A Cylindrical GEM Detector with Analog Readout for the BESIII Experiment

Gianluigi Cibinetto
(INFN Ferrara)
on behalf of the BESIIICGEM consortium

Program of Great Relevance PGR00136 INFN-MOST-MAECI 2013-2015

Outline

- The BESIII experiment
  - the Inner tracker
- The BESIII Cylindrical GEM-IT
  - innovations and peculiarities
  - construction of a cylindrical layer
  - test beam with a planar prototypes
- Summary and Conclusions

BESIII @ IHEP

BESIII (Beijing Spectrometer III) is τ-charm factory located at the Beijing e+e- collider BEPC-II working in the energy range from 2 GeV to 4.6 GeV.

Very rich physics program: Charm, charmonium and exotic states spectroscopy, light hadrons, F.F., τ physics.

Upgrade of BEPC (started 2004, first collisions July 2008)

Beam energy	$1 \cdots 2.3$ GeV
Optimum energy	1.89 GeV
Single beam current	0.91 A
Crossing angle	± 11 mrad

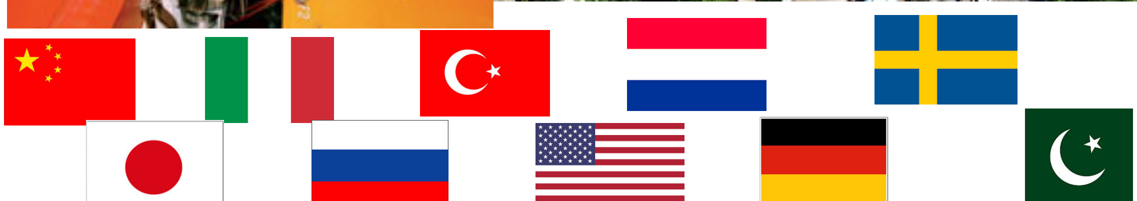
Design luminosity	$10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Achieved	$8 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Beam energy measurement:

Laser Compton backscattering

$\Delta E/E \approx 5 \times 10^{-5}$

($\approx$ 50 keV at τ threshhold)



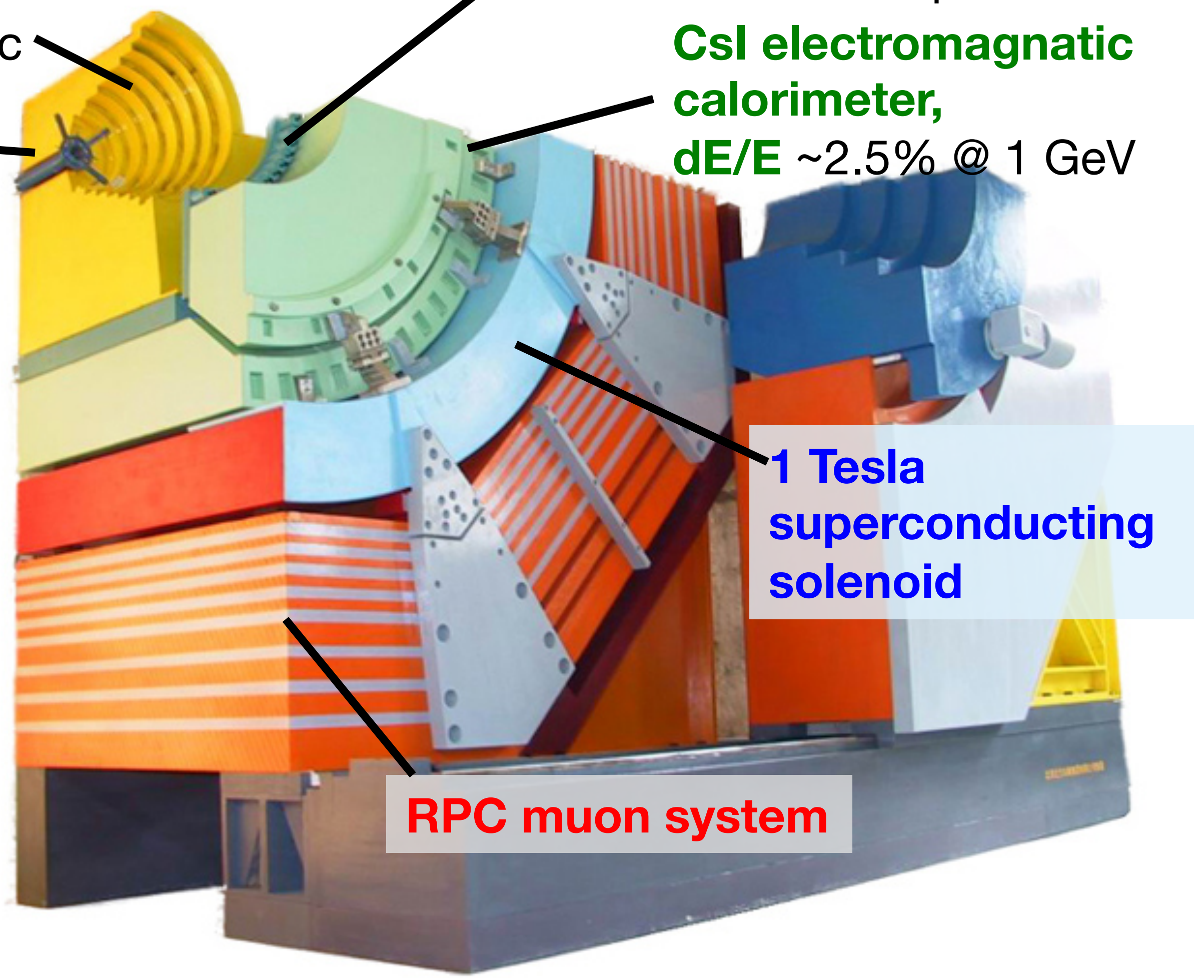
The BESIII detector

Multilayer Drift Chamber
120 μm resolution ,
dp/p ~0.5% at 1 GeV/c

Time-of-flight,
time resolution 90ps

CsI electromagnatic calorimeter,
dE/E ~2.5% @ 1 GeV

Be beam pipe



1 Tesla superconducting solenoid

RPC muon system

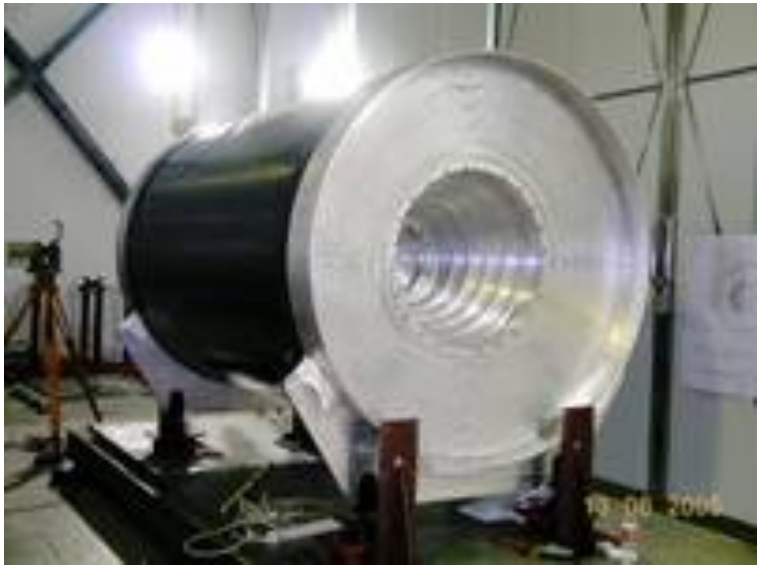
Angular coverage
- 93% of 4π for the tracking system
- 95% of 4π for the calorimeter

