A proposal for the GridPixel Tracker for the ATLAS sLHC upgrade.

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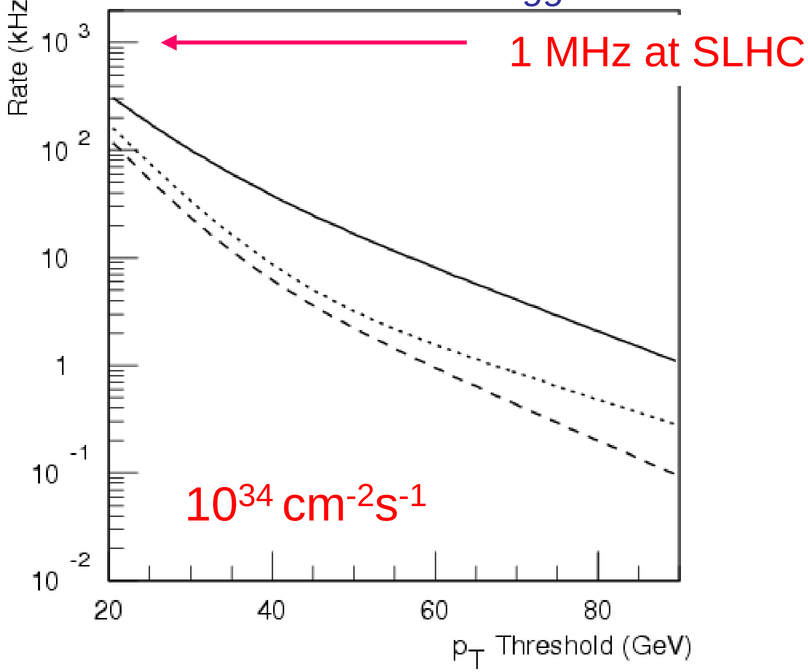
Introduction: Inner tracking at SLHC

What means increase of luminosity from 10^{34} to 10^{35} $cm^{-2}s^{-1}$?

1. Increase of the track density by factor of 10.
2. Increase of background by factor of 10.
3. More stringent requirements for the radiation hardness of all the components (by factor of 10 for total dose dependent and more then by factor 10 form dose rate dependent.
4. Difficulties for the pattern recognition- require much larger garnularity of the detectors for the same fake rate.
5. L1 trigger rate increase by factor of 10 (already at the limit for the data starsfere now)
6. L2 trigger processing time which require track reconstruction might be too long -> new approaches and more powerful computer farms (orders with respect to the present ones).
7. Longer processing time to reconstruct events: non linear effect (almost as power of 3 with number of hits).
8. As a sequence of above limitations for HLT (factor of 1000 for the processing time at Event Filter level).
9. …..

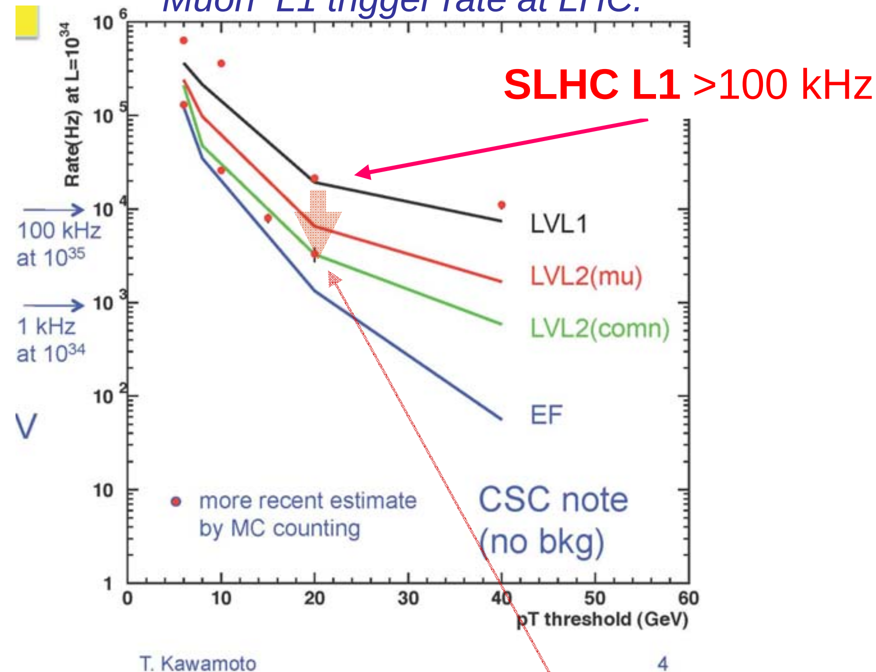
Introduction: L1 trigger in the ATLAS

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

An ID track segment with Pt > 20 GeV would reduce a trigger rate by 1 order of magnitude.

Introduction: L1 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 from this (W, Z, top for instance).

Among other measures L1 Tack trigger in the Inner Detector would significantly improve the performance of the experiment.

Level 1 ID track trigger:

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.

Introduction: Operating conditions at SLHC

ATLAS/Inner Detector.

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

P_T> 0.3 GeV - > ~ 7000 GHz
P_T> 3 GeV - > ~ 70 GHz
P_T> 10 GeV -> ~ 70 MHz
P_T> 20 GeV -> ~ 0.70 MHz

It would be great to have a Low P_t BLIND Outer Tracker with good momentum measurement accuracy already at L1.

Basic requirements:

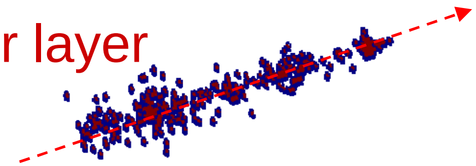
- Space point accuracy ~30 μm
- L1 track trigger cut ~ 20 GeV
- Fast track/momentum reconstruction algorithms at L2

That is the place where the MPGDs can help very much!

Introduction: Motivation

Pixelization of the information from the particle track offers new possibilities to combine in one detector the most important tracking features.

A certain conditions ONE detector layer provides particle track image.

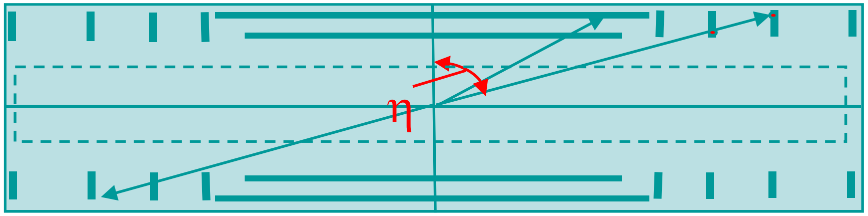


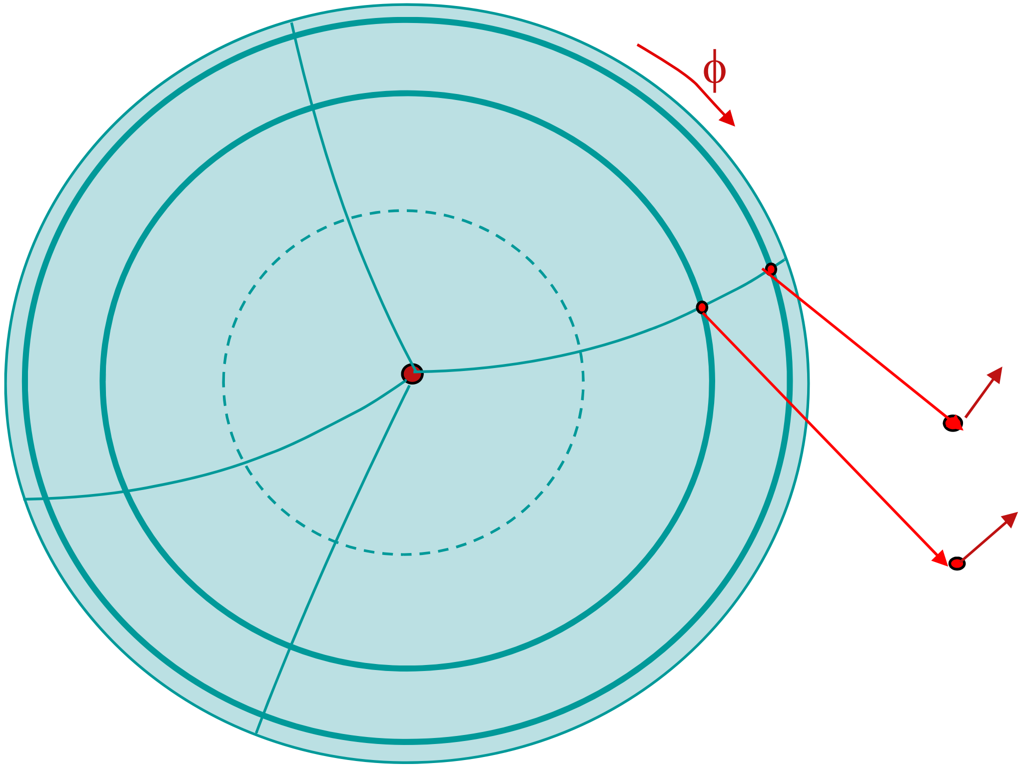
1. Precise coordinate measurements.
2. Vector track reconstruction.
3. Very good multi-track resolution.
4. Low Pt track suppression
5. Powerful pattern recognition features.
6. L1 trigger possibilities for high Pt tracks.
7. Fast L2 processing
9. dE/dX measurements
10. Enhanced Particle ID with Transition Radiation
11. High radiation resistance

The most important properties.

Introduction: Possible GridPixel Tracker layout

It is assumed that this detector will occupy the outer radii of the Inner Tracker and contains two layers interleaved with moderator or dense TR radiator





What is new?

A vector tracking !

(*TR information is a complementary feature*)

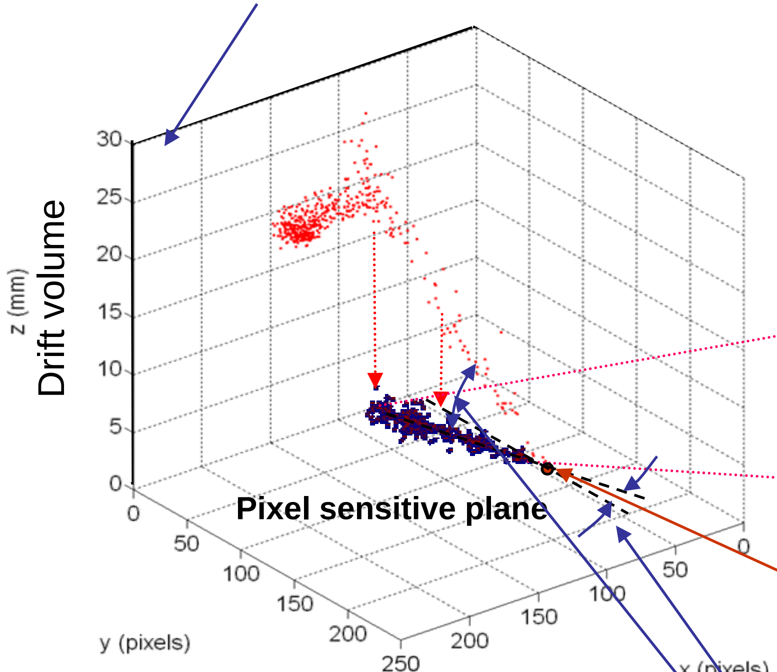
1. **Precision space points:**
   X (ϕ-direction) and **Y** (η – direction)
2. **Vector direction** ϕ and η

ϕ *and* **X** *are very important*
for the momentum reconstruction and pattern recognition

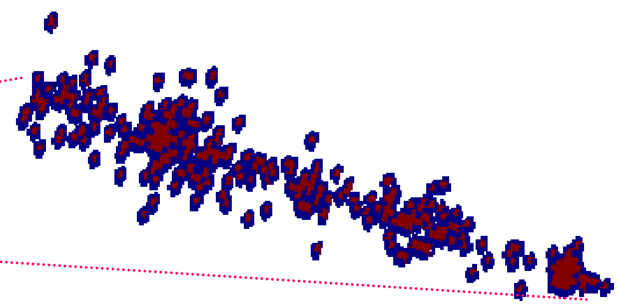
η *and* **Y** *are important*
for the pattern recognition and interaction point measurements

Introduction: How it works?

A drift gap of ~ 16 mm is requited for this detector



Particle track image.



Space points (X,Y) and two angles are measured:

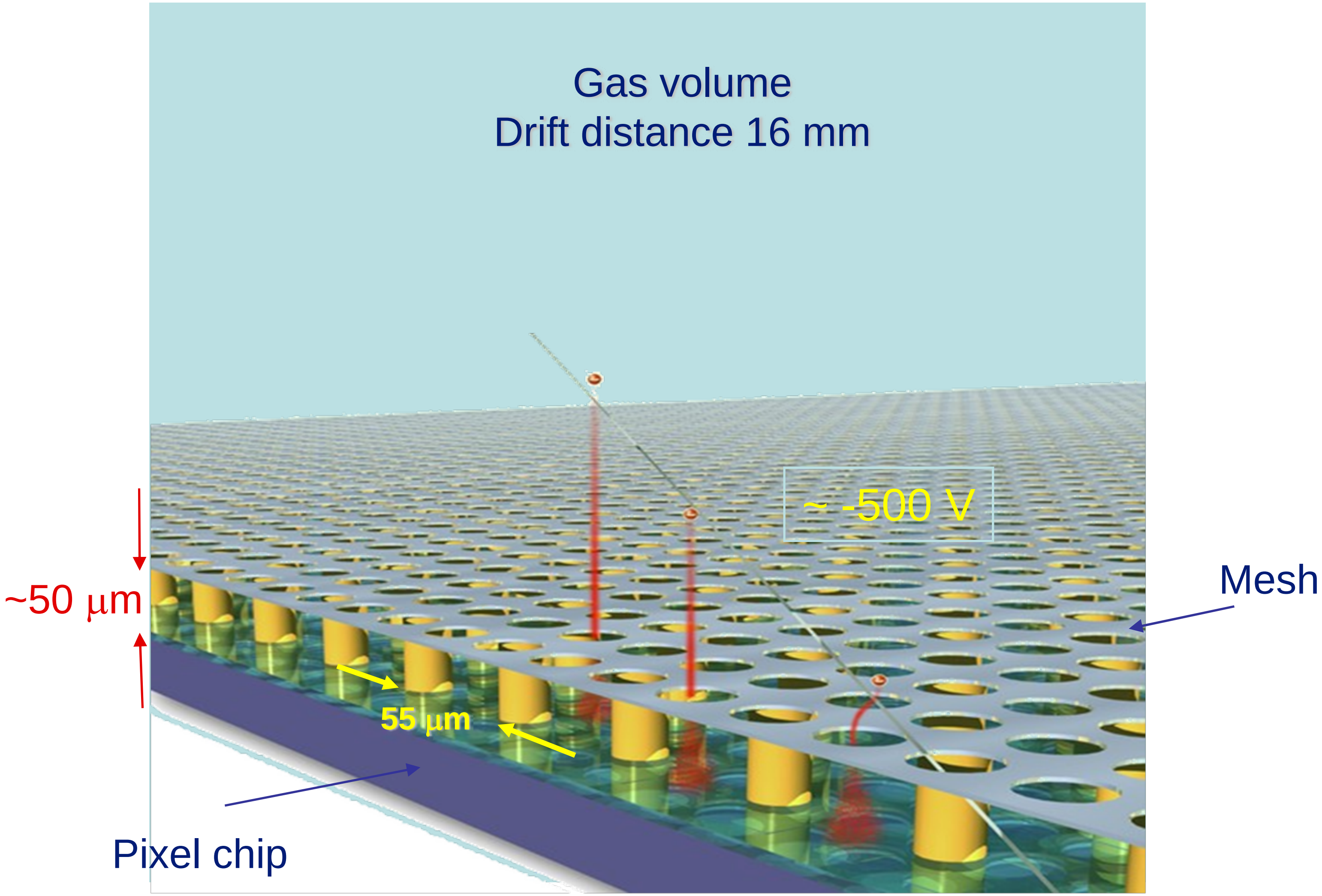
"ϕ" – In the pixel plane

η – is and angle to the pixel plane

Prove of principle ⟹ Test beam

Test beam studies: Prototype

InGrid TimePix detector, 14 x 14 mm^2
256 x 256 pixels (pixel size **55 μm**)

