Development of resistive-strip micromegas for the ATLAS upgrade

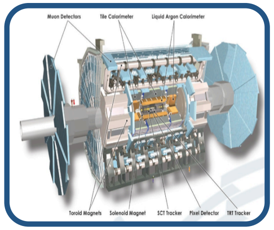
Marcin Byszewski (CERN)

MAMMA Collaboration

Arizona, Athens (U, NTU, Demokritos), Brandeis, Brookhaven, CERN, Carleton, Istanbul (Bogaziçi, Doğuș), JINR Dubna, MEPHI Moscow, LMU Munich, Naples, CEA Saclay, USTC Hefei, South Carolina, Thessaloniki

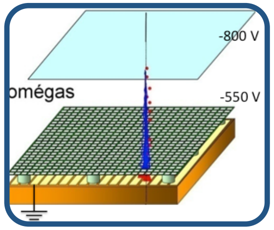
Work performed in close collaboration with CERN/TE-MPE PCB workshop (Rui de Oliveira)
Lots of synergy from the RD51 Collaboration

Outline



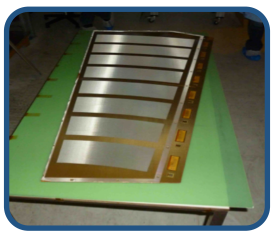
ATLAS SW upgrade

- The Small Wheel
- Requirements for upgrade
- MM is one of candidate technologies



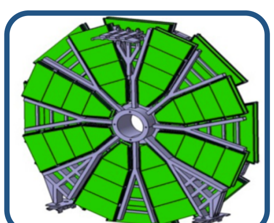
Resistive Micromegas

- Micromegas
- Performance



Development milestones

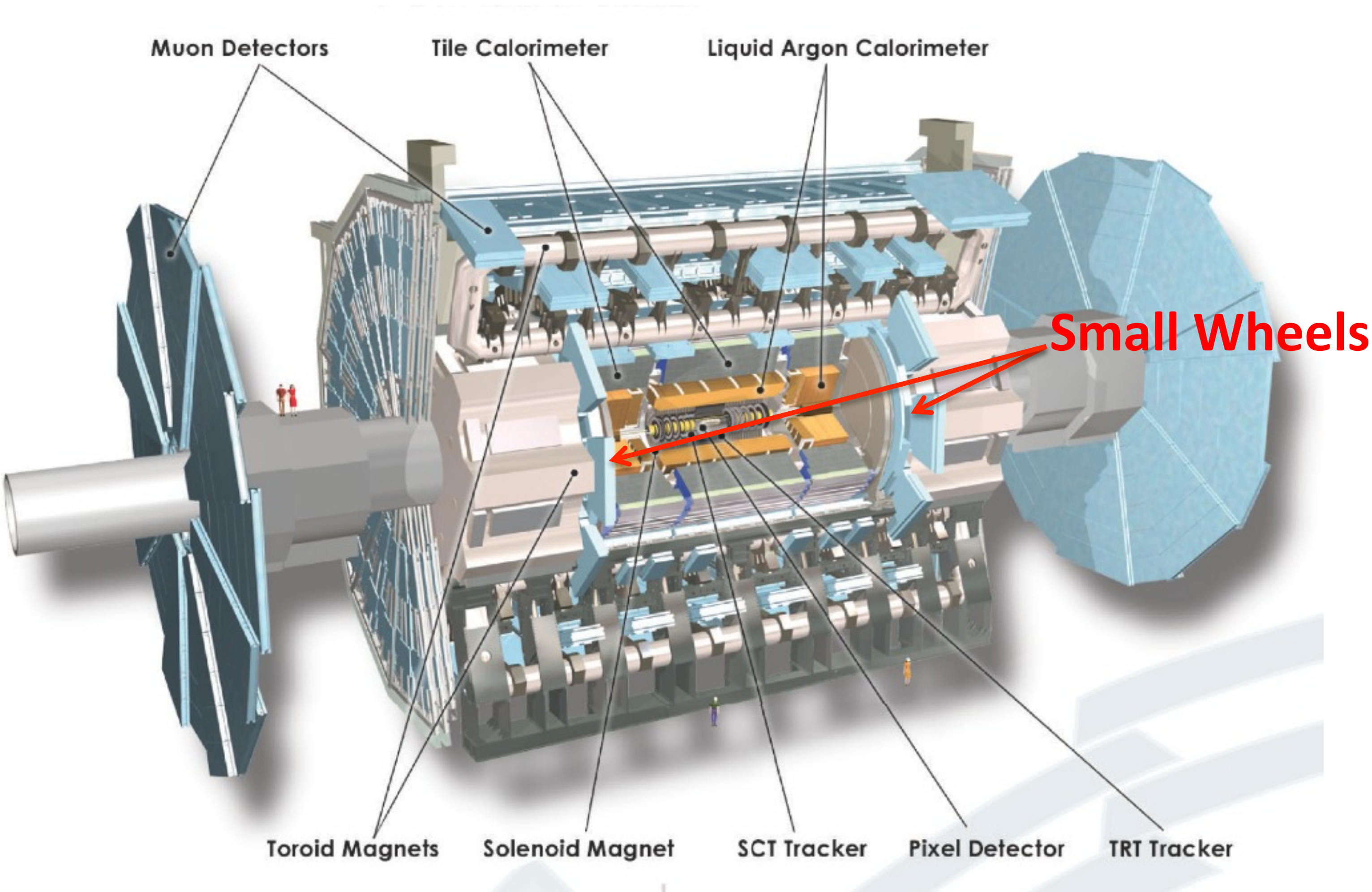
- 2D
- Large-area chambers



Outlook 2012

- Test chambers in ATLAS
- Module 0

ATLAS Small Wheels Upgrade



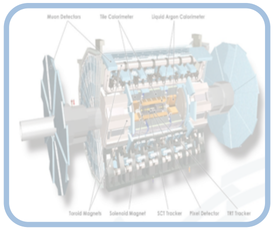
requirements for NSW detector

- Rate capability 15 kHz/cm^2 ($L \approx 5 \times 10^{34}\ cm^{-2}s^{-1}$)
- Efficiency > 98%
- Spatial resolution ≈100 μm ($\Theta_{track} < 30°$)
- Good double track resolution
- Trigger capability (BCID, time resolution ≤ 5–10 ns)

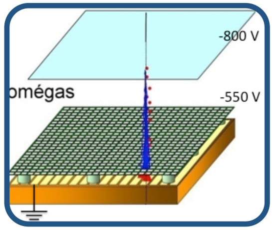
- Radiation resistance
- Good ageing properties

All requirements can be met with micromegas

Outline



ATLAS SW upgrade



Resistive Micromegas

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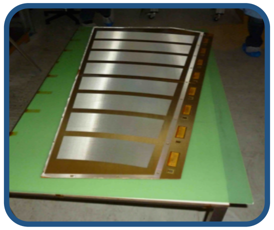
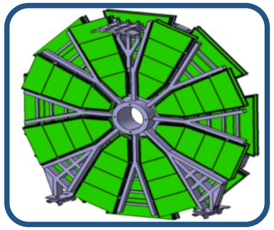


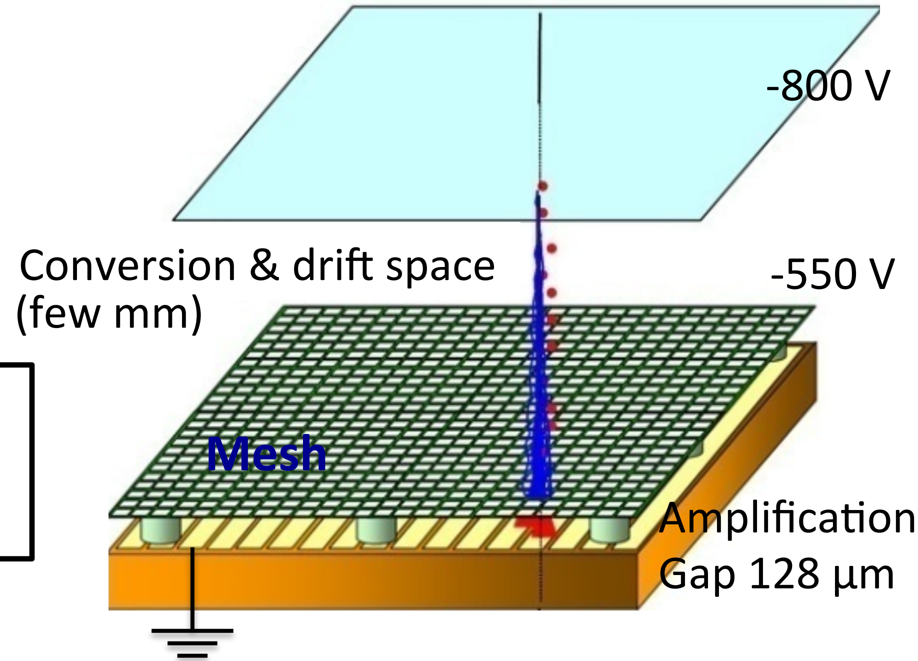
Development milestones



Outlook 2012

Micromegas, operation principle

- Micromegas are parallel-plate chambers where the amplification takes place in a thin gap, separated from the conversion region by a fine metallic mesh



Drift region of a few mm with moderate electric field of 100–1000 V/cm, function of the gas

The principle of operation of a micromegas chamber

REF: I. Giomataris et al., NIM A 376 (1996) 29

Micromegas, operation principle

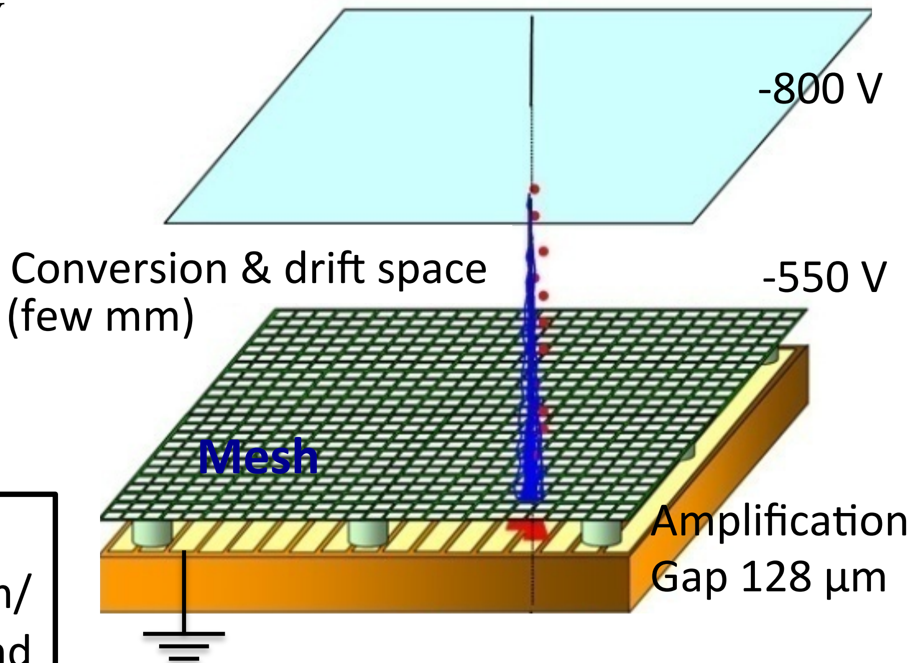
- The thin amplification gap (short drift times and fast absorption of the positive ions) makes it particularly suited for high-rate applications

Narrow amplification gap with high electrical field (40–50 kV); typically a factor 70–100 is required to make the mesh fully transparent for electrons

Charged particles ionize the gas in the drift region, the electrons move with typically 5 cm/μs (or 20 ns/mm) to and through the mesh and are amplified in the amplification gap

