Strangeness in Heavy-Ion Collisions — An Updated Review

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GOETHE UNIVERSITÄT FRANKFURT AM MAIN

HIC for FAIR
Helmholtz International Center

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Outline

Strangeness in heavy-ion physics
Overview on strangeness measurements by different experiments

Global Λ polarization
First significant measurement
Vorticity and magnetic field strength

Hyperon interaction
ΛΛ interaction and search for bound states
Hypernuclei measurements

Small systems and strangeness enhancement
Strangeness as QGP signal
Proton-proton and proton-nucleus collisions
Multiplicity dependence

Baryon-meson ratios
Hadronization mechanisms, evidence for recombination?

Overview on Strangeness Measurements
Experiments

GSI-SIS
FOPI, KAOS, HADES

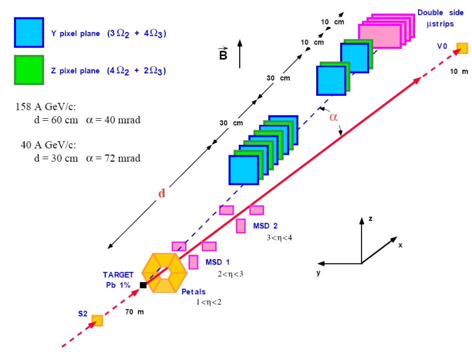
BNL-AGS
E802, E810, E866, E895, …

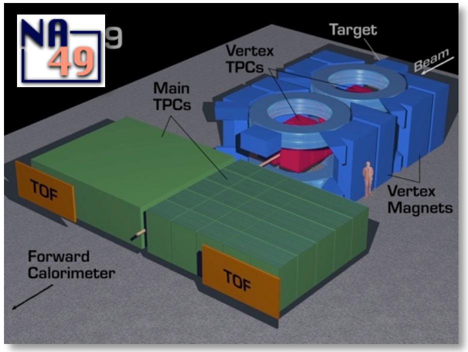
CERN-SPS (Pb beam)
WA97, NA44, NA45, NA50
NA49, NA57, NA61

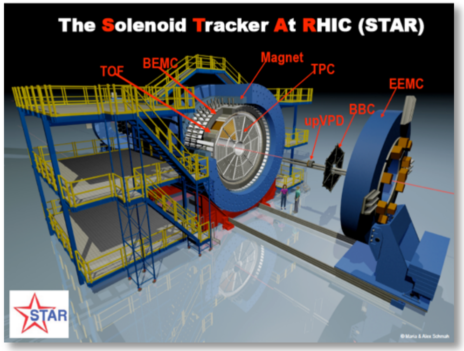
BNL-RHIC
STAR, PHENIX, BRAHMS

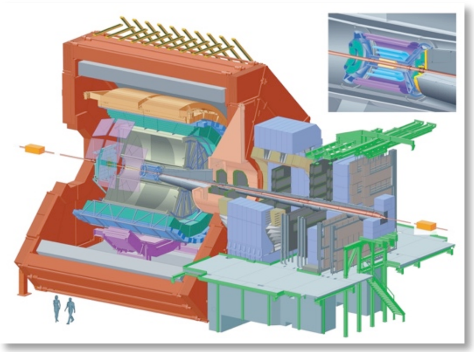
CERN-LHC
ALICE

New low energy programs
CBM@FAIR, NICA



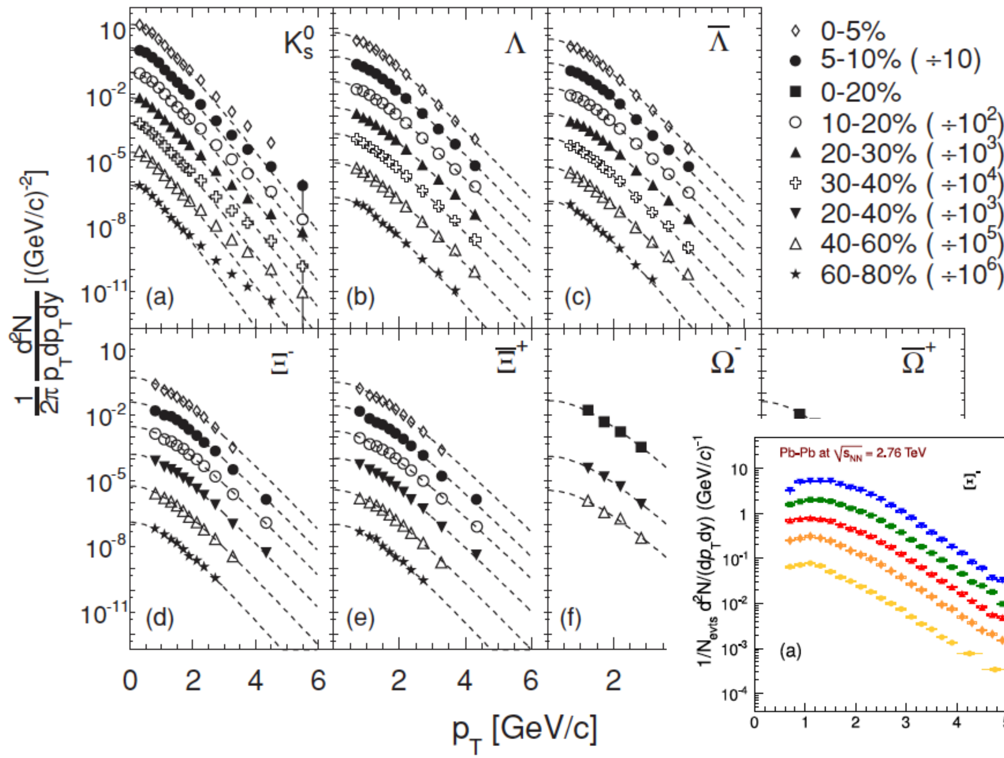




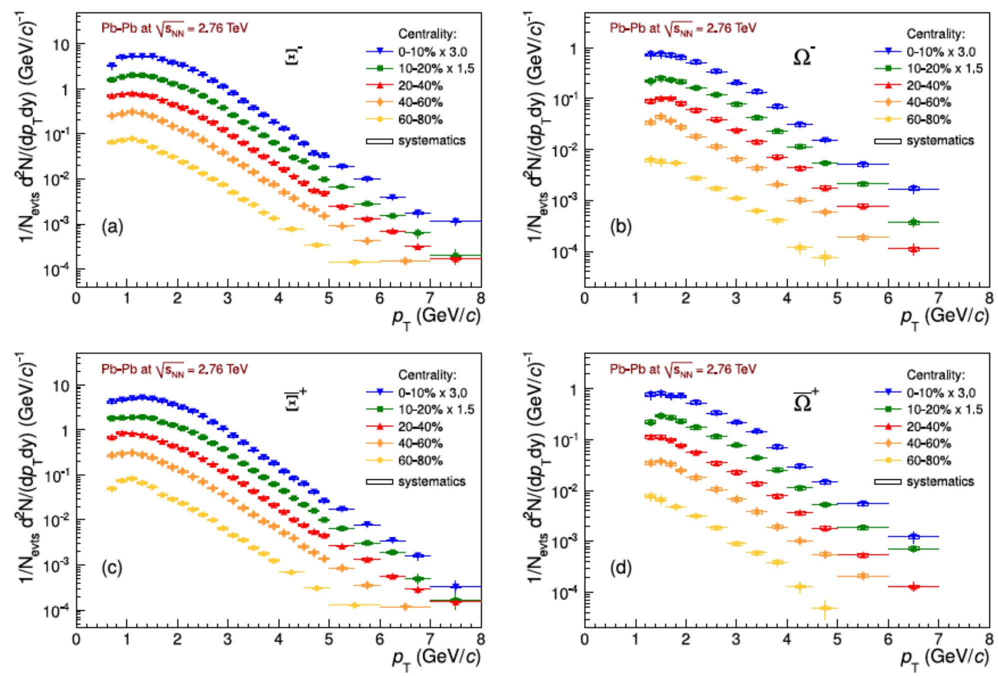


Overview on Strangeness Measurements

RHIC and LHC



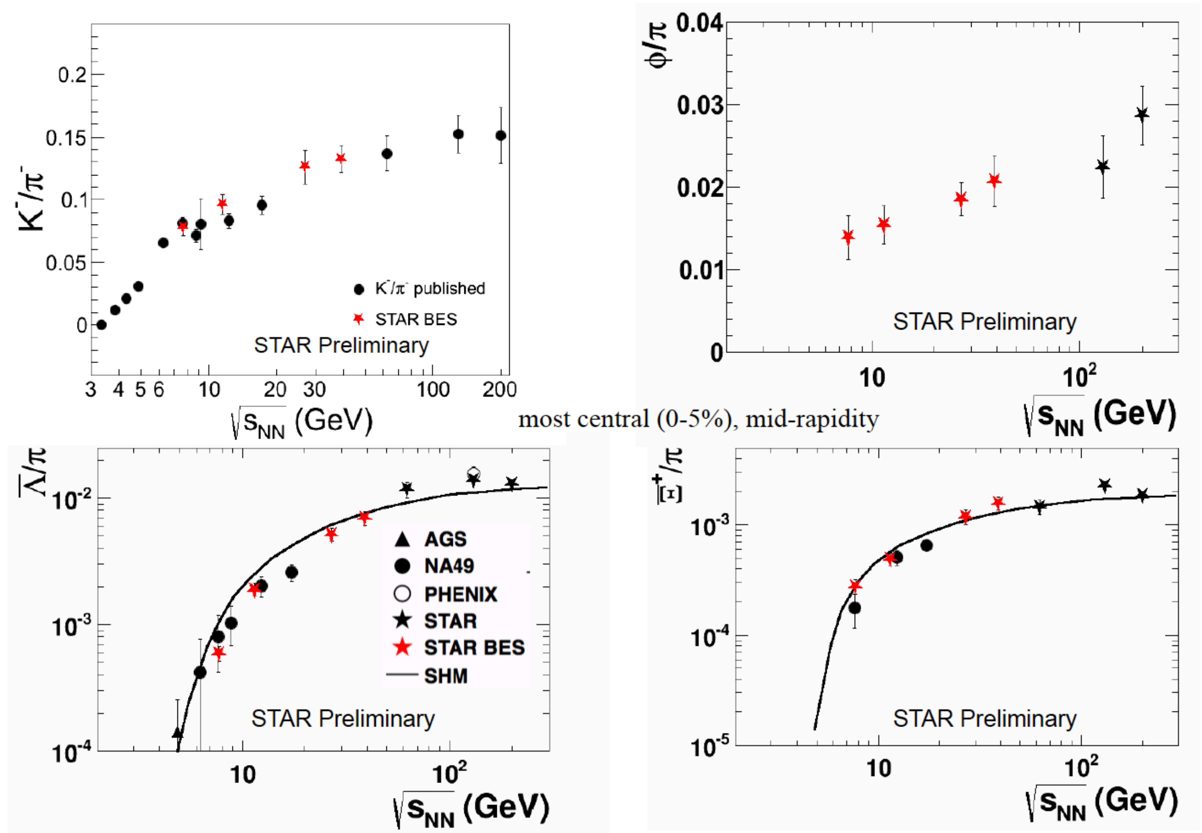
STAR
PRC83, 024901 (2011)
$\sqrt{s_{NN}}$ = 62.4 GeV



ALICE
PLB728, 216 (2014)
$\sqrt{s_{NN}}$ = 2.76 TeV

Overview on Strangeness Measurements

Beam Energy Scan at RHIC



Overlap with SPS data

Good agreement with NA49 yields

Most particle species covered for $\sqrt{s_{NN}}$ > 7 GeV

STAR
Shusu Shi SQM16

SHM
A. Andronic et al., NPA772 (2006) 167

Overview on Strangeness Measurements

Beam Energy Scan at the CERN-SPS: NA61 / SHINE

Systematic study of pp

Beam energies
20, 31, 40, 80, 158 GeV

Before: collection of “historic” data as reference

Data on charged kaons and Λ available up to now

Large rapidity coverage

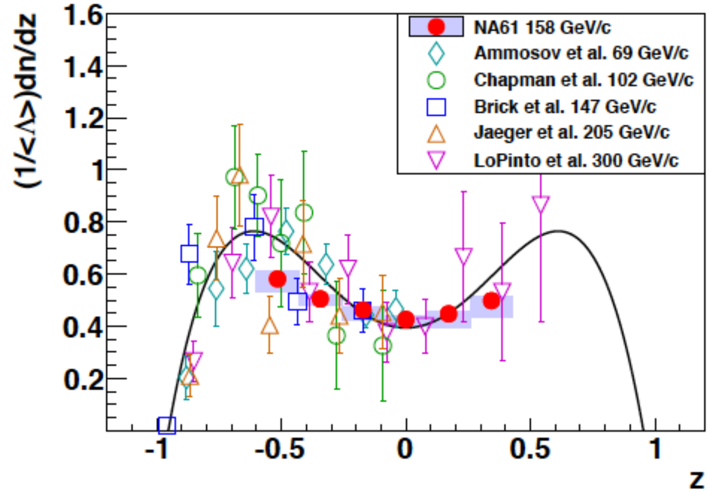
Results from Be+Be

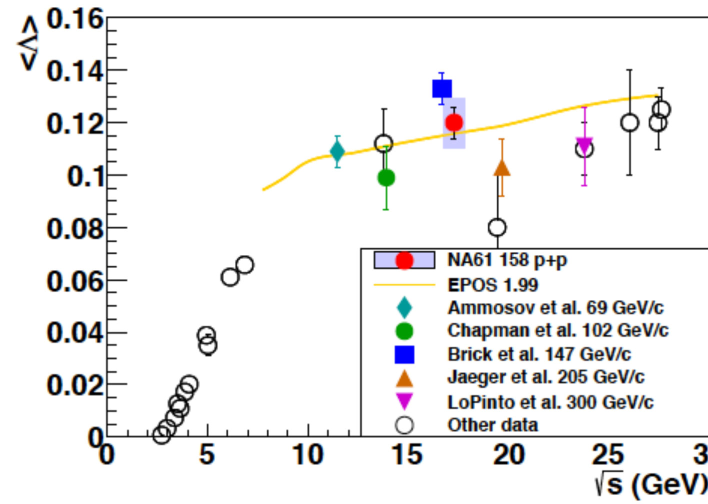
Beam energies
13, 19, 31, 40, 75, 150 *A*GeV

Charged pions shown so far

Heavier systems

Analysis of Ar+Sc ongoing



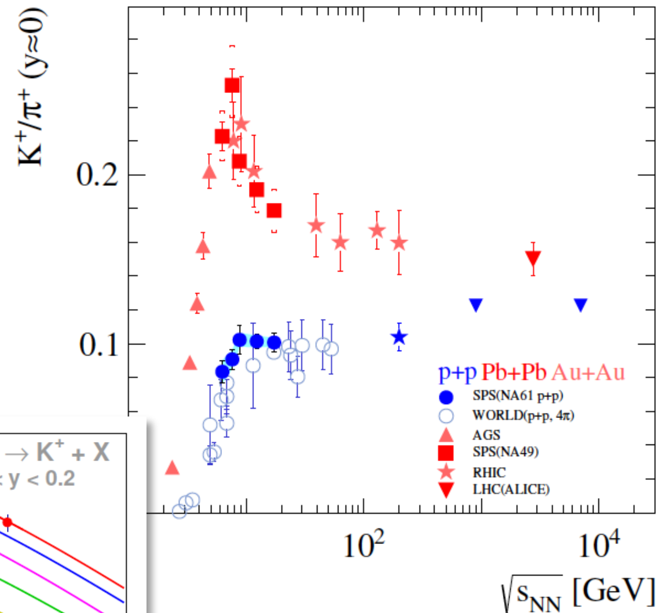


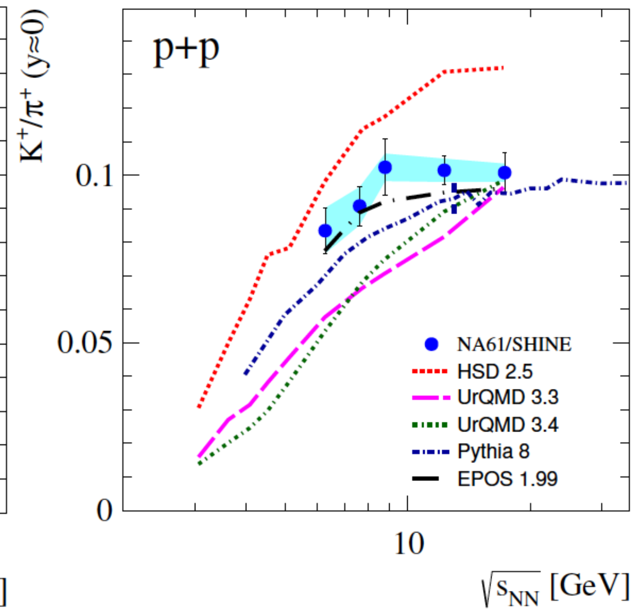
NA61
EPJC76, 198 (2016)

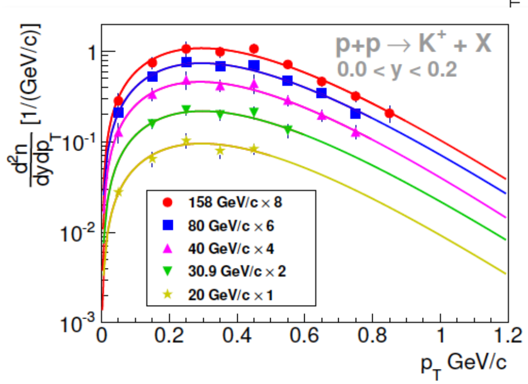
H. Stroebele, SQM2015

Overview on Strangeness Measurements

Beam Energy Scan at the CERN-SPS: NA61 / SHINE







NA61
arXiv:1510.08239

H. Stroebele, SQM2015

Energy dependence of K^+/π^+ yields

Reduced statistical and systematic errors in comparison to “historic” data

Important benchmark for models

Overview on Strangeness Measurements

Energy Dependence of Total Yields

Covered CM-energies

AGS: $2.4 \leq \sqrt{s_{NN}} \leq 4.8$ GeV

SPS: $6.3 \text{ GeV} \leq \sqrt{s_{NN}} \leq 17.3$ GeV

RHIC: $7 \text{ GeV} \leq \sqrt{s_{NN}} \leq 200$ GeV

LHC: $\sqrt{s_{NN}} = 2760$ GeV

High energies

All particle species measured

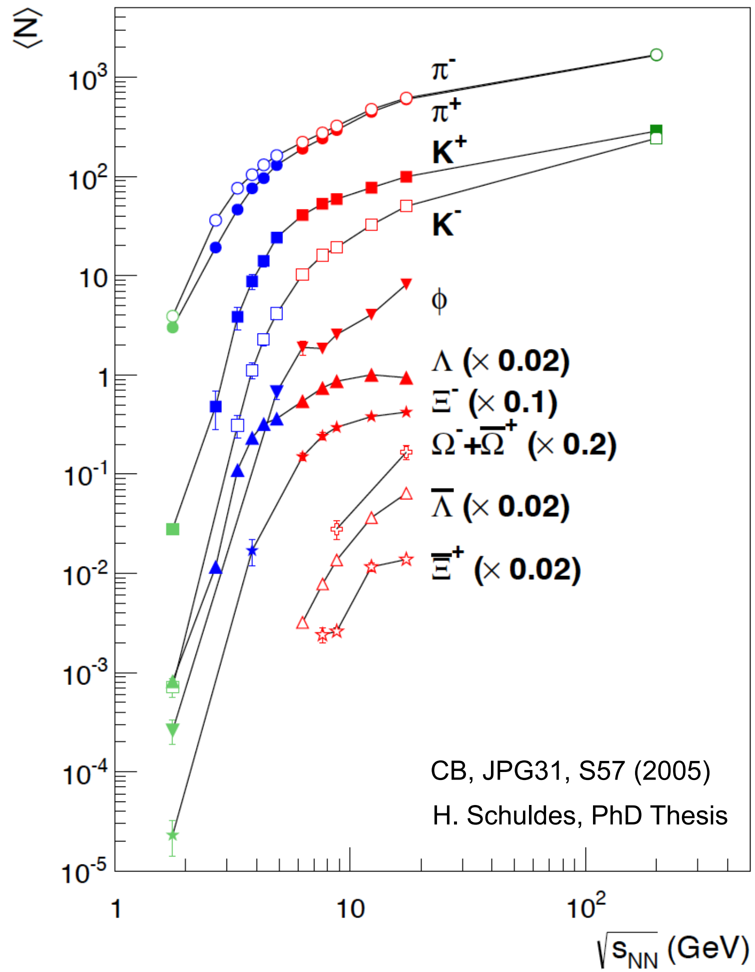
Only mid-rapidity data

Low energies

Mostly limited to bulk particles

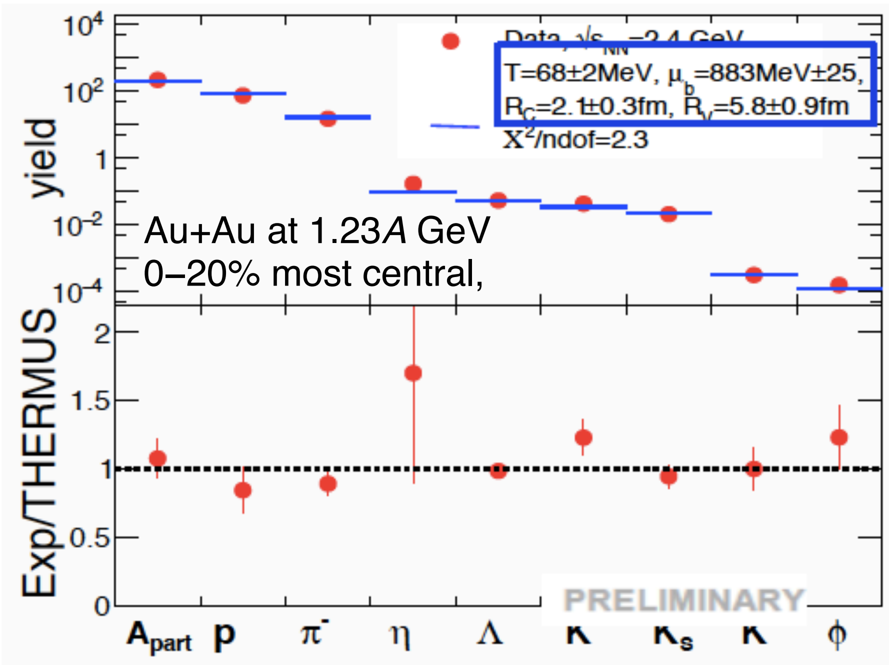
Almost no rare strange (anti-)particles (Ξ^-, Ω^-) at low energies

4π data available

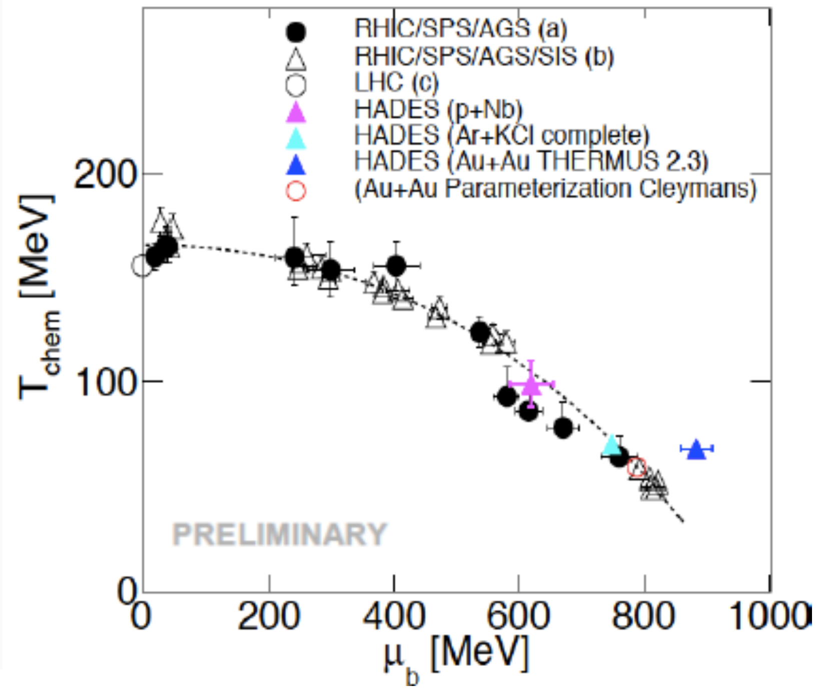


Overview on Strangeness Measurements

SIS-18: HADES Data Compared to Statistical Model



R. Holzmann SQM2016 | SHM: S. Wheaton et al. CPC180, 84 (2009)



Quite extensive data set!

