Pion-proton correlations and asymmetry measurement in Au+Au at $\sqrt{s_{NN}}$ =200GeV data

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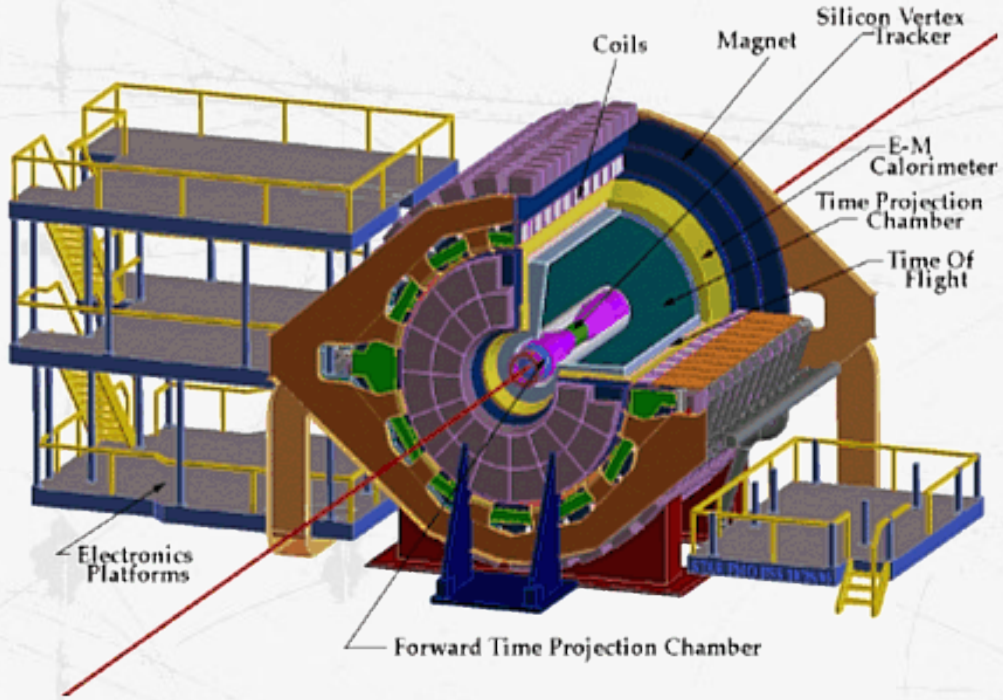
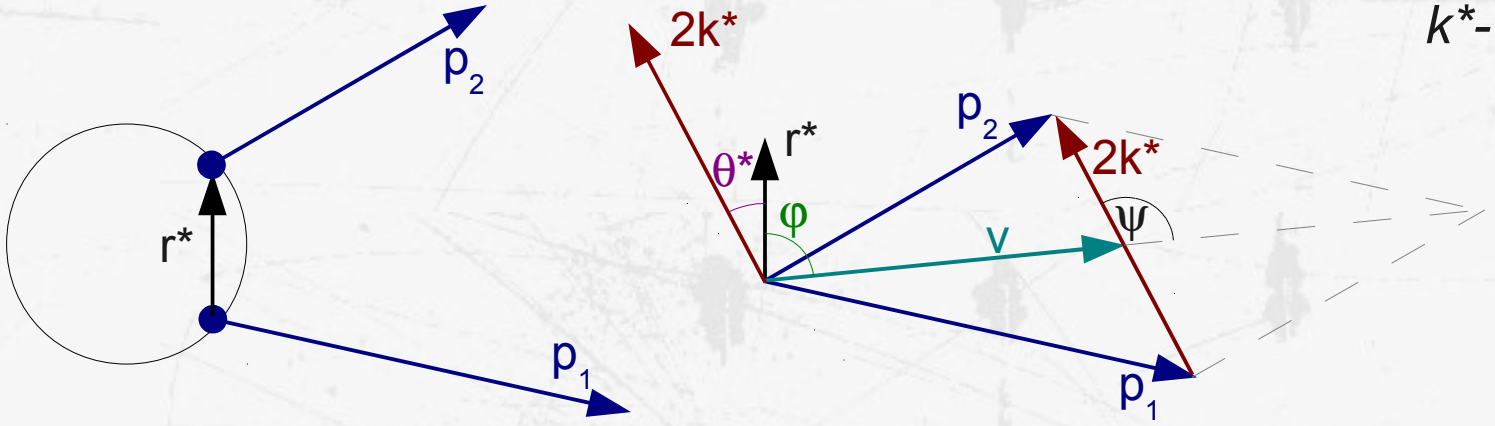
Outline

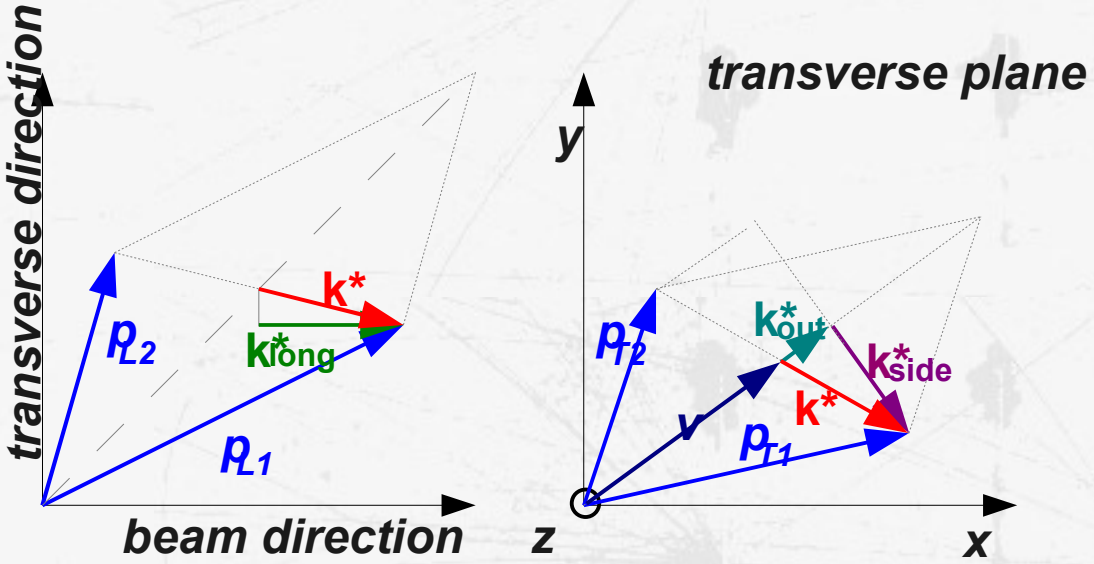
- Physics motivation
- Data analysis
- Experimental results
- Model results
- Conclusions



Construction of experimental correlation function



*k**- momentum of the first particle in PRF (Pair Rest Frame), half of the relative momentum



k* distribution of **correlated** pairs coming from the same event

$$C(k^*) = \frac{N(k^*)}{D(k^*)}$$

k* distribution of **uncorrelated** pairs particles coming from different events

FSI as an origin of asymmetry

$$CF = A_C(k^*)\left[1 + 2\underbrace{\langle r^*(1+\cos\theta^*)\rangle}_{\text{integrated over space}} / a_c + \ldots\right]$$

Gamov factor

Source of the asymmetry

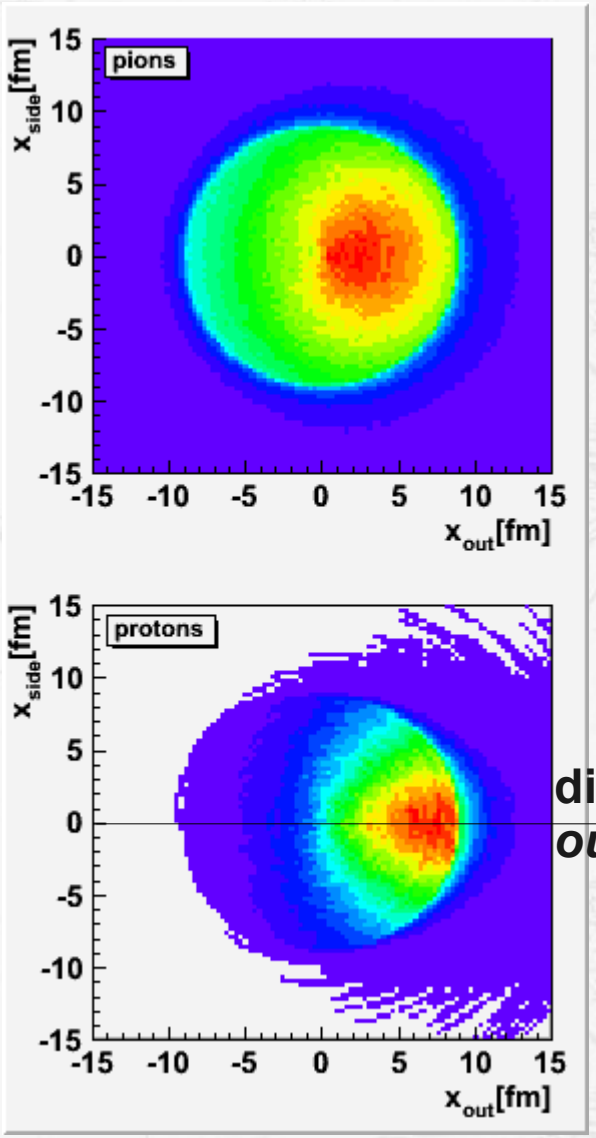
Bohr radius for $\pi-p$ $a_c = \pm 222$fm

In pion-proton system only coulomb interaction plays significant role.

