Impressions from SQM2017 and future directions
facts, puzzles and opportunities

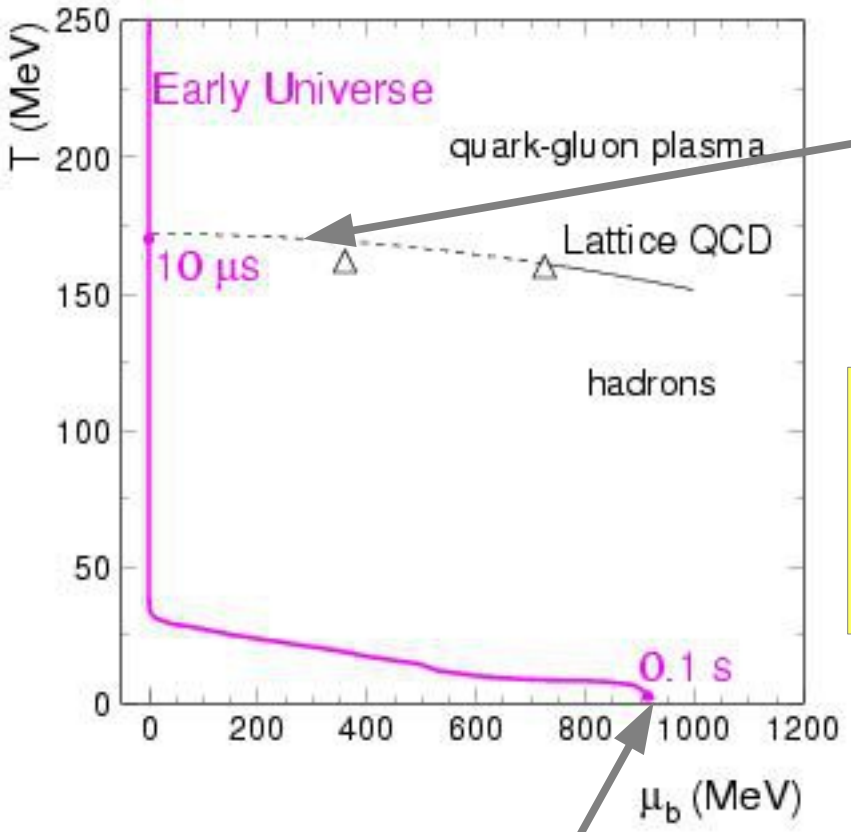
This is not a summary of the many beautiful new results shown at the conference.
Rather I will make very selected comments on results in the following areas:

- u,d,s sector spectra and flow
- u,d,s sector hadro-chemistry and statistical hadronization
- hyper-triton 'anomaly'
- heavy quarks spectra and flow
- quarkonia color screening, (re-)combination and statistical hadronization
- net particle fluctuations

17th International Conference on
Strangeness in
Quark Matter

Universiteit Utrecht
10-15 July 2017
Utrecht, the Netherlands

evolution of the early universe and the QCD phase diagram



QCD phase boundary

homogeneous Universe in equilibrium, this matter can only be investigated in nuclear collisions

- charge neutrality
- net lepton number = net baryon number
- constant entropy/baryon

neutrinos decouple and light nuclei begin to be formed

why do we do all this?

QCD has special features, that make its study especially attractive:

It is precisely defined

numerical ***realization***

It has enormous symmetry

beauty, uniqueness

It *embodies* many deep aspects of relativistic quantum field theory (confinement, asymptotic freedom, anomalies/instantons, spontaneous symmetry breaking ...)

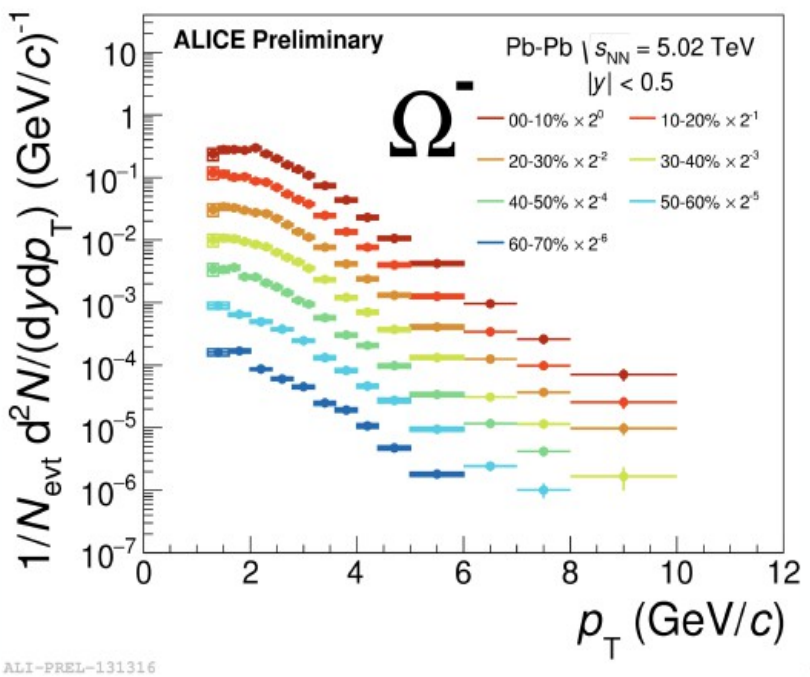
slide from Frank Wilczek, QM2014 introductory talk

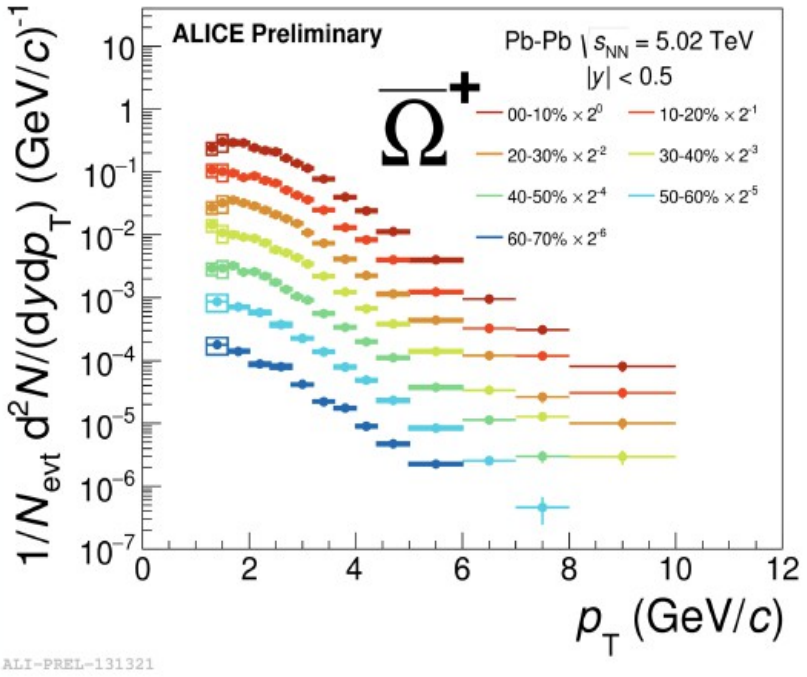
all relevant for QGP physics (pbm)

1. light flavor spectra, hydrodynamic flow and hydro comparison

beautiful new data from STAR and ALICE

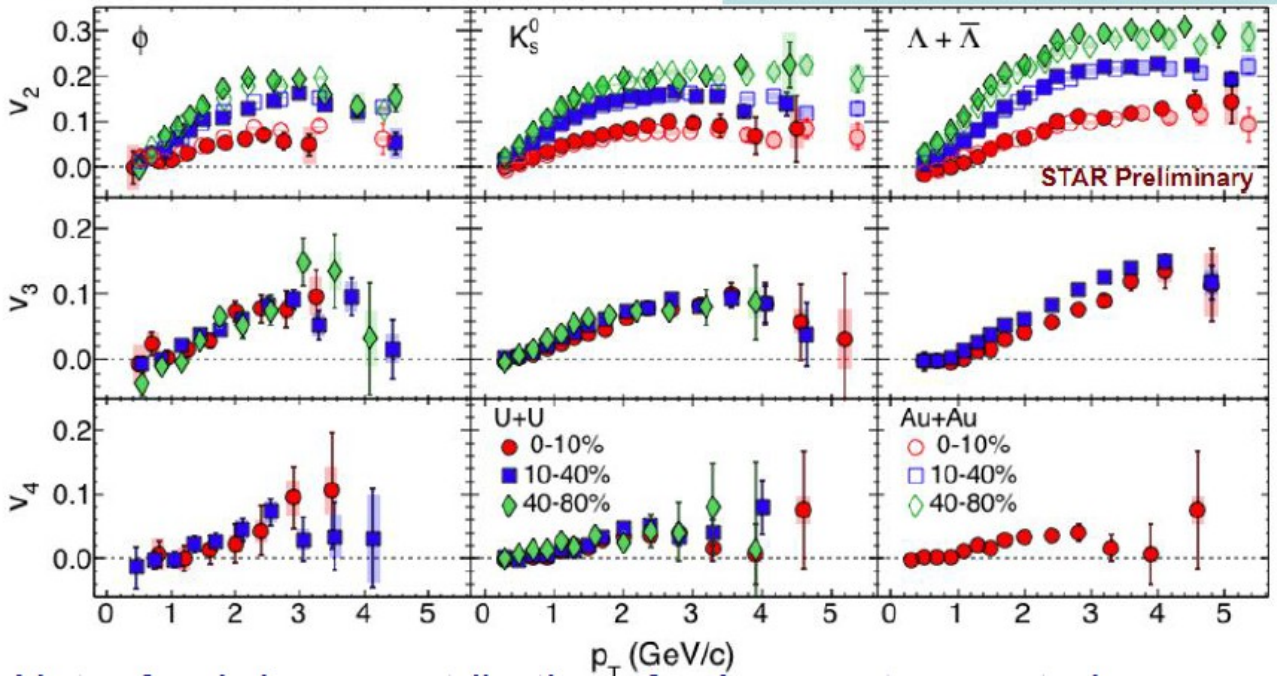
precision p_T spectra and flow for all light flavor hadrons at sqrt{s_NN} = 0.2 and 5 TeV





Flow harmonics of v_n strange hadrons

By Vipul Bairathi on Thu. 09:40



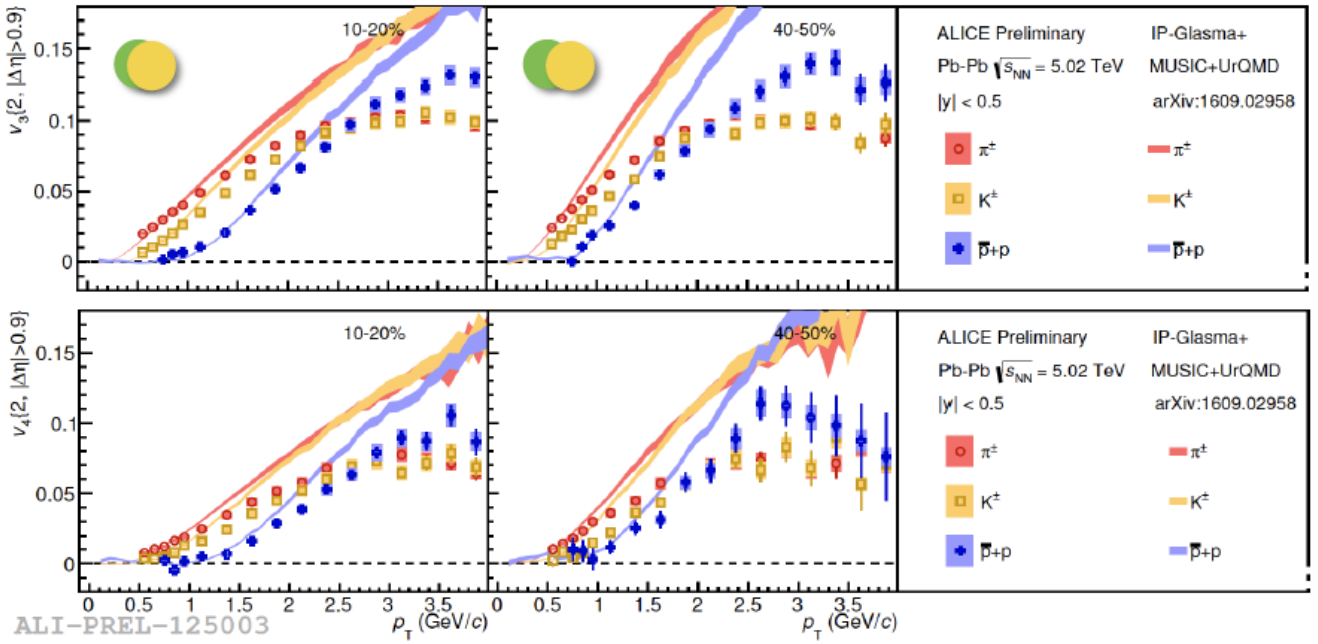
Au+Au:
Phys. Rev. C 77, 054901 (2008)

is the hydro paradigm in trouble? data only described in low p_T region < 1.5 GeV

hard scattering becomes an important component at LHC energy and needs to be taken into account!

v_n of identified particles

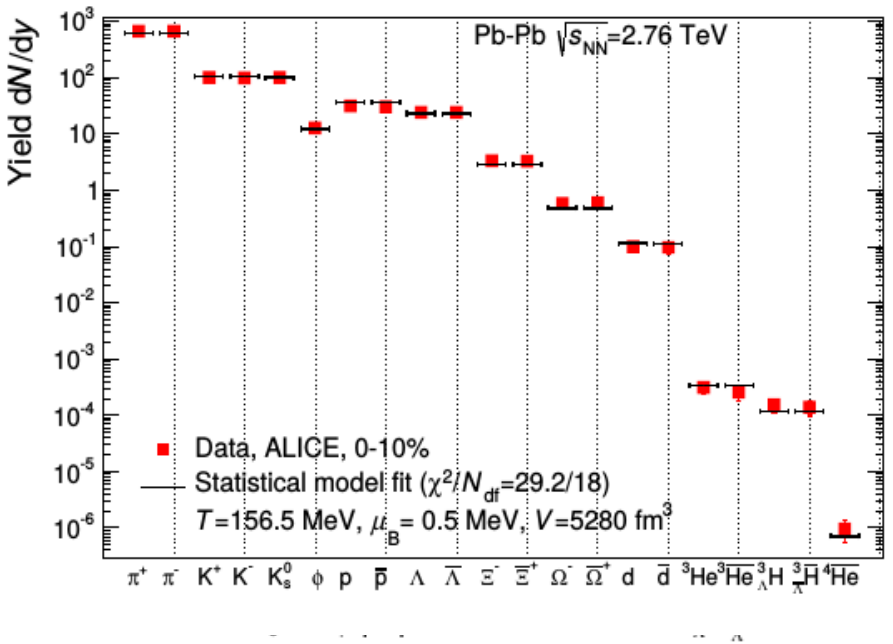
☑ v_n; n>2 are more sensitive to transport coefficients of medium than v_2