T and μ_B right now above expectation from freeze-out curve …

Overview on Strangeness Measurements

SIS-18: HADES Data on ϕ Meson

Φ/K⁻-ratio

Rapid rise towards low energies

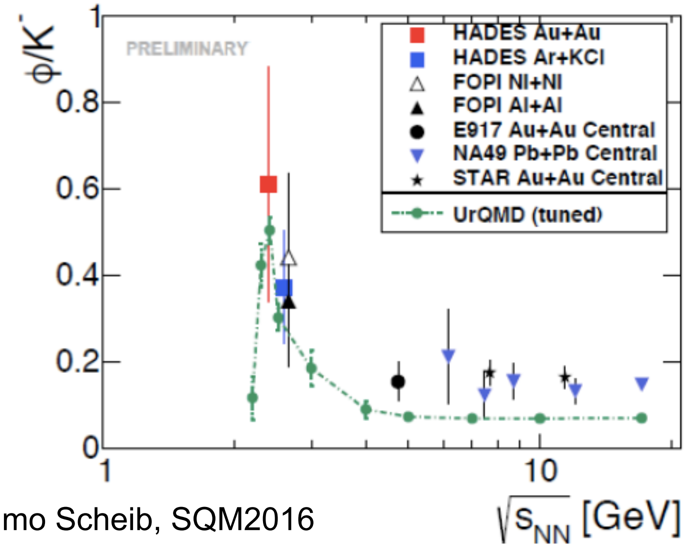
Qualitatively predicted by statistical model

Described my (modified) UrQMD

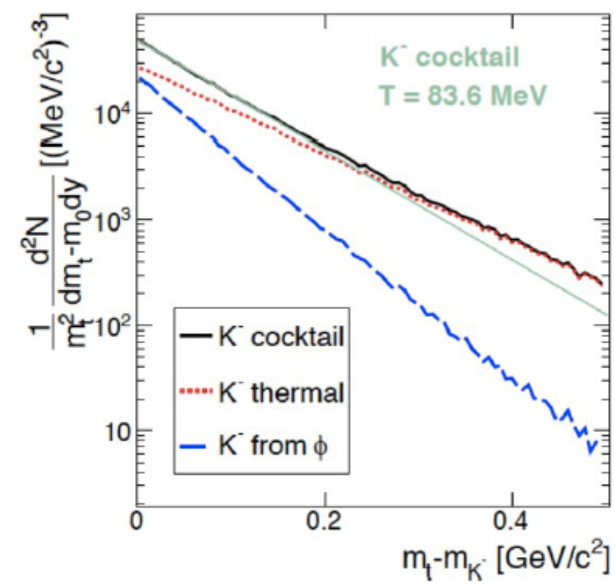
Feeddown into kaons

Can explain the different slope parameters of K^+ and K^-

Important role of ϕ at low energies



Timo Scheib, SQM2016



Global Λ Polarization

Basic Idea

Polarization of quarks

Coupling of system orbital momentum $\vec{L}$ to spins of (anti-)quarks in QGP
(for non-central A+A collisions)

Might survive hadronization as a polarization of hadrons

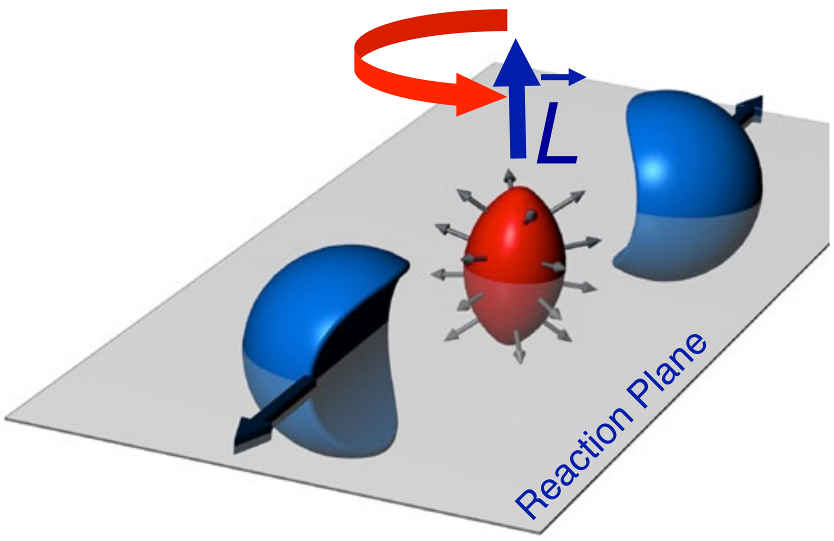
Λ polarization P_H

Relative to the reaction plane

α_H = Hyperon decay parameter
θ^* = Angle between momentum of daughter (anti-)proton in Λ frame relative to $\vec{L}$

Standard technique for event plane determination

$\Psi_{EP}^{(1)}$ = Event plane angle
$R_{EP}^{(1)}$ = Event plane resolution
ϕ_p^* = Azimuthal angle relative to EP



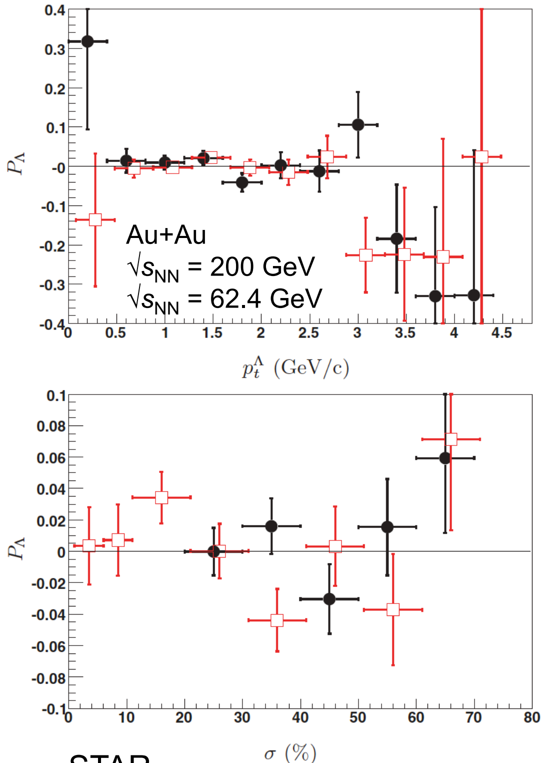
Globally polarized QGP
Z. Liang and X.N. Wang,
PRL94 (2005) 102301

$$\frac{dN}{d\cos\theta^*} \propto 1 + \alpha_H P_H \cos\theta^*$$

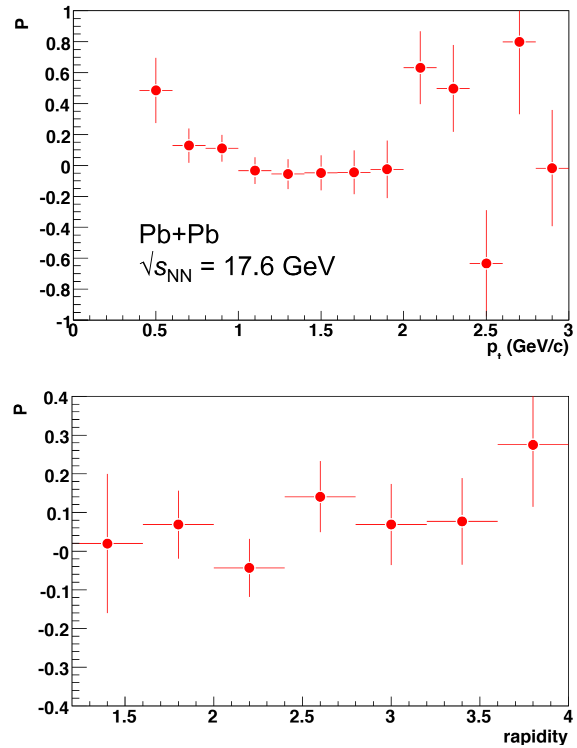
$$P_H = \frac{8}{\pi\alpha_H} \frac{\langle \sin(\phi_p^* - \Psi_{EP}^{(1)}) \rangle}{R_{EP}^{(1)}}$$

Global Λ Polarization

Previous Measurements



STAR
PRC76 (2007) 024915



NA49
JPG35 (2008) 044004

No significant signal observed at SPS and RHIC

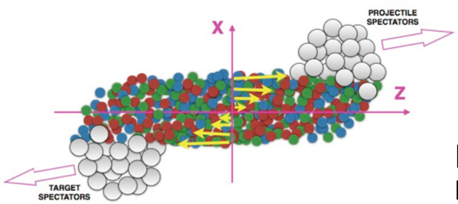
First attempts, limited statistics at SPS (no systematic errors!)

Global Λ Polarization

Access to Vorticity and Magnetic Field Strength

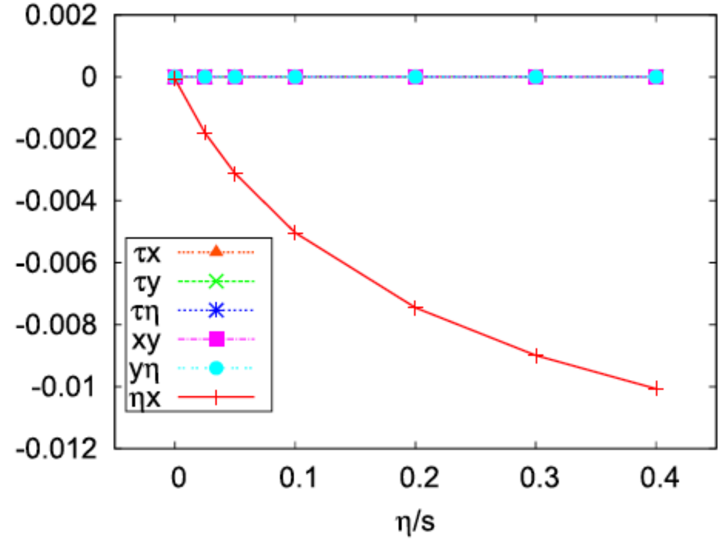
Viscous hydro calculations

Vorticity: $\vec{\omega} = \vec{\nabla} \times \vec{v}$



F. Becattini et al.,
EPJC75 (2015) 406

Non-vanishing vorticity along initial angular momentum for $\eta/s > 0$



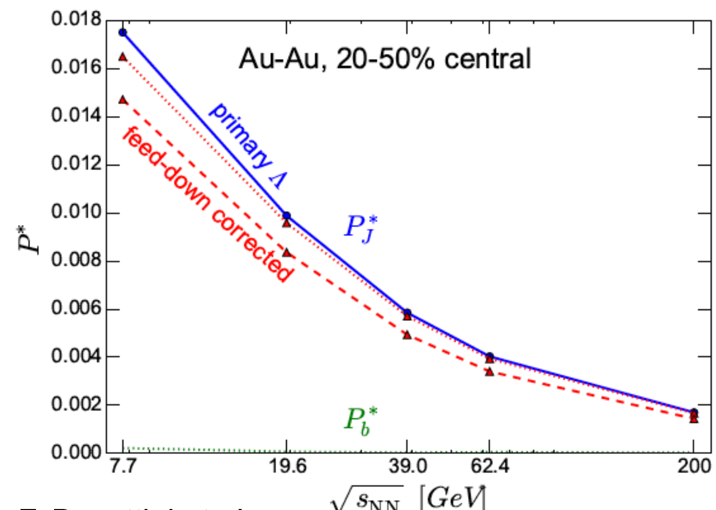
Energy dependence

E-by-E UrQMD+vHLLE calculation

Strong energy dependence of integrated polarization vector P_J^*

Shorter fluid lifetime + stronger directed flow

Feed-down from resonance decays



F. Becattini et al.,
arXiv:1610.02506, arXiv:1610.04717

Global Λ Polarization

Previous Measurements

First observation: STAR-BES

Positive polarization in
non-central Au+Au collisions

Resolution corrected

Energy dependence

Increase towards lower energies

Splitting between Λ and $\bar{\Lambda}$?

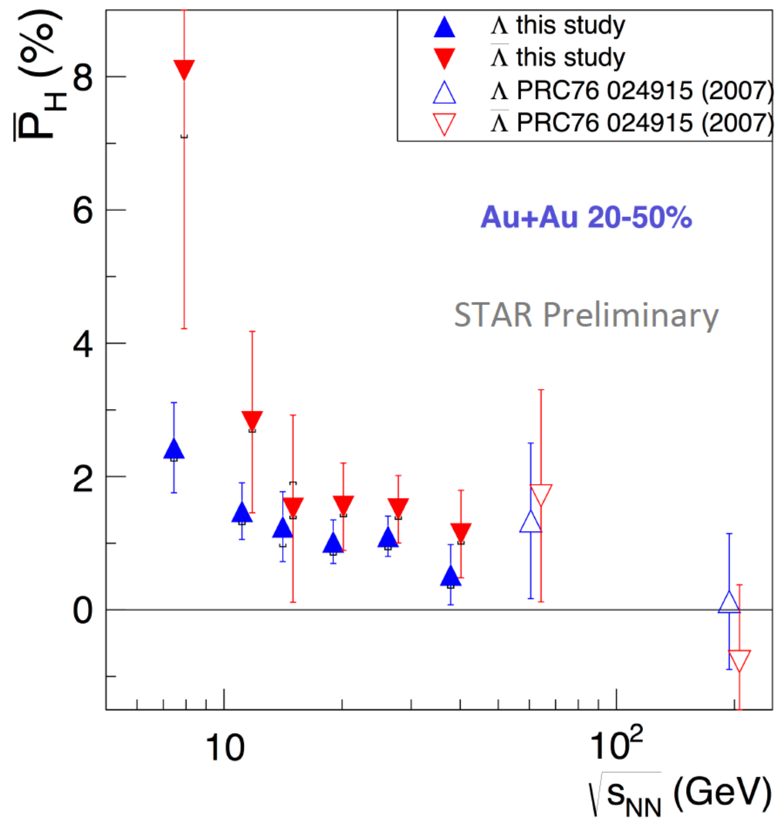
Magnetic component: P_M
Vortical component: P_V

$$P_{\Lambda,prim} = P_V + P_M \quad \Leftrightarrow \quad P_{\bar{\Lambda},prim} = P_V - P_M$$

Model interpretation

Feed-down correction (model-dep.)
⇒ magnetic component ≈ 0
$B[10^{14}\mathrm{T}] \approx \bar{P}_M[\%]$ expected

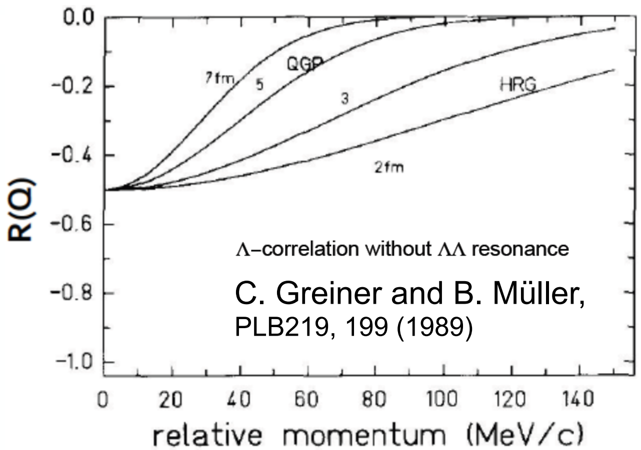
Thermal vorticity
$\omega \approx$ 0.02−0.16 fm^{-1} (for T = 200 MeV)



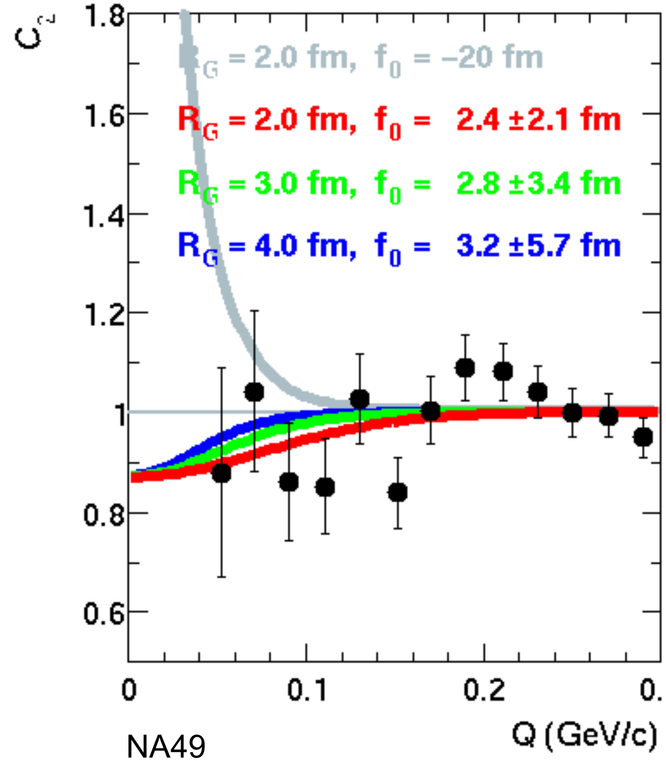
STAR
Mike Lisa SQM16

Hyperon Interaction
ΛΛ Correlations

ΛΛ correlation function
Information on ΛΛ interaction can be extracted from two-particle c.f.



Experimental challenge
High statistics on low-*Q* pairs needed



NA49
NPA715, 55c (2003)

Hyperon Interaction

ΛΛ Correlations

High statistics measurement

Corrected ΛΛ two-particle c.f. obtained by STAR:

$$C'(Q) = \frac{C_{measured}(Q) - 1}{P(Q)} + 1$$

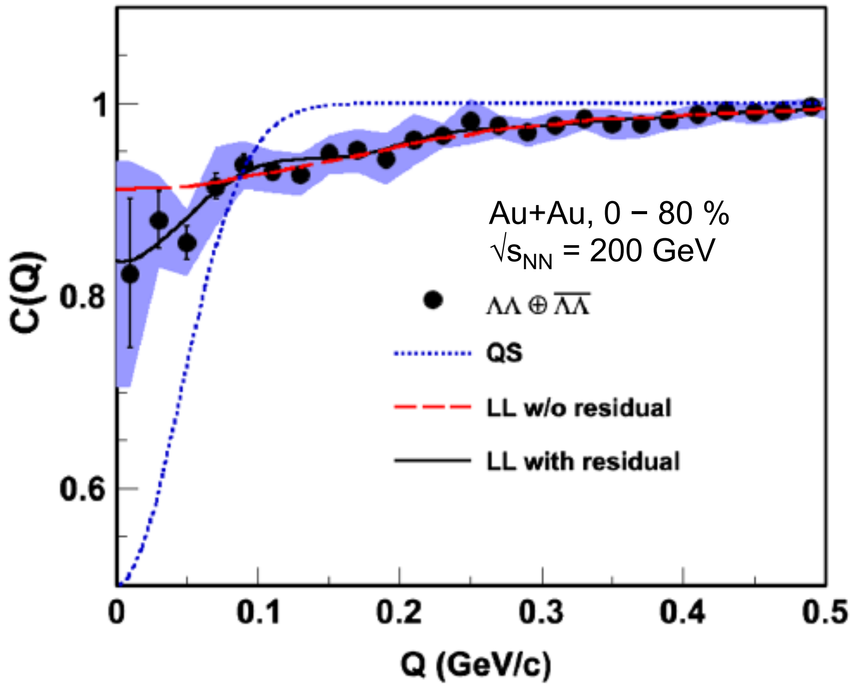
Corrections: Λ purity ($P(Q)$)

Feed down: $\Sigma^0\Lambda$, $\Sigma^0\Sigma^0$, $\Xi^-\Xi^-$ interaction not known
⇒ effect not subtracted here

Effects in ΛΛ c.f.