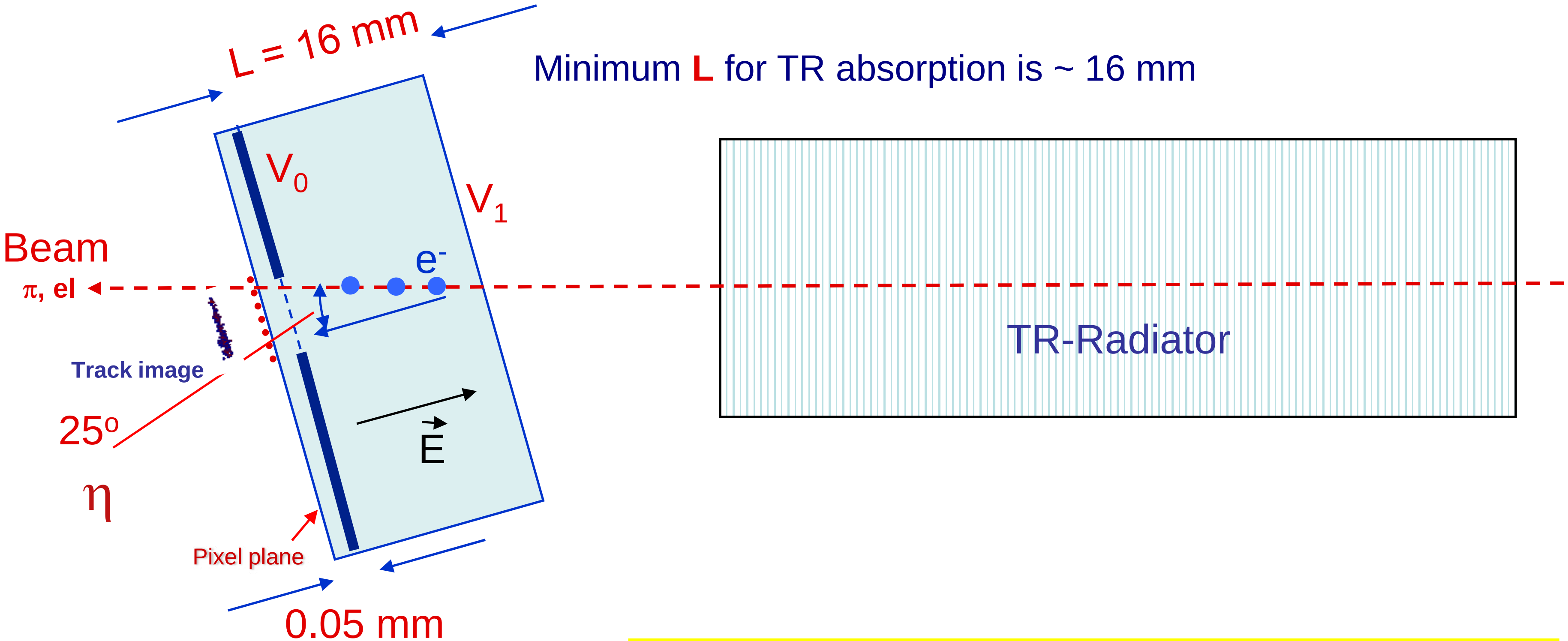


Test beam studies: Set-up

Exposed to PS 5 GeV particle beam in May 2008.

Operated with different gas mixtures.
The results will be presented for Xe/CO2 (70/30) mixture.

Minimum **L** for TR absorption is ~ 16 mm



MC simulations studies were performed and compared with the test beam data using the same analysis tools.

Test beam studies: Operation parameters

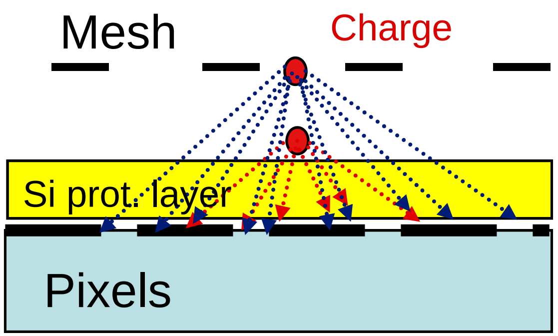
May 2008 test chamber:

- InGrid technology
- Drift distance= 16 mm
- V_{drift} = 3800 V
- E_{drift}= 2000 V/cm
- V_{amp} ~470 V
- Gas gain ~ 800 – 3500
- Protection layer 30 μm
- Amplification gap - 50 μm
- Orientation: 25 degree to the beam

  and horizontal.
- Gas Mixtures
- Ar/CO2
- Xe/CO2
- He/Isobutane

For the gas mixture 70%Xe+30%CO_2

Total drift time ~ 300 ns
Ion signal ~ 80 ns
Transverse diffusion σ_T ~240 $\mu m/cm^{1/2}$
Longitudinal diffusion σ_L ~120 $\mu m/cm^{1/2}$



Effective threshold > 1600 el.
+ *induced charge effect*

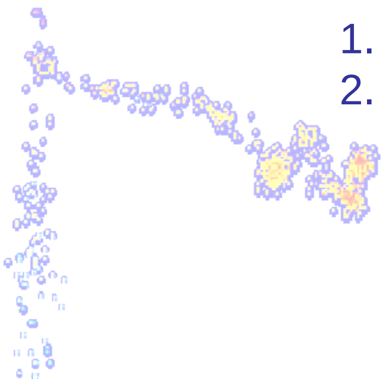
Electronics operating
threshold: ~ 800 el.

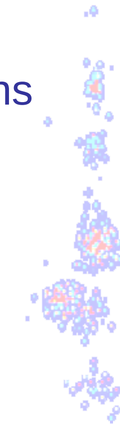
Gas gain range: 800 - 1800

Effective operating threshold
> 1 primary electron

Test beam studies

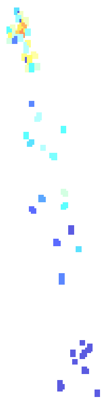
Main objectives:

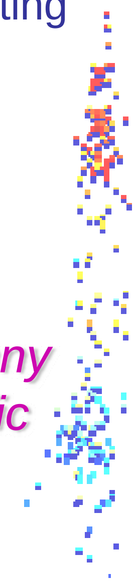




1. Understand potential limitation of the new technology
2. Verify MC model to be able to make the extrapolations to the different conditions and to the detector design.

Two aspects were studied:





1. Particle identification properties using the transition radiation with a total energy and a cluster counting techniques.
2. Tracking properties: angular and space point accuracies

A part of test beam set-up geometry, no any special detector optimisation for a specific application was done.

The results have a generic character.

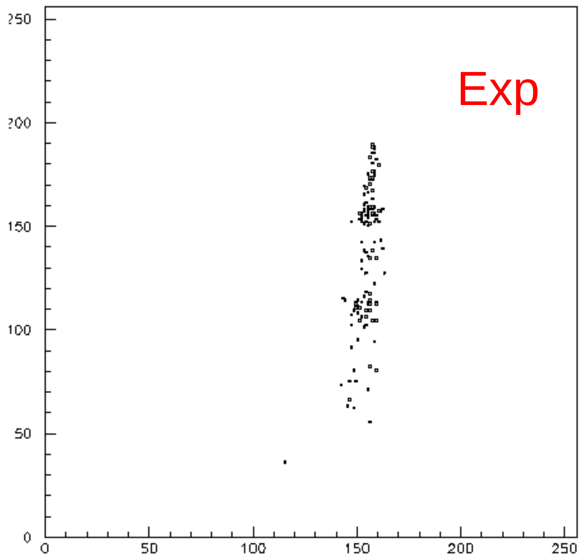
Test beam studies (5 GeV).

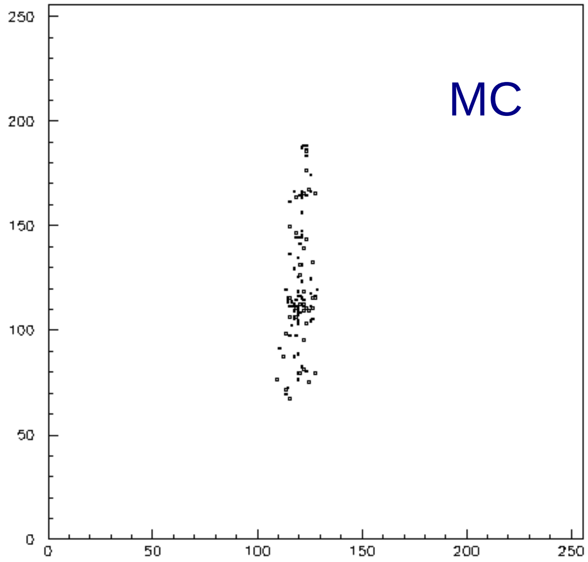
Comparison EXP data with MC

Particle tracking including all interactions + geometry - GEANT3
Ionisation losses - PAI model
TR generation - ATLAS TRT code

After all 3 basic parameters were tuned to fit the MC model to the experimental data:

- ***Diffusion coefficient*** *- was chosen to match a track widths.*
- ***Threshold*** *- tuned to satisfy number of fired pixels.*
- ***Energy scale*** *- scaled using some calibration factor.*

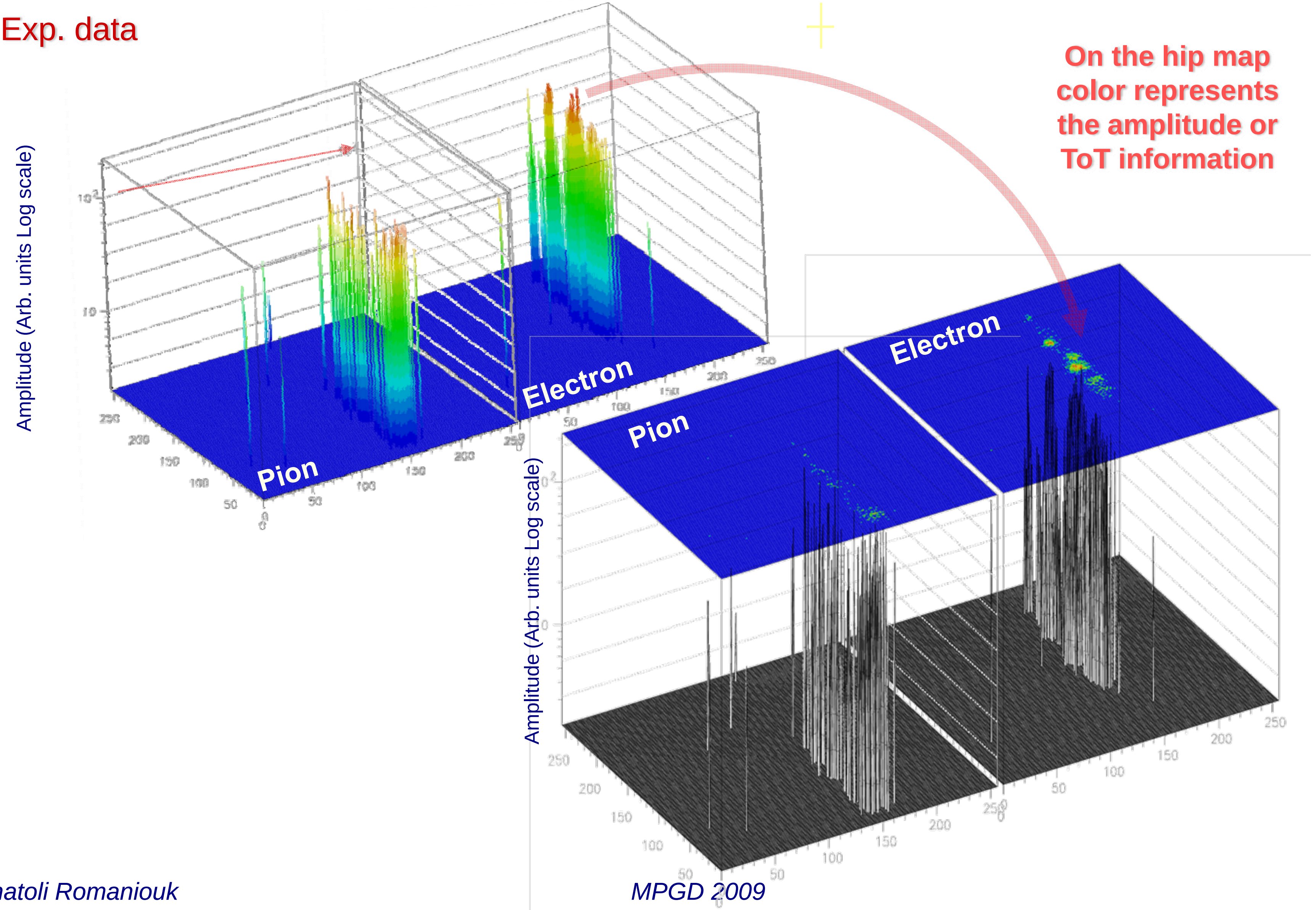




Particle Identification.

Time-Over-Threshold representing a signal amplitude was measured for each pixel

Exp. data

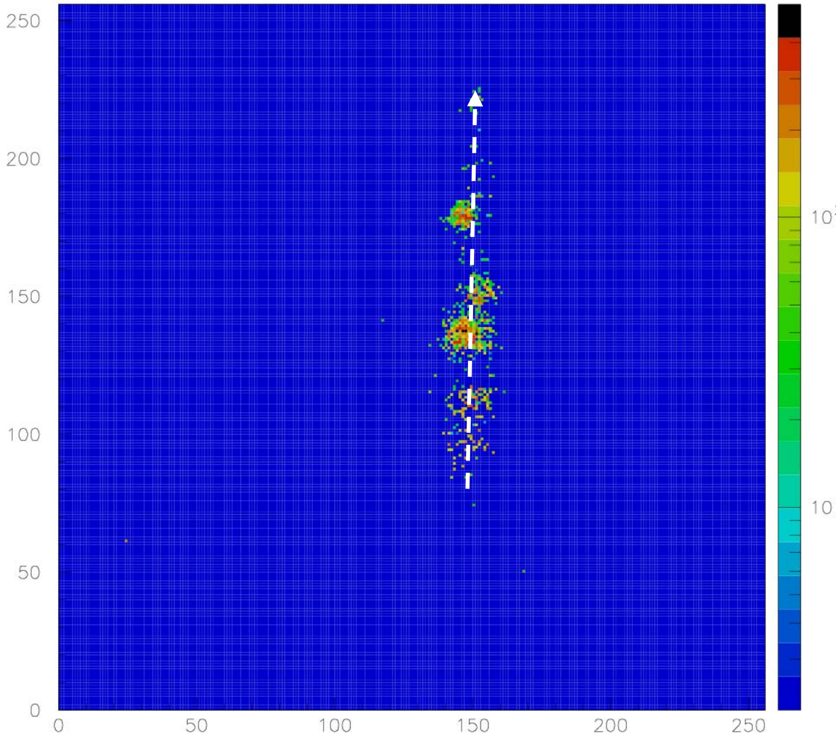


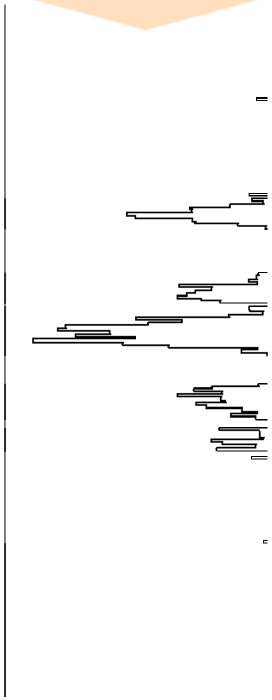
On the hip map color represents the amplitude or ToT information

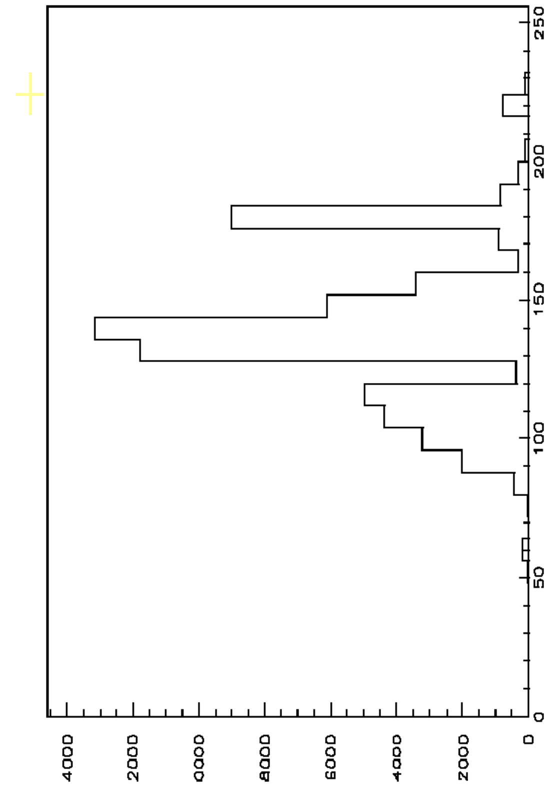
Test beam results: Particle Identification

Exp. data

Sum of the signals projected to the reconstructed track (binning is 55 μm).



