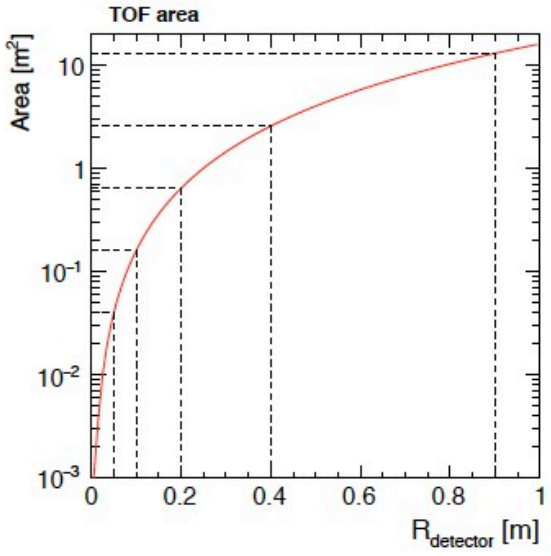
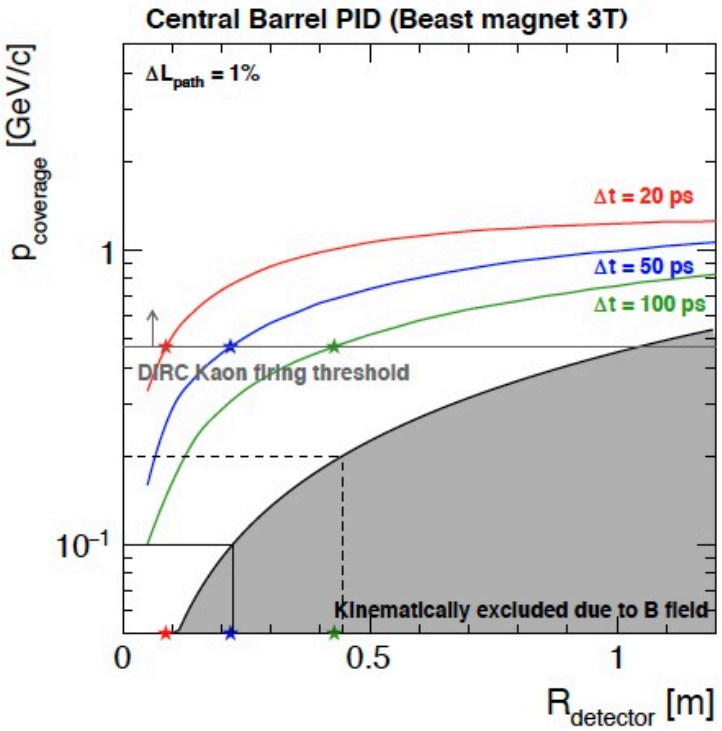
Barrel TOF for ATHENA (B=3T)

Wenqing Fan and Rey Cruz Torres (LBNL)

Effect of B field and timing resolution

- TOF with better intrinsic resolution can be put closer to the interaction point → smaller area





20ps: 5-25cm (45cm) to reach down to 0.1GeV (0.2GeV)

50ps: 10-25cm (45cm) to reach down to 0.1GeV (0.2GeV)

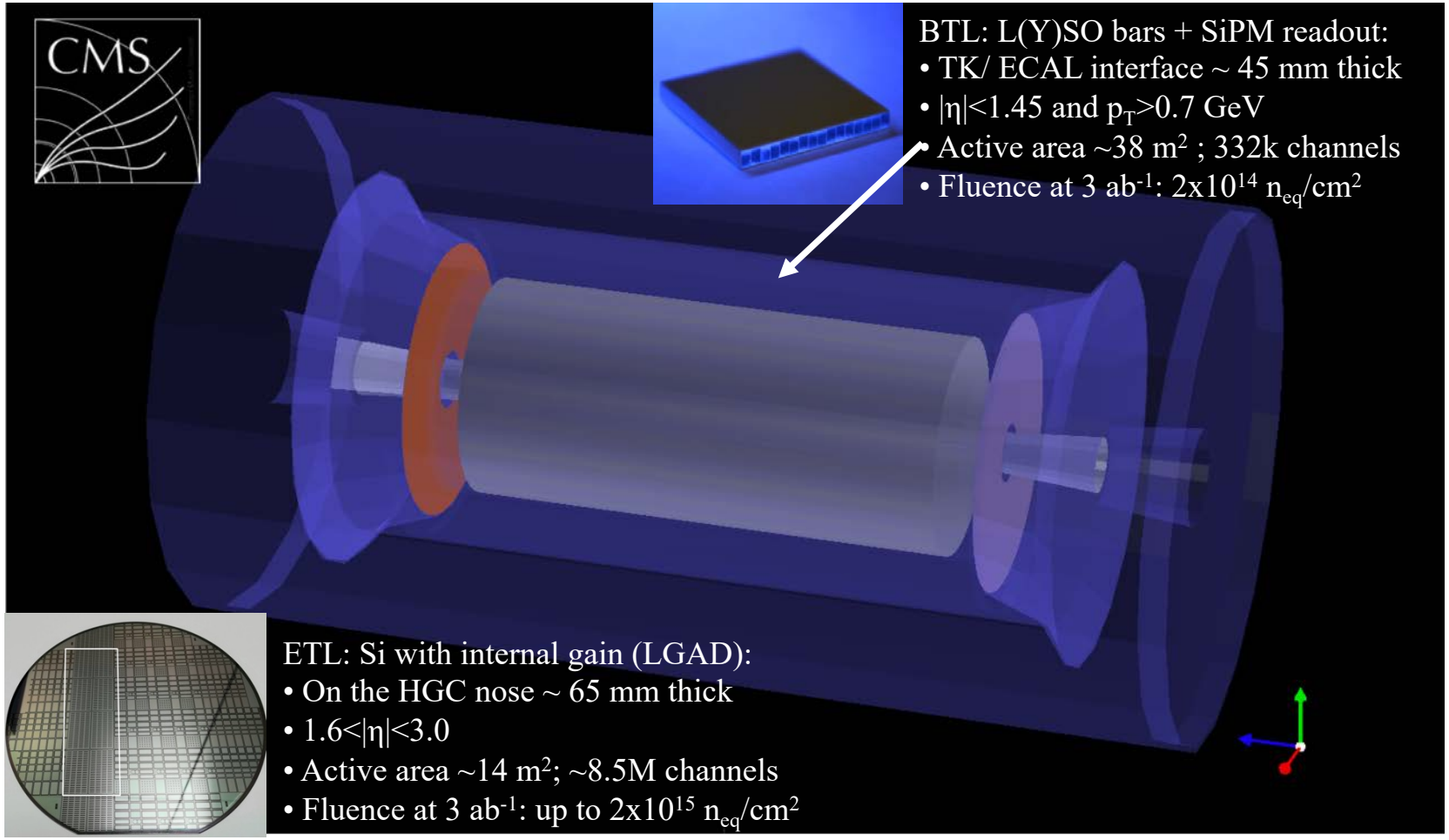
100ps: cannot reach down to 0.1GeV, ~45cm reach down to 0.2GeV

3

To provide PID for low p in the Barrel region @ 3T magnetic field, the TOF layer needs to be placed not too far from the beam.

