Ultra-light high-resolution Inner Tracker based on Cylindrical micro-RWELL

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1 - Laboratori Nazionali di Frascati – INFN

2 – INFN - Ferrara

Motivations for Cylindrical MPGD (I)

Very recently in view of the **BINP/NSU project of the Super c-tau factory (SCTF) we have been invited for a two-days Workshop devoted to the realization of this project held on May 26-27, 2018, in NOVOSIBIRSK (Russia).**

SCTF – Novosibirsk, Russia

Budker Institute of Nuclear Physics is starting a new project of the Super C-Tau Factory (SCTF). This facility, an electron-positron collider, will operate at center-of-mass energies from 2 to 5 GeV with unprecedented high luminosity of 10^{35} $cm^{-2}s^{-1}$ and the longitudinal polarization of the electrons at the interaction region. The main purpose of the experiments at SCTF is a search for effects of CP violation in decays of charmed particles, tests of the Standard Model in tau lepton decays, a search for and study of entirely new forms of matter: glueballs, hybrids, tetraquarks etc.

HIEPA-STCF – Hefei - USTC, China

At the Novosibirsk Workshop in may there was also a presentation on the HIEPA-STCF Chinese project. *The STCF will be a double-ring electron-positron collider with about 1000 meters in circumference. It will have a beam energy from 1 to 3.5 GeV and a peak luminosity of $1x10^{35}$ $cm^{-2}s^{-1}$ optimized at the center of mass energy of 4 GeV. The STCF would enable us to explore tau-charm physics in unprecedented depth and detail, representing an irreplaceable and crucial precision frontier in particle physics.*

Motivations for Cylindrical MPGD (II)

From presentation on "Super Charm-Tau Factory at Budker INP - Detector Concept " by Yu. A. Tikhonov (BINP – Novosibirsk).

Vertex Detector

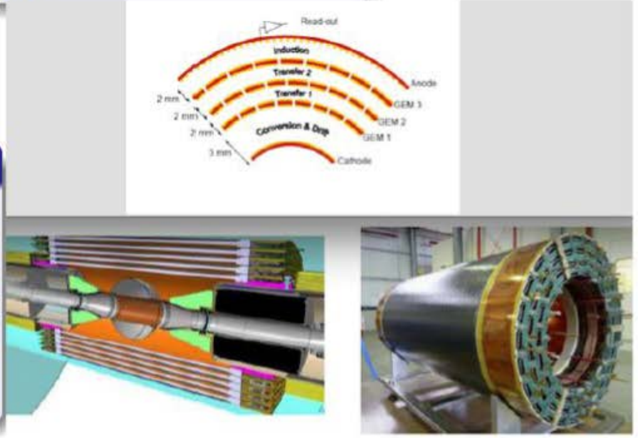
Vertexing is not very important as it at B-factories.
It can simplify a design of main tracker- drift chamber.

Tasks& Parameters:

- Secondary vertices detection & track length measurement for K_S^0, Λ, . . . ?
- Increase a solid angle of the detector (up to 98 %)
- Detection of particles with momentum less than 50 MeV/c
- $\o_{inner} \geqslant 50$ mm; $\o_{external} \leqslant 600$ mm; $L < 900$ mm;

Cylindrical GEM

- Material budget $\sim 1.5 X_0$;%
- $\sigma_{X-Y} \leqslant 100$ μm/layer;
- $\sigma_t \leqslant 7$ ns;
- $\frac{dE}{dx}$ – NO;



Cylindrical GEM (KLOE-2)

Motivations for Cylindrical MPGD (III)

From the presentation on : "Options of the Inner Tracker for SCTF Detector" by Lev Shekhtman, Budker INP Novosibirsk State University:

Main purpose of the Inner Tracker:

- ❑ Continue tracks from the Drift Chamber to Inner region
- ❑ Tracking of low momentum particles

IT options

	Material budjet	Resolution	Number of channels	Electronics	Collaboration
TPC	1%X0	100-150 mm	$3x10^5$	CSA+shaper+an.memory for 10-30 ms+buffer & on-line tracking	TUM (ALICE TPC)
Si-strips	0.6%X0 per layer = 2.4% X0	10-20 mm	$2x10^4$	CSA+shaper+an.memory for ~1ms	?
C-GEM/RWELL	0.3%X0 per layer = 1.2%X0	100mm	$5x10^4$-10^5	CSA+shaper+an.memory for ~1ms	INFN Frascati+... (CGEM KLOE2)

Letter of intent for Collaboration

SCTF Project Leader: Yu. A. Tikhonov

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TO WHOM IT MAY CONCERN

June 15, 2018

Budker Institute of Nuclear Physics is starting a new project of the Super C-Tau Factory (SCTF). This facility, an electron-positron collider, will operate at center-of-mass energies from 2 to 5 GeV with unprecedented high luminosity of 10^{35} $cm^{-2}s^{-1}$ and the longitudinal polarization of the electrons at the interaction region. The main purpose of the experiments at SCTF is a search for effects of CP violation in decays of charmed particles, tests of the Standard Model in tau lepton decays, a search for and study of entirely new forms of matter: glueballs, hybrids, tetraquarks etc.

Russian Federation Government Order No. 1325-r of June 24, 2017 approved the plan of activities for the implementation of the first phase of the Strategy for Scientific and Technological Development of the Russian Federation (for 2017–2019), according to which a program for the creation and development of a network of unique "megascience" class facilities on the territory of the Russian Federation (activity 30) should be developed. Among the anticipated results of this activity is formation of international collaborations, completion of the stage of design of the second-stage "megascience" class facilities on the territory of the Russian Federation, including SCTF, and transition to the stage of their construction. The decision on the transition to the construction phase is expected to be adopted at the end of 2019, and since that moment the machine construction will take approximately 7 years.

Hereby we invite various groups from INFN to join the collaboration and take part in the development and construction of the detector for the SCTF. In particular, taking into account the strong level of expertise INFN has, we would like to encourage INFN groups joining work on the development of an MPGD-based Inner Tracker, gamma-gamma tagger and luminometer and ultra-light drift chamber. At the present stage of the project the joining groups from leading scientific organizations should participate in the research and development program aiming at the completion of the Conceptual Design Report and preparation of the Technical Design Report, as well as take part in annual (or once per 6 months) collaboration meetings. We would also like to express our readiness to make a presentation at the INFN Scientific Committee about the machine project, physics program and detector concepts.

BINP Deputy Director
SCTF Project Leader

Yu. A. Tikhonov

…encouraging INFN groups joining works on MPGD based Inner Trackers …

STCF-HIEPA Project Manager: Prof. Haiping Peng

中国科学技术大学

University of Science and Technology of China

To whom it may concern

The Chinese high energy physics community working on the tau-charm physics sector has proposed constructing an accelerator facility called "Super Tau-Charm Facility" (STCF) in China. The STCF will be a double-ring electron-positron collider with about 1000 meters in circumference. It will have a beam energy from 1 to 3.5 GeV and a peak luminosity of $1x10^{35}$ $cm^{-2}s^{-1}$ optimized at the center of mass energy of 4 GeV. A preliminary estimate of the total project cost is about 4 billion RMB (1 USD ~6.7 RMB). The STCF would enable us to explore tau-charm physics in unprecedented depth and detail, representing an irreplaceable and crucial precision frontier in particle physics. The proposed site for the STCF is located in Hefei Integrated National Science Center which is one of three national centers of such to be established in China. And the STCF project has been listed in the implementation plan of Hefei Integrated National Science Center as a potential mega-science project for the center.

An concerted effort led by the University of Science and Technology of China have been pushing forward the STCF project. Seven workshops have been organized since 2011 to discuss the STCF project, two of which were international and attracted many participants around the world.

[illegible]

The project has been reported to the provincial government of Anhui (whose capital is Hefei) and Chinese Academy of Sciences. As a result of increasingly wide recognition of the STCF project in China and around the world, a pre-R&D program for the STCF project has been launched with an initial funding support of 10 million RMB (for 2018) from the University of Science and Technology of China.

The proposed schedule for the STCF project is as follows:
2018-2019: Conceptual Design Report
2019-2022: Technical Design Report
2023-2029: Project construction
2030-2040: Commissioning and physics running
2014-2042: Upgrade

We hereby invite INFN groups interested in the STCF project to collaborate on R&D towards its TDR. In particular, taking into account the level of expertise of INFN in HEP detector design and development, we would like to encourage INFN groups to join the development of inner tracking device based on Cylindrical-MPGD technology (such as GEM or micro-RWELL) as well as ultra-light drift chambers, gamma-tagger and luminometers.

The INFN groups interested in joining the STCF R&D are invited to participate in future yearly STCF workshops till the completion of the STCF TDR.