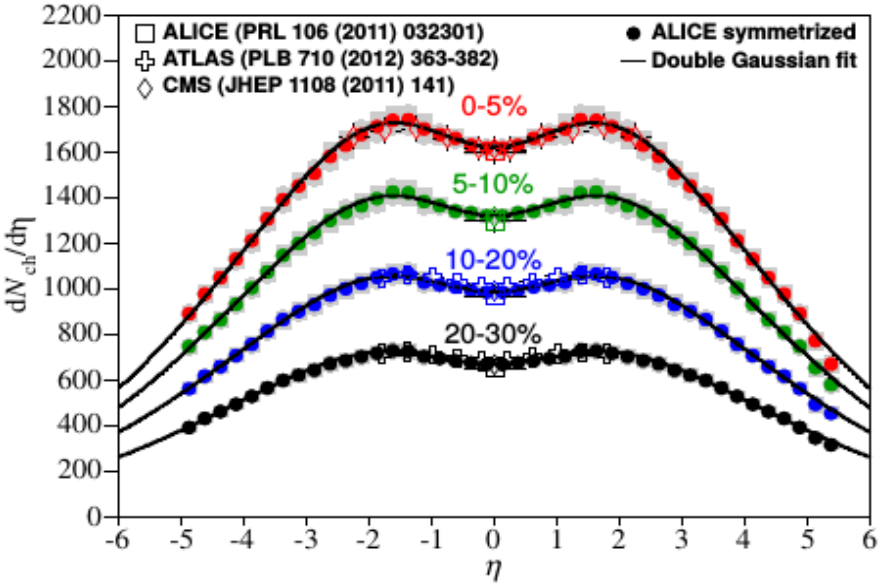
2. integrated yields and the statistical hadronization model

Hadron production in central nuclear collisions excellent description of LHC data with statistical hadronization model

T, $V(\Delta y = 1)$ from thermal fit



$\mathrm{d}N_{ch}/\mathrm{d}\eta$ data



ALICE, PLB 726 (2013) 610

proton discrepancy 2.7 sigma

fit includes loosely bound systems such as deuteron and hypertriton
hypertriton is bound-state of (Λ,p,n), Λ separation energy about 130 keV
size about 10 fm, the **ultimate halo nucleus,**
produced at T=156 MeV. close to an Efimov state

J. Stachel, A. Andronic, P. Braun-Munzinger and K. Redlich, Confronting LHC data with the statistical hadronization model, J.Phys.Conf.Ser.**509** (2014) 012019, arXiv:1311.4662 [nucl-th].

news on the proton puzzle

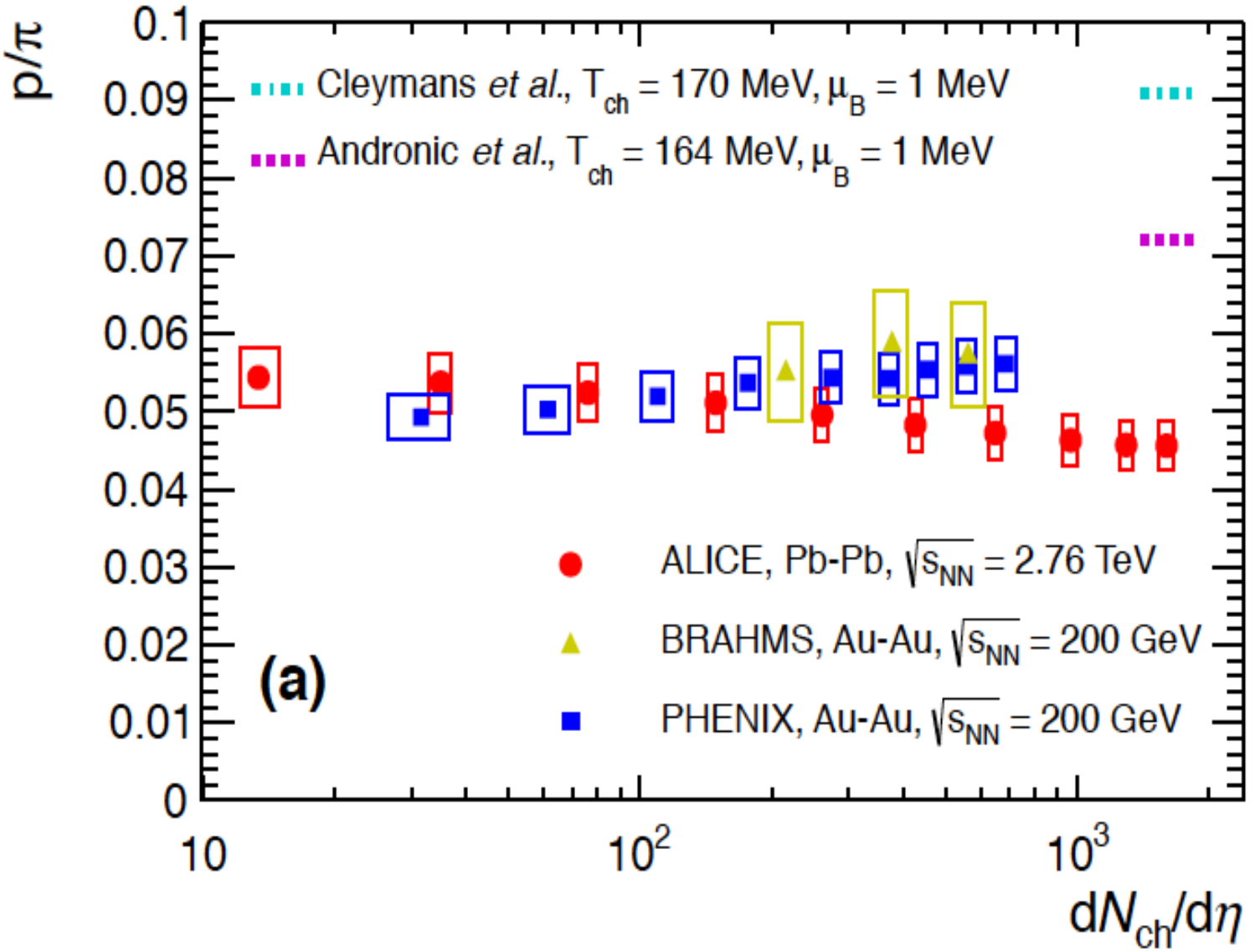
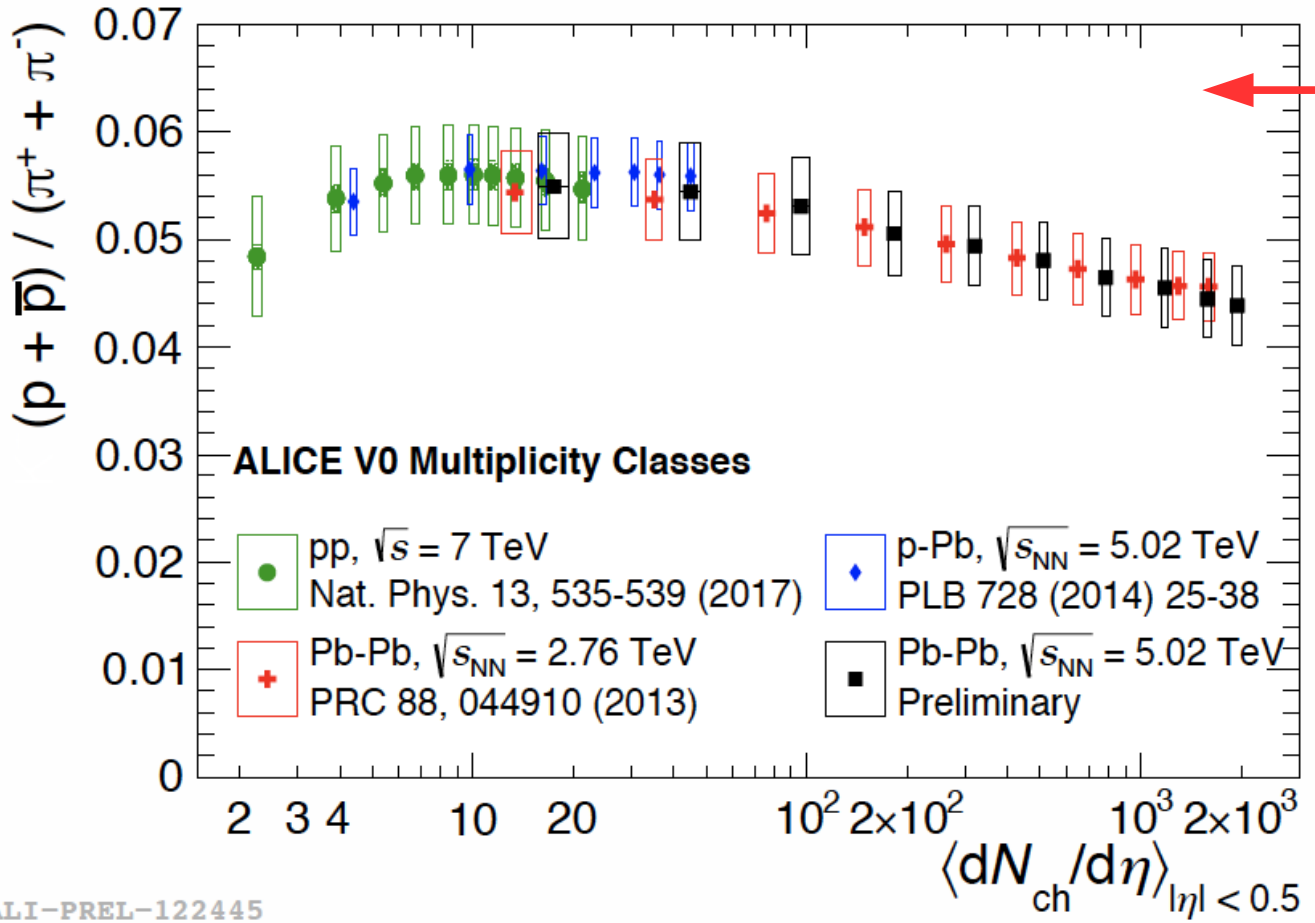


Fig. 9 of Phys.Rev. C88 (2013) 044910, ALICE

anomalous centrality dependence of p/pi ratio? Is the difference between RHIC and LHC data due to an increasing hard scattering production?

the anomalous centrality dependence in the p/pi ratio at LHC energy



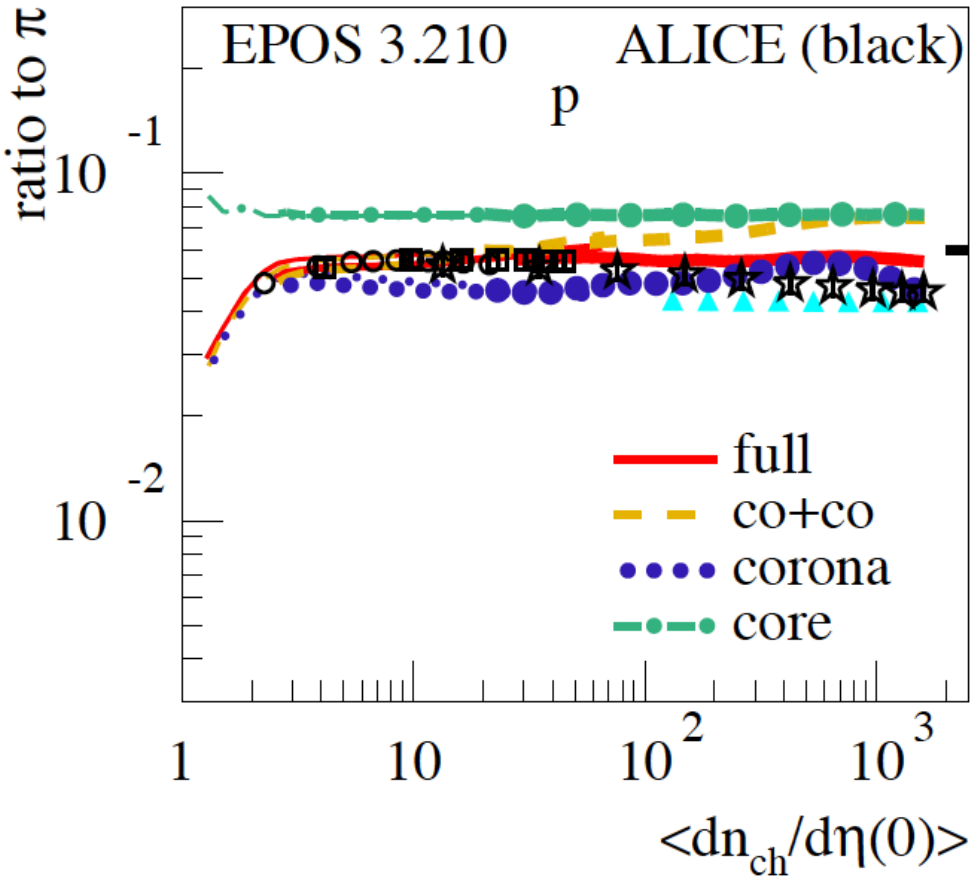
grand-canonical limit at T = 156 MeV for p/pi

new ALICE result

more pions from hard scattering processes at LHC energy?
how to deal with this for statistical hadronization analysis?

core-corona picture (Klaus Werner)

Proton to pion ratio



inelastic interactions (annihilation)

thin lines = pp (7TeV)
intermediate lines = pPb (5TeV)
thick lines = PbPb (2.76TeVVV)

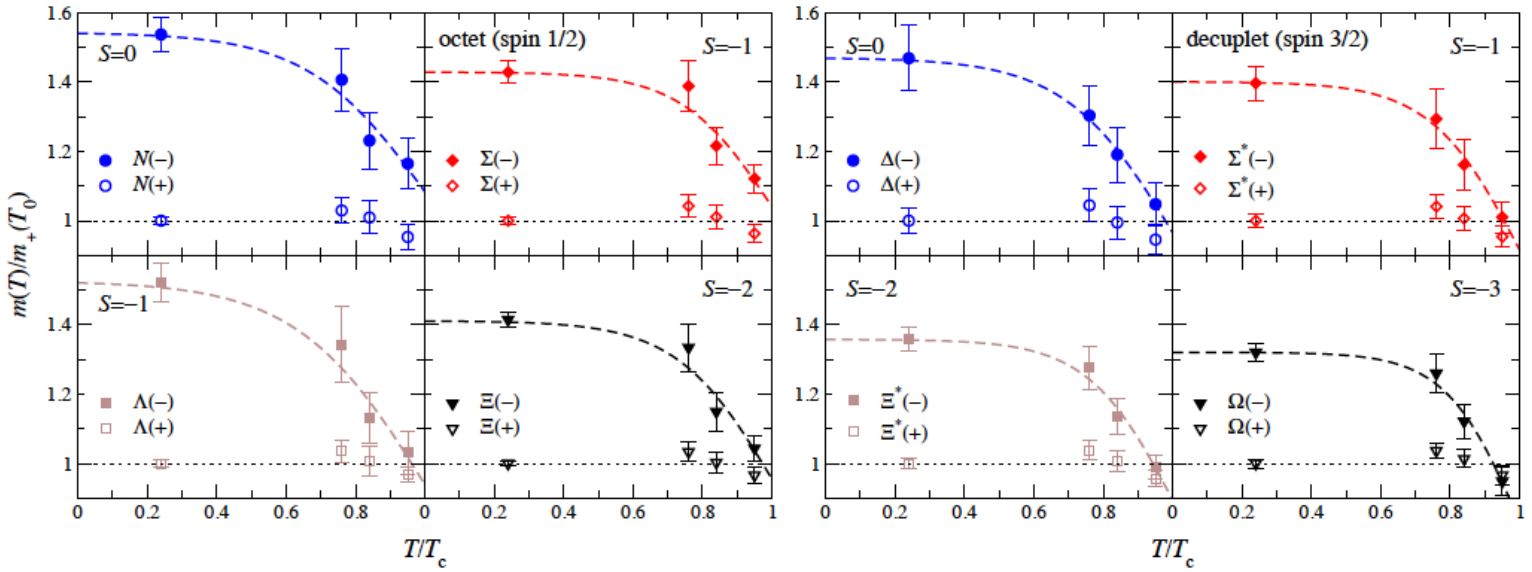
circles = pp (7TeV)
squares = pPb (5TeV)
stars = PbPb (2.76TeV)

no visible p/pi variation with centrality in core/corona model

LQCD results (G. Aarts)