A 30 (40) ps resolution of TOF at R=25 (45) cm can cover 0.1 (0.2)<p<0.7 GeV/c. A 20 ps TOF at 45 cm will reach 1 GeV/c.

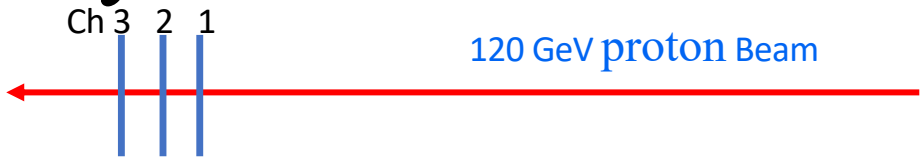
CMS MIP Timing Detector (2026+)



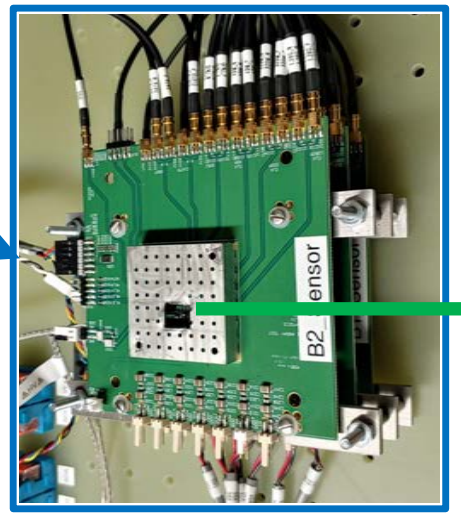
- Thin layer between tracker and calorimeters
- Hermetic coverage $|\eta| < 3.0$
- Time resolution of 35 ps for minimum ionization particles before irradiation
- Sufficient radiation tolerance to maintain σ_t<60 ps up to 3000 fb^{-1}

The ETROC Project: ASIC Development for CMS MTD Endcap Timing Layer (ETL) Upgrade, Zhenyu Ye, APS April meeting 2021

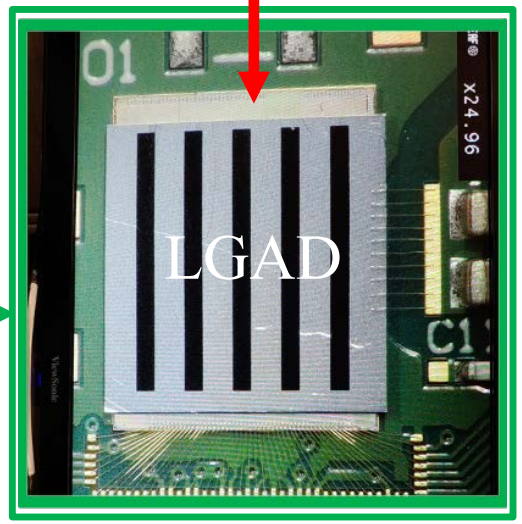
CMS LGAD+ETROC1 – Preliminary Test Beam Results

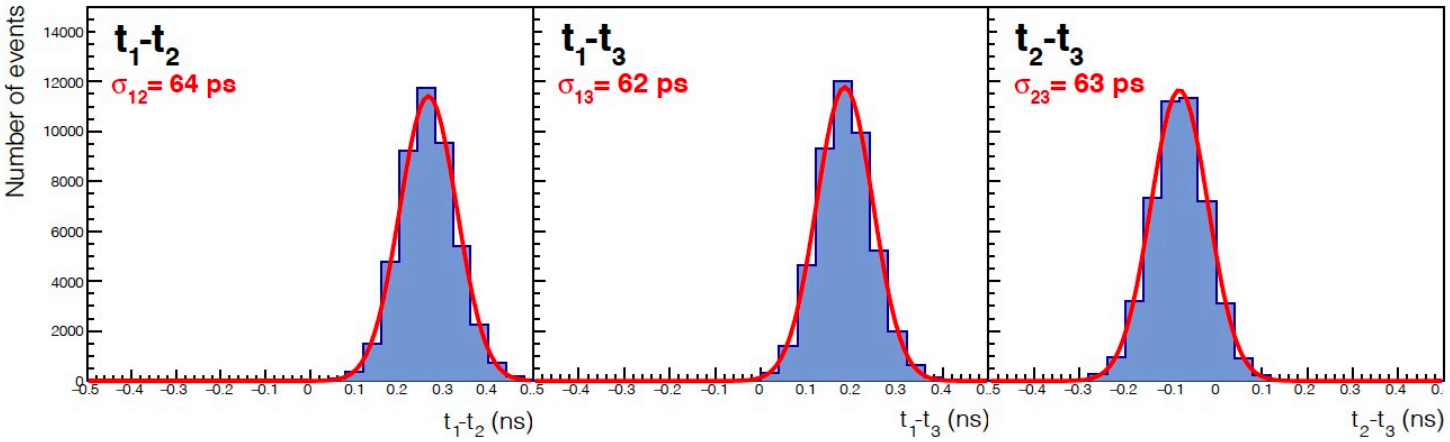


ETROC1 Test Board



ETROC1





From preliminary analysis of the data from ongoing beam test at FNAL, the resolution of single LGAD+ETROC1 devices with large signal amplitude is 42-46 ps.

