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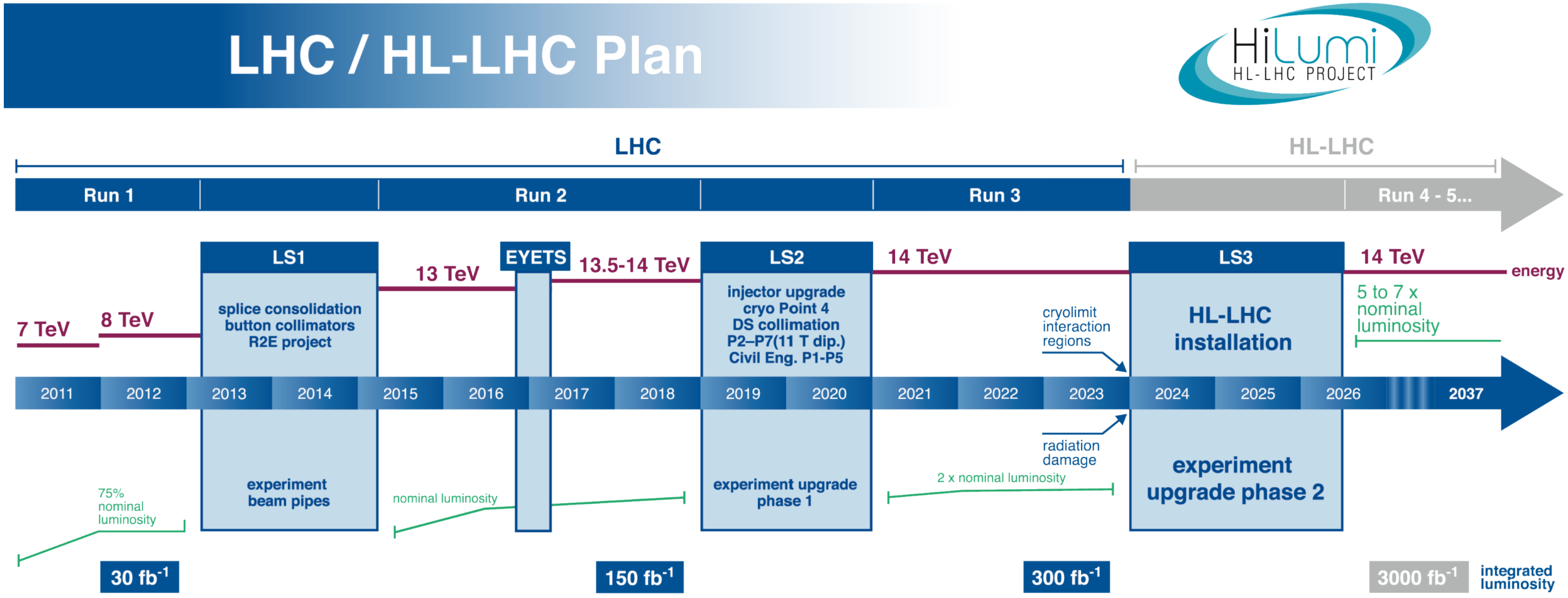
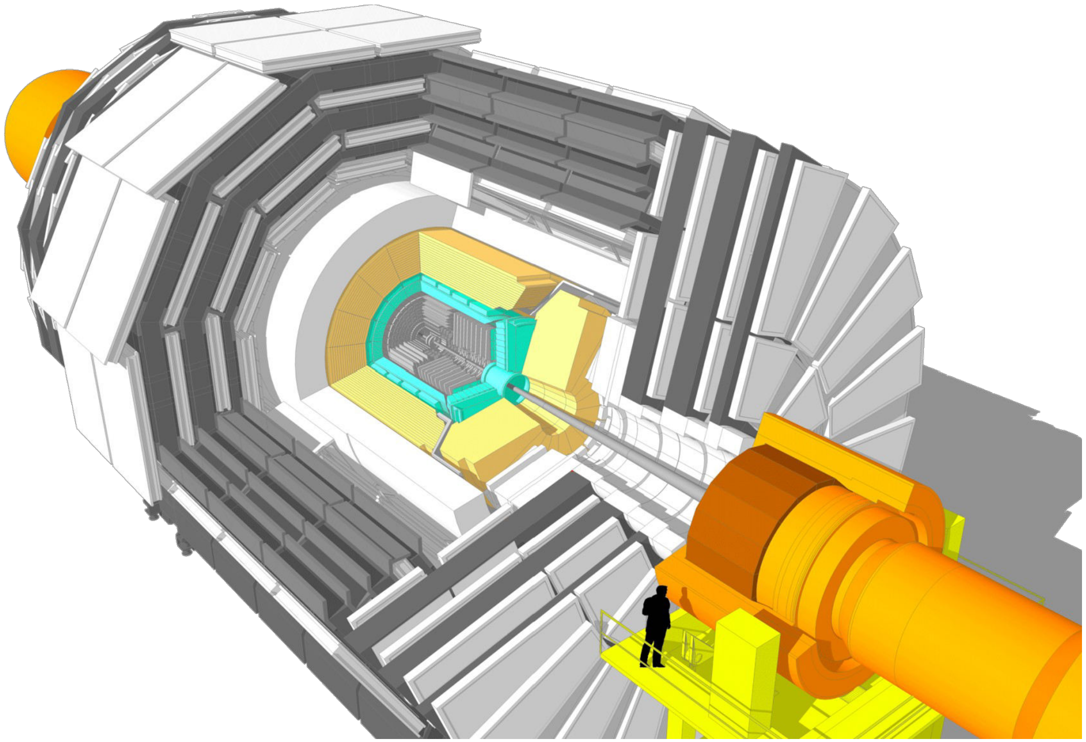
High Luminosity upgrade for the LHC: HL-LHC

- Increase the luminosity: from 300 fb^{-1} (2011-2023) to 3000 fb^{-1} (2026-2037)
- The goal for HL-LHC:

1) Peak Luminosity: 5.0 (7.5) x 10^{34} cm^{-2} s^{-1}
2) Integrated Luminosity over 10 years: 3000 (4000) fb^{-1}
3) PU: 150-200



The Tracker Phase-II Upgrade



Replace Tracker:

