Test beam and simulation studies on thin gap chambers

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Outline

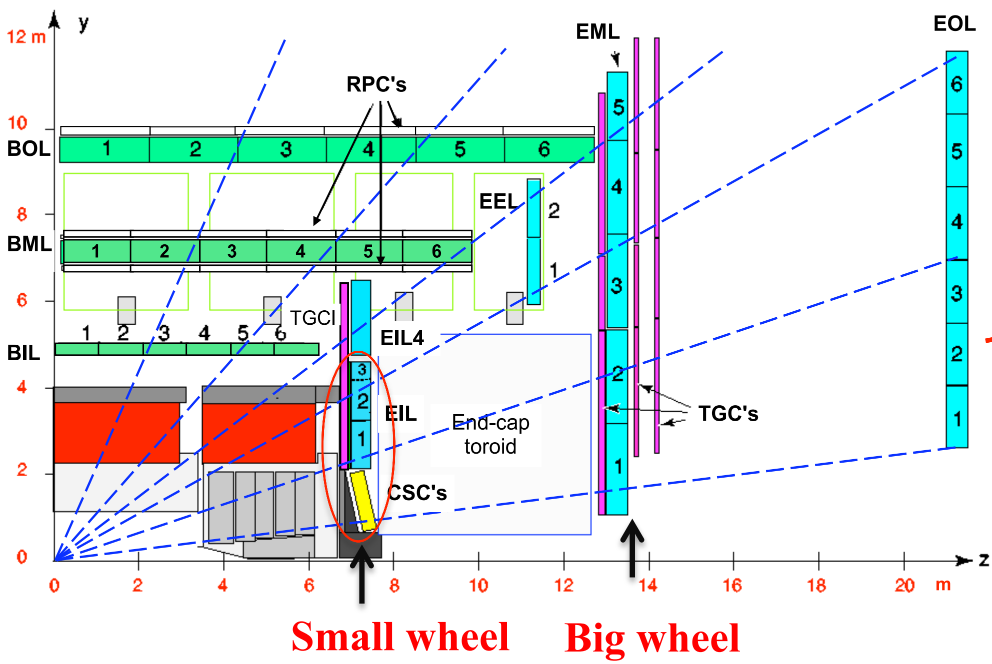
- Introduction
- Small-strip Thin Gap Chambers (sTGC) for the ATLAS phase-I upgrade
- Test beam results
  - ✓ Spatial resolution studies
  - ✓ Timing performance studies
- Detector simulation
- Summary

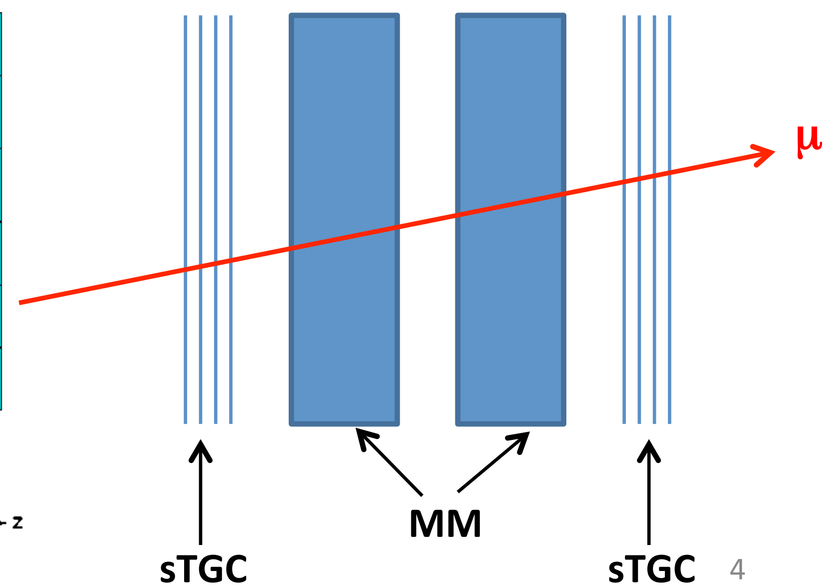
Introduction

- The LHC machine plans to increase the instantaneous luminosity to 2 - 5×10^{34} $cm^{-2}s^{-1}$ after its phase-I and phase-II upgrades and collects 300 – 3000 fb^{-1} of data
- The luminosity upgrade is a big opportunity of higher physics potential
- Detector performance must be maintained to fully profit from the upgrade
- ATLAS plans to replace its forward muon detector for the phase-I upgrade (before 2018) to fix problems with
    - L1 muon trigger rate: high fake muon rate, limited L1 muon pT resolution → high L1 trigger rate → prescale/higher thresholds → loss of interesting physics
    - Muon precision tracking: performance deterioration due to high background and low detection efficiency

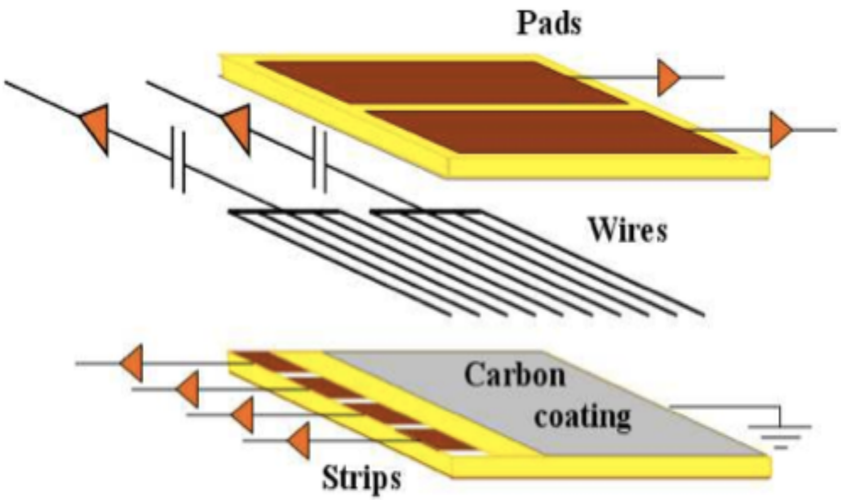
New Small Wheel

- Plan to replace the present SW detector (MDT + one station of TGC) with NSW (two stations of MM + two stations of sTGCs)
- sTGCs: (1) Kill fake trigger muons by requiring high quality IP-pointing segments in NSW; (2) measure muon incident angle at NSW with a resolution of 1 mrad; (3) improve L1 muon p_T resolution
- MM: precise muon hit position measurement and high muon detection efficiency
- Improve trigger (tracking) in the forward region $1.4<|\eta_{det}|<2.4$ (2.7)

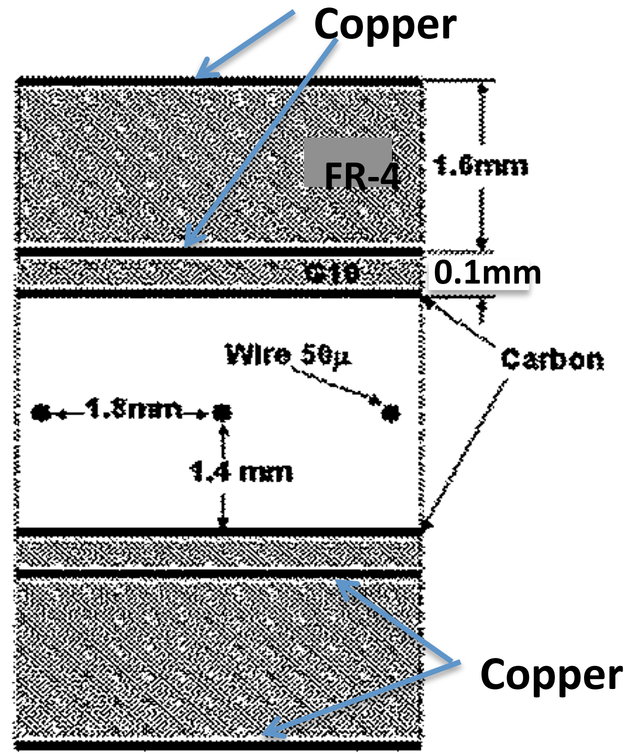




sTGC structure



TGC geometry	
Wire-carbon gap	1.4 mm
Wire-wire space	1.8 mm
Strip-carbon gap	0.1 mm
Strip pitch	3.2 mm
Inter-strip gap	0.5 mm
TGC additional parameters	
Wire length in layers	0.4 m
Number of wires ganged together	5
Strip length	0.6 m
Pad size	8.7 × 8.7 cm^2
Carbon plan resistance	100 kΩ/square
HV blocking capacitance	470 pF