Total weight 730 ton

~40,000 readout channels

Data rate: 5 kHz, 50 Mb/s

The Multilayer Drift Chamber Inner Tracker

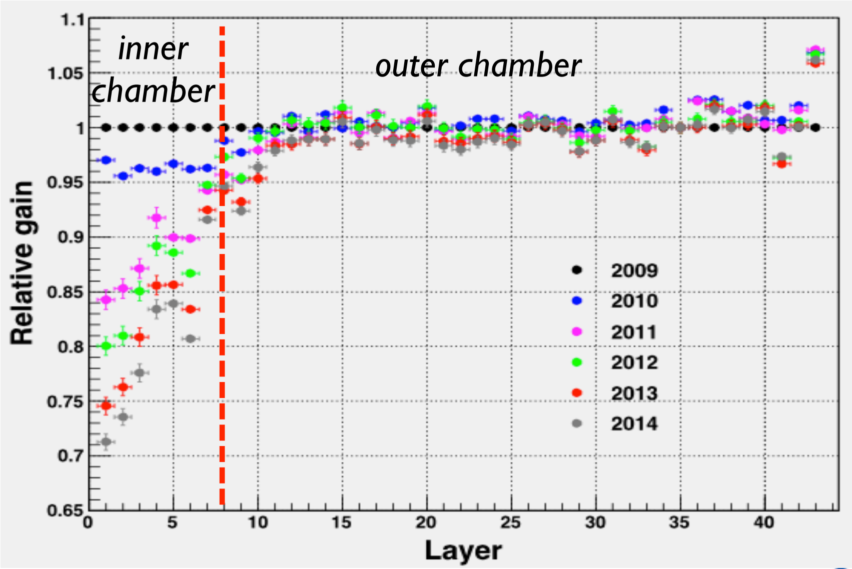


- MDC performs momentum and dE/dx measurement for charged particle identification.
- Spatial resolution is 130 μm in r-φ plane (azimuthal) and 2 mm in the z-coordinate (polar).
- Inner and Outer MDC are two separate chambers sharing the same gas volume.

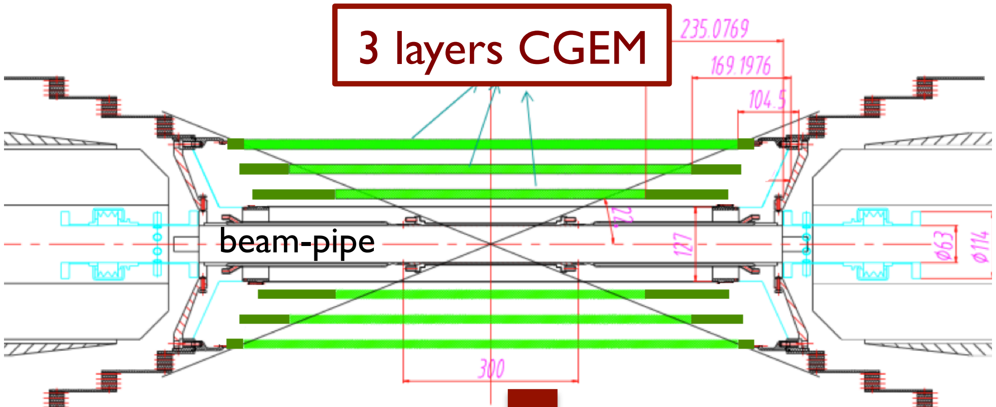
The increases of the luminosity is speeding up the aging the the inner tracker (IT).

The gain of the innermost layers is decreasing of about 4% per year of data taking.

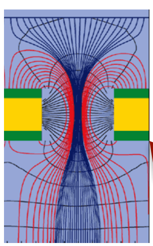
BESIII will run at least up to 2022 → a replacement is needed.

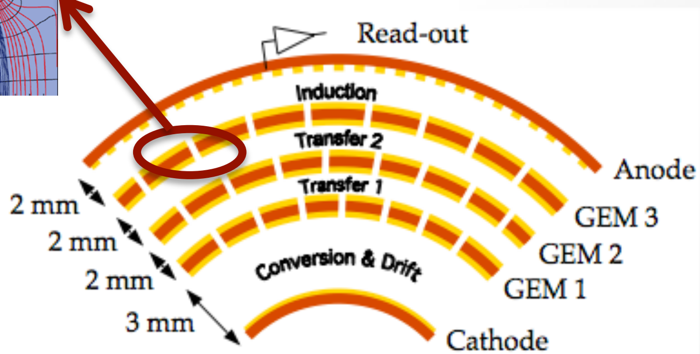


The Cylindrical GEM Inner Tracker



each CGEM layer composed by a triple GEM detector with cylindrical shape





Detector requirements

- Rate capability: ~10^4 Hz/cm^2
- Spatial resolution: σ_{xy} =~130 μm, $\boxed{\sigma_z =\sim 1 \text{ mm}}$
- Momentum resolution:: σpt/Pt =~0.5% @1 GeV
- Efficiency = ~98%
- Material budget ≤ 1.5% of X_0 for all layers
- Coverage: 93% 4π
- Operation duration ~ 5 years

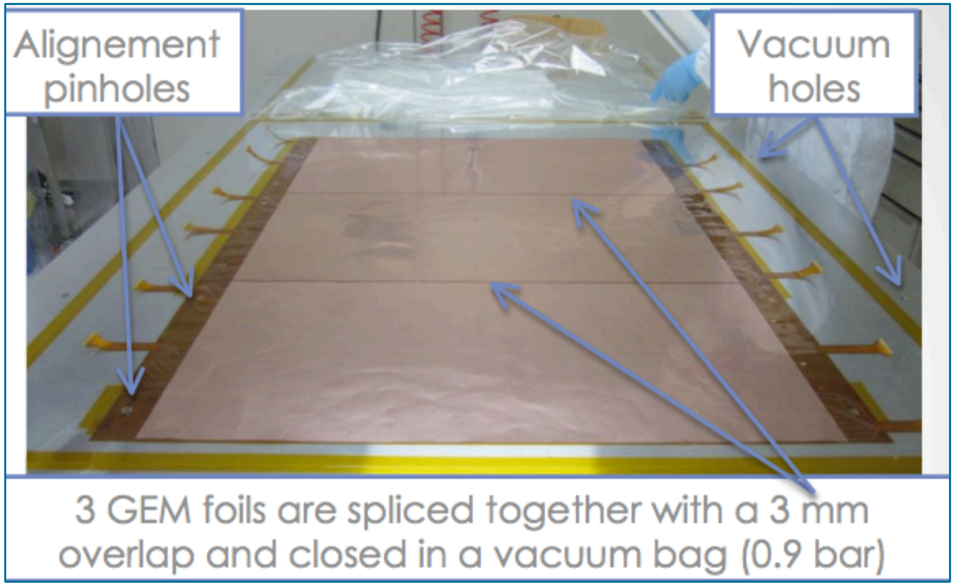
Detector peculiarities and innovations

- **Rohacell** will be used in the cathode and anode structure with a substantial reduction of the thickness of the detector.
- **Analogue readout** to reach the required spatial resolution with a reasonable number of channels. A dedicated ASIC chip will be developed.
- **Anode plane with jagged strips** to limit the parasitic capacitance

