Overview of ePIC Tracking System

Francesco Bossù (CEA), Kondo Gnanvo (JLab), Laura Gonella (U. of Birmingham), Xuan Li (LANL).

On behalf of EIC ePIC Detector Tracking Working Group

ePIC Collaboration Meeting

Jefferson Lab, January 09 – 11, 2023

Outline

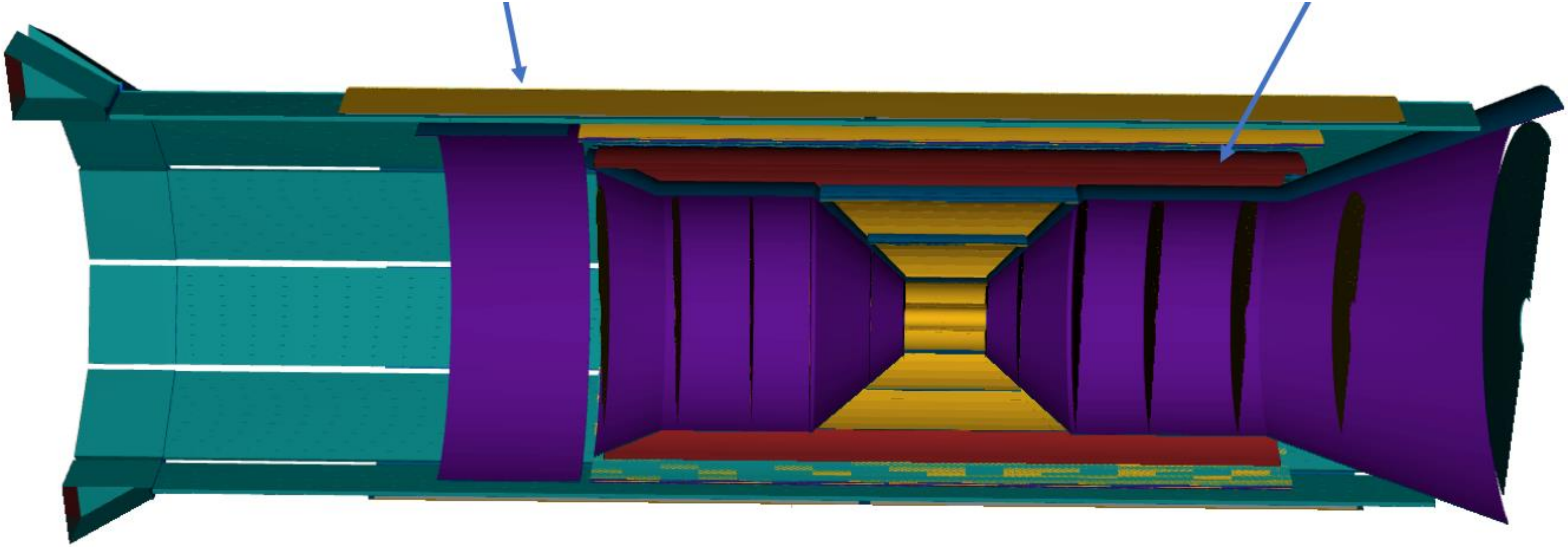
- Overview of ePIC tracking detector
  - Current design geometry
  - Tracking performance
- Update on tracking detector technologies
  - ESC Consortium – Si R&D effort
  - eRD108 Consortium – MPGD R&D effort
- Remaining issues
  - Background simulation
  - Further detector geometry Optimization
  - Integration & services

ePIC Tracking Detector WG

- ePIC Tracking working group:
  - Conveners: Xuan Li (xuanli@lanl.gov), Kondo Gnanvo (kagnanvo@jlab.org), Laura Gonella (laura.gonella@cern.ch), Francesco Bossu (francesco.bossu@cea.fr)
  - Email mailing list: eic-projdet-tracking-l@lists.bnl.gov
  - We have weekly meetings scheduled at 11:00AM US eastern time every Thursday and the meeting indico link: https://indico.bnl.gov/category/404/
  - Mattermost channel: https://eic.cloud.mattermost.com/main/channels/tracking
  - WIKI page: https://wiki.bnl.gov/EPIC/index.php?title=Tracking#Tasks_list
- ESC : EIC Silicon Consortium
  - Mailing list: https://lists.bnl.gov/mailman/listinfo/eic-rd-silicon-l
  - Indico: https://indico.bnl.gov/category/386/
  - Contacts: Laura Gonella (laura.gonella@cern.ch), Giacomo Contin (giacomo.contin@ts.infn.it), Ernst Sichtermann (epsichtermann@lbl.gov)
- eRD108: EIC MPGD Consortium
  - Contacts: Kondo Gnanvo (kagnanvo@jlab.org), Francesco Bossu (francesco.bossu@cea.fr)
  - Bi-weekly meetings on Wednesday at 1:30PM EST - indico link: https://indico.bnl.gov/category/425/
  - WIKI page: https://wiki.bnl.gov/eic/index.php/Eic-rd-meeting

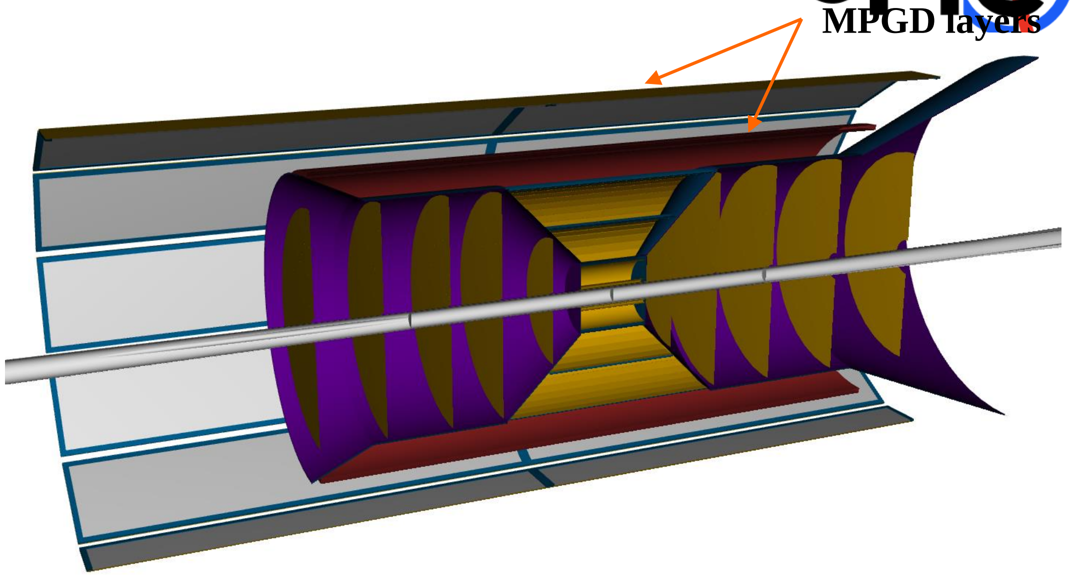
ePIC Barrel tracker: Current configuration

- The EPIC tracking detector consists of the MAPS, MPGD and AC-LGAD layers/disks. Latest geometry has been implemented in the default simulation configuration.
  - MAPS: 5 barrel layers (3 vertex layers and 2 sagitta layers), 5 hadron-endcap disks, 5 electron-endcap disks.
  - MPGD: 1 MPGD Barrel layer in the “Bryce Canyon” tag, 1 MPGD Barrel layer and 1 MPGD DIRC layer in the “Arches” tag.
  - AC-LGAD: 1 AC-LGAD barrel layer and 1 AC-LGAD hadron endcap disk



Barrel tracker: Current configuration

- Vertex layers:
  - Radii of two innermost vertex layers optimised for beam pipe bake out (5 mm clearance) and ITS3 sensor size.
  - 3rd vertex layer at r = 120 mm, dual purpose vertexing & sagitta layer, without increase in material (i.e. 0.05% X/X0, bent layer).
- Sagitta layers:
  - Moved at larger radii to increase lever arm with high precision measurements to improved momentum resolution.
  - Layer at 27 cm made two halves of 0.25% X/X0.
- Cyl. Micromegas & AC-LGAD layers:
  - Additional space point for pattern recognition / redundancy
  - Ongoing geometry optimization
- µRWELL planar layer behind hpDIRC
  - Impact point and direction for the ring seeding of hpDIRC
  - Additional space point for pattern recognition / redundancy
  - Not be required if imaging calorimeter is used

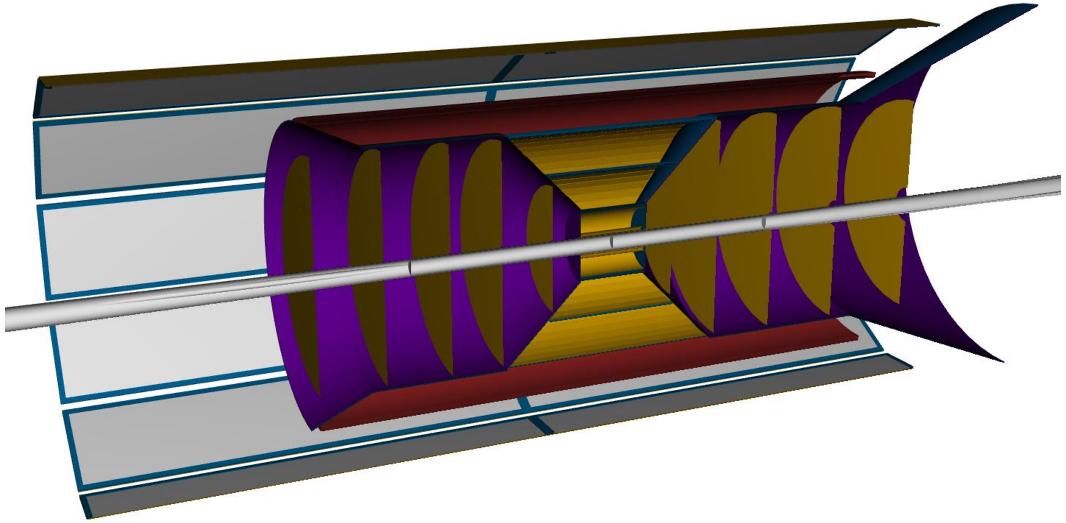


BARREL	r [mm]	l [mm]	X/X0 %
Si vertex layer 0	36	270	0.05
Si vertex layer 1	48	270	0.05
Si layer 2	**120**	270	**0.05**
Si sagitta layer 3	**270**	540	**0.25**
Si sagitta layer 4	**420**	840	0.55
Cyl.Micromegas layer	550	2300	0.5
AC-LGAD layer	640	2400	1.0
µRWELL behind DIRC	**730**	3420	~1.0%

See talk by Stephen & Ernst at https://indico.bnl.gov/event/16261/
See talk by Laura & Ernst at https://indico.bnl.gov/event/16582/

ePIC end cap trackers: Current configuration

- Number of disks in the electron direction increased to improve acceptance at high eta/increase number of points on track.
  - At |eta| >= 3 in the electron going direction, hits on three disks only in reference detector. Insufficient considering noise and inefficiency.
- Use all available space in z to increase lever arm.
  - The table below show the current layout implemented in simulation. This is the envelop assuming the pfRICH in the electron going direction. The disk design can be symmetric if the mRICH is used (i.e. envelop on electron side up to ~1350 mm).



DISKS	+z [mm]	-z [mm]	X/X0 %
Disk 1	250	-250	0.24
Disk 2	450	-450	0.24
Disk 3	700	-650	0.24
Disk 4	1000	-900	0.24
Disk 5	**1350**	**-1150**	0.24

See talks by Ernst at https://indico.bnl.gov/event/16582/ and https://indico.bnl.gov/event/17348/

Tracking performance

- Performance studies of the current ePIC tracker configuration are presented in detail in next three talks by **Stephen, Wenqing and Rey** https://indico.bnl.gov/event/17621/
- Will just present two slides that highlight the areas to focus our next effort for the ePIC detector geometry optimization
  - Studies of the average number of hits per track for performance optimisation
  - Study of the role of the MPGD and AC-LGAD layers in the barrel tracker

Tracking WG 1h

Speakers: Francesco Bossu (CEA-Saclay), Kondo Gnanvo (Jefferson Lab), Laura Gonella (University of Birmingham), Xuan Li (Los Alamos National Laboratory)

Tracking overview 20m

Speaker: Kondo Gnanvo (Jefferson Lab)

Tracking momentum and spatial resolution (online) 10m

Speaker: Stephen Maple (University of Birmingham)

Track angular resolution and magnetic field dependence 10m

Speaker: Wenqing Fan (Lawrence Berkeley National Laboratory)

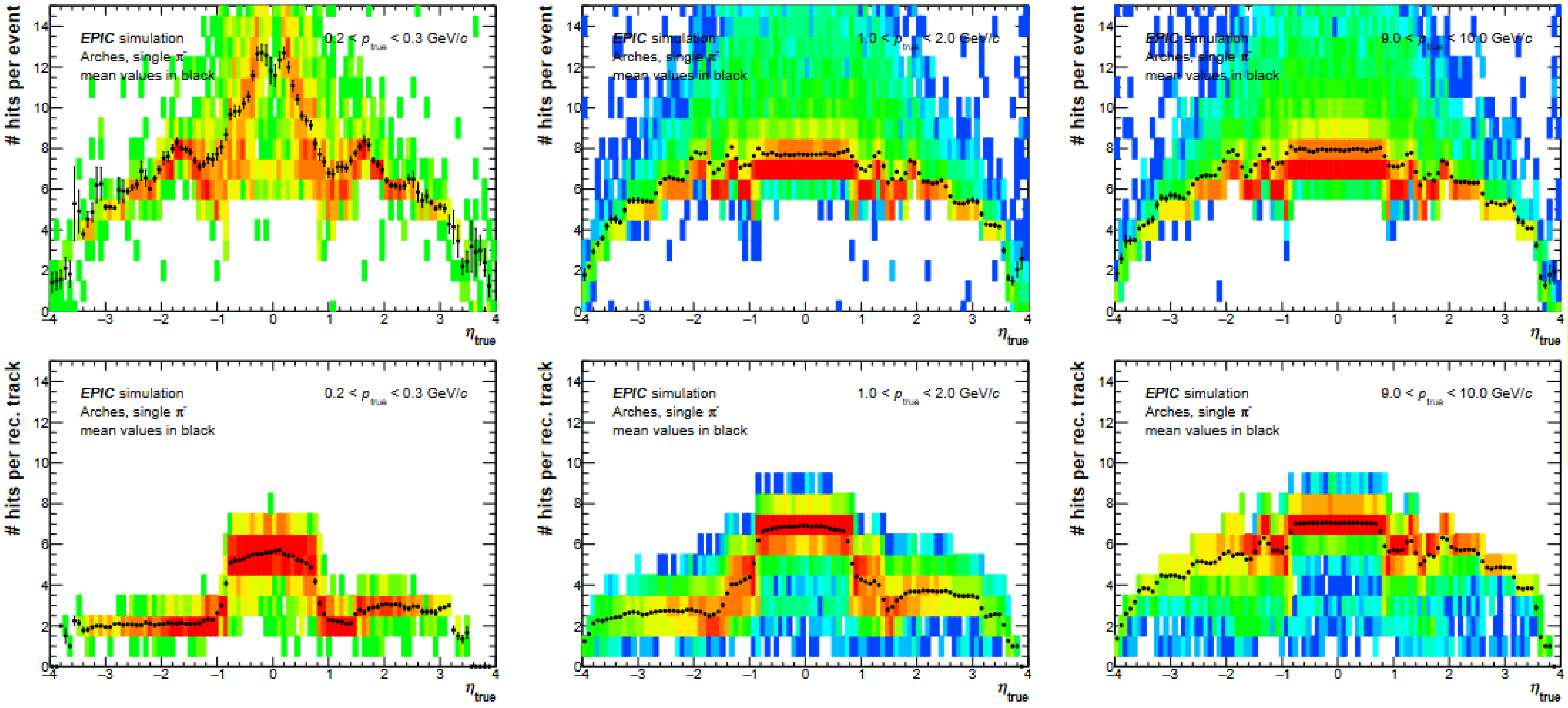
Background and track reconstruction software (online) 15m

Speaker: Reynier Cruz-Torres (Lawrence Berkeley National Lab)

Tracking performance: Average number of hits per track

EPIC detector performance studies with DD4hep and eicrecon: Average number of reconstructued hits per tracks vs. eta and p

Hits per event and per rec. track with ACTS

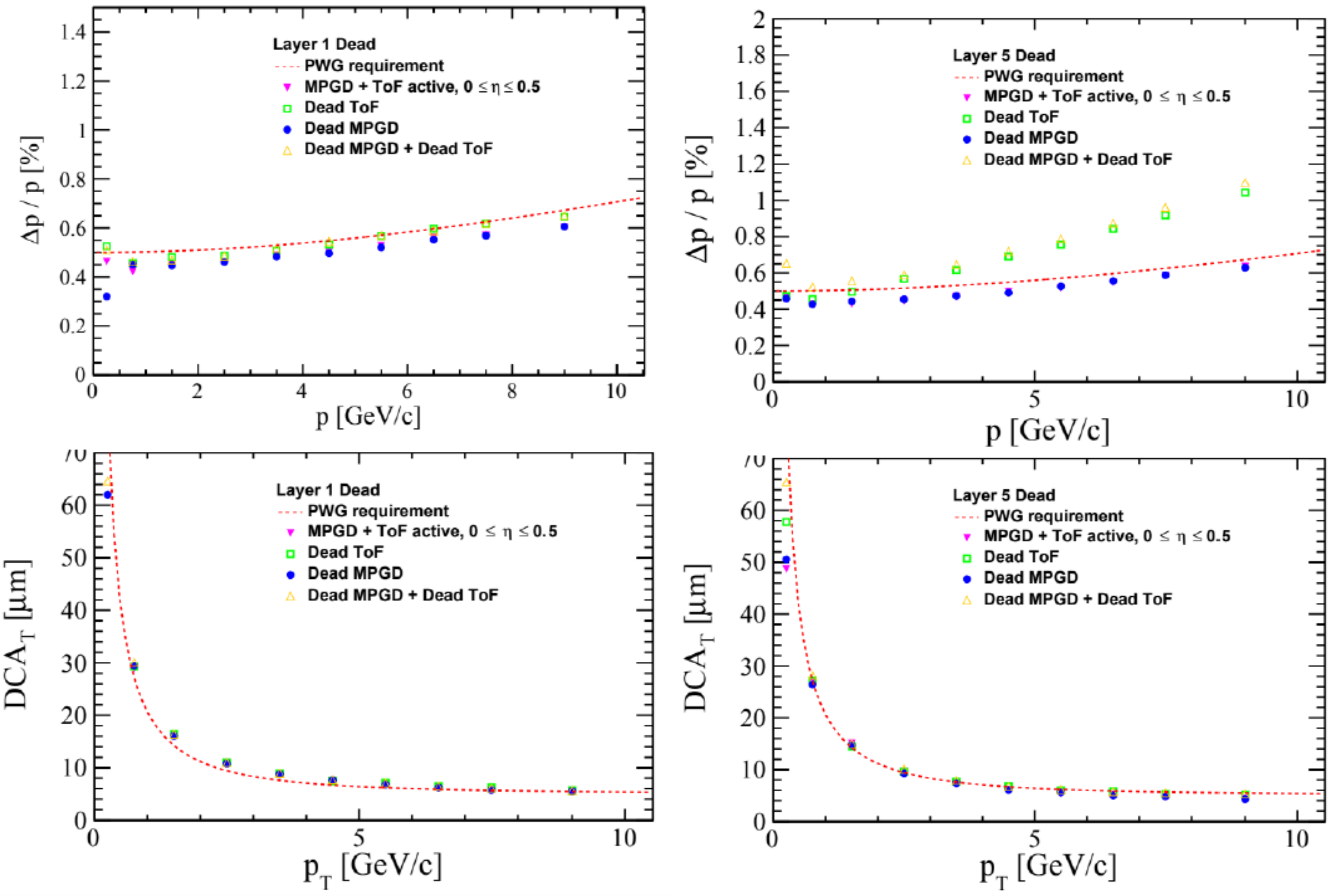


See talk by Nicolas Schmidt at https://indico.bnl.gov/event/17752/

Tracking performance: Role of MPGD & AC-LGAD layers

Simulations in Fun4All to study the contribution of the barrel MPGD and AC-LGAD layers to momentum and DCA resolutions

Missing hit in inner Si layer | **Missing hit in outer Si layer**



See talk by Stephen Maple at https://indico.bnl.gov/event/17752/

Hits in all 5 Si layers:

- Momentum & DCA resolutions dominated by Si layers
- Small improvement of momentum resolution with ToF
- Negligible contribution by MPGD or ToF to either p or DCA measurement

Hits missing in one of the 5 Si layers:

- Negligible impact on momentum and DCA resolution, except for Si layer 5
- Improvement to momentum resolution by ToF layer if missing hit from outer Si layer (layer 5).
- MPGD helps improve performance at low momentum only when hits are missing in both Si and ToF layers

To summarize:

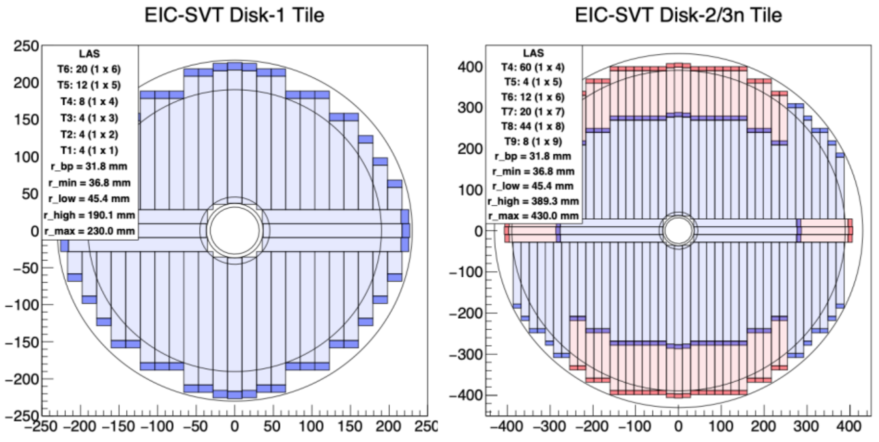
- Barrel MPGD has minimal impact on performance even for redundancy when hit are missing in Si layers
- Performance improvement by ToF layers when single hit missing in Si layers
- MPGD will be mostly needed for pattern recognition
- **Very important study for further optimization of tracking detector geometry**

EIC Silicon Consortium – R&D effort

- Overarching goal is the development and construction of a full tracking and vertexing detector subsystem for the EIC detector(s) based on 65 nm Monolithic Active Pixel Sensors (MAPS),
- Consortium grew out of the previous Generic EIC Detector R&D program; eRD16, eRD18, and eRD25 (2015—2021), contributed to all detector proposals, and many members are active within ePIC,
- Open to collaborators new to the effort,
  - Mailing list: https://lists.bnl.gov/mailman/listinfo/eic-rd-silicon-l
  - Indico: https://indico.bnl.gov/category/386/
  - Contacts: Laura Gonella, Giacomo Contin, Ernst Sichtermann
- Two streams of R&D:
  - Targeted R&D for the ePIC detector:
    - eRD104 – services reduction aims to significantly reduce the all-important services (powering; readout)
    - eRD111 – development of tracking and vertexing solution (modules; barrel and disks; mechanics, integration, cooling)
    - eRD113 – development of the EIC MAPS sensor (sensor design; sensor characterization)
  - Generic R&D for ePIC improvements and upgrades, or for a future second detector

EIC Silicon Consortium – R&D effort (eRD111)

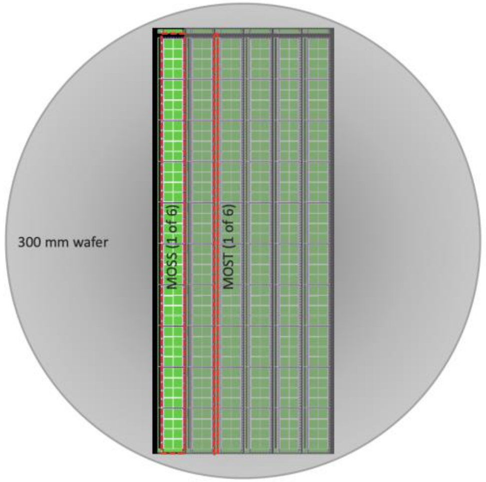
- The EIC science program requires a well-integrated, large acceptance tracking and vertexing solution designed with high-granularity and minimized material (including services),
- 65 nm MAPS technology – being spearheaded by the ALICE ITS3 project – choice and focus was a carefully considered outcome from a broad survey, see e.g. Laura Gonella's talk at the 1st Yellow Report Workshop, https://indico.bnl.gov/event/7449/
- The path to ePIC / an EIC detector based on 65 nm MAPS thus requires us to develop:
  - ITS3-like vertex layers re-using the ITS3 large-area sensor (LAS) as is in a configuration adapted to the larger EIC radii (R&D)
  - EIC variant optimized for large area coverage for outer barrels and disks – that is high yield, cost, etc. This sensor will have the same interfaces as ITS3 and will be stitched, but not to wafer scale (R&D). More conventional carbon fiber support structures with integrated cooling (R&D).
- Ongoing studies on tiling of staves and disks, illustrated on the right for two representative disks, to inform the EIC LAS formats (stitching plan, digital periphery).



EIC Silicon Consortium – R&D effort

Sensor design (eRD113) - Current EIC SC designer groups: RAL and (new) BNL and LBNL,

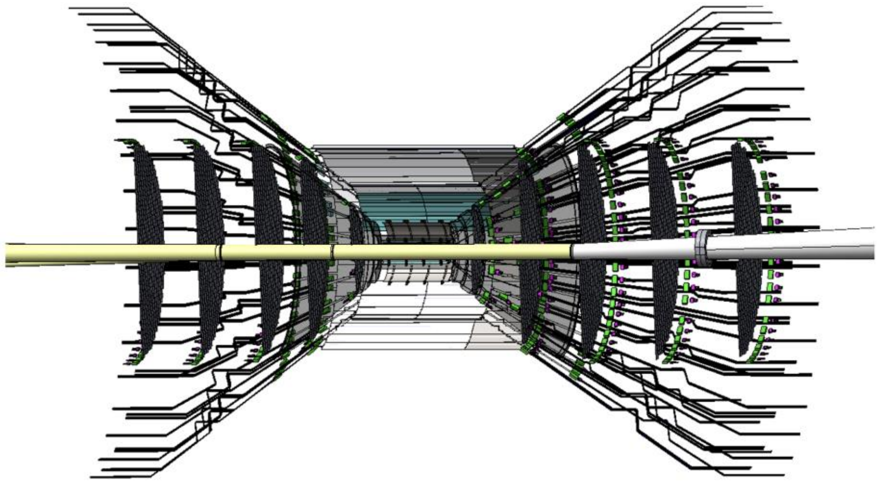
- MLR1 – Q4 2020
  - First submission in Towerjazz 65 nm; scoped within CERN EP R&D WP1.2, significant drive from ITS3, important contributions from many groups,
  - Scope: Technology exploration and prototype circuit blocks for future sensors,
  - Large number of test structures included,
  - RAL contributions: high-speed data transmission IP blocks (LVDS receiver, CML transmitter),
- ER1 – Q4 2022
  - First Engineering Run, driven by ITS3 stitched sensor prototype,
  - Scope: learning about stitching and yield of LAS
  - Two large stitched sensor chips (MOSS, MOST) plus small test and development chips,
  - RAL contributions: high-speed data transmission IP blocks (PLL, CML receiver); on-chip signal transmission I2C block; DFM cell improvements.



EIC Silicon Consortium – R&D effort

- Sensor characterization efforts gearing up **(eRD113),**
  - INFN groups leading tests of DPTS circuits,
  - INFN and Berkeley groups participated in test beams,
  - Test setups received and being commissioned (and produced) – currently LBNL, ORNL, UK groups,
  - Characterization of the MLR1 RAL IP blocks – UK groups,

- Power and Readout are integral to service reduction **(eRD104)**,
  - Powering – as the outcome of a survey, serial powering and DC-DC conversion with integrated regulator is currently being considered as the most promising candidate for the ePIC MAPS-based tracking and vertexing subsystem – pursued by UK groups,
  - Readout – ongoing exercises to estimate and refine hit loads; candidates for radiation tolerant FPGA and optical interconnect, and electrical / optical interface being identified – pursued by ORNL,



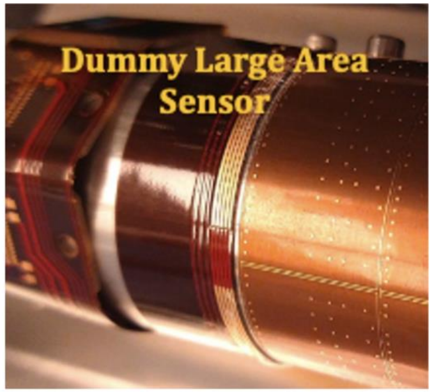
- CAD modeling continues from the effort for the initial detector proposals at JLab and LANL,

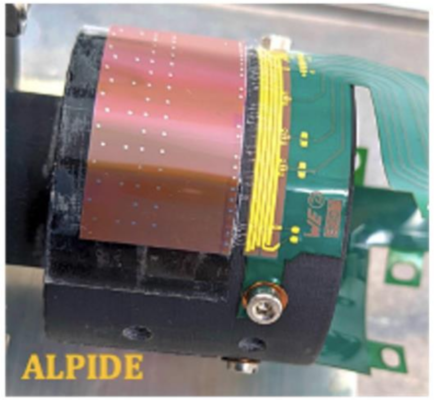
EIC Silicon Consortium – R&D effort

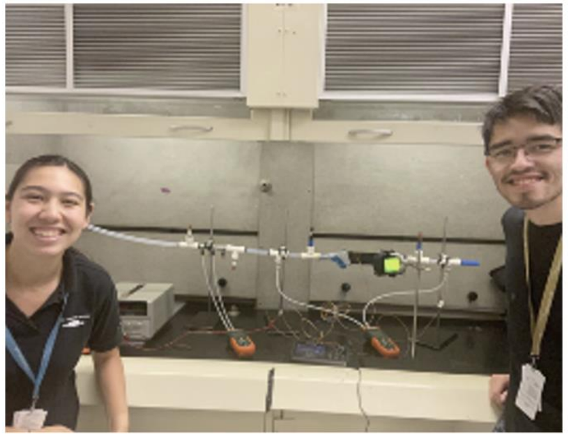
- Mechanical studies on single-reticle and large-size MAPS are ongoing at INFN,
  - Bending, thinning, and interconnection,
  - Characterization in flat and curved geometries,
  - Bending and wire-bonding have been successfully exercised at EIC vertex-layer radii,

- Studies of cooling option for staves and disks – for example, air cooling internal to the mechanical structures – are ongoing at LBNL,

- Starting assessments of materials to construct disks and supports at LANL, LBNL.



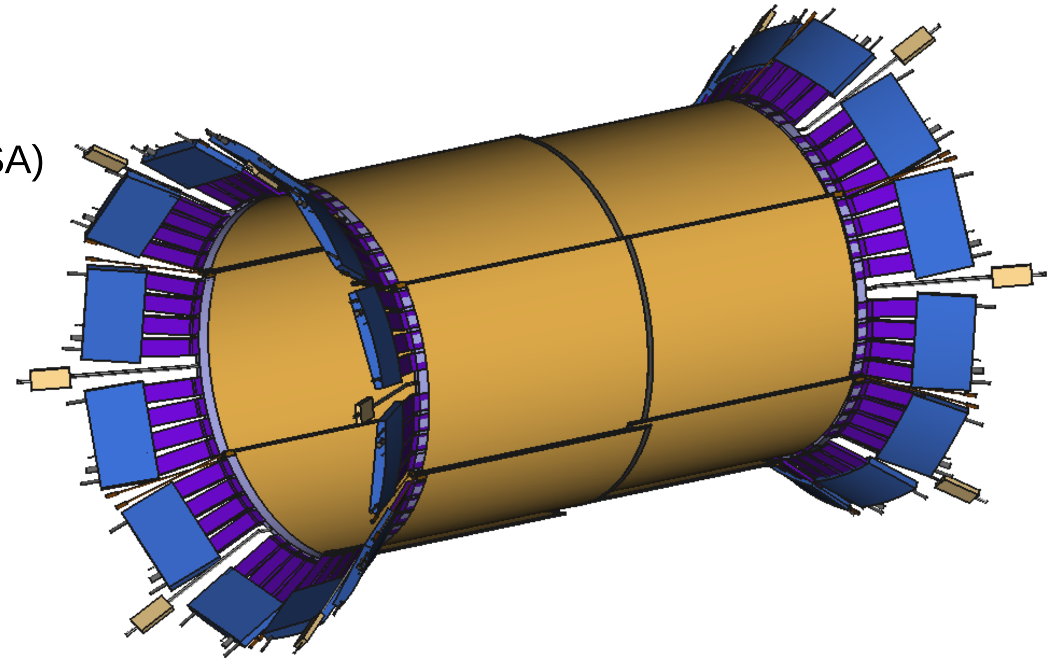




MPGD - Barrel Cylindrical Micromegas

Motivation

- ❖ Build a full acceptance light-weight modular MPGD barrel tracker to complement the silicon vertex detector
- ❖ Due to space limitations and material budget limits: cylindrical tiles
- ❖ Light cylindrical Micromegas technology is already in use (CLAS12 and ASACUSA)
- ❖ Cylindrical µRWELL is viewed as back up technology for Micromegas



Objectives

- ❖ Resolutions of ~150µm
- ❖ Fewest possible number of channels to limit the material budget
- ❖ Keep the material budget at ~0.5% X0 per layer

R&D ongoing within eRD108

- ❖ 2D readout, with large strips (~1mm)
  - 2022–2023: optimization and choice of the 2D pattern on small prototypes
- ❖ Optimize the production by limiting the number of types of modules:
  - 2023-2024: production of full scale tile (50x70cm^2) and a mockup of longer size

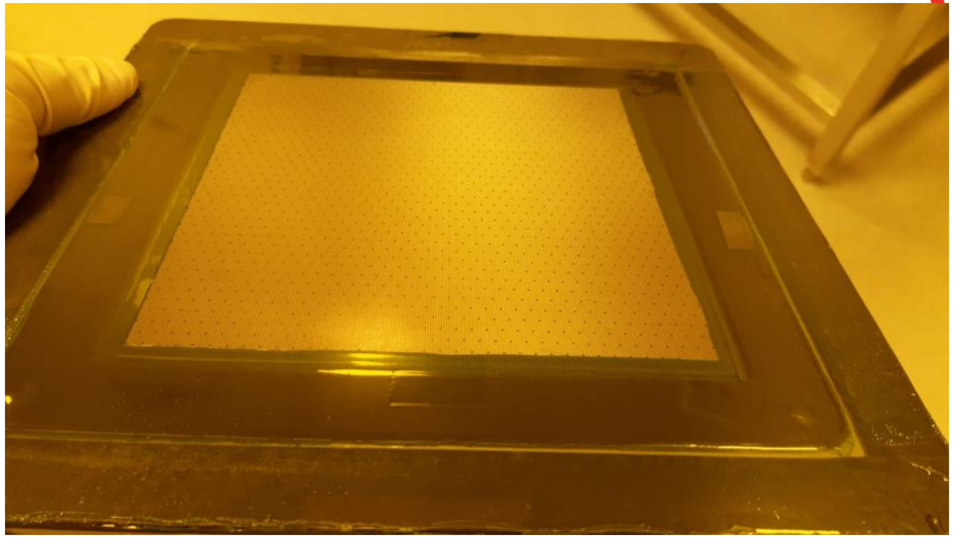
CAD design of one layer of overlapping cylindrical tiles with FEE and services

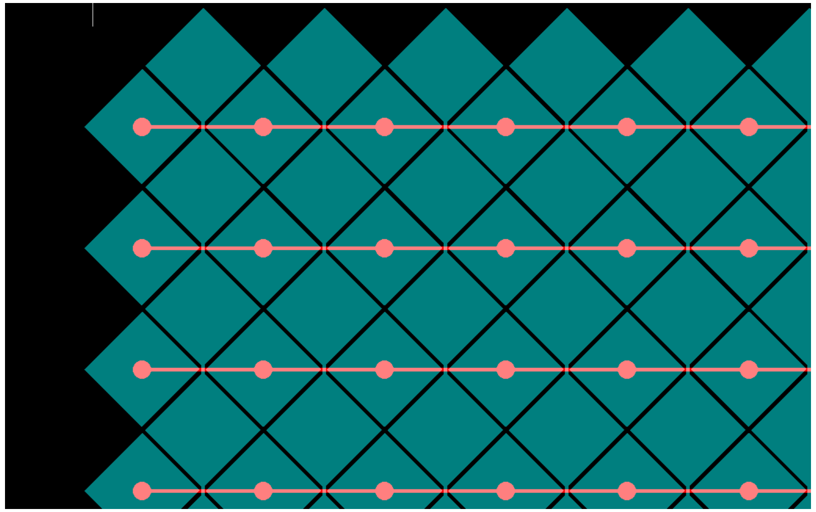
R ~ 50cm, L ~ 140cm

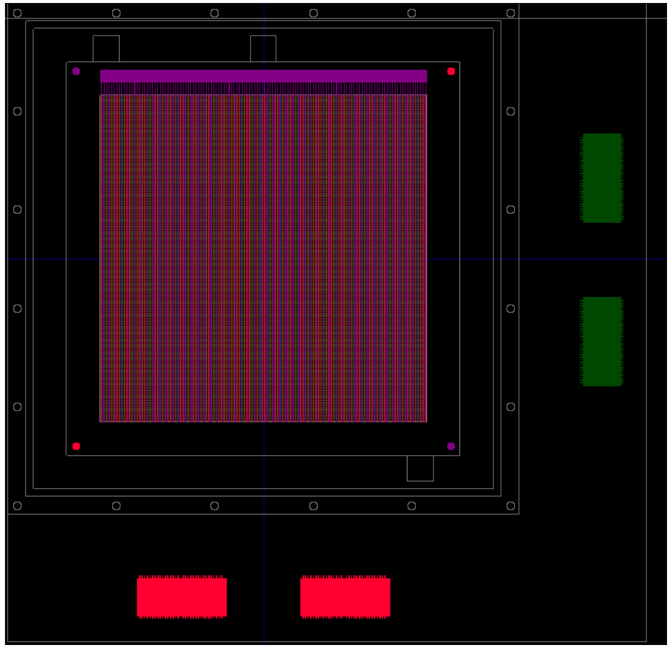
MPGD - R&D effort (eRD108)

2022 – 2023: 2D readout optimization on small prototypes

- **Amplification Kapton (AK):** a Kapton foil with resistive paste stretched on a carbon fiber frame and then bulk with a micromesh
  - AKs with different resistivity will be glued together with Kapton foils with 2D readout patterns
- **Readout pattern design:**
  - Several design 2D patterns:
    - Orthogonal strips
    - ASACUSA like readout
- **Tests:**
  - **Beam test in June 23**





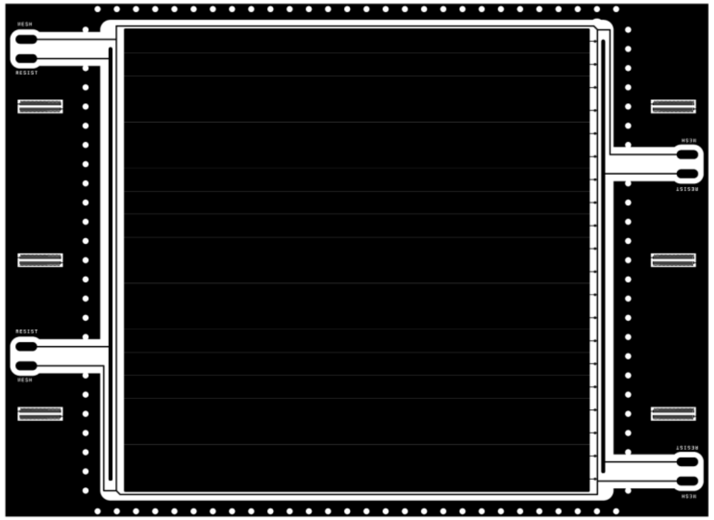


MPGD - R&D effort (eRD108)

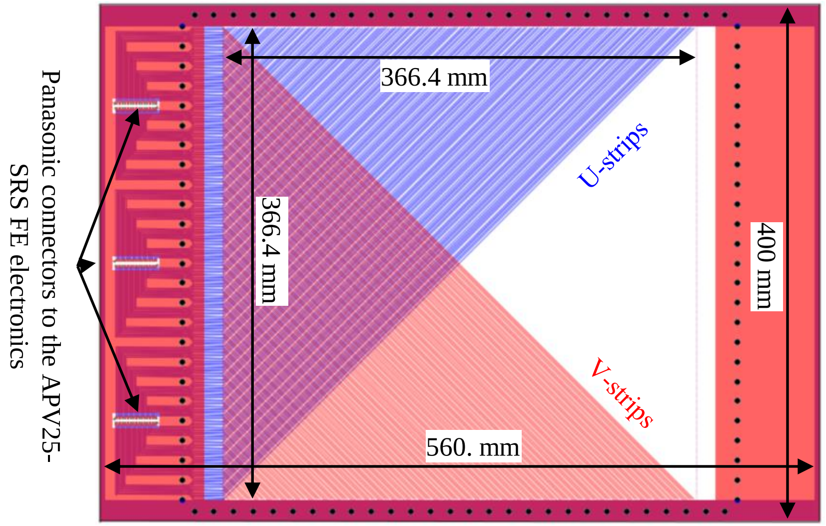
Development of cylindrical µRWELL prototype: (BNL, Florida Tech, JLab, Temple U.)

