High-D Consortium Meeting
21 - 22.02.2022

Material Budget Imaging with ALPIDE sensors

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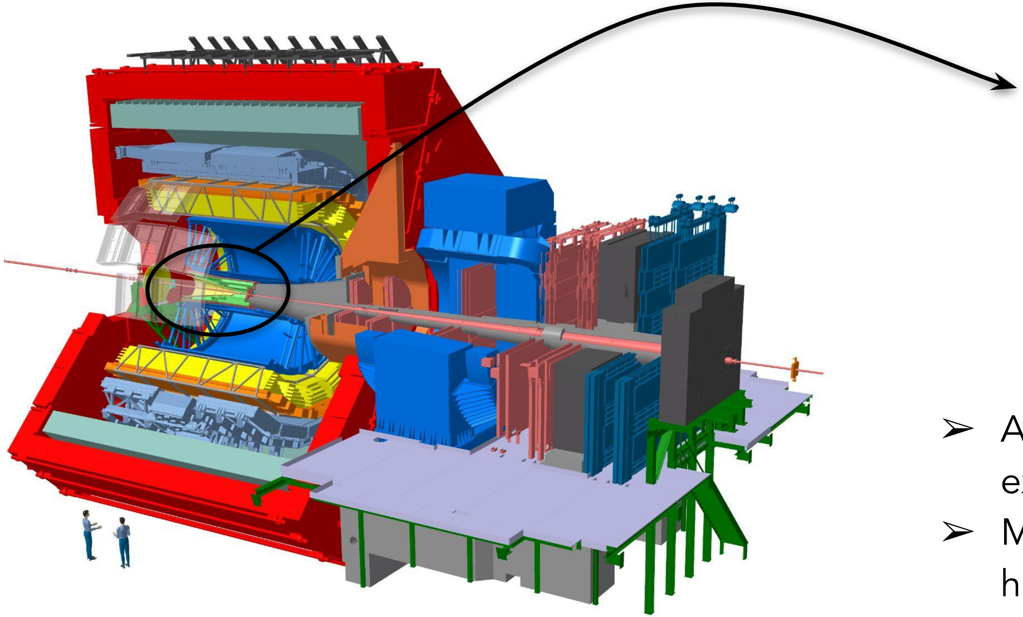
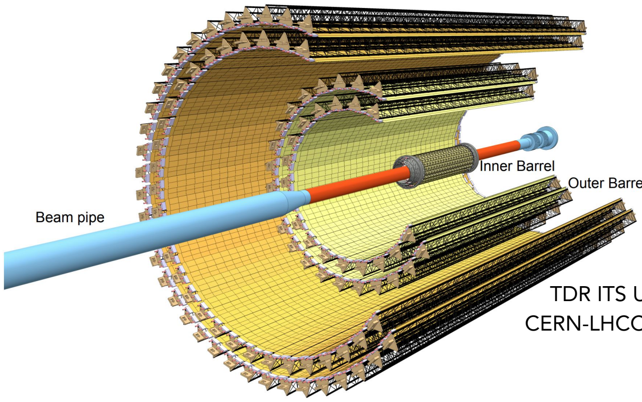
21.02.2022

ALICE detector - the Inner Tracking System (ITS2)



ALICE figure repository

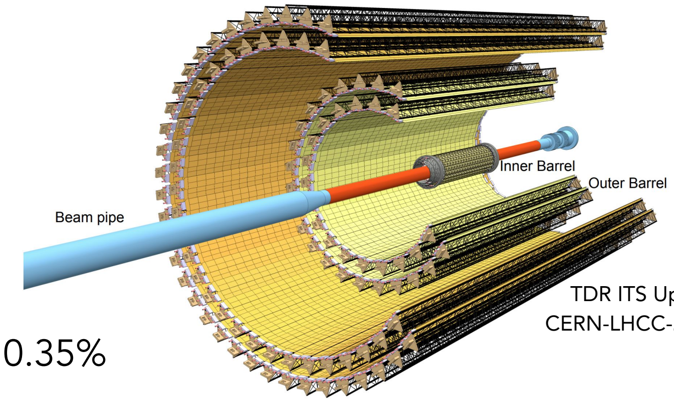


TDR ITS Upgrade
CERN-LHCC-2013-024

- ALICE is the heavy-ion physics-focused experiment at the LHC
- Main goal: study of the quark-gluon plasma in heavy-ion collisions
- Currently LHC LS2 → detector upgrades
- Inner Tracking System 2 (ITS2)

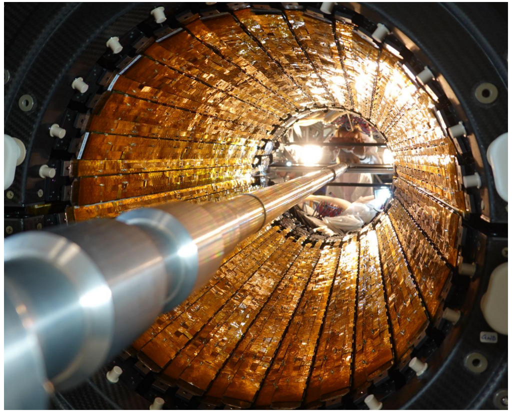
ALICE detector - ITS2

- ITS2 (installed)
  - Entirely MAPS based detector design
  - Seven layers of ALPIDE sensors
  - Increased vertexing and tracking performance with respect to the ITS
    - Layer 0 closer to IP: 39mm → 23mm
    - Reduced material budget (x/X_0) per layer: 1.14% → 0.35%



