Tracking Technologies and Muon ID for the 2nd EIC Detector

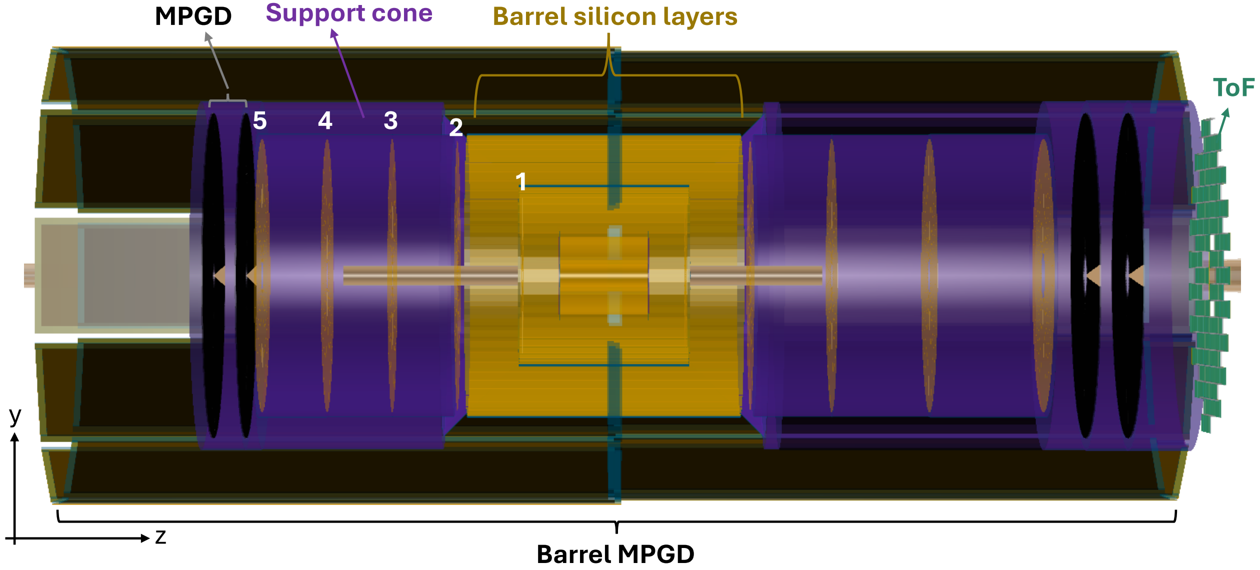
Cheuk-Ping Wong

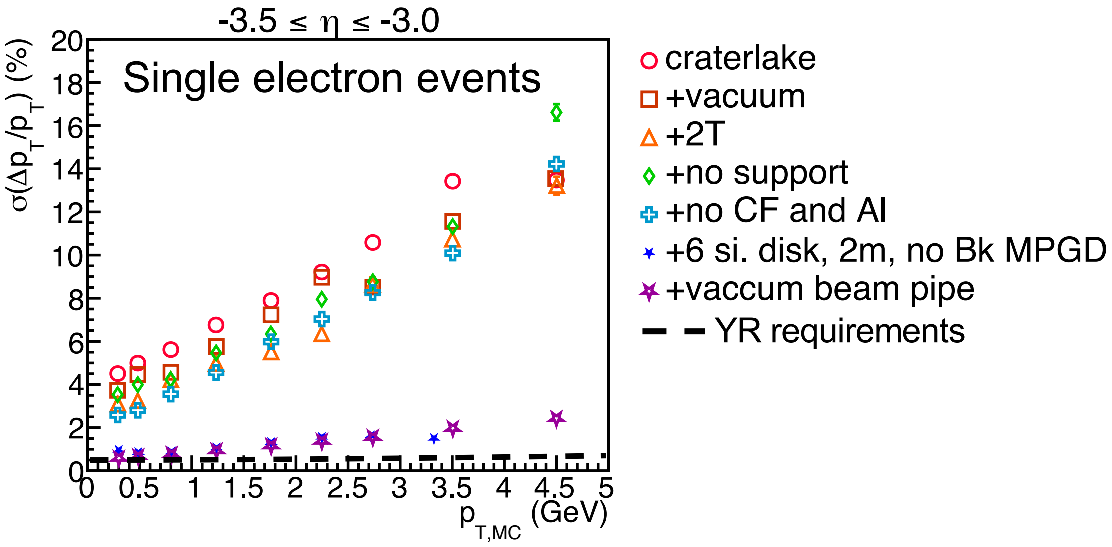
05-09-2024

Backward Tracking

- Scattered electron measurement is essential in EIC to obtain Q^2
  - More backward, lower Q^2
- Can I optimize the ePIC silicon tracking system to achieve p_T resolution <1% (YR requirement) in the backward region? **Very challenging**

ePIC central tracking system





New Direction

- Shifting the focus from an all-silicon design to a mixed-tracking technologies design
  - Pros: (1) More hits: better pattern recognition, redundancy, resistance against backgrounds
    (2) Complementary
  - Cons: higher material budget
- Potential tracking technologies: scintillating fiber, drift chamber, TPC…
  Other Suggestions are welcome!

Increasing the number of hits could improve tracking resolution

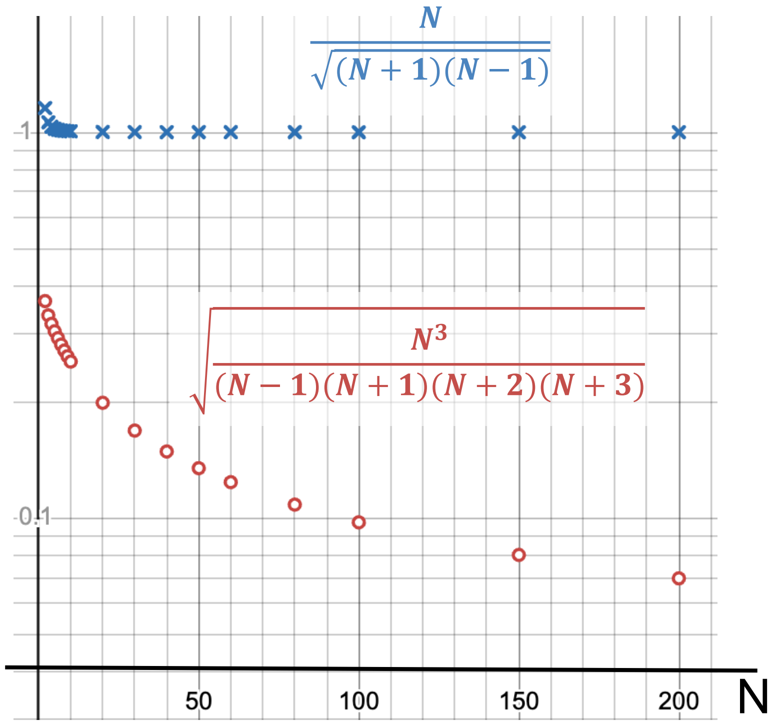
NIMA 910 (2018) 127

Resolution from detector pixel

$$\frac{\Delta p}{p}_{res} = \frac{\sigma_{pix} \cdot p}{0.3BL^2}\sqrt{\frac{720N^3}{(N-1)(N+1)(N+2)(N+3)}}$$