Quantum statistics ⇒ anti-correlation

Strong interaction between ΛΛ pairs
⇒ $C(Q = 0) \neq 0.5$



STAR
PRL114, 022301 (2015)

Hyperon Interaction

Strong Interaction between Λs

ΛΛ scattering length

Fit with Lednicky-Lyuboshitz model

Parameters:

S-wave scattering length a_0

Effective radius r_{eff}

Emission radius r_0

(Normalization N and suppr. par. λ)

Term for residual correlations (a_{res}, r_{res})

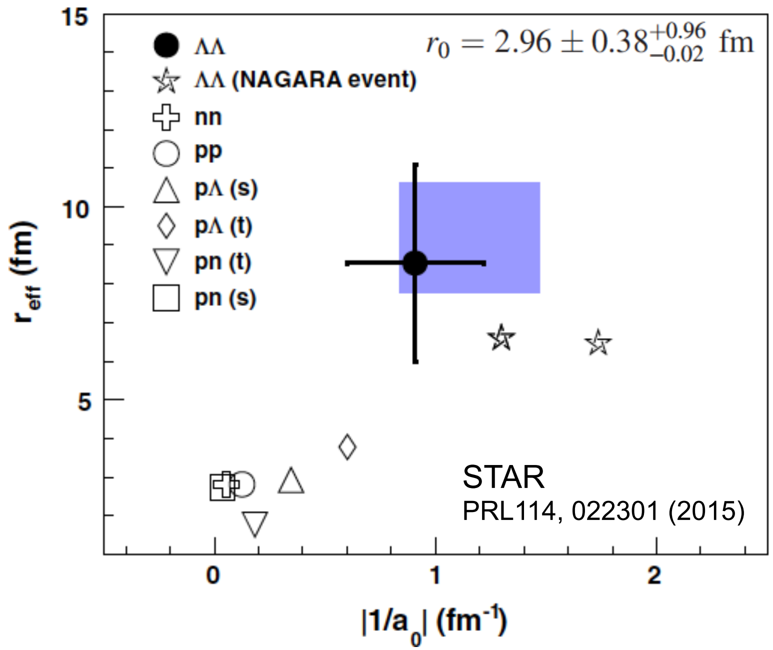
Interaction is weak

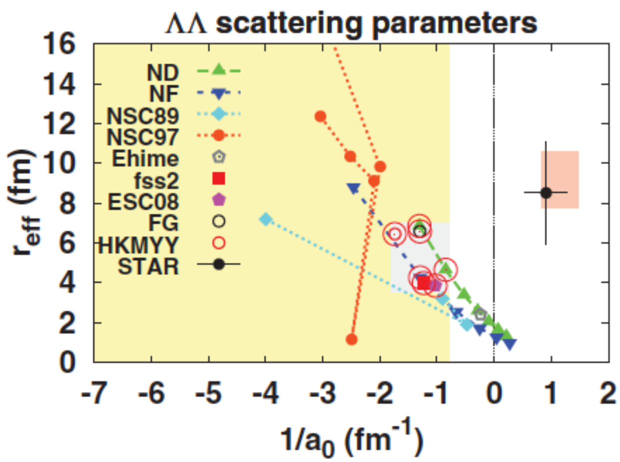
$|a_{\Lambda\Lambda}| < |a_{p\Lambda}| < |a_{NN}|$

Sign not yet conclusive

Fit suggests weak repulsive interaction

Morita et al. favor weak attraction (radial expansion included)





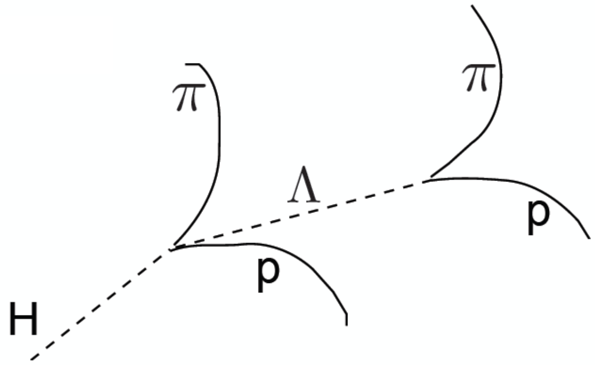
K. Morita et al. PRC91, 024916 (2015)

Hyperon Interaction

Direct Searches for H-Dibaryon

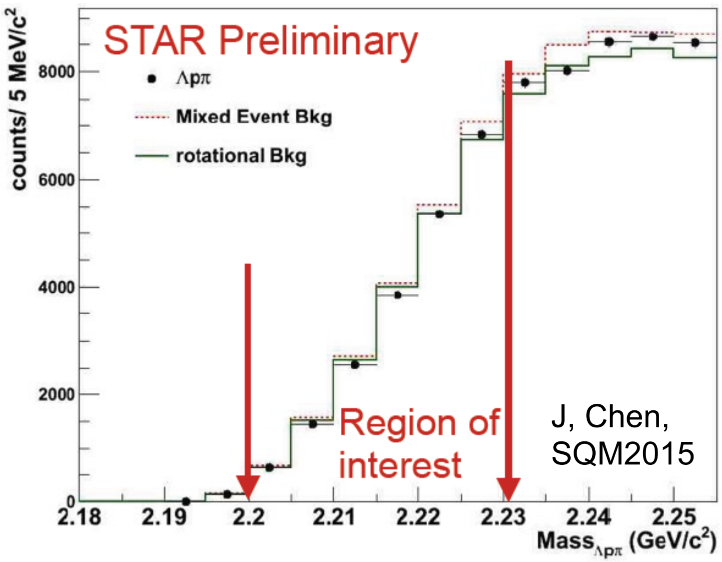
Invariant mass studies

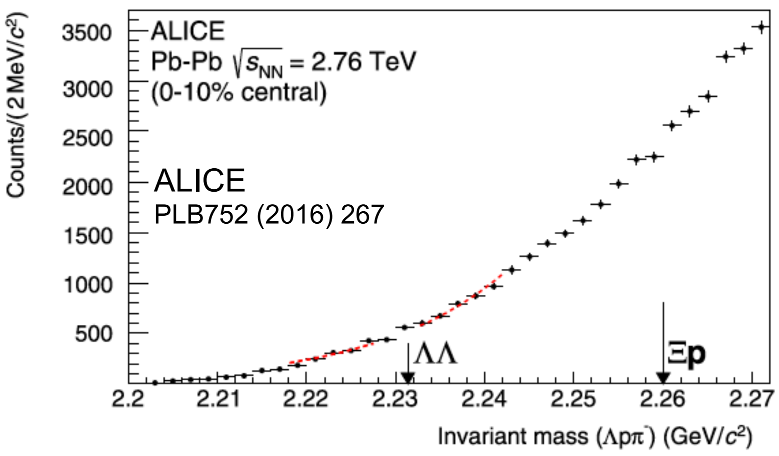
Topological reconstruction of πpΛ



No signals observed

STAR and ALICE data





Hyperon Interaction

Direct Searches for H-Dibaryon

Extraction of upper limits

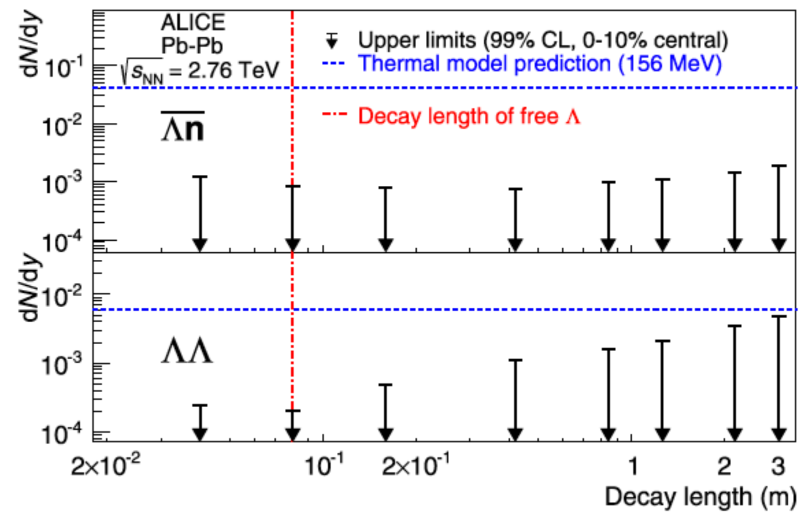
Λ-bound states: ΛΛ and $\overline{\Lambda n}$

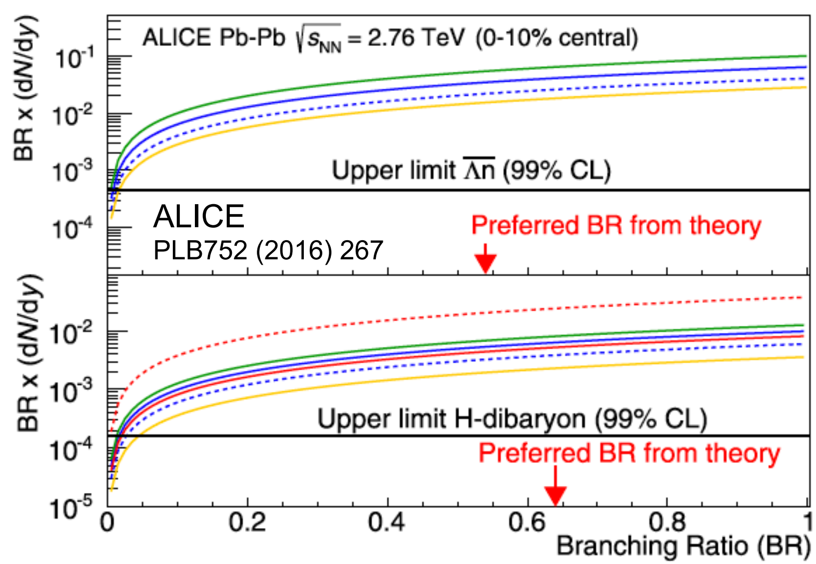
$\underline{H} \rightarrow \Lambda\, \underline{p}\, \pi^-$

$\overline{\Lambda n} \rightarrow \overline{d}\, \pi^+$

Upper limits as function of lifetime and branching ratios

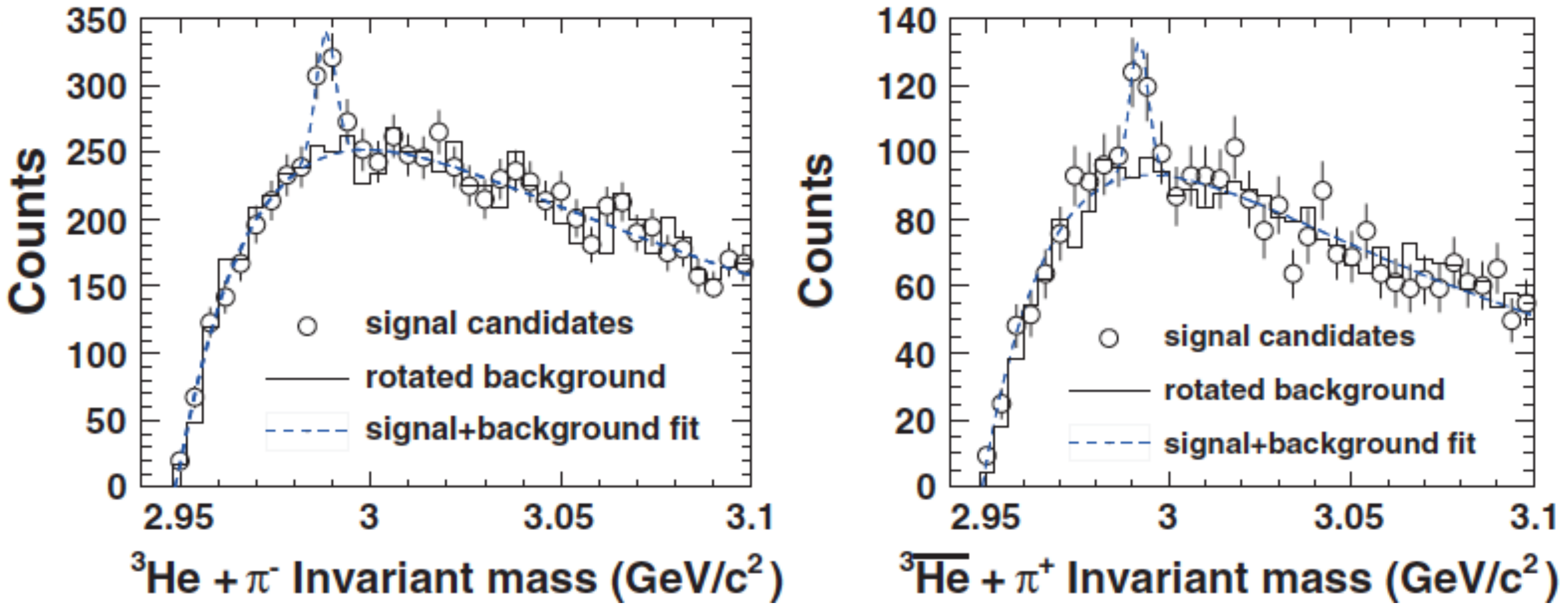
Theory expectations from thermal model (eq. and non-eq.), hybrid UrQMD, and coalescence model (for H-dibaryon)





Hypernuclei

Hypertriton Measurement by STAR



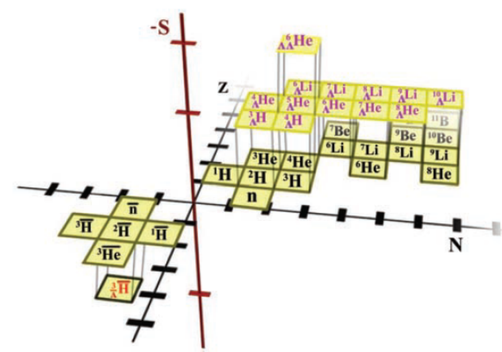
STAR
Science vol.328, 58 (2010)

First observation of an anti-hypernucleus

Extends chart of nuclei

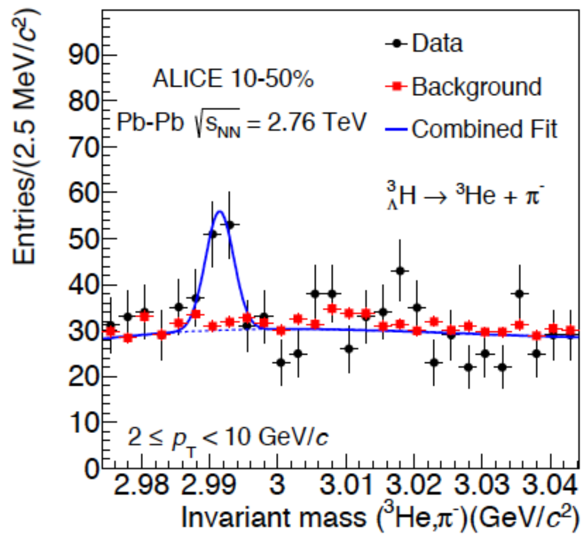
Bound Λ-nucleon states

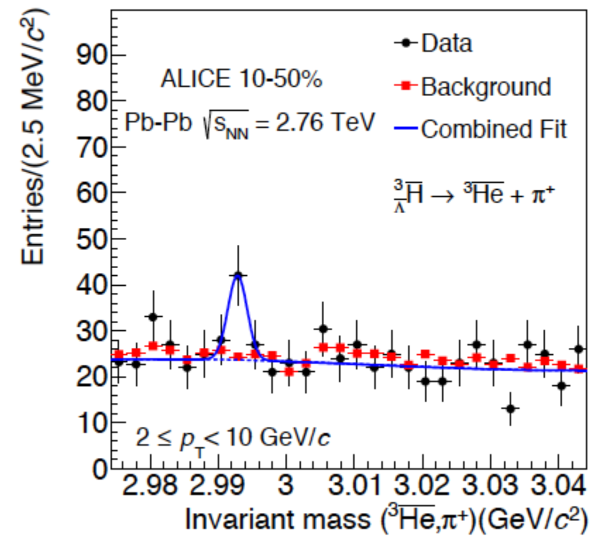
Good agreement with thermal model expectation in contrast to ΛΛ and $\overline{\Lambda\text{n}}$



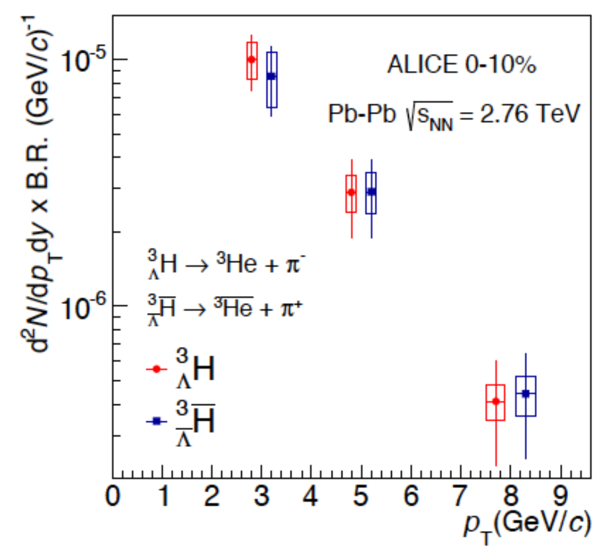
Hypernuclei

Hypertriton Measurement by ALICE





ALICE
arXiv:1506.08453

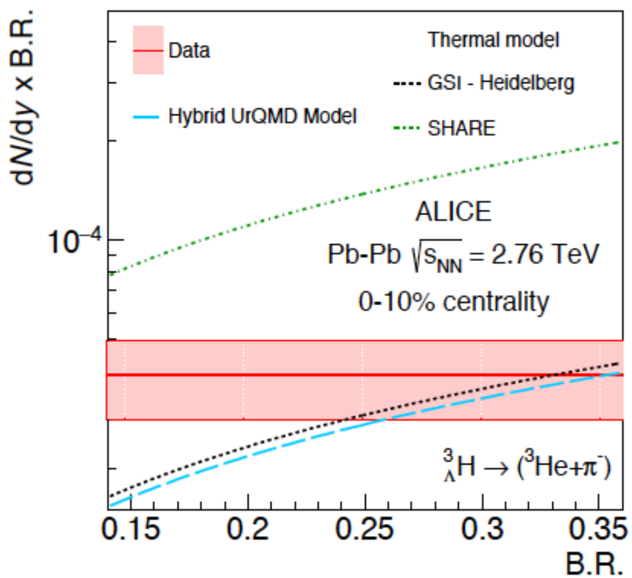


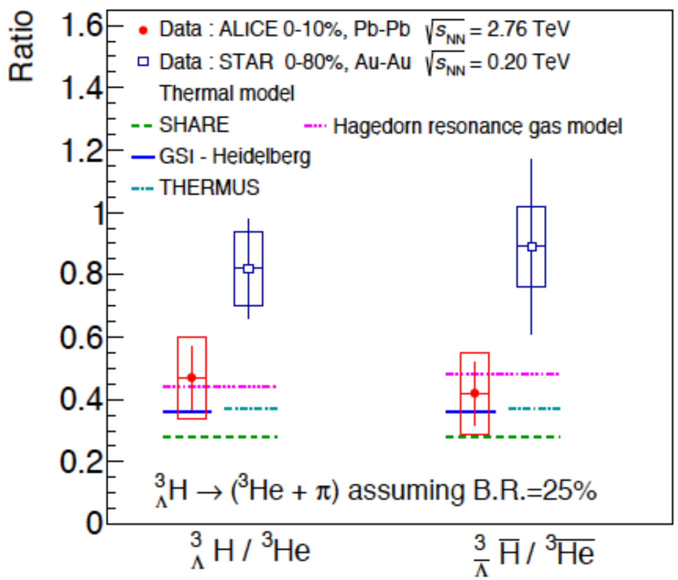
Same yield of hypertriton and anti-hypertriton

p_T dependence measured

Hypernuclei

Hypertriton Measurement by ALICE





ALICE
arXiv:1506.08453

Yield of hypertriton

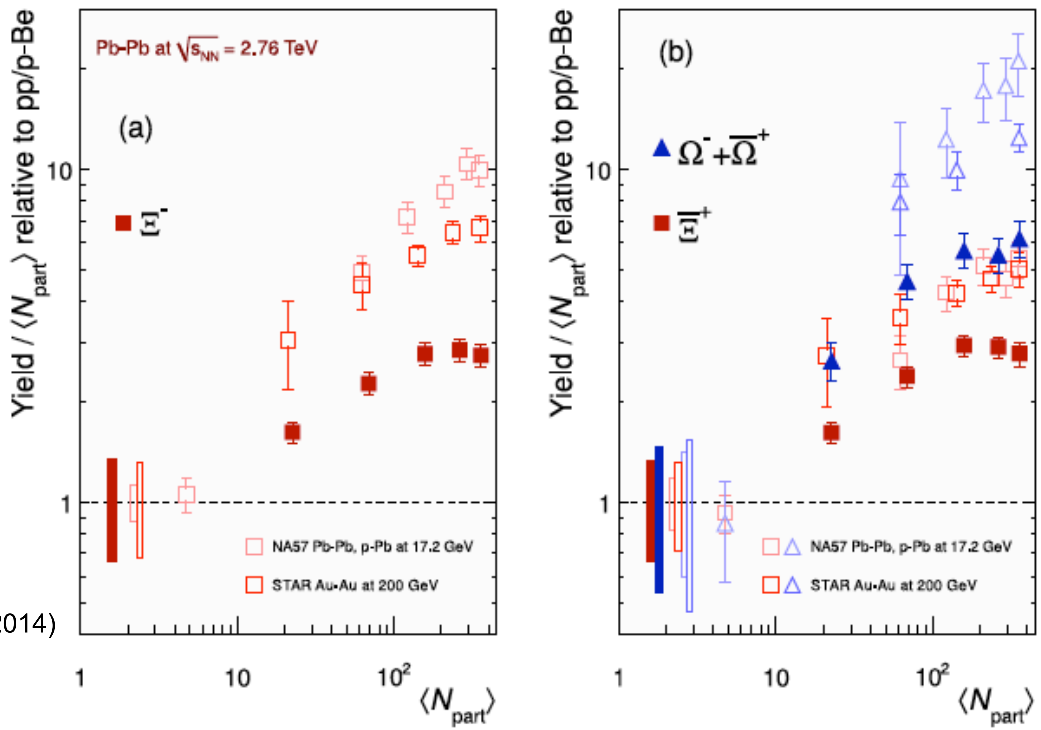
Good agreement with equilibrium thermal models and hybrid UrQMD

Ratio hypertriton/^{3}He

Good agreement with thermal model expectations

Small Systems

LHC Data (ALICE) on Strangeness Enhancement



ALICE
PLB728, 216 (2014)

Enhancement factor

Relative to p+p

$$E = \frac{2}{\langle N_{part} \rangle} \left[\left. \frac{dN(Pb+Pb)}{dy} \right|_{y=0} \Big/ \left. \frac{dN(p+p)}{dy} \right|_{y=0} \right]$$

