede
- 5 global parameters for each of the outer layers (relative to the inner layer)



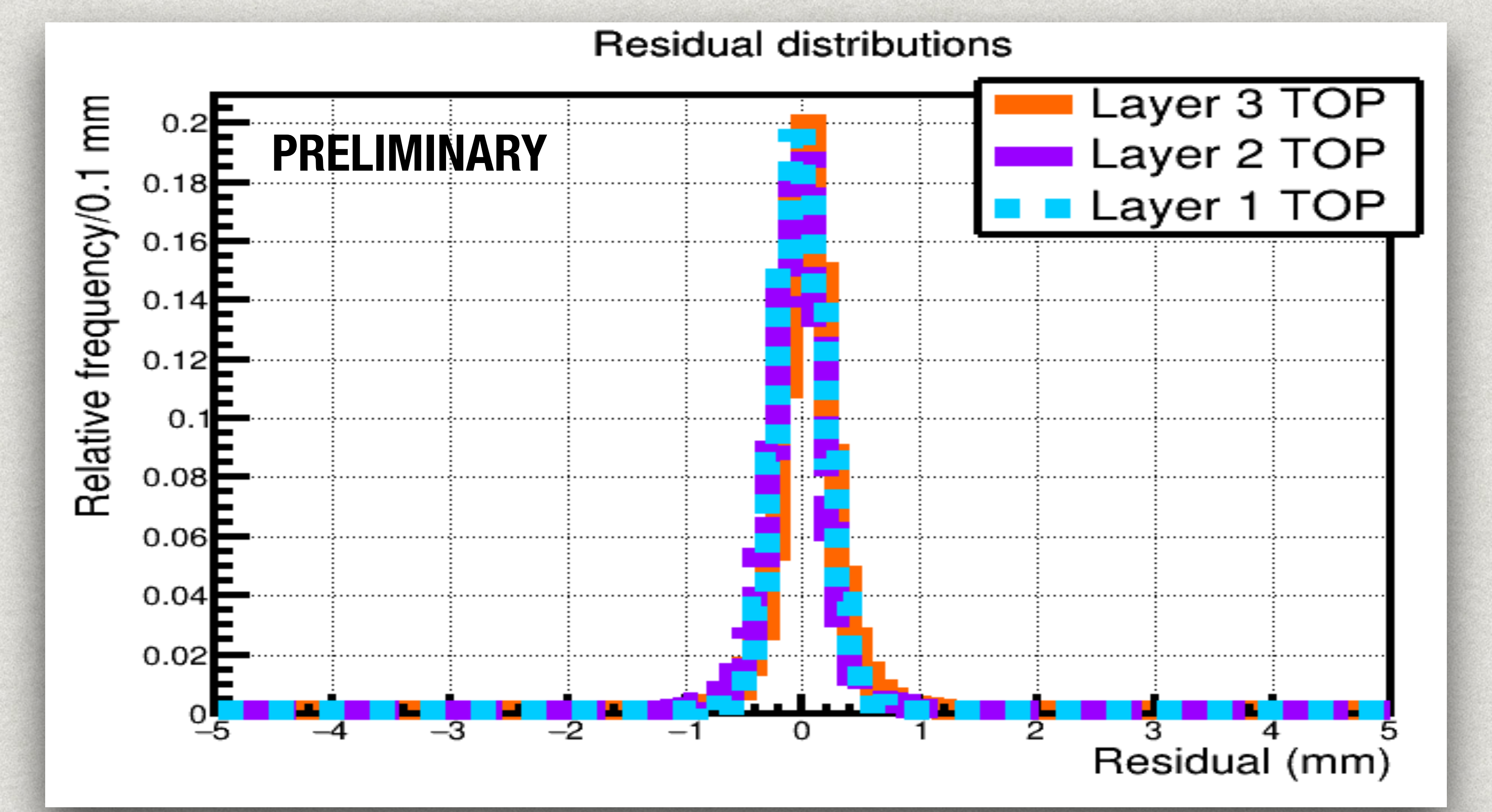


Detector performance



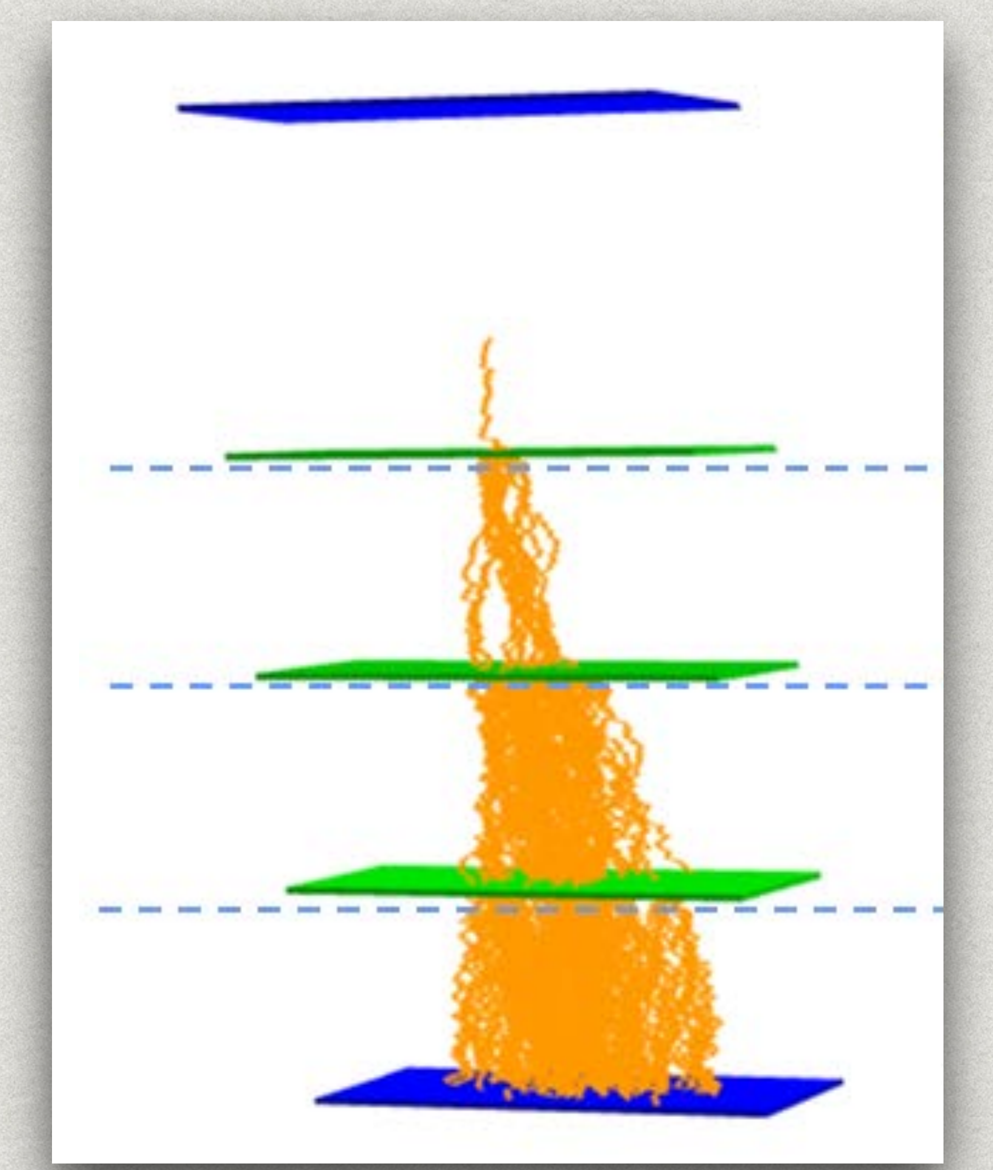


- Double-view efficiency above 95% for all layers
- HV segmentation clearly visible in the φ view
- Residual distributions for almost orthogonal tracks $< 200\ \mu m$ including contribution from tracking

