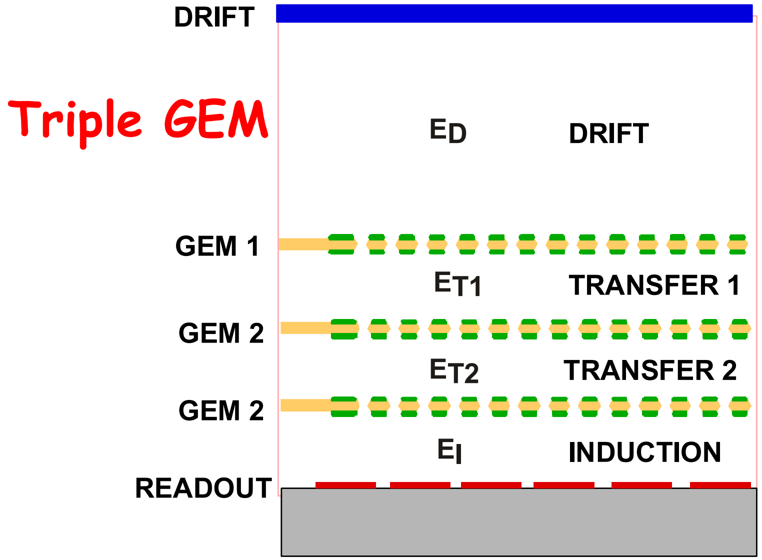
GEM Digital (KLOE) and Analog (COMPASS) readout
&
BesIII readout requirements (DAQ & FEE)

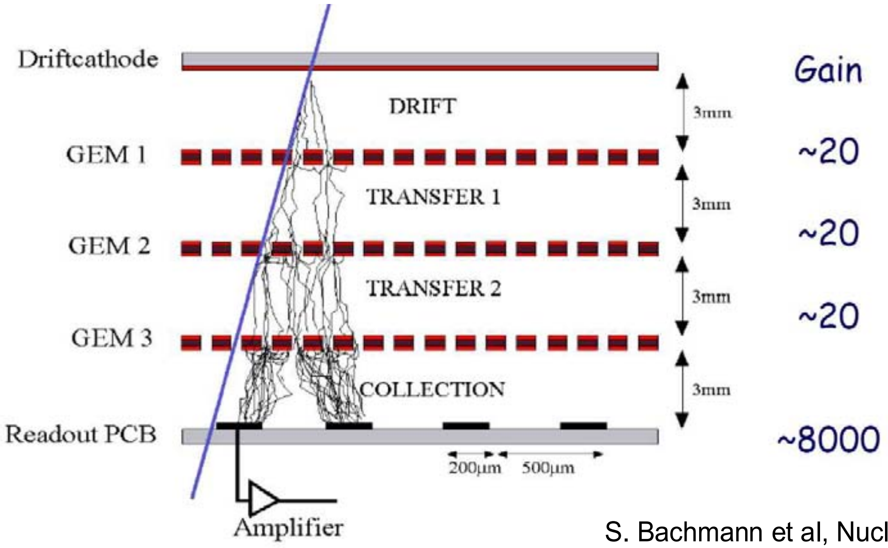
Outline

1. *GEMs - main parameters*
   - *Gain*
   - *Discharges*
   - *Cluster multiplicity*
2. *GEM Digital Readout (KLOE IT)*
   - *readout electrodes*
   - *layer instrumentation*
   - *HV sectors*
   - *HV distribution network*
   - *readout plane details*
   - *FEE integration*
   - *HV & FEE chain*
   - *readout chain*
3. *GEM Analog Readout (COMPASS)*
   - *readout electrodes*
   - *chambers*
   - *position accuracy*
   - *efficiency vs track multiplicity*
   - *time measurements accuracy*
   - *APV 25 front-end*
4. *GEM operation in magnetic fields*
   - *charge broadening (simulation)*
   - *Test beam setup*
   - *resolution*
   - *efficiency*
   - *cluster size*
5. *BES IT DAQ & FEE requirements*
   - *DAQ requirements*
   - *2D readout*
   - C_{STRIPS} *effect on SNR*
6. *Conclusions*

GEMs

GEM: Triple GEM



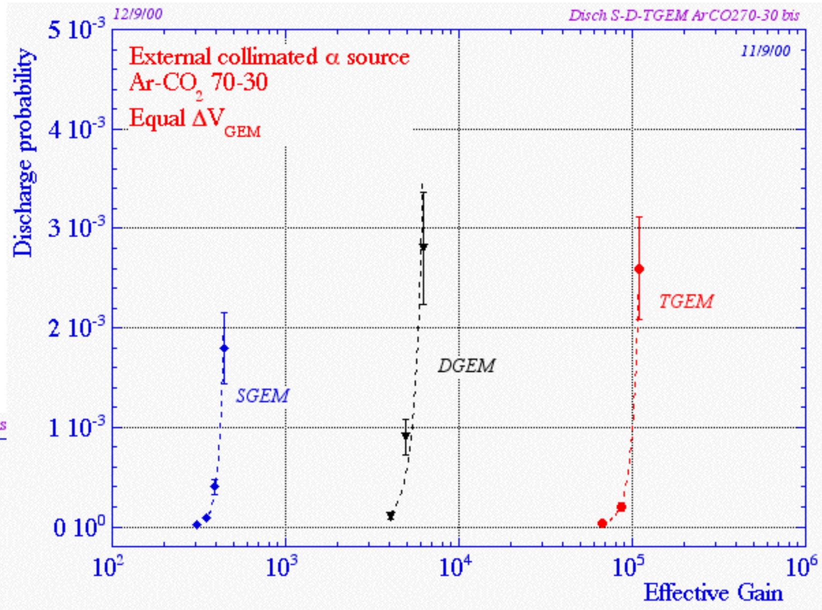


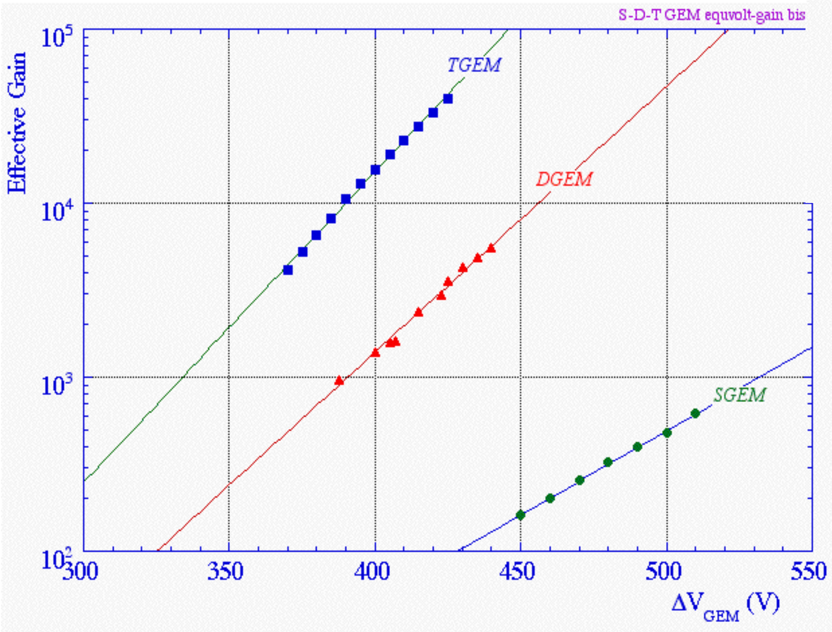
S. Bachmann et al, Nucl. Instr. and Meth. A 443(1999)464

Multi-GEM Detectors

Multiple structures provide equal gain at lower voltage.

The discharge probability on exposure to a particles is strongly reduced.

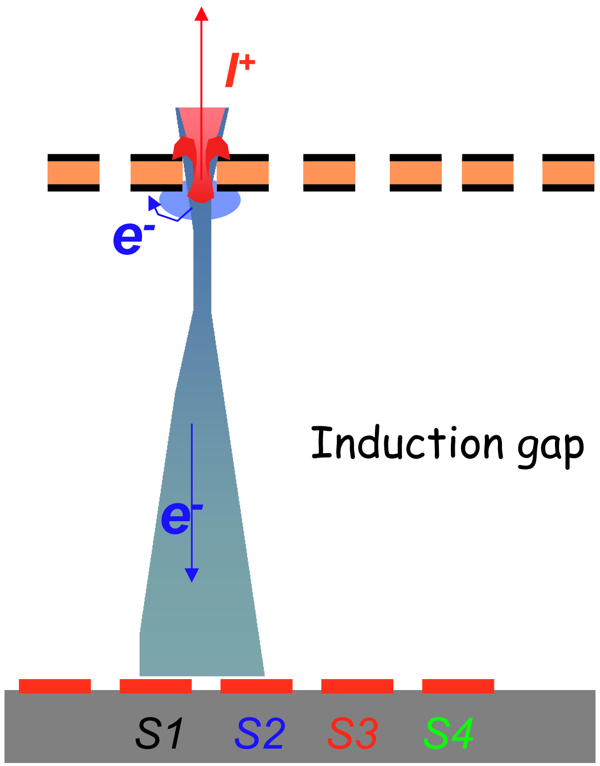


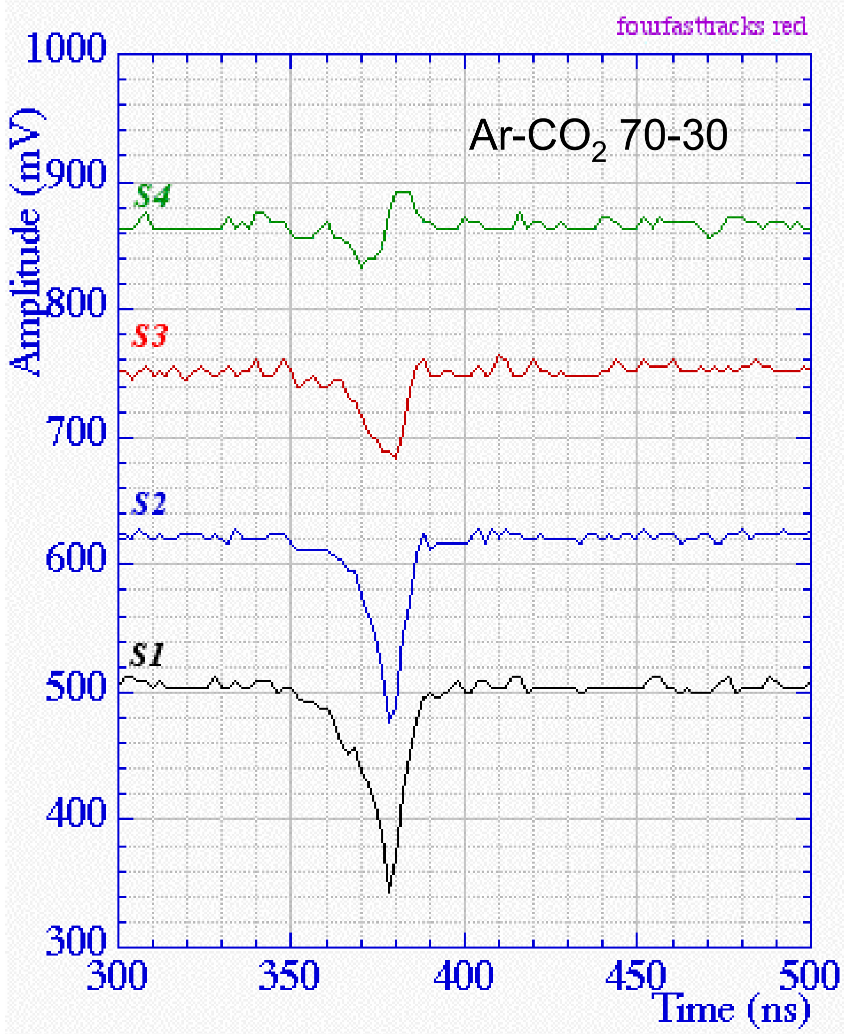


S. Bachmann et al, Nucl. Instr. Meth. A479 (2002) 294

TOTEM GEM detectors for tracking and triggering
Leszek Ropelewski CERN PH-DT2-ST & TOTEM