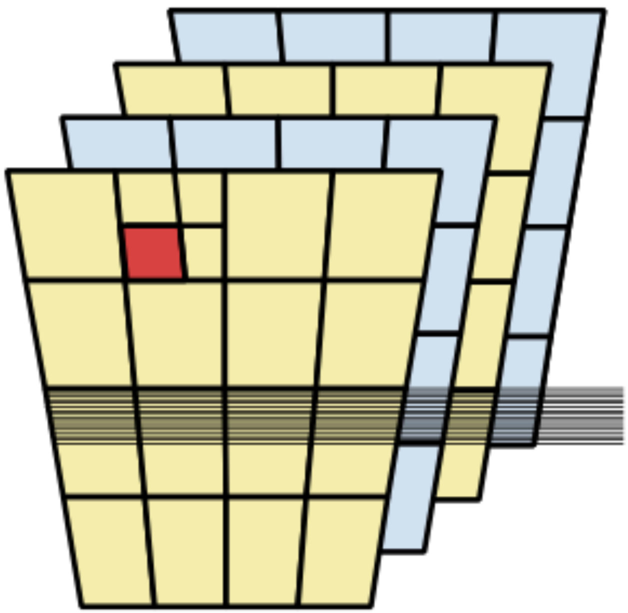
Copper/Graphite : 0.02mm

Gas : 55%CO_2 + 45%N-pentane

Strip and pad signals used for trigger purpose

Pad trigger

sTGC quadruplet



Physical pads, each layer staggered by ½ pad in both directions

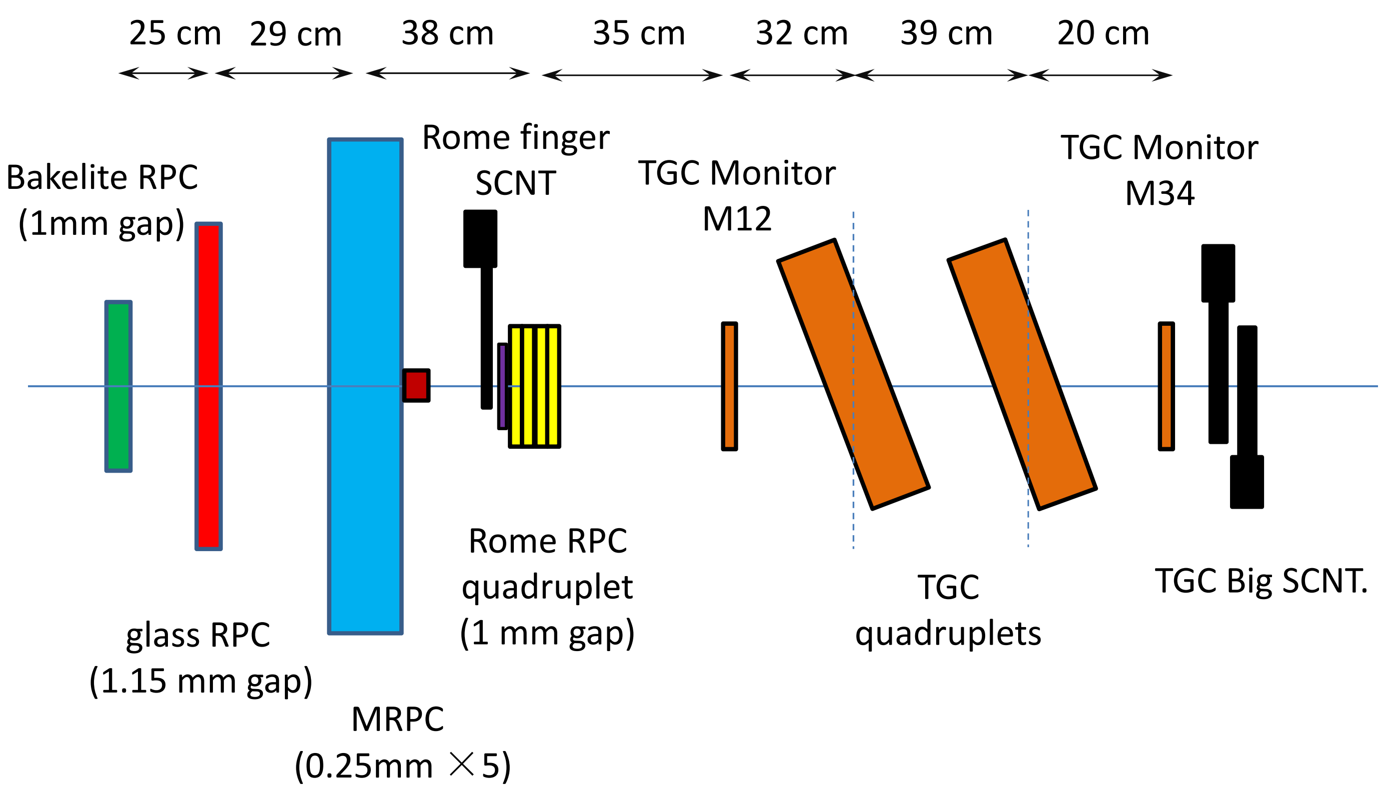
Logical pad-tower defined by projection from 4 layers of staggered pad boundaries

Pad trigger selects a band of strips under row of logical pads

Test beam results
(CERN H8 Oct-Nov 2012)

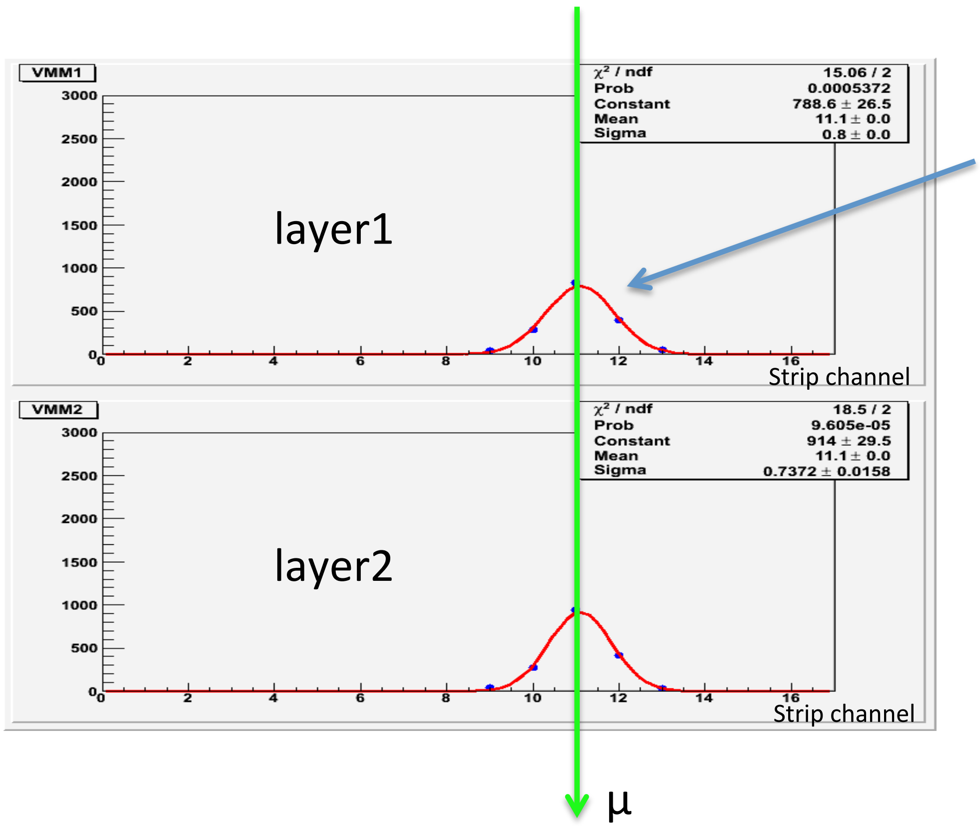
Test beam setup

- Performed a few beam tests to understand the sTGC spatial resolution and pad timing performance as trigger devices, also to have better understanding of the ASD (VMM) chip designed by BNL



Spatial resolution

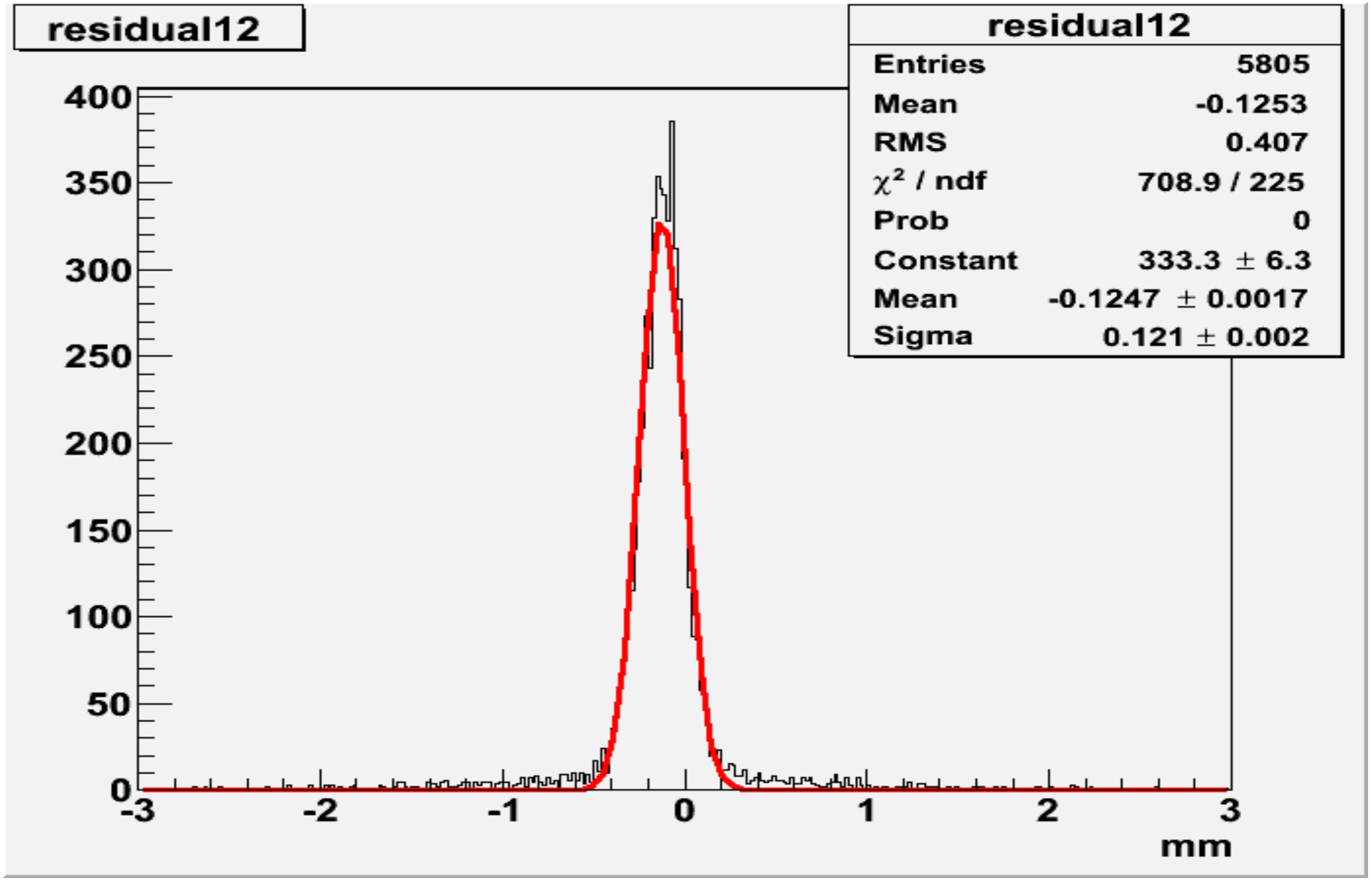
A single event display (two layers)



Fit Gaussian :

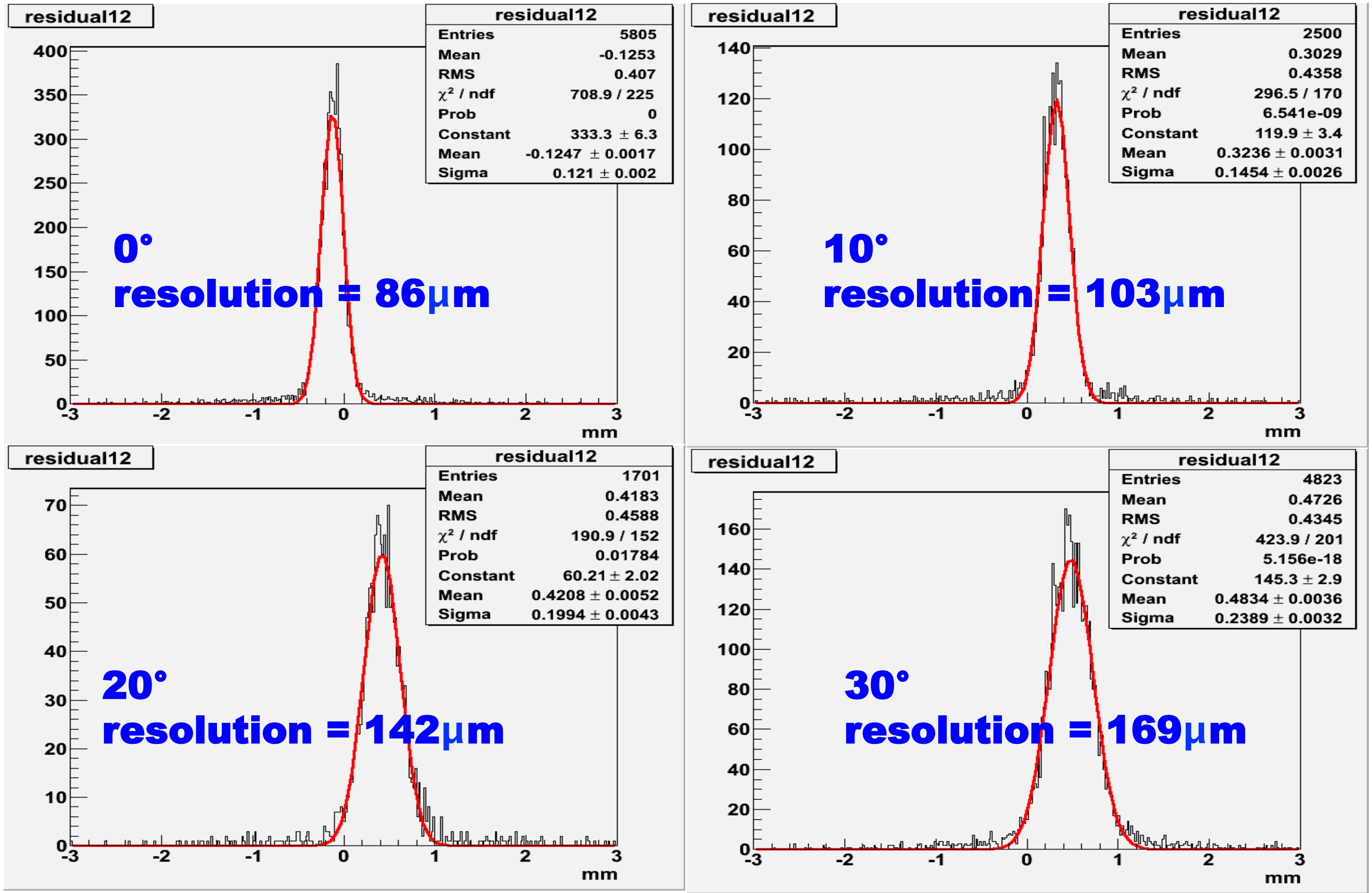
- ✓ Mean : X_i
- ✓ Residual12 = $X_2 - X_1$
- ✓ Spatial resolution ≈ σ(residual12) ÷ √2

