Impact of Baryon anti-Baryon annihilation on apparent strangeness enhancement in $\bar{\Lambda}/\bar{p}$ at SPS energy

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Outline

- Strangeness enhancement
- Measures of strangeness enhancement.
- Importance of anti-łambda to anti-proton ratio ($\bar{\Lambda}/\bar{p}$)
- Effects of hadronic interactions importantly baryon-anti- baryon annihilation on $\bar{\Lambda}$, Λ $\bar{\Lambda}/\bar{p}$.

Baryon-anti- baryon ($B\bar{B}$) annihilation effect on

- $<m_T>$ of $\bar{\Lambda}$, Λ
- $<m_T>$ with Centrality of $\bar{\Lambda}$, Λ
- Yield $\bar{\Lambda}$, $\bar{p}$ w.r.to p_T and rapidity
- Annihilation fraction with beam energy
- $\bar{\Lambda}/\bar{p}$ Ratio

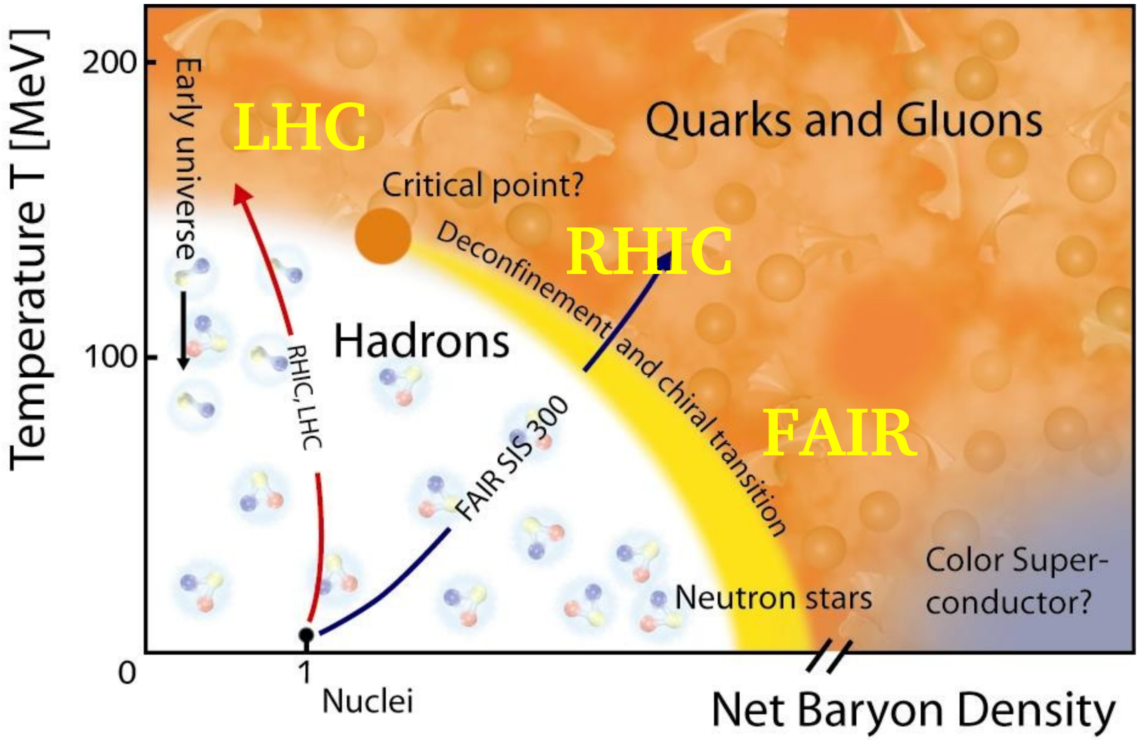
- Summary

Ref: **Ekata Nandy and Subhasis Chattopadhyay, European Physical Journal A**, 58 (2022) 10, 199

Phase diagram of nuclear matter

- Under extreme conditions of temperature or pressure normal nuclear matter (hadronic phase) is likely to undergo a deconfinement phase transition to a quark gluon plasma phase.

- Effort to locate the phase boundary at different regions using different experiments.



LHC – Large Hadron Collider
(E_{cm} = 2.76TeV – 5.02 TeV)

RHIC BES – Relativistic Heavy Ion Collider Beam Energy Scan
(E_{cm} = 7.7 GeV – 200 GeV)

FAIR – Facility for Antiproton & Ion Research
(E_{cm} = 3 GeV – 9 GeV)

Signatures of QGP

There is no unique signal that will identify QGP. Different signatures are used to search for QGP.

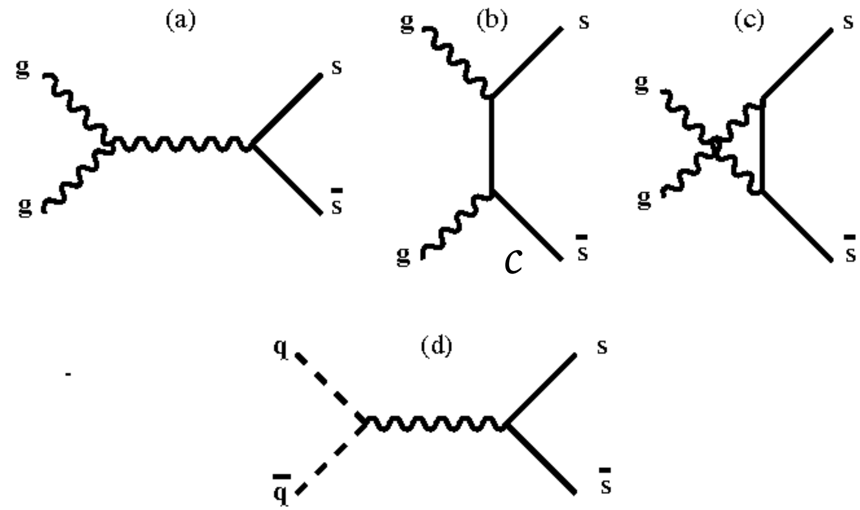
- *J/Ψ suppression*
- *Strangeness enhancement*
- *Jet quenching*
- *Dilepton production*

Strangeness production

J. Rafelski and B. Müller first predicted Strangeness enhancement as a signature of deconfinement
As there is no initial valence strange quark, it produces from the reactions only.

