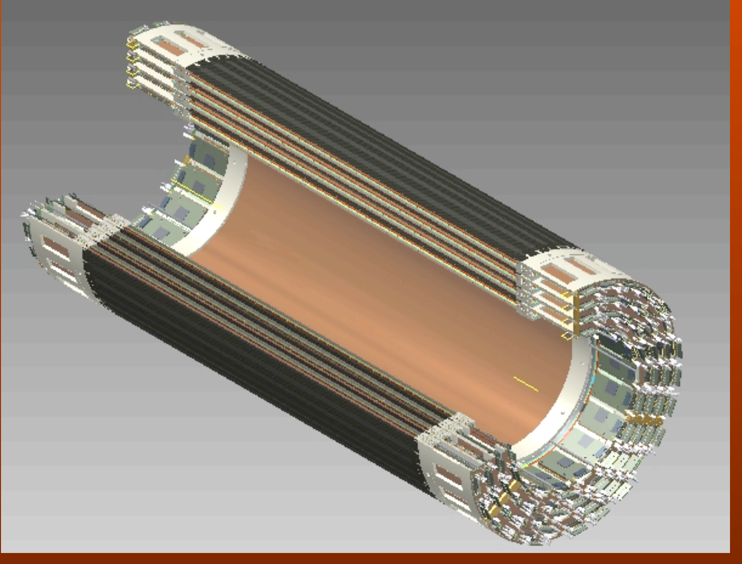
PROGRESS ON THE CGEM PROPOSAL

BESIII Italian Collaboration

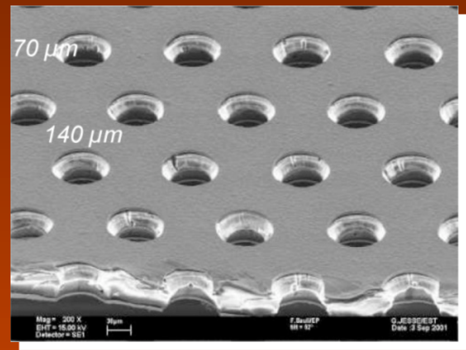


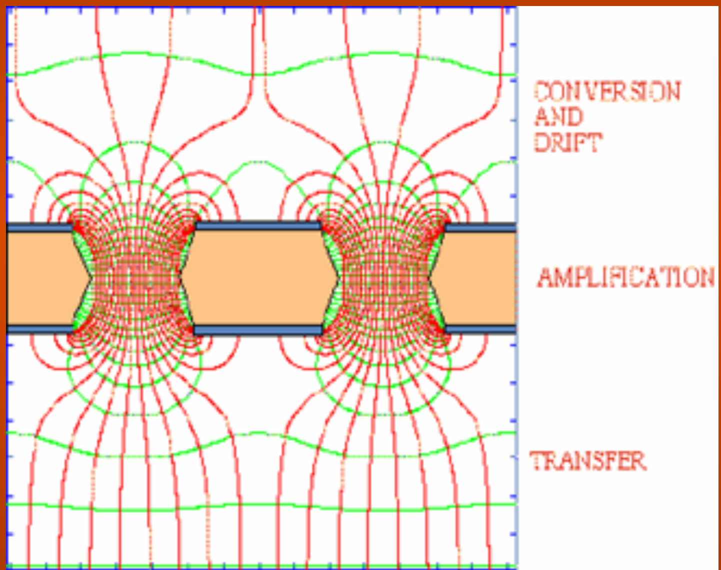
Summary

- Short review of the KLOE2 CGEM
- CGEM in BESIII
- Analog readout
- Resolutions: preliminary results
- BESIII gas mixture
- Cost, timing, prototype
- LNF workshop in october

GEM: principle of operation

The GEM (Gas Electron Multiplier) [F.Sauli, NIM A386 (1997) 531] is a thin (50 μm) metal coated by a kapton foil perforated by a high density of holes (70 μm diameter, pitch of 140 μm) → standard photo-lithographic technology.

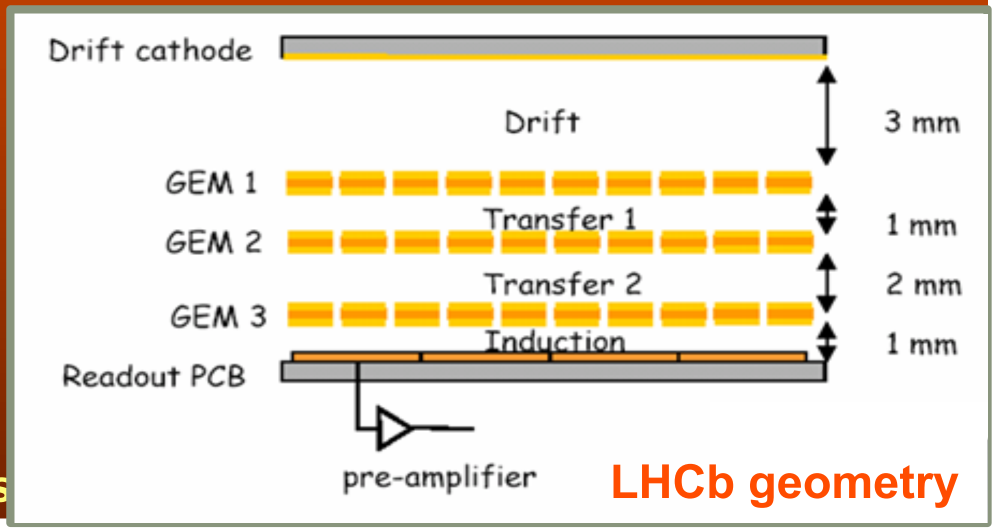




By applying 400-500 V between the two copper sides, an electric field as high as ~100 kV/cm is produced into the holes which act as multiplication channels for electrons produced in the gas by a ionizing particle.

Gains up to 1000 can be easily reached with a single GEM foil. Higher gains (and/or safer working conditions) are usually obtained by cascading two or three GEM foils.

A Triple-GEM detector is built by inserting three GEM foils between two planar electrodes, which act as the cathode and the anode.



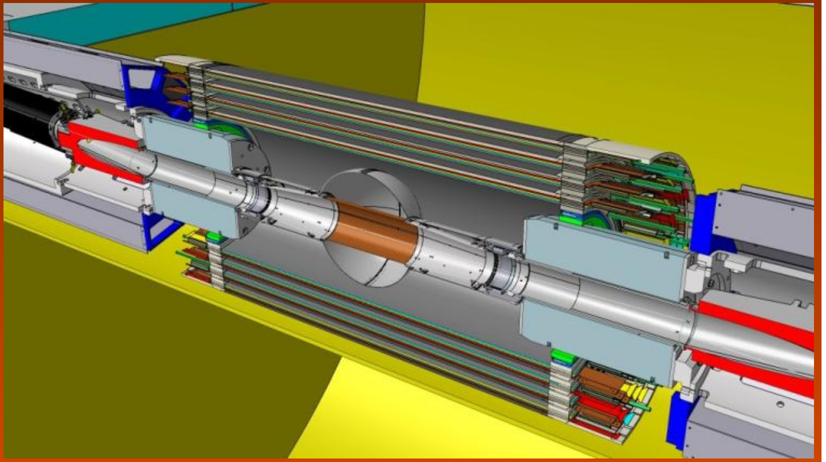
GEM detector features

- **flexible geometry** → arbitrary shape: rectangular, cylindrical …
- **ultra-light structure** → very low material budget: <0.5% X0/chamber
- **gas multiplication separated from readout stage** → arbitrary readout pattern: pad, strips (XY, UV), mixed …
- **high rate capability:** >50 MHz/cm2
- **high safe gains:** > 10^4
- **high reliability:** low discharge, $P_d < 10^{-12}$ per incoming particle
- **rad hard:** up to 2.2 C/cm^2 integrated over the whole active area without permanent damages (corresponding to 10 years of operation at LHCb1)
- **high spatial resolution:** down to 60µm (COMPASS with analog readout **Nucl.Phys.Proc.Suppl. 125 (2003) 368-373**)
- **good time resolution:** down to 3 ns (with CF_4)

KLOE-2 Inner Tracker

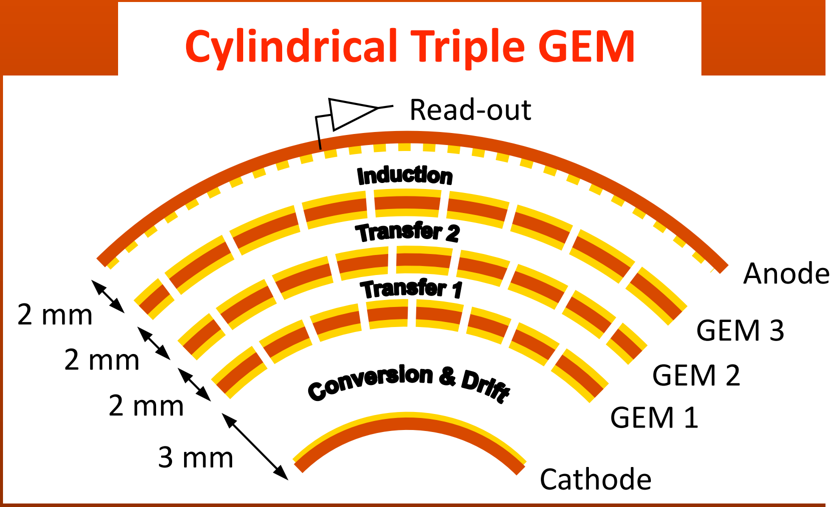
To improve vertex reconstruction of **K_s , η and η'** and **K_s- K_L interference measurements:**

1. **$\sigma_{r\varphi}$ ~ 200 μm and σ_z ~ 350μm**
2. **low material budget**: < 2% X_0



Cylindrical GEM detector is the adopted solution

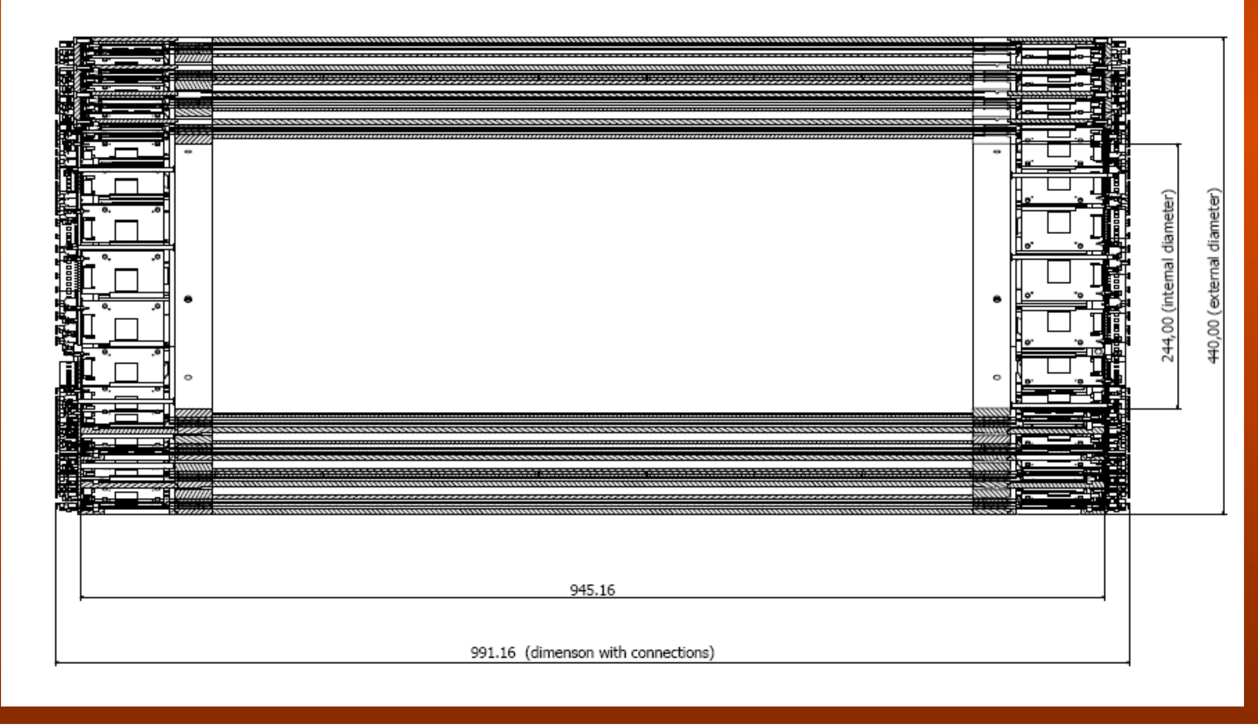
- **4 CGEM** layers :from IP to DC Inner wall
- **700 mm** active length
- **XV strips-pads readout (~40° stereo angle)**
- **<2%X_0** total radiation length in the active region



$K_S \rightarrow \pi^+ \pi^-$ vertex resolution **will improve of about a factor 3** from present **6mm**