Fast Electron Signal



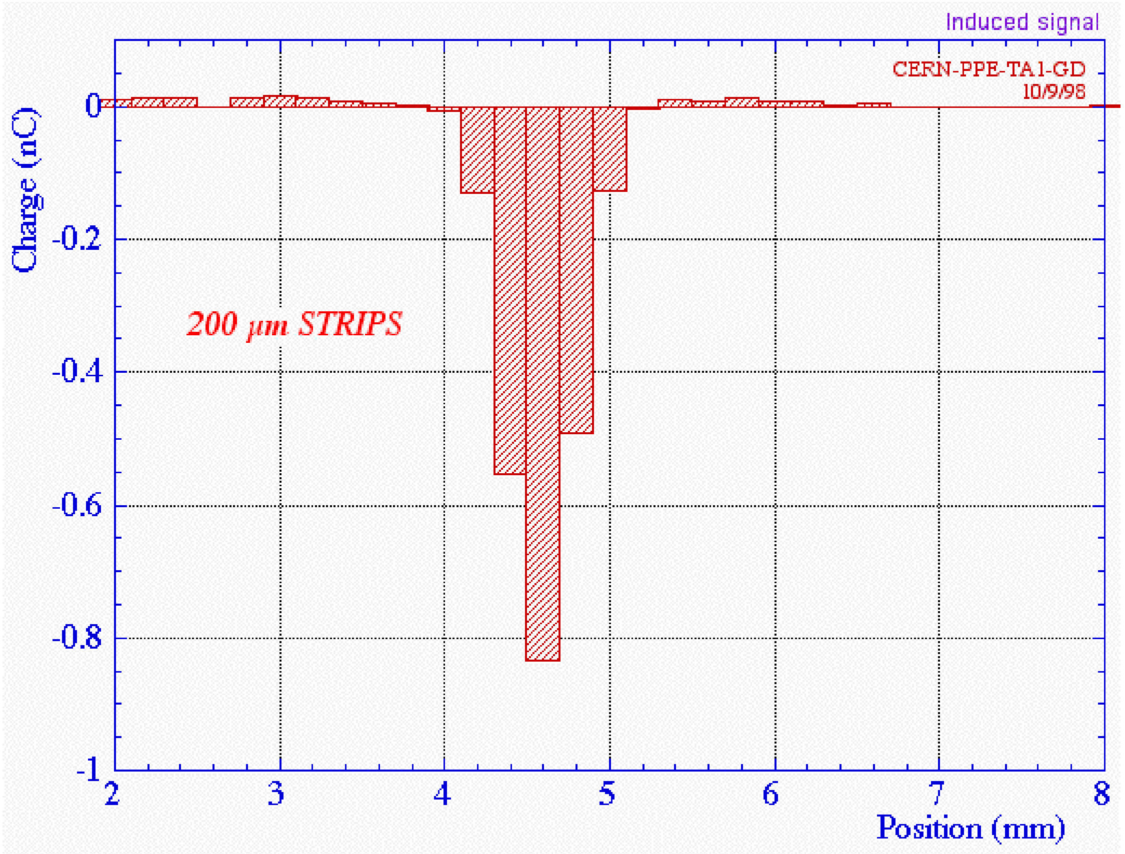


No positive ion tail ⟶ very good multi-track and time resolution

GEM: strips induced signal

TOTEM GEM detectors for tracking and triggering
Leszek Ropelewski CERN PH-DT2-ST & TOTEM

Cluster Charge Distribution



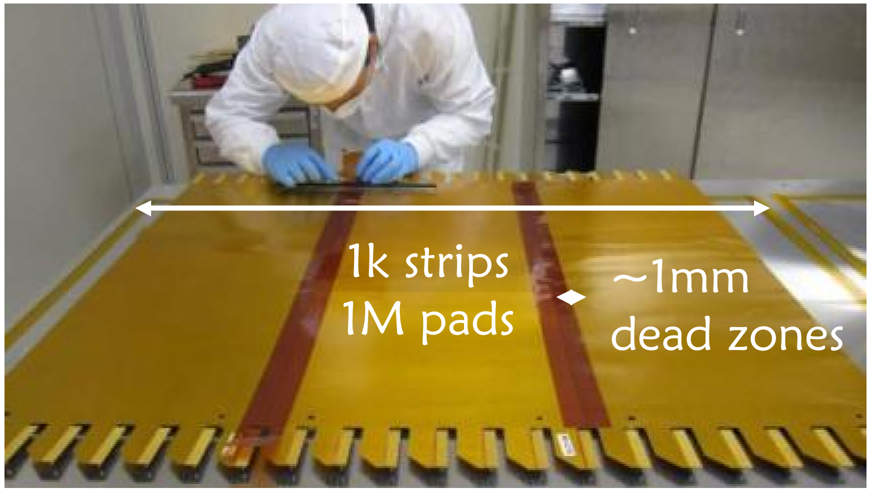
Very good multi-track resolution

Requires high density of readout channels

Digital Readout - KLOE IT

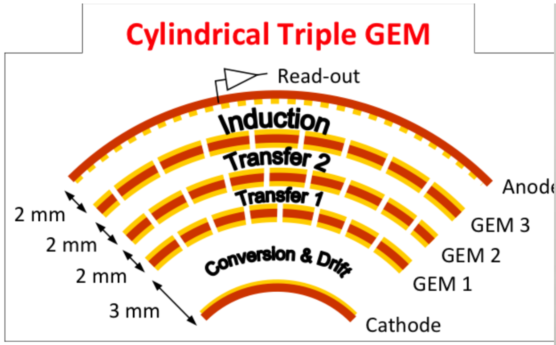
KLOE2 IT - readout electrodes

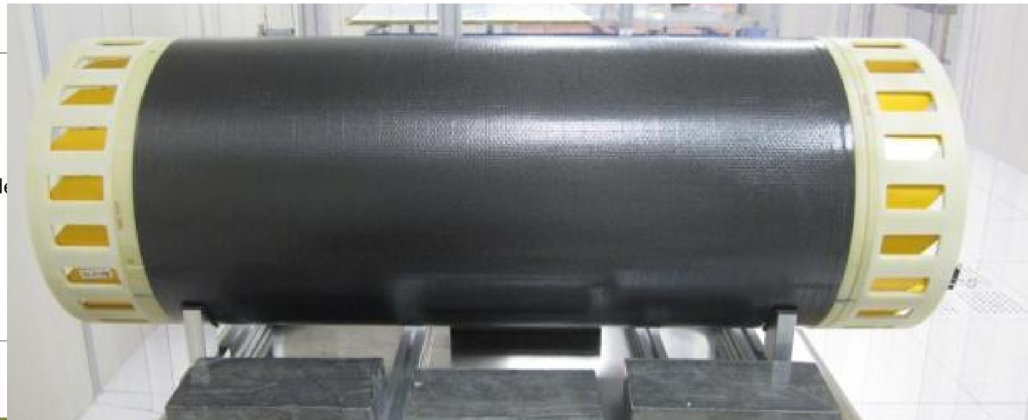
- *4 independent tracking layer*
- *XV readout strips*
  - *25-30° stereo angle (depending on the layer)*
  - *X strips (r-φ coordinate): 650 µm pitch - 250 µm width - 694 mm length → C ≈ 100 pF*
  - *V strips (z coordinate): 650 µm pitch (V-pads connected through vias) - length range: 1÷773 mm → C ≈ 1-200 pF*
  - *Overall resolution: $\sigma_{r\varphi}$= 200 µm - σ_z= 500 µm*
- *≈ 30k readout channels*
- *Strip signals readout through a 120-pin connectors (each connector collects 40 X strips and 80 V strips)*

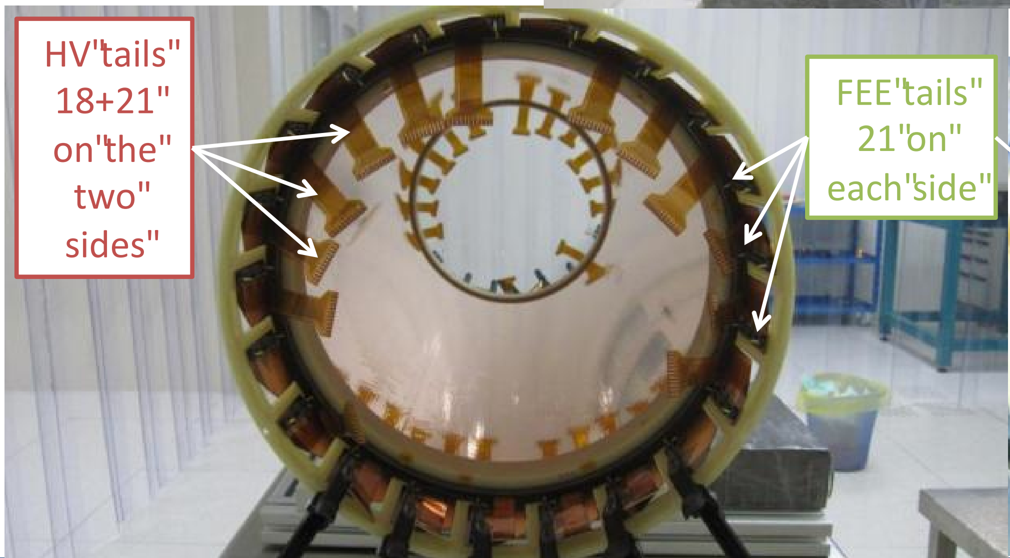


3 foils spliced without overlap: kapton strips are glued on the back of head-to-head joints

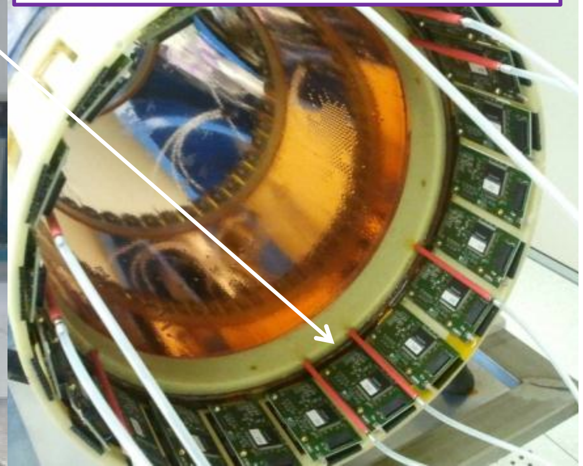
The"1st"CGEM"layer"completed"







Layer2'with'Gastone'FEE"



Erika'De'Lucia'>>'2012'Nuclear'Science'Symposium'&'Medical'Imaging'Conference" 9"

KLOE2 IT - X strips and HV sectors

Layer'2/Layer'3'Test'with'' ^{90}Sr''Source'(II)''

- 'S1‐S12'HV'Sectors''
- 'Source'Scan'posi, oning' ^{90}Sr'on'each'HV'sector''

Unrolled'Anode'Foil:'X‐view'Strips''

FEE Boards →

Source'on'S1''

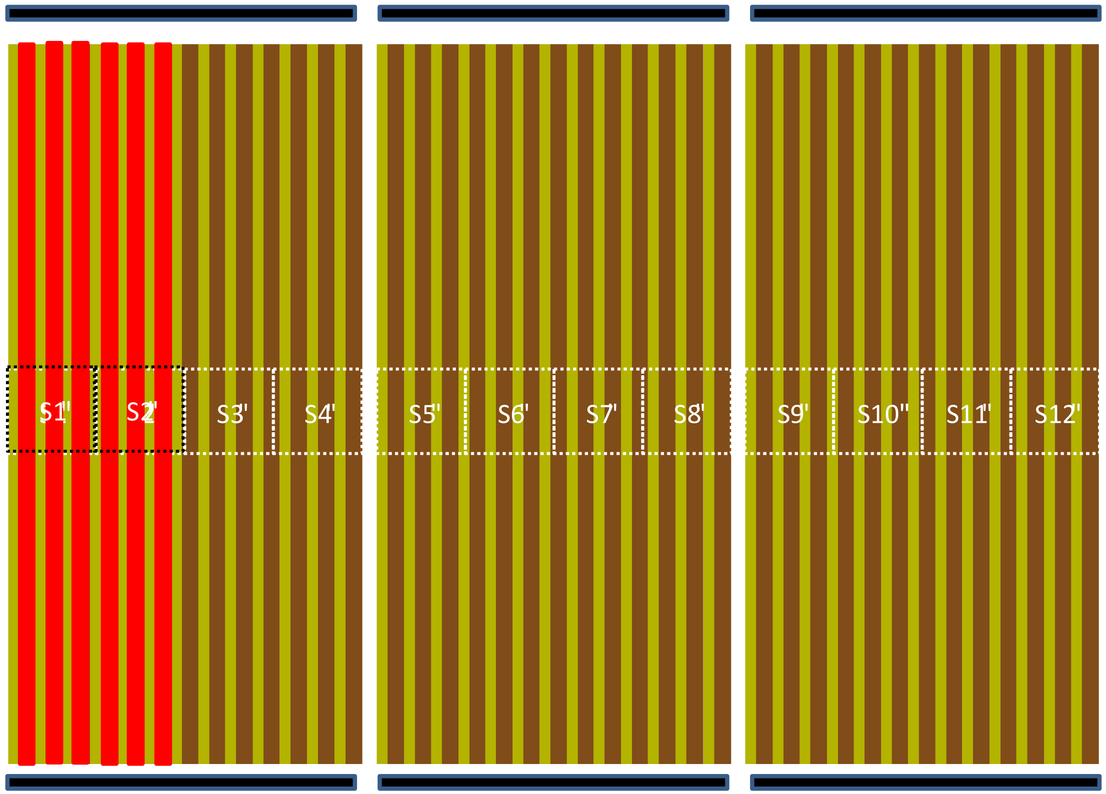
X‐view'Fired'Strips''

All'X‐view'Strip''
illuminated'with' ^{90}Sr''

Source'on'S2''

X‐view'Fired'Strips''

FEE'Boards''→



KLOE2 IT - V strips and HV sectors

Layer'2/Layer'3"Test'with"^{90}Sr"Source'(III)"

- 'S1<S12'HV'Sectors"
- 'Source'Scan'posi, oning'^{90}Sr"on'each'HV'sector"

Unrolled'Anode'Foil:'V<view'Strips"

FEE'Boards"

Source"on'S1"

