Advancements in Nuclear Instrumentation Measurement Methods and their Applications

20-24 April 2015, Lisbon Congress Center

A Cylindrical GEM Detector with Analog Readout for the BESIII Experiment

Gianluigi Cibinetto
(INFN Ferrara)
on behalf of the CGEM BESIII group

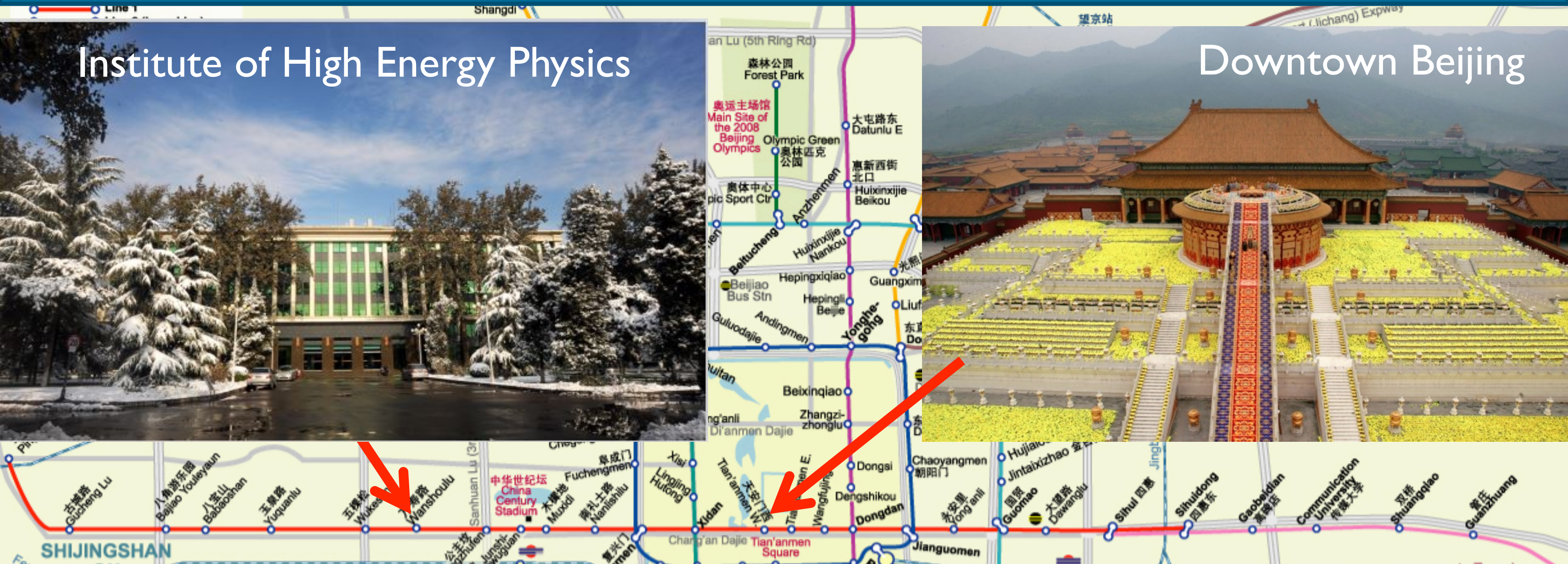
Outline

- The BES III experiment
  - the Inner tracker
- The Gas Electron Multipliers
- The BESIII Cylindrical GEM-IT
  - innovations and peculiarities
  - construction of a cylindrical layer
  - test beam with a planar prototypes
- Project status and schedule
- Summary and Conclusions

The BES III experiment

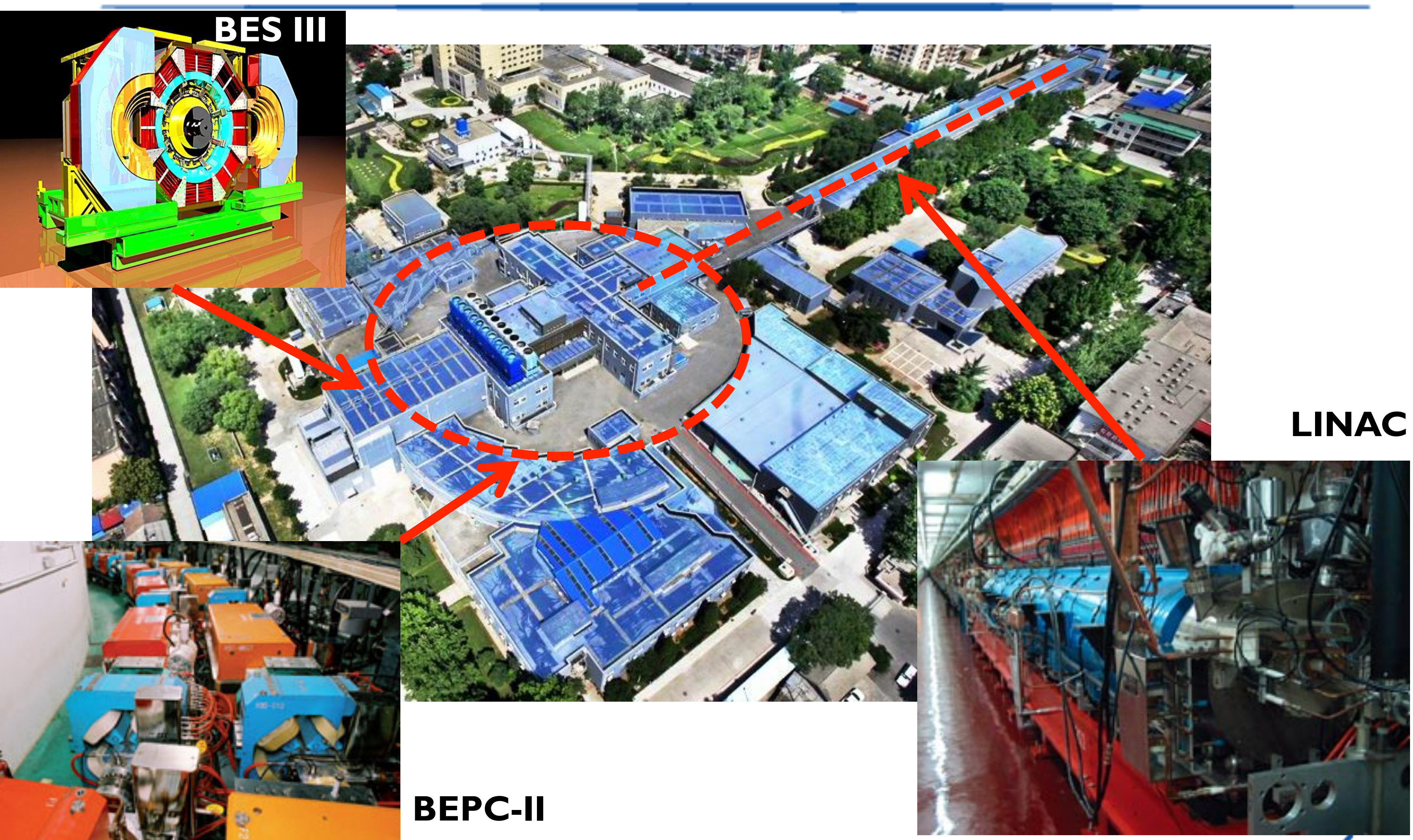
BESIII: a τ-charm factory

BES-III (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.

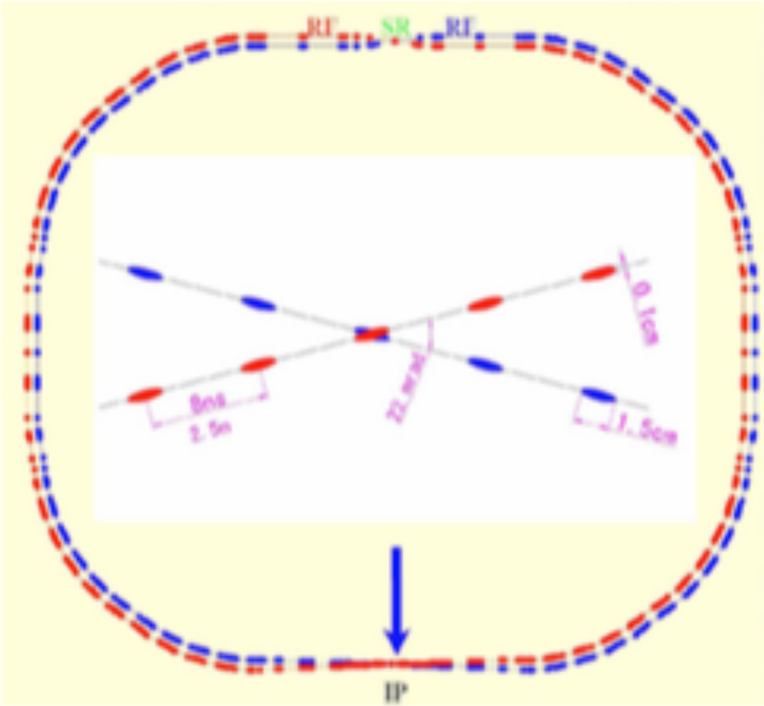


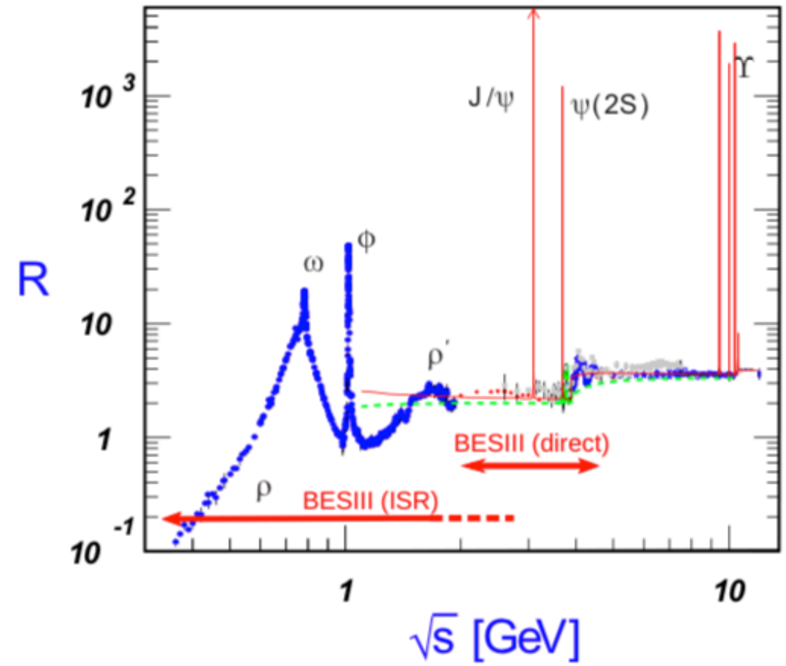
Very rich physics program: Charm, charmonium and exotic states spectroscopy, light hadrons, F.F., τ physics.

BEPCII at IHEP



BEPCII storage rings





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

Beam energy	**1 · · · 2.3 GeV**
Optimum energy	**1.89 GeV**
Single beam current	**0.91 A**
Crossing angle	**±11 mrad**

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

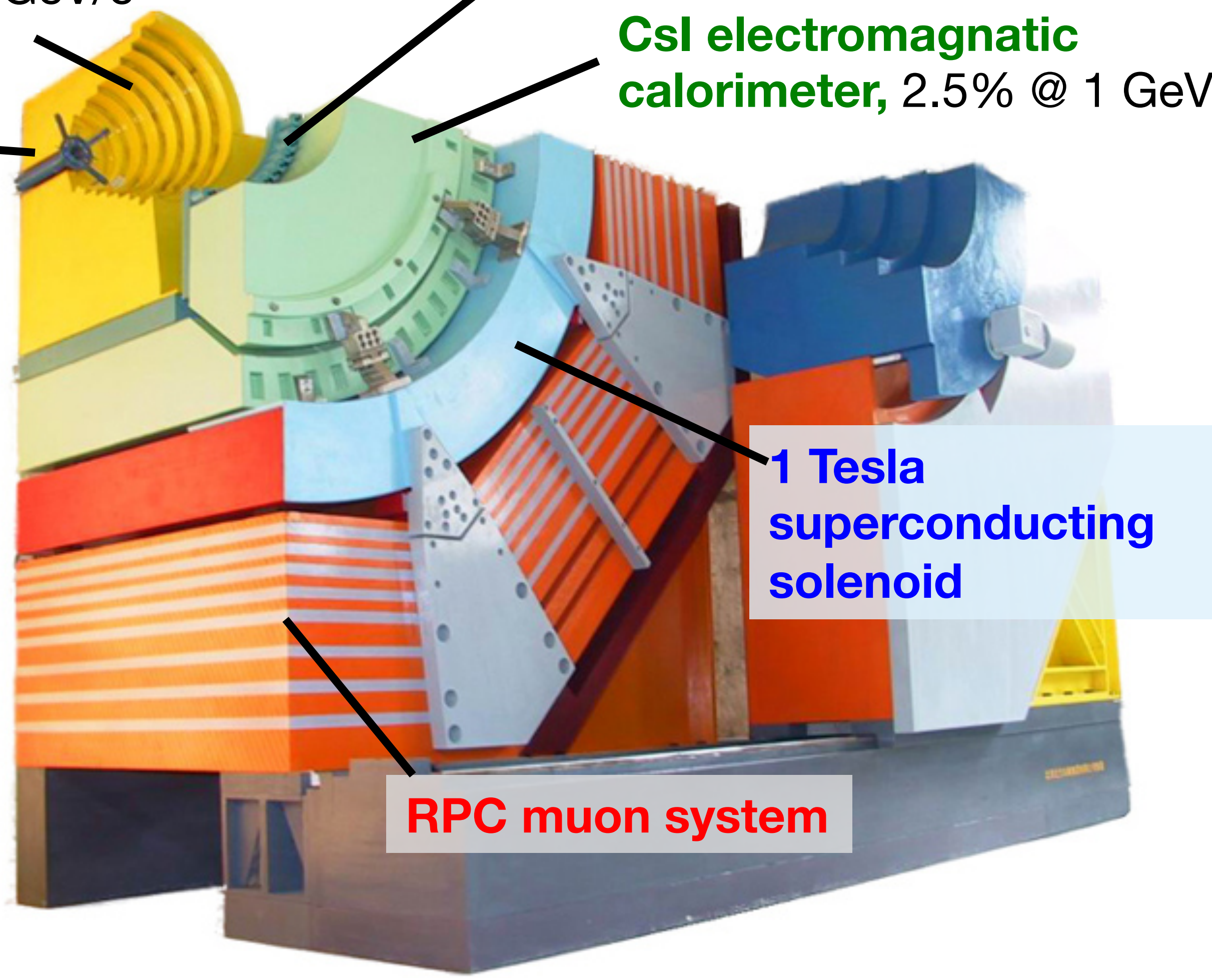
Beam energy measurement:

Laser Compton backscattering

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

($\approx$ 50 keV at τ threshhold)

