Track trigger in ATLAS?

Anatoli Romaniouk

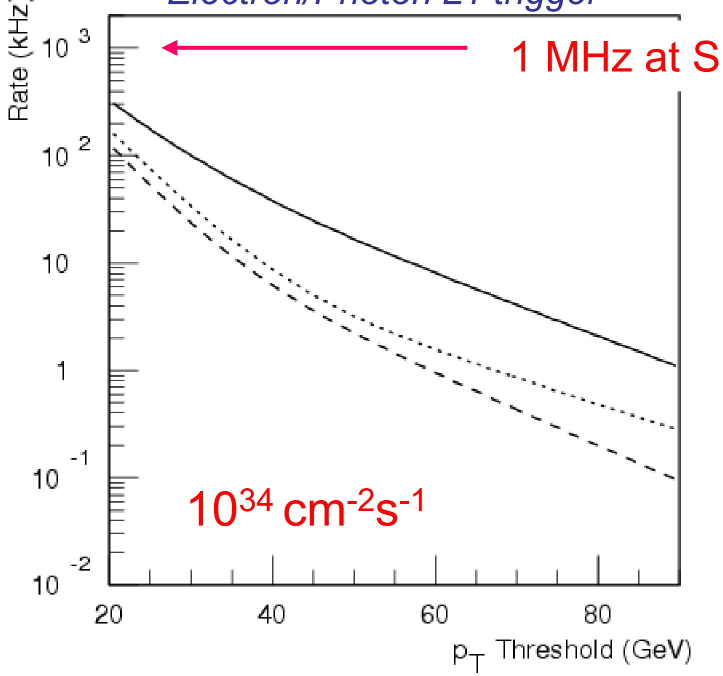
Moscow Physics and Engineering Institute (MEPHI)

1. Motivations for the track Trigger for the ATLAS.
2. Operation conditions at SLHC.
3. L1 track trigger ideas:
   - *ROI based L1A trigger*
   - *Si-strip L1 trigger*
   - *GasPix tracker/L1 Trigger*
4. Conclusions.

Motivation for the track trigger in the ATLAS

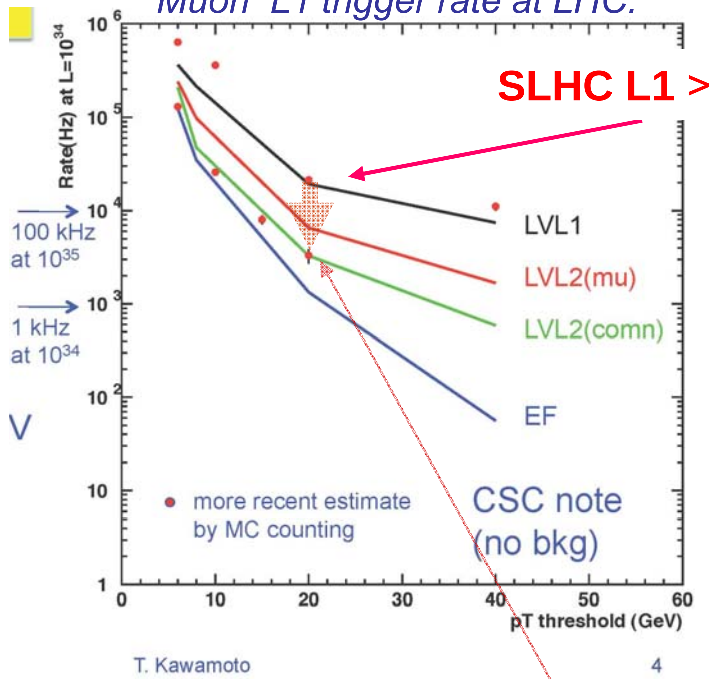
L1 trigger rates at SLHC.

Electron/Photon L1 trigger



Inclusive electron trigger rate for nominal luminosity without isolation cut (solid), requiring only hadronic isolation cut (dotted and requiring both Electromagnetic and hardronic Is isolation (Phys. TDR).

Muon L1 trigger rate at LHC.



One more muon trigger layer would reduce significantly this rate
This option is under study now.

Some not linear rise of the trigger rate might be expected and extrapolation to SLHC for trigger rate is rather uncertain.
Inclusive thresholds will be at least at the range of 50-60 GeV

The only alternative is L1 ID tack tagger.
An ID track segment with Pt > 20 GeV would reduce a trigger rate by 1 order of magnitude.

Motivation for the track trigger in the ATLAS

Obvious steps:

1. Increase L1 trigger rate

Very difficult to push L1 trigger rate above 100 kHz. Even at that frequency a much larger readout bandwidth is required especially for the ID tracker.

2. Rely more on multi-object triggers.

Not without consequences - fraction of the lost events might be rather large

3. Raise P_T thresholds

Many questions still to be answered but physics unavoidably will suffer form this (W, Z, top for instance).

Directions the ATLAS looking at:

1. Increase L1 trigger granularity of the EM calorimeter.
2. Add one more Muon layer to improve Pt L1 cut.
3. Increase L1 trigger rate operation ability.
4. Track trigger possibilities.

Motivation for the track trigger in the ATLAS

What L1 track triggers would offer?

1. Would allow to keep the same thresholds at for LHC
2. Would enhance the physics composition of the L1A events.
3. Would increase robustness of the trigger system to the uncertainties in the cavern background and possible non linear raise of the trigger rates
4. Would certainly provide more flexibility for HLT.

Operation conditions at SLHC

ATLAS – CMS difference

ID magnet banding power in the ATLAS is two times less.

1. Background rate at outer radii is larger than for CMS.
   2-3 MHz/cm^2 at R=100 cm
2. Particle angle is less.
   For P_T=10 GeV an angle between particle momentum and the radial direction is ~ 1.7^o at R=100 cm.

Track trigger implementation may require different approaches!

Track trigger for the ATLAS

A few ways of doing the things:

(*not exhaustive list)*

1. "RoI" based processing using L1Calo/Muon info (L0A).
2. Processing in parallel with L1Calo/Muon using dedicated Si-strip layers.
3. GasPixel Tracker

For the last two approaches momentum cut for L1 track trigger is a critical parameter

One should remember that at the SLHC a particle rate in the ID volume:

P_T> 3 GeV - > ~ 70 GHz
P_T>10 GeV -> ~ 70 MHz
P_T>20 GeV -> ~ 0.70 MHz

1. "RoI" based processing.

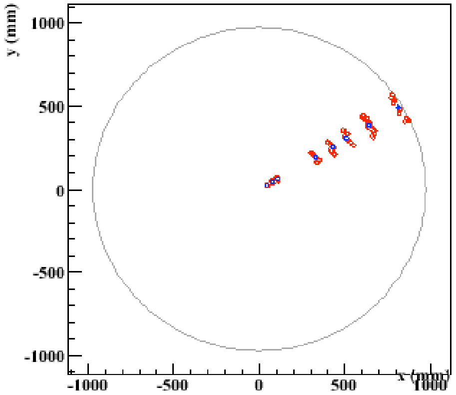
Presented by Nikos Konstantinidis at the ATLAS Upgrade WS 23-27 Feb 2009:

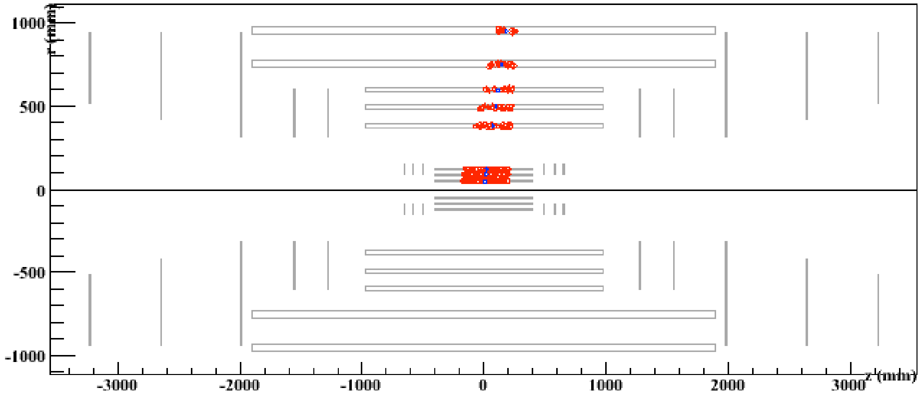
- L1Calo/Muon bring the rate down from 40MHz to ~500kHz within ~2.5 μs
- They then initiate L1Track in an RoI, i.e. only a small fraction of the tracker is read out
- Tracker has another ~2.5 μs to readout and extract features, then CTP makes decision
- Average additional rate very small and only in the tracker (not the whole of ATLAS)
  - *E.g. (500kHz)x(2% of tracker) = 10kHz*
  - *But the RoI data has to come out fast (<~1μs)*

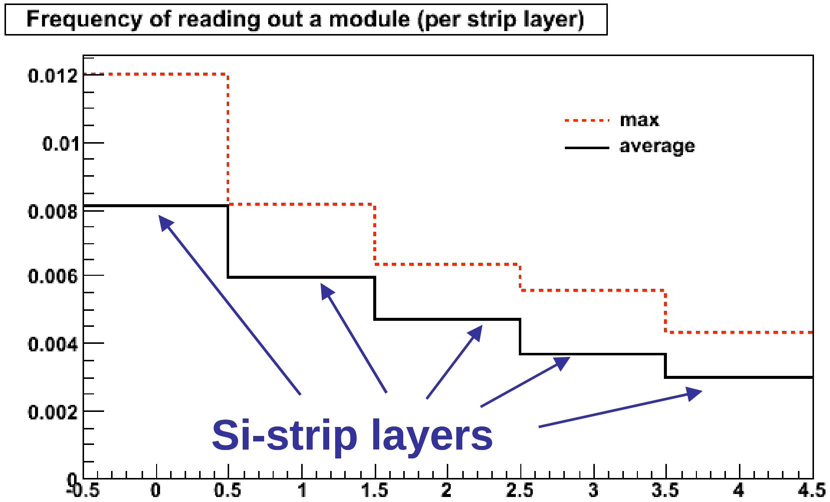
For high Pt tracks might be enough to deal with the Si-strip outer layers only.

