p_{T} spectra as a function of Multiplicity and Transverse Spherocity in pp collisions using a Bayesian Unfolding

J. David Romo

16/11/21

Glosary

Physical Variables: Transverse Momentum (p_T)

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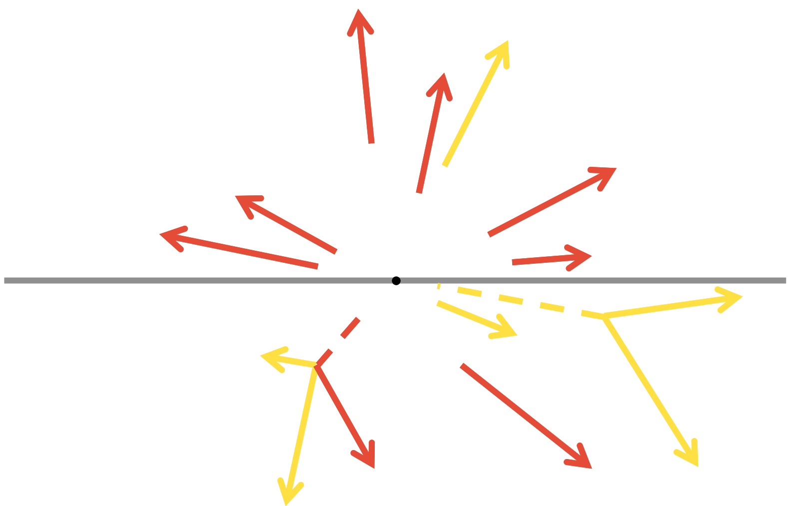
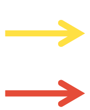


- In a hadron collision we have the emisión of charged and neutral particles, that could be stable or decaying.



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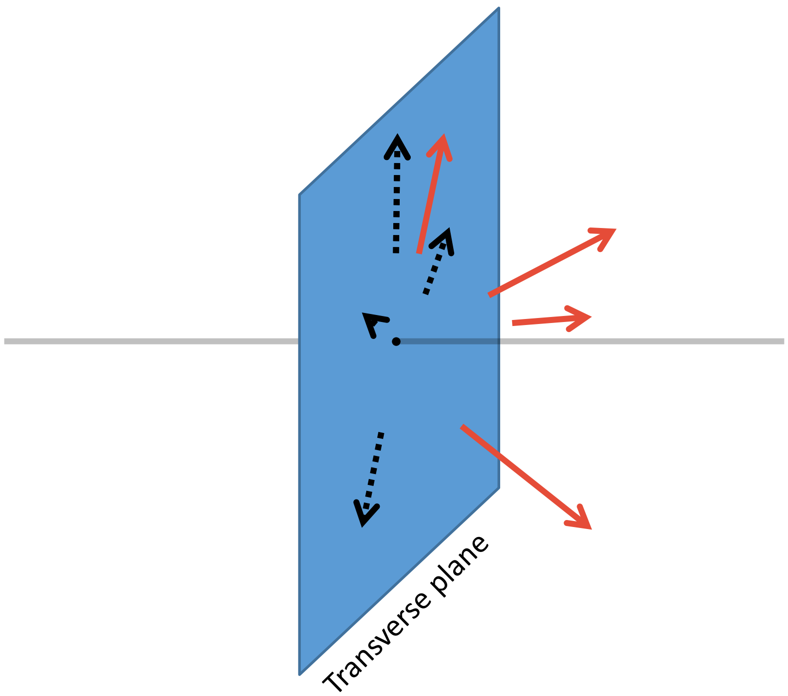
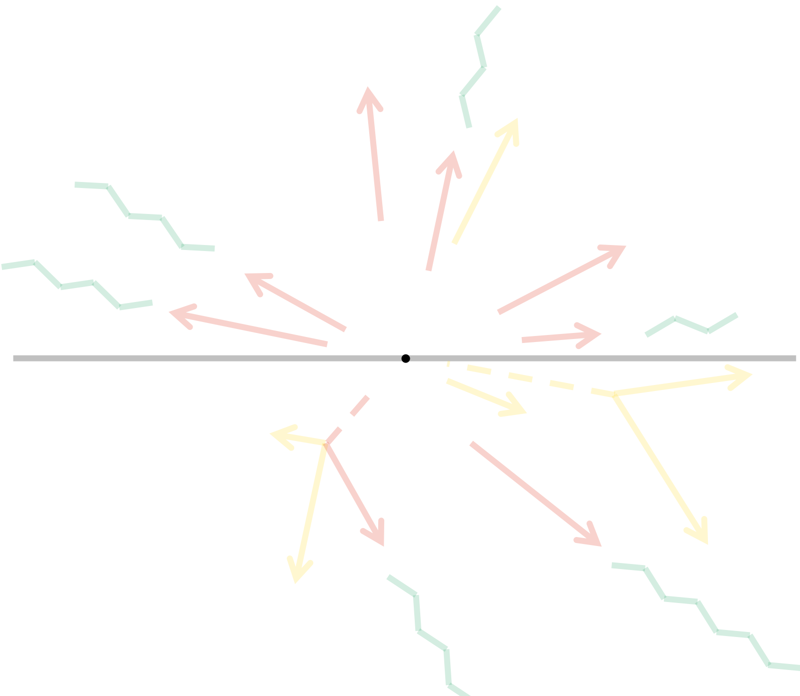


- In a hadron collision we have the emisión of charged and neutral particles, that could be stable or decaying.
- We are interested in the transverse momentum as it reflects better the parton interactions that the longitudinal part (also can be measured for charged particles).

Charged particle momentum

Charged particle transverse momentum

Physical Variables: Multiplicity (N)



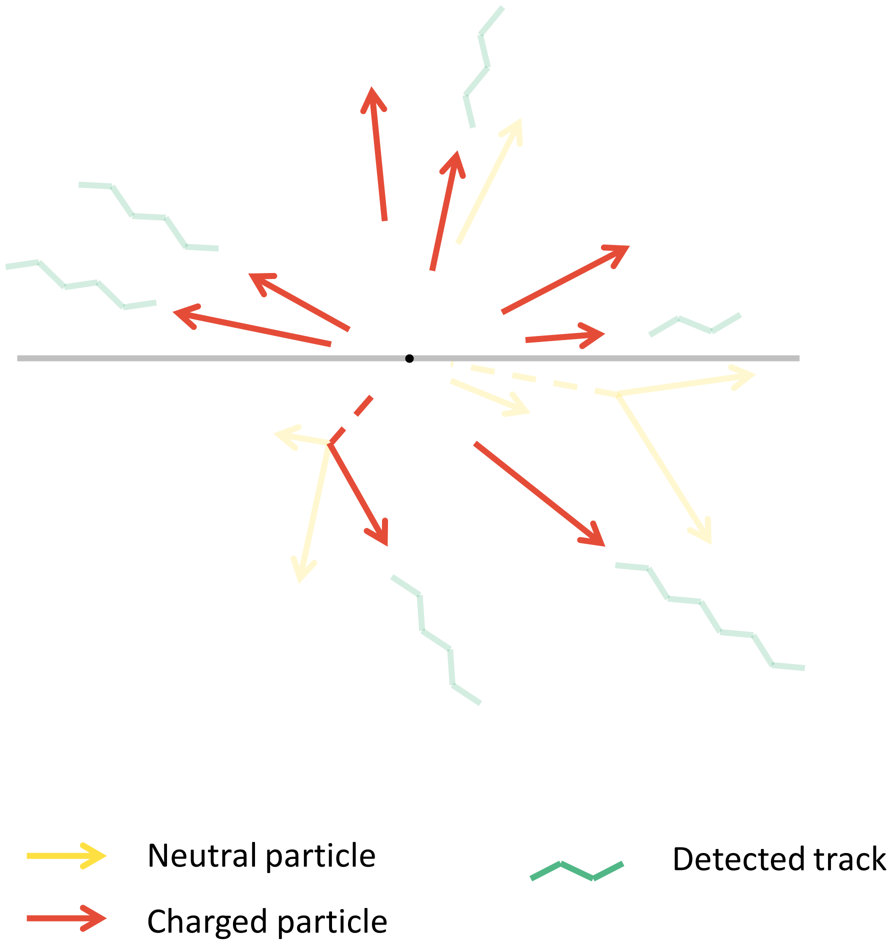
Multiplicity counts the number of participants after an event collision, being either:

Neutral particle

Charged particle

Detected track

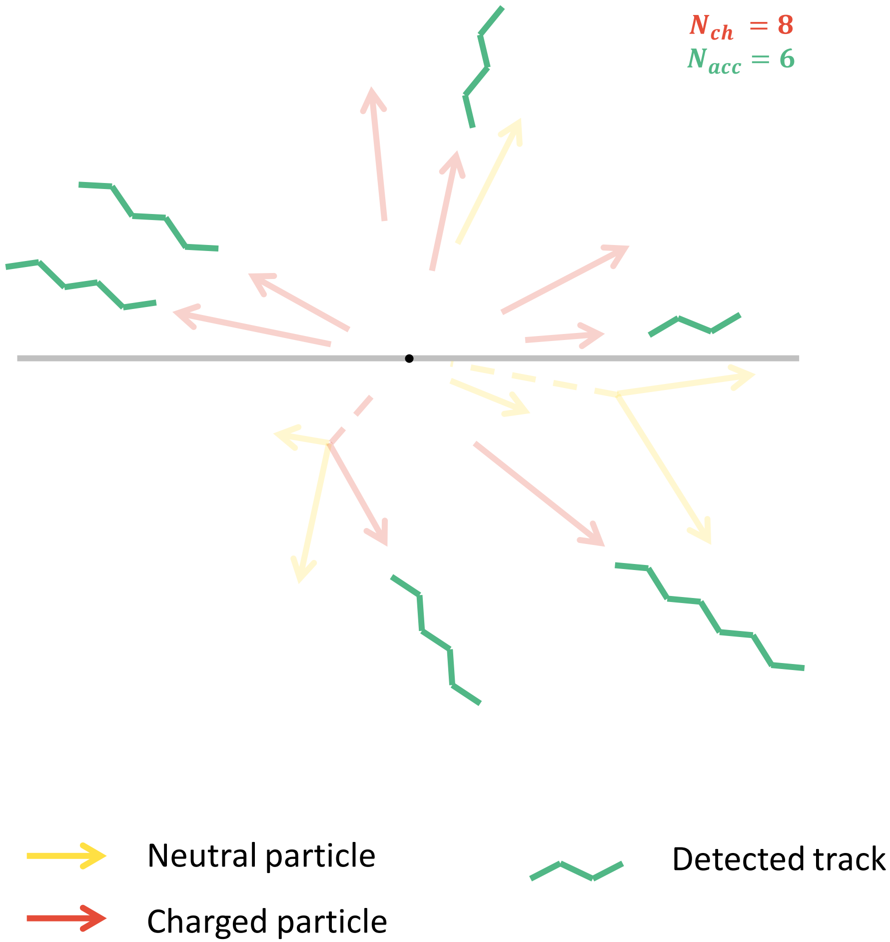
Physical Variables: Multiplicity (N)



Multiplicity counts the number of participants after an event collision, being either:

- the **charged particles** (N_{ch}) at generator level

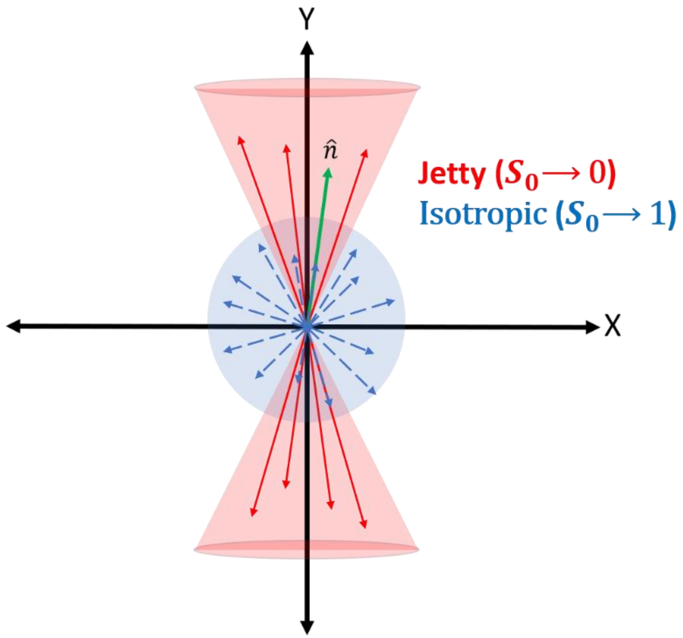
Physical Variables: Multiplicity (N)



Multiplicity counts the number of participants after an event collision, being either:

- the **charged particles** (N_{ch}) at generator level
- the **tracks accepted** (N_{acc}) at reconstruction level.