The BESIII detector



Angular coverage

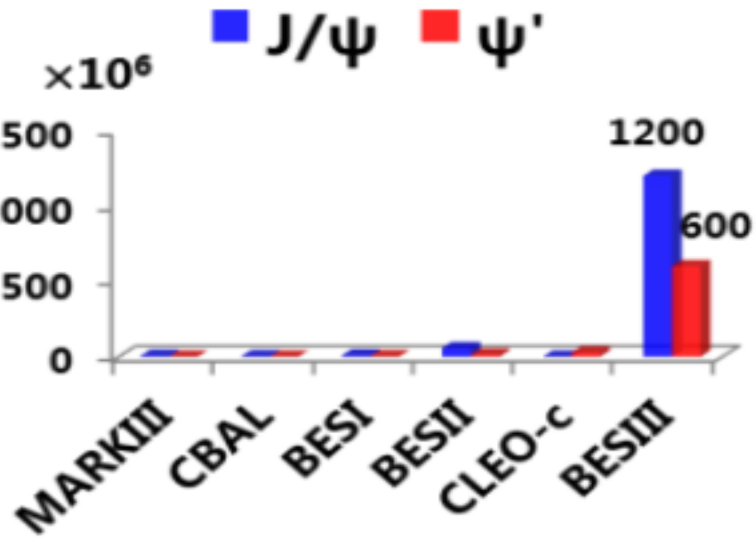
- 93% of 4π for the tracking system
- 95% of 4π for the calorimeter

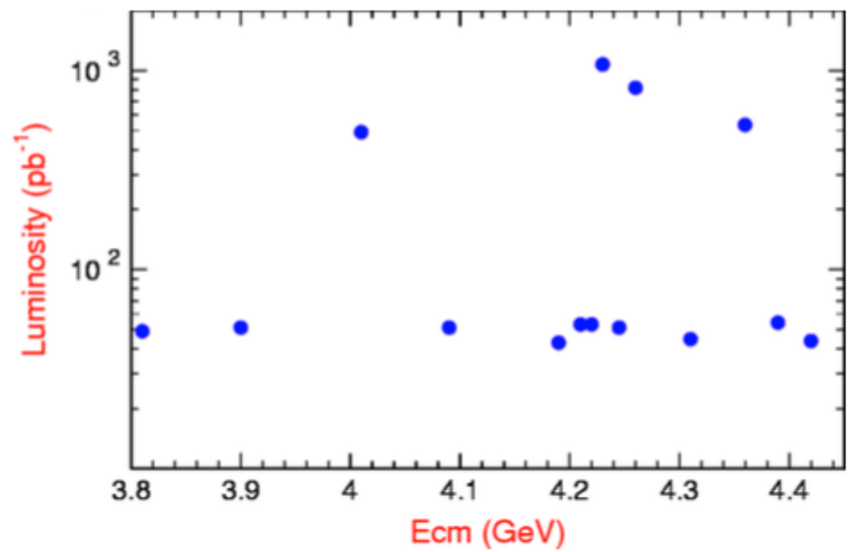
Total weight 730 ton

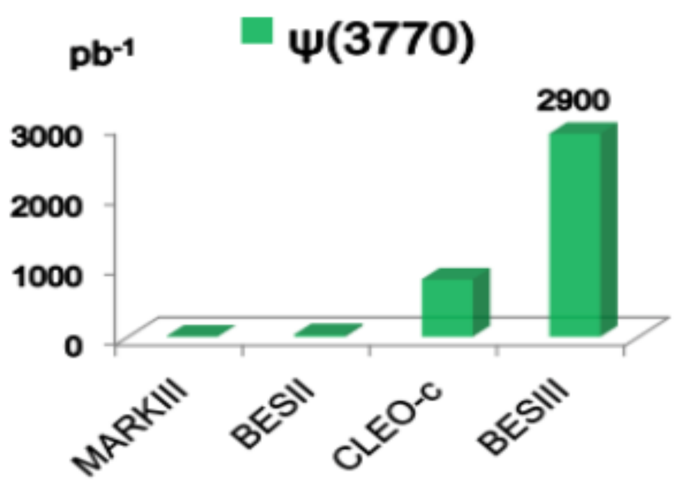
~40,000 readout channels

Data rate: 5kHz, 50Mb/s

The dataset







+ 104 energy points between 3.85 and 4.59 GeV

+ ~ 20 energy points between 2.0 and 3.1 GeV (*ongoing*)

Direct production of 1−− states studied with world's largest scan dataset

Physics Highlights

nature International weekly journal of science

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Archive > Volume 498 > Issue 7454 > News > Article

NATURE | NEWS

عربي

Quark quartet opens fresh vista on matter

First particle containing four quarks is confirmed.

Devin Powell

18 June 2013

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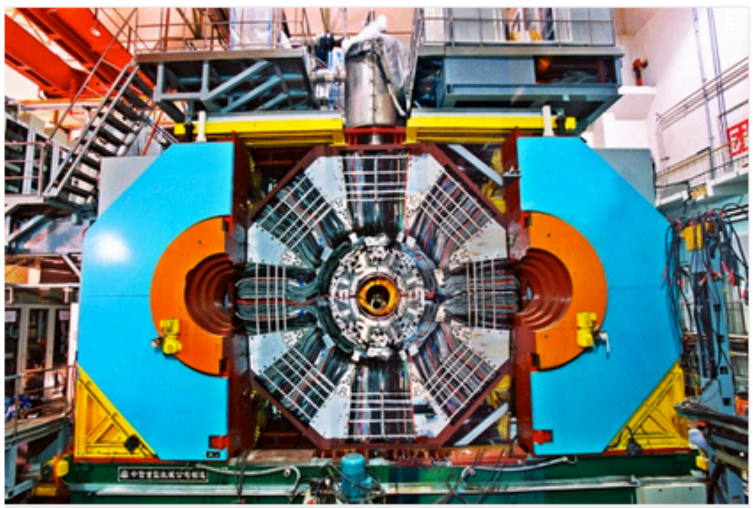

IHEP

The BESIII detector in China is one of two experiments to detect four-quark particles.

Scientists discover first tetraquark particle

See also Science & Space / Particle Physics

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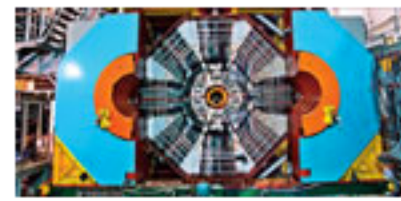
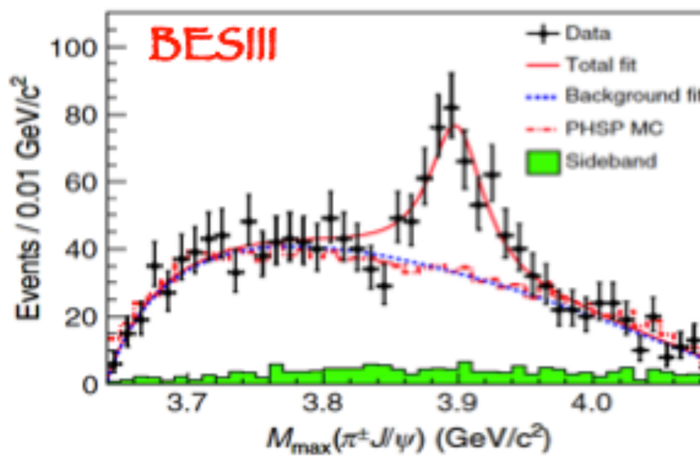
Apr 26, 2013

BESIII observes new mystery particle

In a striking and unexpected observation from new studies aimed at an understanding of the anomalous Y(4260) particle, the international team that operates the Beijing



BESIII spectrometer



alert

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Nature | 31 January 2014
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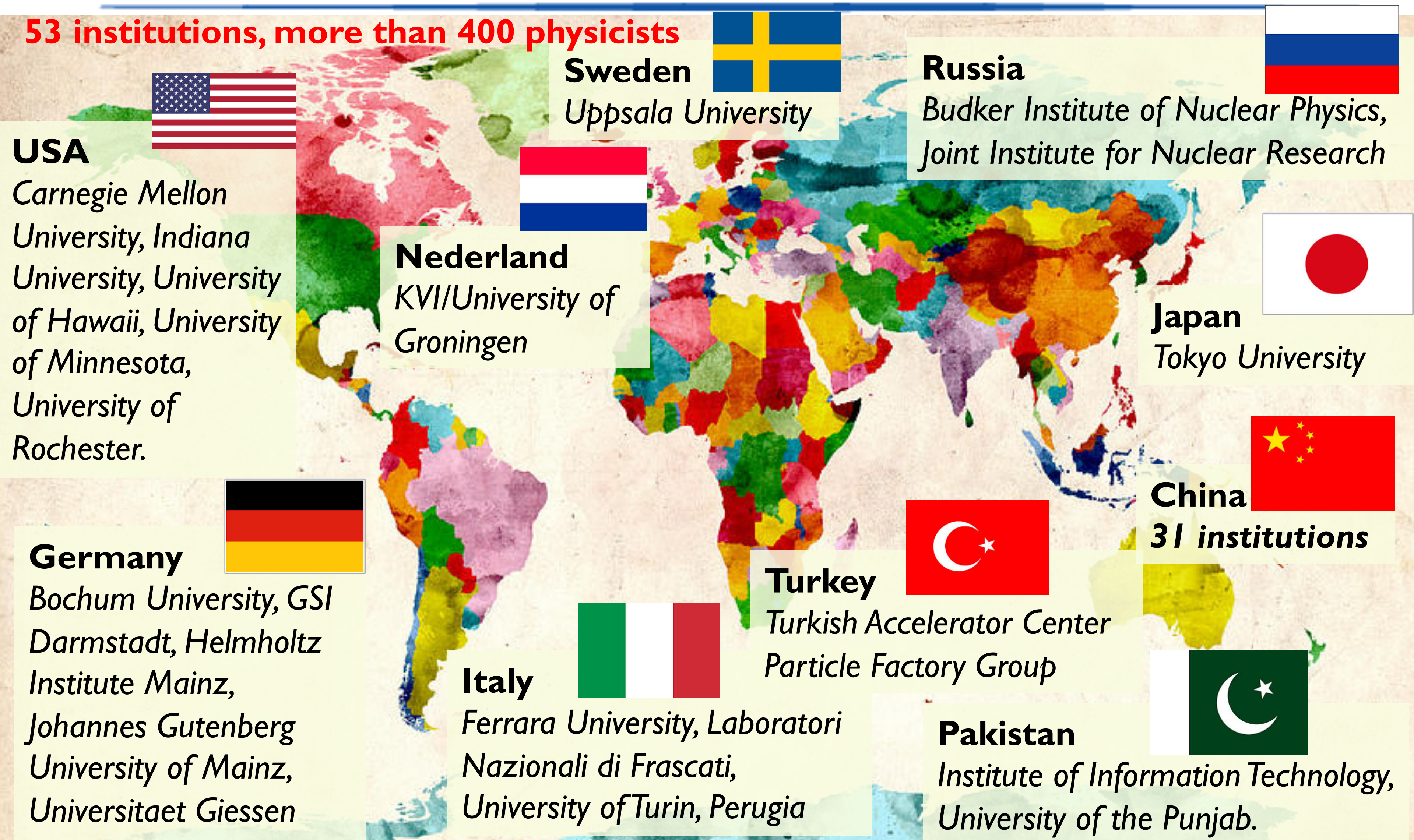
Nature | 30 January 2014
3. Brain responds to tiniest speech details
Nature | 30 January 2014

The BESIII collaboration



53 institutions, more than 400 physicists

USA
Carnegie Mellon University, Indiana University, University of Hawaii, University of Minnesota, University of Rochester.

Sweden
Uppsala University

Nederland
KVI/University of Groningen

Russia
Budker Institute of Nuclear Physics, Joint Institute for Nuclear Research

Japan
Tokyo University

China
31 institutions

Germany
Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen

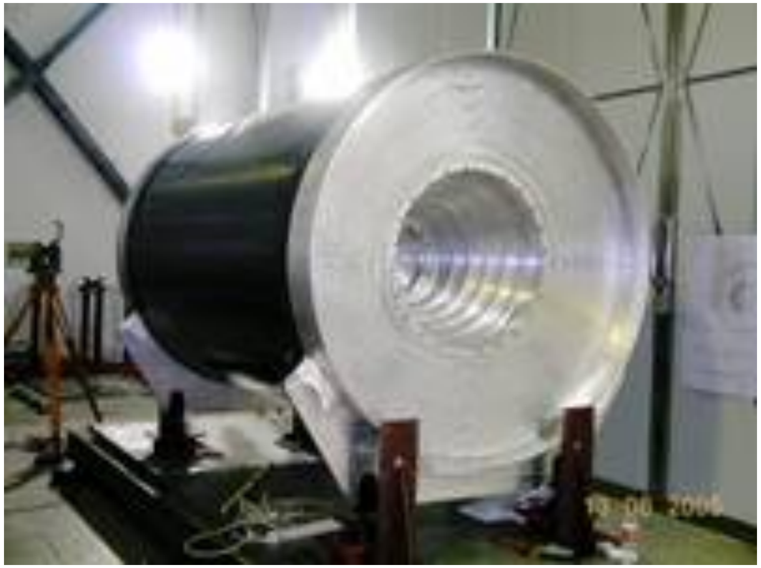
Italy
Ferrara University, Laboratori Nazionali di Frascati, University of Turin, Perugia

Turkey
Turkish Accelerator Center Particle Factory Group

Pakistan
Institute of Information Technology, University of the Punjab.

MDC-IT aging issue

The Multilayer Drift Chamber Inner Tracker

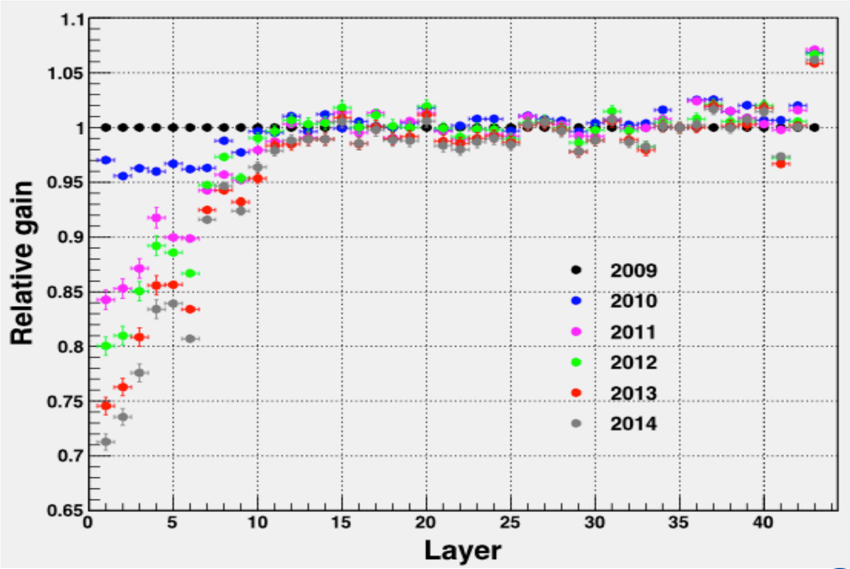


- MDC performs momentum and dE/dx measurement for charged particle identification.
- Spatial resolution is 130 μm in r-φ plane (azimuthal) and 2 mm in the z-coordinate (polar).
- Inner and Outer MDC are two separate chambers sharing the same gas volume.

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.

