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Femtoscopy at CBM current status and future

Daniel Wielanek

Warsaw University of Technology, Faculty of Physics

46th CBM Collaboration Meeting, 2025

Warsaw University of Technology

Outline

- Introduction
- Motivation
- Femtoscopy in CBM
- Plans and summary

Femtoscopy group in WUT

- Professor
  - Hanna Zbroszczyk - coordinator
- Post-docs
  - **Somen Gope – π,p - femtoscopy**
  - Daniel Wielanek – software development
- Master students
  - Julia Ejsmont – pΛ-Λ Λ femtoscopy
- Bachelor students
  - **Wojciech Bojakowski – development of algorithms for cascades analysis**
  - **Kacper Zięba – d-Λ, π-femtoscopy**

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Introduction to femtoscopy

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Femtoscopy

Technique used to extract information about spatio-temporal structure of event

Base on two particle correlations

Correlation function defined as

Spatio-temporal structure of the event

$$C(q) = \frac{P(p_1, p_2)}{P(p_1)P(p_2)} = \int \rho(x_1, p_1)\rho(x_2, p_2)\left|\Psi(x_1, p_1, x_2, p_2)\right|^2 dx_1 dx_2$$

Interactions + quantum statistic

where $q = \sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2}$

Denominator is created from mixed pairs (each particle is from different event)

The standard procedure:

- Calculation of experimental CF
- Taking into account all detector's effects
- Fitting of CF with theoretical one

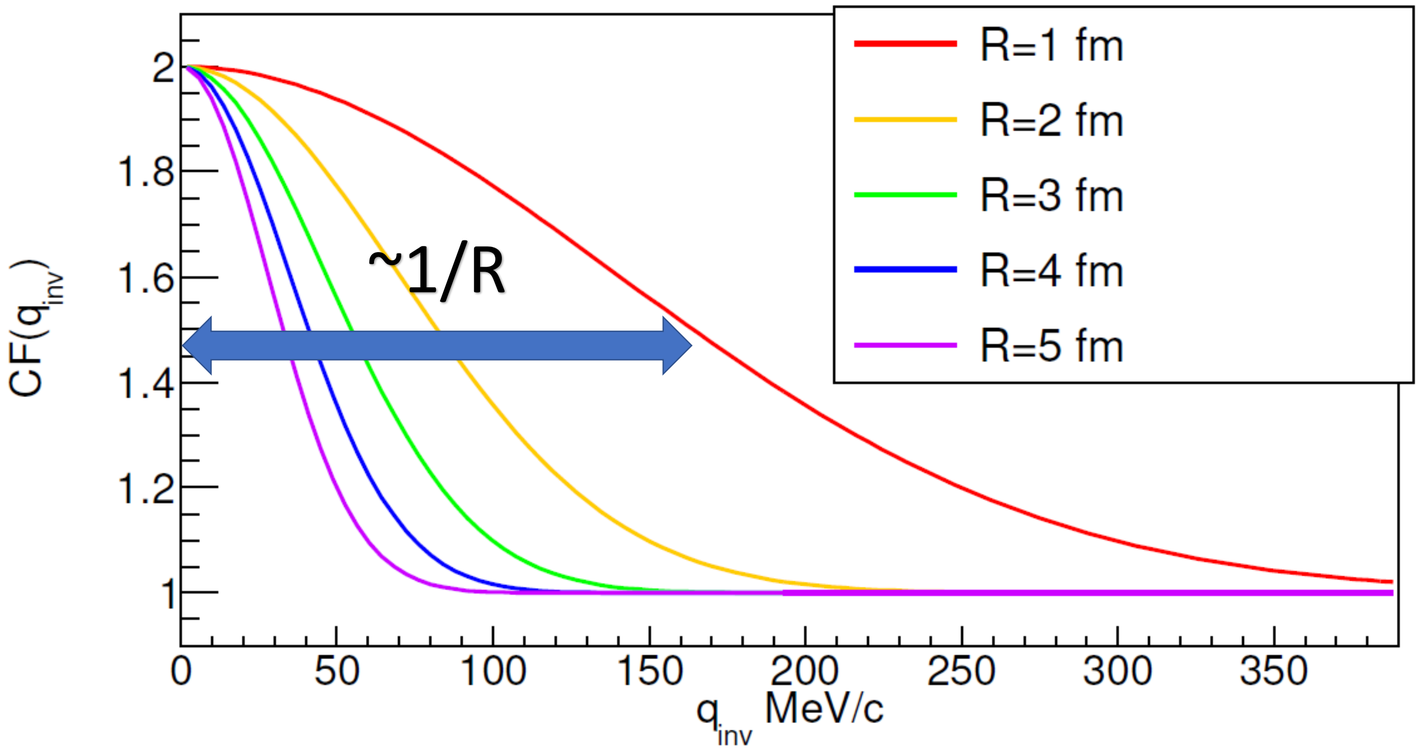
Femtoscopy

Technique used to extract information abou
Base on two particle correlations
Correlation function defined as

$$C(q) = \frac{P(p_1}{P(p_1)}$$

where $q = \sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2}$
Denominator is created from mixed pairs (e
The standard procedure:

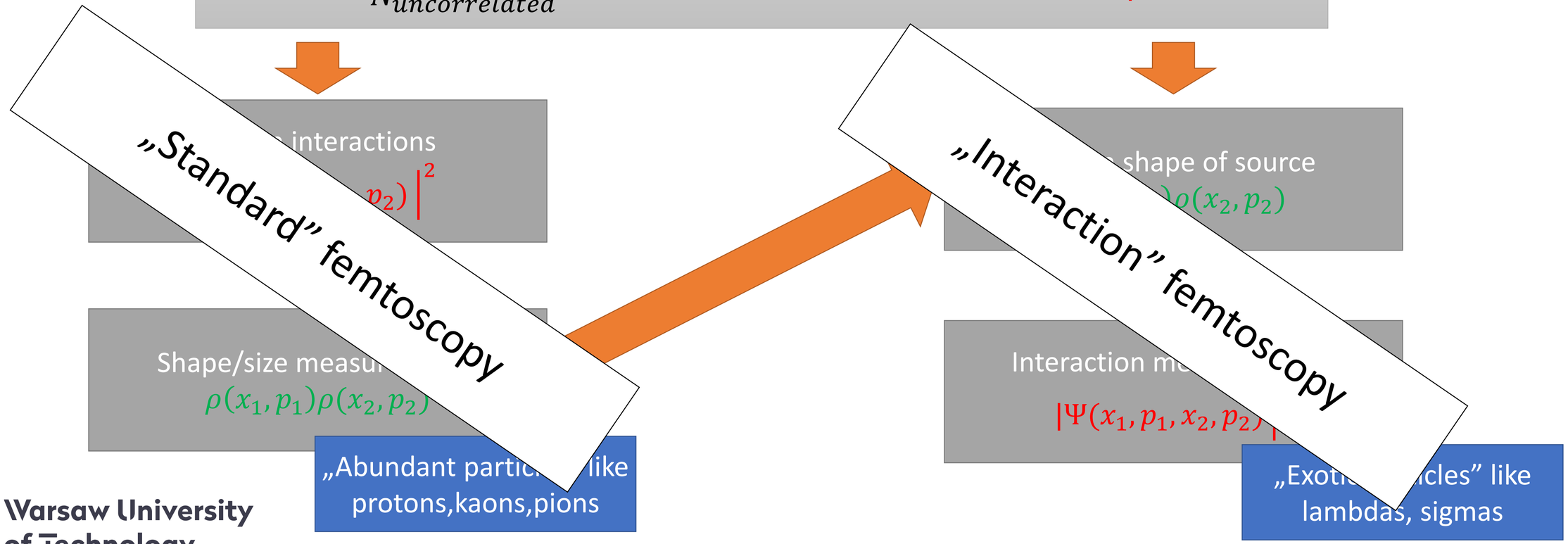
- Calculation of experimental CF
- Taking into account all detector's effects
- Fitting of CF with theoretical one
- Important note – MC models usually don't contain femtoscopic effects – we expect flat CF (CF(q)≈1)*