Physical Variables: Spherocity (S_O)



- Transverse spherocity is an event shape capable in distinguish **jet-like** ($S_O \to 0$) and **isotropic** event ($S_O \to 1$), which correspond to two different physics regimes <u>hard</u> and <u>soft</u> QCD processes.

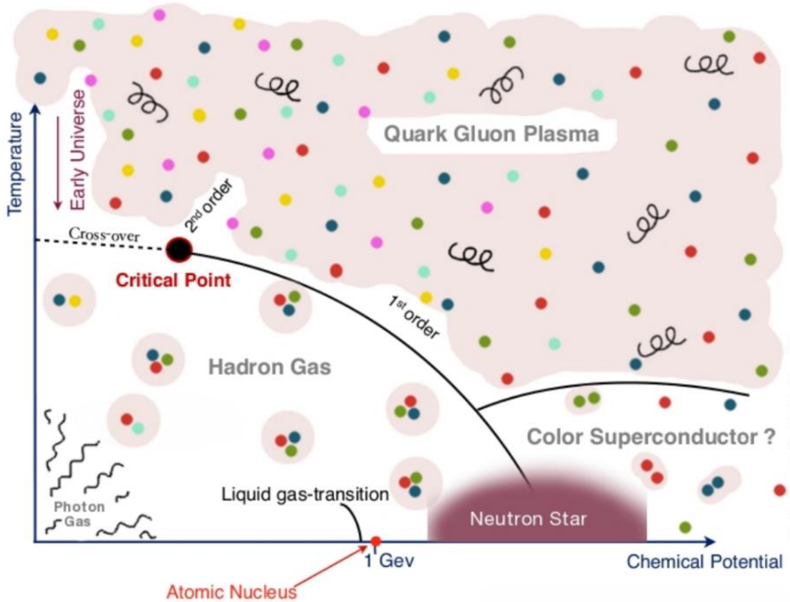
$$S_O = \frac{\pi^2}{4} \min_{\hat{n}_s} \left(\frac{\sum_i |p_{T,i} \times \hat{n}_s|}{\sum_i |p_{T,i}|} \right)^2$$

- Distinguish between generated spherocity ($S_{O,t}$), using all charged particles and the measured spherocity ($S_{O,m}$), based on the tracks after selection.

Introduction

Quark Gluon Plasma

A new state of matter in which quarks and gluons become **deconfined** from hadronic matter. It is accesible at the very highest temperature ($T_c \approx 150\,\mathrm{MeV}$) energy and energy density ($\rho \geq 1\,\mathrm{GeV}$).

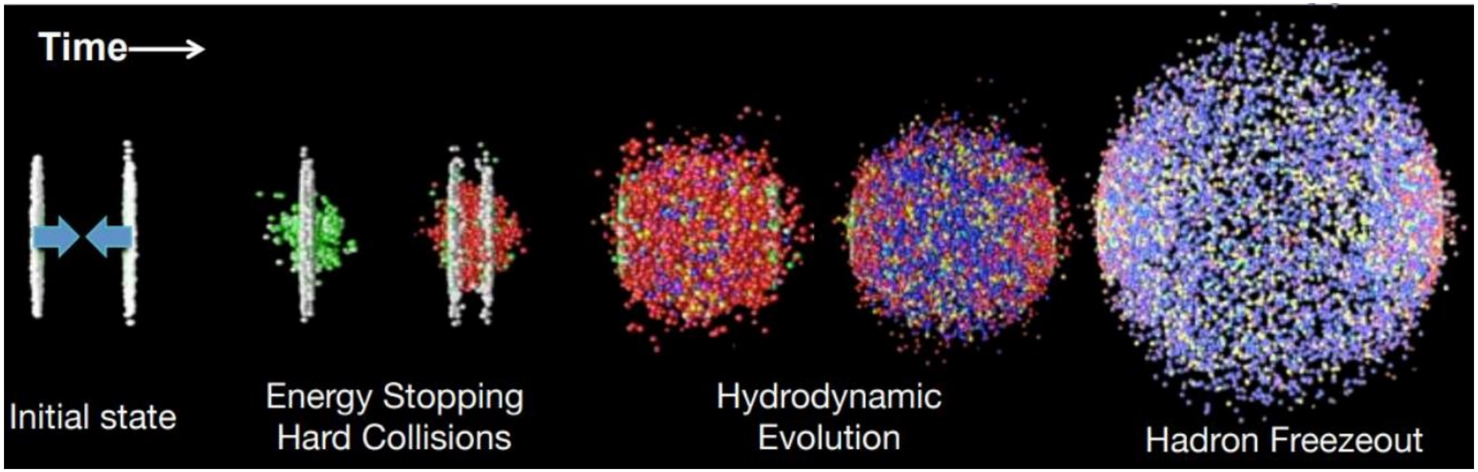


QCD phase diagram

Only two systems to study:

- primordial matter in the time interval 10^{-10}– $10^{-6} s$ after the Big Bang.
- heavy ion collisions in hadron colliders.

Heavy ions collisions and QGP



- Initial state as a two compressed cupcakes of hundreds of initial nucleons ($\mathrm{Au-Au}$, $\mathrm{Pb-Pb}$, $\mathrm{Xe-Xe}$).
- Hardest collisions between partons (**pQCD**).
- Formation of a hot and dense fireball of **QGP** after a process of rapid process of **thermalization** and **hydrodynamization**.
- Expansion as a strongly interacting **perfect liquid** with low viscosity.
- Formation of confined matter (**hadronization).**
- End of inelastic and elastic collisions (**chemical** and **kinetical freeze-out**)

What about small system collisions?

Collectivity in pp collisions

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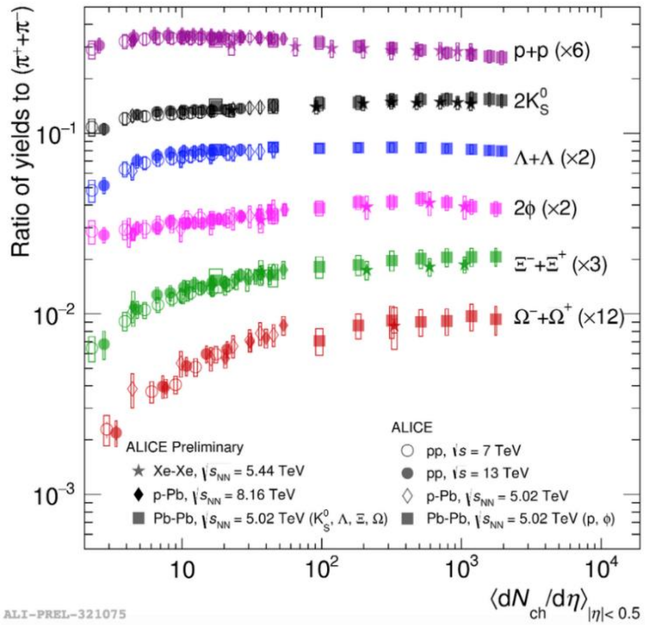
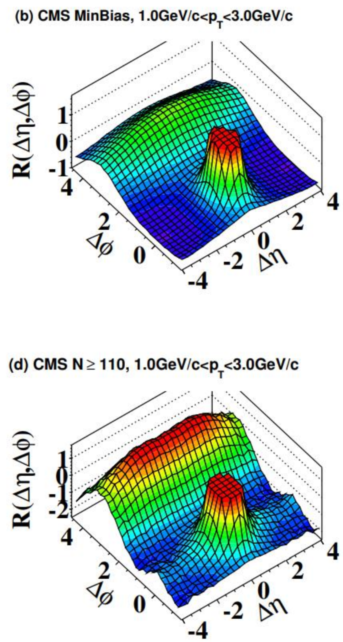
Measurements at the LHC have revealed that small collision systems exhibit **heavy-ion-like** behavior, formerly thought to be a distinctive feature of heavy-ion collisions.

ALICE, Nature Physics 13, 535-539 (2017)



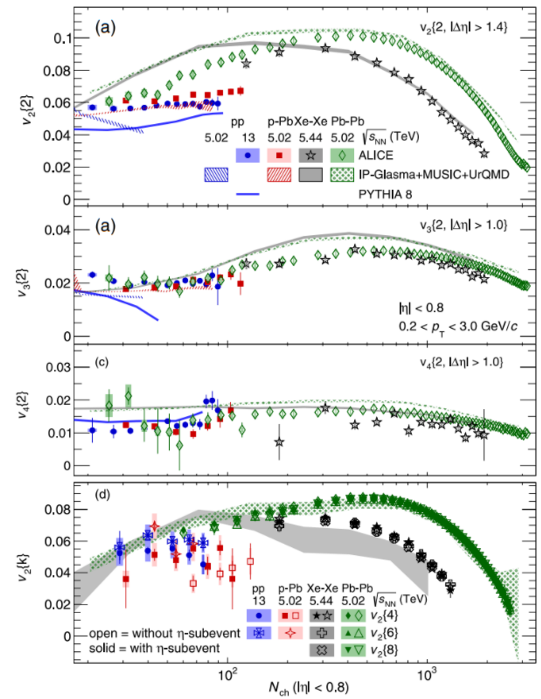
Strangeness enhancement in high multiplicity pp and p-Pb are similar to Pb-Pb

CMS, JHEP 1009:091 (2010)



Ridge structure in high multiplicity pp collisions

ALICE, Phys. Rev. Lett. 123, 142301 (2019)



A continuous evolution of v3 and v4 across collision systems. Finite v2 in small systems

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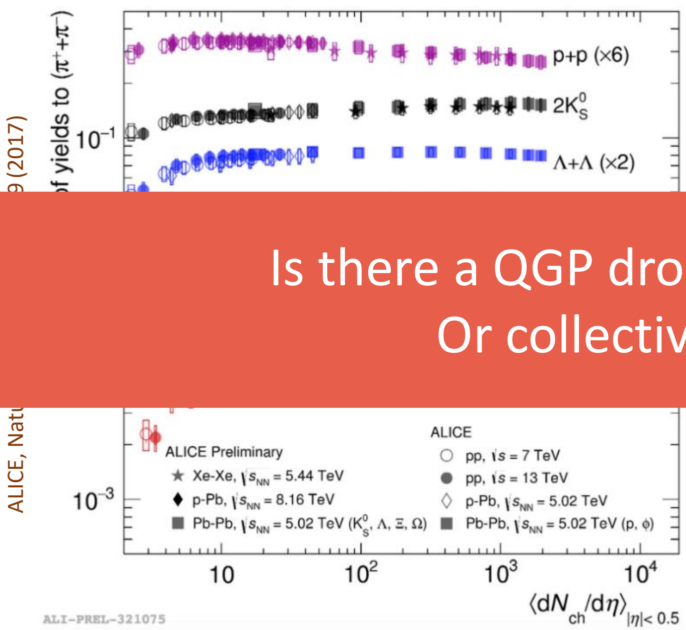
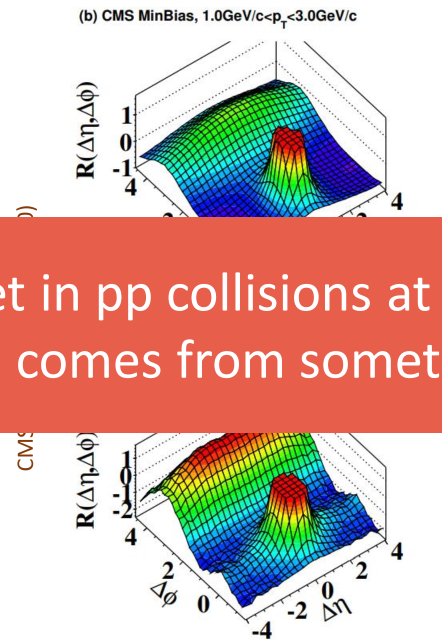
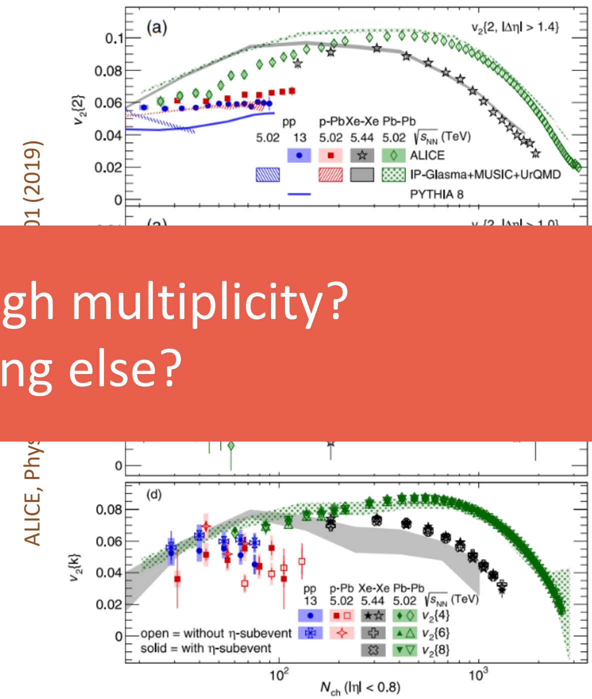






Is there a QGP droplet in pp collisions at high multiplicity?
Or collectivity comes from something else?