Enhancement for Ω factor ≈ 6

Small Systems

Energy Dependence of pp Data

Ratio strange/non-strange

Hyperon-to-pion ratios

Increase with $\sqrt{s}$ stronger in pp than in A+A

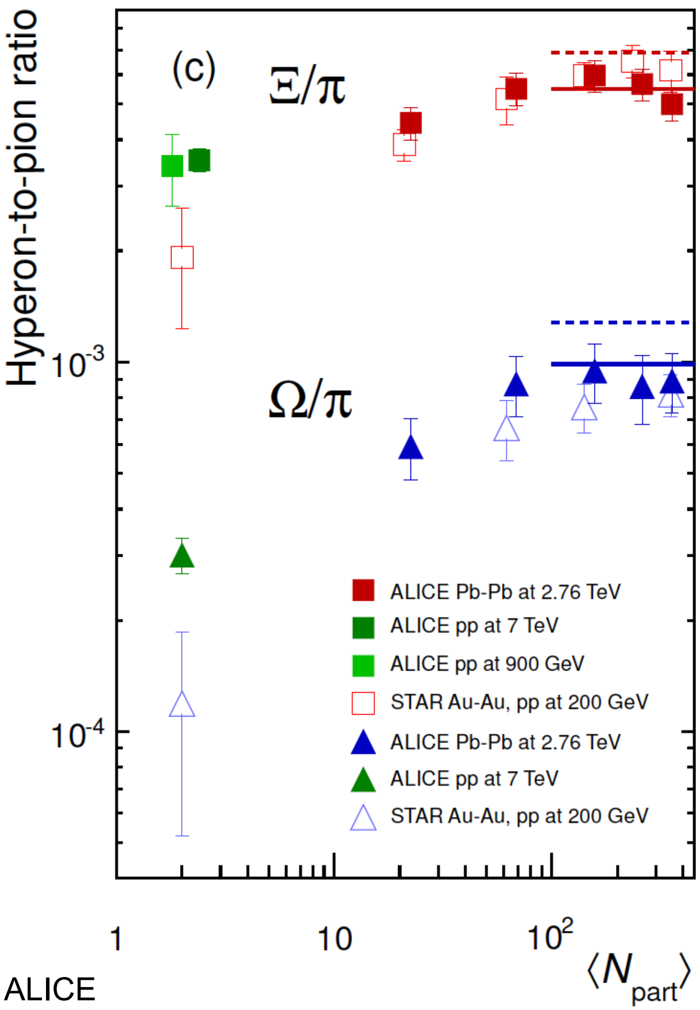
AA: $\Xi/\pi(\text{LHC}) \approx \Xi/\pi(\text{RHIC})$

$\Omega/\pi(\text{LHC}) \gtrsim \Omega/\pi(\text{RHIC})$

pp: $\Xi/\pi(\text{LHC}) > \Xi/\pi(\text{RHIC})$

$\Omega/\pi(\text{LHC}) \gg \Omega/\pi(\text{RHIC})$

Strangeness-suppression in pp released at high energies



ALICE
PLB728, 216 (2014)

Small Systems

Particle Ratios in Proton-Nucleus: Ξ/π and Ω/π

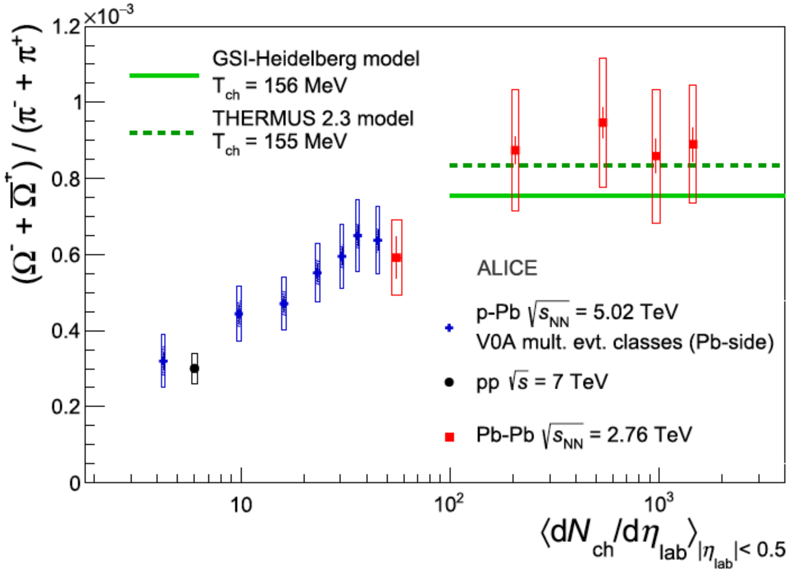
Multiplicity Dependence

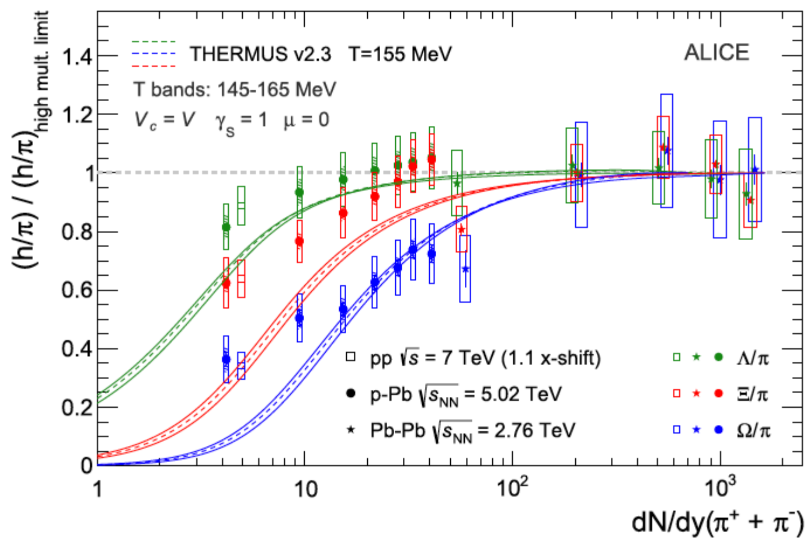
p-Pb provides qualitative connection between pp and Pb-Pb also for multistrange particles

Better scaling with multiplicity density?

Reaches level of statistical model (GC) expectation

ALICE
PLB758 (2016) 389





Small Systems

Particle Ratios in pp, p-Pb and Pb-Pb Compared

Multiplicity Dependence

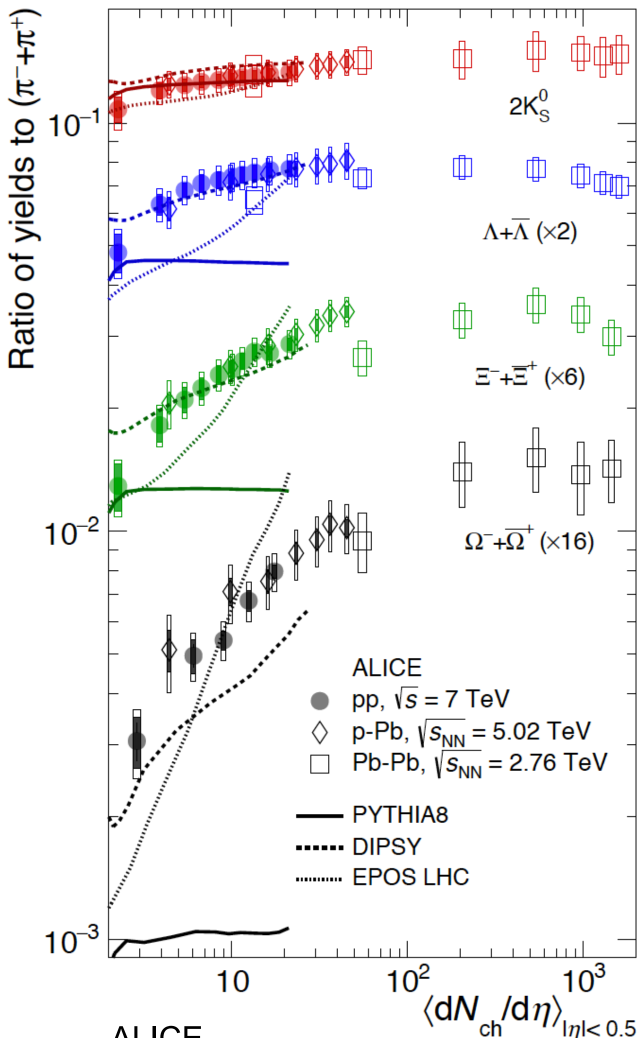
pp event classes, measure of reaction violence: $\langle dN_{ch}/d\eta \rangle$

Similar dependence than in p-Pb! Not trivial, since physics in high mult. pp ≠ high mult. p-Pb

Overlap with peripheral Pb-Pb (K^0_s, Λ)

Universal scaling

Strangeness enhancement evolves with multiplicity dependence



ALICE
arXiv:1606.07424

Small Systems

Particle Ratios in pp and p-Pb Compared

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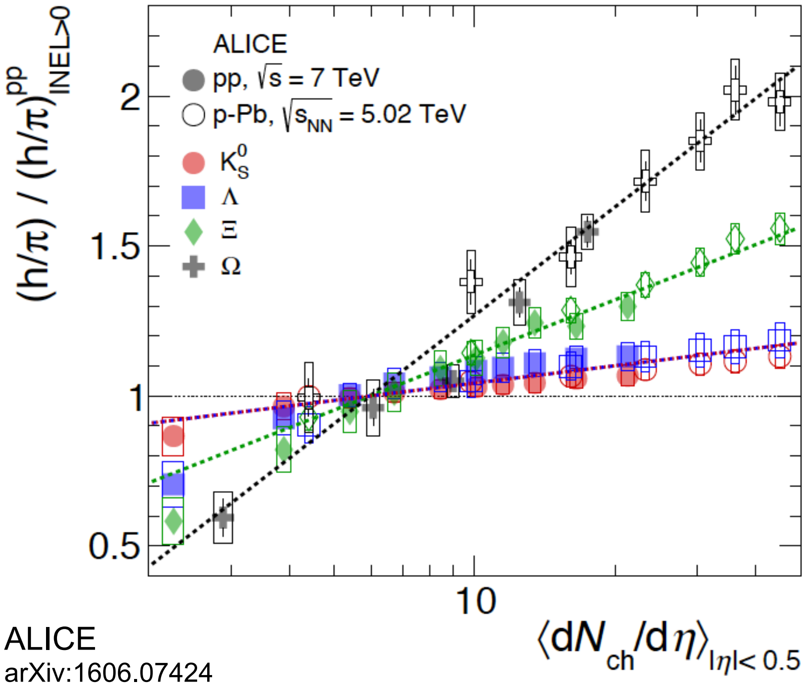
Strangeness hierarchy

Stronger multiplicity dependence for higher strangeness content



ALICE
arXiv:1606.07424

Small Systems

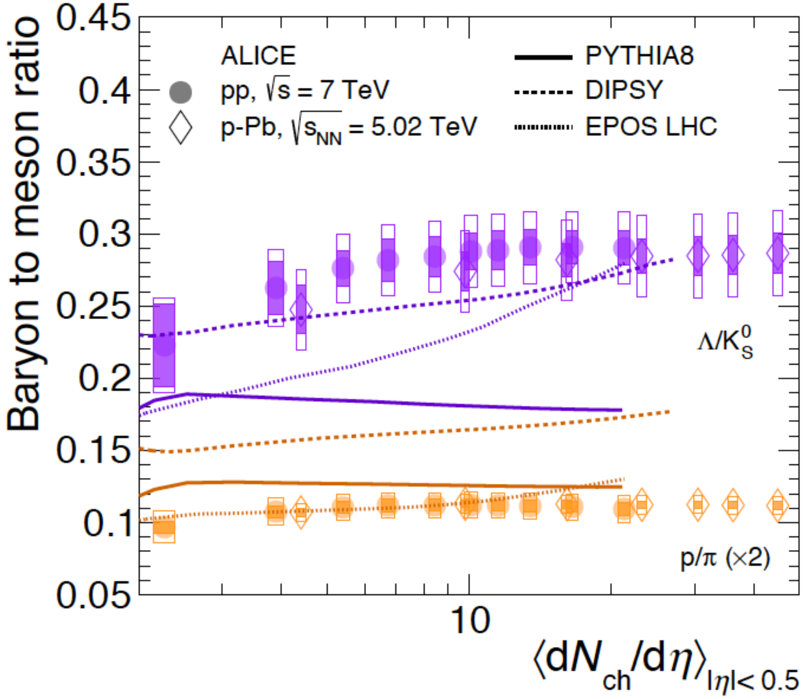
Particle Ratios in pp and p-Pb Compared

Multiplicity Dependence

Λ/K^0_s and p/π

Common evolution with $\langle dN_{ch}/d\eta \rangle$

Ratios show no strong increase
⇒ not mass related,
but depends on strangeness content



ALICE
arXiv:1606.07424

Small Systems

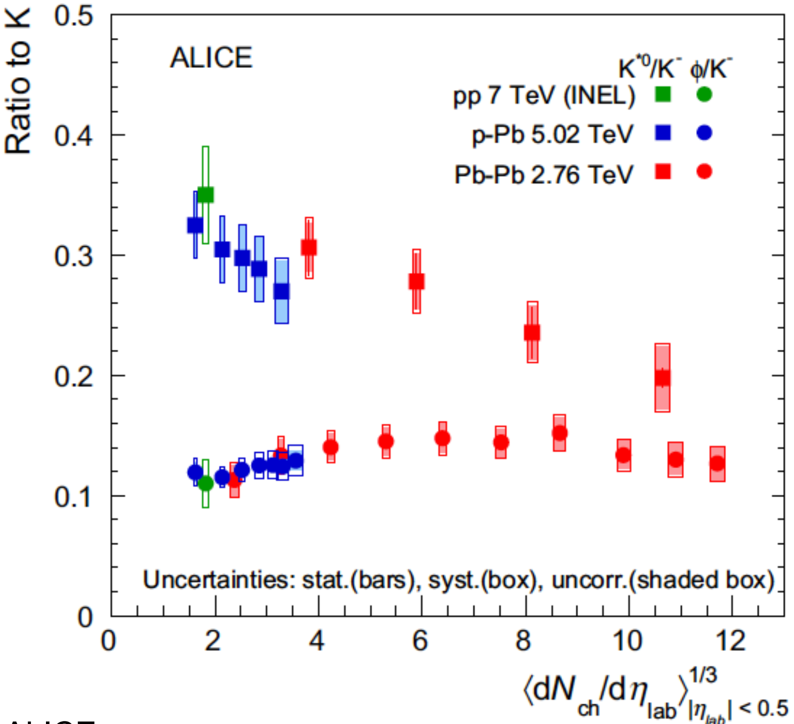
Particle Ratios in pp, p-Pb and Pb-Pb Compared

Multiplicity Dependence

p-Pb provides qualitative connection between pp and Pb-Pb also for resonances

Stronger suppression at higher multiplicity densities for K* (rescattering)

No suppression for ϕ



ALICE
EPJC76 (2016) 245

Small Systems

Particle Ratios in pp, p-Pb and Pb-Pb Compared

Multiplicity Dependence

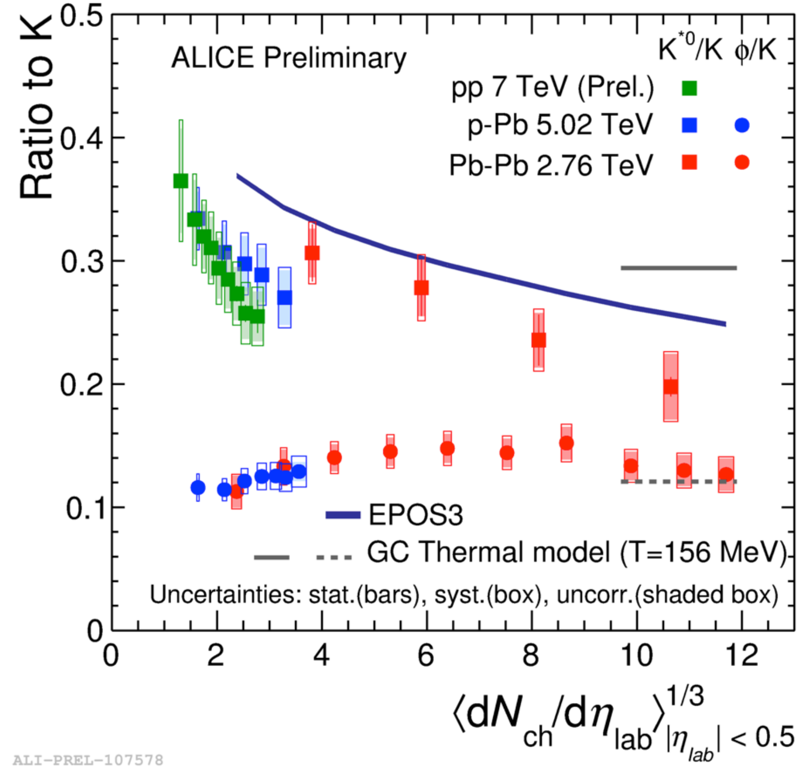
p-Pb provides qualitative connection between pp and Pb-Pb also for resonances

Stronger suppression at higher multiplicity densities for K* (rescattering)

No suppression for ϕ

Stronger trend seen in pp!

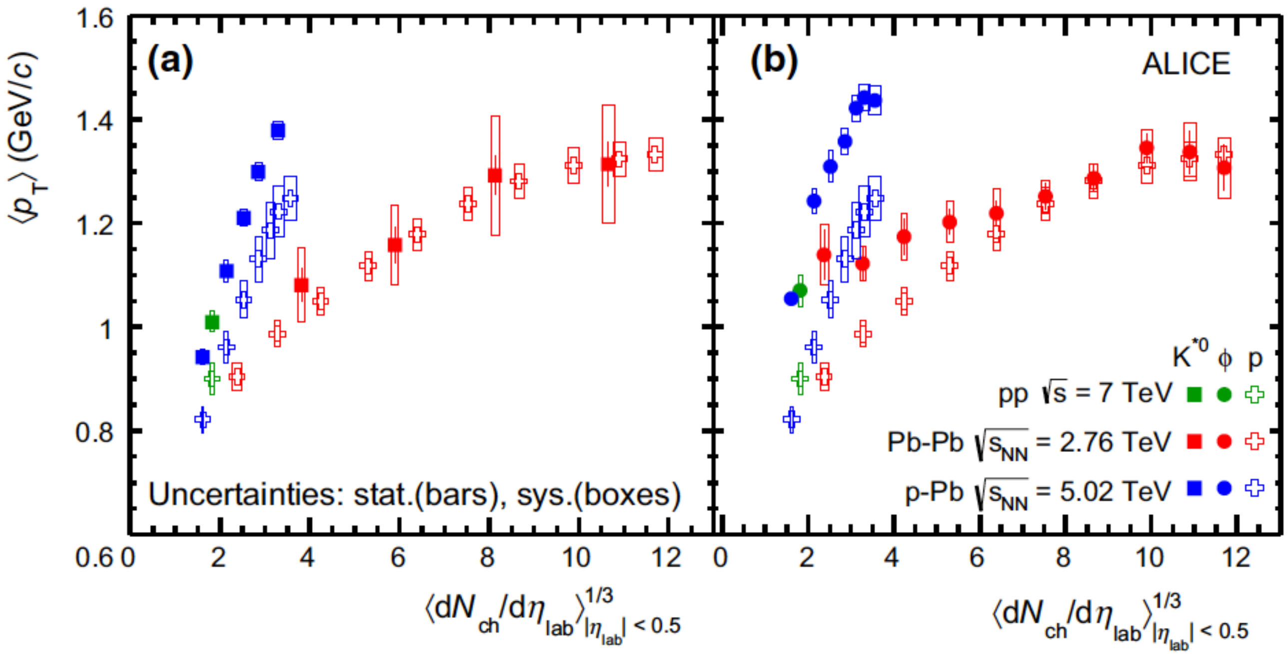
Different physics …



ALICE
Anders Knospe, SQM16

Small Systems

$\langle p_T \rangle$ in pp, p-Pb and Pb-Pb Compared



ALICE
EPJC76 (2016) 245

No universal scaling for dynamical quantities

$\langle p_T \rangle_{\text{p-Pb}} > \langle p_T \rangle_{\text{Pb-Pb}}$ at the same $\langle dN_{ch}/d\eta \rangle$, also true for higher moments

Small Systems

Side Remark: J/ψ vs Multiplicity in pp

Multiplicity Dependence

Similar strong increase of relative J/ψ yield with multiplicity density

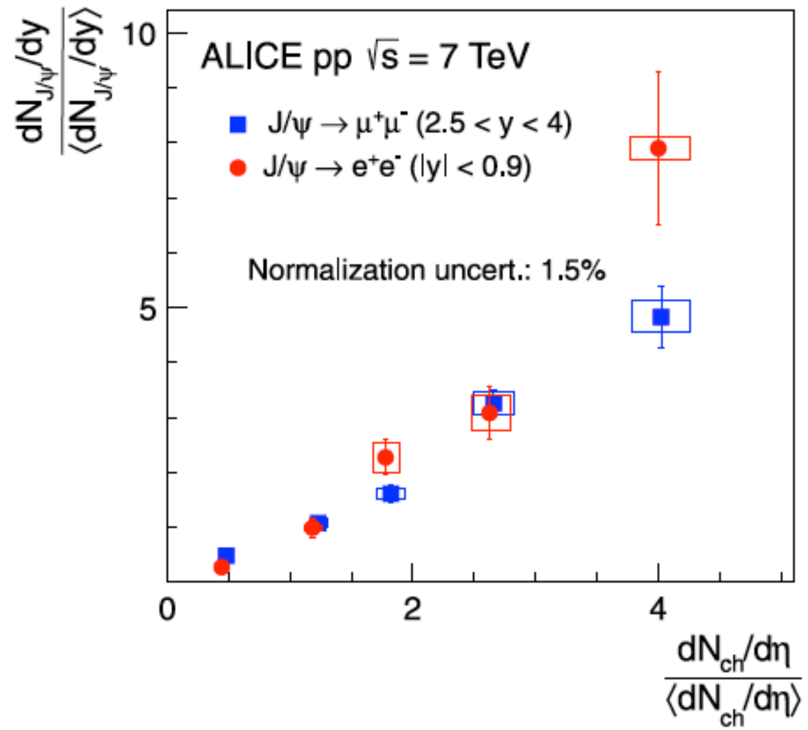
Comparable to p-Pb (not public yet)

Similar for open charm!

Interplay soft+hard physics

dN_{ch}/dη: soft scale, described via Multi Parton Interactions (MPI)

J/ψ production: hard scale, also affected by MPI ?