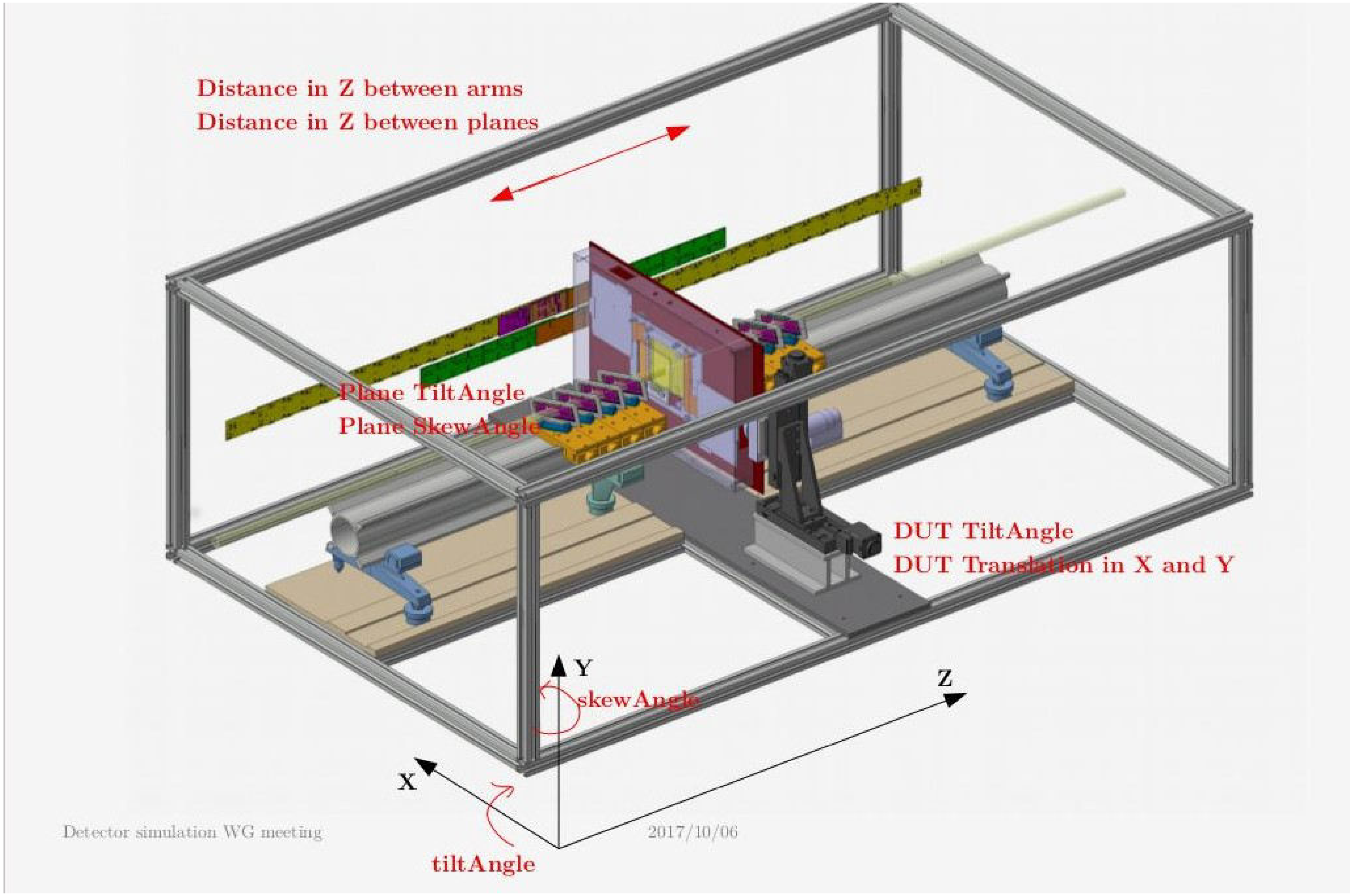
- High granularity, less material, high p_T resolution
- Selective readout of outer tracker at 40 MHz for L1 trigger
- Extend η coverage to 4

Thanks to D. Loukas

Why do we need a new Pixel Telescope for beam tests?

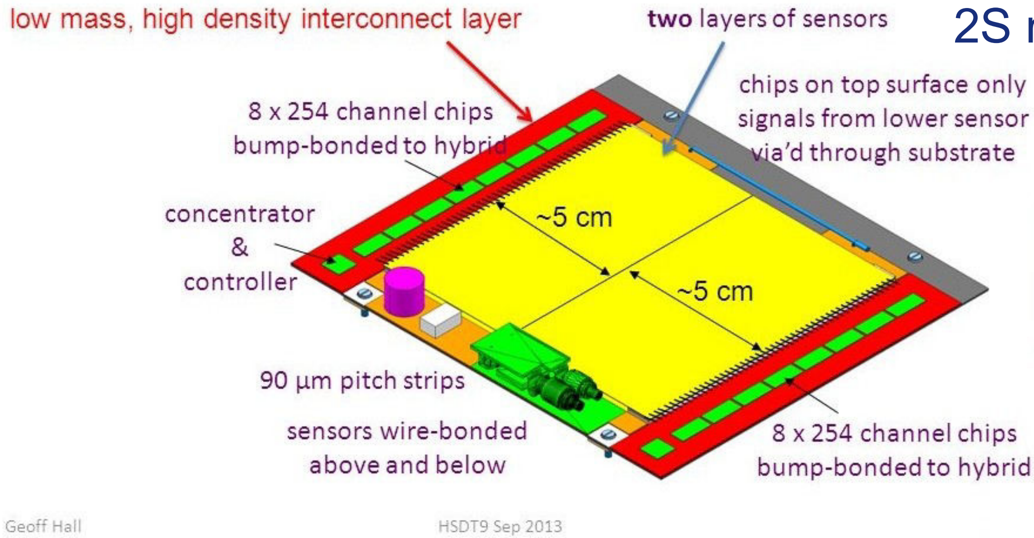
- The best existing particle telescope today is the one built by the AIDA collaboration. It is based on the MIMOSA26 Monolithic Active Pixel Sensor (MAPS) chip and has an integration time of 115.2 μs or 8.68 kHz readout frequency.
- Integration time in Phase II tracker modules (and other HL-LHC sensors) is 25 ns → 40 MHz (x4600 the AIDA telescope readout frequency).
- We cannot test Phase-II modules at nominal rates with the AIDA telescope.

