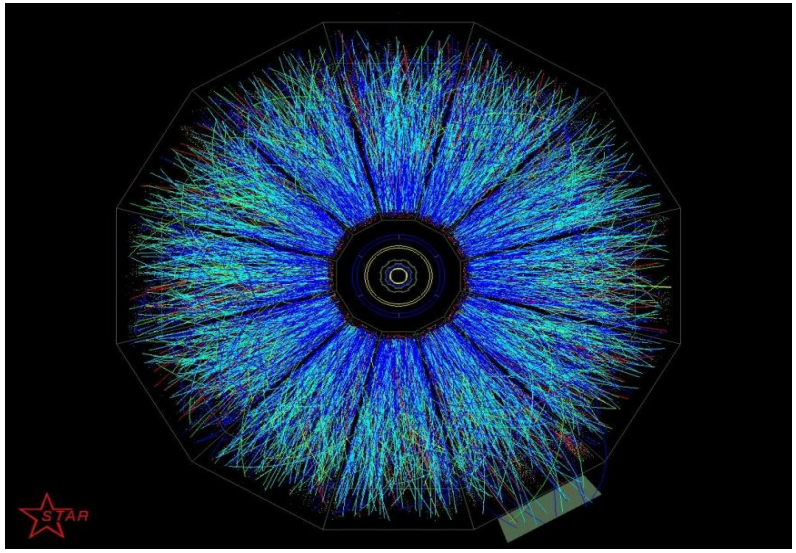
Study of Λ-Λ correlations with the STAR detector at RHIC

Neha Shah

For the STAR collaboration

University of California Los Angeles



Outline

- **Introduction**
- **Results and discussions**
  - **Correlation Function for ΛΛ**
  - **Λpπ mass spectrum**
- **Summary & outlook**

Introduction

- **Heavy Ion Collisions: unique place**
  - **Hadronic physics involving short-lived particles**
  - **Search of exotic particles with multiple strangeness**
- **RHIC: high rate of strange particle production**
- **Hyperon-hyperon interactions :**
  - **Determination of ΛΛ, ΛΞ interactions**
  - **Also possible to study ΛΩ, ΞΞ, ΞΩ, ΩΩ interactions, which are difficult to study @ kaon beam facilities**
- **Exotic di-hyperons:**
  - **H-dibaryon* (uuddss, S= -2) really exist?**
  - **Do we have more six quark states with higher strangeness?**
    - ✓ **like ΞΞ (S= -4), ΩΩ (S = -6)!**

***Jaffe, Phys. Rev. Lett. 38 (1977) 195**

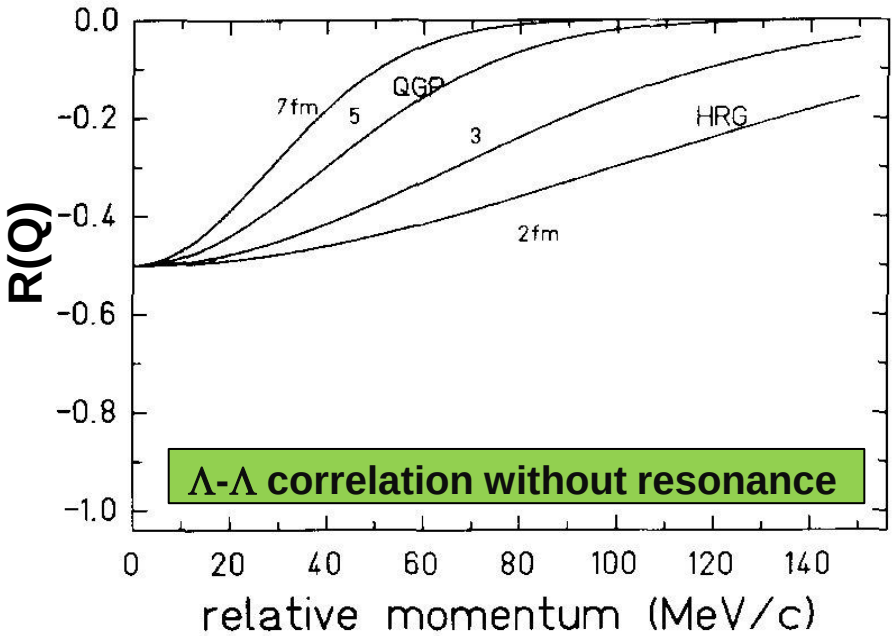
Introduction

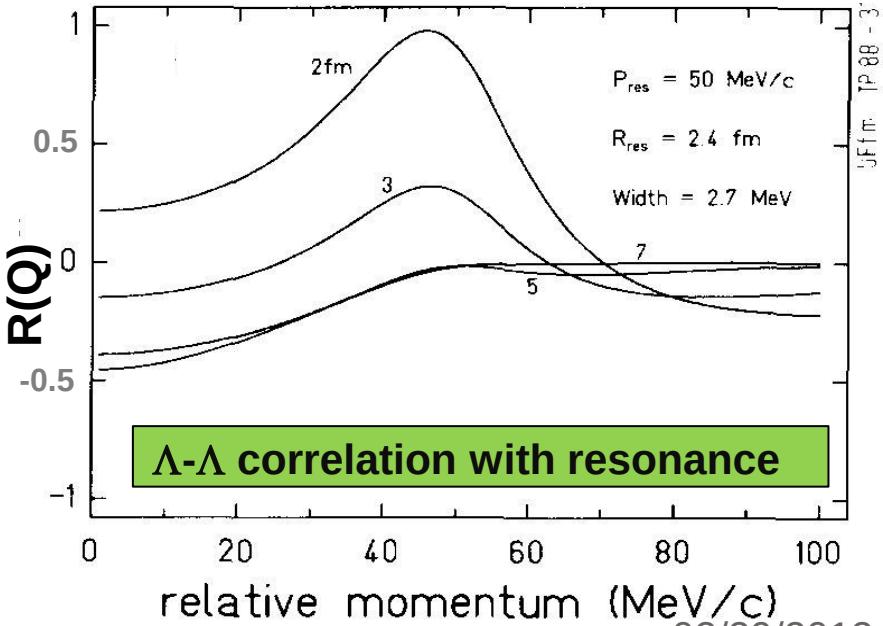
- **Measurement of ΛΛ correlation functions:**
  - **Related to the size r_0 of the emitting region**
  - **no Coulomb interactions**
  - **The two particle Correlation Function** (Greiner and Muller, Phys. Lett. B 219 (1989) 199)

$$R(Q) = \lambda * \exp(-Q^2 r^2)$$

Where Q is relative momentum between two particles and λ is degree of incoherence of the source

- **Depletion of phase space due to bound state formation of H ⇒ inclusive measurement, sensitive to total yield**



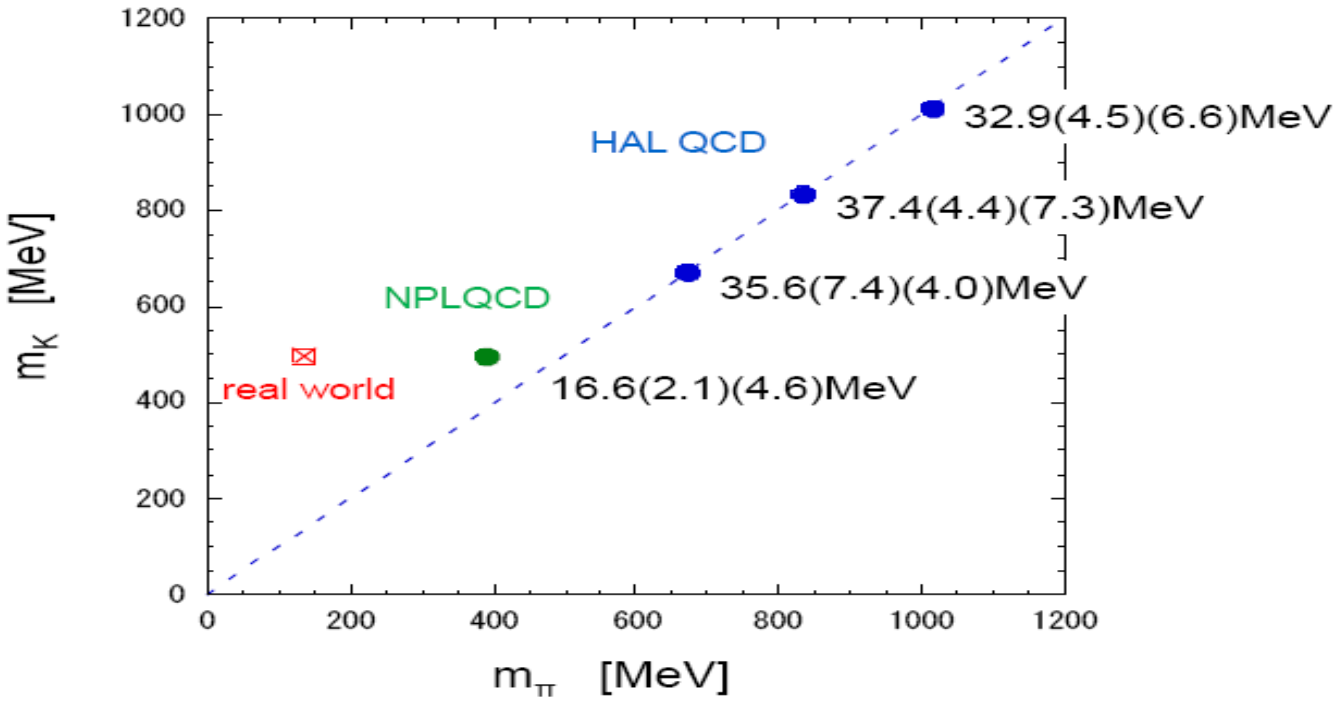


H dibaryon

- Properties : $J^{\pi} = 0^{+}$, mass : (1.9-2.8) GeV/c^2

$$\psi(\mathbf{H}) = \sqrt{\frac{1}{8}}\psi(\Lambda\Lambda) + \sqrt{\frac{4}{8}}\psi(\mathcal{N}\Xi) - \sqrt{\frac{3}{8}}\psi(\Sigma\Sigma)$$