- Prototype consists of 2 half-cylinder chambers with different readout structures
  - **CapaSh-uRWELL:** uRWELL/readout foil with U-V capacitive-sharing readout
  - **Zigzag-uRWELL:** uRWELL/readout foil with U-V :zigzag" readout structure
- Design of all parts (2 uRWELL/RO foils) and mechanical structure are completed,
- Fabrication at CERN assemblyt of the prototype at Florida Tech ➔ **April 2023**
- Tests in hadron beam at FNAL ➔ **June 2023**
- Data analysis, report / presentation at DAC committee meeting and preparation for publication in peer-review journal ➔ **June – December 2023**

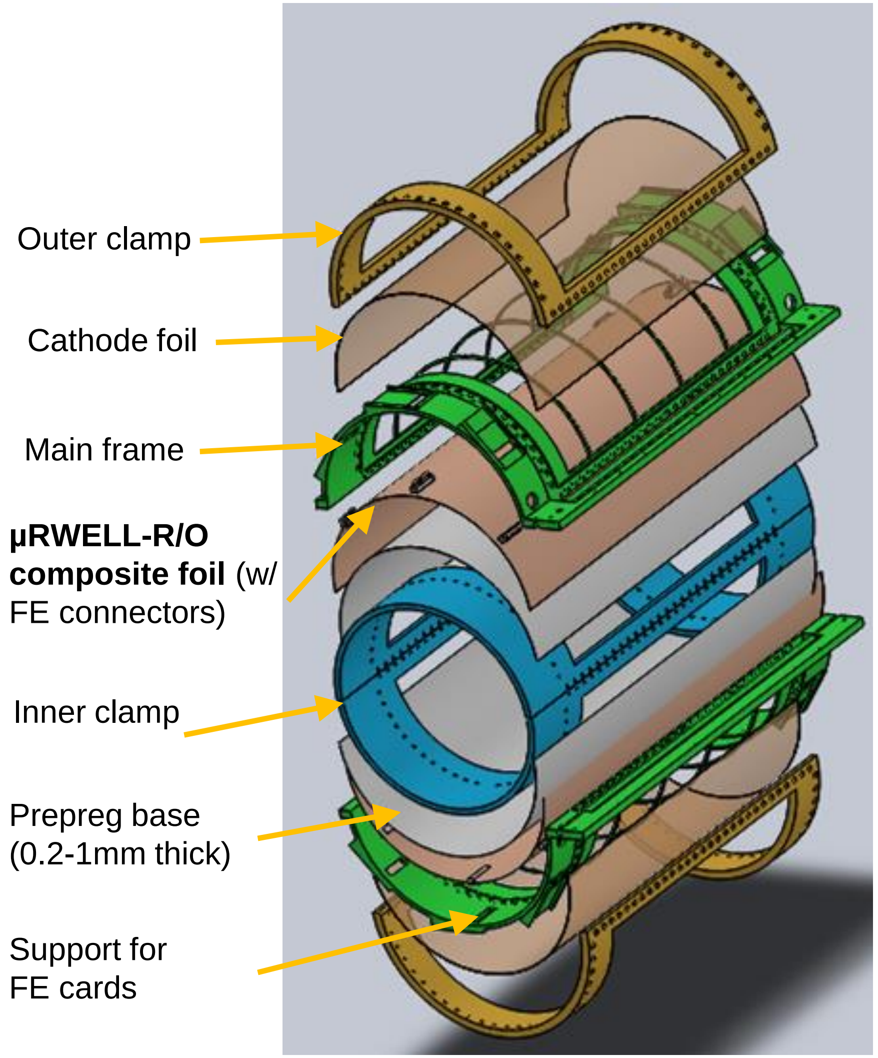
uRWELL foil design completed



U-V strip readout design completed



CAD drawing / mechanical design completed

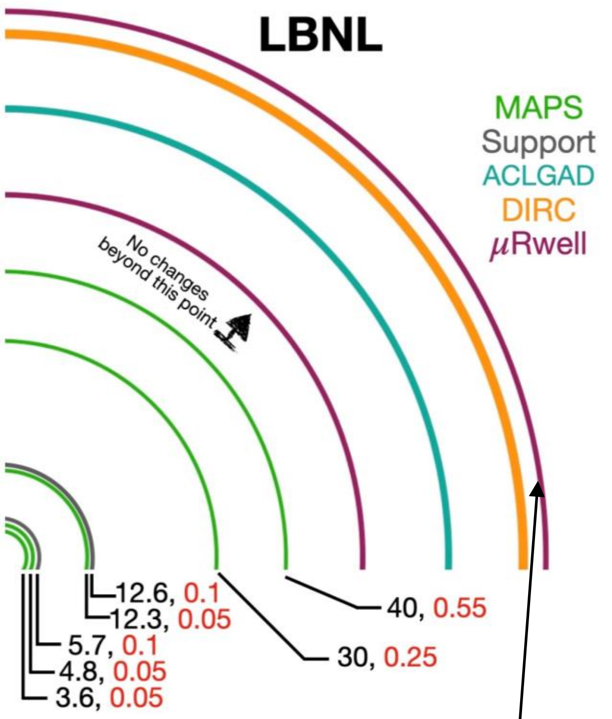


https://wiki.bnl.gov/eic/upload/ERD108_Proposal_FY23.pdf

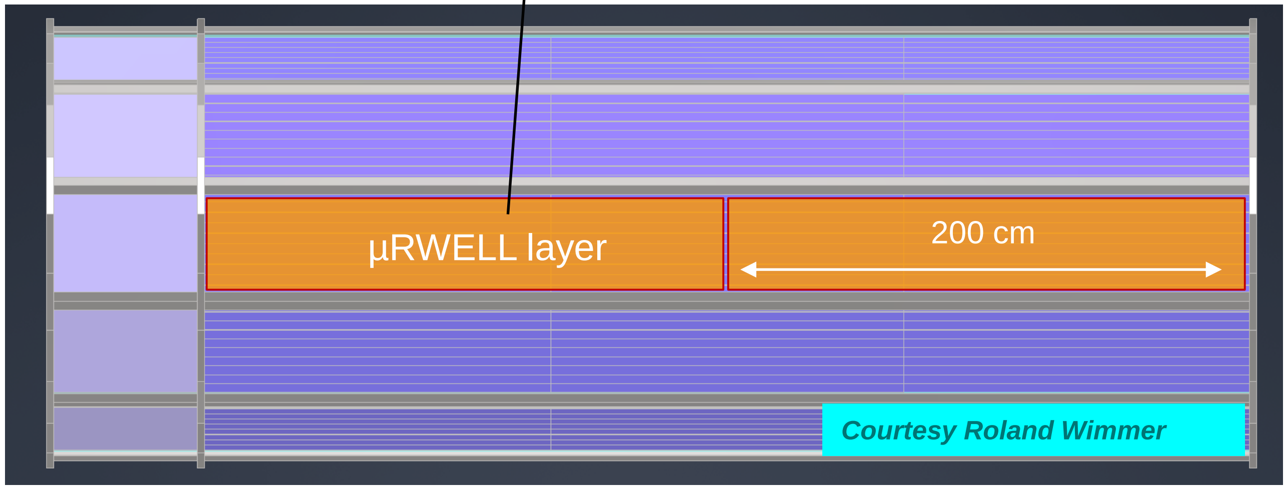
MPGD - Planar µRWELL layers

Requirements & expectations from YR & various detector proposals:

- Low mass (< 1% X0) not justified here ➔ **1% to 2% X0** in front of EM Cal. is not an issue
- But space limitation for layer behind hpDIRC ➔ 2 cm thick box space for MPGD layer
- Spatial resolution (50 - 100 µm) in both phi and z



µRWELL layer behind hpDIRC



EIC Detector Generic R&D - EICGENRandD_2022_23

Development of Thin Gap MPGDs for EIC Trackers

K. Gnanvo*[1], S. Greene[4], N. Liyanage[2], H. Nguyen[2], M. Posik[3], N. Smirnov[5], B. Surrow[3], S. Tarafdar[4], and J. Velkovska[4]

[1]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[2]University of Virginia, Department Of Physics, Charlottesville VA 22903, USA
[3]Temple University, Philadelphia, PA 23606, USA
[4]Vanderbilt University, Department of Physics and Astronomy, Nashville, TN 37240, USA
[5]Yale University, Physics Department, New Haven, CT 06520, USA

July 25, 2022

Abstract

The EIC physics program requires precision tracking and PID over a large kinematic acceptance, as highlighted in the Yellow Report [1]. MPGDs are able to provide space point measurements to aid in both tracking and PID. These MPGD detectors will span a large pseudorapidity range (e.g. angular acceptance) and will see tracks entering over a large angular range, in addition to tracks bending due to the EIC's magnetic field. The position measured by an MPGD structure for a track impinging at a large angle is no longer determined by the detector structure (e.g. readout structure) but the gap in the ionization gas volume that the particle traverses before reaching the amplification stage, leading to a deterioration in the spatial resolution that grows with the angle. To minimize the impact of the track angle on the resolution, several prototype thin gap MPGDs (tg-MPGDs), where the ionization gas volume is significantly reduced with respect to typical MPGD detectors, will be built and tested in beam. In addition various gas mixtures will be studied within simulation to identify optimal mixtures for future use.

https://www.jlab.org/research/eic_rd_prgm/receivedproposals

Remaining tasks / issues

- Implementation of the background in simulation for tracking performance studies
  - MPGD trackers for pattern recognition
    - How many barrel MPGD layers are required, what is the best configuration (radii and size …) for optimal configuration
    - Do we need additional Si disks in the forward and backward regions to increase the number of hits in background environment
- Optimization of the interface between barrel MPGD layer and the Si support structure
  - Do we need barrel MPGD layers to cover an eta range > 1.1? or rather increase the Si disks radii in the end cap
  - Complement with MPGD rings instead
- MPGD layer behind dRICH
  - Simulation studies is needed to evaluate the impact dRICH ring reconstruction and overall tracking performance
- Integration & Services
  - More realistic evaluation of the services (cables, FE cards, HV …) and integration issues only after new geometry optimization phase
  - detector geometry description, both Si and MPGDs, still lacks a lot of engineering details that are still being worked out
- Technology review:
  - Complete review of the choice of tracking technologies.
  - Identify risks & fallback solutions for each technology.
  - Close coordination with the detector consortia (EIC Silicon consortium, MPGD consortium)

Summary & Outlook

- Optimization of ePIC tracking detector
  - Good progress on the optimization of the detector geometry
  - Effort focused on first on Silicon layers
  - Tracking performance satisfy for most part the requirements for
- R&D Tracking detector technologies
  - Intense R&D effort by both ESC and eRD108 for both the Silicon and MPGD technologies to achieve ePIC performance requirements
  - Both consortia welcome new members / group to join and contribute to developing the perfect detector for ePIC tracking needs
- A few remaining issues to address
  - Background simulation studies is the next step for further optimization of the overall tracking subdetector, more specifically to better define the role of barrel MPGD trackers
  - Integration & services will be the focus of the activities of the tracking WG, under the guidance of the GD & I WG

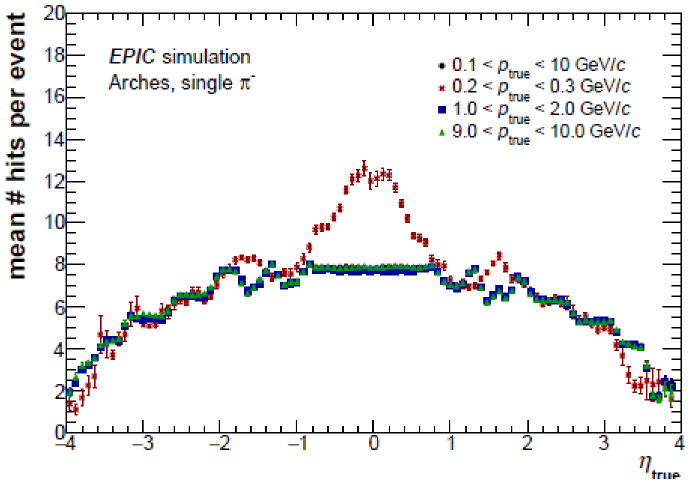
Backup

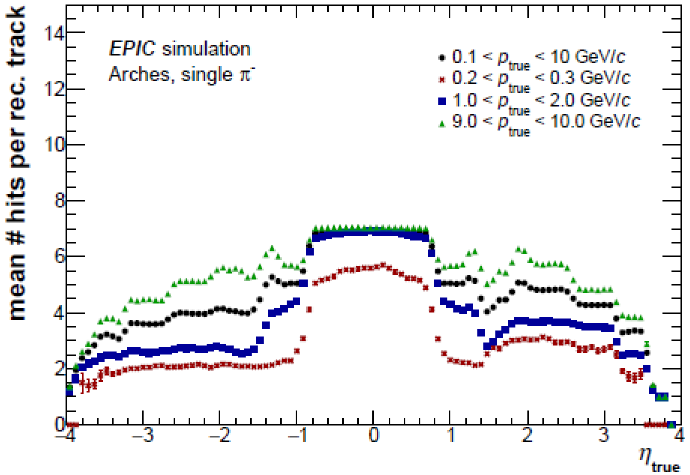
Tracking performance: Average number of hits per track

EPIC detector performance studies with DD4hep and eicrecon: Average number of reconstructued hits per tracks vs. eta and p

Hits per event and per rec. track with ACTS

See talk by Nicolas Schmidt at https://indico.bnl.gov/event/17752/



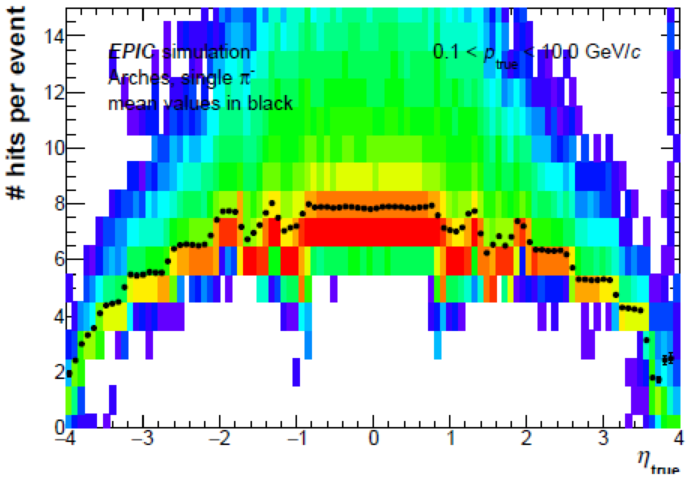


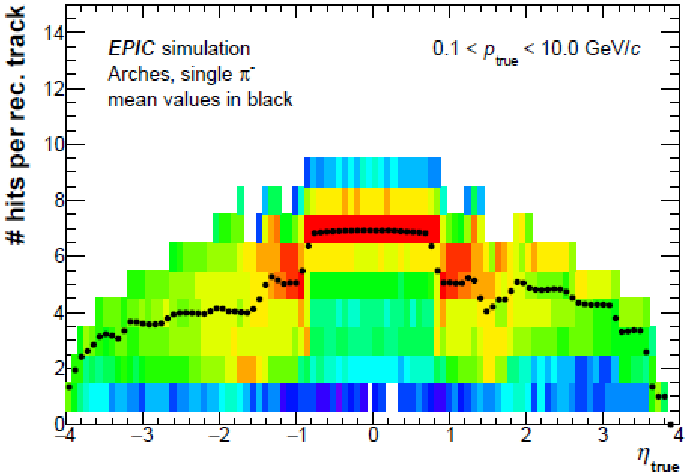
Information shown in plots:

- Hits per event:
  → all hits saved for "SiBarrelHits", "MPGDBarrelHits", "VertexBarrelHits", "TrackerEndcapHits", "TOFEndcapHits", "TOFBarrelHits", "MPGDDIRCHits"
- Hits per track:

```
auto acts_results = event->Get<eicrecon::TrackingResultTrajectory>("CentralCKFTrajectories");
for (const auto& traj : acts_results) {
    const auto &mj = traj->multiTrajectory();
    const auto &trackTips = traj->tips();

    const auto &trackTip = trackTips.front();
    auto trajState = Acts::MultiTrajectoryHelpers::trajectoryState(mj, trackTip);
    if (traj->hasTrackParameters(trackTip)) {
        int  m_nMeasurements = trajState.nMeasurements;
    }
}
```





MPGD – Generic R&D: Thin Gap MPGDs

Proposal - EICGENRandD_2022_23

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July 25, 2022

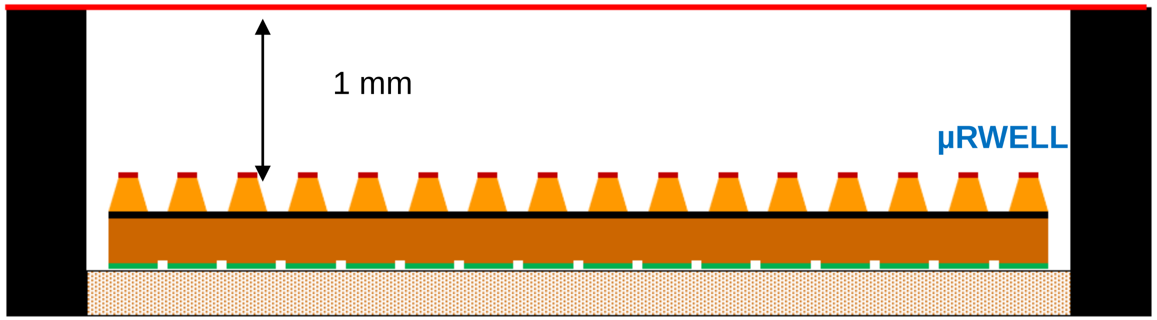
Abstract

The EIC physics program requires precision tracking and PID over a large kinematic acceptance, as highlighted in the Yellow Report [1]. MPGDs are able to provide space point measurements to aid in both tracking and PID. These MPGD detectors will span a large pseudorapidity range (e.g. angular acceptance) and will see tracks entering over a large angular range, in addition to tracks bending due to the EIC's magnetic field. The position measured by an MPGD structure for a track impinging at a large angle is no longer determined by the detector structure (e.g. readout structure) but the gap in the ionization gas volume that the particle traverses before reaching the amplification stage, leading to a deterioration in the spatial resolution that grows with the angle. To minimize the impact of the track angle on the resolution, several prototype thin gap MPGDs (tg-MPGDs), where the ionization gas volume is significantly reduced with respect to typical MPGD detectors, will be built and tested in beam. In addition various gas mixtures will be studied within simulation to identify optimal mixtures for future use.

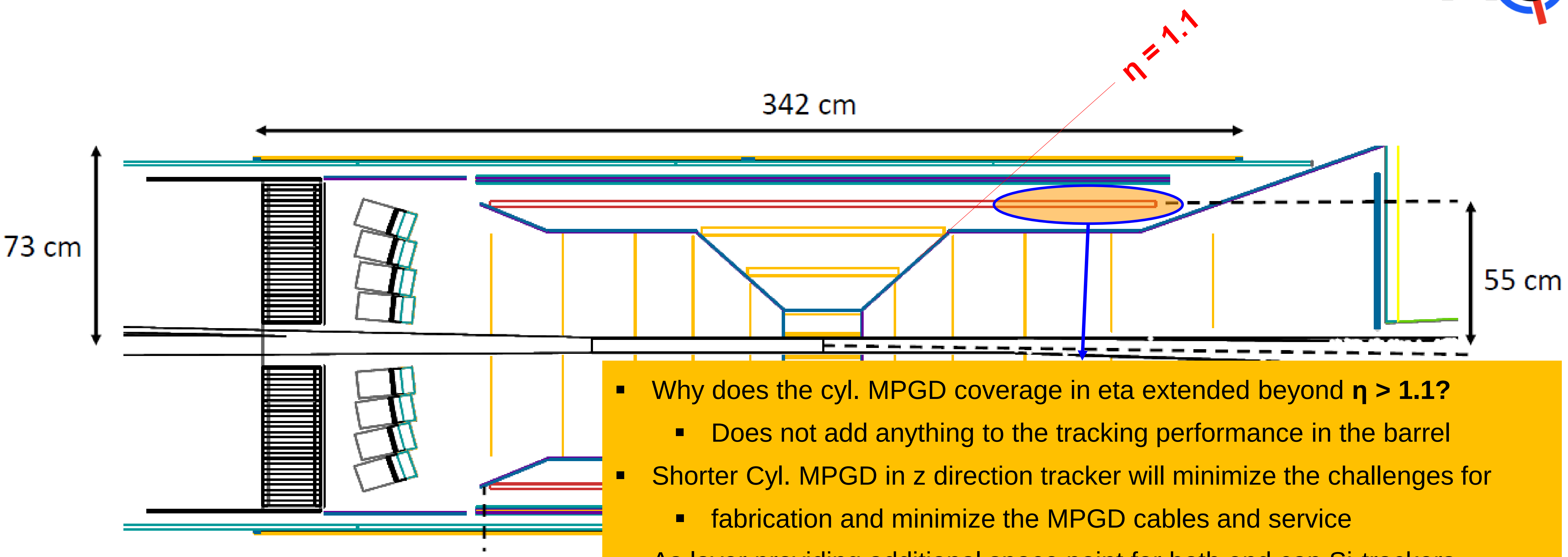
https://www.jlab.org/research/eic_rd_prgm/receivedproposals

Motvation for thin gap MPGDs

- **Limitation with standard gap MPGDs (~ 3mm):**
  - deterioration of spatial resolution with track angle .
  - Degradation spatial resolution due to E x B effect inside magnetic field.
- **Thin Gap MPGDs** will address the above issues ➔ Reduce drift gap (< 1mm)
  - Improve spatial resolution over a large angle range
  - Minimize E × B effect on resolution dependence
  - Improve timing resolution by a factor > 2
- **Challenges:**
  - affect detector efficiency ➔ use heavier gas
  - Mechanical stability for large area detector
- **EICGENRandD_2022_23 Proposal:**
  - Multi institution protosal
  - Prototypes with all 3 MPGDs technologies (MM, GEM, µRWELL)
  - Explore single and double amplification stages to recover efficiency
  - **Will directly benefit ePIC MPGD tracking layers.**

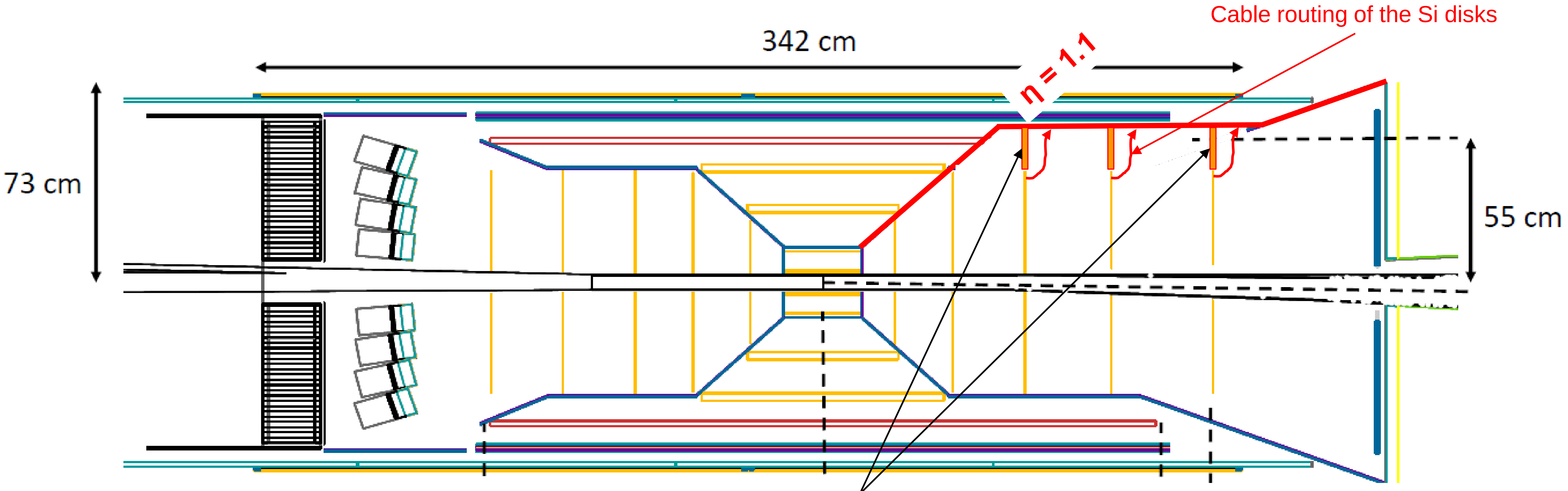


EPIC reference detector: Question 2



- Why does the cyl. MPGD coverage in eta extended beyond **η > 1.1?**
  - Does not add anything to the tracking performance in the barrel
- Shorter Cyl. MPGD in z direction tracker will minimize the challenges for
  - fabrication and minimize the MPGD cables and service
- As layer providing additional space point for both end cap Si-trackers
  - Poor space point resolution ➔ because of large track angles (> 45°)
  - Material of the Si support cone structure in front of the layer …
- **Similar argument can be held for the AC-LGAD disk**
  - **But this is a discussion for another day**

EPIC reference detector: Possible option to question 2



- Complement the Si disks with thin gap MPGD rings (or extending Si disks radius)
- Optimizing the Si-layer cable and services "cone" support ➔ (red lines)
- Could the cables of the Si-disks be routed vertically up to the cone structure?
  - This will be optimal for performances

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Tracker Performance Simulations

L. Gonella, P. G. Jones, S. Maple, P. R. Newman

Tracking requirements

- High precision tracking measurements required for EIC physics program
  - Precise measurement of scattered electron (or hadrons) to reconstruct DIS kinematics
  - Momentum measurements for e.g. invariant mass resolution, E/p etc
  - Jet measurements (need tracks for particle-flow)
  - Determination of primary vertex, secondary vertex separation

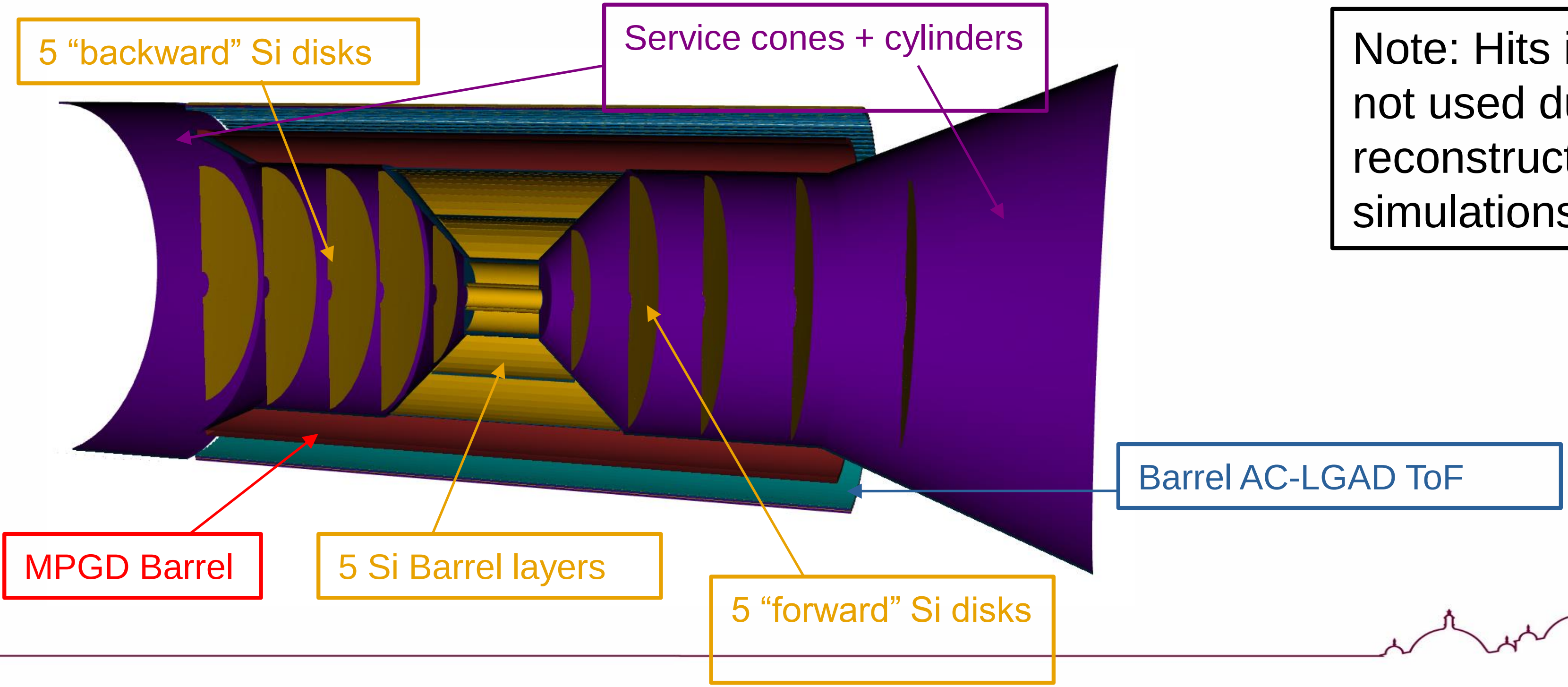
$$Q^2 = 2E_eE'_e(1+\cos\theta_e)$$
$$y = 1 - \frac{E'_e}{2E_e}(1-\cos\theta_e)$$

Tracking requirements from PWGs						
			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
η						
-3.5 to -3.0			σp/p ~ 0.1%×p ⊕ 0.5%		100-150 MeV/c	
-3.0 to -2.5		Backward Detector			100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0					100-150 MeV/c	
-2.0 to -1.5			σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
-1.5 to -1.0					100-150 MeV/c	
-1.0 to -0.5						
-0.5 to 0	Central Detector					
0 to 0.5		Barrel	σp/p ~ 0.05%×p ⊕ 0.5%	~5% X0 or less	100-150 MeV/c	dca(xy) ~ 20/pT µm ⊕ 5 µm
0.5 to 1.0						
1.0 to 1.5					100-150 MeV/c	
1.5 to 2.0		Forward Detector	σp/p ~ 0.05%×p ⊕ 1%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
2.0 to 2.5					100-150 MeV/c	
2.5 to 3.0			σp/p ~ 0.1%×p ⊕ 2%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 60 µm

EPIC tracker design informed by desire to meet momentum and DCA_T requirements set by physics working groups

Tracker Simulation Configuration

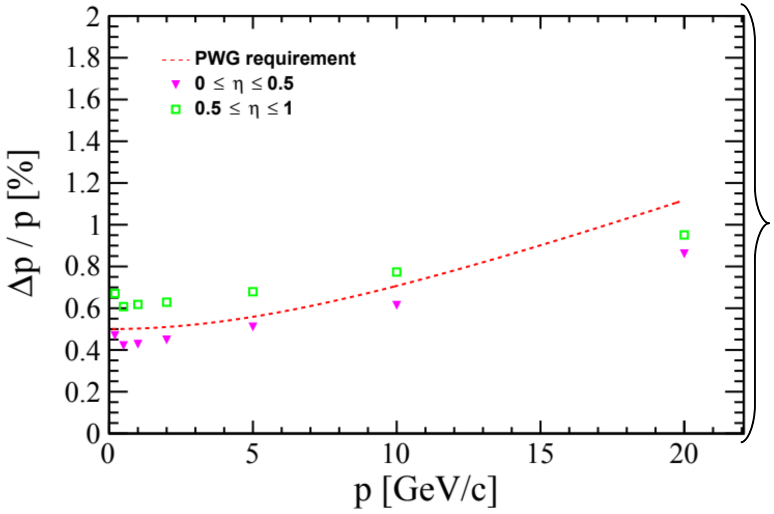
- Results shown in following slides use the single pion simulation files available on S3 (EPIC Brycecanyon 22.11.2)
  - Simulation geometry defined with layers positioned as detailed in summary talk
  - Pions of energies between 100MeV and 20GeV fired from particle gun at origin
  - Hits recorded and tracks reconstructed with EICrecon/Juggler* (ACTS)



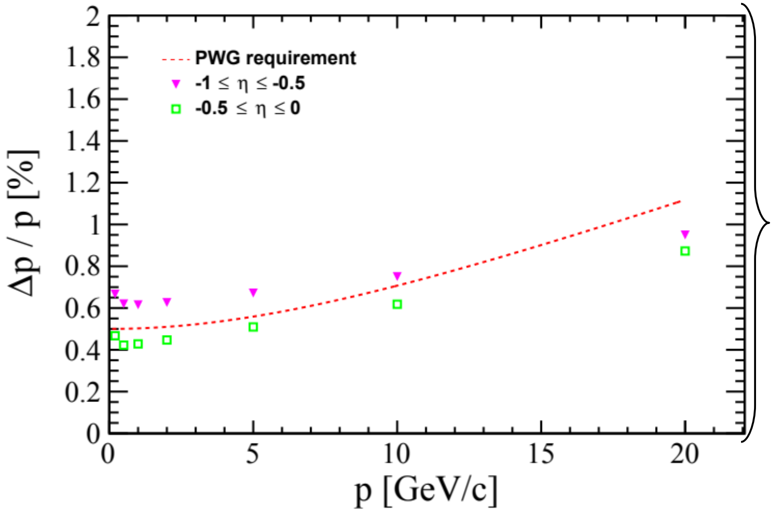
Note: Hits in the ToF are not used during track reconstruction in these simulations

Relative Momentum Resolution (Central)

- PWG requirement met for |η| < 0.5 for all momenta
- Requirement not met for 0.5 < |η| < 1
  - Note: Service cone begins at η = 0.88 therefore extra material seen in range 0.5 < |η| < 1
  - Requirement met for -0.88 < |η| < 0.88 (see backup)