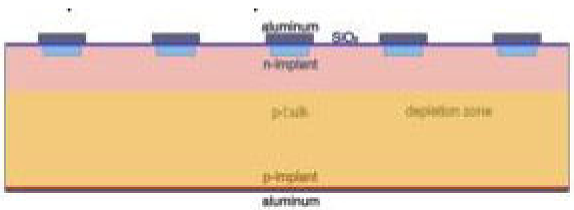
The new CMS Pixel Telescope

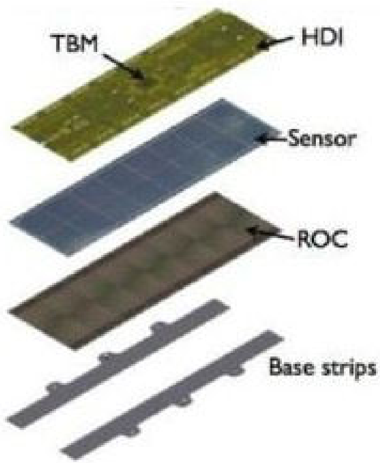


Modules of the telescope and the device under test (DUT)

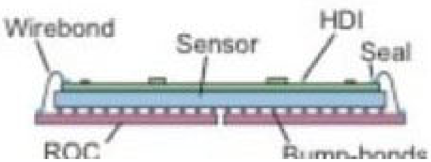
2S module (two strip sensors)





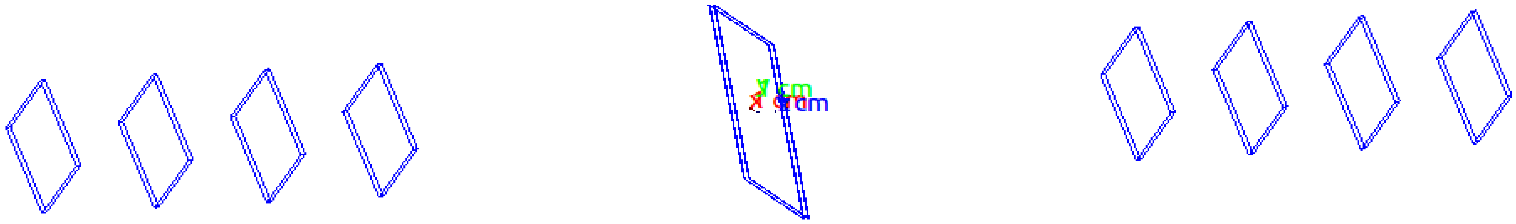


BPIX module

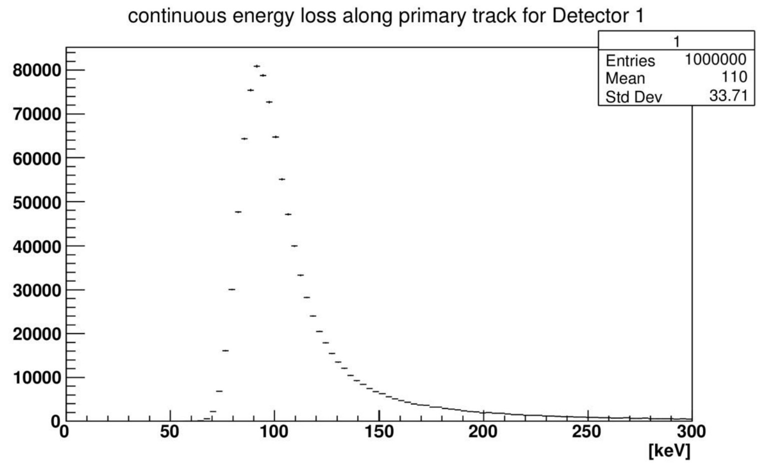


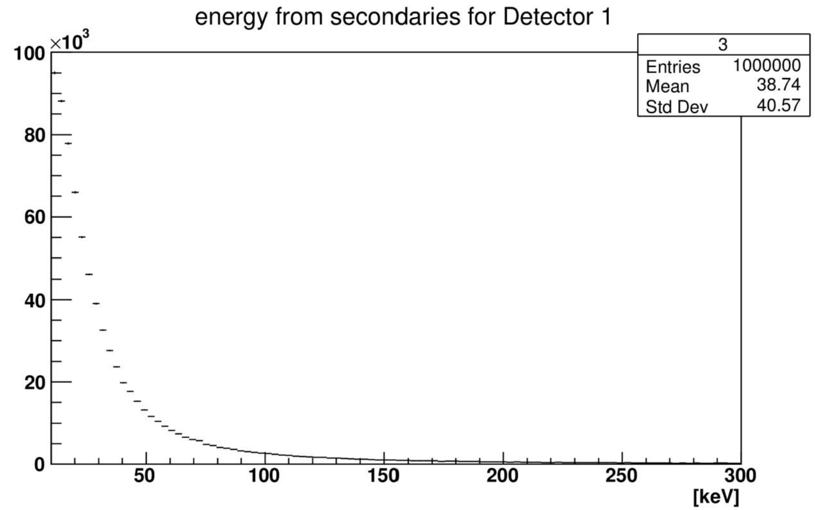
The Geant4 simulated geometry of the Telescope

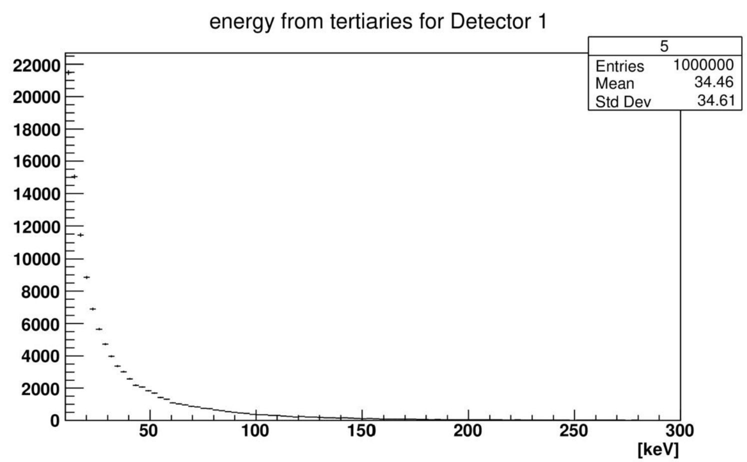
- A 2S module (DUT) and 8X2 modules (with same dimensions as those of BPIX) of a telescope
- 120 GeV π^+ beam in z-direction initially (can be changed)
- Origin: Center of World
- World material: Nitrogen
- DUT angle X = 10 deg, BPIX angle X = 20 deg, BPIX angle Y = 20 deg