Strangeness enhancement in high multiplicity pp and p-Pb are similar to Pb-Pb

Ridge structure in high multiplicity pp collisions

A continuous evolution of v3 and v4 across collision systems. Finite v2 in small systems

Analysis Motivation

How the events with multiple jets affect the high multiplicity pp collisions?

We are interested how the production of charges particles depends on the two physics regimes: soft (high sperocity) and hard (low sperocity) QCD.

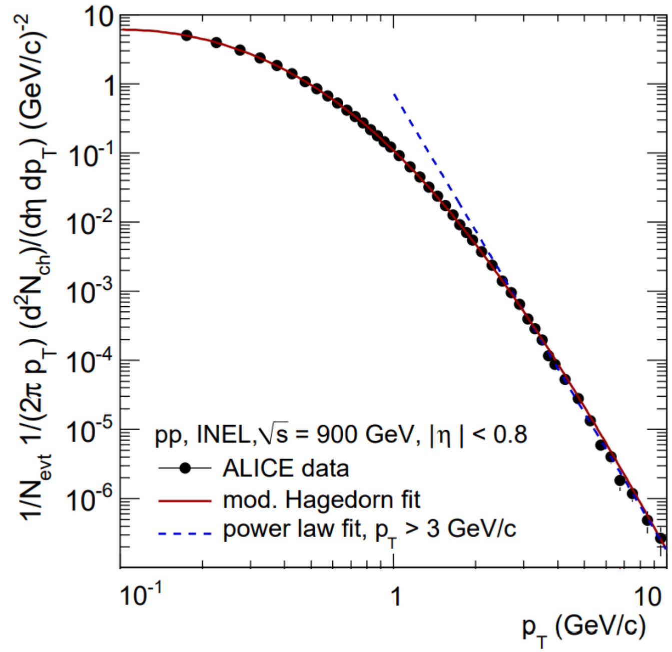
We propose a differential study of both multiplicity and spherocity to have a better understanding

p_{T} Spectra

- We are looking for the number of primary particles N_{ch} per event N_{ev} in a specific *spherocity* and *multiplicity* class.

- The relativistic version is the invariant yield.

$$IY(p_{\mathrm{T}}) = \left(\frac{1}{N_{ev}}\frac{1}{2\pi p_{\mathrm{T}}}\frac{d^2N_{ch}}{\mathrm{d}\eta d p_{\mathrm{T}}}\right)_{S_{O,t},N_{ch}}$$



ALICE, Phys. Lett. B 693 (2010) 53-68

primary charged particle Invariant Yield for ALICE pp collisions at 900 GeV

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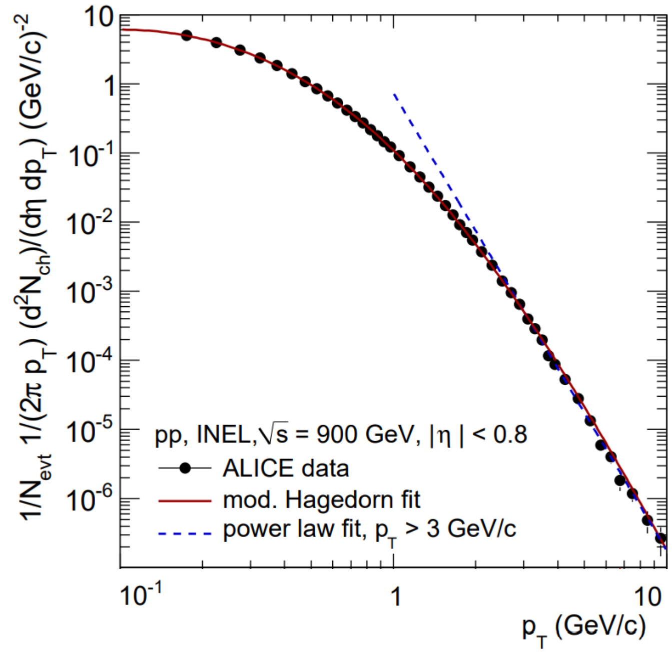

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primary charged particle Invariant Yield for ALICE pp collisions at 900 GeV

Then we want to obtain the **true** variables particle and event distributions $N_{ch}(p_{T,t}, S_{O,t}, N_{ch})$ and $N_{ev}(S_{O,t}, N_{ch})$.

How we get the true distribution?

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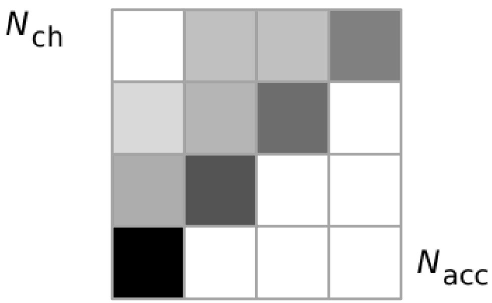

Detector response matrix

- Detectors are not perfect!
  → measured value ≠ true value

- The detector response matrix can be expressed as the conditional probability $\mathrm{p}(N_{acc}|N_{ch})$ that a **true** value N_{ch} is **measured** as N_{acc}.

- After the measurement the measured distribution $n_{evt}(N_{acc})$ becomes smeared!
  → measured distribution ≠ true distribution

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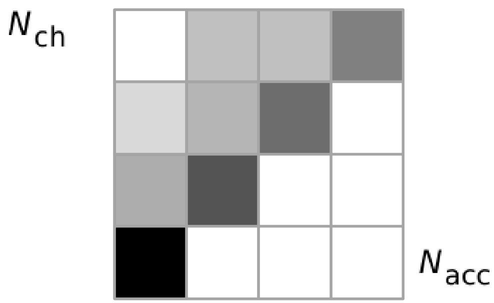

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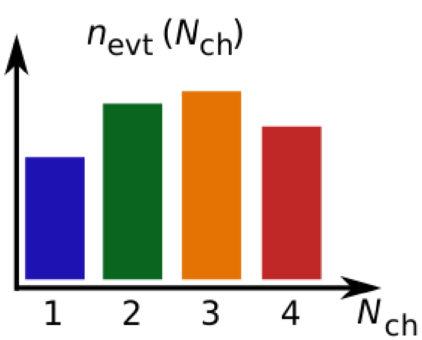
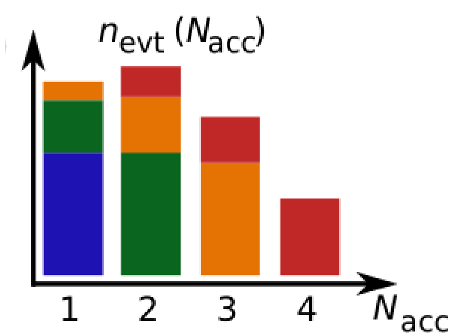
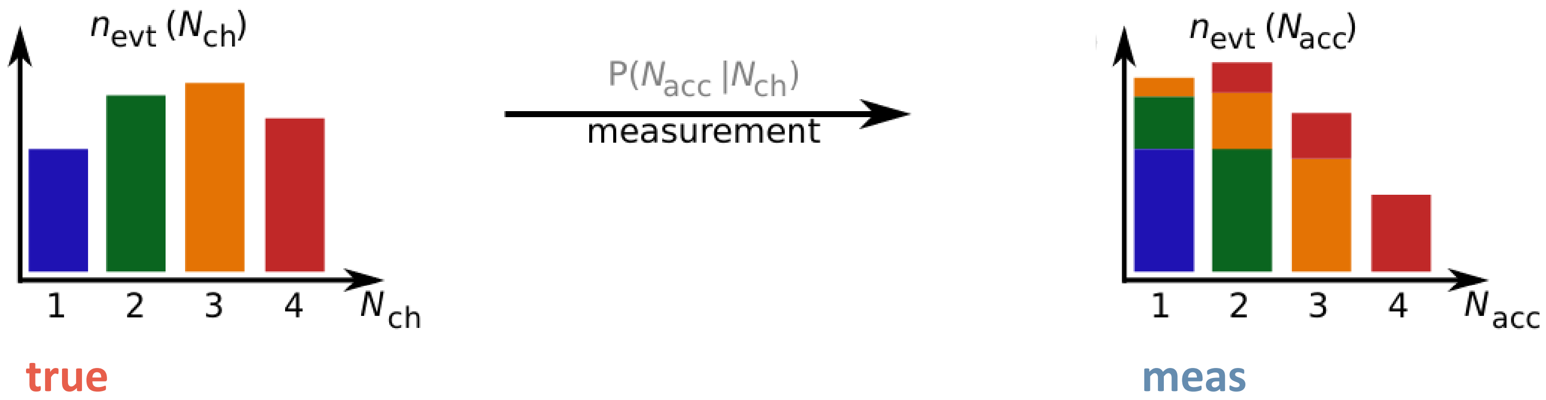


true



meas

How we get the true distribution?



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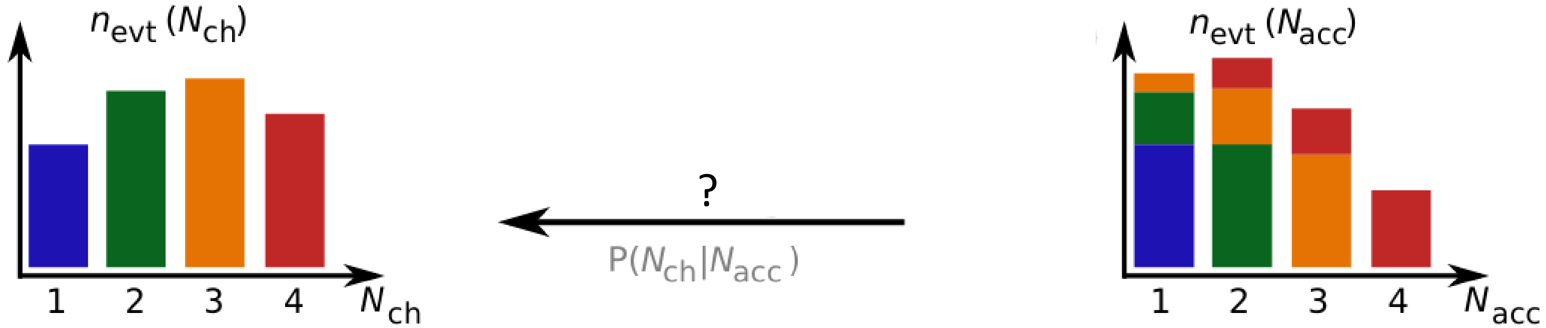
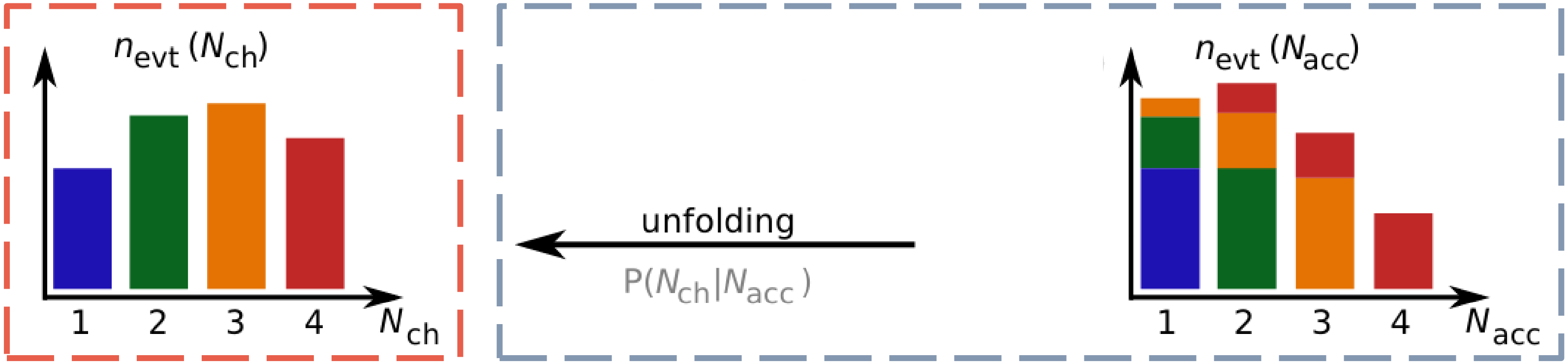


true

meas

How we get the true distribution?