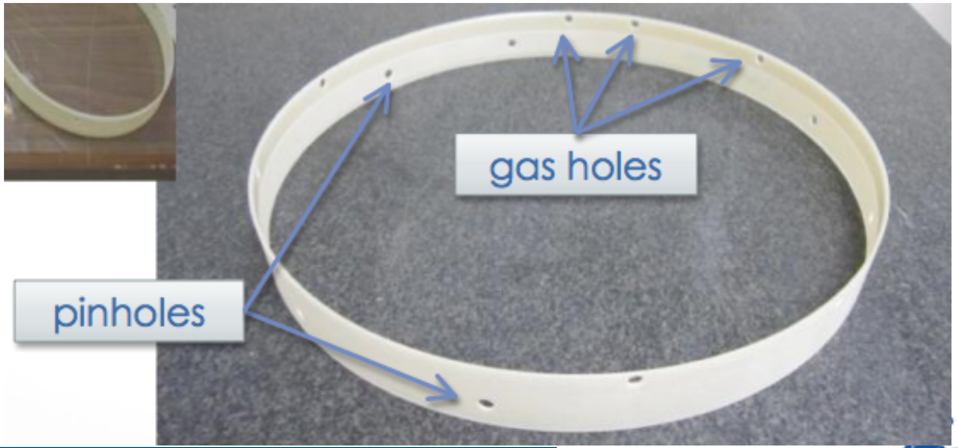
CGEM Construction Technique

To obtain cylindrical electrodes the foils are wrapped around molds, there is one mold for each of the 5 electrodes.

The electrode foils are first glued on a plane

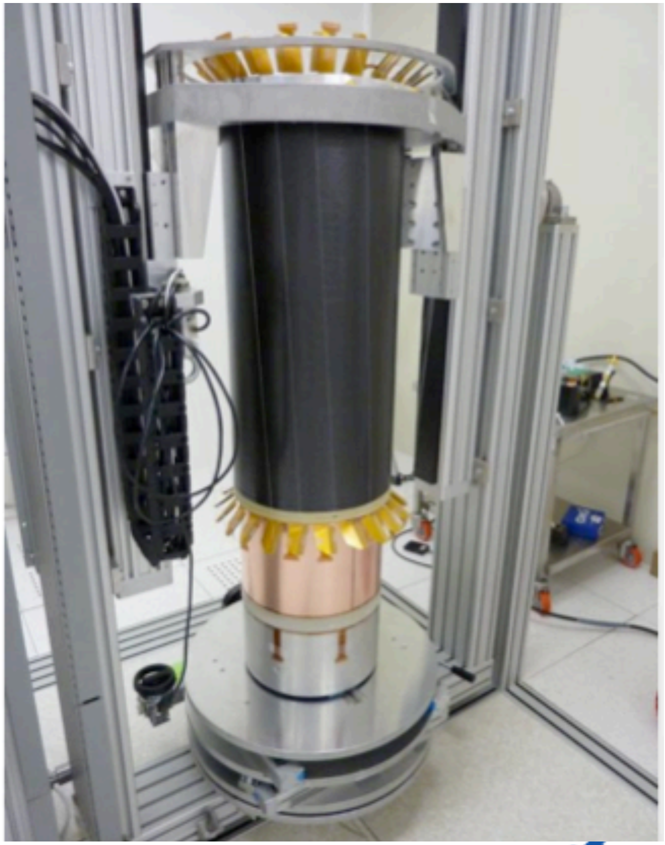


Fiberglass supports are outside the active area

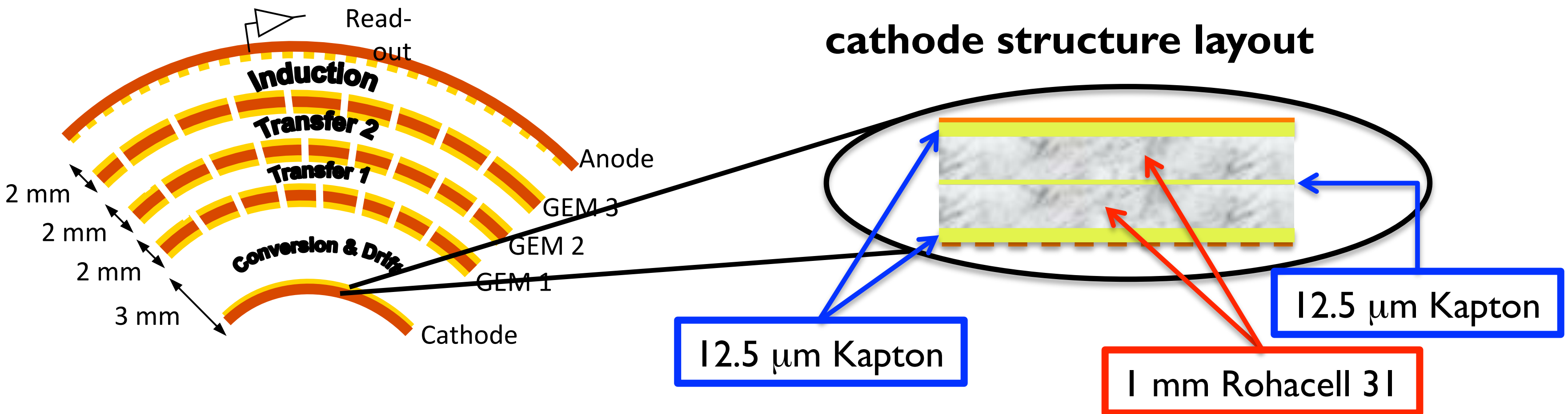


CGEM Assembly Technique

- A dedicated assembling machine has been designed and realized to perform the insertion of the electrodes.
- Axial alignment has a precision of 0.1mm/1.5m.
- The structure can rotate by 180° around its central horizontal axis.



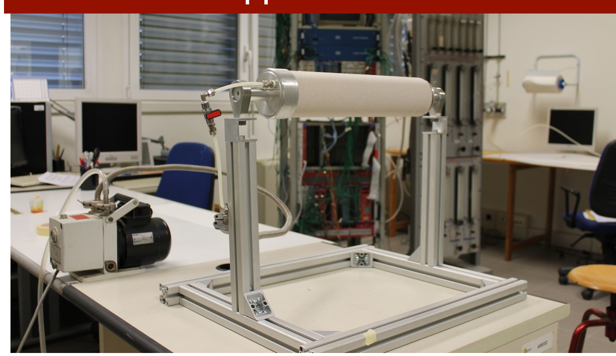
Rohacell technique for mechanical structure



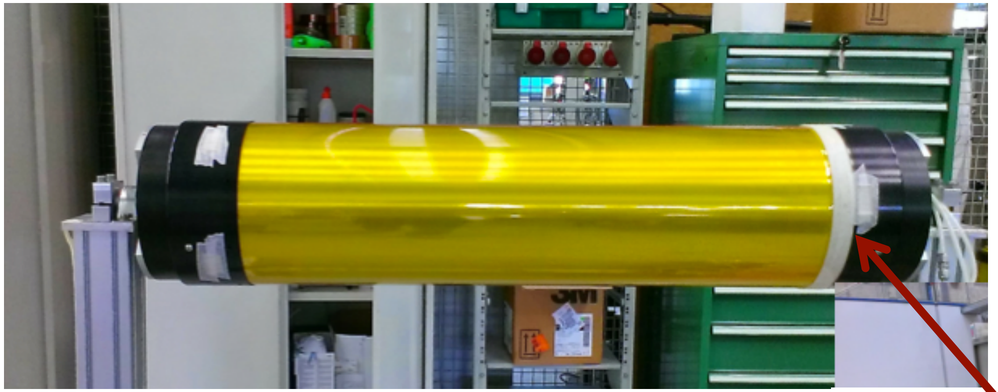
Rohacell is a very light polymeric material (density 31 kg/m^3) that will be used to give mechanical rigidity to the cathodes and anodes.

