A Silicon Pixels Layers Active Stopping Hodoscope

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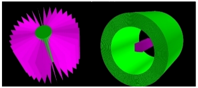
LPNHE Paris

Workshop on silicon detectors for g-2/EDM/COMET experiments



Paris, 20-21 february 2014

Outline

- Introduction
- An active target : possibility to use Si pixels

→ Ideal case

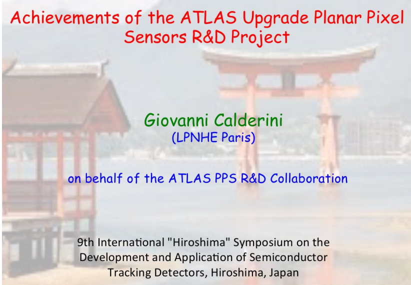
→ Using ATLAS pixels

- Starting simulation studies
- Outlook

Motivations

Motivations for an active target

- Add an additional point to e$^-$ trajectory reconstruction
- Add energy deposition measurement for e$^-$ trajectory reconstruction
- A better background control (beam content)
- Use of pixels developped for ATLAS at LPNHE.



Achievements of the ATLAS Upgrade Planar Pixel Sensors R&D Project

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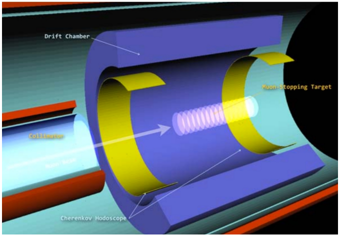
(LPNHE Paris)

on behalf of the ATLAS PPS R&D Collaboration

9th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors, Hiroshima, Japan

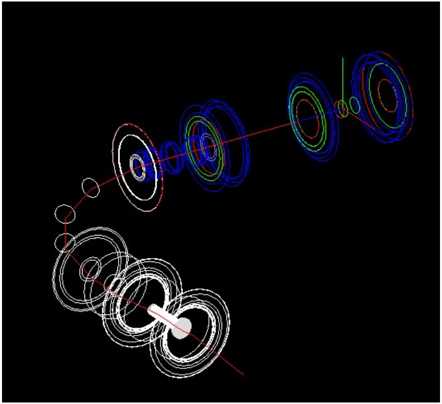
5 september 2013

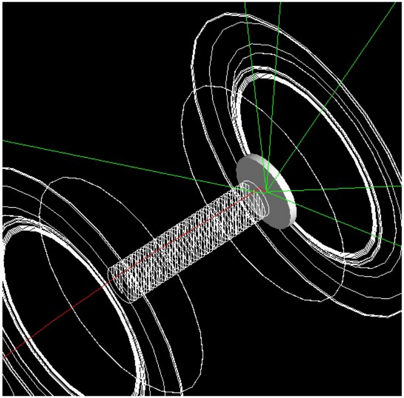


Needs to explore:

- Full beam simulation : particle content, momentum and timing ⇒ pixel occupency rate, · · ·
- Detector simulation : sensors, electronics,
- Simulation of heat transfer : cooling (mechanical support,· · ·)
- Full track reconstruction (and pixels detector optimization) ⇒ quantify the tracking improvement

The stopping target (Al → Si) as from comet_g4 (same soon with ICEDUST)





Beam structure : what the pixels will see

Detection of signals from:

- electrons from muon conversions, decays...
- stopped muons.

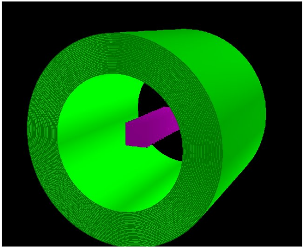
Replace the 17 Al disks with

- 20 cm x 20 cm squares of
- 100μm x 100μm Si pixels
- 300μm thick.