TDR ITS Upgrade
CERN-LHCC-2013-024

- ALPIDE
  - 30×15 mm, 50(100) µm thick IB(OB), 29×27 μm^2
  - Full CMOS circuitry within the pixel matrix
  - 180 nm CMOS IP
  - 5 µm spatial resolution, ≫ 99% detection efficiency, « 10^{-6} fake hits /px /event, ~40 mW/cm^2



- ITS2 is a state of the art MAPS detector
- Further improvements are possible

ALICE detector - what the future entails

➢ ITS2 (installed)

- Entirely MAPS based detector design
- Seven layers of ALPIDE sensors
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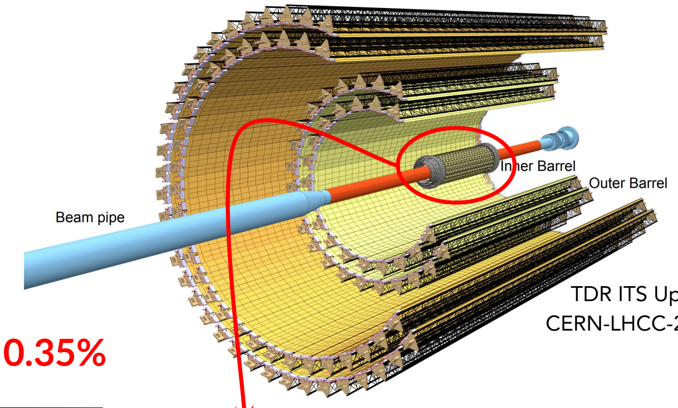
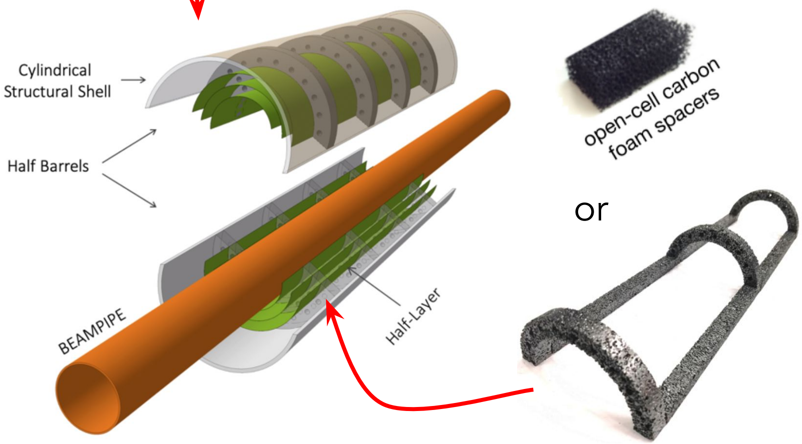
  - Layer 0 closer to IP: 39mm → 23mm
  - Reduced material budget (x/X_0) per layer: **1.14% → 0.35%**



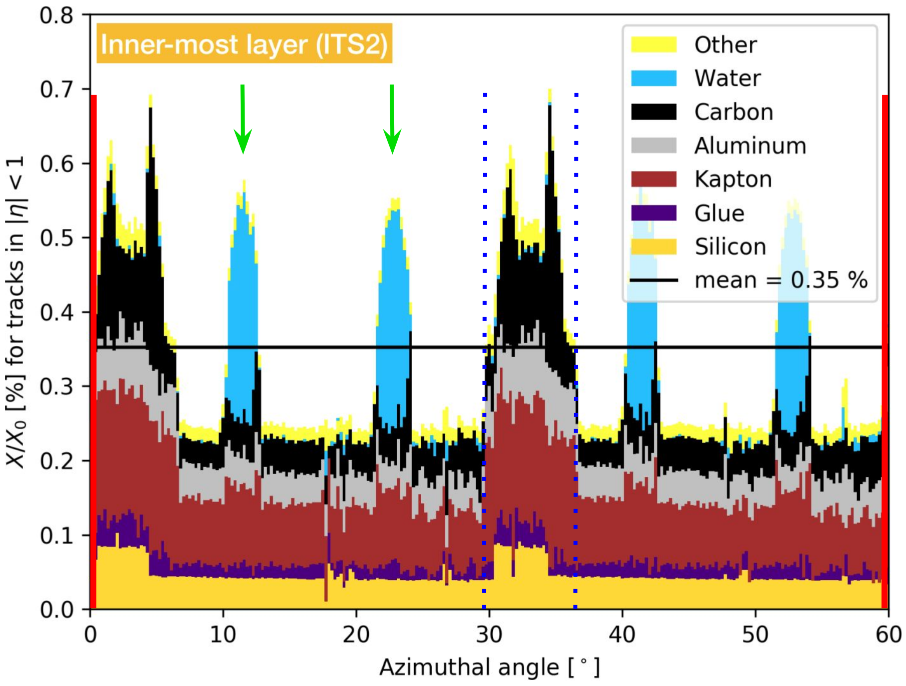
TDR ITS Upgrade
CERN-LHCC-2013-024

➢ ITS3 (LHC LS3, 2026-2028)