A procedure that is able to recover the **true** distribution from the **measured** distribution is an **unfolding**.



true

meas

Bayesian Unfolding

$$p(N_{ch}|N_{acc}) = \frac{p(N_{acc}|N_{ch})\, p(N_{ch})}{\sum_{N_{ch}'} p(N_{acc}|N_{ch}')p(N_{ch}')}$$

Bayes theorem

$$p_0(N_{ch})$$

(first guess)

$$p(N_{ch}) = \frac{n(N_{ch})}{\sum_{N_t'} n(N_{ch}')}$$

$$n(N_{ch}) = \sum_{N_{ch}} p(N_{ch}|N_{acc})n(N_{acc})$$

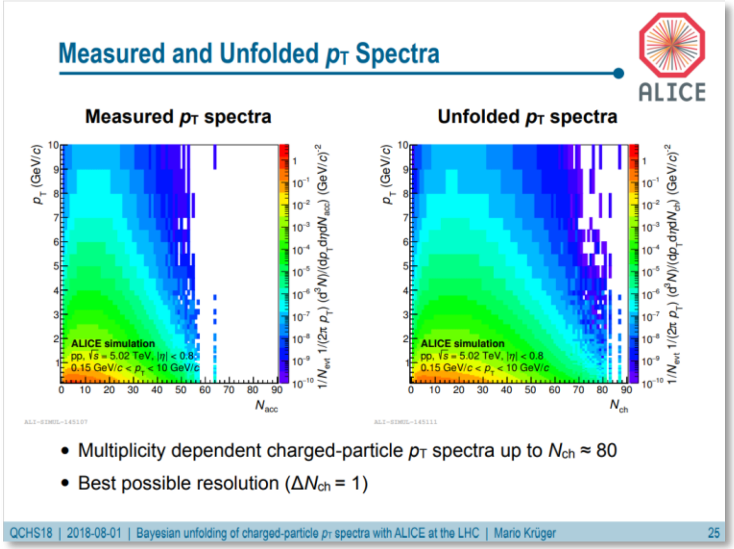
- Interative unfolding method based on the Bayes theorem, to estimate the conditional $p(N_{ch}|N_{acc})$ from the **measued** distribution and the detector **response matrix**. At each iteraction we actualize the value of the **true** multiplicity distribution.

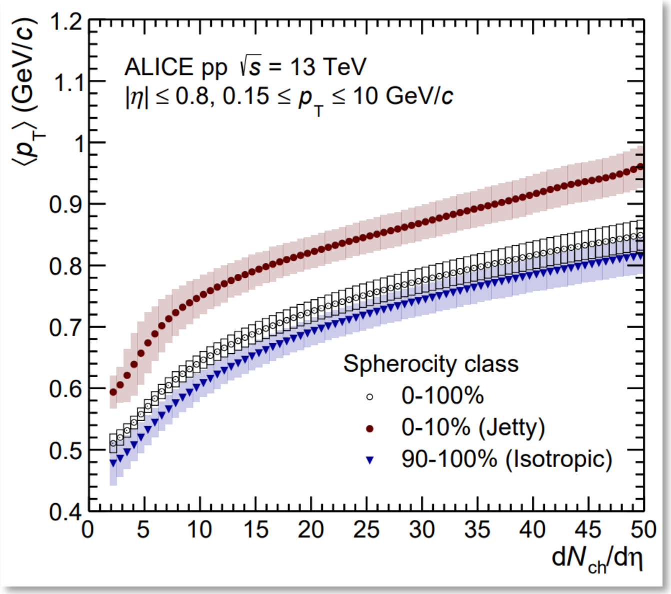
- The number of iteractions is limited to less than 10, which usually is enough for the chi square χ^2 between the current and previous iteration to saturate.

- It requieres the detector response matrix $p(N_{acc}|N_{ch})$, in our analysis it comes from MC simulation

Previous Analysis

Krüger M., XIIth Quark Confinement and the Hadron Spectrum Conference





Analysis Strategy

Analysis

- Develop the unfolding technique for $N_{ch}(p_{T,t}, S_{O,t}, N_{ch})$ and $N_{ev}\,(S_{O,t}, N_{ch})$ and testing the method through the MC closure test.

- Apply the method to pp collisions ALICE data and compare with published results.

Event and Track Selection

- Event Selection
  - MB trigger condition
  - DAQ Complete
  - Remove Pileup
  - Position reconstructed vertex $|V_z| < 10 \text{ cm}$
  - At least 3 tracks in the acceptance región (Spherocity condition).
  - Cluster-vs-tracklet background cut.

- Track Selection
  - Aceptance $|\eta| < 0.8$ and momentum Interval $0.15 \leq p_{\mathrm{T}} \leq 10 \text{ GeV}$
  - p_{T} Spectra: Standard TPCITS2015 with DCA dependent cut
  - Spherocity: TPC only tracks cuts + TPC refit
  - Multiplicity: TPC only tracks cuts + TPC refit

Distribution Rebinning

- The bayesian unfolding is a method capable of recover the **1D** true distribution from the measured one and the response matrix.

- How can we extend this technique to more dimensions?

  such as $N_{ch}(p_{T,t}, S_{O,t}, N_{ch})$ or $N_{ev}(S_{O,t}, N_{ch})$?

We translate our multidimensional distribution to a one dimensional distribution

Distribution Rebinning

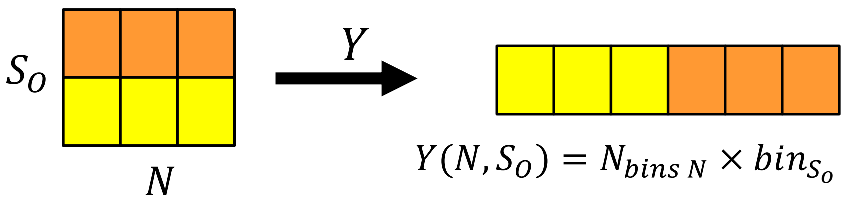
We define:

Distribution Rebinning

We define:

Event Distribution

$$h\left(Y_{\{m,t\}}\right) = \ N_{ev}\ \left(S_{O,\{m,t\}}, N_{\{m,t\}}\right)$$



$$Y(N, S_O) = N_{bins\ N} \times bin_{S_o} + bin_N$$

Distribution Rebinning

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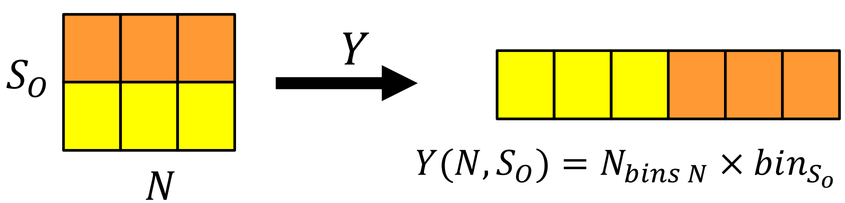
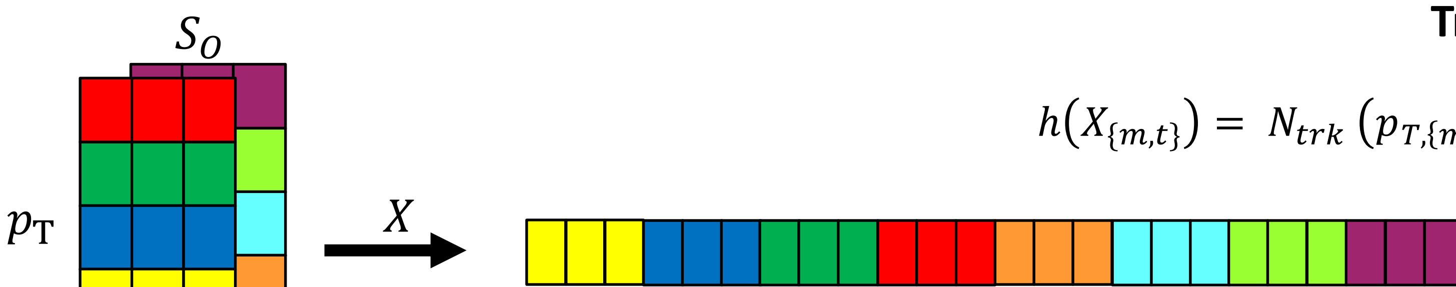


$$Y(N, S_O) = N_{bins\ N} \times bin_{S_o} + bin_N$$

Track Distribution

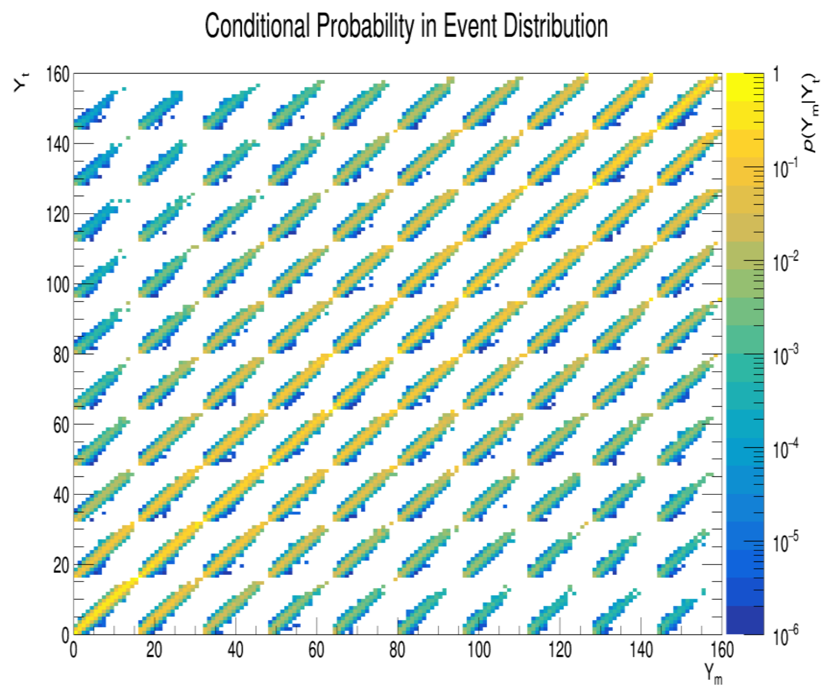
$$h\left(X_{\{m,t\}}\right) = N_{trk}\left(p_{T,\{m,t\}}, S_{O,\{m,t\}}, N_{\{m,t\}}\right)$$



$$X(N, p_{\mathrm{T}}, S_o) = N_{bins\ N} \times N_{bins\ p_T} \times bin_{S_o} + N_{bins\ N} \times bin_{p_T} + bin_N$$

Detector Response

After this change in variables we arrive to a much bigger (but 2D!) detector response matrix



N_{acc} : N_m Number of measured tracklets with the TPC
N_{ch} : N_t Number of true charged particles at generator level

Spherocity Percentiles (Binning)