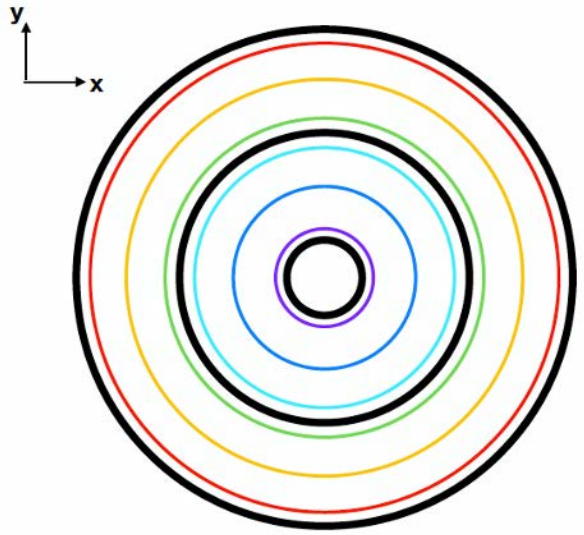
$$\sigma_i = \sqrt{0.5 \cdot \left(\sigma_{ij}^2 + \sigma_{ik}^2 - \sigma_{jk}^2\right)}$$

The ETROC Project: ASIC Development for CMS MTD Endcap Timing Layer (ETL) Upgrade, Zhenyu Ye, APS April meeting 2021

Barrel TOF for ATHENA (B=3T)

Rey Cruz Torres (LBNL)

LGAD Placement



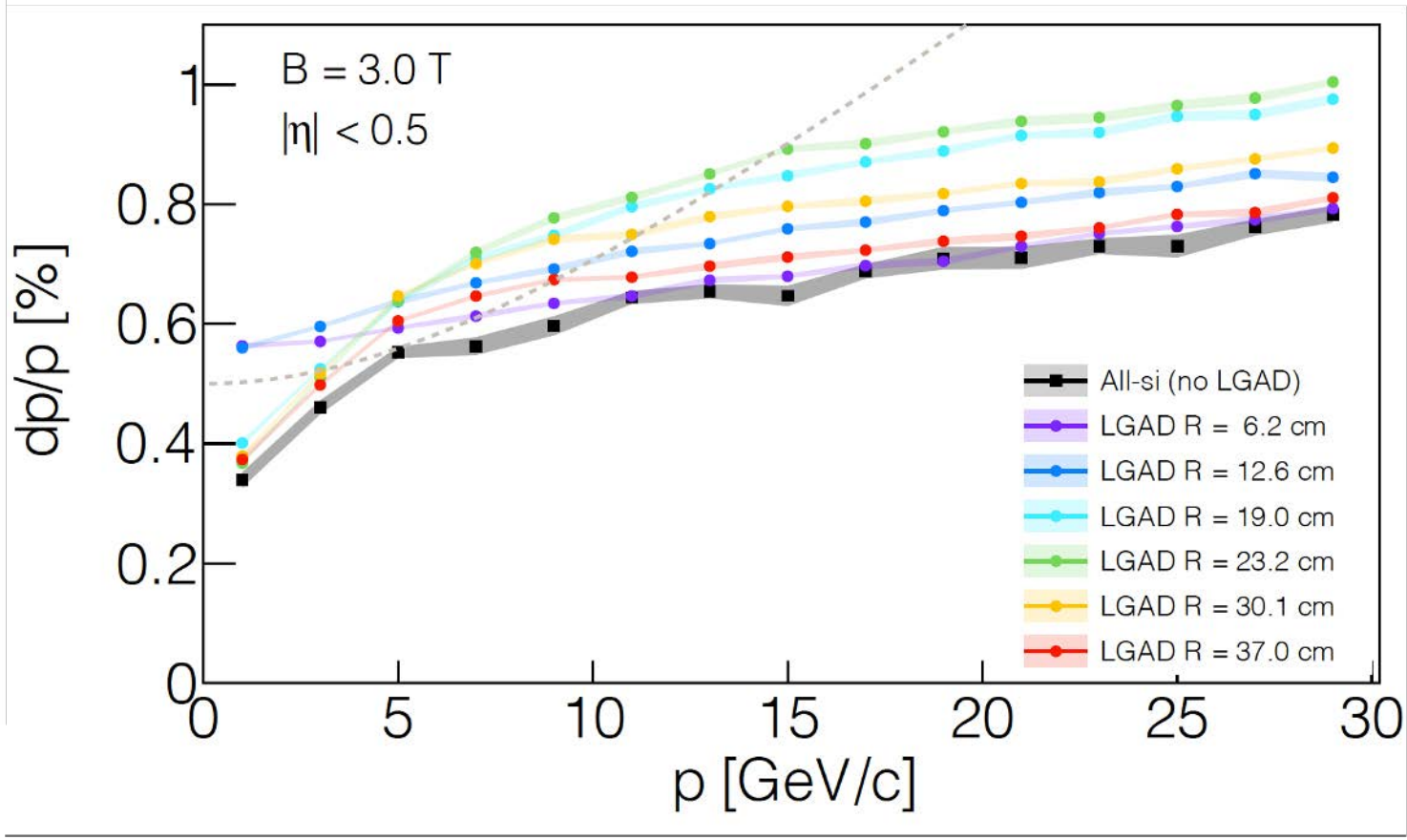
All-silicon tracker layers

Barrel layer	radius [cm]
1	3.30
2	5.70
3	21.00
4	22.68
5	39.30
6	43.23

Black: all-si layers

Colored: different placements of LGAD

R_{LGAD} = 6.2 cm
R_{LGAD} = 12.6 cm
R_{LGAD} = 19.0 cm
R_{LGAD} = 23.2 cm
R_{LGAD} = 30.1 cm
R_{LGAD} = 37.0 cm



MAPS: 10um* 10um pixel pitch
Vertex layer: 0.03% X0, Tracking layer: 0.55% X0

LGAD: 1.1% X_0, $500/\sqrt{12}$ μm in both phi and Z

All-Si tracker: adding a LGAD layer inside the tracker may deteriorate the momentum resolution

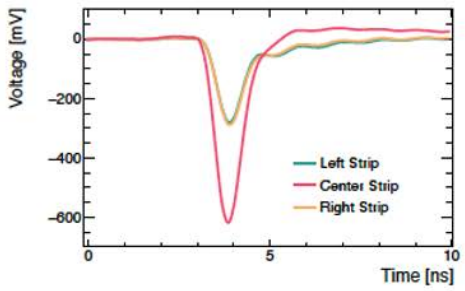
AC-Coupled LGAD

Alexandro Tricoli (BNL)

