(Anti-)matter and hyper-matter production at the LHC with ALICE

TECHNISCHE UNIVERSITÄT DARMSTADT

Nicole Martin for the ALICE Collaboration

INTERNATIONAL WORKSHOP ON DISCOVERY PHYSICS AT THE LHC KRUGER 2012
03.12.2012

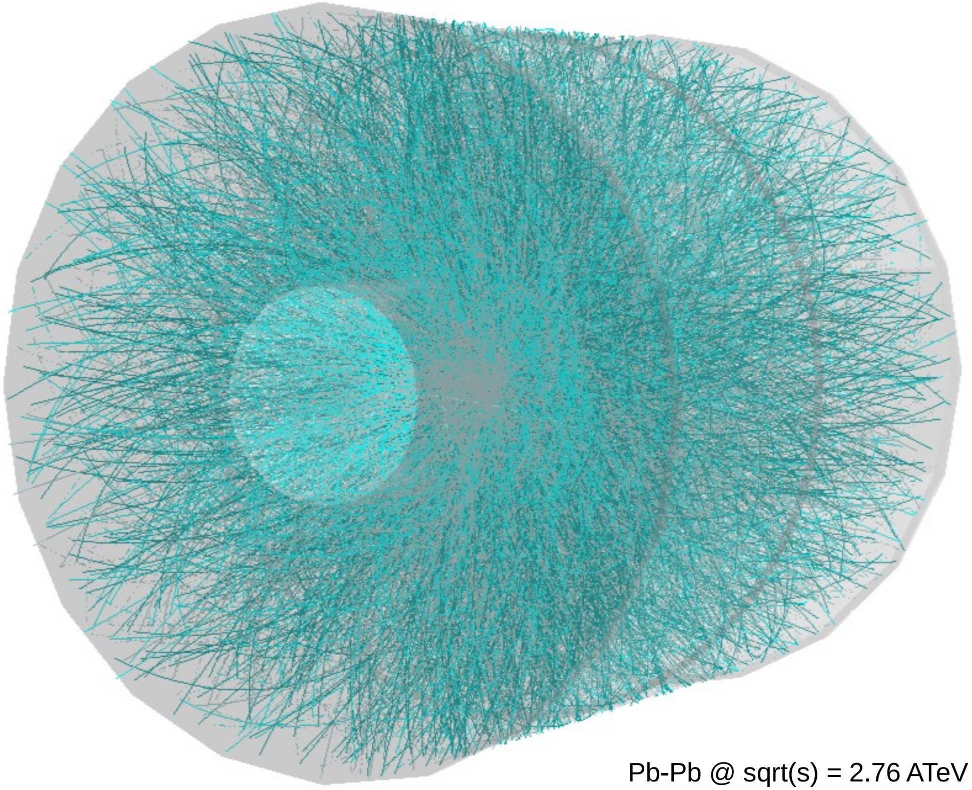
ALICE

H-QM Helmholtz Research School Quark Matter Studies

EMMI

Outline

- Motivation
- The ALICE detector system
  - Particle Identification
- Anti-nuclei
  - $^{3}\overline{He}$, $^{4}\overline{He}$
- (Anti-)Hypertriton
- Exotic bound states
  - Λn bound state
  - H-Dibaryon (ΛΛ)