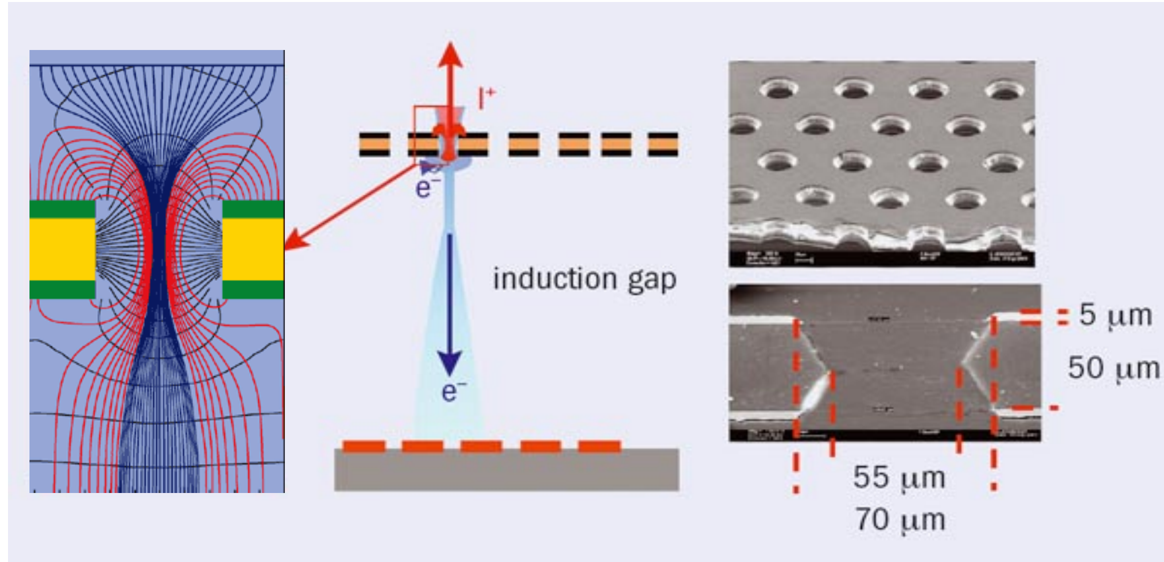


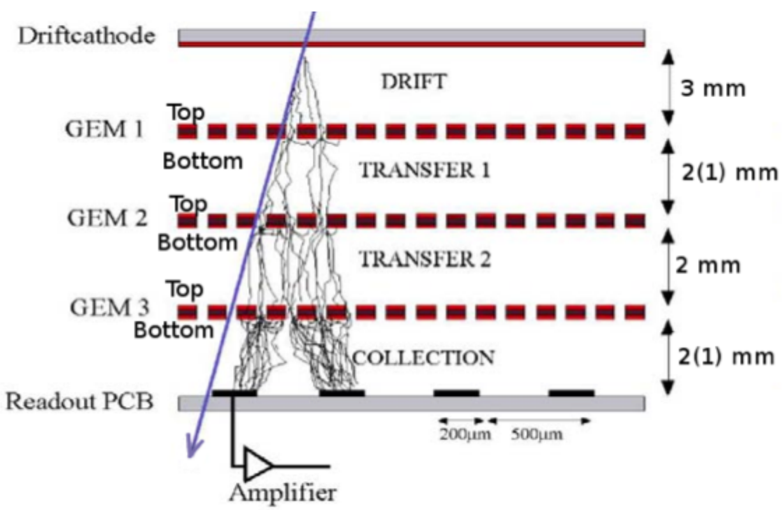
The Gas Electron Multipliers

GEM in a nutshell

A thin polymer foil, metal-coated on both sides, is chemically pierced by a high density of holes.

On application of a voltage gradient, electrons released on the top side drift into the hole, multiply in avalanche and transfer the other side.





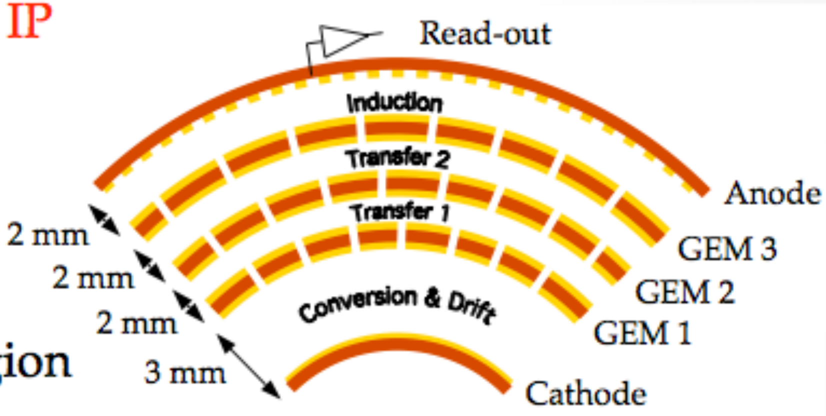
Proportional gains above 10^3 are obtained in most common gases.

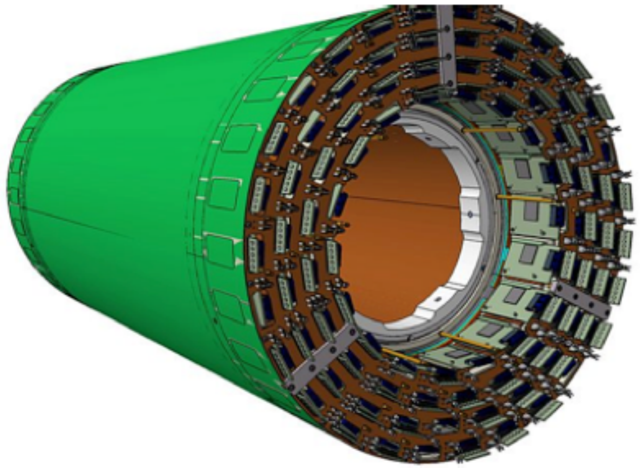
Cascaded GEMs permit to obtain larger gains

Spatial resolution determined by chamber and readout electrode geometries

Cylindrical GEM detector

- 4 CGEM layers at 13/15.5/18/20.5 cm from IP inside outer Drift Chamber
- 700 mm active length
- XV strips-pads readout (25°÷30° stereo angle)
- 2% X_0 total radiation length in the active region including Carbon Fiber shield





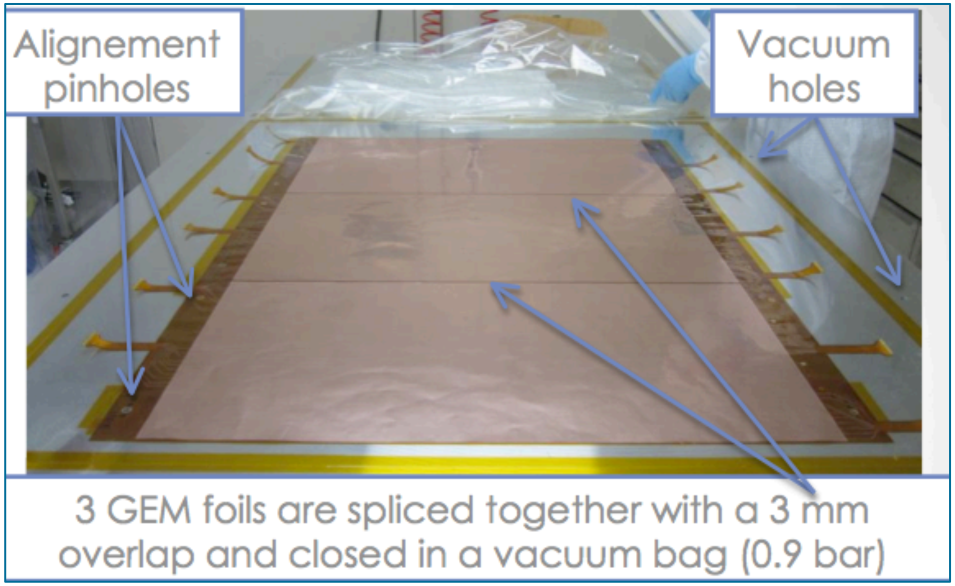
The KLOE-2 Collaboration built the only existing CGEM based detector currently under commissioning.

Performance evaluation in progress.

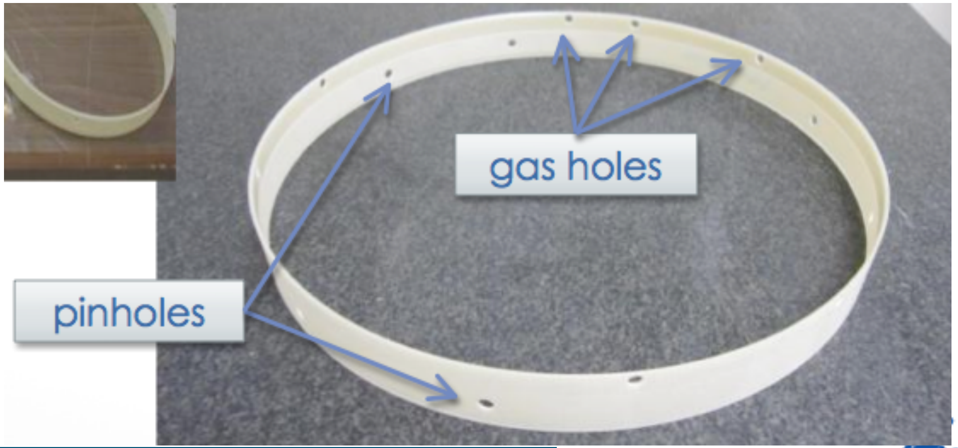
CGEM Construction Technique

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



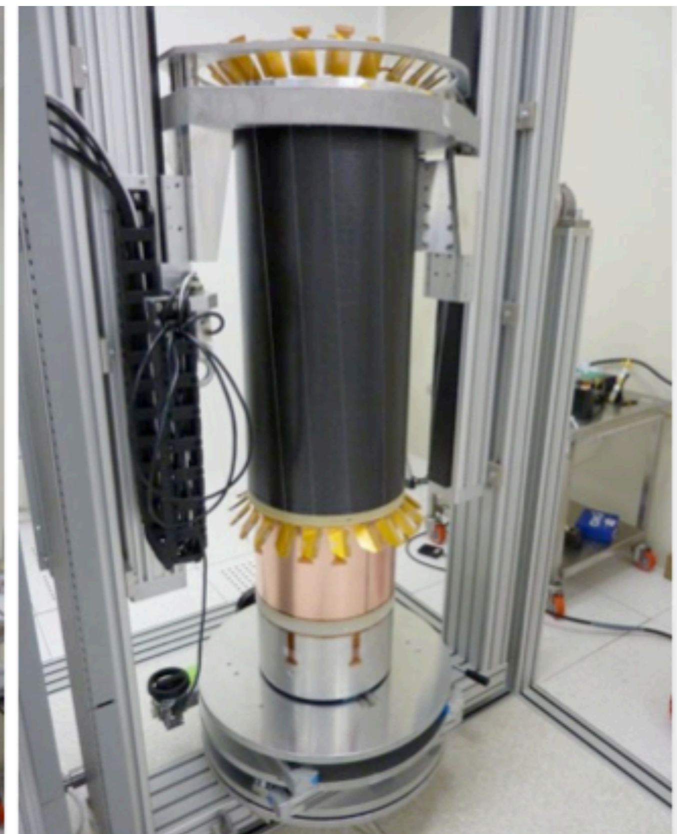
Fiberglass supports are outside the active area



CGEM Assembly Technique

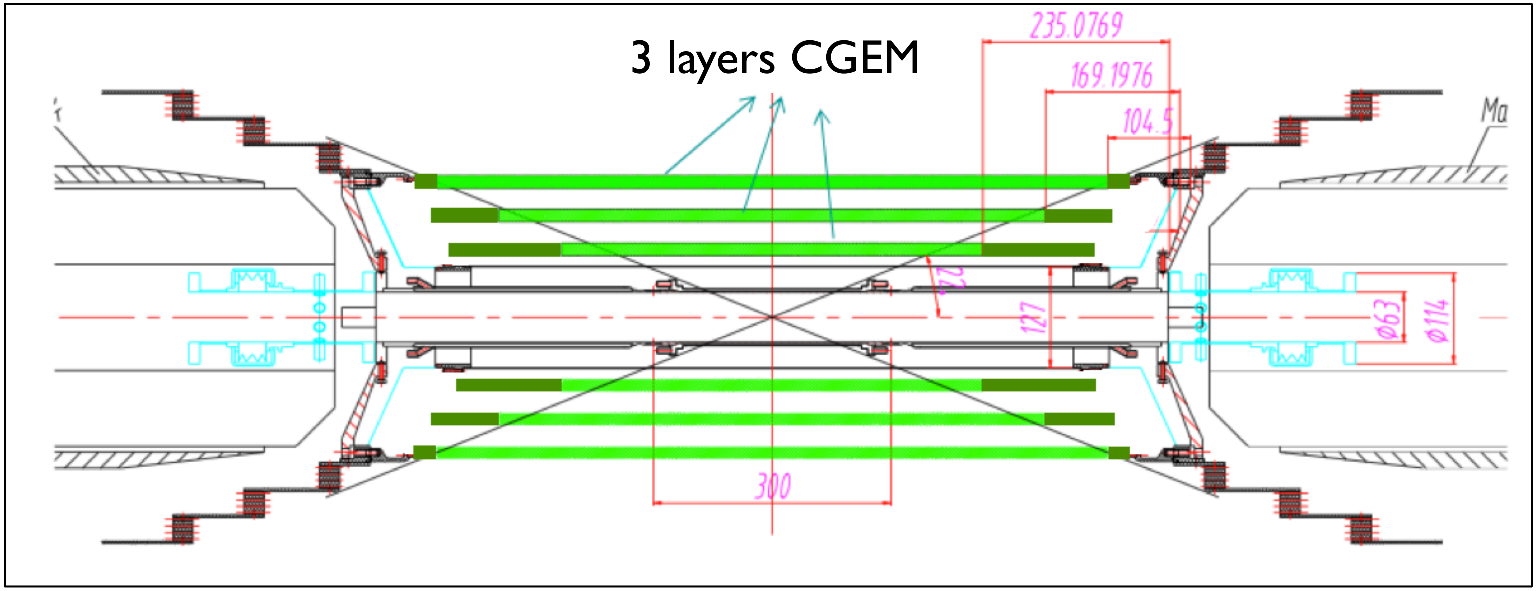
- A dedicated assembling machine has been designed and realized to perform the insertion of the electrodes. BESIII will use the same machine.
- Axial alignment has a precision of 0.1mm/1.5m.
- The structure can rotate by 180° around its central horizontal axis one into the other.