Spatial resolution

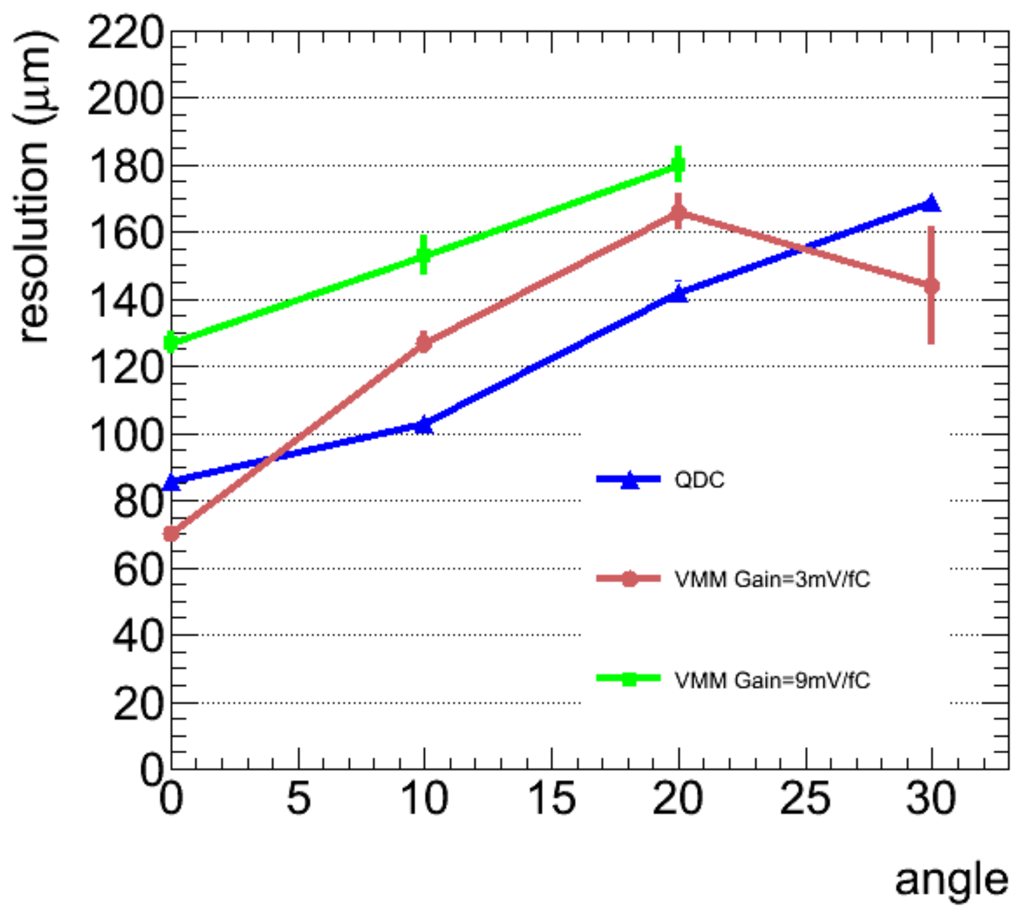


resolution : 0° : 121.3 ÷ √2 ≈ 86 μm

Resolutions @ different angles

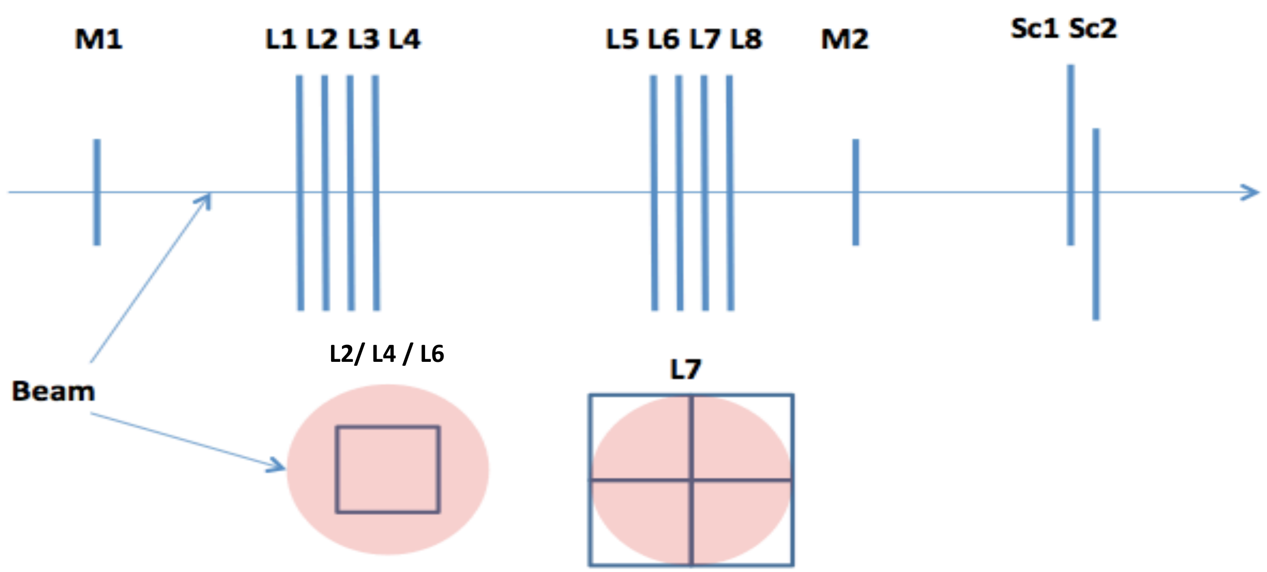


Resolutions @ different angles



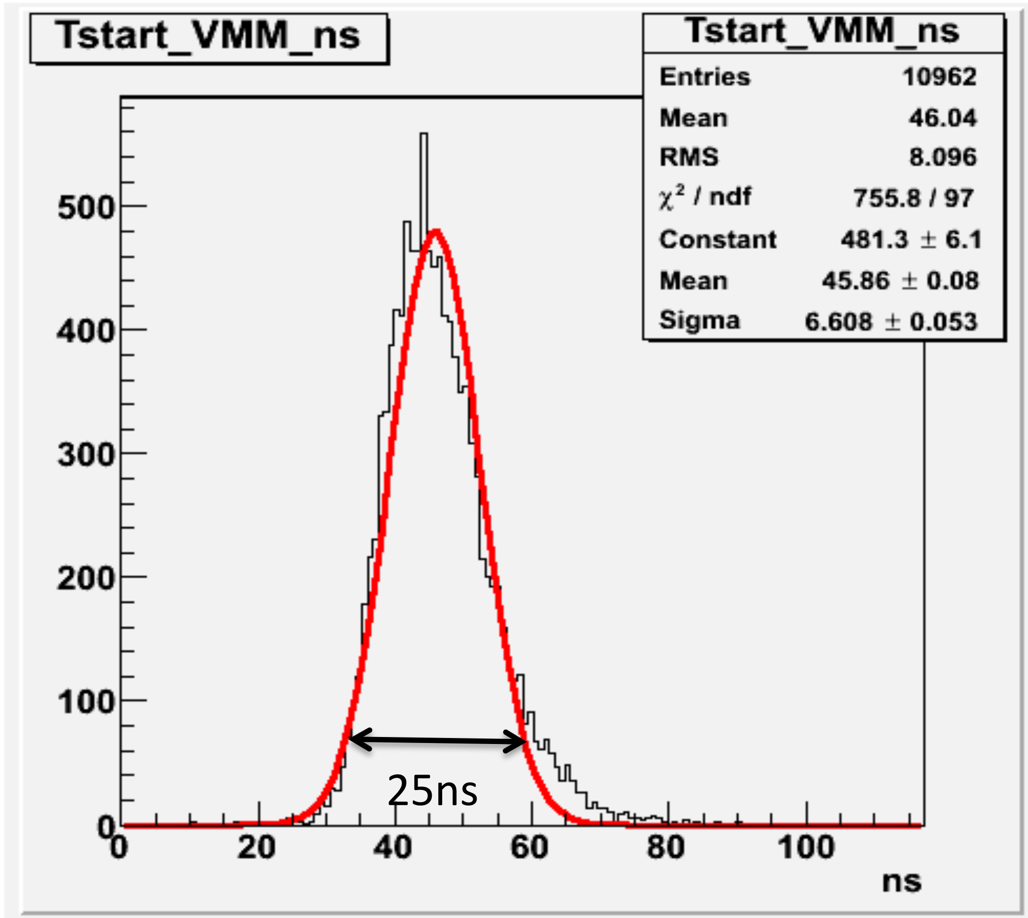
Pad timing study

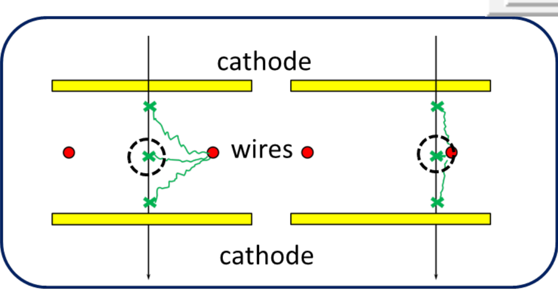
- 25ns bunch crossing :
  - Fast signal
  - a quite “narrow” distribution of signal time to get correct BC Tagger
- Aiming to have >97% events getting the correct BCId with 25ns bunch crossing