ALICE
PLB712 (2012) 165

Small Systems

Side Remark: J/ψ vs Multiplicity in pp

Multiplicity Dependence

Similar strong increase of relative J/ψ yield with multiplicity density

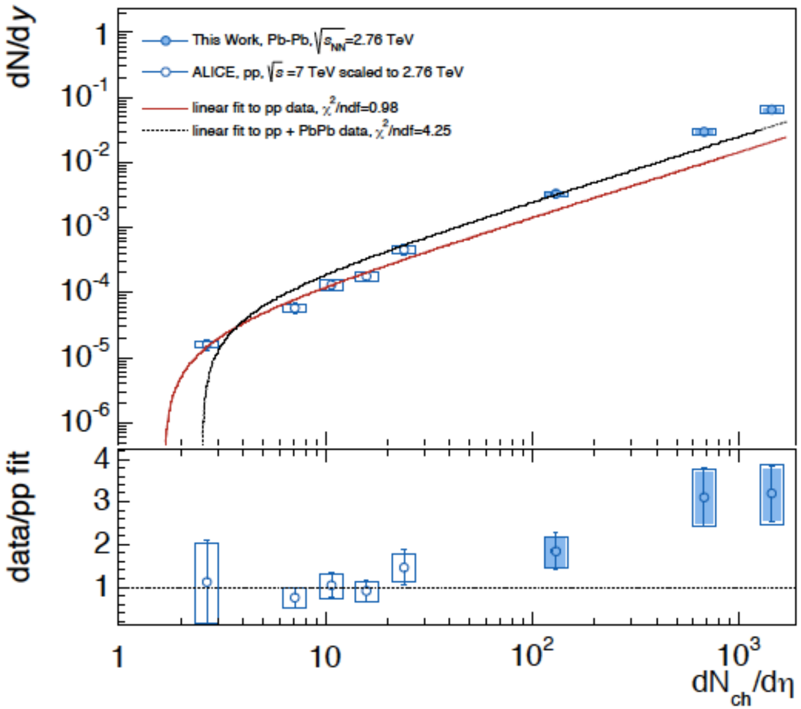
Comparable to p-Pb (not public yet)

Similar for open charm!

Connection to Pb-Pb?

Maybe also not so bad …

Add p-Pb data



Julian Book
PhD Thesis

Conclusions

Lots of new and precise data in the last few years
At high **and low** energies!

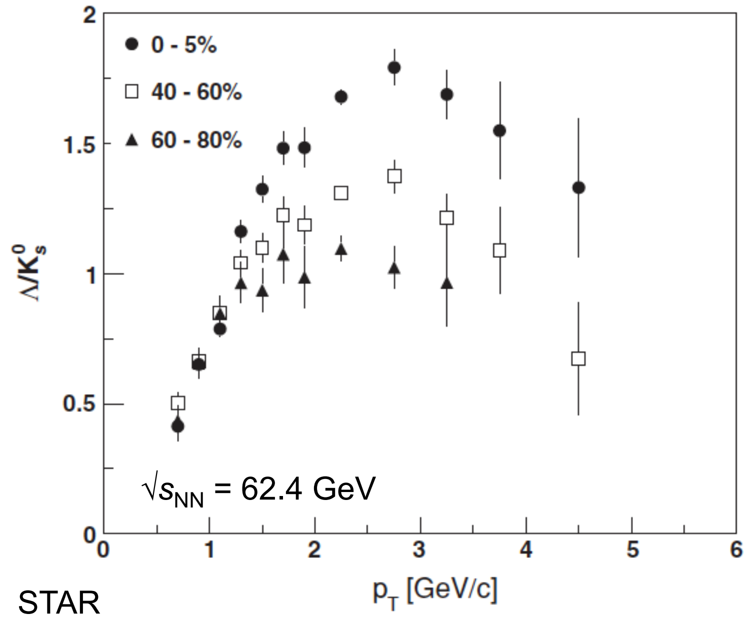
New topics (re-)appear
Global Λ polarization ⇒ 1st significant measurement
ΛΛ interaction: information from correlation measurements
Hypernuclei measurements

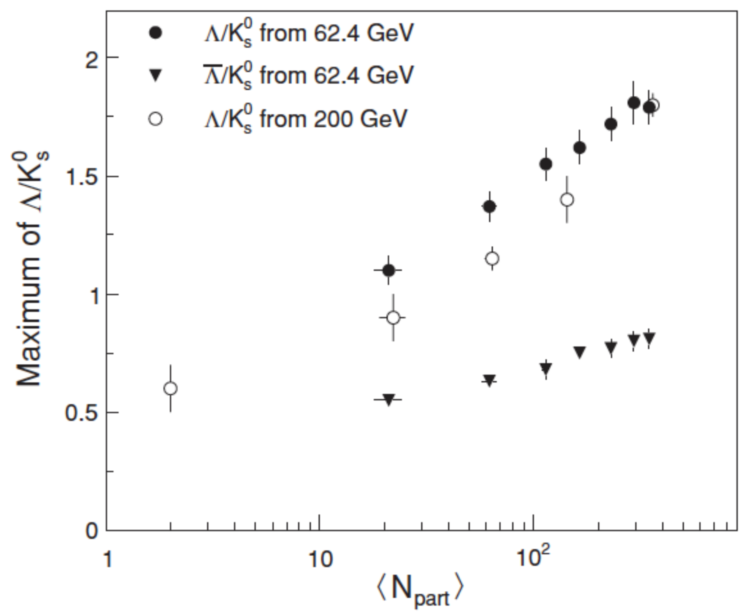
Interesting results from small systems at high energies
Smooth evolution of strangeness enhancement with multiplicity density
Same for Pb-Pb, p-Pb and **pp**!
However, does not work for all observables

Baryon-Meson comparisons
Sign of recombination or hydrodynamic flow?
Indication for change of medium properties around $\sqrt{s_{NN}} \leq 14.5$ GeV?

Baryon-Meson

Λ/K^0_s-Ratio vs p_T at RHIC



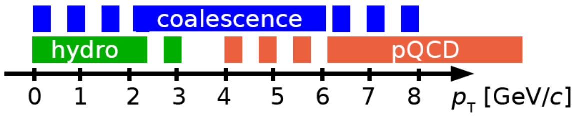


STAR
PRC83, 024901 (2011)

Physics of intermediate p_T region

Dominance of baryon production ⇒ Λ/K^0_s > 1 for 1.5 < p_T < 4 GeV/c

Recombination



Hydro flow

Other (baryons as color singlet, transparent to final state interactions)

S. Brodsky and A. Sickles, PLB668, 111 (2008)

Baryon-Meson

$\bar{\Lambda}/K^0_s$-Ratio vs p_T at RHIC

Energy dependence

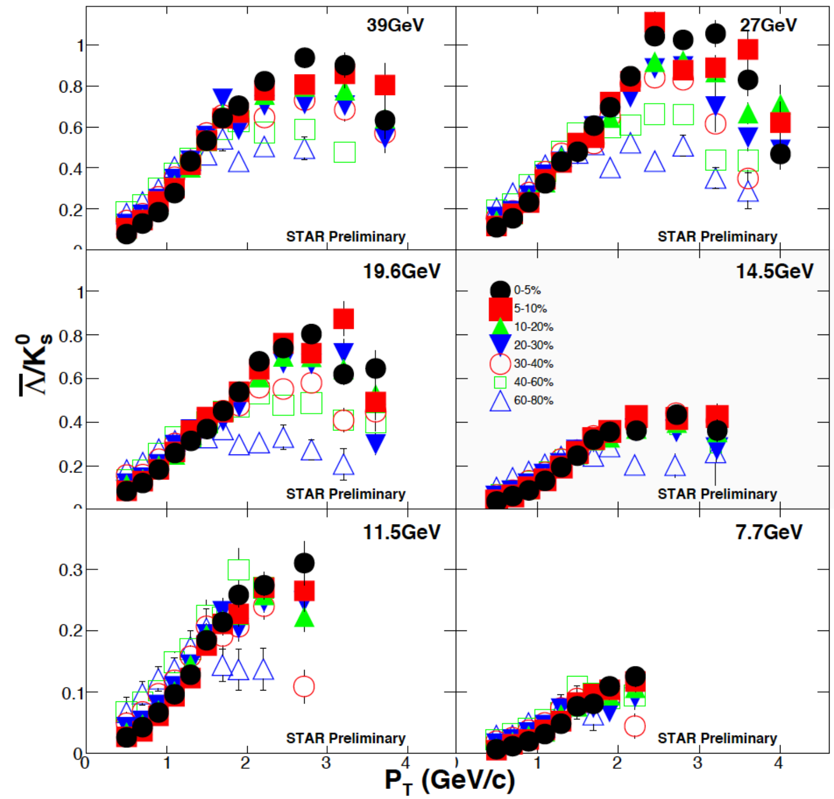
Maximum in Λ/K^0_s-ratio decreases with decreasing energy

Centrality dependence seems to get weaker

Medium properties

Transition around $\sqrt{s_{NN}} \leq 14.5$ GeV? Or rather smooth evolution?

⇒ More statistics needed



STAR
Shusu Shi SQM16

Baryon-Meson

v_2 of Antiparticles at RHIC

Energy dependence

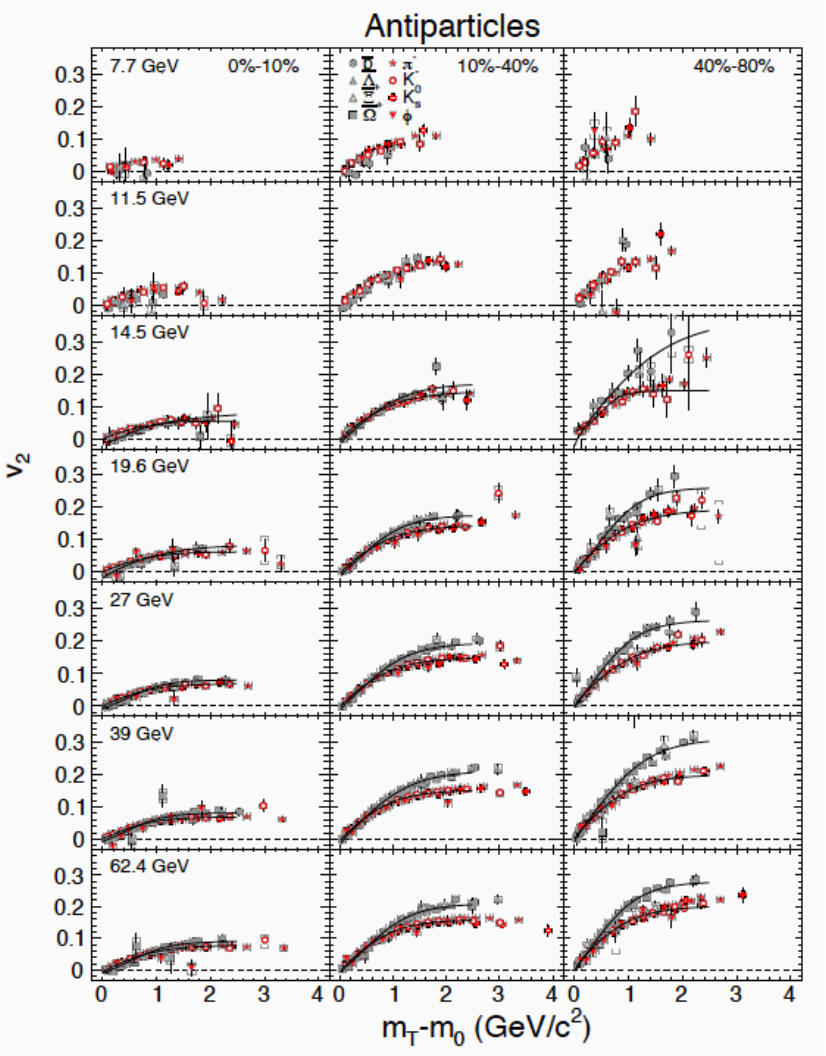
Many different anti-baryons analyzed

Splitting between baryon and meson seen for $\sqrt{s_{NN}}$ > 11.5 GeV

Medium properties

Transition around $\sqrt{s_{NN}} \leq$ 14.5 GeV?
Or rather smooth evolution?

⇒ More statistics needed



STAR
PRC93 (2016) 014907

Baryon-Meson

Λ/K^0_s-Ratio vs p_T at LHC

Same baryon dominance

Height of maximum similar to RHIC
$(\Lambda/K^0_s)_{max} \approx 1.5$

Position of maximum
shifted to slightly higher p_T

Strong centrality dependence
pp: $(\Lambda/K^0_s)_{max} \approx 0.5$

High p_T (> 7 GeV/c)

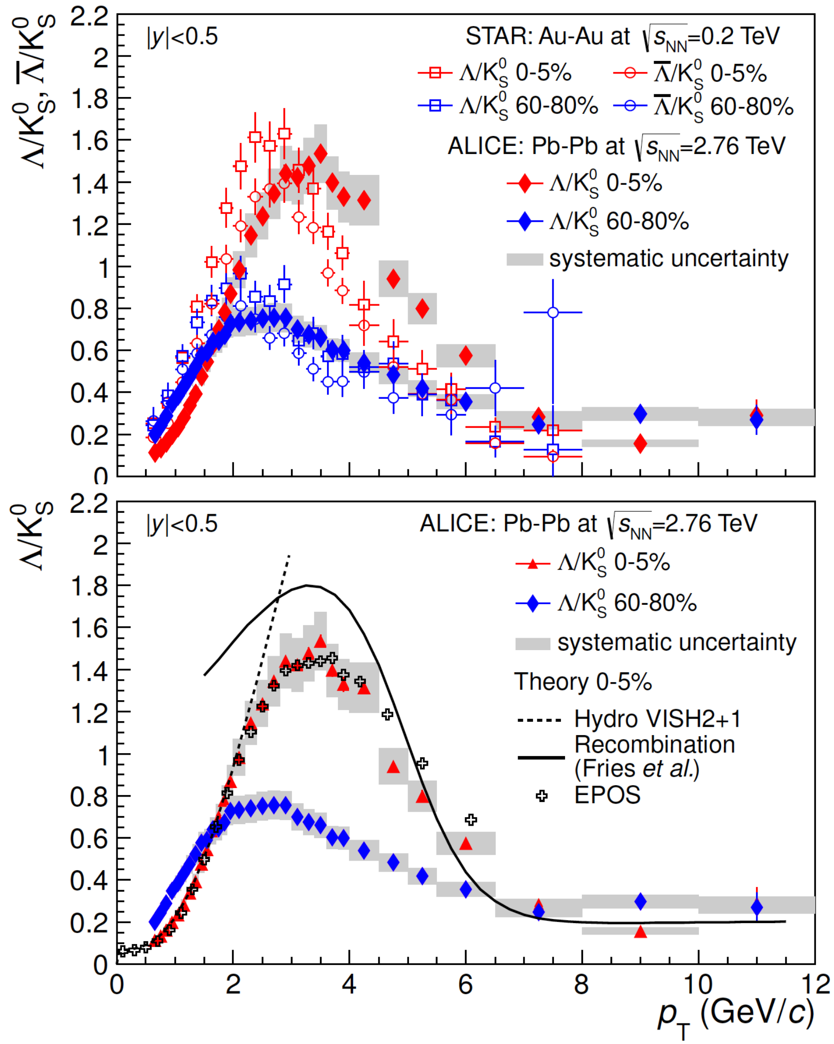
Ratio the same in pp and A+A (~ 0.3)

Model comparisons

Hydro works up to $p_T \approx 2$ GeV/c

Recombination model describes shape, but overestimates ratio

Good description by EPOS



ALICE
PRL111, 222301 (2013)

Baryon-Meson

Λ/K^0_s-Ratio vs p_T at LHC

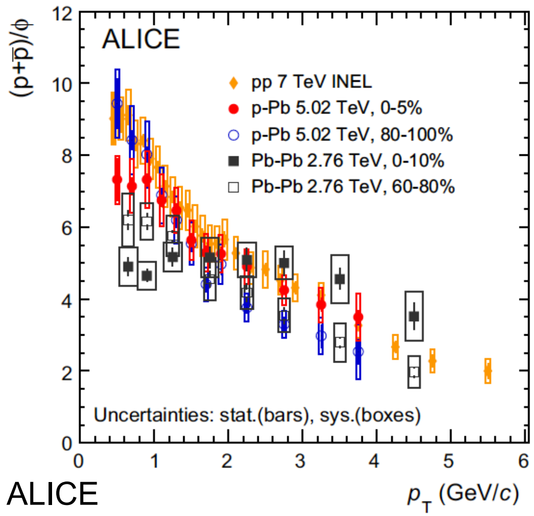
Baryon/meson or mass?

Comparison of Λ/K^0_s and p/ϕ

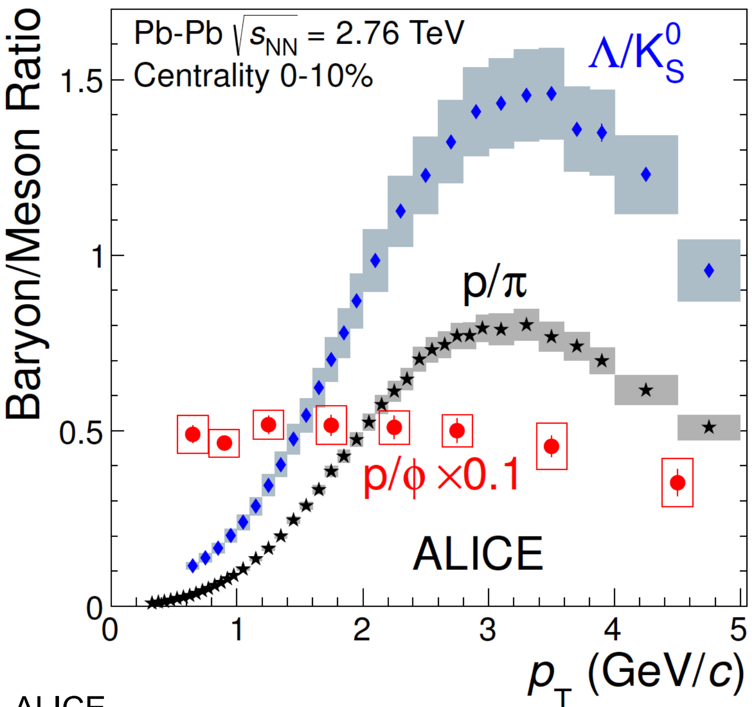
p/ϕ-ratio is flat as function of p_T (central collisions)

⇒ Mass difference the driving factor

Strong centrality dependence of p/ϕ
Role of rescattering?



ALICE
EPJC76 (2016) 245



ALICE
PRC91, 024609 (2015)

Baryon-Meson

Ω/ϕ-Ratio vs p_T at RHIC and LHC

Only strange quarks

Baryon (sss) and meson ($s\bar{s}$)

Small hadronic cross section
⇒ partonic phase

Ratio Ω/ϕ

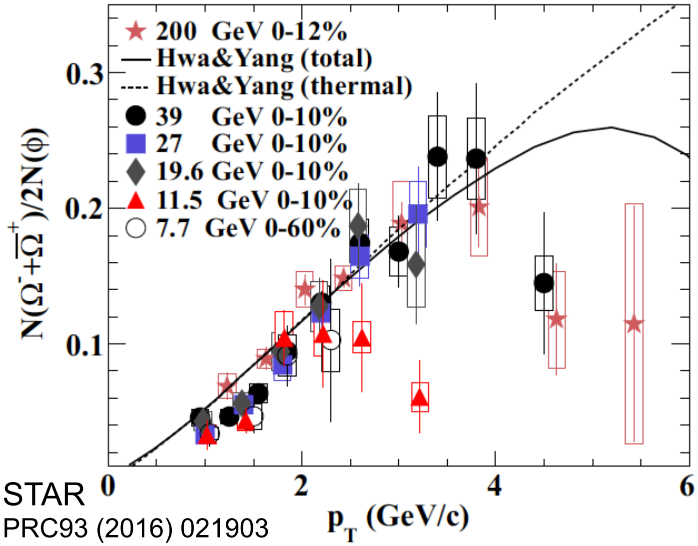
Rising up to $p_T \approx 4$ GeV/c

Consistent with quark coalescence model up to $p_T \approx 4$ GeV/c
Maximum at different position

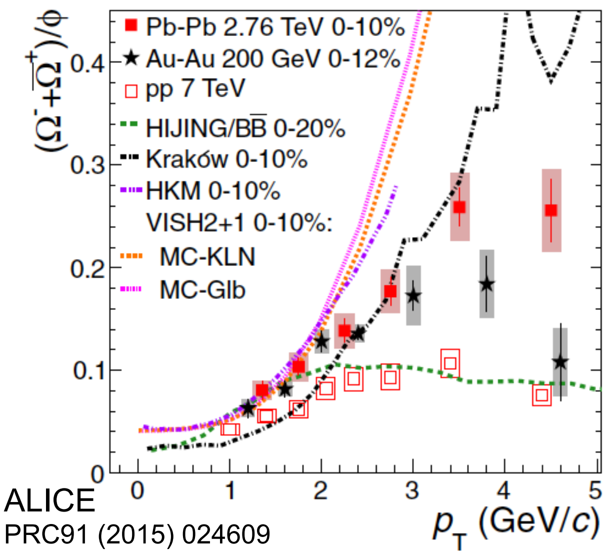
p_T dependence not described by any model