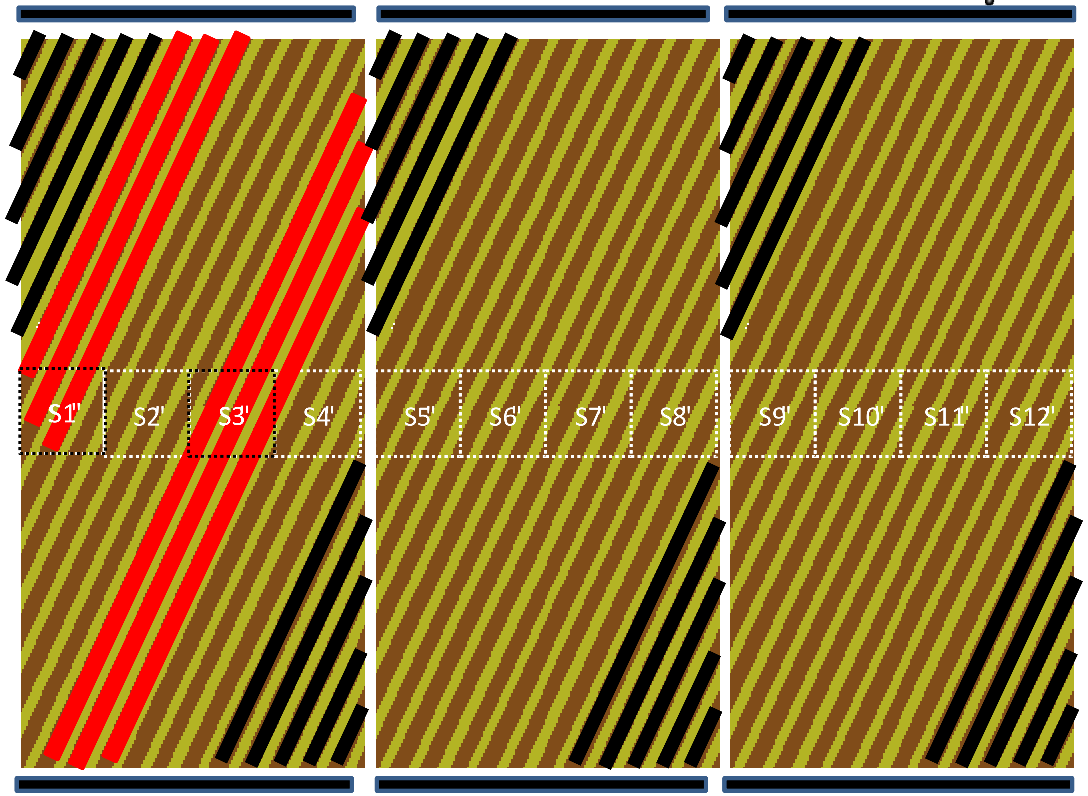
V<view'Fired'Strips"

V<view'Strips'not" illuminated'with'^{90}Sr"

Source"on'S3"

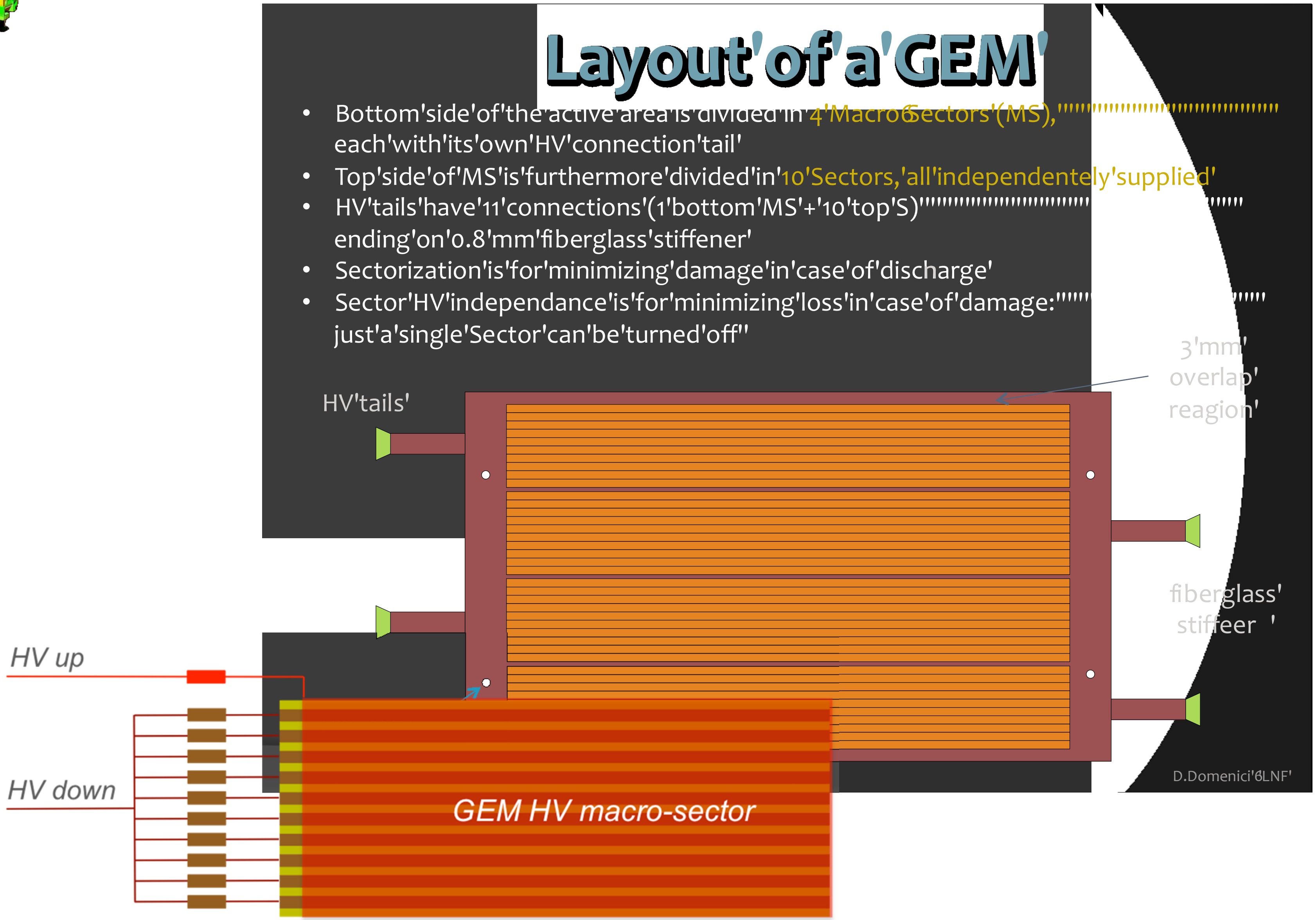
V<view'Fired'Strips"

FEE'Boards"



Erika'De'Lucia'>>'2012'Nuclear'Science'Symposium'&'Medical'Imaging'Conference" 15

KLOE2 IT - HV Distribution Network



KLOE2 IT – Readout Plane (Detail)

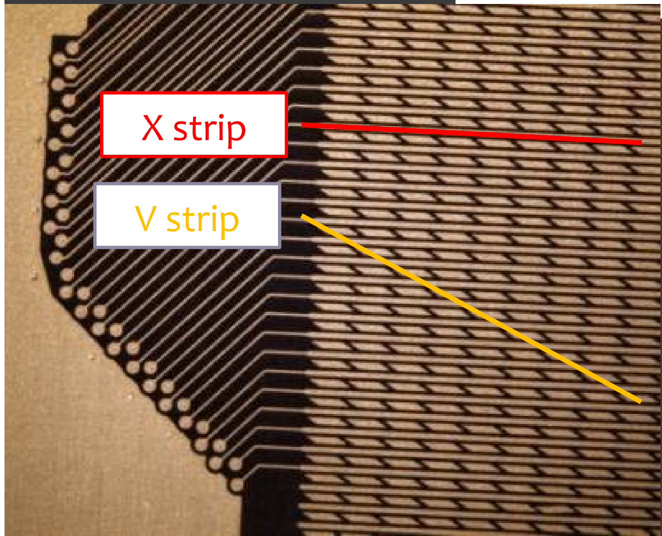
Readout Plane

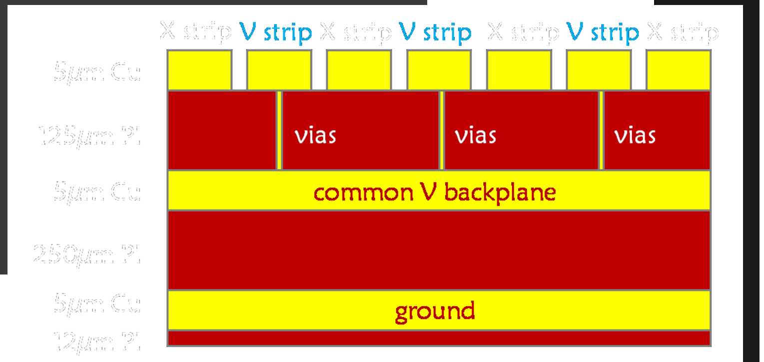
Readout plane is realized at CERN E-EM

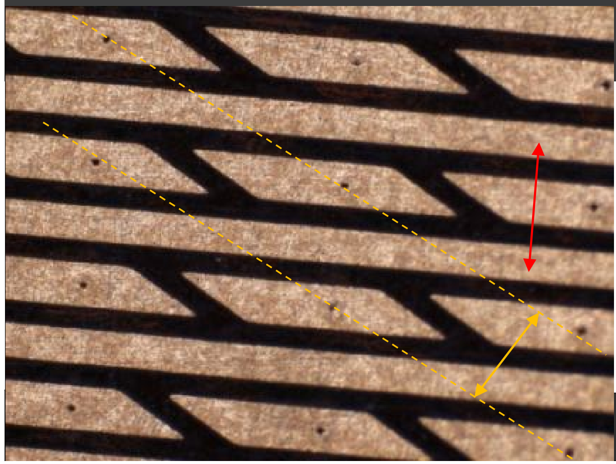
It is a kapton/copper multilayer flexible circuit

Provides 2-dimensional readout w ips on the same plane

- X are realized as longitudinal s
- V are realized by connection o h conductive holes and a comm
- Pitch is 650 μm for both







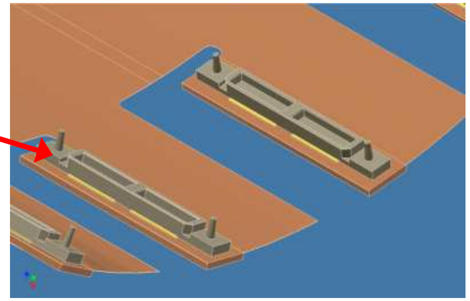
650μm → Y res 350μm

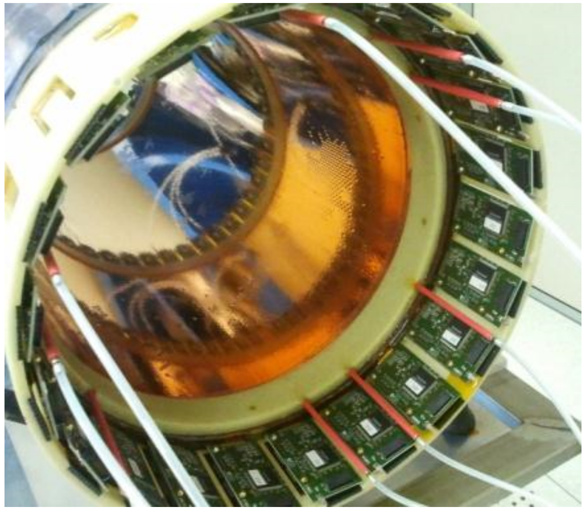
32

D.Domenici - LNF

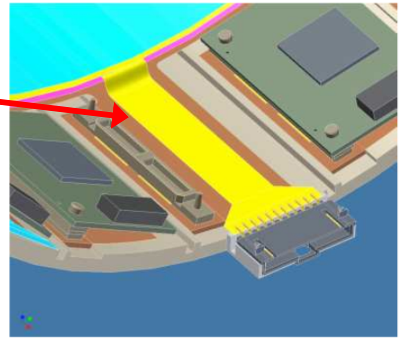
KLOE2 IT - FEE Integration

Readout (XV) plane connectors





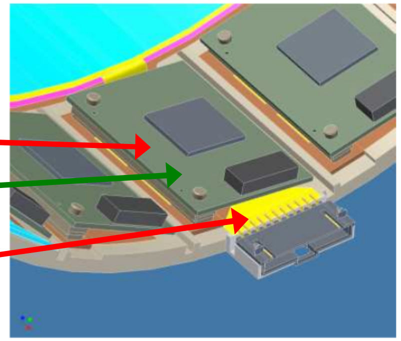
HV macro-sector connector



Readout boards

GND

HV max ≈ 5 kV !!



