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Update on like-sign pion collisions in proton-proton collisions

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Quick reminder about femtoscopy

- Basis – Koonin-Pratt equation:

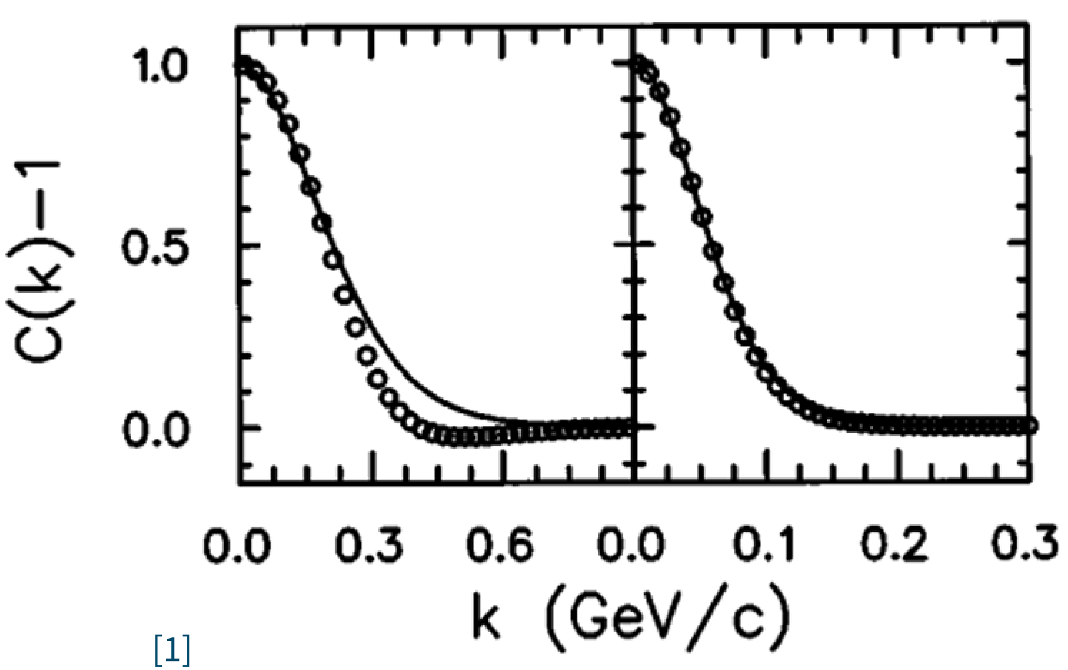
$$CF(\vec{q}_{inv}) = \int d^3 r S(\vec{r})|\Psi(\vec{q}_{inv}, \vec{r})|^2 = \frac{S(q_{inv})}{B(q_{inv})}$$

- But is it always a correct approach?

- What happens if there is a very small amount of particles produced?

Smoothness Approximation

- Koonin-Pratt equation assumes a so-called „smoothness approximation”
- This approximation requires a large number of particles, as it is a kind of a mean-field approxmiation
- Either large energy or large system (or preferably both)
- None of those are present in p+p collisions at $\sqrt{s} = 3.46$ GeV
- The goal of my PhD is to test the limits of this approximation



[1]

- Circles – CF with smoothness approximation
- Solid line – CF without smoothness approximation
- Left: R=1 fm, Right: R = 2 fm

Momentum resolution

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Momentum resolution

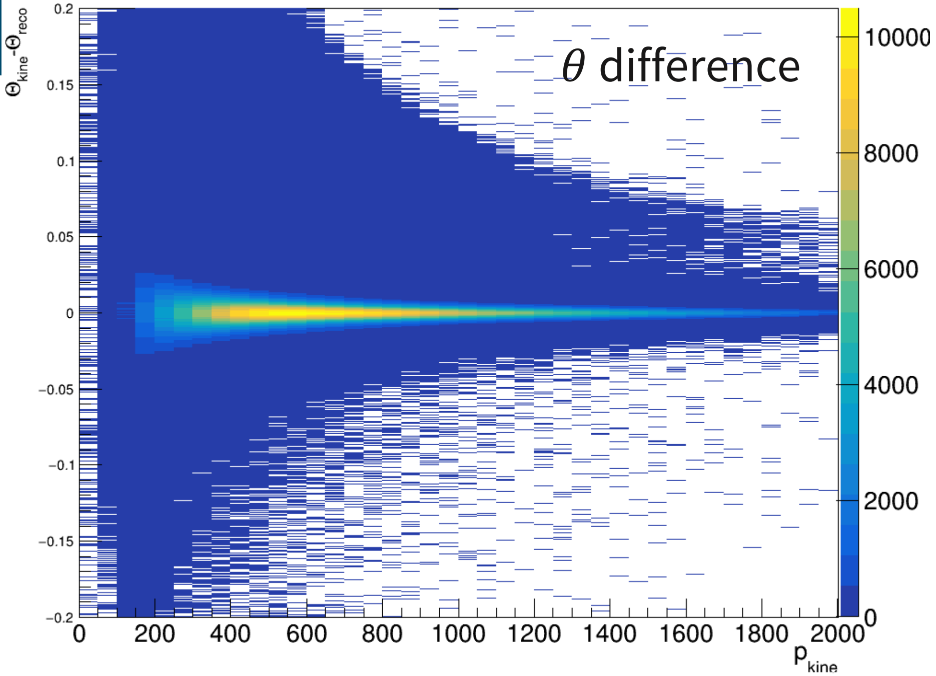
- Because femtoscopic correlations use the relative pair momentum as a studied variable, nonperfect momentum reconstruction by detector can significantly alter the obtained results
- Thus a study of how the momenta are changed comparing to „perfect” ones is needed to estimate this effect
- To do so, 1 600 000 000 events from UrQMD were produced and used for this estimation

