BESIII MDC upgrade

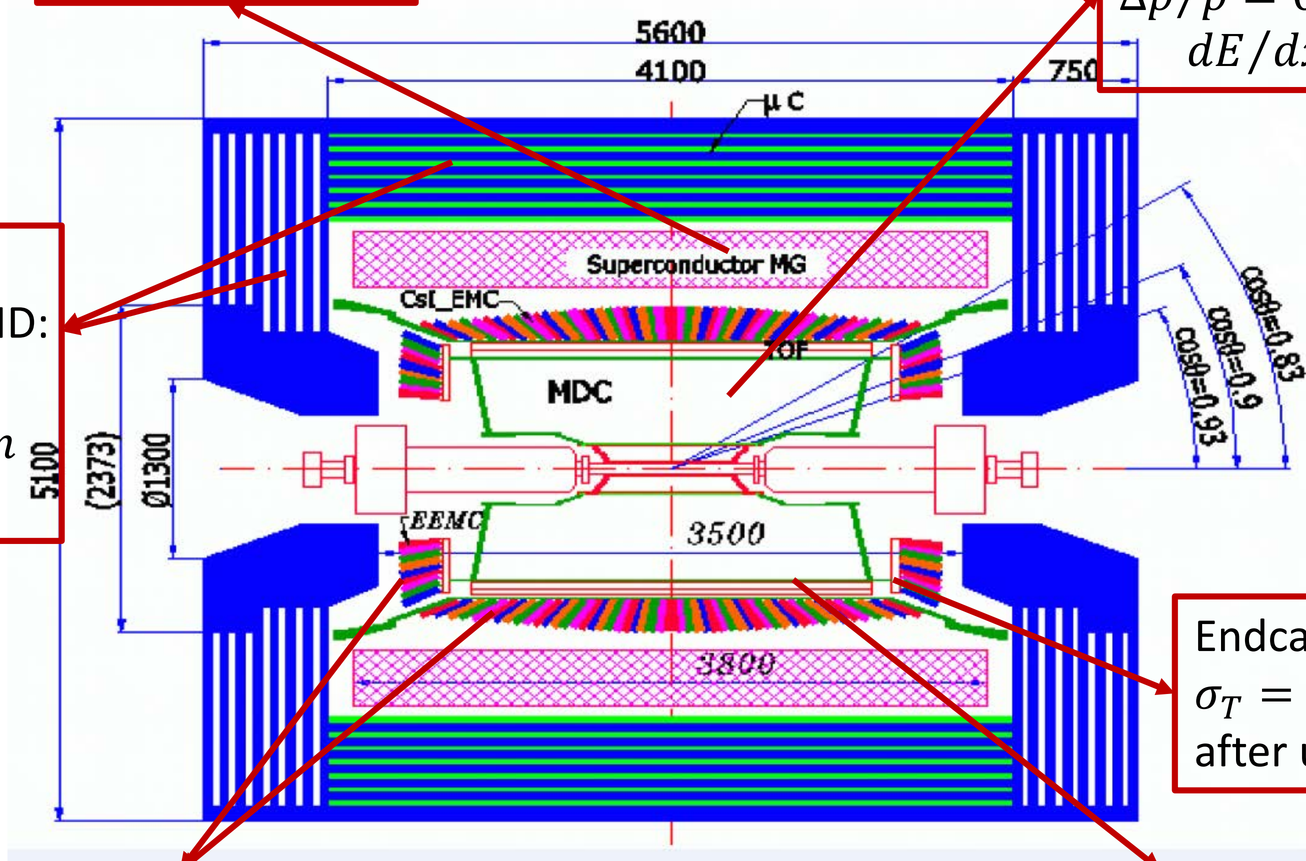
Mingyi Dong (董明义)
On behalf of the working group

The BESIII detector

SC Magnet: 1T

MDC: $\sigma_{r\phi} = 115\mu m$
$\Delta p/p = 0.47\%@1GeV$
$dE/dx = 5.2\%$

Barrel and endcap Muon ID:
$\sigma_{r\phi} = 14mm\sim15mm$
$\sigma_z\sim17mm$



Endcap TOF:
$\sigma_T = 60ps\sim70ps$
after upgrade

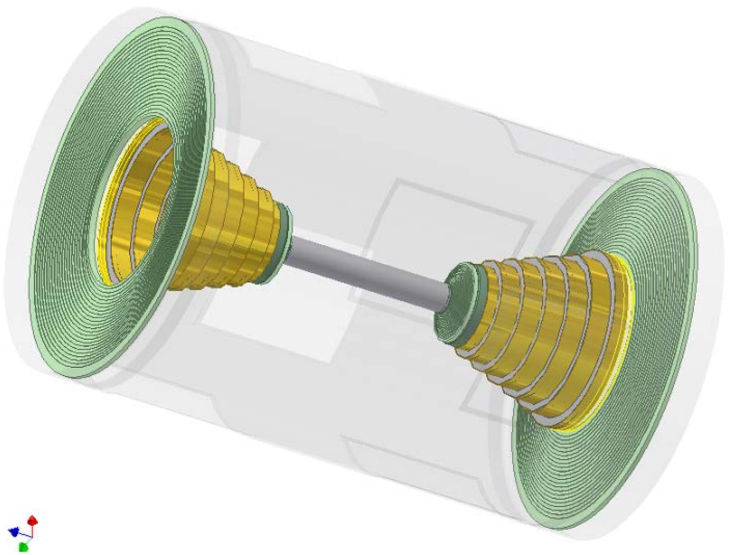
Barrel and endcap EMCAL
$\Delta E/E = 2.5\%\ @1GeV,\ \sigma = 6\ mm/\sqrt{E}$

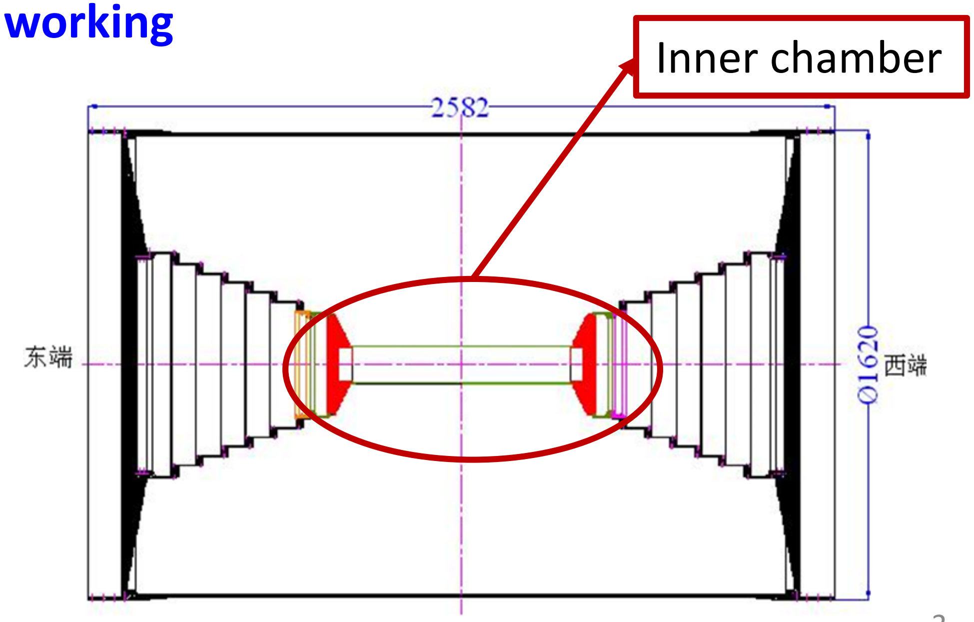
Barrel TOF:
$\sigma_T = 67\sim70\ ps$

- General purpose detector at BEPCII, $E_{cm} \approx$ 2-4.6 GeV, $L_{peak} \approx 10^{33}/cm^2/s$
- Versatile researches in τ-charm physics

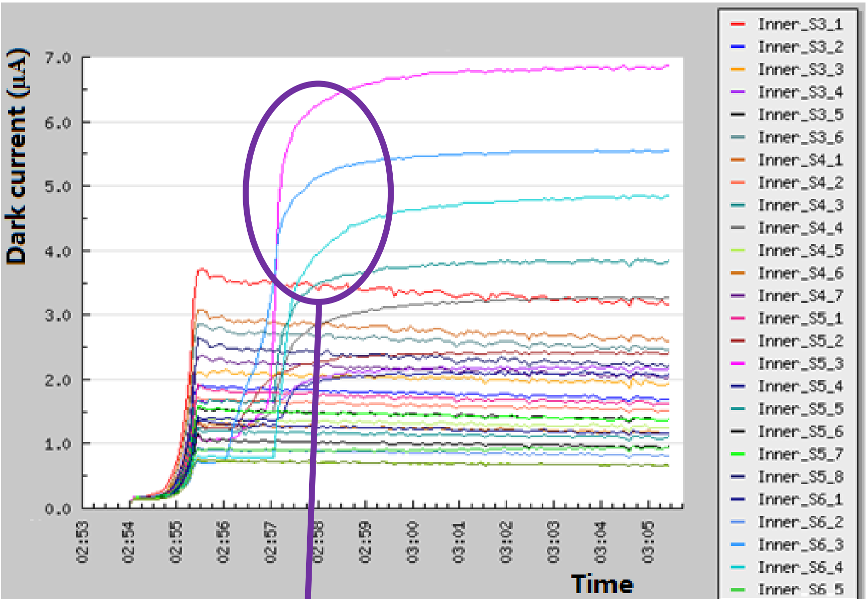
Main drift chamber (MDC)

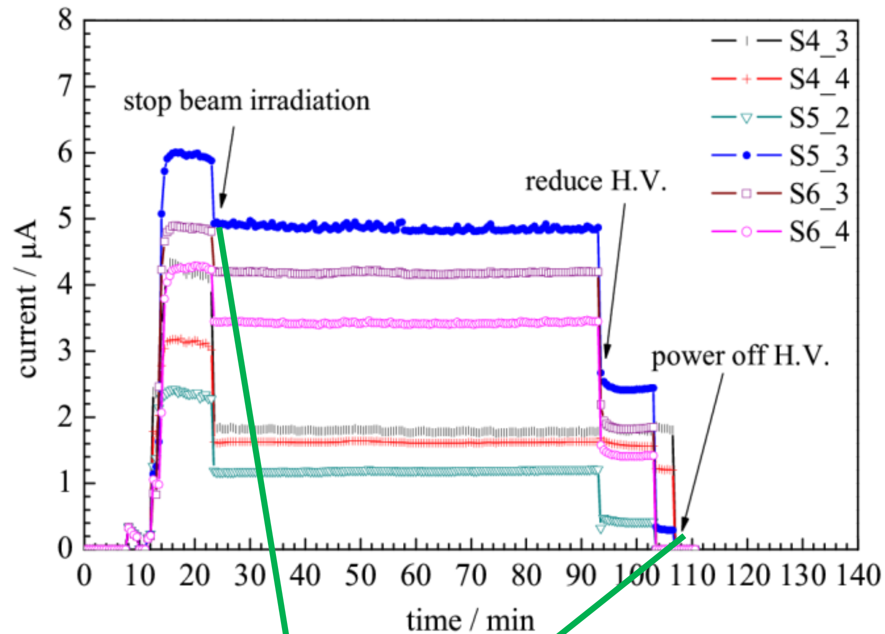
- Main tracking detector for the charged particles
  position, momentum and dE/dx measurements
- Plays a key role in BESIII tau-charm physics research
- inner chamber (8layers)+ outer chamber (35 layers)
- Aging problems of the MDC
  - High background. Reduce HV of the innermost 4 layers, gain decreased to 31% for the first layer cell
  - Cathode aging: Malter discharge
  - Anode aging: gain dropped dramatically (39% for the first layer cells)
  - **Performance decrease, risk of not working**





MDC cathode aging problem



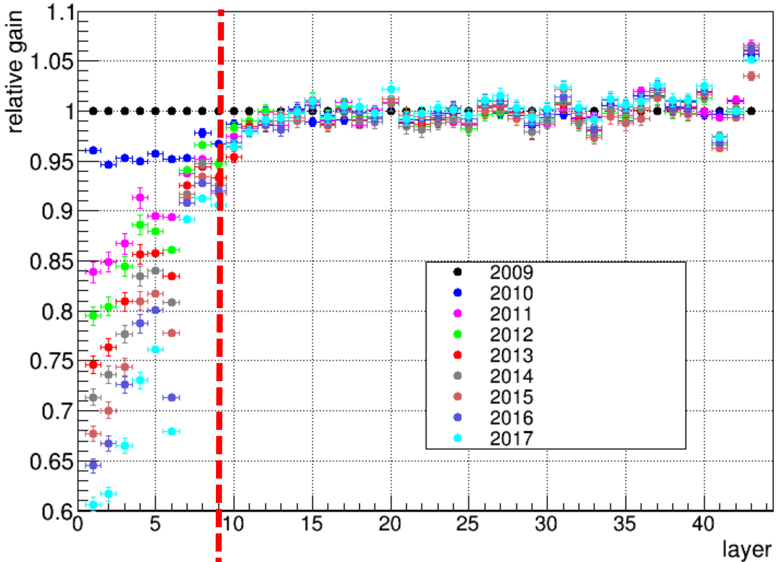


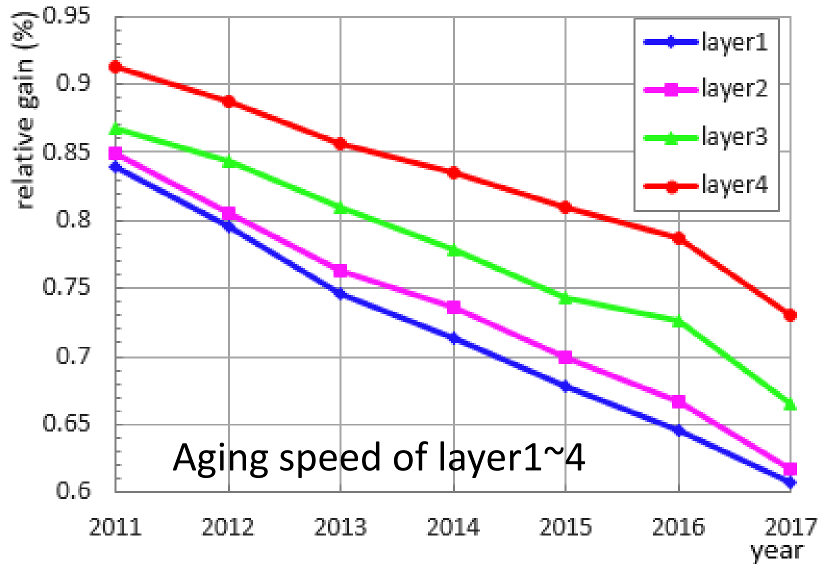
Malter discharge : a self-sustaining local discharge

Did not disappear even after stopping the irradiation, until the HV was powered off

- 2000ppm water vapor @ 21 ℃ was added to the gas mixture to solve the problem
- Water attemperator is used to control the temperature of the water vapor system in the variation range of ±0.3 ℃

