# Charm Reconstruction Studies in Fast and Full PYTHIA Simulations

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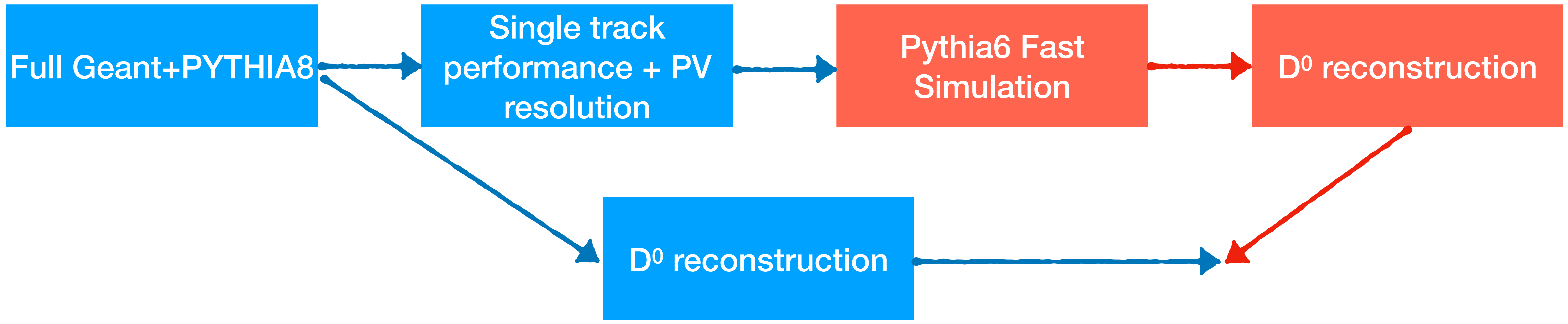
*Jets+HF Quarks PWG Meeting Sep. 21, 2020*

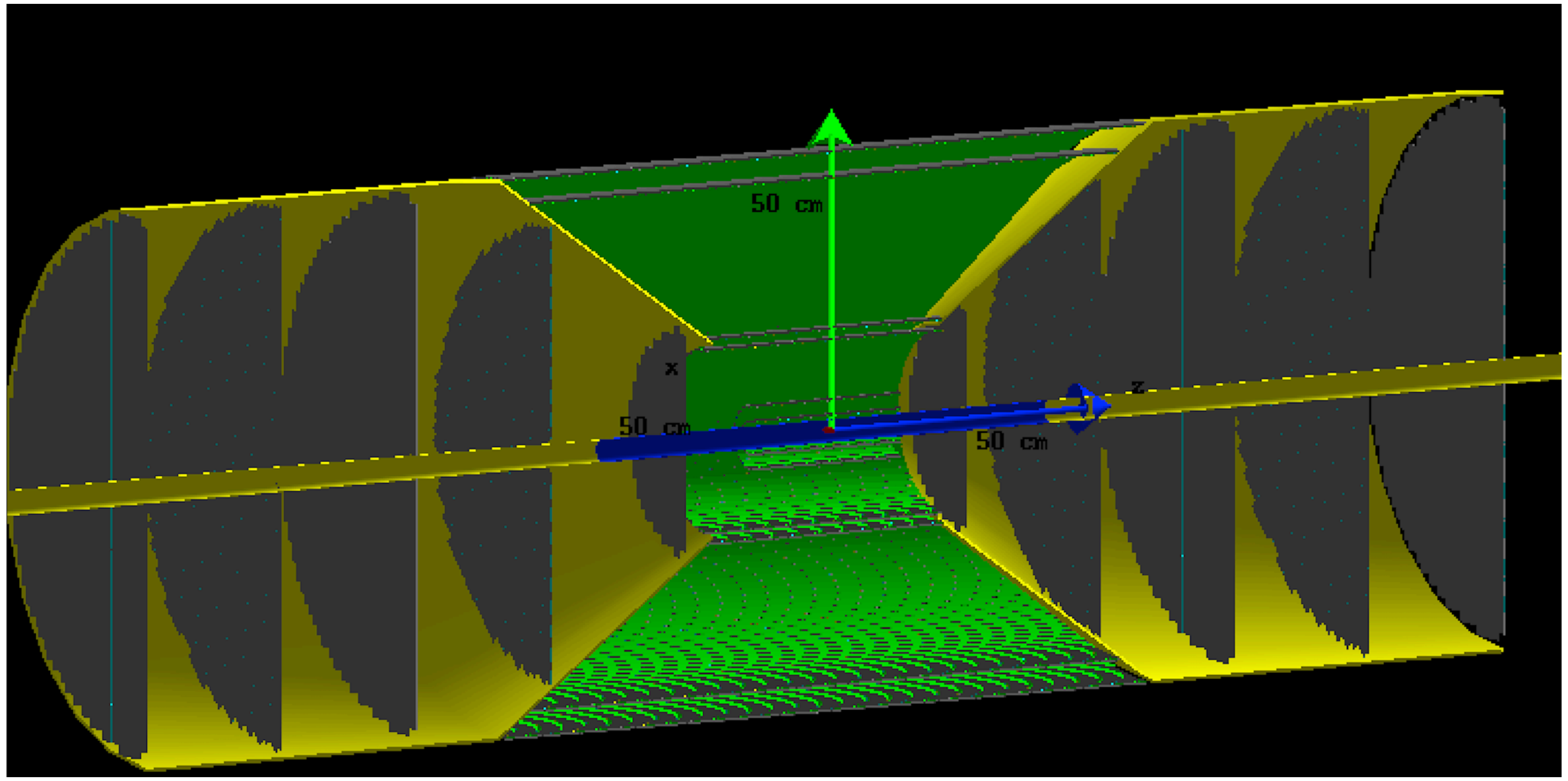
# Introduction

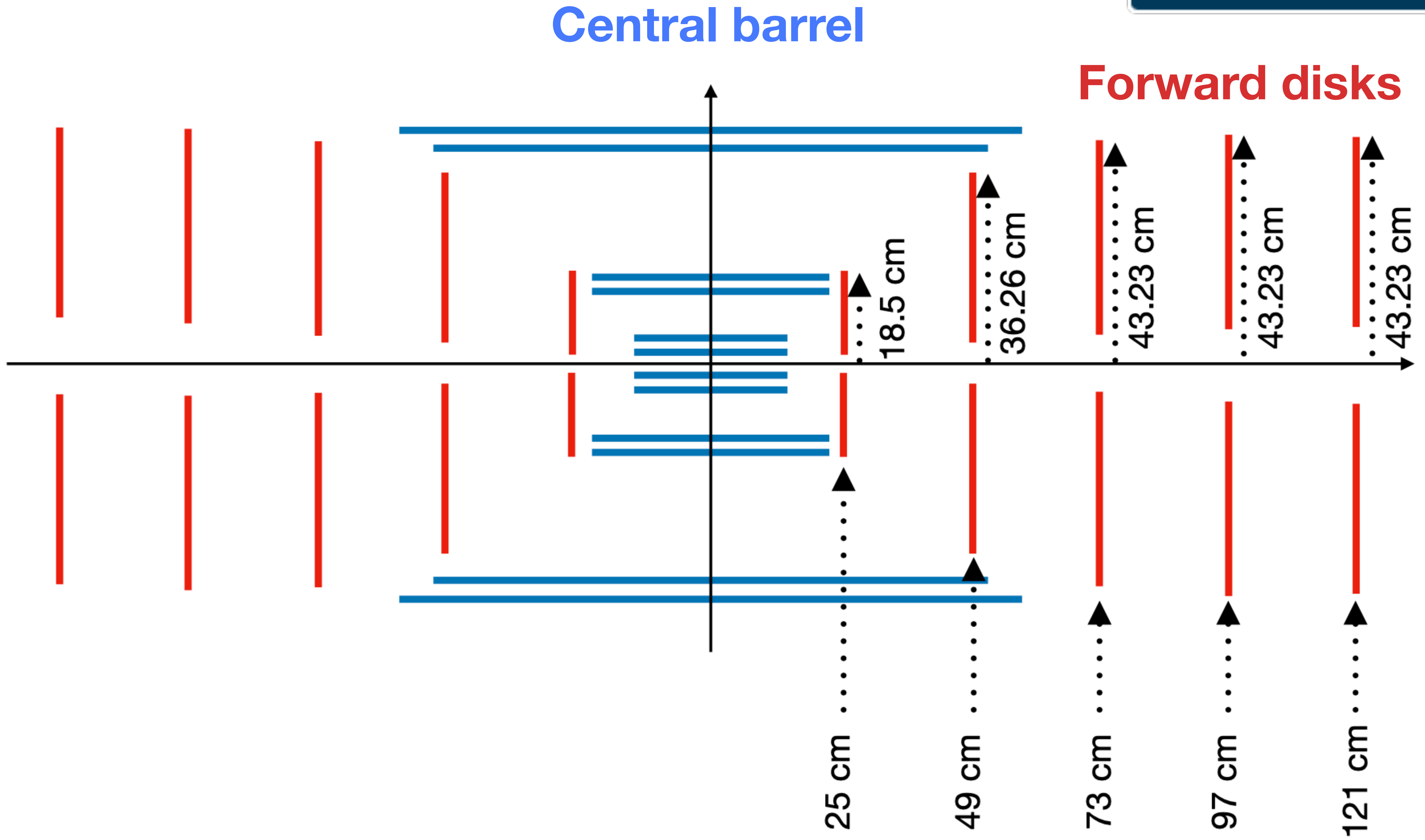
Physics performance of open heavy-flavor at future EIC evaluated with fast simulation projections

Goal is to verify fast simulation evaluation with a full simulation setup



# All-Si Detector Concept



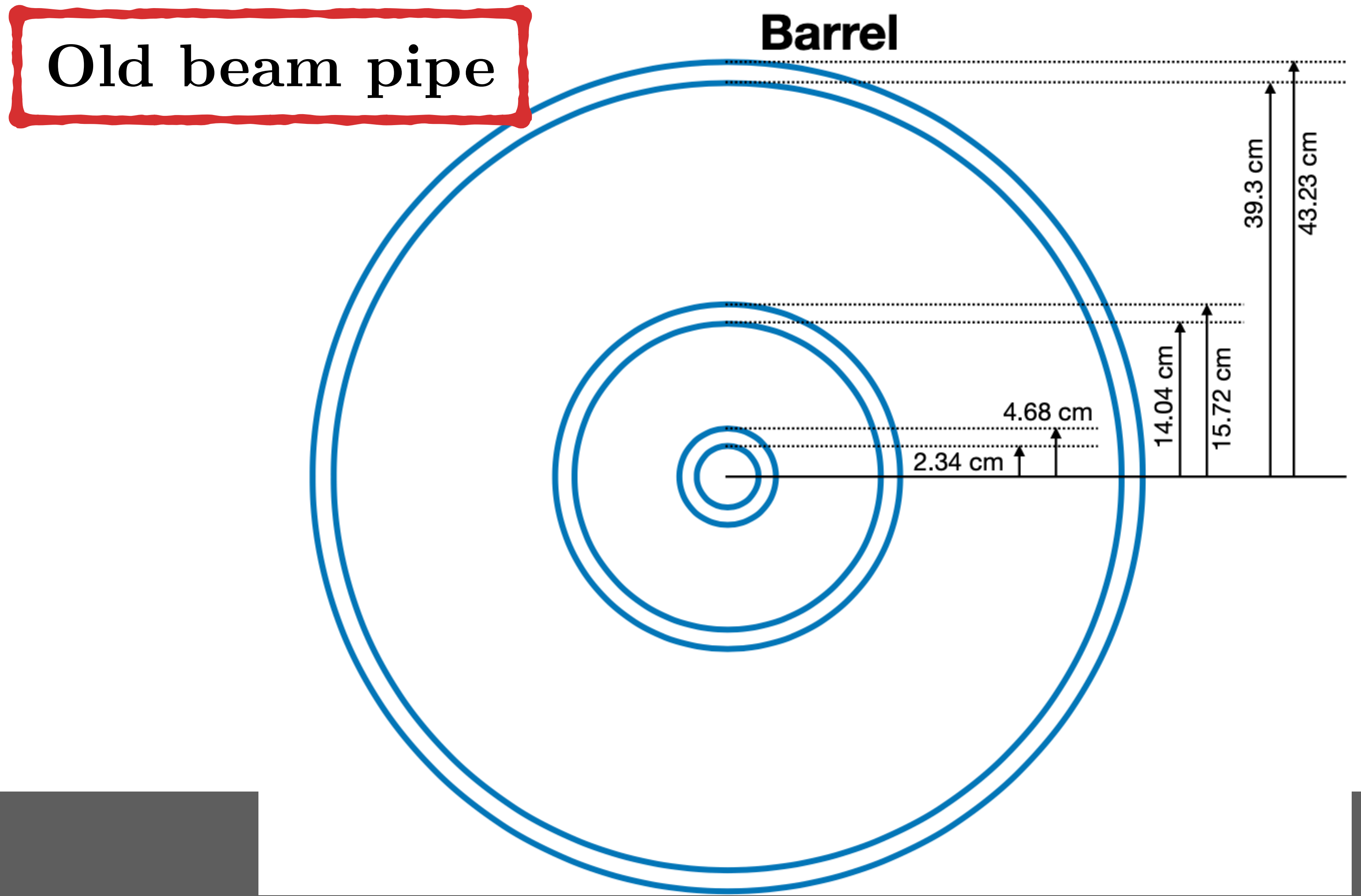



**All-silicon tracker composed of MAPs devices**

- Si. pixel size: 20x20 μm or 10x10 μm
- 0.3% radiation length

**3x2 barrel layers with coverage approx. $|\eta|<1$**

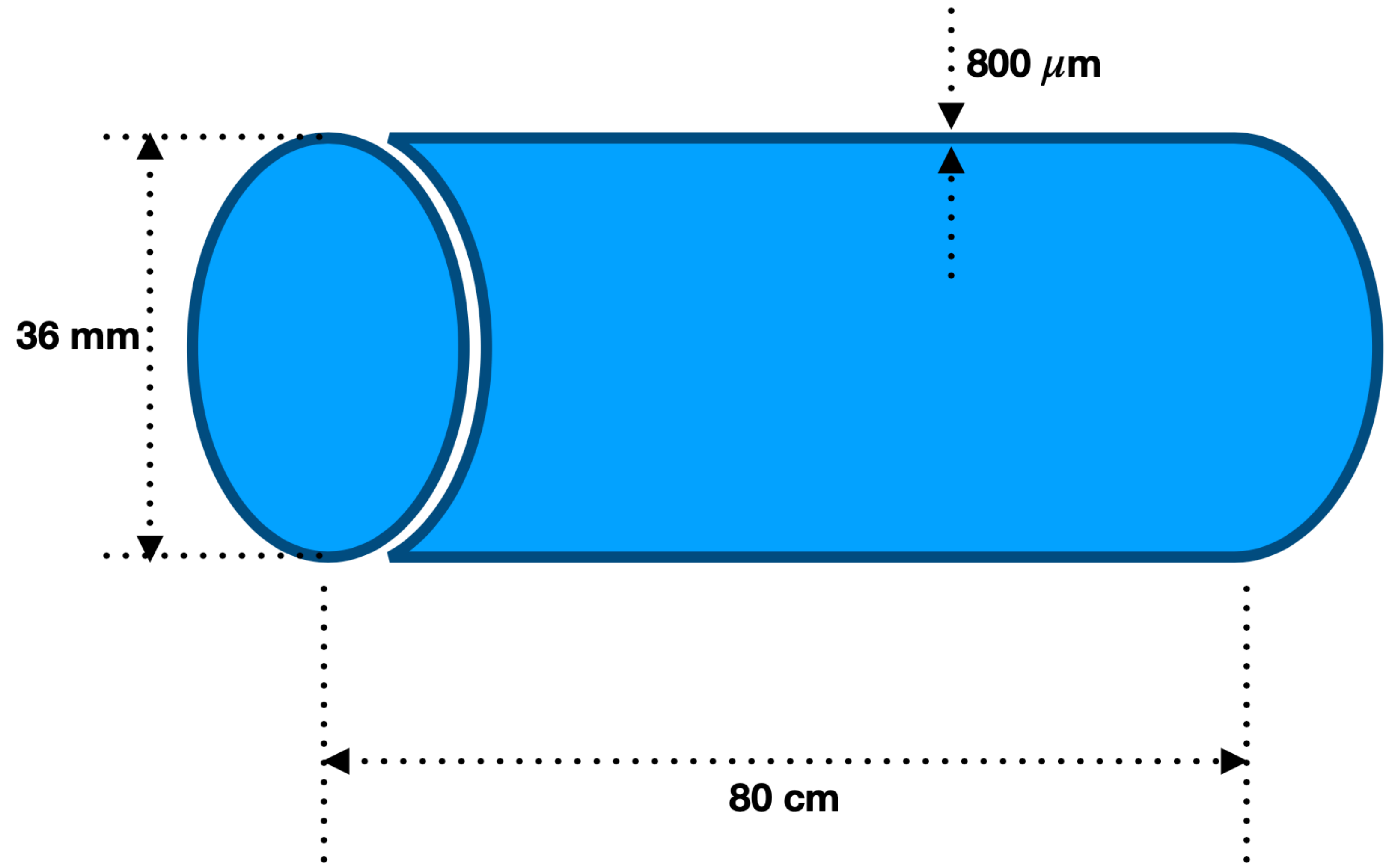
**5 disks in forward and backward regions with coverage approx. $1<|\eta|<3$**