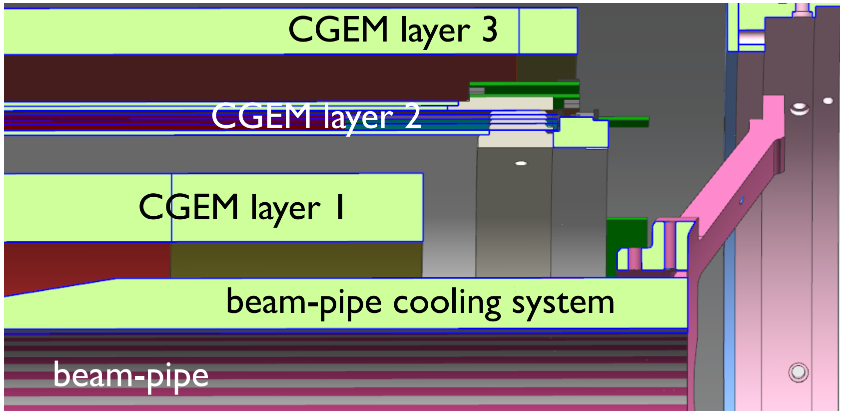




A Cylindrical GEM Inner Tracker for BES III experiment

The CGEM-IT

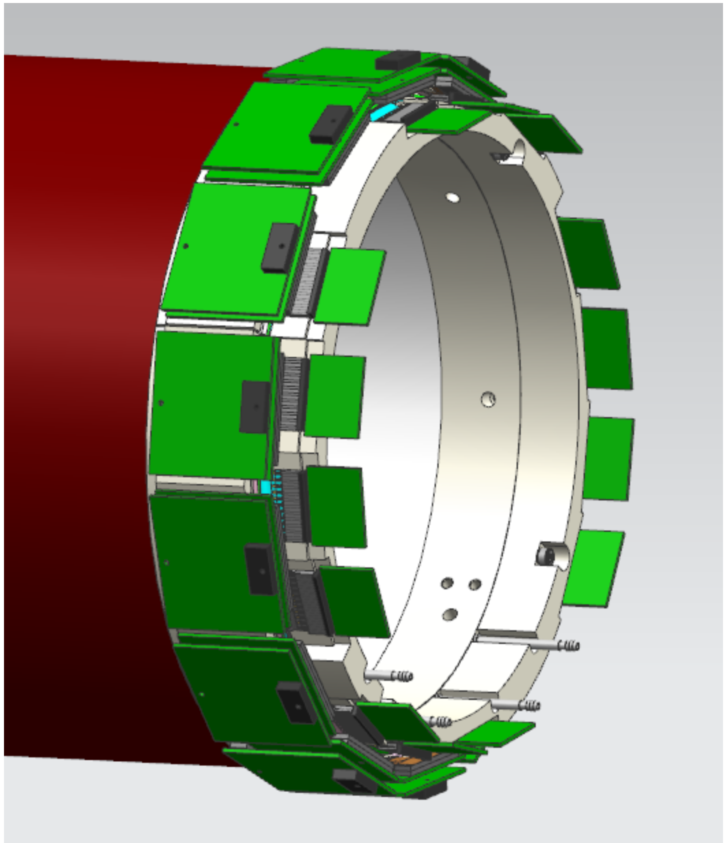


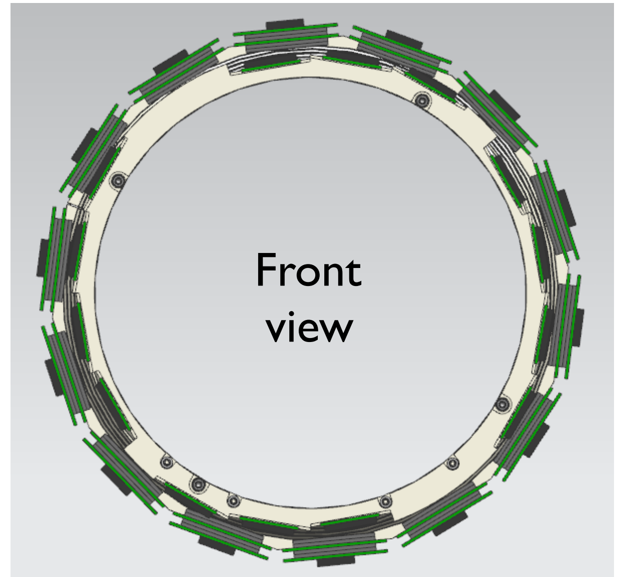


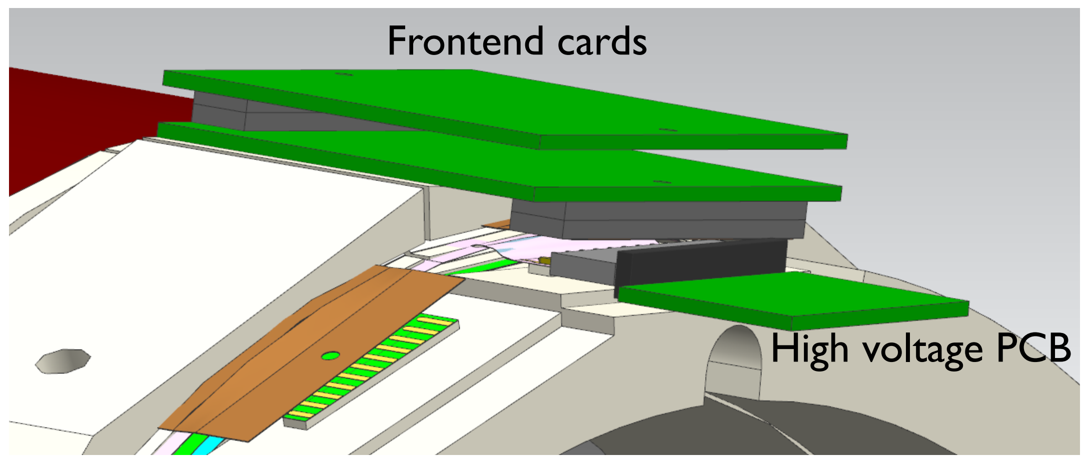
Requirements

- Rate capability: ~10^4 Hz/cm^2
- Spatial resolution: σ_{xy} =~120μm : σ_z=~1 mm
- Momentum resolution:: σ_{pt}/P_t =~0.5% @1GeV
- Efficiency = ~98%
- Material budget ≤ 1.5% of X_0 all layers
- Coverage: 93% 4π
- Operation duration ~ 5 years

Mechanical Design





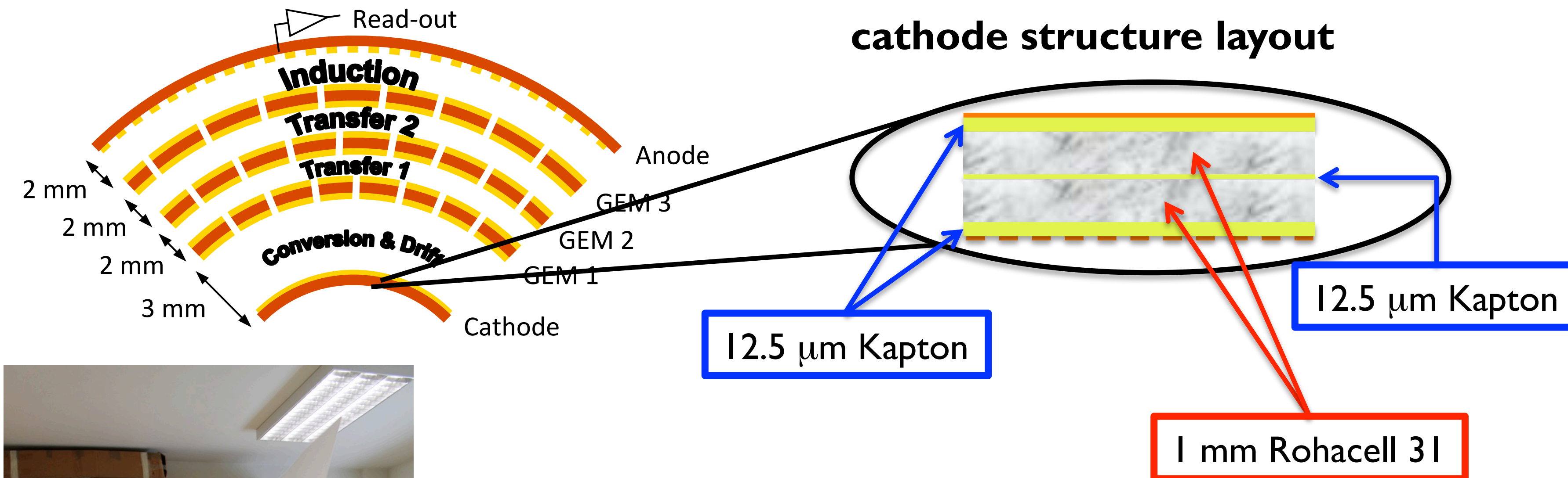


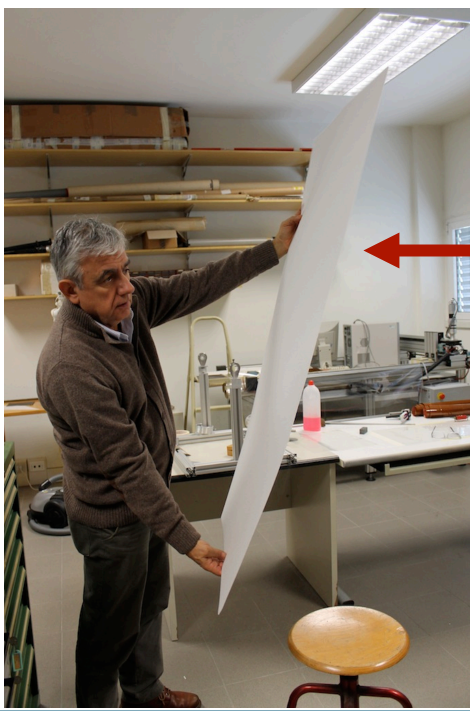
The frontend electronics cards will be located in the dead space available between the layers outside the active area.

Peculiarities and innovations of the BES III design

- The innovative aspects are mainly related, but not limited, to the following three items:
  - the material used to give the mechanical rigidity to the detector structure (that will be Rohacell instead of Honeycomb);
  - the anode design: Compass-like with jagged-strip layout;
  - analog readout to achieve the required spatial resolution with a limited number of channels. The position is measured with charge centroid calculation.

The Rohacell structure



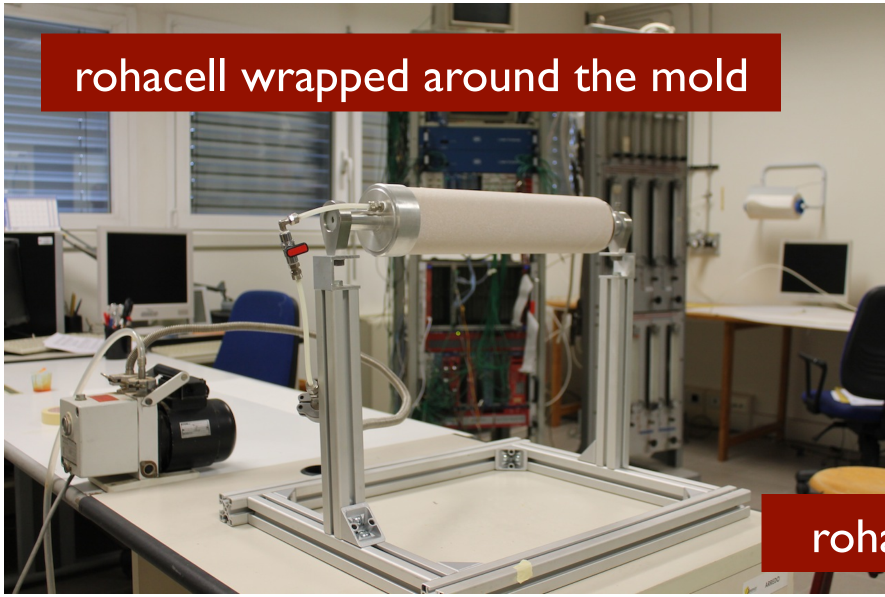


Rohacell is a very light material (density of 31 kg/m^3) that will be replace the honeycomb in the cathode and anode construction with substantial reduction of the thickness of the detector.

	BESIII	KLOE-2
# of X_0 for 1 layer	0.33	0.49
# of X_0 for 3 layers	0.99	1.47

This technique has been successfully tested in Ferrara

Test of the Rohacell technique

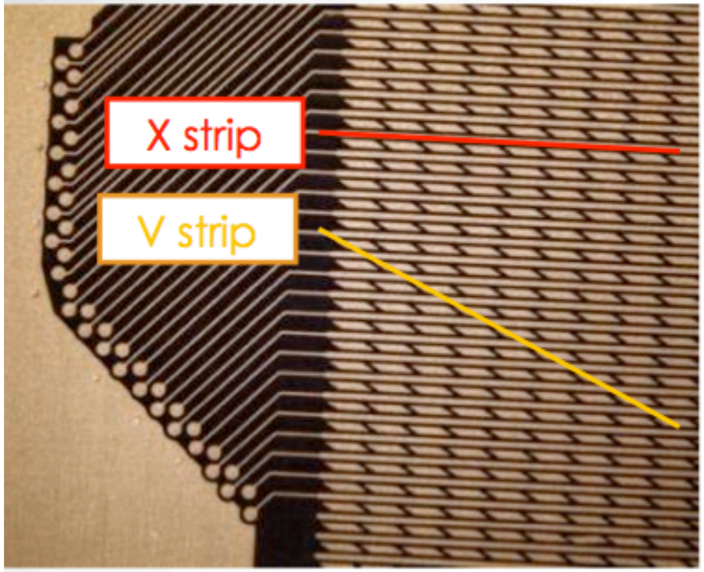


rohacell wrapped around the mold

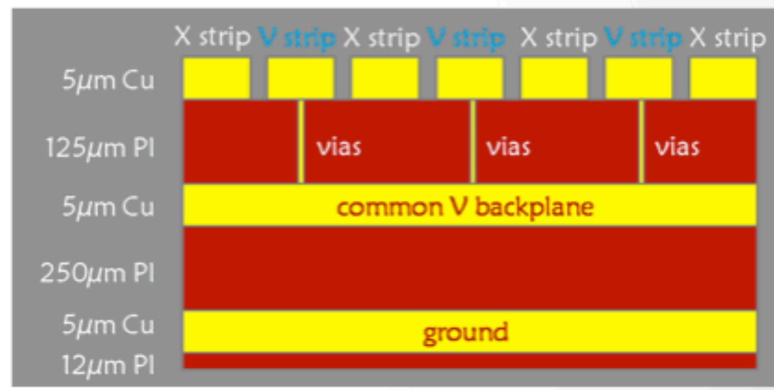
rohacell machined in the Ferrara workshop

cathode foil wrapped on the rohacell

The KLOE-2 anode design



Readout plane is realized at CERN TE-MPE-EM
It is a kapton/copper multilayer flexible circuit
Provides 2-dimensional readout with XV strips on the same plane
- X are realized as longitudinal strips
- V are realized by connection of pad through conductive holes and a common backplane
- Pitch is 650 μm for both



X pitch 650µm → X res 190µm

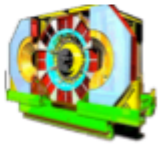
V pitch 650µm → Y res 350µm

with digital readout and ~0.5 T magnetic field

25/10/2012 • 17

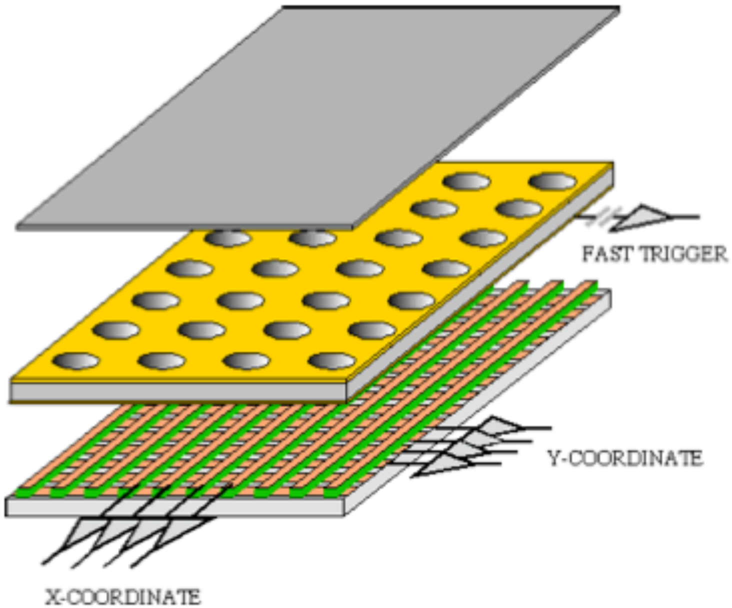
Presented by D. Domenici @ LNF CGEM workshop