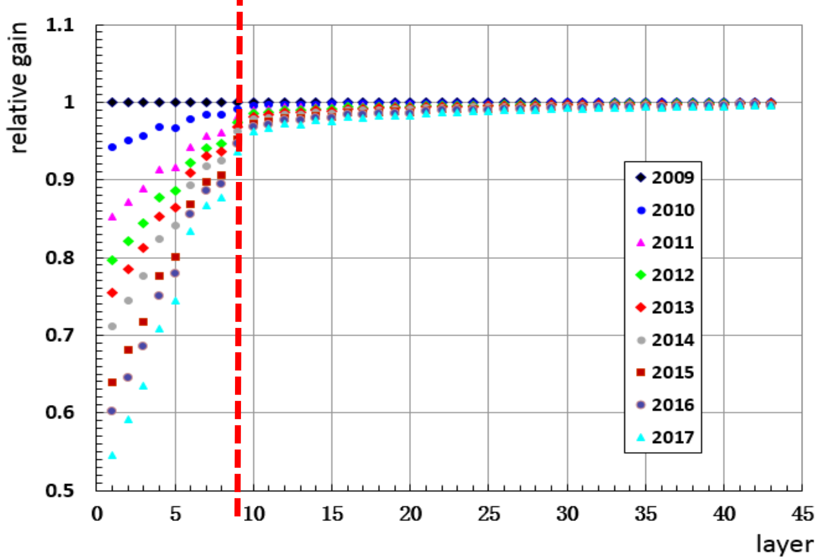
MDC anode aging problem

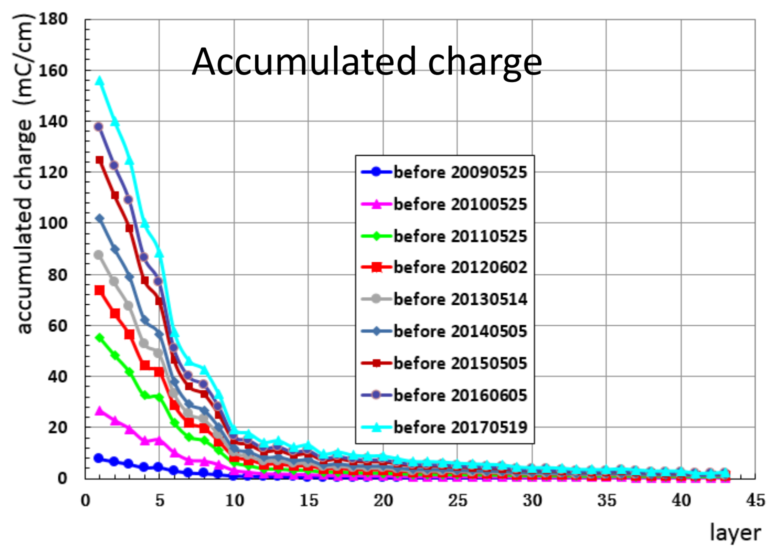




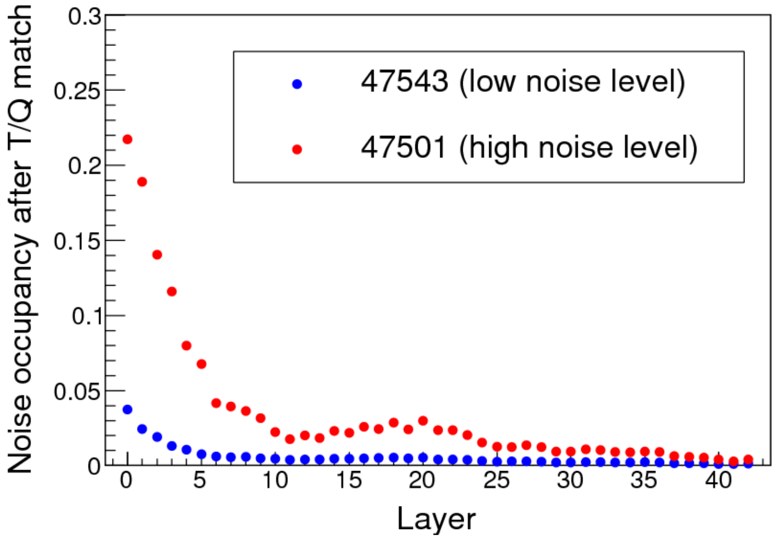
Inner chamber

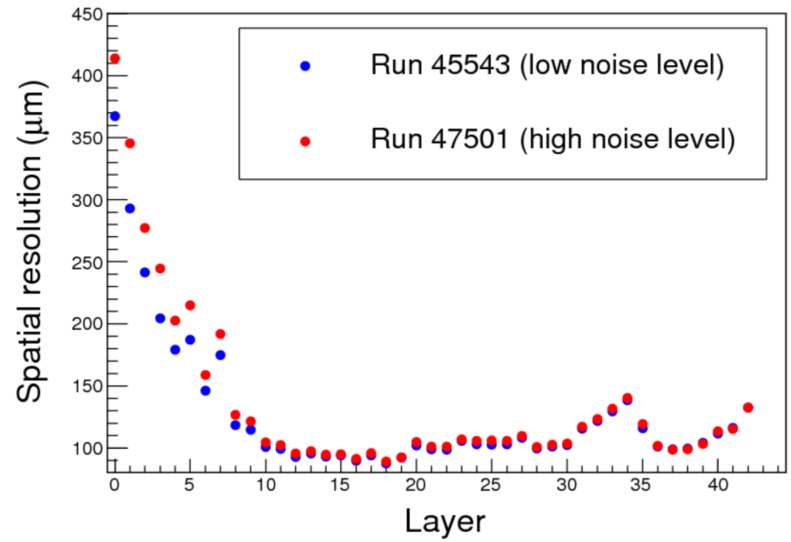
outer chamber



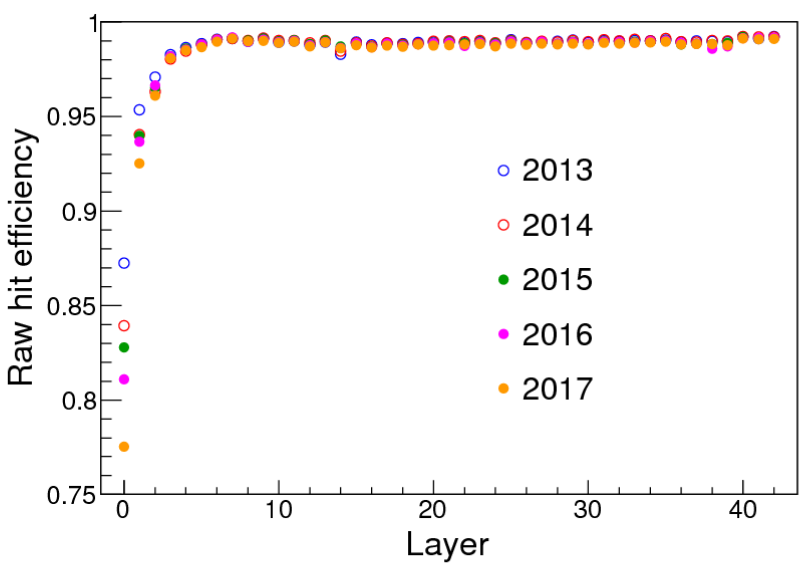


MDC Performance

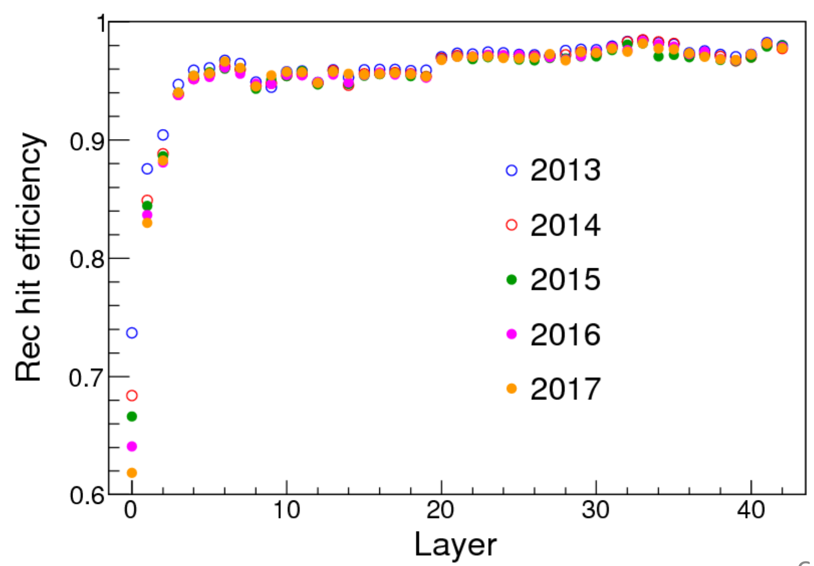




Raw hit efficiency vs layer



Rec hit efficiency vs layer



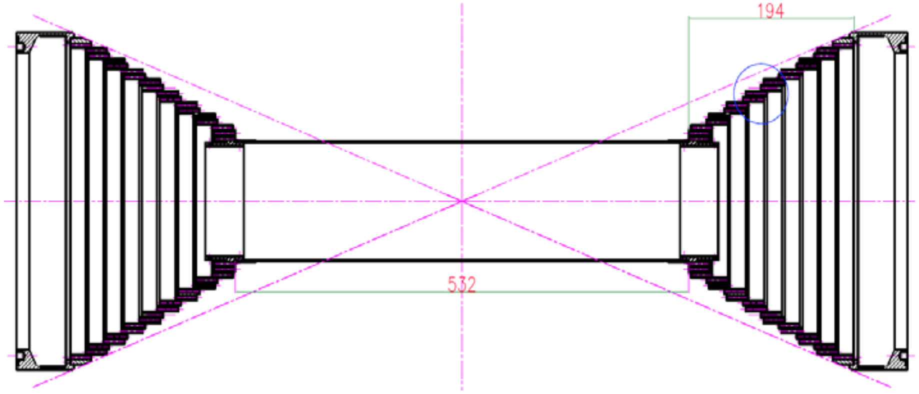
Upgrade of the inner chamber

Three options with different goals

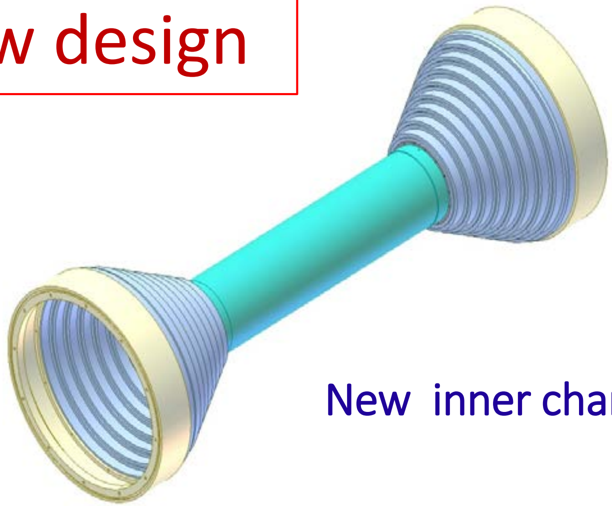
- New inner drift chamber
- Cylindrical GEM inner tracker (CGEM)
- R&D of a COM pixel sensor tracker prototype

New inner drift chamber

New inner chamber

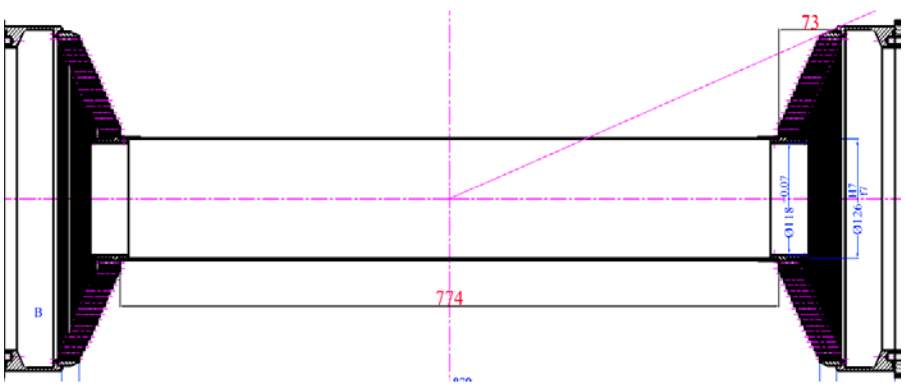


8 layers, 484 cells



New design

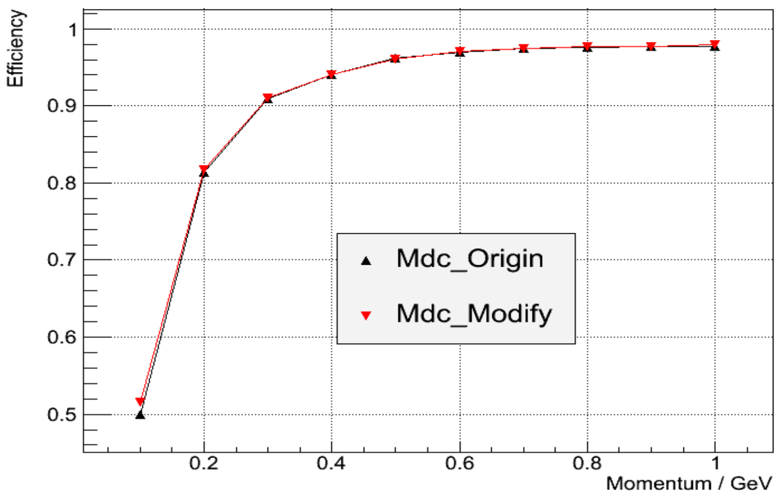
New inner chamber

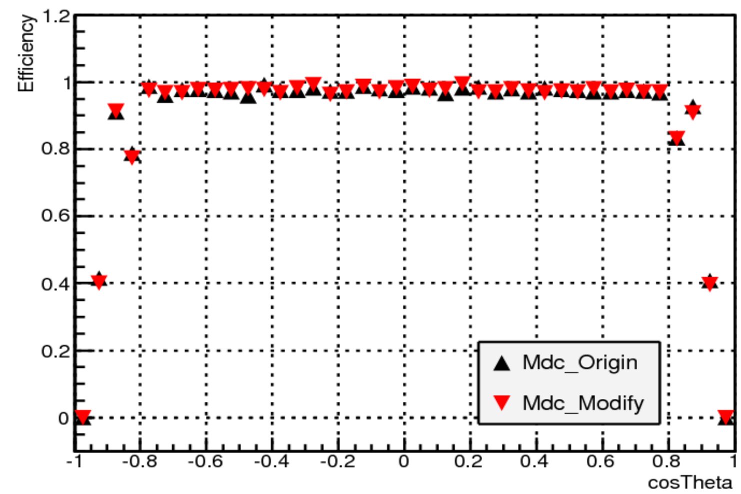


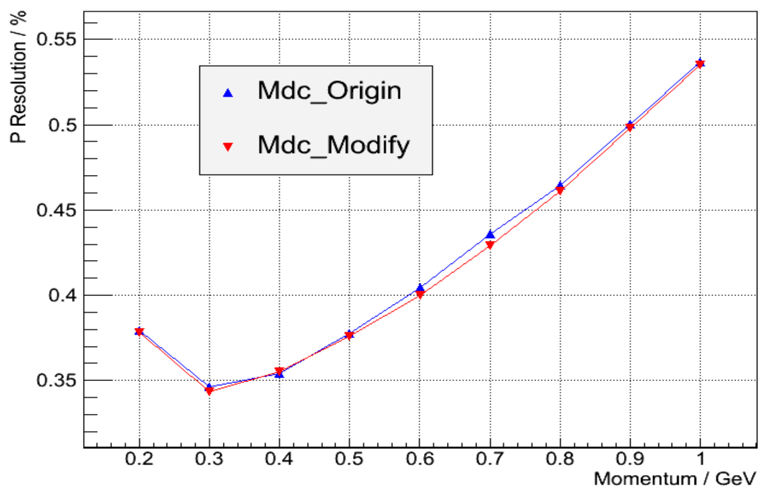
Old inner chamber

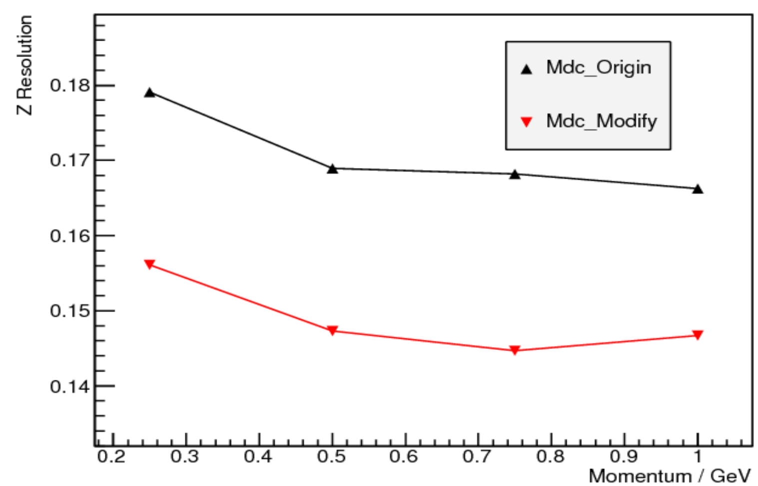
- An improved new inner drift chamber with multi-stepped end-plates
- Shorten wire length exceeding the effective sold angle
- Reduce the background counting hits (currents) of a cell, decrease the risk of wire broken

Performance combined with outer chamber



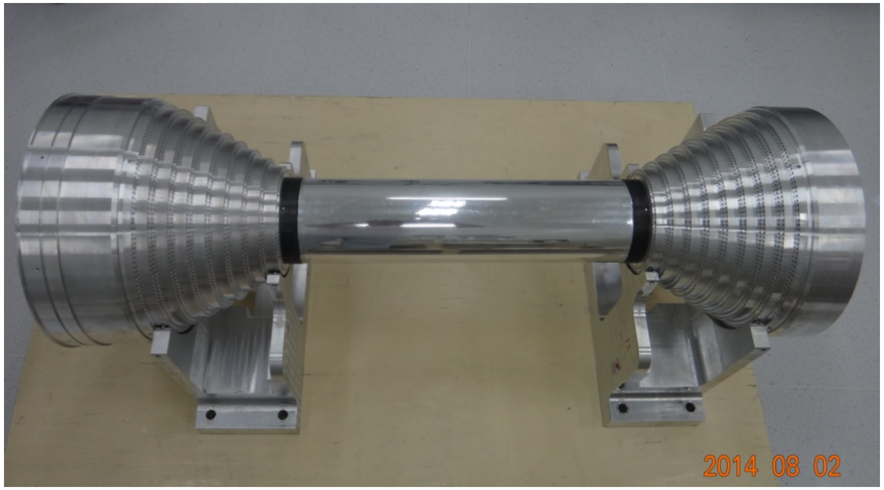


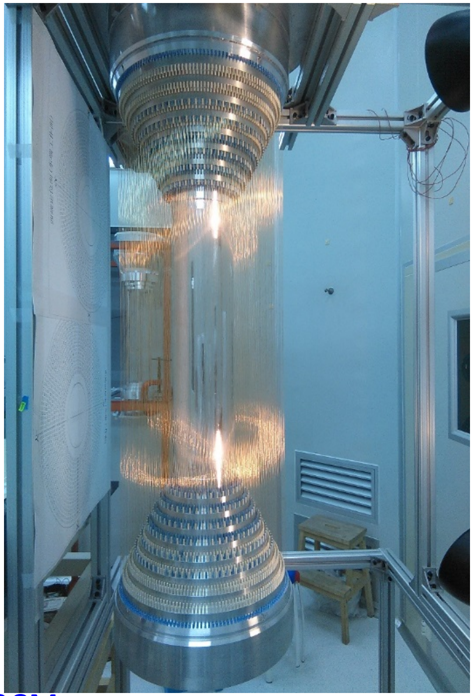




- Tracking efficiency and momentum resolution are similar to the old chamber
- Spatial resolution in z improved a little bit since larger stereo angle

Construction



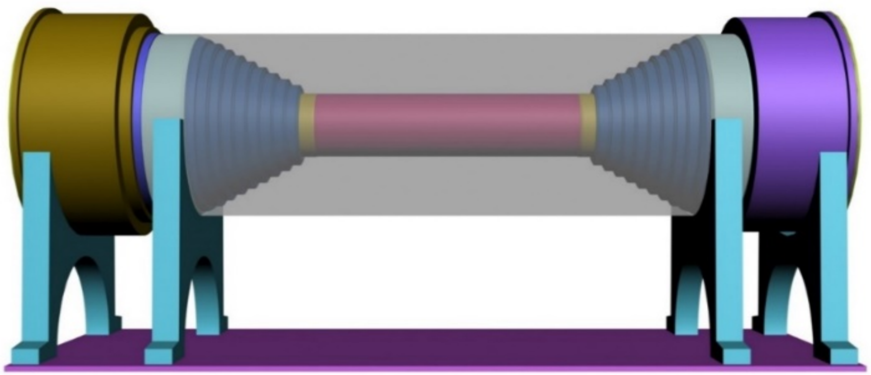


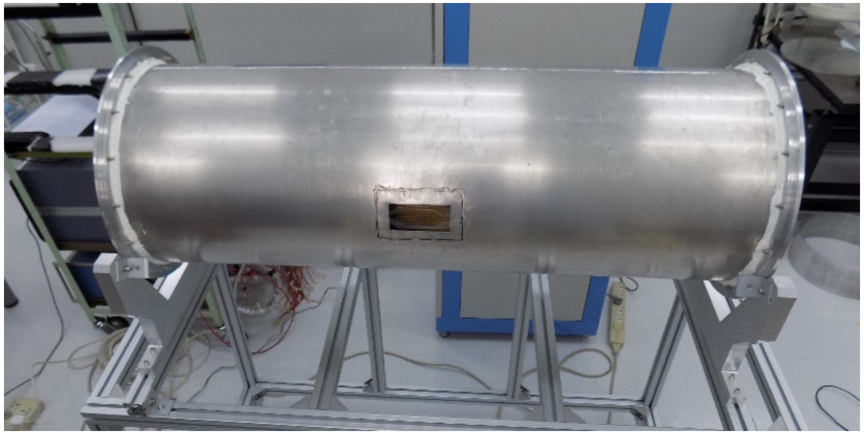
① **Mechanical structures assembly and measurement**

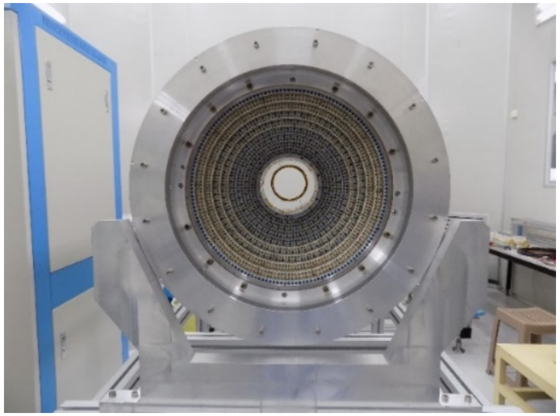
② **Wiring, wire tension and dark current measurement**