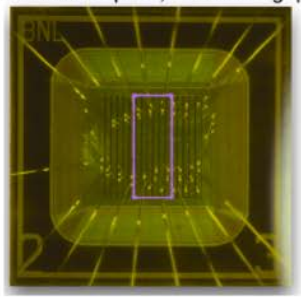
Performance of BNL's AC-LGADs

- Time resolution of AC-LGADs can be controlled to match LGADs (e.g. gain and n+ layer doping)
- AC-LGADs can measure space points with resolution better than pixel detectors by exploiting signal sharing between AC-coupled electrodes
- Measurements Space+Time resolution
  - Lab measurements with lasers and radioactive sources
  - FNAL Test Beam Facility (FTBF) with 120 GeV protons

AC-LGADs
- **Fast-timing: ~30 ps** (50 μm thickness)
- **Pixelation** as in pixel detector ~10s μm
- **High S/N** ratio
- **100% fill factor**
- **Edgeless** demonstrated: **<150 μm**
- **Signal sharing → improved space resol.**
- **Produced by BNL**



100 micron pitch, 20 micron gaps



→ <10-15 μm space resolution
→ ~30 ps time resolution
→ 100% particle detection efficiency

Signal induced on neighboring electrodes is exploited to improve space resolution

U.S. DEPARTMENT OF ENERGY

5

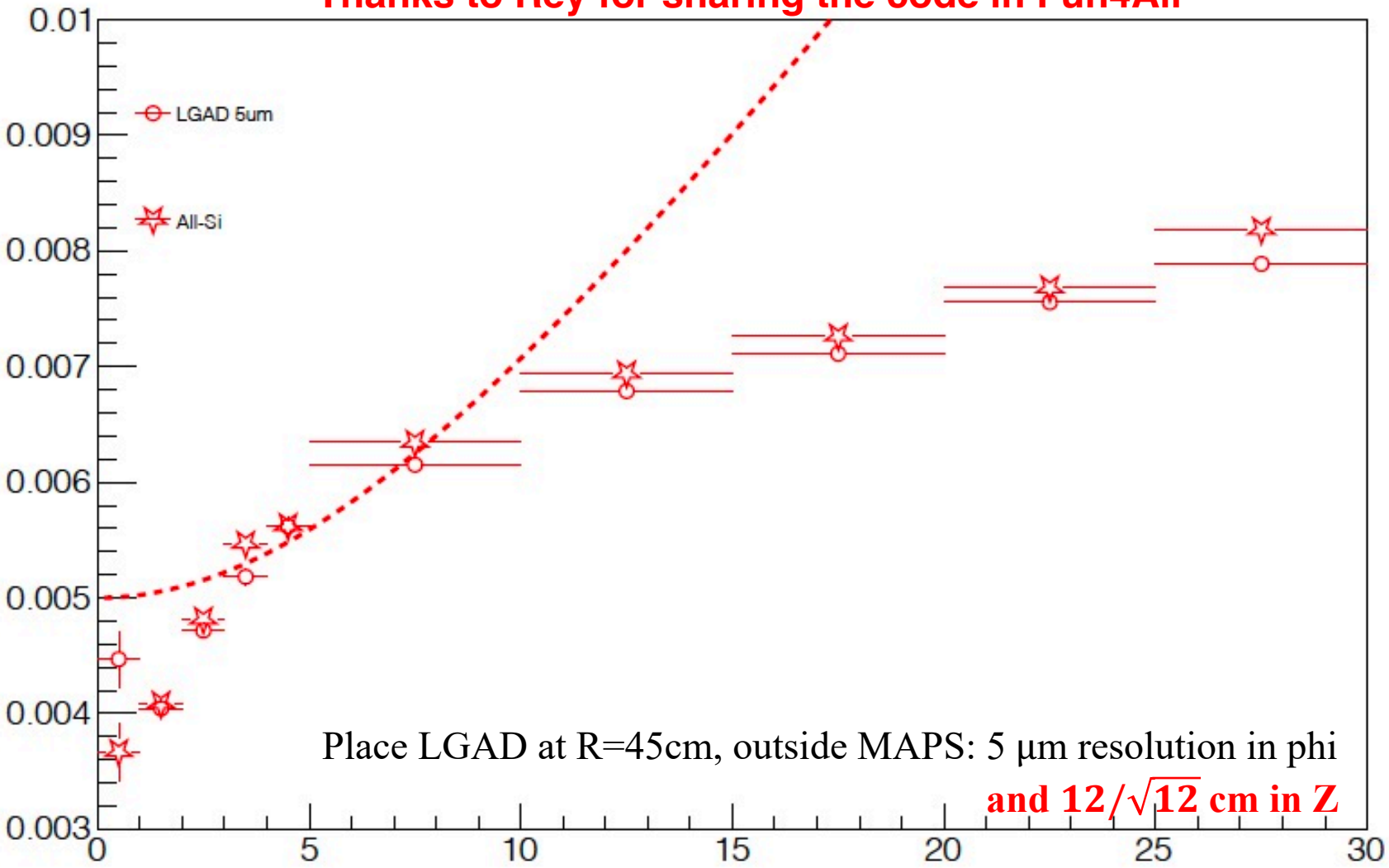
BROOKHAVEN NATIONAL LABORATORY

AC LGAD can provide both precise time (30ps) and space resolution (<10-15 μm), serving dual purposes of PID and tracking

Further improvements in time resolution to 20 ps and position resolution to microns are under study.