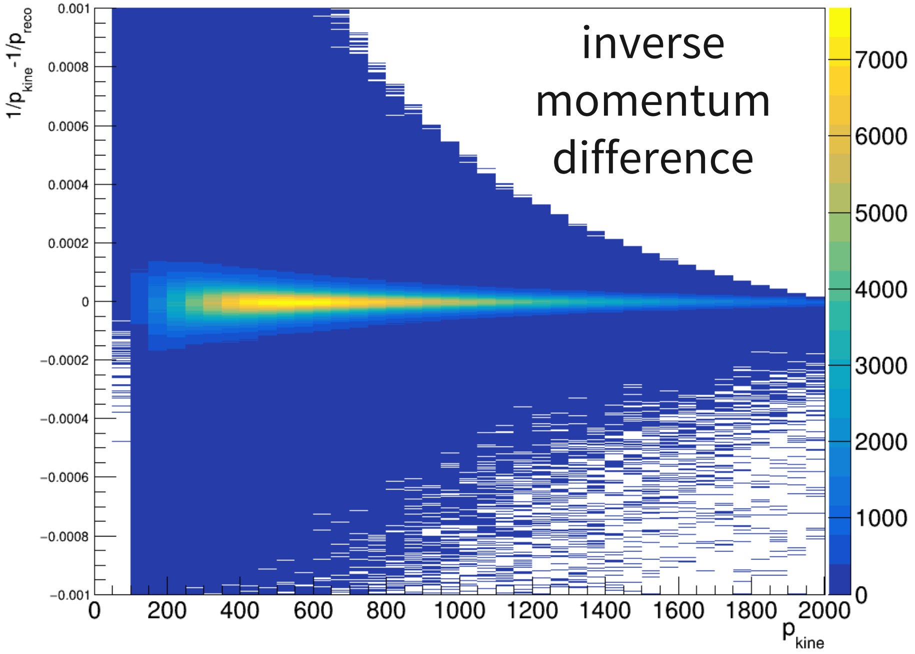
Momentum resolution - workflow

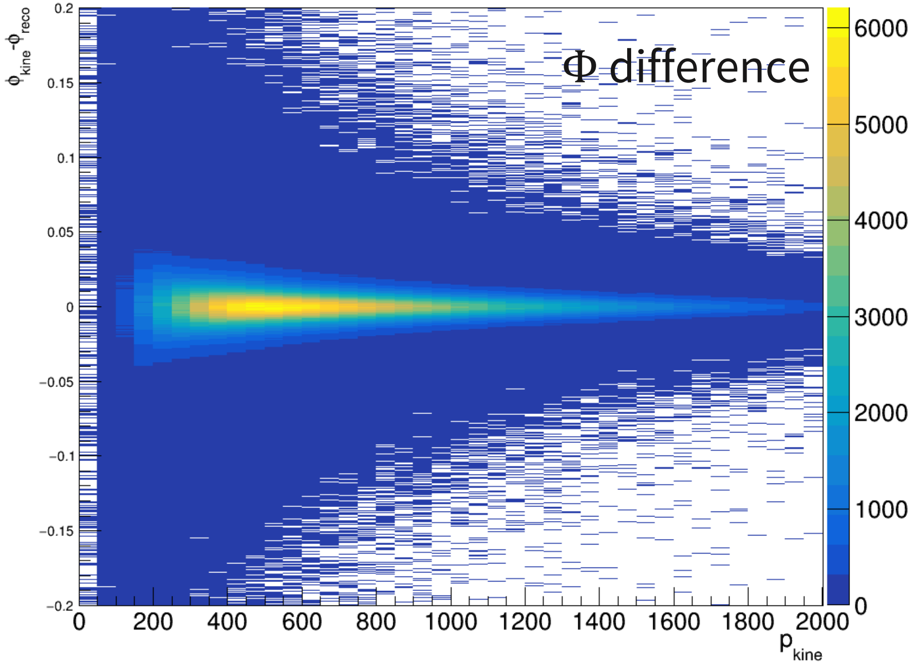
- Prepare following plots from simulated dst:
  - $1/p_{kine} - 1/p_{reco}$ vs p_{kine}, $\Phi_{kine} - \Phi_{reco}$ vs p_{kine}, $\theta_{kine} - \theta_{reco}$ vs p_{kine}
- Fit a gaussian to slices of these plots
- boost the UrQMD data to lab frame
- Smear the 3-momentum
  - $1/p_{smear} = 1/p_{org} + gaus$
  - $\Phi_{smear} = \Phi_{org} + gaus$
  - $\theta_{smear} = \theta_{org} + gaus$
- Set new px, py, pz and Energy
- Check for acceptance (in pT-y)
- Divide unsmeared CF from UrQMD by smeared

Momentum resolution: Obtaining smearing parameters

- 2D histograms were prepared
- y axes – differences between kine (geant) and reconstructed values
- differences in angular distributions and inverse momentum



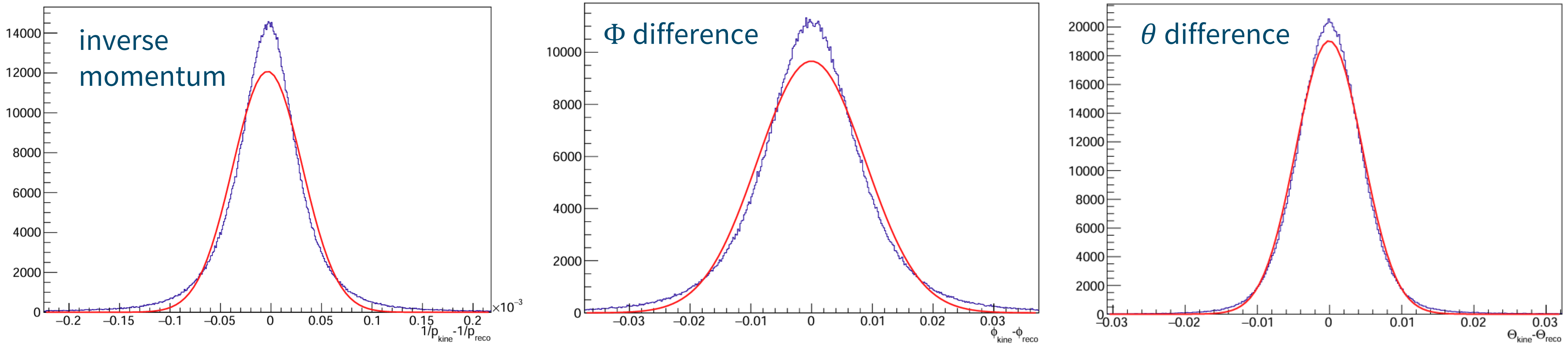




Momentum resolution – obtaining smearing parameters

- The plots shown on previous slide were divided into 50 MeV wide slices along x axis, and to each projection of such a slice a gaussian was fitted
- Probelm: distributions aren't very gaussian…