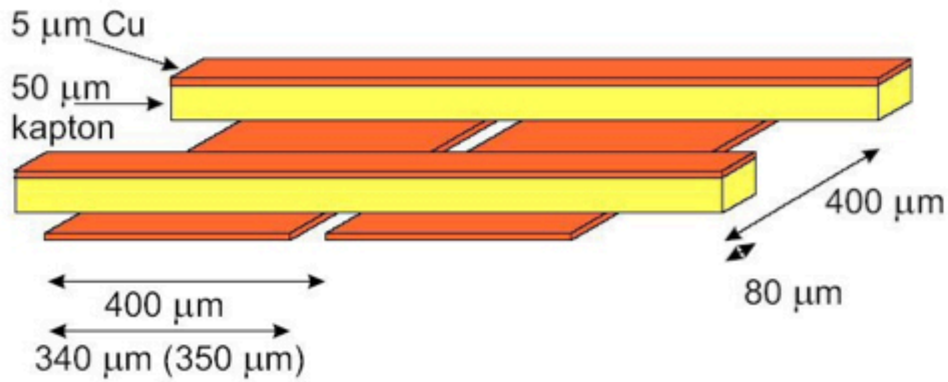
Compass anode design



COMPASS: readout electrodes

large strip capacitance ~100 pF





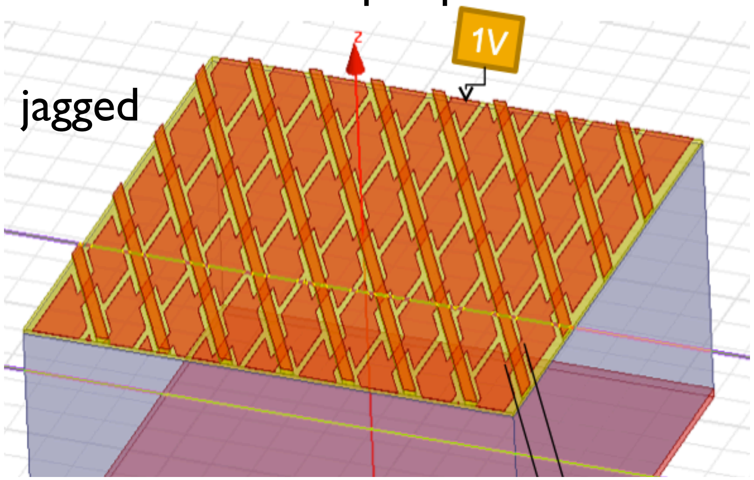
- ***Due to diffusion the charge cloud collected on the readout board is bigger than the strip width (≈ 3.5 x pitch)*** *and a weighting method is used for calculate the exact track position in two dimensions*

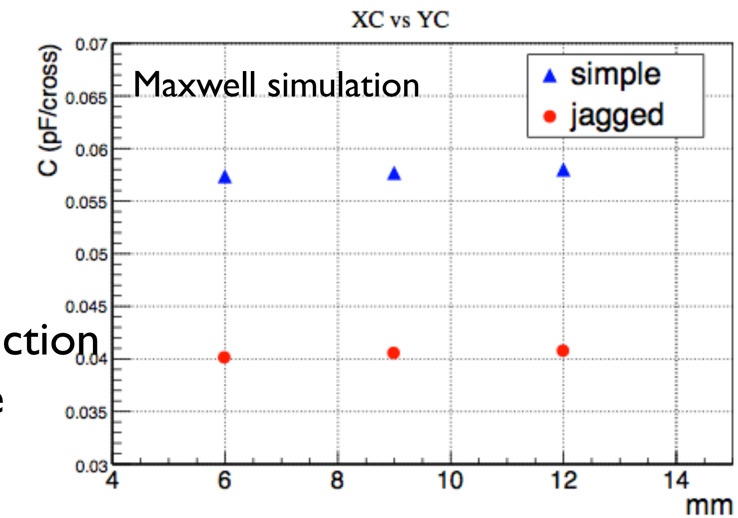
BESIII anode will be Compass-like
650/570/130 μm (pitch,X,V);
stereo angle depending on
the layer geometry

Jagged strip design

A jagged-strip layout has been studied to minimize the strip capacitance:

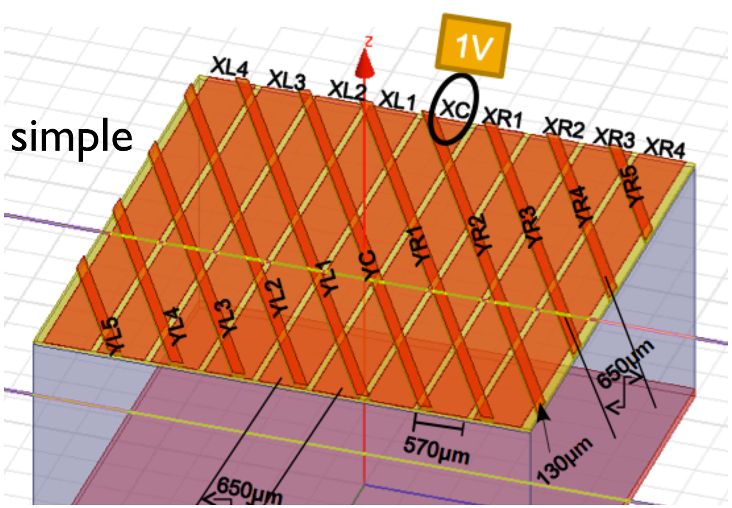
jagged





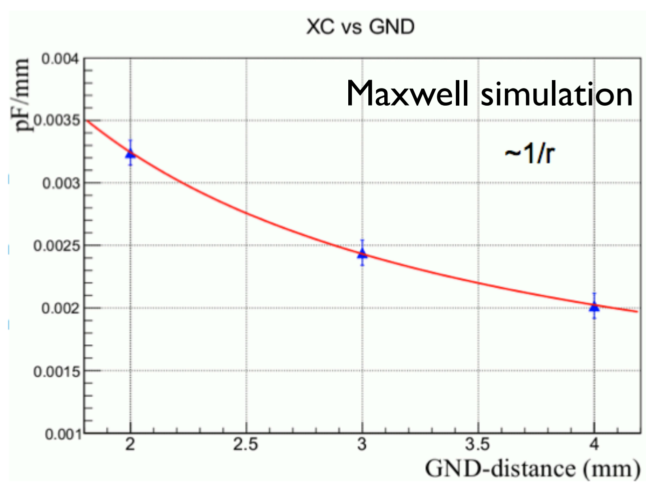
~30% inter-strip capacitance reduction compared to the standard strip configuration

simple



In addition:

- the ground will be kept at 2 – 4 mm from the strip plane
- support structure made of Rohacell



Frontend electronics

- The analog readout is mandatory to limit the number of electronics channels. The charge measurements is performed by a dedicated ASIC chip.

- 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

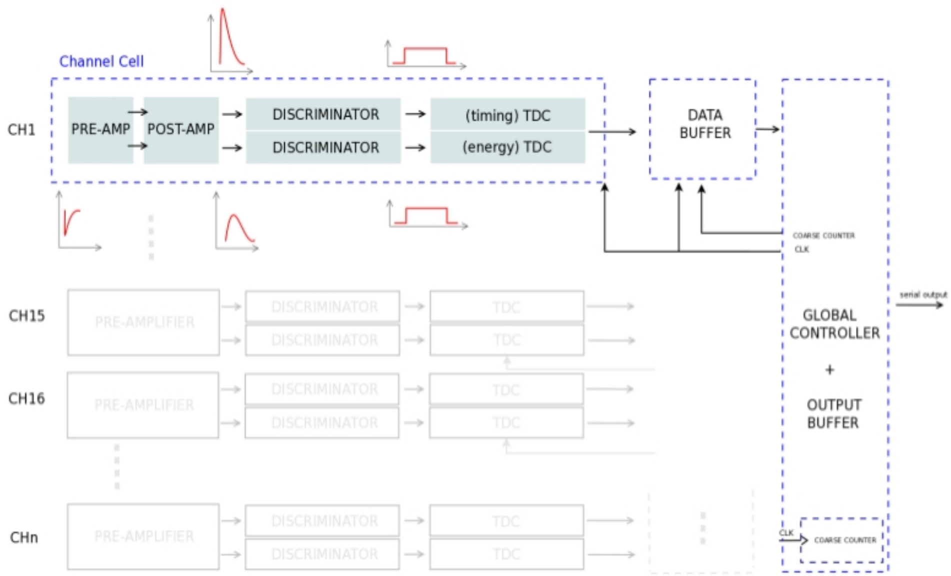
- FrontEnd Simulations
  - input stage optimized to handle capacitance in the range 20pF-150pF - circuit tested with a delta-pulse and GEM-like signal.

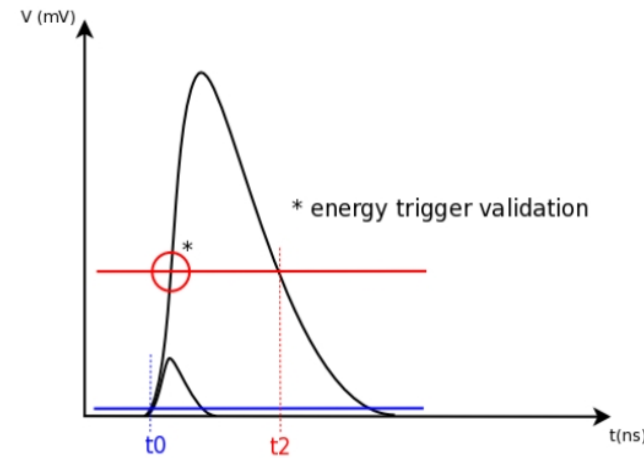
Main feature of the ASIC design

- UMC 110 nm technology
  - (limited power consumption, to be tested for radiation tolerance)
- Input charge: 3-50 fC
- Sensor capacitance 100-150 pF
- Input rate (single strip): 7-15 kHz
- Time and Charge measurements by independent TDCs
- TDC time binning > 50 ps   **⇒ CGEM needed time resolution ~ 1 ns**
- Double threshold discrimination
- Time over Threshold (ToT) to measure the charge   **⇒ CGEM: Linear ToT**
- Power consumption < 7 mW p/channel ⇒ 4 mW p/channel feasible

developed by INFN Turin

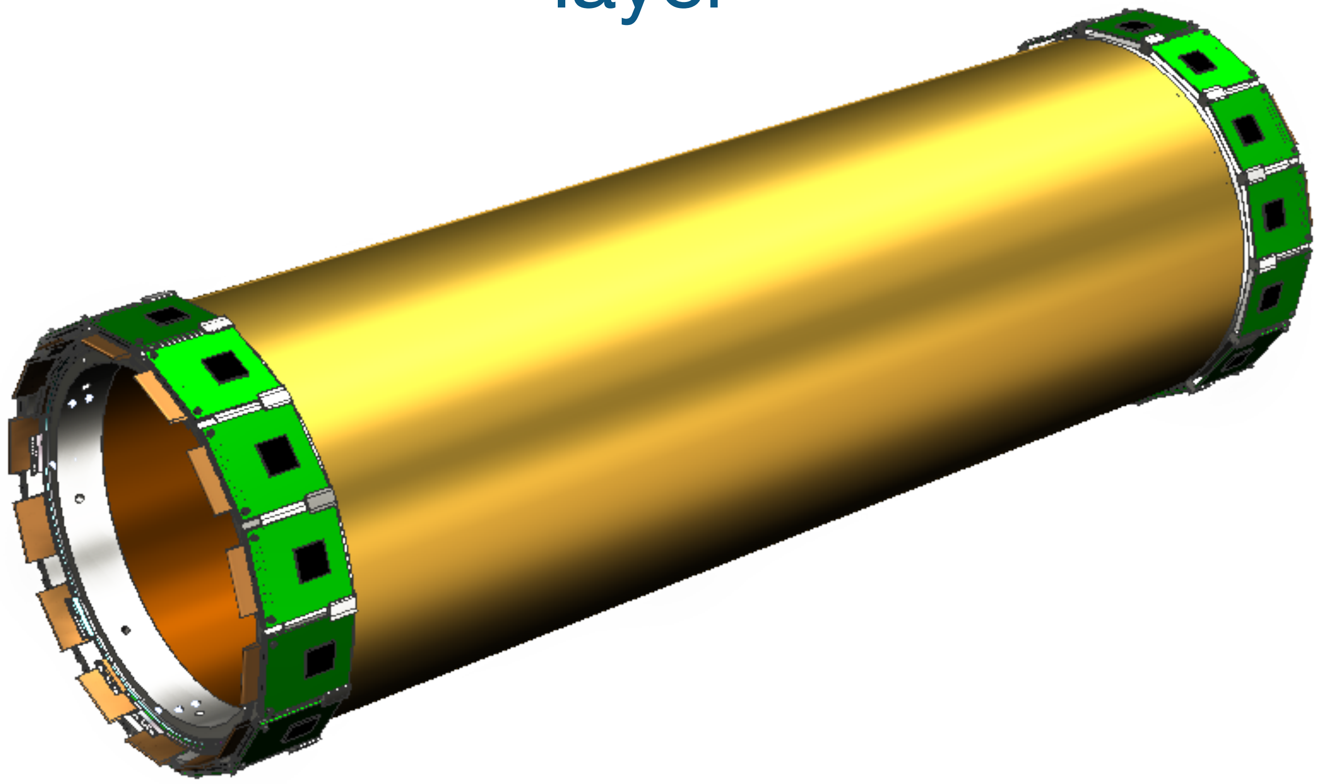
Overview of the FEE architecture



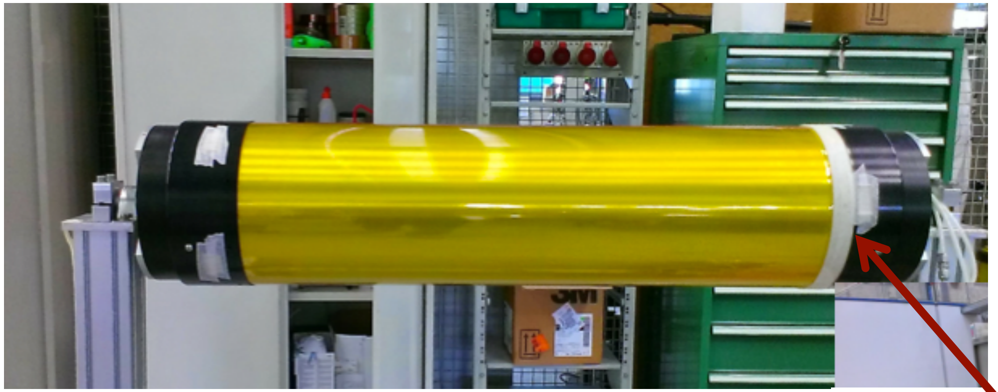


- Time and charge measurements with independent TDCs
- TDC time binning 50 ps
- Charge measured with Time-over-threshold
- Typ. power consumption is 7mW p/channel (**trigger 0.5 p.e.** w/ $SNR > 23dB$ for 9 mm^2 MPPC, 40 KHz event rate, 1MHz DCR)