1. “RoI” based processing.

ROI area for the barrel part of the Inner Detector







Frequency with which data is requested from a module in the barrel strip layers

Data reduction actions are required.

- Hit clustering (only central strip location is sent
- Rejection of the wide strips (min low-Pt track suppression
- Limit max number of clusters per chip and max number of bits per module

1. “RoI” based processing.

Nikos Konstantinidis:

1. Data transfer from MCC to SMC takes longer, hence drives overall latency
   - Based on our study, it seems possible that the readout of an RoI can be within <~1μsec
2. Dead time – assuming:
   - 500kHz L0A
   - average frequency of module requests per RoI 1%
   - ~2 lepton RoIs per event
   - dead time per module of ~0.5μsec **=>** an average ~1% of the modules will not be readout

A **lot of thing to be addressed the most urgent ones:**

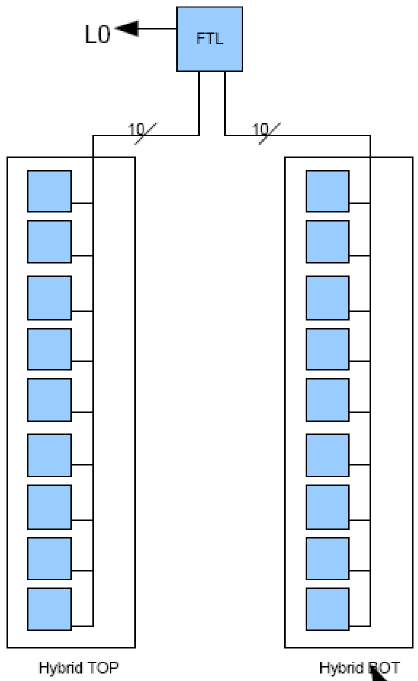
- Pattern recognition issues with the data reduction cuts.
- Data compression optimisation.
- Readout from SMC to L1 track processor.

2. Processing in parallel with L1Calo/Muon using dedicated Si-strip layers.

Presented by Richard Brenner at the ATLAS Upgrade WS 23-27 Feb 2009:

This approach is similar to that proposed by CMS but:

- For the ATLAS cluster width cut is not that powerful as for CMS.
- Two stave layer distance must be at least ~ 6 mm

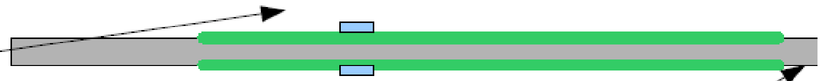


Add services on hybrid for a fast trigger decision

- Connect modules on top and bottom of the stave in pairs → extra lines and connector
- Add Fast Trigger Logic to MCC
- Distance between module (stave thickness) ~6mm

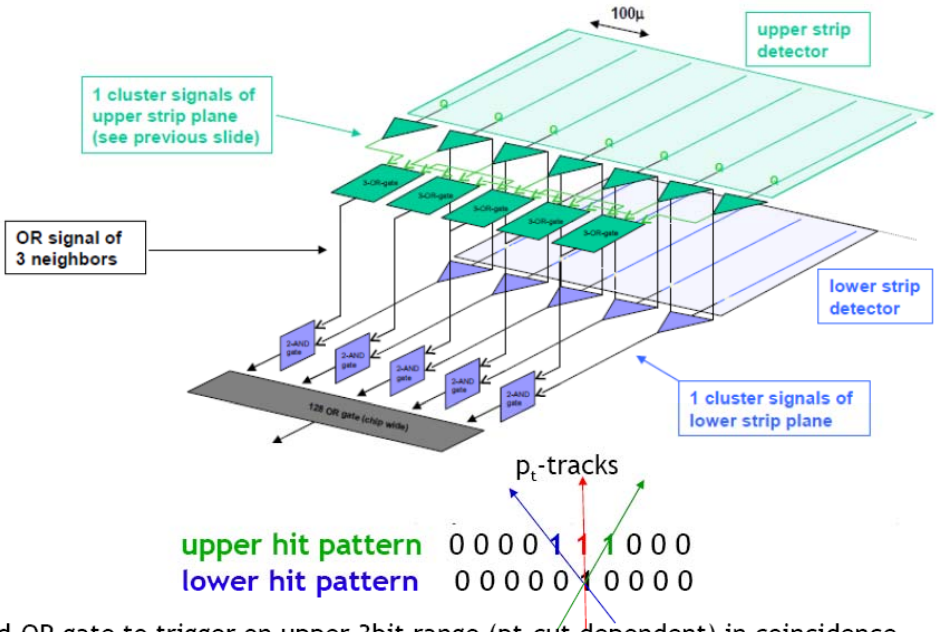
Grouped scheme

- 10 trigger lines/hybrid (STAR configuration)
- Clock speed to be decided (40/80/160/320 MHz)
- Simple OR-logic with 40MHz BCO:
  - 40 MHz = 80 Mbit → 64 channels/bit
  - 80 MHZ = 160 MBit → 32 channels/bit
  - 160 MHz = 320 MBit → 16 channels/bit



2. Processing in parallel with L1Calo/Muon using dedicated Si-strip layers.

2-layer hit correlation



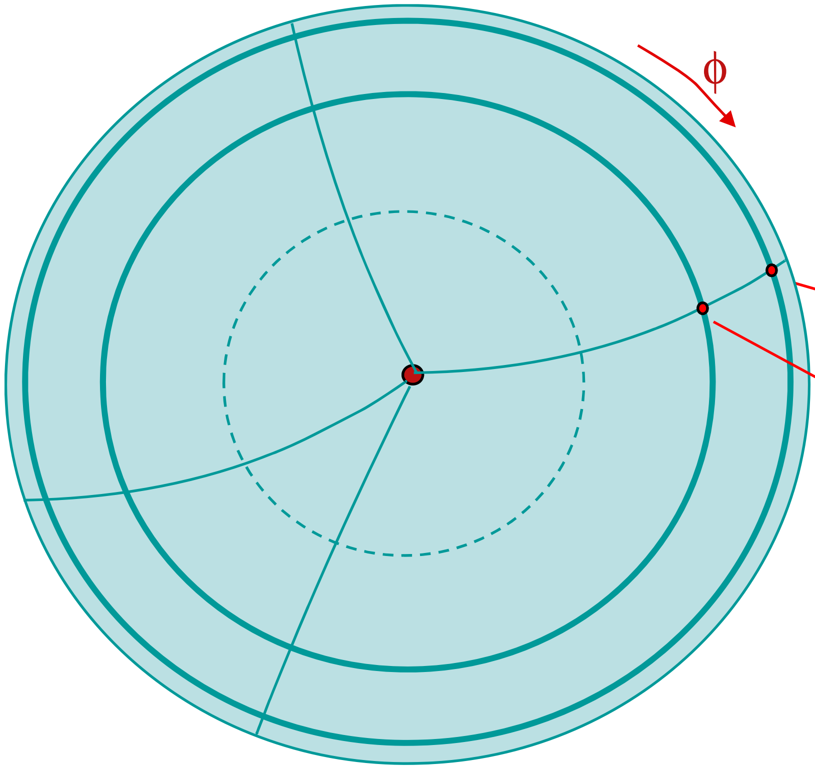
=>Need 3-fold-OR gate to trigger on upper 3bit range (pt-cut dependent) in coincidence with lower hit.

The power of one double layer most likely will not be enough => two outer double layers separated by about 200 mm must be involved.

Preferable solution to combine this approach with “RoI” based processing.

3. Alternative technology: GasPixel Tracker

Presented by Anatoli Romaniouk at the ATLAS Upgrade WS 23-27 Feb 2009:

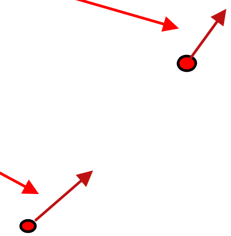


Why is that interesting?

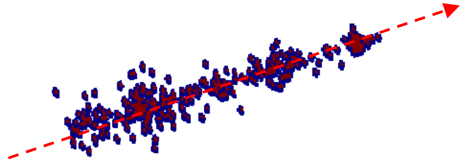
A vector tracking !