Projections of slices for $p_{kine} \in (600, 650)$ MeV



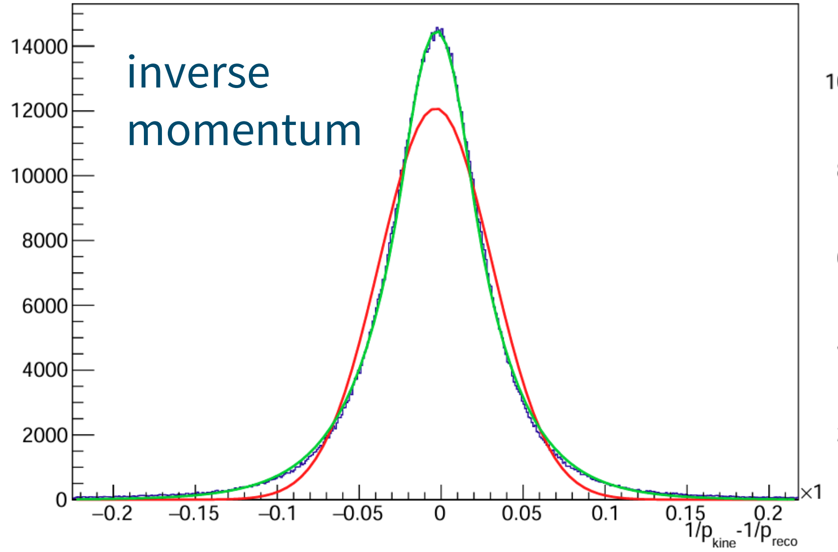
Momentum resolution – obtaining smearing parameters

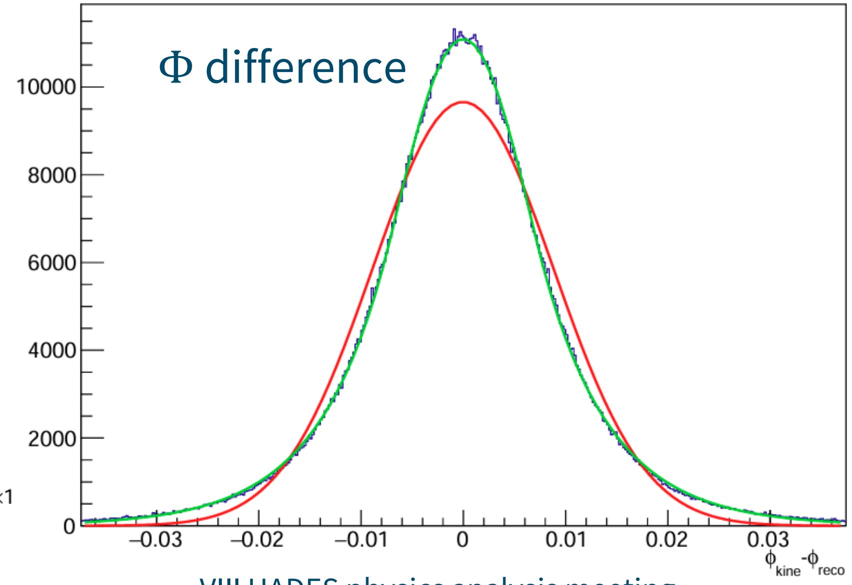
- Solution to the problem: instead of simple gaussian use „crystal ball function" for fitting!

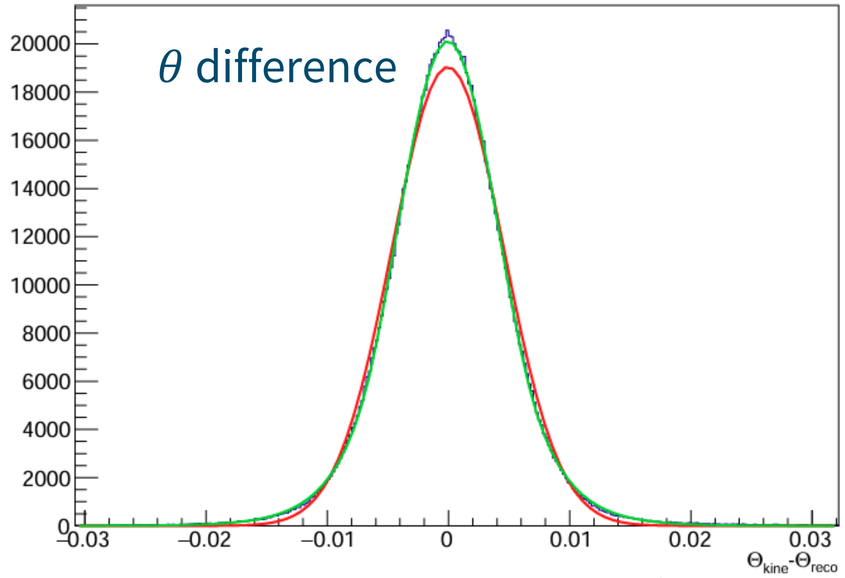
$$
\begin{aligned}
f(x;\bar{x},\sigma,k_L,k_H) &= e^{\frac{k_L^2}{2}+k_L\left(\frac{x-\bar{x}}{\sigma}\right)}, \quad \text{for} \quad \frac{x-\bar{x}}{\sigma} \le -k_L \\
&= e^{-\frac{1}{2}\left(\frac{x-\bar{x}}{\sigma}\right)^2}, \quad \text{for} \quad -k_L < \frac{x-\bar{x}}{\sigma} \le k_H \\
&= e^{\frac{k_H^2}{2}-k_H\left(\frac{x-\bar{x}}{\sigma}\right)}, \quad \text{for} \quad k_H < \frac{x-\bar{x}}{\sigma}
\end{aligned}
$$