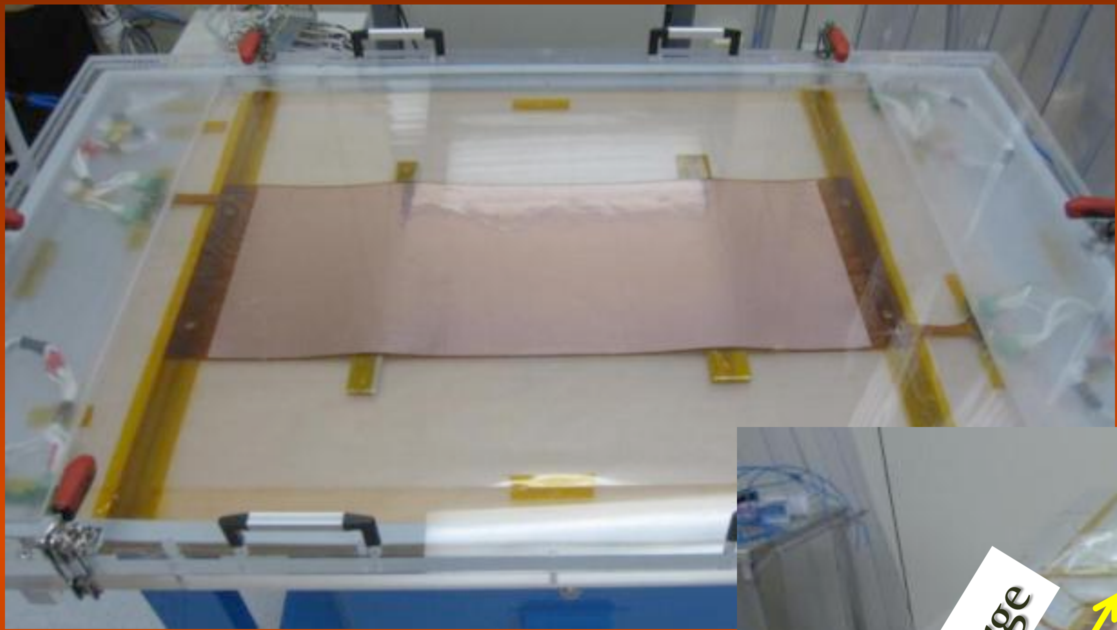
KLOE - IT dimensions

	Ext diam (mm)	Int diam (mm)
Layer 1	290	244
Layer2	340	294
Layer3	390	344
Layer4	440	394

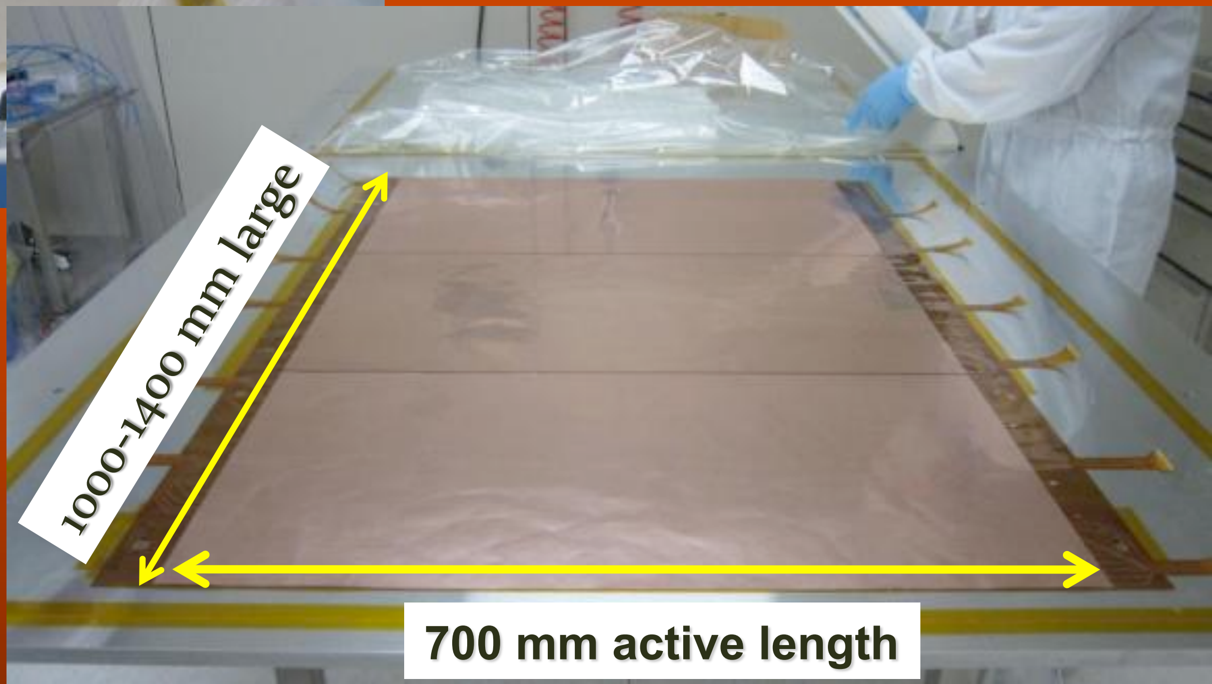


Total lenght 945,16 mm + connectors ~ 991,16 mm

The Large GEM Foils



Before gluing each GEM foil, it is tested with HV (up to 600V) in a N_2 flushed plexiglass box, to reduce RH below 10%



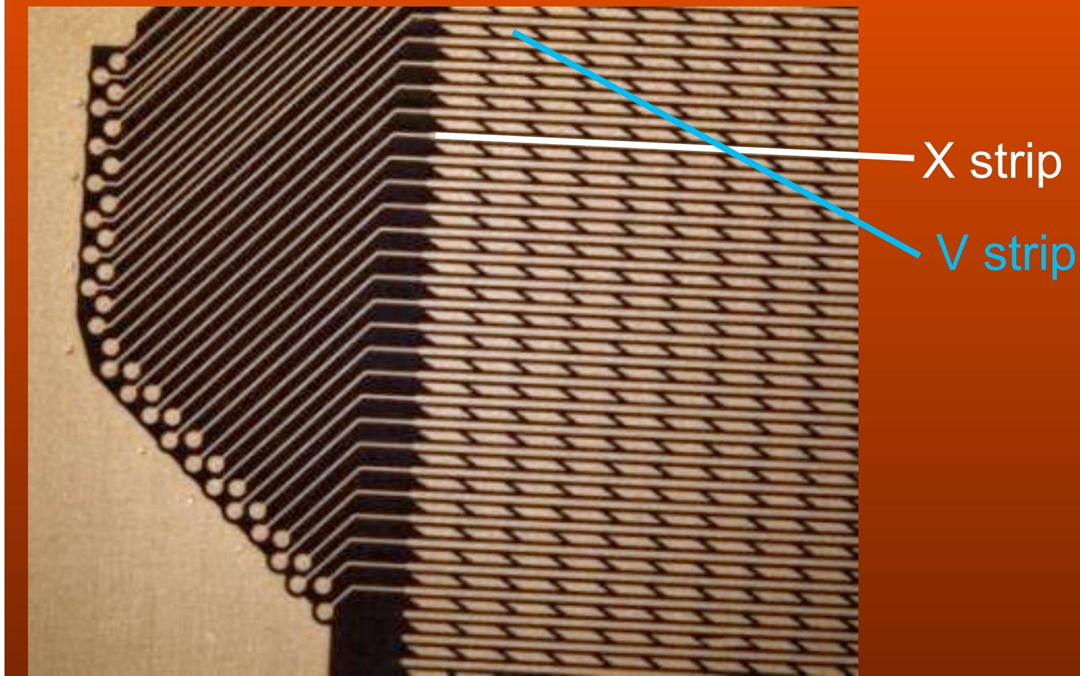
3 GEM foils spliced and envelopped in a vacuum bag

Anode Readout

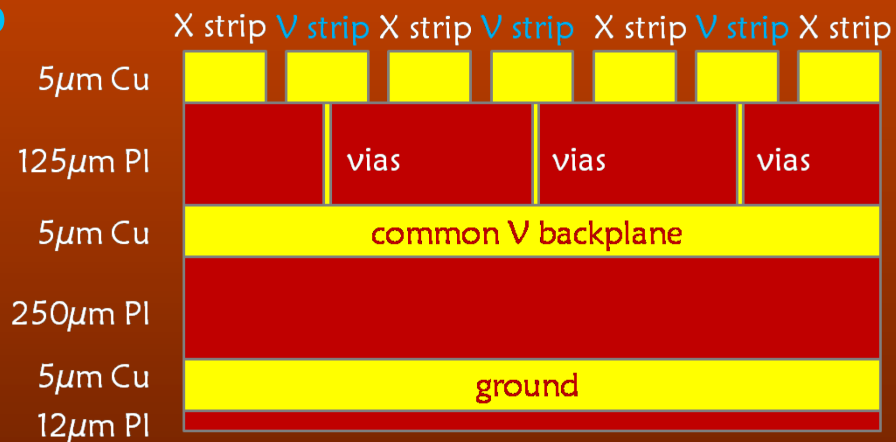
2-D readout with XV strips on the same plane

X pitch 650μm → X res 190μm

V pitch 650μm → Y res 350μm



Multilayer Kapton circuit realized at CERN

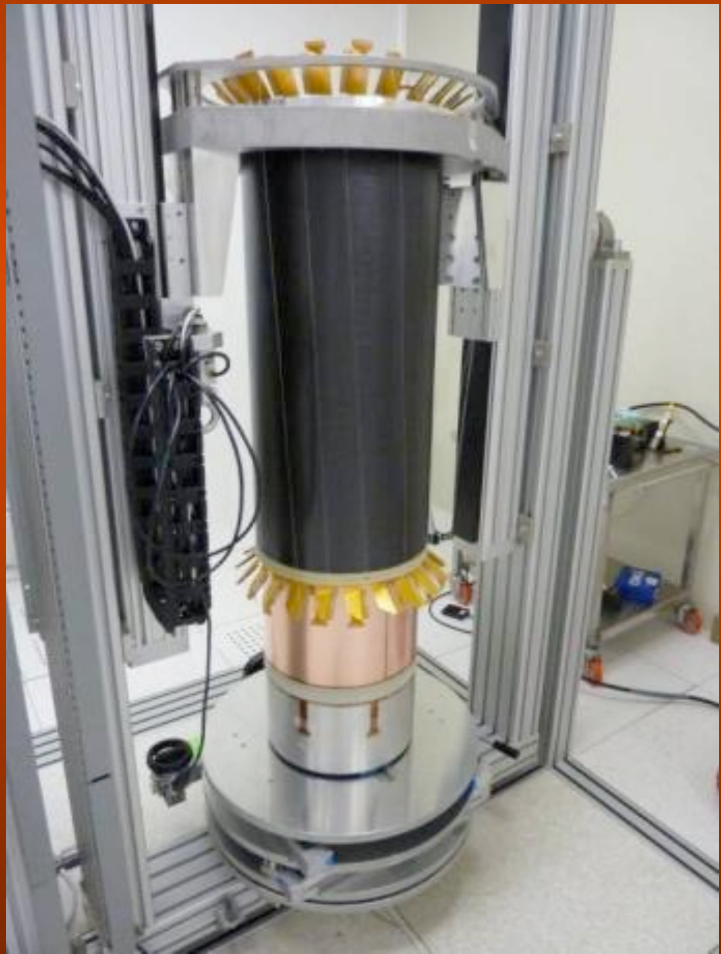


Costruction toolings (I)

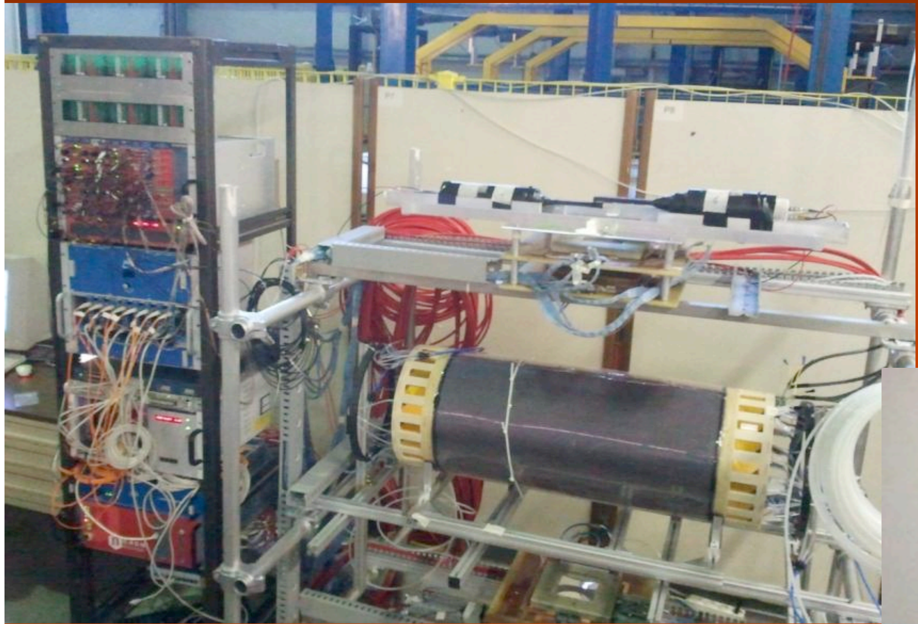
Special molds for cylindrical electrodes (cathode, GEMs, anode readout) constructions.
N.5 molds per layer (total 20 molds)

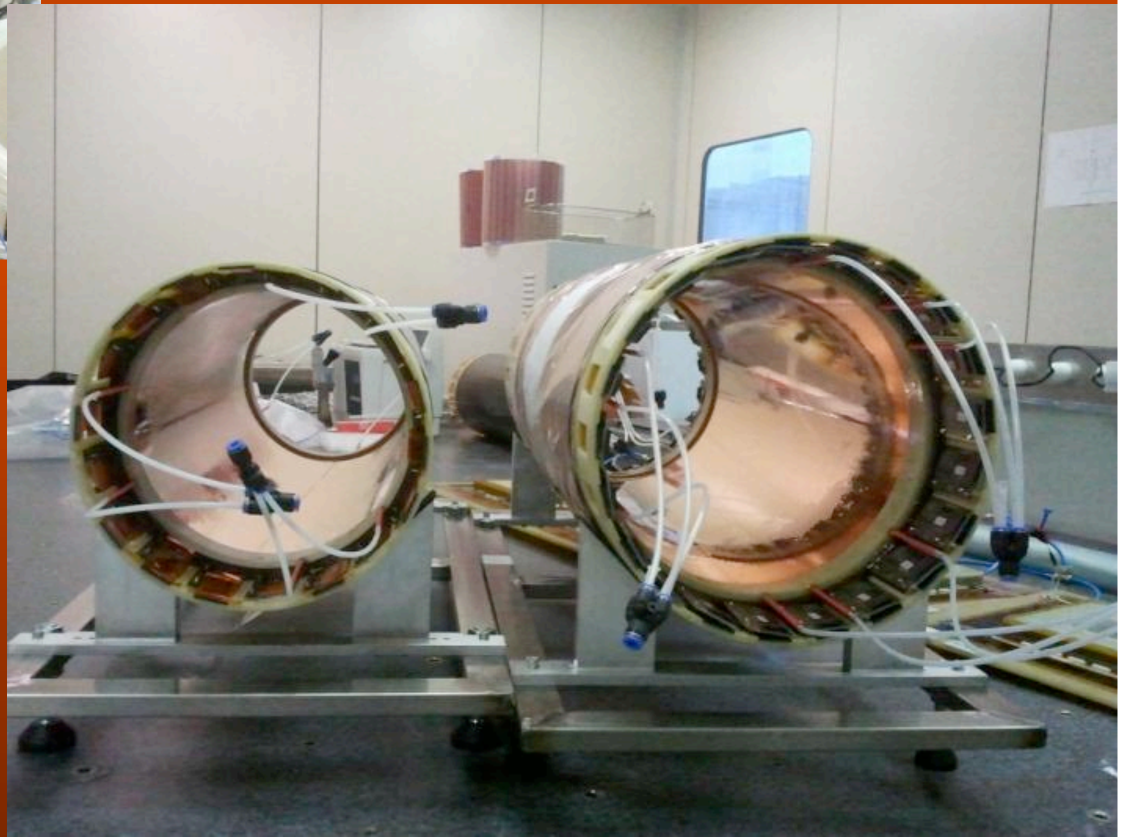
Costruction toolings (II)