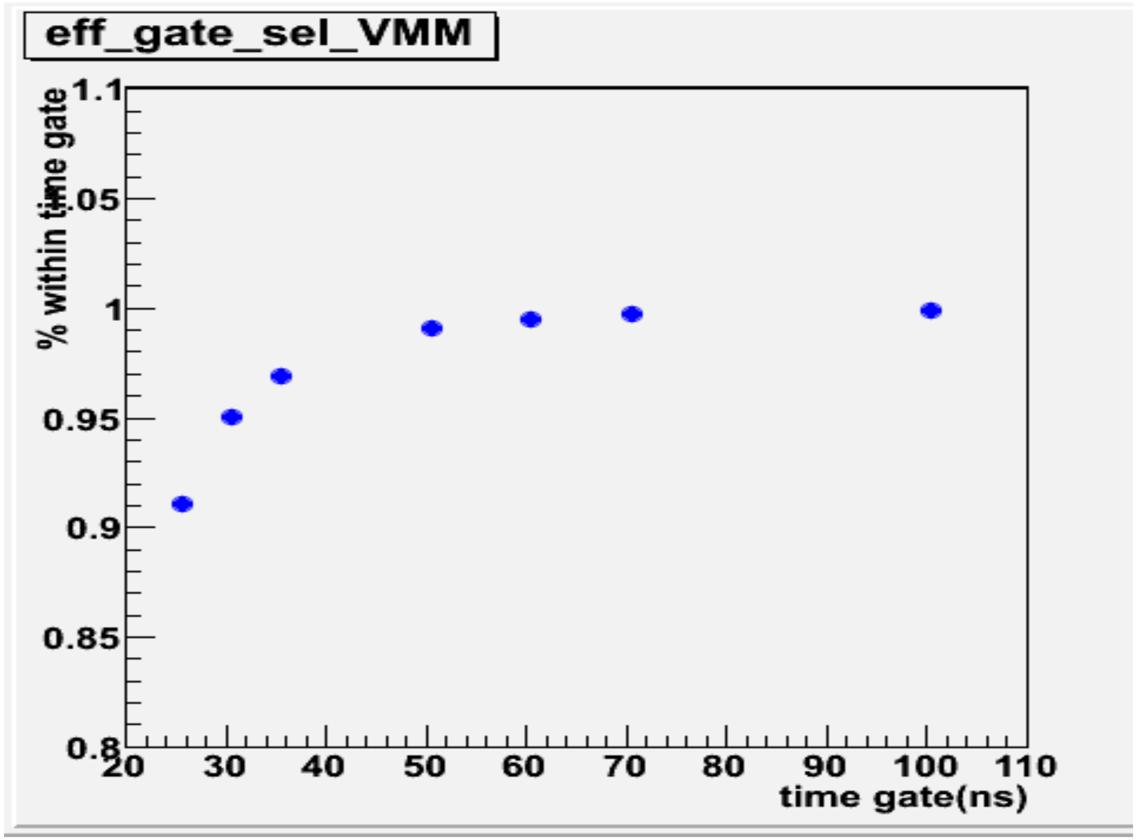
Pink area : beam size
Square : pad size

Pad timing distribution



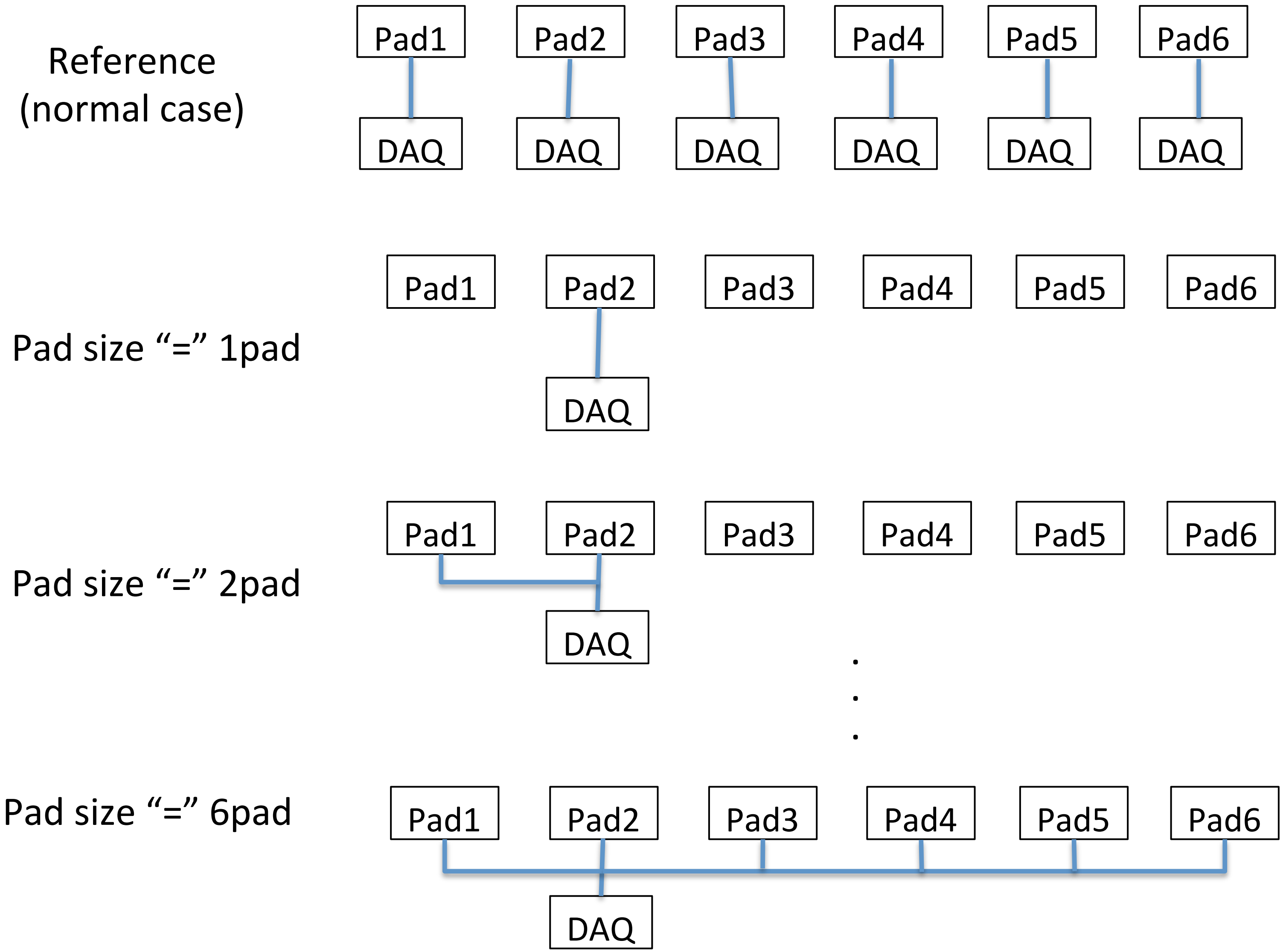


Pad timing performance

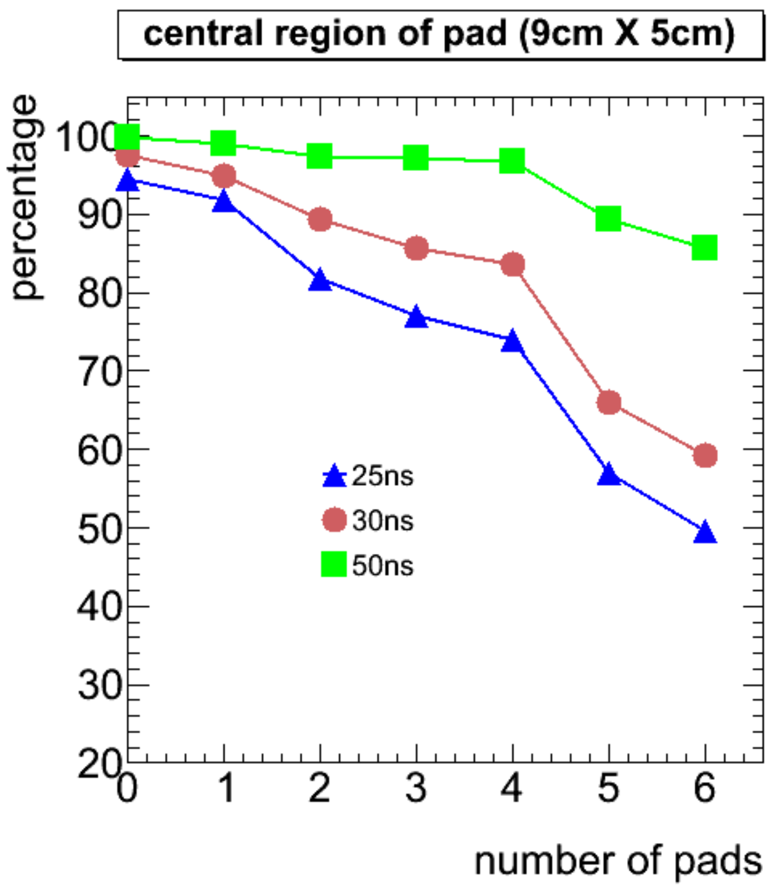


Typical : 91% at time gate = 25ns
Best : 95%

Pad size study



Pad size study

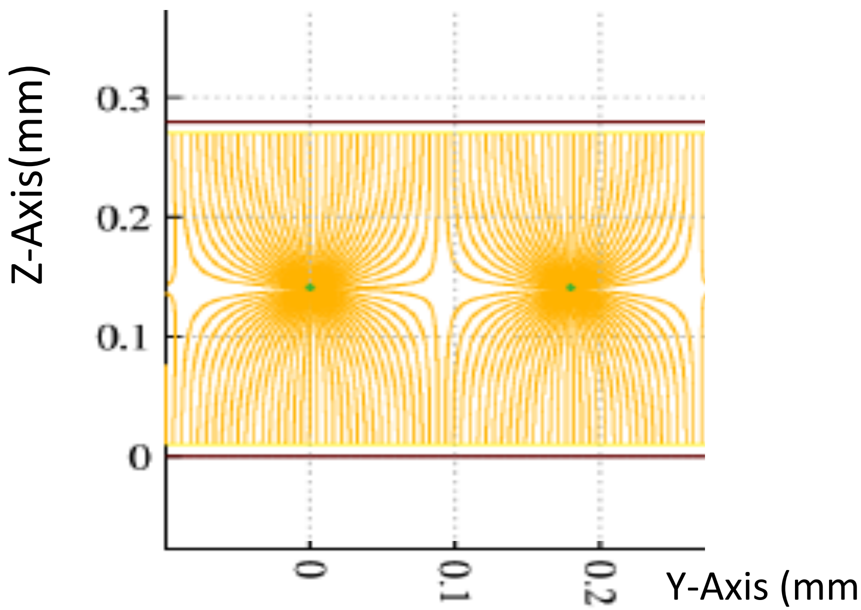


Peaking time = 25ns, Threshold = 400 counts, Gain=9mV/fC

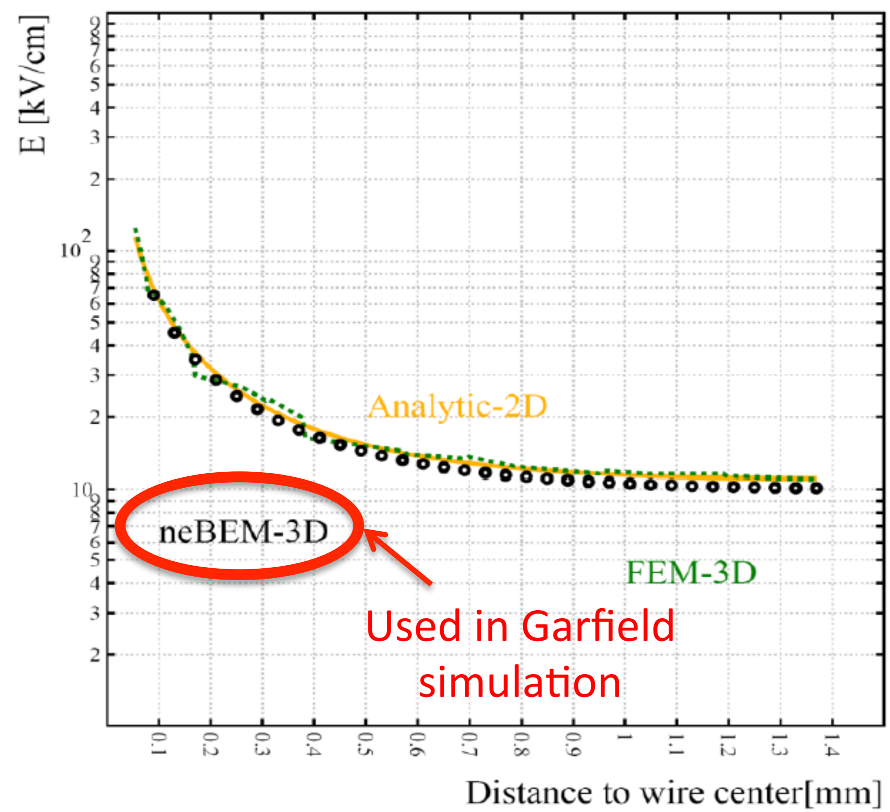
Detector simulation

Electric-field simulation