Projections of slices for $p_{kine} \in (600, 650)$ MeV

Green: crystal ball
Red: gaussian

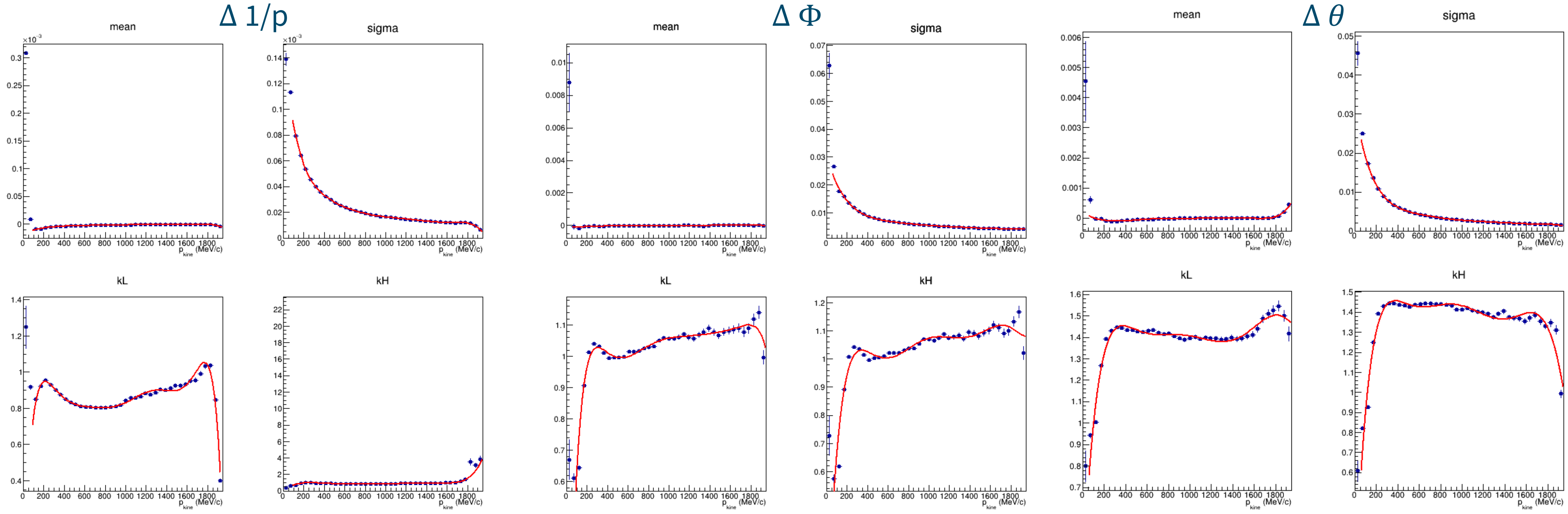






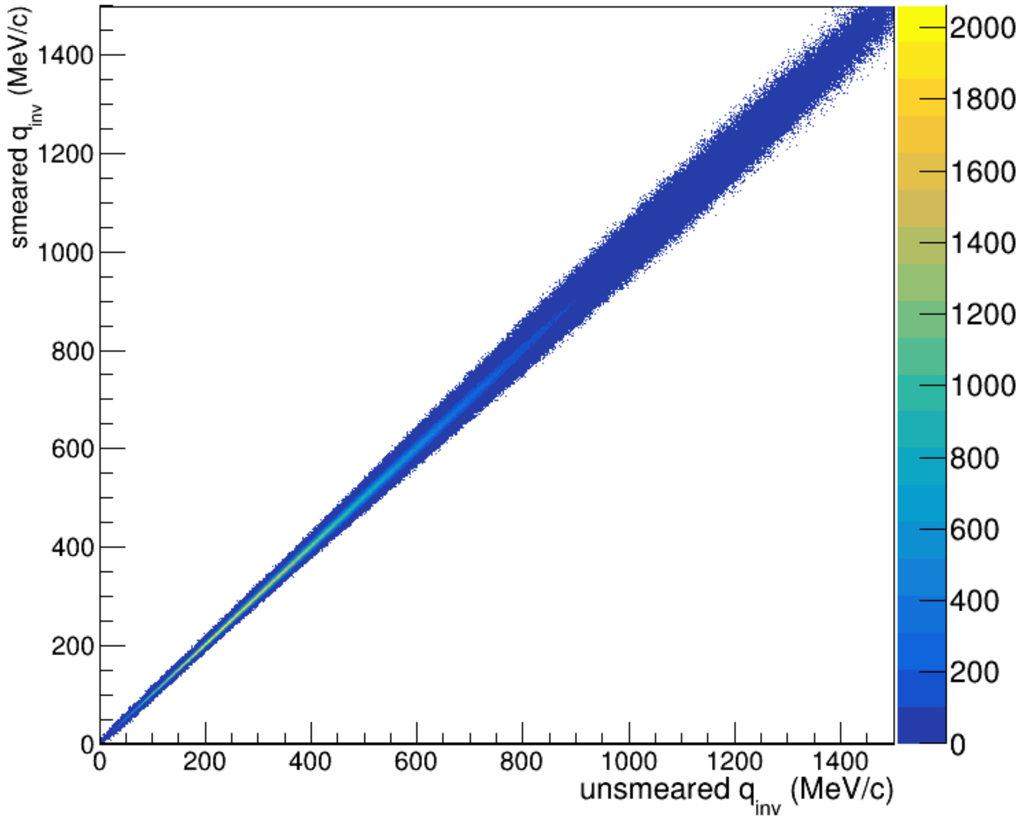
Obtained smearing parameters

- To all distributions 9th order polynomials were fitted
- These functions were later used for obtaining parameters for smearing (creating a function from given p_kine points and then generating random numer from its distribution)