Quality control : ±10% of the design value, 5nA/cell @ 2200V

Construction





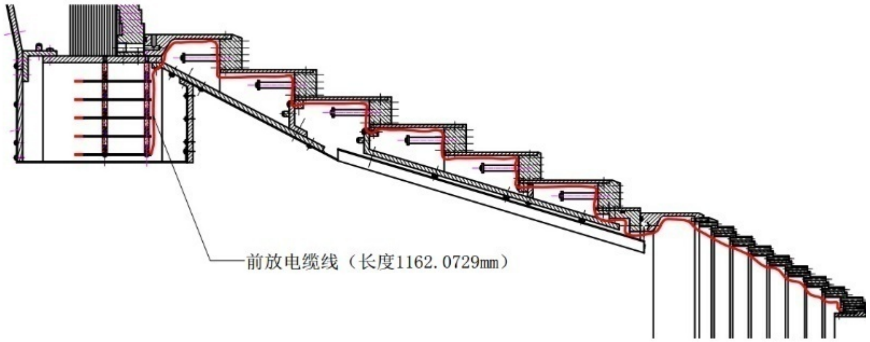


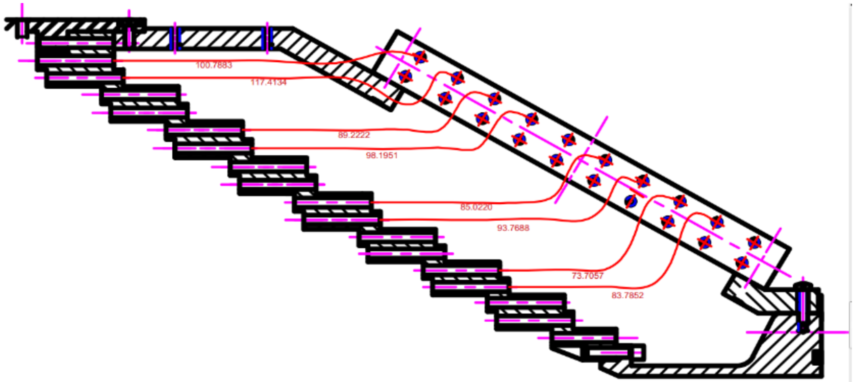
③ **Outer cylinder assembly for cosmic-ray test**

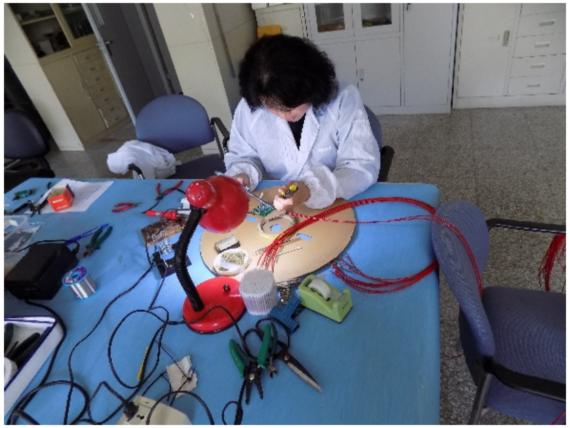
④ **Sealing and leakage test:**

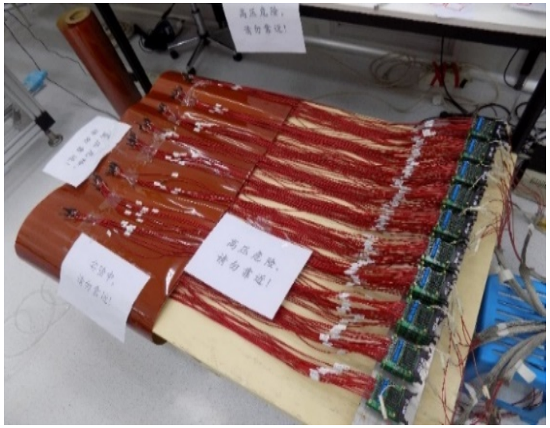
leakage rate < 0.1% / h @ 5 times operating gas pressure

Construction







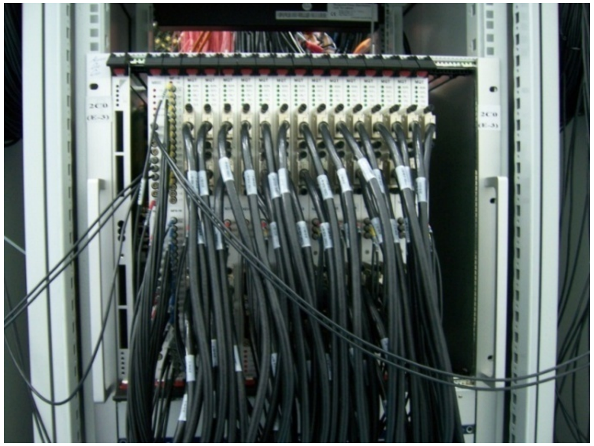


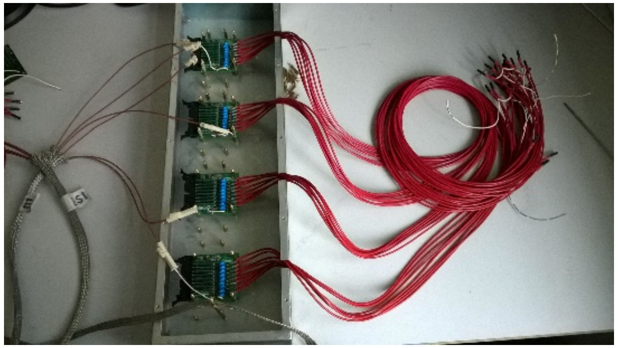
⑤ **Cable preparing and test**

The connection between feed-throughs and preamplifiers

⑥ **Field wire grounding connector and cables preparing**

Cosmic-ray test preparation



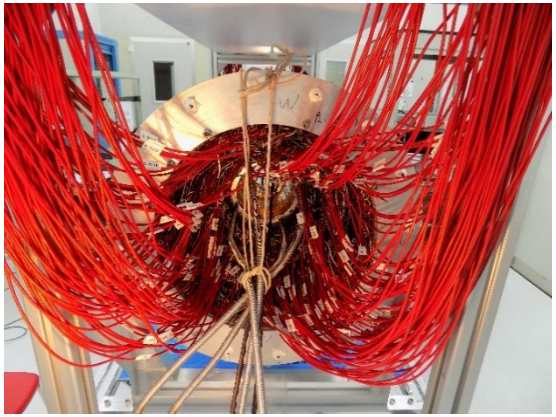


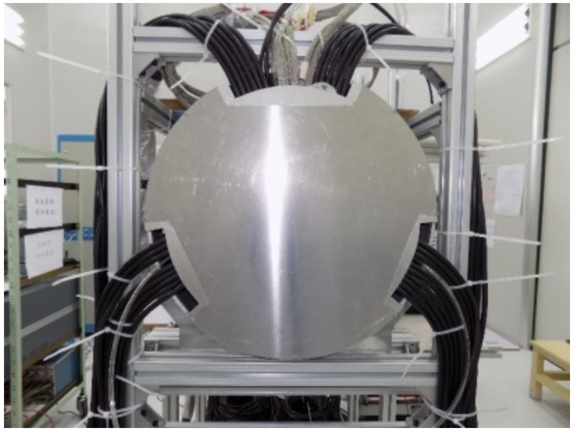
⑦ Gas, high voltage preparing

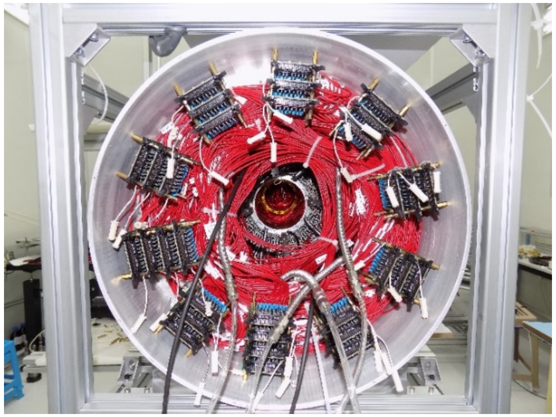
⑧ Electronics test (long-term crate class test)

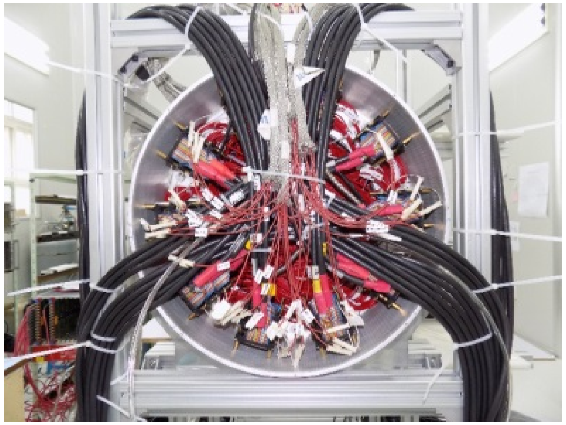
⑨ Cabling and test

Cosmic-ray test setup









⑩ **Field wire grounding**

⑪ **Preamplifiers mounting**

⑫ **Signal and HV cabling**

⑬ **Long term cosmic-ray test**

Cosmic-ray test

- High Voltage setting

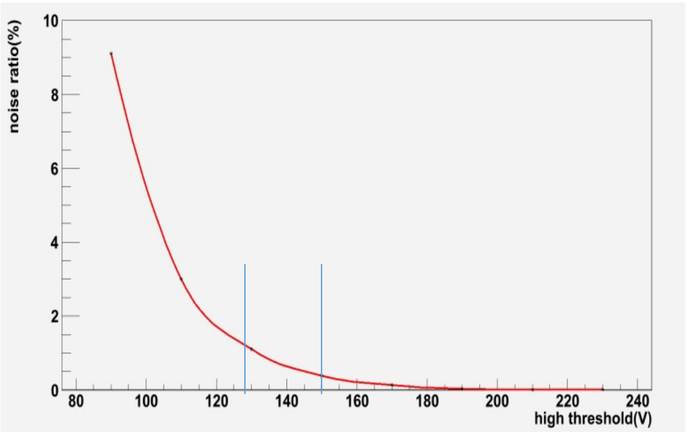
  both 2200V and 2150 were tested

Layer	High Voltage (2200V)	High Voltage (2150V)
S1	1997	1948
S2	2091	2044
S3	2108	2058
S4	2088	2039
S5	2093	2045
S6	2080	2031
S7	2064	2018
S8	2033	1986

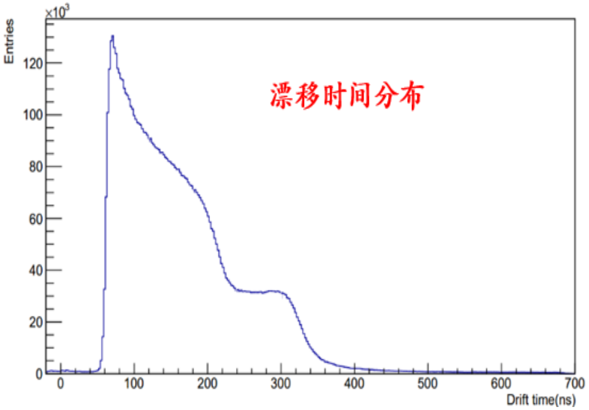
the applied High Voltage

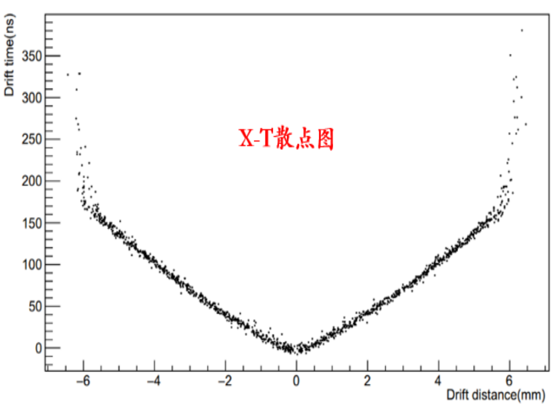
- Noise rate measurement to determine the final threshold

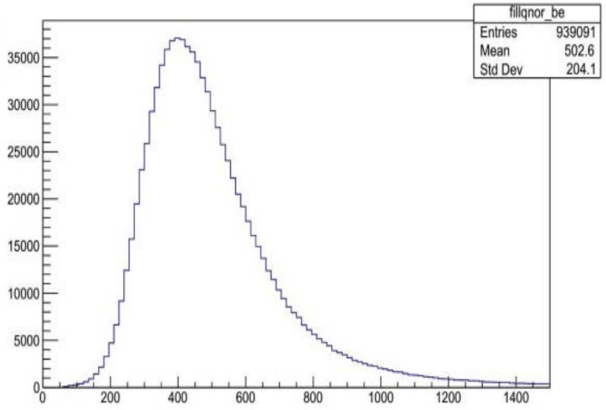
  Low threshold: 130, High threshold: 150



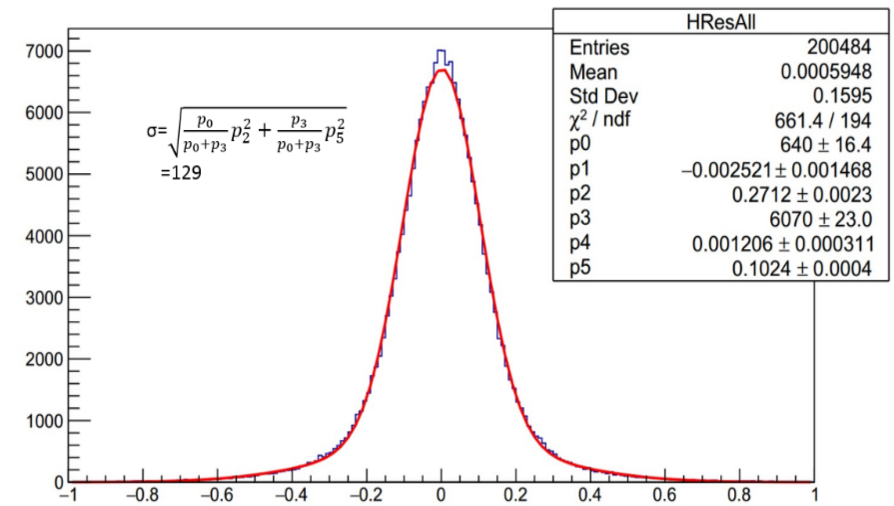
noise trigger rate vs threshold



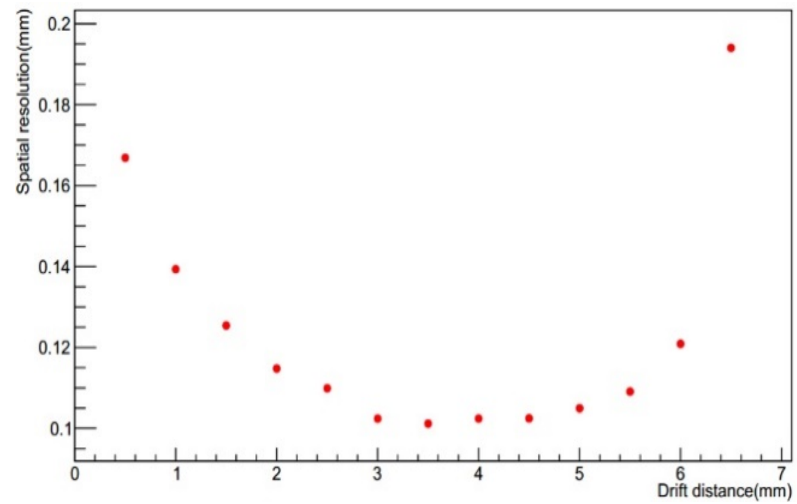




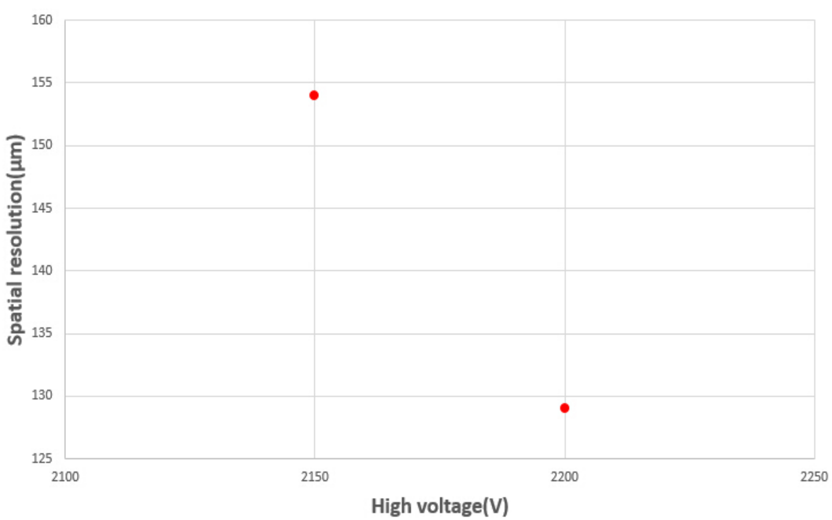
Performance of the new chamber



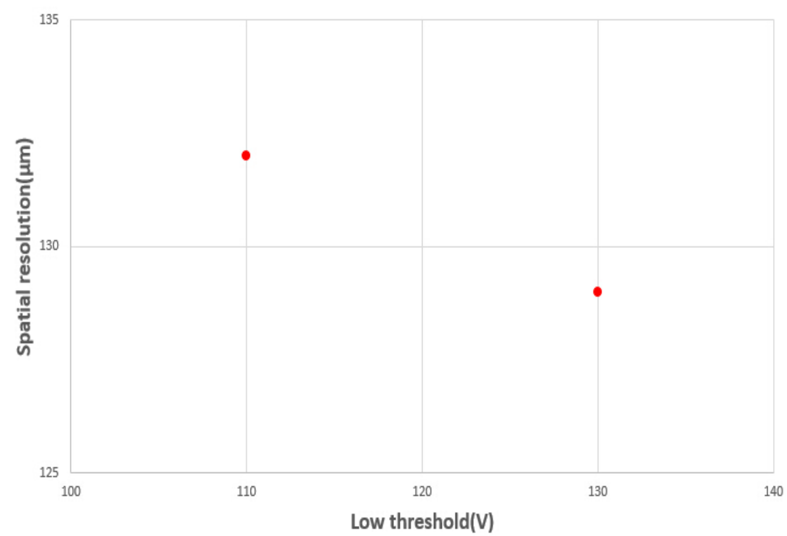
Spatial resolution: 129µm (HV = 2200V)