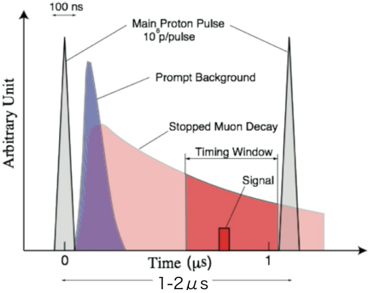
Phase-I basic numbers :

- Using a muon stopping rate of $5.810^{9}\ s^{-1}$ and a stopping efficiency of 0.34
- We have in a pulse $5.810^{9}x1.75110^{-6}/0.34 = 3.10^{4}\ \mu$/bunch arriving on the stopping target.
- Fraction of muon capture $f^{Al}_{cap} = 0.61$
- Among the 10^{4} stopped μ $6.110^{3}\ \mu$ are captured
    - giving 3.910^{3} DIO e^{-}
    - and 0.910^{3} emitted p.

- Si Pixels Layers Active Stopping Hodoscope



- Beam time structure



Beam structure and rates (per pixel per bunch)

- Start the acquisition with a fast trigger just after the first short intense signal (prompt electron, pions, $\cdots$).

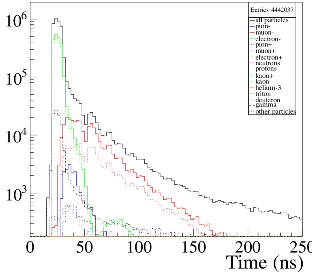
  - Muon occupancy rate : $\simeq 10^{-2}$ μ /pixel/bunch ($\simeq$ 10kHz) (uniform beam hypothesis).

  - Identify pixels with
    - low signal (electrons in timing window, unstopped muons at low time ? + $\cdots$)
    - high signals (stopped muons + ...).

- ... need to estimate the silicon pixels capabilities after the short intense pulse $\Rightarrow$ recovery time (beam tests could help).

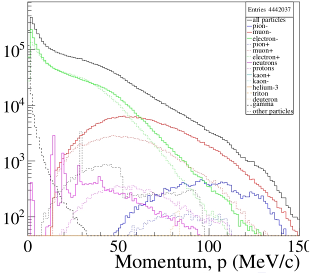
- ... need also a simulation with full beam structure and pixel simulation with SILVACO

- Bunch time structure



  - Green curve : e$^-$ Red curve : μ^-

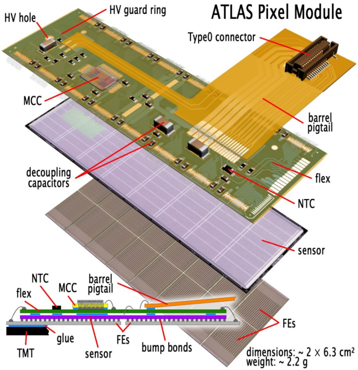
- Momentum structure



A more realistic view

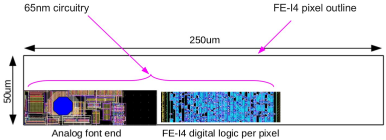
- Typical current pixel size :
  - ATLAS Typical pixel size 50μm x 400 μm
  - Thickness : 280 μm
- ATLAS occupancy rate
  - 56 hits cm^{-2} per BX $\simeq 10^{9}$ cm^{-2} s^{-1} (to compare to $\simeq 10^{7}$ cm^{-2} s^{-1} on a pixel layer for COMET)
- ATLAS Readout:
  - Sensor tile (purple) : $\simeq 410^{4}$ pixels on 2 x 6.3 cm^{2}.
  - For a COMET layer : 30 sensors to cover 18 x 20 cm^{2} leading to $\simeq 10^{6}$ pixels
  - Data transfer 40-160 MHz (depending on layer)
  - Hit data: pixel ID + timestamp + ToT (Time over Threshold)
- The FE layer will increase the material budget :
  - decrease the number of layers ?
  - improve the FE layer.

- ATLAS pixels

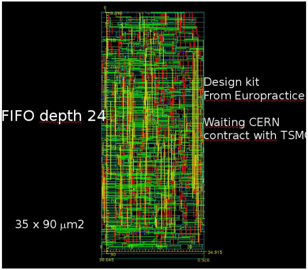


ATLAS chip development (long term · · ·)

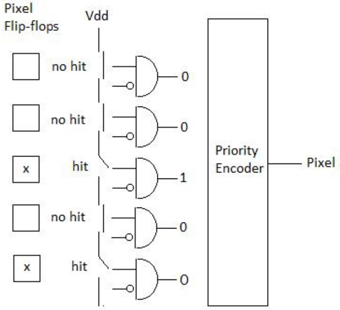
- Towards smaller pixels and FE chips
- New FEI4 readout chip with 50 μm x 250 μm pixels.