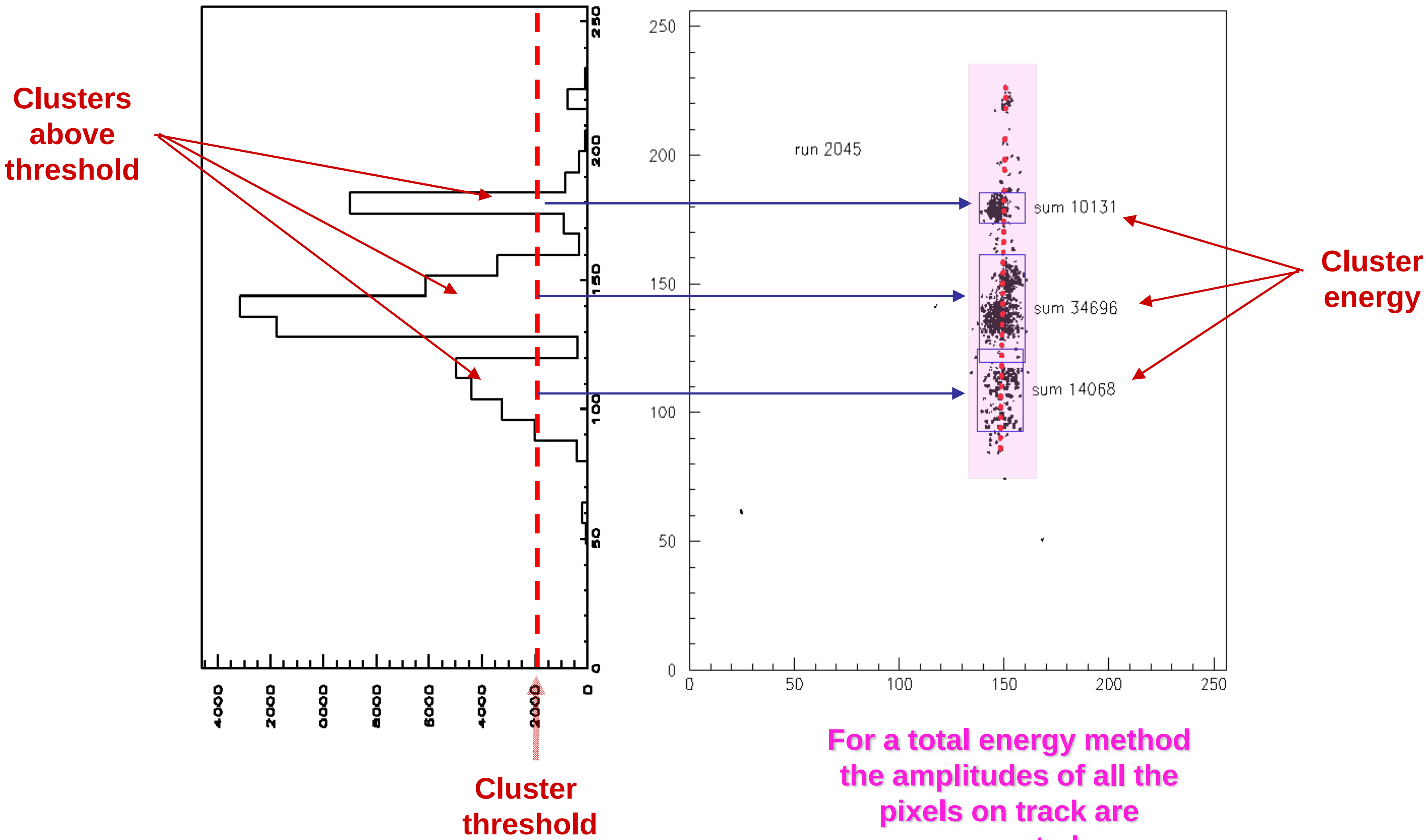




In order to reduce statistical effects data is rebinned.

Particle Identification: Methods.

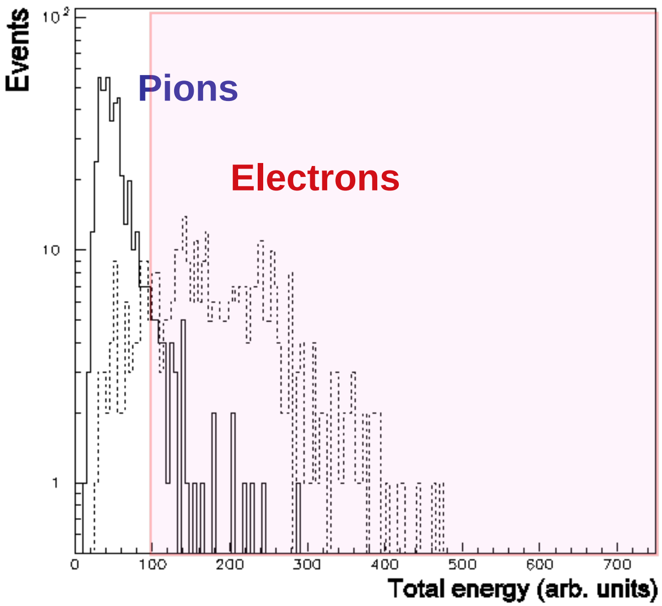
Exp. data



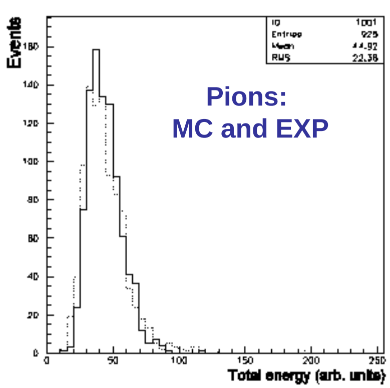
For a total energy method the amplitudes of all the pixels on track are accounted.

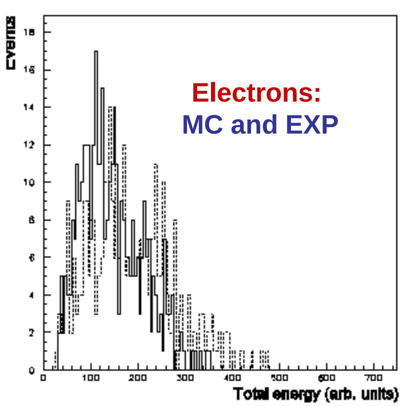
Particle Identification: Total energy measurements.

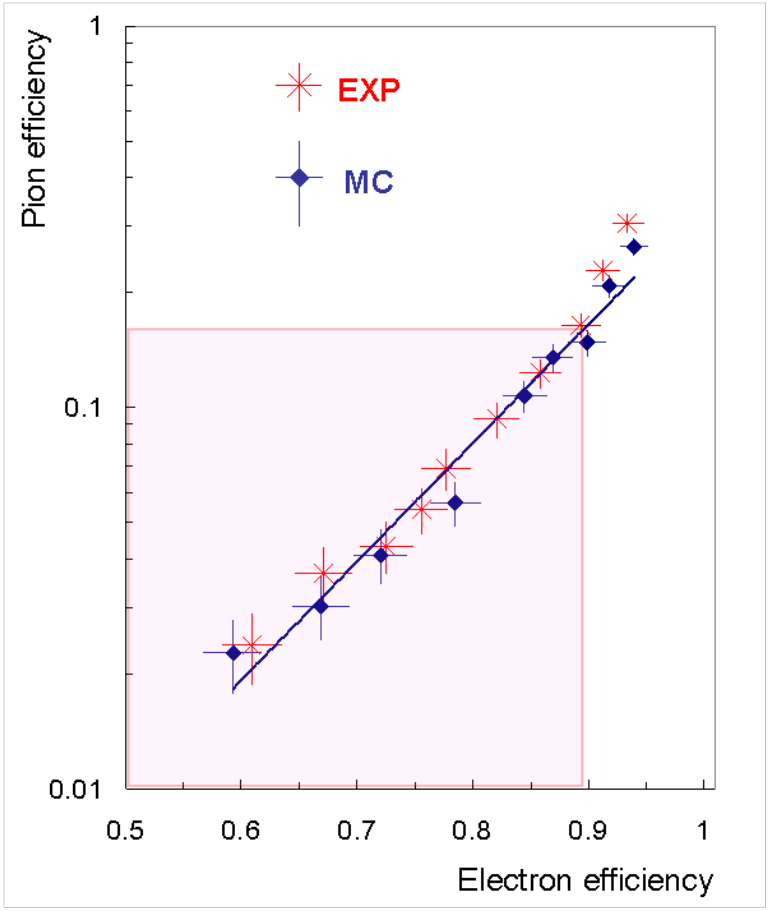
Total energy distribution



Comparison EXP data and MC





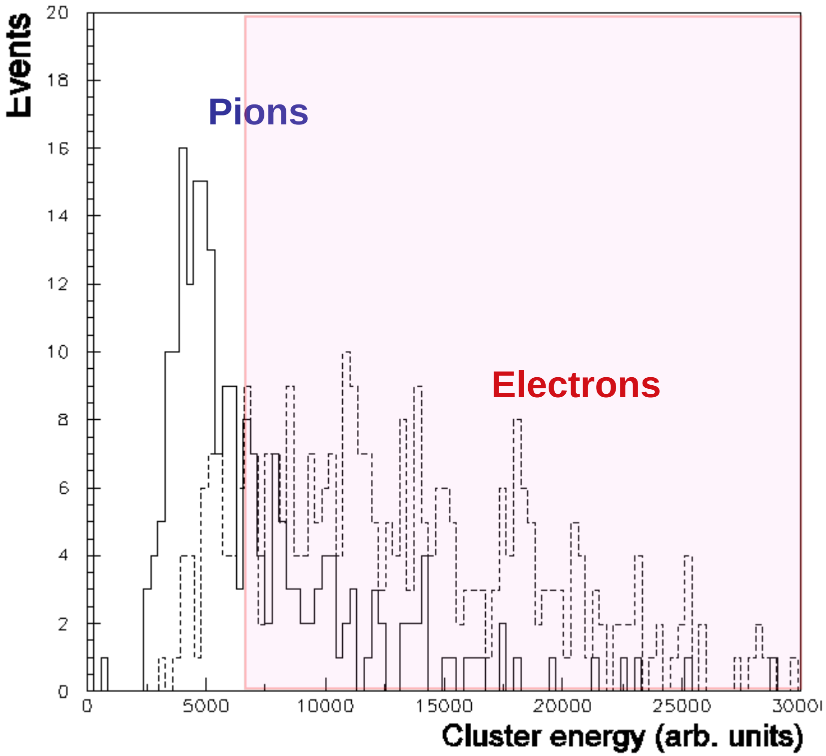


Pion registration efficiency as a function of electron efficiency.

For 90% electron efficiency pion rejection factor is **~7** for the total energy method.

Particle Identification: Cluster counting technique.

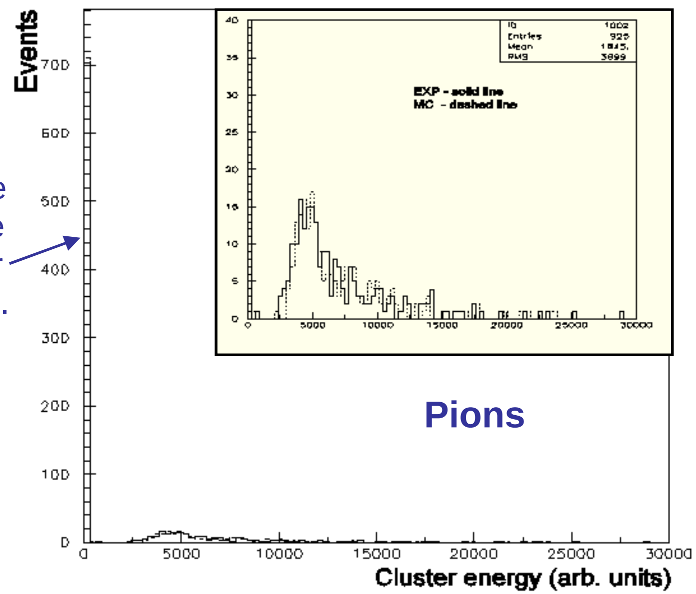
Cluster energy spectrums.



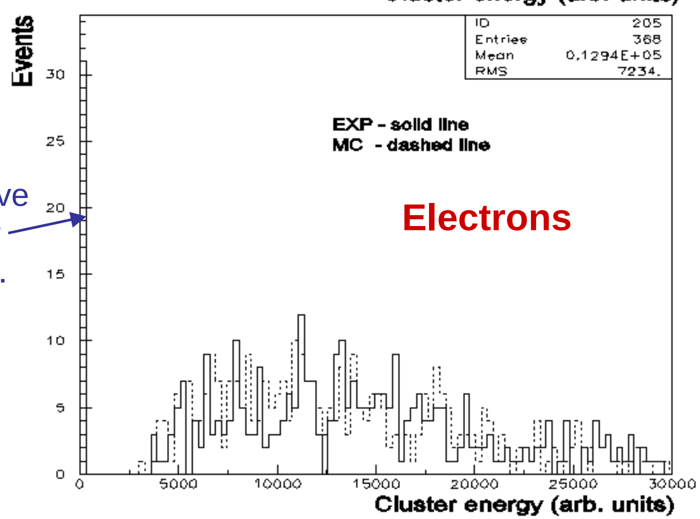
Energy distribution of the clusters have a different character for electrons and pions.

Comparison EXP data and MC

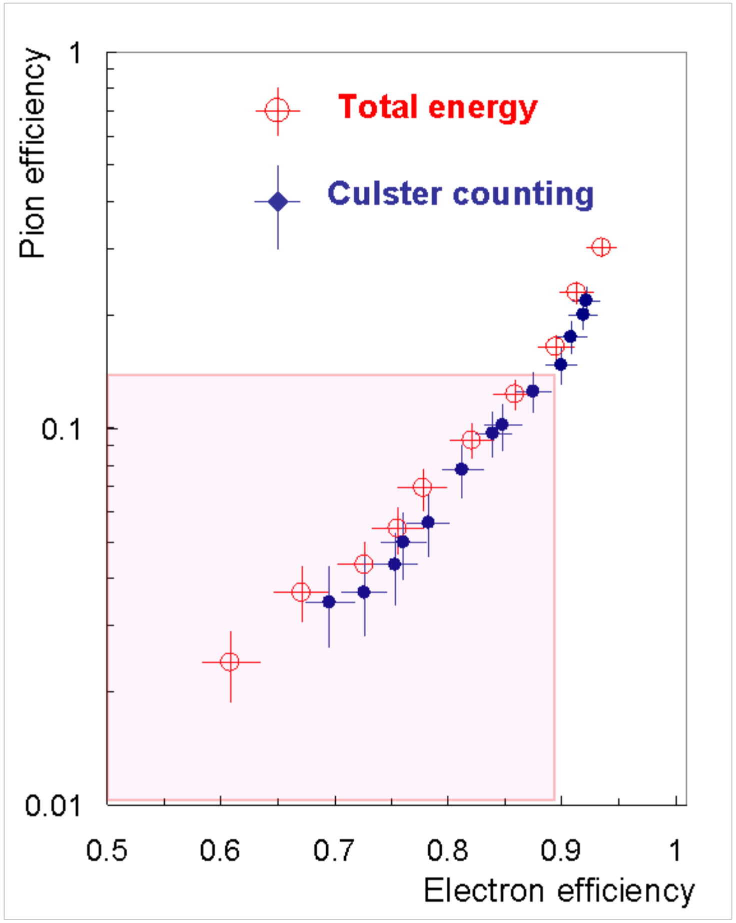
Most of the pions have NO cluster candidates.



