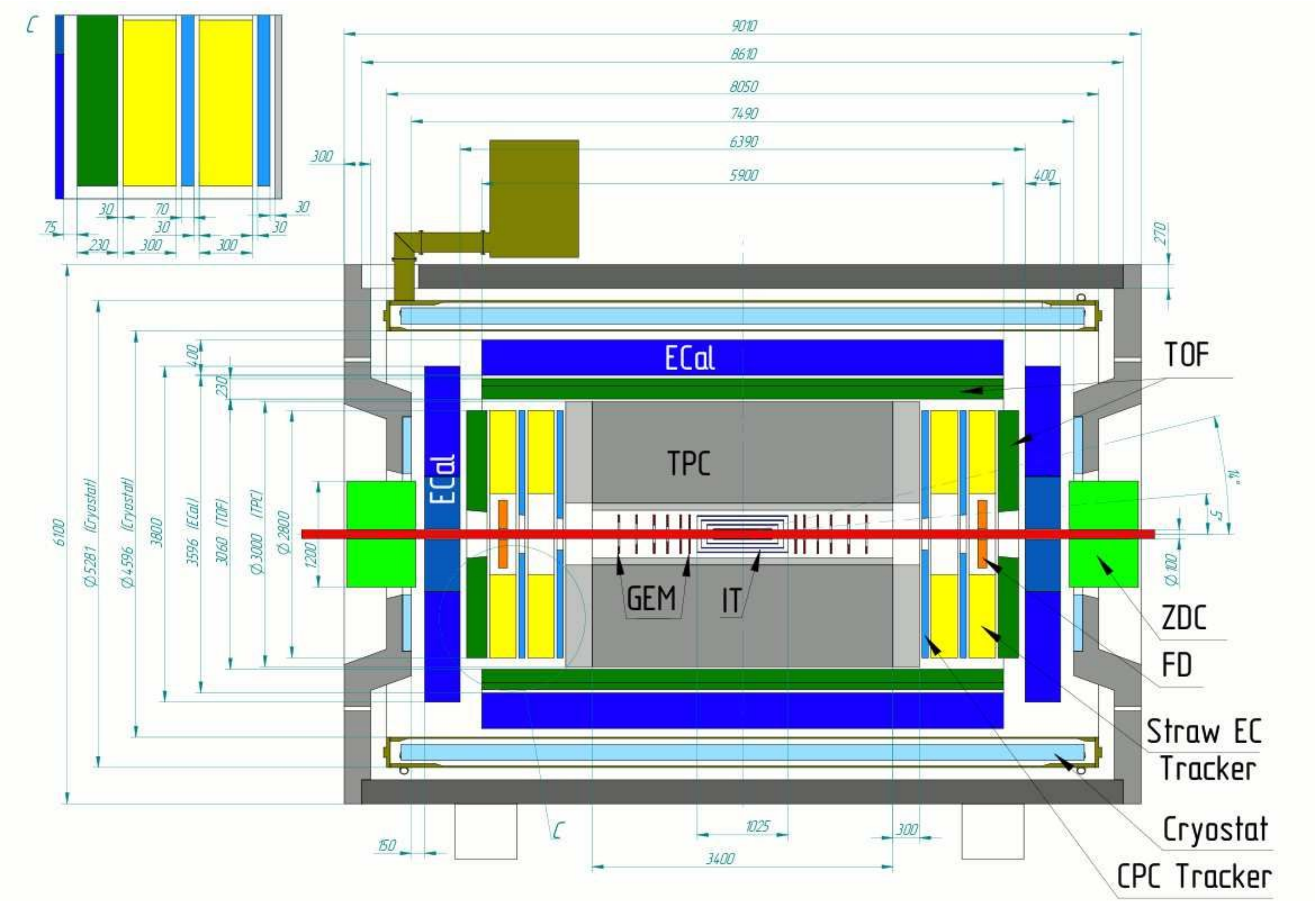
Forward tracker for the MPD experiment

R. Abdulin, O. Fedin, E. Kryshen, A. Riabov, G. Zalite, M. Zhalov

Petersburg Nuclear Physics Institute

The subject is not new…



Considered in MPD CDR (2008)

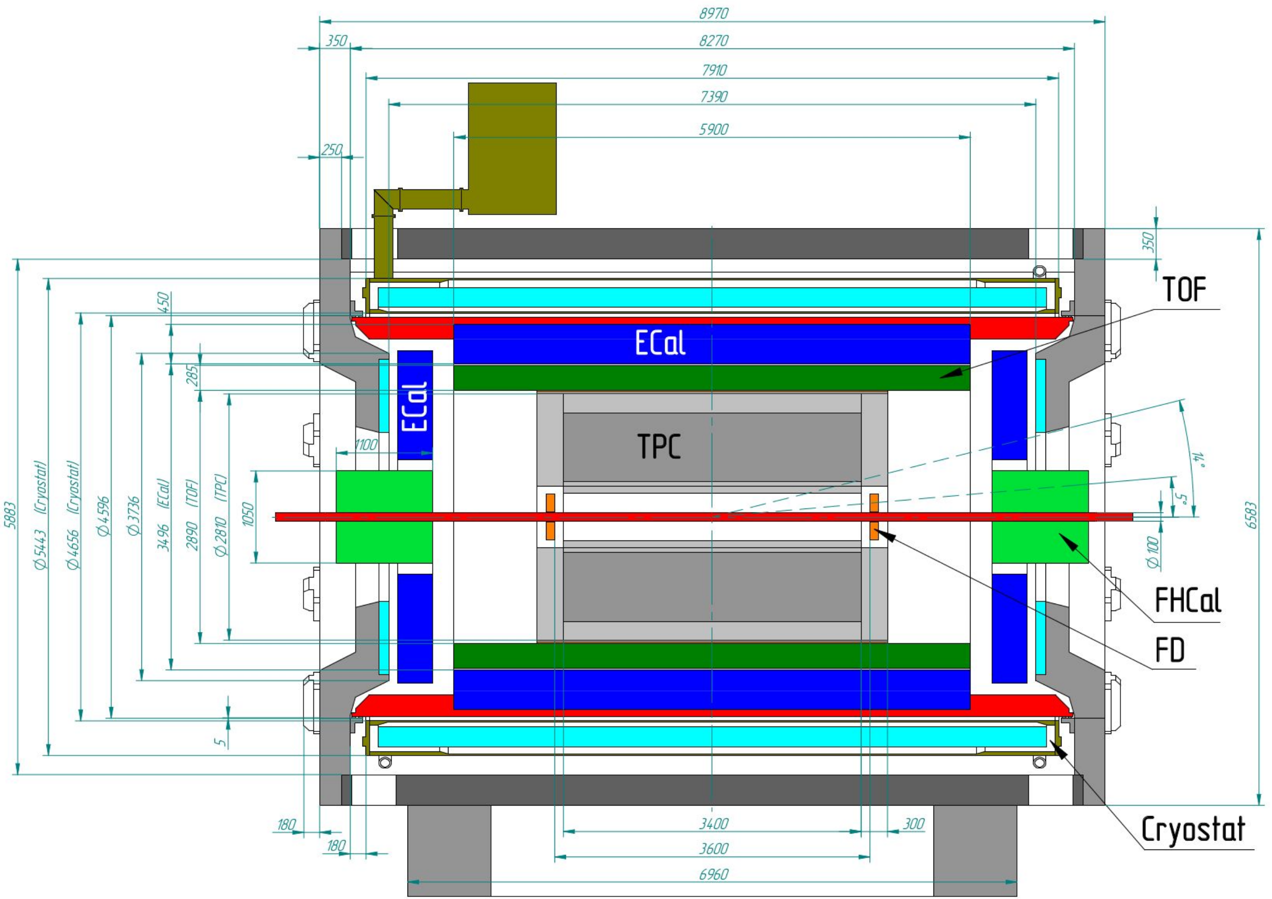
On straw tracker:

- V. Kekelidze, V. Peshekhonov, N. Topilin, Phys. Part. Nucl. Lett. 9 (2012) 180
- J. Fedorishin, PoS Baldin ISHEPPXXII (2015) 130

On cathod pad chambers:

- J. Fedorishin, O. Rogachevsky, Y. Kiryushin, PoS Baldin ISHEPP-XXI (2012) 004

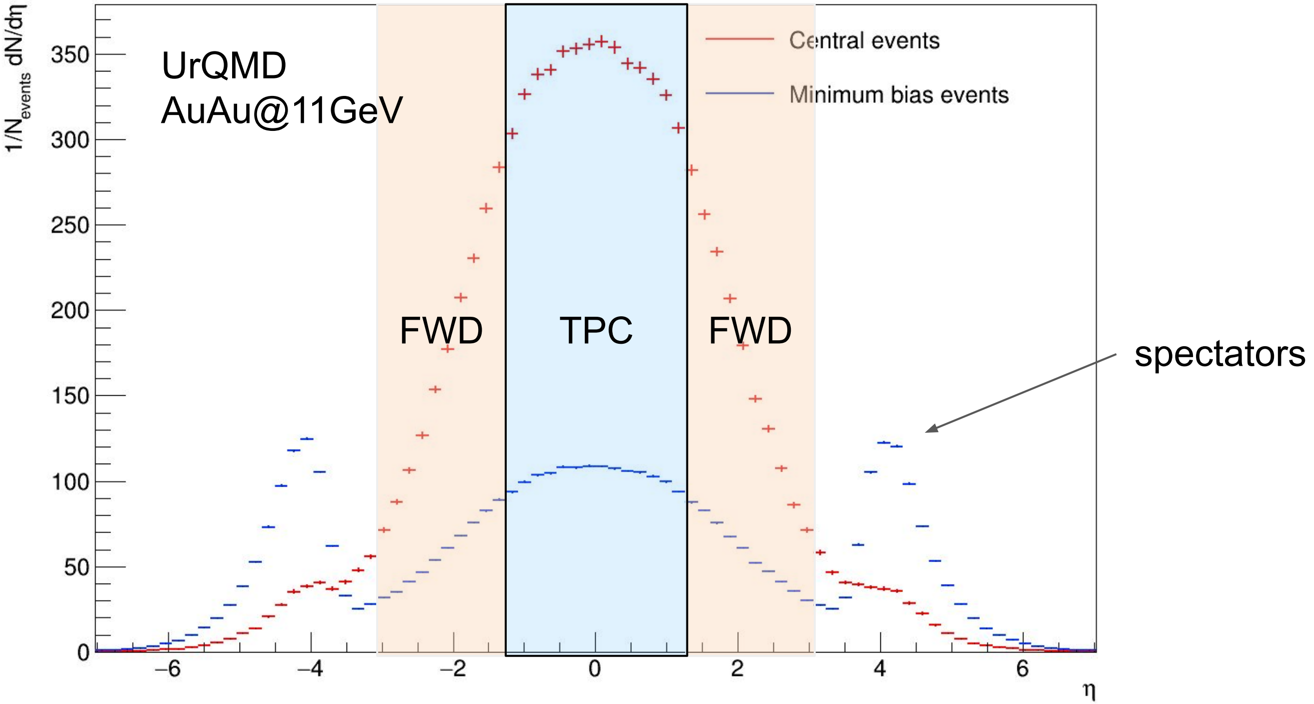
Excluded from Stage I setup…



Status and initial physics…,
EPJA 58 (2022) 140

Do we actually need forward tracker?