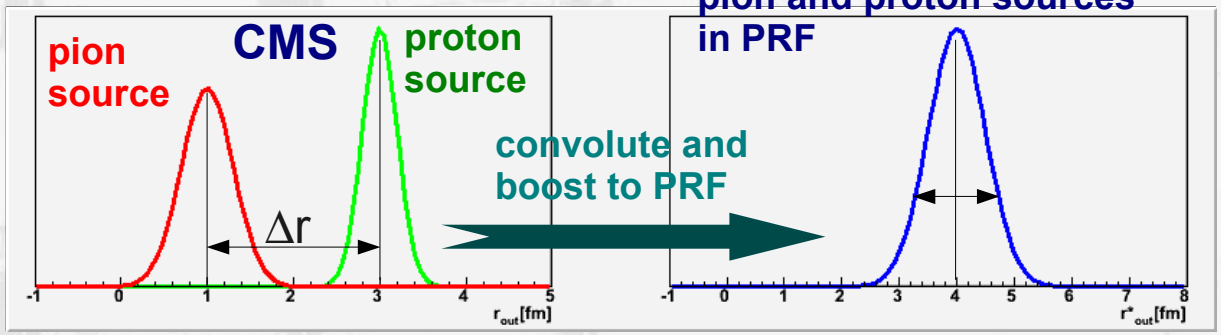
k- momentum of the first particle in PRF*
r - separation between emission points*
θ - angle between **k*** and **r*** vectors*

Correlation is stronger when *cosθ*<0* – *k and *r** are anti-aligned and weaker when *cosθ*>0* – *k** and *r** are aligned.**

Observed asymmetry



direction of a pair
out



$$\sigma_{\pi p} = \sqrt{\sigma_\pi^2 + \sigma_p^2}$$

two particle width

single particle widths

Observed separation in PRF comes from

- **space asymmetry (flow)**

and from

- **emission time difference**

$$\langle r^* \rangle = \langle \gamma_T (\Delta r - \beta_T \Delta t) \rangle$$

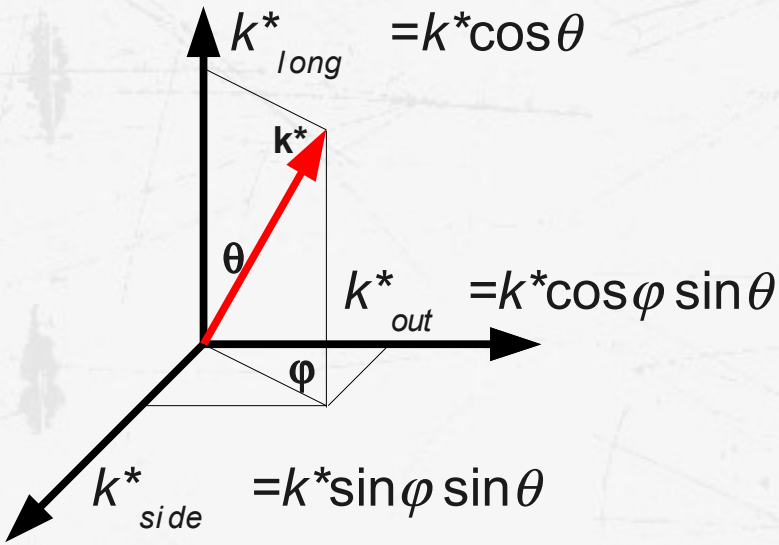
Phys.Lett.B373 (1996) 30

Correlation function in spherical harmonics

distribution of correlated pairs — correlation function — distribution of uncorrelated pairs

$$\boldsymbol{T}(\vec{k}^*) = \boldsymbol{C}(\vec{k}^*) \cdot \boldsymbol{M}(\vec{k}^*)$$

$$\boldsymbol{C}(\vec{k}^*) = \sqrt{4\pi} \sum_{l,m} C_{lm}(\vec{k}^*) \cdot Y_{lm}(\theta, \varphi)$$



$$Y_0^0(\theta, \varphi) = \frac{1}{2}\sqrt{\frac{1}{\pi}}$$

C^0_0 function does not depend on θ and φ give information about overall size

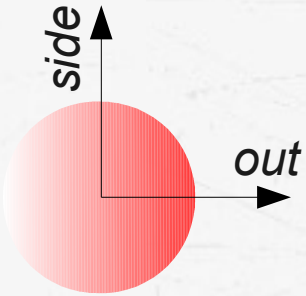
$$Y_1^0(\theta, \varphi) = \frac{1}{2}\sqrt{\frac{3}{\pi}}\cos\theta$$

C^0_1 function is related to *long* direction should vanish due to symmetric mid-rapidity region

$$Y_1^1(\theta, \varphi) = \frac{1}{2}\sqrt{\frac{3}{2\pi}}\left(\cos\varphi \sin\theta + i \sin\varphi \sin\theta\right)$$

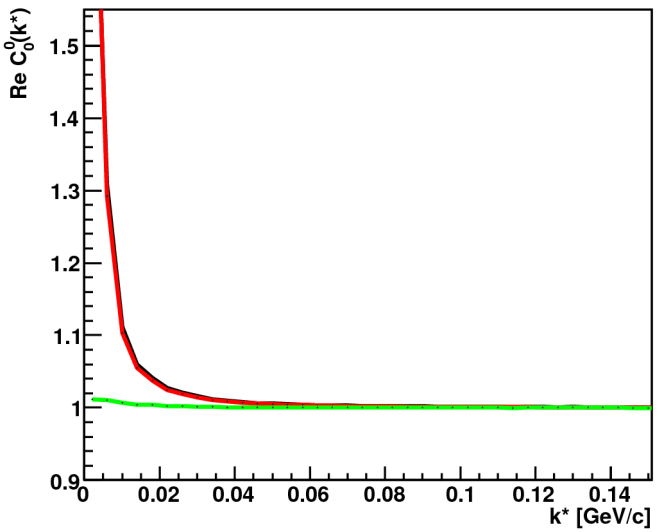
Re C^1_1 component is related to *out* direction gives information about asymmetry.

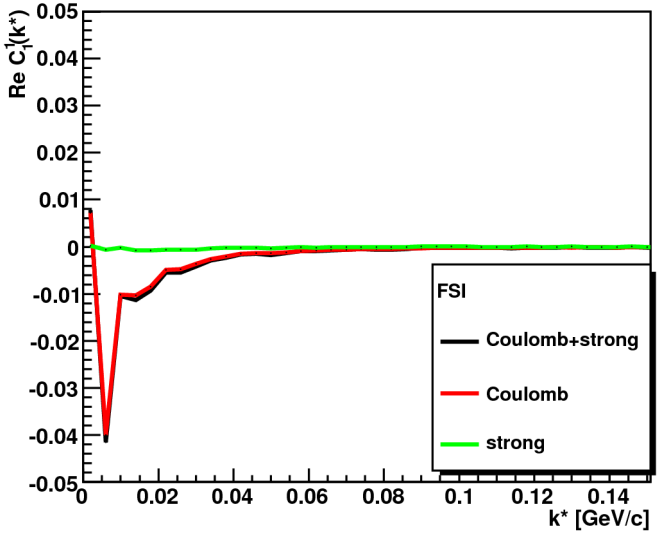
Im C^1_1 component is related to *side* direction should vanish as the function is integrated over reaction plane angle.

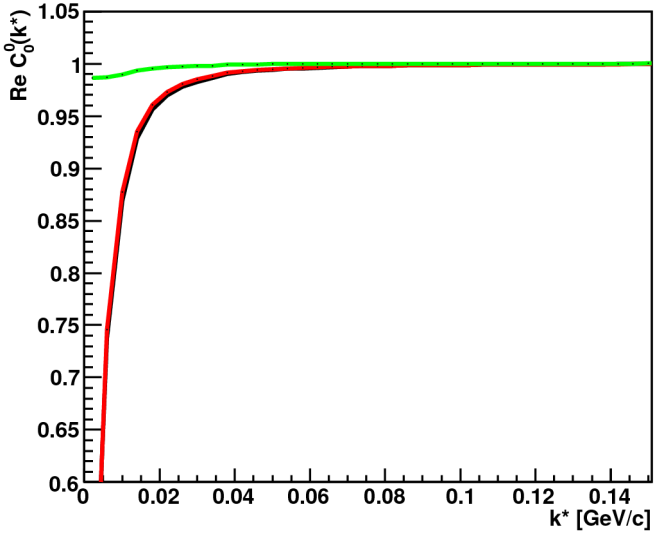


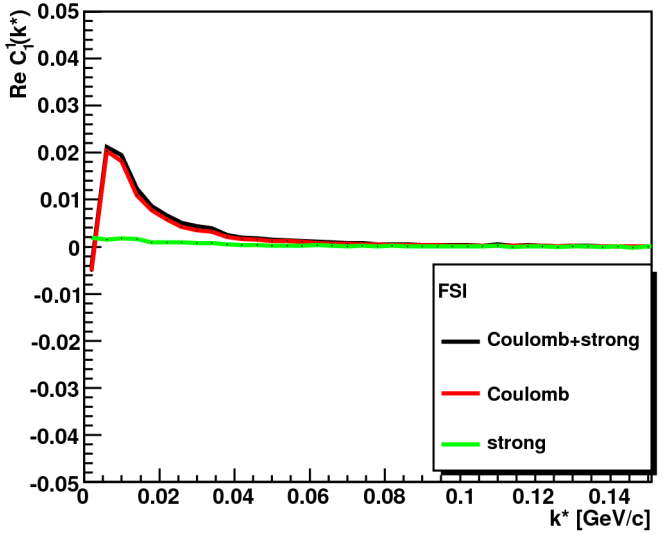
Z.Chajęcki, M.Lisa; Phys.Rev.C78:064903,2008
A. Kisiel, D.Brown; Phys.Rev.C80:064911,2009

Final State Interaction in pion-proton system







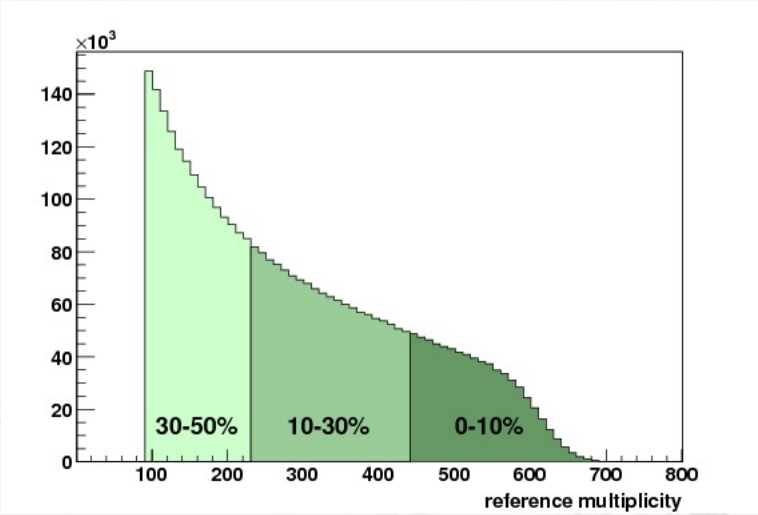


Final State Interaction in pion-proton pairs is dominated by Coulomb interaction (red line), strong interaction (green line) is negligible.

Coulomb interaction for like-sign pairs is repulsive thus correlation effect is negative. For unlike-sign pairs Coulomb interaction is attractive thus observed correlation effect is positive.