Vertical Insertion System for the cylindrical electrodes insertion and final detector assembly



Layer 1 & Layer2

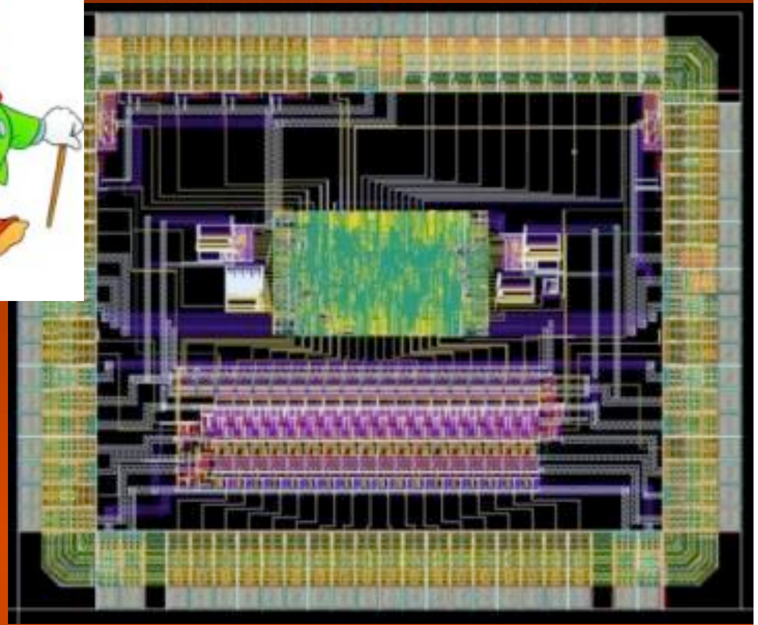




The installation in KLOE is foreseen by the end of 2012

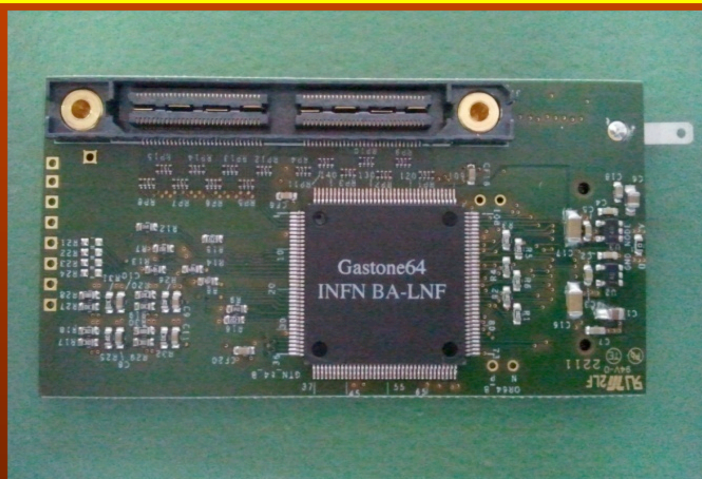
GASTONE: the IT dedicated FEE chip

Sensitivity (pF)	20 mV/fC
Z_{IN}	400 Ω (low frequency)
C_{DET}	1 – 50 pF
Peaking time	90 – 200 ns (1-50 pF)
Noise (erms)	800 e^- + 40 e^-/pF
Channels/chip	64*
Readout	LVDS/Serial
Power consum.	≈ 0.6 mA/ch

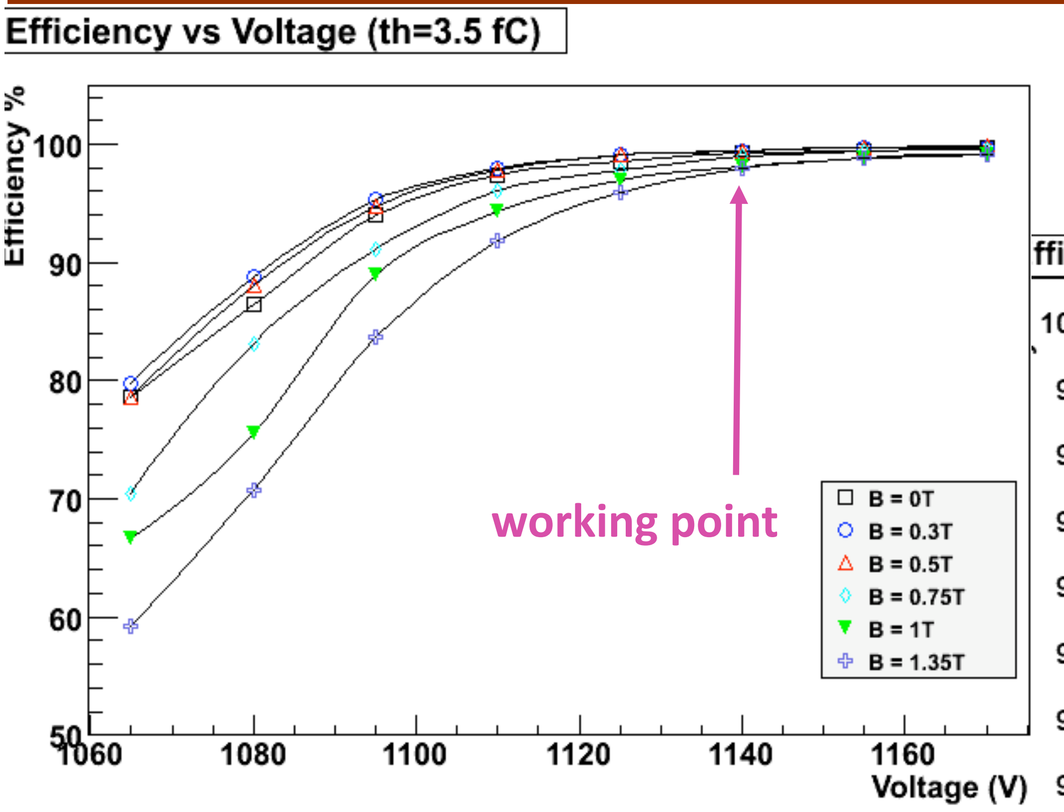


- **Mixed analog-digital circuit** (KLOE-2 dedicated);
- **Low input equivalent noise, low power consumption** and **high integrated chip;**
- 4 blocks:
  - **charge sensitive preamplifier**
  - **shaper**
  - **leading-edge discriminator** (prog. thr.)
  - **monostable** (stretch digital signal to match the trigger timing of the experiment)

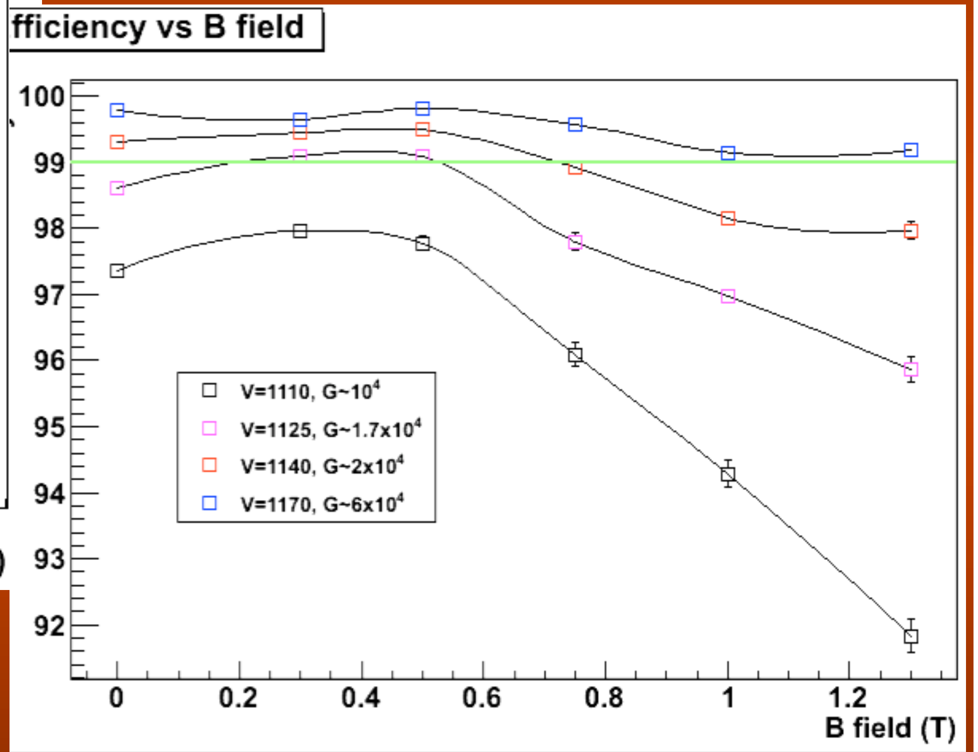
0.35 CMOS technology- no Rad-Hard



Efficiency vs B field and Gain

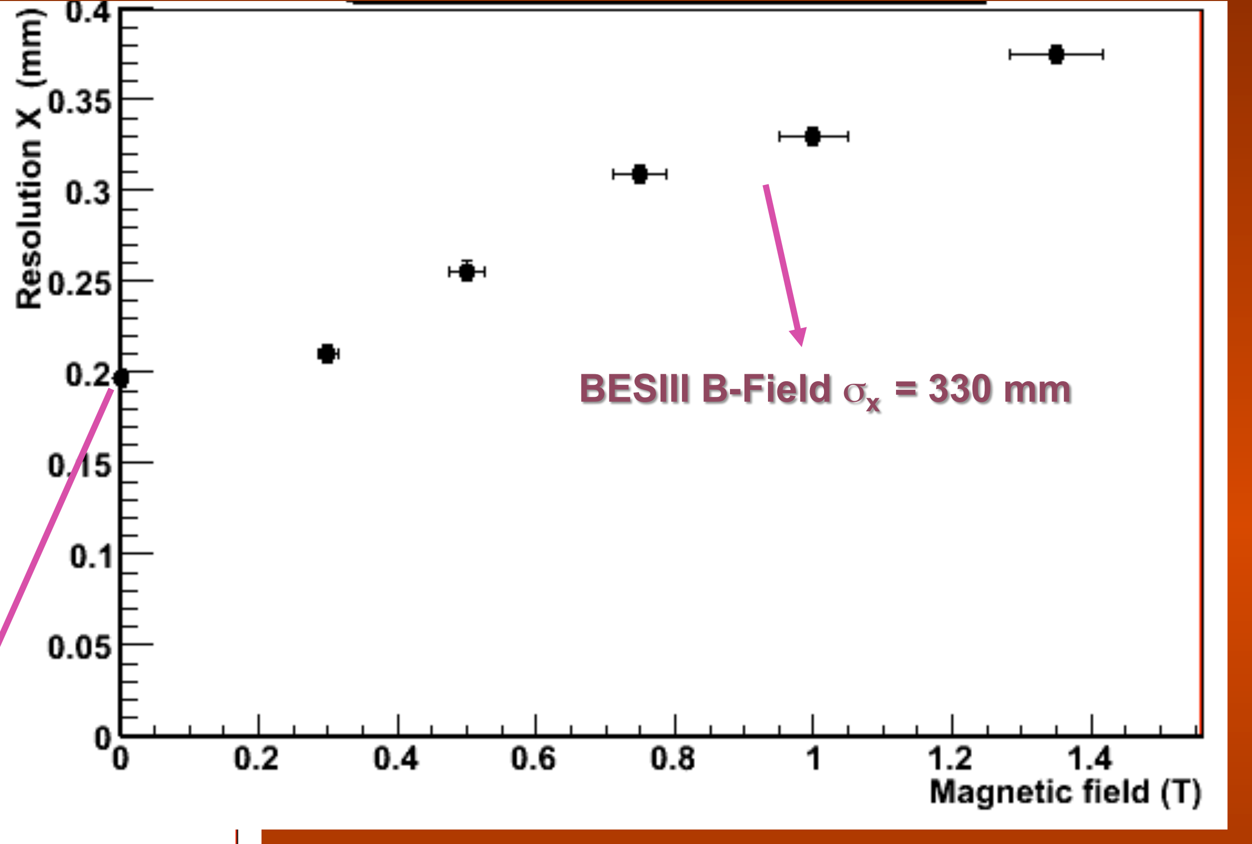


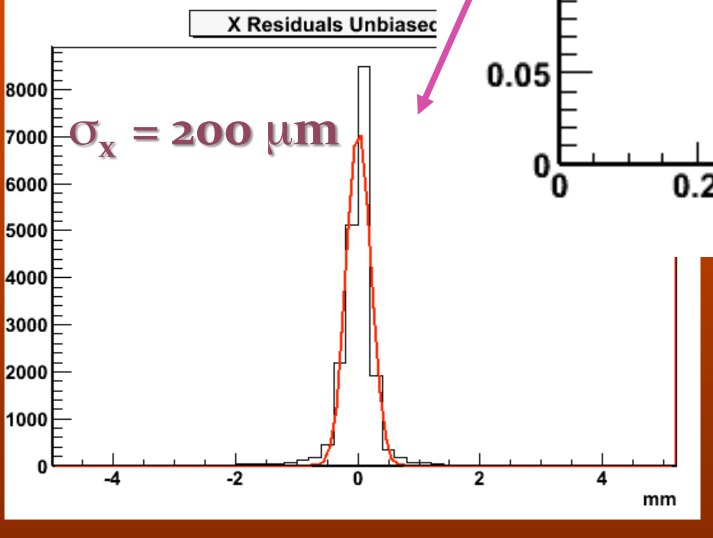
At working point, V_G = 1140 Volt, G~2x10^4, **efficiency drop is negligible for B < 0.5 T**