Spatial resolution vs. drift distance

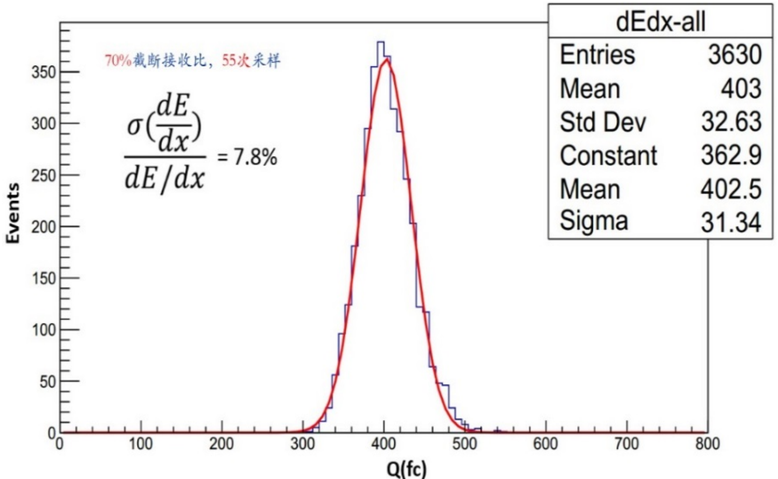


Spatial resolution vs. HV

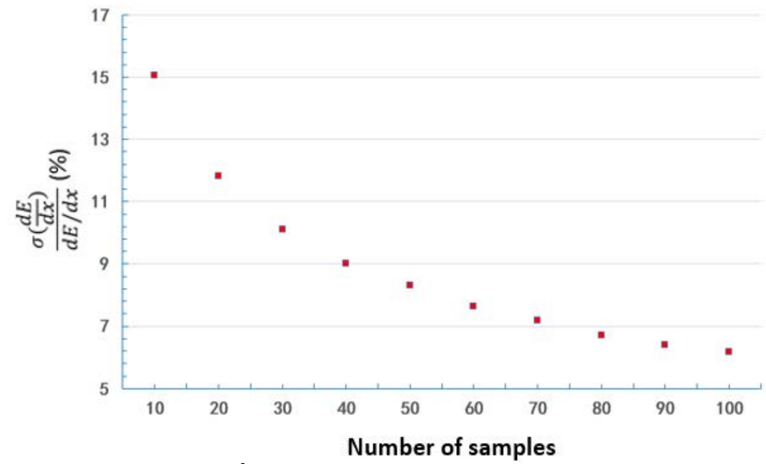


Spatial resolution vs. time threshold

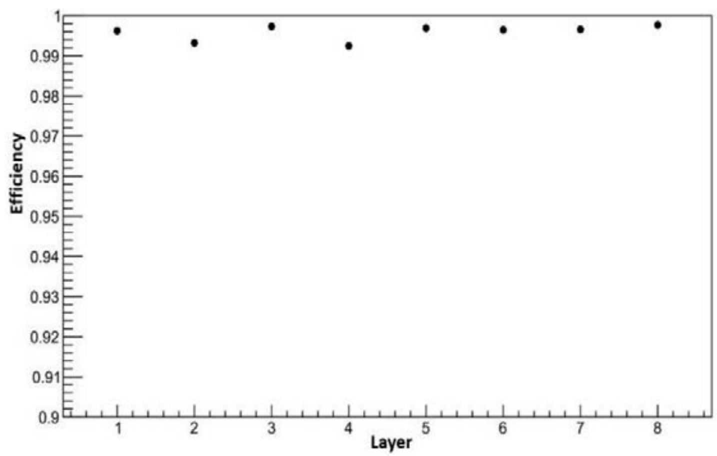
Performance of the new chamber



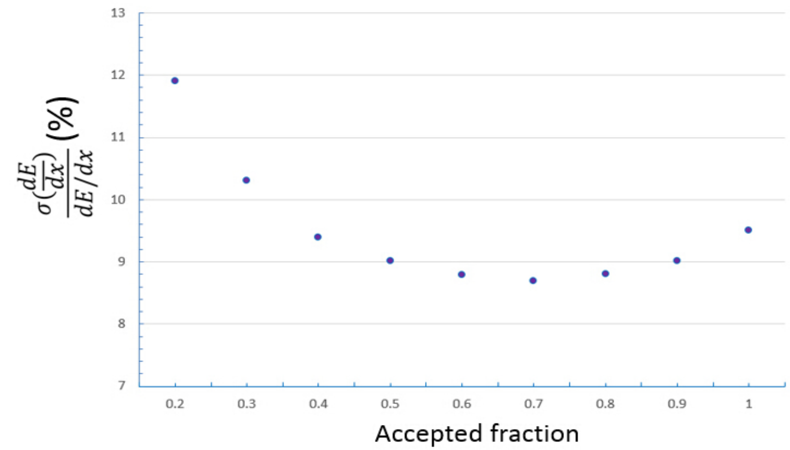
dE/dx resolution: 7.8% (HV = 2200V)



dE/dx resolution vs samplings



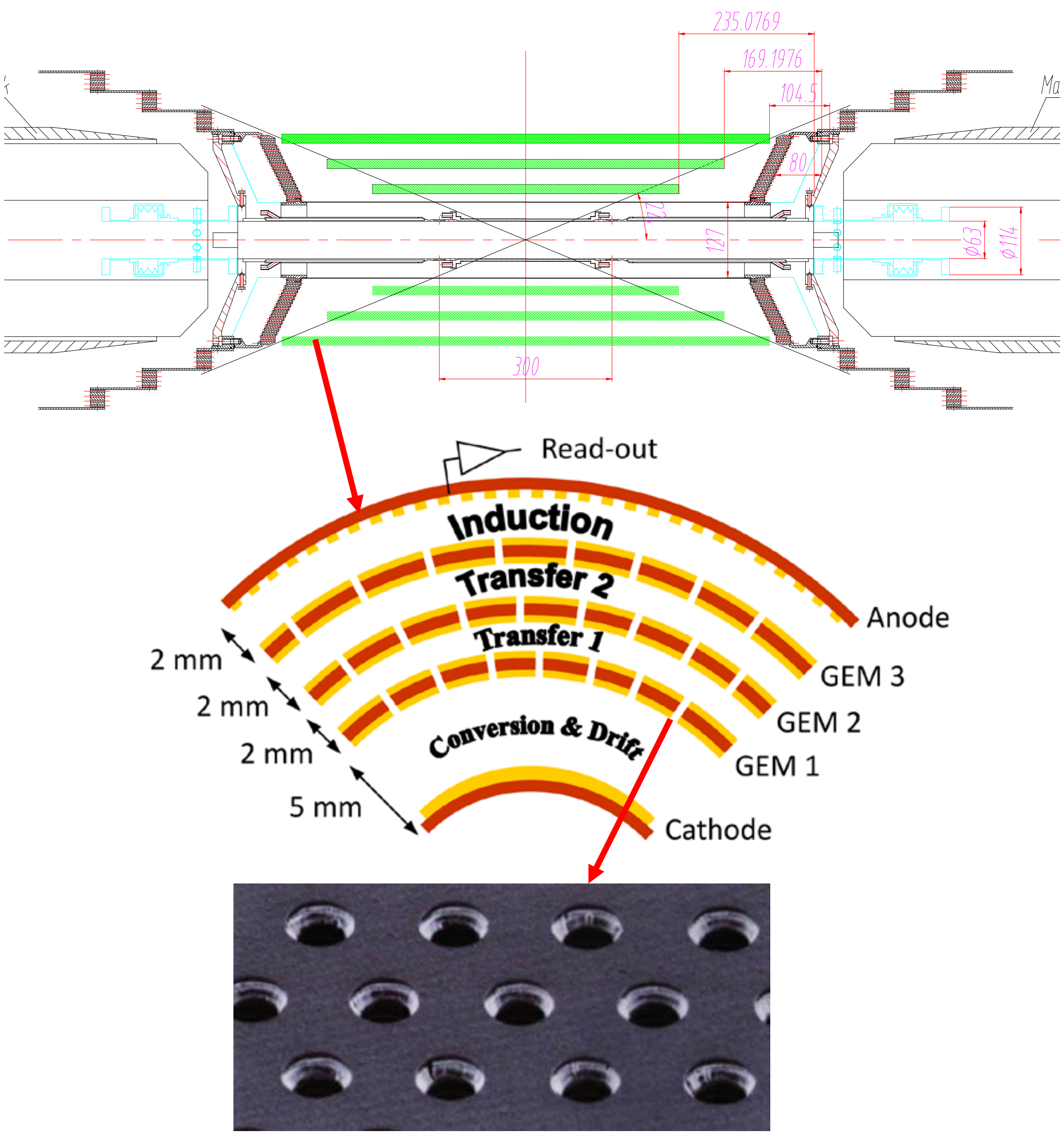
Efficiency: > 99% (HV = 2200V)



dE/dx resolution vs fraction

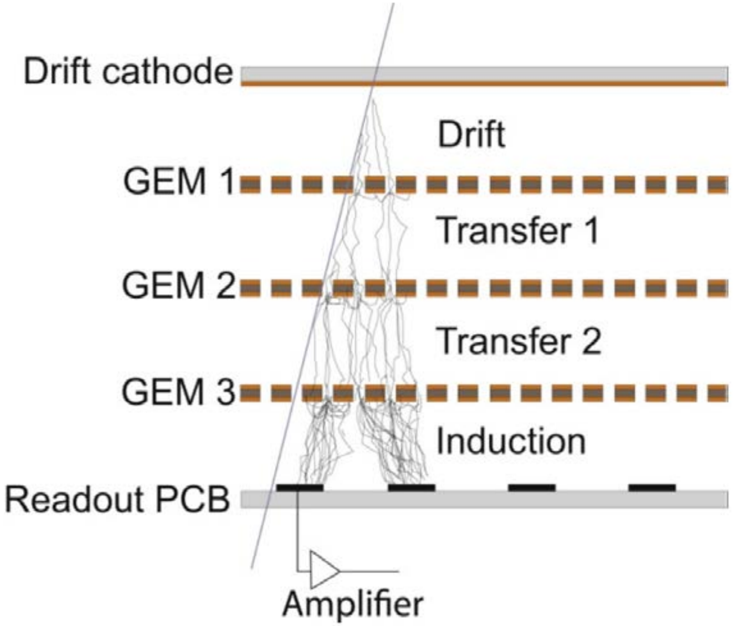
- The performance meets the requirements of BESIII
- The new inner chamber is ready and can be used in the case of unexpected failure of the old chamber

Cylindrical GEM inner tracker (CGEM)



- Layout: three layers
- Low Material budget: ≤1.5% of X_0 For all layers
- Momentum resolution: σ_{Pt}/P_t = ~0.5%@1GeV
- High Rate capability: ~10^4 Hz/cm^2
- Coverage: 93%
- Spatial resolution: $\sigma_{r\varphi}$: 130 - 150μ m, σ_z<1mm
- 1 T magnetic filed
- Operation duration: at least 5 years
- Active area
  - – L1 length 532mm
  - – L2 length:690mm
  - – L3 length:847mm
- Inner radius:78mm
- Outer radius:178mm

Why CGEM?

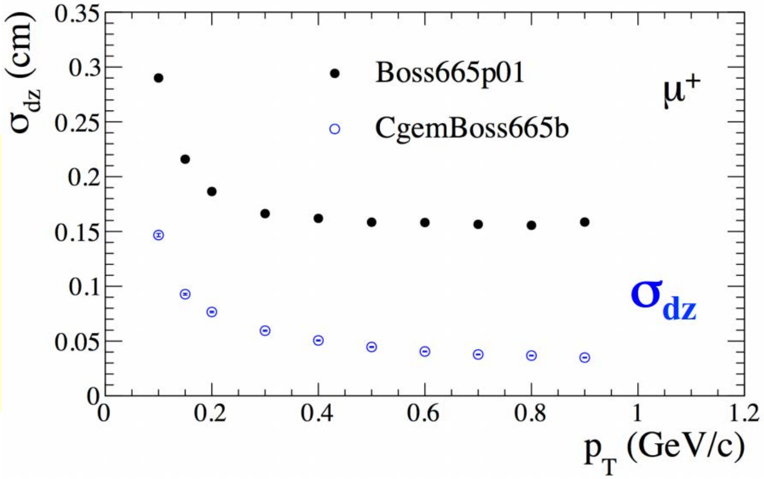


- Higher particle rates capability
- Less sensitive to the aging
- Significantly improvement of σ_z
- Less background expected
  - The volume for primary ionization is 6-7 time smaller
- Improvements from Micro-TPC reconstruction

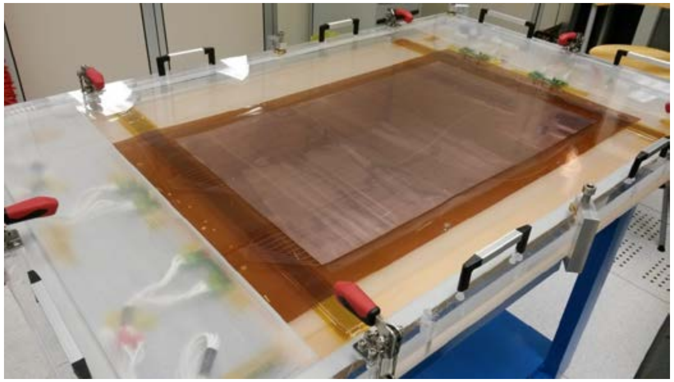
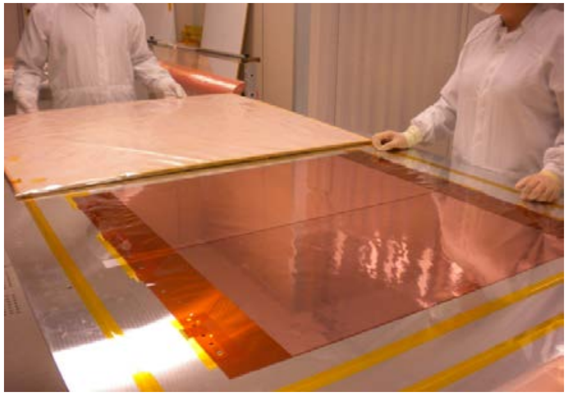
CGEM- inner tracker , new technology

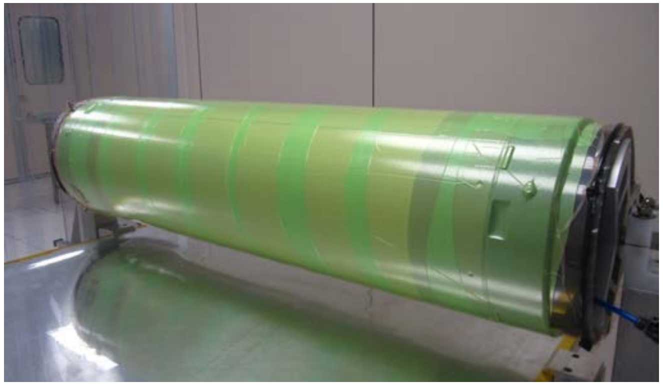
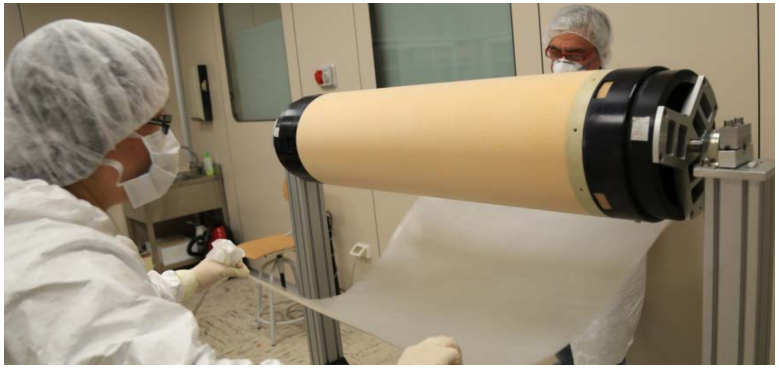
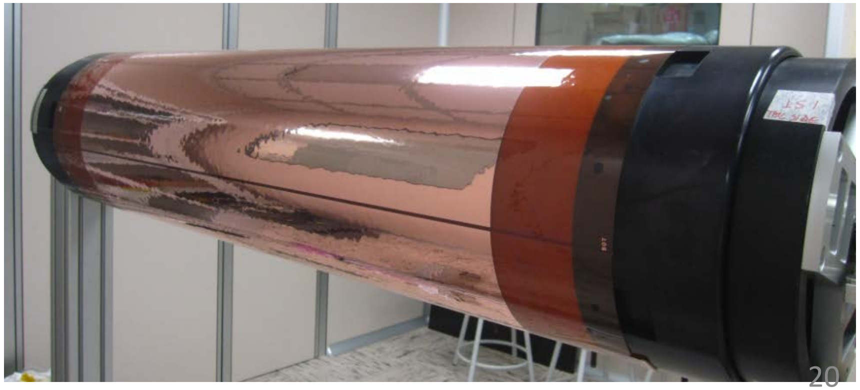
In BESIII, first used