Data selection **Au+Au $\sqrt{s_{NN}}$ =200GeV**

Events



Single track level cuts (π,p)

- dE/dx
- $p_T(\pi) \in$<0.1,0.6> [GeV/c]
- $p_T(p) \in$<0.4,1.25> [GeV/c]
- $y \in$<-0.7,0.7>

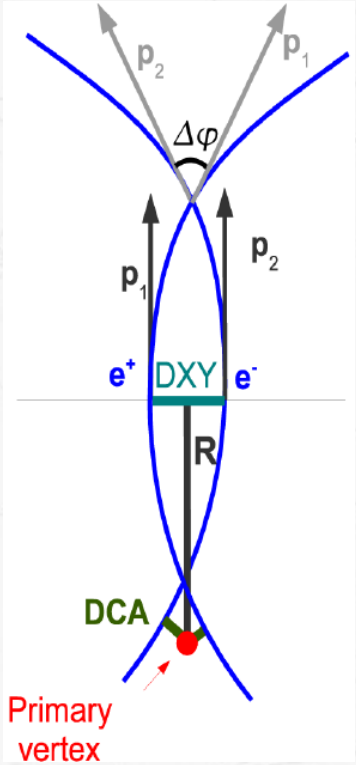
Pair level cuts:

pairs with merged hits of tracks (<10%)

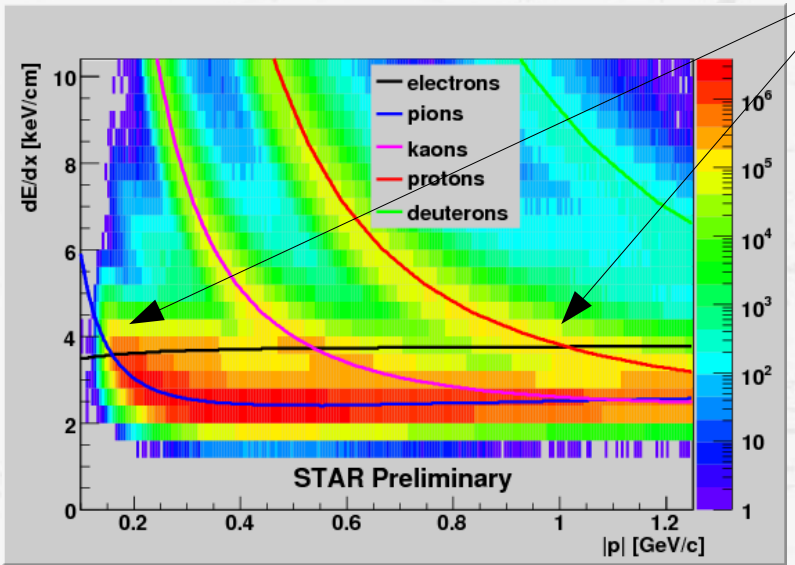
pairs with split tracks

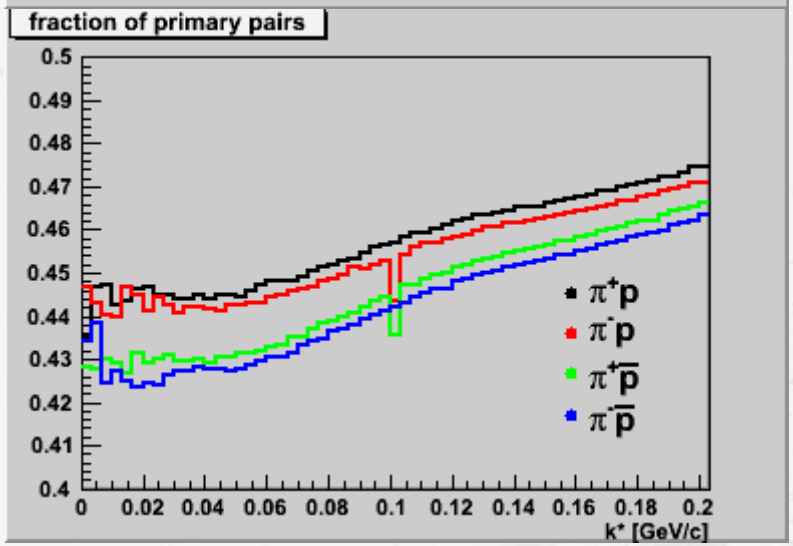
electron-positron pairs from gamma conversion (advanced topological cut)

non π-p pairs based on pair probability



Data analysis





Low relative momentum in PRF corresponds to close relative velocities in CMS.
E.g. pion with p_T=0.1GeV/c has a close velocity proton with p_T=0.67GeV/c. Pion p_T=0.15GeV/c corresponds to proton p_T=1GeV/c. In these regions pions and protons are crossing the electron line.

$$C_{\text{Real}} = C_{\text{Exp}} \cdot C_{\text{Purity}}^{-1}$$

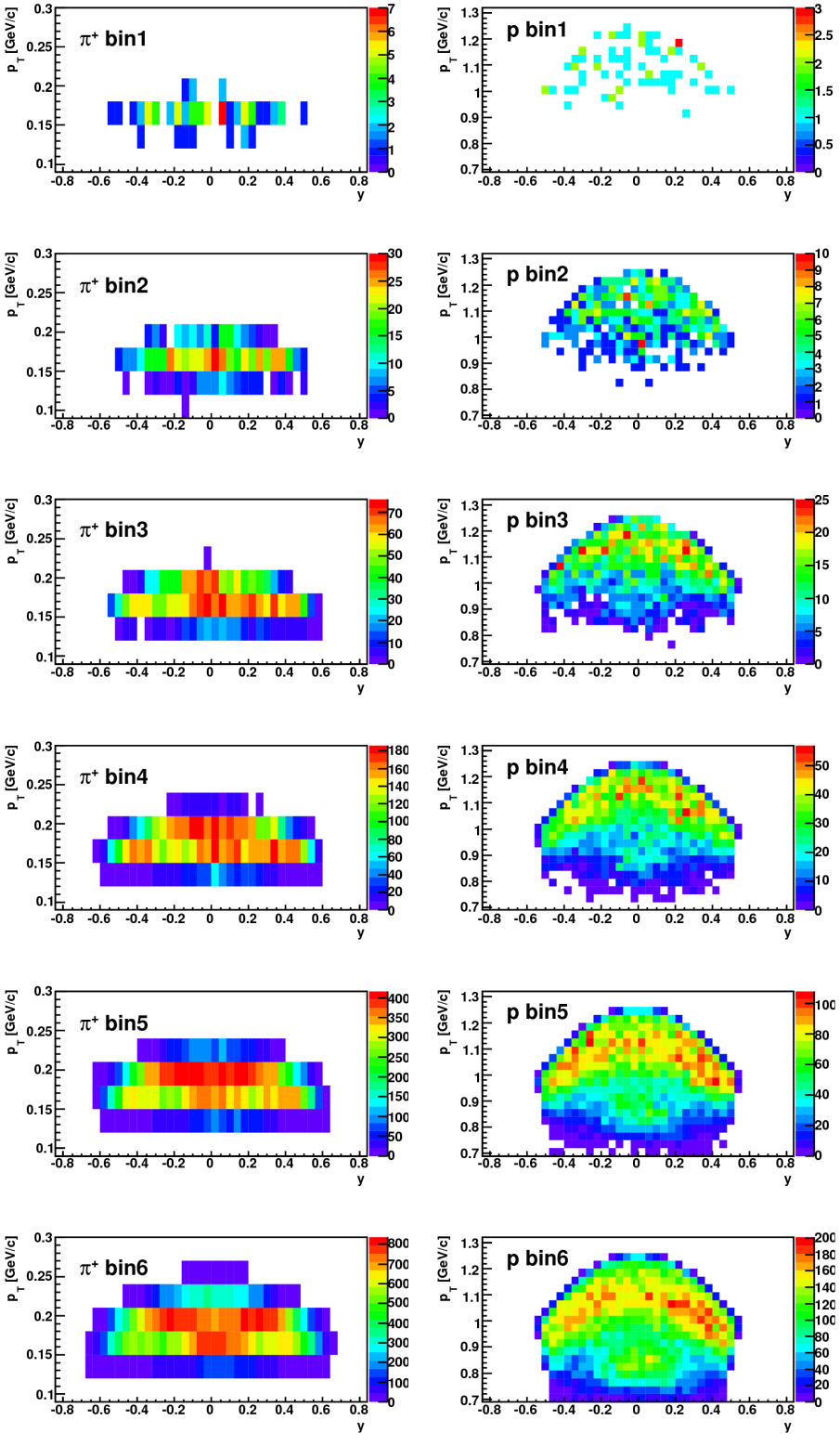
C_{Purity} – two particle distribution weighted with experimental PID probability and fraction of primary pairs

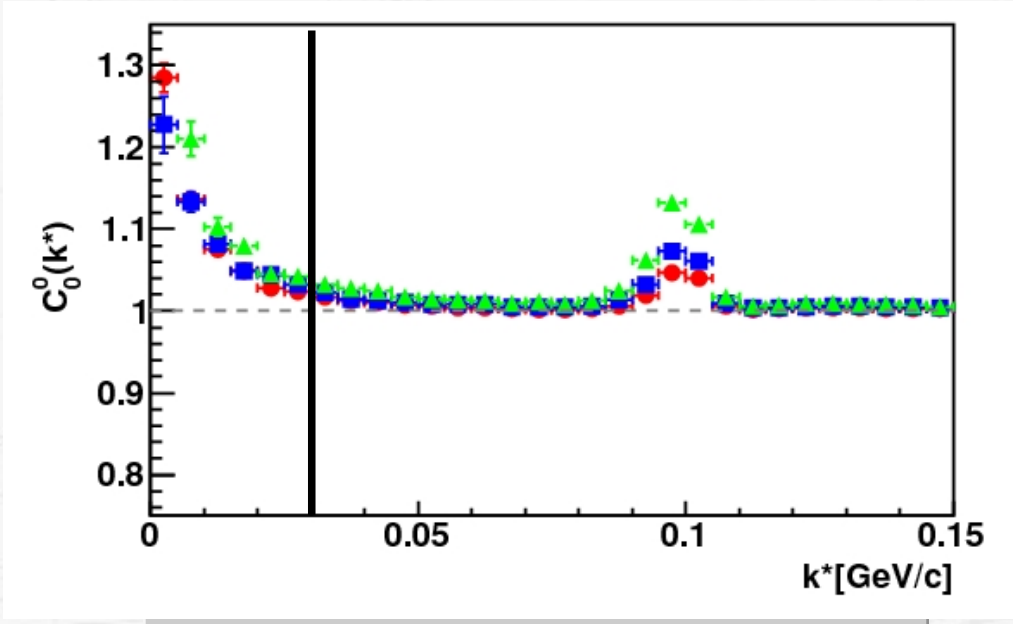
mixed pairs are constructed only from events with similar characteristics:

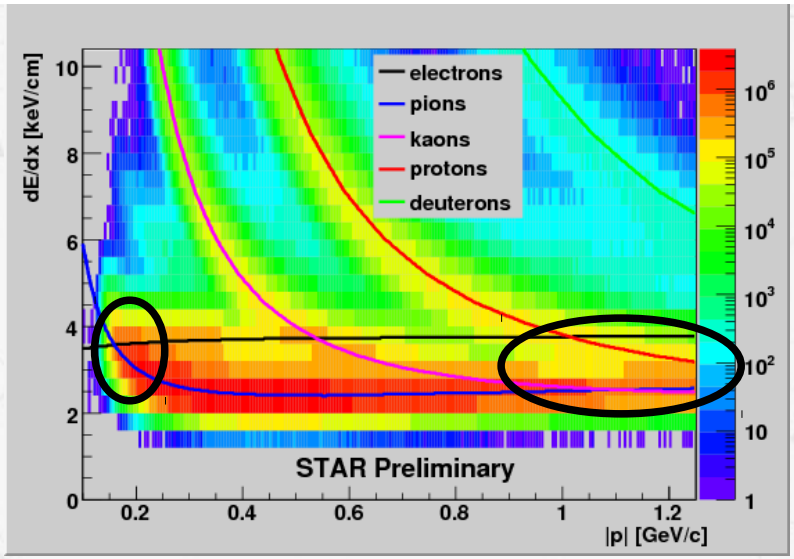
- z-vertex position 15 bins
- multiplicity 6 bins
- event mean p_T 3 bins

Total 270 bins

Particle identification limitations

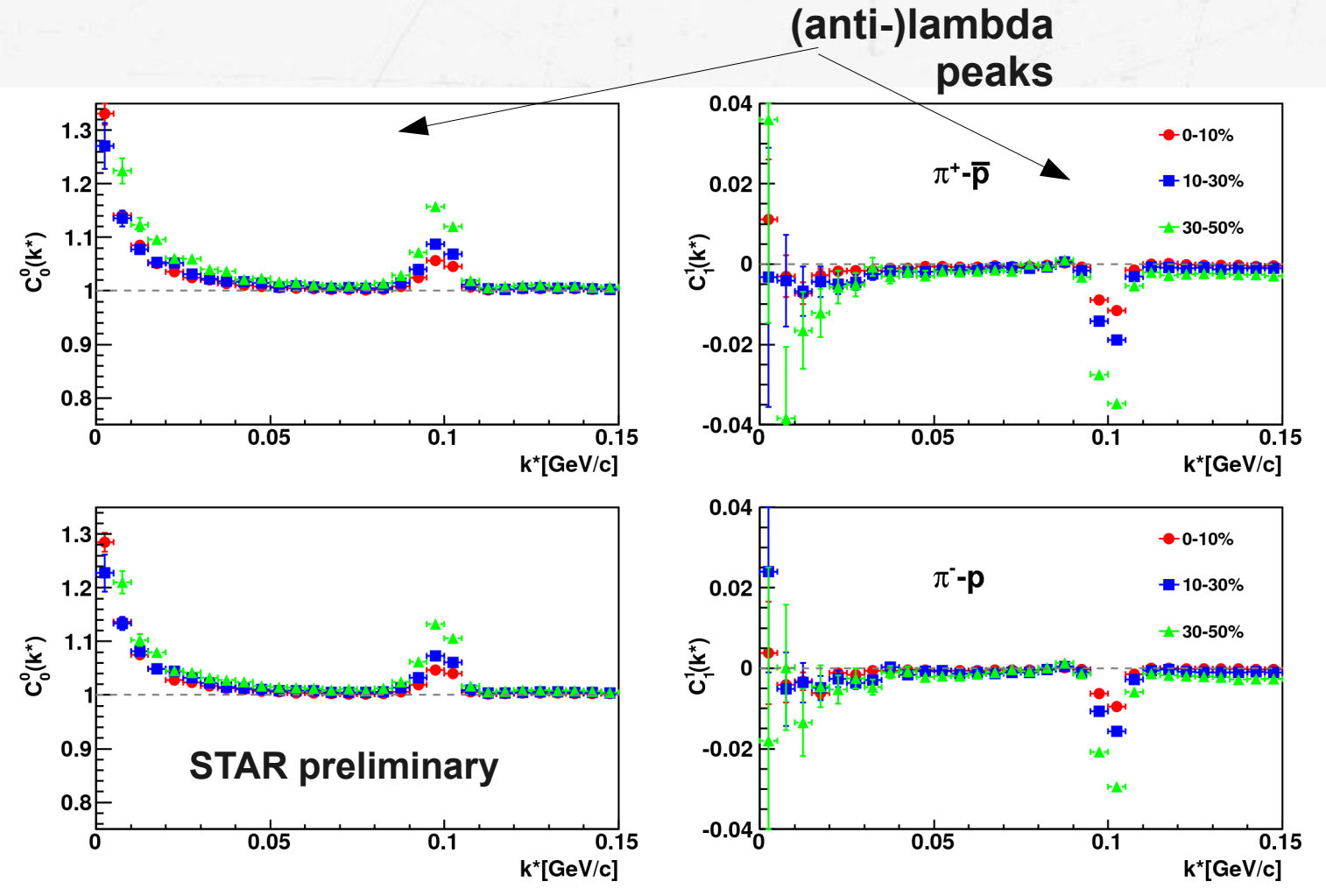






data collected in 2010 with ToF will provide higher statistics with extended PID capabilities

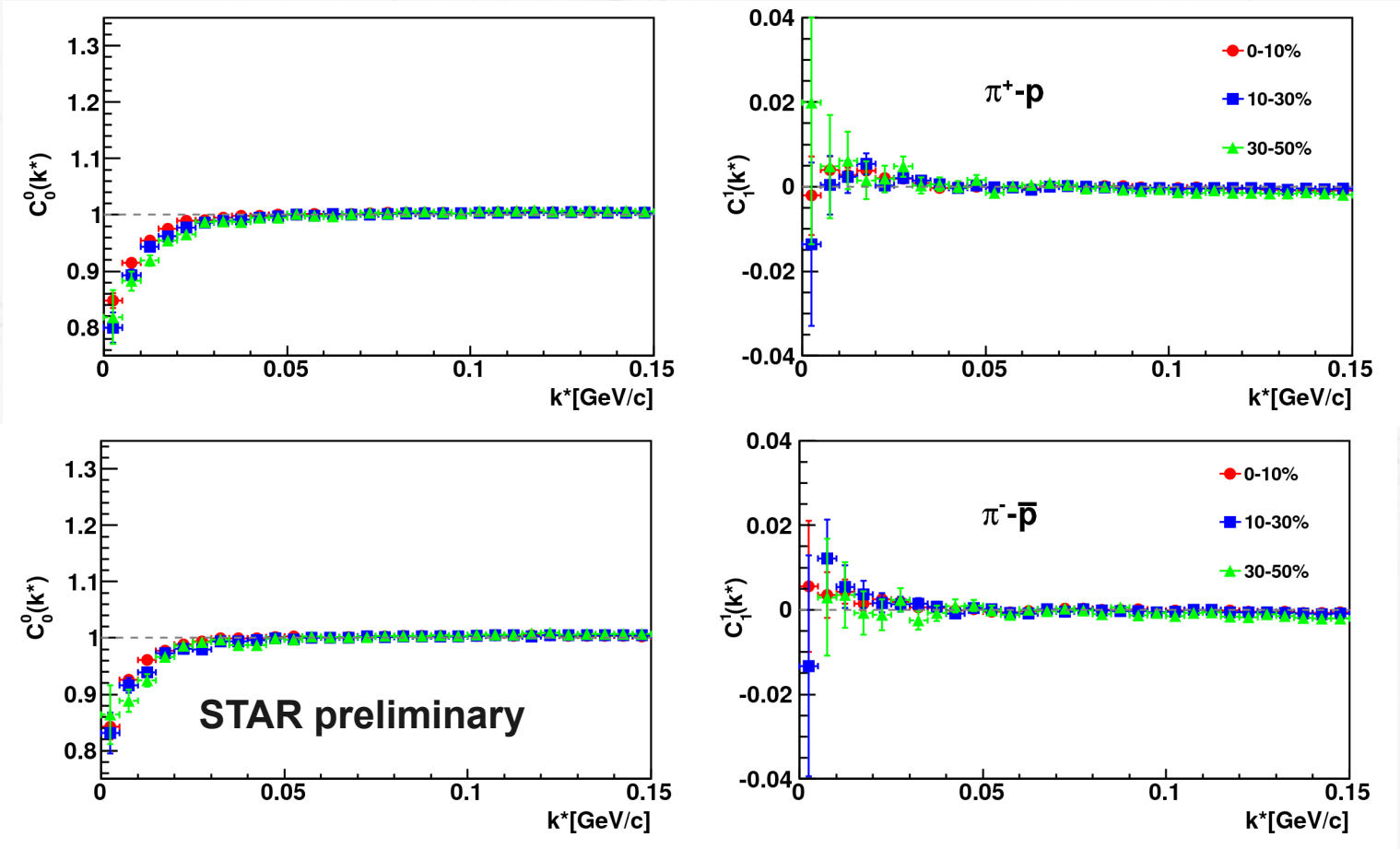
Pion-(anti)proton correlation functions in AuAu at $\sqrt{s_{NN}}$ =200GeV



Lambda peaks do not overlap with femtoscopic correlation effect.

Re C11 at low k* reveals asymmetry between average space-time emission points of pions and protons.