Baryons in the hadronic phase

masses $m_{\pm}(T)$, normalised with m_+ at lowest temperature

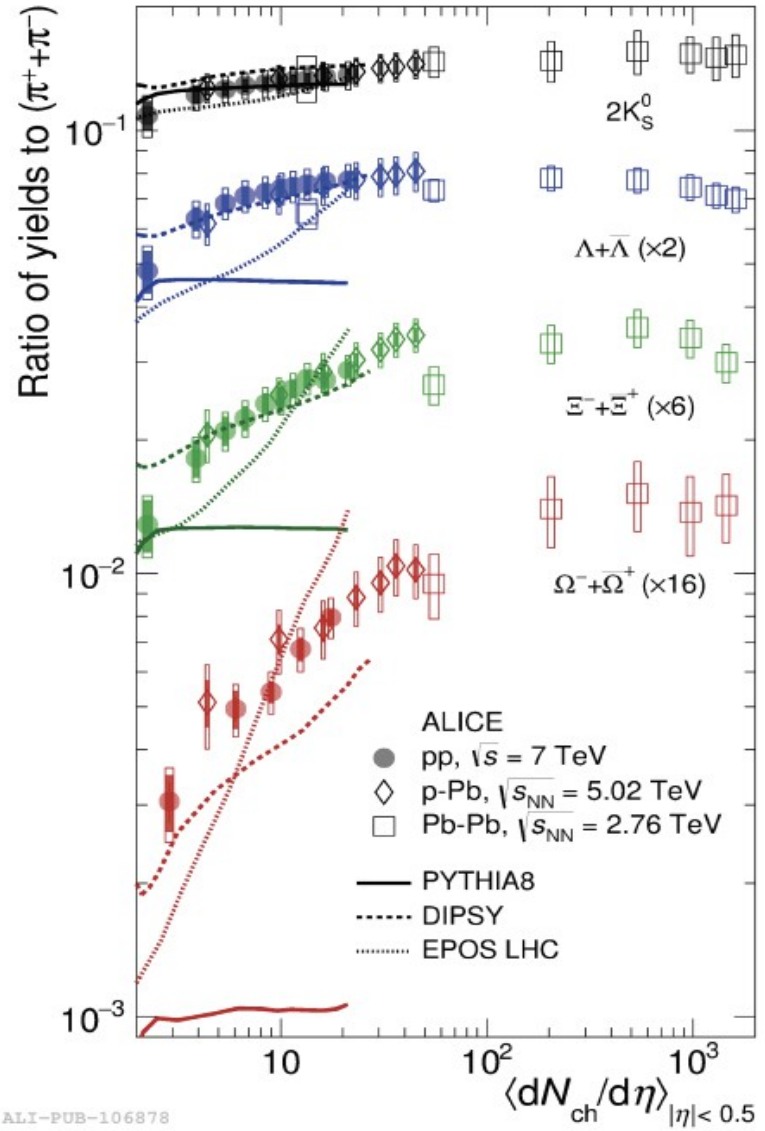


in each channel:

- emerging degeneracy around T_c
- negative-parity masses reduced as T increases
- positive-parity masses nearly T independent

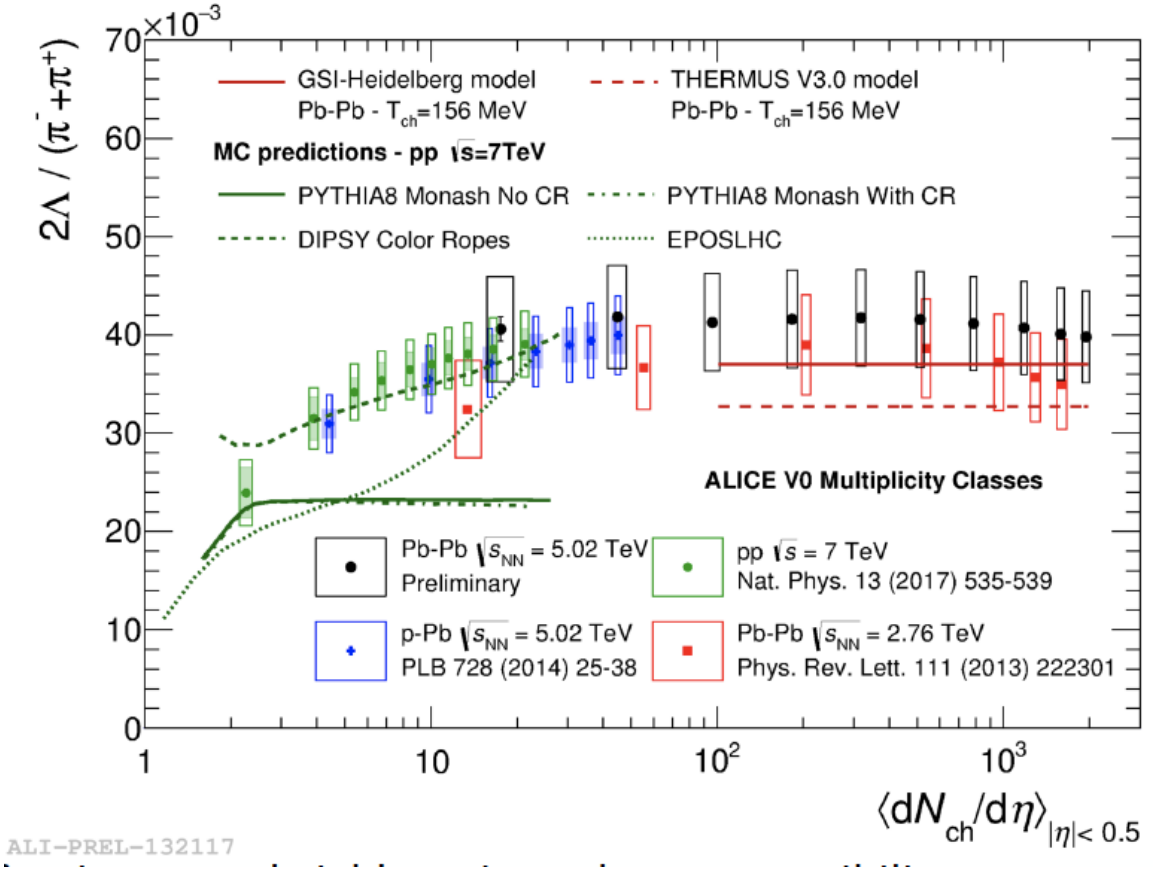
current statistical hadronization fits use 'vacuum' masses. All detectors measure vacuum masses. What gets these off-shell masses on the mass-shell? Entropy reduction? What about mesons?

beautiful demonstration of approach to grand-canonical plateau



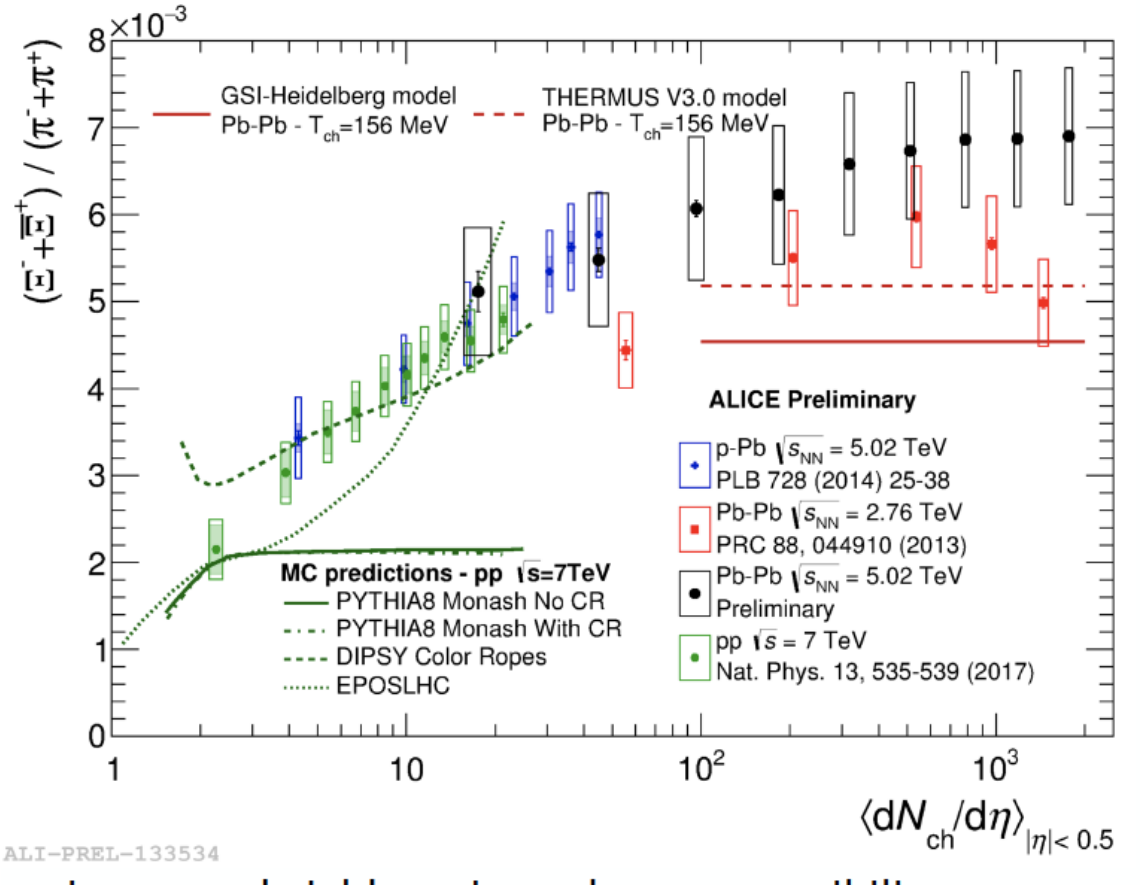
Nature Phys. 13 (2017) 535-539, ALICE

Hadrochemistry

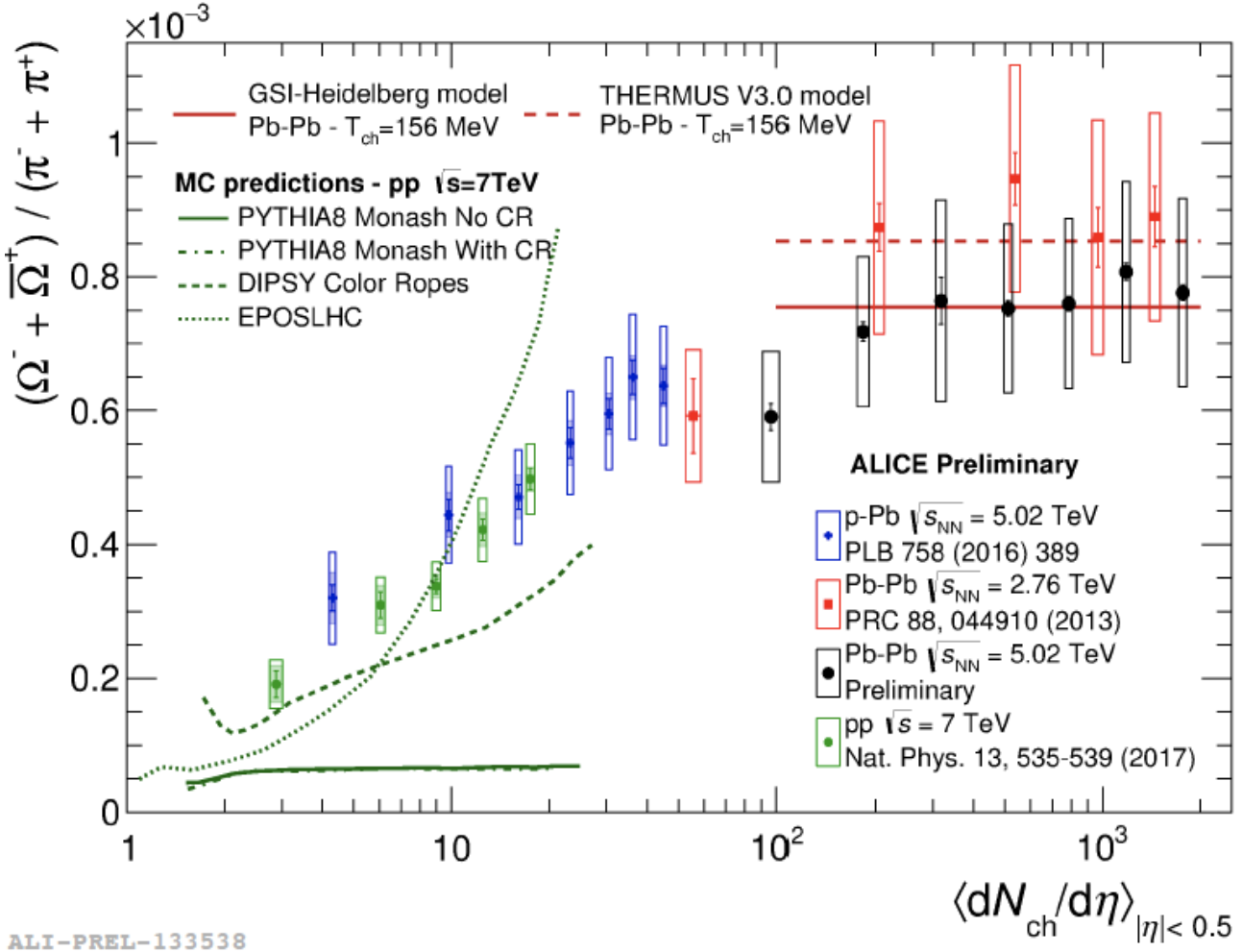


ALI-PREL-132117

Hadrochemistry



is there something special for cascades?



