Micromegas for the Upgrade of the ATLAS Muon Chambers

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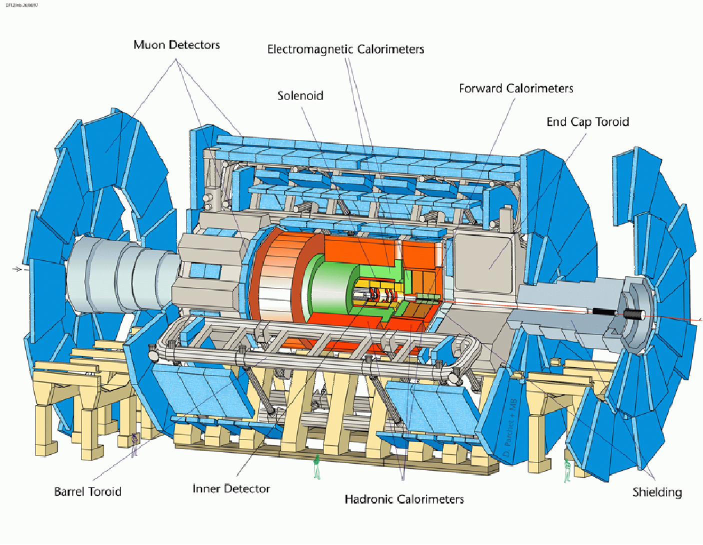
on behalf of MAMMA-RD51 R&D Program

Arizona, Athens (U, NTU, Demokritos), Brookhaven, CERN,
Harvard, Istanbul (Bogaziçi, Doğuş), Naples, Seattle, USTC
Hefei, South Carolina, St. Petersburg, Shandong, Thessaloniki

RD51 – mini week @ CERN, 25.09.2009

thanks to P. Iengo & K. Nikolopoulos for providing some of the material

ATLAS upgrade for the s-LHC



LHC upgrade to happen in two phases

$L_{\text{Phase 1}} \sim 3\ L_{\text{LHC}}$ (~2014)

$L_{\text{Phase 2}} \sim 10\ L_{\text{LHC}}$ (s-LHC >2018)

Bunch Crossing = 25 ns / possibly 50 ns (Phase 2)

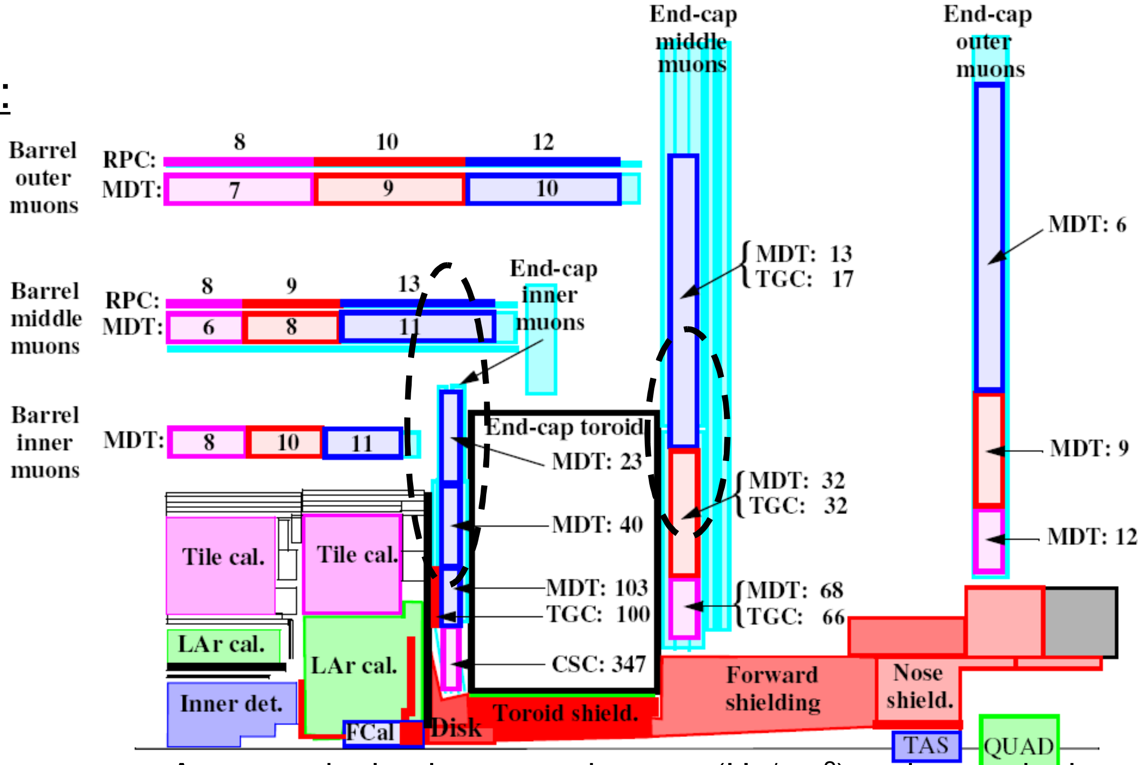
<u>Muon Spectrometer affected regions :</u>

- End-Cap Inner (CSC,MDT,TGC)
- End-Cap Middle |η|>2 (MDT,TGC)

Total area ~400 m^2

Phase I : augment the existing Cathode Strip Chambers (CSC)

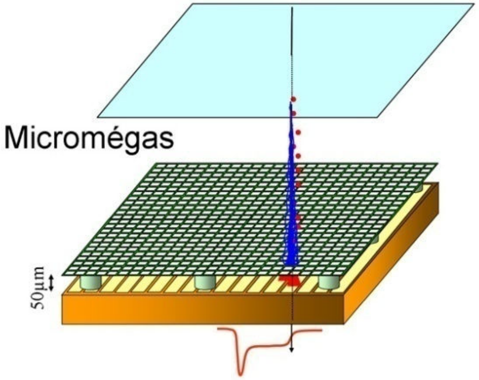
Counting rates to be measured with first LHC collisions → Reduce uncertainty



Average single plane counting rate (Hz/cm^2) at the nominal LHC luminosity (CERN-ATL-GEN-2005-001)

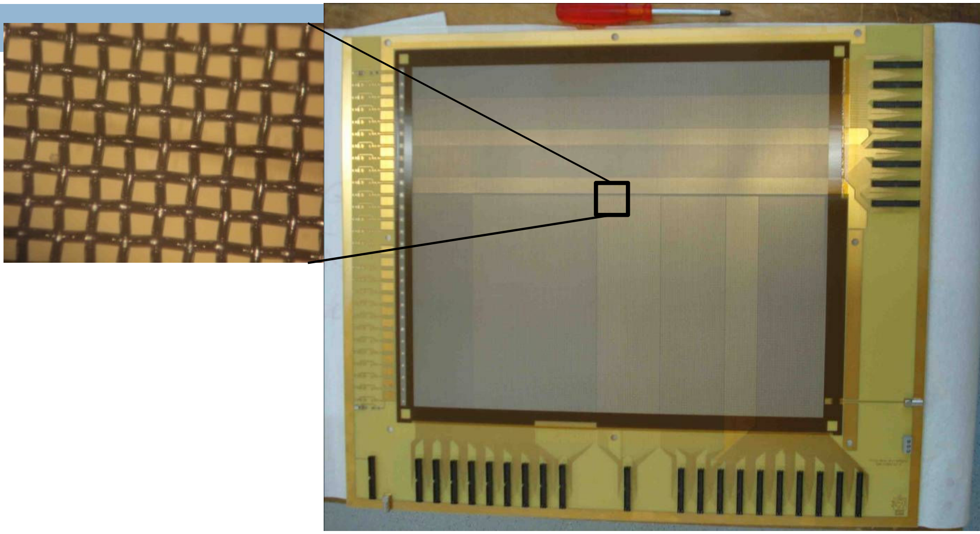
Micromegas for ATLAS Muon upgrade

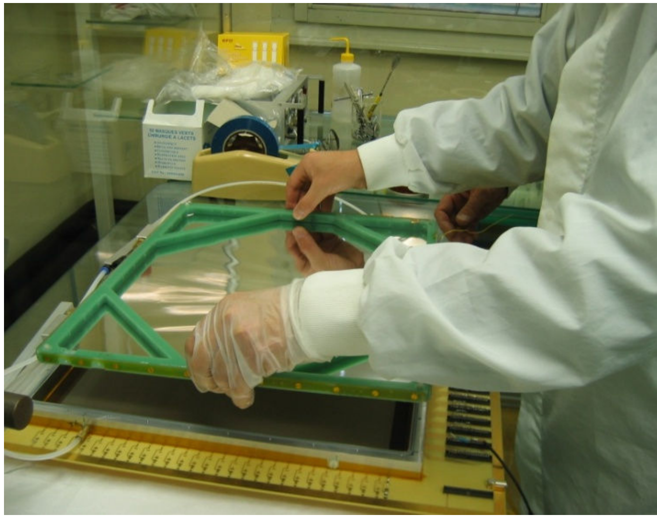
- Combine triggering and tracking functions
- Matches required performances:
  - Spatial resolution <80 μm (Θ_{track}< 45°)
  - Good double track resolution
  - Time resolution ~ 5 ns
  - Efficiency > 99%
  - Rate capability > 5 kHz/cm^2
  - 200 Hz/cm^2 due to neutrons with E>100 keV
  - Stability over about 5 years at phase-1 luminosity (≅1000 fb^{-1})



- Potential for going to large areas ~1m x 2m with industrial proc.
  - Cost effective & Robustness

Prototype P1/P2





- Standard bulk micromegas fabricated at CERN-TS/DEM
- Homogeneous stainless steel mesh
- 325 line/inch = 78 μm pitch
- Wire diameter ~25 μm
- Amplification gap = 128 μm
- 450mm x 350mm active area (P1),

  100mm x100mm active area(P2)
- Different strip patterns (250, 500, 1000, 2000 μm pitch; 450mm and 225 mm long) for P1, 250/150 for P2
- Drift gap: 5 mm
- Characterized in lab and tested on beam

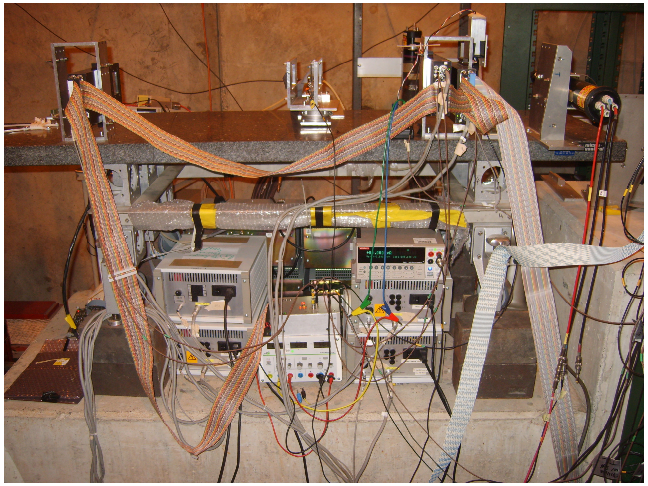
Test beam set up

- P1 tested @ CERN H6 beam line in November 2007, June to August 2008 & July 2009
- P2 tested during July 2009
- 120 GeV pion beam
- Scintillator trigger
- External tracking with three Si detector modules (Bonn Univ.); independent DAQ
- Three non-flammable gas mixtures with small isobutane percentage used in 2008:

  $Ar:CO_2:iC_4H_{10}$ (88:10:2), $Ar:CF_4:iC_4H_{10}$ (88:10:2), $Ar:CF_4:iC_4H_{10}$(95:3:2)

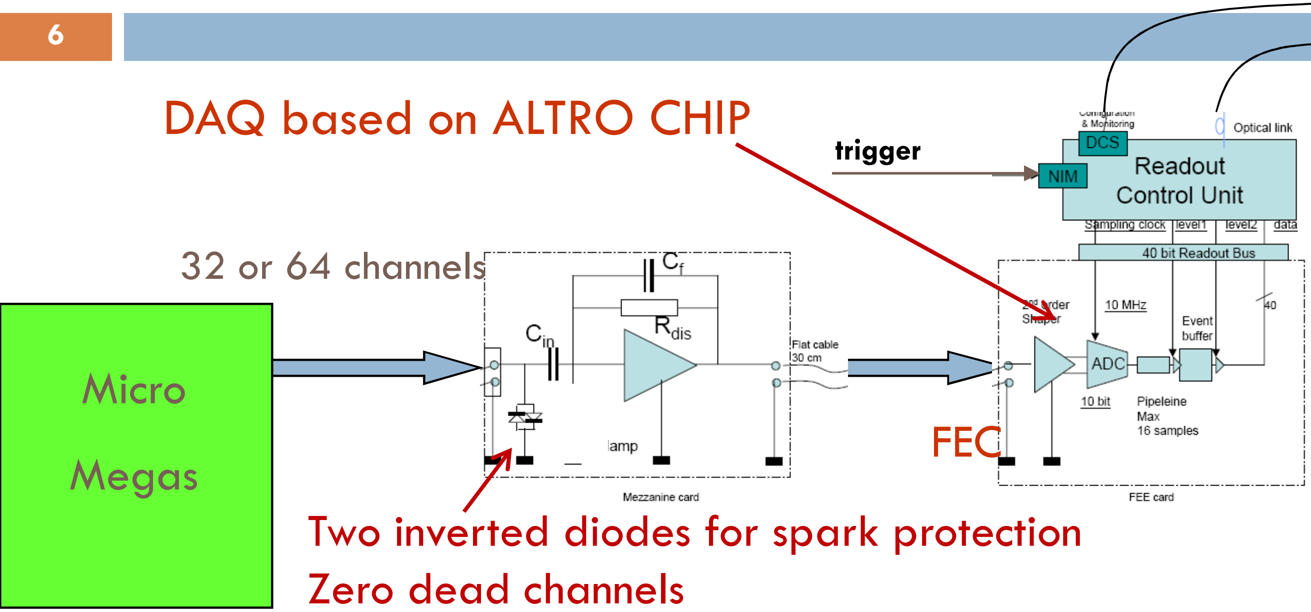
  $Ar:CO_2$ (85:15) for P2
- Data acquired for 4 different strip patterns and 5 impact angles (0 to 40 degrees) for P1 and P2

