3rd EMMI workshop: anti-matter, hyper-matter and exotica production at the LHC
Wrap-up

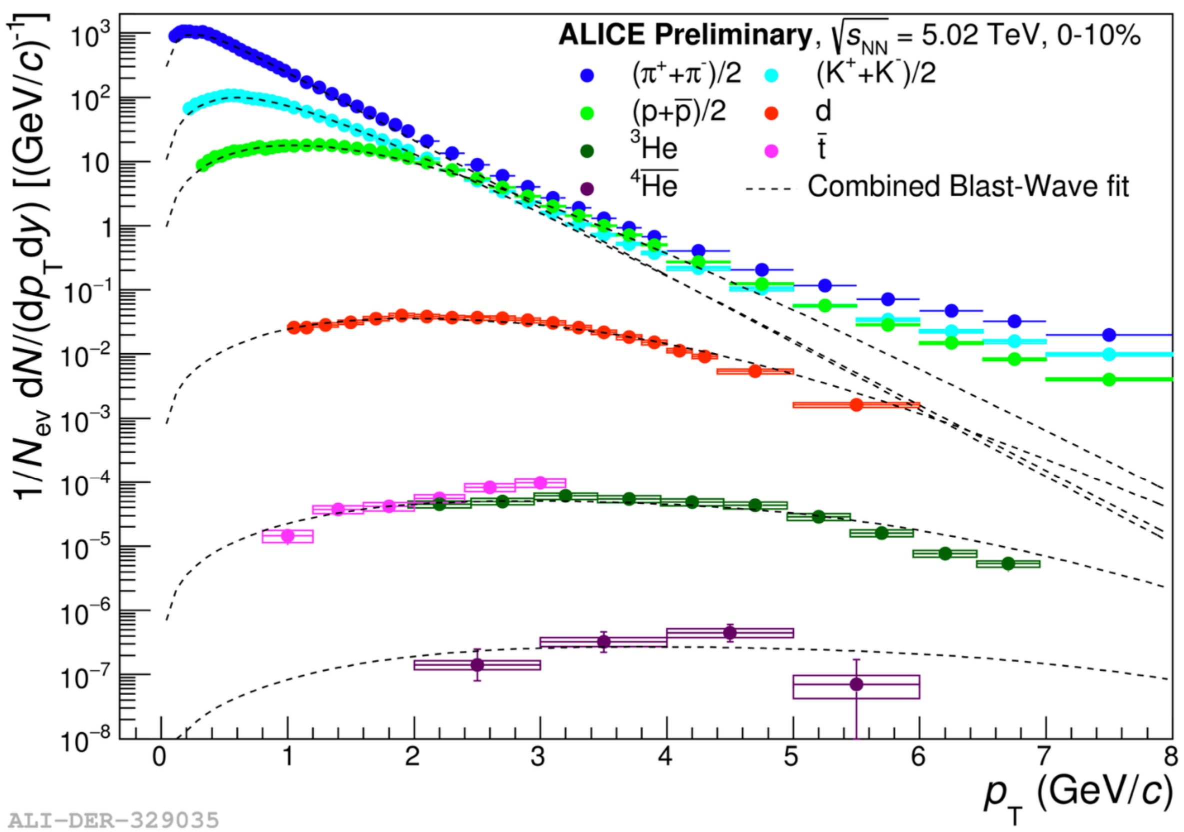
Alberto Calivà

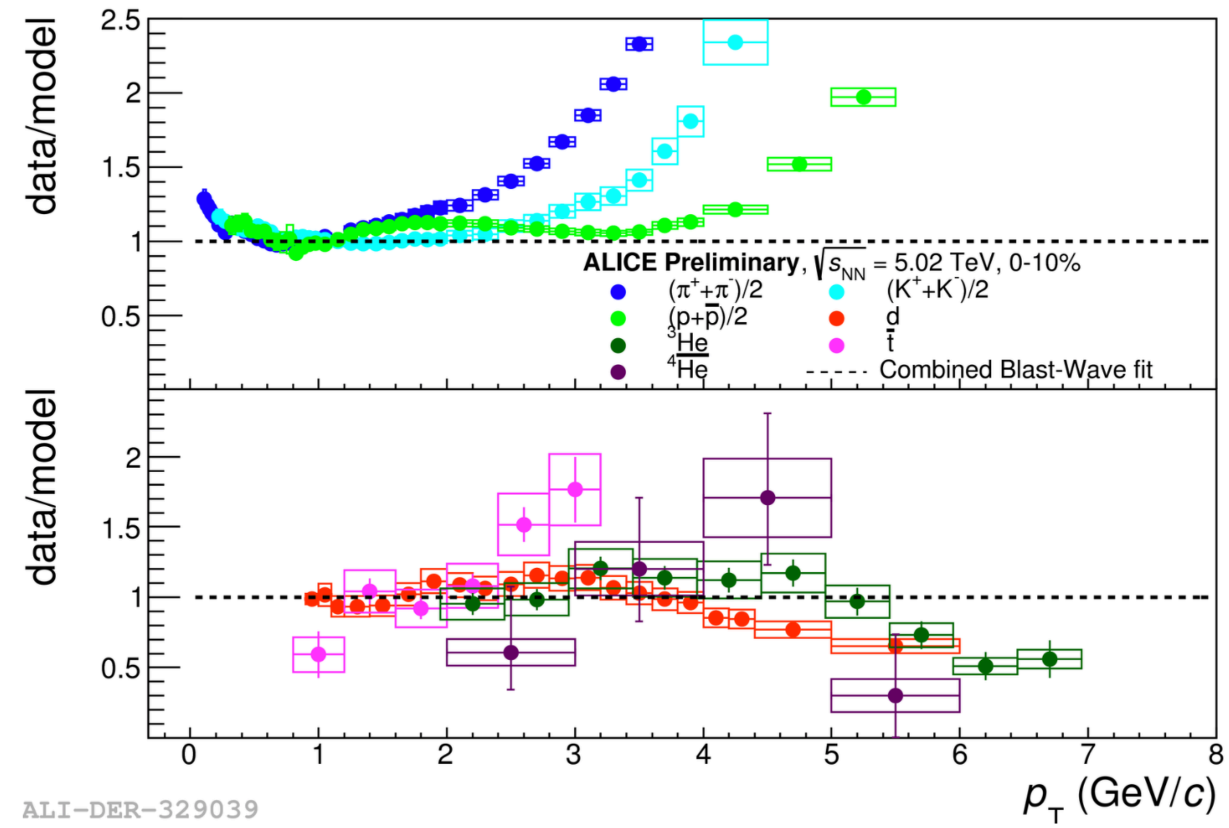
University of Wroclaw

December 2, 2019

Common kinetic freezeout?

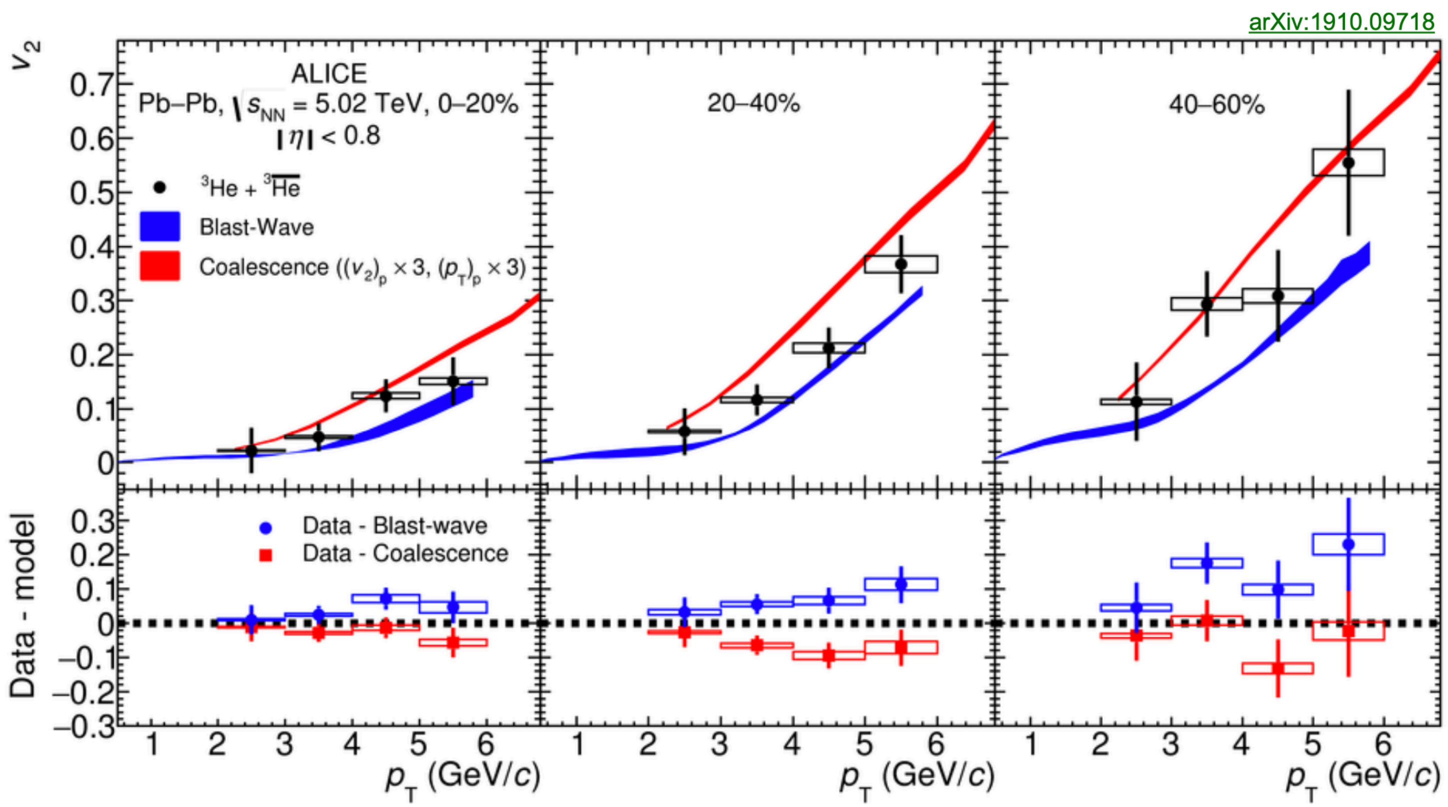
M. Puccio





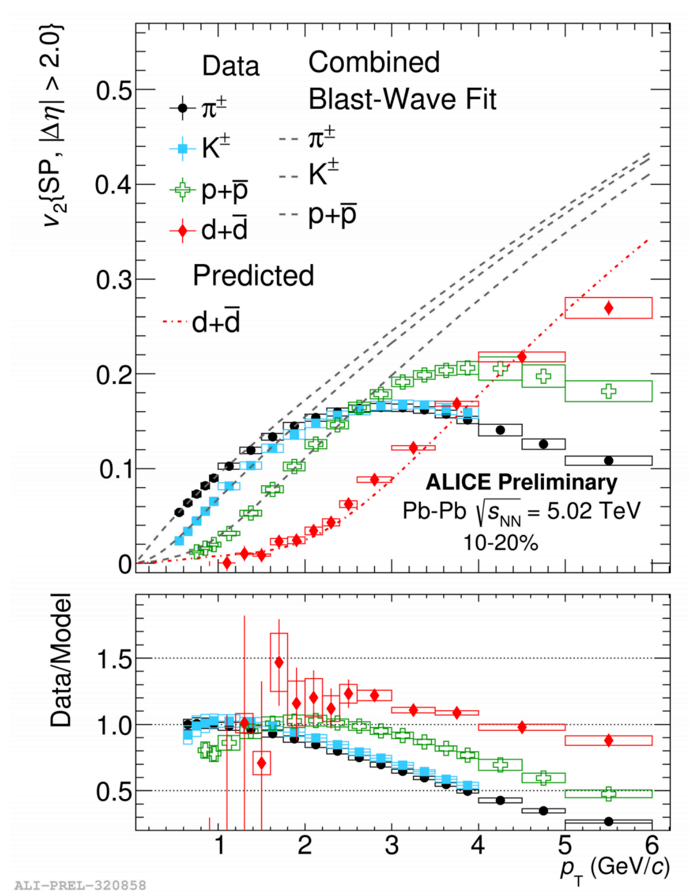
- First measurement of (anti)alpha p_T spectrum
- Common Blast-Wave fit to light flavoured particles gives
  - Decent description of the observed spectra at the low-intermediate transverse momenta
  - Similar to what observed in Pb-Pb 2.76 TeV
  - Is this a enough to claim a common freeze-out surface?

