Status of the physics studies by MEPhI group

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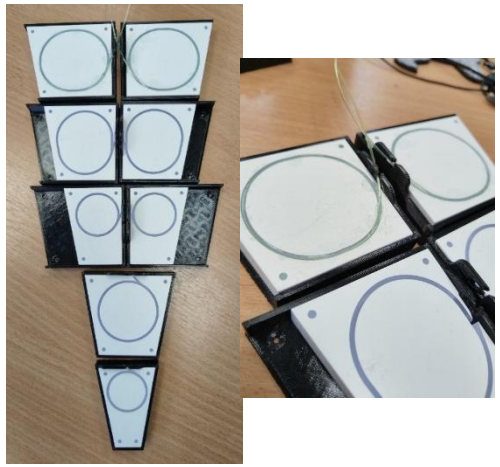
IX SPD Collaboration meeting in Armenia

Introduction: MEPhI group activities

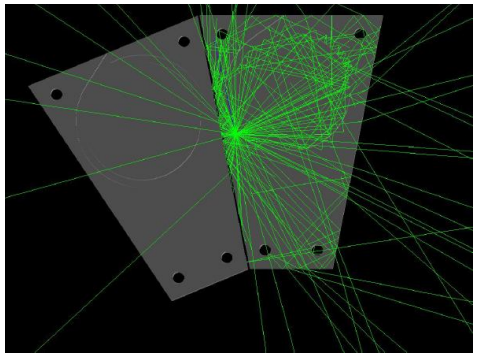
- BBC detector development with JINR group (see talks by Andrey Durov and others, presented on Tuesday)

Preparation for mass-production of a reduced size (128 tiles/wheel) prototype



Tests with CAEN FERS 5202 +Alternative to CAEN 5202 electronics

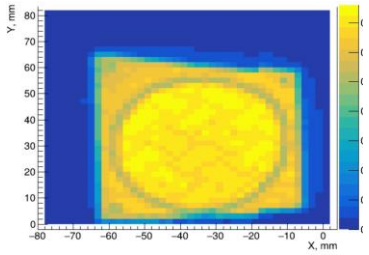
Detailed tile-to-tile GEANT4 modeling



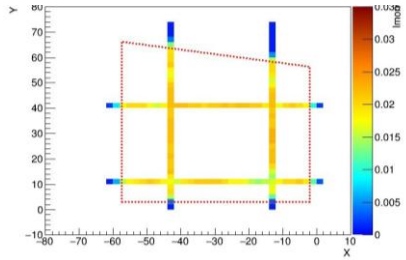
- **SiPM "Transmission boxes" development**
- **Optical cable (clear) and connectors development**

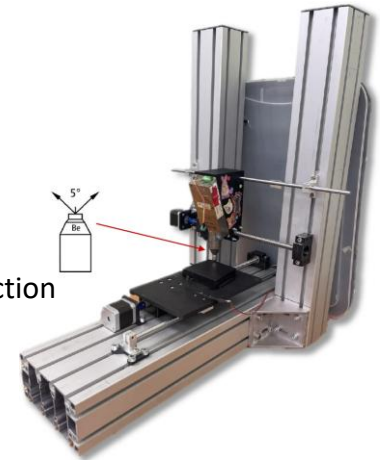
X-ray scanner For BBC tile testing

Complete tile scan



Reduced scan for mass-production





- Based on Amptek mini-x

detectors

Today:

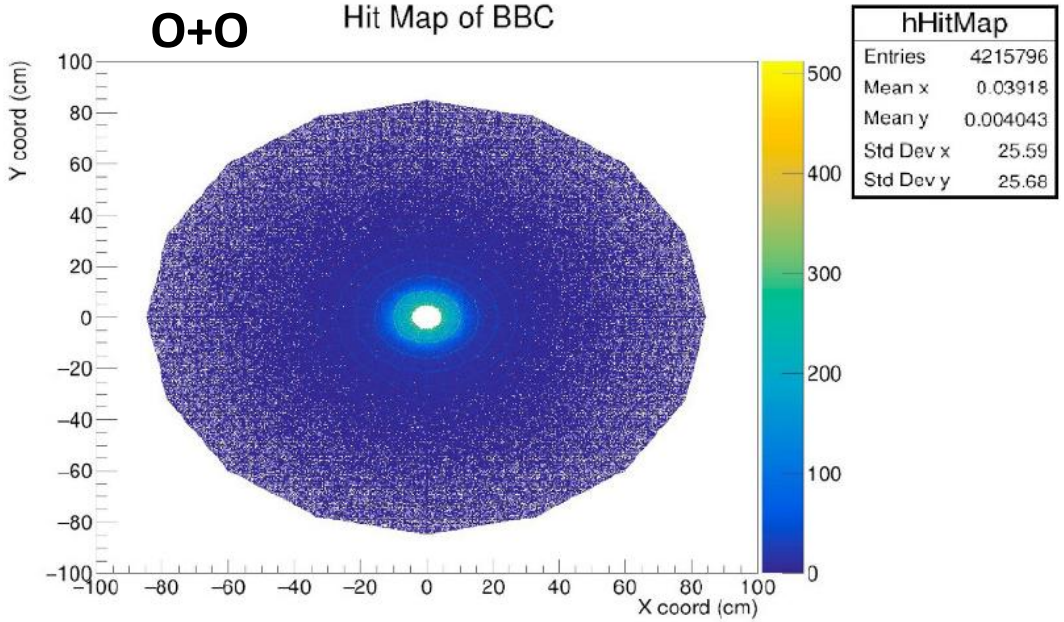
- Investigation of BBC performance basing on its current G4 geometry using SPDRoot
- Development of the SPD heavy ion program: limits from Straw tracker, particle spectra and flows
- J/Ψ angular coefficient study

physics

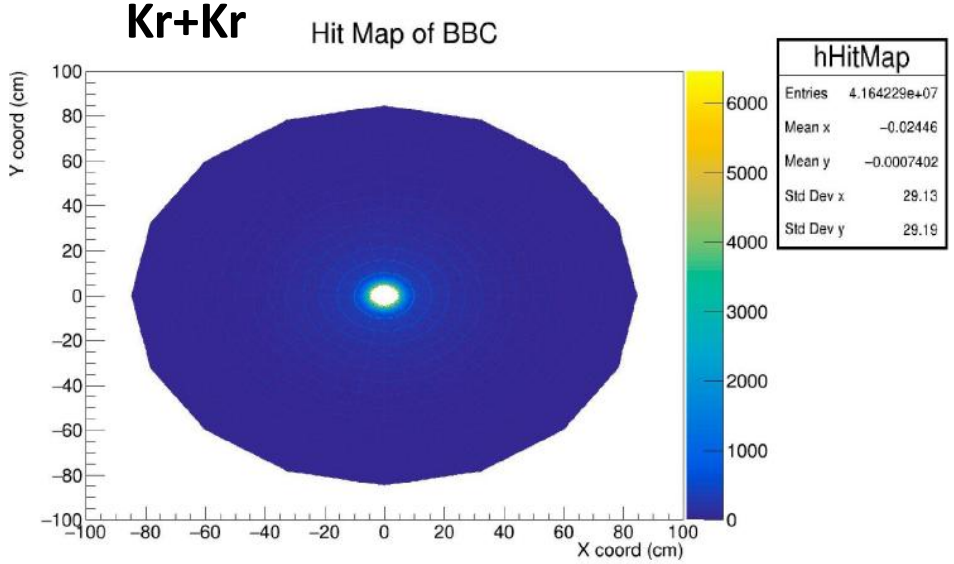
First look at the BBC occupancy maps for different colliding systems

- Occupancies with O+O, Kr+Kr, Xe+Xe systems.
- UrQMD generator, full SPDRoot chain (only BBC enabled), minbias **50 kEvents.**
- sqrt(s_{NN})=**12 GeV** (6 GeV in back-up).

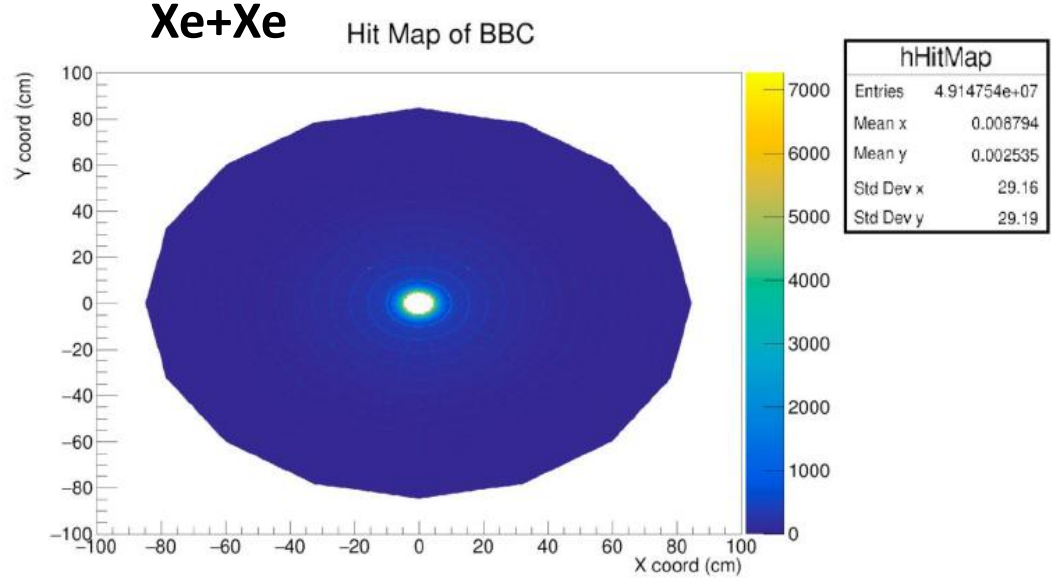
O+O



Kr+Kr



Xe+Xe



Ion physics at SPD

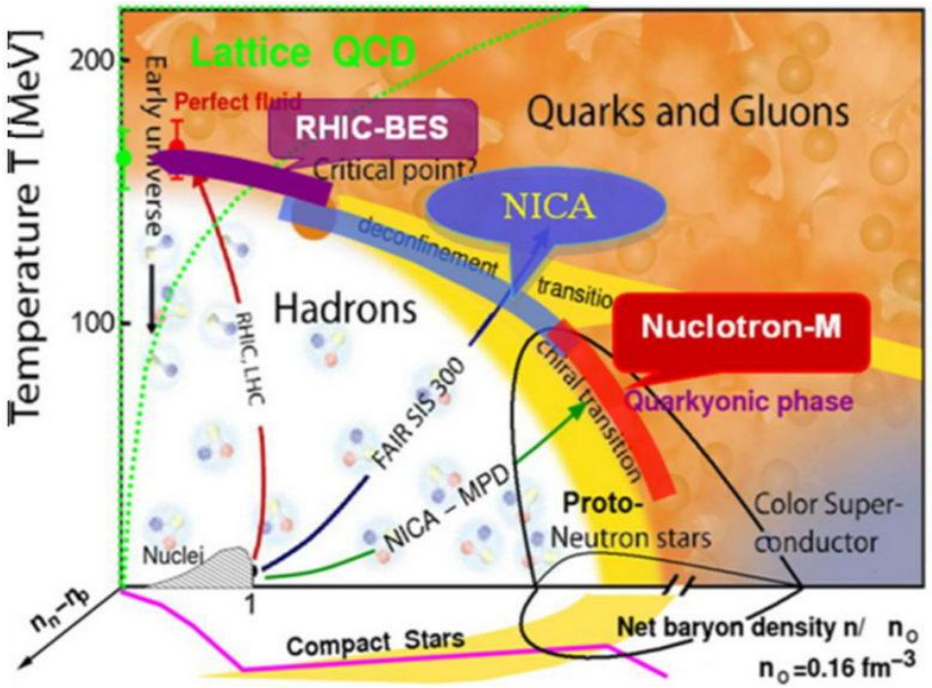
What can be done?

Study the quark-gluon matter properties in small systems (p+p, d+d, O+O, Ar+Ar, Xe+Xe ...)

- Influence of the initial state on the system dynamics
- Dynamics and final state effects, transport coefficients
- Vortical structure
  - Access via various particle decays (hyperons, meson resonance and J/psi) in a broad acceptance.
  - Energy dependence of vortical structure.
- Heavy flavor production
  - Dissociation and recombination, partonic energy loss.
  - Access to J/psi and charmonium via dielectron and dimuon channels.

Why SPD?

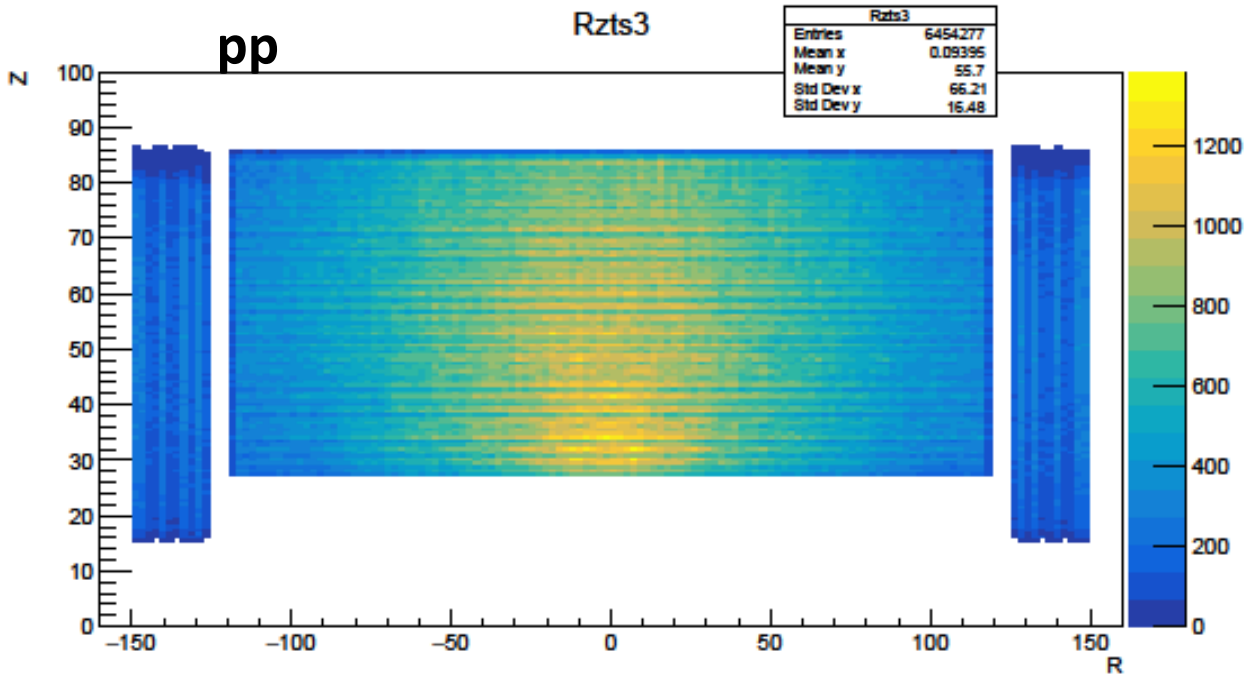
- High trigger rates and spatial resolution.
- Large pseudorapidity acceptance.
- Complementary to MPD, but with unique physics opportunities.



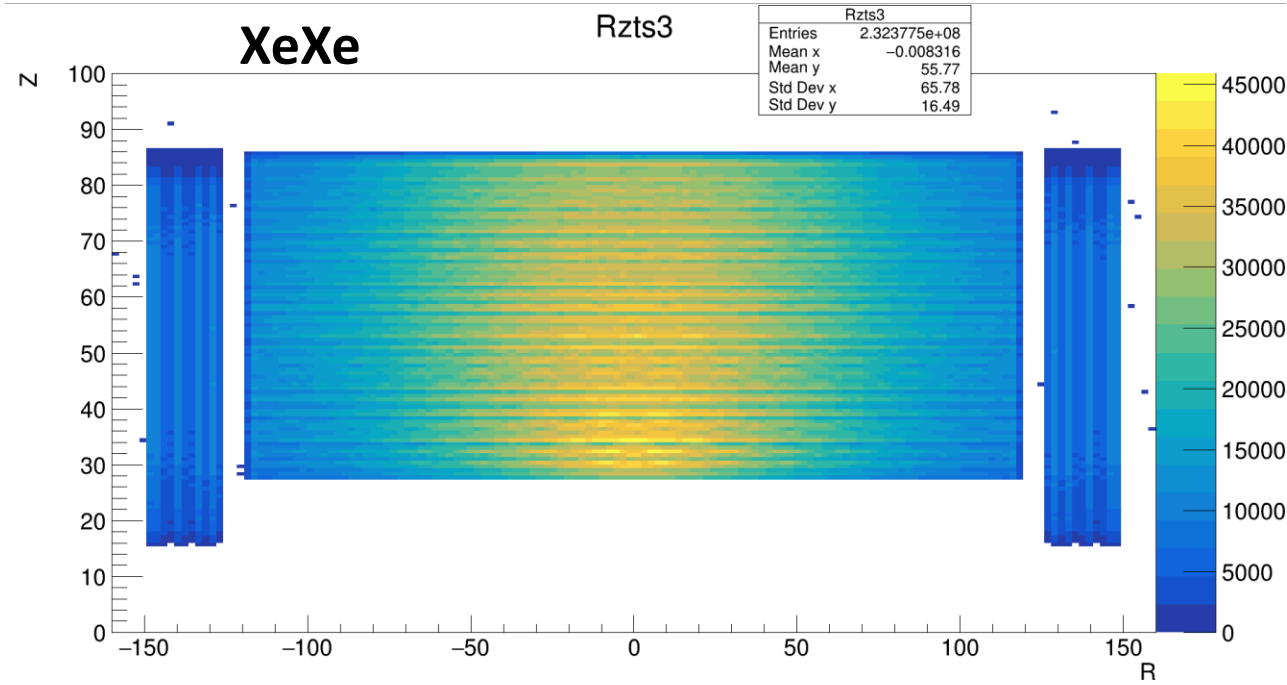
Straw tracker occupancies

- The limitation could come from the straw tracker since the high charged particle multiplicity events (ion-ion collisions) lead to degradation of the detector resolution.
- The ongoing study is aimed to determine occupancy effects on the tracking efficiency.