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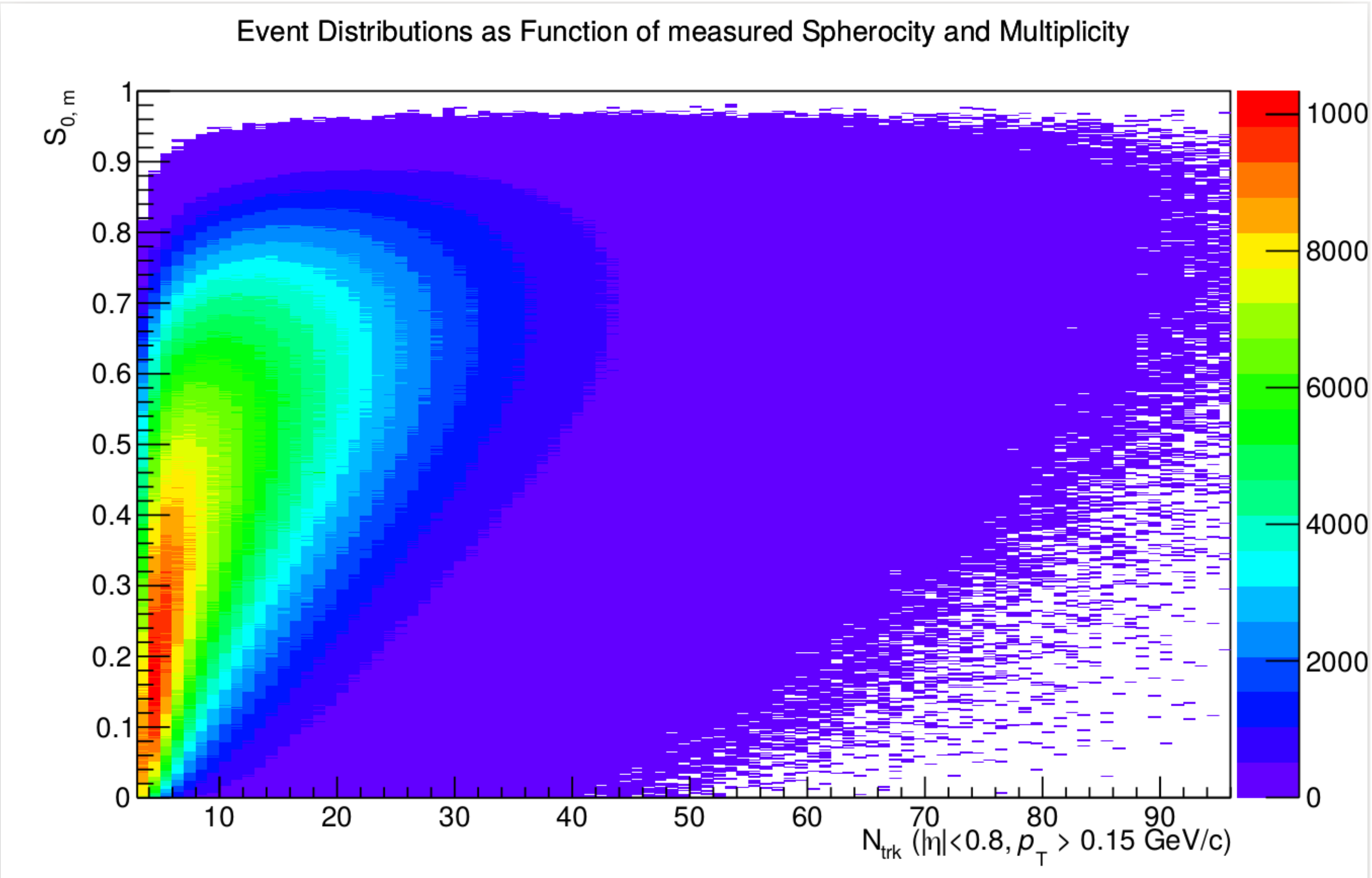

- Statistics very dependent on multiplicity → homogenize distribution

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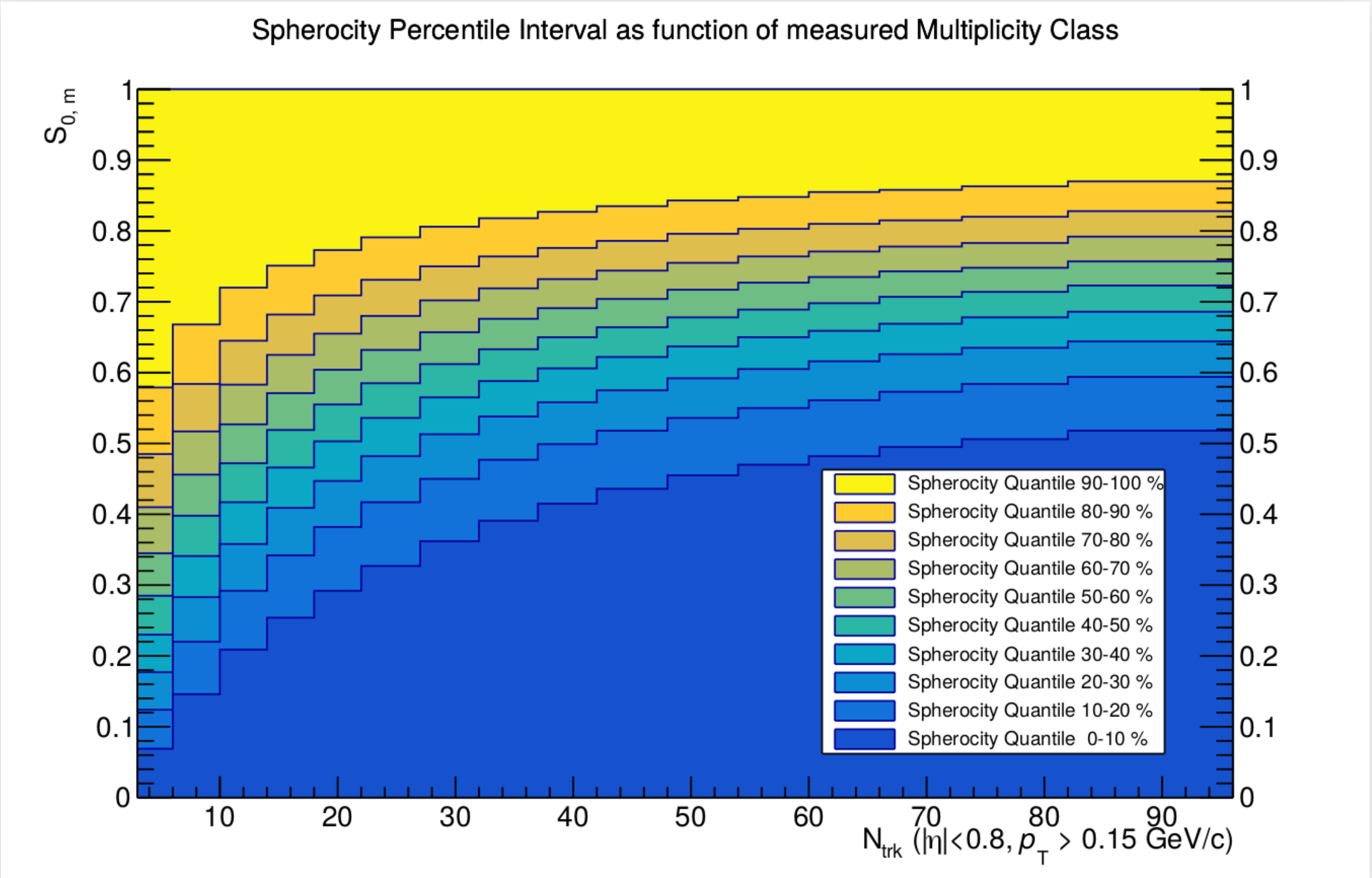
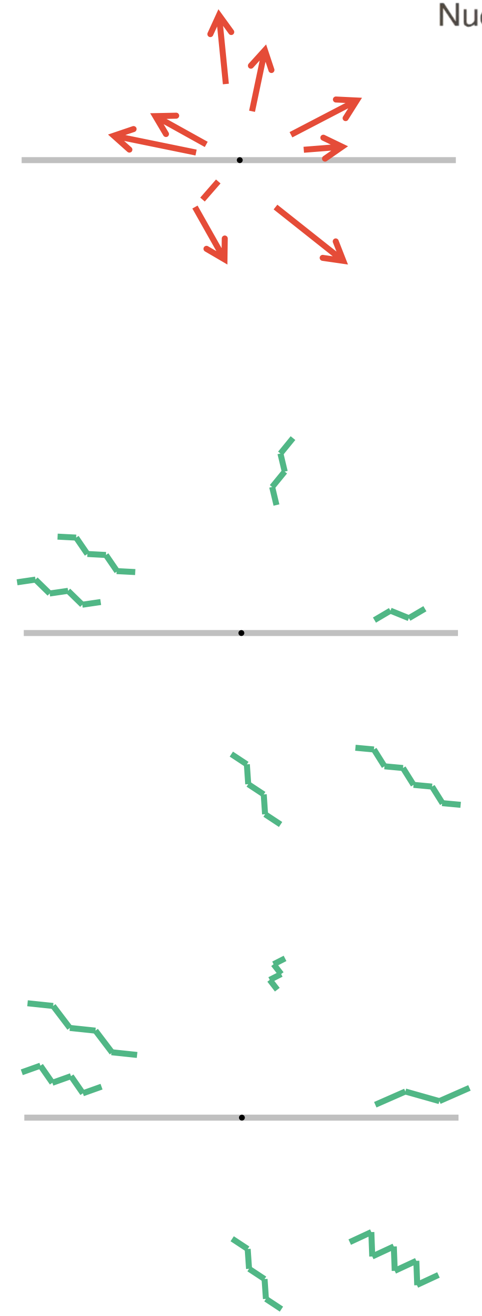


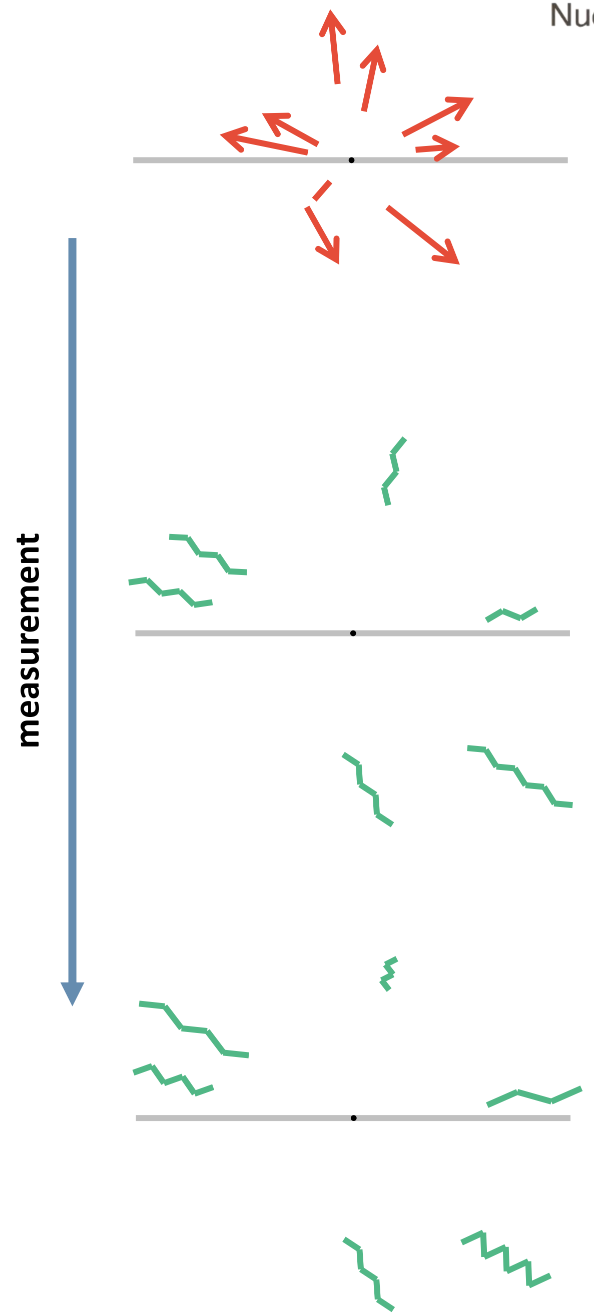
- Statistics very dependent on multiplicity → homogenize distribution
- Binning in spherocity determined by tracks (not necesarly equal binning for particles!)

