The RPC-based proposal for the ATLAS forward muon trigger upgrade

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On the behalf of the ATLAS Muon Collaboration

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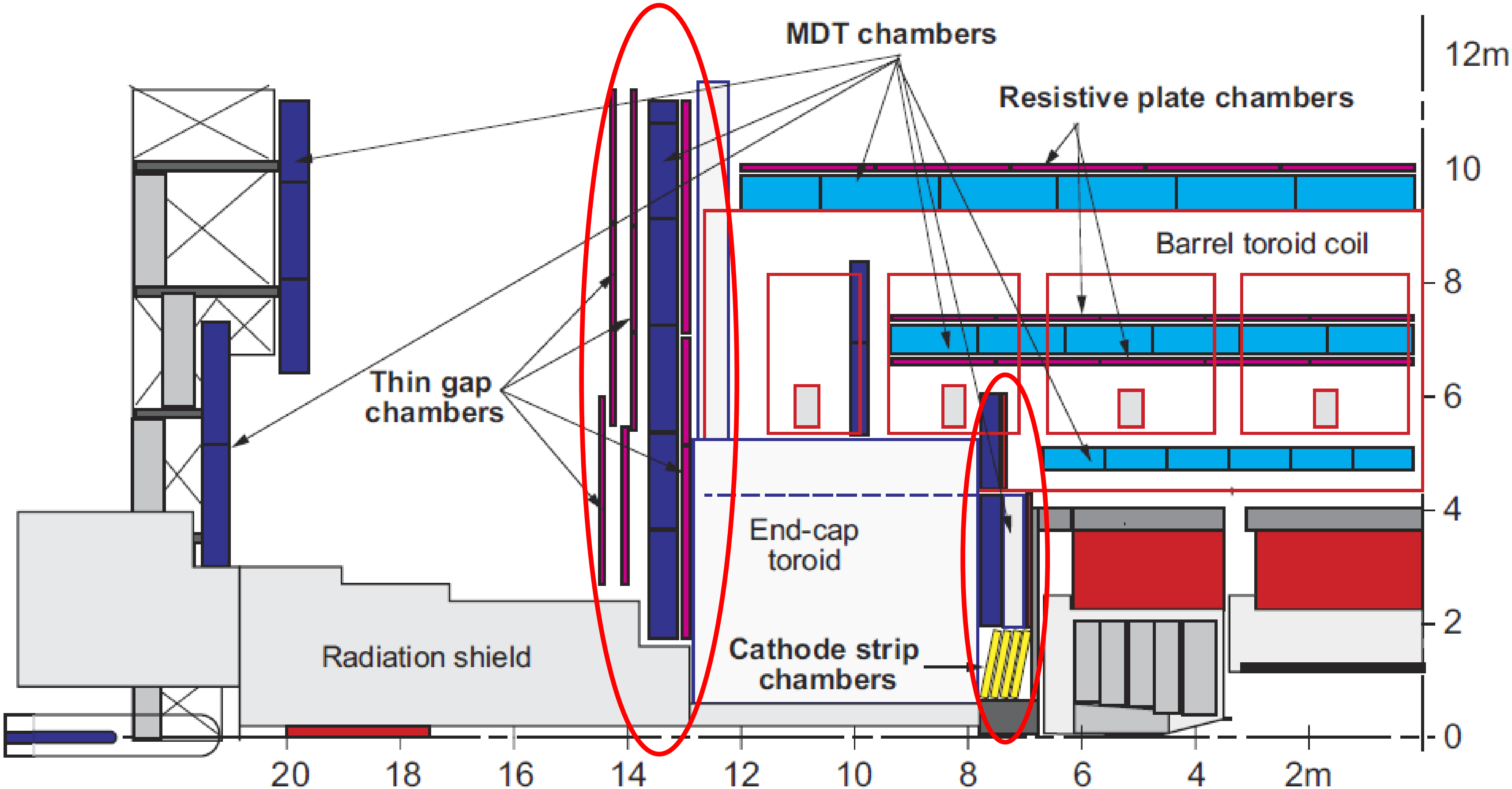
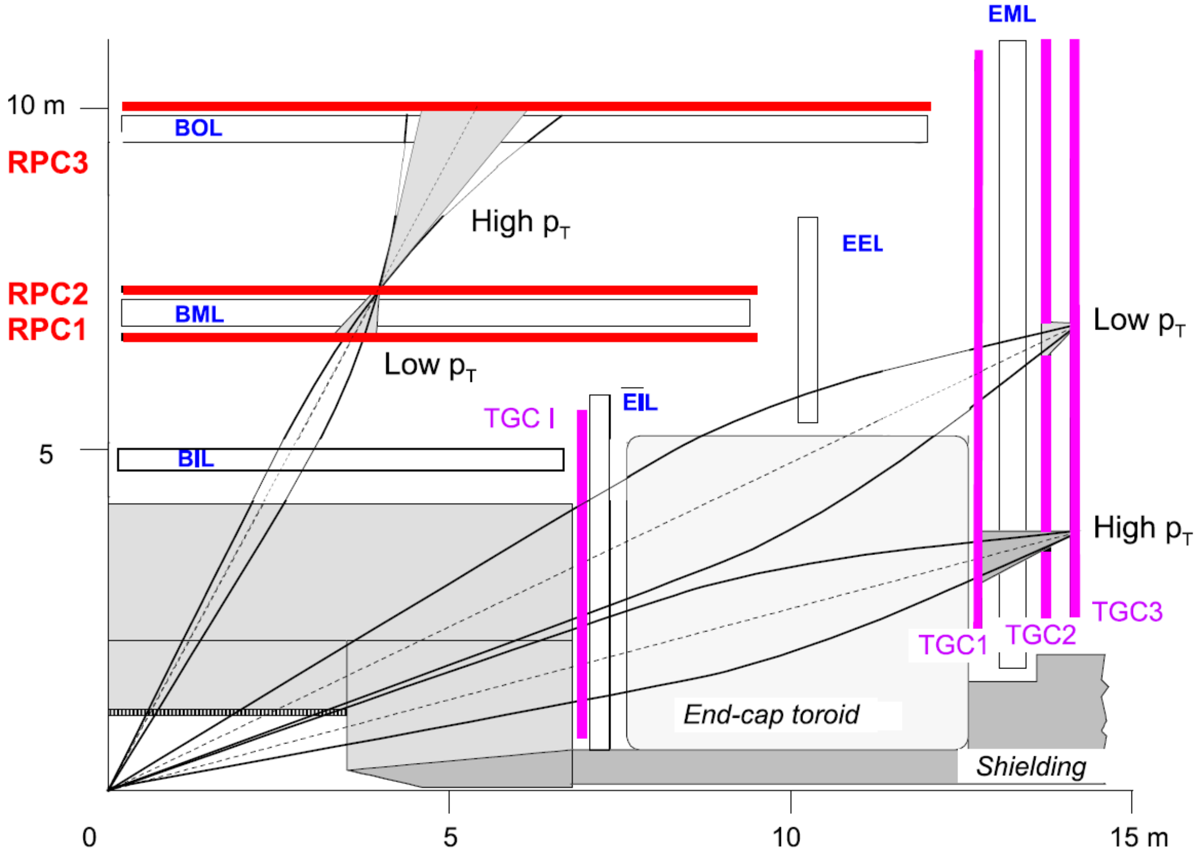
ATLAS muon spectrometer

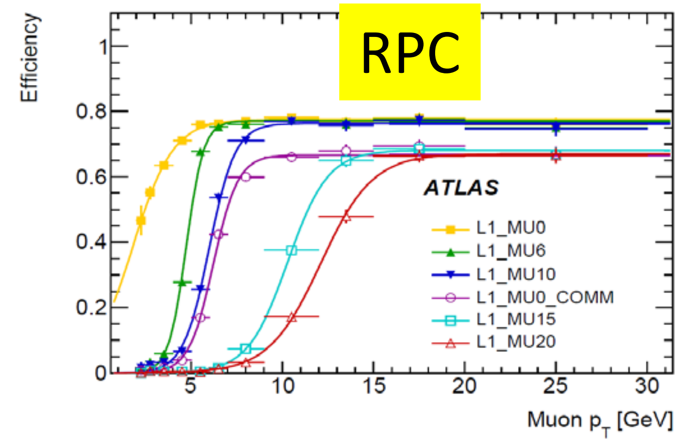


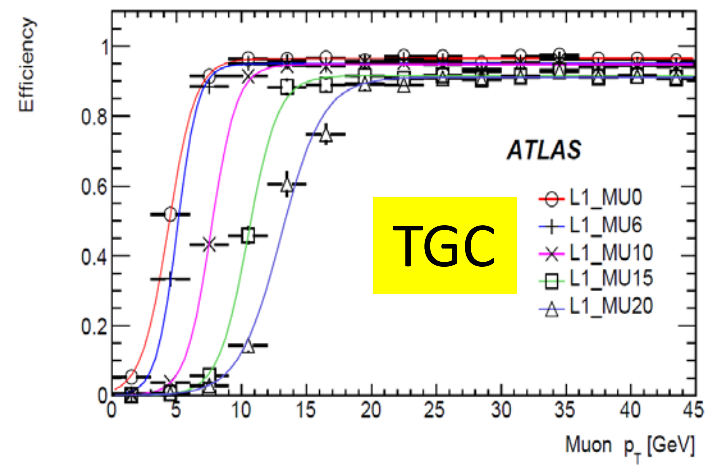
Big wheel (BW) **Small wheel (SW)**

- Precision tracking chambers:
  Muon Drift Tube (|η| < 2) , Cathode Strip Chamber (2 < |η| < 2.7)
- Trigger chambers:
  Resistive Plate Chamber (|η|<1.05) and Thin-Gap Chamber (1.05<|η|<2.4)