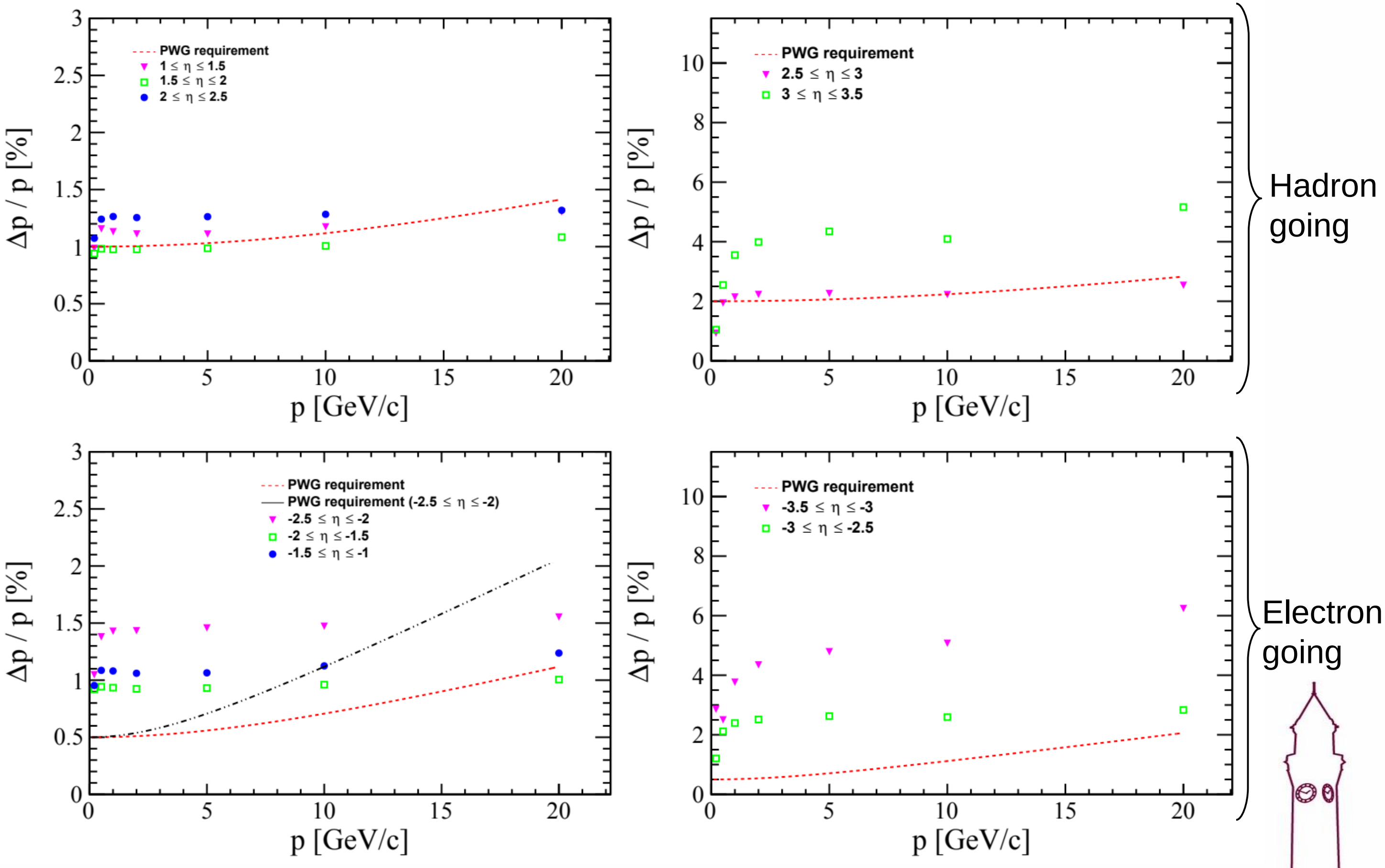
Hadron going



Electron going

Relative Momentum Resolution (Forward/Backward)

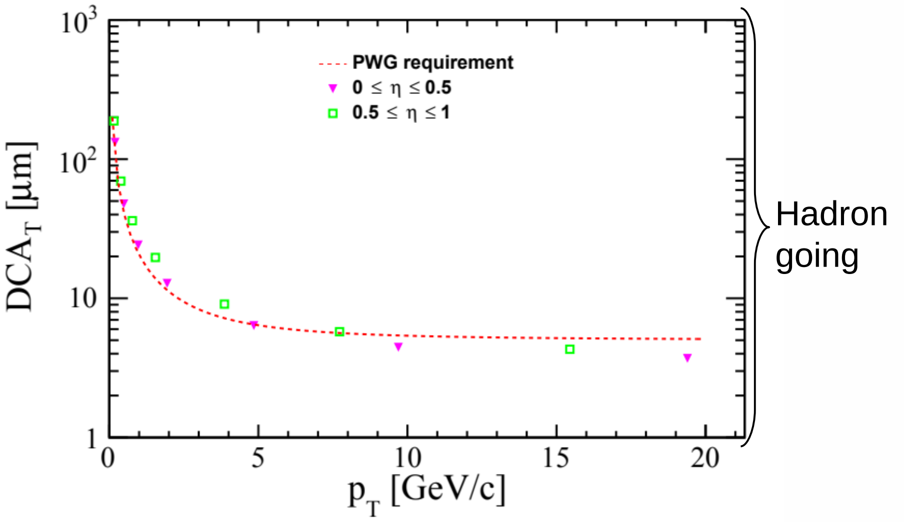
- Smaller lever arm for disks in the electron going direction → worse resolution compared to hadron going direction
- Different amount of support and service material crossed in different η ranges (See diagram in backup)
- Fwd/Bwd requirements only met over full momentum range for 1.5 < η < 3
  - Different reqs for Fwd/Bwd

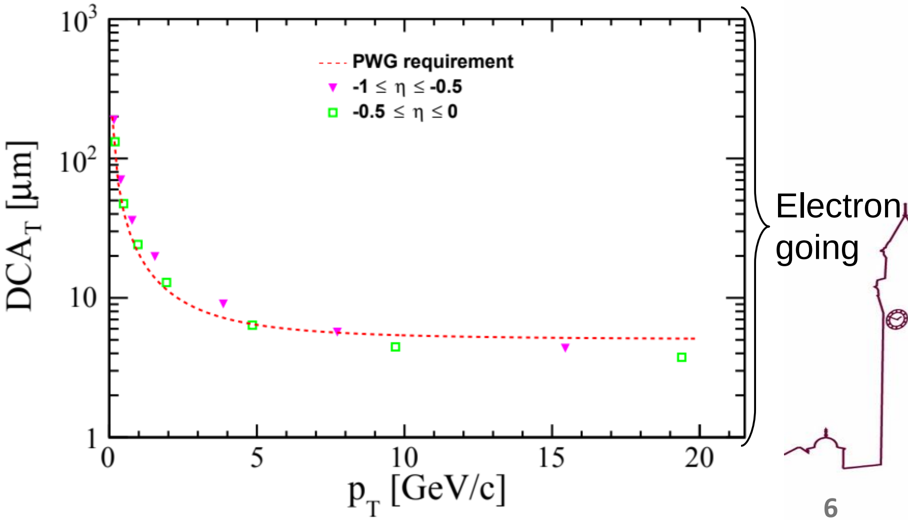


Transverse Pointing Resolution (Central)

- Performance consistent with requirement for |η| < 0.5 at all momenta
- Requirement not met for |η| > 0.5 in barrel region below ~8 GeV

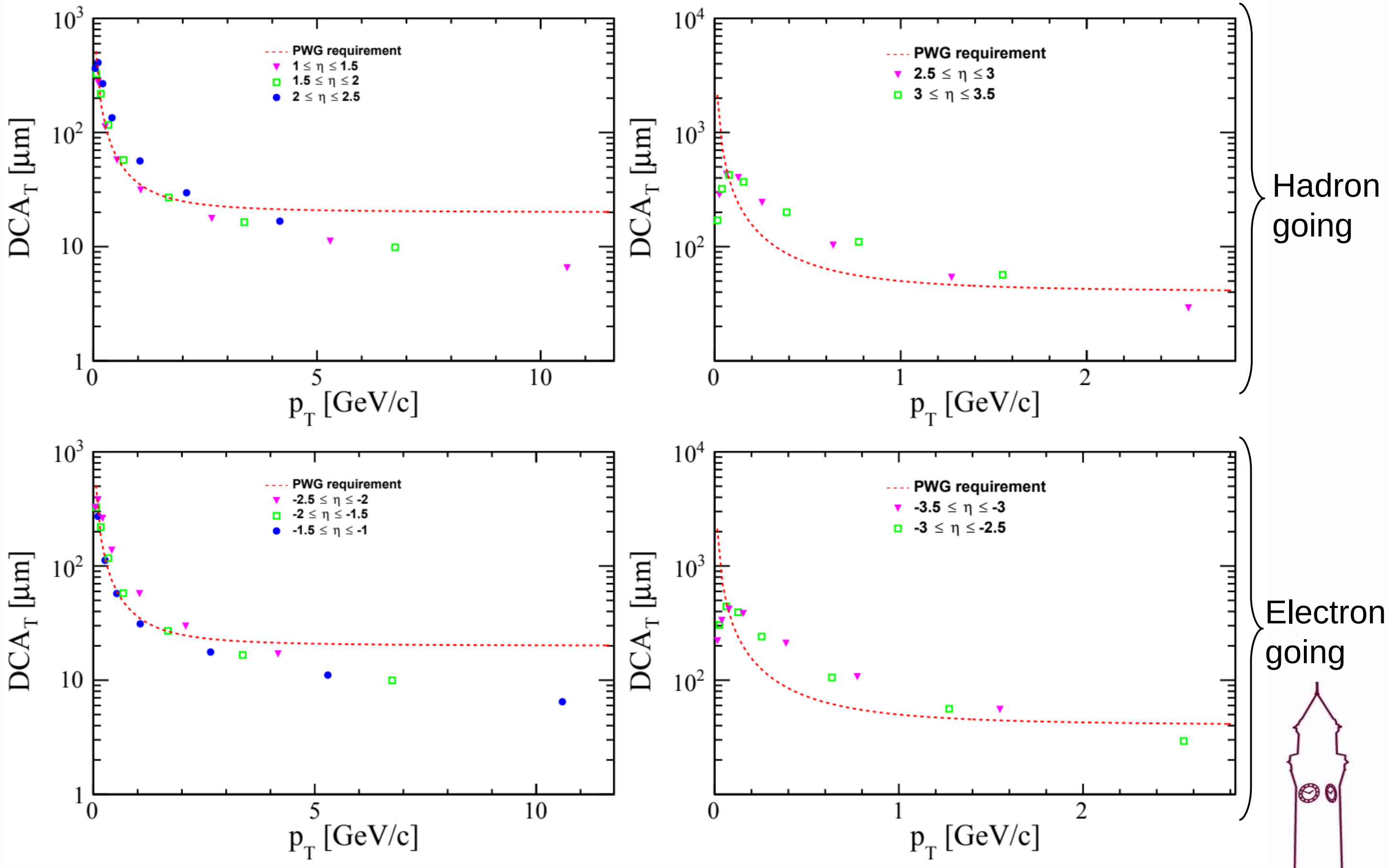
Note: x-axes are p_T for DCA_T resolutions





Transverse Pointing Resolution (Forward/Backward)

- Fwd/Bwd pointing resolution consistent with requirements at all momenta for 1 < |η| < 2
- Requirements met at |η| > 2 for p_T > ~2 GeV

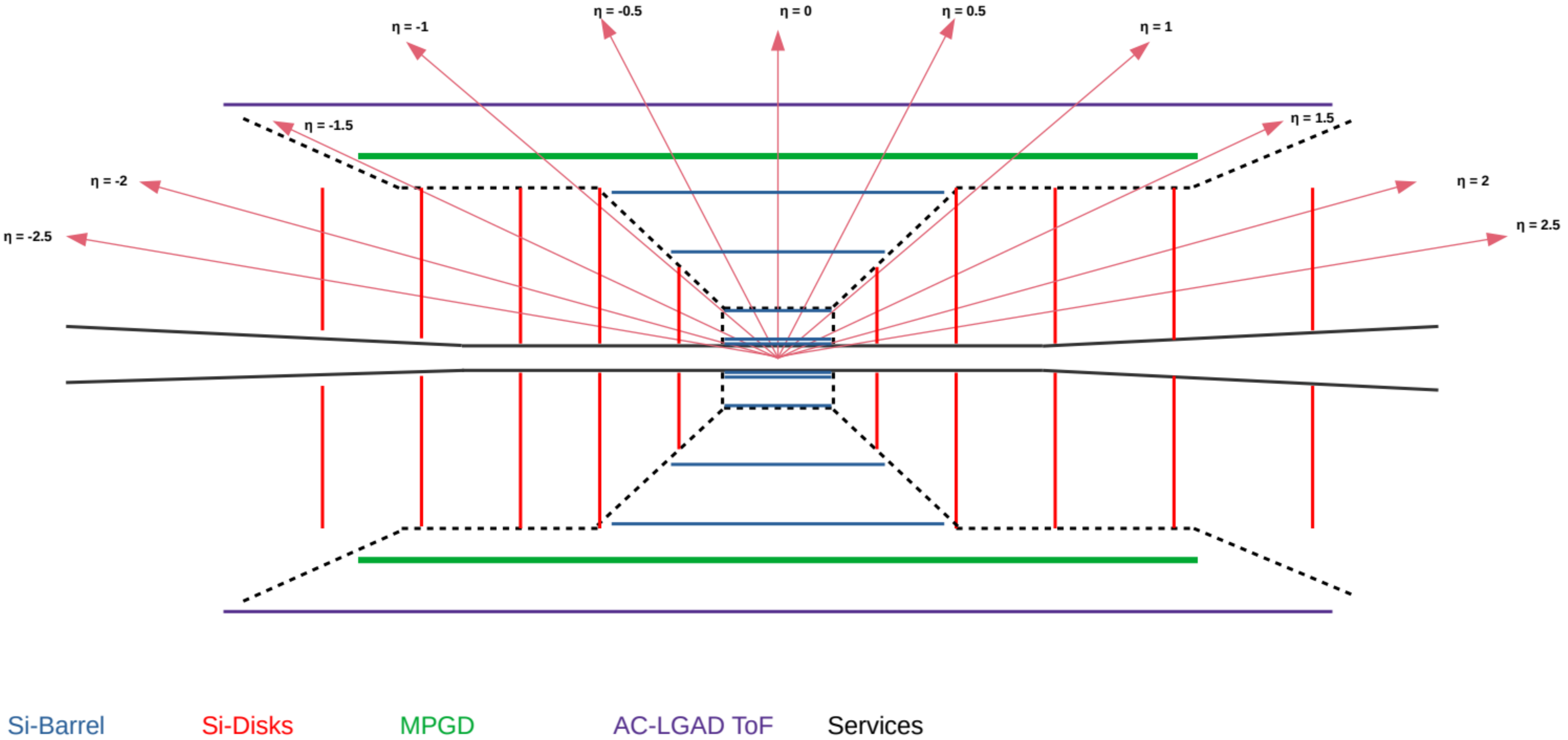


Summary

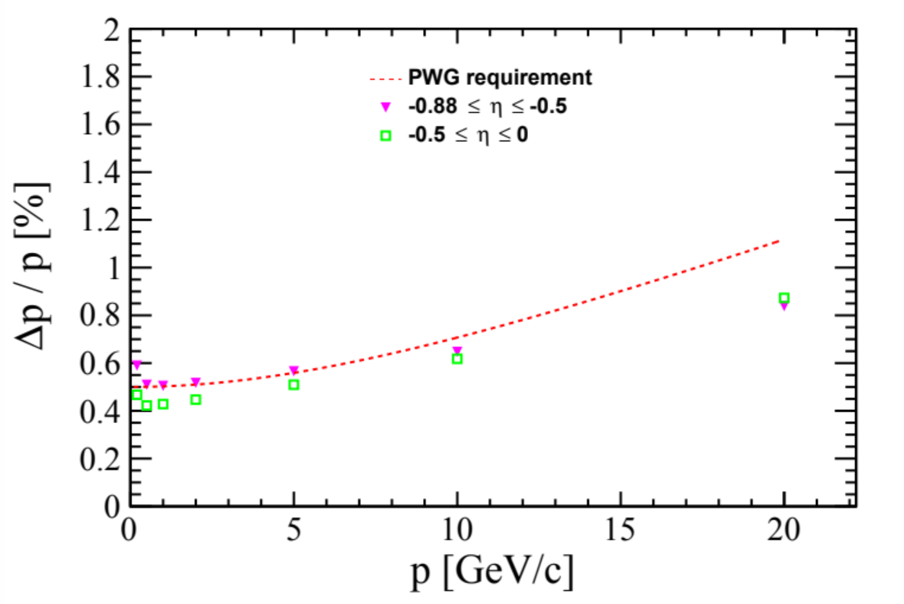
- The measurements necessary for the EIC physics program impose stringent requirements on the momentum and pointing resolution of the EPIC detector
  - For both momentum and DCA_T resolution there are challenges meeting requirements in the forward and backwards directions, this has been the case for previous configurations studied in the yellow report and detector proposals
- Effect from passive material on tracking and vertex performance is notable. Geometry description to be kept up to date with R&D progress on low material solutions

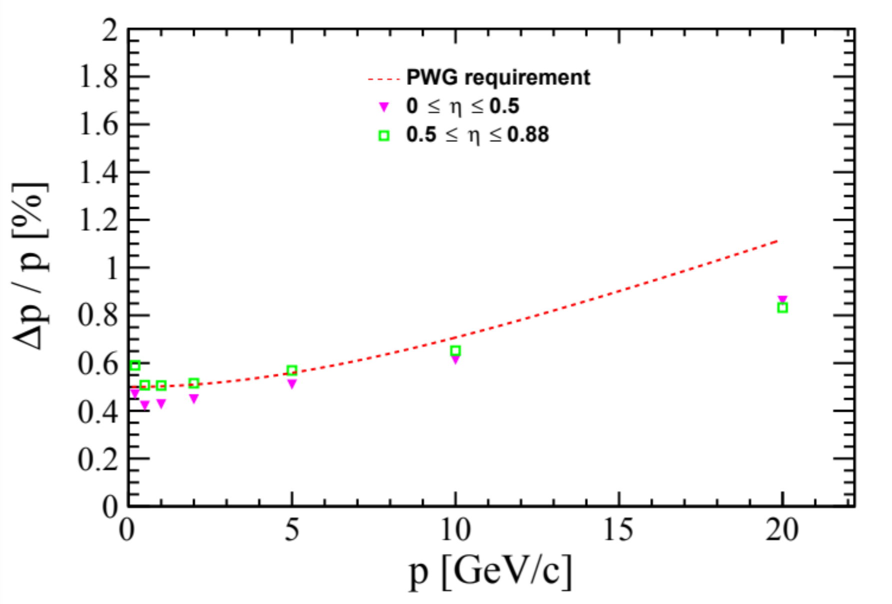
Backup

Detector layout



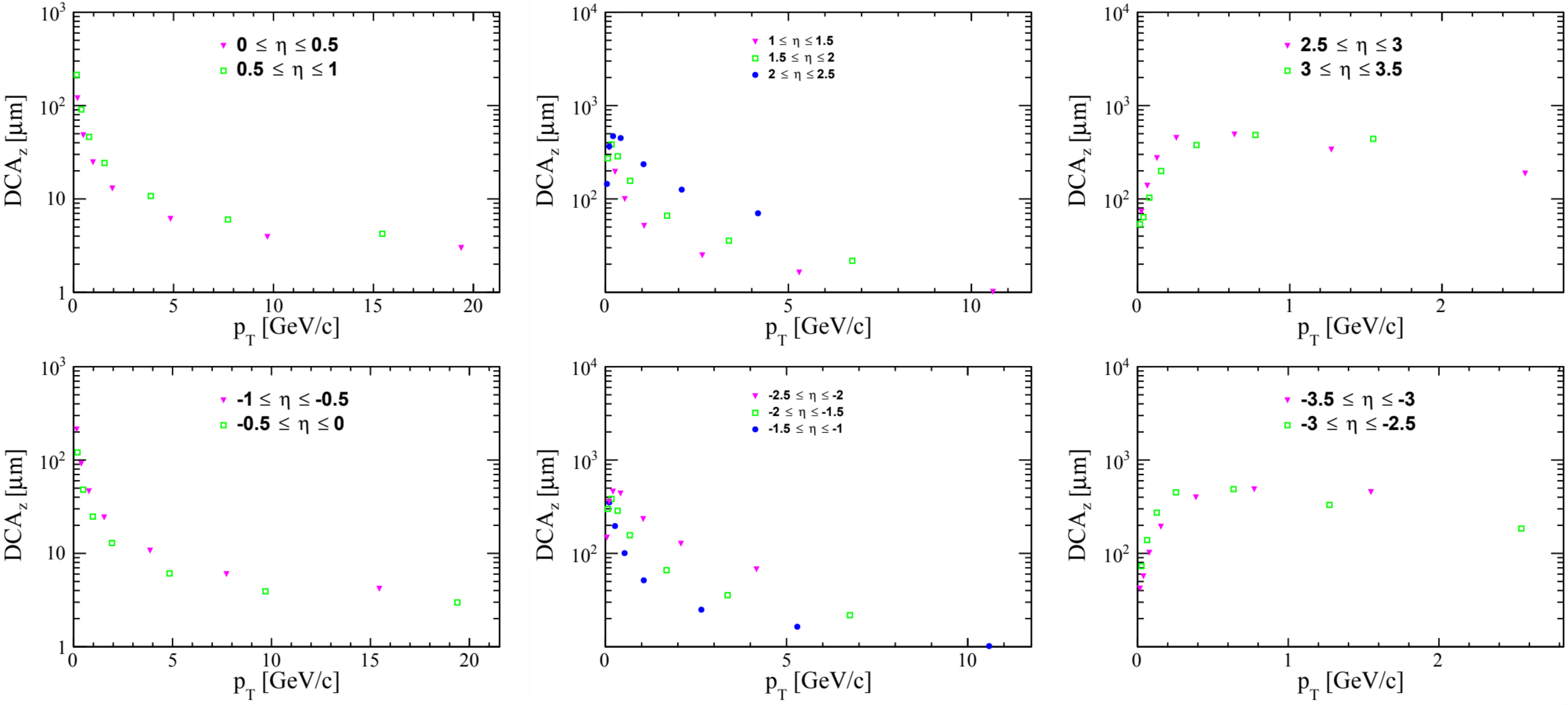
Before Support Cone Momentum Resolution





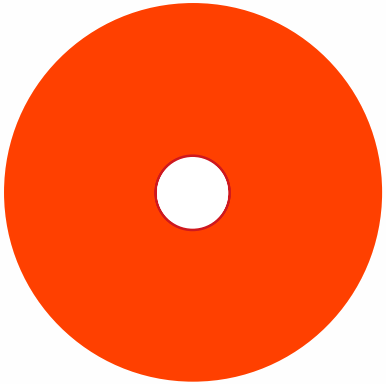
Momentum resolution consistent with requirements up to η=0.88 (support cone)

Longitudinal Pointing Resolution

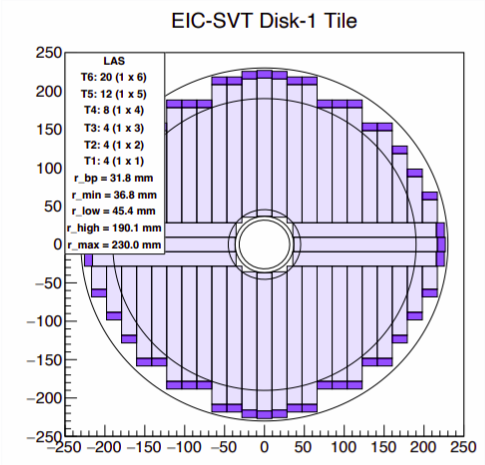


Acceptance around beampipe

- Disks consist of tiles of ITS3-like sensors, with length and width determined by the ITS3 reticle
  - The result is that the inner opening of the disks is not perfectly circular → instead they are squared off
  - This means that there isn't full azimuthal acceptance at the inner radii we've been using (beampipe radius +5mm)



Disks in simulations



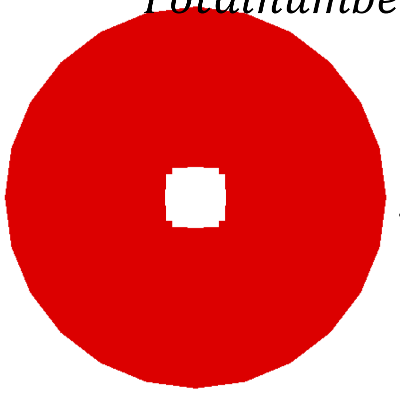
Realistic disks

* P. G. Jones https://indico.bnl.gov/event/15486/contributions/62590/attachments/40656/67919/EIC-Sensors-Jones.pdf

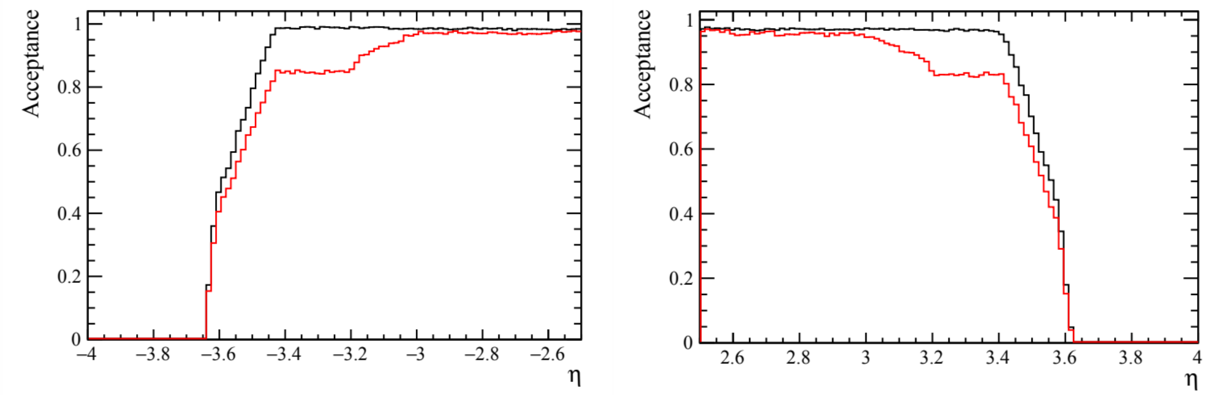
Disk acceptance vs η

- Implemented disk modules in Fun4All with inner cutouts in the same shape as the “realistic” disks as produced by the tiling algorithm
  - Particles propagated by Geant4, tracks reconstructed by Genfit (instead of ACTS)
- Generated events in far forward/backward region and studied acceptance in η bins:

$$Acceptance = \frac{Number of events with at least 3 hits}{Total number of events}$$



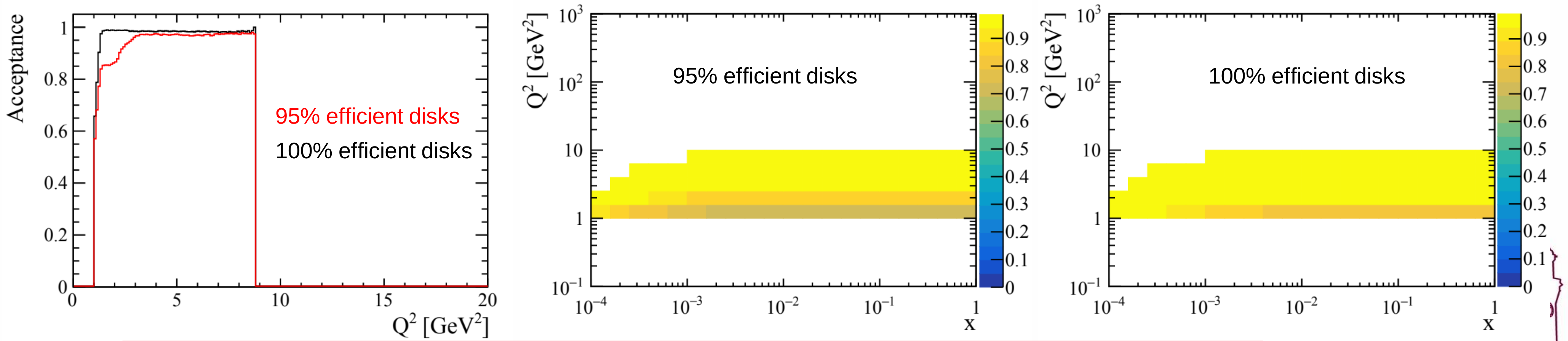
95% efficient disks
100% efficient disks



Disk acceptance vs (x-)Q^2

- Considered only 18x275 GeV^2 NC-DIS events (Pythia8, $Q^2 > 1\ GeV^2$)
  - Scattered electron mapped to relevant η bin and weighted number of reconstructed events by acceptance in this η bin and recorded x-Q^2 for the event
    → Acceptance here is fraction of events reconstructed in a given x-Q^2 range

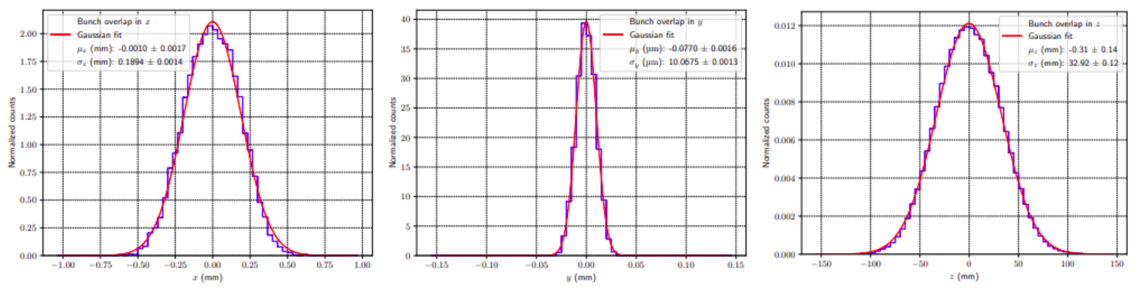
Higher x lower Q^2 bins lose acceptance



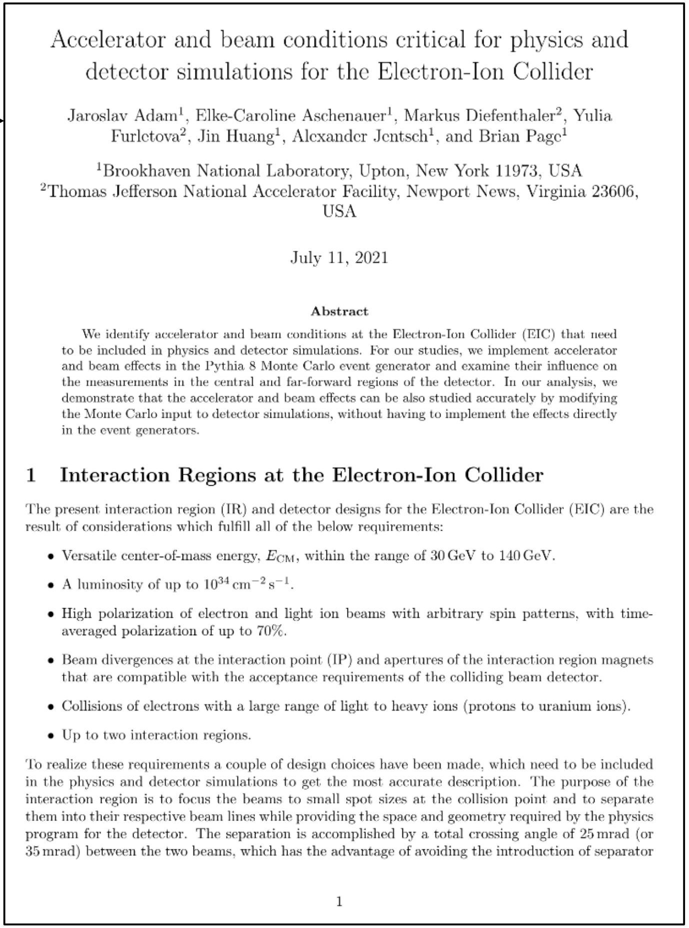
Acceptance > ~80% for all bins Q^2>1GeV^2 for 100% efficient disks https://github.com/eic/documents/blob/master/reports/general/Note-Simulations-BeamEffects.pdf

Effect of beamspot on tracking performance

- A very helpful report on beam conditions at EIC was produced last year
  - This included a transport model which allows one to obtain the primary vertex distribution in terms of x, y, z



- → Generated single particle events in Fun4All with the origin vertex distributed according to these distributions



Accelerator and beam conditions critical for physics and detector simulations for the Electron-Ion Collider

Jaroslav Adam[1], Elke-Caroline Aschenauer[1], Markus Diefenthaler[2], Yulia Furletova[2], Jin Huang[1], Alexander Jentsch[1], and Brian Page[1]

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July 11, 2021

Abstract

We identify accelerator and beam conditions at the Electron-Ion Collider (EIC) that need to be included in physics and detector simulations. For our studies, we implement accelerator and beam effects in the Pythia 8 Monte Carlo event generator and examine their influence on the measurements in the central and far-forward regions of the detector. In our analysis, we demonstrate that the accelerator and beam effects can be also studied accurately by modifying the Monte Carlo input to detector simulations, without having to implement the effects directly in the event generators.

1 Interaction Regions at the Electron-Ion Collider

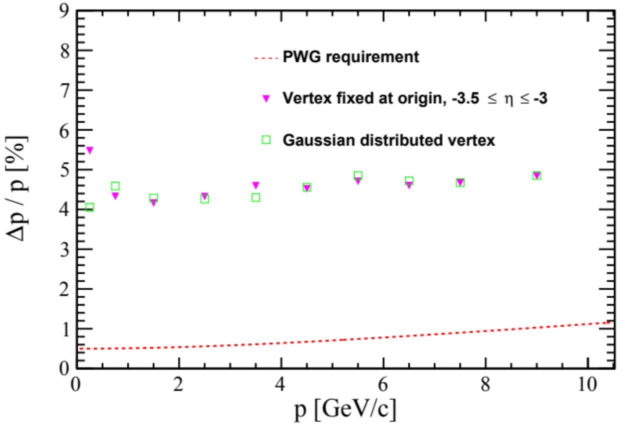
The present interaction region (IR) and detector designs for the Electron-Ion Collider (EIC) are the result of considerations which fulfill all of the below requirements:

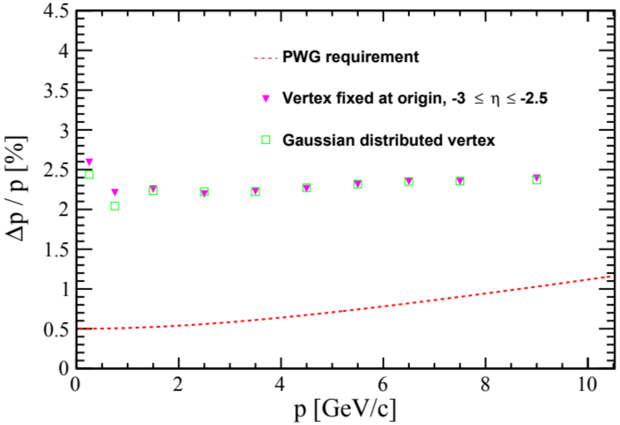
- Versatile center-of-mass energy, E_{CM}, within the range of 30 GeV to 140 GeV.
- A luminosity of up to $10^{34}\,cm^{-2}\,s^{-1}$.
- High polarization of electron and light ion beams with arbitrary spin patterns, with time-averaged polarization of up to 70%.
- Beam divergences at the interaction point (IP) and apertures of the interaction region magnets that are compatible with the acceptance requirements of the colliding beam detector.
- Collisions of electrons with a large range of light to heavy ions (protons to uranium ions).
- Up to two interaction regions.

