WIFAI 2024

Workshop Italiano sulla Fisica ad Alta intensità

Bologna 12-15 Novembre 2024
Palazzo Hercolani, Aula Poeti
Str. Maggiore, 45 - Bologna

THE CGEM INNER TRACKER OF BESIII

G. CIBINETTO (INFN FERRARA)
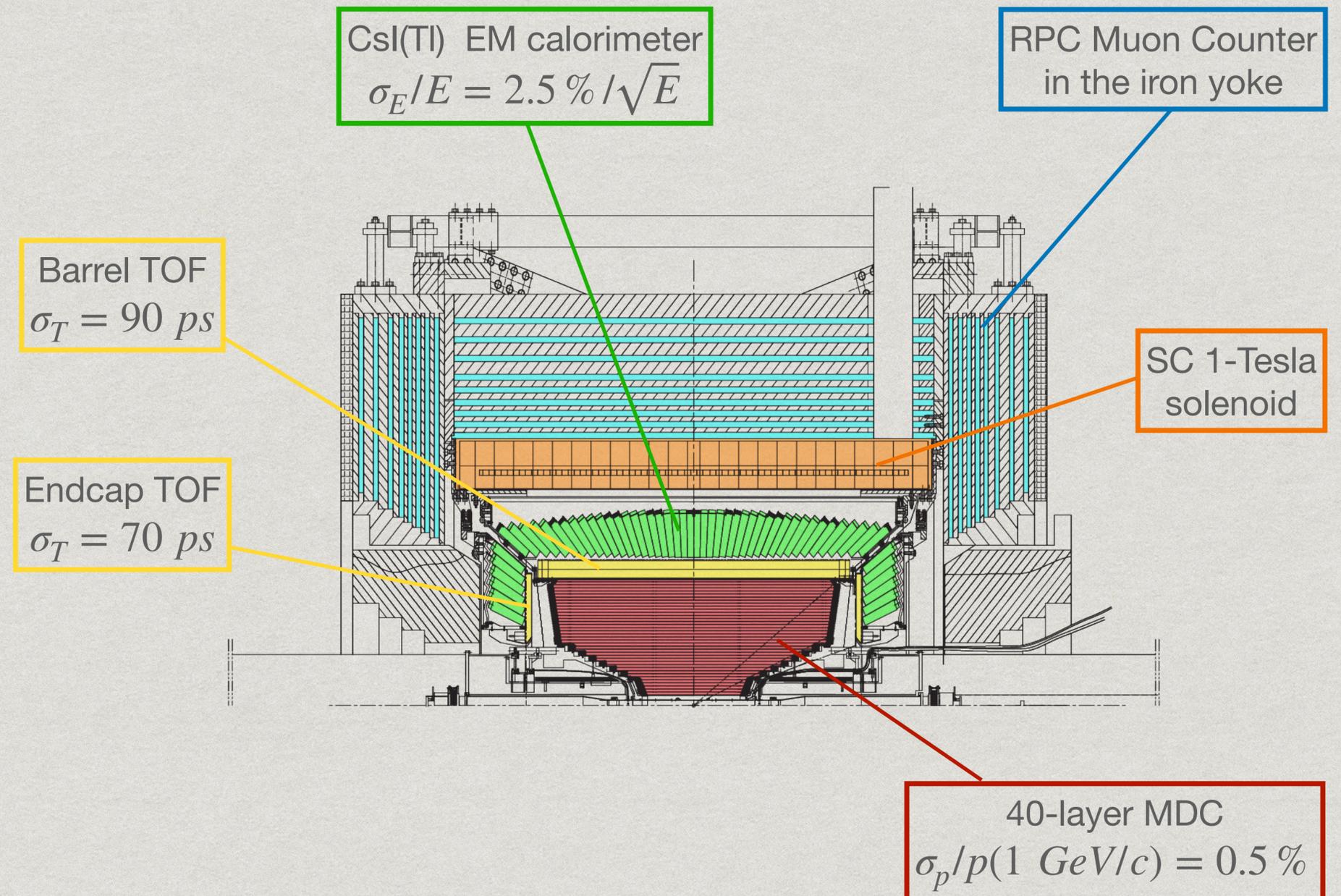on behalf of the CGEM-IT group

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
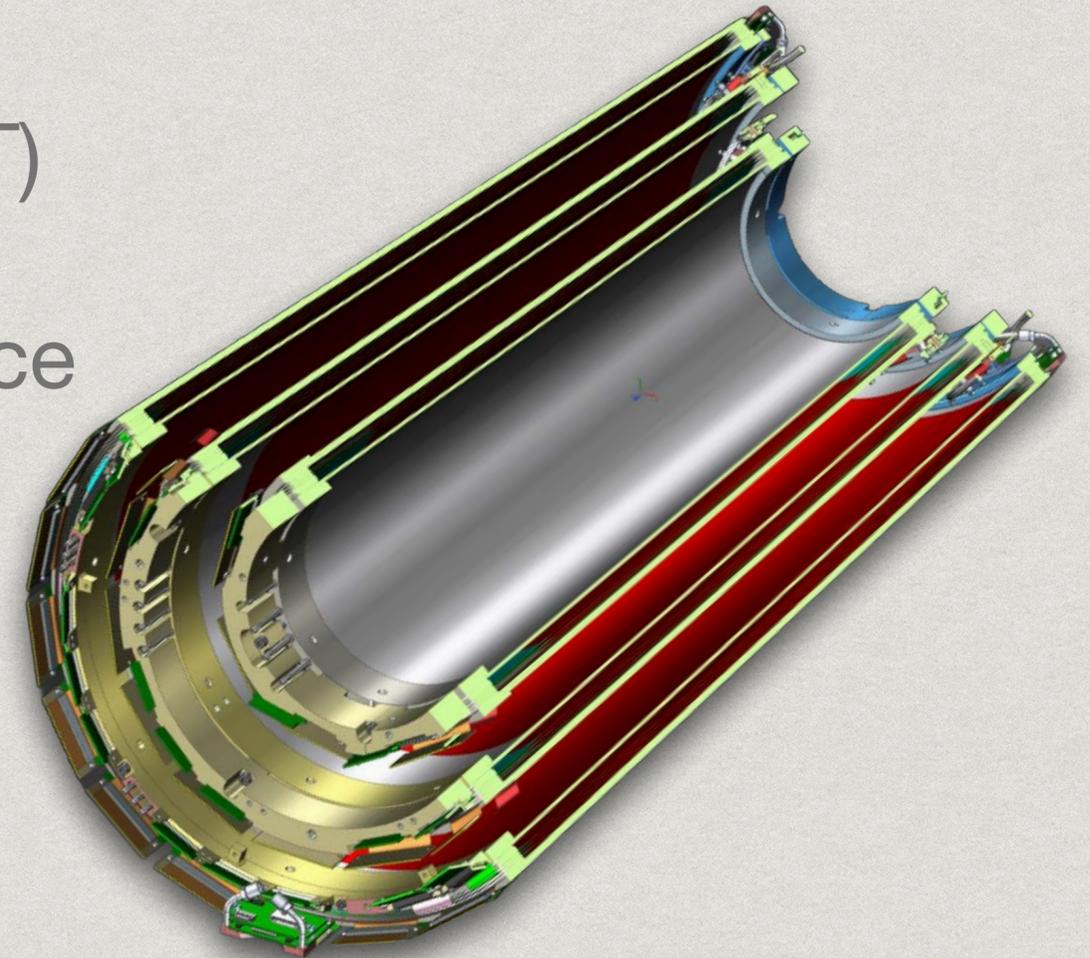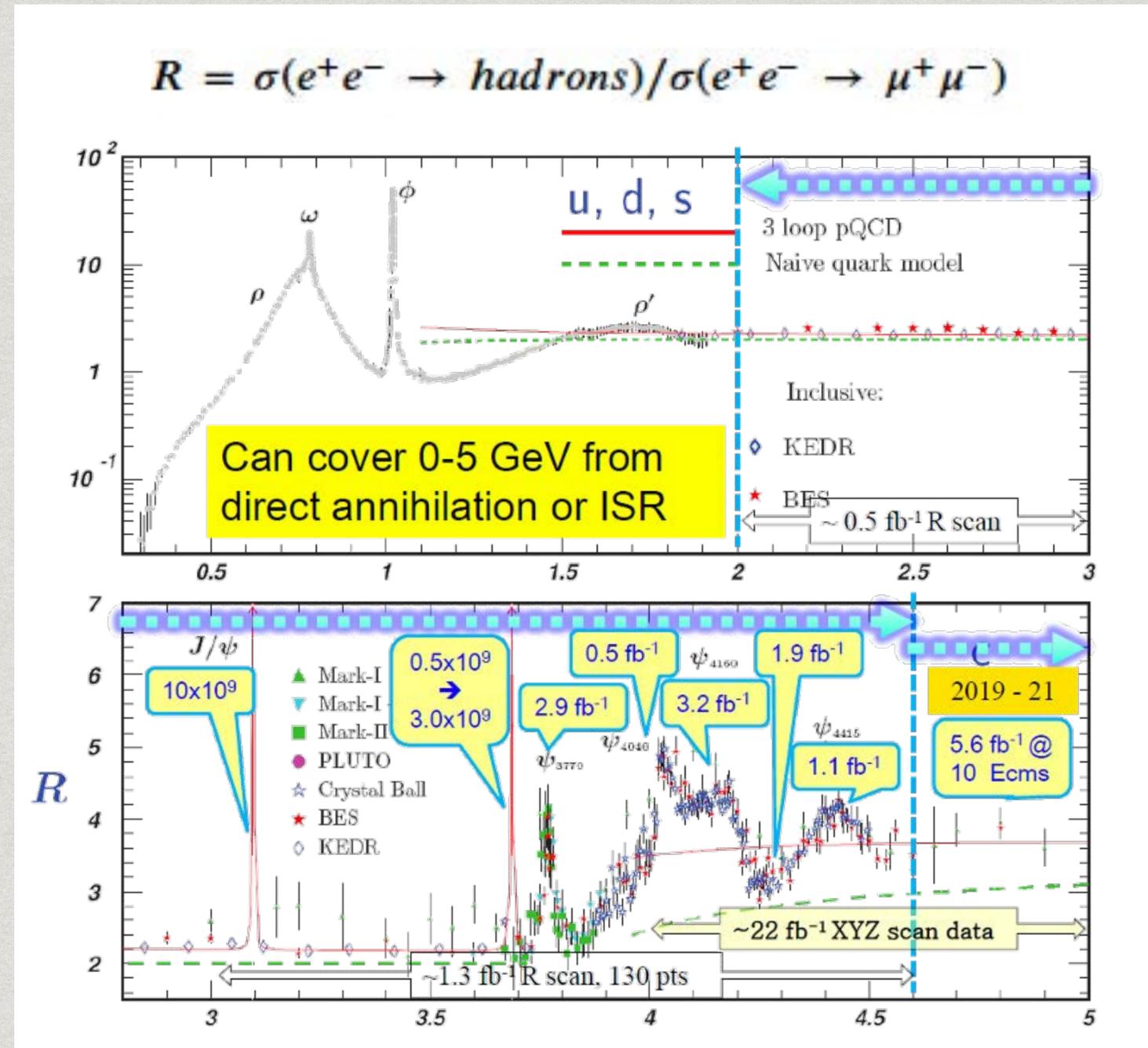
THE BESIII EXPERIMENT AND ITS UPGRADE PROGRAM

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

  - $J/\psi \longrightarrow$ 10 billions

  - $\psi(2S) \longrightarrow$ 3 billions

  - $\psi(3770) \longrightarrow$ 20 fb^{-1}

- About 22 fb^{-1} of data for Exotic Charmonium Spectroscopy

CsI(Tl) EM calorimeter
$\sigma_E/E = 2.5\ \%/\sqrt{E}$

RPC Muon Counter in the iron yoke

Barrel TOF
$\sigma_T = 90\ ps$

SC 1-Tesla solenoid

Endcap TOF
$\sigma_T = 70\ ps$

40-layer MDC
$\sigma_p/p(1\ GeV/c) = 0.5\ \%$

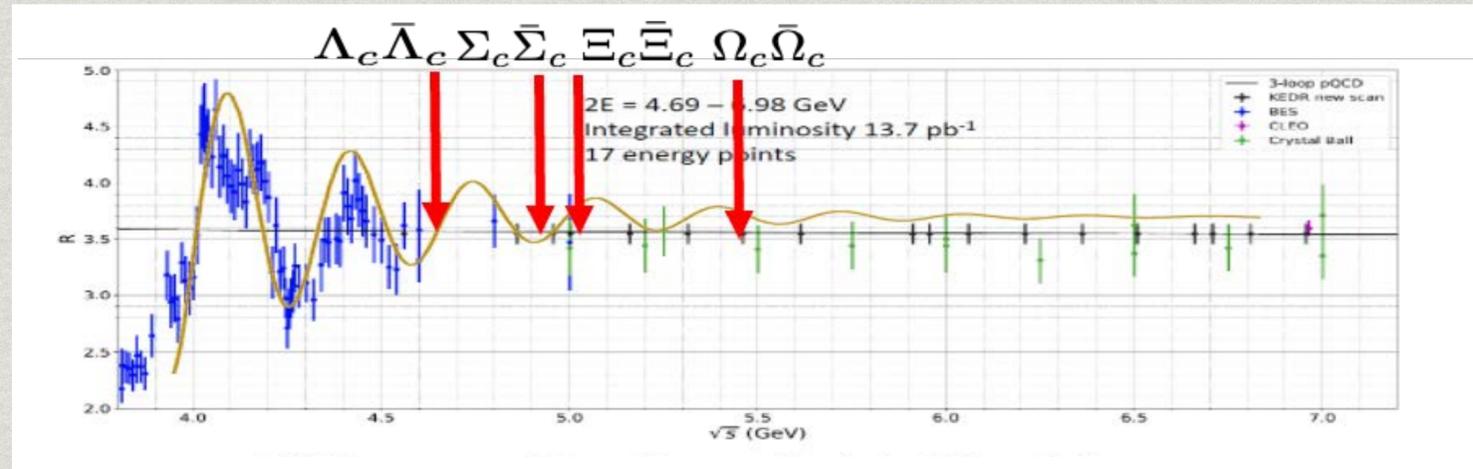# The BESIII experiment @ BEPCII

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$$R = \sigma(e^+e^- \rightarrow hadrons)/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$$

u, d, s
3 loop pQCD
Naive quark model

Can cover 0-5 GeV from direct annihilation or ISR

Inclusive:
◇ KEDR
★ BES
~ 0.5 fb[-1] R scan

10x10⁹
0.5x10⁹ →
3.0x10⁹
2.9 fb[-1]
0.5 fb[-1]
3.2 fb[-1]
1.9 fb[-1]
1.1 fb[-1]
2019 - 21
5.6 fb[-1] @ 10 Ecms