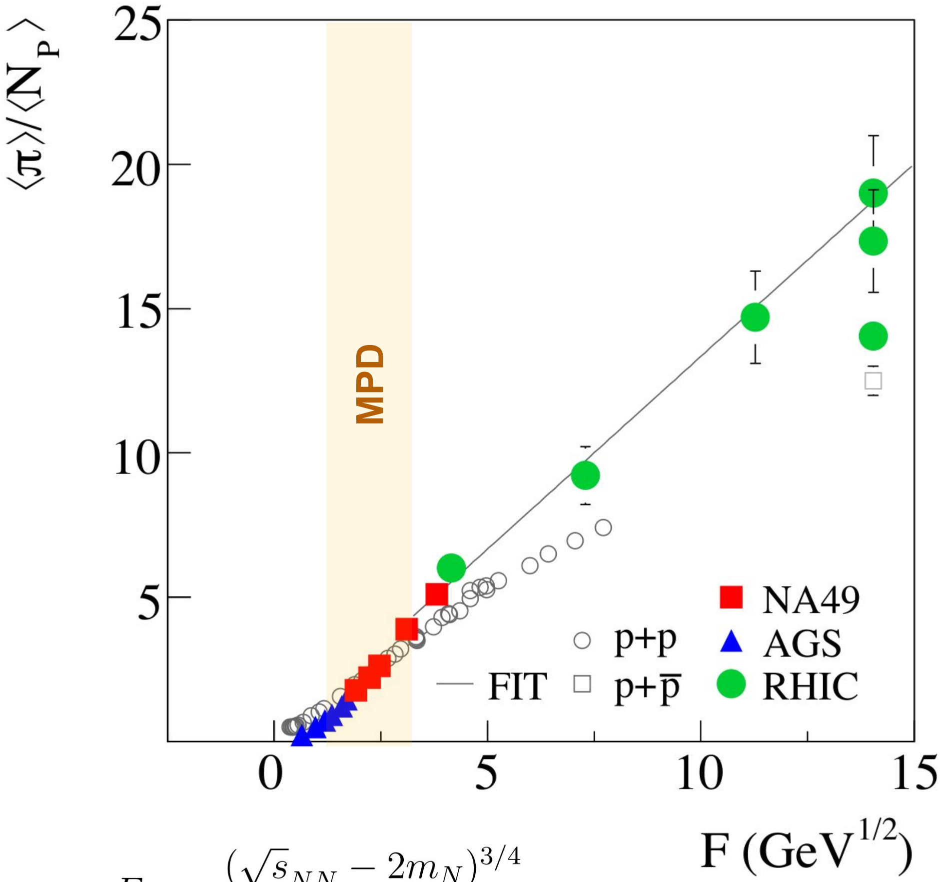
Pseudorapidity coverage



- TPC covers only ~55% of particle production yield in central events
- Forward tracker would allow us to cover more than 90%

Acta Phys.Polon.B 42 (2011) 307

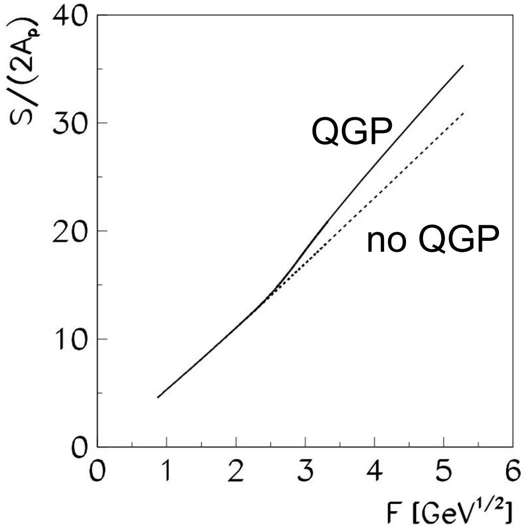
The Kink



$$F = \frac{(\sqrt{s}_{NN} - 2m_N)^{3/4}}{(\sqrt{s}_{NN})^{1/4}}$$

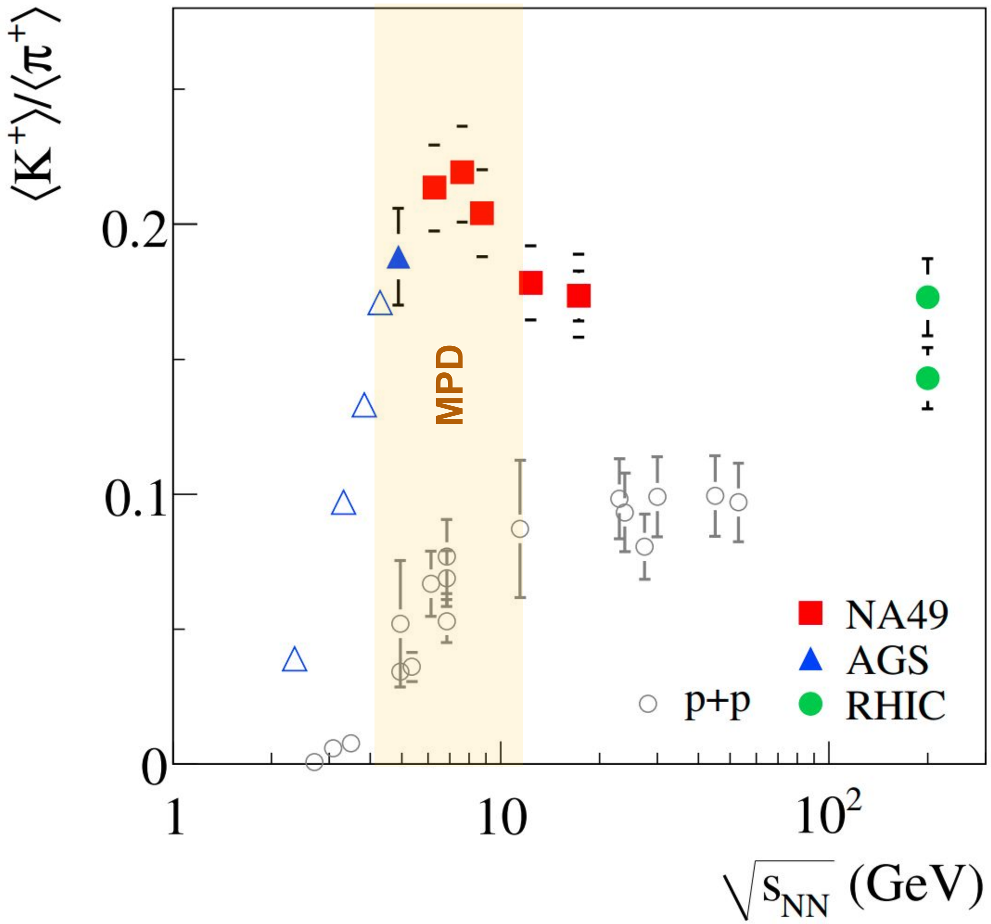
Fermi-Landau variable

- Entropy is expected to increase in the deconfined phase
- Pion multiplicity ~ entropy
- Signal of deconfinement: mean pion multiplicity per participant changes the slope as function of energy
- Need charged pions in the full phase space including 1.2<|η|<3.0

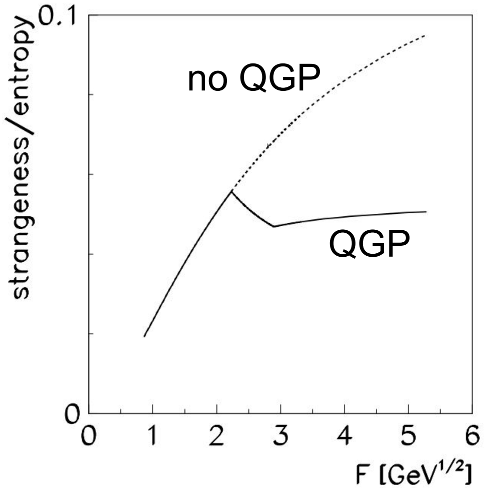


Acta Phys.Polon.B 42 (2011) 307

The Horn

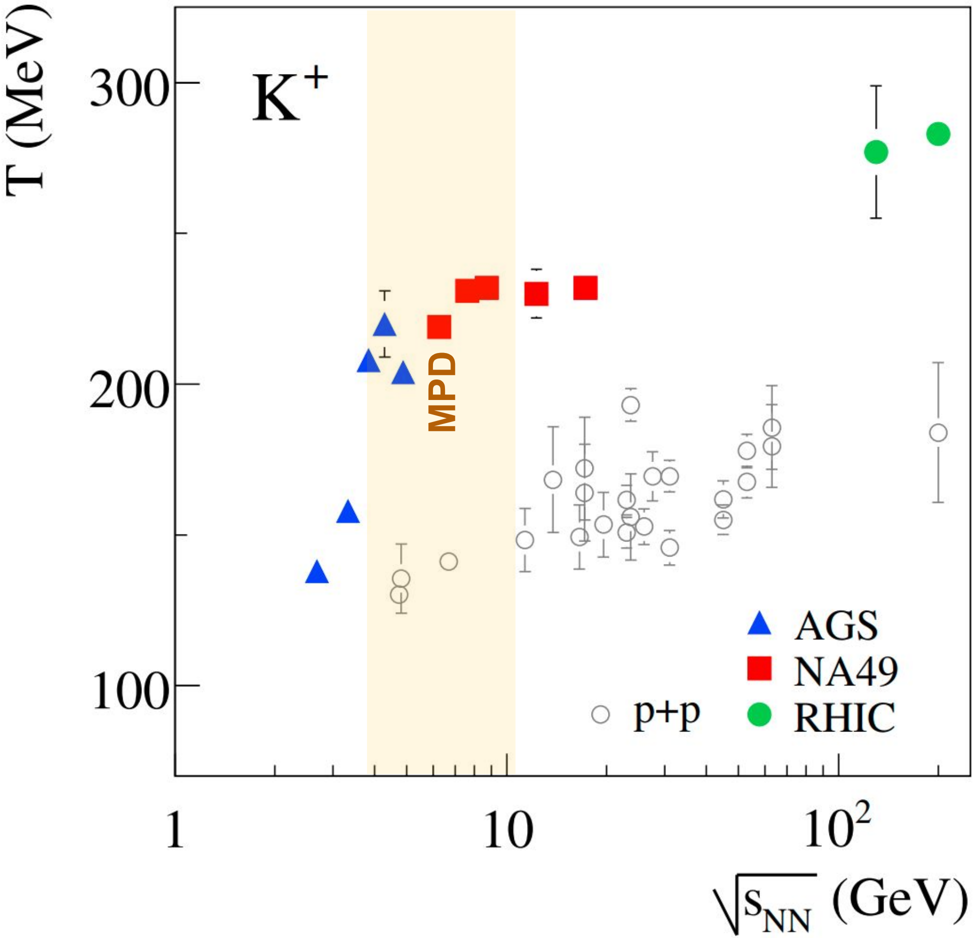


- **The horn:** sharp maximum in the ratio of strange particle to pion yields
- **Interpretation in statistical model**: change of strangeness / entropy ratio due to deconfinement transition
- For precision measurements, we need strange particle yields (K, Λ) in the full phase space including 1.2<|η|<3.0