Pb-Pb @ sqrt(s) = 2.76 ATeV

Motivation

Motivation

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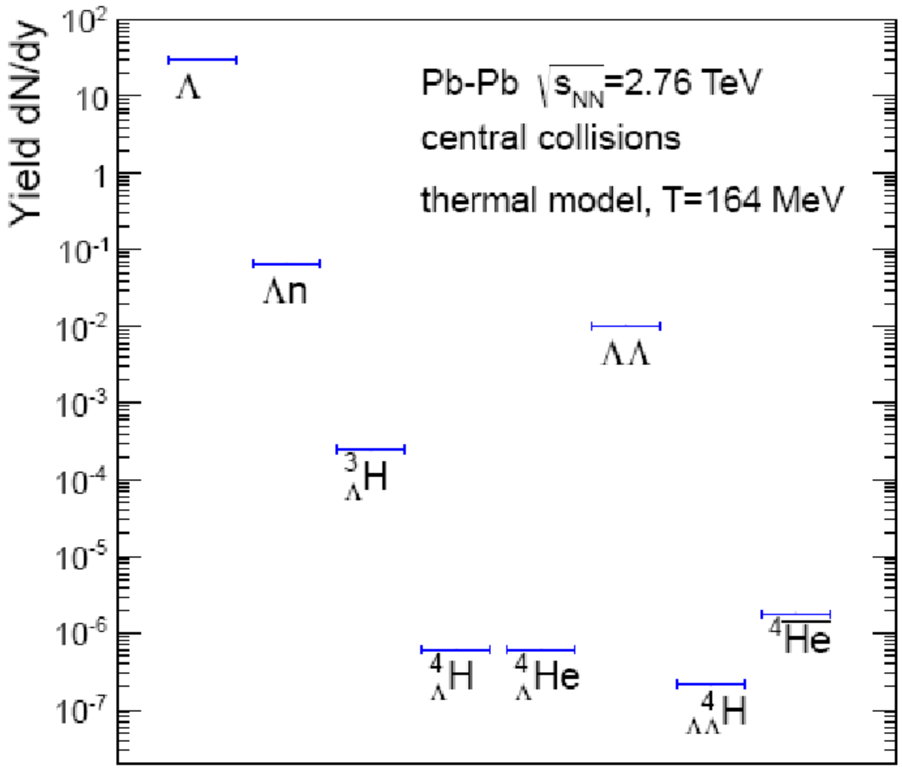
- Explore QCD predictions for unusual multi-baryon states
- Search for rarely produced anti- and hyper-matter
- Test thermal model predictions

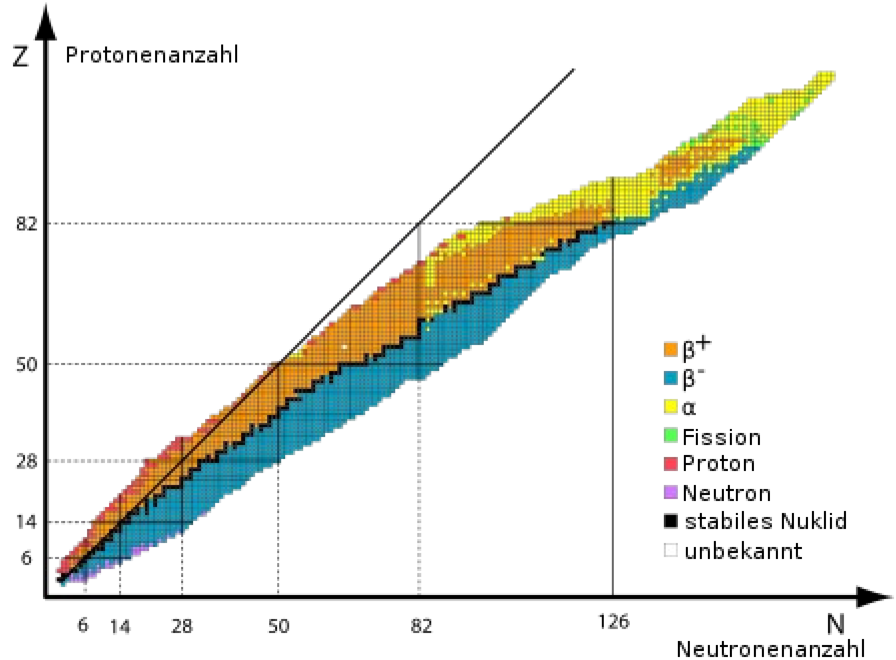


A.Andronic, private communication, model described in Andronic *et a*l., PLB 697, 203 (2011) and references therein