Femtoscopy

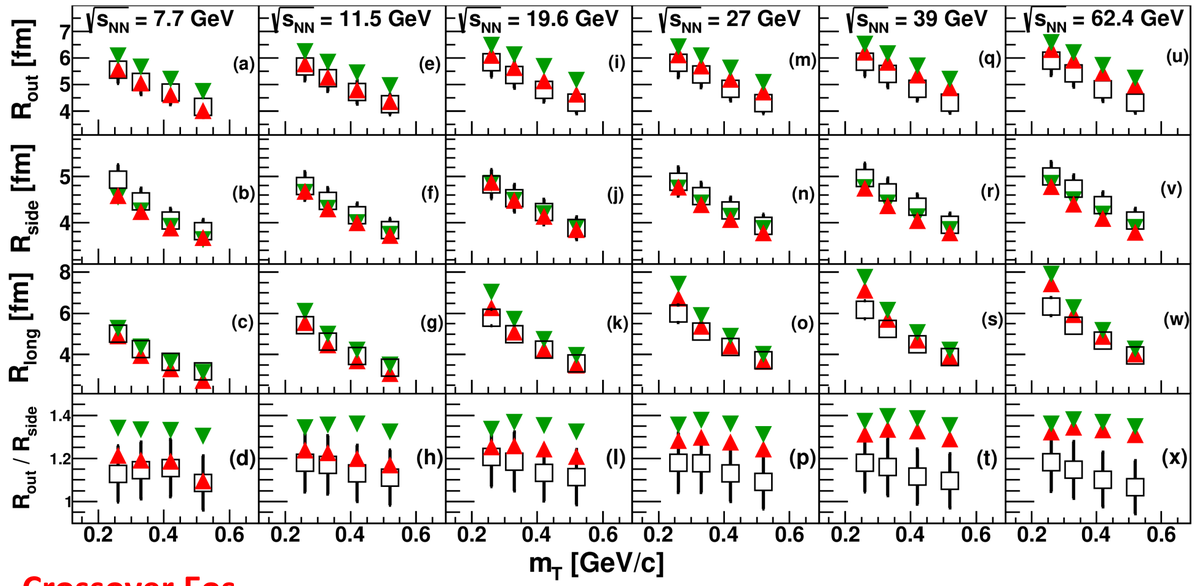
Femtoscopy can be used for measurements of interaction between exotic particles:

$$C(q) = \frac{N_{correlated}}{N_{uncorrelated}} = \int \rho(x_1, p_1)\rho(x_2, p_2)\left|\Psi(x_1, p_1, x_2, p_2)\right|^2 dx_1 dx_2$$



„Standard” femtoscopy

- Access to geometry of the fireball
- Probing the dynamics of system



Crossover Eos

1st order Eos

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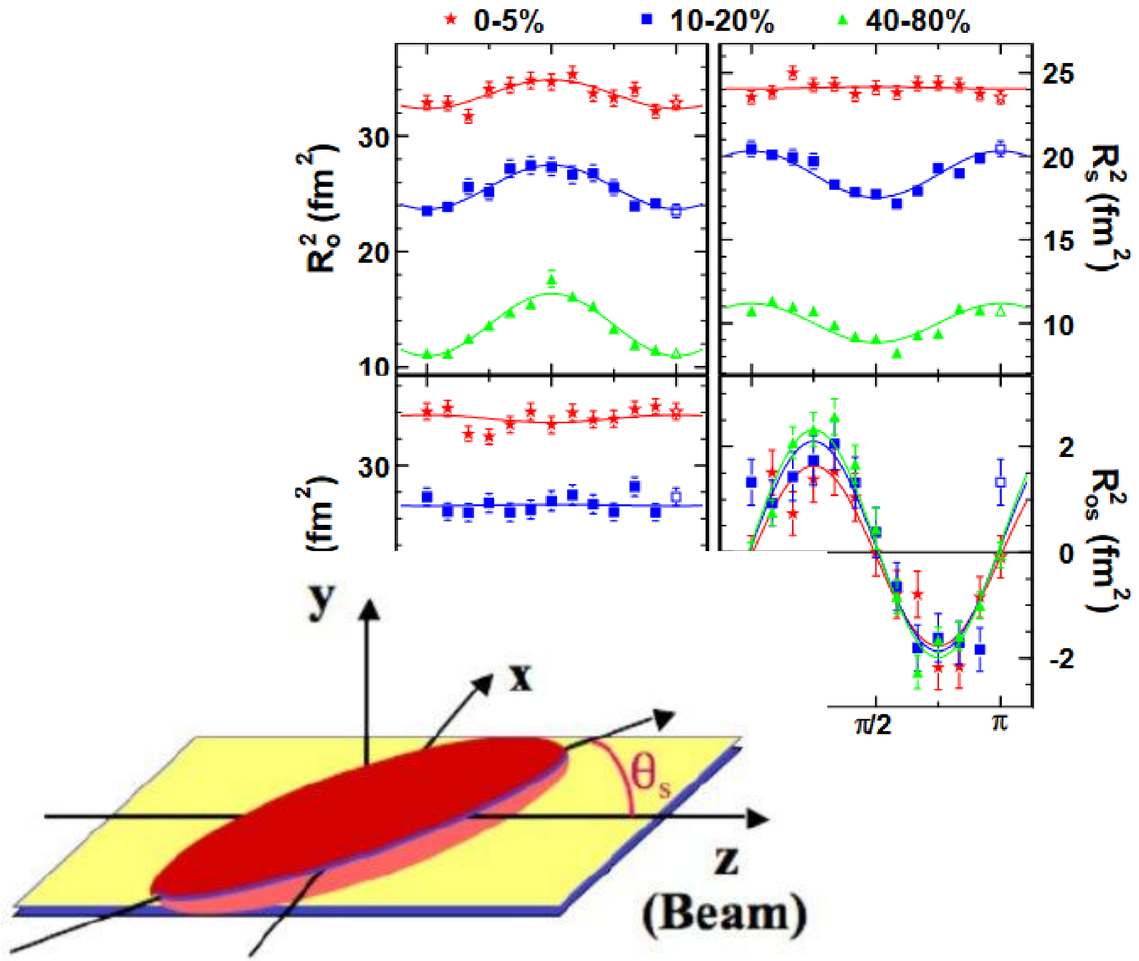
Correlation femtoscopy study at energies available at the JINR Nuclotron-based Ion Collider fAcility and the BNL Relativistic Heavy Ion Collider within a viscous hydrodynamic plus cascade model, Phys. Rev. C 96, 024911, 2017, P. Batyuk, Iu. Karpenko, R. Lednicky, L. Malinina, K. Mikhaylov, O. Rogachevsky, D. Wielanek

HBT radii from the UrQMD transport approach at different energies, **The European Physical Journal Conferences,** Gunnar Graef &et al. 2011

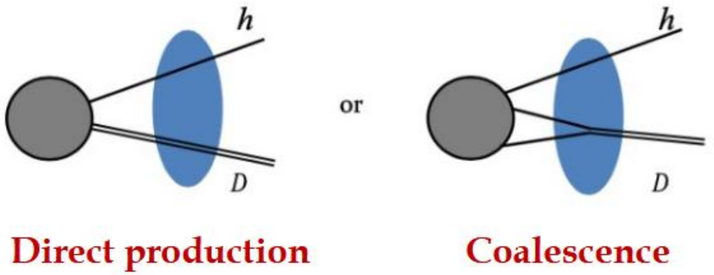


Azimuthally Sensitive Hanbury Brown-Twiss Interferometry in Au+Au Collisions at √sN N = 200 GeV, STAR collaboration, 2004 arxiv

„Standard” femtoscopy

Probing the mechanism of formation of light nuclei – e.g. deuteron femtoscopy

- Binding energy of neutron ~2 MeV
- Fireball temperature ~150 MeV
- But if deuterons are formed after thermal freezeout – no problem
- In such case: formation volume > fireball volume



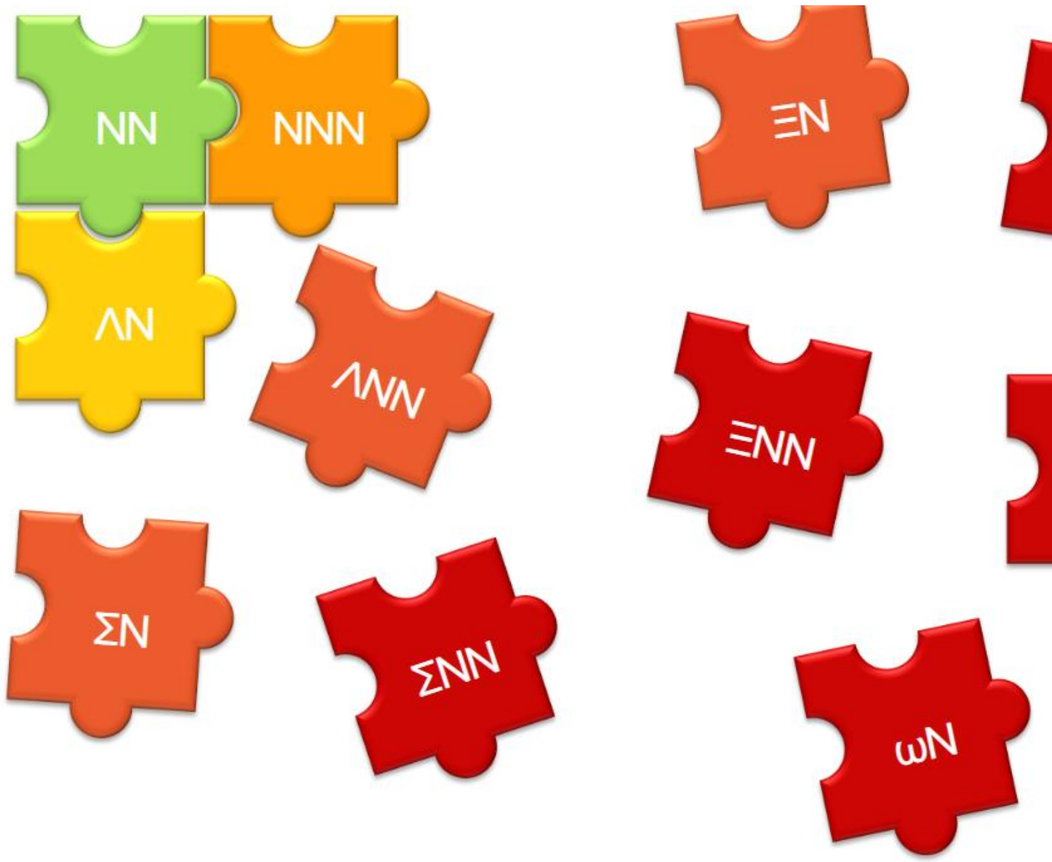
St. Mrówczyński and P. Słoń, Acta Physica Polonica B 51, 1739 (2020)