▲ Mark-I
▼ Mark-I
■ Mark-II
● PLUTO
☆ Crystal Ball
★ BES
◇ KEDR

~22 fb[-1] XYZ scan data
~1.3 fb[-1] R scan, 130 pts

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
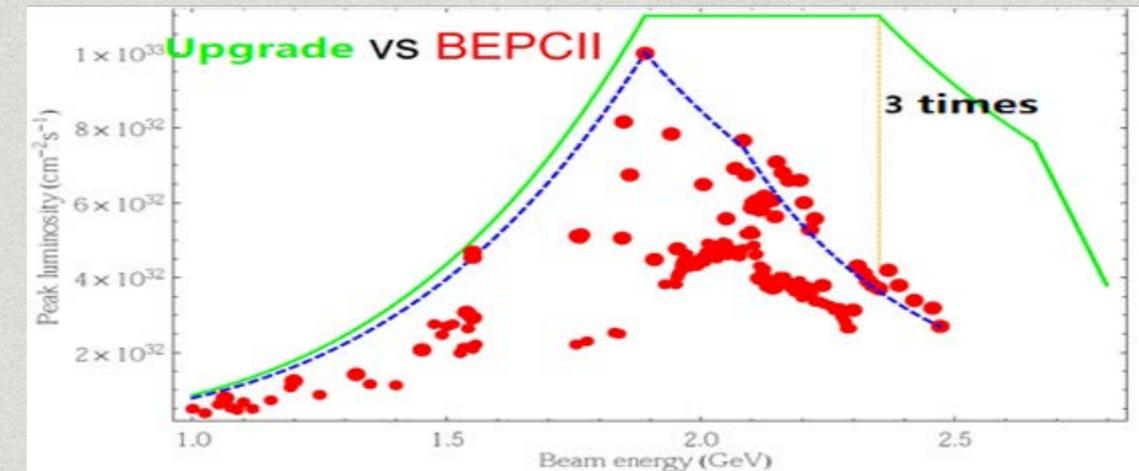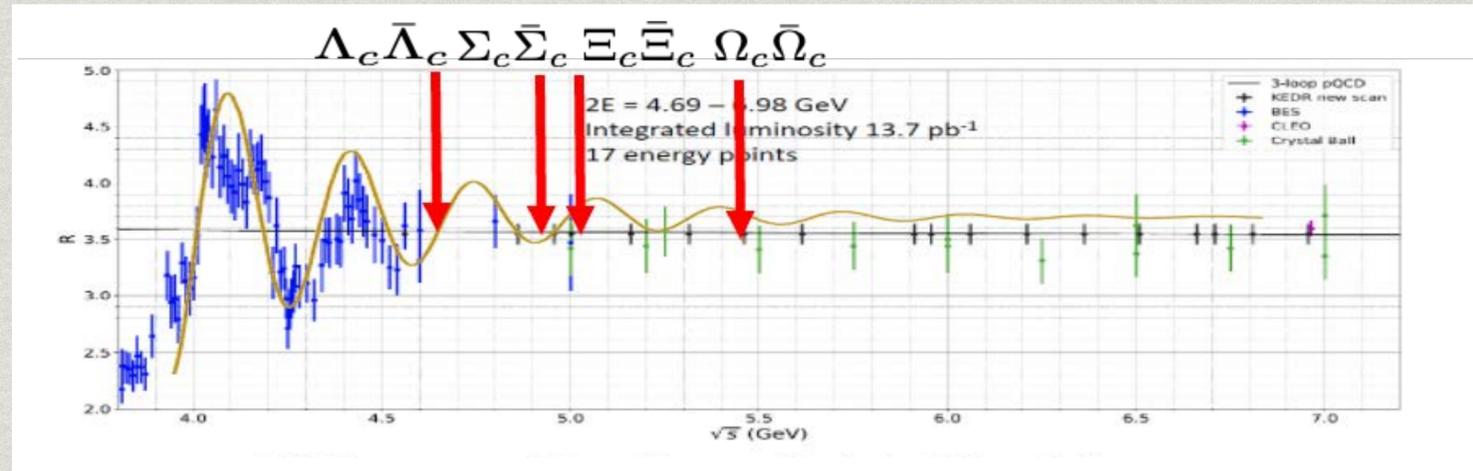
* BEPCII upgrade aims at increasing luminosity by a factor of 3 & increasing beam energy to 2.8 GeV

* 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
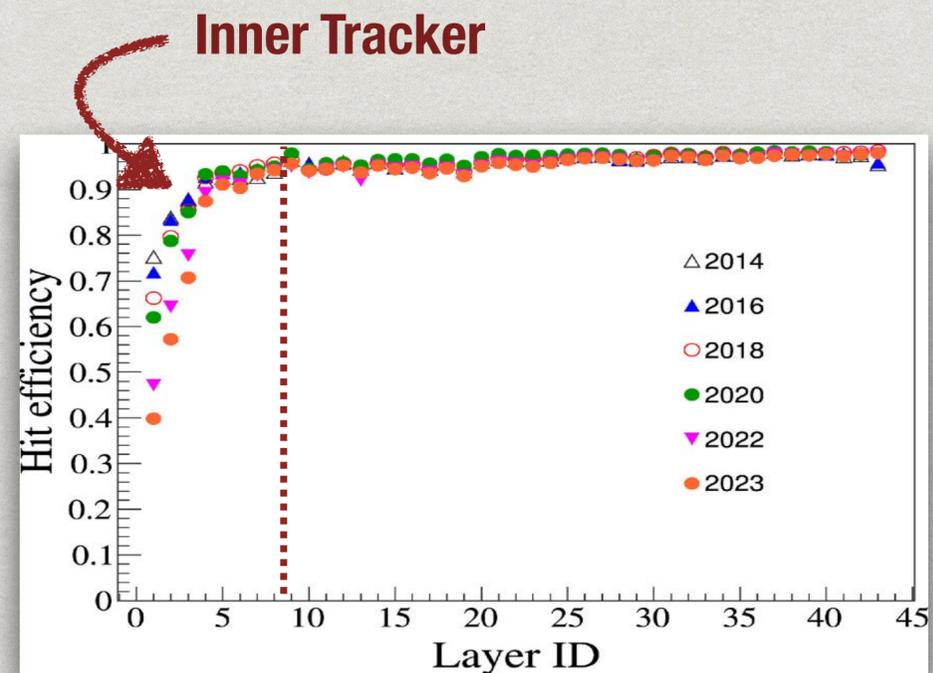
Inner Tracker

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

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)

Det...
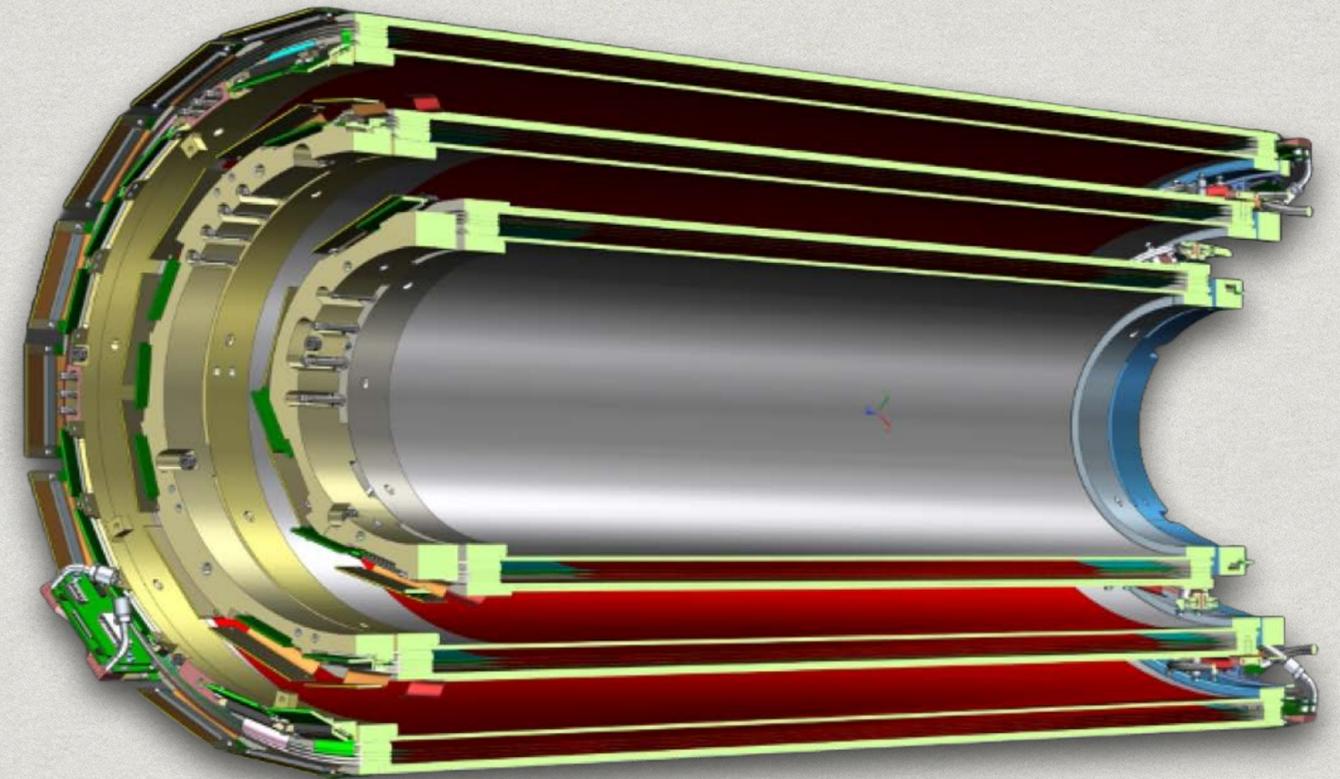
Designed to provide mechanical robustness

with relatively low material budget

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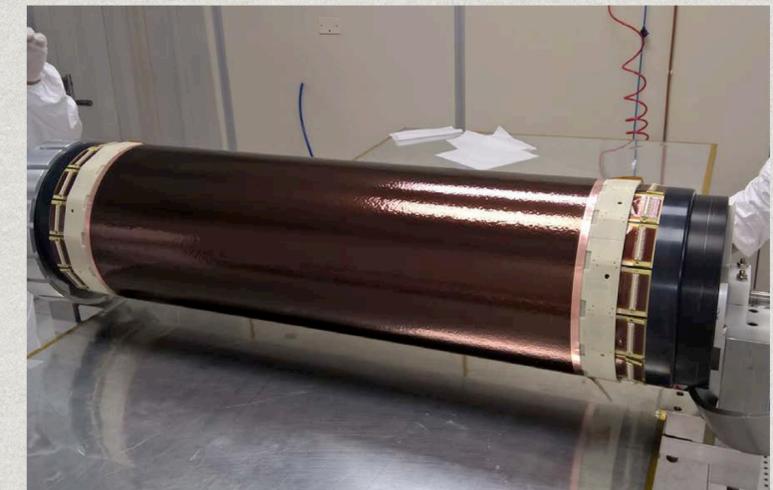* Gas mixture: Ar/Isobutane 90/10
* Large drift gap for microTPC

L3
L2
L1

94.2 mm
136.7 mm
179.25 mm

ANODE

GEM 3 — 2 mm
GEM 2 — 2 mm
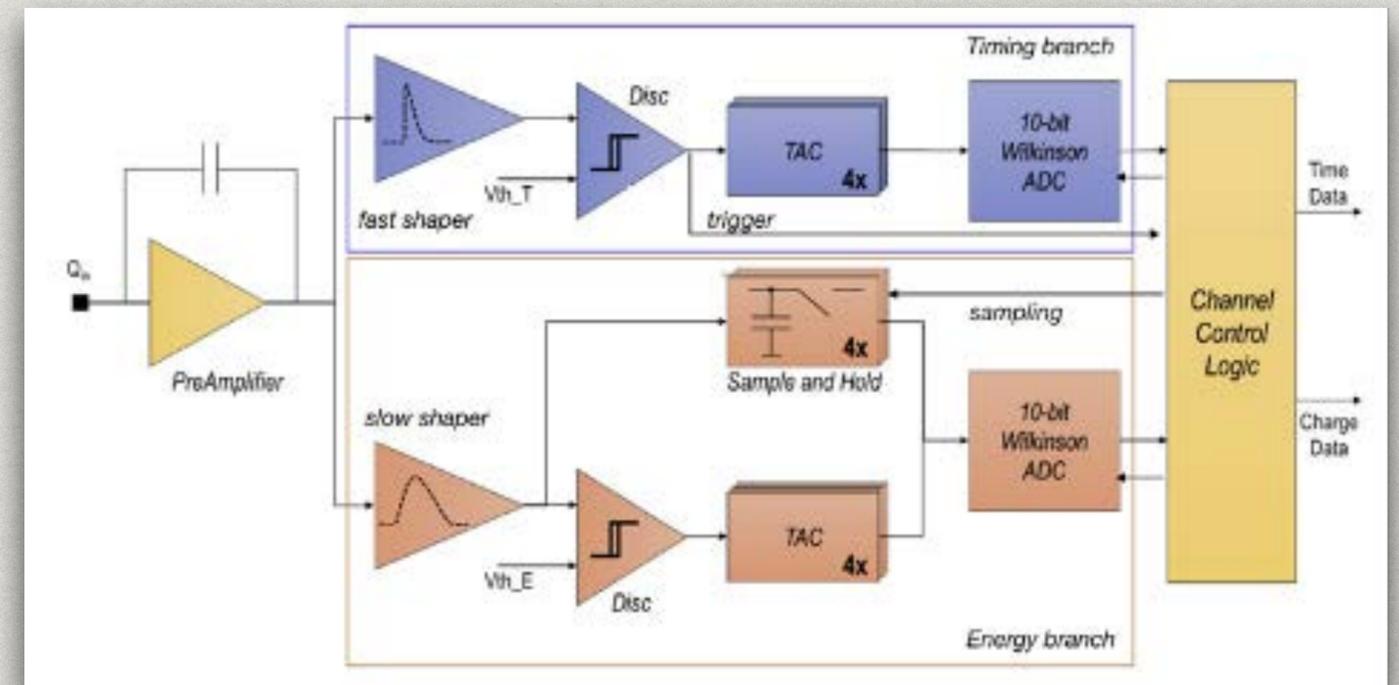GEM 1 — 2 mm
— 5 mm
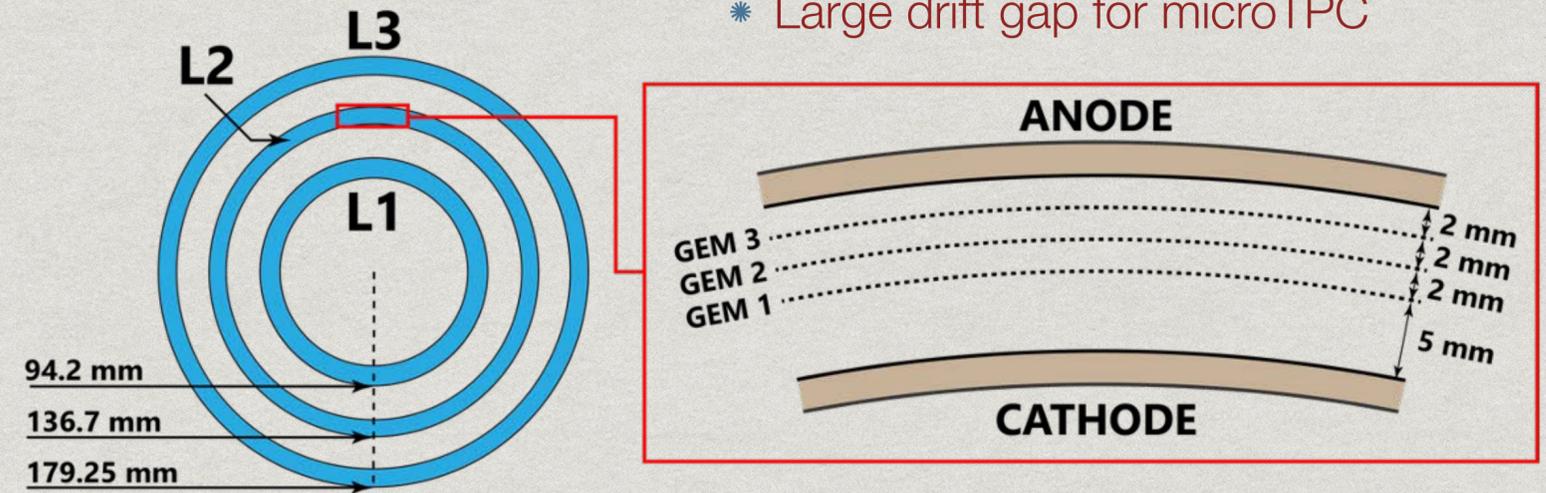
CATHODE