# Updated Beampipe

<u>Old</u>

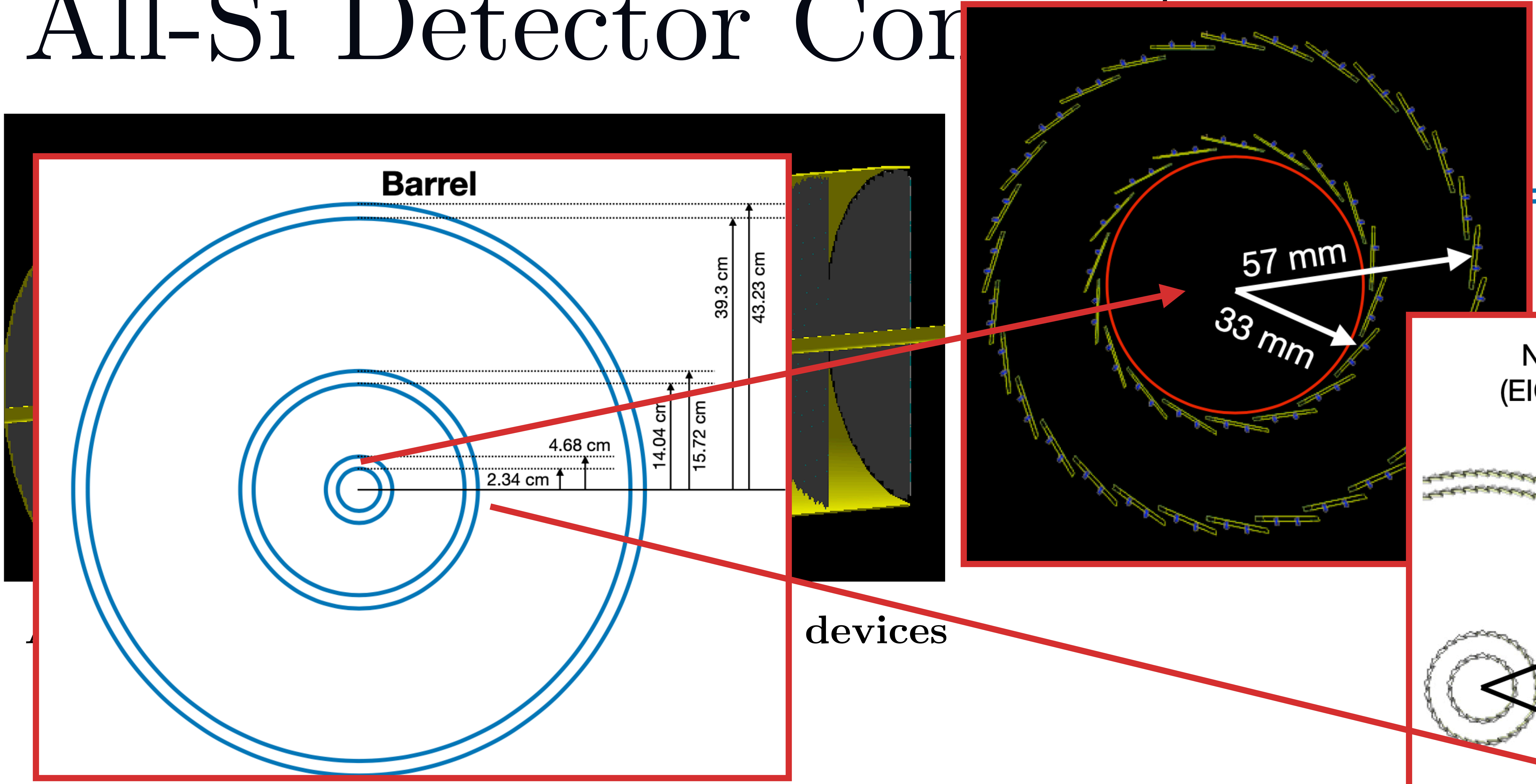
**Beryllium beampipe**

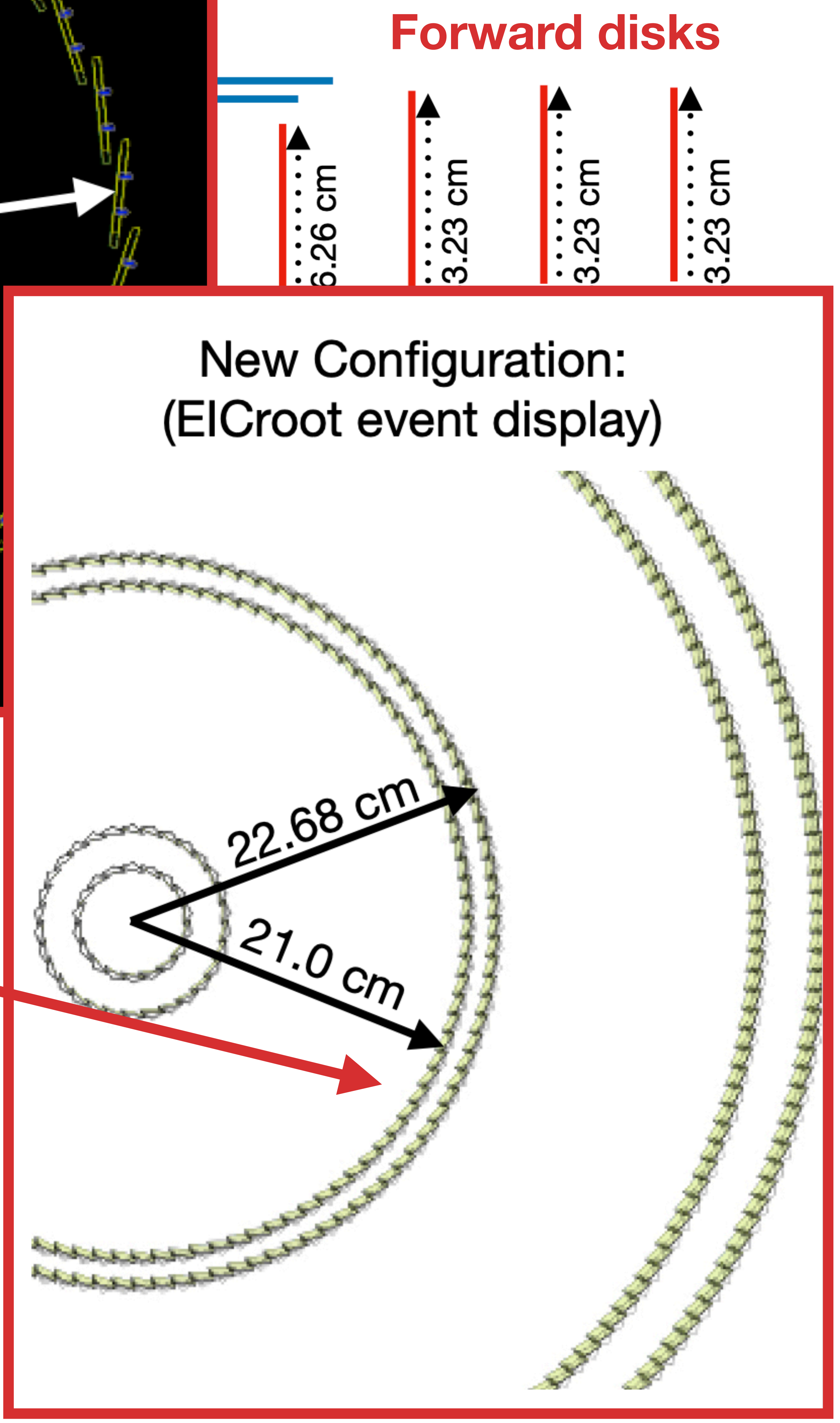



**New beampipe:**

- R=3.1 cm
- Thickness = 0.762 mm
- -79.8 cm < z < 66.8

# All-Si Detector Con




devices

3x2 barrel layers with coverage approx. $|\eta|<1$

5 disks in forward and backward regions with coverage approx. $1<|\eta|<3$

# Simulation Setup

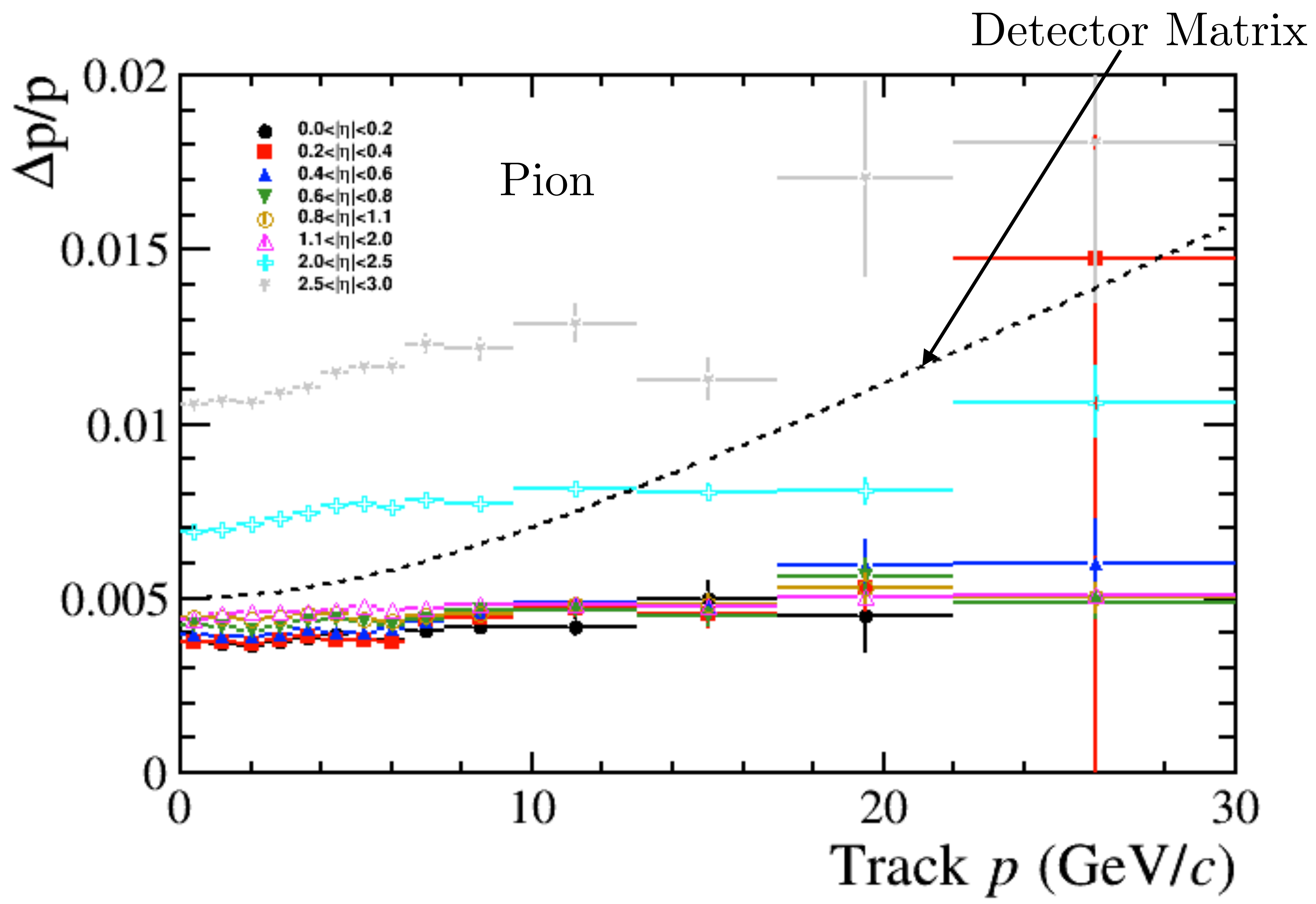
**Electron-proton collisions generated using PYTHIA 8**

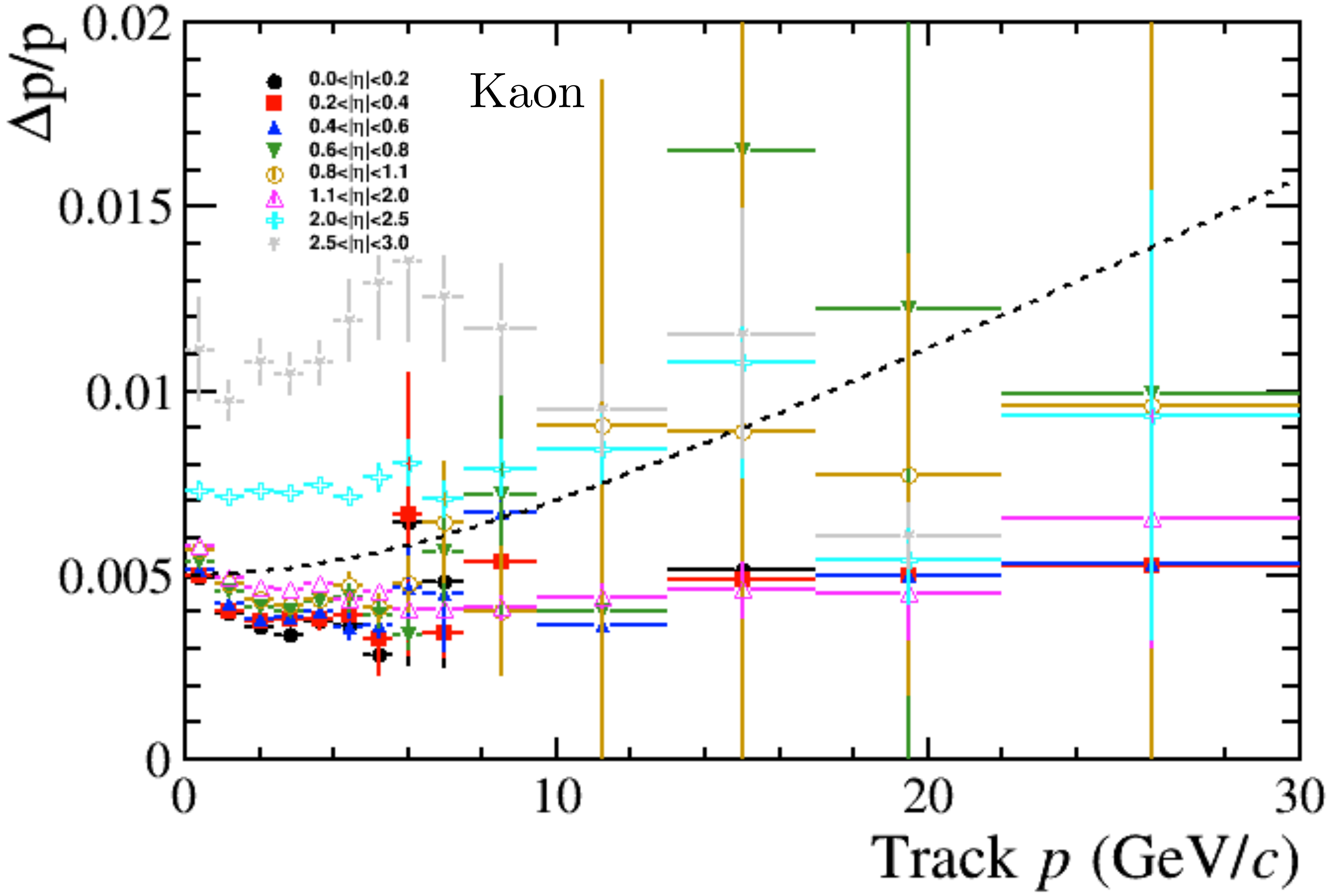
- 18 GeV electrons on 275 GeV protons

**Full Geant4 simulation using the Fun4All framework**

```
Beams:idA = 2212    ! first beam, p = 2212, pbar = -2212
Beams:idB = 11      ! second beam, e = 11, ebar = -11
Beams:eA = 275      ! proton beam 275 GeV/c
Beams:eB = 18       ! electron beam 18 GeV/c
Beams:frameType=2   ! beams are back-to-back, but with different energies
! Settings related to output in init(), next() and stat()
Init:showChangedSettings = on
Main:timesAllowErrors=900000
Next:numberShowInfo = 1             ! print event information n times
! PDF
#PDF:pSet = 7 ! CTEQ6L, NLO alpha_s(M_Z) = 0.1180.
Tune:preferLHAPDF = 2
Tune:pp=14 #default one

MultipartonInteractions:pT0Ref=3
PDF:lepton=off
PhaseSpace:mHatMin=0.
# PhaseSpace:mHatMin=0.
PhaseSpace:pTHatMinDiverge=0.5
SpaceShower:dipoleRecoil=on
SpaceShower:pTmaxMatch=2
TimeShower:QEDshowerByL = off

PhotonCollision:all=on
PhotonParton:all=on
PromptPhoton:all=on
WeakBosonExchange:all=on
WeakSingleBoson:all=on
WeakDoubleBoson:all=on
#should not open the following
HardQCD:all=on
# # SoftQCD:elastic=on
# # SoftQCD:nonDiffractive=on
# # Diffraction
Diffraction:doHard=on
Charmonium:all=on
Bottomonium:all=on
# PhaseSpace:pTHatMin = 1
# PhaseSpace:pTHatMax = 2
PhaseSpace:Q2Min=1

Random:setSeed = on
Random:seed = 0

PDF:extrapolate = on
```