Acta Phys.Polon.B 42 (2011) 307

The Step

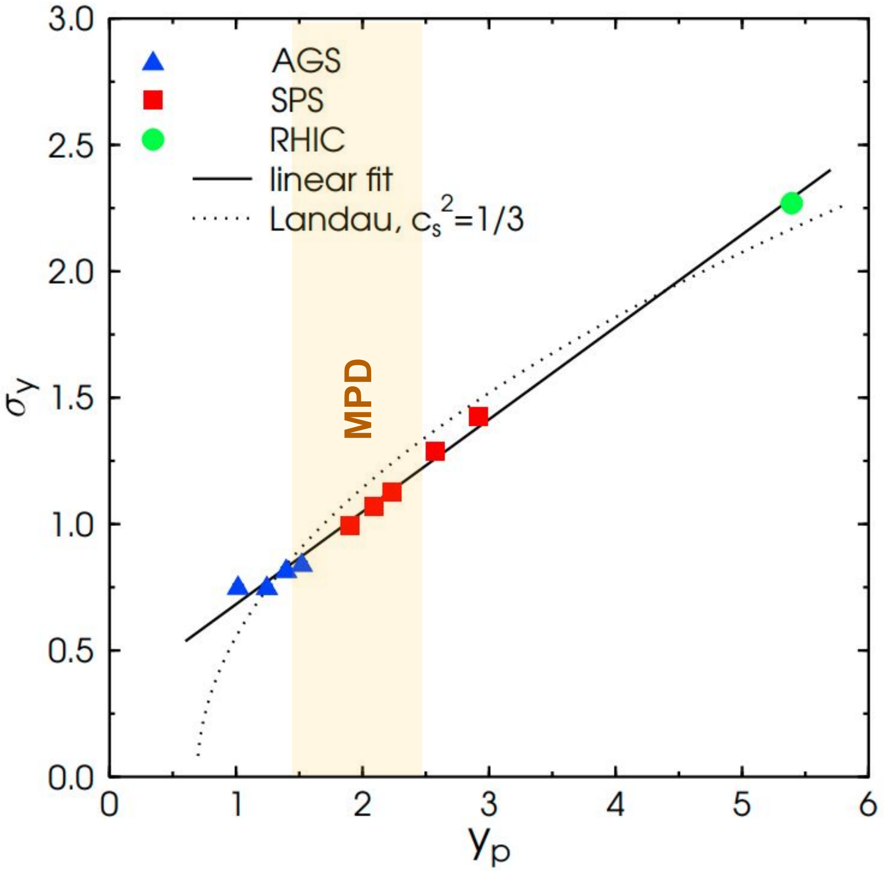


- **The Step:** flattening of the inverse slope parameter T^* extracted from m_T spectra of various particle species
- Also seen in $\langle m_T \rangle$ - m vs energy
- Interpretation in statistical model: mixed phase at early stages
- Studied at midrapidity up to now. m_T or p_T spectra for various particle species at forward rapidity would be desirable

$$\frac{dN}{m_T dm_T} \cong C \exp\left(-\frac{m_T}{T^*}\right)$$

The Dale

Acta Phys.Polon.B 42 (2011) 307



beam rapidity

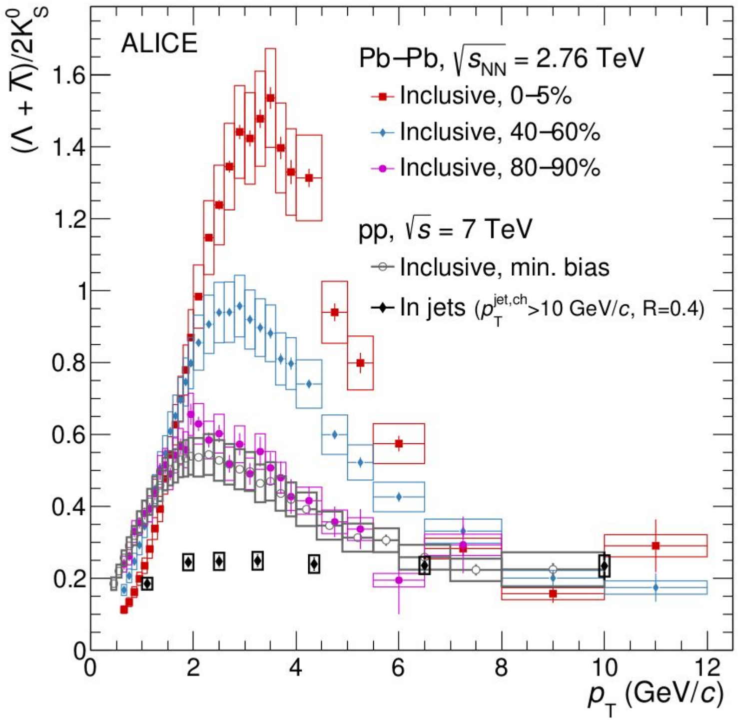
- Rapidity distributions well described by Gaussians in a wide range of energies
- **The Dale:** deviation of rapidity width behaviour from the shape motivated by Landau model (full stopping and thermalization)
- Can be attributed to the softening of EoS due to deconfinement
- Wider rapidity coverage →better determination of the pion rapidity shape

Baryon anomaly

- **Baryon anomaly**: growth of p/π and Λ/K ratios in the p_T range 1-4 GeV
- Tiny yields in this range at low energies → might be difficult to study with MPD at midrapidity
- However: the growth in the p_T range 1-4 GeV is usually explained by coalescence: recombination of constituent quarks into hadrons

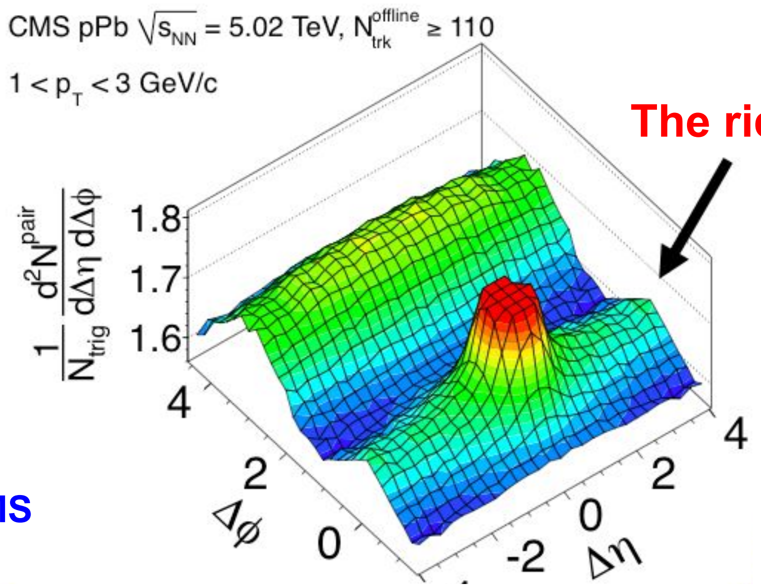
→ full momentum (not p_T) matters

→study at forward rapidity?



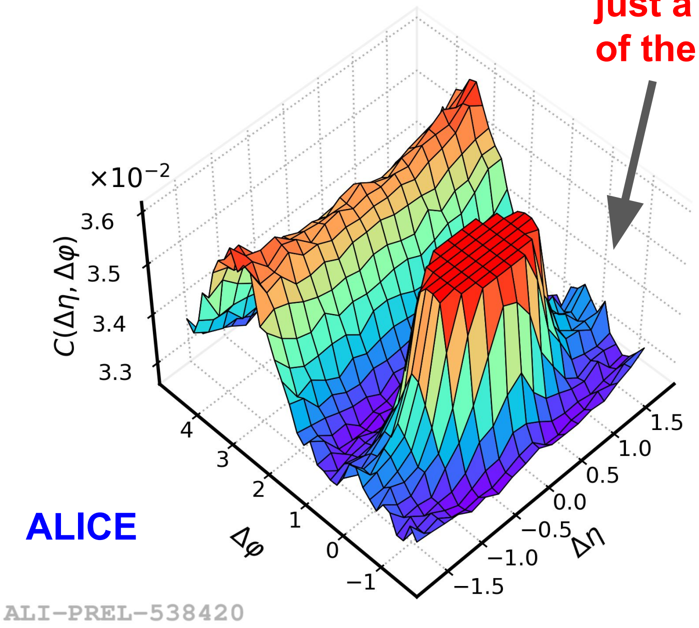
Angular correlation studies

The ridge



CMS

The ridge or just a pedestal of the jet peak?

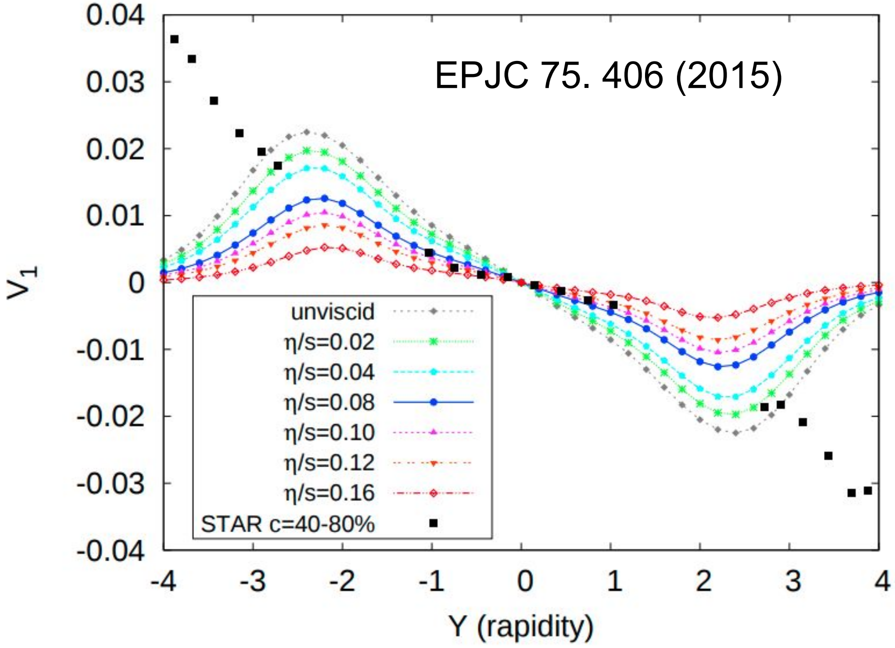


ALICE

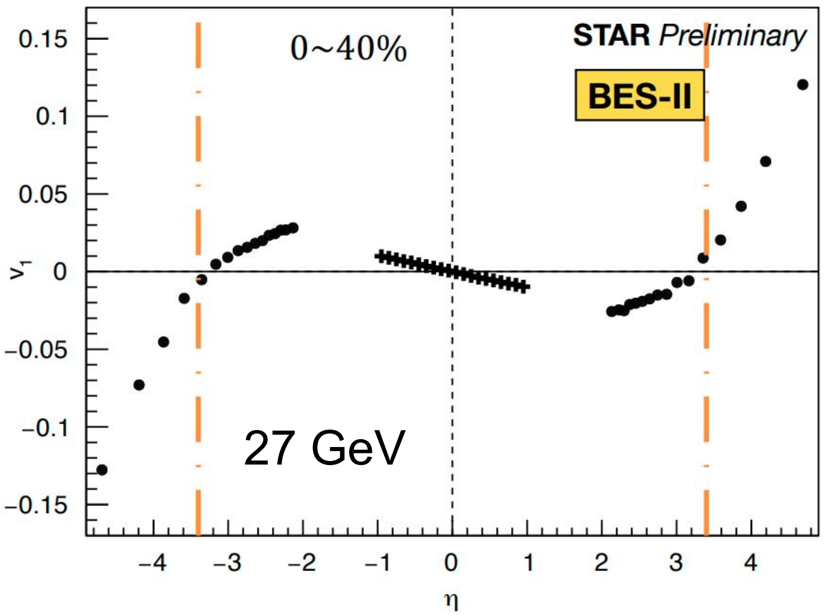
Angular correlation studies strongly profit from extended pseudorapidity coverage:

- stay away from jet peak
- much higher statistics for 4-particle and 8-particle cumulants
- study decorrelation effects vs η…