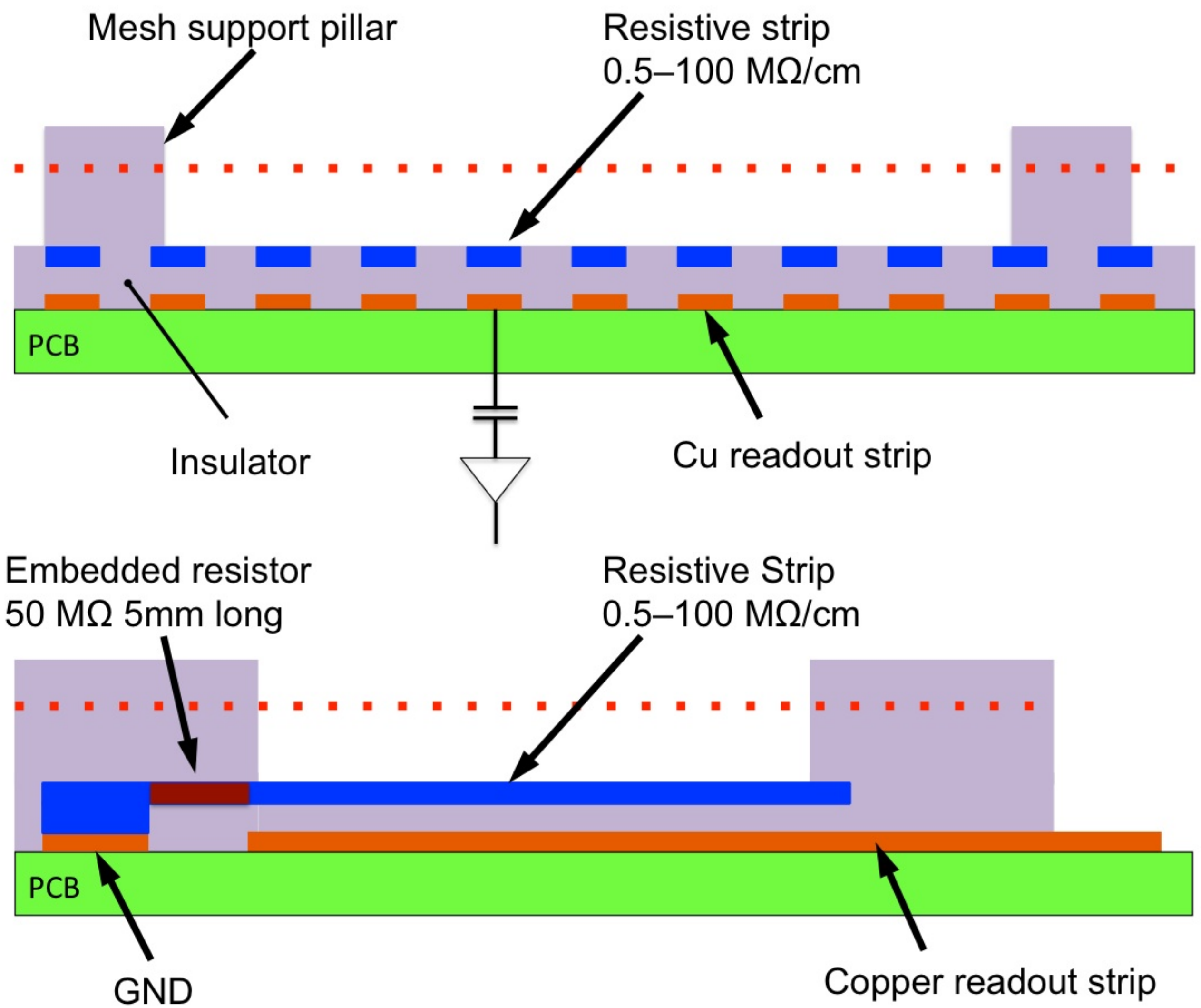
By measuring the arrival time of the signals a MM functions like a TPC

REF: I. Giomataris et al., NIM A 376 (1996) 29



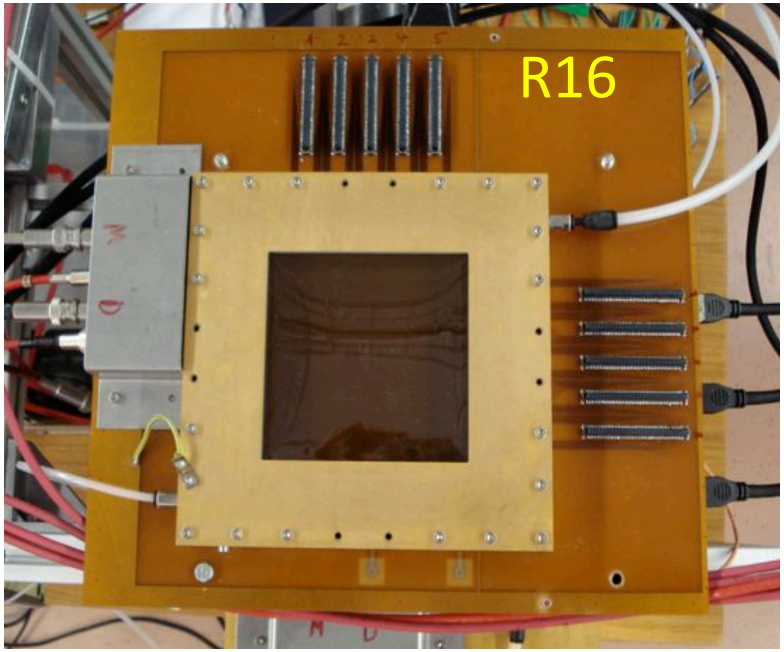
The principle of operation of a micromegas chamber

The resistive-strip protection concept



Large number of resistive-strip detectors tested

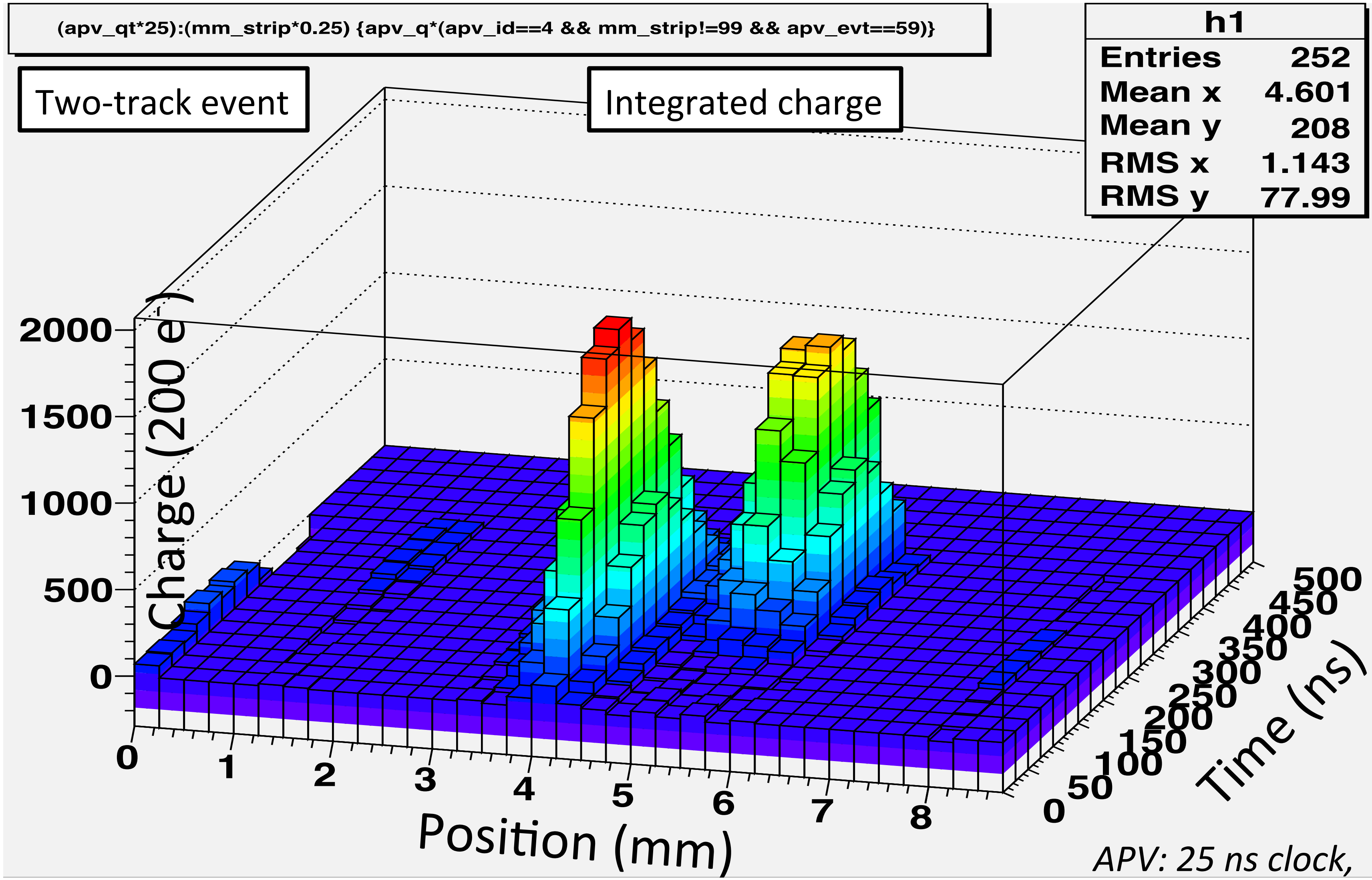
- Small chambers with 9 x 9 cm^2 active area
- Large range of resistance values
- Number of different designs
- Gas mixtures
  - $Ar:CO_2$ (85:15 and 93:7)
- Gas gains
  - 2–3 x 10^4
  - 10^4 for stable operation



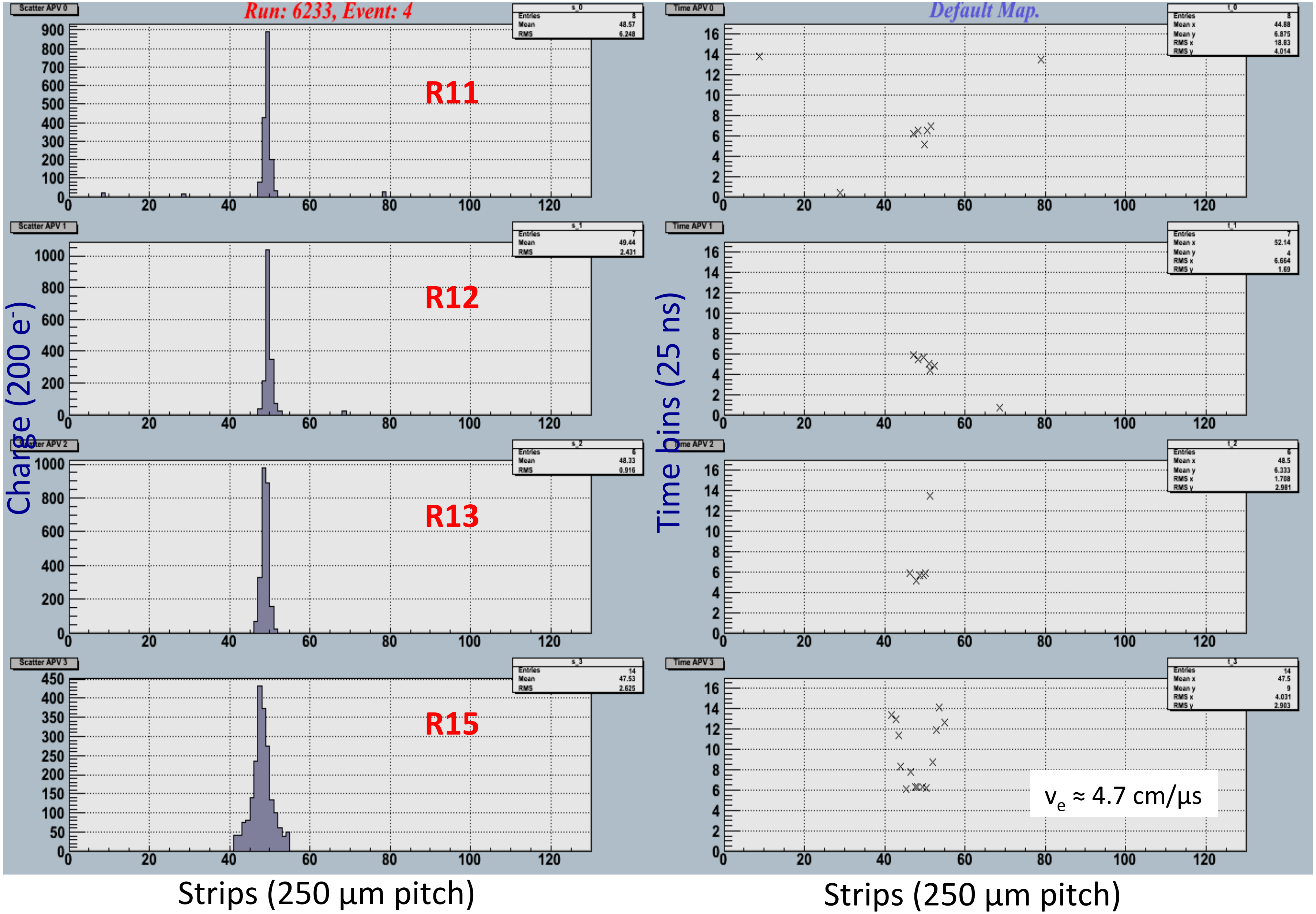
R16, first chamber with 2D readout

APV25 Analogue Si CMS's tracker readout chip, not the final choice
Scalable Readout System, SRS (CERN RD51)