Table of nuclides

Table of nuclides well explored - from the valley of stability to the boundaries and the heaviest elements

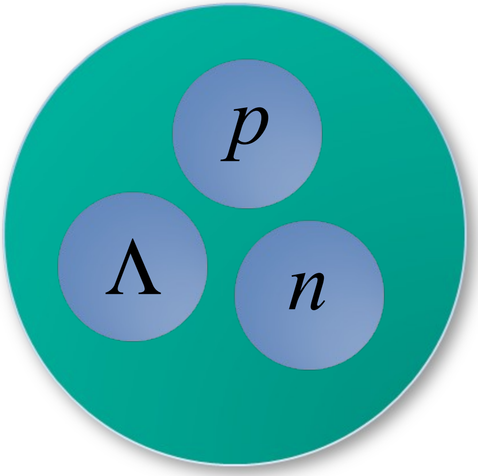
In high energy nuclear physics experiments like ALICE, we have the unique possibility to study also the production of the corresponding anti-nuclei in pp and
- in particular –
in Pb-Pb collisions.



Compared to e.g. π, K, p these particles are only rarely produced and the production probability decreases quickly with increasing mass

Hyperons and hyper-nuclei

- Hyperons: Baryons, which have at least one s-quark as one of their 3 valence-quarks
  - for example Λ, Σ, Ξ, or Ω
- Hyper-nuclei: nuclei, in which at least one hyperon is bound in addition to the normal nucleons
- All hyperons are unstable, even if they are bound in a nucleus



Hyper-nuclei

- Hyper-nuclei (not anti-hyper-nuclei) have a long tradition in nuclear physics
- 1st Discovery in the 1950s by M. Danysz and J. Pniewski in a photographic emulsion exposed to cosmic rays

Polish Post in May 1993 (designer - Maciej Jedrysik)

http://fizjlk.fic.uni.lodz.pl/rut/stamps/HyperNuc/Hyp_Nuc.htm

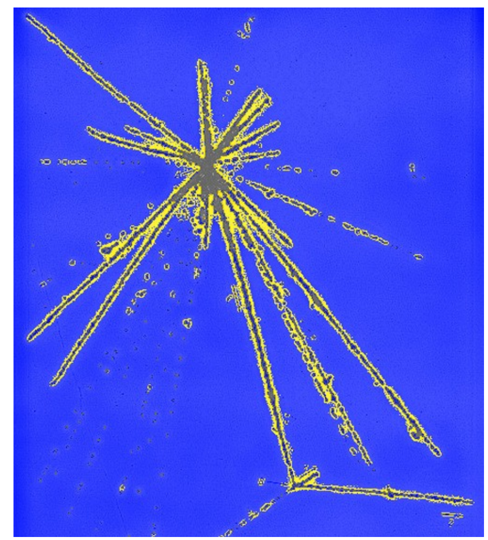


image credit: Danysz and Pniewski, Philosophical Magazine 44 348 (1953)

Source: http://www.particlephysics.ac.uk/news/picture-of-the-week/picture-archive/strange-nuclei.html