Cathode

3 GEMs

Anode

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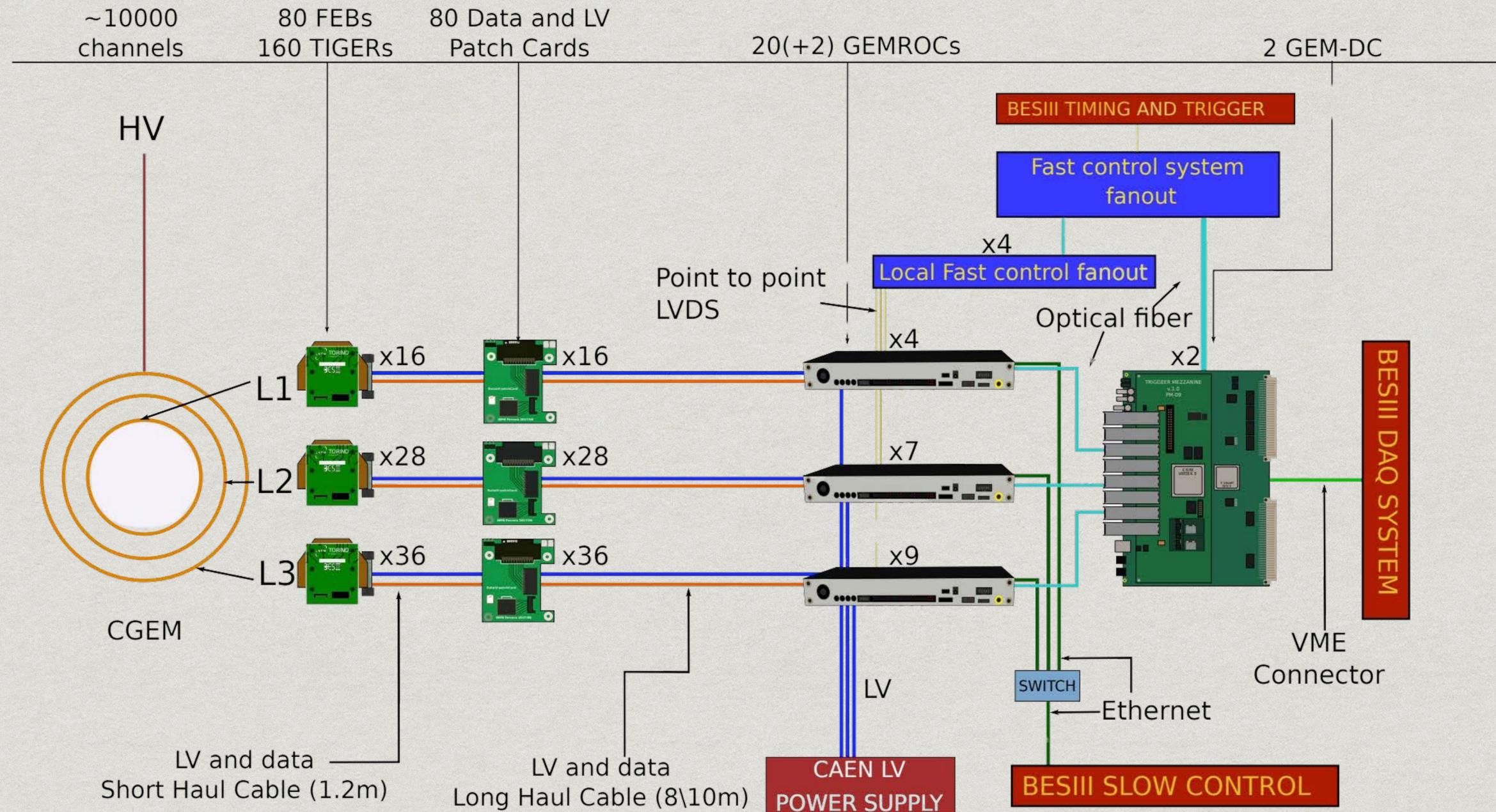
Electronics design

* 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
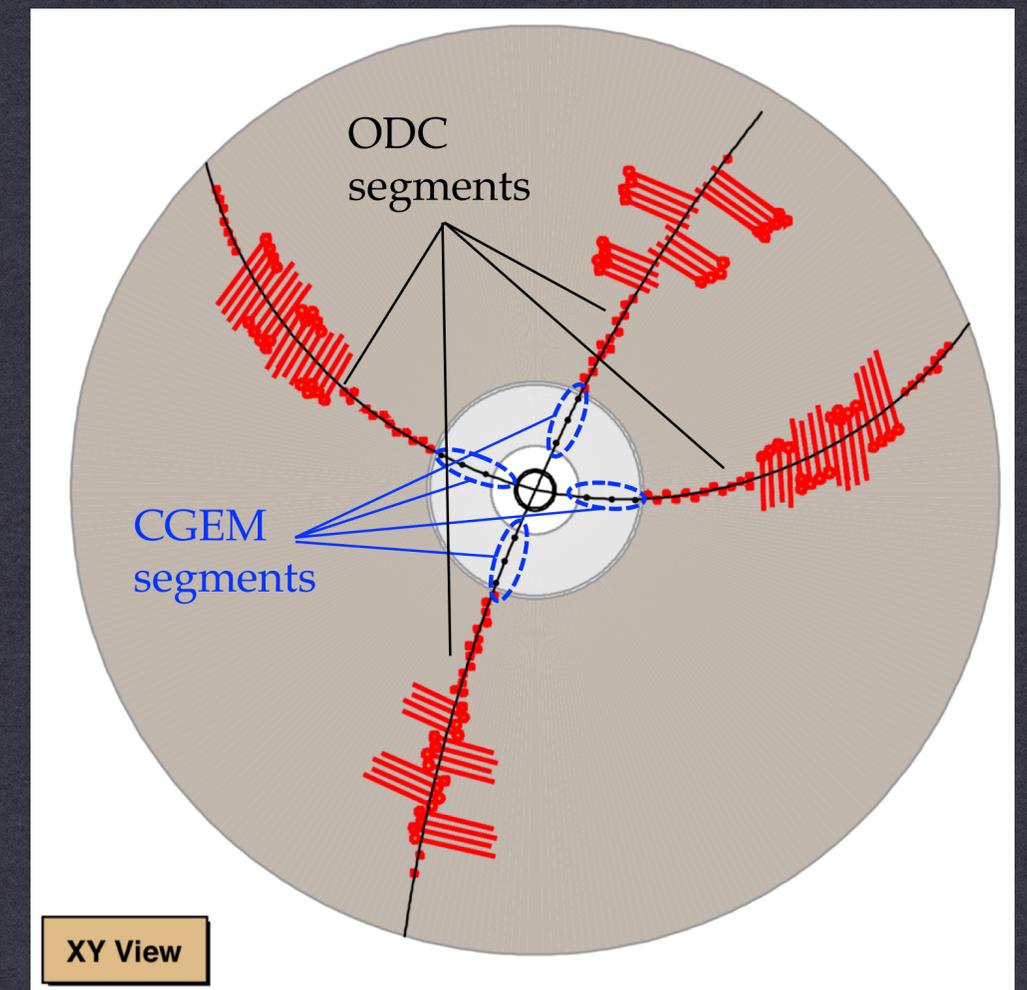
* 12 mW/ch power

* SEU tolerant digital part

Tested also on microRWELL

CGEM-IT system implementation

~10000 channels

80 FEBs
160 TIGERs

80 Data and LV
Patch Cards

20(+2) GEMROCs

2 GEM-DC

HV

BESIII TIMING AND TRIGGER

Fast control system fanout

x4

Local Fast control fanout

Point to point LVDS

x4

Optical fiber

x2

HV

L1 x16 x16

L2 x28 x28 x7

L3 x36 x36 x9

CGEM

BESIII DAQ SYSTEM

LV

VME Connector

SWITCH

Ethernet

LV and data
Short Haul Cable (1.2m)

LV and data
Long Haul Cable (8\10m)

CAEN LV
POWER SUPPLY

BESIII SLOW CONTROL

more at JINST 16 P08065

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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
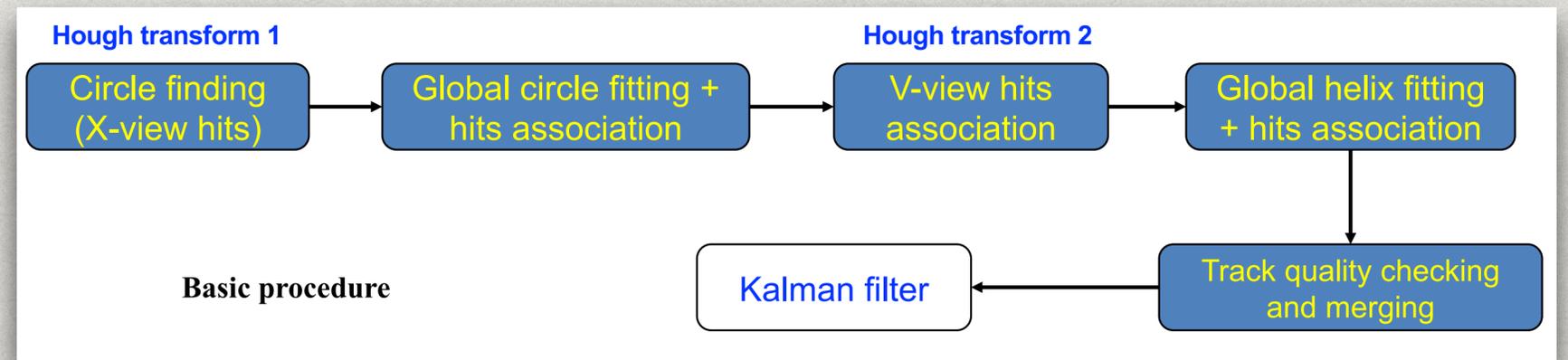
* Both steps use Hough transform to get track candidates and initial track parameters

* A global fitting with Least-Square method is done after each step

Hough transform 1 | Hough transform 2

Circle finding (X-view hits) → Global circle fitting + hits association → V-view hits association → Global helix fitting + hits association

Kalman filter ← Track quality checking and merging

Basic procedure

$X=2x/(x^2+y^2)$
$Y=2y/(x^2+y^2)$

circle pattern (real space) — conformal transform → line pattern (image space) $\rho=X\cos\theta+Y\sin\theta$ **Hough transform 1** → sinusoids (parameter space)

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

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

Expected performance

XY vertex resolution

MDC
CGEM

Z vertex resolution

MDC
CGEM

momentum resolution

MDC
CGEM
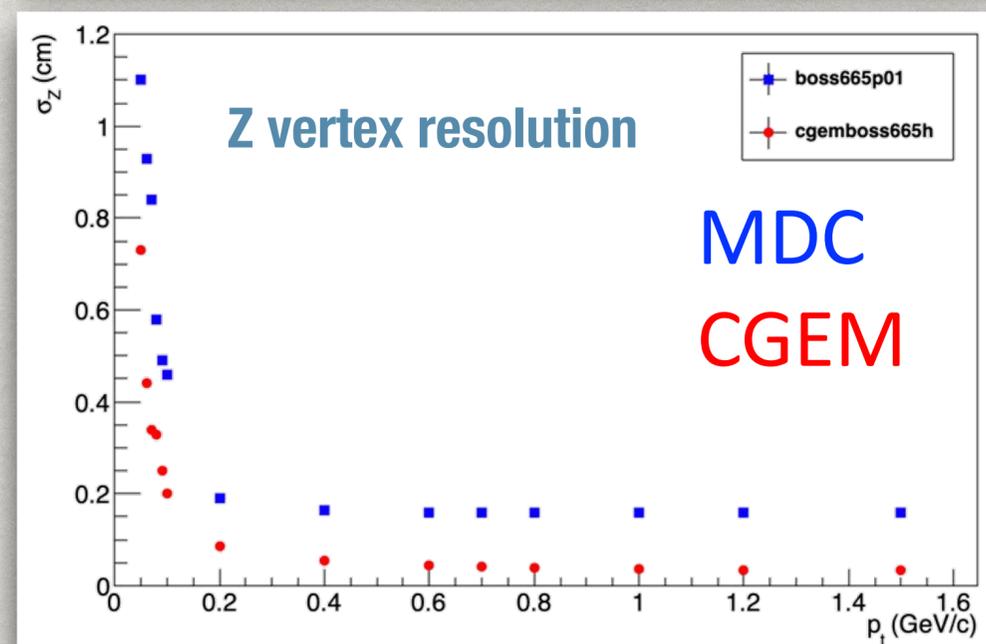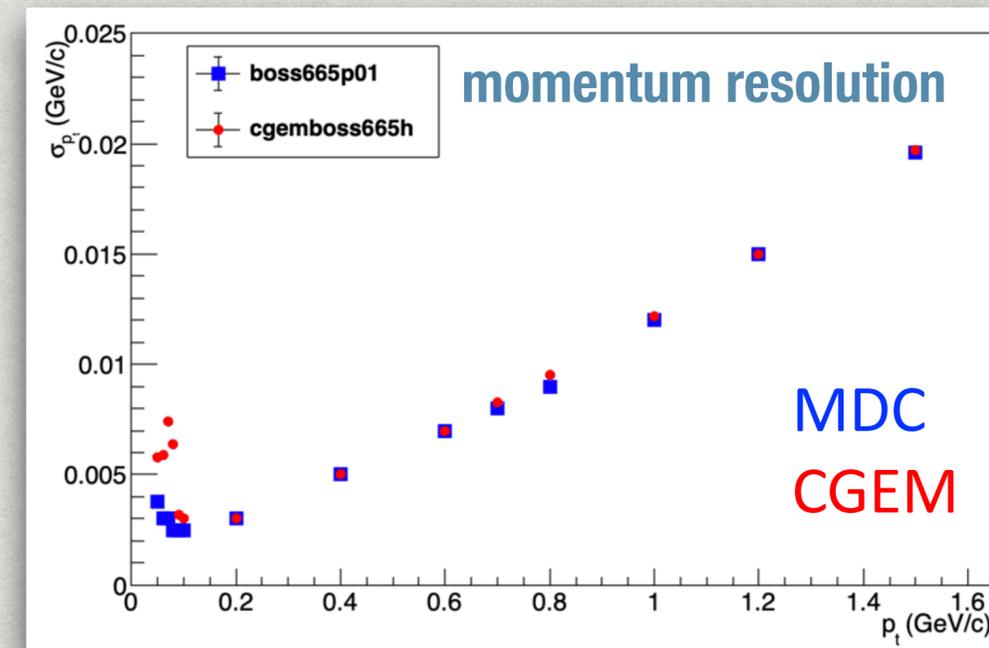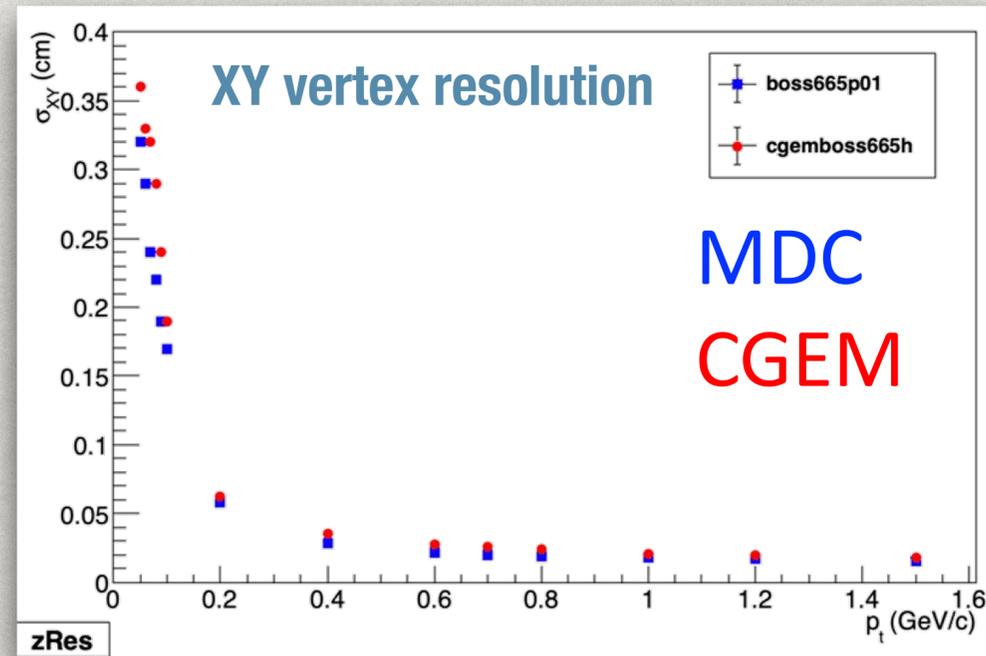
* No
* CGEM XY resolutions slightly worse at low pt
* CGEM Z resolution much better
* Momentum resolution worse only at very low pt