Resolution from multiple scattering

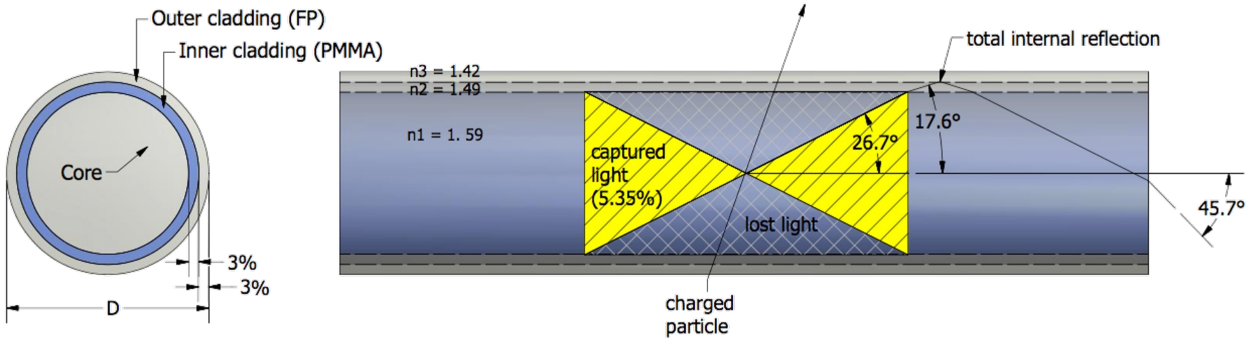
$$\frac{\Delta p}{p}_{ms} = \frac{N}{\sqrt{(N+1)(N-1)}} \frac{0.0136\sqrt{X/X_0}(1+0.038 \cdot ln\sqrt{X/X_0})}{0.3BL \cdot \frac{p}{\sqrt{m^2+p^2}}}$$



LHCb: arXiv:2305.10515
CERN-DRDC-2024-001

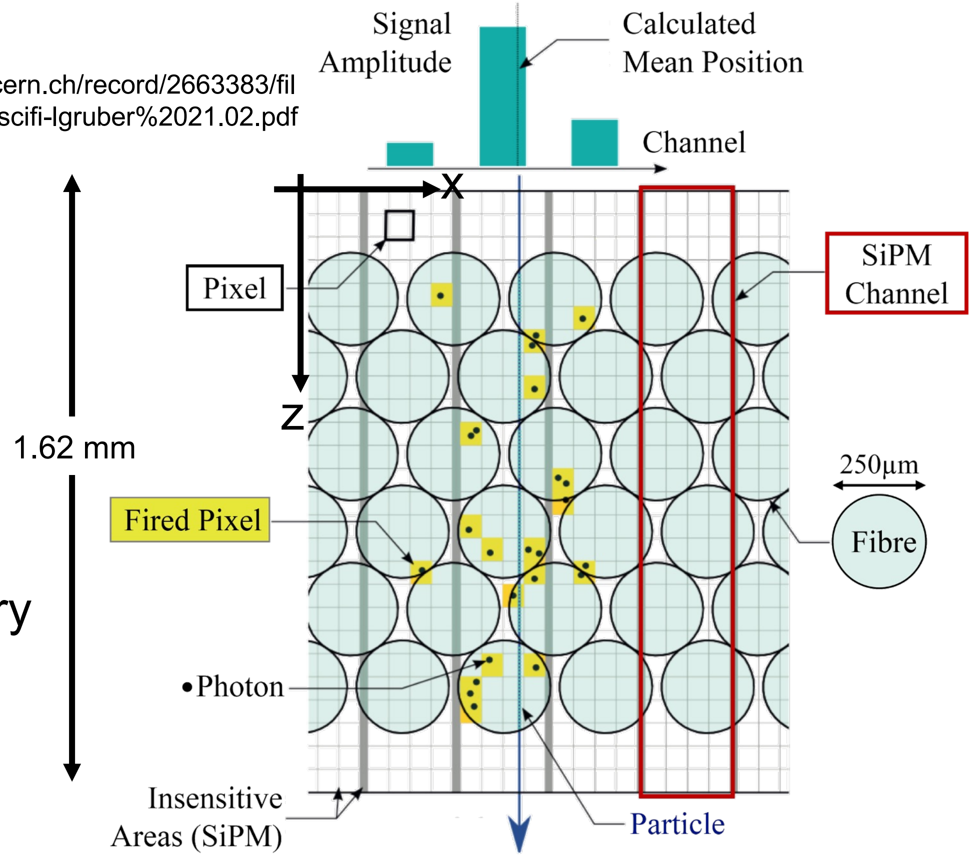
Scintillating Fiber (LHCb)

Double-clad polystyrene fiber
- D=250 um → hit pos. res. < 70 um
- 8k photons per MeV of ionization energy
- Excited electron decay times=2.4 ns
- Attenuation length~3.5 m



Hamamatsu SiPM (MPPC S13552 – H2017)
- Pixel size ~ 60 um
- <10% noise cluster rate with front-end clustering and -50 ℃ cooling using Novec

https://cds.cern.ch/record/2663383/files/vci2019-scifi-lgruber%2021.02.pdf



Material budget=1.1% x 12 layers

Technology advancement
- Scintillating fiber with improved radiation hardness
- Modify claddings to boost light yield
- Cryogenic cooled SiPMs with microlenses for light recovery

IDEA: EPJ Plus (2022) 137:231
MEG II: NIMA 936 (2019) 501

Drift Chamber (IDEA/MEG II)