Extended table of nuclides

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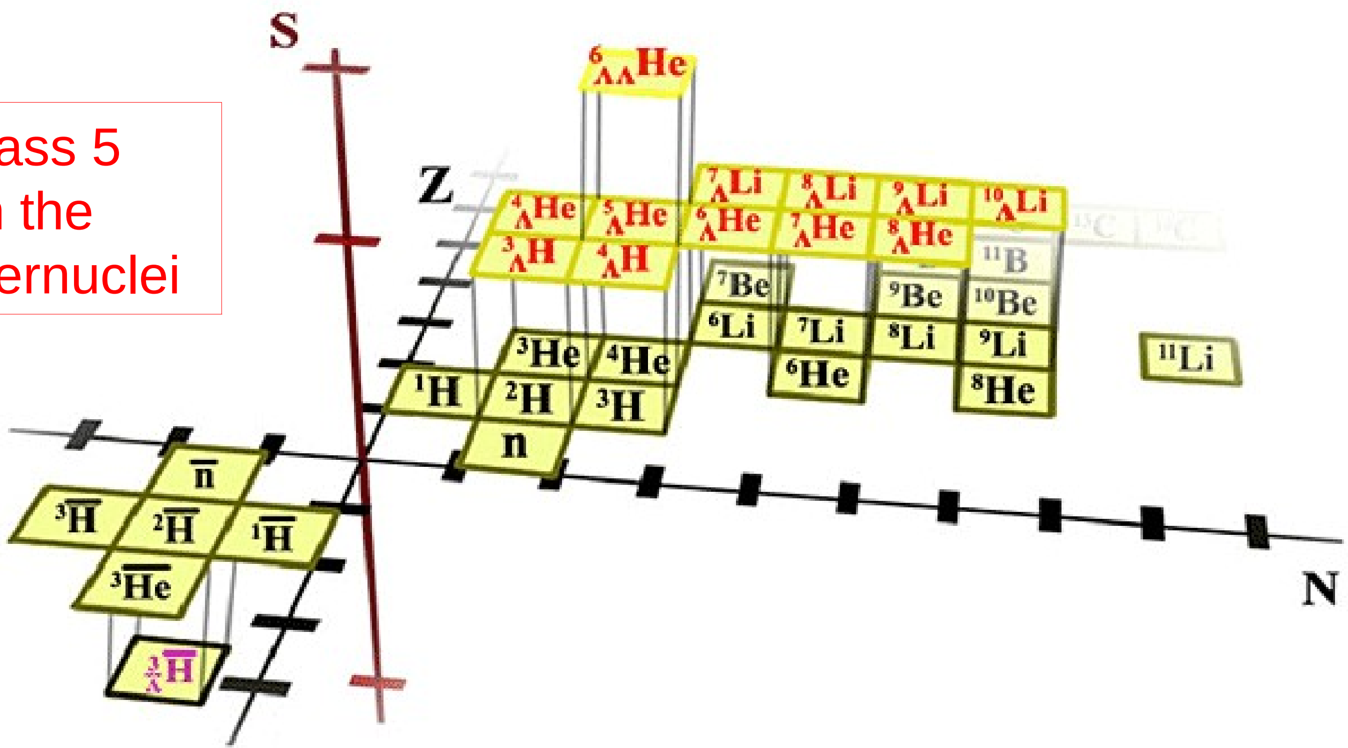
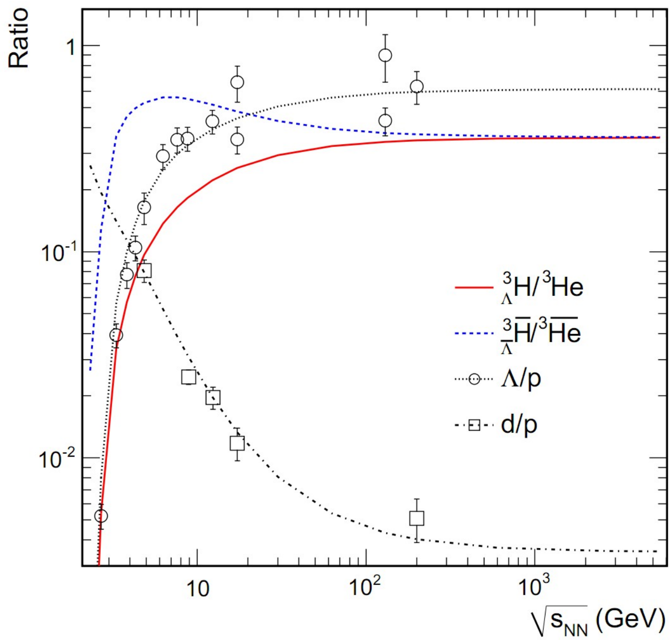
Nuclei of mass 5 only exist in the form of hypernuclei

