SQM 2019

The 18th International Conference on

Strangeness in Quark Matter (SQM 2019)

10 -15 June 2019, Bari (Italy)

Orlando Villalobos Baillie
University of Birmingham
20th November 2019

Plan of Talk

- SQM conference
- Heavy flavour and quarkonia
- Thermal Systems
- Small Systems
- Hyperon nucleon potentials and their uses
- Future experiments
- Summary

Why *Strangeness in Quark Matter* (SQM)?

- I have had a long interest in the series, having been to most of the conferences, including one of the contenders for the "original" conference (Kolymbari, Crete, 1994), and having hosted one at Birmingham in 2013
- The size and scale of the conference has grown a lot over the years, from ~40 participants in 1994 to ~170 in Birmingham and ~290 in Bari.
  - Now regarded as one of the "major" conferences for Heavy Ion physics, and one to which (for example) the ALICE collaboration gives a high priority.


SQM2000 Berkeley

Cape Town 2004

SQM 2013 Birmingham


SQM 2019 Bari

Why *Strangeness*?

- The scope of “strangeness” has been extended over the years to include not only the features of *strange* quark production in heavy ions, but also that of heavier flavour quarks, *c* and *b.*
- They are all good probes of the development of a quark-gluon plasma
  - Strange quarks are not present (much) in the initial state, but are produced copiously in a heavy ion interaction – mainly *thermal* production
  - Heavier flavours *c* and *b* have been considered to be too heavy to be produced thermally, and therefore must be produced through hard scattering
    - → calculable cross sections to compare with pp scattering!
  - At LHC energies, the temperatures achieved in a heavy ion collision are so high that this is not quite true for *c* quarks, where there is now a lot of evidence for a thermal component, but remains true for *b* quarks.
- These differences in production, coupled with full use of the analysis of dynamics developed using unidentified hadrons (e.g. jet production, azimuthal dependence, etc.) make the use of flagged flavour production a very powerful tool in studying the QGP.

Why *Quark Matter*?

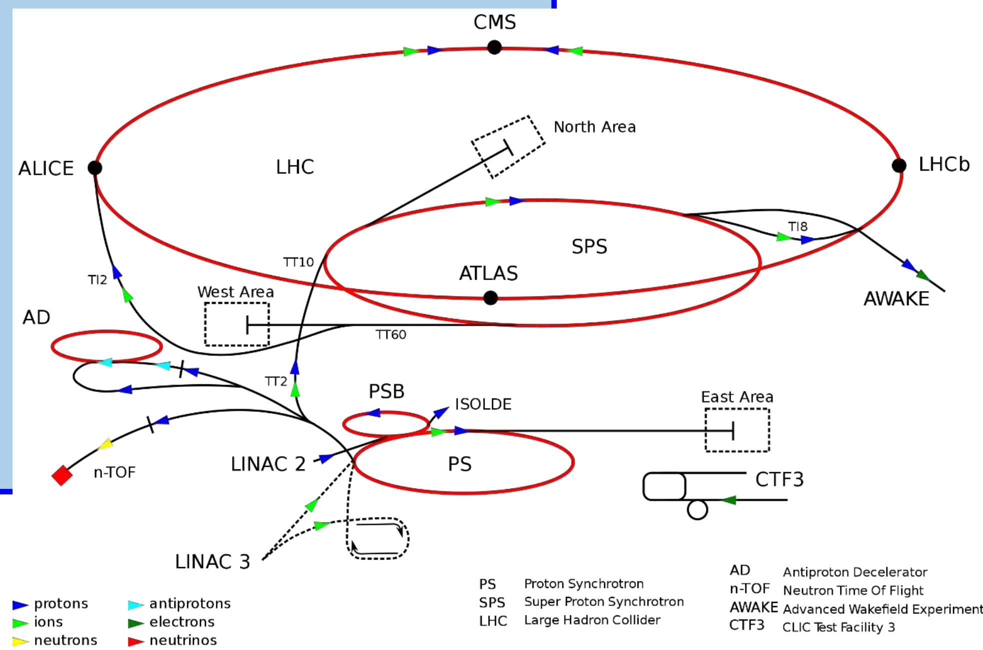
- Of course, the main focus of the conference has been to discuss the findings from the experimental studies of (ultra-relativistic heavy ion collisions), (BNL, CERN, GSI, with more in future) and their interpretation (hot quark matter)
- However, the origins of the conference stem from an interdisciplinary project with astrophysicists). The scope was originally intended to cover (i) the origins of the Universe in cosmology, and (ii) evidence for large strange objects ("strange stars") in the current universe.
  - Unfortunately, it has been a long time since the early universe was discussed at these conferences (Schramm in Chicago was a fan…, but there has not been a lot of activity more recently), but
  - Strange stars have remained, and very recently there has been a linking of the two studies.

The Experiments

Experimental facilities: LHC

- LHC, CERN:
    - pp up to 13 TeV (0.9, 2.36, 5.02, 7, 8, 13 TeV)
    - Pb–Pb up to 5.02 TeV (2.76, 5.02 TeV)
    - Xe–Xe 5.44 TeV
    - p–Pb up to 8.16 TeV (5.02, 8.16 TeV)
    - possibly other nuclei

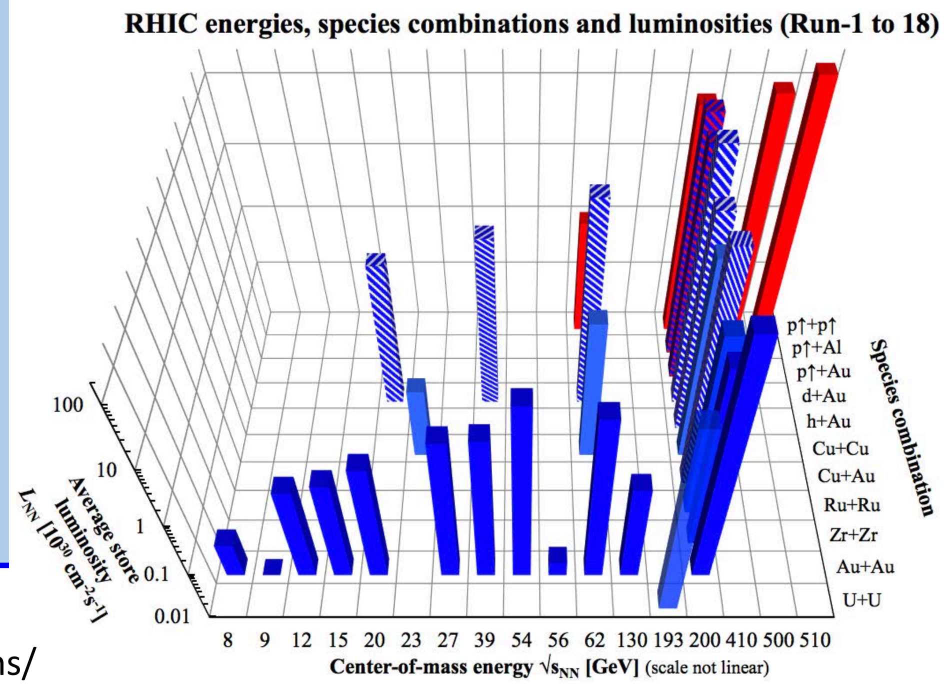
- ALICE – dedicated heavy-ion experiment
- ATLAS – general-purpose detector, HI capabilities
- CMS – general-purpose detector, HI capabilities
- LHCb – forward beauty experiment, HI capabilities forward and fixed target



Experimental facilities: RHIC

- RHIC, BNL
  - pp up to 500 GeV (62, 200, 400, 500 GeV, polarized)
  - Au–Au up to 200 GeV (many from 7.7 GeV) BES
  - Cu–Cu up to 200 GeV (22, 62, 200 GeV)
  - U–U 193 GeV
  - Cu–Au 200 GeV
  - Zr–Zr; Ru–Ru 200 GeV
    special run with isobar nuclei
  - p, d, He–Au 200 GeV
    (d–Au 19.7, 39, 62, 200 GeV) BES
  - possibly fixed target Au–Au BES

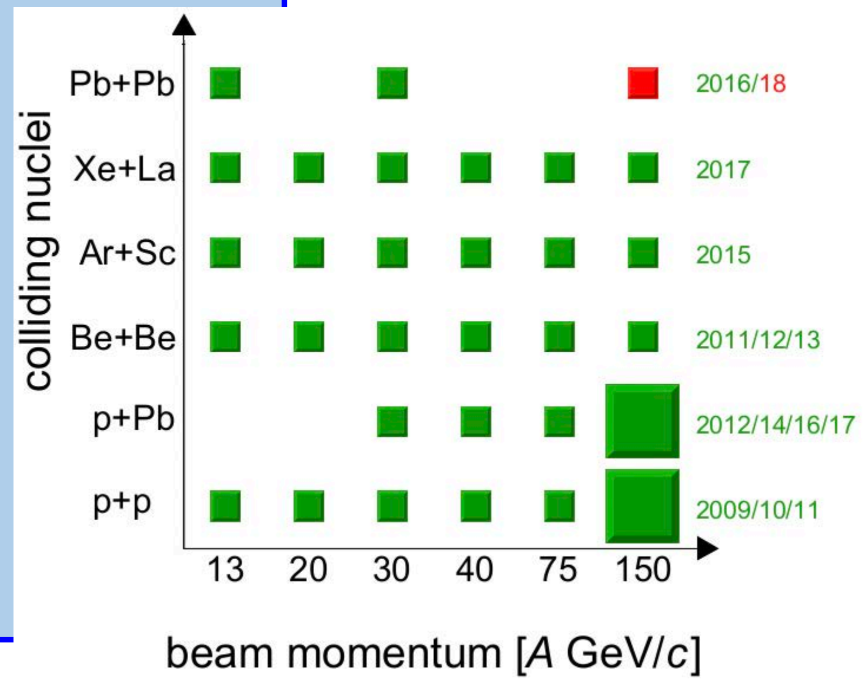
- STAR – multipurpose HI detector (hadrons)
- PHENIX – multipurpose HI detector (leptons)
  -> sPHENIX



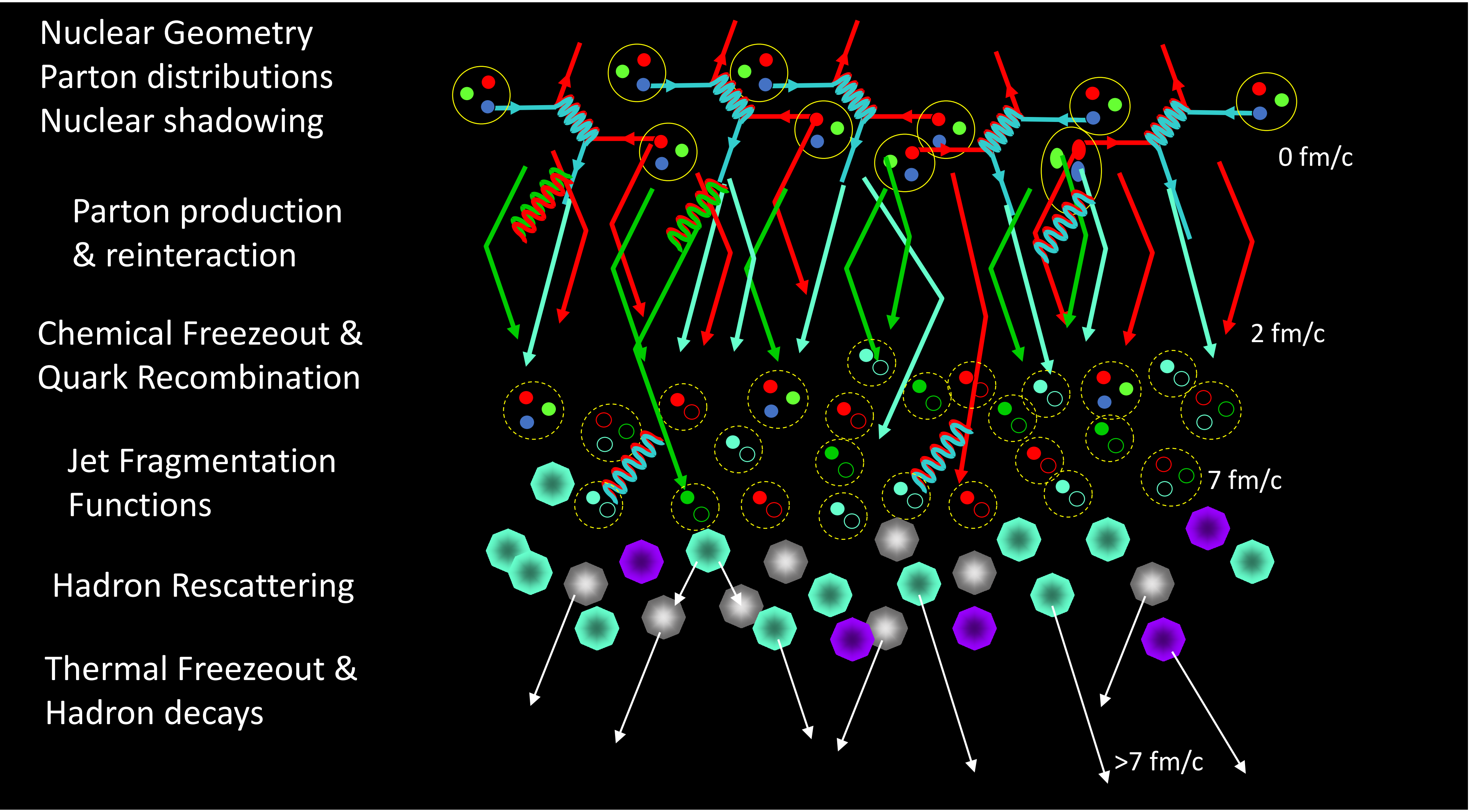
http://www.rhichome.bnl.gov/RHIC/Runs/

Experimental facilities: SPS, SIS18

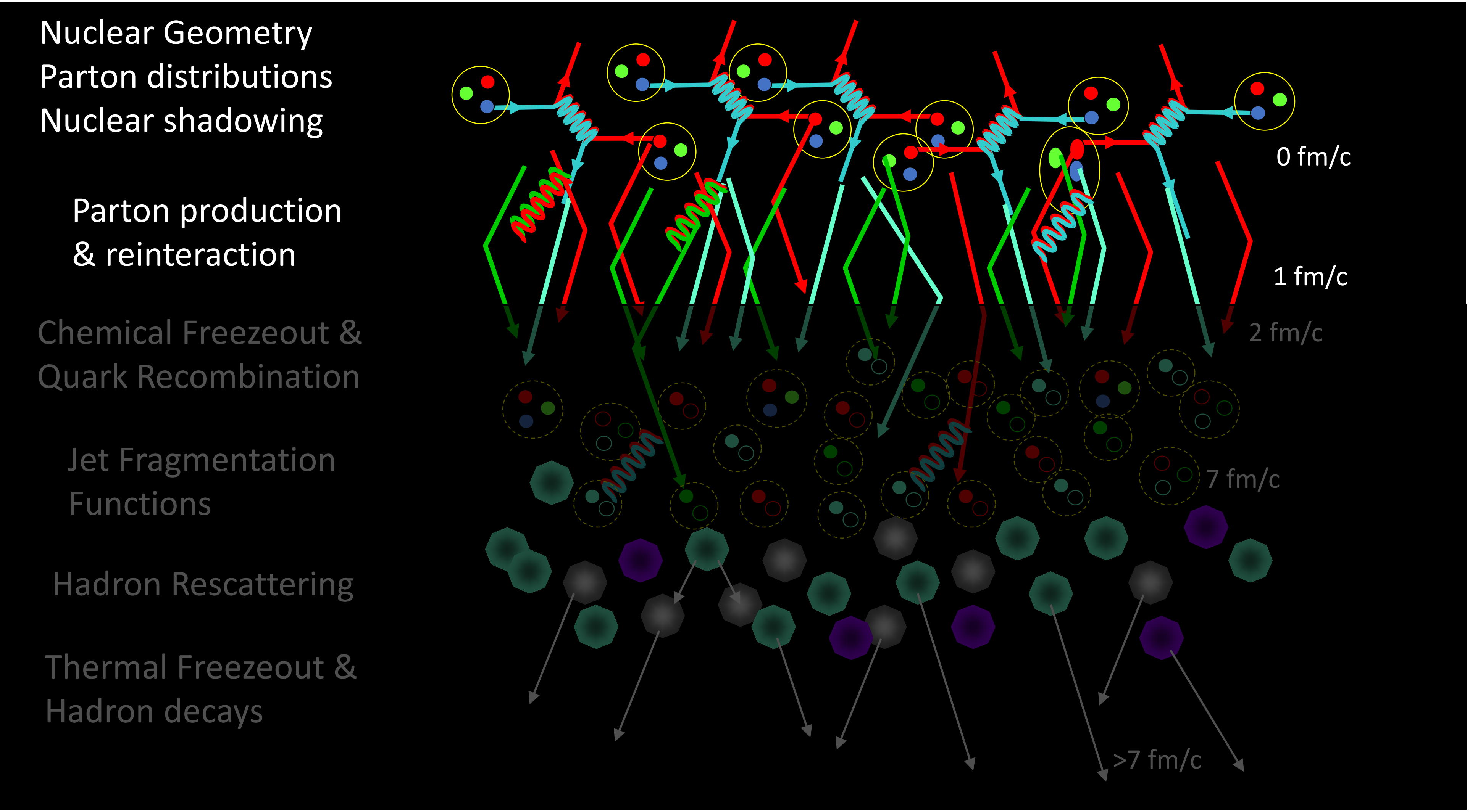
- SPS, CERN
    - pp up to 29 GeV (450 GeV in lab)
    - Pb–Pb up to 17 GeV (156 GeV in lab) BES
    - many other combinations from fragmented beams BES
  - NA61/SHINE – follow-up of NA49
- SIS18, GSI
    - pp up to 2.9 GeV (4.5 GeV kinetic in lab)
    - Ne–Ne up to 1.9 GeV (1.9 GeV kinetic in lab)
    - U–U up to 1.4 GeV (1.1 GeV kinetic in lab)
  - HADES – high acceptance spectrometer for di-electrons and hadrons
  - FOPI – 4π spectrometer, hadron identification



A Brief Dynamical History of Time



A Brief Dynamical History of Time



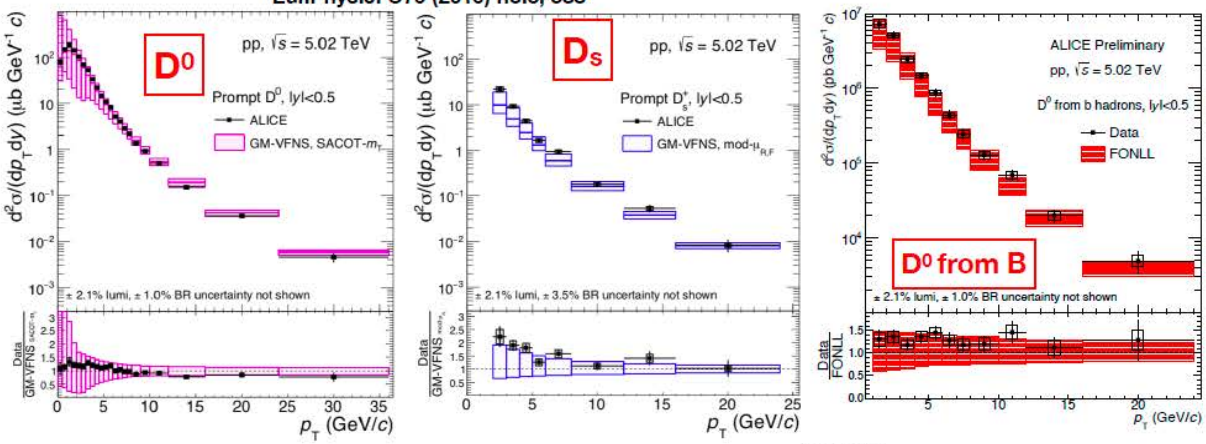
Heavy Flavour

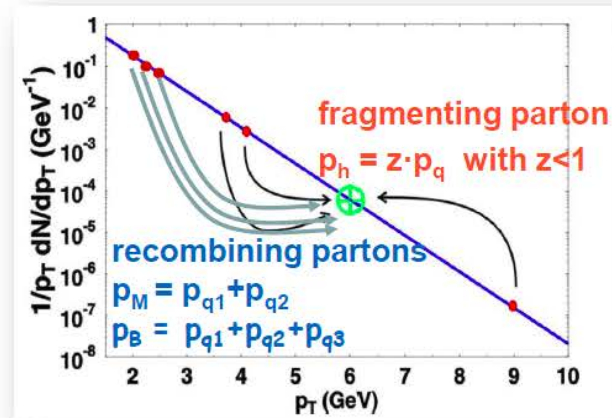
Open Heavy Flavour

- Heavy flavour is a probe of the *early* stages in a heavy ion collision. (quarks formed in initial hard collisions at $t<0.1$ fm/c, before the QGP has developed.)
- Rates in pp are calculable by pQCD, so a comparison with production in AA gives us an indication of how the quark interacts with the medium.