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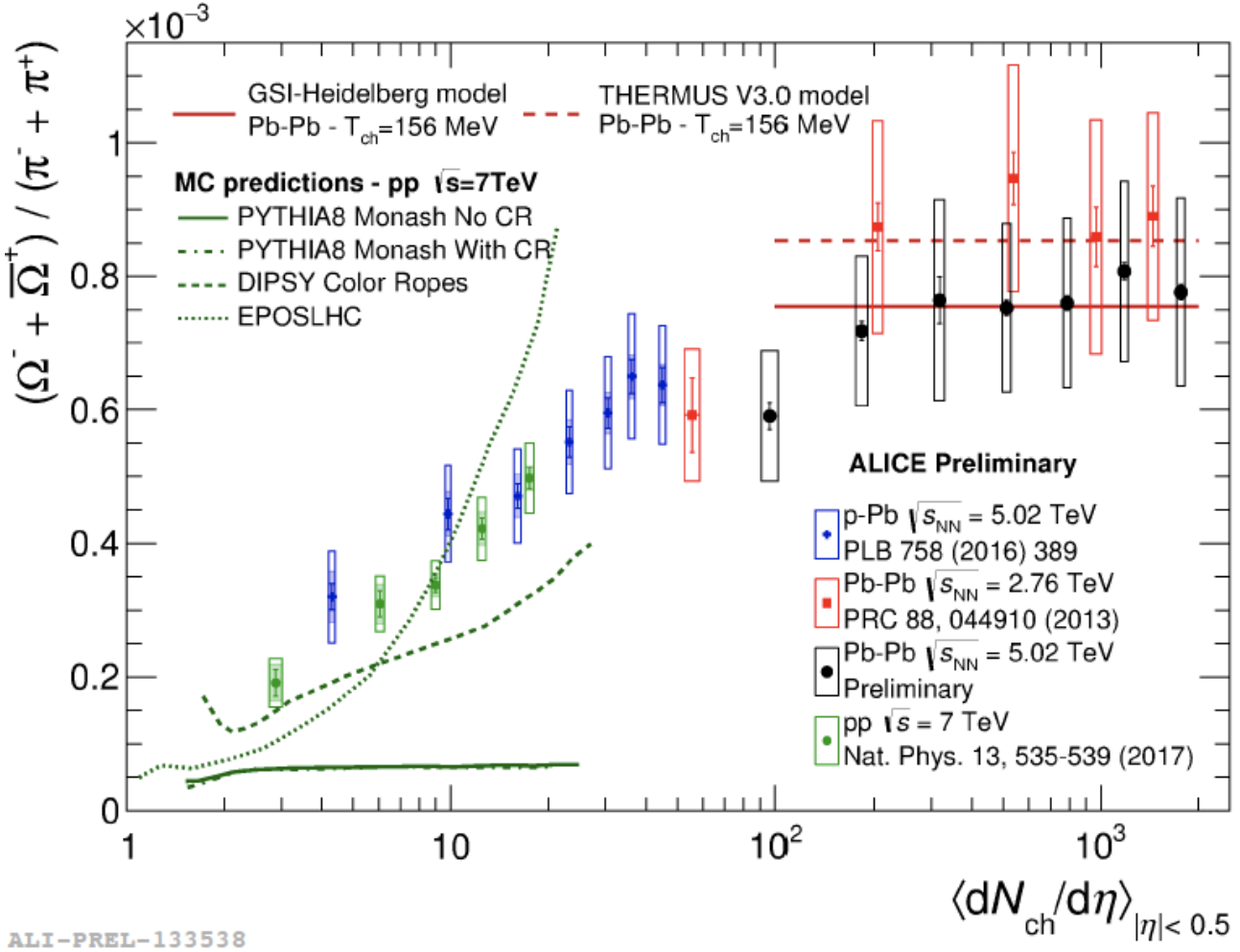
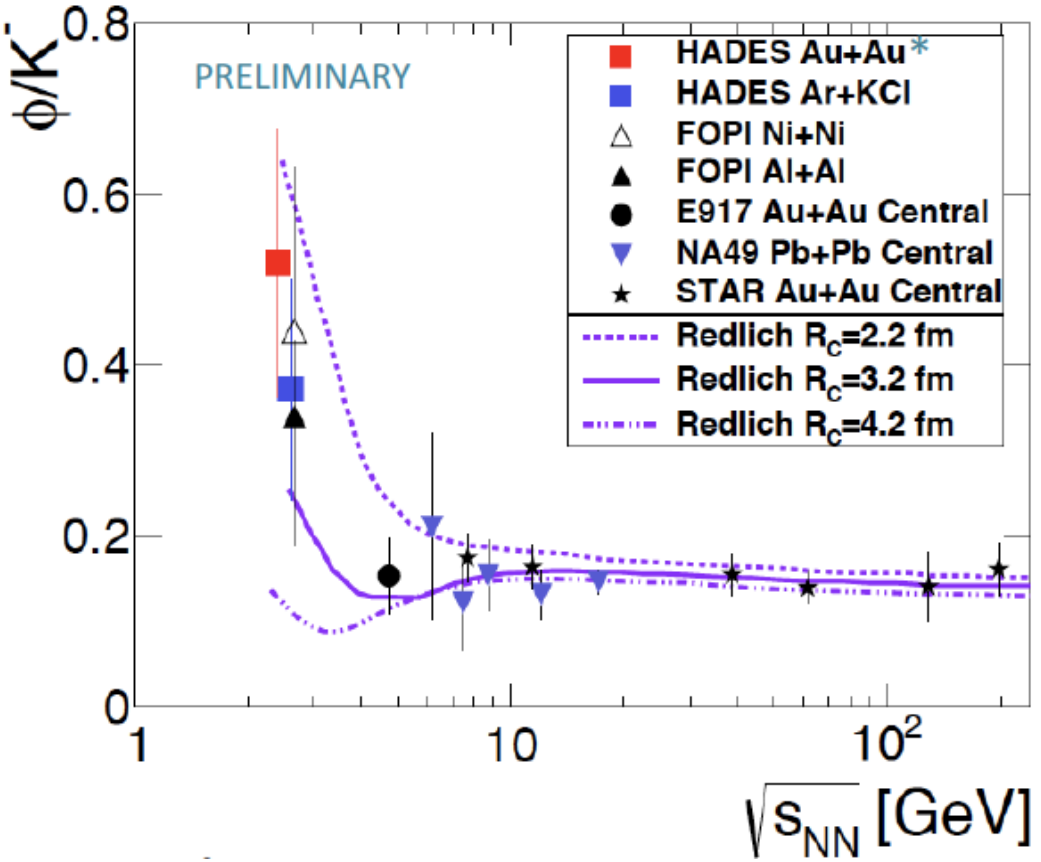
… but Omega/pi looks fine

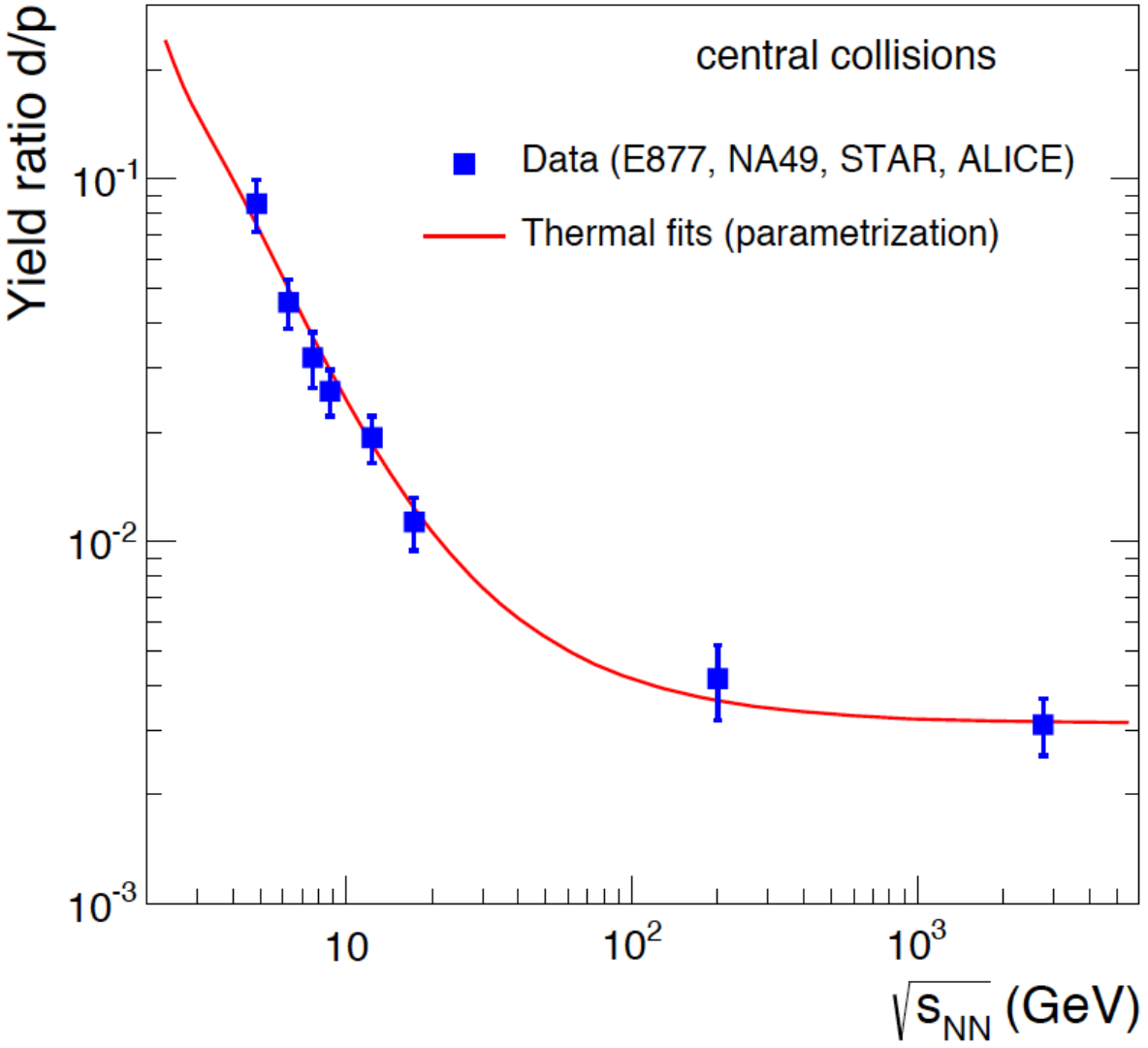


HADES result at SIS energy



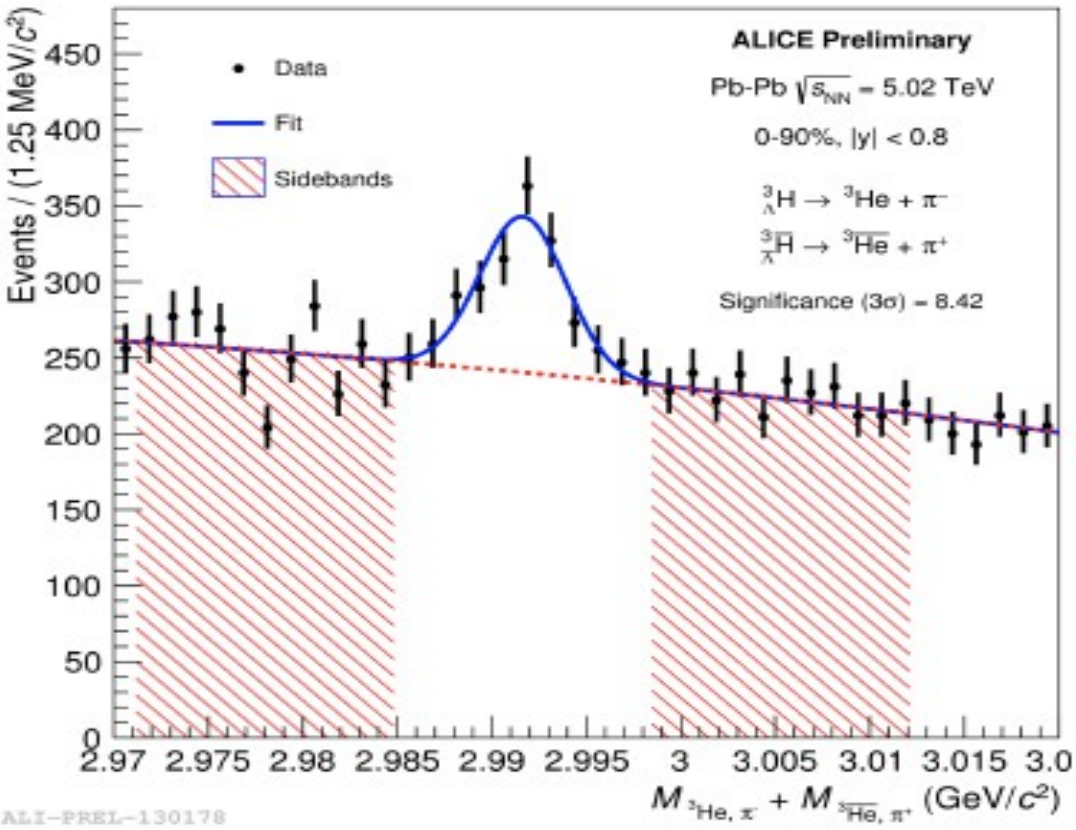
ratio increased → K^- is canonically suppressed

energy dependence of d/p ratio – data and statistical hadronization model prediction