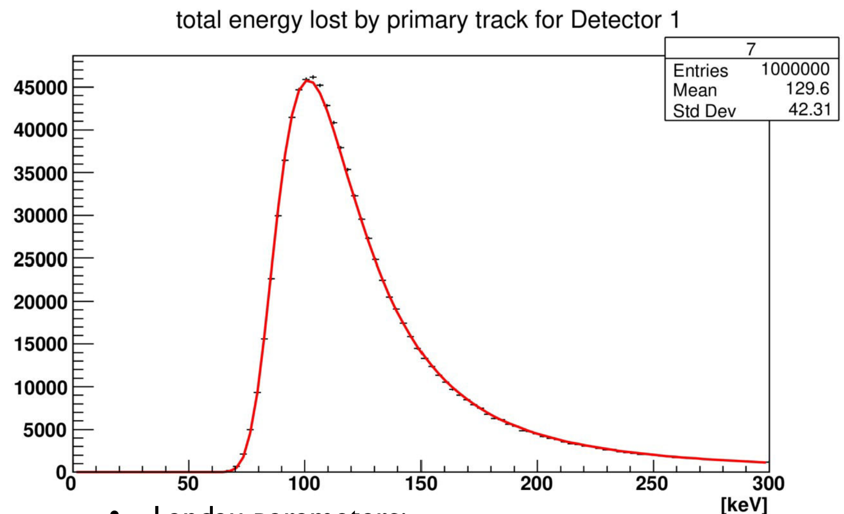


Vertical incidence, 120 GeV π+



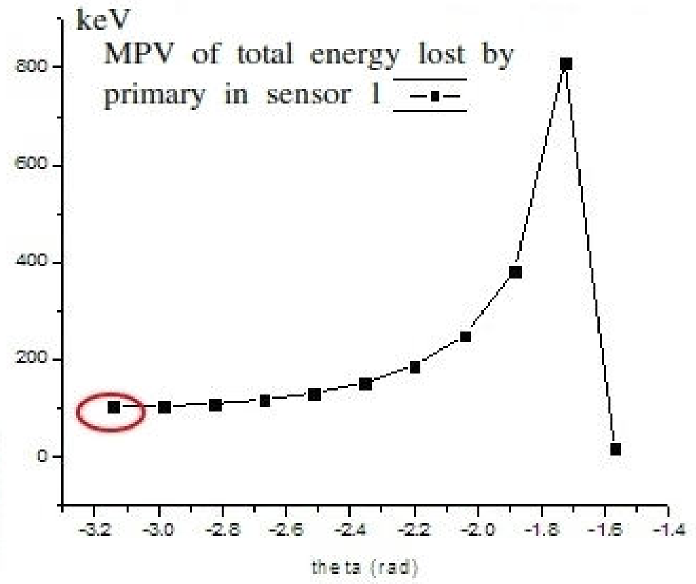


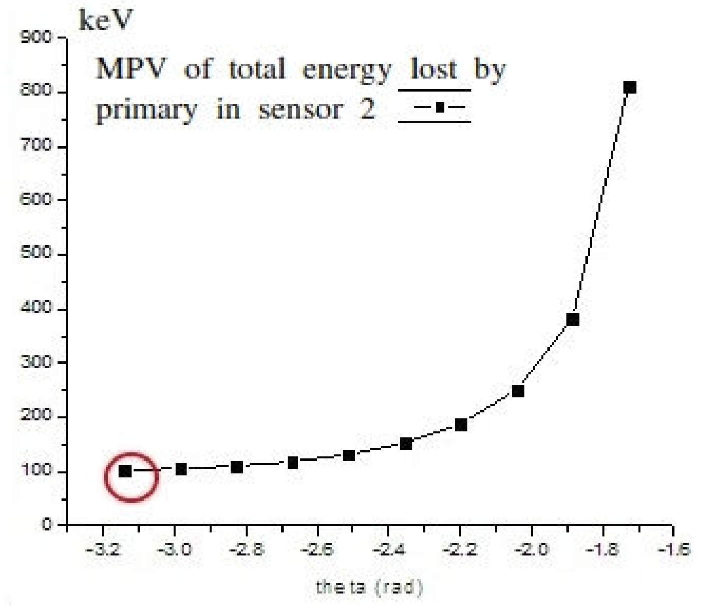




- Landau parameters:
  - Constant: 252202
  - MPV: 104.695 (keV)
  - Sigma: 11.9282 (keV)

Energy lost by primary particle (120 GeV π+) for different angles

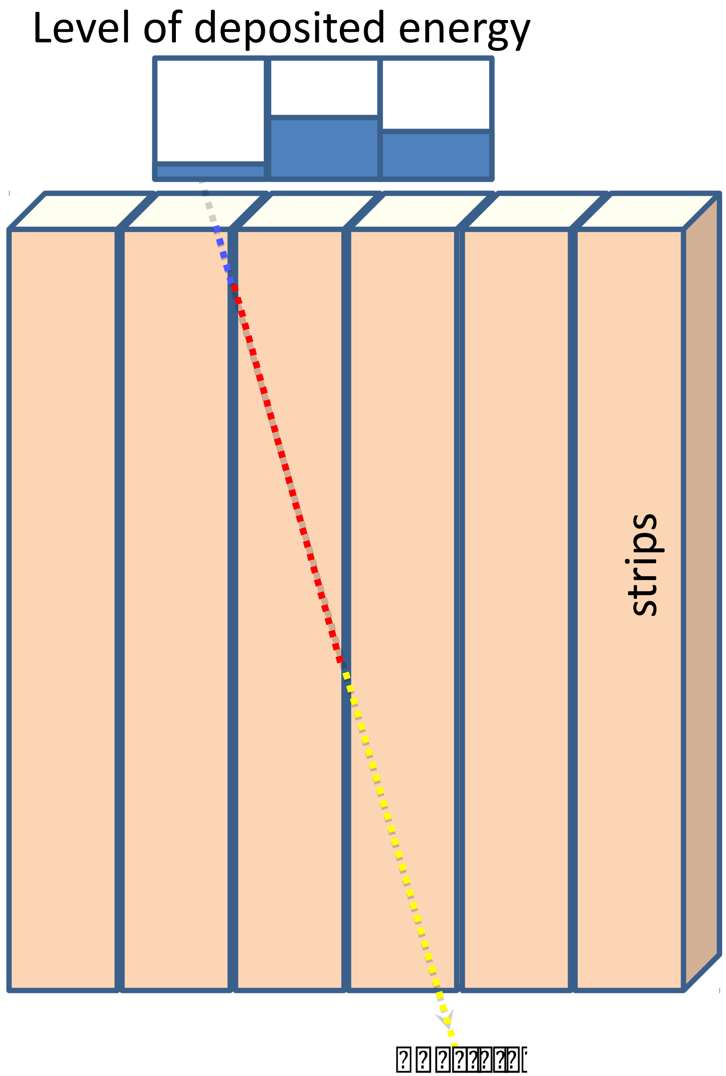




Sensitive detector (1)

- 1016 strips added to the active region (with active depth = 240 μm). Each strip is associated with an active volume below it with y-width = pitch = 90 μm. Geant4 attributes each current position of a delta electron to the closest strip.
- Outputs:
  - Ntuple with the continuous energy deposition per strip (sensitive calorimeter)
  - Number of secondary electrons created per strip for the central strips (sensitive tracker)