It would be our wish to introduce the STCF project including its physics program, accelerator and detector concepts and status to the INFN Scientific Committee in the form of a seminar at a convenient time.

Prof. Haiping Peng
Project Manager, University of Science and Technology of China

… encouraging INFN groups to join the development of inner tracking devices based on MPGD technology (GEM and RWELL)

CREMLIN2

e-mail di M.Zobov – responsabile INFN per CREMLIN2:

… **progetto unico è CREMLIN2** (**25 mln. Euro**) che include **NICA, PIK, XCELS, SCTF, SSRS-4 + scambi personale**.

Tentativamente - **25 ME** - totali di cui:

1. **20 ME** - per i **5 progetti mega-science** russi (non c'è IGNITOR):

- **8 ME** per le infrastrutture "quasi pronte" - NICA, PIK
- **12 ME** per **SSRS-4, SCELS** e **SuperC-Tau CDR/TDR** + **<u>Joint development technologies</u>** . La stima per **SSRS-4 è 3-3.5 ME**, **SuperC-Tau - 2.5-3 ME**

2. **5 ME** - programmi per lo scambio ricercatori, accesso alle infrastrutture russe

Deadline **Call – INFRASUPP-01-2018-2019:**

- Opening of the topic: **14 November 2018**
- Deadline of the topic: **20 March 2019**

What-else ???

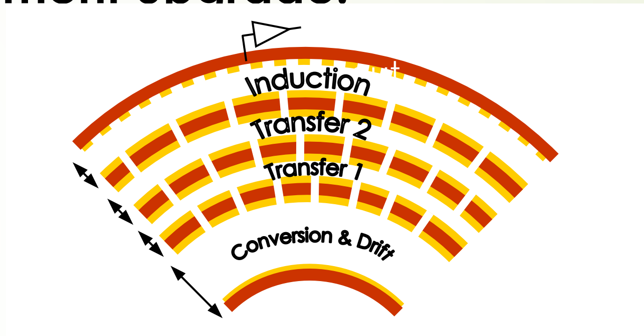
Inner tracker di IDEA con micro-RWELL cilindrica (per FCC-ee)

«… a causa dell'elevato fondo previsto nella parte piu' interna (ossia a piu' piccolo raggio) della zona di tracciamento di FCC-ee ...

Potrebbe essere necessario inserire un inner tracker prima della camera a fili e far cominciare la stessa ad un raggio piu' grande (ora copre da 30 a 200 cm in R) in modo da vedere un background inferiore.
Potrebbe significare un miglioramento significativo di IDEA.
Una micro-RWELL cilindrica che coprisse un intervallo di R tra 30 e 50-60 cm ad esempio potrebbe probabilmente risolvere il problema del fondo per la camera a fili … »

Cylindrical GEM technology (I)

The **Cylindrical MPGD technology** has been **introduced and developed by DDG-LNF in 2006** in the framework of the **R&D and successive construction** of **the first Cylindrical GEM detector for the KLOE experiment upgrade.**



To technique exploit:

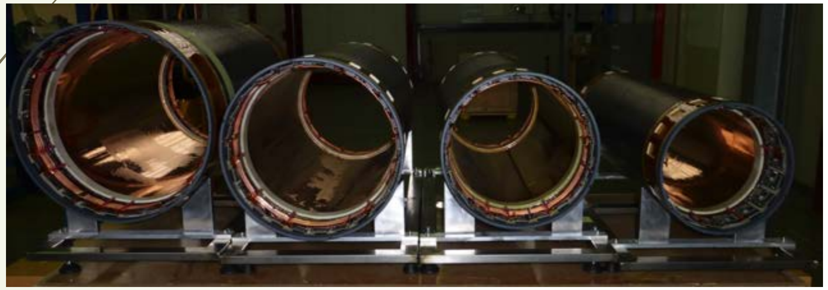
- **the remarkable flexibility of polyimide**
- **the *vacuum bag* technique**

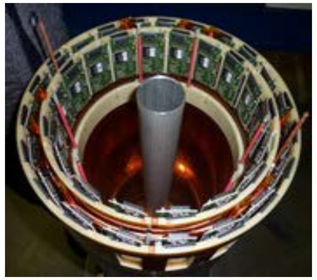
The foil (GEM, anode, cathode) is wrapped on a fine machined PTFE cylindrical mould (five each CGEM layer – expensive toolings), then enveloped in a vacuum bag.
After epoxy polymerization the cylindrical electrode is easily extracted.

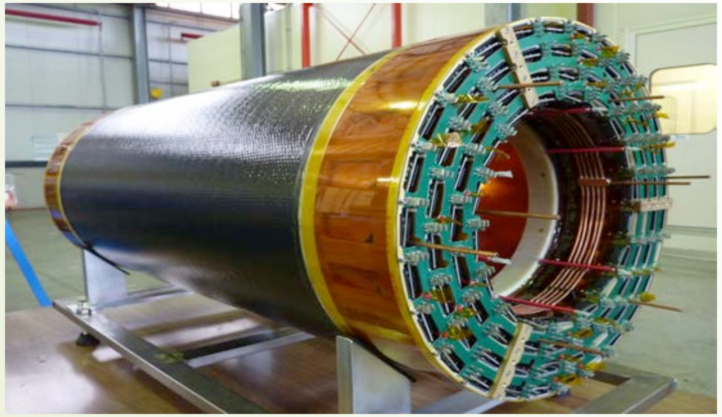
Cylindrical GEM technology (II)

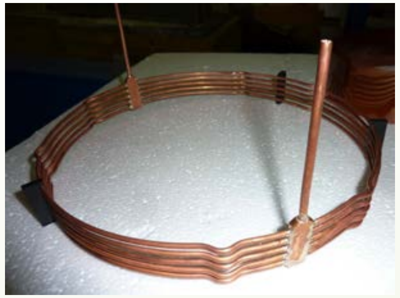
The **single CGEM is obtained inserting one into the other the five cylindrical structures** (*"self supporting": NO stretching is needed)*, by means **a special insertion tool (developed by A. Pelosi INFN-Roma)**

The assembly of the Inner Tracker, with the insertion of all the triple-CGEMs one into the other, and the implementation of the services (fee – cooling, faraday cage, gas piping etc ...)