Explaining Snowball-in-hell Phenomena in Heavy-ion Collisions Using a Novel Thermodynamic Variable
Eric Braaten et. Al, https://arxiv.org/pdf/2408.03935v3

„Interaction femtoscopy”

- Probing the interaction between „exotic” baryons:
  - Neutron Star (NS) puzzle – how to get a strange matter in NS AND have heavy star?
    - 3-particle femtoscopy
    - femtoscopy of hypernuclei
  - Detecting possible bound states (H-dibaryon in ΛΛ correlation measurements)
  - Testing of QCD models (potentials)
  - Possible to extract scattering parameters of particles that cannot be accelerated

Hyperon-nucleon femtoscopy, nuclear production, and bearing on astrophysics V. Manovain Sarti (2021 SQM)



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Femtoscopy in CBM

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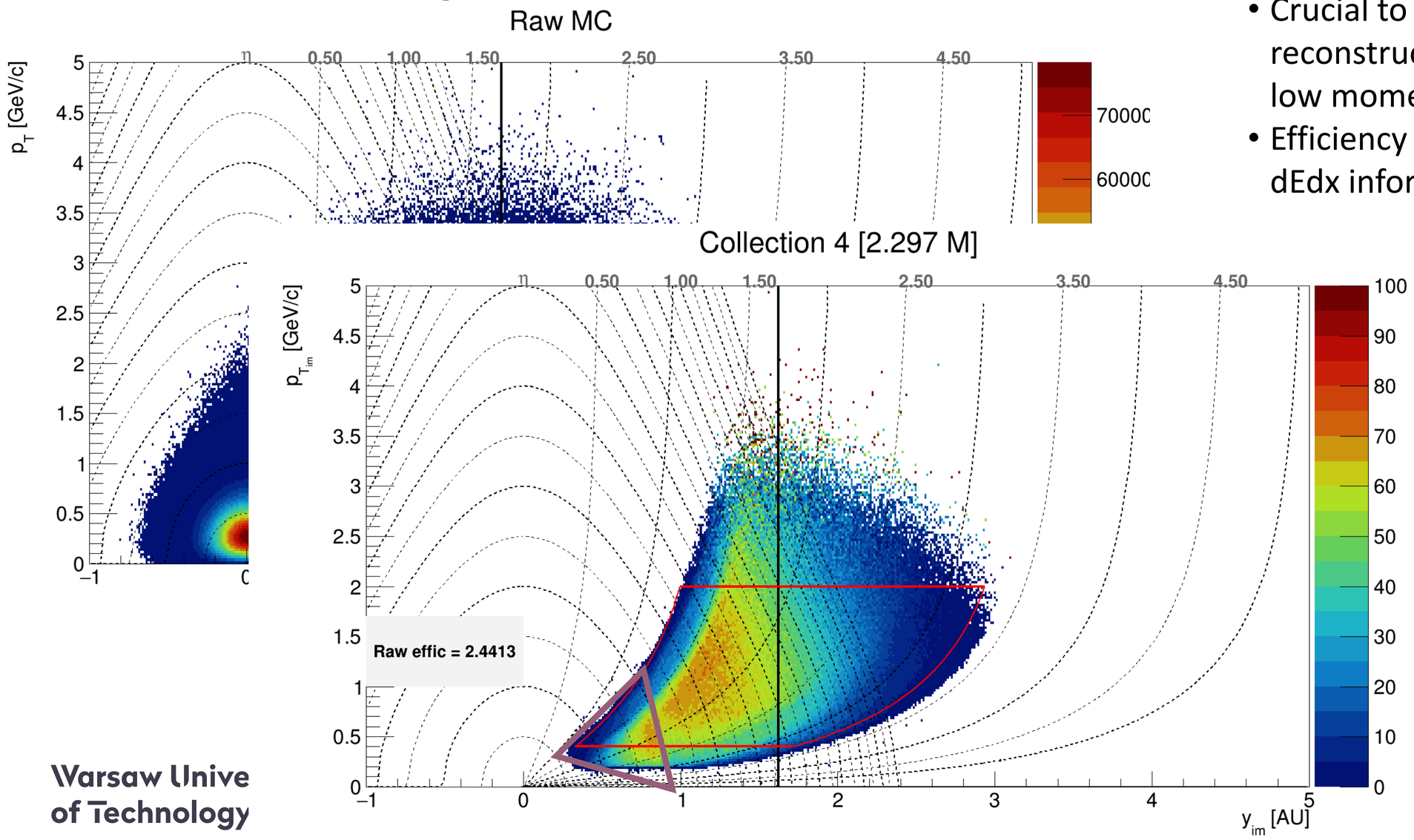
Framework update

- Software divided in two parts:
  - External independent package - HAL (core of analysis)
  - Module to support of CBM data
- Extending femtoscopic part of CbmRoot data by supporting:
  - TRD information
  - RICH information
  - **dEdx (STS) information**
- Macros to plot basic distributions (track cut optimization)
  - Efficiency
  - Acceptance
  - Primary/secondary fraction (as functions of DCA cuts)
  - Purity
- Possibility of using KFParticle V0 Finder (Y. Zhou, I. Vassiliev)
- Other minor improvements (bug fixes, ignoring broken files)

Deuteron yields

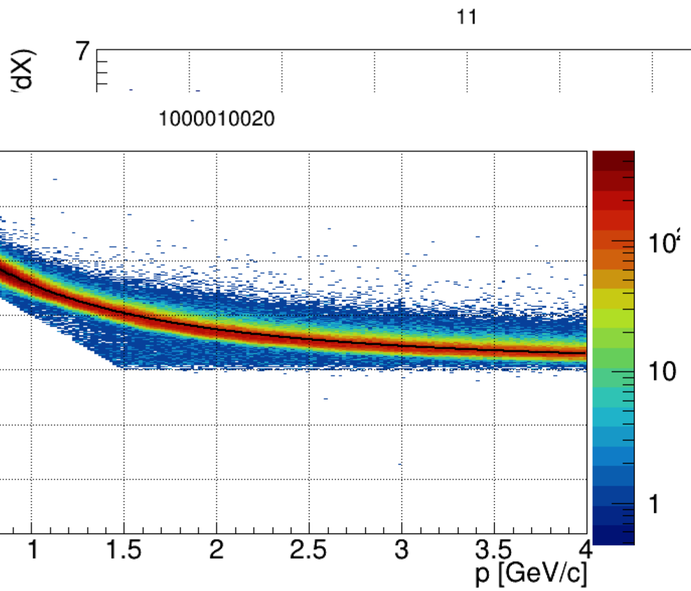


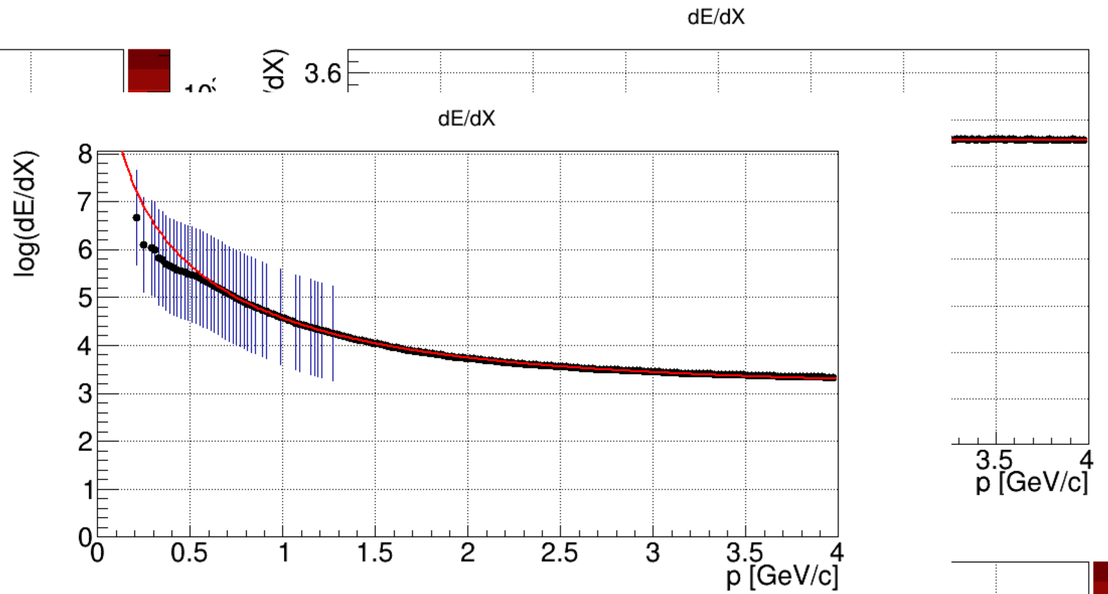
- Most of deuterons at region of spectators
- Crucial to have ability to reconstruct particles with low momenta
- Efficiency improved by using dEdx information