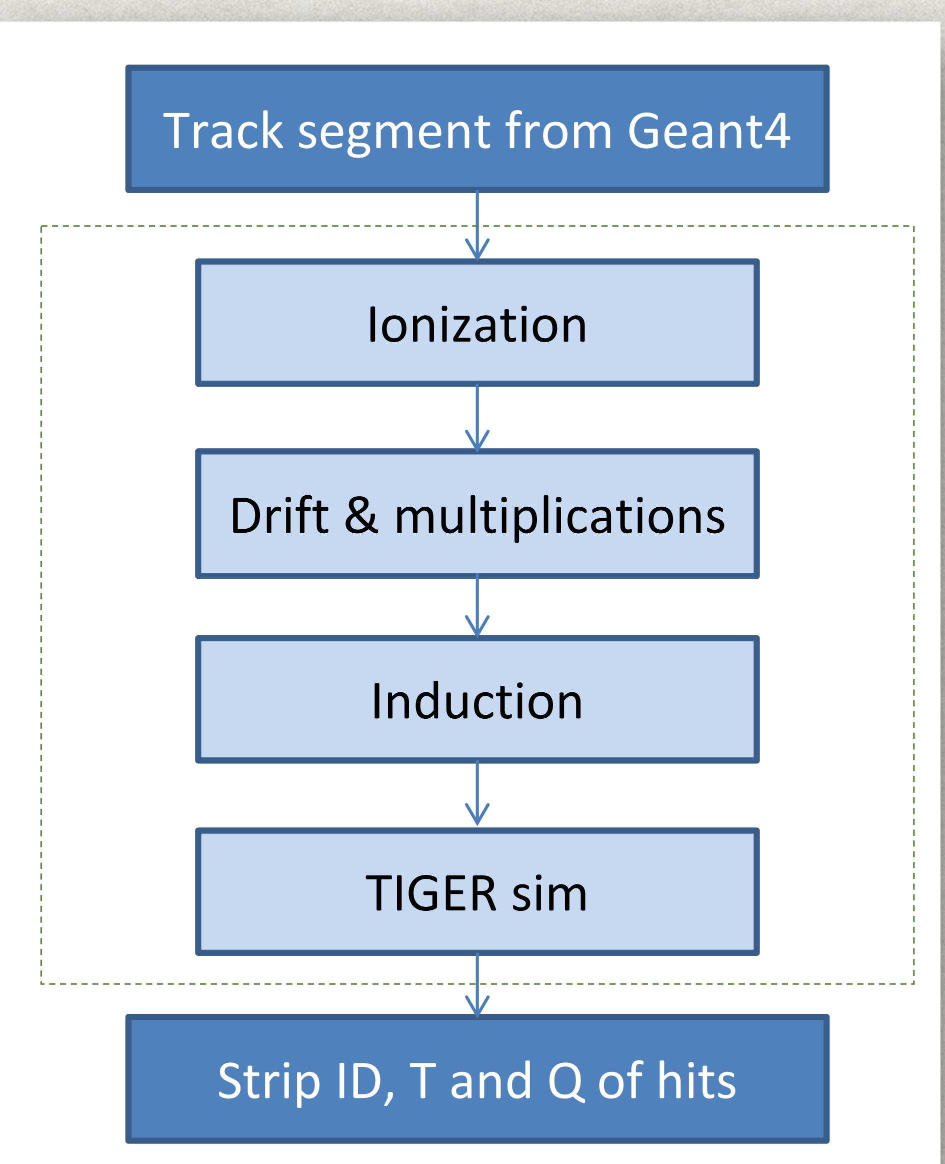


$r\varphi$ residuals for track with azimuthal incident angles between 0° and 5°

Detector digitization



- Digitization is the simulation of detector response
- Processes in digitization of CGEM-IT