Some electrons have NO cluster candidates.

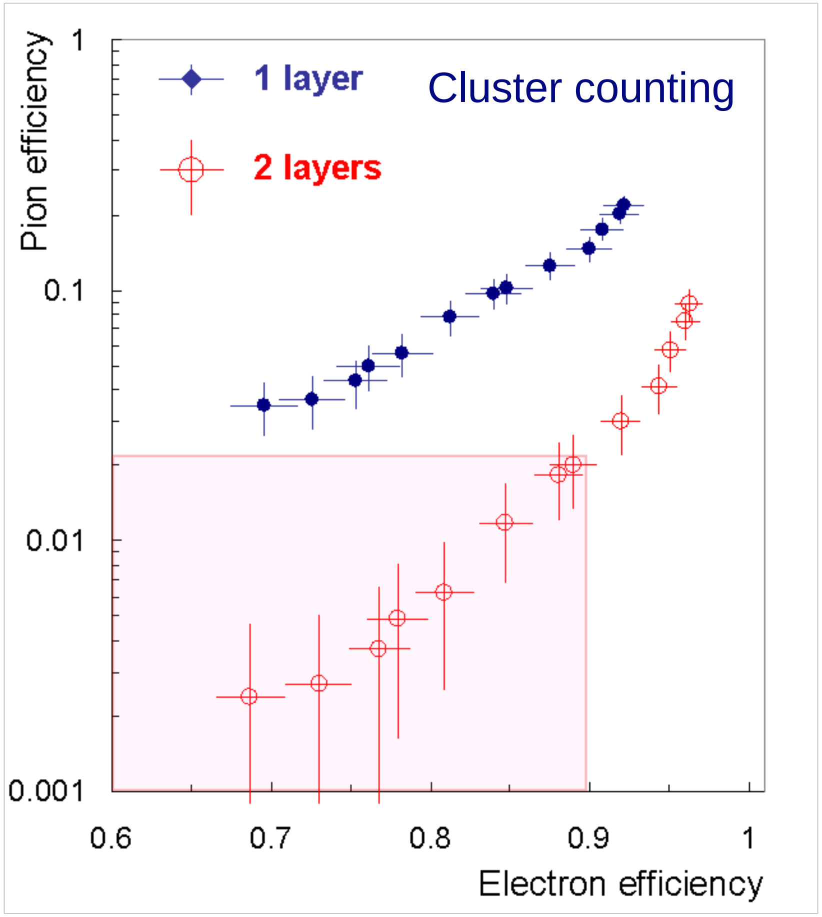


Particle Identification: Electron/Pion separation efficiency



Pion registration efficiency as a function of electron efficiency for the total energy method and Cluster counting method.

Cluster counting method has a bit larger rejection power. For 90% electron efficiency pion rejection factor is **~8**.

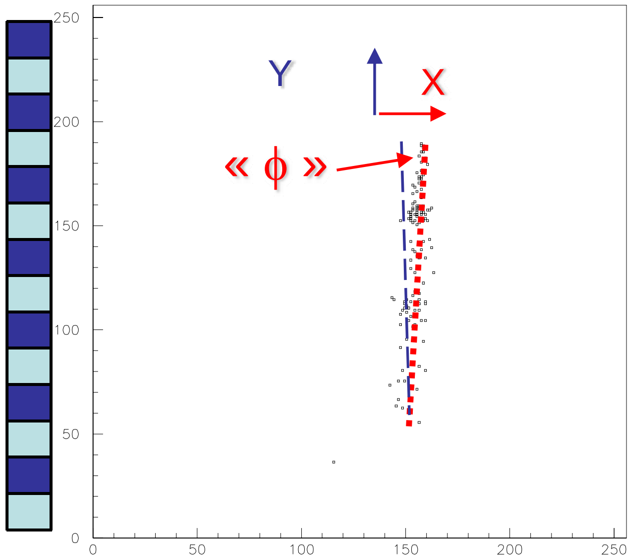


Pion registration efficiency as a function of electron efficiency for 1 and 2 layers of the detector. Cluster counting method.

TRD with two detector layers (total thickness ~ 40 cm) allows to achieve rejection factor of **~ 50** for 90% electron efficiency.

Tacking.

Technique used for the tacking property studies.



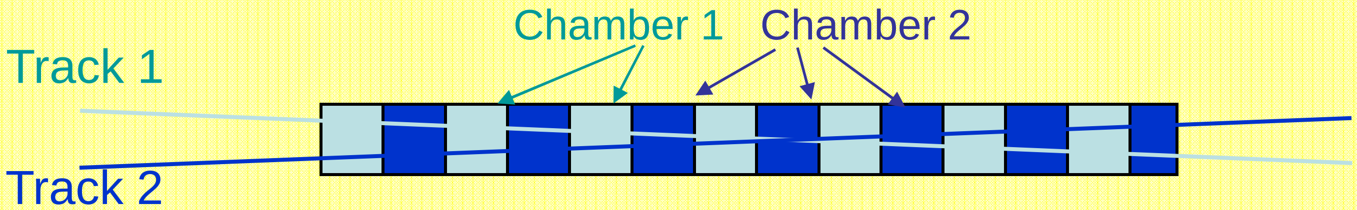
How well we understand the results?
The answer is in MC simulations which use the same technique.

Reminder:
Diffusion coefficient and threshold in MC were chosen to satisfy a track widths and number of fired pixels observed in test beam.

Only tack projection to the pixel plane is used (no time information taken into account).

What we can measure with the beam without reference detector?

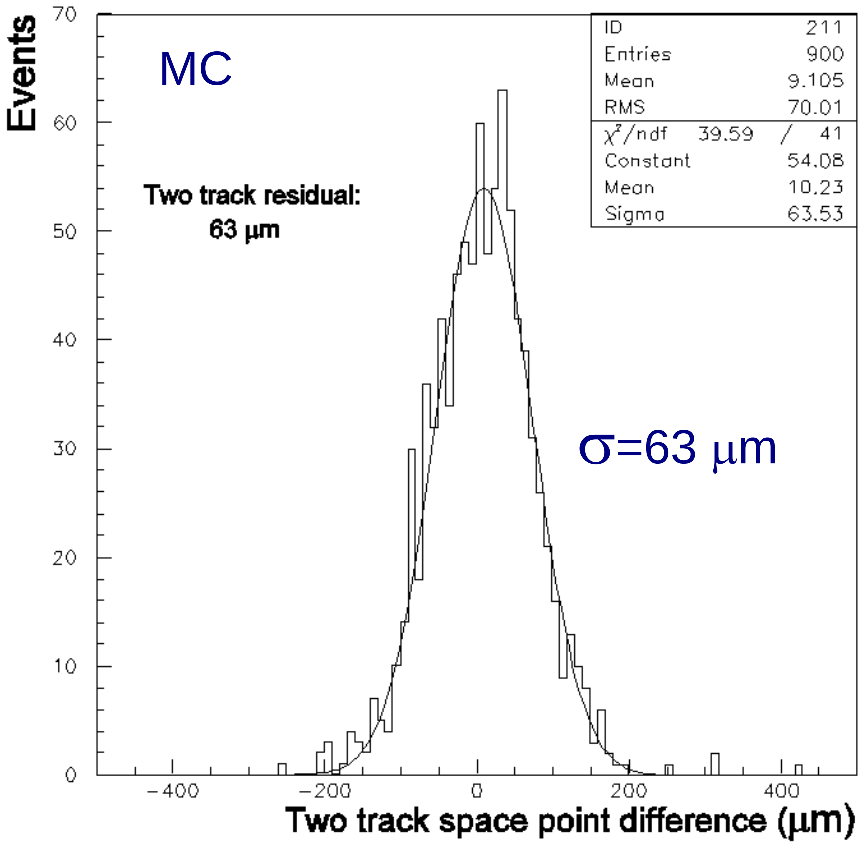
Represent the chamber as two independent interleaved units and measure parameters of two "tracks" (pseudo-tracks) reconstructed independently!

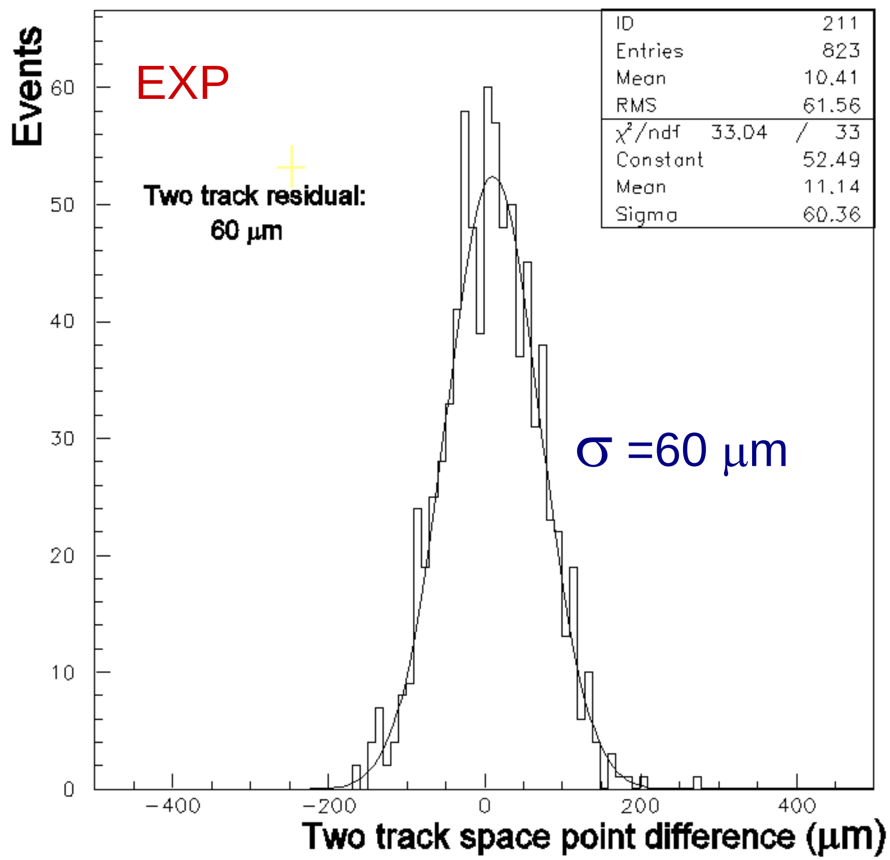


A real resolution is about ½ of the measured one with this method.

Tracking: Space point accuracy (X).

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



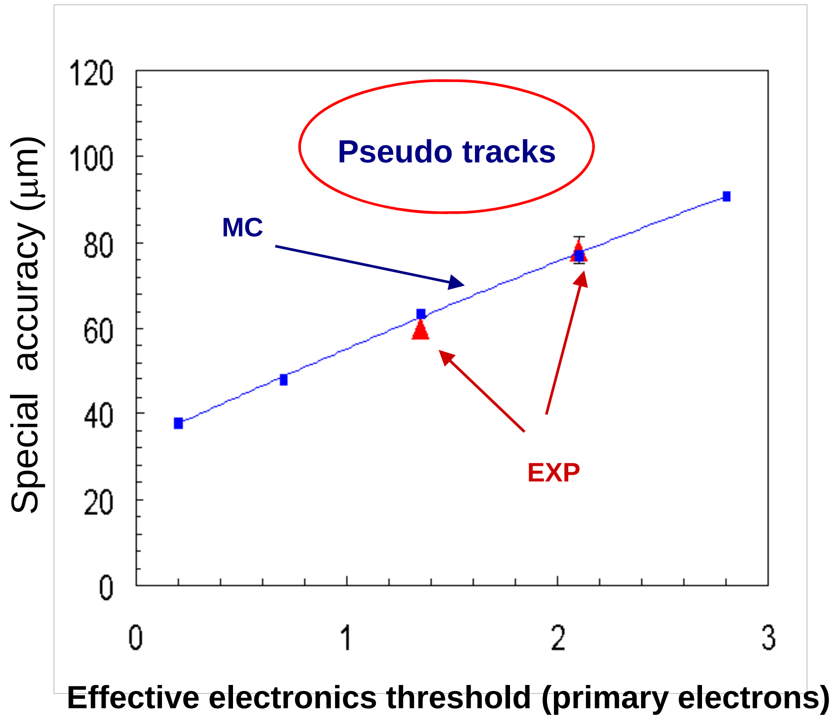


Difference between reconstructed space points for two pseudo tracks.

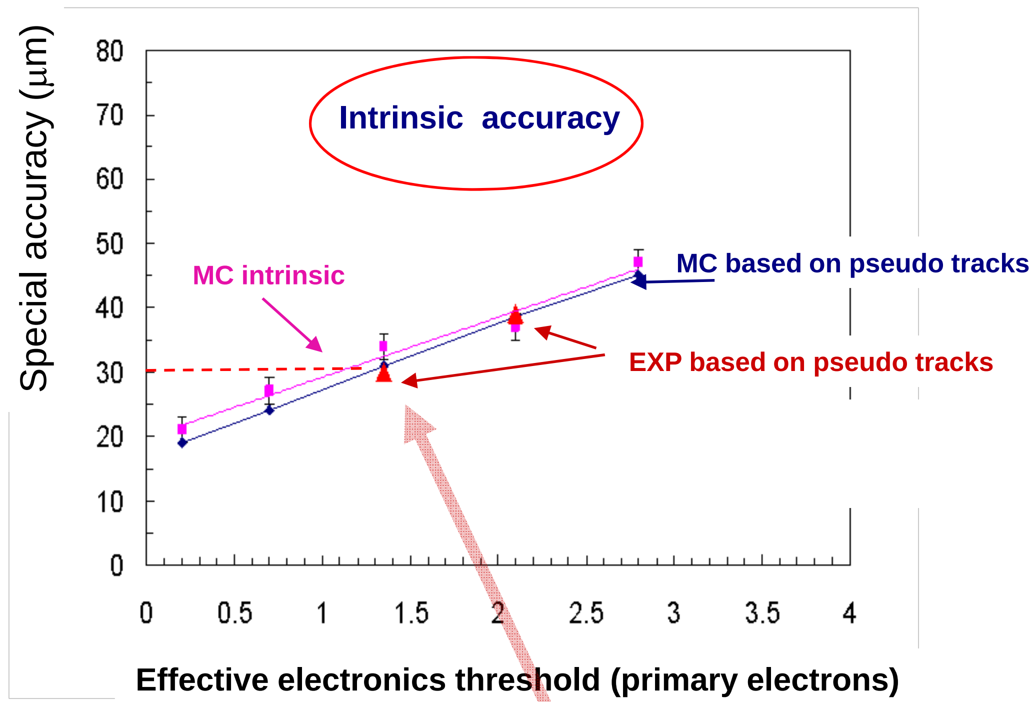
Direction across the beam (X)

Tracking: Space point accuracy.

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



Residual of the difference between the reconstructed space points for two pseudo tracks as a function of threshold (MC and EXP).