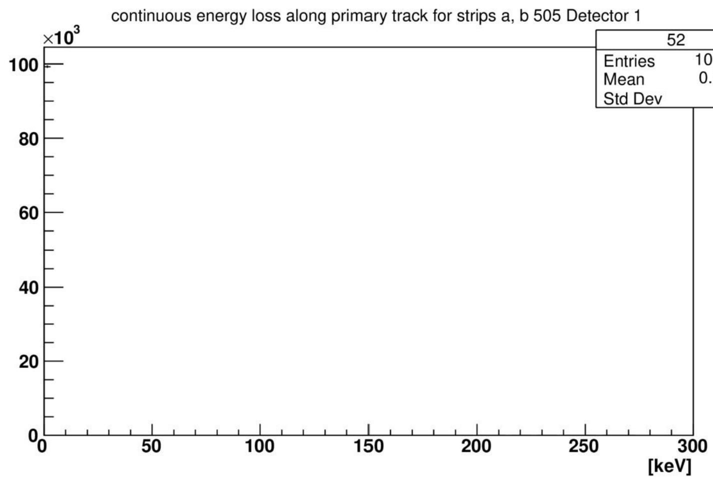
Sensitive detector (2)

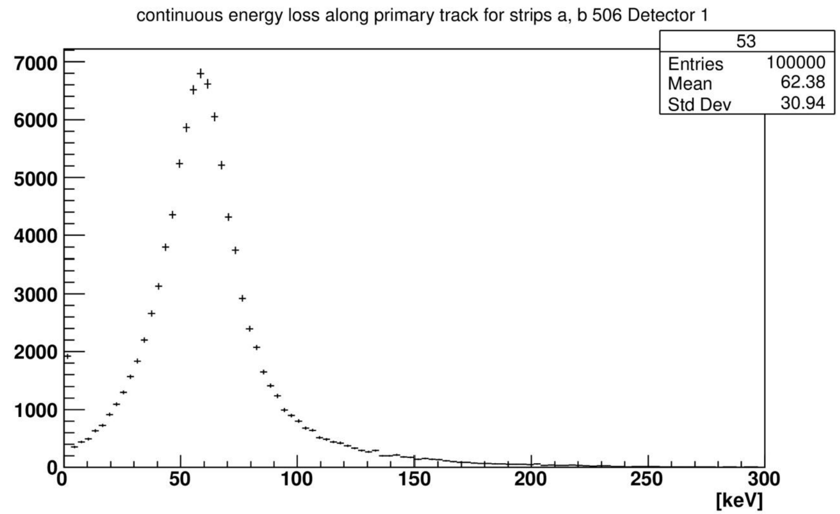


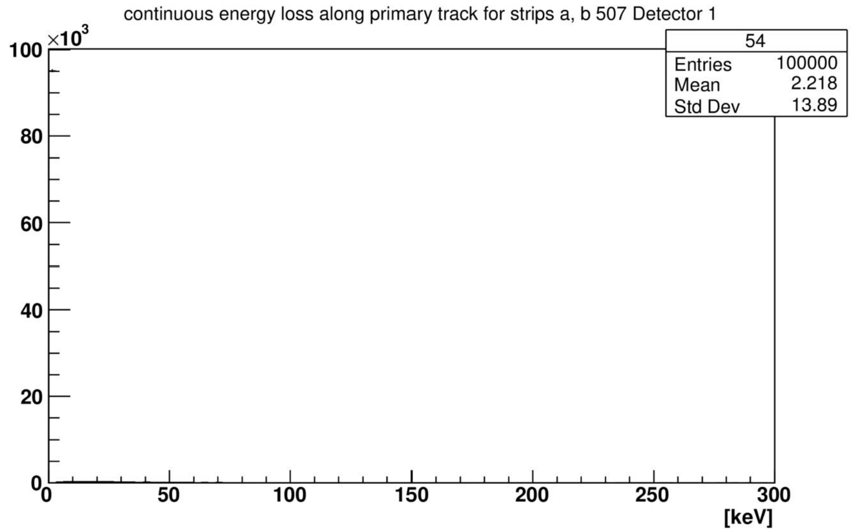
Electric field added to sensors

- Local electric fields applied to each sensor, high voltage on backplane ~-200 V for non-irradiated (and -600 V for irradiated), ground on strip plane
- First approximation: No segmentation of strips considered for electric field
- 4th order Runge-Kutta used (with minimum step = 0.01 mm)

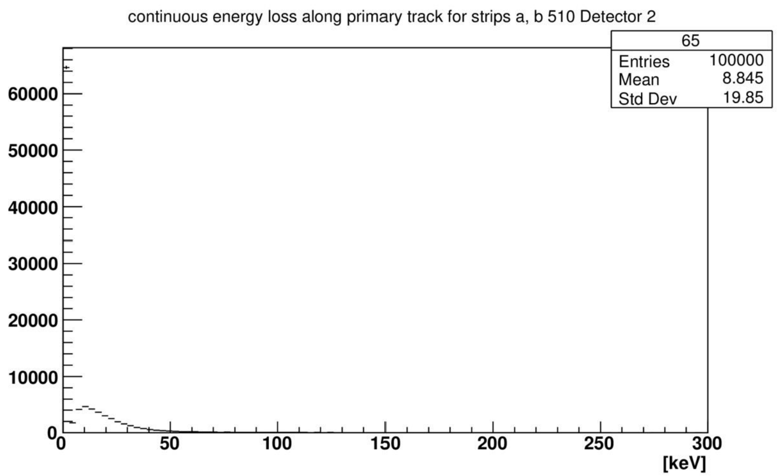
Continuous energy deposition per strip pair (120 GeV π+, DUT X-angle = 10°) (1)