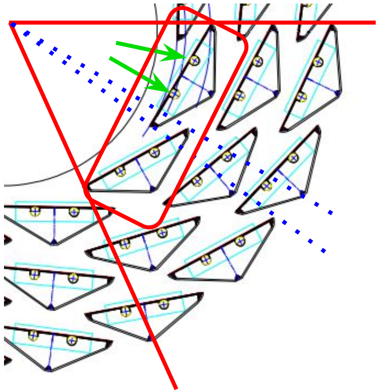
- Aim: replace the Inner Barrel (3 inner layers) of the ITS2
- Ultra light, wafer-scale, curved sensors
- Extremely low material budget (**0.35% → 0.05%** per layer)
- Mechanical support by carbon foam spacers + used to define the radial distance between the layers



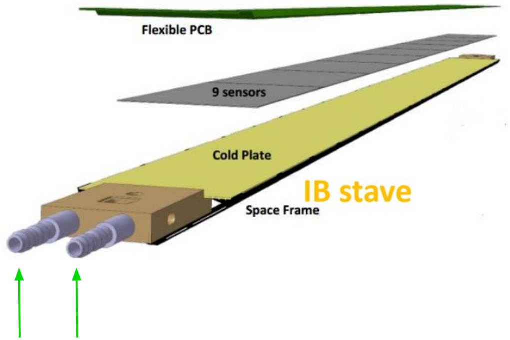
Motivation for the ITS3



➢ Si accounts for 1/7[th] of the total material (irregularities due to support/cooling)

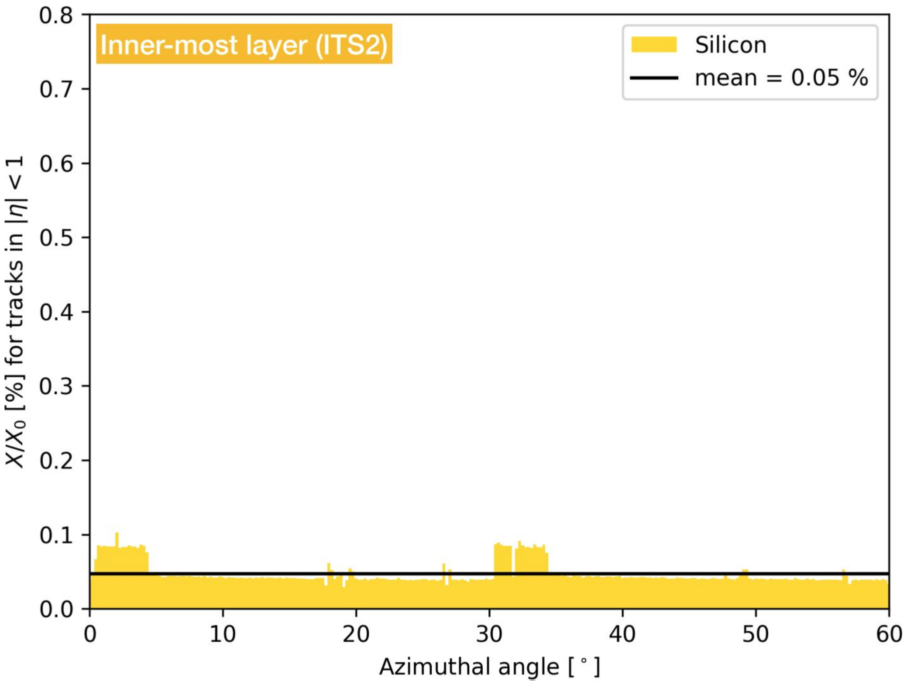


ITS2 TDR, CERN-LHCC-2013-024



LoI for ITS3, CERN-LHCC-2019-018

Motivation for the ITS3

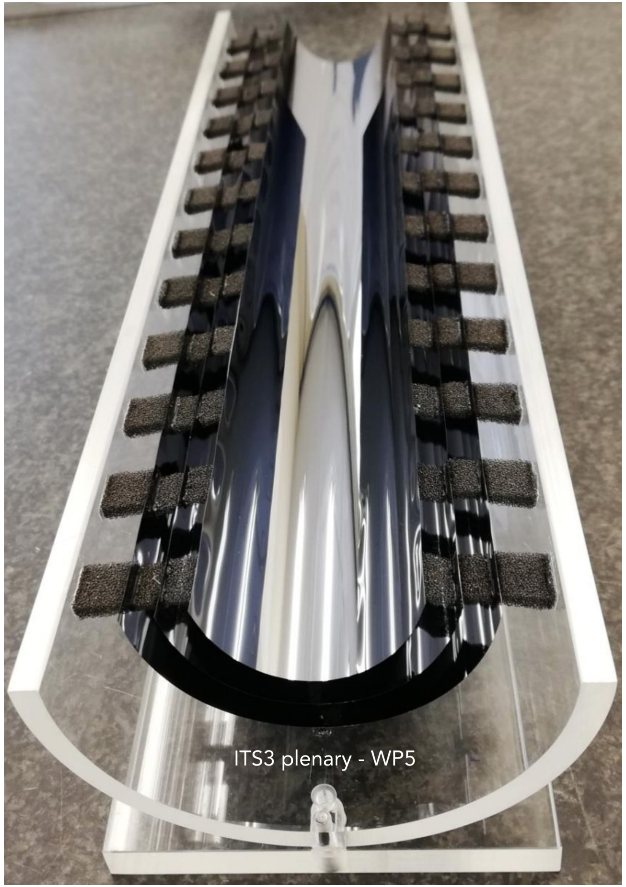


LoI for ITS3, CERN-LHCC-2019-018

- ➢ Si accounts for 1/7th of the total material (irregularities due to support/cooling)
- ➢ Removal of water cooling possible
  → if power consumption < 20 mW/cm^2 (ALPIDE: 40 mW/cm^2, 7 mW/cm^2 matrix)
- ➢ Removal of the circuit board for power distribution and data lines possible
  → if integrated on chip (make single large chips, use CMOS metal layers)
- ➢ Move mechanical support outside acceptance → benefit from self-supporting bent Si (+ ultra-light carbon foam spacers)

An almost all-Si detector is possible!
Ultra-light spacers needed!