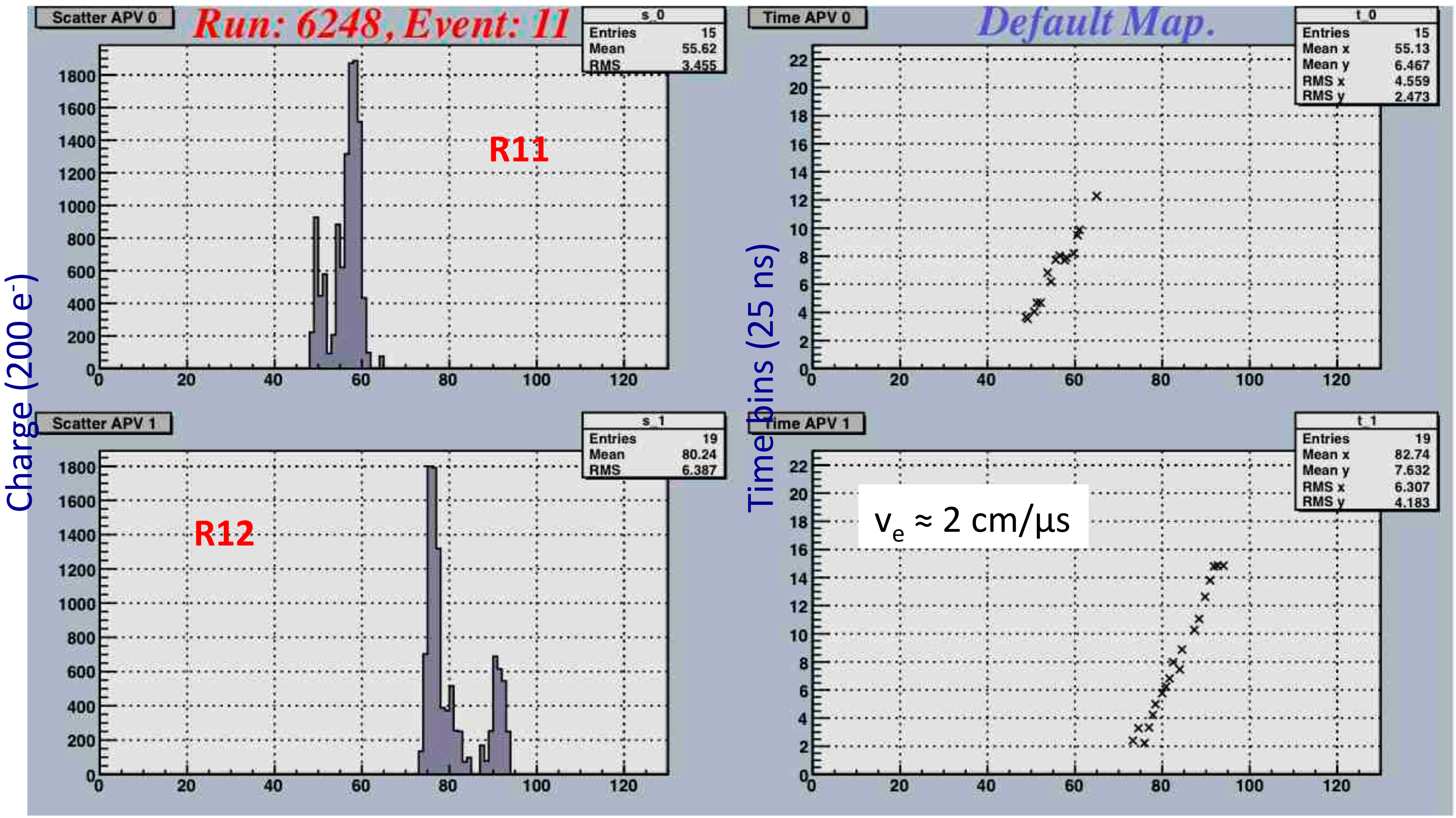
Event Display Example (APV25)



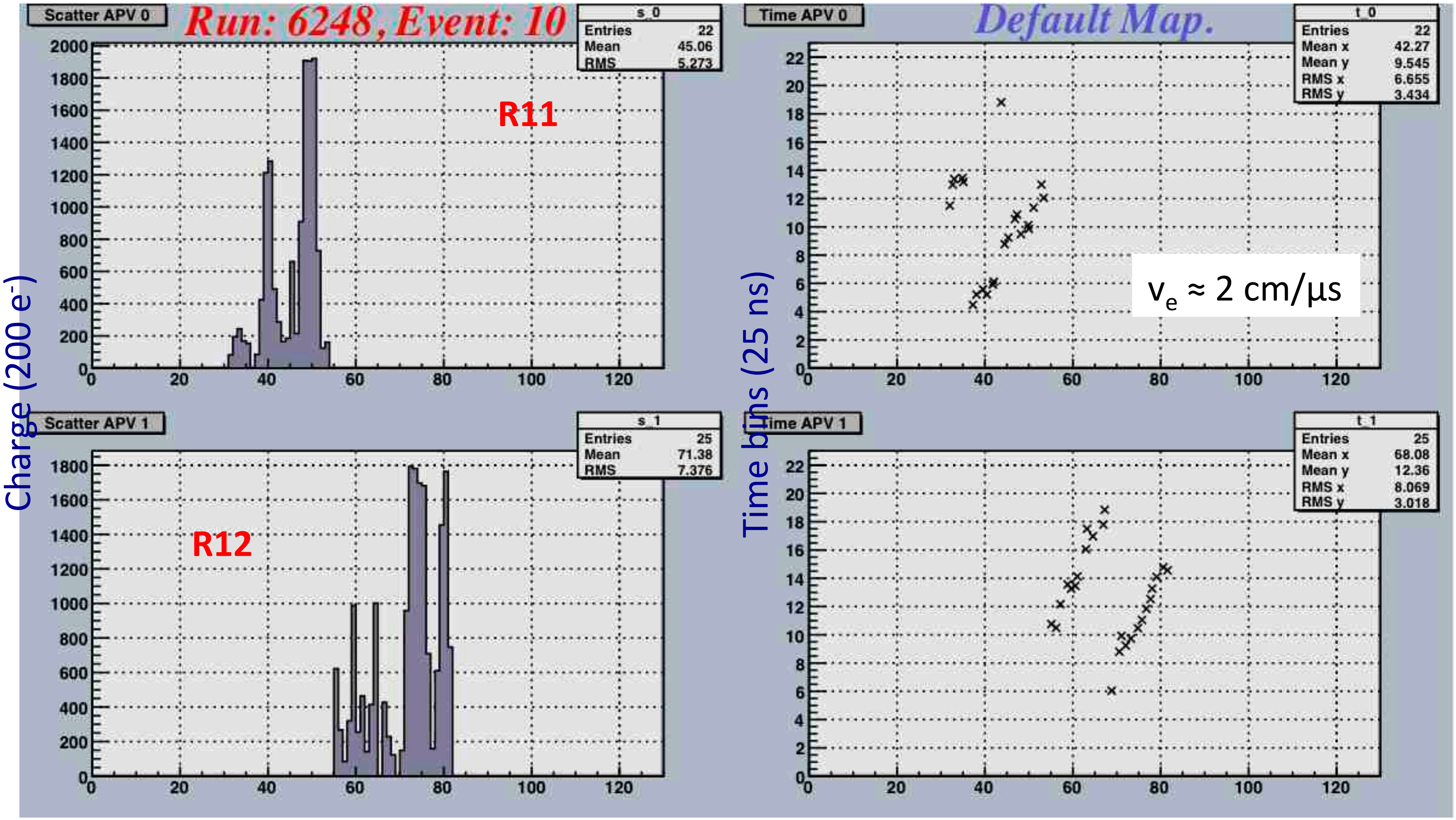
APV: 25 ns clock, 75 ns ADC integration


Run: 6233, Event: 4
Default Map.
R11
R12
R13
R15
Charge (200 e⁻)
Time bins (25 ns)
$v_e \approx 4.7$ cm/µs
Strips (250 µm pitch)
Strips (250 µm pitch)