Ω/ϕ(LHC) > Ω/ϕ(RHIC, 200 GeV) for p_T > 3 GeV/c

Also deviation at $\sqrt{s_{NN}}$ = 11.5 GeV



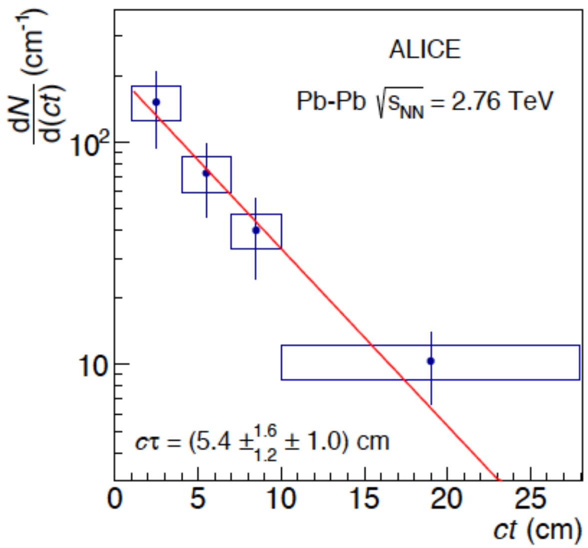
STAR
PRC93 (2016) 021903

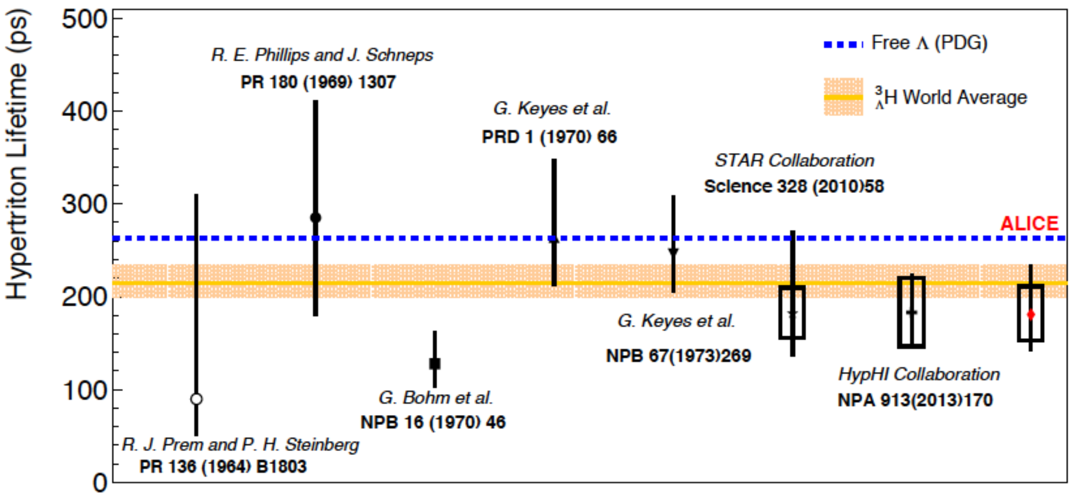


ALICE
PRC91 (2015) 024609

Hypernuclei

Lifetime of Hypertriton



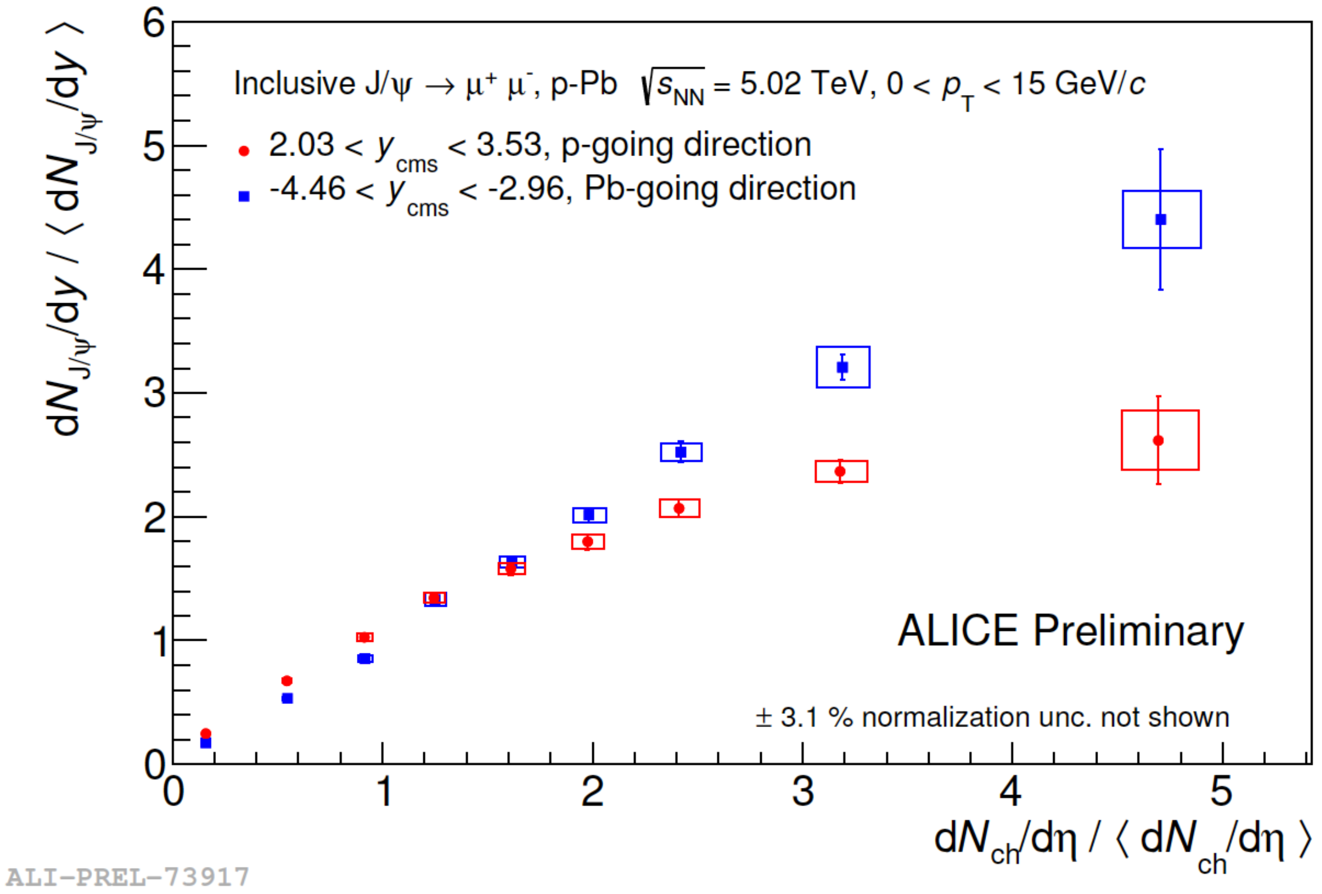


ALICE
arXiv:1506.08453

New world average $\tau = 215^{+18}_{-16}$ ps

Good agreement with STAR and ALICE measurement

Slightly below expectation for free Λ


Inclusive J/ψ → μ⁺ μ⁻, p-Pb √s_NN = 5.02 TeV, 0 < p_T < 15 GeV/c
2.03 < y_cms < 3.53, p-going direction
-4.46 < y_cms < -2.96, Pb-going direction
ALICE Preliminary
± 3.1 % normalization unc. not shown
dN_J/ψ/dy / ⟨ dN_J/ψ/dy ⟩
dN_ch/dη / ⟨ dN_ch/dη ⟩
0
1
2
3
4
5
6
ALI−PREL−73917

Hyperon Interaction

Implications for Bound States (H-Dibaryon)

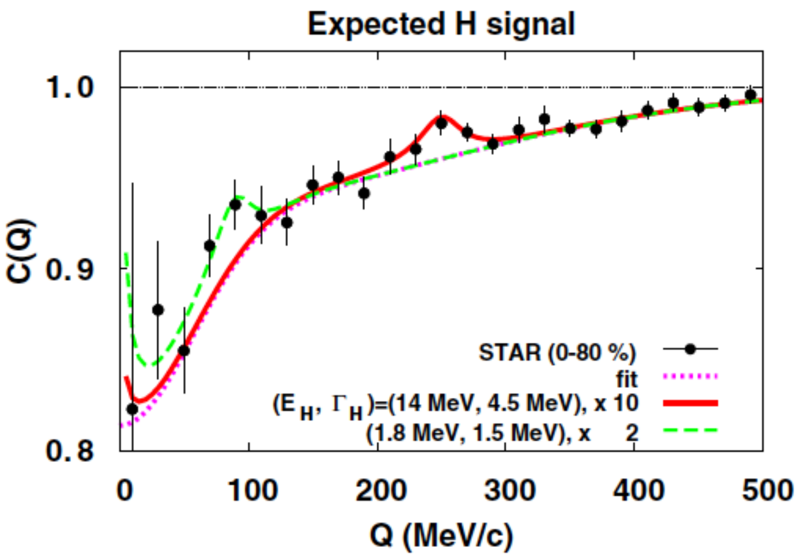
ΛΛ bound state

Disfavored, since it would imply a depletion below 0.5 of c.f. at $Q = 0$

Resonance above ΛΛ thres.

Very small signal expected

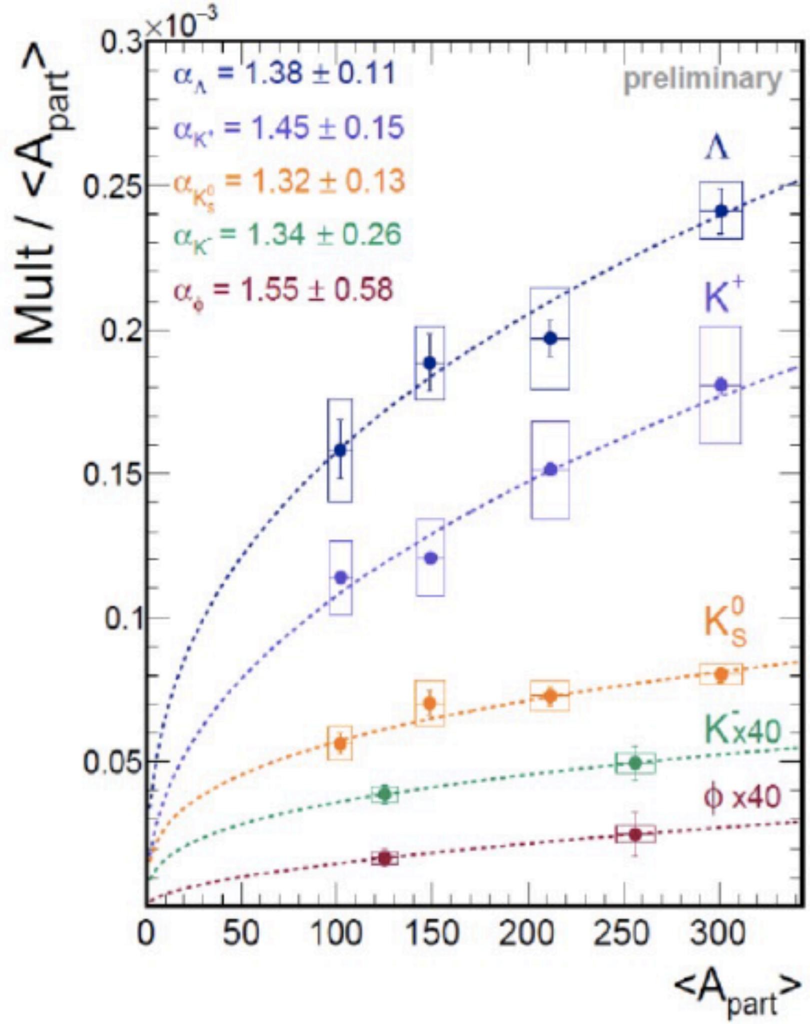
More statistics needed



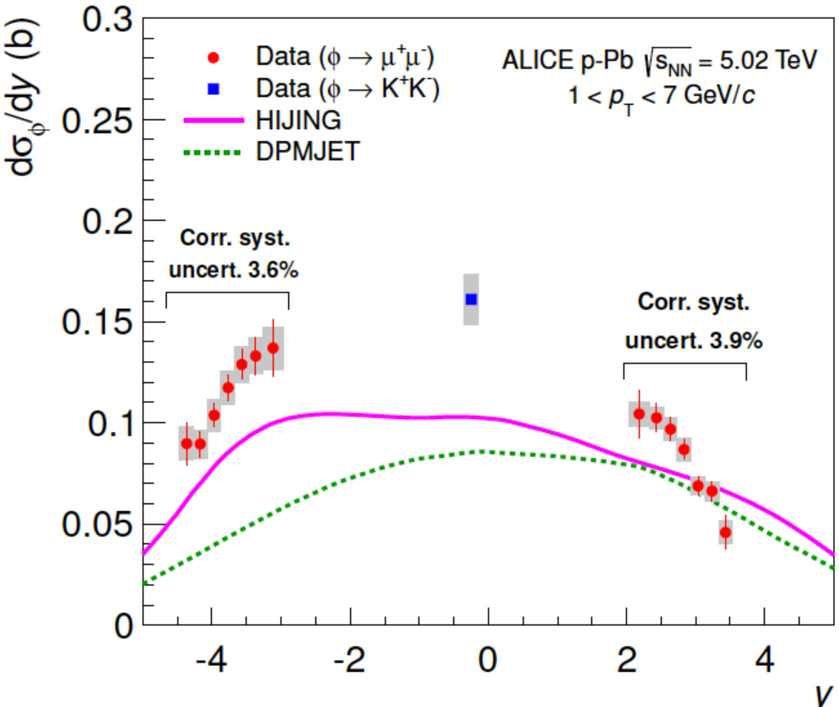
K. Morita et al.
PRC91, 024916 (2015)

Overview on Strangeness Measurements

SIS-18: HADES Data



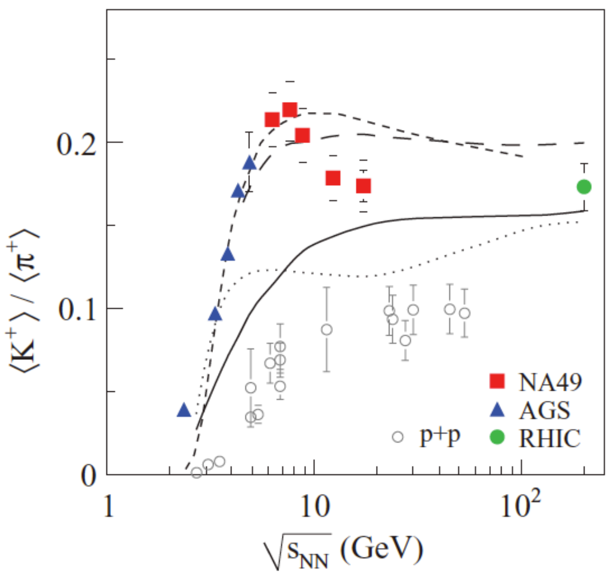
Timo Scheib,
SQM2016



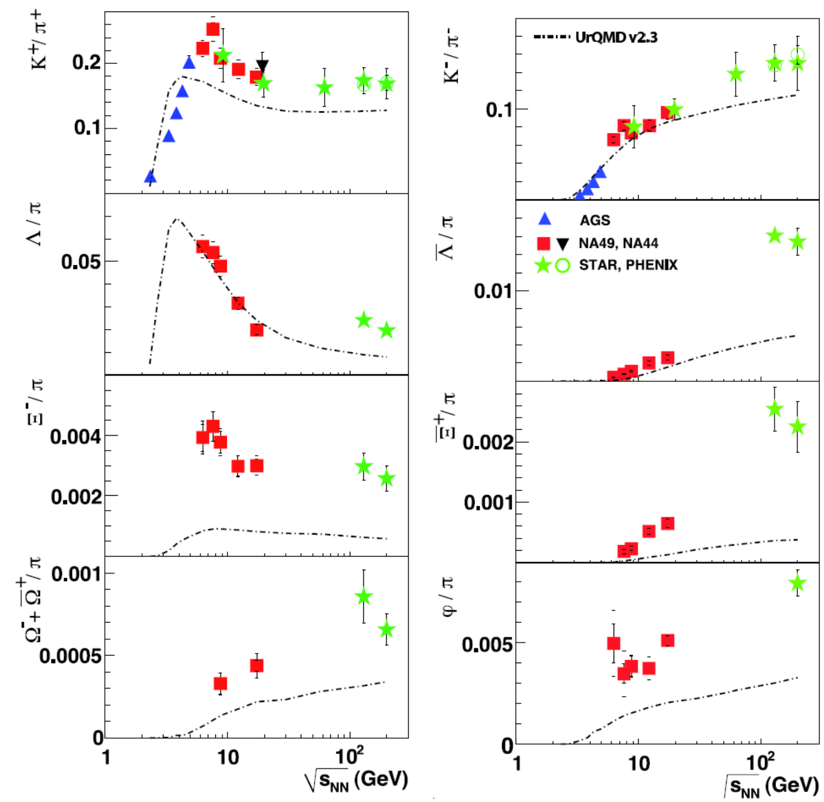
ALICE
arXiv:1506.09206.

Overview on Strangeness Measurements

Yields at Lower Energies (NA49 + AGS)



NA49
PRC66, 054902 (2002)
PRL93, 022302 (2003)
PRL94, 192301 (2005)
PRC77, 024903 (2008)
PRC78, 034918 (2008)
PRC78, 044907 (2008)



Available data

Central events: π, K, p, Λ (statistics ok) and Λ*, K*, Ξ, Ω, ϕ (low statistics)

System size: π, K, p, (Λ), not at all energies

Overview on Strangeness Measurements

Yields at Lower Energies (NA49): System Size Dependence

Transport models

OK for Λ

Slightly below $\bar{\Lambda}$

Too low for Ξ

UrQMD: H. Petersen et al.
arXiv: 0903.0396

HSD: W. Cassing and
E. Bratkovskaya,
PR 308, 65 (1999)
and private communication

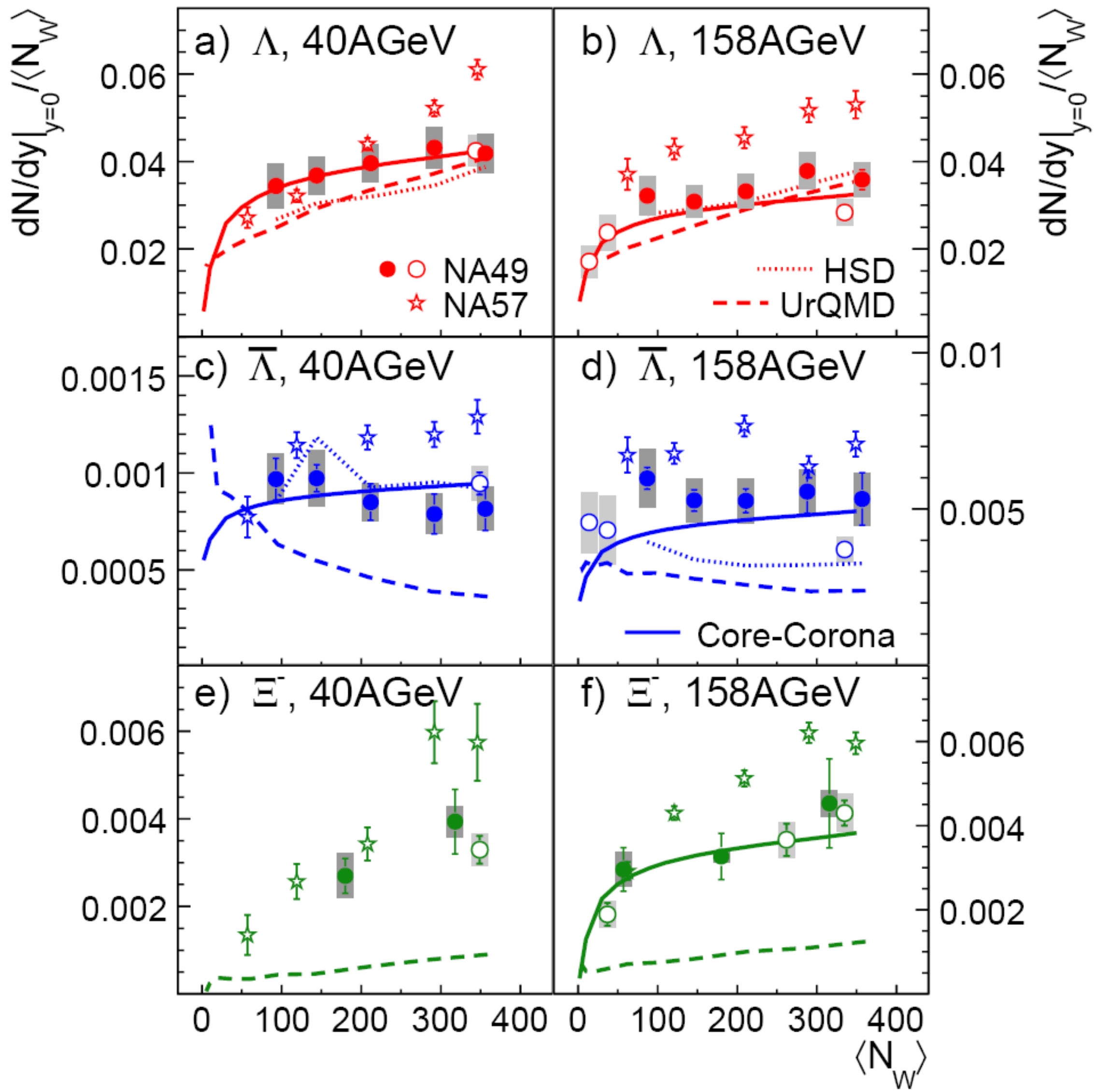
Core Corona model

OK for Λ and Ξ

F. Becattini and J. Manninen,
PLB673, 19 (2009)

J. Aichelin and K. Werner,
arXiv:0810.4465

NA49
PRC80, 034906 (2009)



Overview on Strangeness Measurements

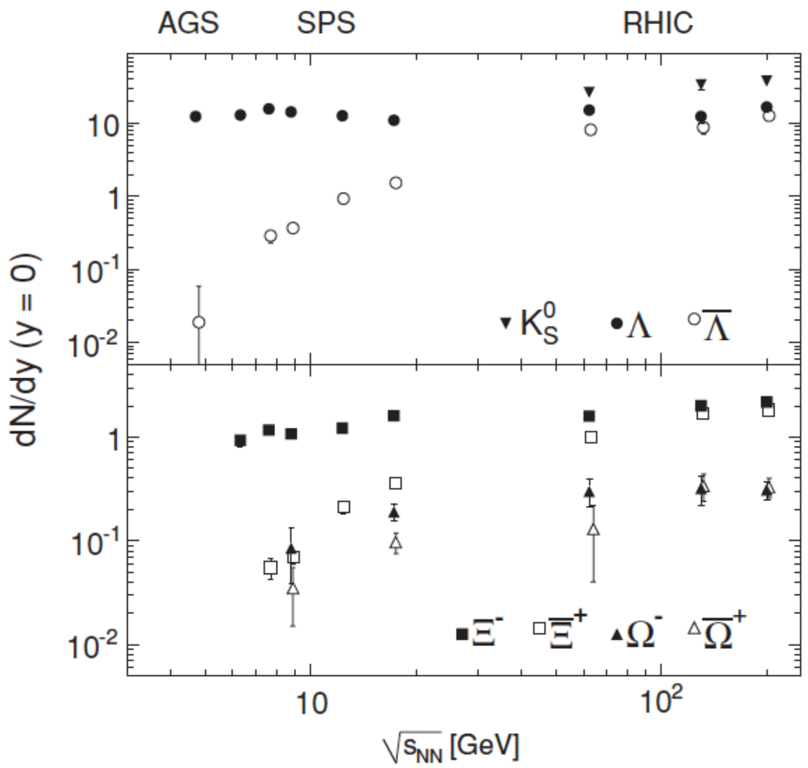
Yields at Lower Energies (NA49, NA57, STAR)