- **pp**: Minbias events using Pythia8, 10 GeV, 10k events through the full SPDRoot chain
- **XeXe**: Minbias events using UrQMD model, 10 GeV, 10k events through the full SPDRoot chain



Average fraction of fired straws in event: **2.1%**



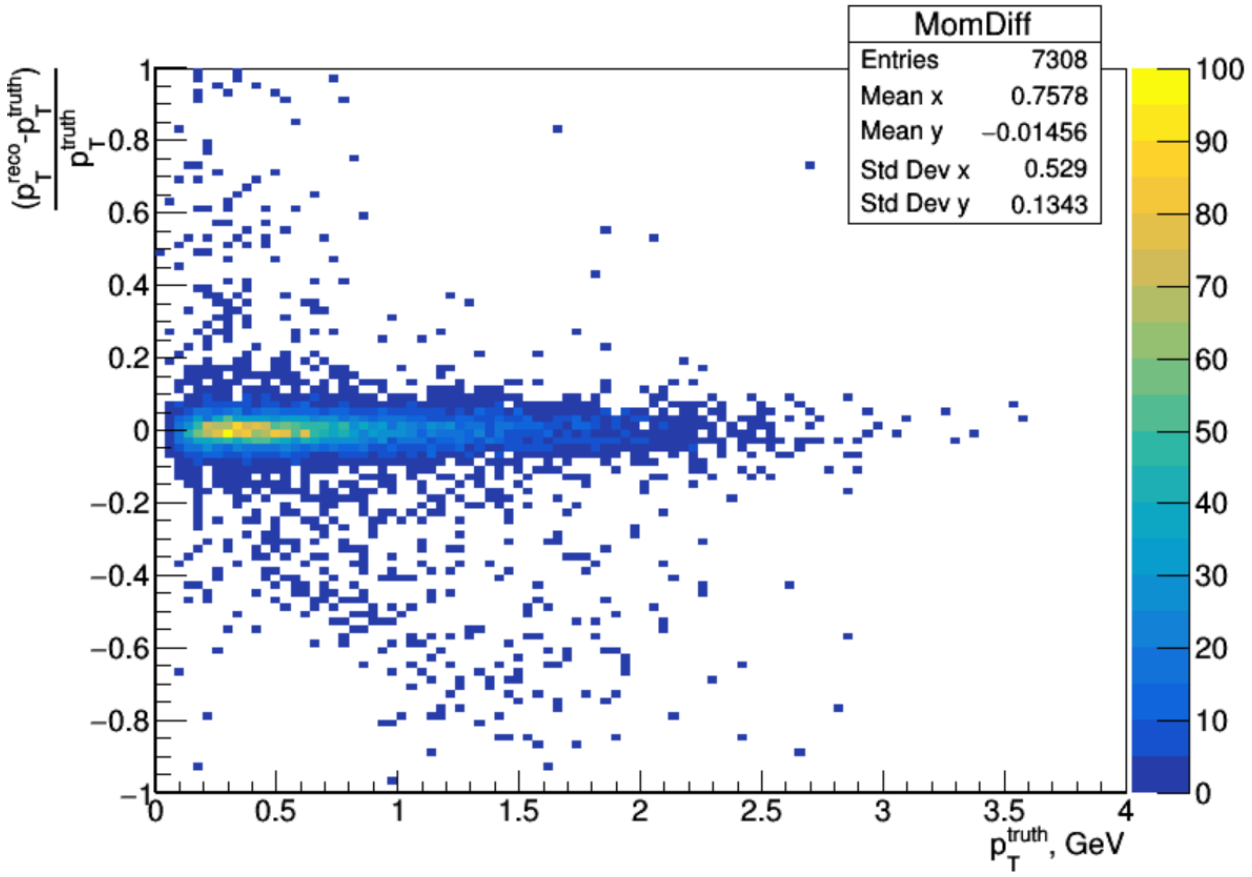
Average fraction of fired straws in event: **35.8%**

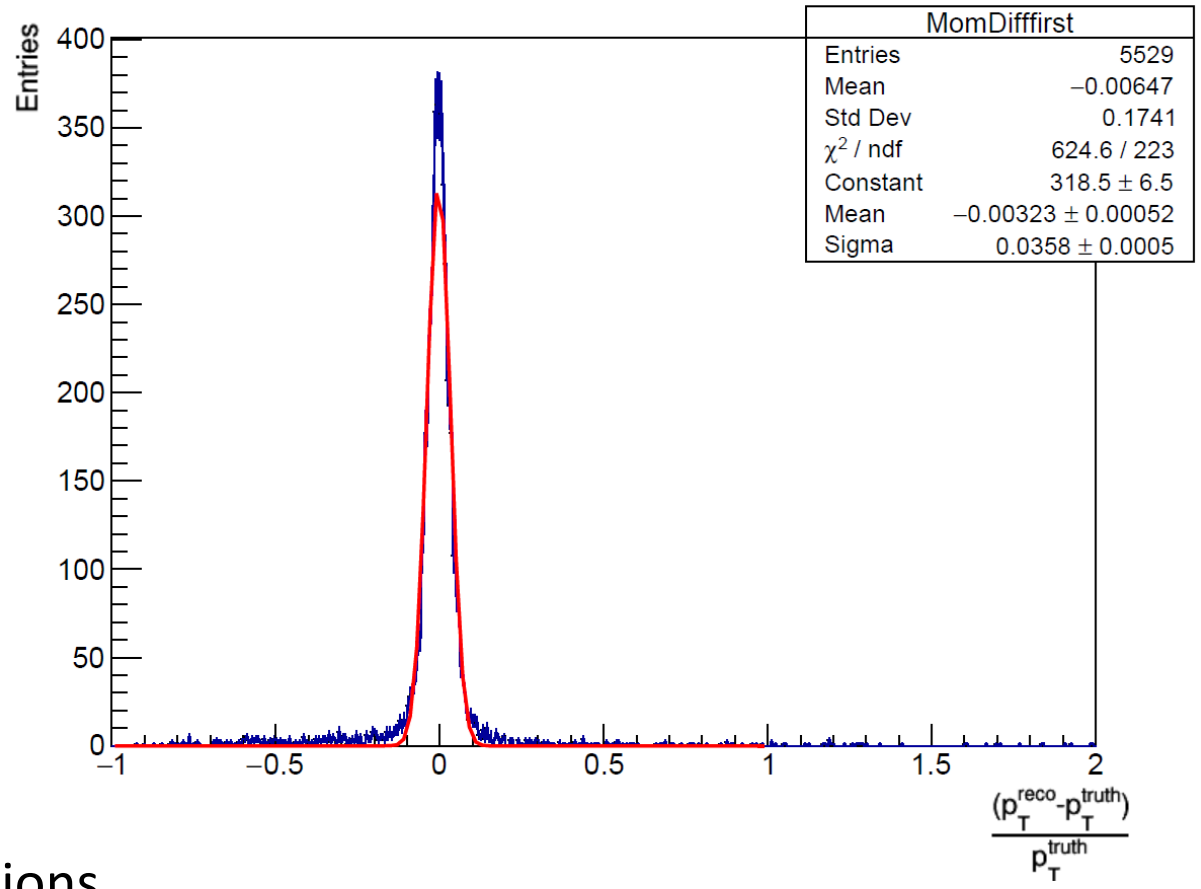
Straw tracker track reconstruction

"First" tracks were taken.

To test the resolution change we check the track quantity (reco_pT-truth_pT)/truth_pT.

pp collisions





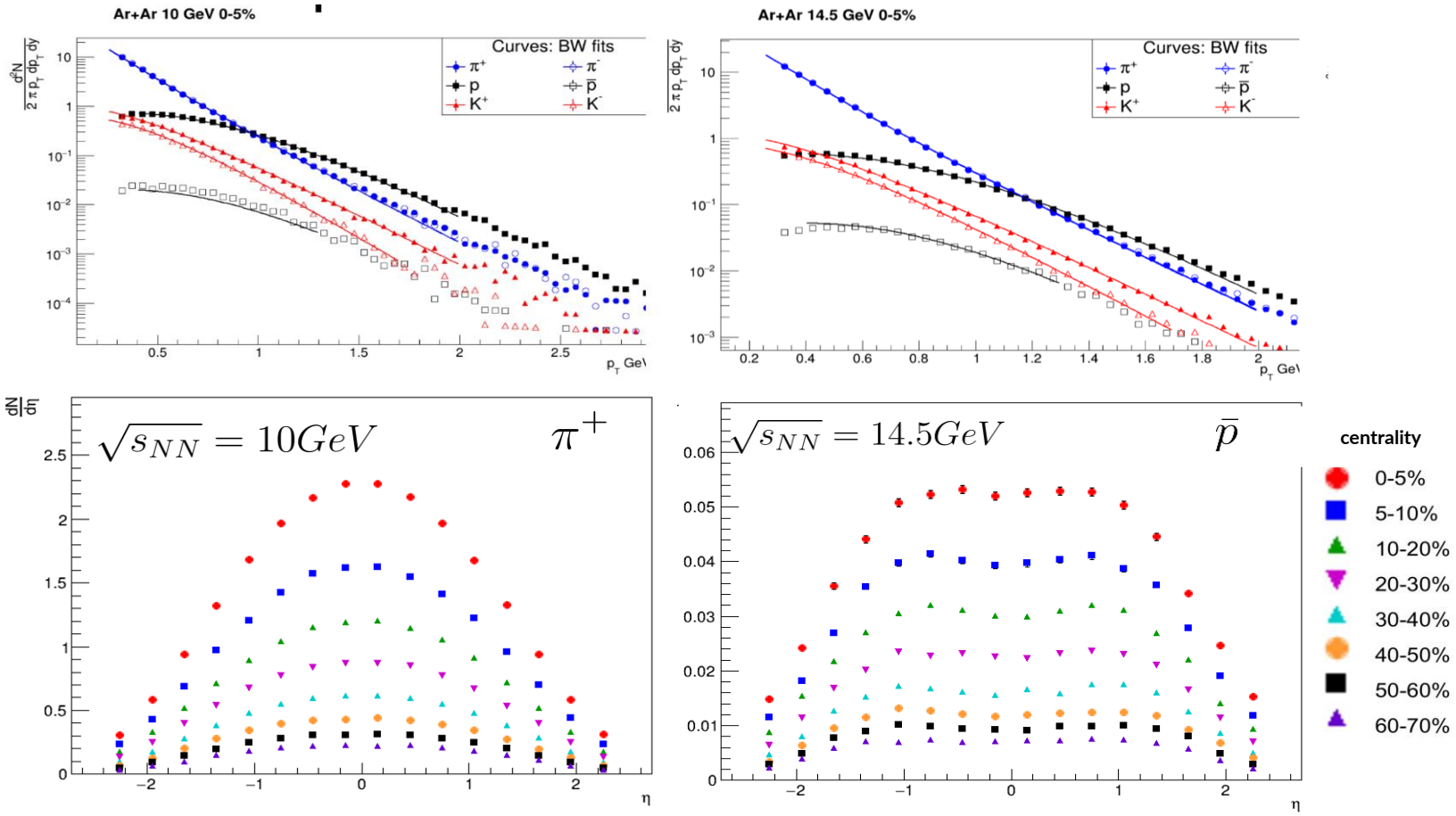
Momentum resolution is about **3.6%** in pp collisions.

Ion physics at SPD: spectra

Yields and p_T spectra of of identified hadrons in Ar+Ar collision

UrQMD, Ar+Ar, $\sqrt{s_{NN}}$ = 4, 10, 14.5 GeV

~ 10M events



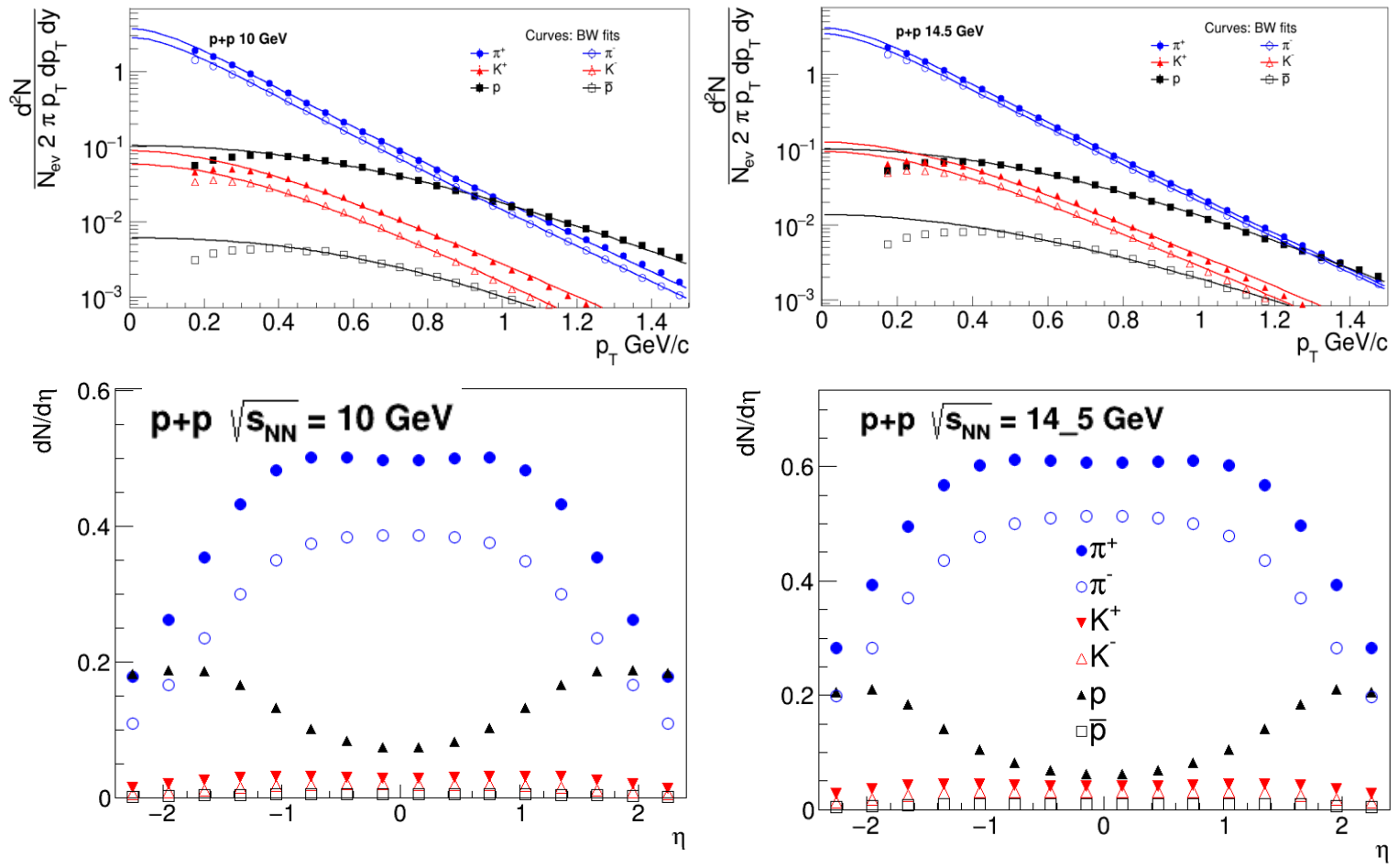
Spectra and yields of identified hadrons allow to get values of freeze-out and that may provide information about the temperature of the system and chemical potentials.

Ion physics at SPD: spectra

Yields and p_T spectra of of identified hadrons in p+p collision

UrQMD, Ar+Ar, $\sqrt{s_{NN}}$ = 4, 10, 14.5, 27 GeV

~ 10M events



Spectra and yields of identified hadrons allow to get values of freeze-out and that may provide information about the temperature of the system and chemical potentials.