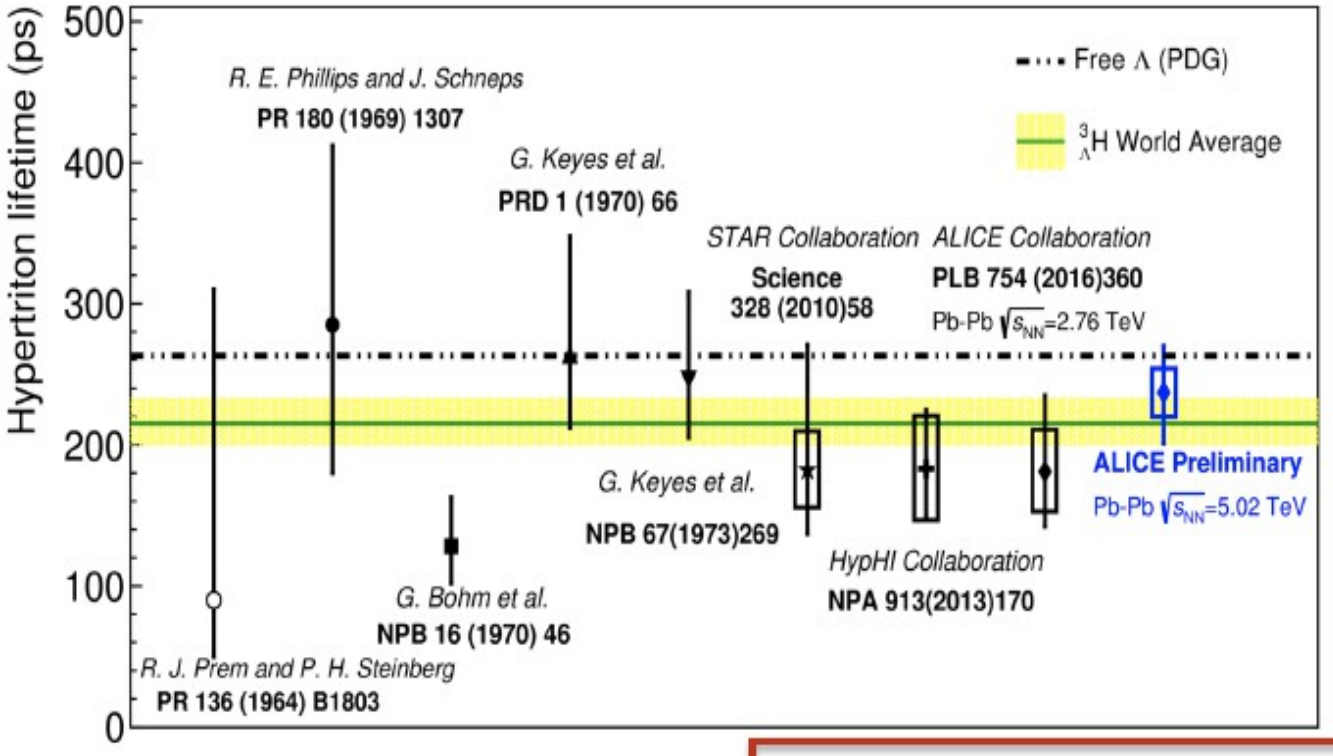


1. production of light nuclei and hypernuclei: a puzzle with deep implications

production of (anti-)hypernuclei experimentally well under control

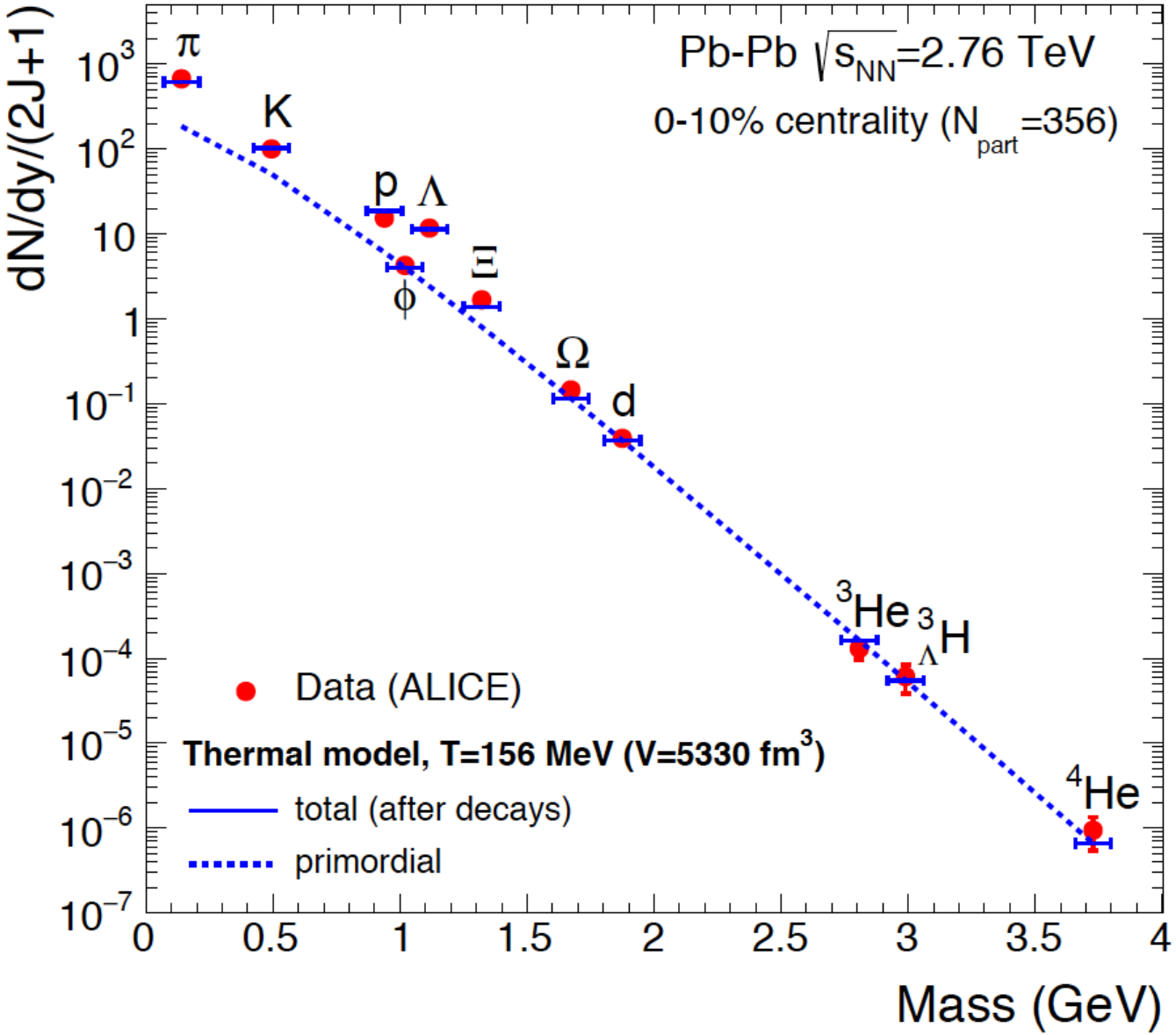


Hyper-triton lifetime compatible with Lambda lifetime within 1 sigma

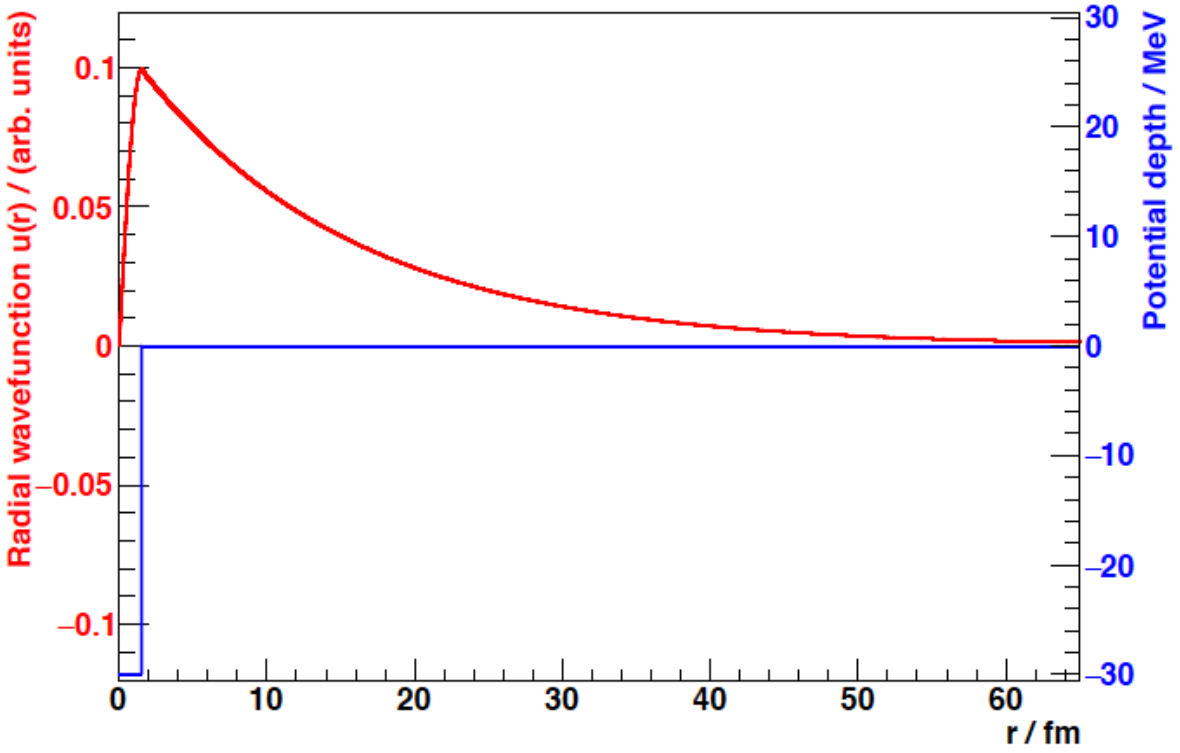


ALI-PREL-130195

$$\tau = 223^{+41}_{-33}(stat.) \pm 20(syst.)\ ps$$


dN/dy/(2J+1)
Mass (GeV)
Pb-Pb $\sqrt{s_{NN}}$=2.76 TeV
0-10% centrality (N_{part}=356)
π
K
p
Λ
Ξ
ϕ
Ω
d
^{3}He
$^3_\Lambda$H
^{4}He
Data (ALICE)
Thermal model, T=156 MeV (V=5330 fm^3)
total (after decays)
primordial

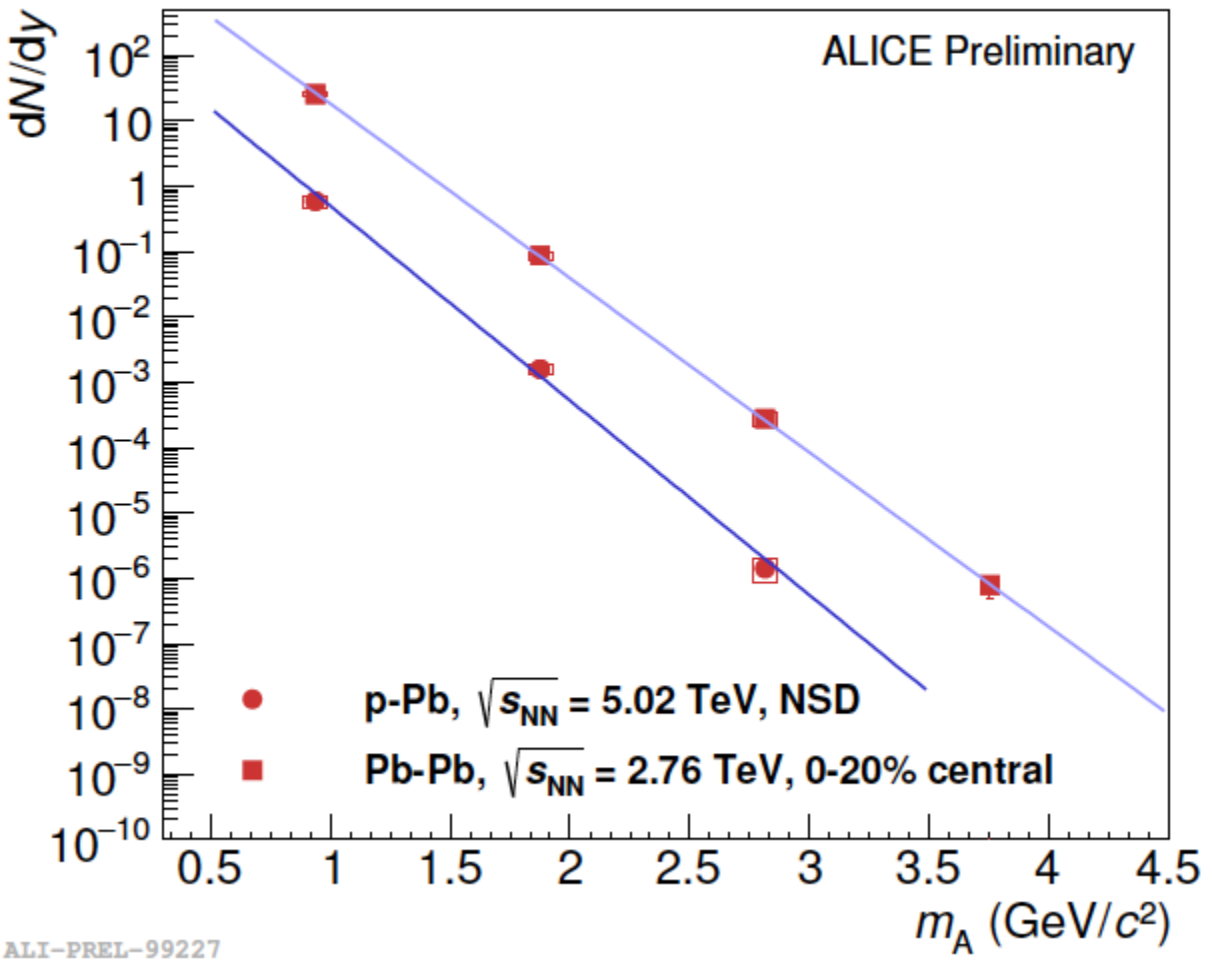
hyper-triton wave function



Wavefunction (red) of the hypertriton assuming a s-wave interaction for the bound state of a Λ and a deuteron. The root mean square value of the radius of this function is $\sqrt{\langle r^2 \rangle} = 10.6$ fm. In blue the corresponding square well potential is shown.

Benjamin Doenigus

Thermal pattern of production of nuclei at LHC enery



CERN Courier

Aug 26, 2015

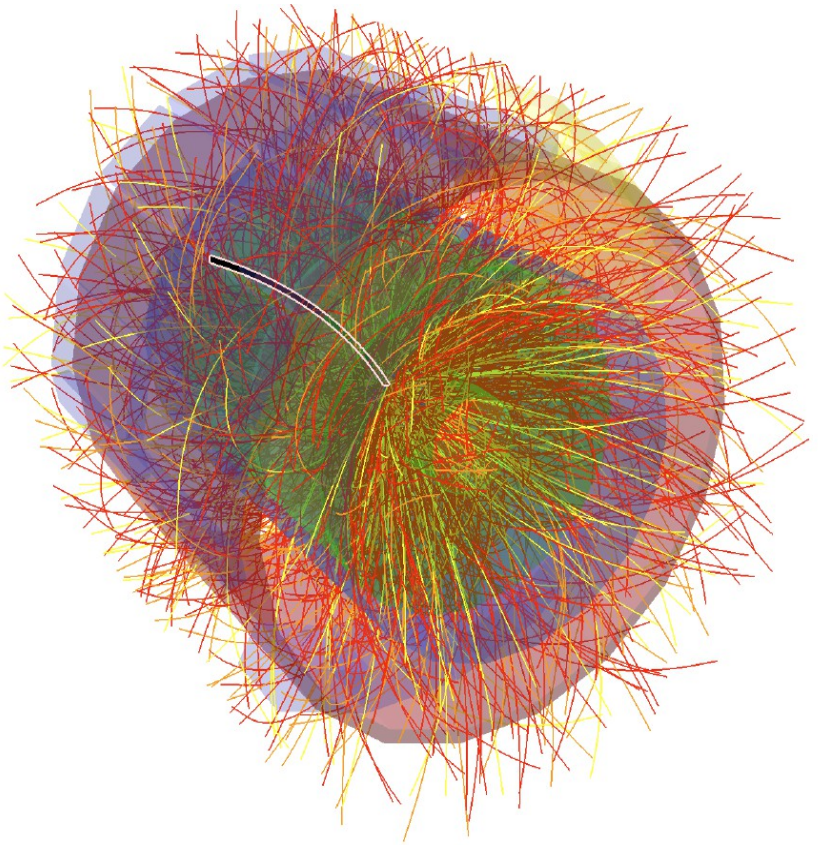
ALICE investigates ‘snowballs in hell’

How is it that loosely bound objects are observed in high-energy nuclear collisions? The ALICE collaboration finds out.