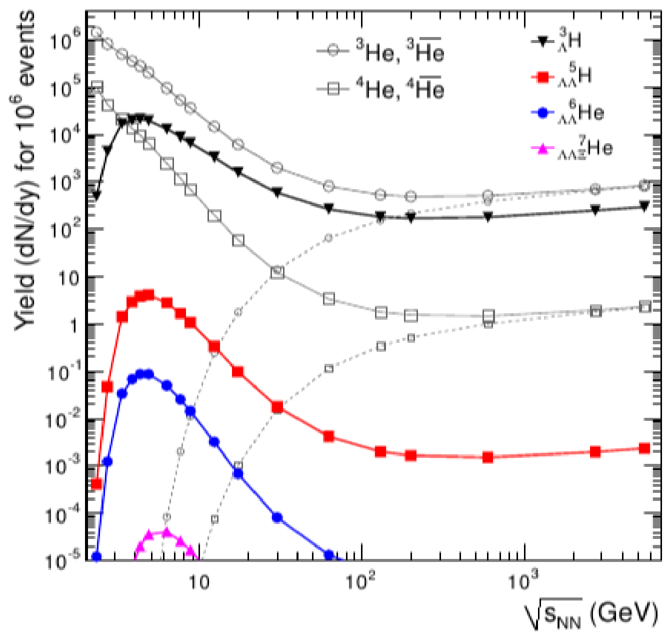


The STAR Collaboration, **Science 328, 58 (2010)**

Theory predictions

- Compare particle ratios and yields to theoretical predictions
- e.g.: Thermal model predictions
  (here for central Pb-Pb collisions)