Open charm: D, B meson measurements in pp

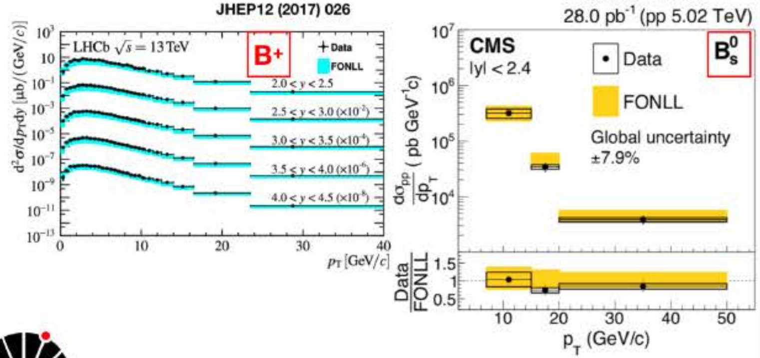
Eur.Phys.J. C79 (2019) no.5, 388





JHEP12 (2017) 026

arxiv:1810.03022



- pp: fragmentation reference
- Plethora of open charm measurements
- NLO description reasonable within uncertainties
- Fundamental reference for QGP studies

Rossi, Monday 16:30

Dhanker, Tuesday 17:30

Jaelani, Tuesday 16:10

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SQM2019 - Experimental Summary talk

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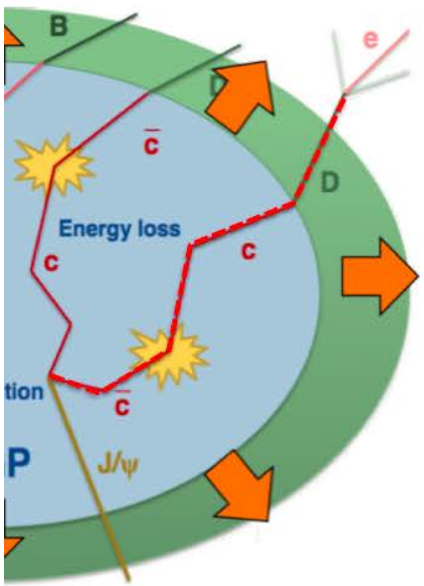
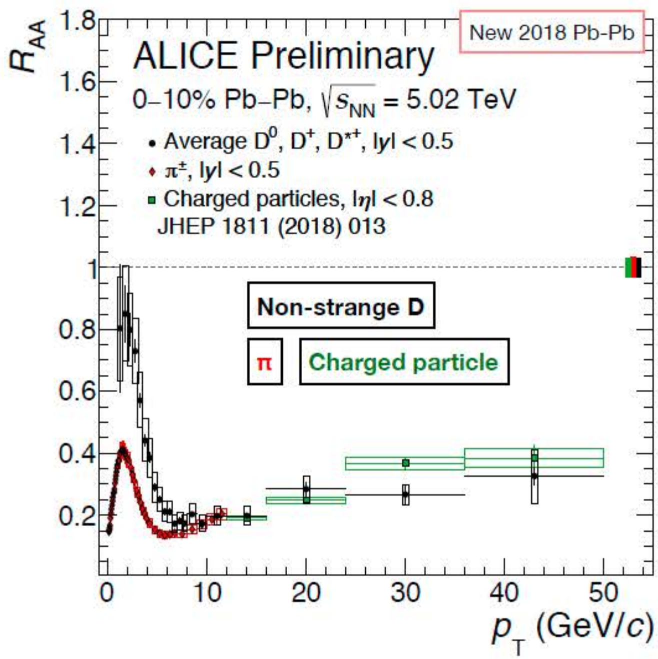
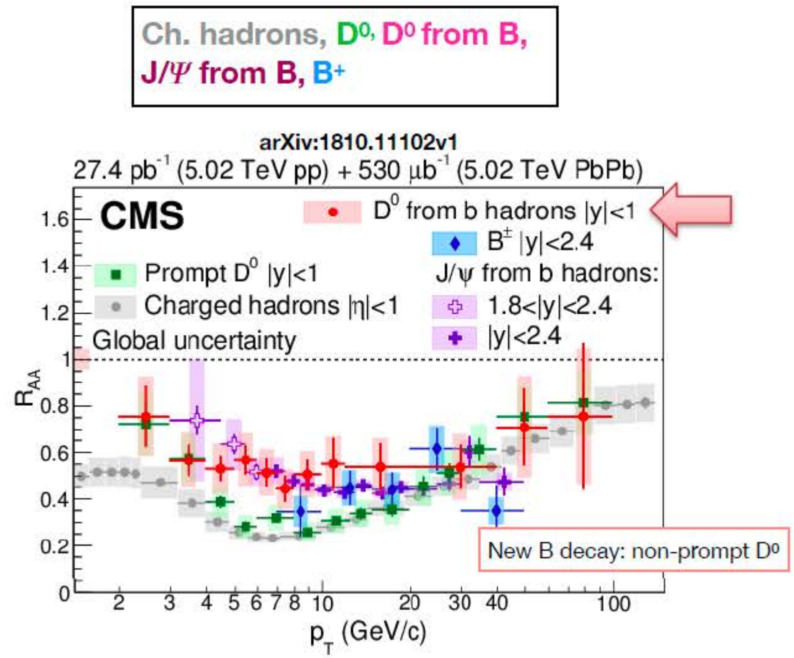
Open charm R_{AA}







- New results from ALICE and CMS quantify suppression: D^0, $D^0 \leftarrow b$
- Suppression similar at high p_T, different at low p_T:
  - $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$

Wang, Tuesday 17:30

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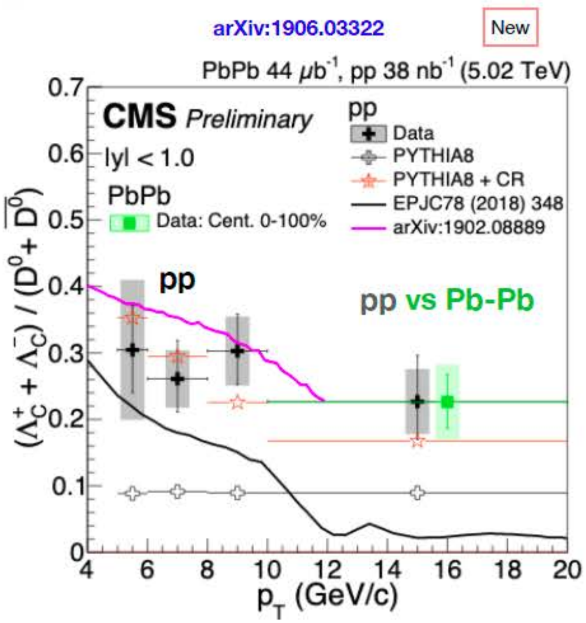
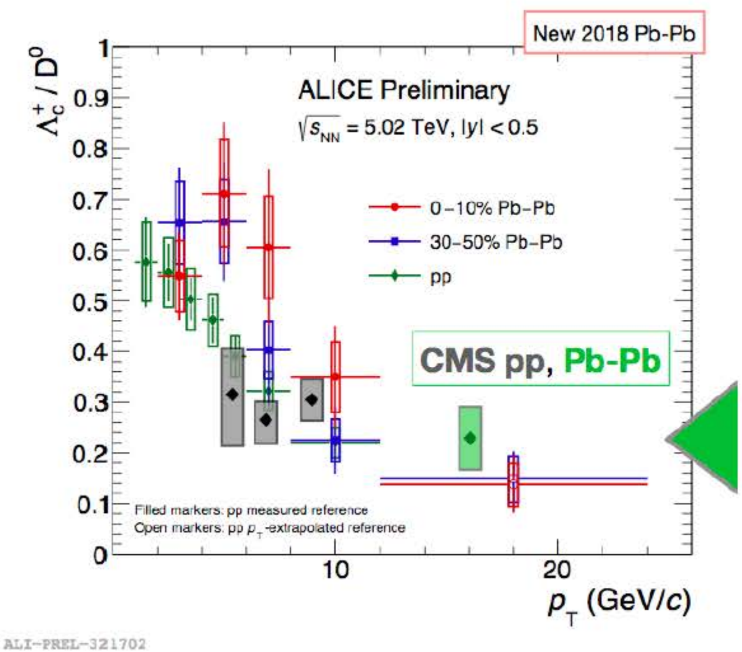
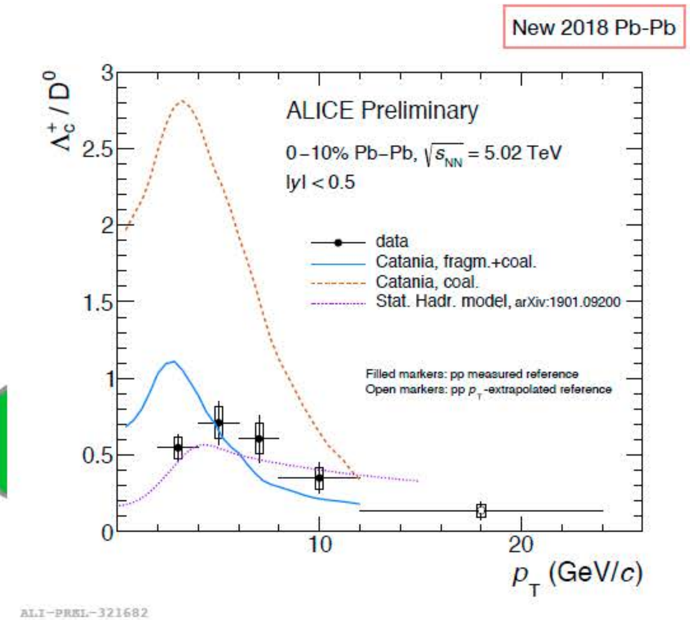
Baryon/meson in the charm sector: Λ_c/D^0







- Λ_c/D^0 in pp: matched by improved CR in PYTHIA (but beware caveats)
- Λ_c/D^0 in Pb-Pb: hint of increase at mid-p_T? Reminiscent of Λ/K^0_S?
- Pb-Pb: coalescence+fragmentation or stat. hadr. Model
  - Improved measurements needed to constrain models

Prino, Wednesday 12:00

Xiao, Tuesday 14:20

Zampolli, Tuesday 15:20

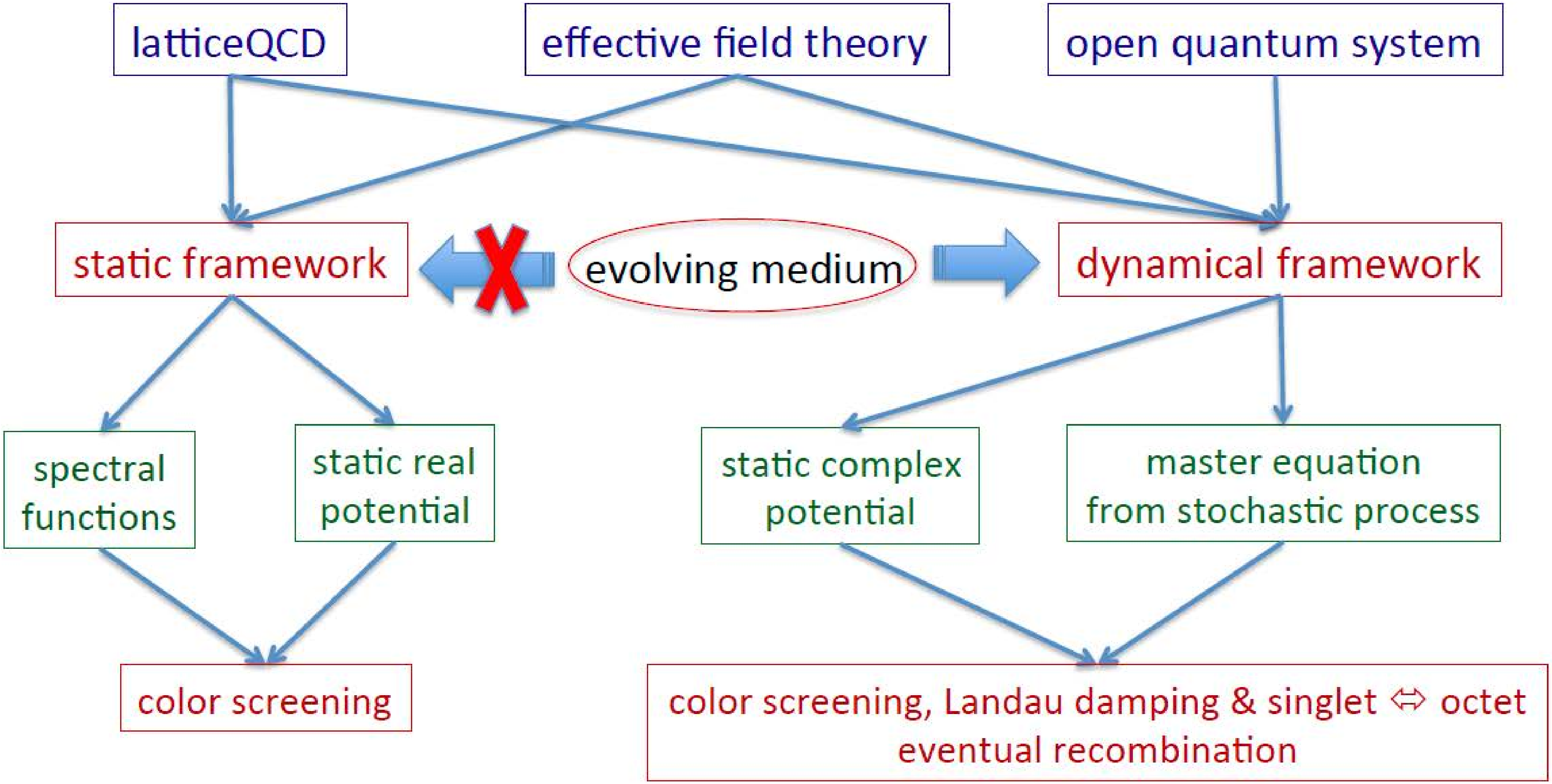
Quarkonia

Quarkonia

- A long history. J/ψ suppression was one of the first signatures proposed for detecting the QGP (Debye screening)
  - T. Matsui and H. Satz. Phys.Lett. B178 416 (*2951 citations!*)
- Many other explanations possible.

Summarizing: theory elements on quarkonia in a QGP

Caveat I: we need firm theoretical understanding of quarkonium production in pp collisions



Caveat II: how to extrapolate pA effects –initial & final- to AA? Factorization?

If yes… nature of the medium in pA?

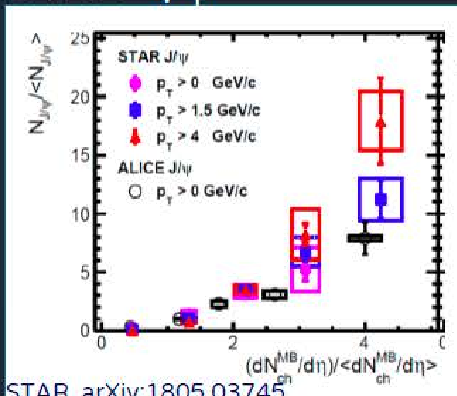
Quarkonia

- A long history. J/ψ suppression was one of the first signatures propose for detecting the QGP (Debye screening)
  - T. Matsui and H. Satz. Phys.Lett. B178 416 (*2951 citations!*)
- Many other explanations possible.
  - No time to go through them. Will mention a few as we go through.