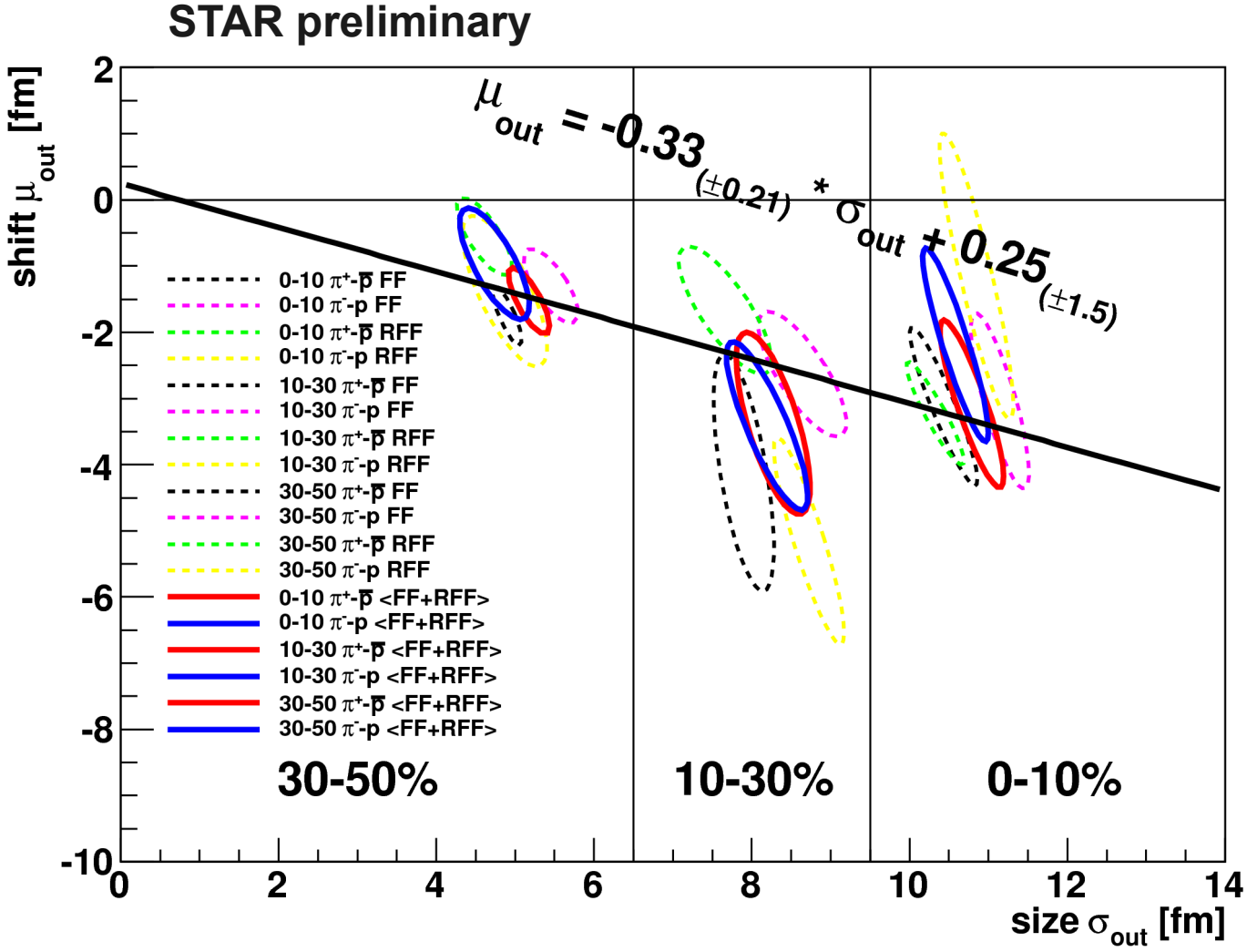
Pion-proton correlation functions in AuAu at $\sqrt{s_{NN}}$ =200GeV (like sign pairs)



Negative correlation for attractive Coulomb interaction

Re C11 at low k* reveals asymmetry between average space-time emission points of pions and protons.

Gaussian 3D fit results LCMS

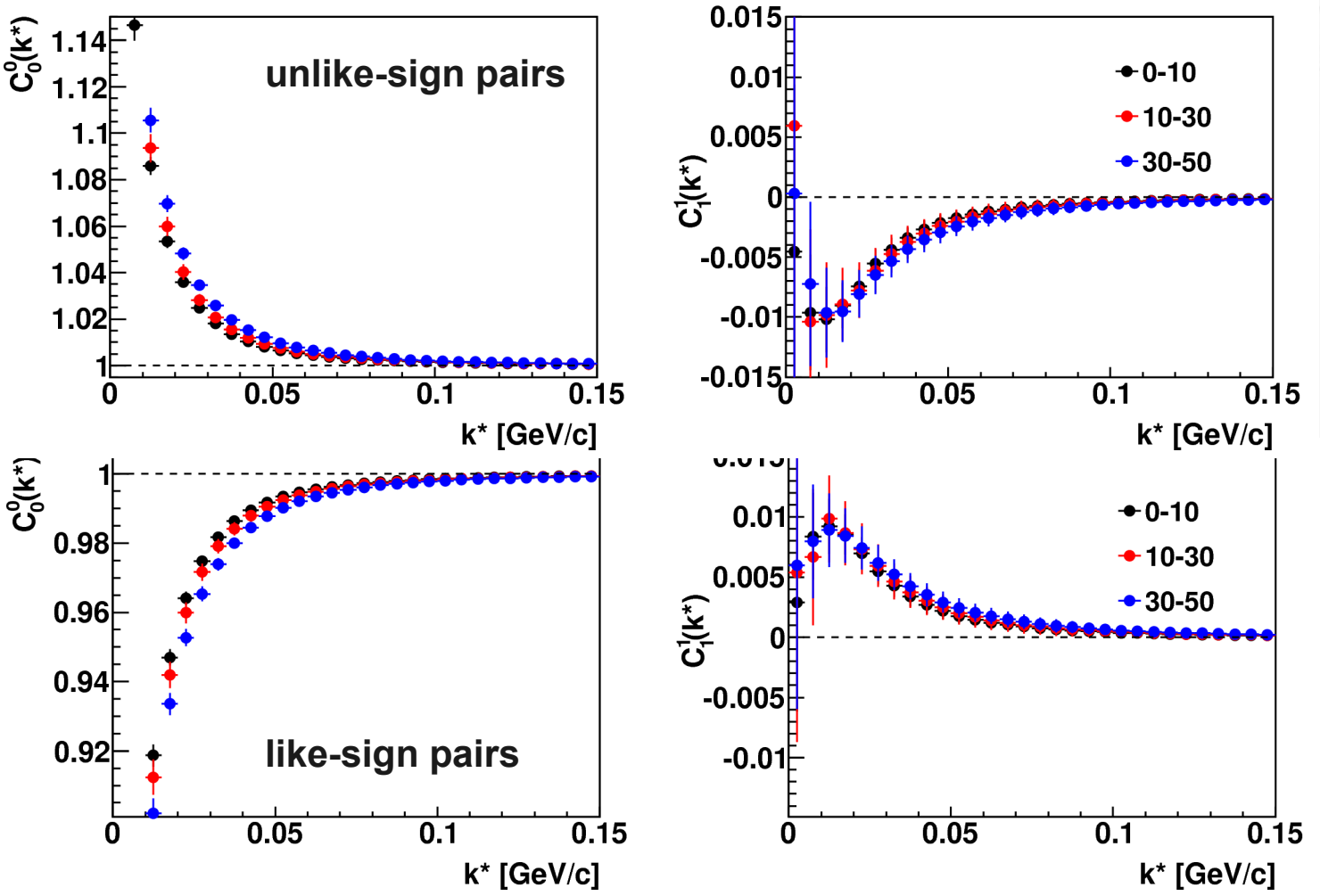


Asymmetry between average emission points of pions and protons and size of the pion-proton source are correlated and depend on centrality.

$$\mu_{out} \sim \langle r^* \rangle = \langle \gamma_T (\Delta r - \beta_T \Delta t) \rangle$$

STAR preliminary

Pion-proton correlation functions in Therminator+Lhyqyid



functions show asymmetry

asymmetry may arise from:

- bulk collective effects
- differences in the freeze-out scenario
- decays of resonances

Comp. Phys. Comm. 174 (2006) 669
Phys.Rev.C80:034902,2009 [arxiv:0812.3393v1 [nucl-th]]
Phys.Rev.Lett.101:022301,2008 [arxiv:0801.4361v1 [nucl-th]]
Phys.Rev.C79:014902,2009 [arxiv:0808.3363v2 [nucl-th]]
[arXiv:0909.5349v3 [nucl-th]]

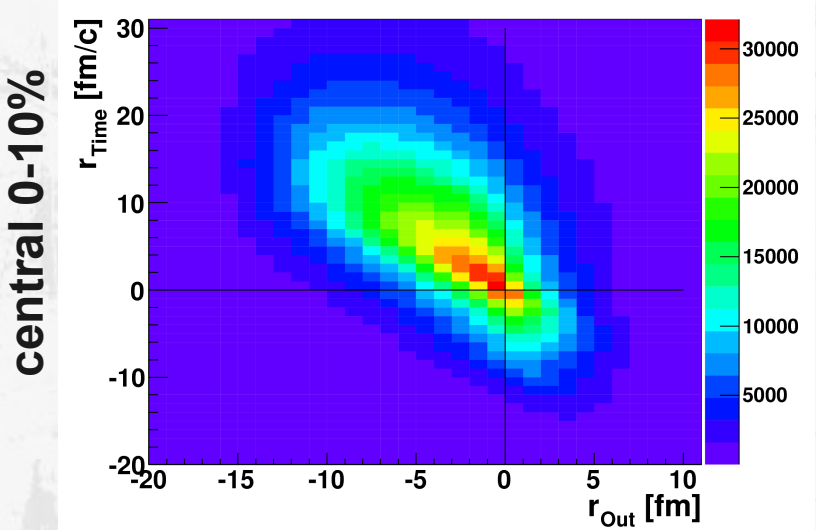
Asymmetries in *out* and *time* components in two particle separation distributions are correlated - Therminator

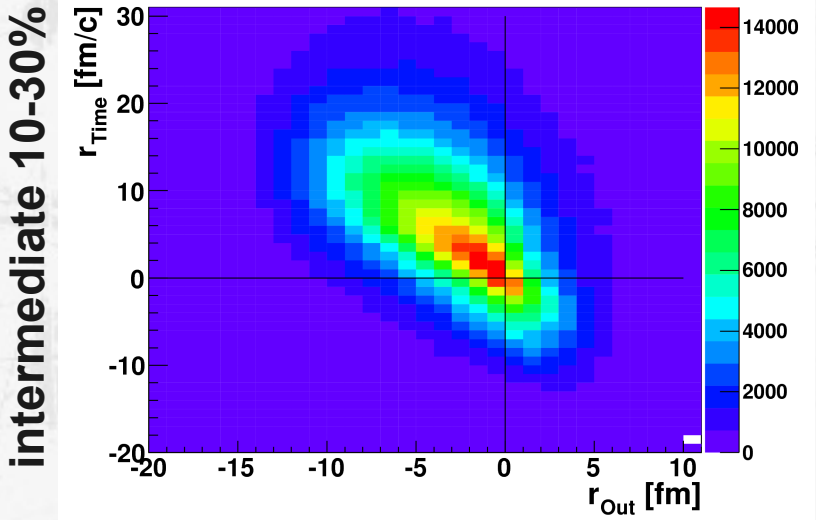
Positive values of r_{Time} corresponds to pion emitted later than proton.

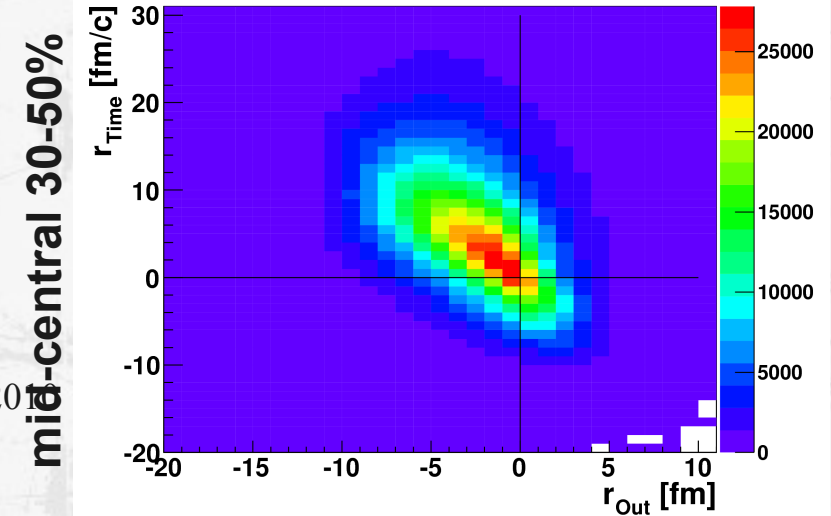
Scenario when pion is emitted earlier than proton is rare.