Ion physics at SPD: directed flow

v_1 of identified hadrons for cent 0-10%, 10-40% and 40-80%

UrQMD, O+O, $\sqrt{s_{NN}}$ = 6 GeV, **~ 64M events**

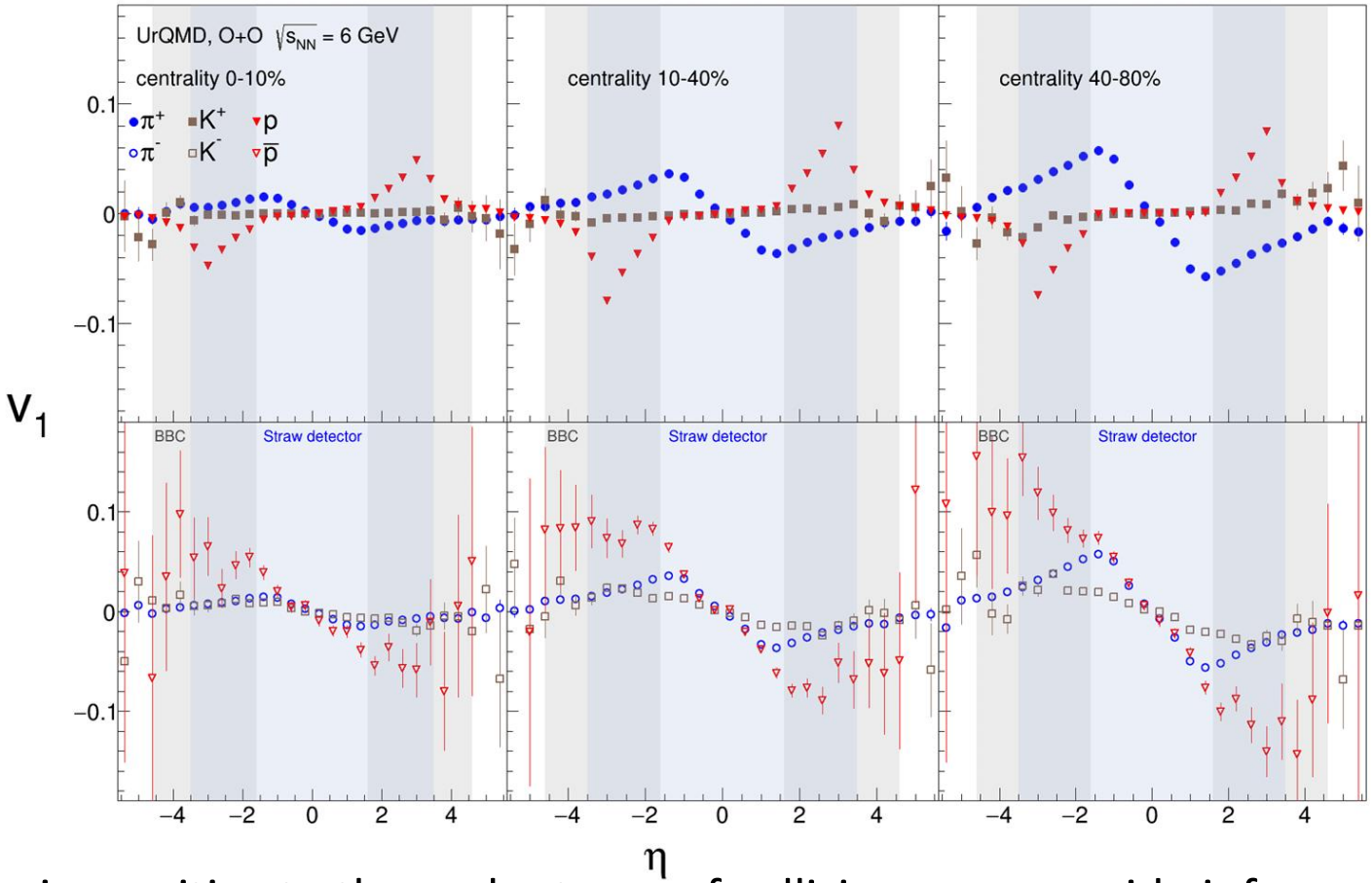
ST (barrel and end-caps) |η| < 3.5 and BBC 1.6 <|η|< 4.6

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos(n(\phi-\Psi_{RP}))\right)$$

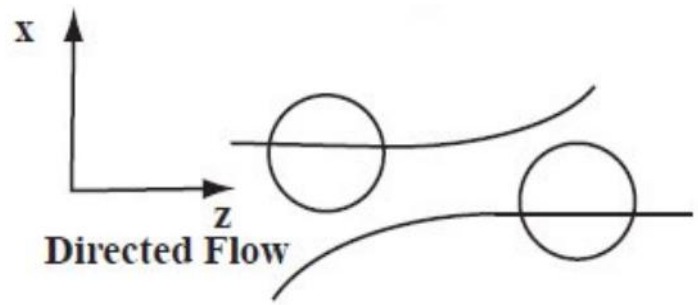
$$v_n = \langle \cos[n(\phi_i - \Psi_{RP})] \rangle$$

$$v_1 = \langle \cos(\phi) \rangle$$

(in this case)

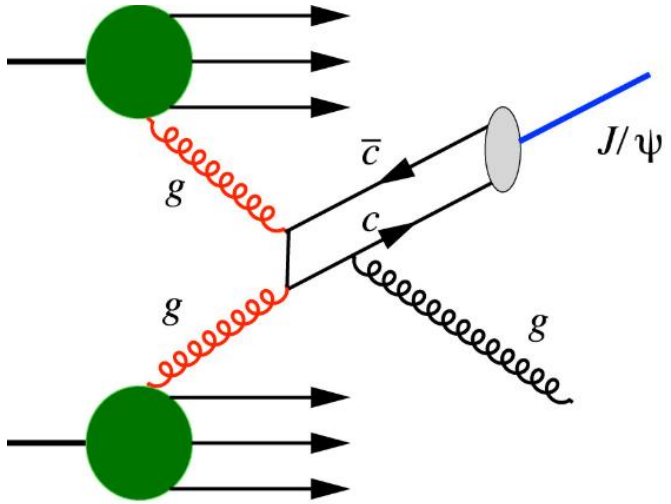


Directed flow sensitive to pressure gradients on early stages of collisions



v_n is sensitive to the early stages of collision, may provide information of transport properties: EOS, η/s, ζ/s, etc.

Angular coefficients in J/Ψ events using lepton pairs in pp

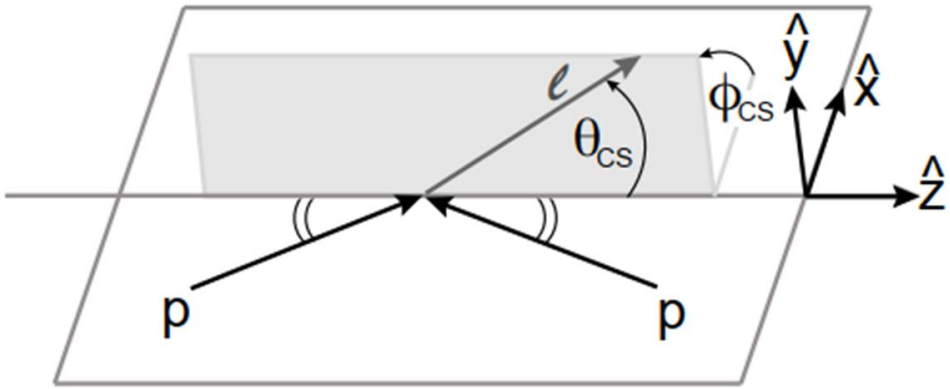


J/ψ → $\mu^+ \mu^-$; BF = 5.96 ± 0.03%, Γ = 304 ± 9 keV

$$\frac{d\sigma}{dp_T dy dm d\cos\theta\, d\varphi} = \frac{3}{16\pi}\frac{d\sigma^{U+L}}{dp_T dy dm}\left[(1+\cos^2\theta) + \frac{1}{2}A_0(1-3\cos^2\theta) + A_1 \sin 2\theta \cos\varphi + \frac{1}{2}A_2 \sin^2\theta \cos 2\varphi\right]$$

$$A_0 = \frac{2\, d\sigma^L}{d\sigma^{U+L}}, \qquad A_1 = \frac{2\sqrt{2}\, d\sigma^I}{d\sigma^{U+L}}, \qquad A_2 = \frac{4\, d\sigma^T}{d\sigma^{U+L}}$$

The Collins-Soper (CS) reference frame:
$\theta = \theta_{CS}, \varphi = \varphi_{CS}$



σ^L, σ^T, σ^I - the longitudinal, the transverse and the longitudinal-transverse interference cross sections.

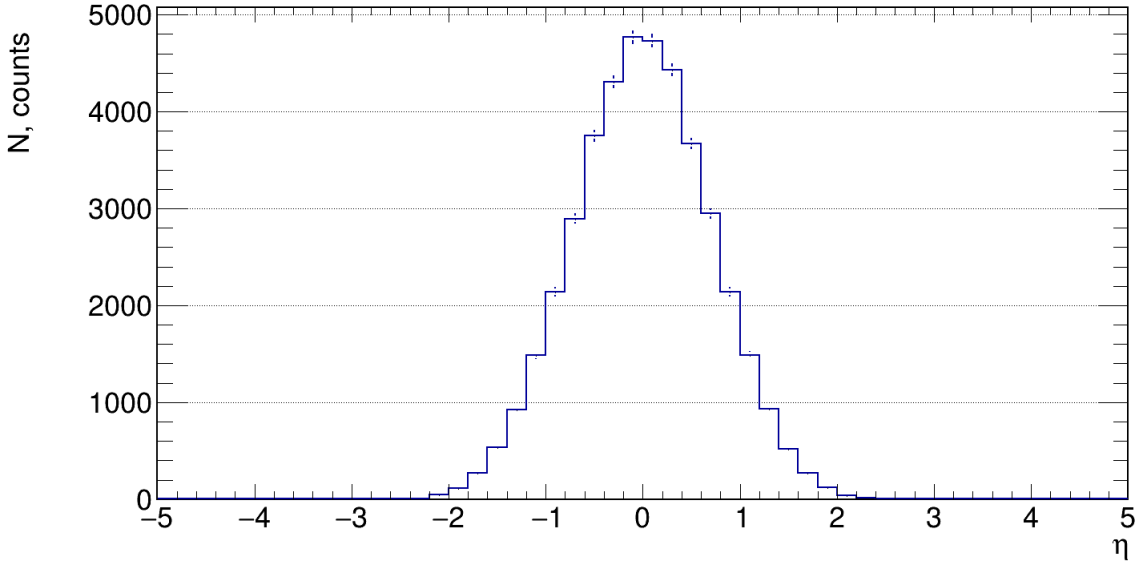
σ^{U+L} - the unpolarized production cross section.

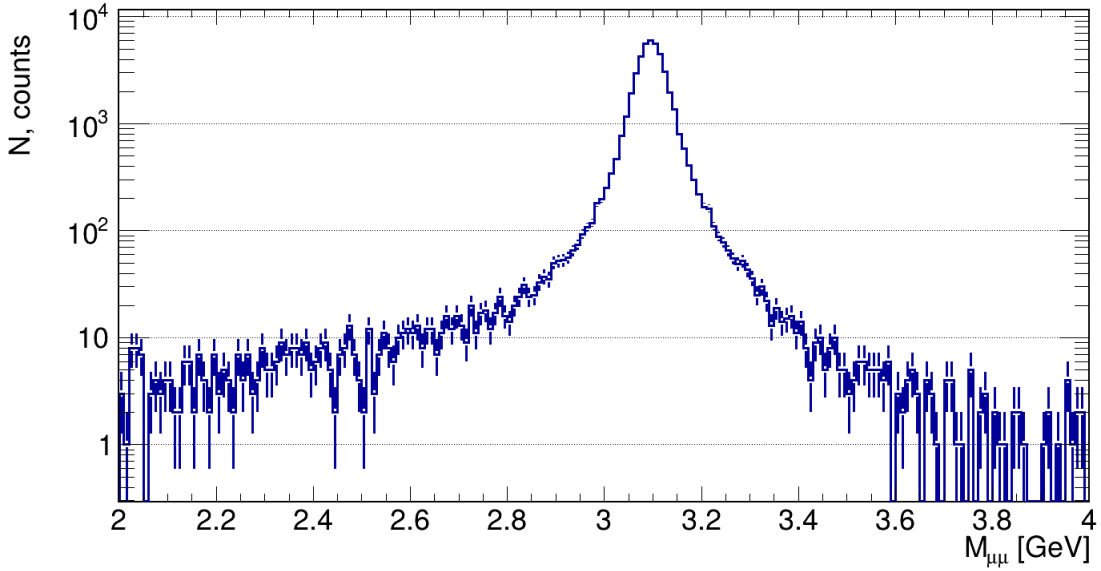
Mirkes E., Kim C. S. J/Ψ decay lepton distribution in hadronic collisions //Physics Letters B. – 1995. – Т. 346. – №. 1-2. – С. 124-128.

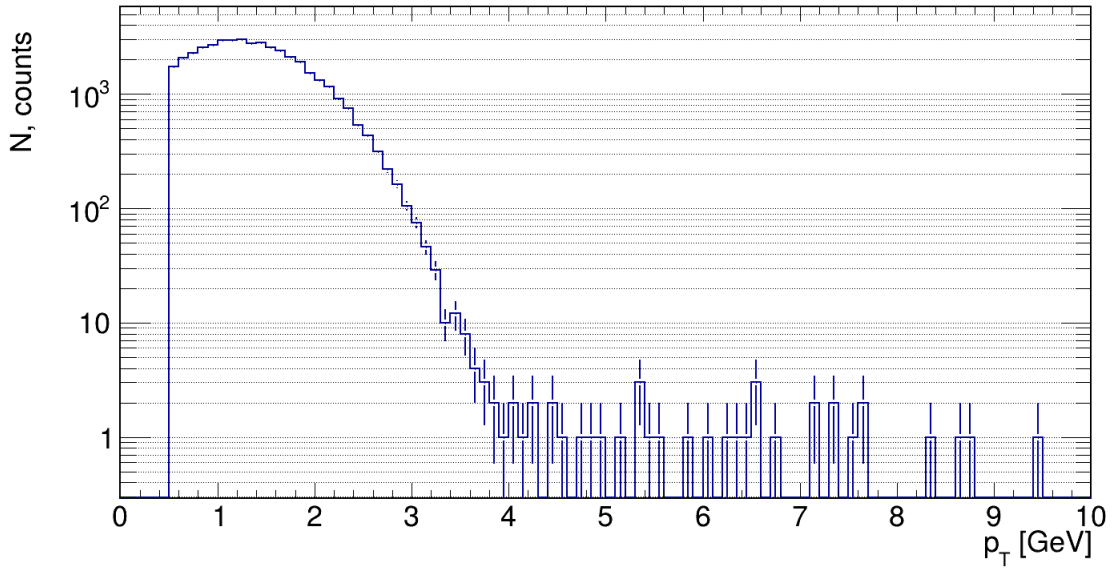
J/ψ kinematic distributions

- Using the Pythia8 generator, 100k events with $J/\psi \rightarrow \mu^+ \mu^-$ production in pp collisions at $\sqrt{s}$=10 GeV were simulated under the conditions of the first phase of the SPD experiment.

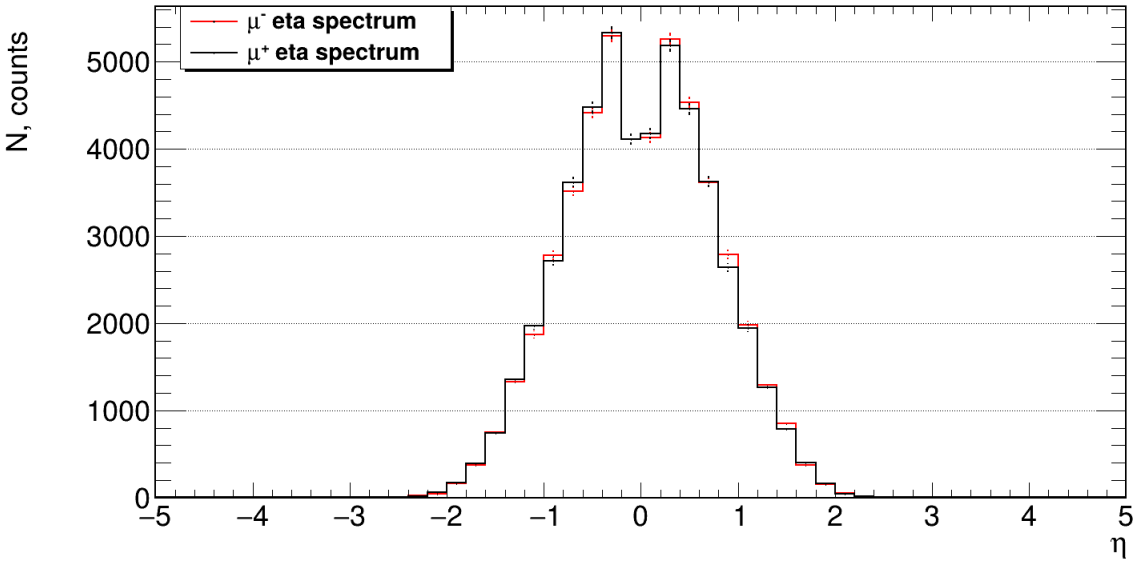
- The KFParticle package was used to reconstruct J/ψ.
- When selecting muons, their PDG codes and the type of the parent particle were checked.