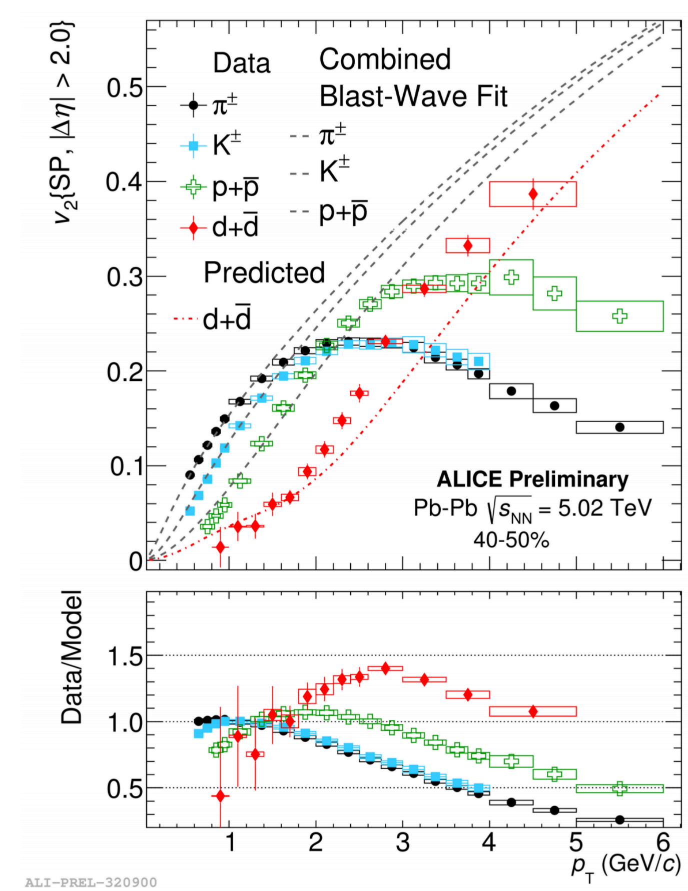
Blast-wave vs. coalescence



M. Puccio

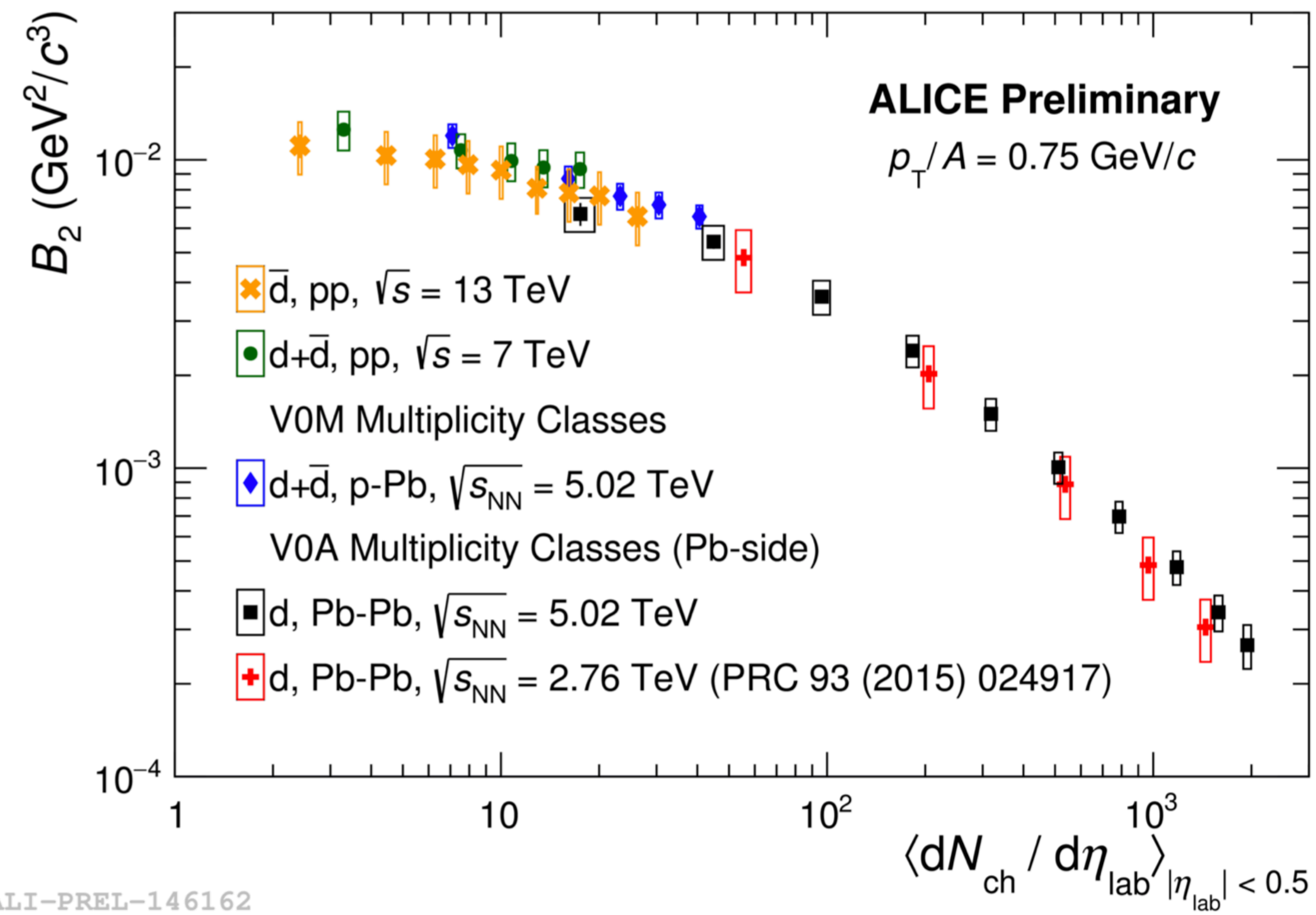
Elliptic flow of light (anti-)nuclei is
Between BW and coalescence

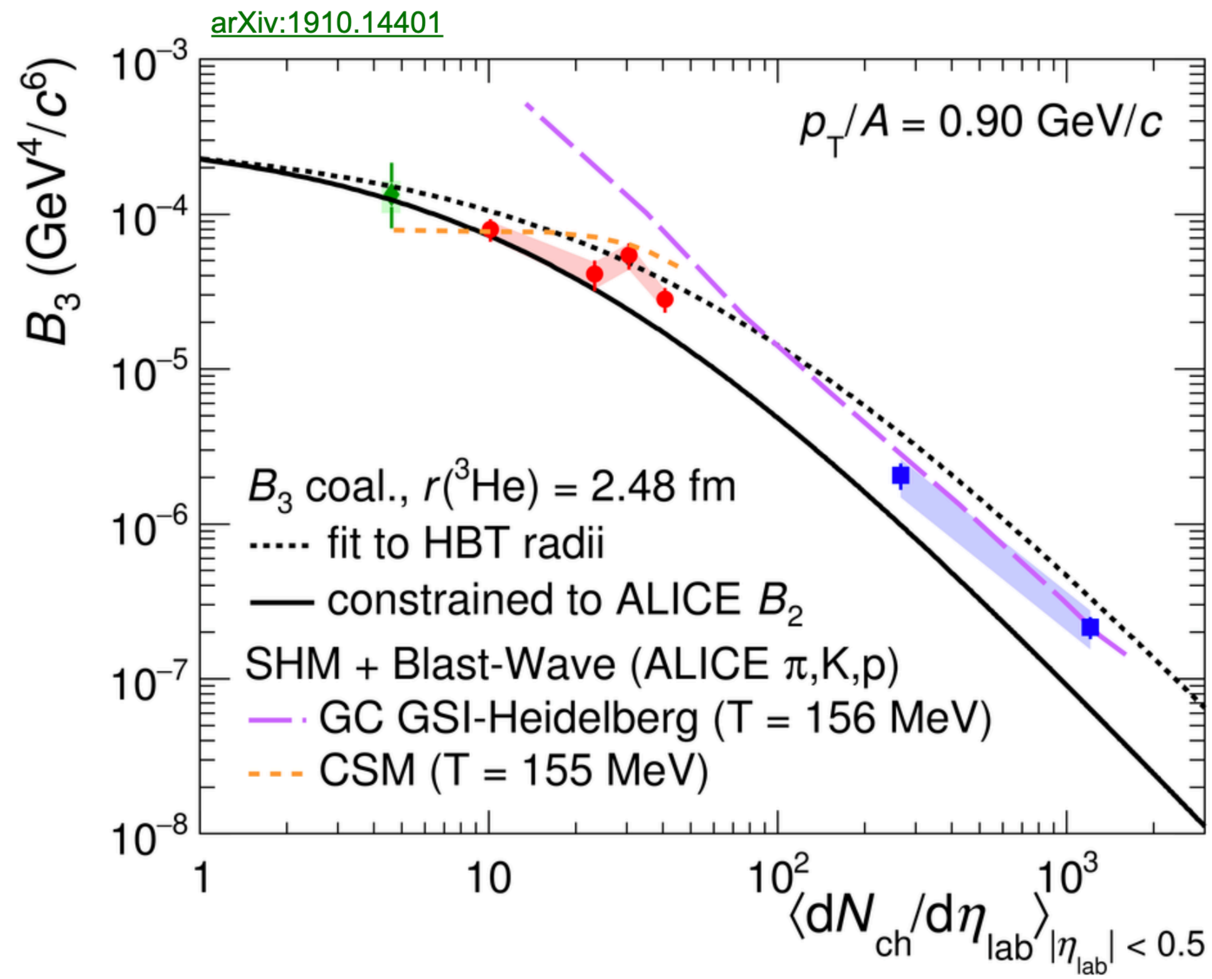




System-size dependence

M. Puccio





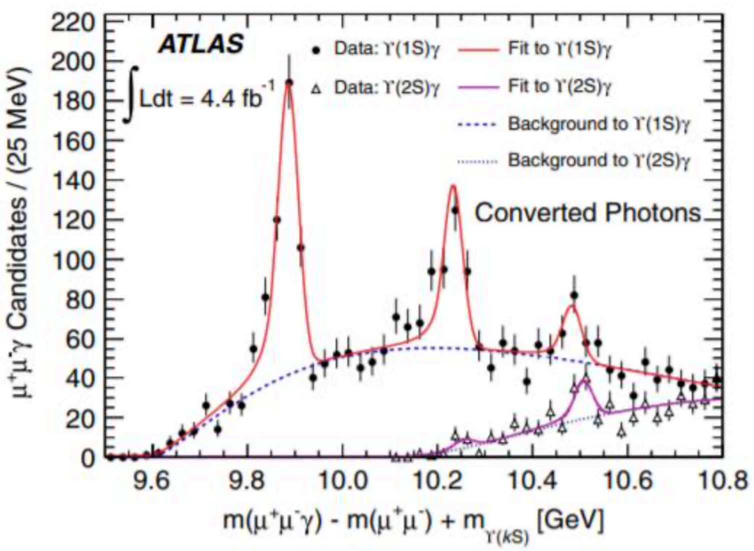
Hint of a smooth evolution of dominant production mechanism with multiplicity

Exotic states with CMS

Nikita Petrov

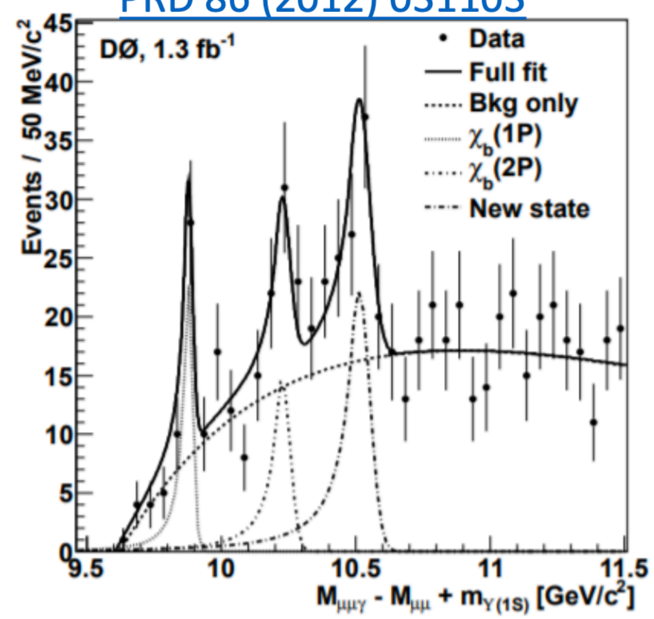
CMS: Observation of the $\chi_{b1}(3P)$ and $\chi_{b2}(3P)$

PRL 108 (2012) 152001

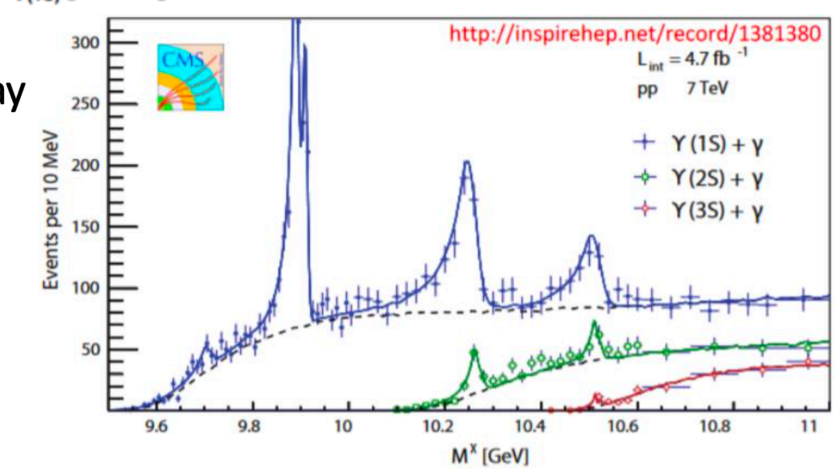


In 2011 the ATLAS Collaboration observed the $\chi_b(3P)$ state in $\Upsilon(1S)\gamma$ and $\Upsilon(2S)\gamma$ modes.

PRD 86 (2012) 031103

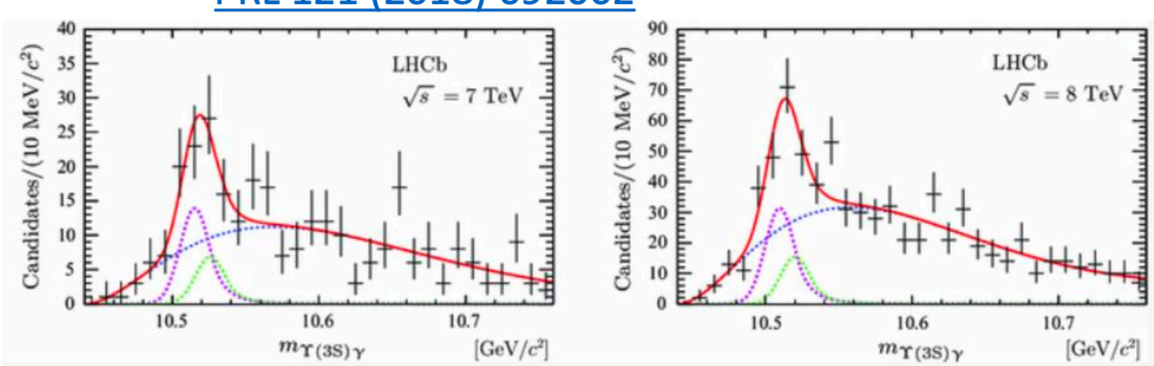


Then D0 confirmed the $\chi_b(3P) \to \Upsilon(1S)\gamma$ decay



The CMS Collaboration saw the $\chi_b(3P)$ in all modes 5

PRL 121 (2018) 092002



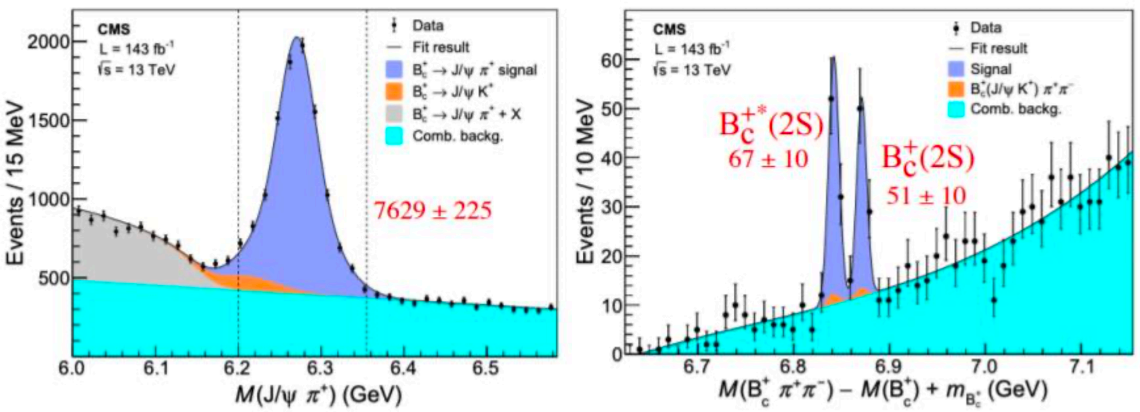
The LHCb observed new decay $\chi_b(3P) \to \Upsilon(3S)\gamma$

Good signal extraction performance

Observation of two exited $\mathbf{B_c^+}$ states

Using full Run II statistics the CMS collaboration observed two well separated $B_c^+(2S)$ and $B_c^{+*}(2S)$ states

Nikita Petrov



CMS very competitive compared to LHCb

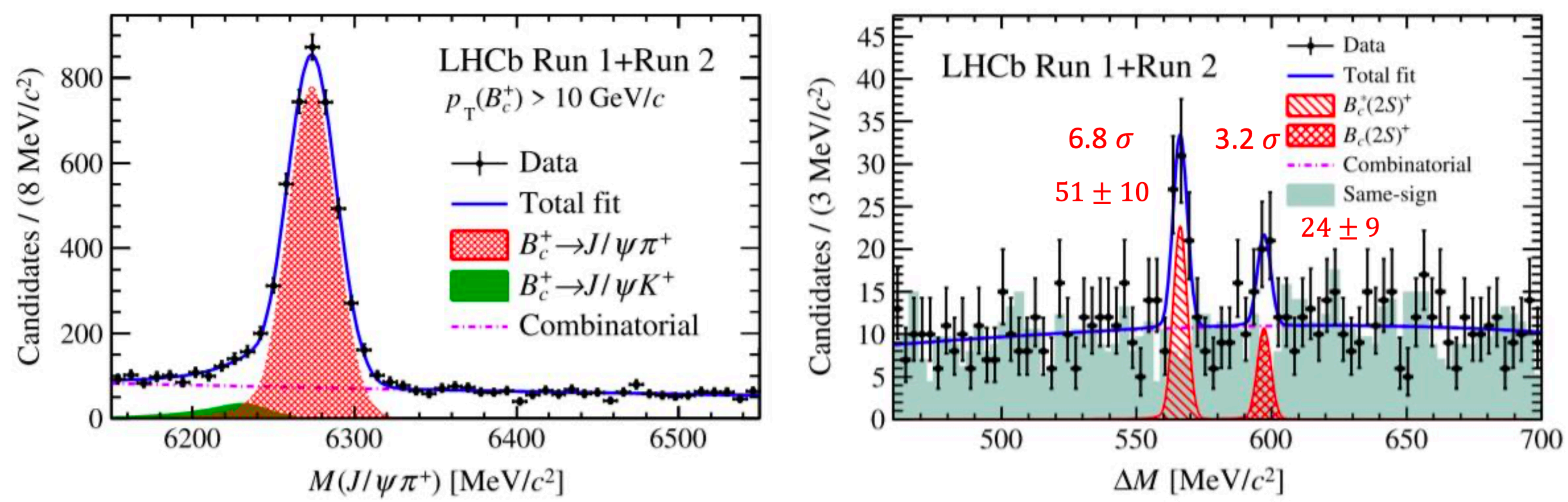
- $M(B_c^+(2S)) = 6871.0 \pm 1.2(stat.) \pm 0.8(syst.)$
- $\Delta M = 29.1 \pm 1.5(stat.) \pm 0.7(syst.)$ MeV

Once these yields will be corrected for detection effici
ratios of production cross sections to be compared wi

Observation of two excxited B_c^+ states

Recently the LHCb collaboration has confirmed the two-peaks structure using Run I and Run II statistics.