	% of X_0
# of X_0 for 1 layer	0.33
# of X_0 for 3 layers	0.99

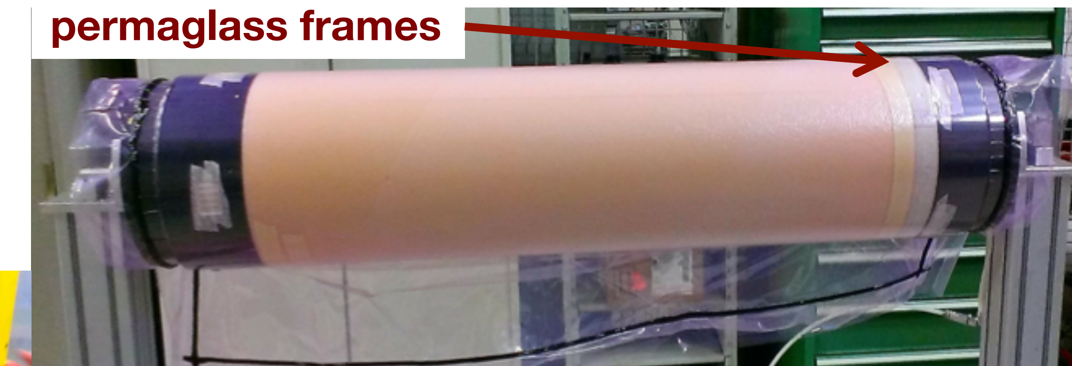
rohacell wrapped around the mold



Cathode construction



- the first 12.5 micron kapton foil around the aluminum mold; that is the most critical part.

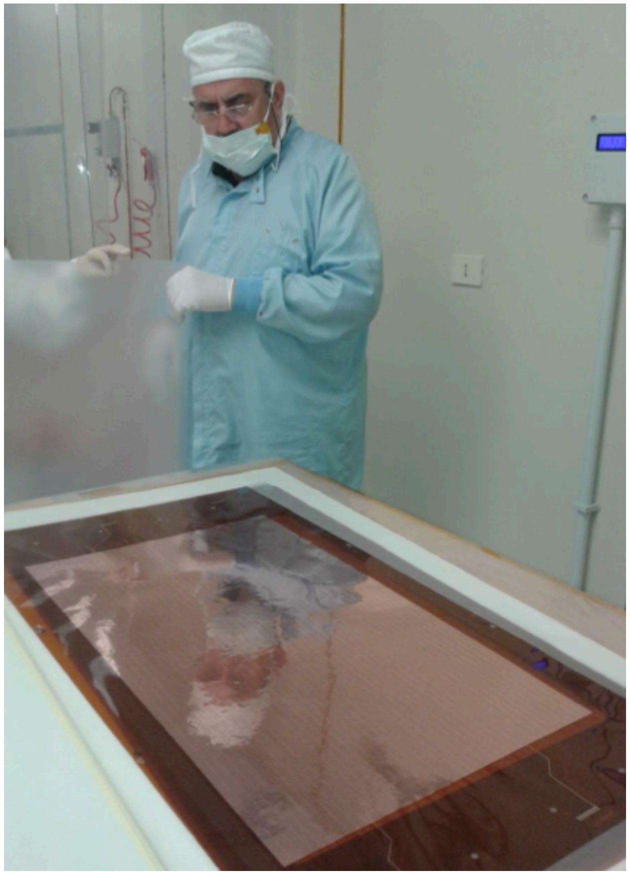


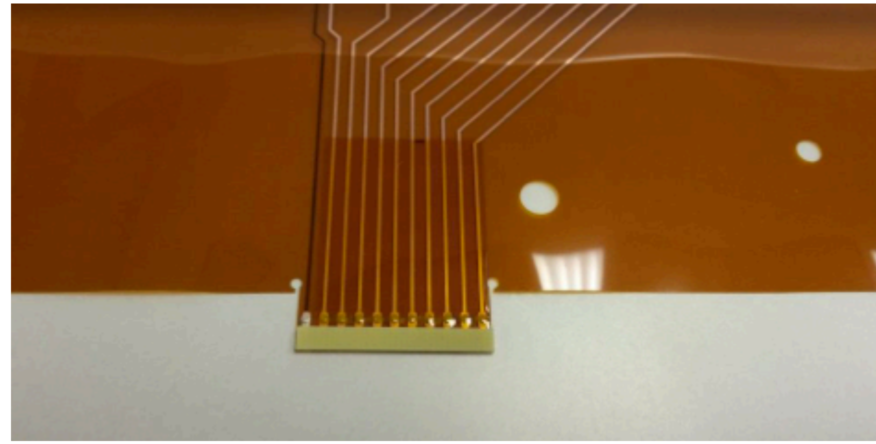
- the Rohacell helix is glued under vacuum on the kapton.

- the Rohacell plane is machined with a high precision milling machine.

GEM testing

GEM foils arrived from CERN and have been tested in the clean room.





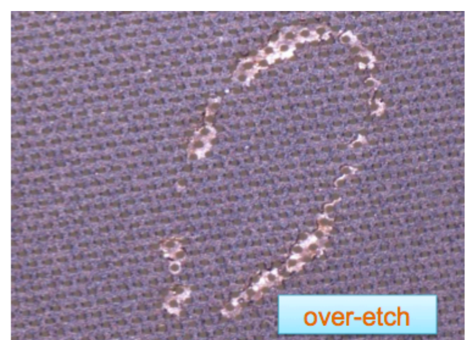
GEM production quality test.

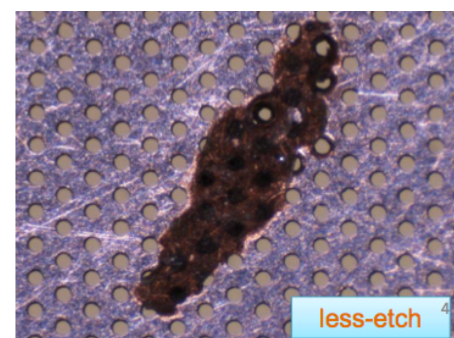
Before gluing, a HV test is performed on the GEM foils.