- Lattice QCD (HAL QCD Collab.,Phys. Rev. Lett. 106 (2011) 162002 & NPLQCD Collab., Phys. Rev. Lett. 106 (2011) 162001) predicts bound H at large pion mass



H dibaryon

- **RHIC and LHC are the best place to look for H dibaryon**
- **Depending on the mass we have different decay modes of H:**

Channel	Threshold mass (GeV/c2)	ΔS
ΛΛ	2.231	0
Λpπ	2.192	1
NNππ	2.152	2

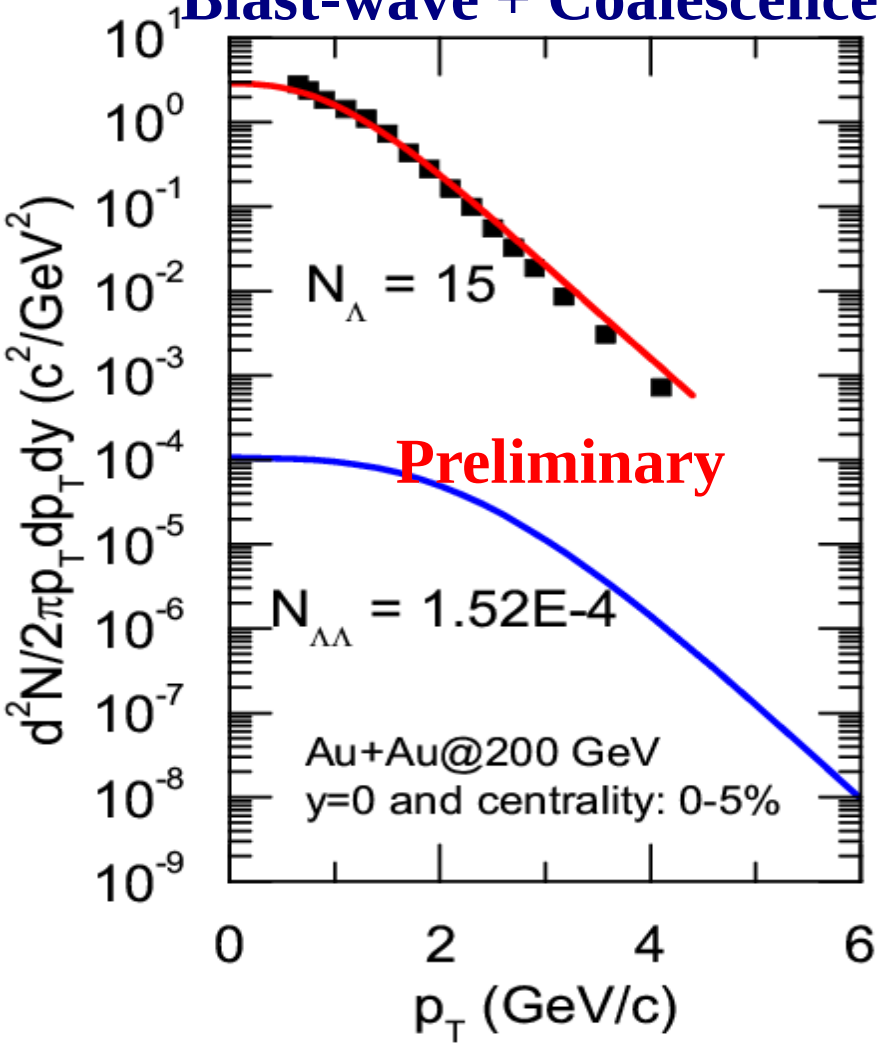
Phys. Rev. C 40 (1989) 115

Possible to look with STAR

- **What about production rates?**

H-dibaryon production

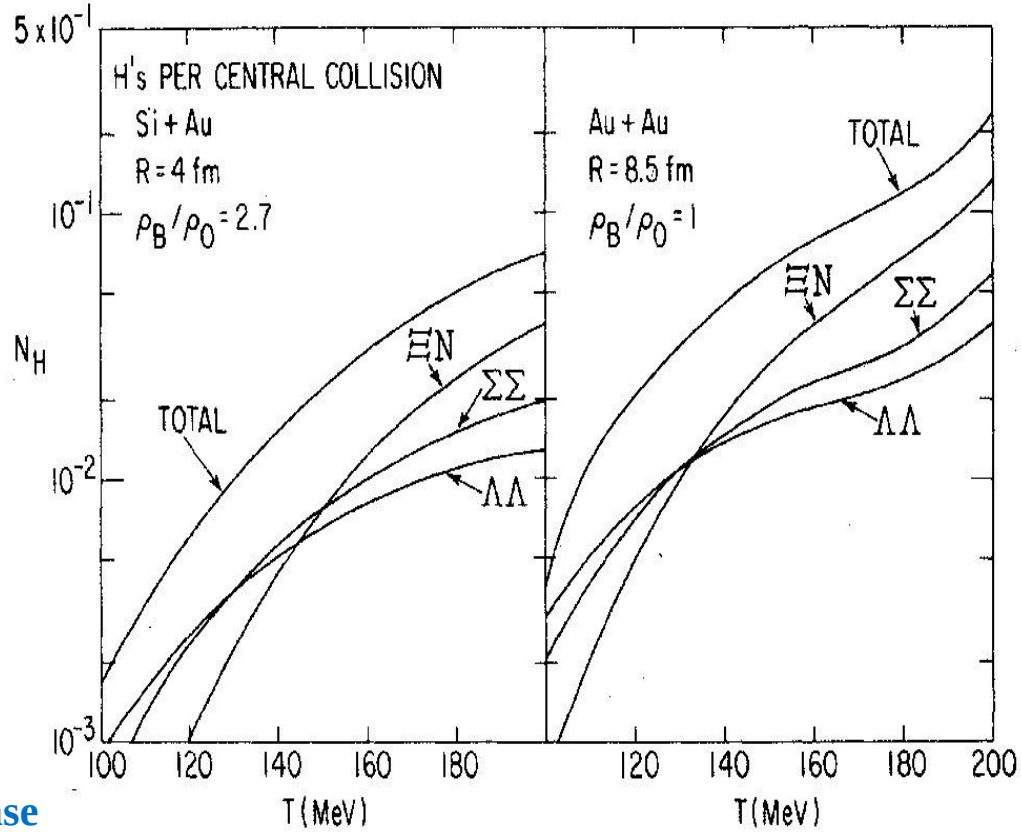
Blast-wave + Coalescence*



*Lie-Wen Chen, 9th Workshop on QCD phase transitions and relativistic heavy ion collisions, China July 18-20 , 2011

- **Predicted production rate: 10^{-3}-10^{-4}**

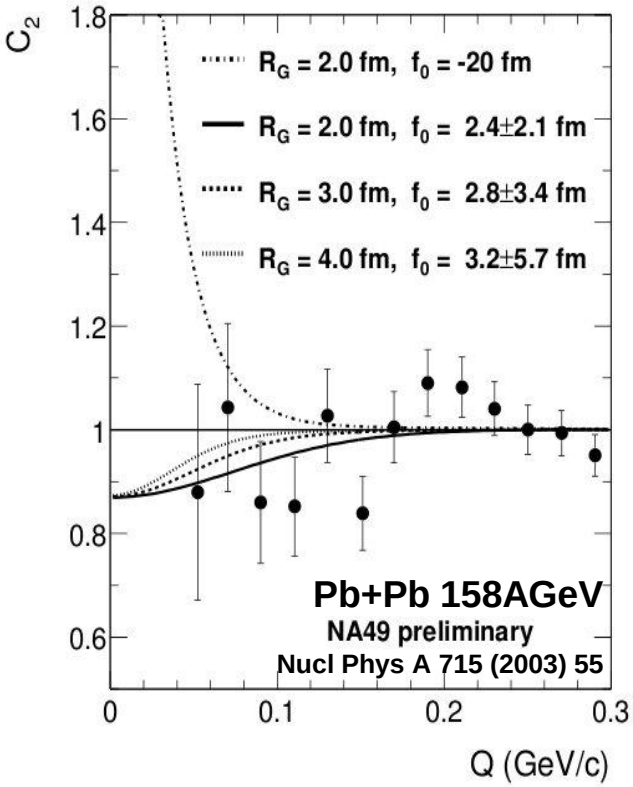
Coalescence Model



Dover, Koch and May, Phys. Rev. C 40 (1989) 115

Previous measurements

ΛΛ correlations



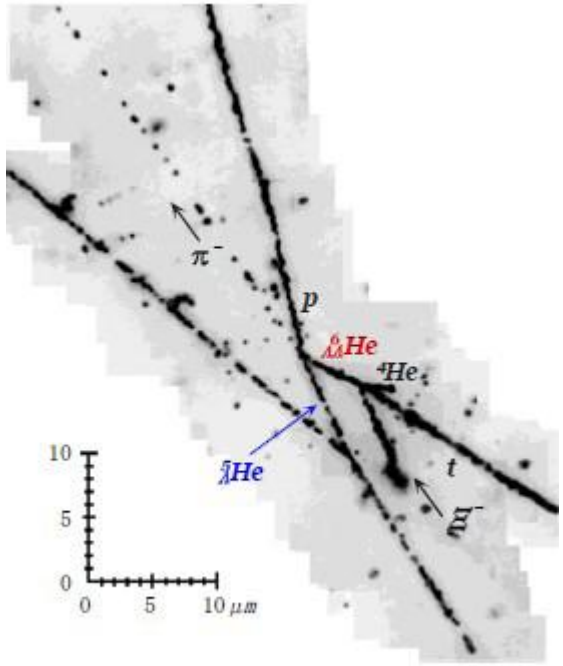
- Nagara Event (KEK-E373 experiment) : $_{\Lambda\Lambda}{}^{6}$He hypernuclei