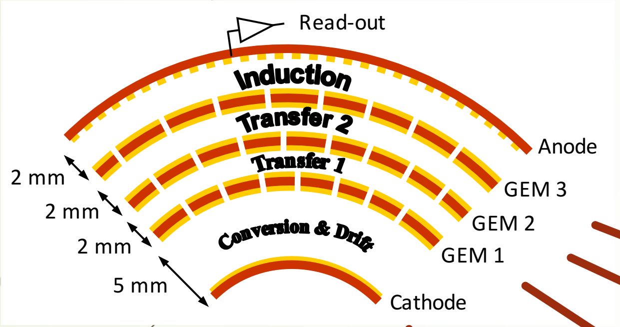


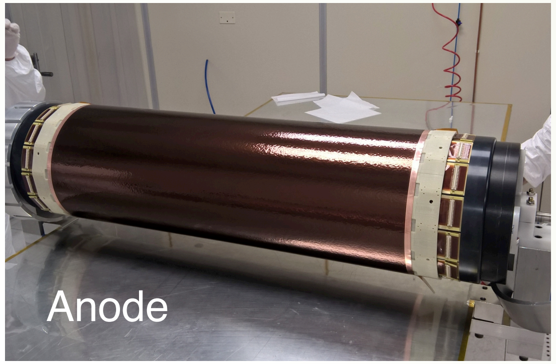


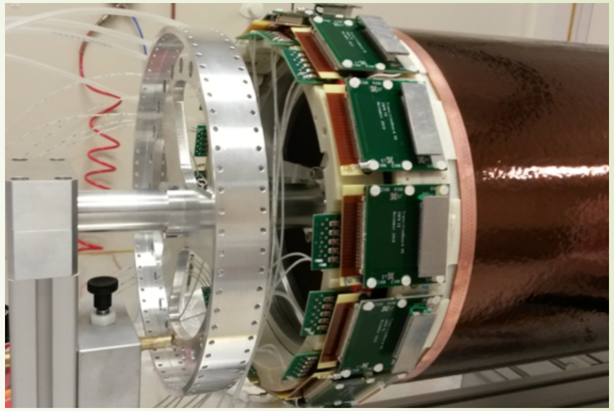


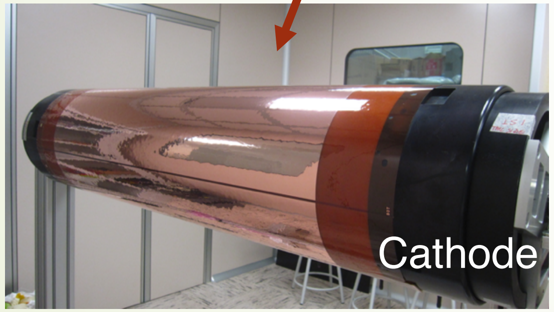


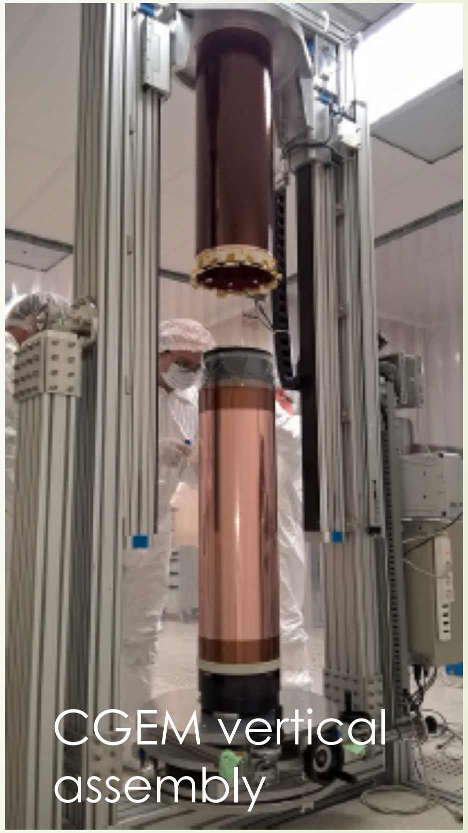
Cylindrical GEM technology (III)











Peculiarities of the BESIII CGEM

	KLOE-2	BESIII	action
Number of detector layers	4	3	→ 5 mm drift gap
Drift gap	3 mm	5 mm	also for μTPC
Material budget per layer	0.5% X_0	0.4% X_0	rohacell and anode
Momentum resolution @1 GeV	not used	σ_{pt}/P_t =~0.5%	
Rate capability – radiation hardness	< 10 kHz/cm^2	few 10 kHz/cm^2	
Spatial resolution ϕ	250-350 μm (B=0.5T)	100-150 μm (B=1T)	with μTPC
Spatial resolution Z	~1 mm	<500 μm	with μTPC
Magnetic filed	B = 0.52 T	B = 1 T	→ μTPC
Internal/external diameter	244/440 mm	156/356 mm	higher rate
Readout	digital	charge + time	new ASIC chip

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	KLOE-2	BESIII	action
Numbe…		3	→ 5 mm drift
Drift ga…		5 m…	
Materia…		…4%	
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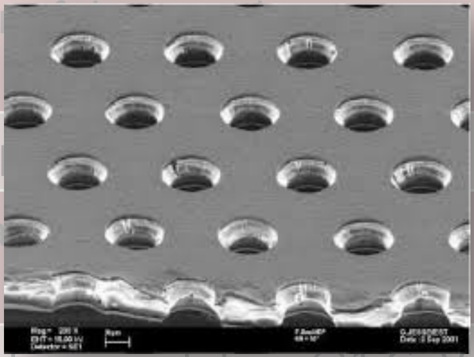

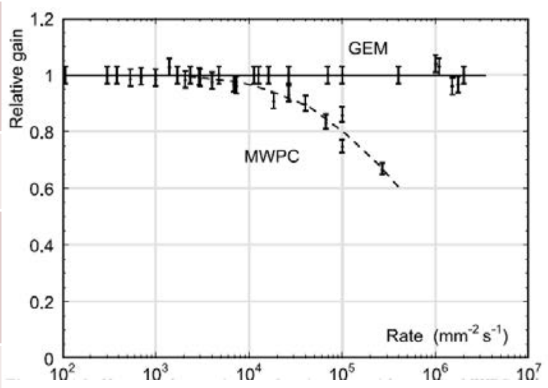

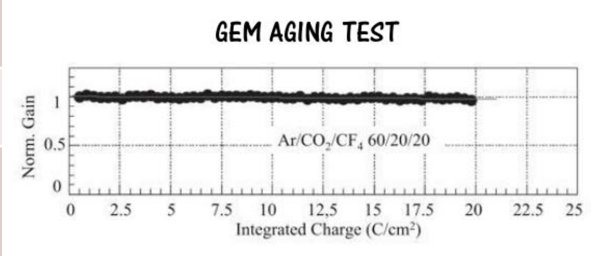

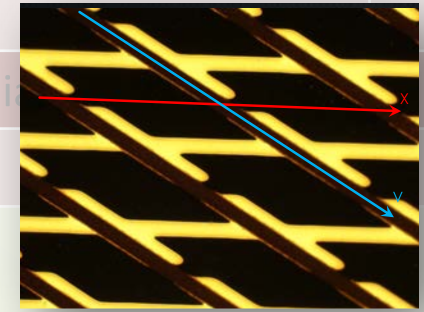

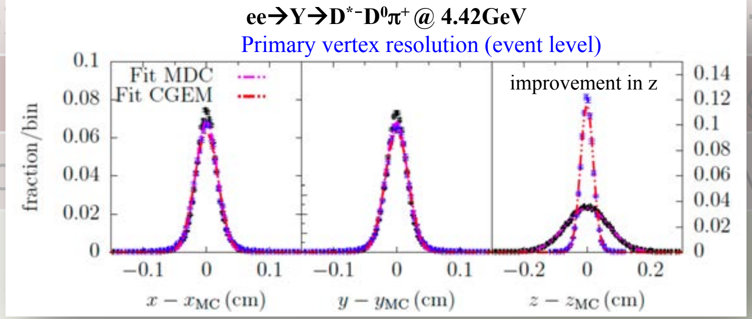

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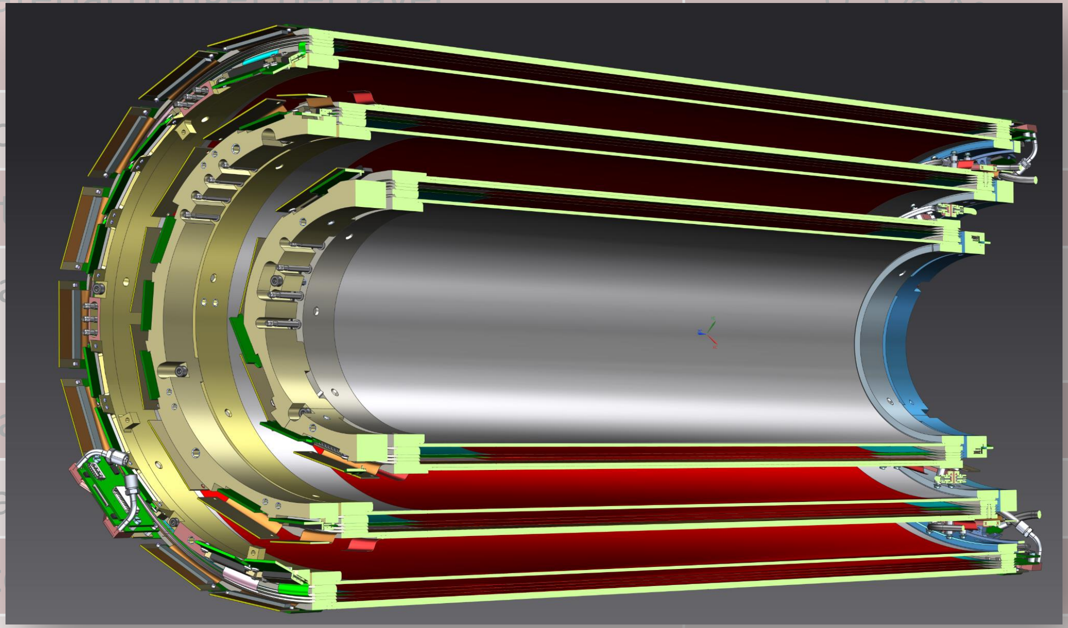
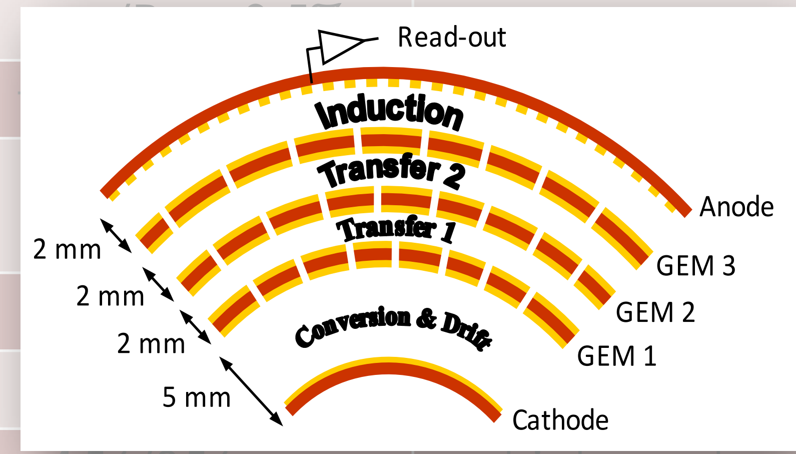
Mo			
Ra			
Sp			
Sp			
Ma			
Int		156/356 mm	higher rate
Readout	digital	charge + time	new ASIC chip