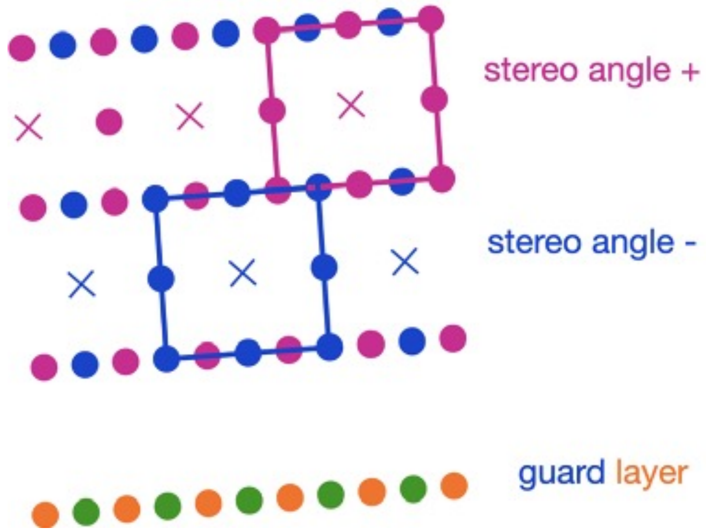
Reduction of material
by storing helium gas in the wire support endplates
IDEA: $0.016X_0$ ($0.05X_0$) in the barrel (forward and backward) region

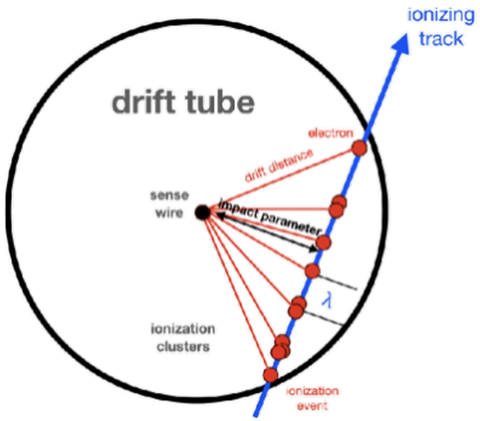
More uniform equipotential surface
A high ratio of the field to sense wires and a high wire density by enmeshes the positive and negative stereo angle orientations
IDEA: 4 m long, r = 35-200 cm, 400k wires, res ~ 100 um

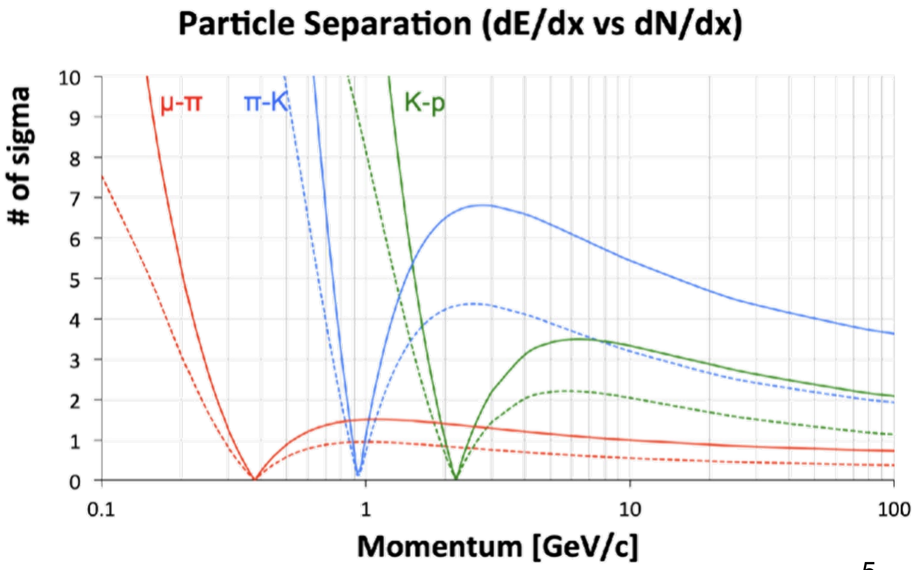
PID capability with the cluster counting method
Adding timing information to the wires to count individual ionizing events of the traversing track and dE/dx information

Technology advancements

- Carbon-fiber wire vs tungsten wire reduce X/X_0 by a factor of 5
- Low - mass service/cooling structures
- See Andy's slides from last week





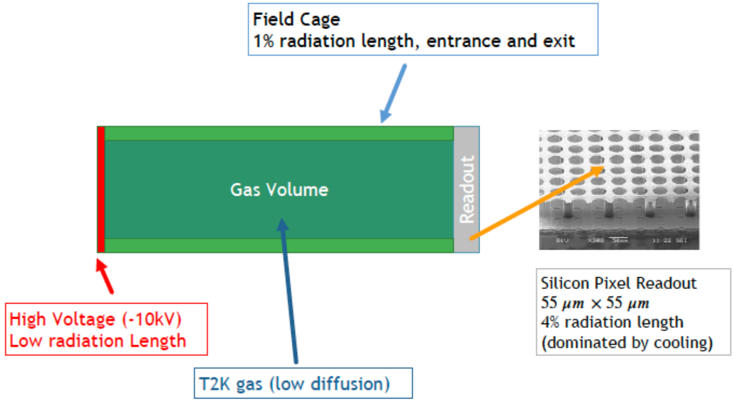


TPC/mini TPC

GridPIX aka miniTPC

https://indico.bnl.gov/event/18414/contributions/76157/attachments/47563/80668/EIC_Technology_Inventory_Temple.pdf

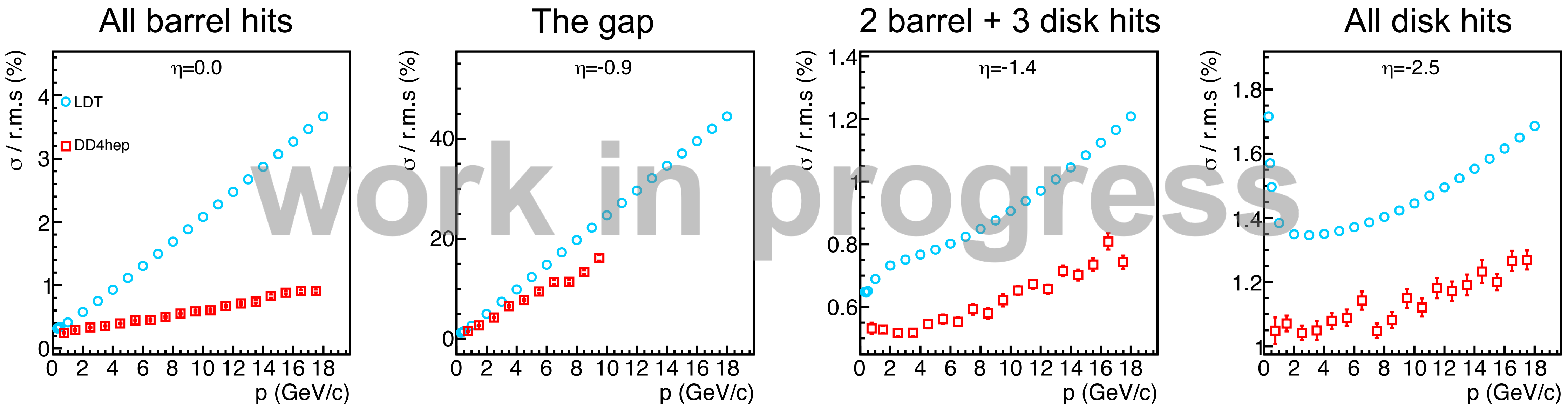
- Basic idea: Small ΔR TPC with Si Pixel readout on one endcap
  - PID ($\pi - K - p$) from 100 MeV/c to 800 MeV/c
  - Tracking with large number of hits (pattern recognition)
  - Works only in barrel (field!)
- GridPIX
  - Avalanche grid in front of 55 x 55 μm^2 pixels.
  - >90% efficiency for single electrons.
  - Small area is not particularly expensive: 1800 chips (order/produce/test 3600) = $716k
  - Careful: 1.2-5.4 kW of power
  - Services bulky: Gas, power, cooling
  - Realistic X/X_0?