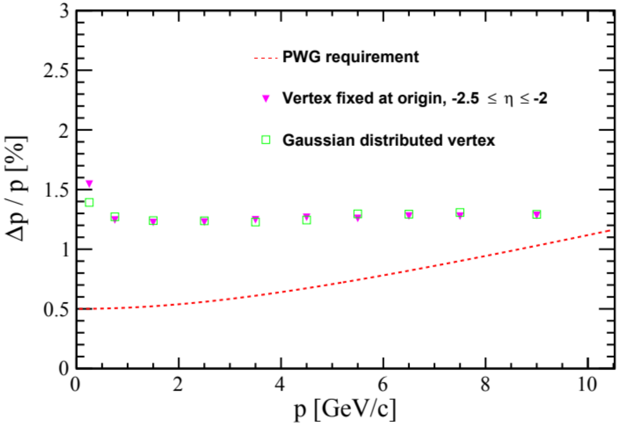
To realize these requirements a couple of design choices have been made, which need to be included in the physics and detector simulations to get the most accurate description. The purpose of the interaction region is to focus the beams to small spot sizes at the collision point and to separate them into their respective beam lines while providing the space and geometry required by the physics program for the detector. The separation is accomplished by a total crossing angle of 25 mrad (or 35 mrad) between the two beams, which has the advantage of avoiding the introduction of separator

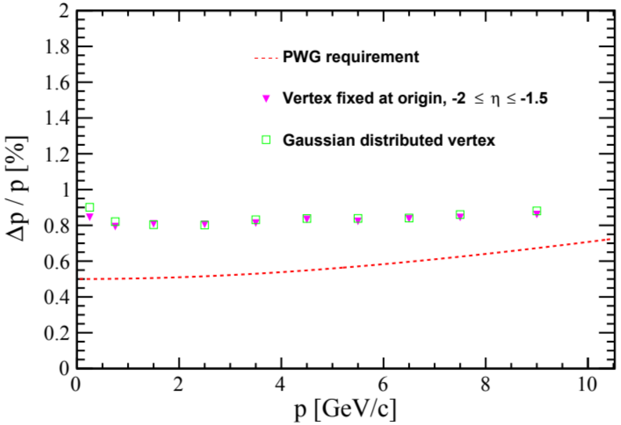
1

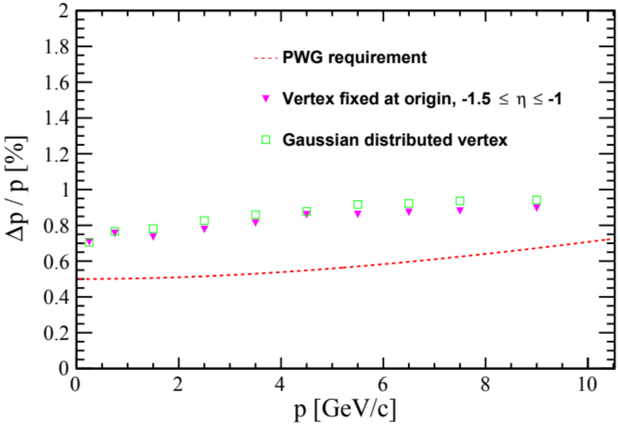
Momentum resolution - Backward





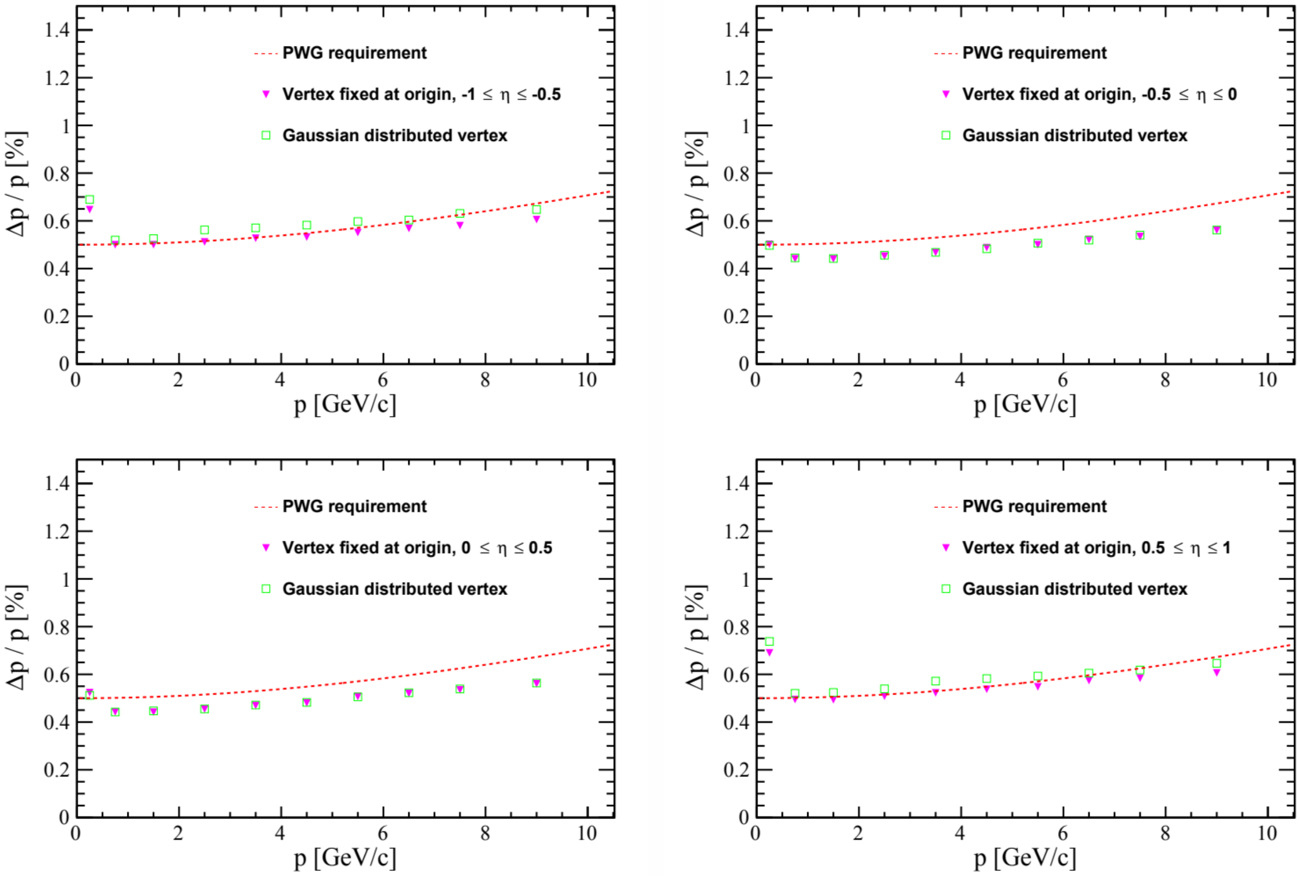






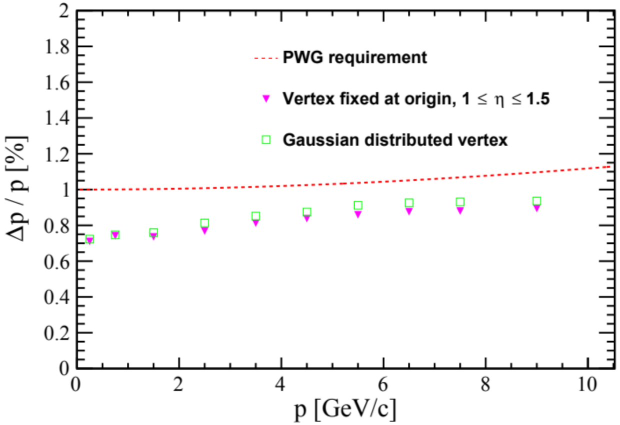
- A very small loss of performance for $-1.5<\eta<-1$, with other regions being mostly the same

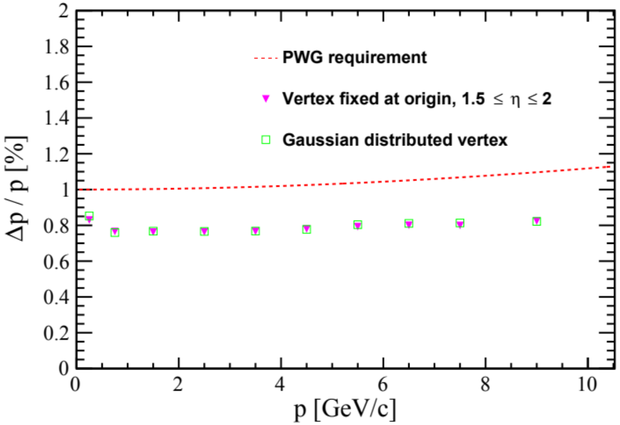
Momentum resolution - Central

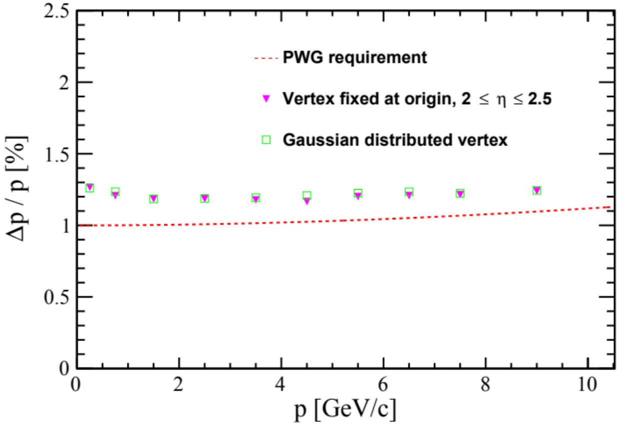


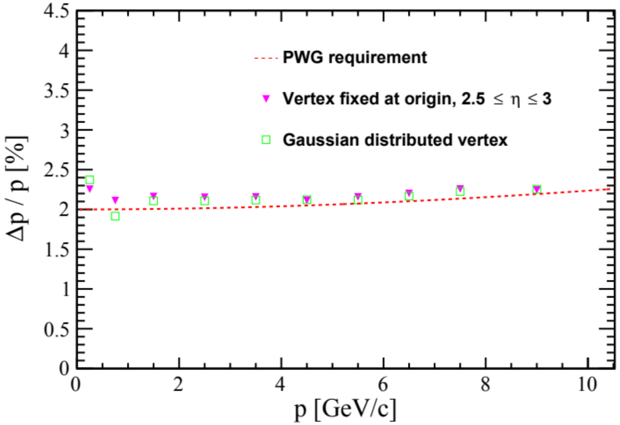
- Small difference in performance for 0.5<|η|<1

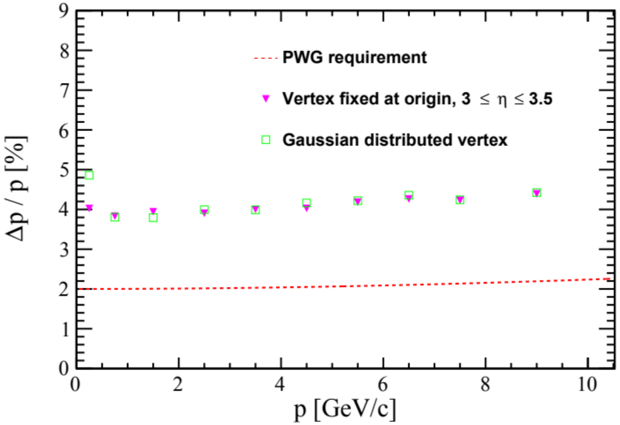
Momentum resolution - Forward





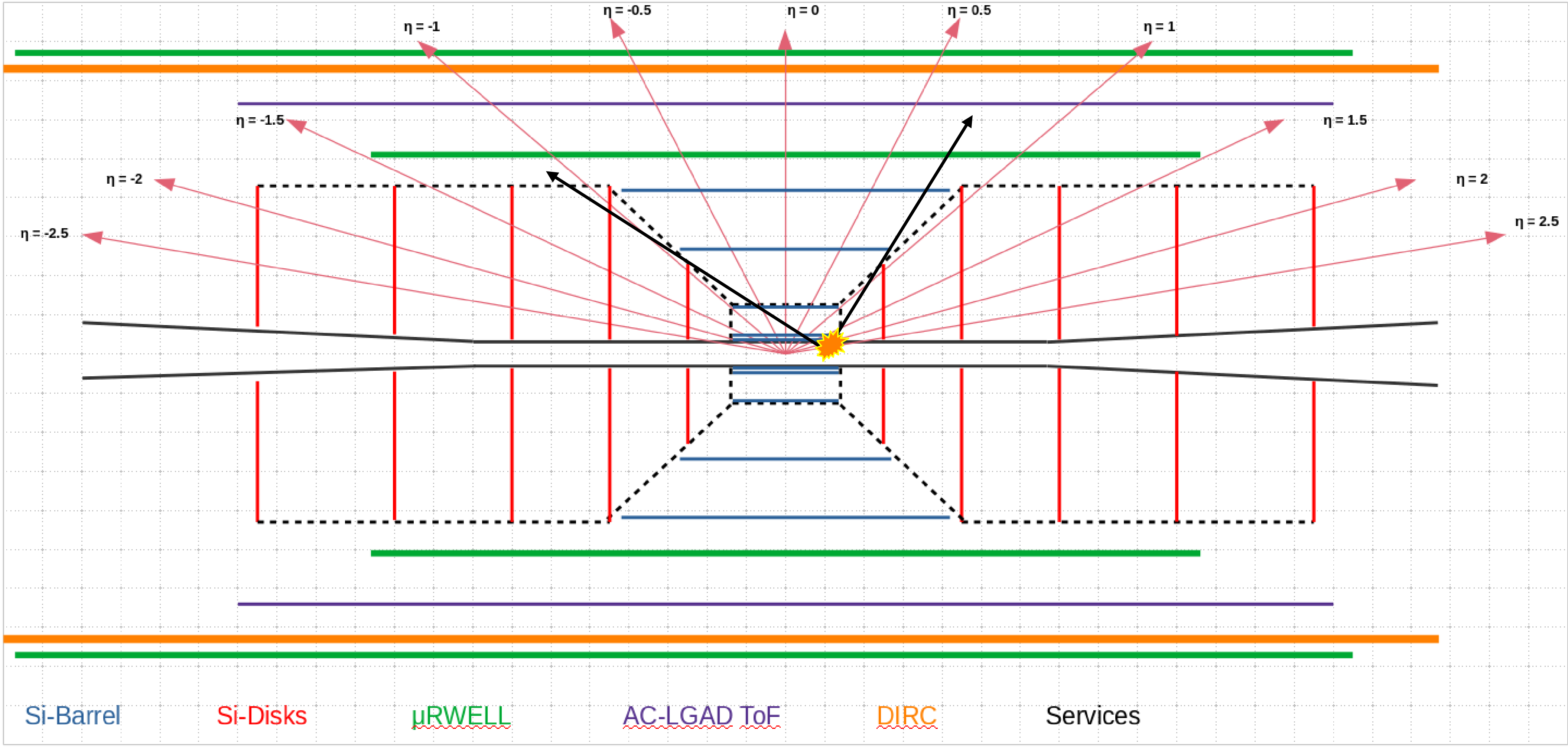




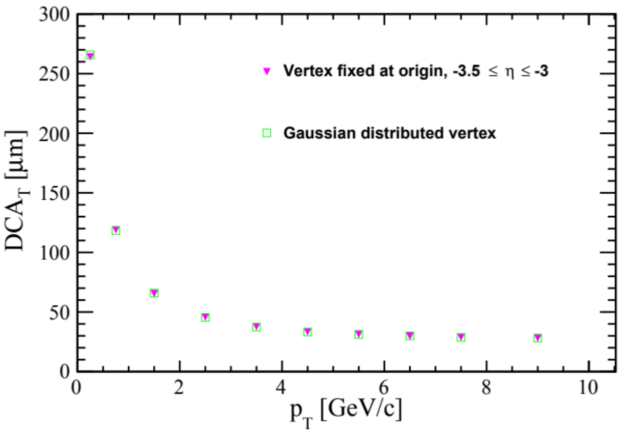


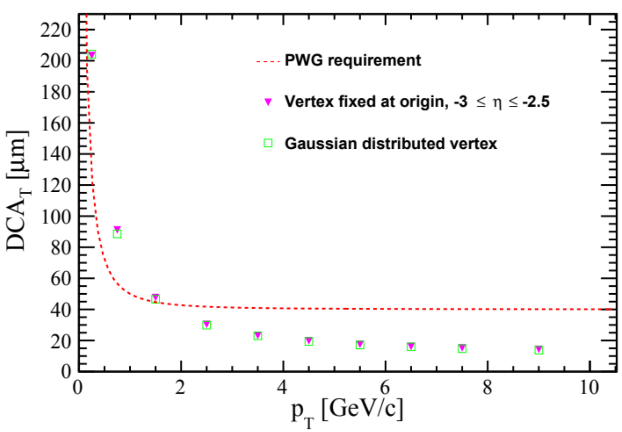
- Same trend as for Backward: only $1<\eta<1.5$ shows a small loss of performance
- Can attribute this to extra material seen when crossing over service cone

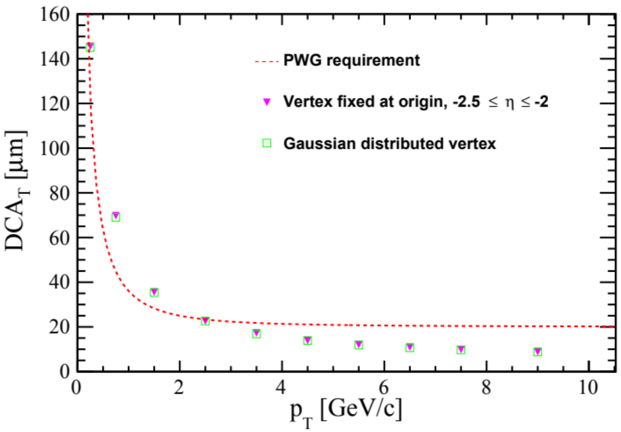
Extra material seen by particles from offset vertex if they traverse service cone

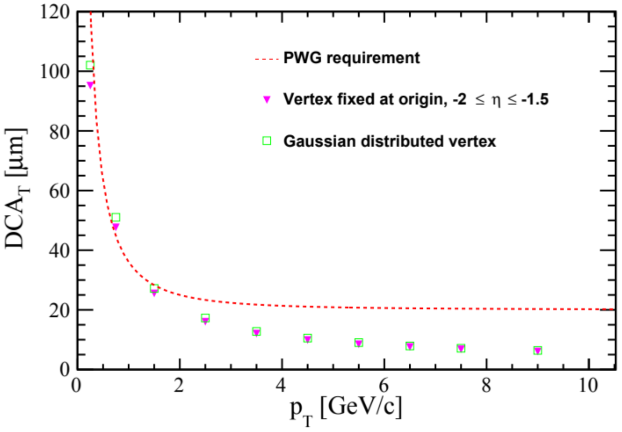


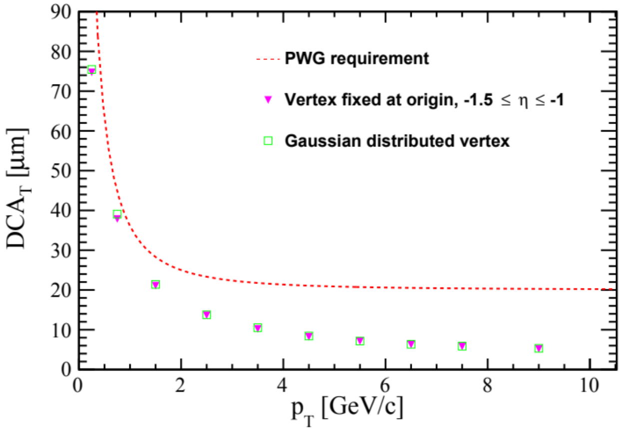
Transverse pointing resolution - Backward





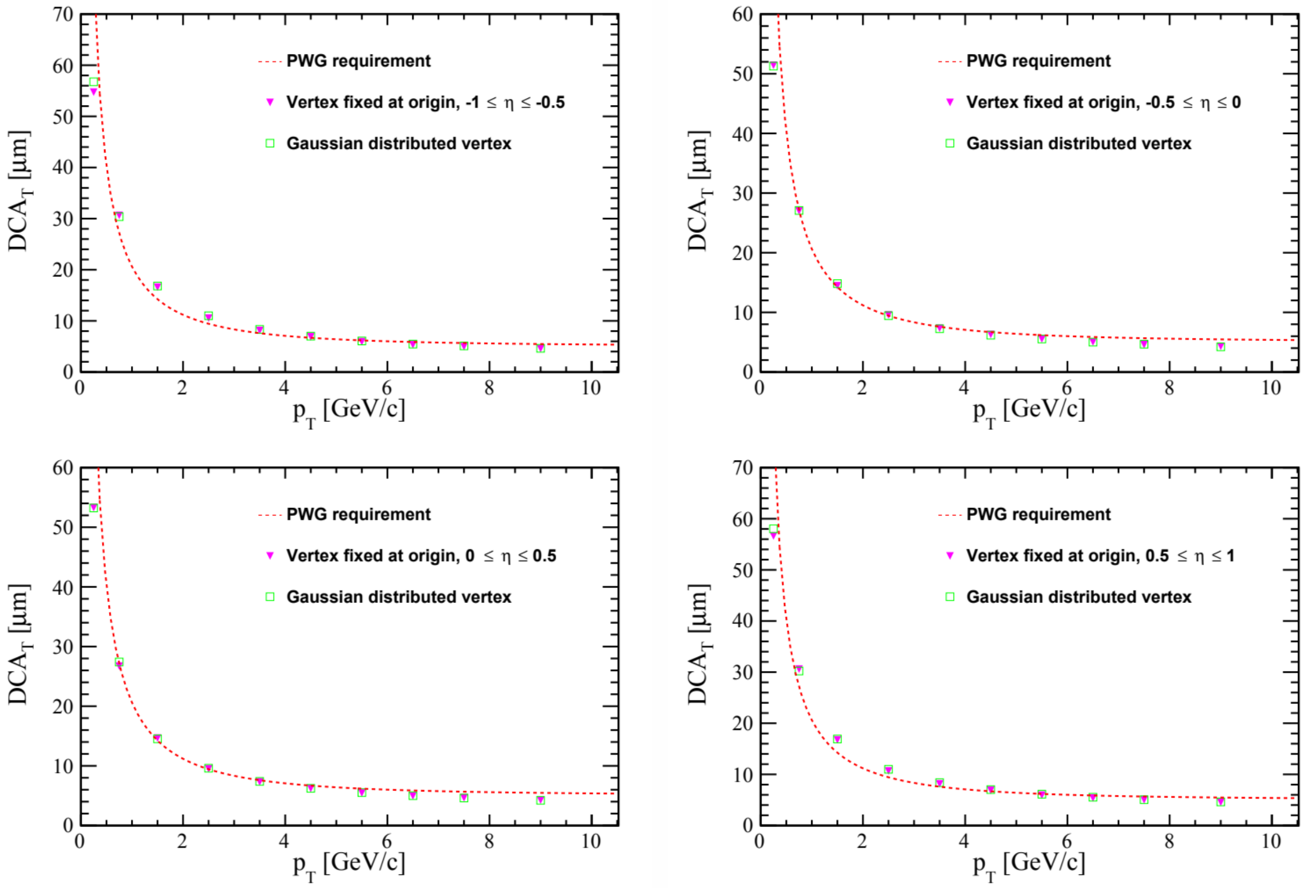






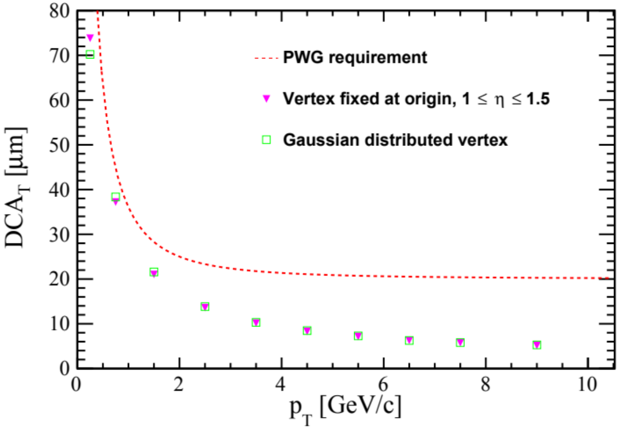
- No significant differences in transverse pointing resolution

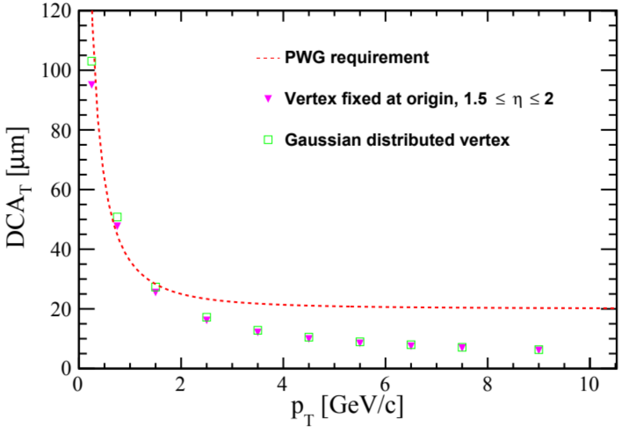
Transverse pointing resolution - Central

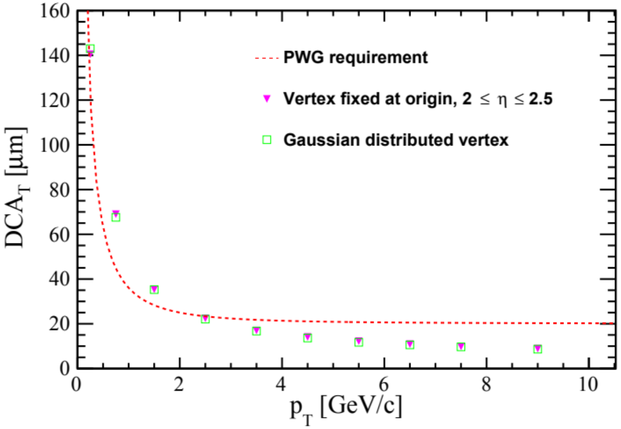


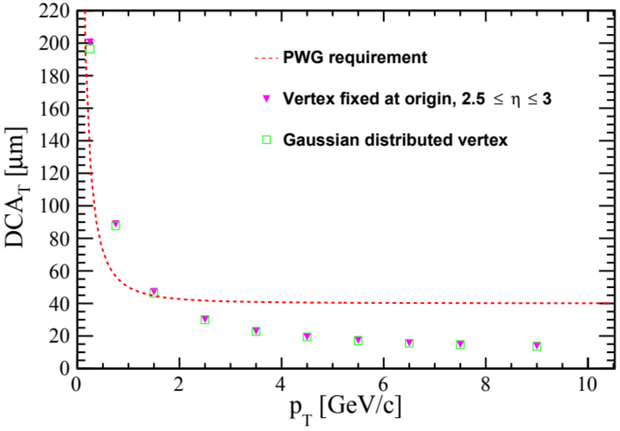
- No significant differences in transverse pointing resolution

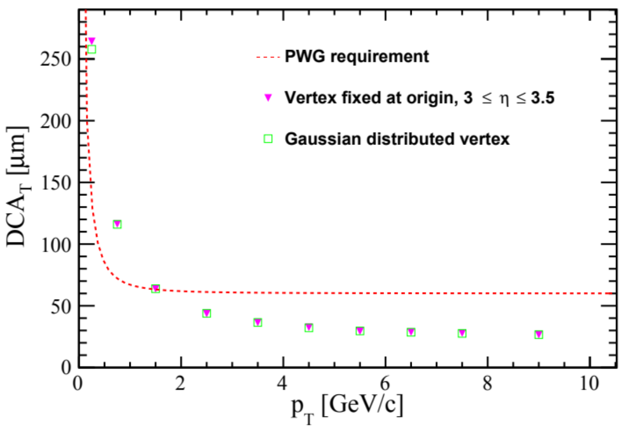
Transverse pointing resolution - Forward











- No significant differences in transverse pointing resolution

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Bringing Science Solutions to the World

Track angular resolution and magnetic field dependence

Wenqing Fan

ePIC collboration meeting, 01/10/2023

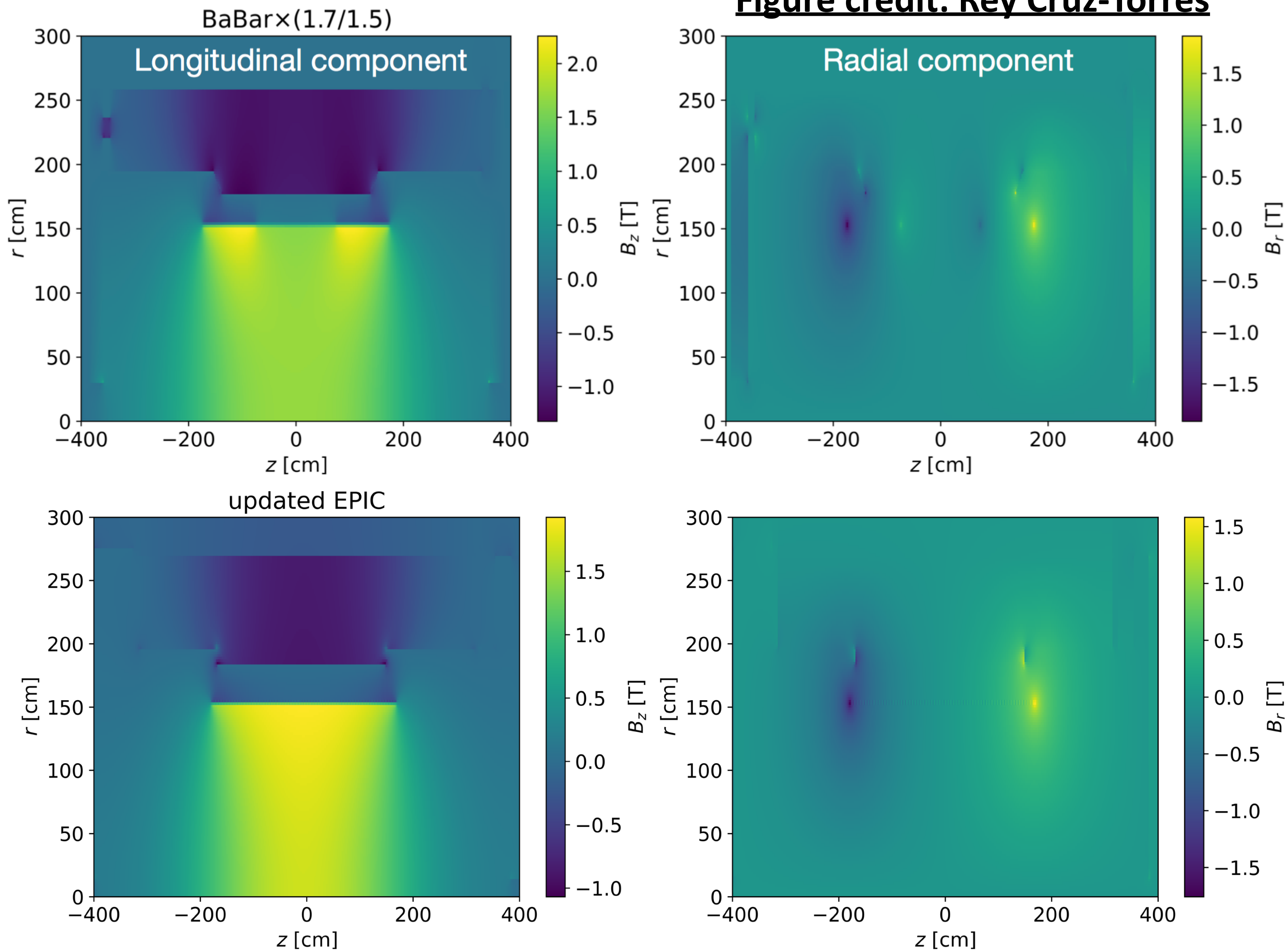
Field map for the new magnet MARCO

- New magnet (MARCO) will be used for the ePIC experiment
  - Decreasing field stength at larger z

Figure credit: Rey Cruz-Torres

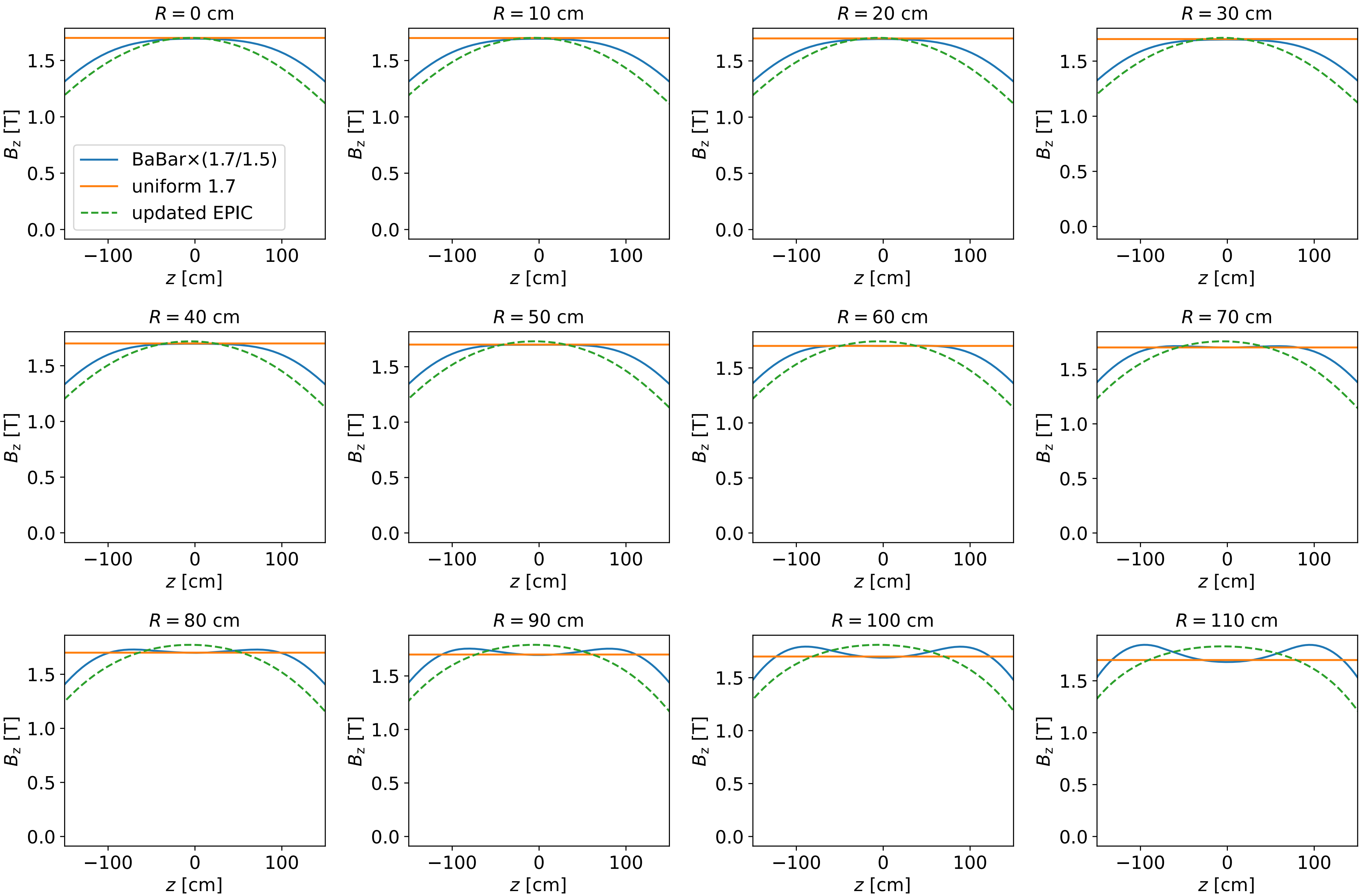
Scaled BaBar field map

Marco field map



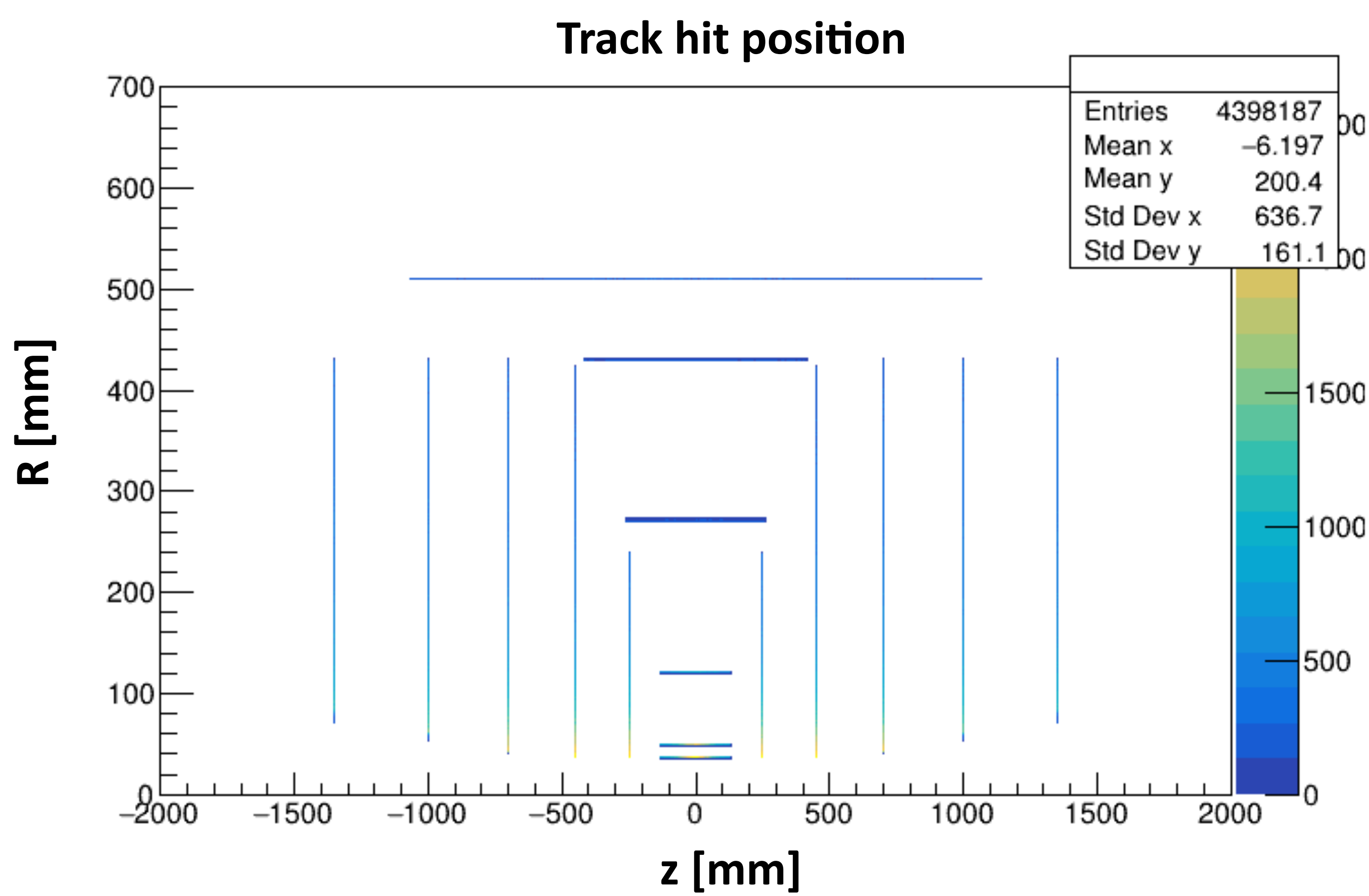
Field map comparison

Figure credit: Rey Cruz-Torres



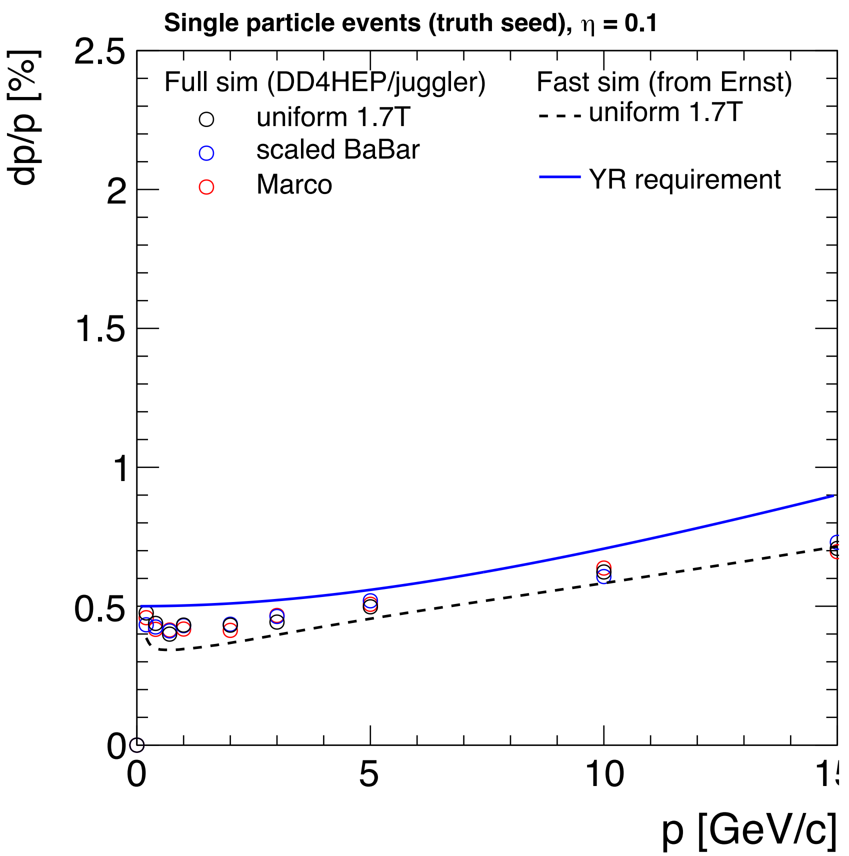
Tracking geometry for the B field study

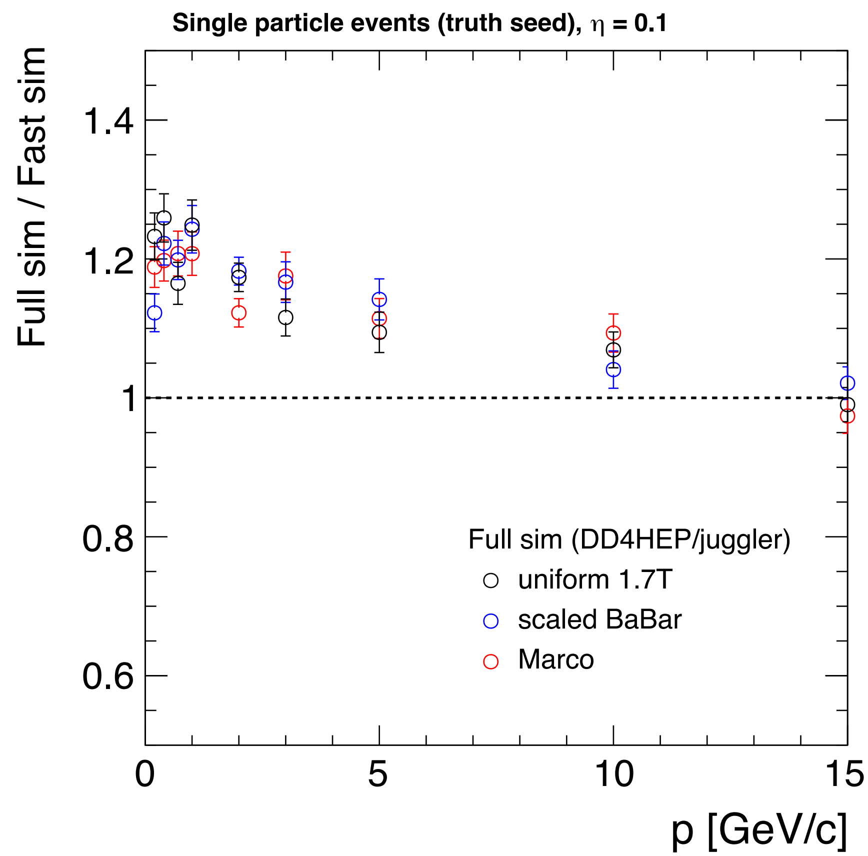
- Symmetric geometry (<u>not tagged geometry</u>) with different B field settings
  - Barrel MPGD: spatial resolution 150µm, r= 51cm
  - Barrel silicon: spatial resolution 10µm/sqrt(12), r= 3.6, 4.8, 12, 27, 42cm
  - Endcap silicon: spatial resolution 10µm/sqrt(12), z = 25, 45, 70, 100, 135cm