ATLAS trigger at L1

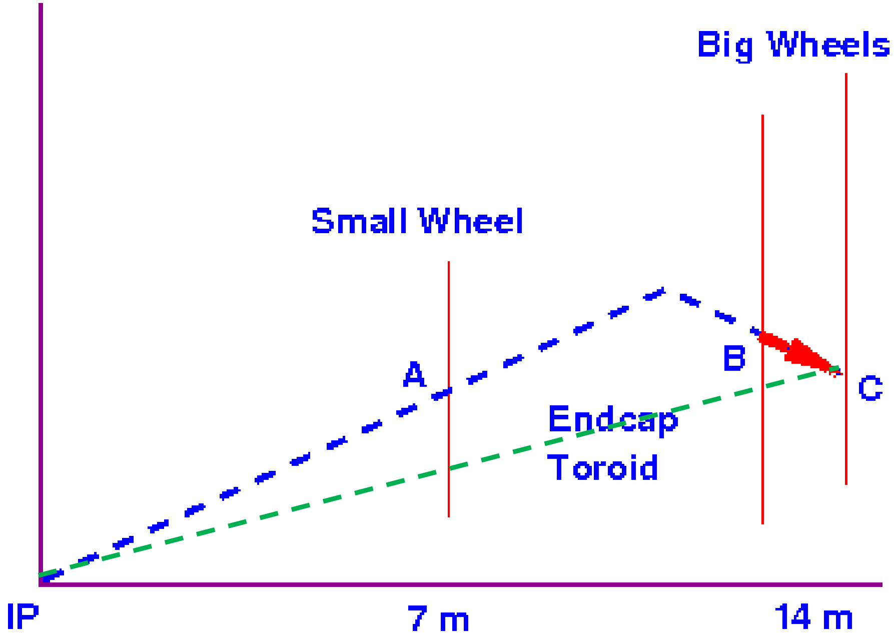


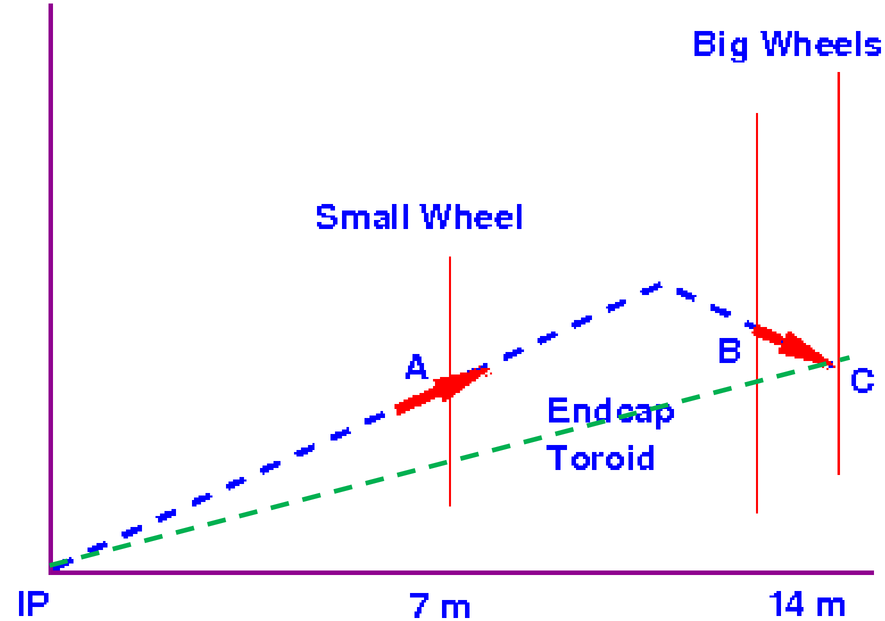




- RPC: Low-p_T trigger (RPC1 + RPC2) High-p_T trigger (+RPC3)
- TGC: Low-p_T trigger (TGC2 + TGC3) High-p_T trigger (+TGC1)
- A road represents an envelope containing the trajectories, from the origin, of muons of either charge with a p_T above a given threshold
- Geometrical acceptance: 80% for RPC and 95% for TGC

Problems with high p_T muon triggers in endcaps





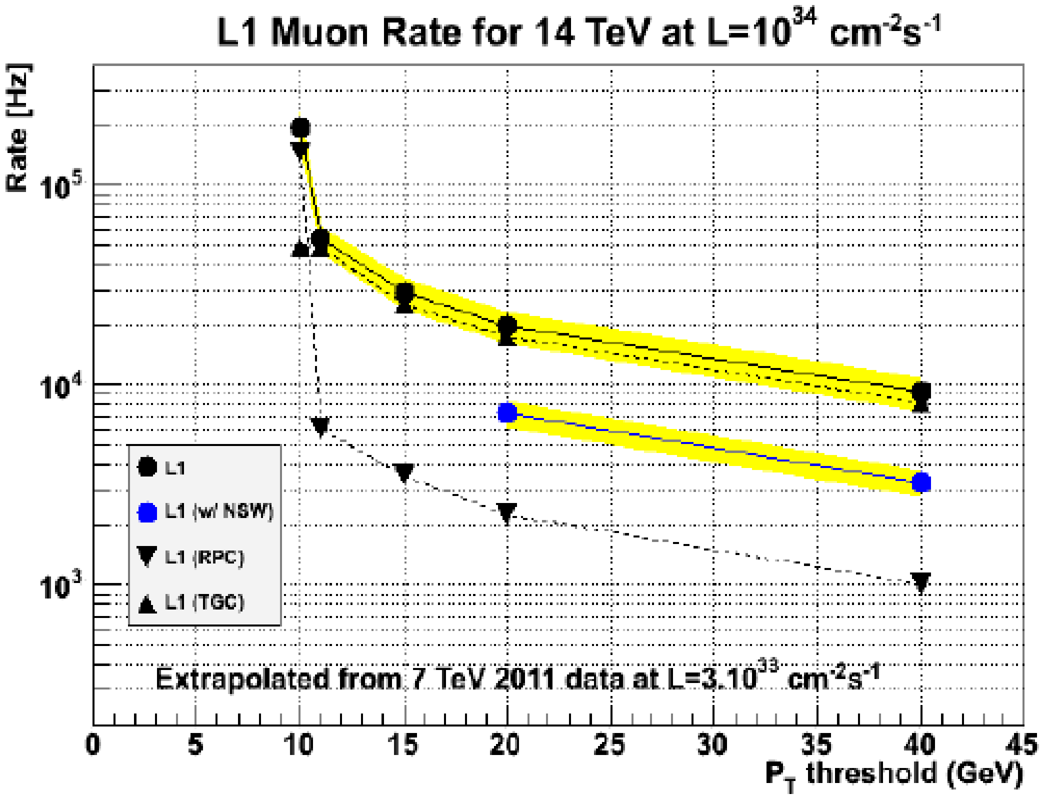
Current Endcap Trigger

- Only a vector BC at BW is measured
- Momentum defined by implicit assumption that track originated at IP
- Random background tracks can easily fake this condition
- ~30% resolution at L1 for 20 GeV muons
- Fake tracks and worse momentum resolution → large L1 trigger rate that will be difficult to handle

Proposed Trigger

- Provide a vector A at new small wheel (NSW)
- Use the deflection angle between A and BC to determine muon p_T
- Powerful constraint for real tracks
- ~95% of events triggered by MU20 endcap triggers do not have associated inner tracks
- With pointing resolution of 1 mrad, NSW will also improve p_T resolution (15~20% for 20 GeV muons) and sharpen the trigger turn-on curve