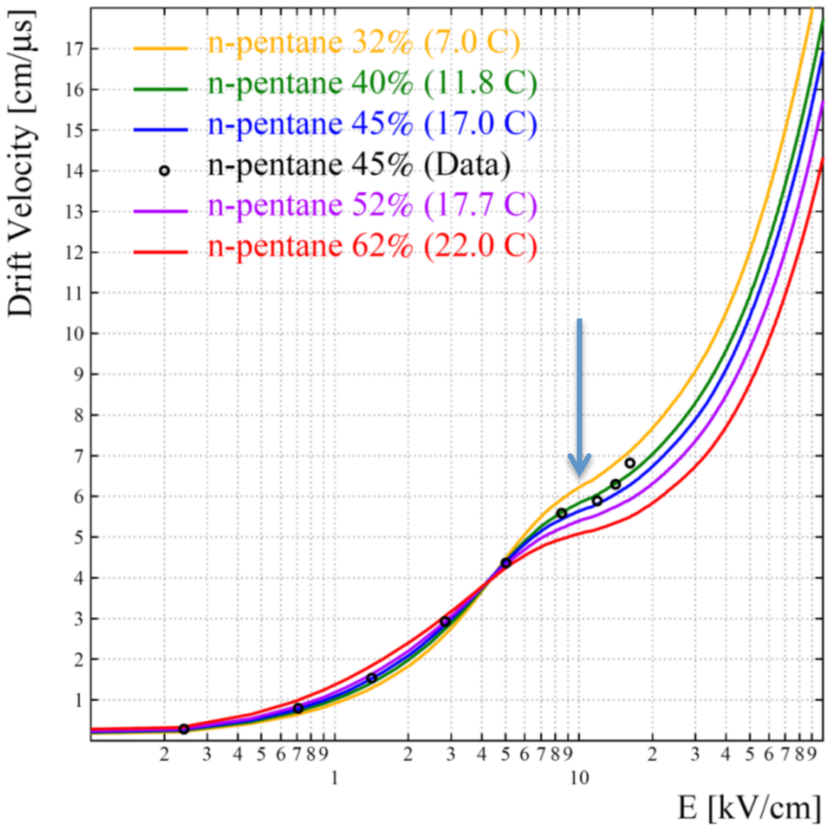
- Electric field calculation is important for understanding the ionization, electron transportation, avalanche in gaseous detectors

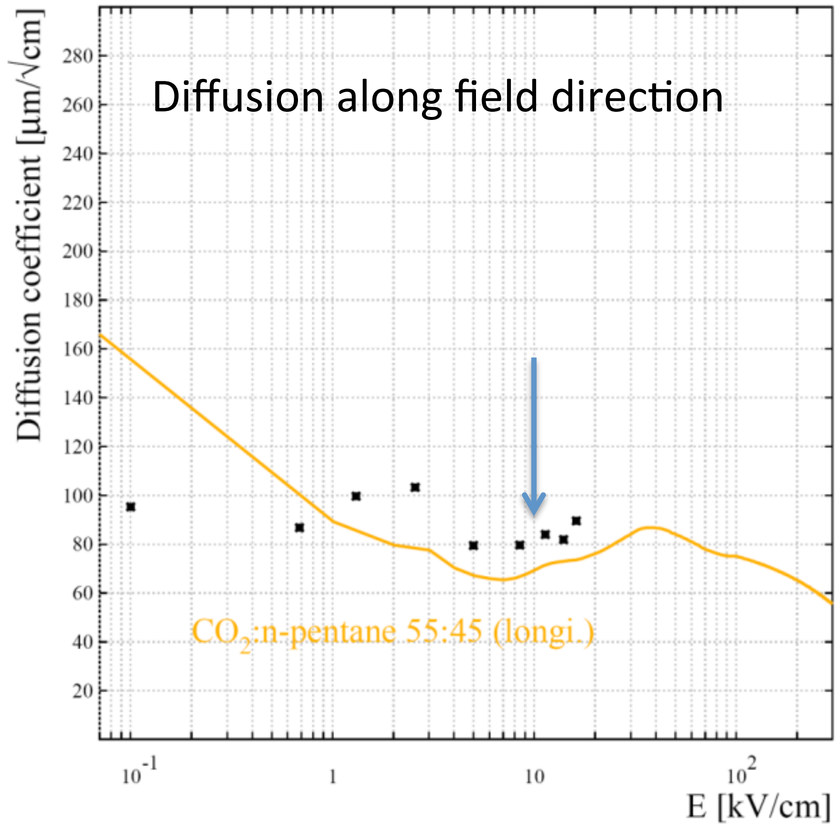


Electron drift lines(no diffusion) by Garfield (HV=3kV



Gas properties





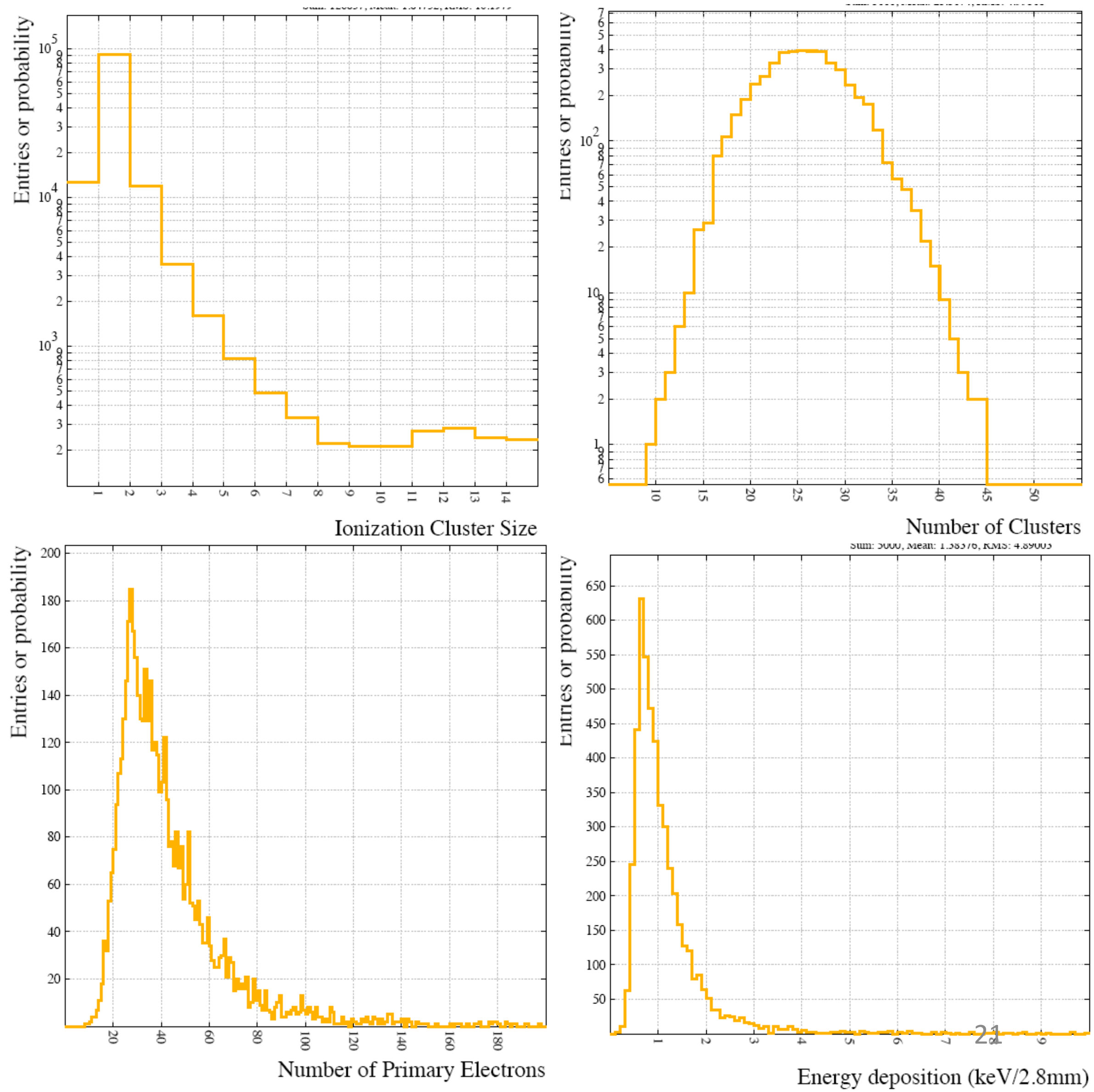
* *Data points taken from D.Lazic et al., NIM A 410 (1998) 159*

- Drift Velocity: simulation has good agreement with data
- Small longitudinal diffusion in the gas: < 30 µm in 1 mm drift path