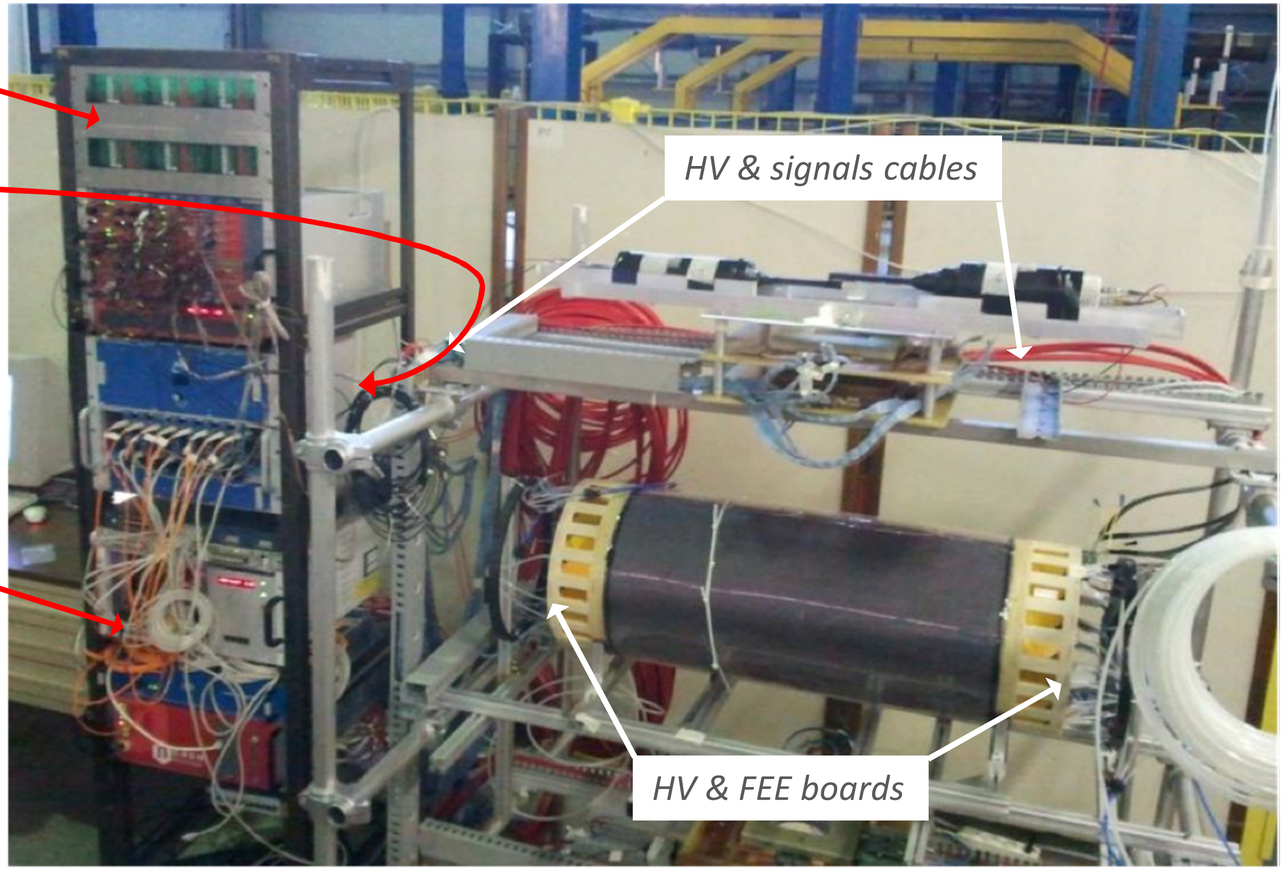
HV distribution must be carefully designed

KLOE2 IT - HV & FEE chain (I)

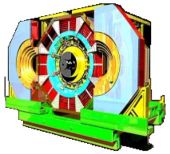
Custom HV distributors

Signals cables collected by means of special boards on the back side of a custom crate

Concentrator (hidden by fibers)

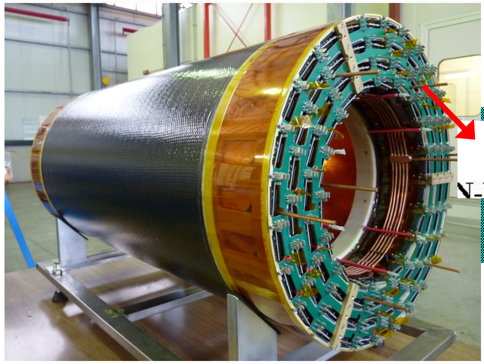


A. Aloisio et al., “An FPGA Based General Purpose DAQ Module for the KLOE-2 Experiment” Journal of Physics: Conference Series **331** (2011) 022033



KLOE2 IT - FEE chain

128 channels



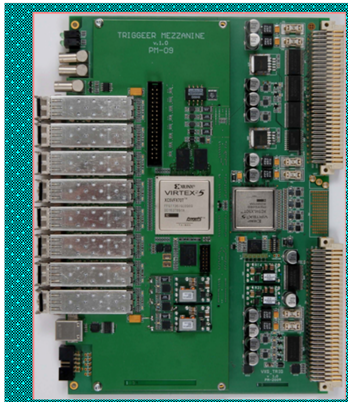
BARI

5 mt Twisted pairs

Optical Links

Concentrator Board

- *manages 16 GIB boards*
- *Event building*



D A Q

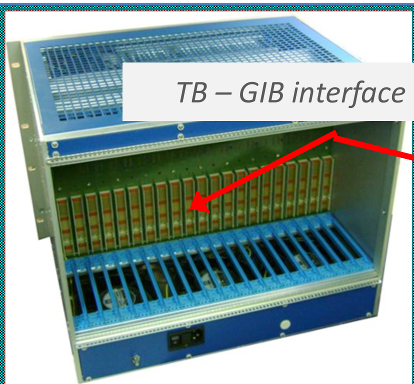
Uppsala Institute (Pawel Marciniewski)

A. Balla et al., "GASTONE: A new ASIC for the cylindrical GEM inner tracker of KLOE experiment at DAFNE", ,Nucl. Inst. & Meth. A, vol. 604, no. 23, 2009

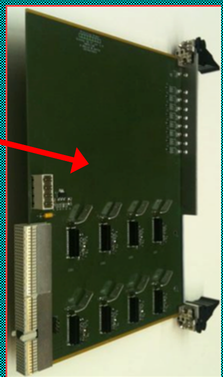
GIB Board
(manages up to 8 Gastone Boards)

- *Data download*
- *Lev1 distriution*
- *Gastone boards parameters setting*
- *1024 channels*

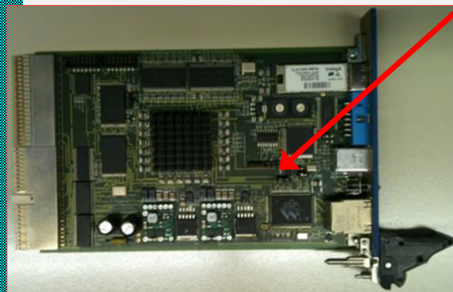
TB – GIB interface



GIB crate (back view)



Transition Board (collects cables from 8 Gastone boards)

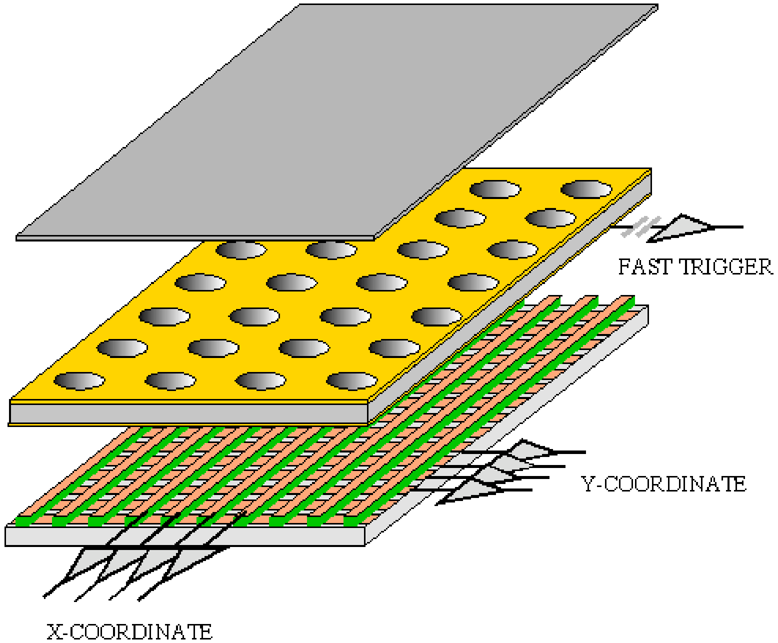


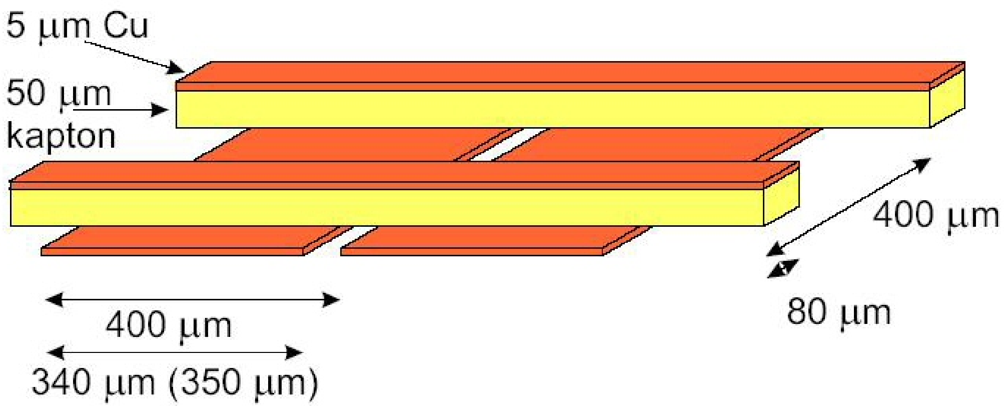
LNF

GIB crate (front view)

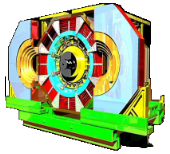
Analog Readout - COMPASS

COMPASS: readout electrodes

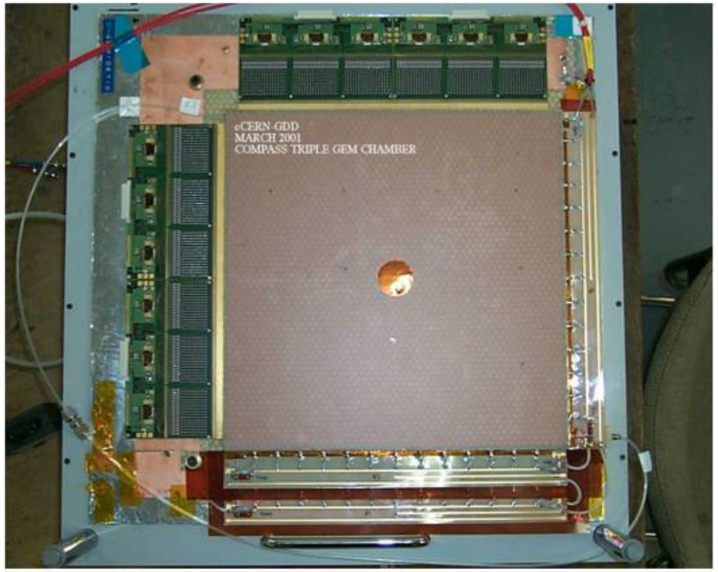


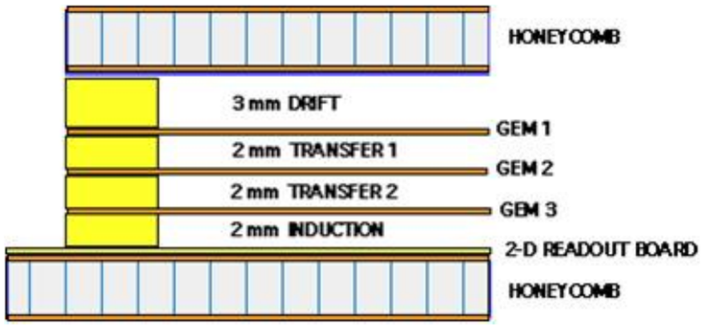


- ***Due to diffusion the charge cloud collected on the readout board is bigger than the strip width (≈ 3.5 x pitch)*** *and a weighting method is used for calculate the exact track position in two dimensions*
- *Every single strip versus the other readout coordinate acts as a plate capacitor. With the permittivity ε=3.9 of Kapton and an area of* $2.27 \cdot 10^{-1} cm^2$, ***this capacitance is 15.7 pF***



