ALICE

# LIGHT (ANTI-)NUCLEI AND (ANTI-)HYPERNUCLEI PRODUCTION WITH ALICE AT THE LHC

Stefano Piano on behalf of ALICE Collaboration
INFN sez. Trieste

INFN
Istituto Nazionale di Fisica Nucleare

# MOTIVATION

- **(anti-)(hyper)nuclei are good probes of coalescence mechanism**
- **(anti-)(hyper)nuclei yields are sensitive to the freeze-out temperature in heavy-ion collision** due to their large mass (e.g. in the Thermal Model yield scales roughly $\propto e^{(-M/T_{chem})}$)
- light (anti-)(hyper)nuclei have small binding energy and small Λ separation energy,

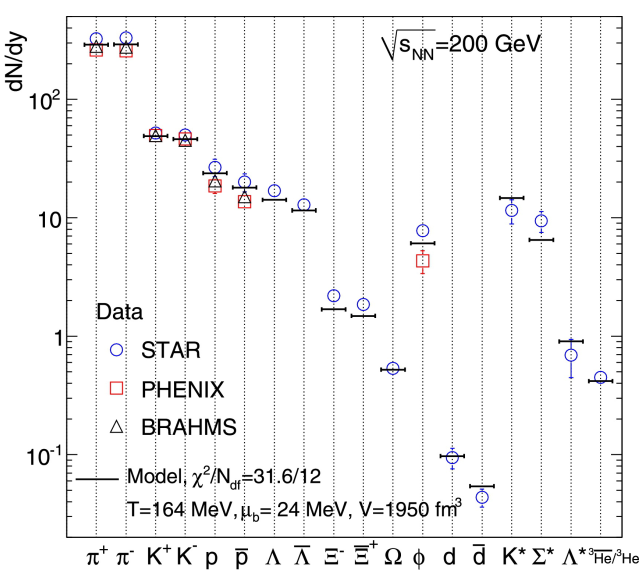
  e.g. $B_{\Lambda}(^{3}_{\Lambda}H) = 0.13 \pm 0.05$ MeV [H. Bando et al., Int. J. Mod. Phys. A 5 4021 (1990)] :
  - **they should dissociate in a medium with high $T_{chem}$** (~156 MeV) and be suppressed
  - if their yields equal to thermal model prediction ⇒ sign for **adiabatic (isentropic) expansion** in the hadronic phase
- A=3 (anti-)($^{3}$He, t, $^{3}_{\Lambda}$H), a simple system of 9 valence quarks:
  - $^{3}_{\Lambda}$H / $^{3}$He and $^{3}_{\Lambda}$H / t (and anti) ⇒ Λ-nucleon correlation (**local baryon-strangeness correlation**)
  - t / $^{3}$He (and anti) ⇒ **local charge-baryon correlation**
- Anti-nuclei in nature:
  - **matter–antimatter asymmetry**

    [J.Adam et al. (ALICE Collaboration), Nature Phys. 11, no.10, 811 (2015) ]
  - light nuclei measurements in high energy physics can be used in dark matter searches to estimate the background coming from the secondary anti-nuclei [K. Blum, Phys. Rev. D 96 (2017) 103021]

# (ANTI-)(HYPER)NUCLEI PRODUCTION IN URHIC

## Statistical Thermal model

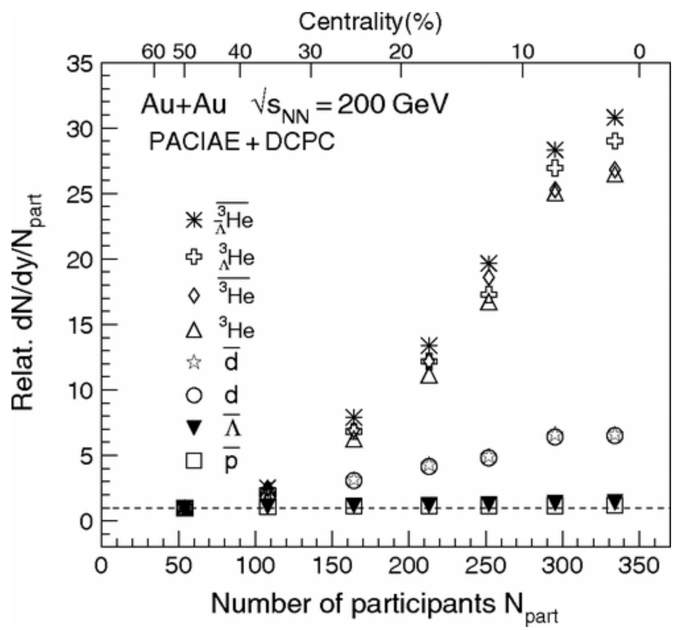
- Thermodynamic approach to particle production in heavy-ion collisions
- Abundances fixed at chemical freeze-out ($T_{chem}$) (hyper)nuclei are very sensitive to $T_{chem}$ because of their large mass ($M$)
- Exponential dependence of the yield $\propto e^{(-M/T_{chem})}$




A. Andronic et al., Phys. Lett. B 697, 203 (2011)

## Coalescence

- If baryons at freeze-out are close enough in Phase Space an (anti-)(hyper)nucleus can be formed
- (Hyper)nuclei are formed by protons ($\Lambda$) and neutrons which have similar velocities after the freeze-out




G. Chen et al., Phys. Rev. C 88, 034908 (2013)

# (ANTI-)(HYPER)NUCLEI PRODUCTION AT LHC

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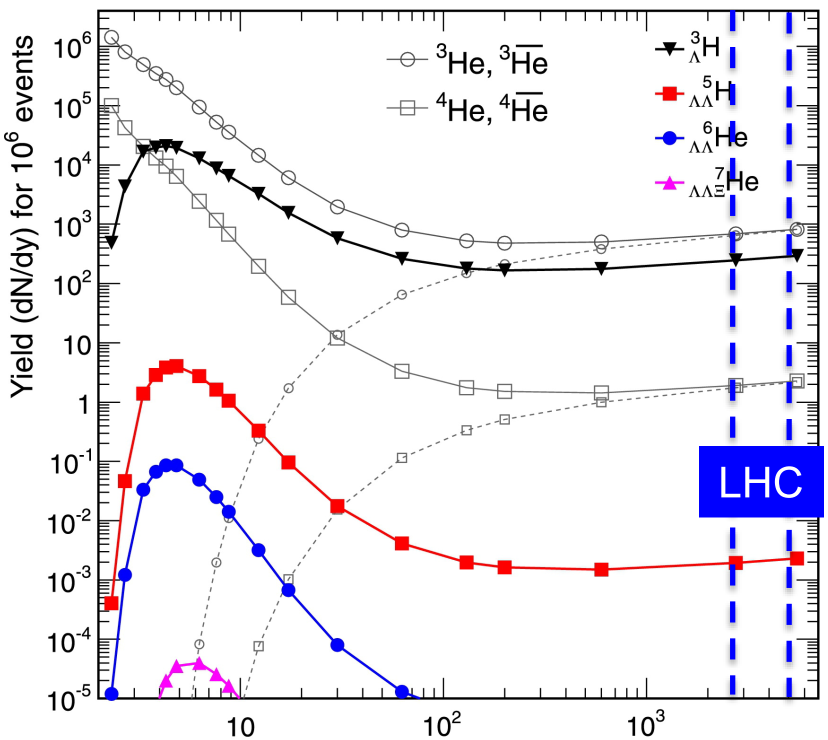
Production yield estimate of (anti-)(hyper)nuclei in central heavy-ion collisions at LHC energy based on thermal model:

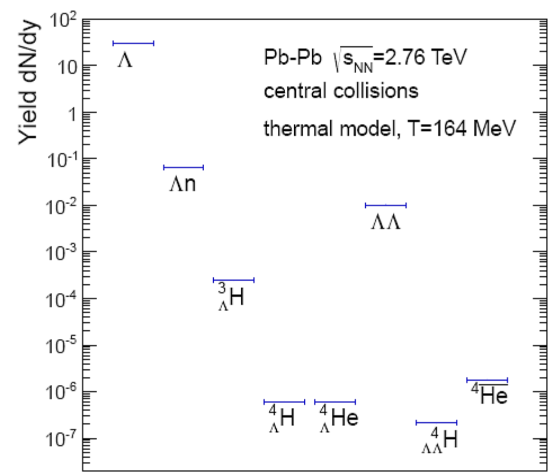



A. Andronic et al., Phys. Lett. B 697, 203 (2011) $\sqrt{s_{NN}}$ (GeV)

A. Andronic et al., Phys. Lett. B 697, 203 (2011)

| | Yield/event at mid-rapidity and central collisions |
|---|---|
| π | ~800 |
| p | ~40 |
| Λ | ~30 |
| d | ~0.17 |
| $^3$He | ~0.01 |
| $^3_\Lambda$H | ~0.003 |

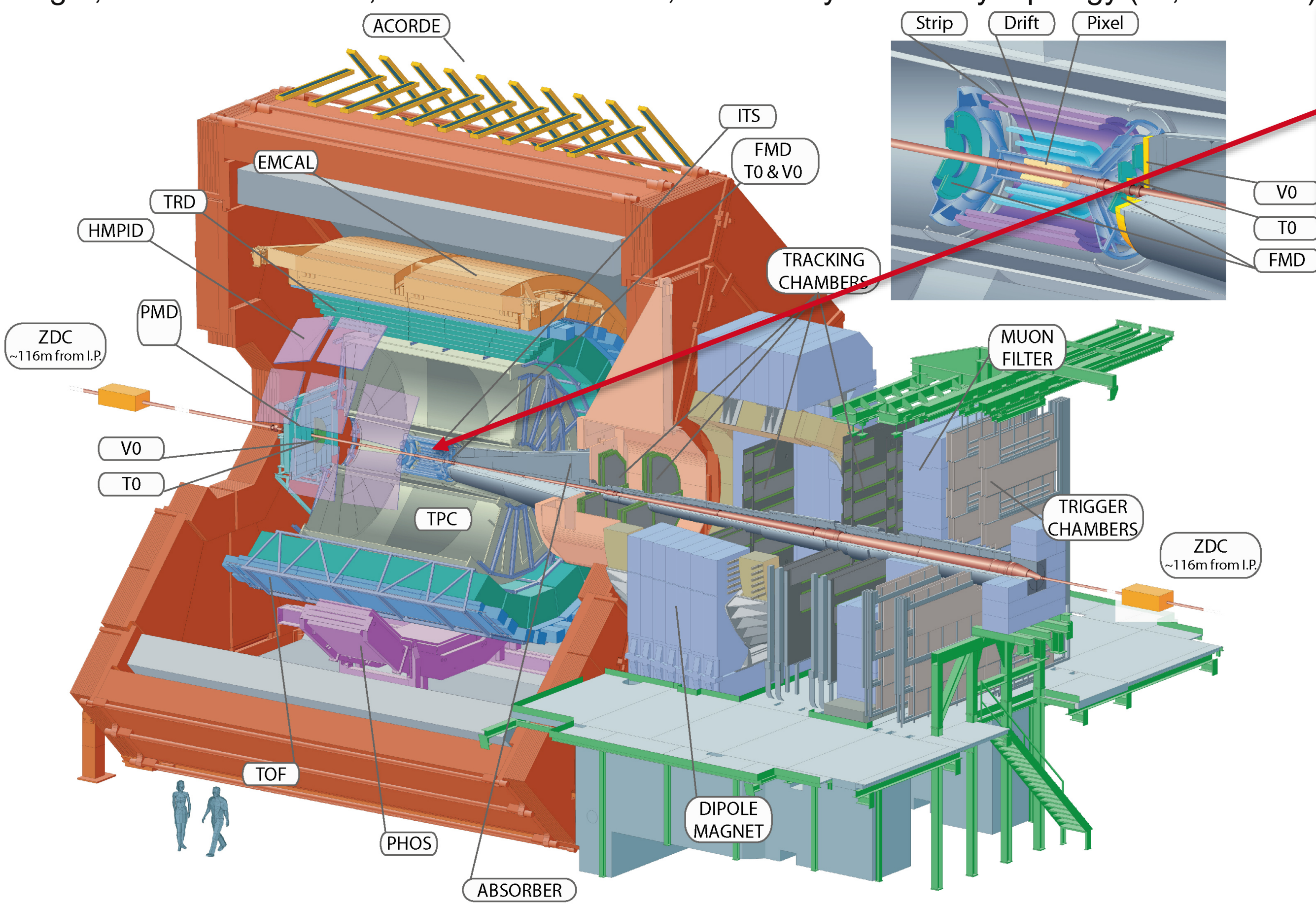
- ✓ Light nuclei
- ✓ Hypertriton
- ✓ Search for: Λn, ΛΛ dibaryons




A. Andronic, private communication

# A LARGE ION COLLIDER EXPERIMENT

ALICE particle identification capabilities are unique. Almost all known techniques are exploited: d$E$/dx, time-of-flight, transition radiation, Cherenkov radiation, calorimetry and decay topology ($V^0$, cascade)




**ITS:** precise separation of primary particles and those from weak decays (hyper-nuclei) or knock-out from material

K. Aamodt et al. (ALICE Collaboration), JINST 3 (2008) S08002
B. B. Abelev et al. (ALICE Collaboration), Int. J. Mod. Phys. A 29 (2014) 1430044

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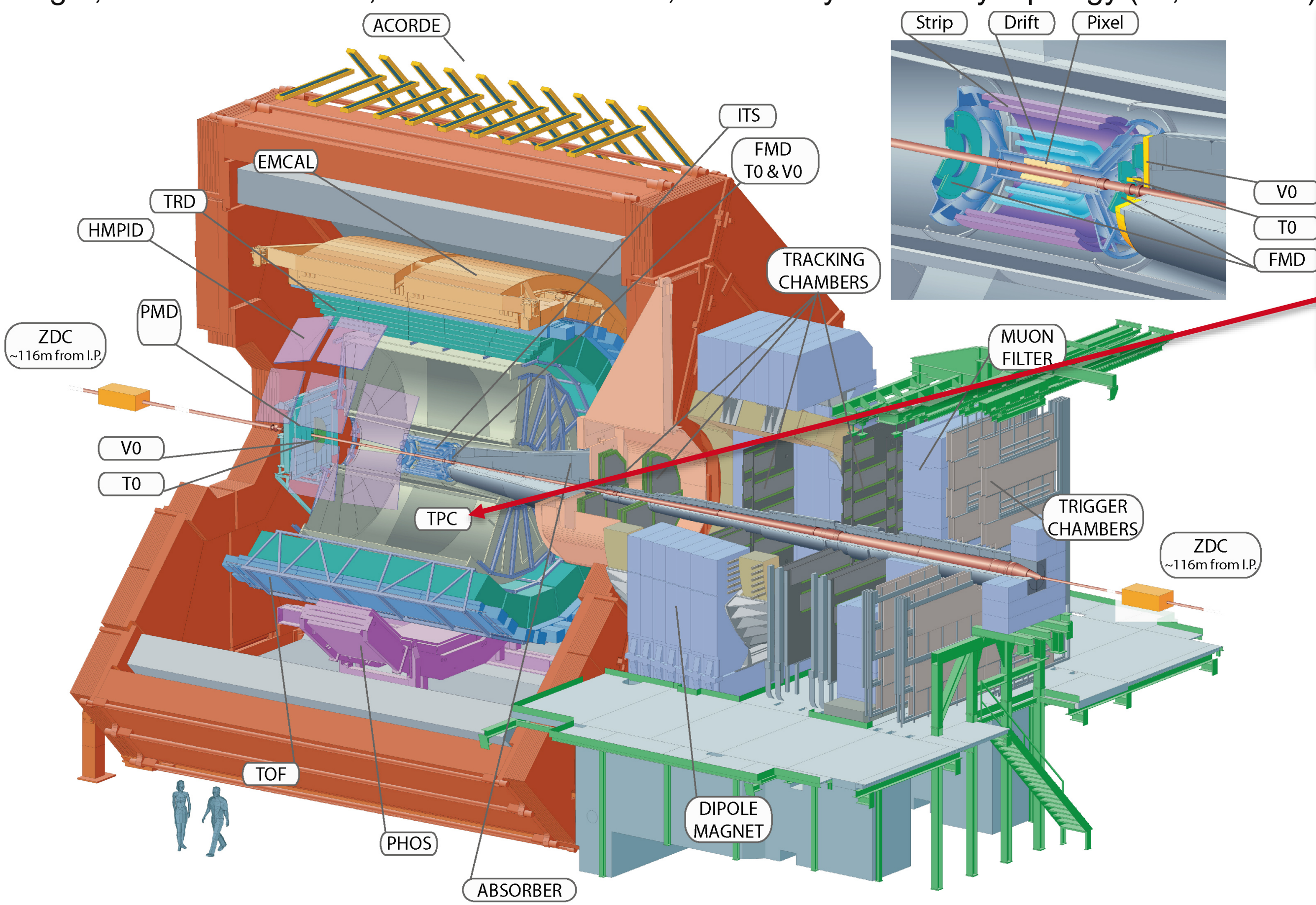


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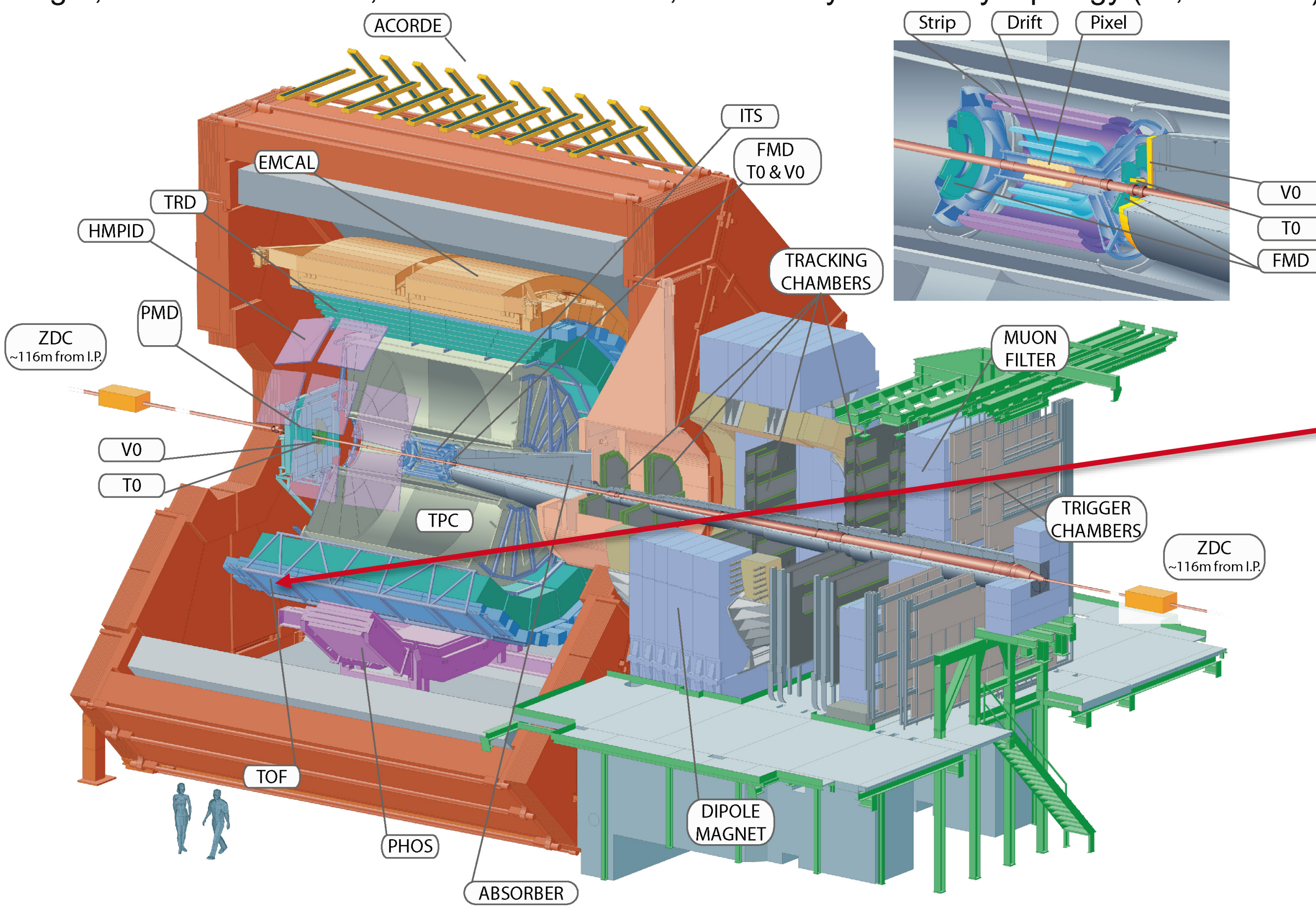