Toward the construction of a cylindrical layer

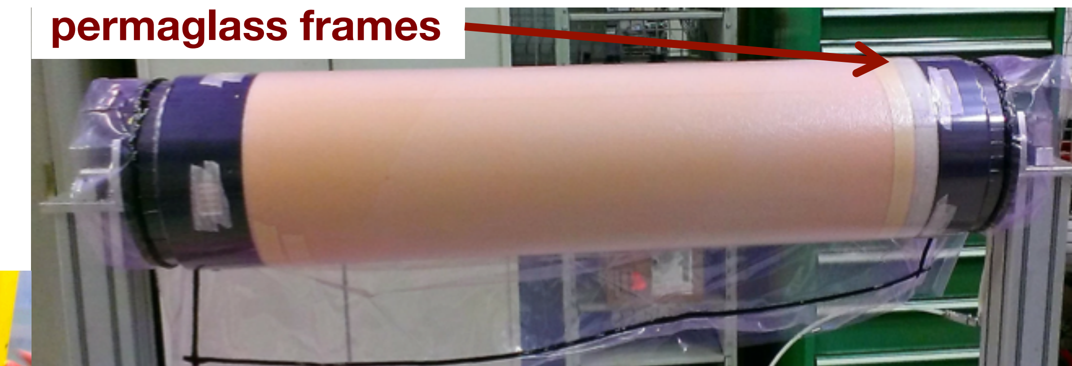


Cathode construction



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

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

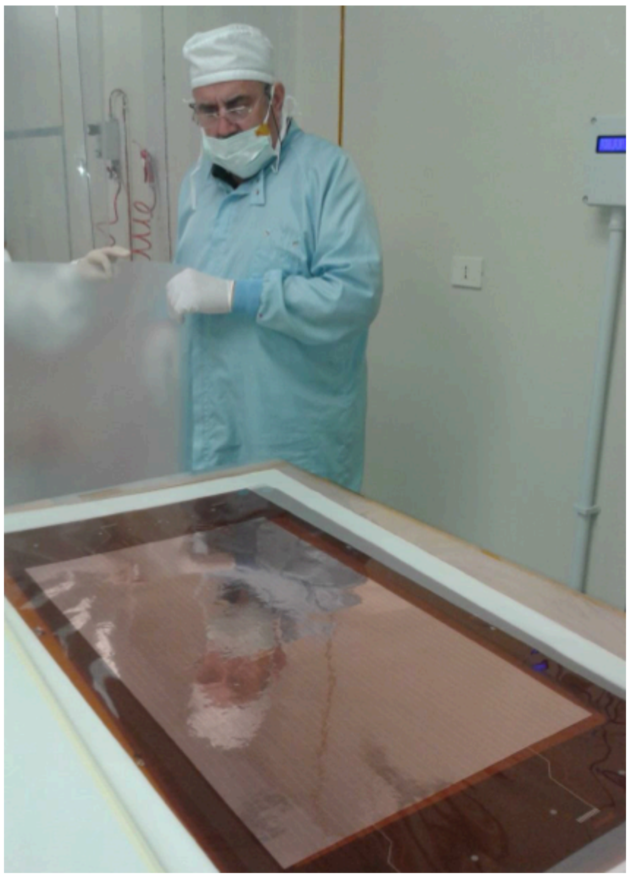


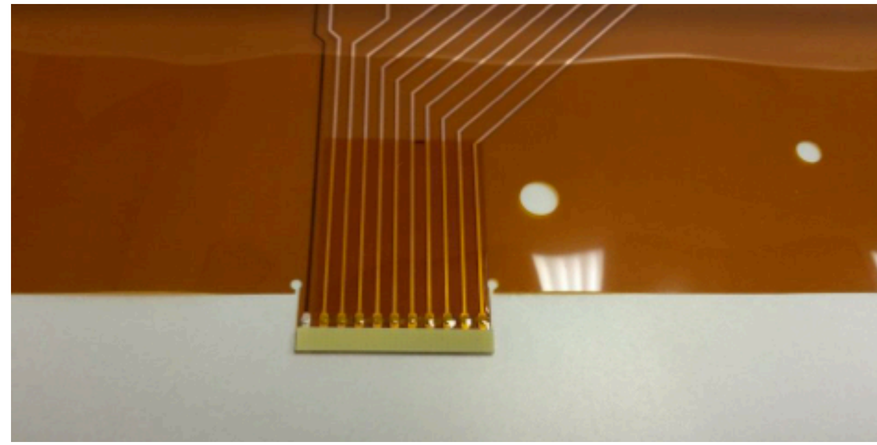
- the Rohacell plane is machined with a high precision milling machine.

Picture from INFN-Ferrara assembly site.

GEM testing

Layer-2 GEM foils arrived from CERN and have been tested in the clean room.





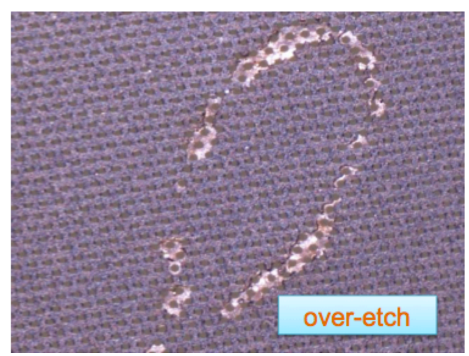
GEM production quality test.

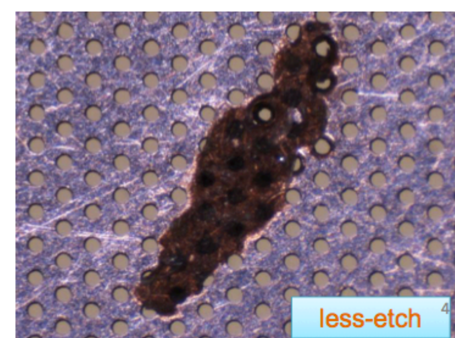
Before gluing, a HV test is performed on the GEM foils.

Good GEM must satisfy both:

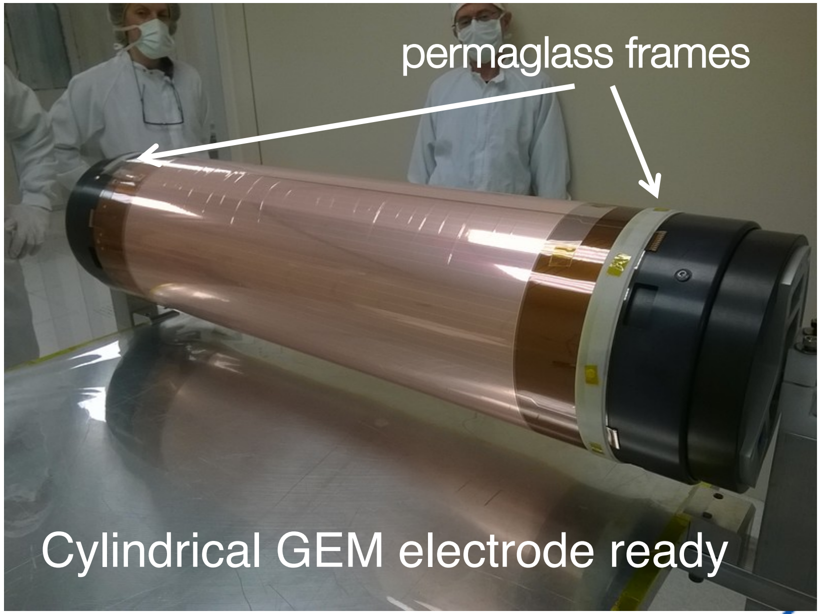
- <1 nA @ 600 V
- <2 discharges/30mins

Microscope pictures of GEM defects





GEM assembly



- Pictures of GEM cylindrical assembly in the INFN-LNF clean room
- Plan to move to the vertical assembly next summer.

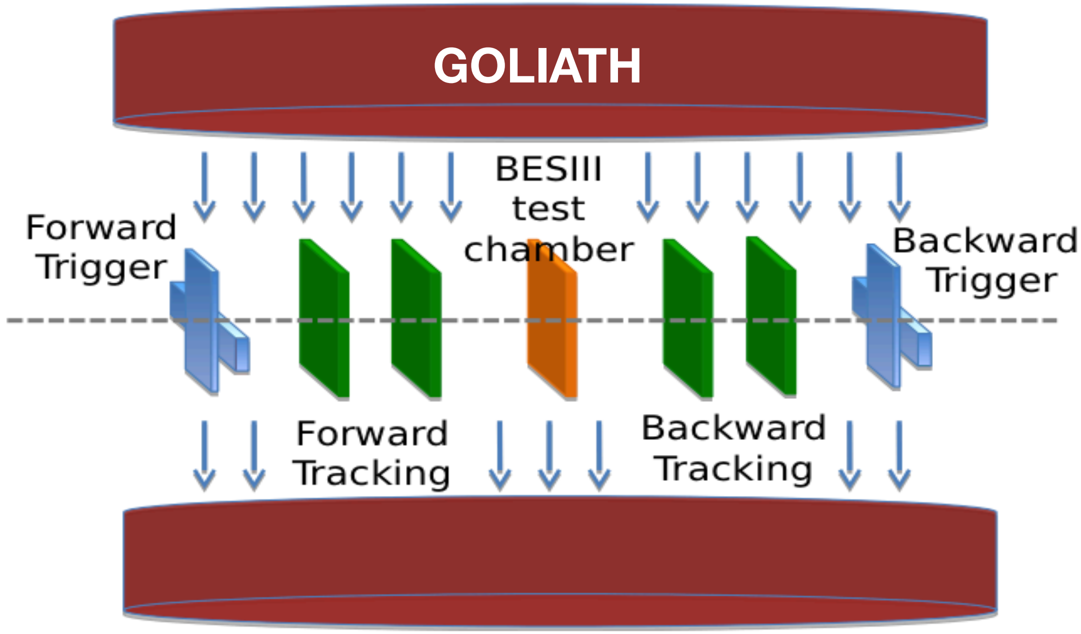
Planar Detector Prototype Test Beam

Test Beam with a planar prototype

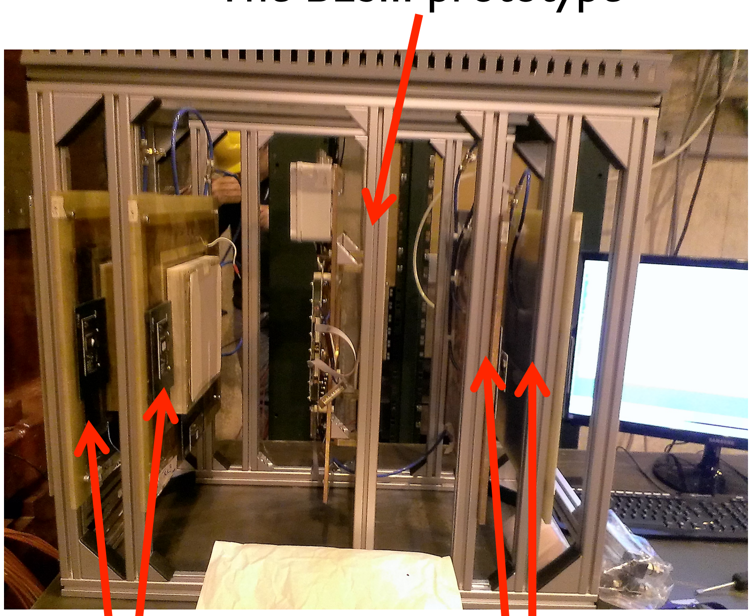
- A test beam has been performed last December at CERN to:
  - Validate GEM analog readout in magnetic field.
  - Validate Garfield simulation and extract useful information for hit digitization.
- We performed the following measurements with different detector geometries:
  - Spatial resolution as function of the magnetic field
  - Cluster size as function of the magnetic field
  - Efficiency measurements at different gain
  - Test different gas mixture: Ar/CO_2 (70/30) and Ar/Isobutene (90/10)
  - Different incident beam angle: 0°/10°/30°/45°

BESIII setup

We performed a beam test last December to test a planar prototype inside a magnetic field.



The BESIII prototype



Forward Tracking

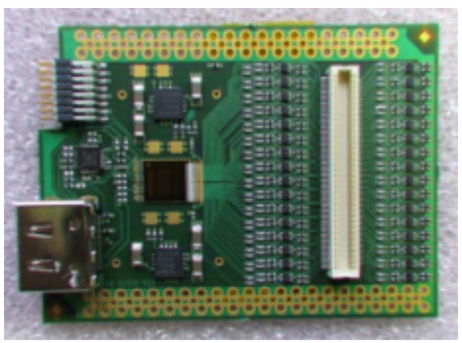
Backward Tracking

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

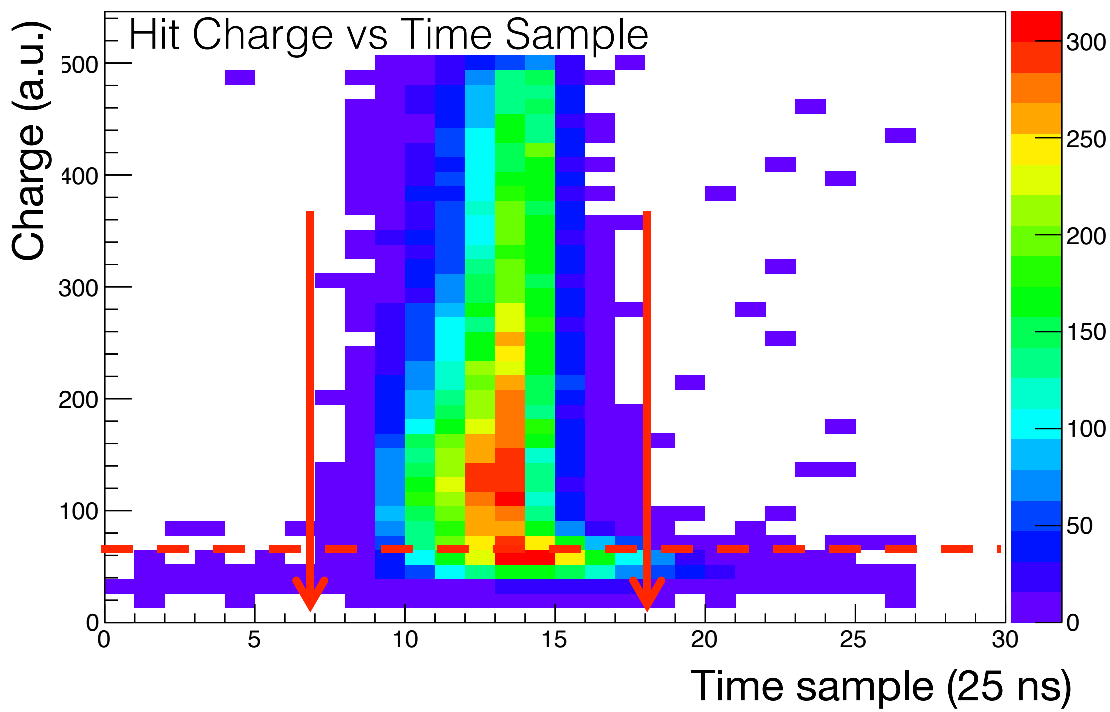
The test beam setup

Some readout details

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

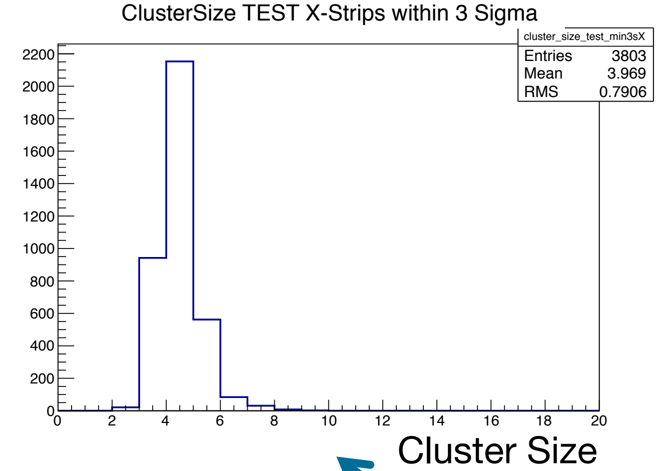


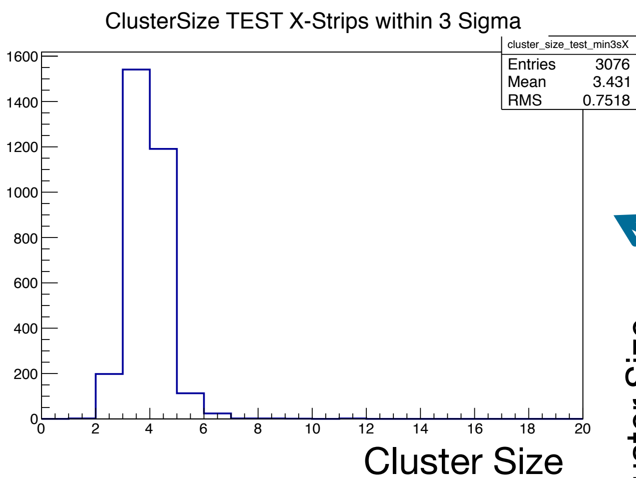
- Charge is sampled in 25 ns bins → possibility to combine charge and time information.