# Momentum Resolution

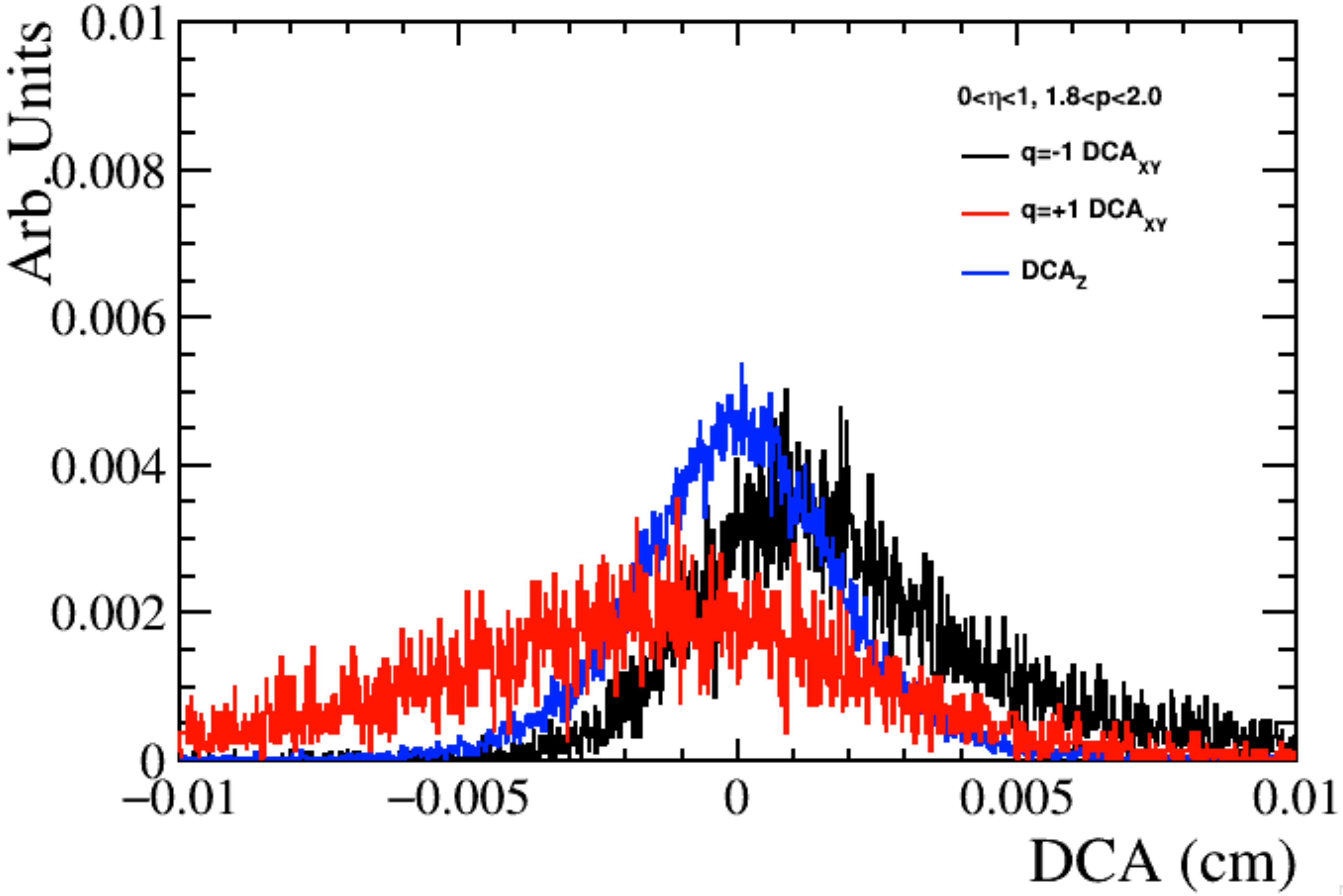


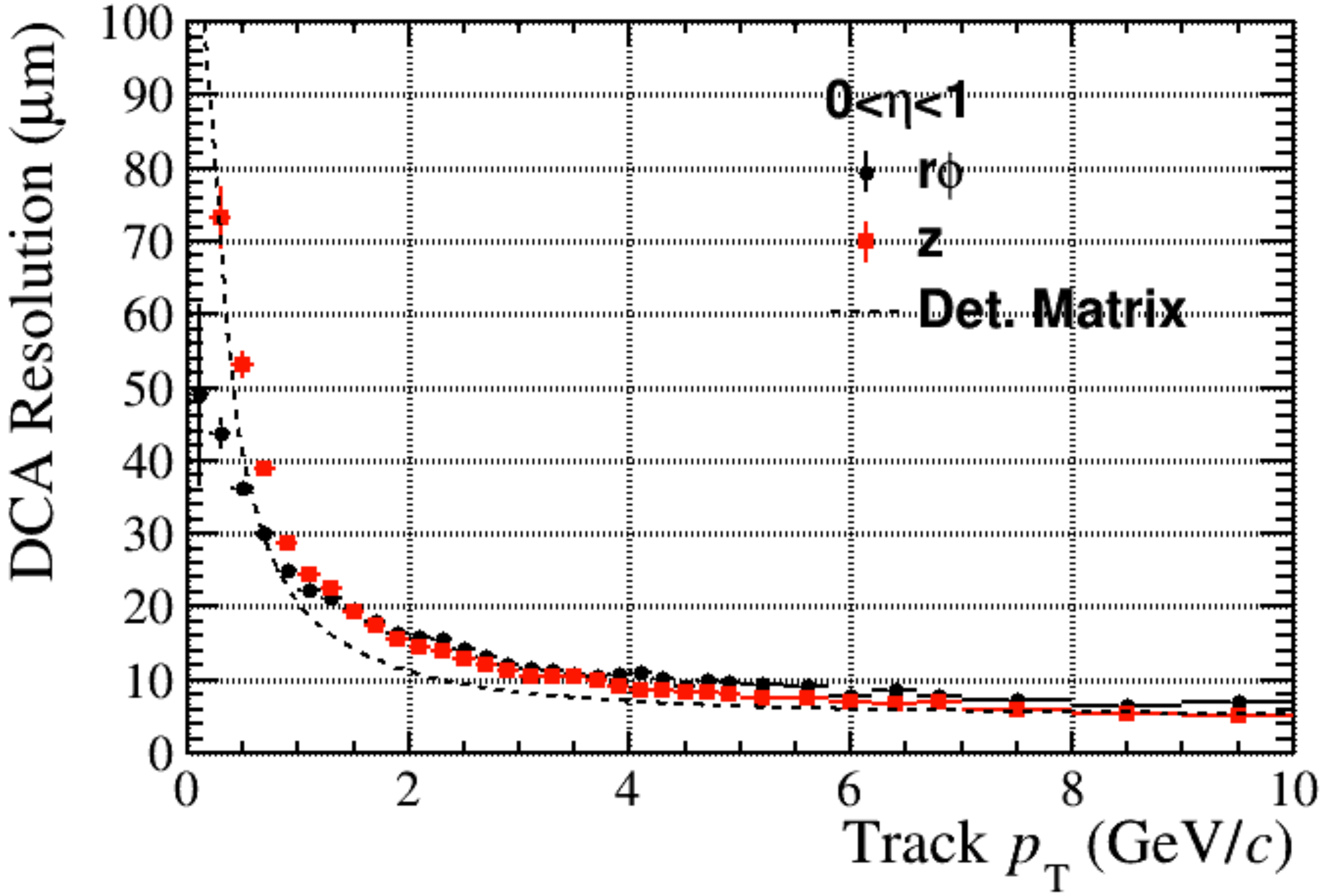




**Resolution across kinematic space mostly less than 0.5%**

**Comparable momentum resolution between these PYTHIA studies and Rey's previous studies (within $\eta<2.0$)**

# Single Track Pointing Resolution



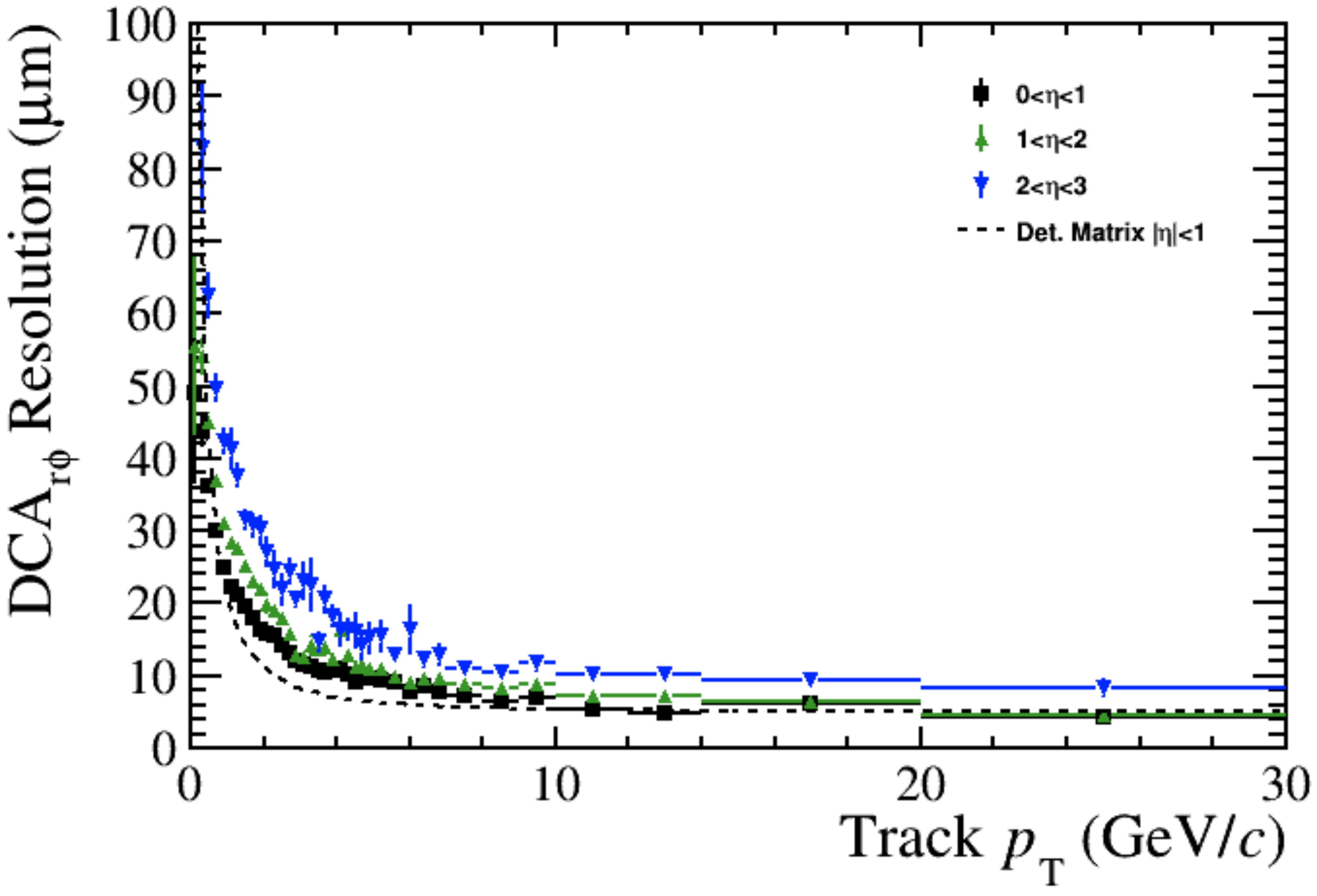



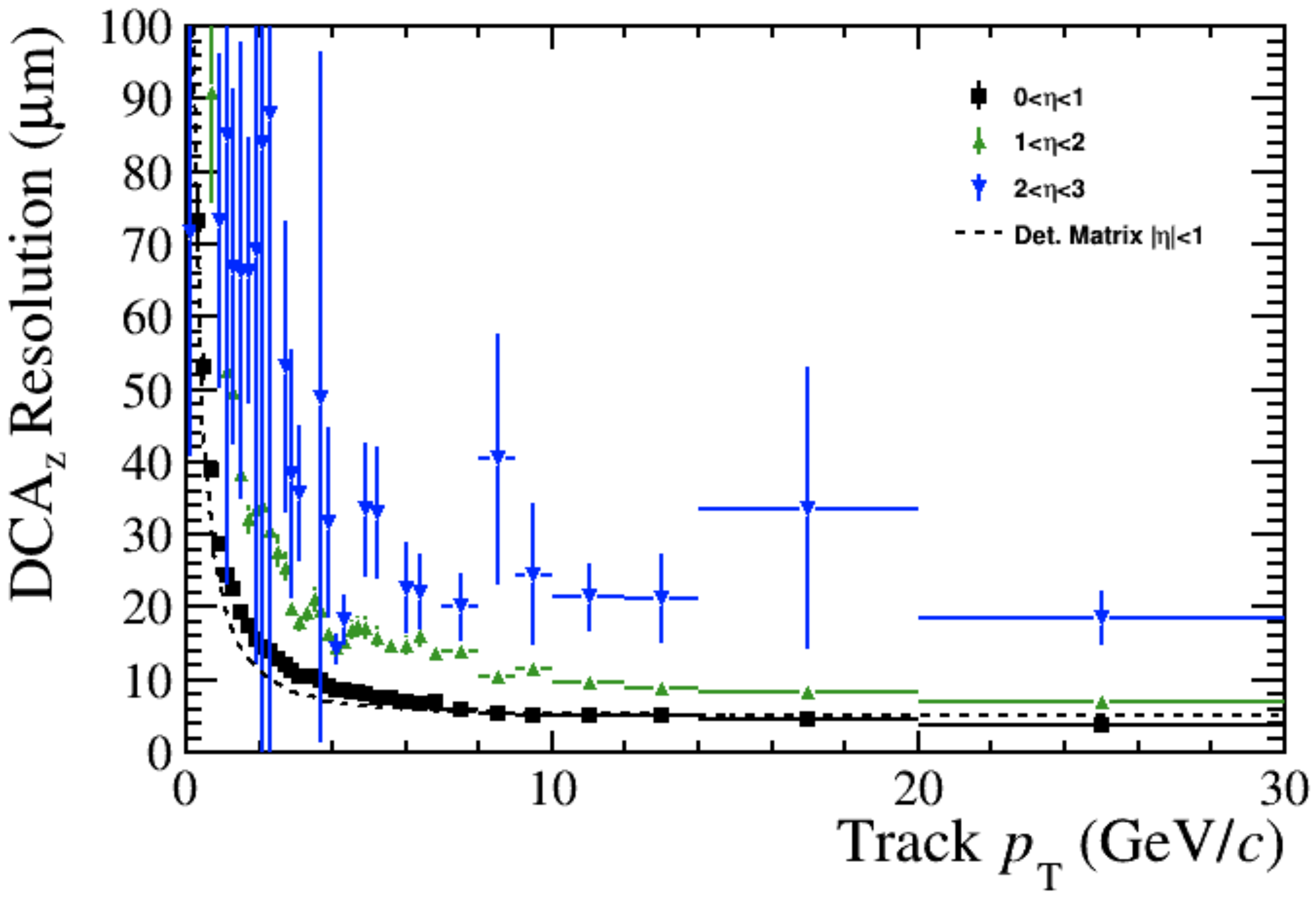

**Significant charge asymmetry in transverse DCA distributions (core Gaussian width used in resolution plots)**

- Present for tracks in both barrel and disk; cause TBD

**Similar values for pointing resolution compared to detector matrix parameterization**

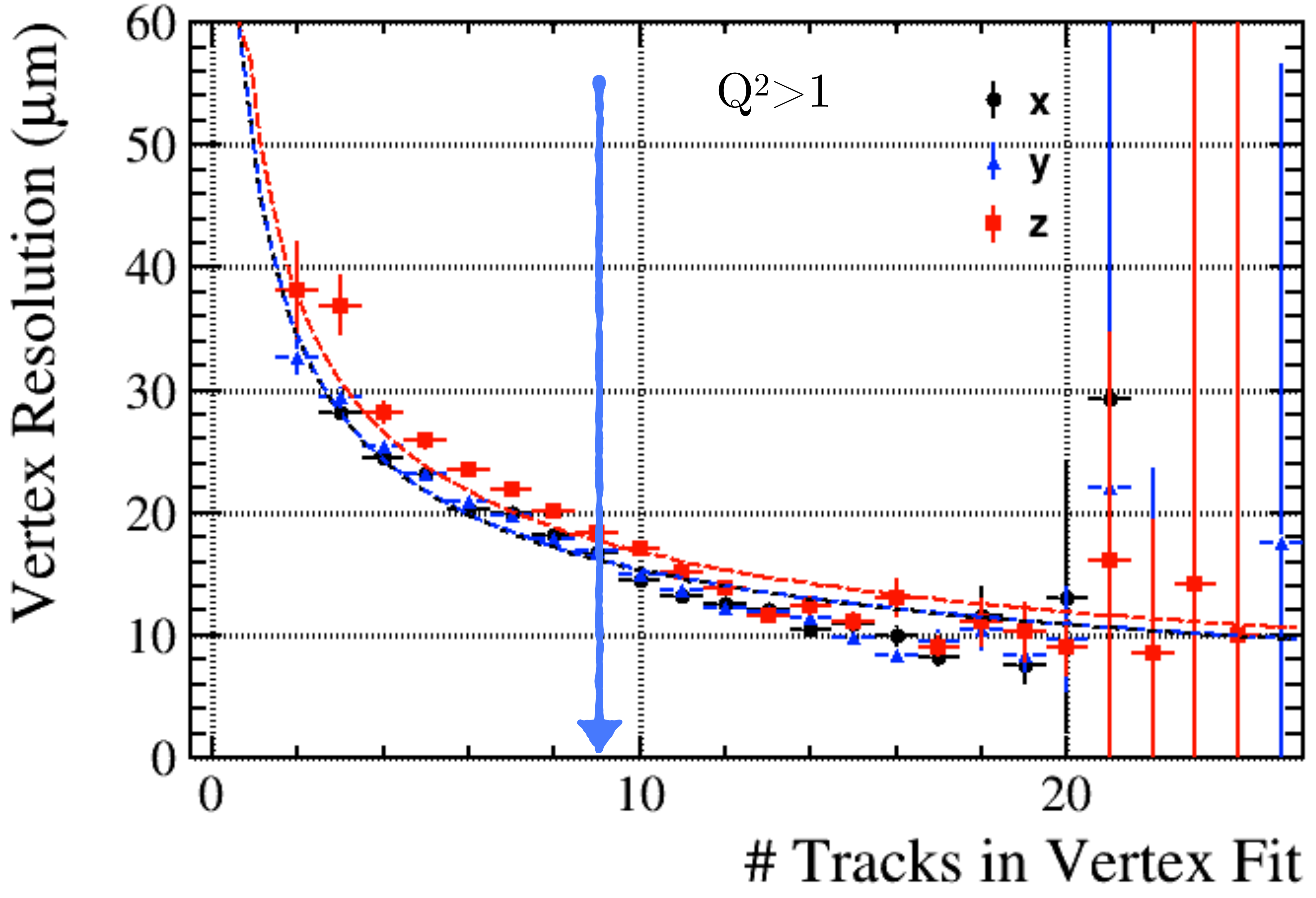
# Single Track Pointing Resolution

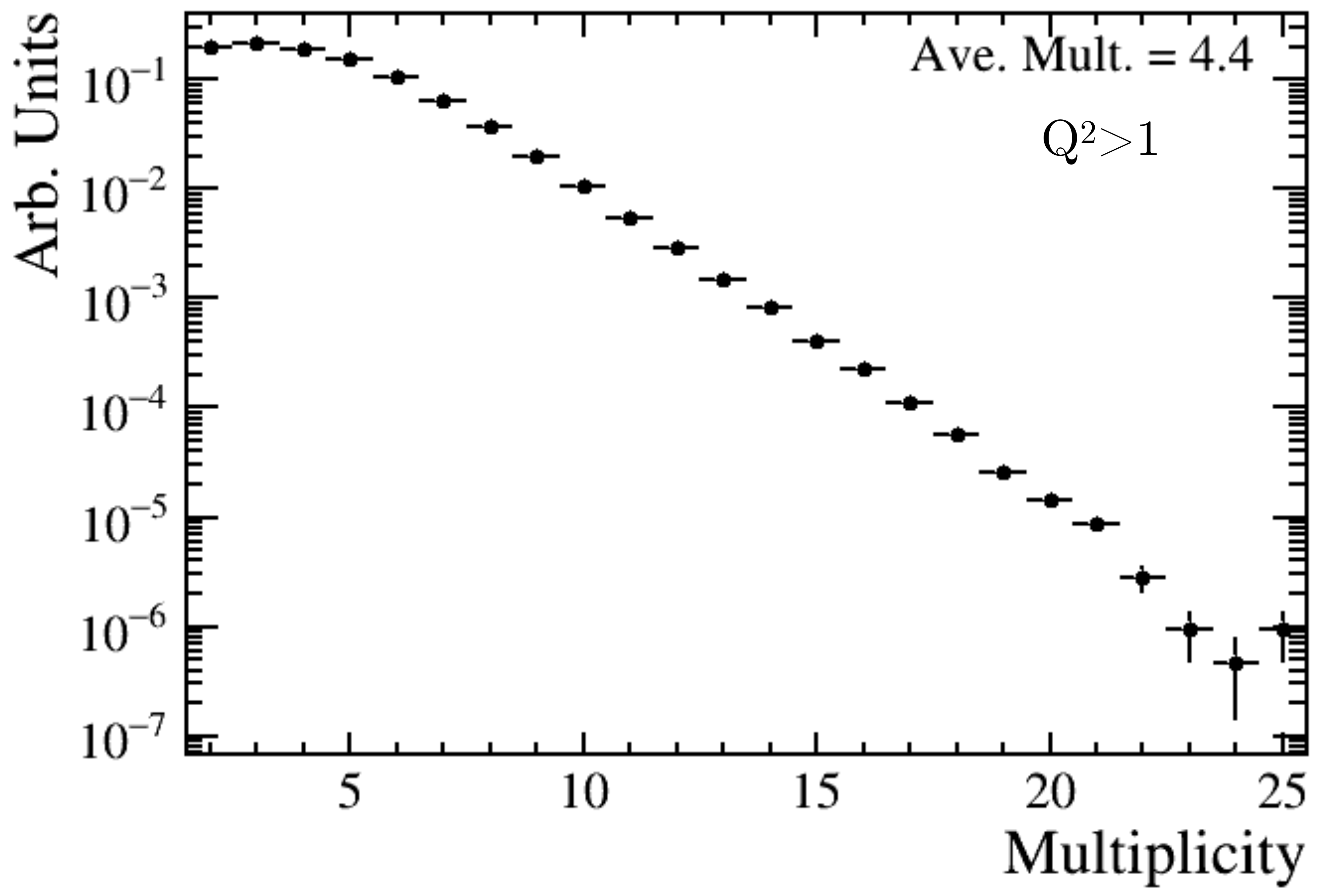



**Slight degradation for transverse DCA; larger dependence of η on longitudinal DCA**

# Vertex Resolution



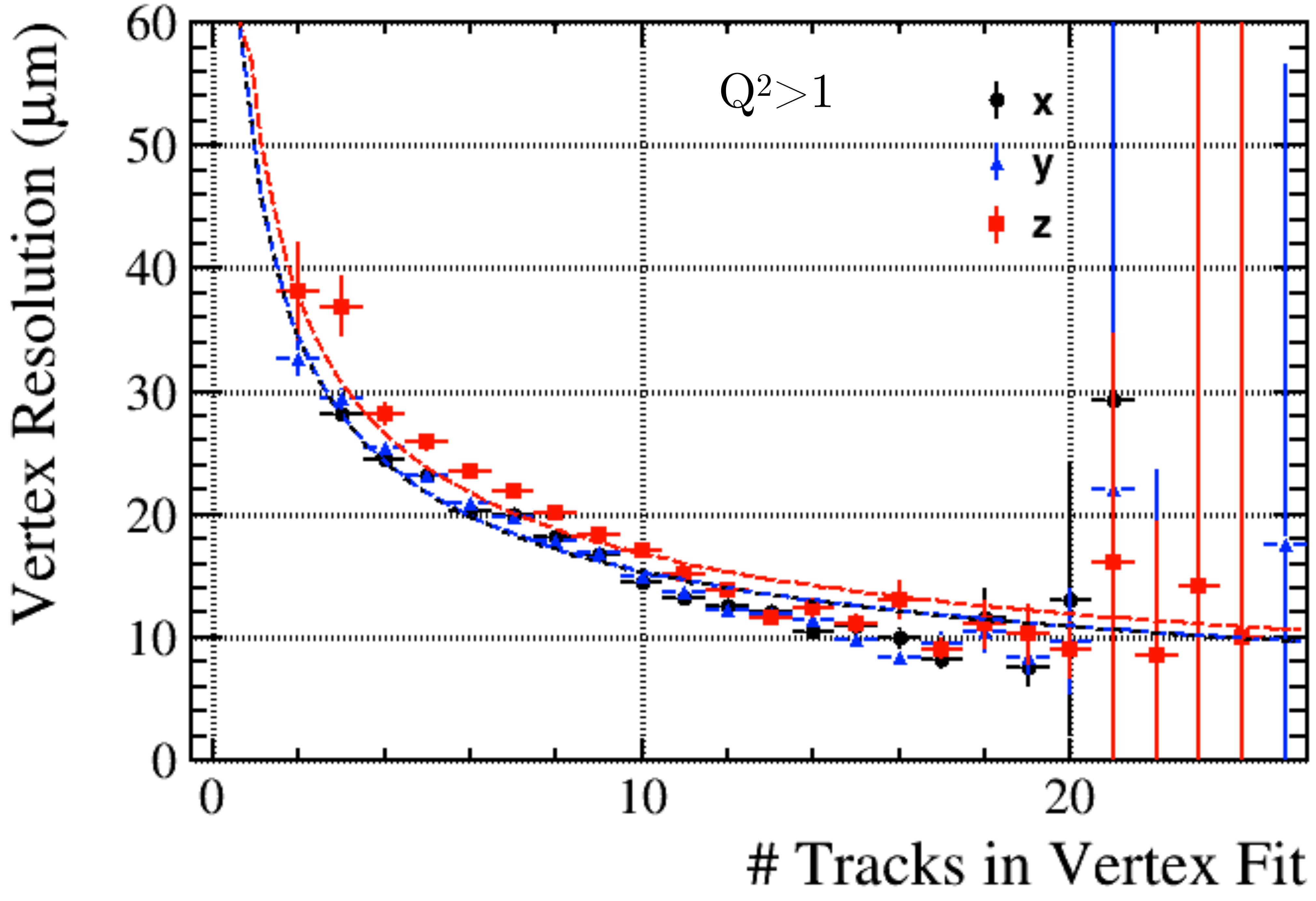




**Average multiplicity in minimum bias DIS events: 4.4; for HF events: 9**

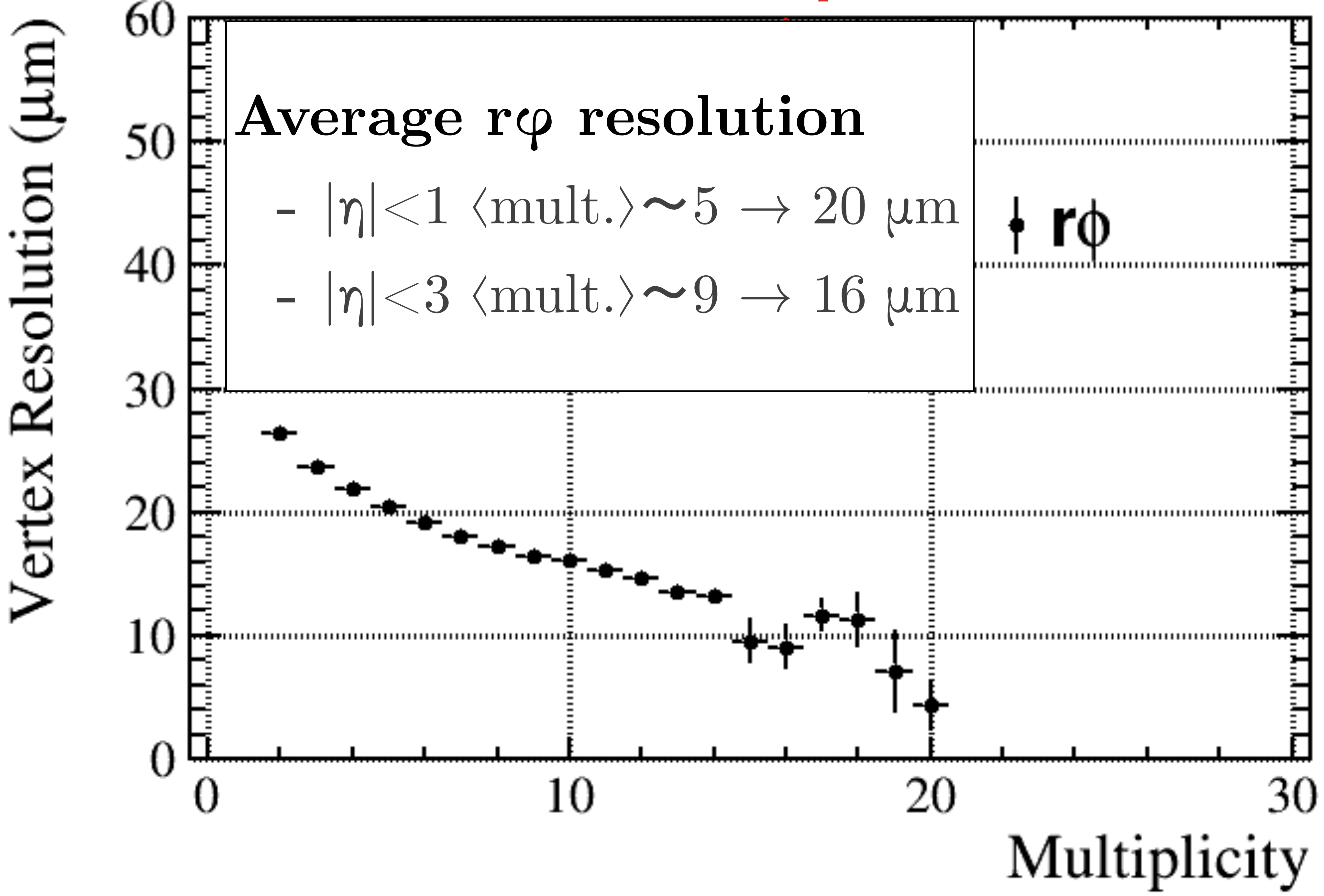
**Fitting resolution with form: A/sqrt(n)**

- X/Y: $A = 45.7 \pm 0.2$