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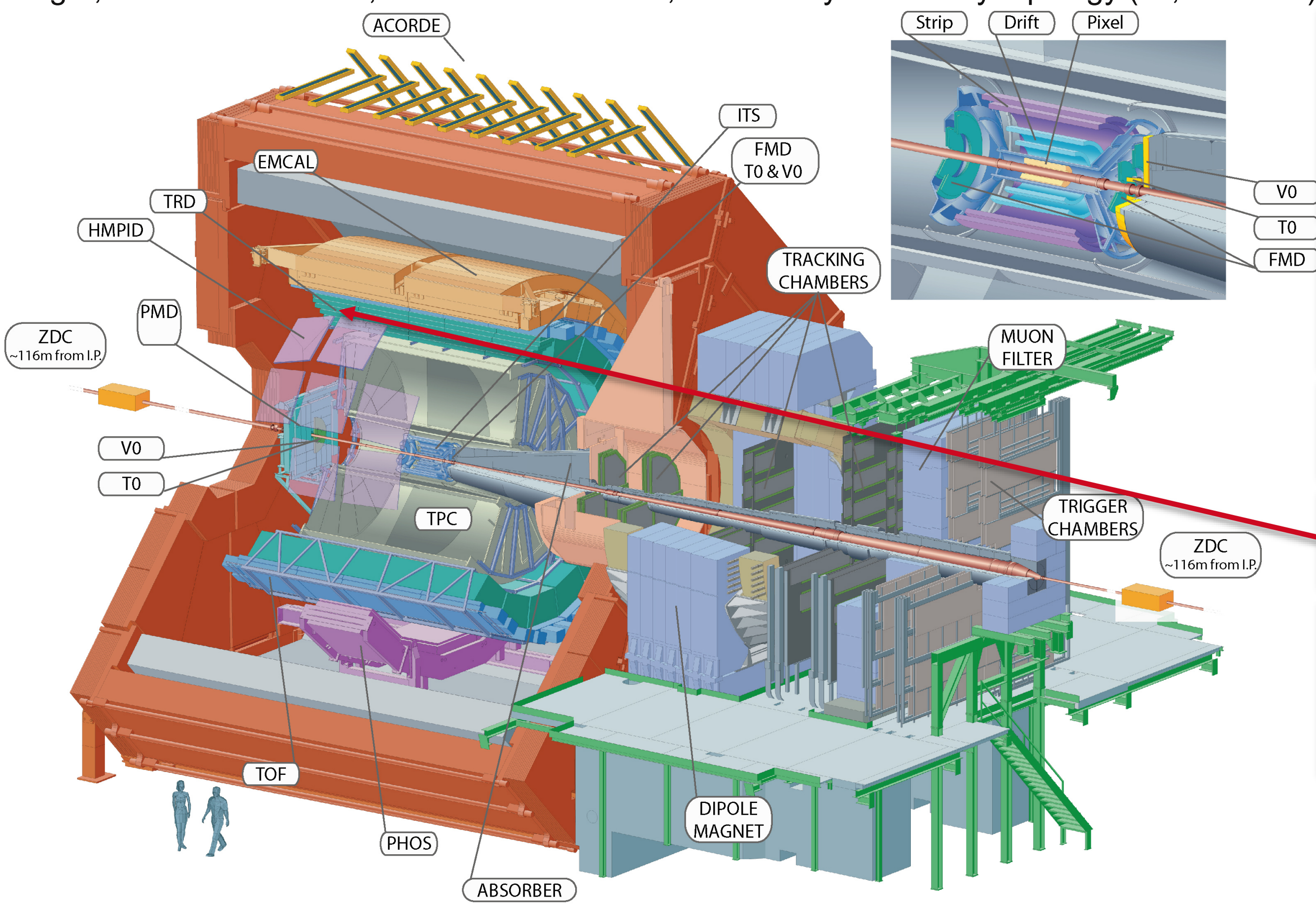


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**ITS+TPC+TRD:** excellent track reconstruction capabilities in a high track density environment

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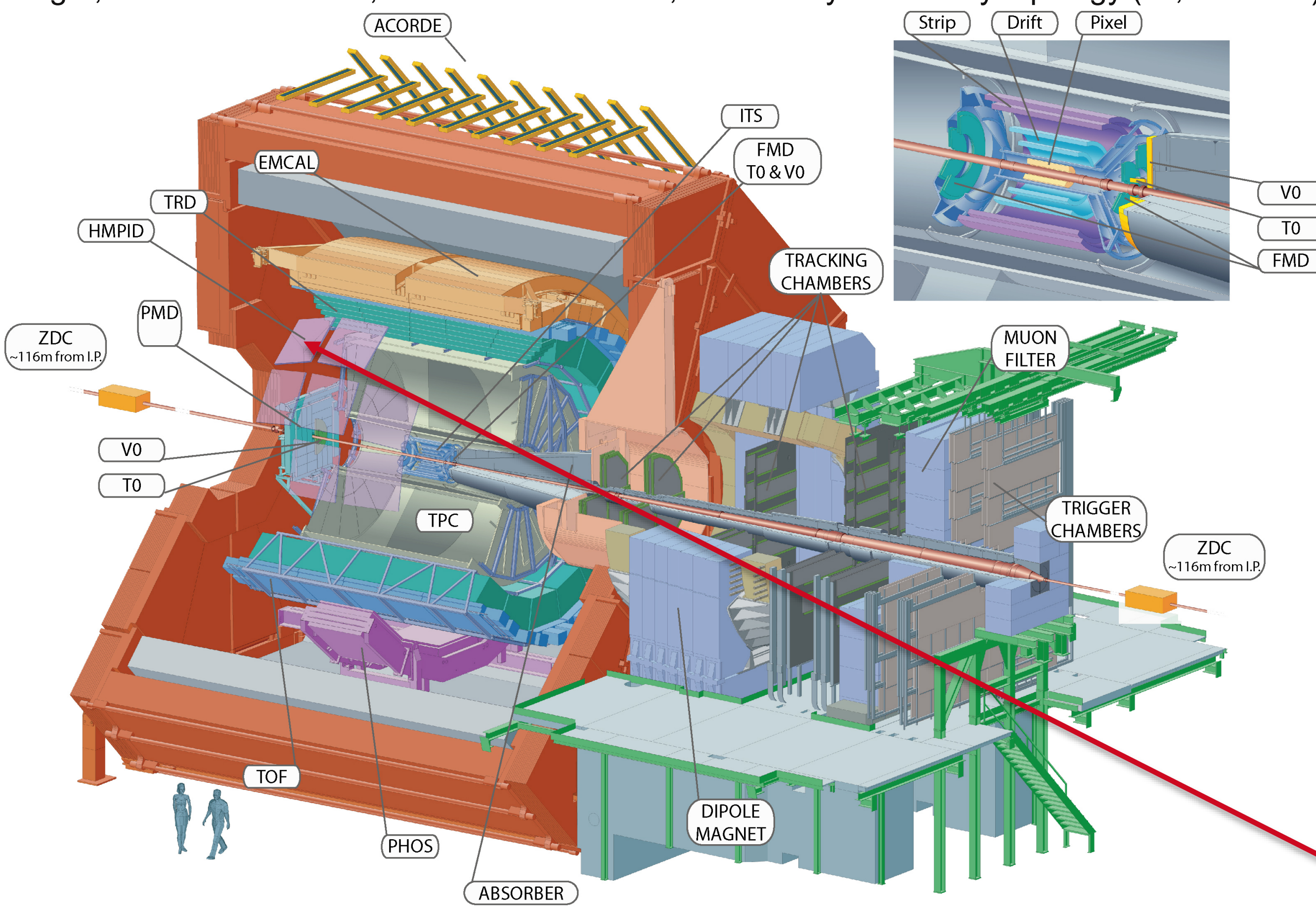


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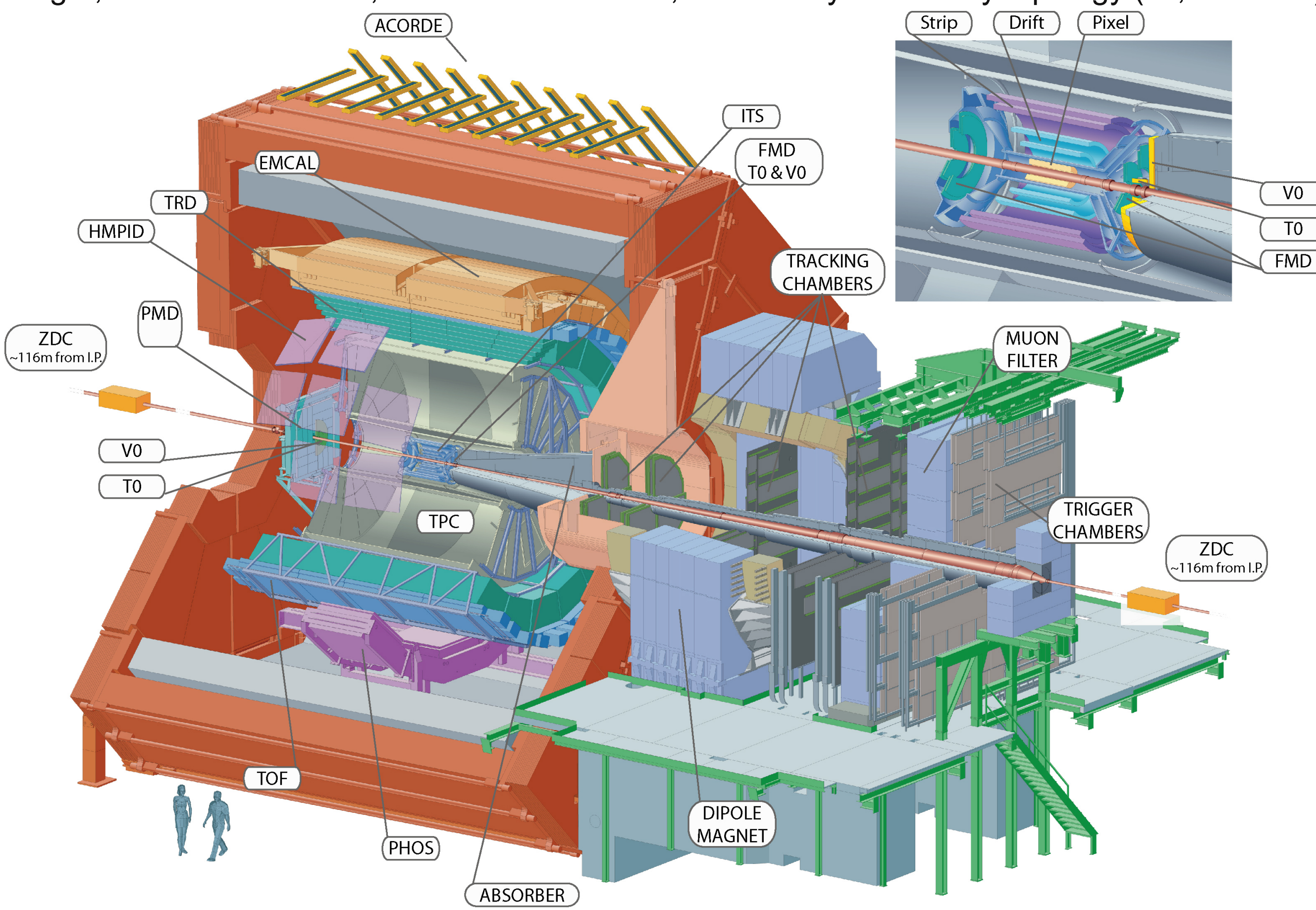


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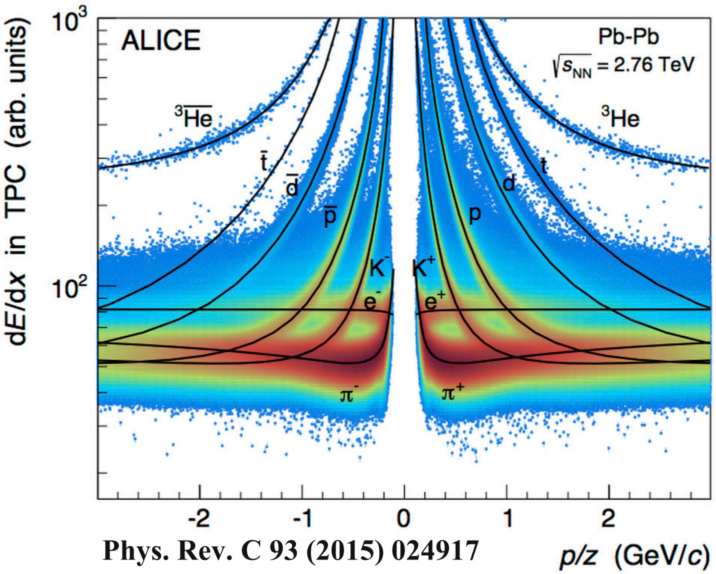
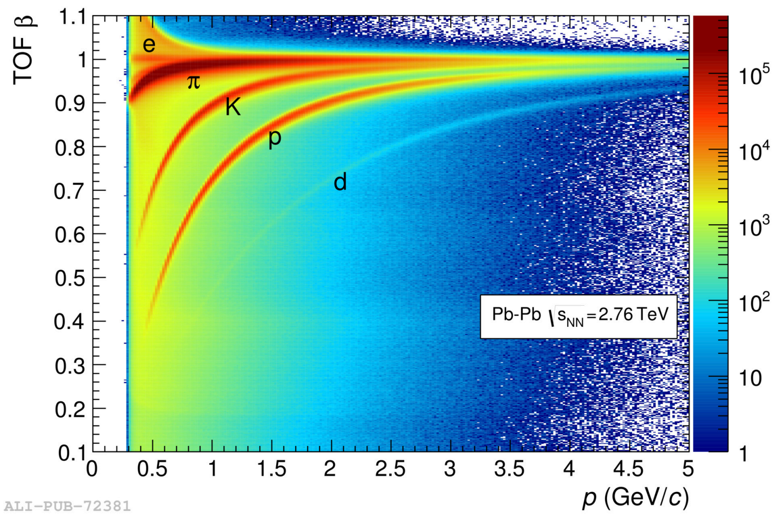
ALICE is ideally suited for the identification of light (anti-)(hyper)nuclei

# NUCLEI IDENTIFICATION




## Low momenta

Nuclei identification via d*E*/d*x* measurement in the TPC:

- d*E*/d*x* resolution in central Pb-Pb collisions: ~6.5%
- Excellent separation of (anti-)nuclei from other particles over a wide momentum range
- About **10 anti-alpha candidates** identified out of 23x$10^6$ events by combining TPC and TOF particle identification

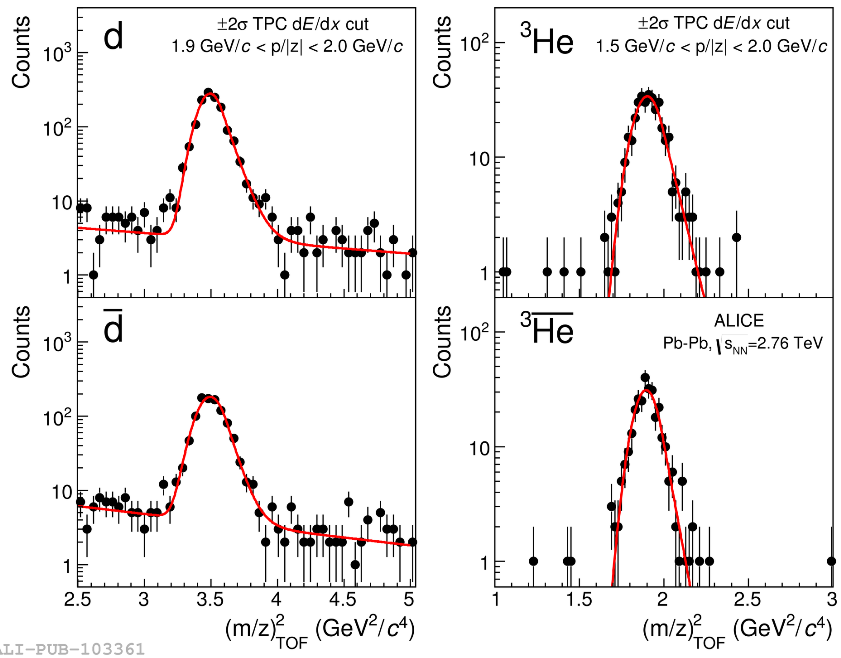
## Higher momenta

Excellent TOF performance:

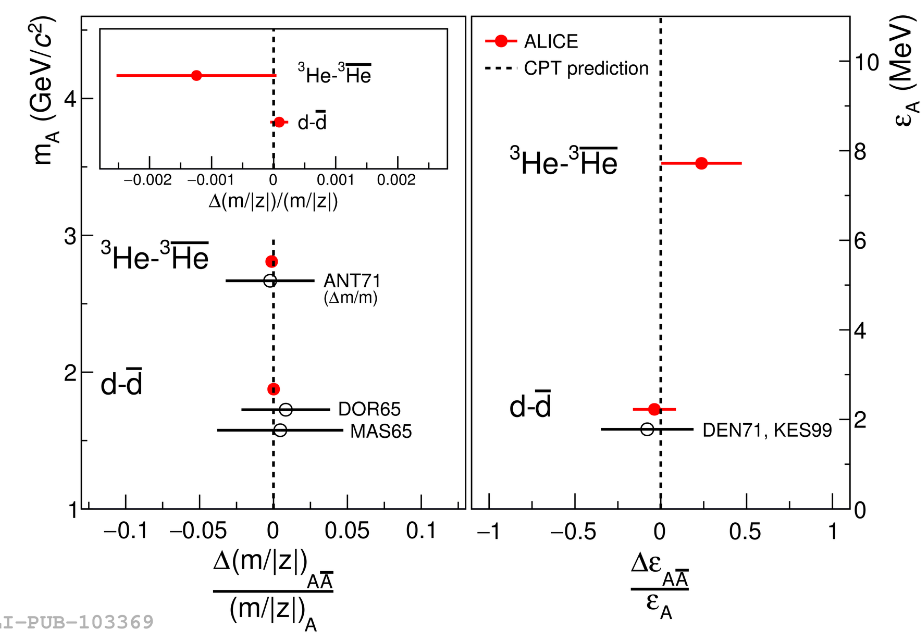
- $\sigma_{TOF}$ ≈ 85 ps in Pb-Pb collisions allows identification of light nuclei over a wide momentum range
- Velocity measurement with the TOF detector is used to evaluate the $m^2$ distribution and to subtract background from the signal in each $p_T$-bin by fitting the $m^2$ distribution

# PRECISE MASS MEASUREMENT

ALICE Collaboration, Nature Phys. 11, 811 (2015)



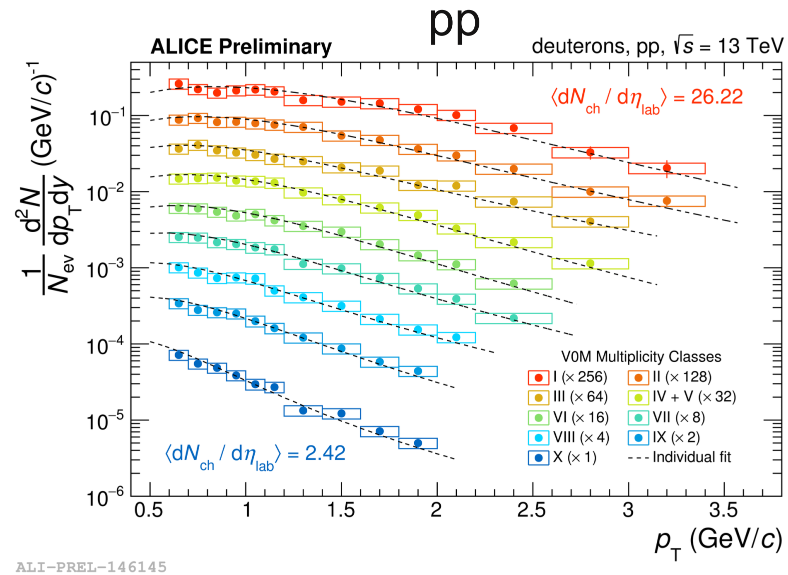

- The precise measurement of the mass difference between nuclei and their anti-counterparts allows one to probe any difference in the interaction between nucleons and anti-nucleons.
- Looking at the mass difference between nuclei and their anti-nuclei it is possible to test the CPT invariance of the residual QCD "nuclear force"

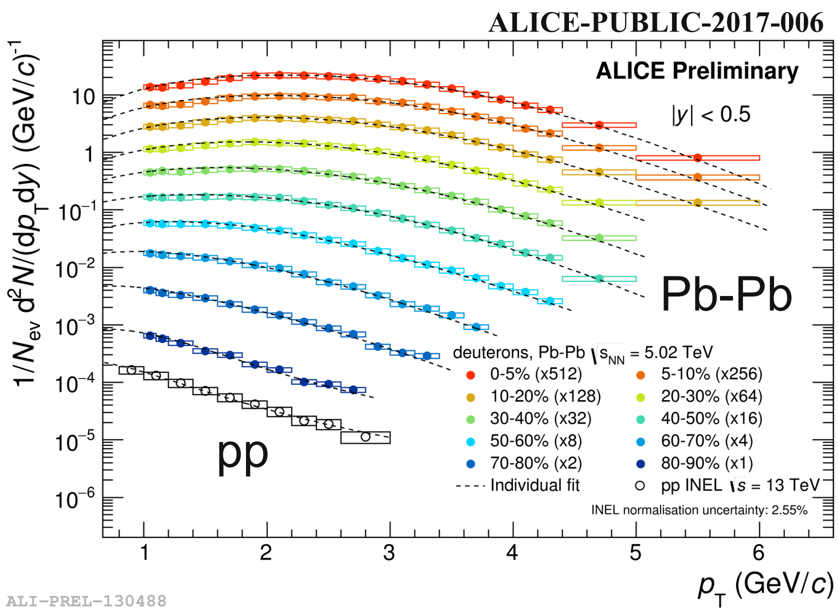


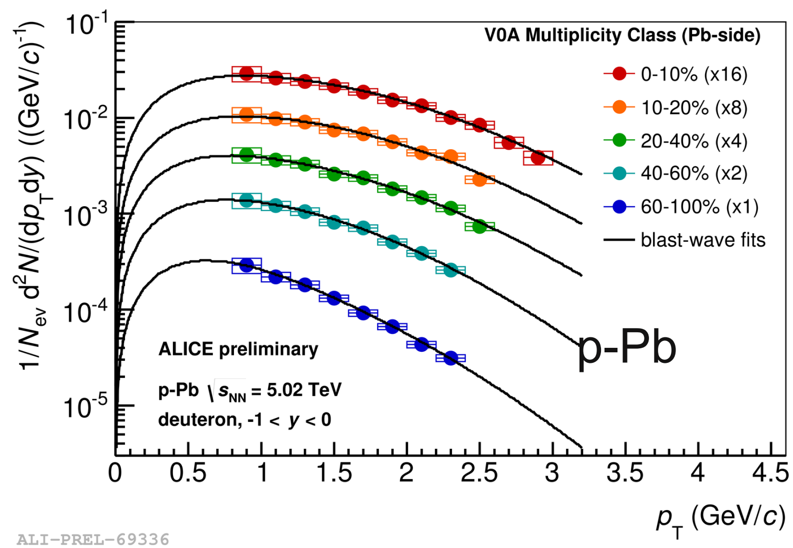

- ✓ Masses and binding energies of nuclei and anti-nuclei are compatible within uncertainties
- ✓ Measurement confirms the CPT invariance for light nuclei