- lower material budget: 0.4% X0
- Analogy readout, charge +time

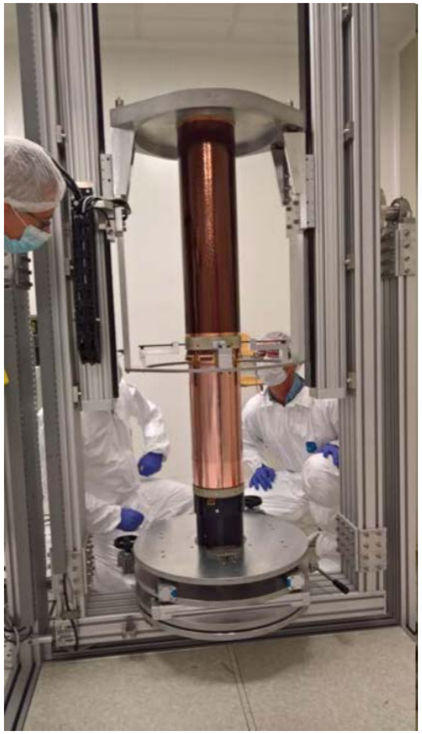


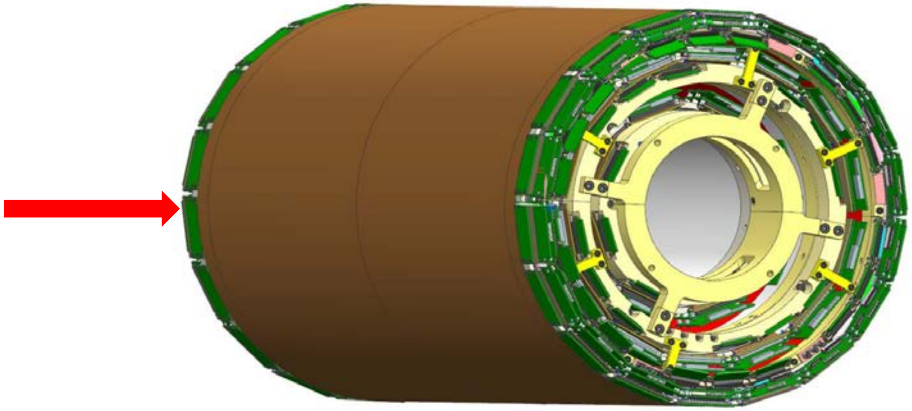
Construction

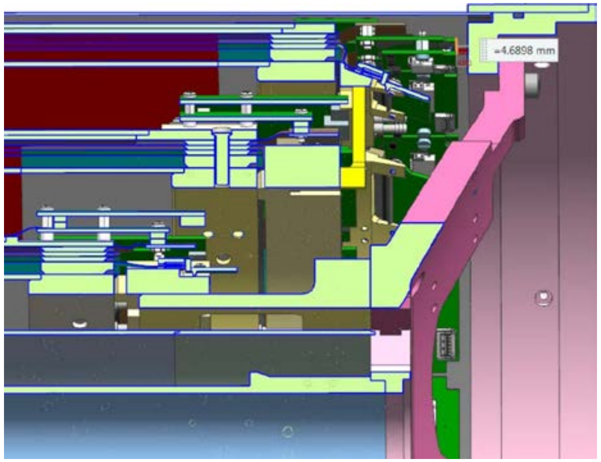




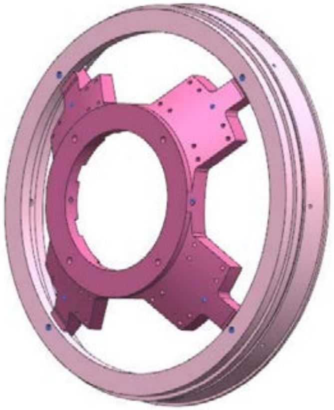




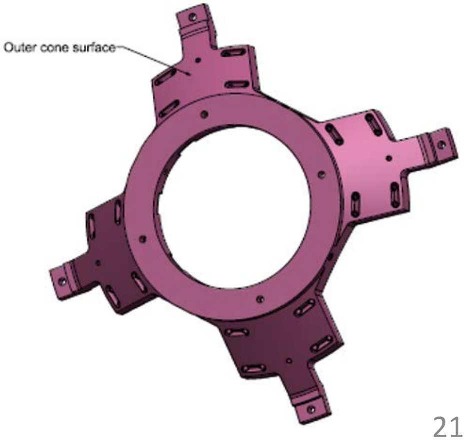
Construction





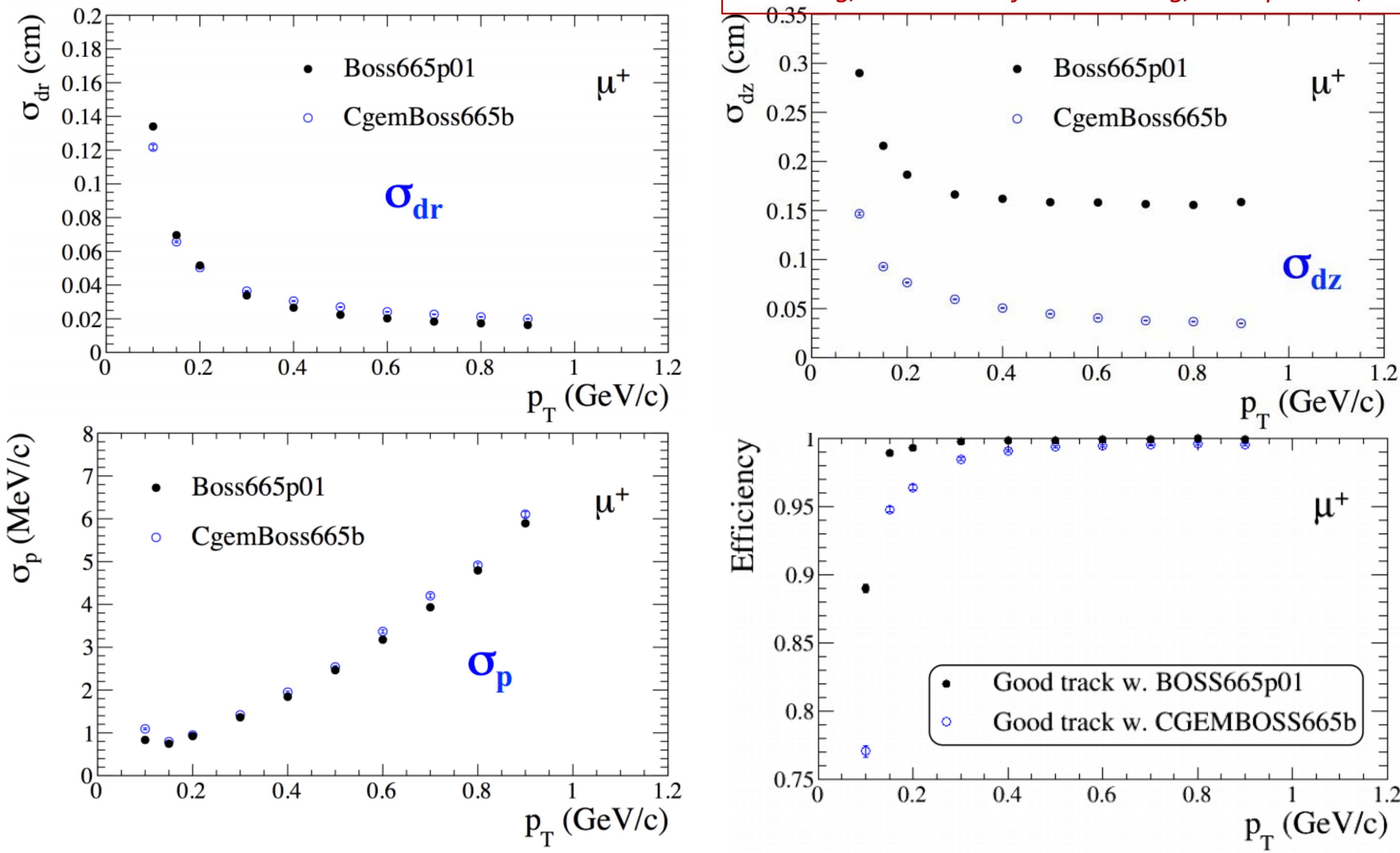






Performance of the CGEM

L.L Wang, CGEM-IT referee meeting, 15 Sep. 2017, IHEP



- Spatial resolution in $r\phi$ & momentum resolution with CgemBoss665b is comparable to Boss665p01
- Spatial resolution in z is significantly improved with CgemBoss665b
- The efficiency for tracks with low transverse momenta which need improvement

Performance of the CGEM

L.L. Wang, CGEM-IT referee meeting, 15 Sep. 2017, IHEP

- Different single track : e, μ, π, K, P
- Different reconstruction (benchmark channels studies):

$K^0_s \rightarrow \pi^+\pi^-$ reconstruction

$\psi(3686) \rightarrow \pi+\pi-J/\psi \rightarrow \pi+\pi-e+e-$

$ee \rightarrow \mu\mu\gamma$ @ 3.773 GeV

$ee \rightarrow$ ppbar

$ee \rightarrow Y \rightarrow D^{*-}D^0\pi^+$ @ 4.42GeV

Tag $D^0 \rightarrow K_sK^+K^-$ in $ee \rightarrow \bar{D}^0D^0$ @ 3.773 GeV

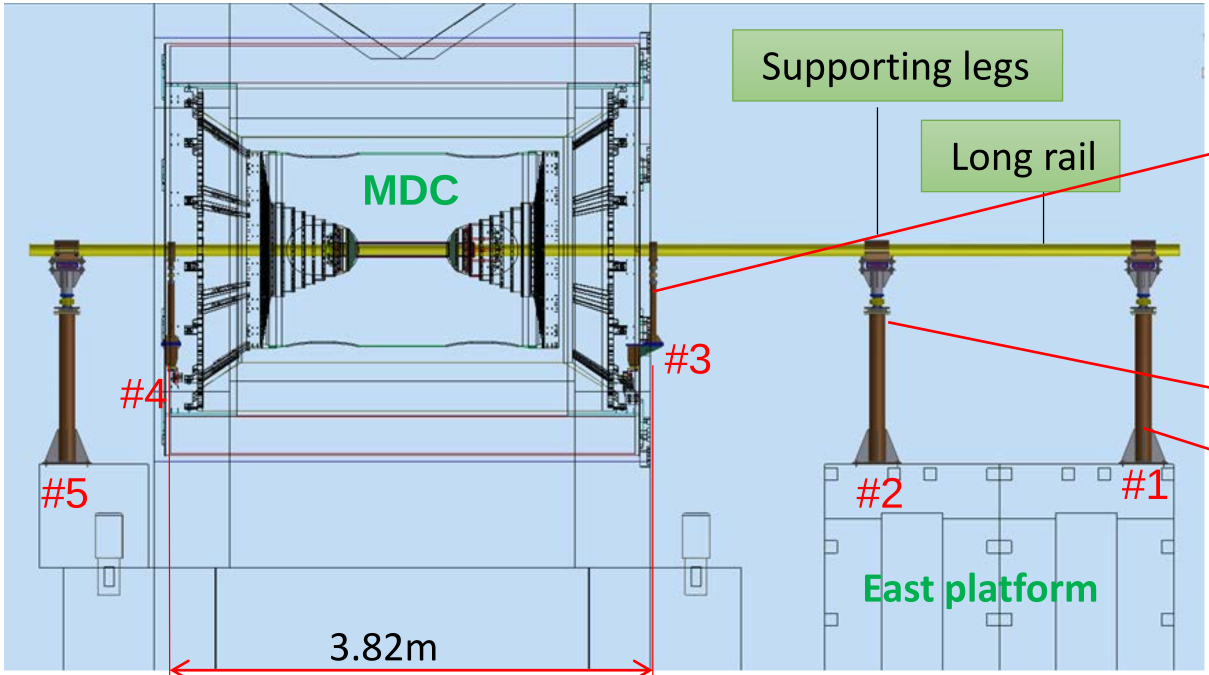
$ee \rightarrow \Lambda\bar{\Lambda} \rightarrow p\pi^-\bar{p}\pi^+$

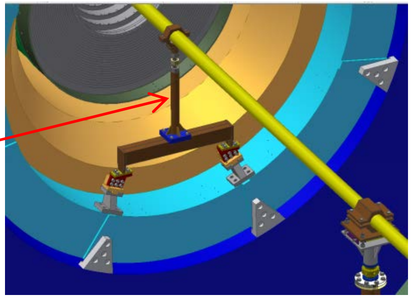
……

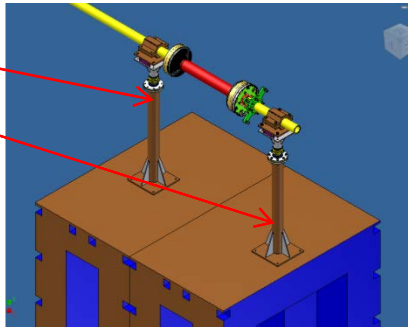
- Performance reasonable (comparable with Boss665p01, dr resolution slightly better at low pt , significant dz resolution improvement)
- The efficiency for tracks with low transverse momenta which need improvement

Extraction tooling for inner MDC

Long rail and supporting legs







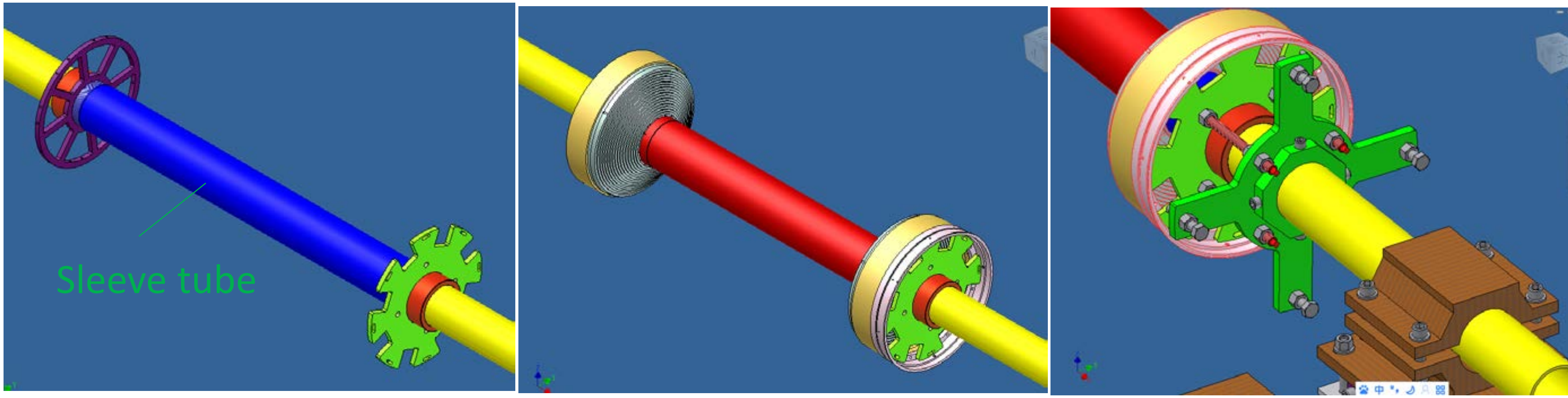
- Tooling :Long rail+ 5 supporting legs (2 in west side, 3 in east side)
- Sliding inner MDC on the rail for extraction
- Span of working area: 3.82m

ID of inner MDC:118mm

Main design parameters of long rail

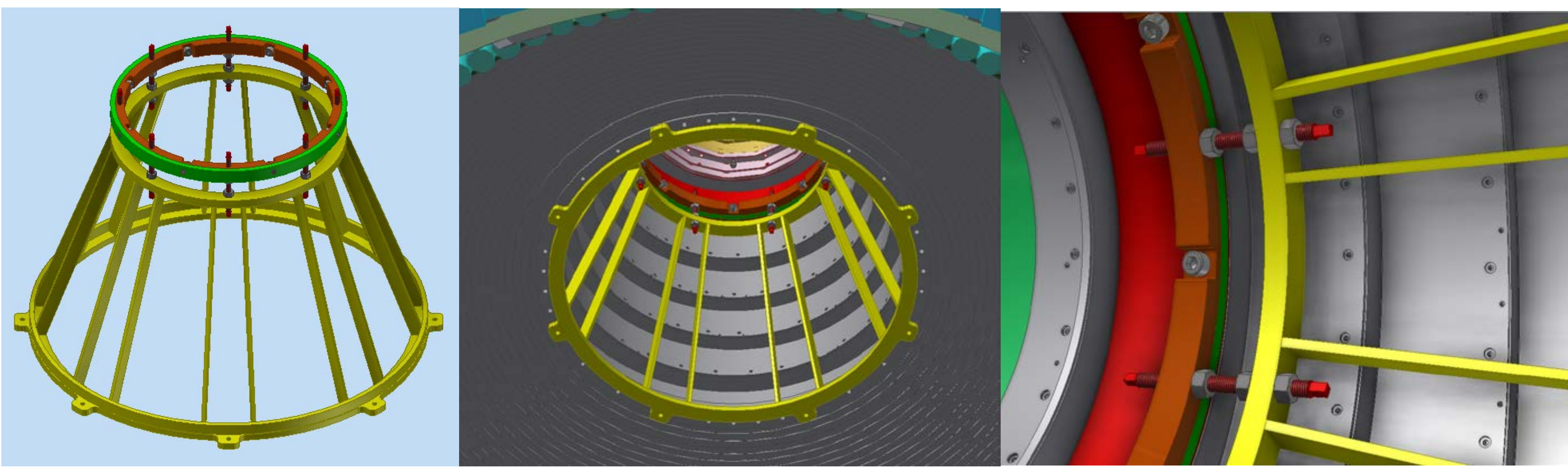
Material	Length (m)	Thickness (mm)	OD (mm)	ID (mm)	Weight (Kg)	Deflection(mm)			
						Span=9.2m		Span=3.8m	
						Self-weight	100Kg concentrated load	Self-weight	100Kg concentrated load
Q345 carbon steel	9.2	6	100	88	128	6.37	10	0.19	0.7

Extraction fixture: MDC protection during operation



Inner MDC protection

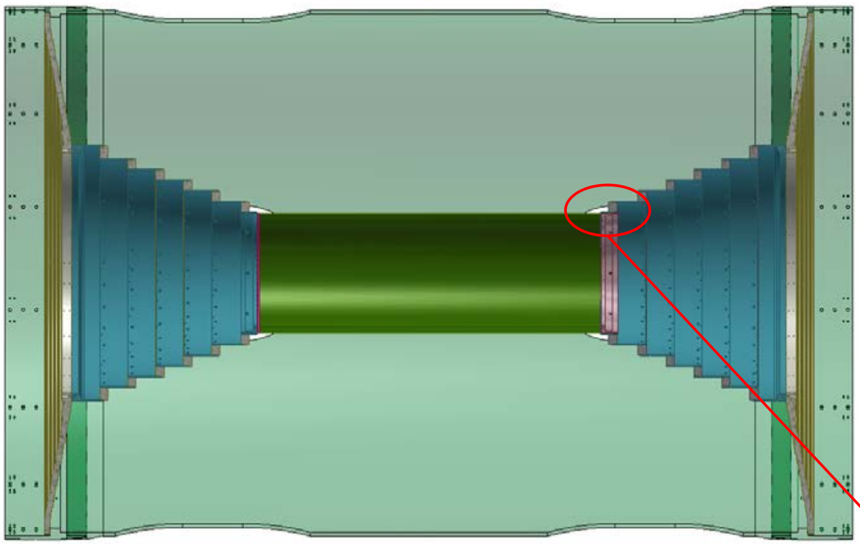
Sleeve tube will be connected to the inner MDC to carry the load together during extraction



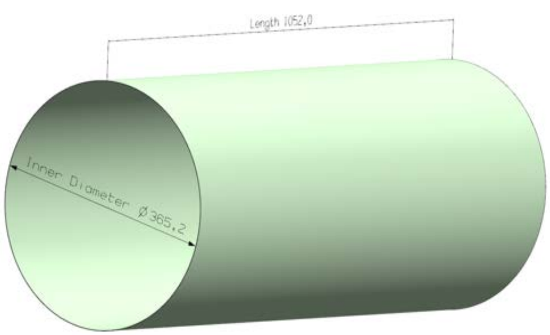
Outer MDC protection

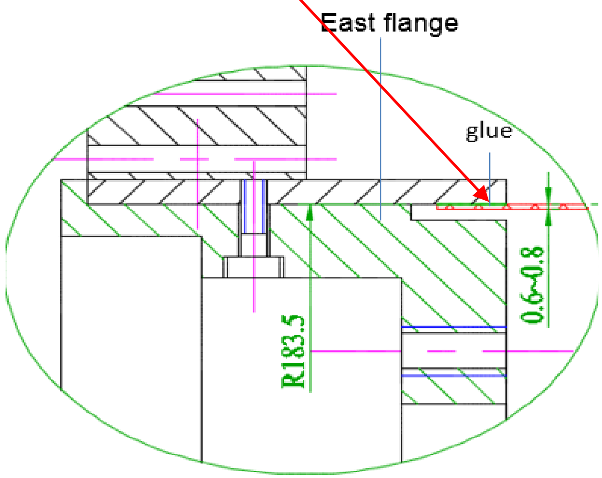
Supporting Frame: fix on the outer MDC and limit the displacement of steps during extraction

New Inner cylinder

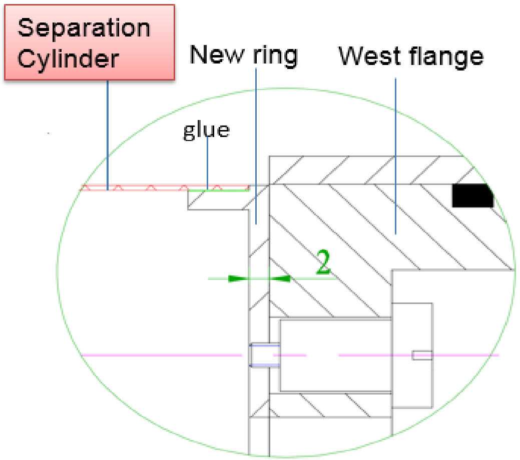


- Material : Carbon Fiber
- Thickness: 500µm-600µm
- Dimension:
  - Cylinder Outer R:183.2mm
  - Cylinder Inner R:182.6mm
  - ID of MDC (step #1): R183.5 mm
  - CGEM R_{max}: R180.7mm





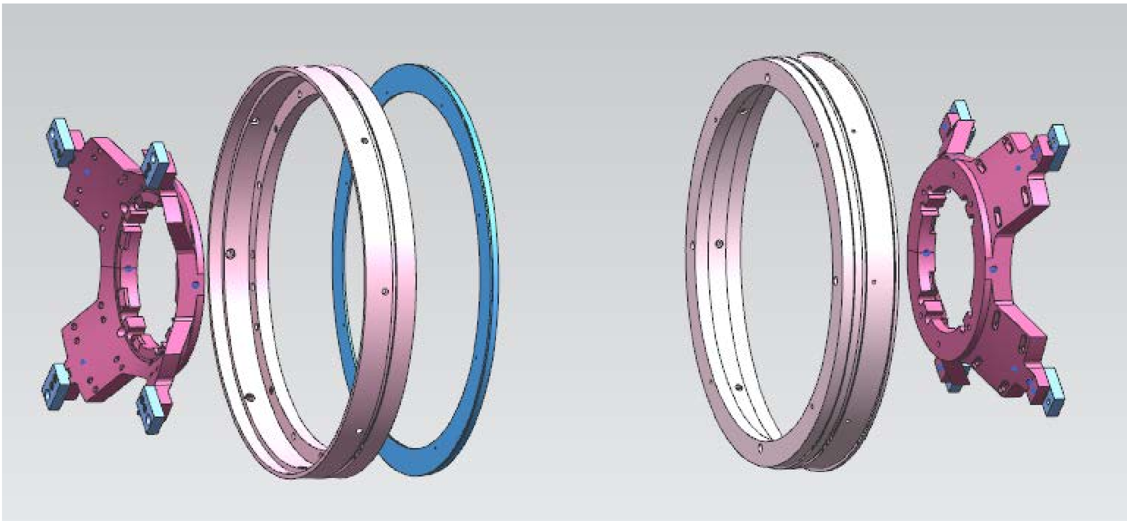
East side

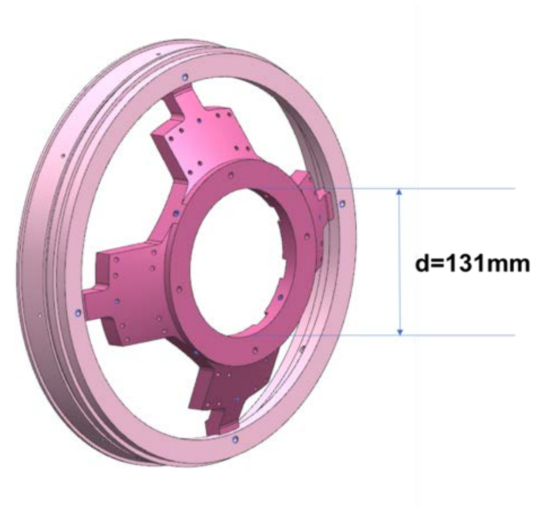


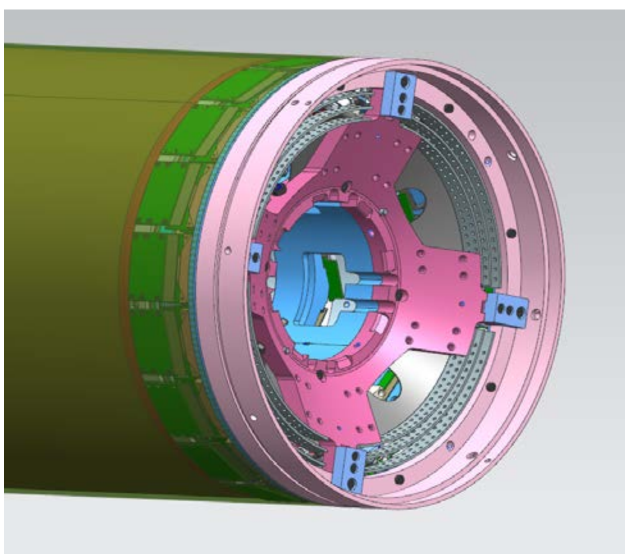
West side

- West side: glue the cylinder to the new west ring
- East side: Gluing the cylinder with first step ring of MDC