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Tracking efficiency with CGEM
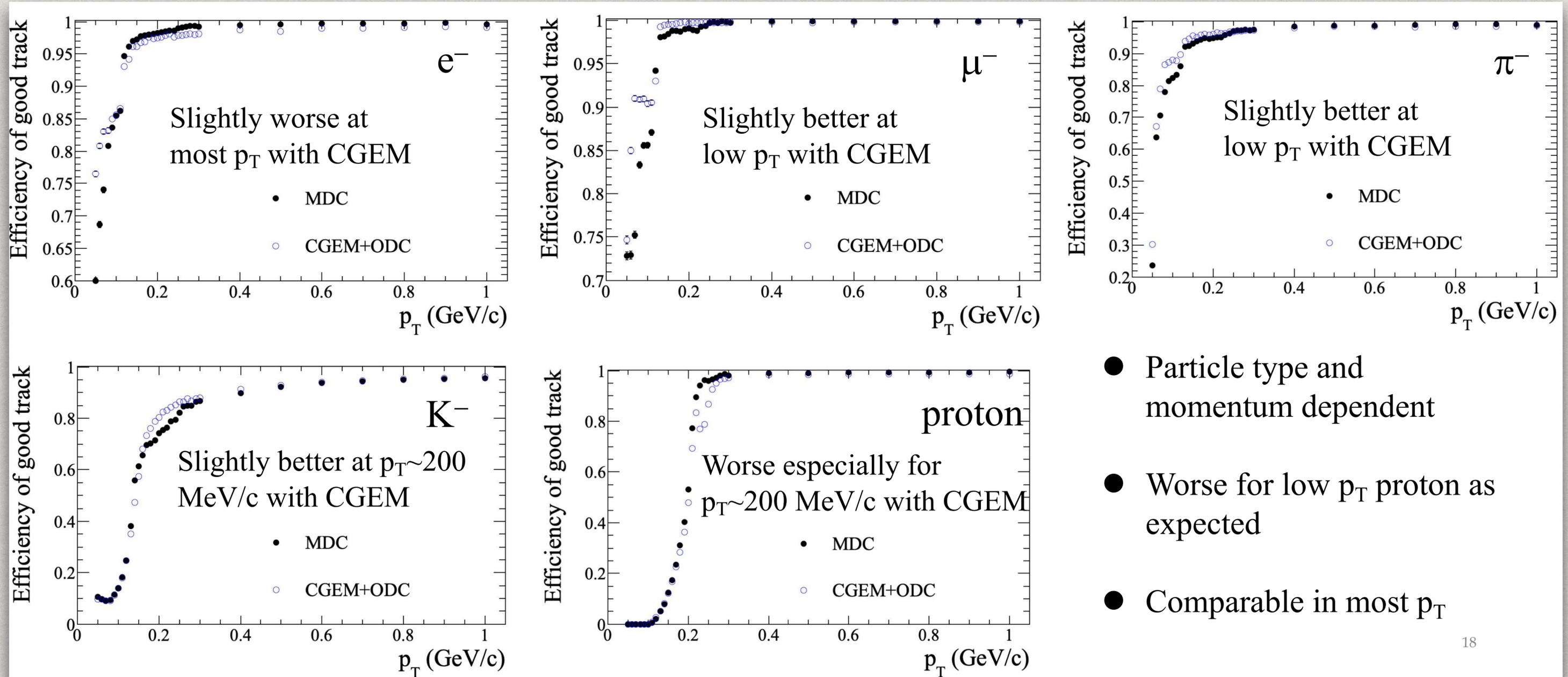
- Particle type and momentum dependent

- Worse for low p_T proton as expected

- Comparable in most p_T

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Impact on vertex reconstruction
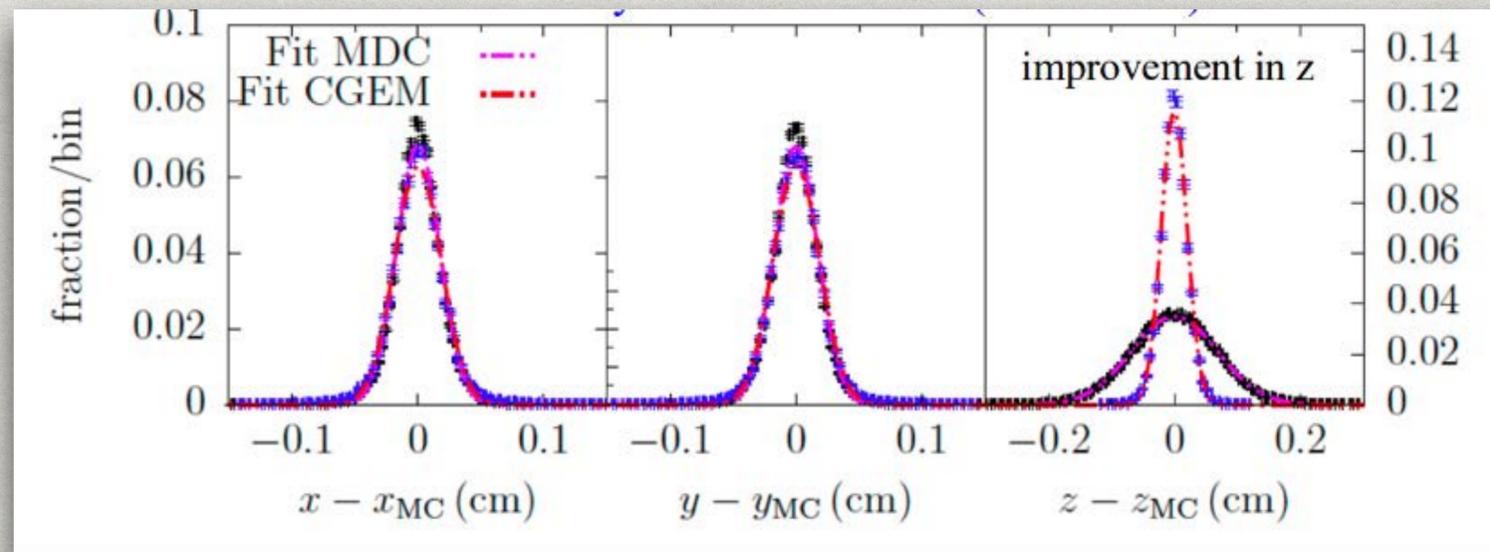
* Expected impact on vertex reconstruction

* Better separation for complex topologies and improvements on secondary vertexes, both crucial for charmed baryon decays

decay topology example

Track finding in a local approach
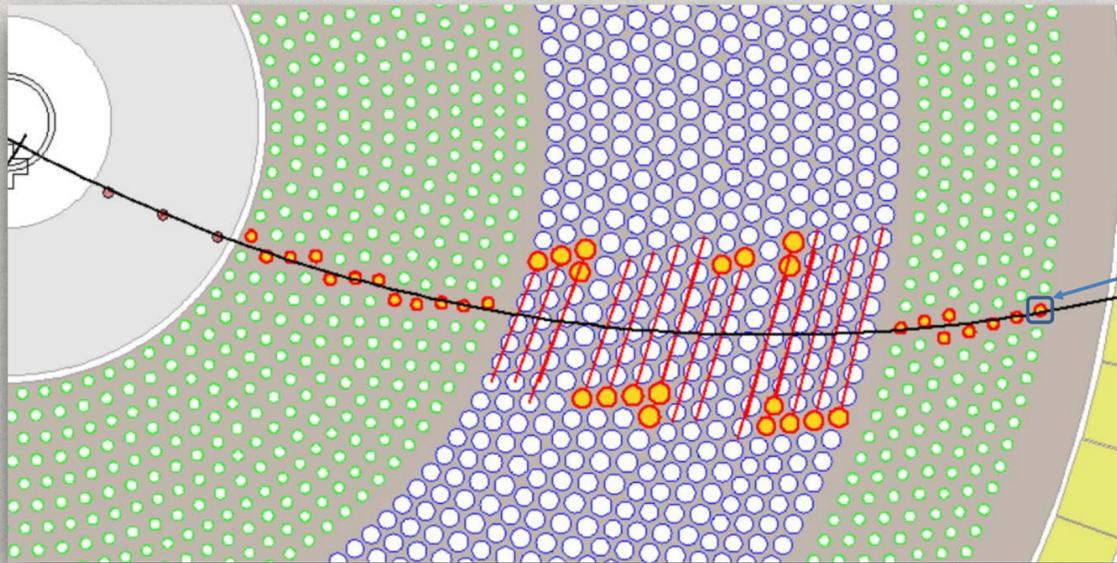
* To keep high efficiency for tracks from displaced vertex the assumption (or constraint) of tracks from origin should not be used