Effect of the different B field settings

- Same geometry with different B field settings
  - New MARCO field map (1.7T), Scaled BaBar field map (by 1.7T/1.5T), Uniform 1.7T field
- Difference between full and fast simulation due to material difference
  - No support cylinder in the fast simulation + more material per disk (including air) in the full simulation





Similar performance from different B field settings

Effect of the different B field settings

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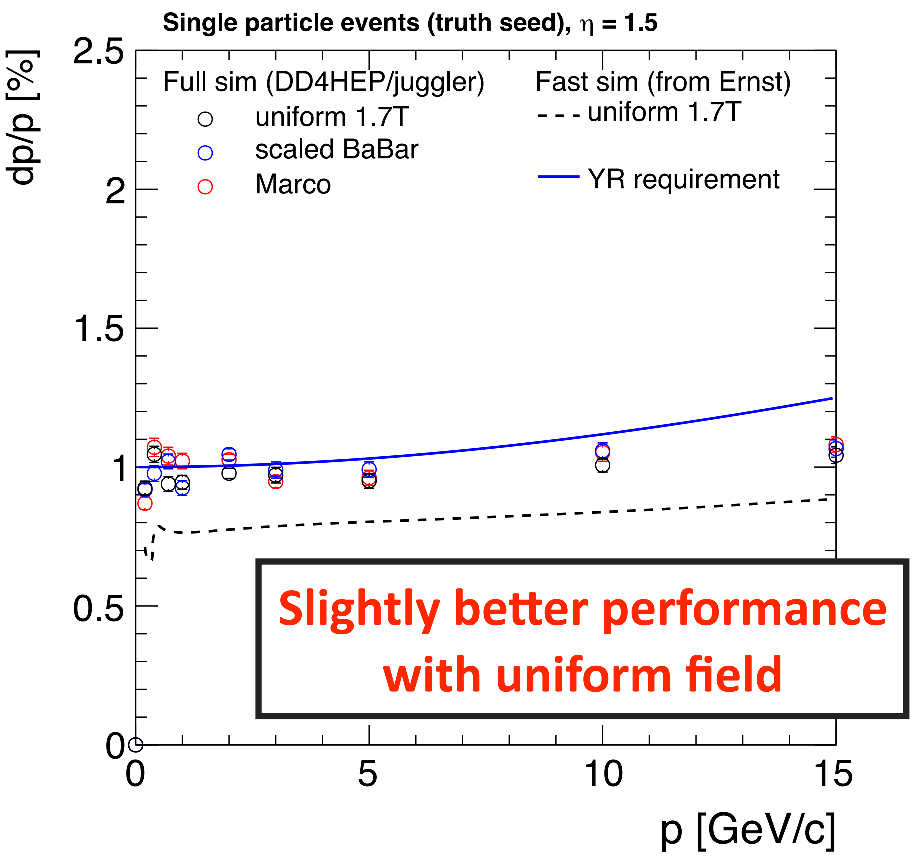
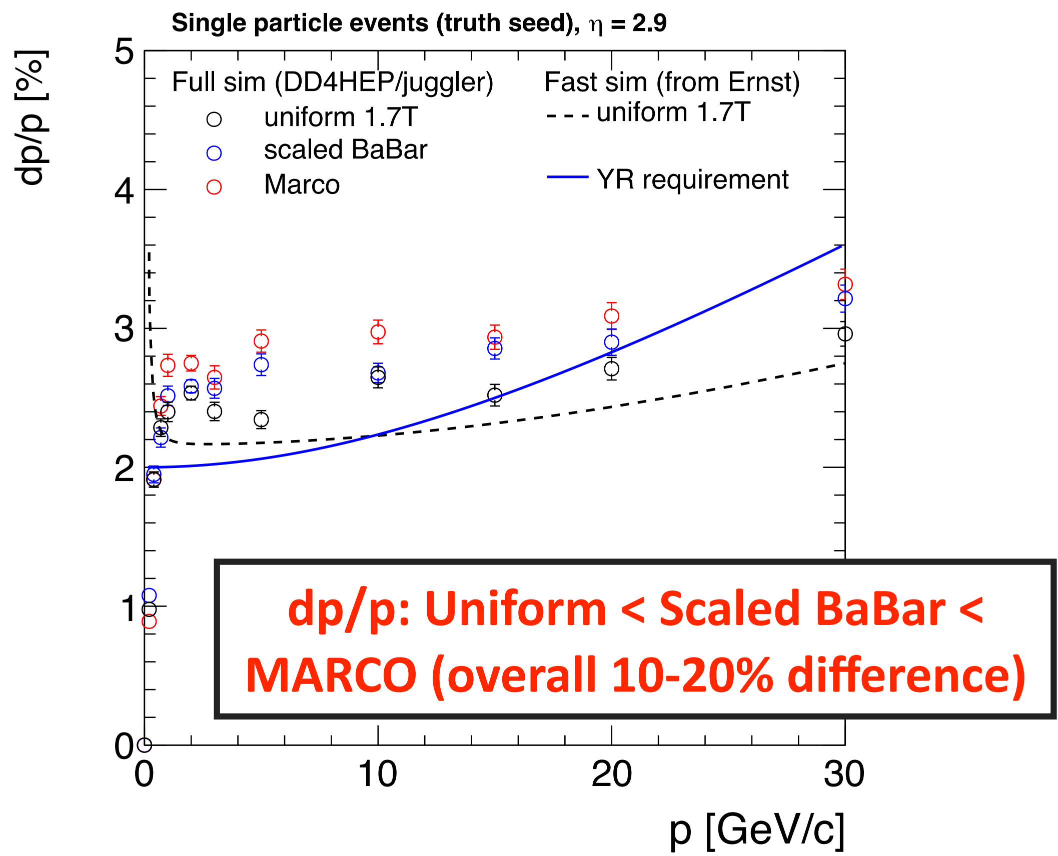
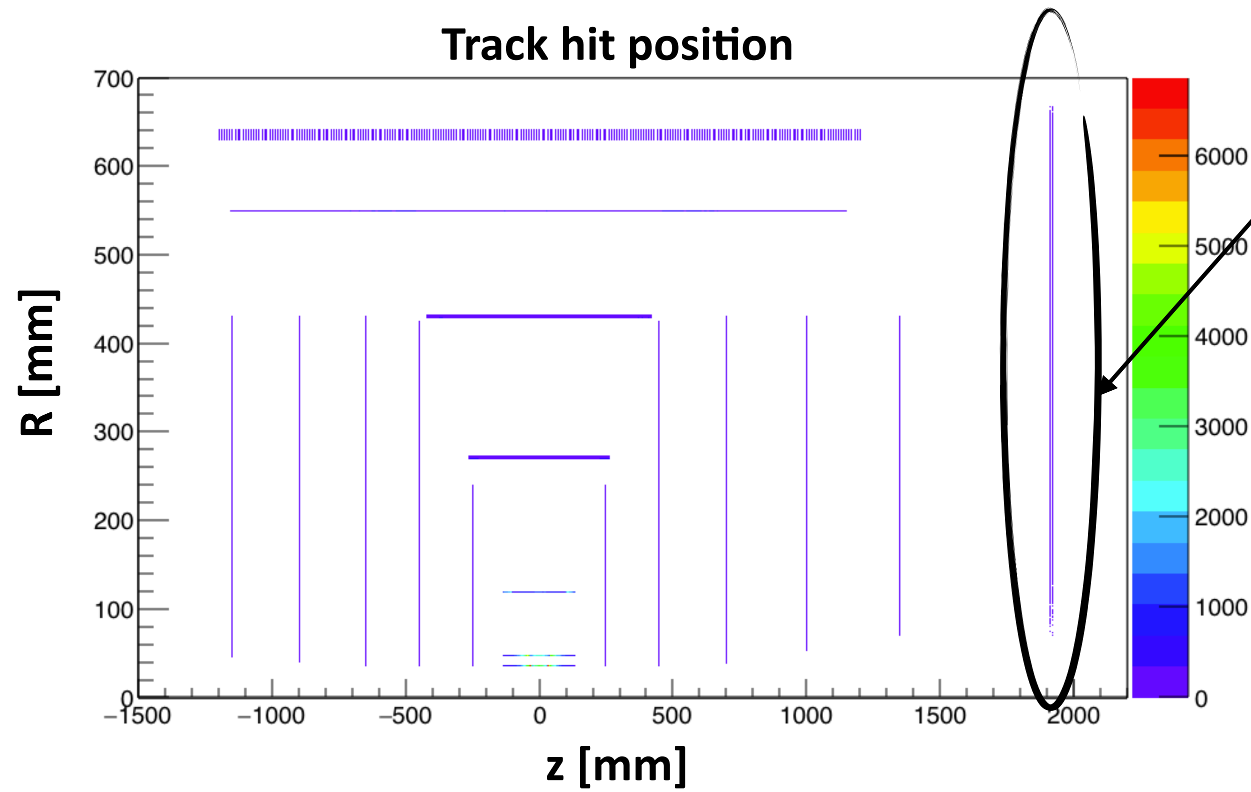




Tagged geometry + new MARCO field map

- Geometry tag: Brycecanyon
  - 5 barrel silicon: spatial resolution 10μm/sqrt(12), r = 3.6, 4.8, 12, 27, 42cm
  - 1 barrel MPGD: spatial resolution 150μm, r = 55cm
  - 1 barrel TOF: spatial resolution 30x3000μm, r = 64.6cm
  - 10 endcap silicon: spatial resolution 10μm/sqrt(12), z = -115, -90, -65, -45, 25, 25, 45, 70, 100, 135cm
  - 1 endcap TOF: spatial resolution 30μm, z = 192cm

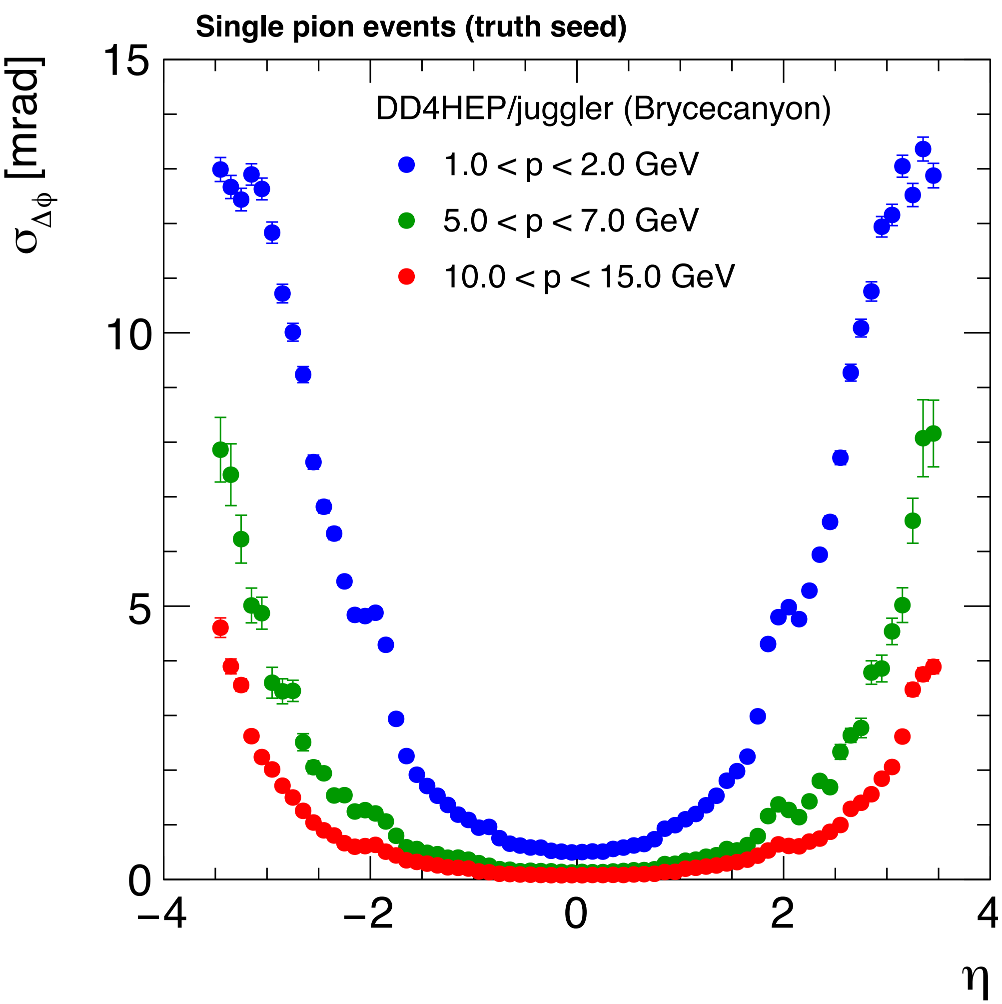
NOT in track reconstruction with juggler/EICrecon

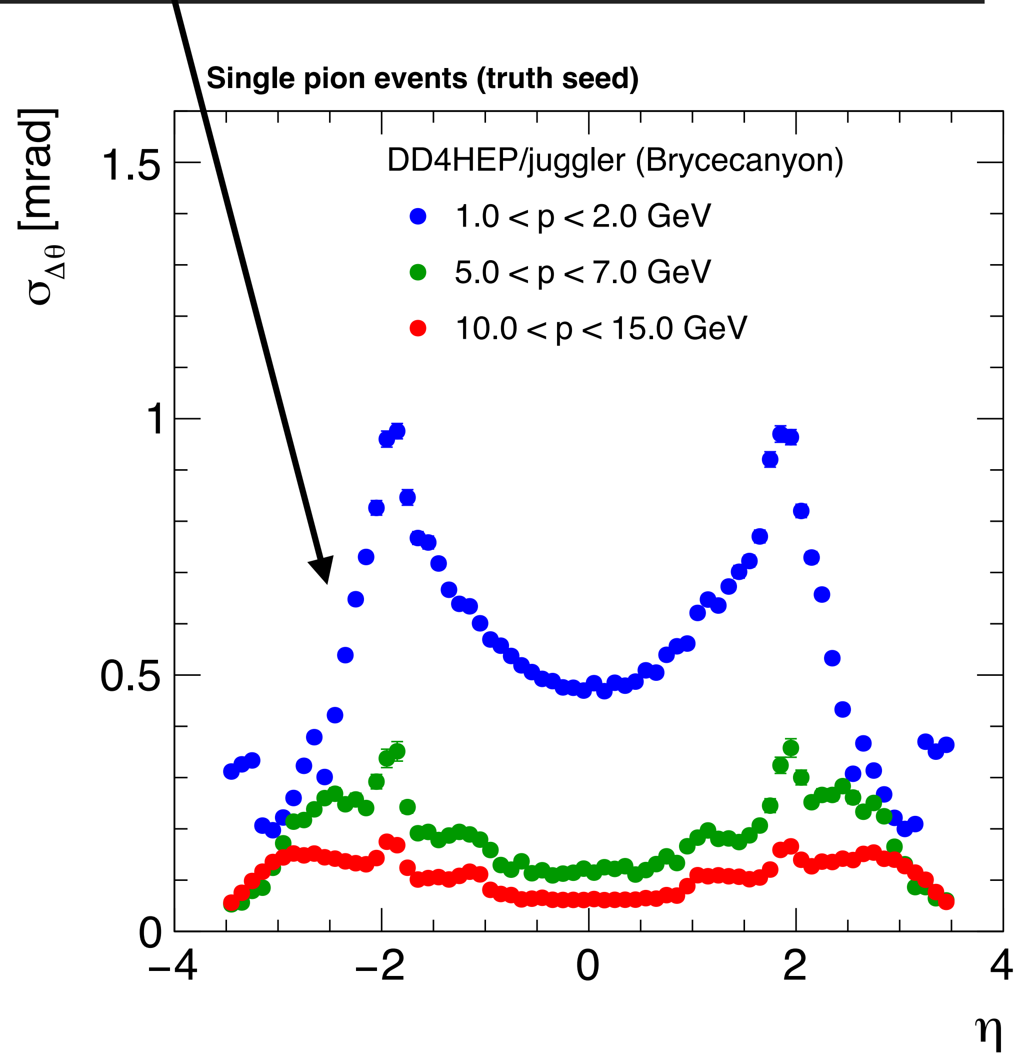


Brycecanyon + new MARCO field map

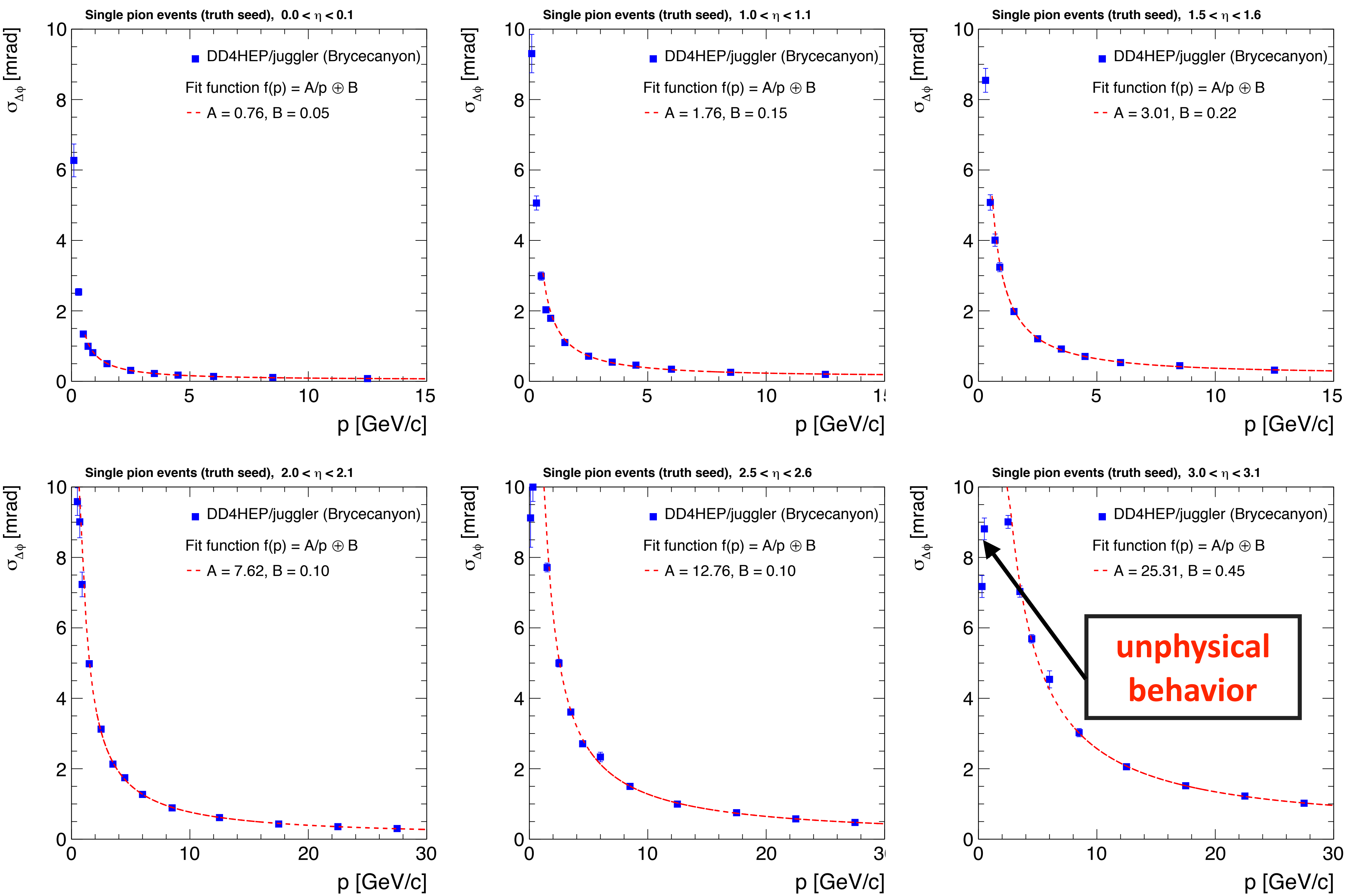
- Caveat: endcap TOF hits at z = 192cm not included in the track reconstruction

Δθ resolution not reliable for the lowest momentum range ar back/forward raidity (see slide 11)

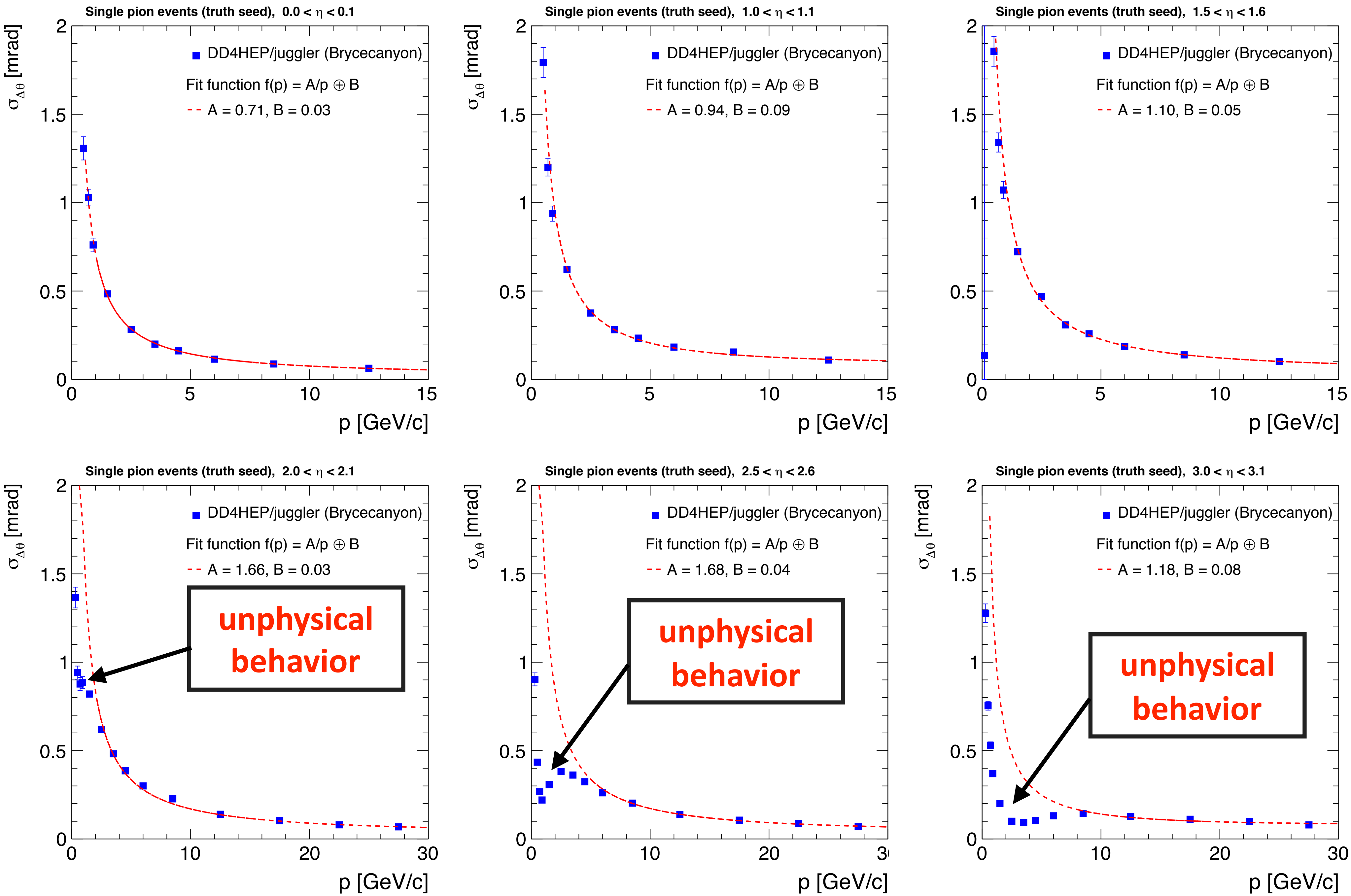




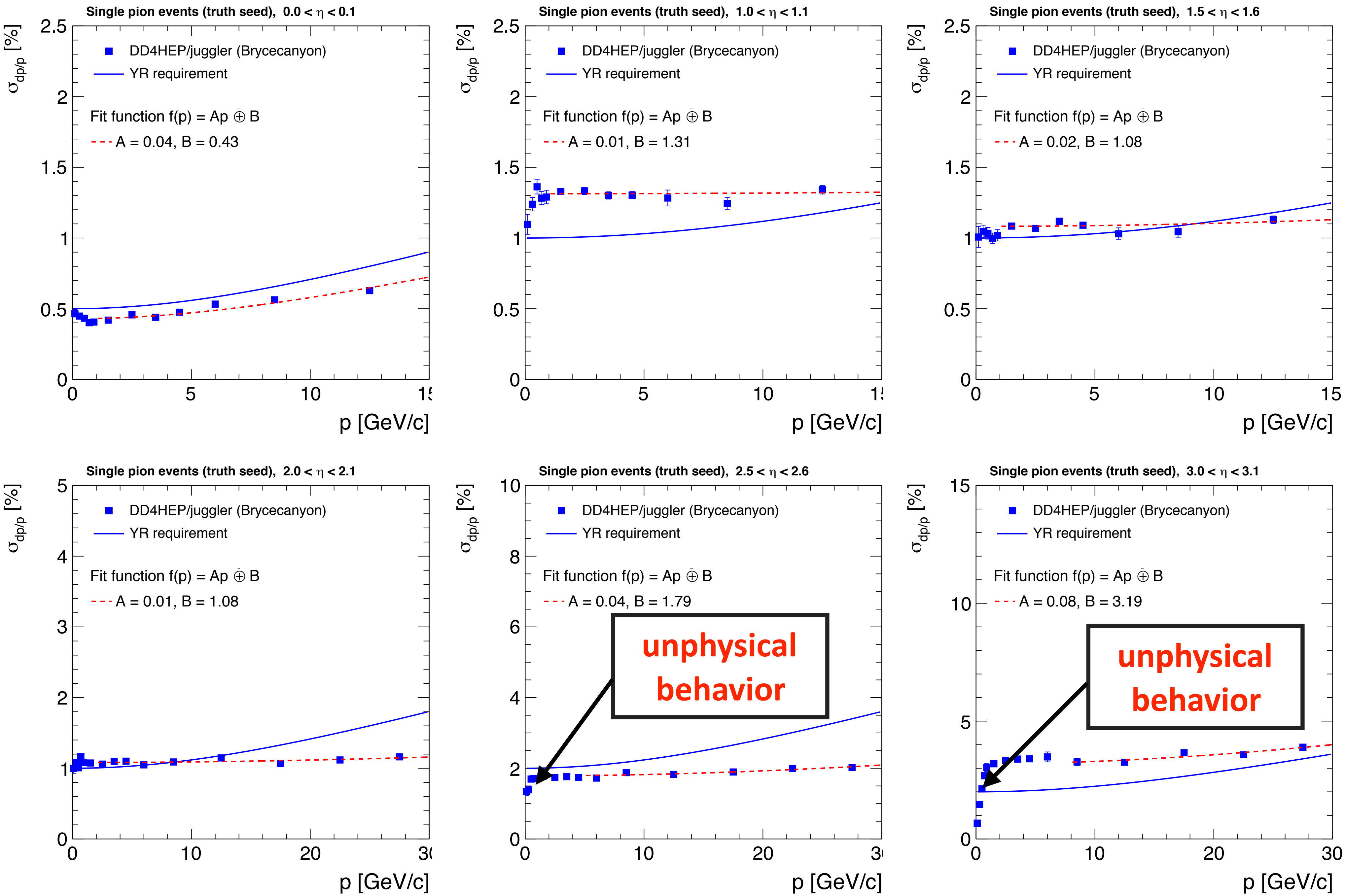
Azimuthal angular resolution (Δϕ resolution)



Polar angular resolution (Δθ resolution)



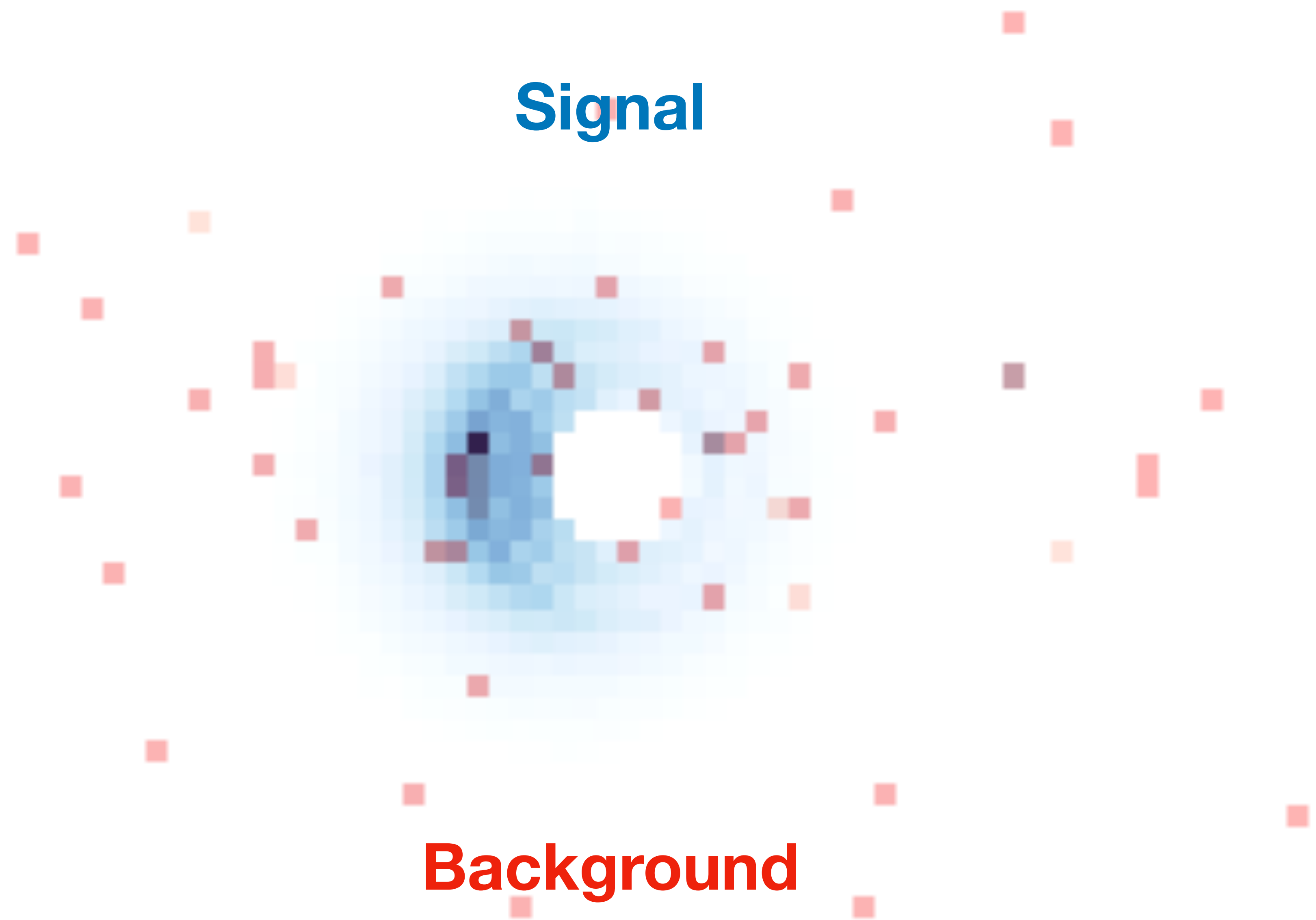
Momentum resolution (Δp/p resolution)



Summary

- Looked at the effect of different magnetic field maps on momentum resolution
  - Small effect on the performance around mid-rapidity
  - 10-20% worse performance from the new MARCO field map comparing to the uniform field map at very forward rapidity
- Looked at the angular resolution with the tagged geometry (Brycecanyon) + new MARCO field map
  - Good resolution for $\Delta\phi$ and $\Delta\theta$
  - Further investigration needed: unphysical behavior at low p range at forward/backward rapidity for $\Delta\theta$ – better resolution toward lower p (also seen for momentum resolution)

Background and track reconstruction studies



Reynier Cruz-Torres
Lawrence Berkeley National Laboratory

Presenting work done by lots of people: J. Adam, E. Aschenauer, W. Deconinck, J. Huang, A. Jentsch, K. Kauder, D. Lawrence, J. Nam, J. Osborn, B. Sterwerf, Z. Zhang, …