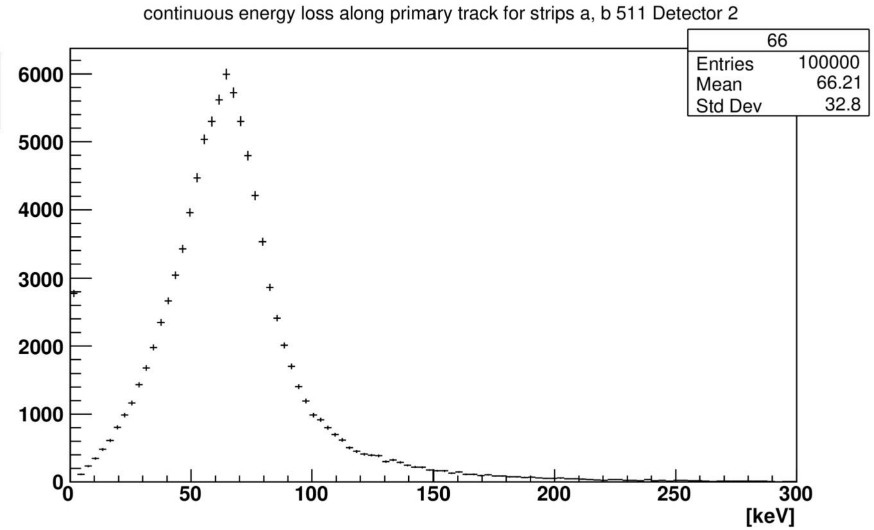


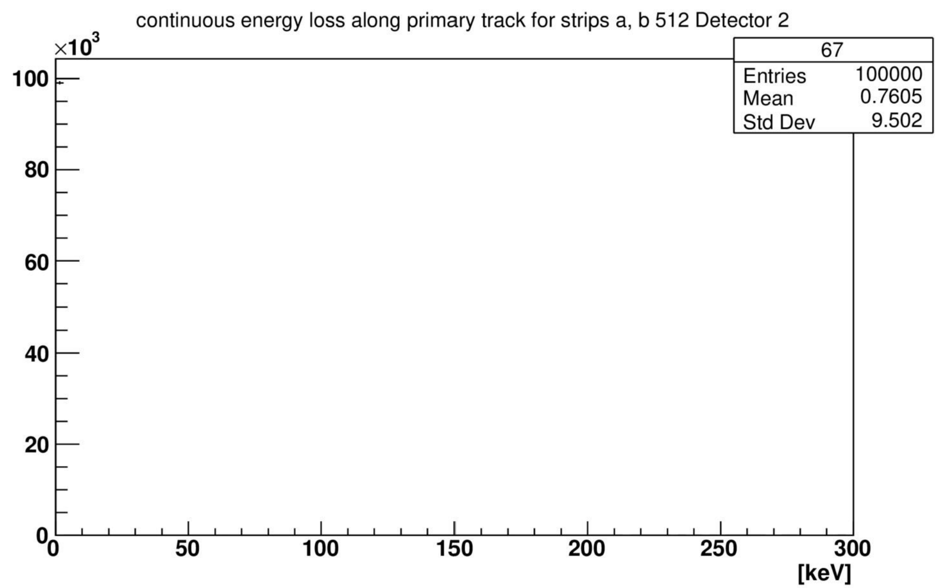




Continuous energy deposition per strip pair (120 GeV π+, DUT X-angle = 10o) (2)







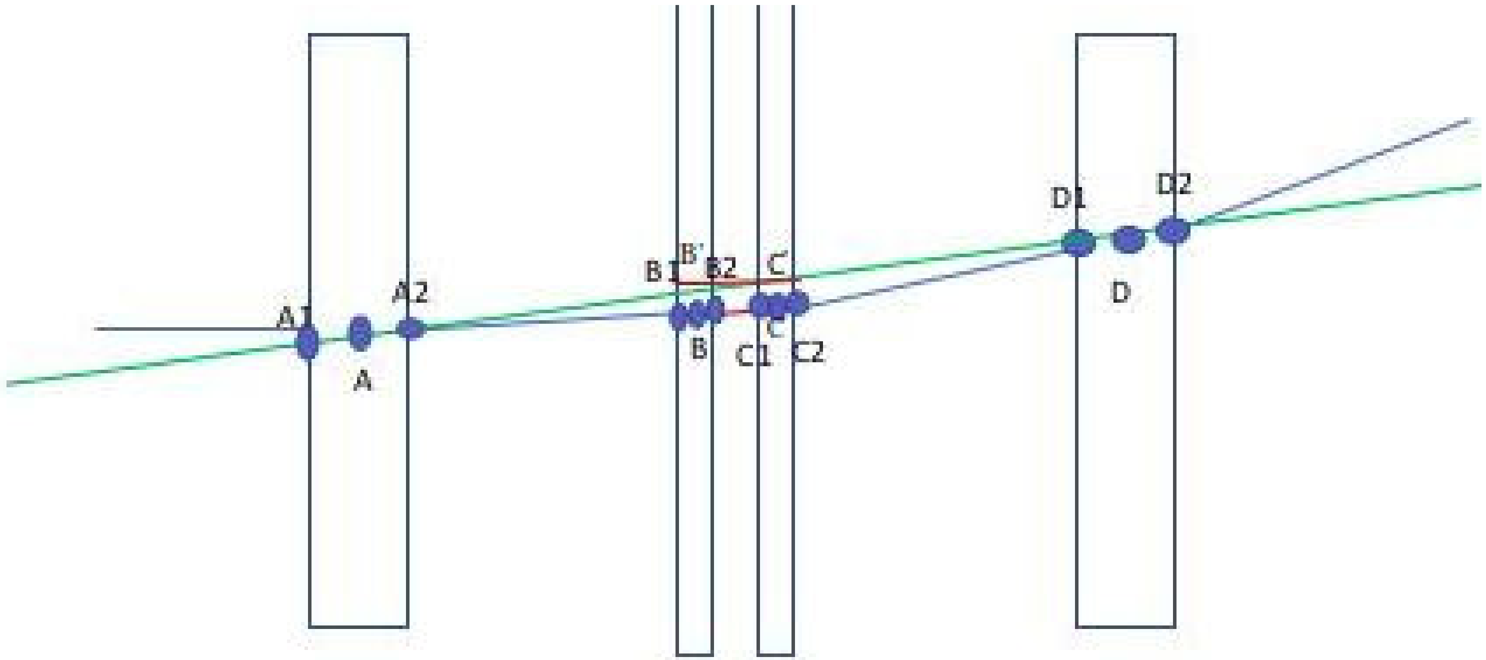
Simulation components for resolution and multiple scattering study

- A 2S module (DUT) between 2 pixel sensors (with their thickness as a variable, now at 50 μm)
- Initially: 25 MeV proton beam along z-direction (consistent with beam at Cyclotron CYRCÉ, IPHC)
- Origin: Center of World
- World material: Air

Simulation goals

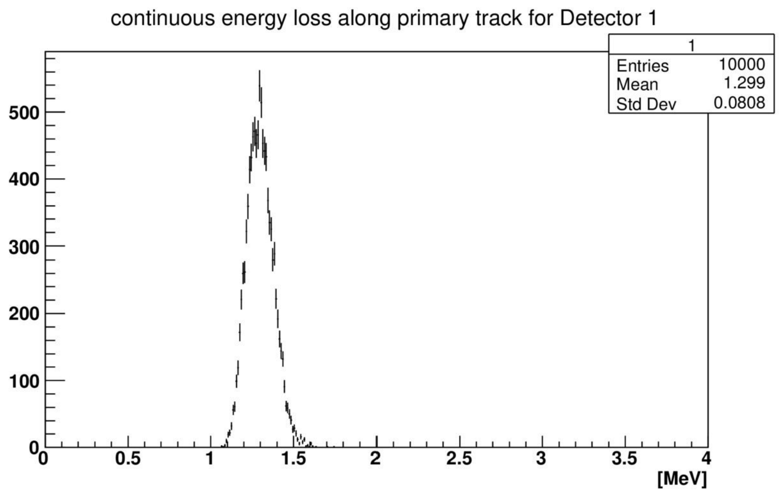
- Main difficulty: 25 MeV protons
  - are stopped by about 3 mm of silicon
  - large energy deposition ("fat" clusters)
  - large multiple scattering
  - simple tracking system required (1 or 2 sensors only, the closest possible to the detector under test)
  - can ionise the air…
- Goals:
  - Understand how many modules could be reached while keeping multiple scattering under control
  - Examine only one detector in front of the DUT and only one behind it for a better study of residuals