Expected rates at sLHC w/ and w/o NSW



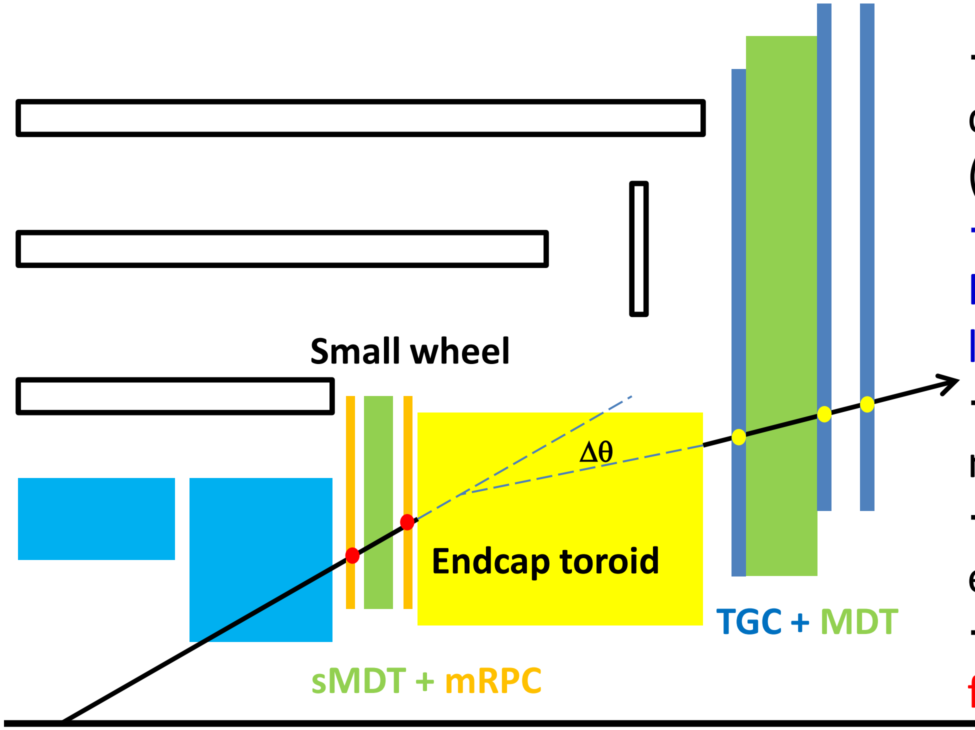
- The error bands shows 7 → 14 TeV extrapolation uncertainty
- Rate numbers for Linst=3×10^{34} $cm^{-2}s^{-1}$
  - Without NSW:
    MU20: 59.6 ± 10.7 kHz
    MU40: 28.8 ± 5.3 kHz
  - With NSW:
    MU20: 21.9 ± 3.2 kHz
    MU40: 10.3 ± 1.6 kHz

~90% of events triggered by TGC triggers for L1_MU20

Current L1 muon trigger bandwidth is 15-20 kHz at ATLAS

Goal: to keep L1_MU20 unprescaled under the sLHC conditions

Proposed multi-gap RPC + small-tube MDT detector



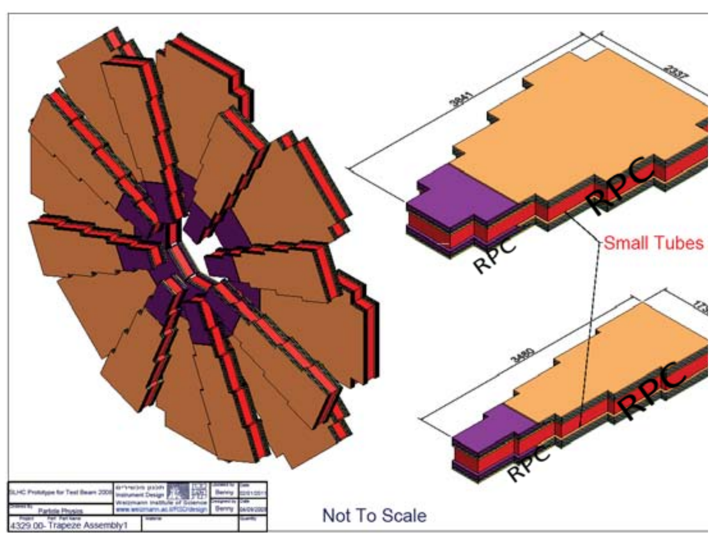
→Dedicated tracking detector (small-radius drift tube → sMDT) and trigger detector (multi-gap RPC → mRPC)

→ Deal with 14 kHz/cm² uncorrelated hits (at R = 1m), 0.3 mm spatial resolution at trigger level, 3000 fb^{-1} and ~1 C/cm²

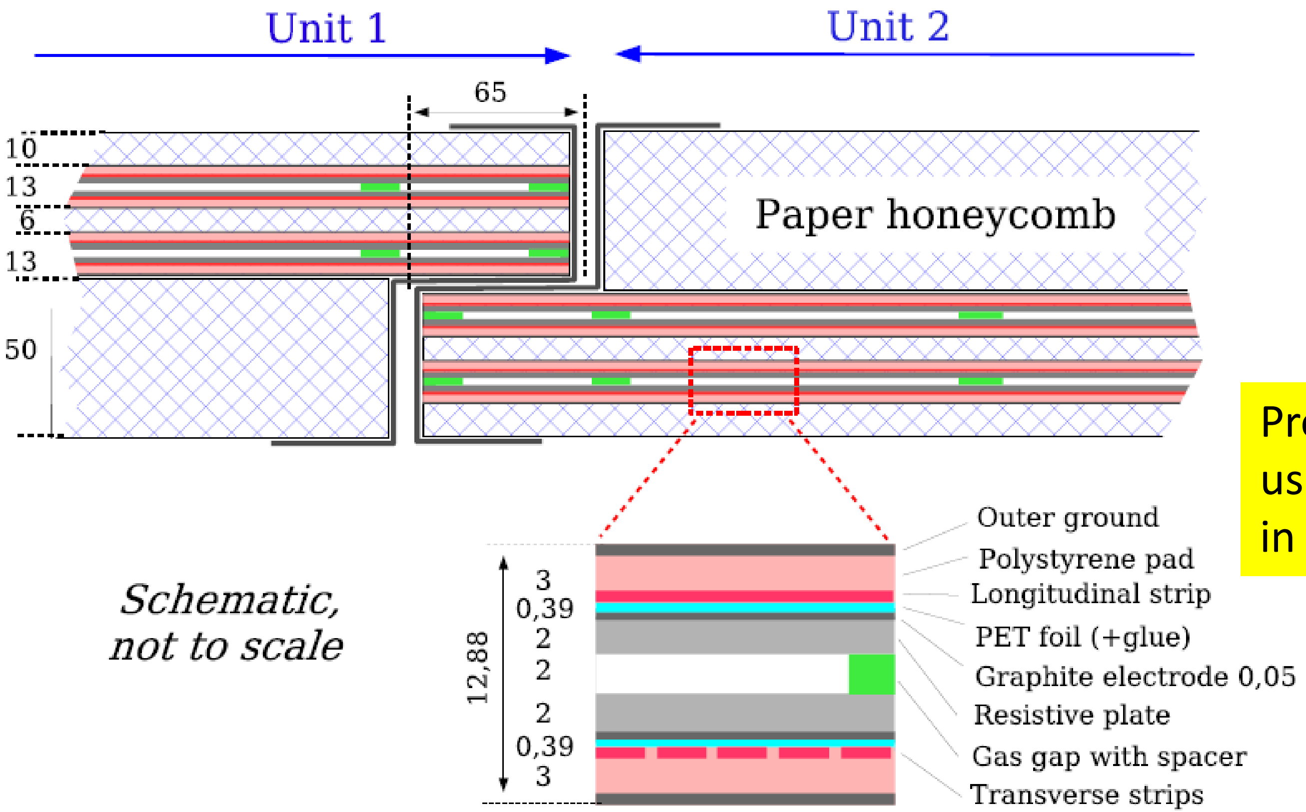
→spatial position resolution ~0.3 mm → 1 mrad angular resolution