- Z: $A = 53.9 \pm 0.4$

# Vertex Resolution (Cont.)




PYTHIA FastSim Simple PV Fitter




**Similar PV resolution compared to simple PV fitter in fast simulation previously shown**

# $D^0$ Reconstruction in Fast Sim.

**PYTHIA6 simulation with EIC setup**

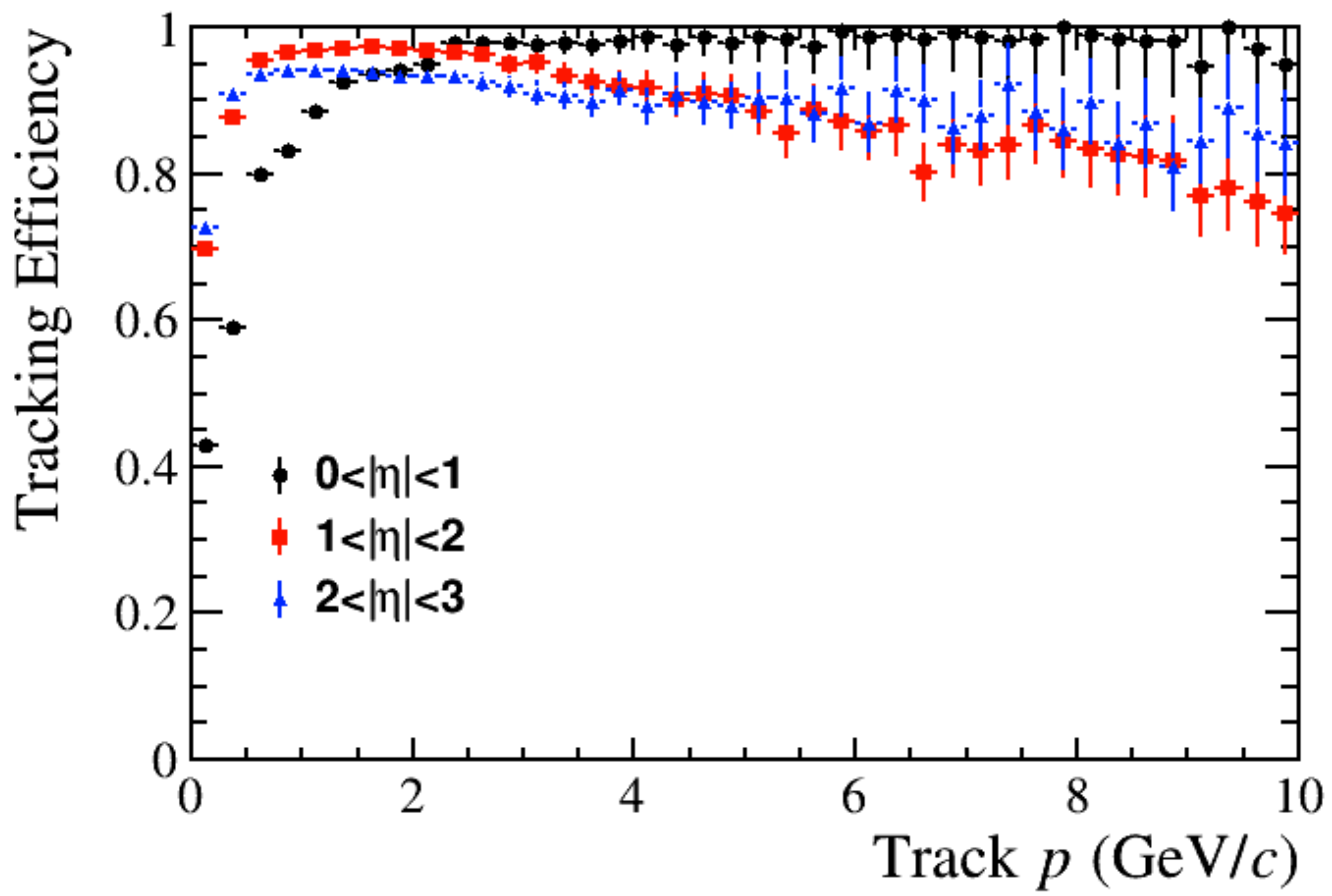
- https://eic.github.io/software/pythia6.html

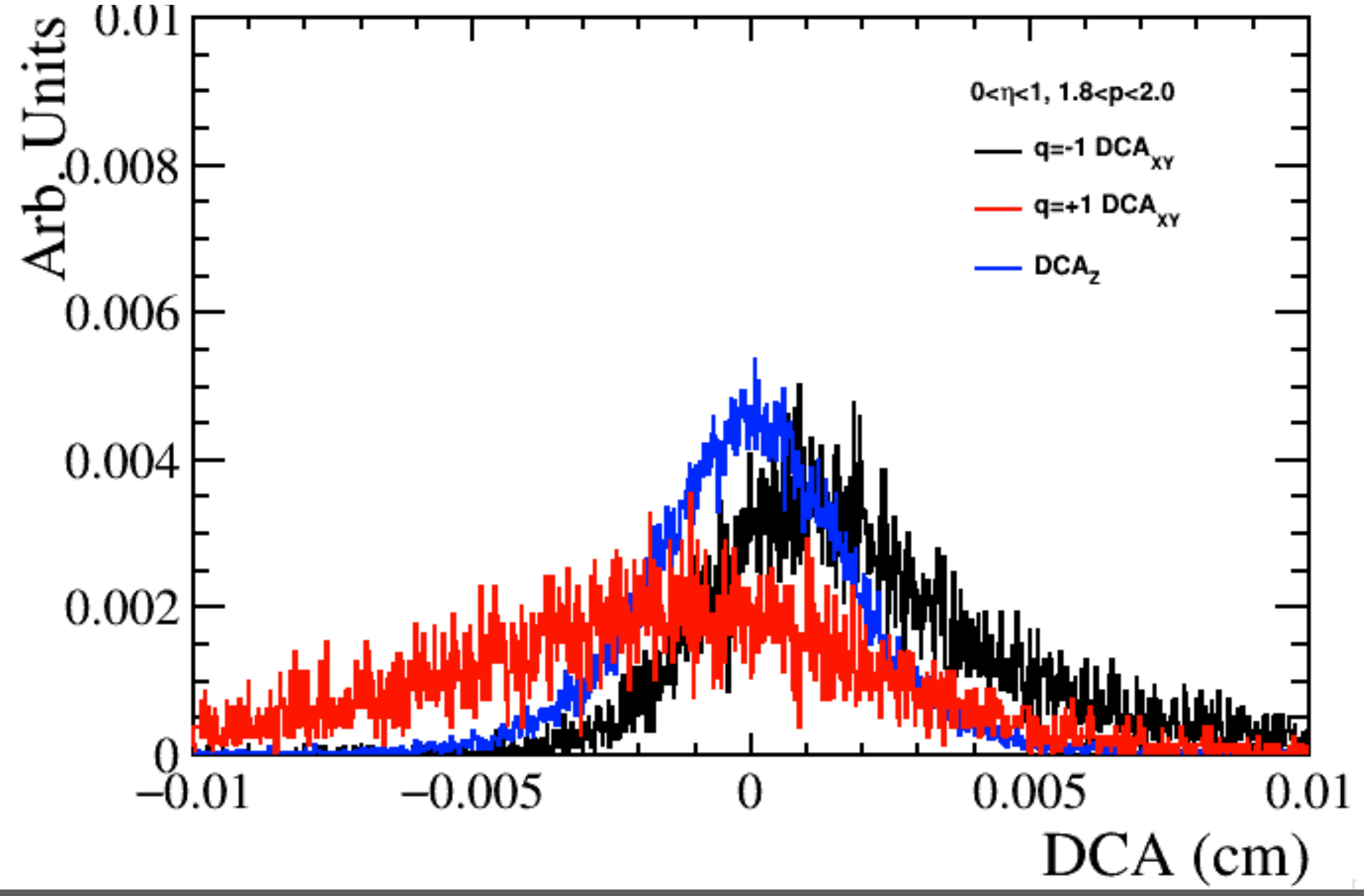
**Smearing procedure (all taken from full simulation)**

- Tracking efficiency vs pT and $\eta$
- Momentum resolution vs p and $\eta$
- Single track pointing resolution (pT vs $\eta$) -> Use $h^+/h^-$ histograms to capture full distribution shape
- Primary vertex resolution vs multiplicity

**$D^0 \rightarrow K\pi$ candidates are reconstructed using a perfect PID hypothesis**

- Effects of applying topological selections compared between fast/full sim.



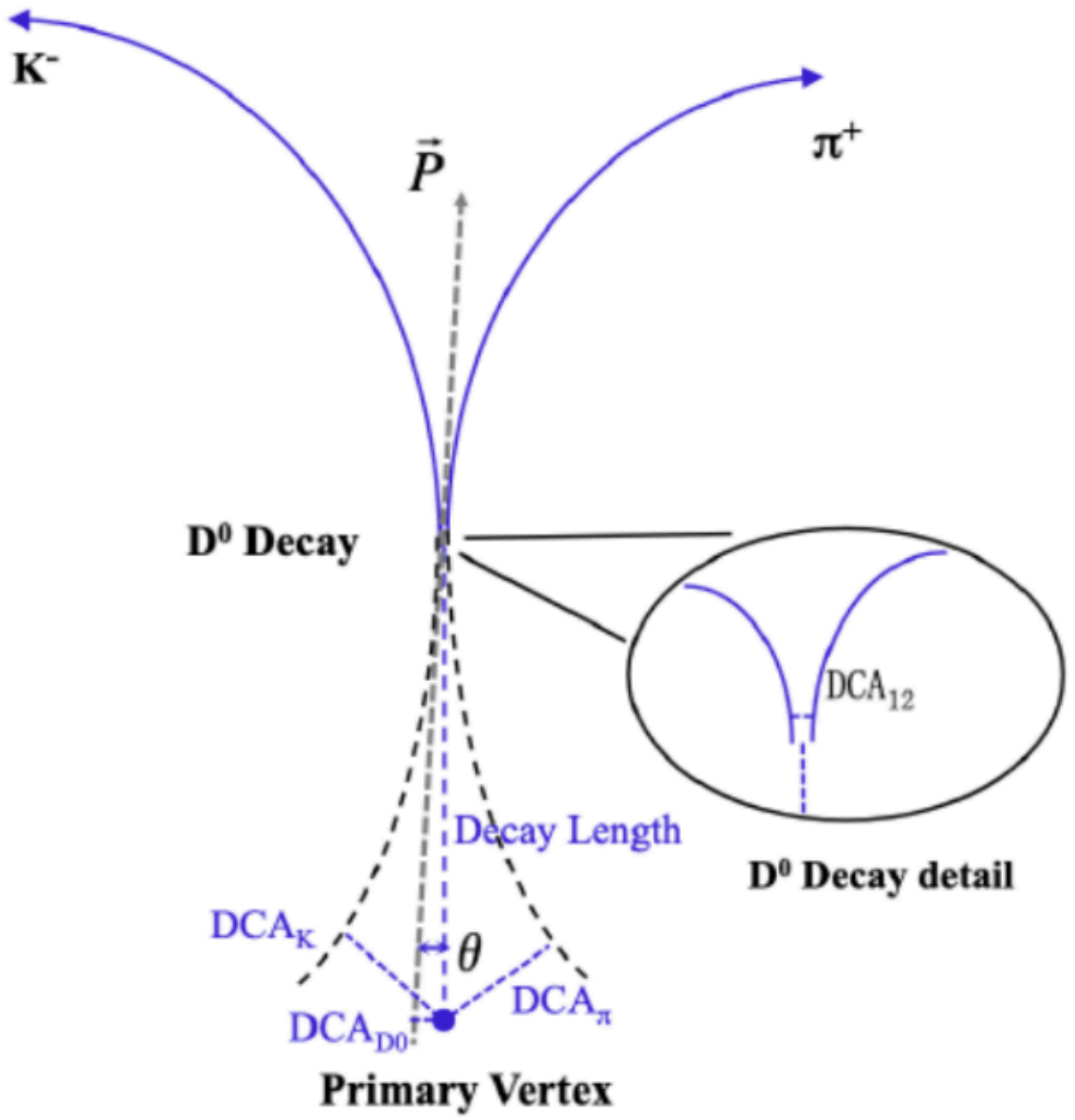



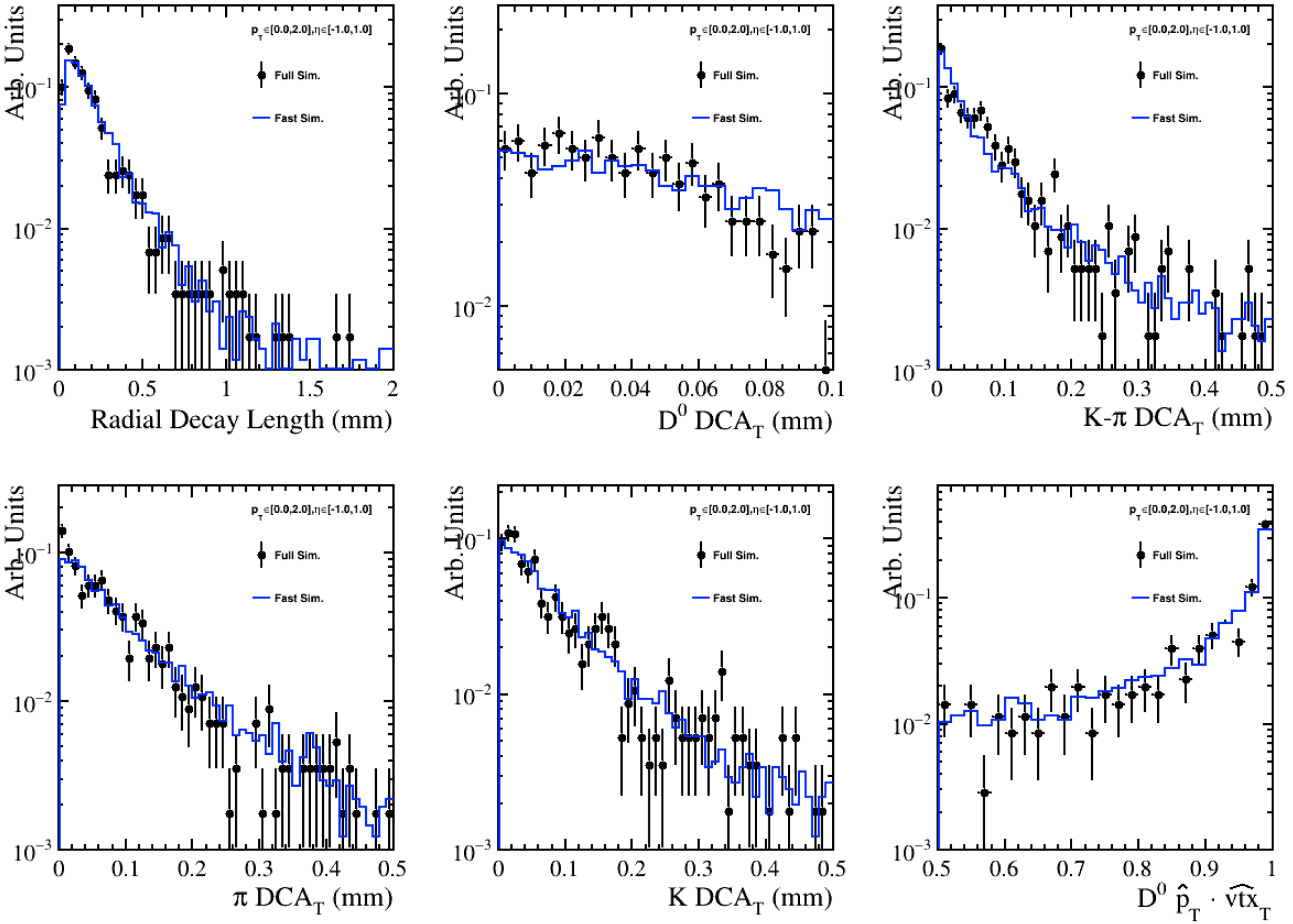
# D0 Topo. Variables

**$D^0$ signal significance improved by cutting on topological variables**

- https://indico.bnl.gov/event/8494/contributions/37480/attachments/28030/43019/EIC_HFJETYRWG_SR_2.pdf