Good GEM must satisfy both:

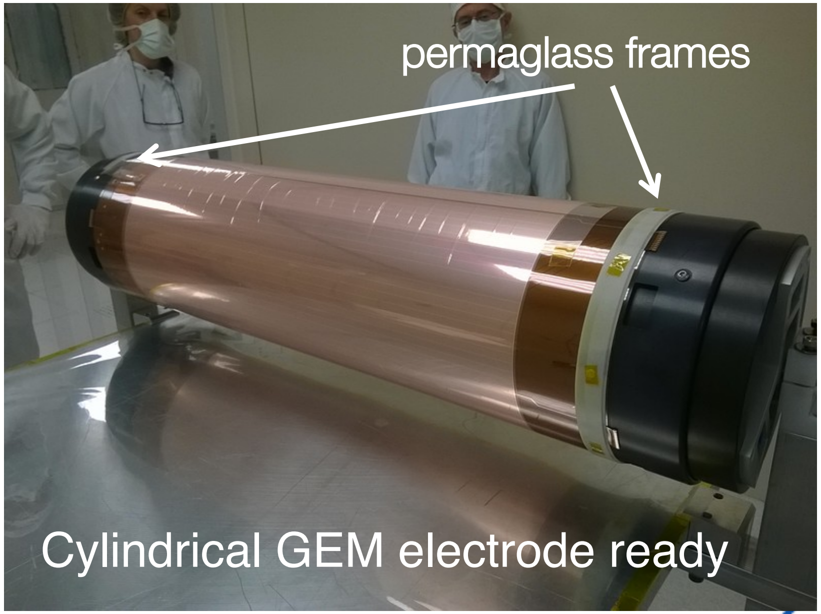
- <1 nA @ 600 V
- <2 discharges/30mins

Microscope pictures of GEM defects





GEM assembly

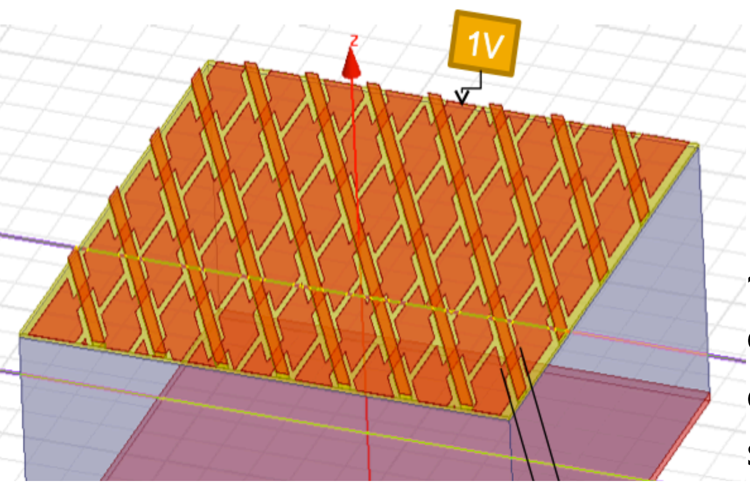


- The mechanical precision of all the item involved is critical for the detector assembly.
- Main issue of the gluing procedure is the mechanical tolerance of the reference holes used for the foils alignment.

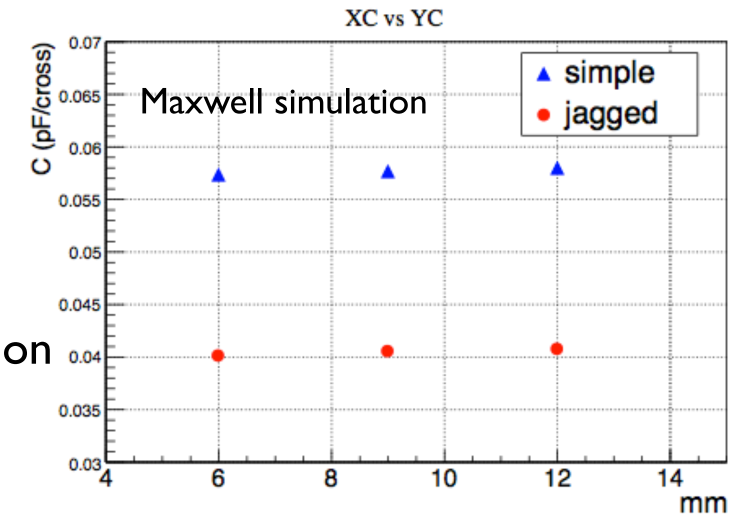
Readout plane design and features

BESIII will deploy a *Compass-like* readout plane produced by TS-DEM department at CERN

- large strip capacitance up to 100-150 pF
- stereo angle, depending on the layer geometry: +45°, -30°, +30°
  - ➢ different stereo angles will help reducing the combinatoric.
- strip geometry is 650/570/130 μm (pitch,X,V) → ~10000 electronics channels
- ground plane at 2 mm from the readout
- *jagged* strips layout studied to minimize the strip capacitance

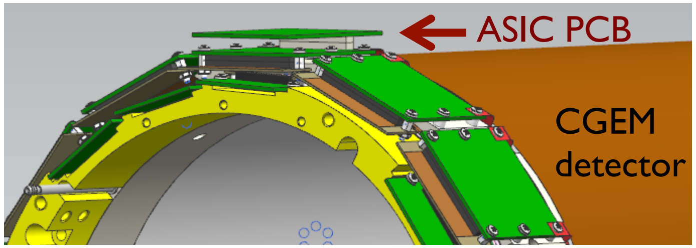


~30% inter-strip capacitance reduction compared to the standard strip configuration



Frontend electronics

- The analog readout is mandatory to limit the number of electronics channels. The charge measurements is performed by a dedicated ASIC chip.
  - with moderate strip pitch (650 μm) ~10000 electronics channels
  - 64 channels per ASIC → 2 ASIC in each frontend PCB→ 80 PCB
  - ASIC PCBs will be located on the detector to preserve the S/N ratio



- Design of CGEM ASIC (UMC .11μm) starting from existing design (IBM .13μm)
  - BackEnd design shared by several projects
  - BackEnd porting to UMC .11 μ m in progress
  - Different input stage (suited for CGEM) to increase signal sensitivity and SNR

- FrontEnd Optimization
  - input stage optimized to handle capacitance in the range 20pF-150pF

Main feature of the ASIC design

- UMC 110 nm technology
  - limited power consumption;
  - to be tested for radiation tolerance

also exportable to P.R.C.

- Input charge: 3-50 fC
- Sensor capacitance up to 100-150 pF
  - wide range of strip capacitance due to stereo angle.
- Input rate (single strip): up to 60 kHz/ch