* 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

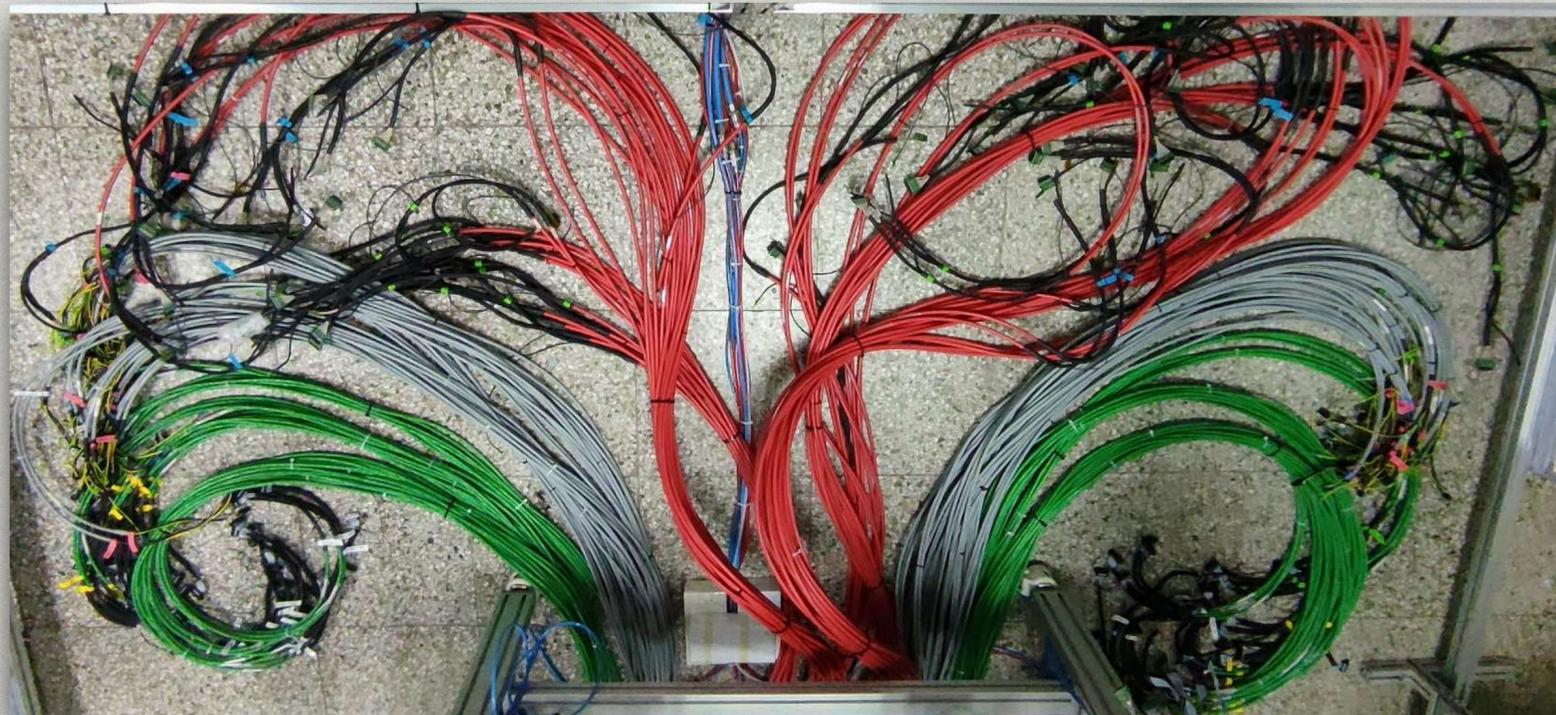* A Track Following (TF) method by selecting adjacent DC hits is implemented
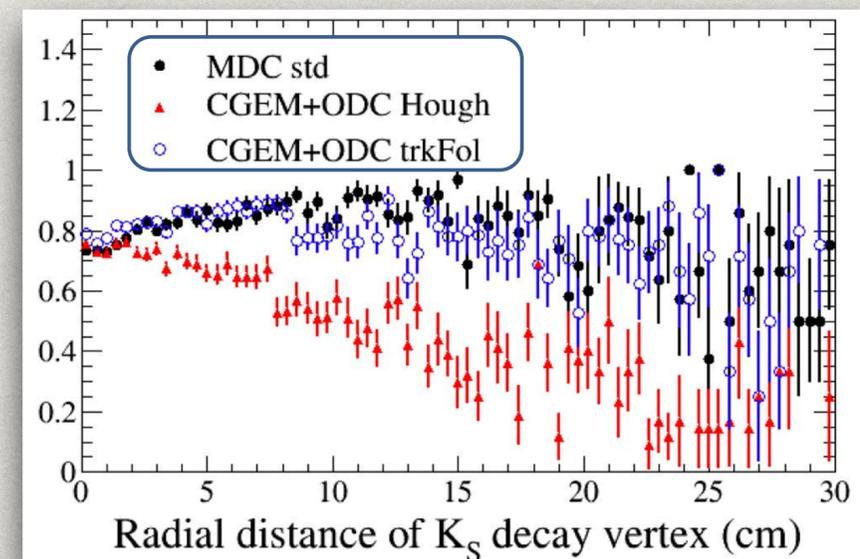
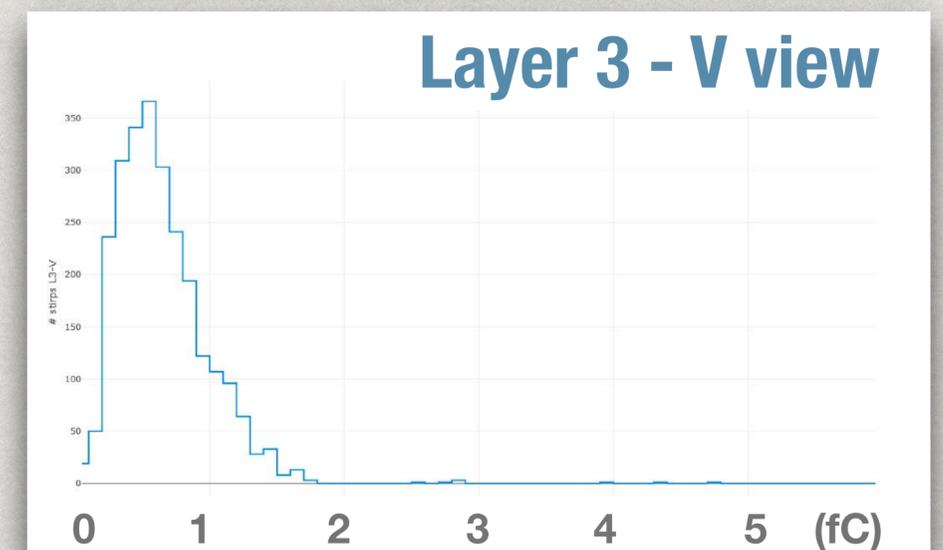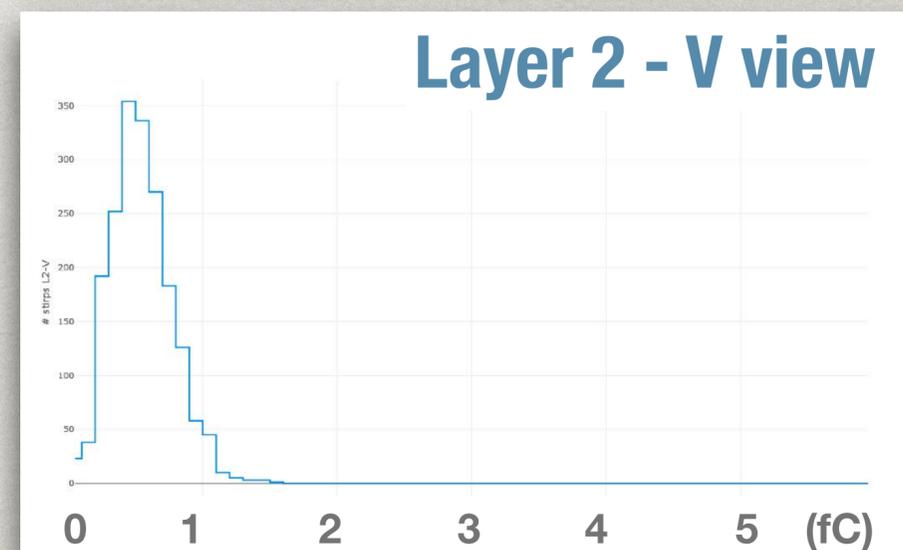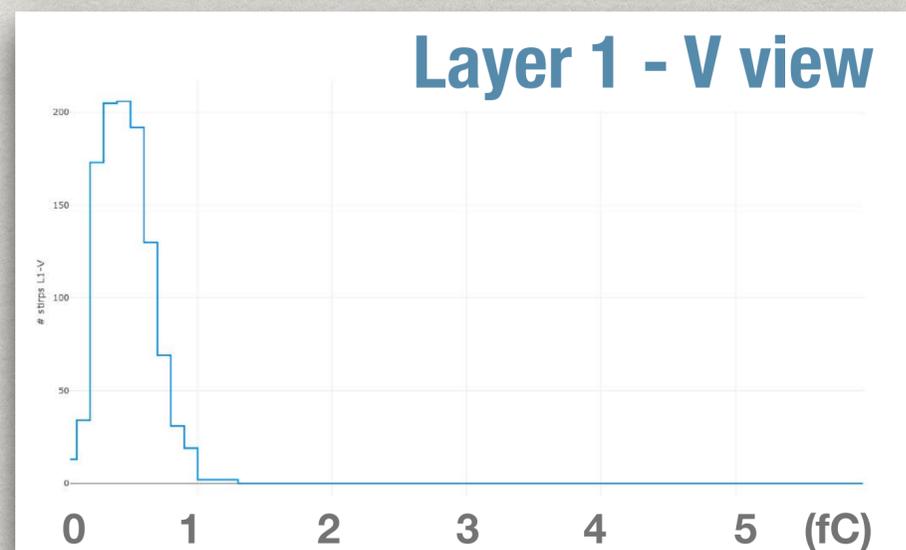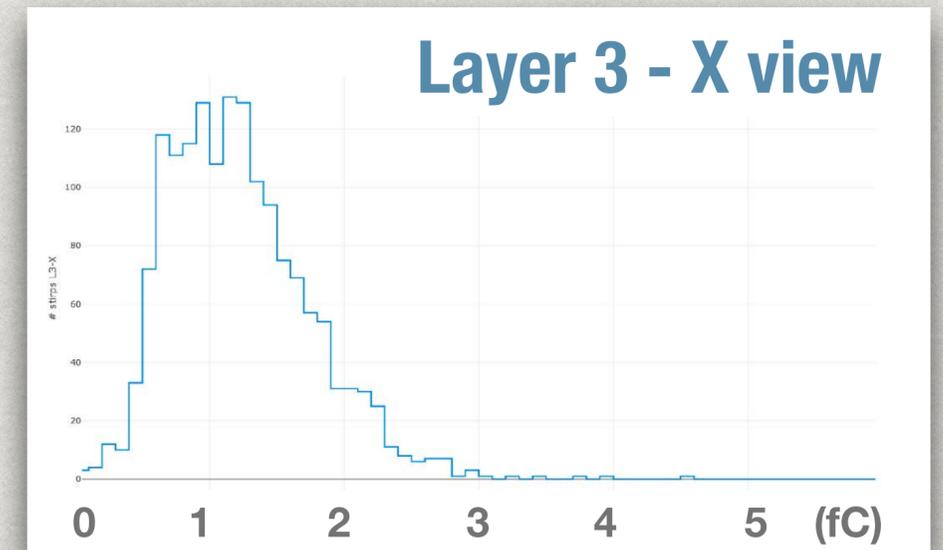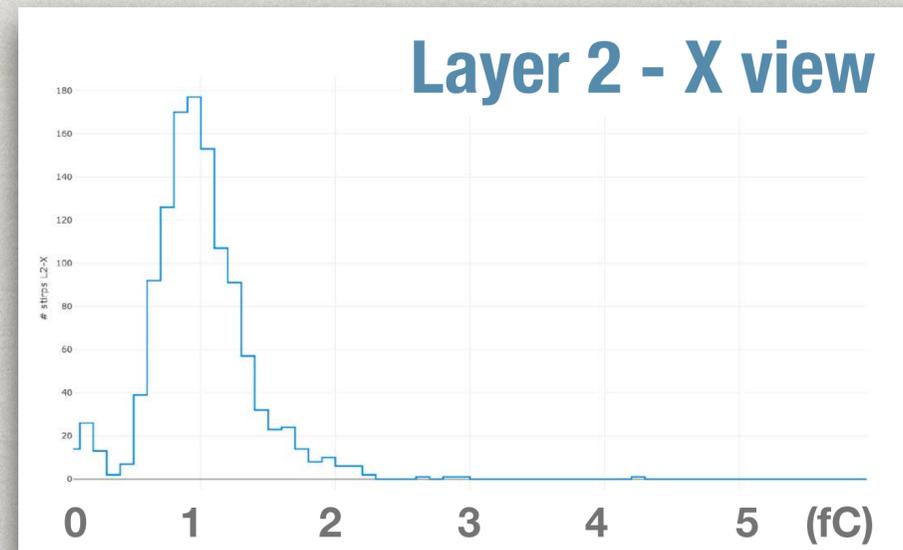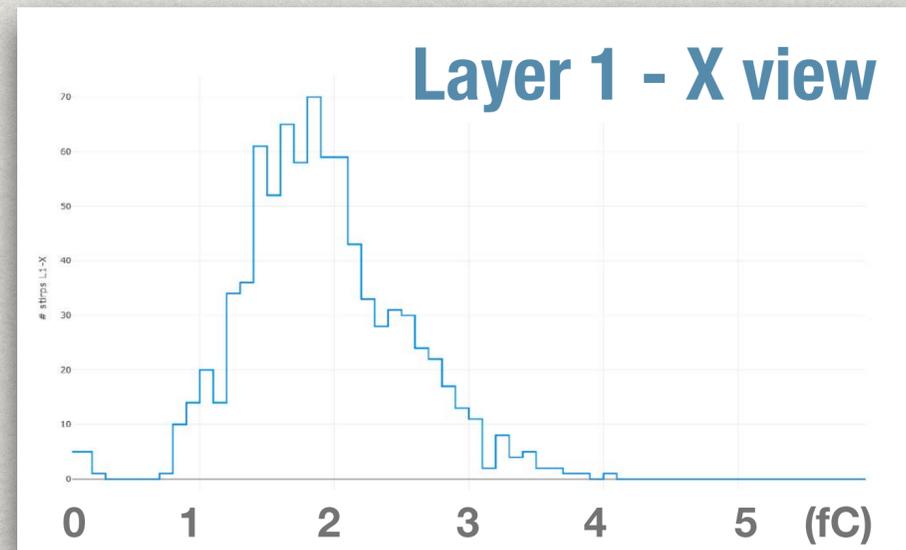K_S sample generated with p=0~2 GeV/c and all decay to $\pi^+\pi^-$

STATUS OF THE PROJECT

Detector staging

* Standalone commissioning with cosmics before installation

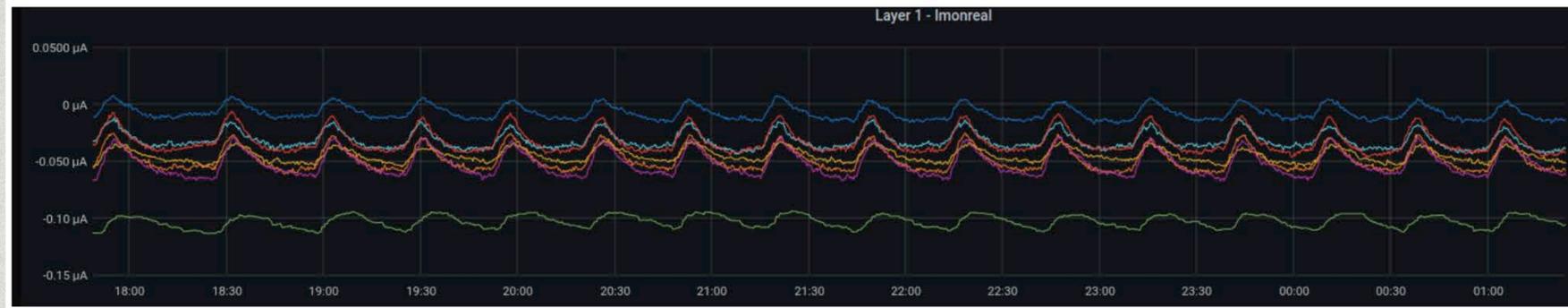* Continuous running for operations and performance
  evaluation

Noise distributions

Layer 1 - X view

Layer 2 - X view

Layer 3 - X view

Layer 1 - V view

Layer 2 - V view

Layer 3 - V view
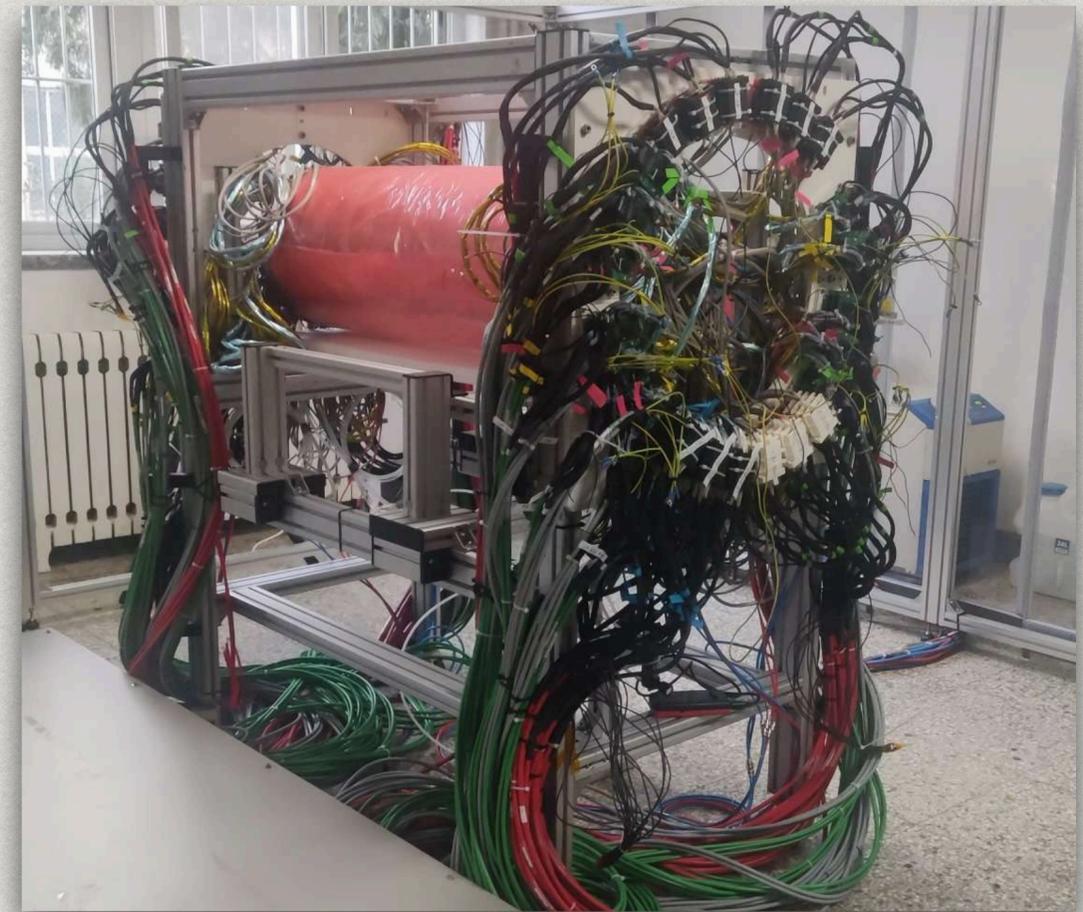
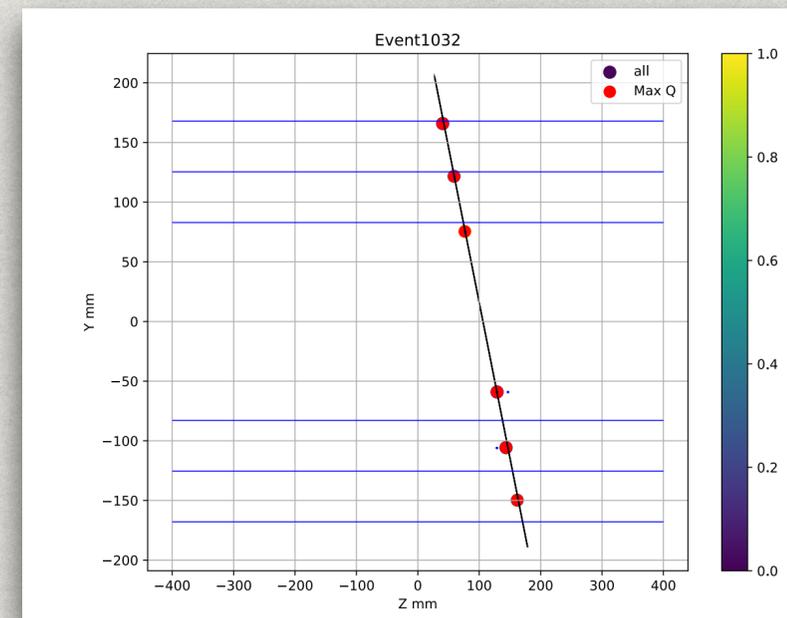# Detector operations