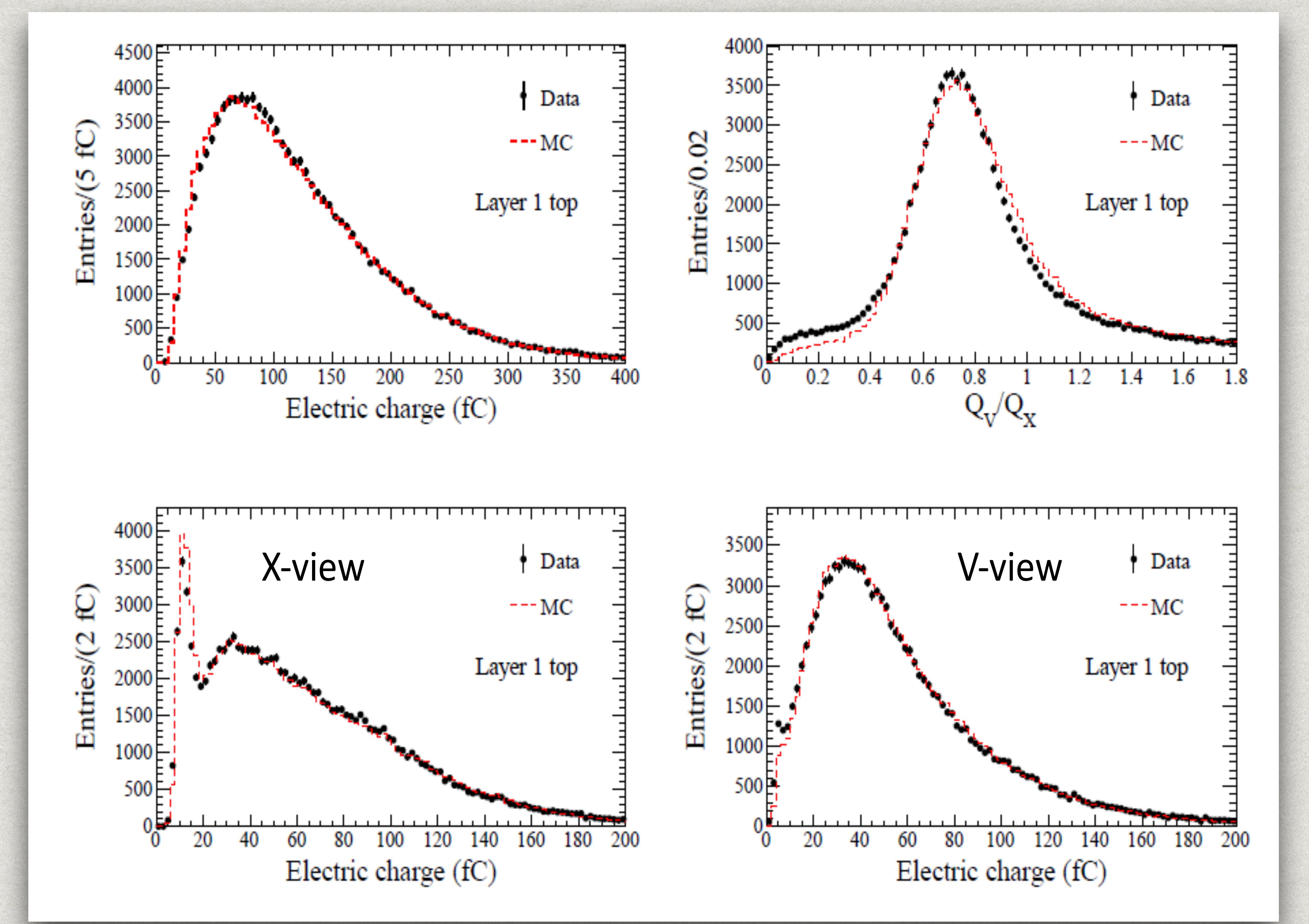


  - Ionization --> Heed in Garfield++
  - Drift & avalanche --> parameterized model based on Garfield++ simulation results
  - Induction --> Digitization from Garfield++ simulation results
  - Electronics measurement --> transfer function of TIGER

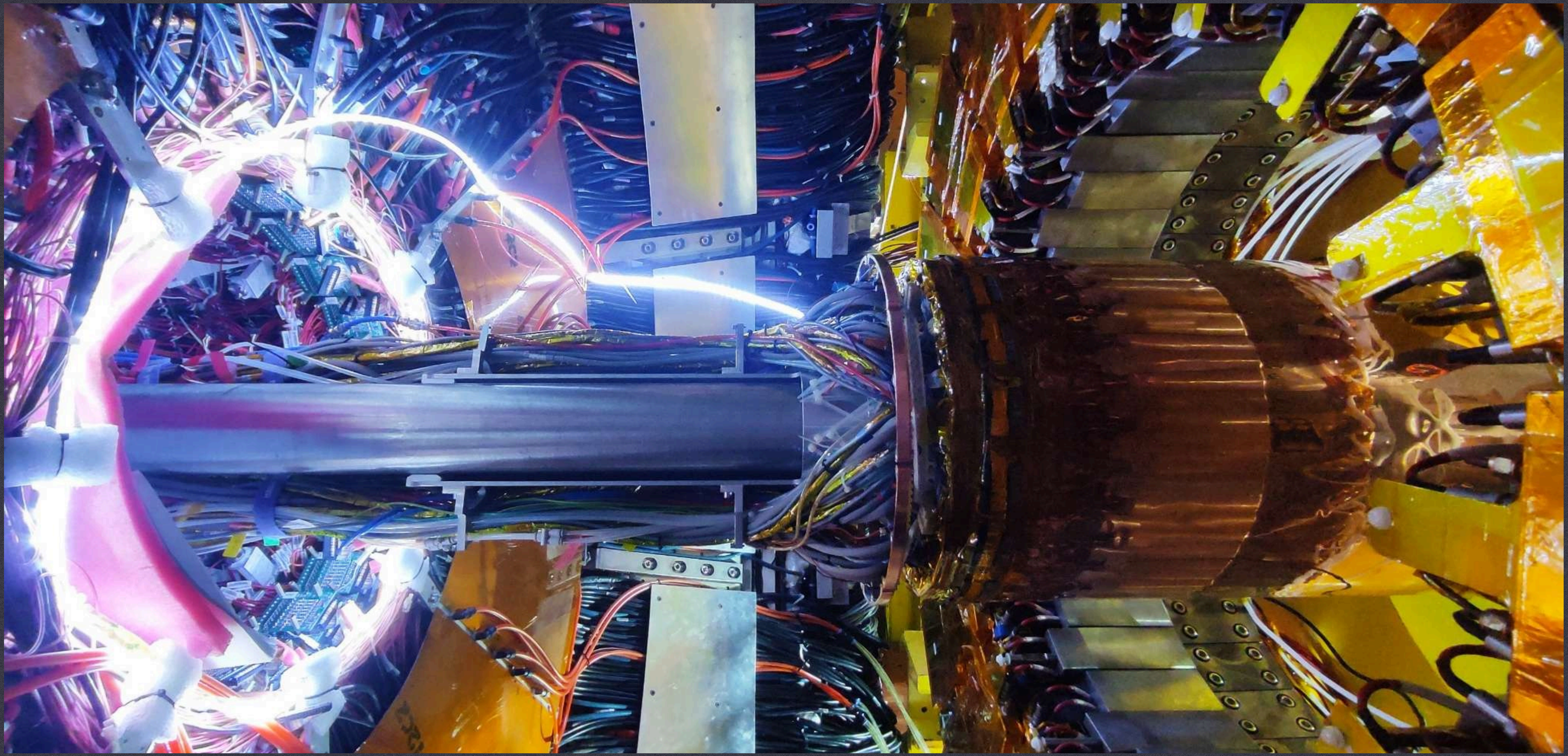
more at JINST 18 P05027 and CPC 295 (2024) 109000 (arXiv:2005.04452)