- With a tendency to use thinner sensors.
- Use ATLAS pixels developped at LPNHE based on 65 nm FEI4 (layout).



- Timing based pixels sparse scan readout (from J.F. Genat at LPNHE Paris)

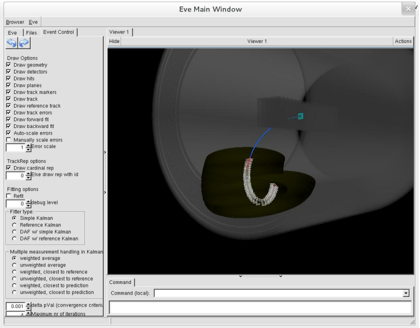


- Fast reading of identified pixels
  - Possibility to define two thresholds : high and low.
  - Efficient with a low occupancy rate.

Track reconstruction: starting preliminary studies with GENFIT

Toy Model (in GENFIT)

- Track (e^{-} trajectory)
  → generated one hit pixel
  → generated hits in "CDC" aera



Draw Options
☑ Draw geometry
☑ Draw detectors
☑ Draw hits
☑ Draw planes
☑ Draw track markers
☑ Draw track
☑ Draw reference track
☑ Draw track errors
☑ Draw forward fit
☑ Draw backward fit
☑ Auto-scale errors
☐ Manually scale errors
1 Error scale

TrackRep options
☑ Draw cardinal rep
0 Else draw rep with id

Fitting options
☐ Refit
0 debug level

Fitter type:
● Simple Kalman
○ Reference Kalman
○ DAF w/ simple Kalman
○ DAF w/ reference Kalman

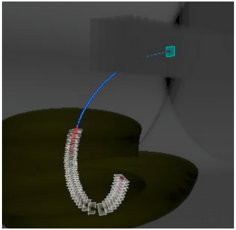
Multiple measurement handling in Kalman
● weighted average
○ unweighted average
○ weighted, closest to reference
○ unweighted, closest to reference
○ weighted, closest to prediction
○ unweighted, closest to prediction

0.001 delta pVal (convergence criteri
4 Maximum nr of iterations

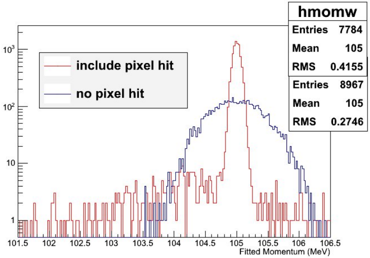
- Fit using GENFIT (Kalman filter)
  → fit only generated hits in "CDC"
  → fit pixel and "CDC" hits

  • No material effect for the moment.

- Reconstructed track



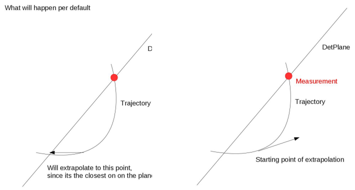
- Momentum resolution improvement



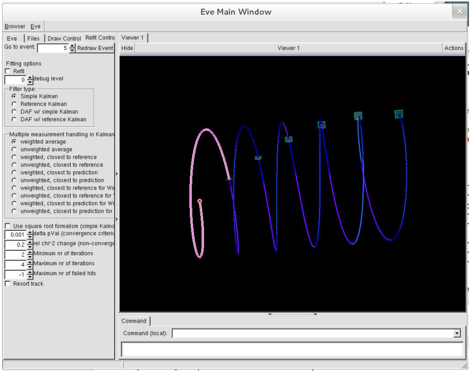
• Next step : use ICEDUST/GENFIT (include multiple scattering, · · · , see extrapolation trajectory effect, · · ·)

Preliminary studies on multi-turn track fitting with GENFIT

- Problematic : Track parameter extrapolation at very long distance :
  → In COMET experiement : track can have multi-turns in CDC
  → method of extrapolation : choice of step distance ? , choice of step direction ?
- In GENFIT For fitting curlers, a few additional things have to be taken into account (cf Johannes Rauch):
  →The hits should be ordered correctly in the track.
  →The propagation direction of the TrackRep should be set to 1 (AbsTrackRep::setPropDir(1)).
  → use finite detector planes.



