# Femtoscopy with multi-strange baryons at RHIC


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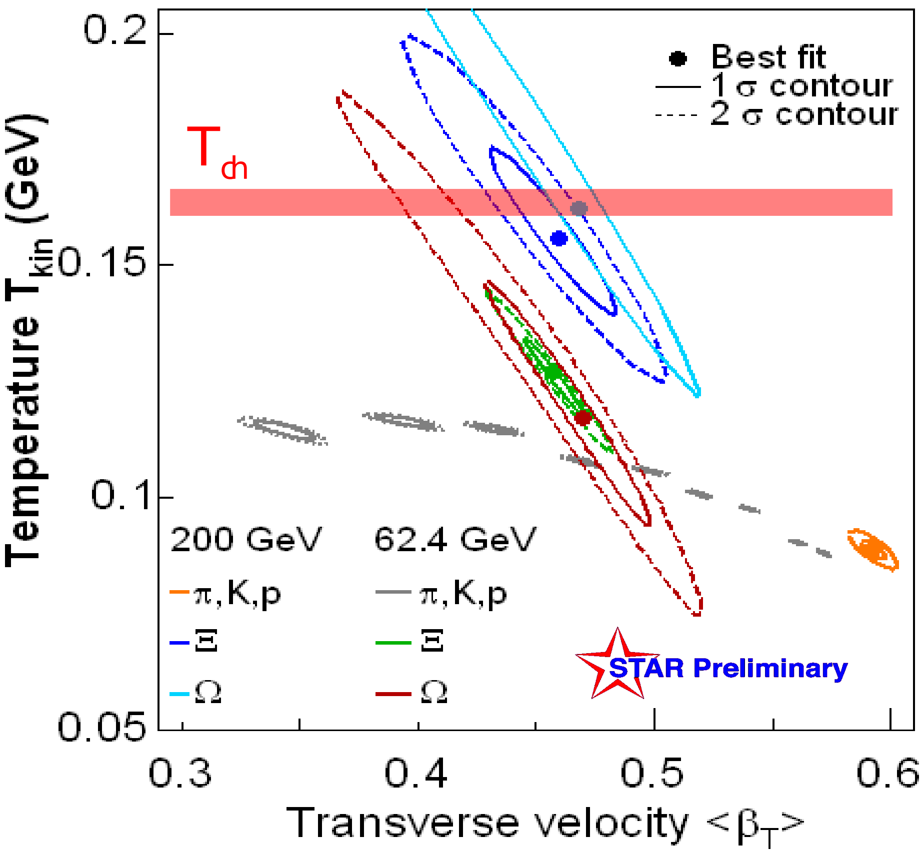
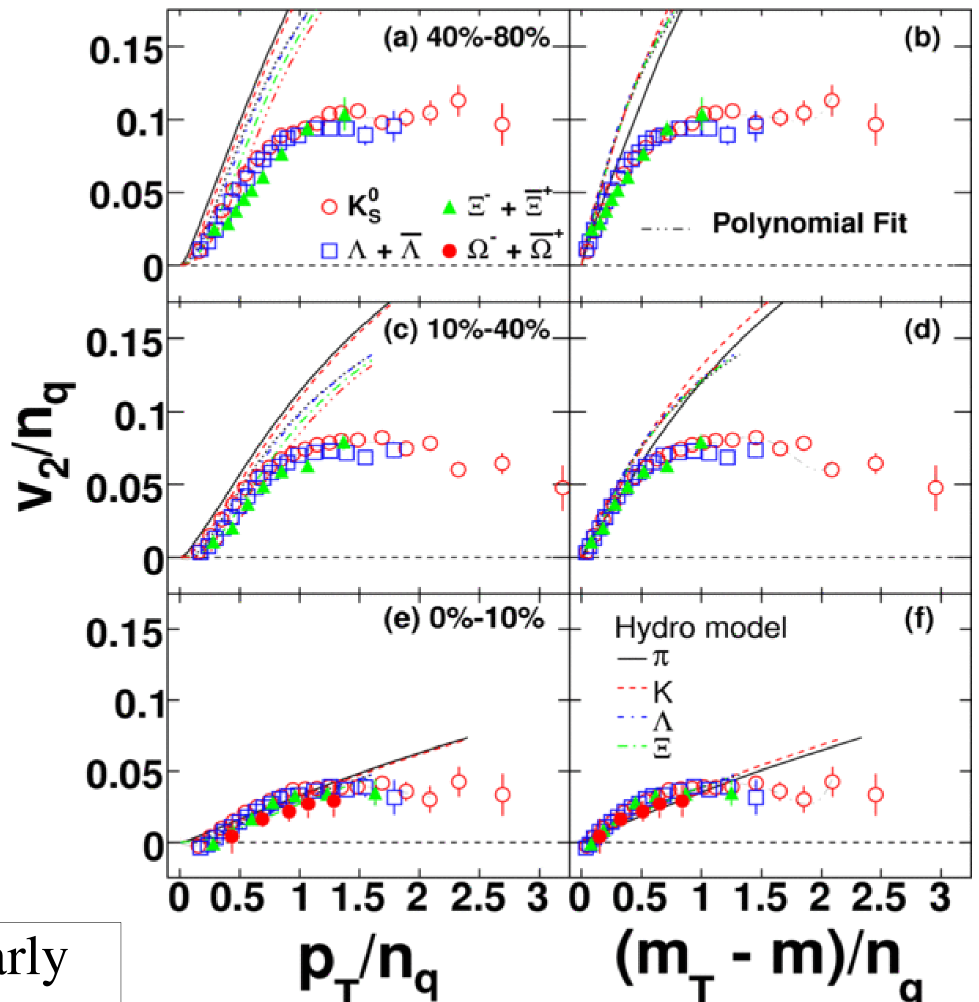
for the STAR collaboration

# Outline

- Motivation for femtoscopy with Ξ
- Current results of π-Ξ
- Coulomb fitting
- Comparison with HYDJET++
- Conclusions

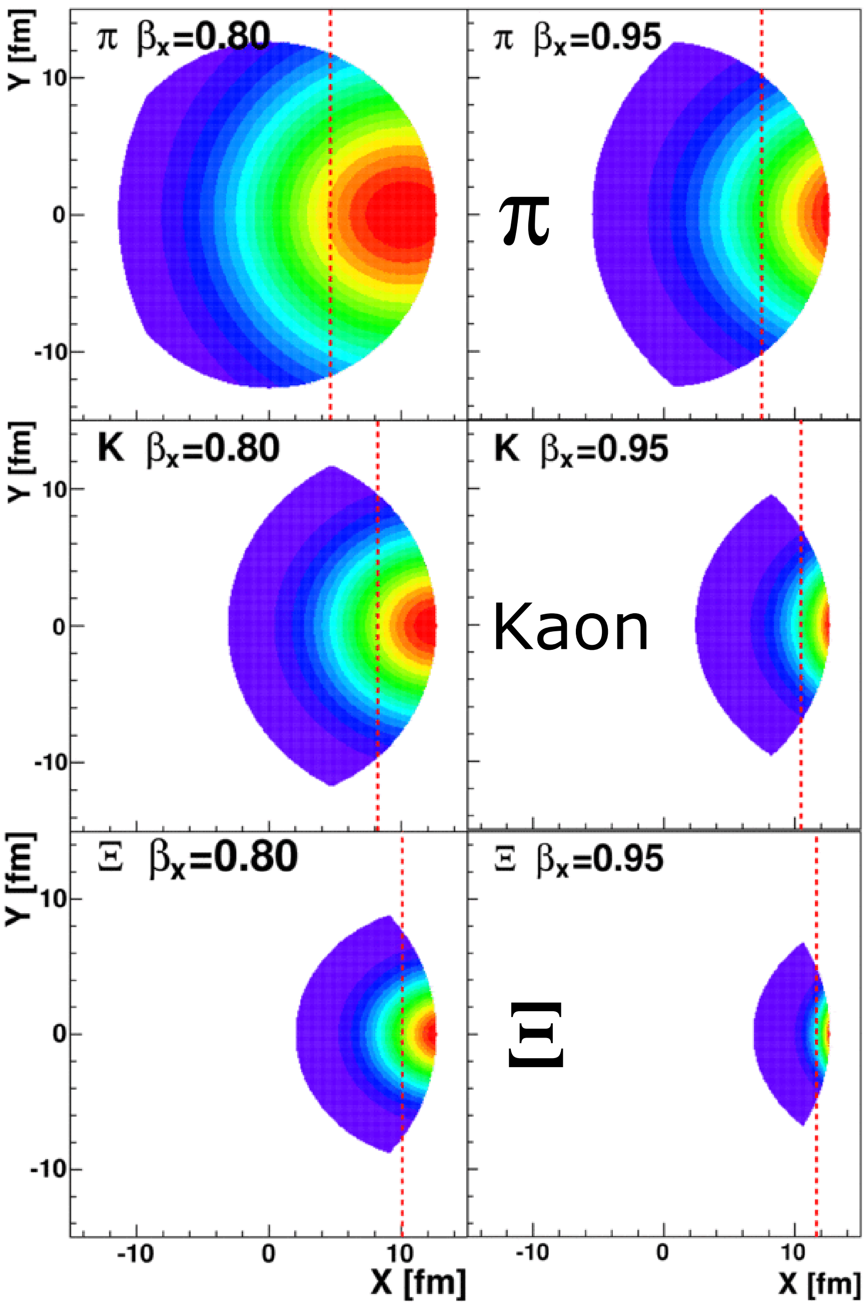
# Multistrange baryons




- Different thermal freeze-out behavior: early decoupling?
- **Elliptic flow** comparable to other hadrons
- Suggesting early partonic collectivity

# Effects of transverse flow



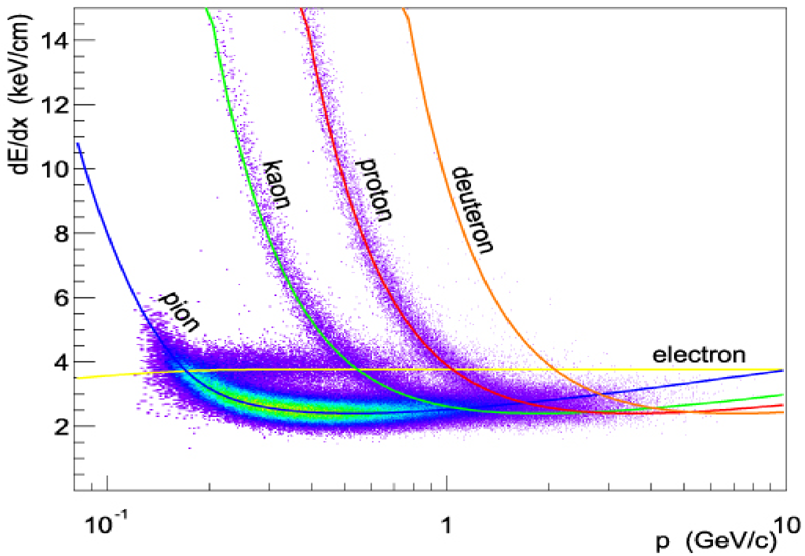

- Correlation between momentum and emission point
- Effective **reduction of source size** and **shift** in average emission point
- Effect **increases with $m_T$**

Non-identical correlations can test flow by measuring sizes and shifts of the sources