Partonic channel

g+g -> ss
q+q -> ss



Hadronic channel

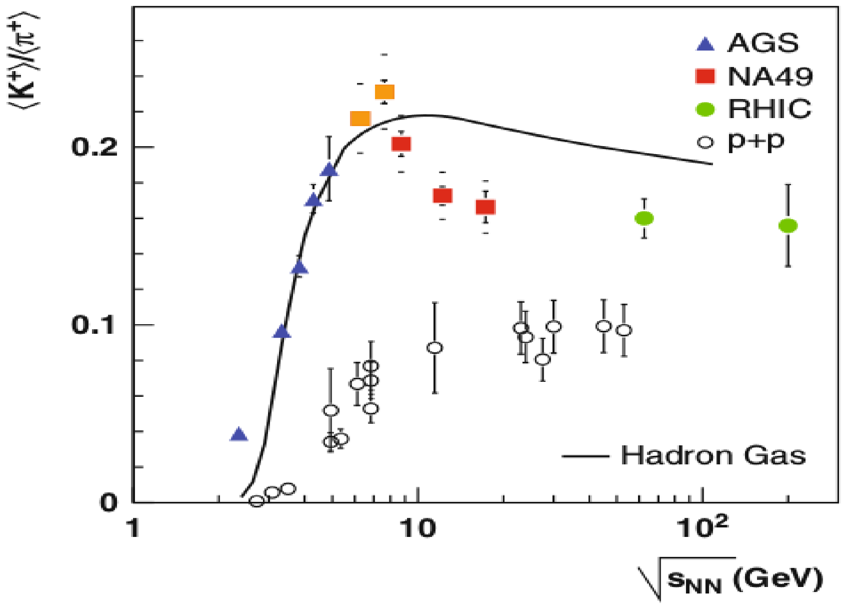
$N + N \to N + K + \Lambda$,
$N + N \to \Lambda + \bar{\Lambda} + N + N$
$\pi^+ + N \to \Lambda + K^+$

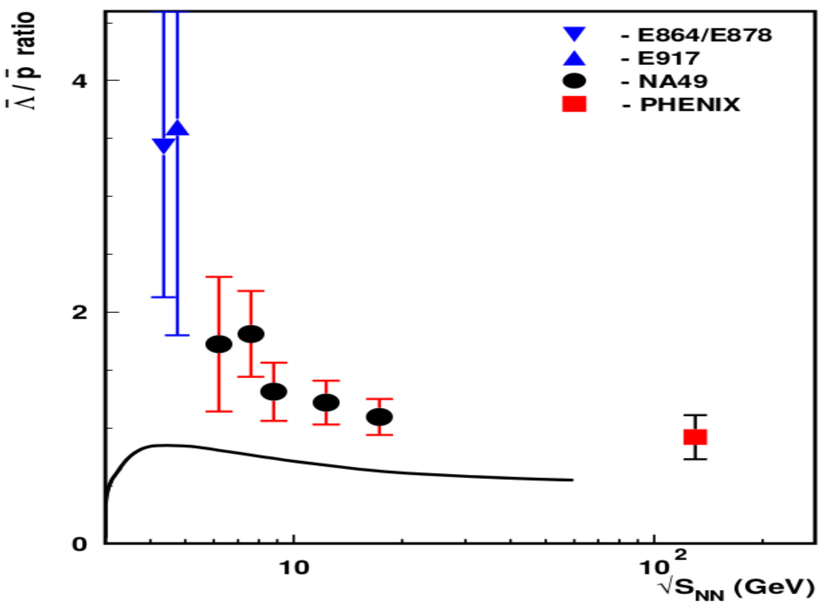
Why do we expect strangeness enhancement at low energy?
(Fermi Energy and Pauli Blocking)

- Because of higher abundance light quarks (u,d) in the medium they fill up the available low energy levels upto the fermi energy. Thus to produce a uu pair , required energy = fermi energy + $2m_u$
- Thus it is energetically favourable to produce ss pairs that require a threshold energy just double the mass of strange quark only.

Measures of strangeness enhancement

- A large enhancement in strange hadrons production relative to pp interaction was first reported at CERN-SPS.
- Enhanceent factor (relative to pp) $\left[\left.\frac{dN(Pb+Pb)}{dy}\right|_{y=0} \middle/ \left.\frac{dN(p+p)}{dy}\right|_{y=0} \right]$
- Interesting structures were observed in the strange-to-non-strange particle ratios.
- Non-monotonic variation of **k/π** as a function of collision energy was first observed at SPS.
- Similar behaviour was also observed in the baryon sector ($\bar{\Lambda}/\bar{p}$), although with large uncertainty.
- Such non-monotonic variation is often attributed to the onset of partonic deconfinement.
- However hadronic interactions such as BB annihilation has a dominant role to play in strangeness baryon production & enhancement in the baryon sector .





Motivation of work

- Understand the contribution of hadronic interactions to the measures of strangeness enhancement.

- Final yields of baryons are highly sensitive to hadronic interactions at later stages of the collisions mainly from the baryon-anti baryon annihilation in a baryon rich environment (FAIR & SPS energies).

- So depending on the different annihilation cross-section of $\bar{p}$ and $\bar{\Lambda}$, this ratio ($\bar{\Lambda}/\bar{p}$) may enhance.

- This study further aims to address whether the enhancement in the ratio ($\bar{\Lambda}/\bar{p}$) can be explained from the consequence of hadronic interactions alone ?

Why $\bar{\Lambda}/\bar{p}$?

Since anti-particles comprise of quarks produced in the reactions only, they are regarded as a cleaner channel to probe strangeness enhancement