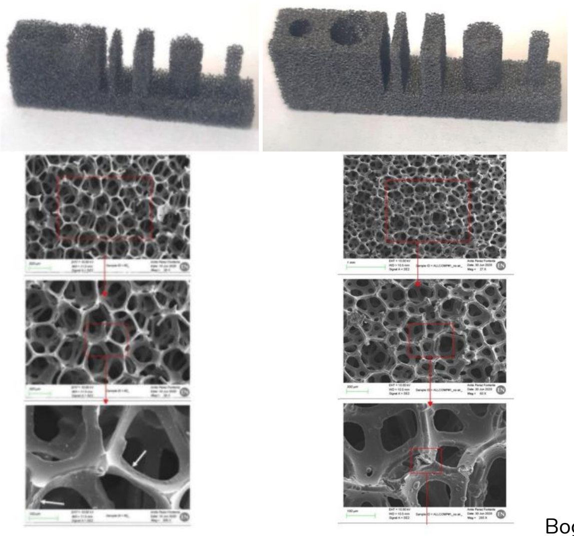
Engineering Model 1 with carbon foam wedges

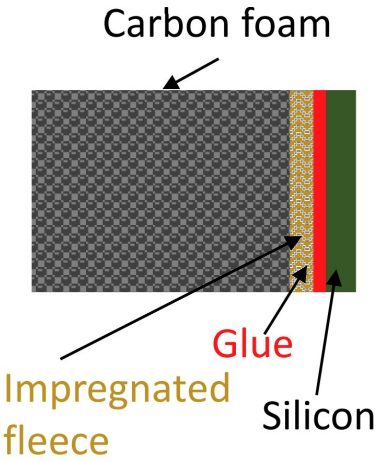


- Engineering Model 1 (half barrel)
- Several types of foams considered (structural, thermal considerations)
- Top choice: ERG, ALLCOMP

ERG DUOCEL_AR
0.06 kg/dm³
0.033 W/m·K

ALLCOMP_LD
0.2-0.26 kg/dm³
>17 W/m·K





- Noticed glue infiltration (capillarity) in the foam → add carbon fleece
- Aim: study material budget of such a wedge composite

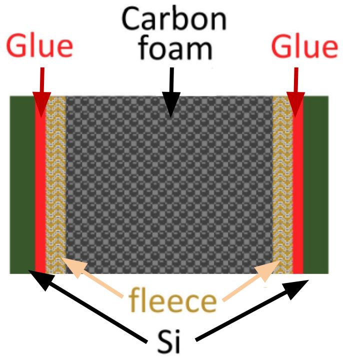
Material budget imaging of carbon foam wedges

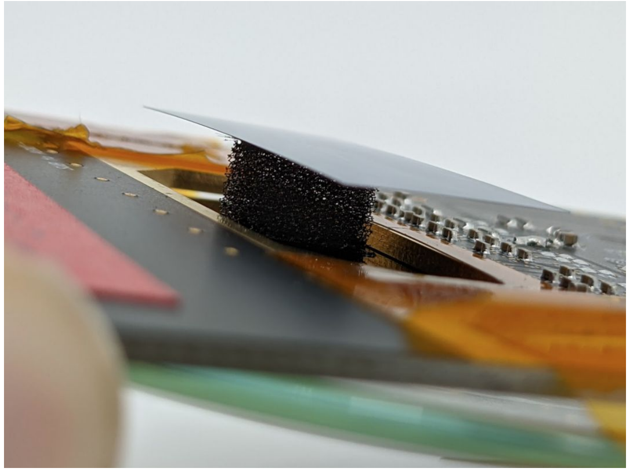
6 mm thick foam + 50 µm fleece + 50 µm glue + 50 µm silicon

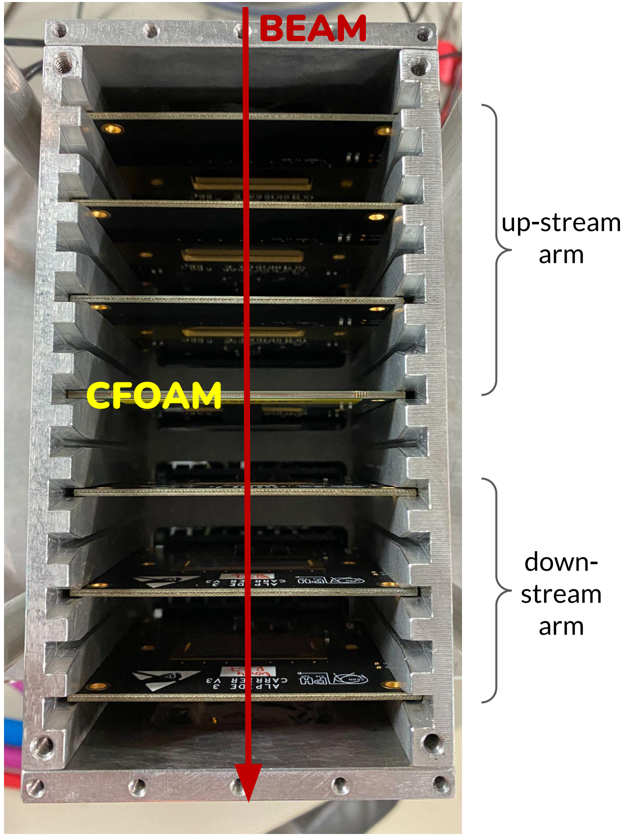
- Mimic an ITS3 layer by glueing a carbon foam wedge to an ALPIDE
- Place inside a 6 plane telescope and subject it to a beam of particles
- Measure (extra) scattering due to extra material (foam)
- Active ALPIDE + non-working ALPIDE