# Particle identification and reconstruction

- **Charged particles at mid-rapidity via dE/dx in TPC**

  π: y={-0.8, 0.8}
  $p_t$={150 , 800} MeV/c

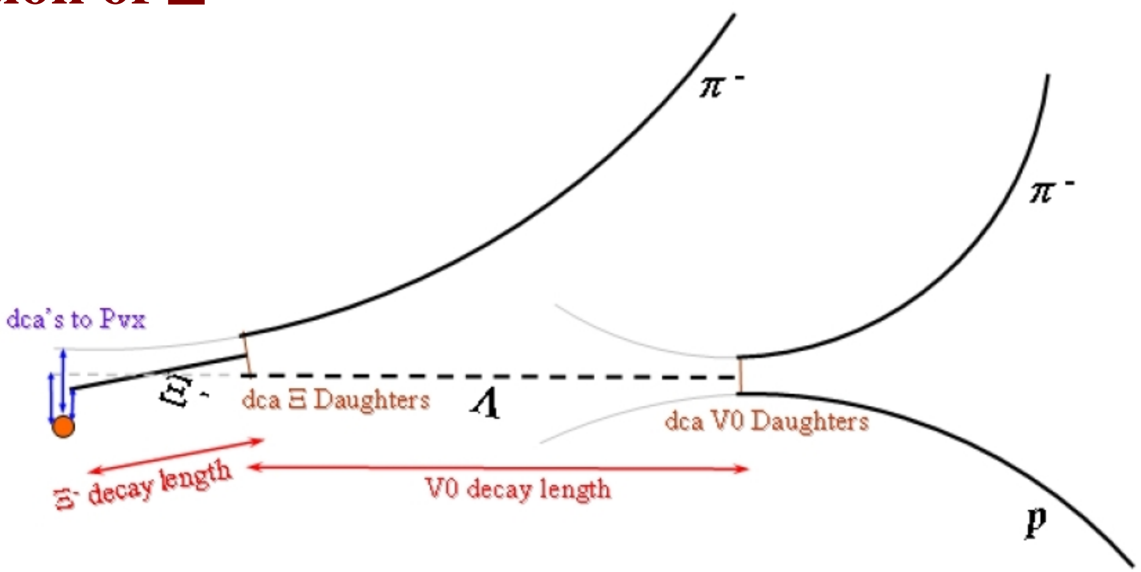



- **Topological reconstruction of $\Xi^{\pm}$**

  **Ξ –> π + Λ**

  **Λ–> π + p**

  Ξ: $p_t$={1 , 3} GeV/c
  $<\beta_t>$=0.85

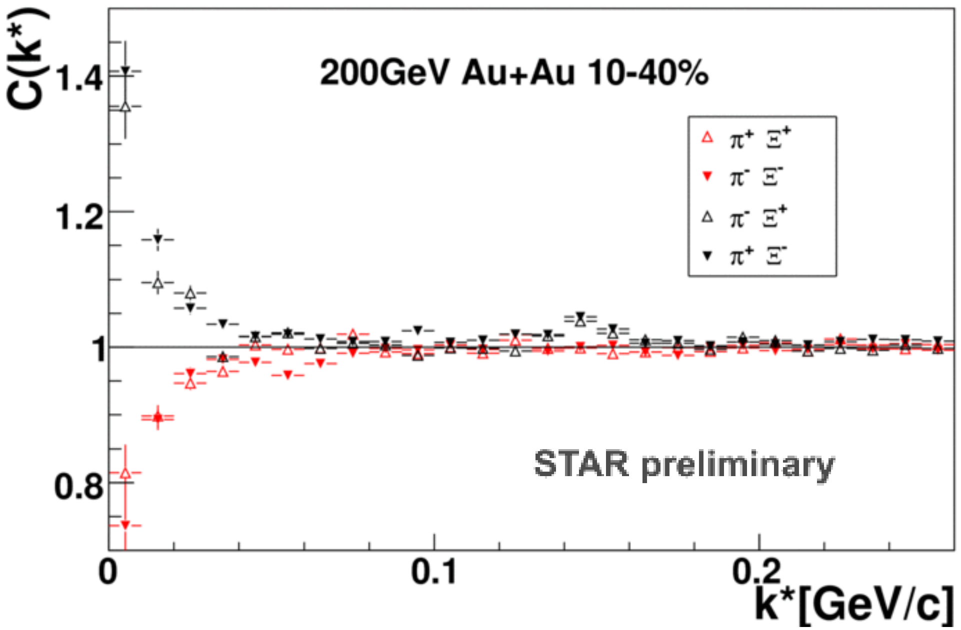


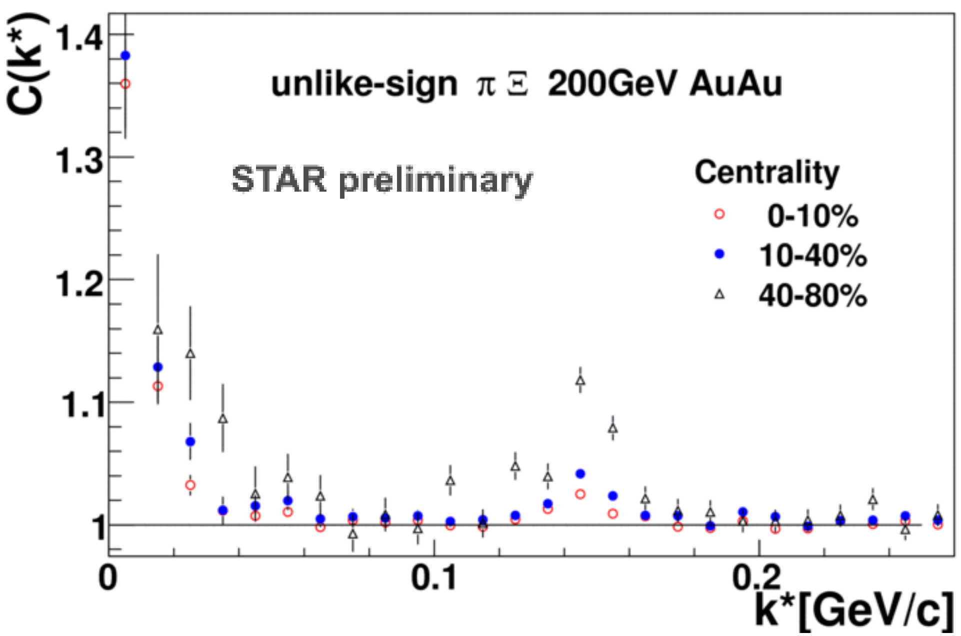
# π-Ξ correlations

- Purity corrected correlation function for **200GeV Au+Au** collisions.

- **Coulomb and strong** ( **Ξ*1530** ) final state interaction effects present.

- **Centrality dependence** observed, particularly strong in the Ξ* region



# π-Ξ correlations

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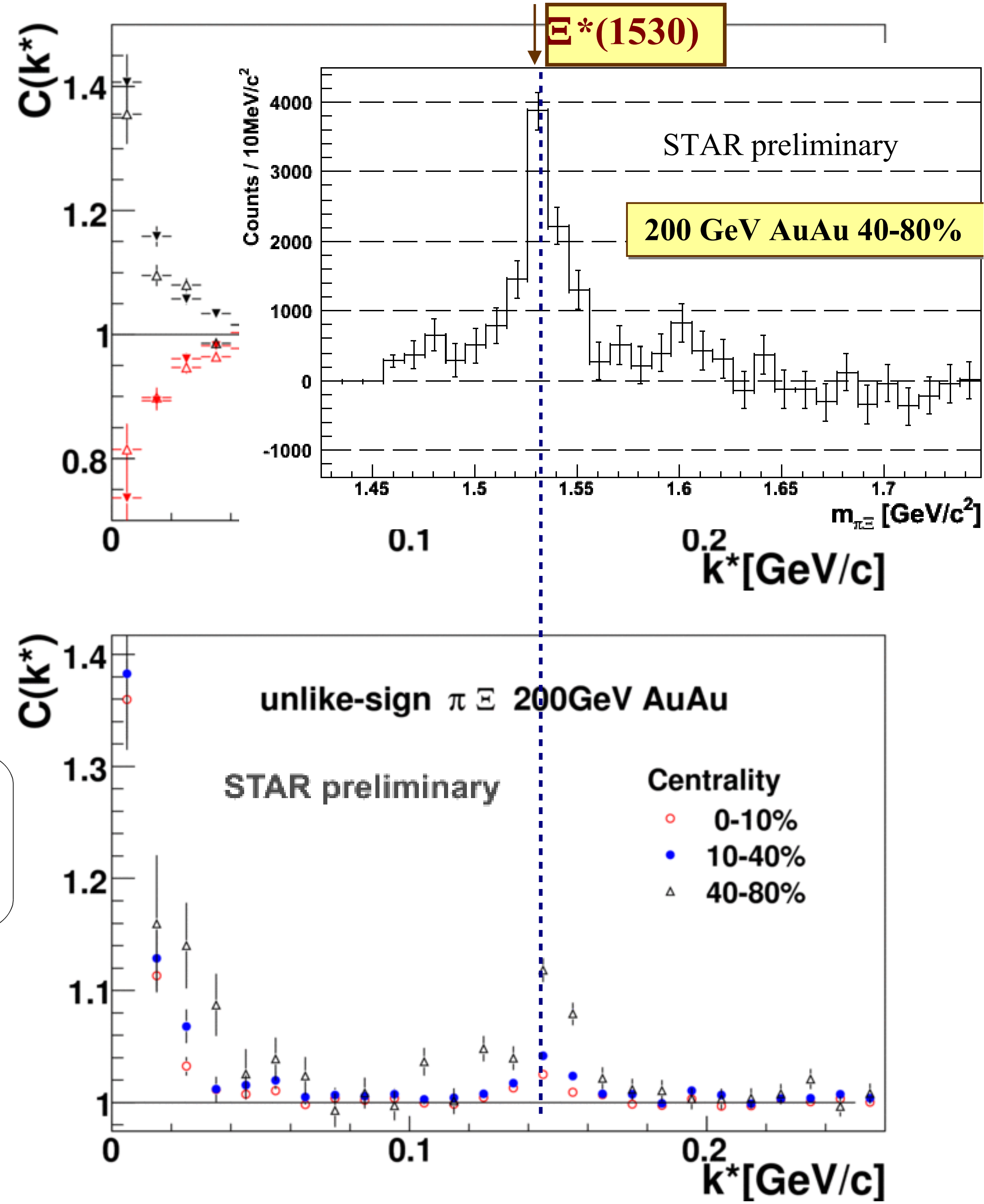
- **Centrality dependence** observed, particularly strong in the Ξ* region

$$k^* = \frac{[M^2 - (m_\Xi - m_\pi)^2]^{1/2}[M^2 - (m_\Xi + m_\pi)^2]^{1/2}}{2M}$$

$$\tau_{\Xi^*(1530)} = 21\ \mathrm{fm/c}$$



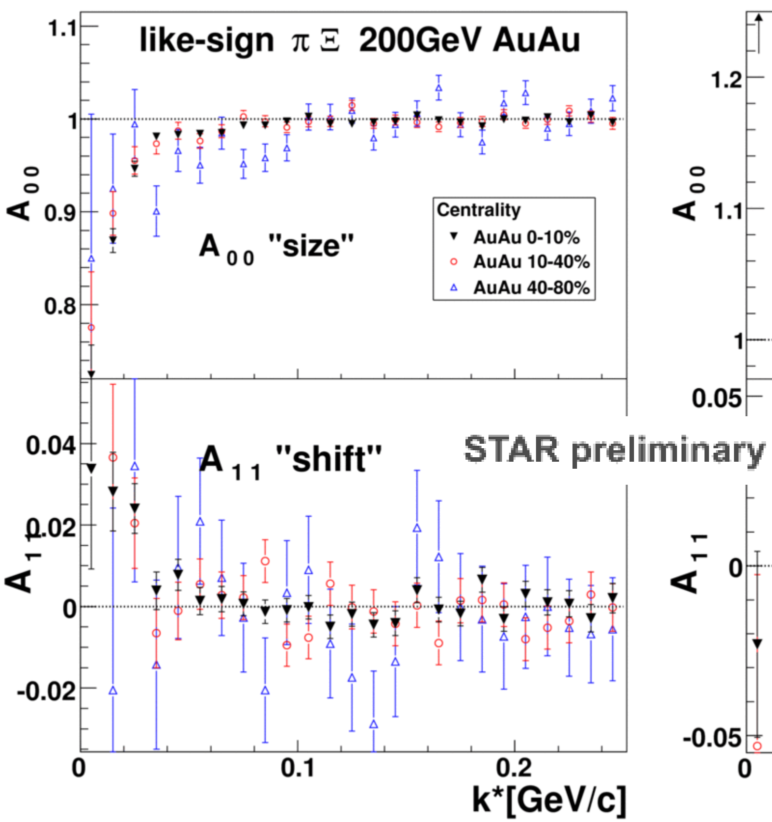
# Spherical decomposition

## Spherical decomposition – accessing emission shift

Z. Chajecki , T.D. Gutierrez , M.A. Lisa and M. López-Noriega, nucl-ex/0505009

$$A_{l,m}(|\vec{k}^*|) = \frac{\Delta_{\cos\theta}\Delta\varphi}{\sqrt{4\pi}} \sum_i^{\text{all bins}} Y_{l,m}(\theta_i,\varphi_i) C(|\vec{k}^*|, \cos\theta_i, \varphi_i)$$

$$\cos\theta = \frac{k^*_{Long}}{|\vec{k}^*|} \qquad \varphi = \arctan\frac{k^*_{Side}}{k^*_{Out}}$$