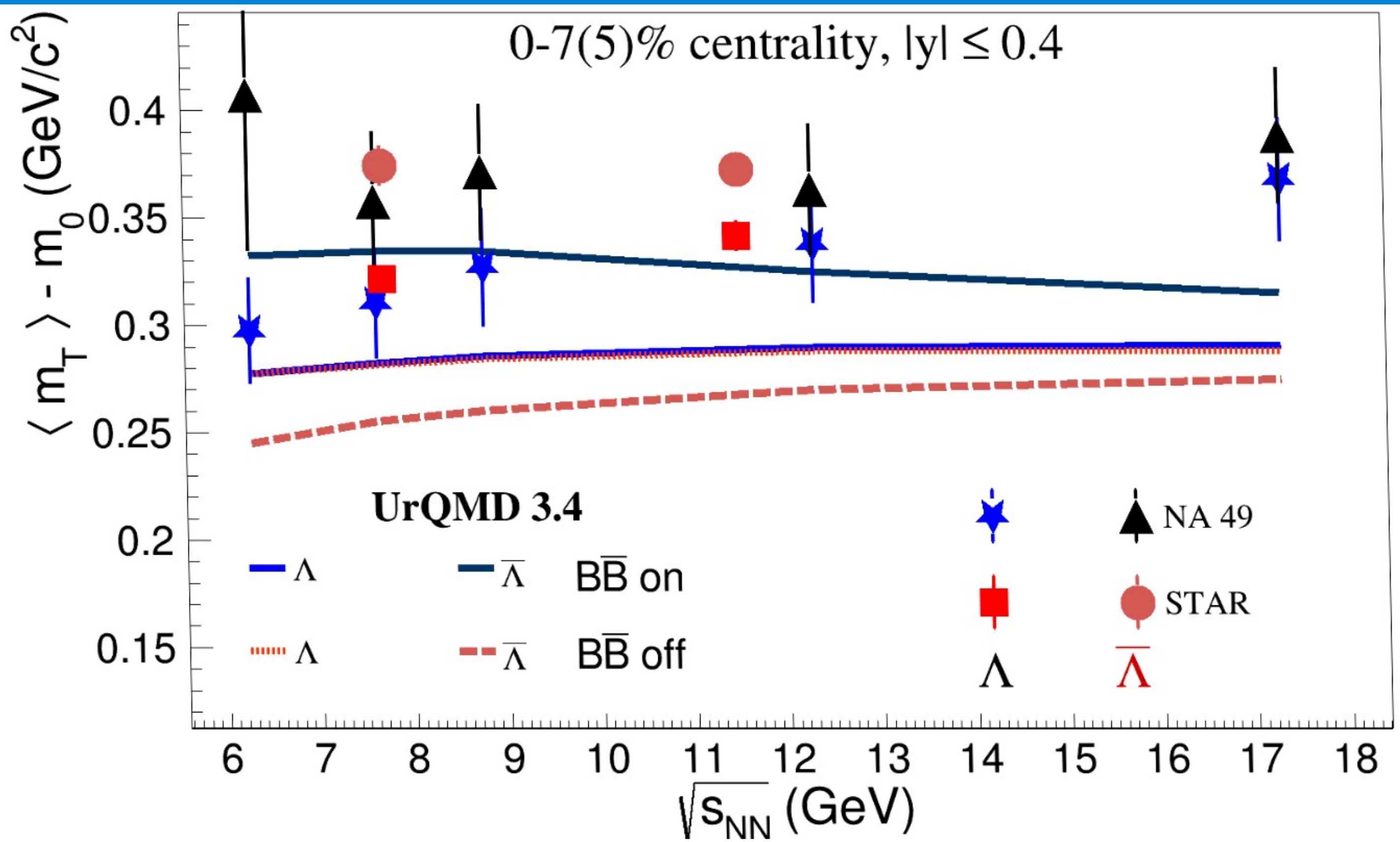
Details of model simulation

UrQMD (Ultra Relativistic Quantum Molecular Dynamics)

- Hadronic model, describe the phenomenology of particle production in pp, p+A and A+A collisions over a broad energy range
- The underlying degrees of freedom in UrQMD are hadrons and strings.
- Here an individual particle propagates on a straight line until the relative distance between two particles is smaller than the total interaction cross-section between two particles.
- The particle production dynamics is either governed by the decays of baryon or meson resonances or via a string excitation and fragmentation.

System : Pb+Pb/Au+Au
With & w/o incorporating baryon -anti baryon annihilation
Energy : 6.27 GeV, 7.62 GeV, 8.77 GeV, 12.3 GeV, 17.3 GeV
Centrality = 0-7%
Observables : $\bar{\Lambda}$,$\bar{p}$

$B\bar{B}$ annihilation effect on Λ, $\bar{\Lambda}$ $<m_T>$



- Average transverse mass ≡ effective temperature. (T_{eff}) . $T_{eff} = T_{th} + 1/2\ m\beta^2$
- Although Λ and $\bar{\Lambda}$ have same mass, their $<m_T>$ are different in magnitude and the difference is seen to increase with the decrease in beam energy or increase in net baryon-density.
- Consequence of $B\bar{B}$ annihilation : $\bar{\Lambda}$s have higher chance to annihilate with p compared to Λs that annihilate with $\bar{p}$ causes lowering of low p_T yields while keeping the high p_T yields unchanged, resulting in a hardening of $\bar{\Lambda}$'s p_T -spectra

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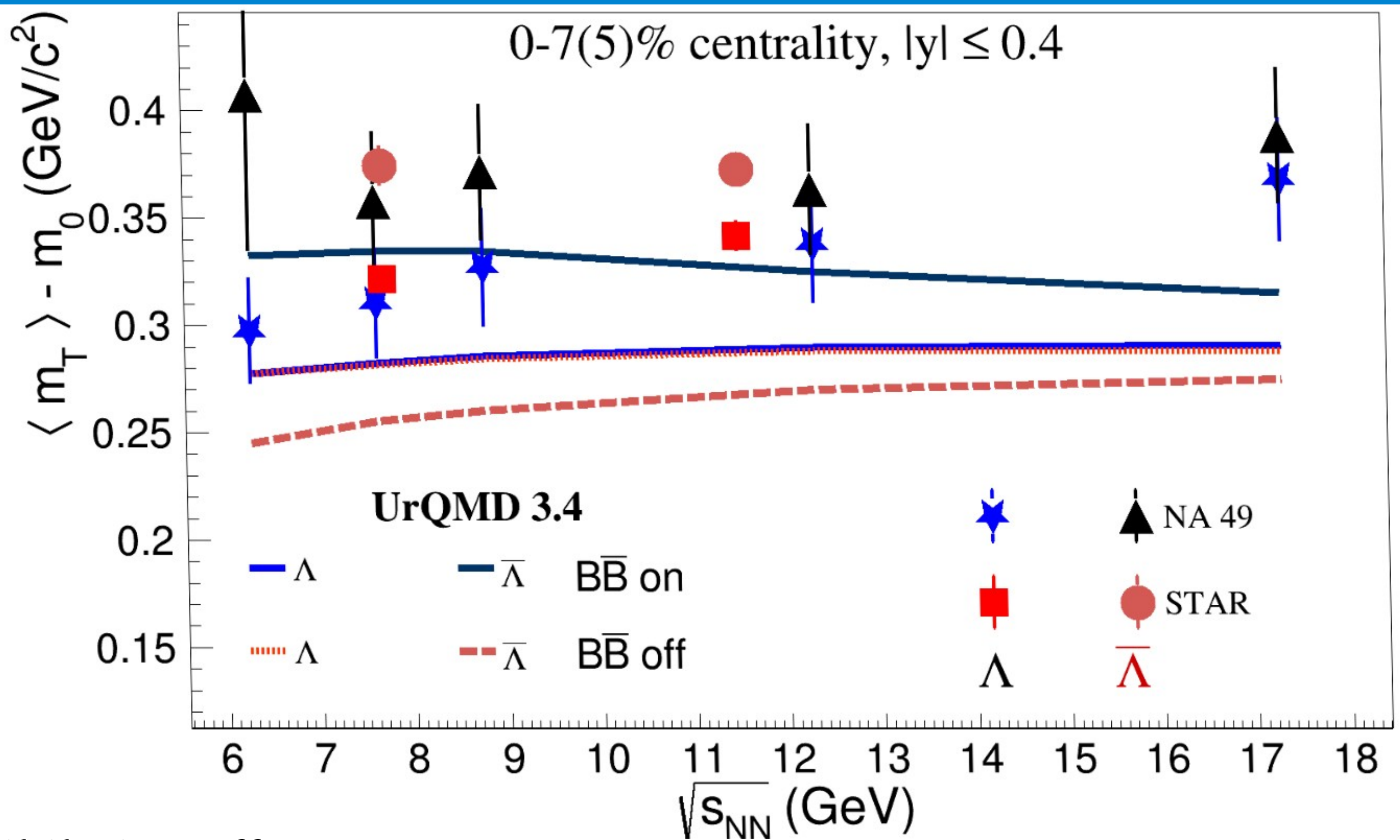
$B\bar{B}$ annihilation effect on Λ, $\bar{\Lambda}$ <m_T>