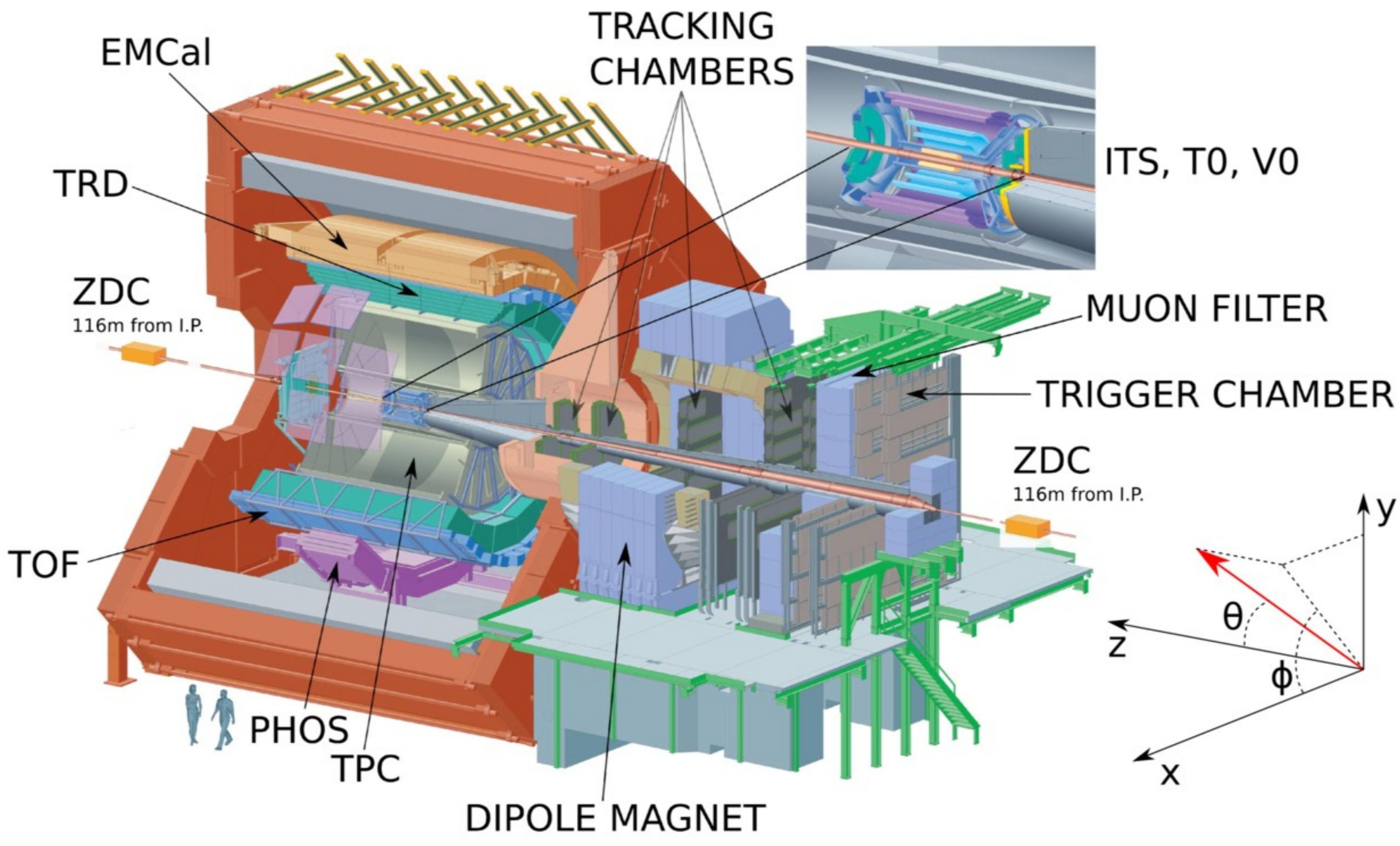




Andronic et al., PLB 697, 203 (2011)