Onia production vs ev. activity

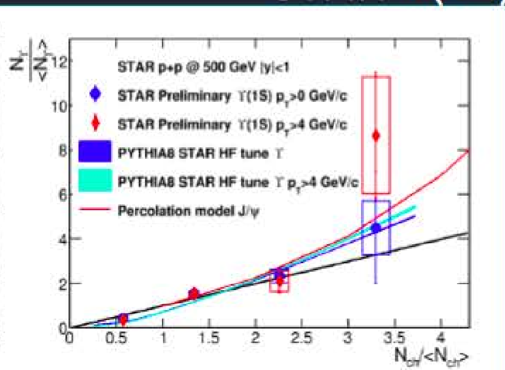
pp

STAR J/ψ

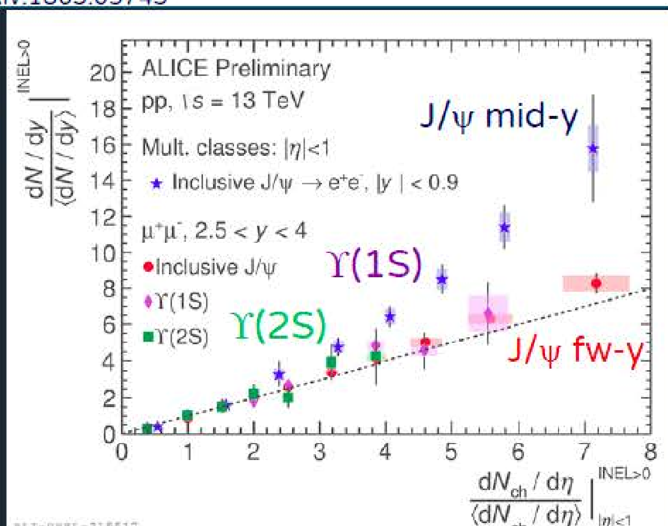


STAR, arXiv:1805.03745

STAR ϒ(1S)



ALICE



Study role of MPI in quarkonium production

Increase of J/ψ and ϒ yields with event activity observed at RHIC and LHC

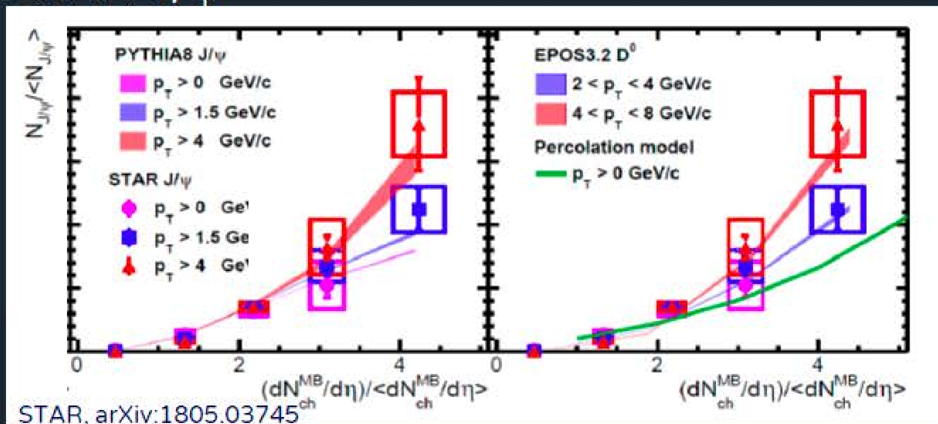
→ Increase is:

- weakly dependent on energy
- stronger for high p_T
- stronger than linear when no rapidity gap is present between quarkonium and multiplicity measurement
- independent on quarkonium state

Onia production vs ev. activity

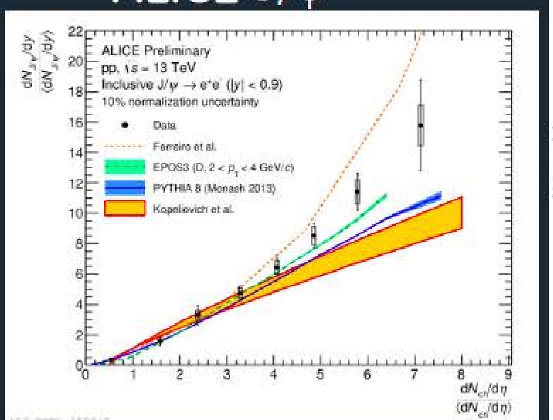
pp

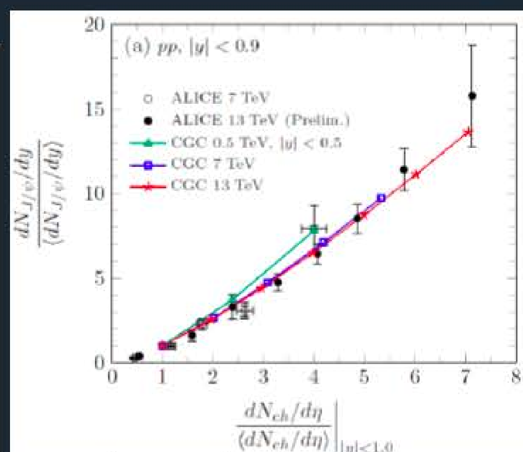
STAR J/ψ



STAR, arXiv:1805.03745

ALICE J/ψ





Ma et al, PRD98 (2018) 074025

Study role of MPI in quarkonium production

Most predictions, based on different underlying processes, are in qualitative agreement with data

- EPOS3 and PYTHIA: include MPI
- Kopeliovich: high multiplicities reached via contribution of higher Fock states
- Percolation: mimic MPI via interactions of colour sources with finite spatial extension
- CGC saturation effects

Percolation Model

- Based on *strings* as fundamental variables in the collision
- Strings have finite extension, and can fuse when drawn too densely
- *Heavy flavour* driven by number of collisions, which follows number of strings *before* fusion

$$N_{\text{coll}} \propto N_{\text{strings}}$$

- Multiplicity determined by number of strings after fusion

$$\mu \propto \sqrt{N_{\text{strings}}}$$

- As multiplicity increases, $N_{\text{heavy-flavour}}$, or $N_{\text{quarkonia}}$ increases more rapidly
- Consequence of multiple parton interactions in the collision.

E.G. Ferreiro and C. Pajares, Phys. Rev. C86 034903

J/ψ in pA collisions at LHC

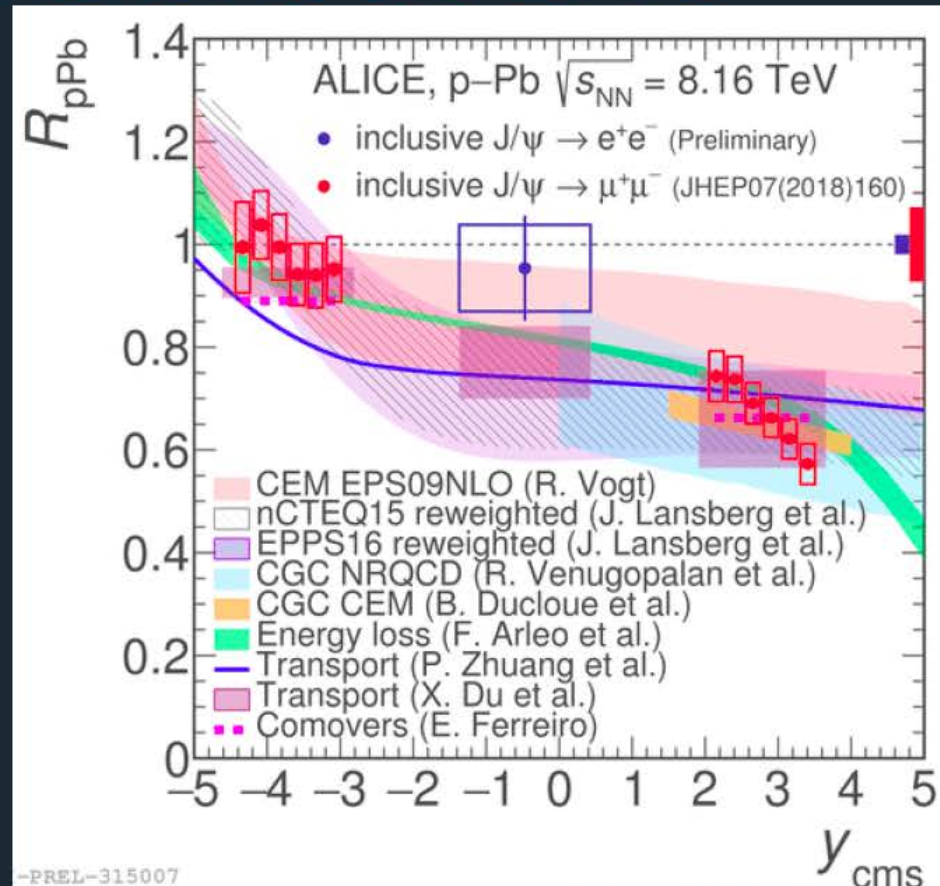
pA

CNM effects affect J/ψ production mainly at forward-y and low p_T

→ consistent results between experiments in similar kinematic range (LHCb, PLB774 (2017) 159)

fair agreement between data and models based on shadowing, CGC, energy loss

→ size of uncertainties (mainly shadowing) still limits a more quantitative comparison



p-going direction: 2.3 10^{-5}<x<1.5 10^{-4}
Pb-going direction: 1.5 10^{-2}<x<10^{-1}

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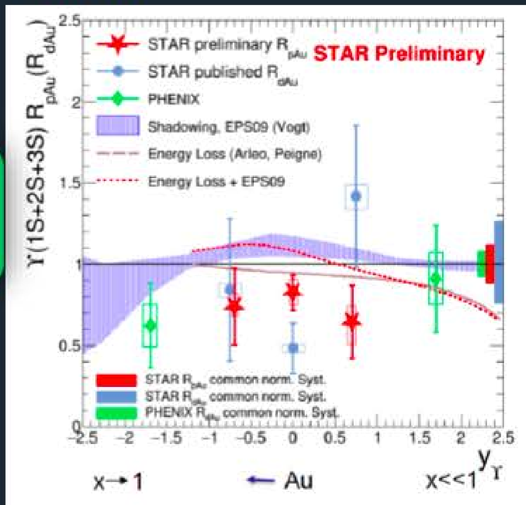
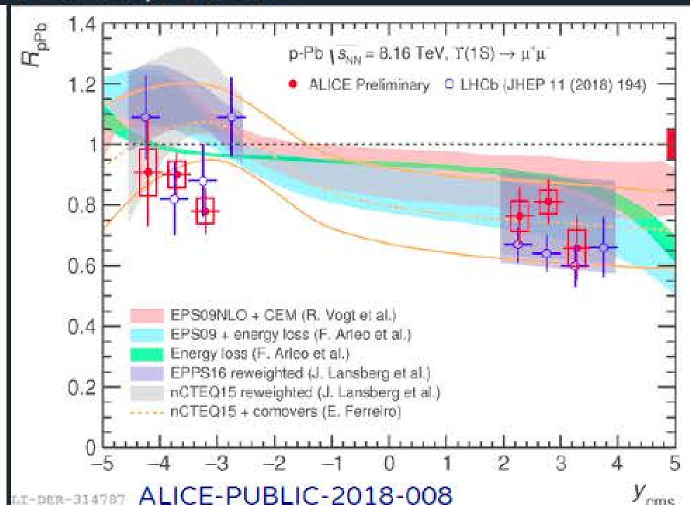
Υ in pA collisions

pA

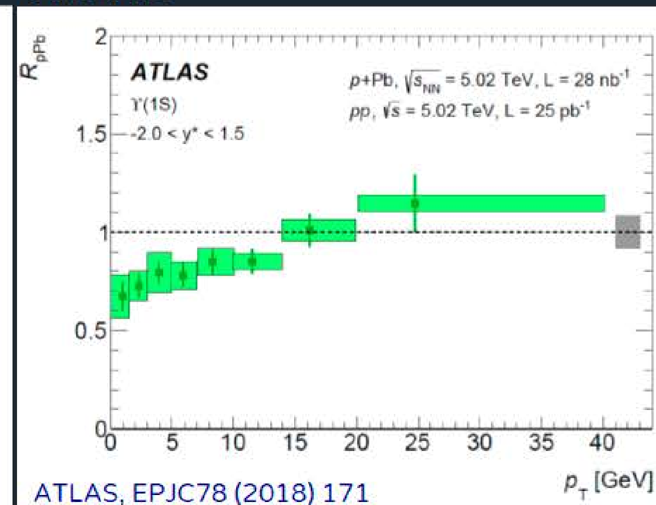
STAR



ALICE, LHCb



ATLAS



RHIC:

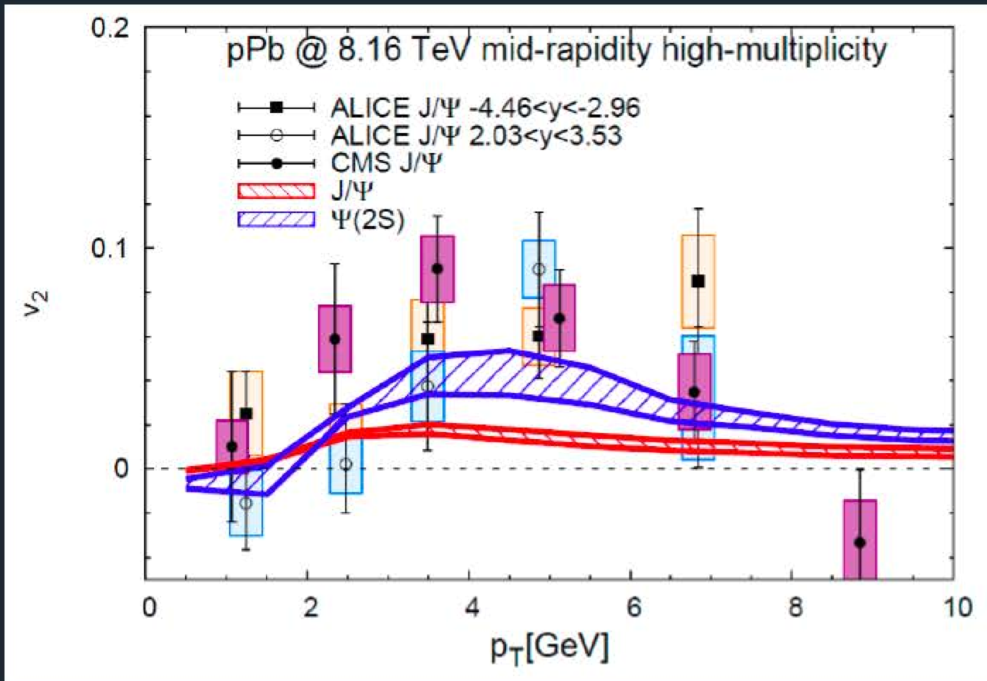
Improved precision in p-Au, but a precise comparison with models is still difficult

LHC:

- suppression stronger at forward-y and low p_T
- shadowing and energy loss models fairly describe data at forward-y and mid-y, but slightly overestimate backward-y R_{pA}?

J/ψ elliptic flow in pA

pA



ALICE, PLB 780 (2018) 7
CMS, PAS HIN-18-010
Rapp et al, JHEP03(2019)015

a significant non-zero v_2 is observed in high-multiplicity p-Pb

- size of v_2 similar to the one measured in PbPb
- however, common v_2 interpretation for PbPb, based on regeneration or path lengths effects doesn't work in pPb
- models where the v_2 originates from final state effects (dissociation/regeration) in the fireball underestimate the data

[E. Chapon, Friday 12.00]

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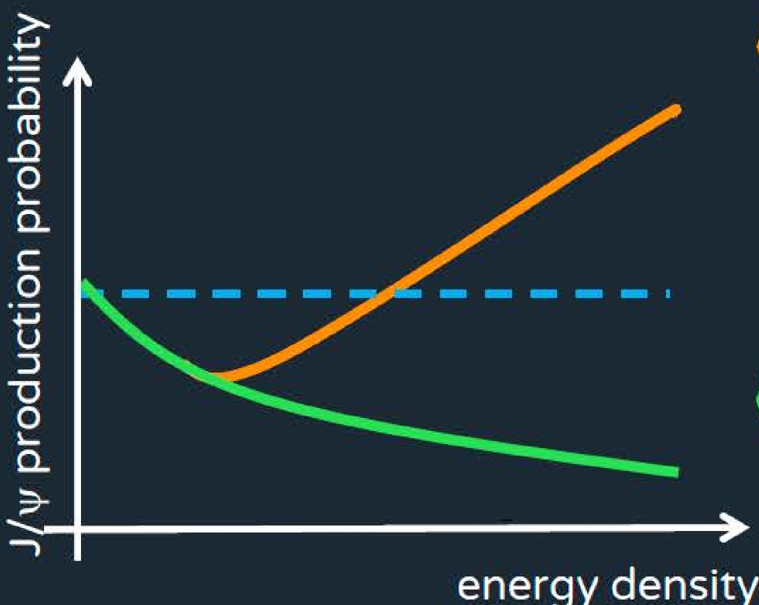
Hot Matter effects

AA

the original idea:
quarkonium production suppressed via color screening in QGP

(T.Matsui,H.Satz, PLB178 (1986) 416)



Recombination

$q\bar{q}$ abundance increases with collision energy

Central AA coll	$N_{c\bar{c}}$ per ev.	$N_{b\bar{b}}$ per ev.
RHIC, 200GeV	~10	-
LHC, 5.02 TeV	~115	~3

→ (re)combination at hadronization or in QGP enhances charmonium production
→ small contribution for bottomonium (also at LHC)

P. Braun-Muzinger,J.Stachel, PLB490(2000)196, R.Thews et al,PRC63:054905(2001)

Sequential melting

differences in quarkonium binding energies lead to a sequential melting with increasing temperature

Digal,Petrecki,Satz PRD 64(2001) 0940150

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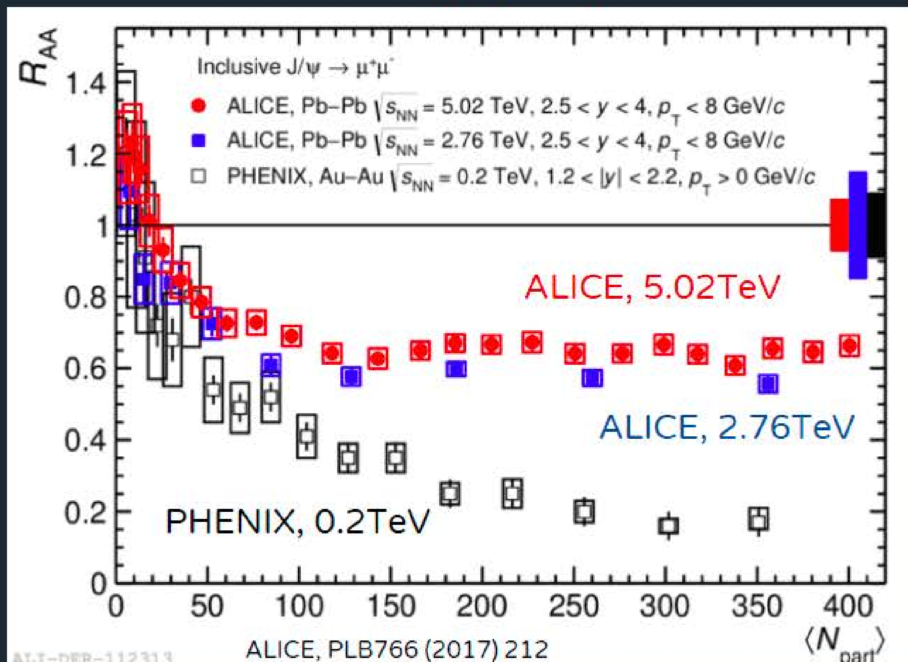
AA