2008 Test beam set up



2009 Test beam set up

Readout



DAQ based on ALTRO CHIP

DAQ PC (ALICE DATE)

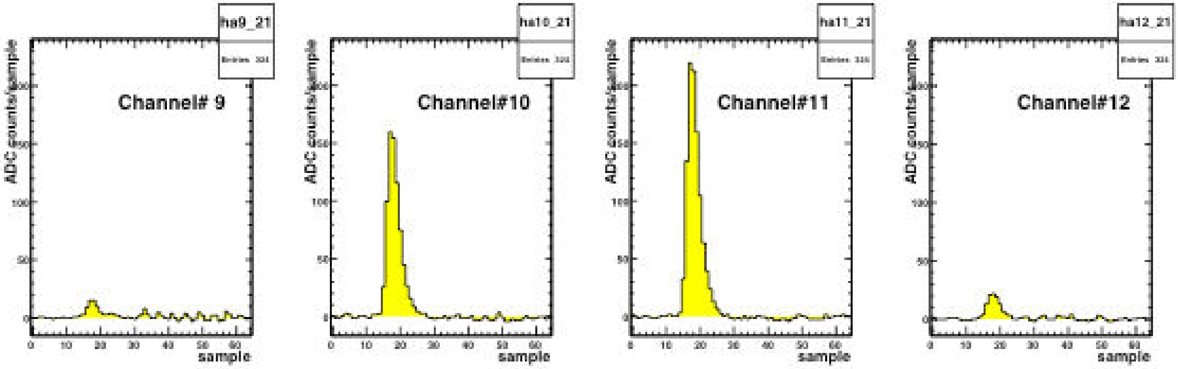
Two inverted diodes for spark protection

Zero dead channels

64 channels
200 ns integration time
65 charge samples/ch
100 ns/sample
15 pre-samples
1 ADC count ~ 1000 e^-

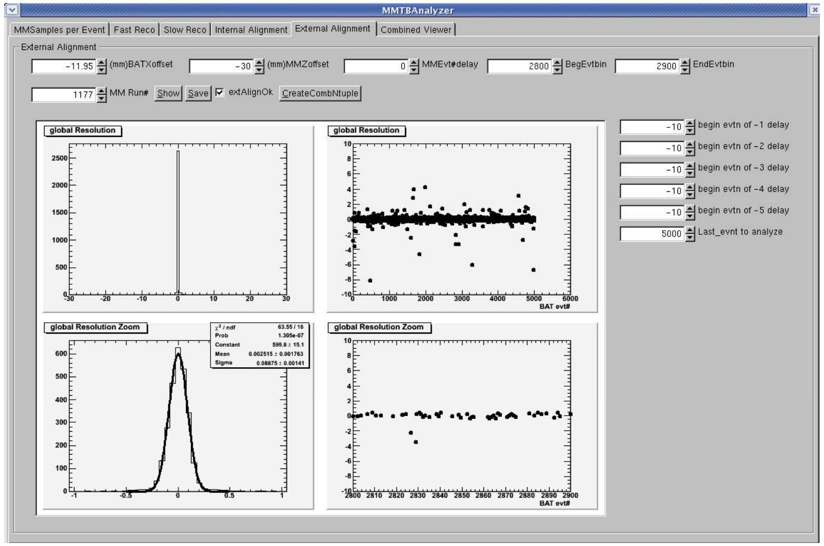
Typical ADC spectra

- Noise subtraction (from 12 pre-samples)
- Custer position from center of gravity



Software tool

- ☐ Software tool for quasi online and off-line reconstruction (based on ROOT)
- ☐ Permits alignment of Si tracker modules with MM chamber
- ☐ Combines data from Si tracker and MM
- ☐ Provides 'online' resolution
- ☐ Also: simple event display



External Alignment

-11.95 (mm)BATXoffset

-30 (mm)MMZoffset

0 MMEvt#delay

2800 BegEvtbin

2900 EndEvtbin

1177 MM Run#

☑ extAlignOk

-10 begin evtn of -1 delay

-10 begin evtn of -2 delay

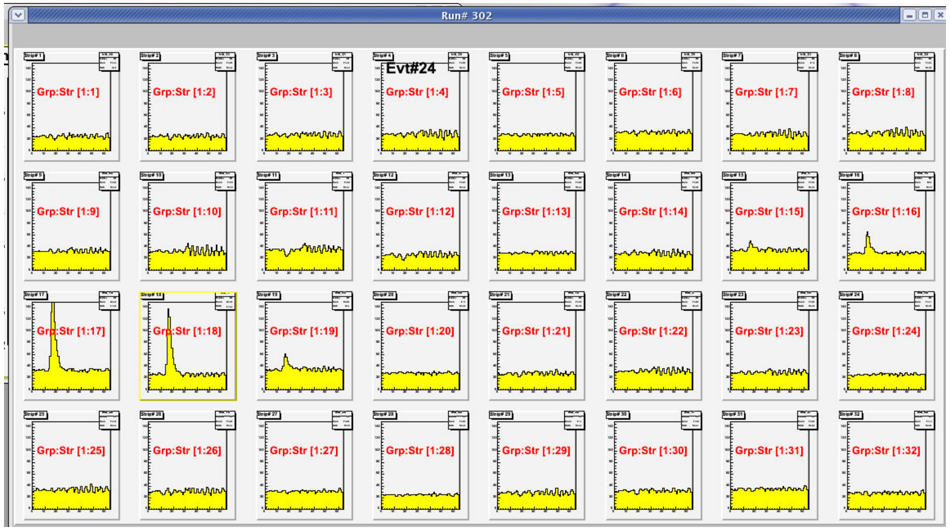
-10 begin evtn of -3 delay

-10 begin evtn of -4 delay

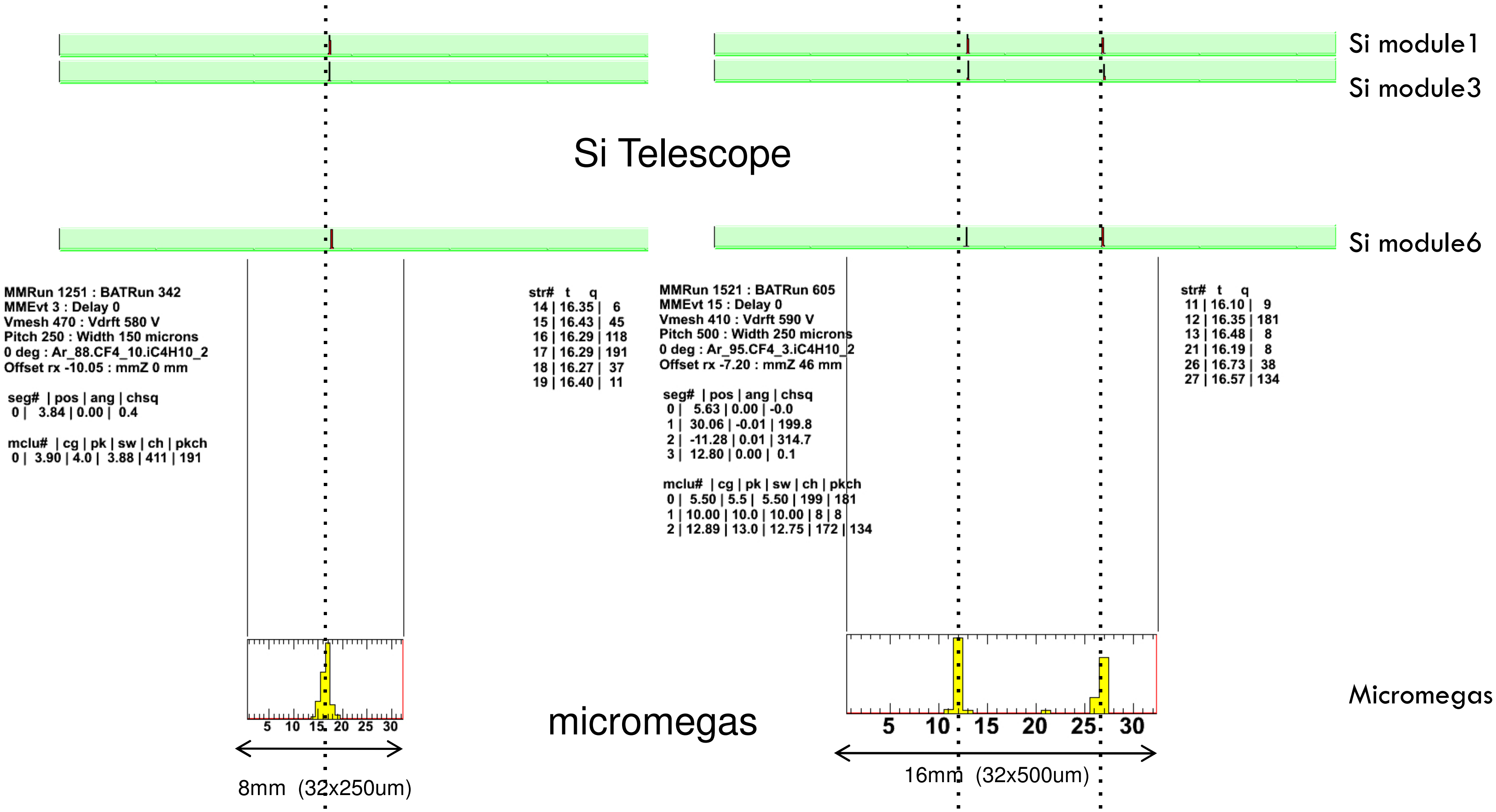
-10 begin evtn of -5 delay

5000 Last_evnt to analyze

χ^2 / ndf	63.55 / 16
Prob	1.305e-07
Constant	599.8 ± 15.1
Mean	0.002515 ± 0.001763
Sigma	0.08875 ± 0.00141



Simple event display



```
MMRun 1251 : BATRun 342
MMEvt 3 : Delay 0
Vmesh 470 : Vdrft 580 V
Pitch 250 : Width 150 microns
0 deg : Ar_88.CF4_10.iC4H10_2
Offset rx -10.05 : mmZ 0 mm

 seg#  | pos | ang | chsq
  0 |   3.84 | 0.00 |  0.4

 mclu#  | cg | pk | sw | ch | pkch
  0 |  3.90 | 4.0 |  3.88 | 411 | 191
```

```
str#   t     q
 14 | 16.35 |   6
 15 | 16.43 |  45
 16 | 16.29 | 118
 17 | 16.29 | 191
 18 | 16.27 |  37
 19 | 16.40 |  11
```

```
MMRun 1521 : BATRun 605
MMEvt 15 : Delay 0
Vmesh 410 : Vdrft 590 V
Pitch 500 : Width 250 microns
0 deg : Ar_95.CF4_3.iC4H10_2
Offset rx -7.20 : mmZ 46 mm

 seg#  | pos | ang | chsq
  0 |   5.63 | 0.00 | -0.0
  1 |  30.06 | -0.01 | 199.8
  2 |  -11.28 | 0.01 | 314.7
  3 |  12.80 | 0.00 |  0.1

 mclu#  | cg | pk | sw | ch | pkch
  0 |  5.50 | 5.5 |  5.50 | 199 | 181
  1 | 10.00 | 10.0 | 10.00 | 8 | 8
  2 | 12.89 | 13.0 | 12.75 | 172 | 134
```

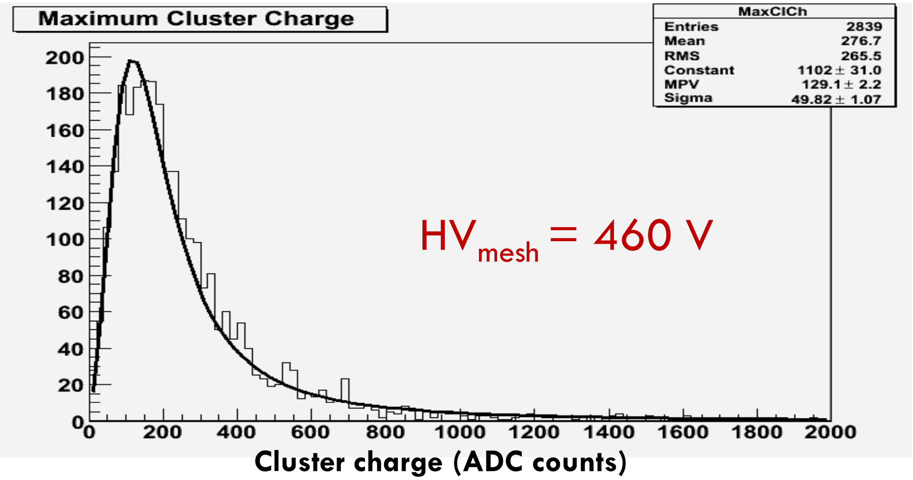
```
str#   t     q
 11 | 16.10 |   9
 12 | 16.35 | 181
 13 | 16.48 |   8
 21 | 16.19 |   8
 26 | 16.73 |  38
 27 | 16.57 | 134
```