- Generated Track (e^- trajectory)
  → generated hits at each length l_i
  $l_i = \frac{R}{\sin\theta} \times i \times \Delta\Phi_{\text{Hits}}$
  • in the example below the angle between hit is always $\Delta\Phi_{\text{Hits}} = 340$ degrees.
- Reconstructed track (No material effect for the moment).



Go to event: 5

Fitting options

☐ Refit

0 debug level

Fitter type:

- ● Simple Kalman
- ○ Reference Kalman
- ○ DAF w/ simple Kalman
- ○ DAF w/ reference Kalman

Multiple measurement handling in Kalman

- ● weighted average
- ○ unweighted average
- ○ weighted, closest to reference
- ○ unweighted, closest to reference
- ○ weighted, closest to prediction
- ○ unweighted, closest to prediction
- ○ weighted, closest to reference for Wi
- ○ unweighted, closest to reference for
- ○ weighted, closest to prediction for Wi
- ○ unweighted, closest to prediction for

☐ Use square root formalism (simple Kalma

0.001 delta pVal (convergence criteri

0.2 rel chi^2 change (non-converge

2 Minimum nr of iterations

4 Maximum nr of iterations

-1 Maximum nr of failed hits

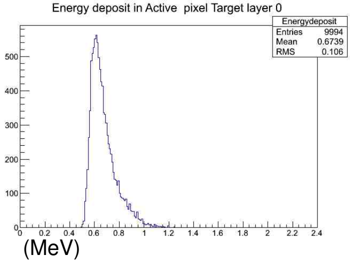
☐ Resort track

- Next step : use ICEDUST/GENFIT (include multiple scattering, · · · , see extrapolation trajectory effect, · · ·)

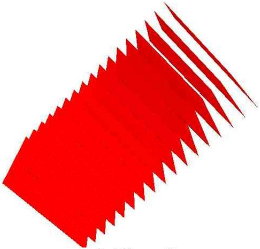
Starting active pixel target implementation in ICEDUST/SimG4

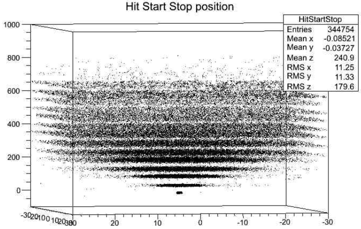
With the friendly help of ICEDUST team software :

- Starting active pixel target geometry implementation in ICEDUST
- Starting preliminary definition of sensitive detector in ICEDUST
  → with the help of ICEDUST sensitive detector "segment"
- Starting retrieve deposited energy information within ICEDUST
  → "truth/g4Hits/ActivePixelTarget"
- Starting create project : cmt create myActivePixelTarge v0r0
  → event loop, · · · , first plots, · · ·


Energy deposit in Active pixel Target layer 0

- Deposited energy in active pixel target by 15 MeV μ^- .




Hit Start Stop position

- Next step : deposited energy by signal, background, use a full beam simulation, · · ·

Outlook

- Use a full beam simulation to estimate the occupency rate in pixel (signal, background, fake in pixel $\cdots$)
- Use ICEDUST for the full simulation in order to quantify the tracking improvement.
- Use a full beam simulation to estimate the background.
- Cooling studies (0.25 W cm^{-2}) : power cycling ?. Use ANSYS for the cooling optimisation.
- Implementation of high and low thresholds : low energy e^- and stopped μ ?
- Beam test to study pixel behavior ($\cdots$,Si pixel recovery after the electron flash, Si desaturation : short-circuit to evacuate charges ?)
- Feasability and costs.
- Hope to get a few answers first half of 2014.
- Thank you