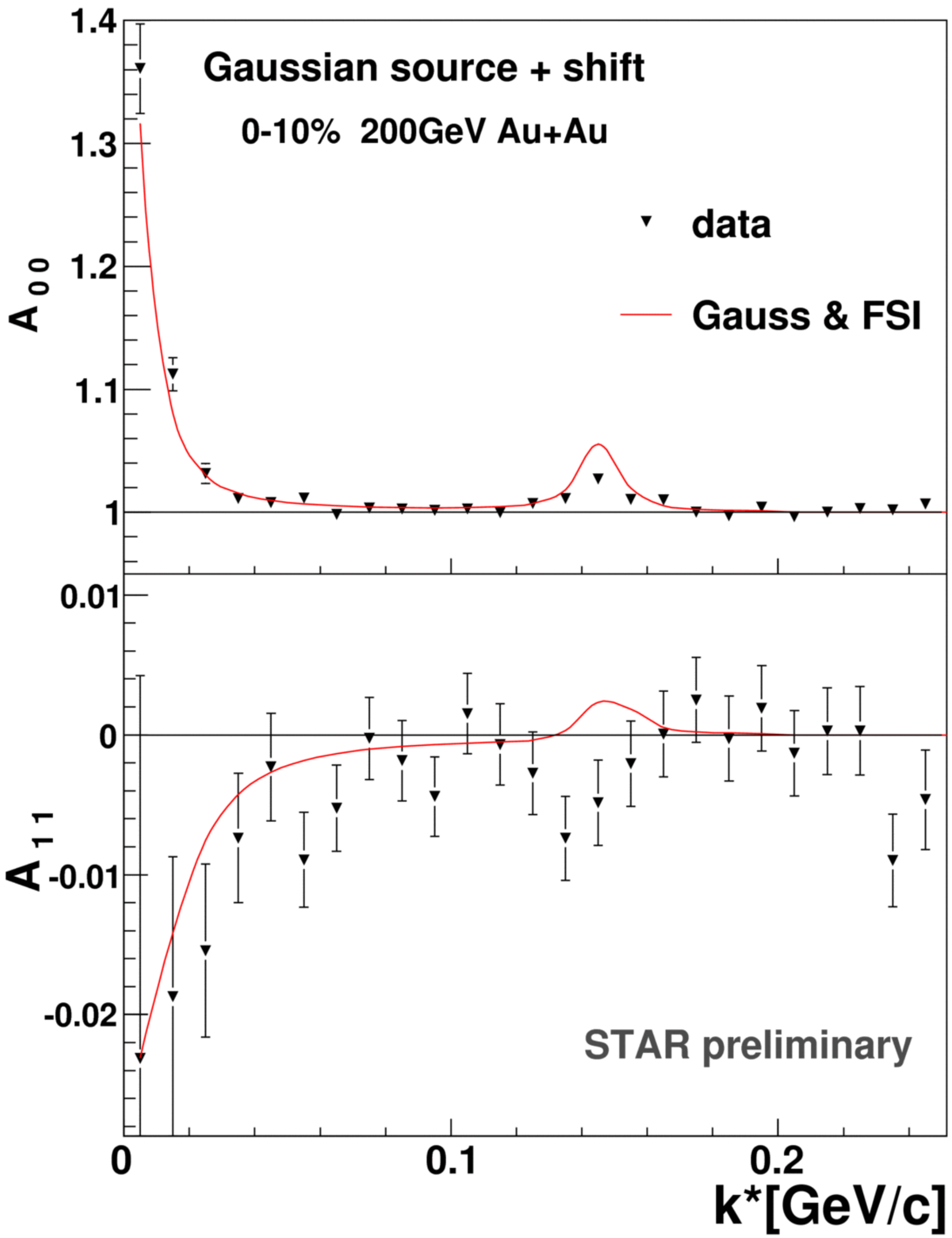



Different $A_{lm}$ coefficients correspond to different symmetries of the source

- $A_{00}$ - monopole – size
- $A_{11}$ - dipole - shift in out-direction

**$A_{11} \neq 0$** - shift in the average emission point between π and Ξ

# FSI model comparison



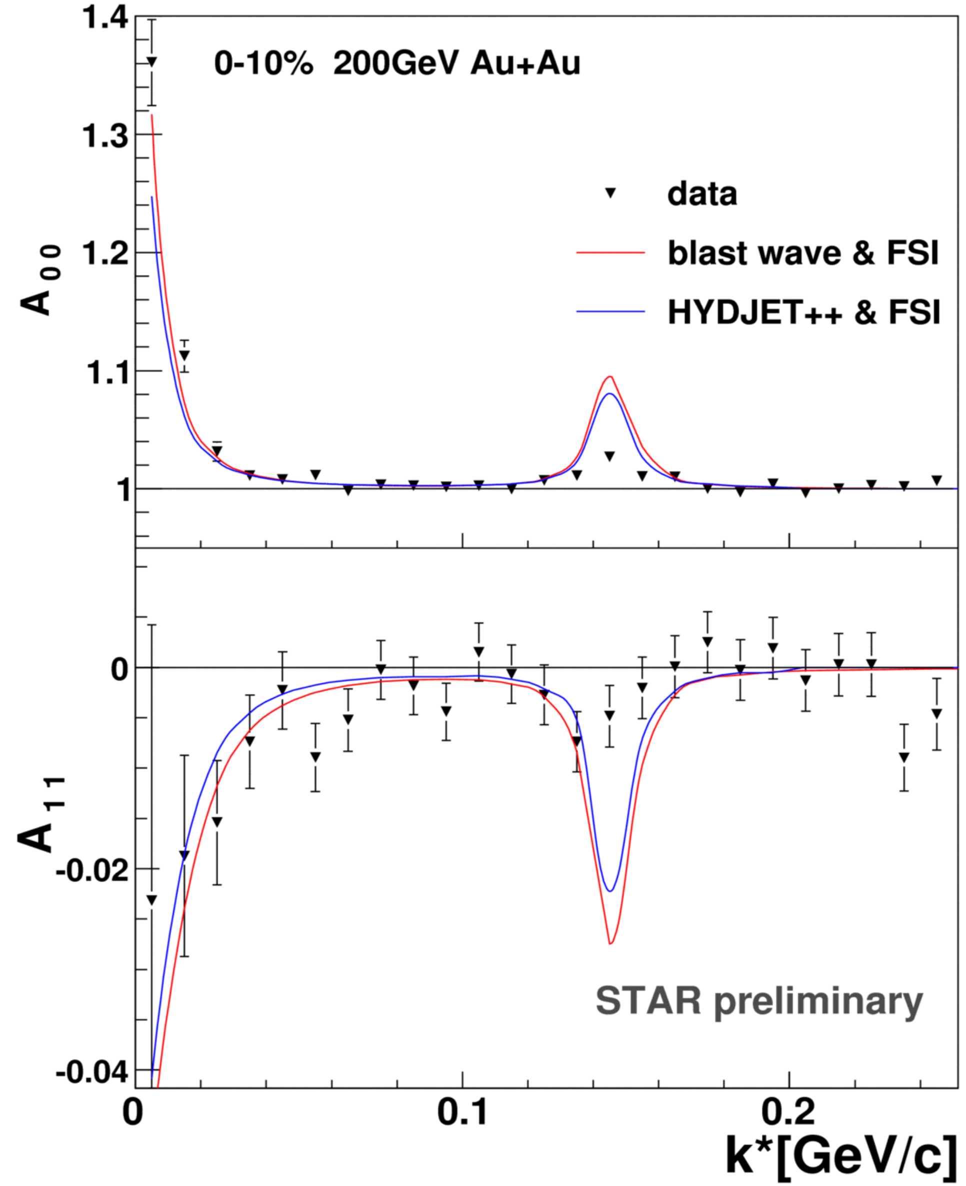

- FSI models with strong FSI:
  - S.Pratt: PRC68:054901, 2003
  - R.Lednicky
- Momenta of pairs from data
- Emission coordinates from model
- **Gaussian source in PRF with shift** in out direction:

| $R_{\pi,out}$ | $R_{\pi,side}$ | $R_{\pi,long}$ | $\Delta r^*_{out}$ | $R_{\Xi}$ |
|---|---|---|---|---|
| 10.2 | 5.4 | 6.6 | -8.0 | 2 |

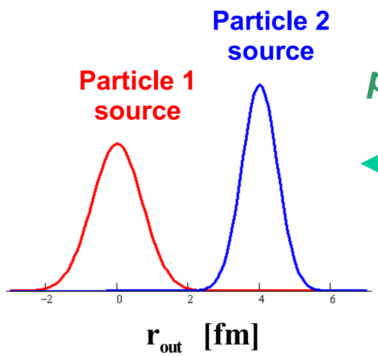
- **Coulomb part in qualitative agreement**
- **Discrepancy in $\Xi^*$ region**
  - over predicts $A_{00}$
  - flipped sign of $A_{11}$

# FSI model comparison

- Hydro based models
  - Blast wave
  - HYDJET++: particle production and resonance decays
- Flow induced correlation between momenta and emission coordinates
- **Qualitative reproduction of the $\Xi^*$ region**
  - overestimates both $A_{00}$ , $A_{11}$
  - observed shift agrees with flow scenario



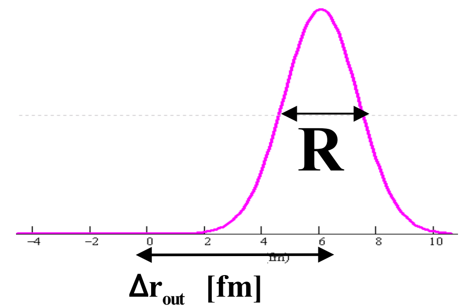
# Gaussian fit – Coulomb only




$<\Delta r_{out}> = <r_{out}(\pi) - r_{out}(\Xi)>$

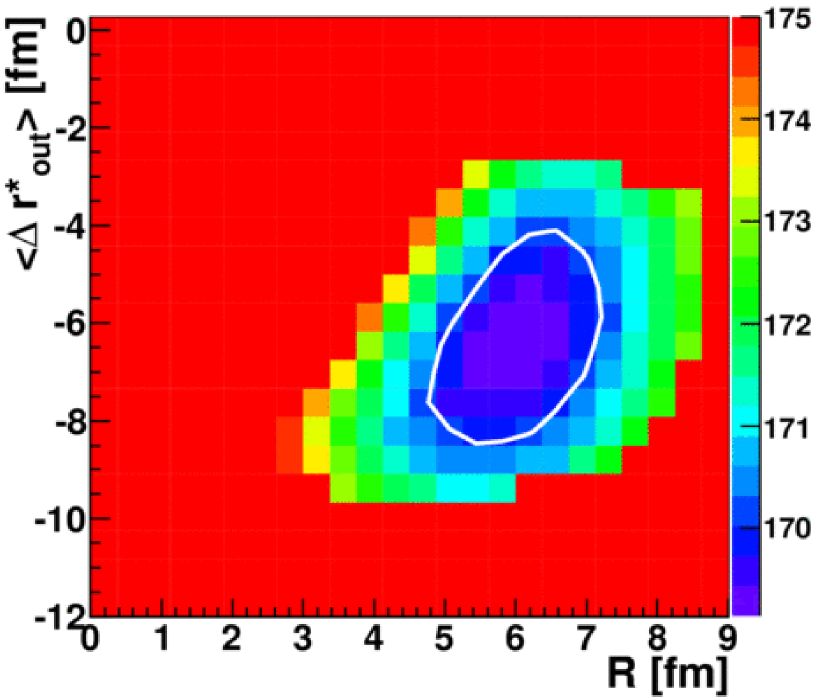
*Separation between particle 1 and 2 boosted to the pair rest frame*

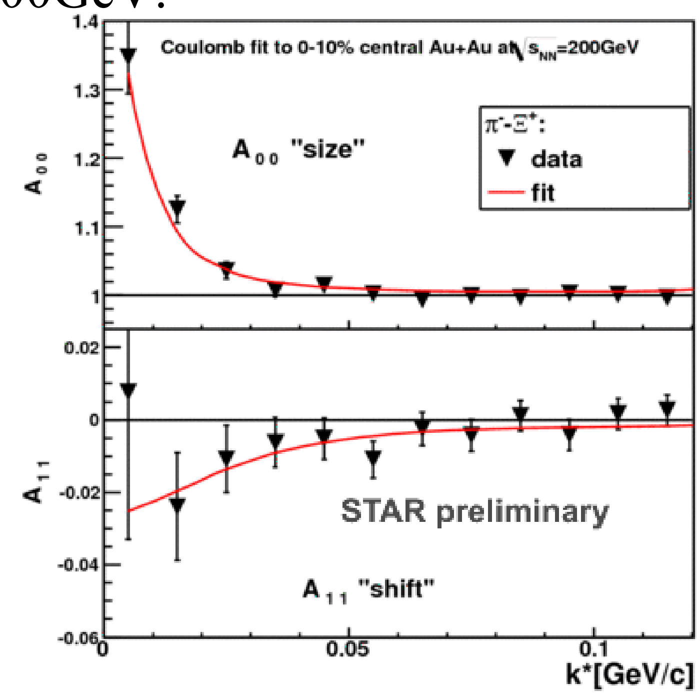
$\Delta r^*_{out} = \gamma_T(\Delta r_{out} - \beta_T \Delta t)$