→ Mounted on MDT chambers and make it easier for relative alignment

→ Combine SW segments with TGC segments from BW to determine muon p_T at L1



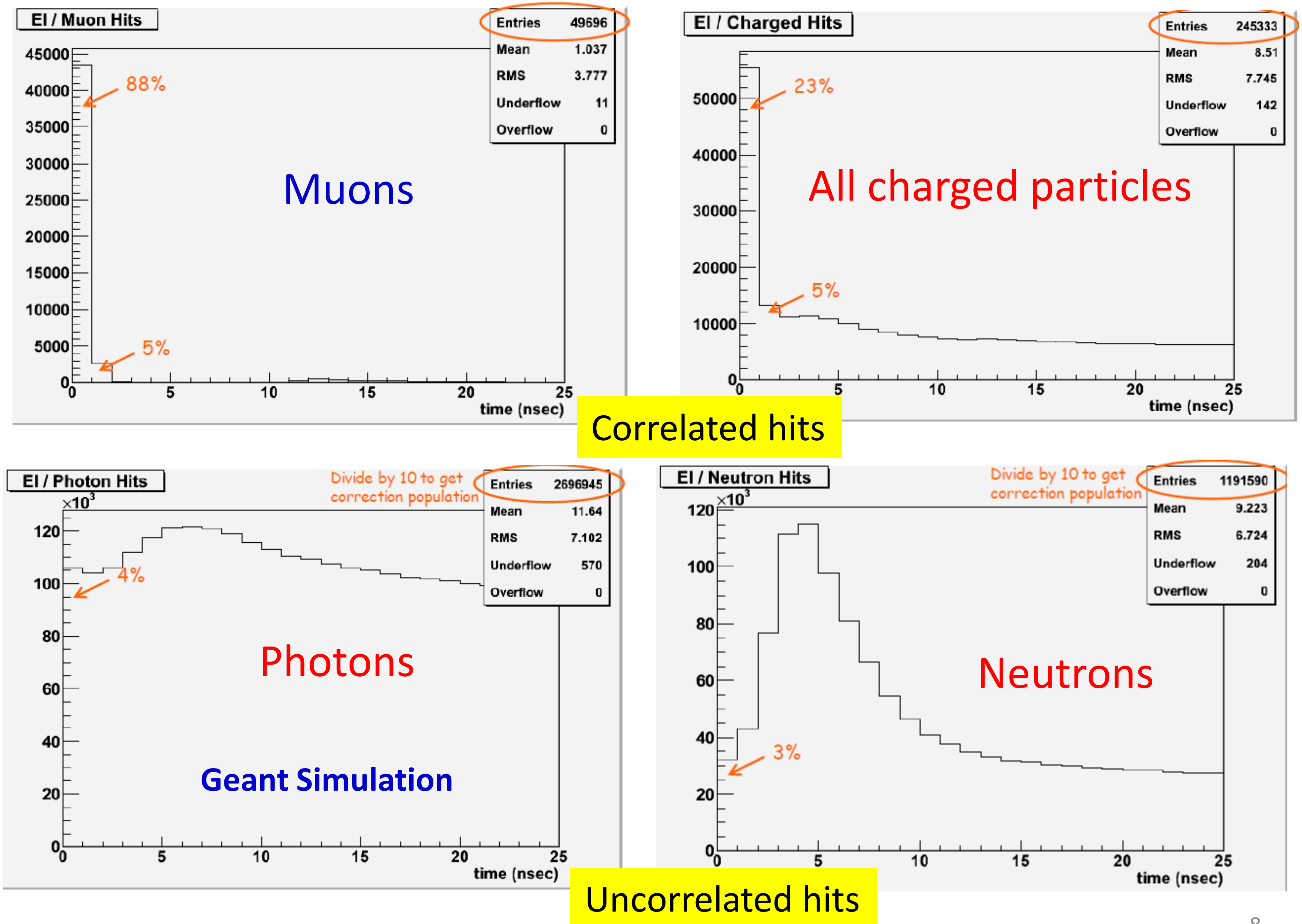
Improvements needed w.r.t. the present ATLAS RPC



Present ATLAS RPCs used for muon triggers in the barrel region

- Resistive (bakelite) plates: thickness (2 mm → 1 mm), volume resistivity (2 - 3×10^{10} Ω cm → 0.5 - 1×10^{10} Ω cm), surface quality etc
- Gas gap: 2 mm → < 1 mm
- Detector structure: single-gap → multi-gap (bi-gap considered so far)
- Readout strips: 1.5 – 2 mm pitch
- Front-end readout electronics: higher sensitivity and better signal to noise separation

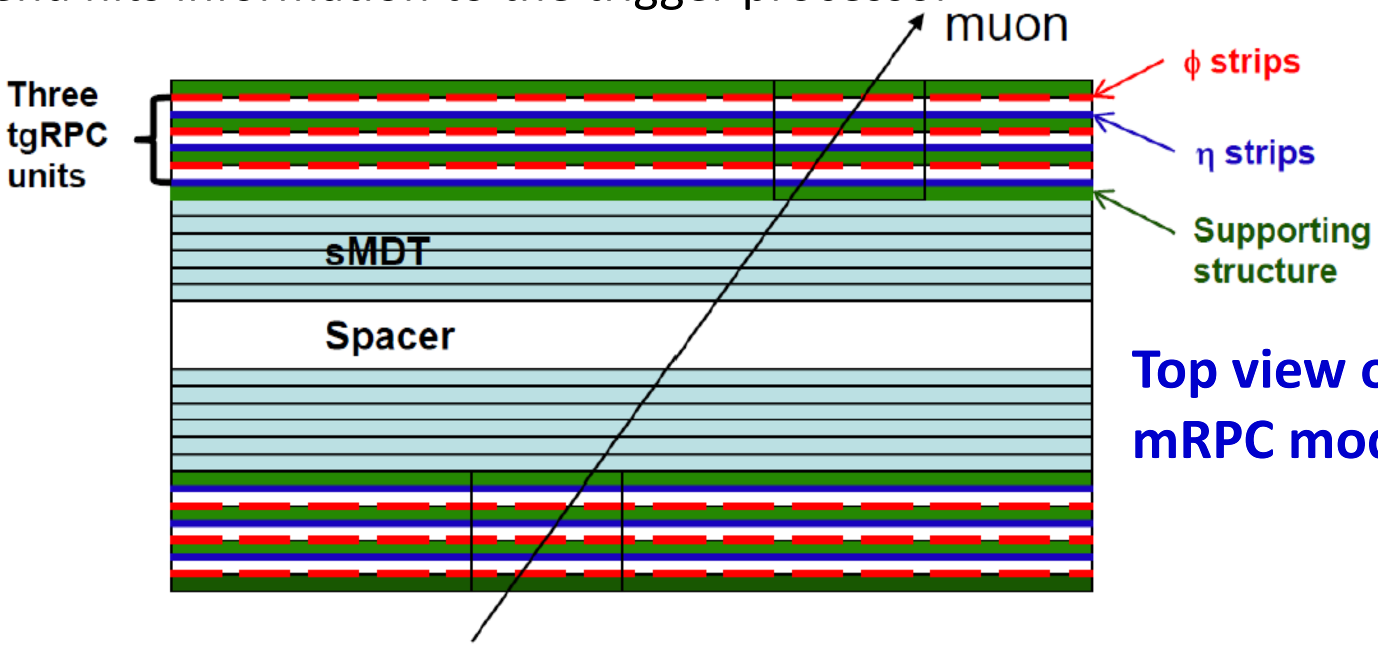
Excellent timing capability is crucial



Number of hits as a function of the arrival time within one LHC BX (25 ns) with TOF subtracted

Proposed detector layout

- Fully exploit the excellent RPC timing resolution to reject backgrounds with high efficiency (see details from G. Chiodini's talk from current ATLAS RPC)
- Main principle of the trigger scheme (quote R. Santonico's words):
  - → Remove as soon as possible and as much as possible fake hits
  - → Send hits information to the trigger processor