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N	4	3	→ 5 mm drift gap
D	3 mm		also for μTPC
M	% X_0		rohacell and anode
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Rate capability radiation hardness	< 10 kHz/cm^2	few 10 kHz/cm^2	
Spatial resolution φ	250-350 μm (B=0.5T)	100-150 μm (B=1T)	with μTPC
Spatial resolution Z	~1 mm	<500 μm	with μTPC
Magnetic filed	B = 0.52 T	B = 1 T	→ μTPC
Internal/external diameter	244/440 mm	156/356 mm	higher rate
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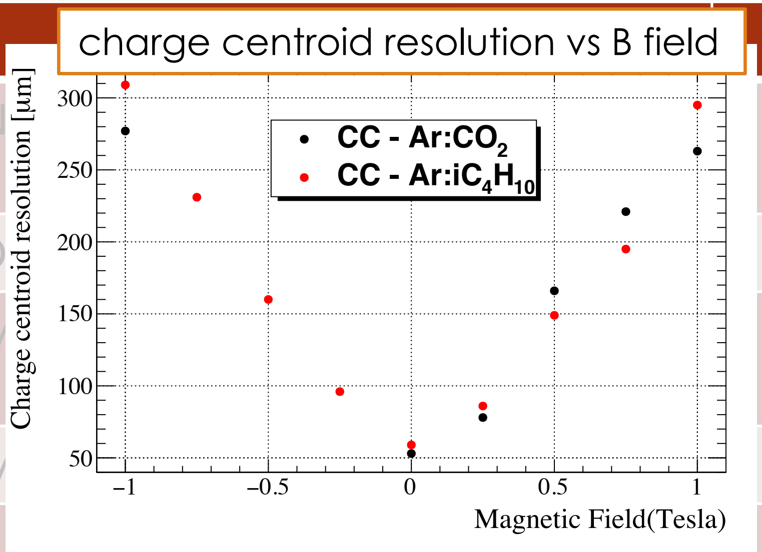
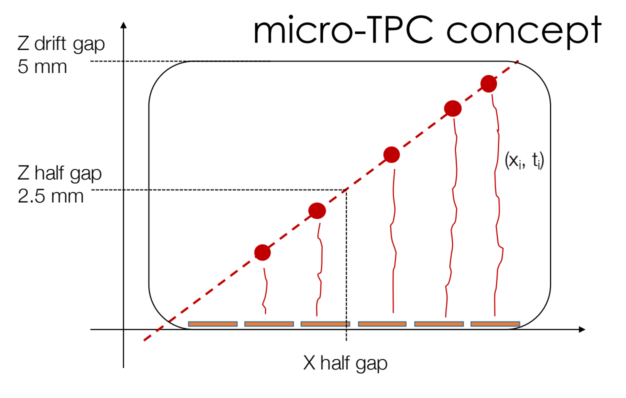
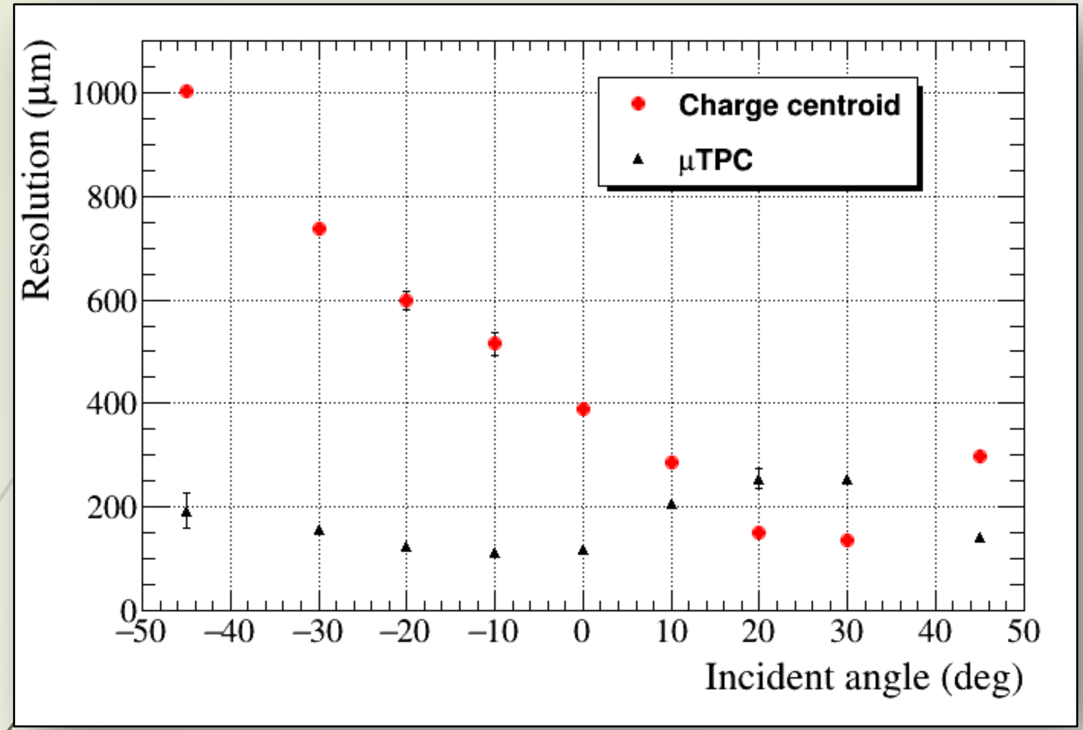
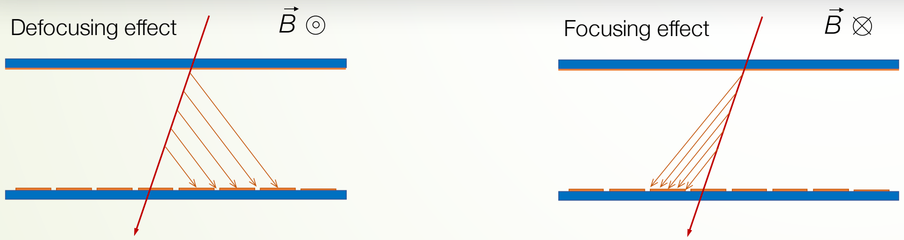


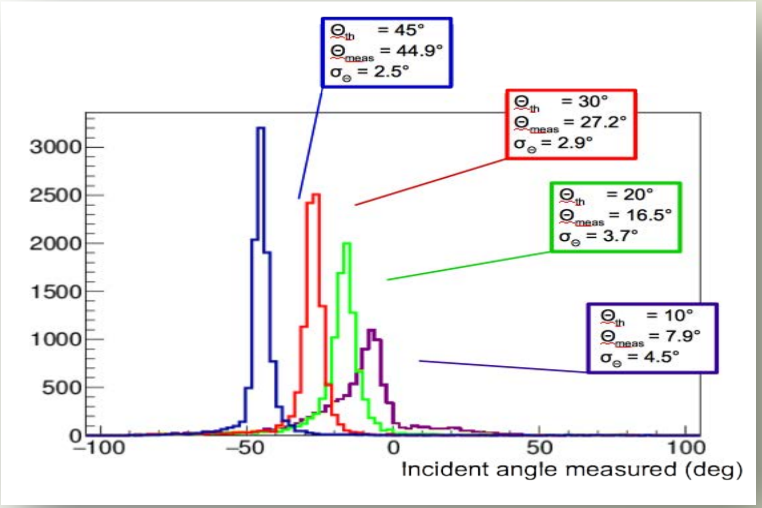


micro-TPC clusterization



- combining CC and μTPC stable spatial resolution over a large range of incident angle.
- possibility to perform 3D track reconstruction with only one layer.