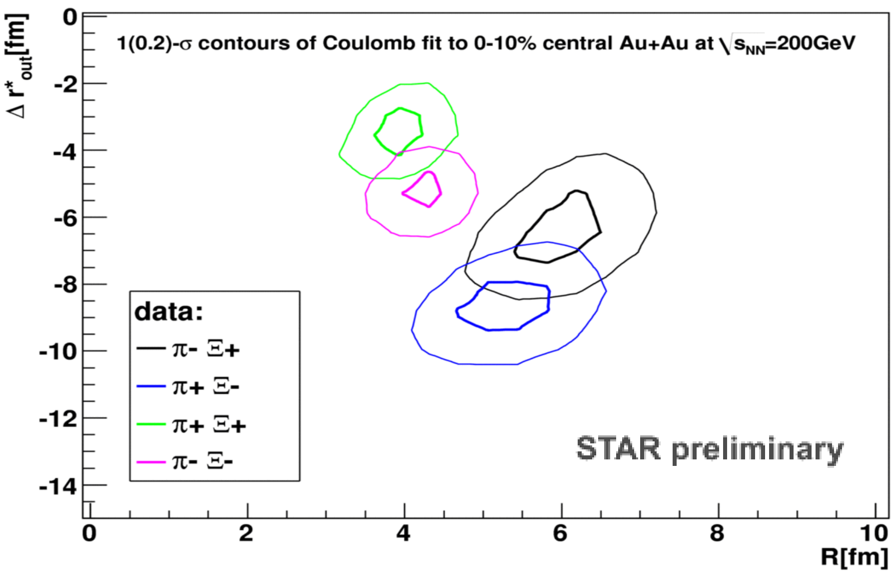

*(R, $\Delta r_{out}$) - two-parameter description of the source in the rest frame*

fit to $\pi^-$-$\Xi^+$ in 0-10% central Au+Au at 200GeV:

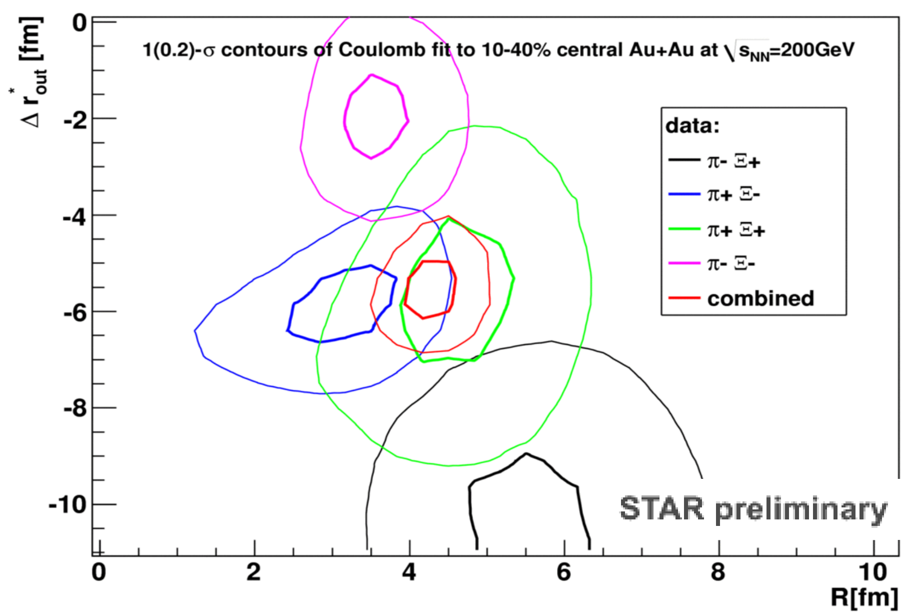


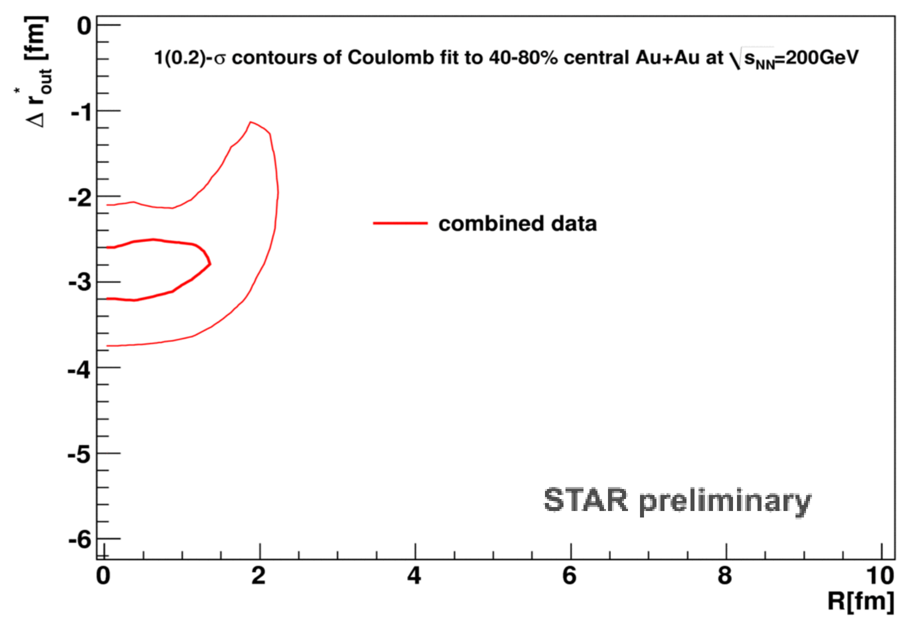



# Coulomb fit




- Central data – possible to fit individual charge combinations.
- 1 and 0.2-σ contours of fit
- Other centralities - simultaneous fit to all CFs.

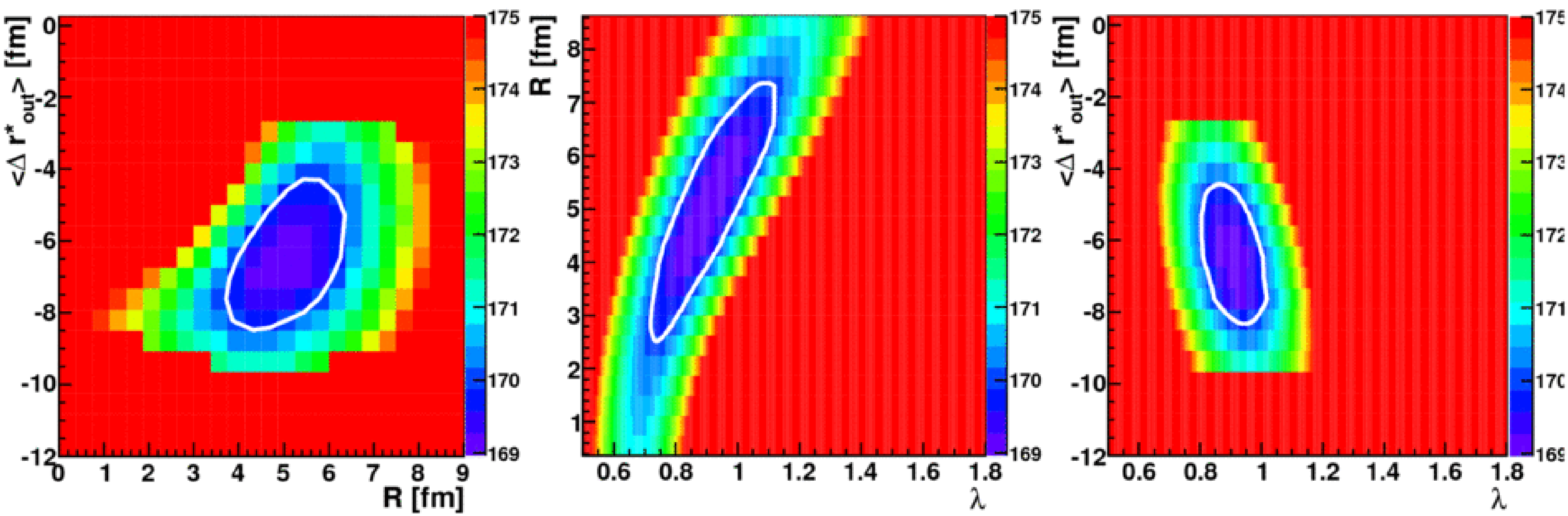


# Fitting with free λ parameter

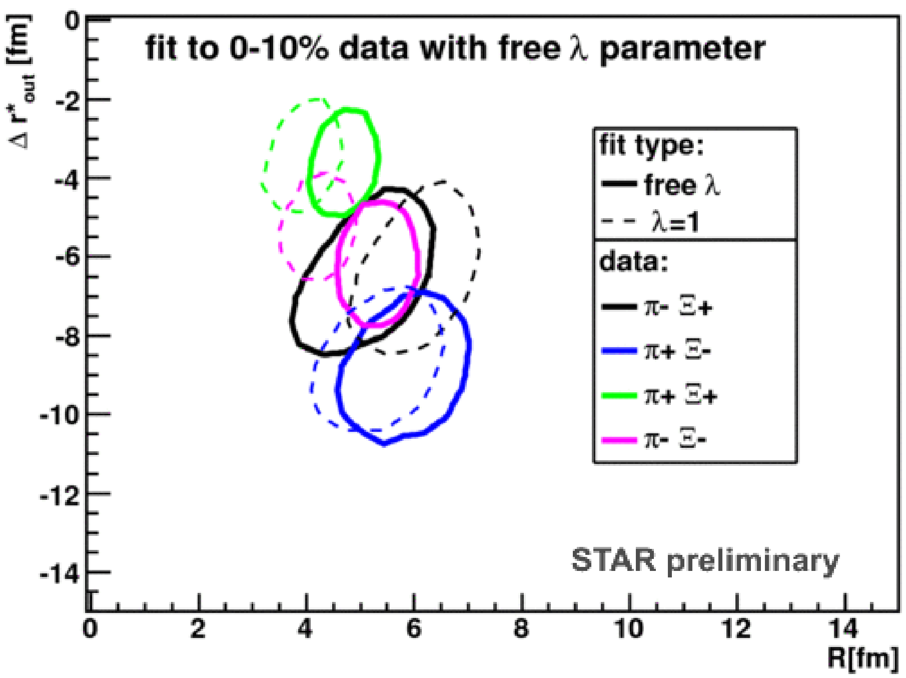
- CF already corrected for pair purity.
- Reintroduction of the λ as a fit parameter $C_{fit}(\vec{k}^*) = \lambda(C(\vec{k}^*) - 1) + 1$
- Estimate of the quality of purity correction and it's influence on extracted parameters.
- Strong correlation between λ and R in the fit.

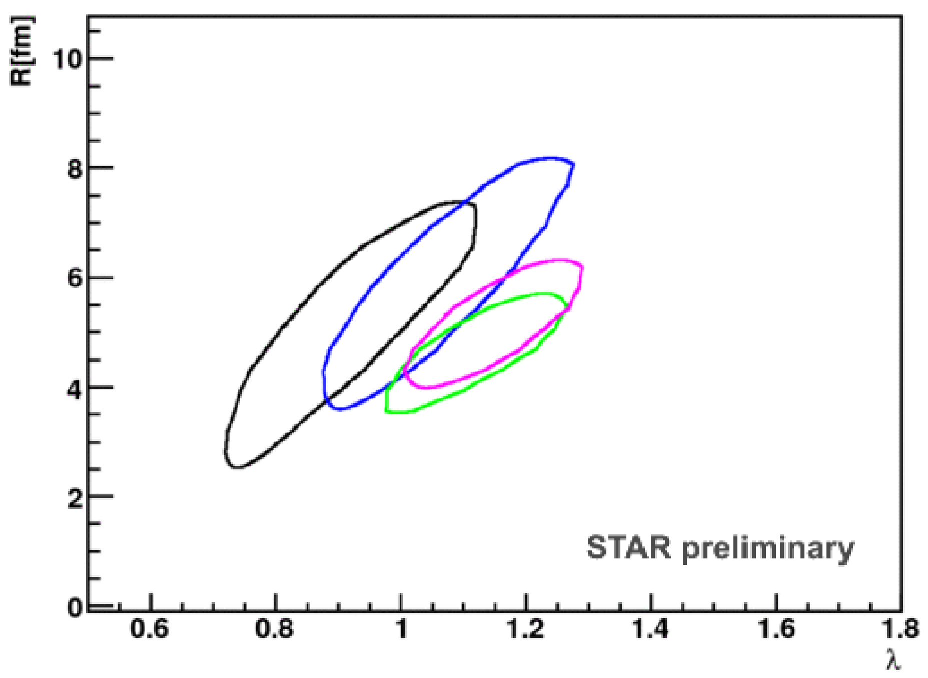
fit to $\pi^- - \Xi^+$ in 0-10% central Au+Au at 200GeV:



# Fitting with free λ parameter

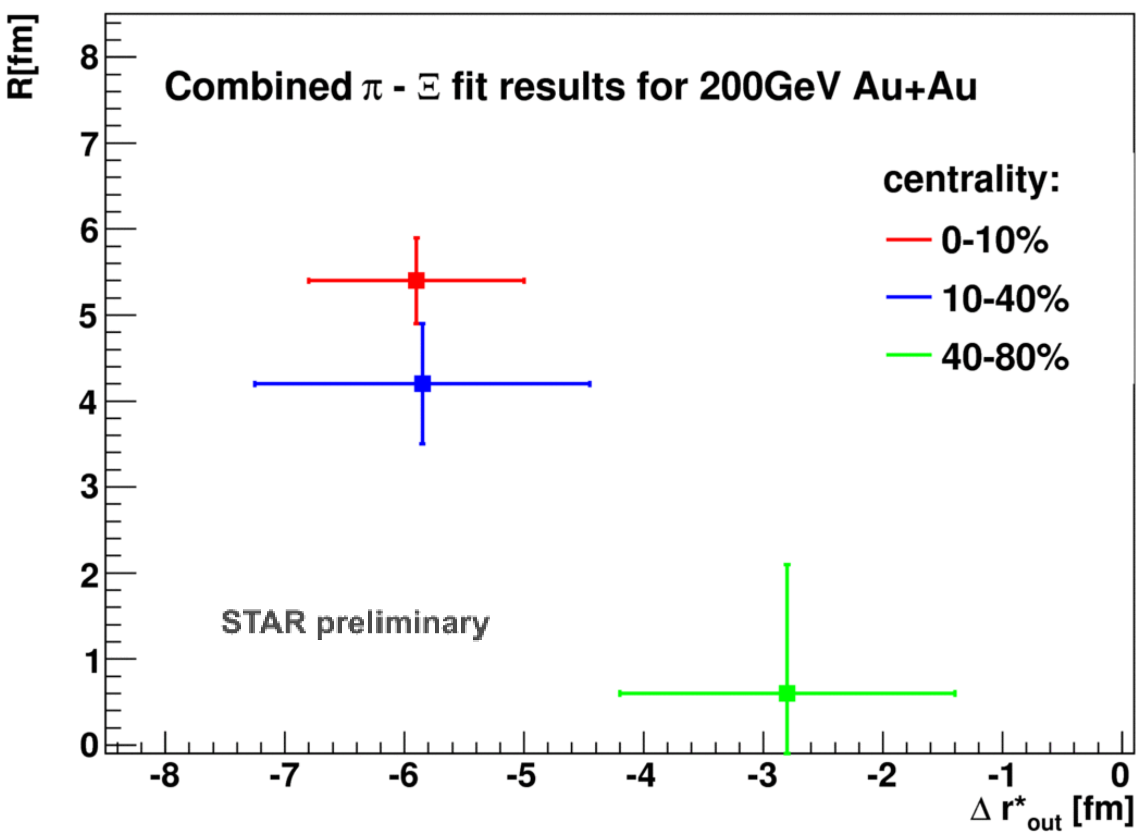
- Statistically possible only for central data
- Fits converge in vicinity of λ=1
- Average 10% error in purity correction ~ 1fm difference in R
- For central data change of extracted R: 4.2->5.4 fm
- Estimate of systematic error due to purity corrections.



# 200GeV Au+Au fit results

- Extracted **centrality dependence** of Gaussian size R and relative shift $<\Delta r^*_{out}>$.
- Both size and shift increase with centrality.
- Average emission point of Ξ is positioned more to the outside of the whole fireball than the average emission point of pion.
- Consistent with significant flow of the multi-strange baryons.



# Comparison to HYDJET++ model

- Bjorken expansion parametrization of freeze-out
  - Blastwave
- Particle production – statistical model
- Three different parameter sets tuned to reproduce spectra
  - $T_{ch}=T_{th}=165$ MeV
  - $T_{ch}=100$MeV, $T_{th}=165$MeV
  - Combined scenario of Ξ early freeze-out.
- Decays of hadronic resonances
- Fast generation of events

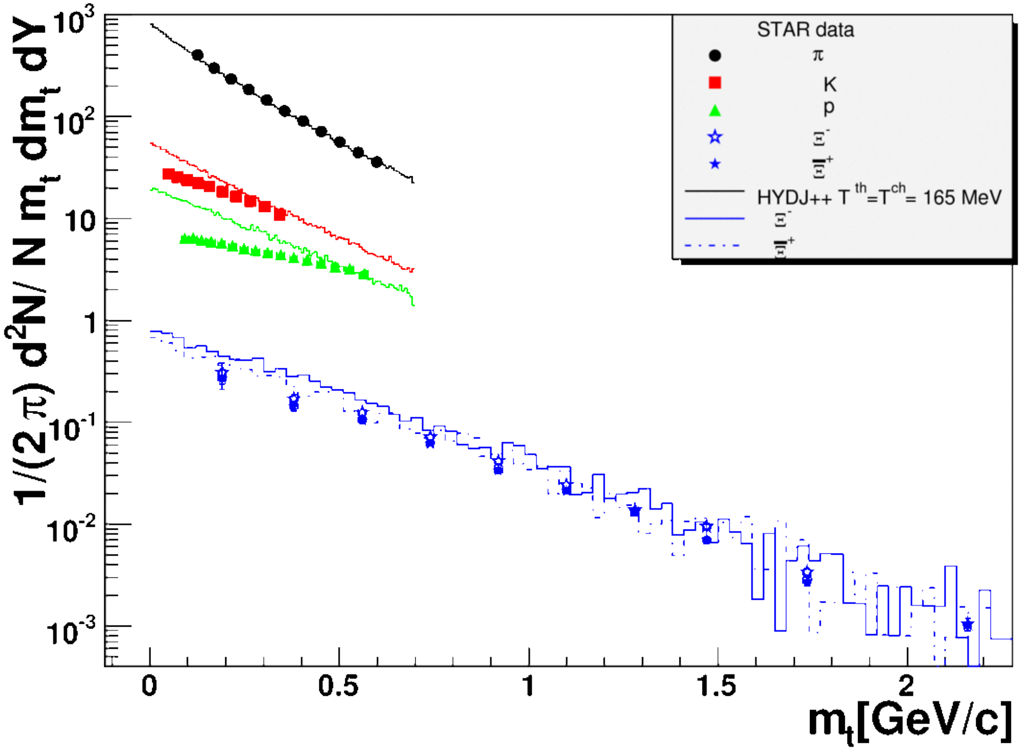
| parameter | Tch=Tth | Tch>Tth |
|---|---|---|
| Tch, GeV | 0.165 | 0.165 |
| Tth, GeV | 0.165 | 0.100 |
| μB, GeV | 0.028 | 0.028 |
| μS, GeV | 0.007 | 0.007 |
| μQ, GeV | -0.001 | -0.001 |
| γS | 1 | 1 |
| τ, fm/c | 7.0 | 8.0 |
| Δτ, fm/c | 2.0 | 2.0 |
| R, fm | 9.0 | 10.0 |
| ηmax | 2 | 2 |
| ρu max | 0.65 | 1.1 |

**N. Amelin et al.**
Phys.Rev.C73:044909,2006
Phys.Rev.C74:064901,2006.
Phys.Rev.C77:014903,2008.

**http://uhkm.jinr.ru**

# The $m_t$ spectra calculated with HYDJET++

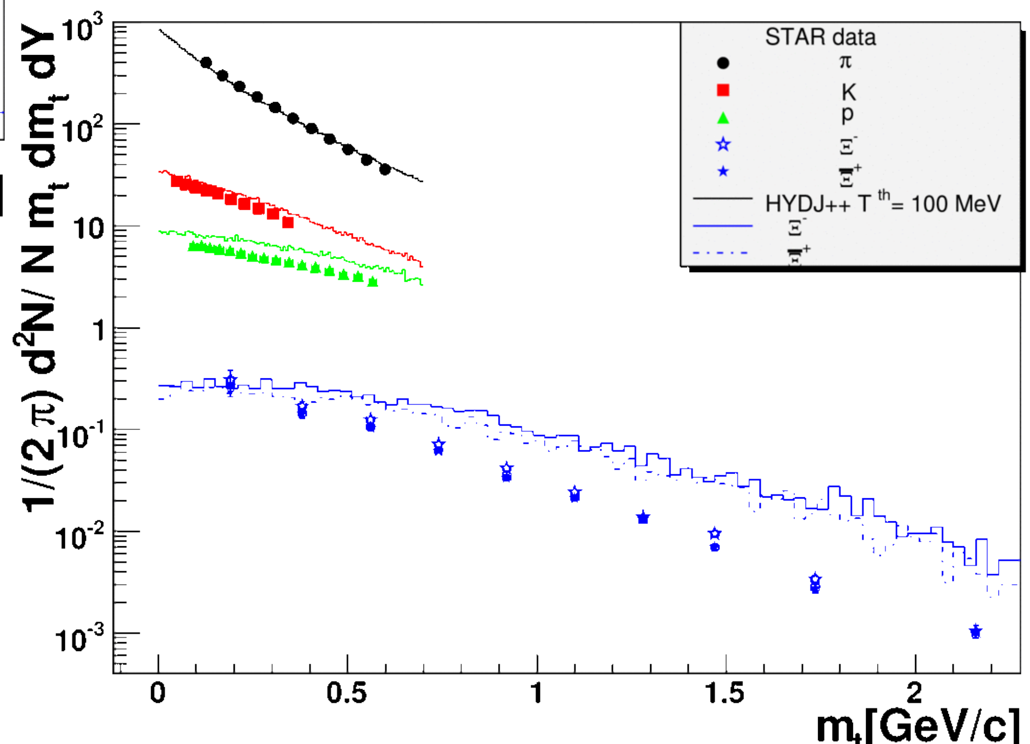
**single freeze-out scenario:**




Single freeze-out describes Ξ

Separate freeze-out describes common particles

**separate freeze-out scenario with Tch=0.165 GeV Tth=0.1 GeV.**



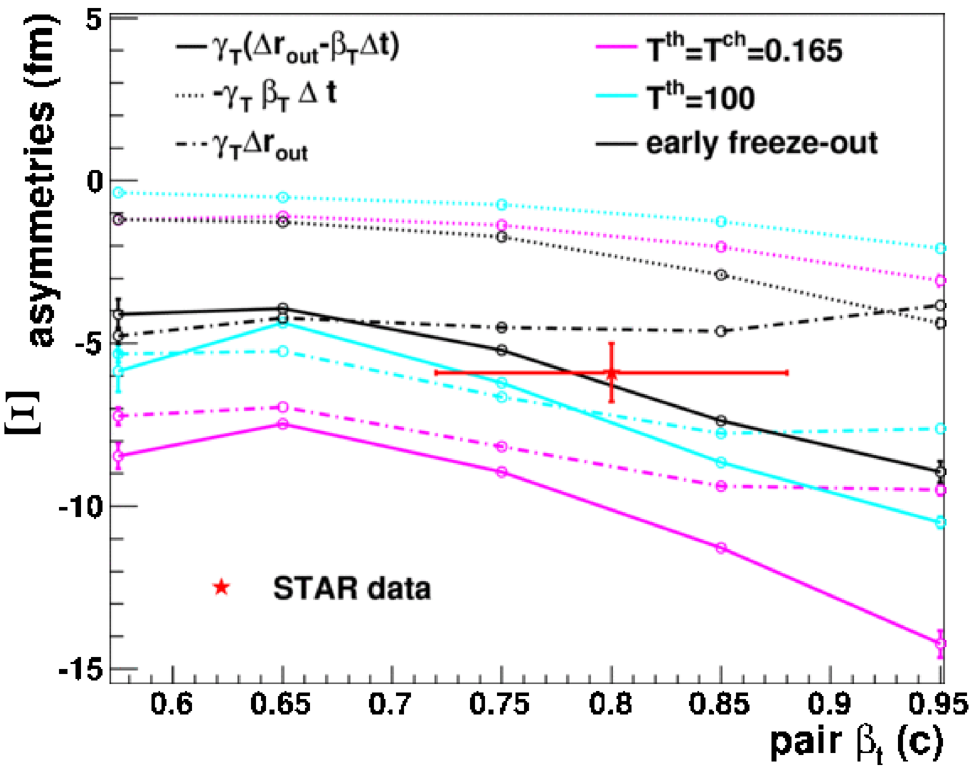

The model cannot simulate different conditions for different species....