Interfaces

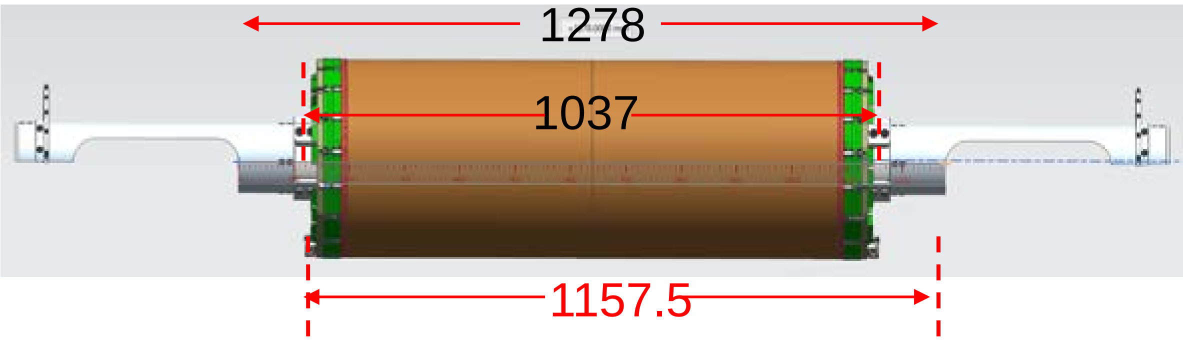




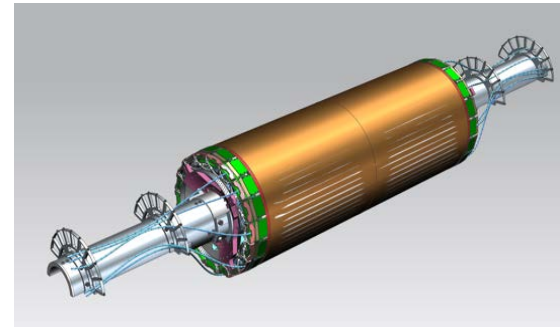


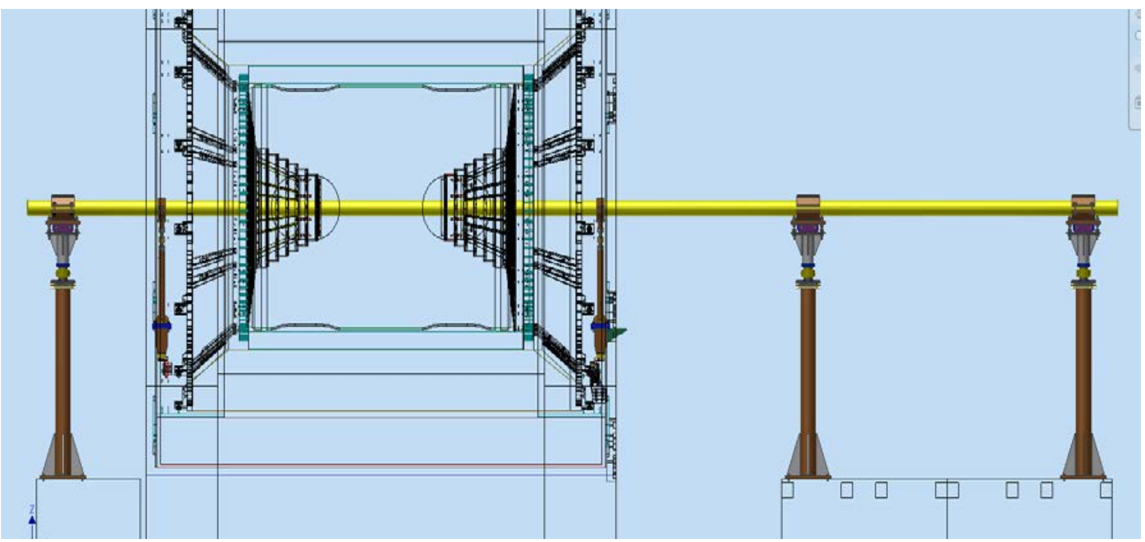
Supporting flange for CGEM:
had been checked and modified

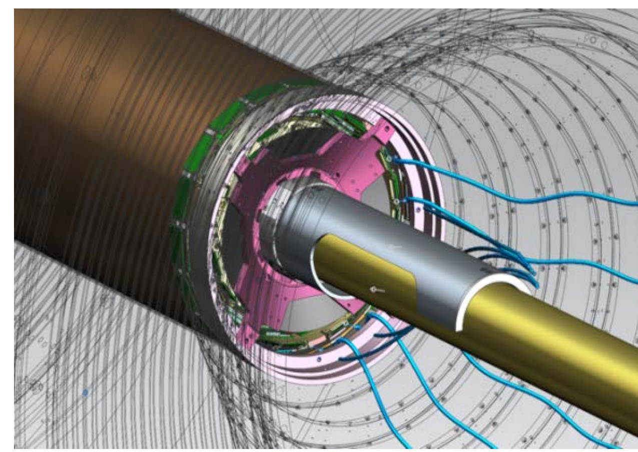
CGEM insertion



CGEM cables supporter

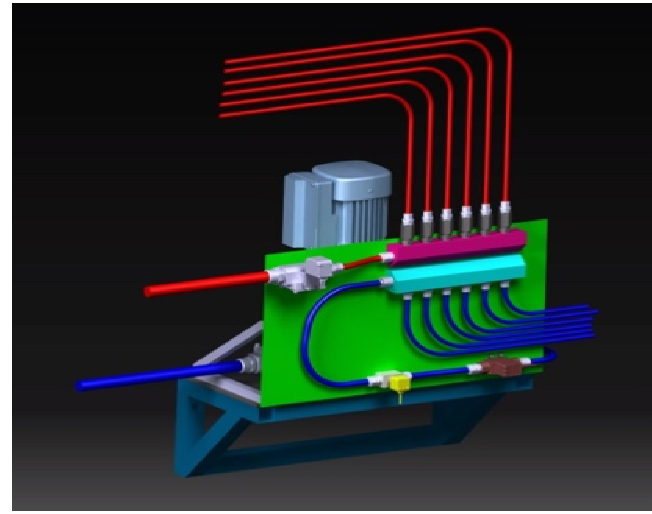






Other issues in integration

- Cooling
- Gas system
- Operating procedure
- Cable routing

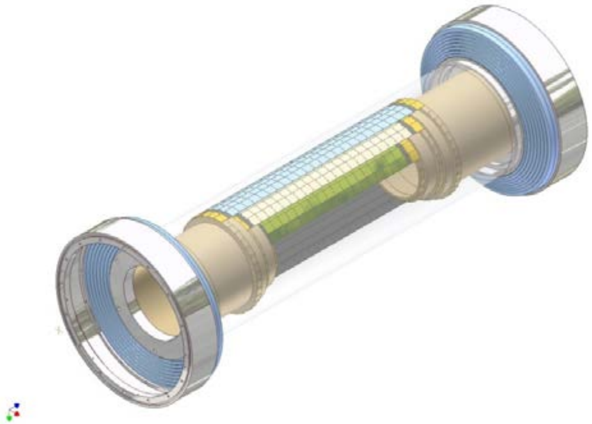


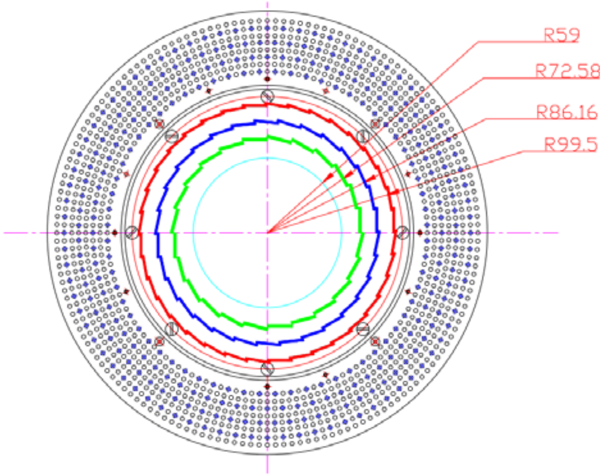
Preliminary Schedule

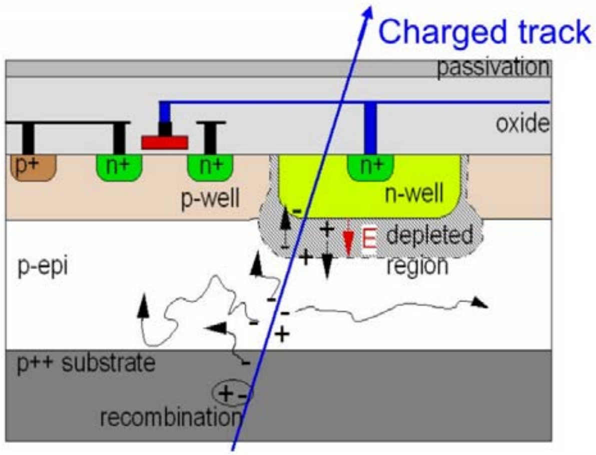
- Electronics production completed: end of Dec 2017
- Detector construction completed: Feb 2018
- Electronics test completed: Feb 2018
- Mechanical assembly test of the three layers: Jan 2018 – Mar 2018.
- End of the installation readiness review: Mar 2018.
- CGEM -IT leaves Italy: May 1th 2018.
- CGEM -IT QC and assembly at IHEP: May – Jun 2018.
- Standalone cosmic run: Jun -Aug 2018.
- Ready for installation: July 1th 2018.
- CGEM installation begins not earlier than August 1th 2018
- Commissioning of the system

A referee committee, weekly meeting, workshop, good cooperation

Inner MDC upgrade with CPS



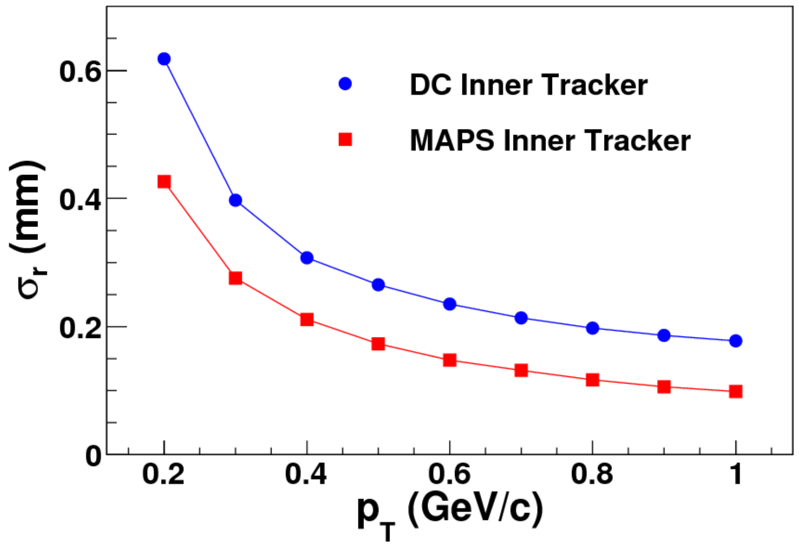


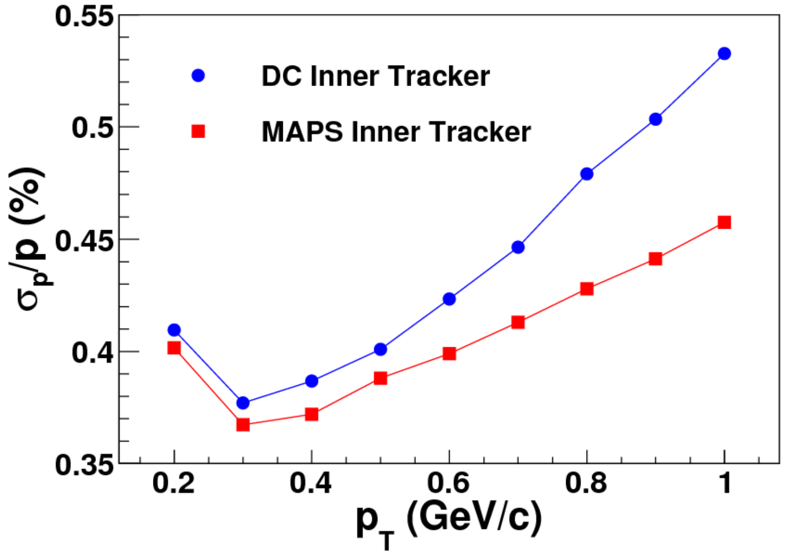


- First domestic study on the development of vertex detector or inner tracker
- Baseline design
  - 3 layers detector with Mimosa28 chips
  - Good spatial resolution (few μm)
  - Low material ladder structure
  - Air cooling
- R&D project
  - institutions: IHEP+ SDU collaboration with IPHC

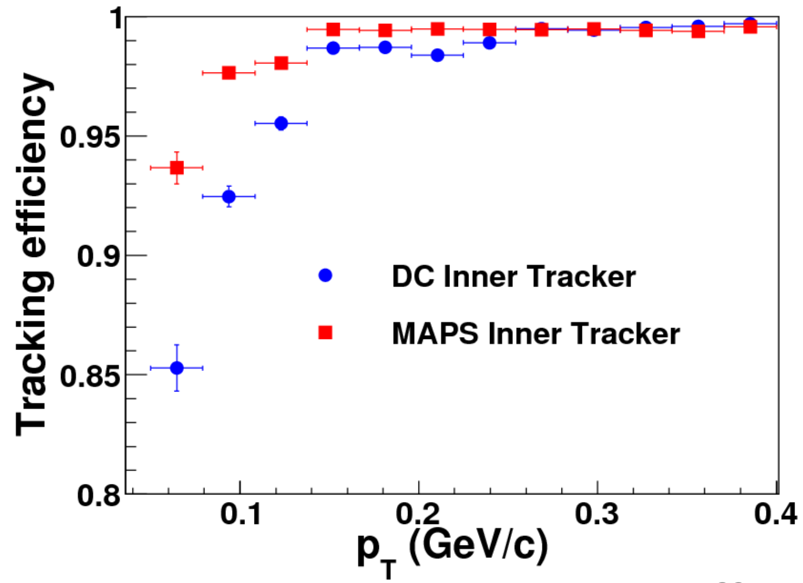
- Monolithic, sensor + readout electronics
- Density: ~20μm pixel pitch, ~0.9Mpixels/chip
- Spatial resolution: a few μm
- Rating capability: ~10^6Hz/cm^2
- Material budget: ~50μm thick
- Radiation tolerance: ~1 MRad, 10^{13} n_{eq}/cm^2
- Power consumption: 175mW/cm^2
- Room temperature operation

Simulation of Inner tracker with CPS

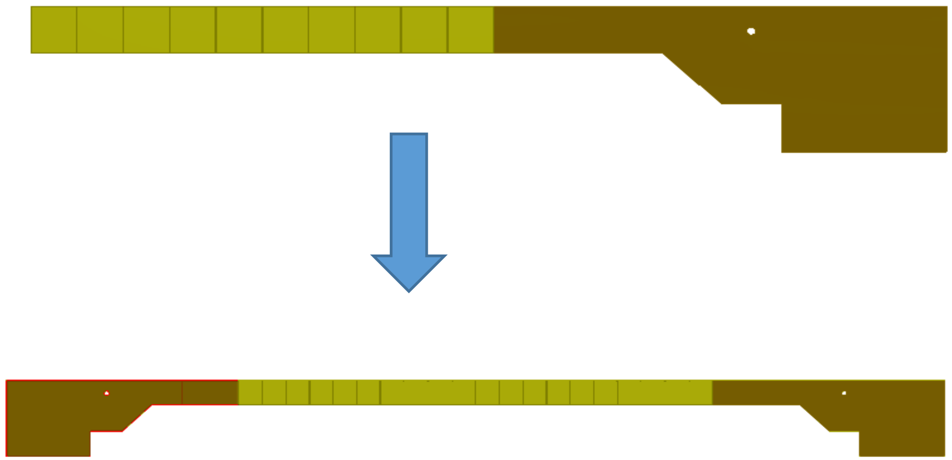


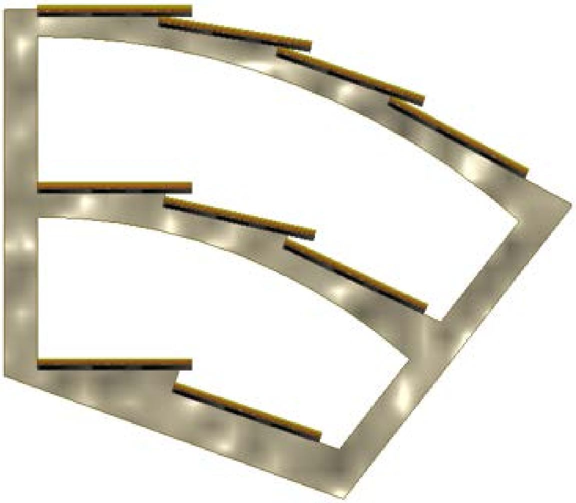


- Simulation to estimate the performance of the whole tracker with CPS inner tracker
- Improvement of the spatial resolution
  - σ_{xy} : 0.18mm → 0.10mm @ 1GeV/c
  - σ_z : 1.6mm → 0.12mm @ 1GeV/c
- Improvement of the momentum resolution and the tracking efficiency