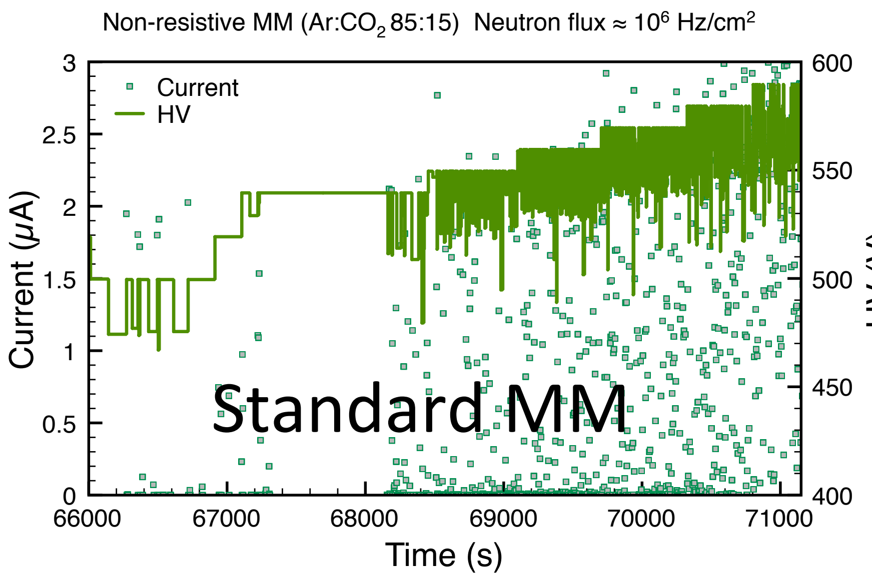
Inclined tracks (40°) – µTPC

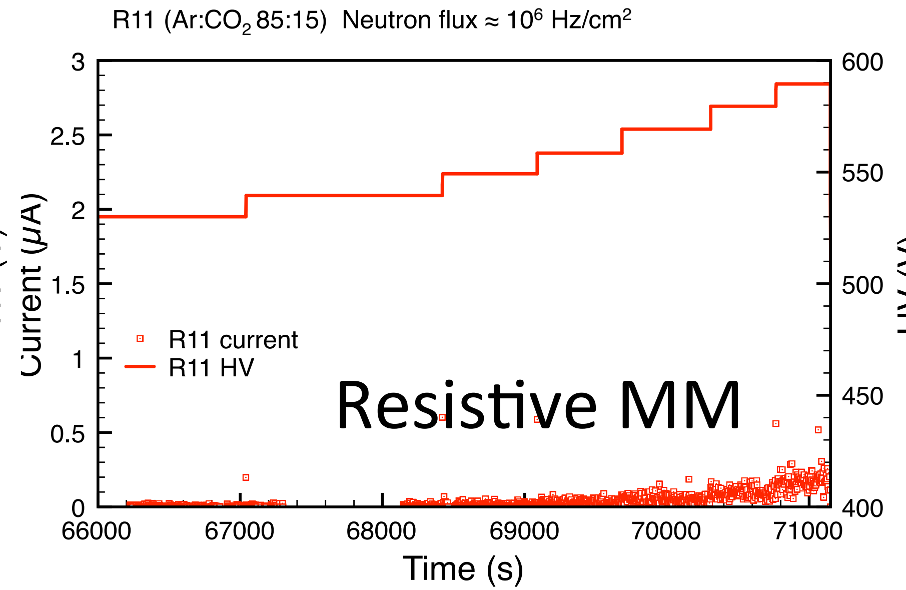


… and a two-track event



Performance in neutron beam



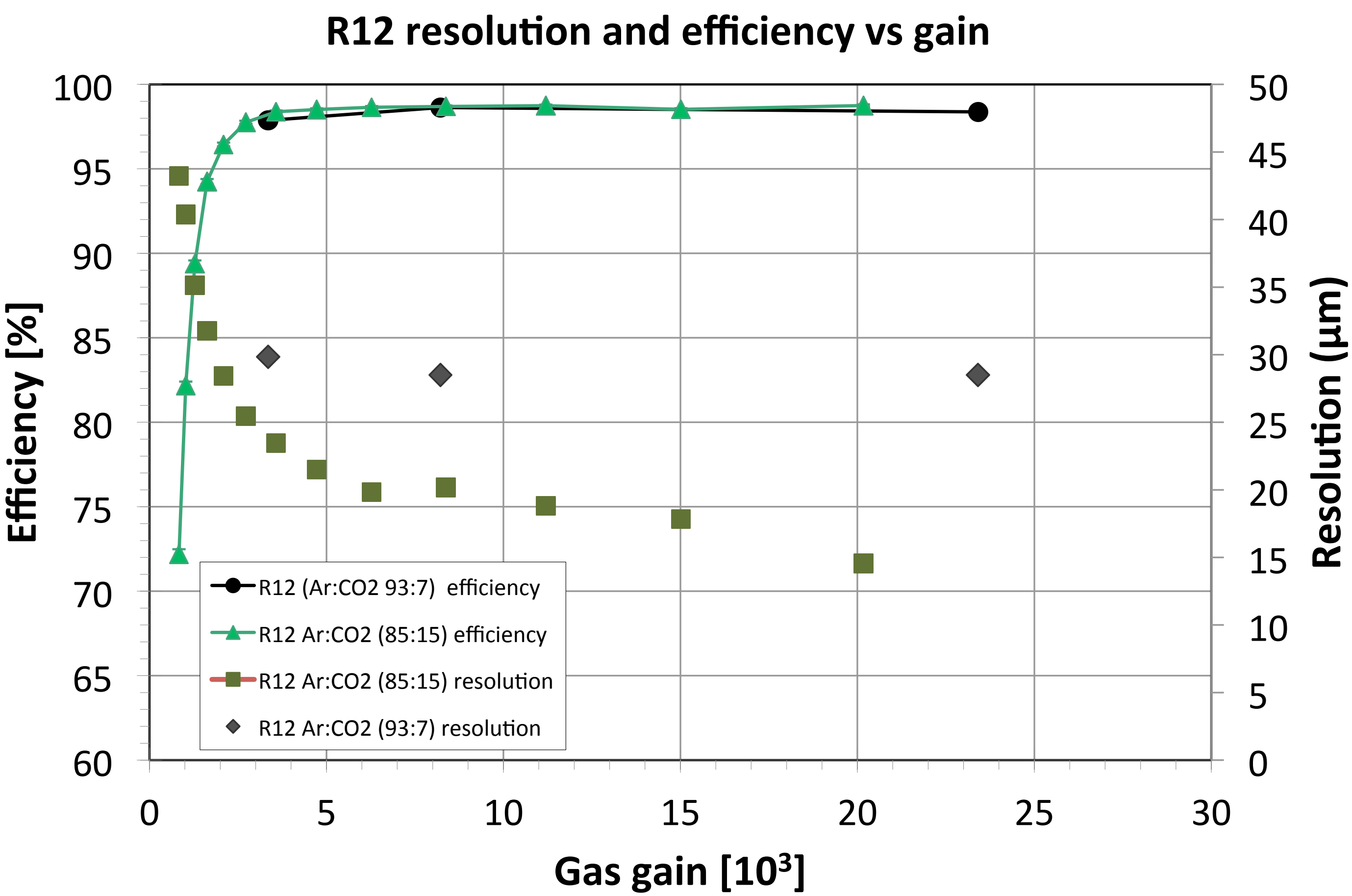


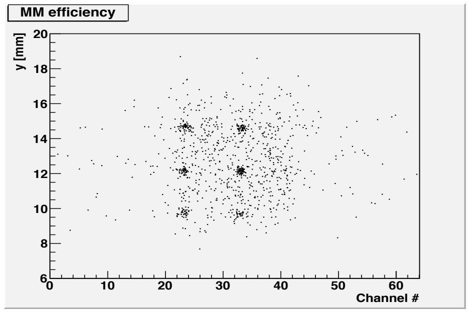
- Standard MM could not be operated in neutron beam
- HV break-down and currents exceeding several μA already for gains of order 1000–2000

- MM with resistive strips operated perfectly well,
- No HV drops, small spark currents up to gas gains of 2 x 10^4

Spatial resolution & efficiency for R12 (250 μm strips)

Analysis of data taken in July 2010



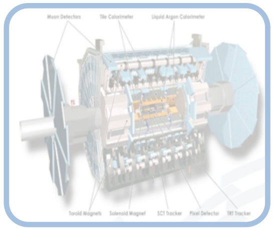


Inefficiency compatible with area of mesh support pillars (d=2.5 mm)

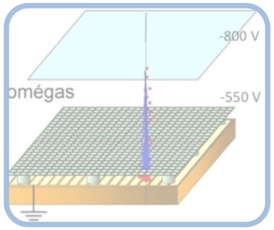
Resistive strip chambers are fully efficient (≈98%)over a wide range of gains

Spatial resolution with 250 μm strip: ≈30 μm with Ar:CO_2 (93:7), even better with 85:15

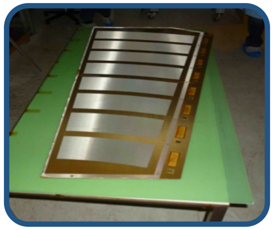
Outline



ATLAS SW upgrade

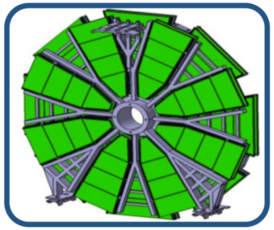


Resistive Micromegas



Development milestones

- 2D
- Large-area chambers
- Test chambers in ATLAS



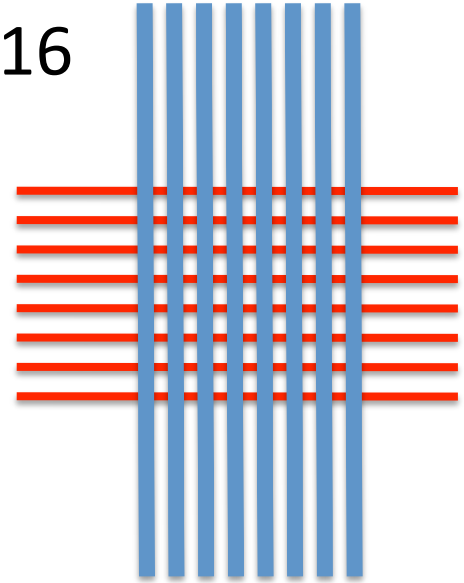
Outlook 2012

2D readout (R16 & R19)

- Readout structure that gives two readout coordinates from the same gas gap; crossed X-Y strips (R16) or X-U-V with three strip layers (R19)
- Several chambers successfully tested