Reality check:
- Very compelling for D2
- Provided tracking an dE/dx (compare with ToF/AC-LGAD)
- Excellent Pattern recognition
- Less sensitive to backgrounds
- Generic R&D ongoing
- Need to see concrete prototype

LDT Fast Simulation

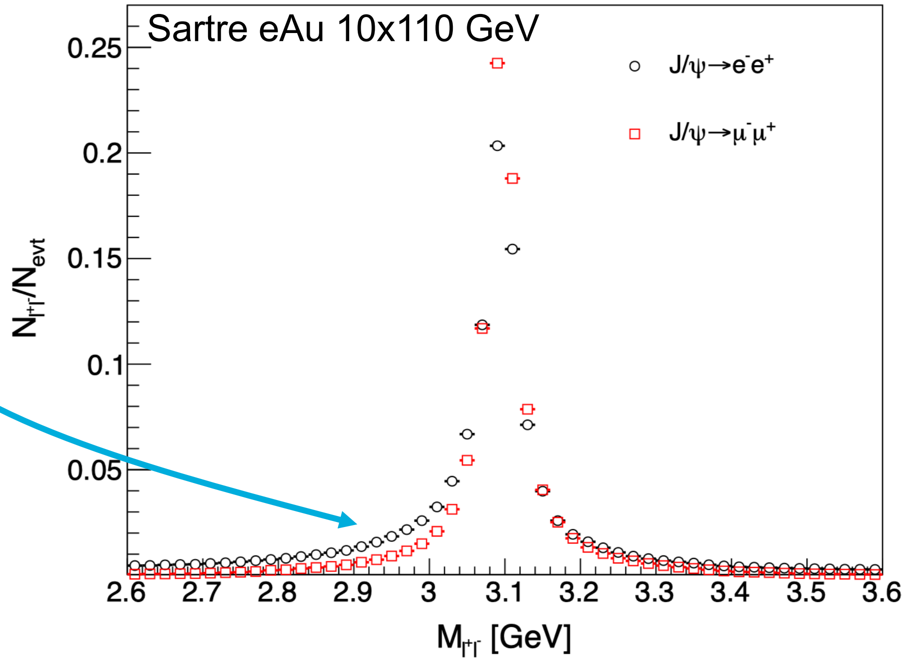
- ePIC craterlake silicon detector as baseline
  - Barrel: cylindrical, Silicon layers (option for TPC)
  - Forward/backward: Silicon disks
- Goals
  - Validating the LDT simulation
  - Implement TPC in the detector setup



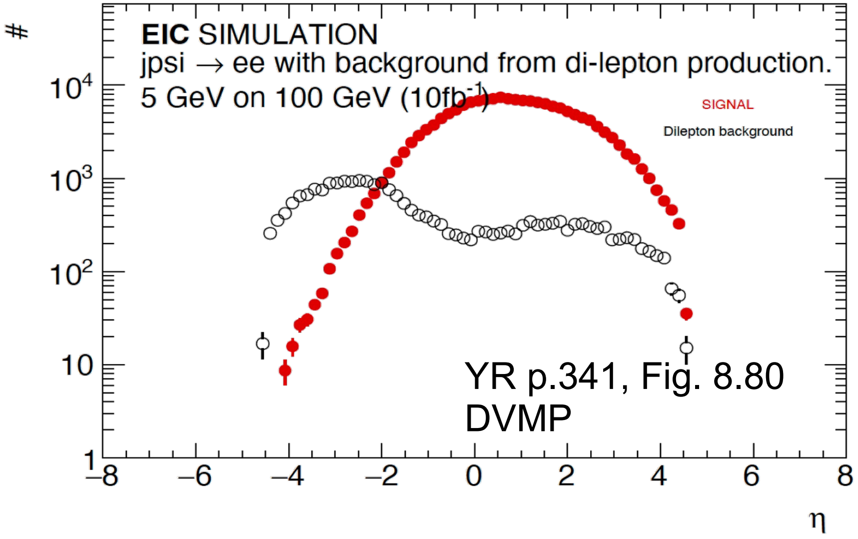
Muon ID

- Heavy quarkonia measurements → reduce ambiguity to the scattered electrons
- Complementary to and cross-checking with ePIC

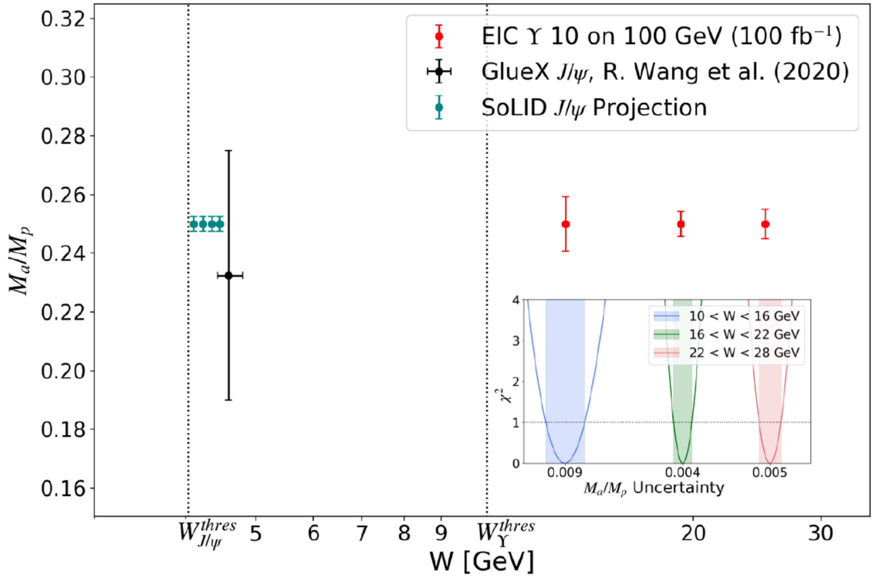
Larger combinatorial background at lower spectrum due to Bremsstrahlung radiation when using dielectron channel