BERKELEY LAB

ePIC

Electron Proton-Ion Collider Experiment Collaboration
January 10th, 2023

Outline

Backgrounds at the EIC

- Synchrotron radiation

- Primary collisions
  - Ionization radiation
  - Low Energy Neutron Radiation

- Beam-gas induced
  - Electron-gas interactions
  - Hadron-gas interactions

Wiki page to document background studies

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Backgrounds at the EIC

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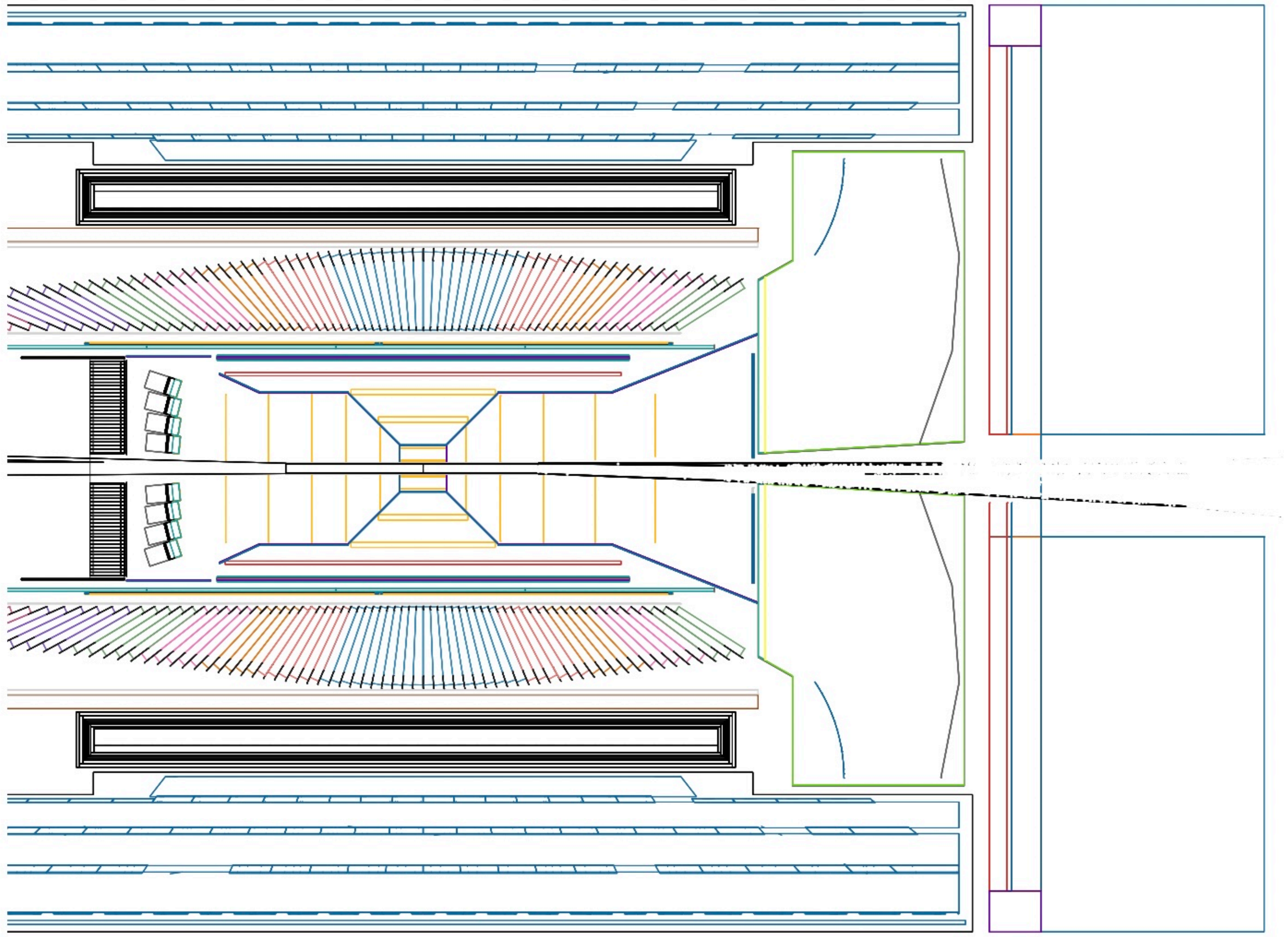


Wiki page to document background studies

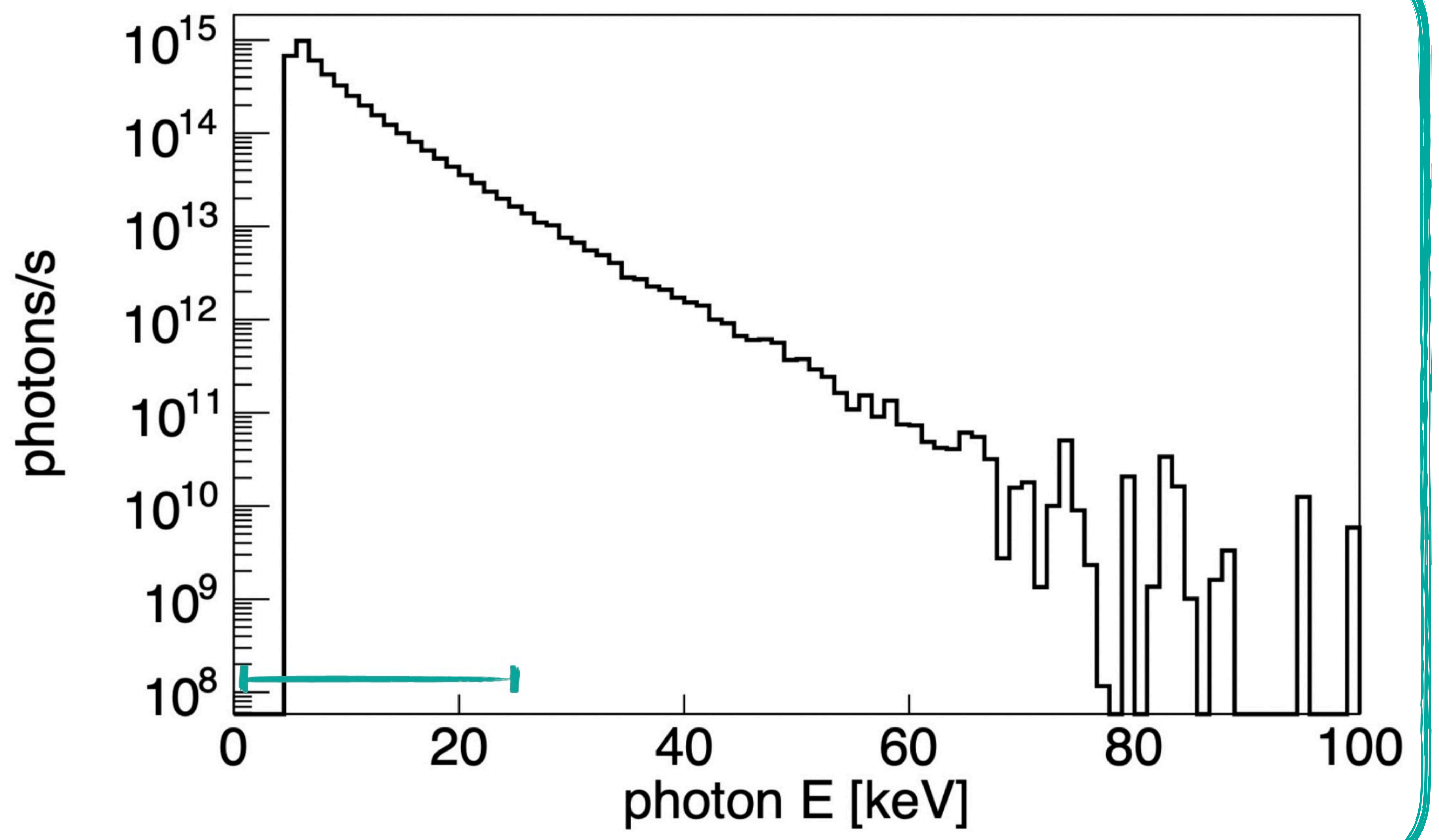
Synchrotron radiation

- Caused by quads and bending magnet upstream of IP

Simulations based on Synrad+ (by M. Stutzman)

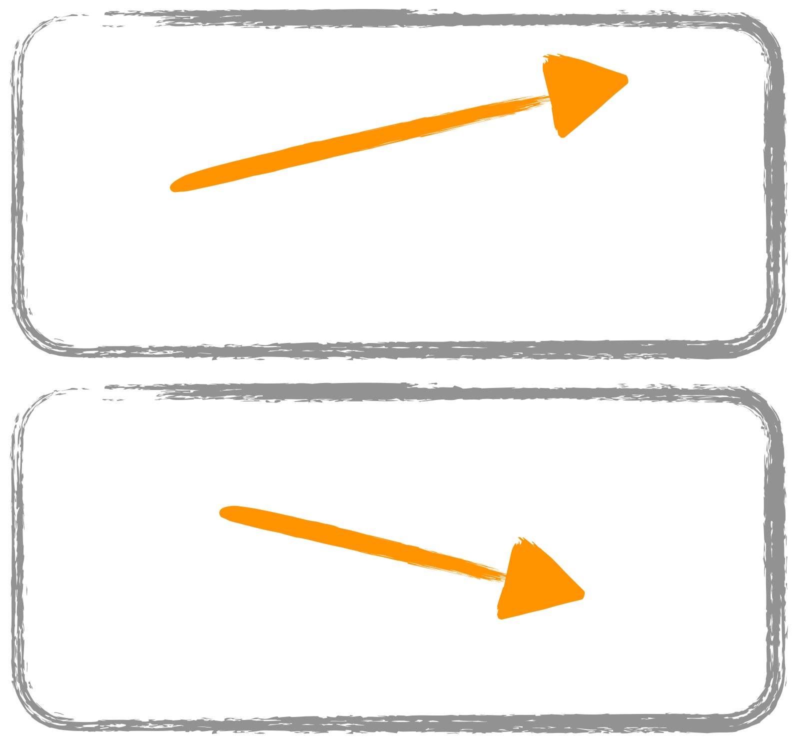
- virtual cylinder placed just inside the IR beampipe
- Electrons are propagated through B field
- resulting photons passing through cylinder are recorded

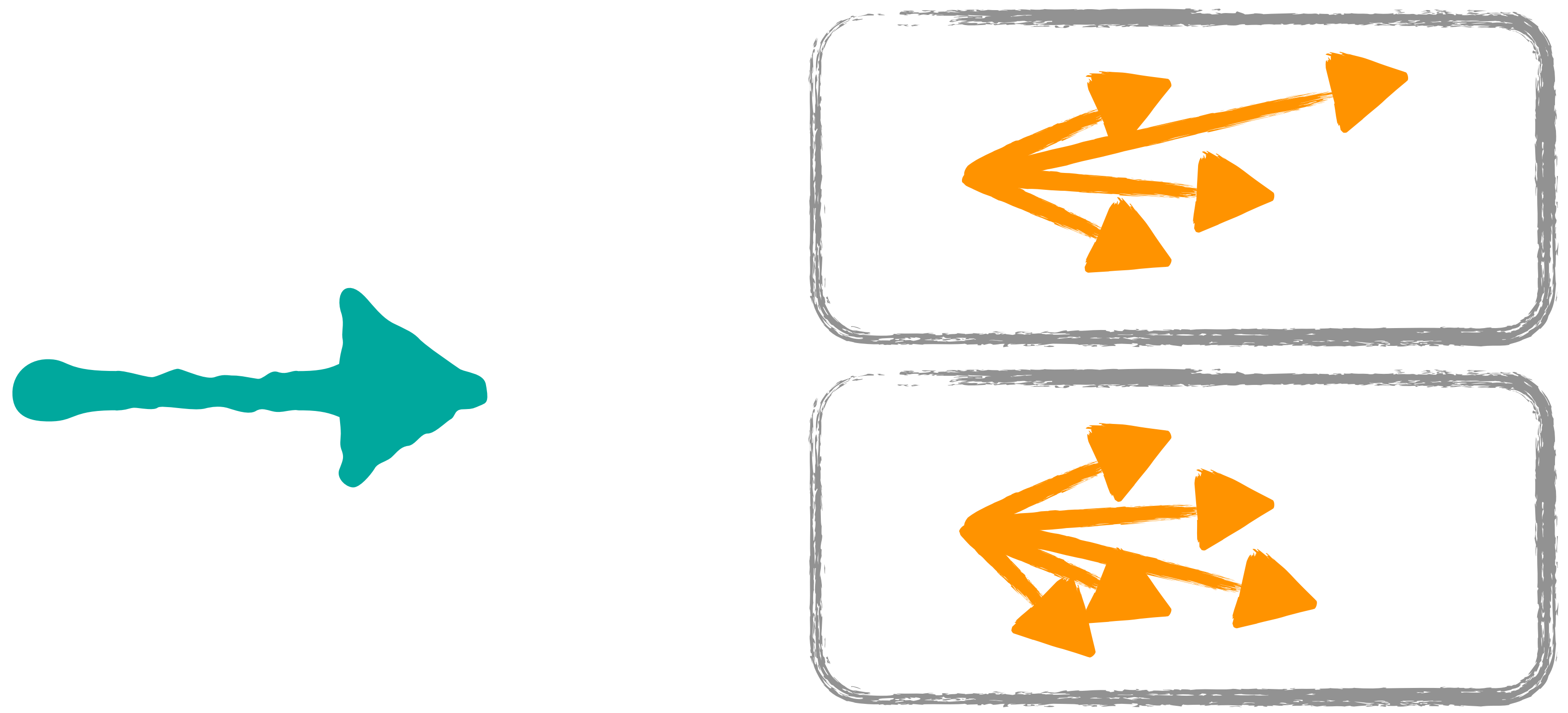
Output: hepmc file with single-photon "events" containing information related to photon vertex, momentum, and weight corresponding to equivalent photons / sec



Have

A series of single-photon events from a Synrad+ simulation.

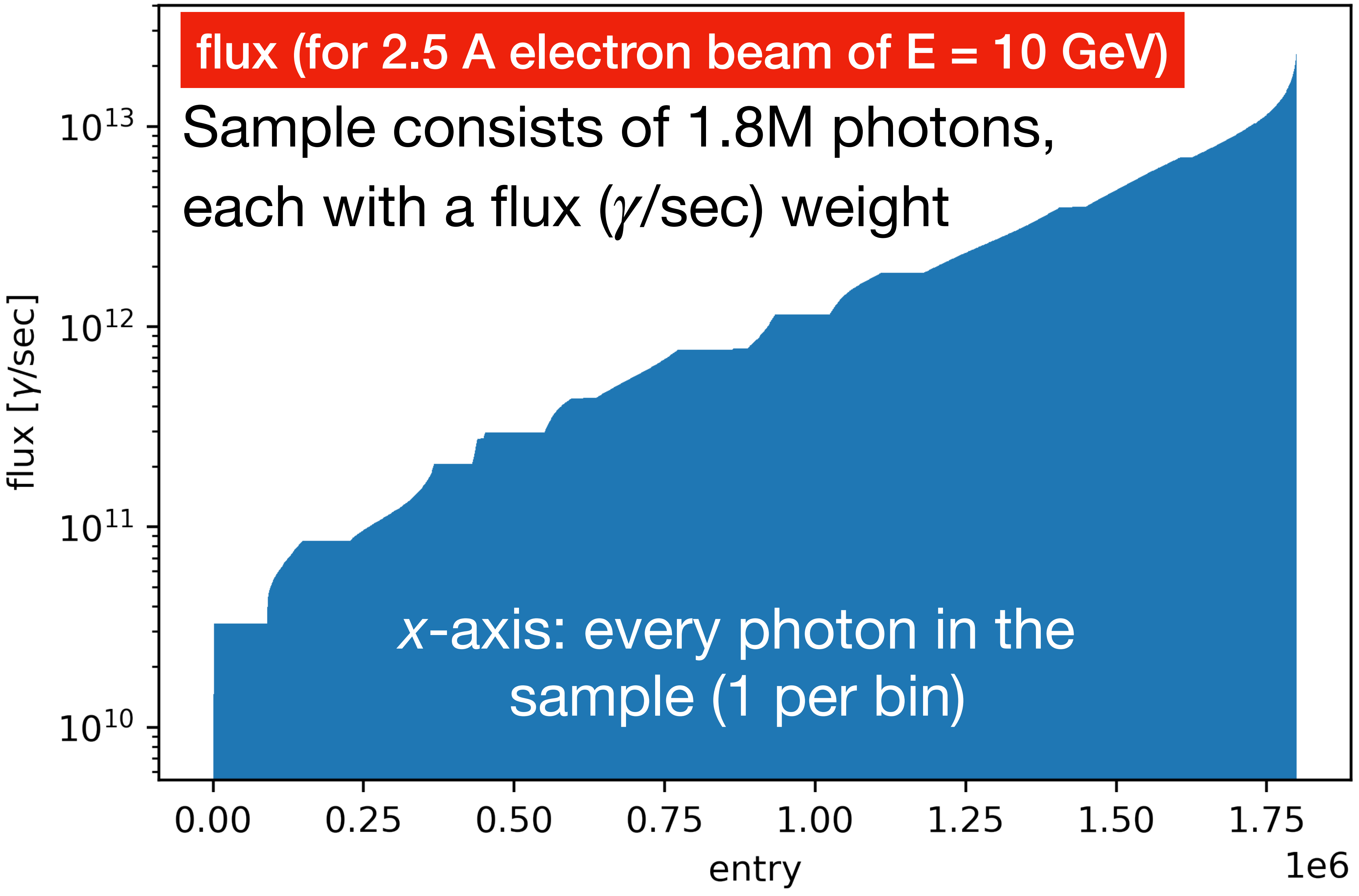




Need

A series of events with many photons corresponding to a time integration window.

Synchrotron radiation event generator

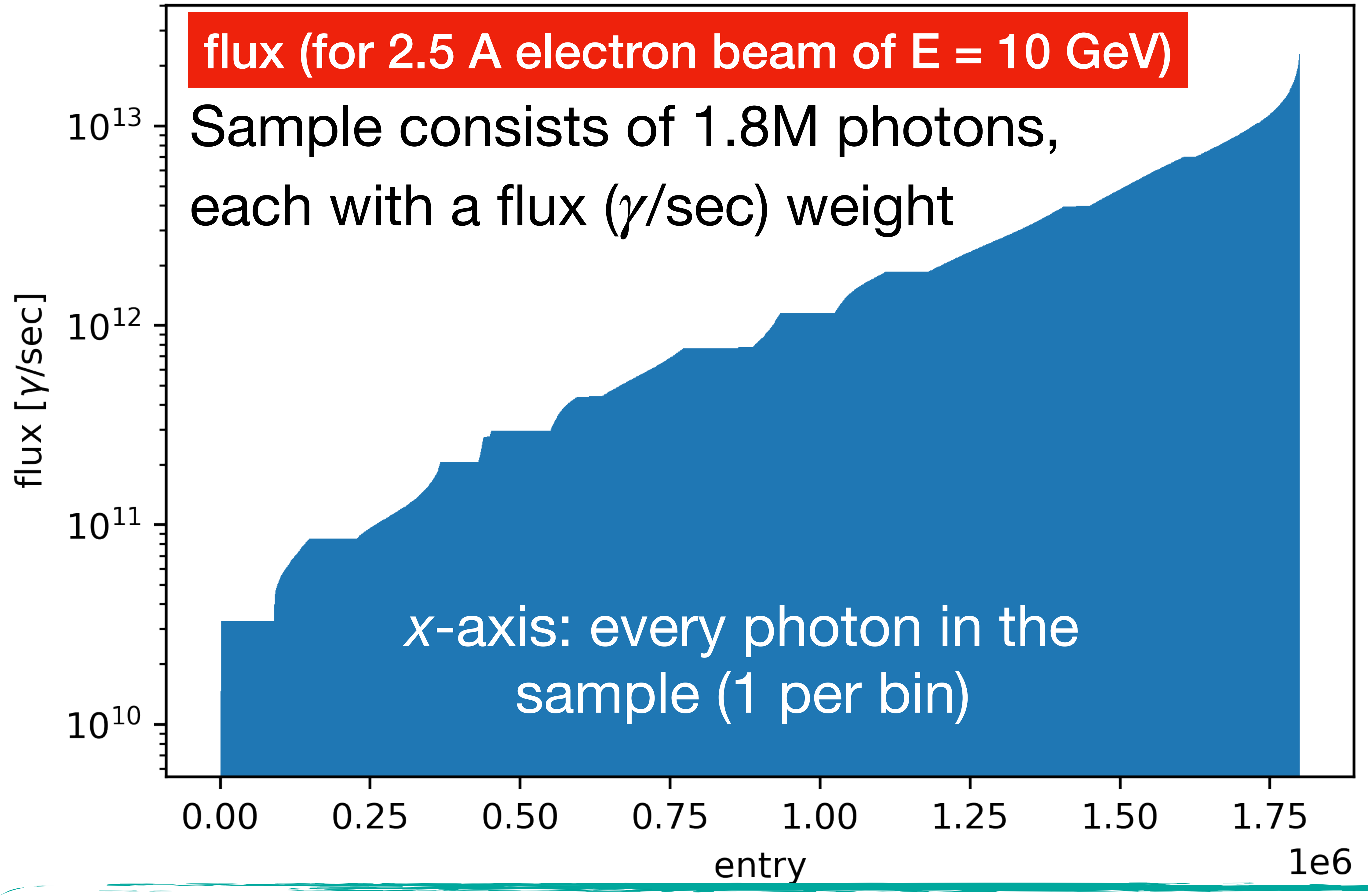


Define an integration window (IW)

```
integral = 0
while integral < IW:
    Randomly sample photon, add it to event
    integral += 1/flux
return event
```

Sample as many photons as fit in the defined time integration window

Synchrotron radiation event generator

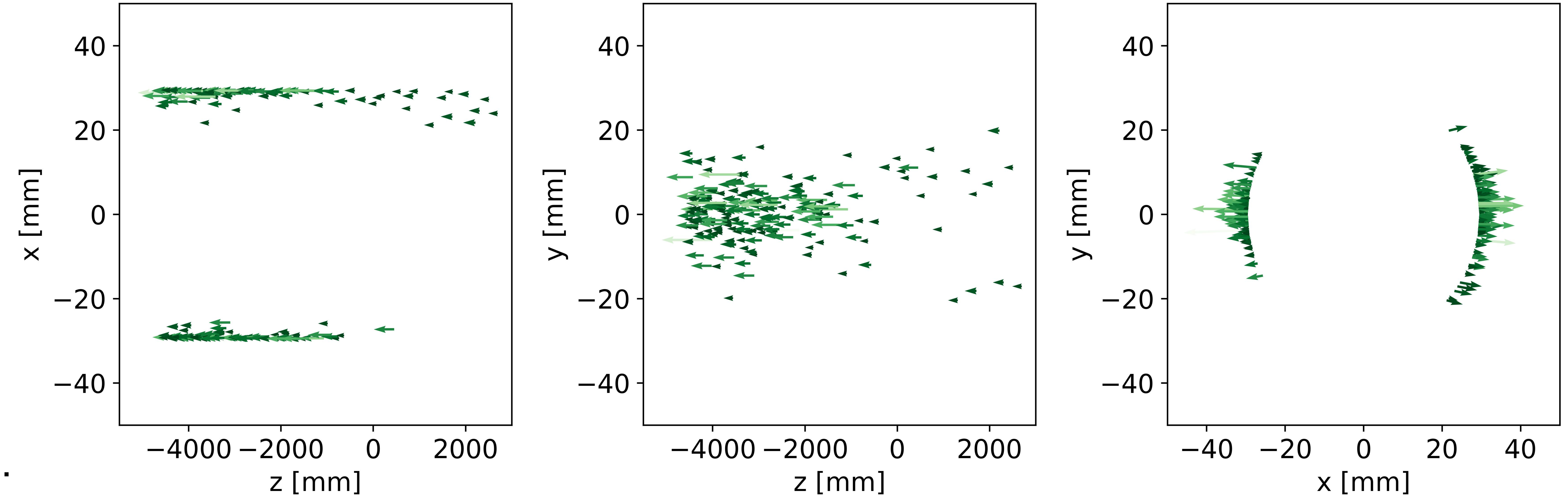


Define an integration window (IW)

```
integral = 0
while integral < IW:
    Randomly sample photon, add it to event
    integral += 1/flux
return event
```

Sample as many photons as fit in the defined time integration window

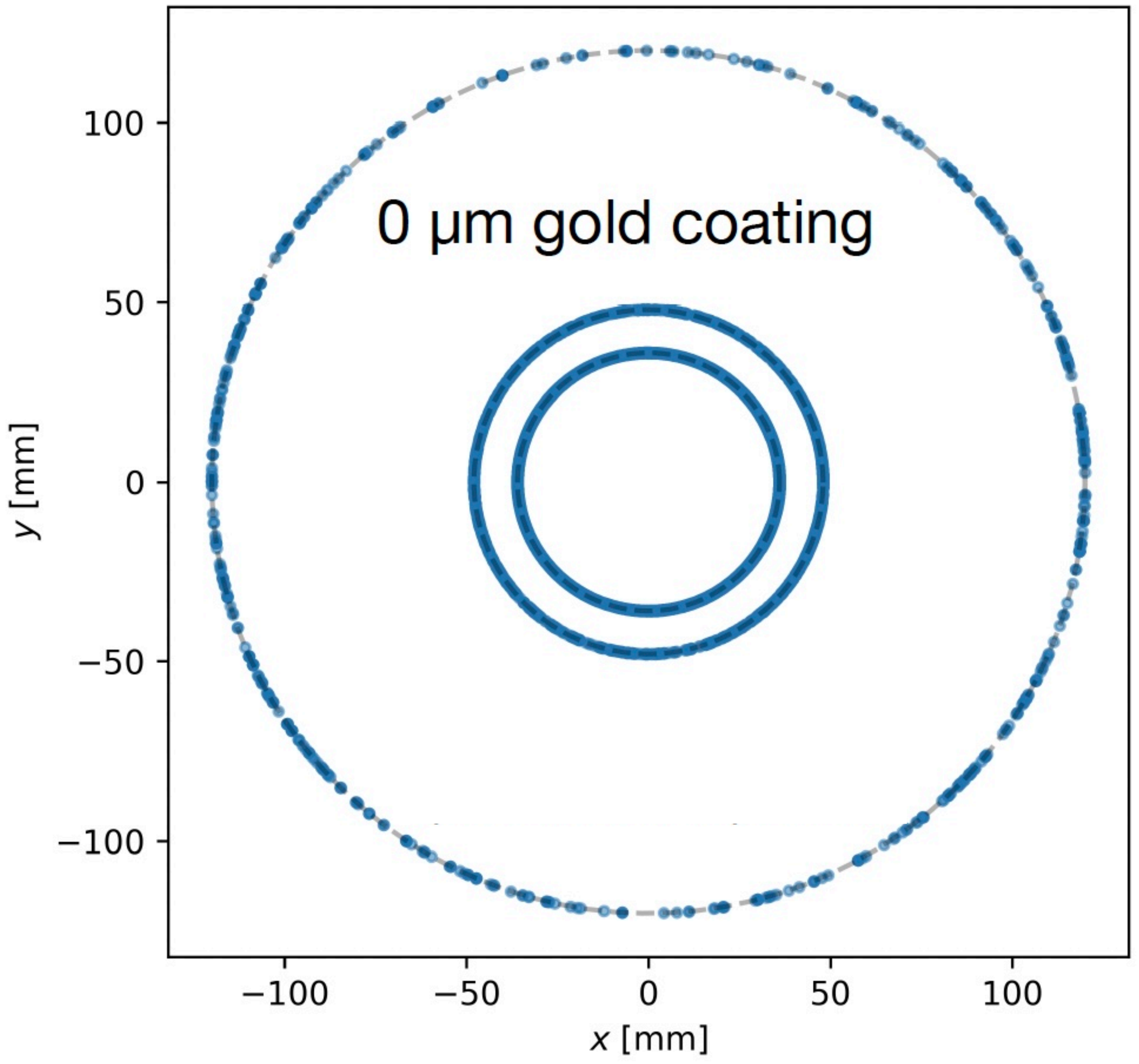
Sample event for a 100 ns time integration window

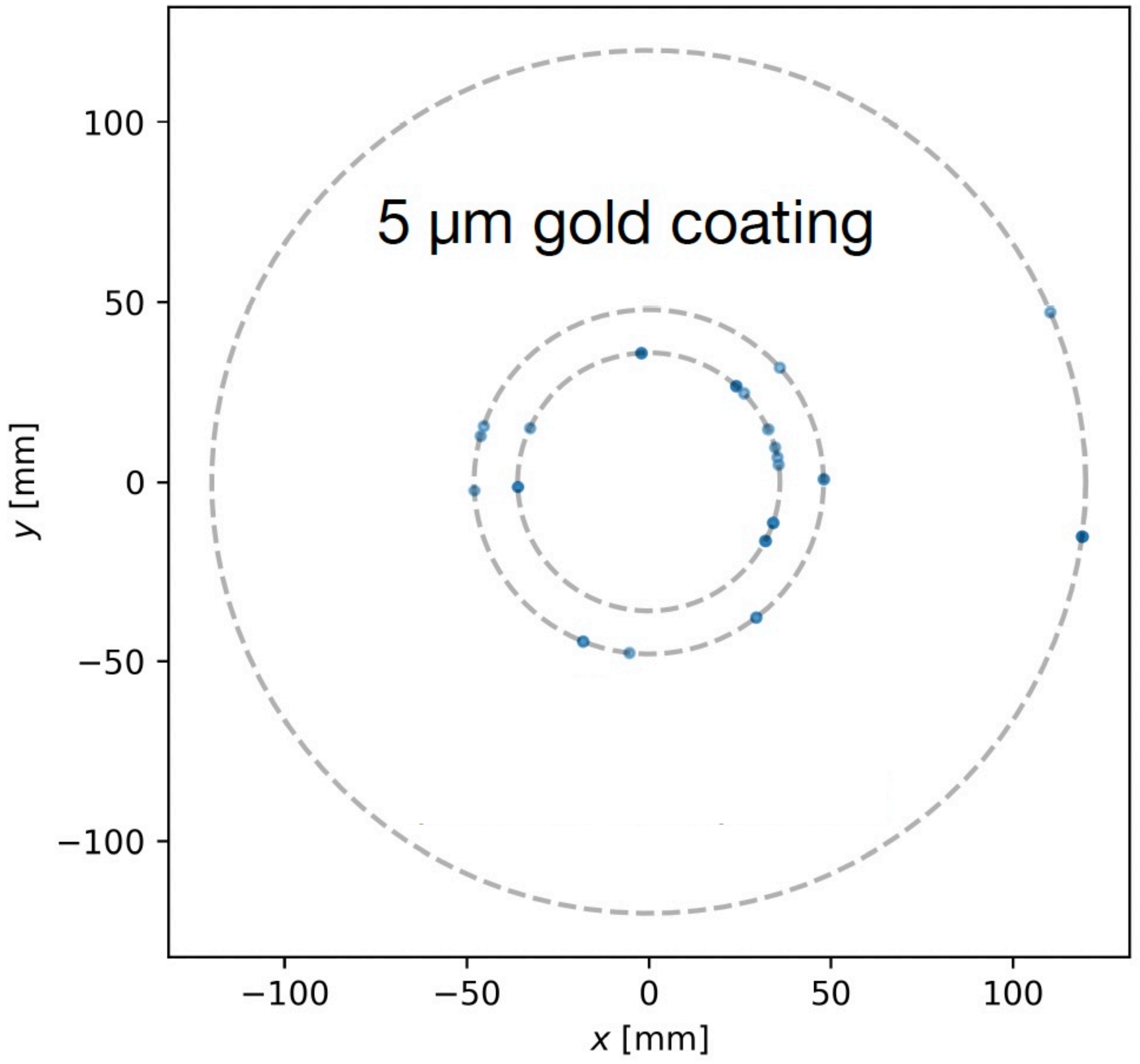


Study by Ben Sterwerf, **RCT**, et al.

Synchrotron radiation results

Impact of gold coating in the beampipe





See more details here

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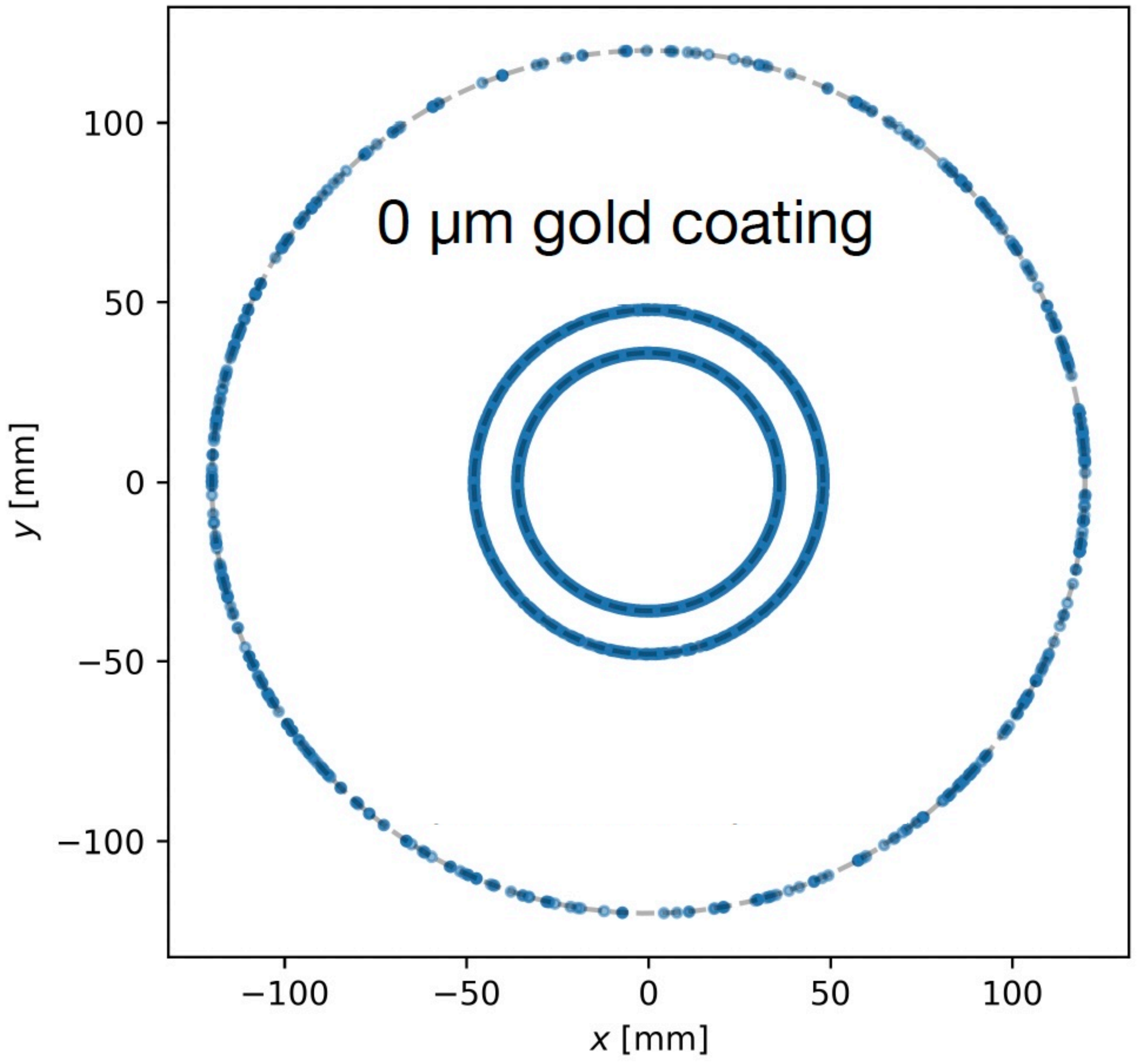
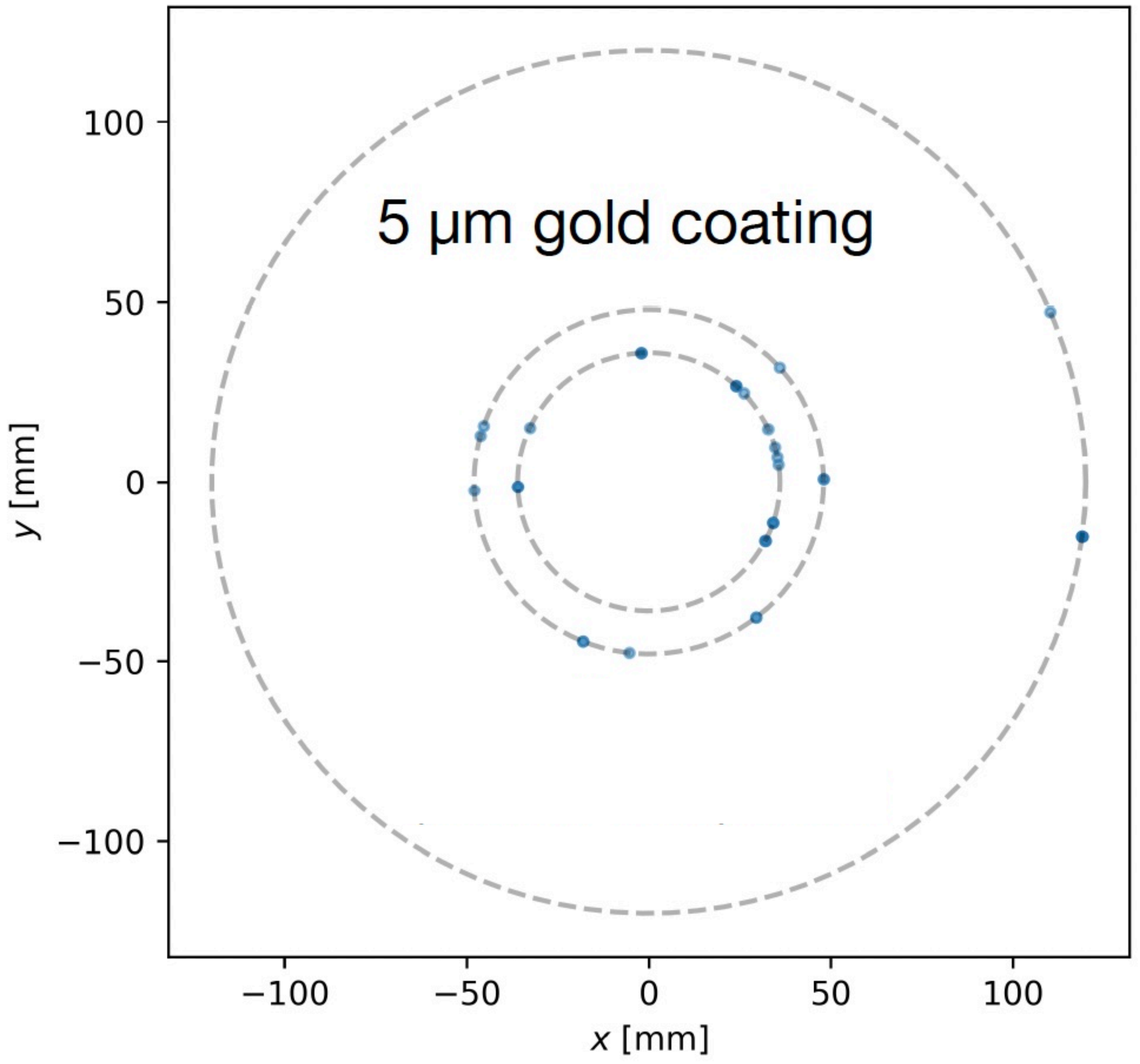
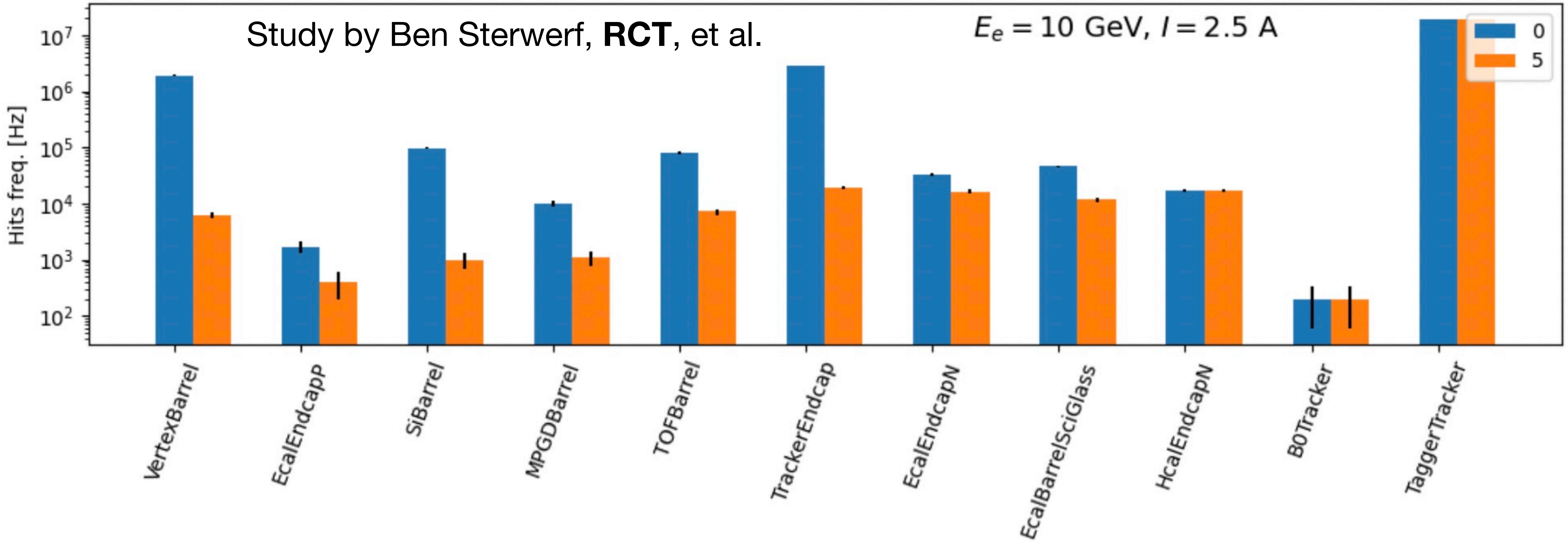