L × l × w

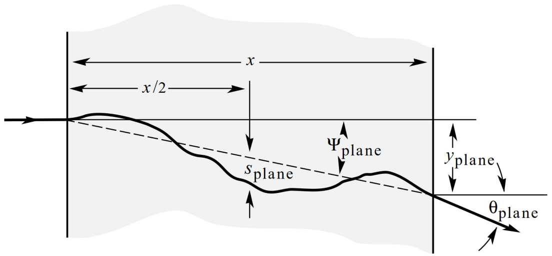
10 × 3 × 6 [mm]



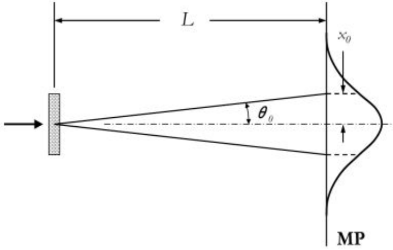


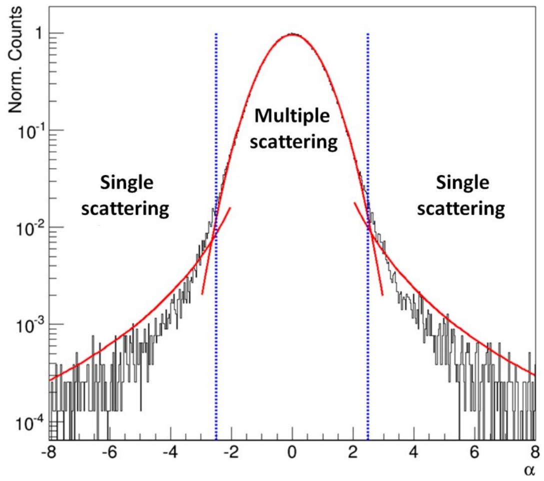


Intermezzo: Multiple Coulomb Scattering



Source: PDG





Source: 10.1103/PhysRevAccelBeams.20.124702

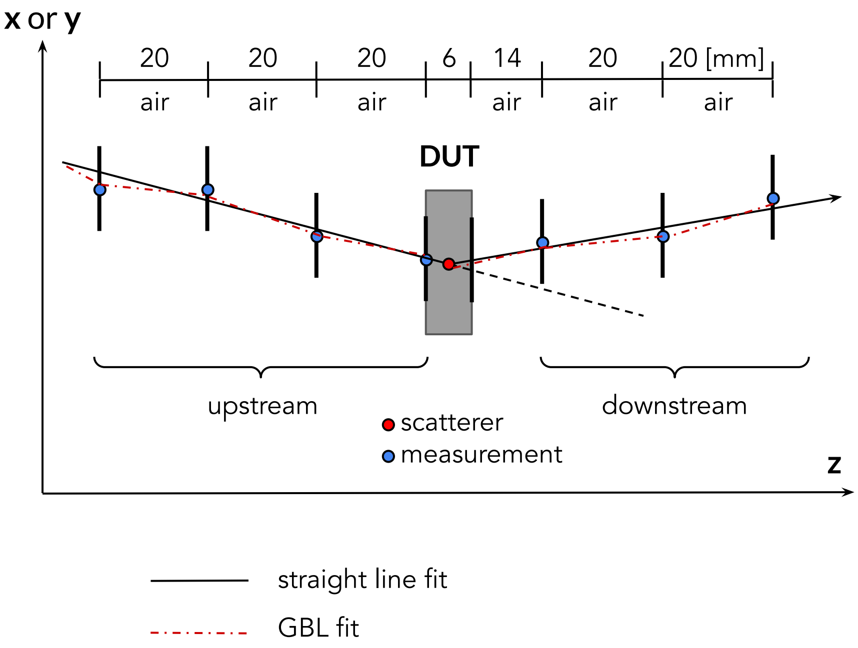
- ➢ The trajectory is altered due to many small deflections (Multiple Coulomb Scattering) or to a single large deflection (Single Rutherford Scattering)
- ➢ Distribution: Gaussian core (98%) with non-Gaussian tails → width given by:

$$\theta_0 = \frac{13.6\ \text{MeV}}{\beta c p}\, z \sqrt{x/X_0}\left[1 + 0.038 \ln(x/X_0)\right]$$ (Highland formula)