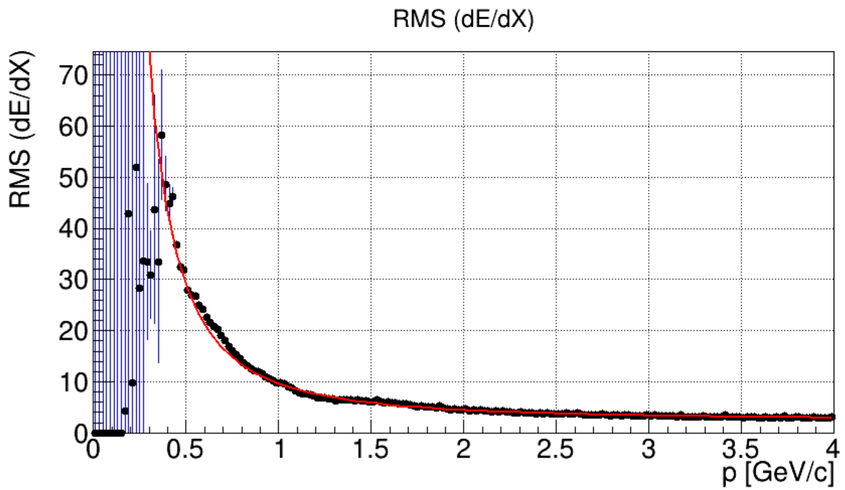
dEdx calibr

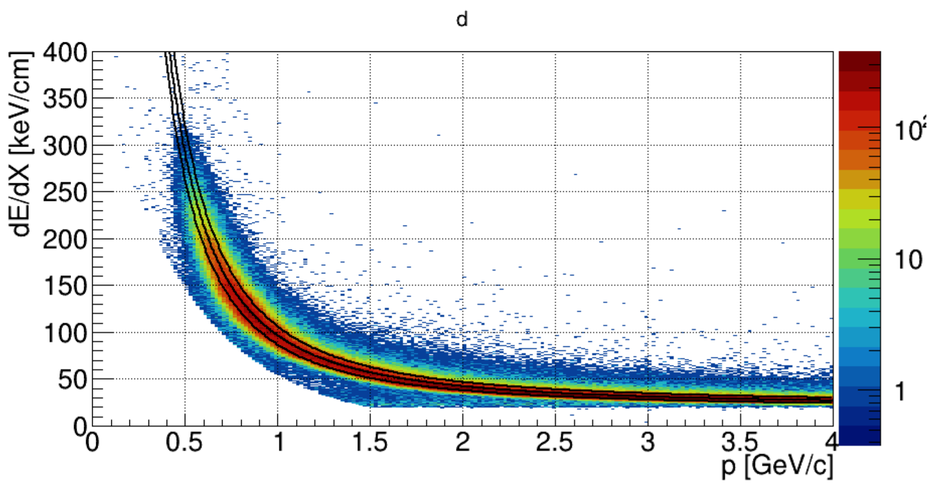
Calibration a
- Estimate th momentun
- Fit as a fun
- Alternative problemati at differen