Track Unfolding and Corrections



Track Unfolding and Corrections

- At the measurement, it happens two things:
  - Particles are lost either by decay or by detector efficiency.
  - The $p_{\mathrm{T},t}$ of the track is measured as $p_{\mathrm{T},m}$, given by the detector resolution



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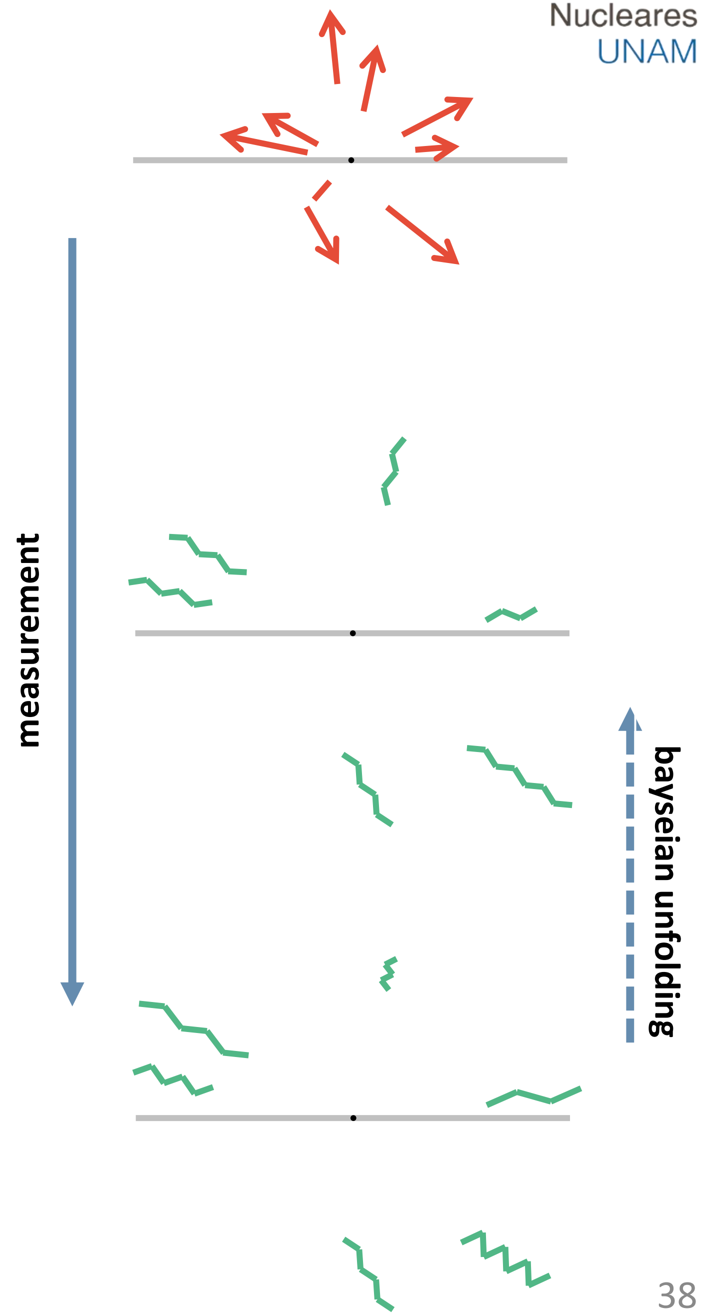
- The bayesian unfolding recovers $p_{\mathrm{T},t}$ of the track.



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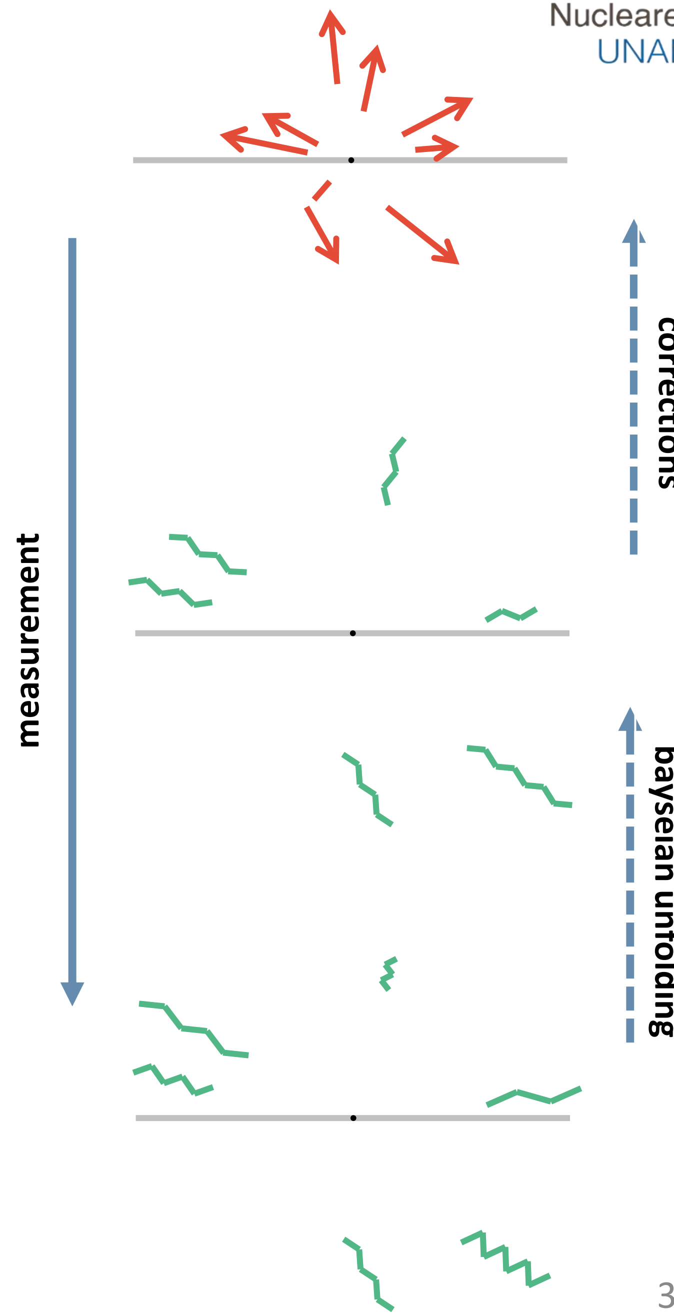
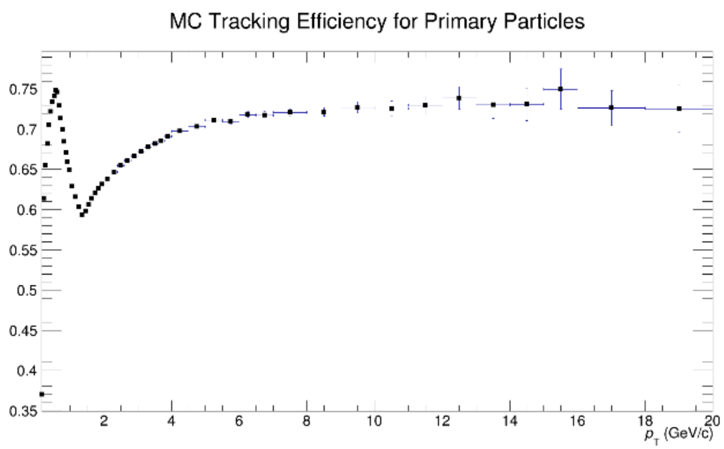
- We apply corrections to the p_{T} spectra to recover the number of charged primary particles.

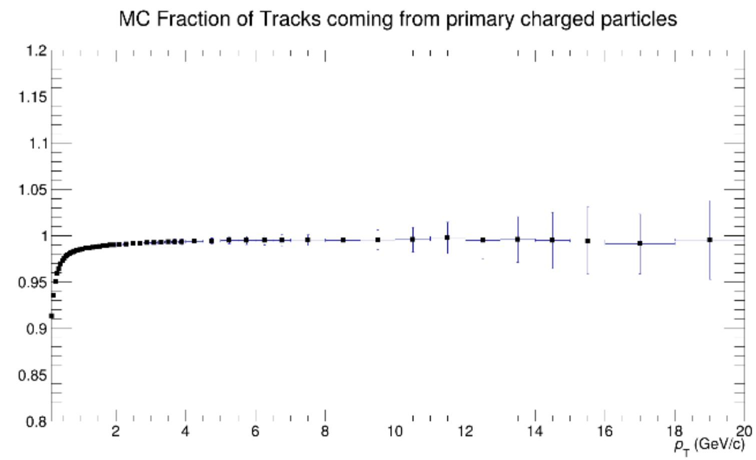


Corrections

$$IY(p_T) = \frac{1}{N_{evt}} \frac{1}{2\pi p_T} \frac{d^2 N_{ch}}{d\eta dp_T} = \frac{1}{2\pi p_T} \frac{1}{N_{events}} \frac{N_{tracks}}{\Delta\eta\Delta p_T} \frac{C_{sec\ cont}}{\varepsilon_{track}} \frac{\varepsilon_{ev\ loss}}{\varepsilon_{sg\ loss}}$$

Corrections applied to the unfolded spectra

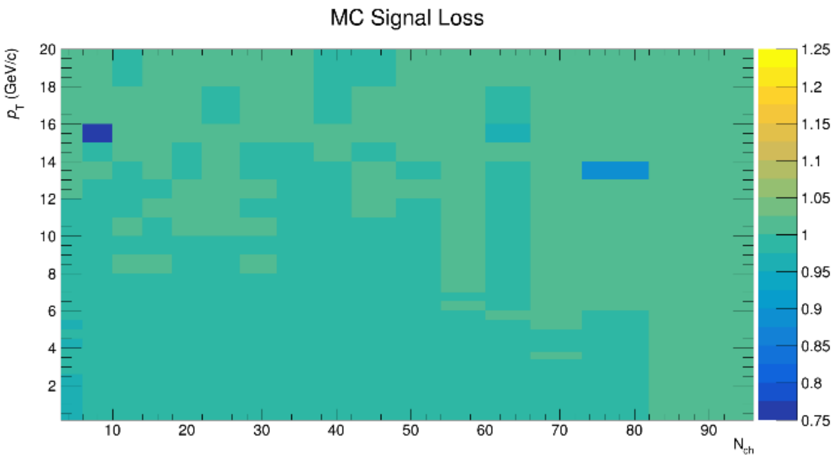




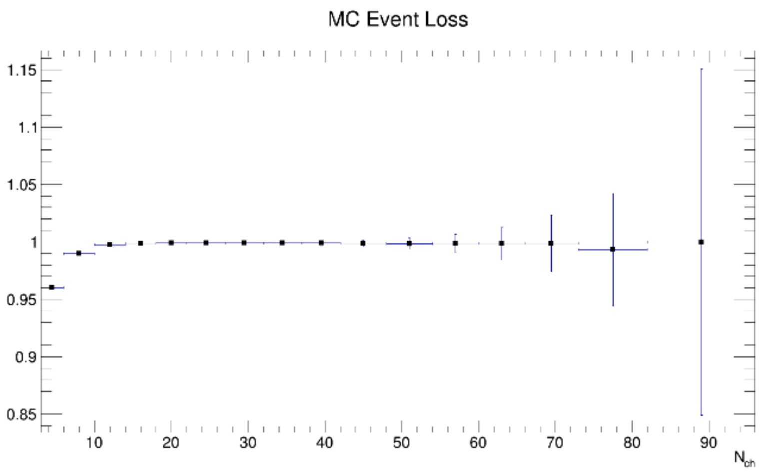
Tracking Efficiency:
Reconstruction of tracklets in the TPC.

Primary Fraction Tracks:
Counts the Secondary Contamination. Quantified with the true variable.