PRL 122 (2019) 232001

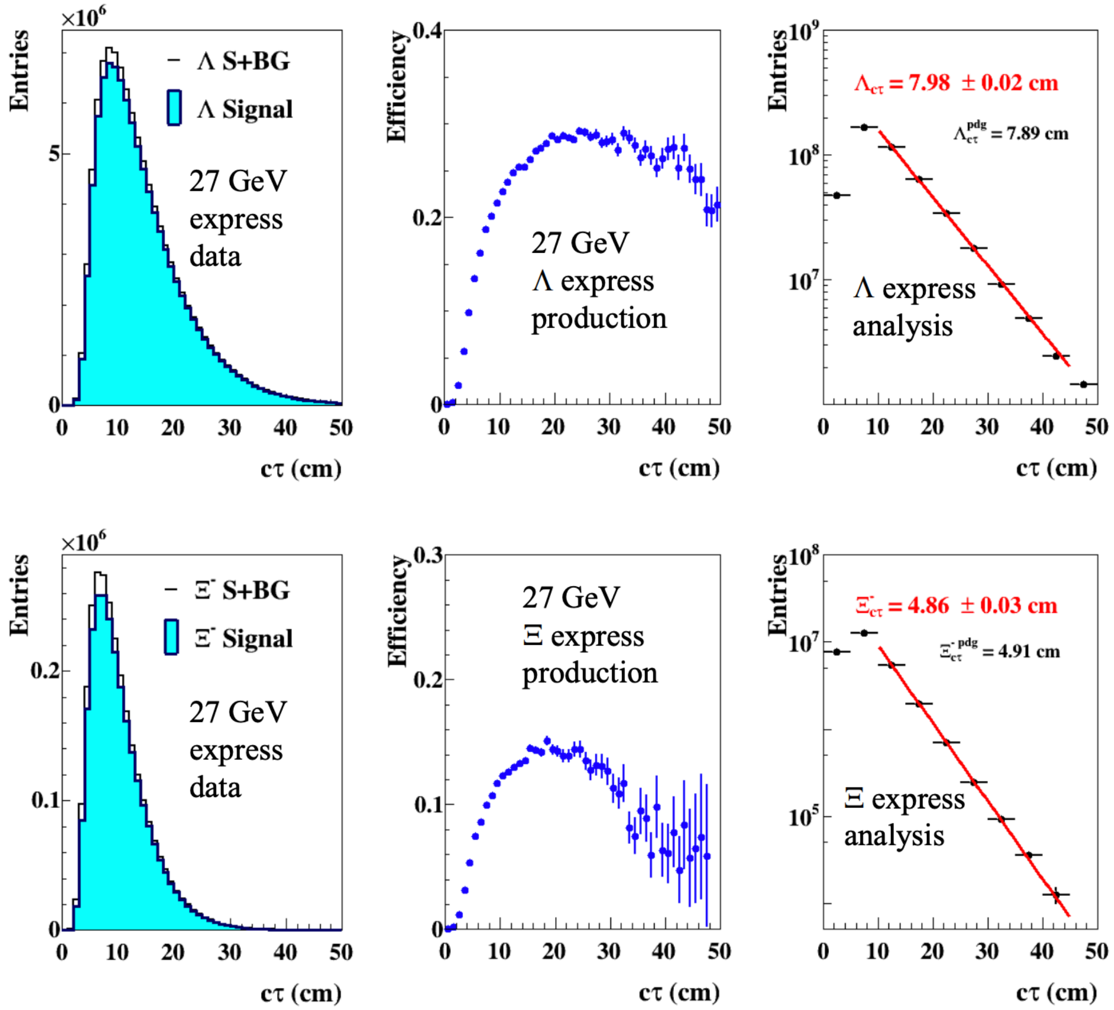


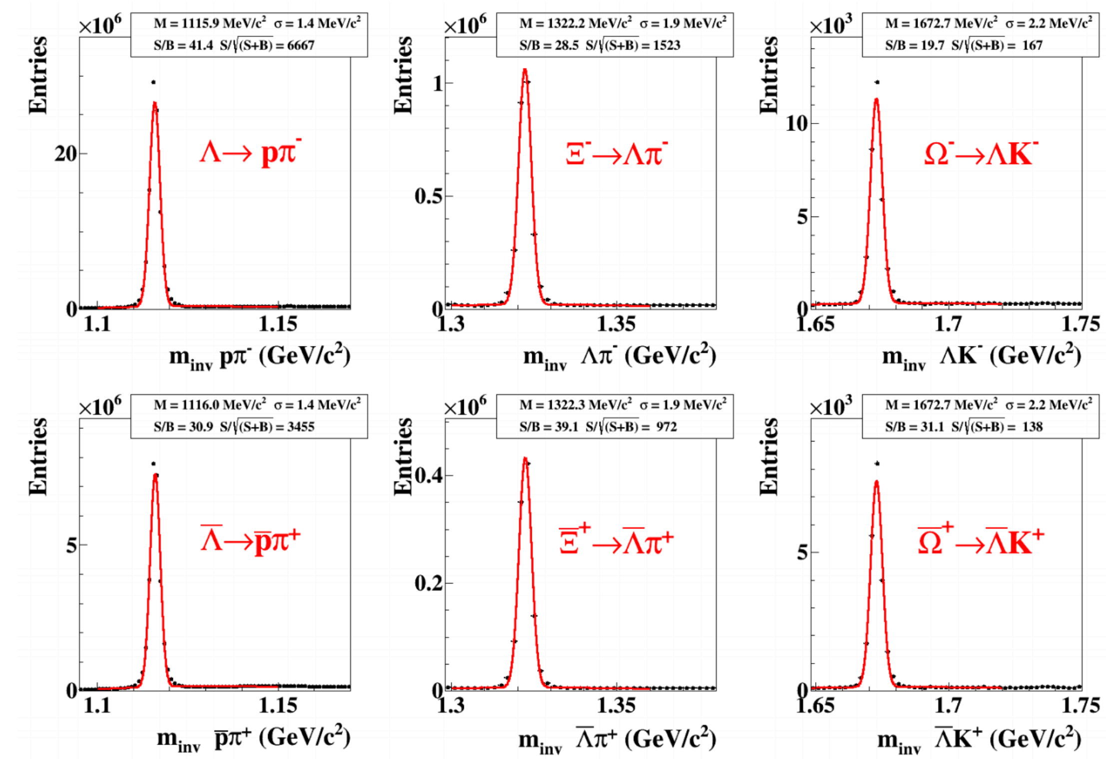
	$\mathbf{M(B_c^+(2S)), MeV}$	$\mathbf{\Delta M, MeV}$
CMS	$6871.0 \pm 1.2 \pm 0.8 \pm 0.8$	$29.1 \pm 1.5 \pm 0.7$
LHCb	$6872.1 \pm 1.3 \pm 0.1 \pm 0.8$	$31.0 \pm 1.4 \pm 0.0$

Results of the LHCb Collaboration are in a good agreement with CMS Collaboration

STAR performance express analysis

Iouri VASSILIEV

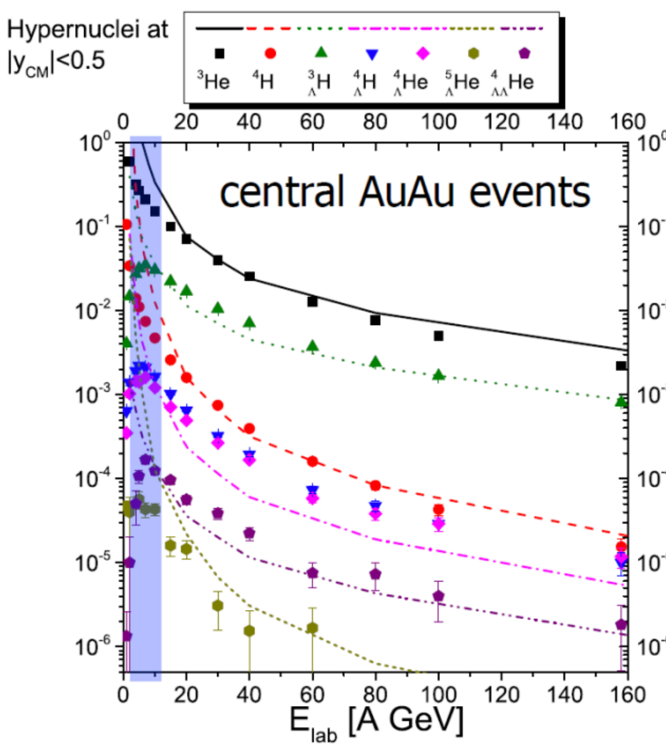




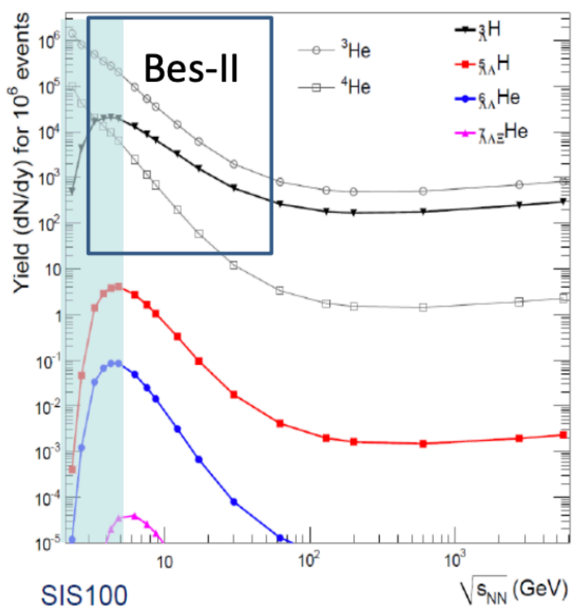
- 27 GeV data are used for extraction of the Λ and Ξ lifetime because of the extremely high significance.
- Lifetime of Λ and Ξ from the simulated data is extracted with high precision, while from the real data with (1-5)% systematic error - efficiency should be understood, embedding is needed.

Hyper nuclei program at FAIR

Iouri VASSILIEV

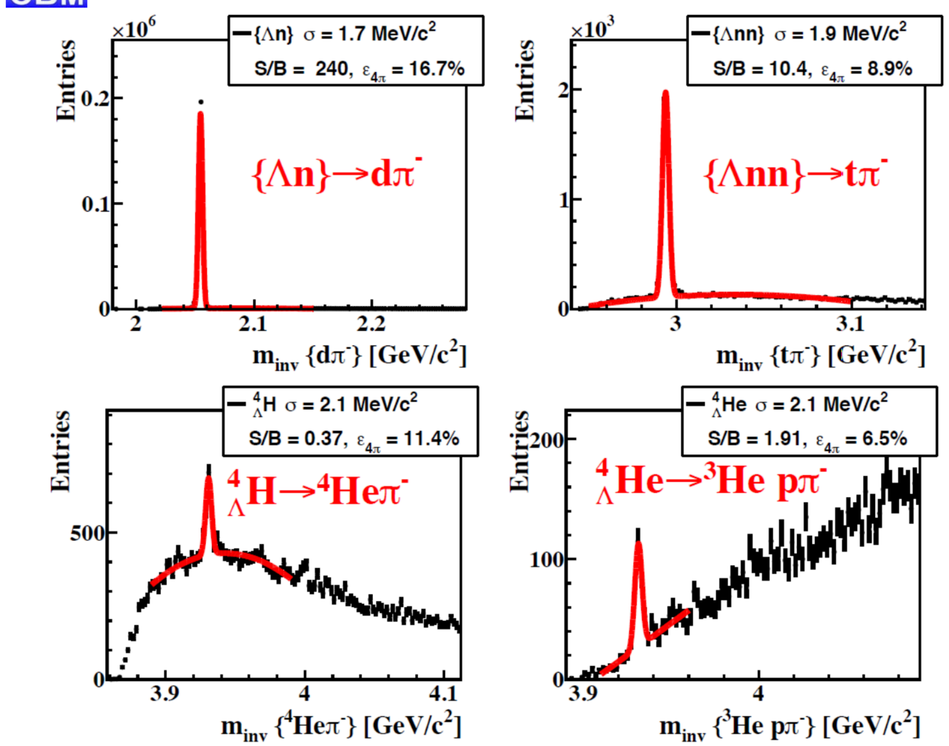


J. Steinheimer et al., Phys. Lett. B 714 (2012) 85

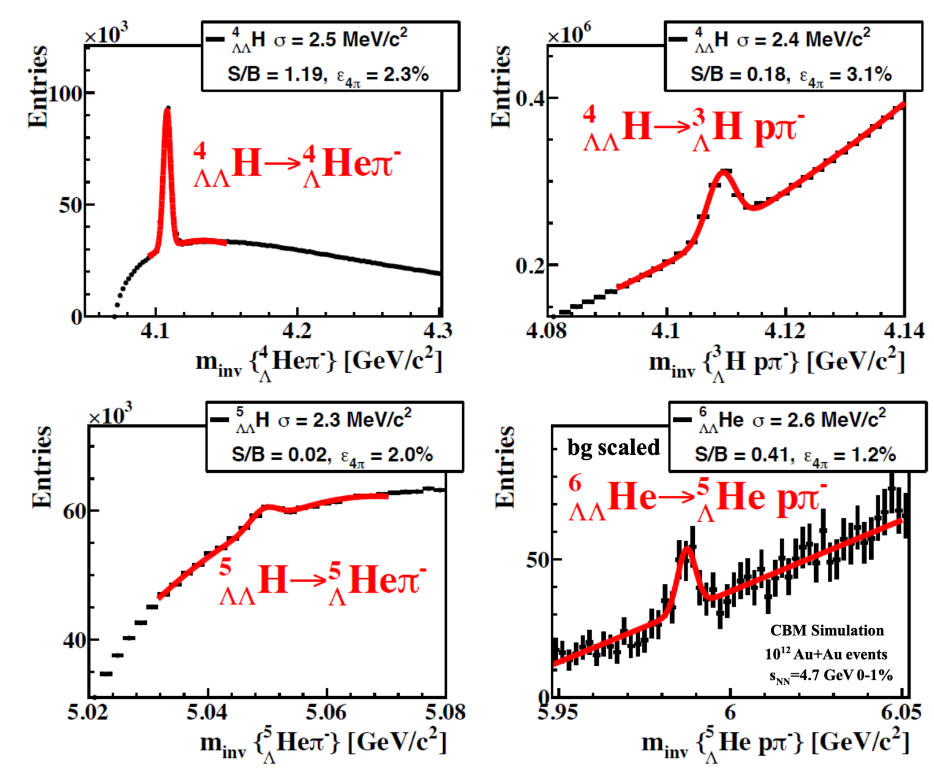


A. Andronic et al., Phys. Lett. B697 (2011) 203

Single-Λ hypernuclei



Double-Λ hypernuclei



Very interesting hyper nuclei program at FAIR:

Optimal energy regime for hyper nuclei production

SHM

Peter Braun-Munzinger

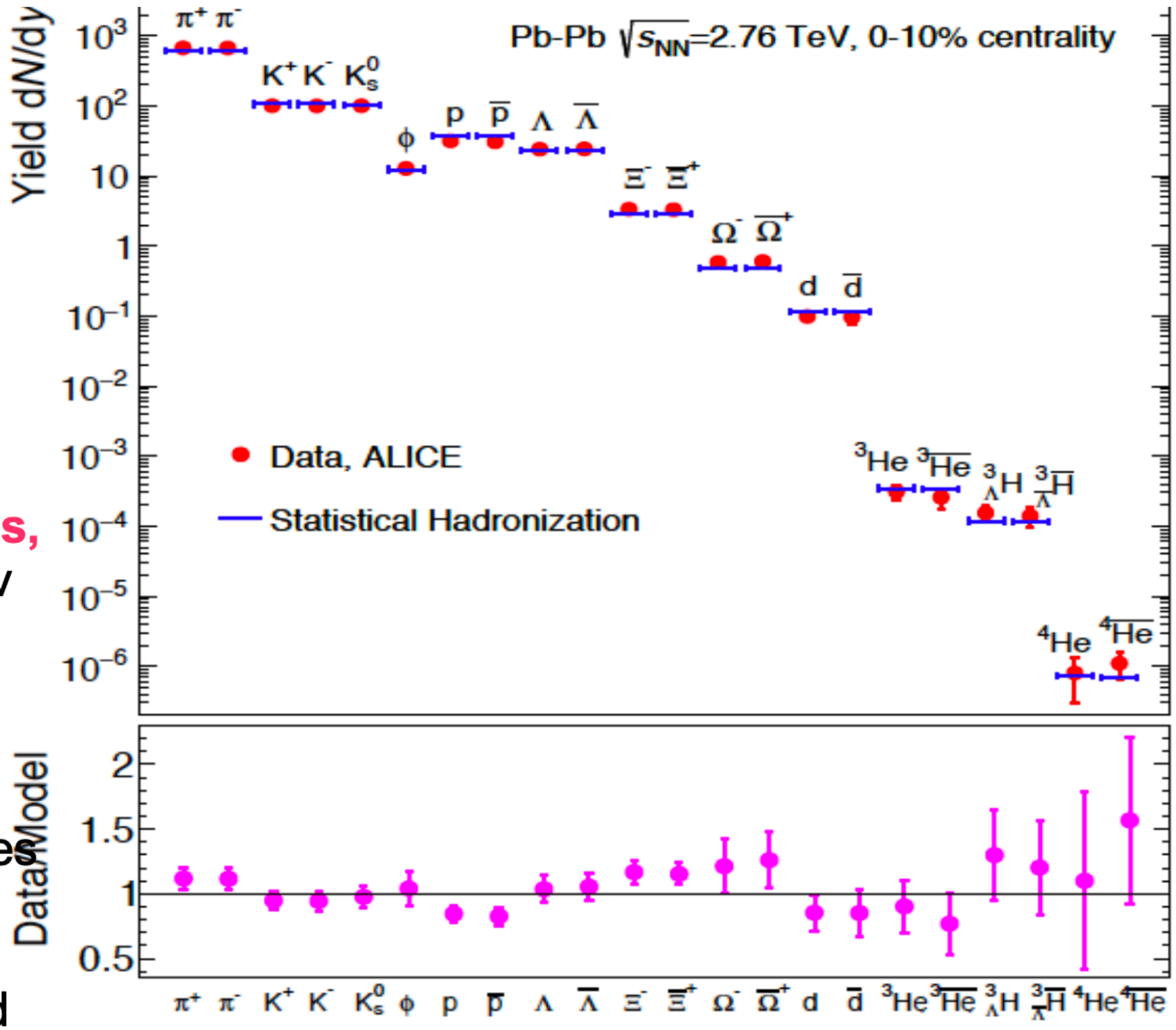
fit includes loosely bound systems such as deuteron and hypertriton
how light nuclei emerge from LQCD see Detmold et al., Eur.Phys.J. A55 (2019) 193

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

proton discrepancy about 2.8 sigma

agreement with hyper-triton yield also implies that hyper-triton has no excited states

for an excited state with J=3/2 the total yield would triple, inconsistent with data



Andronic, pbm, Redlich, Stachel, arXiv:1710.09425,
Nature 561 (2018) 321

SHM

Peter Braun-Munzinger

fit includes loosely bour
deuteron and hypertrito
how light nuclei emerge
Detmold et al., Eur.Phys

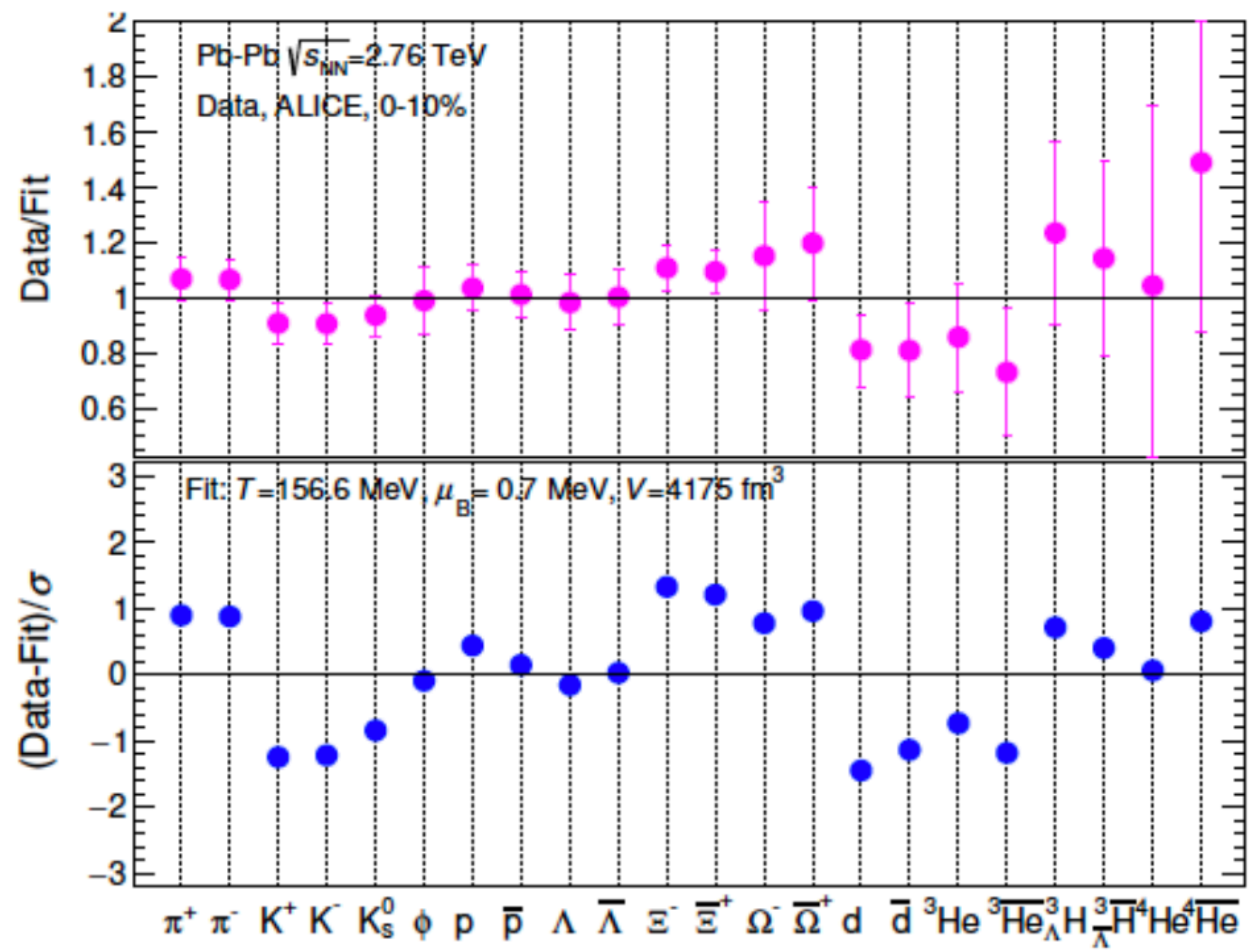
hypertriton is bound-sta
Λ separation energy ab
size about 10 fm, the **ul**
produced at T=156 MeV
state

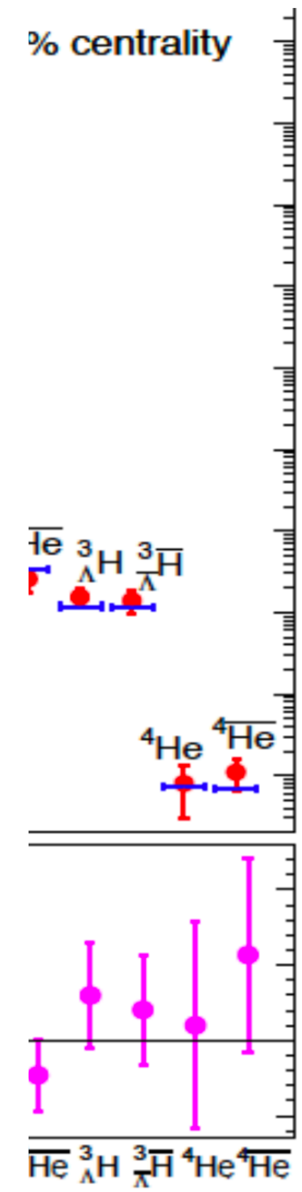
proton discrepancy abo

agreement with hyper-tı
that hyper-triton has no

for an excited state with
would triple, inconsister

Andror





$$\chi^2 = 19.7 \text{ per } 19 \text{ dof}$$

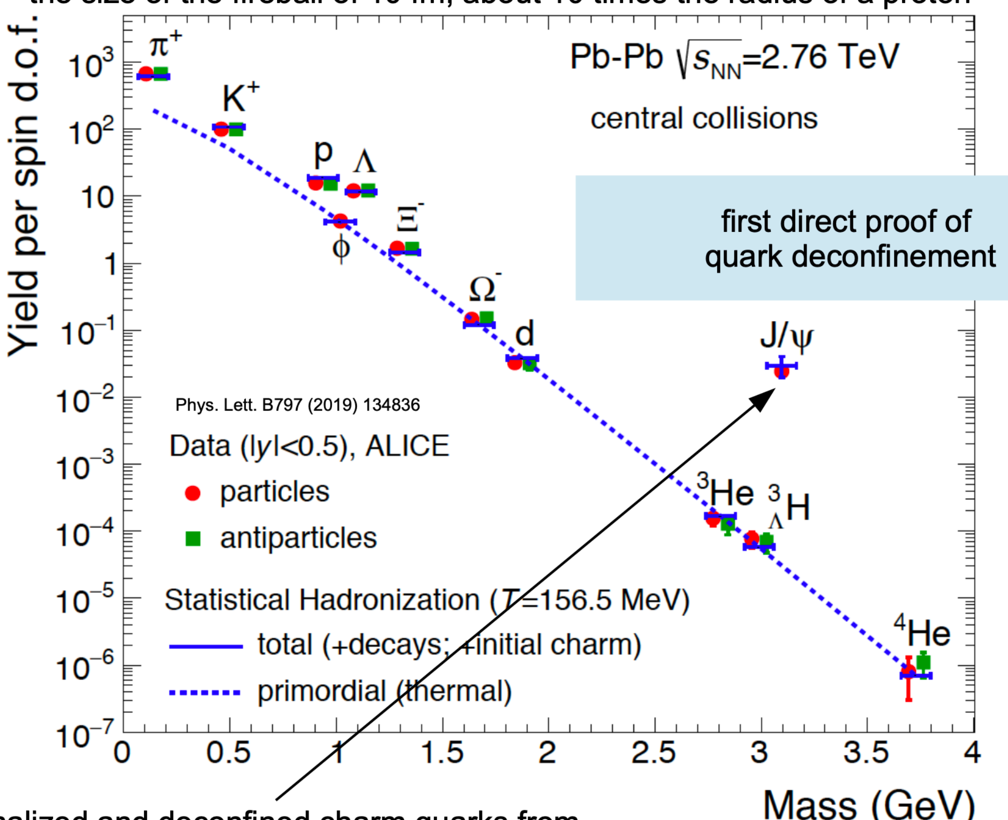
very good fit!

Nature 561 (2018) 321

Charmonium into SHM

Peter Braun-Munzinger

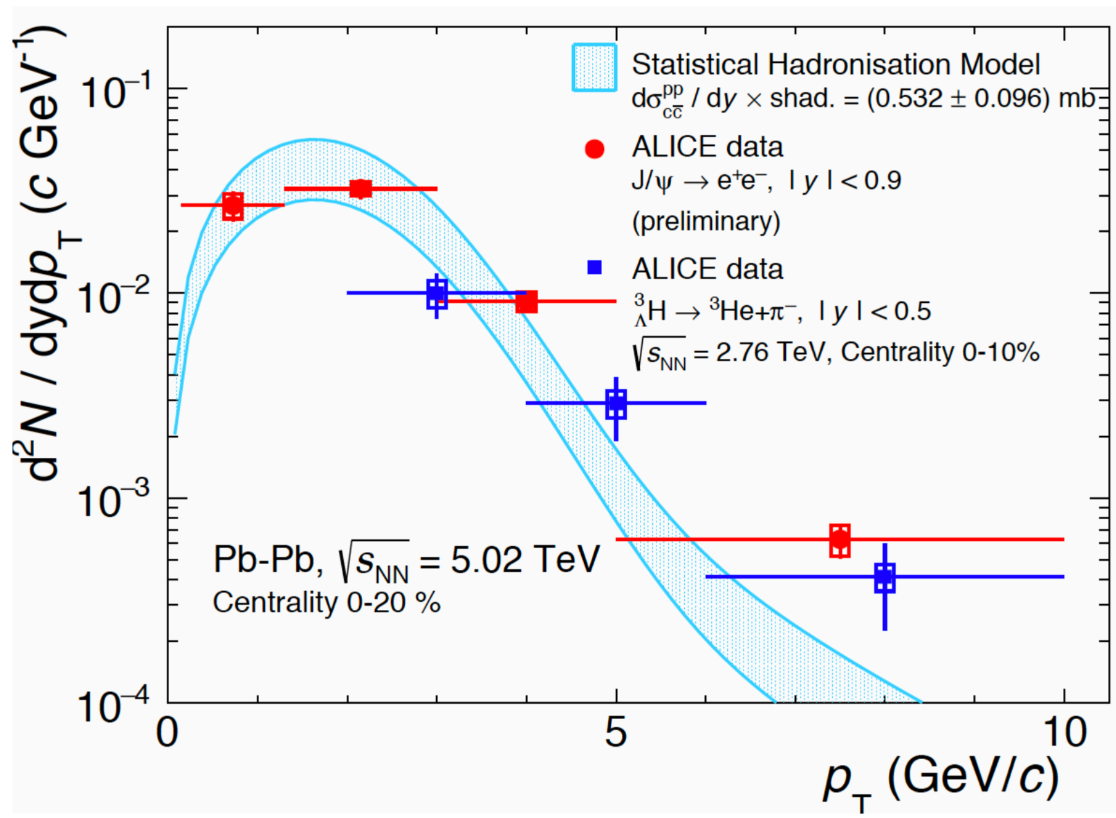
enhancement is precisely prediction by Statistical Hadronization Model
for quadratic scaling in number of charm quarks, they have to travel freely ov--
the size of the fireball of 10 fm, about 10 times the radius of a proton



with thermalized and deconfined charm quarks from
initial hard scattering

Andronic, pbm, Koehler, Redlich, Stachel,
Phys. Lett B797 (2019) 134836

J/psi and hyper-triton described with the same flow parameters in the statistical hadronization model