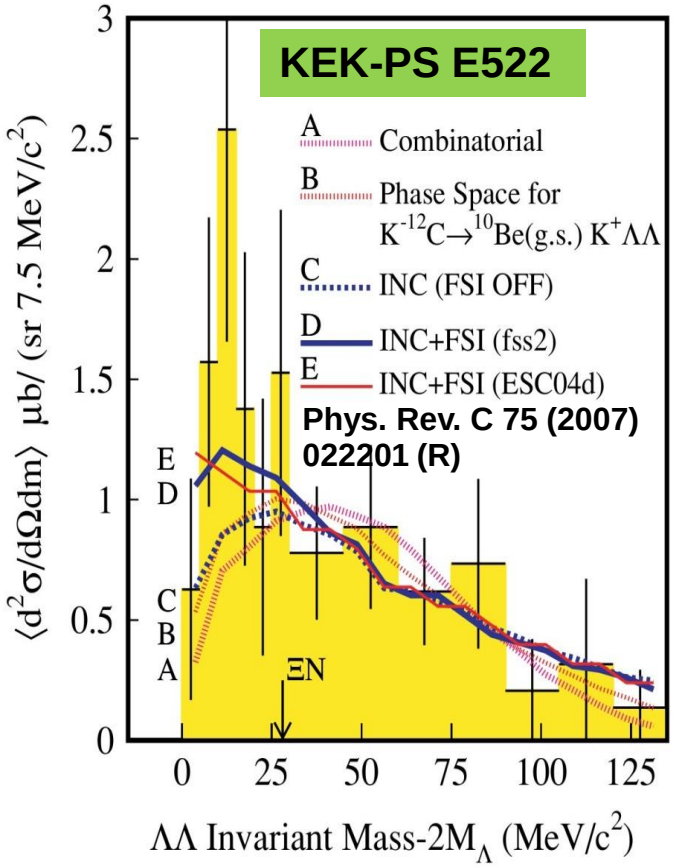
Phys. Rev. Lett. 87(2001)212502

$$\Xi^- + {}^{12}C \rightarrow {}^{6}_{\Lambda\Lambda}He + {}^{4}He + t$$
$${}^{6}_{\Lambda\Lambda}He \rightarrow {}^{5}_{\Lambda}He + p + \pi^-$$

⬇

No deeply bound H





Scattering length

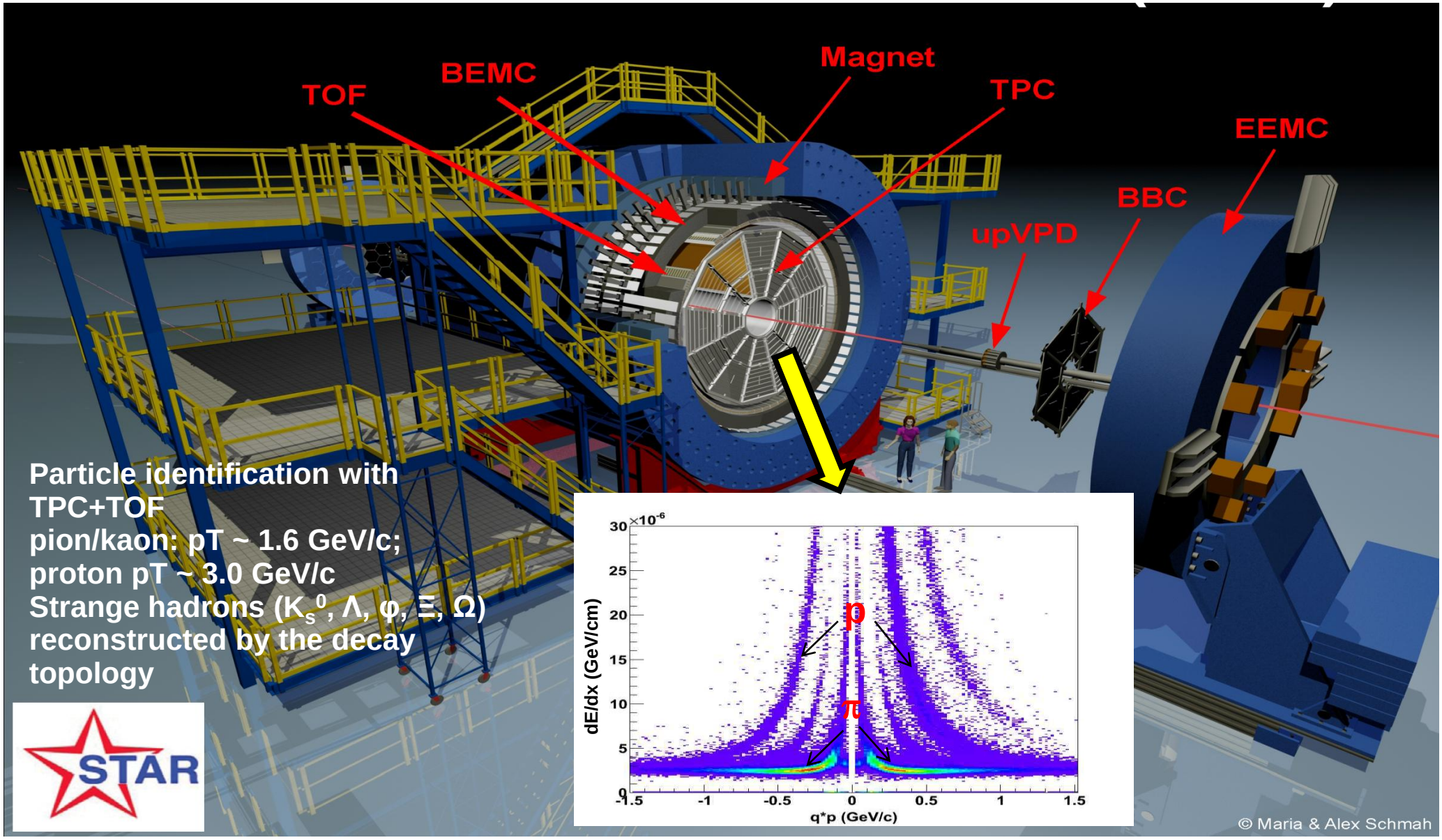
$a_{\Lambda\Lambda} = -0.10^{+0.45}_{-2.35} \pm 0.04$ fm

Int J Mod Phy E 19 (2010) 2448

⬇

Resonance or bound H

STAR detector



Particle identification with TPC+TOF
pion/kaon: pT ~ 1.6 GeV/c;
proton pT ~ 3.0 GeV/c
Strange hadrons (K_s^0, Λ, φ, Ξ, Ω) reconstructed by the decay topology

Current data volume from STAR

- **STAR Run 2010 Au+Au @ 200 GeV data set**

~ 275 Million Minimum Bias Events
~ 100 Million Central Collision Events

- **Au+Au @ 62.4 GeV data set**

~ 67 Million Minimum Bias Events
~ 30 Million Central Events

- **Au+Au@39 GeV data set**

~ 130 Million Minimum Bias Events

Λ reconstruction

$\Lambda \rightarrow p\pi$ (M = 1.1156 GeV/c^2)