Detector currents

layer 1

layer 2

layer 3

Charge per strip distribution
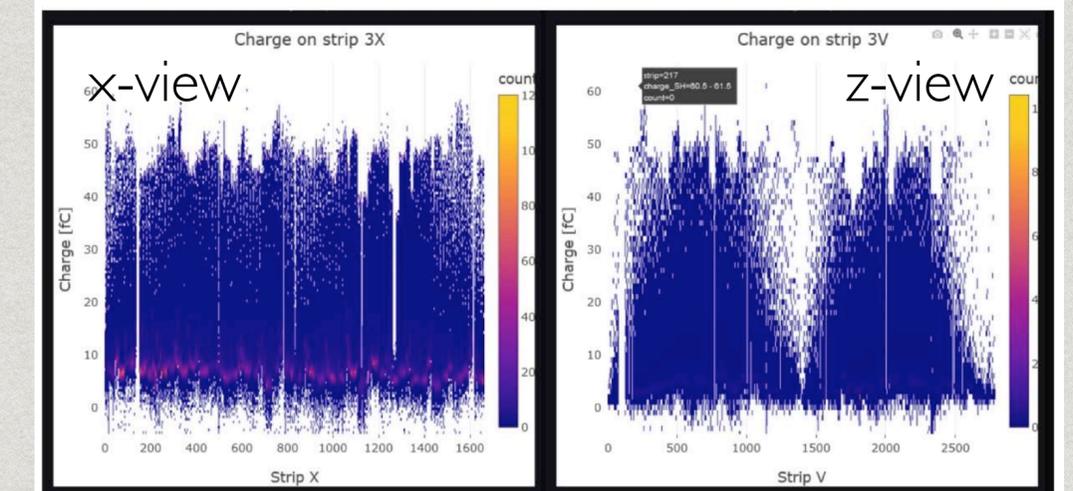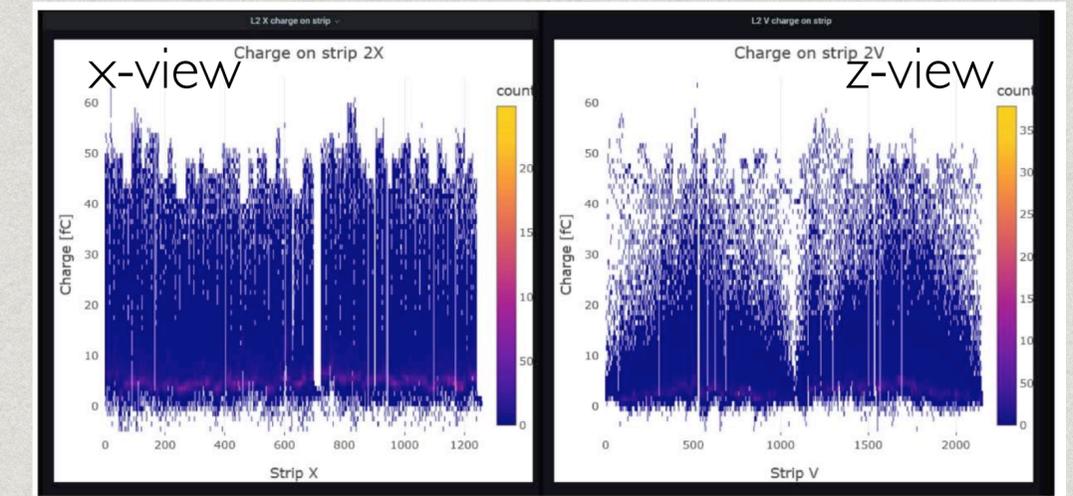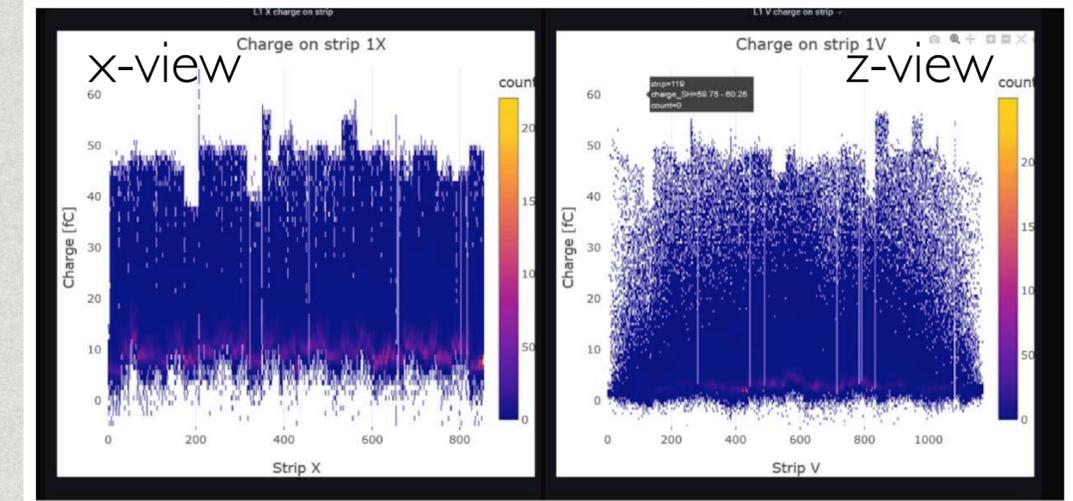
Performance evaluation with cosmics
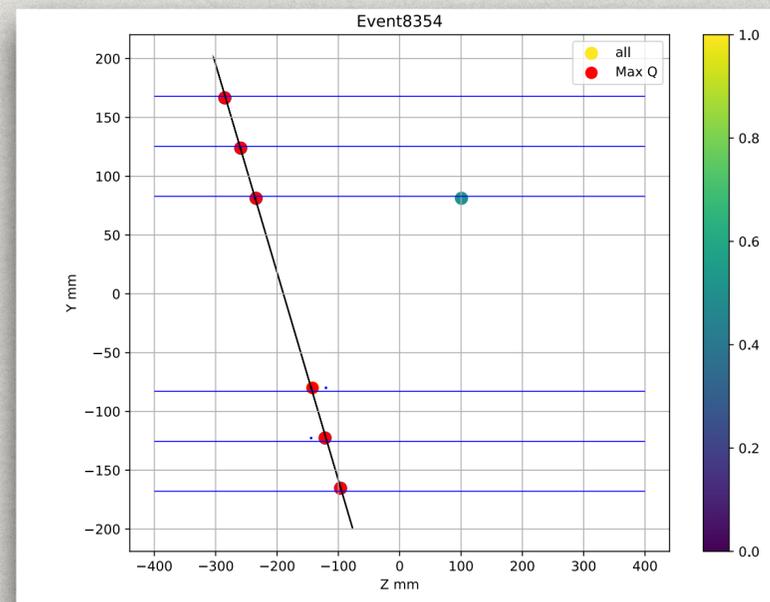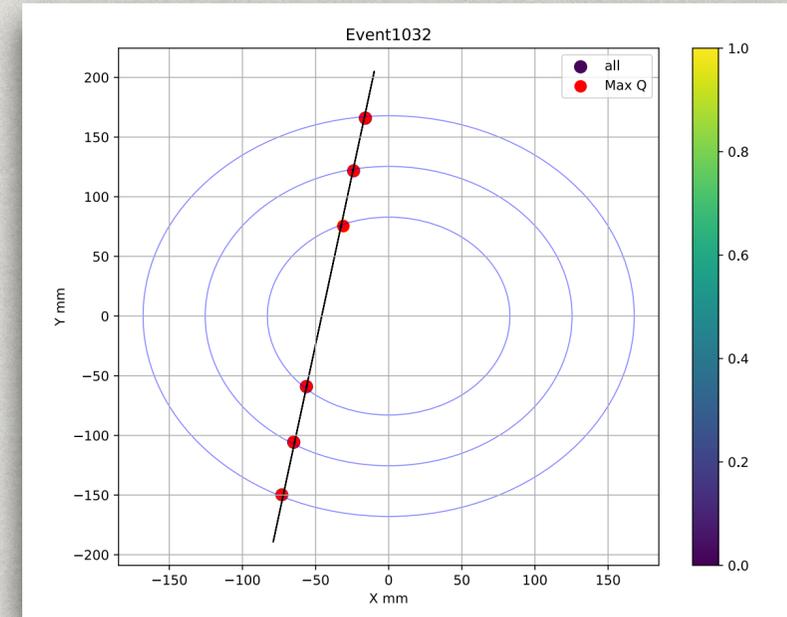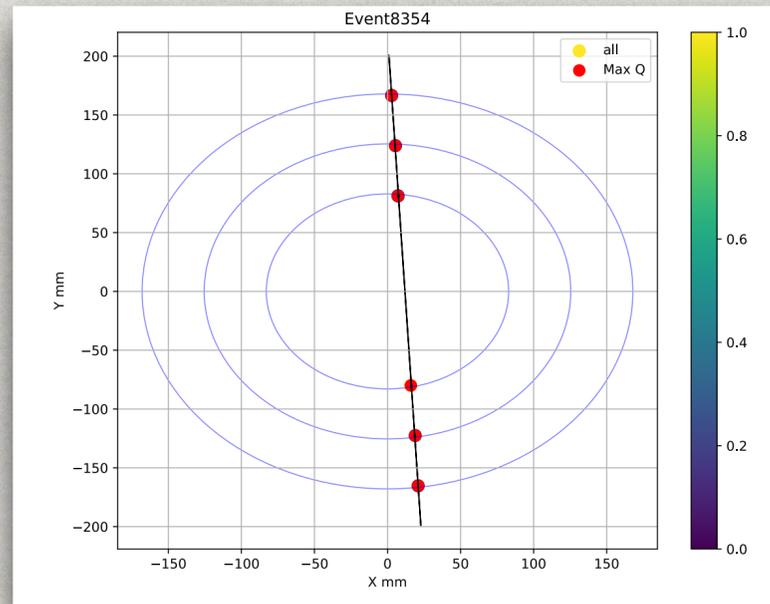
Alignment and residuals

3D event display

- Fired V strip
- Cosmic ray
- 2D clusters
- Fired X strip

* 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)
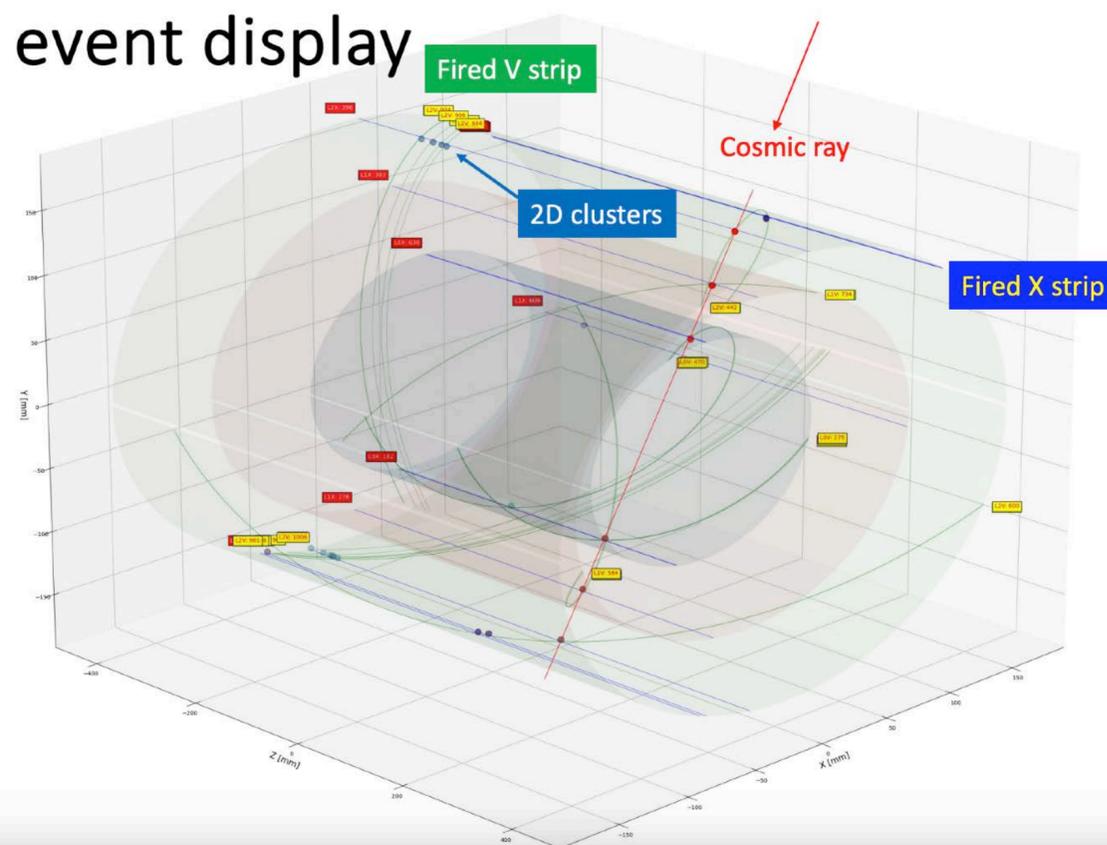
Residual comparison
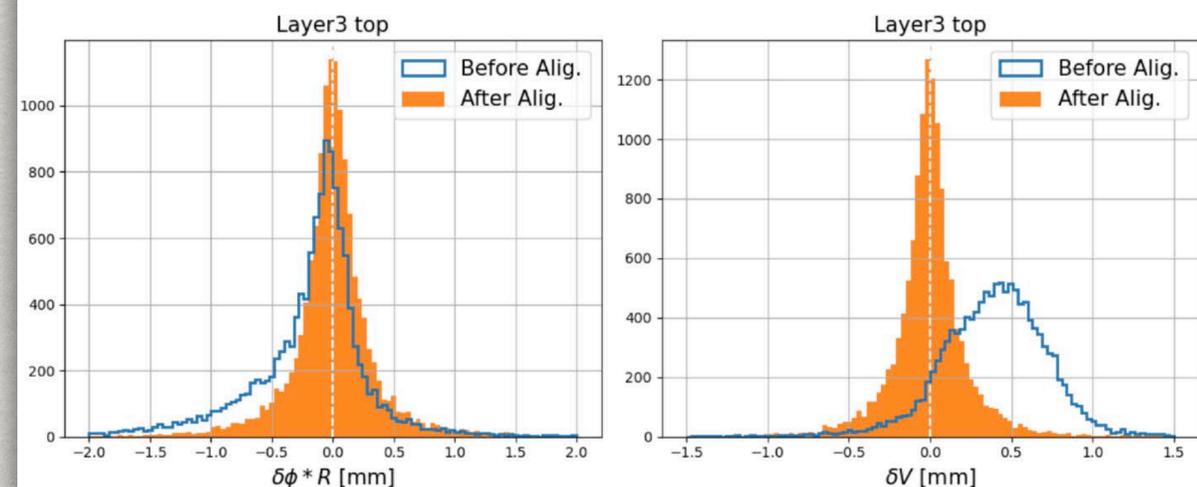
χ^2 comparison
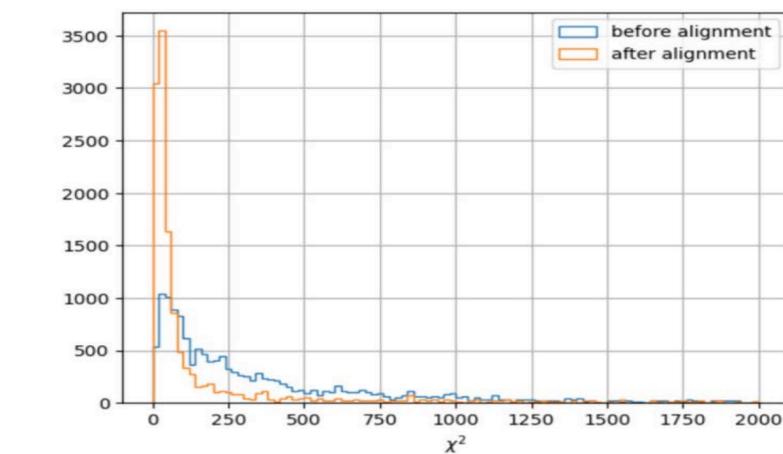
χ^2 distribution is improved significantly after alignment !