**Good agreement at $\eta$ in [-1,1] (same for all $\eta$ + $p_T$ windows)**



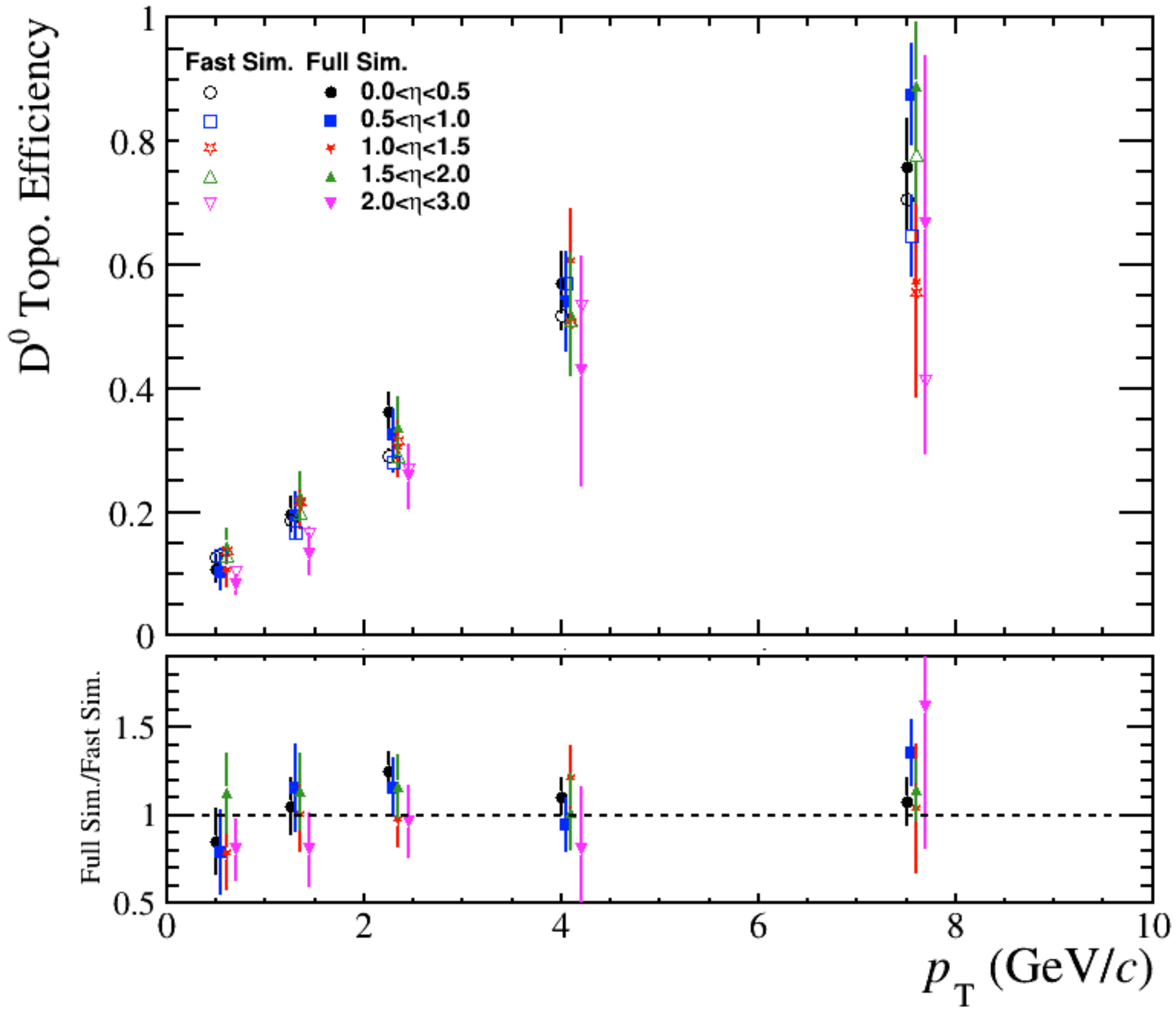
# $D^0$ Topo. Variables

**Radial Decay Vertex>0.04 mm**

**K-π $DCA_T$<0.15 mm**

**cos(D0 pointing angle)>0.98**

**Fast simulation able to reproduce efficiency in full simulation**



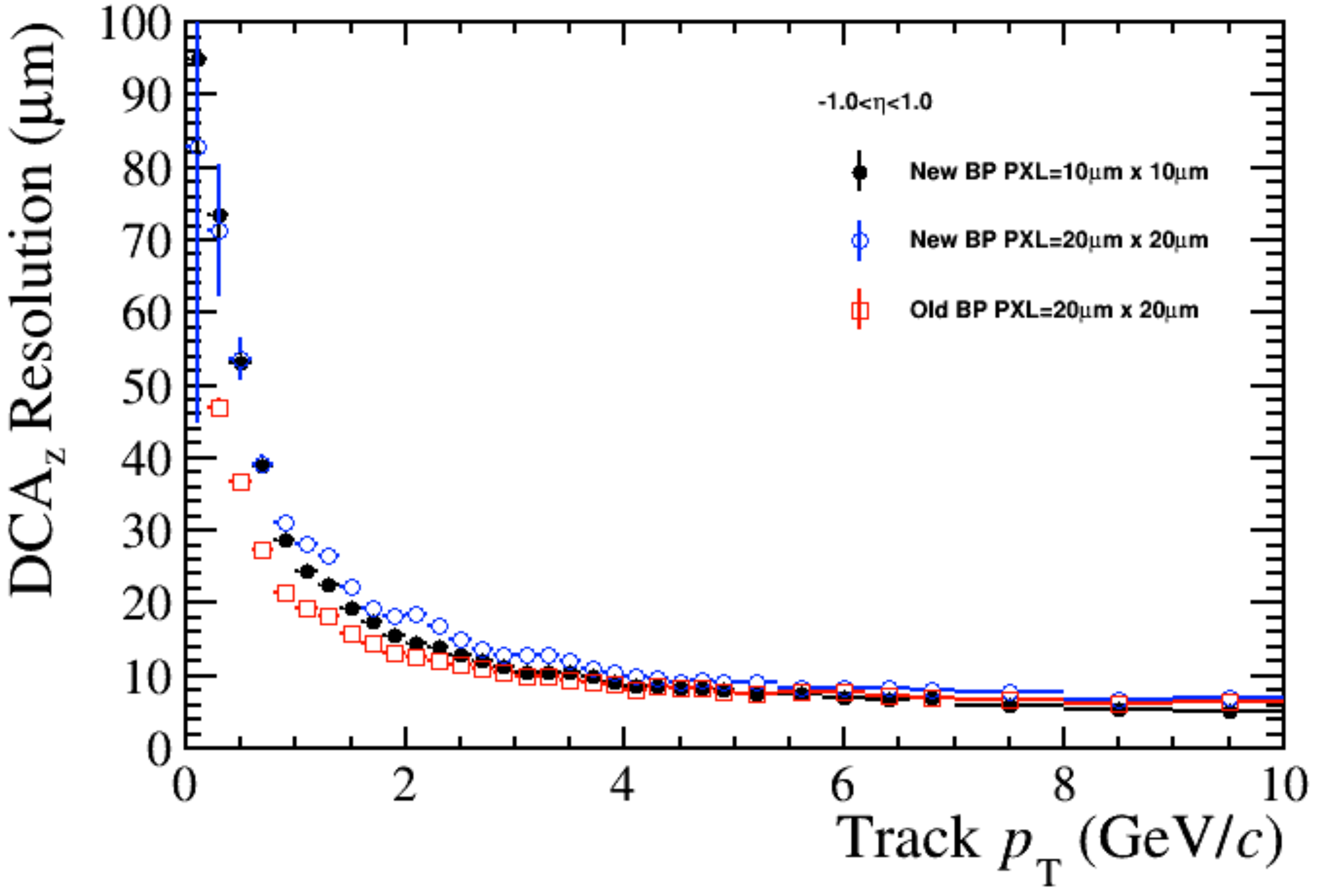
# Summary

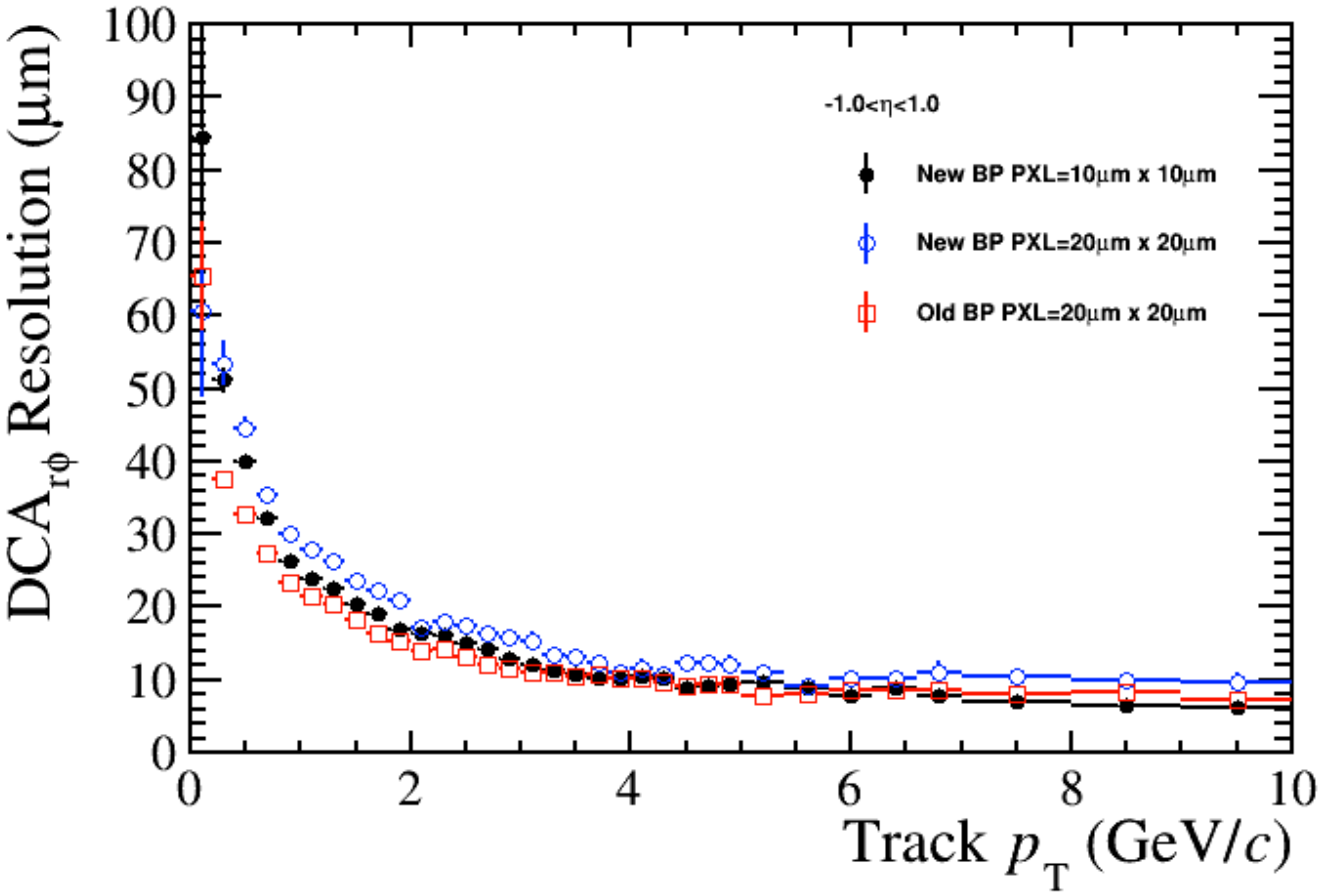
Studied the single track performance and PV resolution in the all-Si full simulation package

Verified that fast simulation procedure of studying charm hadrons is reliable, particularly in the forward region