Ionization

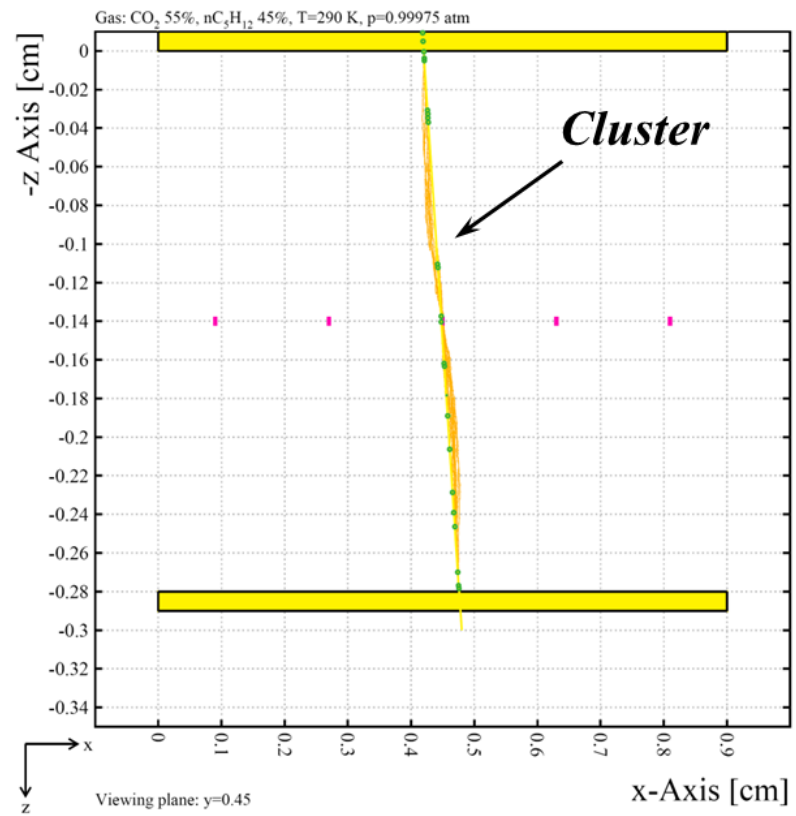
- Ionization of 180 GeV μ^- in 2.8 mm sTGC gas gap

- Electron-ion pairs per cluster: ~1.85
- Mean #. of clusters: ~25
- Total ionization: ~47 electron ion pairs
- Mean energy deposition 1.33 KeV



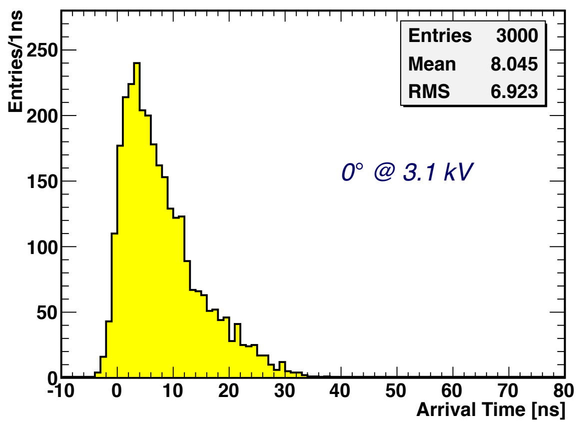
Timing information

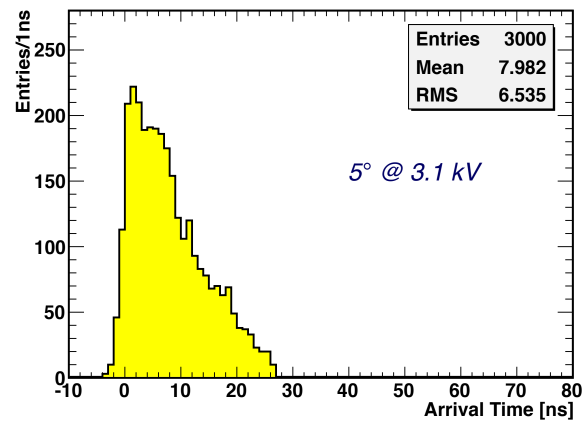
- Free electrons drift from where clusters are produced
- Assumption: the avalanche initiated by the cluster nearest to the wire will give a signal large enough to pass the threshold
- take the minimum arrival (to wire) time as the signal time
- Convolute the time with a Gaussian fluctuation(σ=1.4ns) describing the electronics time jitter

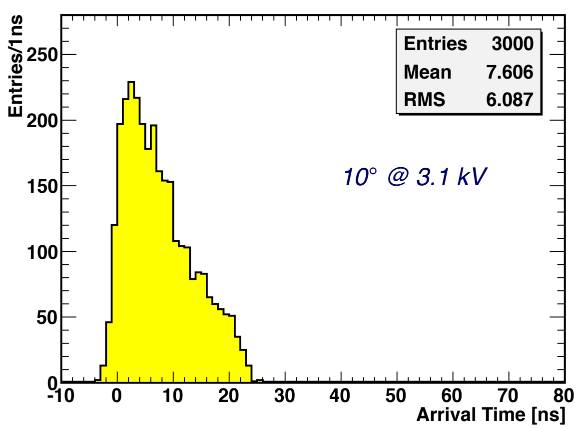


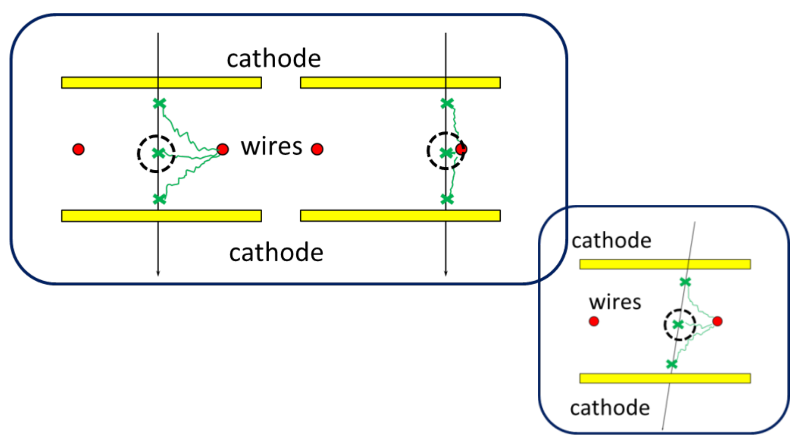
Timing information

- Simulated time spectrum with different particle incident angles



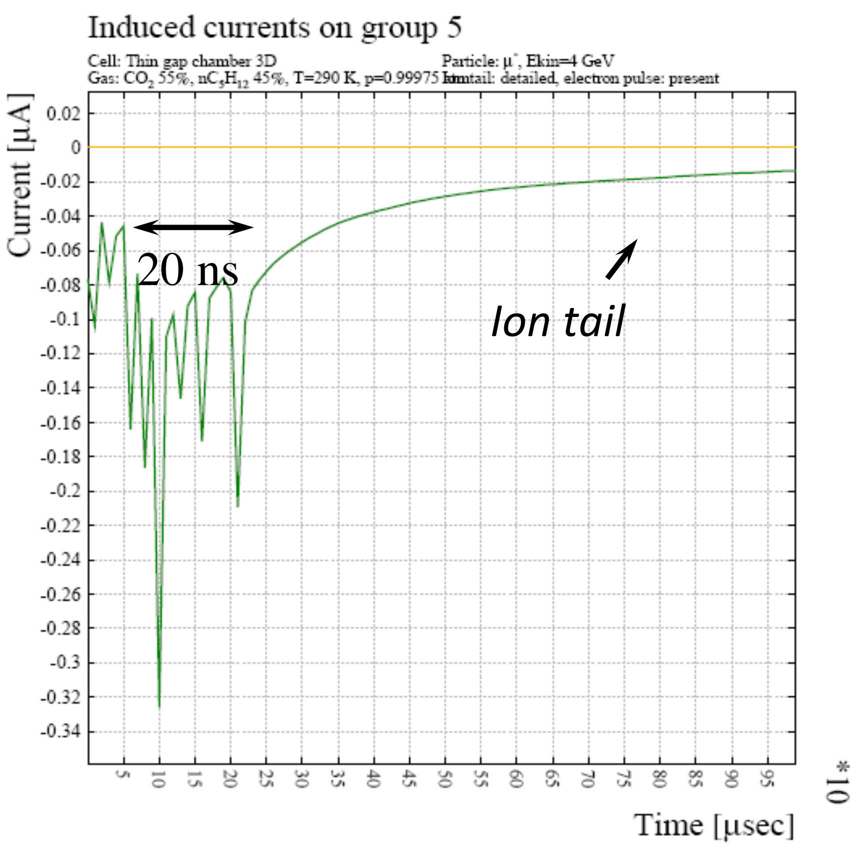






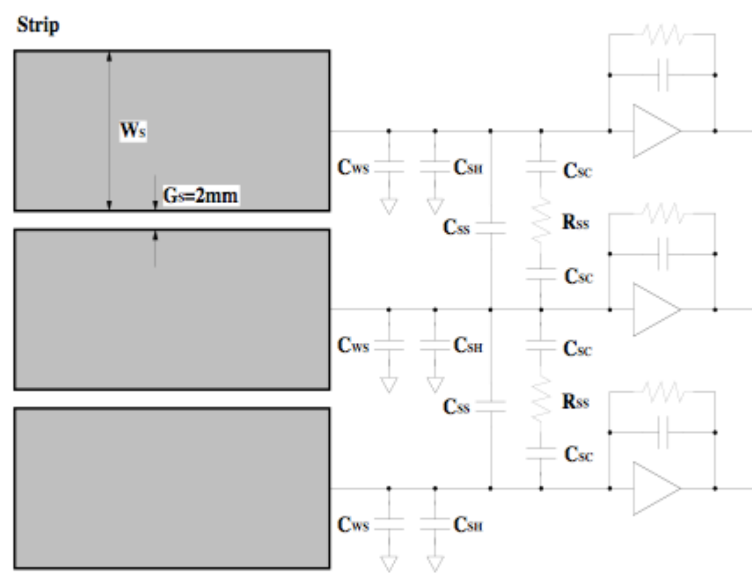
Induced current signal

Signal on the wire



Work plan :

- Charge spread on the resistive layer
- Simulation of electronics response
- The final readout from electronics
- Compare with the signal read from oscilloscope



Summary

- sTGC will be used as the muon trigger device in the forward region for ATLAS phase-I upgrade.
- It will provide high quality segment measurement in small wheel, and help reduce fake muons and improve L1 muon p_T resolution.
- sTGC test beam results :
  - ✓ Spatial resolutions of 90~170μm observed depending on incident angle;
  - ✓ The same level of spatial resolution could be obtained with VMM1 chip;
  - ✓ For the pad time performance, about 91% events are within a 25ns time window on average, 95% at the best.
- Performs studies of electric field and gas properties of sTGC chamber, simulate the timing information and induced current signal on the wire.