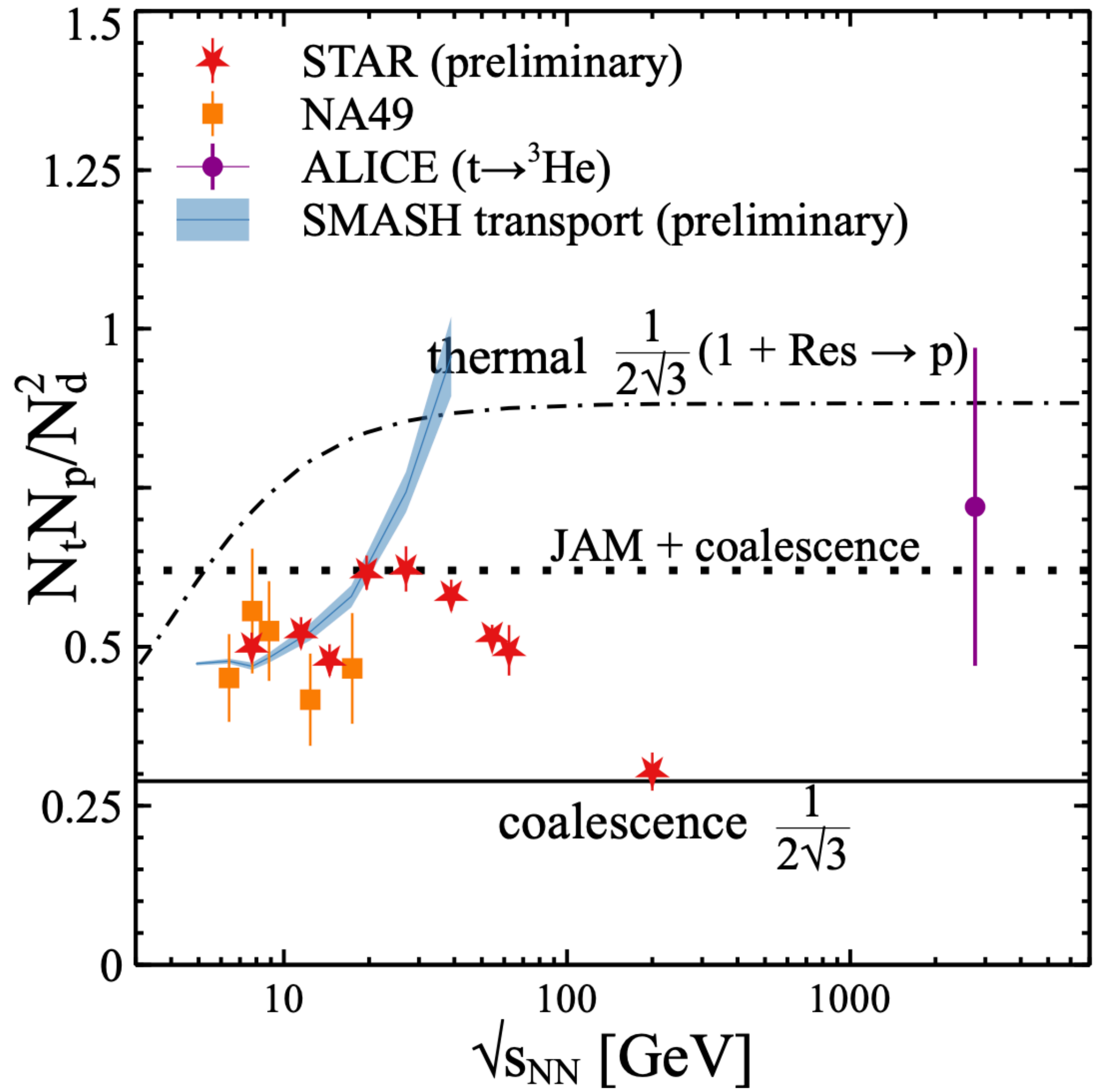
binding energies:
J/psi 600 MeV
hypertriton 2.2 MeV
Lambda S.E. 0.2 MeV

Charm saturation in the medium: thermalization in the medium

Existence of critical point?

Dmytro OLIINYCHENKO

Data: NA49 [Anticic:2010mp,Blume:2007kw,Anticic:2016ckv], STAR [Adam:2019wnb,Zhang:2019wun, talk by Dingwei Zhang], ALICE [Adam:2015vda]; model JAM + coalescence [Liu:2019nii]

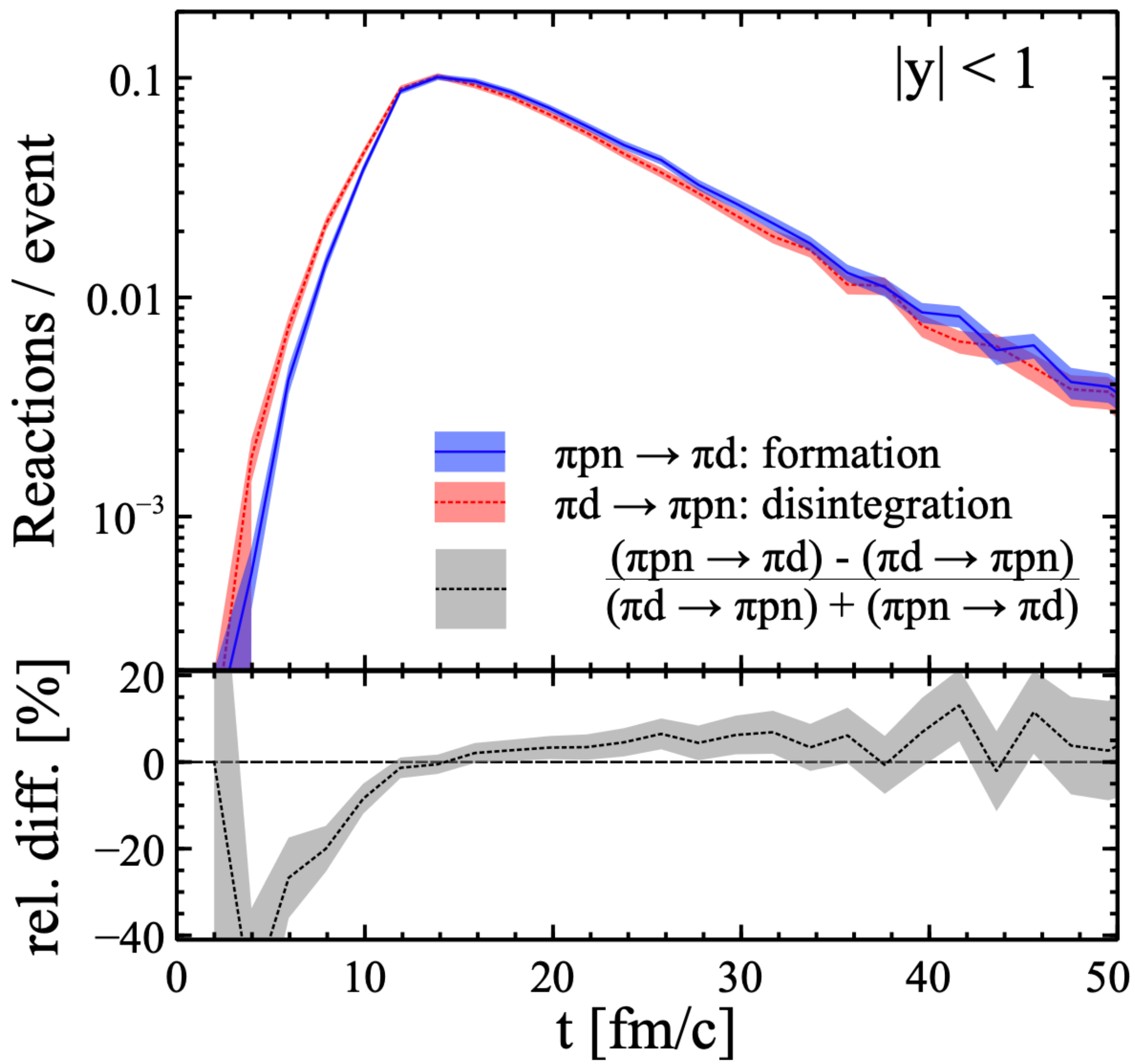


Interesting ratio sensitive to fluctuations in number of particles close to critical point

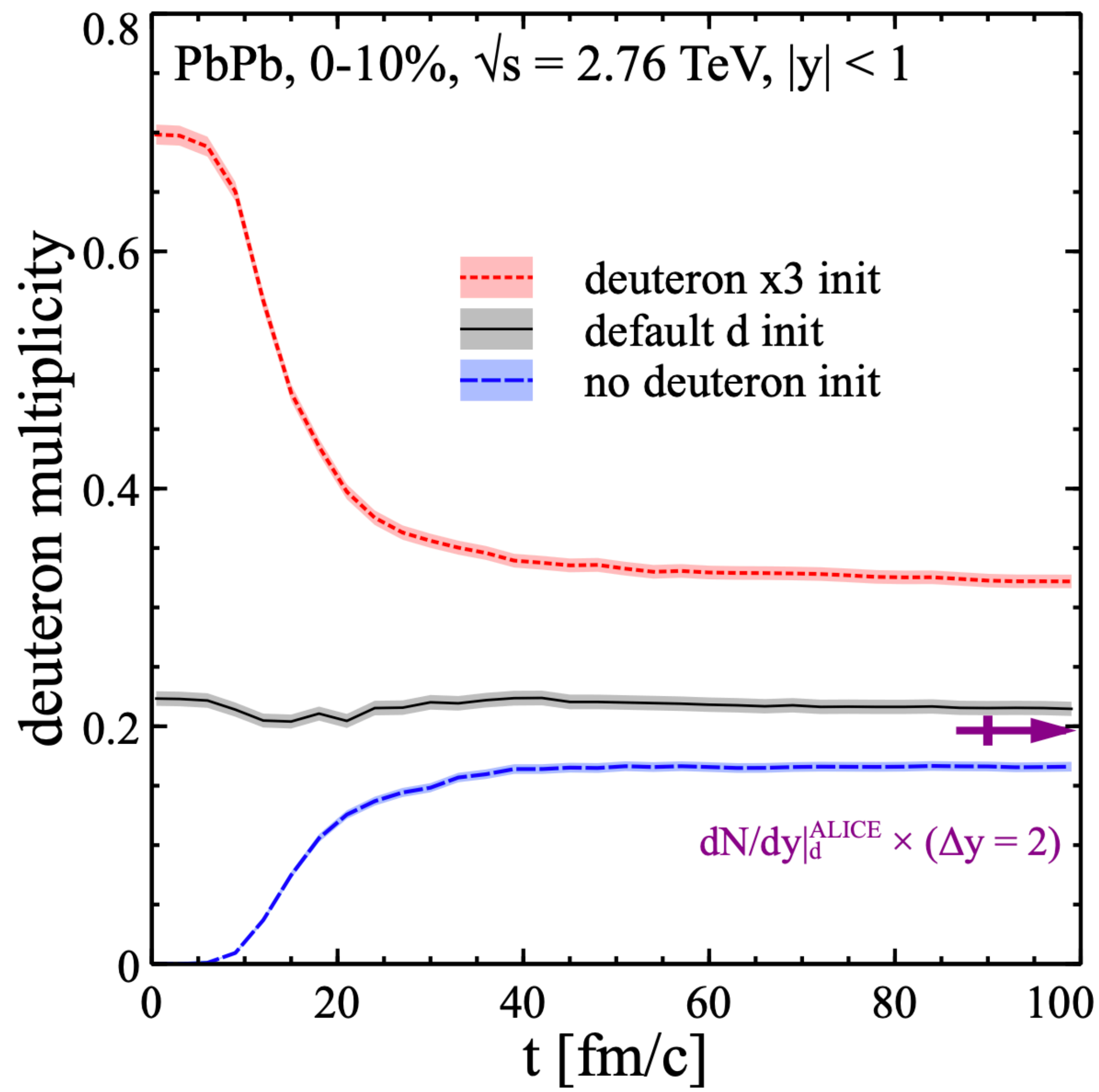
Dynamical model

Dmytro OLIINYCHENKO

DO, Pang, Elfner, Koch, PRC99 (2019) no.4, 044907



DO, Pang, Elfner, Koch, PRC99 (2019) no.4, 044907



Open questions:

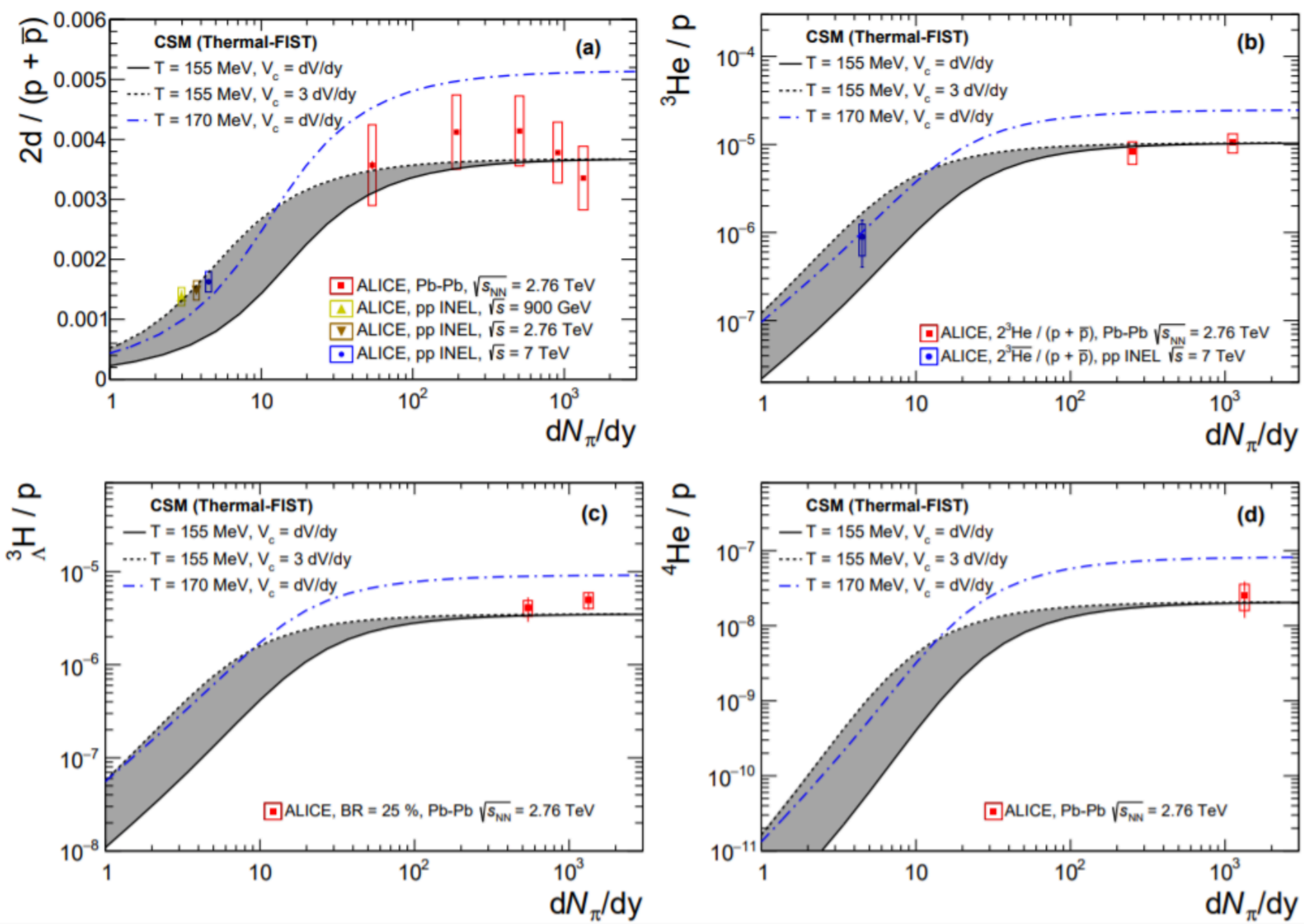
- Formation time of light nuclei
- Lifetime of hadronic phase