Single track event

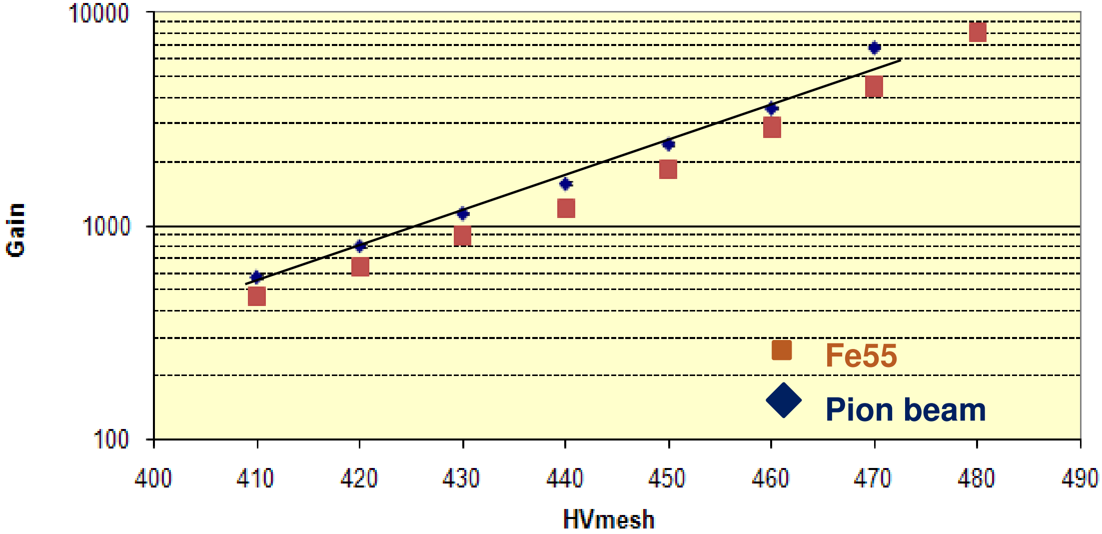
double track event

Gain measurement from HV_{mesh} scan

- Gas mixture: $Ar:CF_4:iC_4H_{10}$ (88:10:2)
- Drift gap 5 mm; drift field = 200 V/cm
- Strip pitch = 250 µm
- 1 ADC count = 1000 electrons

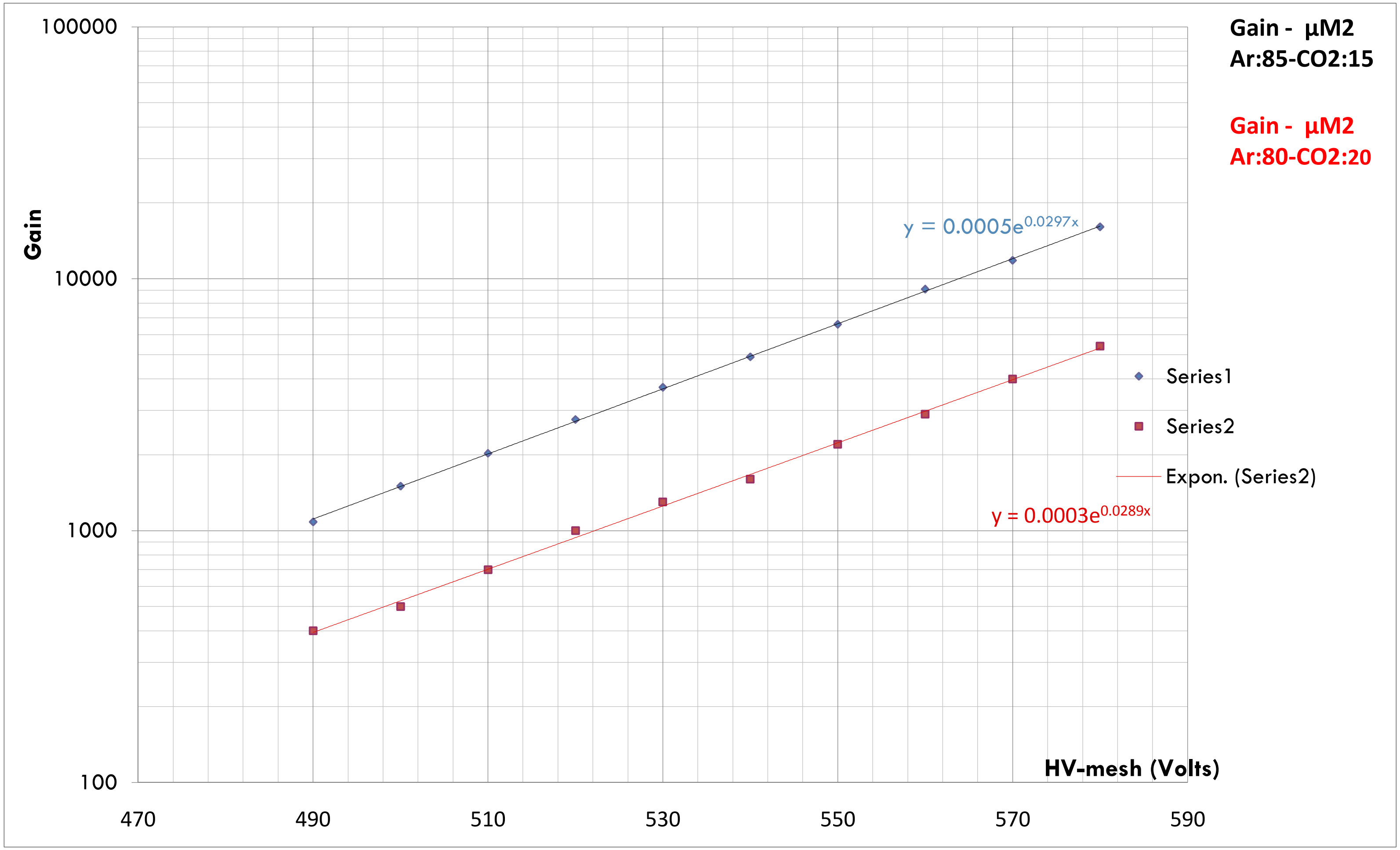


HV_{mesh} = 460 V

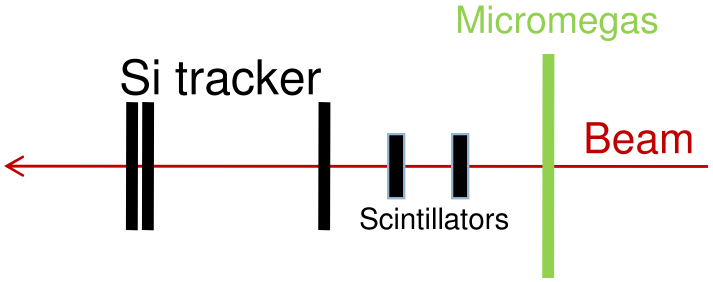


- Good agreement with measurement with ^{55}Fe source
- Stable working point @ gain ~ $3 \cdot 10^3$

Gain measurement from Fe55



Spatial resolution – ‘online’

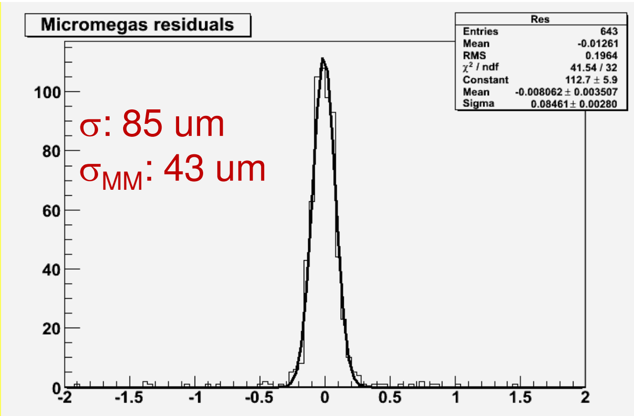


Gas: Ar:CF_4:iC_4H_{10} (88:10:2)
Drift field: 200 V/cm

- Residuals of MM cluster position and extrapolated track from Si
- Convolution of:
  - Intrinsic MM resolution
  - Tracker resolution (extrapolation)
  - Multiple scattering

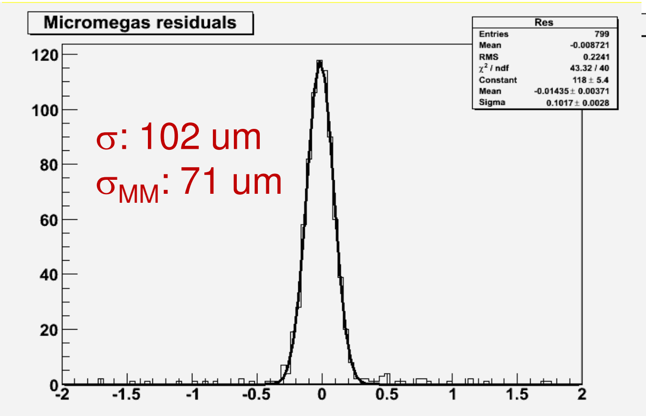
$\left.\begin{matrix}\text{Tracker resolution (extrapolation)}\\ \text{Multiple scattering}\end{matrix}\right\}$ ~73 μm

Strip pitch: 250 μm
Strip width: 150 μm



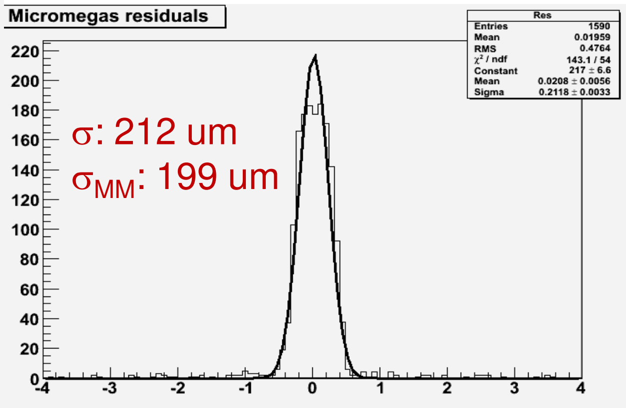
σ: 85 um
σ_{MM}: 43 um

Strip pitch: 500 μm
Strip width: 400 μm



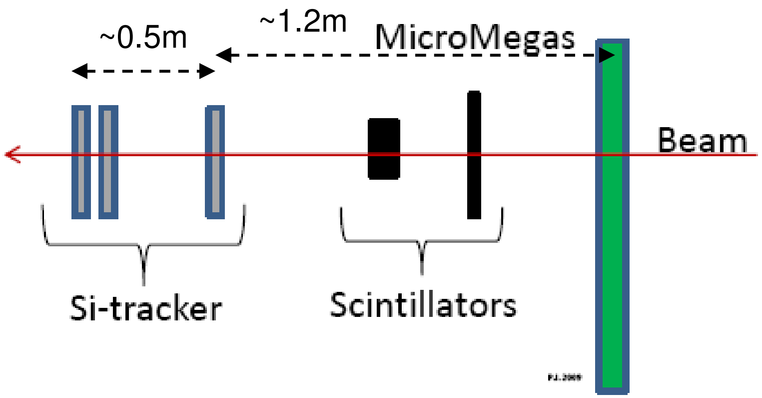
σ: 102 um
σ_{MM}: 71 um

Strip pitch: 1000 μm
Strip width: 900 μm



σ: 212 um
σ_{MM}: 199 um

Spatial resolution – ‘offline’



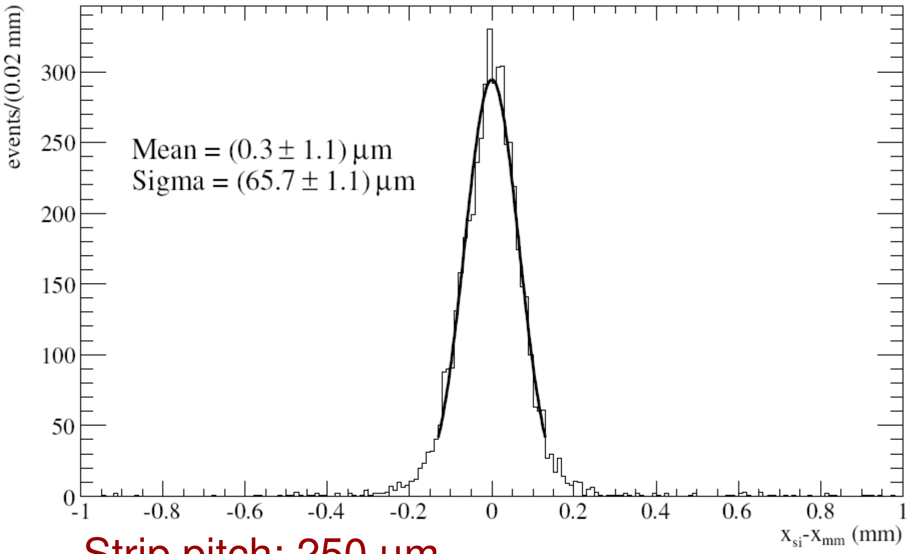
Gas: Ar:CF_4:iC_4H_{10} (88:10:2)
V_{mesh} = 470 V (36.7 kV/cm)
Drift field = 220 V/cm
Perpendicular tracks

Residuals of MM cluster position and extrapolated track from Si.
Three contributions to width of distribution :