Résumé

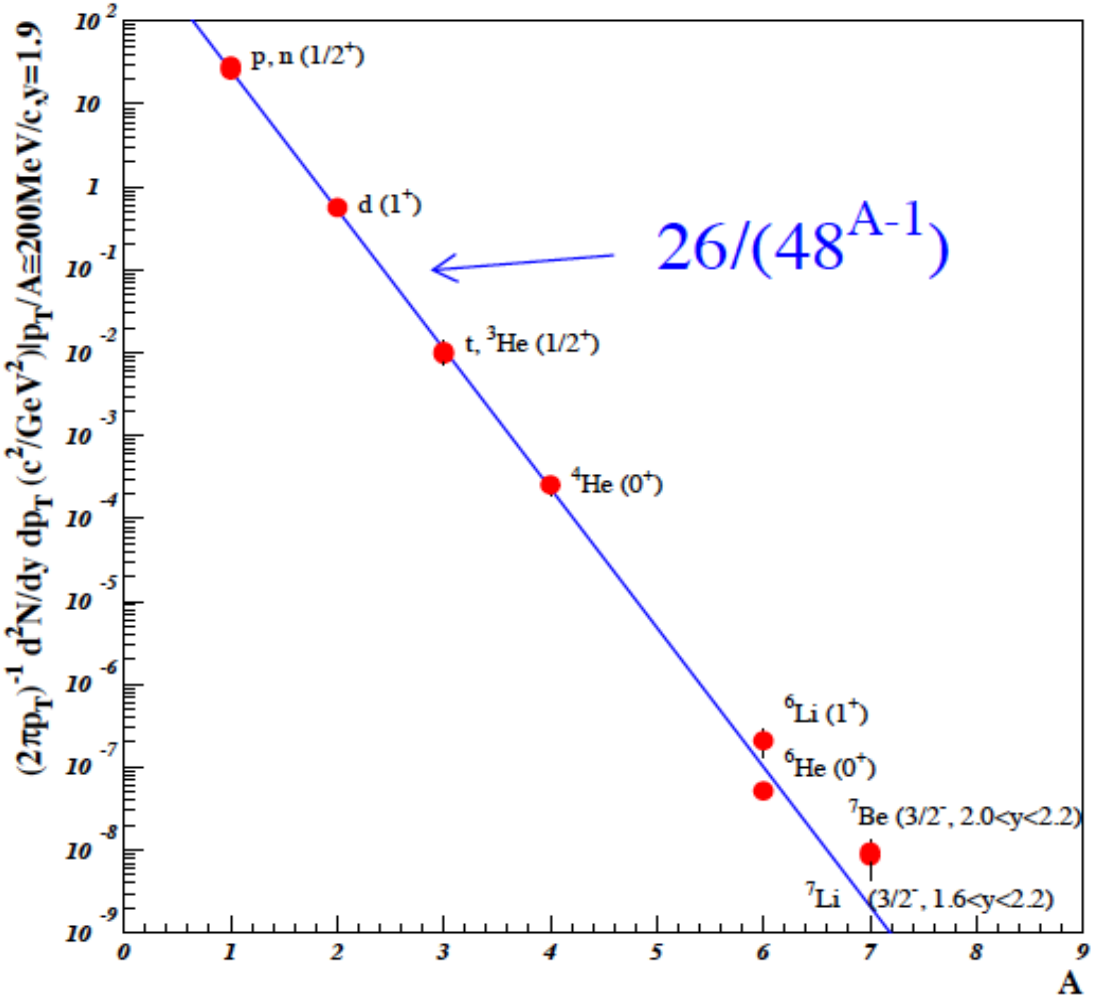
L’omelette norvégienne d’ALICE

pbm, Benjamin Doenigus, Nicole Loeher



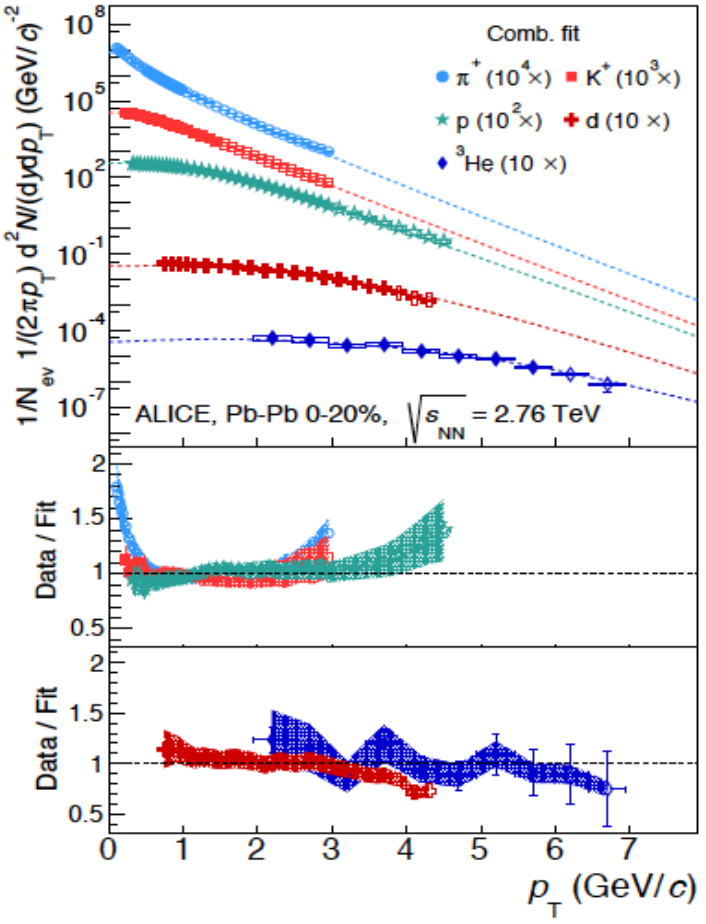
Production of light nuclei in Au-Au collisions at AGS (SIS100) energy

Phys.Rev. C61 (2000) 064908, E864 coll.



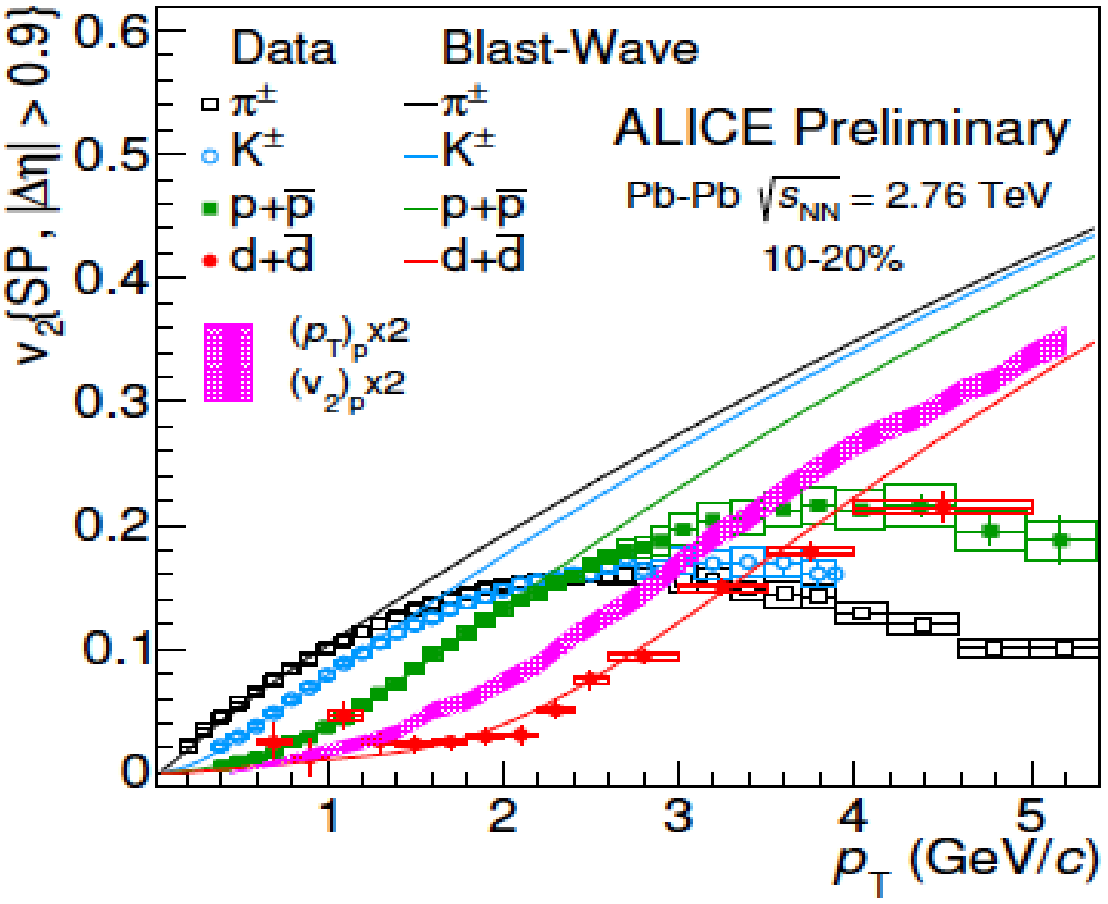
production yield consistent with production at the phase boundary
pbm, Stachel, J.Phys. G28 (2002) 1971-1976

Loosely bound states exhibit hydro flow

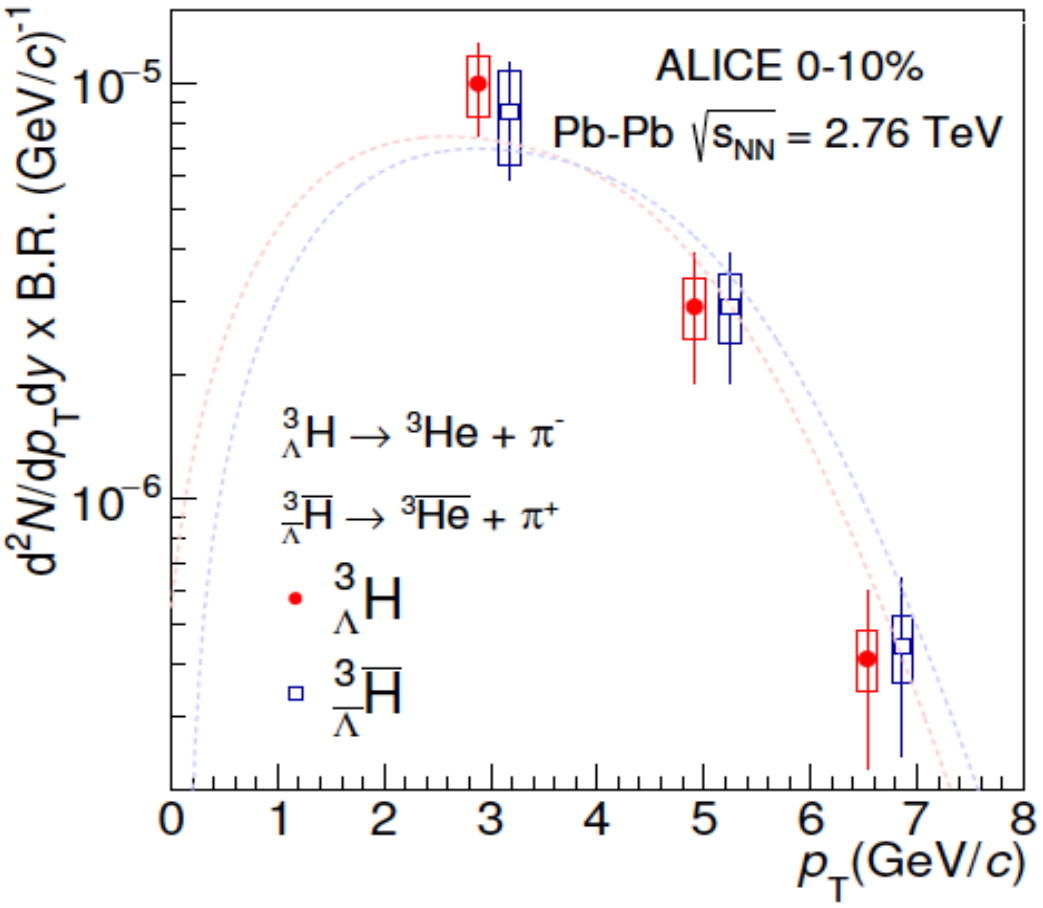


Lines: global 'blast wave' description common flow velocity

Hydro flow continued



Even hyper-triton! But it cannot acquire flow pattern by scattering in hadronic phase. And thermal pattern for particle yields cannot be described by coalescence since hyper-triton wave function is larger than a Pb nucleus.



Quark Model Spectroscopy

Why does the quark model work so well?

Why do M and B body plans dominate?

Why don't multibaryons make one big bag?

Frank Wilczek, QM2014 introductory talk

hypothesis:
all nuclei and hyper-nuclei are formed as compact multi-quark states at the phase boundary. Then slow time evolution into hadronic respresentation.

Andronic, pbm, Redlich, Stachel, in preparation

How can this be tested?

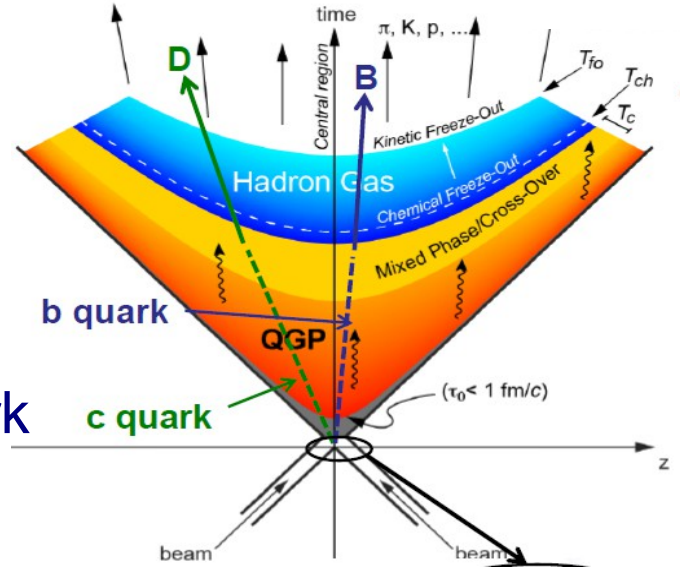
precision measurement of spectra and flow pattern for light nuclei and hyper-nuclei

a major new opportunity for ALICE Run3
and for CBM/NICA/JPARC/NA61

charm quarks in the quark gluon plasma

interest 2-fold:

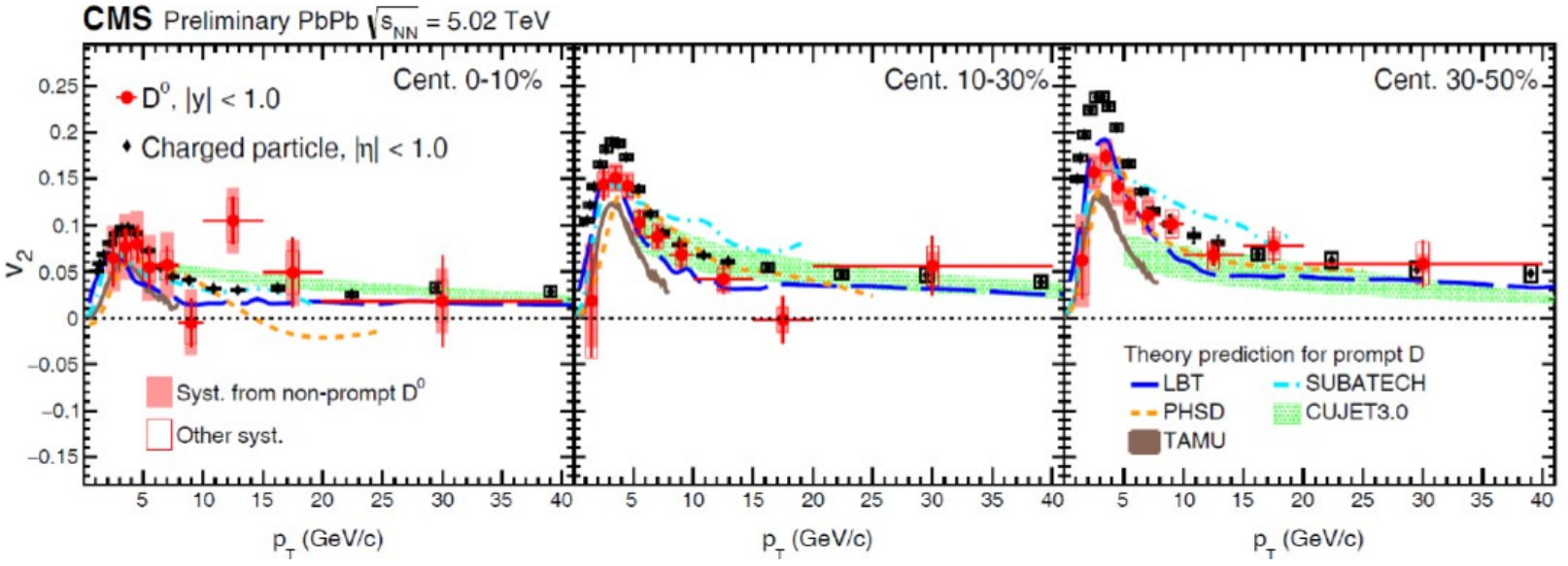
- charm and beauty quarks are produced in early hard scattering processes; time scale $\tau = 1/2m_q$
  t = 0.02 | 0.1 fm i.e. before QGP is even formed
  access to transport coefficient for heavy quarks
  diffusion coefficient vs energy loss of heavy quark
  do charm quarks thermalize?
  do they follow collective dynamics of bulk?