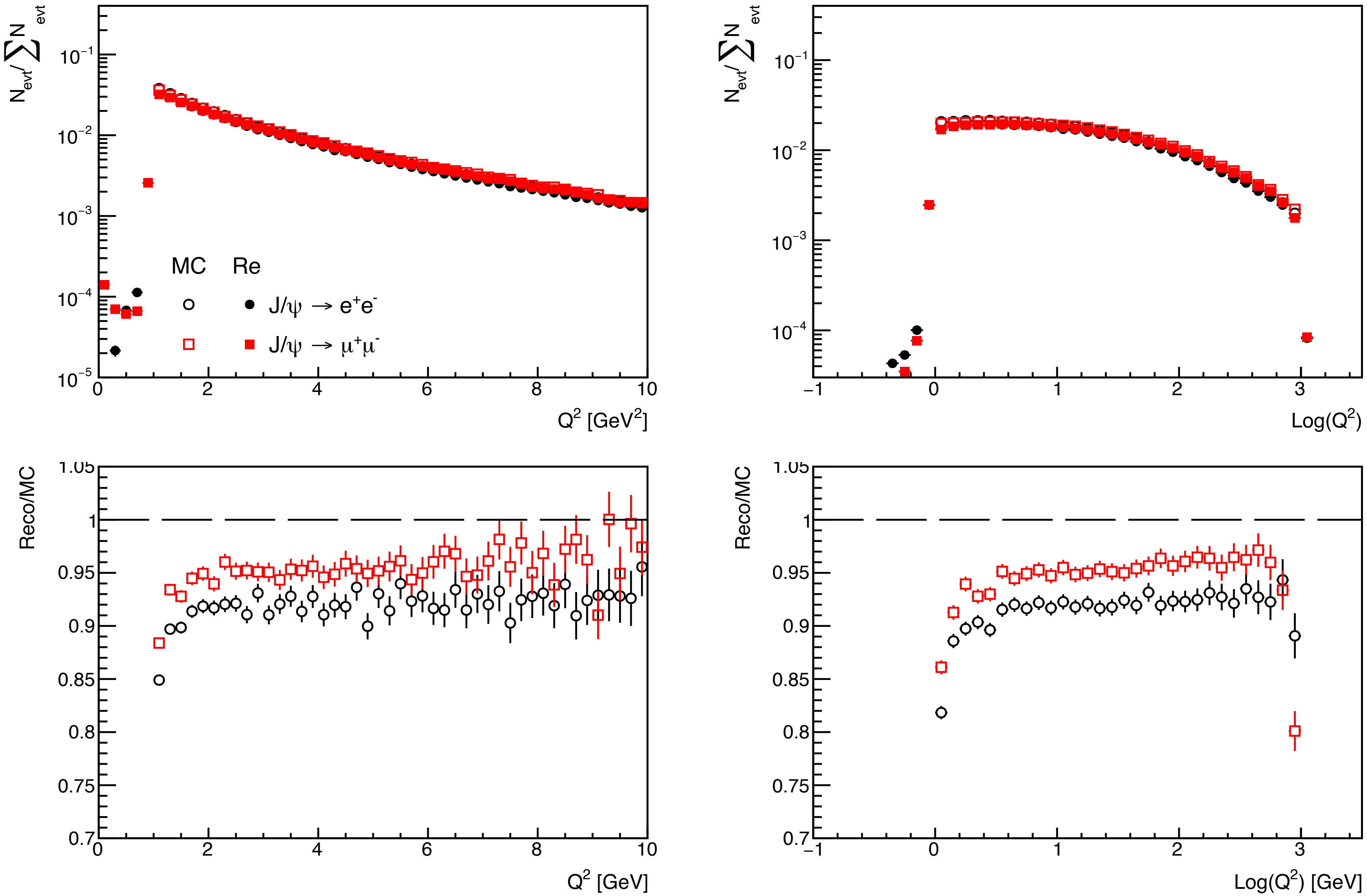
Large background at backward region in DVMP measurements when use di-electron channel



In consideration: Υ measurements at the EIC can extend the W coverage in trace anomaly study (Challenge: require low p_T measurements)

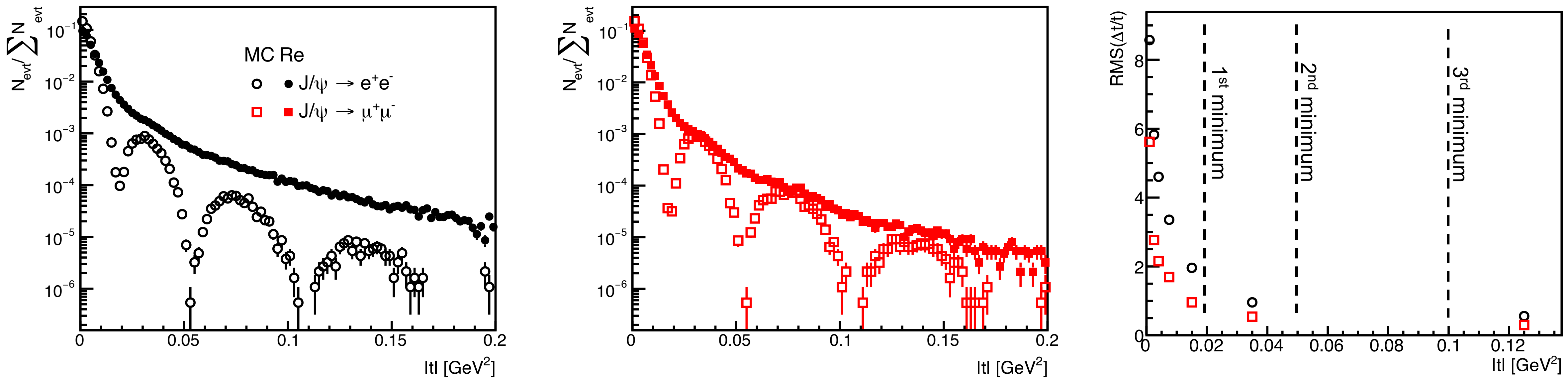


Reconstructed Q^2



- Using dielectron channel may reduce Q^2 efficiency since scattered electron could be mixed up as "J/ψ decayed electron"