including x5 safety factor

- Time and Charge measurements
- Time resolution: 2 ns
  - ok of μTPC readout

TDC based on Time Interpolator

- ADC to measure the charge

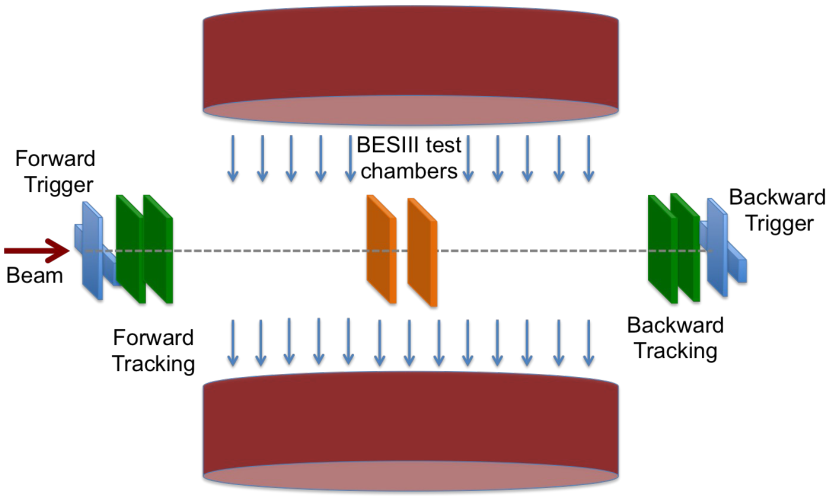
ADC resolution: 10 bits

- Power consumption < 10 mW /channel

about 100 W in total

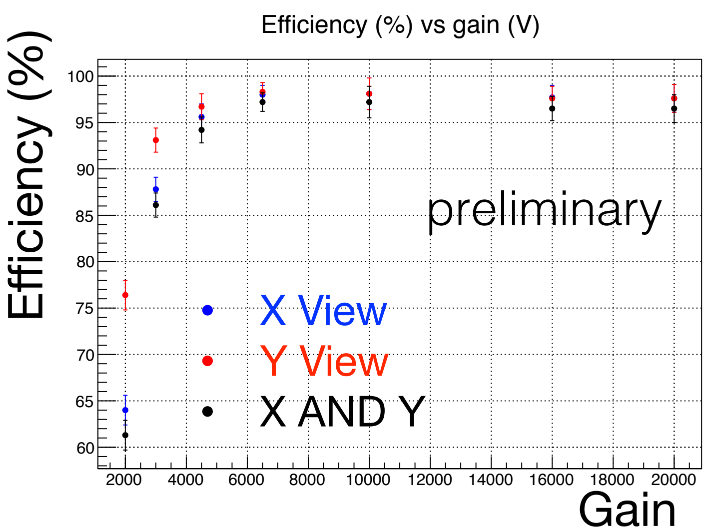
Test beam with planar prototypes

Test Beam Results



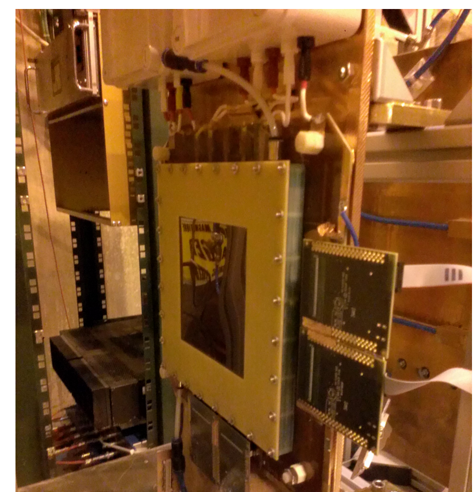
We performed two beam test at CERN to test planar prototypes inside a magnetic field.

- validate analogue readout
- validate Garfield simulation
- test different gas and geometry configurations



The efficiency plateau starts at about a gain of 6000. Efficiency for 2 dimensional clusters ~97%.

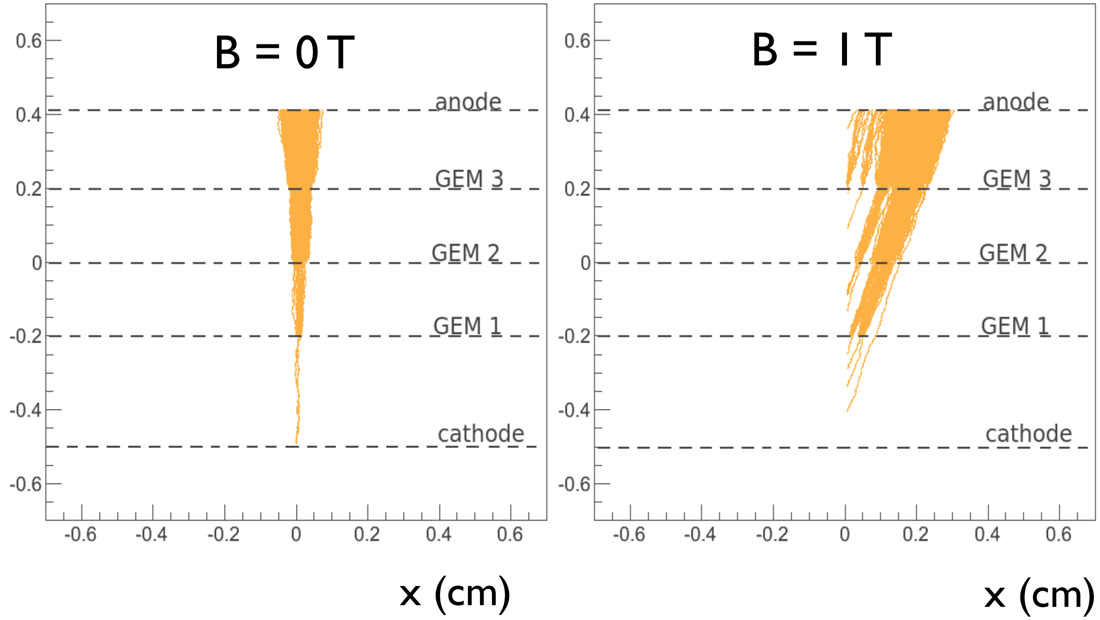
With **no magnetic** field and 650 μm strip pitch we achieved about 90 μm of spatial resolution with Ar/Isob (90/10) gas mixture.



test chamber readout by APV25 hybrids

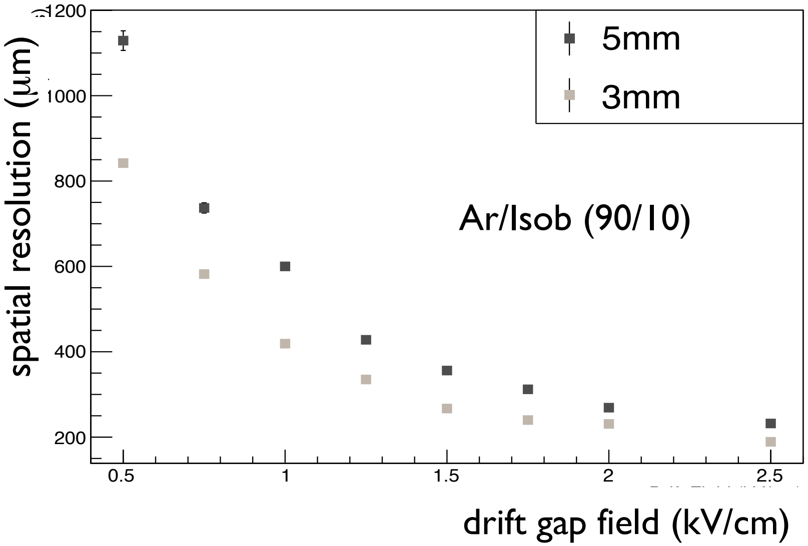
Effect of the magnetic field on the electron avalanche

- The effect of the magnetic filed to the electron avalanche has been studied with *Garfield* simulations.
- The Lorentz force displaces the electron avalanche.
- In addition **the B field produces a broadening of the charge distribution** at the anode.



- The shape of the charge distribution is no longer gaussian and the charge centroid method reduces its performance.
- The charge distribution and thus the spatial resolution have a strong dependence on the intensity of the electric field in the drift gap.