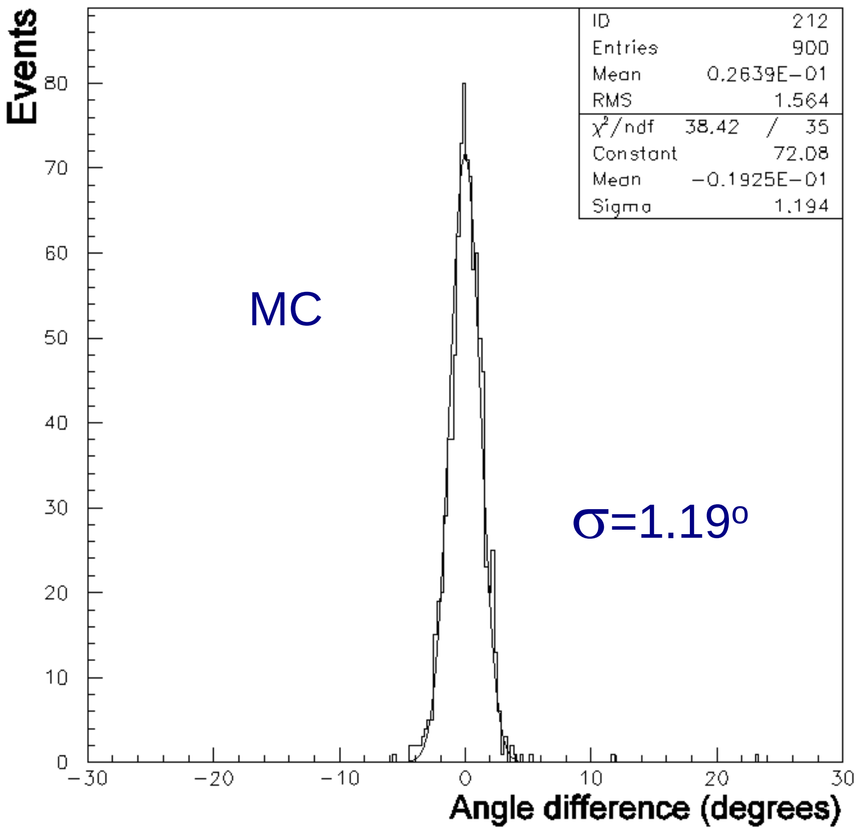


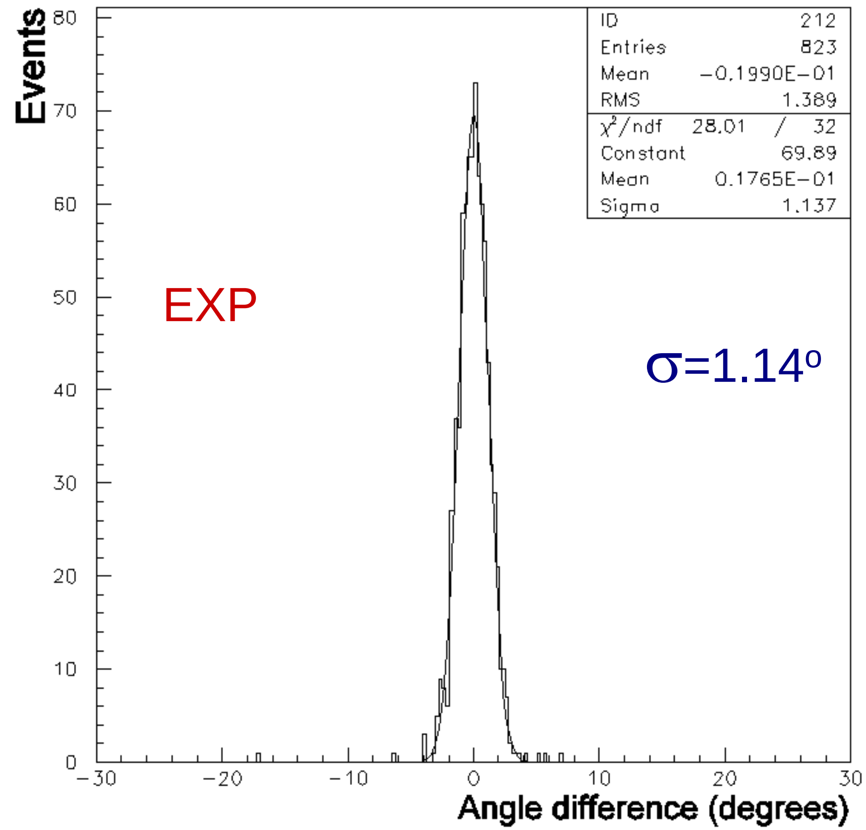
Intrinsic special accuracy of the gas pixel detector (MC and EXP).

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

Tracking: Angular resolution. « ϕ »

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



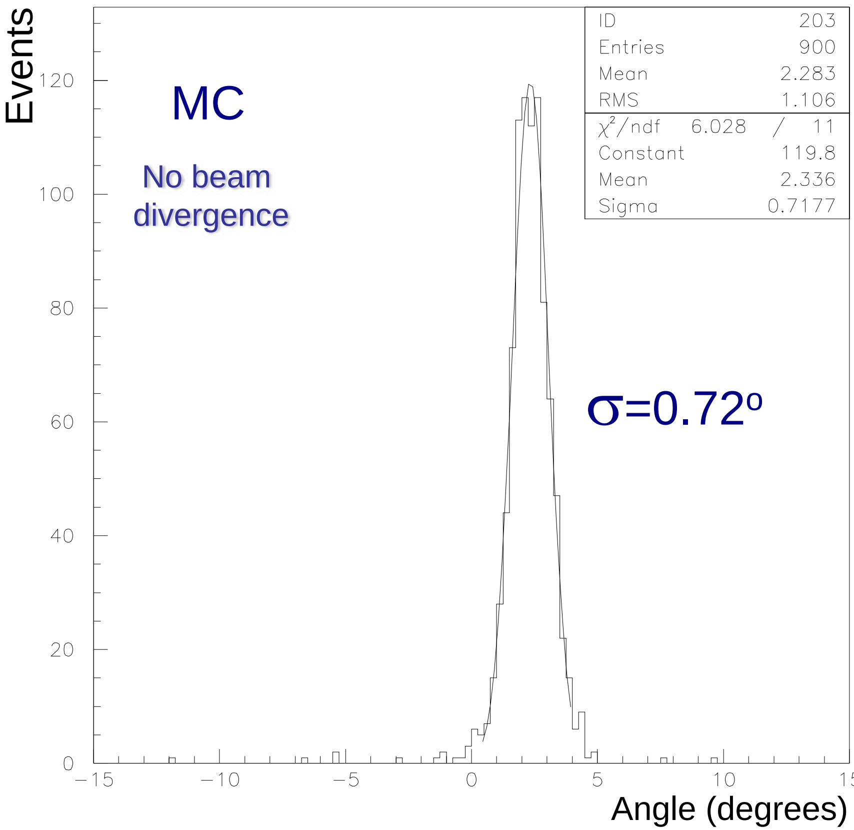


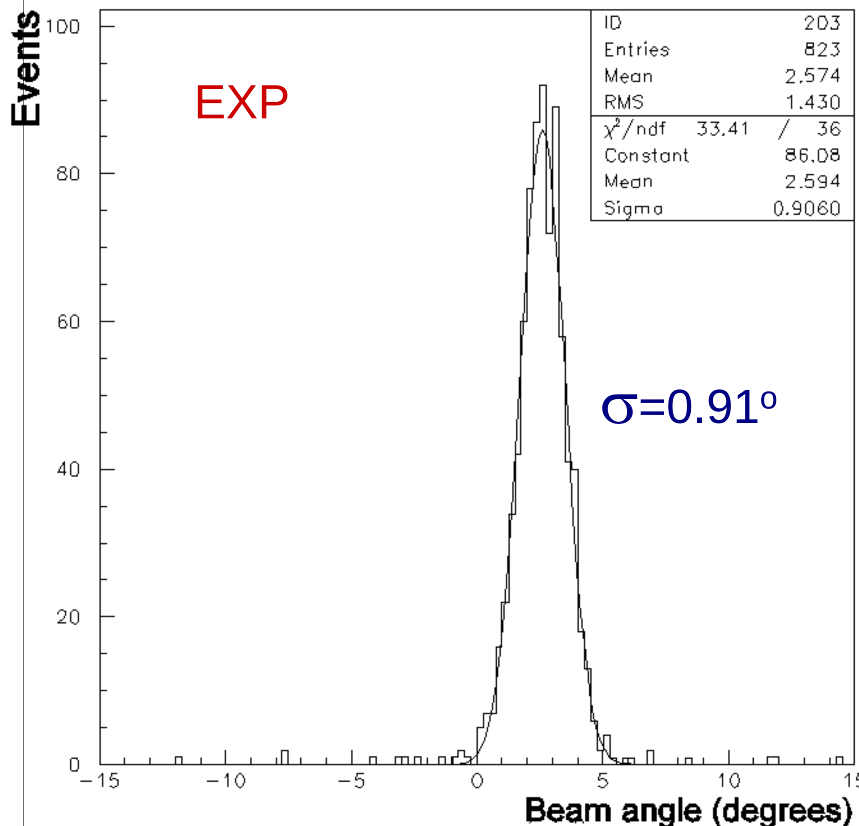
Difference between reconstructed angles for two pseudo tracks.

Tracking: Angular resolution. Beam angle

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

Angular distribution of the particle beam



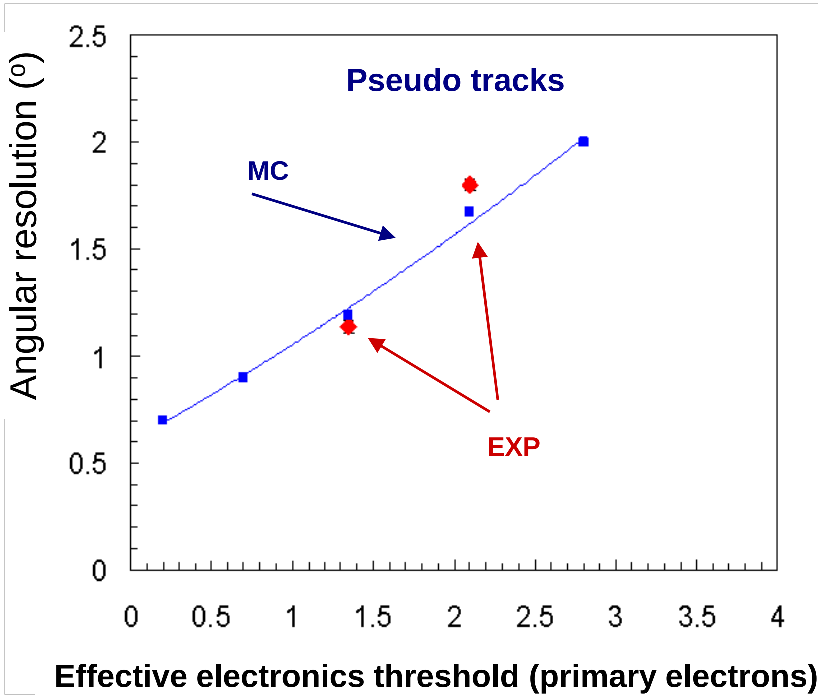


Beam angle reconstruction accuracy: MC and EXP. Full track.

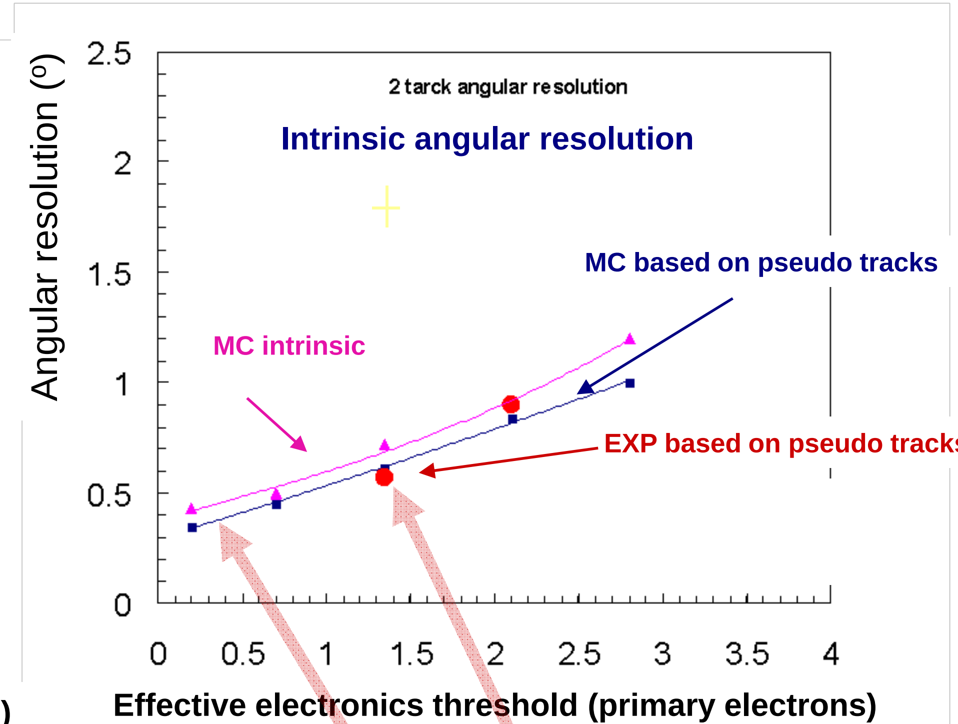
Experimental angular distribution includes the beam divergence

Tracking: Angular resolution. « ϕ »

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



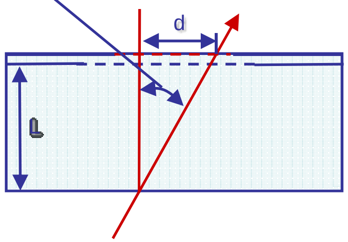
Residual of the difference between the reconstructed track angles for two pseudo tracks as a function of the threshold. (MC and EXP).



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

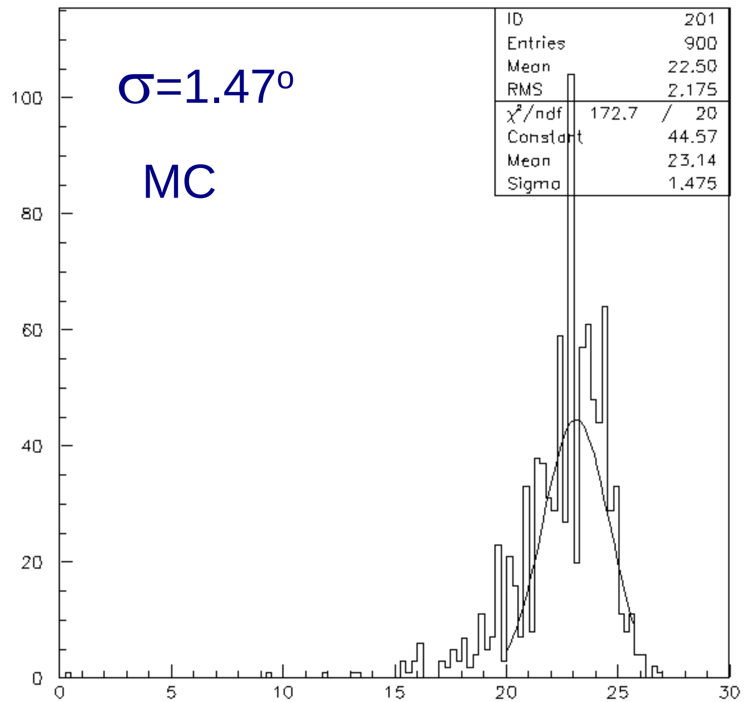
The angular resolution achieved in the test beam is **0.57º**.
It can be improved but it would be very **difficult to get below 0.3º**.

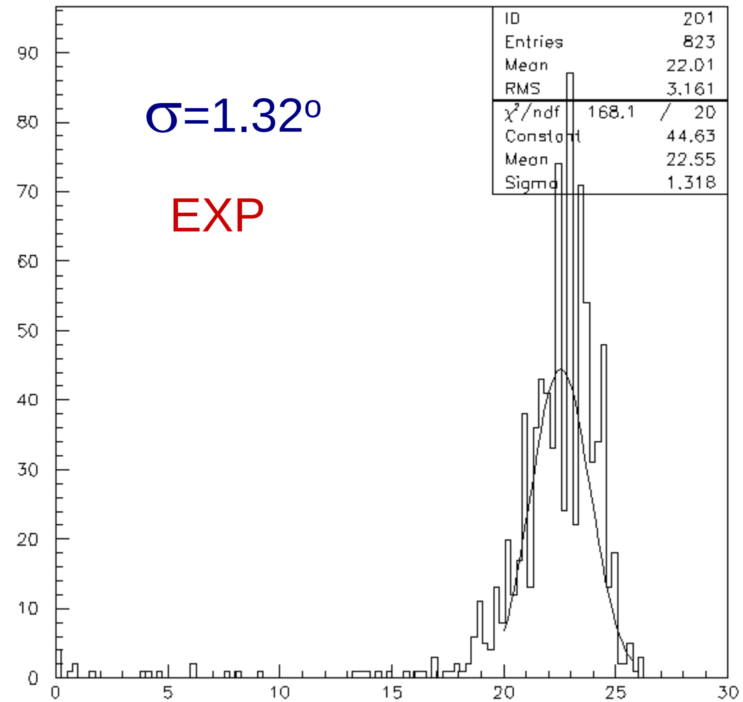
Tracking: Angular resolution. « η »



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

No time information used because of slow signal rise.
Track projection.