(*TR information might be a complementary feature***)**

1. Precision space points X,Y
2. Vector direction ϕ, η

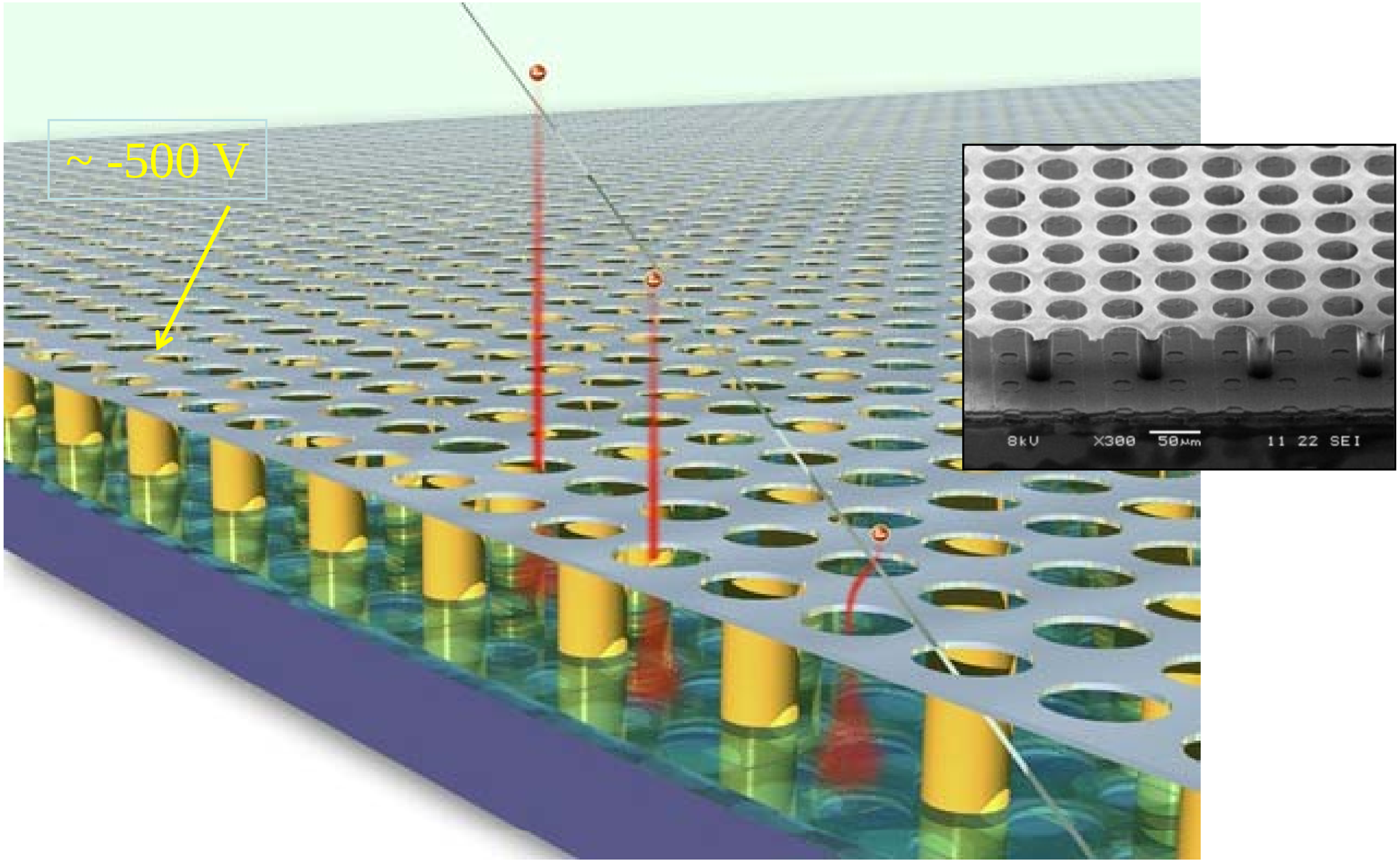


Already one layer provides particle track image.

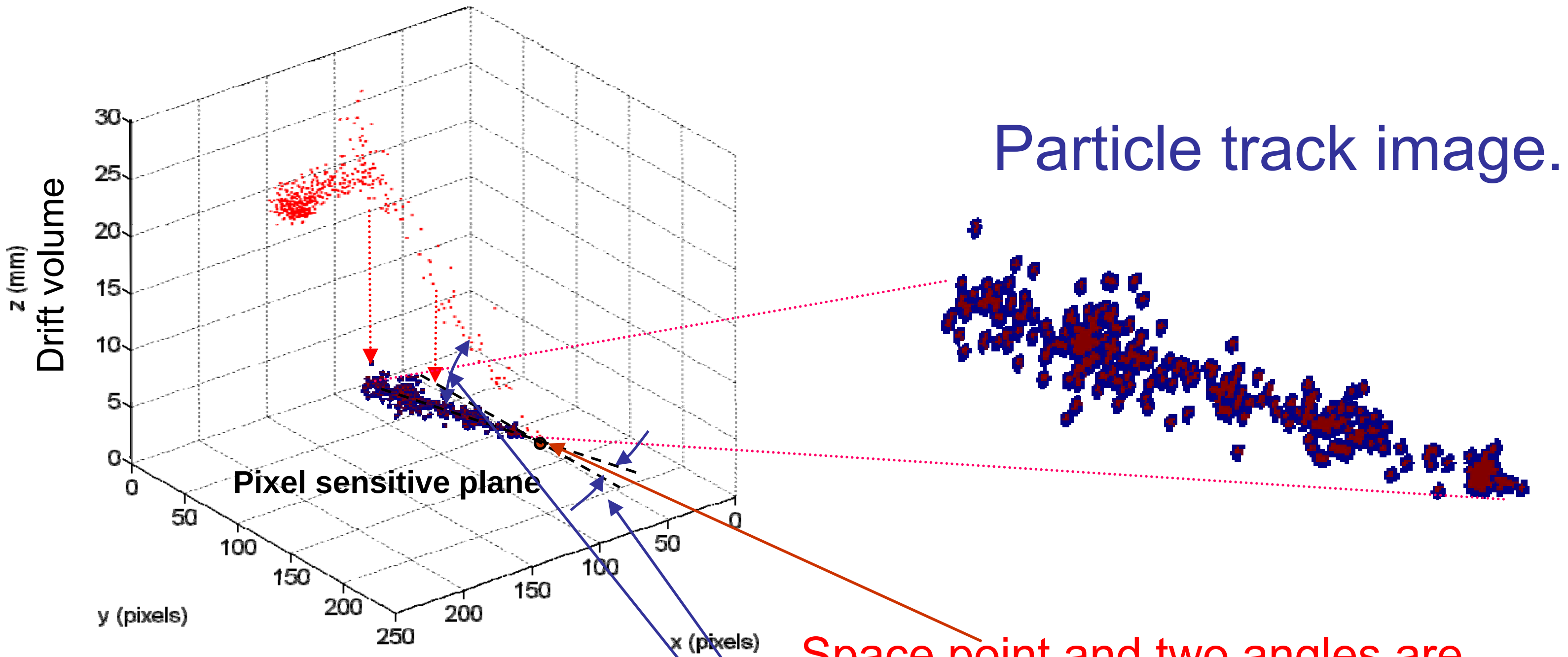


Example -> GridPix technology

Part of the gas detector directly comes after industrial process



How it works?



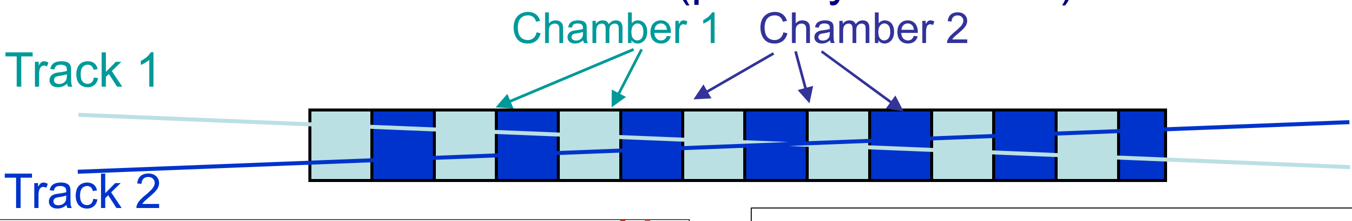
Space point and two angles are measured:

ϕ – In the pixel plane

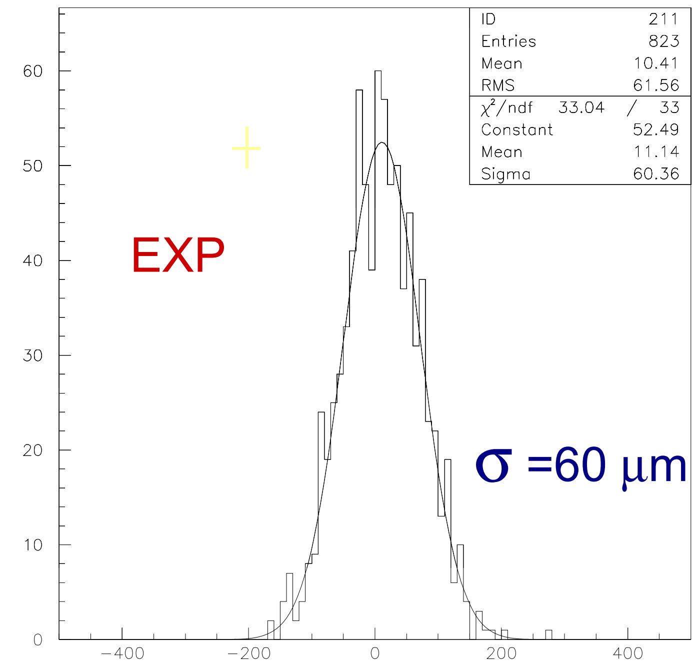
η – is and angle to the pixel plane

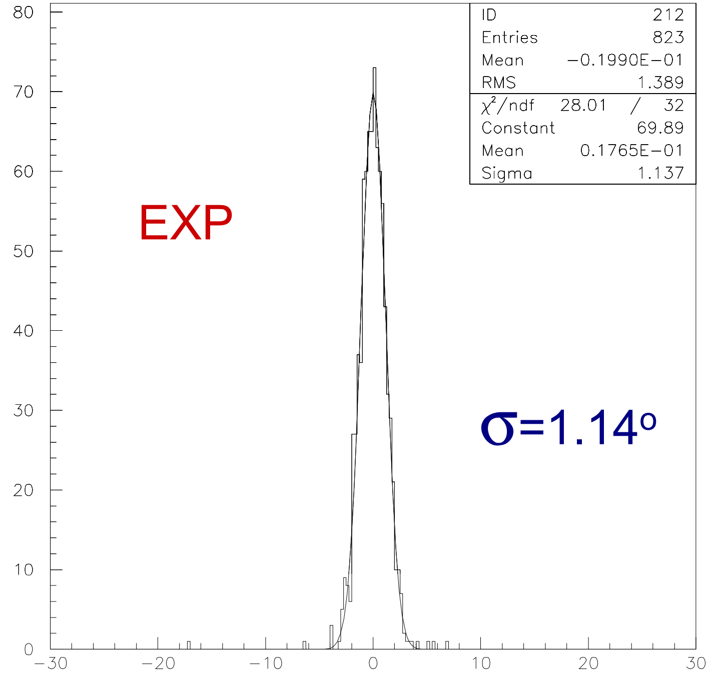
Analysis: **tracking**

Pions, 5 GeV, Xe mixture, 55 μm pixel, 240 μm diffusion, threshold 1.3 el (primary electrons).



Real resolution will be ½ of the measured one with this method.



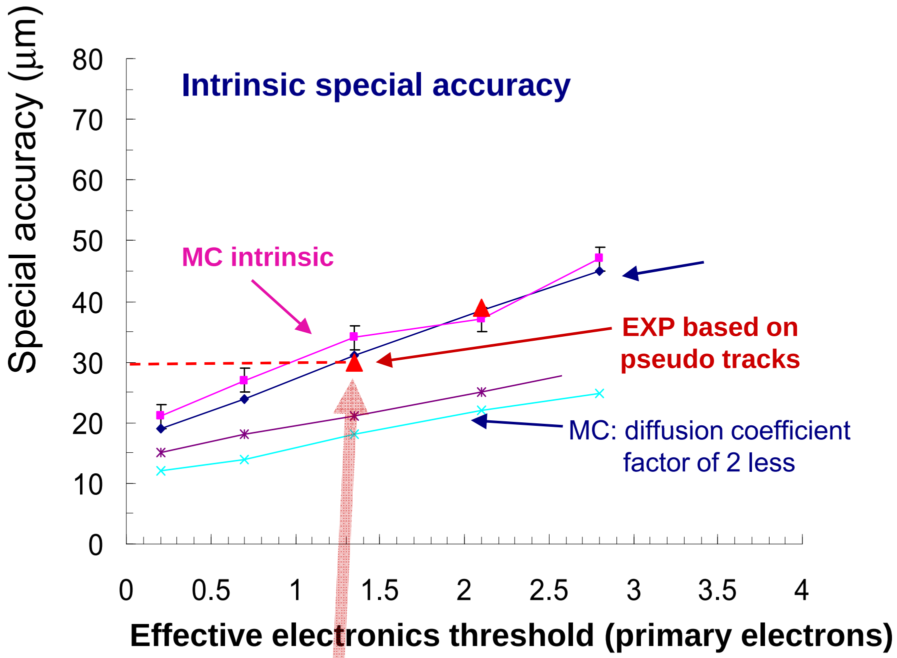


Difference between reconstructed space points for two pseudo tracks.

Difference between reconstructed angles for two pseudo tracks.

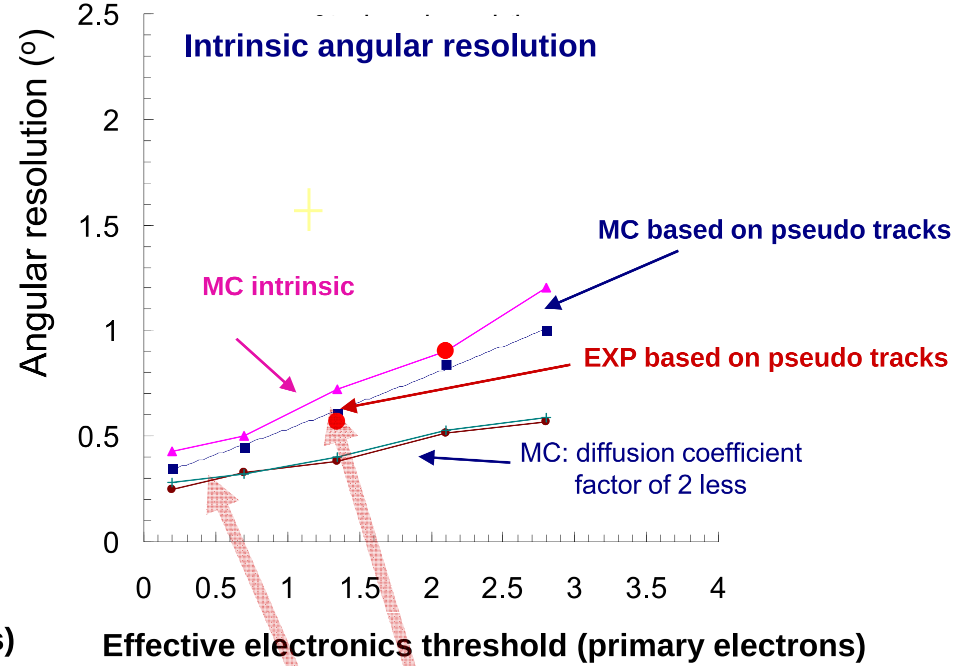
Analysis: **Intrinsic tracking properties.**

Pions, 5 GeV, Xe mixture, 55 µm pixel, 240 µm diffusion,



Intrinsic special accuracy of the gas pixel detector. (MC and EXP).

Special accuracy achieved in the test beam is **~30 µm.** It can be improved lowing down threshold and reducing the diffusion if required.



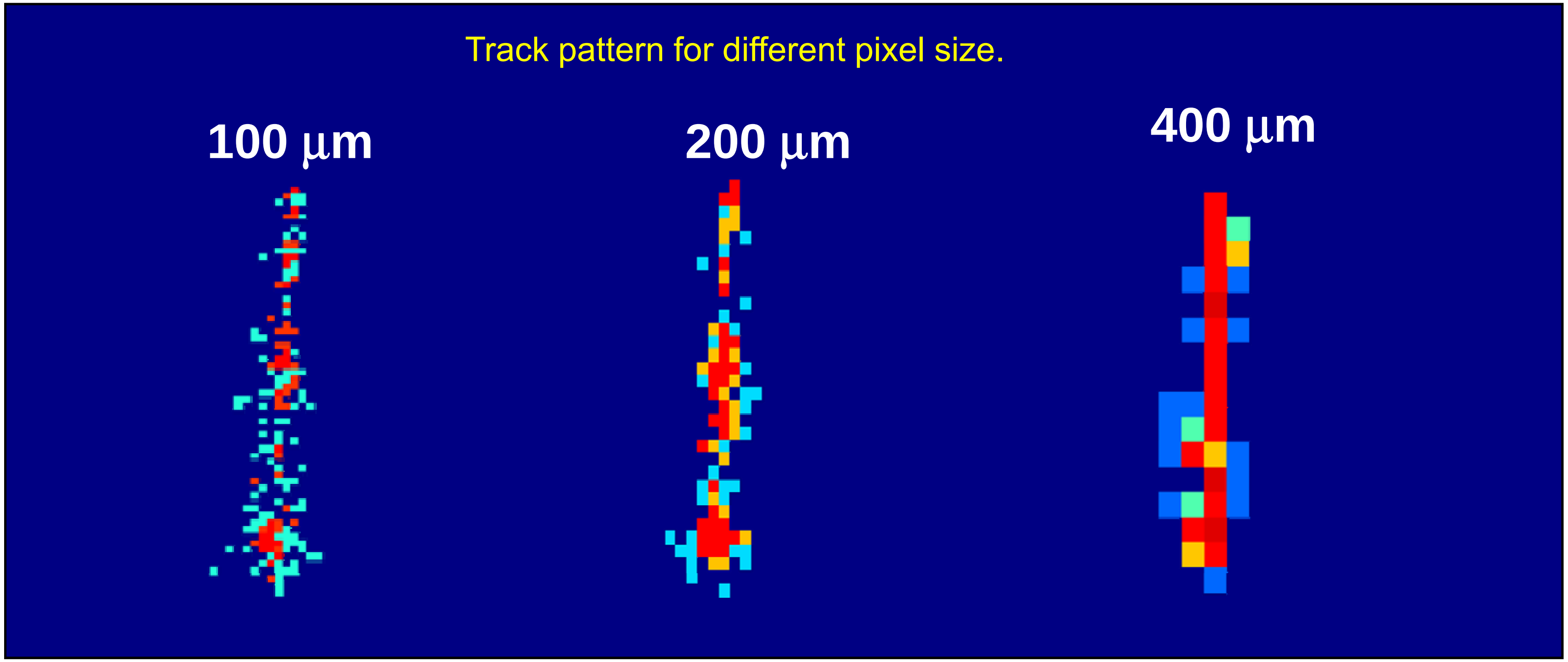
Intrinsic angular resolution of the gas pixel detector. (MC and EXP).