Directed flow of charged pions



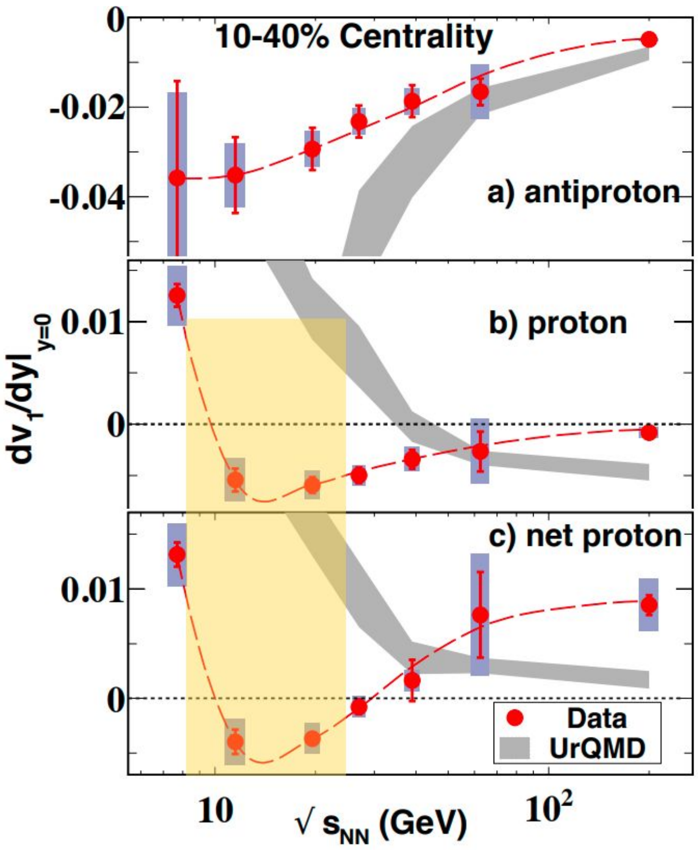
https://indico.cern.ch/event/1176274/contributions/5323690/



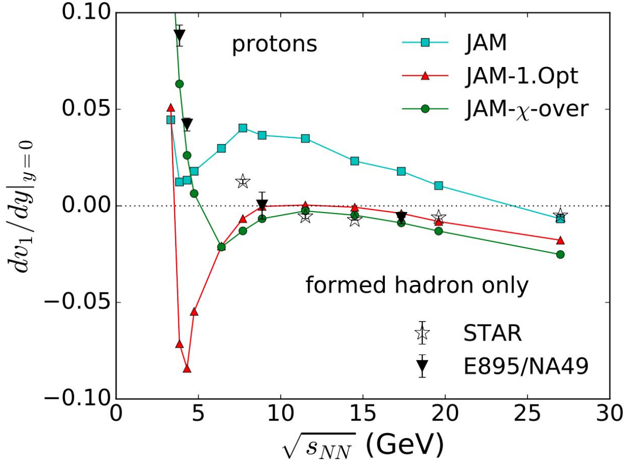
- $v_1(\eta)$ sensitive to the shear viscosity to entropy (η/s) ratio
- $v_1(\eta)$ in both spectator and participant regions may provide insights into the baryon stopping mechanism (see 2211.16408)
- Need wide rapidity coverage!

Directed flow of net protons

STAR BES II



PLB 769 (2017) 543



- Model predicts sign change at ~ 5 GeV with 1st order phase transition
- proton and net-proton v_1 change sign around 10-20 GeV
- Need wide rapidity coverage to measure v_1 shape

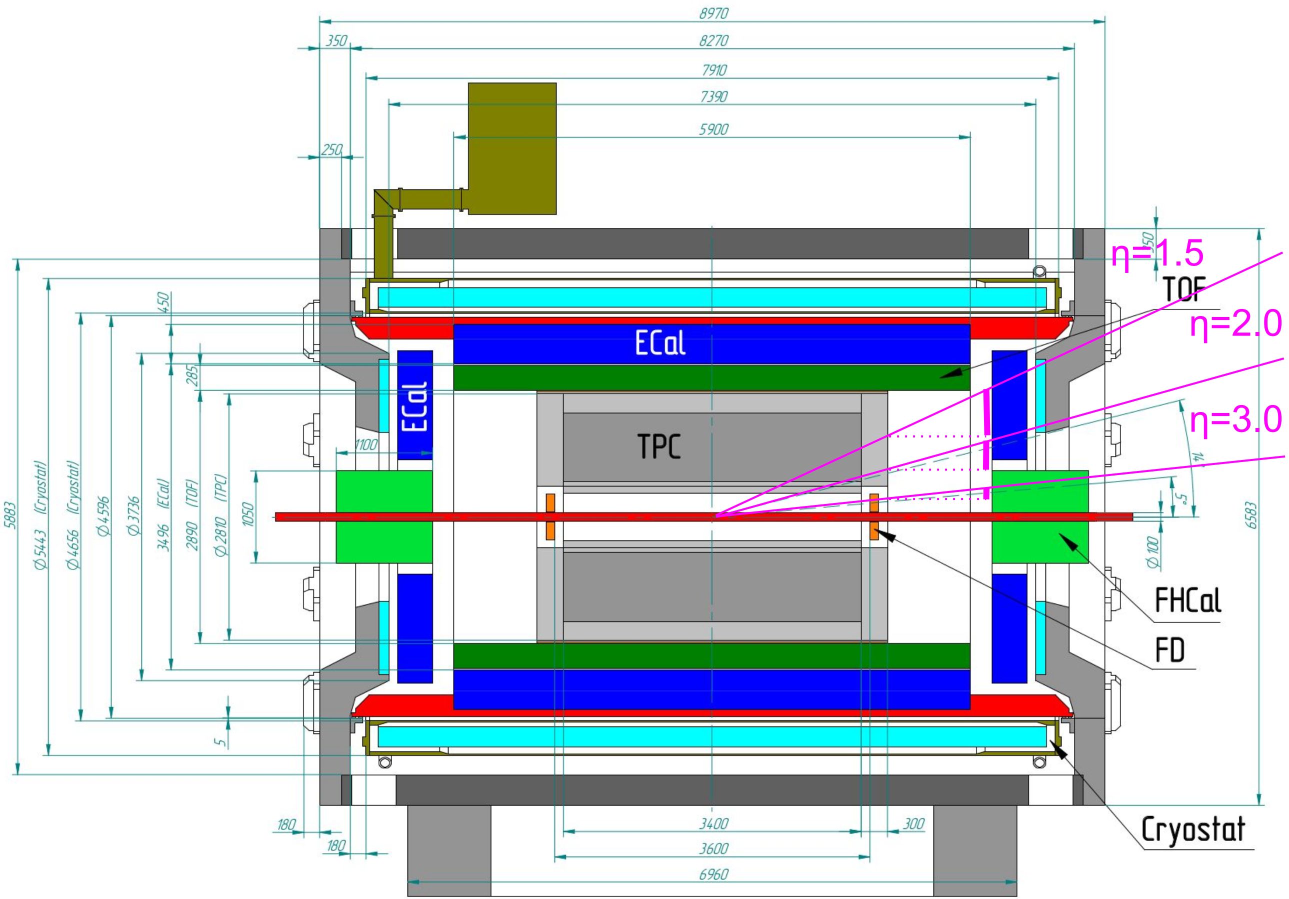
https://indico.cern.ch/event/1176274/contributions/5323690/

And more…

- search for critical point with event-by-event net baryon number fluctuations: ideally need full rapidity coverage to measure total baryon yield
- global polarization of Λ hyperons: rapidity dependence?
- improve precision of centrality and reaction plane determination
- improved trigger efficiency for small systems
- possibility to access various observables of the SPD physics program (need continuous readout)
- aspects of non-perturbative QCD, e.g. diffractive studies, QCD instanton
- and more …

Can we measure track momentum at forward rapidities with existing solenoid field?

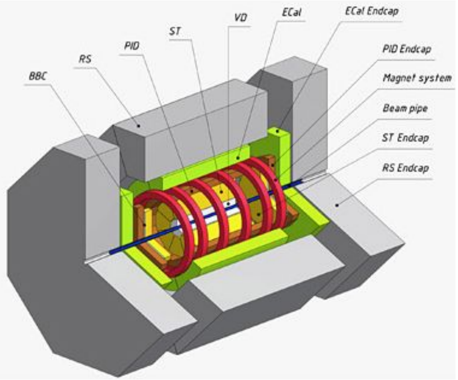
The problem

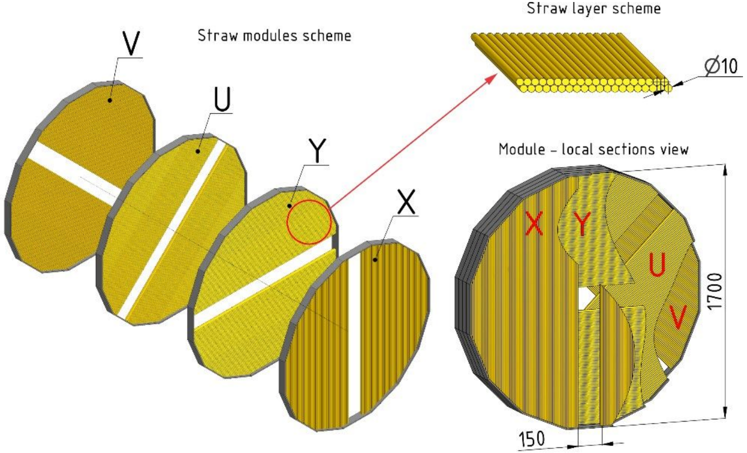


- Momentum resolution in the solenoid field is driven by the radial distance available for track curvature measurement
- Strongly degrades towards large η
- Two options to improve momentum resolution:
  - improve hit resolution
  - minimize multiple scattering effects (reduce effective radiation length)

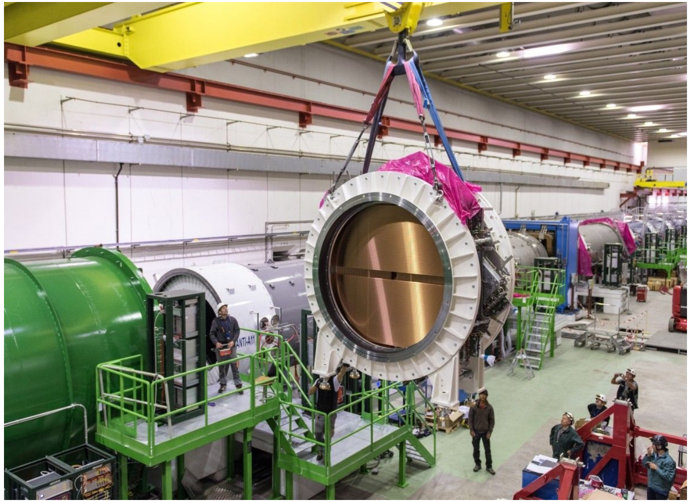
Straws similar to SPD endcap tracker?