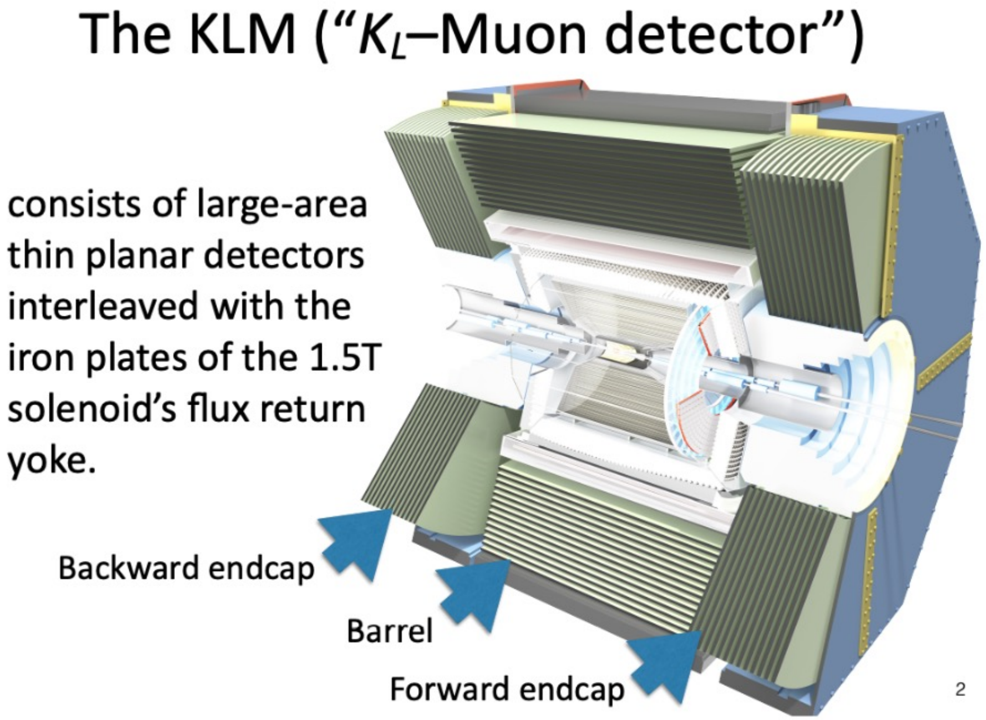
Reconstructed t



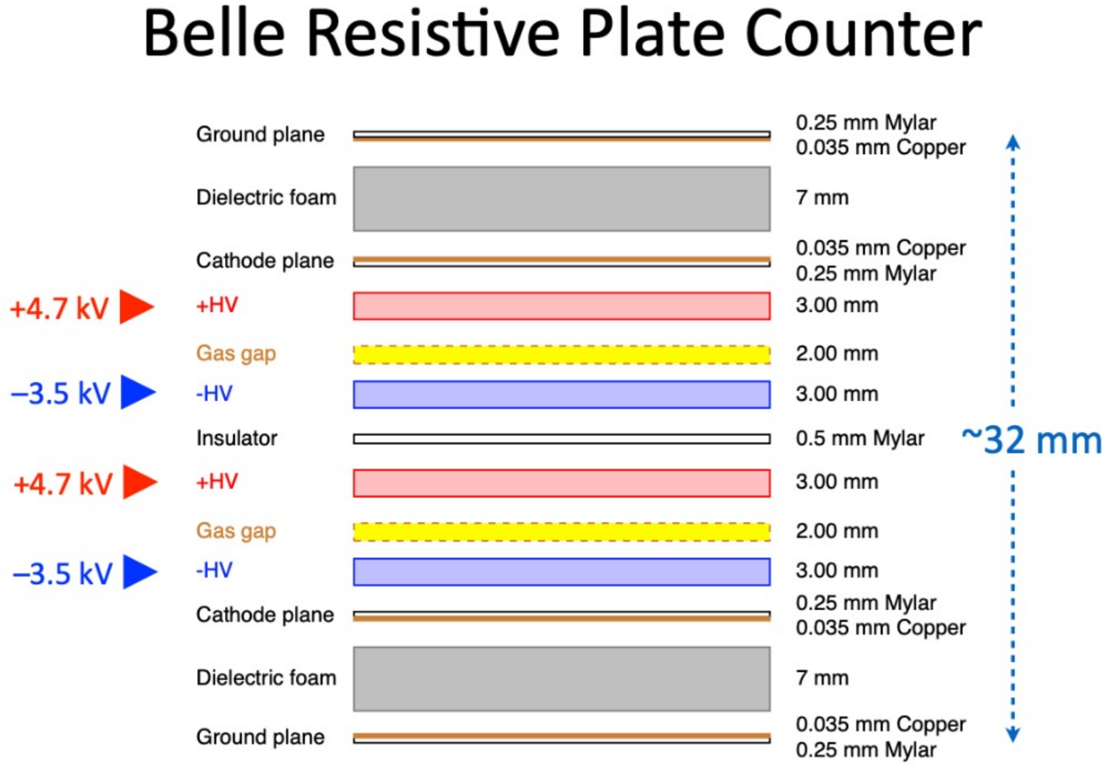
- Using dimuon channel improves the coherent J/ψ diffractive measurement compared to dielectron channel
  - Caveat: still using true PID in the above figures
- But improvement from using dimuon is not enough
  → Require significant improvement in scattered electron measurements
  → Beyond excellent backward tracking/Ecal with a momentum/energy resolution smaller than 1%