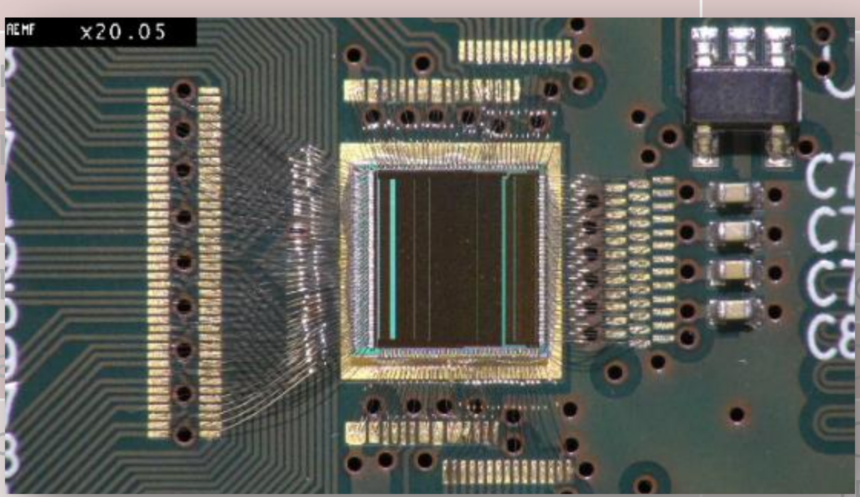




POSTER: Implementation of the code for the simulation of the response of a triple-GEM tracker and its comparison to the experimental data. Lia Lavezzi (INFN Torino and IHEP).

Peculiarities of the BESIII CGEM

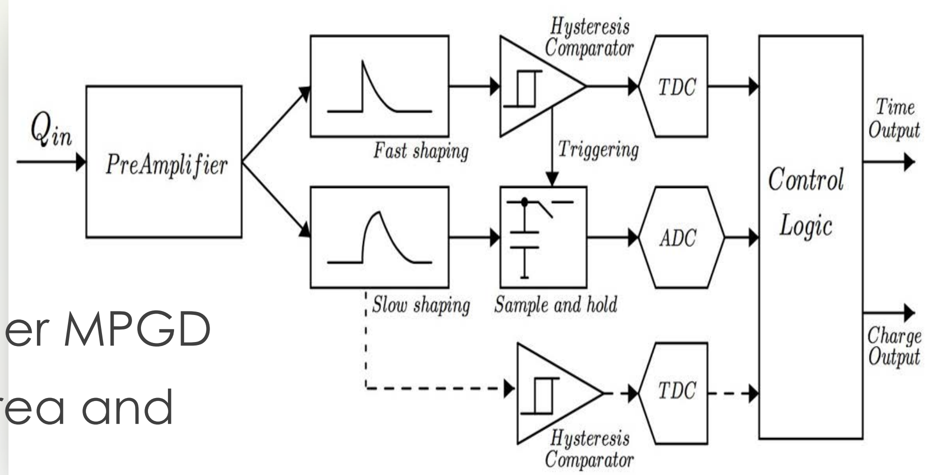
	KLOE-2	BESIII	action
Number of detector layers	4	3	→ 5 mm drift gap
D		3 mm	C
M		.5% X	nd
M		ot use	
Ra		kHz/	
Sp		-350 (B=0.5T	C
Spatial resolution Z	~1 mm	<500 µm	with µTPC
Magnetic filed			→ µTPC
Internal/external diameter	244/440 mm	156/356 mm	higher rate
Readout	digital	charge + time	new ASIC chip



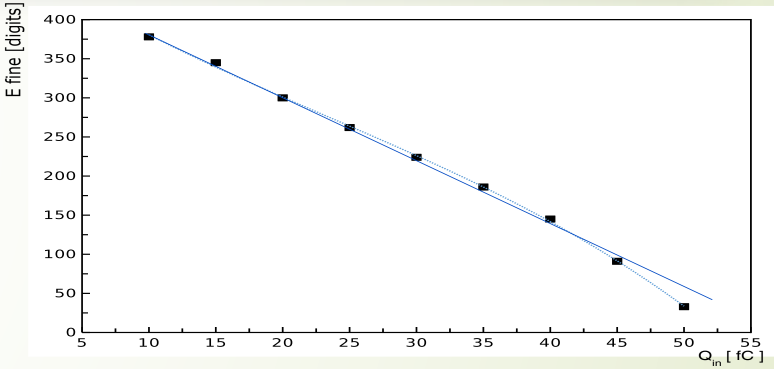
- 64 channels, up to 60kHz/ch rates
- 12 mW/ch power
- Analog charge measurement up to 50fC
- ENC noise below 2000 e- rms for strip capacity < 100pF
- Time-over-Threshold charge measurement possibility
- T and Q branch of every channel
- SEU tolerant digital part

POSTER: Characterization and first field results of a new 64ch custom front-end ASIC for GEM readout. Maxim Alexeev (INFN Torino)

The TIGER chip

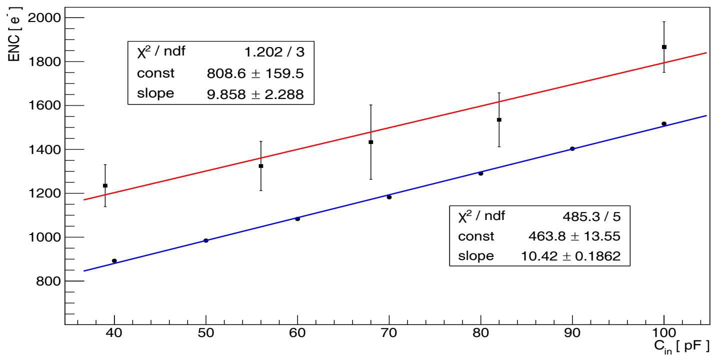


- Very flexible technology adaptable to other MPGD
- Possibility of a pixelated version for large area and high rate



Linearity of the QDC charge reconstruction

- **Time-based readout**
  - Timestamp on rising/falling edge (sub-50 ps binning quad-buffered TDC)
  - Charge measurement with Time-over-Threshold
- **Time and amplitude sampling**
  - Timestamp on rising edge (sub-50 ps binning quad-buffered TDC)
  - Sample-and-Hold circuit for peak amplitude sampling
  - Slow shaper output voltage is sampled and digitized with a 10-bit Wilkinson ADC

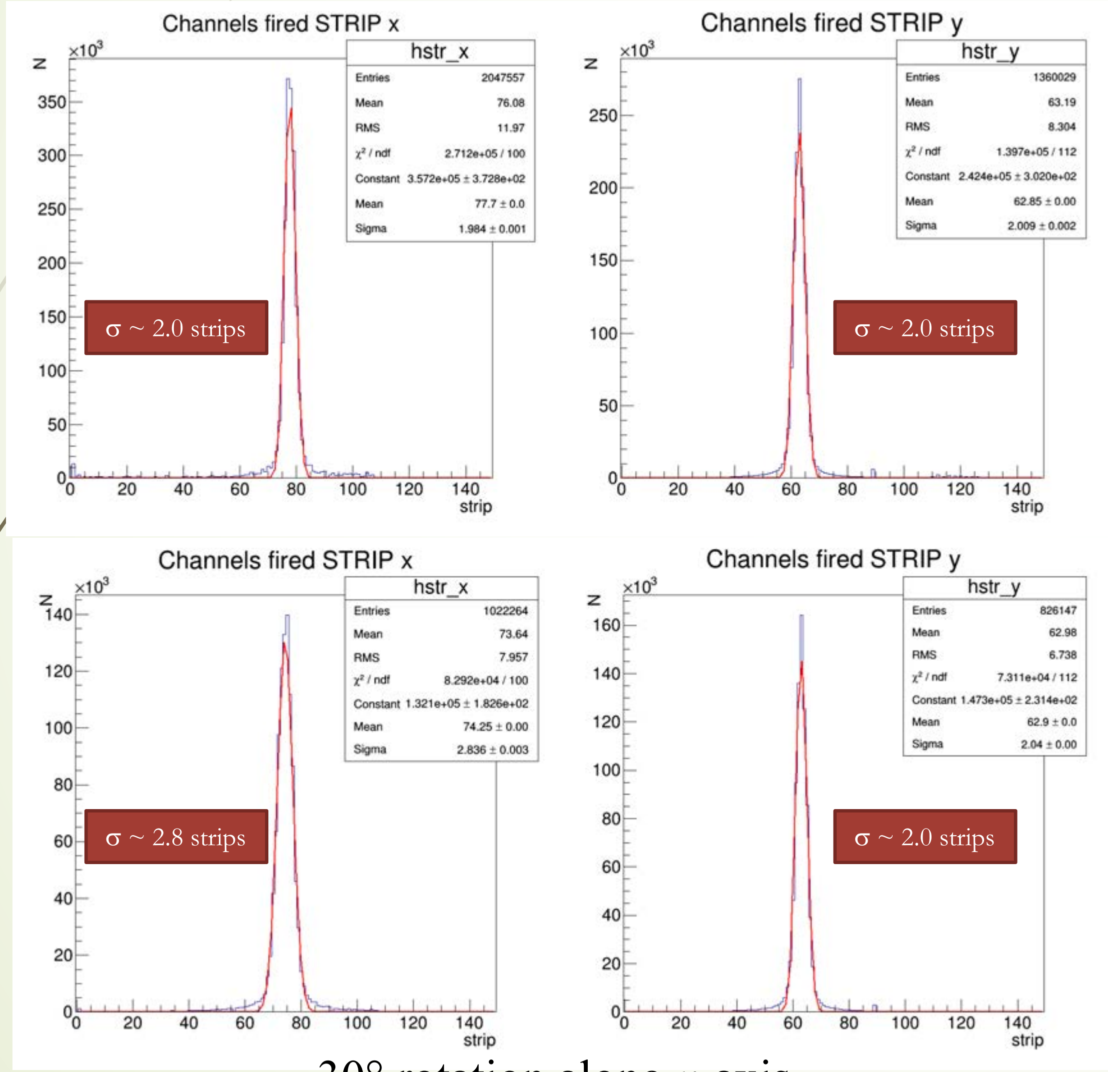


Noise as a functions of strip capacitance.