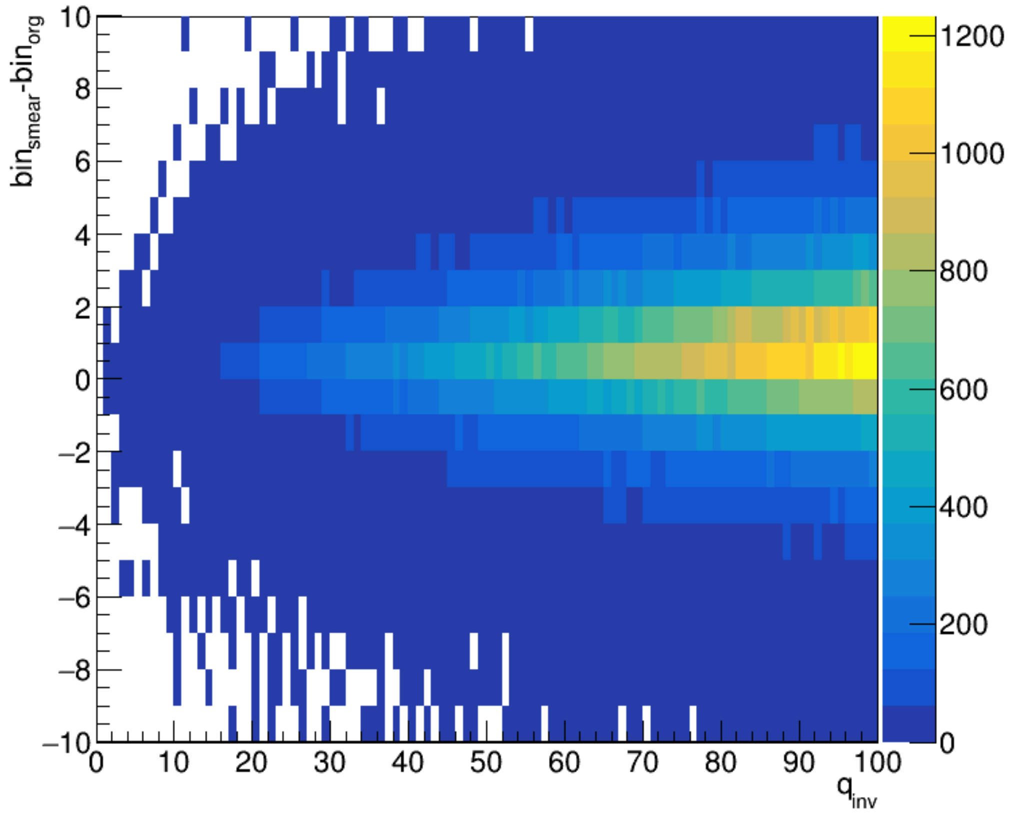
How does the smearing affect the correlation function?

- As can be seen, the smeared vs unsmeared trend is linear
- Also the distribution is very narrowly spread around the y=x linear function
- This suggests that the changes to the correlation function should not be large



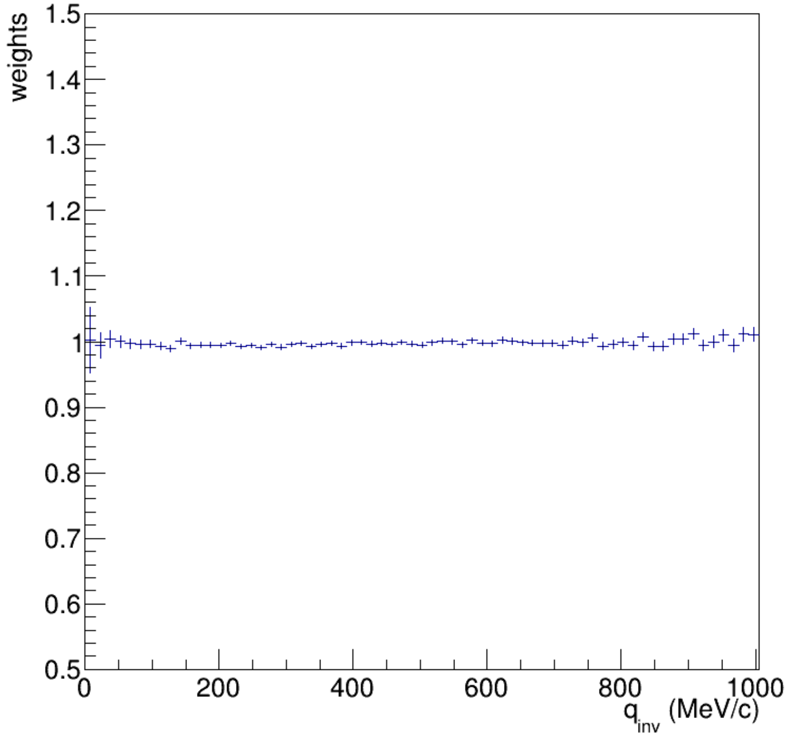
How does the smearing affect the correlation function?

- For low q_{inv} region (the one I am most interested in) smearing momenta almost doesn't change binning
- Difference of bin is usually zero, with rather symmetrical distribution around it
- It means that for the case of my analysis detector behaves very well when it comes to reconstructing momenta



Momentum resolution

- It turns out that for my case detector performs well and the reulting correction is flat
- Therefore I decided not to include it in my analysis, as it would only make the uncertainties larger



Edgeworth expansion

Edgeworth expansion

- Instead of trying to forcefully fit gaussian to non-gaussian I wanted to try to somheow embrace the actual shape and describe it

- In order to do so, edgeworth expansion was employed:

$$CF(q_{inv}) = N \cdot \left((1-\lambda) + \lambda * k_F + \lambda * k_F * e^{-q_{inv}^2 \cdot R^2} \cdot \left(1 + \sum_{n=3}^{\mathrm{inf}} \frac{\kappa_n}{n!} \cdot H_n\left(\sqrt{2} \cdot q_{inv} \cdot R\right) \right) \right)$$