Example: K_L Muon Detector at BELLE II

EIC Generic R&D programs: #18 KLM-type detector



https://doi.org/10.1016/S0168-9002(99)01383-2

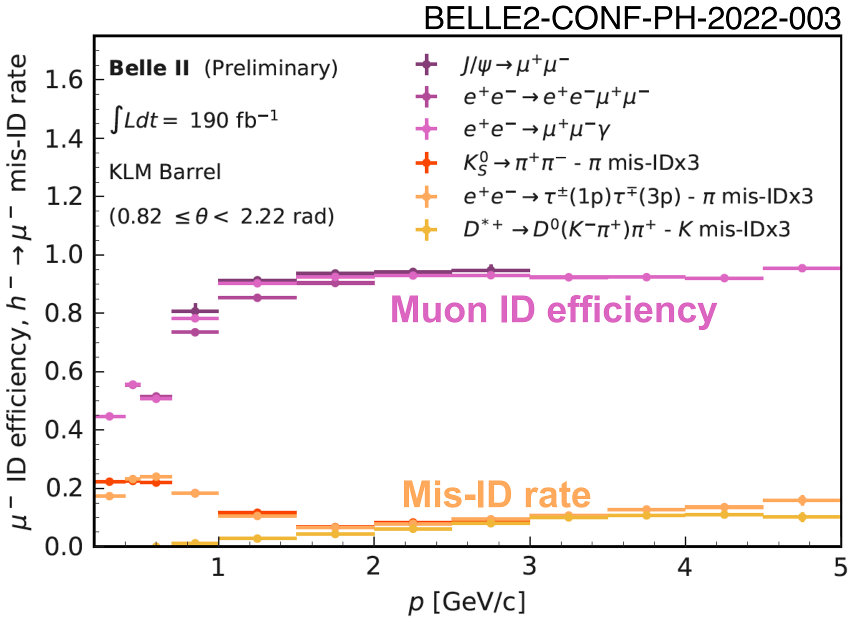


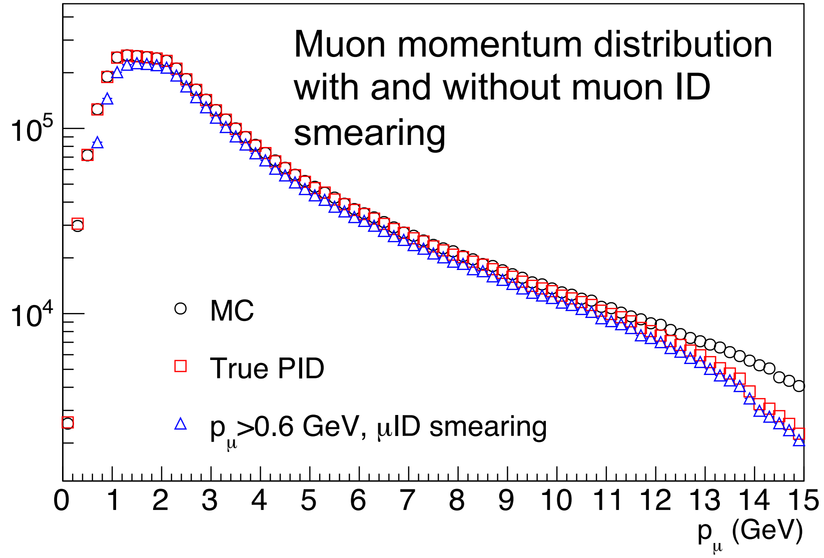
Glass-electrode resistive plate counters

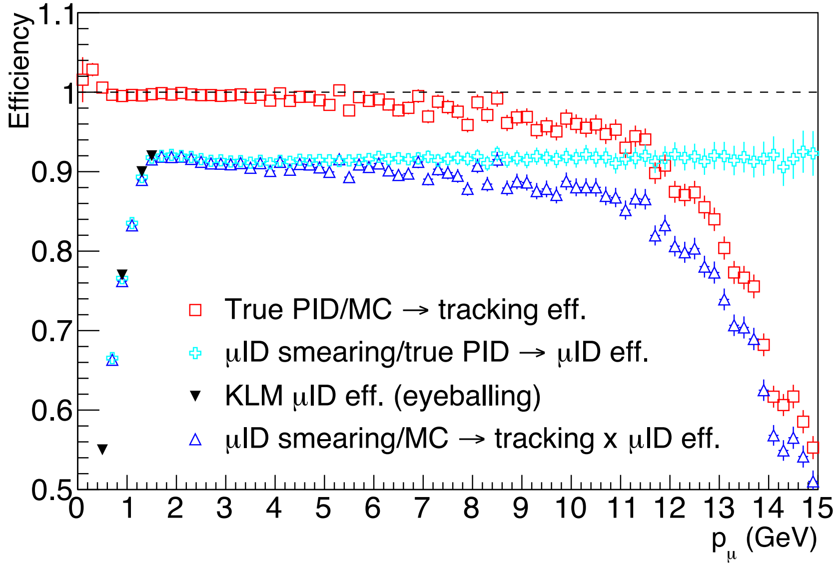
Muon Identification Smearing

Initial implementation using BELLE II KLM performance

- Threshold momentum = 0.6 GeV
- Approximate muon ID efficiency at p < 1.5 GeV
- Constant muon ID efficiency at p > 1.5 GeV
- No mis-ID rate applied