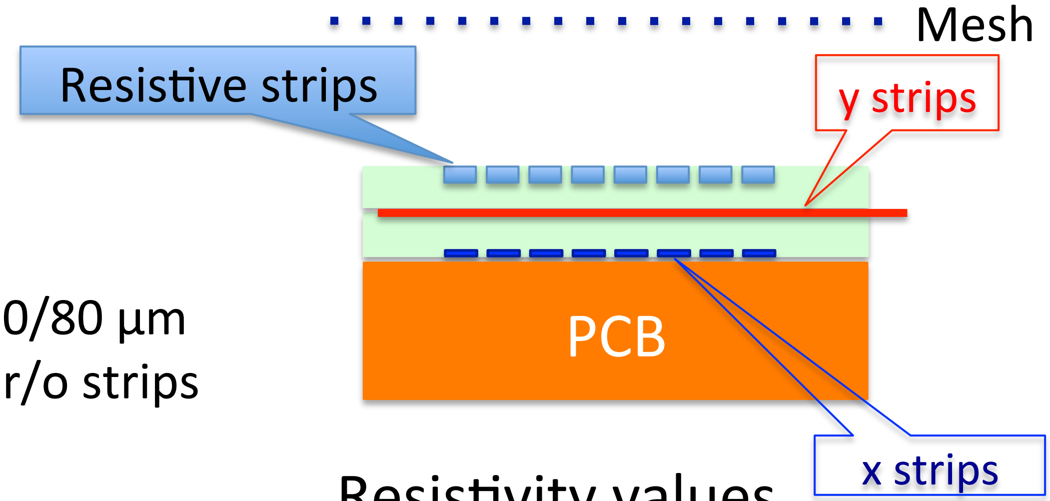
X ≡ precision strips

R16



y: 250/80 μm
only r/o strips

x strips: 250/150 μm
r/o and resistive strips

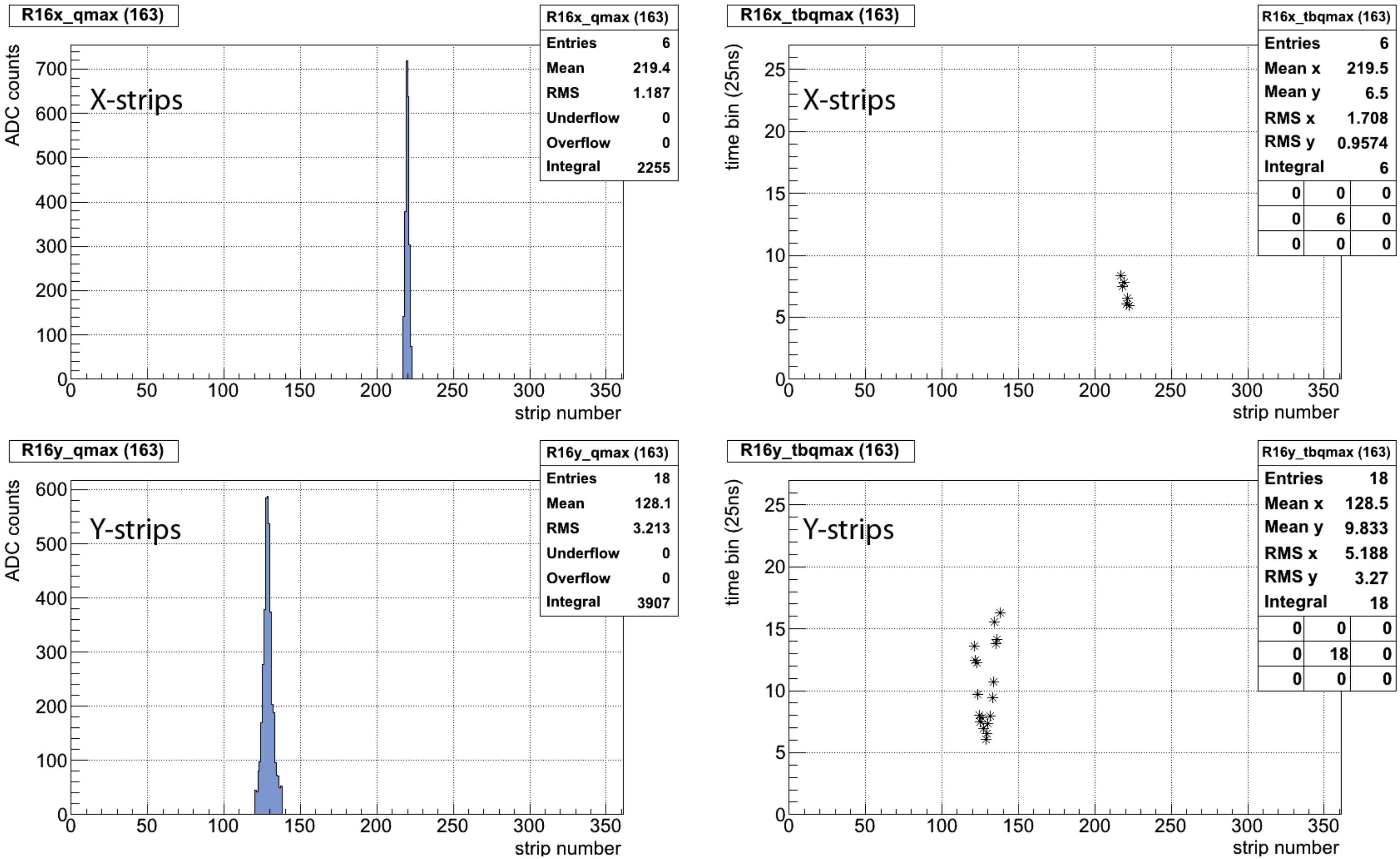


Resistivity values

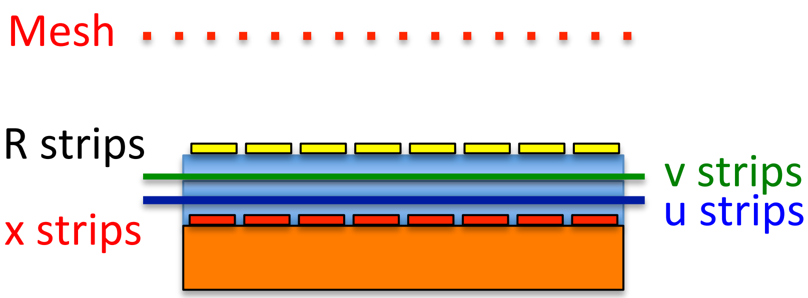
$R_G \approx 55\ M\Omega$

$R_{strip} \approx 35\ M\Omega/cm$

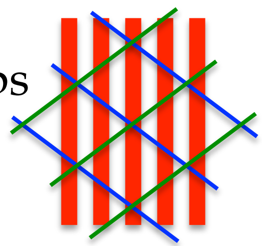
2D chambers: R16 XY event



R19 with xuv readout strips

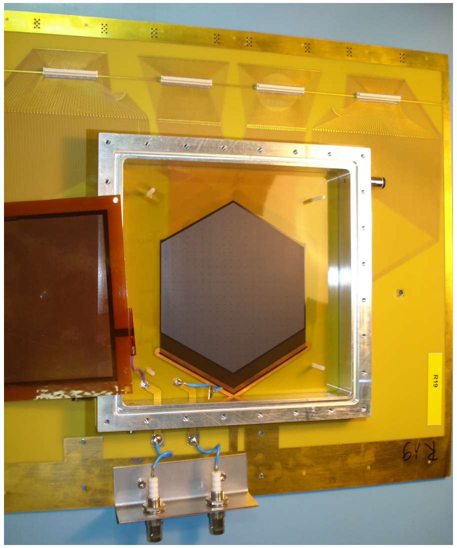


- x strips parallel to R strips
- u,v strips ±60 degree



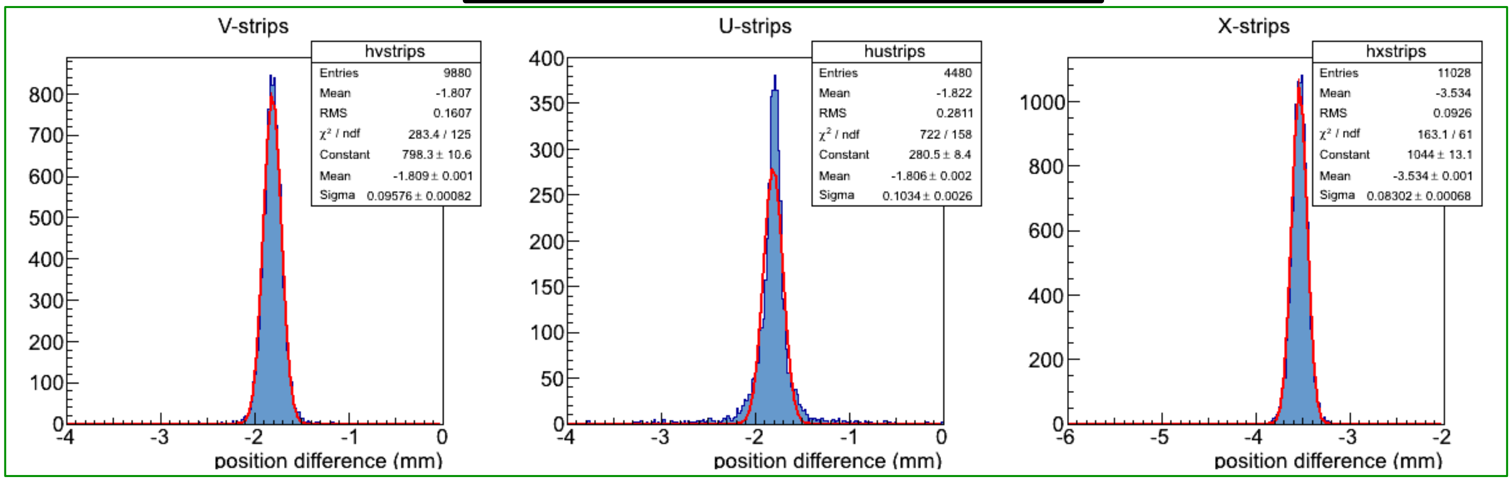
R19	R	v	u	x
Depth (µm)	0	-50	-100	-150
Strip width (mm)	0.25	0.1	0.1	0.25
Strip pitch (mm)	0.35	0.9	0.9	0.35
Q collected (rel.)		0.84	0.3	1

- Tested two chambers with same readout structure (R19M and R19G) in a pion beam (H6) in July
- Clean signals from all three readout coordinates, no cross-talk
- Strips of v and x layers well matched, u strips low signal, too narrow
- Excellent spatial resolution, even with v and u strips



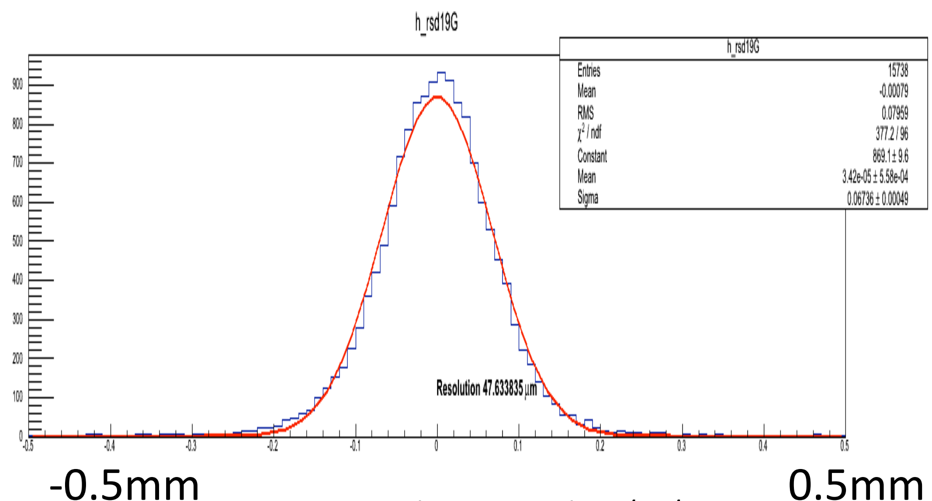
X-U-V R19 chamber resolution

at a first glance - 'online'



(Top) Difference in cluster positions of two XUV chambers, mm apart, 120 GeV pion beam at H6 CERN

- X strips (0.35 mm pitch) 59 µm
- U strips (0.9 mm pitch) 73 µm
- V strips (0.9 mm pitch) 68 µm



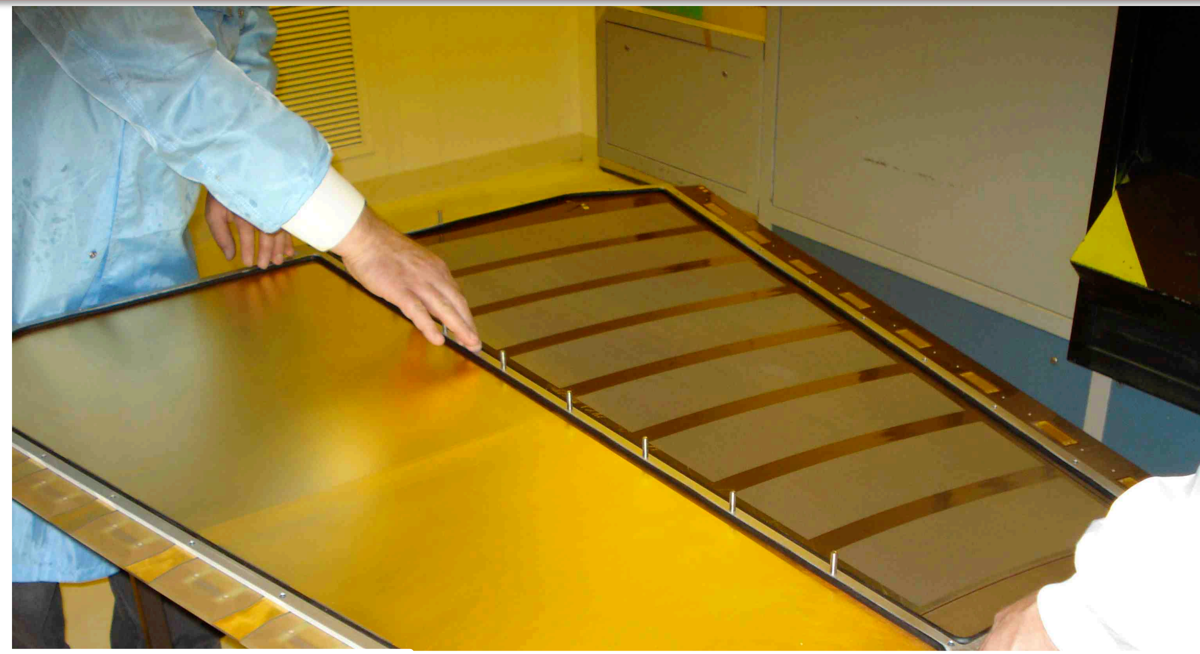
K. Ntekas, internal, 31/01/2012

(Right) Tracker + chamber, convoluted

- X strips (0.35 mm pitch) 48 µm

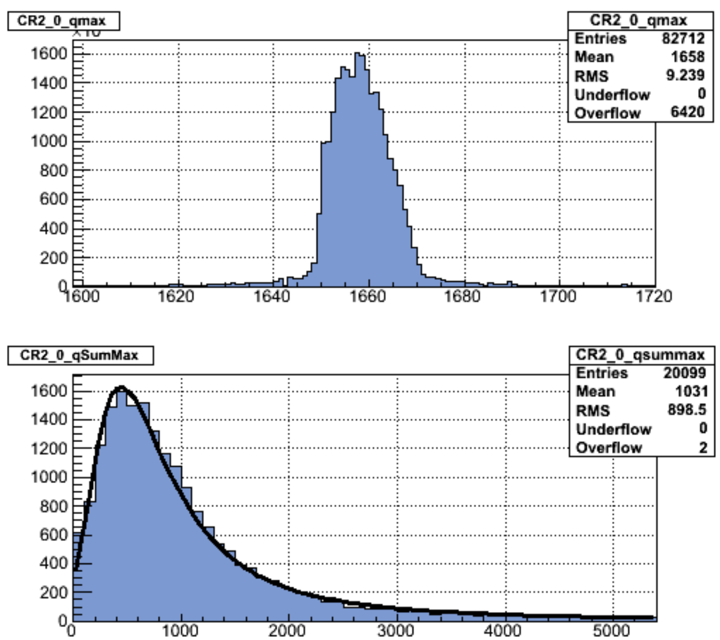
Assembly of 1st large resistive MM in March 2011

- Size: 1.2 x 0.6 m^2
- 2048 circular strips
- Strip pitch: 0.5 mm
- 8 connectors with 256 contacts each
- Mesh: 400 lines/inch
- 5 mm high frame defines drift space
- O-ring for gas seal
- Closed by a 10 mm foam sandwich panel serving at the same time as drift electrode

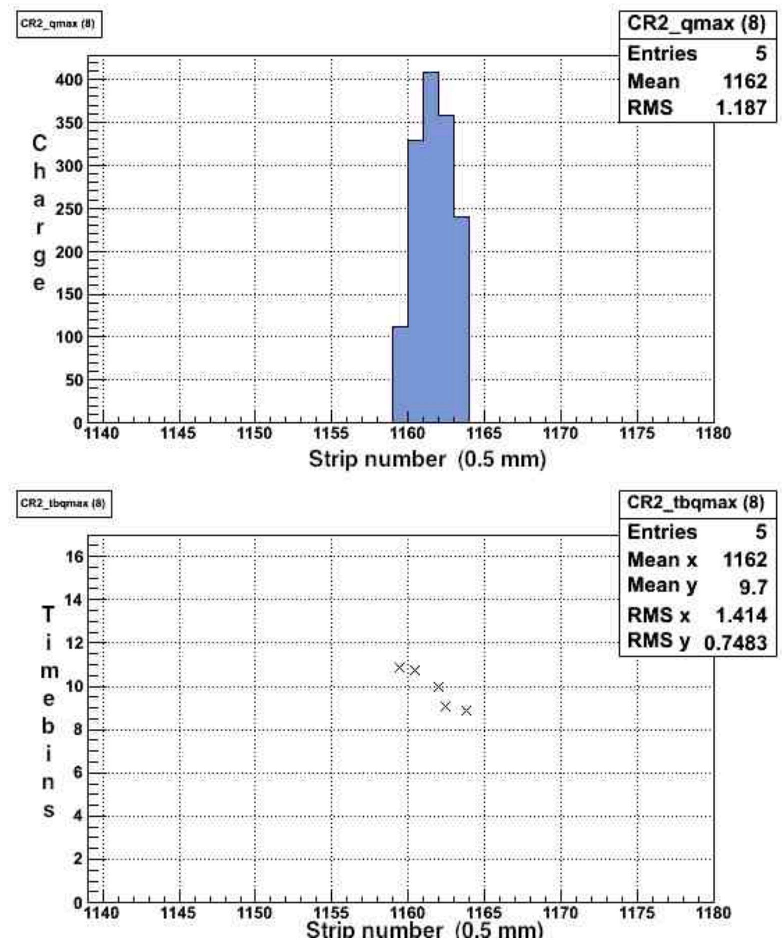


Experience with large (1.2 x 0.6 m^2) MM

- The large MM with resistive strips and 0.5 mm pitch has been successfully tested in July and November in the H6 beam