  - Where κ_n - fit parameter, H_n - nth order Hermite polynomial

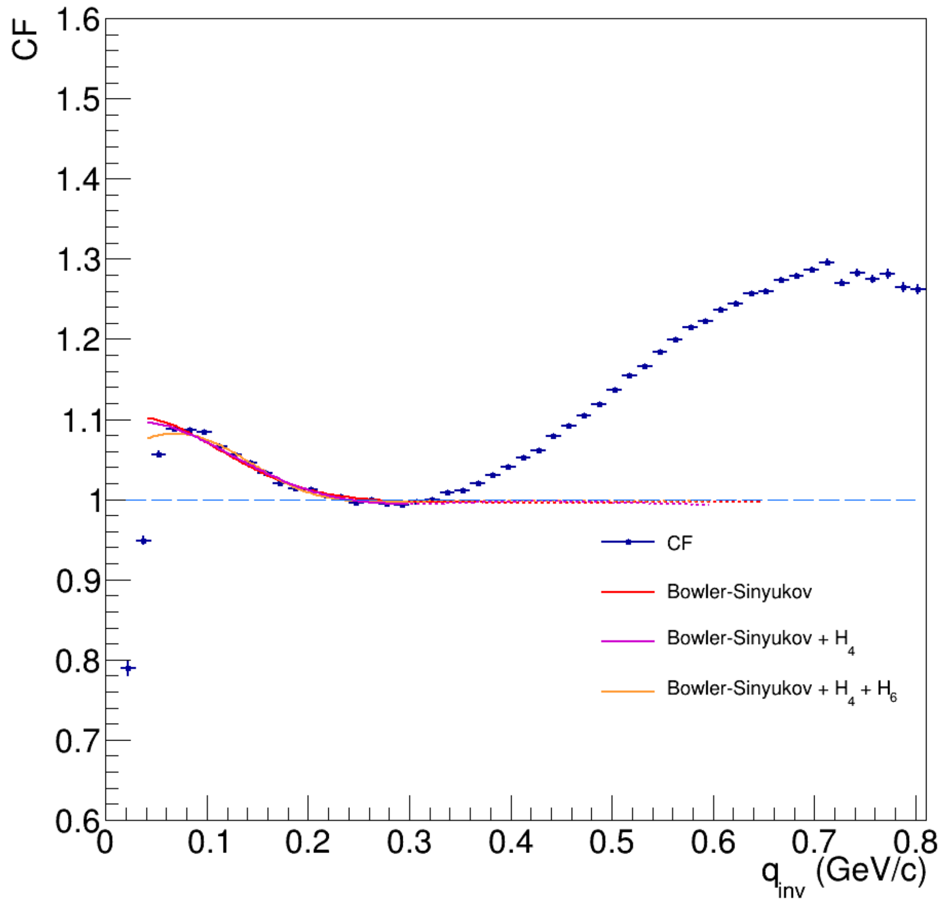
- Hermite polynomials allow to include higher moments of distribution, if deviations from Gaussian are not extreme, then it could give better description of the source

Example of fitting using this method

- Tested two cases, only using H_4 or H_4 and H_6
- No shared wires, $\mathrm{nTracks} \geq 6$
- Generally adding the Hermite polynomials seems to make the fits better

	λ	R (fm)
Bowler-Sinyukov	0.1322 ± 0.0027	1.411 ± 0.028
Bowler-Sinyukov + H_4	0.089 ± 0.018	0.843 ± 0.060
Bowler-Sinyukov + H_4+H_6	0.1170 ± 0.0042	1.530 ± 0.056