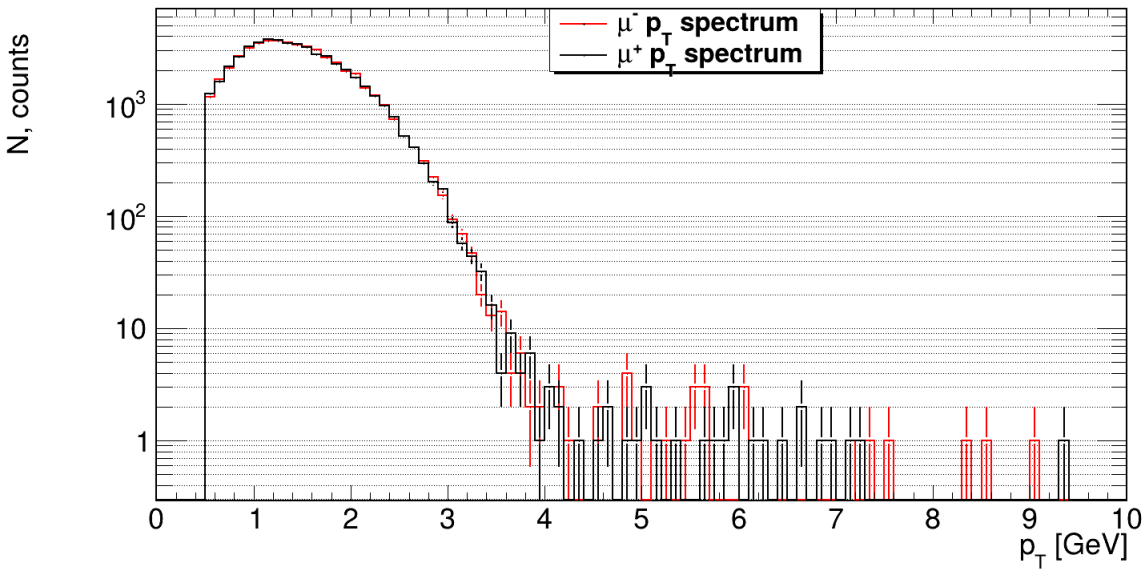


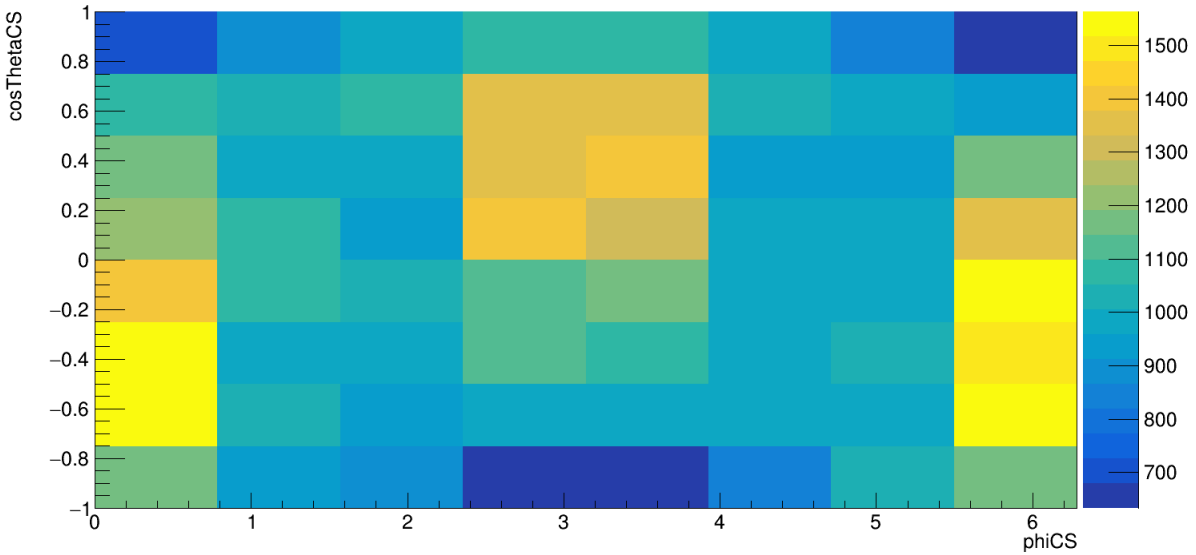




Muon kinematic distributions from J/ψ decays







When selecting muons, only their PDG codes were required.

Current status:

working on implementing folded polynomial templates into the analysis code.

Conclusions

MEPhI group contributes to detector construction and physics studies.

- BBC detector:
  - BBC detector developments are performed in close cooperation with the JINR group.
  - First estimation of the BBC occupancies was obtained.

- Physics analyses:
  - First look at the straw tracker performance for different colliding nuclei systems: occupancies, track momentum resolution.
  - Spectra for the $\pi^{\pm}$, $K^{\pm}$, p and anti-p were constructed for Ar+Ar and pp at SPD energies using UrQMD.
  - Directed flow v_1 of charged hadrons was estimated using UrQMD.
  - Status of J/ψ angular coefficients study was presented.

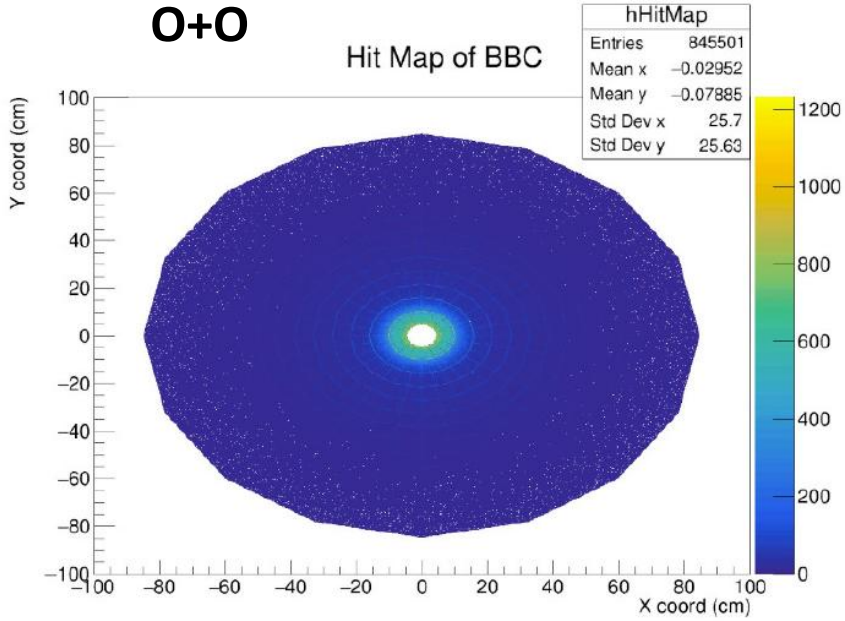
and many more is in progress!

Back-up slides

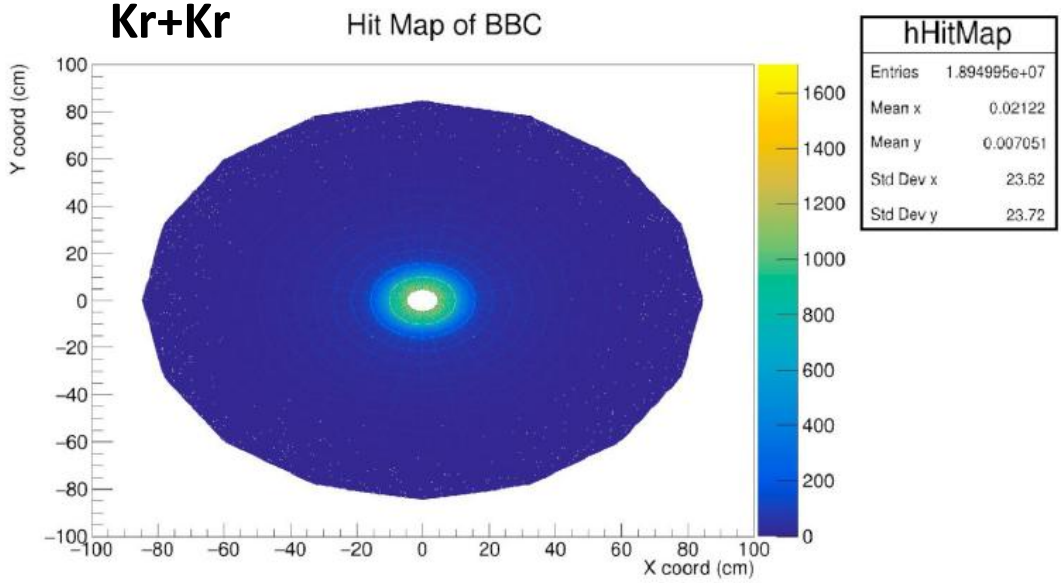
BBC occupancies for different colliding systems

- Occupancies with O+O, Kr+Kr, Xe+Xe systems
- UrQMD generator, full SPDRoot chain, minbias 50 kEvents
- sqrt(s_{NN})=**6 GeV**

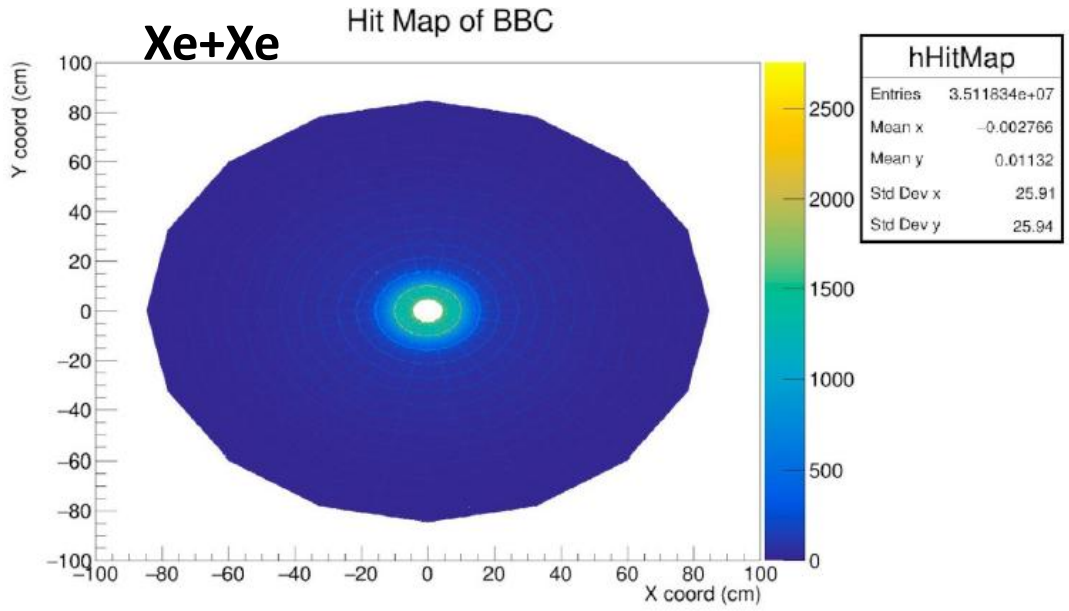
O+O



Kr+Kr



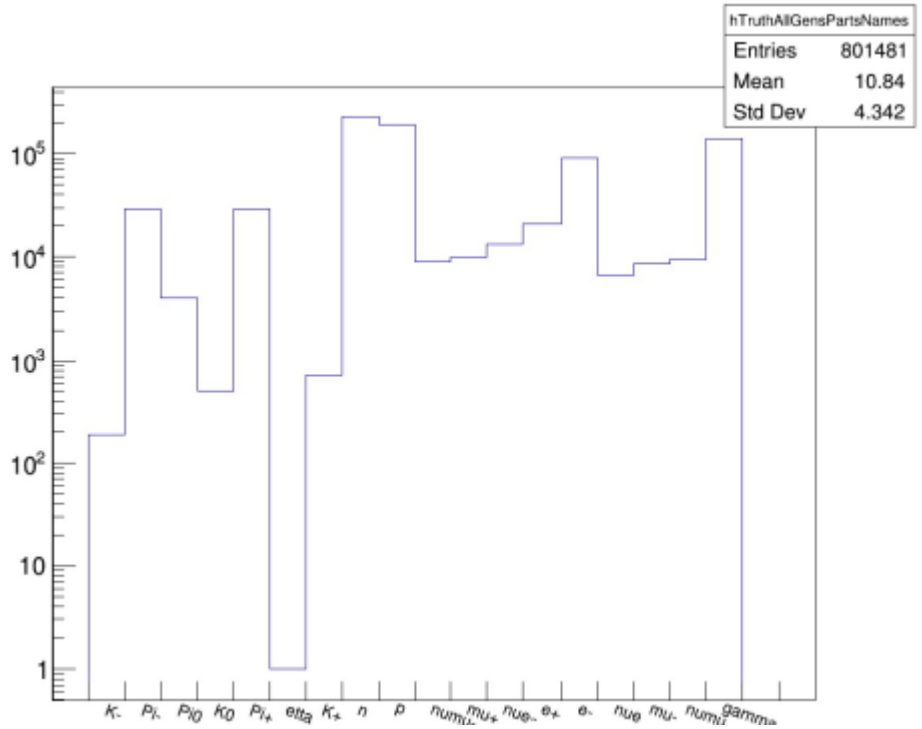
Xe+Xe

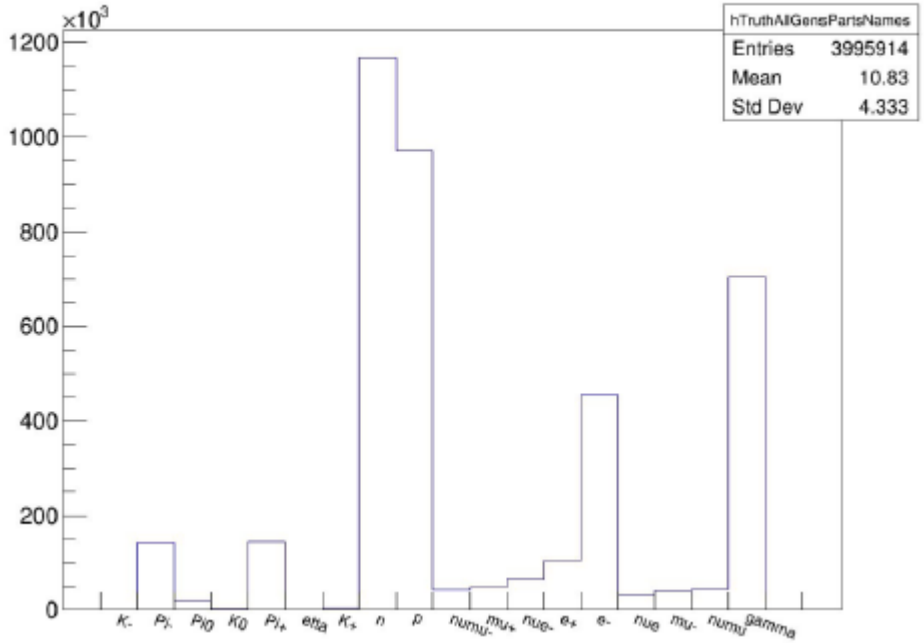


BBC occupancies for different colliding systems: final particles

O+O collisions

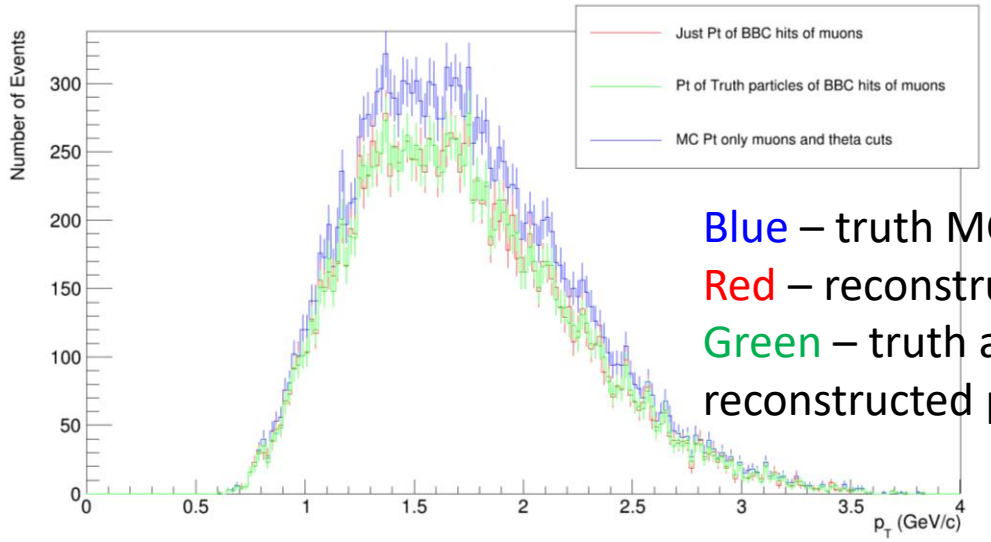
sqrt(s_{NN})=**6 GeV (left);** sqrt(s_{NN})=**12 GeV (right)**