COMPASS: chambers

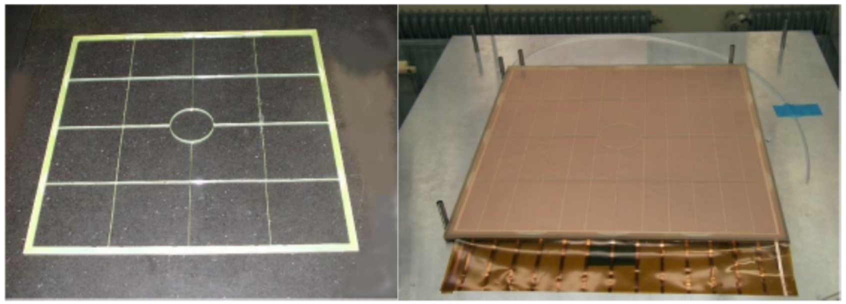




A GEM detector for the COMPASS experiment

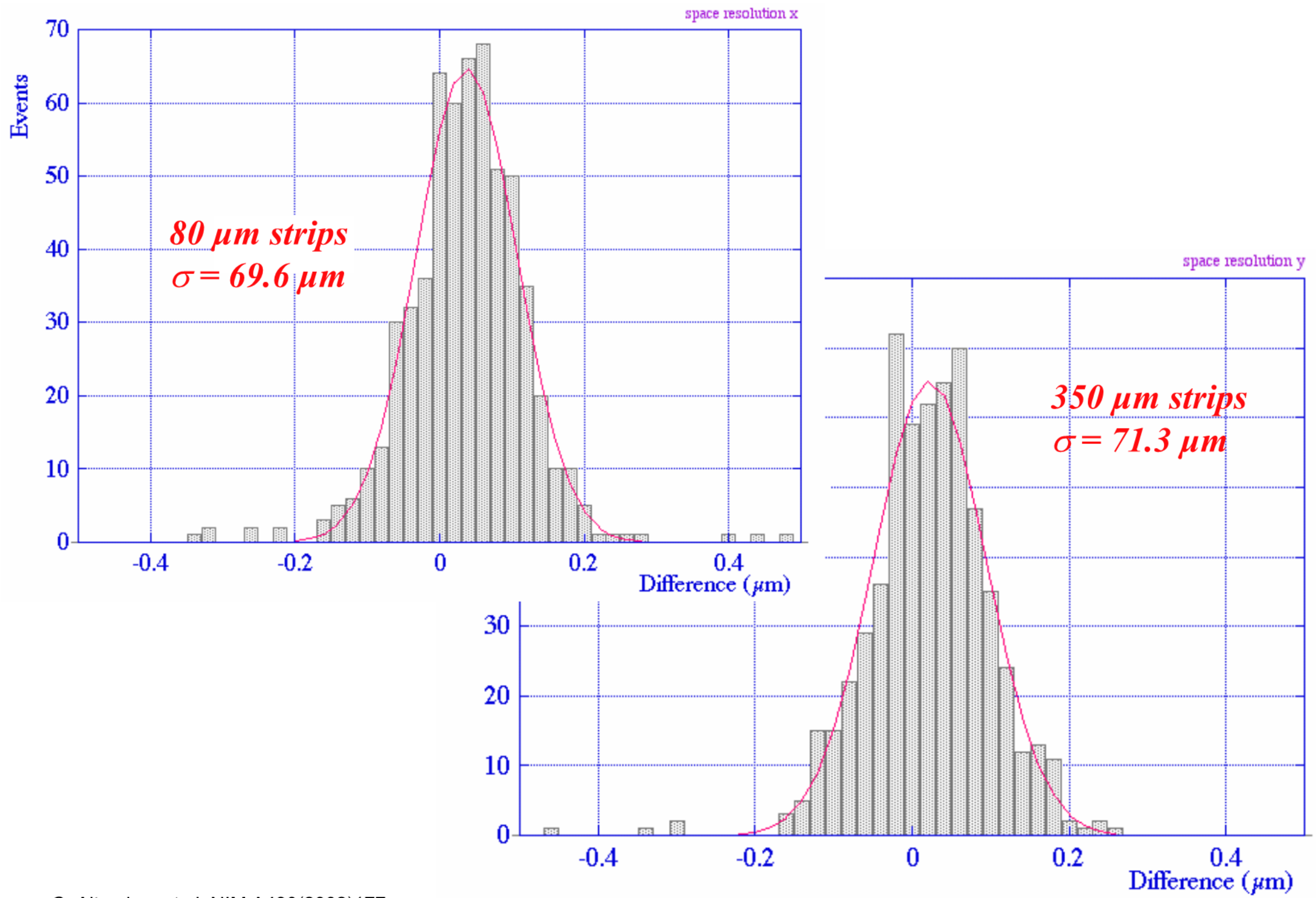
S. Bachmann, A. Bressan□, A. Placci, L. Ropelewski and F. Sauli.

- position resolution σ = 40μm;
- time resolution FWHM = 18ns;
- plateau length in presence of MIPs from S/N= 20 up to S/N 10^3, i.e. a 150V plateau;
- maximum gain for 5.9 keV Fe X-rays □ 10^5;
- maximum gain for 6.4 MeV α particles above 10^4 without detector breakdown;
- maximum gain for a rate of 5×10^5 5.9 keV X-rays converted /mm^2 above 5×10^4;
- no aging up tp 12 mC/mm^2.



COMPASS: position accuracy

Position Accuracy



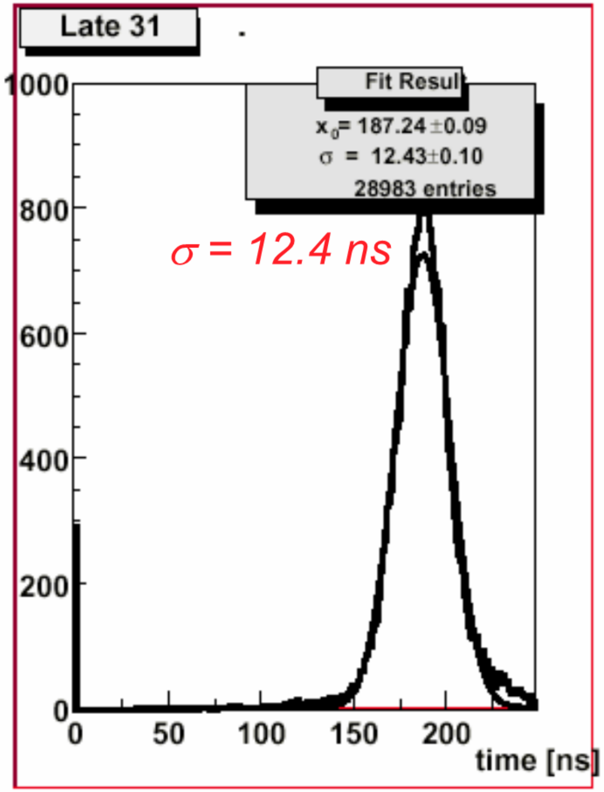
C. Altumbas et al, NIM A490(2002)177

COMPASS: time measurement accuracy

Time Resolution

Ar/CO_2=70/30

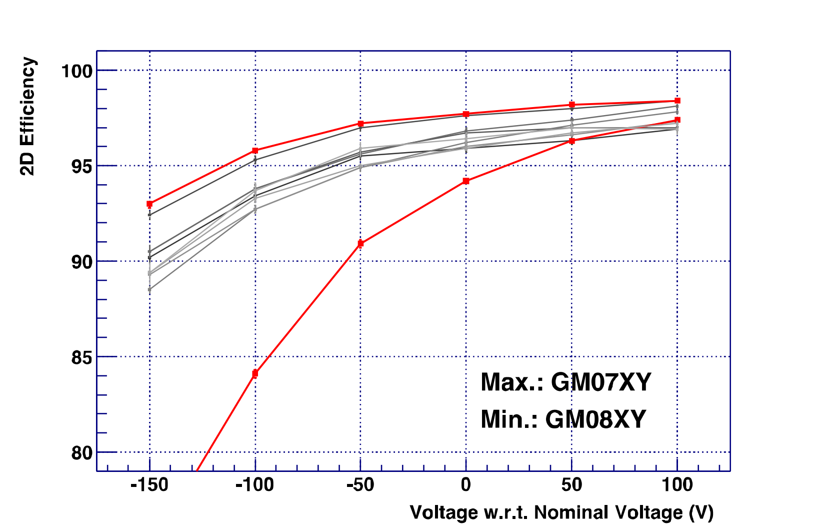
Time resolution: computed from charge in three consecutive samples (at 25 ns intervals) using APV electronics.

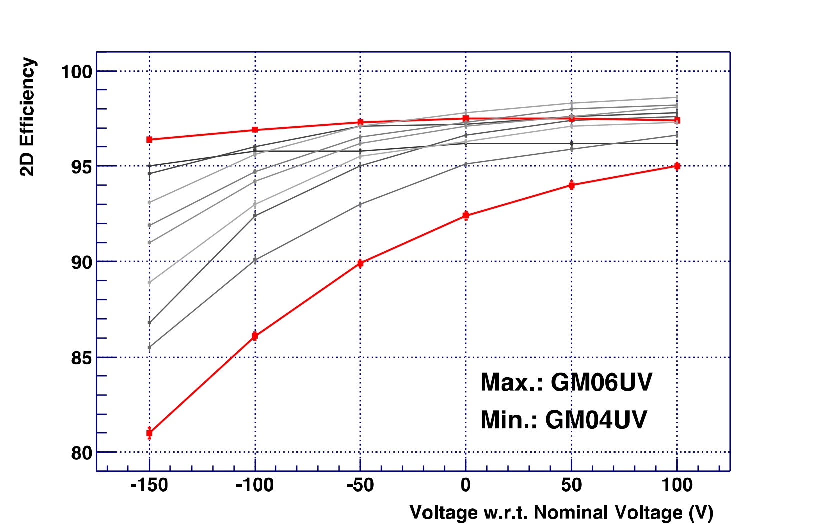


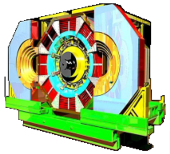
B. Ketzer and Q. Weitzel (COMPASS)

COMPASS: efficiency

- Low intensity beam: $5 \cdot 10^6\,\mu^+/\mathrm{s}$
- Scan in steps of $50\,\mathrm{V}$ around nominal $G = 8000$
- Hit required within $\pm 1\,\mathrm{mm}$ of expected trajectory
- Background correction: $\varepsilon_{\mathrm{app}} = \varepsilon_{\mathrm{real}} + (1 - \varepsilon_{\mathrm{real}}) \cdot b$
- Plateau reached for all 20 detectors
- SNR at full efficiency ~ 18
- Single plane: $\langle \varepsilon_{\mathrm{1D}} \rangle = 98.5\%$
- 2D (space point): $\langle \varepsilon_{\mathrm{2D}} \rangle = 97.5\%$
- Losses due to spacer grid: $1.2 - 1.5\%$



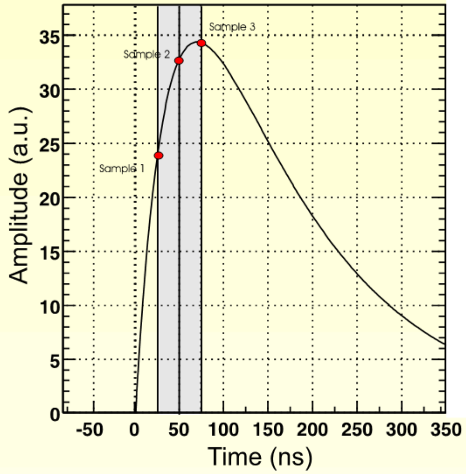


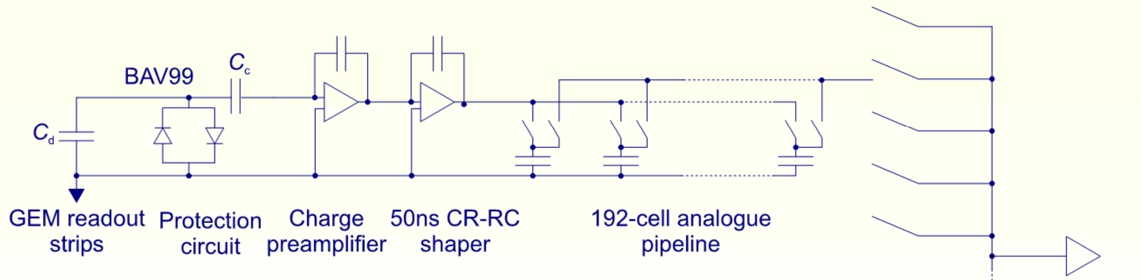


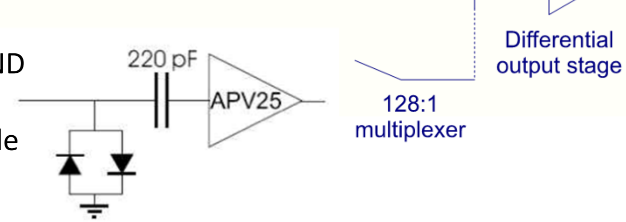
COMPASS: front end (I)

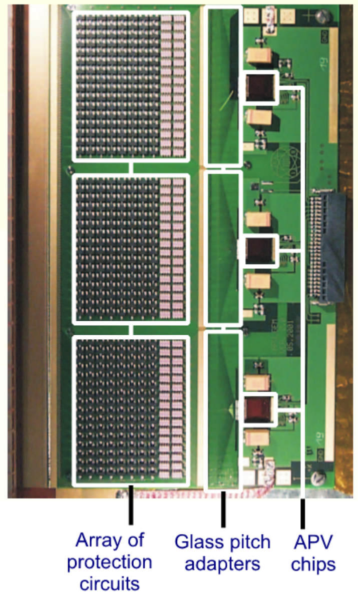
APV25: ASIC ($0.25\,\mu$m technology)

- Preamplifier + shaper ($\sim 50\,$ns peaking time)
- Sampling at $40\,$MHz
- Analogue pipeline: 192 memory cells / channel
- 31 samples FIFO $\Rightarrow$ Latency $4\,\mu$s
- MUX output of 3 samples
- Double diode clamp & AC coupling