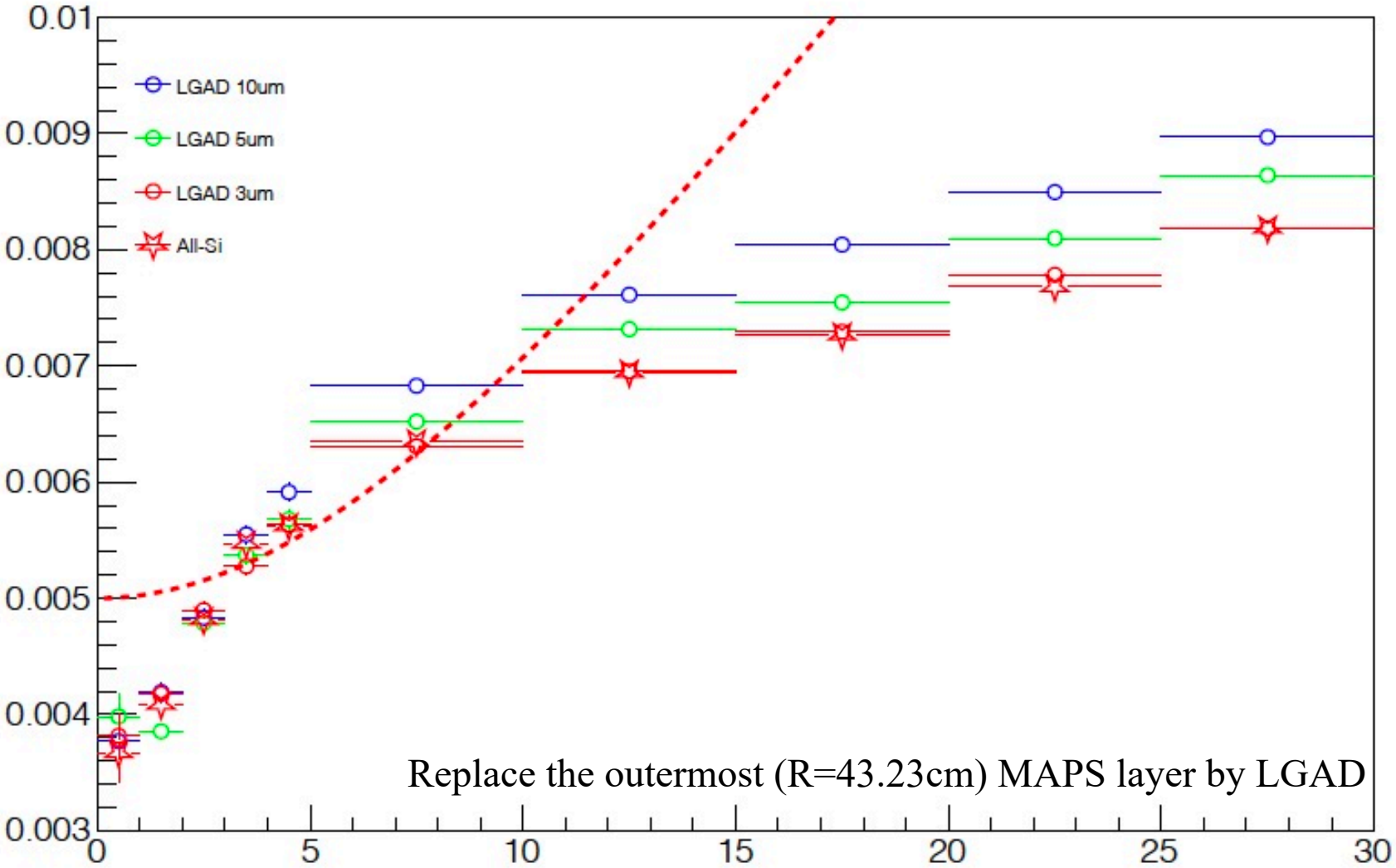
Barrel TOF for ATHENA (B=3T)

Thanks to Rey for sharing the code in Fun4All



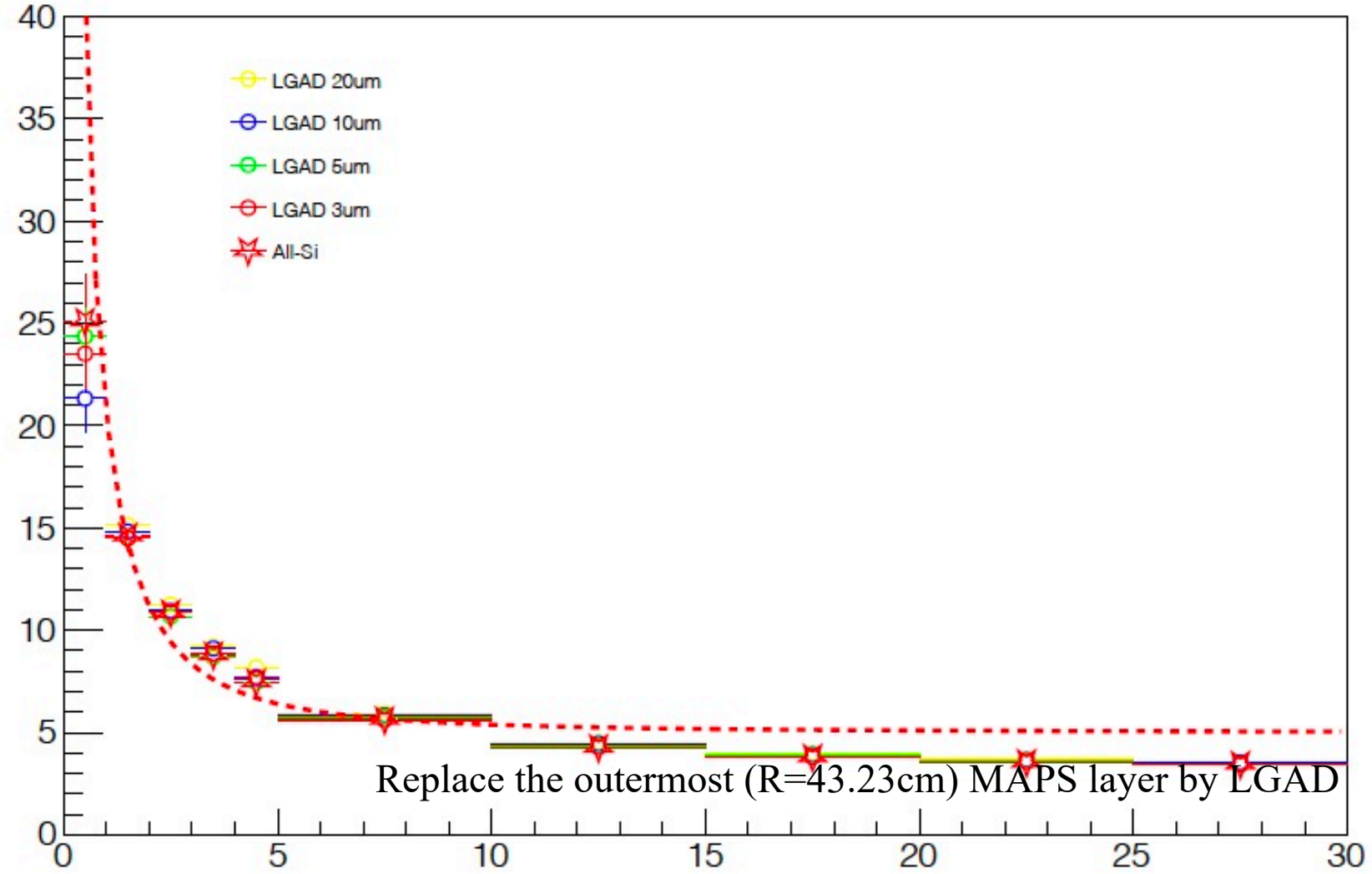
All-Si tracker: adding a LGAD layer outside MAPS won't deteriorate the momentum resolution