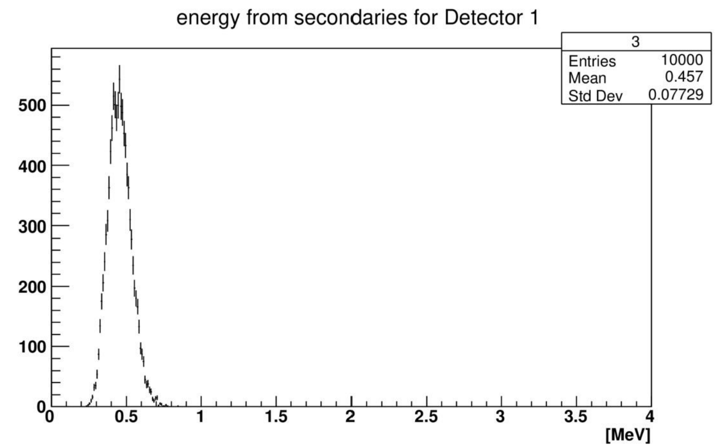
Geometry

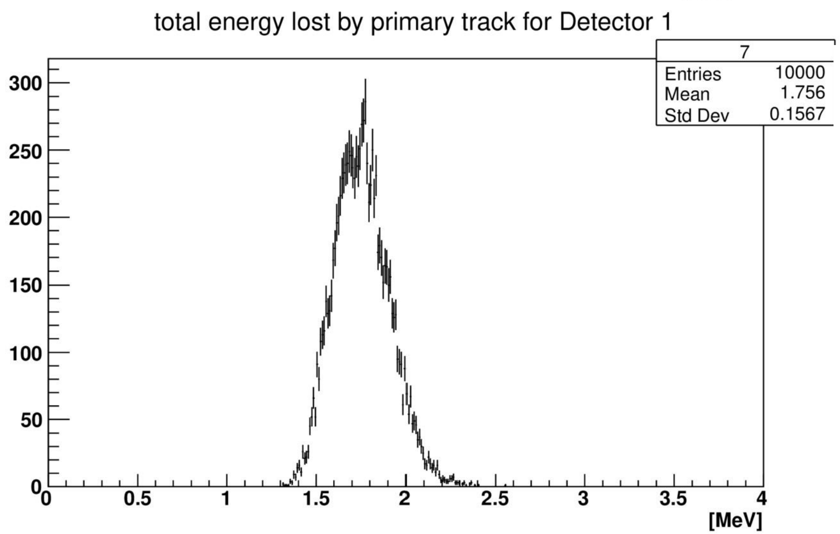


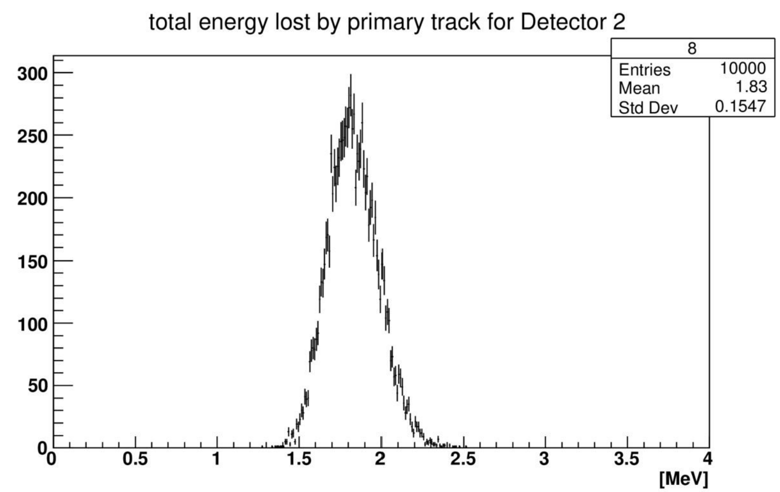
$$deflection\,angle = acos(\vec{u}_{A1} \cdot \vec{u}_{D2}), \vec{u}: momentum\ direction\ unit\ vector$$