$\sigma($

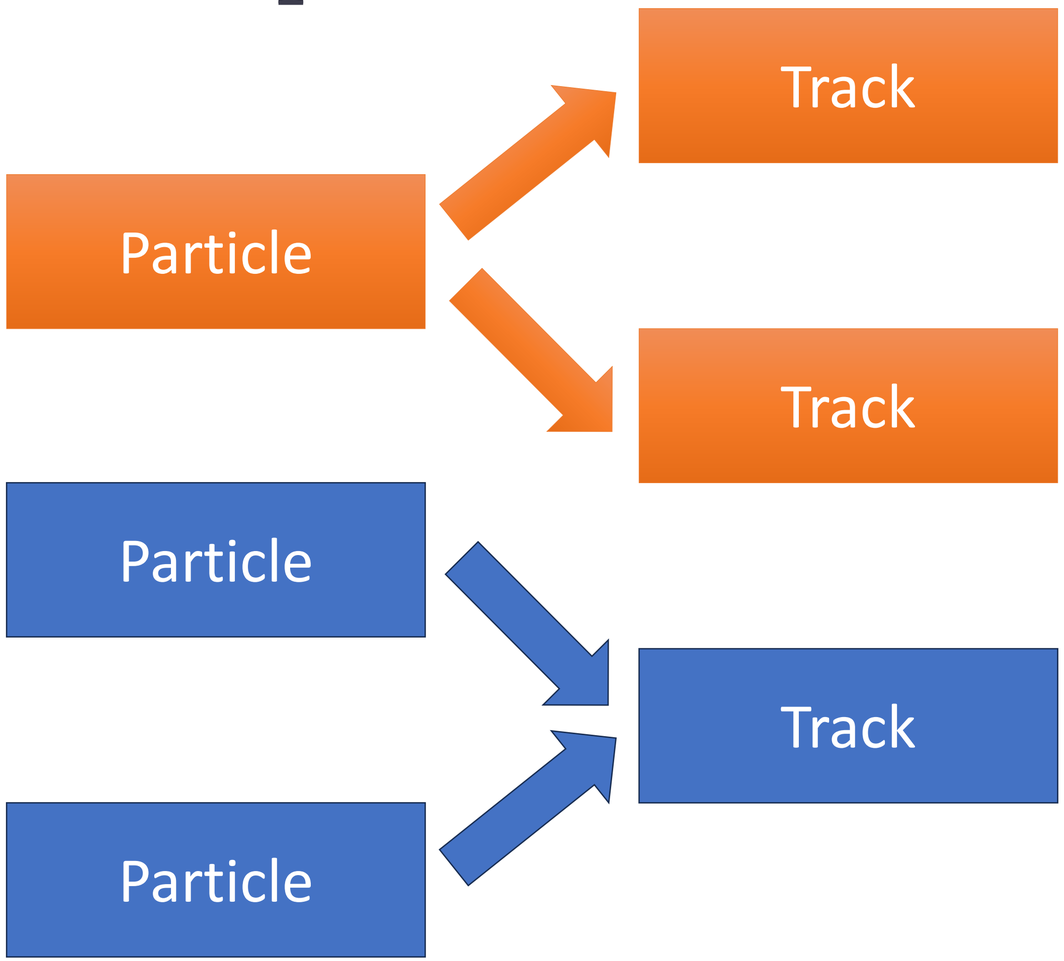








Two-particle effects studies



Splitting

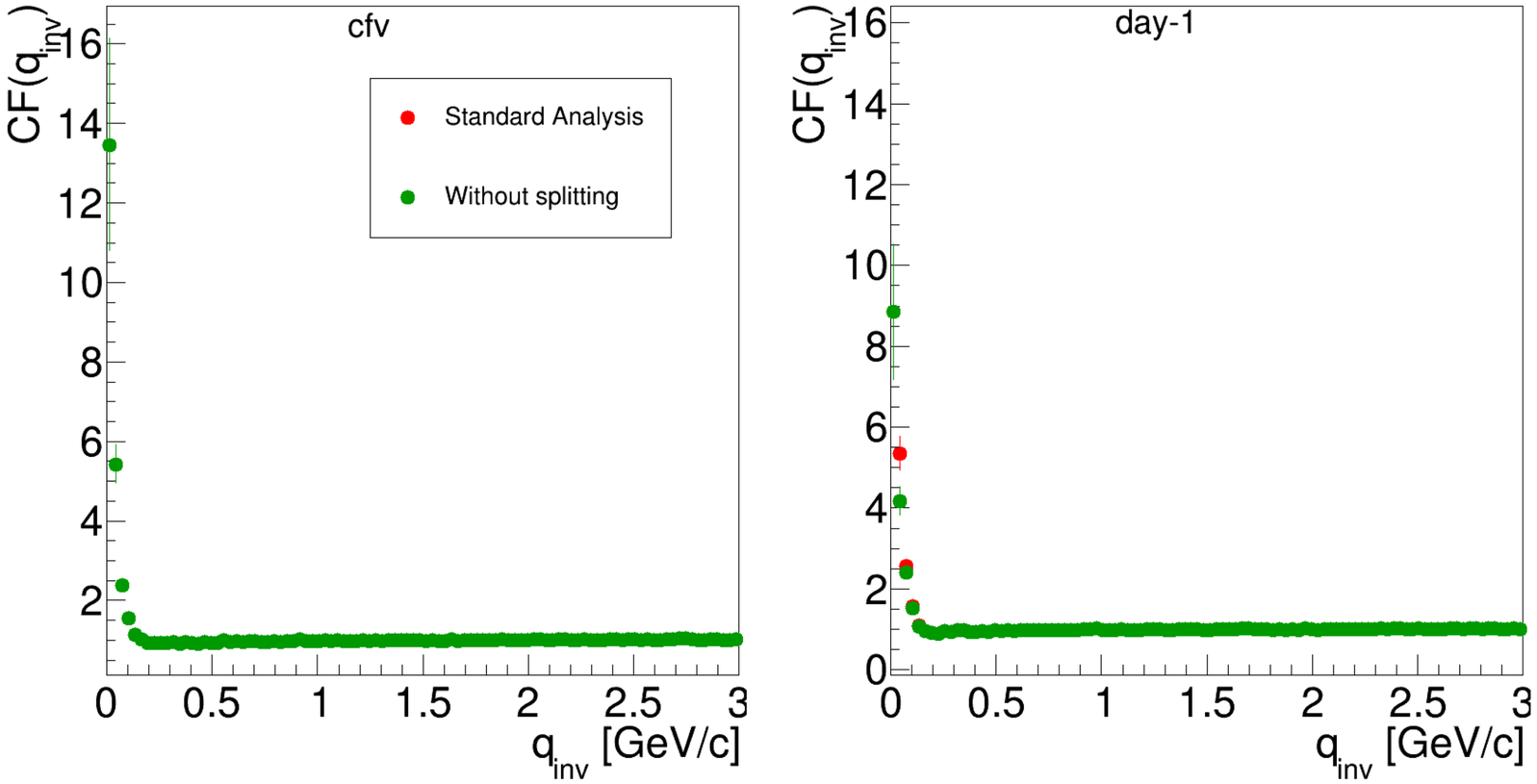
Correlation Function

Merging

Correlation Function

Correlation function (no HBT)

- Correlation function goes up despite anti-splitting cut!
- Another effect must modify CF



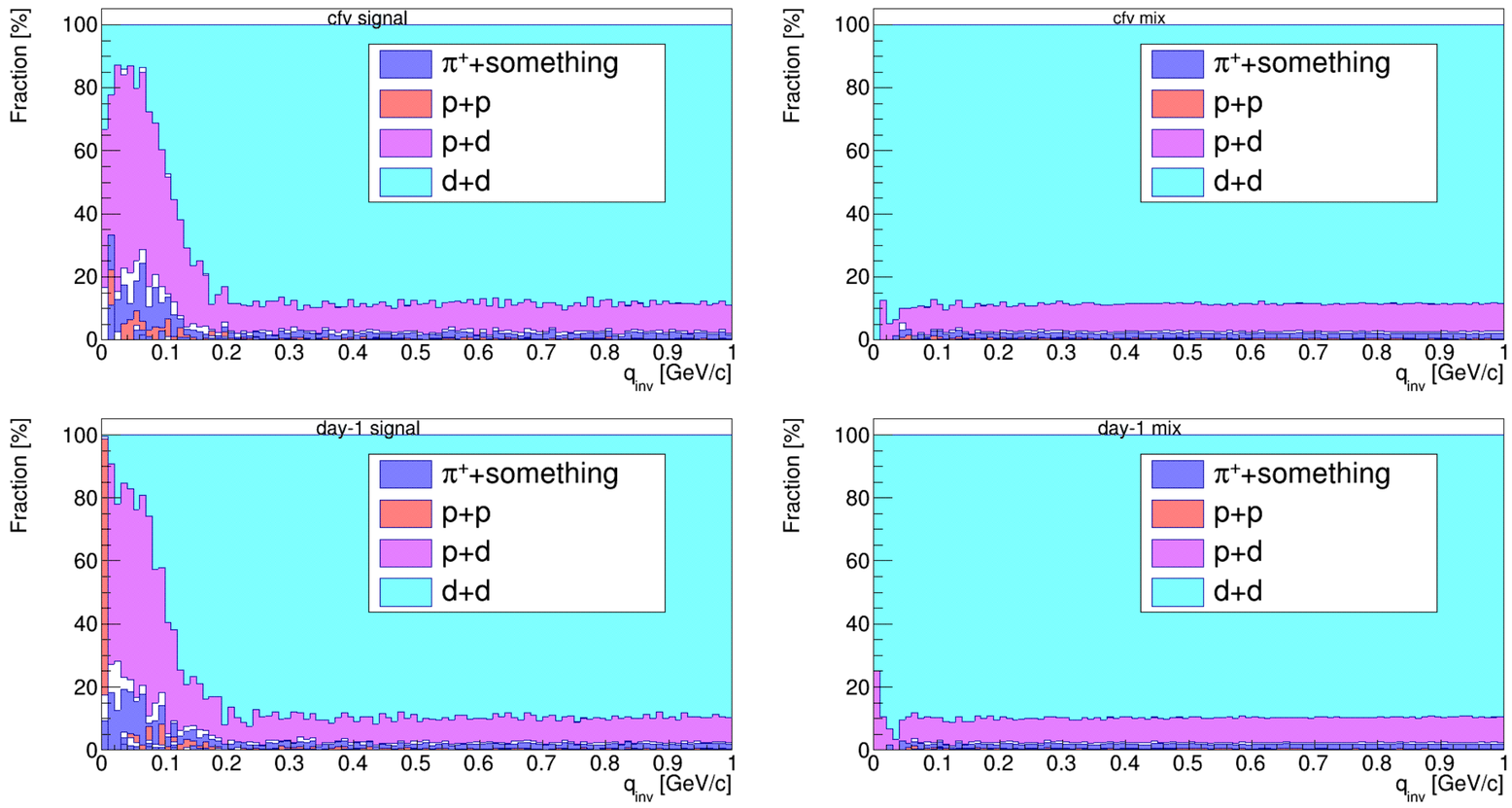
Pseudosplitting

In theory:

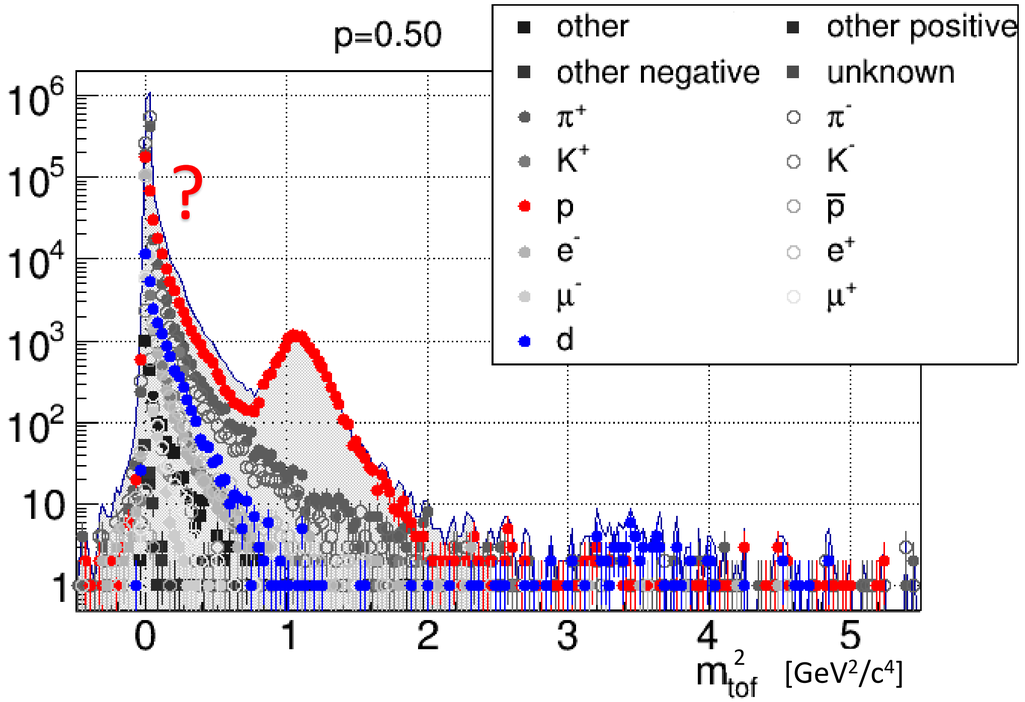
Purity of pair should be like:

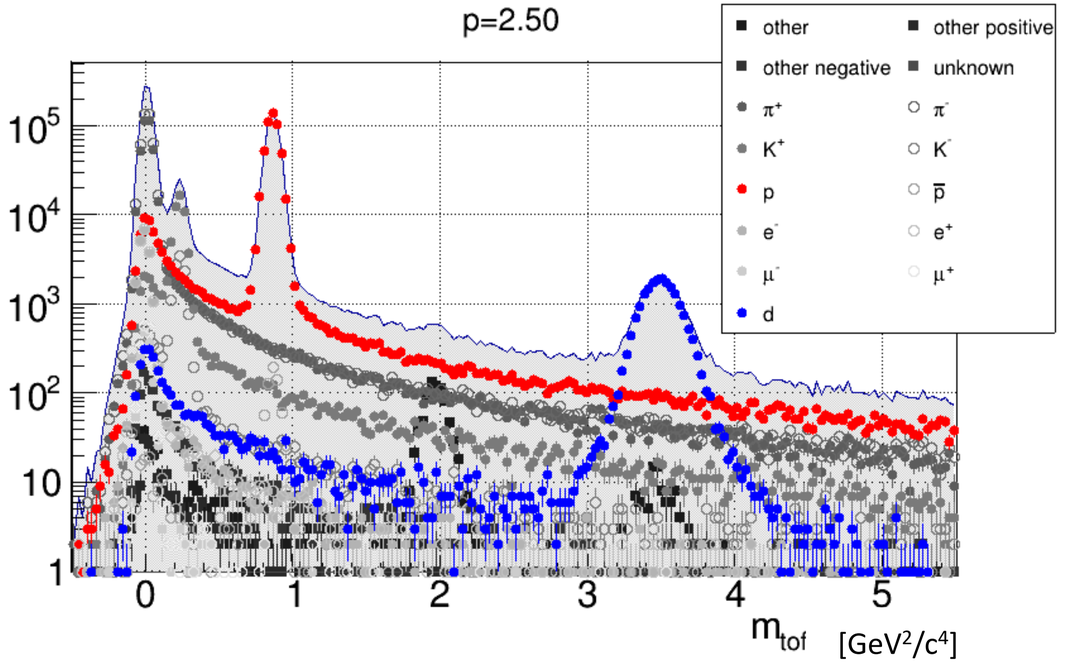
$$purity_{pair} = purity(track\ 1) * purity(track\ 2)$$

Significant contamination of pairs at relatively similar momentum – mostly by protons



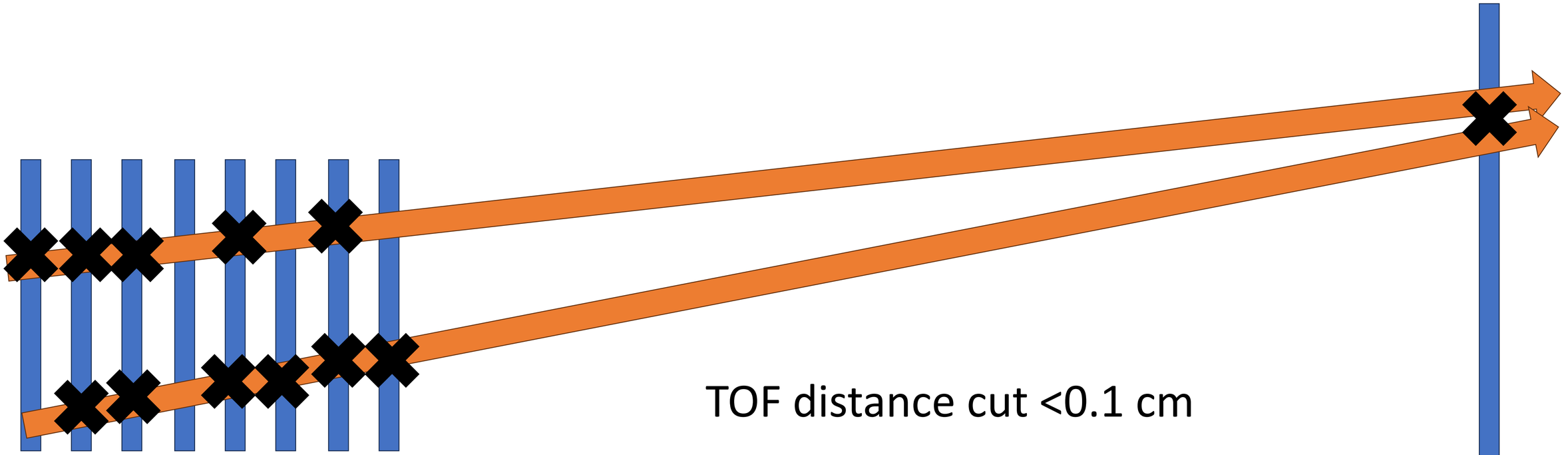
Pseudosplitting





Idea – what if there is problem with identification of two tracks that are flying very close?