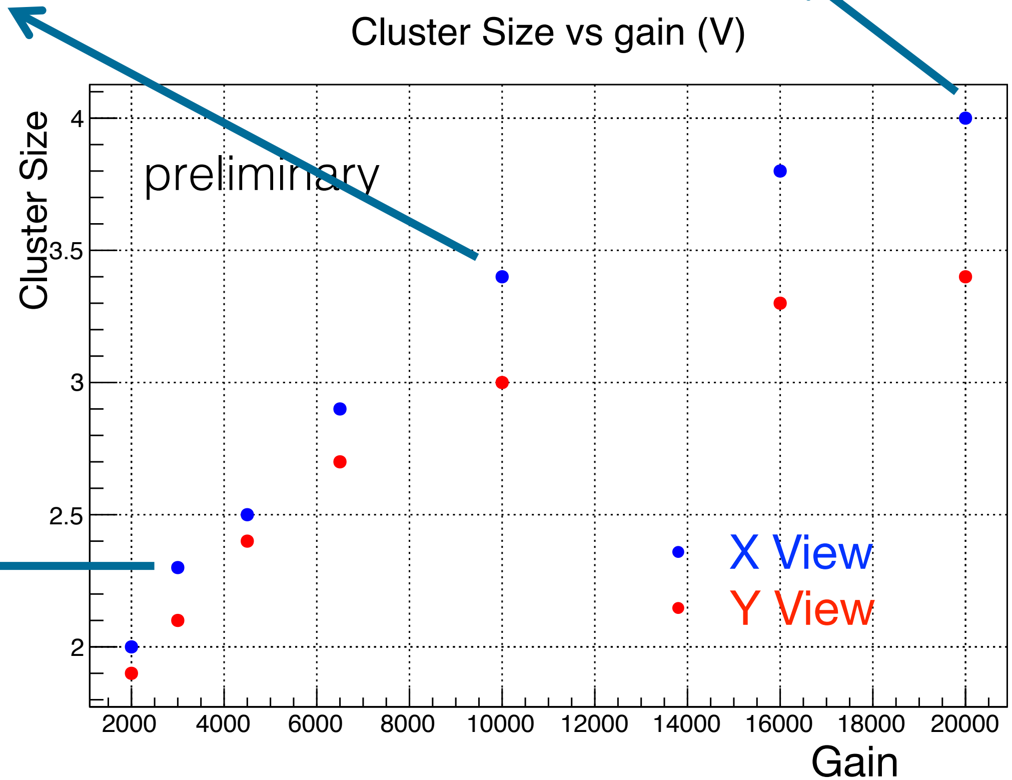


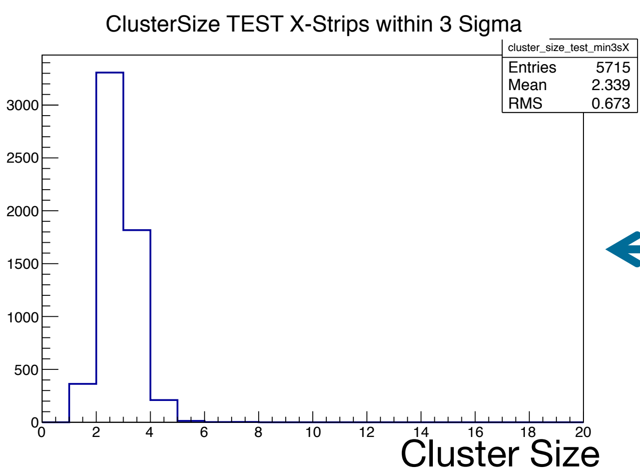
Preliminary Results with no B field

Cluster Multiplicity





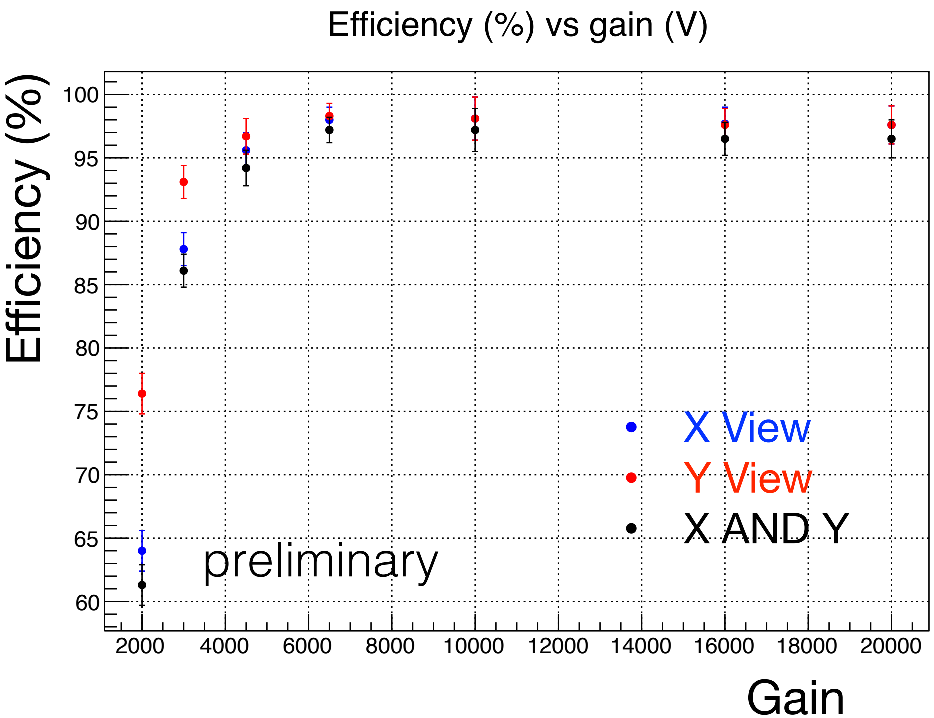


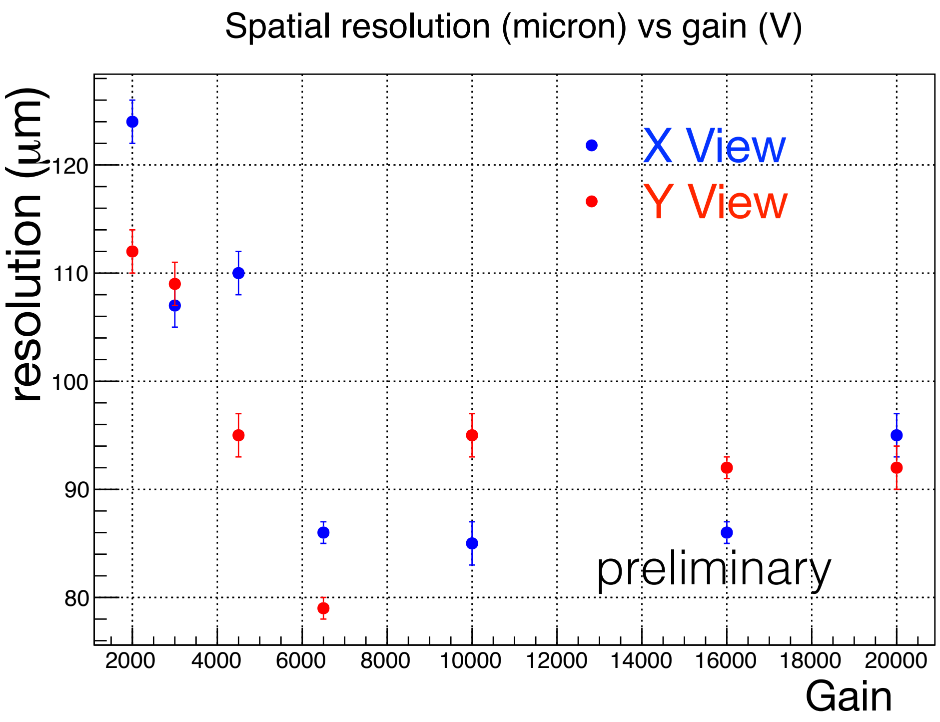


Efficiency and spatial resolution (no B field)

The efficiency plateau starts at about a gain of 6000.

Efficiency for 2 dimensional clusters ~97%.





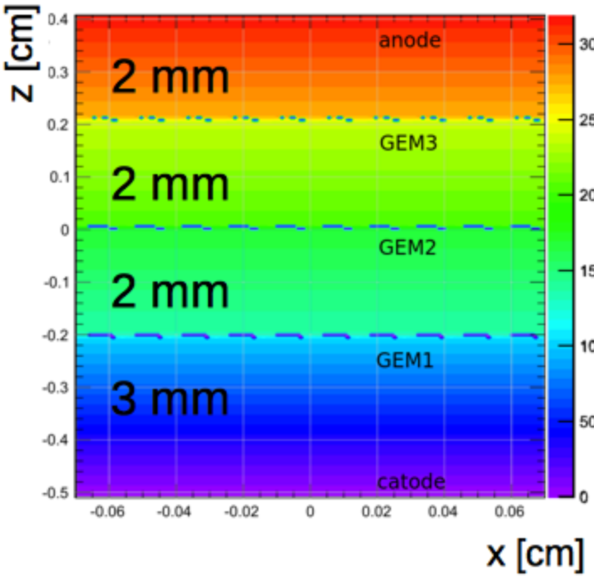
With 650 μm strip pitch we achieved about 90 μm of spatial resolution without magnetic field and Ar/Isob (90/10).

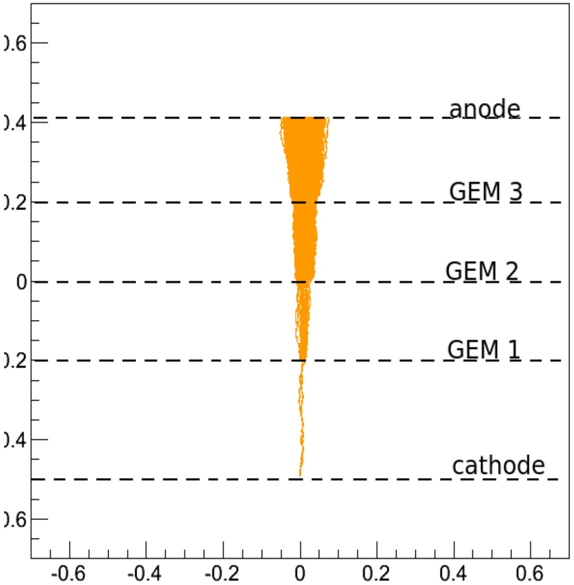
Studies with magnetic field ongoing.

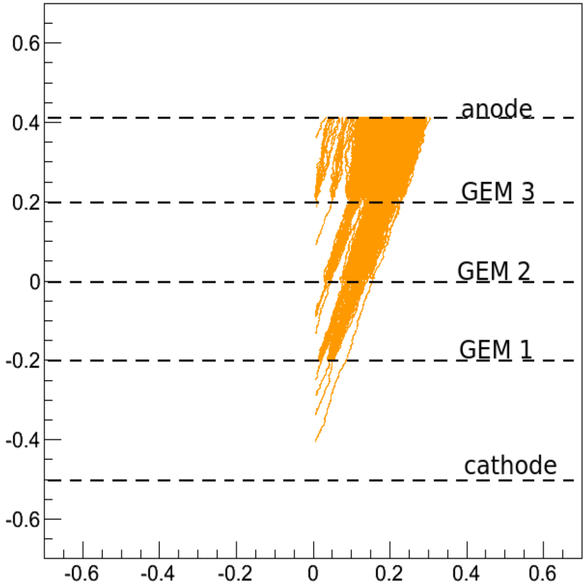
Need for a new beam test to complete our measurements.

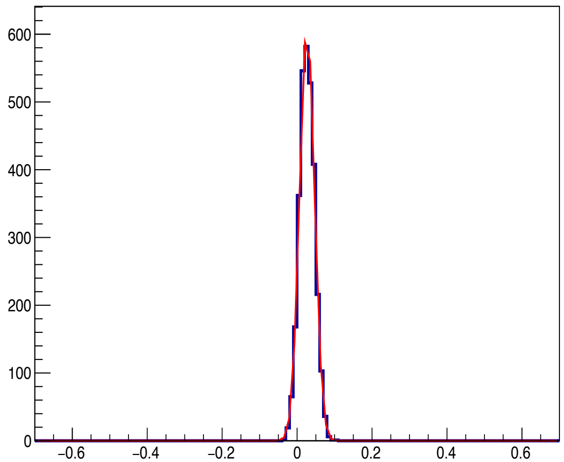
Preliminary Results with B field

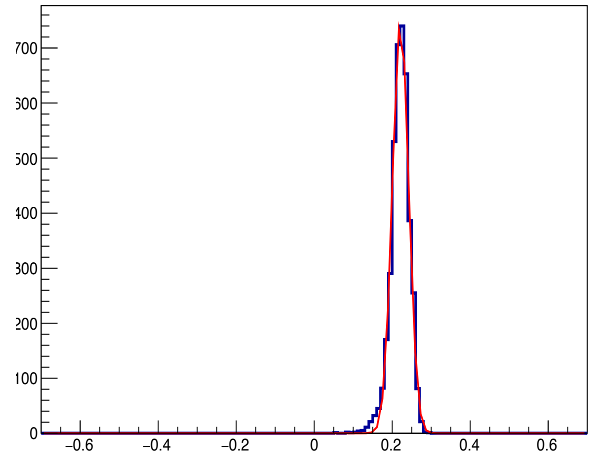
Effect of the magnetic field on the electron avalanche