Digitization tuning with cosmic data

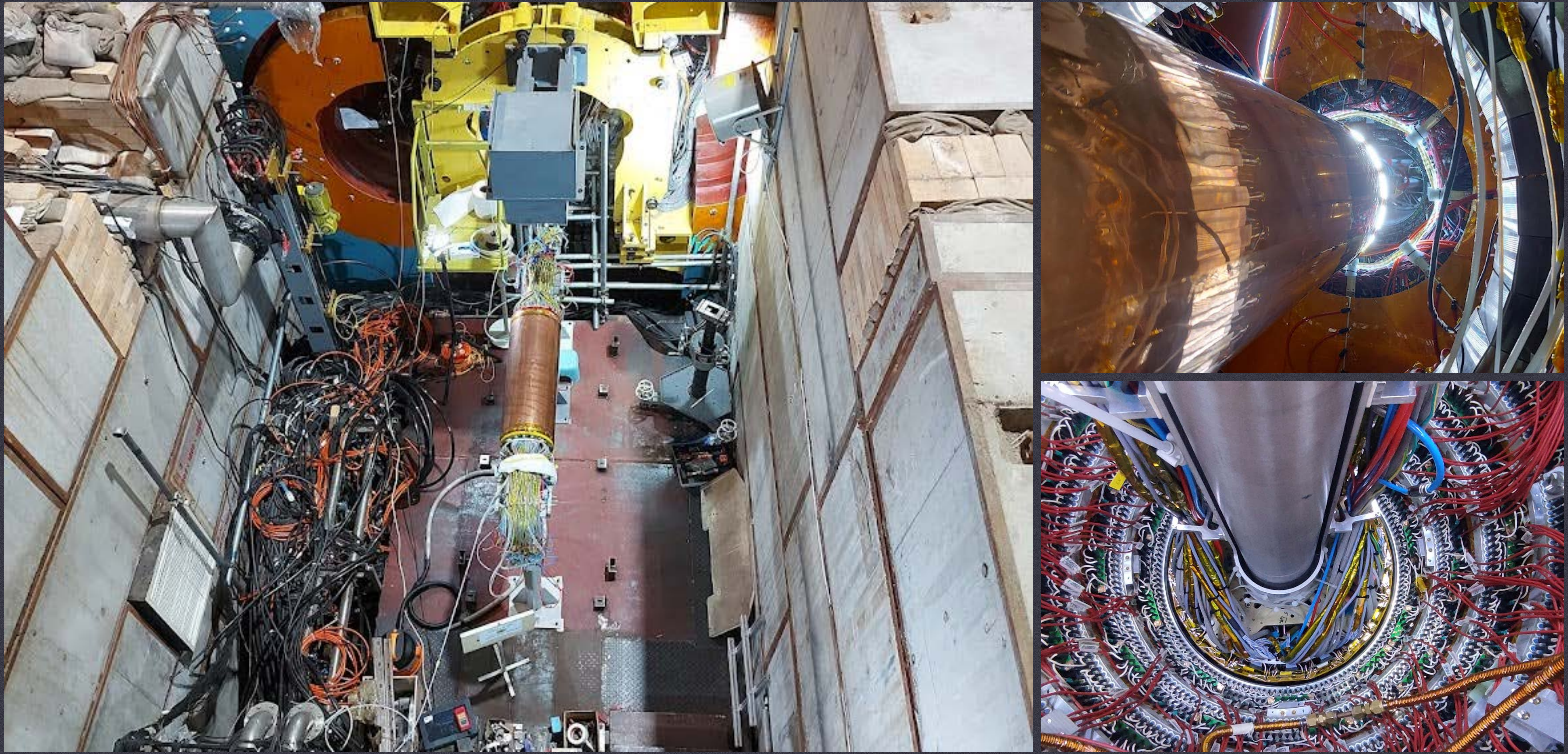
- Data from cosmic runs
  - 2D cluster reconstruction with c.c. method
  - Straight line fit
- Simulation with GEANT4 and CGEM-IT simulation package
- Consistency between data and MC is good after tuning
- Paper published: JINST 18 P05027



more at JINST 18 P05027

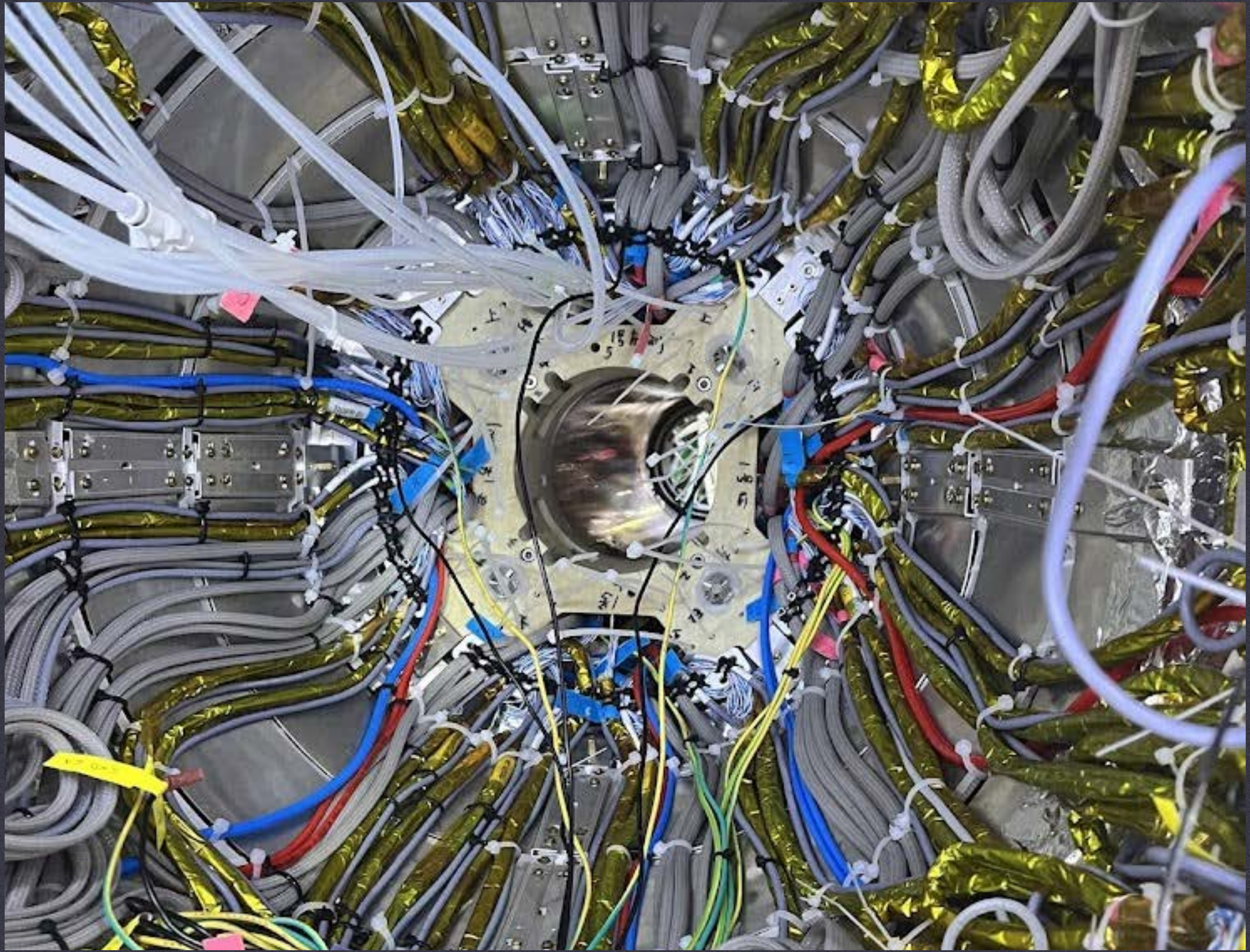


INSTALLATION AND COMMISSIONING OF THE DETECTOR



DETECTOR INSTALLATION

CGEM-IT REACHING ITS NOMINAL POSITION ON OCTOBER 5, 2024



DETECTOR CABLING

COMPLETED ON OCTOBER 18 - DETECTOR POWERED ON AT NOMINAL VALUES ON OCTOBER 19

Integration and commissioning

- Installation of the EM shielding in progress
- Next to do
    - The endcaps of the EM calorimeter will be placed to their nominal position
    - Installation of the beam pipe
    - Installation of the final focus
- First data acquired in standalone for debugging purpose
- The integration with BESIII DAQ and Slow Control is in progress

Summary and outlook

* BESIII is planning to continue taking data up to (at least) 2030 with higher luminosity and higher CM energy

* The Cylindrical GEM Inner Tracker has been designed to improve rate capability and secondary vertex reconstruction

* The detector has just been installed and is currently being integrated with the BESIII spectrometer

* Still quite some time before having some collider data to analyze but the fun part is about to begin