.....we can mix particles from both types of events

# π-Ξ emission asymmetry from the model

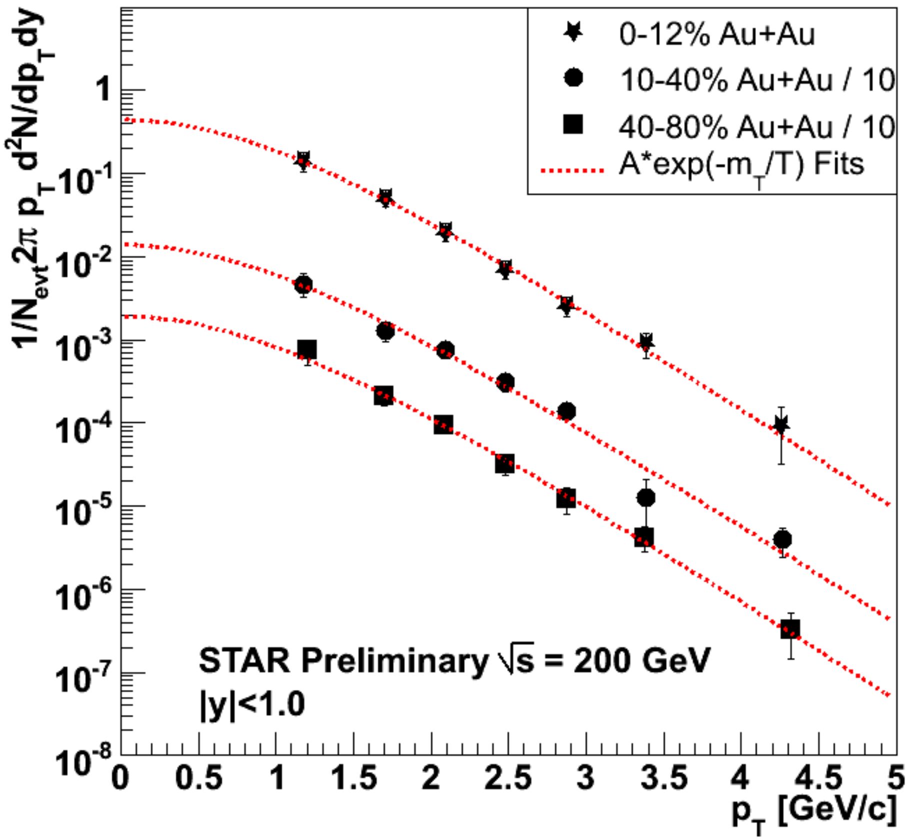
**"mix" events** – taking pions from separate and Ξ from single temperature freeze-out.

Difference between freeze-out scenarios. Decrease of the emission shift in case of Ξ freezing out at higher $T_{th}$.




Does the shift depend on Ξ*/Ξ ratio?

# Ξ* Transverse Momentum Spectra



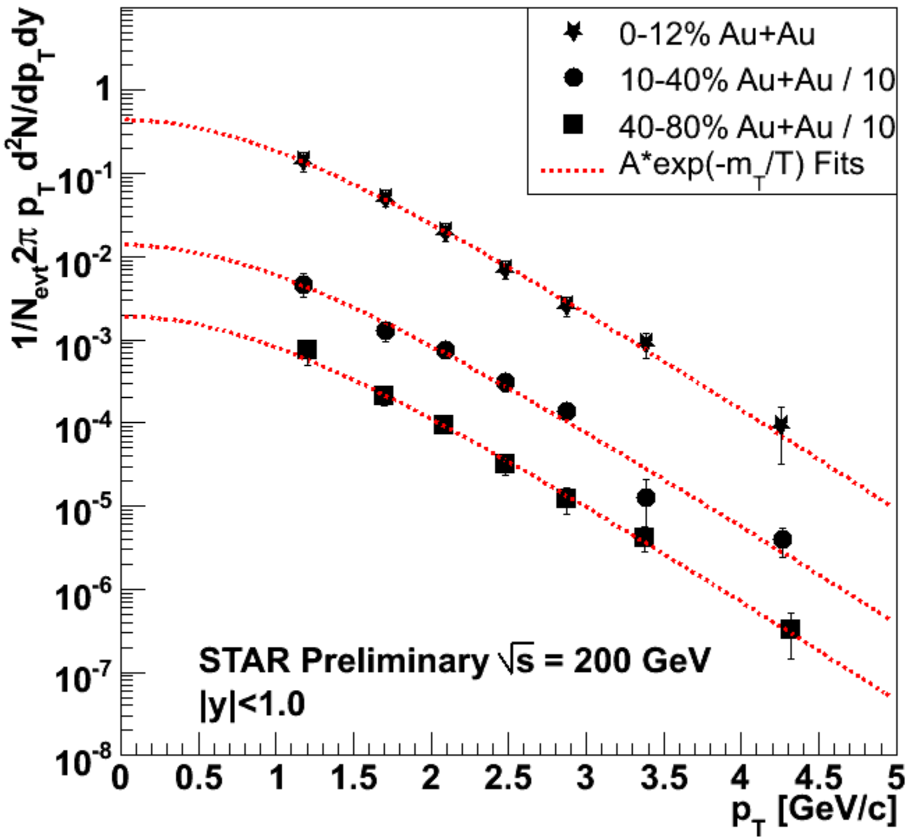

| Centrality | Ξ*/Ξ Ratio |
|---|---|
| 0-12% | **0.92 ± 0.28** |
| 10-40% | **0.60 ± 0.12** |
| 40-80% | **0.51 ± 0.12** |

**Richard Witt – STAR collaboration**

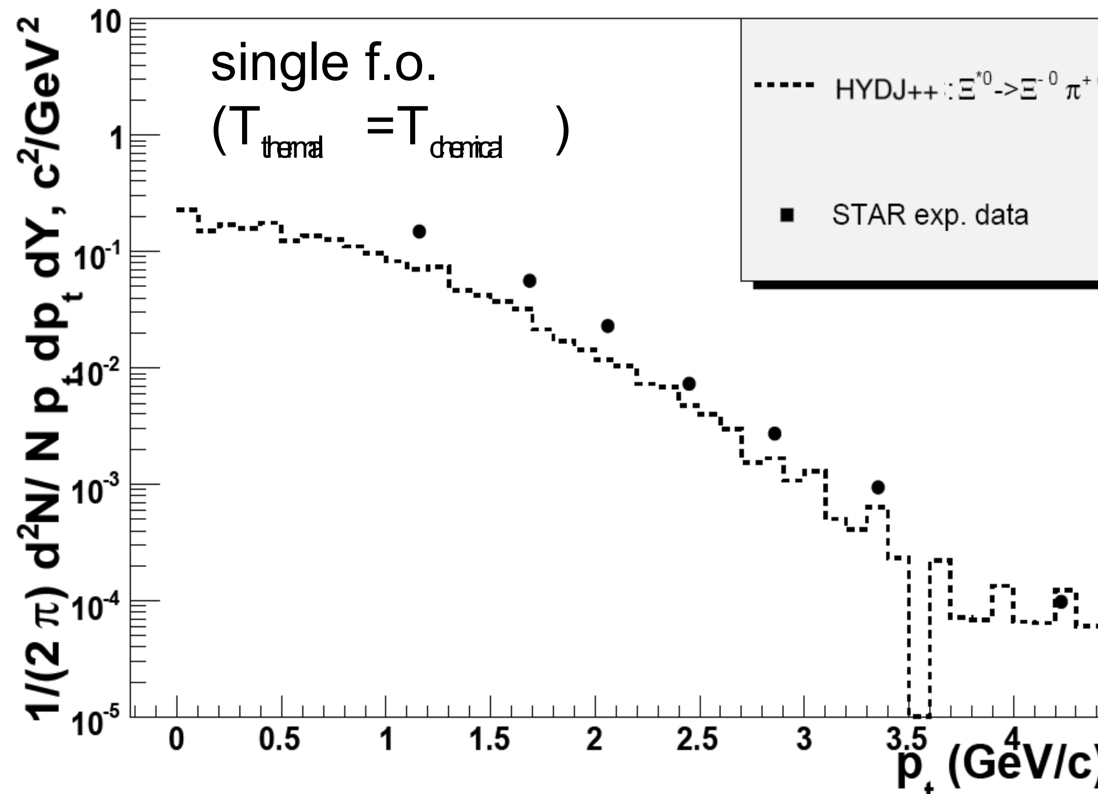
**J. Phys.G34:S921-S924,2007**

- STAR preliminary measurements of Ξ* $p_T$ spectra and Ξ*/Ξ ratio.
- High Ξ*/Ξ ratio compared to statistical model.

# Ξ* Transverse Momentum Spectra




HYDJET++:

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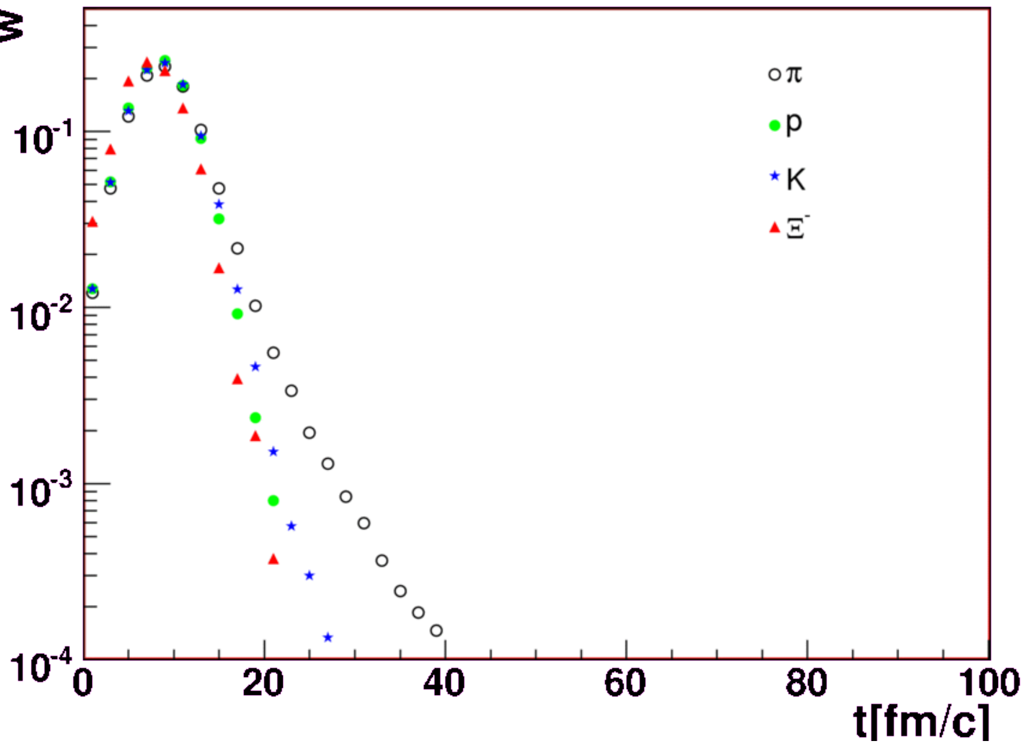
HYDJET++

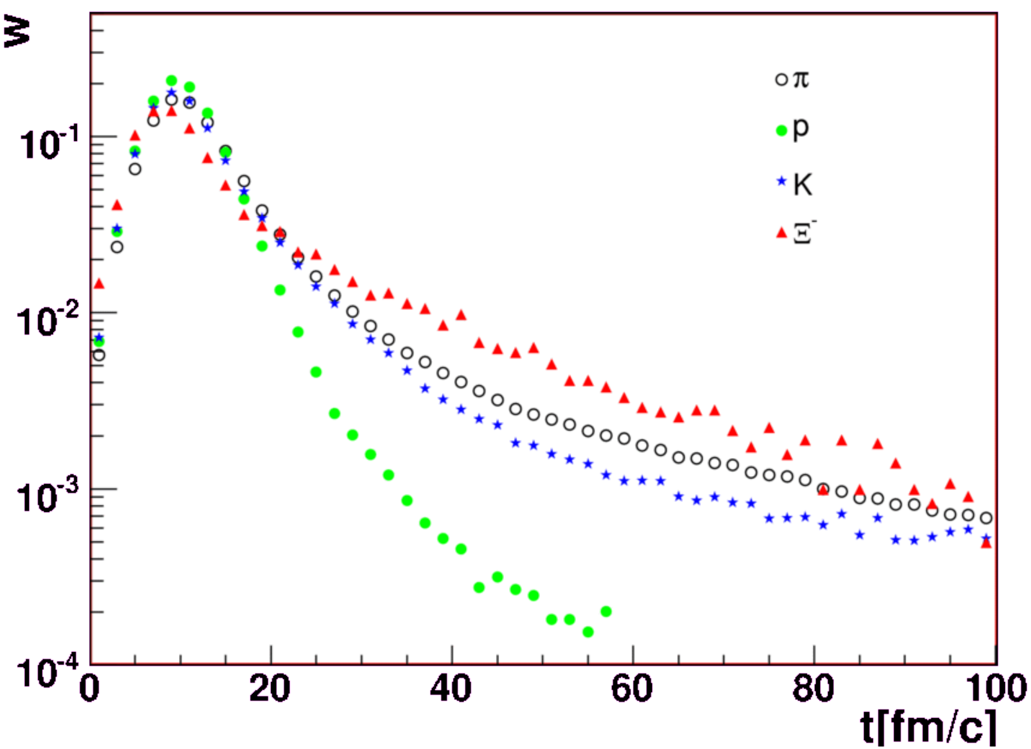
- reproduces shape of spectra with $T_{th}=T_{ch}$
- Underestimates yield
- Study influence of Ξ*/Ξ on the measured asymmetry