- –Si Telescope extrapolation @ µM → ~30 µm
- –Multiple scattering → ~53 µm
- –Intrinsic µM resolution

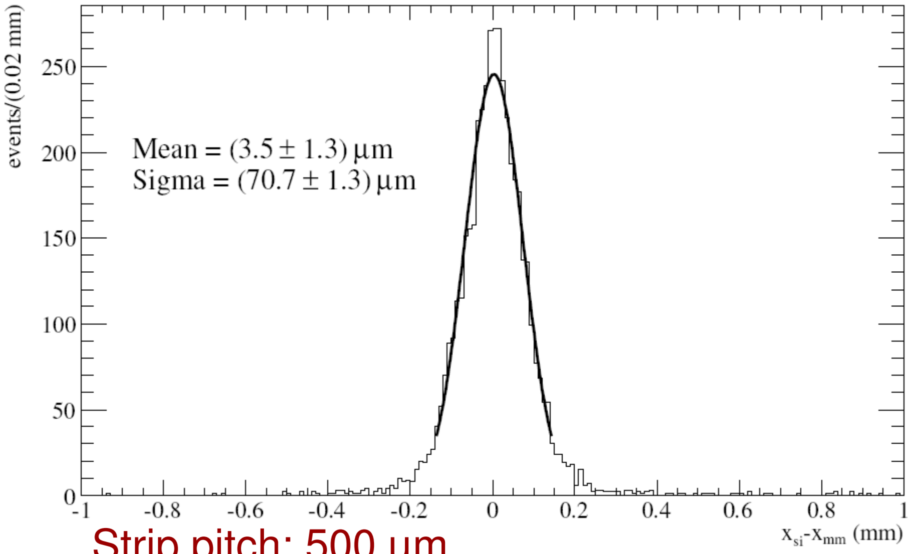
~30 µm and ~53 µm: ~61 µm

$\sigma_{\mu M}$ = (24±7) µm



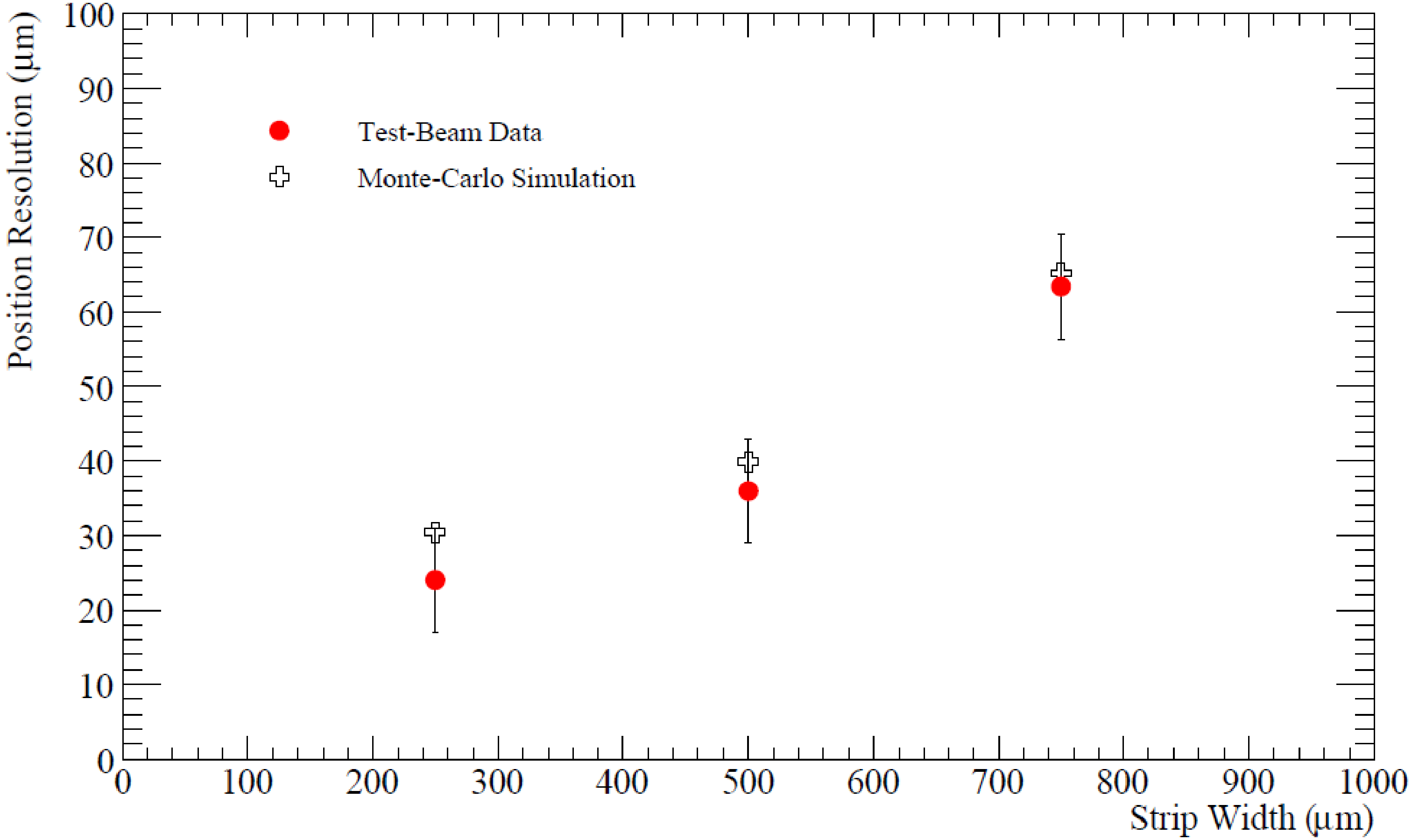
Strip pitch: 250 µm

$\sigma_{\mu M}$ = (36±5) µm



Strip pitch: 500 µm

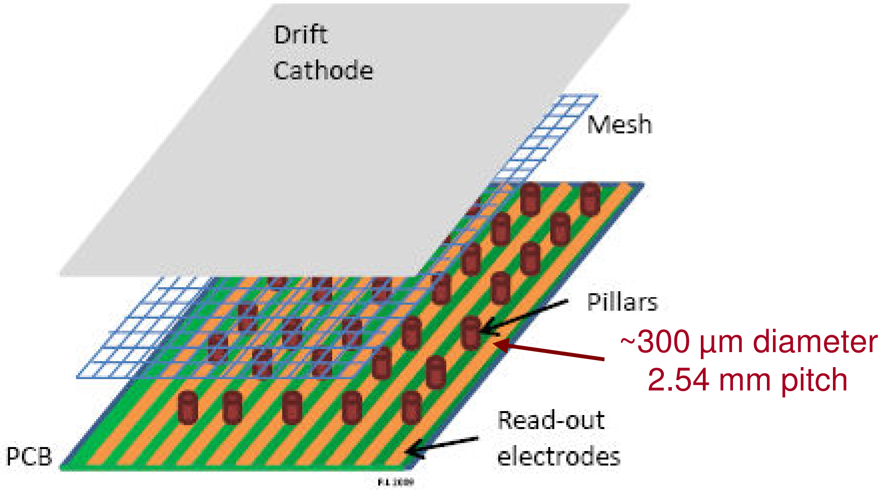
Comparison with real data



The simulated resolution is in agreement with the **test beam data** resolution

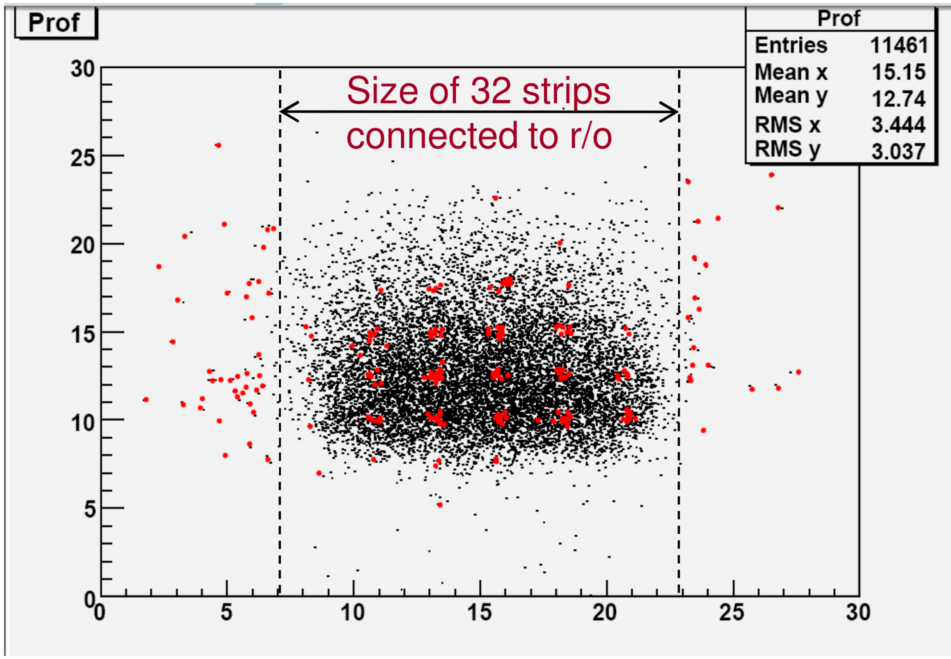
See K.N. talk at MPGD 2009: **http://cern.ch/knikolop/nikolopoulos_MPGD2009.ppt**

Efficiency: pillars localization



~300 µm diameter
2.54 mm pitch

- Ar:CF_4:iC_4H_{10} (88:10:2)
- Strips: 500 µm pitch
- V_{mesh} = 450 V (35.2 kV/cm)
- Drift field = 200 V/cm

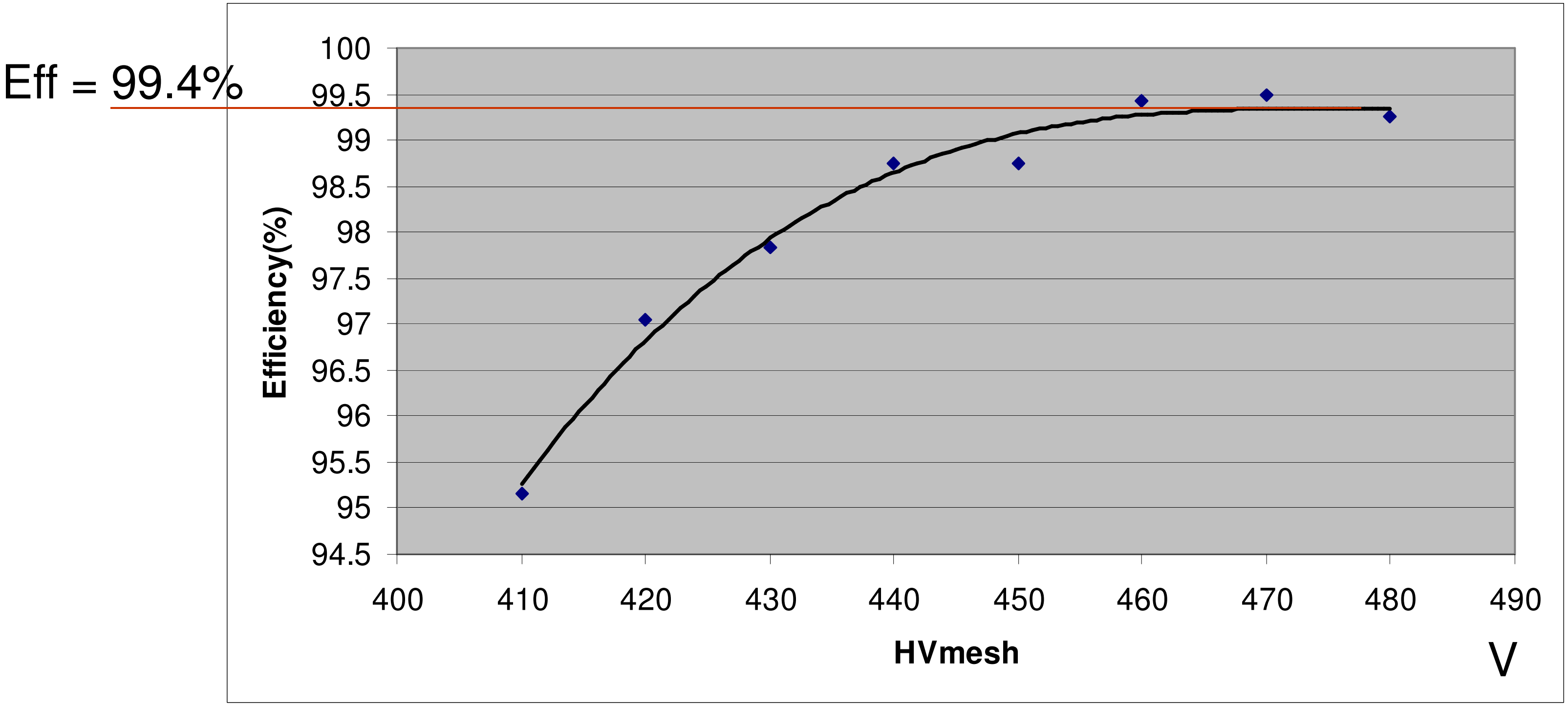


Size of 32 strips
connected to r/o

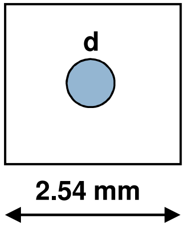
Black: beam profile
Red: tracks w/o Micromegas hit

Pillars contribute to the geometrical inefficiency of the chamber at the ~1% level.