# Backup Slides Follow

# Beampipe impact on DCA



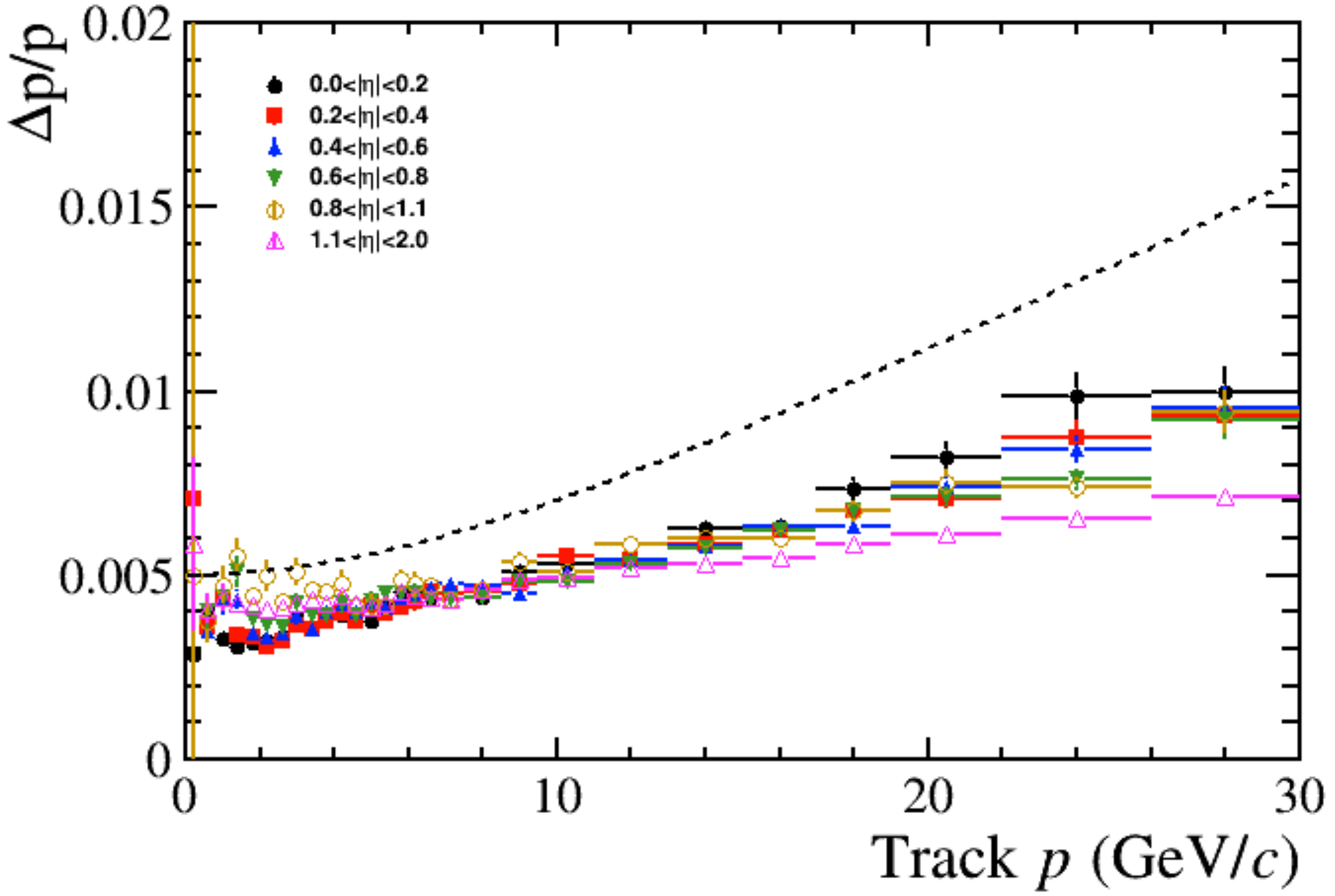



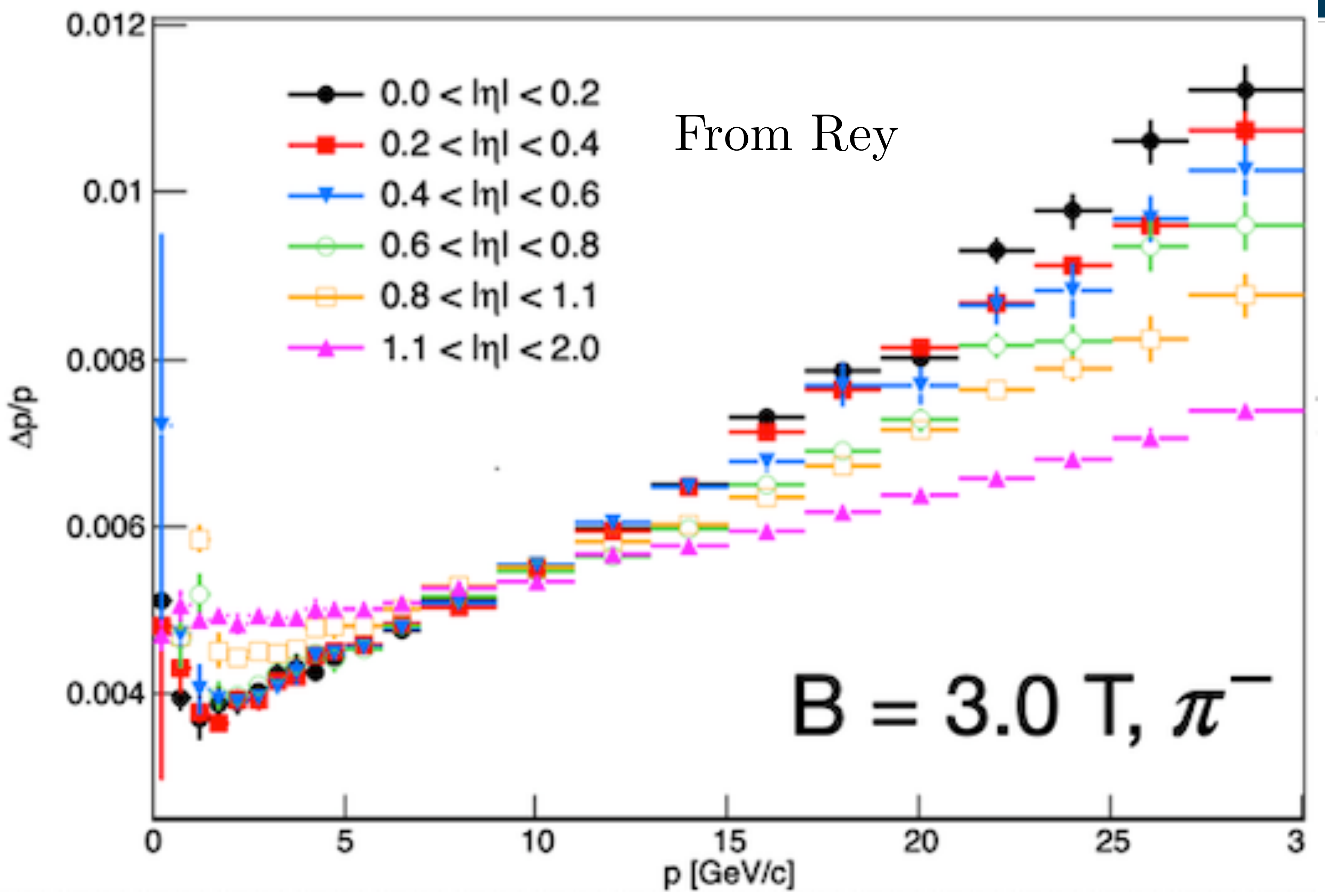

**Low pT (=1 GeV/c) resolution about 10 μm worse by increasing first layer radius**

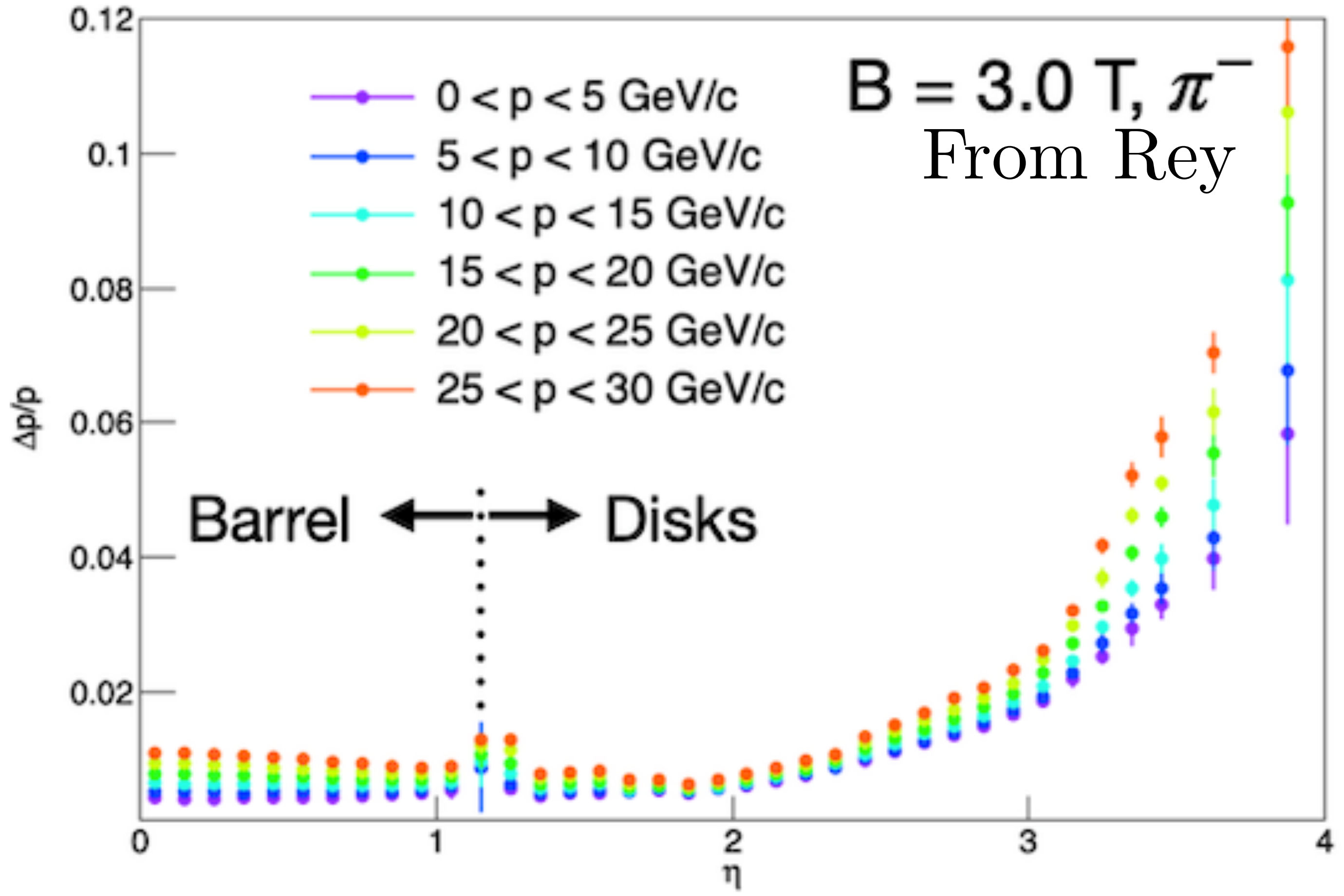
- Improvement by reducing pixel size

**High pT resolution comparable between old and new configurations**

# Sanity Check



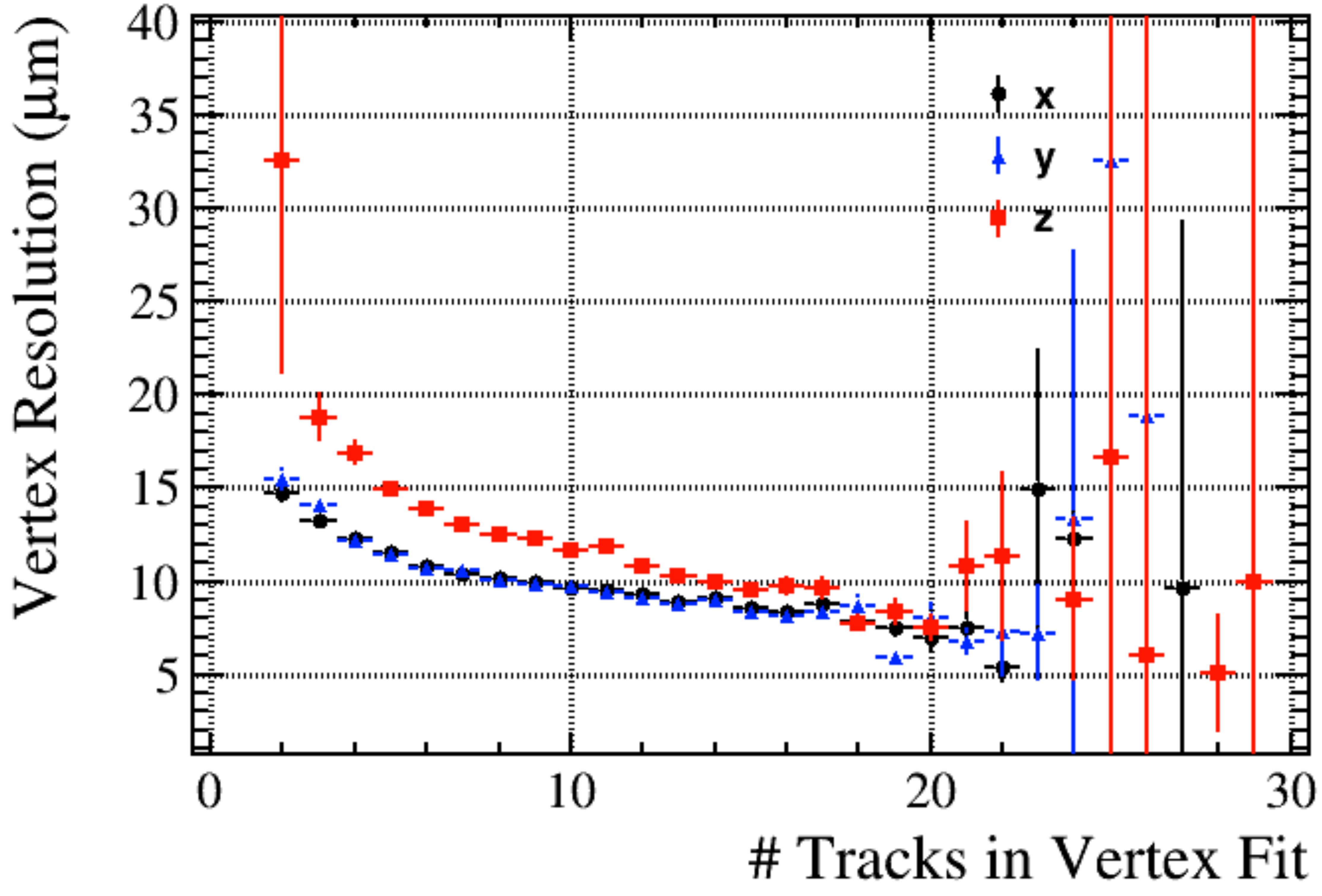



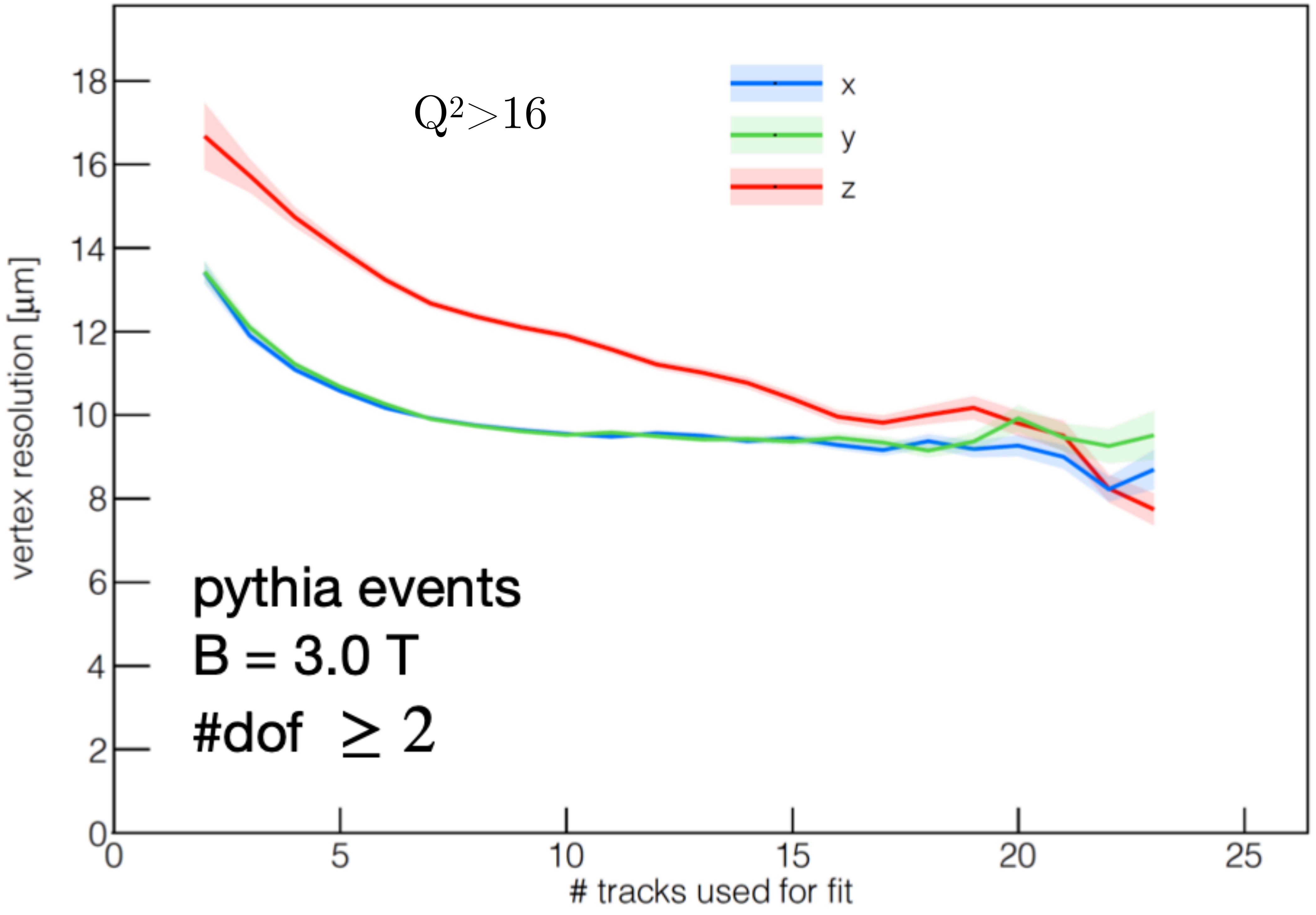




**Momentum resolution of pions utilizing a simple particle generator (1/event)**

**Momentum dependence similar to Rey's studies with same parameters**

# PV Resolution (cont.)

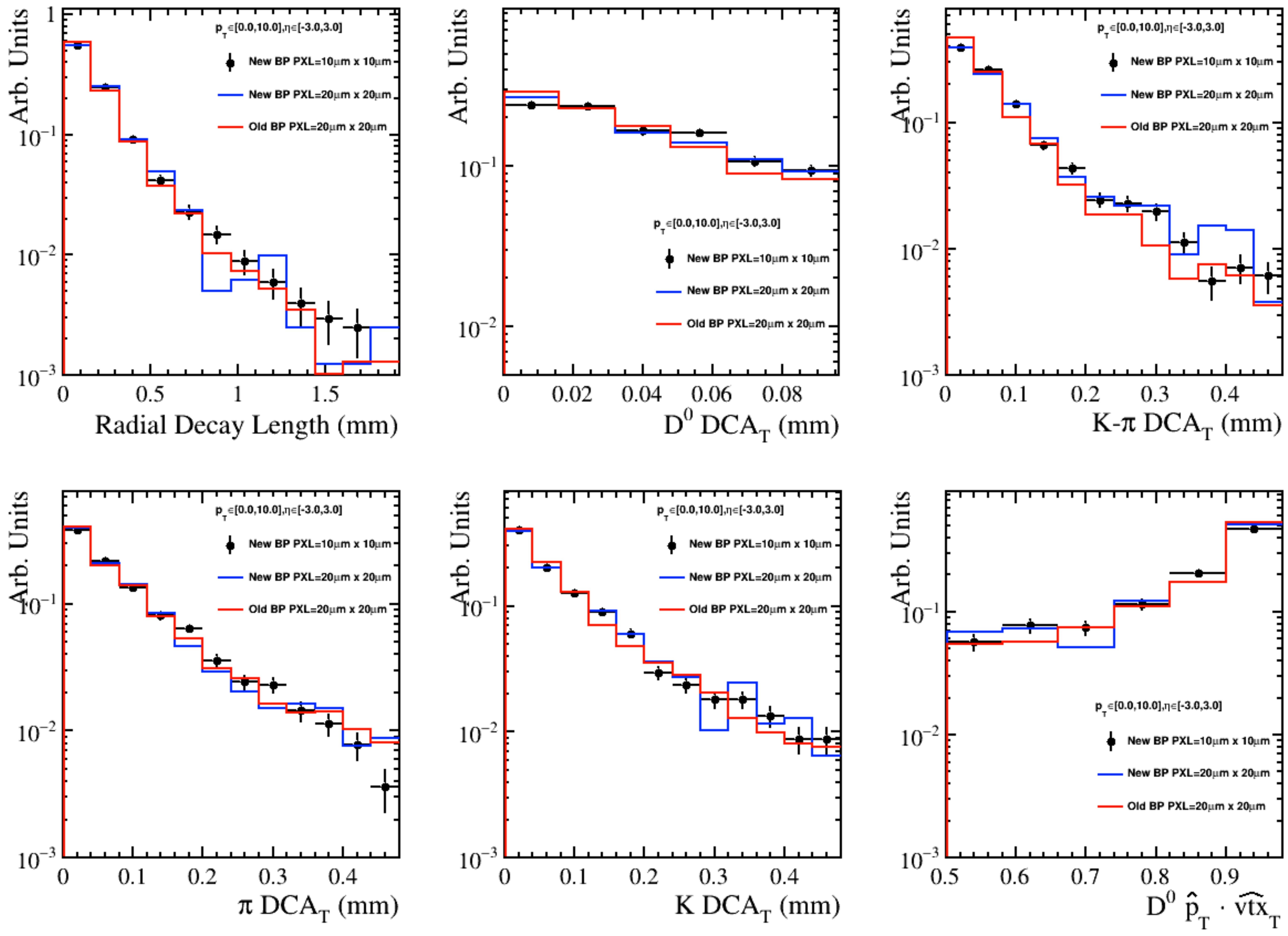



**Agreement with Rey's studies when choosing same $Q^2$ region**

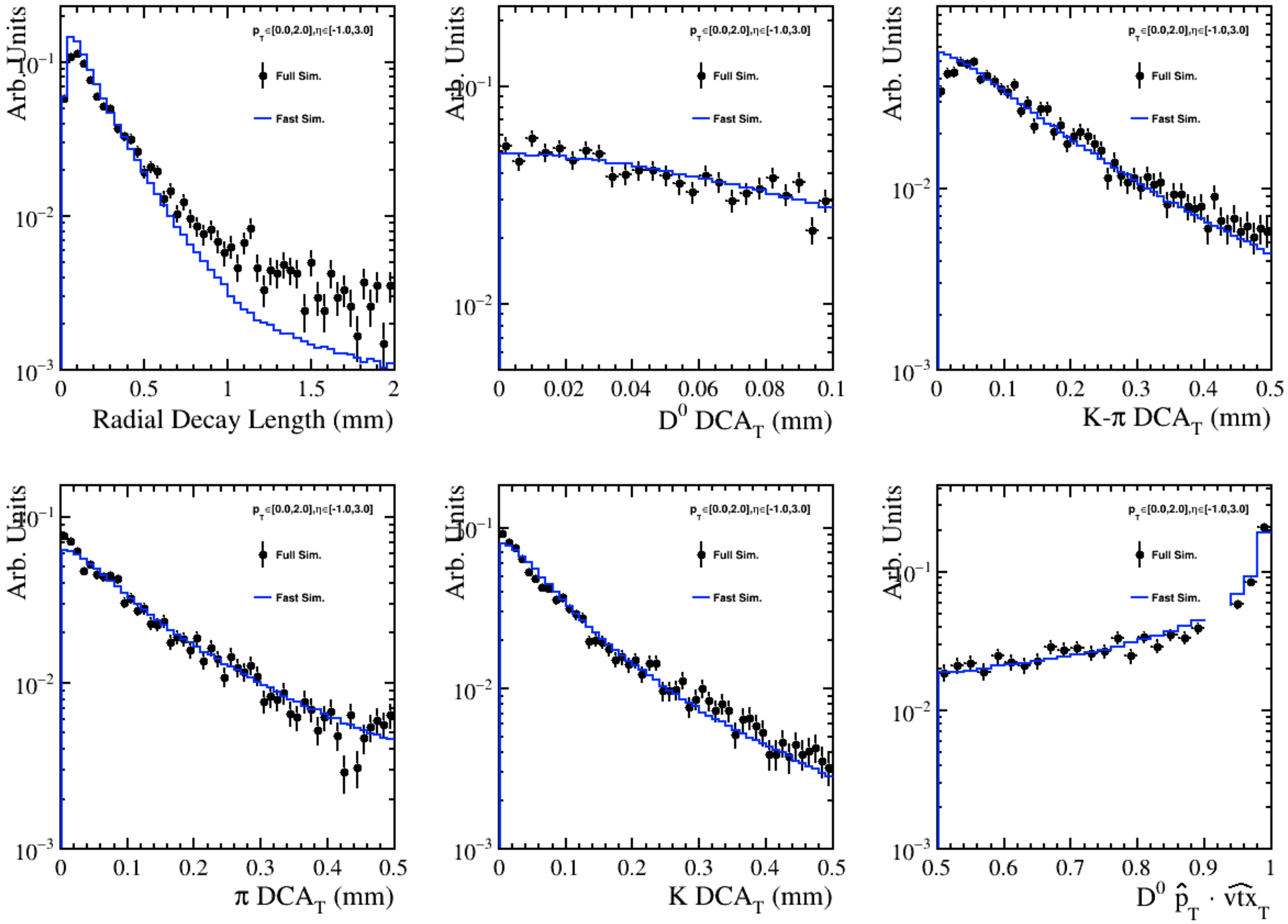
- Reflecting average pT of tracks in event