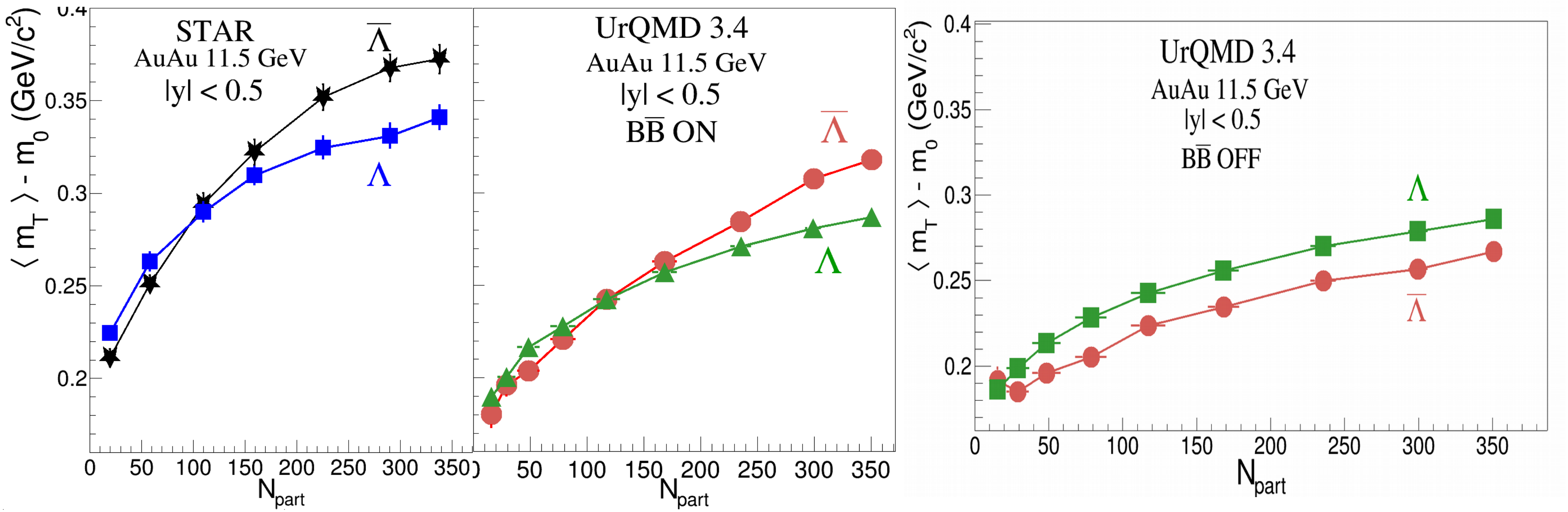


- **$B\bar{B}$ annihilation off -**
  <m_T> Spiltting in opposite trend.

- Energy threshold N + N → N+ K^+ + Λ ~700MeV,
  N + N → Λ + $\bar{\Lambda}$ + N + N ~2200 MeV

- Energy, in excess to threshold energy, available to impart kinetic energy to the production in $\bar{\Lambda}$ pair-production is less. Thus, produced $\bar{\Lambda}$s mostly have smaller transverse momenta.

$<m_T>$ vs centrality for Λ and $\bar{\Lambda}$



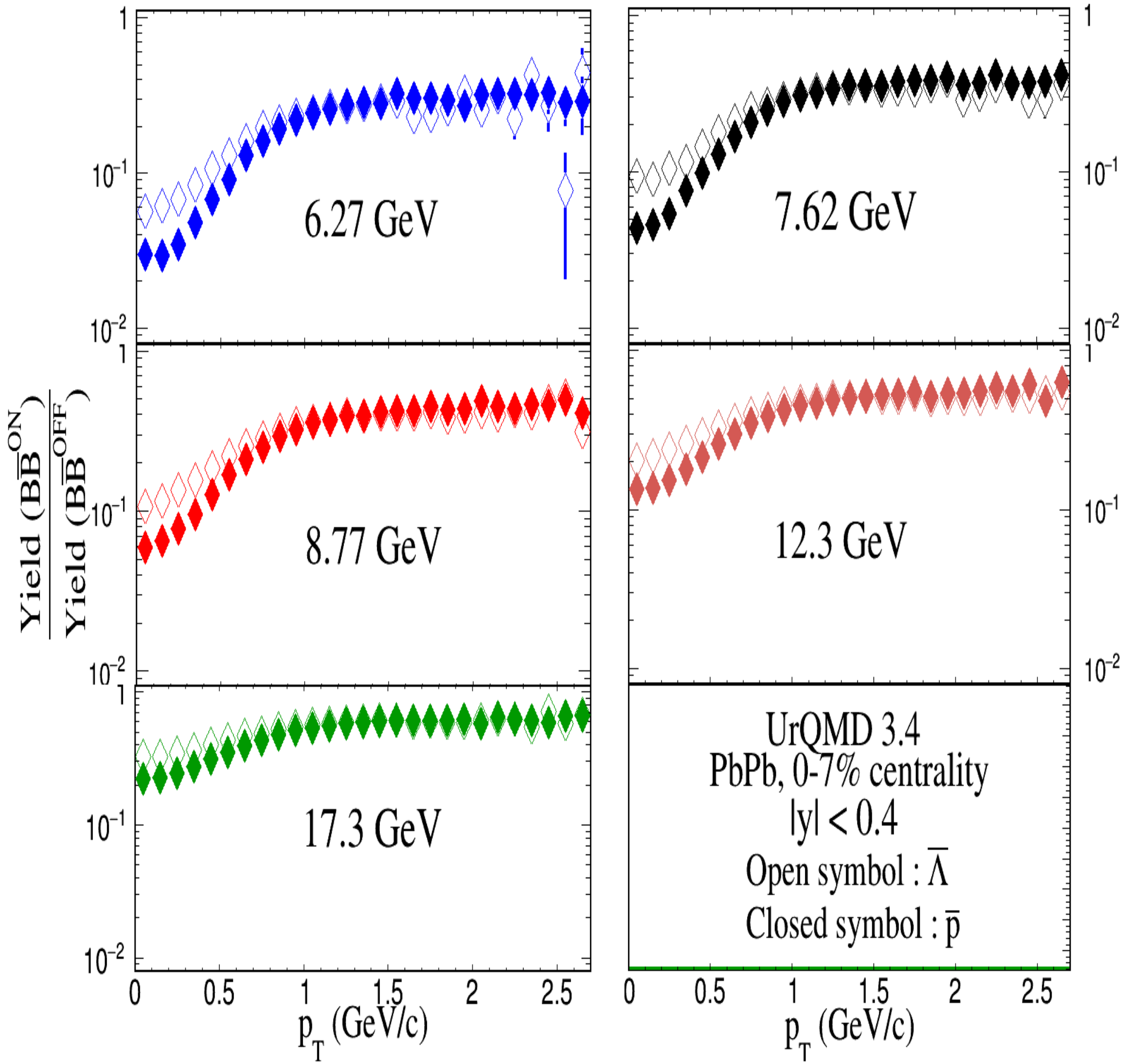
- Shows **interplay between $B\bar{B}$ annihilation and threshold energy**.
  N_{part} <100, "threshold effect" is dominant as the baryon density is low. This results in higher values of $<m_T>$ for Λ than $\bar{\Lambda}$.