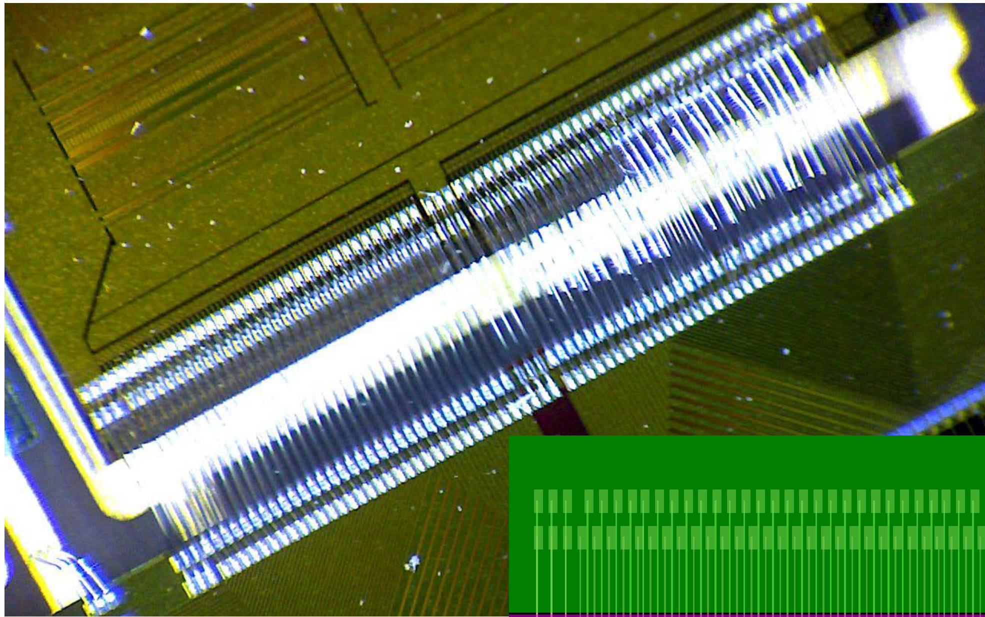


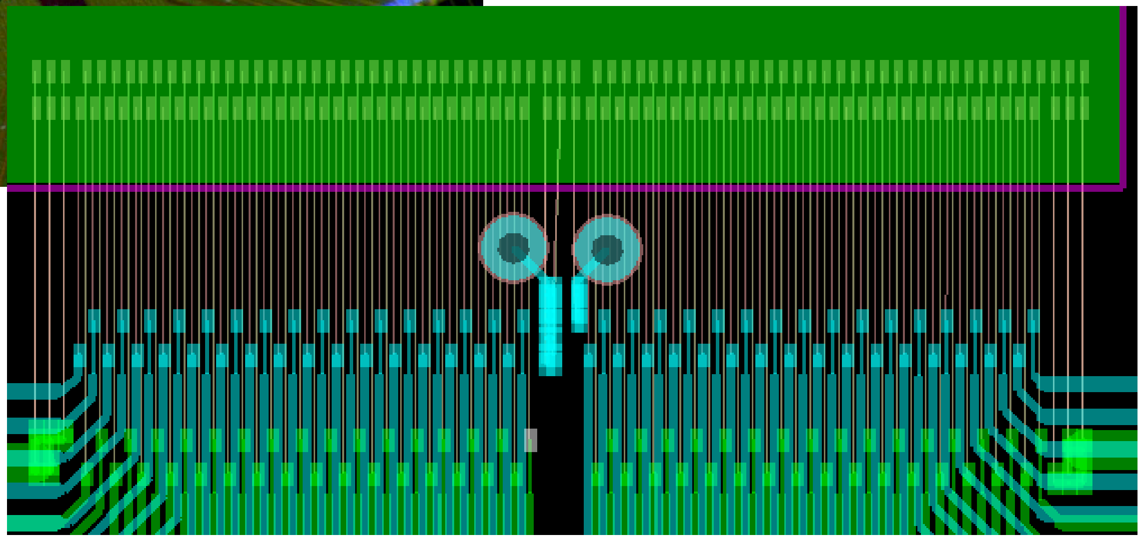
- Anode and cathode connected to GND
- NO DC into preamplifier
- Charging up of strips avoided by diode leakage currents

Bernhard Ketzer

COMPASS: front end (II)

Bonding





24/02/2010 Frontend Hybrid with APV25 chip, S. Martoiu, CERN 7

GEM operation in magnetic field

Magnetic field: charge broadening (sim.)

Design and Construction of a cylindrical GEM detector as the Inner Tracker device of the KLOE-2 experiment
- Gianfranco Morello on behalf of Frascati, Bari and Cosenza groups

Effect of magnetic field

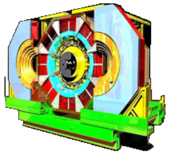
At test beam we used Goliath magnet, B field up to 1.5 T
The chambers were filled with **Ar/CO2**

8 mm

A triple GEM (3/2/2/1) was built with ANSYS and simulation of electrons drift motion with 0.5 T (the foreseen KLOE-2 magnetic field) was done with GARFIELD

Ar/CO_2=70/30
B=0.5 T
Mean Lorentz angle ($<\alpha_L>$) ~ 8°-9°

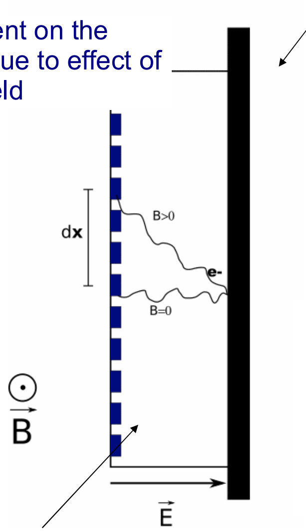
~700 um



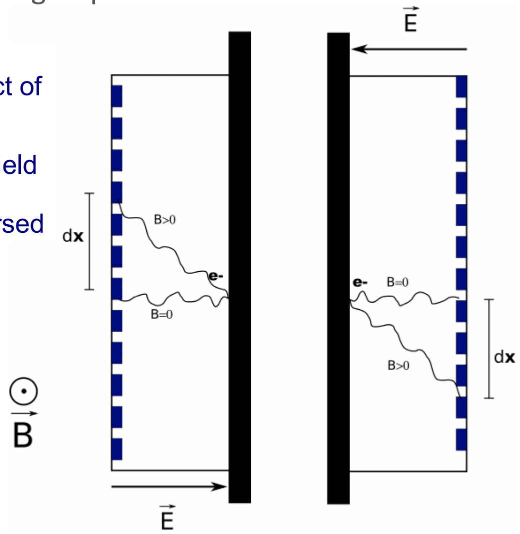
Magnetic field: test beam setup

Design and Construction of a cylindrical GEM detector as the Inner Tracker device of the KLOE-2 experiment
- Gianfranco Morello on behalf of Frascati, Bari and Cosenza groups

- **dx** - displacement on the readout plane due to effect of the magnetic field



- **dx** - displacement on the readout plane due to effect of the magnetic field
- after rotation the electric field changes direction and the displacement will be reversed



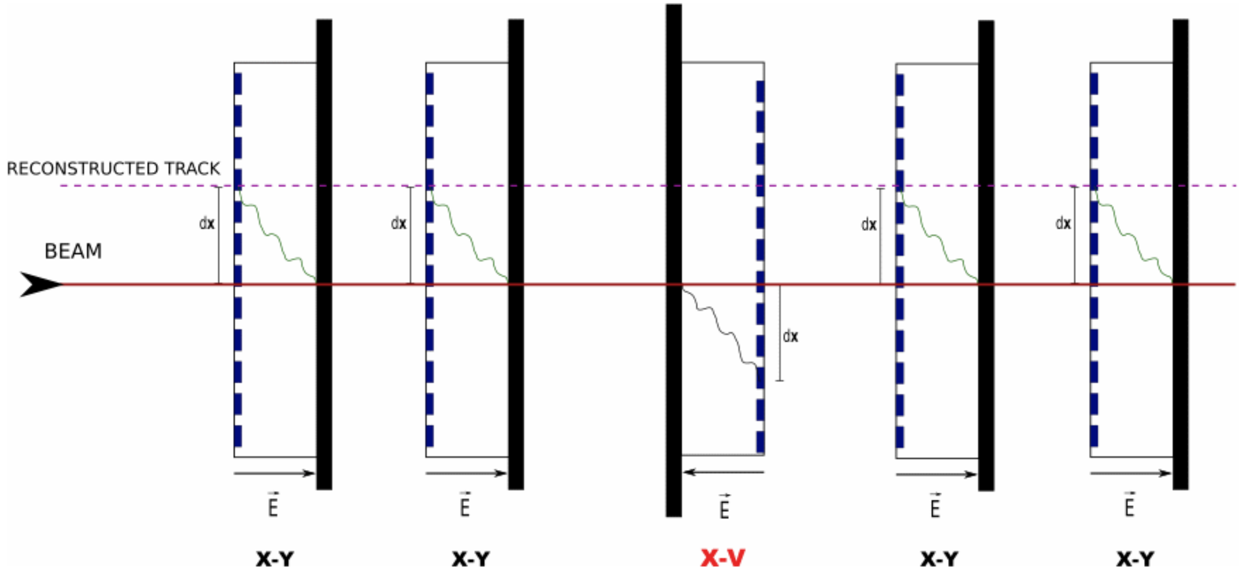
TEST BEAM results

SPS North Area H4 beam line
CERN PREVESSIN

- we align the setup with B = 0
- turn on B field
- we reconstruct the track using only 4 X-Y plane
- we measure the displacement on X-V plane

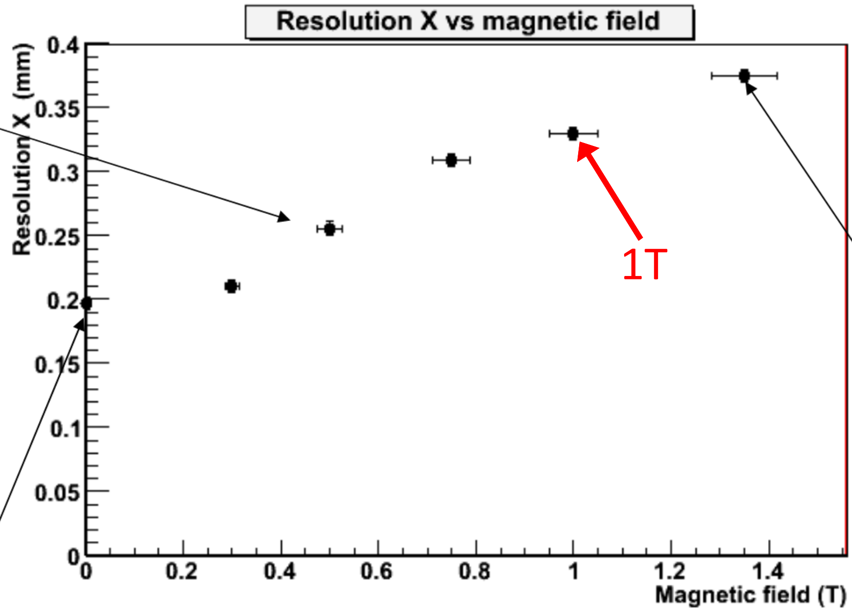
measured displacement D = 2 · ***r*** · tan α_L

(where ***r*** is effective thickness of the detector)



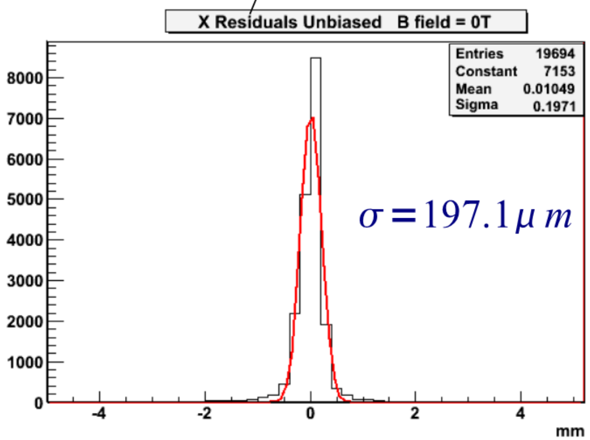
Resolution in X plane (bending plane)