Efficiency measurement



Eff = 99.4%



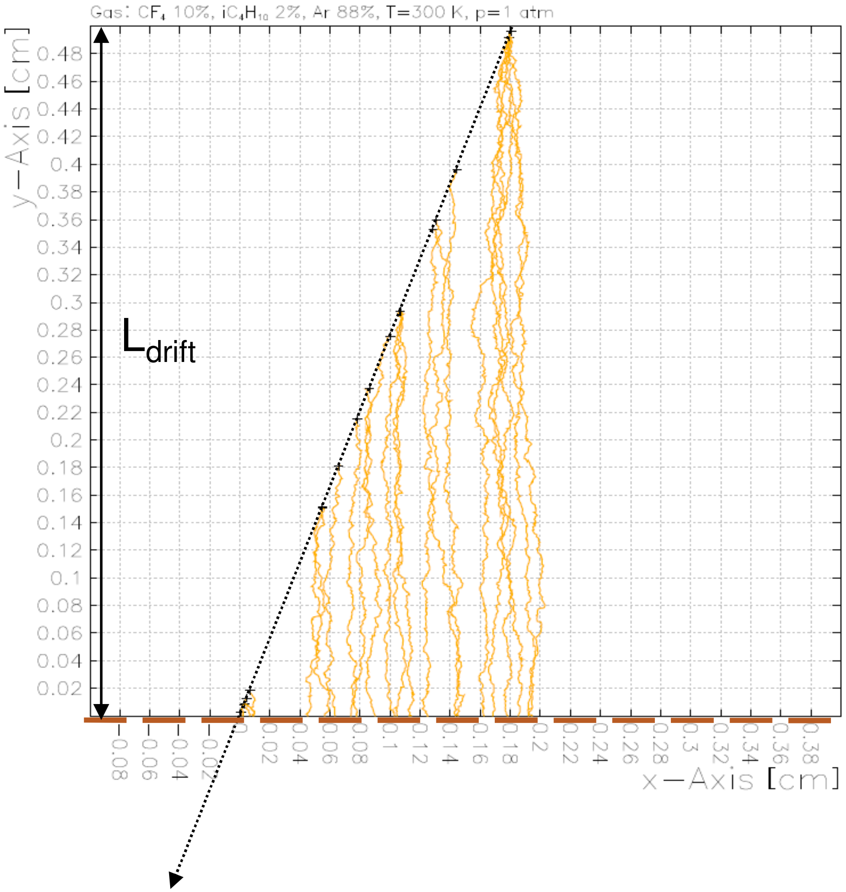
d estimated= 2*sqrt((Ineff)*L^2/pi)) = 222 µm

d real ~ 300 µm

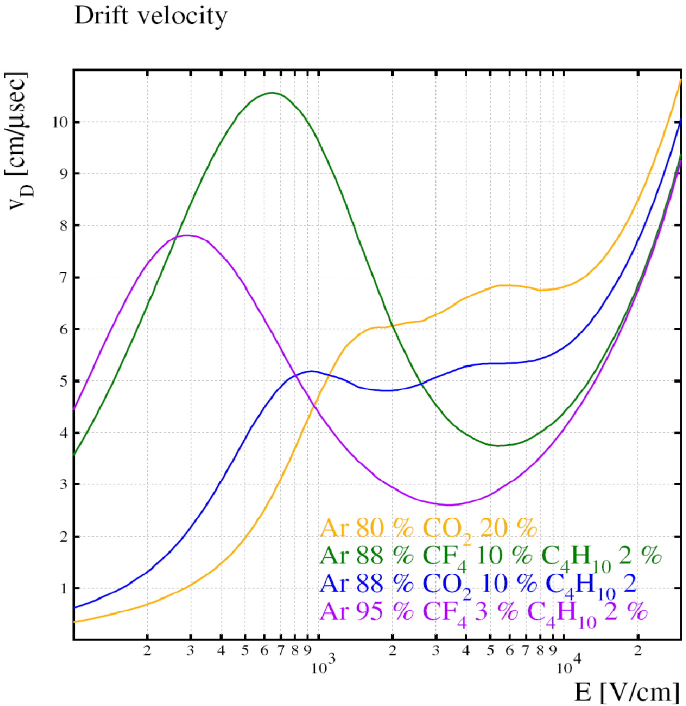
Micromegas as μ-TPC[1]

For non-perpendicular incidence
→ position resolution degraded due to fluctuation of charge deposition along the track

Use the Micromegas as a μ-TPC
→Measure arrival time of signals on strips and reconstruct space points in the drift gap

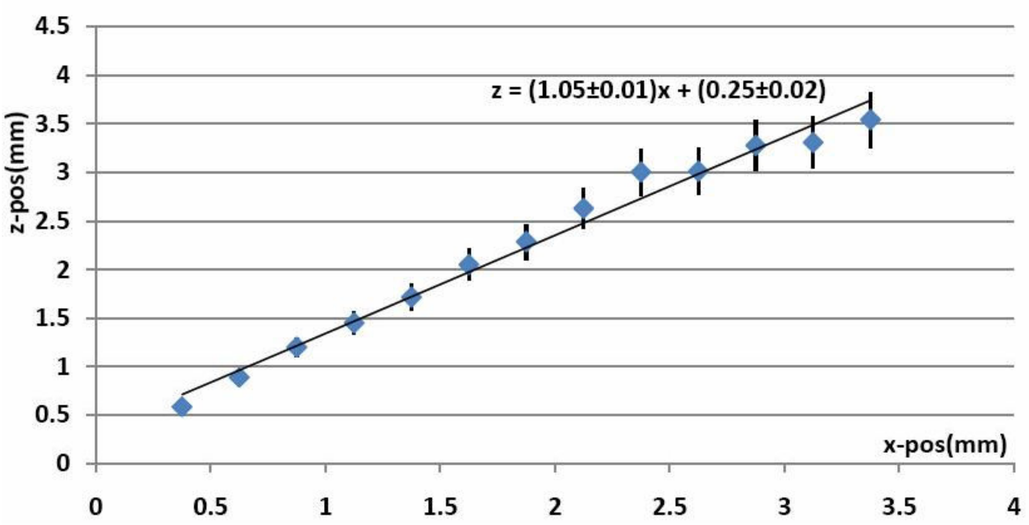


Time resolution 1ns → σ_y ~ 5 -10 μm



Micromegas as μ-TPC²

Even with non-optimal r/o electr. measuring the arrival time on each strip it is possible to measure the drift velocity or, with known drift velocity, the drift distance



Example test-beam event

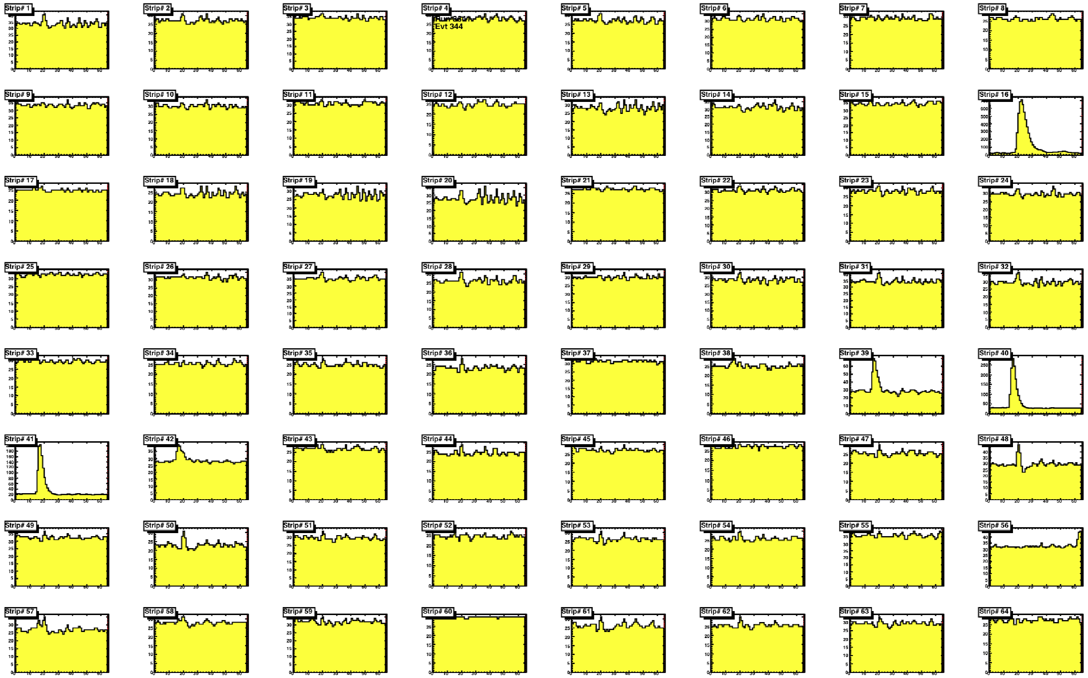
Local track direction can be advantageous for pattern recognition

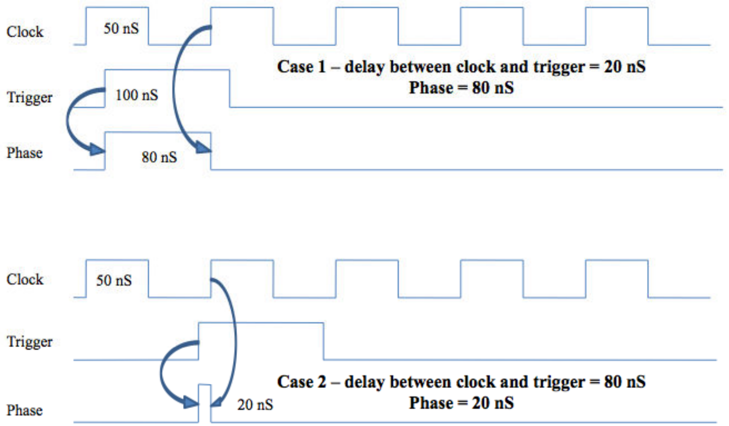
- Gas: Ar:CF_4:iC_4H_{10} (95:3:2)
- Drift field = 360 V/cm
- Drift velocity = 7.8 cm/μs (Magboltz)
- Chamber rotation = (40±3)º
- Reconstructed track inclination = (44±4)º

2008 electronics not ideal for this study
→ but 2009 setup is improved for this due to the timing measurement

Promising/challenging → potentially solves angle problem → Interesting R&D

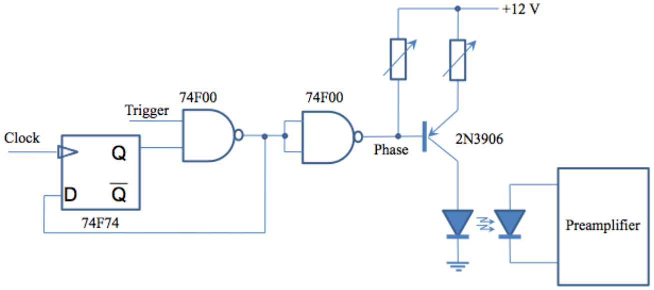
Timing Measurement

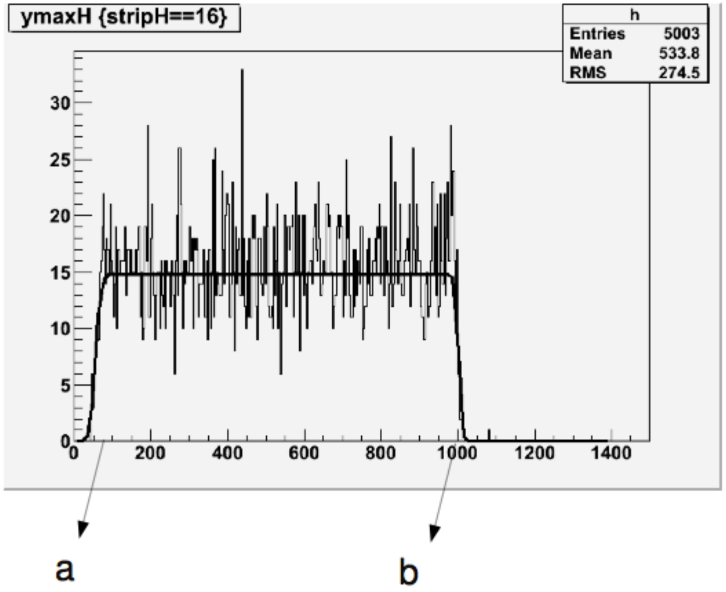




Case 1 – delay between clock and trigger = 20 nS
Phase = 80 nS

Case 2 – delay between clock and trigger = 80 nS
Phase = 20 nS





Test Beam July 2009

Studies:

- **Large Micromegas with T2K gas ($Ar:CH_4$:Isobutane - 95:3:2)**
- **Small Micromegas with $Ar:CO_2$ – 85:15**
- **HV Drift scan 500 V - 890 V**
- **HV Mesh scan 360 V – 590 V**
- **Angular Scans 0°,5°,10°,20°,30°,40°**
- **Different strips configurations**
- **Material in front (iron bricks)**

New for this Run

- **Time measurement**
- **Sparks registration (current & sparking rate)**
- **New gas line for $Ar:CO_2$ – 85:15**
- **New shielding for the 2nd FEC**
- **Different Geometry reducing MS contribution**