The angular resolution achieved in the test beam is **0.57°**. It can be improved but it would be very **difficult to get below 0.3°.**

Two components are the most critical for the detector performance:

- **Diffusion coefficient**
- **Size of the Pixel**

Track pattern for different pixel sizes

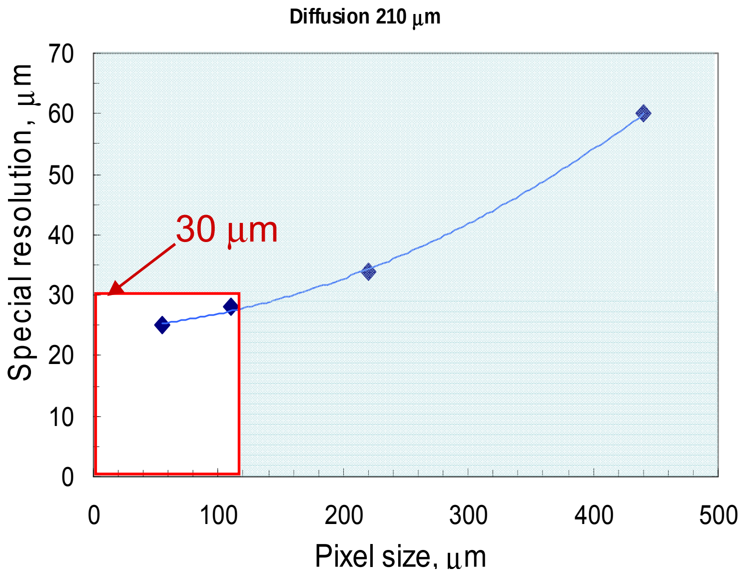


Realistic diffusion coefficient of 210 μm/cm$^{1/2}$ was taken in the simulations

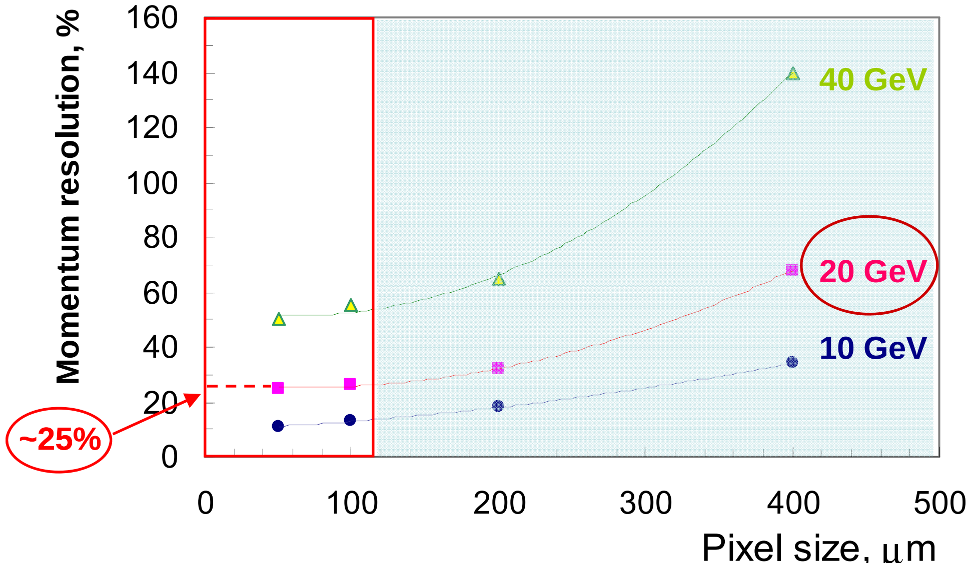
Coordinate and momentum measurements

with one layer of the gas pixel detector situated at R=100 cm from the interaction point.

Tack to chamber angle - 25°
Gas mixture - Ar/CO2 (50/50)
B=2T



Space point accuracy and a function of the pixel size



Momentum resolution as a function of the pixel size for particles with P_T= 10,20 and 40 GeV.

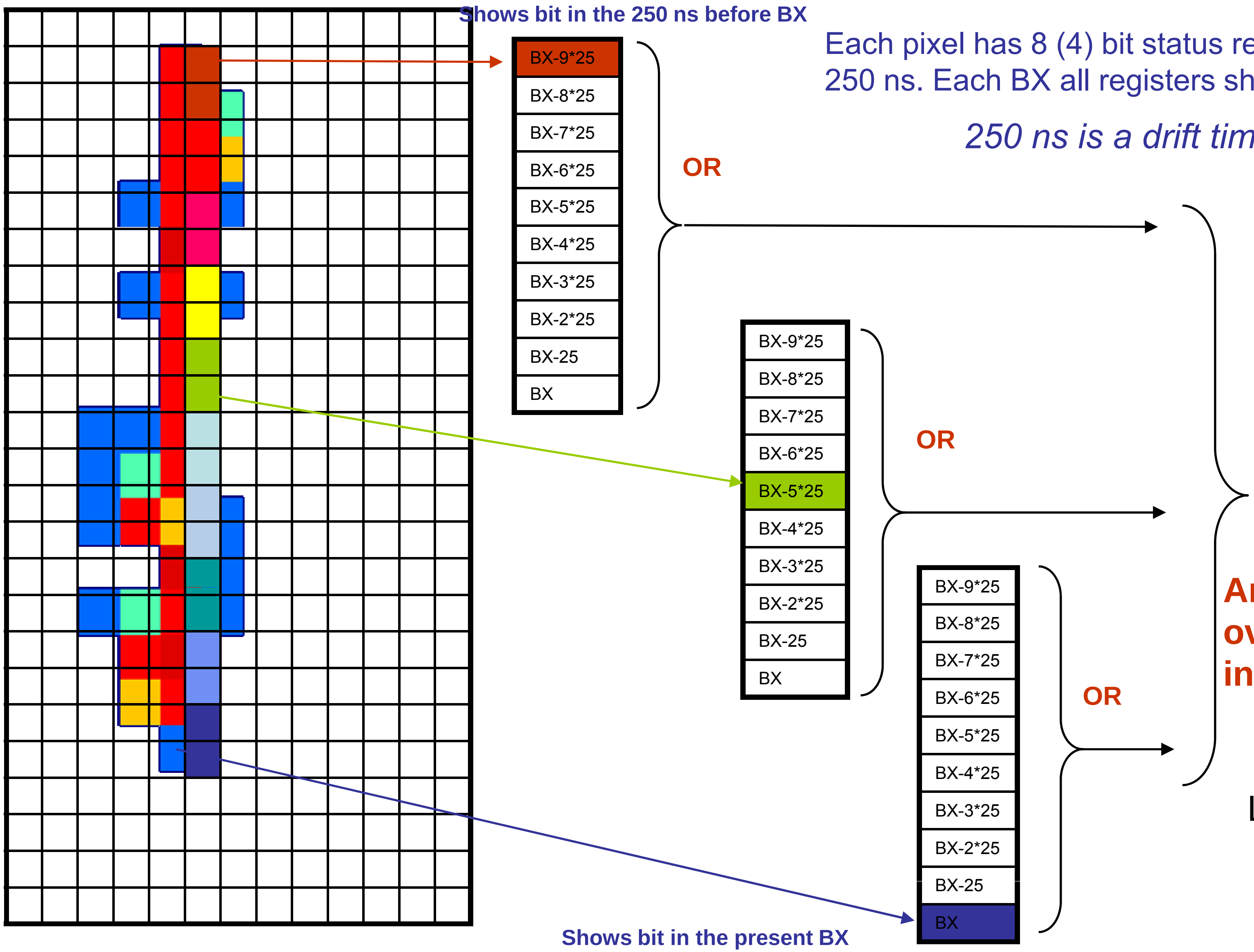
Realistic space point measurement accuracy is ~ 30 µm
Realistic P_T cut for one layer is ~ 20 GeV

Some ideas of the Gas pixel L1 trigger organization:

Status registers

Each pixel has 8 (4) bit status registers covering 250 ns. Each BX all registers shift by 25 (50) ns