# DEUTERON $p_T$ SPECTRA

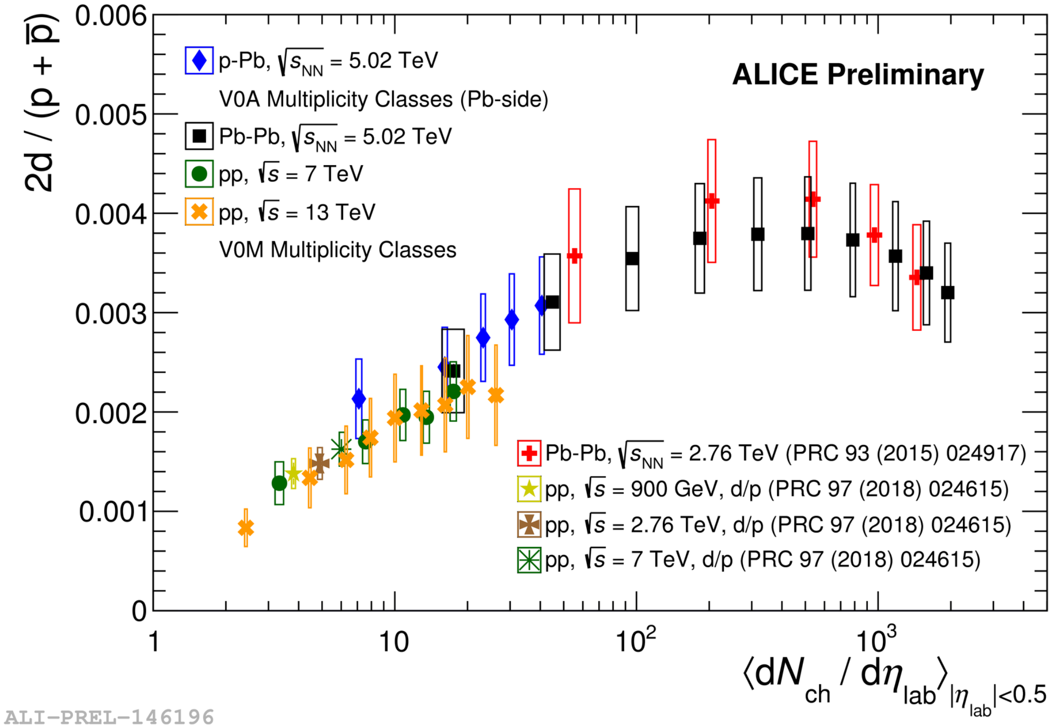
- Spectra become harder with increasing multiplicity in Pb-Pb and show clear radial flow
- The Blast-Wave fits describe the data well in p-Pb and Pb-Pb
- pp and p-Pb spectrum show no sign of radial flow



# DEUTERON TO PROTON RATIO




ALI-PREL-146196

- No significant centrality dependence in Pb-Pb
- Ratio in pp collisions is a factor 2.5 lower than in Pb-Pb collisions
- d/p ratio increases when going from pp to p-Pb and peripheral Pb-Pb, until it reaches the grand canonical thermal model value (d/p ~ $3 \times 10^{-3}$ at $T_{ch}$= 156 MeV)

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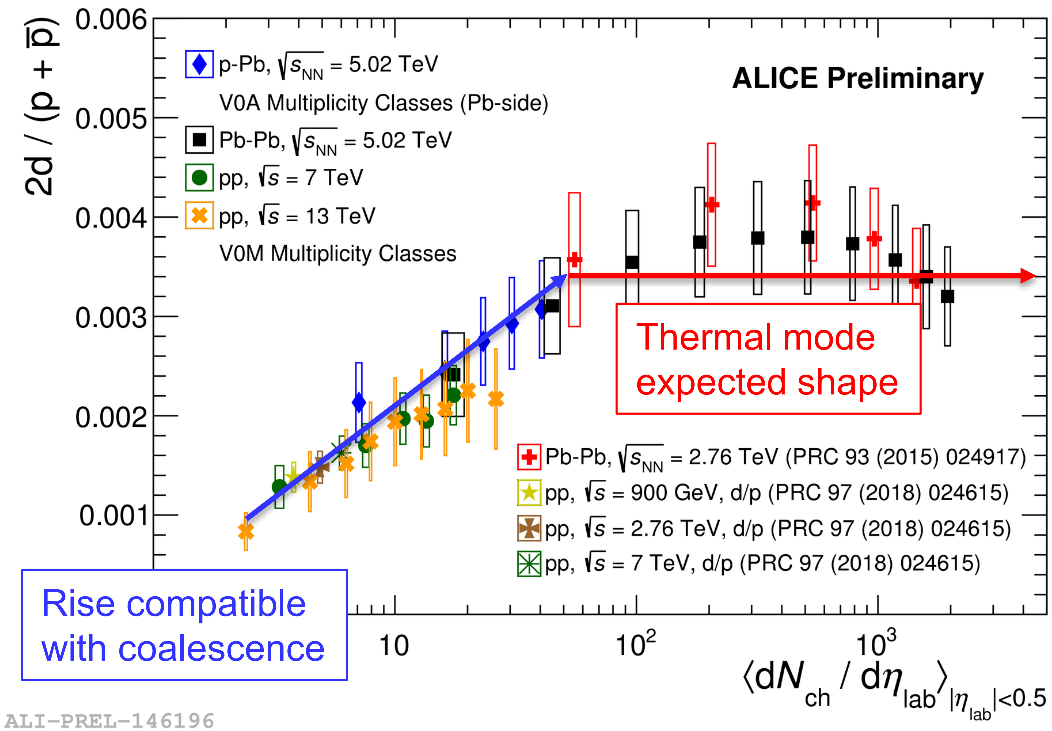
# DEUTERON TO PROTON RATIO




Simple coalescence works in small systems while thermal models describe better the Pb-Pb data

Is this smooth transition suggesting a single description for the nucleosynthesis in HEP?

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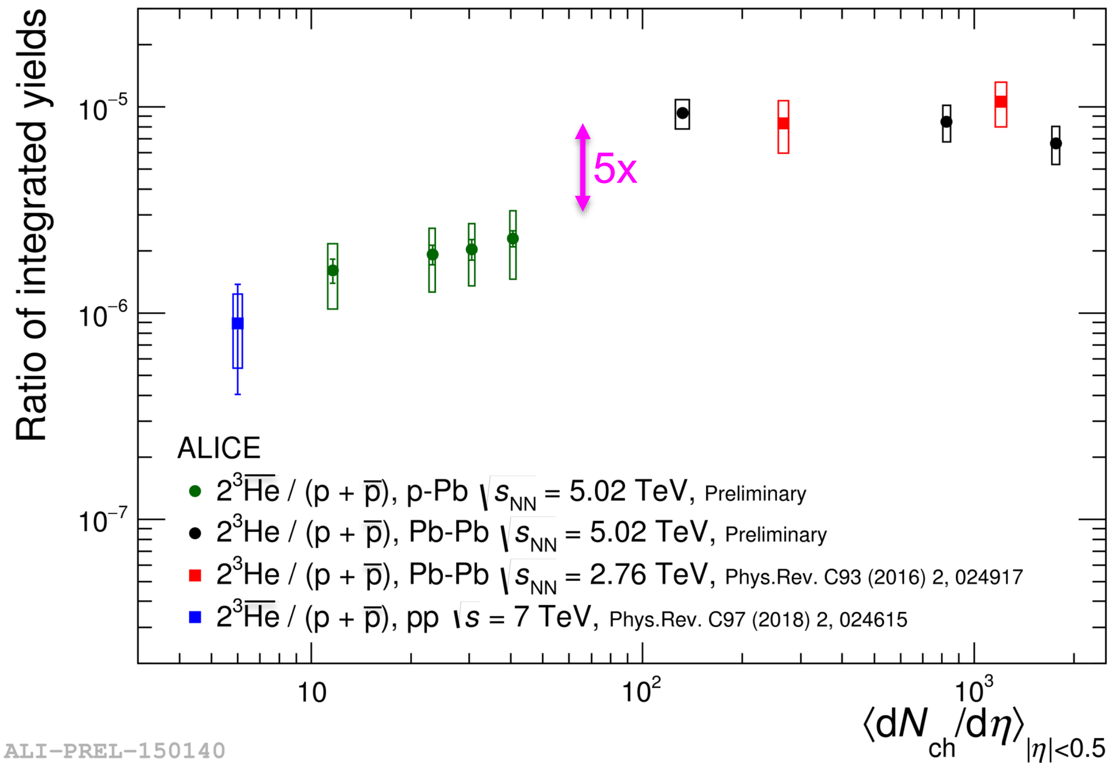
# HELIUM-3 TO PROTON RATIO




Simple coalescence works in small systems while thermal models describe better the Pb-Pb data

Is this smooth transition suggesting a single description for the nucleosynthesis in HEP?

But … there is a change of factor 5 in the $^{3}$He/p between small systems and Pb-Pb

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# COALESCENCE PARAMETER $B_A$

- If baryons at freeze-out are close enough in phase space (i.e. geometrically and in momentum) and match spin state, a (anti-)nucleus can be formed

- Usually, since the nucleus is larger w.r.t. the source, the phase space is reduced to the momentum space

- Assuming that p an n have the same mass and have the same $p_T$ spectra:

$$E_A \frac{d^3 N_A}{dp_A^3} = B_A \left( E_p \frac{d^3 N_p}{dp_p^3} \right)^A$$

- For A=2:

$$B_2 = E_d \frac{d^3 N_d}{dp_d^3} \left( E_p \frac{d^3 N_p}{dp_p^3} \right)^{-2}$$

Measured deuteron $p_T$-spectra

Measured proton $p_T$-spectra

# COALESCENCE PARAMETER $B_2$

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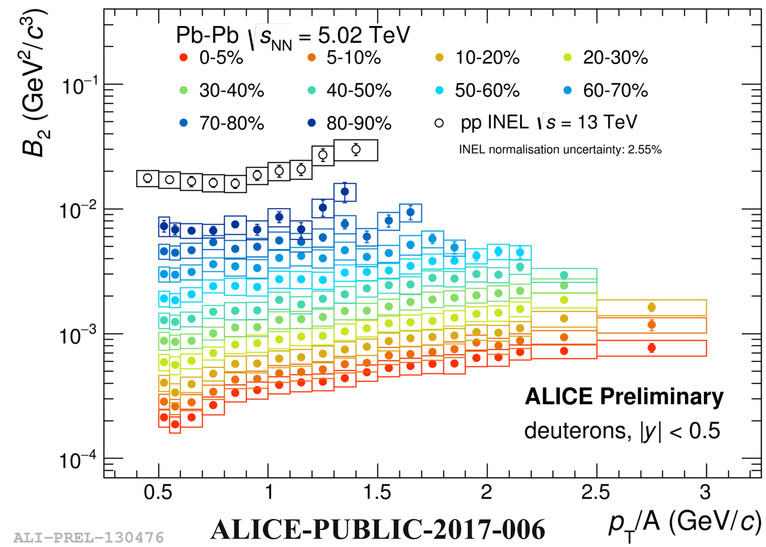
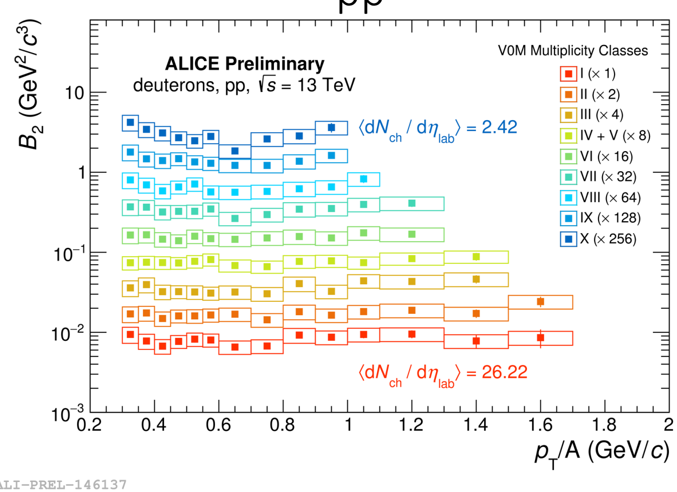
$$B_2 = E_d \frac{d^3 N_d}{dp_d^3} \left( E_p \frac{d^3 N_p}{dp_p^3} \right)^{-2}$$

- Coalescence parameter $B_2$ decreases with centrality in Pb-Pb and increases with $p_T$
- Similar effect seen in p-Pb: decrease with multiplicity, but less pronounced
- Flat behavior for pp and no dependence on multiplicity

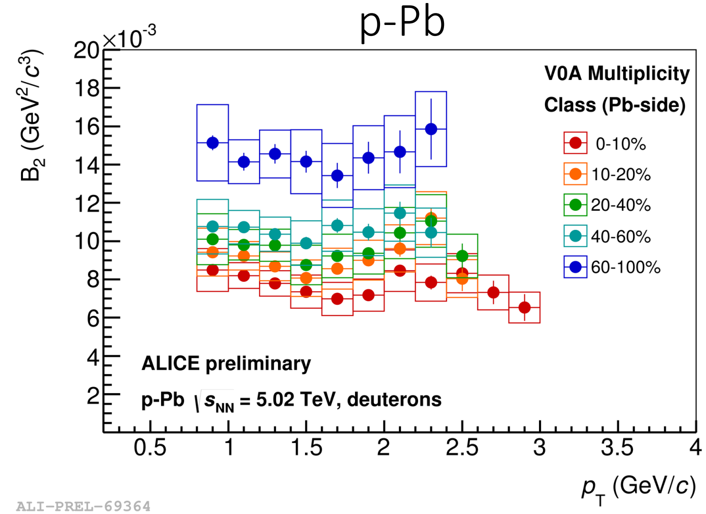
Pb-Pb




pp




p-Pb



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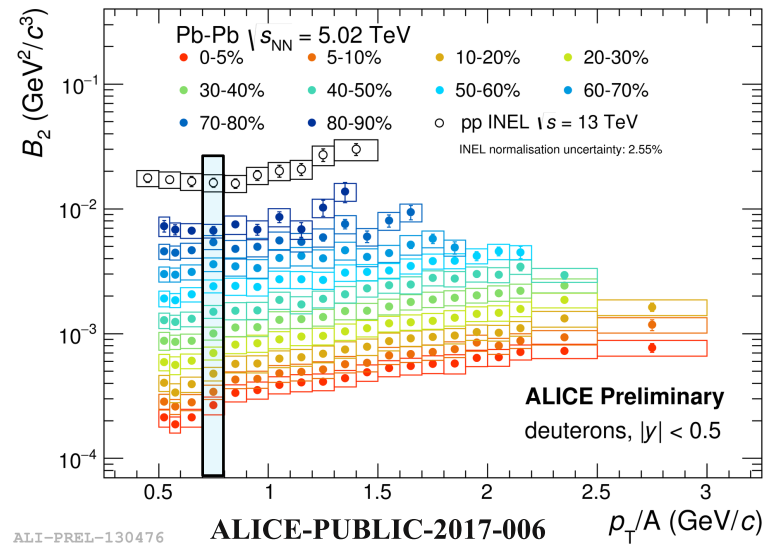


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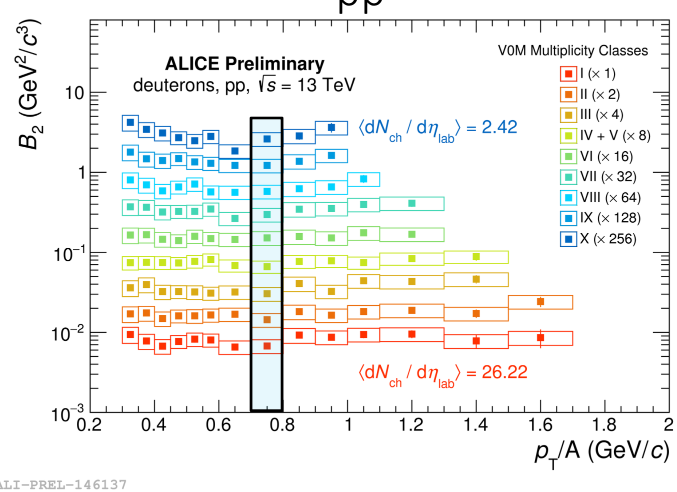
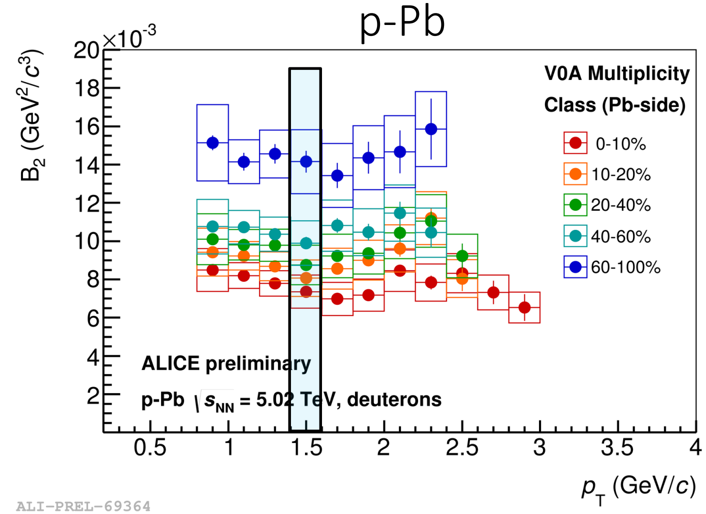
pp




p-Pb




$p_T$/A = 0.75 GeV/$c$

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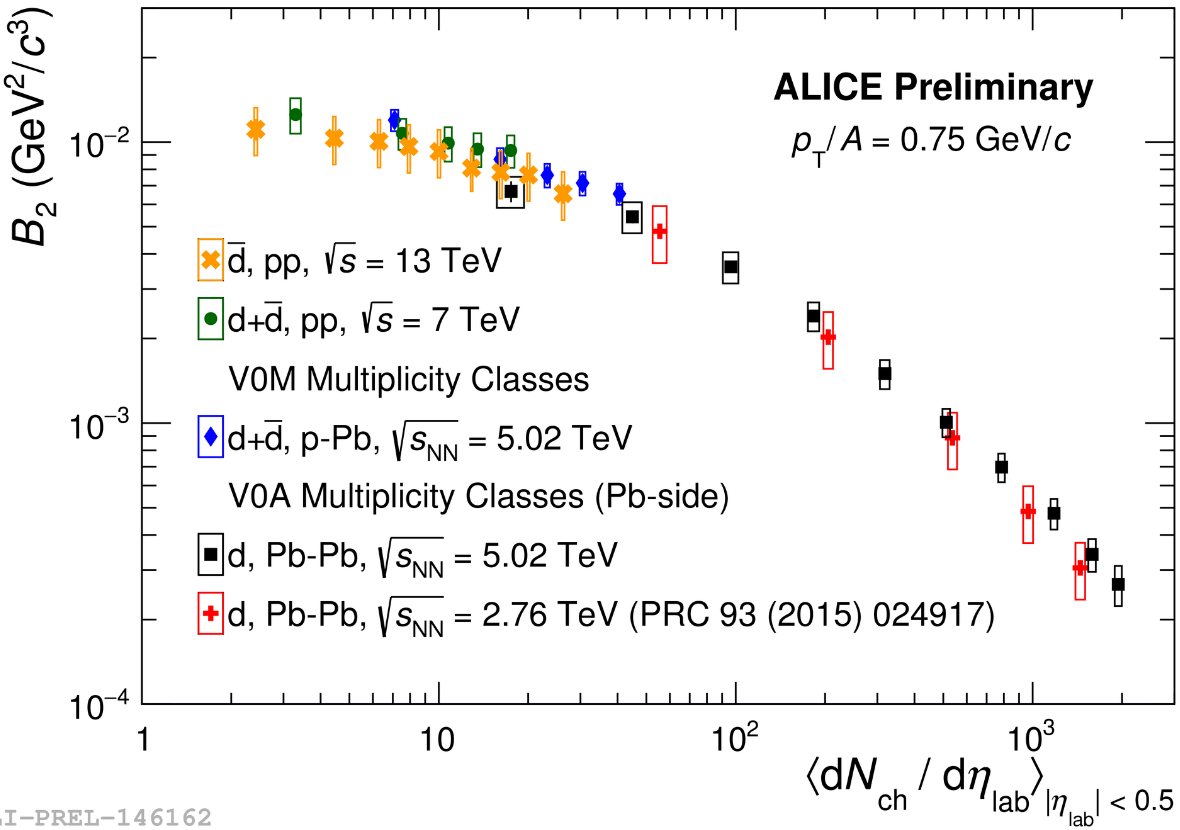
# COALESCENCE PARAMETER $B_2$