The **increase of the magnetic field,** increasing the spread of the charge over the readout strips (less charge is collected by each single pre-amp channel) results in an efficiency drop, thus **requiring for higher gain to efficiently operate the detector.**

Spatial resolution: X-view (r-φ)

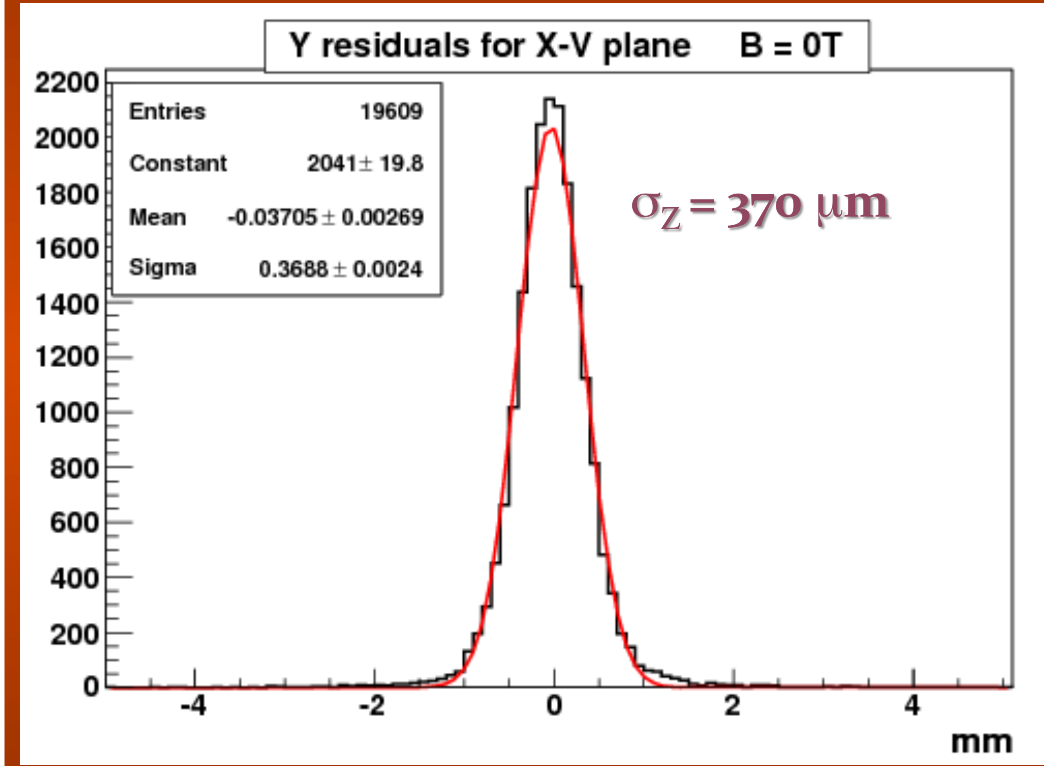


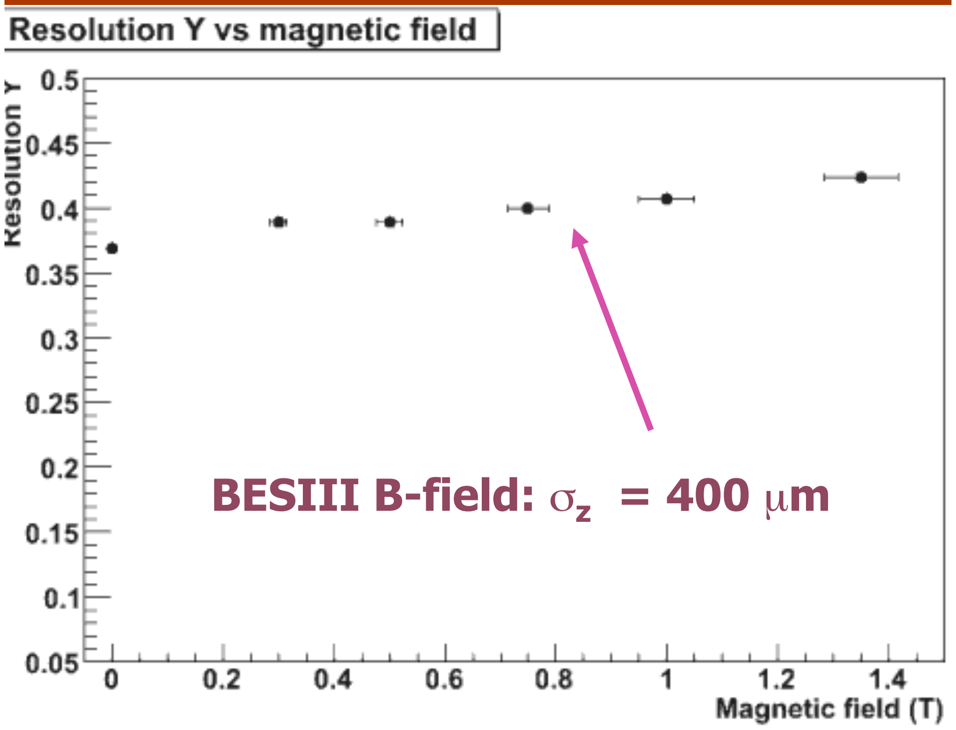


Pitch = 650 μm
Much better if lower pitch or analog readout
(COMPASS σ_x ~ 50 μm)

Spatial resolution : Z-coordinate

The Z coordinate is determined from the crossing of X (r-φ) and V views
(Better z resolution , if lower pitch or analog readout)





In BESIII: σ_z ~ 300 μm
(if analog readout ~ 130 μm)

A Cylindrical_GEM at BESIII

in case a new inner chamber is needed ?

- The manifacture of a Cylindrical GEM, which fulfills many BESIII needs, is on going at LNF and will be installed in KLOE-2 by the end of this year

- BESIII inner chamber is a bit smaller:
  - makes a Cylindrical GEM easier to be built,
  - enough space to allocate 4 triple-GEM,
  - equivalent to the present 8 layers,
  - however, new tools (molds) are needed

BESIII GEM vs KLOE2 possible improvements

- Expertise from KLOE2 and CERN
- Faster construction, if better molds technique
- Lower high voltage, if higher readout gain
- Better spatial res, if reduced pitch or analog readout (COMPASS analog readout σ_x = 46 μm)
- Less material budget

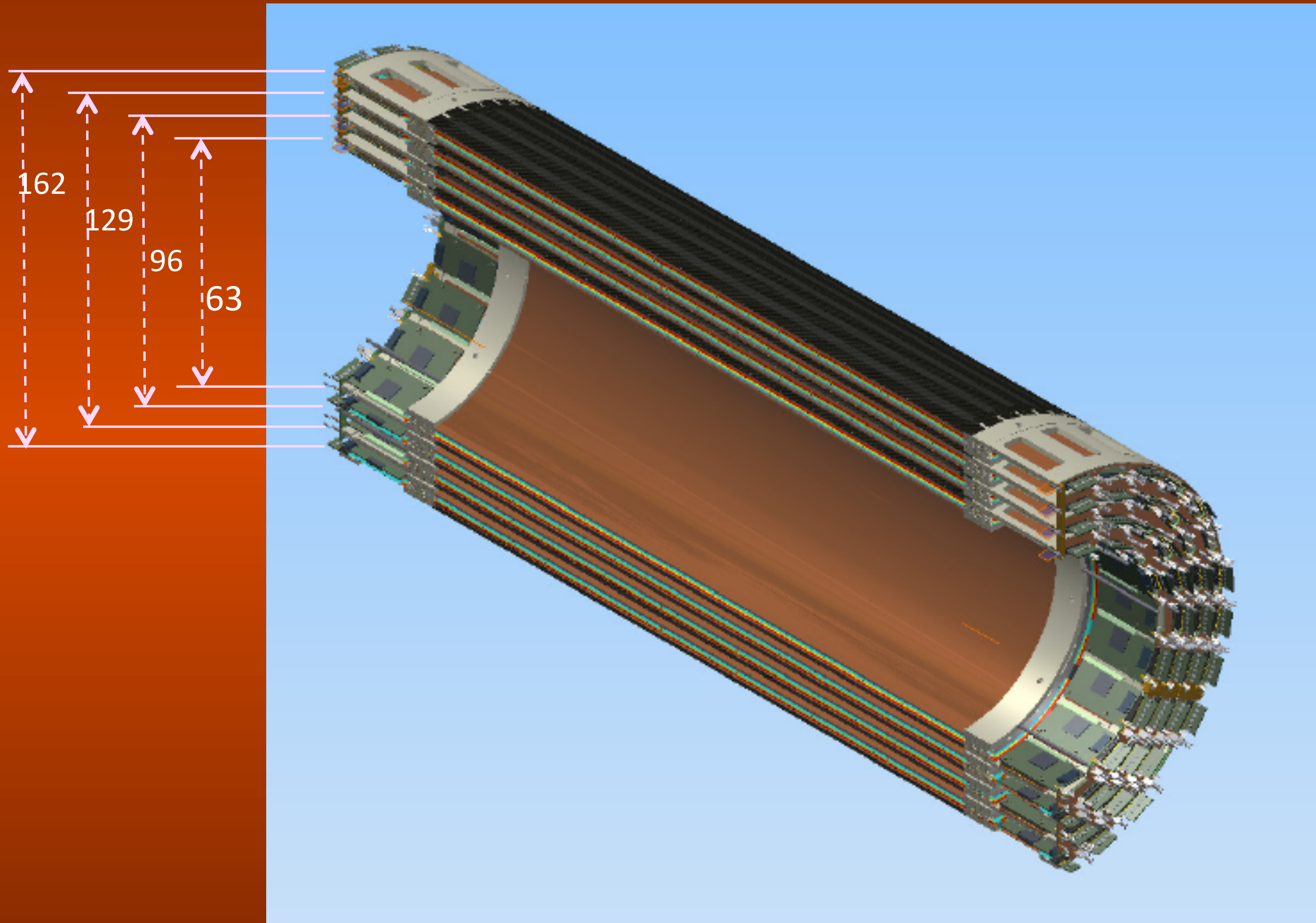
BESIII GEM possible geometrical parameters

Layer	Int.diam (mm)	Length (mm)	Foils
1	126		1
2	192		2
3	258		2
4	324	870	2

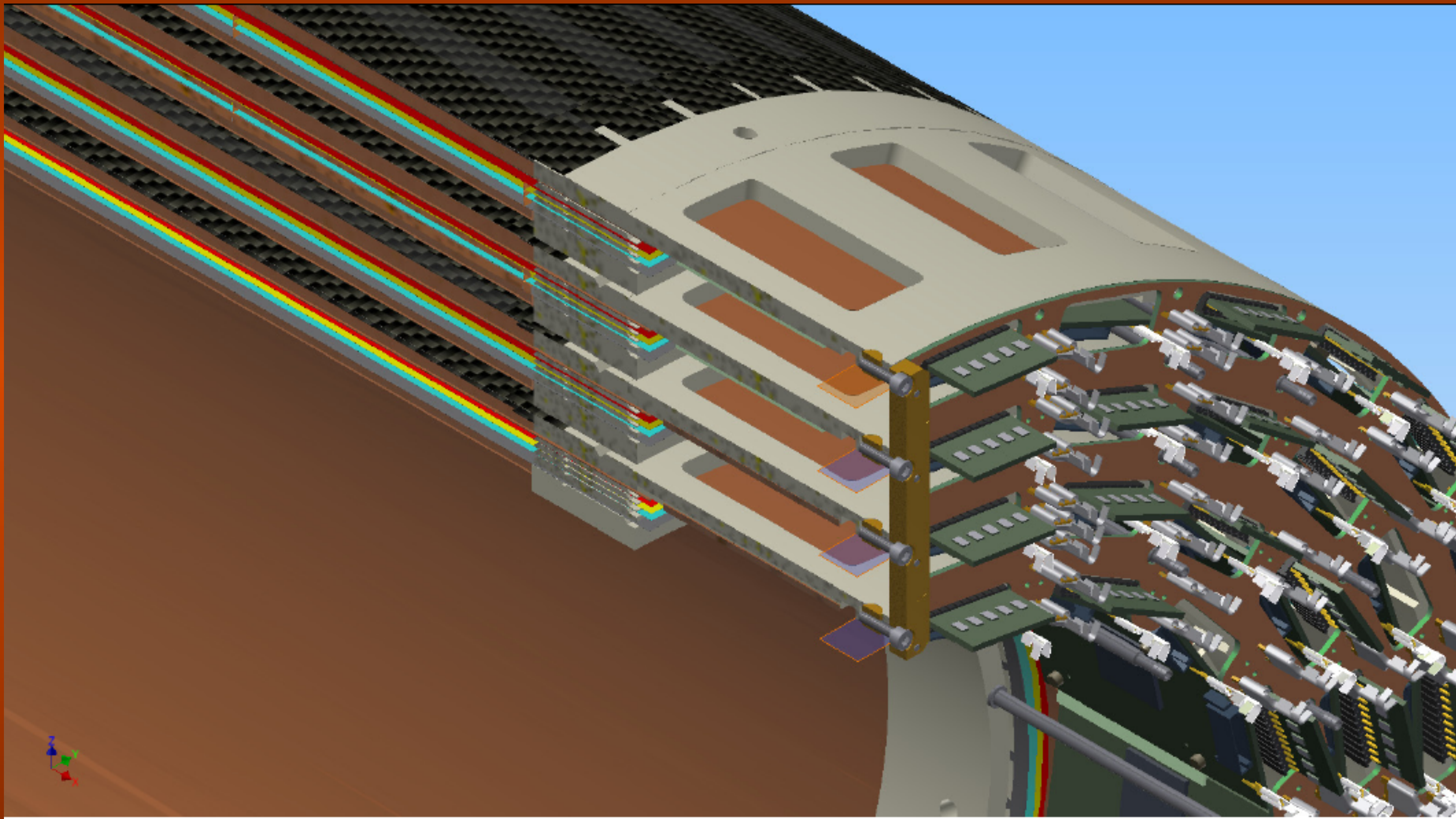
N. strips ~ 20000 (KLOE2 ~ 30000)