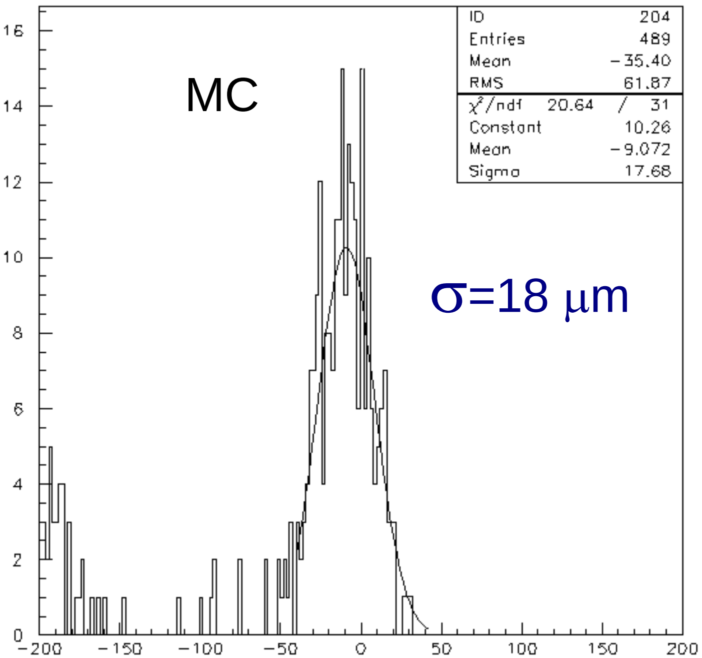


η – angle reconstruction accuracy

Tracking (Z - and η– measurements)

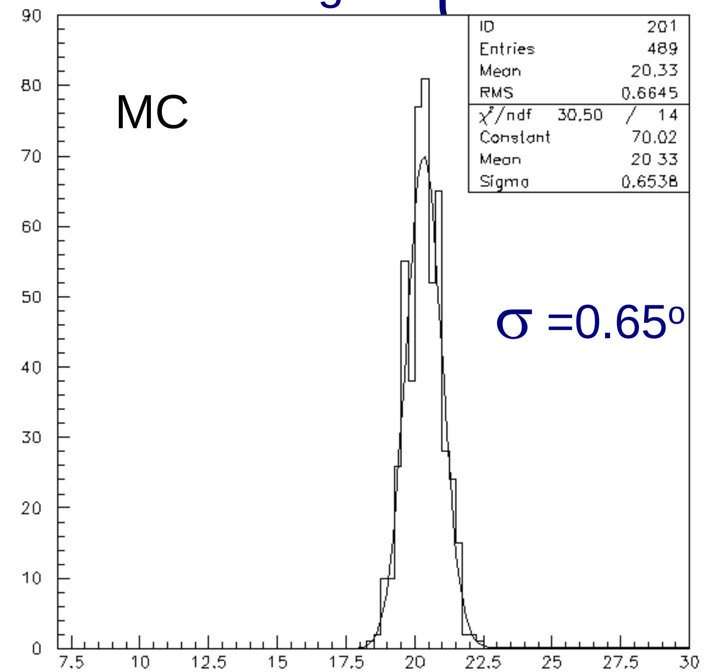
The best want can be achieved for the threshold of 0.5 el
and diffusion ½ of what was in the test beam is.

Space point in Z direction (Y)



Difference between real and reconstructed space point along the track.

Angle η

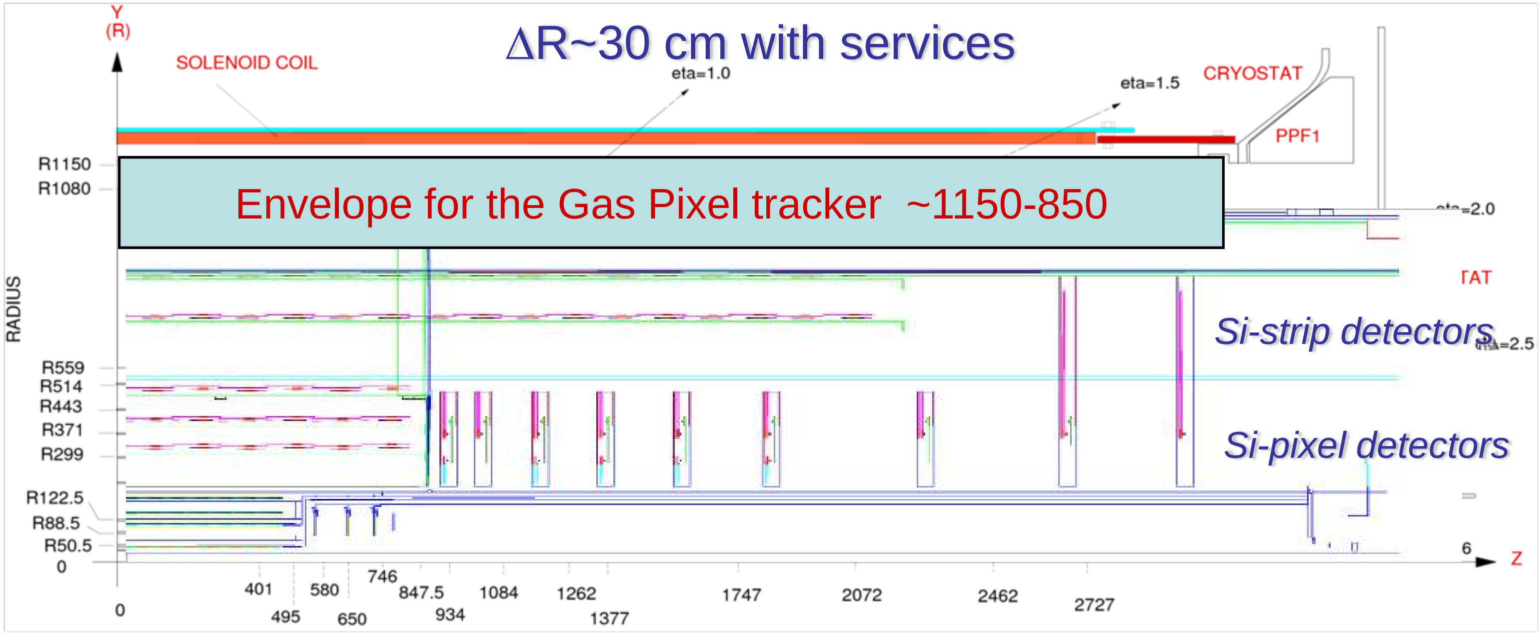


Difference between real and reconstructed angle of the track.

Measurement accuracy of these parameters very much depend on η*!*

GridPixel Tracker for the ATLAS upgrade at sLHC:

Possible layout.



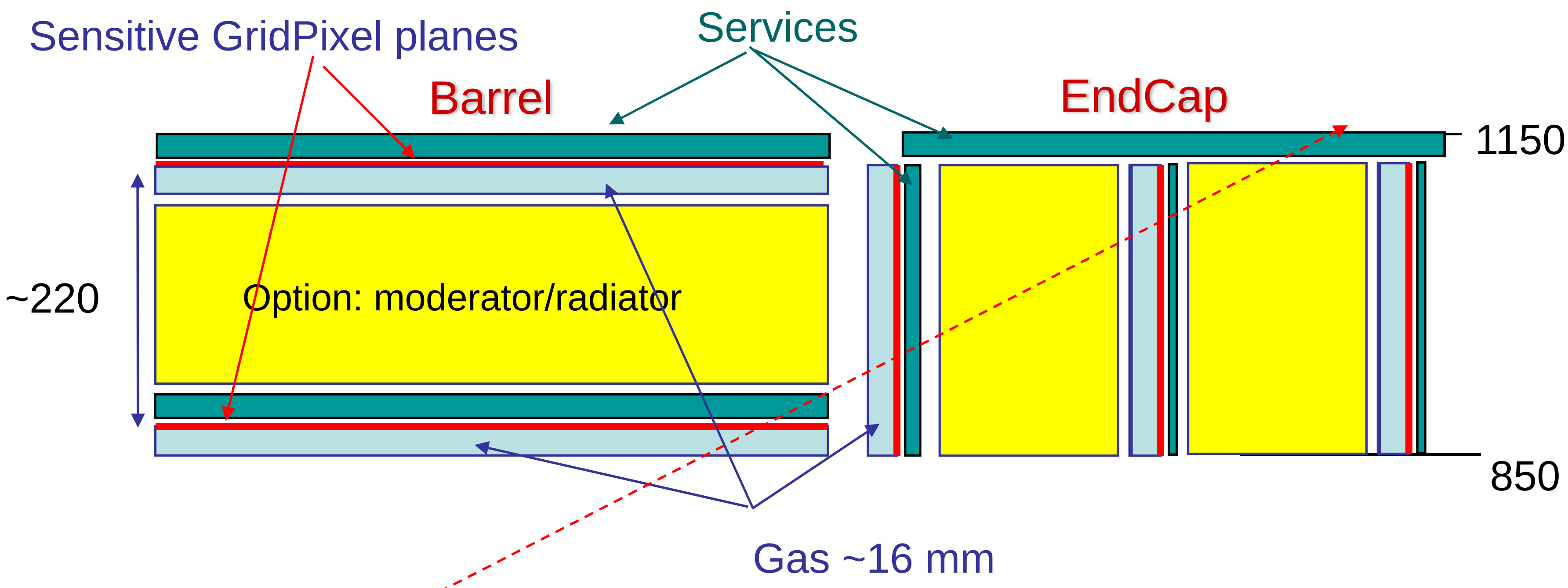
Operation conditions for GridPixel Tracker:

1. Bunch spacing	50 ns
2. Total drift time (depends on the gas)	~200-300 ns
3. Number of bunches overlapped	8-12
4. Particle density at the outer radii	~ 2 MHz/cm^2
5. Occupancy in one bunch	~0.1 per cm^2
6. Effective occupancy	~0.6 per cm^2

} at R=90 cm (items 4–6)

Still there might be uncertainties

GridPixel Tracker: Possible layout.



Two sensitive layers separated by ~ 220 mm.

As an option: dense TR radiator. It can serve a moderator function as well.

With TR we have additional PID function:

e and μ identification with γ > 2000

Might be important for:

- *Long leaving heavy particles/muons separation,*
- *Electron/Photon L1 trigger*
- **BUT** reduces an accuracy of the track parameter measurements.

GridPixel Tracker: Operation in multi particle environment.

Track projection on the pixel plane

On the picture the occupancy Is 4 particles per cm^2

Color code reflects hit arrival time

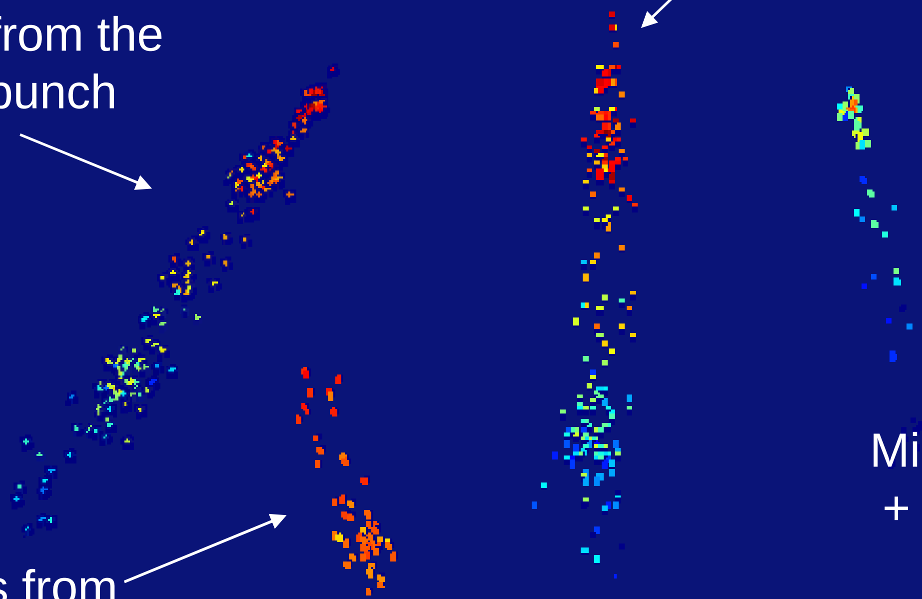
Expected occupancy is 0.6 particles per cm^2

High P_T track

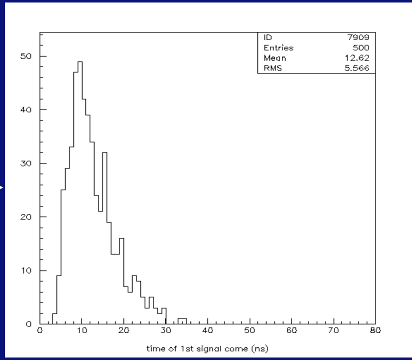
Min bias from the same bunch

Min bias from + 2 bunches

Min bias from - 2 bunches



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.

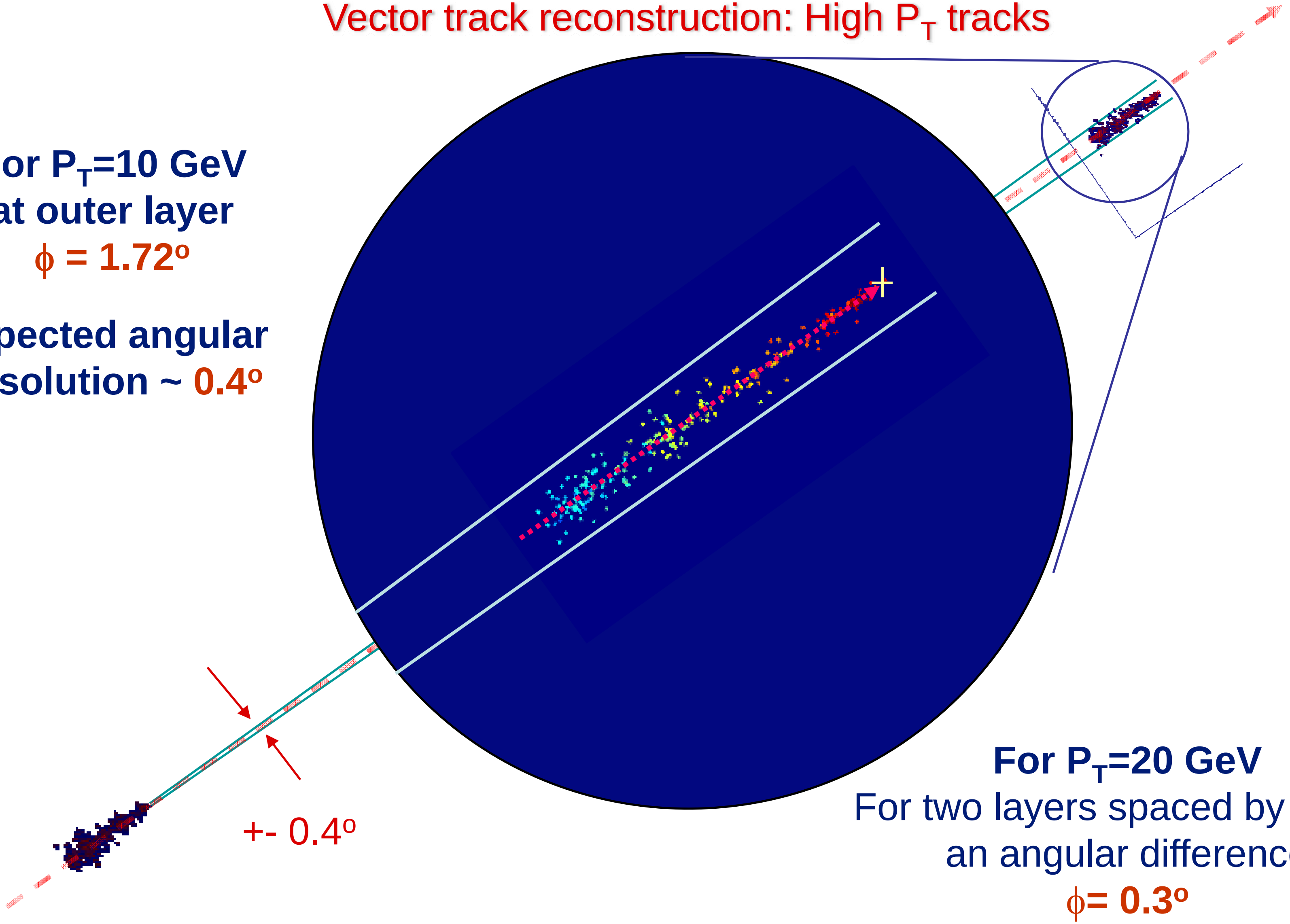
GridPixel Tracker: Pattern recognition.