Corrections losses applied to the unfolded spectra



Signal Loss:
Loss of particles by evento selection

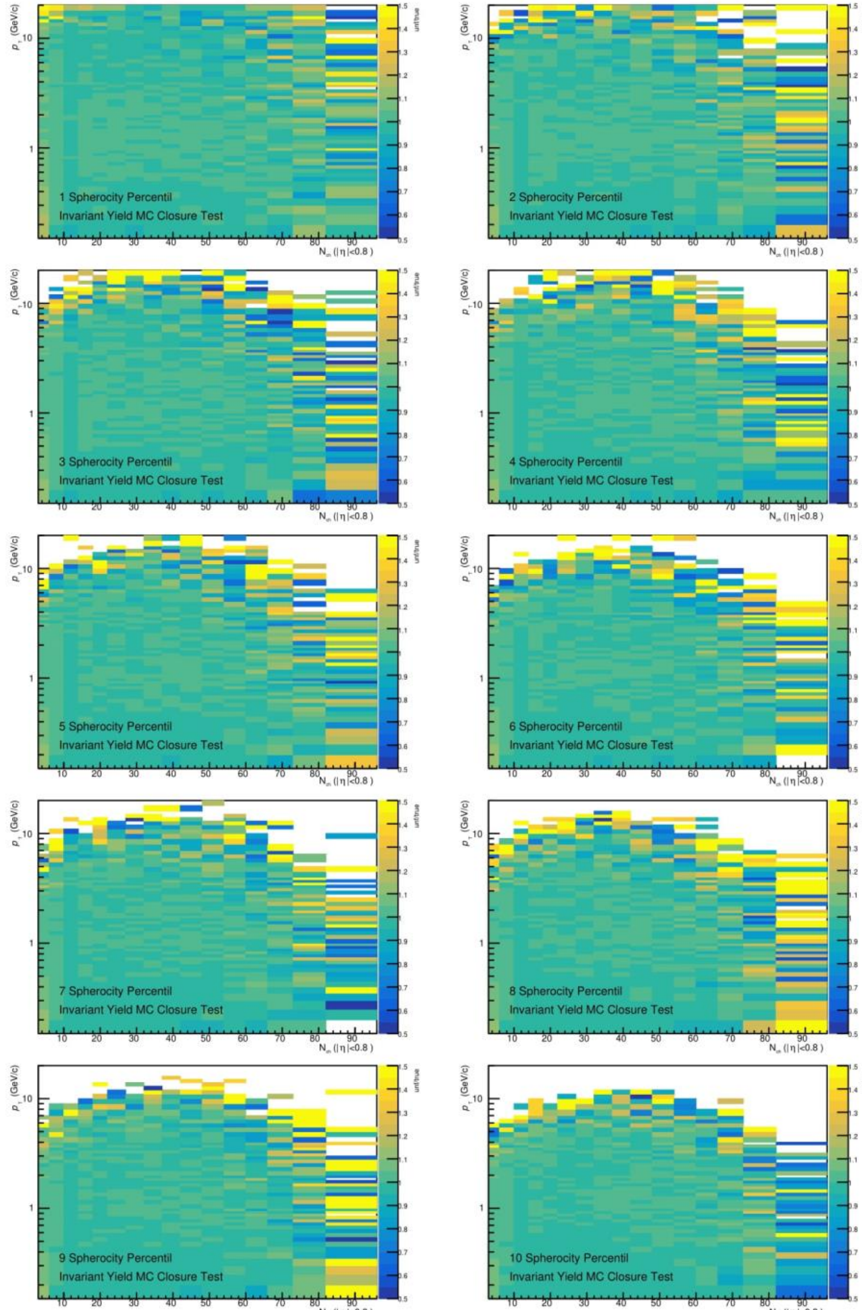


Event Loss:
Loss if events by event selection

Results

Crosscheck: MC Closure Test

Invariant Yield MC Closure Test



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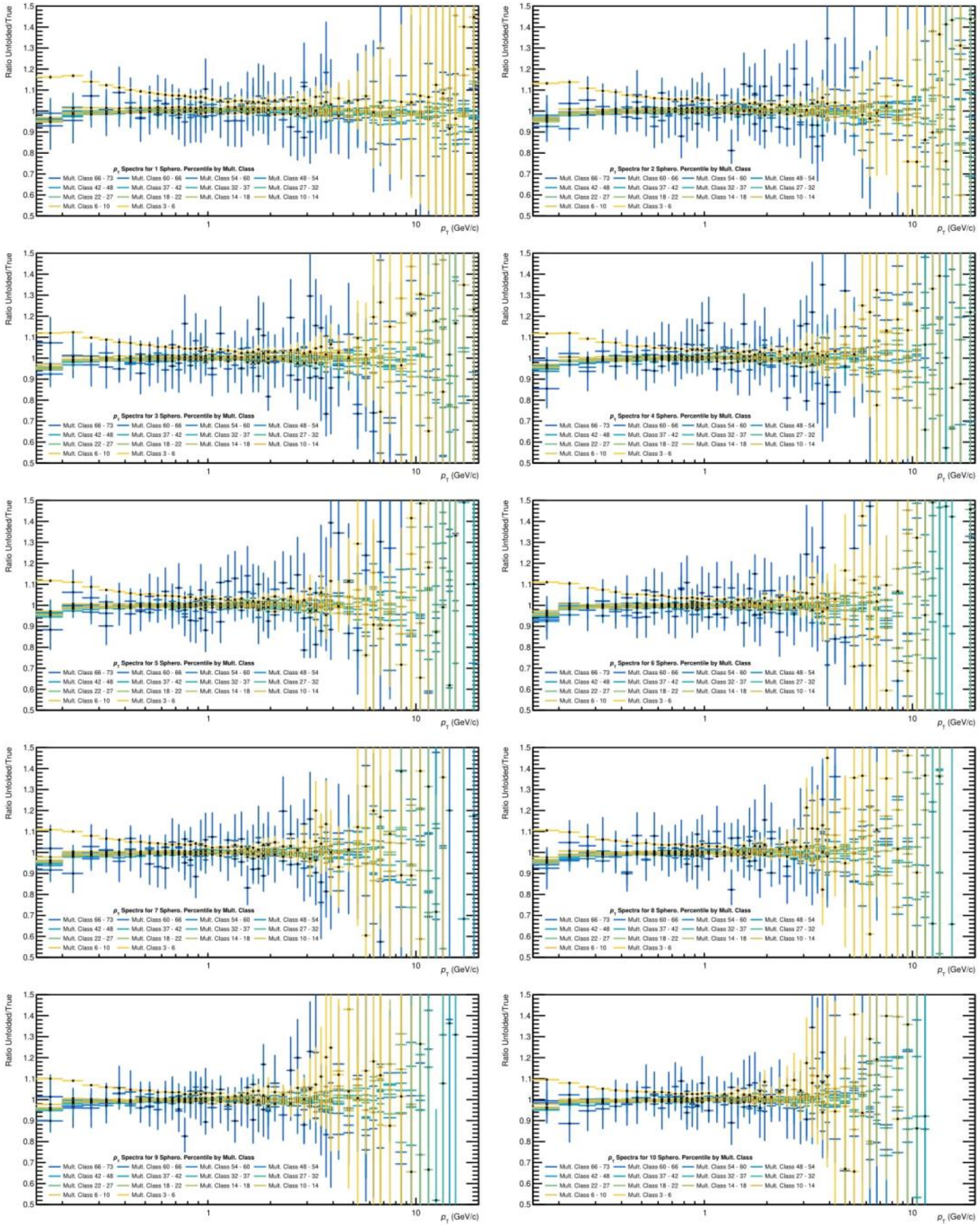