Barrel TOF for ATHENA (B=3T)



All-Si tracker: replacing the outmost MAPS by LGAD, momentum resolution can be maintained with 3μm resolution in azimuthal direction, **insensitive to position resolution in Z**

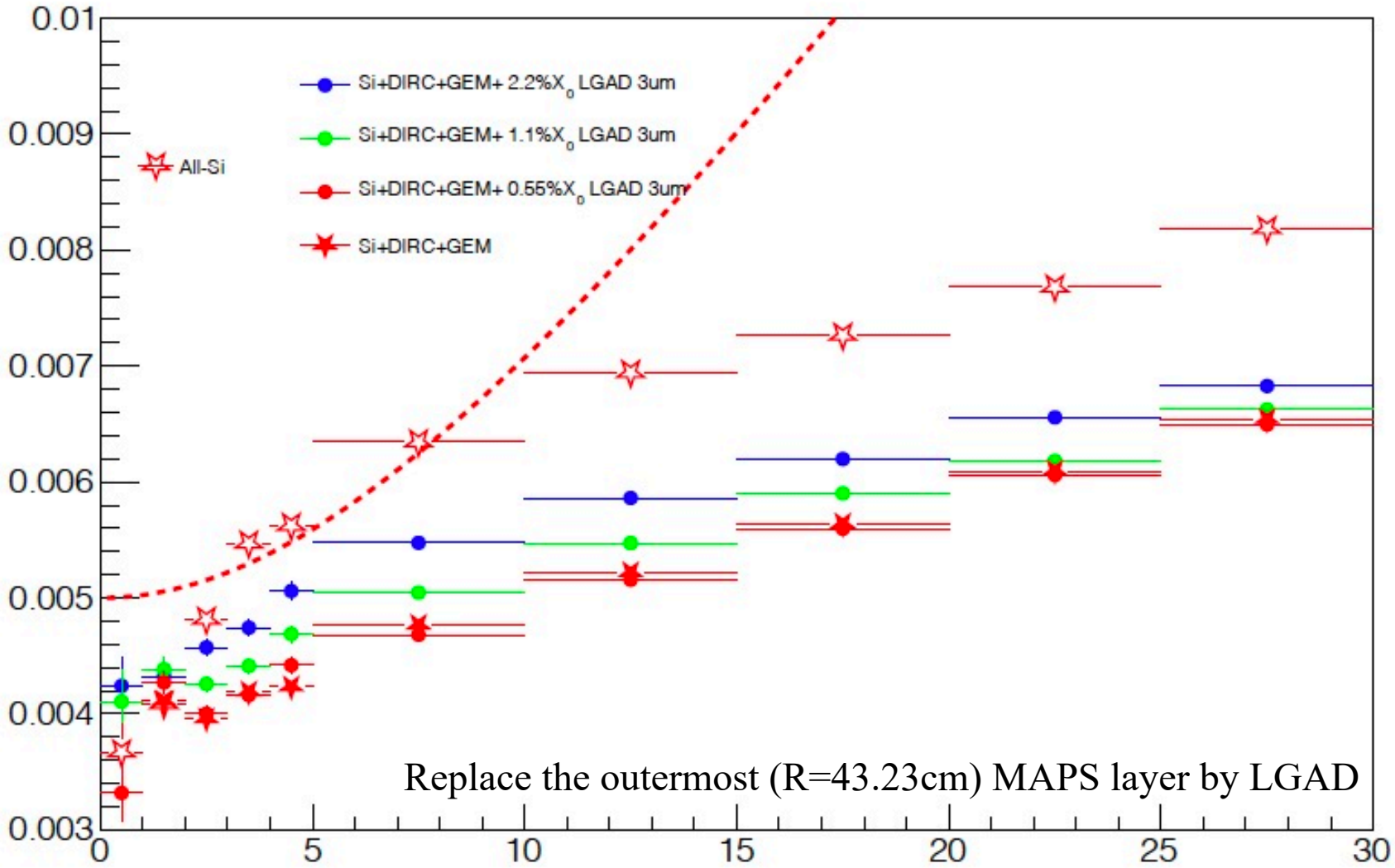
Barrel TOF for ATHENA (B=3T)