- ➢ Expect broader distribution for extra material

MBI: Tracklet based analysis

MBI: Paul Schütze, Jan-Hendrik Arling

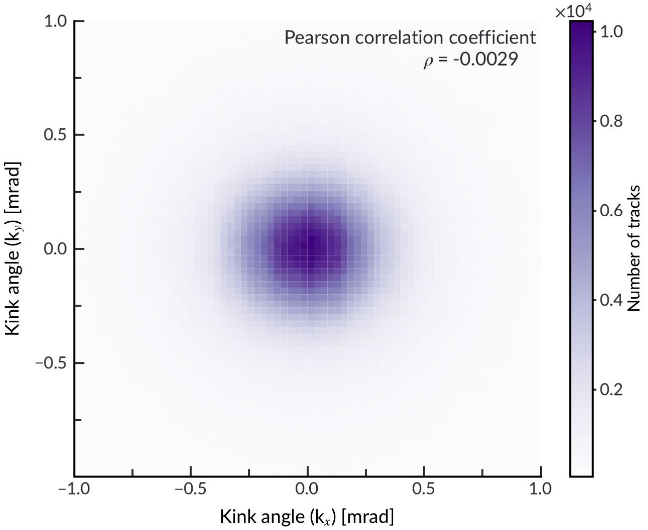


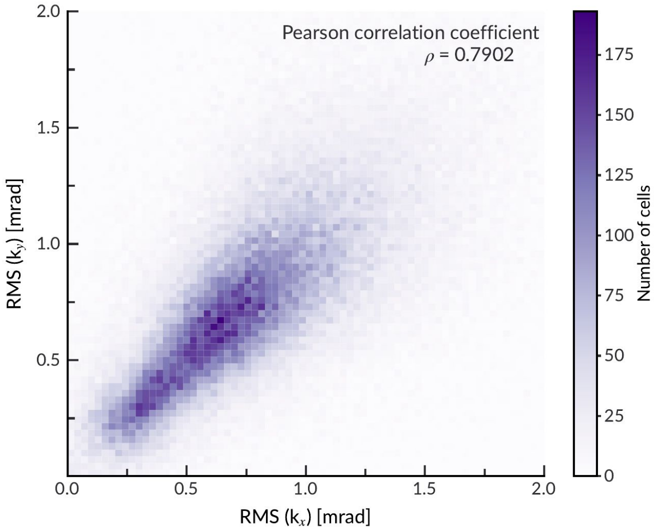
- Tracking
  → require 4 (3) hits in each up(down)-stream telescope arms to form tracklets
  → account for scattering in air and Si before/after the foam composite (General Broken Lines)

- Tracklets connect along z in the middle of the foam, where an arbitrary kink of the track is allowed, representing the scatterer
  → here, a virtual reconstruction plane is defined and divided into image cells (100µm × 100µm)

Correlations

- Two independent measurements of the particle's deflection angle: horizontal and vertical plane, k_x and k_y
- x and y-axis are orthogonal to each other + quantum mechanical nature of the scattering processes
  → the two kink values (k_x , k_y) are fully uncorrelated
  → measurements (RMS(k_x), RMS(k_y)) in x and y used as independent estimators (twice the statistics)

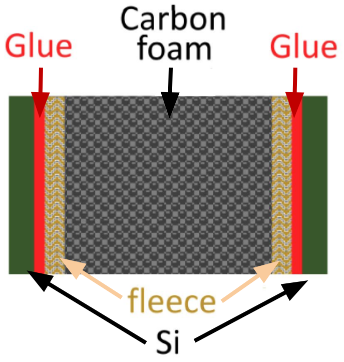




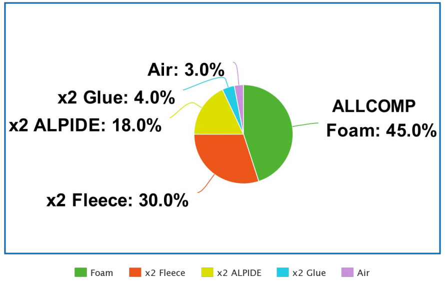
Material budget estimation

$$\theta_0 = \frac{13.6 \text{ MeV}}{\beta c p} z \sqrt{x/X_0}\left[1 + 0.038 \ln(x/X_0)\right]$$

➢ Unknown X_0 for fleece, glue and foam; estimated from densities or basic principles