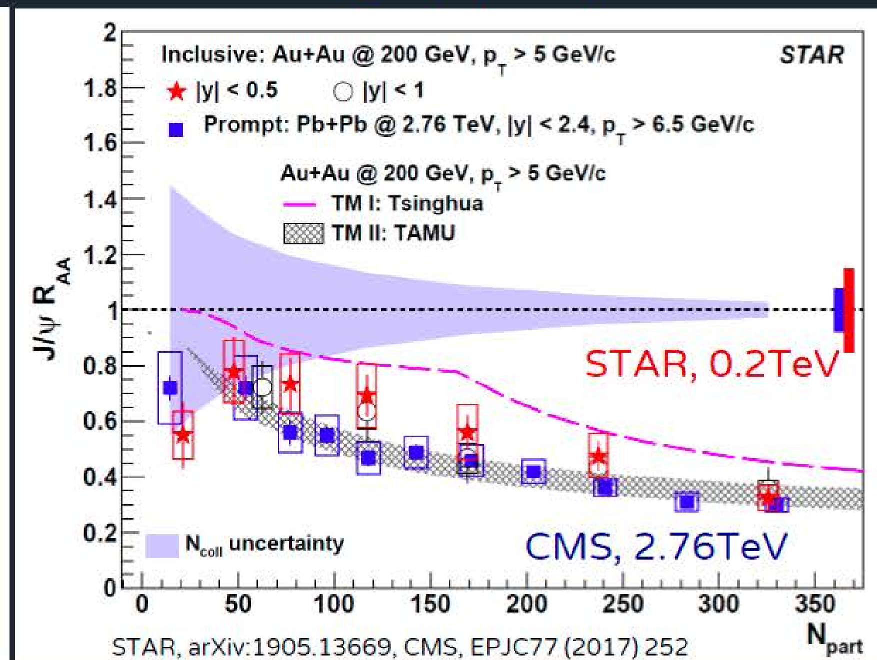
Charmonium in AA

Low p_T J/ψ



stronger suppression at RHIC in central events, in spite of the larger LHC energy densities

High p_T J/ψ



suppression increases towards central events, being of similar size at RHIC and LHC energies

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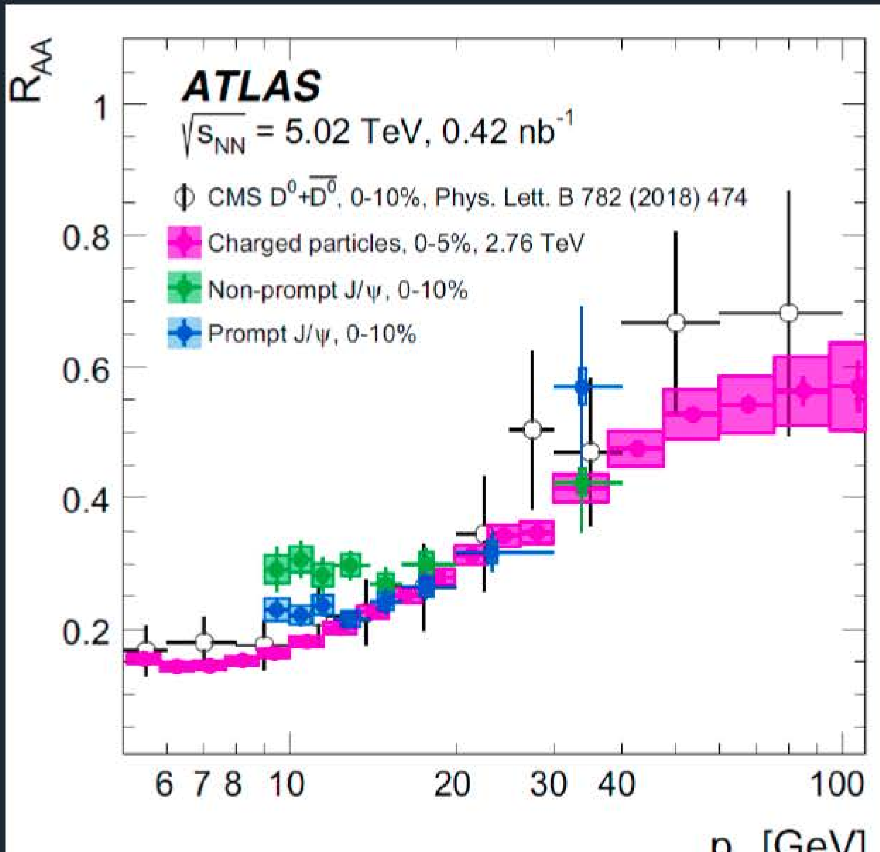
Very high p_T J/ψ

AA

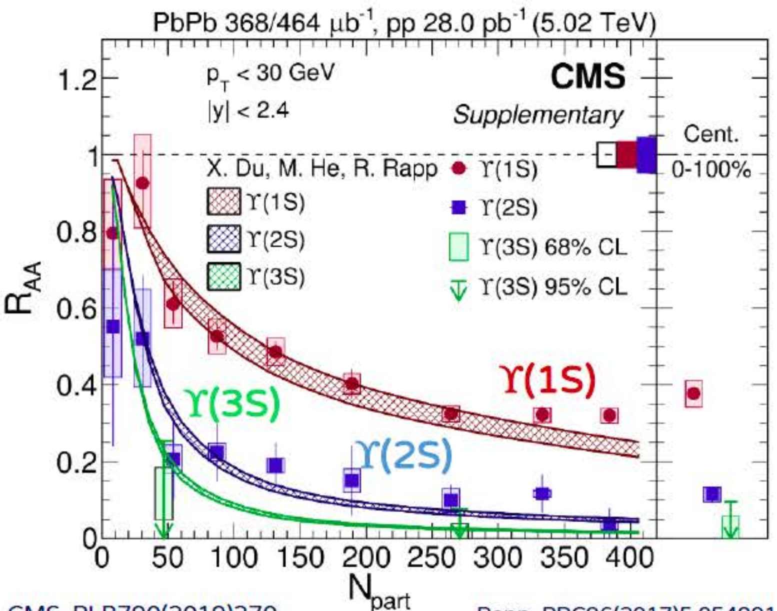


ATLAS, EPJC78(2018) 762

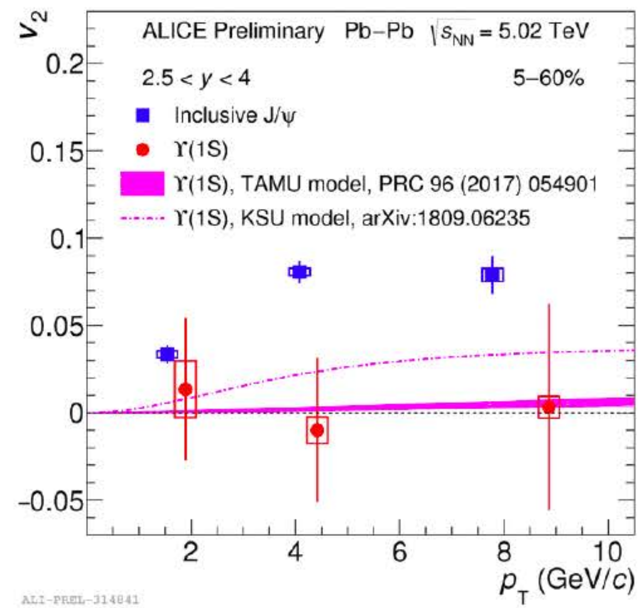
Indication of a high p_T rise, as for charged hadrons or D mesons

→ weak regeneration expected, parton energy-loss at play?

Bottomonium: the Υ family



CMS, PLB790(2019)270 Rapp, PRC96(2017)5,054901



- R_{AA} of Υ(1S) > Υ(2S) Υ(3S): described by models with suppression and regeneration
- But: flow compatible with zero?
- Future measurements will add precision!

Fasanella, Tuesday 17:30

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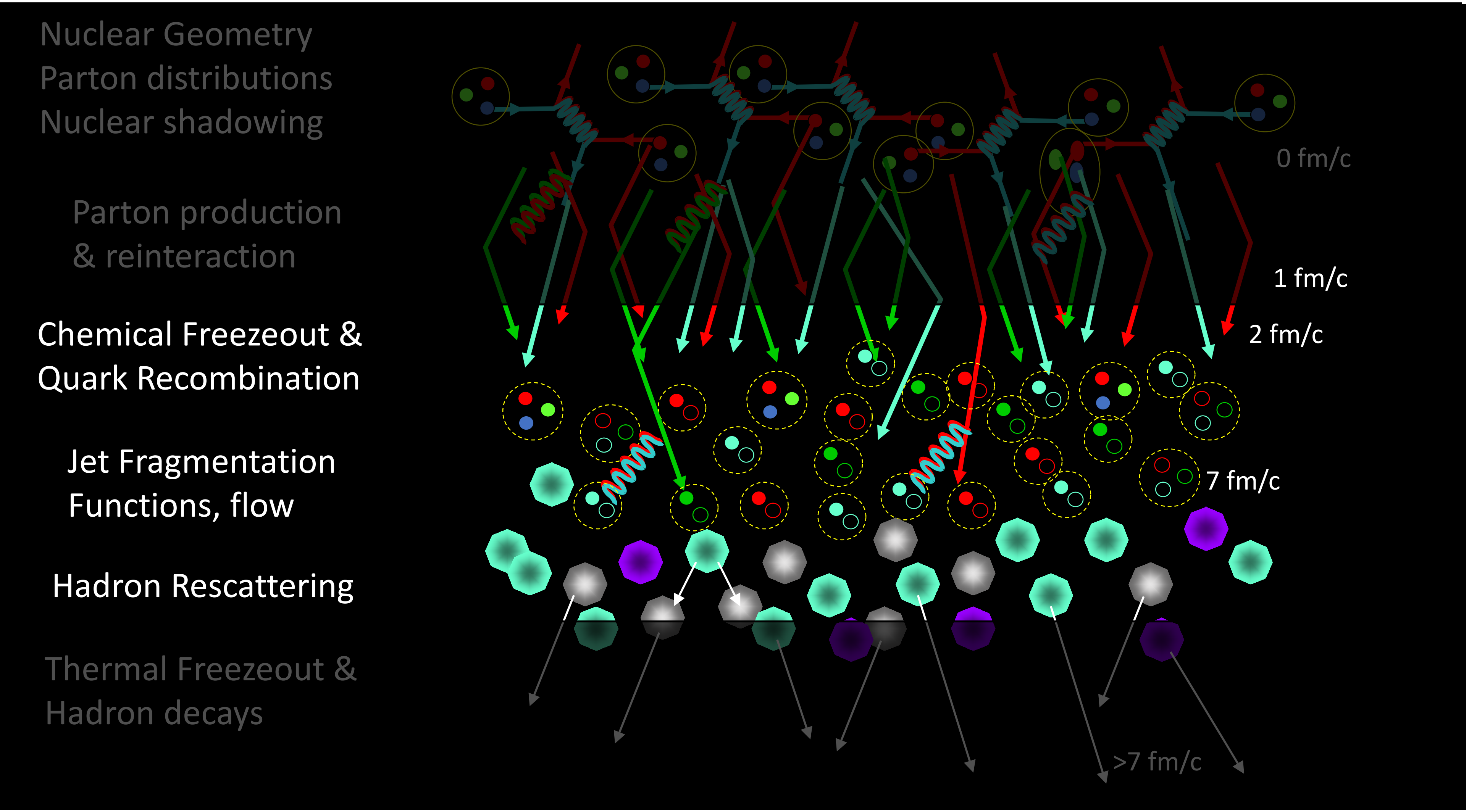
A Brief Dynamical History of Time



Thermal Production

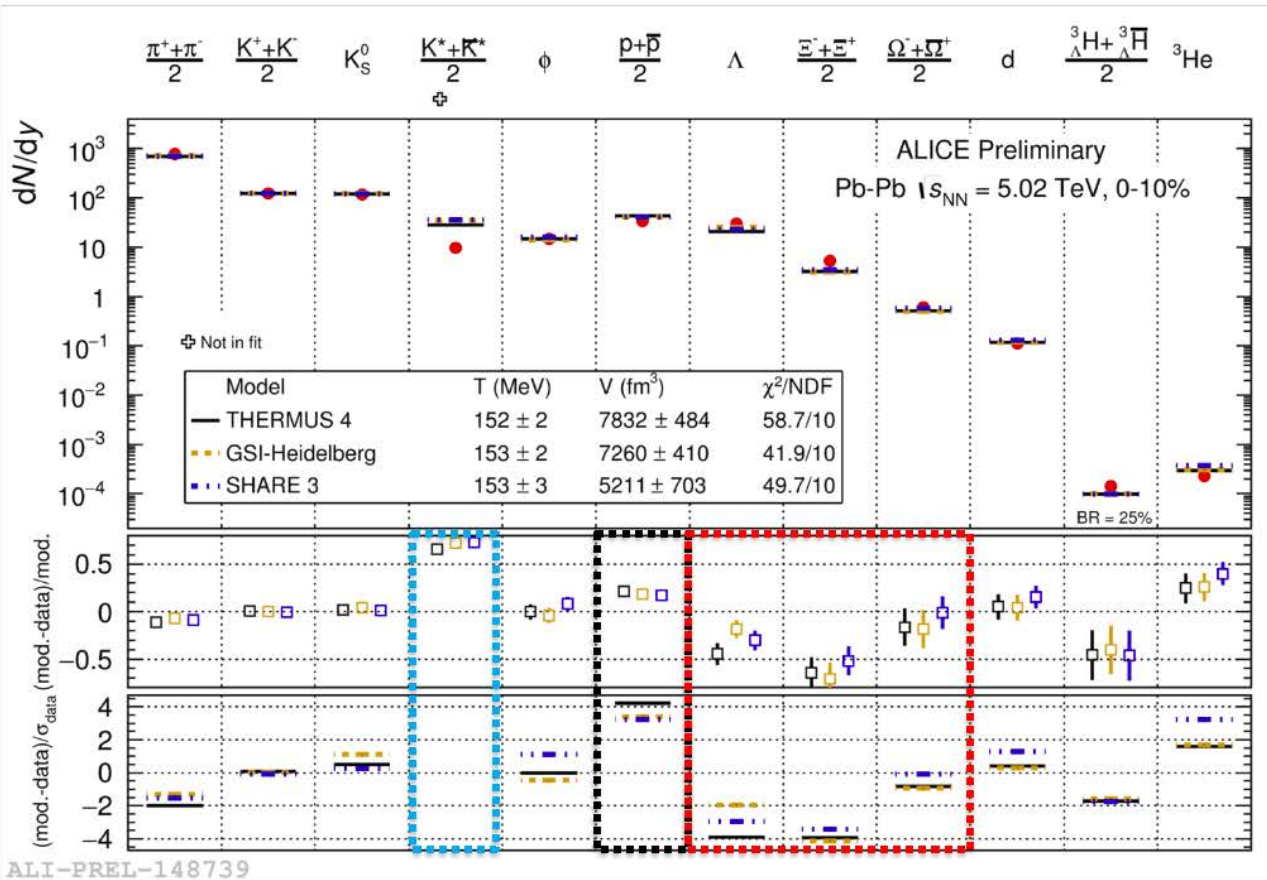
Thermal Production

- One of the most characteristic features of heavy ion collisions is the huge multiplicities achieved in such collisions. The standard interpretation is that
  - In a heavy ion collision very large energy densities are achieved in the early stages of the collision. These lead to copious production of (mainly) gluons, and quarks, which quickly thermalize, giving rise to a rapidly expanding and cooling system of deconfined quarks and gluons. These eventually freeze into hadrons, which may still interact further, but without greatly changing the flavour yields set during the early stages. The final yields should reflect the expectations for a Boltzmann distribution at the temperature at which freeze-out into hadrons occurred.

Thermal Production

- Of course, checking thermal production is complicated.
  - The role of resonances is crucial, as these distort the yields of quarks in the final distributions, typically increasing the numbers of *u* and *d* quarks
  - (For example $K^{*0}(890)(\bar{s}d) \to K^{+}(\bar{s}u)\pi^{-}(\bar{u}d)$ increases the number of light quarks whilst not changing the number of strange quarks.)
  - This is now taken into account for all known resonances with masses below ~ 2 GeV.
  - Remember $T_{\text{freeze-out}}$ ~ 160 MeV, so resonances above this cutoff have little effect: they are not produced thermally.

Thermal model fits to LHC data (5.02 TeV)

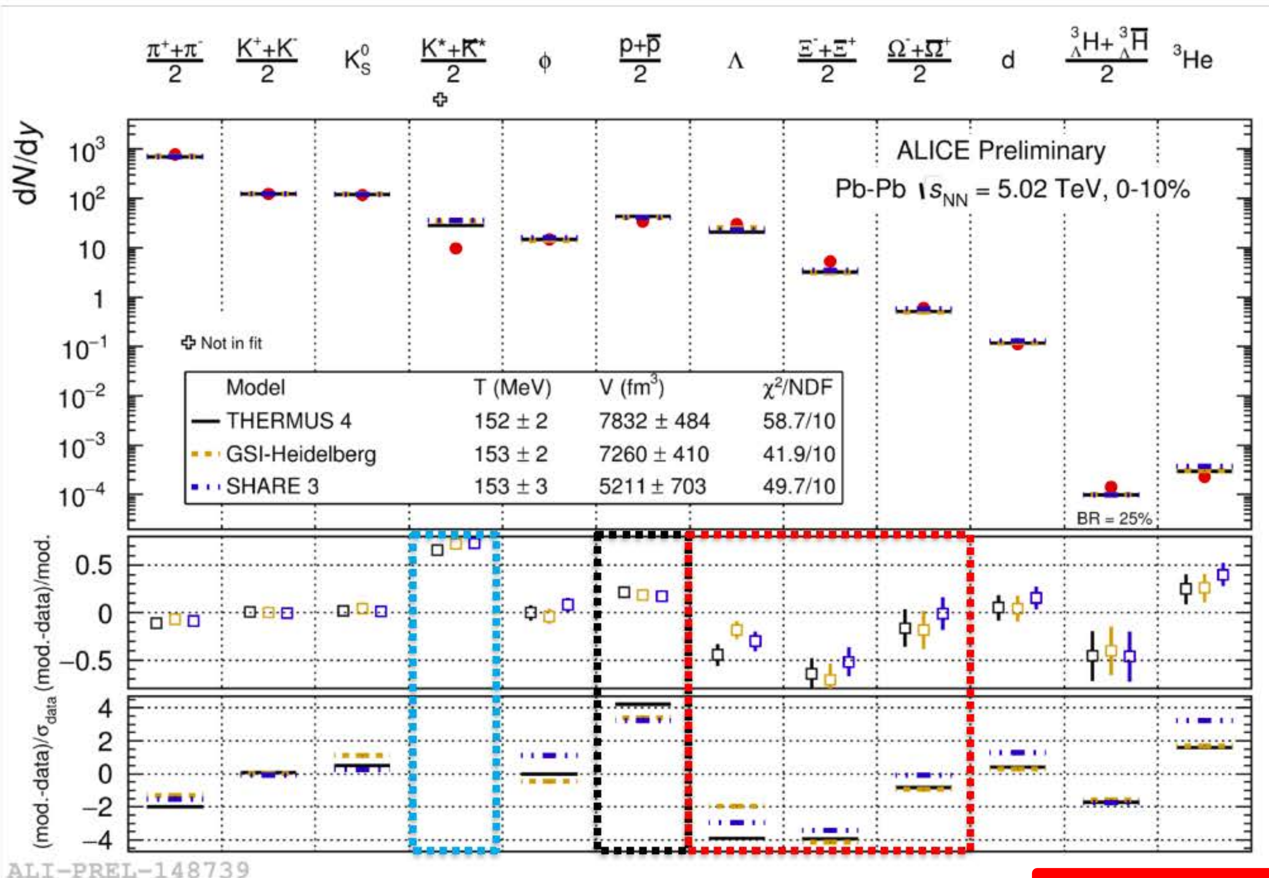


Preliminary data in 0-10% Pb-Pb at 5.02 TeV can be fitted with a slightly lower temperature and higher χ^2/ndf ~ 4-6

$T_{ch} \approx 153$ MeV at 5.02 TeV

Tensions seen at 2.76 TeV are confirmed.