The coalescence parameter evolves smoothly as a function of multiplicity with no discontinuity between different colliding systems

**Simple coalescence model**

- Flat $B_2$ vs $p_T$ and no dependence on multiplicity/centrality
- Observed "small systems": pp, p-Pb and peripheral Pb-Pb

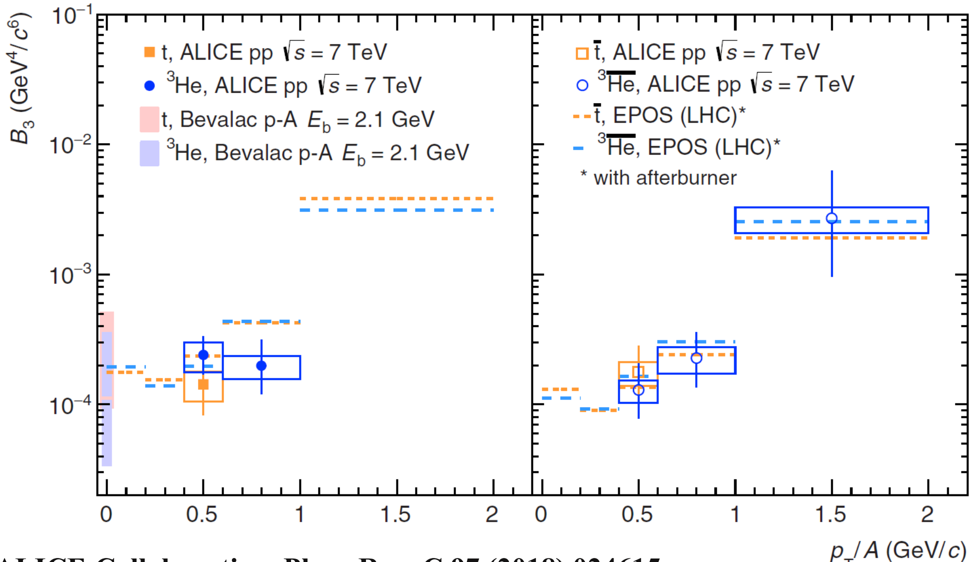
**More elaborated coalescence model** takes into account the volume of the source:

- $B_2$ scales like HBT radii (*)
- Decrease with centrality in Pb-Pb is explained as an increase in the source volume
- Increase with $p_T$ in central Pb-Pb reflects the $k_T$-dependence of the homogeneity volume in HBT
- Qualitative agreement in central Pb-Pb collisions

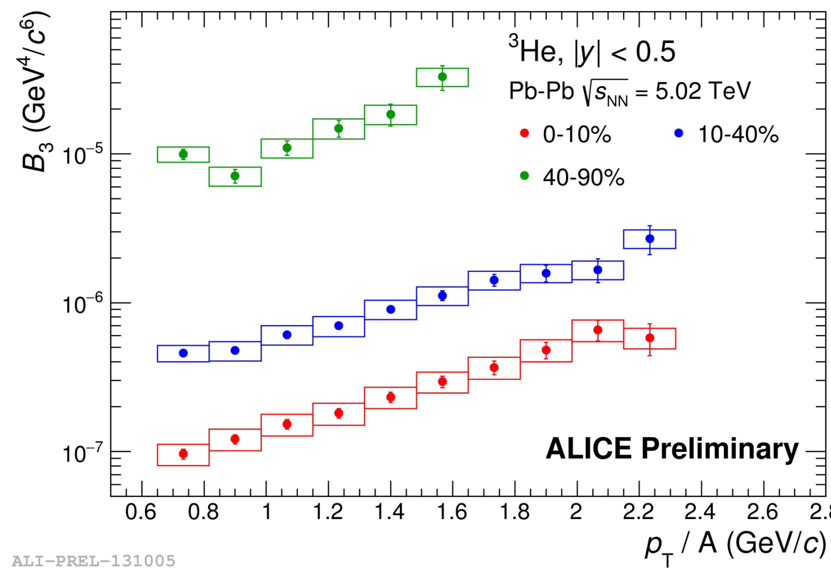
**(*) R. Scheibl and U. Heinz, Phys.Rev. C59, 1585 (1999)**

# COALESCENCE PARAMETER $B_3$

pp

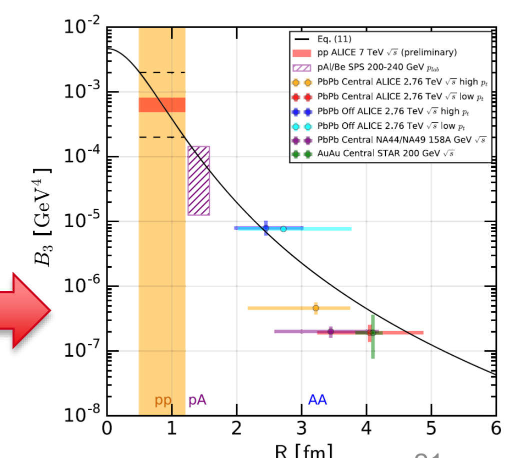



Pb-Pb

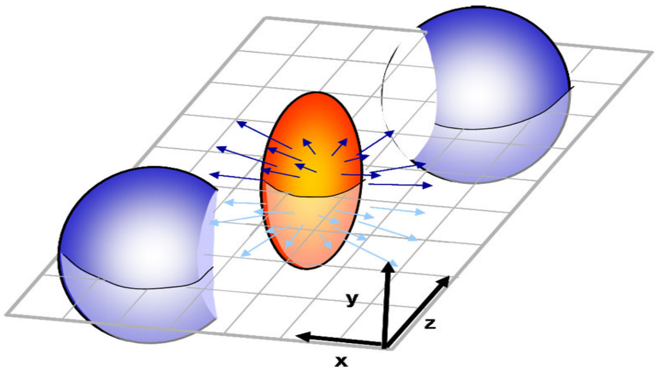



ALICE Collaboration, Phys. Rev. C 97 (2018) 024615

- $B_3$ of ($\bar{\mathrm{t}}$)t and ($^3\overline{\mathrm{He}}$)$^3$He measured in pp and Pb-Pb collisions
- First ever measurements of the $B_3$ of $\bar{\mathrm{t}}$ and $^3\overline{\mathrm{He}}$ in pp collisions
- Increasing trend with $p_{\mathrm{T}}$ and centrality observed in Pb-Pb collision
- Present data allow to make a new estimate to assess the astrophysical secondary flux of antihelium [K. Blum, Phys. Rev. D 96 (2017) 103021]

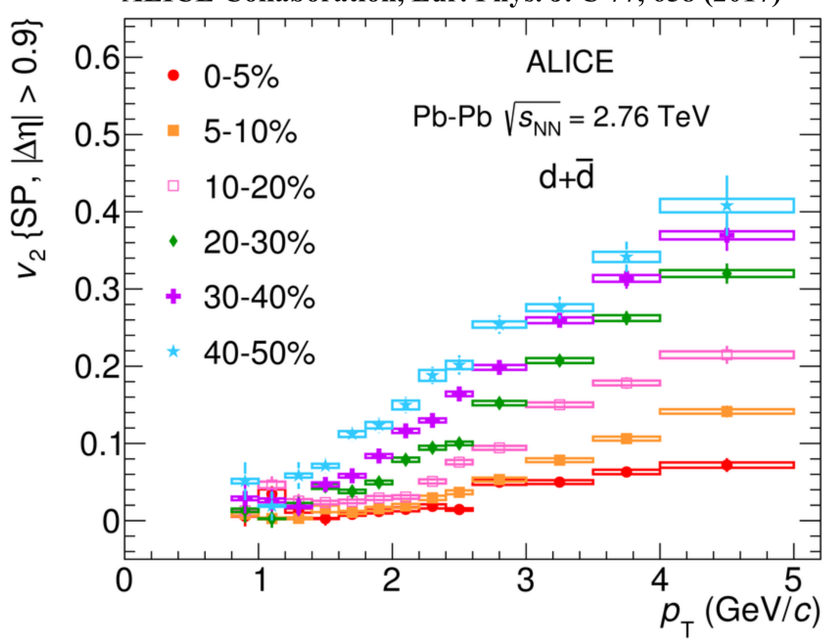


# DEUTERON $v_2$ FOR DIFFERENT CENTRALITIES




- A significant $v_2$ is observed for deuterons
- The value of $v_2(p_T)$ increases progressively from central to semi-central collisions

ALICE Collaboration, Eur. Phys. J. C 77, 658 (2017)




- Angular distribution of reconstructed charged particles can be expanded into a Fourier series w.r.t. symmetry plane:

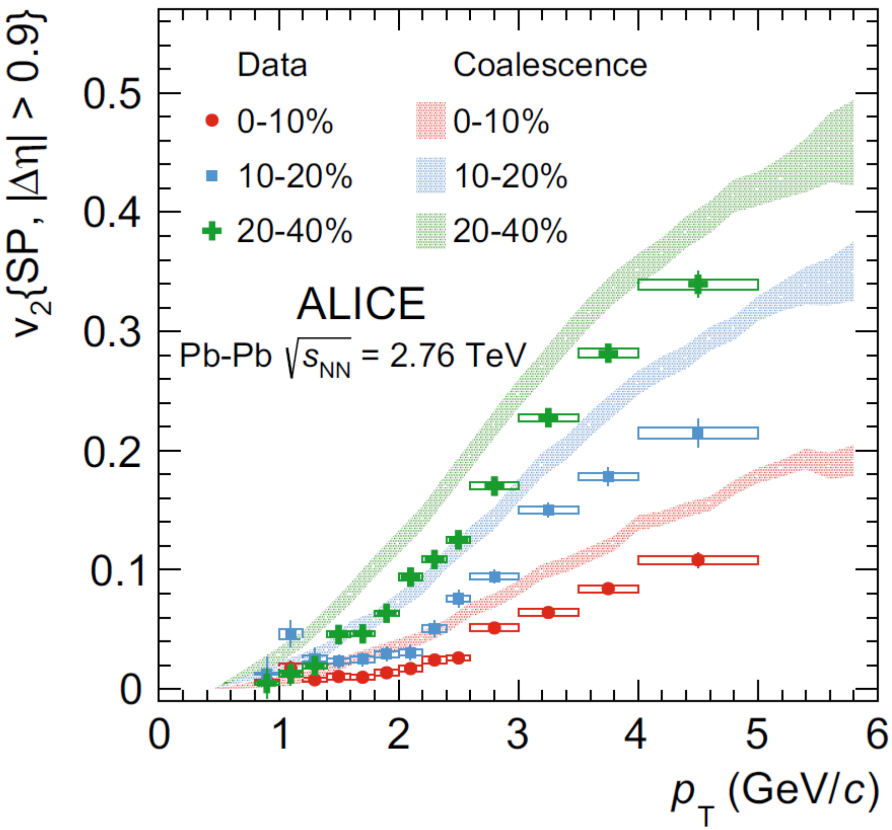
$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + \sum_{n=1}^{\infty} 2v_n \cos\left(n\left(\varphi - \Psi_n\right)\right)\right)$$

$$v_n = \langle \cos\left(n(\varphi - \Psi_n)\right)\rangle$$

- Elliptic flow ($v_2$) is sensitive to the system evolution:
  It probes initial conditions and constrains particle production mechanisms

# DEUTERON $v_2$ FOR DIFFERENT CENTRALITIES

ALICE Collaboration, Eur. Phys. J. C 77, no. 10, 658 (2017)




- A significant $v_2$ is observed for deuterons
- The value of $v_2$ ($p_T$) increases progressively from central to semi-central collisions
- If protons have only elliptical flow
- And if the light nucleus is formed by simple coalescence, $v_2$ can be expressed as

$$v_{2,\mathrm{d}}(p_\mathrm{T}) = \frac{2v_{2,\mathrm{p}}(p_\mathrm{T}/2)}{1 + 2v_{2,\mathrm{p}}^2(p_\mathrm{T}/2)}$$

- Such a simple coalescence model is not able to reproduce the measured elliptic flow of deuterons

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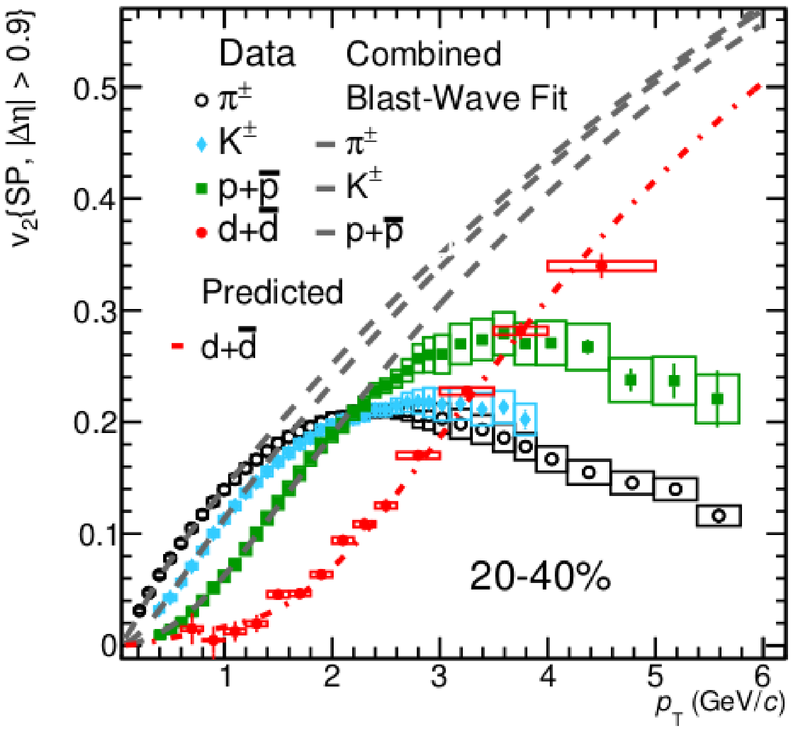


- Simplified hydro model (Blast-Wave) is able to describe spectra and flow at the same time, suggesting an early "freeze out"

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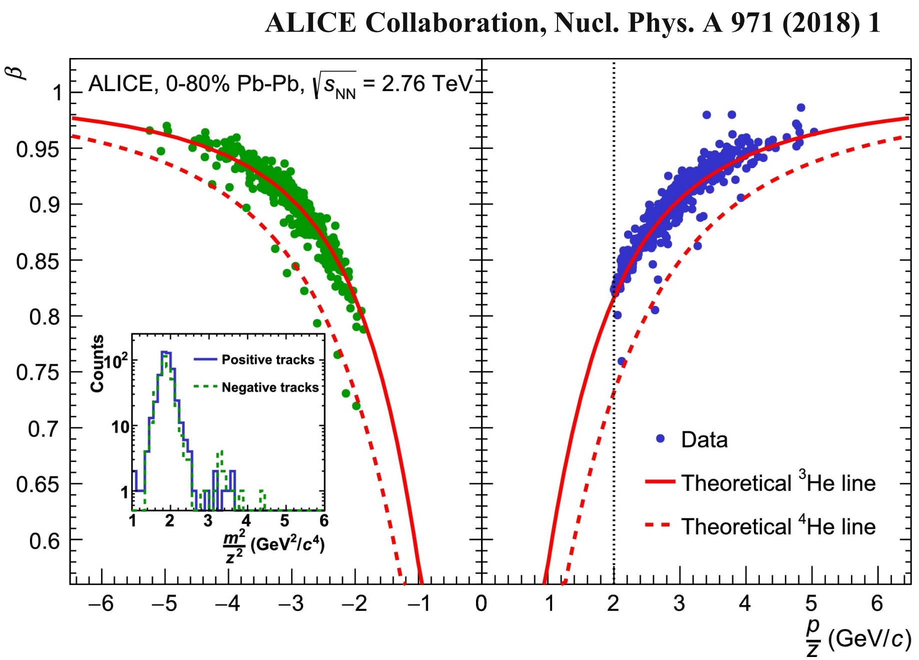
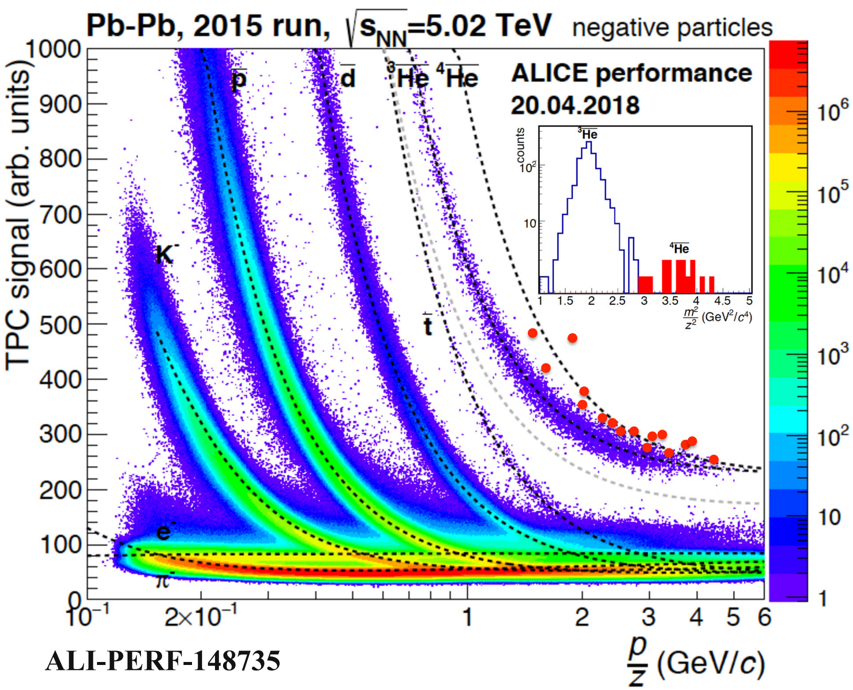
# ANTI-ALPHA



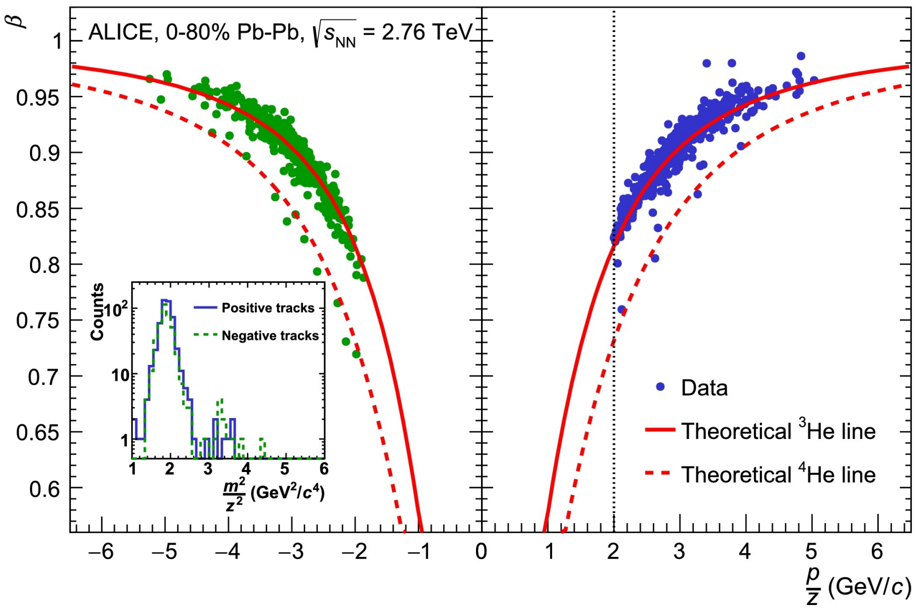

For the full statistics of 2011 (Pb-Pb@2.76 TeV) ALICE identified 10 Anti-Alphas using TPC and TOF

TOF β vs *p/z* after pre-selection of 3σ in TPC shows clear separation → Cut on Alpha's *p/z* needed to suppress secondary

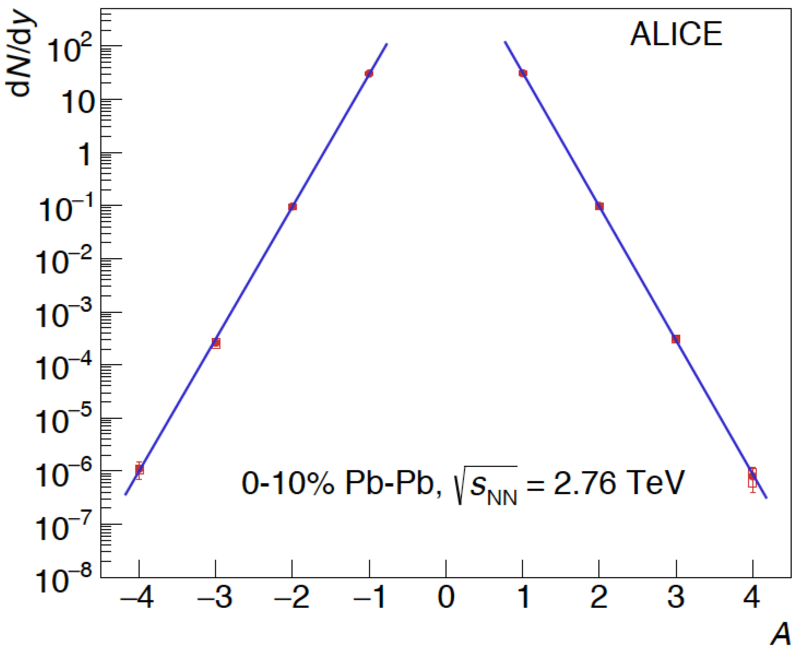
Anti-Alpha re-measured also in the new data sample Pb-Pb@5.02 TeV