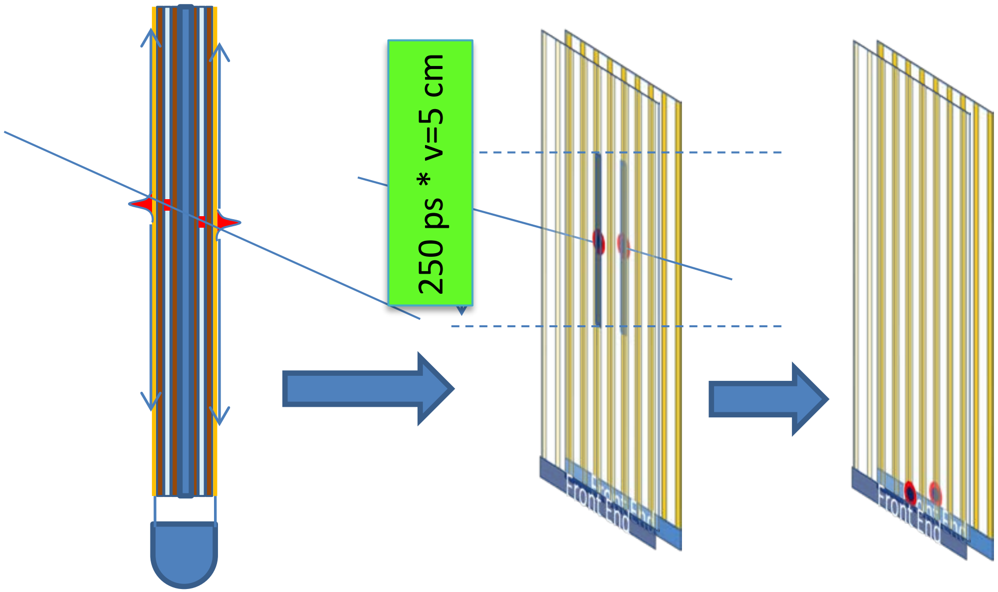
Top view of a sMDT+ mRPC module

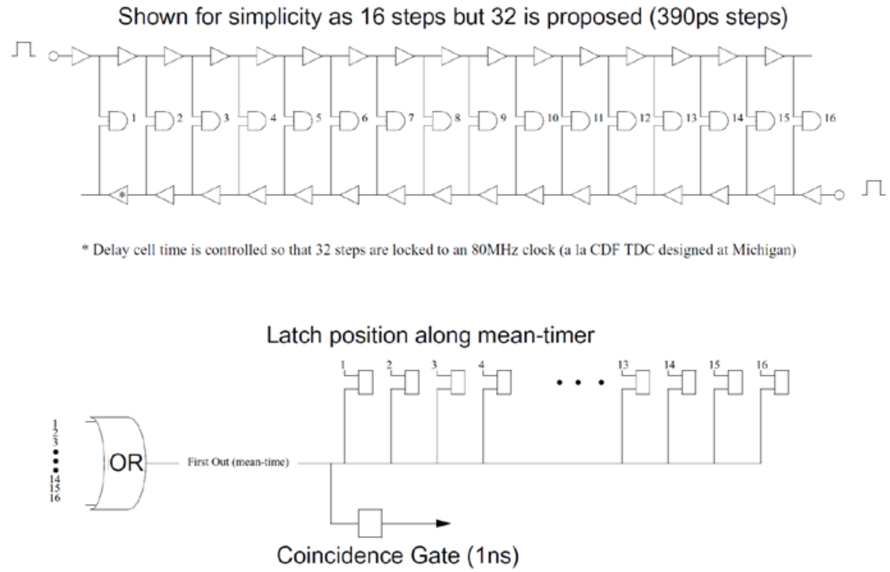
- Each RPC layer: fast timing cut to remove uncorrelated hits
- Each RPC station: 2 out of 3 coincidence to remove uncorrelated hits and retain high efficiency
- Two RPC stations: Track pointing to the IP within certain angles to remove backgrounds from other charged particles

Advantages of the proposed trigger strategy

- Unambiguous identification of Bunch Crossing ID
- Simple on-chamber pattern recognition
- High efficiency per single layer
- Coincidence between two stations can be done using FPGAs in the counting room avoiding high radiation
- Small amount of information sent to combine with track segments found by the BW TGCs
- Significant safety margin as excellent timing will be useful to prevent unexpected things that may happen at high luminosity

Mean timer Circuit



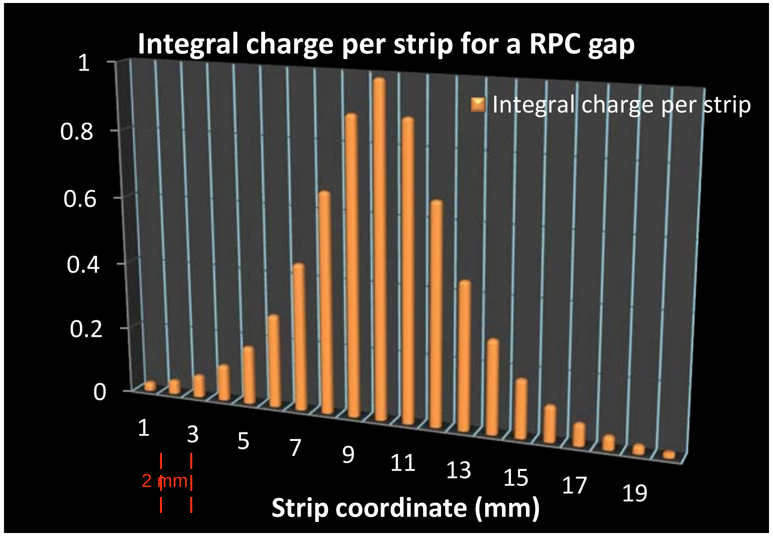


Mean-timer circuit

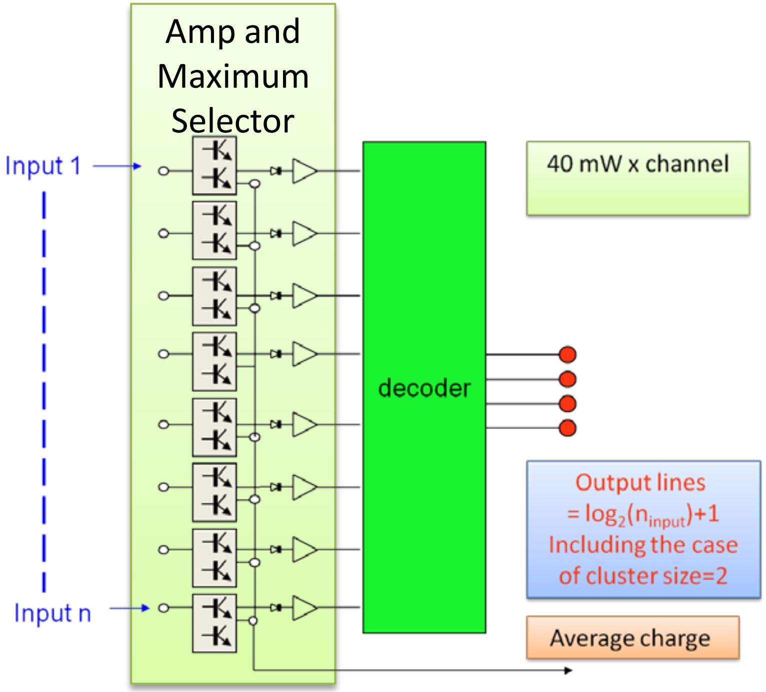
- ❑ The coincidence of two contiguous detector layers with parallel strips and front end electronics at the same end is time walk free → mean timer with 250 ps timing resolution equipped on both ends of the readout strips
  - ❑ Allows the coincidence with Bunch Crossing with sub-nanosecond resolution
  - ❑ Allows to localize the coincidence between contiguous layers to a very small area (~ 4 cm^2) to give an extremely strong rejection power for uncorrelated hits
  - ❑ ~15 cm resolution achieved using ATLAS MDT electronics (0.78 ns resolution), investigating new electronics with 150 ps resolution (expect ~ 3cm)
- ❑ Can be used to determine the centroid of the hit position by exploring the fact that strips with larger charge deposition will cross the thresholds earlier

Sensitive front-end readout electronics

- The new sensitive front-end electronics allows a new working mode with a factor 10 less of charge per count
- Used to find the maximum of the RPC charge distribution