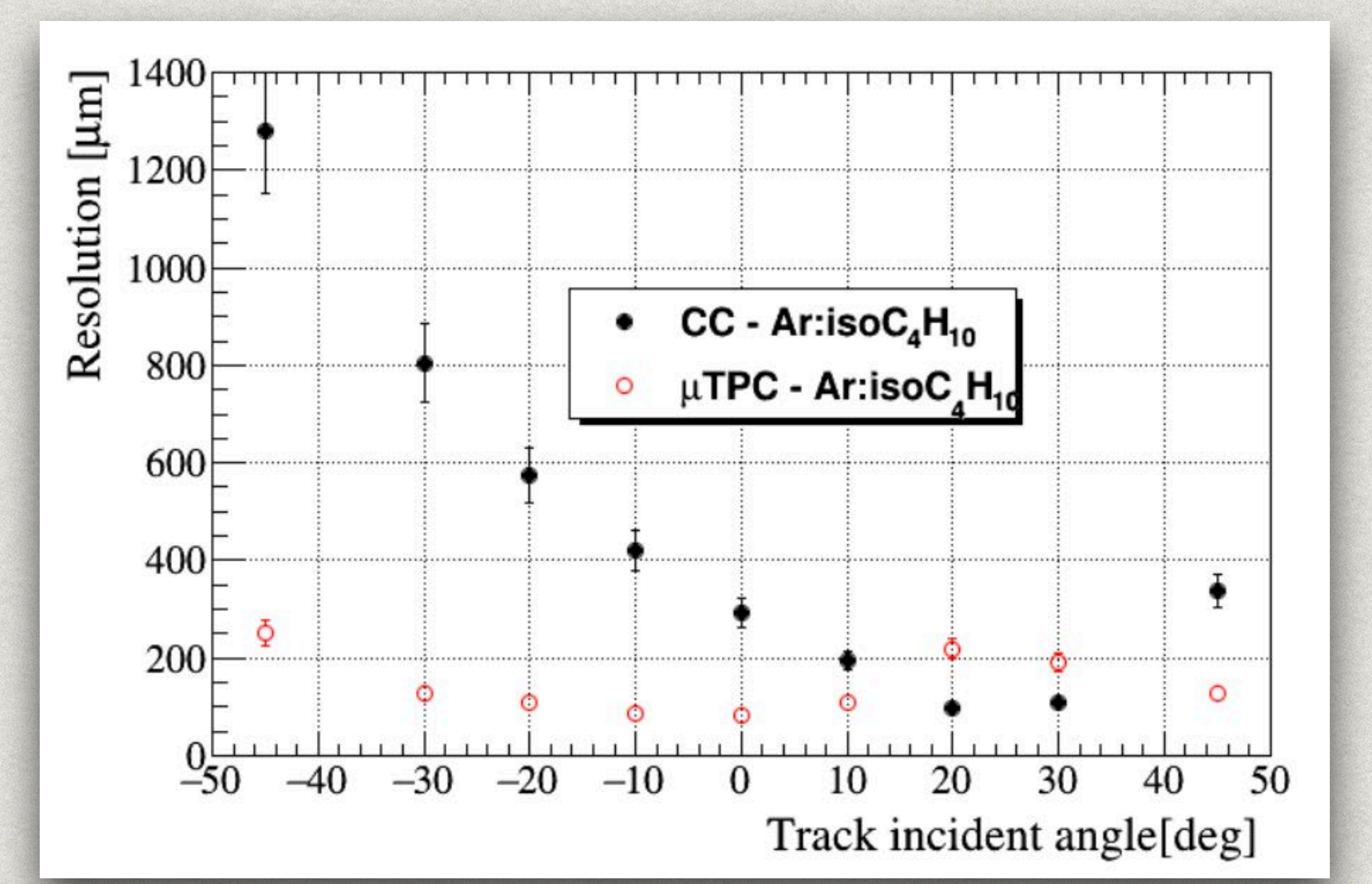
TO BE FILLED
WITH DATA

THANKS FOR YOUR ATTENTION

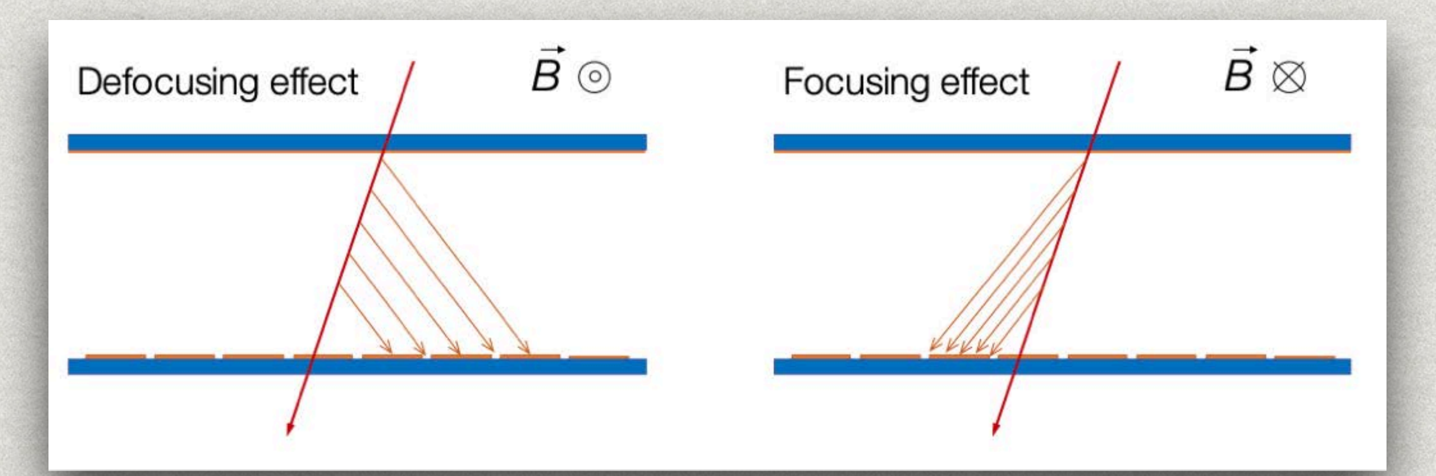
Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^{\pm}$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