25 MeV proton, θ = -π: Output (1)

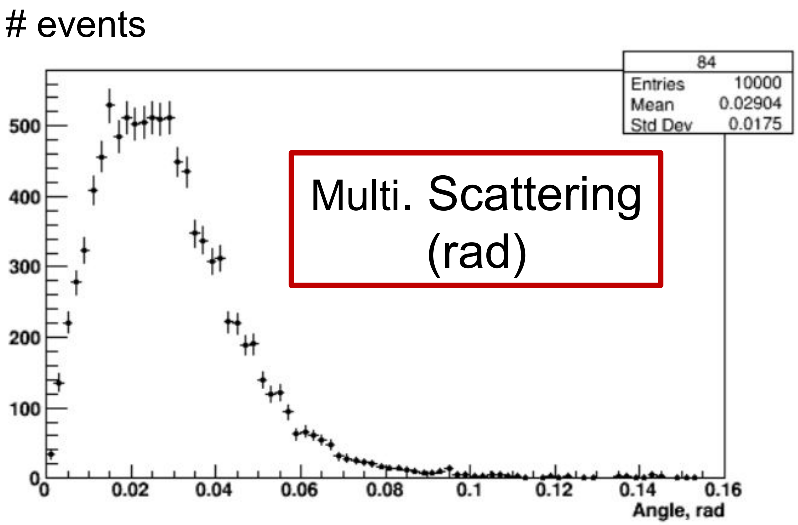


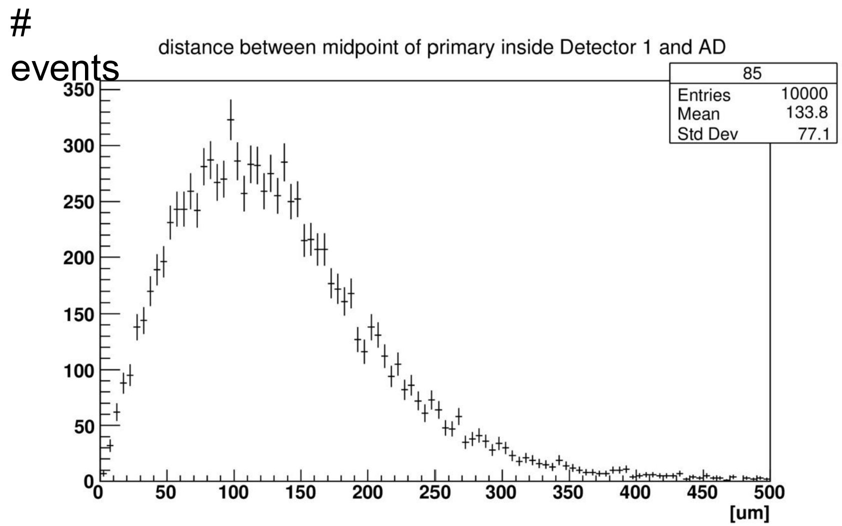


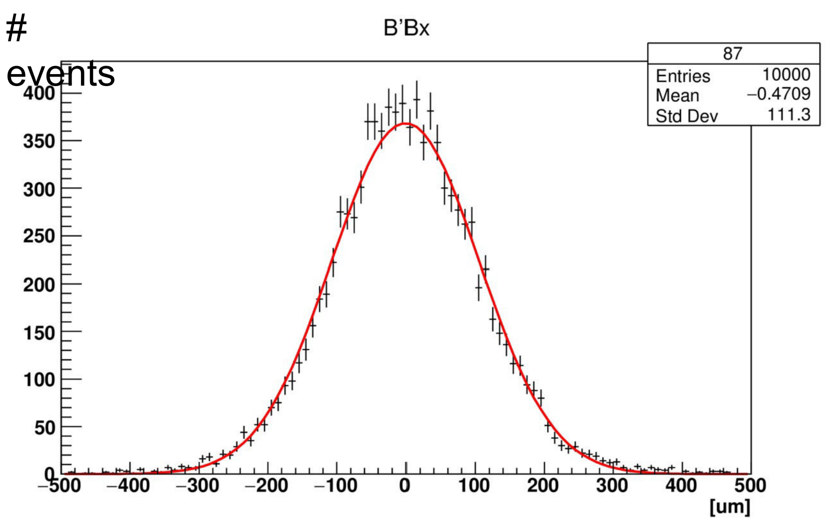


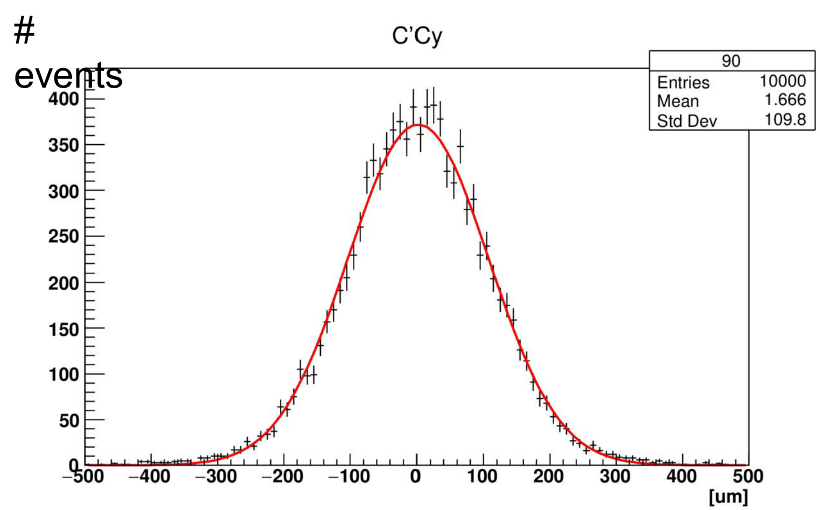


25 MeV proton, θ = -π: Output (2)





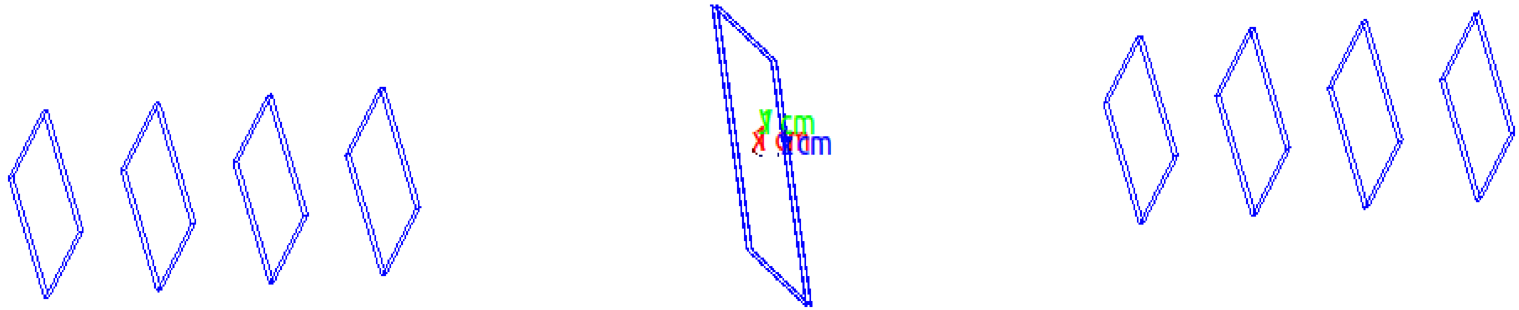




10 GeV electron, θ = -π: Output (2)

	25 MeV proton, θ = -π	25 MeV proton θ = -3π/4	2 GeV proton θ = -π	5 GeV proton θ = -π	10 GeV proton θ = -π	2 GeV e-, θ = -π	5 GeV e-, θ = -π	10 GeV e-, θ = -π
deflection angle Mean Value (rad)	2904E-5	3580E-5	4755E-7	2100E-7	1134E-7	6421E-7	2471E-7	1236E-7
deflection angle Std. Dev. (rad)	0.0175	0.02282	2928E-7	1237E-7	6.93E-5	4329E-7	1444E-7	7.64E-5
B'Bx Std. Dev. (μm)	111.3	221.4	1.726	0.8404	0.3897	2.508	1.004	0.4136
C'Cy Std. Dev. (μm)	109.5	178.7	1.725	0.8406	0.3969	2.45	1.038	0.416

Plans for further work



- Include geometry of 8X2 BPIX models comprising the new CMS Pixel telescope
- Study of the effect of δ-rays on 2S performance

Backup slides

Geant4 angles and particle momentum direction

- $P_x = -\sin\theta\cos\varphi$, $P_y = -\sin\theta\sin\varphi$,

  $P_z = -\cos\theta$