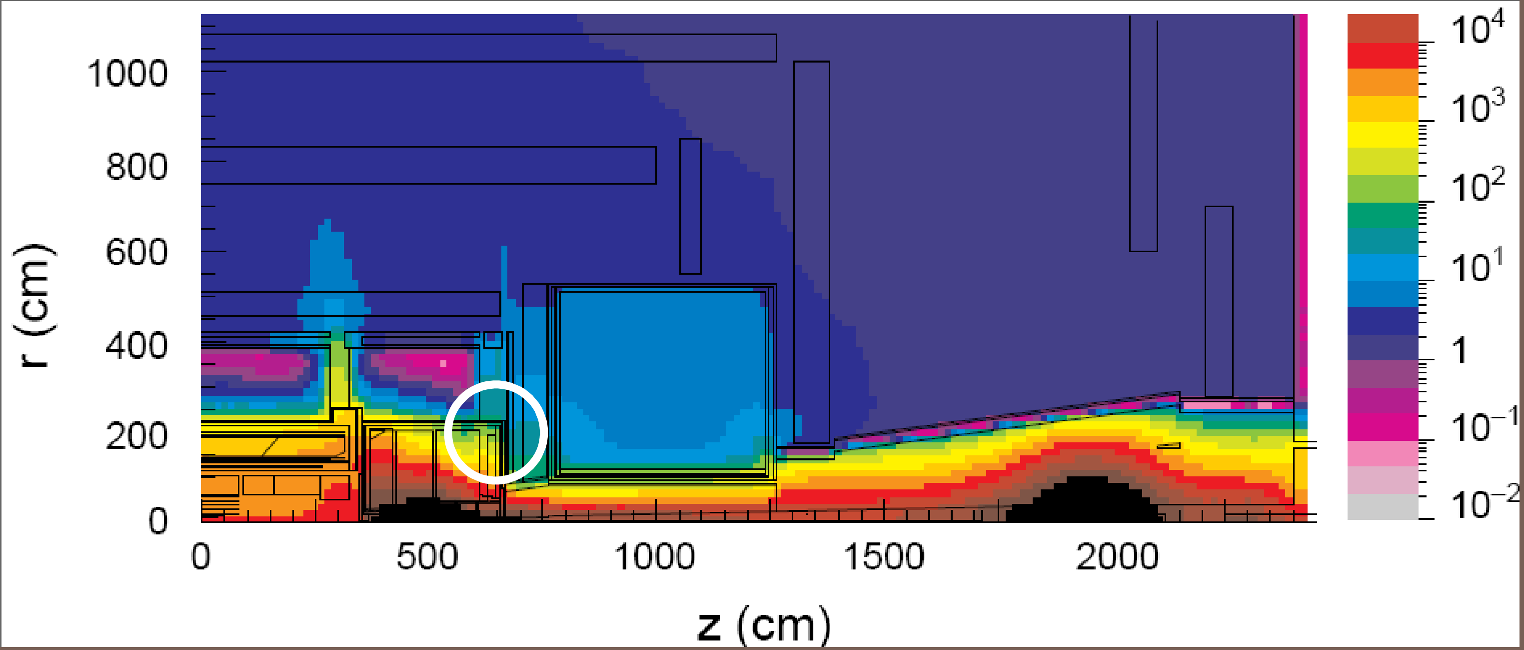
Next steps into consideration

- **More data in parasitic mode**
- **New chamber with resistive coating in the test beam in September**

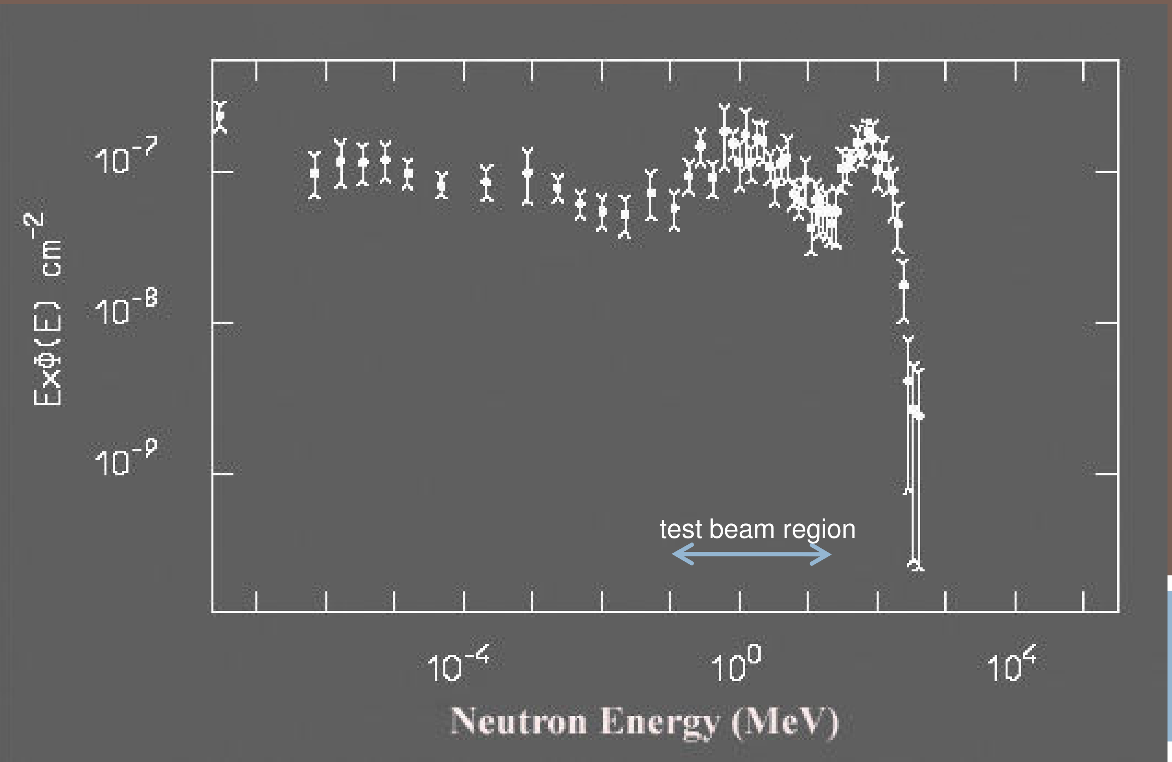
Next tasks

- **Data Analysis**

More than 1 M triggers recorded



The expected neutron fluence (kHz/cm^2) in the ATLAS Hall (ATLAS muon TDR, 1997)



The energy spectrum of the expected neutron background radiation in the Atlas Hall (ATLAS muon TDR, 1997)

The “N.C.S.R. Demokritos” neutron facility

- 5.5 MV TN11 HV Tandem Van der Graaff accelerator
- Three neutron energy ranges can be produced by this facility, via three different nuclear reactions:

Nuclear Reaction	Proton/Deuteron Energy Range (MeV)	Neutron Energy Range (MeV)
^{7}Li(p,n)^{7}Be	1.9 to 8.4	0.1 to 6.7*
^{2}H(d,n)^{3}He	0.8 to 8.4	3.9 to 11.5**
^{3}H(d,n)^{4}He	0.8 to 8.4	16.4 to 25.7***

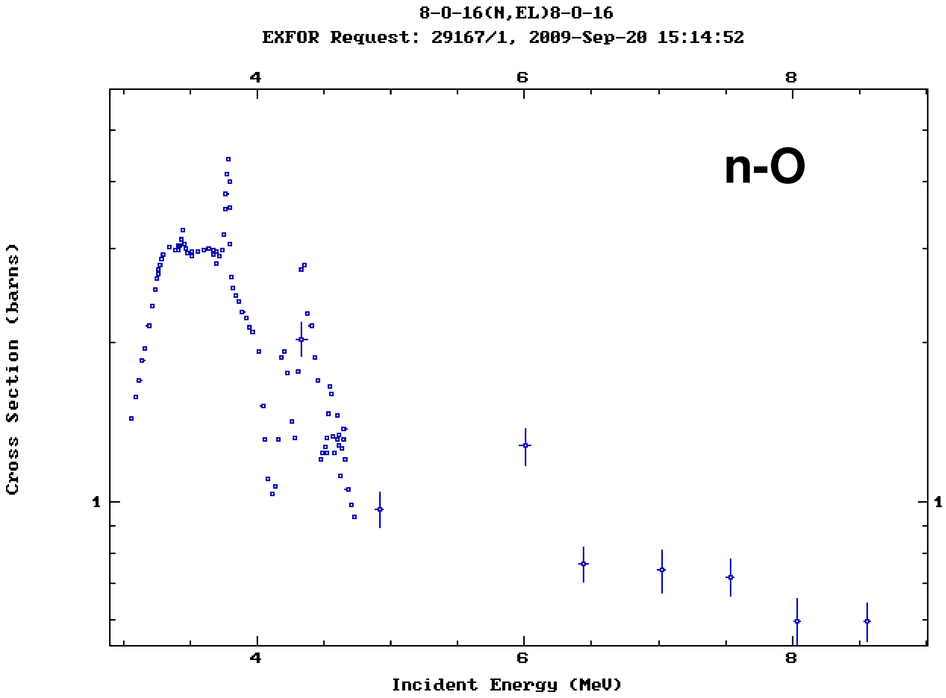
* Monoenergetic neutrons [0.1,0.5] MeV & quasimonoenergetic up to ~2.5 MeV

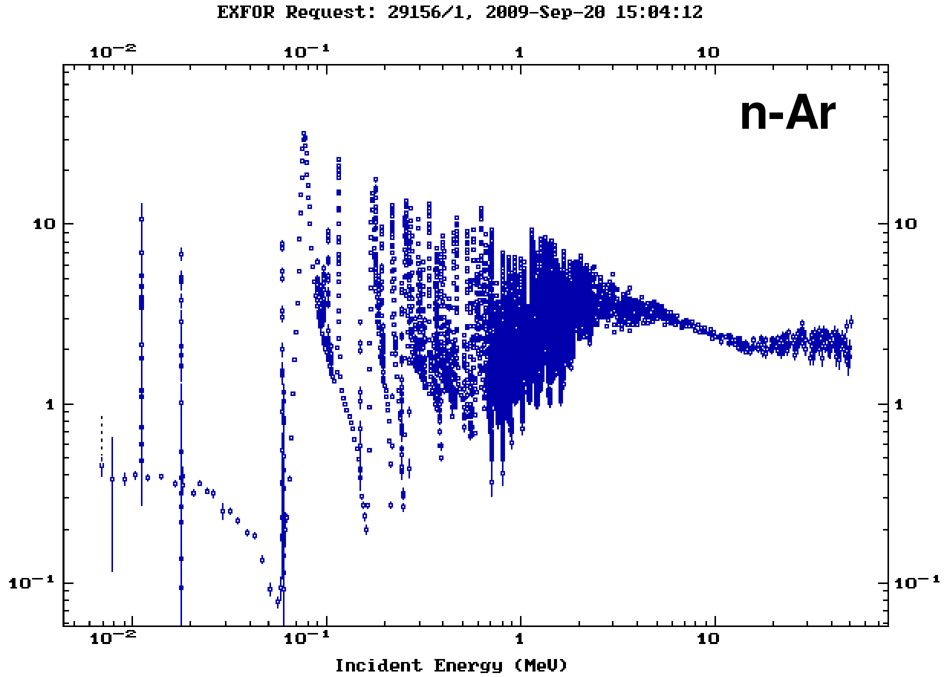
** Quasimonoenergetic neutrons up to ~7.5 MeV

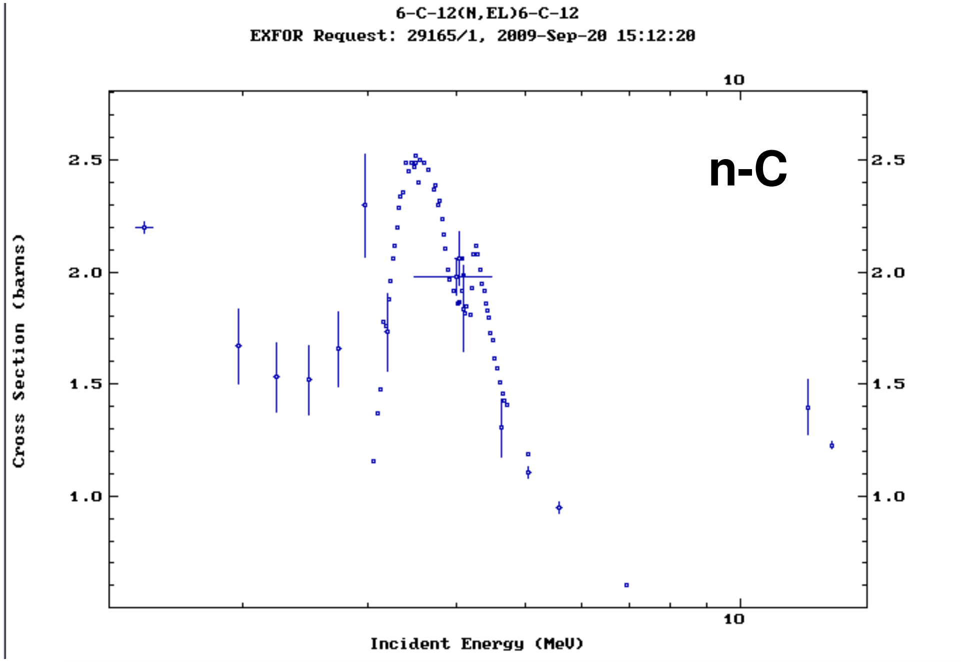
*** Monoenergetic neutrons [16.4,22] MeV

Neutron fluences can reach ~5x10^{6} neutrons/cm^{2} s but for d-^{3}H is lower an order of magnitude compared to the d-^{2}H reaction due to cross section energy dependence