All-Si tracker: replacing the outmost MAPS by LGAD

DCA resolution is insensitive to the LGAD position resolution

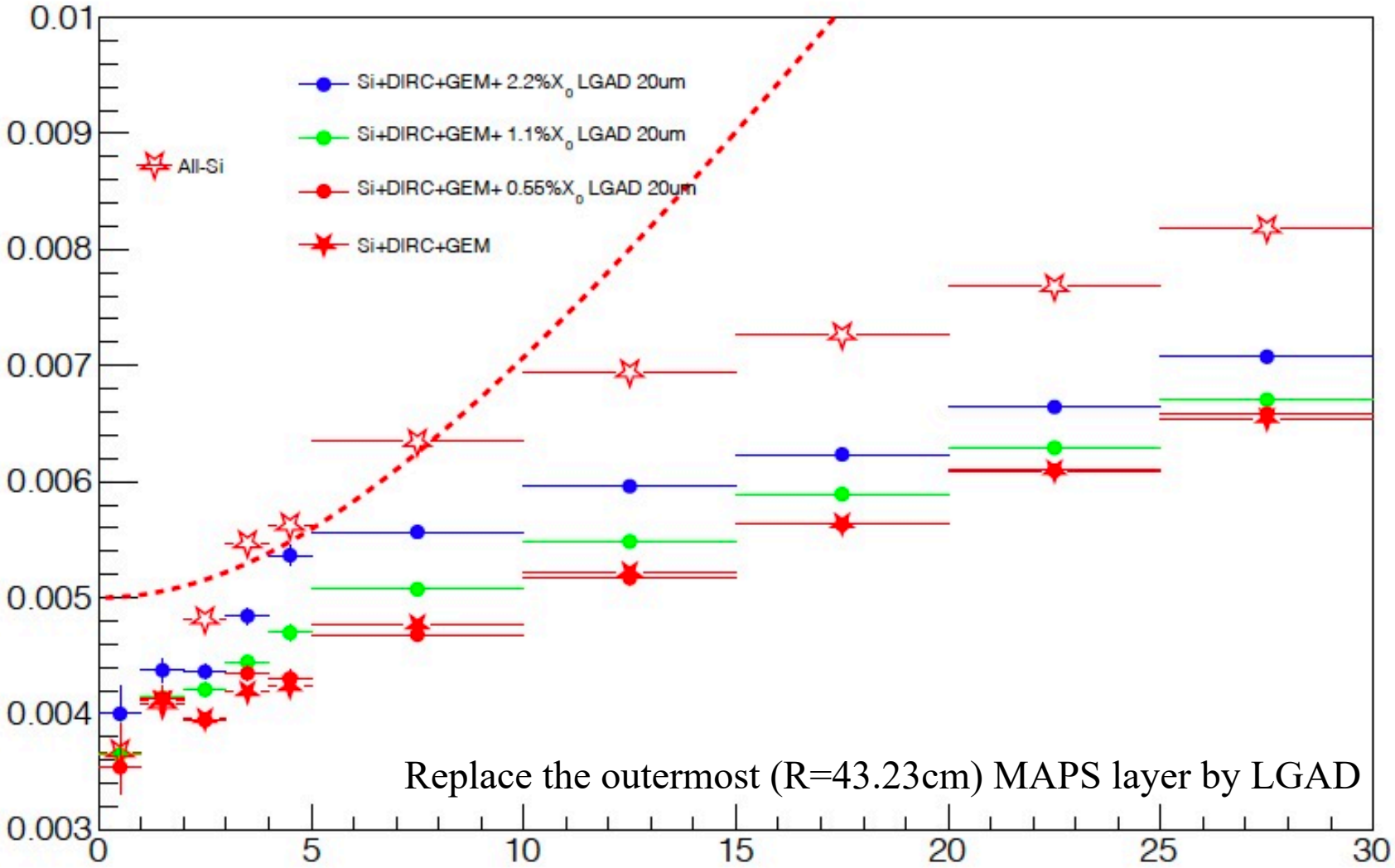
Barrel TOF for ATHENA (B=3T)



GEM: R=92 cm,
50*50μm^2 resolution

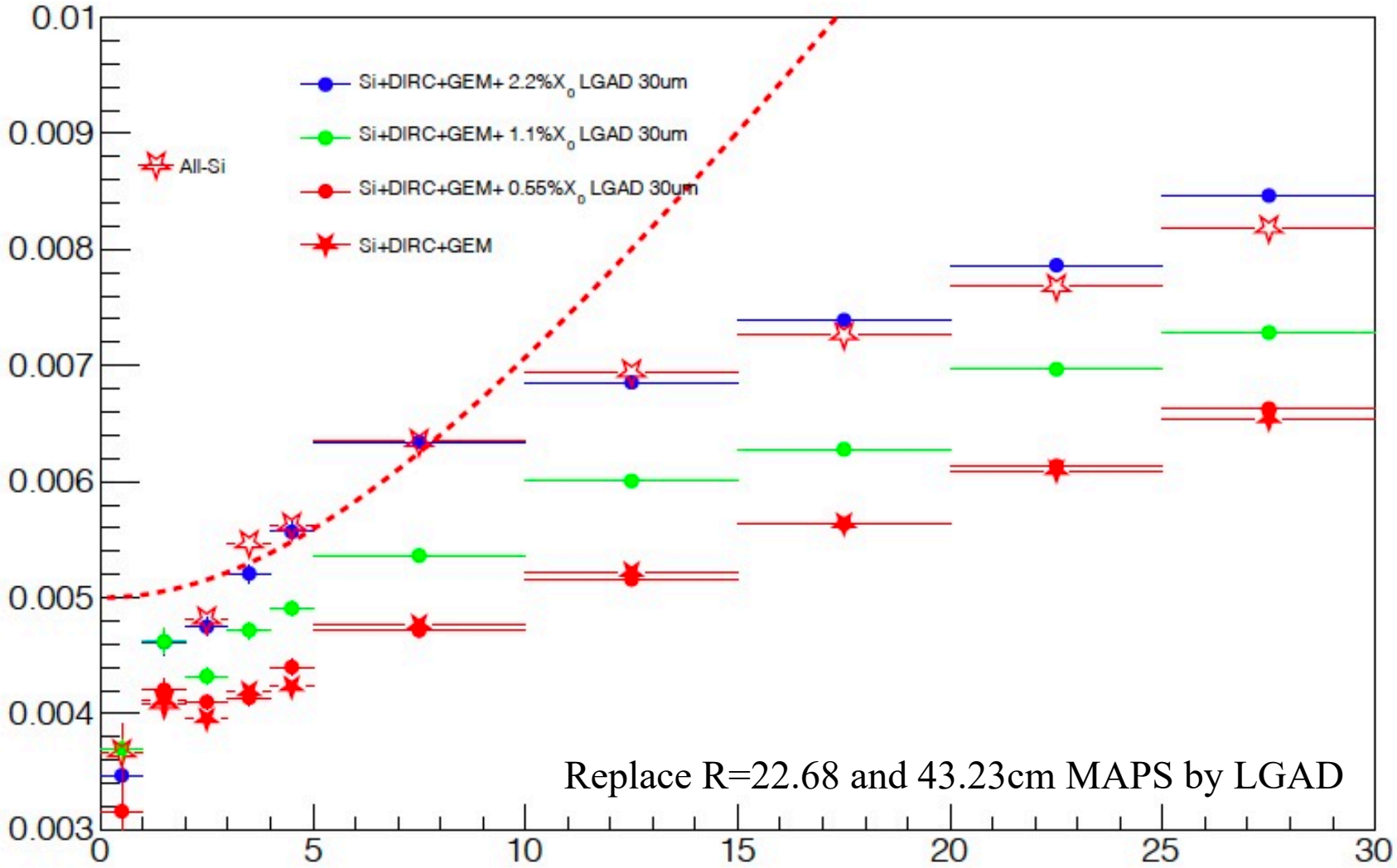
Hybrid tracker: replacing the outmost MAPS by LGAD, momentum resolution can be maintained with 0.55%X_0 material budget, **insensitive to position resolution**