- Switch-over for N_{part} > 100, where the trend get reversed i.e, $<m_T>$ for $\bar{\Lambda}$ is greater than Λ. This happens because as the system size increases, baryon density increases.

- When $B\bar{B}$ annihilation is OFF in UrQMD, $<m_T>$ for Λ is higher than $\bar{\Lambda}$ at all N_{part} .

- Suggests that in central collisions at lower $\sqrt{s}$ effects of $B\bar{B}$ annihilation can not be ignored particularly while considering any phenomenon that involves yields or spectra of baryons and anti-baryons.

p_T dependence of yields of Λ’s & p̄’s



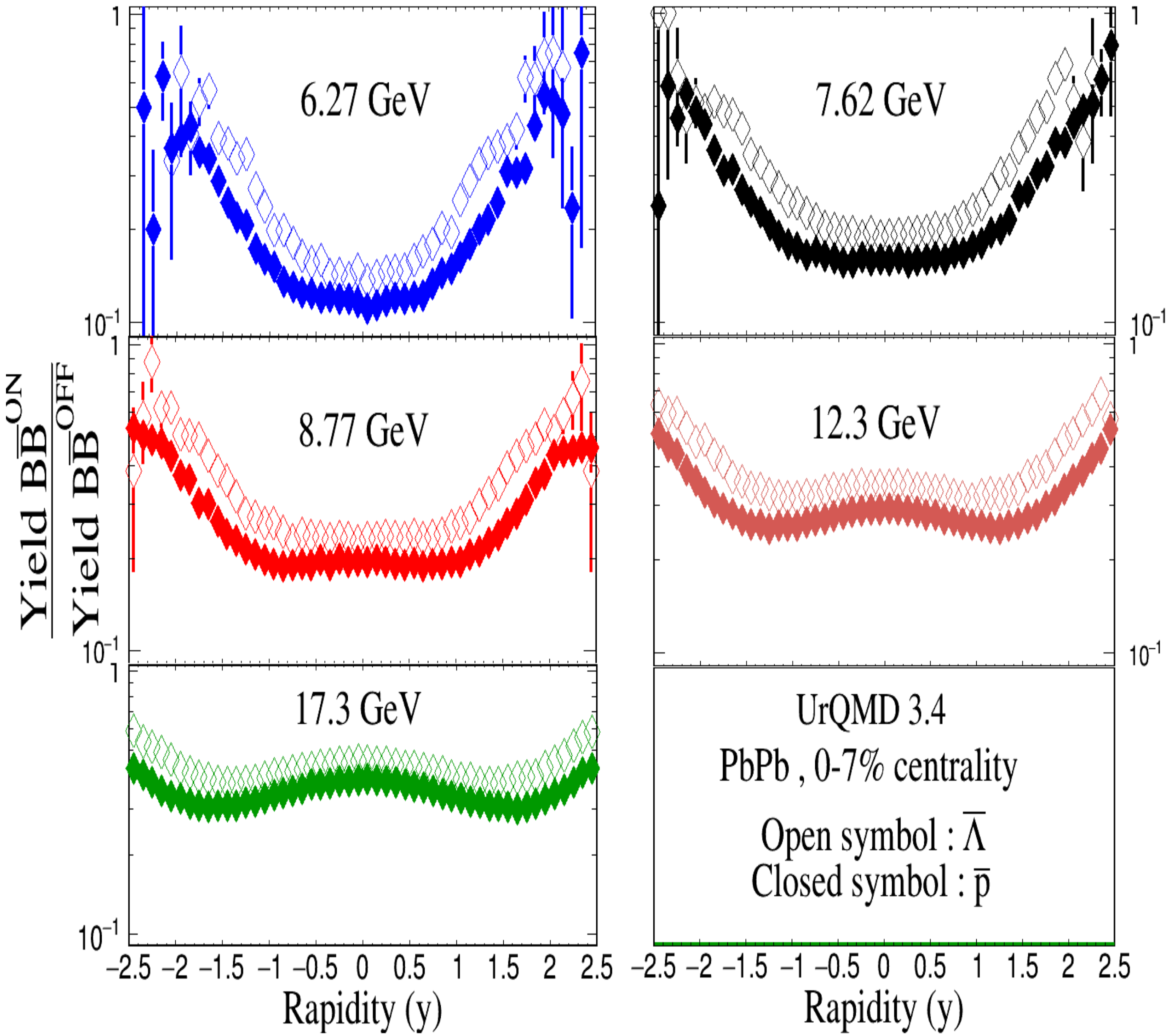
To investigate how $B\bar{B}$ annihilation modify yields of Λ and p̄ as a function of p_T

Suggests that the effect of annihilation is maximum at low-p_T

p̄ is annihilated more than Λ

The magnitude of suppresion decreases with increasing √s, implying more annihilation of Λ and p̄ at lower √s