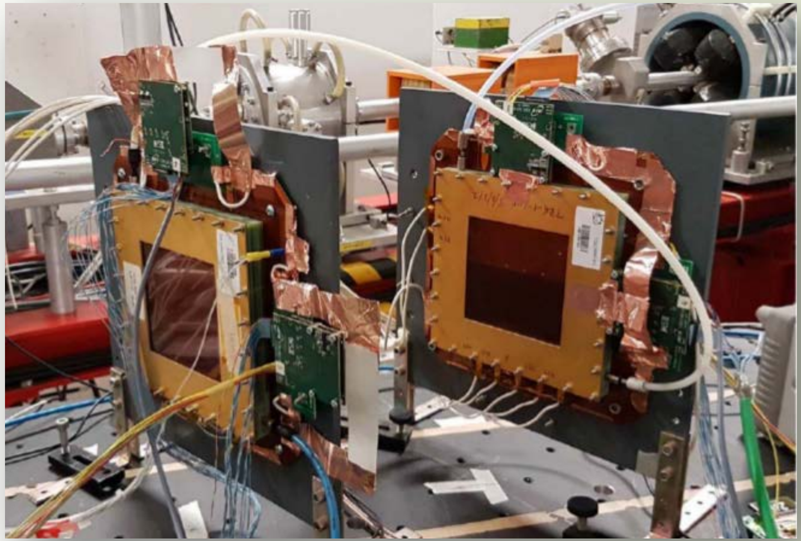
Red- measurement, Blue- simulation

MAMI Test Beam for GEM + TIGER

- Two planar triple GEM XY readout
- ArCO2 (70:30) gas mixture
- electron E(855 MeV)



30° rotation along x-axis

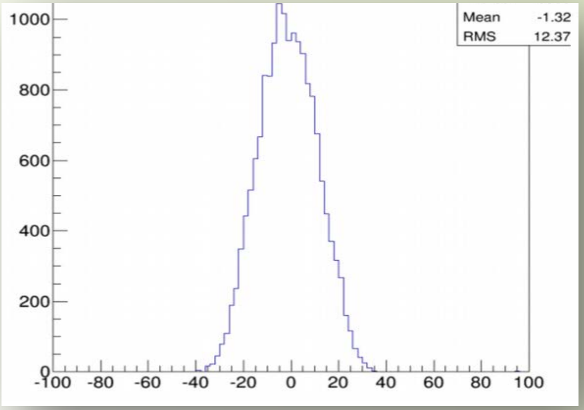


- The beam profile was properly reconstructed.
- Beam intensity correctly estimated from triggerless data.

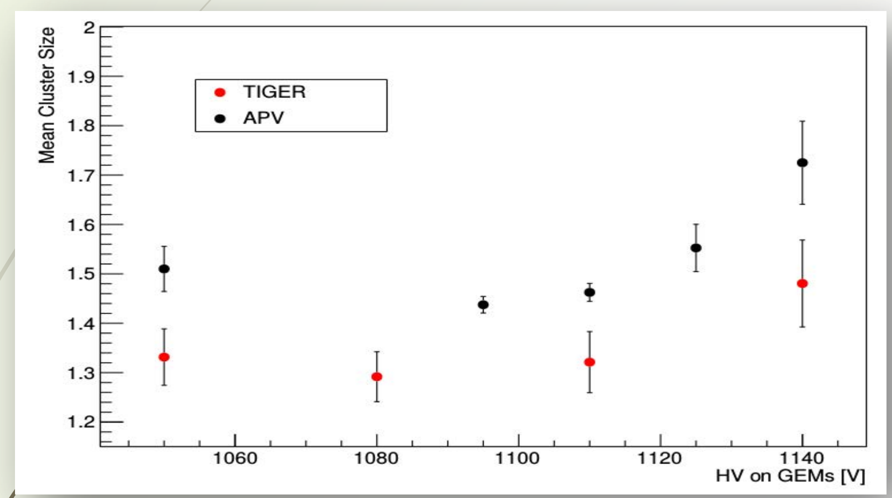
MAMI Test Beam Analysis (cluster level)

For the first time we reconstructed on-time bi-dimensional clusters from two chambers.