Stereo angle ~ 40^0 (like KLOE2)

Pictorial view of IT for BESIII



Zoomed view of electronics area



Compass spatial resolution by means analog readout

Pitch= 400 μm

σ_x ~ 50 μm

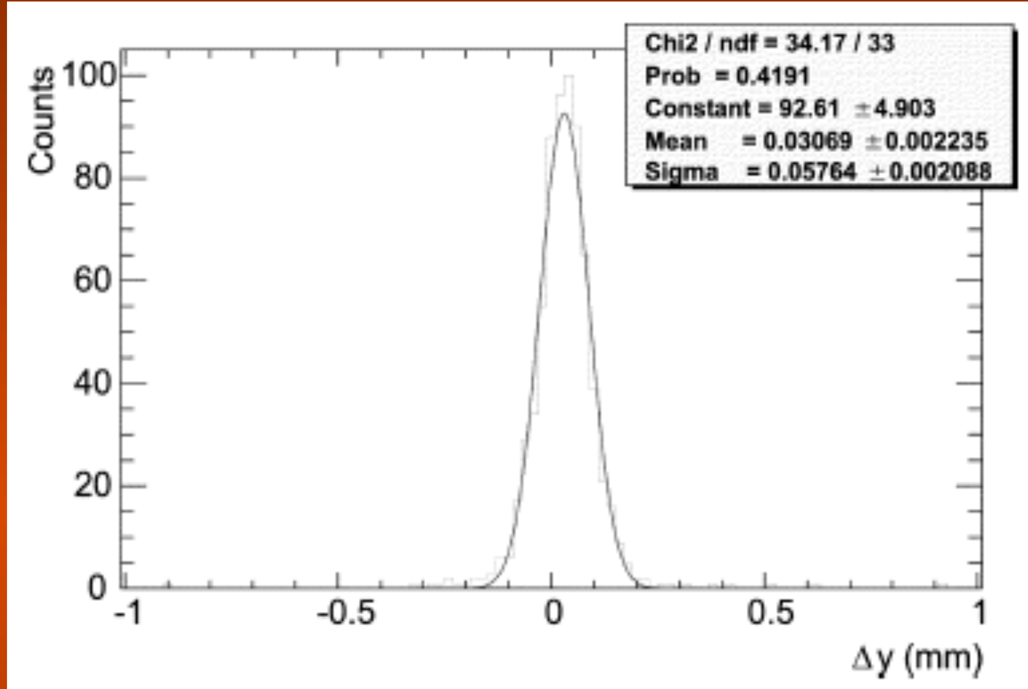


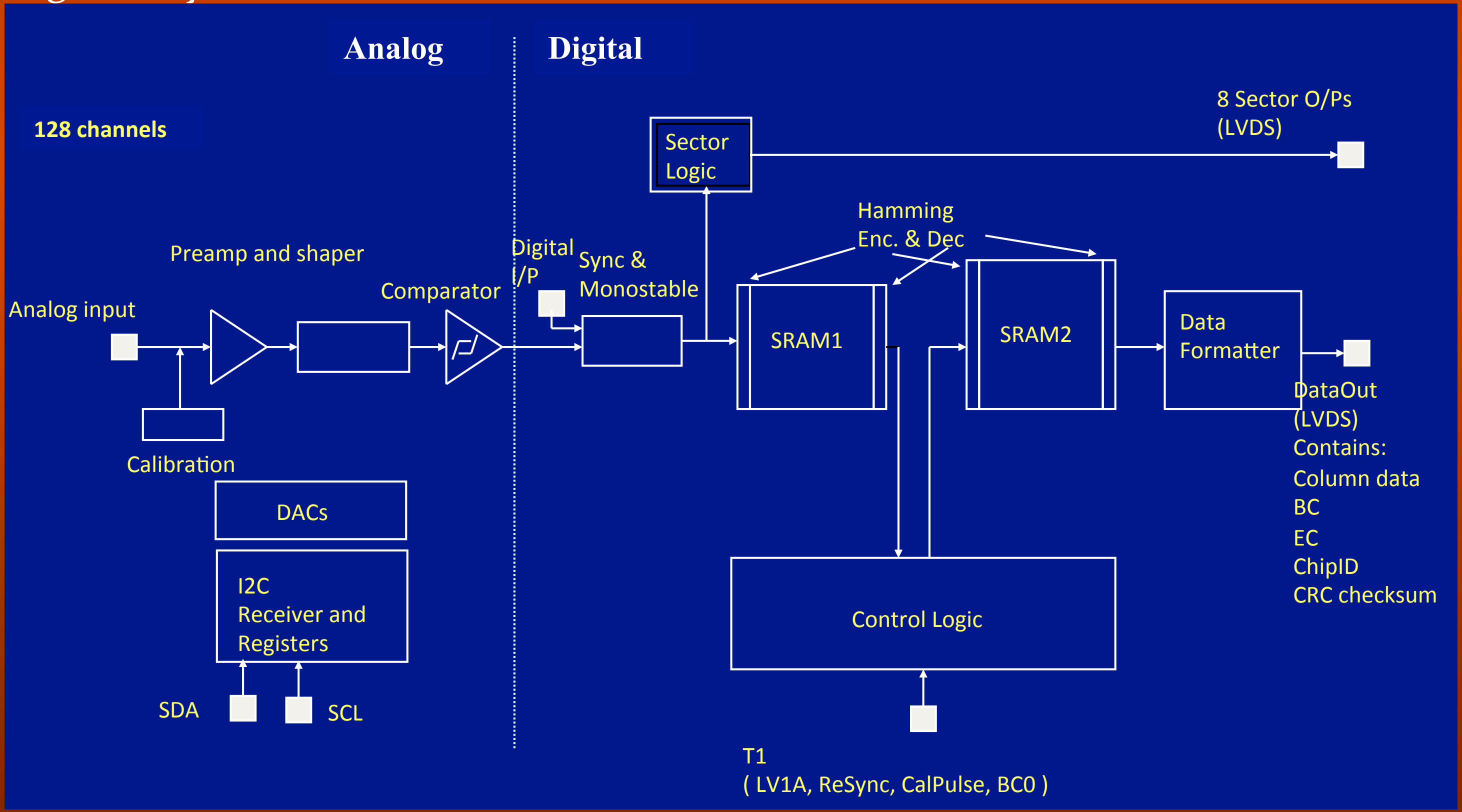
Fig. 17. Distribution of hit-residuals from the predicted track position.

From the distribution of hit-residuals relative to the predicted hit position, shown in Fig. 17, the spatial resolution of the detector can be deduced by deconvoluting uncertainties in the tracking and effects of multiple scattering. The resulting spatial resolution is calculated to be (46 ± 3) μm.

Cylindrical Gem based tracker instrumentation scenario

- Many activities are going on to develop new readouts for GEM based detectors In the framework of LHC experiments upgrades.
- One of them (VFAT3) looks very attractive as it foresees the possibility to measure the center of gravity to archive a good pitch resolution still maintaining a high data throughput (digital readout).
- The development is coordinated by Paul Aspell (CERN) and is finalized to the instrumentation of CMS end-caps GEM-based chambers
- The previous version (VFAT2) was designed for:
  - Trigger: provide programmable "Fast-Or" information for trigger generation
  - Tracking: Binary "hit" information for each of 128 channels

VFAT2-Block Diagram



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VFAT2 main features

Number of channels	128	
Front-end shaping time	22 ns	
ENC	~ 400 e + 50 e/pF	
Internal Calibration test pulse	-2 fC to 18.5 fC, LSB = 0.08 fC with σ(LSB) = 0.3fC	
Sampling frequency	40 MHz	
LV1A Latency	Up to 6.4 us	
Trigger rates	Up to 200kHz continuous trigger rate.	
Storage capacity	128 triggered events	
Slow Control interface	I^2C	
Testability features	Scan Chain, BIST, Probe pads, Auto test patterns, Auto Data Packet,	
Power Consumption	168 mW (Sleep Mode) 572 mW (Run Mode)	
	Properties for 300um silicon detectors	Properties for TOTEM GEM detectors
Dynamic range	± 18 fC	35 fC to 45 fC
Threshold range	18 fC	30 fC
Trim-DAC range	40% of threshold range	
Recovery time after large signals	1us after 100 fC (delta pulse)	

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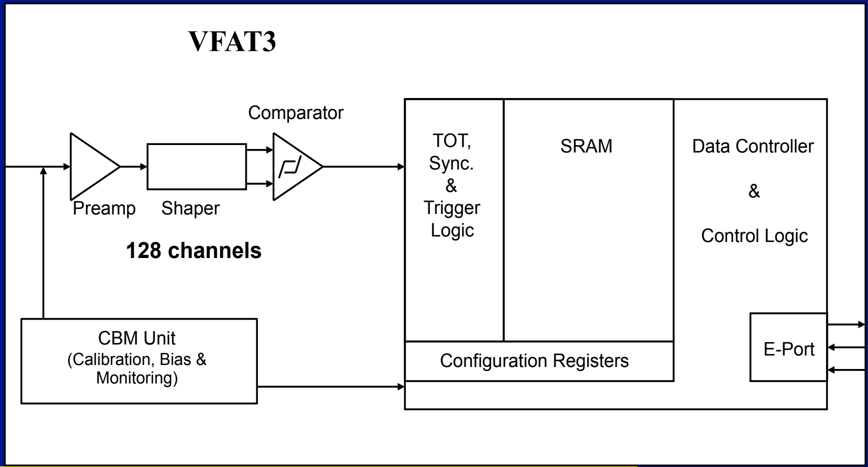
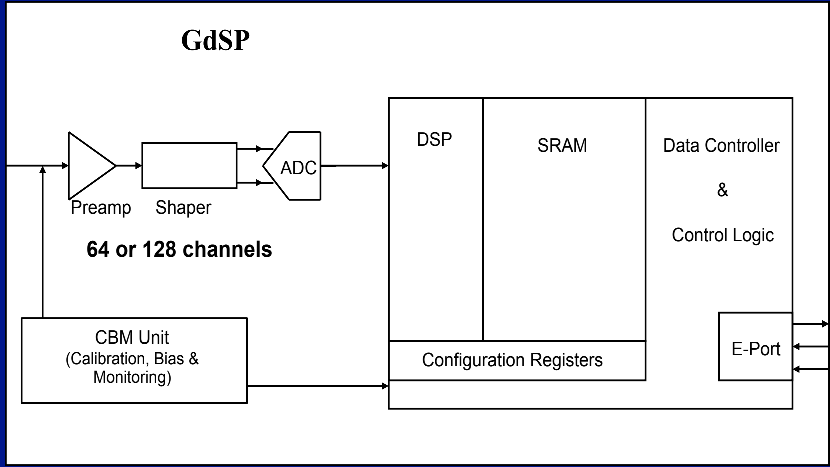
VFAT3/GdSP 2012-2015 ASIC design (IBM 130 nm CMOS)

2 Trigger & Tracking Front-end architectures considered.



OR



VFAT3 :

Front-end with programmable shaping time + comparator.

Internal calibration.

Binary memory

Interface directly to GBT @ 320Mbps.

Designed for high rate (10kHz/cm^2 depending on segmentation)

Design groups involved so far :
CERN
CEA Saclay
University of Bari
ULB (Brussels)

Approx. 8-10 man years of design work expected .

GdSP :

Similar to VFAT3 except has an ADC / channel instead of a comparator.

Internal DSP allows subtraction of background artifacts enabling a clean signal discrimination.

Centre of gravity a possibility to achieve a finer pitch resolution (if needed).