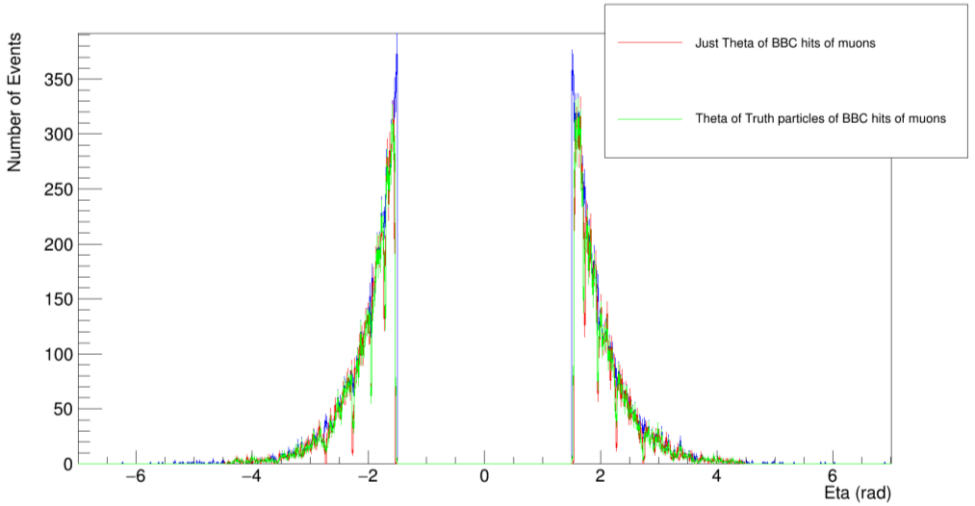


BBC geometry performance

Protons from Minbias (pp), 1.5<|η|<4.5

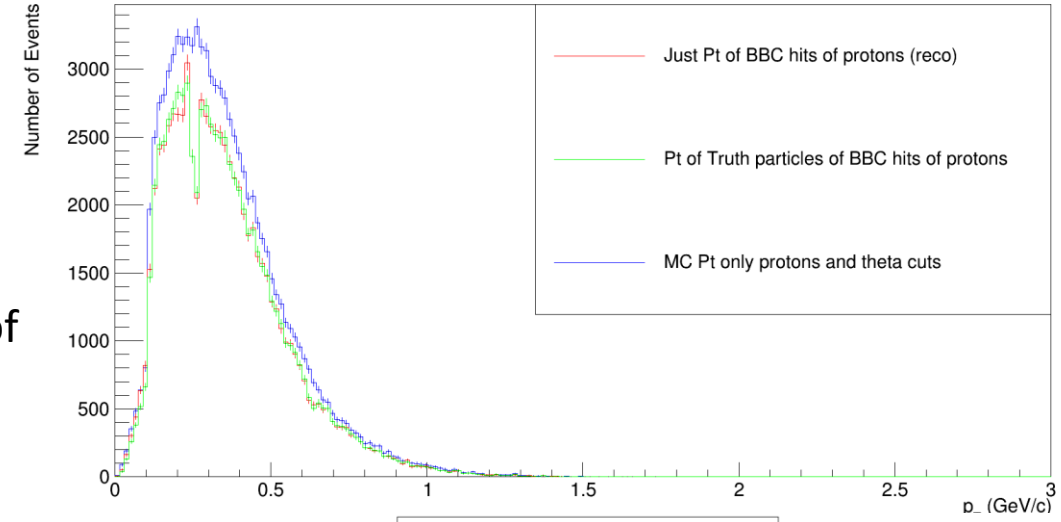


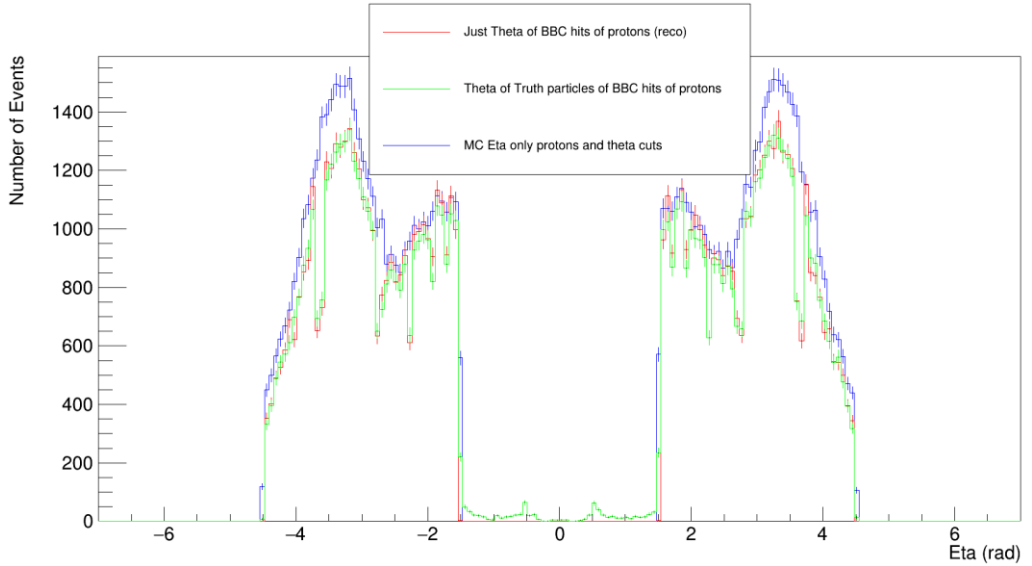
Blue – truth MC
Red – reconstruction
Green – truth analogs of reconstructed particle



Reco efficiency: 86%

Muons from J/Ψ (pp), 1.5<|η|<4.5

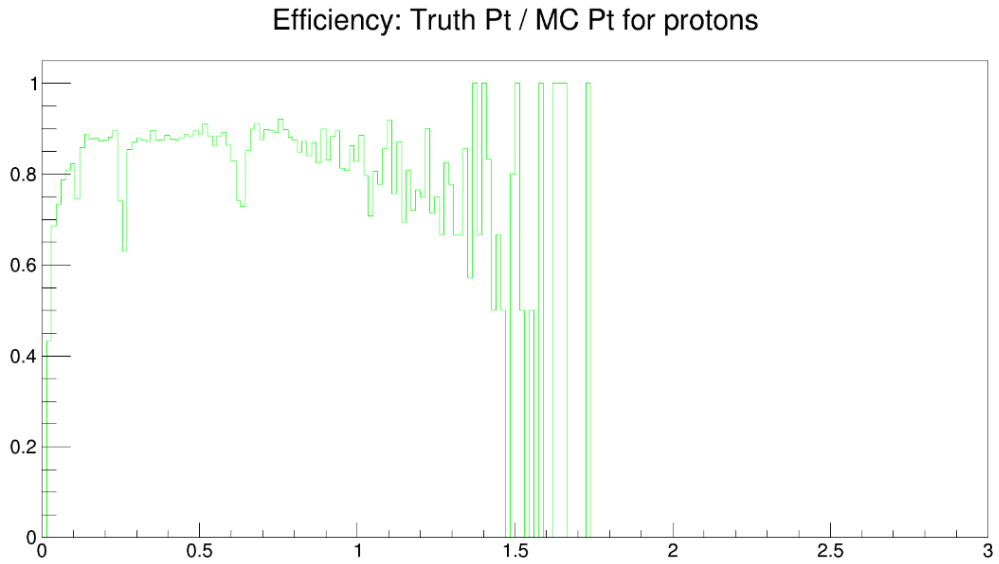


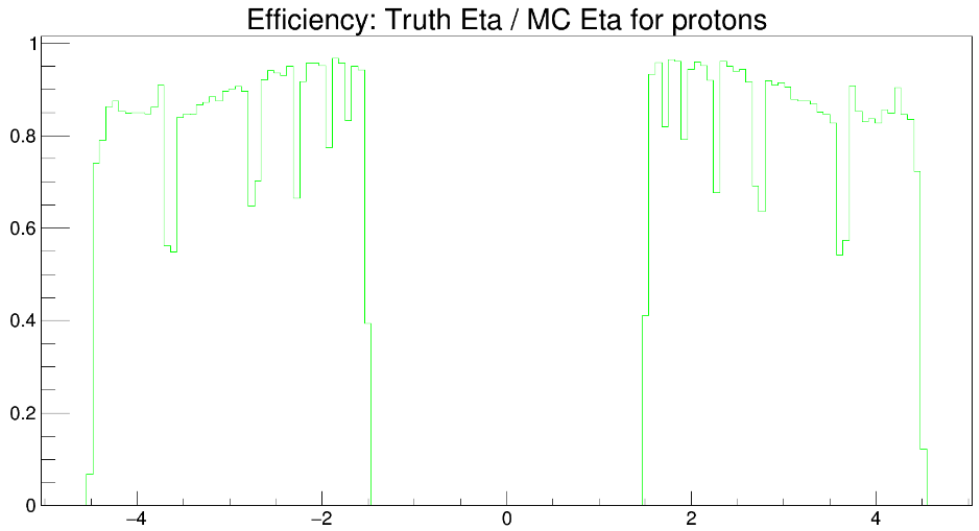


Reco efficiency: 85%

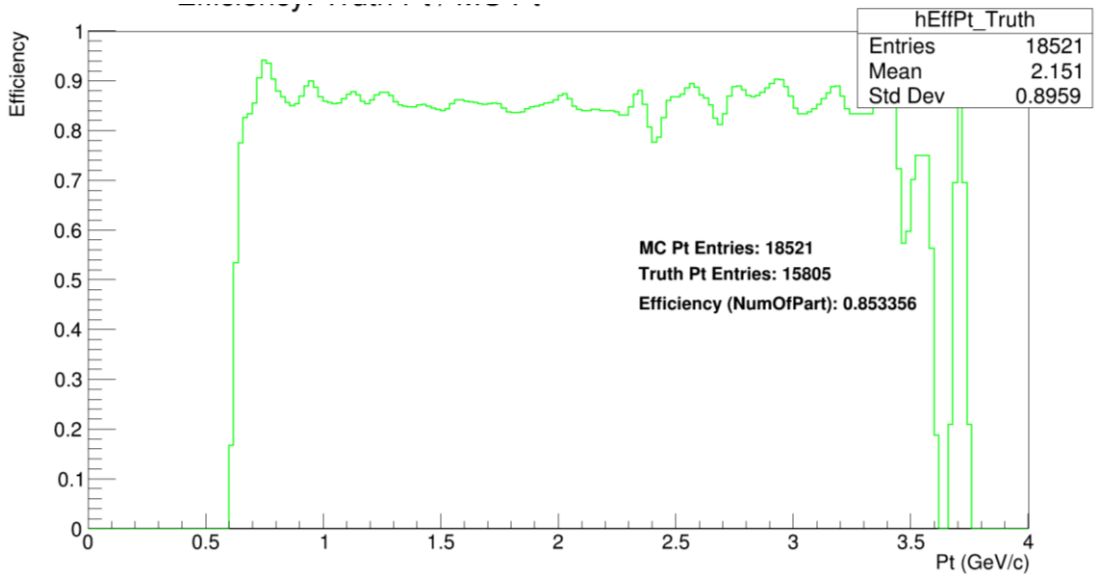
BBC geometry performance

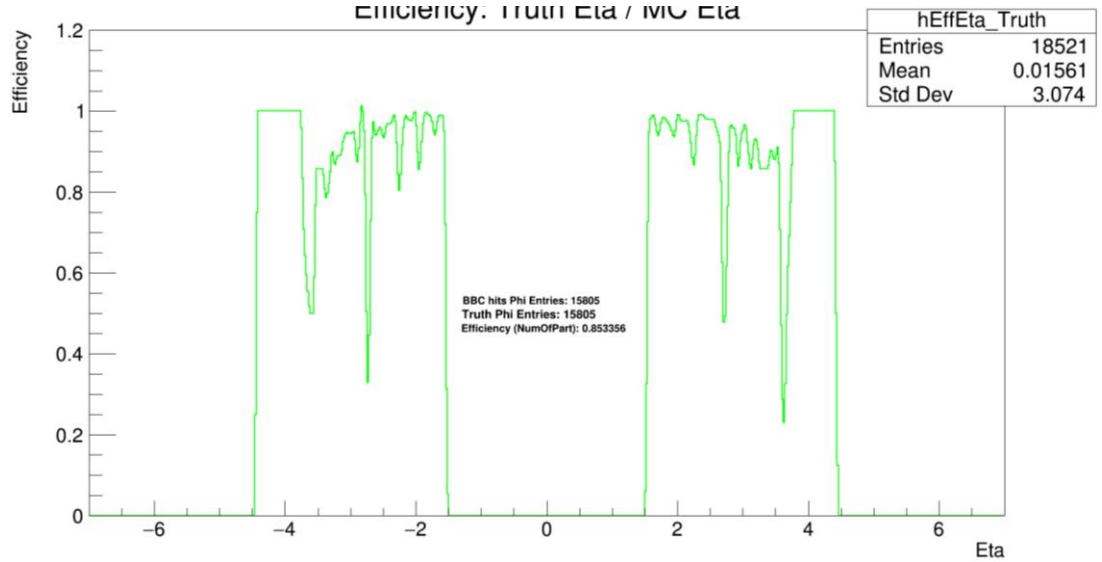
Reco efficiency for protons from Minbias (from pp)





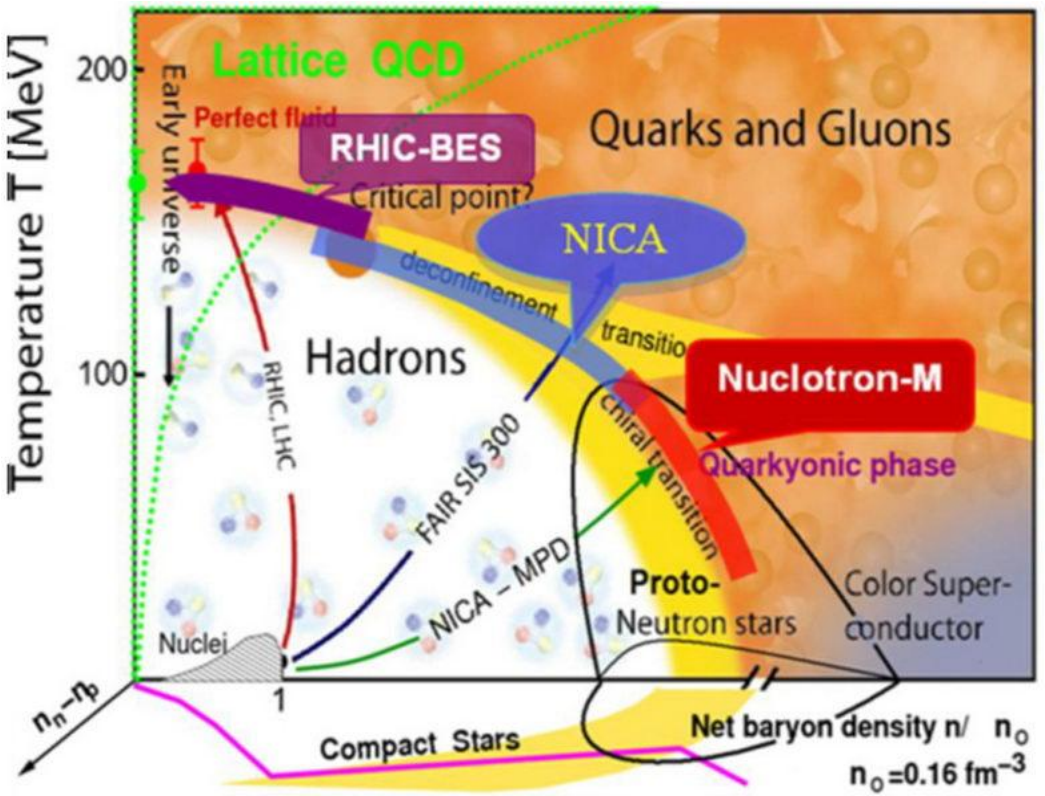
Reco efficiency for muons from J/Ψ (from pp)





Ion physics at SPD

- Searching for the critical point and phase boundary in the QCD phase diagram is currently a focus of experimental and theoretical nuclear physics research.
- Spectra and yields of identified hadrons allow to get values of freeze-out such as T, μB and may provide information about particle production mechanisms.
- v_n sensitive to the early stages of collision, may provide information of transport properties: EOS, η/s, ζ/s, etc.
- Global hyperon polarization as a probe of vortical structure.
- Heavy flavor production.