Rapidity dependence yields of $\bar{\Lambda}$'s & $\bar{p}$'s



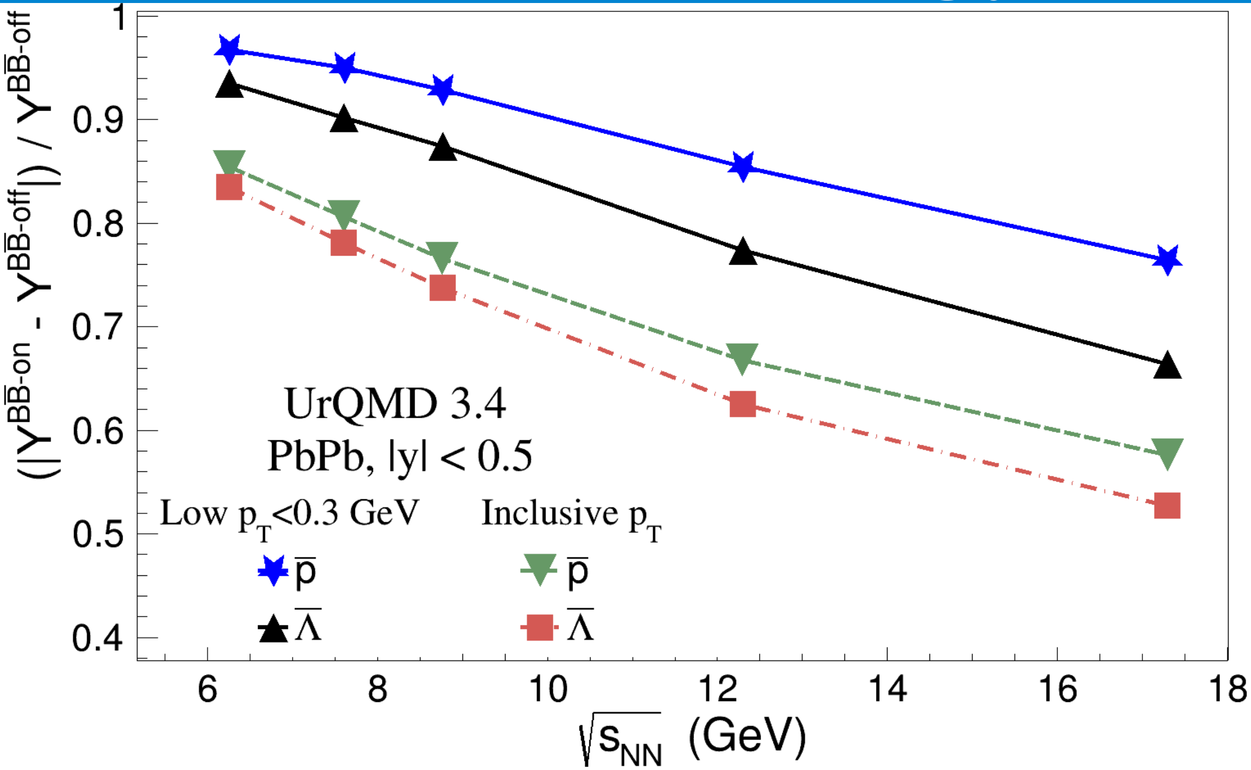
The annihilation effect is most significant at mid-rapidity in low √s for both $\bar{\Lambda}$ and $\bar{p}$

As energy increases, the overall magnitude of suppression start to decrease.

The maximum suppression now occurs at forward rapidity instead of mid-rapidity at higher energy

At high energy baryon stopping is less at mid rapidity & high baryon density region gradually move to forward rapidity.

Annihilation fraction as function of beam energy



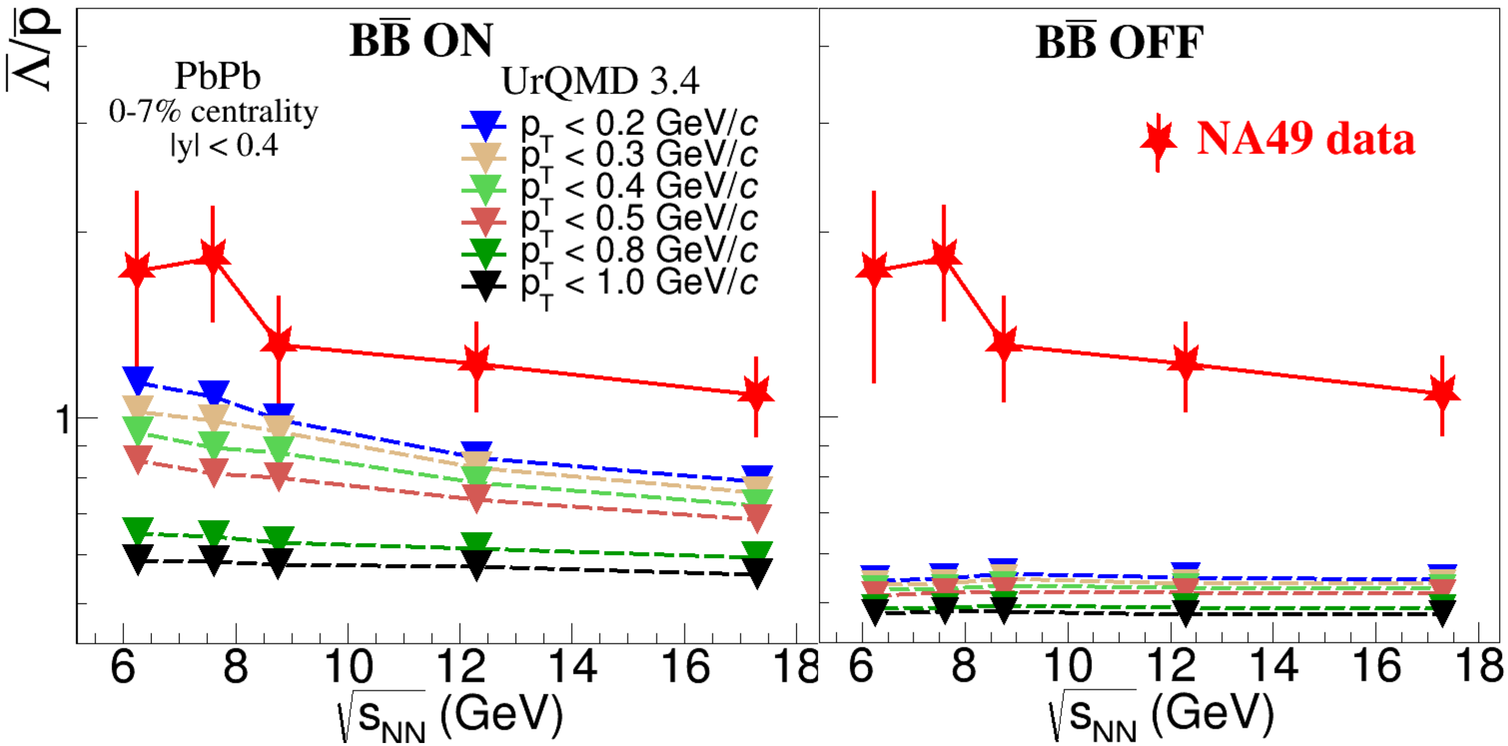
- Magnitude of annihilation interms of a quantity called **annihilation fraction.**

- Annihilation is more at low p_T than inclusive p_T .
  At low √s, say at 6.27 GeV, > 95% of the initially produced low-p_T p̄ are annihilated whereas, for Λ̄ the annihilation fraction is about 92 to 94%

- As the energy increases annihilation fraction drops.