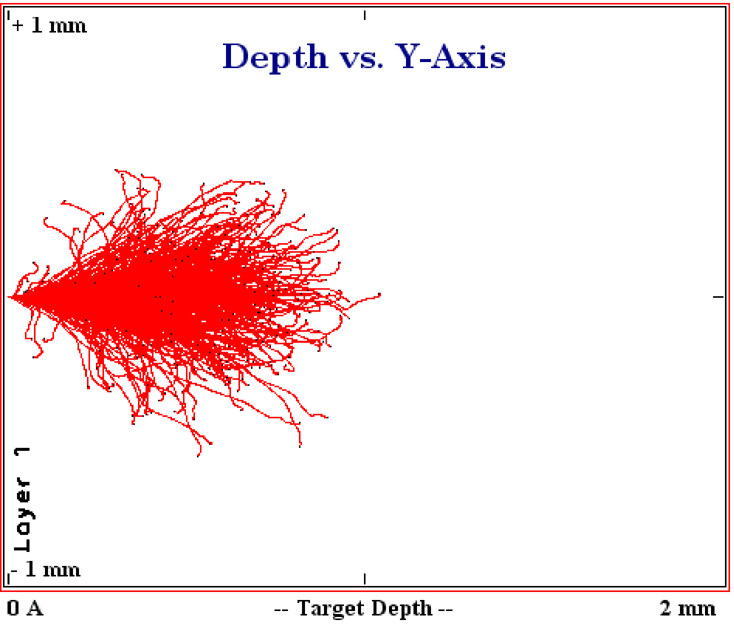
Cross sections
n-O, n-Ar, n-C



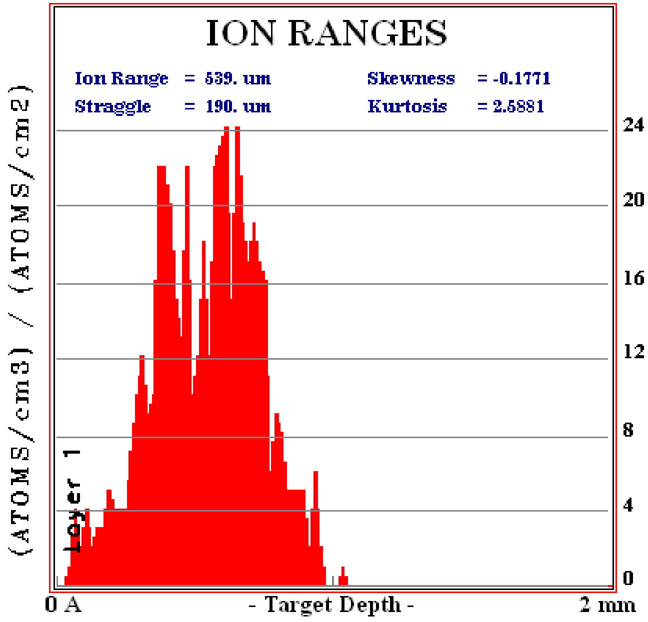


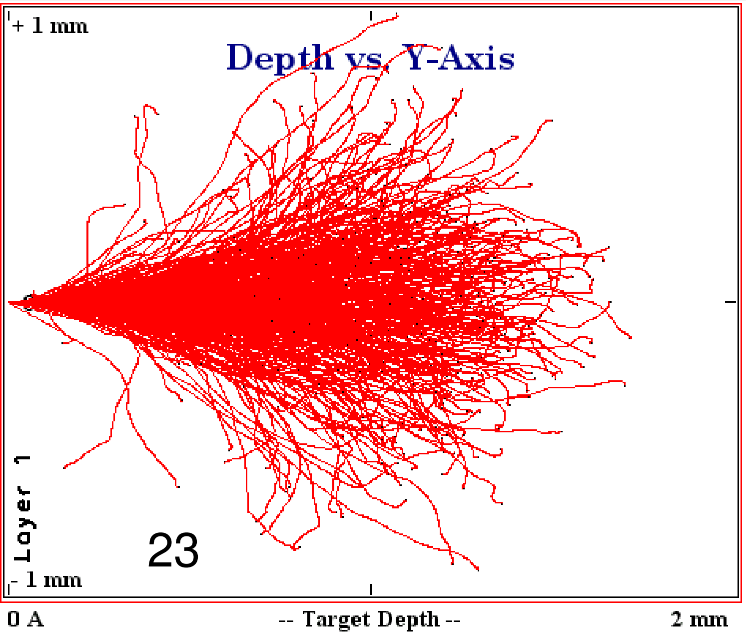


Ar ion in Ar gas
5.5MeV n on Ar

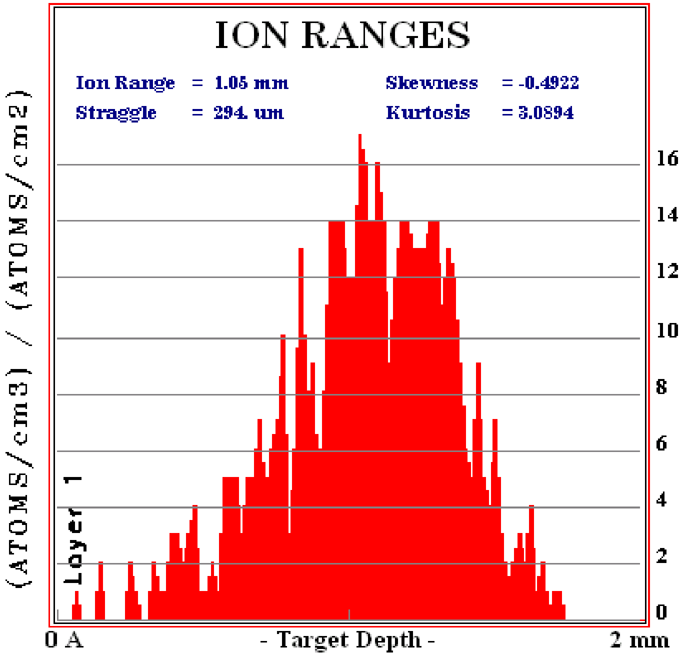


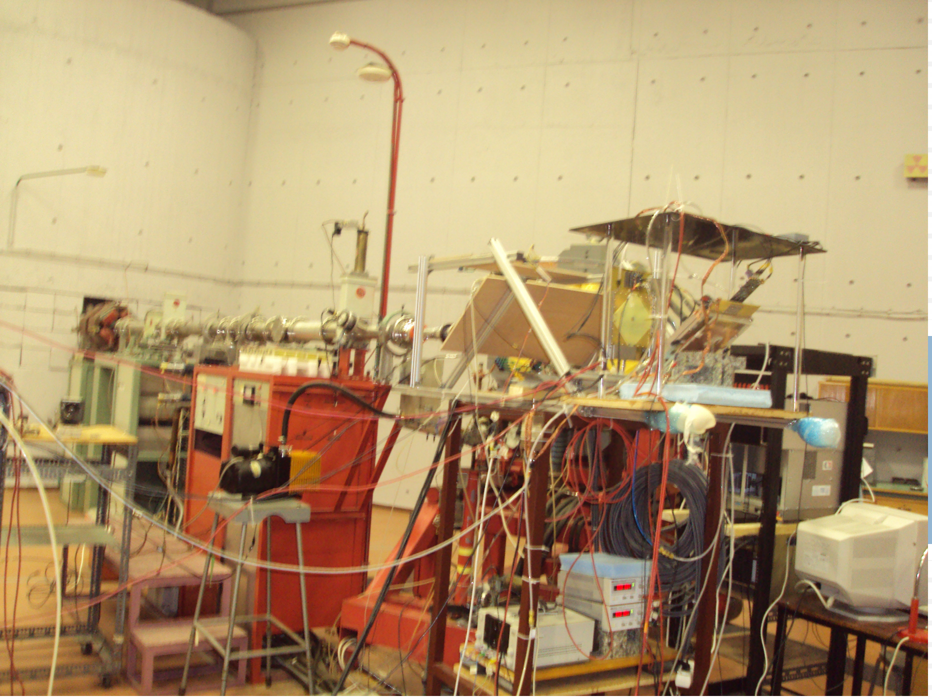
<E>=265 keV

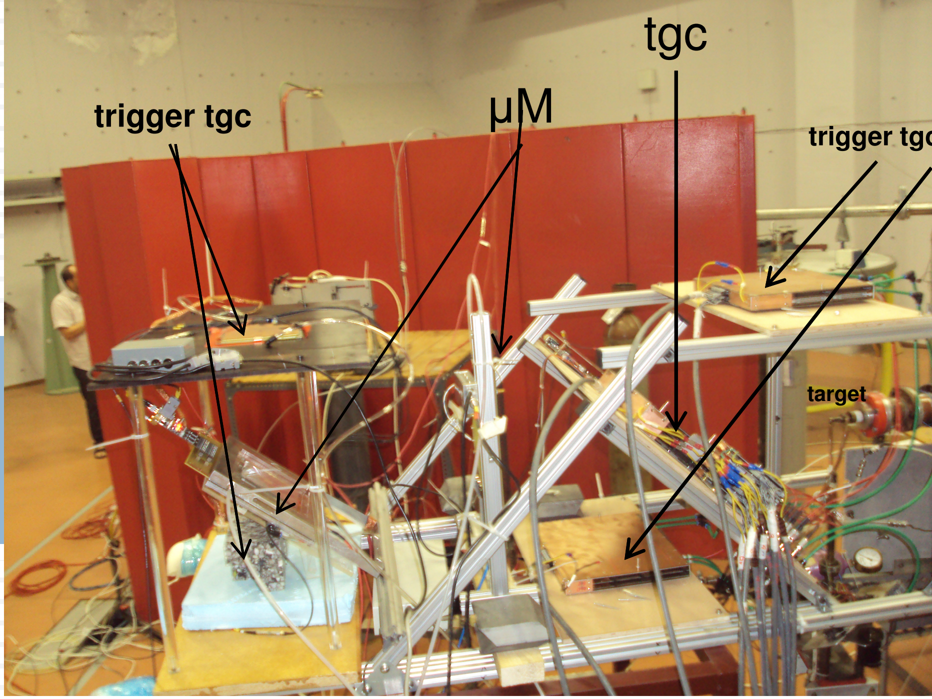




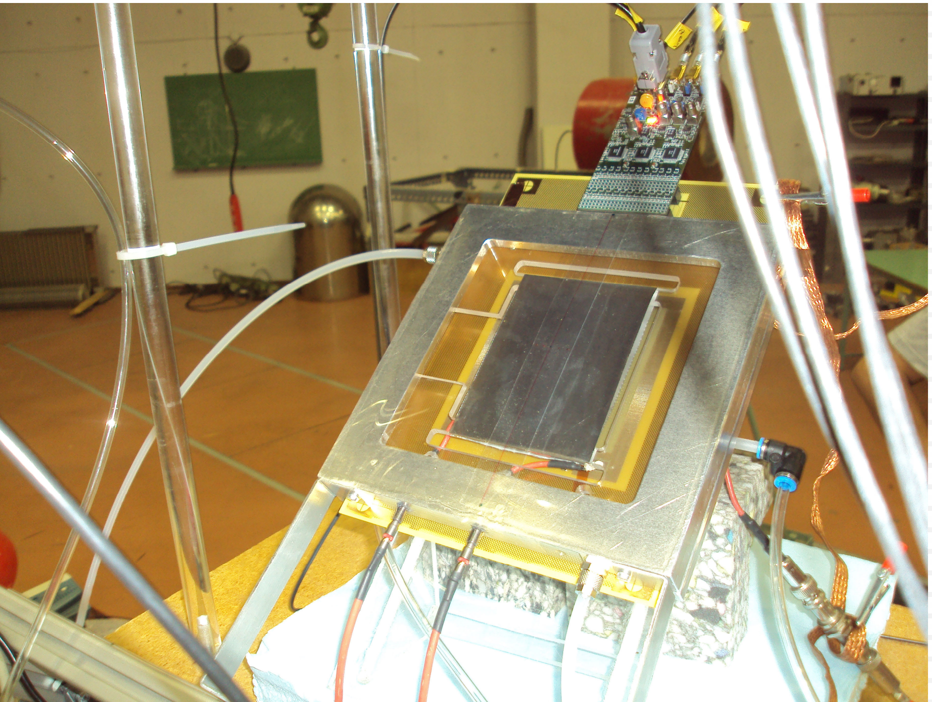
Emax=530 keV

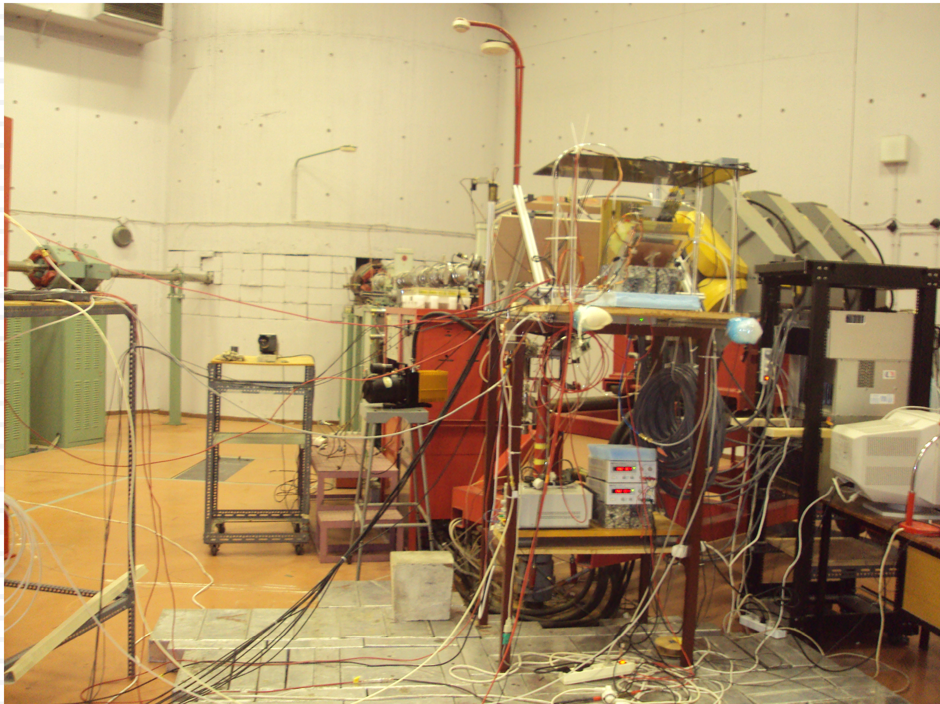




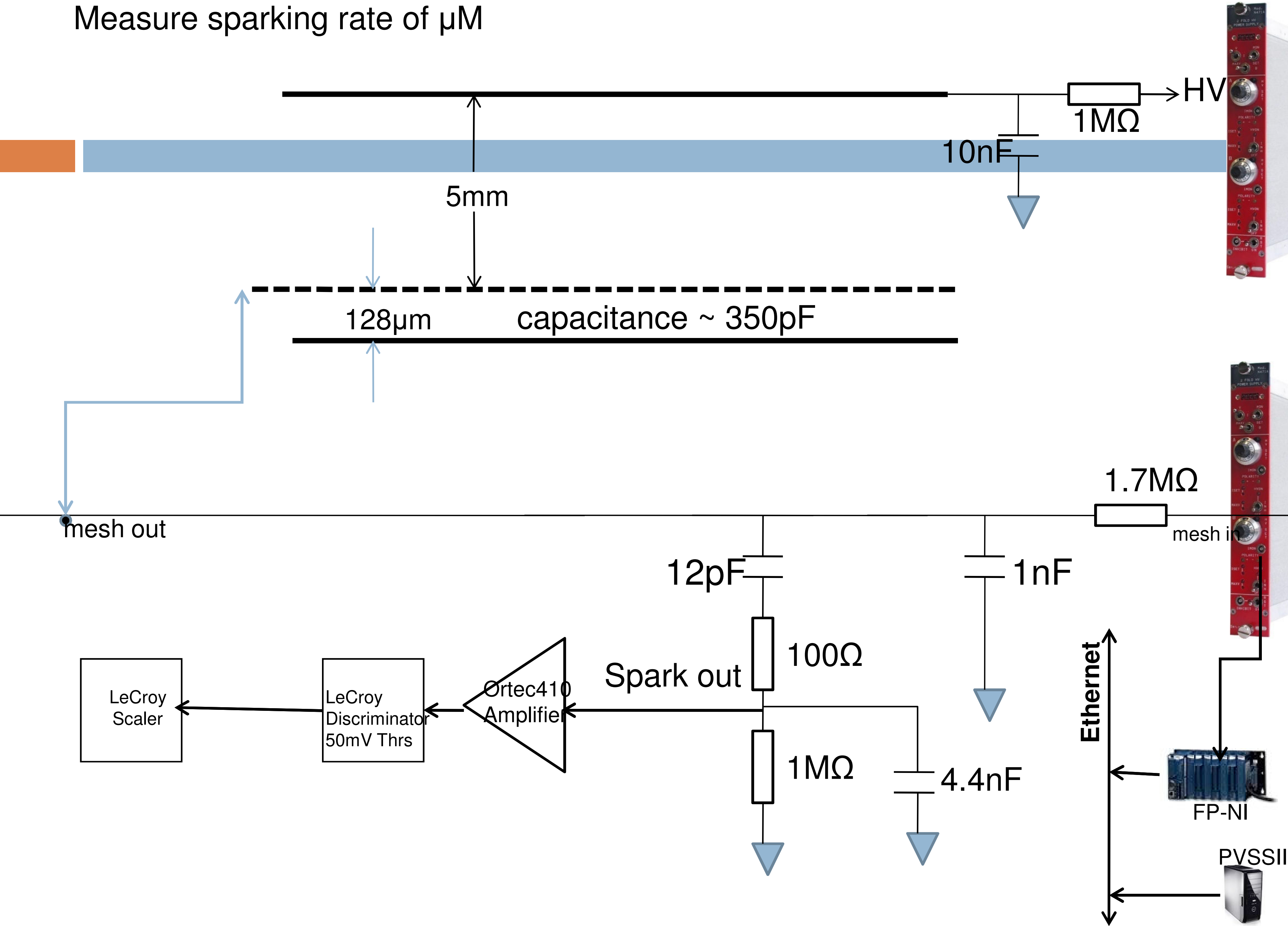


trigger tgc
μM
tgc
trigger tg
target

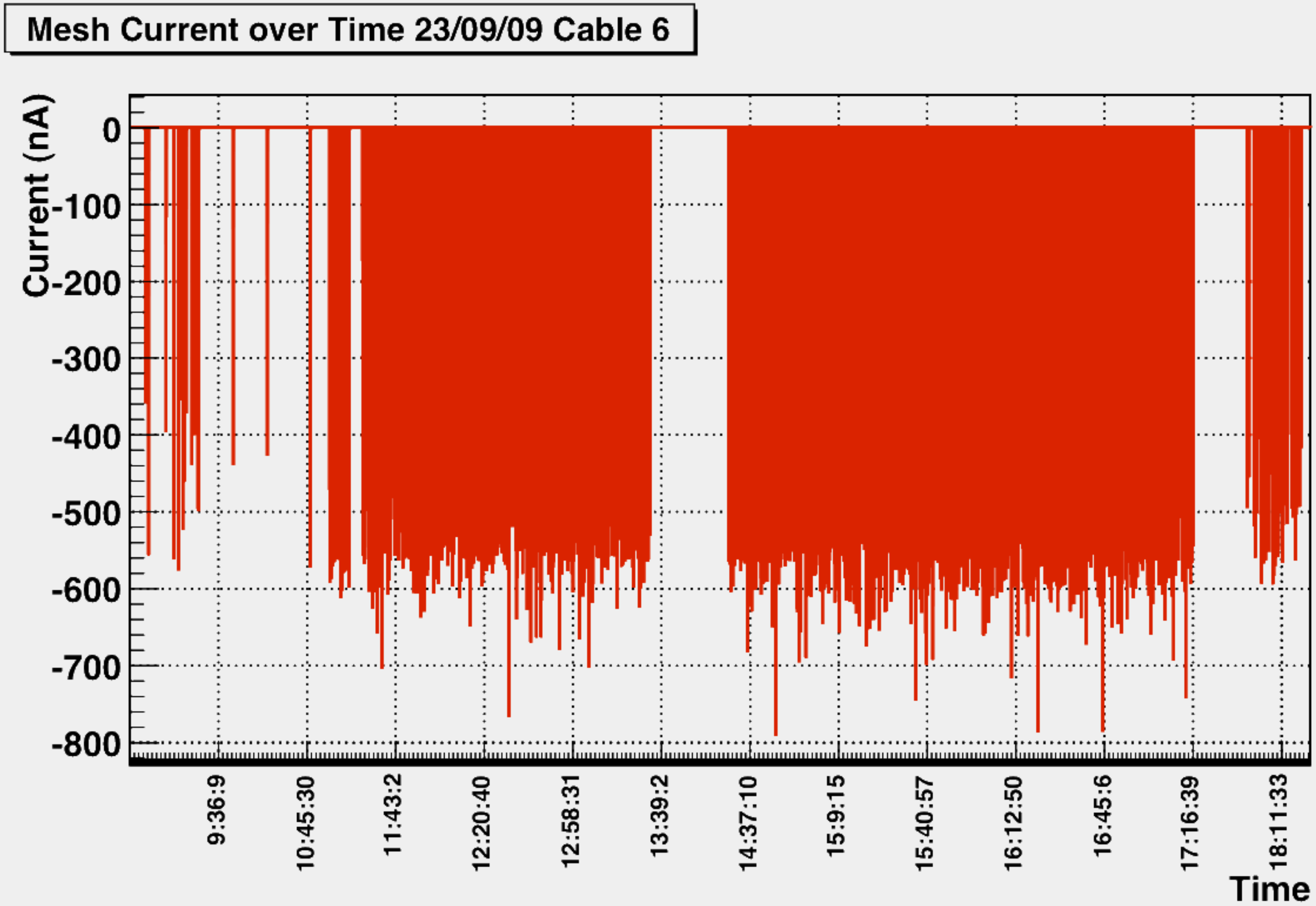




Measure sparking rate of μM



Mesh Current at neutron flux ~5x10^5 Hz/cm^2



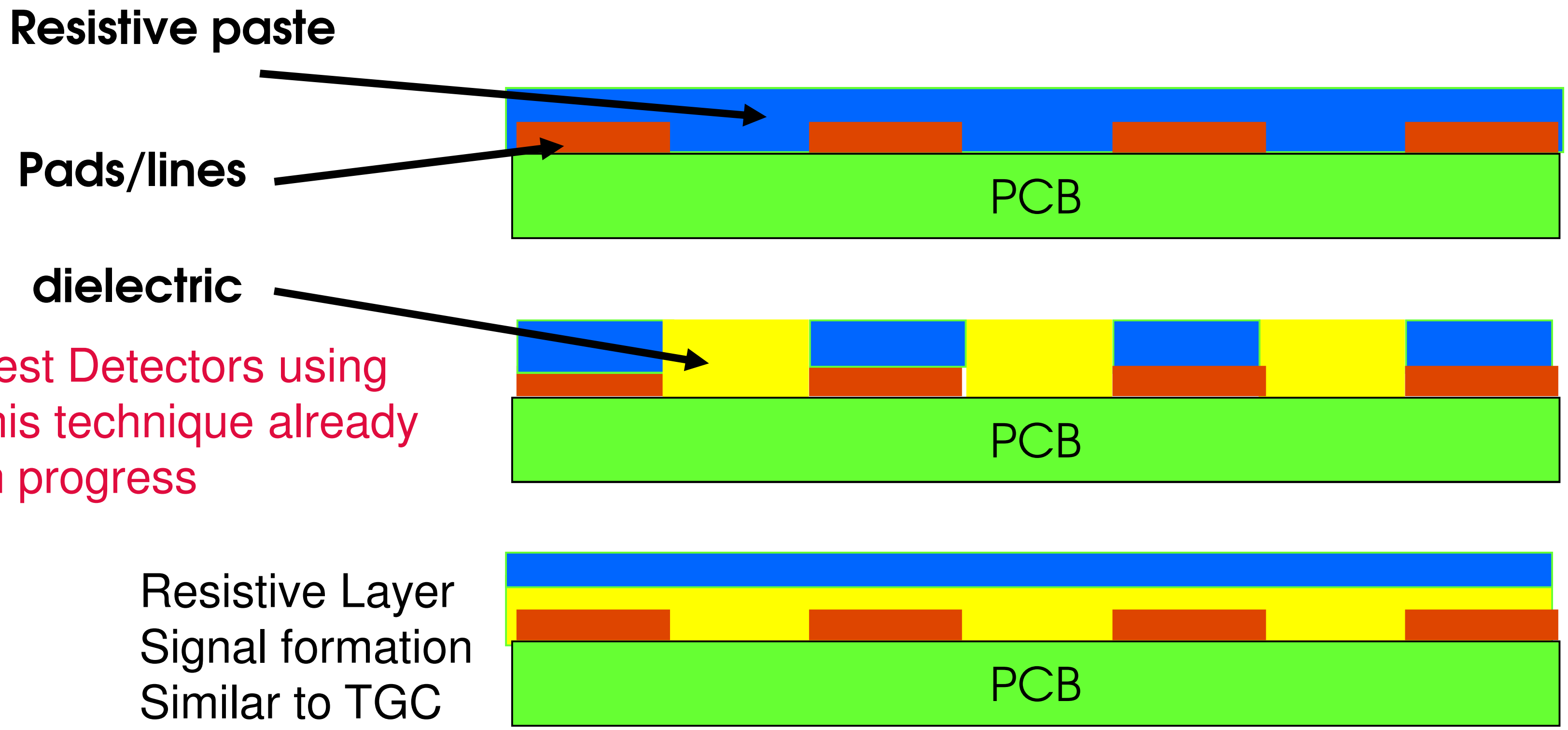
Power supply current limit=4 μA

Future Plans

- Discharges due to localized large ionization from e.g. nuclear recoils from energetic neutron (E>100 keV) scattering is a serious concern at the LHC (ongoing testbeam activity)
- Micromegas electrodes see directly the avalanche
- Discharges may damage the detector and/or result in dead time
- Investigating different approaches:
  - Segmented Mesh → Reduces stored energy
  - Resistive Films/Paste → Reduces effect of discharge (see Rui's talk)
  - Double Amplification → Reduces discharge probability (see Marco's talk)

Test large scale micromegas 1.5 m x 0.5 m – see Rui's talk

Resistive Spark Protection (Rui de Oliveira)


Resistive paste

Pads/lines

dielectric

Test Detectors using this technique already in progress

Resistive Layer
Signal formation
Similar to TGC

- Resistive epoxy based polymers : any decade up to 1Mohm/square
- Resistive polyimide based polymer : only a few values
- Deposition by: screen printing, painting, lamination

Promising result (but seen problem; see Rui's talk) / Very Preliminary