Detector performance
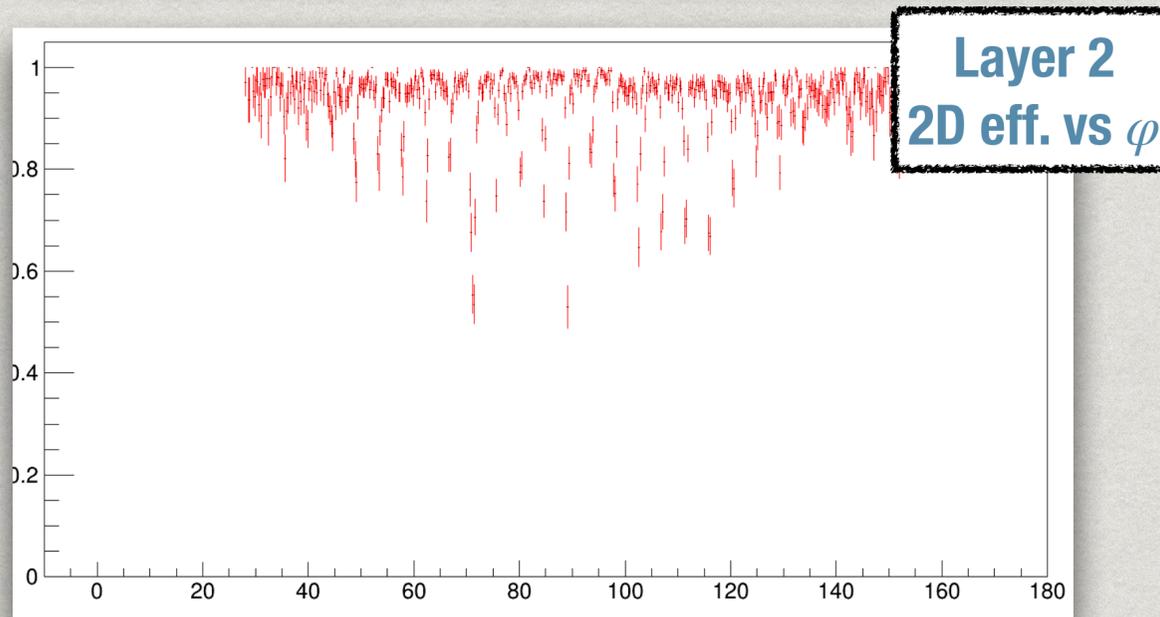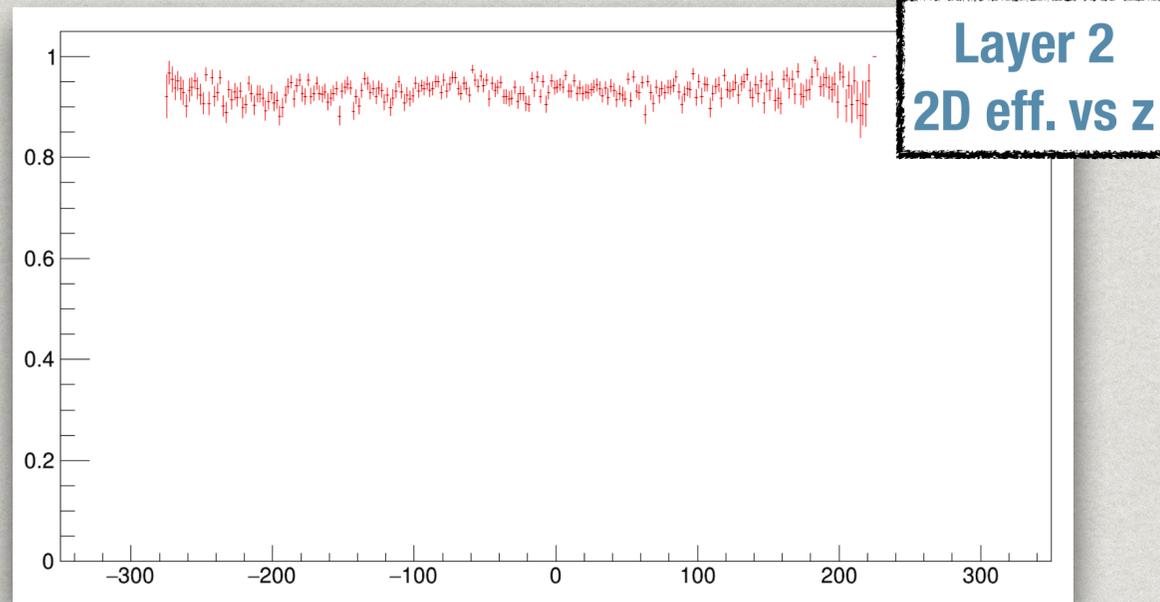
- Double-view efficiency above 95% for all layers

- HV segmentation clearly visible in the φ view

- Residual distributions for almost orthogonal tracks $< 200\ \mu m$ including contribution from tracking

Layer 2 2D eff. vs z

Layer 2 2D eff. vs φ

Residual distributions

Layer 3 TOP
Layer 2 TOP
Layer 1 TOP

Relative frequency/0.1 mm
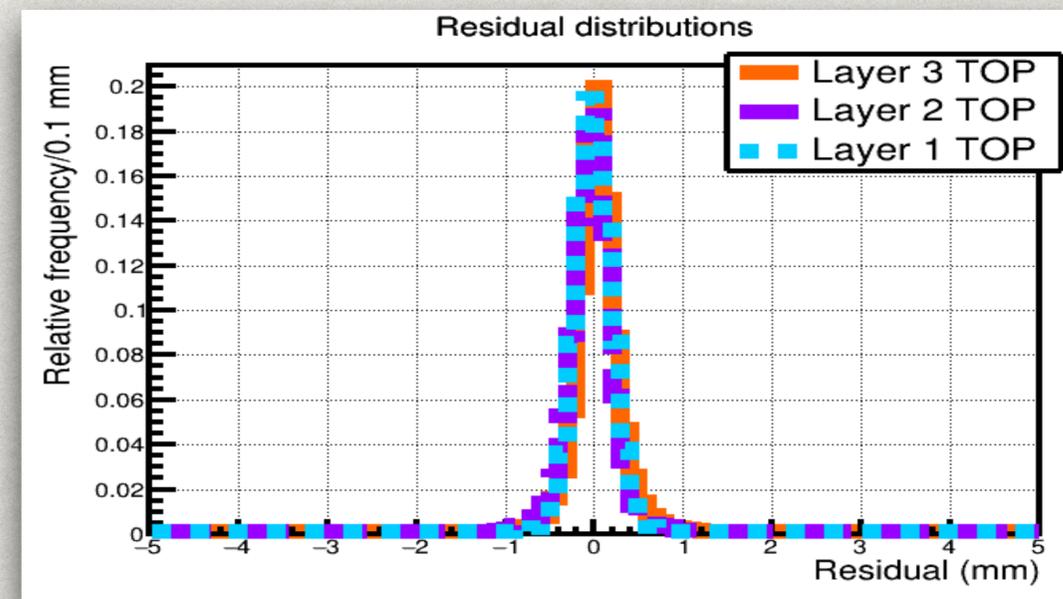
Residual (mm)

$r\varphi$ **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
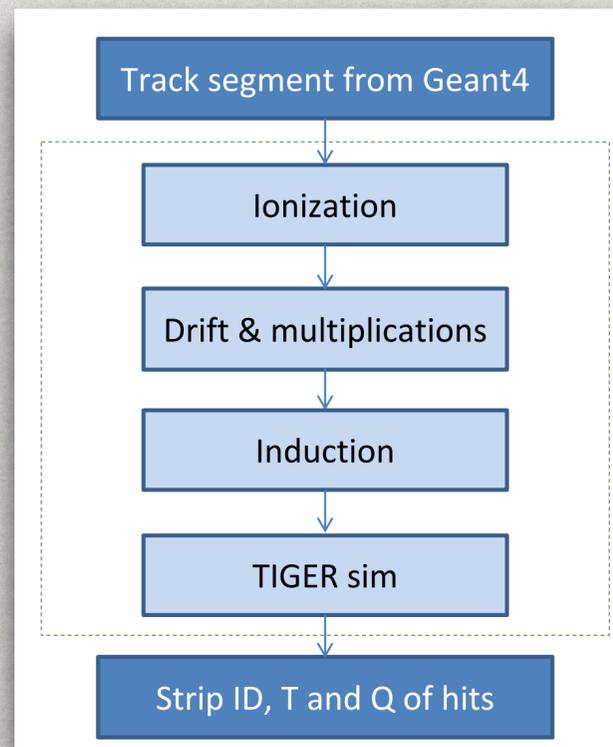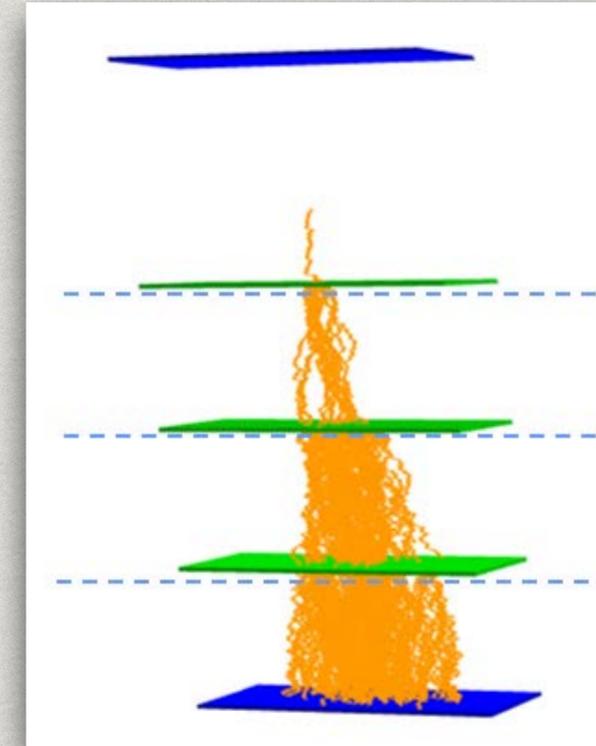
  - Induction ... eed in Garfield++

  - ... e --> parameterized model based on ... ation results

  - ... itization from Garfield++ simulation results

```
Track segment from Geant4
        ↓
    Ionization
        ↓
Drift & multiplications
        ↓
    Induction
```

n_0, ϕ_0, z_0, t_0
(From Garfield++)

n_m, ϕ_m, z_m, t_m
(By sampling)

ID, T & Q of fired

	Drift	Transfer1	Transfer2
(degree)	25.5	10.9	10.9
	$0.0725+0.0918*\delta Y-0.0140*(\delta Y)^2+0.00121*(\delta Y)^3$	0.174	0.174
	$0.0674+0.0762*\delta Y-0.0111*(\delta Y)^2+0.00089*(\delta Y)^3$	0.170	0.169
	$4.917+29.16*\delta Y$	58.47	58.33
	$0.855+1.116*\delta Y-0.202*(\delta Y)^2+0.0200*(\delta Y)^3$	2.152	2.132