# $D^0$ Topo. Variables Comp.



# Background Distributions

**Constructed using same-sign Kπ pairs**



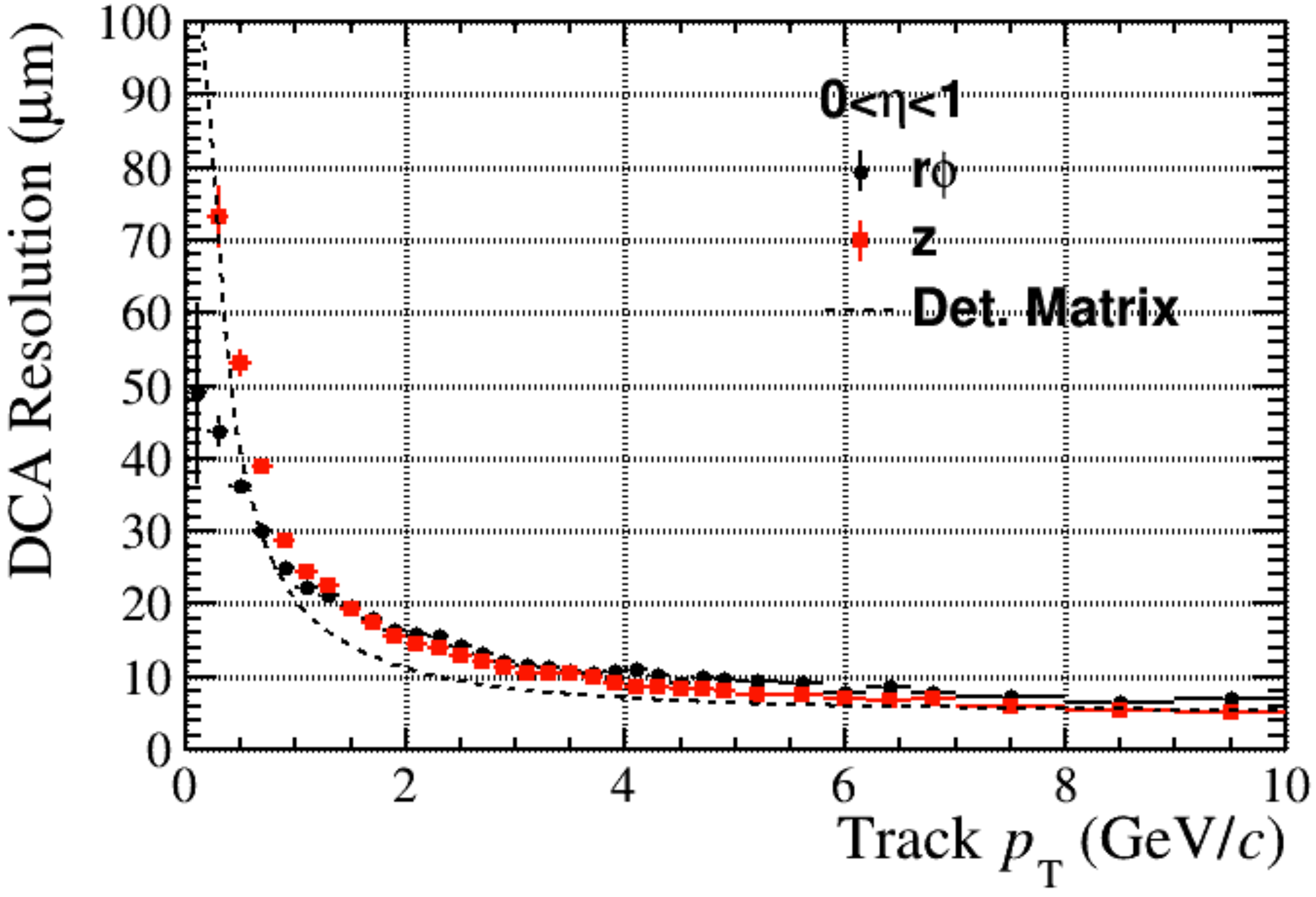
# DCA Calculation

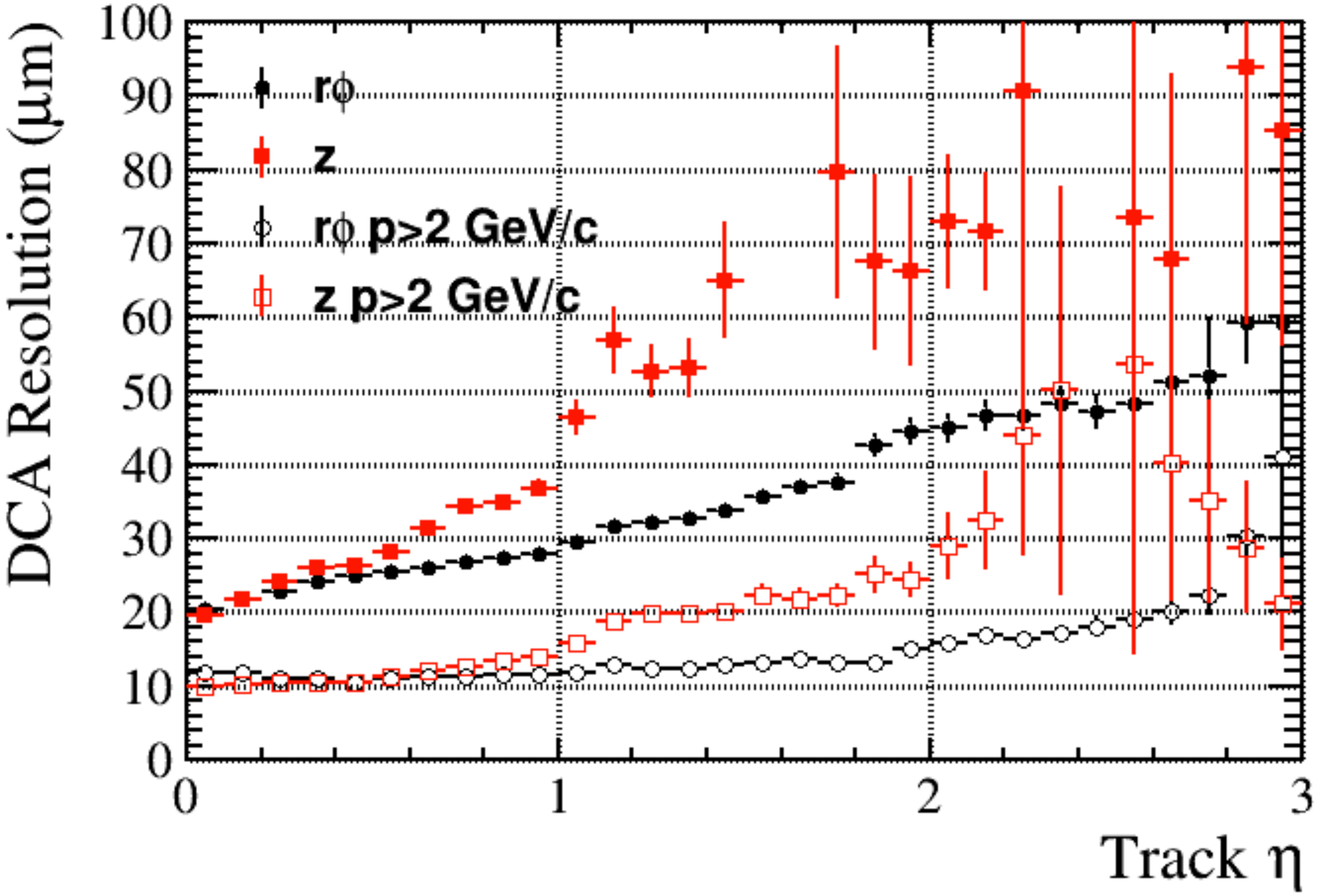
```
float dcaXY(TVector3 const& p, TVector3 const& pos, TVector3 const& vertex){
    TVector3 newPos(pos);newPos.SetZ(0);
    TVector3 newP(p);newP.SetZ(0);
    TVector3 newVertex(vertex);newVertex.SetZ(0);
    TVector3 posDiff = newPos - newVertex;
    float sign = posDiff.x() * p.y() - posDiff.y() * p.x() > 0 ? +1 : -1;
    return sign * (newP.Cross(posDiff.Cross(newP)).Unit().Dot(posDiff));
}
float dcaXYHelix(TVector3 const& p, TVector3 const& pos, TVector3 const& vertex, int charge){
    StPhysicalHelixD Helix(p, pos, 3.*kilogauss, charge);//kilogauss
    double dcaxy = Helix.geometricSignedDistance(vertex.X(),vertex.Y());
    return dcaxy;
}
float dcaZHelix(TVector3 const& p, TVector3 const& pos, TVector3 const& vertex, int charge){
    StPhysicalHelixD Helix(p, pos, 3.*kilogauss, charge);//kilogauss
    double s = Helix.pathLength(vertex);
    return (Helix.at(s) - vertex).Z();
}
float dcaZ(TVector3 const& p, TVector3 const& pos, TVector3 const& vertex){
    TVector3 posDiff = pos - vertex;
    if (sin(p.Theta()) == 0) return 0;
    else return (-posDiff.x() * cos(p.Phi()) - posDiff.y() * sin(p.Phi())) * cos(p.Theta()) / sin(p.Theta()) + posDiff.z();
}
```

# EIC Detector Matrix

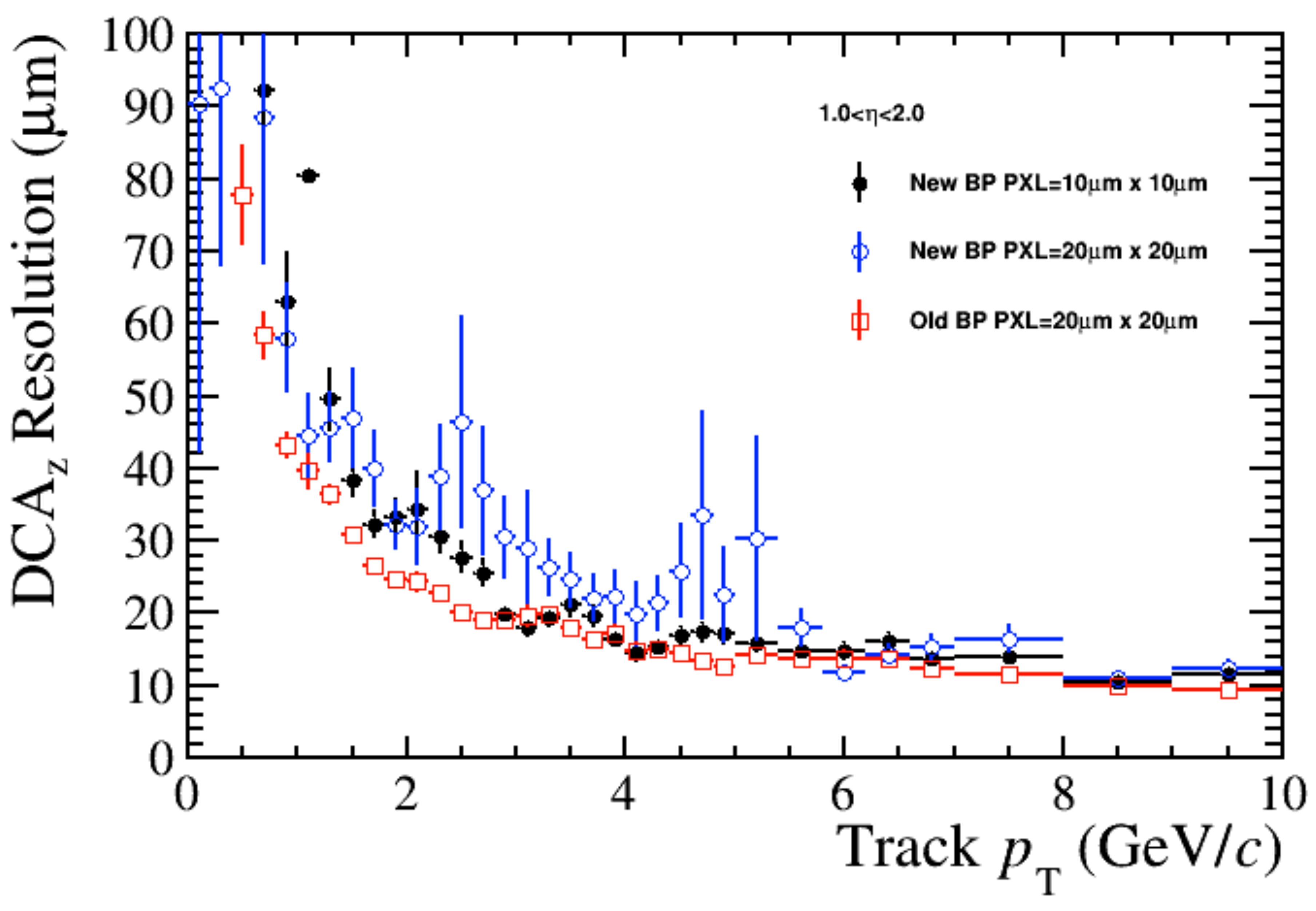
| η | Nomenclature | | | Tracking | | | | Electrons | | π/K/p | | HCAL | Muons |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Resolution | Allowed $X/X_0$ | Si-Vertex | pT Range | Resolution $\sigma_E/E$ | PID | p-Range (GeV/c) | Separation | Resolution $\sigma_E/E$ | |
| -6.9 to -5.8 | | | low-Q2 tagger | $\sigma_\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV2 | | | | | | | | | |
| ... | ↓ p/A | Auxiliary Detectors | | | | | | | | | | | |
| -4.5 to -4.0 | | | Instrumentation to separate charged particles from photons | | | | | | | | | | |
| -4.0 to -3.5 | | | | | | | | 2%/√E | | | | | |
| -3.5 to -3.0 | | | | $\sigma_p/p$ ~ 0.1%⊕0.5% | | | | | | | | | |
| -3.0 to -2.5 | | | | | | | | | | | | | |
| -2.5 to -2.0 | | | Backward Detector | $\sigma_p/p$ 0.1%⊕0.5% | | TBD | | 2%/√E | | ≤ 7 GeV/c | | ~50%/√E | |
| -2.0 to -1.5 | | | | | | | | 7%/√E | | | | | |
| -1.5 to -1.0 | | | | $\sigma_p/p$ 0.05%⊕0.5% | | | | 7%/√E | π suppression up to 1:$10^4$ | | | | |
| -1.0 to -0.5 | | | | | | | | | | | | | |
| -0.5 to 0.0 | | Central Detector | Barrel | $\sigma_p/p$ ~0.05%×p+0.5% | ~5% or less X | $\sigma_{xyz}$ ~ 20 μm, $d_0(z)$ ~ $d_0(r\Phi)$ ~ 20/$p_T$GeV μm + 5 μm | | | | ≤ 5 GeV/c | ≥ 3 σ | ~50%/√E | TBD |
| 0.0 to 0.5 | | | | | | | | | | | | | |
| 0.5 to 1.0 | | | | | | | | | | | | | |
| 1.0 to 1.5 | | | | | | | | | | | | | |
| 1.5 to 2.0 | | | | $\sigma_p/p$ ~0.05%×p+1.0% | | | | (10-12)%/√E | | ≤ 8 GeV/c | | | |
| 2.0 to 2.5 | | | Forward Detectors | | | TBD | | | | | | ~50%/√E | |
| 2.5 to 3.0 | | | | | | | | | | ≤ 20 GeV/c | | | |
| 3.0 to 3.5 | | | | $\sigma_p/p$ ~ 0.1%×p+2.0% | | | | | | ≤ 45 GeV/c | | | |
| 3.5 to 4.0 | | | Instrumentation to separate charged particles from photons | | | | | | | | | | |
| 4.0 to 4.5 | | | | | | | | | | | | | |
| ... | ↑ e | Auxiliary Detectors | Neutron Detection | | | | | | | | | | |
| > 6.2 | | | Proton Spectrometer | $\sigma_{intrinsic}(\lvert t\rvert)/\lvert t\rvert < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c | | | | | | | | | |