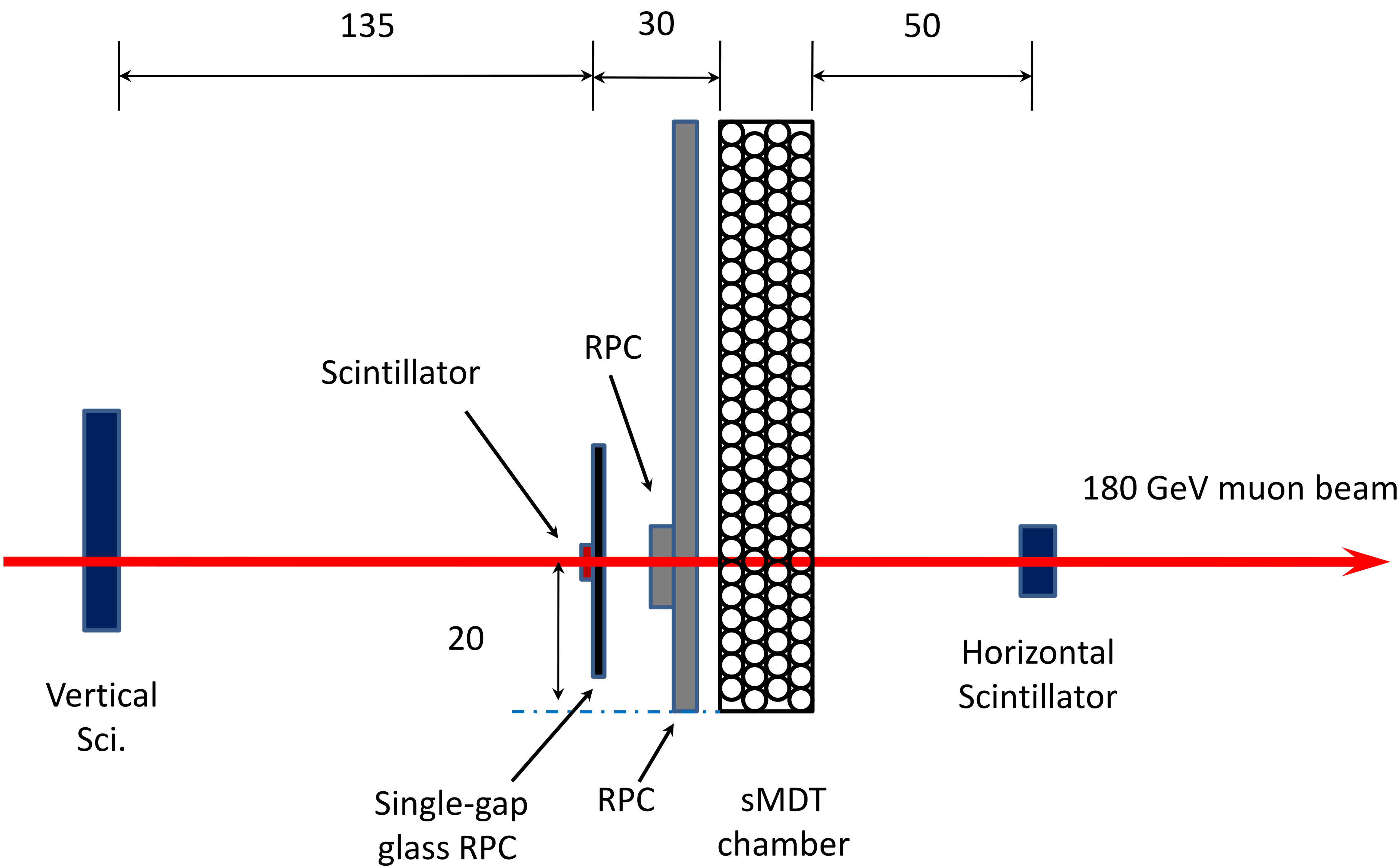
See details from R. Cardarelli's talk



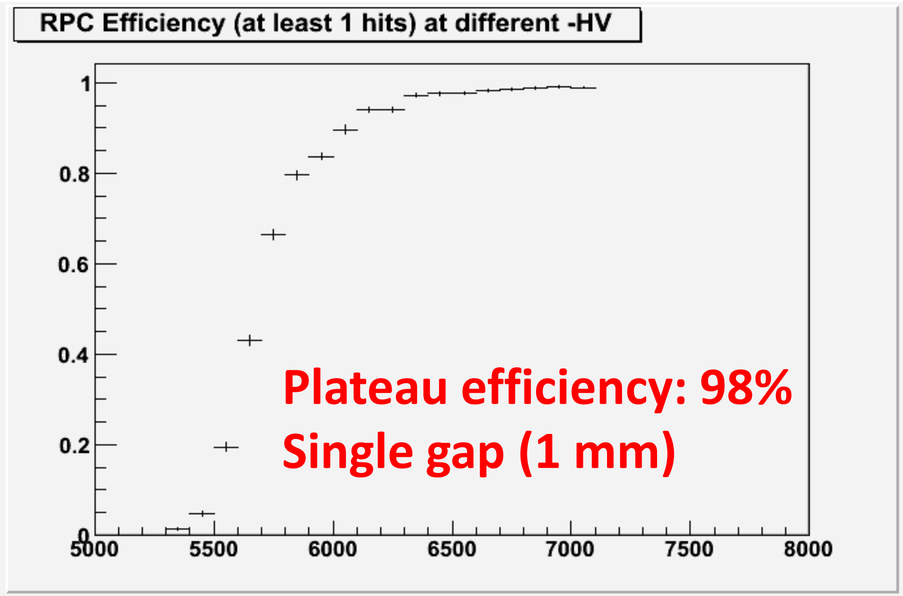
- N strips are processed at the same time
- The circuit amplifies the inputs and provides the output only for the strip above a settable fractional threshold, normalized to the average charge provided
- The threshold is chosen to have one or two strips firing (cluster size 1 or 2)
- The decoder transforms the simple digital pattern in to a number representing the hit coordinate on the chamber