SPD endcap tracker proposal



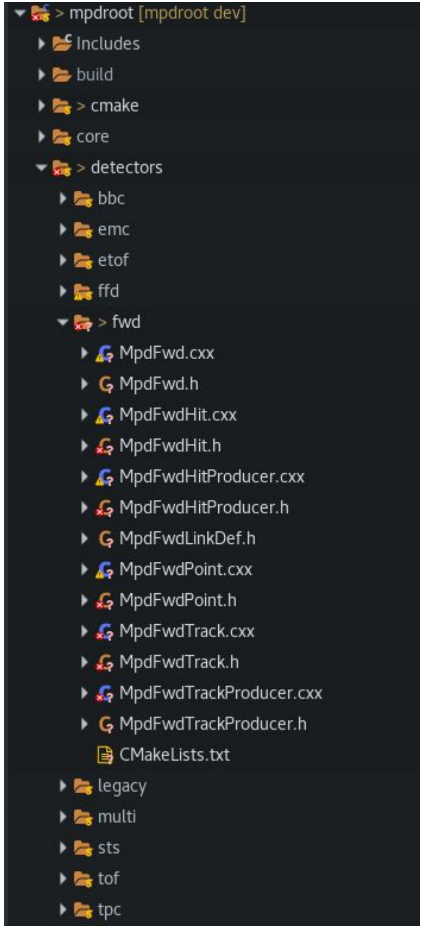


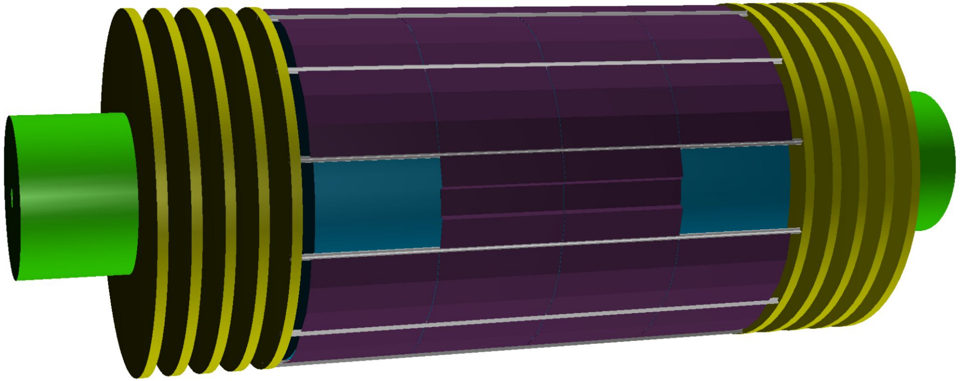
NA62



- Hit resolution ~ 100μm
- Small material budget (~1% X_0)
- Large areas (not feasible with silicon detectors)

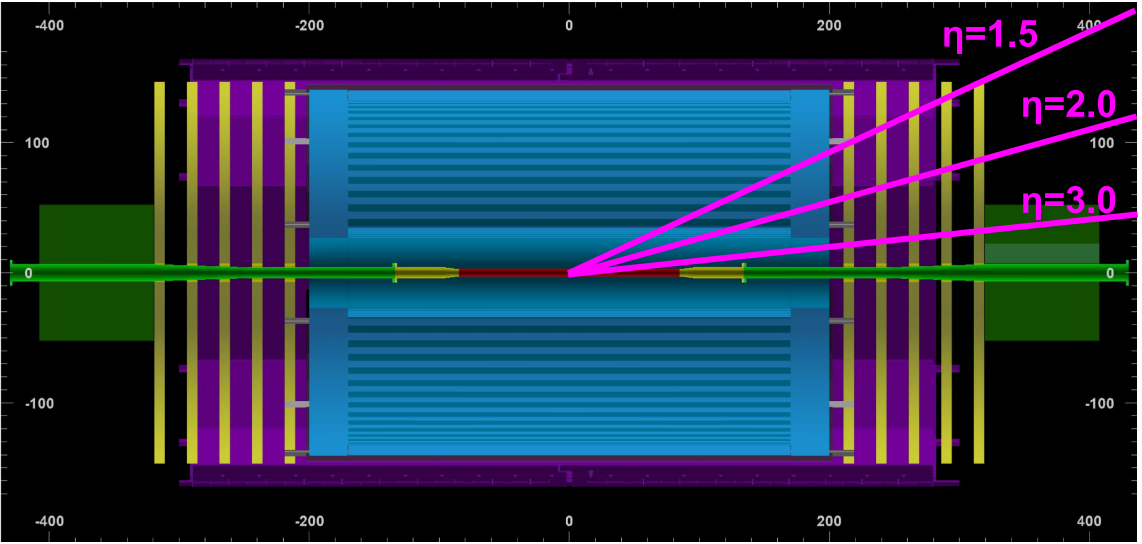
First prototype implemented in MPDROOT

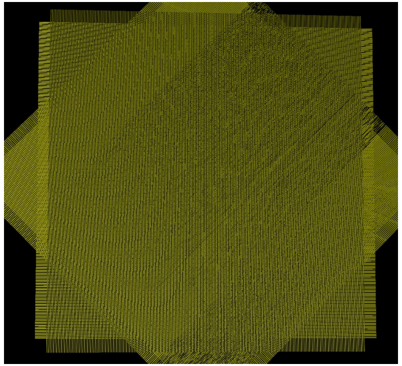


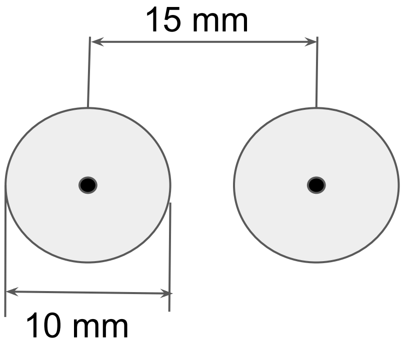


- Flexible detector construction code
  - MpdFwd
- Data structures:
  - MpdFwdPoint
  - MpdFwdHit
  - MpdFwdTrack
- Ideal hit and track producers:
  - MpdFwdHitProducer
  - MpdFwdTrackProducer

Implementation details





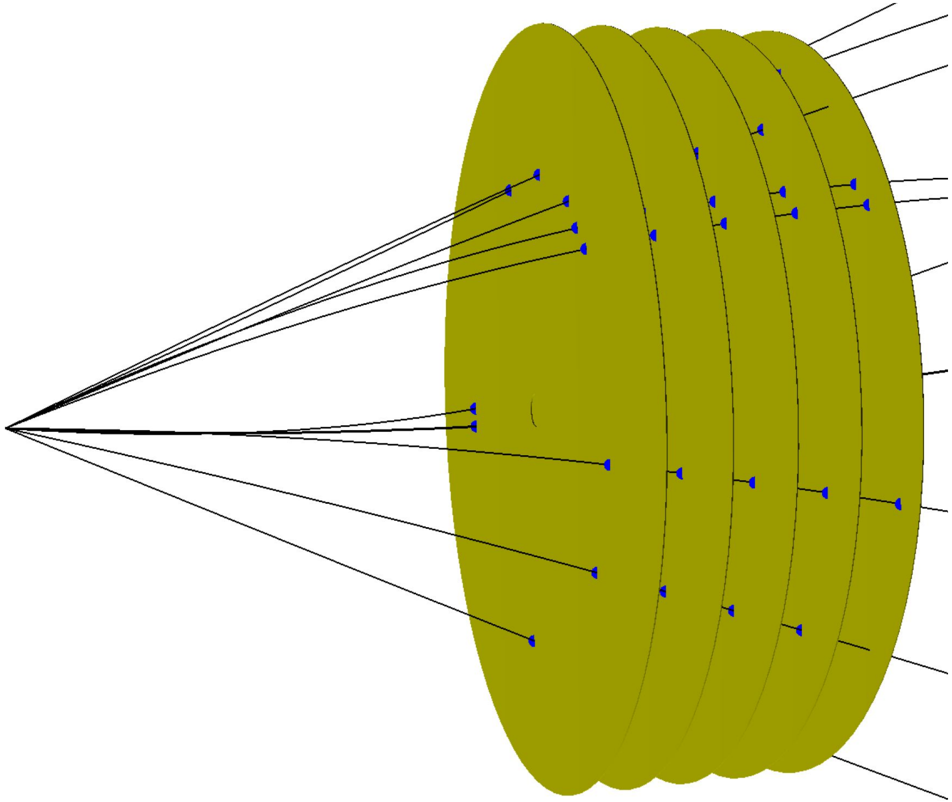


- 5 stations on both sides
  $|z_{min}|$ = 215 cm
  $|z_{max}|$ = 315 cm
- r_{min} = 7 cm
- r_{max} = 147 cm
- Each station: 4 layers (XUVY)

- Each straw tube:
  - Tube diameter: 10 mm
  - Tube thickness: 30 μm kapton
  - Wire diameter: 30 μm tungsten
  - Gas: $ArCO_2$: 70%/30%

- Effective radiation length:
  - 0.112% X_0 per station
  - 0.56% X_0 each side

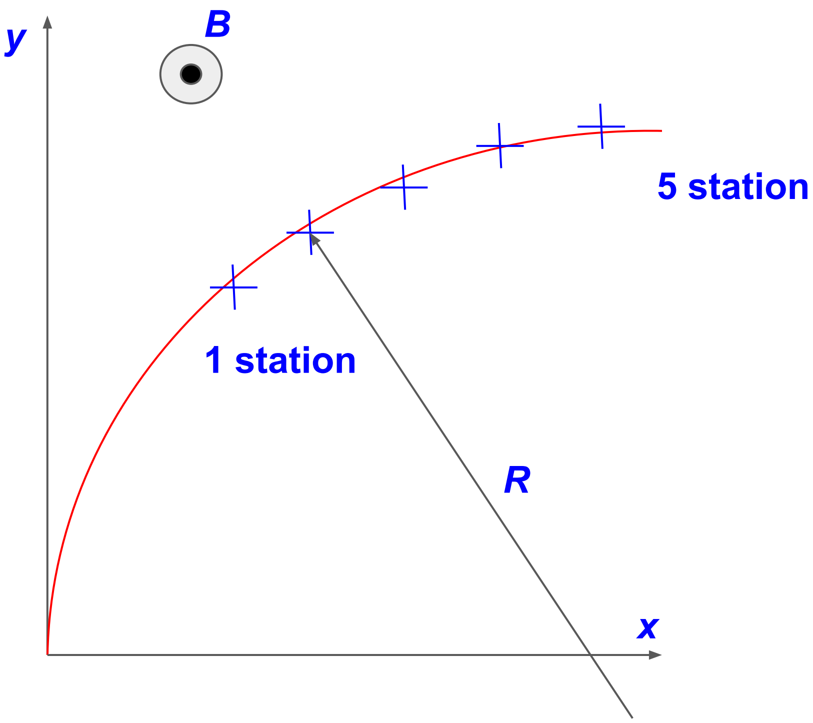
“Ideal” hit producer



Straws not shown to improve visibility

- “Sensitive” layer added in the center of each station to mimic straw tube measurements
- 2D hits produced from each MC point, smeared according to “hit resolution” parameter σ
- Default σ set to 100 μs
- Next: more realistic hit producer with 1D hits per straw and two-fold ambiguity

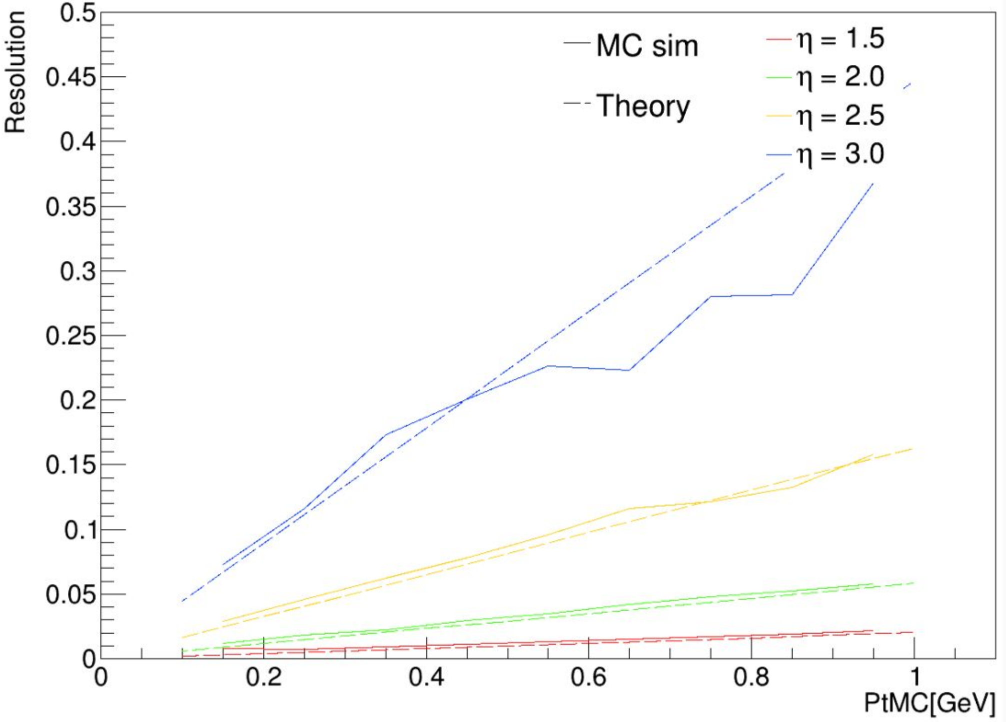
Trivial tracking algorithm



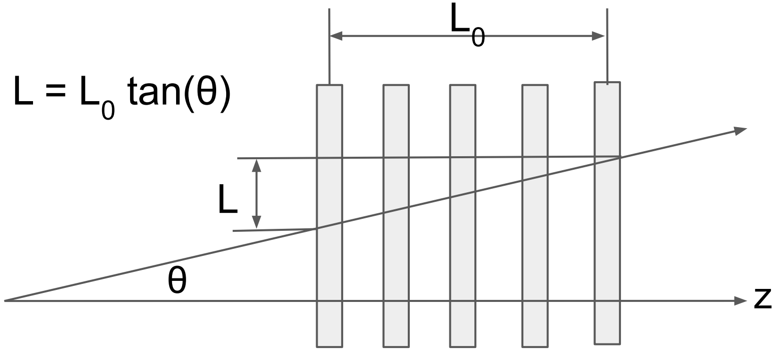
- Collect hits originating from the same MC track
- Fit smeared (x,y) measurements with a circle
- Extract curvature radius R
- Derive reconstructed $p_T = 0.3 \, B \, R$
- Compare with generated p_T
- Caveats:
  - constant B only
  - no energy loss correction
  - no accounting for multiple scattering effects
  - TPC track segments not included
- Anyway, good enough for preliminary momentum resolution estimates