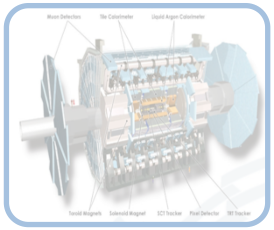


Hit map showing the beam profile (top) and charge spectrum (bottom)



Event display showing a track traversing the CR2 chamber under 20 degree

Outline



ATLAS SW upgrade

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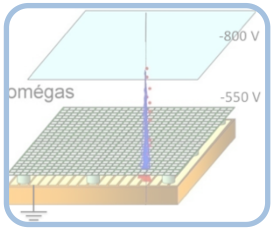
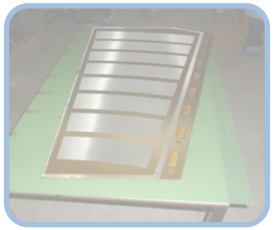
- MM is one of candidate technologies



Resistive Micromegas

- Micromegas
- Resistive spark protection
- Characteristics



Development milestones

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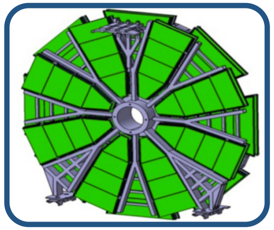


Outlook 2012

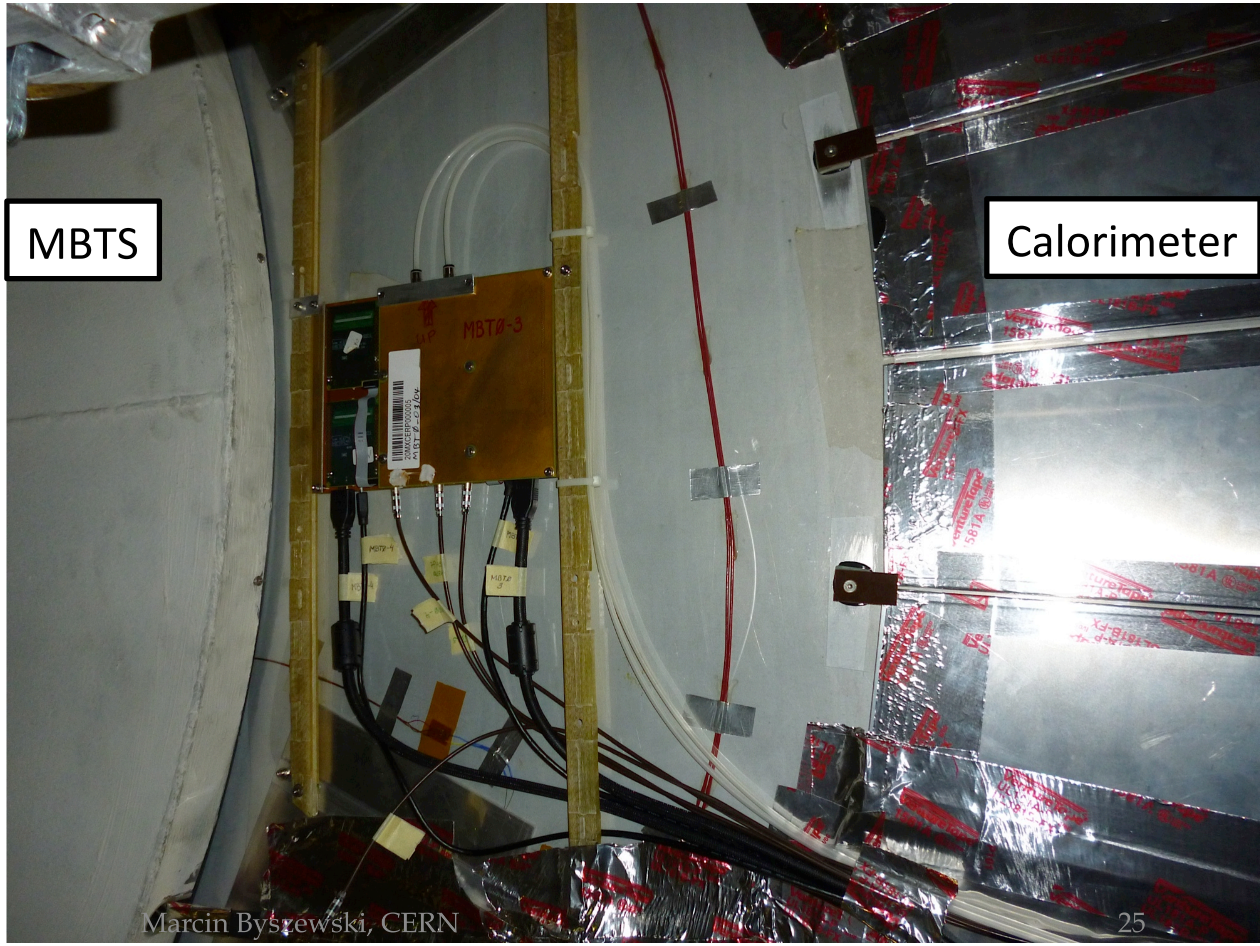
- Test chambers in ATLAS
- Module 0

Prototypes in ATLAS

- Installed during 2012 winter shutdown
- @ MBTS
- @ SW
- @ HO

Prototype: at MBTS location

- ~ MHz/cm^2 region (a rough estimate, scintillators)
- Installed a small 10x7 cm^2 detector at r = 1m

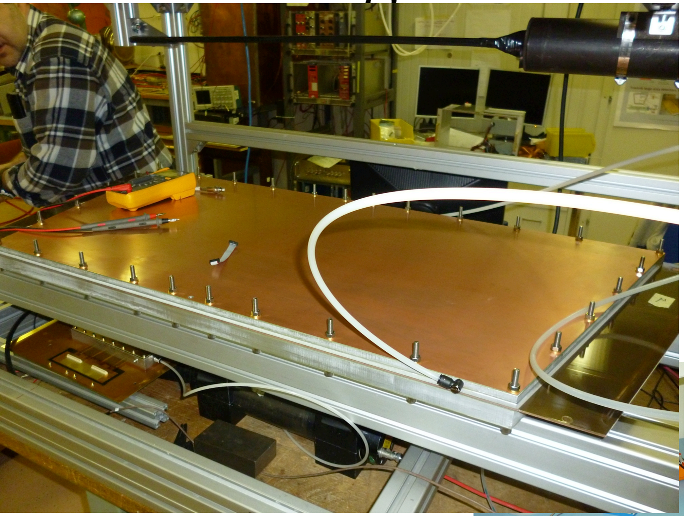


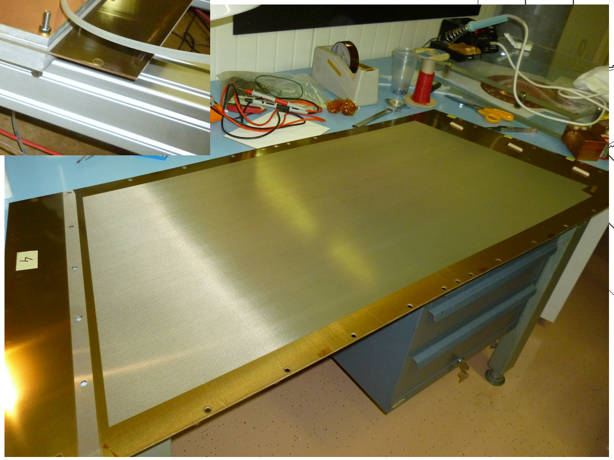
Prototype: at the Small Wheel

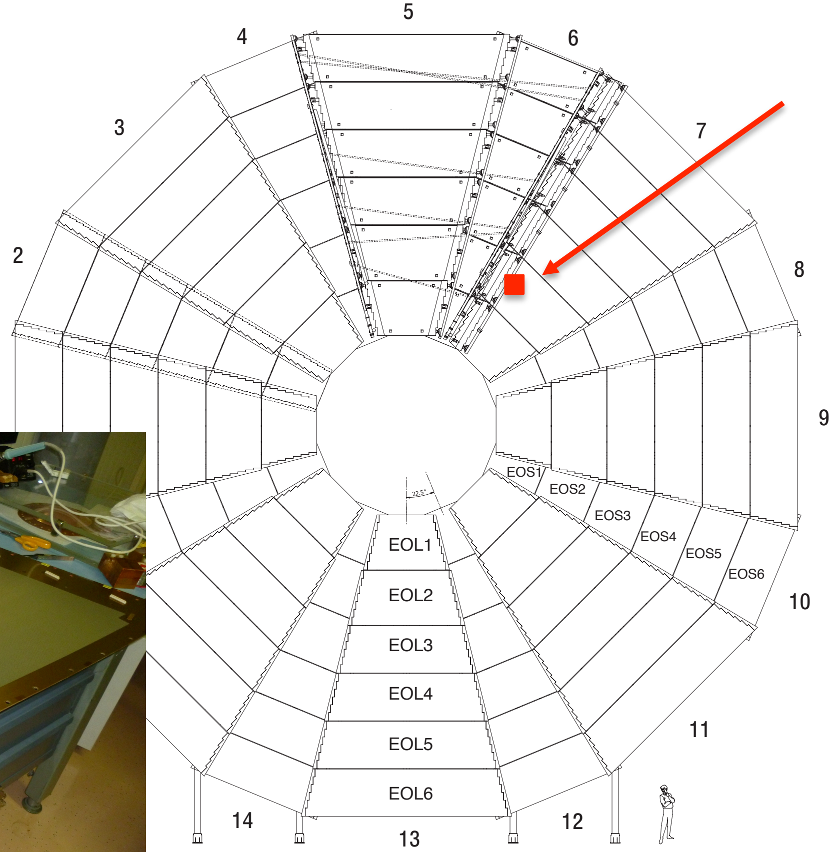
- Set of 4 small chamber prototypes

Prototype: at HO structure

- ~1.2 x 0.5 m^2
- A stack of 4 gas gaps with 2D readout (x,v strips) each
- To be installed behind the last muon station in the coming weeks







Conclusions & Outlook

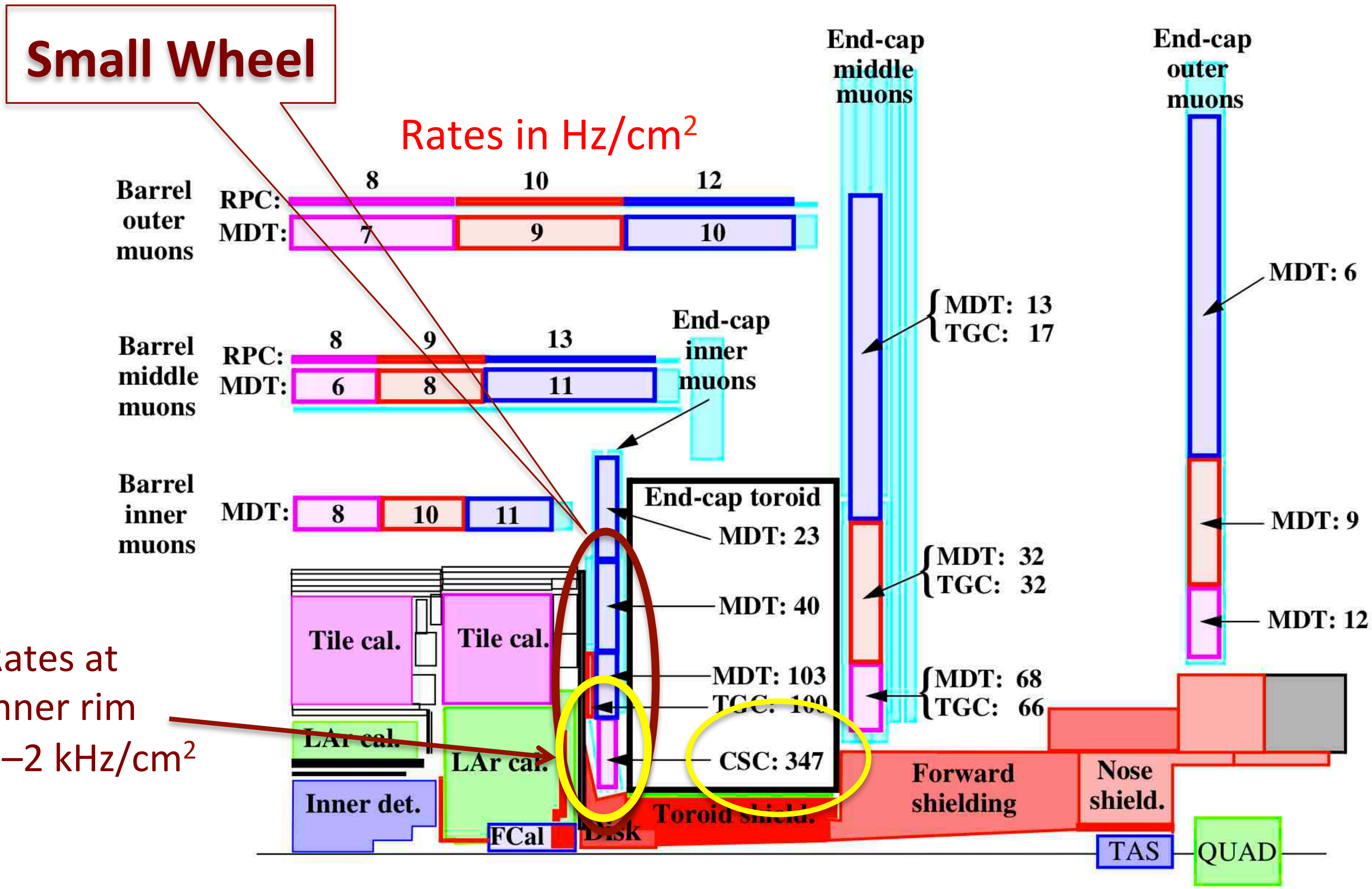
- Resistive Micromegas are very attractive detectors
  - Sparks are neutralized by the resistive protection
  - Excellent rate capability, spatial resolution, and efficiency
  - Potential to deliver track vectors in a single plane

- Prototypes installed in several locations in ATLAS and integrated with ATLAS DAQ.