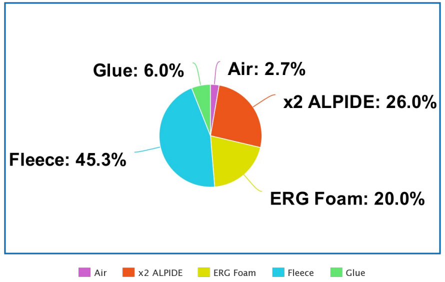


	ERG	ALLCOMP
ρ (g/cm^3)	0.06	0.2
X_0 (mm)	7116	2135
x/X_0 (%)	0.084	0.28



$x/X_0 = 0.613\%$

ALLCOMP

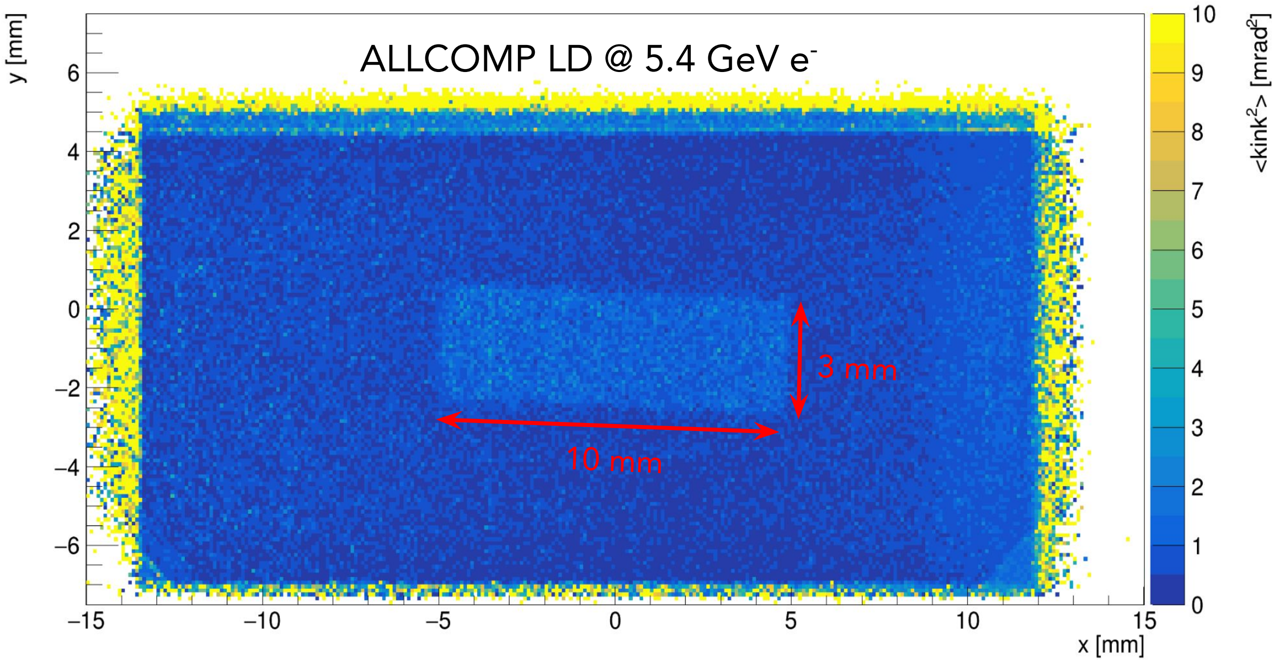


$x/X_0 = 0.417\%$

ERG

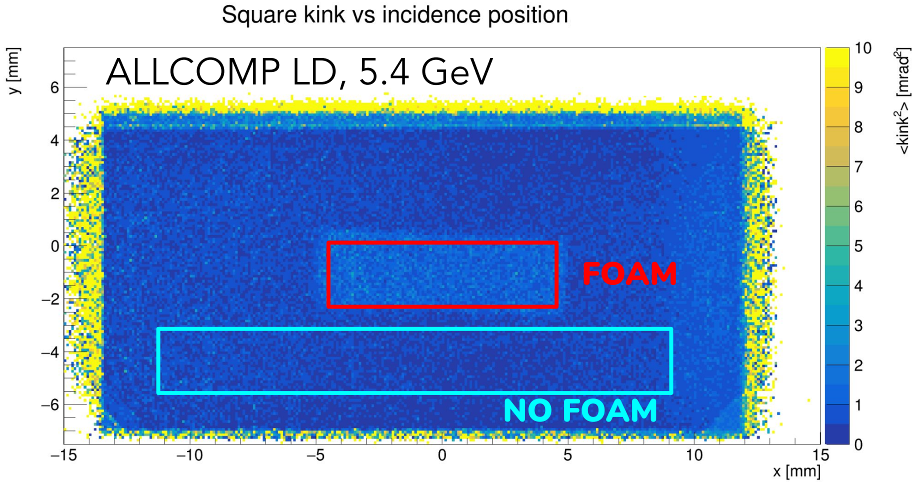
Spatially resolved scattering angle hitmap

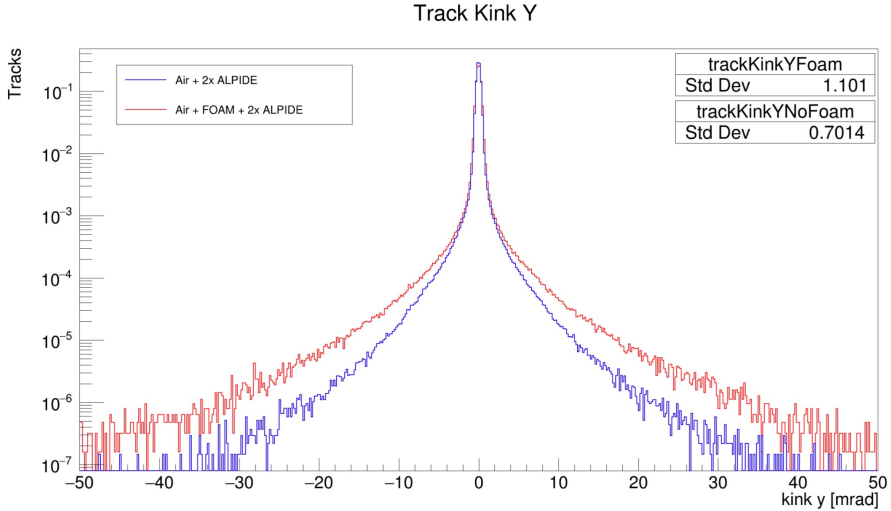
- Reconstructed particle tracks → kink angles: k_x, k_y
- Width of kink angles within a cell (100µm × 100µm): spatially-resolved scattering angle map
- Foam sample recognizable by more scattering



Kink angle distributions: foam vs no-foam

- Define regions of interest
  - → FOAM only area
  - → NO FOAM area
- Compute distribution of kink angles
- Gauss fit (98% core ~2.33σ, no tails)