Branching ratio = 63%

Mean Life time: $\tau = 2.63\times10^{-10}$ s

$c\tau = 7.89$ cm

DCA Λ to Primary Vertex < 0.4 cm

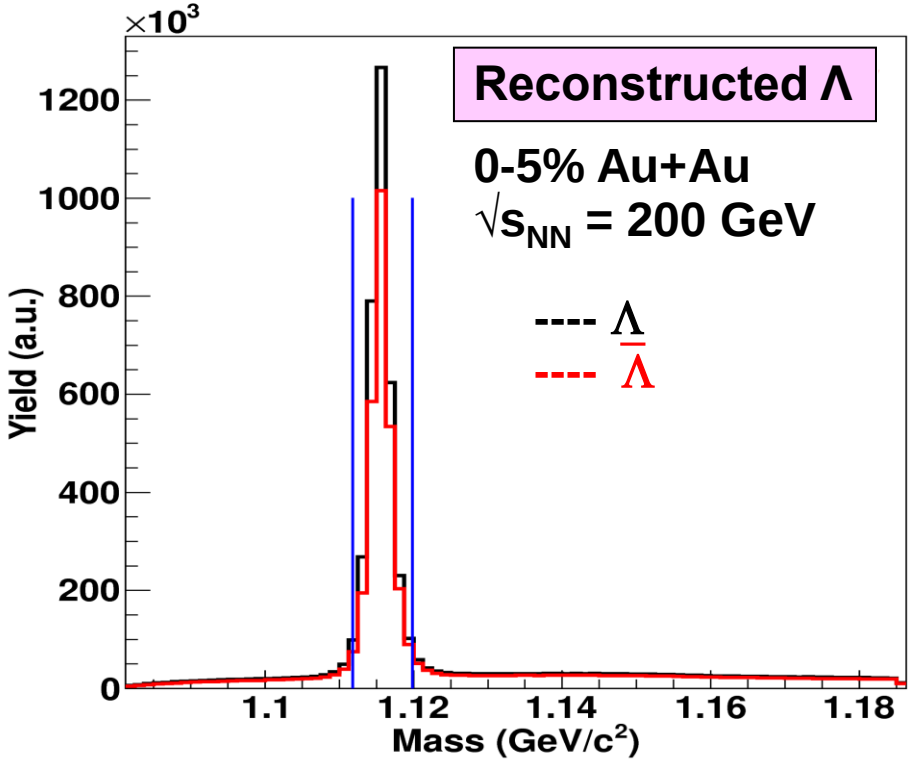
DCA p to Primary Vertex > 0.6 cm

DCA π to Primary Vertex > 1.5 cm

$|M_\Lambda - M_{PDG}| < 0.004$ GeV/c^2

DCA p to π < 0.8 cm

* DCA → Distance of Closest Approach



Correlation Functions

Correlation Function (CF):

$$CF_{measured}(Q) = \frac{A(Q)}{B(Q)}$$

A(Q) – real pair, B(Q) – pair from mixed event and Q – relative momentum between two particles

Purity correction:

$$CF_{corrected}(Q) = \frac{CF_{measured}(Q) - 1}{PP(Q)} + 1$$

Pair Purity PP(Q):

$$PP(Q) = \frac{S}{S+B}(p_{Ti}) \times \frac{S}{S+B}(p_{Tj})$$

93-95%

S – signal , B – background and p_T – transverse momentum

Correlation Functions

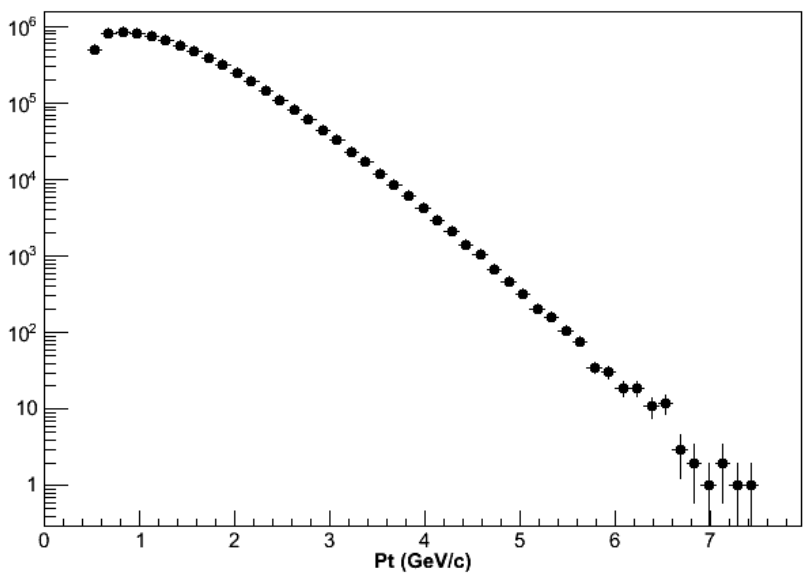
Correction for momentum smearing :

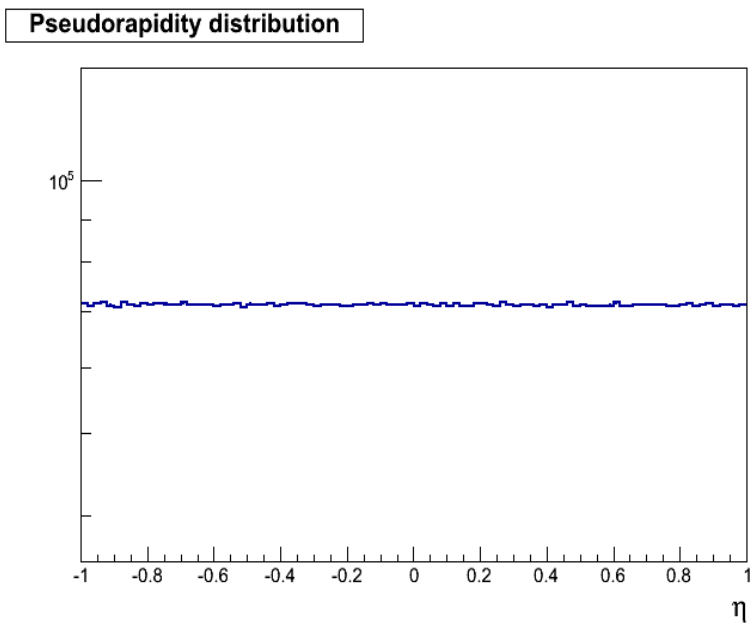
$$CF'(Q) = CF(Q)\frac{CF_{nosmearing}}{CF_{smearing}}$$

- **Smearing in momentum ($\sigma(\Delta p/p)$), θ ($\sigma(\Delta\theta)$) and ϕ ($\sigma(\Delta\phi)$) are obtained from embedding Monte Carlo (MC) tracks in real event**
- **Momentum of mixed event pairs are modified to get $CF_{smearing}$**
- **Effect of momentum smearing is found to be around 1-2 %**

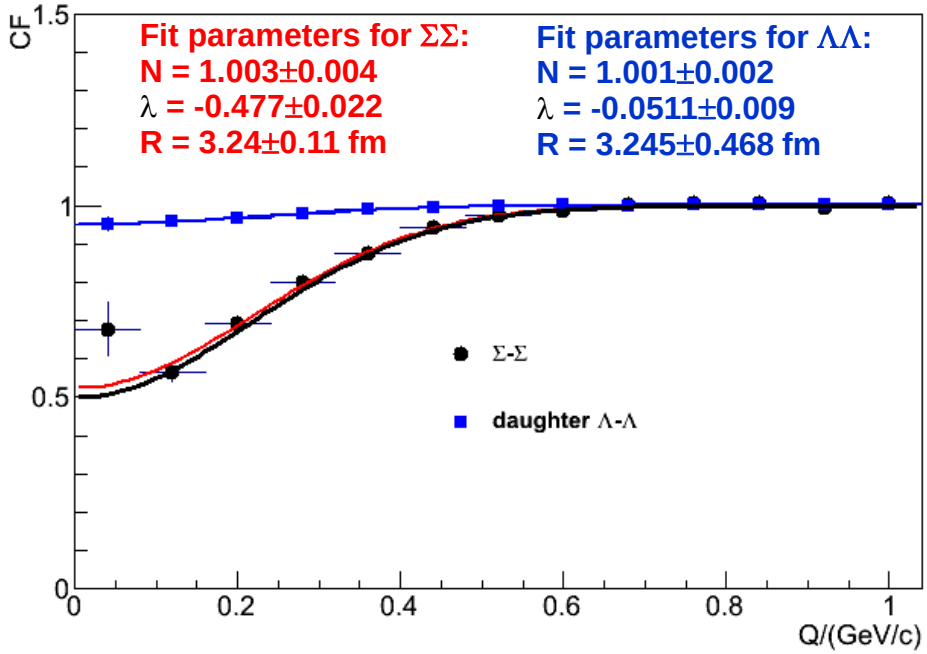
Feed down contribution

- Spectra generated using Boltzmann fit at midrapidity (T = 335 MeV)
- For each pair, we assign a weight according to HBT correlation function $(1-0.5^* \exp(-Q^2R^2))$, where $R = 3.83/\sqrt{m_t}$
- Now let the pair decay and calculate Q for both parent pair and decay pair
- The correlation function is plotted by the mixed event technique



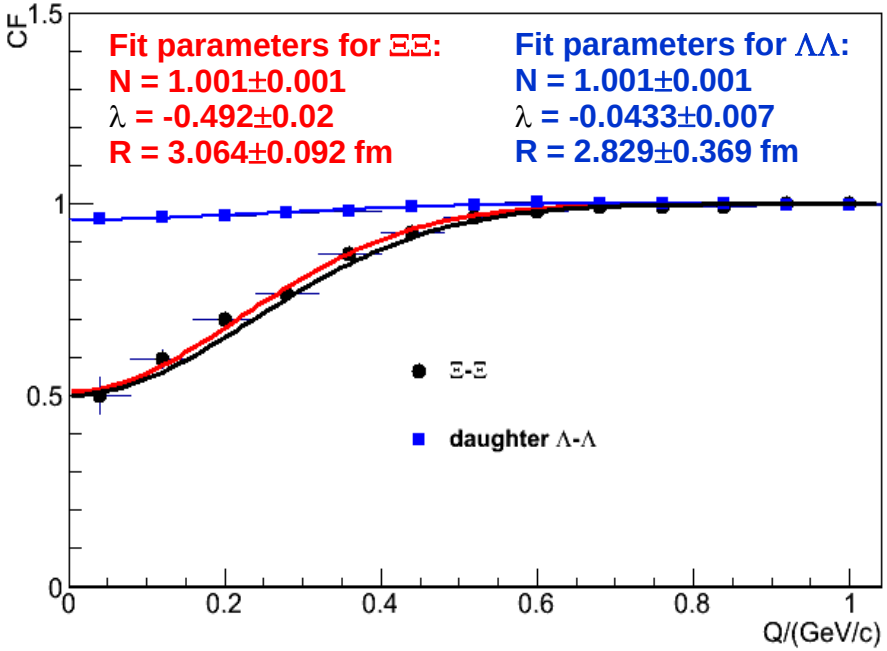


Feed down contribution



- Fit function:

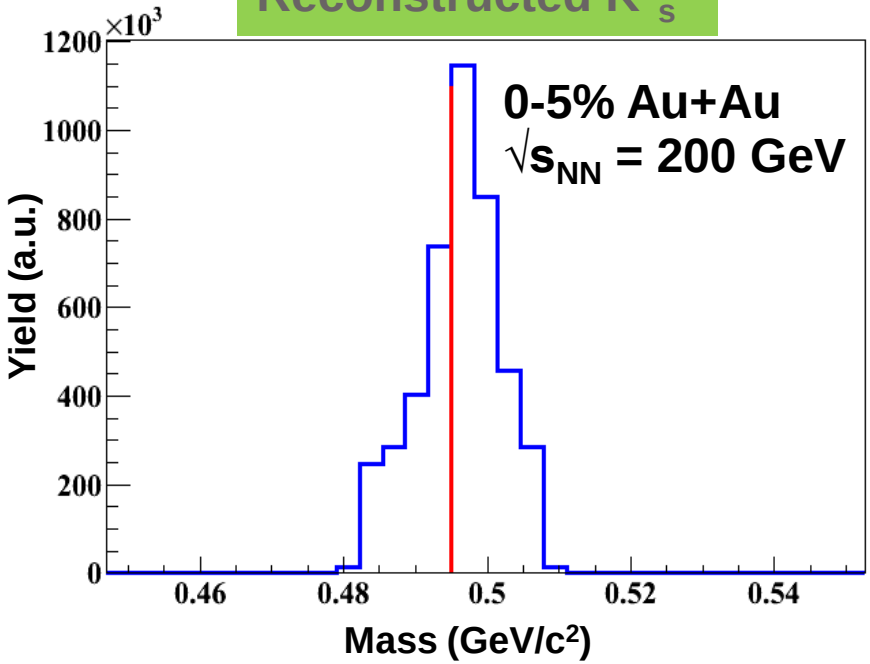
$$CF = N(1+\lambda \exp(-Q^2R^2))$$



Feed down contribution from ΣΣ and ΞΞ is expected to be negligible

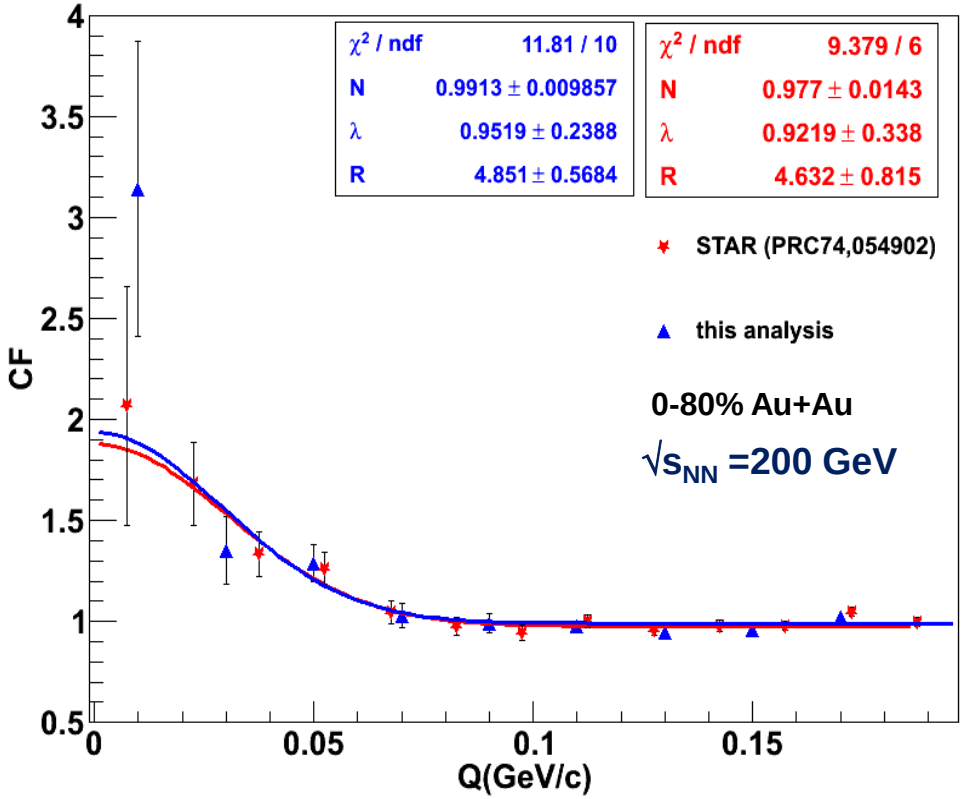
$K^0_s K^0_s$ Correlation Functions

Reconstructed K^0_s



- A quick check on code sanity with previous published STAR measurement of $K^0_s K^0_s$ Correlation Functions

Phys. Rev C 74 (2006) 054902



- Fit function:

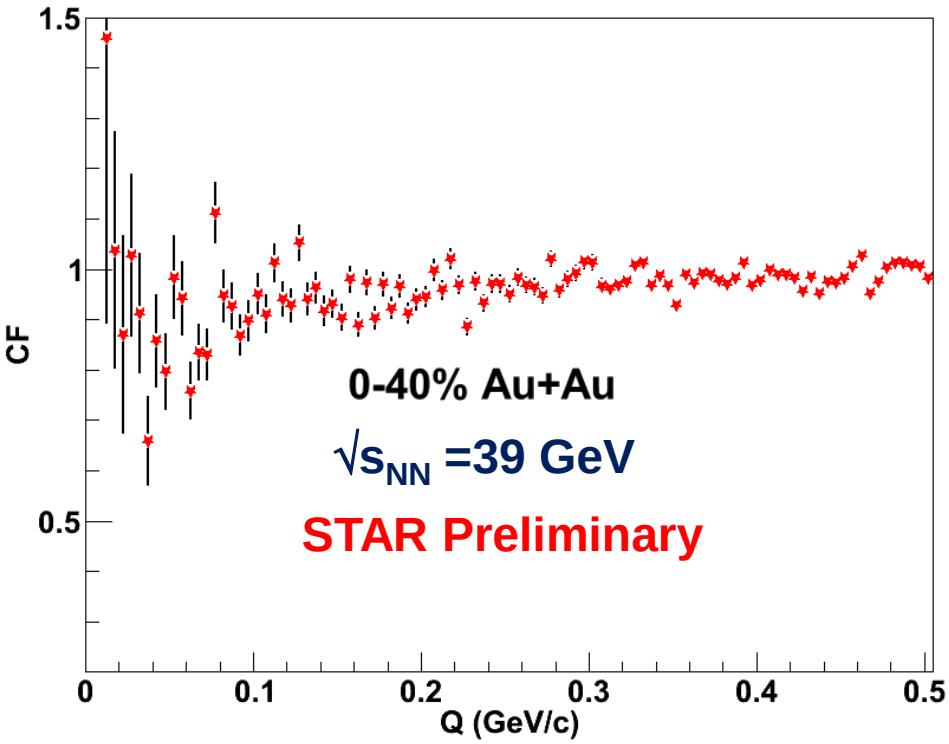
$$CF = N(1 + \lambda \exp(-Q^2 R^2))$$

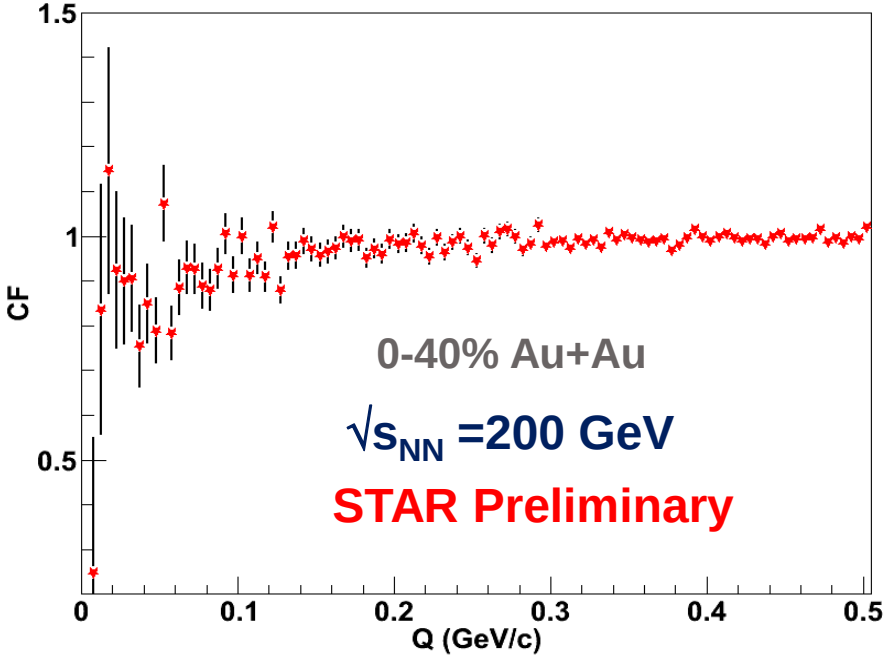
N – normalization, R – size parameter and λ – correlation strength