See more details here

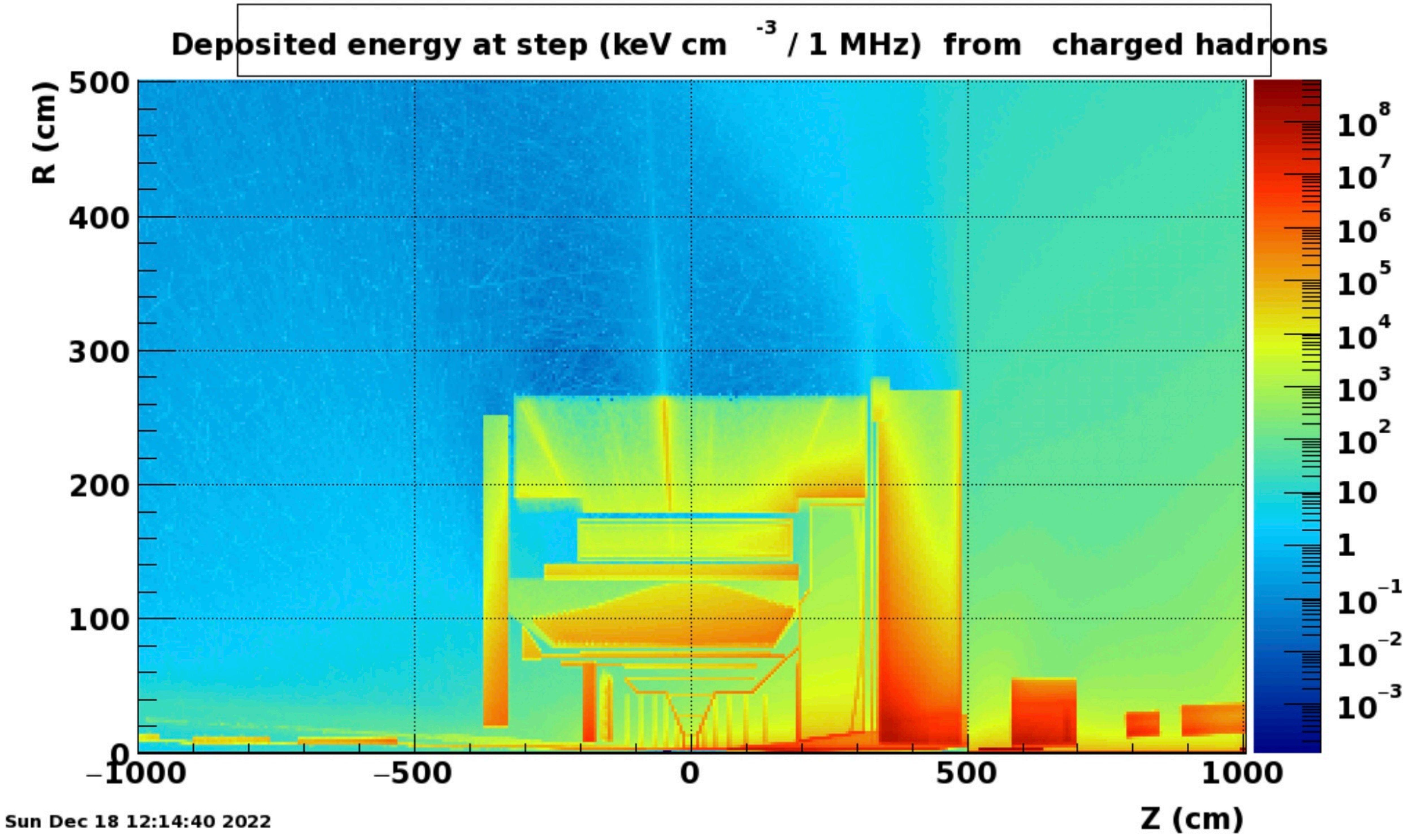


Updated - EPIC

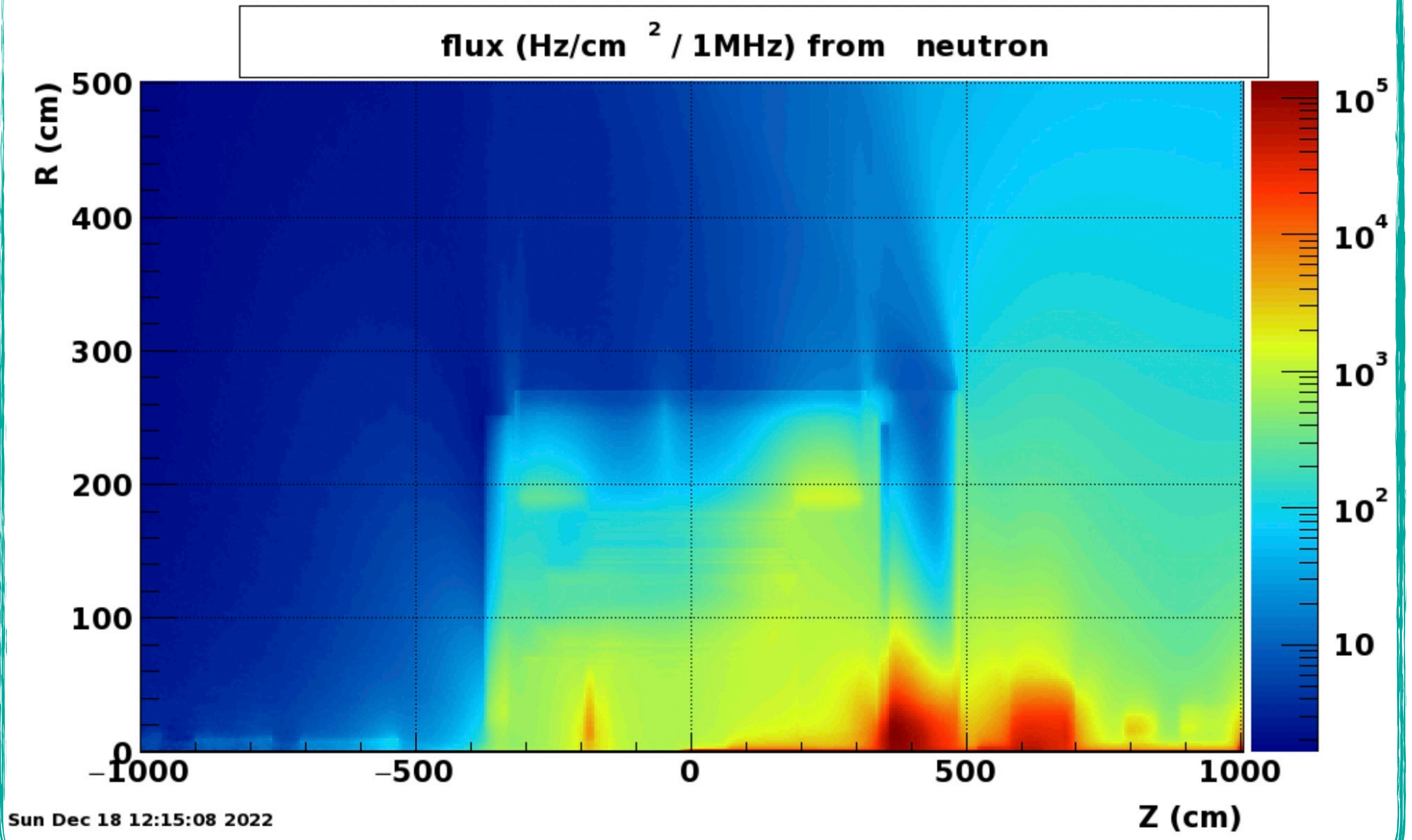
Primary Collisions

- Primary collisions → substantial fraction of ionizing radiation and low-energy neutron flux in the hall
- Simulations based on Pythia 6 tuned to HERMES, COMPASS and HERA with $Q^2 > 10^{-9}$ GeV^2

ionizing radiation



neutron flux



Study by Alex Jentsch, et al.

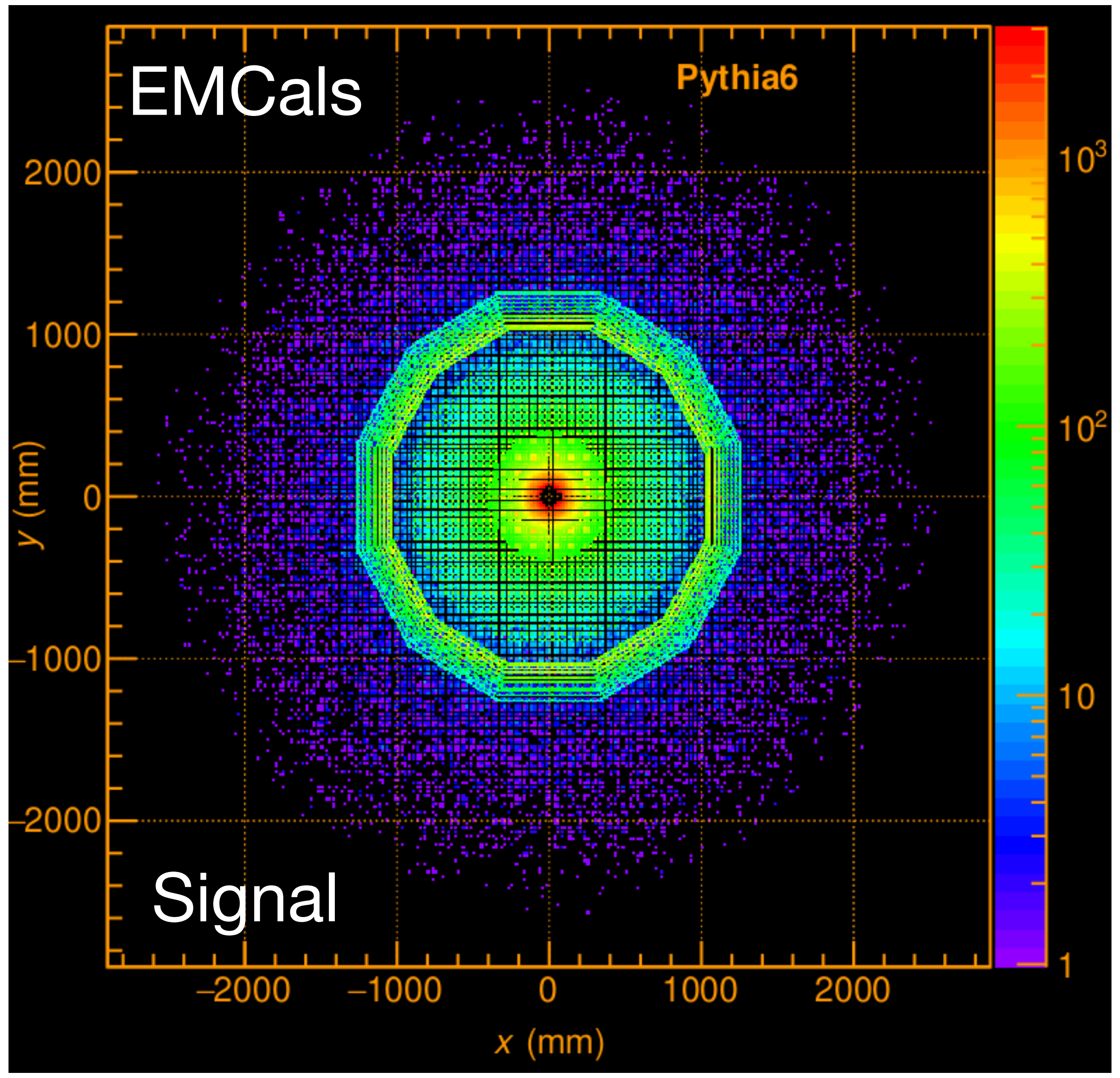
See more details here

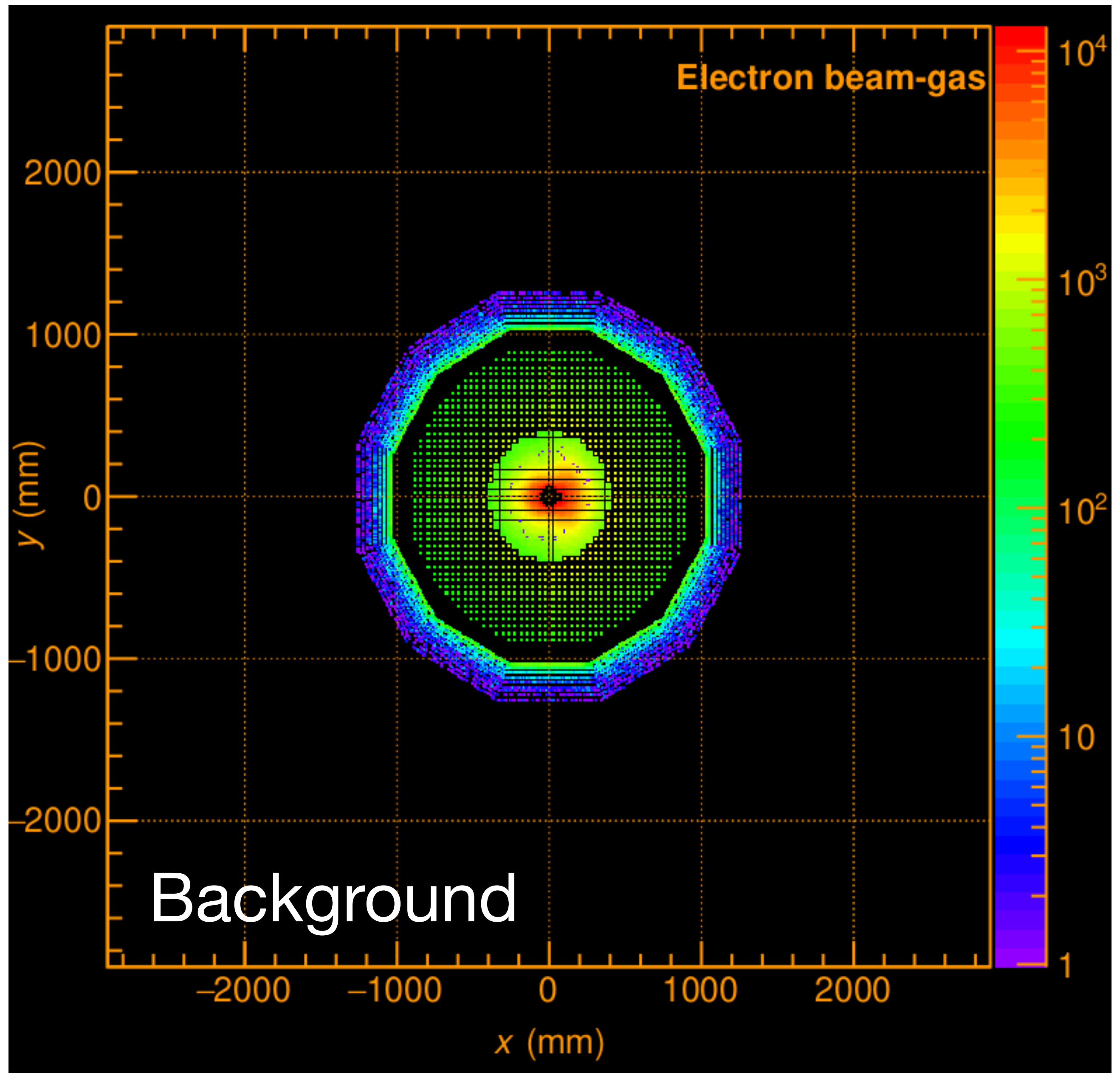
ATHENA detector - update in progress

Electron Beam-Gas interactions

vacuum after 10000 Ah (running of 5 month at 10^{34} cm^{2}s^{-1})

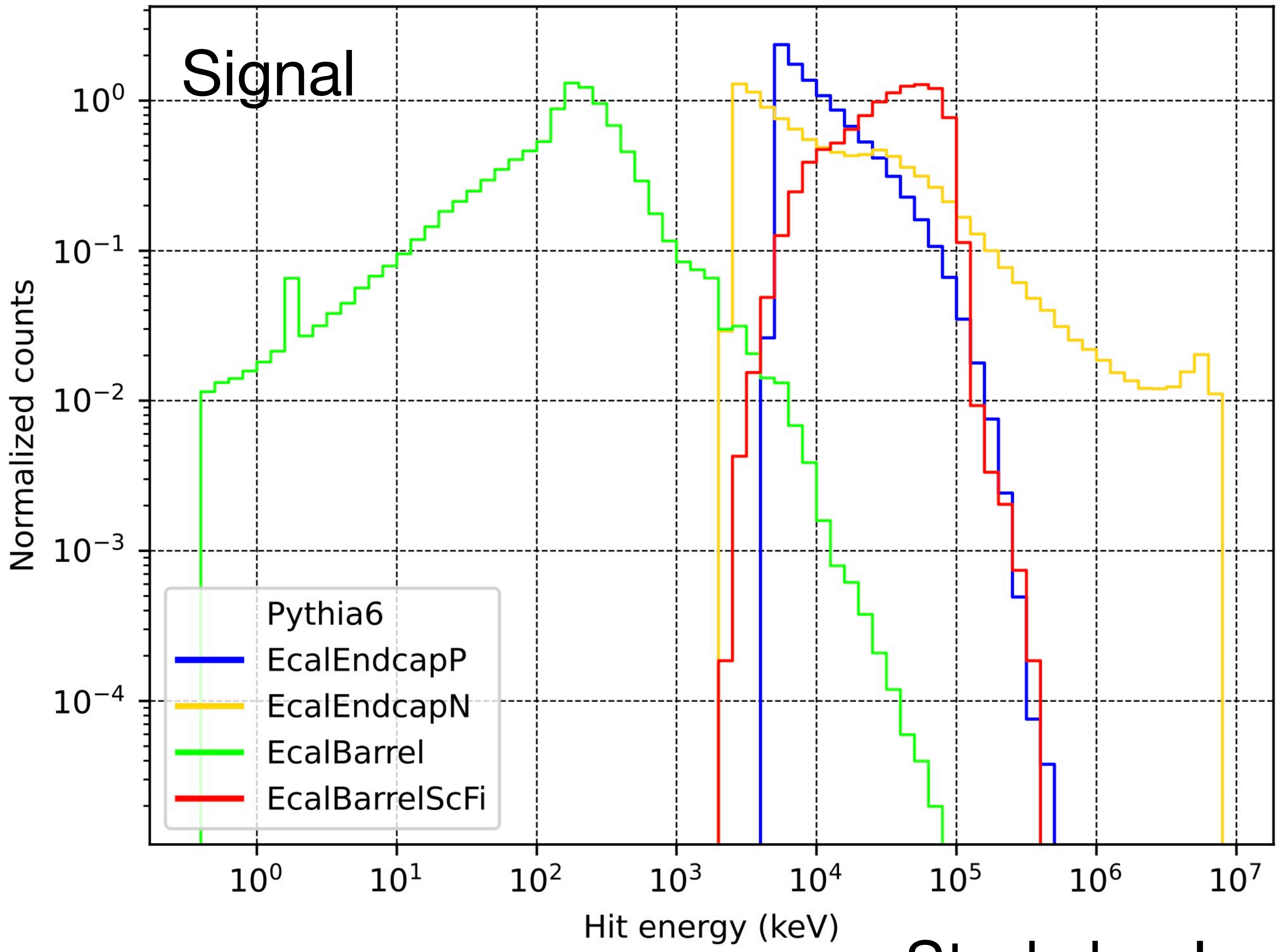
Interaction of beam particles with residual gas molecules in the beam pipe can impact detector performance and/or mimic physics signals

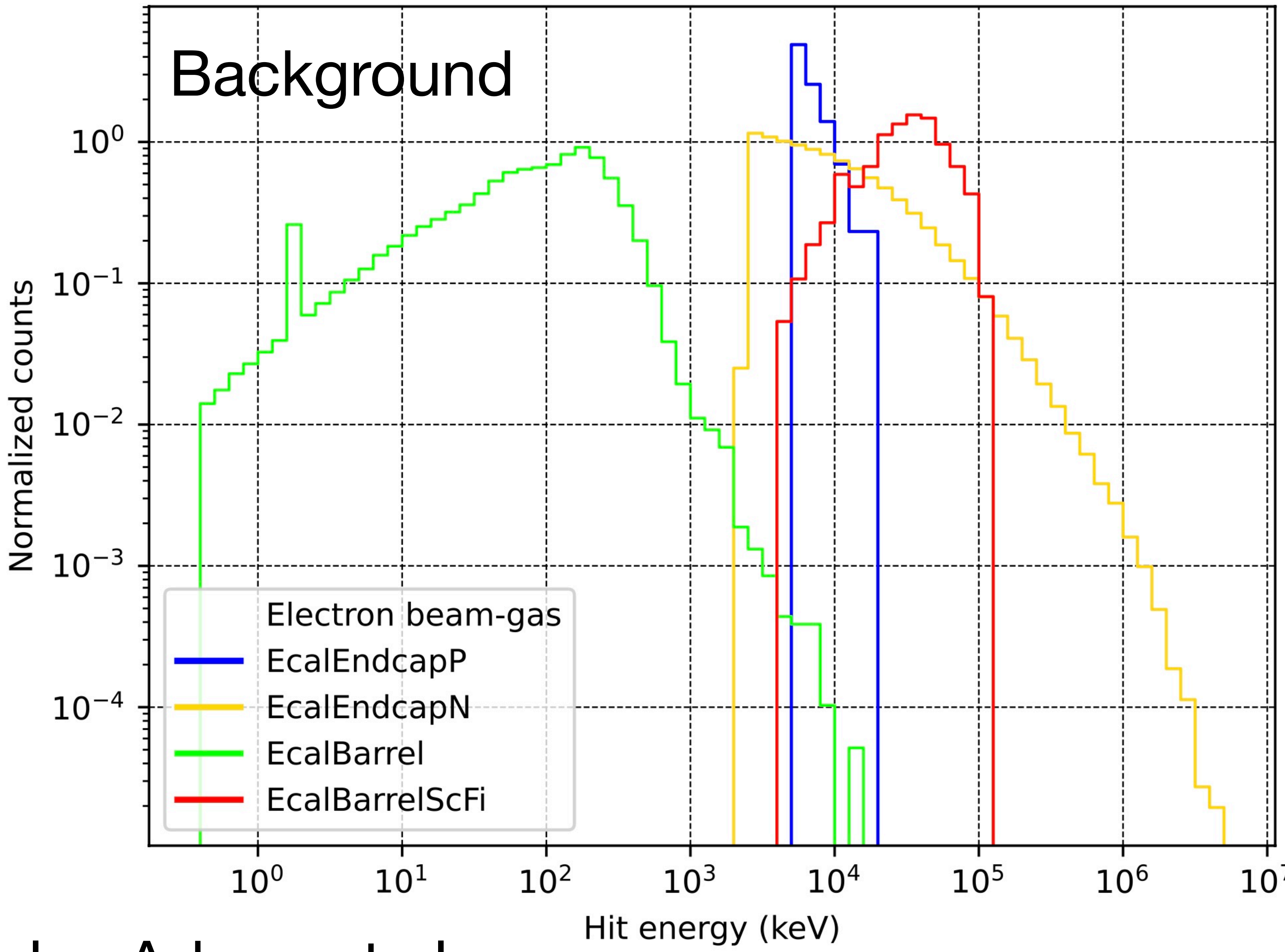




- main contribution to detector background are from Bethe-Heitler process:

$$e_{\text{beam}} + \text{H}^2_{\text{rest gas}} \rightarrow e' + \gamma + \text{H}^2_{\text{rest gas}}$$





off-momentum electrons will be shielded by collimators (detailed simulations of collimation system are underway)

See mode details here

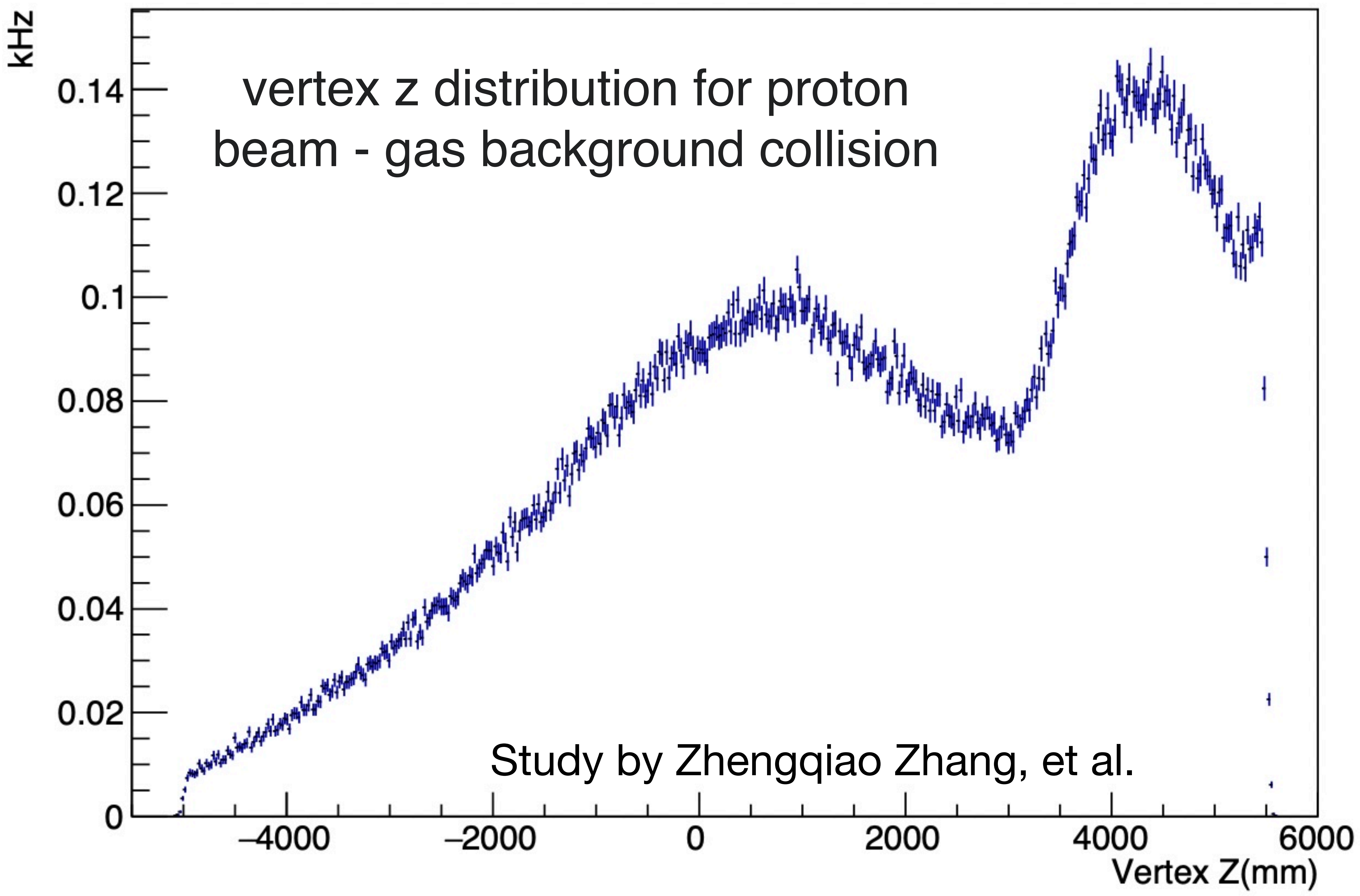
Study by Jaroslav Adam, et al.

Updated - EPIC

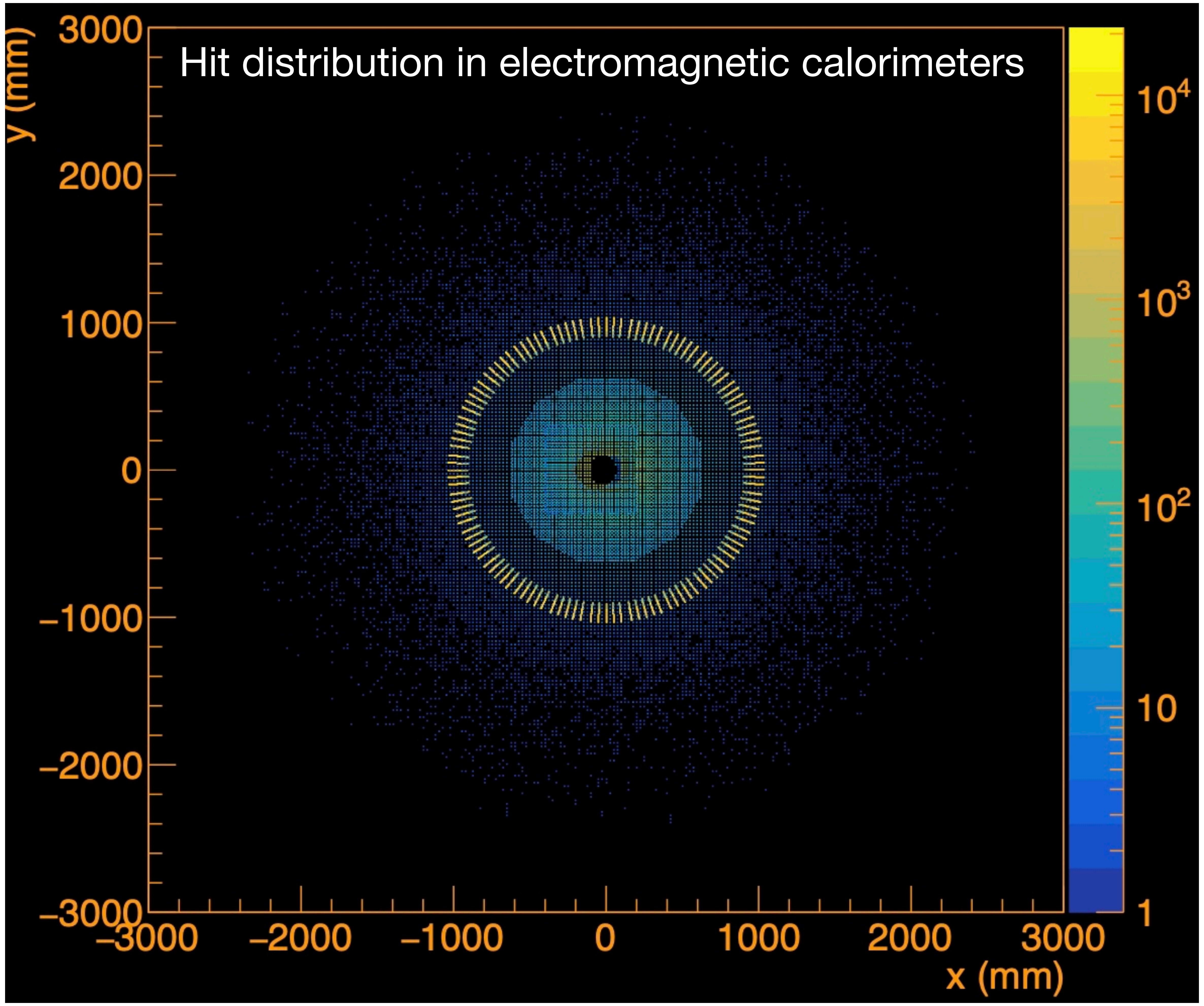
Hadron Beam-Gas interactions

vacuum after 10000 Ah (running of 5 month at 10^{34} cm^2s^{-1})

- concerning large hadronic cross section of the $p/A_{\mathrm{beam}} + \mathrm{H}^2_{\mathrm{rest\ gas}}$ interactions
- Secondary interactions of produced particles with detector components is one of the main sources of neutrons that thermalize within the detector hall