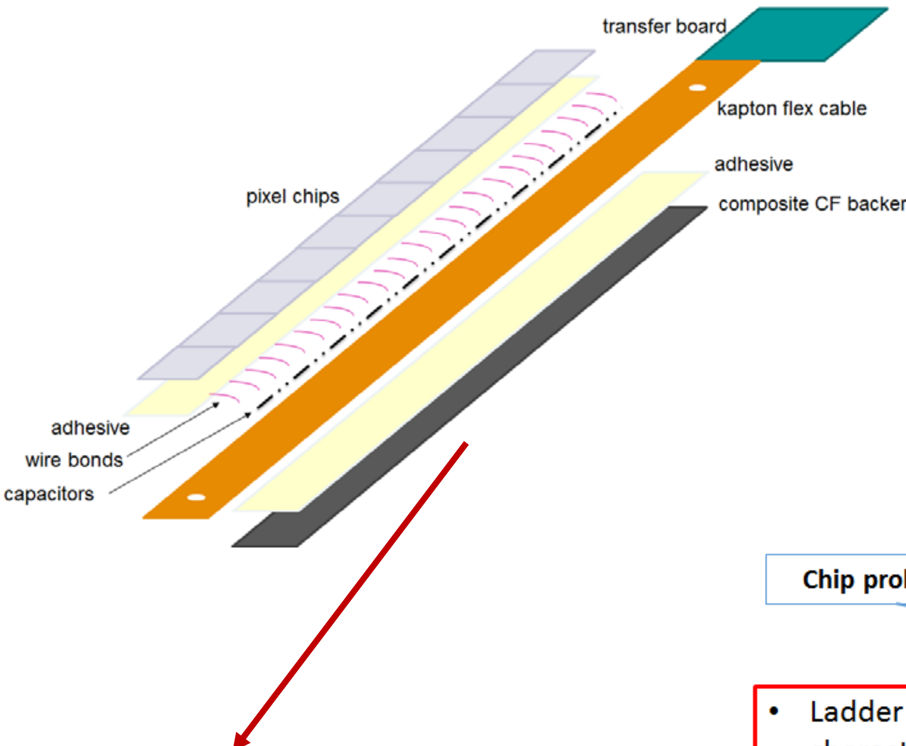
R&D target: a CPS prototype

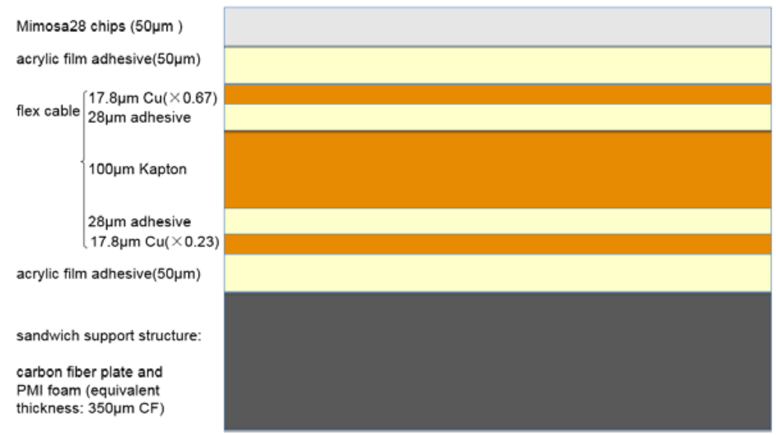




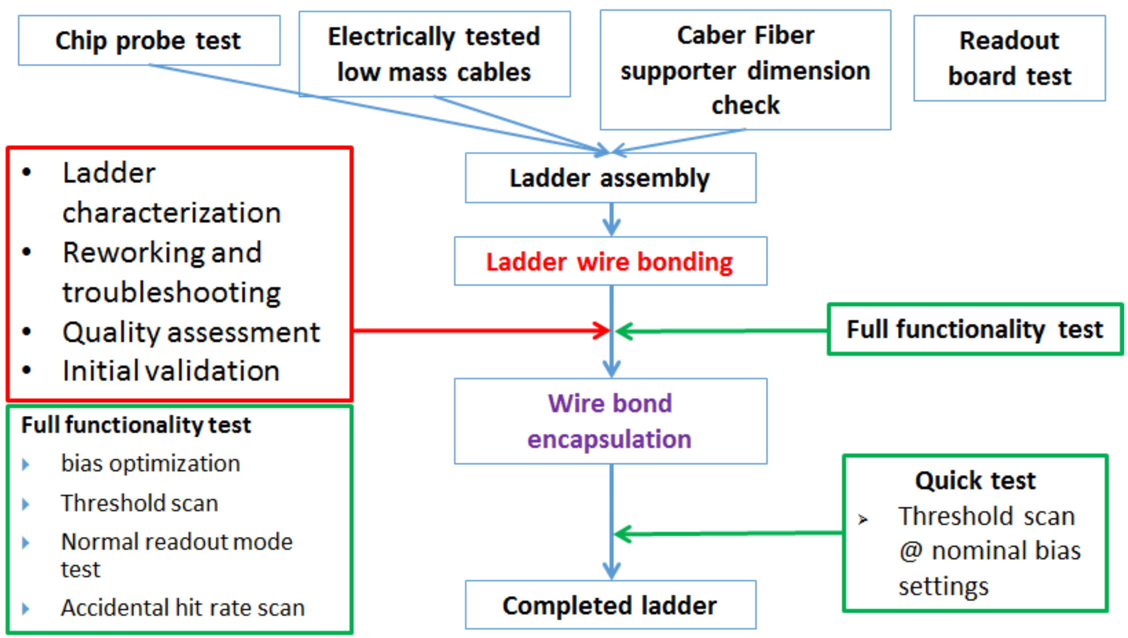
- Prototype layout
  - 1/10 Coverage of the inner tracker (~ 720cm^2→180 chips→180M pixels)
  - ϕ direction: 2 , 3 and 4 ladders for the 1st, 2nd and 3rd layer respectively
  - Z direction: 2 sets of ladders each layer
  - 10 Mimosa28 chips with dimension of 2cm×2cm in each ladder
- Chip →ladder →sector → layer →prototype

Ladder design

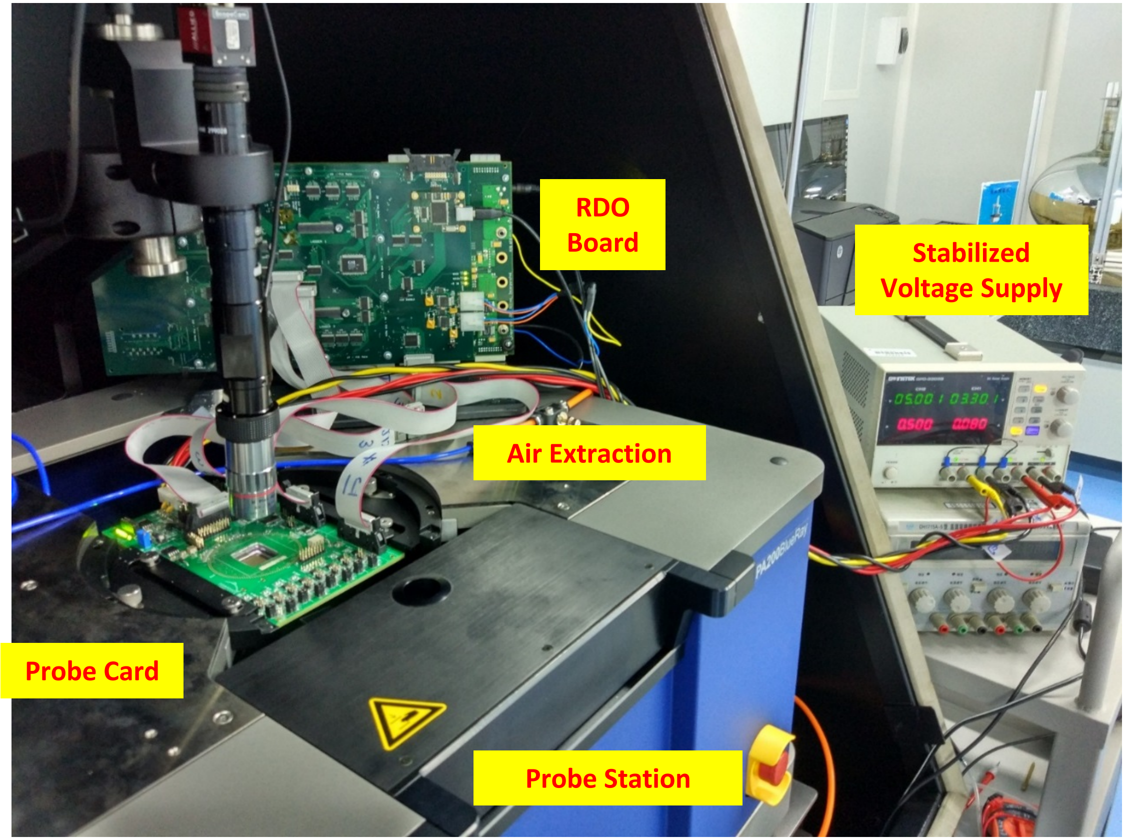


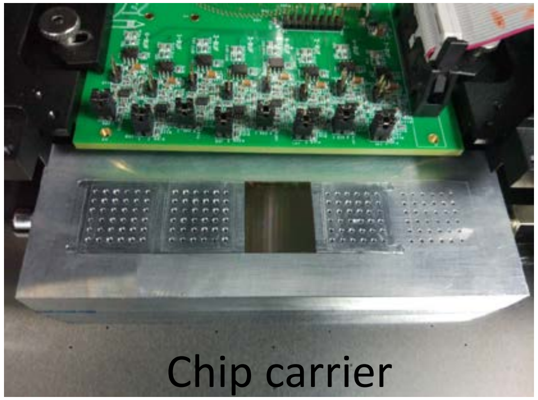


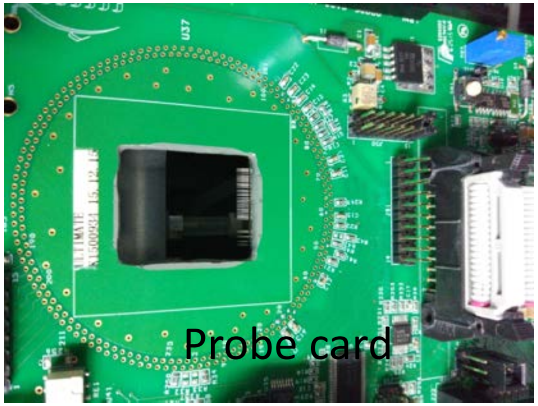
- Ladder: the basic building block of the detector, key issue for the prototype
  - 10 Mimosa28 chips (thinned to 50μm)
  - A flex cable
  - A carbon fiber supporter

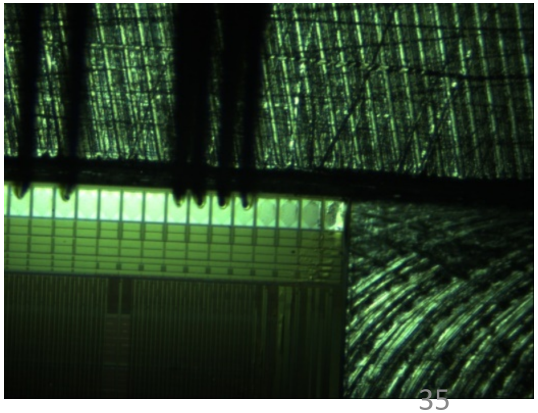


Chip probe test



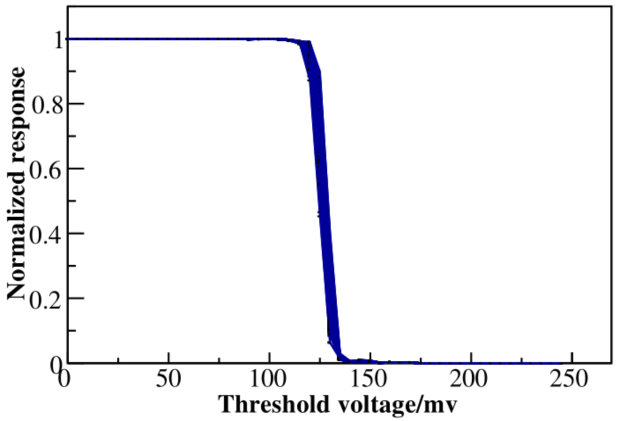

Chip carrier

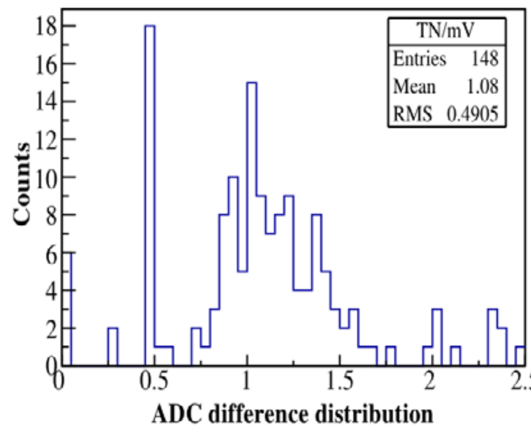

Probe card

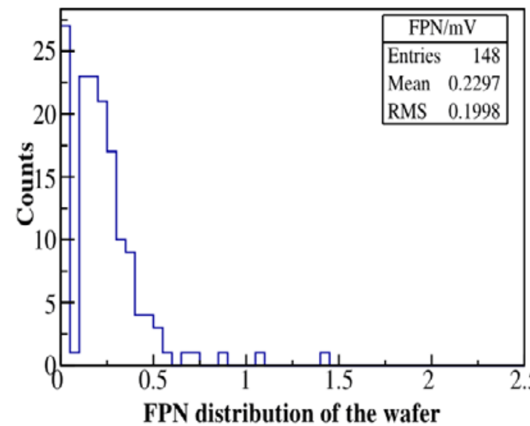


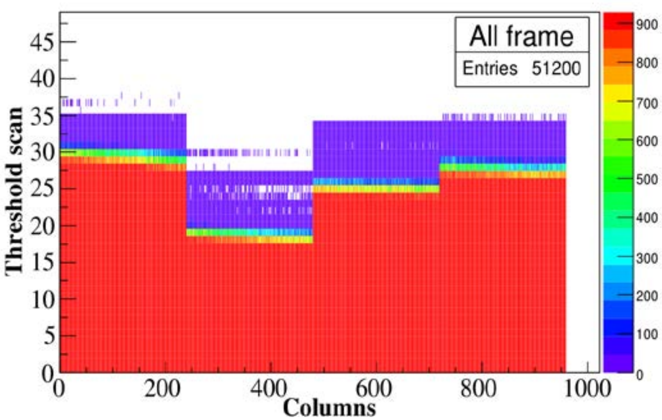
- A probe testing system was set up for the chip functional verification and preliminary performance test
  - pin-pad touched check, power consumption test, data check, clamp voltage scan, threshold scan

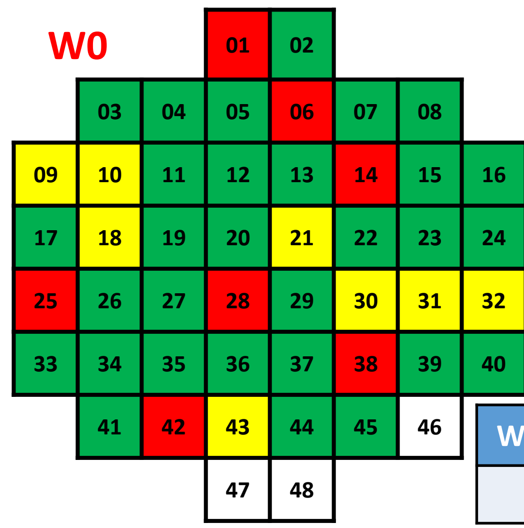
Probe Test results











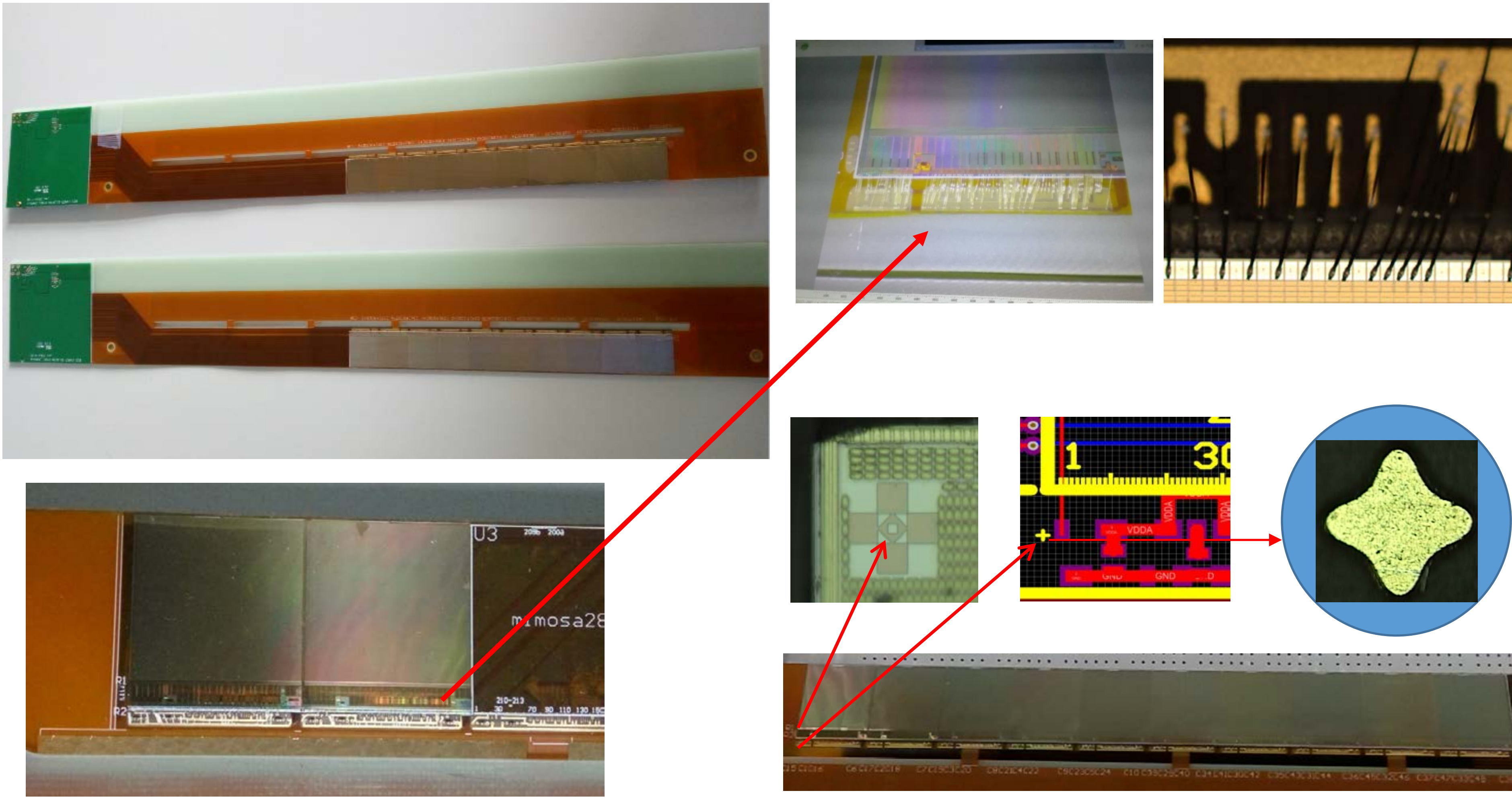
Wafer	Chips	Good	Bad	Dirty
0	45	30	15	8

- 6 wafer chips were delivered, 4 wafer chips were tested
- Typical yield is about 65%