π^- correlation function



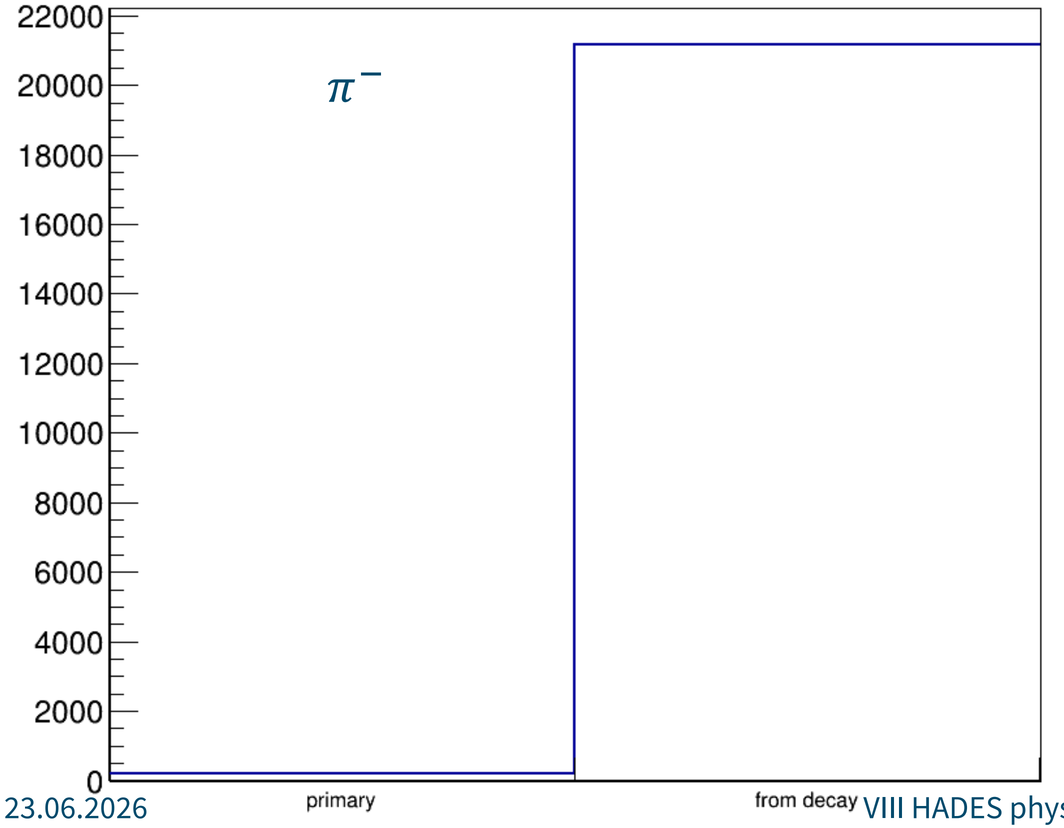
The mystery of small lambda

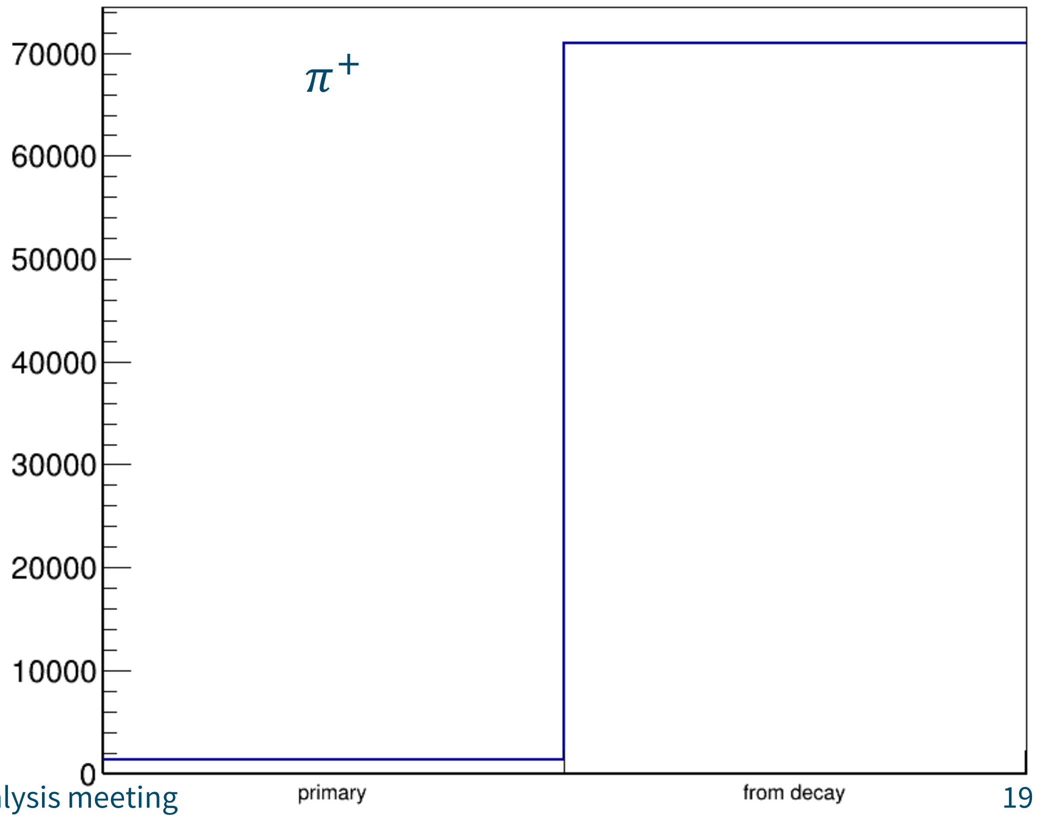
Why the correlation is so weak?

- Generally the only thing contributing to correlation is the quantum statistics (Bose-Einstein in my case)
- The thing that mainly contributes to weakening of the correlation function is the fact, that some particles come from decays
- Also different times of particle creation will cause the correlation to weaken
- I decided to check how the pions are created, to do so I generated 100 000 SMASH events to analyze

Pion creation mechanism

- It turns out that 98.97% of π^- and 98.2% of π^+ come from decays
- This fact definitely contributes to low lambda values, I should not expect it to approach even 0.5





Pion creation mechanism

- It turns out, that most negative pions come from Delta resonances, followed by N resonances and lambdas, for positive pions it's almost exclusively Deltas

- Specific processes are e.g. $\mathrm{p} + \mathrm{p} \rightarrow \begin{cases} \mathrm{n} + \Delta^{++} \rightarrow \mathrm{n} + \mathrm{p} + \pi^{+} \\ \mathrm{p} + \Delta^{+} \rightarrow \mathrm{p} + \mathrm{p} + \pi^{+} \\ \Delta^{0} + \Delta^{++} \rightarrow \mathrm{p} + \mathrm{p} + \pi^{+} + \pi^{-} \end{cases}$