KLOE B field



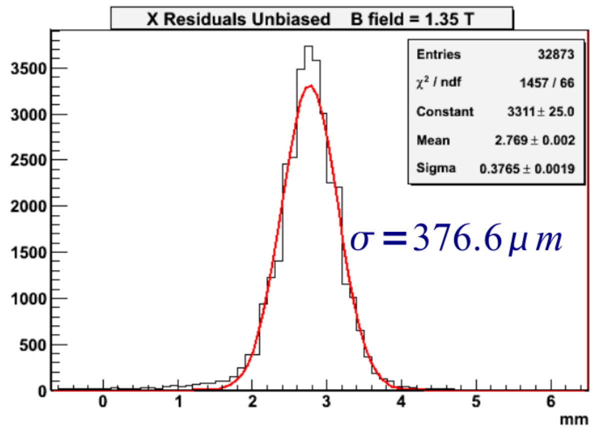
1T

V_{GEM}: 390-380-370 =1140V, gain~$2 \cdot 10^4$



$\sigma = 197.1 \mu m$

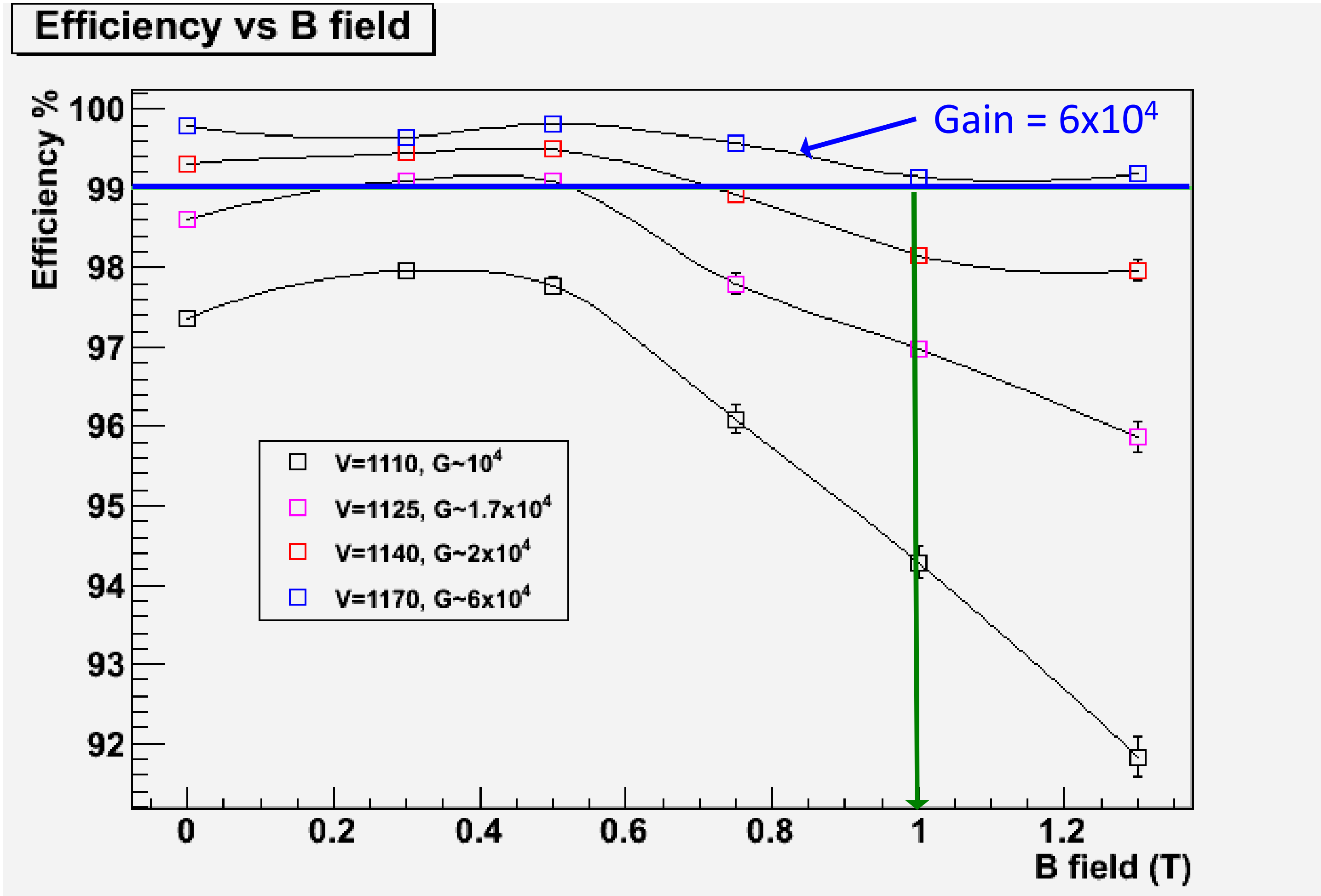
The magnetic field increases the spread of the electrons



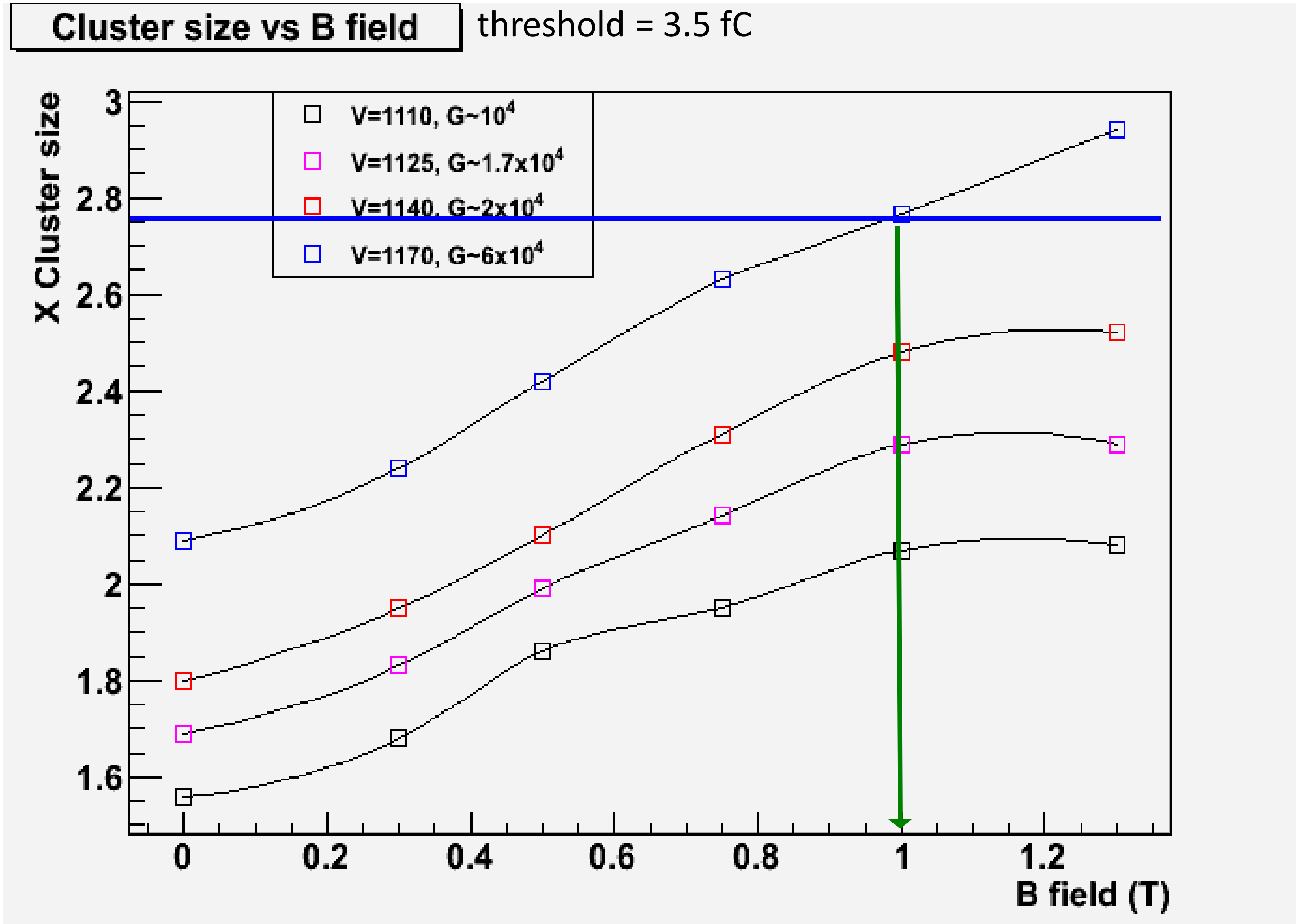
$\sigma = 376.6 \mu m$

Magnetic field (X-V angle = 40°): efficiency

A good efficiency in presence of magnetic field can be reached working at higher gain



Magnetic field (X-V angle = 40°): cluster size



BES IT
DAQ & FEE requirements

BES IT: DAQ requirements

1) Level-1 trigger rate (average): 1 a 2 kHz

2) Dead time: 4 µs

3) Latency: 8 µs +/- 0.5 µs

4) Event size: 12 kB (including ZDD)

5) System (distributed clock) ≈ 42 MHz (3 bunch crossings - 3x8ns)

- Counters to check events alignment ? Timestamp ?

6) Offline t_0 reconstruction

BESIII IT: 2D readout

Main requirements:

- Minimize electrode capacitance to reduce series noise contribution
  - Small width strips
  - Special strips design to reduce X-V $C_{COUPLING}$
  - GND plane far from the anode
- Minimize XV views crosstalk
  - Special strip design to reduce X-V coupling
  - GND plane near to the anode

STRIPS	*COMPASS*		*KLOE IT*		*BES IT (I)*		*BES IT (X view)*	
Width	350µ	80µ	250µ		350µ	80µ	350µ	80µ
Pitch	400µ		650µ		650µ		650µ	
Capacitance	≈ 17 pF		X ≈ 100 pF	V ≈ 1 ÷ 200 pF	≈ 41 pF		X_{SS} ≈ 41 pF	X_{SG}≈ 41 pF
Ground distance	≈ 3 mm (?)		≈ 200µ		≈ 3 mm		≈ 200µ	

BESIII IT: C_{STRIPS} effect on SNR (I)

Q_{STRIP} ≈ 6 fC (average, NO gas gain fluctuations)

- Ar/CO2 (70/30)
- G = 8000
- Factor 1/2 because the two view
- Factor 1/3 because the strip multiplicity

Example 1: COMPASS + APV25

- C_{STRIP} COMPASS ≈ 17 pF
- Z_{IN} APV25 ≈ 900 Ω (?!)

} rise time ≈ 33 ns

- APV25 shaping time ≈ 50 ns

} OK

- APV25 input noise ≈ 396 e + 59.4 e/pF (deconvolution mode) → Noise ≈ 0.26 fC

➡ SNR ≈ 23

BES IT: C_{STRIPS} effect on SNR (III)

$Q_{STRIP} \approx 6$ fC (average, NO gas gain fluctuations)

- Ar/CO2 (70/30)
- G = 8000
- Factor 1/2 because the two view
- Factor 1/3 because the strip multiplicity

Example 2: BES IT + APV25

- **C_{STRIP} BESIII ≈ 41 pF**
- Z_{IN} APV25 ≈ 900 Ω (?!)
- APV25 shaping time ≈ 50 ns
- APV25 input noise ≈ 396 e + 59.4 e/pF (deconvolution mode) → Noise ≈ 0.45 fC

} rise time ≈ 81 ns } NO

➡ SNR < 13 (ballistic deficit not considered !!)

Example 3: BES IT + VFAT2

- **C_{STRIP} BESIII ≈ 41 pF**
- Z_{IN} VFAT2 ≈ 120 Ω
- VFAT2 shaping time ≈ 22 ns
- VFAT2 input noise ≈ 400 e + 40 e/pF → Noise ≈ 0.33 fC

} rise time ≈ 21 ns } NO/OK

➡ SNR < 18 (ballistic deficit not considered !!)

Example 3: BES IT + GASTONE

- **C_{STRIP} BESIII ≈ 41 pF**
- Z_{IN} GASTONE ≈ 120 Ω
- GASTONE shaping time (C_D < 40 pF) ≈ 30 ns
- GASTONE input noise ≈ 800 e + 40 e/pF → Noise ≈ 0.4 fC

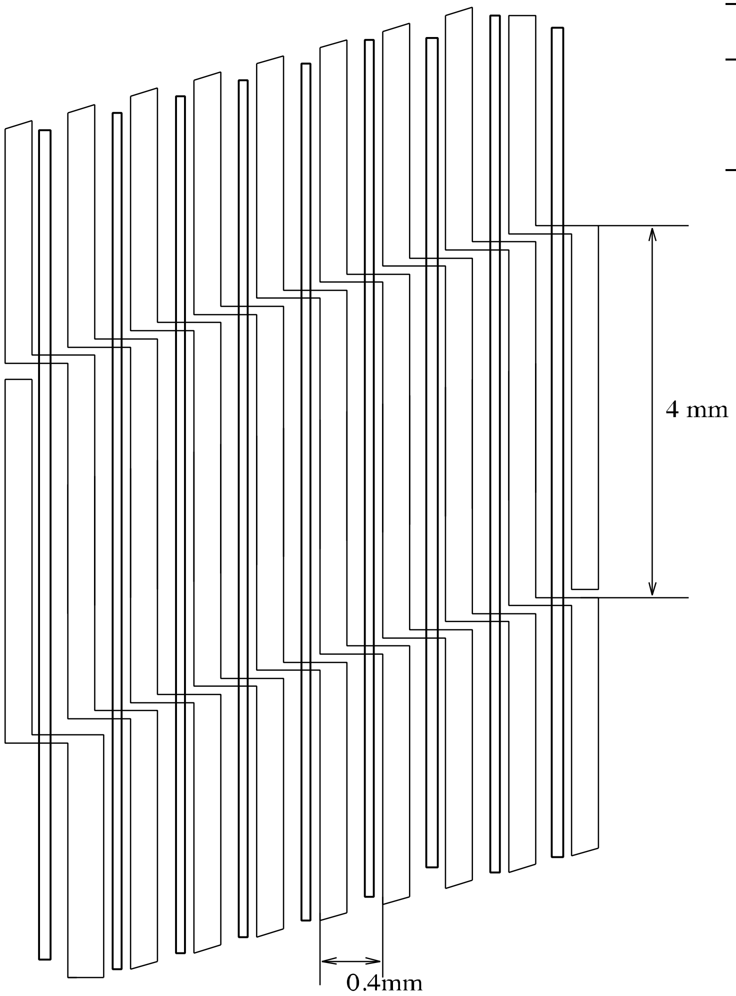
} rise time ≈ 21 ns } OK

➡ SNR ≈ 15

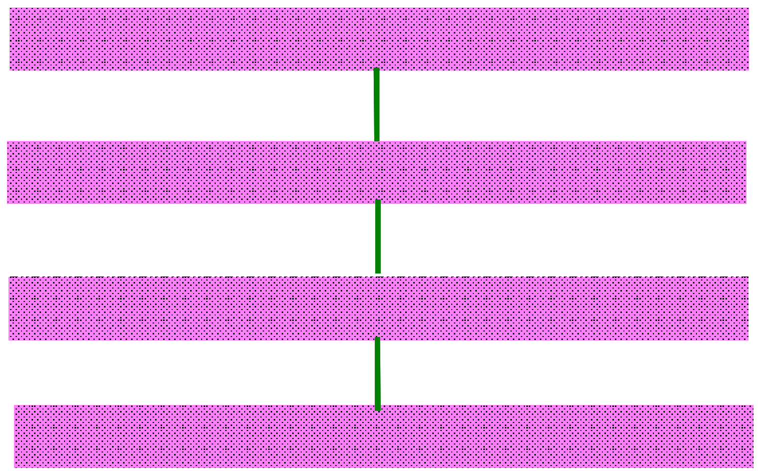
BES IT: readout conclusion (if any …) and open questions