Ladder assembly

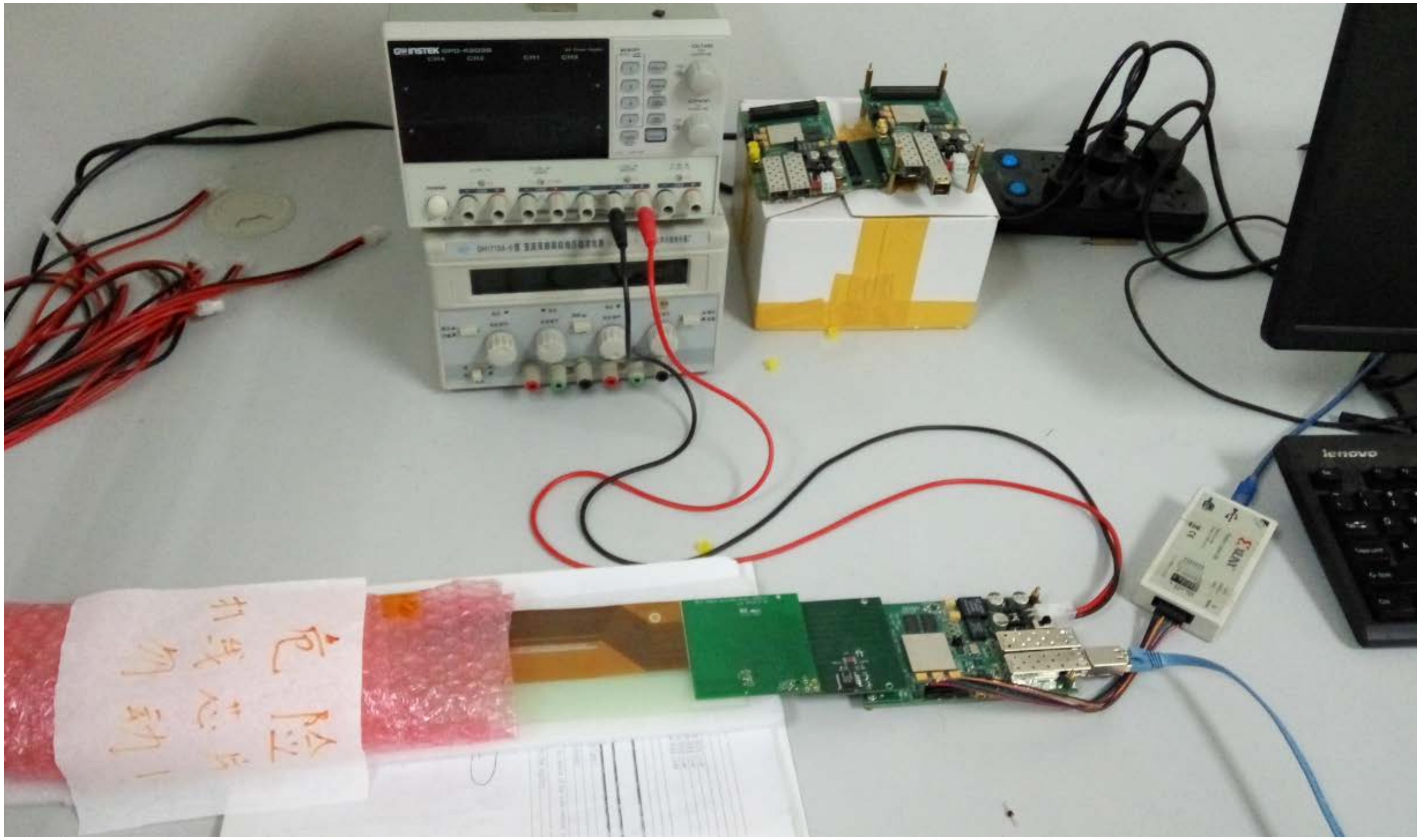
- Ladder assembly was operated at a special platform to ensure the location accuracy of the chips

Ladder assembly



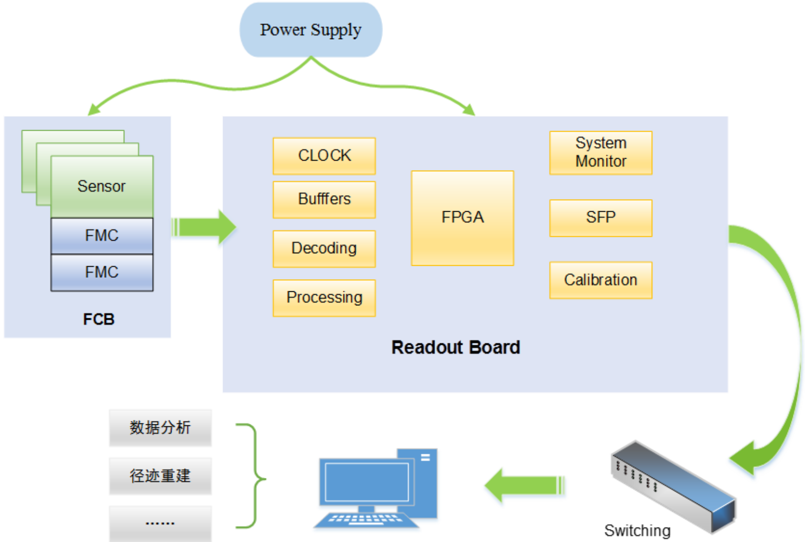
- Low material, high precision ladder
  - Material budget: 0.37% X_0 /ladder, 0.51% X_0 /layer (ladder + supporter)
  - Chip location precision: < 10µm

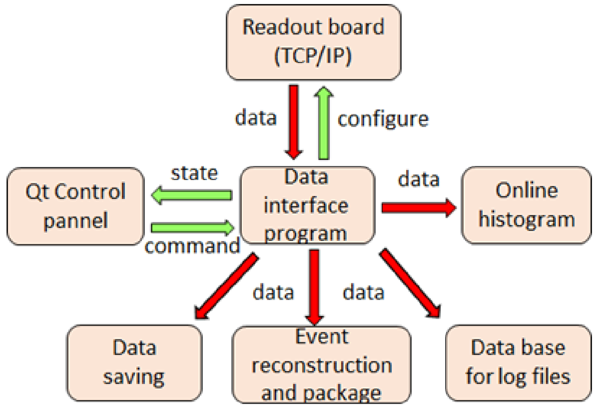
Ladder test

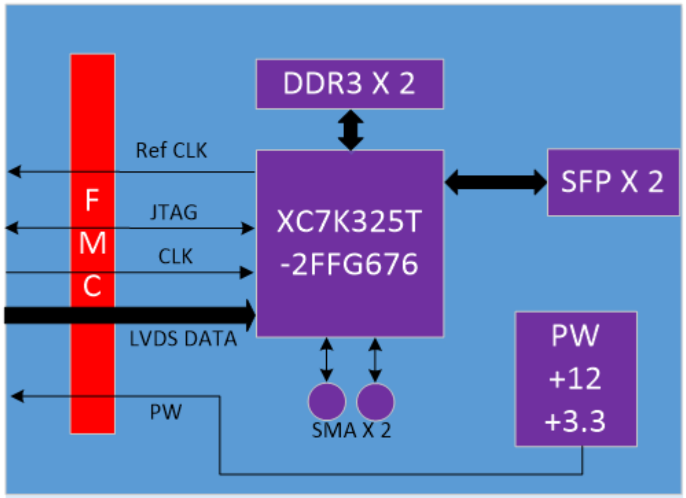


- The ladders together with the readout electronics were test by ^{55}Fe X rays and ^{90}Sr β rays
- The threshold scan, the crosstalk, the imaging performance, and the hit reconstruction algorithm were studied

Readout electronics and DAQ

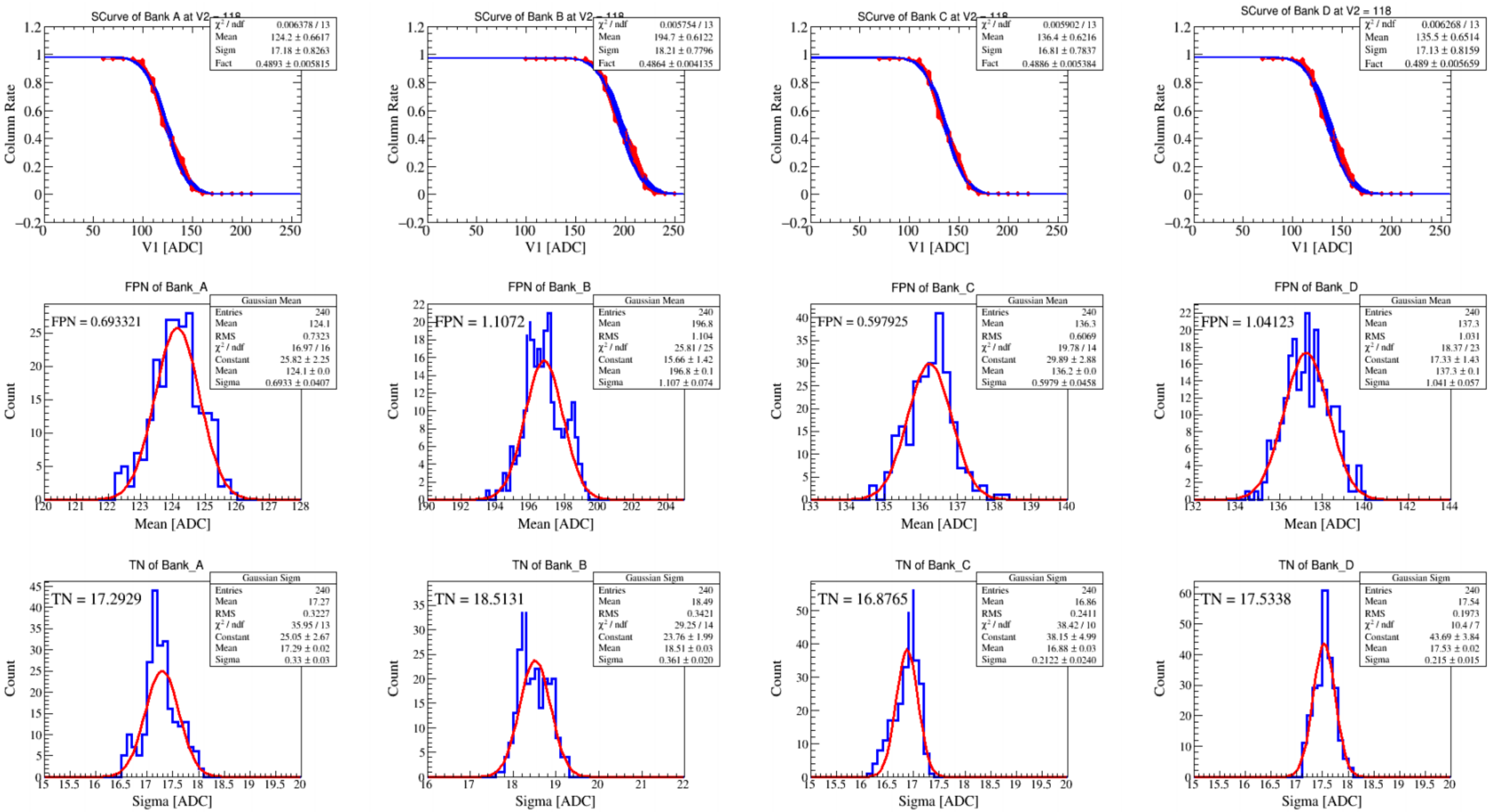






- Distributed system
- Ladder → FCB → Readout Board → Switching → PC
- SiTCP : high-speed and highly reliable data transmission
- Readout speed: 30~40MB/s/ladder

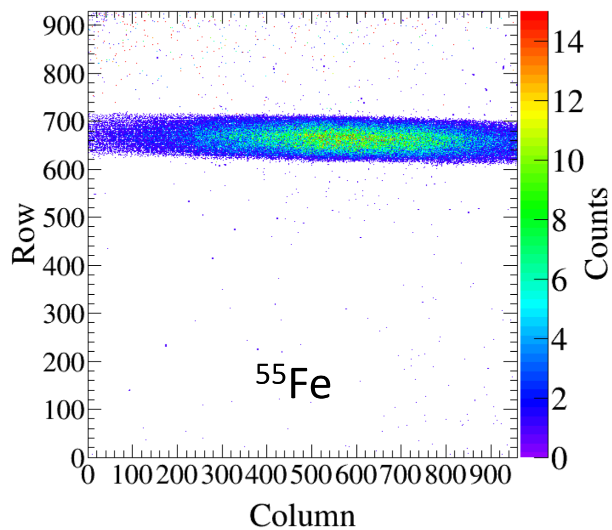
S-curve scan

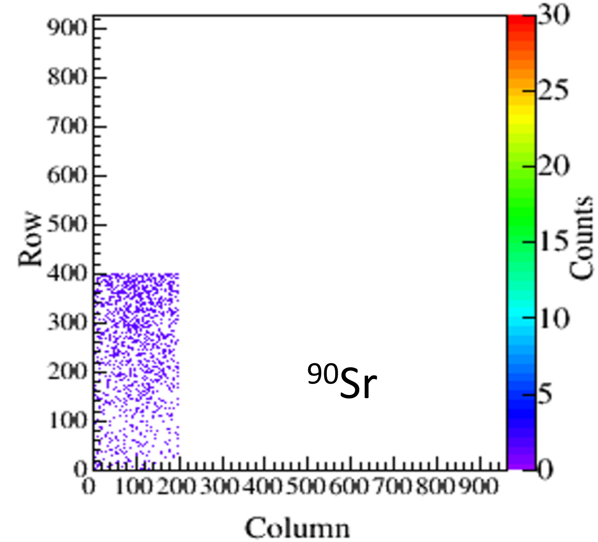


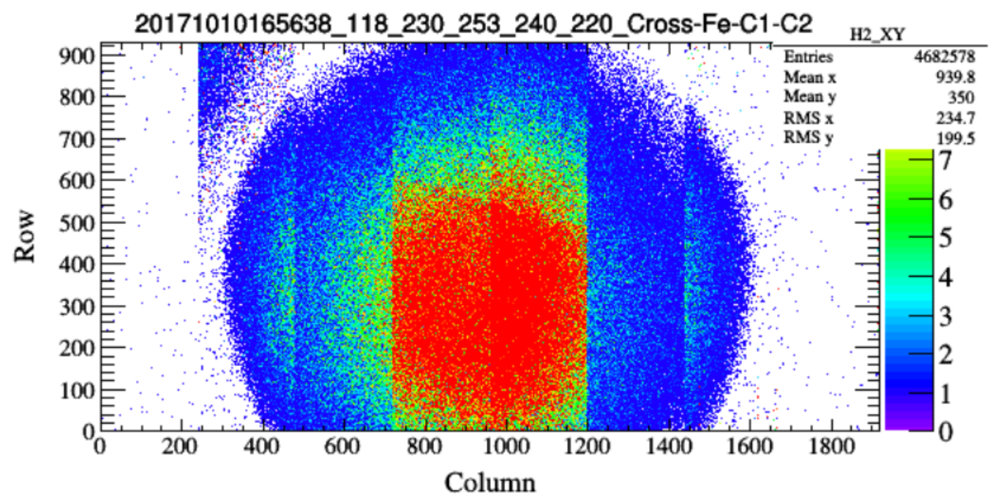
- S-curve scan by column and by pixel
- PFN~1mV, TN~17mV, ENC~ 15e, Threshold ~(3-4)σ

Test by radiation sources

- Pixel response test by ^{55}Fe X rays and ^{90}Sr β rays
- Crosstalk between two neighboring chips test
- Impact of the chip temperature on the noise level



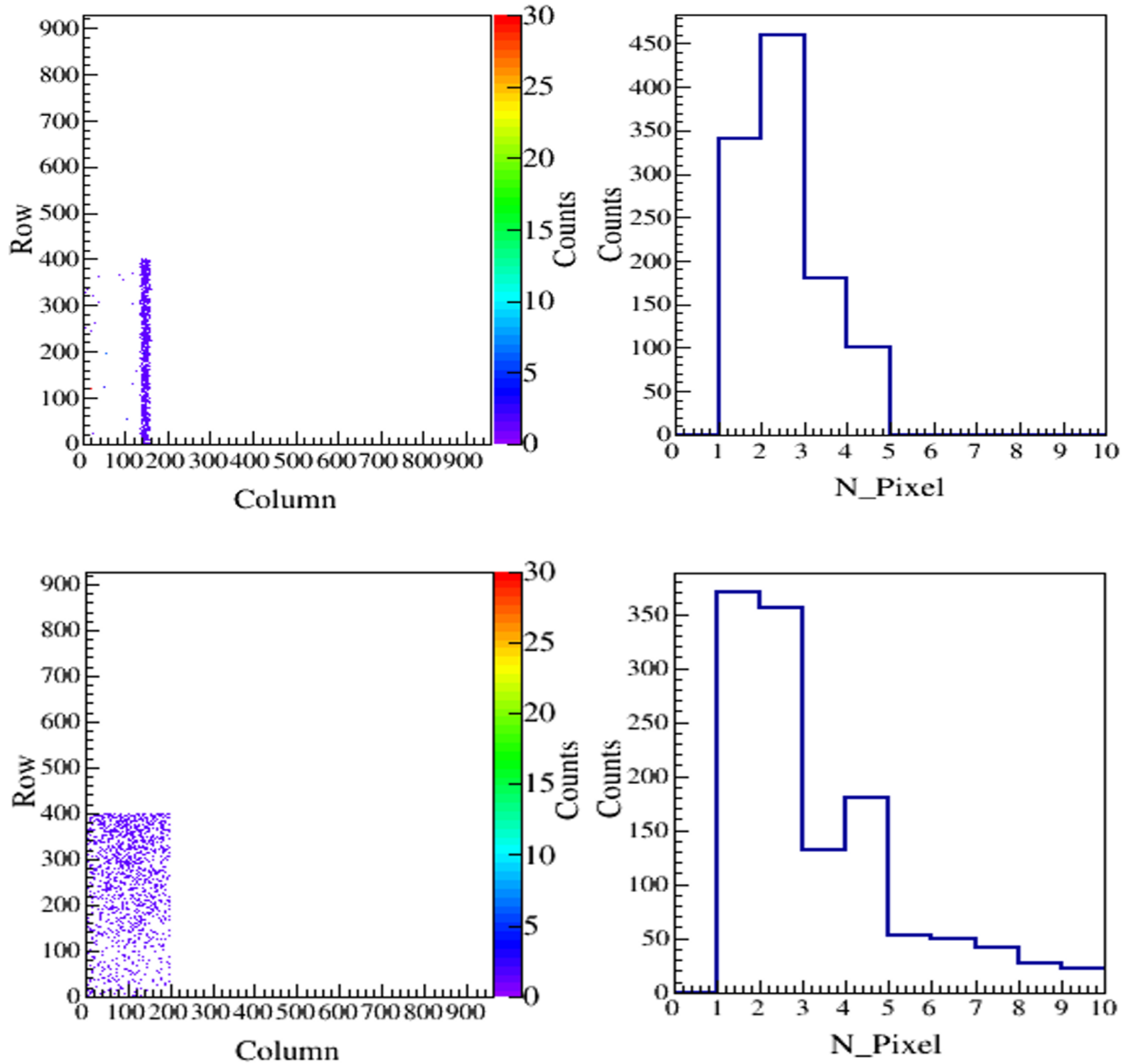




Crosstalk between two neighboring chips test

Hit reconstruction algorithm

- Charge collection by thermal diffusion
- Charges induced by one hit can be sharing with several pixels, be benefit to special resolution
- Digital readout: no seed signal
- Reconstruction algorithm : comparison method



Summary

- Deeply consideration and studies was carried for the inner MDC upgrade
- The construction and test of the new improved inner chamber were completed. It is ready for being used if needed
- The CGEM is under construction as planed. The replacement is considered and well designed in details to ensure the successful upgrade
- The development of CPS prototype going smoothly. We gain the ability and experience on the key technology and method in the construction of Si pixel detector for the BESIII or future high energy physics experiment.

Thanks for your attention !