Canonical statistical model

Volodymyr VOVCHENKO

$T_{ch} = 155$ MeV, $V_C = 3dV/dy$, multiplicity dependence driven by V_C only

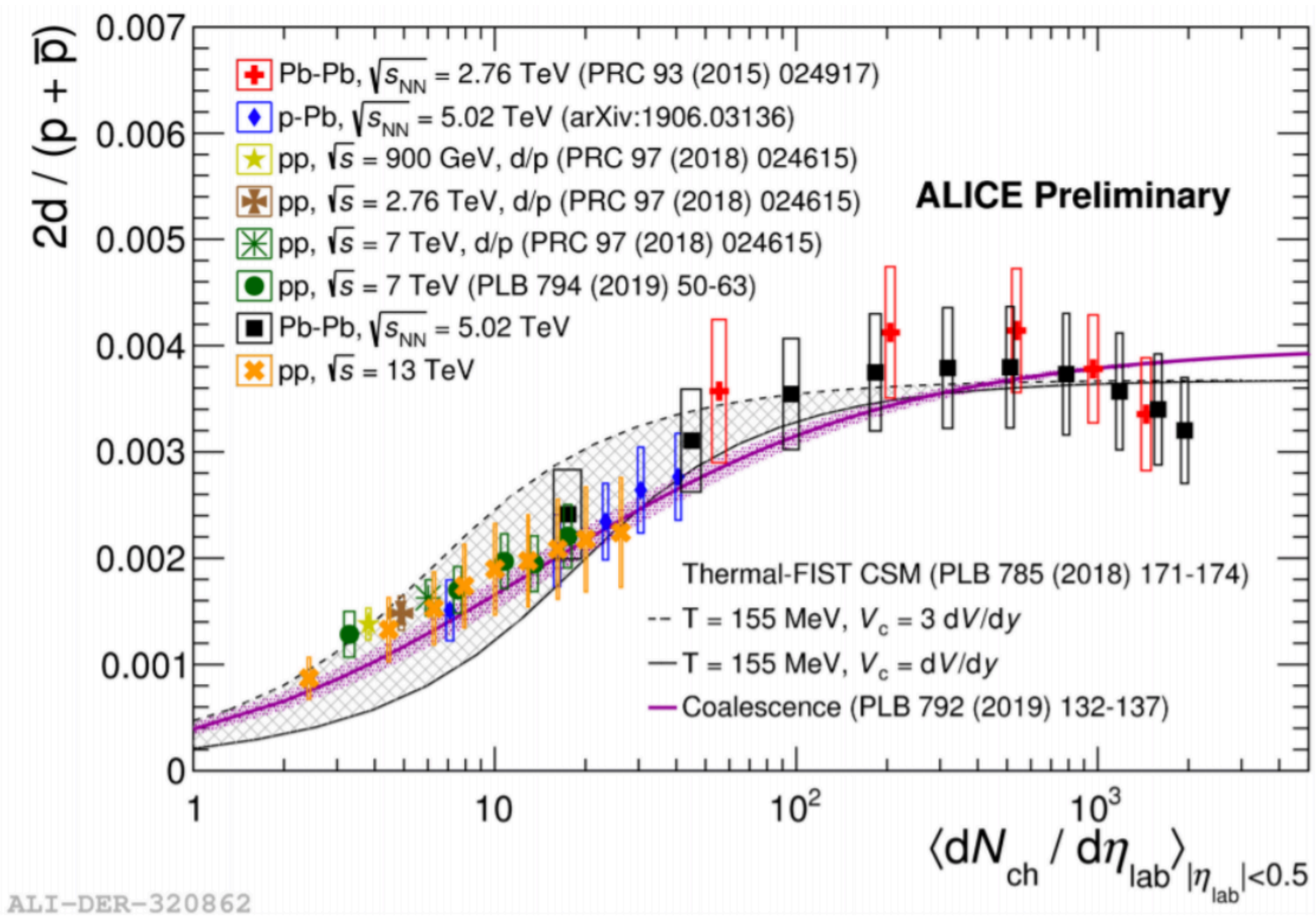
[**V.V.**, Dönigus, Stoecker, 1808.05245, PLB '18]

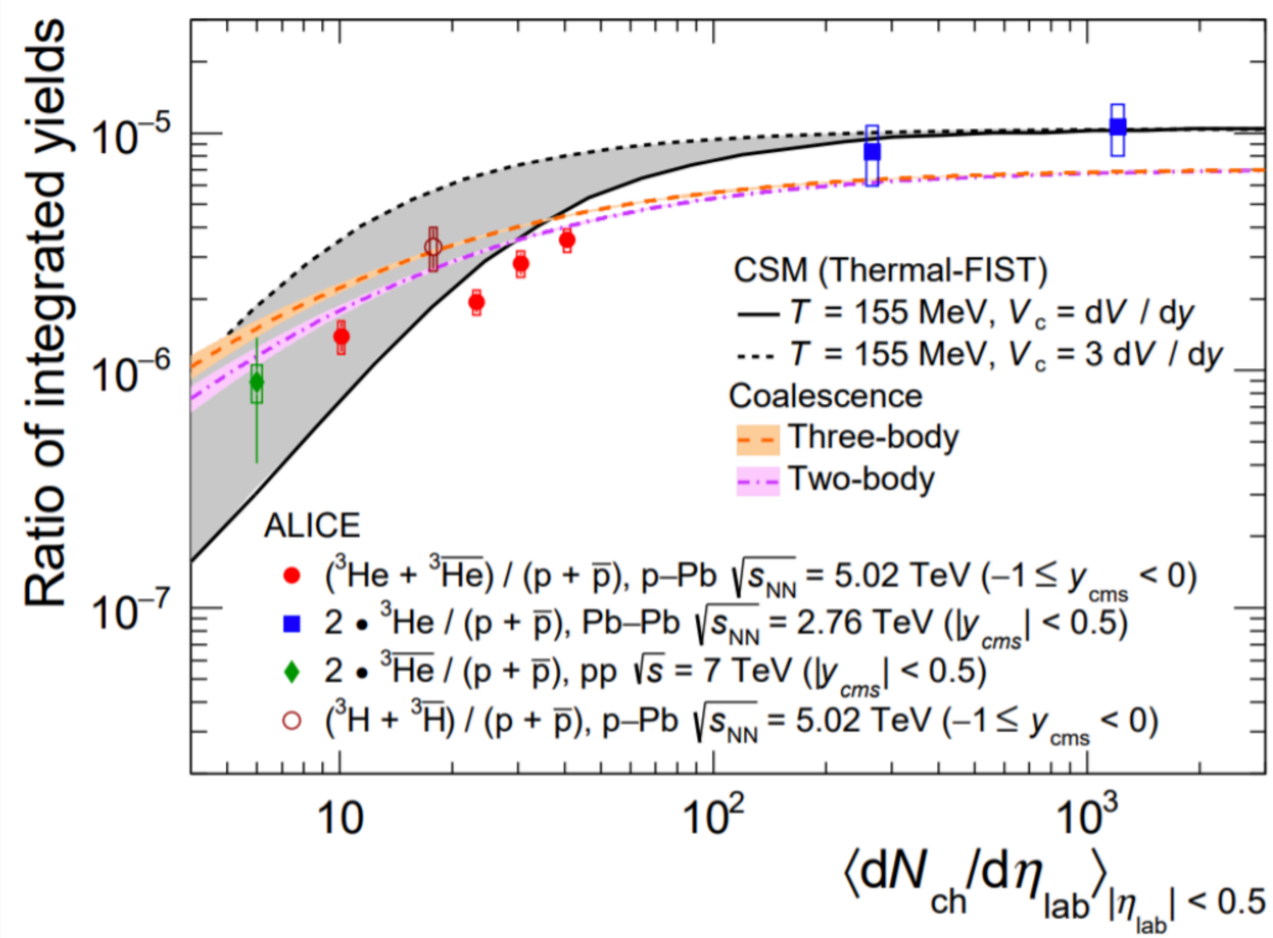


10

Canonical statistical model

Volodymyr VOVCHENKO





[L. Barioglio, QM19] [ALICE collaboration, 1910.14401]

CSM approach works reasonably well for d/p

Some tension is observed for A=3 at intermediate multiplicity

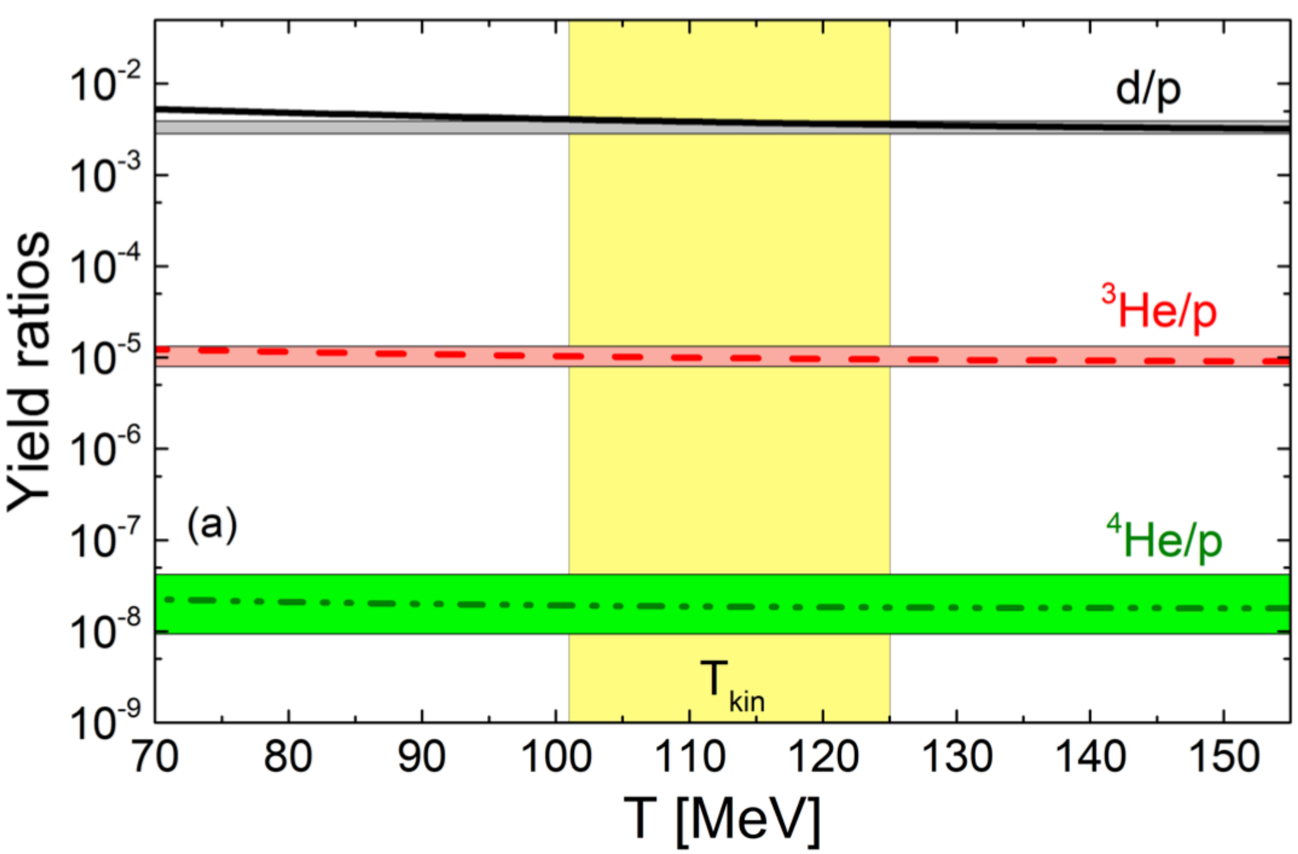
Saha equation

Volodymyr VOVCHENKO

Detailed balance for nuclear reactions, $X + A \leftrightarrow X + \sum_i A_i$, X is e.g. a pion

$$\frac{n_A}{\prod_i n_{A_i}} = \frac{n_A^{\rm eq}}{\prod_i n_{A_i}^{\rm eq}}, \quad \Leftrightarrow \quad \mu_A = \sum_i \mu_{A_i}, \qquad \text{e.g. } \mu_d = \mu_p + \mu_n,\ \mu_{^3\text{He}} = 2\mu_p + \mu_n,\ \dots$$

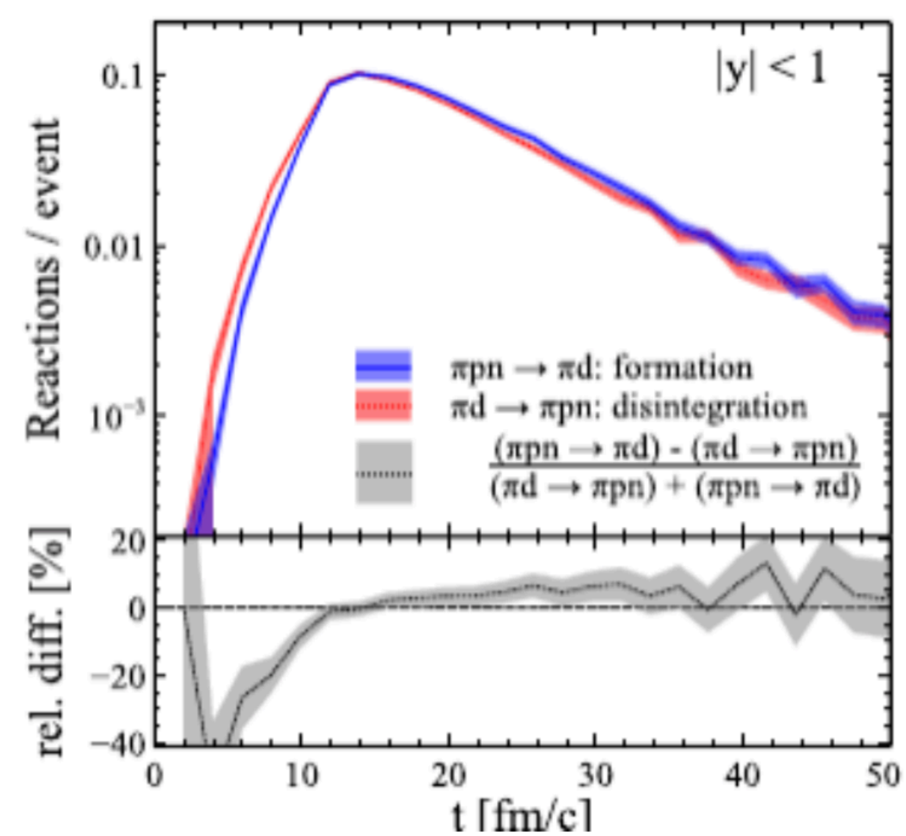
Saha equation



Feed-down contribution calculated:

~5% at LHC energy
Larger contribution at low energy

Transport [Oliinychenko et al., 1809.03071]