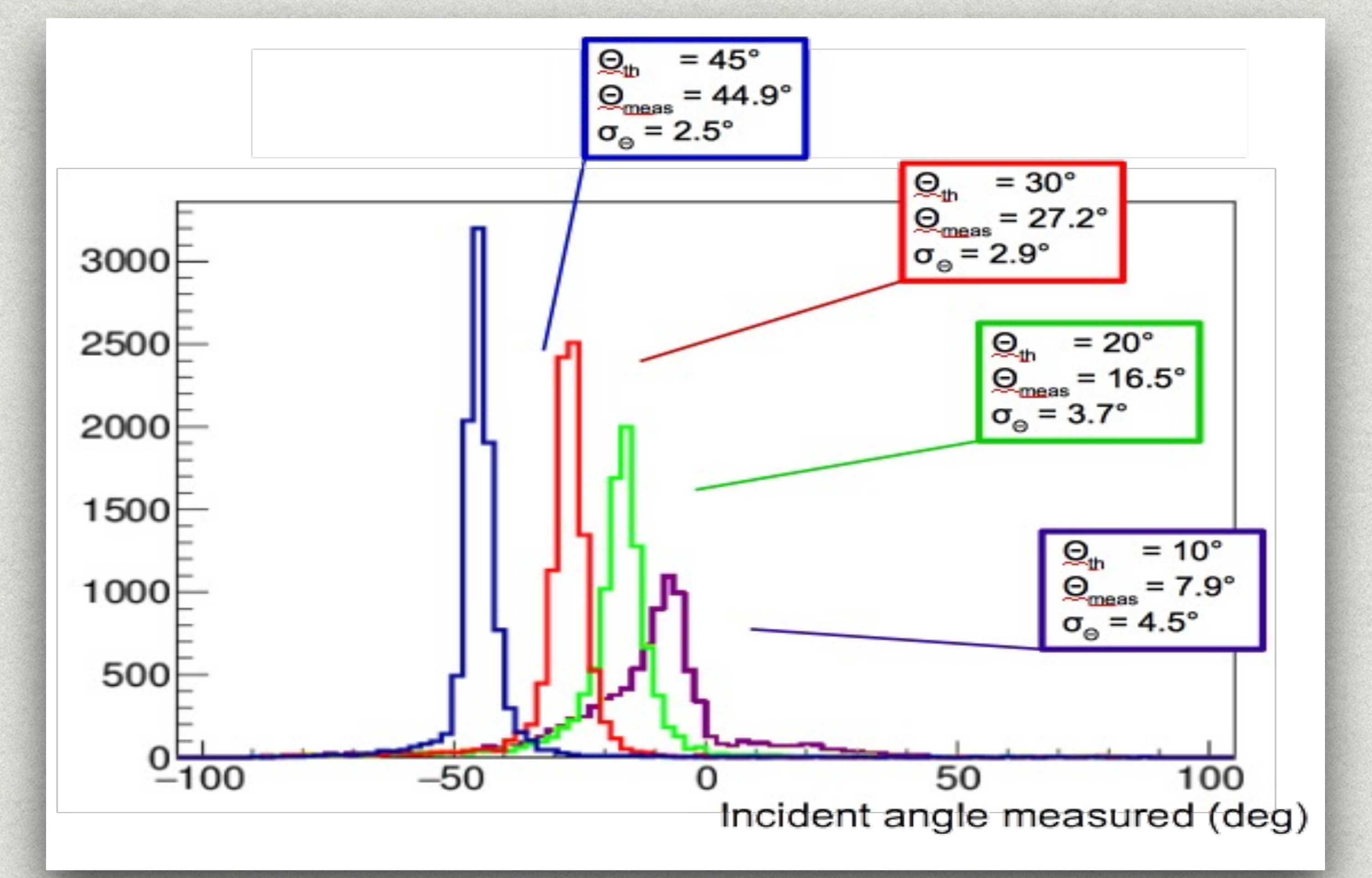
	KLOE-2	BESIII	action
Number of detector layers	4	3	→ 5 mm drift gap
Drift gap	3 mm	5 mm	for mTPC
Material budget per layer	0.5% X_0	0.5% X_0	
Momentum resolution @1 GeV	not used	σ_{pt}/P_t =~0.5%	
Rate capability	< 10 kHz/cm^2	few 10 kHz/cm^2	
Spatial resolution f	250-350 mm (B=0.5T)	100-150 mm (B=1T)	mTPC
Spatial resolution Z	~1 mm	<500 mm	mTPC
Magnetic filed	B = 0.52 T	B = 1 T	mTPC
Internal/external diameter	244/440 mm	156/356 mm	higher rate
Readout	digital	charge + time	TIGER chip

R&D and detector design



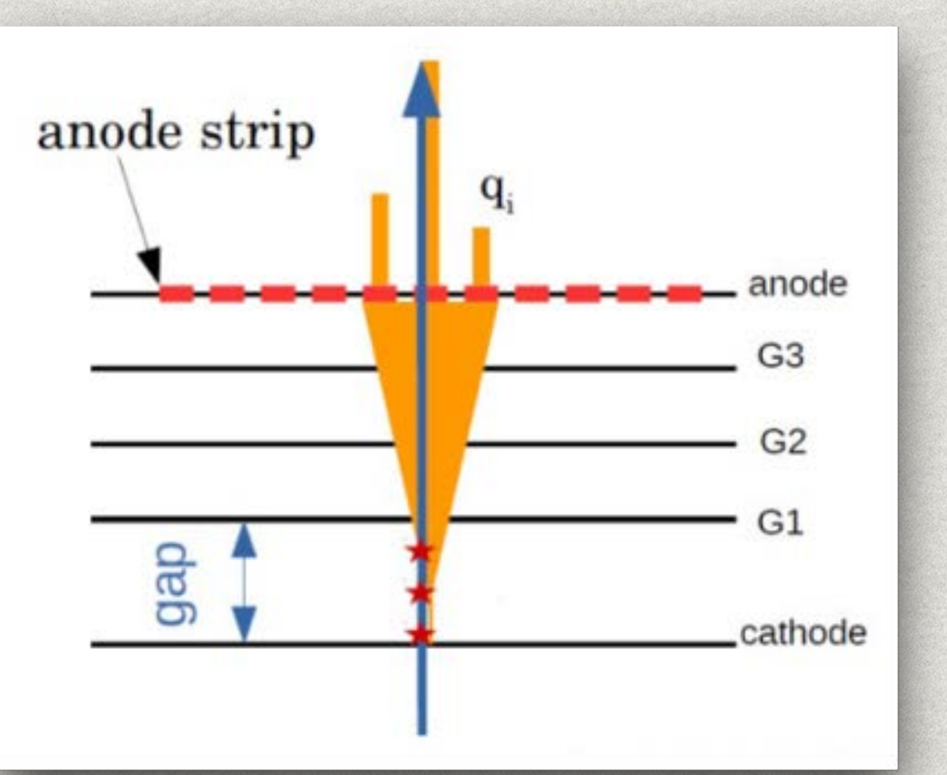
- Combining CC and microTPC stable spatial resolution over a large range of incident angle
- Possibility to perform 3D track reconstruction with only one layer
- A large (5 mm) drift gap is needed for the microTPC readout