# NUCLEI PRODUCTION IN Pb-Pb

ALICE Collaboration, Nucl. Phys. A 971 (2018) 1




ALICE Collaboration, Nucl. Phys. A 971 (2018) 1

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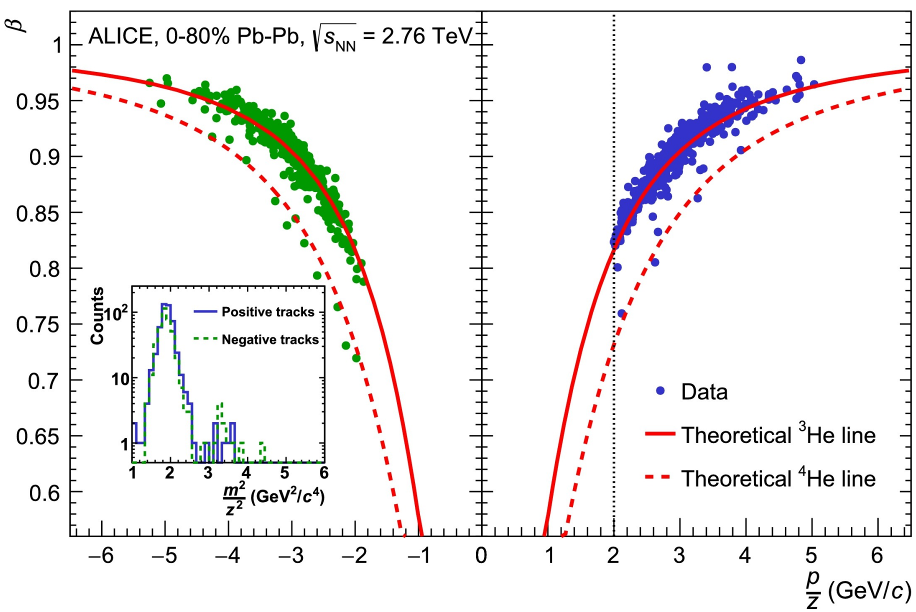
Anti-Alpha re-measured also in the new data sample Pb-Pb@5.02 TeV

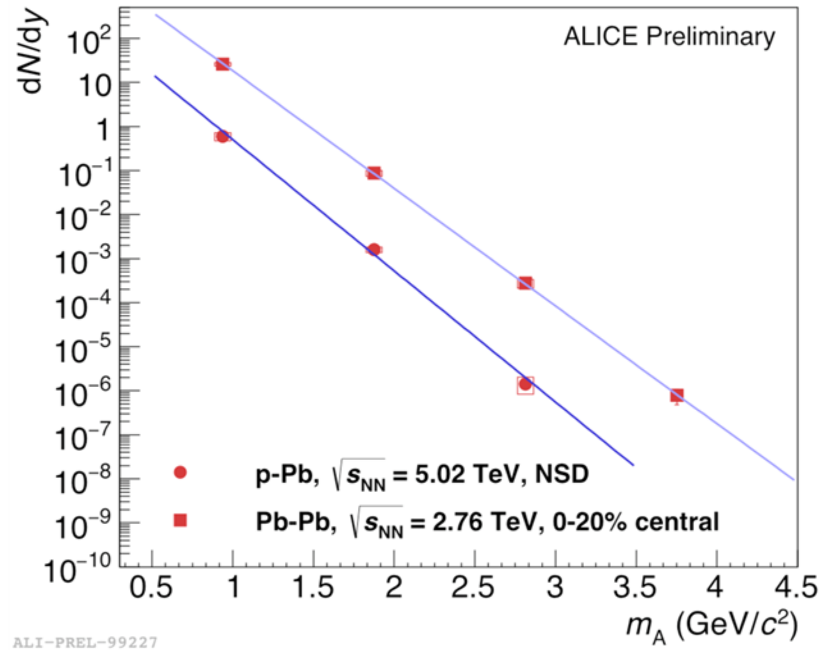
Nuclei yields follow an exponential decrease with mass as predicted by the thermal model

In **Pb-Pb** the penalty factor for adding one baryon is **~350** (for particles and antiparticles)

# NUCLEI PRODUCTION IN Pb-Pb AND IN p-Pb

ALICE Collaboration, Nucl. Phys. A 971 (2018) 1

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Anti-Alpha re-measured also in the new data sample Pb-Pb@5.02 TeV

Nuclei yields follow an exponential decrease with mass as predicted by the thermal model

In **Pb-Pb** the penalty factor for adding one baryon is **~350** (for particles and antiparticles) and **in p-Pb it is ~600**

# (ANTI-)HYPERTRITON IDENTIFICATION

ALICE

## Decay Channels

$^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$ $\quad$ $^{3}_{\Lambda}\overline{\mathrm{H}} \rightarrow {}^{3}\overline{\mathrm{He}} + \pi^{+}$

$^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{H} + \pi^{0}$ $\quad$ $^{3}_{\Lambda}\overline{\mathrm{H}} \rightarrow {}^{3}\overline{\mathrm{H}} + \pi^{0}$

$^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{d} + \mathrm{p} + \pi^{-}$ $\quad$ $^{3}_{\Lambda}\overline{\mathrm{H}} \rightarrow \overline{\mathrm{d}} + \overline{\mathrm{p}} + \pi^{+}$

$^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{d} + \mathrm{n} + \pi^{0}$ $\quad$ $^{3}_{\Lambda}\overline{\mathrm{H}} \rightarrow \overline{\mathrm{d}} + \overline{\mathrm{n}} + \pi^{0}$

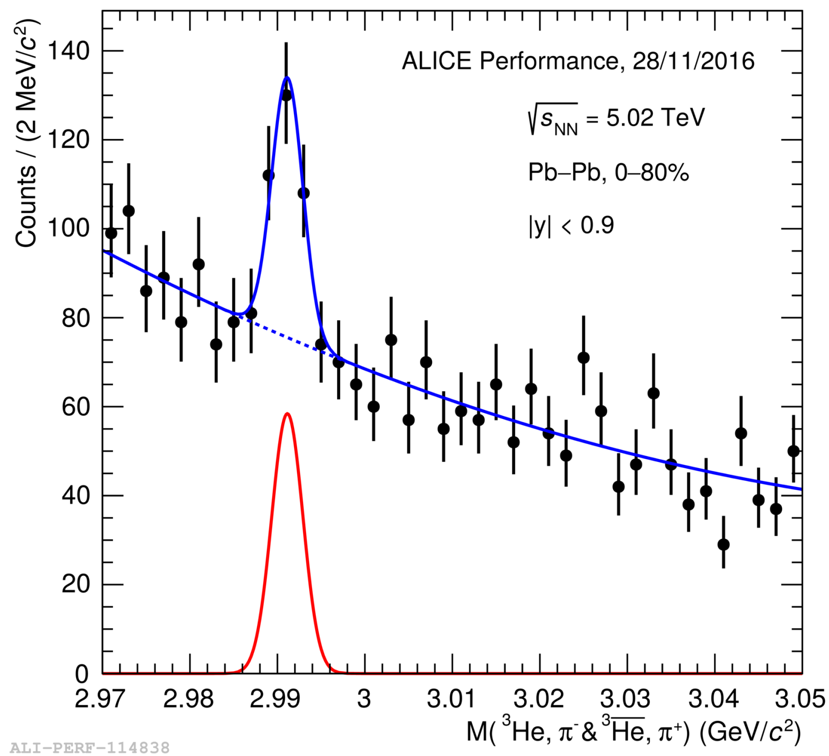
$^{3}_{\Lambda}$H search via two-body decays into charged particles:

- Two body decay: lower combinatorial background
- Charged particles: ALICE acceptance and reconstruction efficiency for charged particles higher than for neutrals

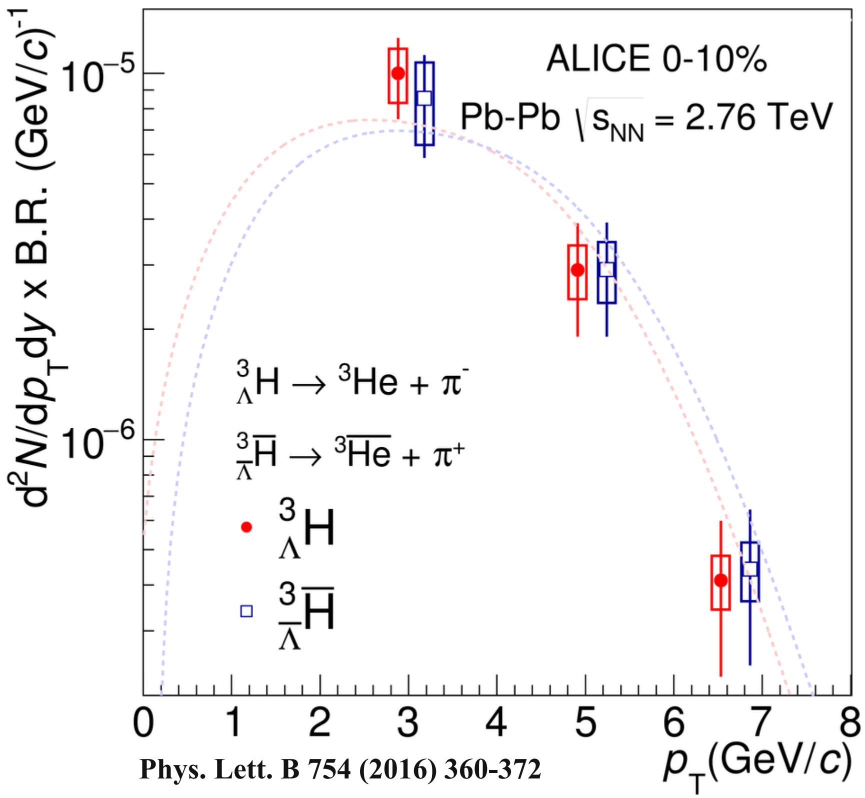
Signal extraction:

- Identify $^{3}$He and π
- Evaluate ($^{3}$He,π) invariant mass
- Apply topological cuts in order to:
  - isolate secondary decay vertex and
  - reduce combinatorial background

New preliminary results at $\sqrt{s_{NN}}$ = 5.02 TeV



# (ANTI-)HYPERTRITON YIELDS



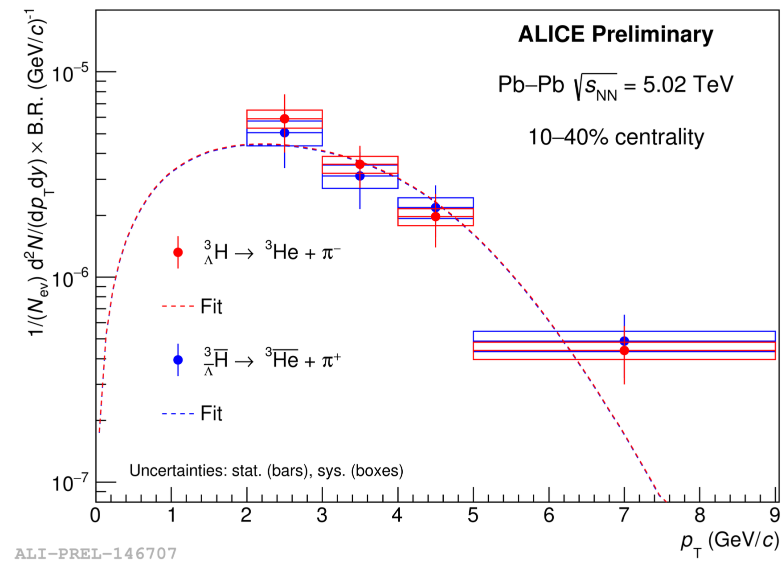

Phys. Lett. B 754 (2016) 360-372

Pb-Pb@2.76Tev:

d$N$/d$y$ x B.R. ($^{3}_{\Lambda}H \rightarrow {}^{3}He\ \pi$) yield extracted

in three $p_T$ bins for central (0-10%) events

for $^{3}_{\bar{\Lambda}}\bar{H}$ and $^{3}_{\Lambda}H$ separately




Pb-Pb@5.02Tev:

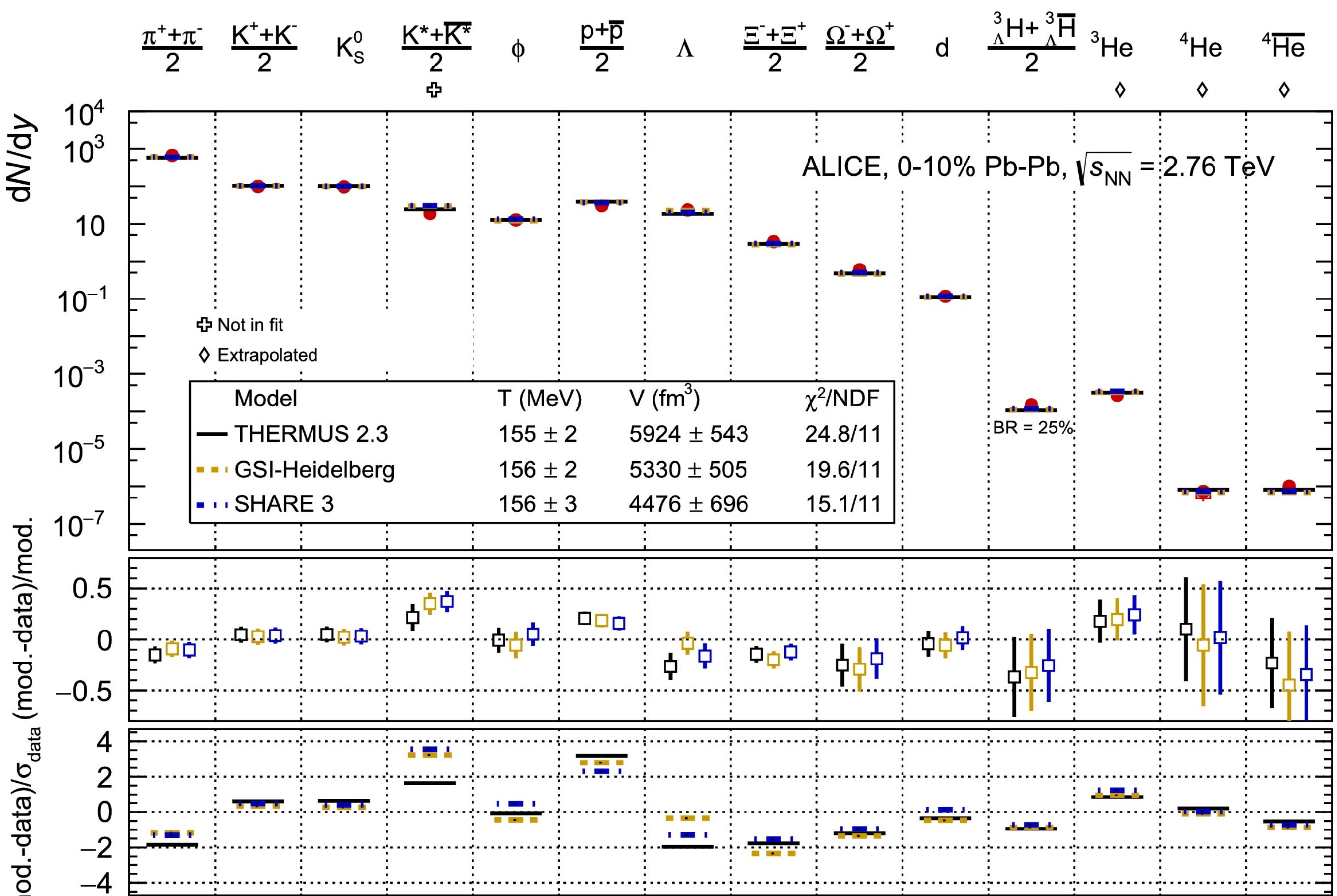
d$N$/d$y$ x B.R. ($^{3}_{\Lambda}H \rightarrow {}^{3}He\ \pi$) yield extracted

in four $p_T$ bins for central (10-40%) events

for $^{3}_{\bar{\Lambda}}\bar{H}$ and $^{3}_{\Lambda}H$ separately

ALICE

# THERMAL MODEL FITS




**ALICE Collaboration, Nucl. Phys. A 971 (2018) 1**

*THERMUS: S. Wheaton, et al., CPC 180, 84 (2009)*

*GSI-Heidelberg: A. Andronic, et al., PLB 697, 203 (2011); PLB 673, 142 (2009) 142*

*SHARE3: G. Torrieri, et al., CPC 167, 229 (2005); CPC 175, 635 (2006); CPC 185, 2056 (2014)*

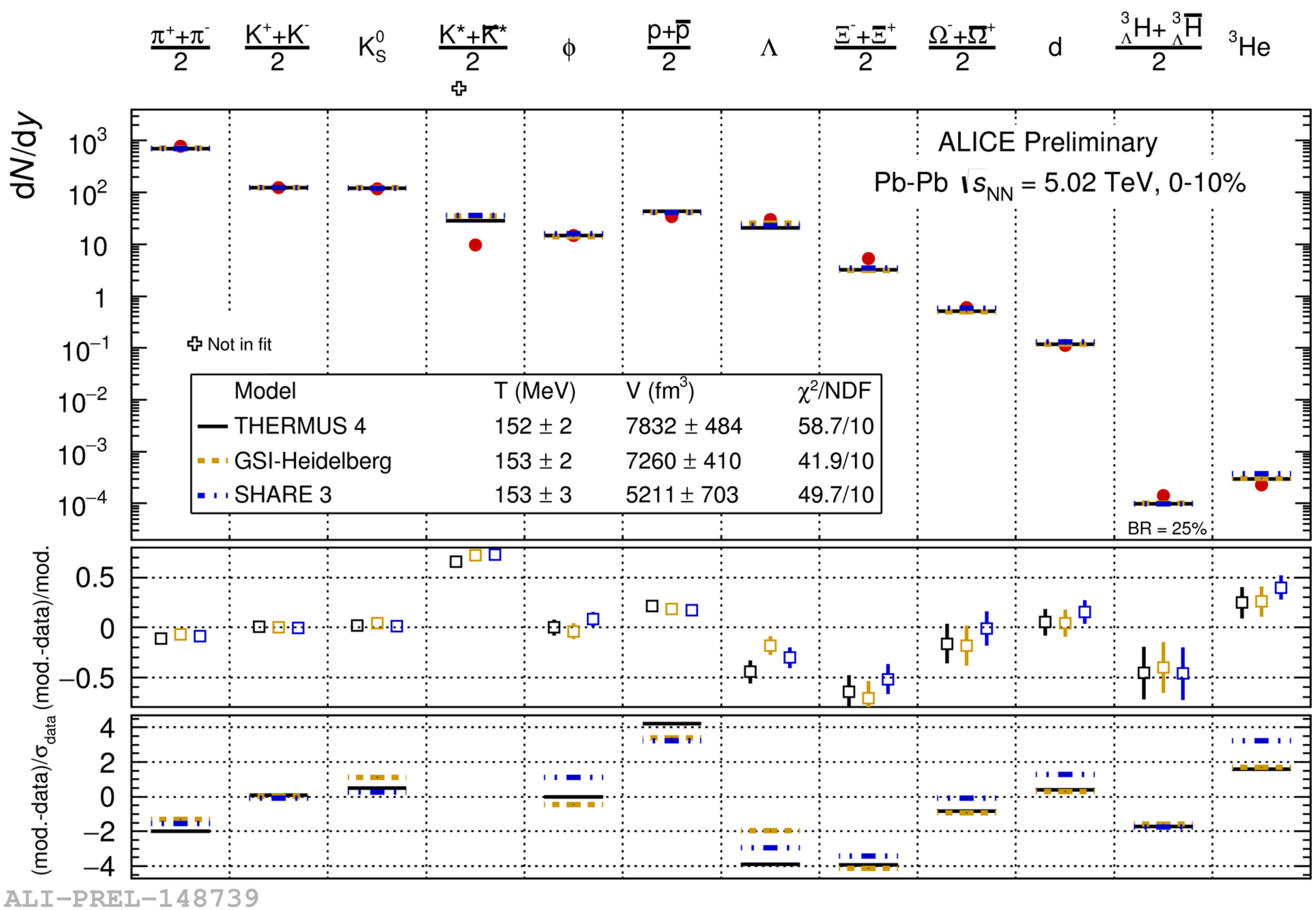
Different models describe particle yields including light (hyper-) nuclei with $T_{ch}$ of about 156 MeV

Including nuclei in the fit causes no significant change in $T_{ch}$

Thermal model is very successful in reproducing the particle yields measured by ALICE in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV

This result, together with the successful Blast-Wave fit to deuteron data suggest that nuclei production happens at the hadronisation, when all the other particles are formed.