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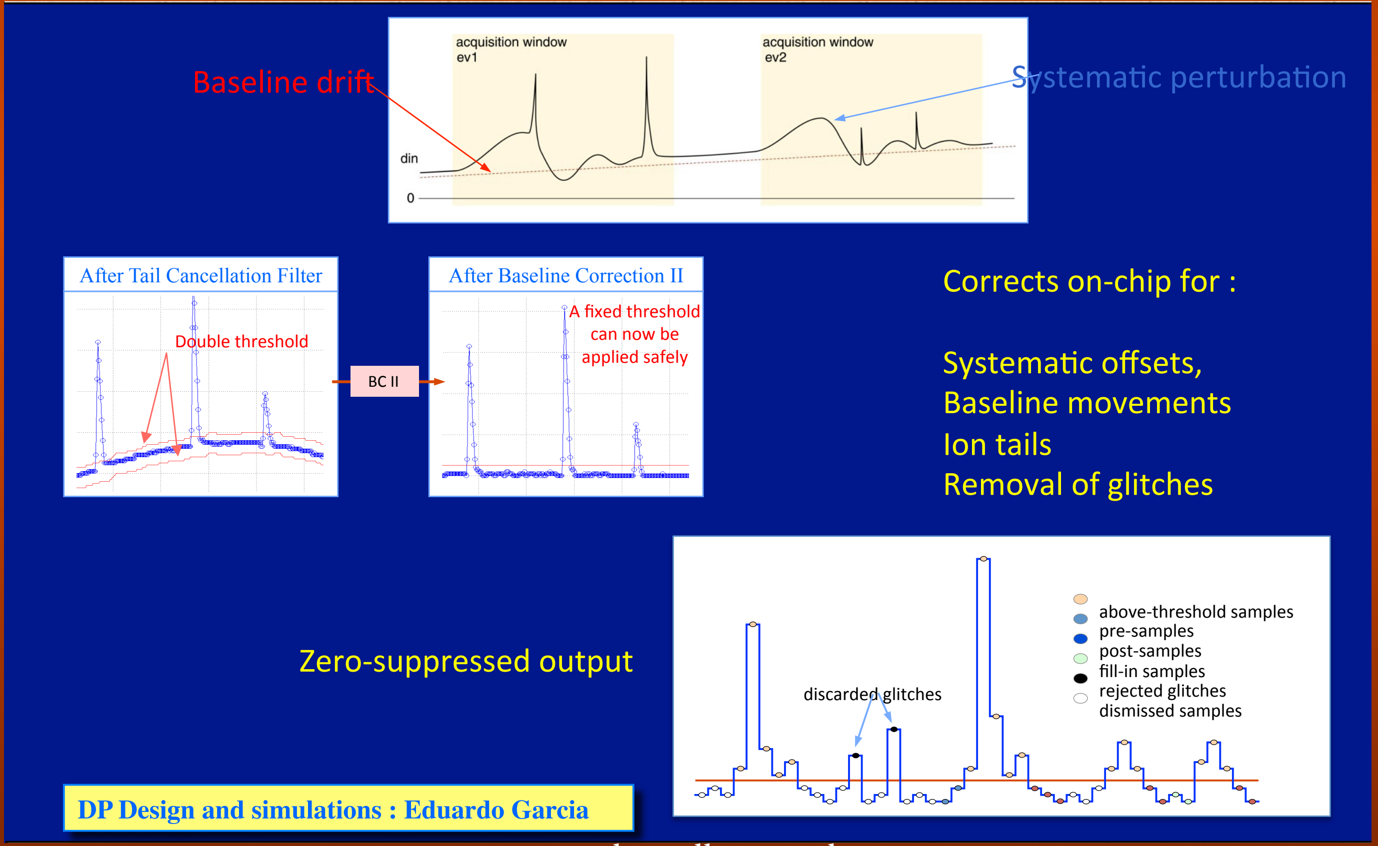
Digital processing advantages

Baseline correction 1	Removes systematic offsets that may have been introduced due to clock noise pickup etc. The SRAM is used for storage of baseline constants which can then be used a look-up table and subtracted from the signal.
Tail cancellation	Compensates the distortion of the signal shape due to undershoot.
Baseline correction 2	Reduces low frequency baseline movements based on a moving average filter.
Zero suppression	Removes samples that fall below a programmable threshold.



Corrects on-chip for :

Systematic offsets,
Baseline movements
Ion tails
Removal of glitches

DP Design and simulations : Eduardo Garcia

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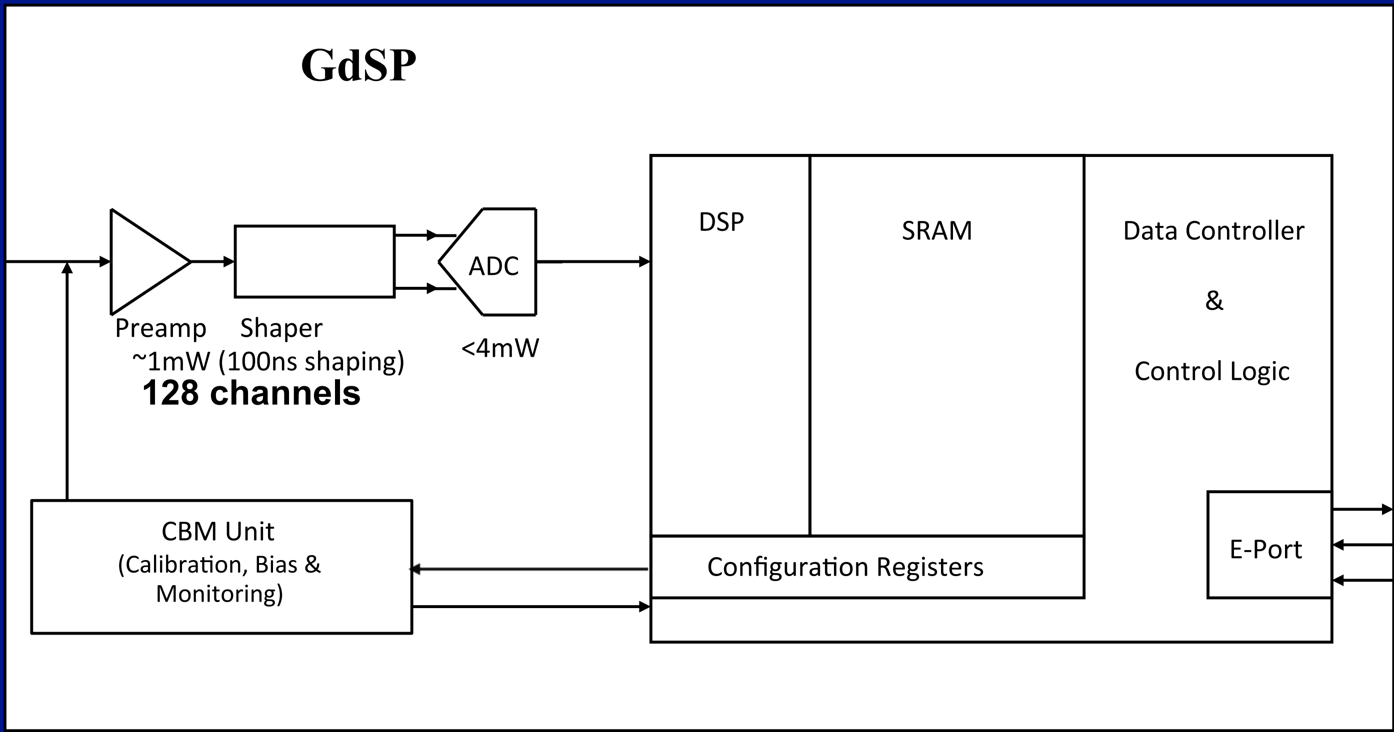
GdSP power consumption (estimation)



128 channels = Analog power 640mW + Digital power ~ some hundreds mW. Approx. ~900mW / chip.

Should be possible to get 7-8 mW/ch for everything on a 128 ch chip.

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Conclusions

- GdSP design looks very attractive as
  - it allows to archive a finer pitch resolution with respect to the standard digital readout (strip pitch/√12)
  - power dissipation estimation per channel is good (of the order of 10 mW) then simplifying cooling requirements.
- But …
  - Cylindrical tracker strip readout (X-V) parasitic capacitance is quite high (of the order of 100 pF) then both noise and shaping time effects must be carefully evaluated.
  - Digital readout is (at the moment) based on the GBT standard (GBT is currently foreseen for many LHC upgrades) then compatibility with exiting readout must be evaluated

For details on the design → paul.asplell@cern.ch

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Toy MC to achieve information on longitudinal resolution

Assuming:

- KLOE2 pitch (650 μm)

- Analog readout (extrapolated from COMPASS results)
- σ_x ~ 650/400 x 330/200 x 50 ~ 130 μm
  pitch B COMPASS
- σ_z ~ 370/200 x 130 ~ 250- 300 μm
  KLOE2
- s_{GEM} ~ 0.45 % X_o (like the inner cylinder)

- Simulation of Outer Chamber stereo wires
  and Inner Chamber or CGEM stereo resolutions, including ms

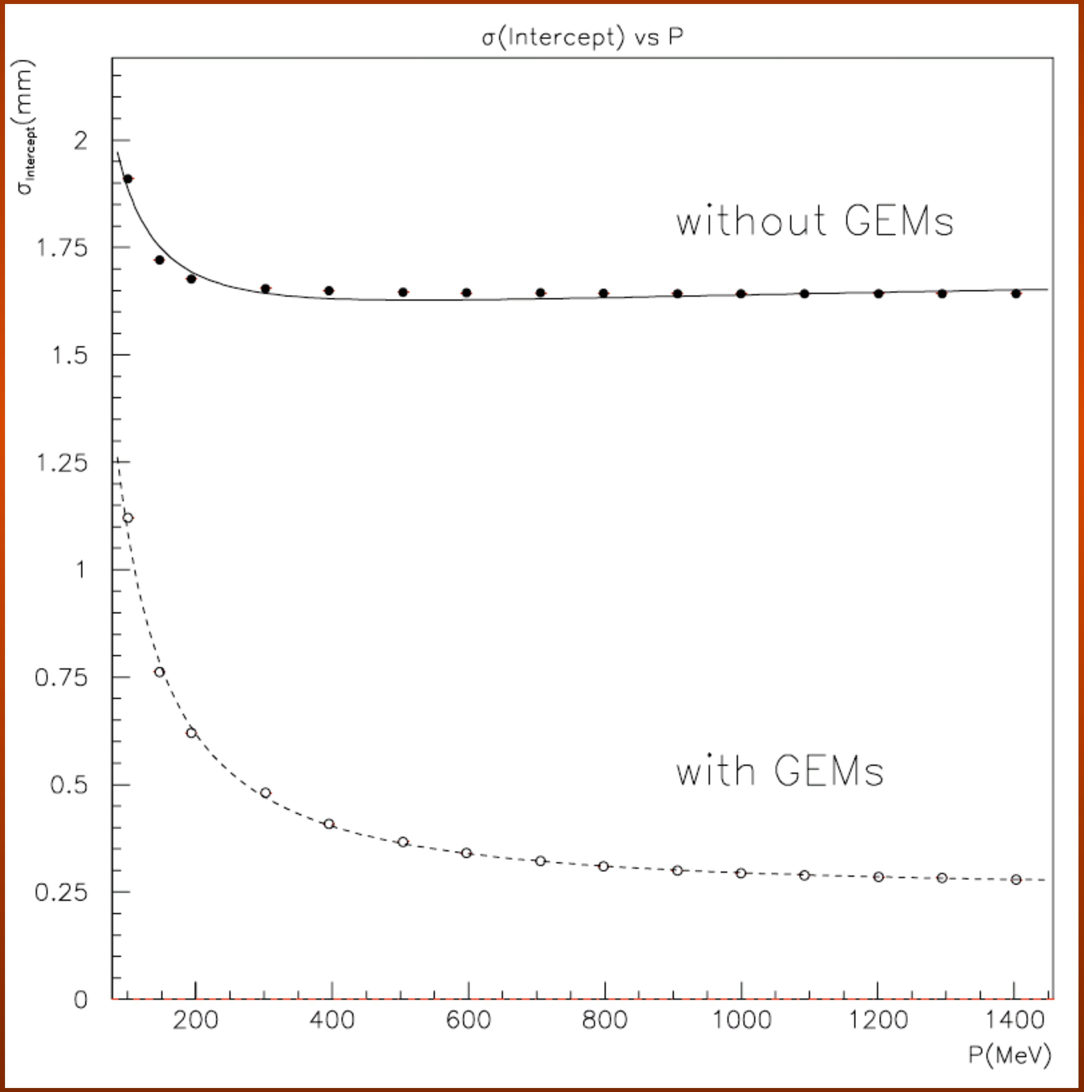
Table 1: Materials used for the assembly of a CGEM

Material	Details	Supplier/ Manufacturer
Epoxy glue (2 comp.)	Araldite AY103 + HD991 Ciba 2012 (for fast applications)	Ciba Geigy Ciba Geigy
Annular frames	3/2/1mm thick Permaglass	Resarm ltd (Be)
CFC support	CF(250μm)-Nomex(3mm)-CF(250μm)	Riba srl (It)
SF support	8mm thick Permaglass annular-flange for FEE/HV/gas-piping location	Nuova Saltini (It)
GEM foils	50μm thick kapton, 3-5μm Cu; 70μm hole dia., 140μm hole pitch	EST-DEM CERN Workshop
Cathode	3-5μm Cu on a 50μm thick kapton	EST-DEM CERN
Anode readout	3-5μm Cu on a 100μm thick kapton with XV strips-pad patterned	EST-DEM CERN
Gas pipes	4 mm out.-dia. brass tube	LNF-workshop
Gas outlet	6 mm out.-dia. rilsan Pa11 tube (not hygroscopic)	Tesfluid srl (Italy)

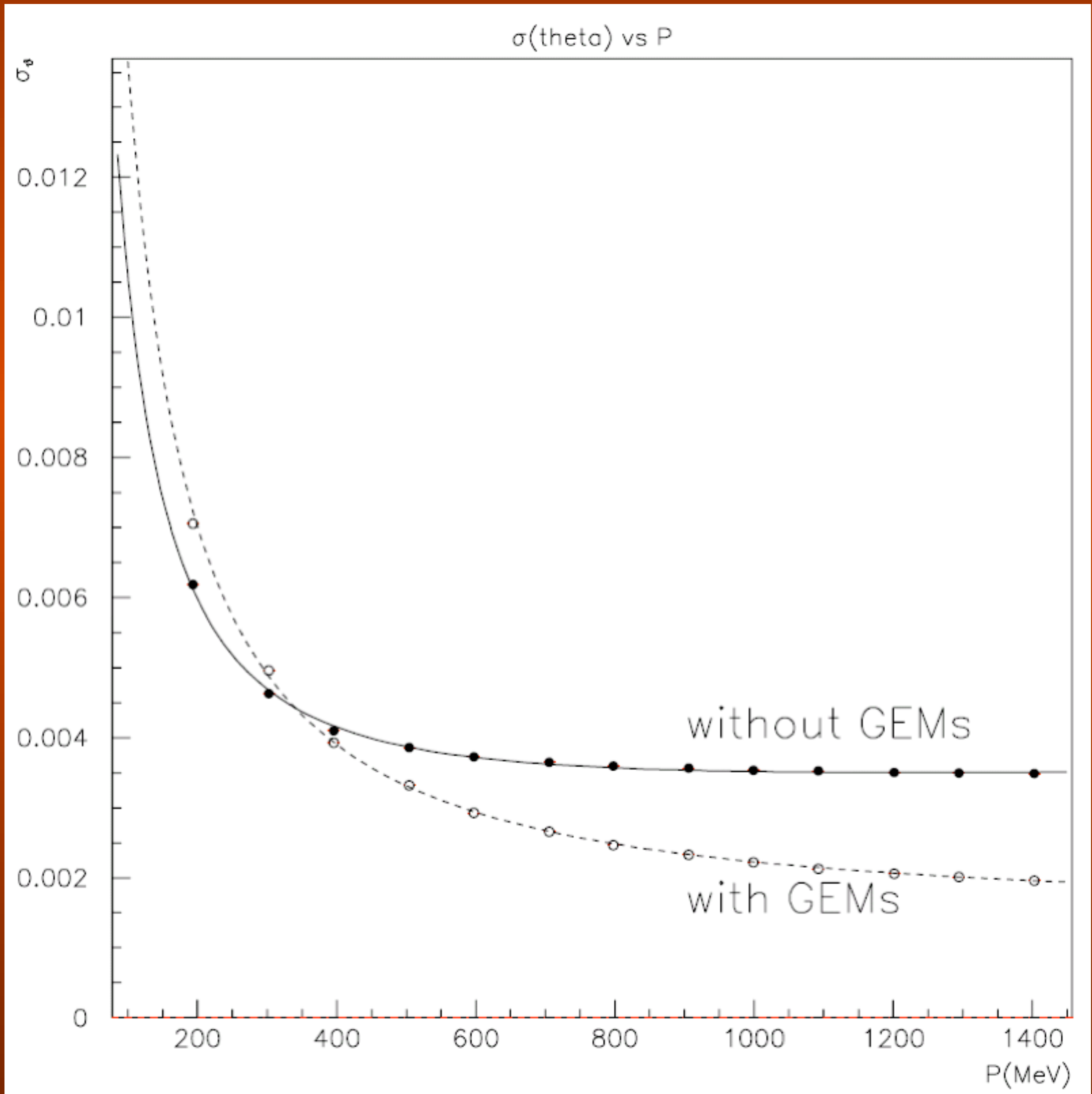
Table 2: Material budget for a CGEM layer detector (active area)