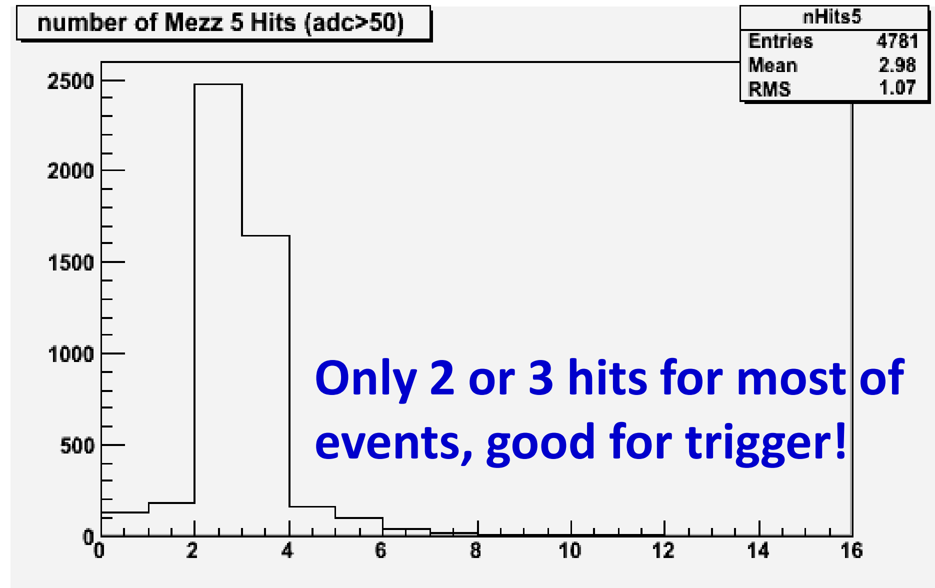
Beam test setup at CERN

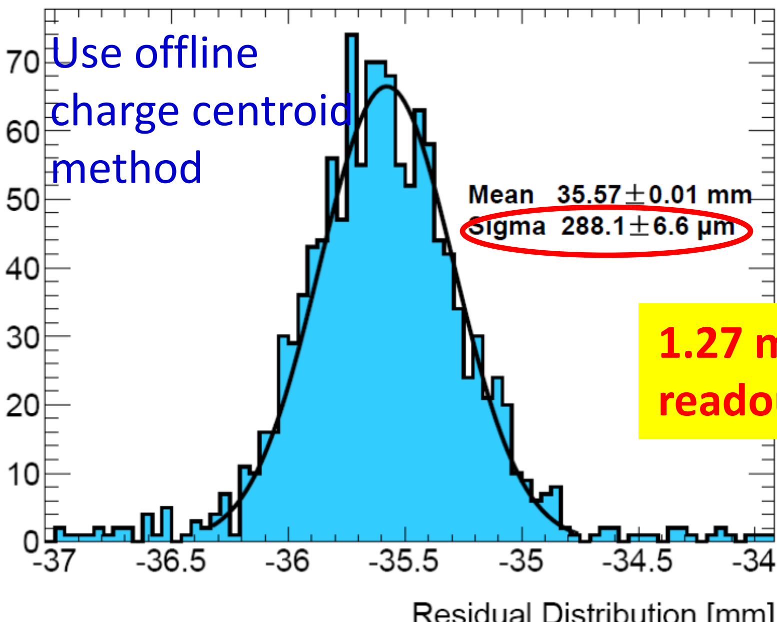
See details from L. Han's talk



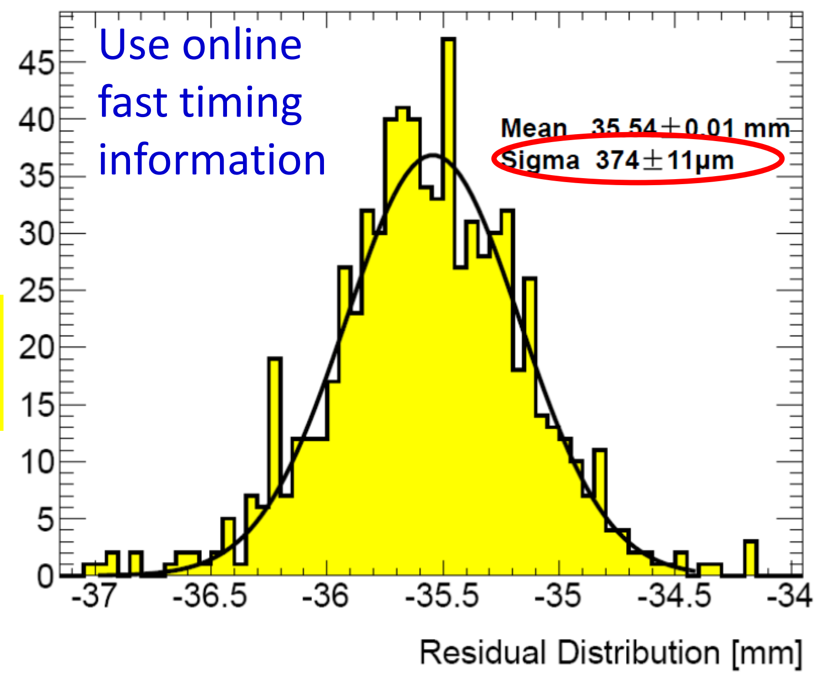
Test beam results





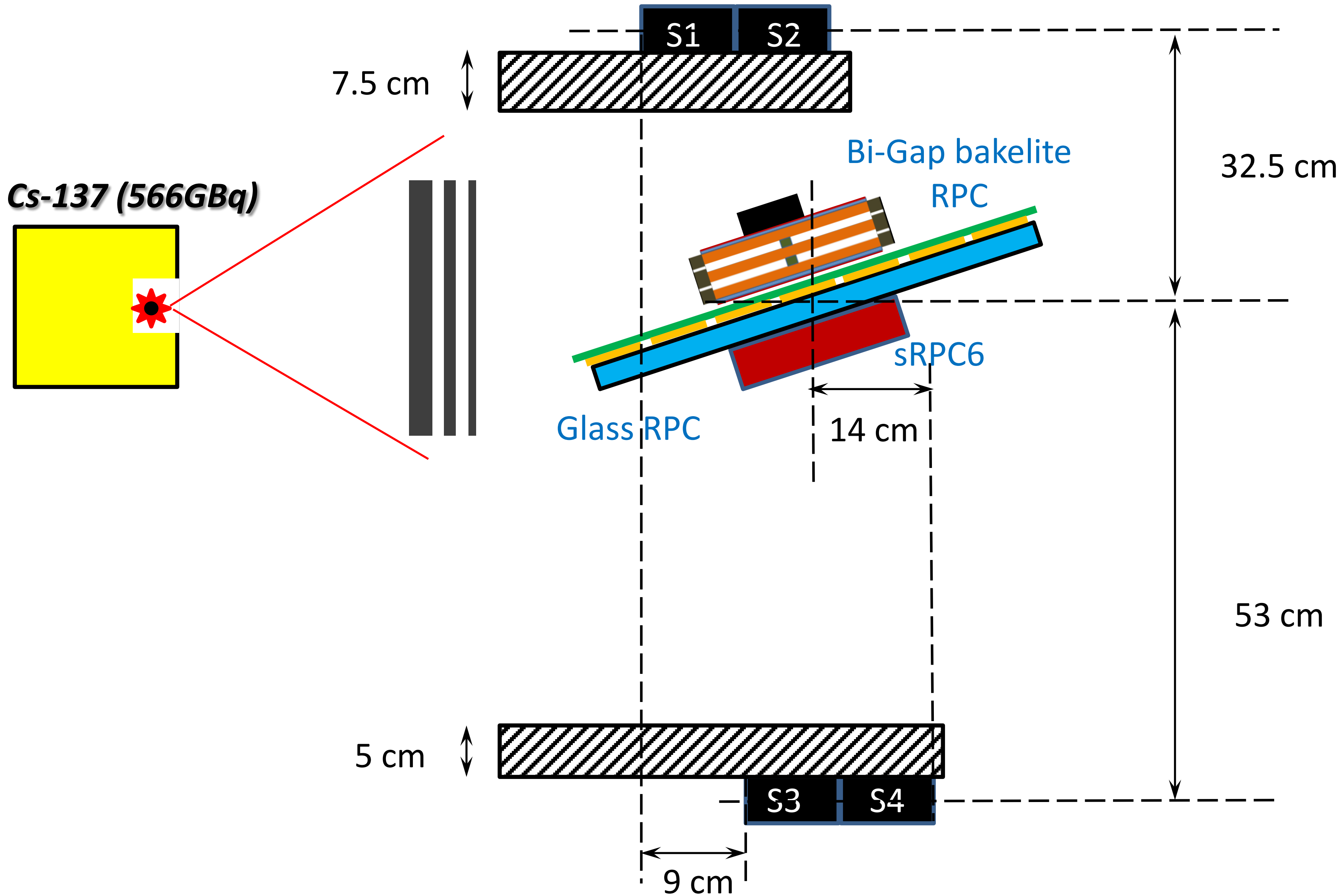


1.27 mm
readout pitch



More than 100 μm uncertainty expected
from sMDT spatial resolution and relative alignment

Rate capability test at GIF (CERN)



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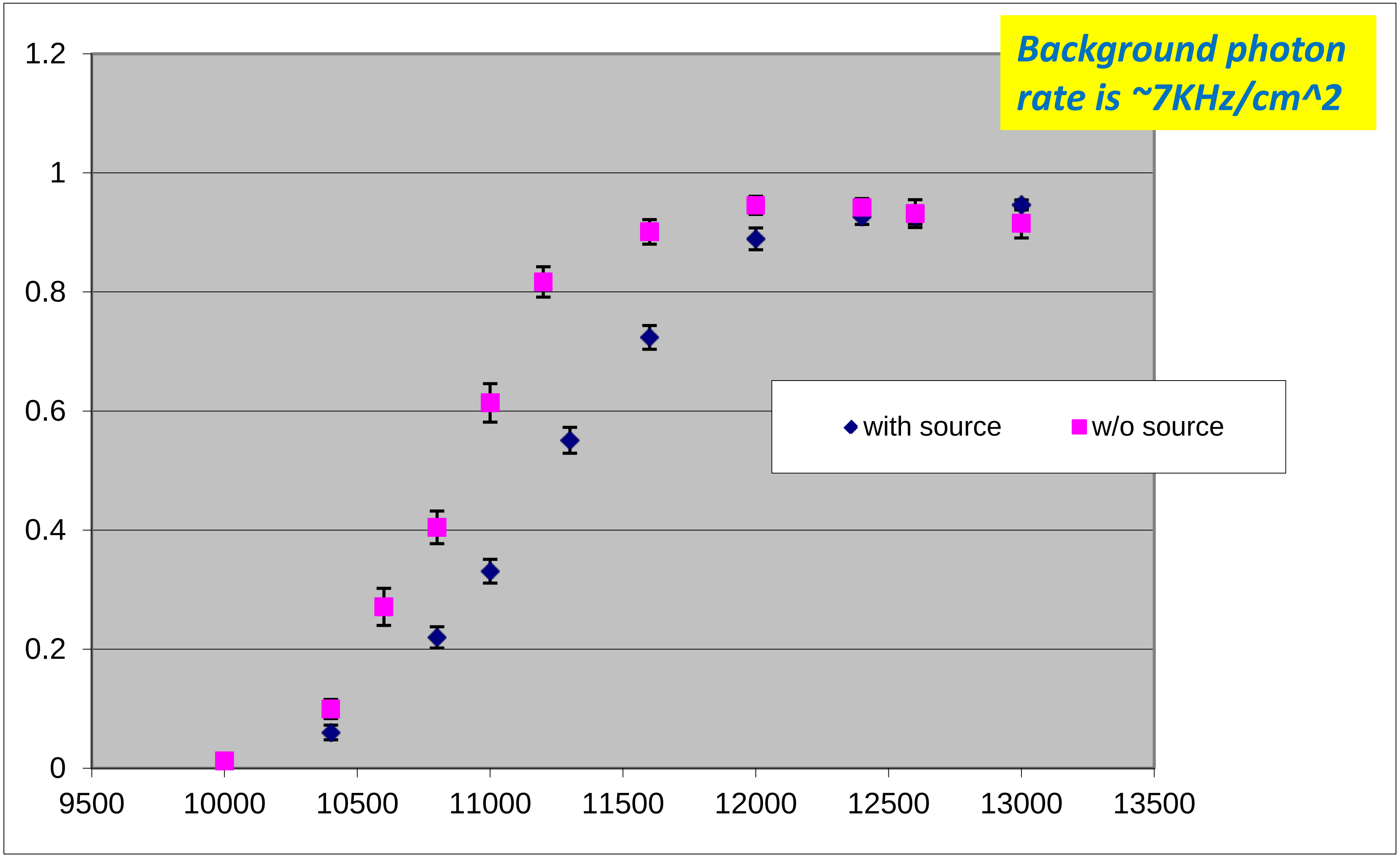