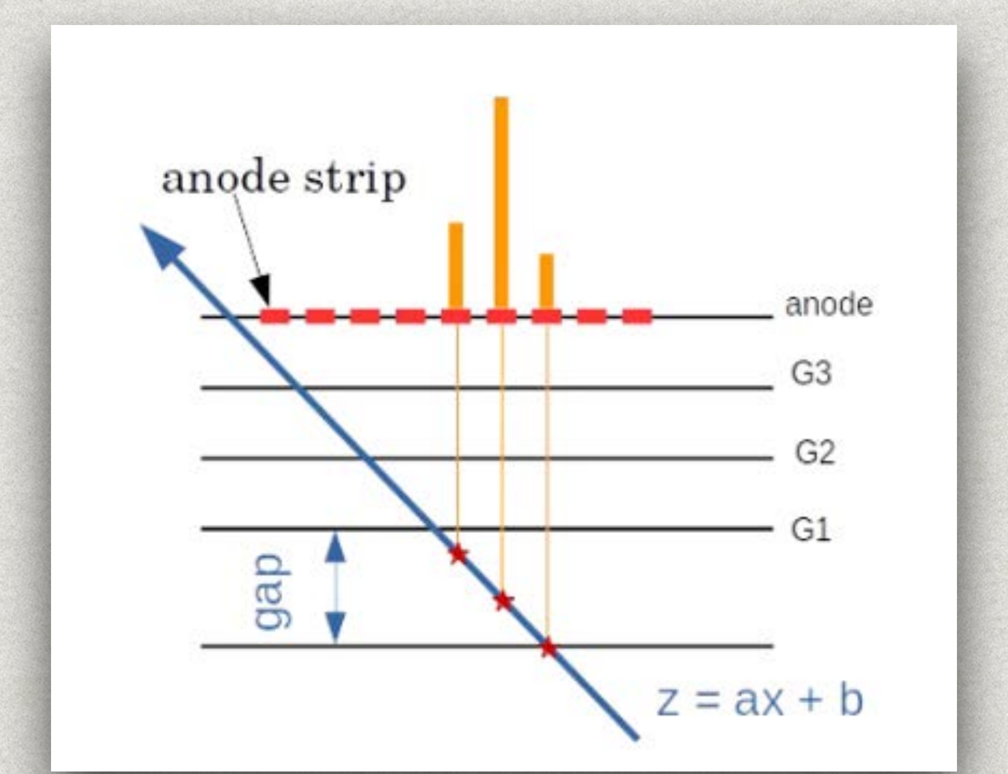


Cluster reconstruction

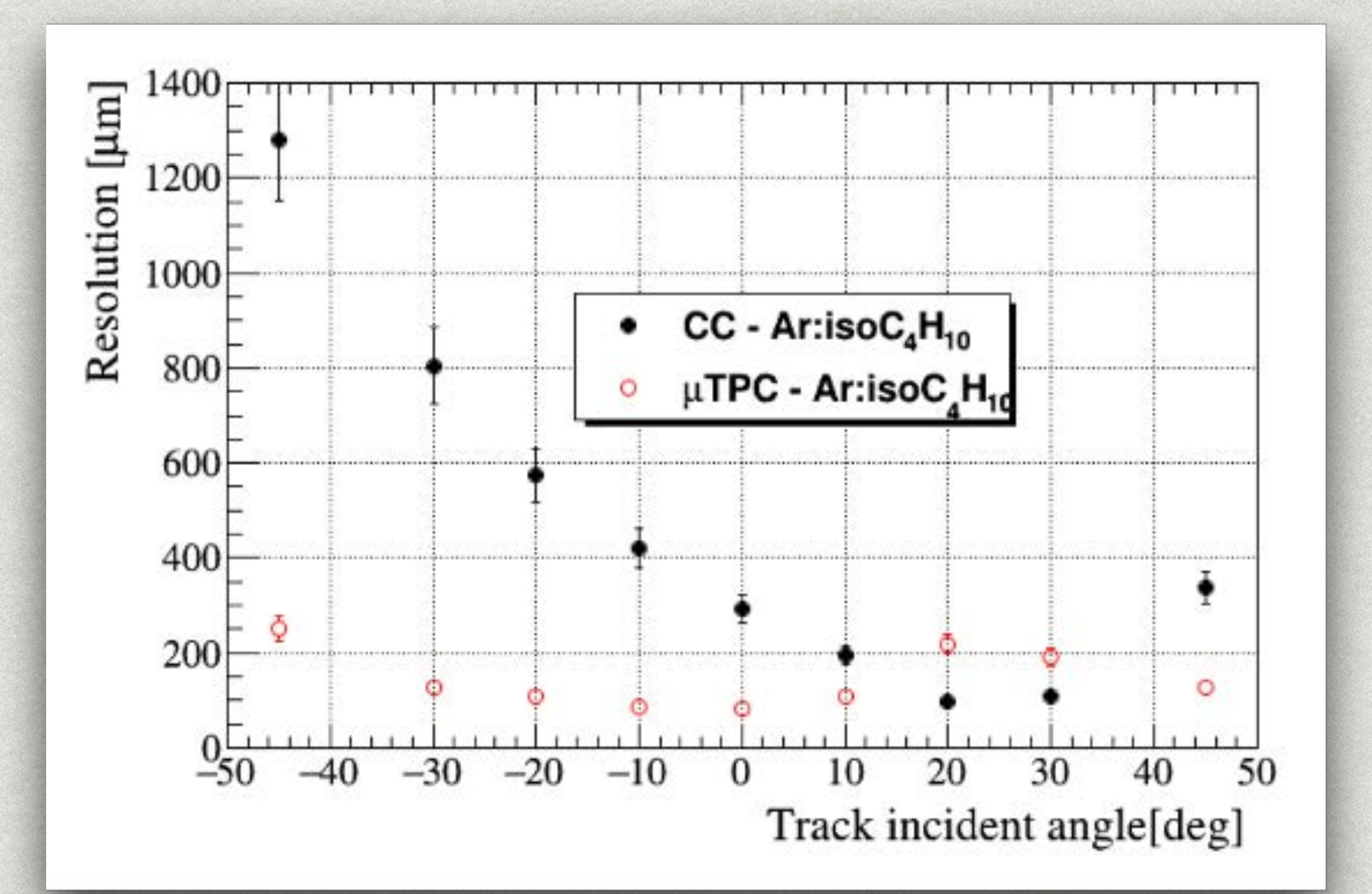
- Contiguous fired strips on the anode form a cluster



$$x_{\mathrm{CC}} = \frac{\sum_i^{N_{\mathrm{hit}}} Q_{\mathrm{hit},i}\, x_{\mathrm{hit},i}}{\sum_i^{N_{\mathrm{hit}}} Q_{\mathrm{hit},i}}$$