Momentum resolution due to hit precision

$$\frac{\triangle p_T}{p_T}|res. = \frac{\sigma \quad p_T}{0.3B_0L^2}\sqrt{\frac{720N^3}{(N-1)(N+1)(N+2)(N+3)}}$$



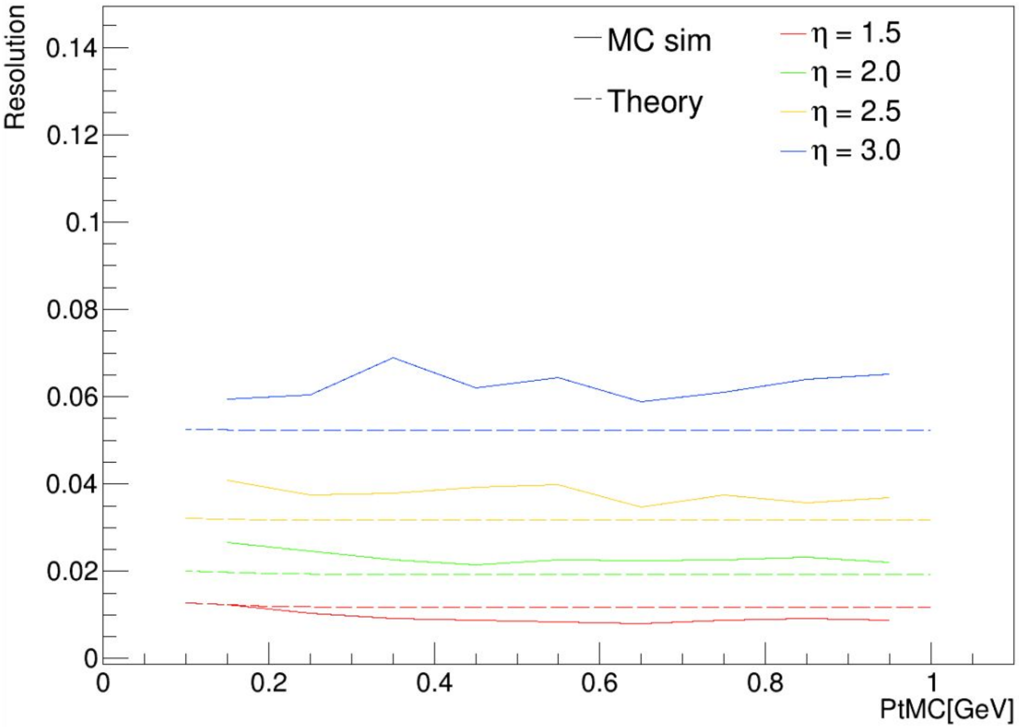
- MC simulations with vacuum-made stations to suppress the effect of multiple scattering
- And applying σ = 100 um hit smearing
- Linear increase of momentum resolution with p_T
- Momentum resolution proportional to σ
- Inverse square dependence on L_0 (the distance between first and last stations)
    - Extend the tracker as much as possible



Formulas adopted from Drasal, Riegler, *NIM A* 910 (2018) 127

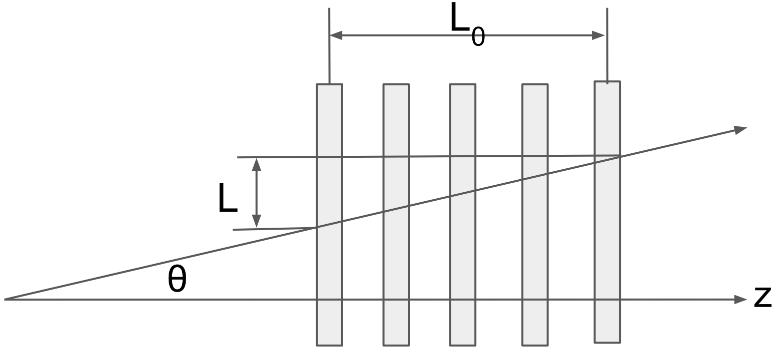
Momentum resolution due to multiple scattering

$$\frac{\Delta p_T}{p_T}\Big|_{m.s.} = \frac{N}{\sqrt{(N+1)(N-1)}} \frac{0.0136 GeV/c}{0.3\beta B_0 L} \sqrt{\frac{d_{tot}}{X_0 \cos\theta}} \left(1 + 0.038 \ln \frac{d}{X_0 \cos\theta}\right)$$



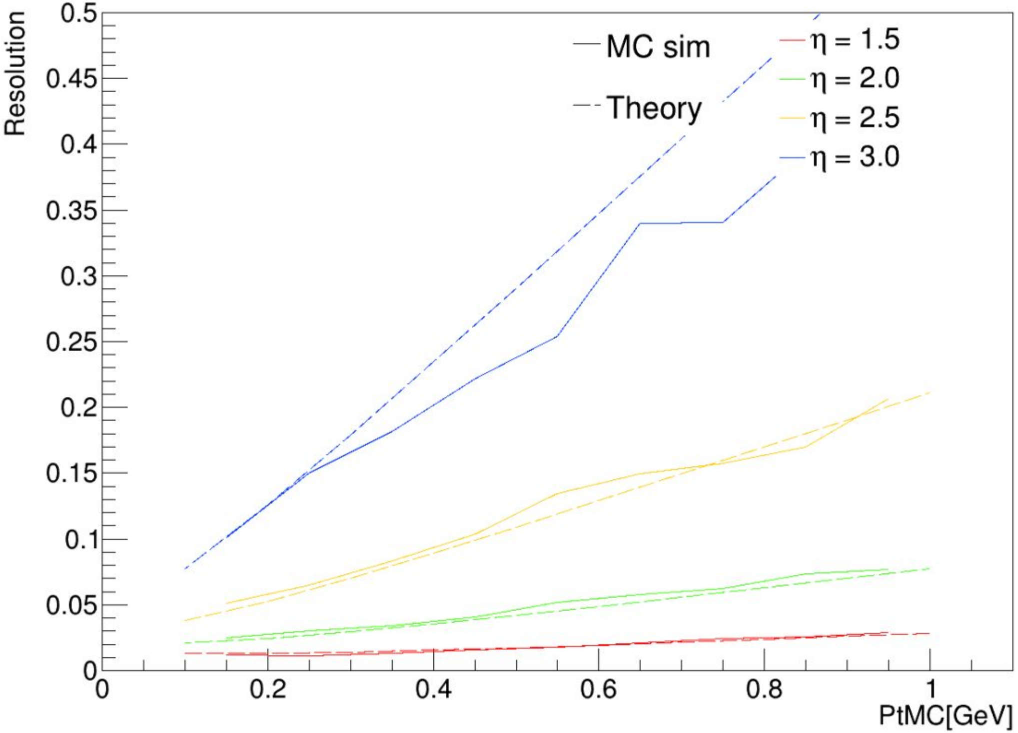
Formulas adopted from Drasal, Riegler, *NIM A* 910 (2018) 127

- MC simulations with ideal hits and realistic material budget
- Momentum resolution practically constant at high p_T (at $\beta \sim c$)
- Momentum resolution proportional to sqrt of effective radiation length
- Degradation at large η due to inverse dependence on $L = L_0 \tan(\theta)$

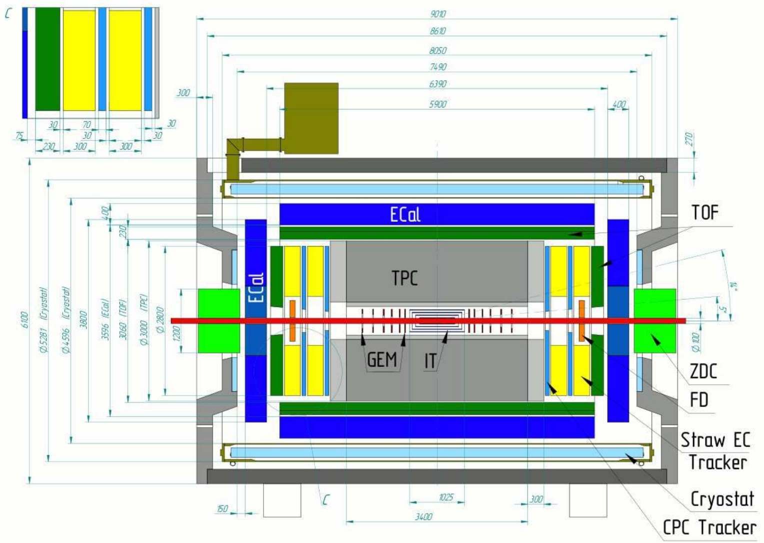


Momentum resolution

$$Resolution = \sqrt{(\frac{\triangle p_T}{p_T}|res.)^2 + (\frac{\triangle p_T}{p_T}|m.s.)^2}$$