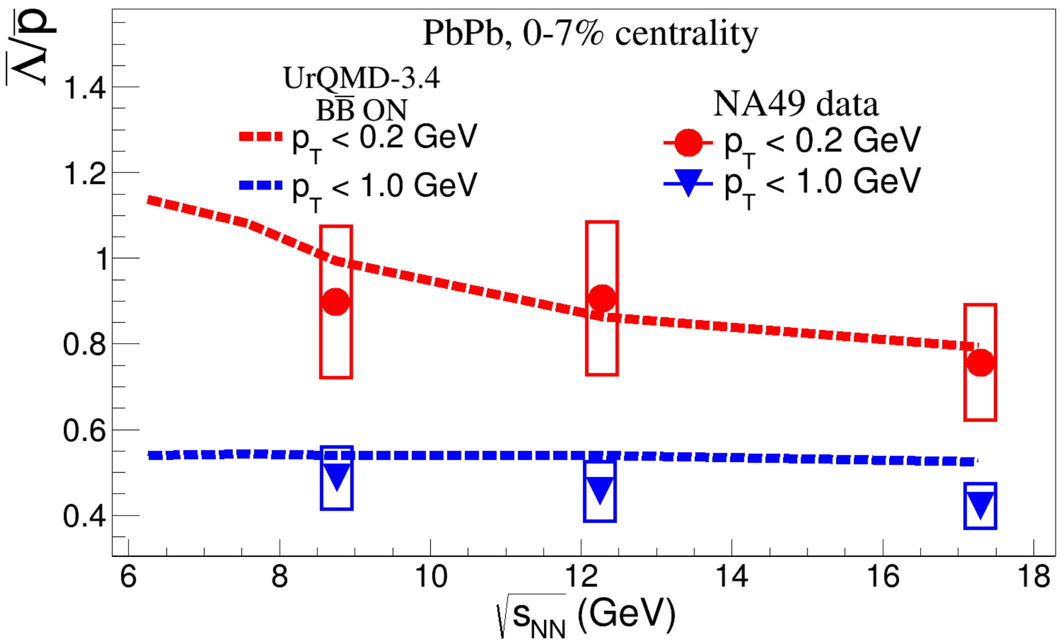
- Annihilation fraction of p̄ is higher than Λ̄.

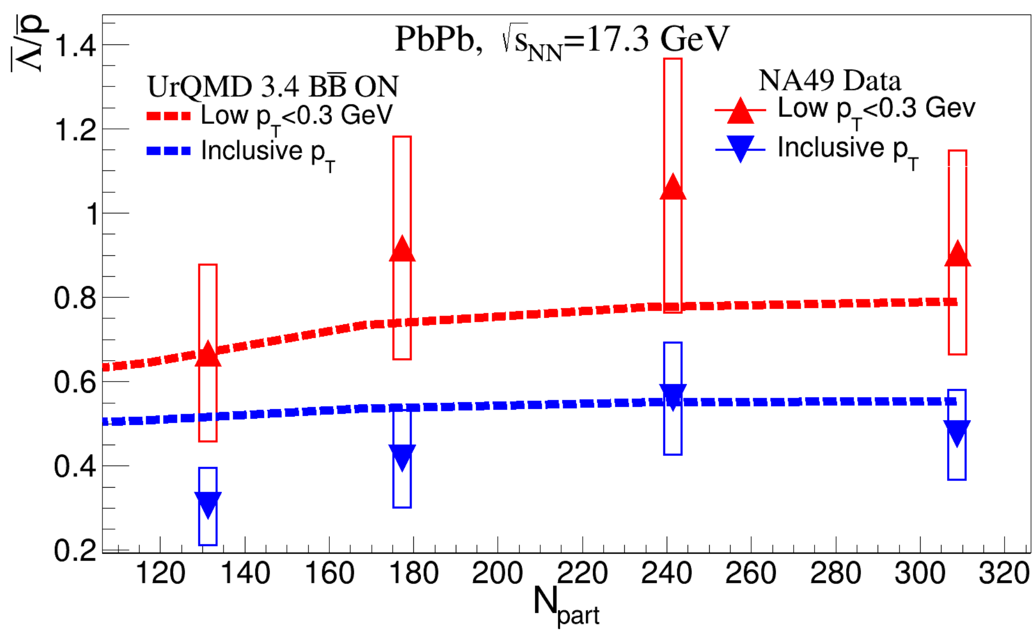
The $\bar{\Lambda}/\bar{p}$ as a function of collision energy



- $\bar{\Lambda}/\bar{p}$ are sensitive to $B\bar{B}$ annihilation and its impact depend strongly on the kinematic selection.
- p_T< 0.2 GeV/c) $\bar{\Lambda}/\bar{p}$ ratios achieve maximum for the lowest collision energy. The trend in UrQMD is qualitatively similar to data
- Enhancement in $\bar{\Lambda}/\bar{p}$: Annihilation cross-sections of $\bar{p}$ is higher than $\bar{\Lambda}$ which results in more suppression of $\bar{p}$ yield compared to $\bar{\Lambda}$, leading to an enhancement.
- When UrQMD calculations are done without incorporating $B\bar{B}$-annihilation, irrespective of the choice of p_T range no enhancement can be seen in $\bar{\Lambda}/\bar{p}$ ratios.

$\Lambda/\bar{p}$ with collision energy & centrality





- we now calculate $\Lambda/\bar{p}$ ratios from the feed-down corrected yields for both Λ and $\bar{p}$
- After the feed-down correction, $\Lambda/\bar{p}$ ratios in data and model calculations show very good agreement.
- For low- p_T , ratio increases from peripheral to central collision in UrQMD as well as in data
- Enhancement in $\Lambda/\bar{p}$ ratios is only observed at low- p_T but for inclusive p_T ratios are almost flat
- Suggests, there is a strong impact of $B\bar{B}$ annihilation on $\Lambda/\bar{p}$ ratios and the enhancement in $\Lambda/\bar{p}$ ratios may not be a necessary indication of partonic deconfinement for strangeness enhancement.