Thermal model fits to LHC data (5.02 TeV)



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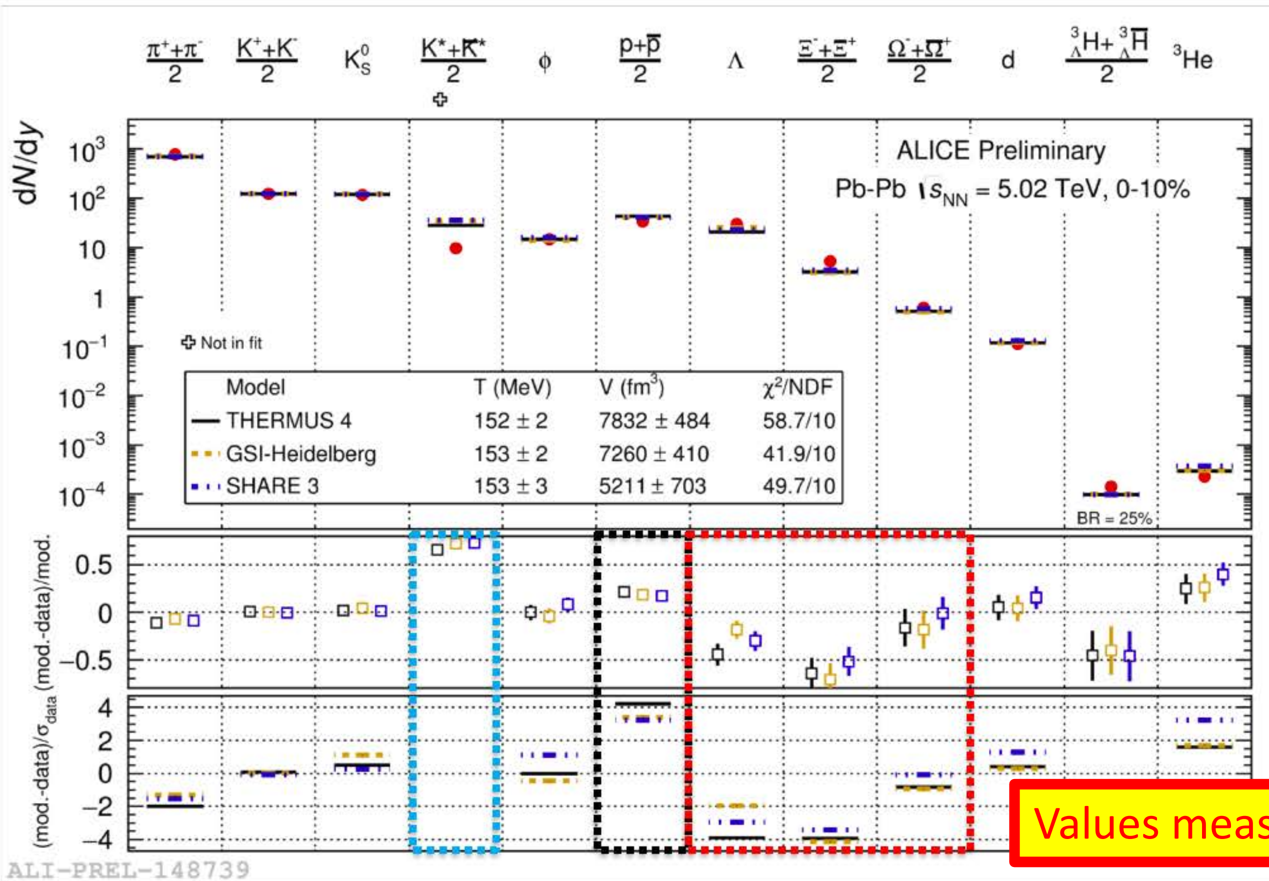
Values measured over 7 orders of magnitude

Bellini- Wednesday

Francesca … e 2019 9

Thermal model fits to LHC data (5.02 TeV)



Preliminary data in 0-10% Pb-Pb at 5.02 TeV can be fitted with a slightly lower temperature and higher χ^2/ndf ~ 4-6

T_{ch} ≈ 153 MeV at 5.02 TeV

Tensions seen at 2.76 TeV are confirmed.

Values measured over 7 orders of magnitude

Bellini- Wednesday

Remarkable agreement, but…

…problems and tensions…

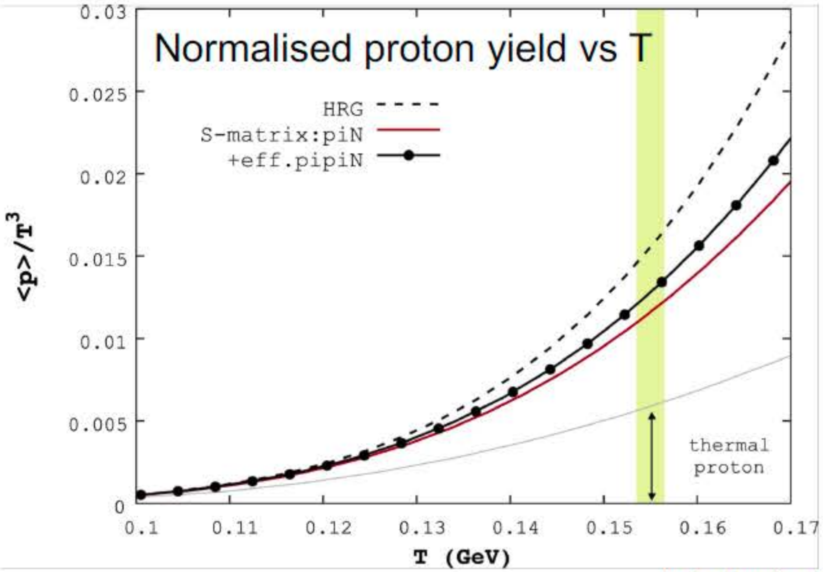
- Protons
- Role of the ϕ
  - Ξ/ϕ ratio
- Deuterons

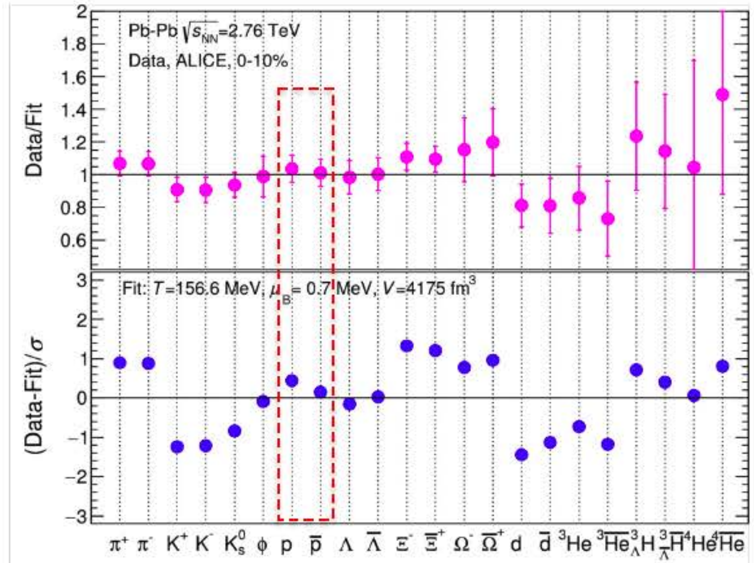
Small systems

- systematics

Towards understanding the thermal proton anomaly

The role of resonant and non-resonant πN and ππN interactions



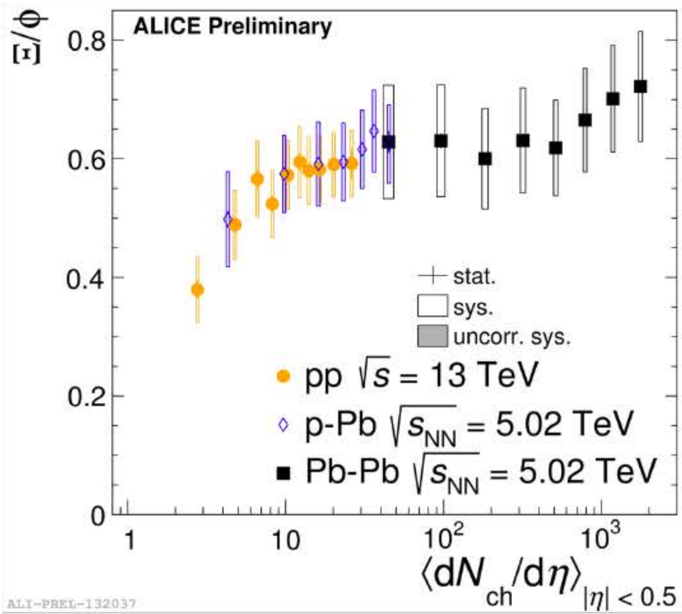


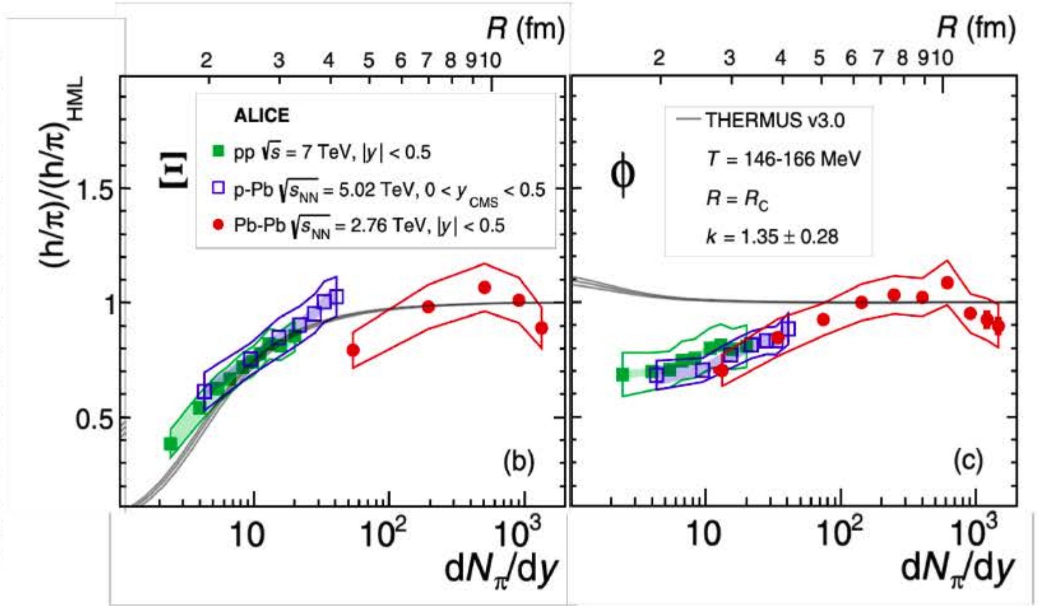
A. Andronic et al., PLB 792 (2019) 304-309

The inclusion of the resonant and non-resonant πN and ππN interactions via the S-matrix formalism has the net effect of reducing by 17% (1%) the proton (pion) yield with respect the HRG case. More specifically, πN reduces the proton, ππN tends to increase it.

⟶ Improved agreement between p ALICE data and thermal model after this correction.

The pivotal role of ϕ meson





ALICE, PRC 99, 024906 (2019)

From the measured multiplicity-dependence of ϕ/π, the behavior of ϕ meson is between that of a S=1 and a S=2 particle.

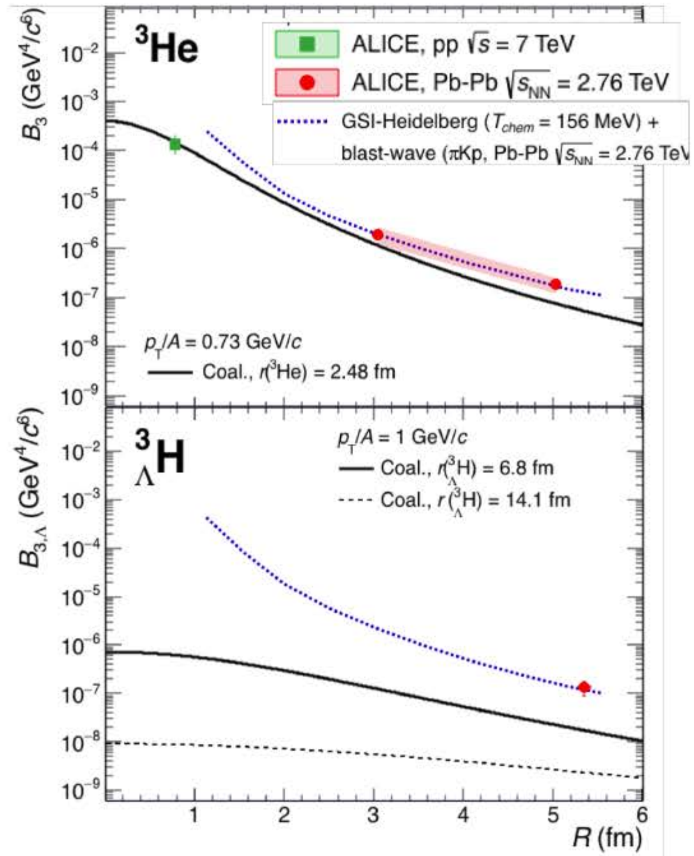
ϕ is the exception that does not fit in the canonical suppression picture that describe all other measured LF and strange hadrons from small to large systems.

"Fragile" objects: production and survival

(Anti-)nuclei puzzle:
how can loosely-bound states (B_E ~ 1 MeV) produced at chemical freeze-out survive the hadronic phase (156 MeV < T < 100 MeV)?

Production via coalescence of nucleons at kinetic freeze-out? Other explanations?
→ More in D. Ollinychenko's talk

→ Experimentally to be addressed with multiplicity-dependent measurements of different nucleus species

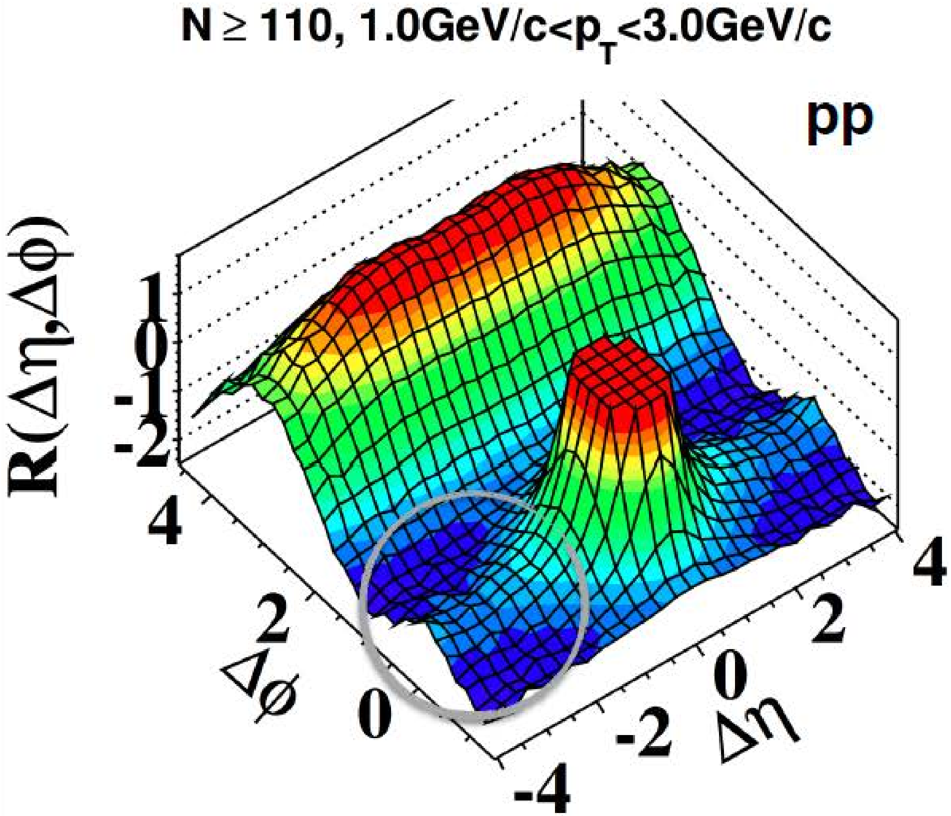


FB, A. Kalweit, PRC 99, 054905 (2019)