# THERMAL MODEL FITS

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Different models describe particle yields including light (hyper-) nuclei with $T_{ch}$ of about 152 MeV

Including nuclei in the fit causes no significant change in $T_{ch}$

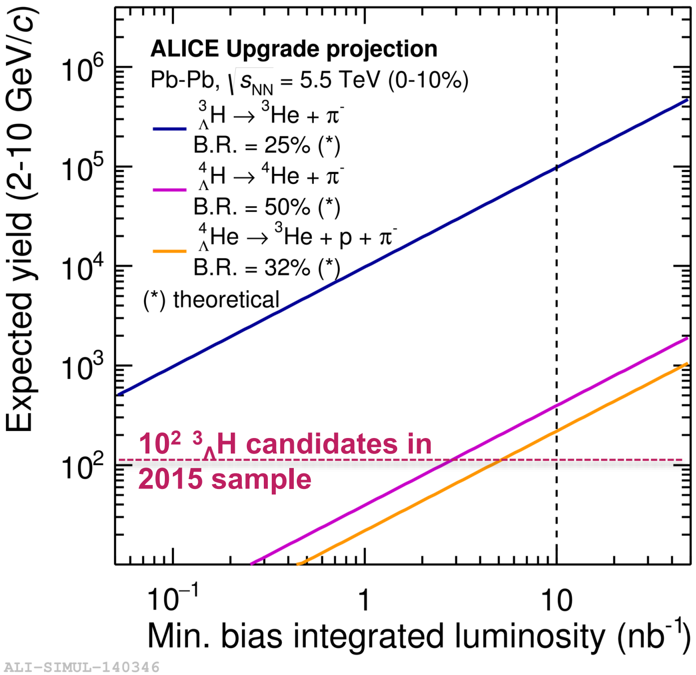
The larger data sample collected in LHC Run2 and improved reconstruction and analysis techniques reduced the uncertainties.
The preliminary data from LHC Run 2 confirm the tensions seen with data from LHC Run 1.

# OUTLOOK – ALICE UPGRADE

At the end of Pb-Pb during RUN2 (Nov. 2018) the expected statistics for A=2,3 is >2x

During the Long Shutdown 2 (2019-2020):

- **New Inner Tracking System (ITS)**
  - ✓ improved pointing precision
  - ✓ less material -> thinnest tracker at the LHC
- **Upgrade of Time Projection Chamber (TPC):**
  - ✓ new GEM technology for readout chambers
  - ✓ continuous readout
  - ✓ faster readout electronics
- **High Level Trigger (HLT):**
  - ✓ new architecture
  - ✓ on line tracking & data compression
  - ✓ 50kHz Pb-Pb event rate




At the end of RUN3 (2023):
the expected Integrated Luminosity: ~10 $nb^{-1}$ (~$8 \times 10^{9}$ collisions in the 0-10% centrality class)

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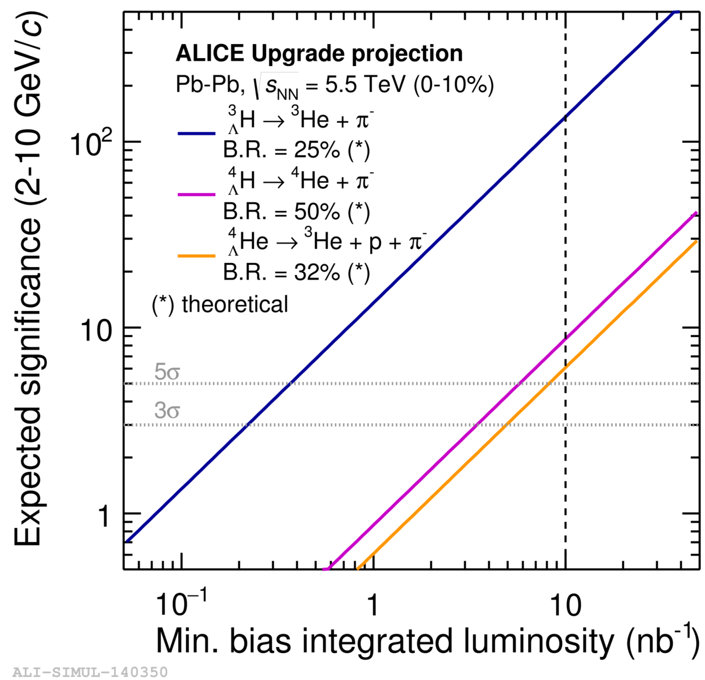



At the end of RUN3 (2023):
the expected Integrated Luminosity: ~10 $nb^{-1}$ (~8x$10^9$ collisions in the 0-10% centrality class)

All the physics which is now done for A = 2 and A = 3 (hyper-)nuclei will be done for A = 4

# CONCLUSIONS

- Excellent **ALICE** performance allows for **detection of light (anti-)nuclei and (anti-)hypernuclei**
- ALICE (anti-)(hyper)nuclei production measurements challenge the production models:
  - ✓ Large production of nuclear clusters measured by ALICE as predicted by the thermal models
  - ✓ Thermal models describe sufficiently well the nuclei production (from proton to $^{4}$He) in Pb-Pb
  - ✓ Simple coalescence models describe the (anti-)(hyper)nuclei only in small systems (pp, p-Pb)
  - ✓ Deuteron yield and $v_2(p_T)$ in Pb-Pb collisions suggest an early “freeze out”, while large effects of re-interactions (favoring late stage coalescence) should be expected
  - ✓ $B_2$ coalescence parameter evolves smoothly as a function of multiplicity with no discontinuity between different colliding system

- **Future LHC runs**, RUN2 and RUN3, and ALICE upgrades will **allow for precise study** of **(anti-)(hyper)nuclei** production yield (and lifetime)
  - ✓ New and more precise data are expected from the LHC in the next years !

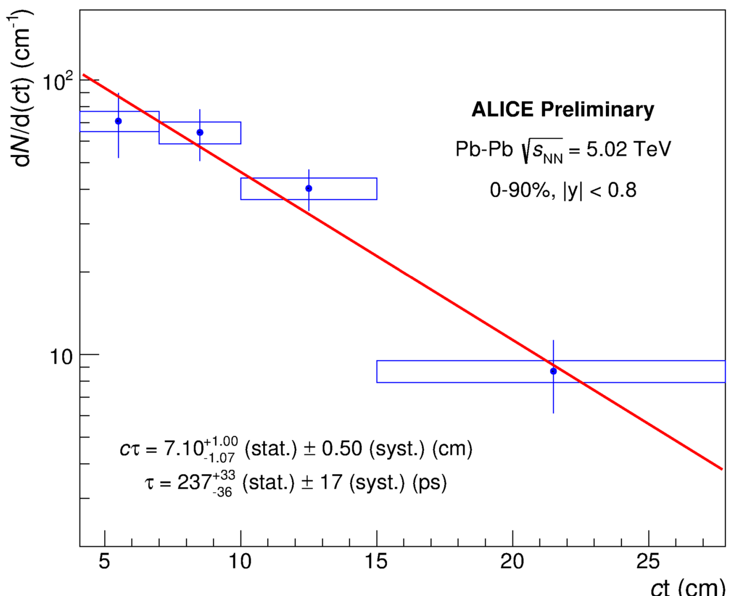
# HYPERTRITON LIFETIME DETERMINATION

Direct decay time measurement is difficult (~ps), but the excellent determination of primary and decay vertex allows measurement of lifetime via:

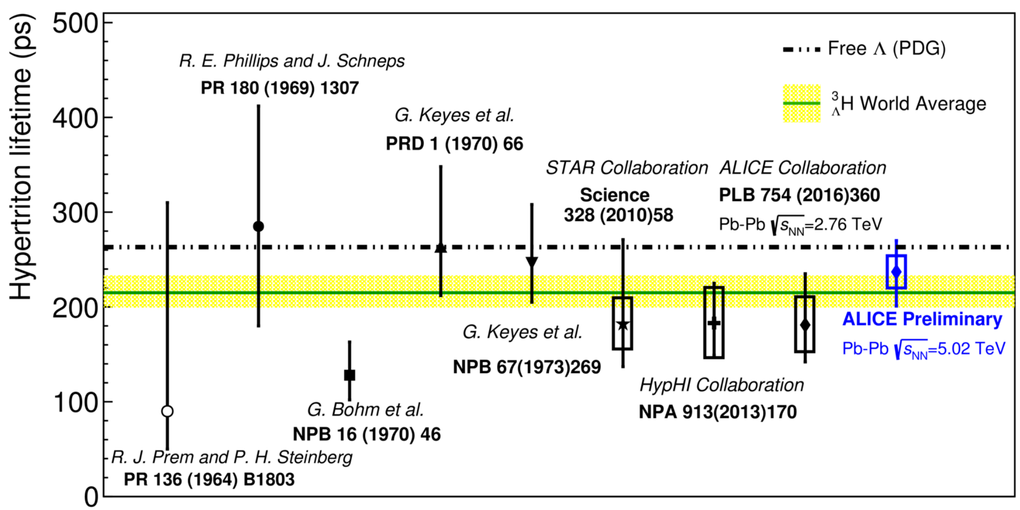
$$N(t) = N(0)\, e^{-\frac{t}{\tau}}$$

where $t = L/(\beta\gamma c)$ and $\beta\gamma c = p/m$ with $m$ the hypertriton mass, $p$ the total momentum and $L$ the decay length

**New preliminary results at $\sqrt{s_{NN}}$ = 5.02 TeV**




$$c\tau = \left(7.10^{+1.00}_{-1.07}(stat.) \pm 0.50(syst.)\right) cm$$
$$\tau = \left(237^{+33}_{-36}(stat.) \pm 17(syst.)\right) ps$$

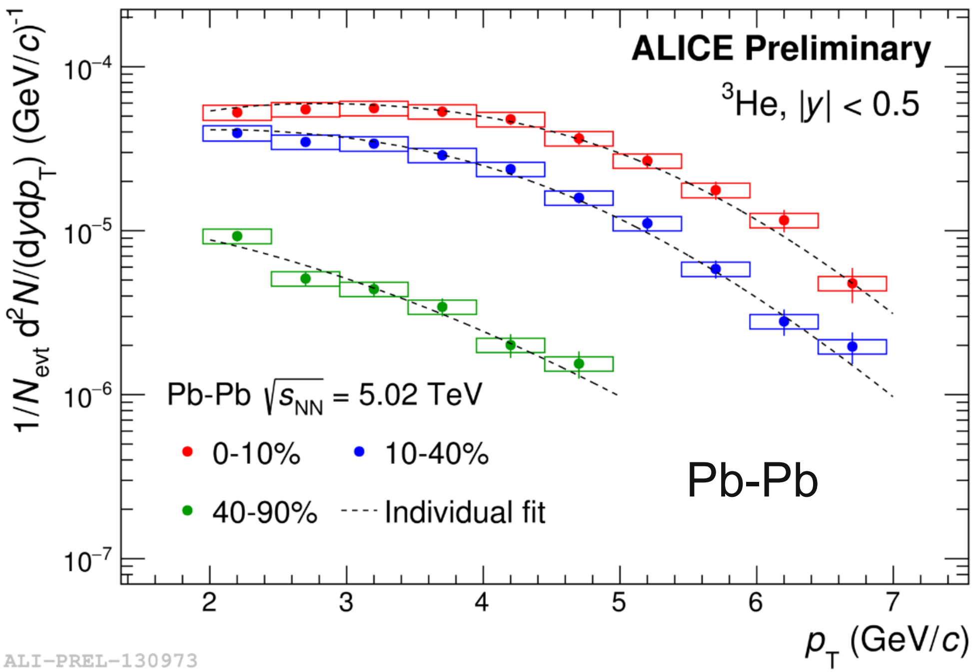


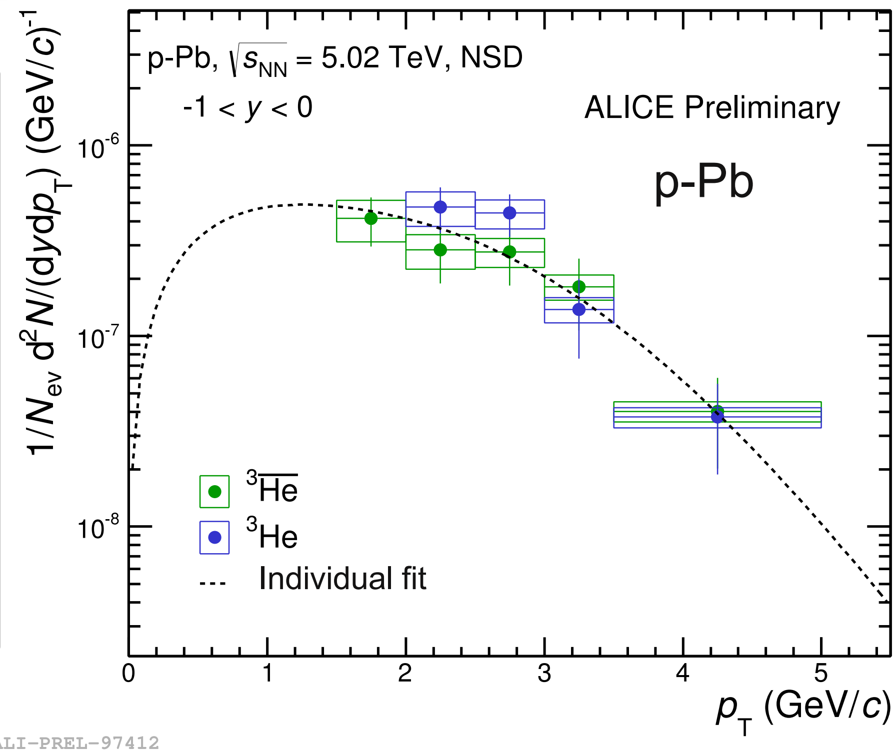

ALI-PREL-130195

- Previous heavy-ion experiment results show a trend well below the free Λ lifetime
- ALICE preliminary result from Pb-Pb at 5.02 TeV is closer to the free Λ lifetime

# 3-HELIUM

ALICE-PUBLIC-2017-006

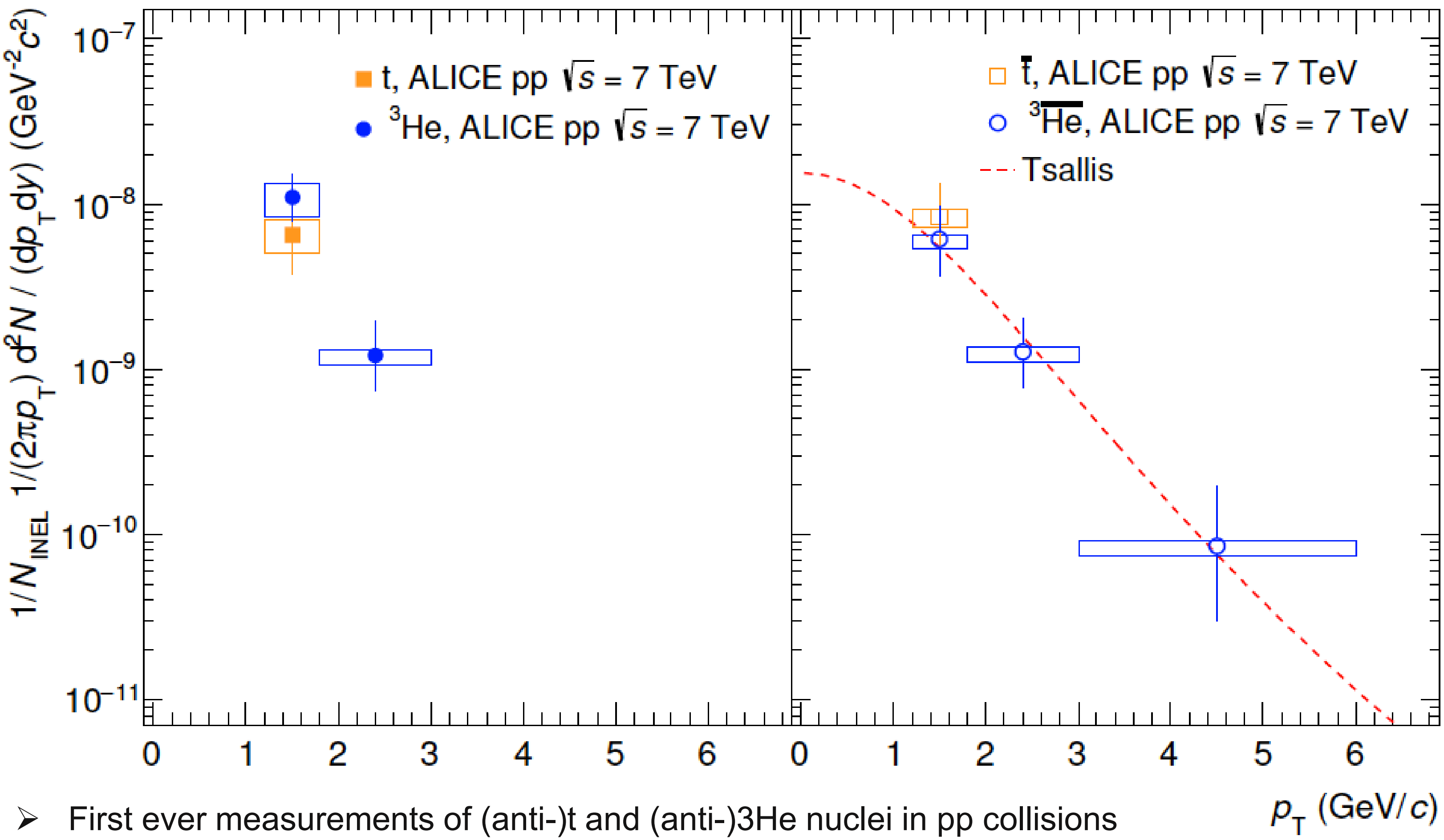



- Dashed curves represent individual Blast-Wave fits
- Spectrum obtained in 3 centrality classes in Pb-Pb and for NSD collisions in p-Pb

# 3-HELIUM AND TRITON

ALICE Collaboration, Phys. Rev. C 97, 024615

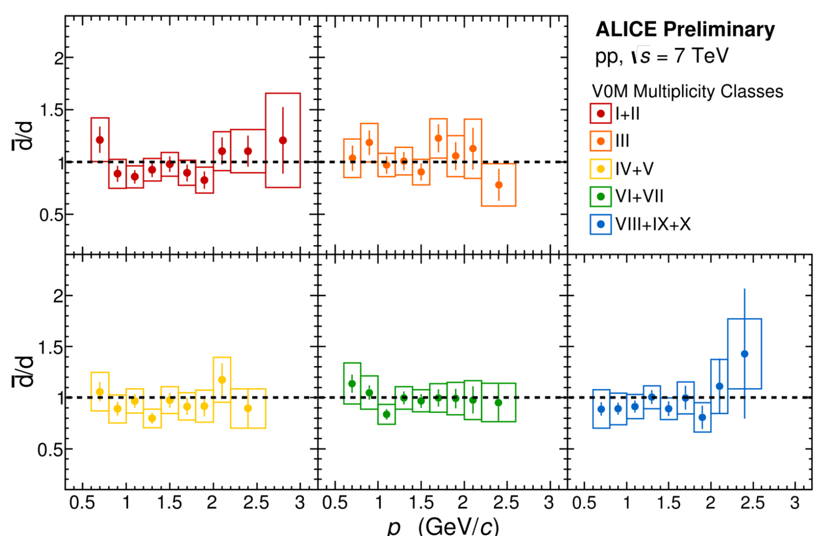



- First ever measurements of (anti-)t and (anti-)3He nuclei in pp collisions
- t and anti-t measurement difficult
- (anti-)t/(anti-)$^3$He agrees with unity

ALICE

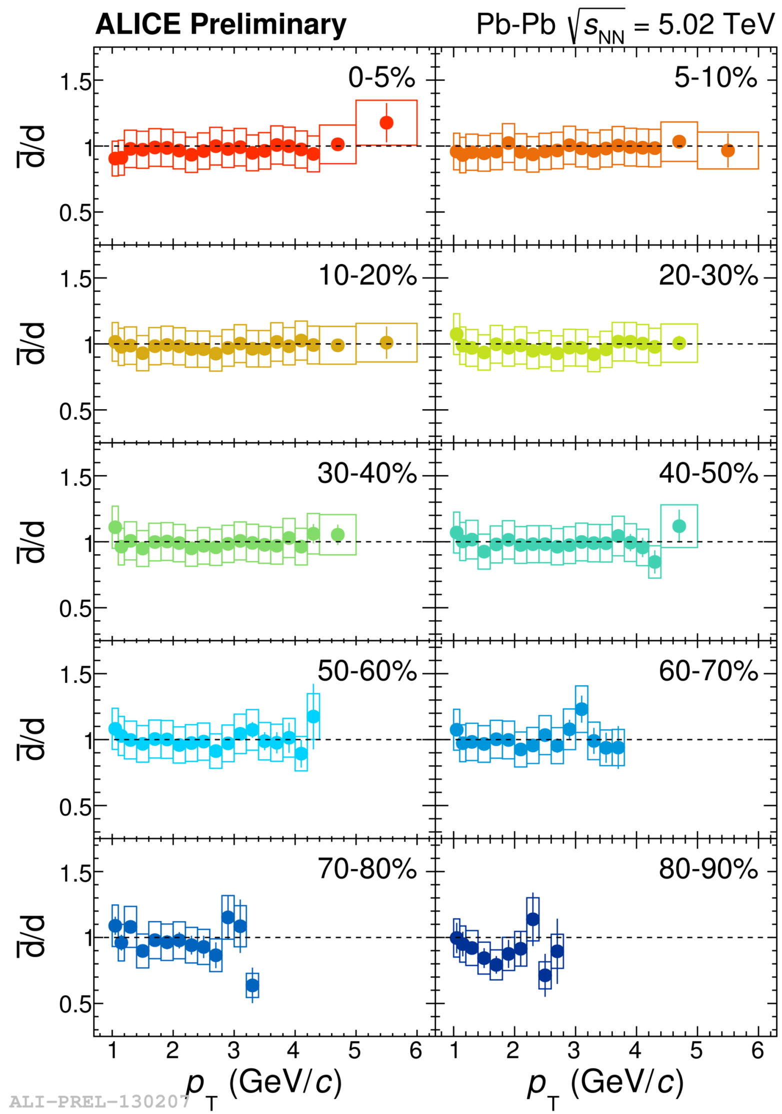
# ANTI-NUCLEI PRODUCTION

- Anti-nuclei / nuclei ratios are consistent with unity (similar to other light flavour species)
- Ratios exhibit constant behavior as a function of $p_T$ and centrality
- Ratios are compatible with unity, in agreement with the coalescence and thermal model expectations
- Also in pp multiplicity intervals, anti-deuterons and deuterons are produced equally