- Module 0 of a SW chamber to be built in 2012

BACKUP SLIDES

Count rates*) in the ATLAS Muon System at $\sqrt{s}$ = 14 TeV for L = 10^{34} cm^{-2}s^{-1}



*) ATLAS Detector paper, 2008 JINST 3 S08003

Three reasons for new Small Wheels

- Small Wheel muon chambers were designed for a luminosity of $L = 1 \times 10^{34}\ cm^{-2}\ s^{-1}$

  The rates measured today are 2–3 x higher than estimated;

  all detectors in the SW will be at their rate limit at $5 \times 10^{34}\ cm^{-2}\ s^{-1}$

- Eliminate fakes in high-p_T (> 20 GeV) triggers

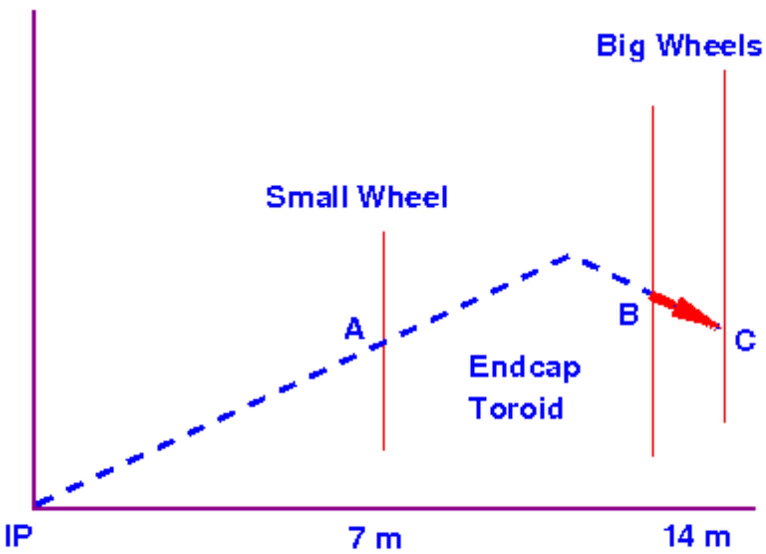
  At higher luminosity p_T thresholds of 20-25 GeV are a MUST

  Currently over 95 % of forward high p_T triggers are fake

- Improve p_T resolution to sharpen thresholds

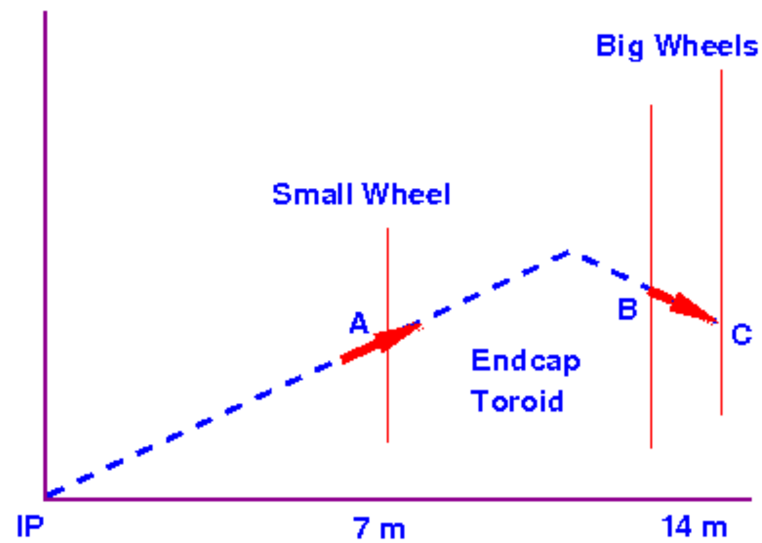
  Needs ≤1 mrad pointing resolution

The problem with the fake tracks



Current LVL1 end-cap trigger

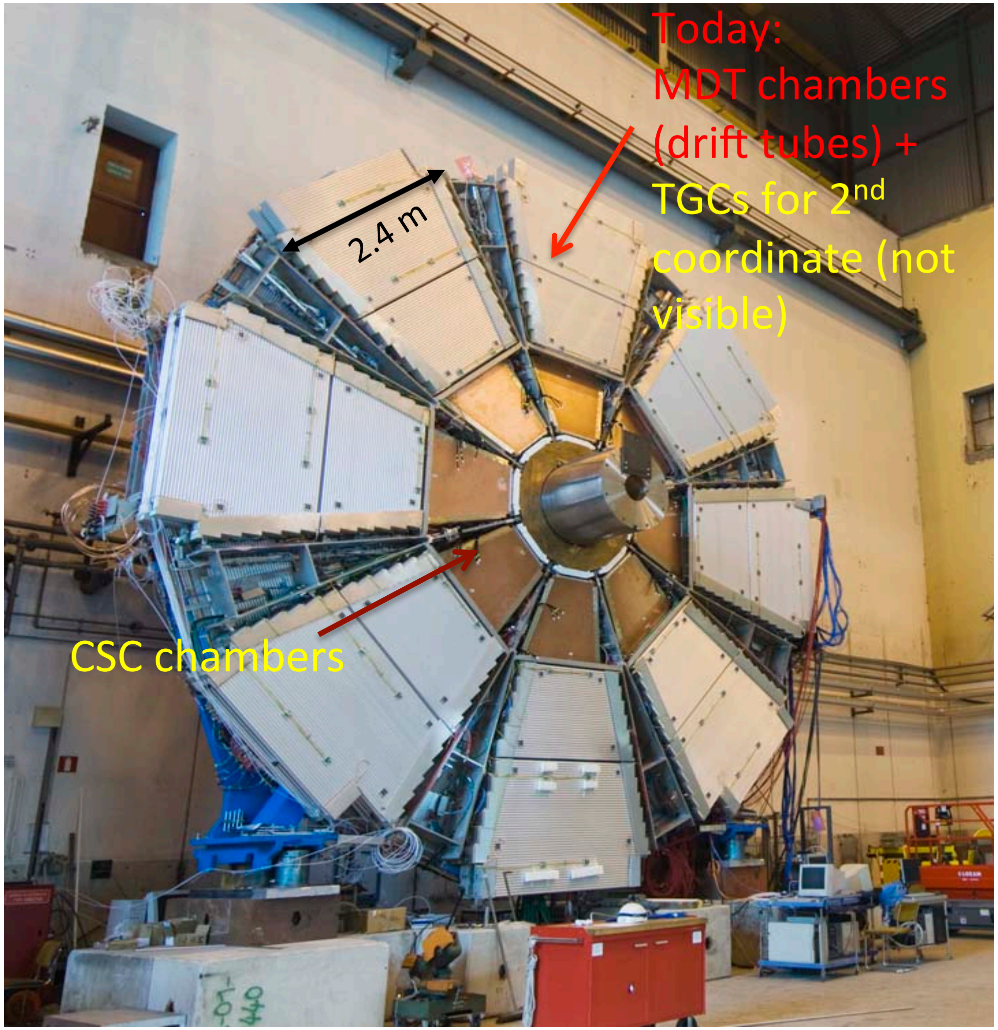
- Only the vector BC at the Big Wheels is measured
- Momentum defined by assumption that track originated at IP
- Random background tracks can easily fake this
- Currently 96% of forward high-p_T triggers (at LVL1) have no track associated with them



Proposed LVL1 trigger

- Add vector A at Small Wheel
- Powerful constraint for real tracks
- A pointing resolution of 1 mrad will also improve p_T resolution

ATLAS Small Wheel upgrade proposal*)

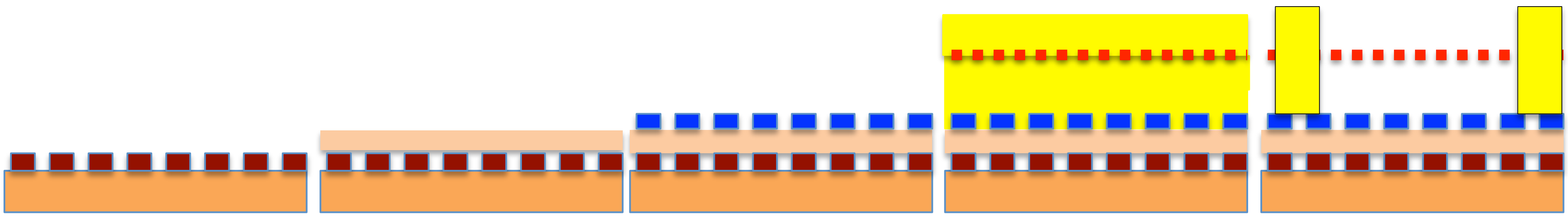


Replace the muon chambers of the Small Wheels with 128 micromegas chambers (0.5–2.5 m^2)

- Combine precision and 2nd coord. measurement as well as trigger functionality in a single device
- Each chamber comprises eight active layers, arranged in two multilayers
  - ⇒ a total of about 1200 m^2 of detection layers
  - ⇒ 2M readout channels

*) other candidates: combined systems sMDT+TGC and sMDT+RPC

The bulk-micromegas* technique + resistive strips+



PCB + r/o strips

Insulating layer
50µm

Resistive strips

2 x Photoresist
(2 x 64 µm)
Mesh
Photoresist
(1x 64µm)

Development
Etching

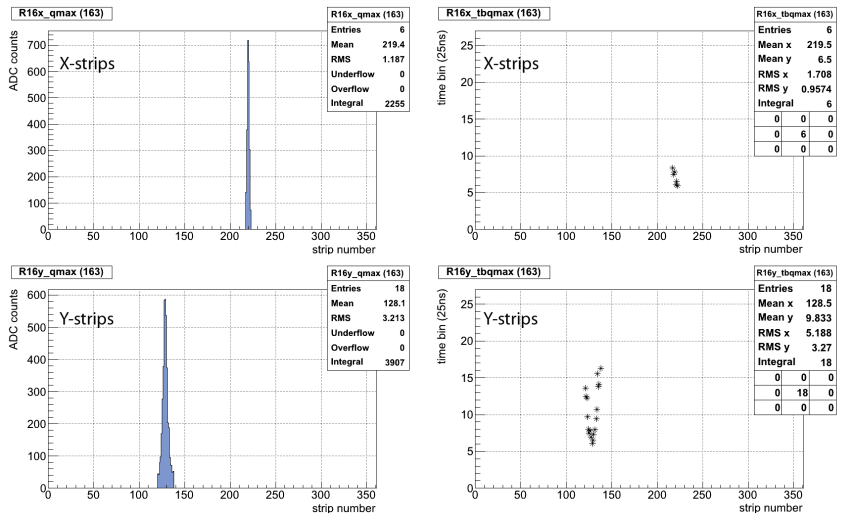
Pillars
($\oslash \approx 300\ \mu m$)