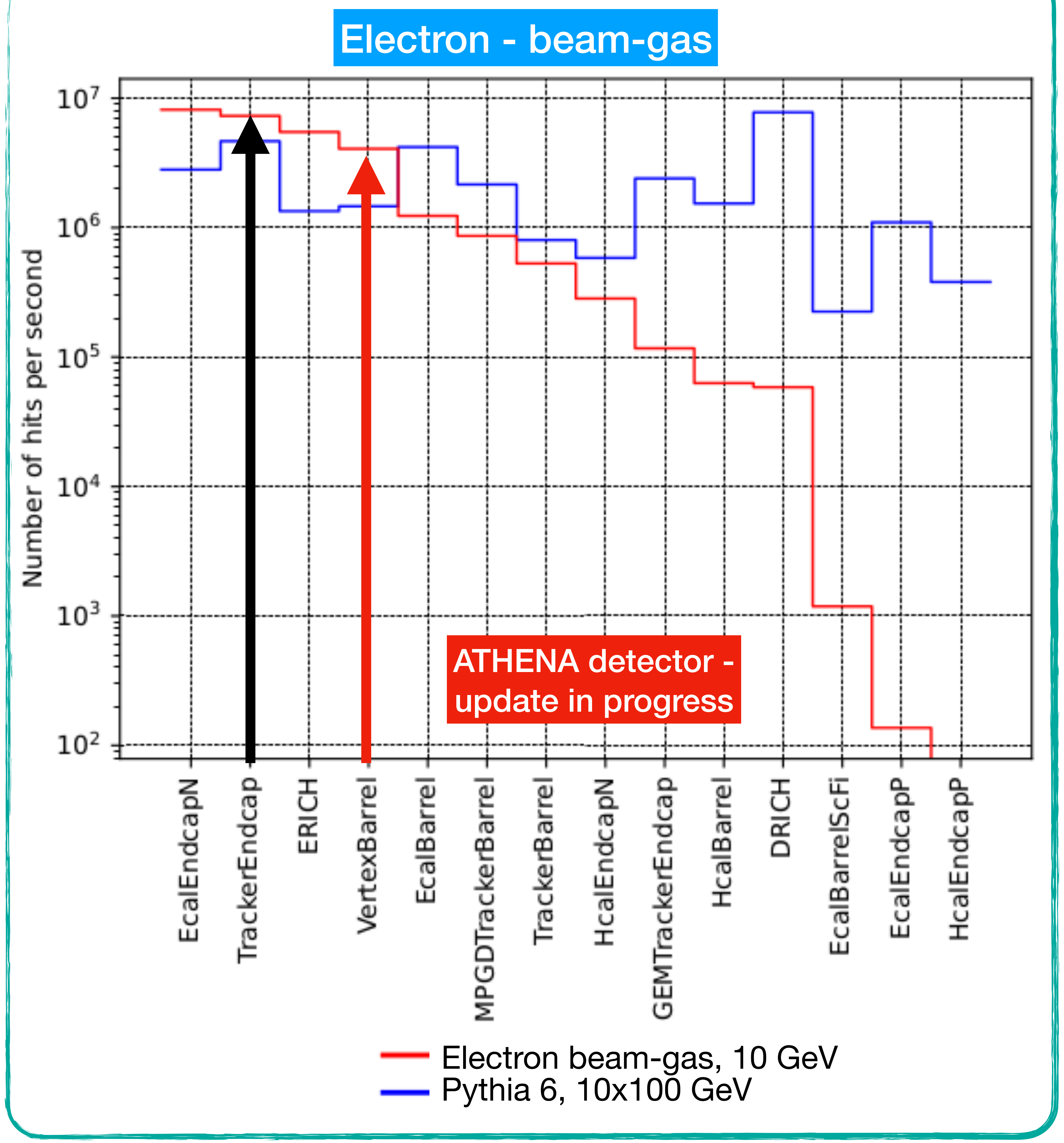


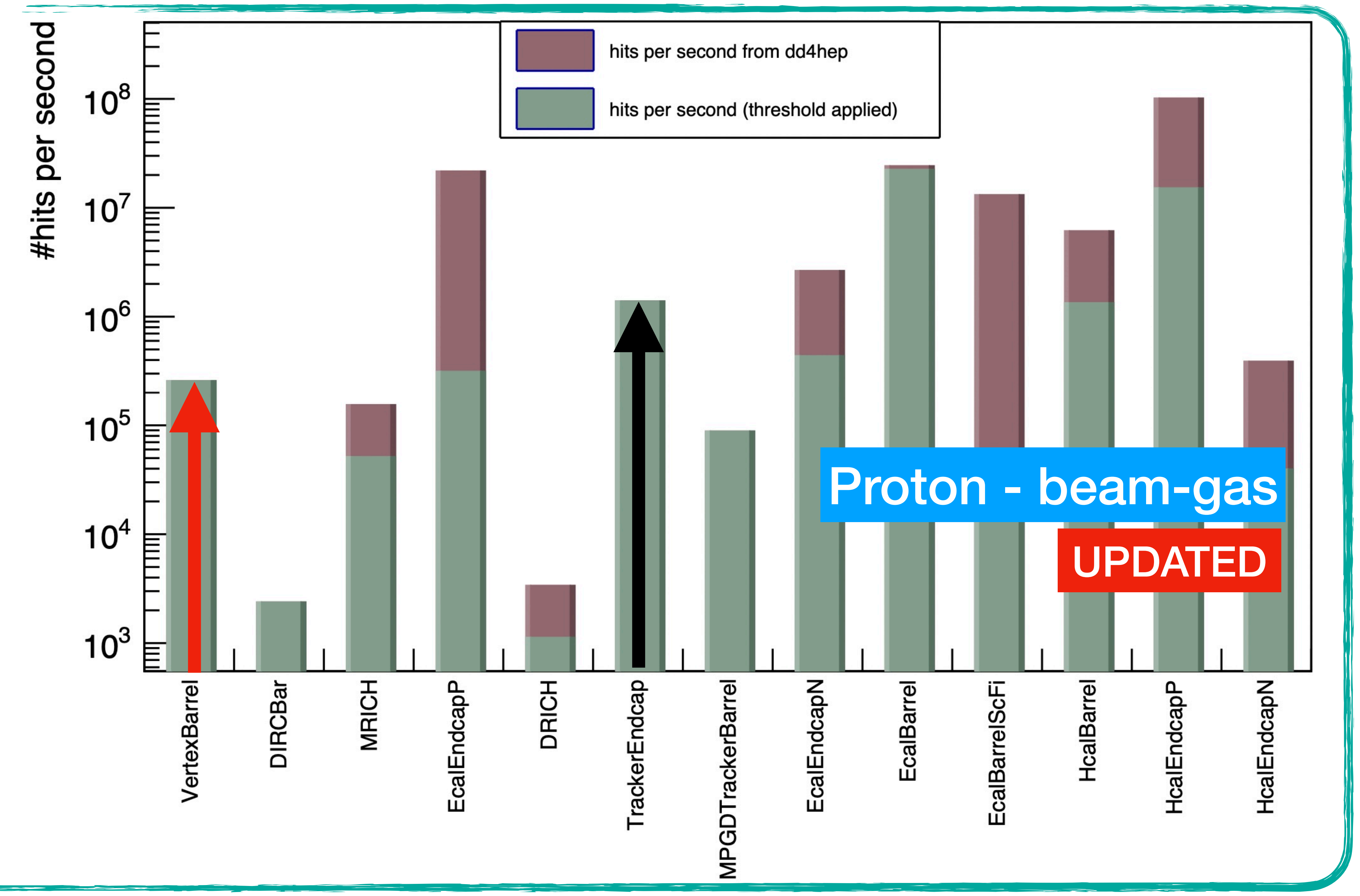
See more details here

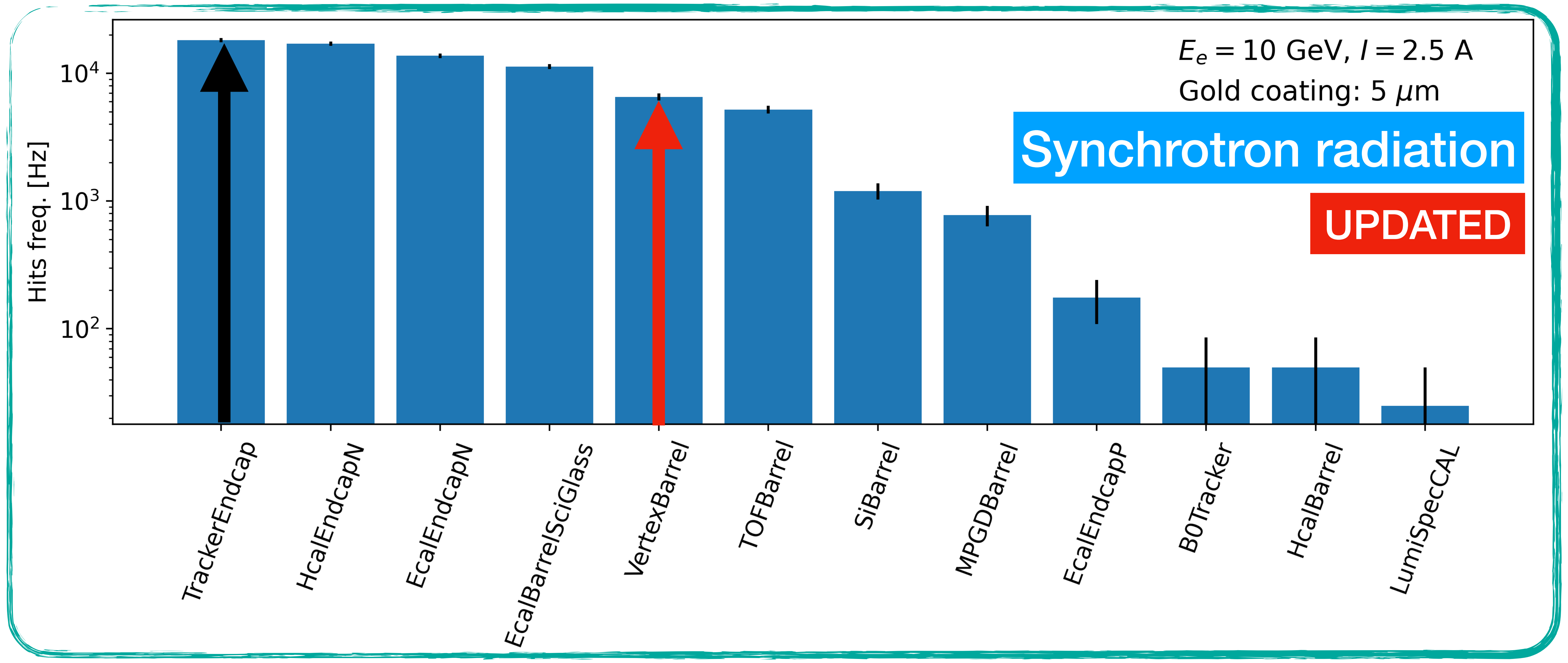


Background comparisons

Electron - beam-gas







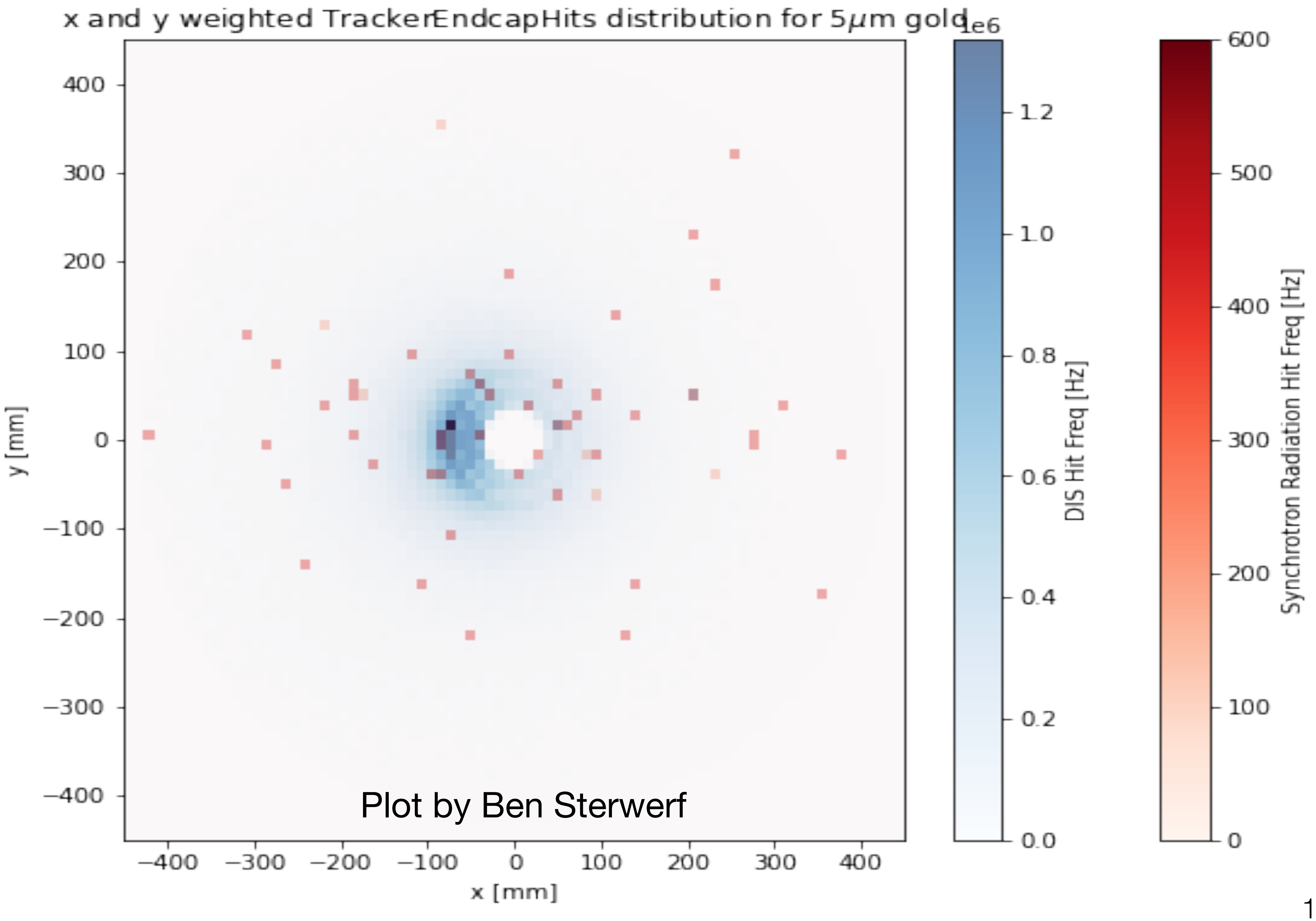
Testing background impact

Need to simulate dataset that emulates true EIC environment as precisely as possible
- mix signal and background sources
- propagate sample through GEANT simulation to assess impact on detector performances

Work by Kolja Kauder, David Lawrence, et al. to implement functionality to mix

$$\text{signal} + \sum_{i=1}^{N} \text{background}_i$$

After mixing, need realistic measurement conditions, e.g. track reconstruction not based on truth seeding



Plot by Ben Sterwerf

Progress on realistic track reconstruction

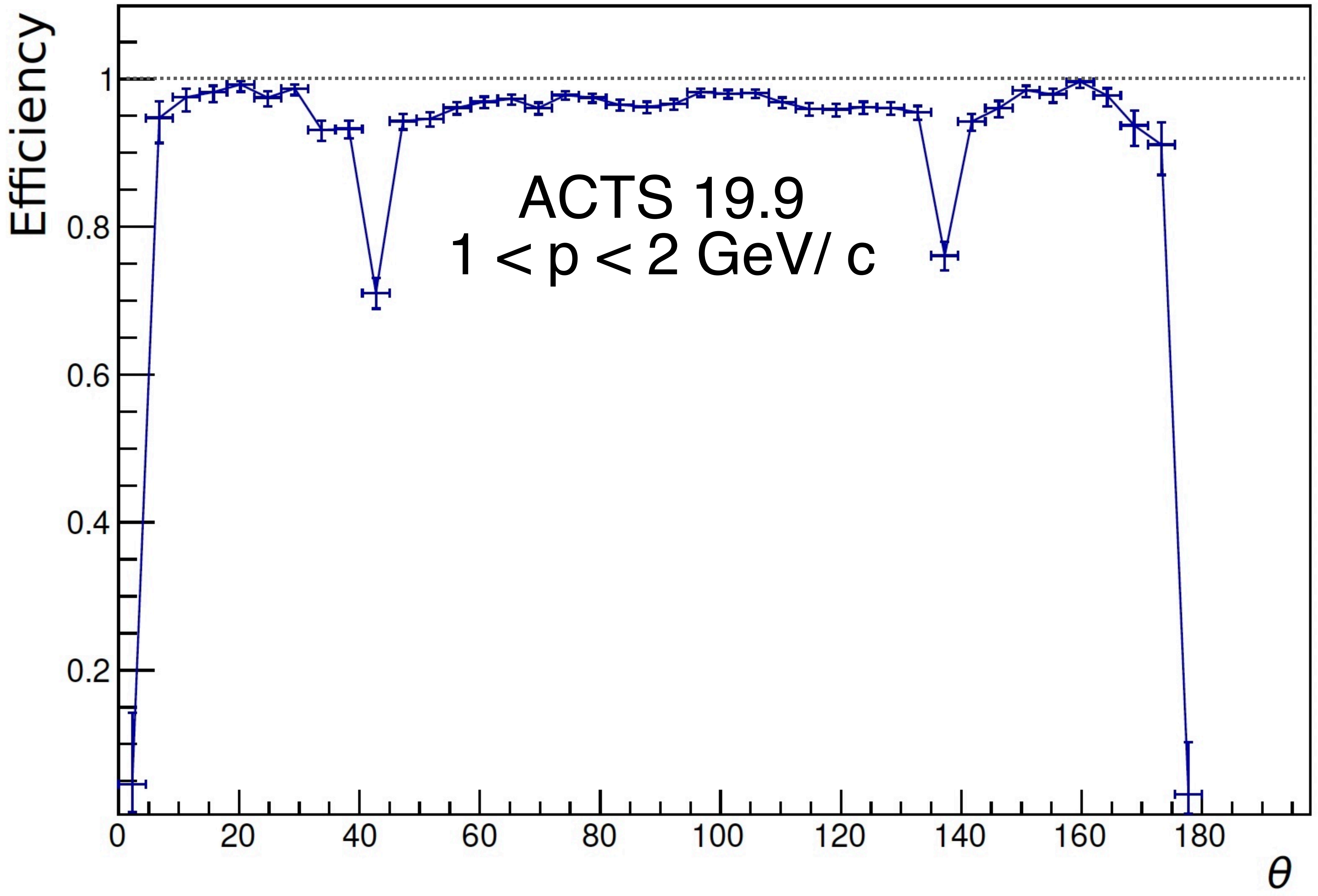
Seeding: retrieval of ≥ 3 space points that can form a track prototype.

- Most studies in EPIC with truth seeding*

*Truth seeding: the actual (experimentally unknown) group of hits associated with a track is given to the Kalman filter

- Realistic seeding is crucial to study background impact

- In ACTS: initial helical fit performed (inside the seeder) to initialize the combinatorial Kalman filter.



Study by Yue Shi Lai, et al.

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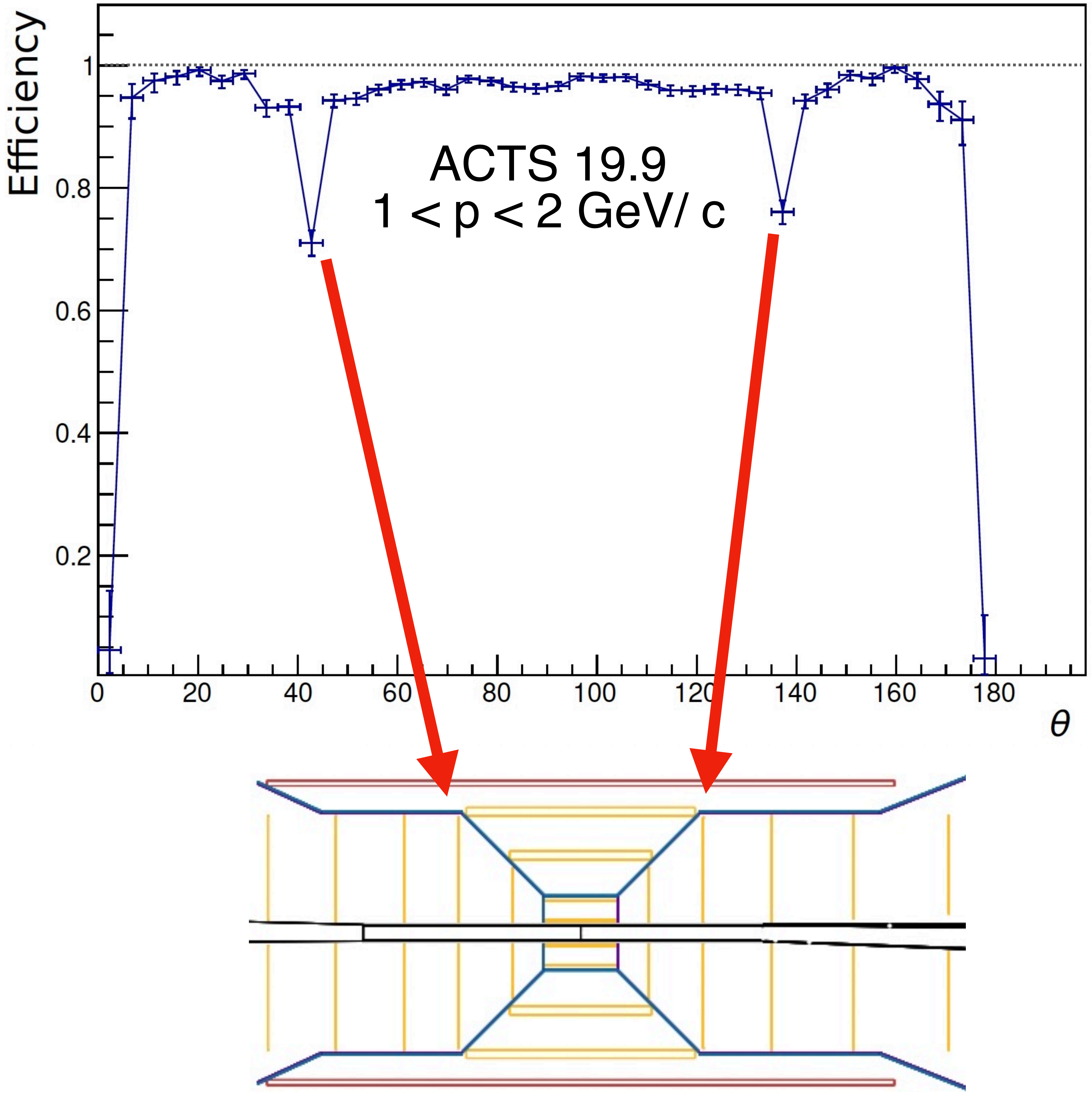
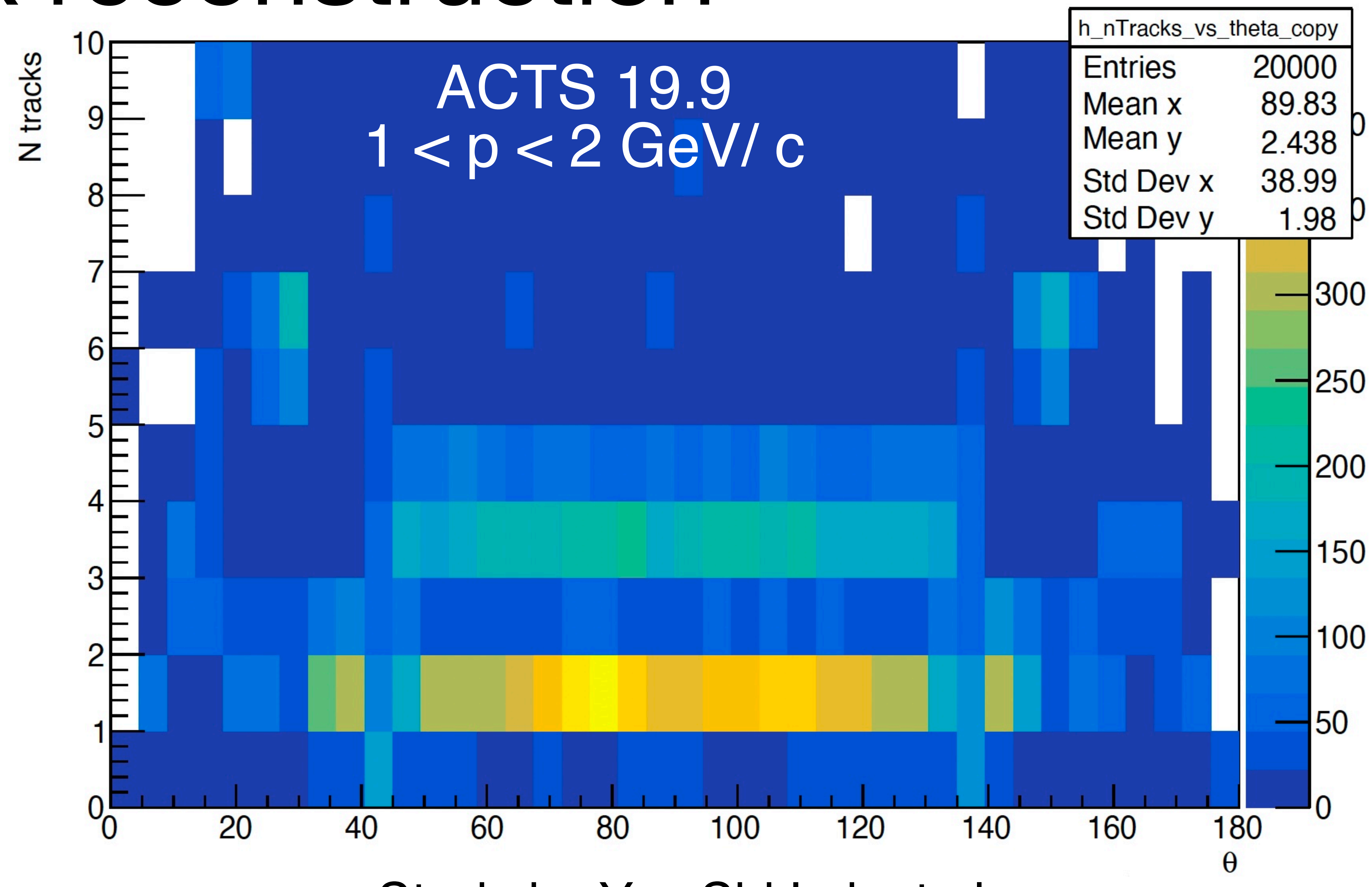


Study by Yue Shi Lai, et al.

Progress on realistic track reconstruction

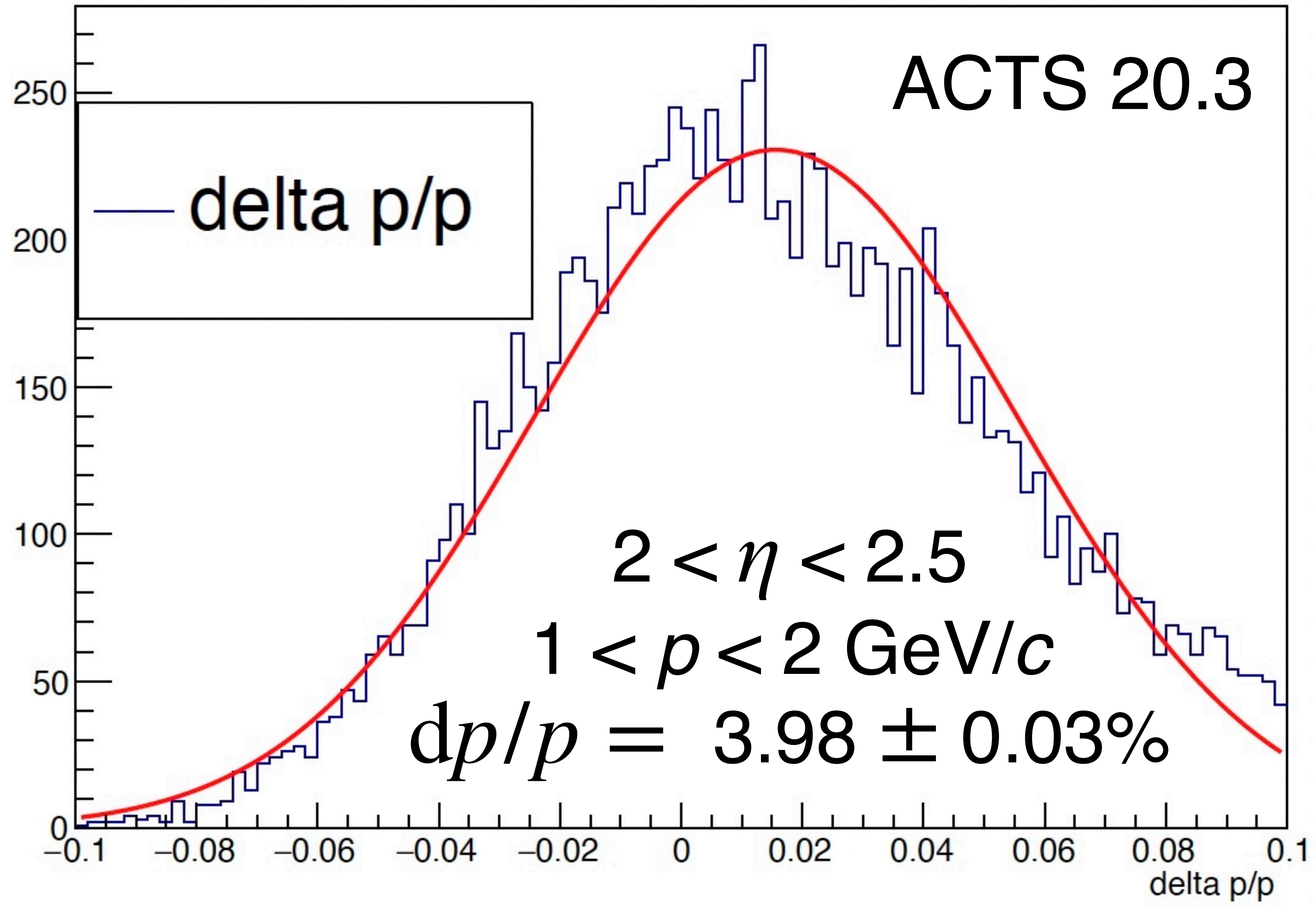
- A functioning binned seeder exists, with some caveats (resulting from the large η range and low p that is unusual for hadron collider ACTS was developed for)

- A unbinned "orthogonal" seeder is being developed, which may address the issue of the binned seeder



Study by Yue Shi Lai, et al.

- Binned seeder, Juggler & ACTS 19.9/20.3
- Mostly 1 seed/track, but some 3 or 4 seeds/track
- $\approx$ 2% of seeds fail due to issues with binned seeder
- Forward $\Delta p/p$ deteriorated vs. truth seeding (~1.5%)



Summary and Conclusions

- Several background sources have been identified and studied. Recently, a background task force was formed

- Most background studies have been updated with newest EPIC detector version. Updated studies on other backgrounds are underway

- Largest background source expected to be beam - gas interactions

- Currently working on functionality to combine backgrounds and signal

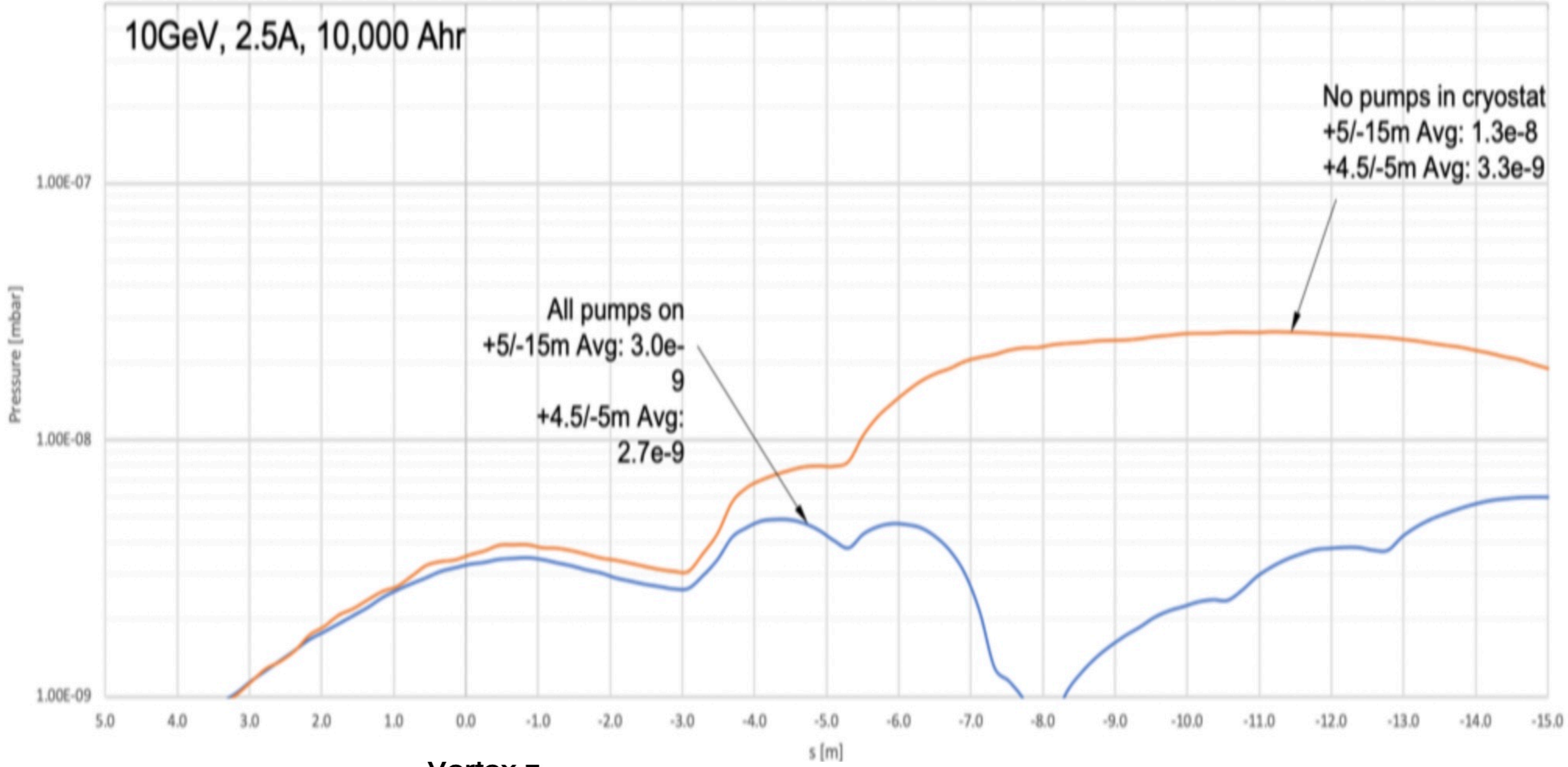
- Next step will be to study background impact on detector performance and physics, e.g. impact on track reconstruction

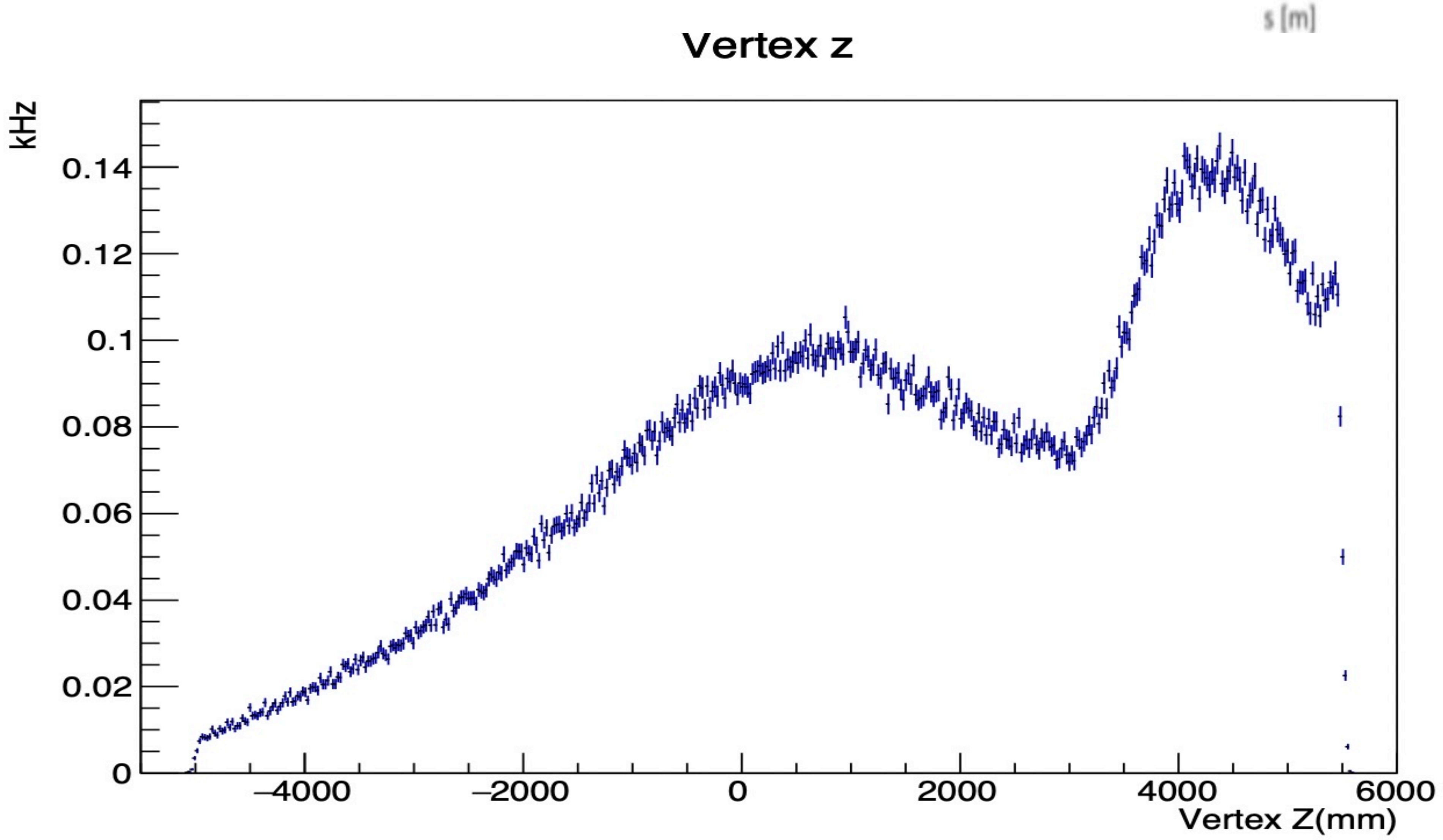
- Realistic track reconstruction is underway

Thanks for your attention

Backup

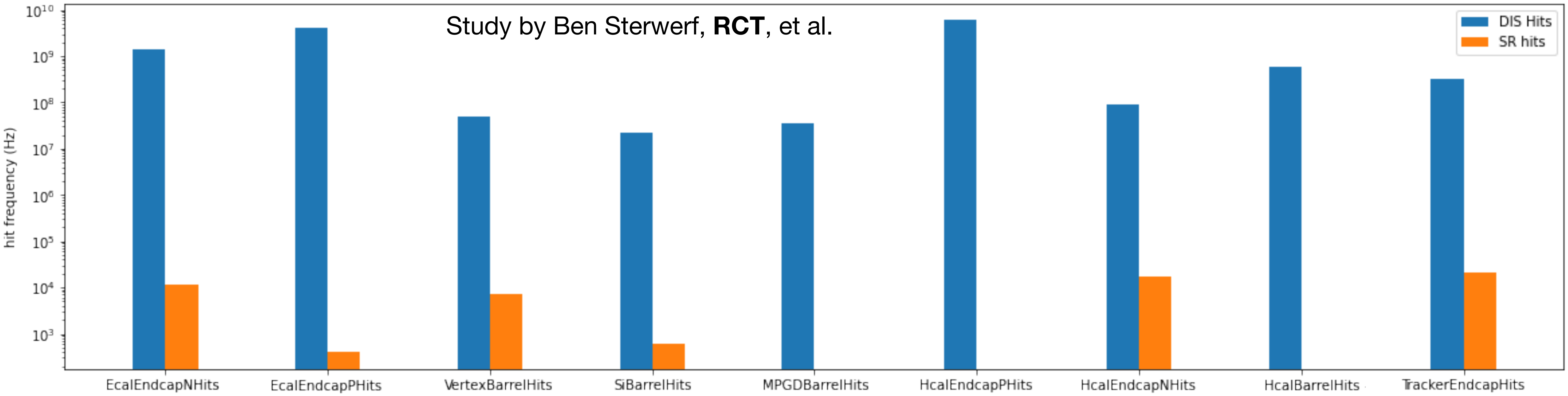
Vertex z distribution in hadron beam gas





Updated - EPIC

Synchrotron radiation results



Synchrotron event generator code

https://github.com/reynier0611/SR_event_generator

1. Download csv file stored here. You can get this file following one of the two methods below:

```
wget -O combined_data.csv 'https://drive.google.com/uc?export=download&id=1XX78_qeuoMK8xhuOB5QgbU
```

or

```
curl -L 'https://drive.google.com/uc?export=download&id=1XX78_qeuoMK8xhuOB5QgbUyye7Lv_xPg&confirm
```

2. Create a yaml configuration file (e.g. `config.yaml`) with the following information:
    - `input_single_photons`: path to csv file downloaded in step 1.
    - `n_events`: number of events to be generated.
    - `integration_window`: time window that will define one event.
    - `seed`: random seed for reproducibility. Set to 0 to leave the seed unconstrained.
3. Run the generator as:

```
python3 sr_generator.py --configFile config.yaml
```

Links to previous studies

Jin Huang - Beam gas, neutron flux, radiation does at EIC

Elke Aschenauer - EIC Physics and Detector

Wiki - ePIC Background

Wiki - ATHENA Background

Wiki - beam backgrounds