Reference

- **NSW requirements and performance**, T. Kawamoto, Aug 29 2012, NSW technical review

https://indico.cern.ch/getFile.py/access?contribId=1&resId=1&materialId=slides&confId=200623

- **sTGC technology status report**, George Mikenberg, Aug 29 2012

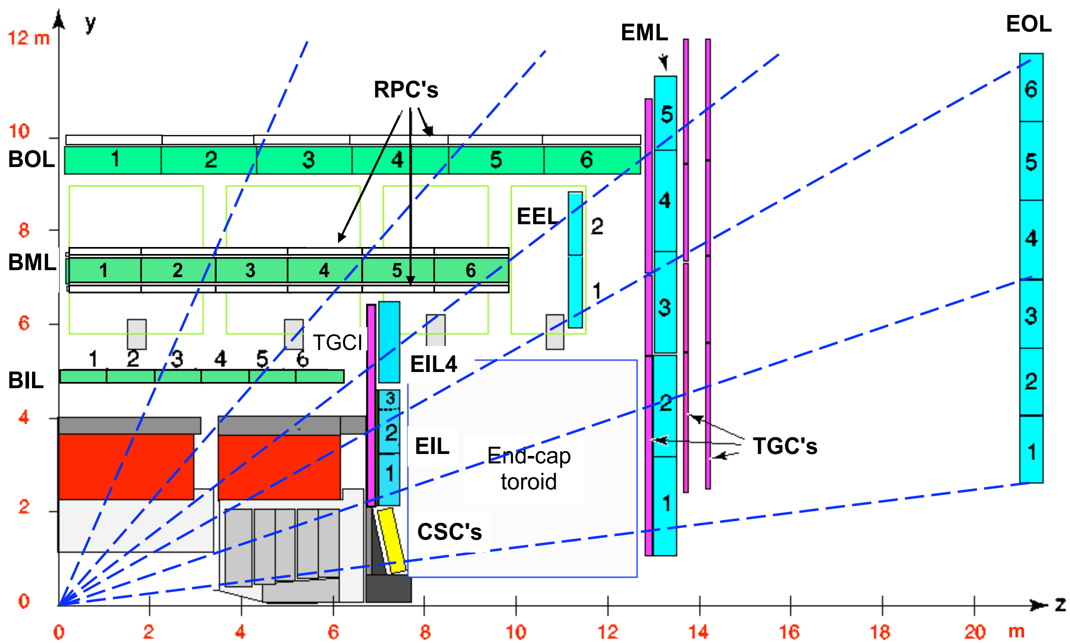
https://indico.cern.ch/getFile.py/access?contribId=5&resId=1&materialId=slides&confId=200623

- **Muon New Small Wheel sTGC Trigger for Phase I**, Lorne Levinson, Aug 30 2012

https://indico.cern.ch/getFile.py/access?contribId=15&resId=1&materialId=slides&confId=200623

Back up

Current Small Wheel



- SW detector : eight layers of Monitored drift tube chambers (MDT) and one station of thin gap chambers (TGC) chamber
- MDT as precision tracking detector and TGC as trigger detectors

- instantaneous luminosity $\sim 2 - 5\times10^{34}$ cm^{-2}s^{-1}
- Replace forward muon detector before 2018 to fix problems with :

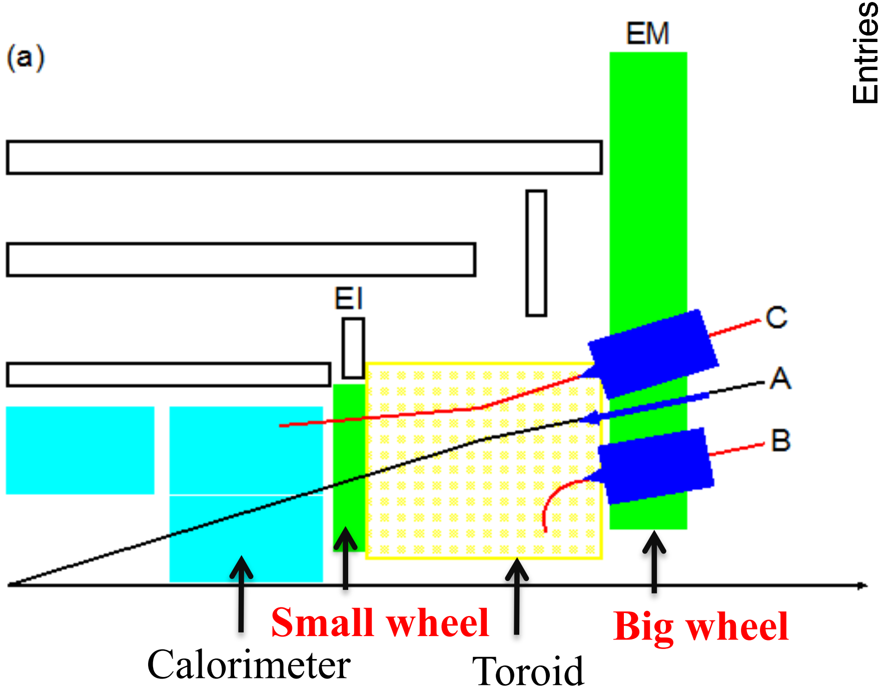
✓ L1 muon trigger rate: high fake muons observed, limited L1 muon pT (~20-30%) resolution

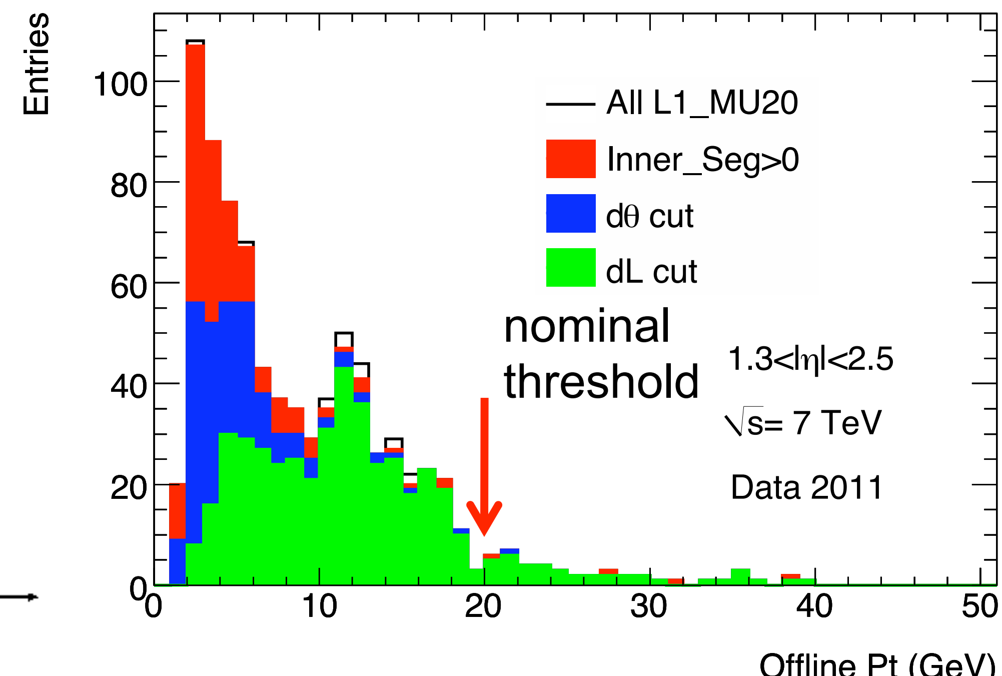
✓ Muon precision tracking: performance deterioration due to high background and low detection efficiency.

Current Small Wheel

The present L1 trigger algorithm is based on the segments only measured by the BW TGCs and with the assumption that the muons originate from the origin

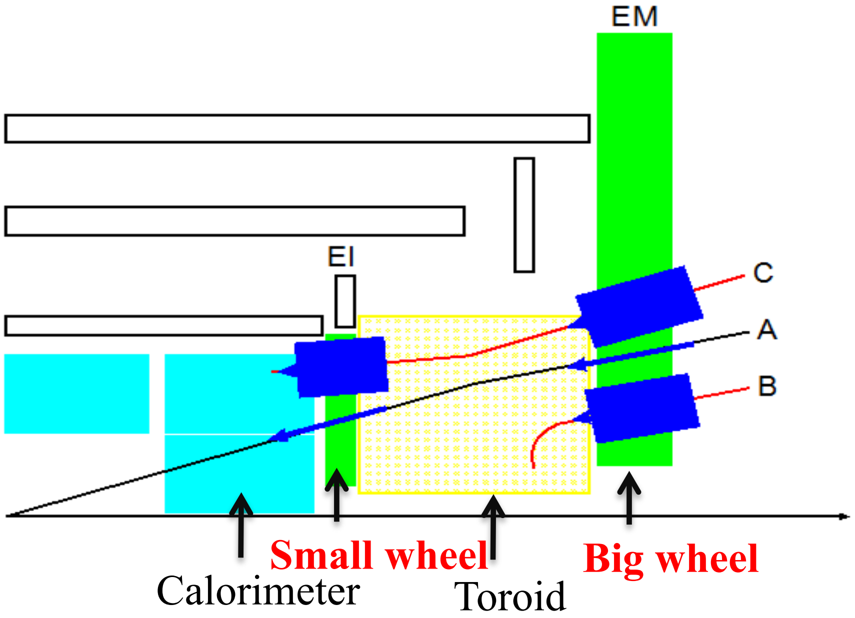
- Many charged particles or slow neutrons produced in or after SW still produce segments in BW and mimic the trigger signal and not pointing to the origin
- BW segment angle measurement (~3 mrad) → worse L1 muon pT resolution (~30% at 25 GeV)



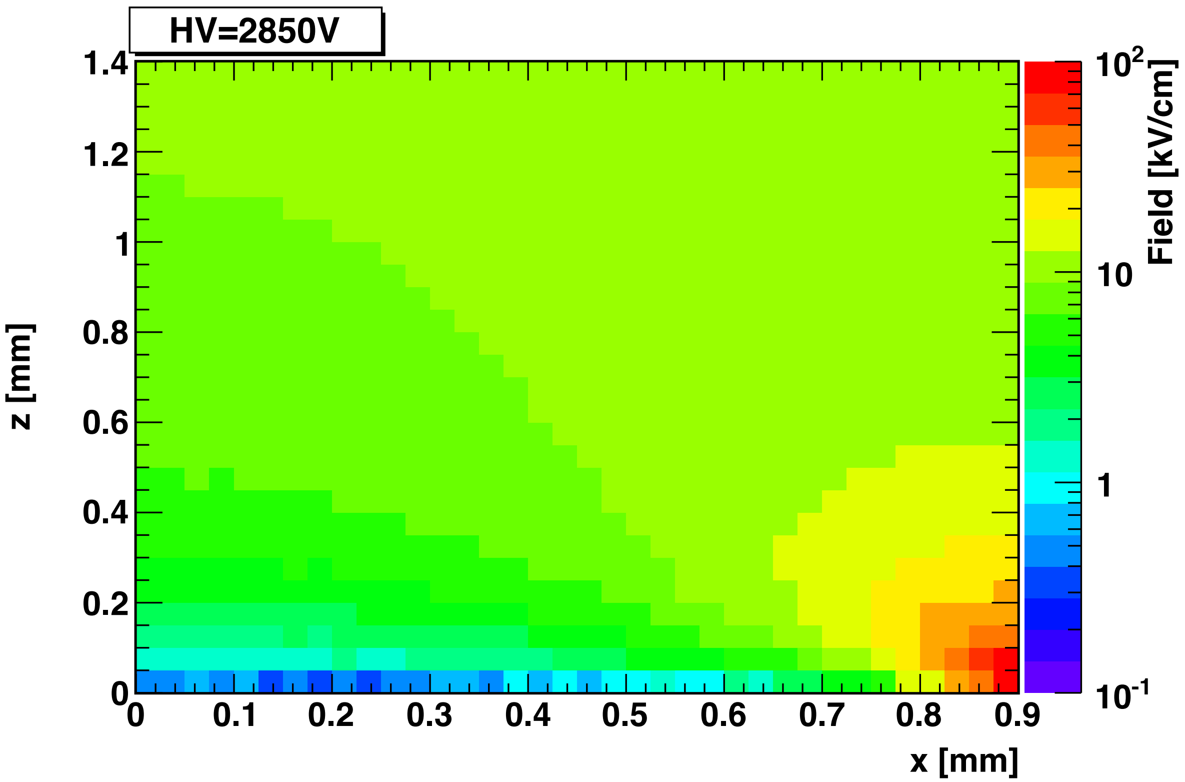


New Small Wheel

- replace the present SW detector with NSW (eight layers of MM detector and two stations of sTGC chambers)
- Kill fake trigger muons by requiring high quality IP pointing segments in NSW
- Help improve L1 muon p_T resolution
- Improve trigger and tracking in the trigger $1.5<|\eta_{det}|<2.5$