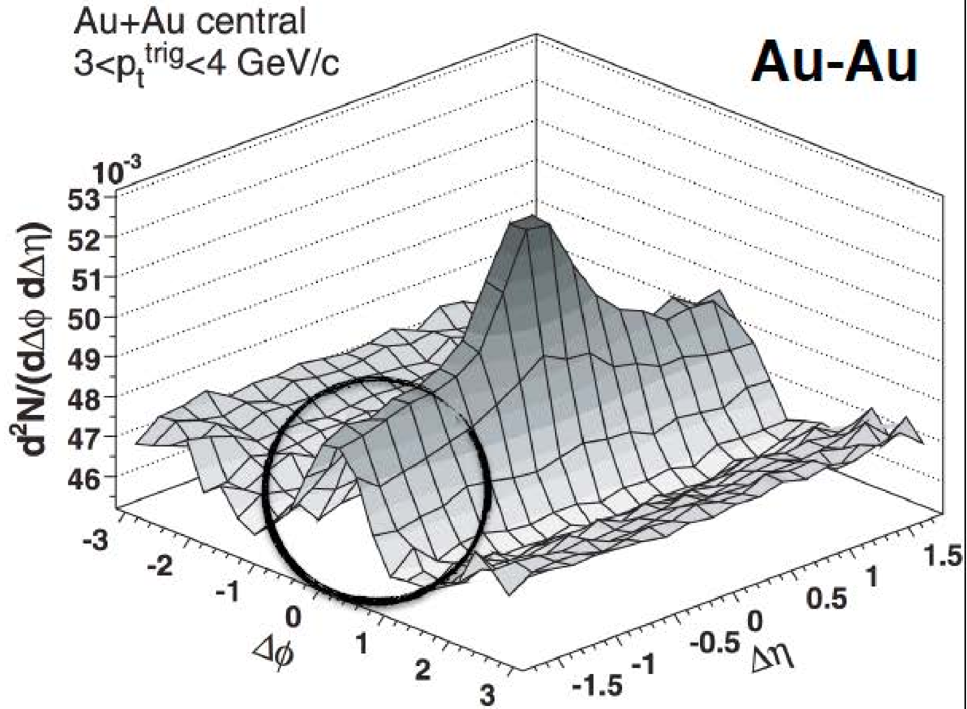
Small Systems

The ridge

resembles the ridge-like correlation seen in A-A collisions
interpreted as consequence of **hydrodynamic flow**



CMS, JHEP 09 (2010) 091

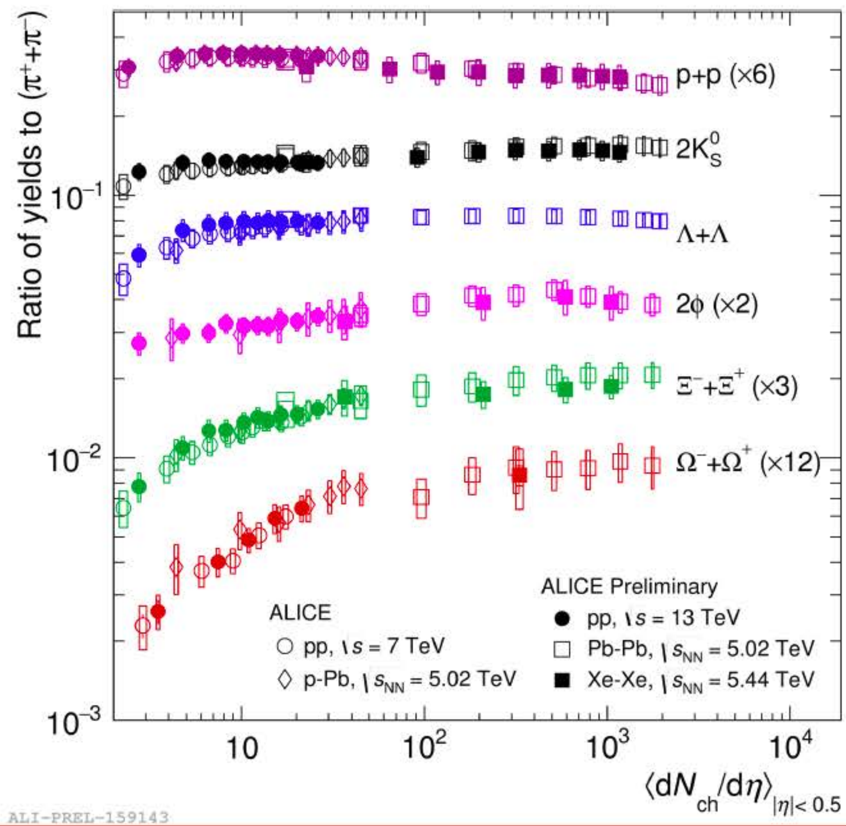


STAR, PRC 80 (2010) 064912

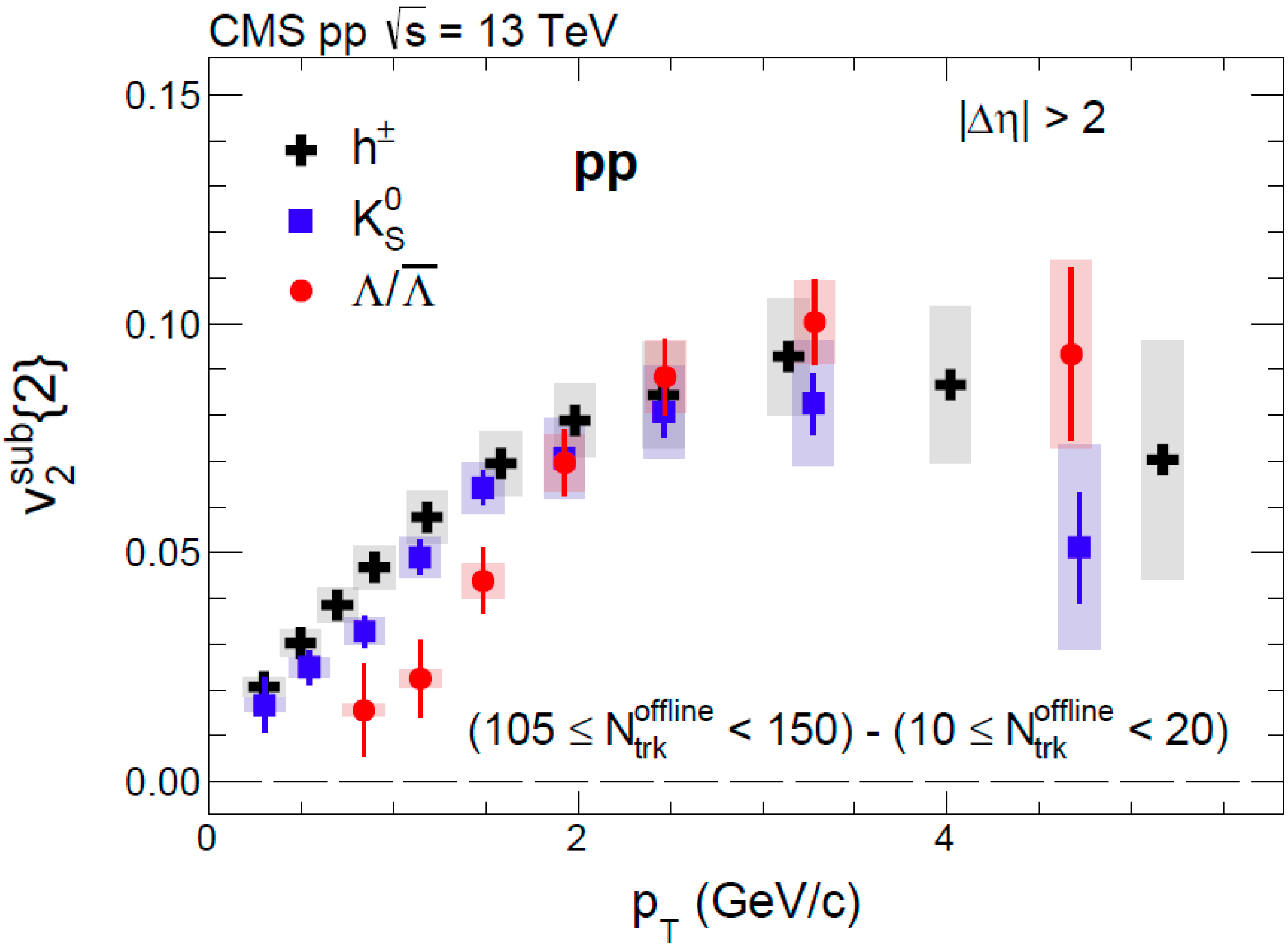
Strangeness Enhancement in Small Systems

ALICE

- Charged particle multiplicity is biggest driver of strangeness enhancement
- Results consistent for different colliding energies and collision systems measured by ALICE (pp, p-Pb, Pb-Pb, Xe-Xe)
- Strangeness production increases until saturation levels are reached



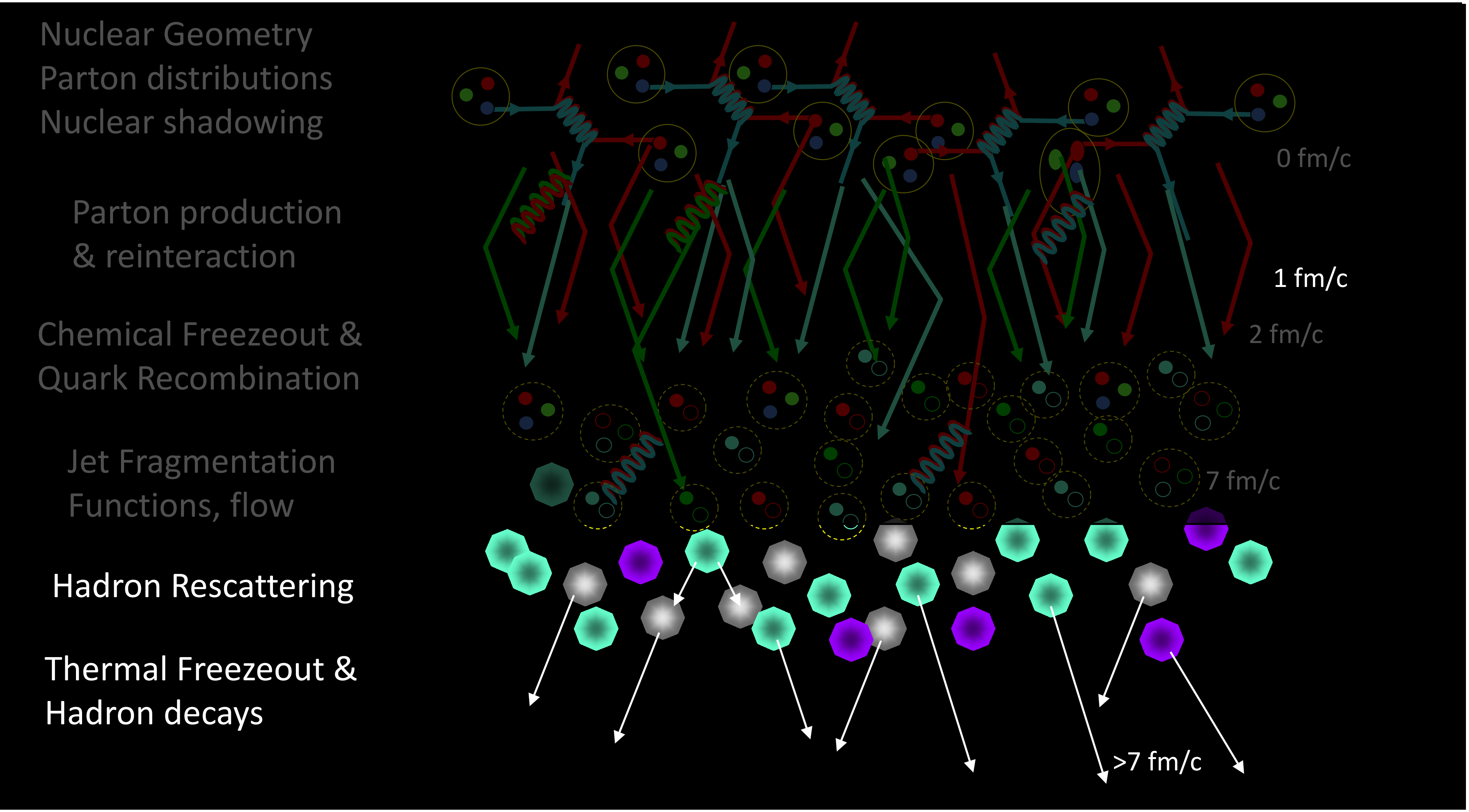
v_2 of identified particles in pp



mass ordering observed at low p_T
also in pp collisions

CMS, PLB 765 (2017) 193

A Brief Dynamical History of Time

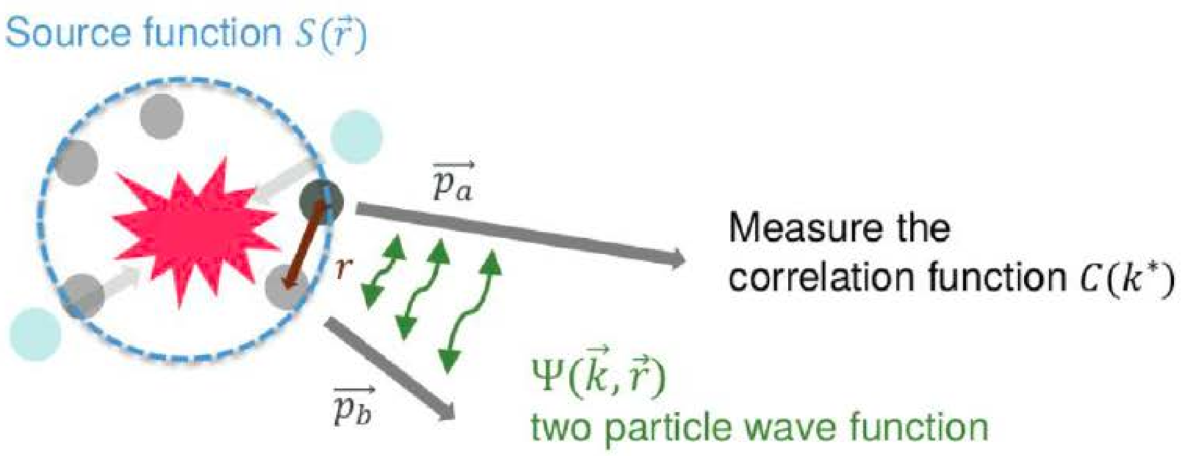


Unlike Particle Correlations

Reminder- *Identical* Particle Correlations

- When two identical bosons (e.g. $\pi^+\pi^+$) are emitted incoherently with very similar momenta, there is a quantum-mechanical correlation between the particles, leading to an enhancement relative to expectations for uncorrelated particles (e.g. those from different events)
- This is known as the Hanbury-Brown Twiss effect, because the same physics applies for photon-photon correlations. Hanbury-Brown and Twiss used this at Jodrell Bank to estimate the size of stellar objects. In particle physics it is also known as the Goldhaber effect, as Goldhaber et al. applied it independently in a particle physics context in a scattering experiment at Berkeley, in both cases in 1954.
- The use of the technique was extensively studied at RHIC in the period 2003-2008. Results were used at LHC as a tool to determine the size of particle-emitting volumes. Nowadays referred to as “femtoscopy”.
- If instead we use two identical *fermions*, we see similar effects, except that now the result is destructive rather than constructive. The ratio of same event correlation to random correlation gives a depletion rather than an enhancement.

The Correlation Function



Experimental definition ***Theoretical definition***

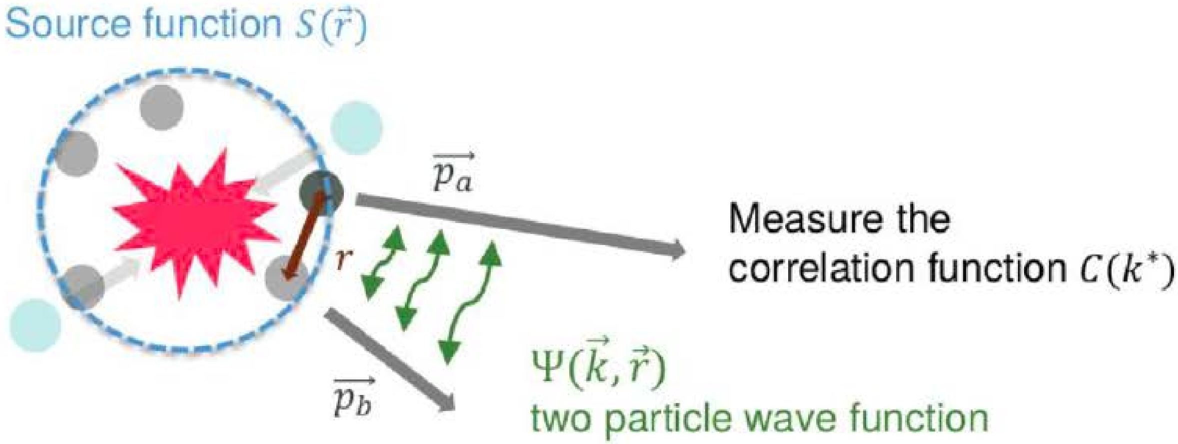
$$C(k^*) = \mathcal{N}\frac{N_{\mathrm{Same}}(k^*)}{N_{\mathrm{Mixed}}(k^*)} = \int S(\vec{r})\left|\Psi(\vec{k}^*,\vec{r})\right|^2 d^3\vec{r} \xrightarrow{k^*\to\infty} 1$$

>1 : **Attractive** Interaction

<1: **Repulsive** Interaction

Relative distance / reduced momentum in the rest frame of the pair

The Correlation Function



By this technique, we learn
- The sign of the potential between two particles
- Its magnitude.