250 ns is a drift time



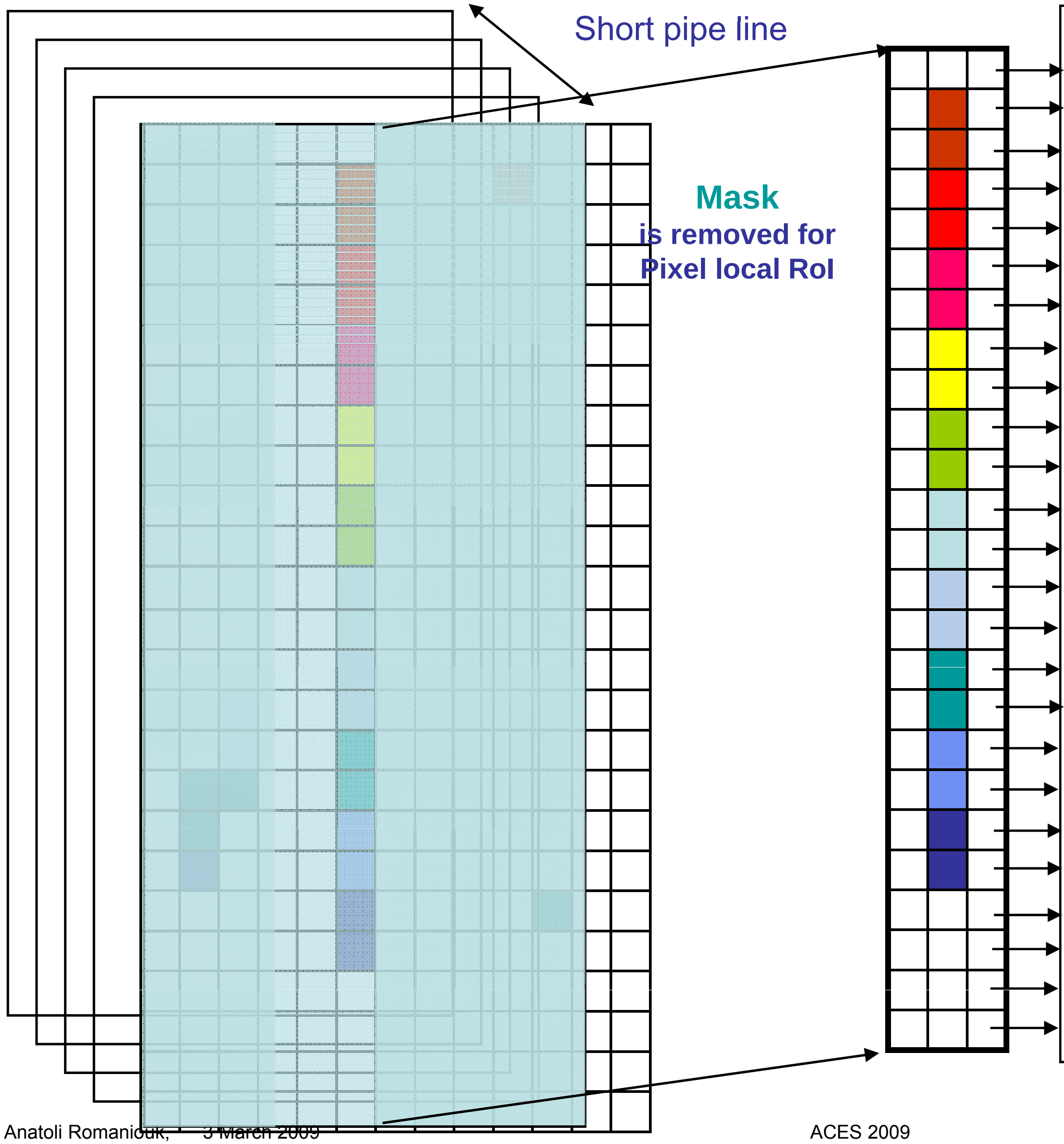
$\Sigma >$ Amp.

Analog sum over all the pixels in the column

Local Pixel RoI

Some ideas of the Gas pixel L1 trigger organization

Status registers



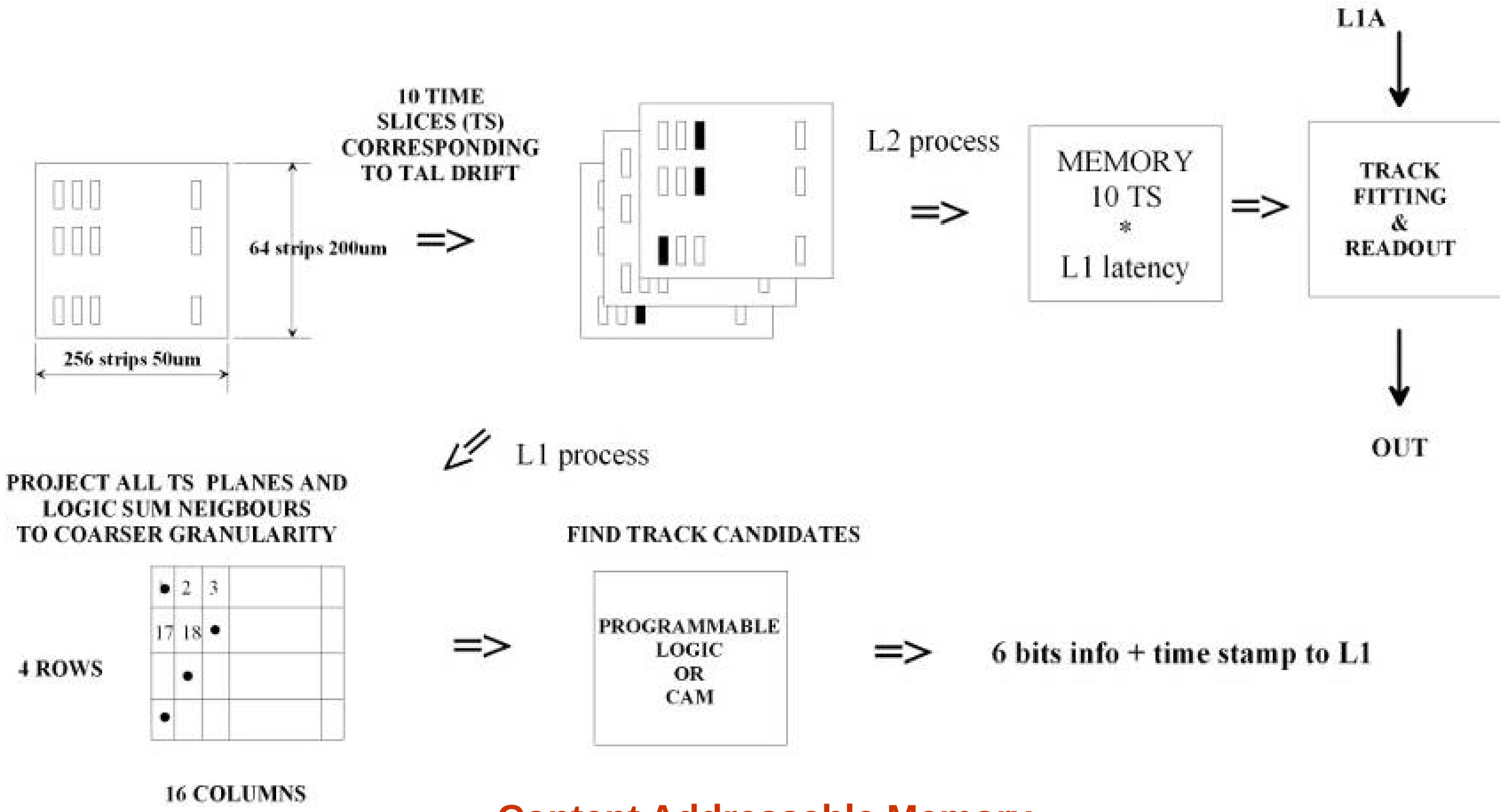
L1 trigger

Check track pattern for all rows in local RoI:

- Register bit sequence (time)
- Track length
- Track attributes
- Analog average- fast histogramming) from the start to the end of the track
  -> momentum

Some ideas of the Gas pixel L1 trigger organization:

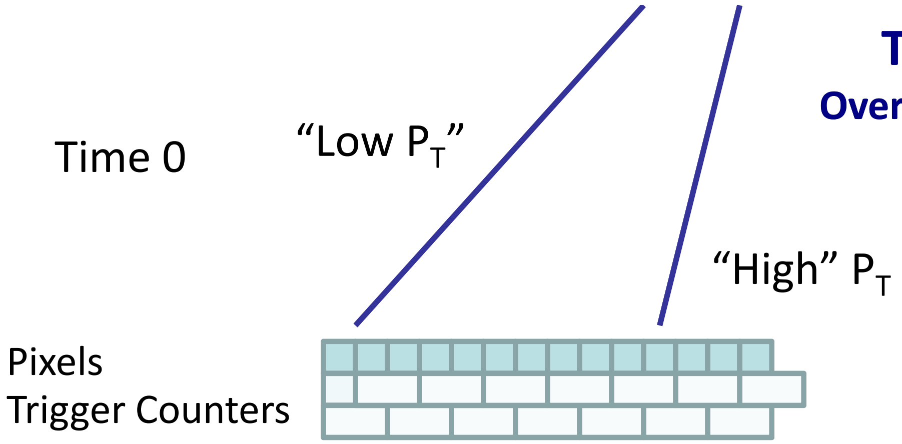
Look-up tables *(Peter Lichard)*

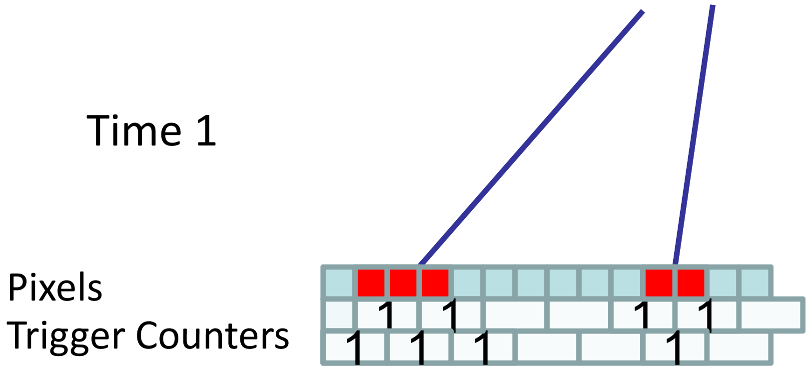


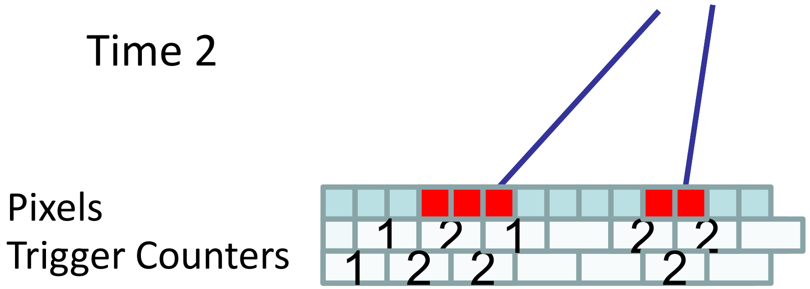
Content Addressable Memory
to search for predefined patterns

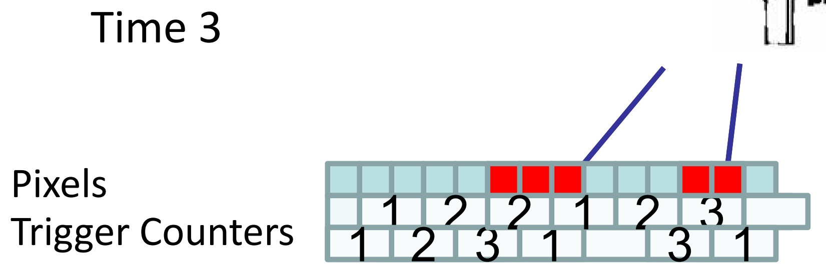
Trigger counters *(Rick Van Berg)*

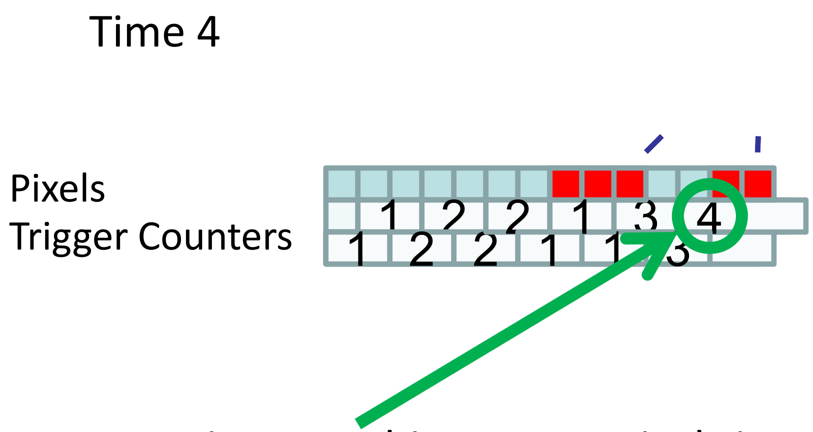
Overly Simple Example of High P_T Track Trigger











Trigger – 4 hits on two pixels in 4 time slices.

Requires one counter per time slice per possible high P_T track pattern

Conclusions:

Gas Pix detector

- First test beam results show that **one layer** of **the GasPixel Tracker (GPT)** is able to provide:
  - space point accuracy of **~30 μm**
  - momentum resolution of **~25%** for P_T=20 GeV.

- Combining two L1 track segments from two layers allows to organize post L1.5 trigger for the high PT track segments => ~10-20% for 100 GeV.
- *New technology offers a lot of advantages **BUT** it requires large investments to the R&D and a substantial change of the ATLAS ID design for the SLHC.*

Si-strip L1 processing (approach similar to CMS)

- Cluster width method seems too weak for the ATLAS magnetic field
- Distance between stave layers must be 6mm at lest
- The best would be to combine this method with “RoI” based processing

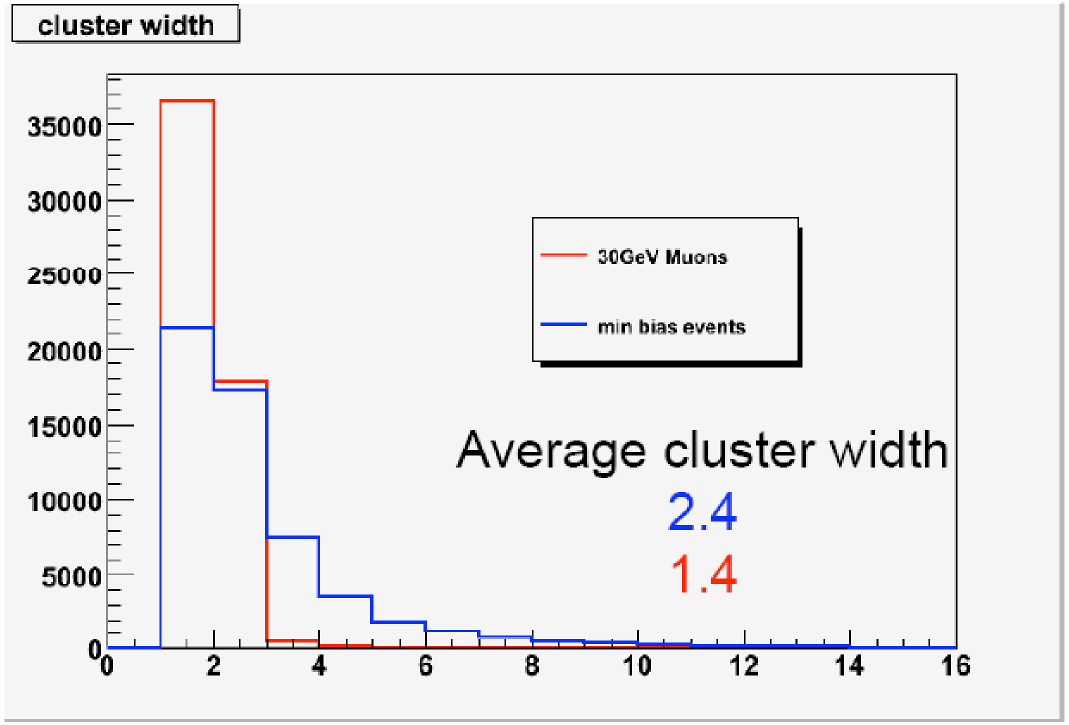
RoI based processing

- Generally no showstoppers found
- Need changes in the read-out architecture allowing readout within 1-2 μs
- Needs fast read-out within RoI (~2% of the detector)

Still at the beginning of the way!

Back Up Slides

Cluster width



Eff (muon clusters with width<3 strips) ~ 99%

Eff (min.bias clusters with width<3 strips) ~ 70%

Cap on max clusters per chip

- To allow fixed max transfer time from chips to MCC (+ possible benefits of fixed data size)
- Assume 7 bits per cluster (location of “central” strip, no width), plus some bits for cluster count

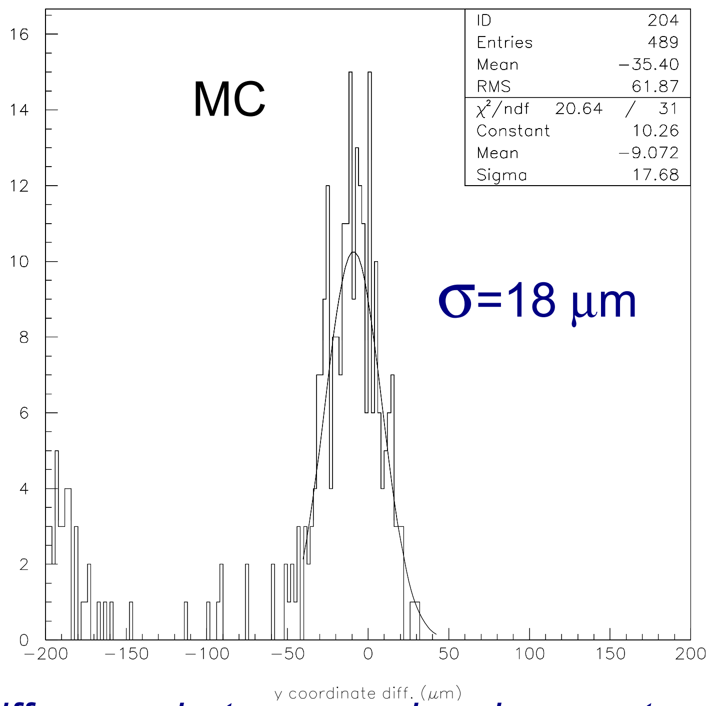
All results from this point on are with 400 pile up

Max # of clusters/chip	% clusters dropped	Max bits from chip to MCC	# of bunch x’s for transfer (160Mbps)
1	32.1	1+1x7 = 8	4+2
2	10.6	2+2x7 =16	4+4
3	3.9	2+3x7 =23	4+6
4	1.6	3+4x7 =31	4+8