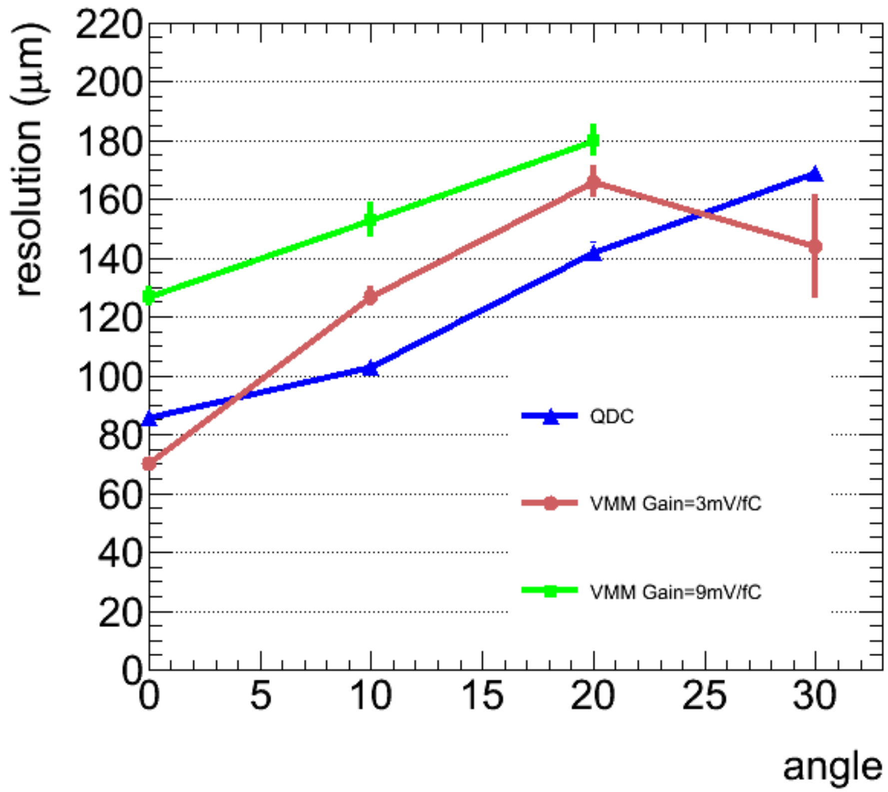


Simulation



HV=2850V
z [mm]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
x [mm]
10^2
10
1
10^{-1}
Field [kV/cm]

Position resolution



angle	QDC(μm)	VMM(μm) Gain=3mV/fC	VMM(μm) Gain=9mV/fC
0°	86	68	127
10°	103	127	153
20°	142	158	180
30°	169	144	--

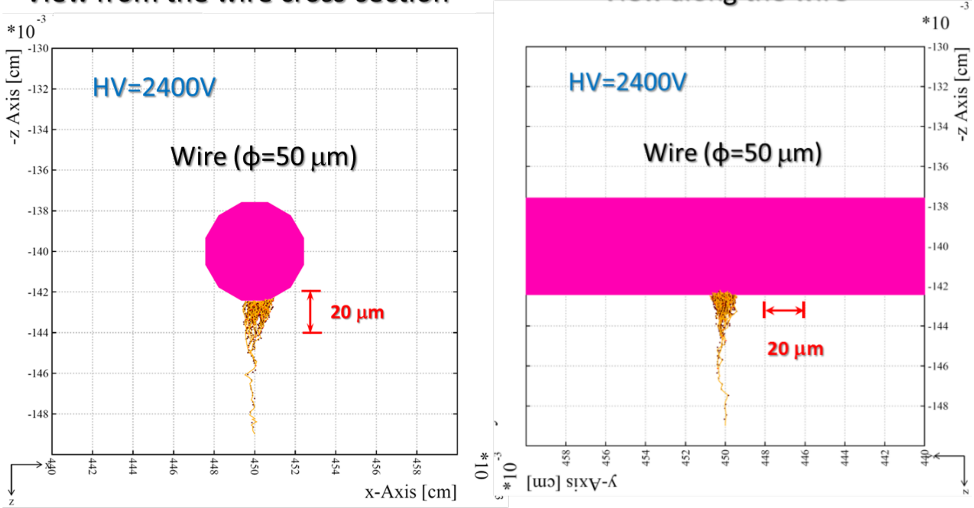
Charge production

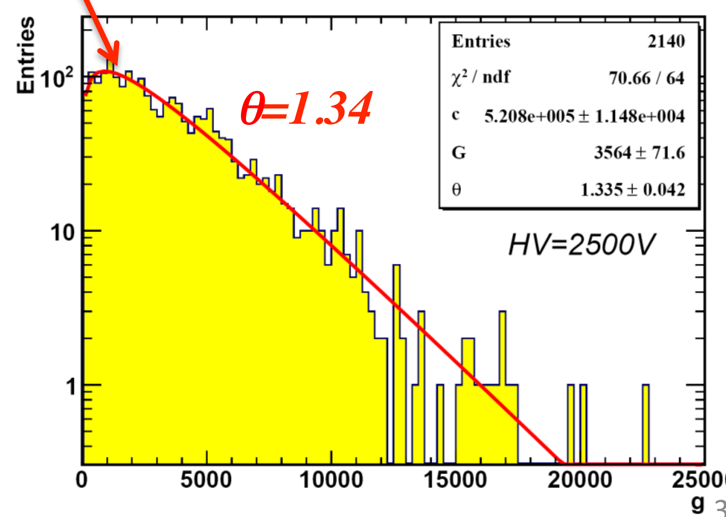
- Simulation of charge production is important to understand gas gain fluctuation → determine the detector performance: efficiency, spatial resolution etc.
- The avalanche is simulated with a microscopic method: trace electrons at molecular level
- Gas gain fluctuation: Polya distribution

$$\rho(g,\theta)=\frac{1}{G}\frac{\theta^{\theta}}{\Gamma(\theta)}\left(\frac{g}{G}\right)^{\theta-1}e^{-g\theta/G}$$

Variance: $f=1/(\theta+2)$

View from the wire cross-section | View along the wire

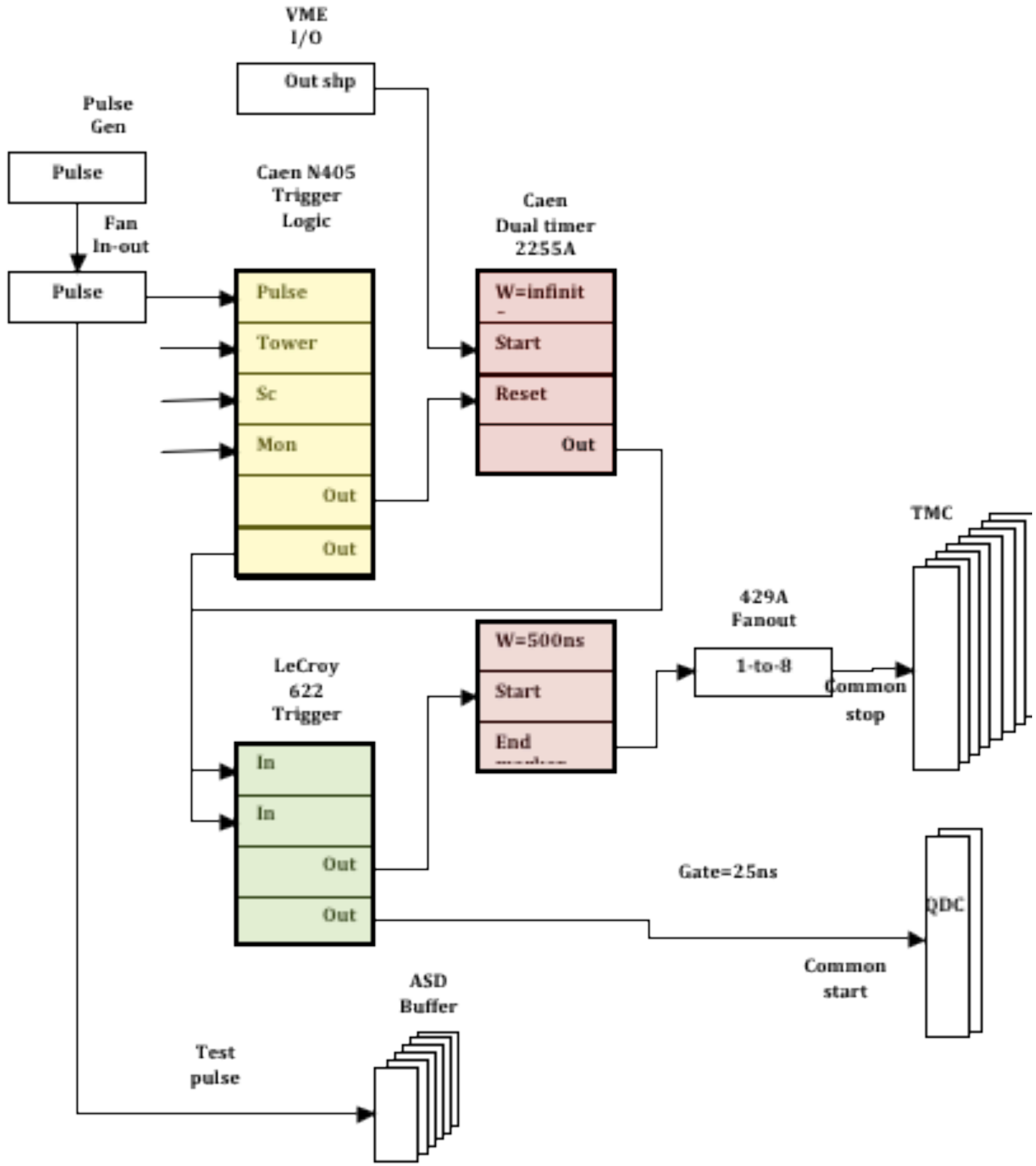




Legend:

- *Excitation*
- *Ionization*

DAQ



VME
I/O
Out shp
Pulse
Gen
Pulse
Fan
In-out
Pulse
Caen N405
Trigger
Logic
Pulse
Tower
Sc
Mon
Out
Out
Caen
Dual timer
2255A
W=infinit
Start
Reset
Out
TMC
429A
Fanout
1-to-8
Common
stop
W=500ns
Start
End
LeCroy
622
Trigger
In
In
Out
Out
Gate=25ns
QDC
Common
start
ASD
Buffer
Test
pulse