# The emission time probabilities for Ξ, π, K, p

for **direct** particles
(emission duration Δτ=2 fm/c)



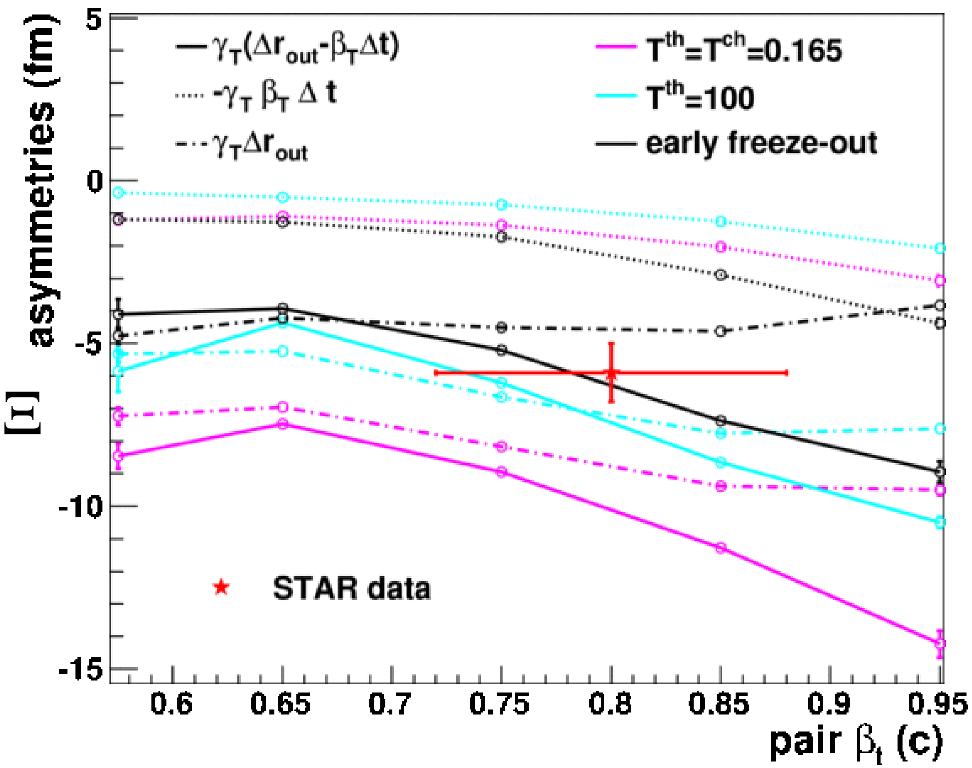

**Including resonance decays**
(emission duration Δτ=2 fm/c)



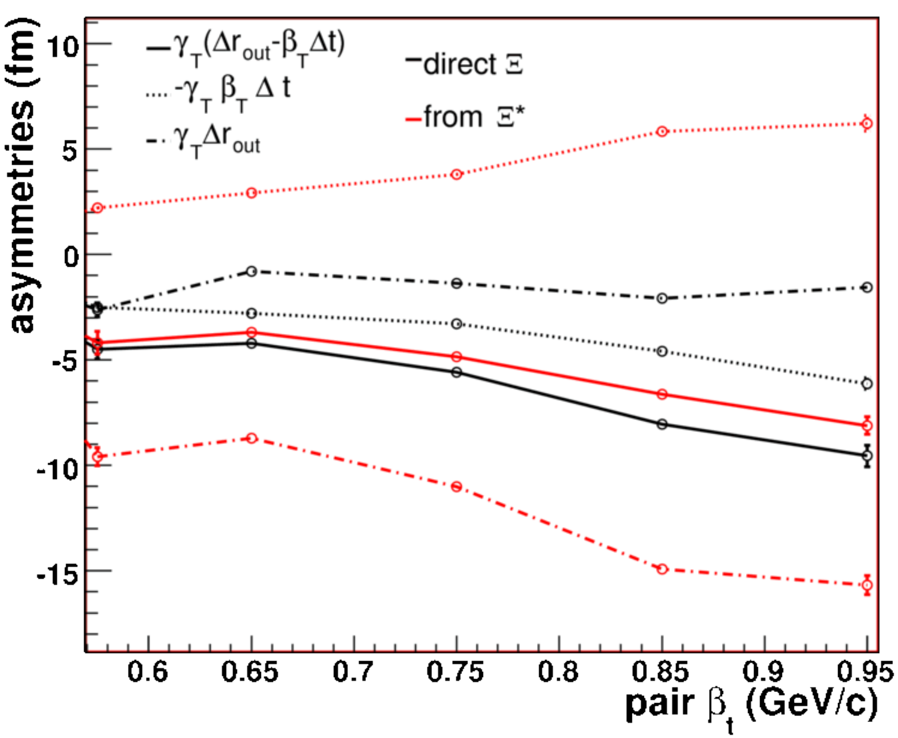

Significant **influence on Ξ**

# π-Ξ emission asymmetry from the model

**"mix" events** – taking pions from separate and Ξ from single temperature freeze-out.




Difference between freeze-out scenarios. Decrease of the emission shift in case of Ξ freezing out at higher $T_{th}$.




Does the shift depend on Ξ*/Ξ ratio?

Small influence of the Ξ*/Ξ ratio on the total R*out shift.

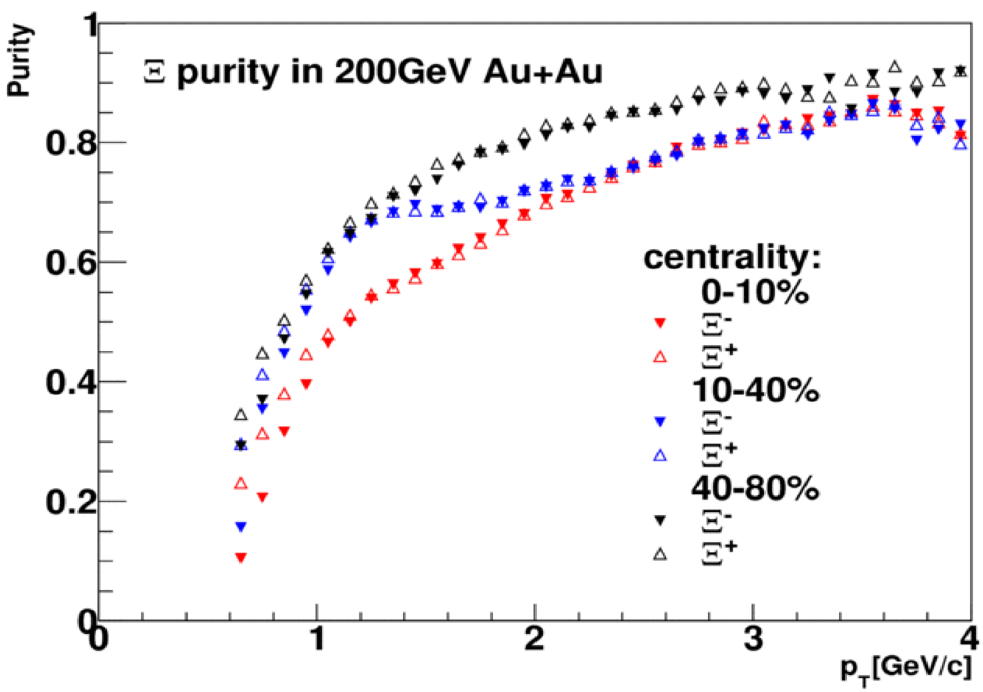
# Conclusions and Outlook

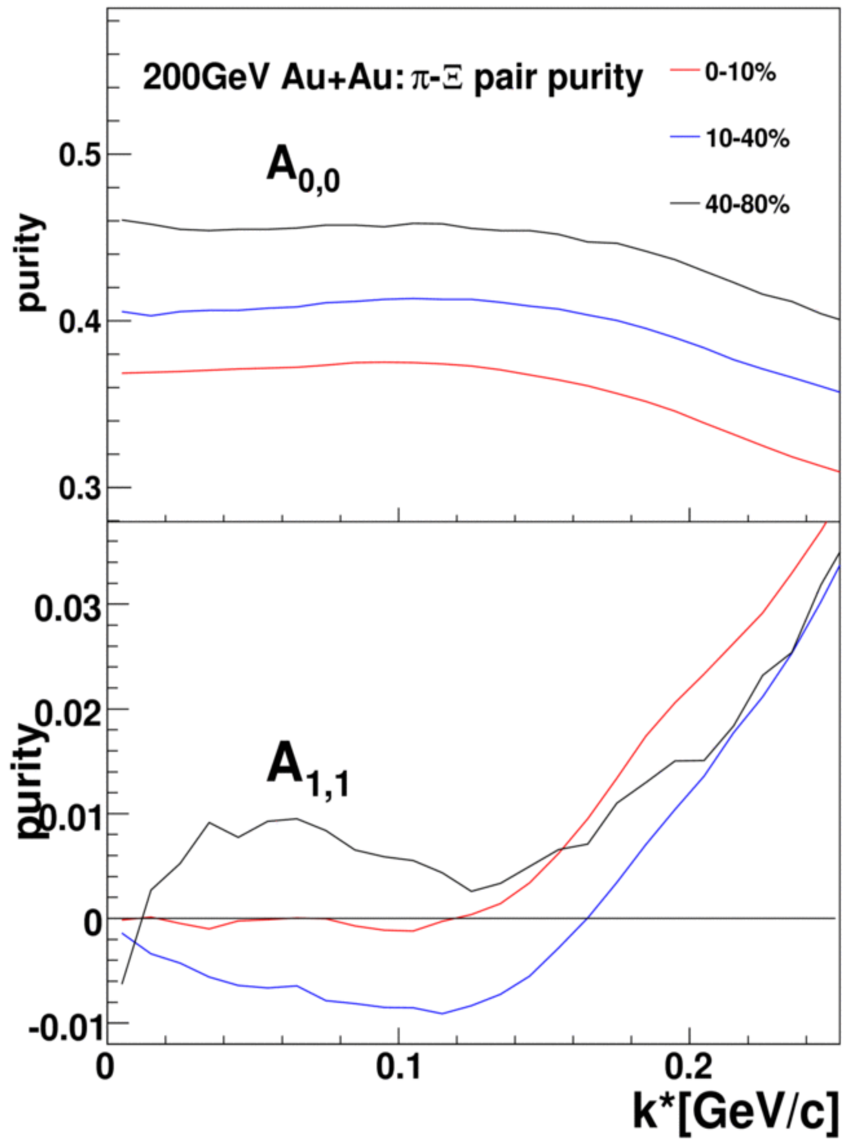
- Extracted source sizes and shifts in the π-Ξ system for three centralities from Coulomb part of the correlation function.
- Results are in agreement with Ξ transverse flow.
- The comparison with HYDJET++ supports previous results suggesting that multistrange baryons decouple earlier – closer to the chemical freeze-out. Higher statistics needed for unambiguous conclusion.
- High statistics data from 2010 run with improved TOF identification on the way.