Experimental definition ***The***

$$C(k^*) = \mathcal{N}\frac{N_{\mathrm{Same}}(k^*)}{N_{\mathrm{Mixed}}(k^*)} = \int S(\vec{r})\left|\Psi(\vec{k}^*,\vec{r})\right|^2 d^3\vec{r} \xrightarrow{k^*\to\infty} 1$$

>1 : **Attractive** Interaction

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Relative distance / reduced momentum in the rest frame of the pair

The Correlation Function

D. Mihaylov (ALICE) WPCF19 slides

Experimental definition **Theoretical definition**

$$C(k^*) = \mathcal{N} \frac{N_{\text{Same}}(k^*)}{N_{\text{Mixed}}(k^*)} = \int S(\vec{r}) \left|\Psi(\vec{k}^*, \vec{r})\right|^2 d^3\vec{r} \xrightarrow{k^* \to \infty} 1$$

Relative distance / reduced momentum in the rest frame of the pair

Assumption of a '**common**' **source** for the **pp**, **p**Λ, **p**Ξ, $\Lambda\Lambda$, pK+, pK-, pΣ and pΩ Correlation Function

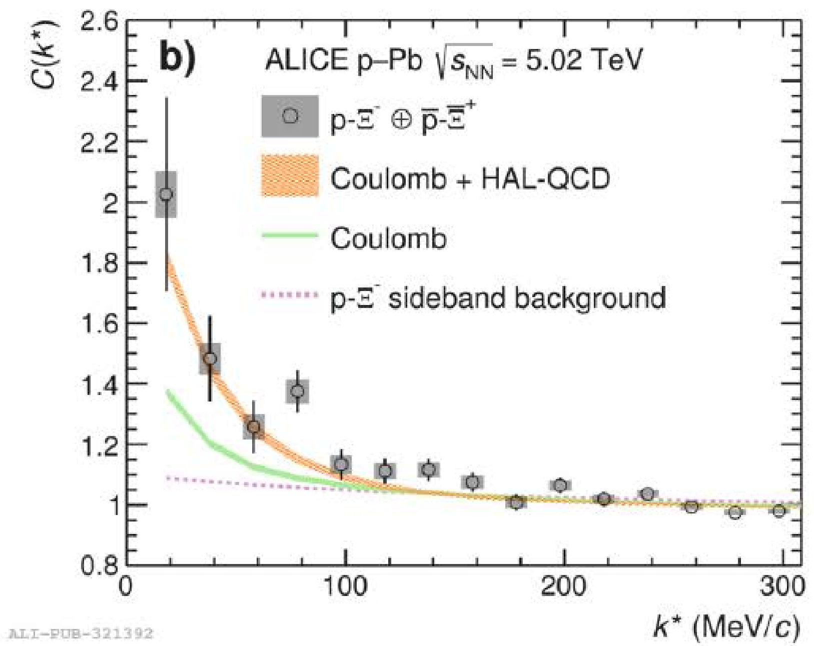
The pp correlation is used to constrain the source, since both Coulomb and Strong interactions are very well known

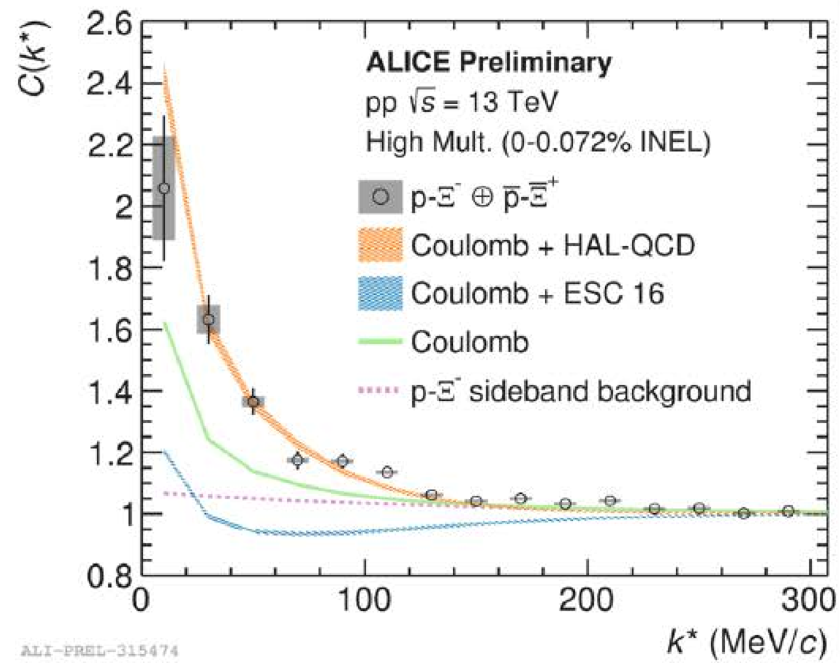
The K+p correlation is used to cross-check the pp benchmark independently since also for this channel the Coulomb and Strong interactions are known

pΞ^- Correlations for p-Pb 5 TeV and pp 13TeV HM

B. Hohlweger (ALICE) WPCF19 slides

ALICE Collaboration, arXiv:1904.12198 [nucl-ex]





$r_0 = 1.4\,fm$

$r_{EFF} = 0.93\,fm$

Coulomb-only excluded at 4-5 σ level

HAL-QCD Correlation is compatible with the data

Coulomb only: > 5.7 σ

HAL-QCD Potential: (1.3-2.5) σ

ESC 16 Potential: > 18 σ

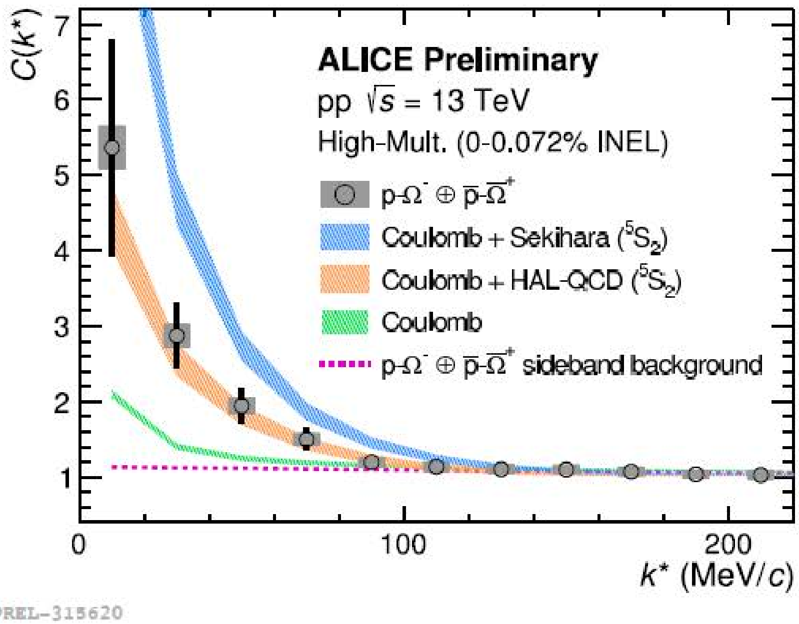
Visit the Poster by O. Vazquez Doce **Tonight**

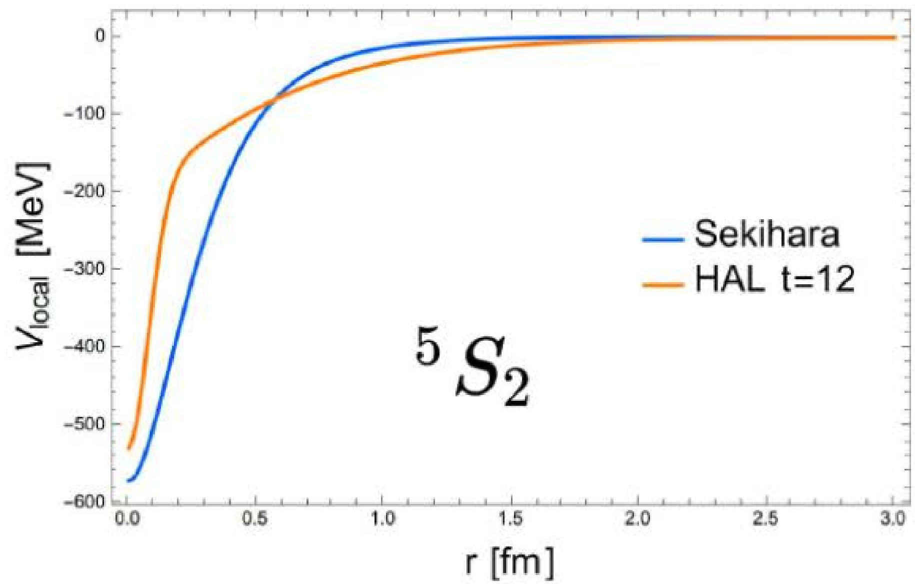
Femtoscopic studies on proton-Ξ and proton-Ω correlations in p-Pb and pp collisions with ALICE

$p\Omega^-$ Correlations for pp 13TeV HM

O.Vazquez Doce (ALICE) WPCF19 slides

$$r_{EFF} = 0.85\ fm$$





Evidence of an attractive strong interaction
Strongly bound states?

Visit the Poster by O. Vazquez Doce **Tonight**
Femtoscopic studies on proton-Ξ and proton-Ω correlations in p-Pb and pp collisions with ALICE

...summarizing...

K^+p, K^-p, pp, $p\Lambda$, $p\Sigma^0$, $p\Xi^-$, $p\Omega$

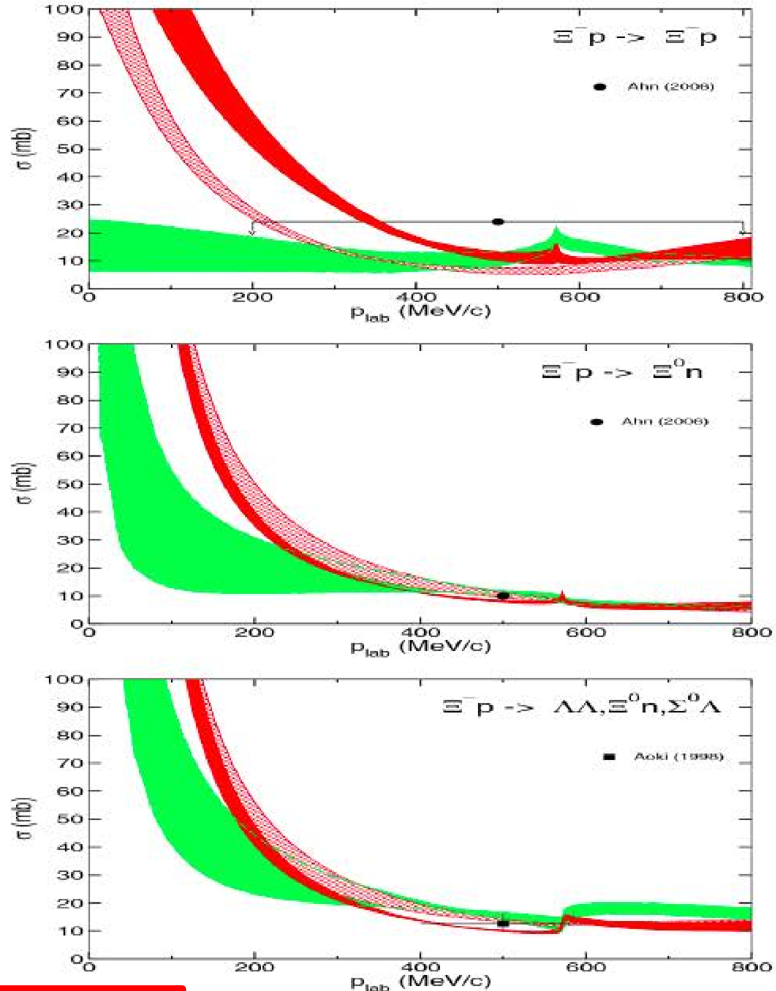
If these two body reactions were so-far poorly determined **how precise** can all the equations of state of dense neutron matter + strange hadrons be?

If the LHC provides a unique and precise testing of the strong interaction at distances lower than 1 fm **we mimic two-body interactions within dense matter.**

RUN3 and RUN4 will provide the possibility of carrying out more differential studies and also investigate three-body interactions.

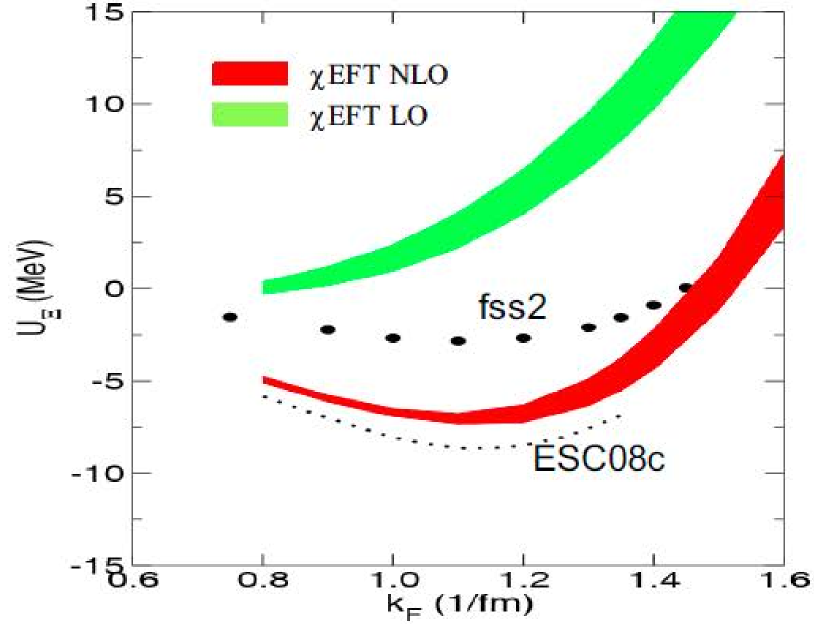
ΞN scattering and Ξ in dense matter J. Haidenbauer and U.G. Meißner EPJA 55 (2019) 23

Using experimental constraints on ΛΛ scattering length to be mildly attractive, whereas ΞN cross sections are small



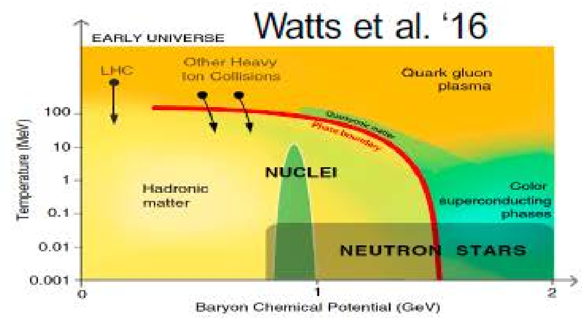
χEFT

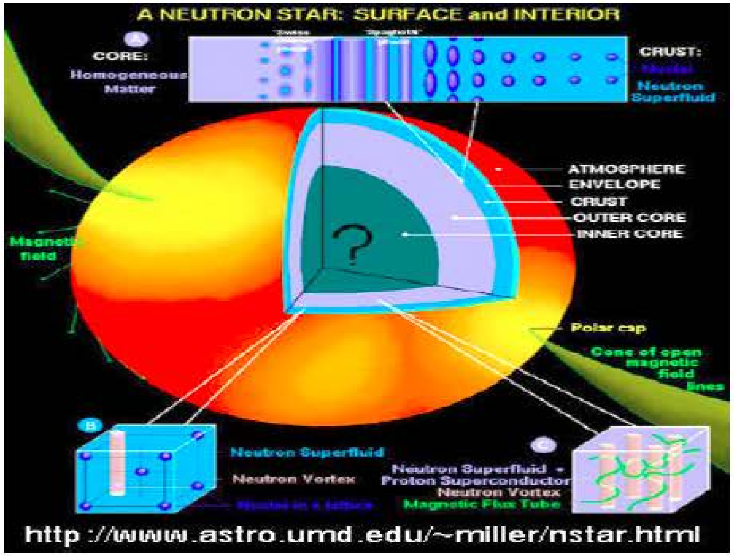
Ξ in dense matter



Moderately attractive Ξ-nuclear interaction, with $U_\Xi(0)$ ~ -3 to -5 MeV.
Smaller than $U_\Xi(n_0)$ ~-14 MeV Khaustov et al'00 and in line with other BHF studies with phenomenological ΞN potentials

Hyperons and Neutron Stars





- produced in core collapse supernova explosions, usually observed as pulsars

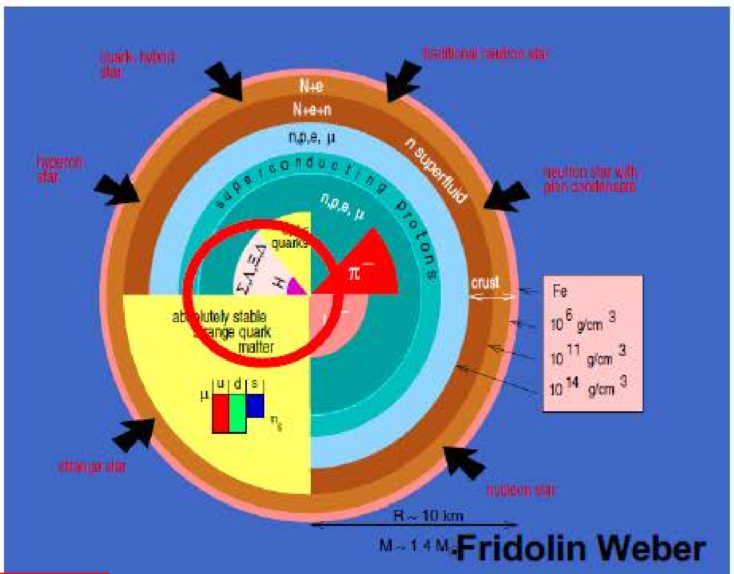
- usually refer to compact objects with $M \approx 1\text{-}2\ M_\odot$ and $R \approx 10\text{-}12$ Km

- extreme densities up to $5\text{-}10\ \rho_0$ ($n_0=0.16\ \text{fm}^{-3} \Rightarrow \rho_0=3 \cdot 10^{14}\ \text{g/cm}^3$)

- magnetic field : $B \sim 10^{8..16}$ G

- temperature: $T \sim 10^{6...11}$ K

- observations: masses, radius (?), gravitational waves, cooling…



What about Hyperons?

credit: Vidana

First proposed in 1960 by Ambartsumyan & Saakyan

Hyperon	Quarks	$I(J^P)$	Mass (MeV)
Λ	uds	$0(1/2^+)$	1115
Σ^+	uus	$1(1/2^+)$	1189
Σ^0	uds	$1(1/2^+)$	1193
Σ^-	dds	$1(1/2^+)$	1197
Ξ^0	uss	$1/2(1/2^+)$	1315
Ξ^-	dss	$1/2(1/2^+)$	1321
Ω^-	sss	$0(3/2^+)$	1672

Traditionally neutron stars were modeled by a uniform fluid of neutron rich matter in β-equilibrium

$$n \rightarrow p\, e^-\, \bar{\nu}_e$$

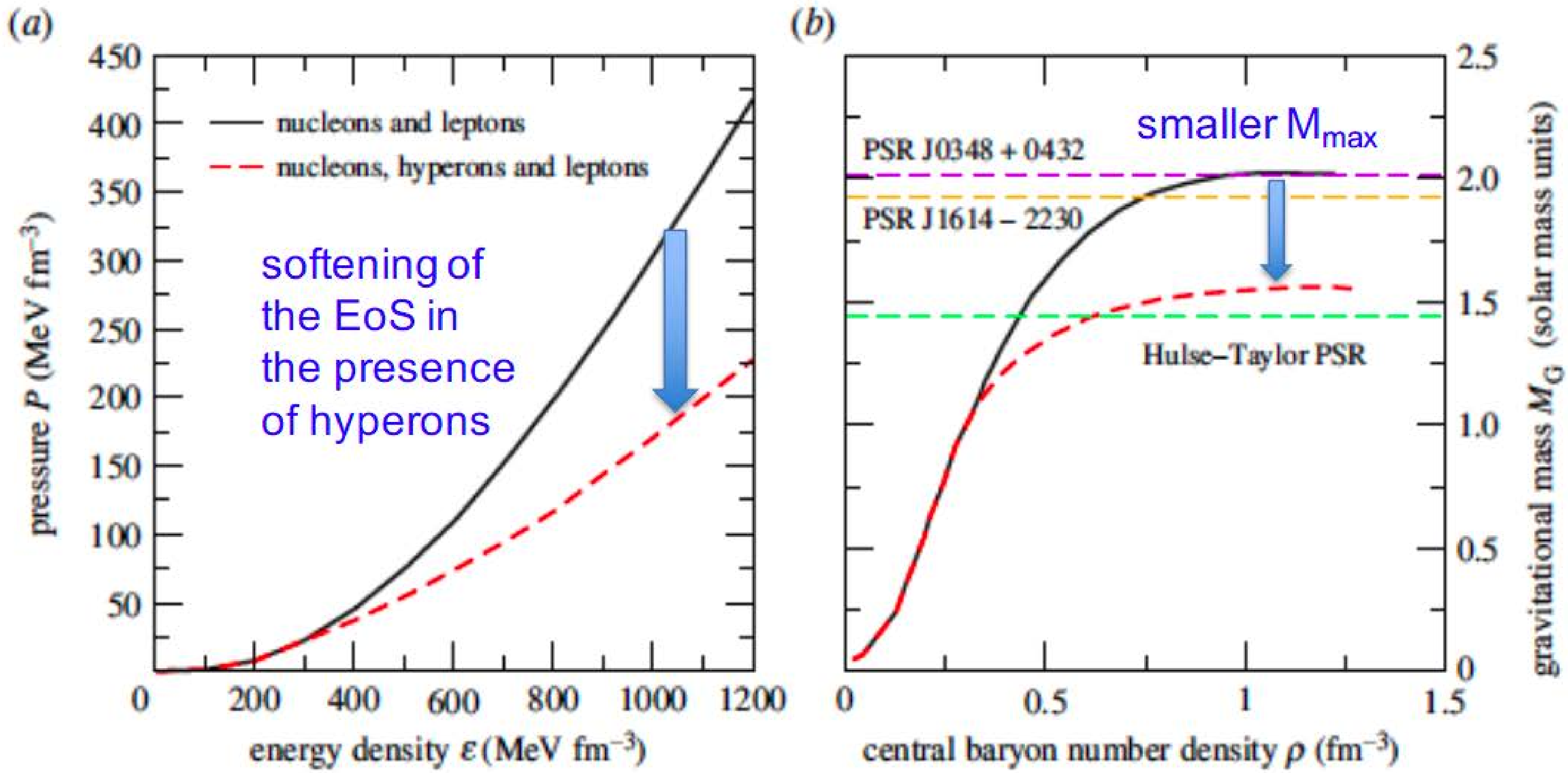
$$p\, e^- \rightarrow n\, \nu_e$$

but more exotic degrees of freedom are expected, such as **hyperons**, due to:

- high value of density at the center and
- the rapid increase of the nucleon chemical potential with density

Hyperons might be present at $n \sim (2\text{-}3)n_0$!!!