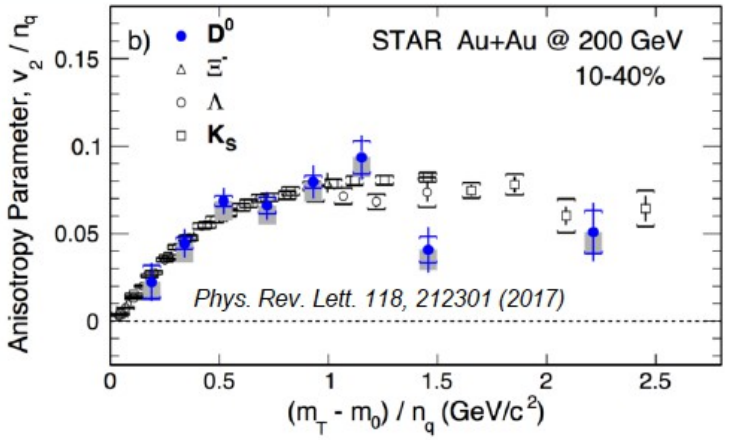


- need total charm cross section for understanding of charmonia (ccbar states)

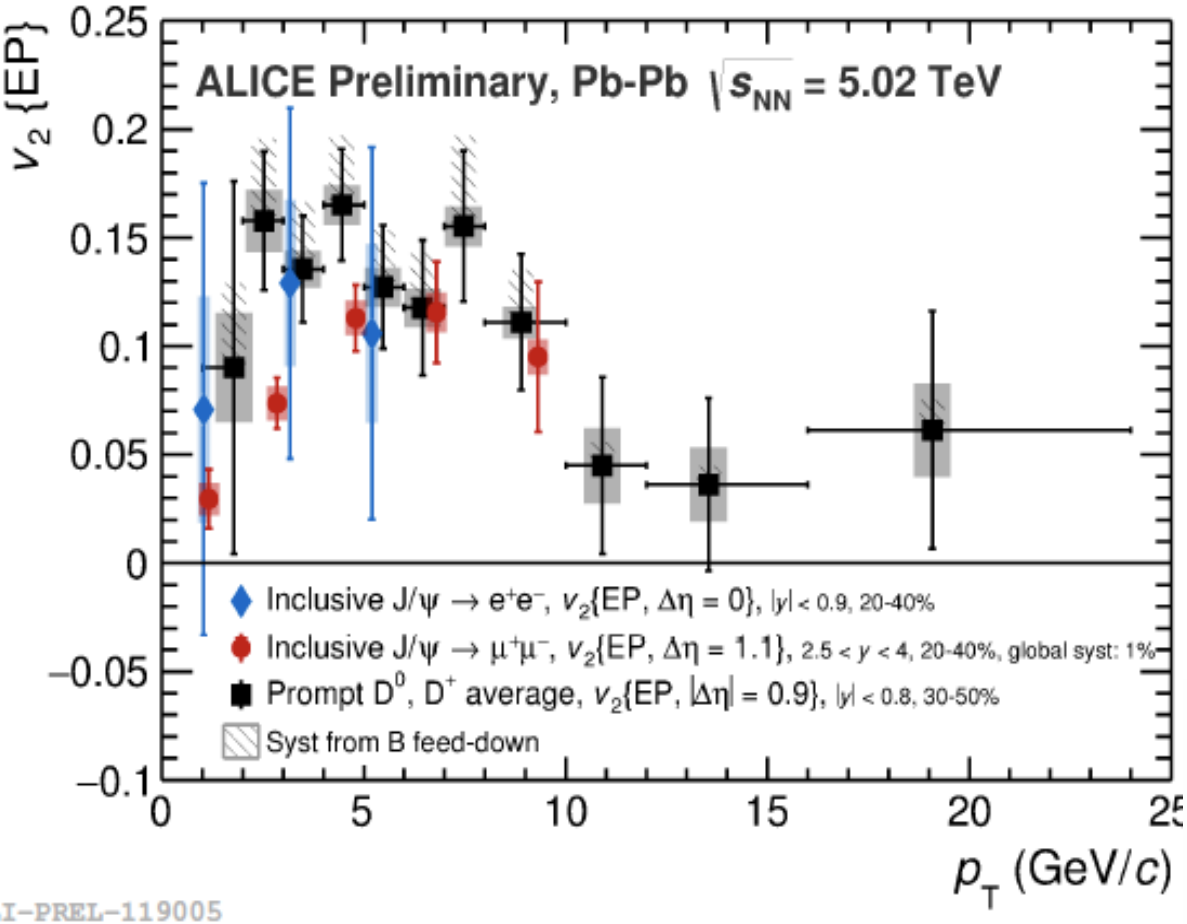
- in pp and pA charm physics interesting on it's own right, tests pQCD and 5parton distribution functions as well as nuclear effects

charm quarks flow – flow amplitude close to but somewhat smaller than that for charged particles

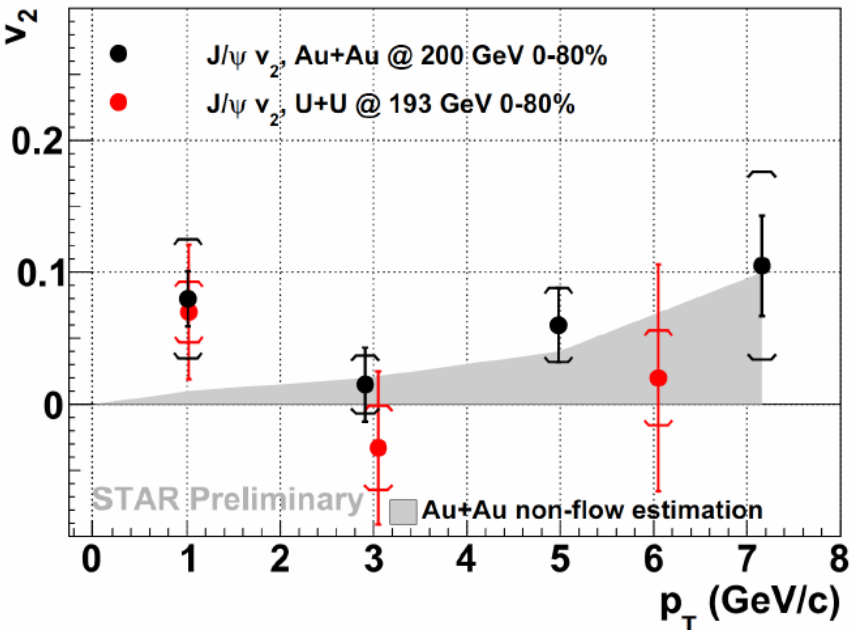




charm quarks and charmonia flow!



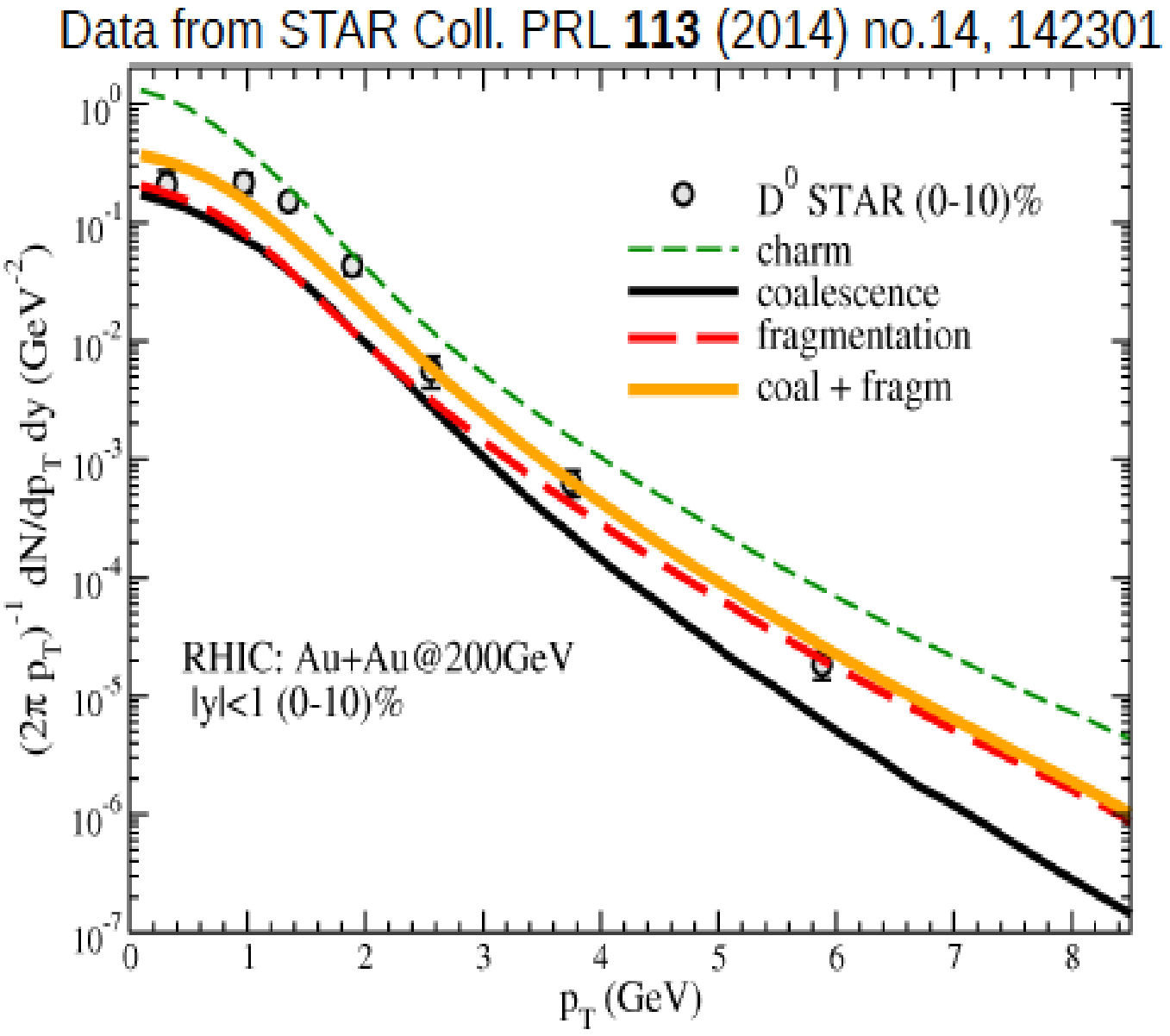
precision measurment of J/psi flow by ALICE



but J/psi does not flow at RHIC energy!? is this significant?

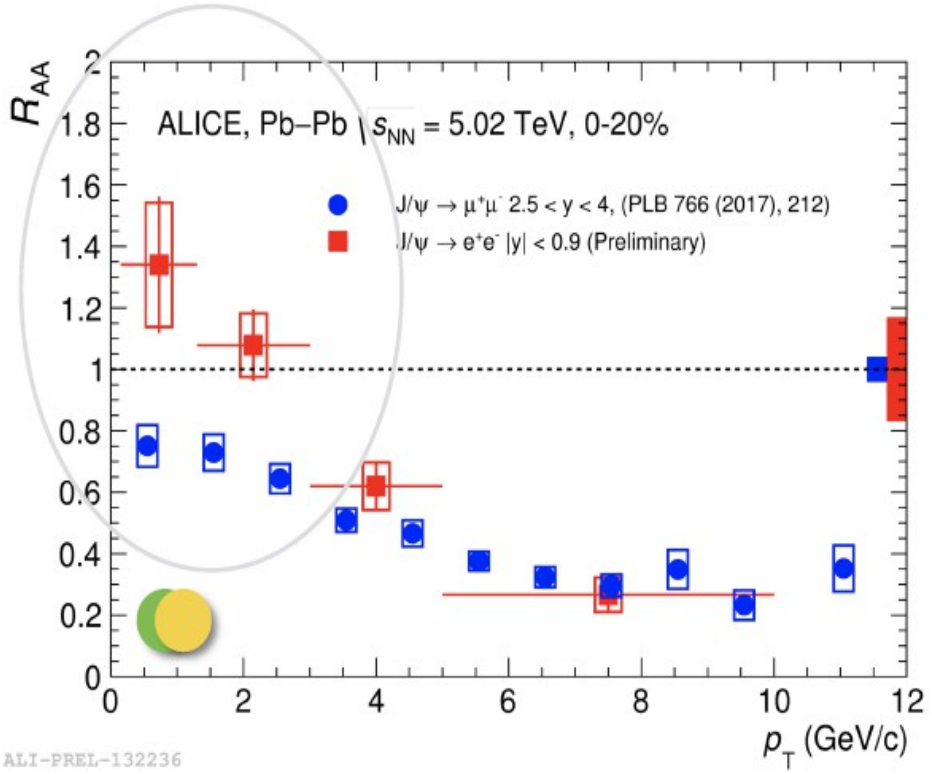
charm quark coalescence and fragmentation

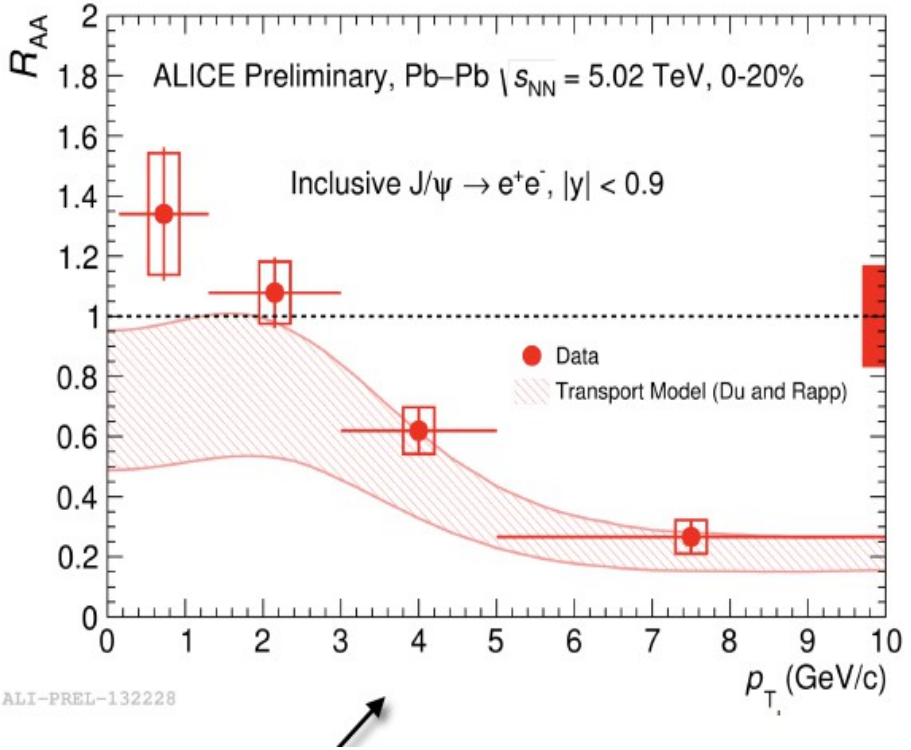
S. Plumari et al.