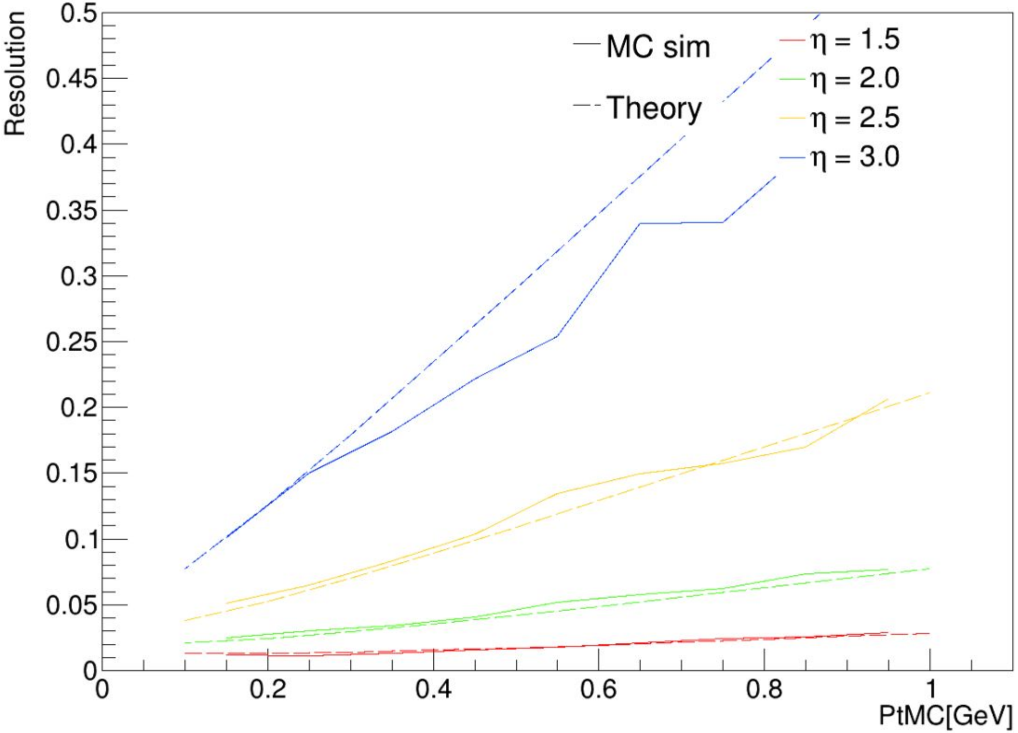


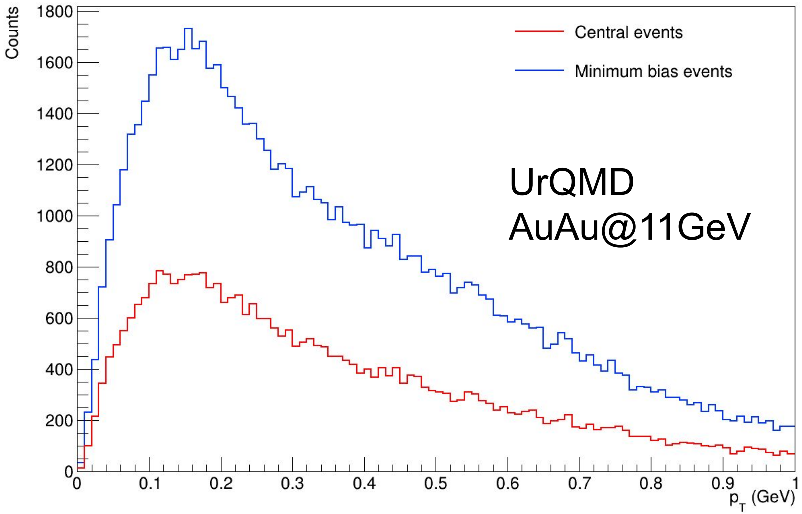
- Good agreement between theory and MC
- Hit resolution is the dominant effect
- η ~ 3 is hardly feasible
- Can we reduce hit resolution below 100 μs?
- Increase effective L?
  Silicon end-cap tracker?



Good news: most of the tracks have p_T ~ 100 MeV

$$Resolution = \sqrt{\left(\frac{\triangle p_T}{p_T}|res.\right)^2 + \left(\frac{\triangle p_T}{p_T}|m.s.\right)^2}$$

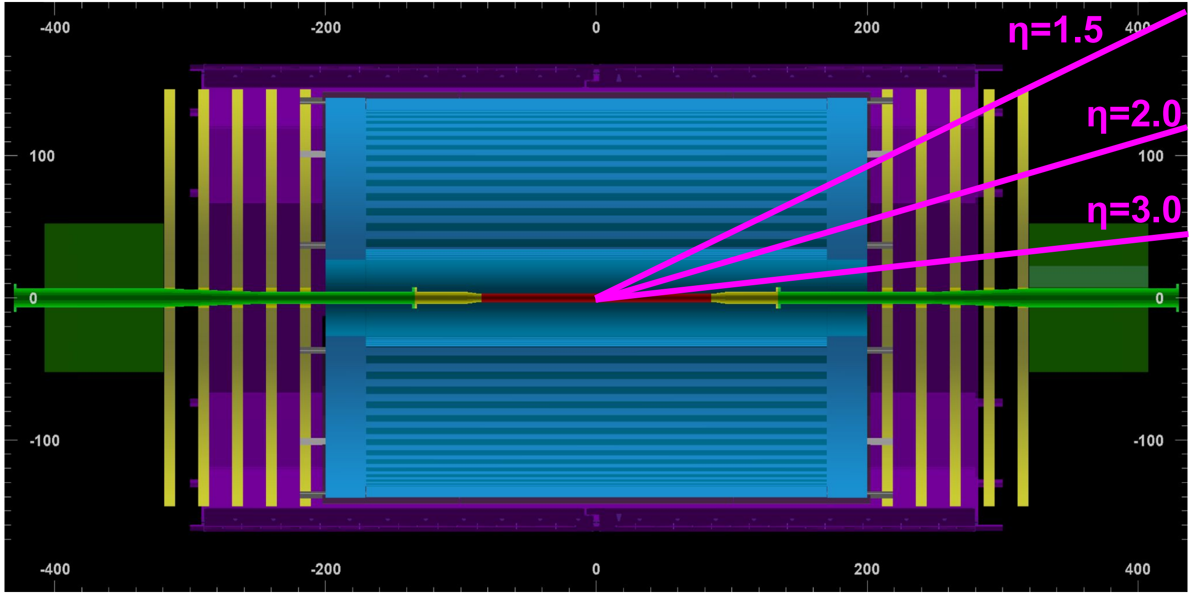




Need to study the impact of poor resolution at high p_T on physics observables

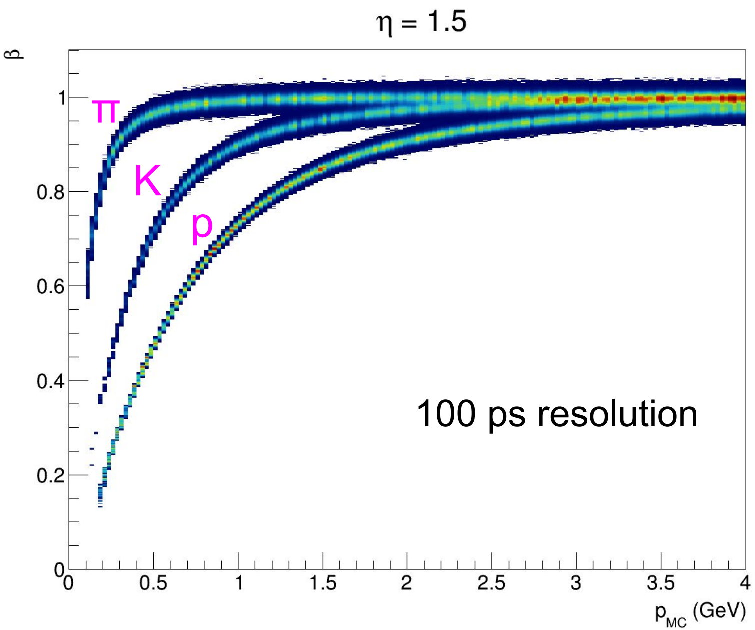
PID at forward rapidities?

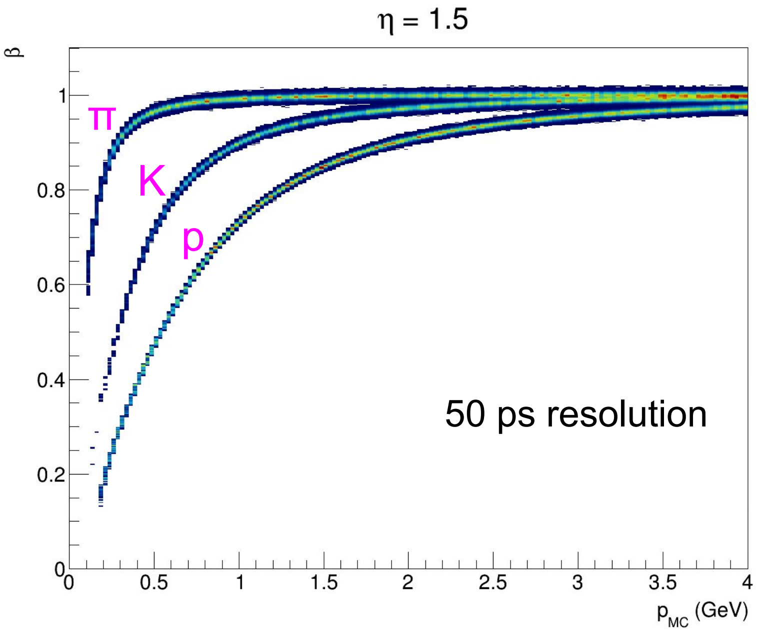
Time-of-flight measurements?



- dE/dx with small number of straw layers might be difficult
- TOF: replace the last station with RPCs?
  - 50-100 ps resolution
  - At relatively large distance (~ 3m)
  - BUT: poor momentum resolution…