**END**

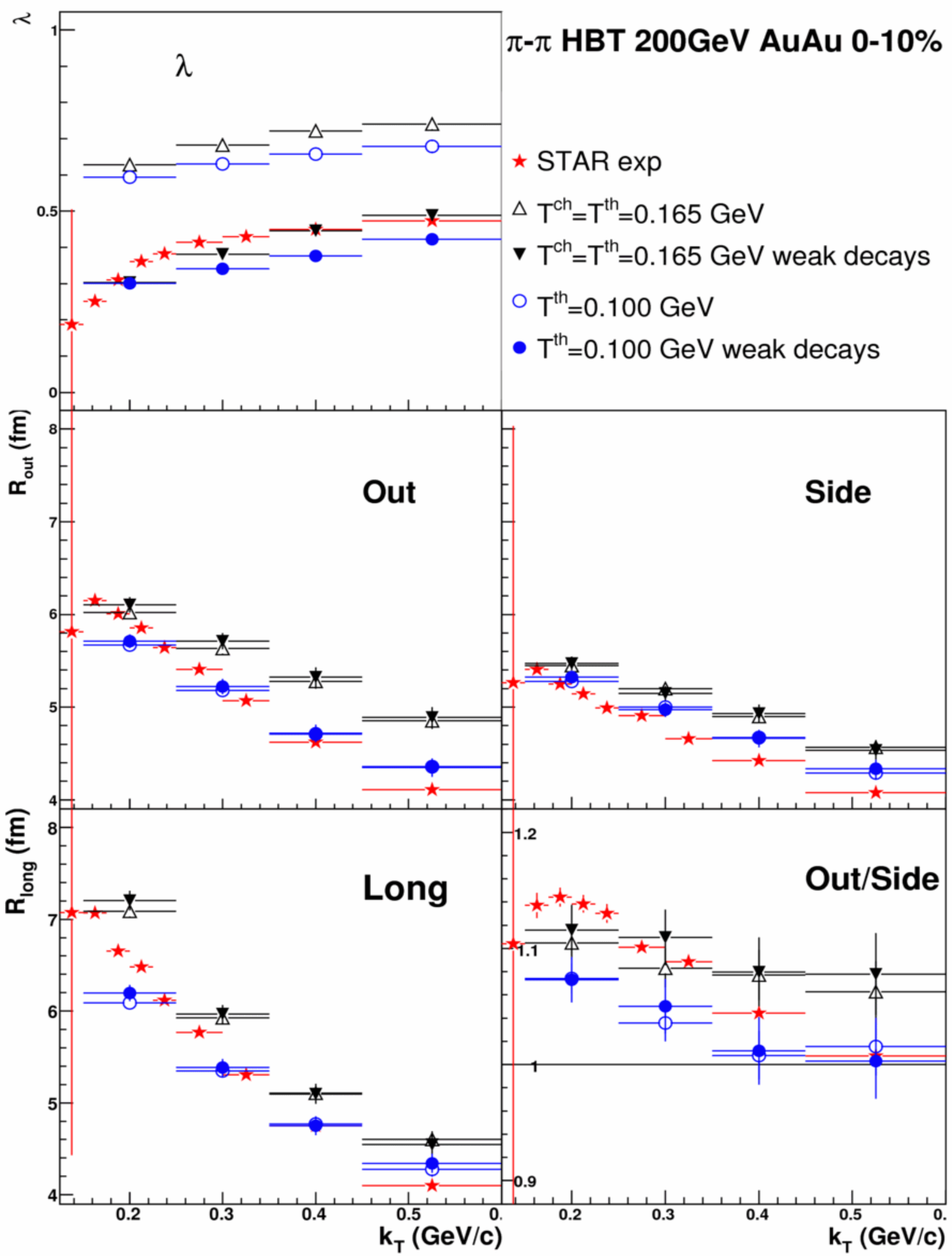
# Note on purity corrections

- CF=la(CF_raw -1)* + 1
- If the purity is independent of k* it can be included in the fit as in pi-pi HBT.
- The purity of pions and Xi are pt dependent => pair puity depends on k*
- CF corrected before fitting



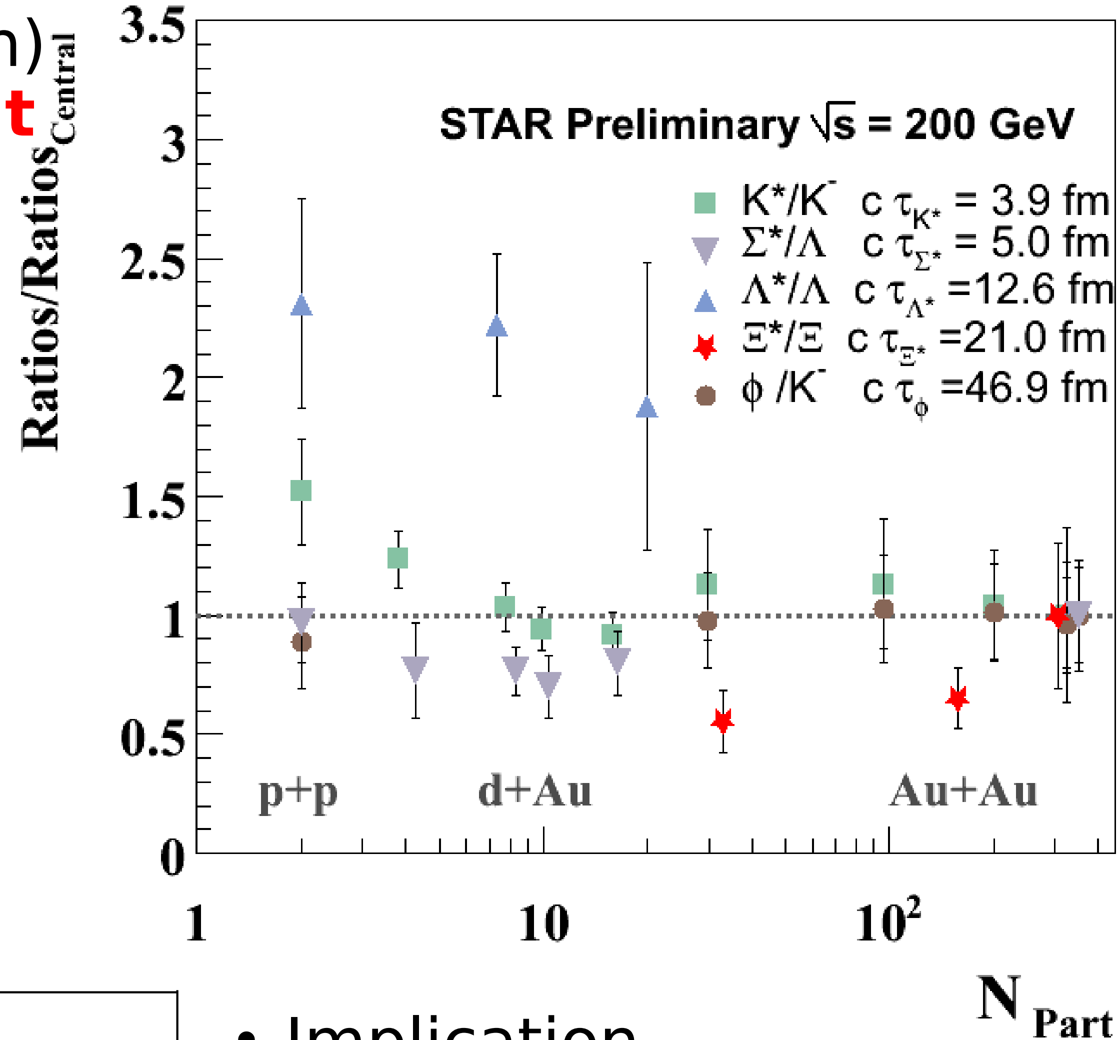
# Pion source size comparison




- Radii extracted by calculating CF and fitting
- π–π HBT radii well described
- With weak decays turned on - lambda is reproduced

# Resonance to Non-Resonance

- Ratios (resonance to non)
  - scaled to **central point**
  - short-lived K* suppressed
    - re-scattering
  - Σ*/Λ level
    - (re-) generation
  - Λ*/ Λ suppressed
    - at creation?
      Y. Kanada-En'yo and B. Muller, nucl-th/0608015
    - L=2 decay?
      M. Kaskalov and E. Oset, PRC 73, (2006)
  - Ξ*/Ξ enhanced

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- Implication
  - significant hadronic scattering
    - density of π bath?
    - large Ξ-π cross-section?

# Comparison to HYDJET++ model

- Matter is thermally equilibrated. Particle multiplicities are determined by the temperature and chemical potentials at chemical freeze-out. Statistical model. .

•"concept of effective volume" T=const and μ=const the total yield of particle species is:

$$N_i = \rho_i(T, \mu_i) V_{eff}$$

$V_{eff}$ , total co-moving volume, ρ-particle number density

- Particles can be generated **on the chemical ($T_{th}=T_{ch}$) or thermal freeze-out** hypersurface represented by a parameterization (or a numerical solution of the relativistic hydrodynamics).
- Various parameterizations of the hadron freeze-out hypersurface and flow velocity

Bjorken-like expansion (Blastwave ) used in our study $\tau = (t^2 - z^2)^{1/2} = const$

linear rapidity profile $\rho_u = \frac{r}{R} \rho_u^{\max}$

- Decays of hadronic resonances
- Fast generation of events

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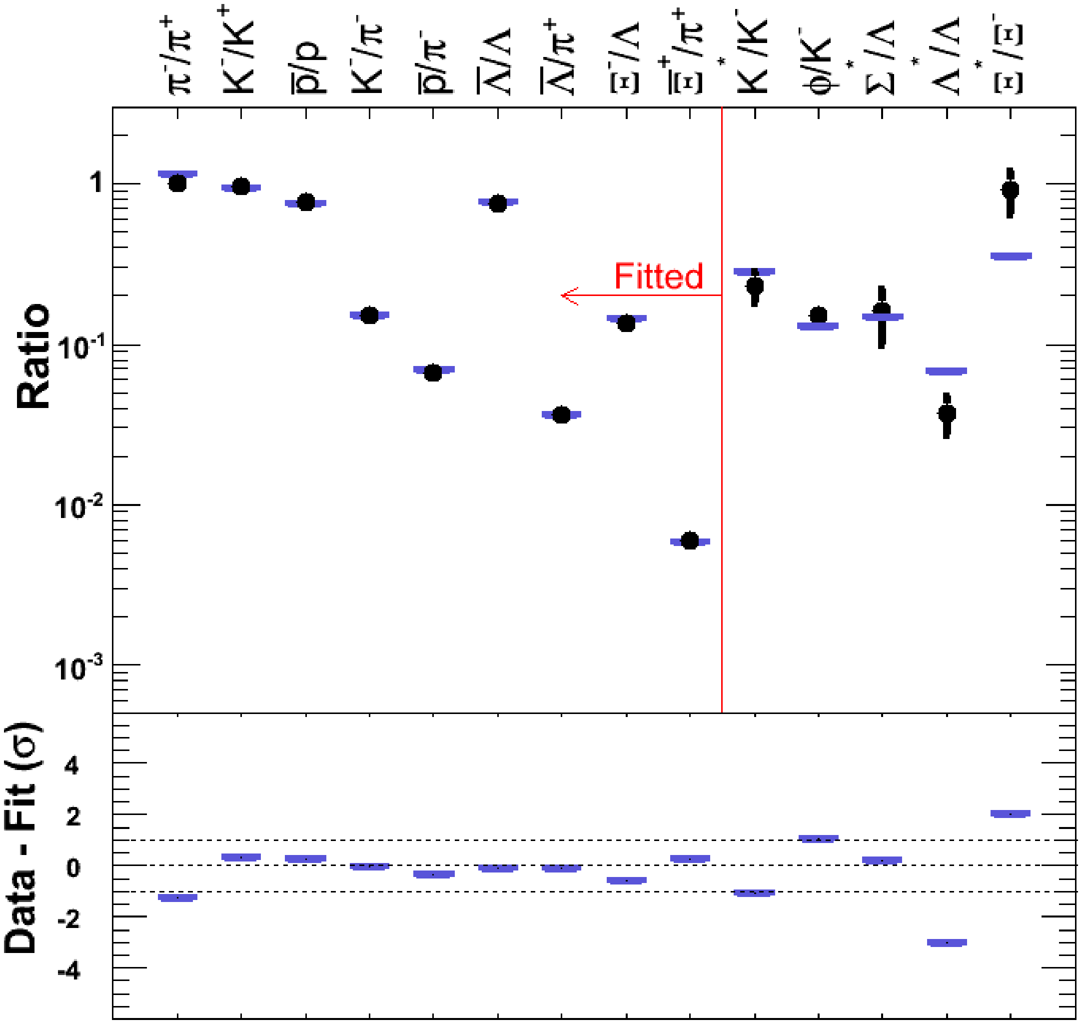
# Thermal Model

- Thermal model (THERMUS)
  - ratios at $\tau_{chem}$
  - enhanced Ξ*/Ξ
  - suggests significant hadronic scattering

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| Parameter | T | $\mu_B$ | $\mu_S$ | $\mu_Q$ | $\gamma_S$ | radius |
|---|---|---|---|---|---|---|
| Value | **0.169 +/- 0.006** | **0.04 +/- 0.01** | **0.016 +/- 0.009** | **-0.01 +/- 0.01** | **0.91 +/- 0.06** | **7.5 +/- 1.0** |

**R. Witt@QM'06 J.Phys.G34:S921-S924,2007**

# FASTMC-Model parameters for central collisions:

**1.** Thermodynamic parameters at chemical freeze-out: $T_{ch}$ , $\{\mu_B, \mu_S, \mu_Q\}$

**2**. If thermal freeze-out is considered: $T_{th}$ , $\mu_\pi$-normalization constant

**3.** As an option, strangeness suppression $\gamma_s < 1$

**4**. Volume parameters:

$\tau$ -the freeze-out proper time and its standard deviation $\Delta\tau$ (emission duration)
**R**- fireball transverse radius

**5.** $\rho_u^{max}$ -maximal transverse flow rapidity for Bjorken-like parametrization

**6.** $\eta_{max}$ -maximal space-time longitudinal rapidity which determines the rapidity interval $[-\eta_{max}, \eta_{max}]$ in the collision center-of-mass system.

7. To account for the violation of the boost invariance, an option corresponding to the substitution of the uniform distribution of the space-time longitudinal rapidity by a Gaussian distribution in $\eta$.

**8**. Option to calculate $T$, $\mu_B$ using phenomenological parameterizations $\mu_B(\sqrt{s}), T(\mu_B)$