Component	times x material (X_0) x quantity	% of X_0
3 GEMs	Copper: 6× 2μm Cu (X_0=14.3mm) ×0.8 Kapton: 3× 50μm kapton (X_0=286mm) ×0.8	0.067 0.042 Total: 0.109
1 Cathode	Copper: 1× 2μm Cu ×1 Kapton: 1× 50μm kapton×1	0.013 0.017 Total: 0.030
1 Readout anode	Copper: 1× 2μm Cu ×0.95 Kapton: 2× 50μm kapton×1	0.013 0.034 Total: 0.047
1 Shielding	Aluminum: 1× 10μm Al(X_0=89mm)×1	Total: 0.011
1 Honeycomb	NOMEX: 1× 3mm Nomex(X_0=13125mm)×1	Total: 0.023
2 CF skins	CF: 2× 250μ CF(X_0=250mm)×1	Total: 0.160
		Total: 0.380

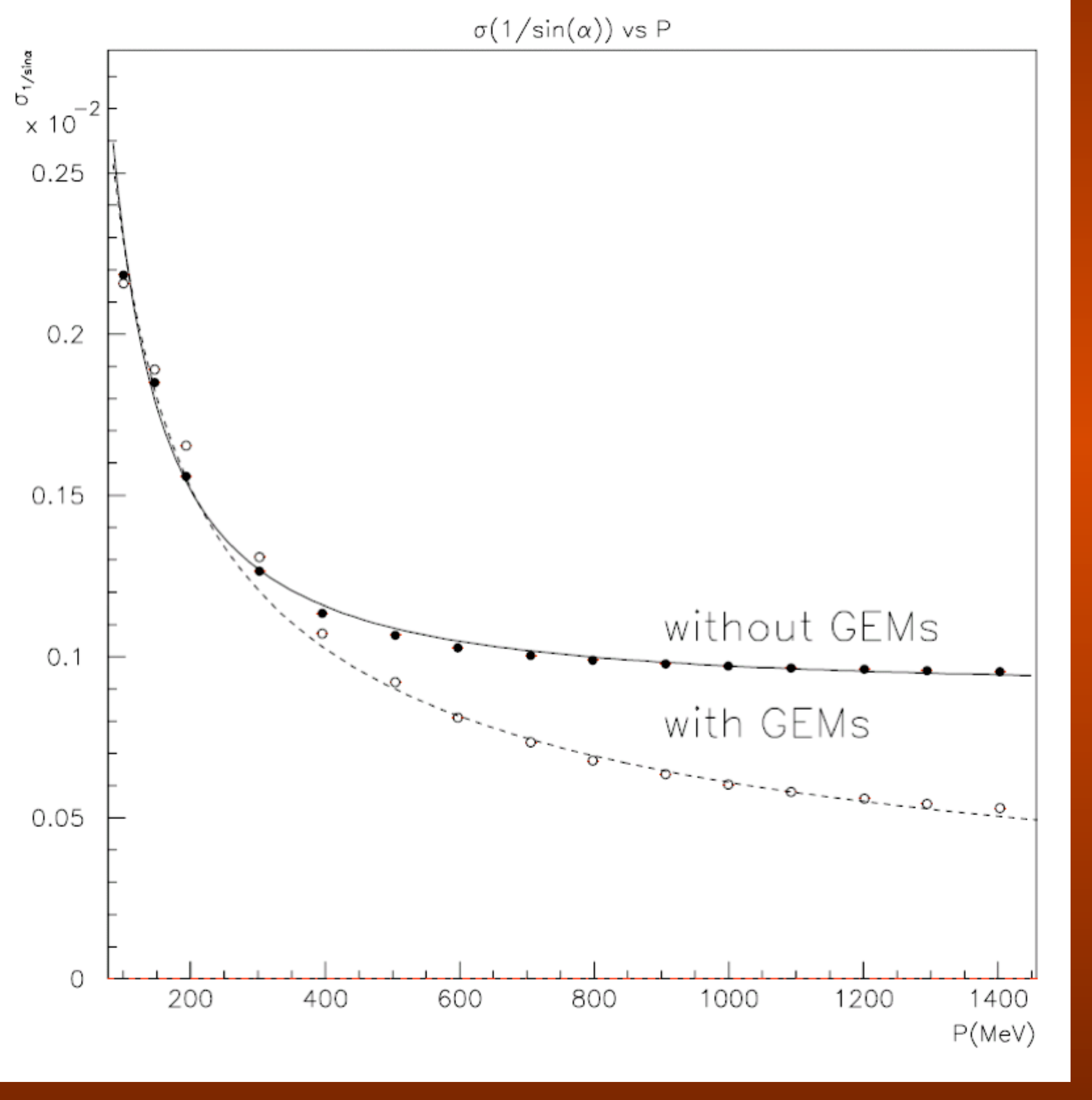
Z Resolution



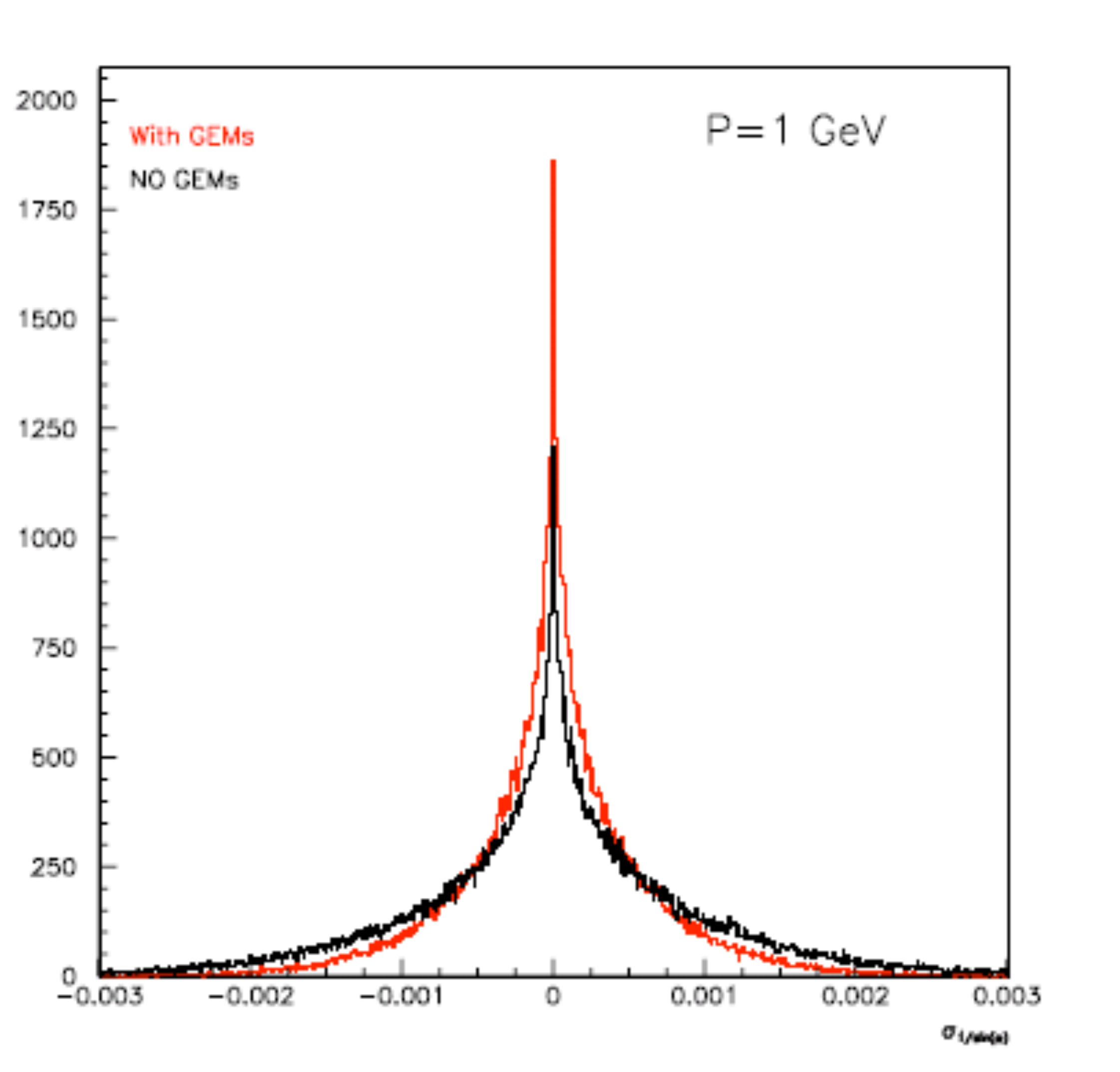
Tgθ Resolution



1/sinθ Resolution



1/sinθ Distribution



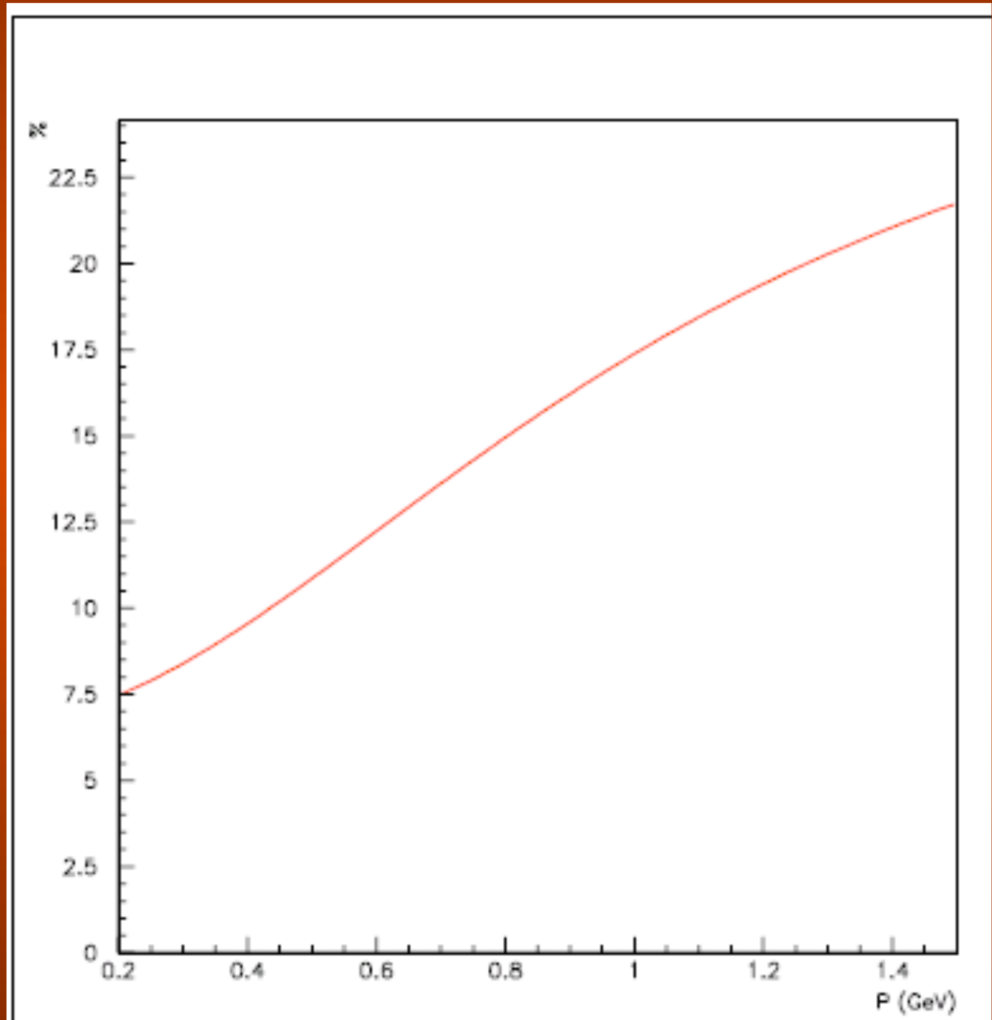
Momentum Resolution

- ϕ resolution: CGEM ~ Inner

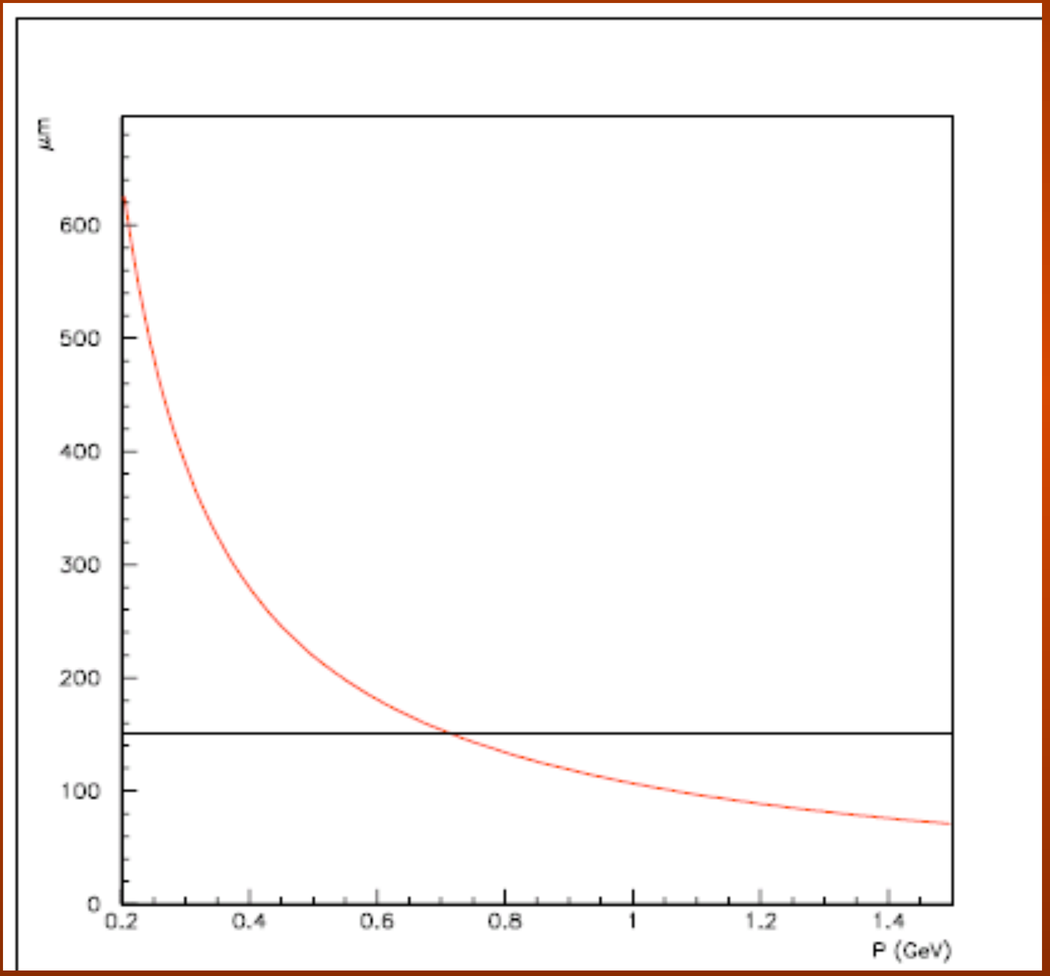
- Momentum resolution:
  The worst scenario (mostly from the outer chamber)
  L : 70 -> 62 cm
  $\sigma_{readout} \propto 1/L^2$, $\sigma_{ms} \propto 1/\sqrt{L}$
  $(\sigma_p / P)_{GEM} \sim (\sigma_p / P)_{Inner}$ x (1.07 -> 1.25 depending on P_t)

- θ_{ms}x $L_{GEM} < \sigma_x$ @ P > 0.7 GeV
  ms should not affect extrapolation from the Outer Chamber
  However a full detailed simulation is needed to settle all that

P_t Resolution worsening (%) because of Outer Chamber only



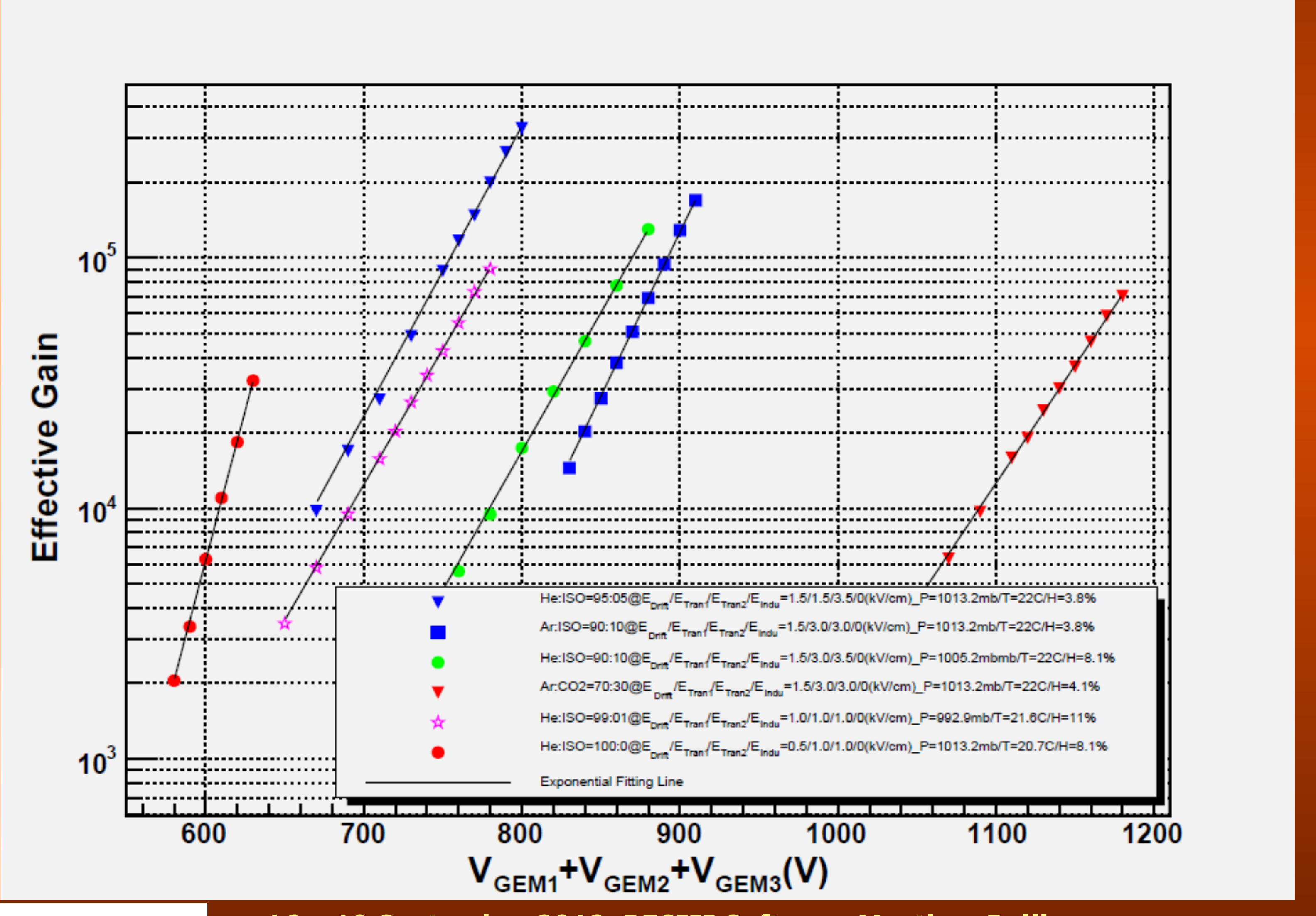