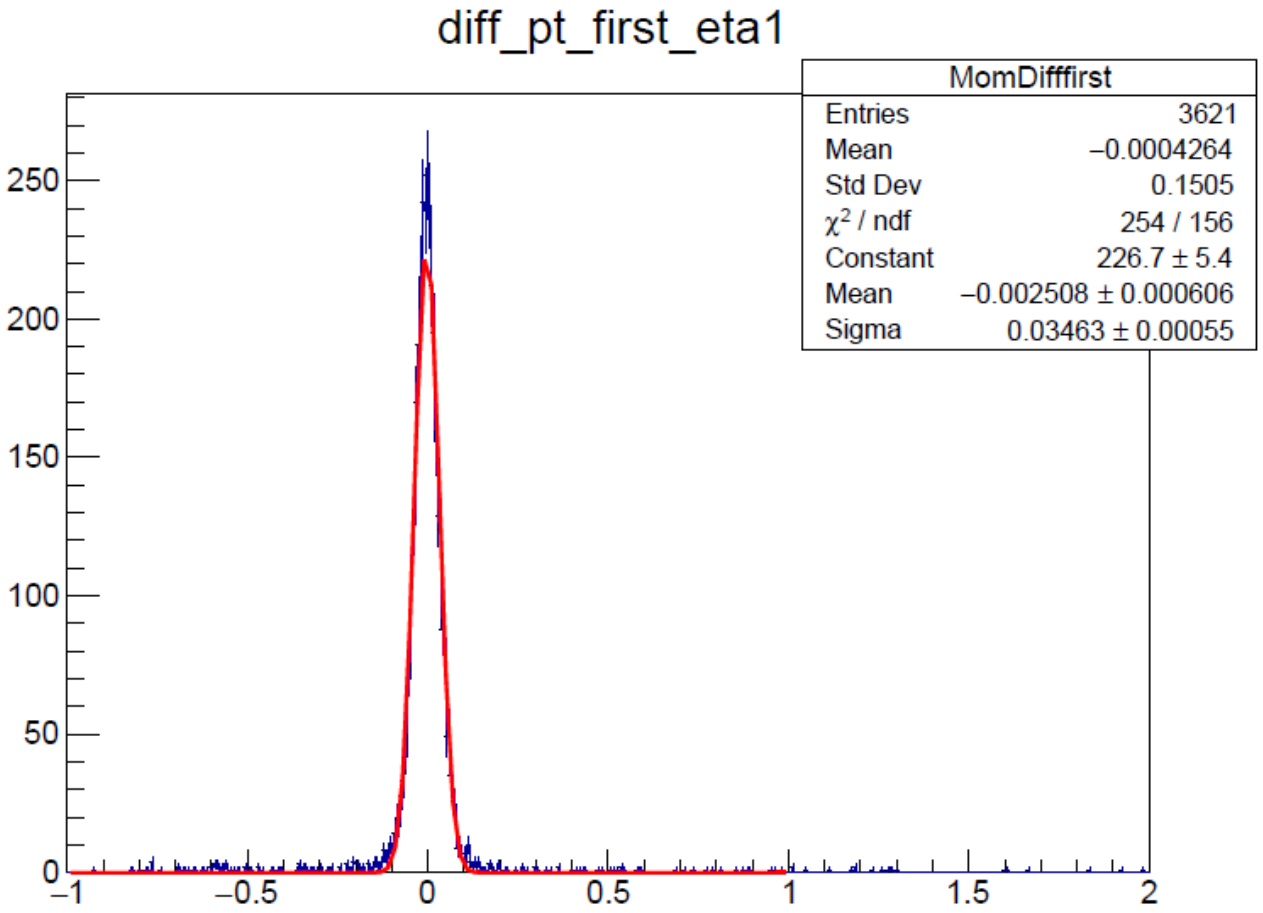


Straw tracker track reconstruction: pp, additional plots

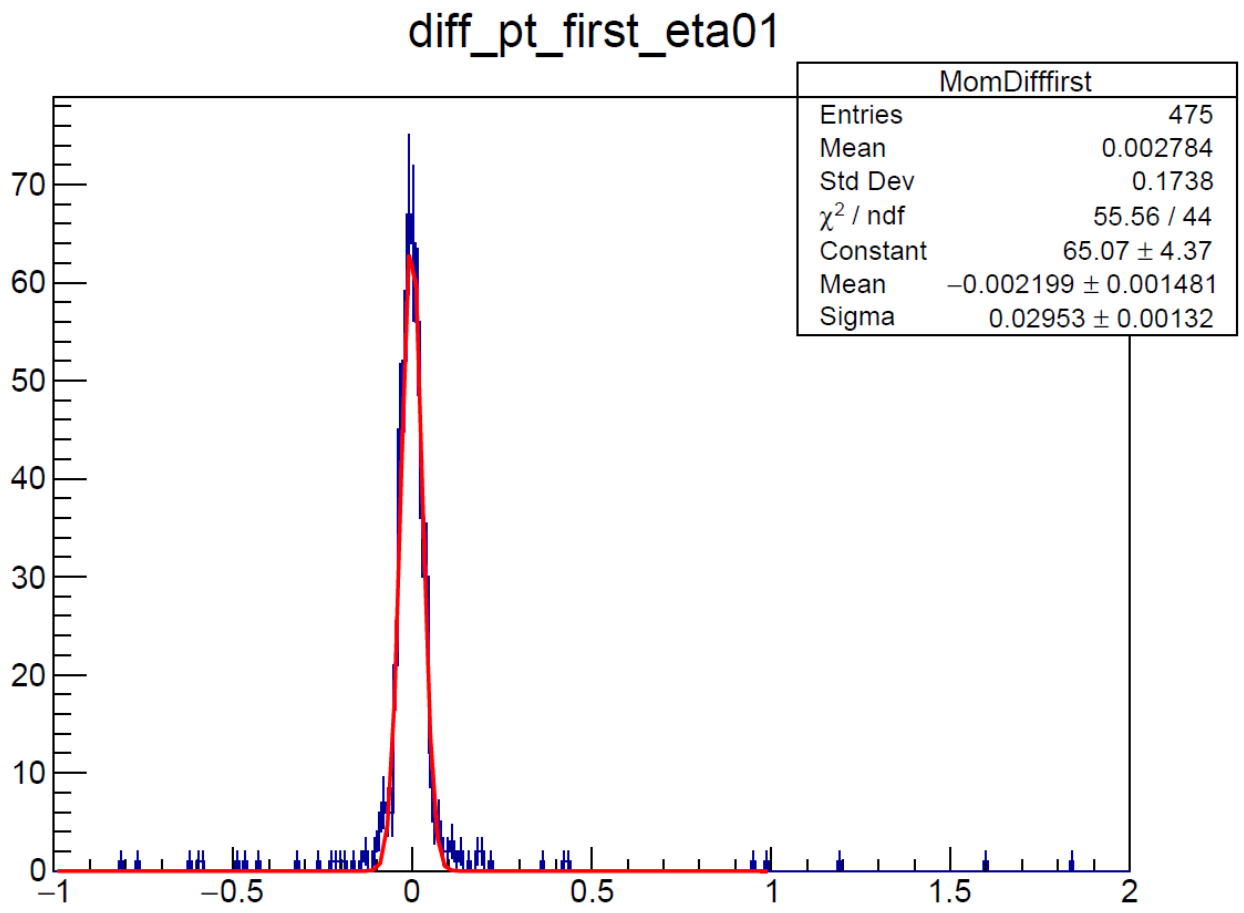
"First" tracks are taken

Difference=(reco_pT-truth_pT)/truth_pT

|η|<1



|η|<0.1

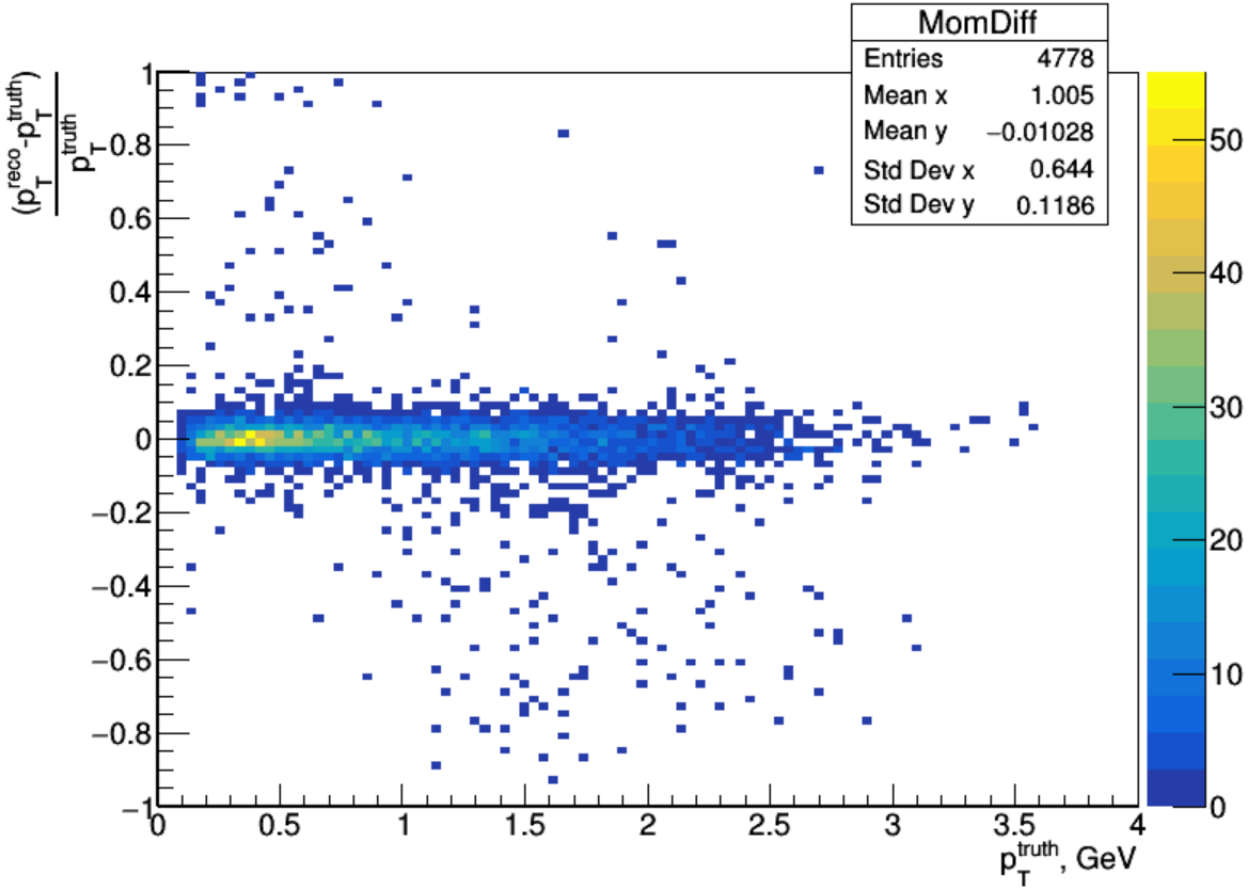


Straw tracker track reconstruction: pp, additional plots

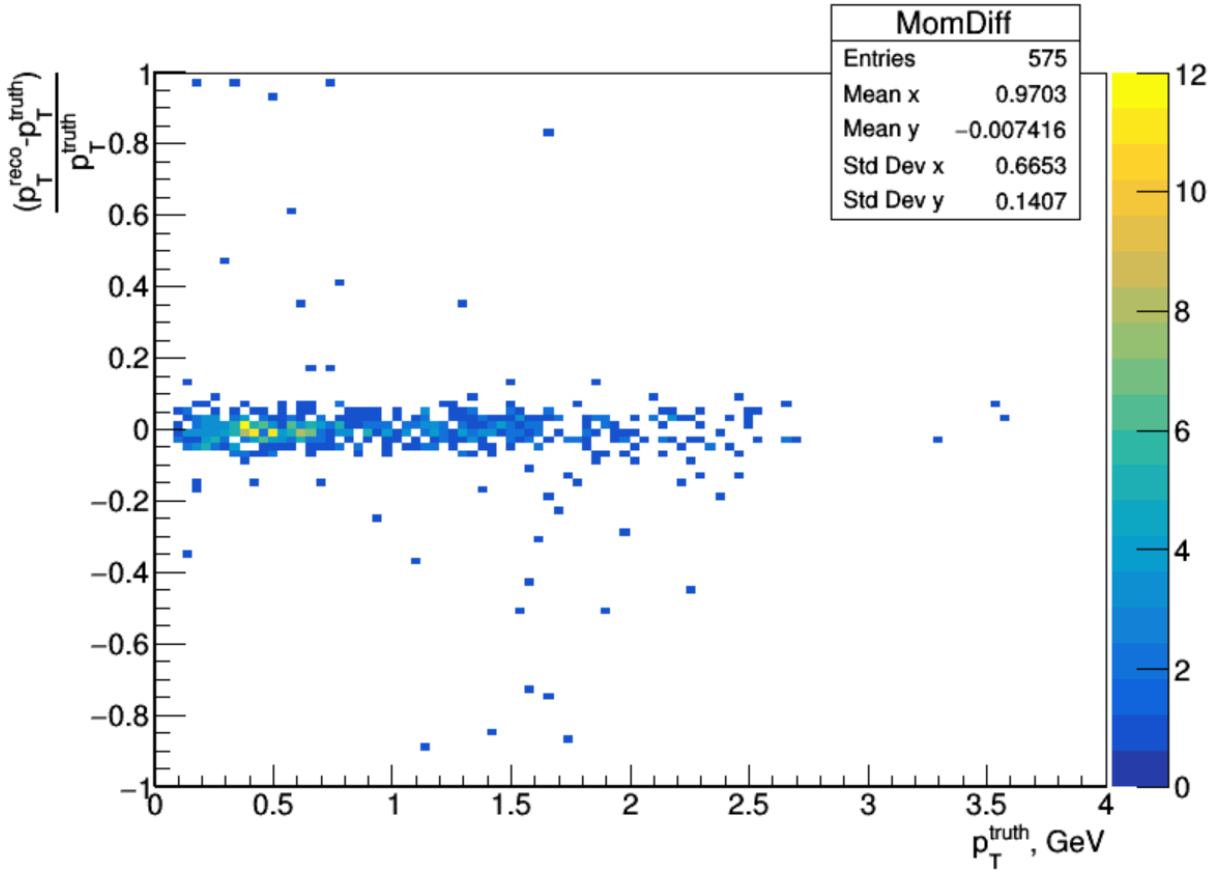
"First" tracks are taken

Difference=(reco_pT-truth_pT)/truth_pT

|η|<1



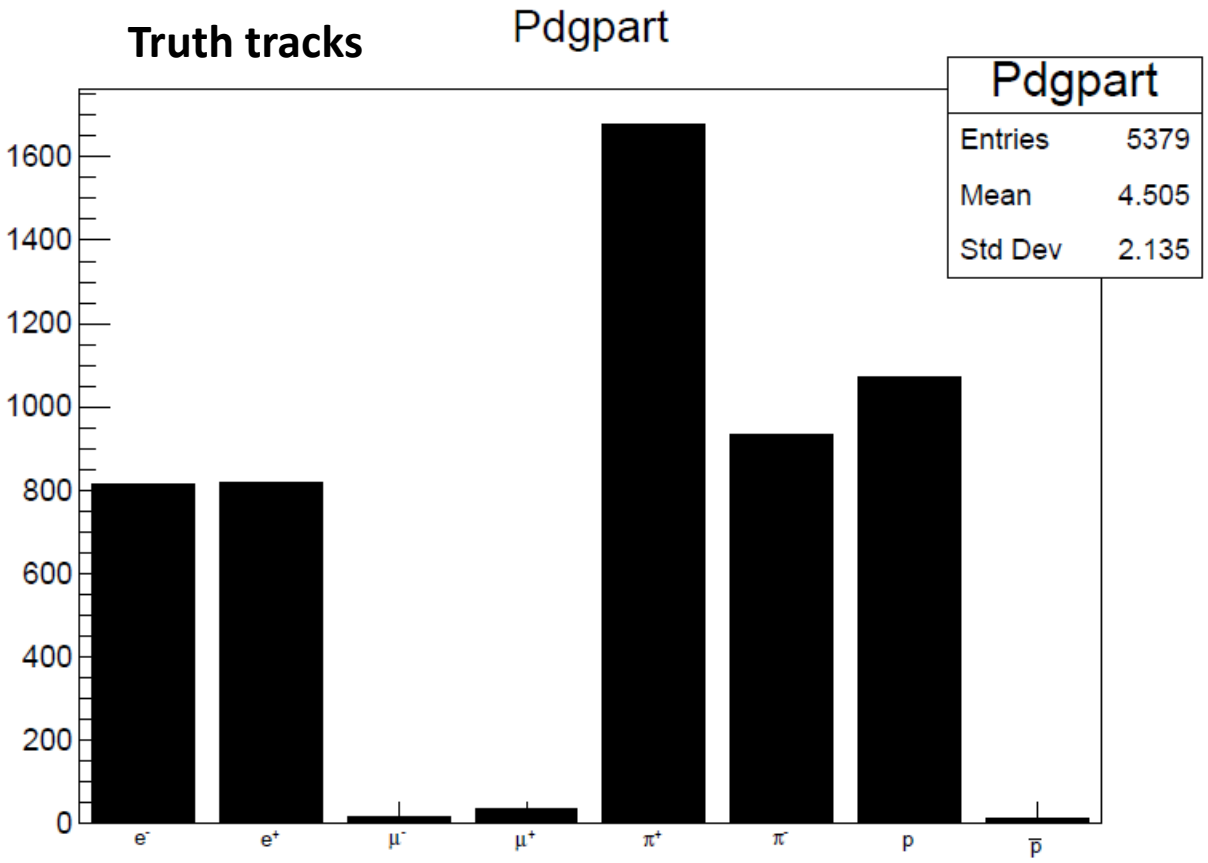
|η|<0.1



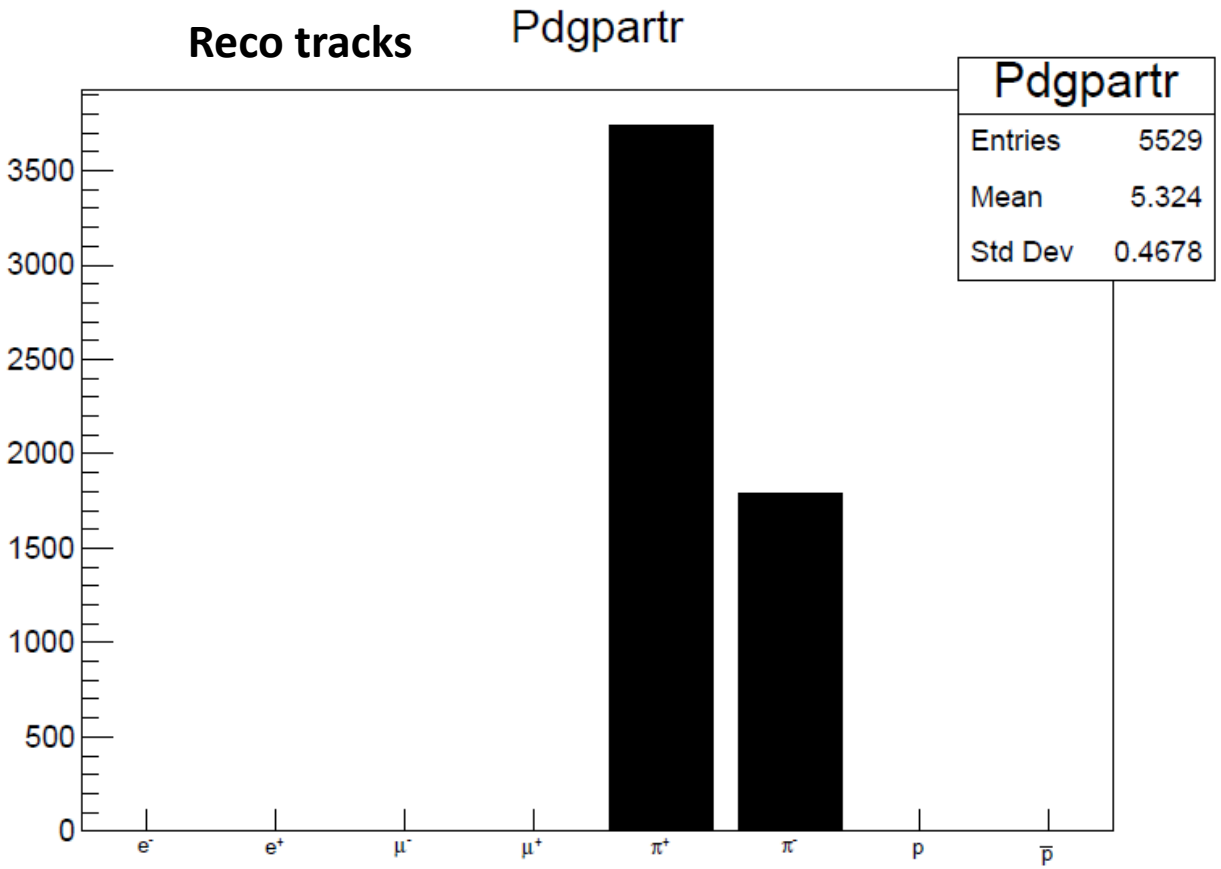