Energy Dependence

Gap between SPS and RHIC is being closed

Overlap with SPS → cross checks

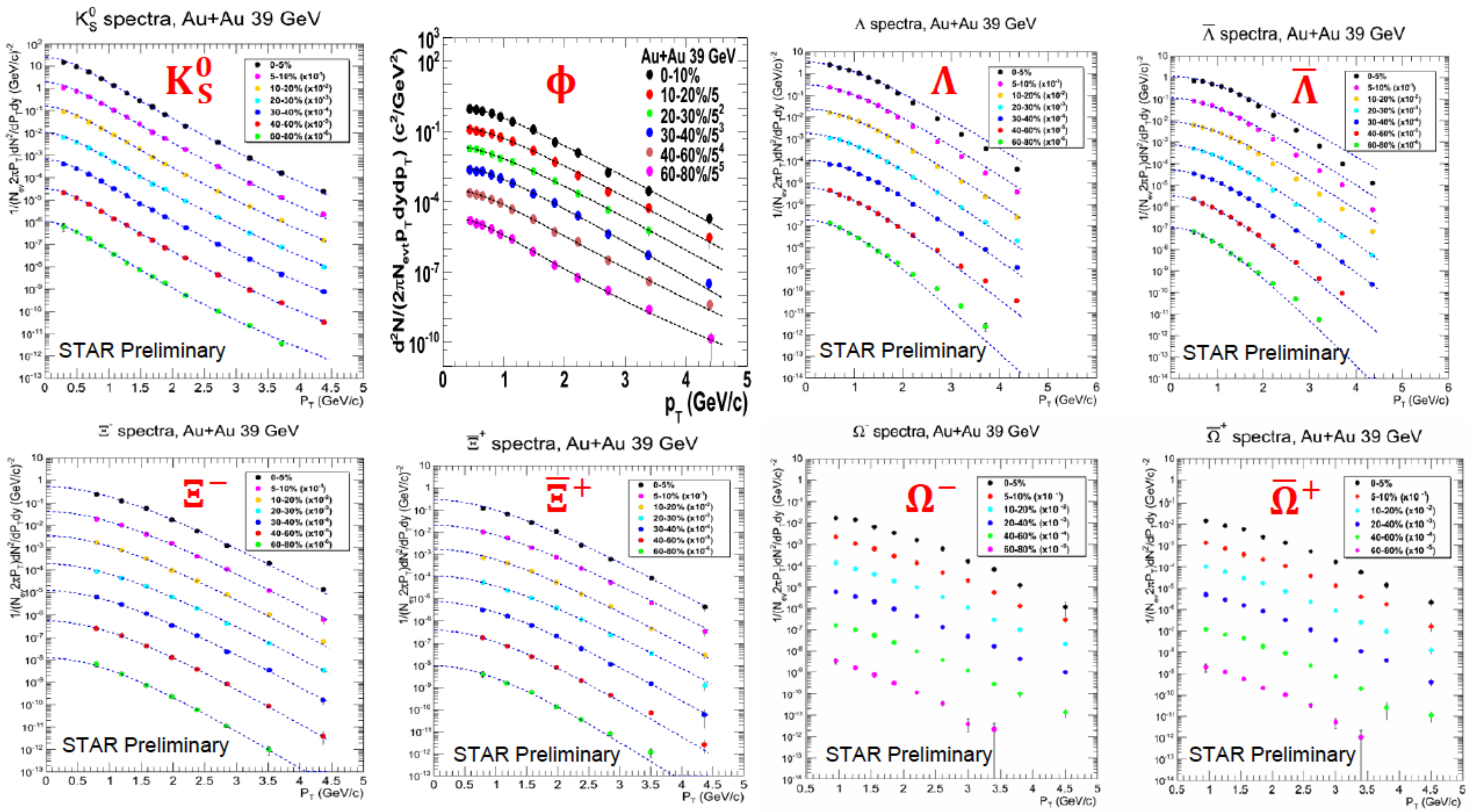
From top SPS energy up to LHC all particle species, including rare Ξ and Ω, are covered



STAR
PRC83, 024901 (2011)

Overview on Strangeness Measurements

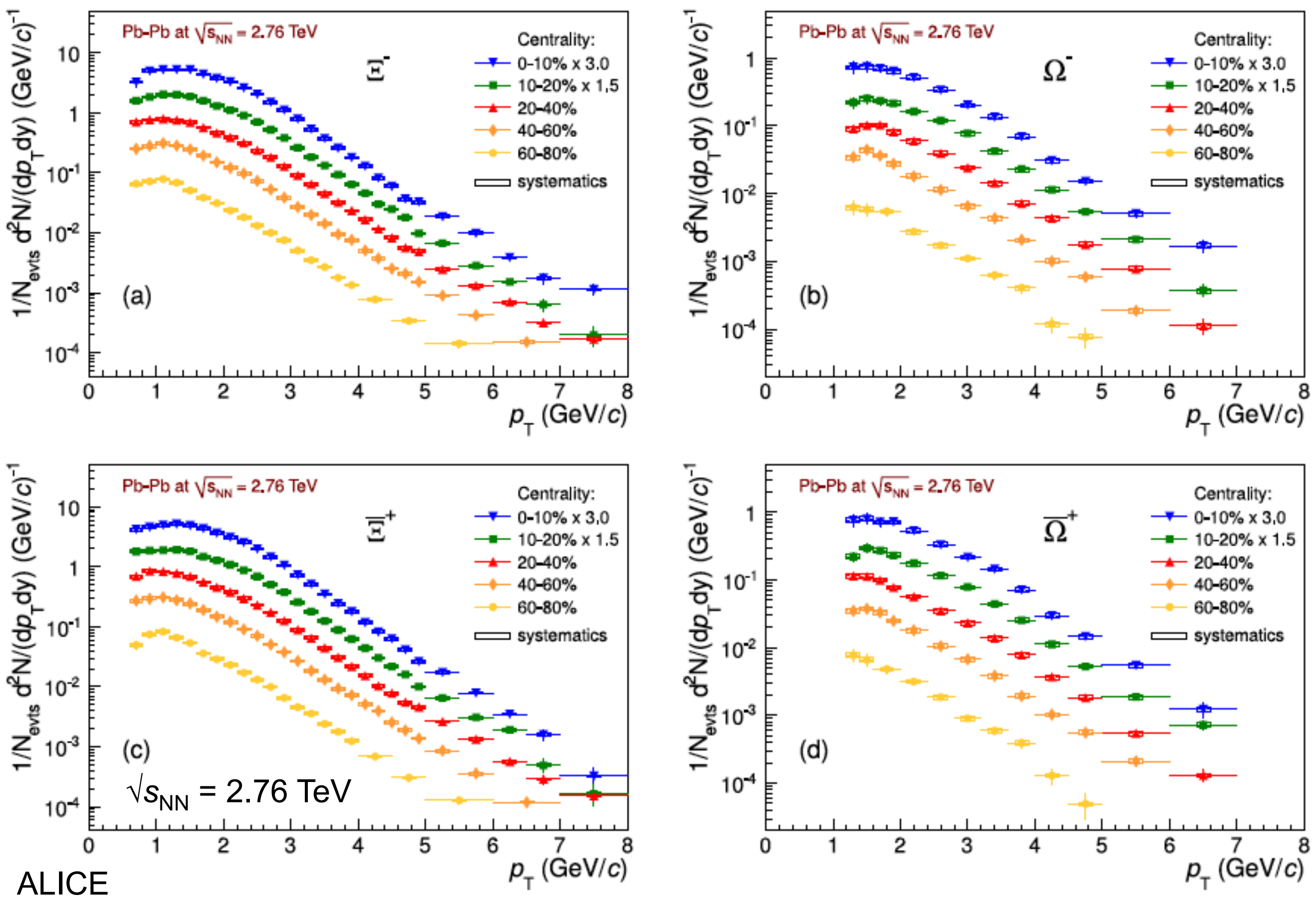
Beam Energy Scan (BES) at RHIC: STAR



X. Zhang, SQM 2015

Overview on Strangeness Measurements

LHC



ALICE
PLB728, 216 (2014)

Overview on Strangeness Measurements

Beam Energy Scan (BES) at RHIC: STAR

Antibaryon-baryon ratios

Mid-rapidity yields

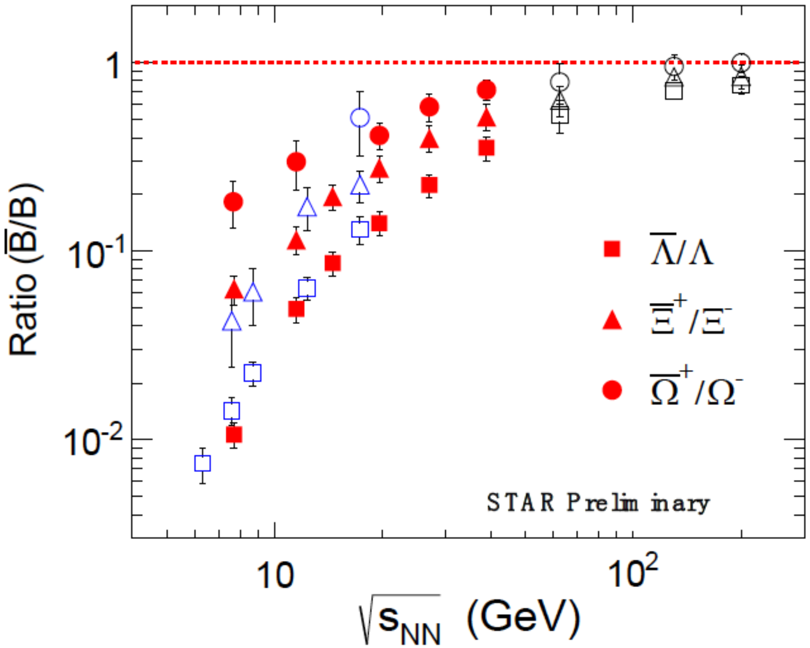
Continuous evolution from SPS to RHIC

Ratios converge towards unity at high energies

$R(\bar{\Omega}^+/\Omega^-) > R(\bar{\Xi}^+/\Xi^-) > R(\bar{\Lambda}/\Lambda)$

Overlap with SPS data

Good agreement with NA49 ratios



X. Zhang, SQM 2015

Strangeness Enhancement

Cascades at Low Energies

Sub-Threshold

Threshold in N+N: E_{thr} = 3.74 GeV

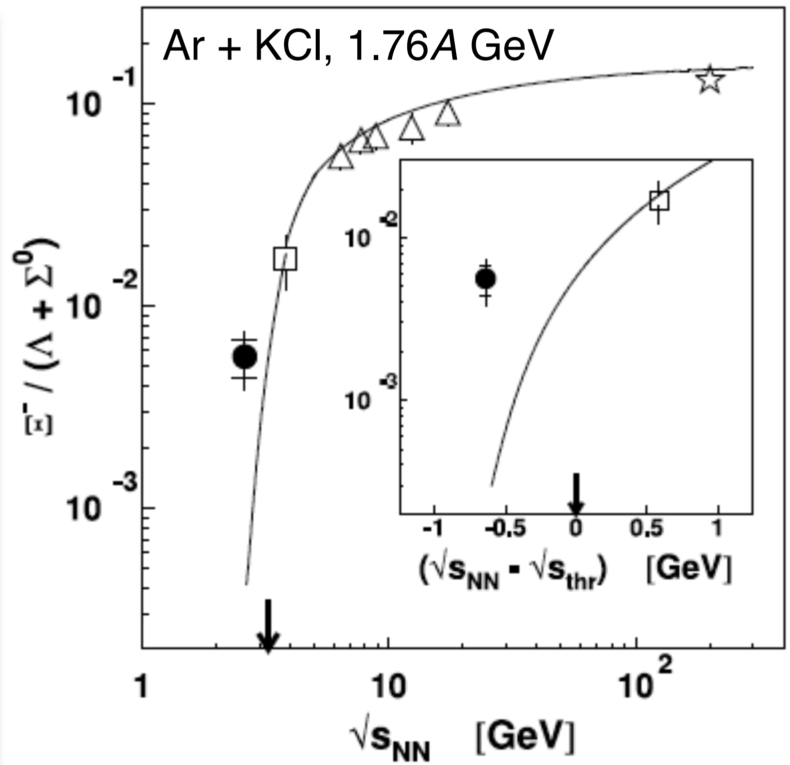
Surprisingly high Ξ^- yield

Statistical model comparison

Data much above model expectation

Similar for transport models

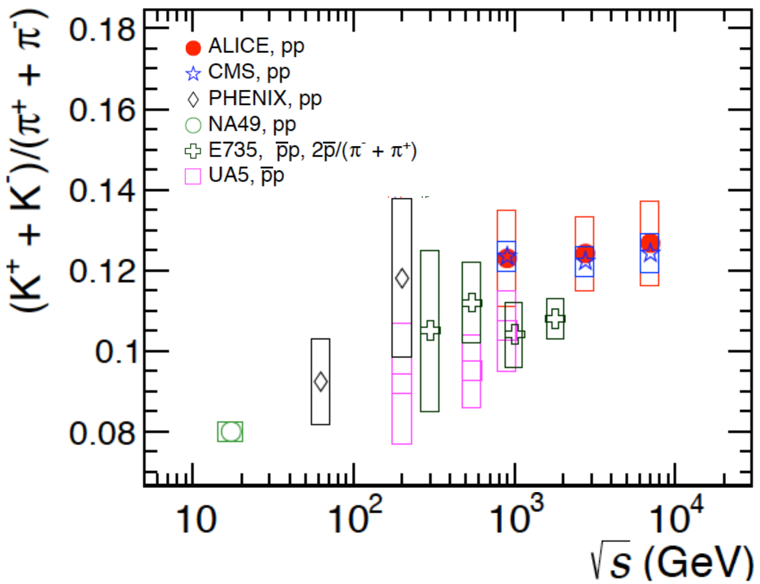
New mechanisms?



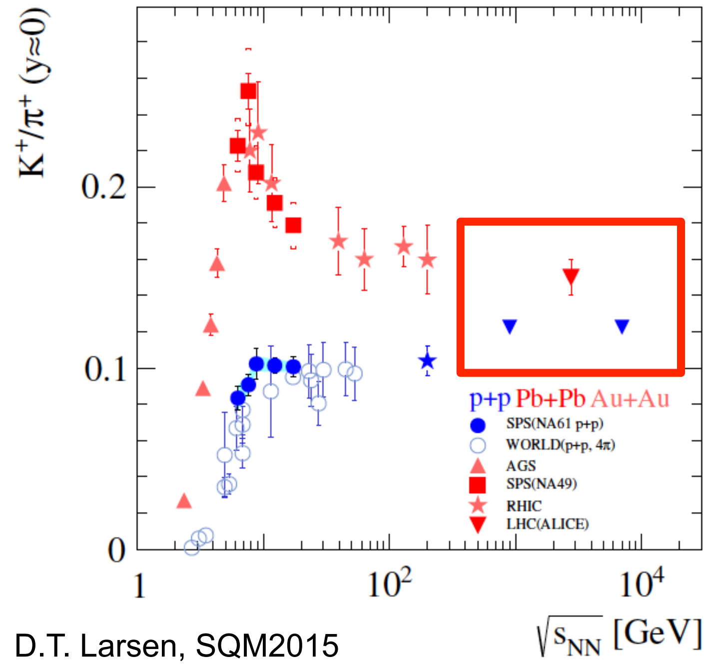
HADES
PRL103, 132301 (2009)

Small Systems

Energy Dependence of pp Data



ALICE
EPJC75,226 (2015)



D.T. Larsen, SQM2015

Strange / non-strange ratio: K^+/π^+

Continuous increase with √s in pp (not in A+A, though)

Ratio converges to approx. same value at high energies

Small Systems

Statistical Model Comparison in pp

Statistical model analysis of pp

Existing for lower energies and
older Tevatron data at higher energies

Based on canonical ensemble

Predictions for pp

Grand-canonical ensemble

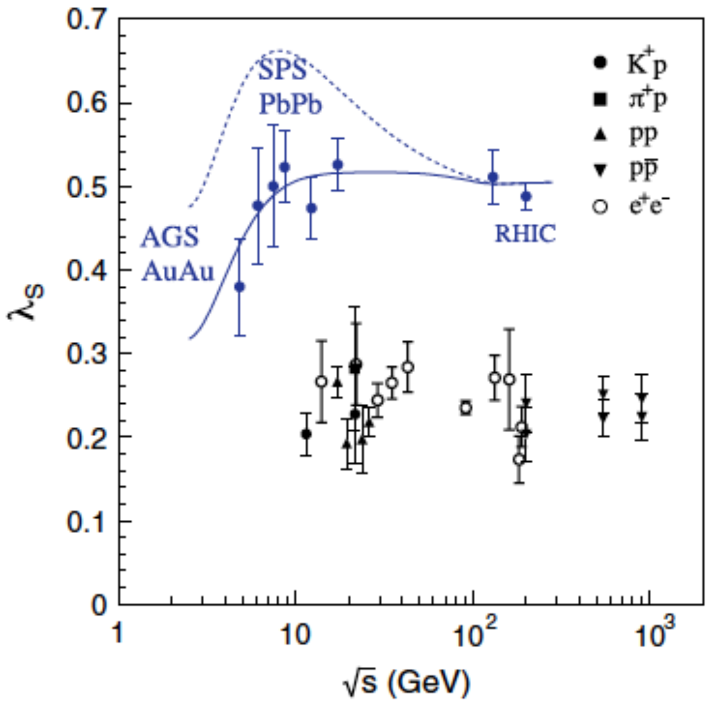
Table 2. Predictions of the midrapidity density of hadrons relative to that of all charged hadrons at $\sqrt{s} = 10$ TeV in the grand-canonical limit. The temperature value is assumed as $T = 170$ MeV, and the numbers *do not* include weak decay products.

Particle	$(dn/dy)/(dn/dy_{ch})$ $\gamma_S = 0.6$	$(dn/dy)/(dn/dy_{ch})$ $\gamma_S = 1$
…		
$\Lambda = \bar{\Lambda}$	0.0112	0.0162
$\Xi^+ = \Xi^-$	0.001 05	0.002 54
$\Omega^+ = \Omega^-$	0.000 121	0.000 488

F. Becattini et al., JPG38, 025002 (2011)

Measurement (pp, $\sqrt{s}$ = 7 TeV):
$\Xi^-/(dN_{ch}/d\eta)$: 0.00131
$\Omega^-/(dN_{ch}/d\eta)$: 0.000112

ALICE PLB728, 216 (2014)



F. Becattini and J. Manninen, JPG35, 104013 (2008)

Wroblewski-factor:

$$\lambda_s = \frac{2\,\langle s\bar{s}\rangle}{\langle u\bar{u}\rangle + \langle d\bar{d}\rangle}$$

Small Systems

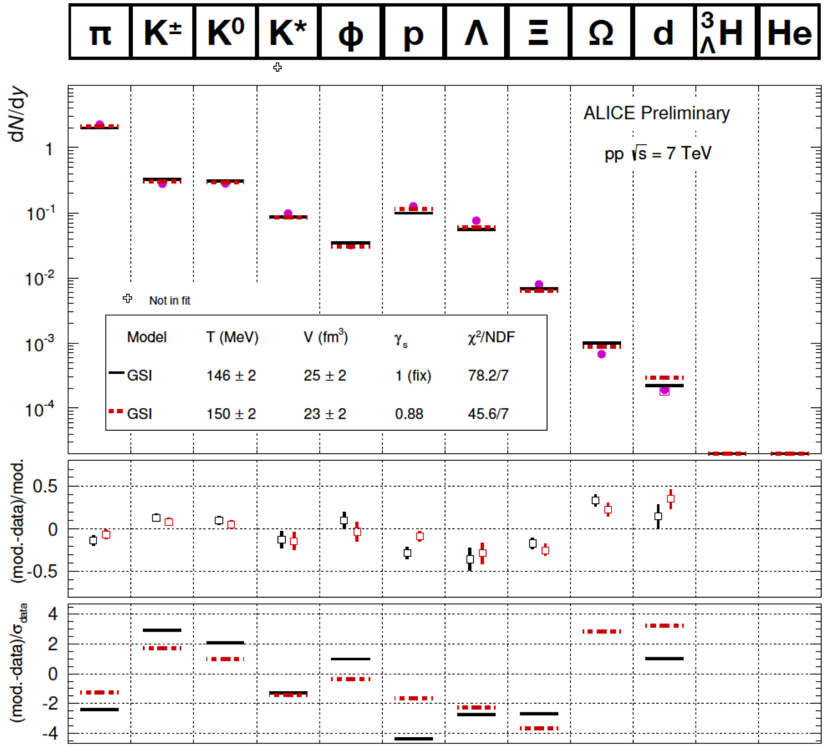
Statistical Model Comparison in pp

Statistical model fit

Grand canonical ensemble

χ^2/NDF not too impressive

Lower temperature than in extrapolation by Becattini et al.