Analysis: **tracking** (Z - and η– measurements)

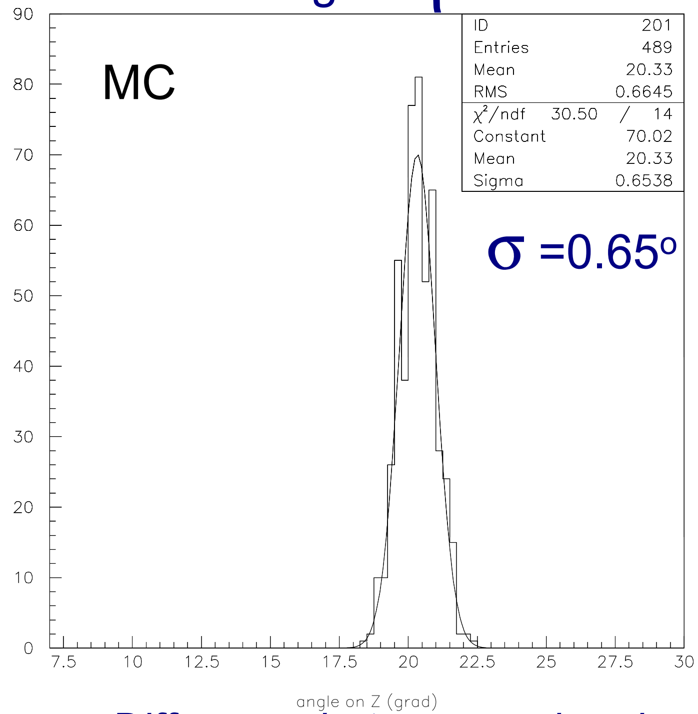
The best want can be achieved for the threshold of 0.5 el and diffusion ½ of what was in the test beam is.

Space point in Z direction (Y)



Difference between real and reconstructed space point along the track.

Angle η



Difference between real and reconstructed angle of the track.

Measurement accuracy of these parameters very much depend on η!

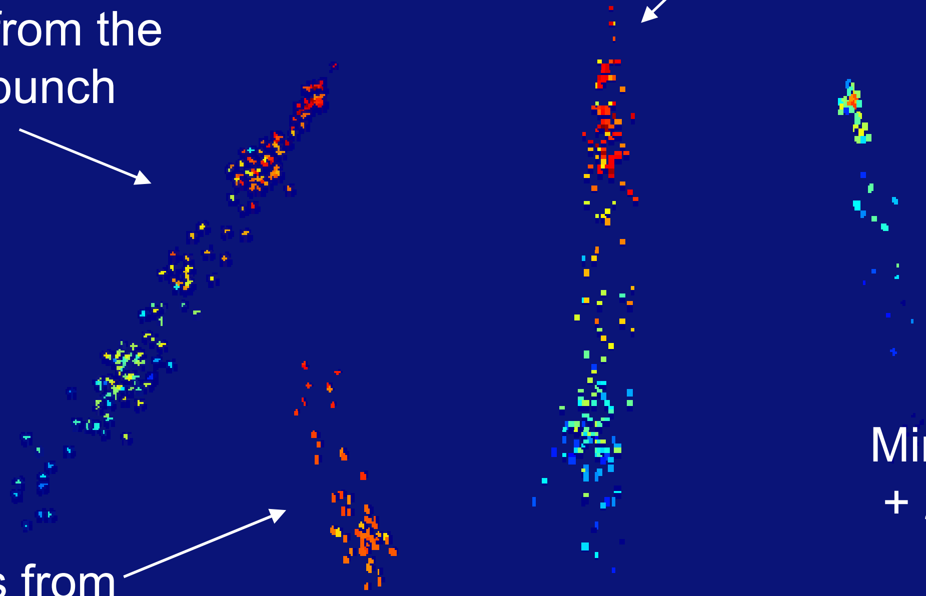
Operation in the multi particle environment

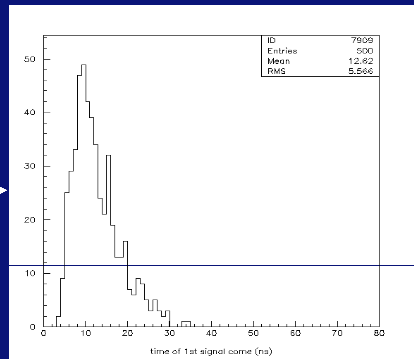
Track projection o the pixel plane

On the picture the occupancy Is 4 particles per cm²

Color code reflects hit arrival time

Expected occupancy is 0.6 particles per cm²





Pattern recognition is already good for one layer: length of the track + angle + bunch identification

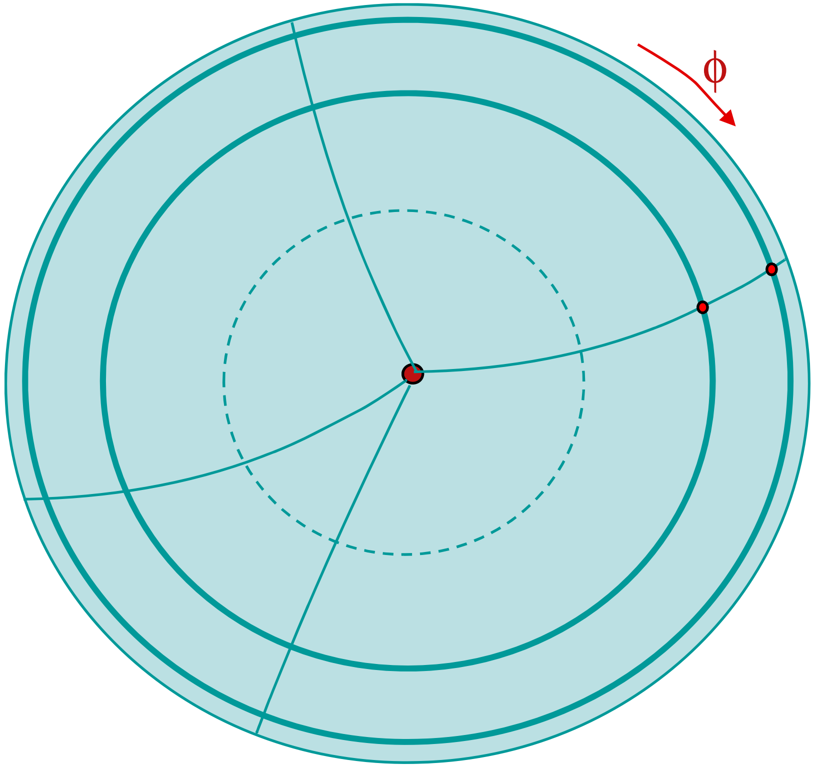
Only High Pt track information will be to be transmitted to Back-End.

L1 trigger

As a natural step after L1 trigger L1.5 trigger can be implemented

It can be based on:

- Track segments of two pixel layers.
- Vertex constrains.



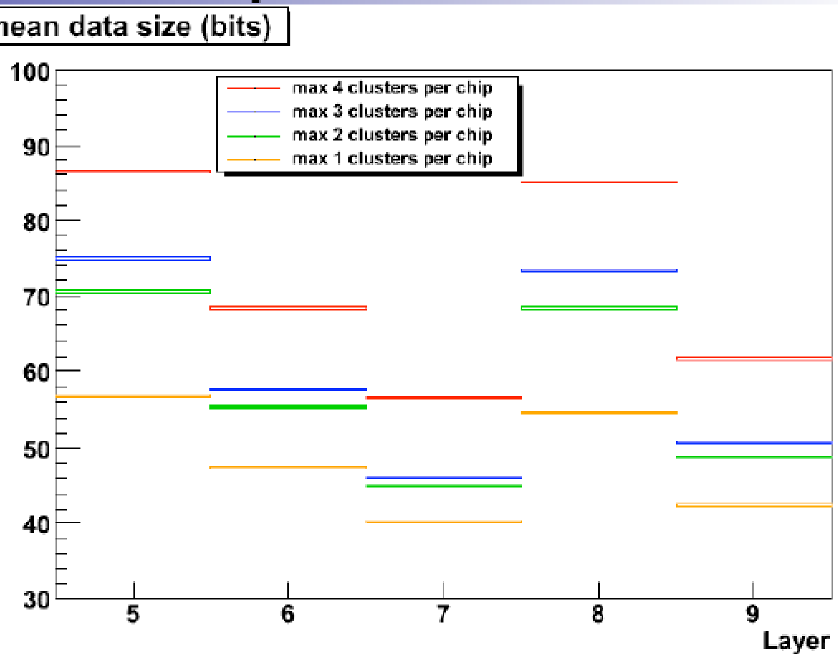
Assuming a realistic space point accuracy of ~ 30 μm

Momentum of 100 GeV can be defined with an accuracy of better than 20% at the L1.5 level

Beam interaction point must be known with accuracy better than 100 μm

Cap on max data per module

- To ensure fixed max latency from MCC to SMC



*(no sharing of the 320Mbps between the two hashIDs)

Max bits from MCC to SMC	Avg bits from MCC to SMC	# of bx's for max transfer (160Mbps)*	% clusters dropped
80	51	~20	8.6
100	56	~25	2.2
120	58	~30	0.4

Nikos Kons 16