Region	GEM foil 1	GEM foil 2	GEM
τ (%)	80.9	61.4	61.6
G_0	20.0	21.0	27.9

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
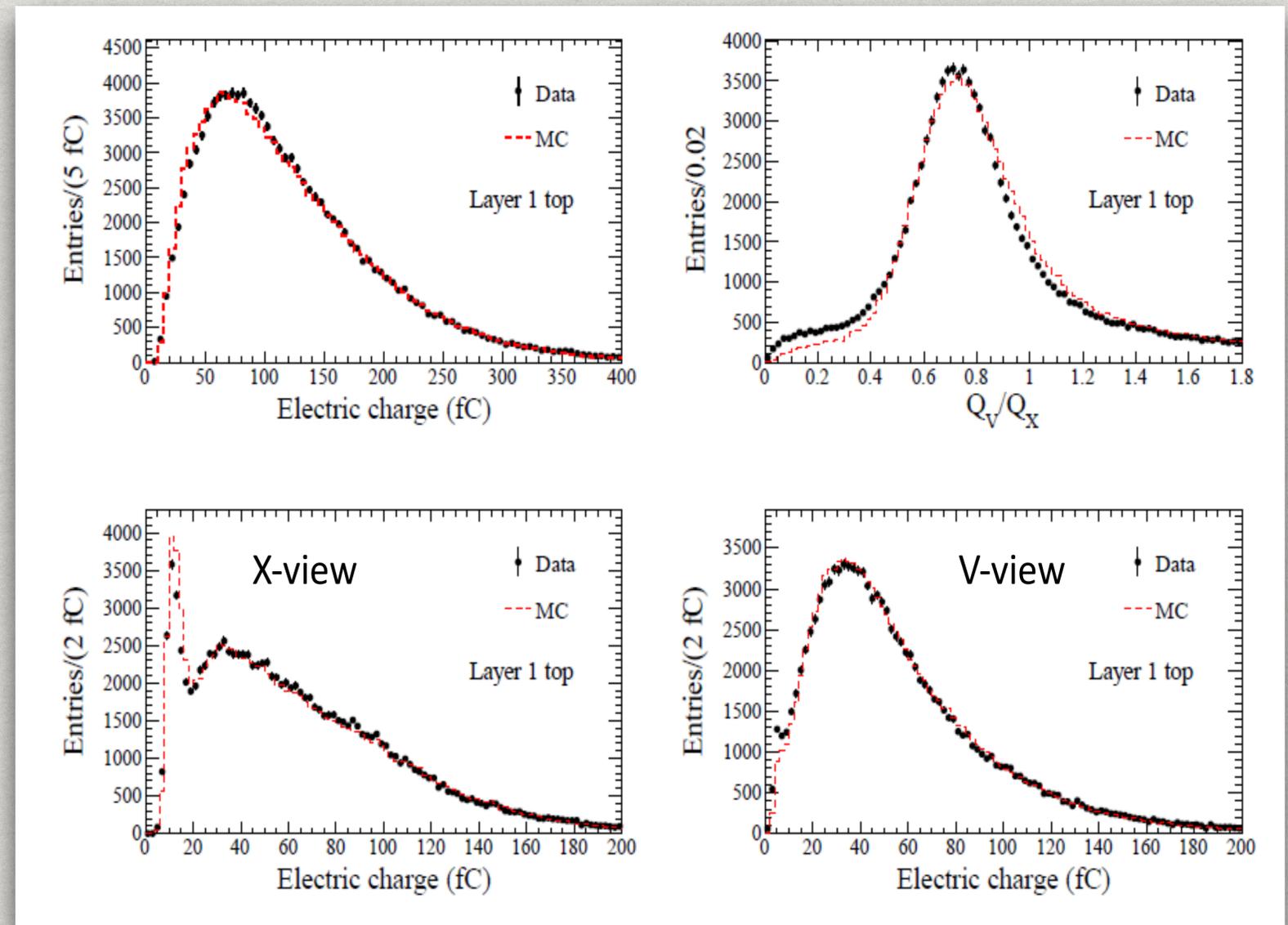
more at JINST 18 P05027
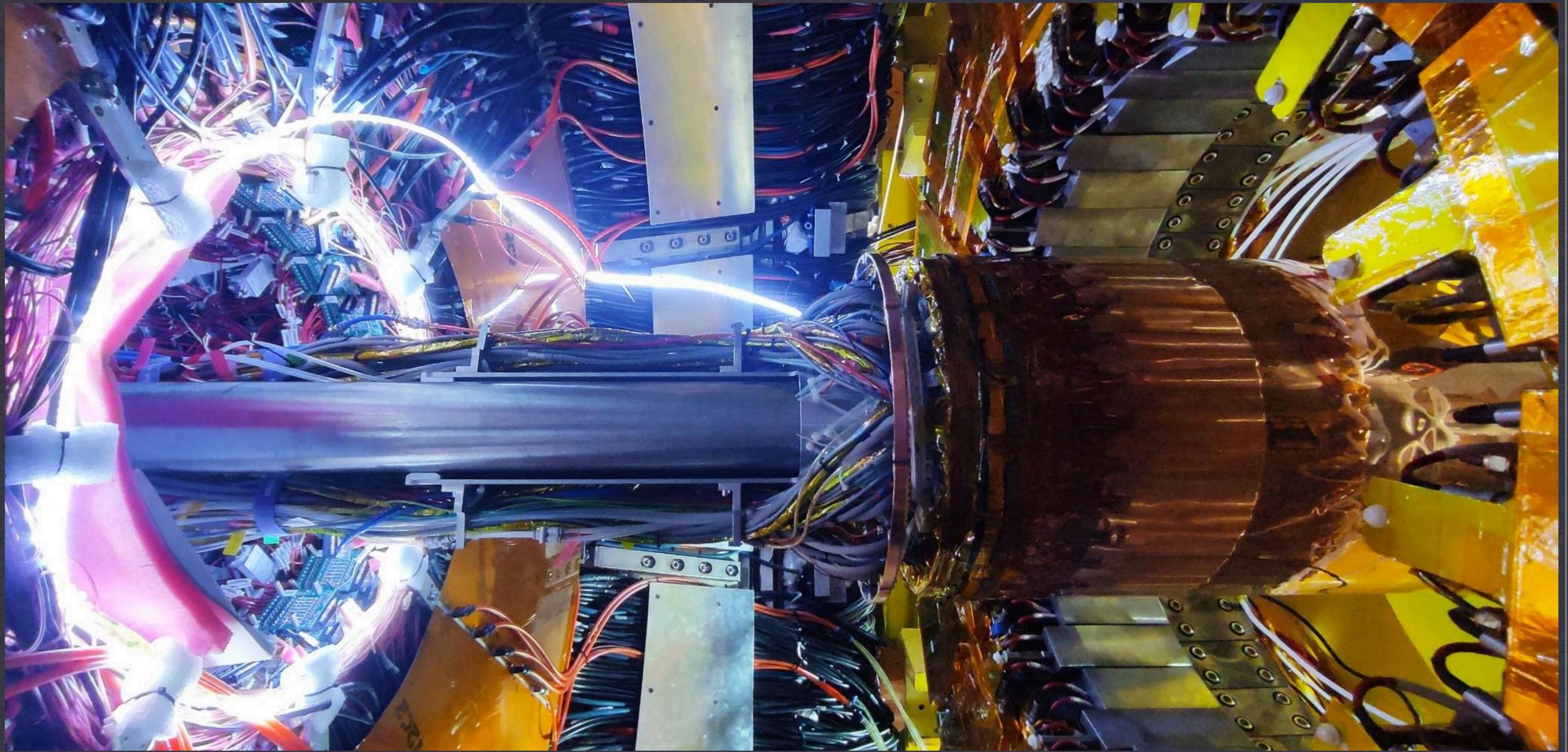
INSTALLATION AND COMMISSIONING OF THE DETECTOR
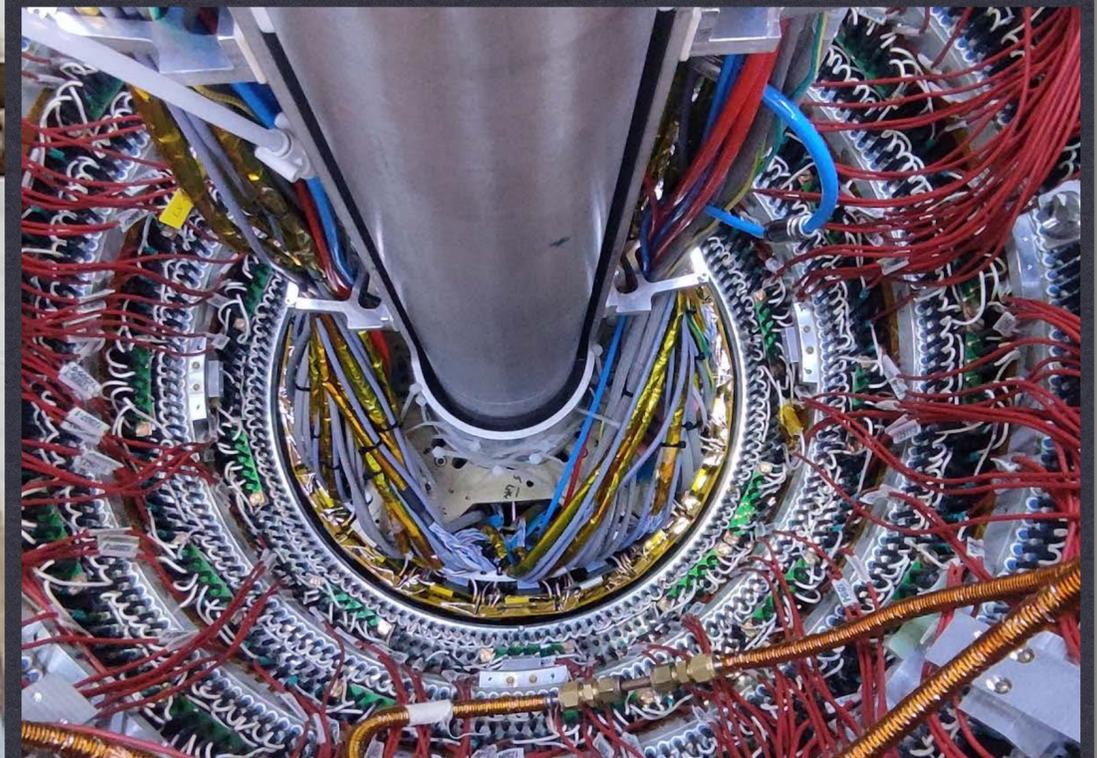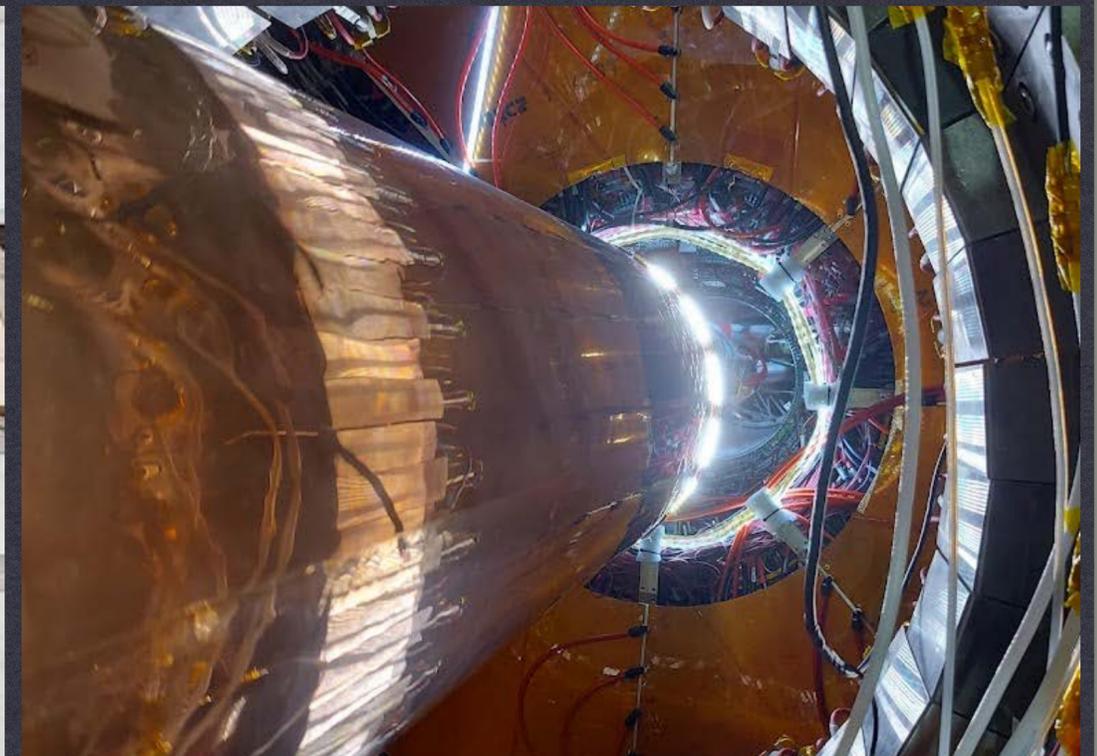
DETECTOR INSTALLATION
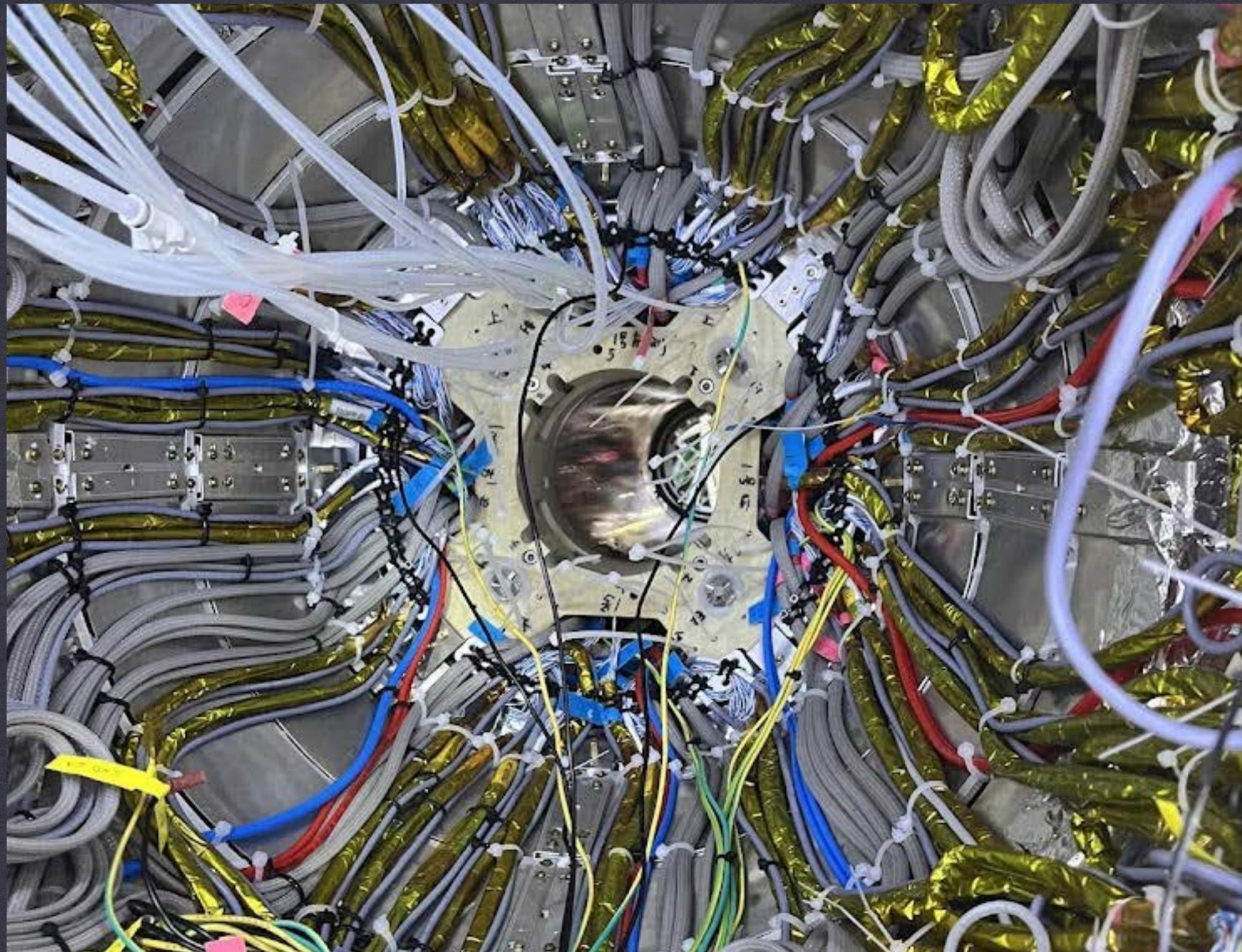
DETECTOR CABLING

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
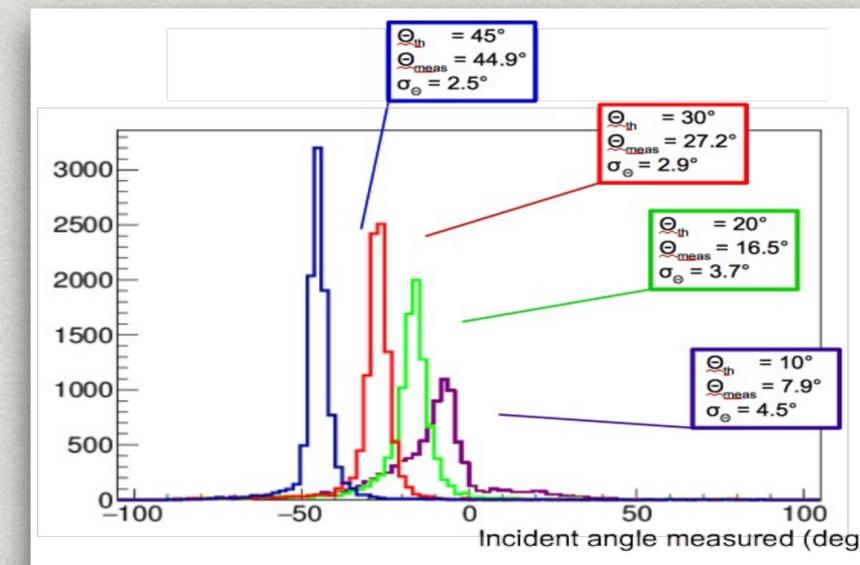WITH DATA

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
ψ(3686) peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
ψ(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
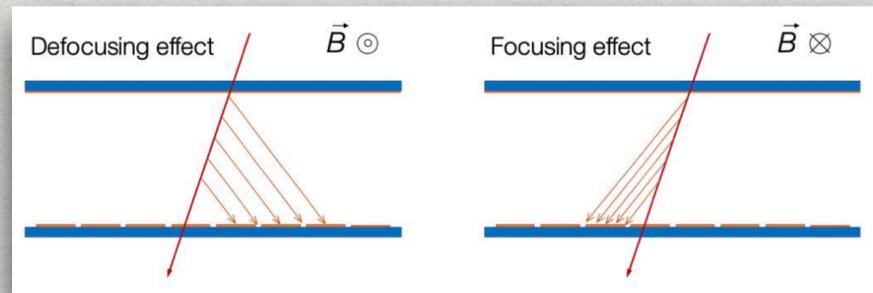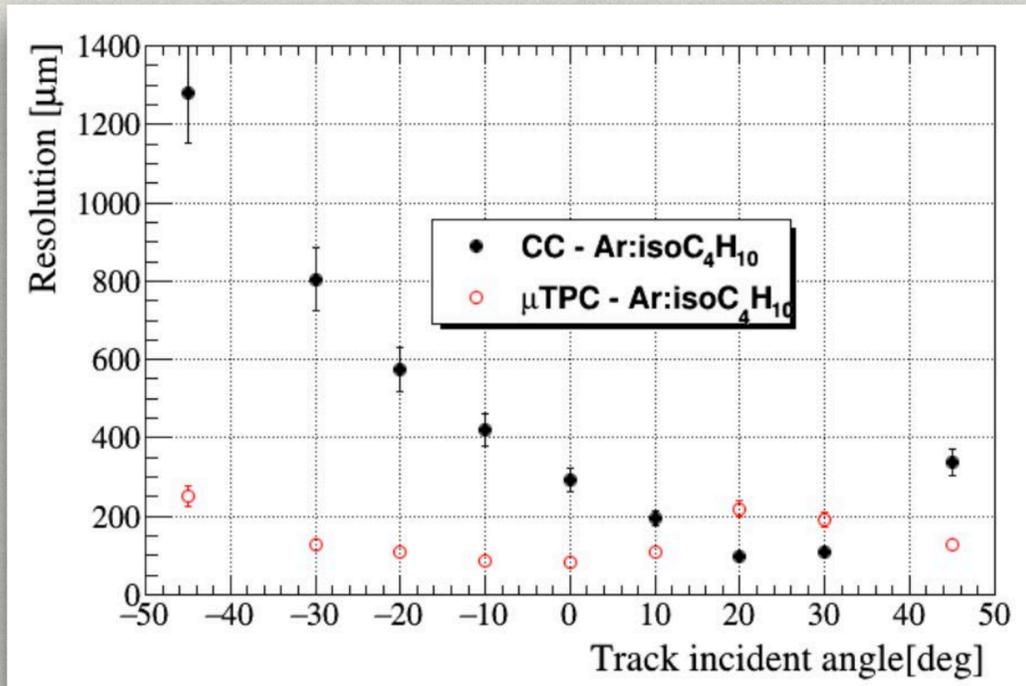
* Combining CC and microTPC stable spatial resolution over a large range of incident angle

* Possibility to perform 3D track reconstruction with only one layer

* A large (5 mm) drift gap is needed for the microTPC readout

Performance evaluation with cosmics