M. Floris, QM2014

Small Systems

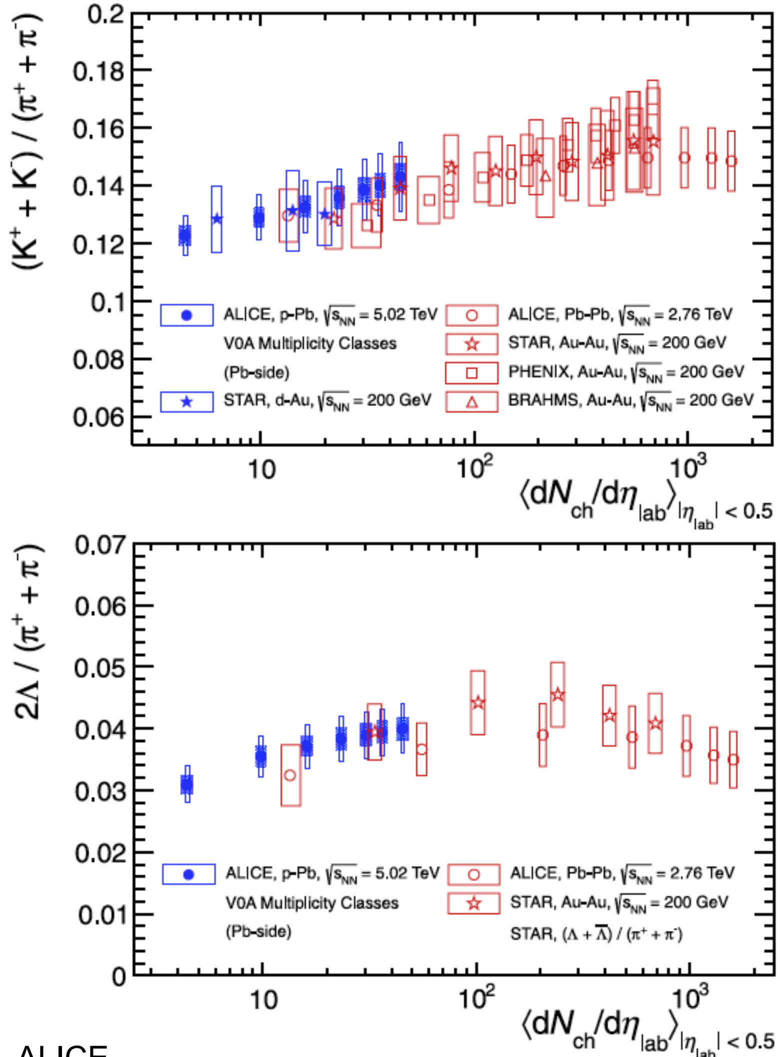
Particle Ratios: K/π and Λ/K^0_s in Proton-Nucleus Collisions

Multiplicity Dependence

Similar increase of strange/non-strange ratios in p-Pb and Pb-Pb

Connection between pp and AA?

How about multistrange particles?



ALICE
PLB728, 25 (2014)

Small Systems

Statistical Model for p-Pb

Statistical model fits

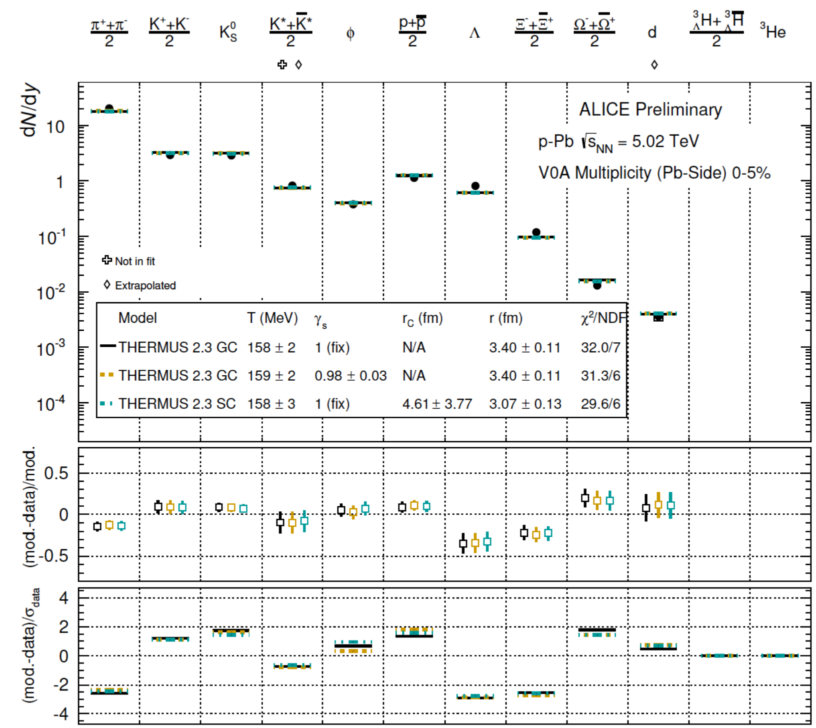
Grand-canonical (GC) and strangeness-canonical (SC)

Most central p-Pb collisions

χ^2/NDF not too impressive

γ_s compatible with unity.

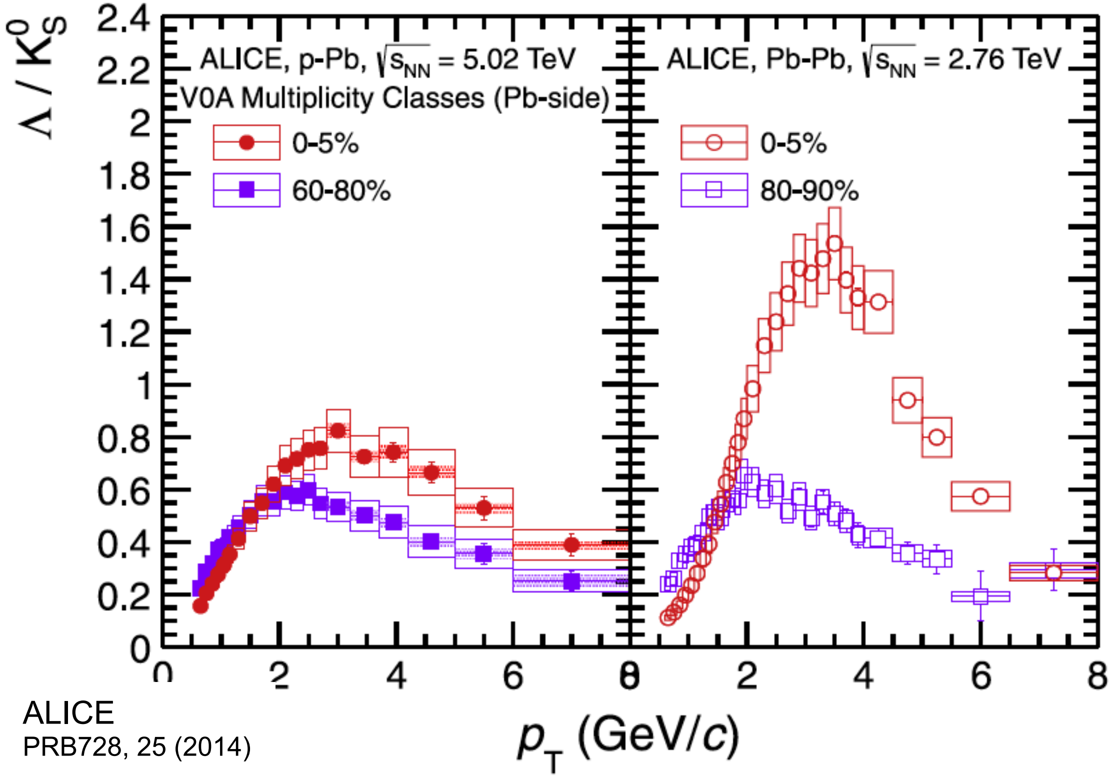
$R_c \approx R_V \Rightarrow$ no canonical strangeness suppression



M. Floris, QM2014

Baryon-Meson Ratios

Λ/K^0_s-Ratio vs p_T at LHC: p-Pb vs Pb-Pb



ALICE
PRB728, 25 (2014)

No enhancement above unity in p-Pb

But higher than in pp, with maximum at similar position than Pb-Pb

Multiplicity dependence in p-Pb seen

Baryon-Meson Ratios

Ω/ϕ-Ratio vs p_T at RHIC

NCQ-scaled Ω/ϕ-ratio

Might reflect strange quark distribution $f_s(p^s_T)$ at hadronization

$$\frac{N(\Omega^- + \bar{\Omega}^+)|_{p_T^\Omega = 3p_T^s}}{N(\phi)|_{p_T^\phi = 2p_T^s}}$$

J.H. Chen et al., PRC78, 034907 (2008)

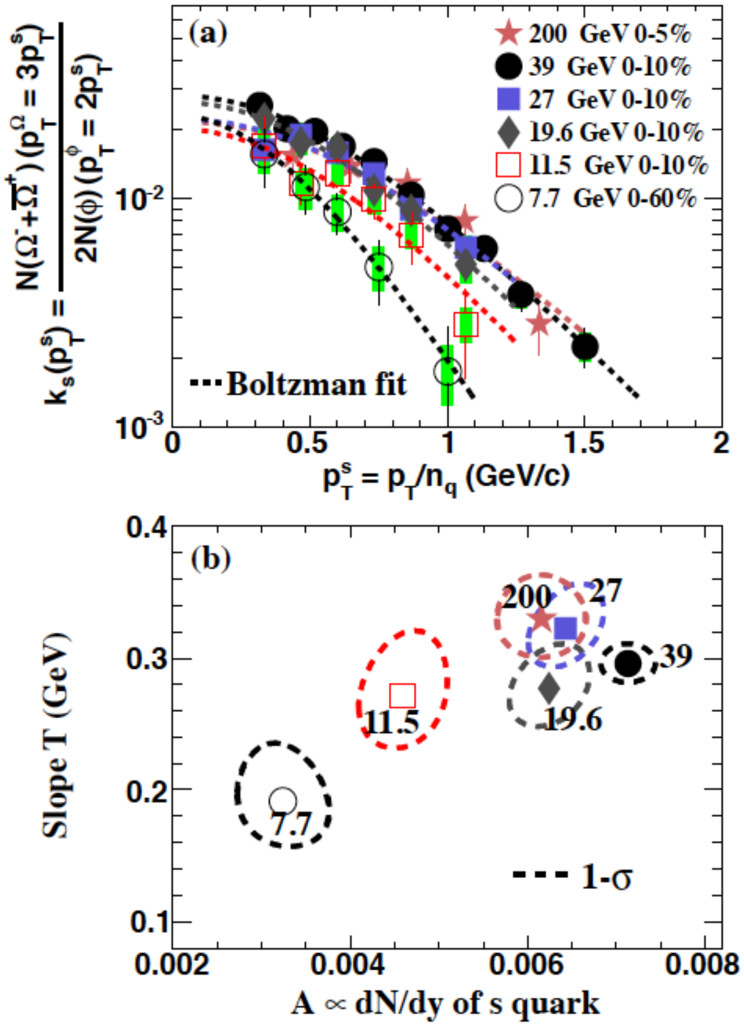
Fit to ratios with Boltzmann

$$g_s\, A\, \frac{m_T}{T\,(m_s + T)}\, e^{-(m_T - m_s)/T}$$

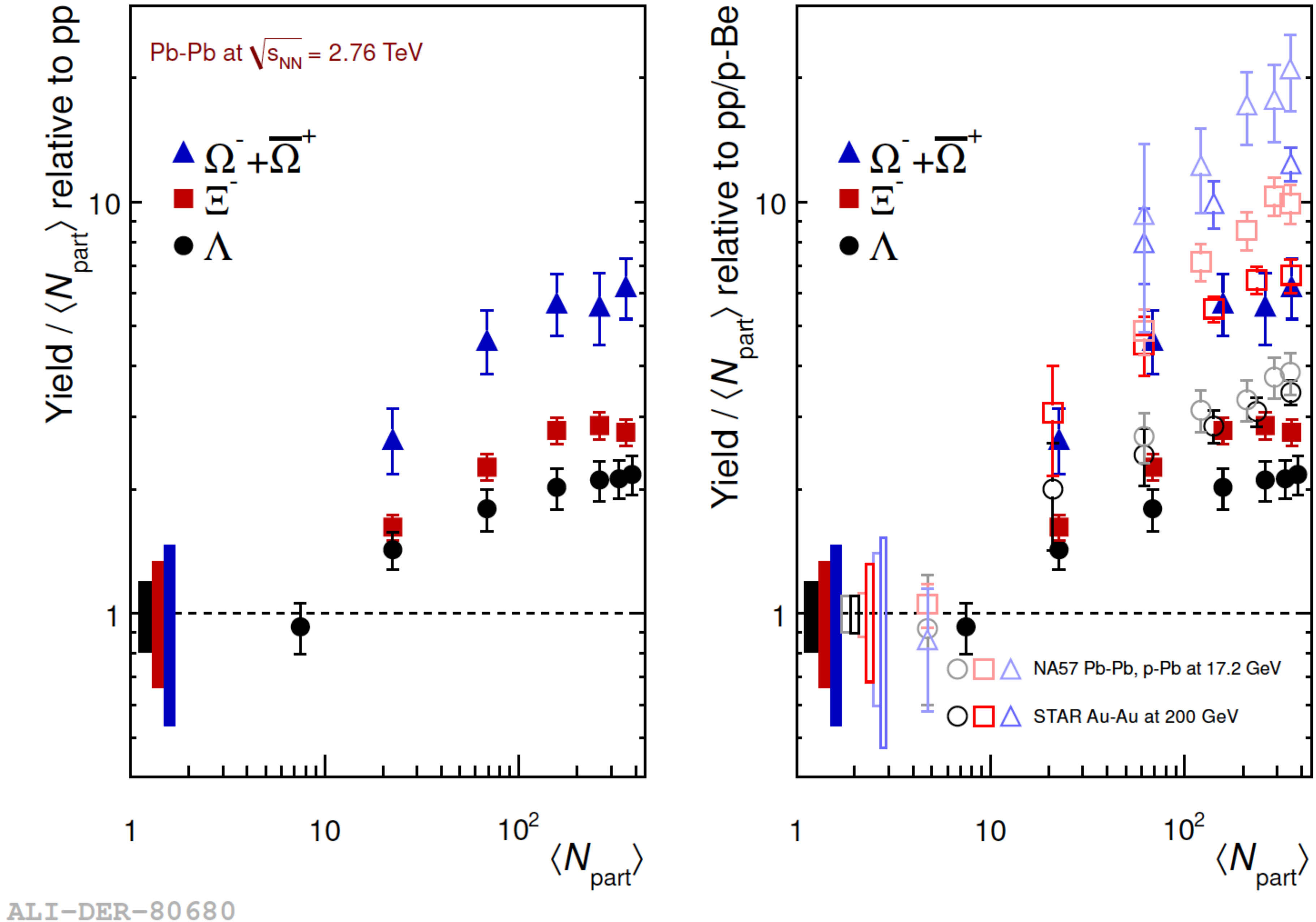
(m_s = 0.46 GeV/c^2, g_s takes $\sqrt{s_{NN}}$-dependent yield ratio $\bar{s}/s$ into account)

Similar fit results for $\sqrt{s_{NN}} \geq 19.6$ GeV deviations below
(note: centrality selection different at 7.7 GeV)

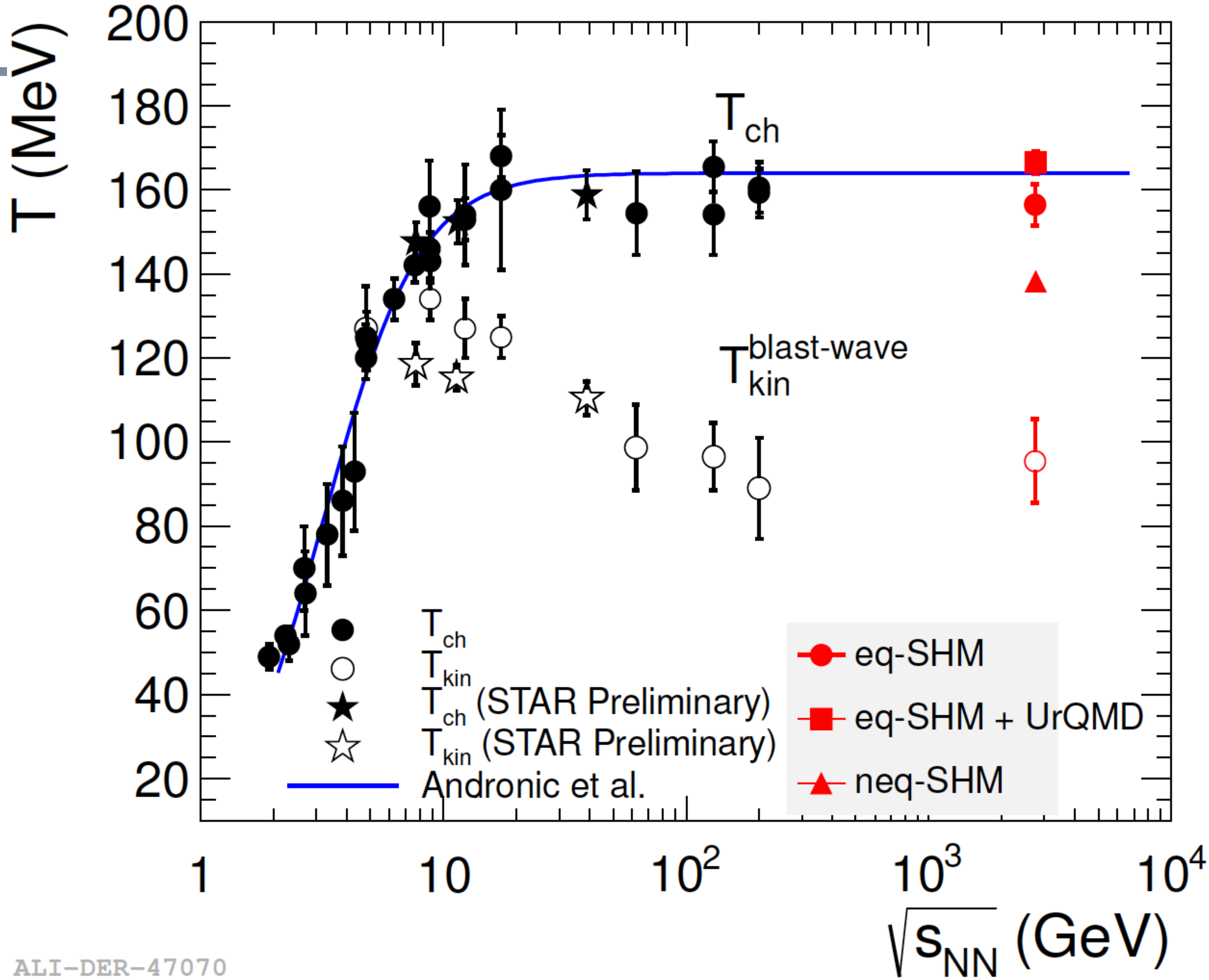
Transition from partonic to hadronic matter below $\sqrt{s_{NN}}$ = 19.6 GeV ?

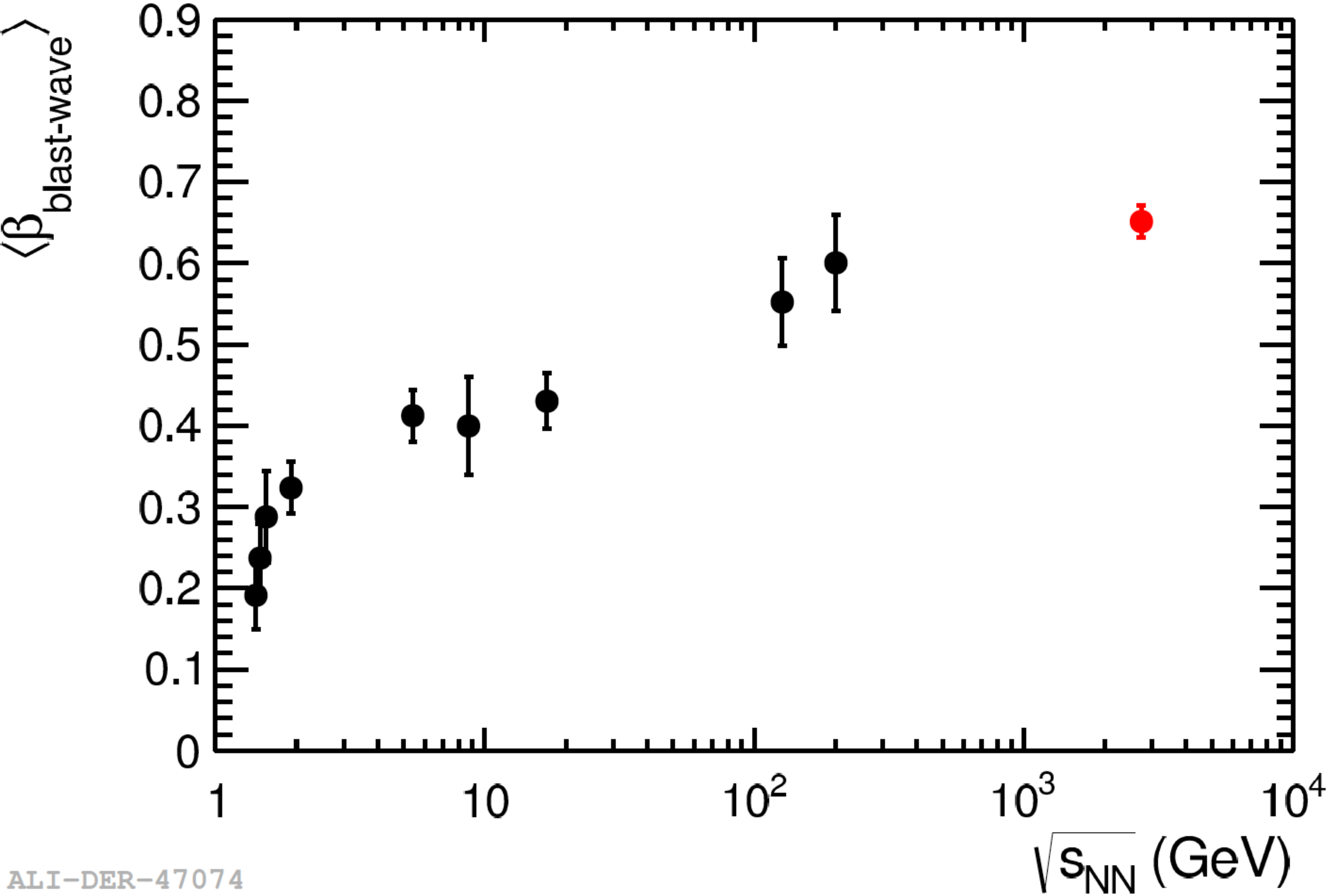


STAR
arXiv:1506.07605



Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV
Yield / ⟨N_{part}⟩ relative to pp
$\Omega^- + \overline{\Omega}^+$
Ξ^-
Λ
Yield / ⟨N_{part}⟩ relative to pp/p-Be
NA57 Pb-Pb, p-Pb at 17.2 GeV
STAR Au-Au at 200 GeV
⟨N_{part}⟩
1
10
10^2
ALI-DER-80680


T (MeV)
200
180
160
140
120
100
80
60
40
20
1
10
10^2
10^3
10^4
$\sqrt{s_{NN}}$ (GeV)
T_{ch}
$T_{kin}^{blast-wave}$
T_{ch}
T_{kin}
T_{ch} (STAR Preliminary)
T_{kin} (STAR Preliminary)
Andronic et al.
eq-SHM
eq-SHM + UrQMD
neq-SHM
ALI-DER-47070



ALI-DER-47074