ALI-PREL-136458

ALICE-PUBLIC-2017-006



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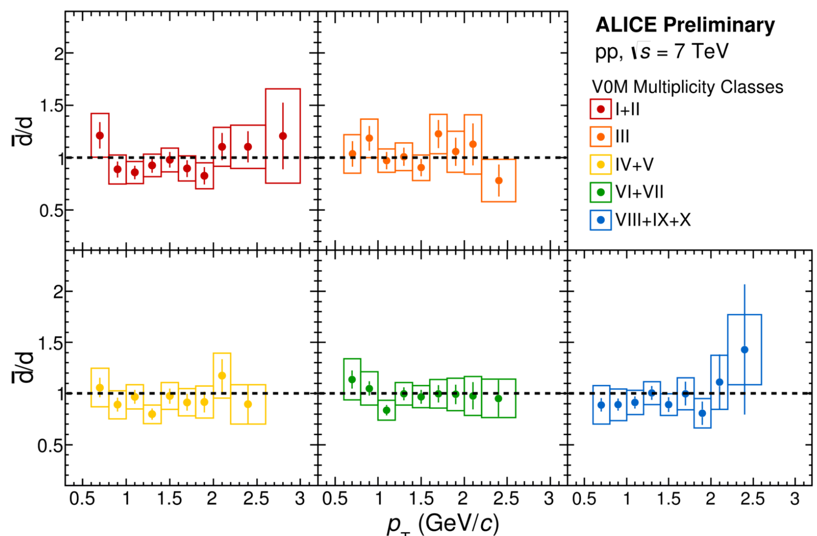
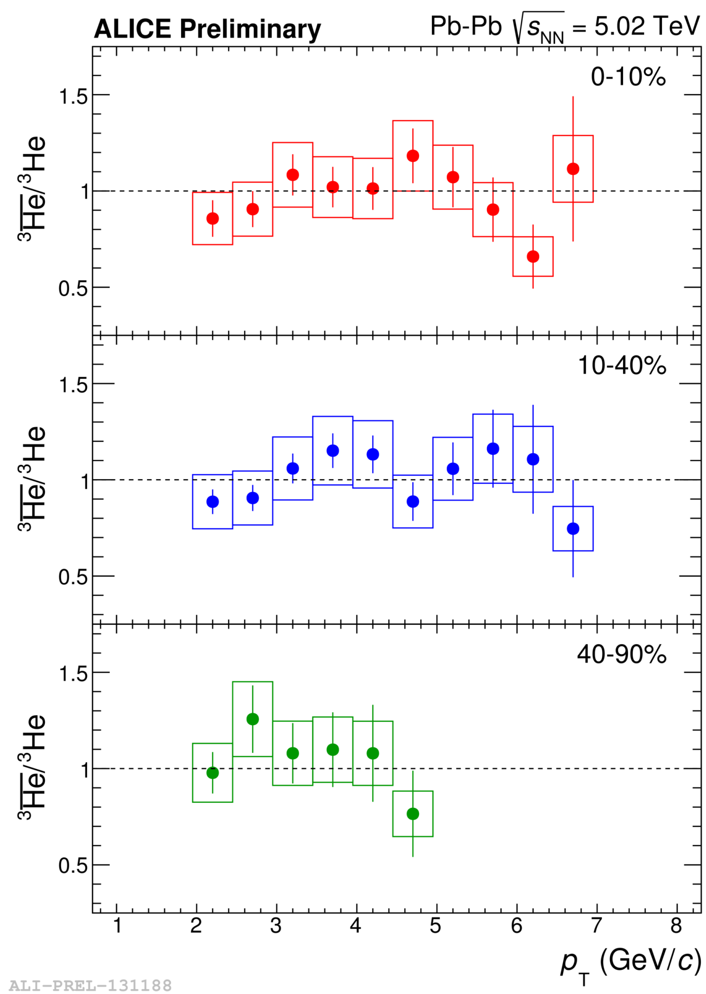
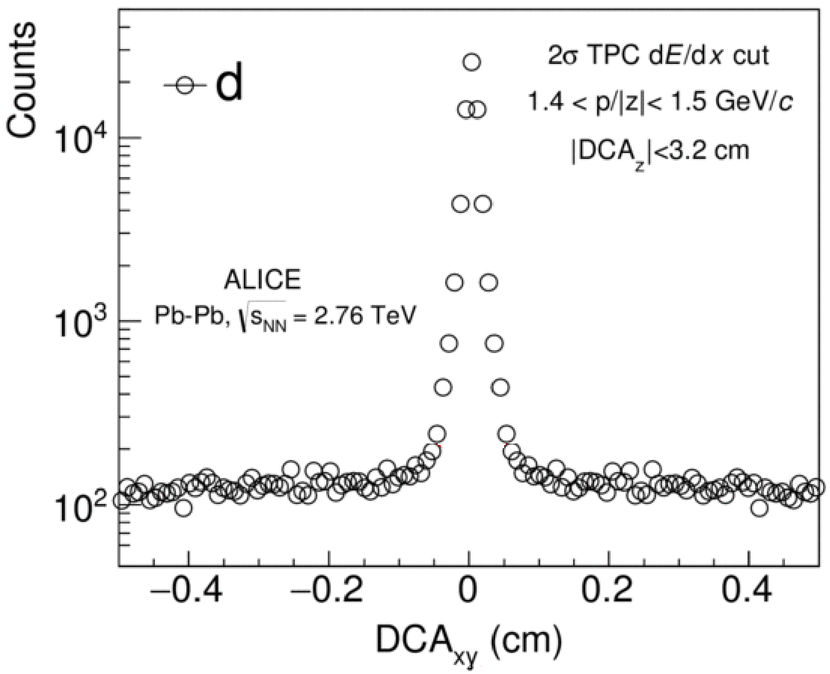
**ALICE-PUBLIC-2017-006**

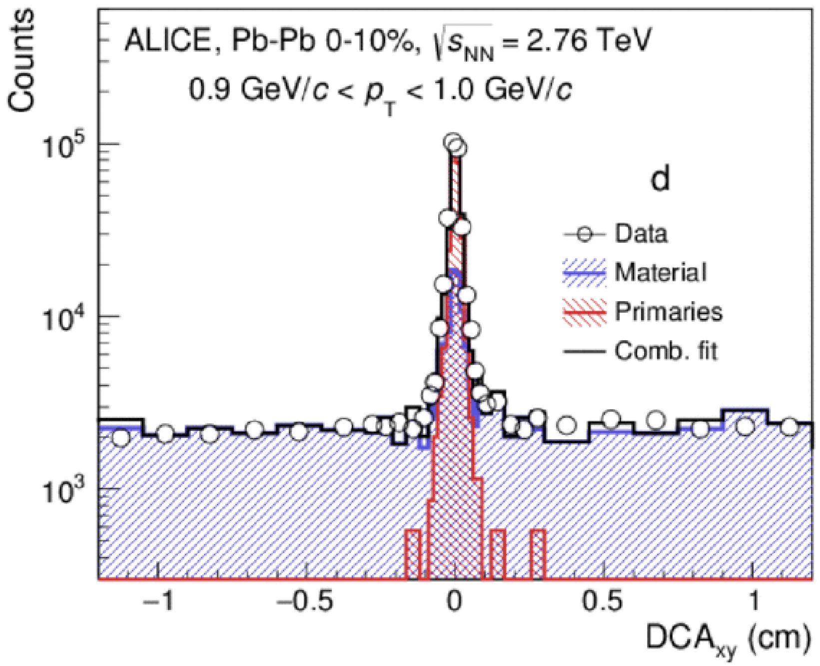


# SECONDARY CONTAMINATION

- The measurement of nuclei is strongly affected by background from knock-out from material
- Rejection is possible by fitting the $DCA_{XY}$ distributions with templates



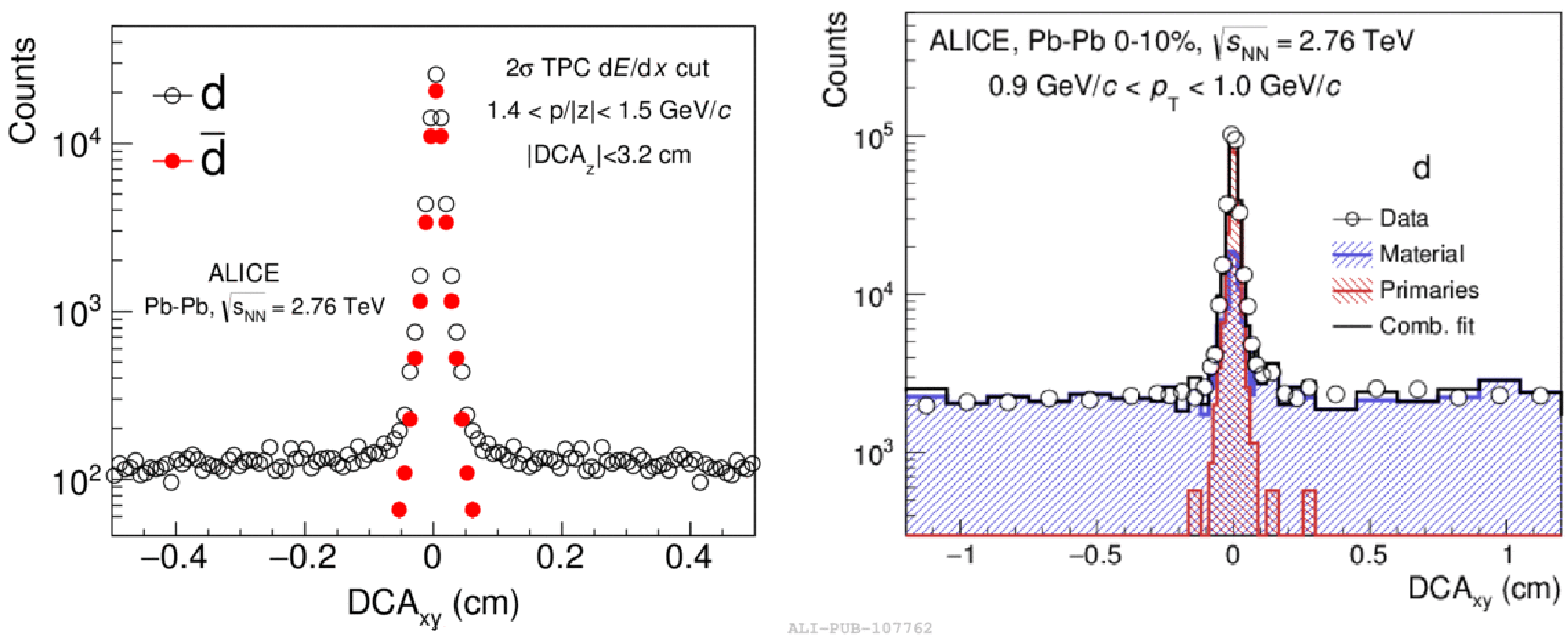




LI-PUB-107762

# SECONDARY CONTAMINATION

ALICE

- The measurement of nuclei is strongly affected by background from knock-out from material
- Rejection is possible by fitting the $DCA_{XY}$ distributions with templates
- Not relevant for anti-nuclei. However, their measurement suffers from large systematics related to unknown hadronic interaction cross-sections of anti-nuclei in material



ALICE

# Λn AND H-DIBARYON SEARCH

**H-Dibaryon:** hypothetical *udsuds* bound state

- First predicted by Jaffe [Jaffe, PRL 38, 195617 (1977)]
- Several predictions of bound and also resonant states.
- Recent Lattice models predict weakly bound states [Inoue et al., PRL 106, 162001 (2011), Beane et al., PRL 106, 162002 (2011)]

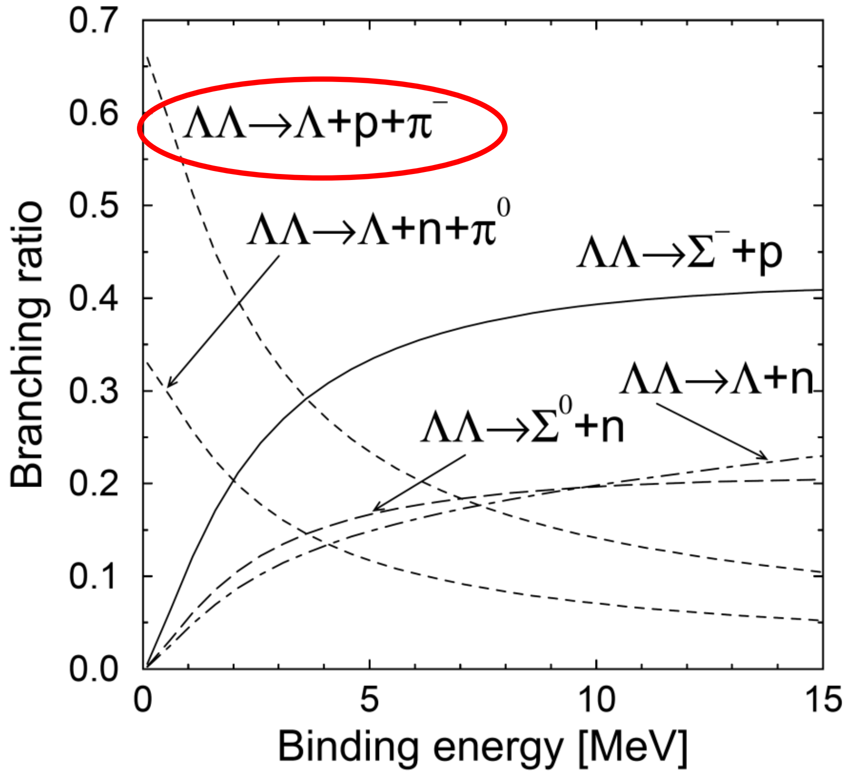
**If H-Dibaryon is bound:** $m_H < \Lambda\Lambda$ threshold

- measurable channel H → Λpπ but BR depends on binding energy

Bound state of **Λn** ?

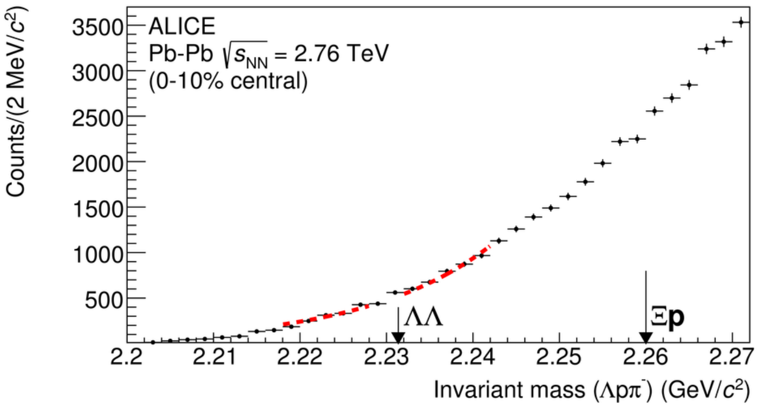
- HypHI experiment at GSI sees evidence of a

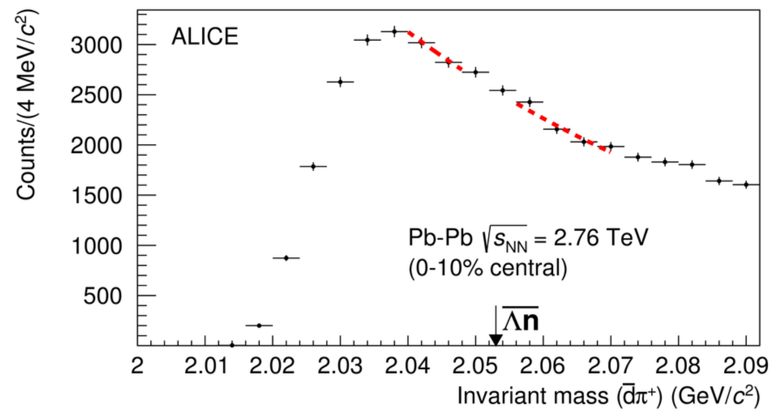
new state: **Λn → d + π⁻** [C. Rappold et al. (HypHI collaboration), Phys. Rev. C88, 041001(R) (2013)]



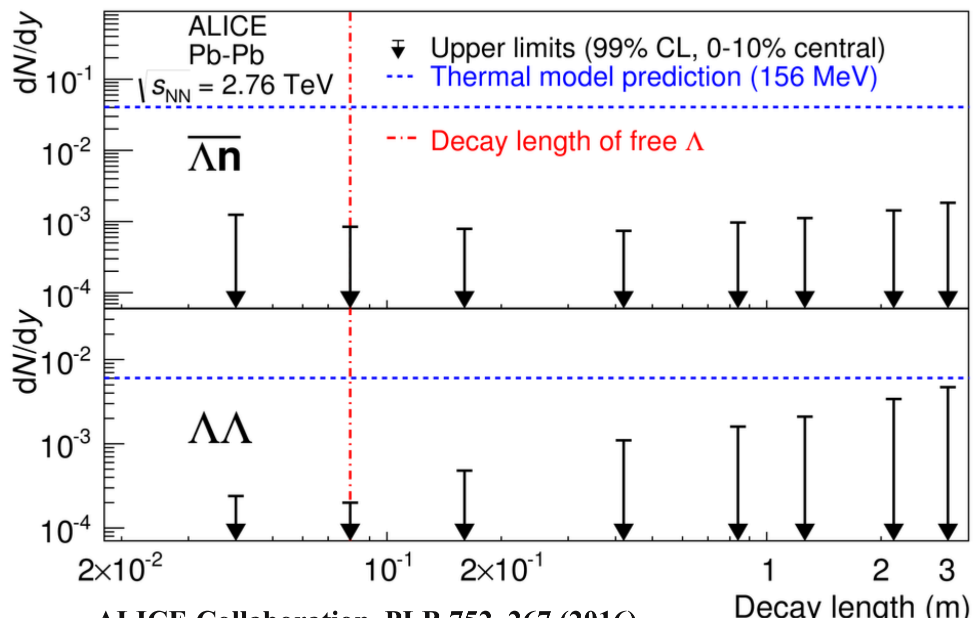

**Schaffner-Bielich et al., PRL 84, 4305 (2000)**

# $\Lambda$n AND H-DIBARYON SEARCH



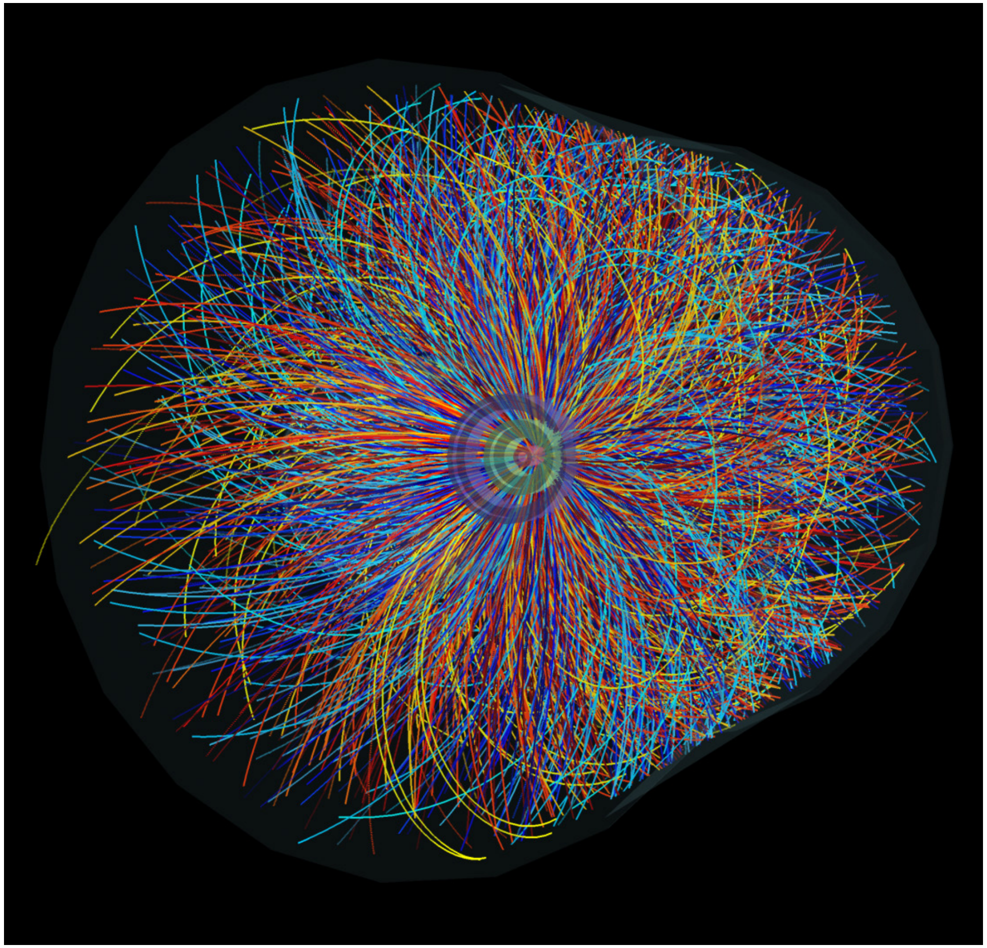

- No signal visible
- The upper limits for exotica are lower than the thermal model expectation by a factor 20
- Thermal models with the same temperature describe precisely the production yield of deuterons, $^3$He and $^3_\Lambda$H
- The existence of such states with the assumed B.R., mass and lifetime is questionable