	FOAM $X_{0,\ FOAM} = 0.0061$	NO FOAM $X_{0,\ NO\ FOAM} = 0.0012$
$\sigma_{98\%}$ (mrad)	0.299	0.258
$\theta_{0\ (Highland)}$ (mrad)	0.159	0.0649

Final results

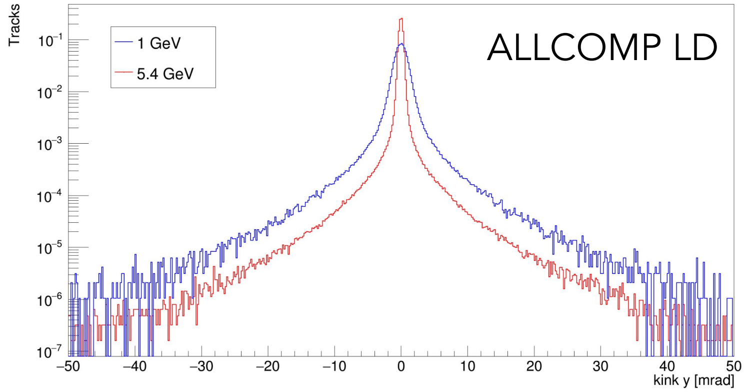
$$\sigma_{diff} = \sqrt{\sigma^2_{98\%\ FOAM} - \sigma^2_{98\%\ NO\ FOAM}}$$

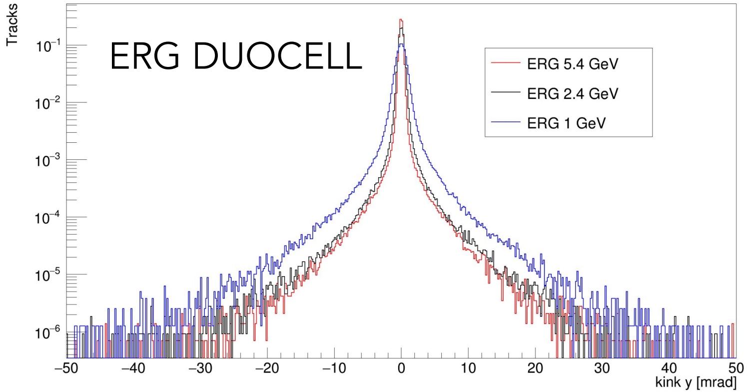
ALLCOMP LD

p [GeV]	σ_{FOAM}	$\sigma_{NO\ FOAM}$	$\sigma_{diff\ (quadr)}$	$\theta_{0\ Highland}$ [mrad]
1	0.978	0.623	0.754	0.764
5.4	0.299	0.258	0.151	0.141

ERG DUOCELL

p [GeV]	σ_{FOAM}	$\sigma_{NO\ FOAM}$	$\sigma_{diff\ (quadr)}$	$\theta_{0\ Highland}$ [mrad]
1	0.787	0.608	0.5	0.579
2.4	0.396	0.337	0.208	0.241
5.4	0.276	0.258	0.098	0.107





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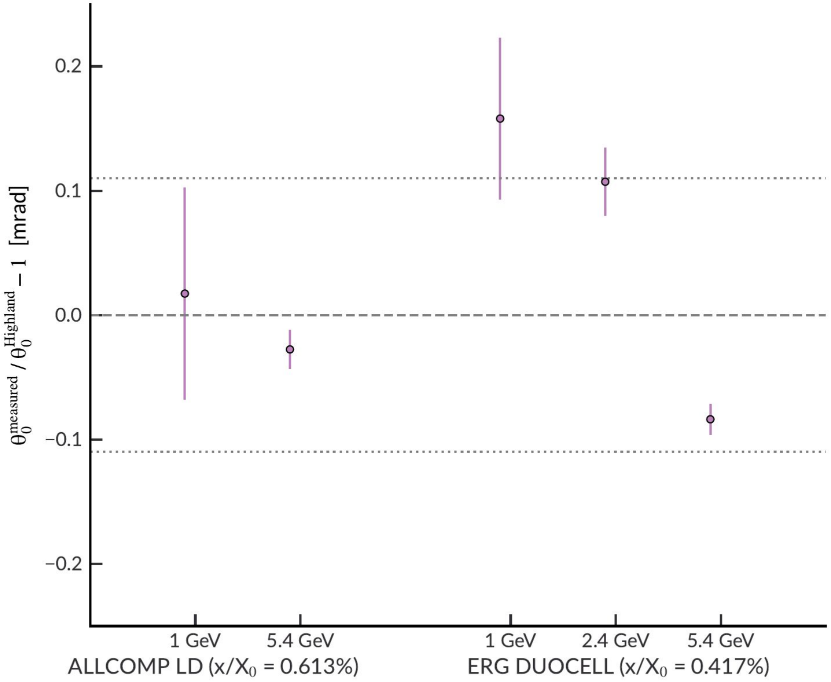

Summary

- ➢ Material budget imaging → powerful technique for measurements of the material budget
- ➢ For the carbon foam choice in ITS3
  → ERG DUOCELL_AR shows the best results in terms of scattering

- ➢ Carbon foam support for next-generation Inner Tracking System in LHC LS3
- ➢ Based on wafer scale, ultra-thin bent MAPS
  → ITS3 will push the technology even further, approaching a massless detector