Pattern recognition with two layers of the GasPix Detector.

Vector track reconstruction: High P_T tracks

For P_T=10 GeV
at outer layer
ϕ = 1.72º

Expected angular resolution ~ 0.4º

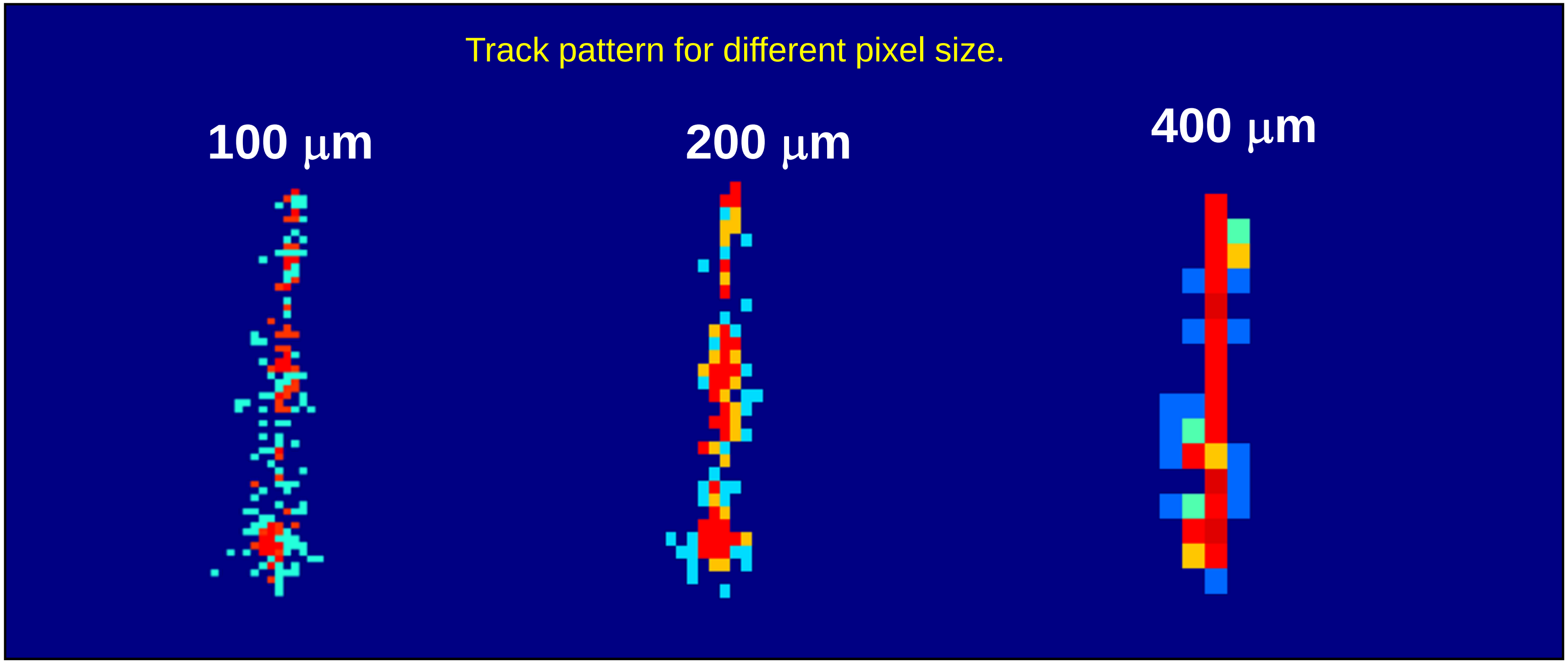


For P_T=20 GeV
For two layers spaced by 20 cm
an angular difference
ϕ= 0.3º
That defines the corridor
for the partner search.

GridPixel Tracker: Pixel size.

Size of the Pixel is a critical parameter which defines detector performance, number of channels and number of electronics devices placed under each pixel.

Track pattern for different pixel sizes



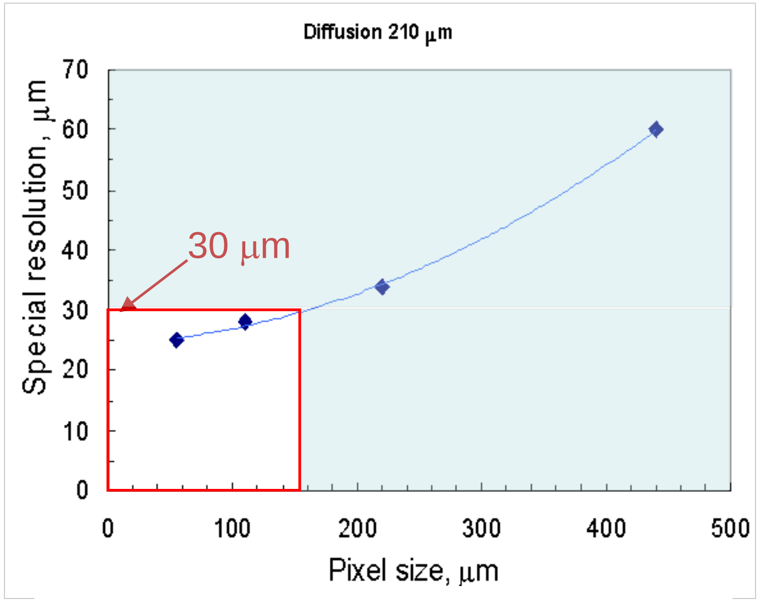
Realistic diffusion coefficient of 210 $\mu m/cm^{1/2}$ was taken in the simulations

GridPixel Tracker: Pixel size.

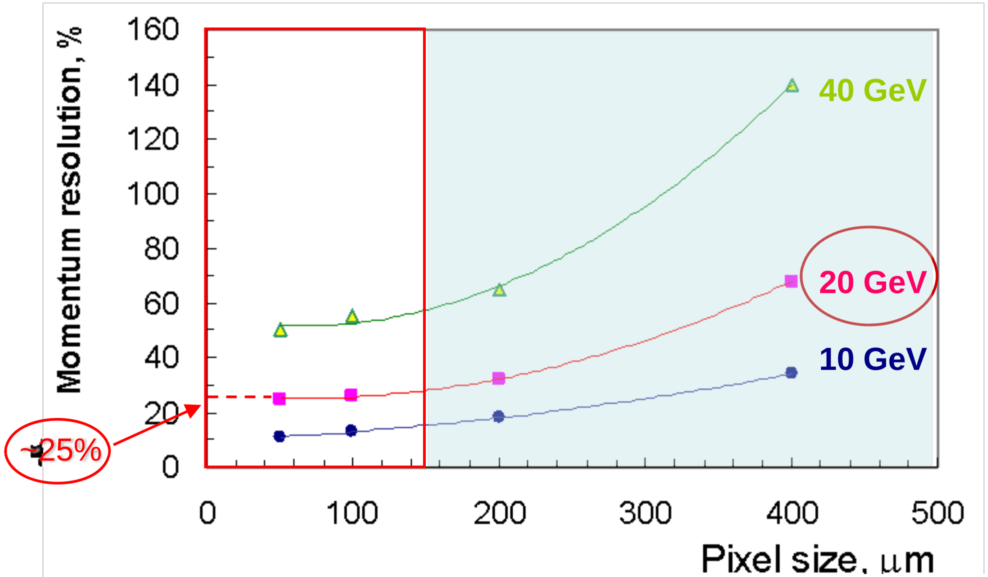
Coordinate and momentum measurements

For one layer of the gas pixel detector situated at R=100 cm

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



Space point accuracy as a function of the pixel size

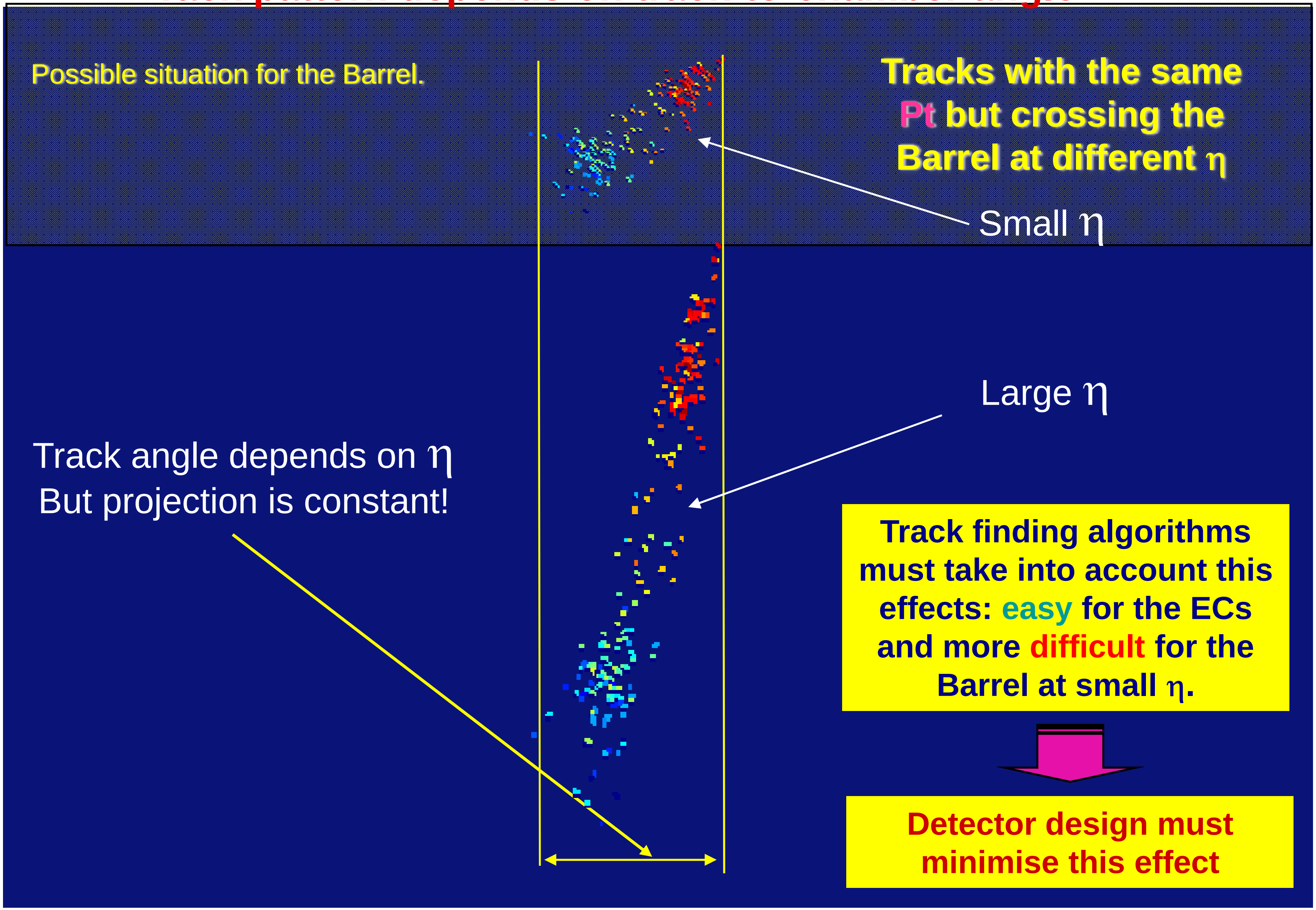


Momentum resolution as a function of the pixel size for particles with P_T= 10,20 and 40 GeV.

- *Maximum pixels size can be chosen ~ 150 µm without significant deterioration of the detector accuracy.*
- *Realistic space point measurement accuracy ~ 30 µm*
- *Realistic P_T cut is ~ 20 GeV*

GridPixel Tracker: η dependance.

Tack pattern depends on track-to-chamber angle.



Track finding algorithms must take into account this effects: easy for the ECs and more difficult for the Barrel at small η.

Detector design must minimise this effect

L1 Trigger

- A very promising feature of the Inner Detector.
- It is supposed to be a complementary tool but it might be critical at certain circumstances.

A part of other issues to be resolved for this detector
a compression of the information **is one of the main problems.**
This require data processing at the FE level.

L 1 trigger might be an organic result of this processing

Maximum electronics devises under one pixel area:

- **Maximum pixel size (150 x 250 mm^2).**
- **3D FE electronics read out.**

When we say high Pt L1 track trigger what rate we are talking about?

At Pt>20GeV L1 track trigger rate is 720 kHz

What else?

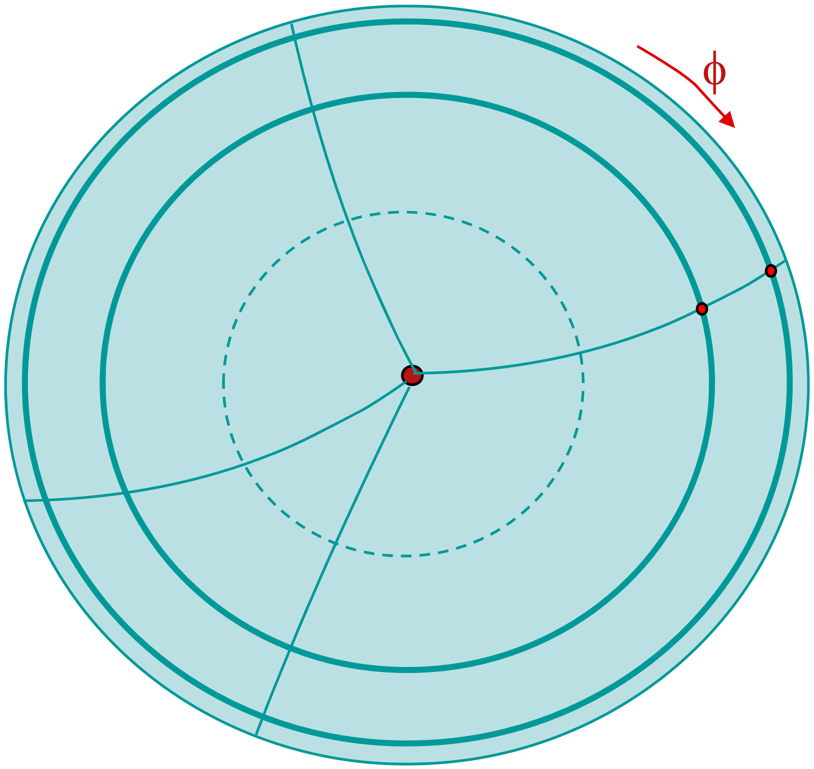
- Combination with L1 Calo RoI and muon system track segments.
- Combination of the track segments from 2 GasPixel Layers
- Single/Multi high Pt track events?