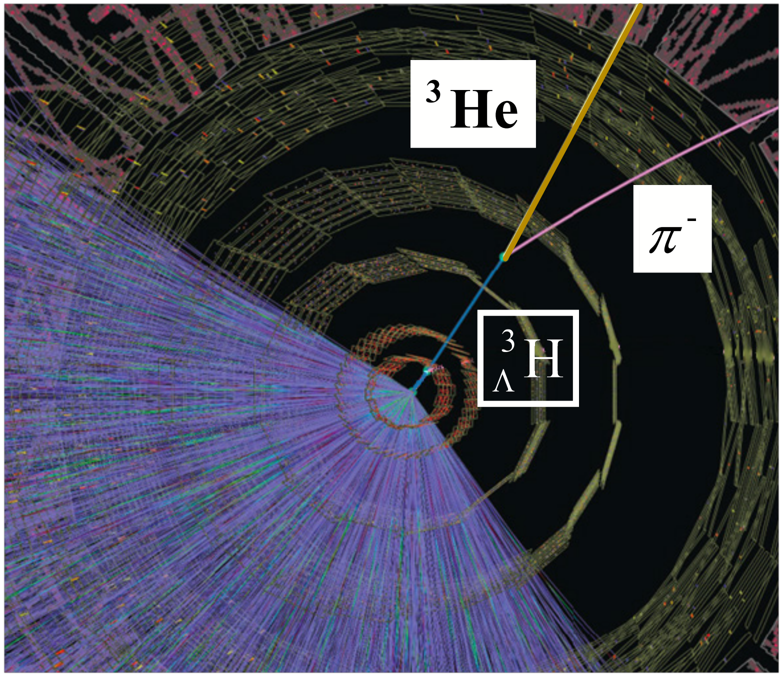

ALICE Collaboration, PLB 752, 267 (2016)

# THE EXPERIMENTAL CHALLENGE

The challenge: extract the $^{3}_{\Lambda}H$ signal from an overwhelming background



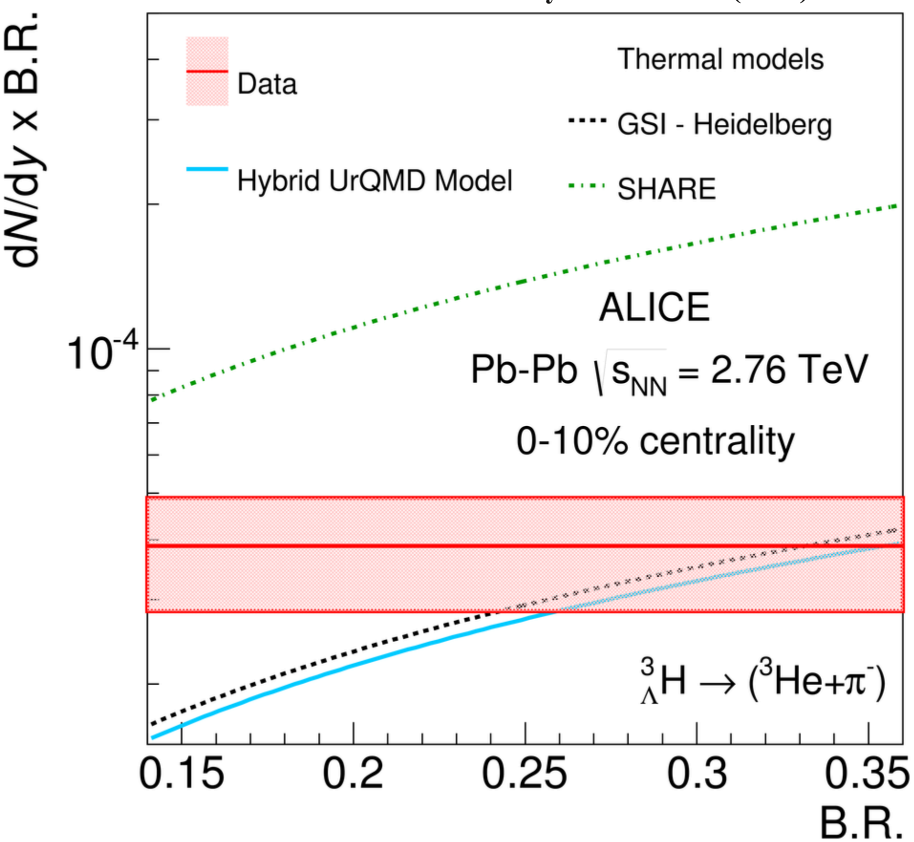
| At $\sqrt{s_{NN}}$ = | 2.76 TeV | 5.02 TeV |
|---|---|---|
| Centrality | $dN_{ch}/d\eta$ ($\|\eta\| < 0.5$) | |
| 0-5 % | 1601 ± 60 | 1943 ± 54 |




K. Aamodt et al. (ALICE Collaboration) Phys. Rev. Lett. 106, 032301 (2011) ; J. Adam et al (ALICE Collaboration) Phys. Rev. Lett. 116, 222302 (2016)

# COMPARISON WITH THEORETICAL PREDICTIONS

Phys. Lett. B 754 (2016) 360-372



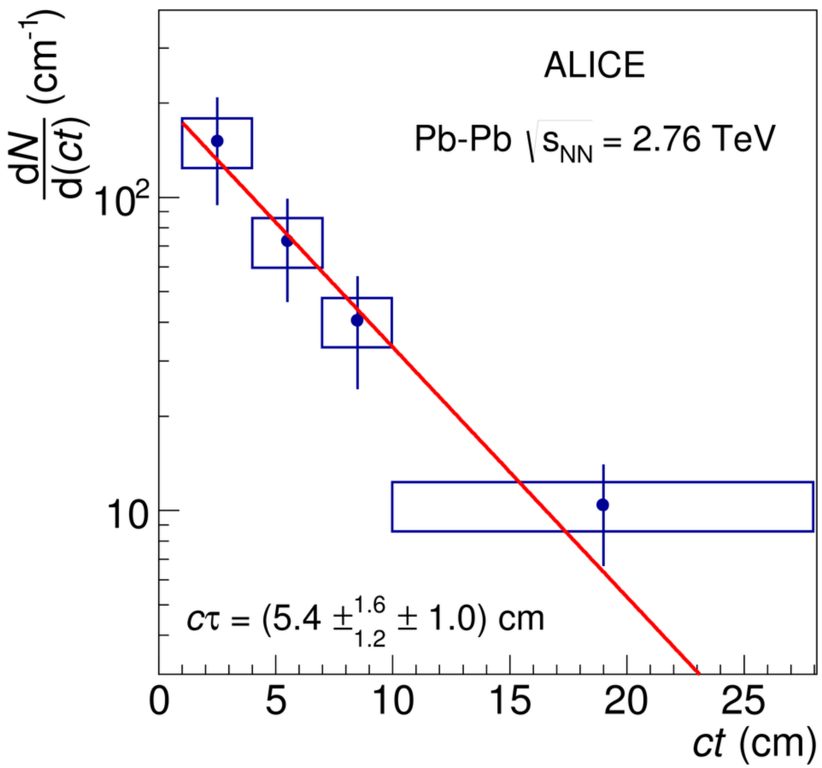

Three different theoretical predictions drawn as a function of BR($^{3}_{\Lambda}H \rightarrow {}^{3}He+\pi^{-}$) after being multiplied by BR:

- ✓ **Hybrid UrQMD**: combines the hadronic transport approach with an initial hydrodynamical stage for the hot and dense medium (**J. Steinheimer et al., Phys. Lett. B 714, 85 (2012)**)
- ✓ **GSI-Heidelberg**: equilibrium statistical model with $T_{chem}$=156 MeV (**A. Andronic et al., Phys. Lett. B 697, 203 (2011)**)
- – **SHARE**: non-equilibrium thermal model with $T_{chem}$=138.3 MeV (**M. Petráň et al., Phys. Rev. C 88, 034907 (2013)**)

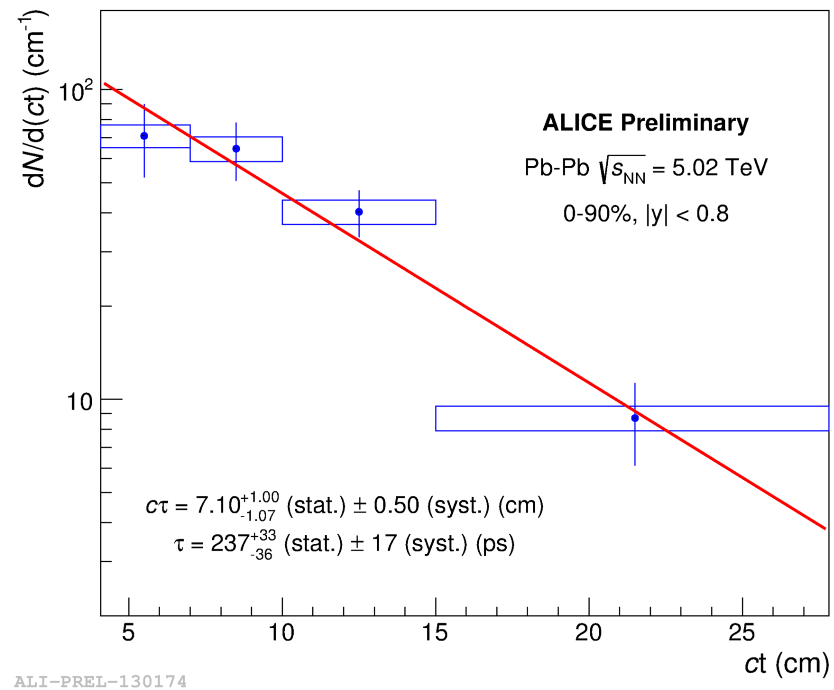
- Great sensitivity to theoretical models parameters
- Non–equilibrium statistical thermal model (Petráň-Rafelski SHARE) provides better global fitting ($\chi^2$~1) to lower mass hadrons but **misses $^{3}_{\Lambda}$H** and light nuclei
- Experimental data closest to equilibrium thermal model with $T_{chem}$ = 156 MeV and to Hybrid UrQMD

# HYPERTRITON LIFETIME DETERMINATION

Phys. Lett. B 754 (2016) 360-372




**New preliminary results at $\sqrt{s_{NN}}$ = 5.02 TeV**




$$c\tau = \left(5.4^{+1.6}_{-1.2}(stat.) \pm 1.00(syst.)\right) cm$$
$$\tau = \left(181^{+54}_{-39}(stat.) \pm 33(syst.)\right) ps$$

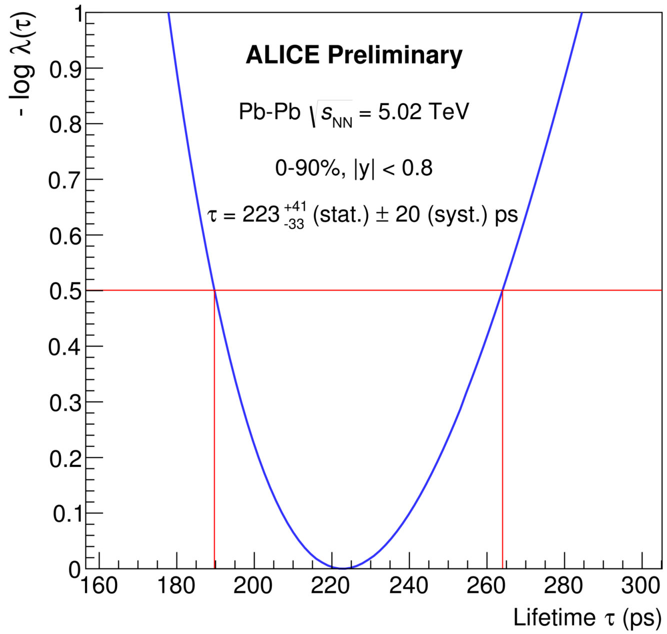
$$c\tau = \left(7.10^{+1.00}_{-1.07}(stat.) \pm 0.50(syst.)\right) cm$$
$$\tau = \left(237^{+33}_{-36}(stat.) \pm 17(syst.)\right) ps$$

# HYPERTRITON LIFETIME DETERMINATION

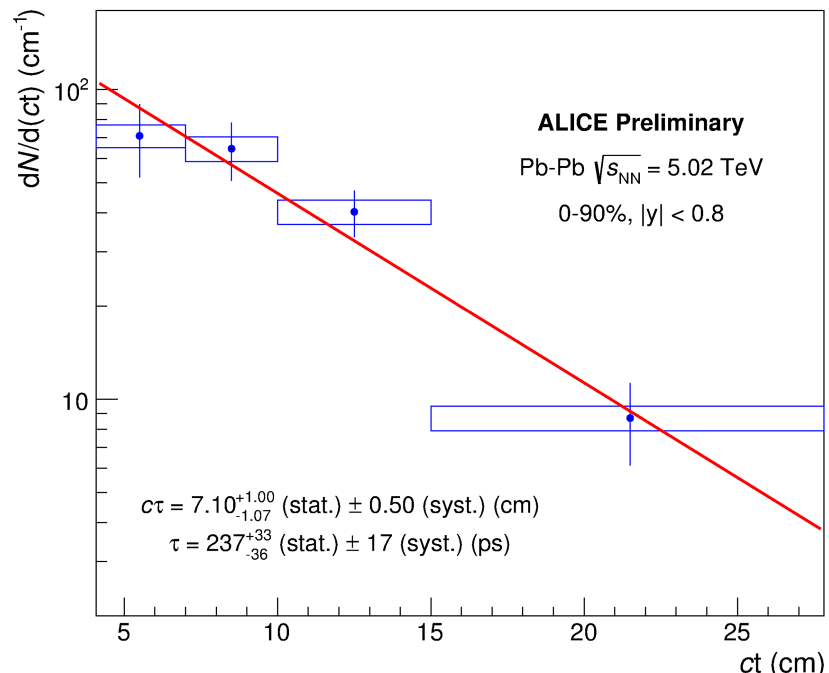
Two methods for estimation:

- *ct* spectra fit (exponential fit to the differential yield in different *ct* bins)
- *ct* unbinned fit as crosscheck method

**New preliminary results at $\sqrt{s_{NN}}$ = 5.02 TeV**




ALI-PREL-130191




ALI-PREL-130174

$$c\tau = \left(7.10^{+1.00}_{-1.07}(stat.) \pm 0.50(syst.)\right) cm$$

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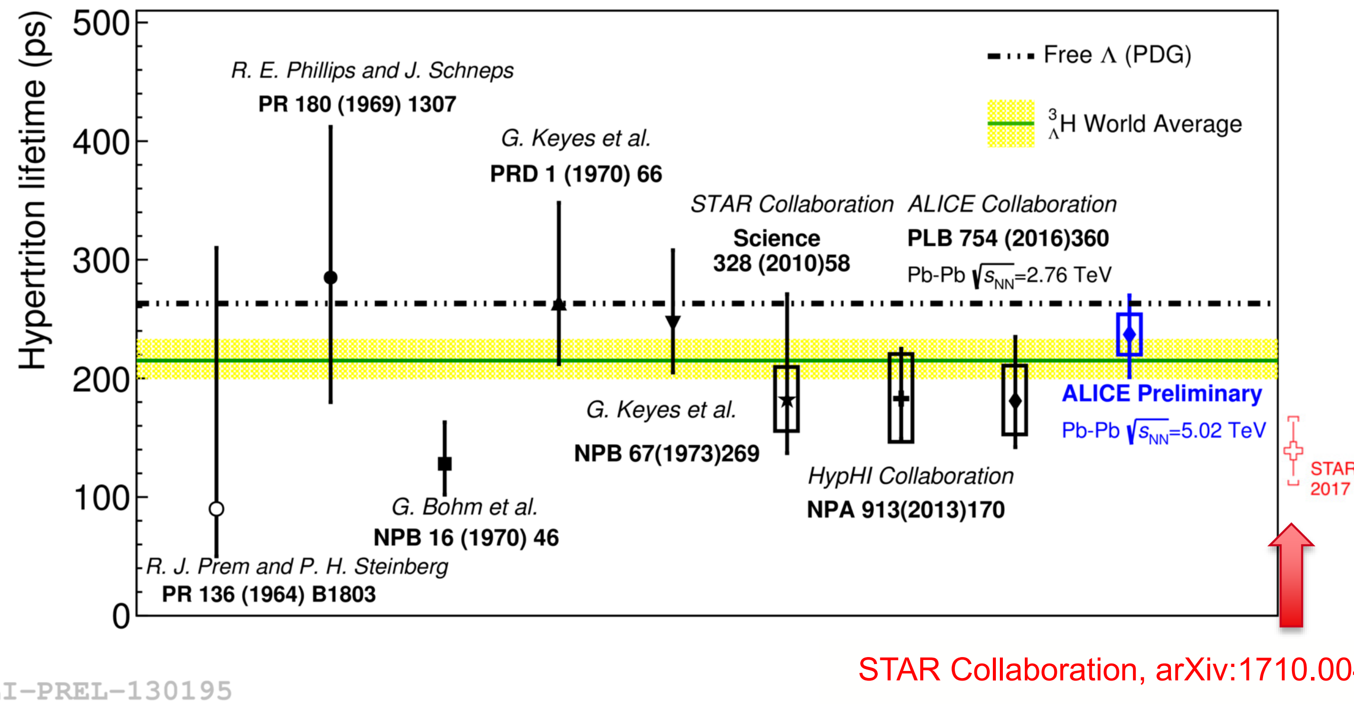
# HYPERTRITON LIFETIME WORLD AVERAGE

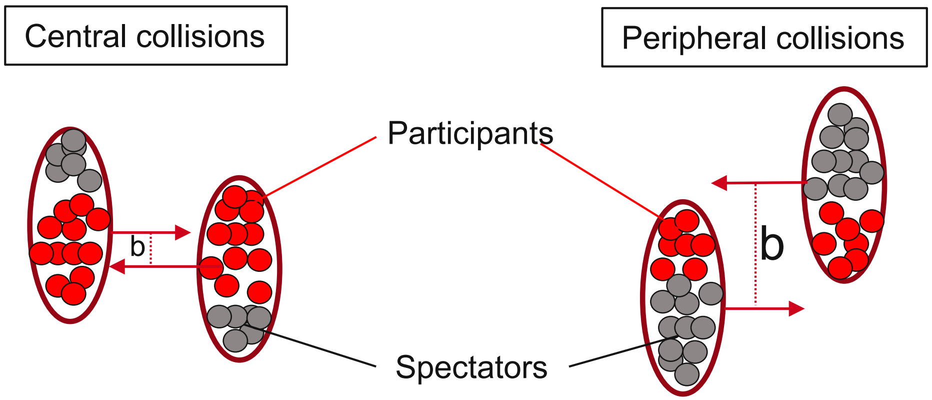


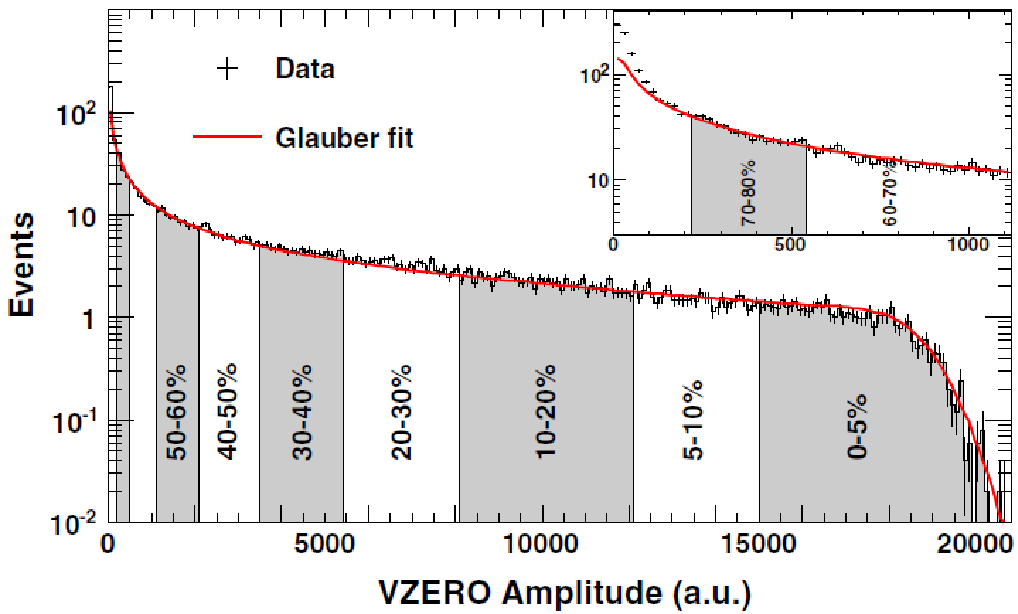

STAR Collaboration, arXiv:1710.00436v1 [nucl-ex]

$$\tau = \left(142^{+24}_{-21}(stat.) \pm 31(syst.)\right) ps$$

- Previous heavy-ion experiment results show a trend well below the free Λ lifetime
- ALICE preliminary result from Pb-Pb at 5.02 TeV is closer to the free Λ lifetime
- STAR result from Au-Au collision is about 50% shorter than the free Λ lifetime
- The puzzle of the $^{3}_{\Lambda}$H lifetime is still open

# COLLISION GEOMETRY




K. Aamodt et al. (ALICE Collaboration), Phys. Rev. Lett. 106, 032301 (2011)

- Nuclei are extended objects
- Geometry not directly measurable
- Centrality (percentage of the total cross section of the nuclear collision) connected to observables via Glauber model

- Data classified into centrality percentiles for which the average impact parameter, number of participants, and number of binary collisions can be determined