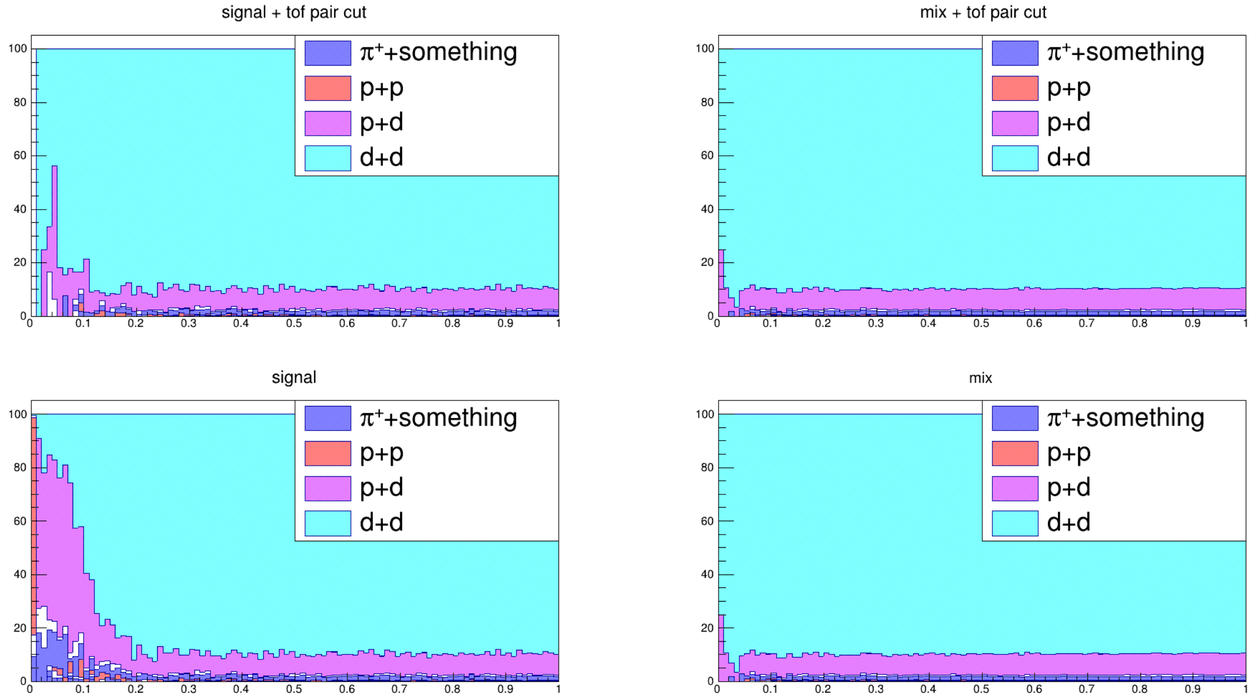
Pseudosplitting

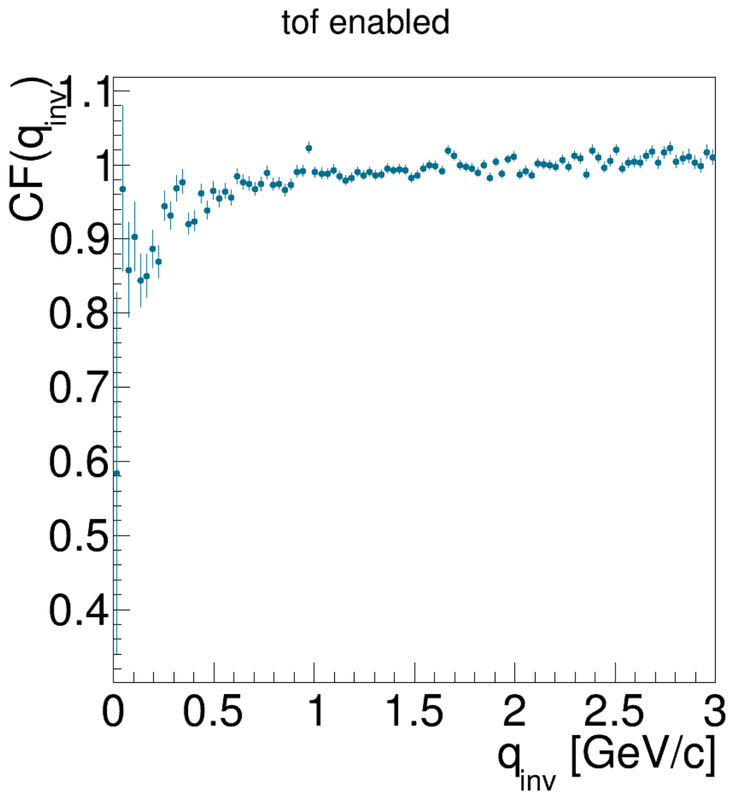


TOF distance cut <0.1 cm

$$TOF_{distance} = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2}$$

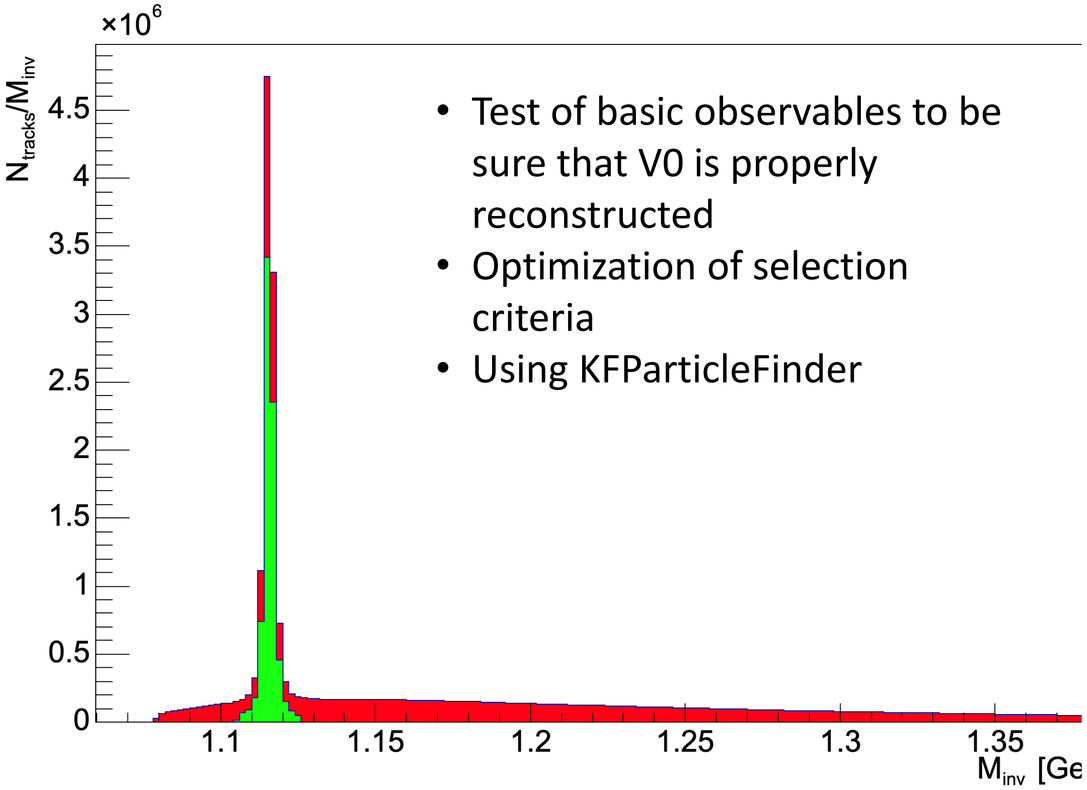
Pseudosplitting





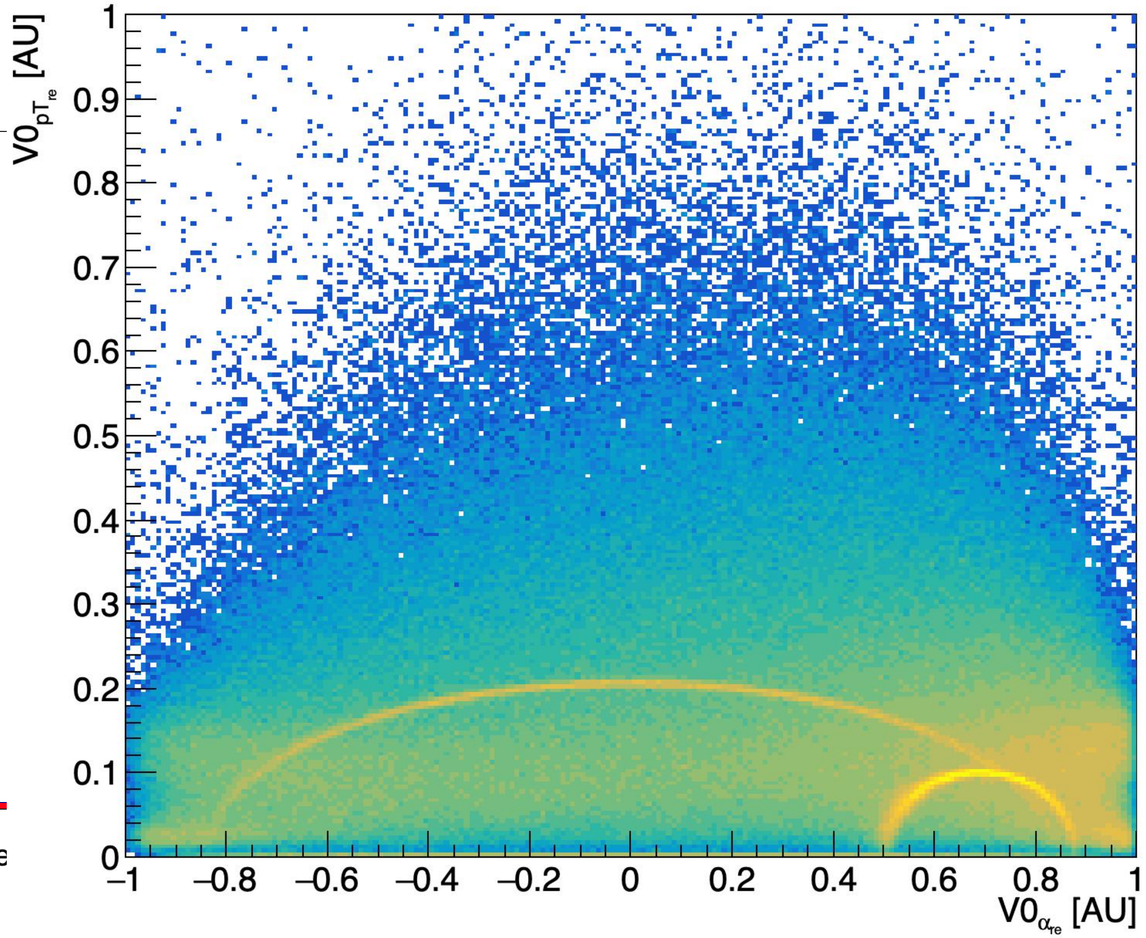
- New cut removes misidentified pairs, now purity is not depend on q (not strongly).
- Merging appears – function goes below unity at low q
- More statistics needed to study merging effect

Deuteron-Lambda HBT

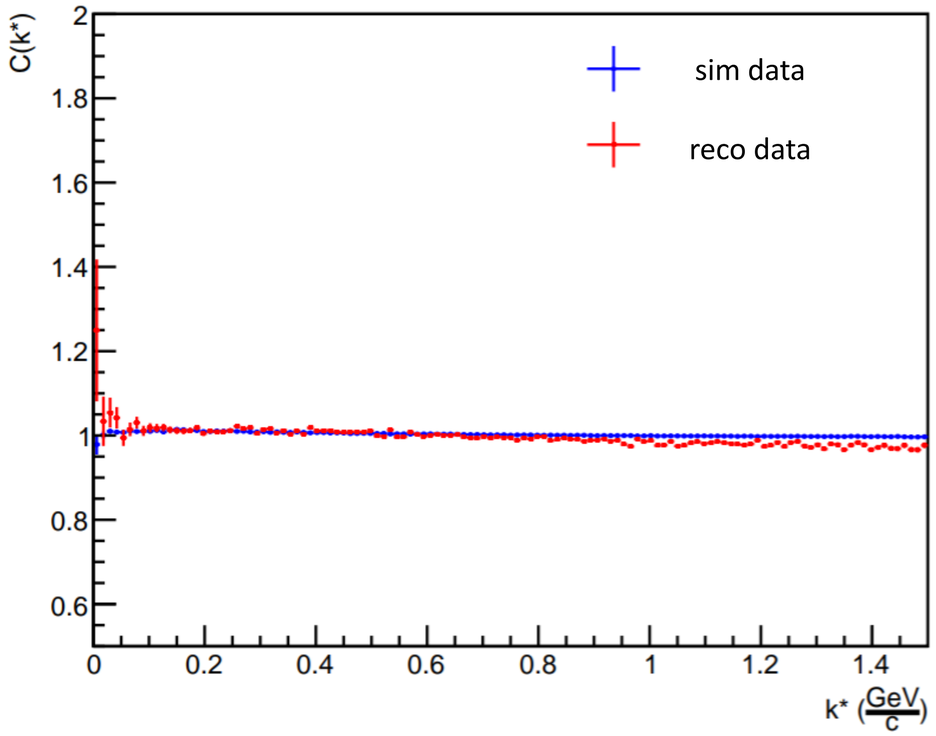


- Test of basic observables to be sure that V0 is properly reconstructed
- Optimization of selection criteria
- Using KFParticleFinder