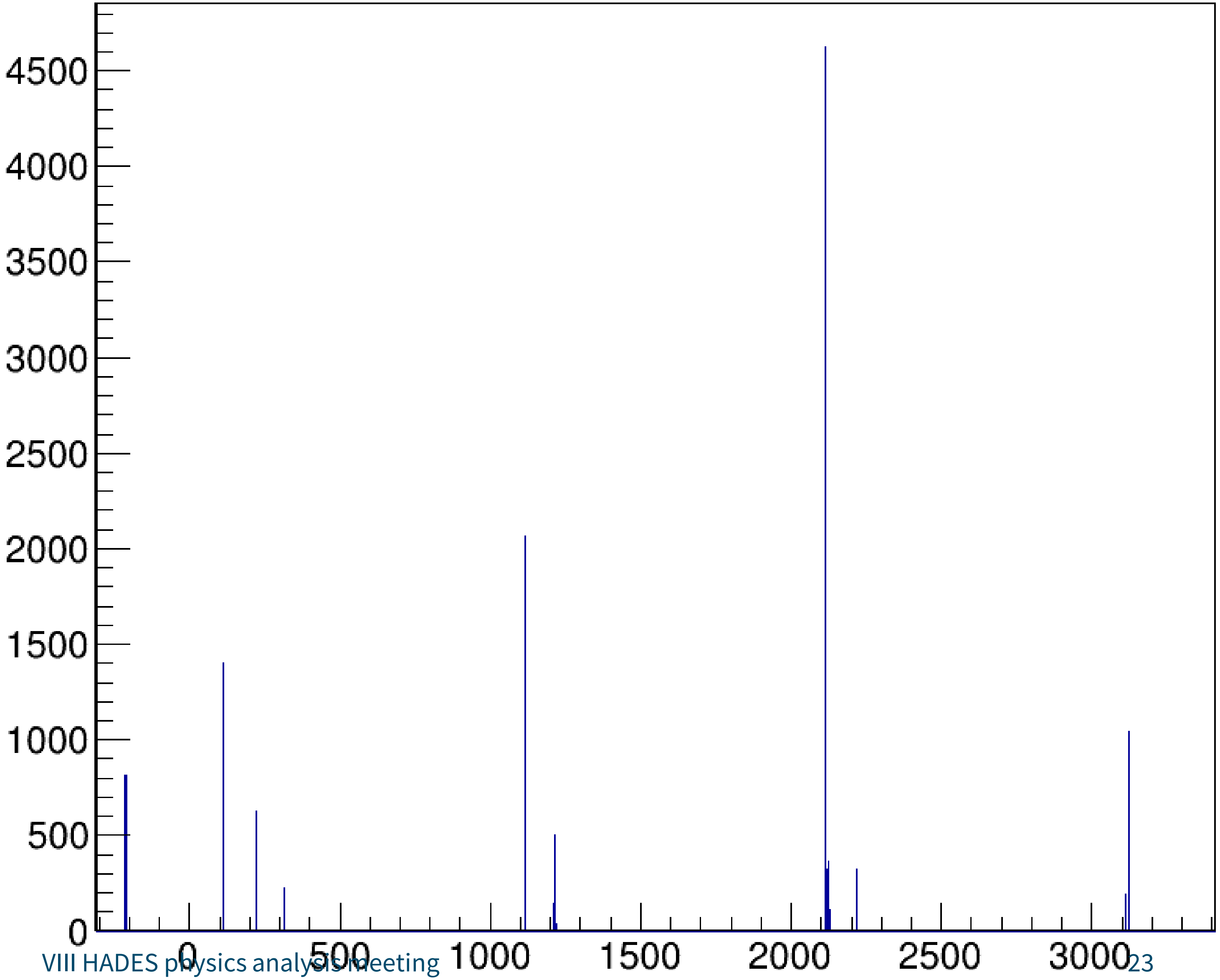
- Deltas are not produced in a usual sense of the word, rather they are a transition state during the system evolution created by nucleon excitation

- Because the pions come from Deltas the correlation is weaker, although due to short lifespan of Delta resonances the reduction is not as huge as it could be

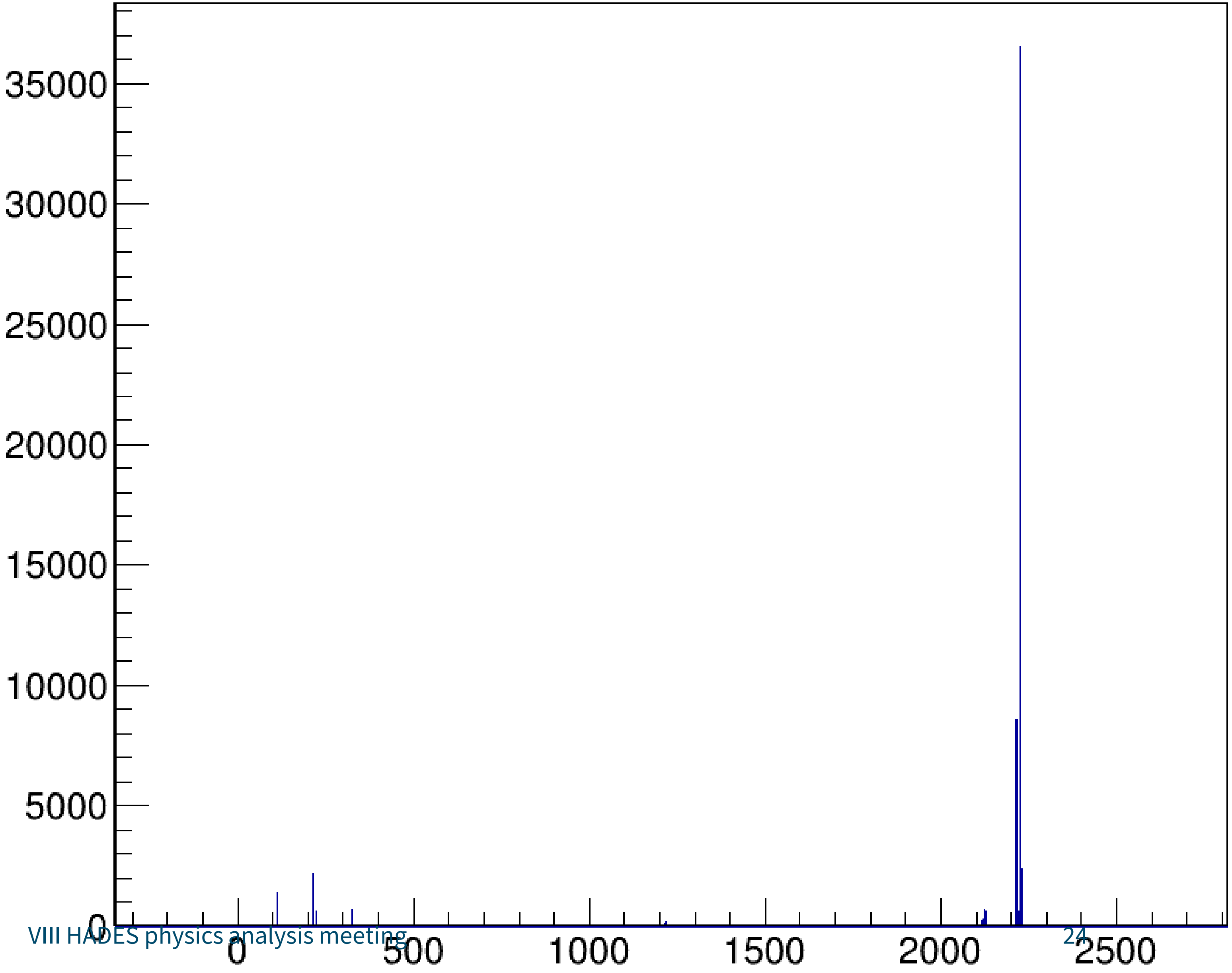
Thank you for your attention!

Backup

π^- mother pid



π^+ mother pid



All final particle pids