L1 trigger

If gas pixel Pixel L1 exists then a fast L1.5 trigger might be a natural step

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 level

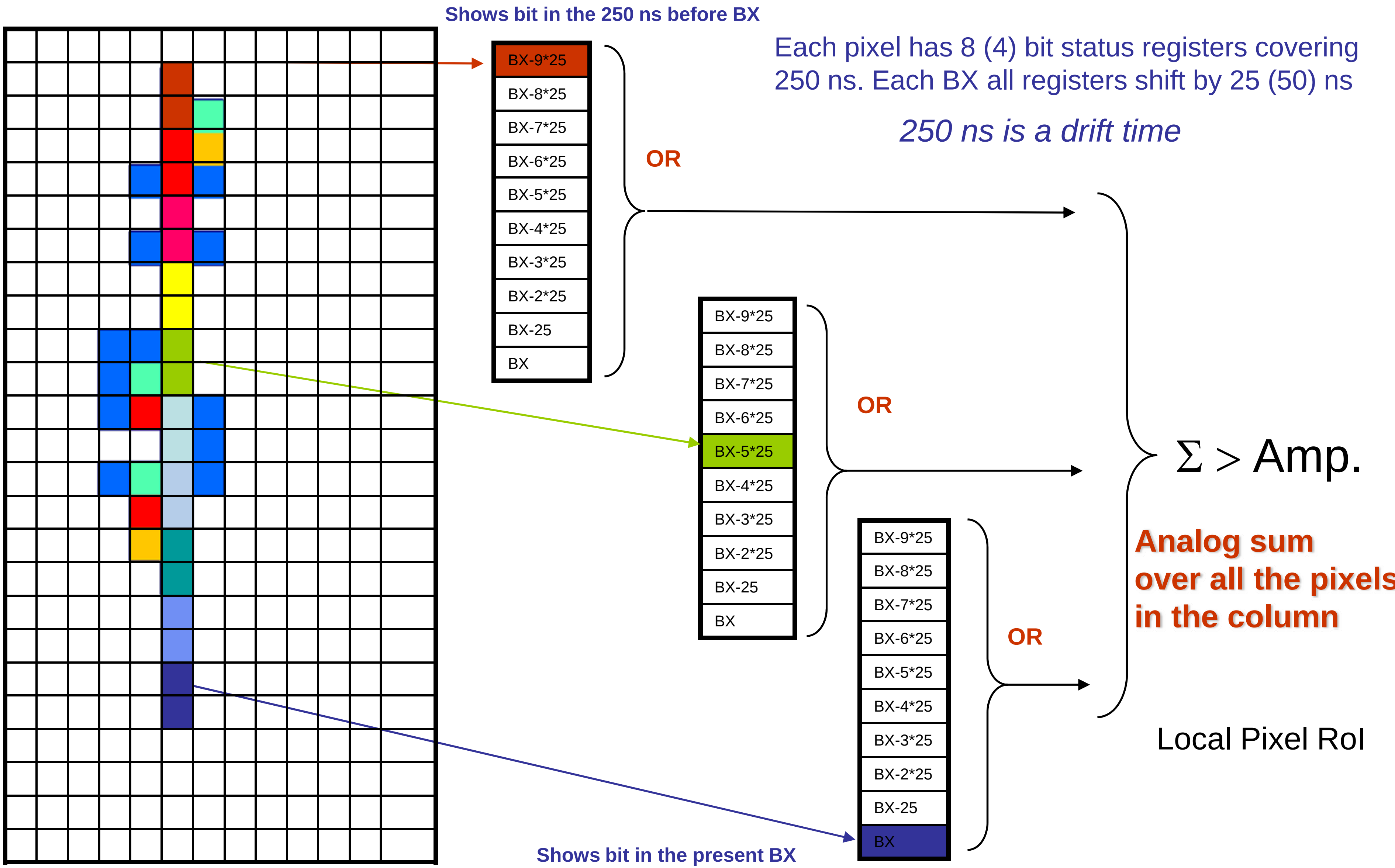
Beam interaction point must be known with accuracy better than 100 μm

Some ideas of the Gas pixel L1 trigger organization:

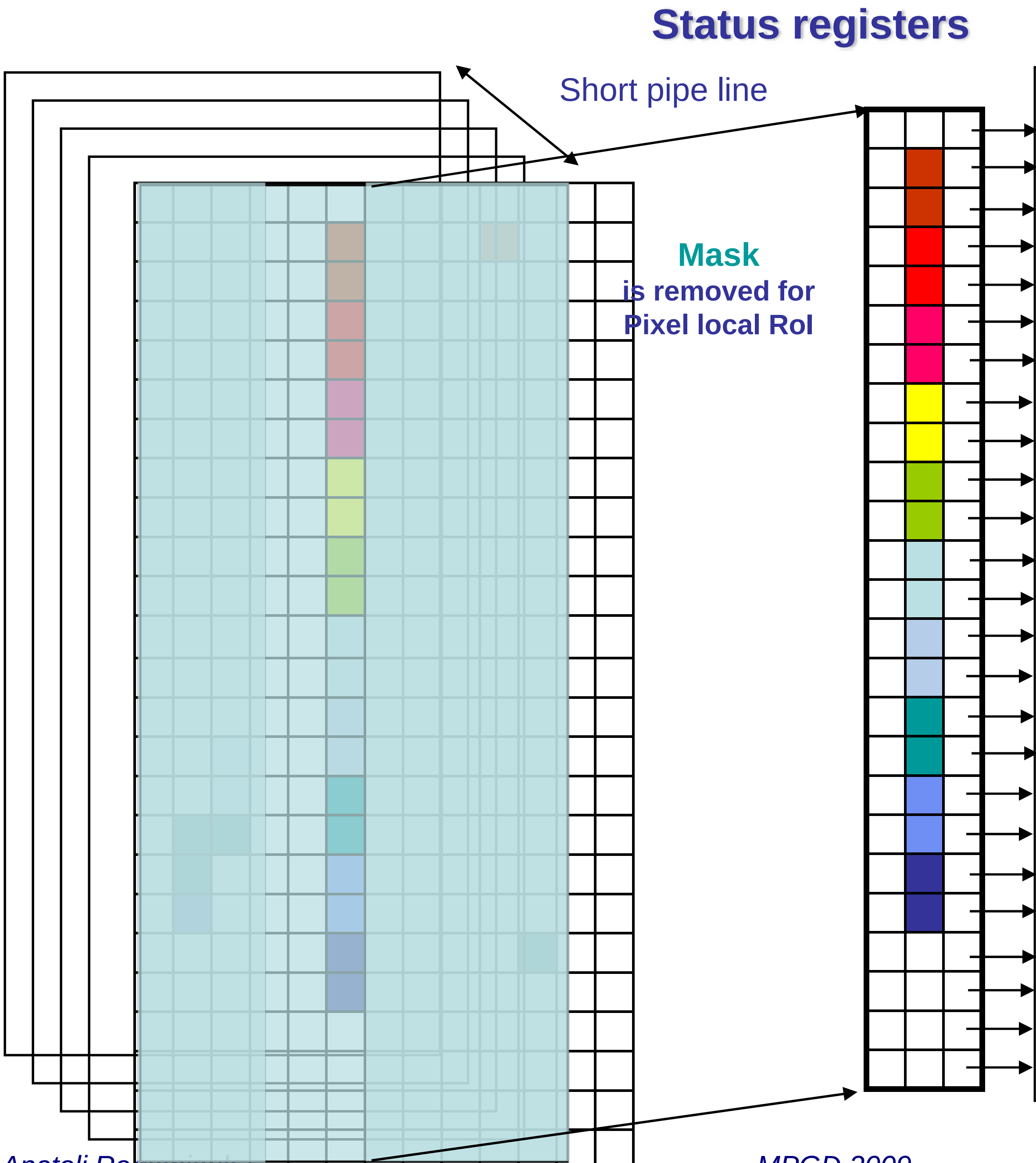
Status registers

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



Some ideas of the Gas pixel L1 trigger organization



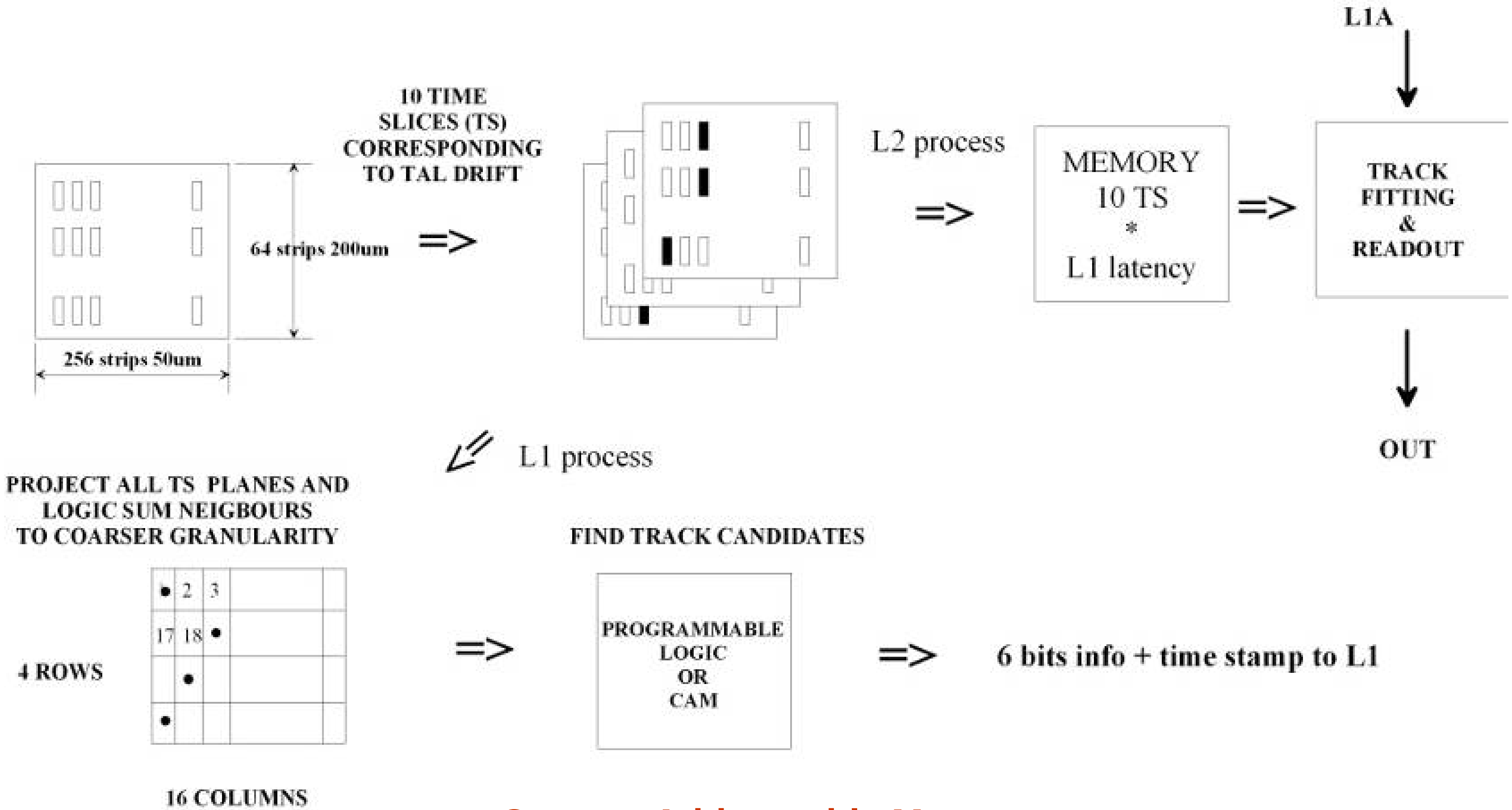
L1 trigger

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:

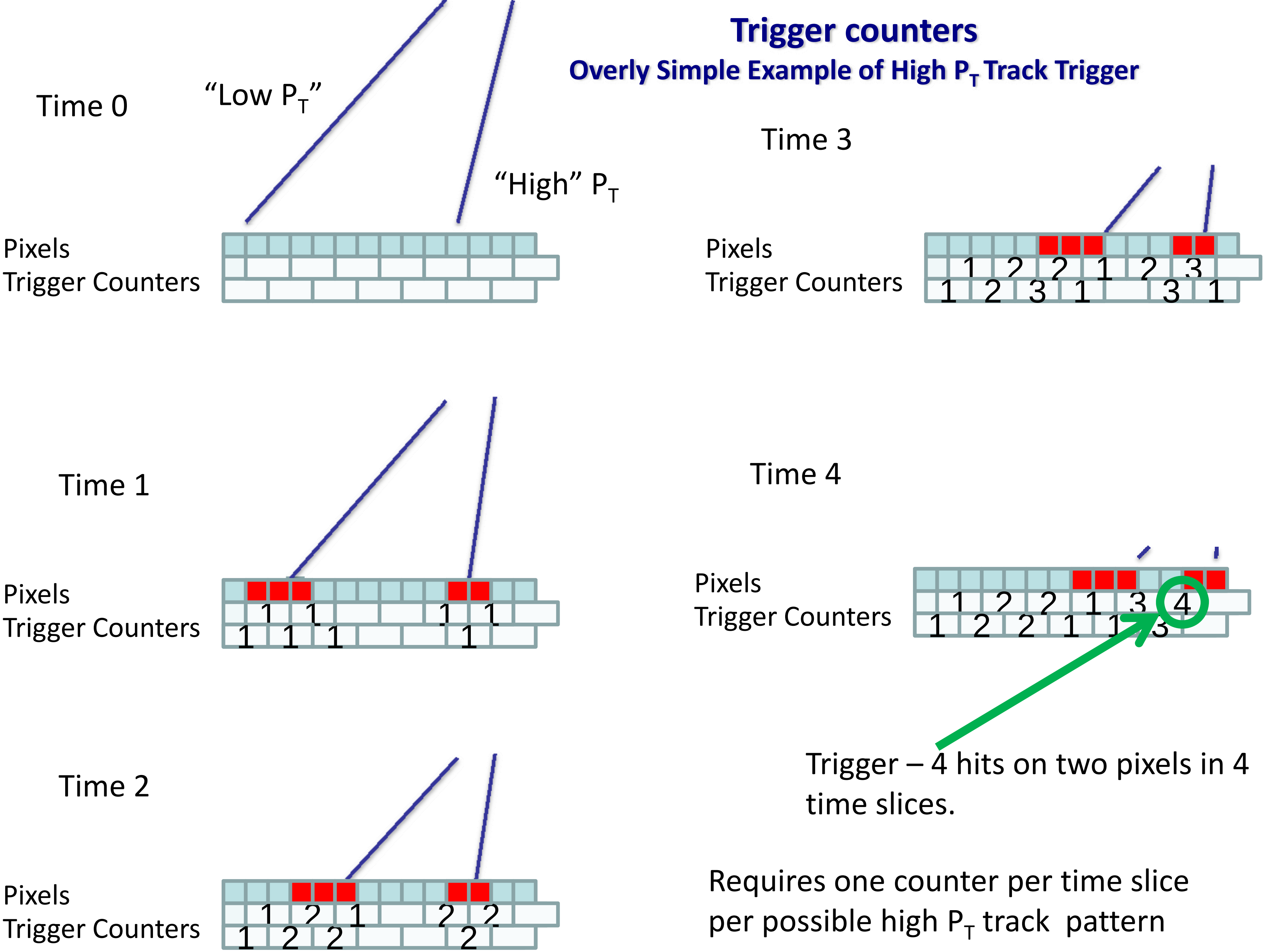
Look-up tables



Content Addressable Memory
to search for predefined patterns

Trigger counters

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:

Test beam results:

- Electron pion separation for 1 layer factor of 7 (2 layers factor of 50)
- No large difference between clusters and total energy methods
- Space point accuracy 30 μm
- Angular resolution 0.57º (~20% for 10 GeV)

GridPixel Tracker (GPT):

- **One layer** of **the GridPixel Tracker** is able to provide:
  - space point accuracy of **~30 μm**
  - momentum resolution of **~25%** for P_T=20 GeV.
- Operation of this detector requires the data preprocessing at the F-E side which makes natural a realization of the L1 track trigger.
- Even 20 GeV cut for the track segments would reduce muon trigger rate at least by one order of magnitude.
- Combining two L1 track segments from two layers allows to organize post L1 trigger for the high PT track segments => ~10-20% for 100 GeV.
- A powerful patter recognition using vector tracking of the **GPT** will drastically reduce a data processing time at L2, HLT and off-line event reconstruction.
- Combination with EM-calorimeter triggers => allows to implement E/P cut during L1 processing => E/Gamma P_T threshold is back to that used at the nominal LHC luminosity.
- Change P_T cut from **10 GeV => 20 GeV** leads to reduction of a trigger rate by factor of 100.