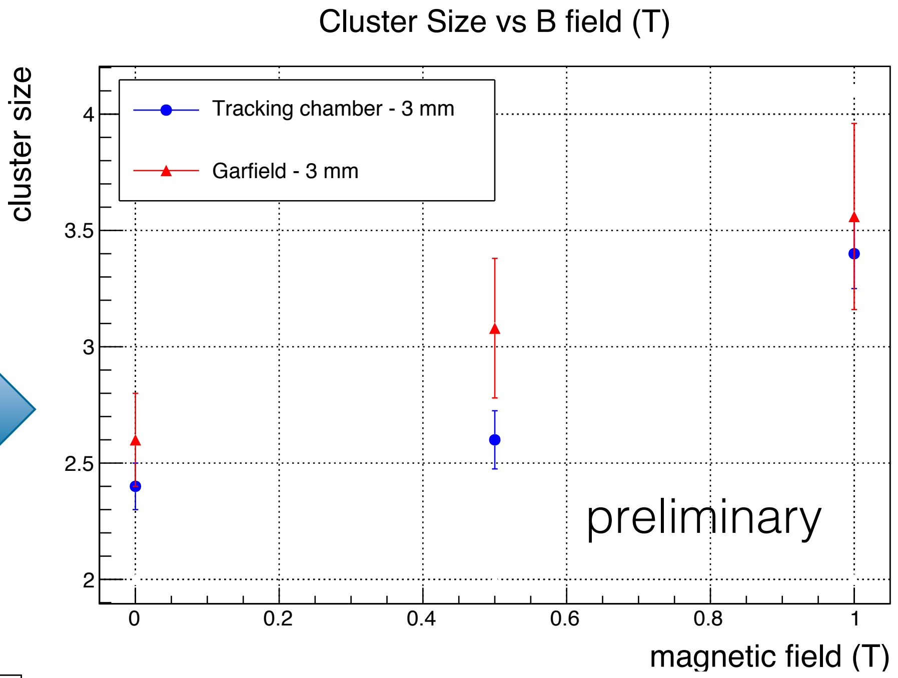


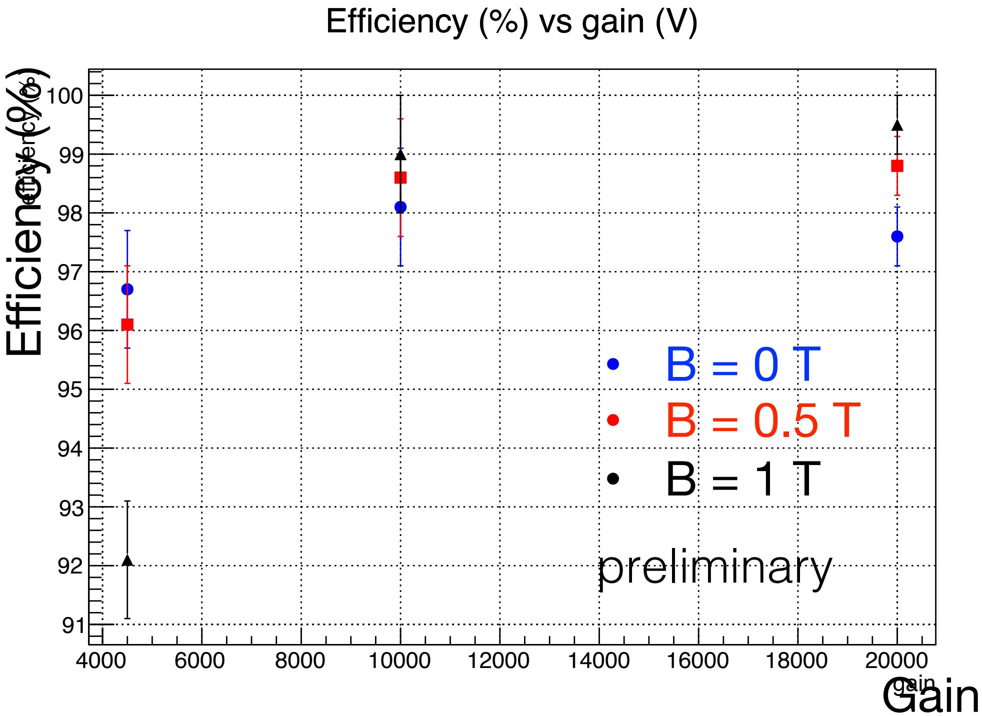




Results with B field

- Effect of B field on cluster multiplicity and comparison with Monte Carlo simulation.

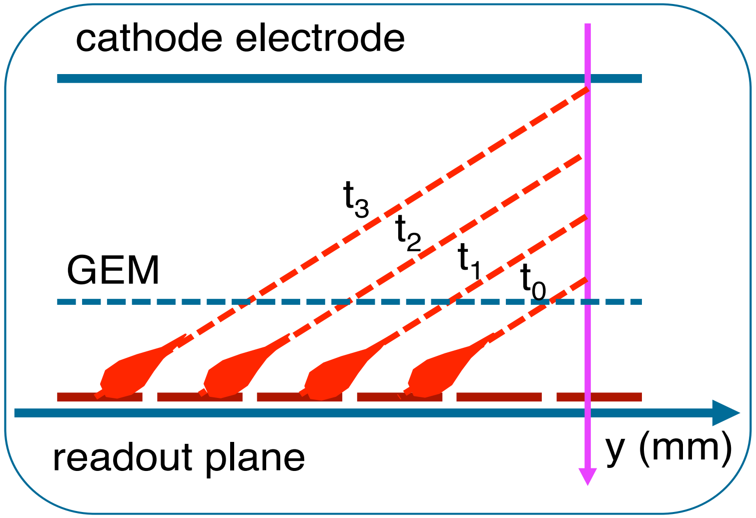




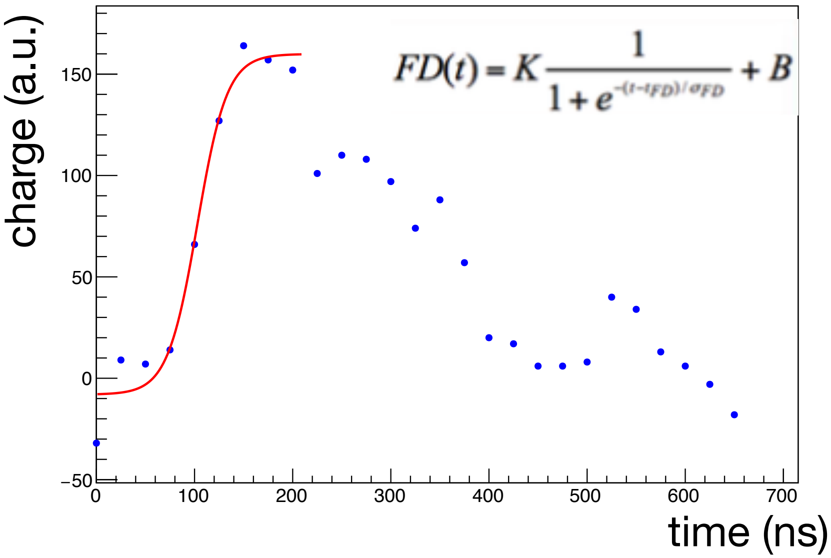
- No effect of magnetic field on tracking efficiency.

Exploring the GEM technology potentialities: μTPC readout

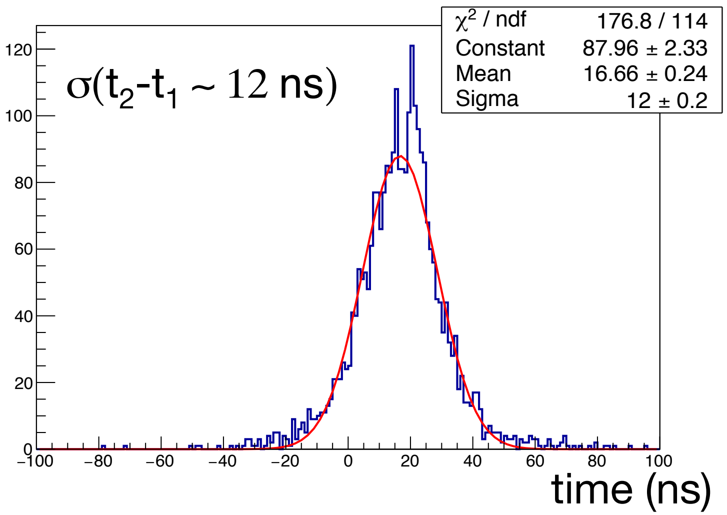
- The time information can be used to improve the spatial resolution with B field.
- Time information can be extracted from the sampling of the APV signal.



Fit to the charge samples to extract the drift time

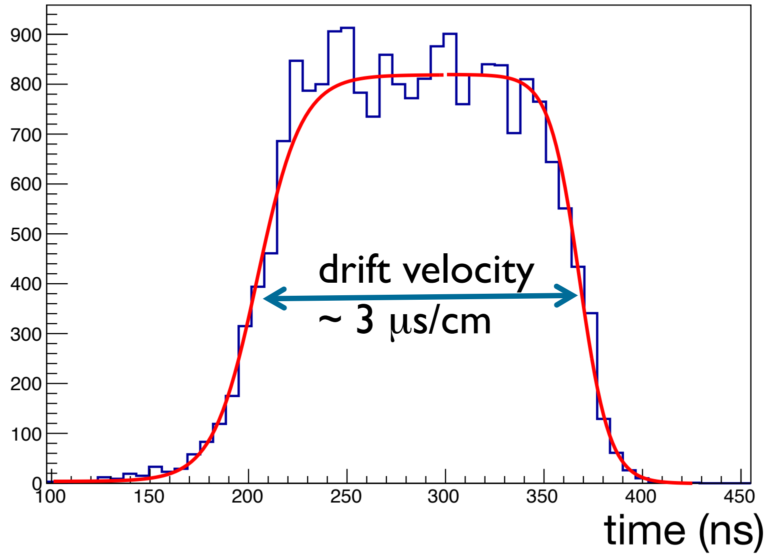


difference from t_2 and t_1

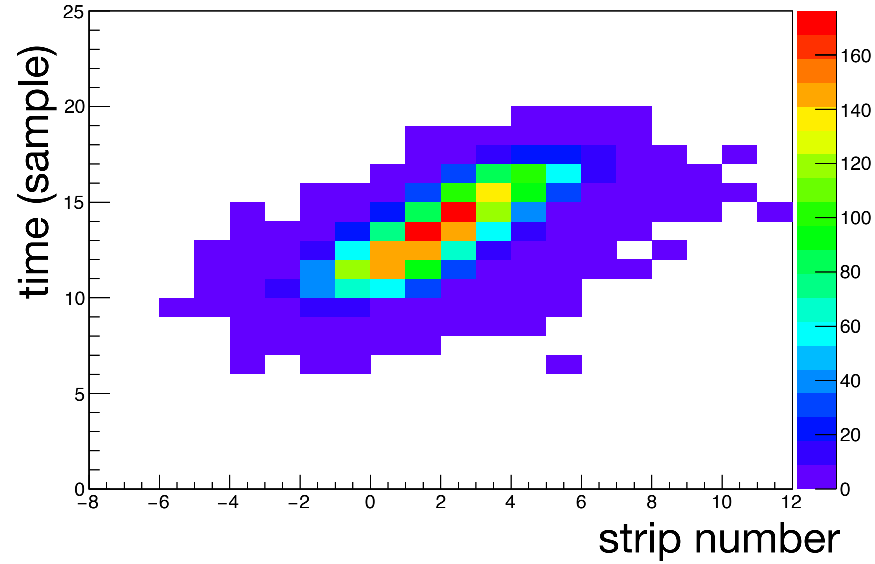


μTPC readout feasibility study

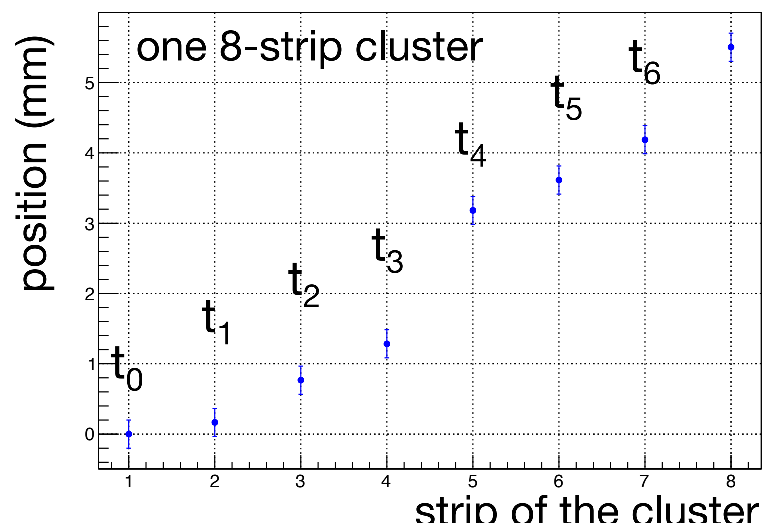
Hit Time distribution for all clusters



correlation between time and strip position



track reconstruction in a 5 mm gap



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

Project status and schedule

June 2014: Conceptual Design Report

1. Introduction
   1. The present BESIII Inner Tracker
   2. Luminosity Issues
      1. Present and expected backgrounds
   3. Inner Tracker Upgrade Requirements
2. Detector design
   1. Operating principle of a triple Cylindrical GEM detector
      1. The KLOE2 Inner Tracker: know-how and first results
   2. BESIII CGEM innovations
      1. Rohacell
      2. Anode design
      3. Analog vs. digital, expectations and measurements
3. The BESIII CGEM-IT
   1. CGEM-IT vs DC-IT
   2. Mechanical Design
   3. Tooling and Construction
4. Simulation of Cylindrical GEM Inner Track
   1. Parametric Simulations (Liang)
   2. CGEM-IT full Offline Reconstruction
      1. Pattern Recognition
      2. Tracking
      3. Acceptance, Resolutions and Reconstruction Efficiencies
   3. Monte Carlo simulation results
      1. Physics Benchmark

5\. Front End Electronics

   5\. Requirements

      5\. Power Consumption

   6\. System Block Description

   7\. On-Detector Electronics

      5\. ASIC

   8\. Off-Detector Electronics

6\. DAQ and Trigger

   5\. Requirements

   6\. Dead time and bandwidth

   7\. Possible second level trigger future upgrades

   8\. Storage

7\. Integration of the CGEM-IT with the Spectrometer

   5\. Mechanical design

      5\. Interfacing with beam pipe

      6\. Interfacing with Outer DC

   6\. Power Dissipation and Cooling

   7\. Gas Systems

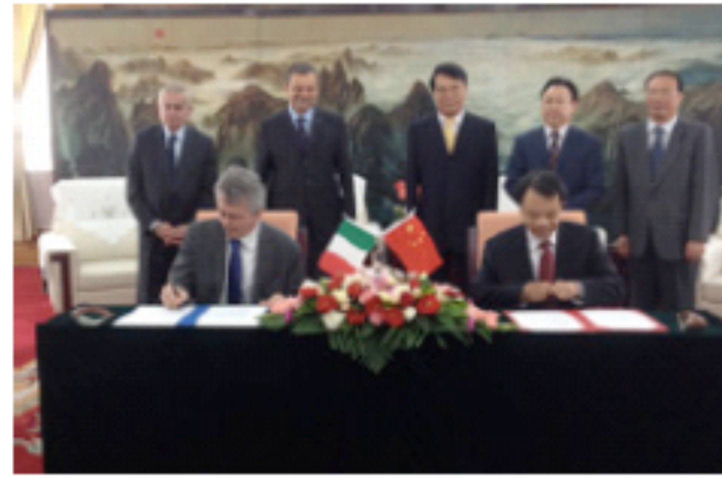
   8\. HV Systems

   9\. Slow Controls

8\. Money, manpower, schedule, task subdivision…..

External funding

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".



BESIII Winter Collaboration Meeting,Guilin

Horizon 2020 MSCA RISE 2014

Proposal Evaluation Form

EUROPEAN COMMISSION

Horizon 2020 - Research and Innovation Framework Programme

Evaluation Summary Report

Call:	H2020-MSCA-RISE-2014
Funding scheme:	Marie Skłodowska-Curie Research and Innovation Staff Exchange (RISE)
Proposal number:	645664
Proposal acronym:	BESIIICGEM
Duration (months):	48
Proposal title:	An innovative Cylindrical Gas Electron Multiplier Inner Tracker for the BESIII Spectrometer

Criterion 1 - Excellence (weight 50%)

Score: 4.40 (Threshold: 0.00/5.00 , Weight: 50.00%)

Project Schedule

2018	commissioning and data taking
2017	installation
2016	QA and test complete construction
2015	begin detector construction finalize the detector design
2014	R&D and simulation for detector design

Summary and Outlook

Summary and conclusions

- 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 the end of 2017.
- The detector concept is inherited by the KLOE-2 inner tracker with some substantial innovations:
  - lighter mechanical structure
  - different anode electrode
  - analog readout performed by a dedicated ASIC chip
- Data analysis of a test beam with planar prototype is ongoing to exploit the full potential of the GEM technology.
- 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 recently selected as one of the project funded by the European Commission within the call H2020-MSCA-RISE-2014.

Thanks