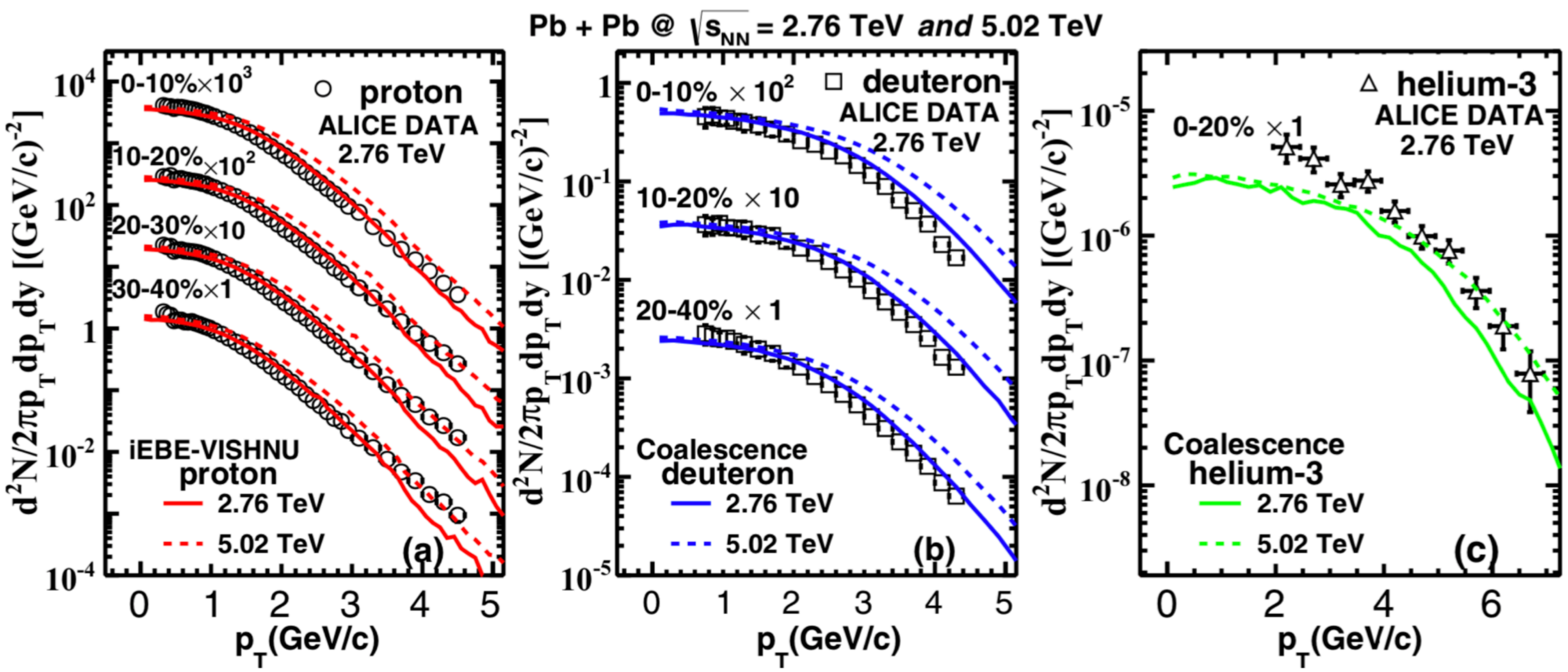


- **Law of mass action at work**

State-of-the-art coalescence

IEBE-VISHNU hybrid model with AMPT initial conditions

Che-Ming KO

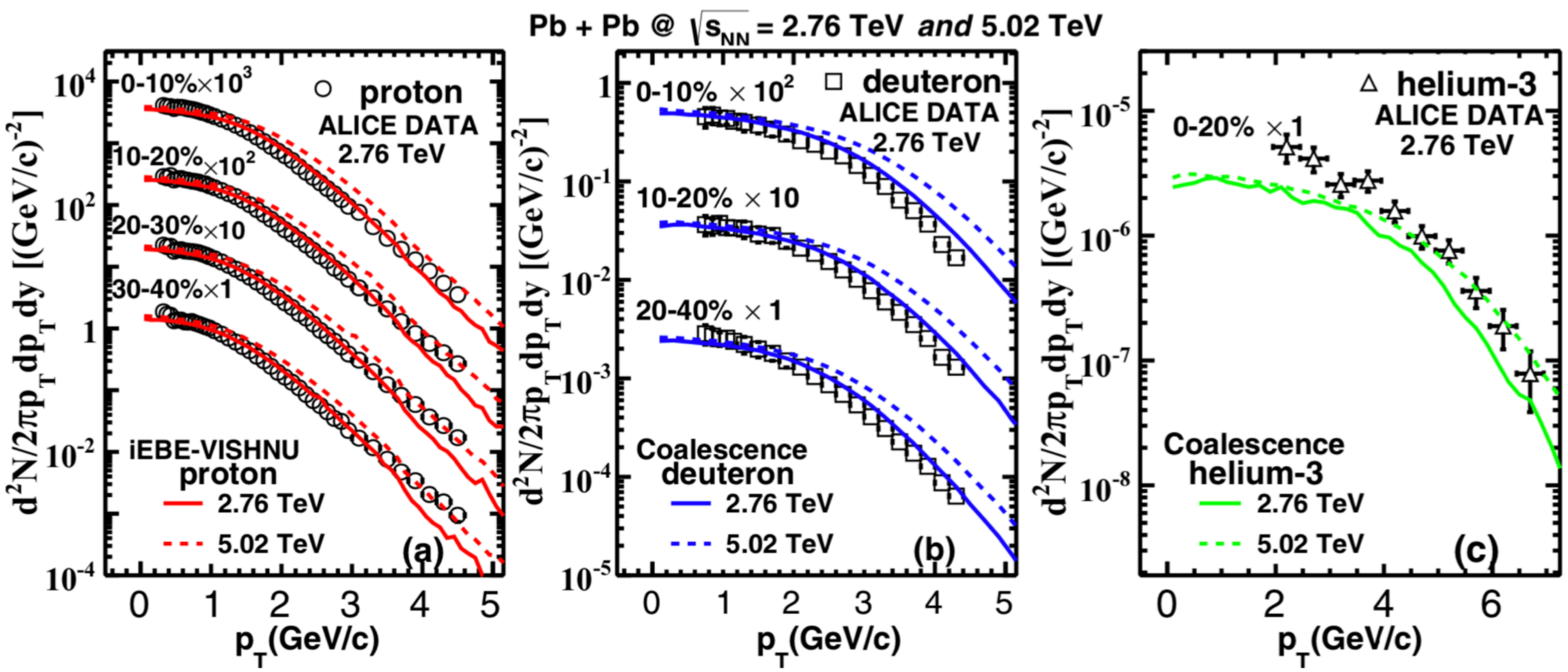


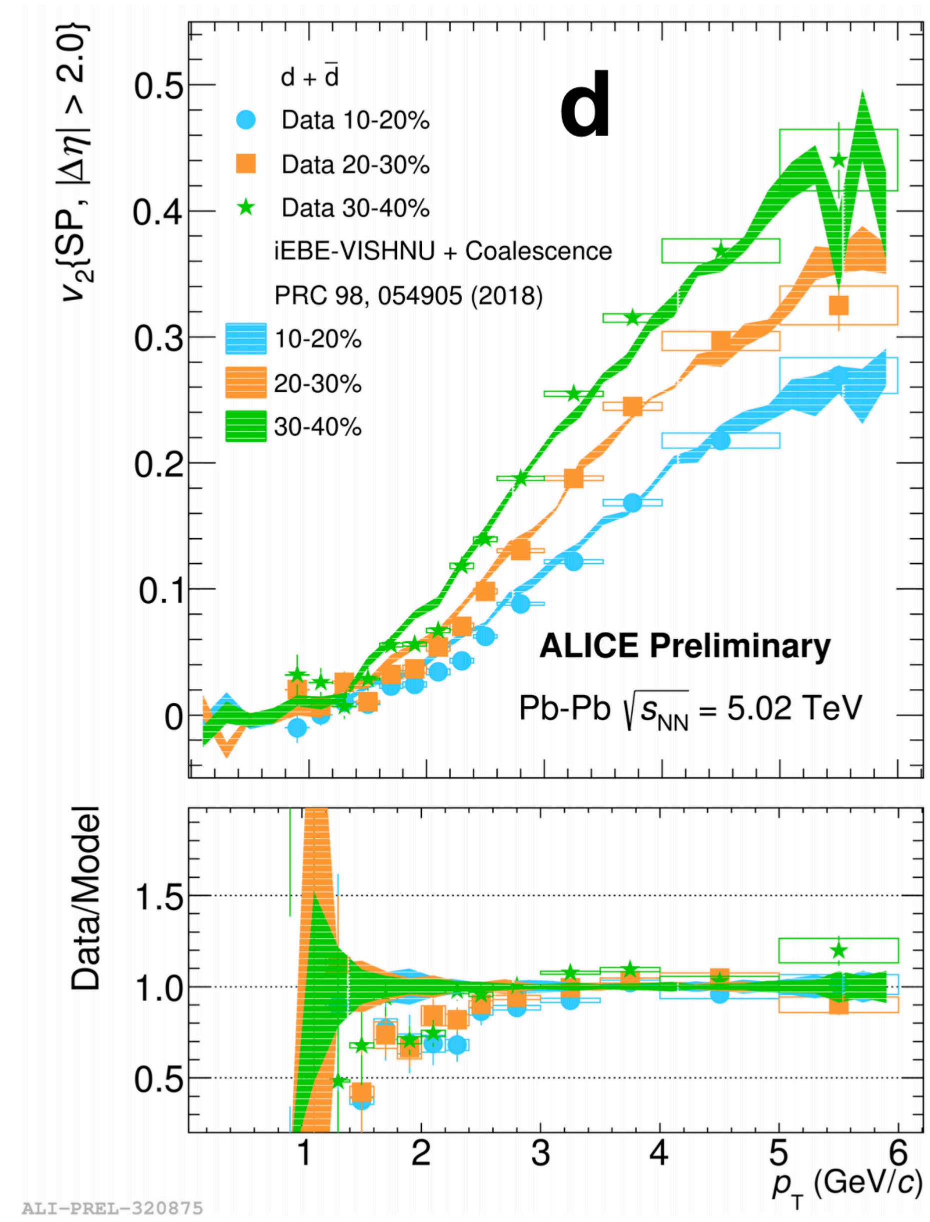
Elliptic flow of deuteron measured by ALICE is also satisfactorily described. [9]

State-of-the-art coalescence

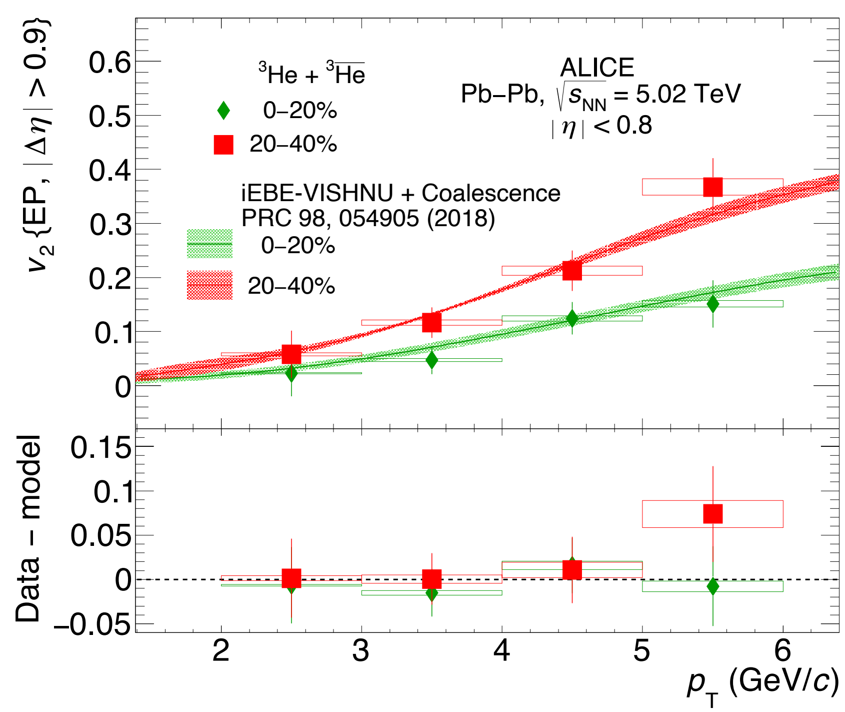
IEBE-VISHNU hybrid model with AMPT initial conditions

Che-Ming KO





Elliptic flow of deuteron measured by ALICE is also satisfactorily described. [9]



Flow of 3He well described

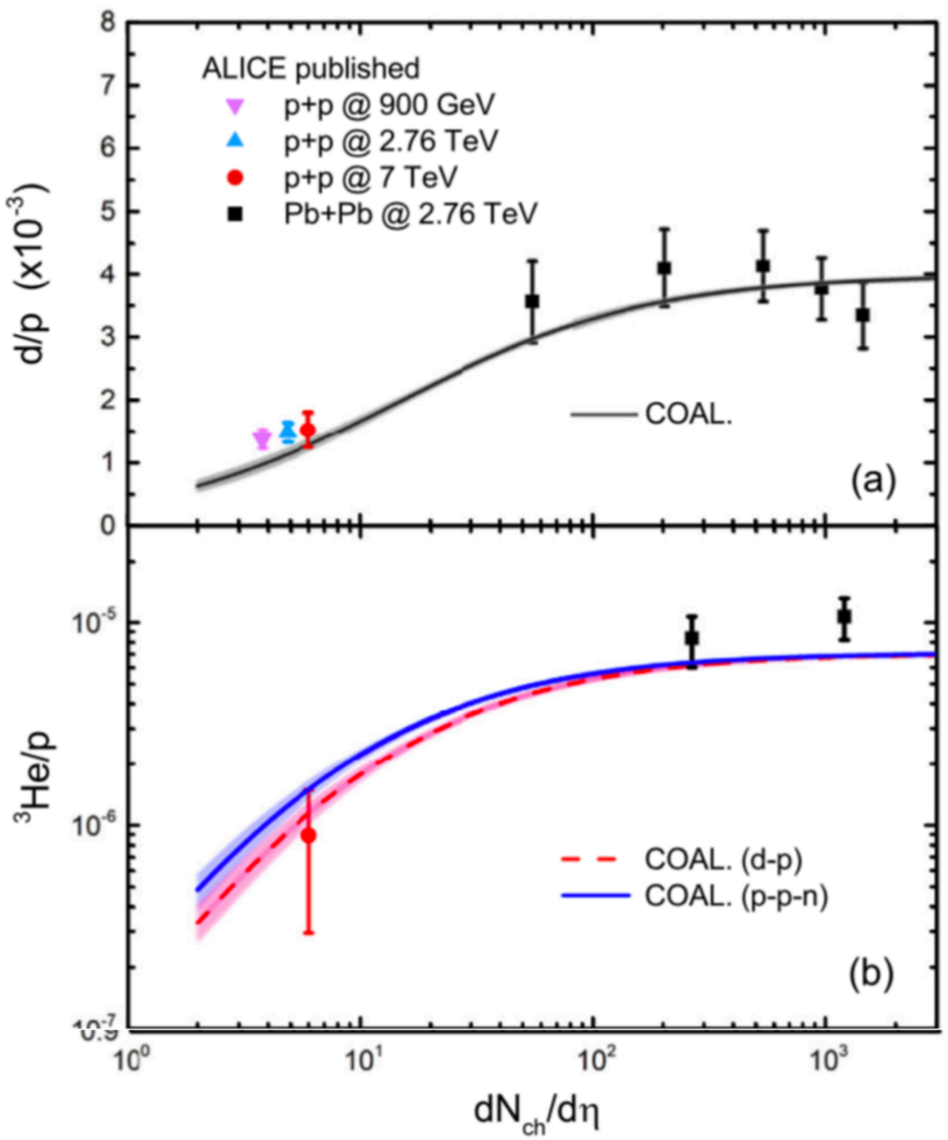
Tension at low p_T for d

System-size evolution

System size dependence of light nuclei yield

Che-Ming KO

Sun, Ko & Doenigus, PLB 792, 132 (2019)