Straw tracker track reconstruction: pp, additional plots

"First" tracks are taken

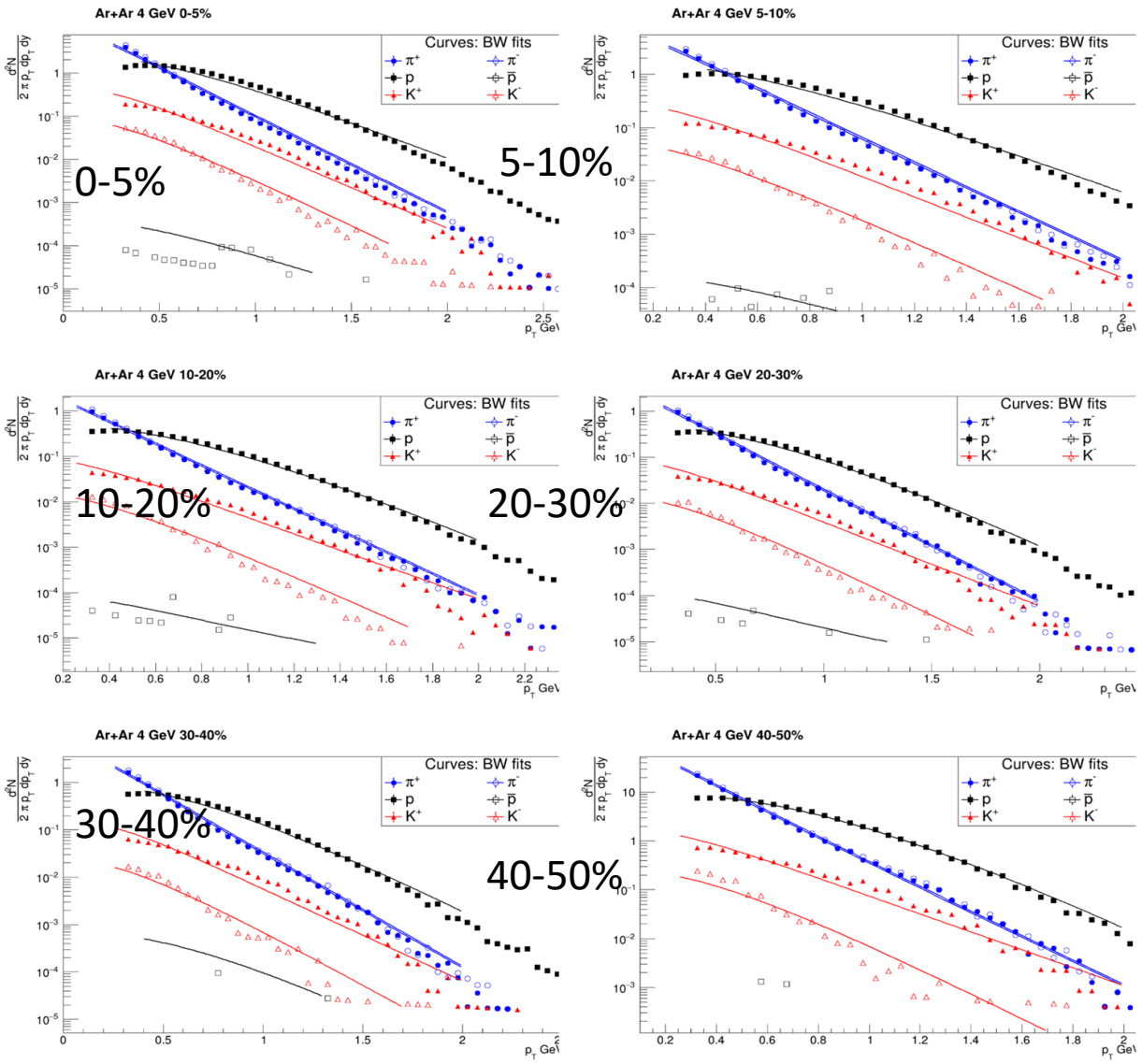
Truth tracks



Reco tracks



Ion physics at SPD: additional slides

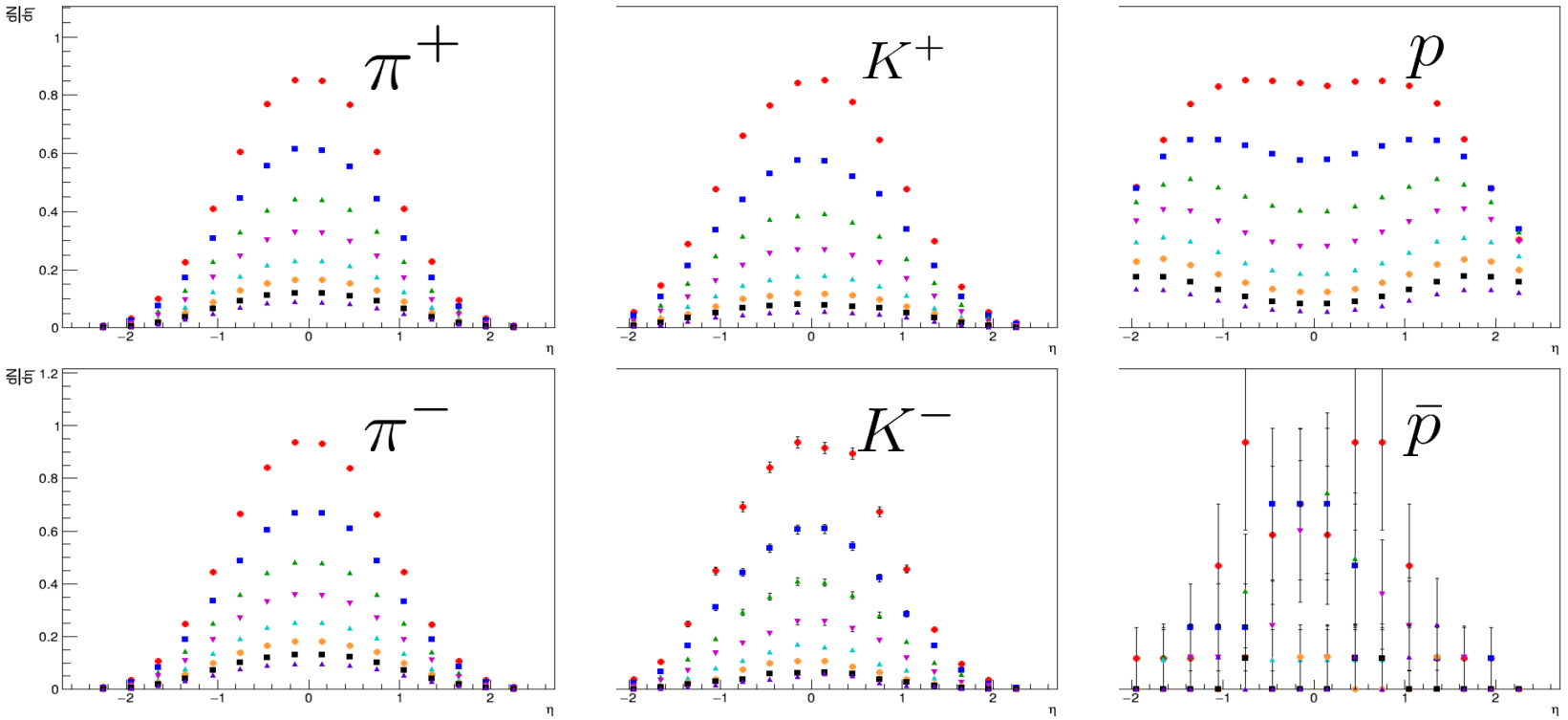


$$\sqrt{s_{NN}} = 4GeV$$

Centrality (%)	β	T (MeV)
0–5%	0.2926 ± 0.0004	145.522 ± 0.03
5–10%	0.307 ± 0.001	138.57 ± 0.03
10–20%	0.3775 ± 0.0007	122.84 ± 0.03
20–30%	0.3703 ± 0.0008	121.86 ± 0.03
30–40%	0.326 ± 0.001	128.53 ± 0.04
40–50%	0.409 ± 0.001	103.64 ± 0.04
50–60%	0.443 ± 0.003	88.0 ± 1.0