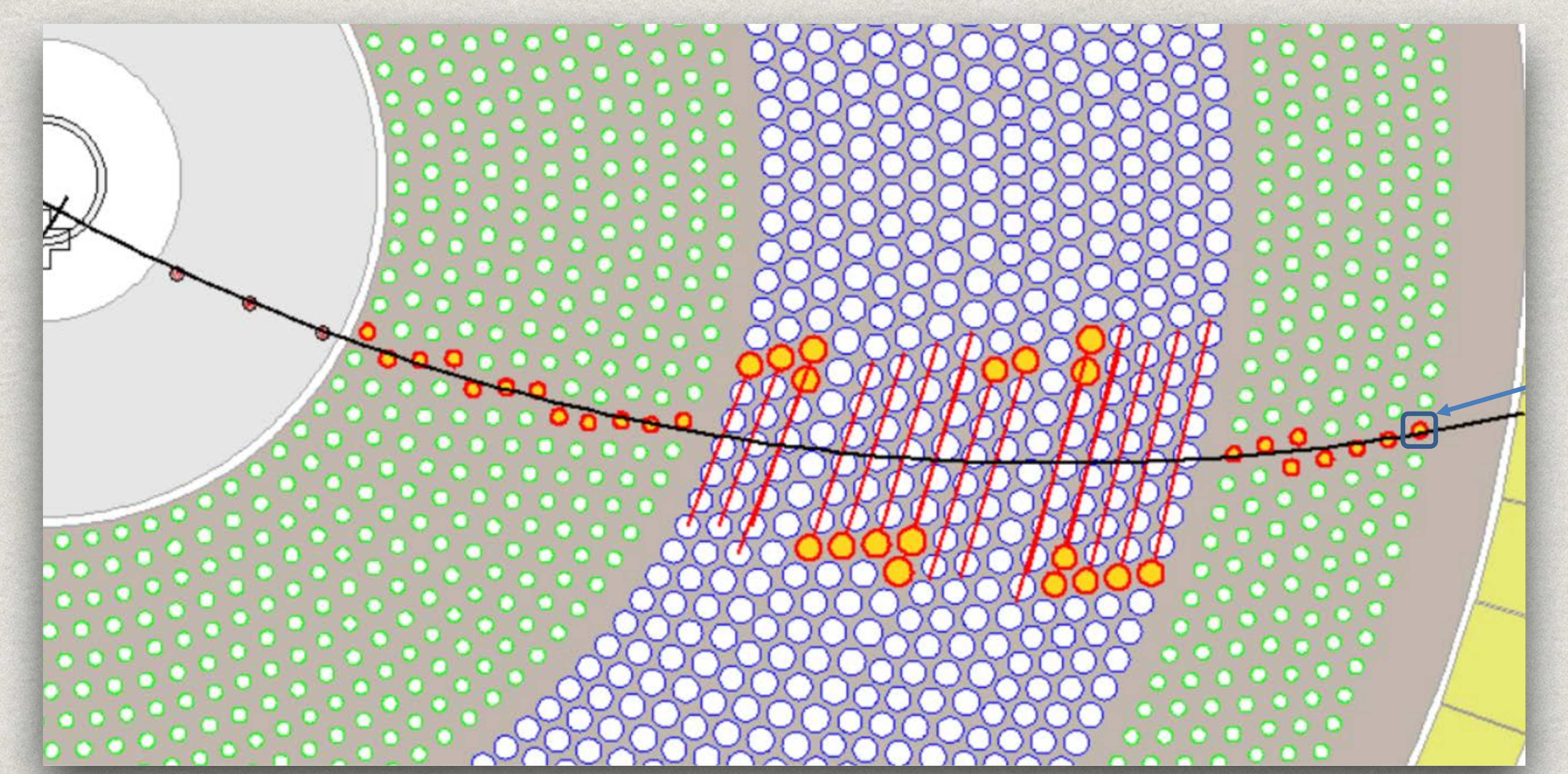


$$x_{\mu\mathrm{TPC}} = \frac{gap/2 - b}{a}$$



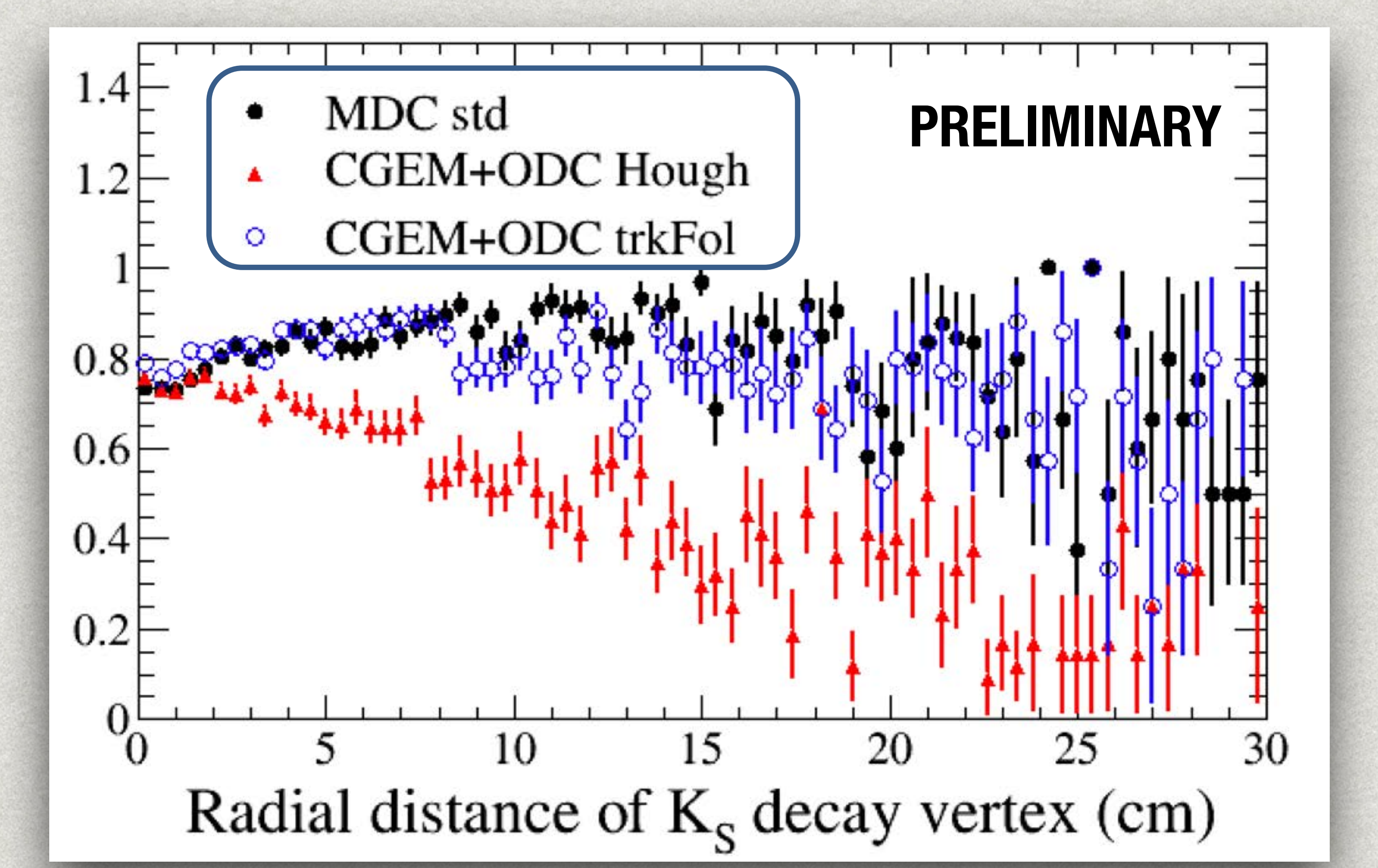
more at 2019 JINST 14 P08018

Track finding in a local approach



- To keep high efficiency for tracks from displaced vertex the assumption (or constraint) of tracks from origin should not be used
- Track finding with a local method usually use some local constraints to get track seeds (or segments) and then to associate more hits (or combine segments) to get complete track candidates.

- So track finding with a local approach should be also efficient for tracks from displaced vertex
- A Track Following (TF) method by selecting adjacent DC hits is implemented



K_S sample generated with p=0~2 GeV/c and all decay to $\pi^+\pi^-$