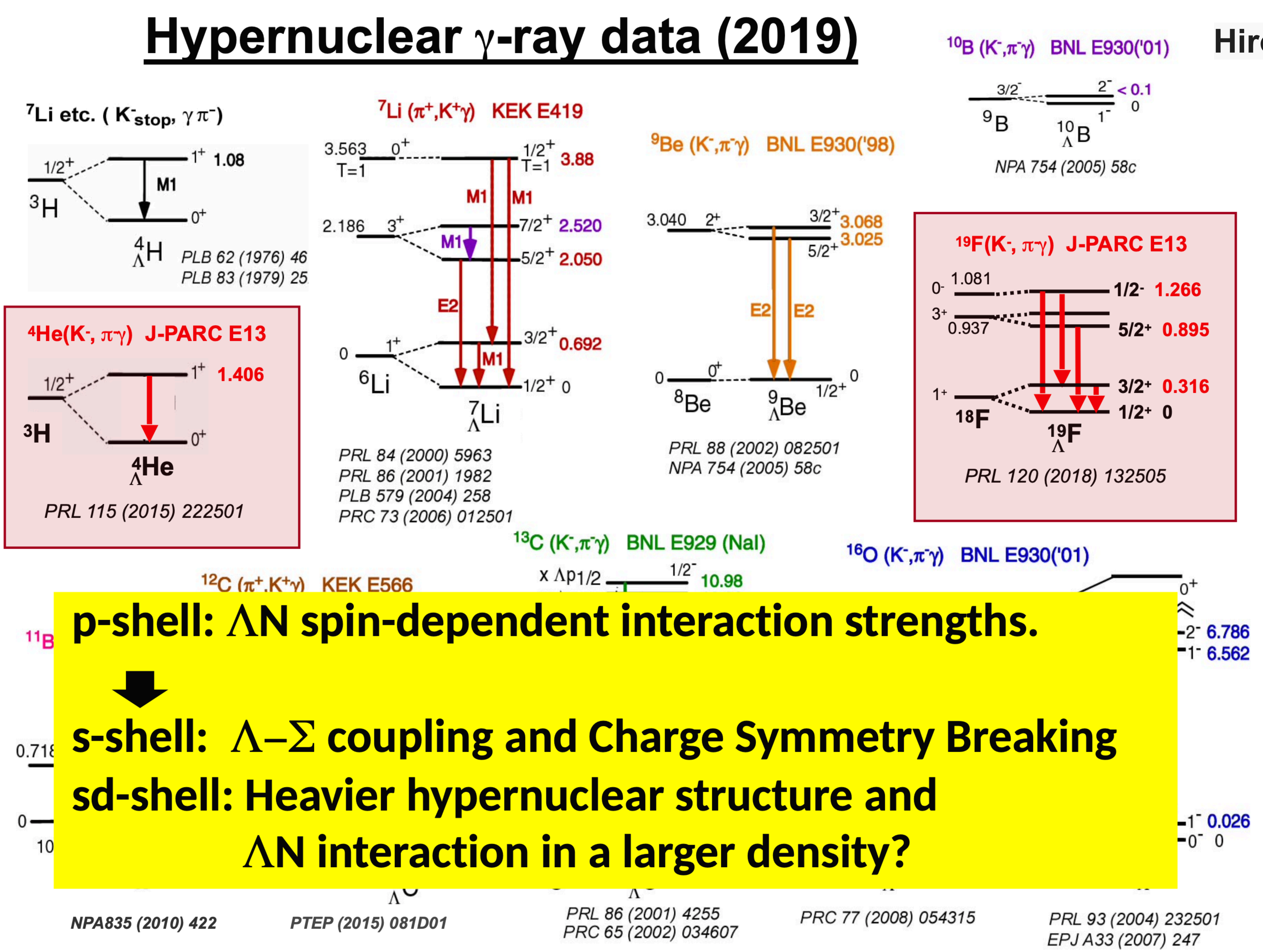


$$\frac{N_d}{N_p} \approx \frac{3N_n}{4(mT_K R^2)^{3/2}} \frac{1}{1+\frac{2r_d^2}{3R^2}}$$

$$\frac{N_{^3He}}{N_p} \approx \frac{N_n N_p}{4(mT_K R^2)^{3/2}} \frac{1}{1+\frac{r_{^3He}^2}{2R^2}}$$

- Coalescence model gives a natural explanation for the suppressed production of light nuclei in small collision systems.
- Thermal model requires an unrealistically large canonical correlation volume for charge conservation. [Vovchenko, Doenigus & Stoecker, PLB 785, 171 (2018)]

Gamma-ray spectroscopy



p-shell: ΛN spin-dependent interaction strengths.

⬇

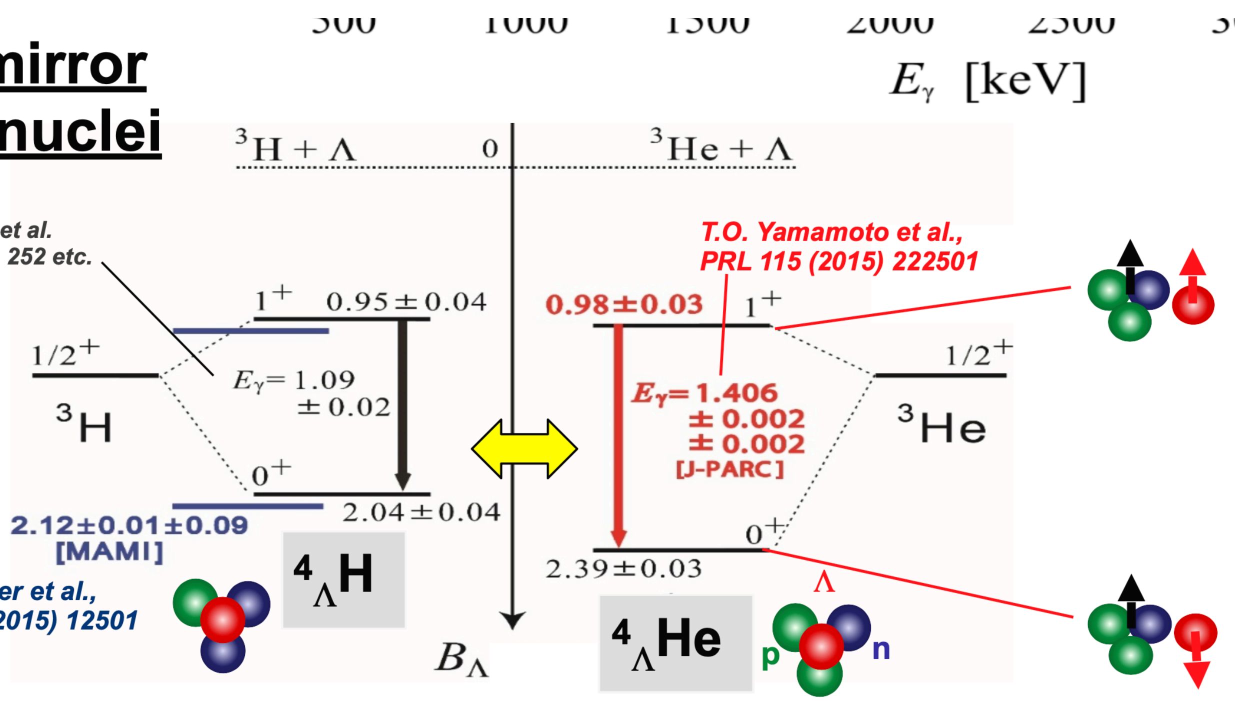
s-shell: Λ–Σ coupling and Charge Symmetry Breaking

sd-shell: Heavier hypernuclear structure and ΛN interaction in a larger density?

CSB and ΛΛ and Ξ hyper-nuclei events

Hirokazu TAMURA

A=4 mirror hypernuclei

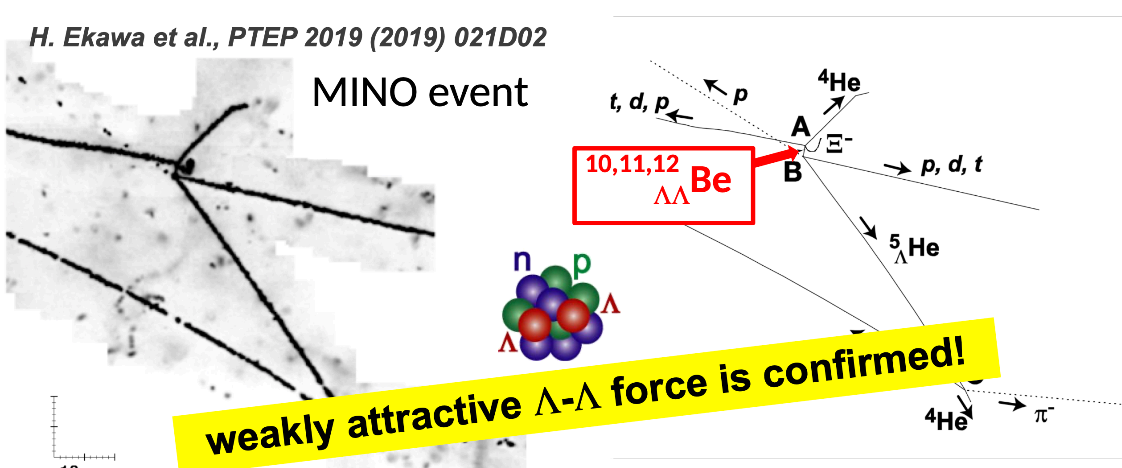


A large Charge Symmetry Breaking effect is confirmed!

A new ΛΛ hypernuclear event

~30 events of ΛΛ / Ξ hypernuclei have been observed at present.

H. Ekawa et al., PTEP 2019 (2019) 021D02



$^{11}_{\Lambda\Lambda}$Be is most probable

$\Xi^- + {}^{16}O \to {}^{17}_{\Xi}N \to {}^{11}_{\Lambda\Lambda}Be + {}^4He + d$

$\to {}^5_\Lambda He + d + p$

$\to {}^4He + p + \pi^-$

$\Delta B_{\Lambda\Lambda}$= 1.87±0.37 MeV

Slightly different from $\Delta B_{\Lambda\Lambda}$= 0.67±0.17 MeV for $^6_{\Lambda\Lambda}$He

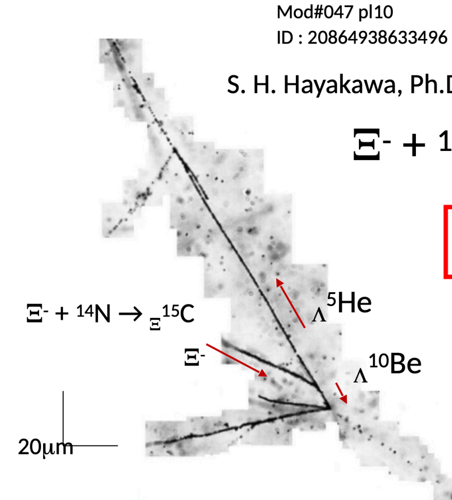
=> Binding effect? ΛΛ-ΞN effect?

A new Ξ hypernuclear event

IBUKI event

Mod#047 pl10
ID : 20864938633496

S. H. Hayakawa, Ph.D. Thesis, Osaka Univ. (2019), to be published



$\Xi^- + {}^{14}N \to {}_{\Xi}{}^{15}C \to {}_{\Lambda}{}^{10}Be + {}_{\Lambda}{}^{5}He$

B_{Ξ^-} = 1.27 ± 0.21 MeV

The same reaction as KISO

KISO

B_{Ξ^-} = 4.38 ± 0.25 MeV,

or 1.11 ± 0.25 MeV

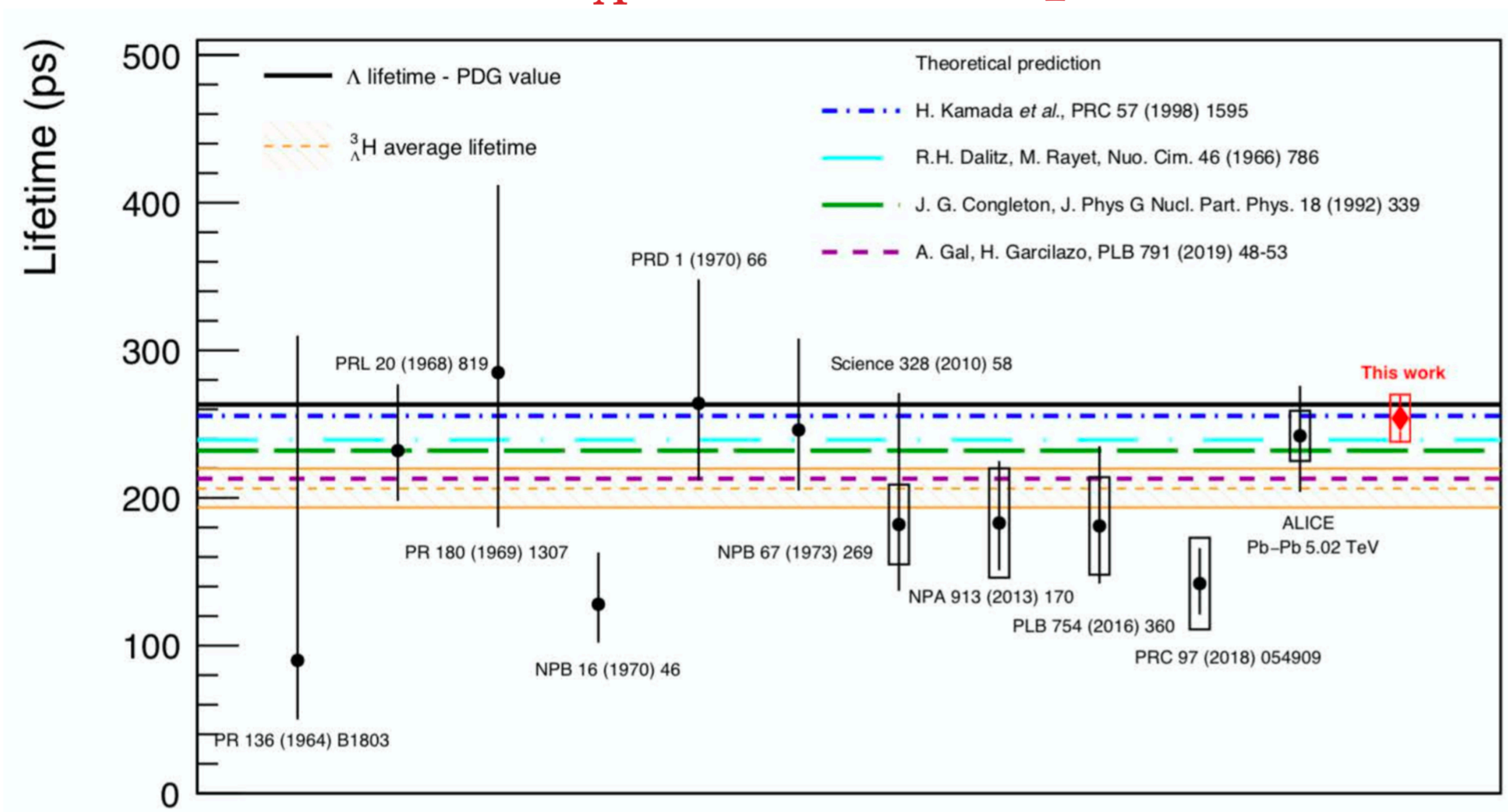
This interpretation seems correct.

-> Suggesting that this state has a rather narrow width < 1 MeV

Hypertriton lifetime puzzle

Avraham GAL

Is there a ${}^{3}_{\Lambda}$H lifetime puzzle?



E. Bartsch for ALICE at Quark Matter 2019

Wuhan, China, Nov. 2019

Pion final-state interactions need to be taken into account into the calculation

pion-3He interaction is found attractive (from pionic atoms & scattering data)

Smaller lifetime compared to free lambda