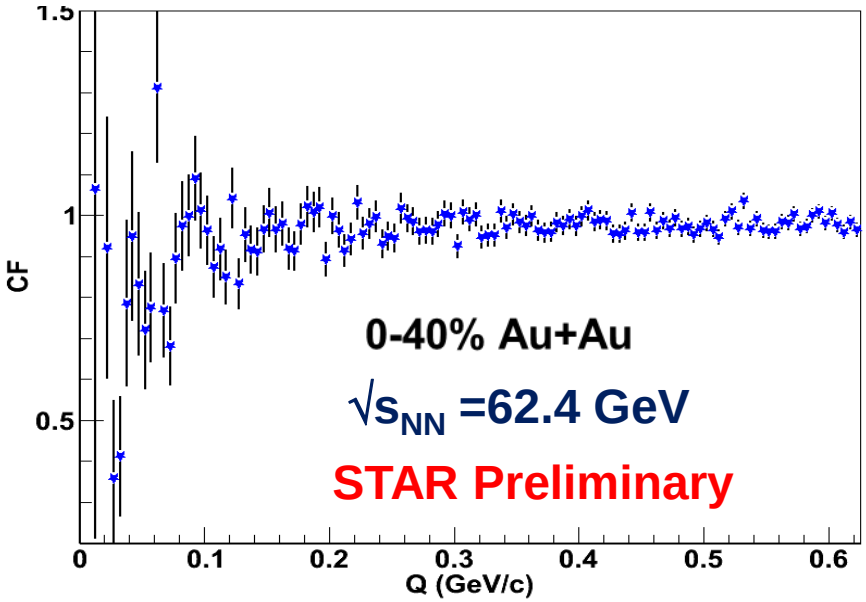
- Fitting parameters are consistent with the published result within statistical errors

$\Lambda\Lambda$ analysis

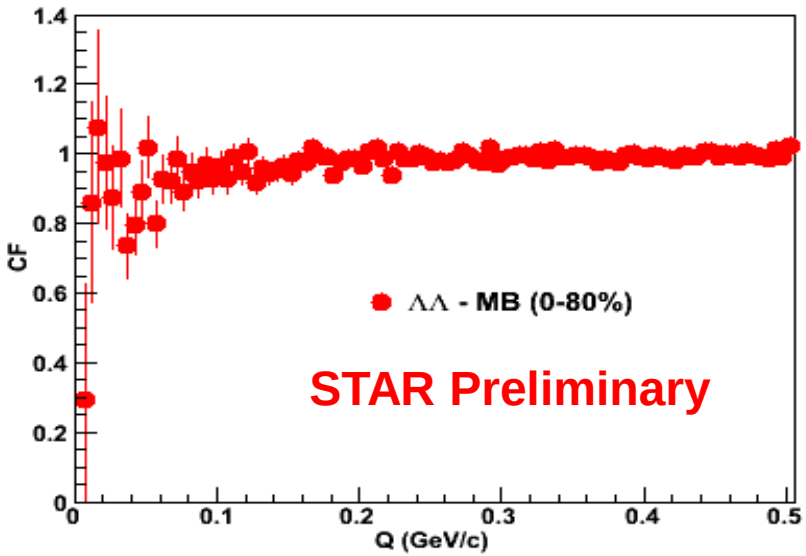
- Purity corrected correlation functions for 0-40 % Au+Au collisions at $\sqrt{s_{NN}}$ = 39, 62.4 and 200 GeV
- Statistical error only



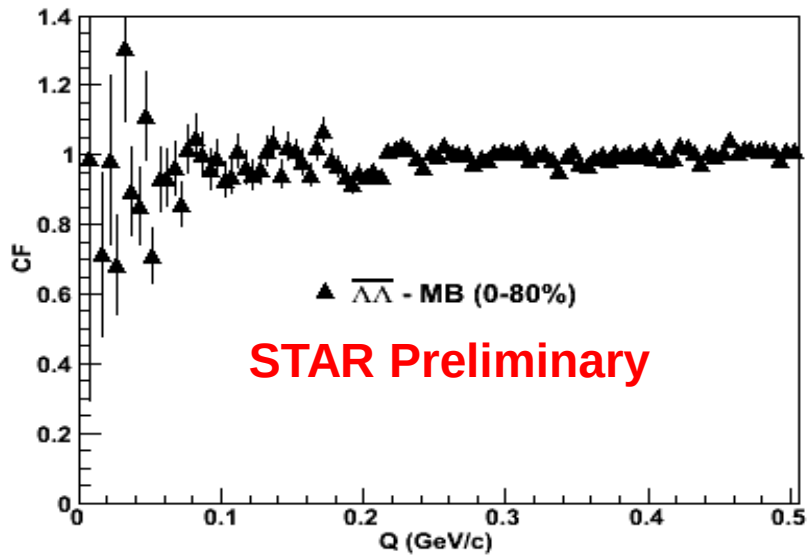


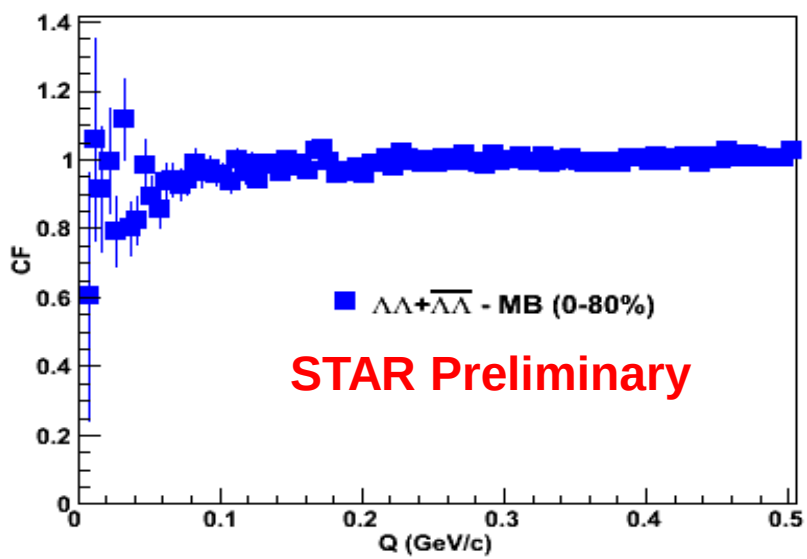


ΛΛ analysis

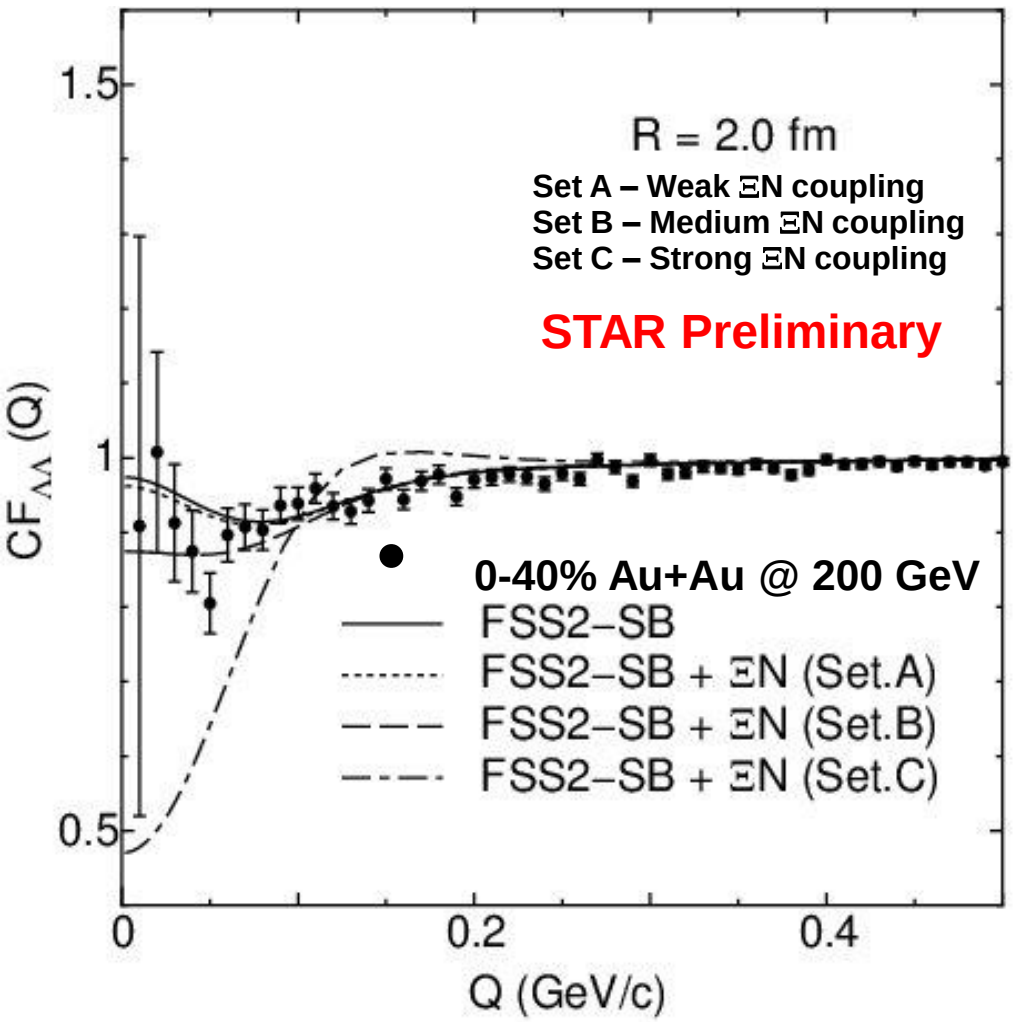


- Purity corrected correlation functions for 0-80% Au+Au collisions $\sqrt{s_{NN}}$ =200 GeV
- Statistical error only





ΛΛ analysis



- The coupling effects with Ξ-N channel in FSS2 interaction (Y. Fujiwara et al., Phys. Rev. C64 (2001) 054001) (Talk by A. Ohnishi)

- Calculation roughly explains data, in no coupling case (ΛΛ single channel), and with small coupling to Ξ-N channel (Sets A and B).