Invariant Yield MC Closure Test

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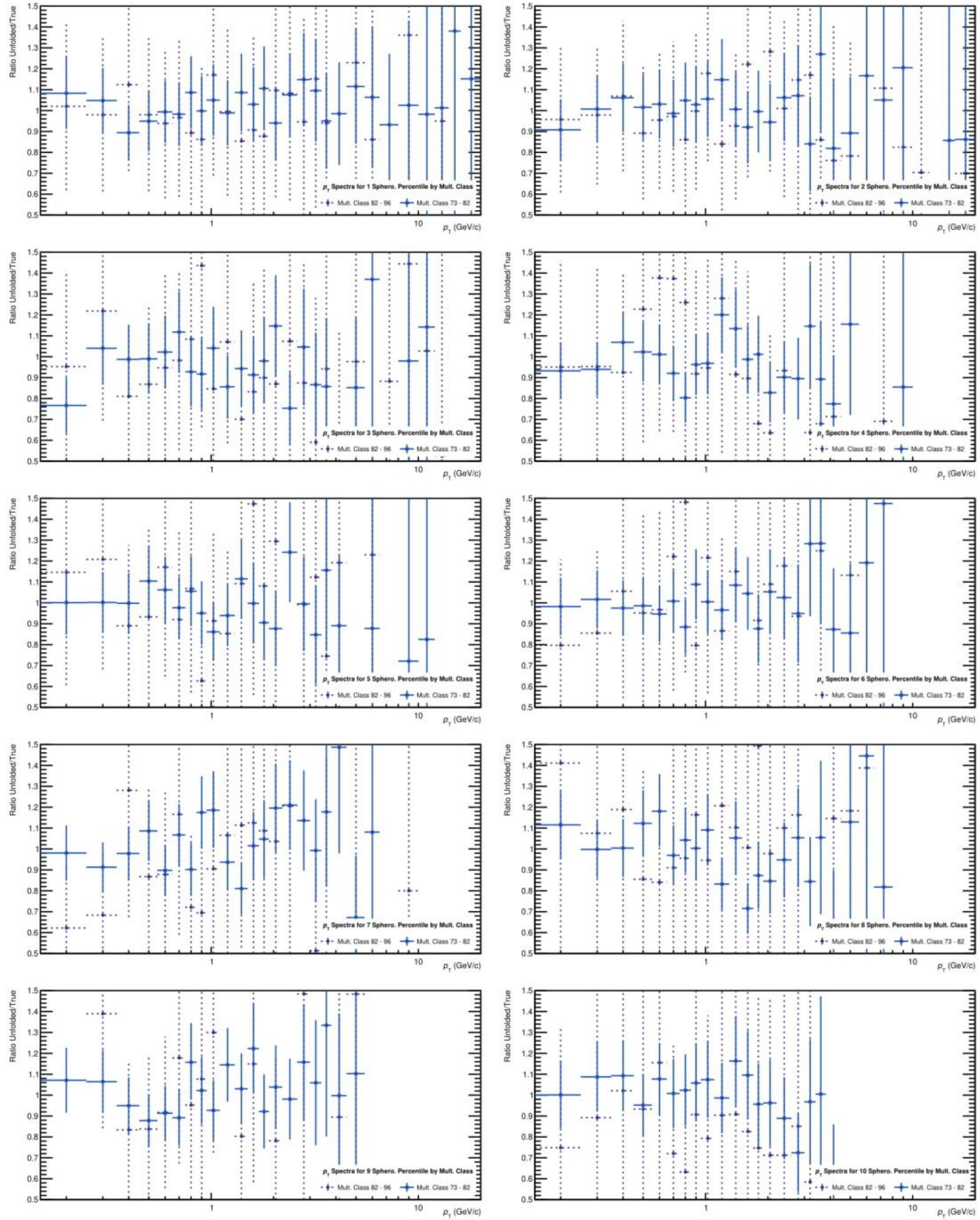
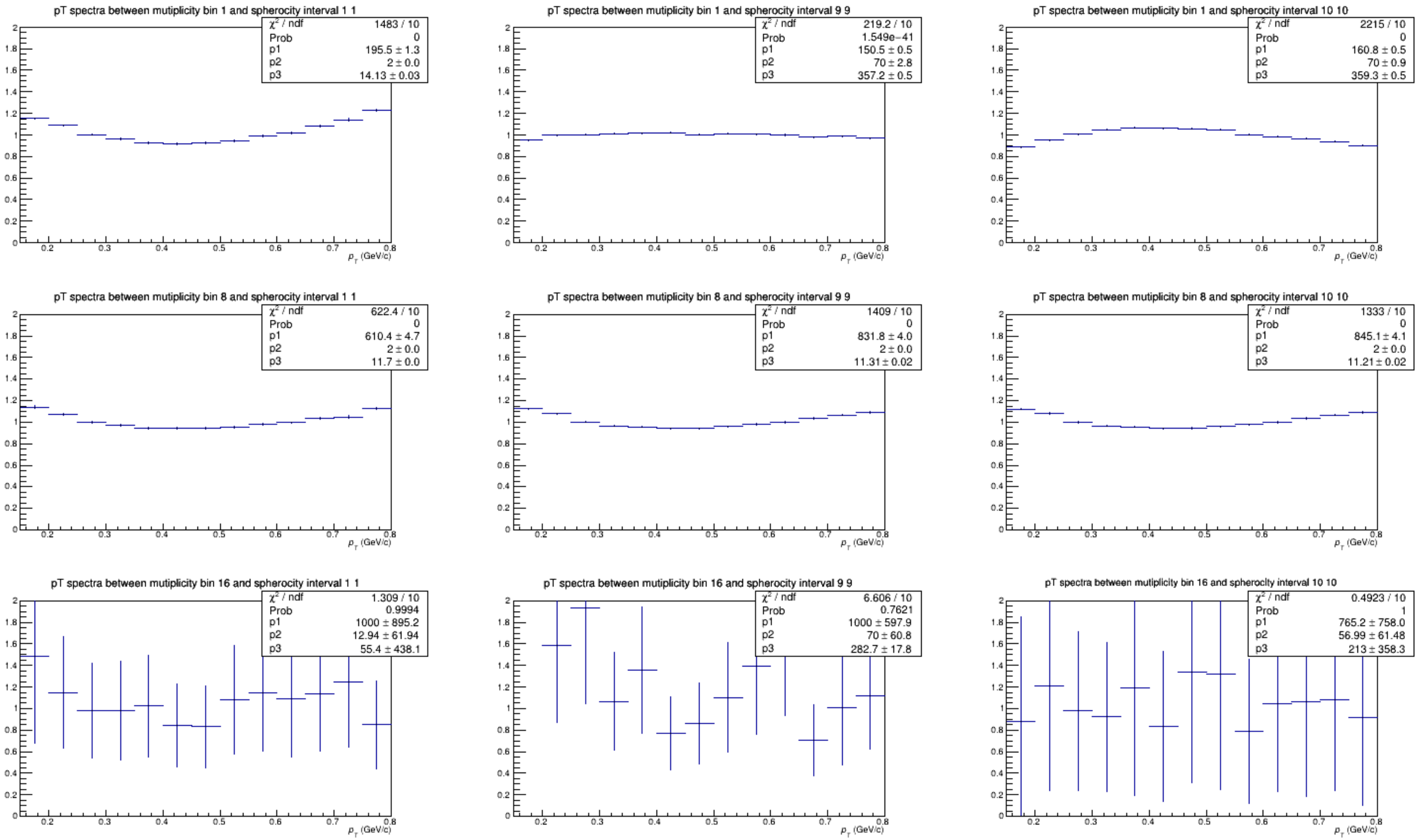
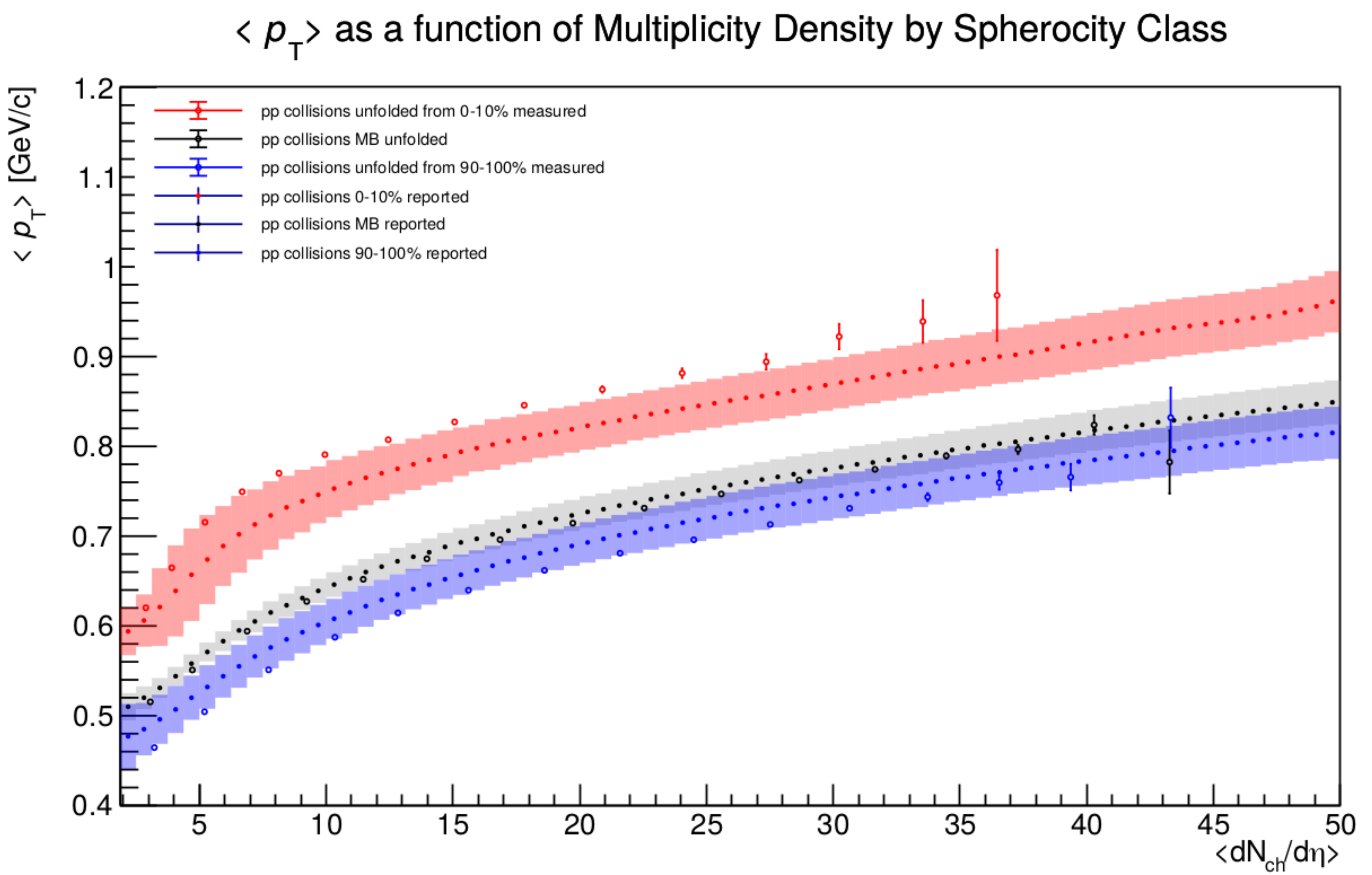


Crosscheck: Mean pT for pp collisions ALICE

Multiplicity Density Fit



Mean pT as a function of Multiplicity Density

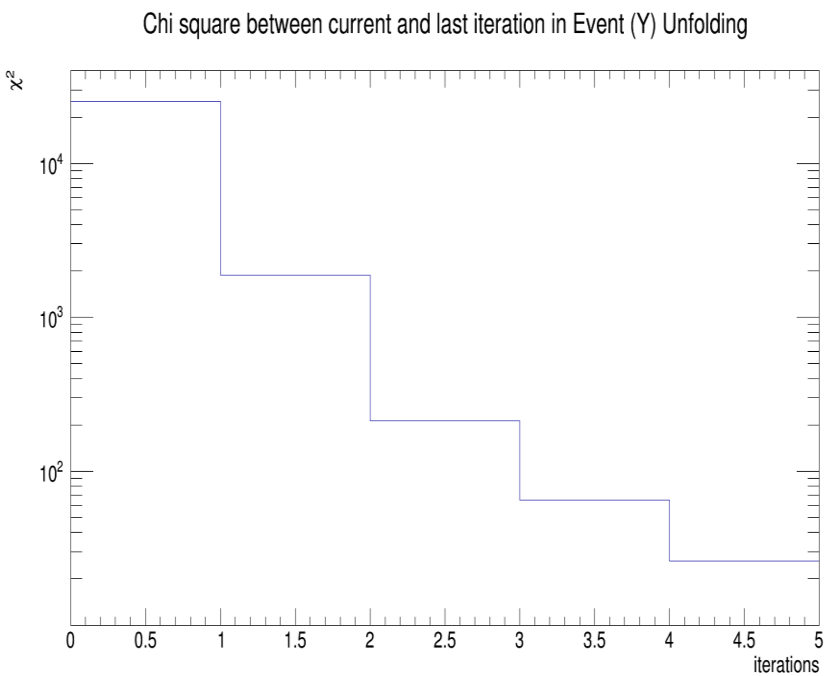


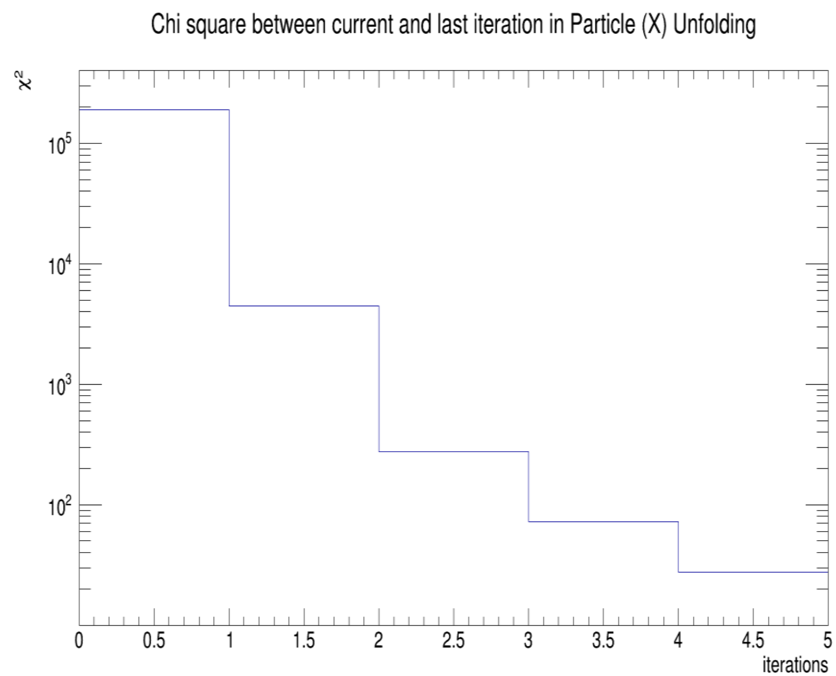
Conclusions

- The unfolding method is a powerful tool to describe the p_{T} Spectra in a multidifferential analysis.

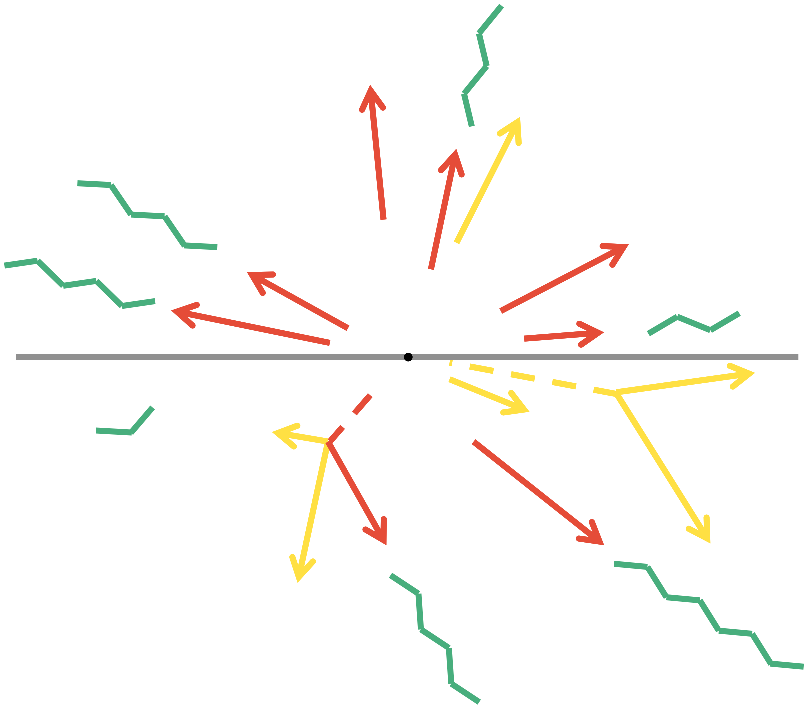
Backup

χ^2 for the event and particle unfolding





Physical Variables: Transverse Momentum (p_T)



■ In a hadron collision we have the emisión of charged and neutral particles, that could be stable or decaying.