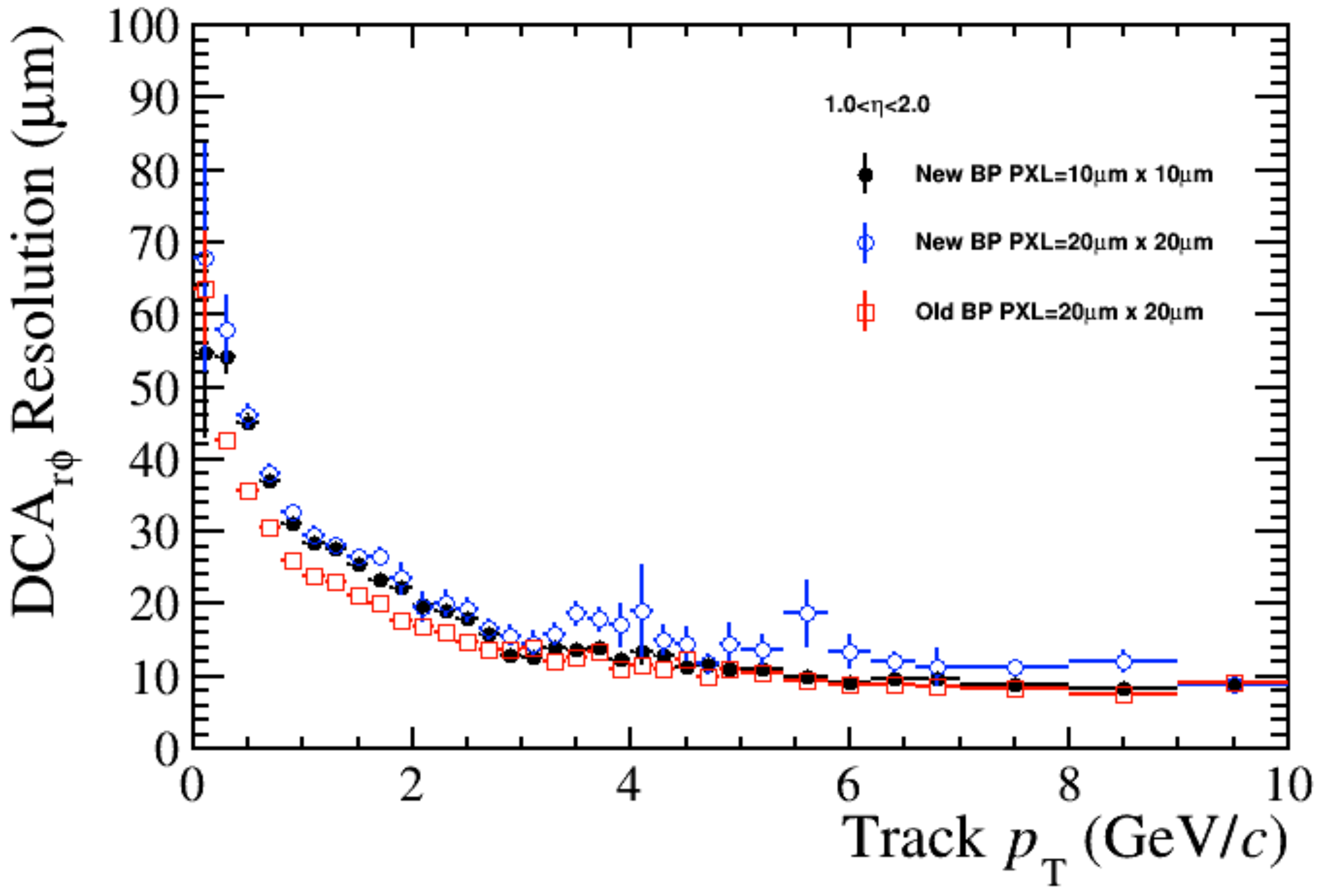
# Single Track Pointing Resolution

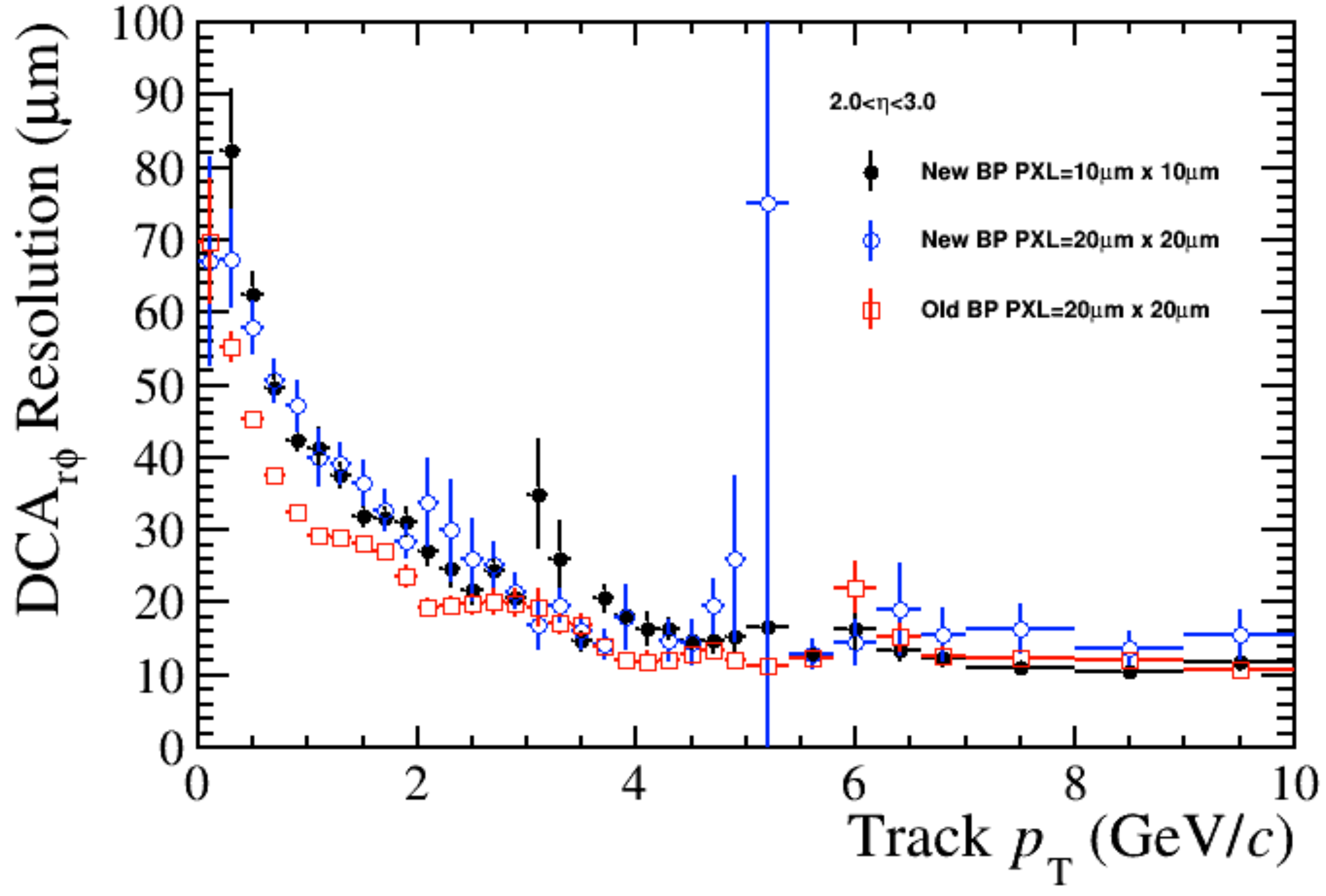


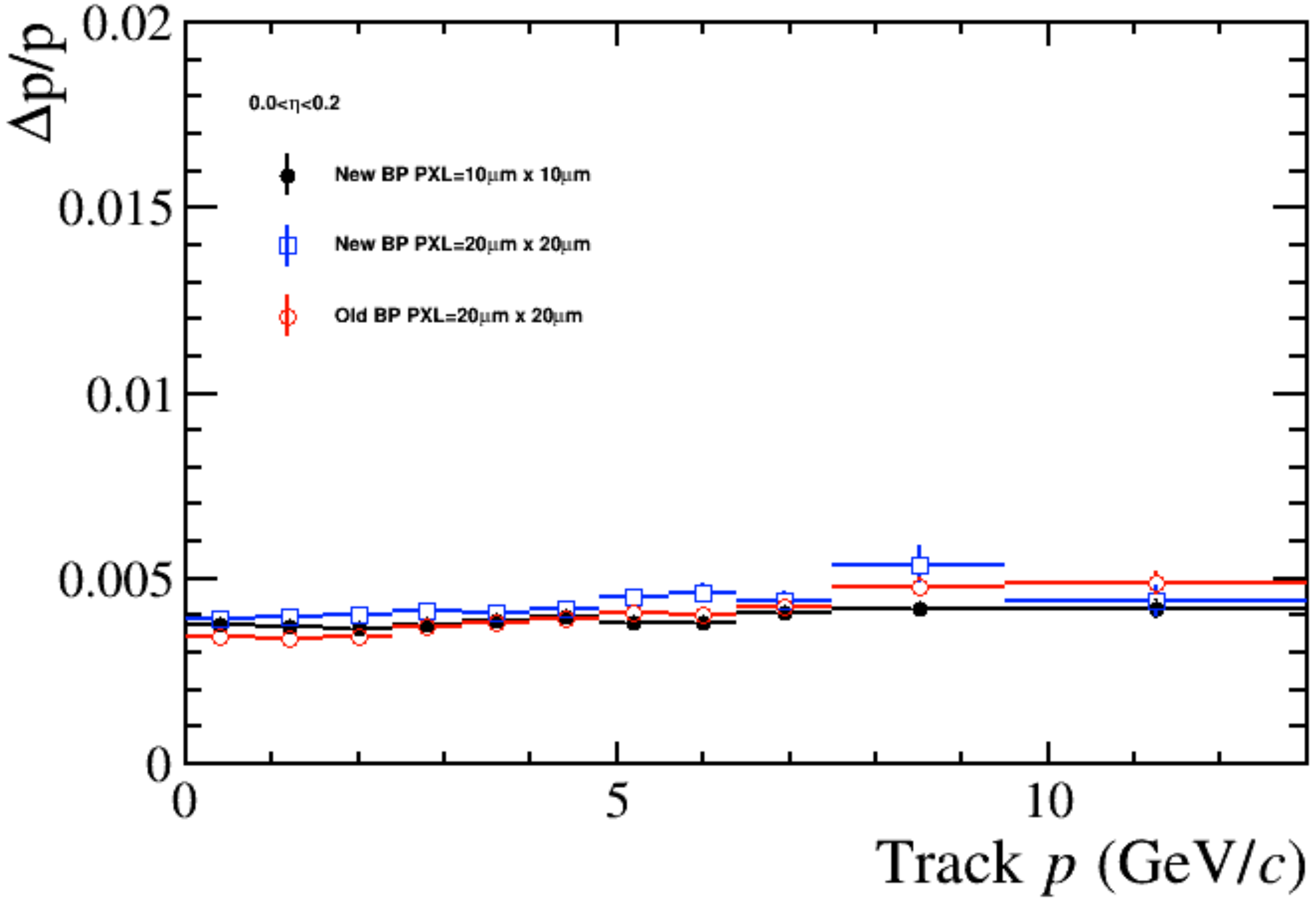
# DCA Comparisons

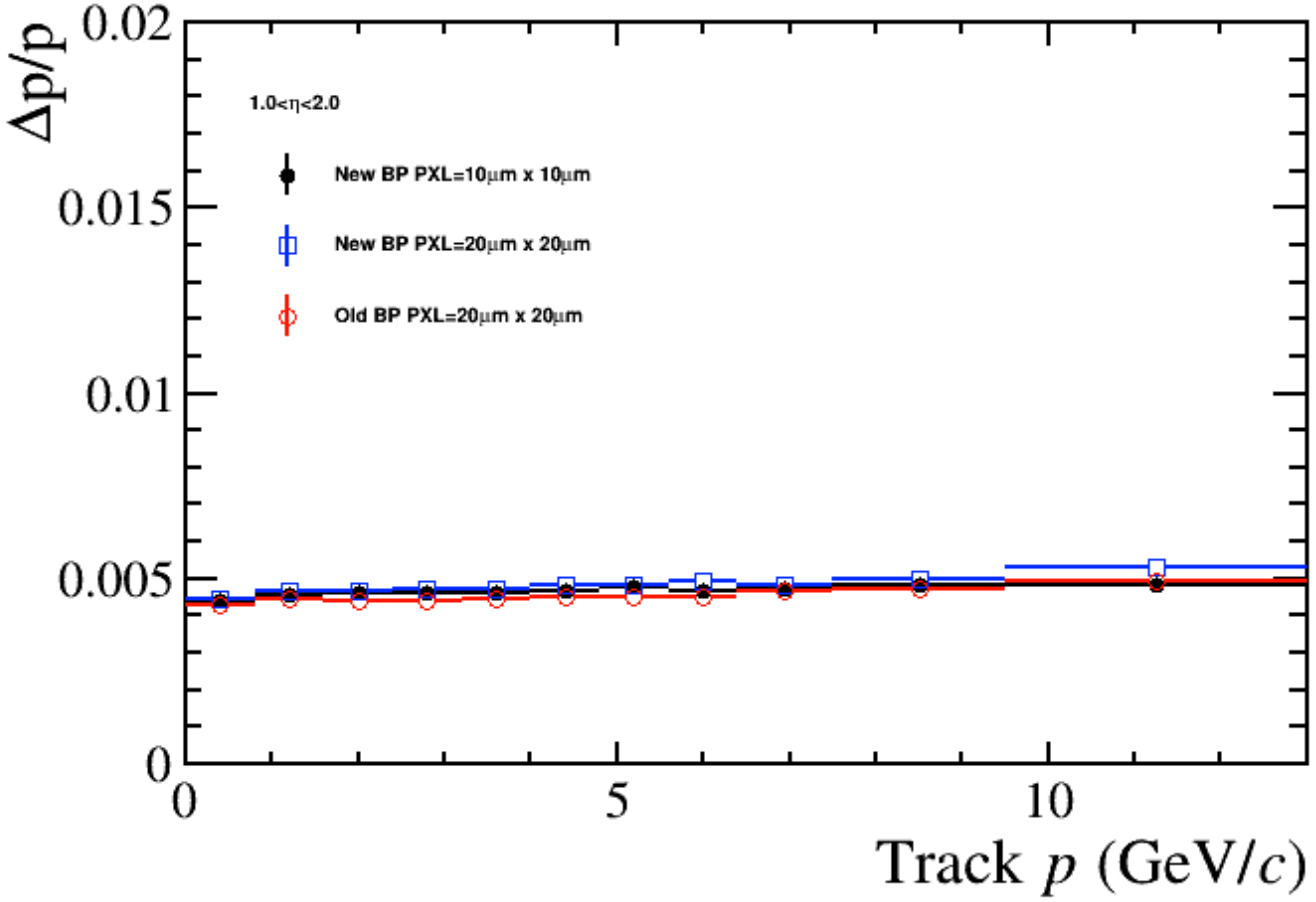


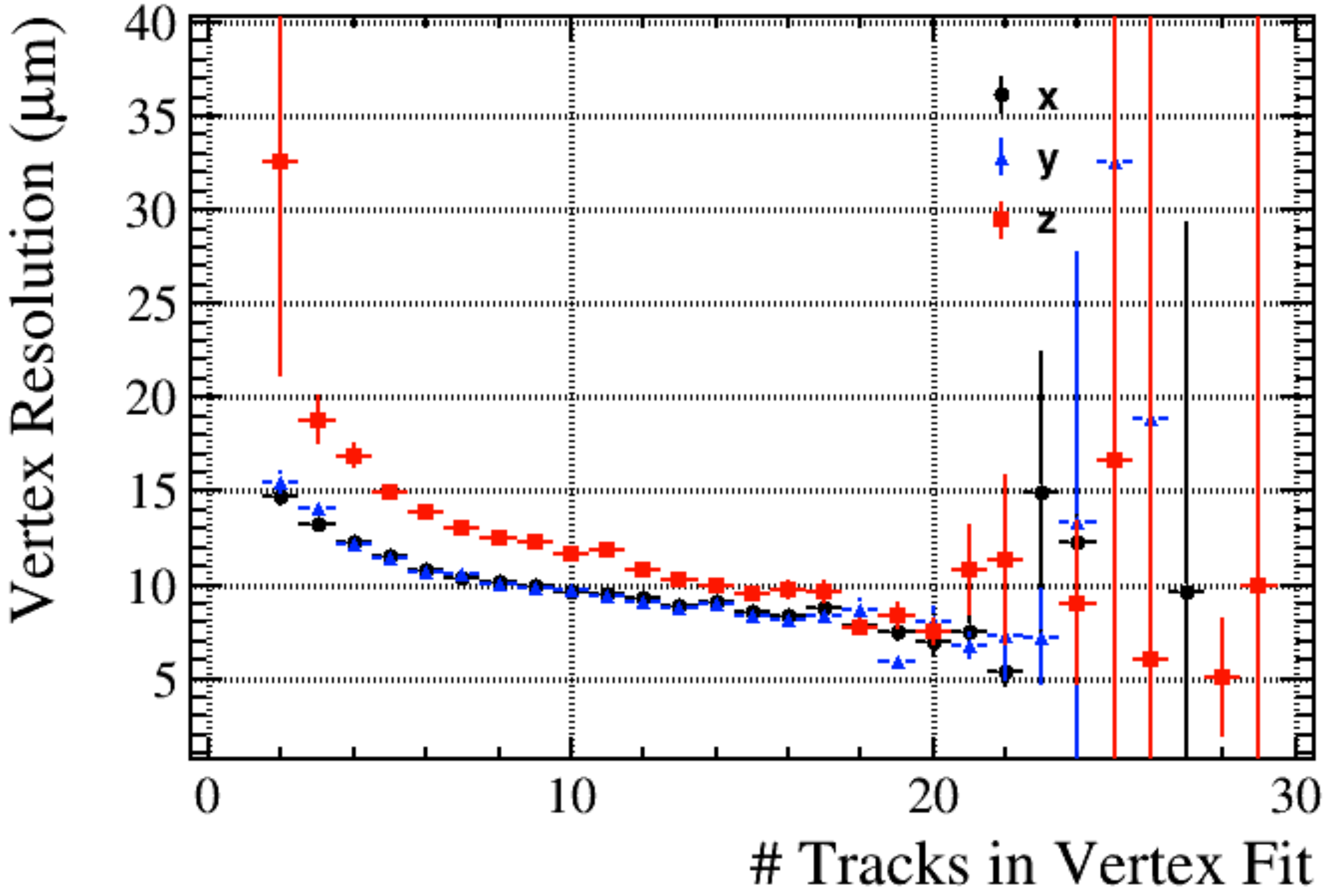



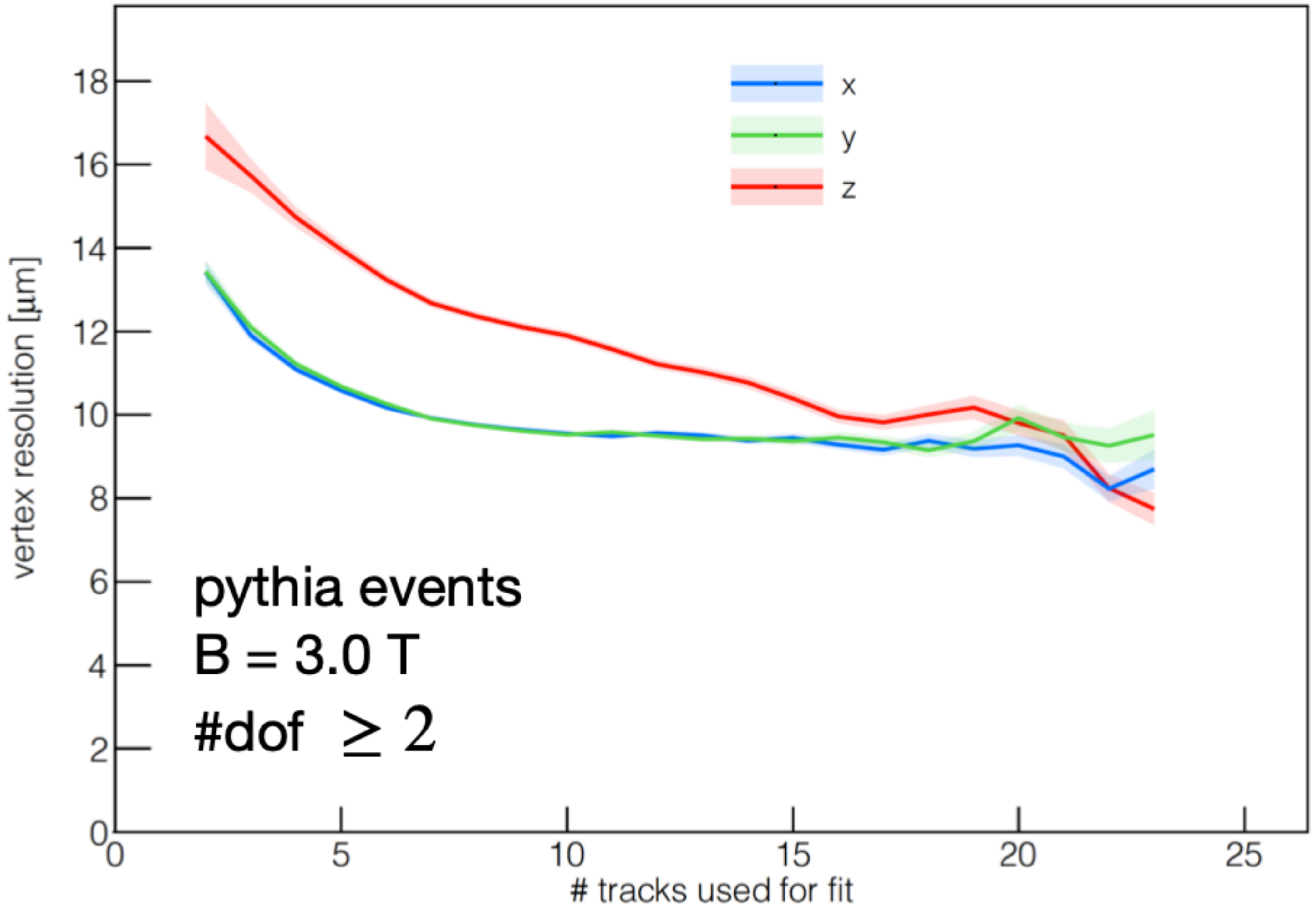
# Momentum Res. Comparisons



# Vertex Resolution (Cont.)




Similar PV resolution compared to simple PV fitter in fast simulation previously shown

Different $Q^2$ selection than what Rey previously shown (>16); Nice agreement when aligning event selection (in backup)