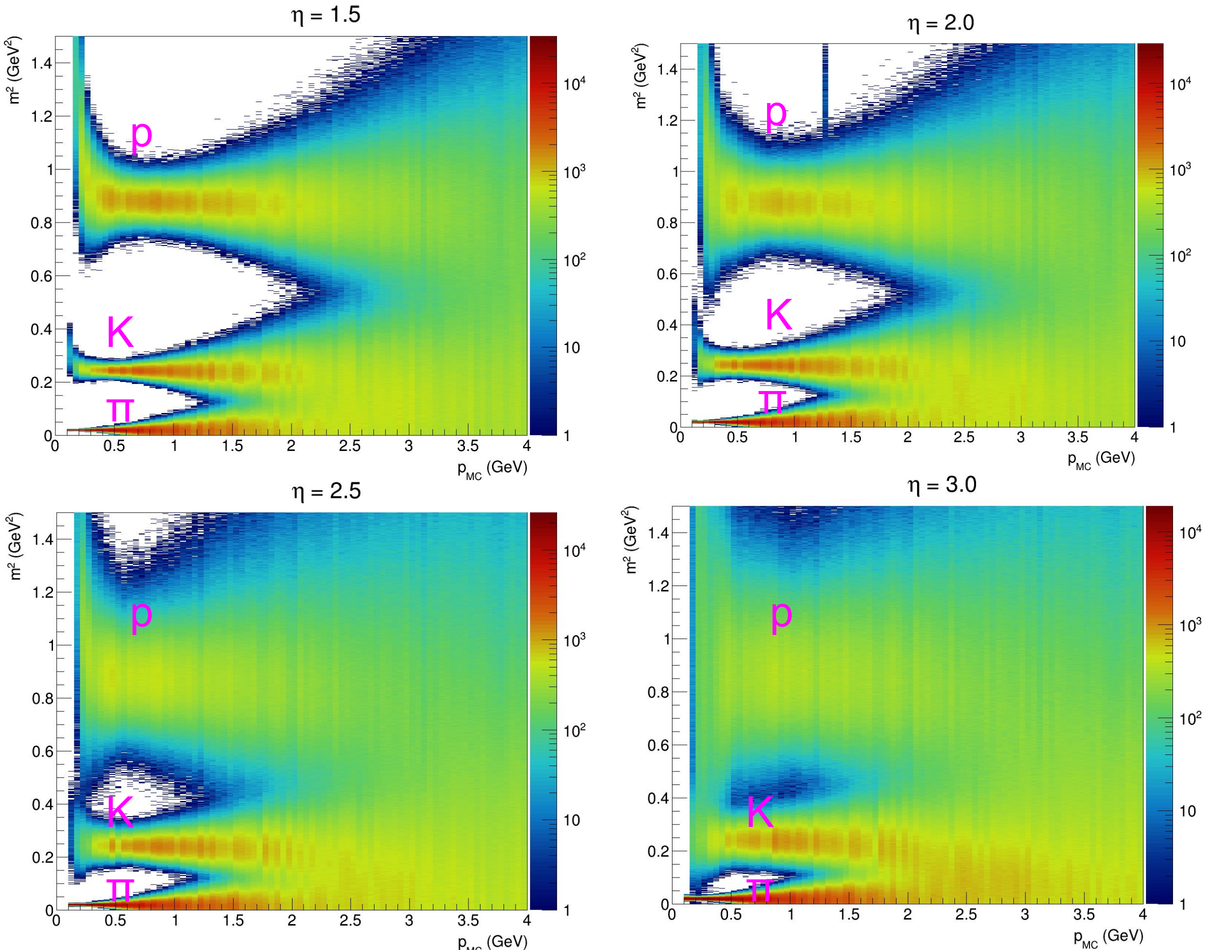
Toy model for TOF resolution estimates





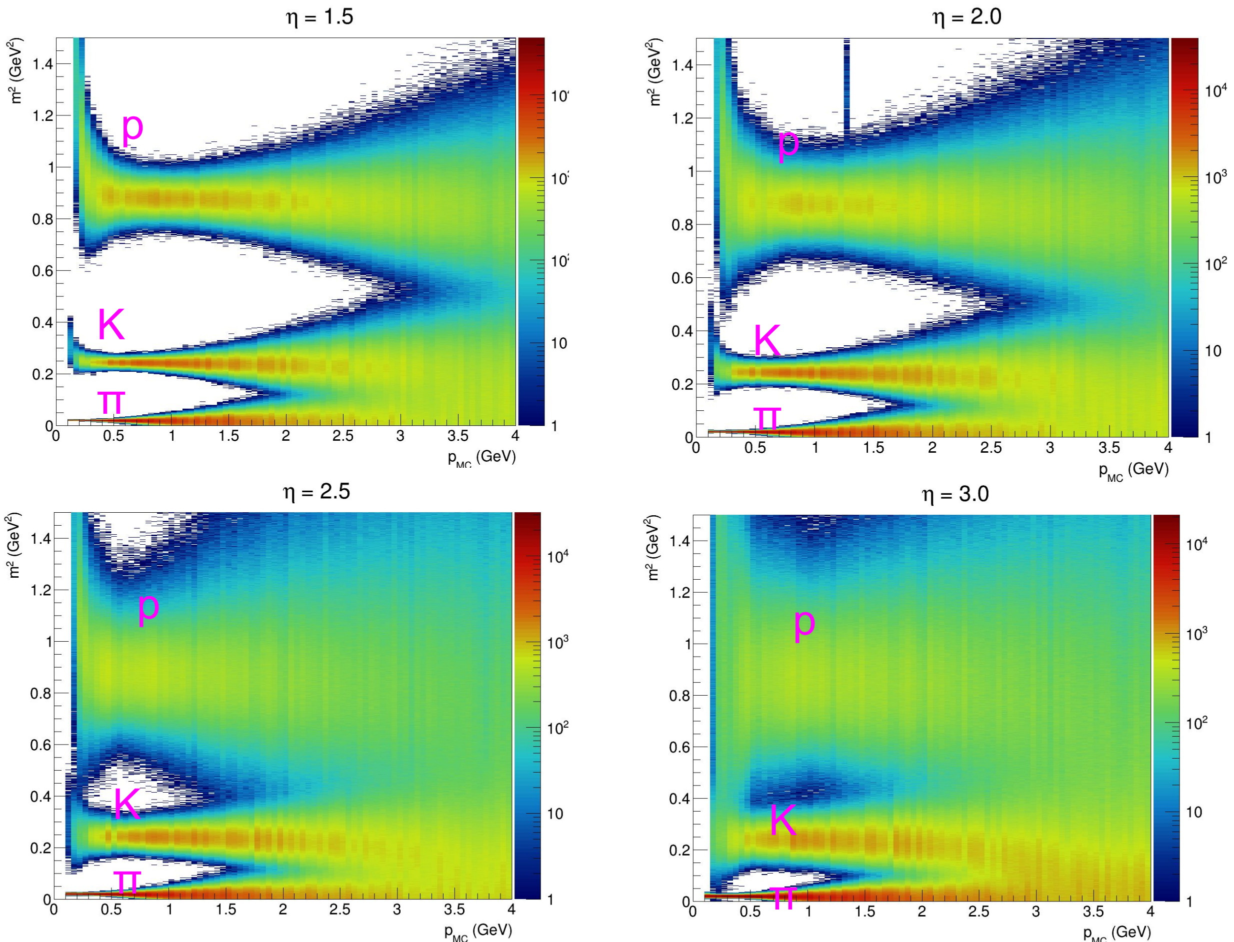
- Generate π, K, p with box generator in different η ranges
- Extract time (t_{MC}) and track length (L) from the measurement in the last station
- Apply Gaussian smearing to the MC time to mimic reconstructed time t
- Derive $\beta = L/t/c$
- Smear MC momentum according to theoretical momentum resolution estimates
- Derive m^2

Squared mass distributions for 100 ps TOF resolution



- Good π/K and K/p separation up to η~2.0
- TOF at η~3.0 is hardly feasible

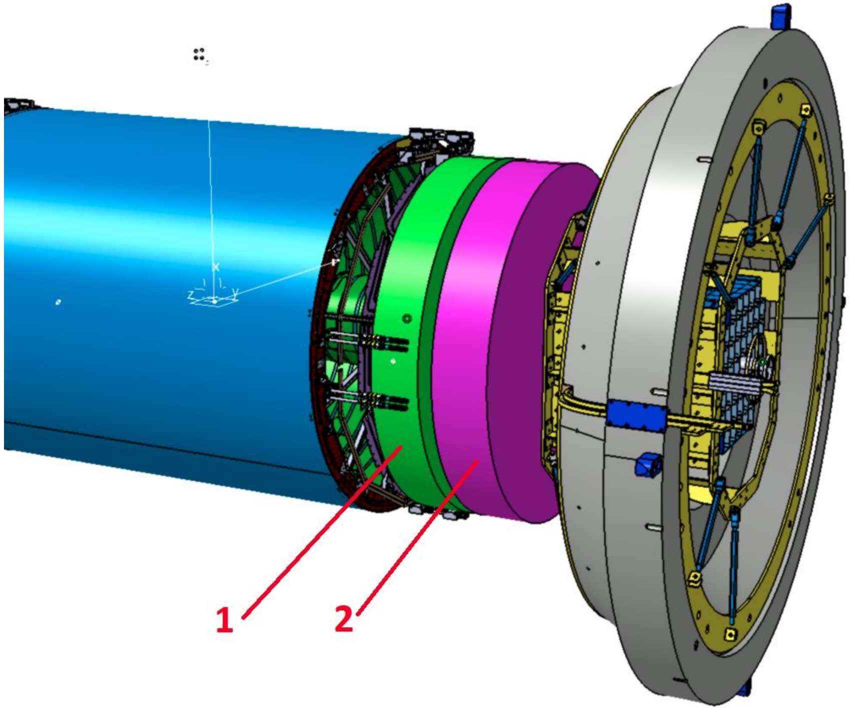
Squared mass distributions for 50 ps TOF resolution



- Much better π/K and K/p separation up to η~2.0
  - π/K up to p ~ 2 GeV
  - K/p up to p ~ 3 GeV
- Also reasonable at η~2.5
- Not feasible at η~3.0

Can we actually integrate the tracker in the current MPD setup?

Realistic 3D model



- Just received a realistic 3D model with all mechanical substructures
- Defines a more realistic envelope for the forward tracker
- Radial limitations:
  - R_{inner} = 357 mm
  - R_{outer} = 1300 mm
- Two volumes possible:
  - Green: z from 2100 to 2450 mm
  - Pink: z from 2550 to 2950 mm
  - The gap due to beam pipe support (can be eliminated if beam pipe is fixed to the tracker volume)

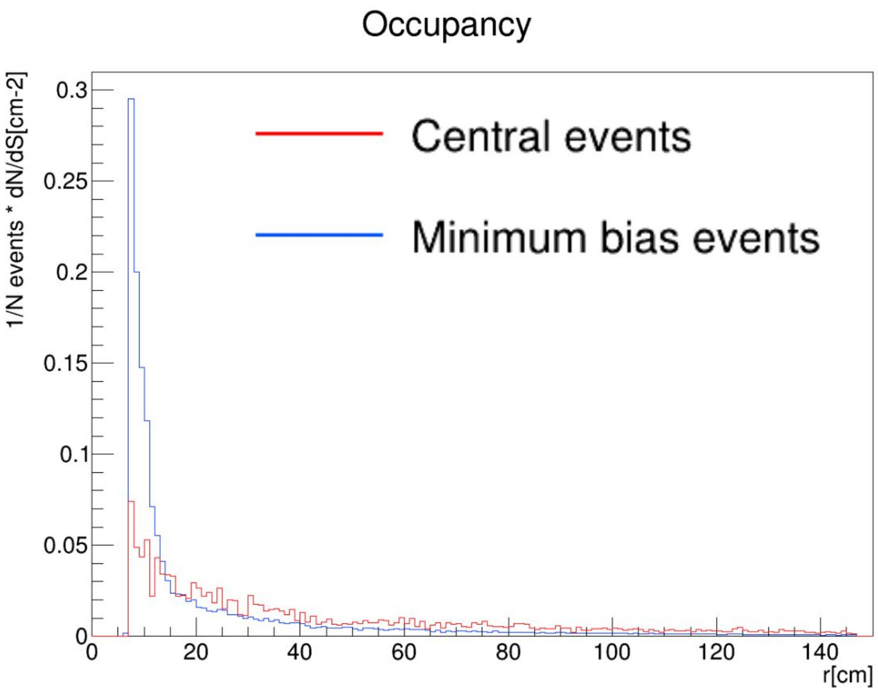
- L_0 = 85 cm instead of 100 cm in the toy model
- η_{min} = 1.55
- η_{max} =2.47

Conclusions and next steps

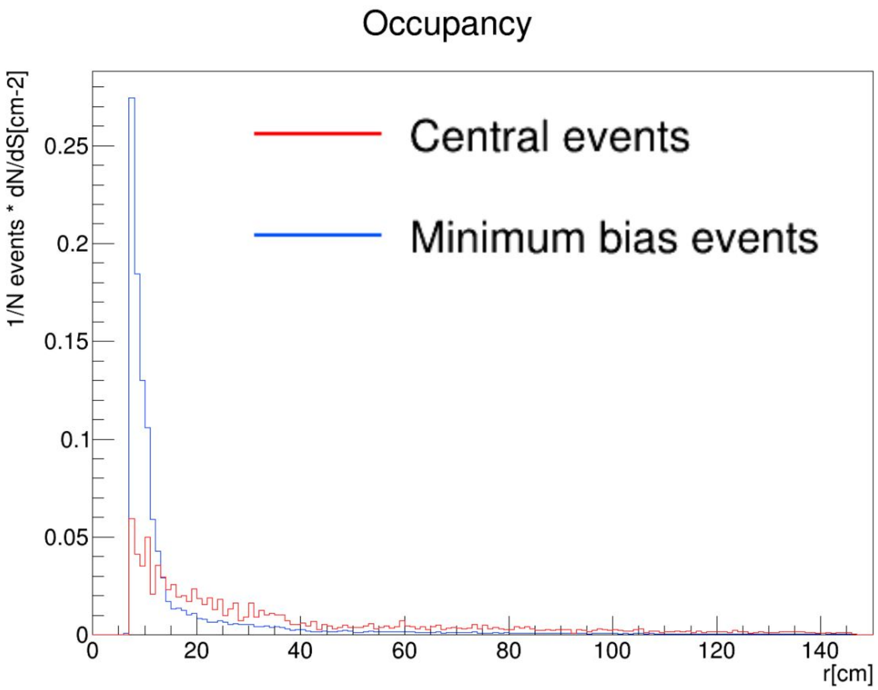
- Strong physics potential of the forward tracker
  - need further polishing and detailed quantitative studies
- First straw tube tracker prototype implemented in mpdroot
- Track momentum can be measured with reasonable precision up to η~2.5
- Particle identification can be performed up to η~2.5
- NEXT:
  - study the impact of momentum/PID resolution effects on physics observables
  - more realistic simulations and further optimization of the forward tracker setup

BACKUP

Occupancy



All particles



Primary particles

Primary and secondary particles @ station 1