Bigger difference between emission points of a pion and a proton means bigger difference in emission times – *out-time* correlation

Emission time difference r_{Time} reaches higher values for central collisions than for non-central collisions

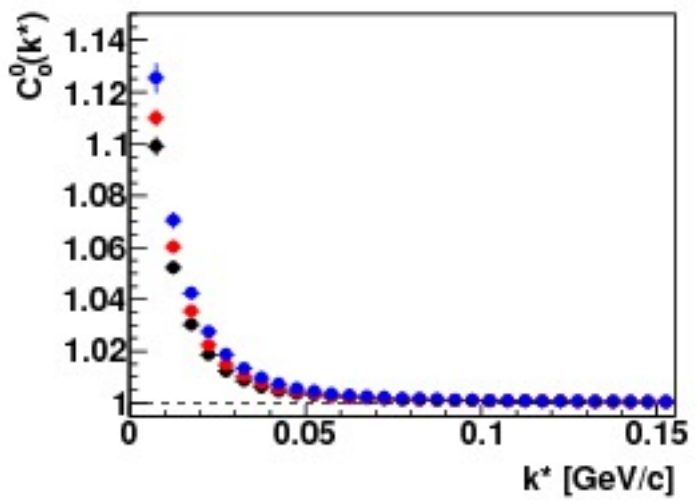


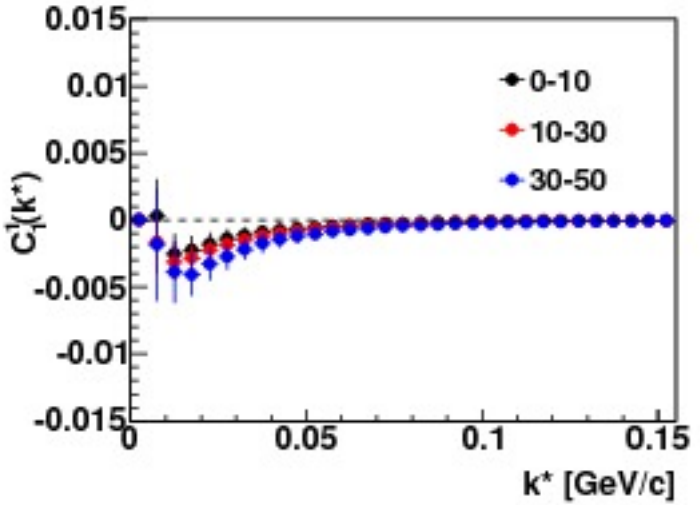


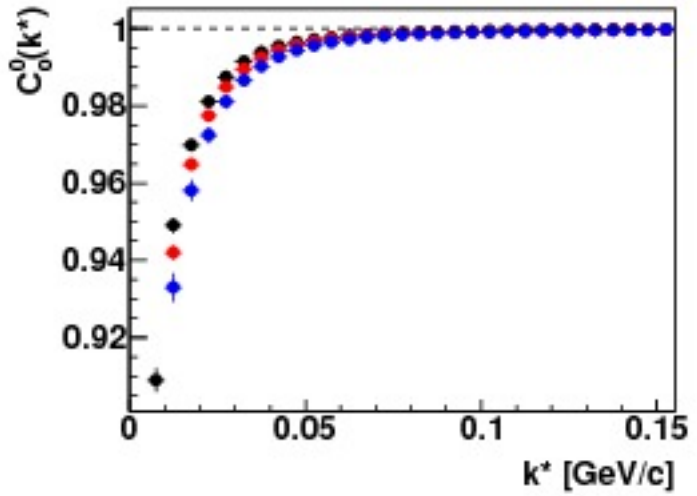


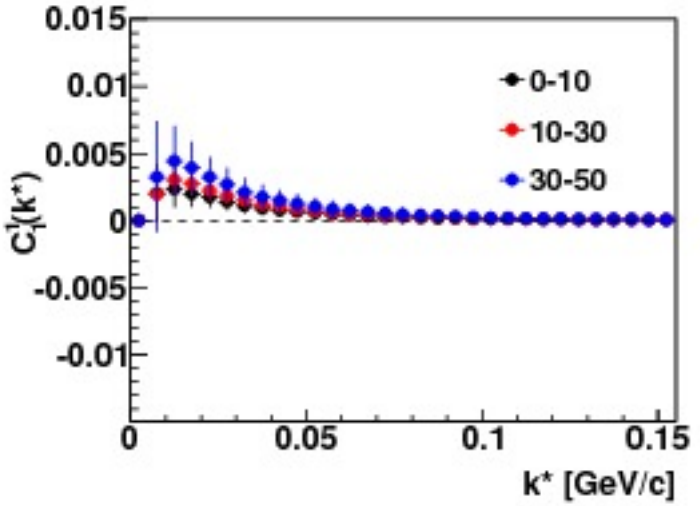
UrQMD – asymmetry is observed only in the *out* direction, no asymmetry in emission time difference is observed