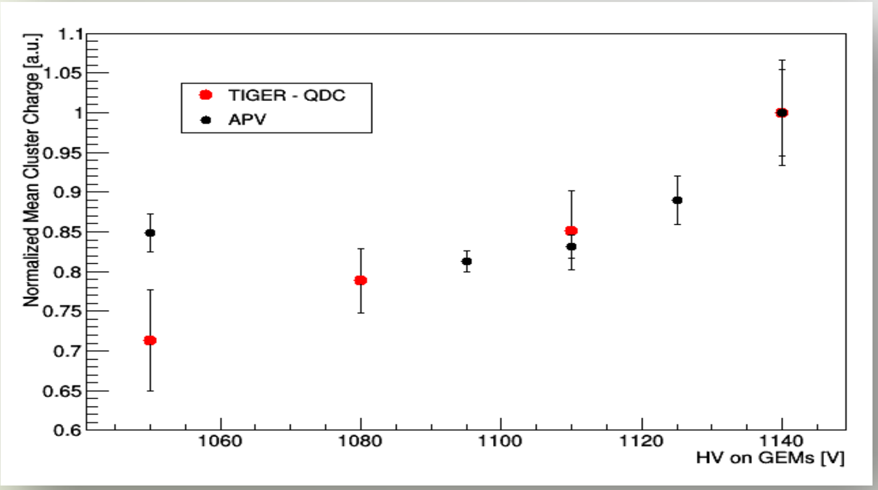
Time difference



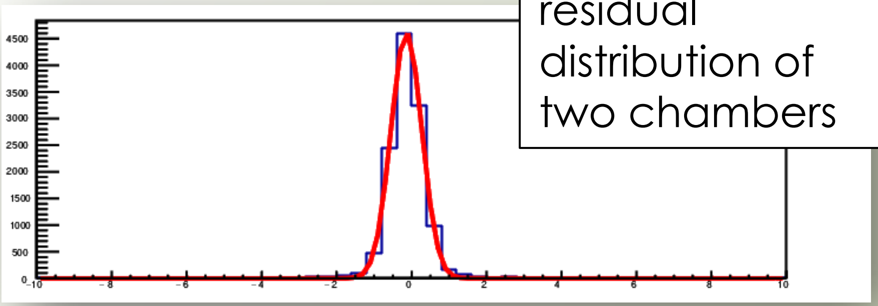
- Comparison with previous test beam



the cluster size

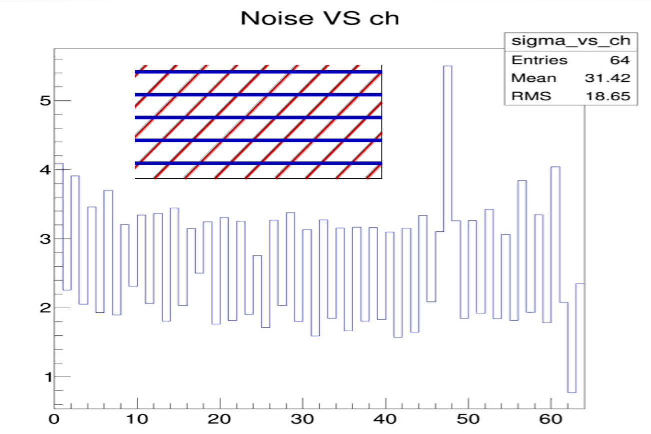


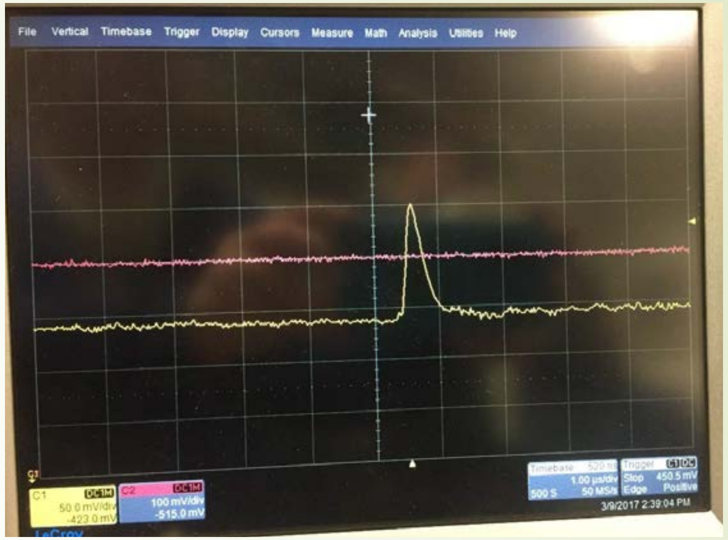
the cluster charge

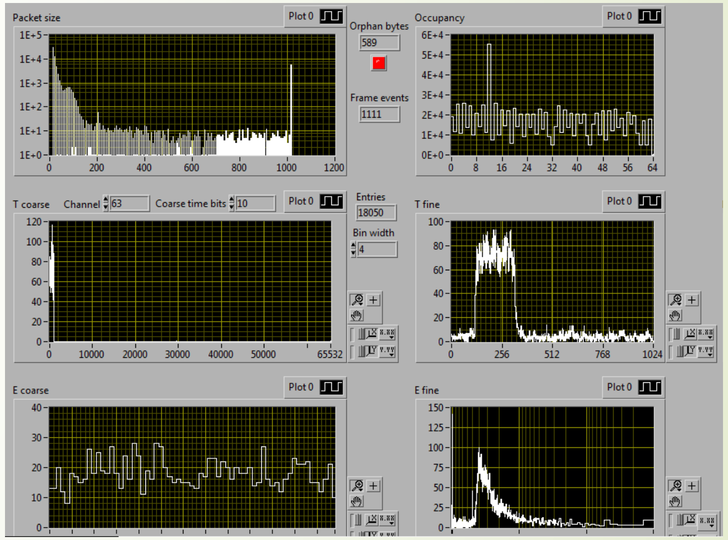


residual distribution of two chambers

Full Readout Integration Tests







The limit of the CGEM technology

The CGEM is a very challenging technology:

- very light detector, < 2% X_0
- full sensitive - almost dead-free zone
- high spatial resolution if operated in micro-TPC mode

BUT

There are some important limitations:

- the construction/assembly are very delicate and time consuming operations
- the construction of the detector electrodes needs five fine machined PTFE cylindrical mould (expensive toolings)
- the GEM, as all non-resistive MPGD, is not completely discharge protected

Replacing the GEM technology with the µ-RWELL, the Cylindrical Inner Tracker becomes extremely more simple and also with higher performance in terms of material budget, space resolution and stability/protection against discharge

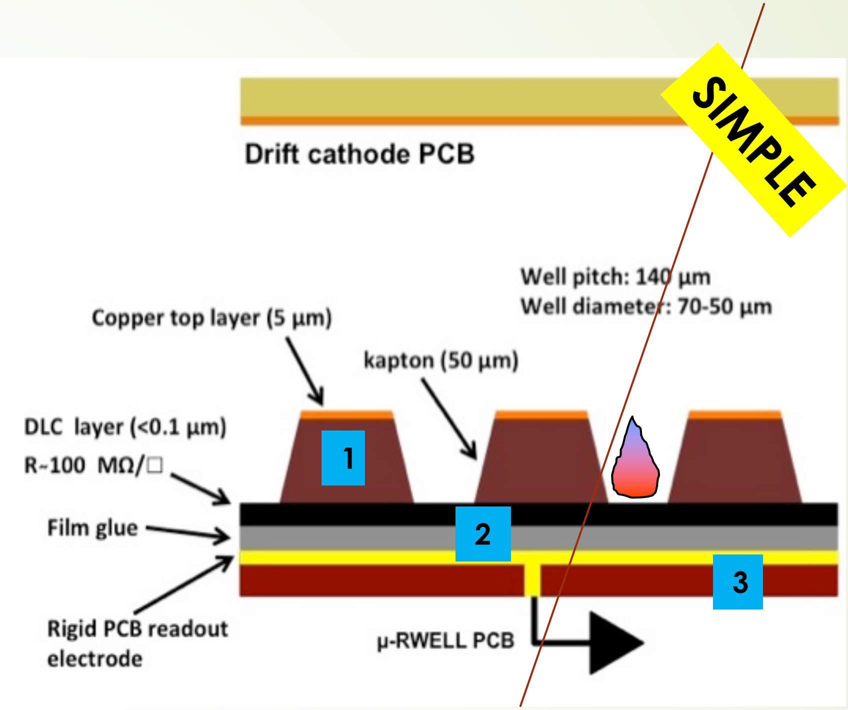
The μ-RWELL: the detector architecture

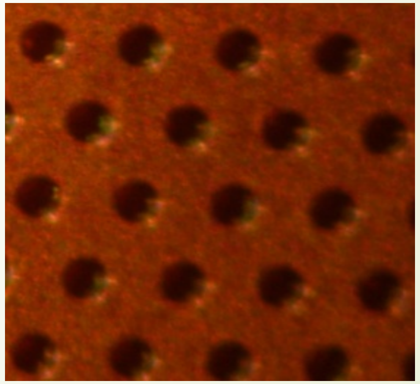
The μ-RWELL is composed of only two elements:

the **μ-RWELL_PCB** and the **cathode**

The **μ-RWELL_PCB, the core of the detector,** is realized by **coupling:**

1. a **WELL patterned kapton foil** as **amplification stage**
2. a **resistive layer (*)** for discharge suppression & current evacuation:
   i. **Single-resistive layer (SRL) <100 kHz/cm²:** surface resistivity ~100 MΩ/□(**SHiP** …)
   ii. **Double-resistive layer (DRL) >1 MHz/cm²**: for LHCb-Muon upgrade & future colliders (CepC, Fcc-ee/hh)
3. a **standard readout PCB**

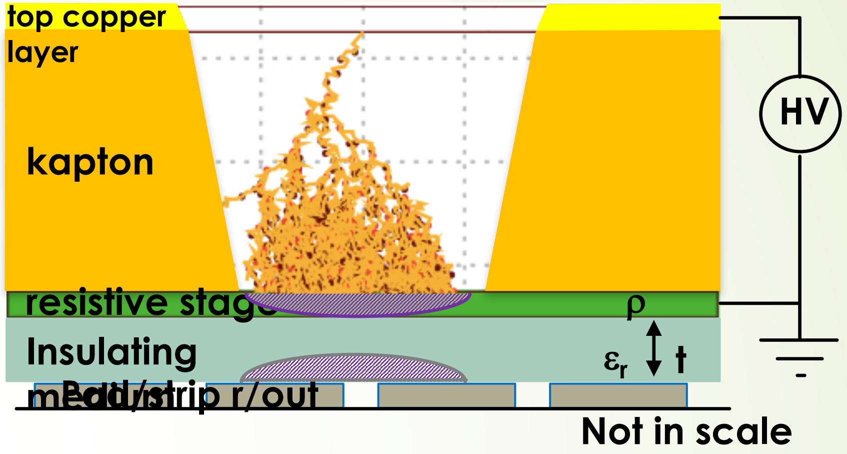




(*) DLC = Diamond Like Carbon
mechanical & chemical resistant

Principle of operation

Applying a suitable voltage between **top copper layer and DLC** the "**WELL" acts as multiplication channel for the ionization.**



The charge induced on the resistive foil is dispersed with a *time constant, τ = ρC ,* determined by:

- the **DLC surface resistivity**, ρ
- the **capacitance per unit area**, which depends on the **distance between the resistive foil and the pad/strip readout plane, t**
- the **dielectric constant** of the insulating medium, ε_r **[M.S. Dixit et al., NIMA 566 (2006) 281]**
- **The main effect of the introduction of the resistive stage is the suppression of the transition from streamer to spark**
- As a drawback, the **capability to stand high particle fluxes is reduced**, **but an appropriate grounding of the resistive layer with a suitable pitch solves this problem (see High Rate scheme)**

Cylindrical μ-RWELL

The Cylindrical MPGD concept can be applied also to μ-RWELL (C-RWELL), with several advantages wrt the CGEM design:

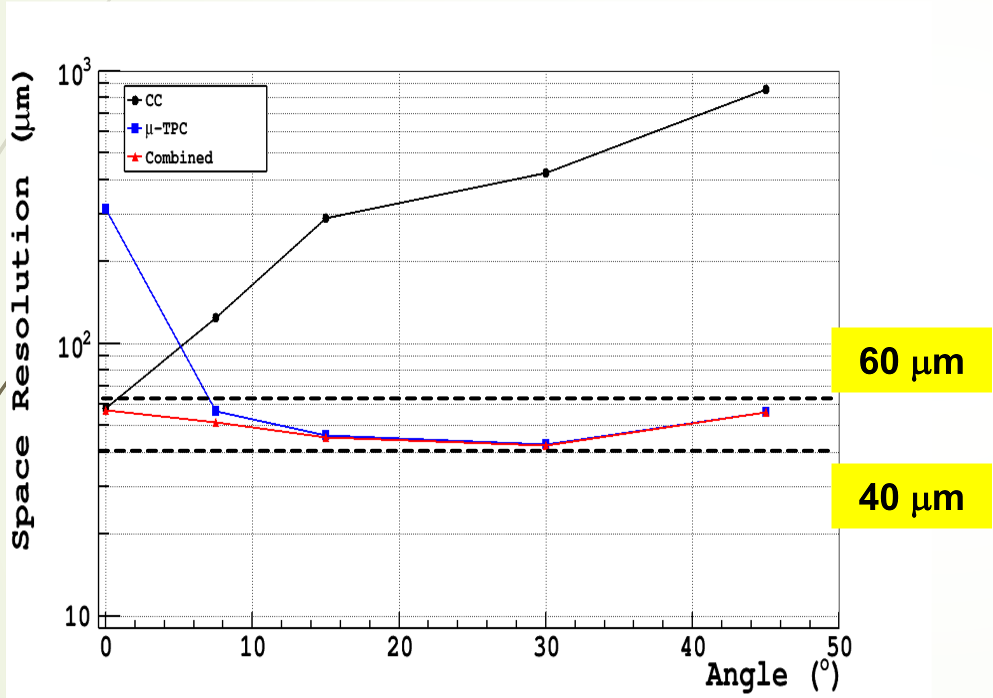
- The **"flexible option"** of μ-RWELL , with r/out layer on polyimide or also very thin FR4 (down to 0.1 mm or less …), could be sensibly lighter than CGEM (<1% for n. 4 C-RWELL layers)
- It is decisively more simple in terms of construction and less expensive : **less toolings (only n.2 moulds instead of 5); less cylindrical electrodes (2 instead of 5)**
- The concept of the **"openable detector"**, as well as **"floating-amplification"** can be easily and safely implemented with μ-RWELL technology
- From recent results of a TB **with μ-RWELL operated in micro-TPC mode** come out a very surprising result: the detector exhibits a **spatial resolution down to 40-60 μm over a wide incidence angle range (0-45°)** – wrt the 100-150 μm with GEM or 100 μm with MM.

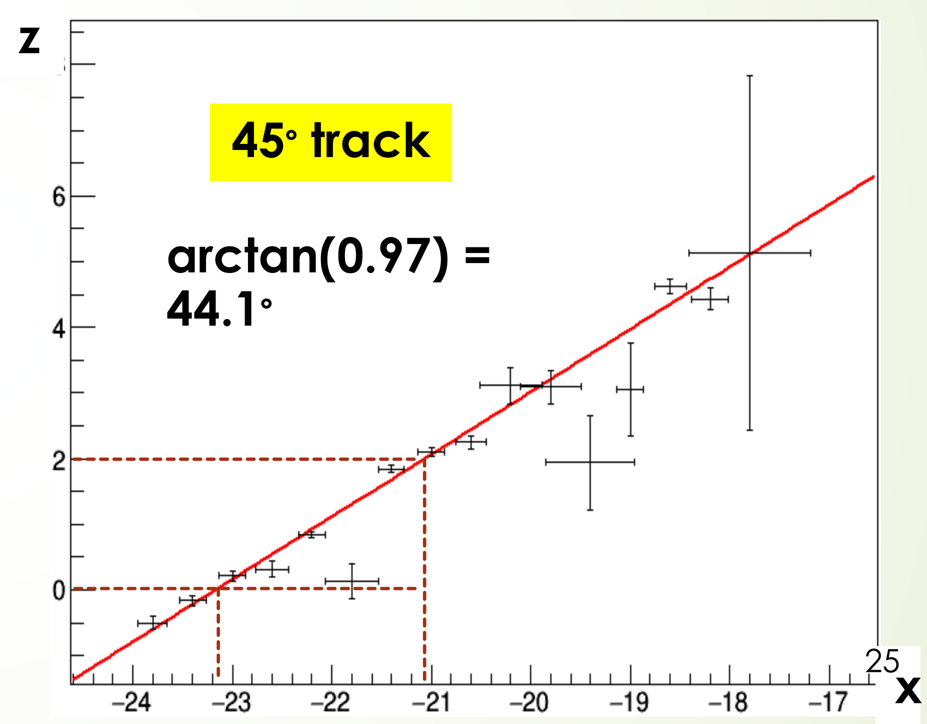
μ-RWELL in micro-TPC mode

Collaboration DDG-LNF & BESIII-CGEM (R.Farinelli (INFN-Fe) & L.Lavezzi (INFN-To))

NEW

$Ar:CO_2:CF_4$ 45:15:40 - HV=600V, Ed=0.5kV/cm, Gain ~10^4





CC and the μ-TPC mode with E_d= 0,5 kV/cm
Combined space resolution over a wide range of incidence angles well below 60μm

C-RWELL options (I)

Apart the standard option (**Option #1 – all embedded**) with amplification stage, DLC layer and r/out all embedded as in the planar micro-RWELL

Option #2 (= *bare amplification stage*):

- 1-D (2-D) r/out on Polyimide or ultra-thin flexible FR4 with DLC single-layer on kapton coupled with the r/out through a thin insulating layer (pre-preg 106 like)

  plus

- Single-amplification stage realized with a simple GEM foil with copper only on one side

Option #3 (= *bare readout stage*):

- 1-D (2-D) r/out on Polyimide or ultra-thin flexible FR4

  plus

- Standard RWELL single-amplification stage with DLC single-layer on the back-side coupled with a thin insulating layer (pre-preg 106 like)

C-RWELL options (II)

Comparison among the three C-RWELL options

- **Option #1:** openable, cleaning of the amplification stage possible, amplification stage not replaceable (it's embedded with the PCB r/out)
- **Option #2:** openable, cleaning of the amplification stage possible, amplification stage easy to be replaced (it's a bare GEM foil !!!)
- **Option #3:** openable, cleaning of the amplification stage possible, amplification stage replaceable

Further **advantage of Option 2 wrt the Option 3 and Option 1** is that the **manufacturing at ELTOS is completely decoupled** from the etching of the Polyimide of the amplification stage by Rui or TECHTRA.

In addition for the **Option 2** the simplification of the work at ELTOS and TECHTRA (or Rui) is maximized. As consequences the **costs should be minimized.**

C-RWELL tentative plans for 2019-2020

2019:

- **Design of the C-RWELL assuming**
  - the use of the Cathode and GEM3 molds of BESIII CGEM Layer1
  - maximum size (650x750 mm^2) of the PCB r/out at ELTOS (Opt. 1 & Opt.3)
  - mechanical test: Polyimide vs flexible-thin FR4 PCB

  LNF: gerbers of r/out, ampli-stage, drift-cathode+Polyimide vs flexible-thin FR4 PCB
  Ferrara: detector mechanical design and modifications of the molds

- **study & optmization of a 2-D readout** μ-RWELL (charge-sharing problem) , with small planar prototype construction and test beam at Mainz/Desy.

  LNF: gerbers of r/out, ampli-stage, drift-cathode and construction
  Ferrara: test beam and data analysis

2020:

- **Construction/test of the C_RWELL**

  LNF: construction of the readout + amplification stage depending on the Option
  Ferrara: construction of the cathode , test with APV at Mainz/Desy?

Funds requests

2019:

• Construction of a 2-D readout µ-RWELL:	4000 € (LNF)
• Modifica meccanica molds	3000 € (Ferrara)
• Test Polyimide vs flexible-thin FR4 PCB	2000 € (LNF)
• missioni per contatti (CERN/ELTOS)	3000 € (50%LNF+ 50%Ferrara)
• Missioni per test beam	4000 € (50%LNF+ 50%Ferrara)

2020:

• Construction of readout + amplification stage	15000 € (LNF)
• Construction of cathode	1000 € (Ferrara)
• Detector mechanics + cathode	3000 € (Ferrara)
• Missioni per contatti (CERN/ELTOS)	3000 € (50%LNF+ 50%Ferrara)
• Missioni per test beam	4000 € (50%LNF+ 50%Ferrara)