newest results on J/psi production at LHC energy and low p_T

Pb-Pb: J/ψ→e⁺e⁻ (μ⁺μ⁻) at (forward)mid-rapidity

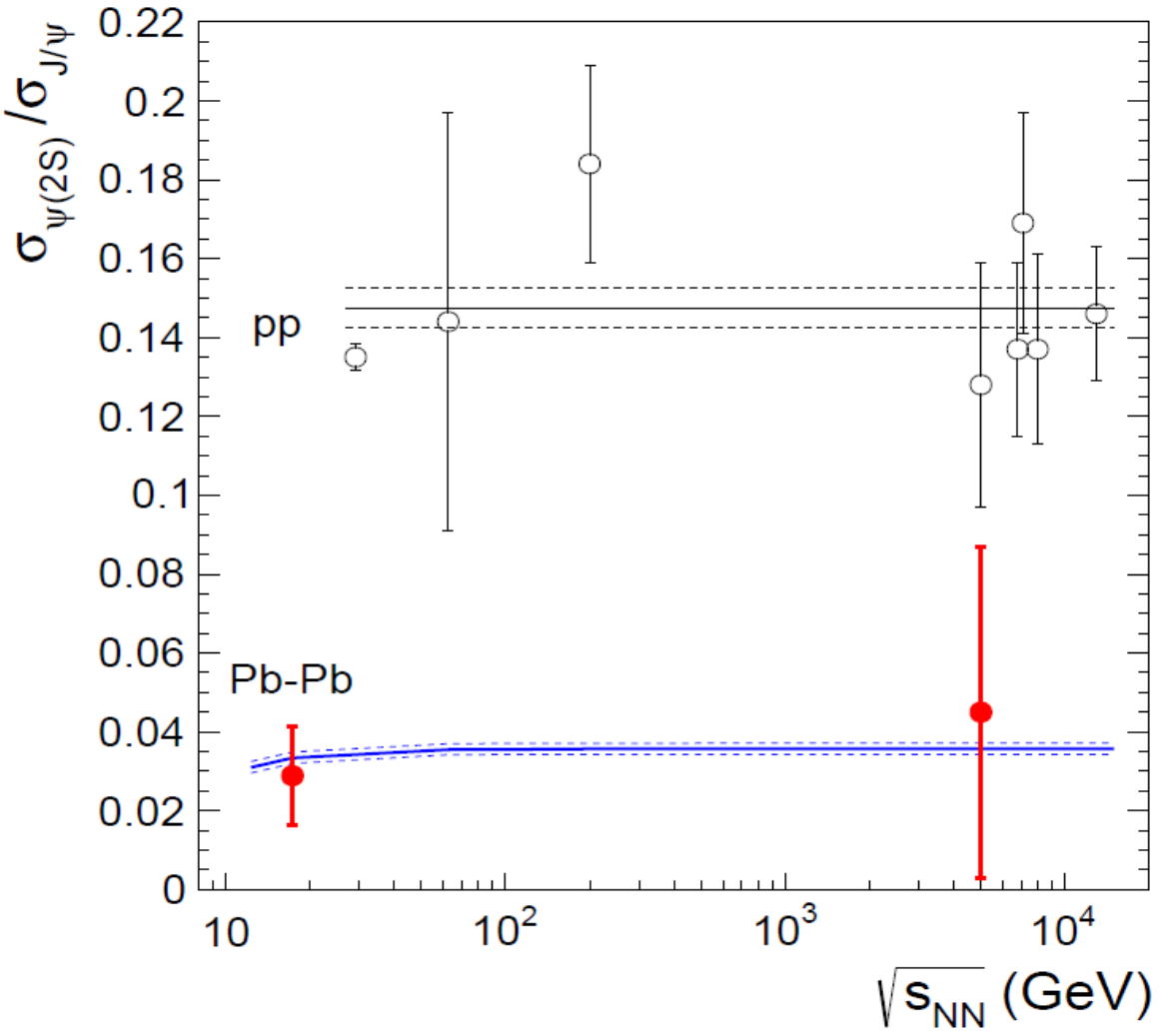




statistical hadronization/recombination picture strongly confirmed by 5 TeV measurements – signature of deconfinement

psi'/(J/psi) ratio and statistical hadronization model

first hint for charmonium freeze-out at phase boundary
much more statistics needed and to come from Run2/3



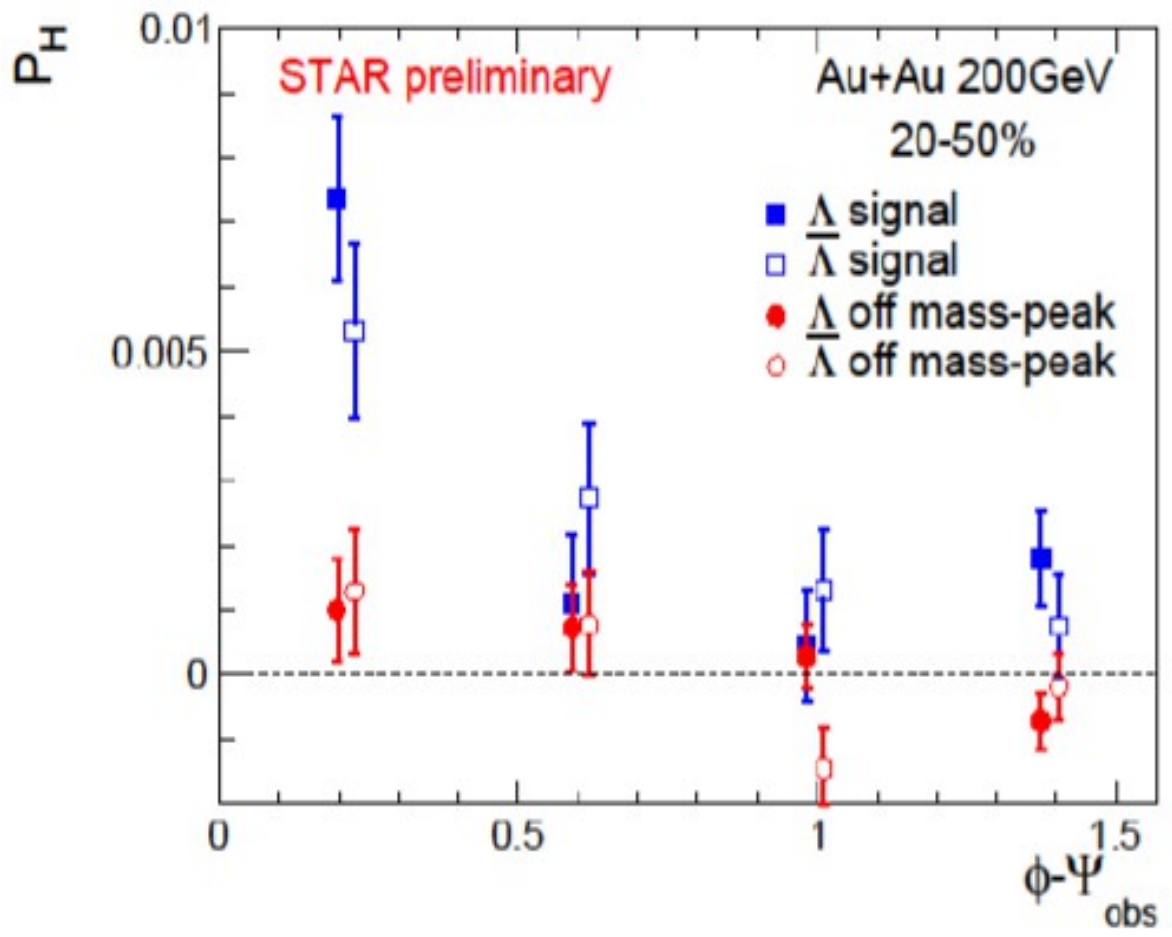
note: with charm quark fugacity the statistical hadronization model works not only for (u,d,s) quarks but also for charm quarks and maybe in the beauty sector

Andronic et al.

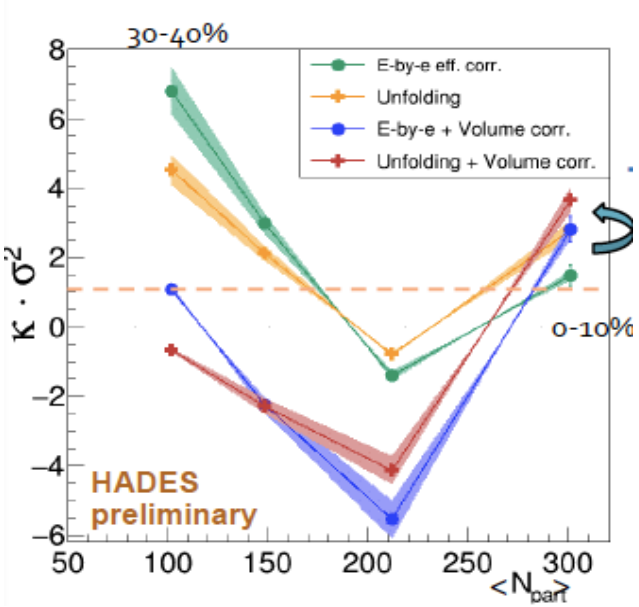
Phys.Lett. B678 (2009) 350-354

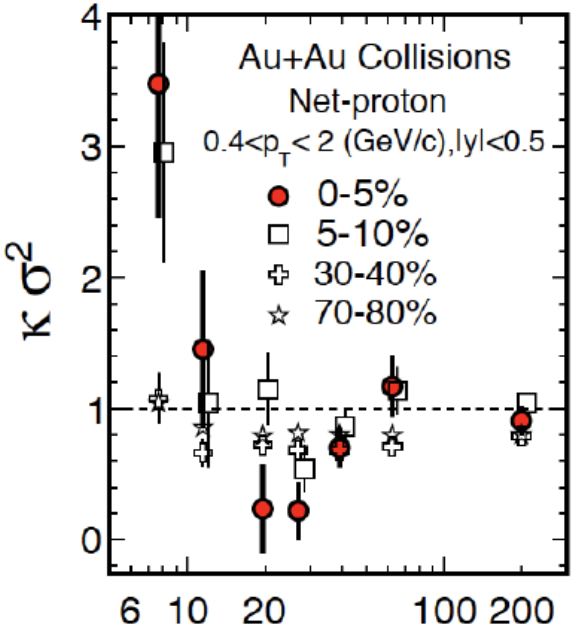
statistical hadronization at the phase boundary

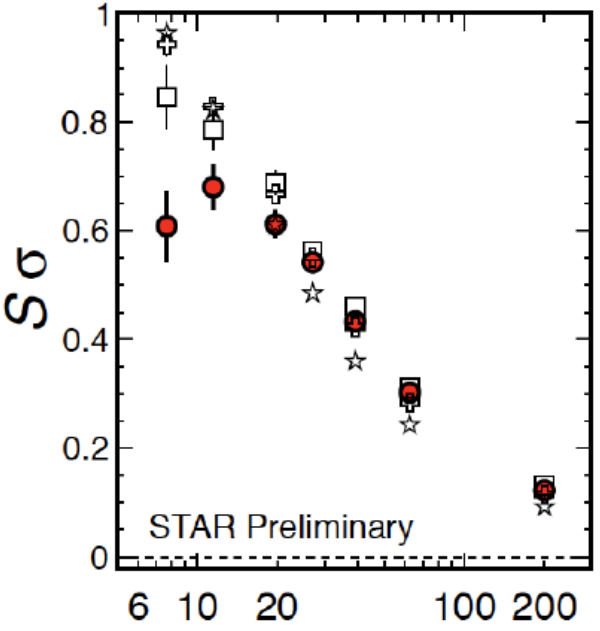
Star global lambda polarization – an interesting signal, implications??



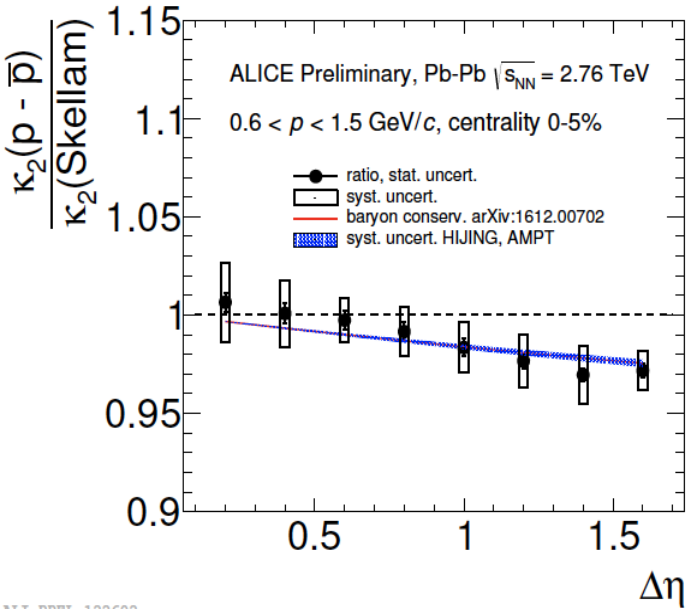
fluctuations of conserved charges and search for critical effects near

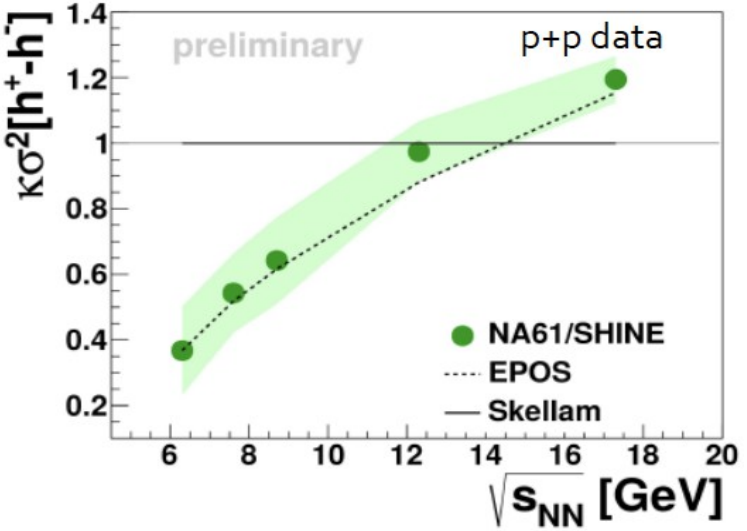






Colliding Energy $\sqrt{s_{NN}}$ (GeV)





can non-critical fluctuations be precisely determined and corrected?

Anar Rustamov

a personal selection of major open questions:

- is there critical behavior near the QCD phase boundary?
  precision measurement of higher (up to 6^{th}) moments of net baryon distributions

- are there colorless bound states inside a QGP?
  precision measurement of psi'/(J/psi) ratio in pp, pA, AA collisions

- is there an energy dependence of T_{chem} between RHIC and LHC energies?
  control of feed-down using the heavy flavor tracker (RHIC) and inner trackers (LHC)

- is Y suppression connected to Debye screening in the QGP?
  precision measurement of rapidity dependence of Y(1s), Y(2s), Y(3s)? Production

- what is the role of in-medium masses?
  implementation into hadron-resonance description?

- is centrality dependence of p/pi ratio anomalous?
  take account of hard scattering components at LHC energy

Steven Weinberg

In complexity, it is only simplicity that can be interesting.

SQM2017

impressively many new data and new theoretical developments

lively and stimulating discussions

professional organization in a beautiful venue

Local Organisation Committee

Cristina Bedda (UU)

Alessandro Grelli (UU)

Paul Kuijer (Nikhef, co-chair)

Marco van Leeuwen (Nikhef)

André Mischke (UU, chair)

Thomas Peitzmann (UU)

Raimond Snellings (UU, co-chair)

Barbara Trzeciak (UU)