Summary

- $B\bar{B}$-annihilation has a significant effect on Λ and $\bar{\Lambda}$ hyperon production at high net baryon density or lower energy region.
- Data model comparison reveals that $B\bar{B}$ annihilation is responsible for the splitting of $\langle m_T \rangle$ as a function of $\sqrt{s}$ for Λ, $\bar{\Lambda}$
- $\langle m_T \rangle$ with N_{part} shows a interplay between threshold energy and $B\bar{B}$ annihilation effect
- $\bar{\Lambda}/\bar{p}$ ratio enhancement is seen to be well explained by UrQMD with $B\bar{B}$ annihilation at low and inclusive p_T and matches well with feed-down corrected data
- This investigations suggest $\bar{\Lambda}/\bar{p}$ enhancement is not necessarily because of strangeness enhancement due to partonic deconfinement and $B\bar{B}$-annihilation has a significant role to play.

Thank You

Parametrization of Bbbar annihilation in UrQMD

UrQMD use some form parametrization of Bbar annihilation cross section, which are nevertheless data-driven.

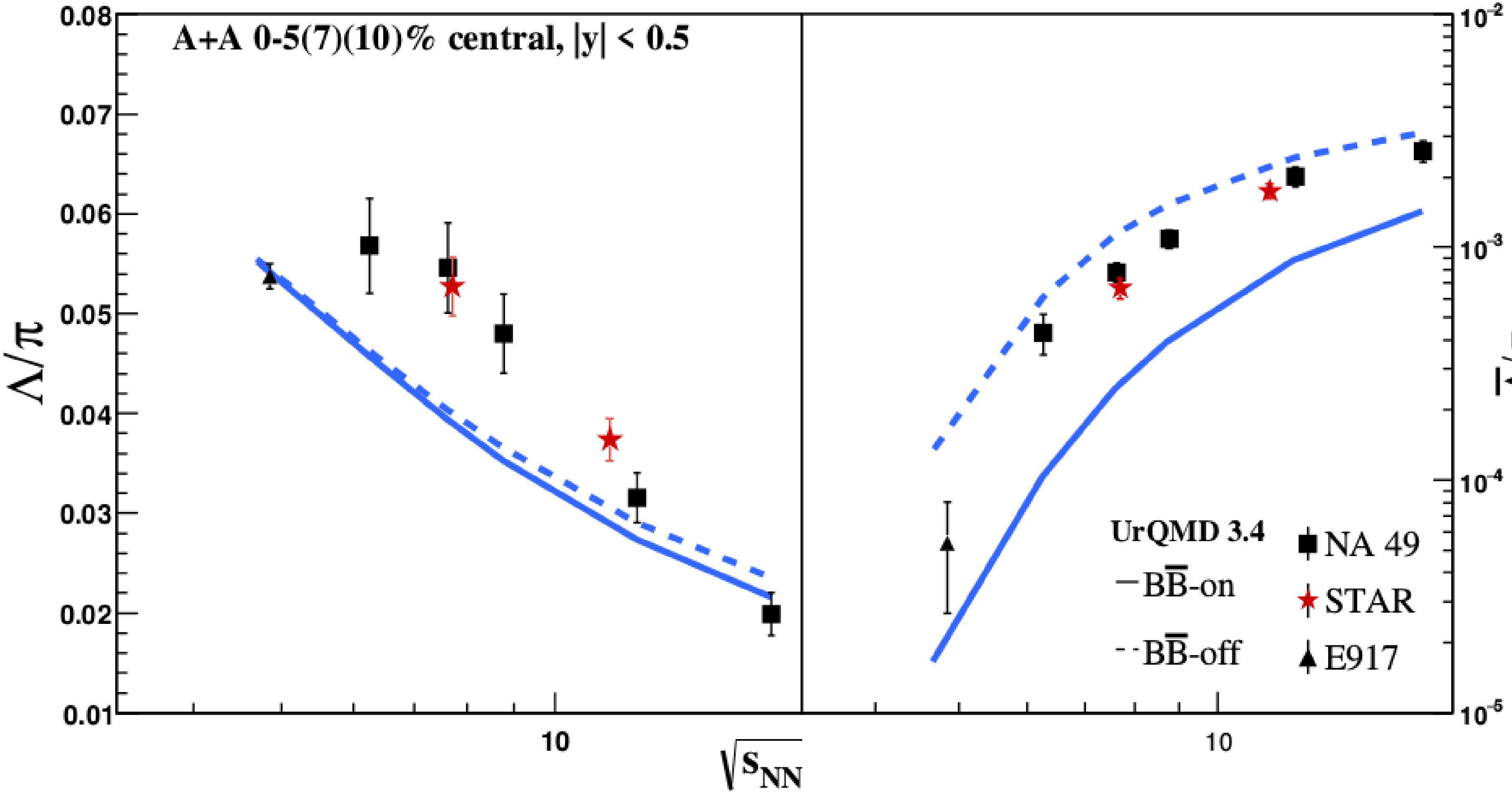
$$\sigma_{ann}^{\mathrm{p\bar{p}}} = \sigma_0^{\mathrm{N}} \frac{s_0}{s} [\frac{A^2 s_0}{(s-s_0)^2 + A^2 s_0} + B]. \qquad (2)$$

Where $\sigma_0^{\mathrm{N}} = 120$ mb, $s_0 = 4\mathrm{m}_N^2$, A = 50 MeV and B = 0.6 [36].

For annihilation channels that involve a strange-baryon/antibaryon, such as $\bar{\Lambda}\mathrm{p}$ or $\Lambda\bar{\mathrm{p}}$, an additional correction factor is introduced based on AQM, given by

$$\sigma_{ann}^{\mathrm{B\bar{B}}} = (1 - 0.4\frac{s_B}{3})(1 - 0.4\frac{s_{\bar{B}}}{3})\sigma_{ann}^{\mathrm{p\bar{p}}}[36], \qquad (3)$$

where s_B and $s_{\bar{B}}$ is the strangeness number for baryon and antibaryon, respectively. Thus, annihilation cross-section of $\bar{\Lambda} - \mathrm{p}$, ($\sigma_{ann}^{\bar{\Lambda}\mathrm{p}}$) is less than annihilation cross-section of p-$\bar{\mathrm{p}}$ ($\sigma_{ann}^{\mathrm{p\bar{p}}}$). From equation [2] we see the annihilation cross-section (σ_{ann}) has an approximate $\frac{1}{\sqrt{s}}$ dependence with beam energy.



A+A 0-5(7)(10)% central, |y| < 0.5
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Λ/π
10
$\sqrt{s_{NN}}$
10
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$\bar{\Lambda}/\pi$
UrQMD 3.4
$B\bar{B}$-on
$B\bar{B}$-off
NA 49
STAR
E917