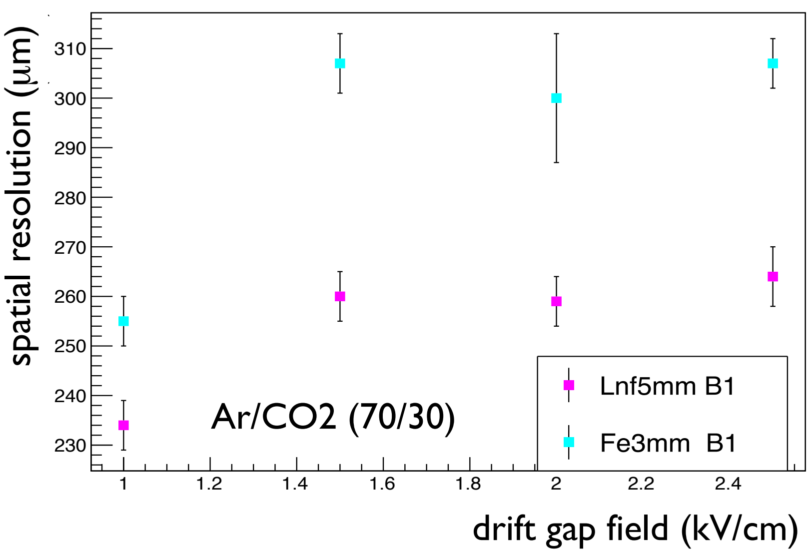
Spatial resolution in 1 T magnetic field

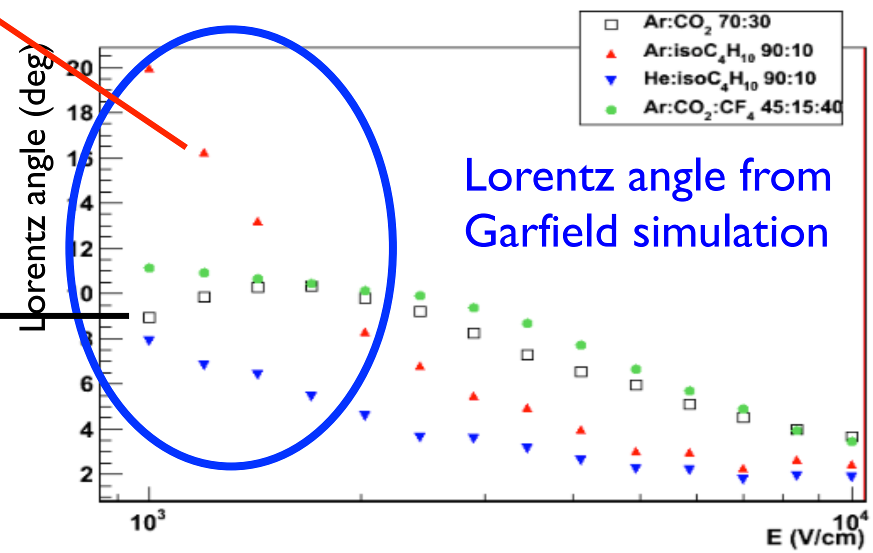


The resolution as function of the drift electric filed copies the behavior of the Lorentz angle.

Subtracting the contribution of the tracking system we achieved a **spatial resolution of about 190 um** with charge centroid readout.

The effect of the magnetic field will be reduced in the BESIII CGEM stereo view.

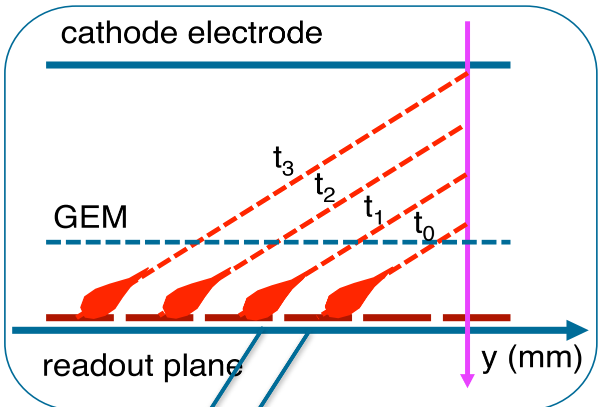




Gas gain 10 k. No effect on the efficiency.

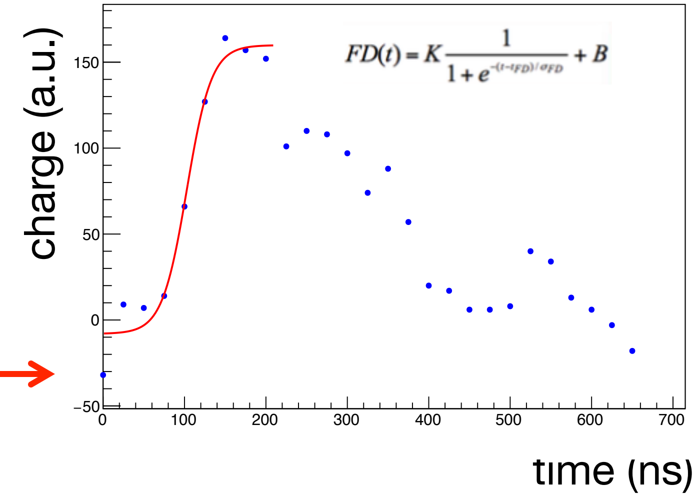
μTPC readout feasibility study

For diagonal tracks and/or in high magnetic field

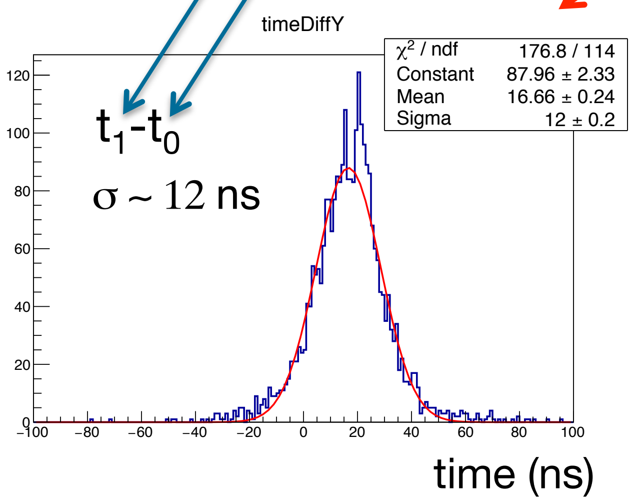


- Exploring a μTPC readout to further improve the spatial resolution

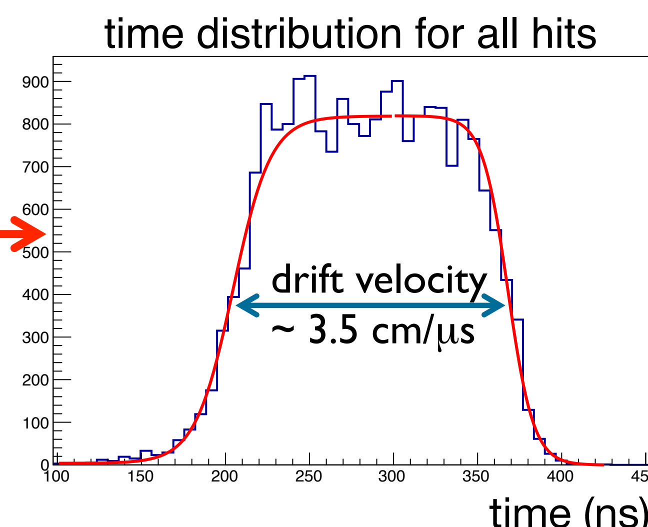
- Fit the charge samples to extract the drift time