Barrel TOF for ATHENA (B=3T)



Hybrid tracker: replacing the outmost MAPS by LGAD, momentum resolution can be maintained with 0.55%X_0 material budget, **insensitive to position resolution**

Barrel TOF for ATHENA (B=3T)



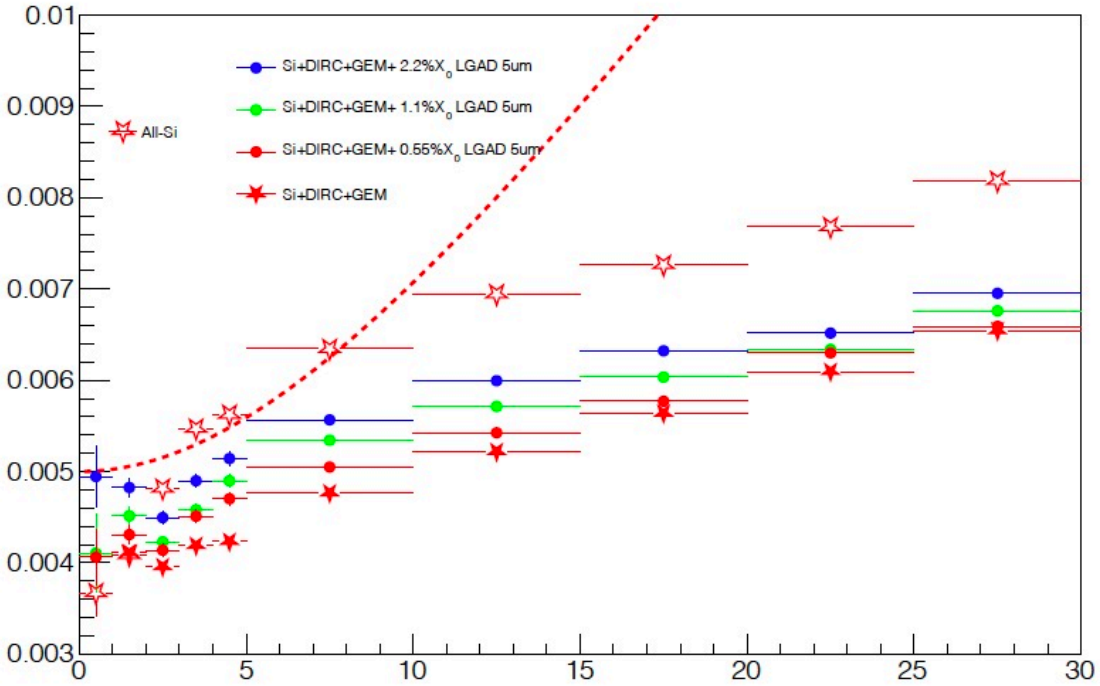
Hybrid tracker: replacing the R=23.68 and 43.23cm MAPS layres by LGAD, momentum resolution can be maintained with 0.55%X_0 material budget, **insensitive to position resolution**

Barrel TOF for ATHENA (B=3T) - Summary

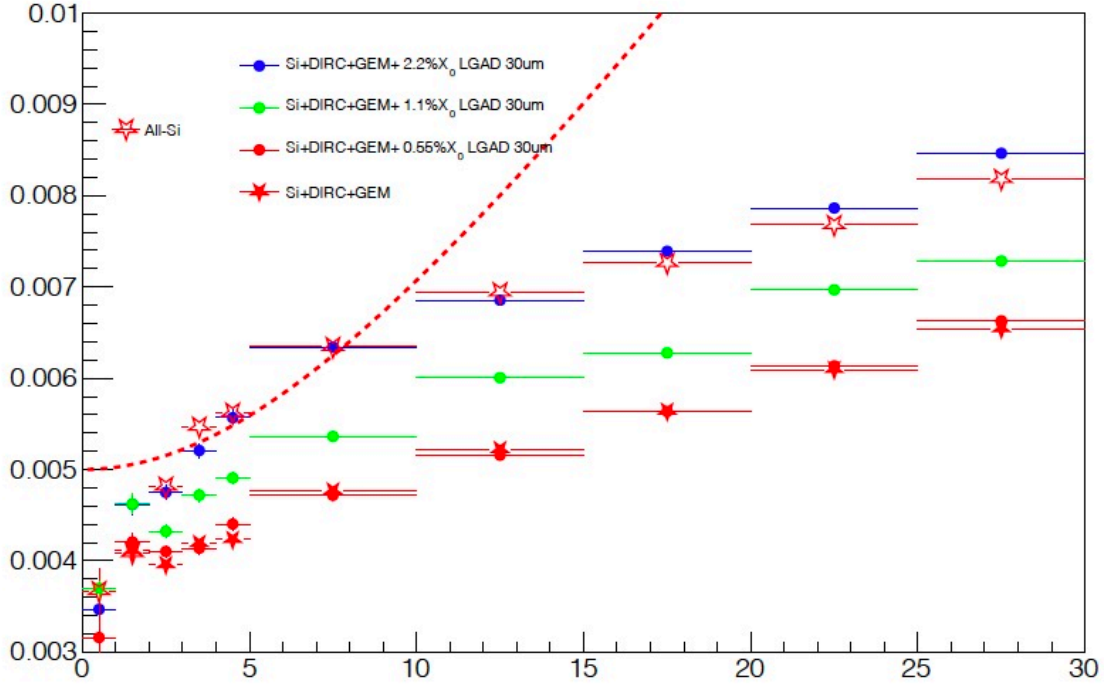
- **To provide PID for low p in the barrel region @ 3T magnetic field, TOF needs to be placed not too far from the beam. To cover 0.1(0.2)<p<0.7 GeV/c, a 30 (40) ps resolution of timing layer at R=25 (45) cm can do the job, which is within the reach of the current LGAD technology.**

- **An important design consideration would be to have low material budget to reduce the impact on the momentum resolution for the hybrid-tracker design, while the position resolution along the beam direction does not seem to play any significant role. Depending on the exact tracker design, strip AC LGAD with good position resolution (3um) in the azimuthal direction could be used as additional tracking layers or replacing outer MAPS layers.**

Barrel TOF for ATHENA (B=3T)



Add one LGAD layer (R=45cm) outside the Si



Replace R=22.68 and 43.23cm tracker layer by LGAD