Kacper Zięba's work



Deuteron-Lambda HBT



Kacper Zięba's work

- MC function is flat
- Reconstructed data:
  - No two-particle cuts used
  - Function goes up at low q – splitting?
  - Function goes down at large q – require further studies

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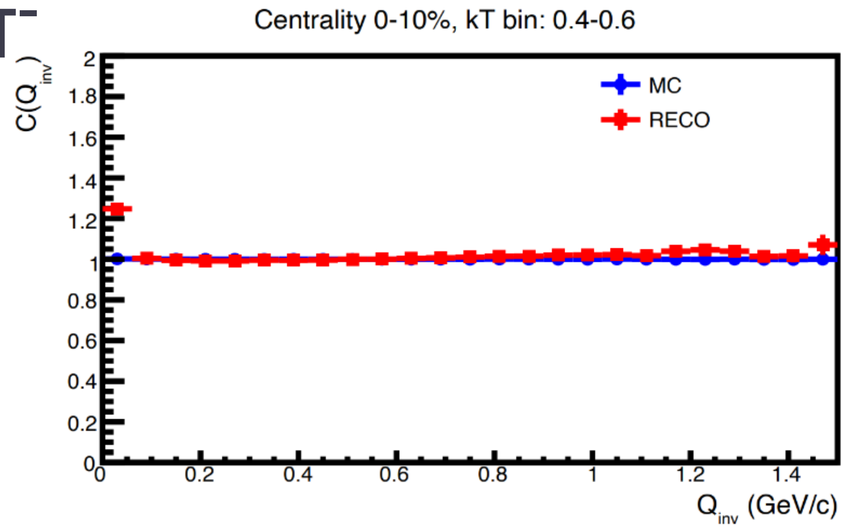
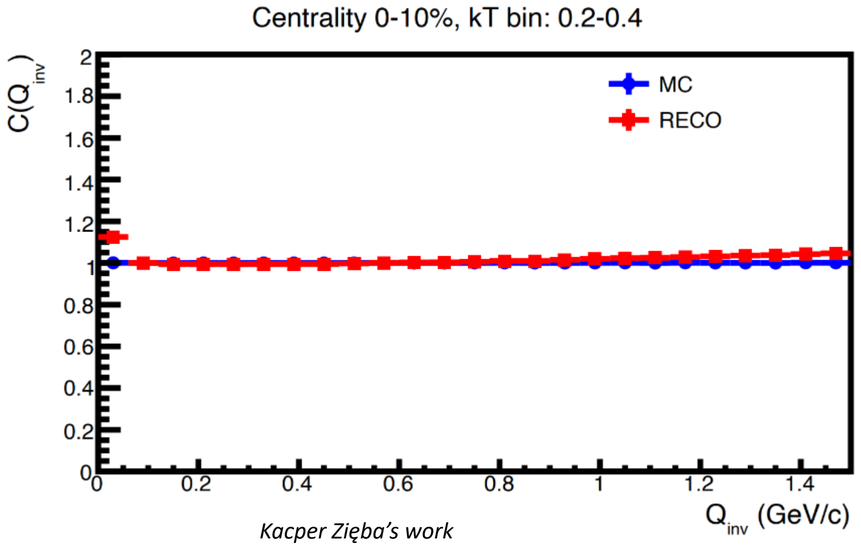




Kacper Zięba's work

- No two-particle cuts in analysis
- Function goes up for low q – splitting?
- Effect seems to depend on kT/centrality
- Tuning of two-particle cuts required to suppress detector effects

kT – half o total pair transverse momentum

Plans

„Standard femtoscopy”

- Pion, proton femtoscopy:
  - Systematic studies with MC models
    - As function of centrality and pair transverse momentum
    - 1D, 3D femtoscopy
    - Estimation of needed statistics
    - Probing the sensitivity of femtoscopy to different phenomena
  - Systematic studies of detector effects
    - Optimization of track cuts
    - Ideally: a tool for study the two-particle detector effects
- Feasibility study of kaon femtoscopy

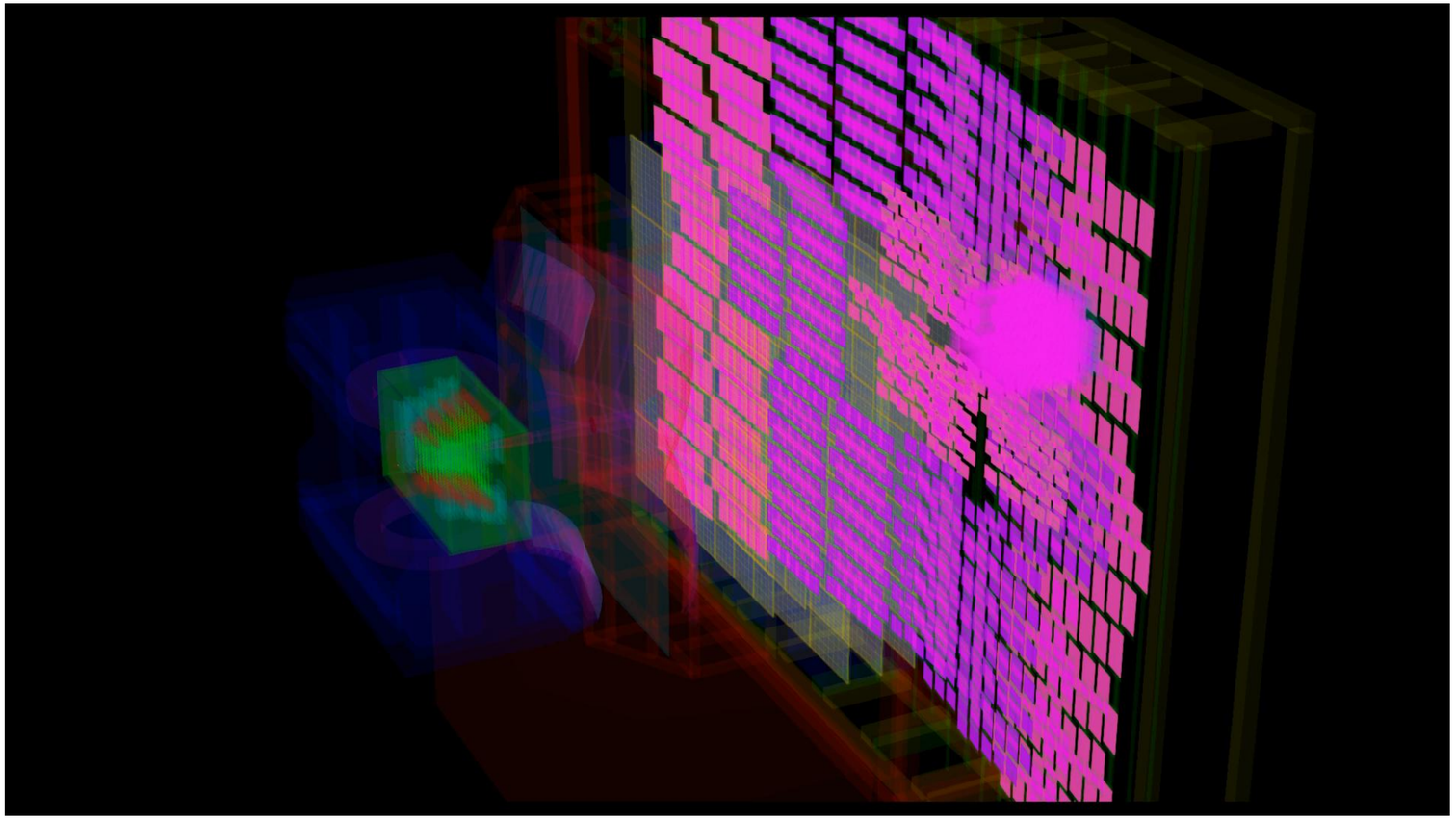
„Interaction” femtoscopy

- Feasibility studies of heavy baryon measurements
- Development of software for cascade analysis
- Extending HAL tools for fitting parameters of interaction (beyond simple Lednicky-Luboshitz model)

Summary

- First studies of deuteron-deuteron correlations were performer
  - Problem with matching TOF hits observed
  - Further studies require better statistics
- First studies of deuteron-lambda correlations were performed
  - No significant two-particle effects observed (but analysis is in early stage)
- Further plans were presented

Thank you for your attention



Deuteron cuts

- 6<=nStsHits <=8
- 0.4<pT<10 GeV/c
- 1.25<η<3.25
- DCAxy<0.1 cm
- 3.3<m2tof<3.8 GeV/c2
- dEdx threshold 1 (2 sigma) + 1.5 (1 sigma)

Lambda cuts

- Daughter distance <0.2 cm
- m_{Λ} -10 MeV/c^2 < Invariant mass < m_{Λ} + 10 MeV/c^2
- Chi^{2}topo <5
- L/dL>5
- 0.45<Armenteros alpha <0.9
- 0.<Armenteros p_T <0.11
- 0.2<y<10
- 0.2<p_T<10 GeV/c

dEdx calibration