- *The experience with the KLOE IT has shown that the preamplifier and the shaper must be carefully designed to maximize readout SNR for $C_D > 20$ pF*
- *A custom device is required for analog strips readout (mainly because the ≈ 8 µs DAQ latency and the foreseen value of C_D)*
  - *64/128 channels board*
    - *discharge protection network*
    - *charge measurement - resolution ?*
    - *time measurement - resolution ?*
    - *latency buffer up to 8 µs*
    - *Serial data readout (analog or digital)*
- *XV anode strips readout electrode must be designed to minimize parasitic capacitance*
- *XV crosstalk must be minimized as well*
  - *new strip size/geometry?*
- *Radiation background ? Do we need rad-tol devices near to the detector ? Probably NO, but …*

BES IT: Example of 2D optimized readout



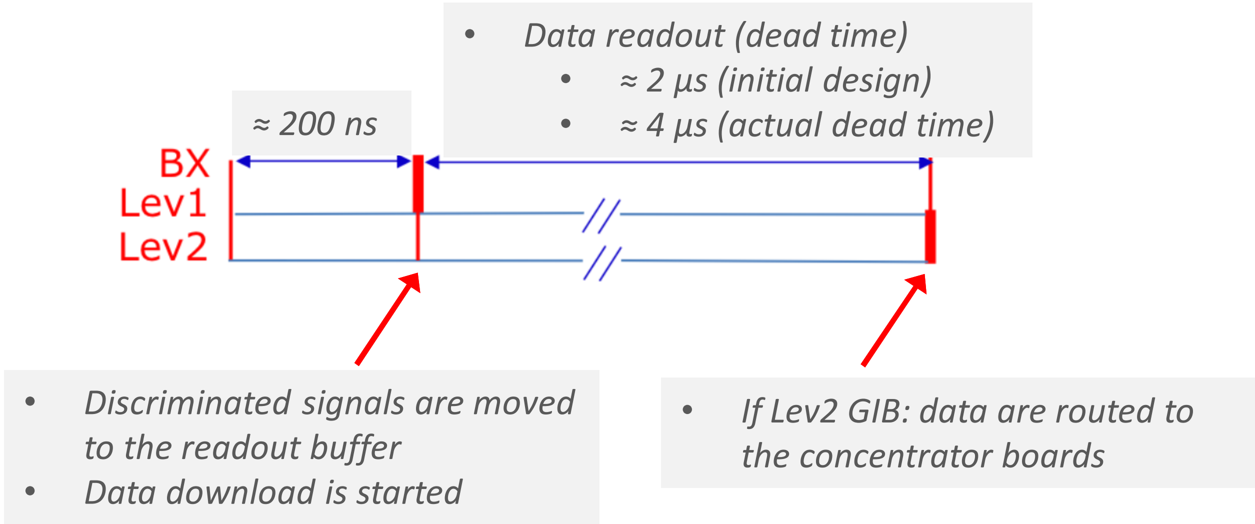
layer	strip width	pF/cm (calculation)	pF/cm (measurement)
bottom	150μ	0.62	0.73
top	60μ	0.32	0.54



A.Bondar et al., Performance of the triple-GEM detector with optimized 2-D readout in high intensity hadron beam

Spares

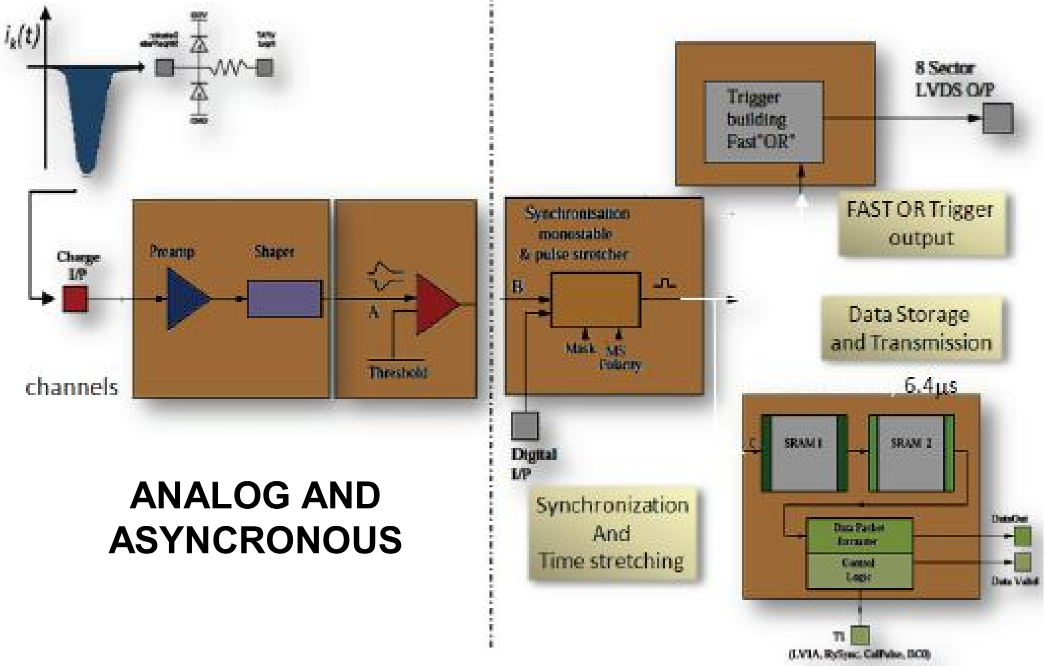
Spares: KLOE DAQ timing



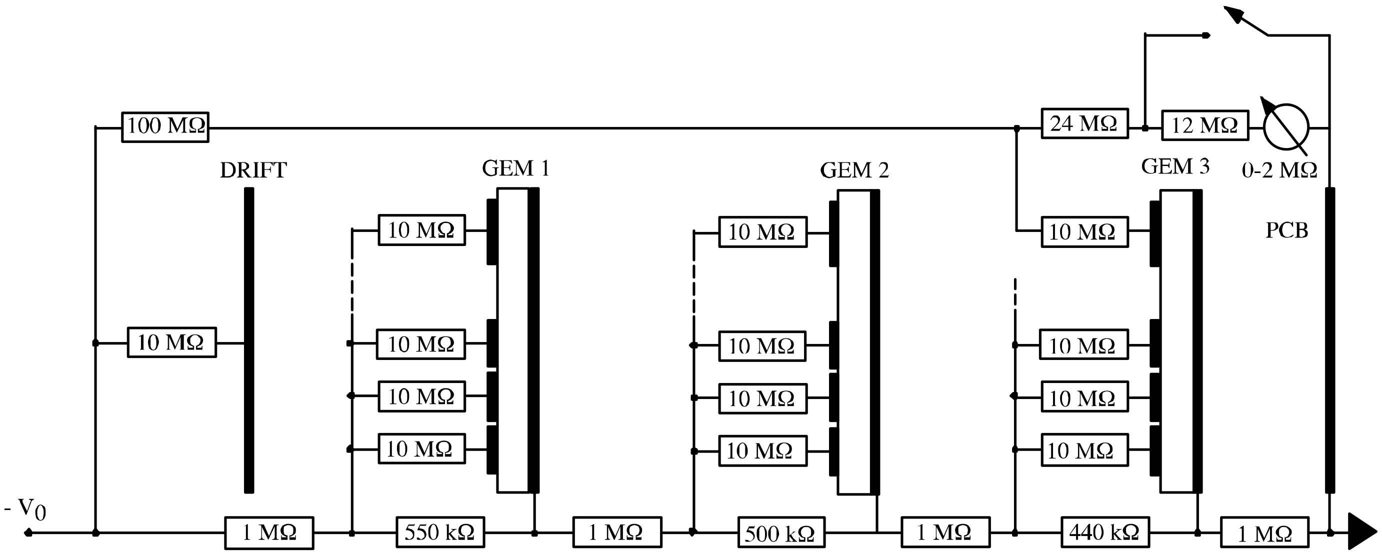
Spares: VFAT chip

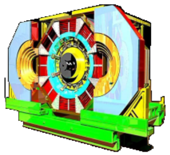
The VFAT(TOTEM) is a digital on/off chip for tracking and triggering with an adjustable threshold for each of the 128 channels; it uses 0.25μm CMOS technology and its trigger function provides programmable "fast OR" information based on the region of the sensor hit.

DIGITAL AND SYNCRONOUS

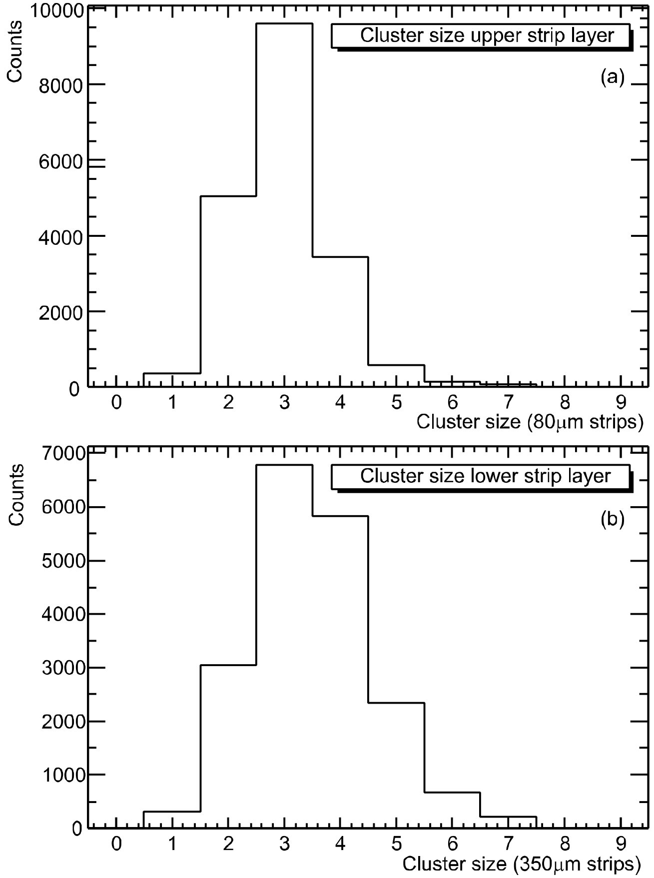


Spares: KLOE DAQ timing

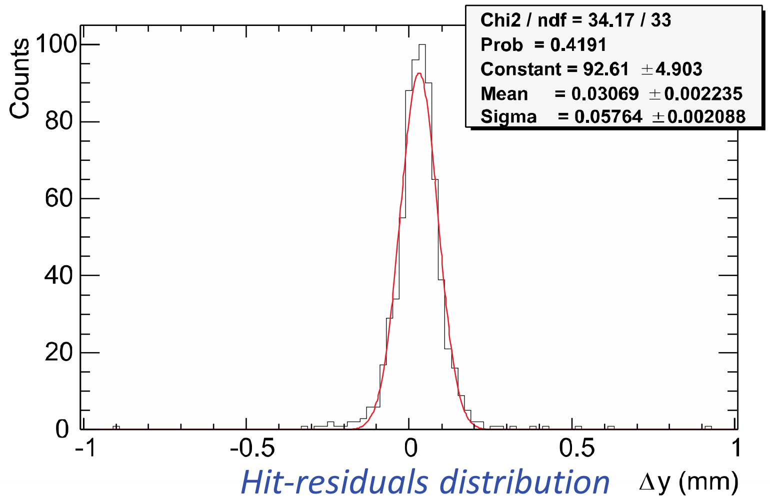




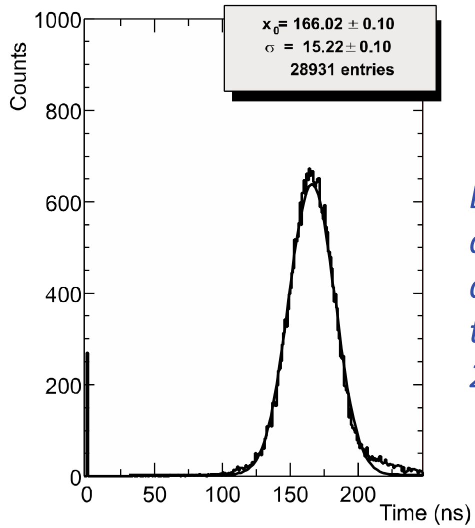
Some results from COMPASS



Cluster size distribution for 80 μm and 350 μm wide strips



Hit-residuals distribution



Events arrival time distribution (signal amplitudes measured in three successive time bins of 25 ns)