- ~12 ns time resolution



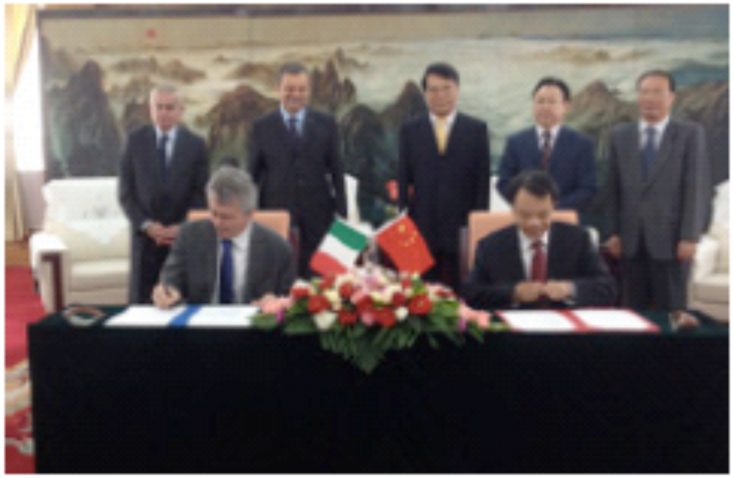
- The electron drift velocity can be extracted by the hit time distribution and its consistent with simulations.



- The track can be reconstructed from the time measurement.

MAE project (2013-15)

- Design, construction and test of a CGEM prototype and readout electronics funded by the Foreign Affairs Ministry agreement of scientific cooperation for a Joint laboratory "INFN-IHEP".
- The MAE executive program will host a workshop in Frascati next November: you are welcome



BESIII Winter Collaboration Meeting,Guilin

https://agenda.infn.it/conferenceDisplay.py?confId=9782

4th LNF Workshop on Cylindrical GEM Detectors

16-18 November 2015 *INFN - Laboratori Nazionali di Frascati*
Europe/Rome timezone

see you in Frascati!

Overview
Timetable
Registration
Registration Form
List of registrants
How to reach us
Accommodation

This meeting continues the series of workshops on the Cylindrical GEM detectors, held in the Frascati Laboratory of INFN.

We are indebted to INFN, IHEP, USTC and MAECI (the Italian Ministry for Foreign Affairs and International Cooperation) for jointly contributing funding to this meeting, in the cadre of the 3-year Program of Great Relevance PGR00136, Italy-China 2013-2015.

INFN Istituto Nazionale di Fisica Nucleare

IHEP

Ministero degli Affari Esteri e della Cooperazione Internazionale

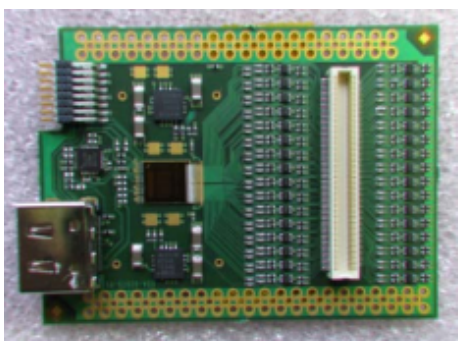
Summary and conclusions

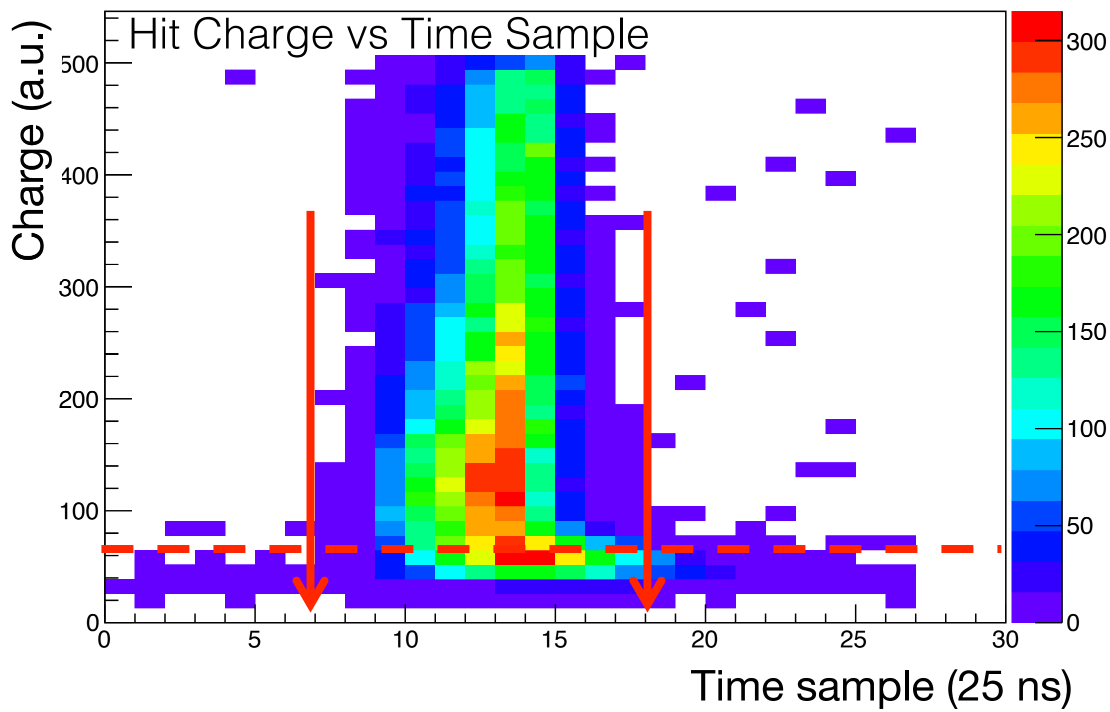
- The development of a Cylindrical GEM detector for the upgrade of the BESIII inner tracker has been presented.
  - The project aims to design, build and and commission a CGEM-IT by 2018.
- The detector peculiarities and innovations are:
  - light Rohacell based mechanical structure
  - jagged strip anode readout
  - analog readout performed by a dedicated ASIC chip
- Data analysis of a test beam with planar prototype is exploiting the full potential of the GEM technology
  - achieved an unprecedented spatial resolution: 190 μm in 1 T magnetic field
  - μTPC readout might boost it in a state of the art detector
- The project has been recognized as a Significant Research Project within the Executive Program for Scientific and Technological Cooperation between Italy and P.R.C., and selected as one of the project, BESIIICGEM, funded by the European Commission within the call H2020-MSCA-RISE-2014.

Thanks

Some readout details

- The prototype is readout by Scalable Readout System developed by RD51 collaboration.
- The analog APV25 front-end ASIC combines a sensitive preamplifier, switched-capacitor analog memory array, and low-voltage differential analog output buffer.





- Charge is sampled in 25 ns bins → possibility to combine charge and time information.