Efficiency as a function of HV for the bi-gap RPC

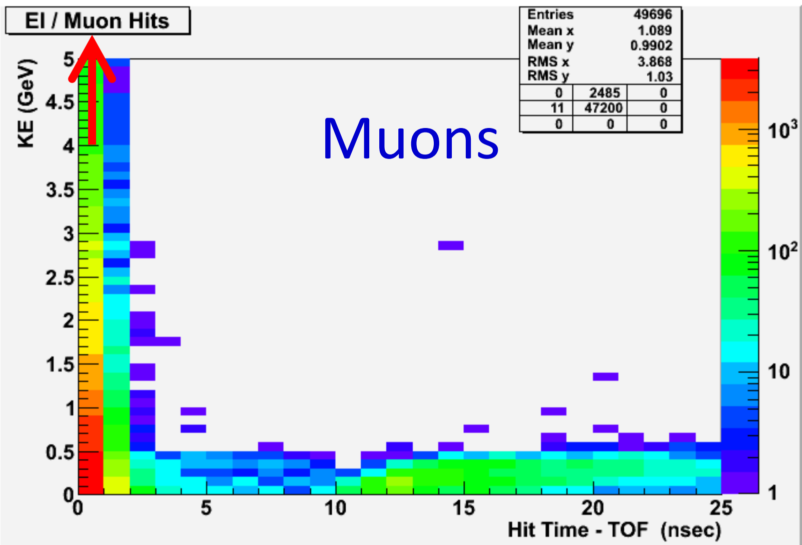
Rate test is limited by the available source flux in GIF

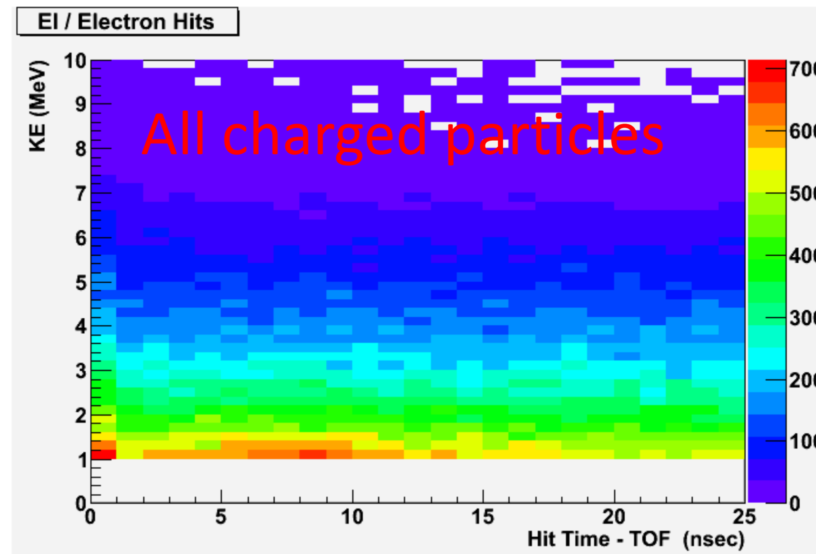
Conclusions

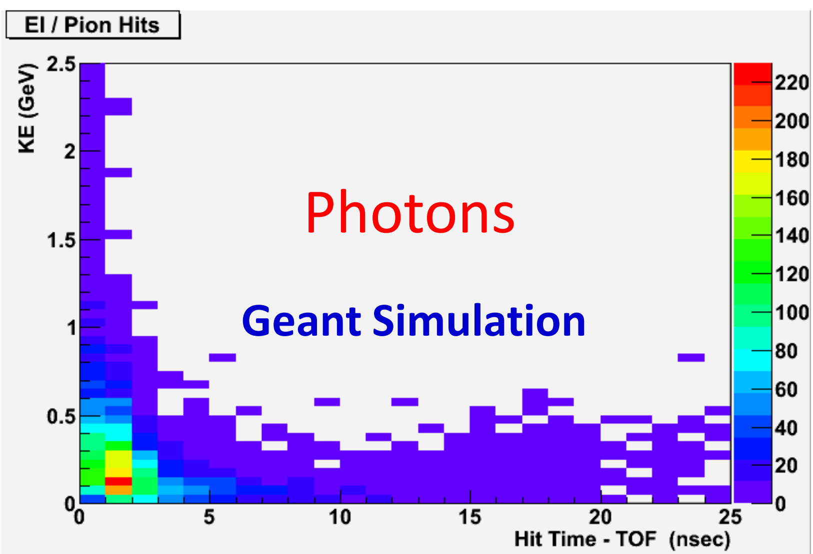
- Propose to upgrade the ATLAS SW detector with a combined tracking detector (using small-radius drift tube) and trigger detector (using multi-gap RPC) for the sLHC
- Need to deal with 14 kHz/cm^2, 0.3 mm spatial resolution at trigger level, 3000 fb^{-1} and ~1 C/cm^2
- Main principle of the trigger scheme: Remove as soon as possible and as much as possible fake hits, and then send all information to the trigger processor
    - Thin bi-gap RPCs with high efficiency per detector unit
    - Equipped with ~ 2 mm pitch strips to achieve ~300 μm resolution
    - Equipped with mean-timer circuit on both ends to remove uncorrelated background hits
    - Equipped with sensitive front-end electronics to deal with smaller charge and improve the signal to noise ratio
- Ongoing studies with RPC prototypes, front-end readout electronics, trigger algorithm and ageing

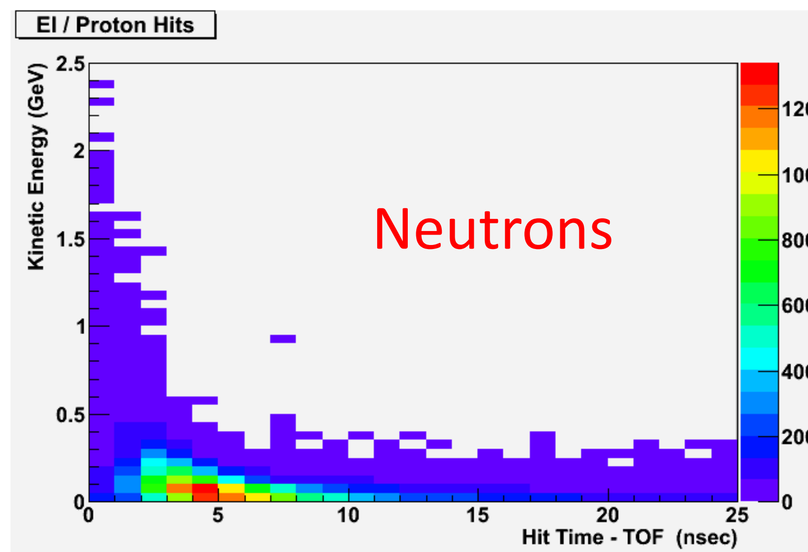
Backup

Energy distributions









Current parameters for RPC in the ATLAS barrel region

Parameter	Design value
E-field in gap	4.9 kV/mm
Gas gap	2 mm
Gas mixture	$C_2H_2F_4/\text{Iso-}C_4H_{10}/SF_6$ (94.7/5/0.3)
Readout pitch of η and ϕ-strips	23–35 mm
Detection efficiency per layer	$\geq$98.5%
Efficiency including spacers and frames	$\geq$97%
Intrinsic time jitter	$\leq$1.5 ns
Jitter including strip propagation time	$\leq$10 ns
Local rate capability	$\sim$1 kHz/cm^2
Streamer probability	$\leq$1%

Designed parameters for ATLAS NSW

Parameter	Designed values
Operation mode	Avalanche
Time resolution	≤ 0.5 ns
Rate capability	14 kHz/cm^2
Gas gap	~1 mm
Bakelite plate thickness	~1 mm
Bakelite plate resistivity	~$1x10^{10}$ Ω-cm
Spatial resolution with eta-strip	~0.3 mm
Spatial resolution with phi-trip	~3 mm
Eta-strip readout pitch	~ 2 mm
Phi-strip readout pitch	0.8 – 2.0 cm
Gas mixture	$C_2H_2F_4$/Iso-C_4H_{10}/SF_6 (94.7/5.0/0.3)
Operation voltage	11 - 12kV (for bi-gap chamber)