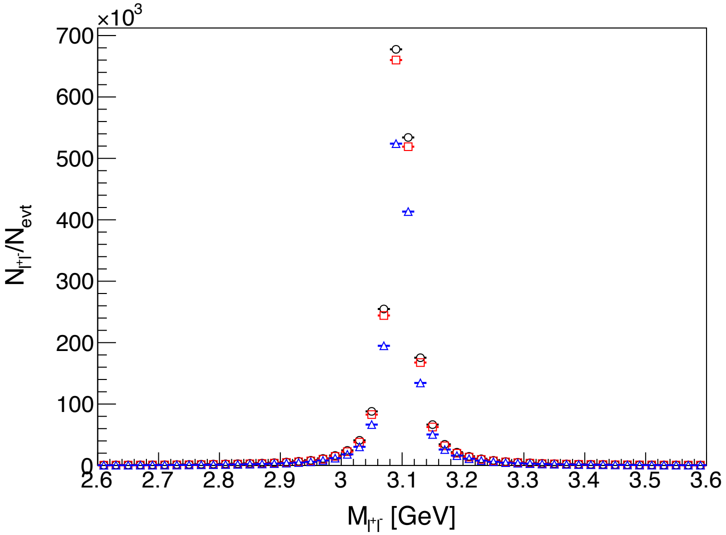


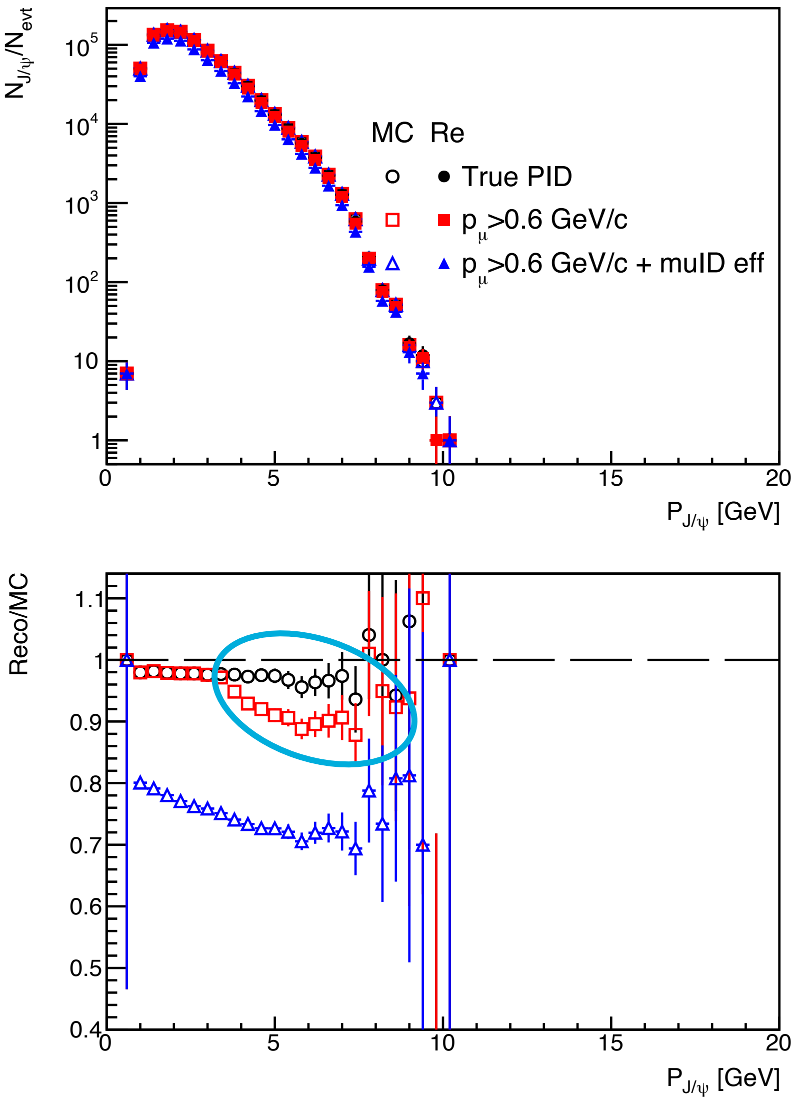


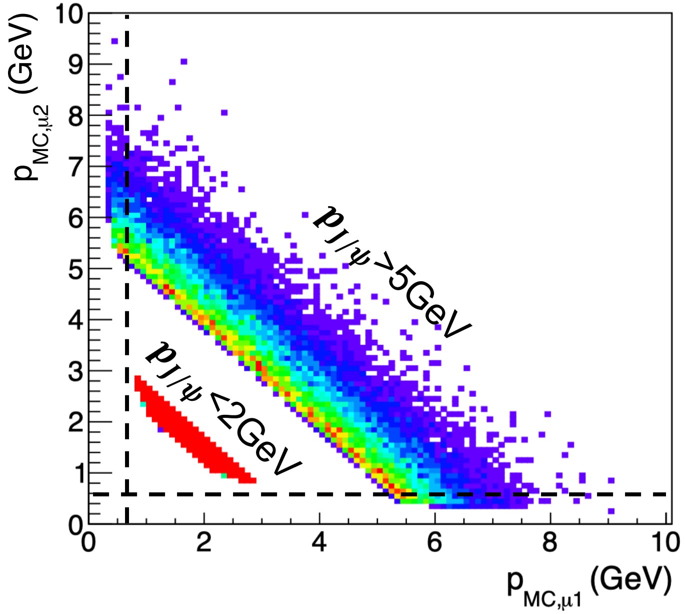


- https://docs.belle2.org/record/2895/files/Lepton_identification_Moriond_2022__v2.pdf
- https://arxiv.org/pdf/1011.0352.pdf

Reconstructed J/ψ with Muon ID Smearing



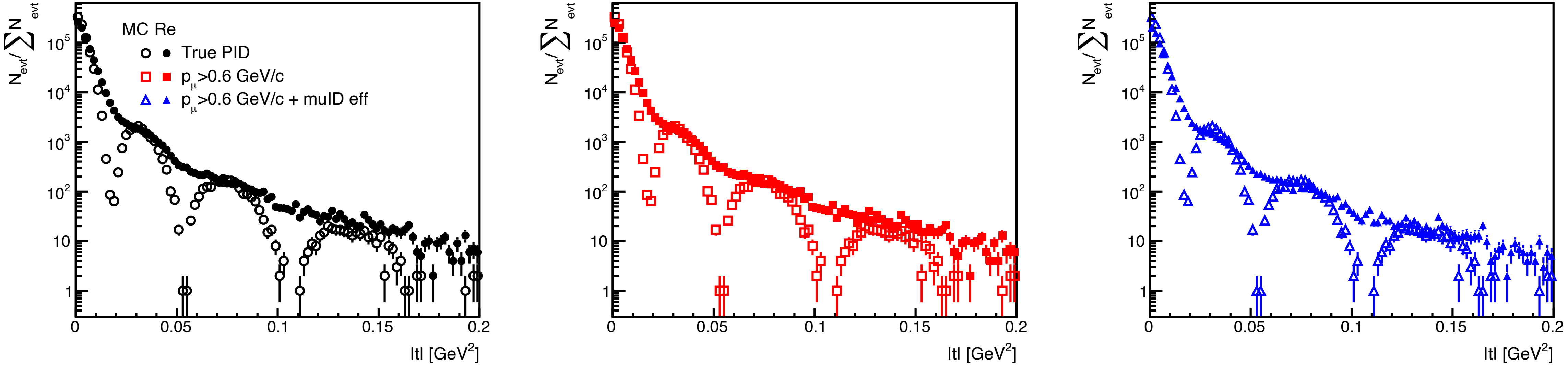


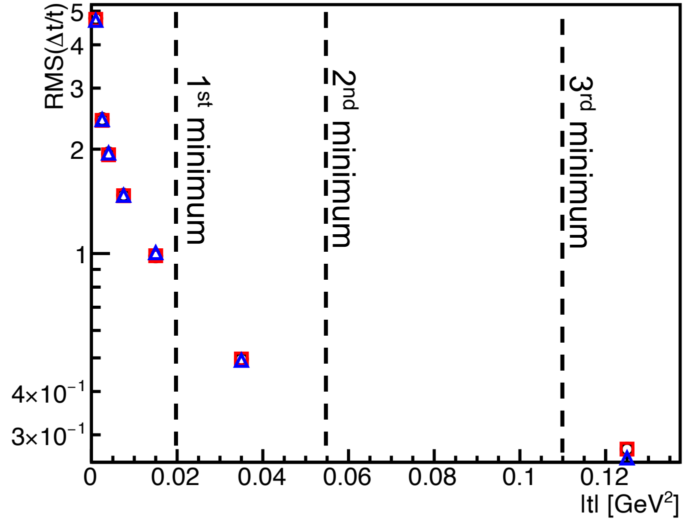


- Threshold muon momentum cut reduces reconstructed J/ψ at p > 4 GeV
- Statistics are reduced by 15-20% after μID efficiency implementation

Soft muon is important to high momentum J/ψ reconstruction

Reconstructed t ($1 \le Q^2 \le 10$ GeV²)





No significant changes in t resolutions from muon ID smearing

Summary

- Study mixed-tracking technologies design for the 2nd EIC detector
    - Reliable tracking and complementary to ePIC
    - LDT fast simulation
        - Working on simulation validation
        - Implement TPC
- Muon ID for quarkonia reconstruction
    - Reduce ambiguity to the scattered electrons and complementary to ePIC
    - Implement muon ID smearing using KLM performance