θ_{ms} x L_{GEM} vs P_t compared to σ_x



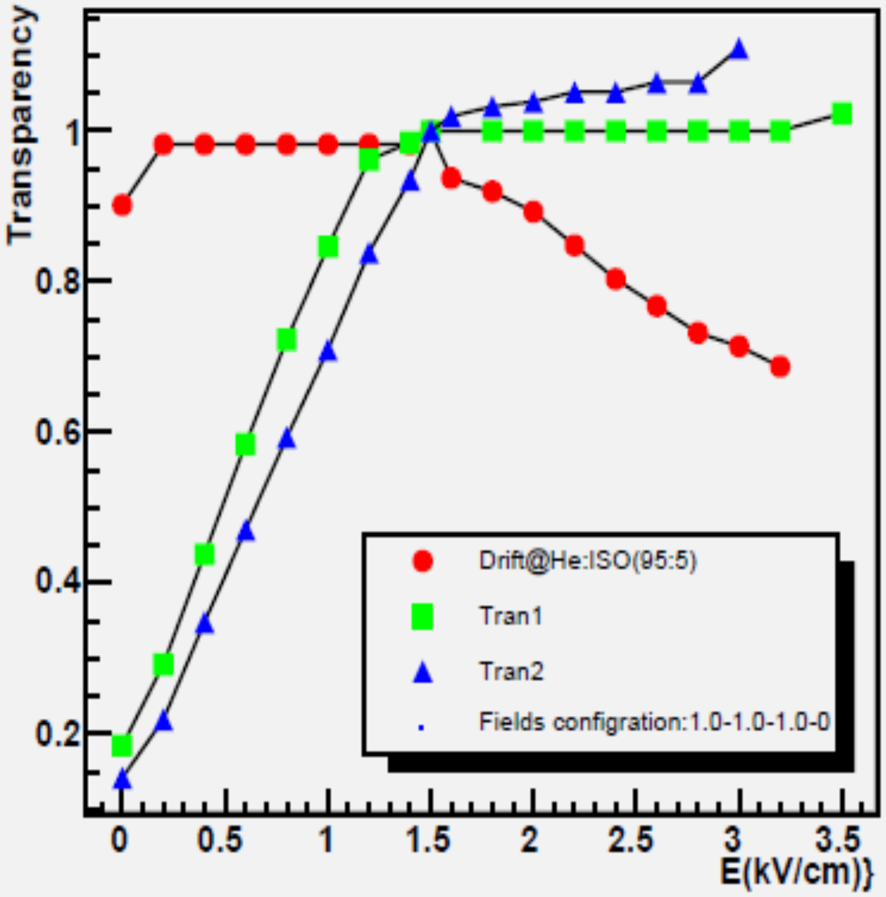
GAS Mixture

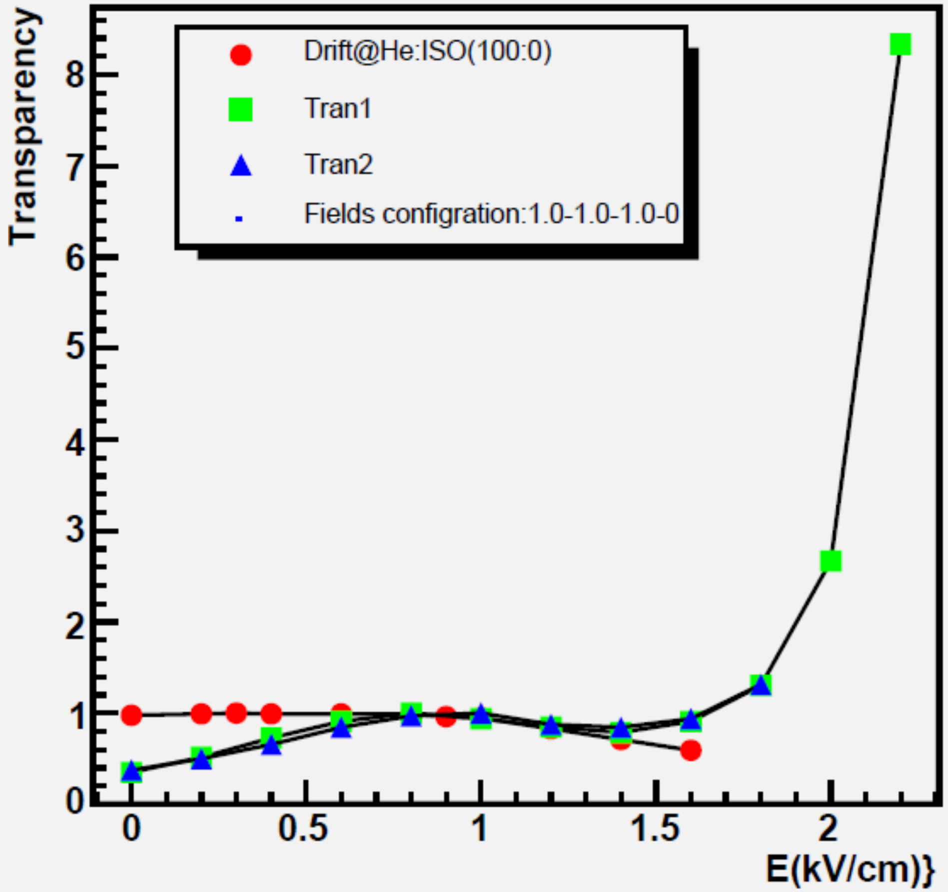
- CGEM Ar/CO_2 (70/30) , BESIII Drift He/C3H_8 (60/40)
- Might be possible, in principle to use for the CGEM the same Drift Chamber gas
- However a He based mixture might be unstable

Different He based mixtures gain



Too much He instability





Cost, Timing, Prototype
a very preliminary guess

- KLOE2 CGEM cost, including tests and R&D ~ 8000 KRMB
  BESIII ~ 3200 KRMB
  - Construction Toolings (II) and others available
  - Molds ~ 600 K RMB (x 1/4 ?)
  - GEM ~ 1000 KRMB
  - Readout ~ 1600 KRMB (Italy?)
- KLOE2 CGEM construction and R&D ~ 2 years
  BESIII ~ 1.5 year, including readout analog R&D
- INFN and IHEP have asked MAEs financial support for an analog readout CGEM prototype
- CGEM Workshop October 27-28 in Frascati (LNF, Bari, BESIII, CMD2 , Rui De Oliveira)

Conclusions

- CGEM could be a solution for a new Inner Tracker
- A relevant gain is achieved in the longitudinal view
- Transverse momentum resolution worsening should be no more than 10 %
- A rough estimation of cost and time schedule is provided
- A dedicated workshop is organized in October at LNF
- A prototype with analog readout is foreseen

Thanks again for

谢谢

your attention