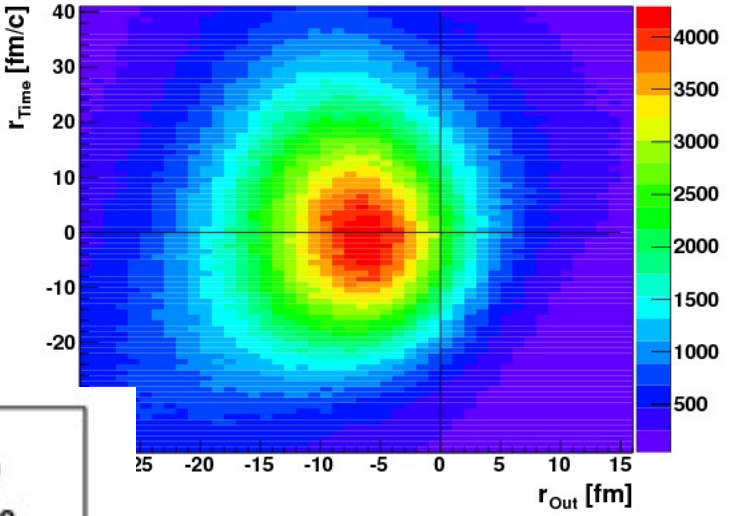
central 0-10%

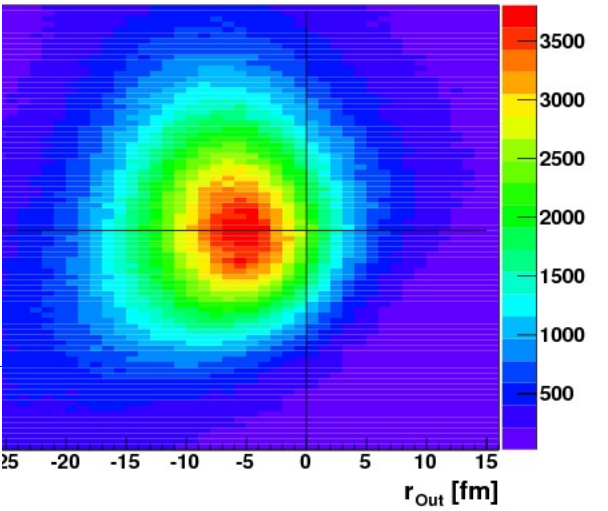


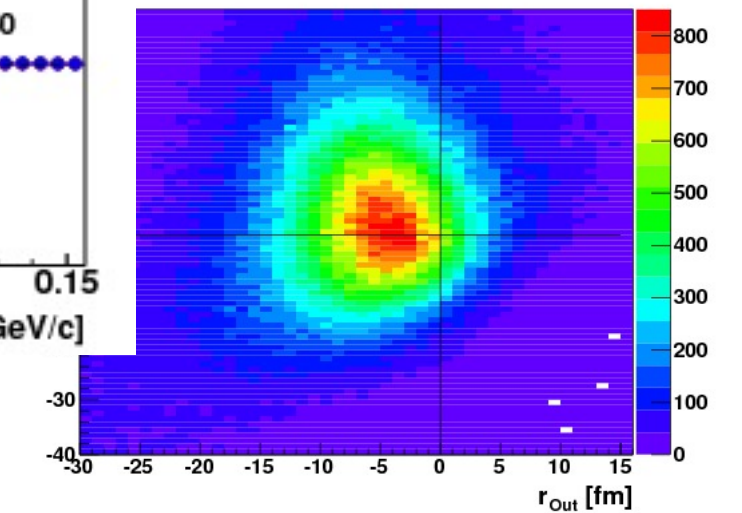




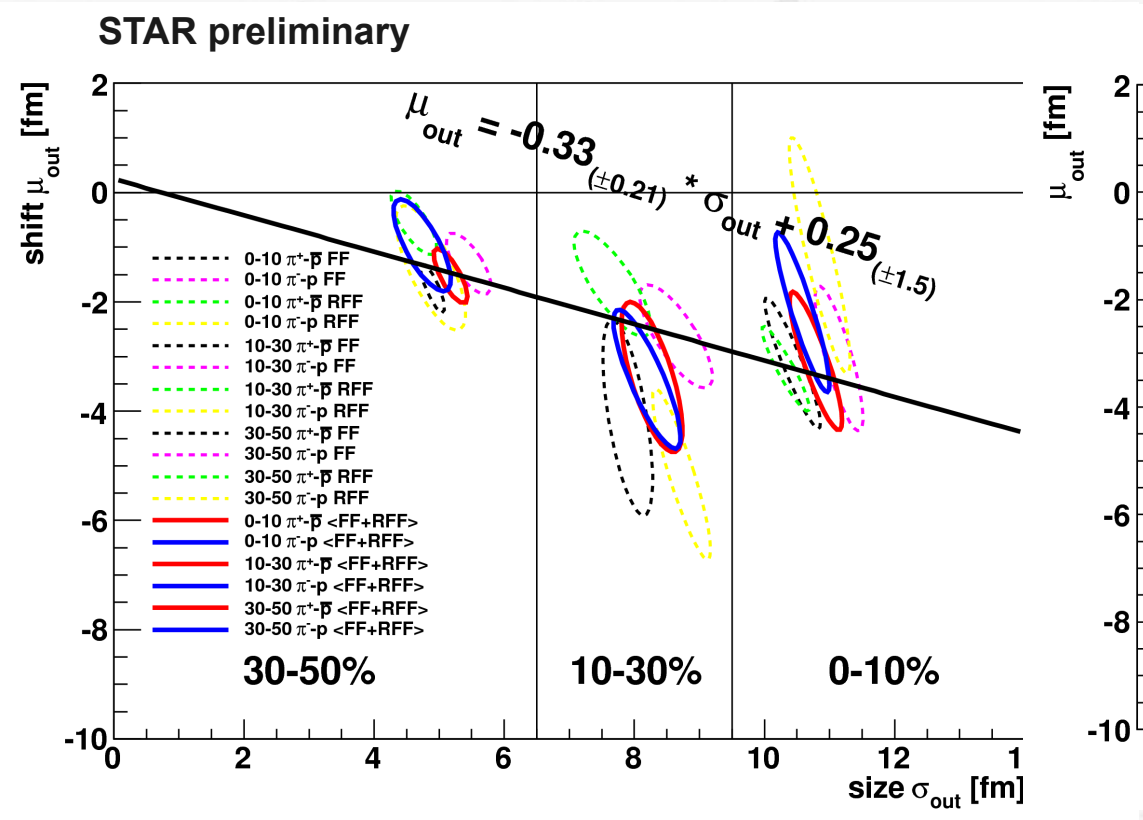


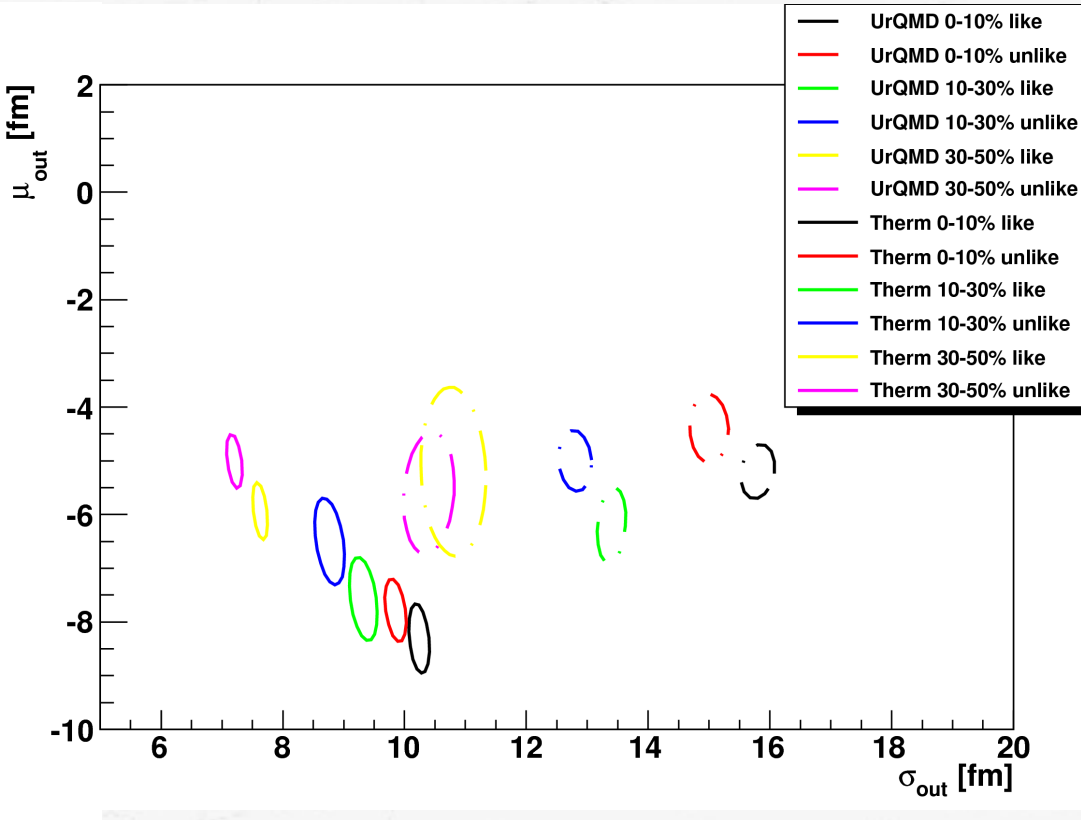






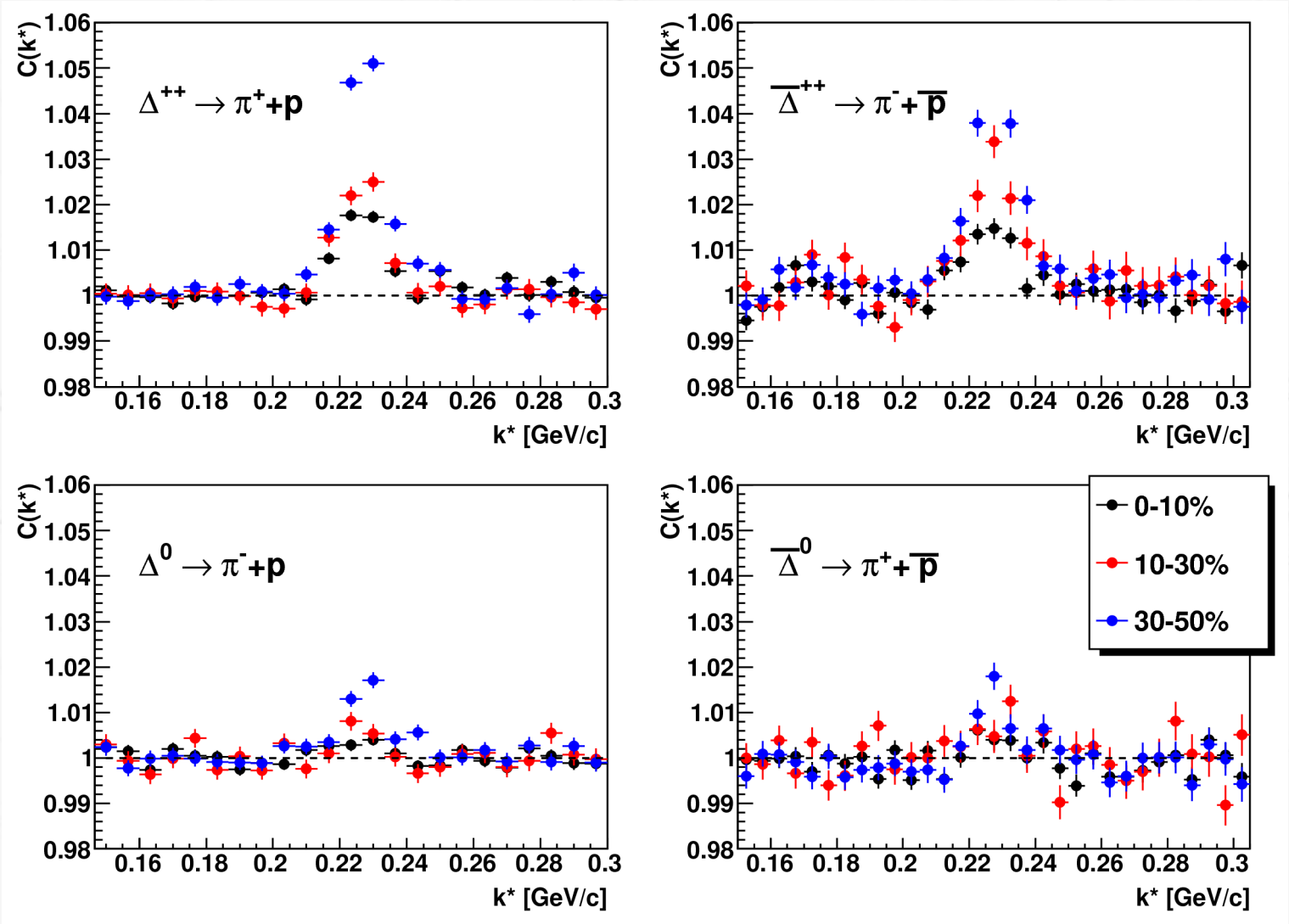
Experiment and models ellipses of covariances





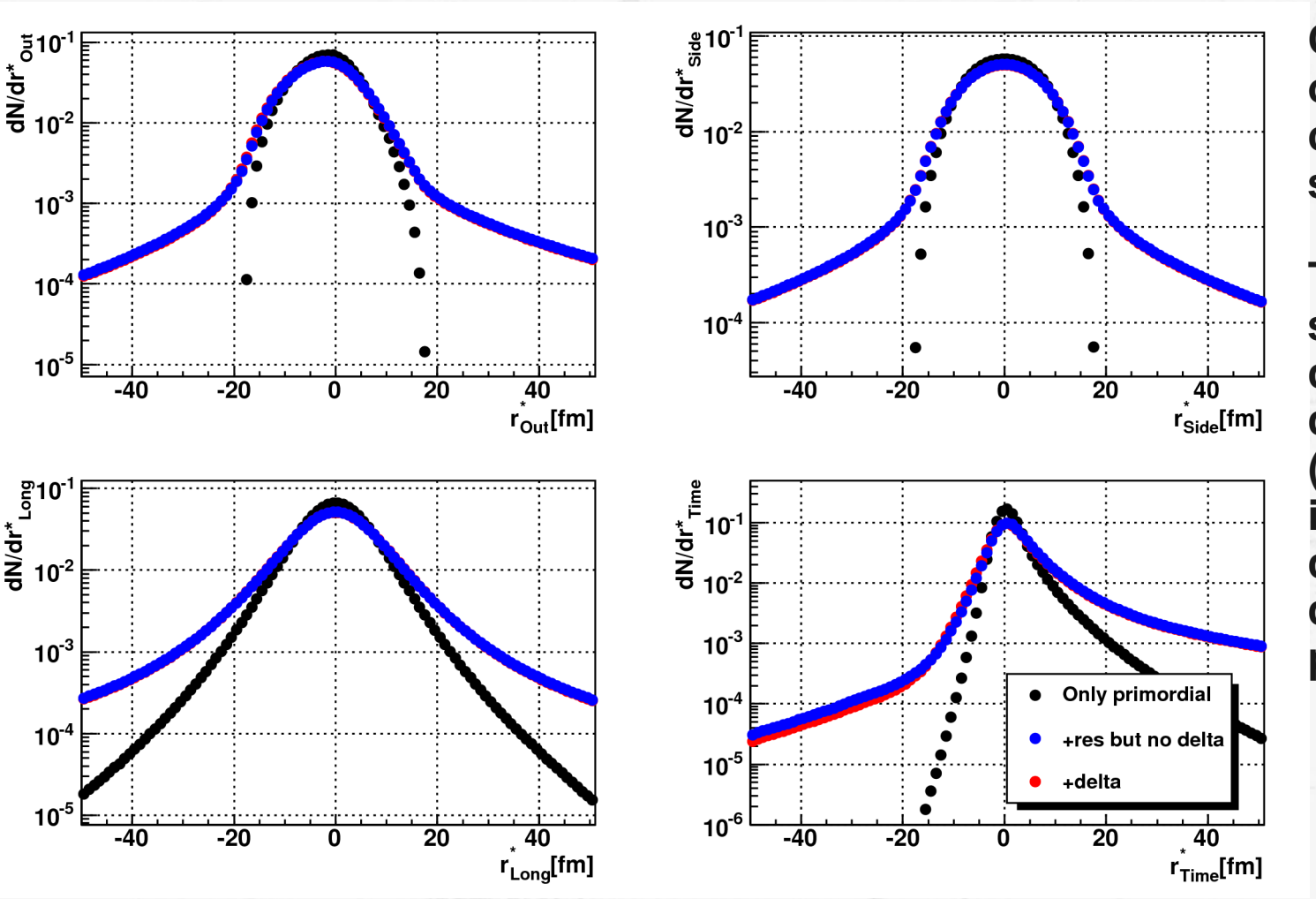
- Therminator overestimates asymmetry of the system
- UrQMD overestimates size of the system

Delta in pion-proton correlation function - Therminator



Delta resonance is observed above region of the femtoscopic correlation effect.