Ion physics at SPD: additional slides

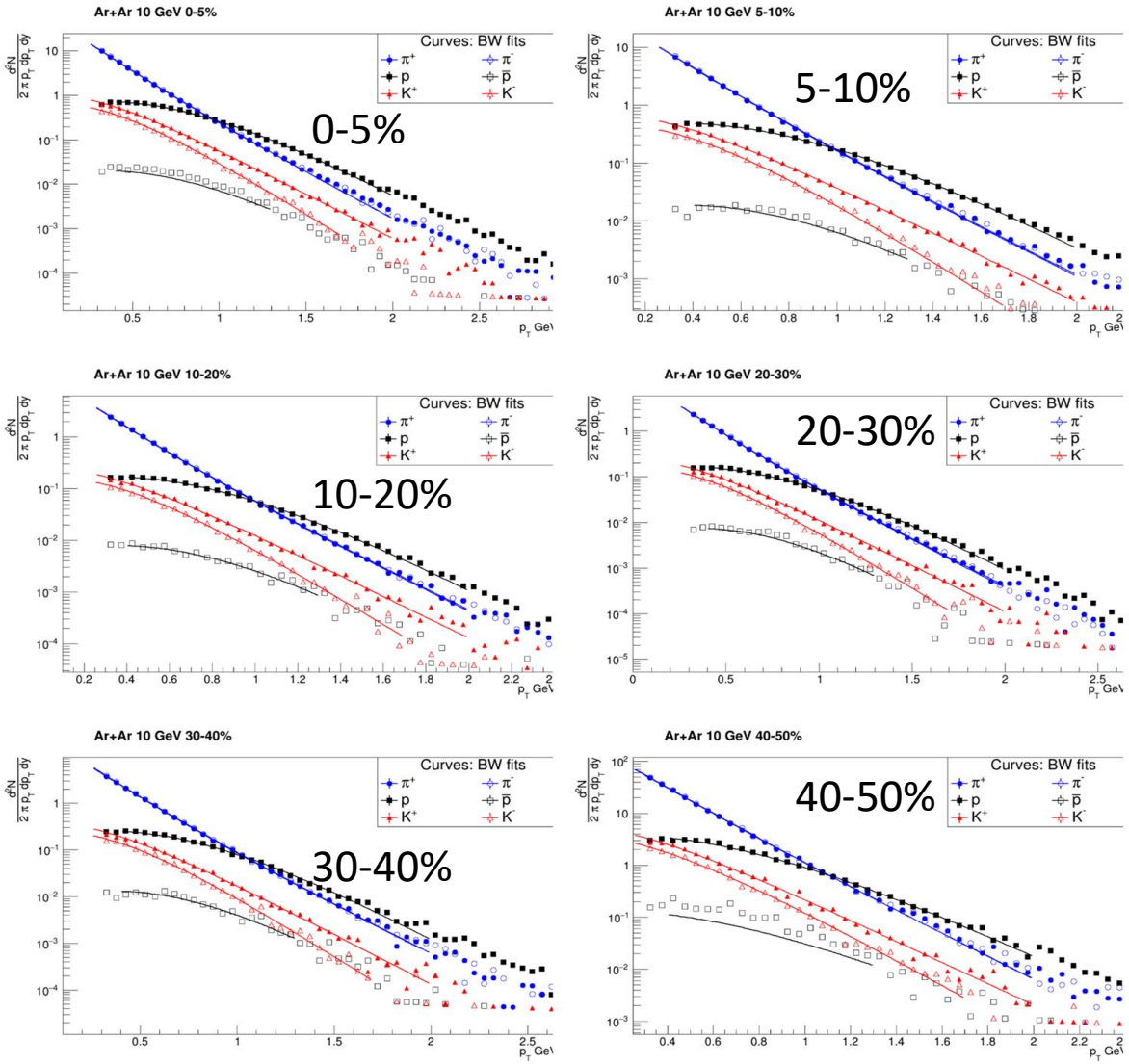
$$\sqrt{s_{NN}} = 4GeV$$



Centrality

- 0-5%
- 5-10%
- 10-20%
- 20-30%
- 30-40%
- 40-50%
- 50-60%
- 60-70%

Ion physics at SPD: additional slides

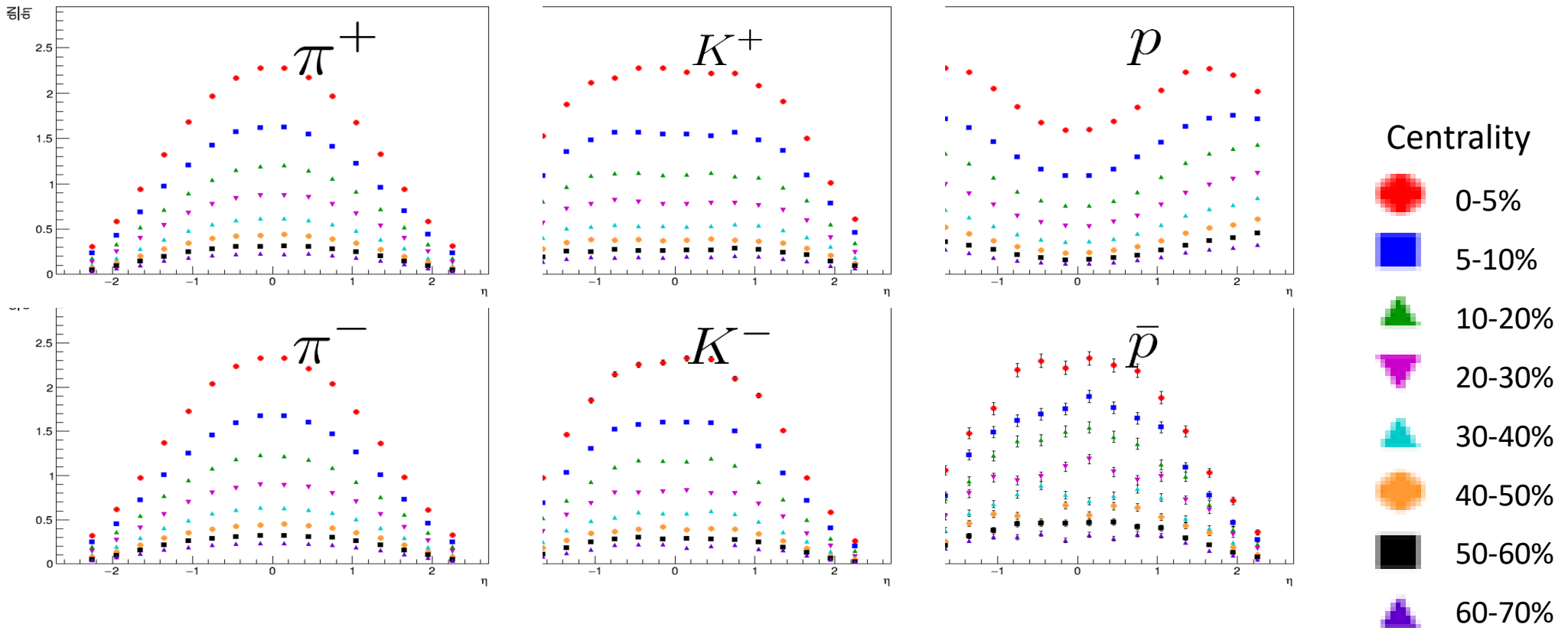


$$\sqrt{s_{NN}} = 10GeV$$

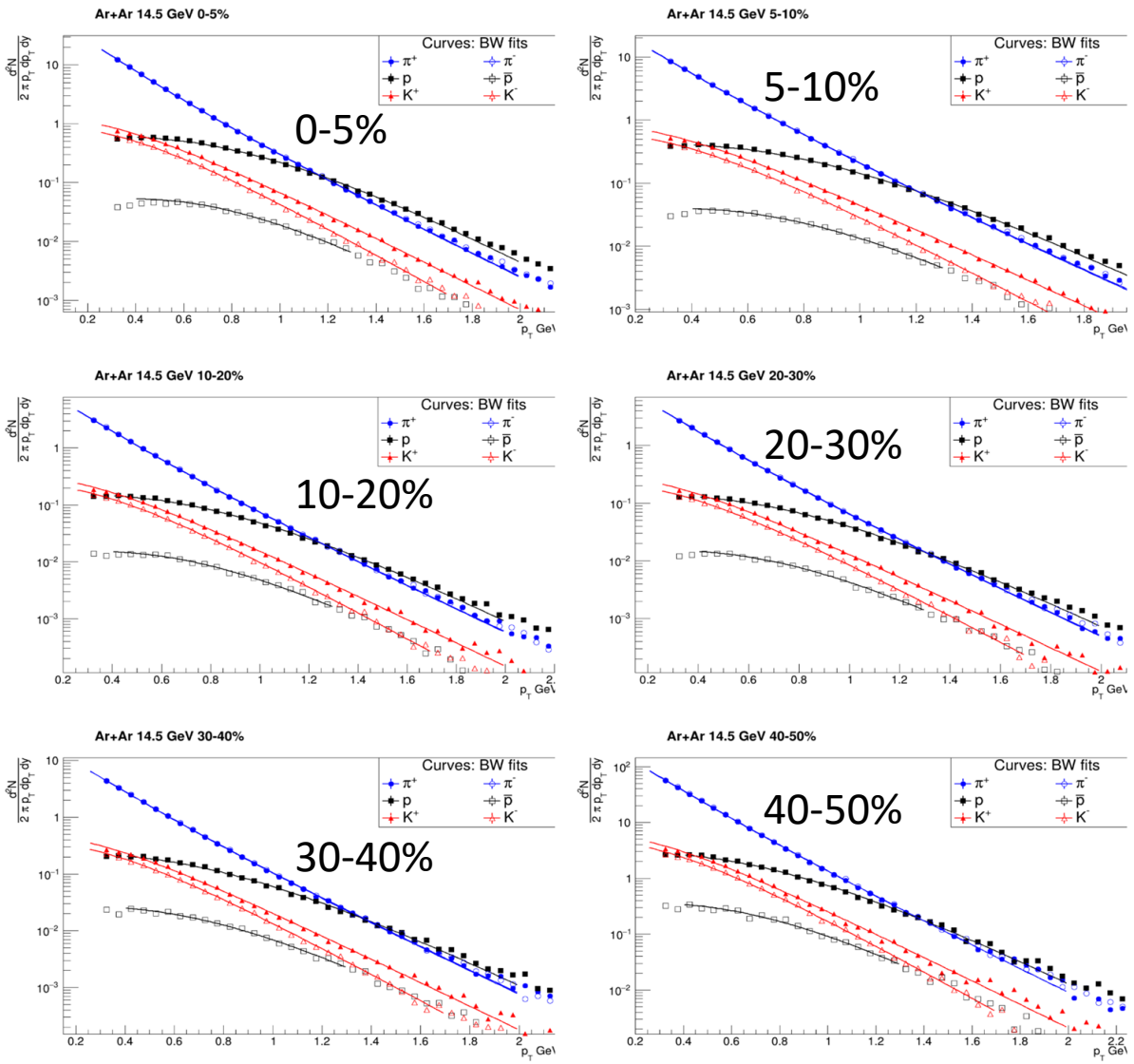
Centrality (%)	β	T (MeV)
0–5%	0.490 ± 0.001	93.3 ± 0.3
5–10%	0.487 ± 0.002	92.5 ± 0.3
10–20%	0.483 ± 0.003	88.0 ± 1.0
20–30%	0.474 ± 0.004	91.0 ± 1.0
30–40%	0.475 ± 0.004	91.4 ± 1.0
40–50%	0.422 ± 0.006	108.0 ± 1.0
50–60%	0.449 ± 0.008	96.0 ± 2.0

Ion physics at SPD: additional slides

$\sqrt{s_{NN}} = 10GeV$



Ion physics at SPD: additional slides

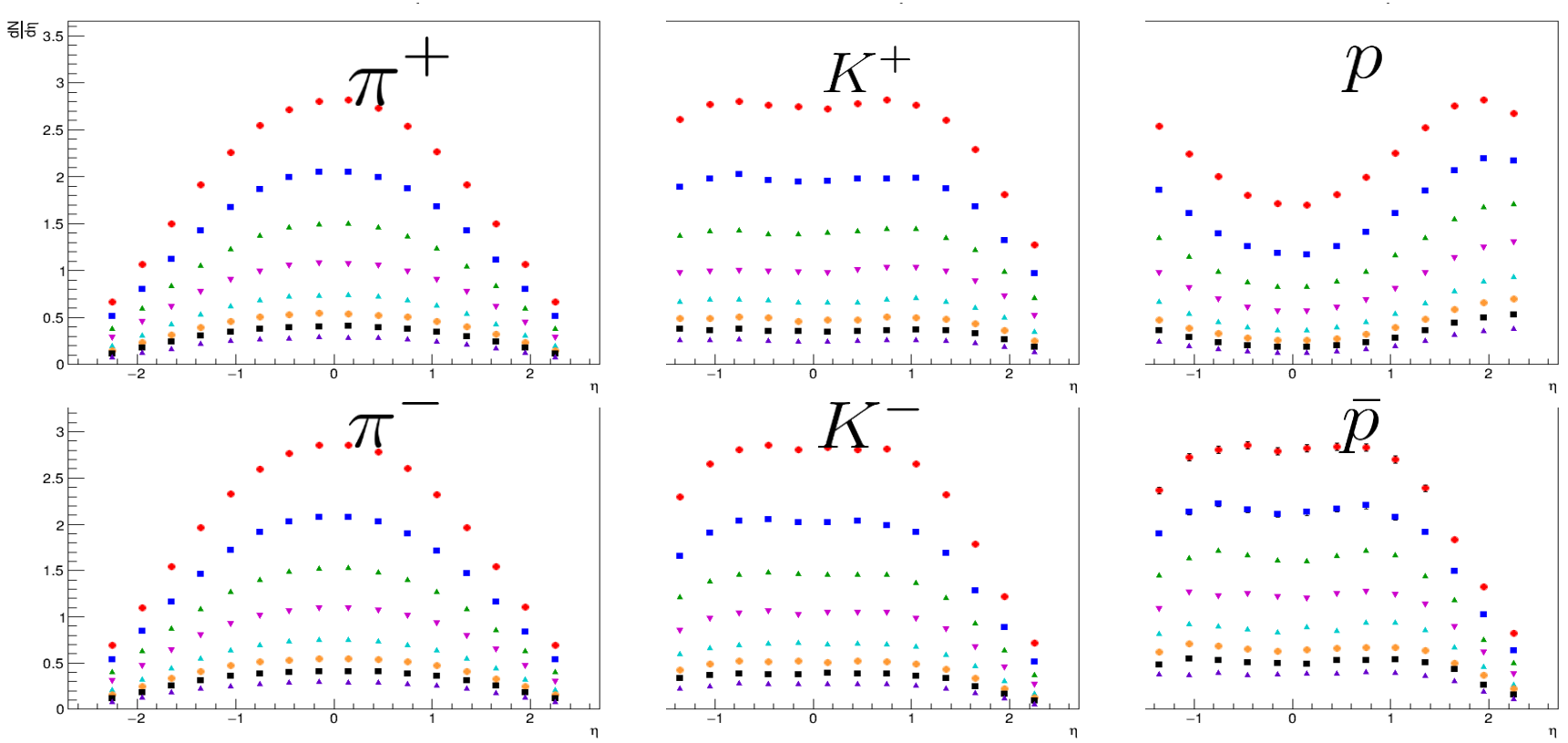


$$\sqrt{s_{NN}} = 14.5GeV$$

Centrality (%)	β	T (MeV)
0-5%	0.5005 ± 0.0002	86.112 ± 0.01
5-10%	0.490 ± 0.001	89.5 ± 0.5
10-20%	0.478 ± 0.002	91.3 ± 0.6
20-30%	0.463 ± 0.003	95.2 ± 0.8
30-40%	0.450 ± 0.003	98.0 ± 0.9
40-50%	0.445 ± 0.004	101.0 ± 1.0
50-60%	0.437 ± 0.002	101.7 ± 0.2

Ion physics at SPD: additional slides

$$\sqrt{s_{NN}} = 14.5GeV$$



Centrality

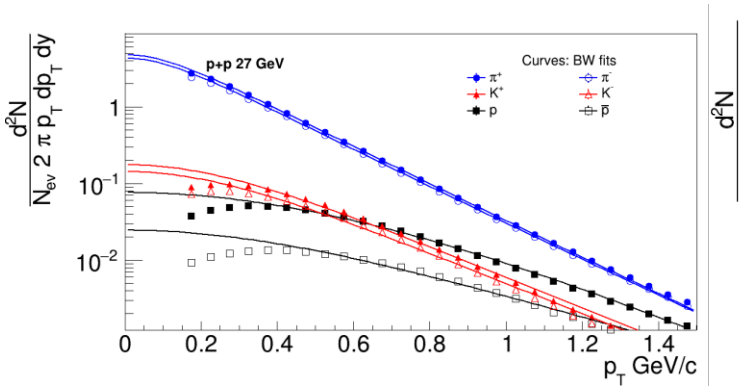
- 0-5%
- 5-10%
- 10-20%
- 20-30%
- 30-40%
- 40-50%
- 50-60%
- 60-70%

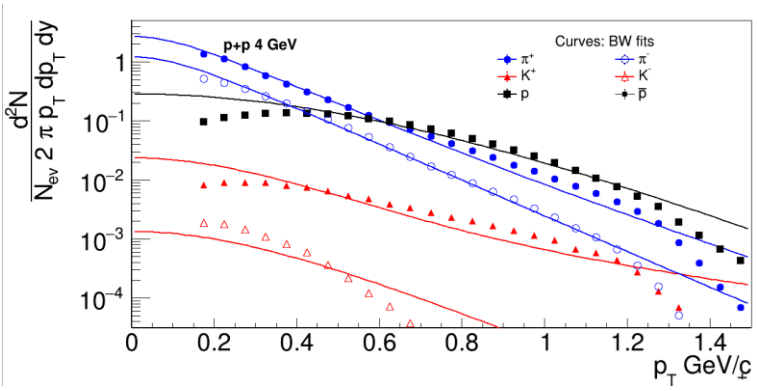
Ion physics at SPD: additional slides

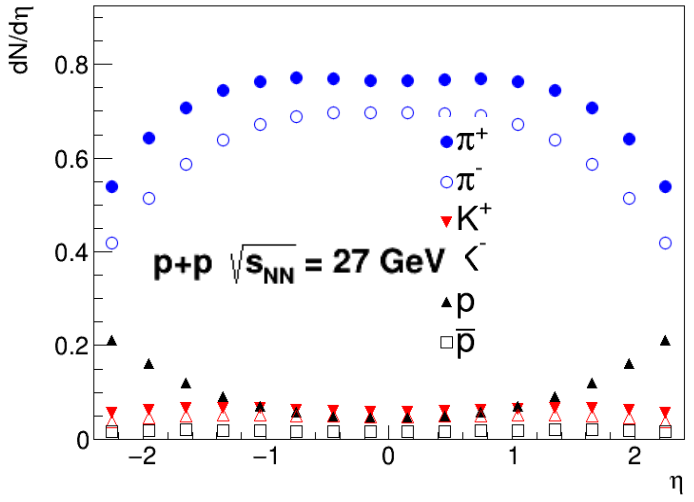
Yields and p_T spectra of of identified hadrons in p+p collision

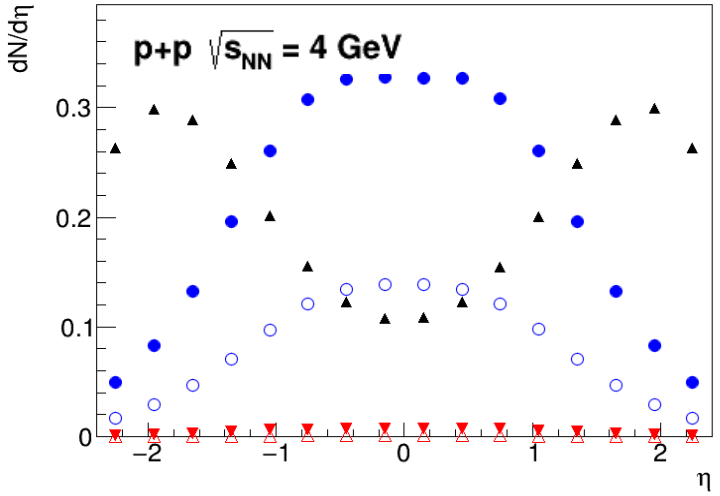
UrQMD, Ar+Ar, $\sqrt{s_{NN}}$ = 4, 10, 14.5, 27 GeV

~ 10M events









Spectra and yields of identified hadrons allow to get values of freeze-out and that may provide information about production mechanisms

J/ψ angular coefficients study: Methodology overview

- Build reference coefficients $A_{i\,ref}$ with moments method from MC predictions
- Fold signal templates using $A_{i\,ref}$ and MC simulation
- Build background, data templates
- Make workspace (containing likelihood, data, parameters)
- Fit Ais, σ, NPs

Likelihood formalism

Cross-section parameters · Ai parameters · Polynomial templates · Background templates

$$N^n_{\text{exp}}(A,\sigma,\theta) = \left\{ \sum_{j=0}^{N^{\text{ana}}_{\text{bins}}} \sigma_j \times L \times \left[t^n_{8j}(\beta) + \sum_{i=0}^{7} A_{ij} \times t^n_{ij}(\beta) \right] \right\} \times \gamma^n + \sum_{B}^{\text{bkgs}} T^n_B(\beta),$$

Observed events · Expected events · MC stat + NP constraints

$$\mathcal{L}(A,\sigma,\theta|N_{\text{obs}}) = \prod_{n}^{N_{\text{bins}}} \left\{ P(N^n_{\text{obs}}|N^n_{\text{exp}}(A,\sigma,\theta)) P(N^n_{\text{eff}}|\gamma^n N^n_{\text{eff}}) \right\} \times \prod_{m}^{M} G(0|\beta^m,1)$$

Folded polynomial templates are used to build a likelihood

Variational templates also present to take into account systematic uncertainties

Angular coefficients are parameters that normalize the polynomial templates

Cross-section scales all signal templates independently in each measurement bin

Background templates are added to likelihood

Maximum likelihood fit is performed to the **reconstructed data** to determine the coefficients and cross-sections in full phase space of leptons