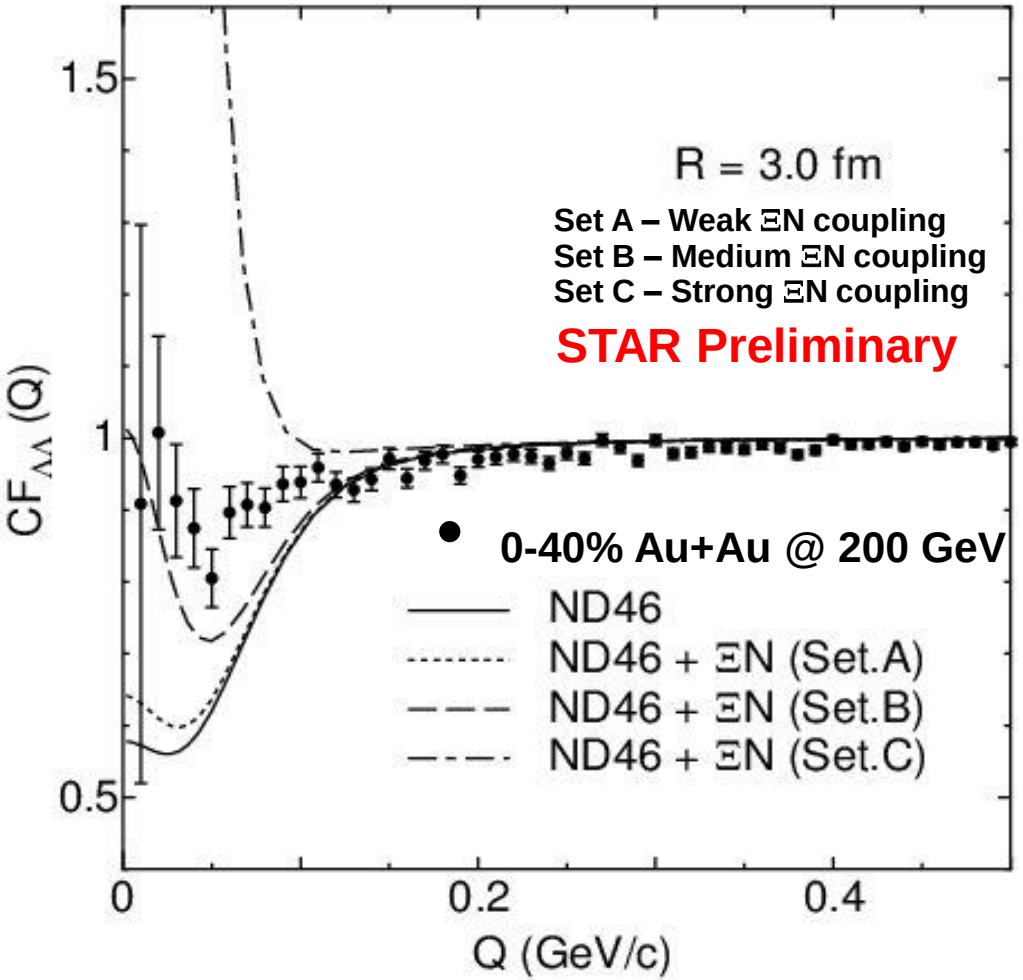
- Consistent with Nagara event (Double-Λ hyper nuclei, $_{\Lambda\Lambda}{}^{6}$He (*Takahashi et.al., Phys. Rev. Lett. 87 (2001) 212502*))

Model Fit →A. Ohnishi and T. Furumoto (WPCF 2011, Japan)

ΛΛ analysis

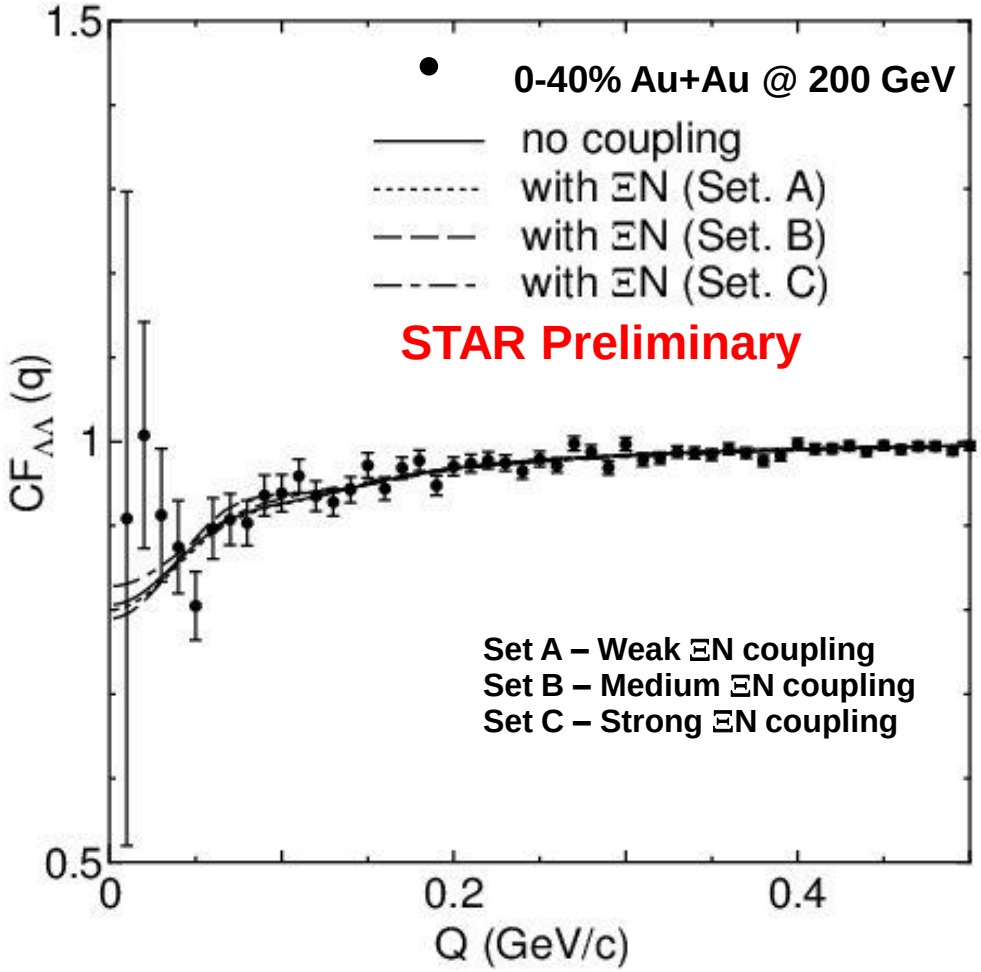
The possibility of bound H:

- **Nijmegen model D (hard core radius = 0.46 fm), which predicts a bound H state.**
- **With no or small coupling to Ξ-N, the suppression of the correlation is strong. (A. Ohnishi et al., Nucl. Phys. A 670 (2000))**
- **However can't exclude the combination ND46+medium Ξ-N coupling (Set B)**



Model Fit →A. Ohnishi and T. Furumoto (WPCF 2011, Japan)

ΛΛ analysis



- The scattering length (a_0) and the effective range (r_{eff}) with no, weak, medium, and strong coupling to Ξ-N :

	a_0 (fm)	r_{eff} (fm)
No coupling	-2.42	-6.36
weak (Set.A)	-2.47	-6.65
medium (Set.B)	-2.98	-13.53
strong (Set.C)	-2.27	-2.61