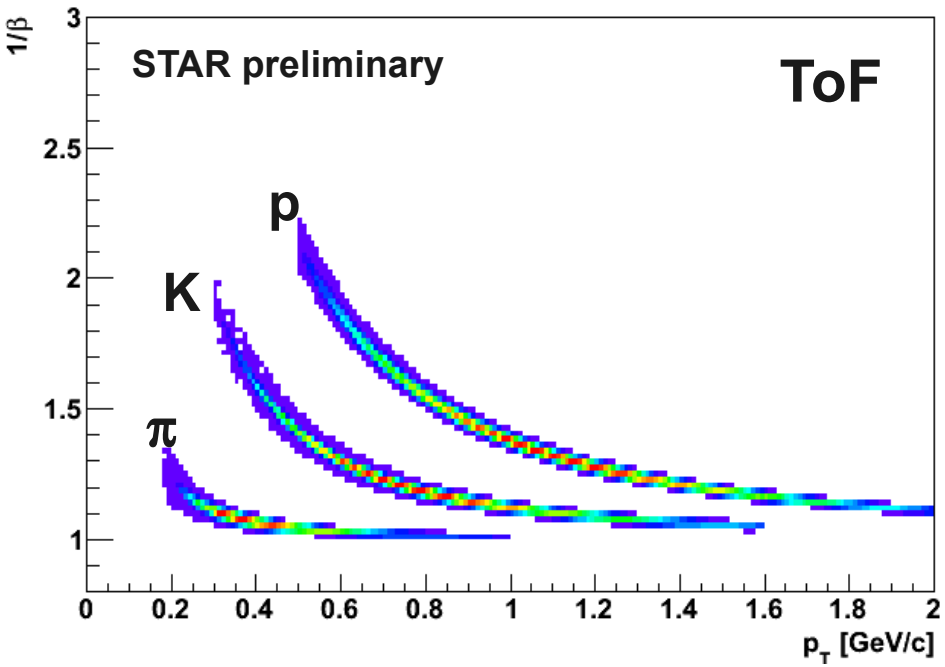
Delta in pion-proton correlation function - Therminator

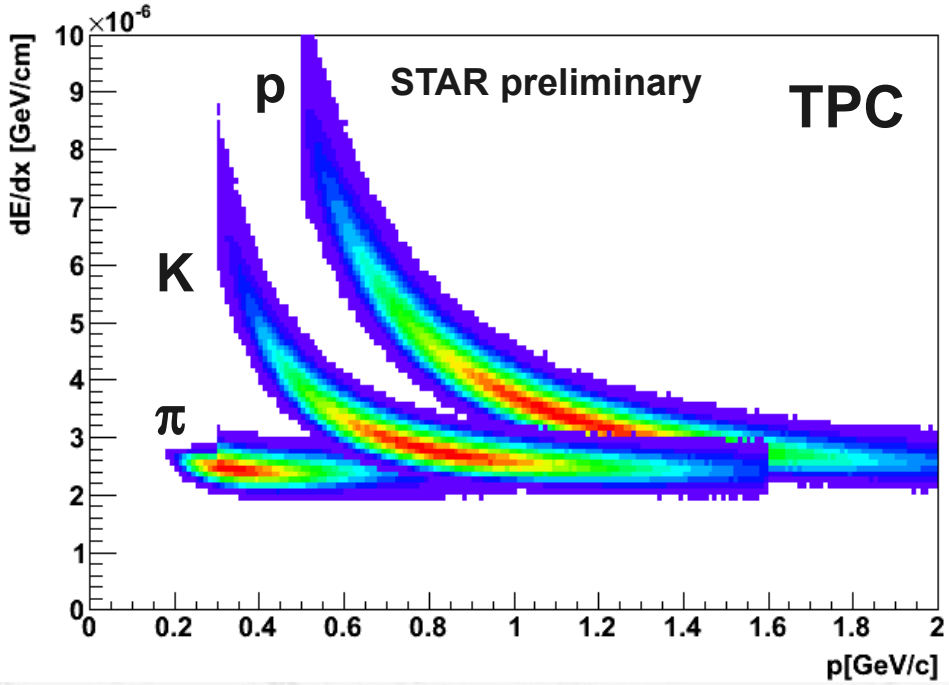


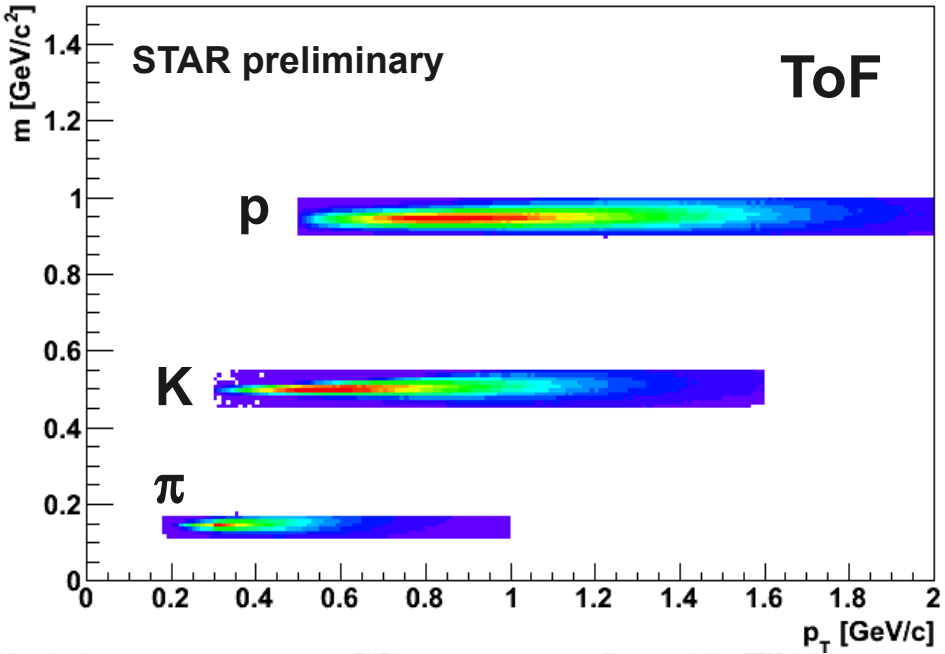
Correlated products of delta decay do not change observed source profile.

Two particle separation distributions where delta is excluded (blue points) are identical to the distributions where delta is included (red points).

Analysis with Time of Flight – near future







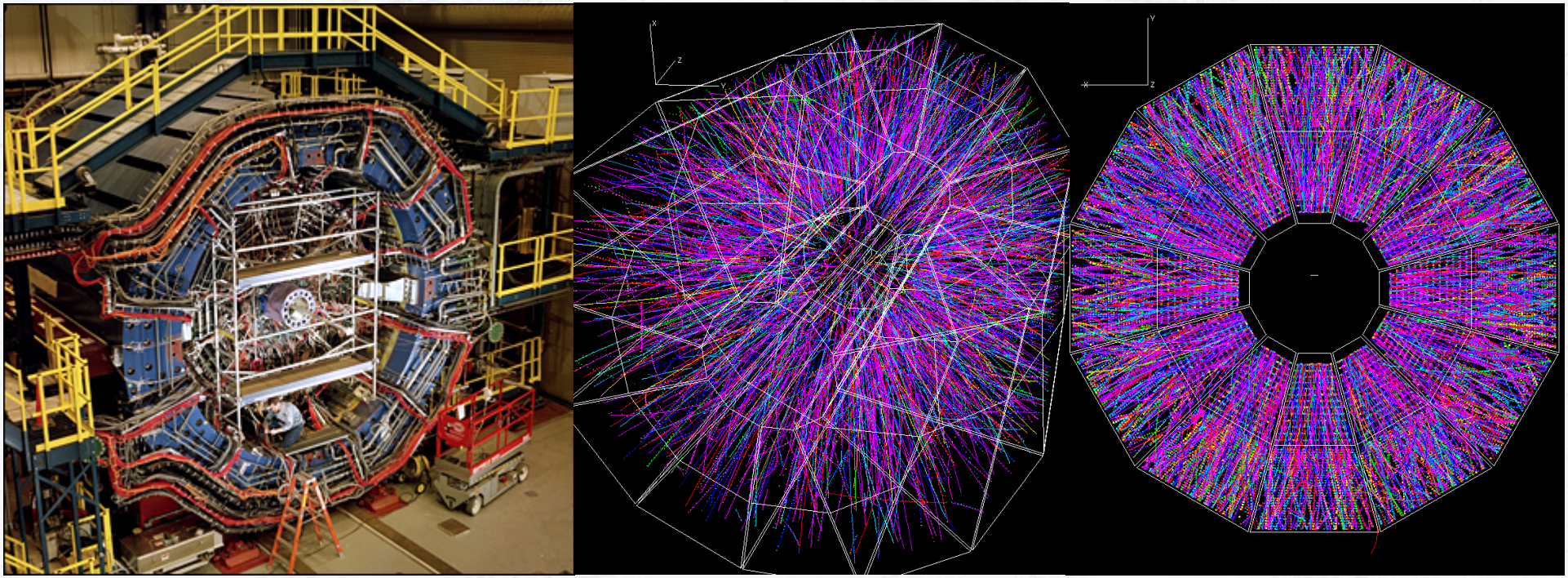
Au+Au at sqrt(sNN)=39GeV 2010 data

Time of Flight detector significantly improves particle identification.

Analysis of 200GeV data with ToF coming soon.

Conclusions

- We observe space-time asymmetry between average emission points of pions and protons
- Observed asymmetry suggest collective behavior of the created matter
- Space-time asymmetry and size of the $\pi-p$ source are correlated and depend on centrality
- Results from 2010 data with ToF expected in near future



Thank you for your attention