Inclusion of hyperons….



….. induces a strong softening of the EoS that leads to **M_{max}< 2M_{sun}**

Chatterjee and Vidana, Eur.Phys.J. A52 (2016) 29
Vidana, Proc. Roy. Soc. Lond. A474 (2018) 0145

The Hyperon Puzzle

The Future

Future Projects

- *Not counting the Run 3 and Run 4 LHC plans…*
- Four different projects were presented
- Low Energy (search for onset of QGP)
  - J-PARC (Japan)
  - CBM at FAIR, GSI. (Germany)
  - NICA, Dubna, (Russia)

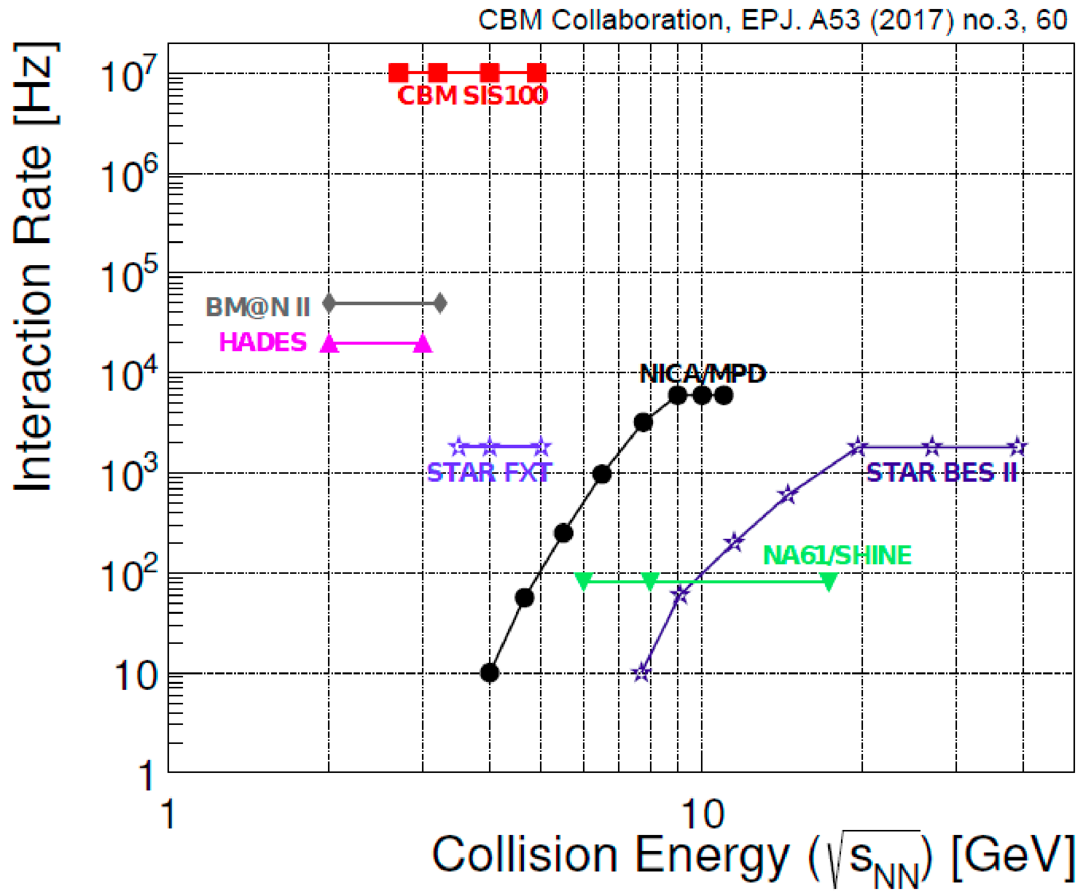
- High Energy
  - Next Generation Heavy Ion Experiment (CERN)

New Heavy Ion Projects

	Collision Rate	Energy	Ions	Target Date
J-PARC		$\sqrt{s_{NN}}$=2-5GeV	U^{238}	2024
CBM at FAIR	10^7	10 A.GeV	Au	2025
NICA	10^4	$\sqrt{s_{NN}}$=4-12GeV	Au	2022
CERN	$1\text{-}2.5\times10^6$	$\sqrt{s_{NN}}$=5.02GeV	Pb	CERN Run 5

All projects (except CERN) are currently under construction.
CERN "new generation" detector first presented at ECFA meeting in Granada, May 2019

Experiments in the high net-baryon density

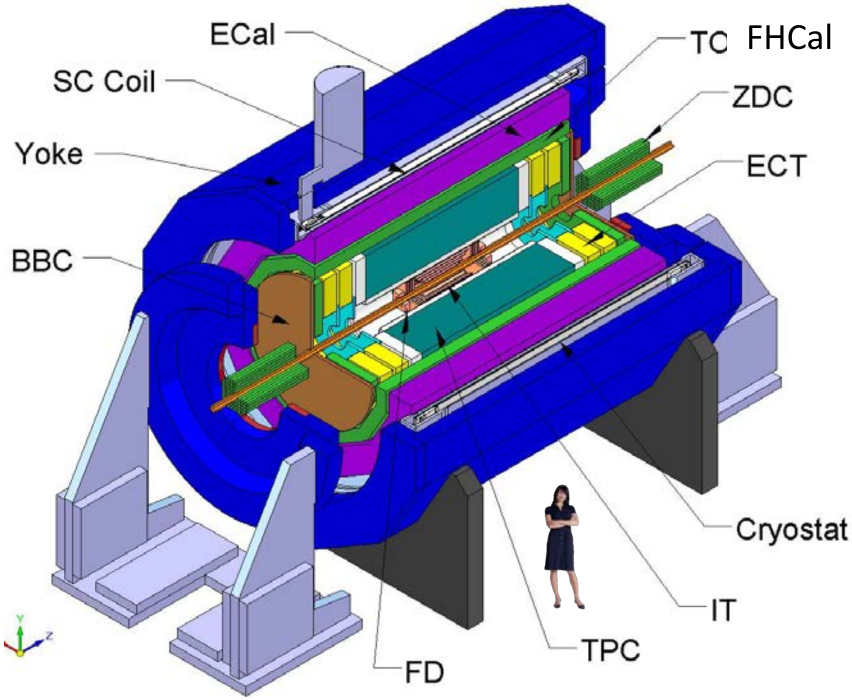


CBM will operate at high reaction rates:

10^5 - 10^7 Au+Au reactions/sec

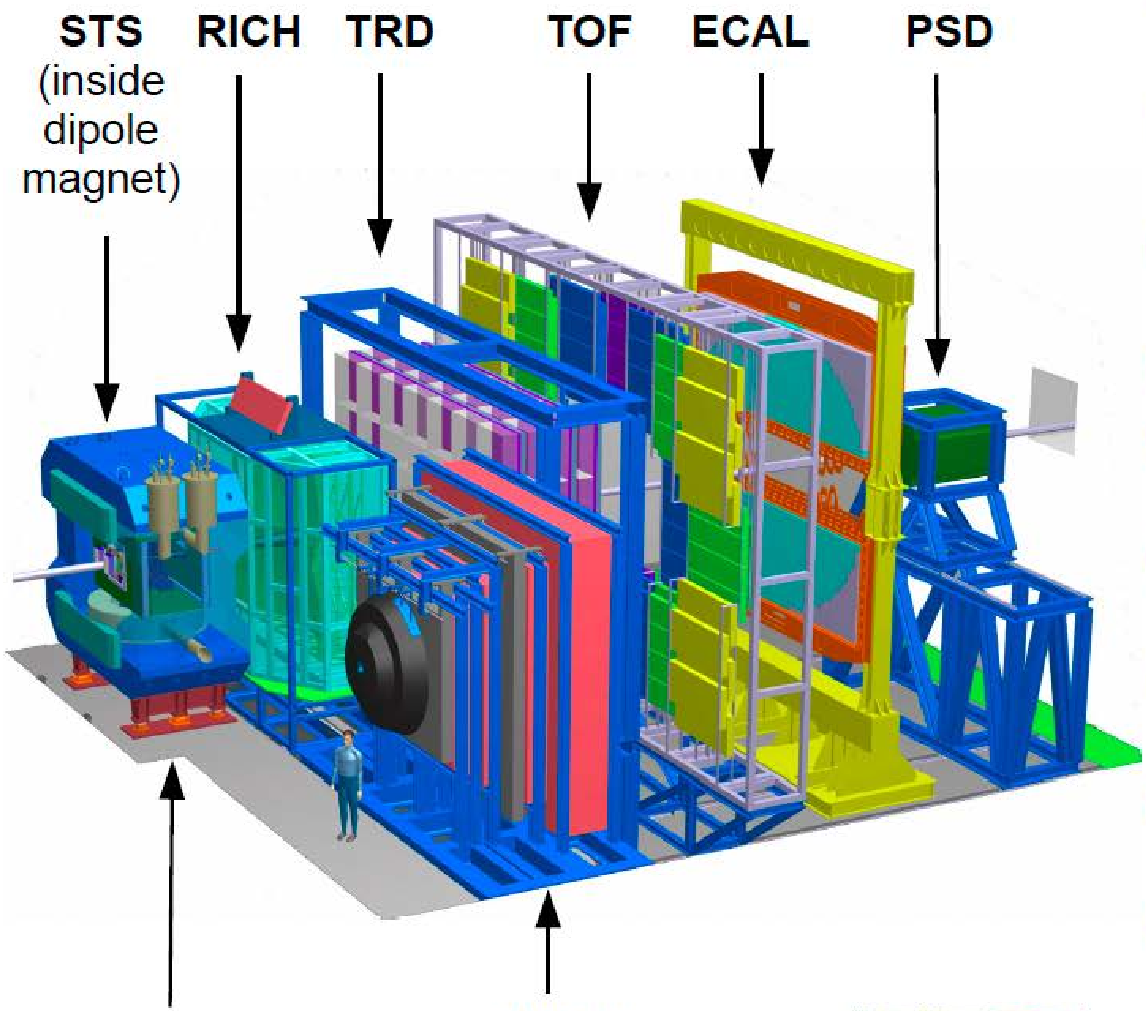
MPD Collaboration: *spokesperson – A. Kiesel WUT, Poland*

10 Countries, 32 Institutes, 465 participants



*Baku State University, NNRC, **Azerbaijan**;*
*University of Plovdiv, **Bulgaria;***
*University Técnica Federico Santa Maria, Valparaiso, **Chili**;*
*Tsinghua University, Beijing, **China**;*
*USTC, Hefei, **China**;*
*Huizhou University, Huizhou, **China**;*
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China**;*
*Central China Normal University, **China**;*
*Shandong University, Shandong, **China**;*
*IHEP, Beijing, **China**;*
*University of South China, **China**;*
*Palacky University, Olomouc, **Czech Republic**;*
*NPI CAS, Rez, **Czech Republic**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*Tubingen University, Tubingen, **Germany**;*
*Tel Aviv University, Tel Aviv, **Israel**;*
Joint Institute for Nuclear Research;
*IPT, Almaty, **Kazakhstan**;*
*UNAM, Mexico City, **Mexico**;*
*Institute of Applied Physics, Chisinev, **Moldova**;*
*WUT, Warsaw, **Poland**;*
*NCN, Otwock – Swierk, **Poland**;*
*UW, Wroclaw, **Poland**;*
*Jan Kochanowski University, Kielce, **Poland**;*
*INR RAS, Moscow, **Russia**;*
*MEPhI, Moscow, **Russia**;*
*PNPI, Gatchina, **Russia**;*
*INP MSU, Moscow, **Russia;***
*KI NRS, Moscow, **Russia**;*
*SPSU - Dept. of NP, **Russia;***
*St. Petersburg, **Russia**;*
*SPSU – Dept. of HEP, St. Petersburg, **Russia**;*
*North Ossetia State University, Vladikavkaz, **Russia**;*

CBM detector subsystems



Dipole Magnet
bends charged particle's trajectories

STS (Silicon Tracking System)
charged particle tracking

MVD (Micro-Vertex Detector)
secondary vertex reconstruction

RICH (Ring Imaging Cherenkov)

TRD (Transition Radiation Detector)
electron identification

TOF (Time of Flight detector)
hadron identification

MUCH (MUon CHambers)
muon tracking & identification

ECAL (Electromagnetic Calorimeter)
electron/photon identification

PSD (Projectile Spectator Detector)
collision centrality and
reaction plane determination

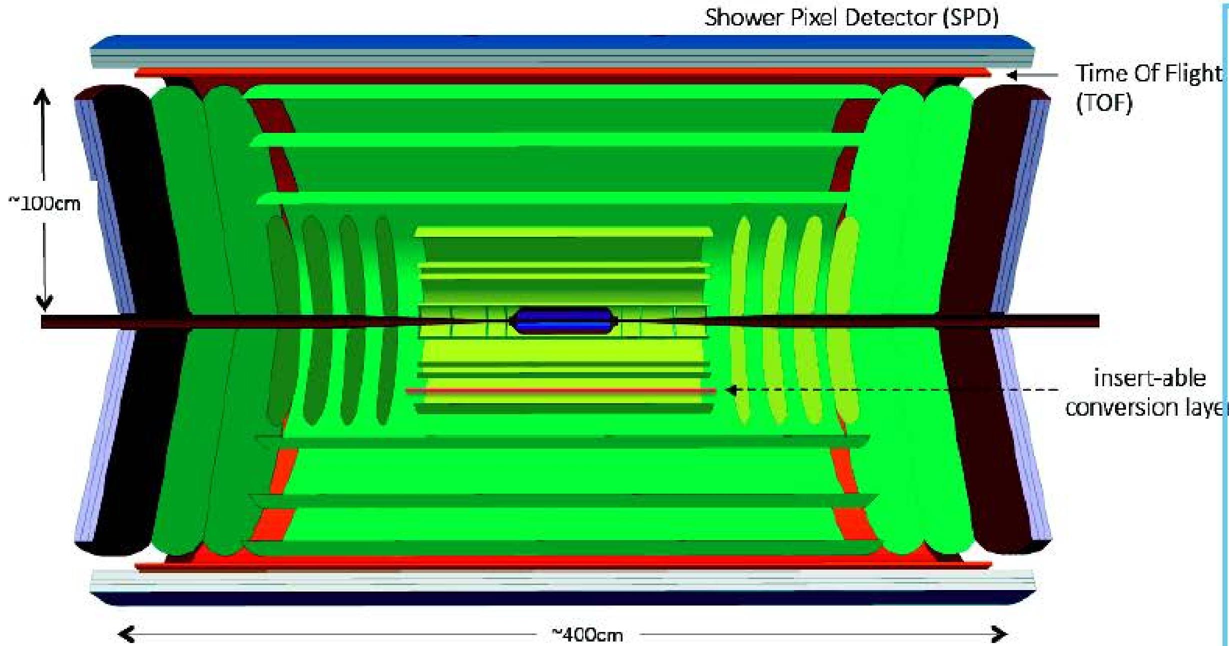
FLES (First-level Event Selector)
online reconstruction / event selection

Concept of an all silicon detector

Tracker: ~10 tracking barrel layers (blue, yellow, green) based on CMOS sensors $|\eta| < 1.4$
plus 2 endcaps with ~ 10 disks $1.4 < |\eta| < 4$

Hadron ID: TOF with 3 outer silicon layers (red)

Electron ID: < 500 MeV via TOF, > 500 MeV pre-shower pixel detector (blue)



Preliminary studies

Magnetic field
B = 0.5 to 1 T

Spatial resolution
Inner most 3 layers: 10x10 μm^2
0.05 % X_0, $\sigma < 3\ \mu m$
Outer layers: 30x30 μm^2
0.5 % X_0, $\sigma \sim 5\ \mu m$

Time measurement
3 layers with $\sigma_t \sim 20$ ps

arXiv:1902.01211

Summary

- Heavy ion physics now following several different strands
- Properties of deconfined quark matter (high energy)
- Properties of small systems (pp, pA) at high multiplicity
- Search for Critical Point and properties of matter in this region (low energy)
- Several new detectors will address low energy region at very high intensities in the 2020s
- CERN programme now being considered into 2030s