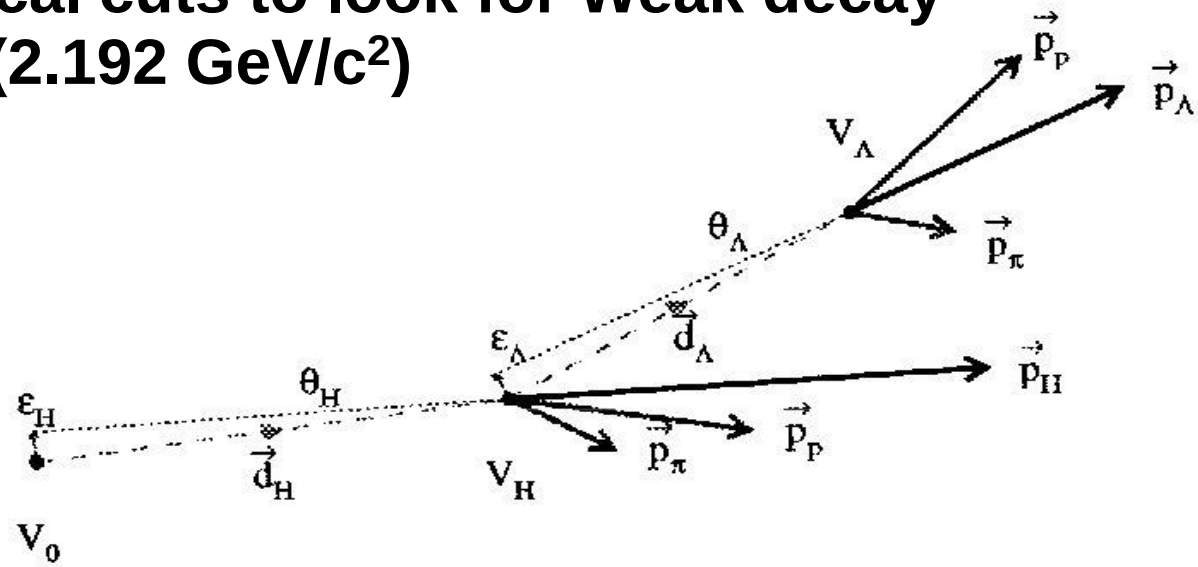
- Current fit gives indication towards non-existence of strong bound state of ΛΛ

Fit →A. Ohnishi and T. Furumoto

$H \rightarrow \Lambda p \pi$ analysis

Cuts for $\Lambda p \pi$ analysis

- **Topological cuts to look for Weak decay $H \rightarrow \Lambda p \pi$ (2.192 GeV/c²)**



0.25 cm < Λ dca to PV < 1cm

Λ decay length > 5 cm

P π decay length > 3 cm

$|d_\Lambda|$ > 3.5 cm

$|M_\Lambda - M_{PDG}| < 0.004$ GeV/c²

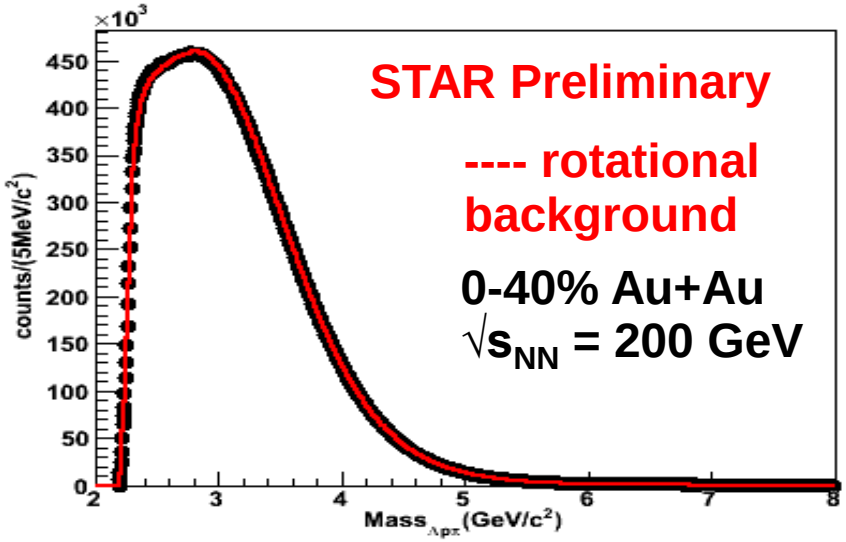
$M_{p\pi} < 1.110$ GeV/c²

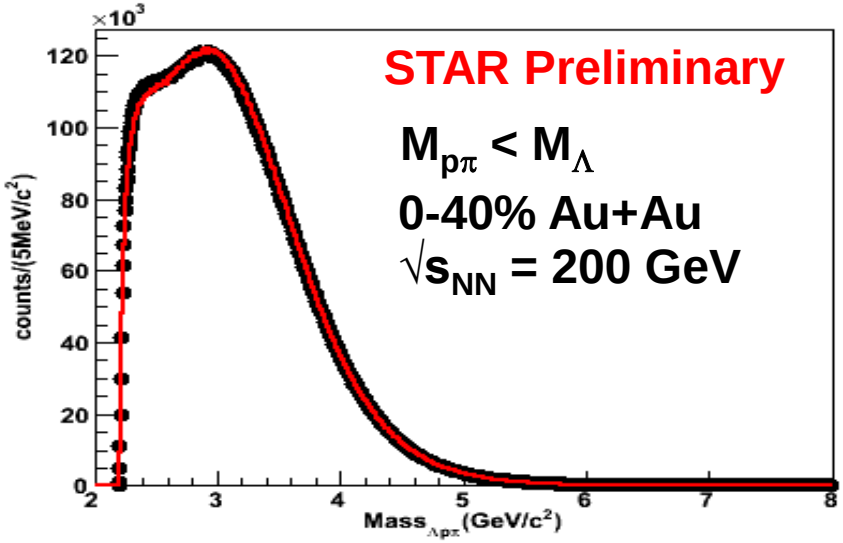
$\theta_\Lambda < 3$ Deg

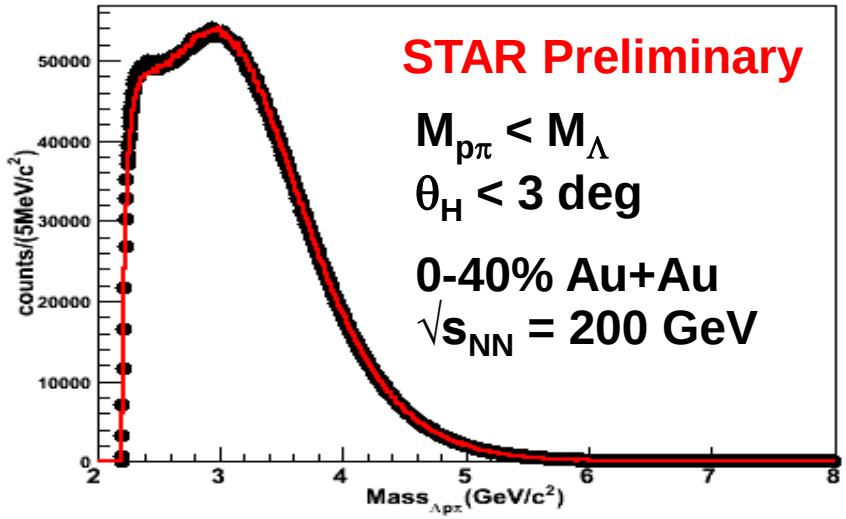
$\theta_H < 3$ Deg

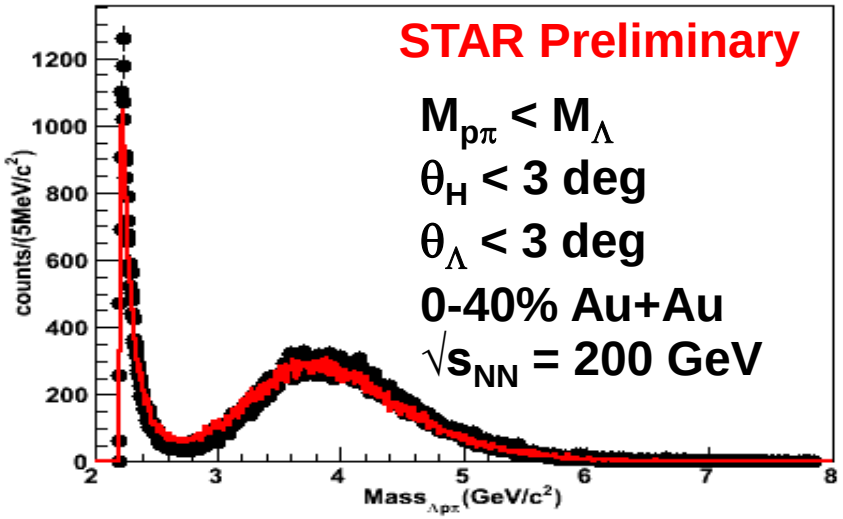
$\Lambda p\pi$ mass spectrum

- **$\Lambda p\pi$ mass spectrum after placing cuts one by one**









Summary

- **The Λ-Λ interaction is attractive**

- **Quark model interaction (FSS2) describes the data fairly for small ΞN coupling as well as without ΞN coupling ⇒ consistent with Nagara event**

- **ND46 shows strong suppression in the presence of ΞN coupling as compared to data**

- **Current fit to the data for a_0 and r_{eff} gives indication towards non-existence of strong bound state of ΛΛ and a_0 ~ (-2,-3) fm.**

- **Preliminary measurement of Λpπ mass spectrum to look for H signal is presented**

Outlook

- In 2011, STAR collected ~700 Million Minimum Bias events for Au+Au@ 200 GeV
  - ✓ further improved statistics for $\Lambda\Lambda$ correlation function and $H \rightarrow \Lambda p \pi$ analysis
  - ✓ able to study $\Lambda\Xi$, $\Xi\Xi$ and $\Omega\Omega$ interactions
- Future upgrade: HLT (Talk by A. Tang)
- Stay tuned!

Thank you!