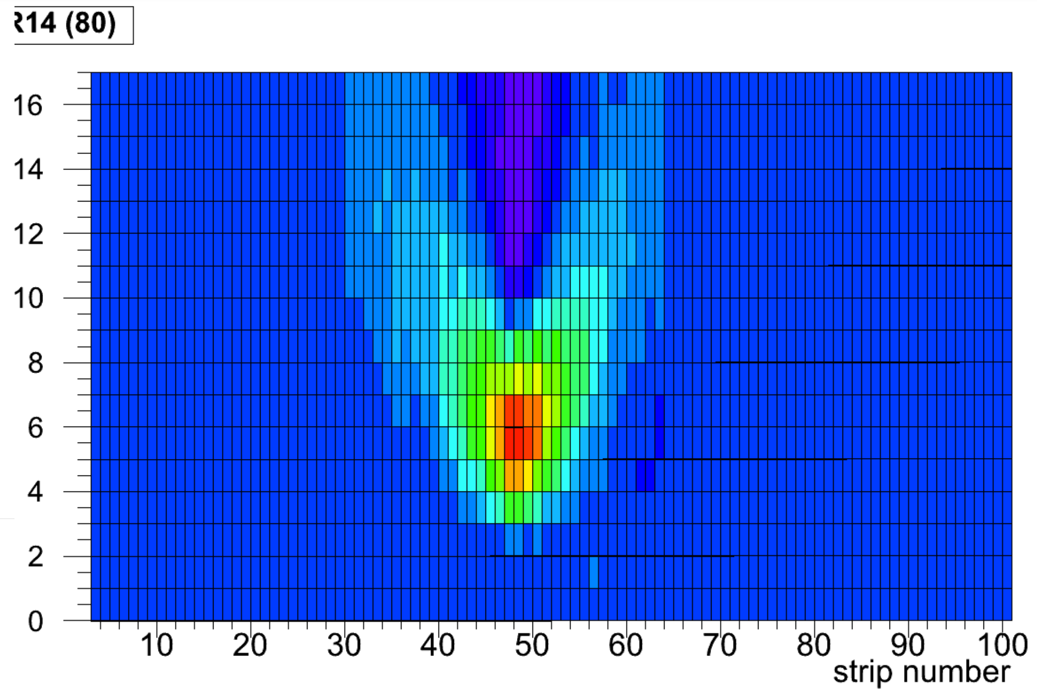
*) I. Giomataris et al., NIM A 560 (2006) 405
+) T. Alexopoulos, et al., NIM A 640 (2011) 110

Small resistive-strip detectors

Chamber	R_{GND} (MΩ)	R_{strip} (MΩ/cm)	Readout coord. (N_R:N_{ro})	Strip pitch (µm)	
R11	15	2	x (1:1)	250	
R12	45	5	x (1:1)	250	
R13	20	0.5	x (1:1)	250	
R14	100	10	x (1:1,2,3,4,72)	250	
R15	250	50	x (1:1,2,3,4,72)	250	
R16	55	35	x-y	250	
R17a,b	100	45	x-y	250	Used for ageing tests
R18	200	100	x-y	250	
R19	50	50	xuv	350/900/900	Mesh & GEM
R20	80	25	x	250	+HV on strips
R21	250	150	x-y	500/1000	+HV on strips
MBT0	100	100	x-u (x-v)	500/1500	2 gaps/+HV on strips

X precision strips vs. 2^{nd} coordinate



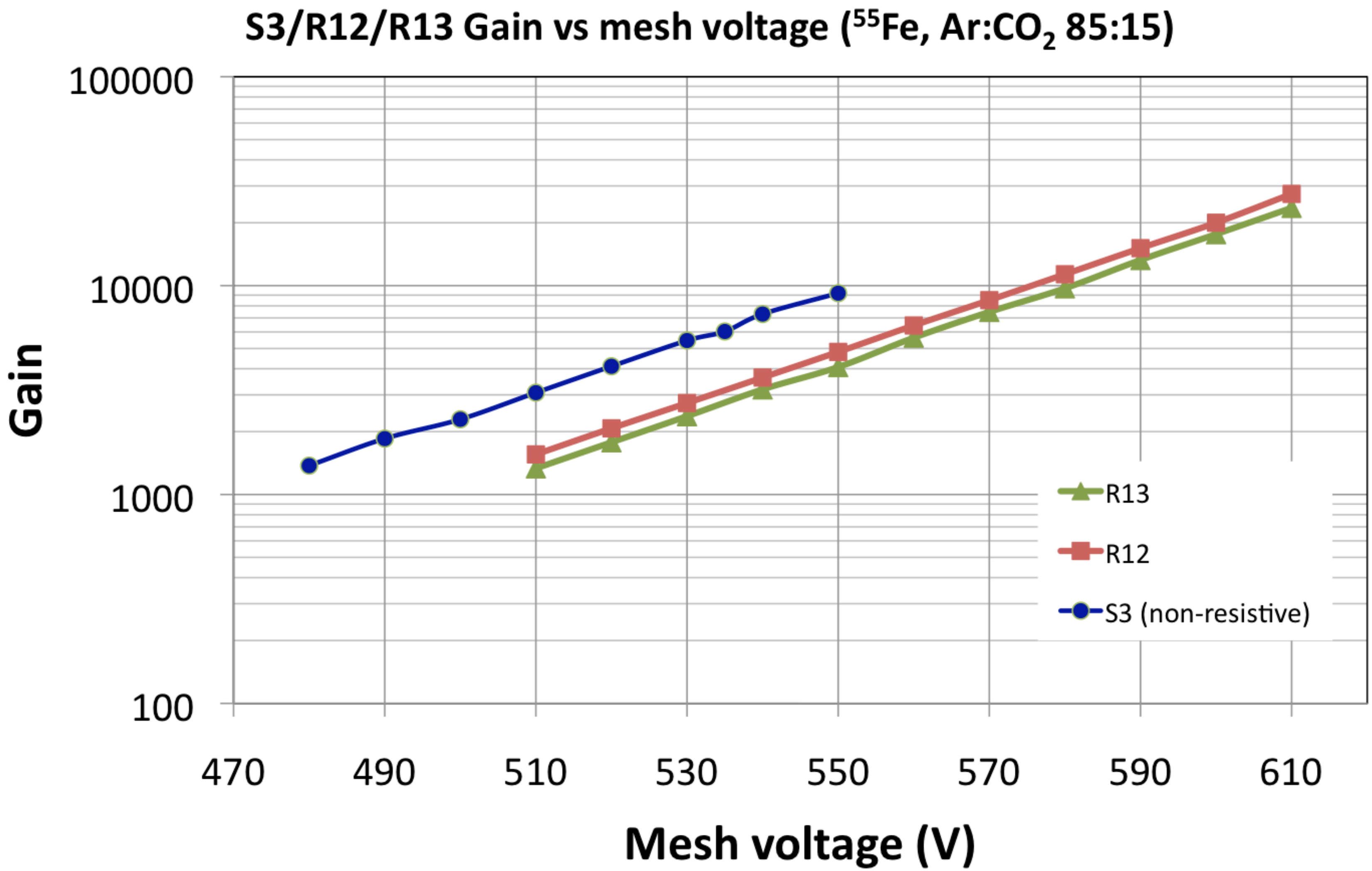


- Charge spread across readout strips
- Late residual signals in chamber

The 2nd large resistive chamber November 2011

- Electrical tests are OK
- Employs the new HV scheme with mesh on ground potential and resistive strips on +HV

Detector response



Long-time X-ray exposure 2

- In a second measurement the same chamber (R17a) was exposed again to the X-ray source, irradiating a non-irradiated area of the chamber. In parallel an 'identical' chamber (R17b) was measured without being irradiated continuously. Exposure time: 21.3 days

  Accumulated charge: 918 mC/4 cm^2

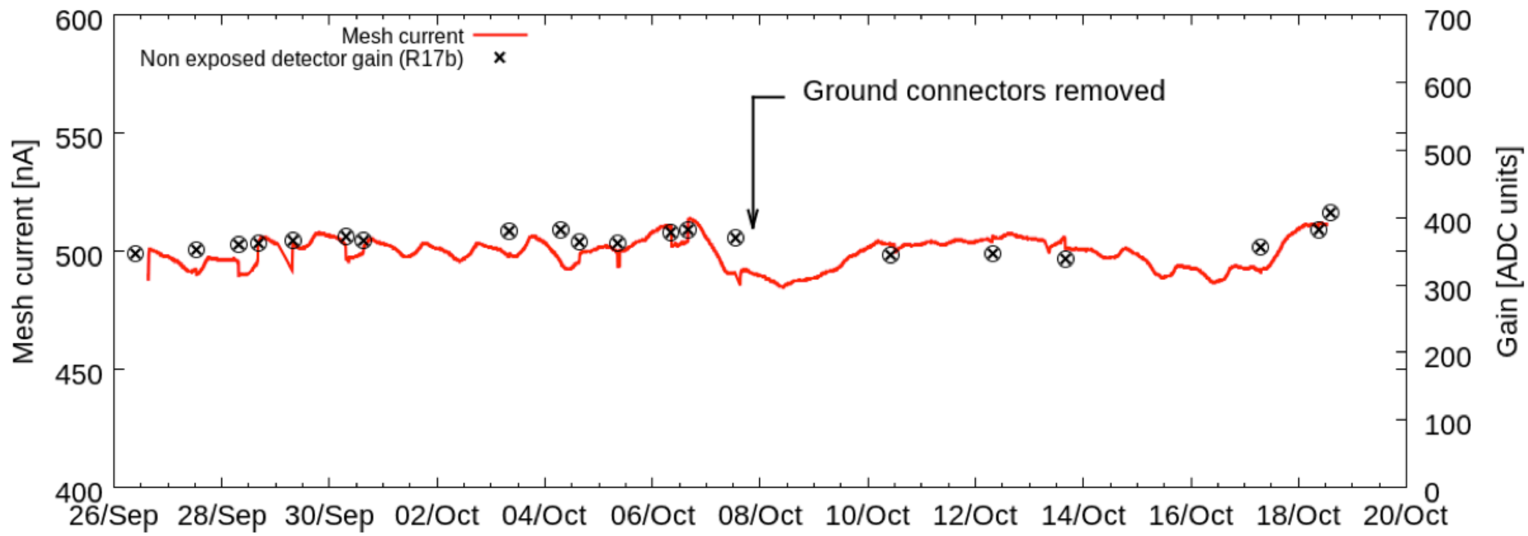
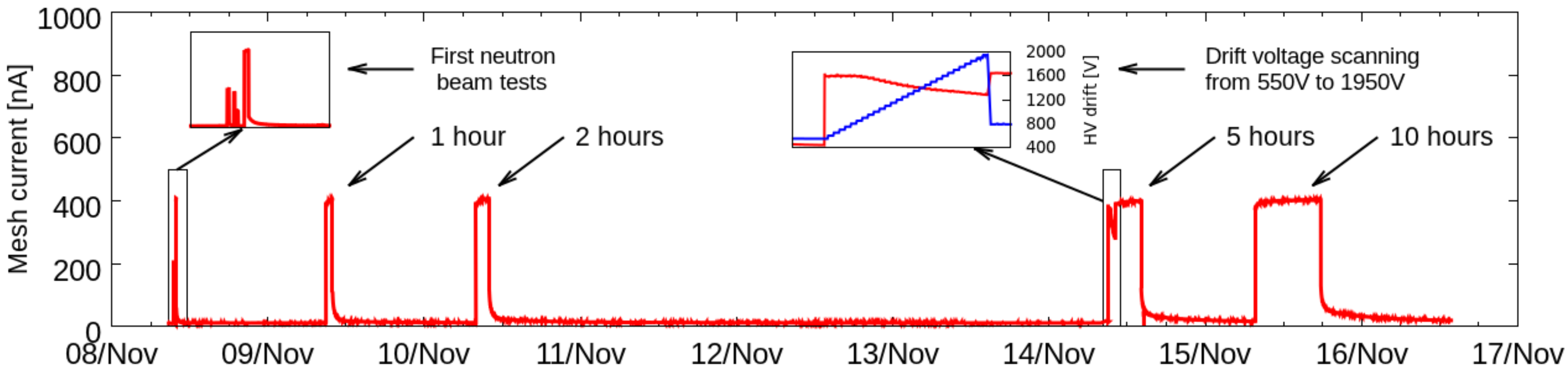


Figure 9. Mesh current evolution provided by the high voltage power supply (red line) and the R17b gain control measurements with R17b detector (black circles).

Exposure to thermal neutrons

- R17a was then moved to the Orphee reactor at Saclay and has been under radiation from 7 – 17 Nov 2011
- Neutron flux is ≈0.8 x 10^9 n/cm^2/s with energies of 5–10 x 10^{-3} eV
- Total exposure on-time: 40 hrs equivalent to ≈20 years LHC at 5 x 10^{34} $cm^{-2}s^{-1}$ (including a safety factor of 3)
- Detector response perfectly stable over full duration of irradiation



Sparks in resistive chambers

- Spark signals (currents) for resistive chambers are about a factor 1000 lower than for standard micromegas (spark pulse in non-resistive MMs: few 100 V)
- Spark signals fast (<100 ns), recovery time a few µs, slightly shorter for R12 with strips with higher resistance
- Frequently multiple sparks