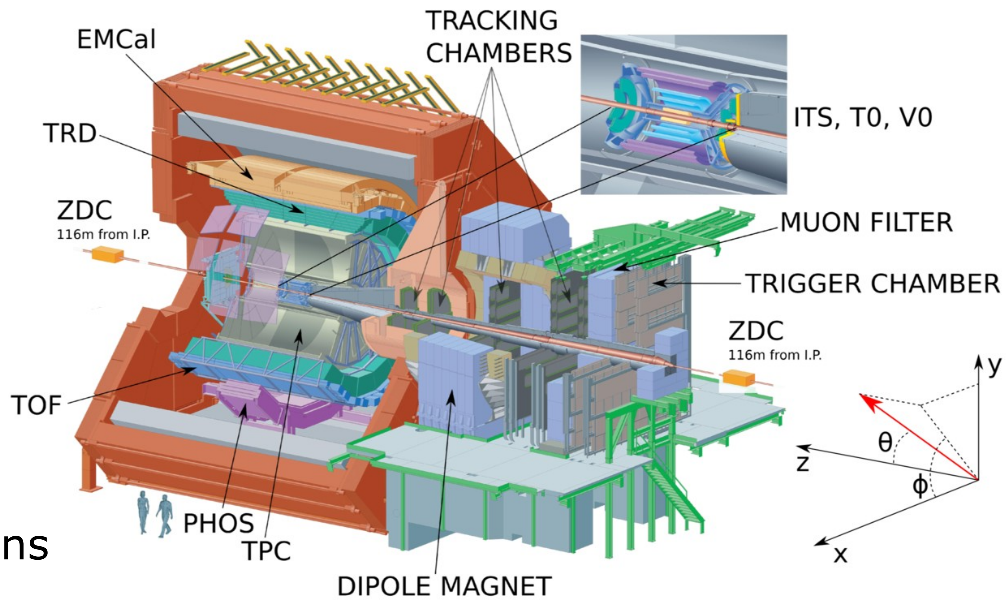
A Large Ion Collider Experiment
ALICE

ALICE detector system

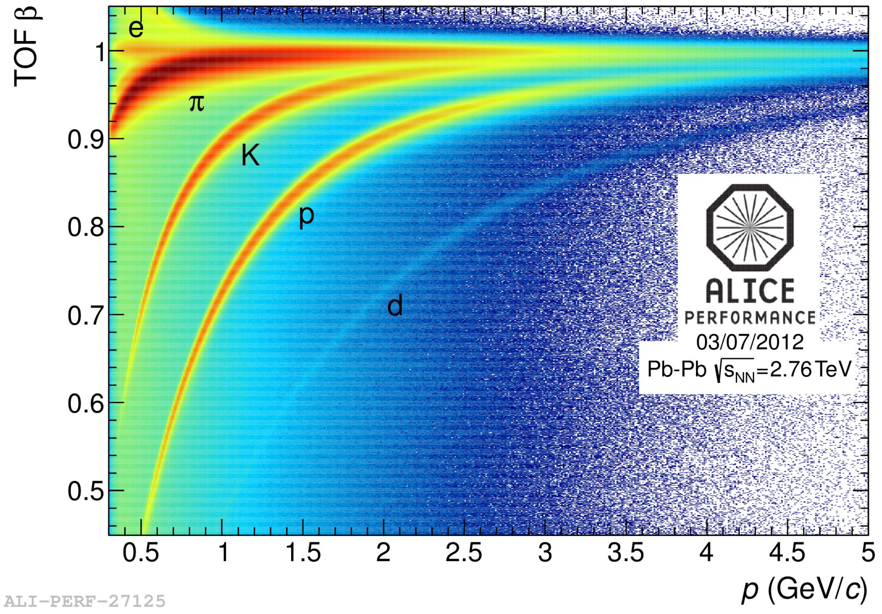


ALICE detector system

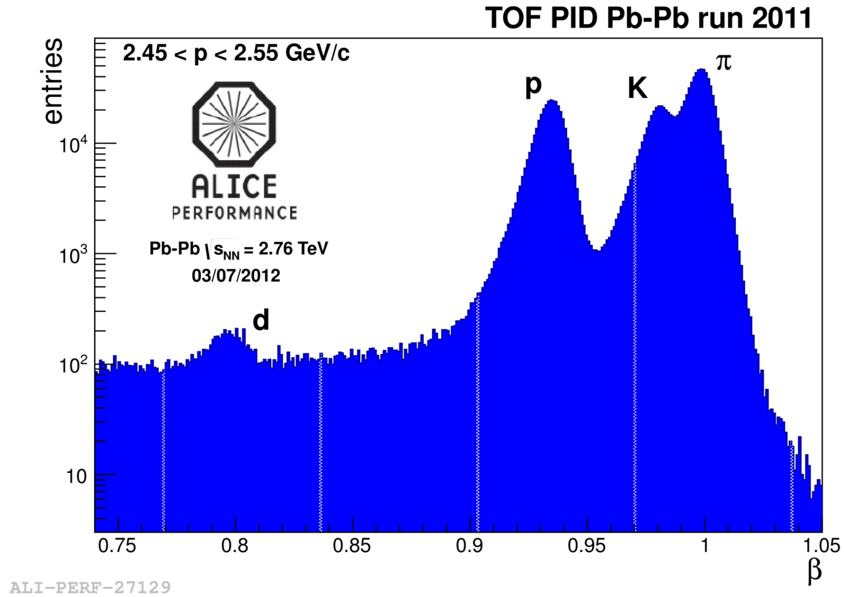
- Particle identification techniques involved:
- Energy loss (dE/dx) in TPC, at low and very high momenta (rel. rise), σ ≈ 5.2% (pp) -> 6.5% (2010)/7.2% (2011) resolution in central Pb-Pb collisions
- Time-Of-Flight, intermediate p_T, σ ≈ 85 ps (Pb-Pb) -> 120 ps (pp)
- Identification of particles via their decay topology



Particle Identification - TOF



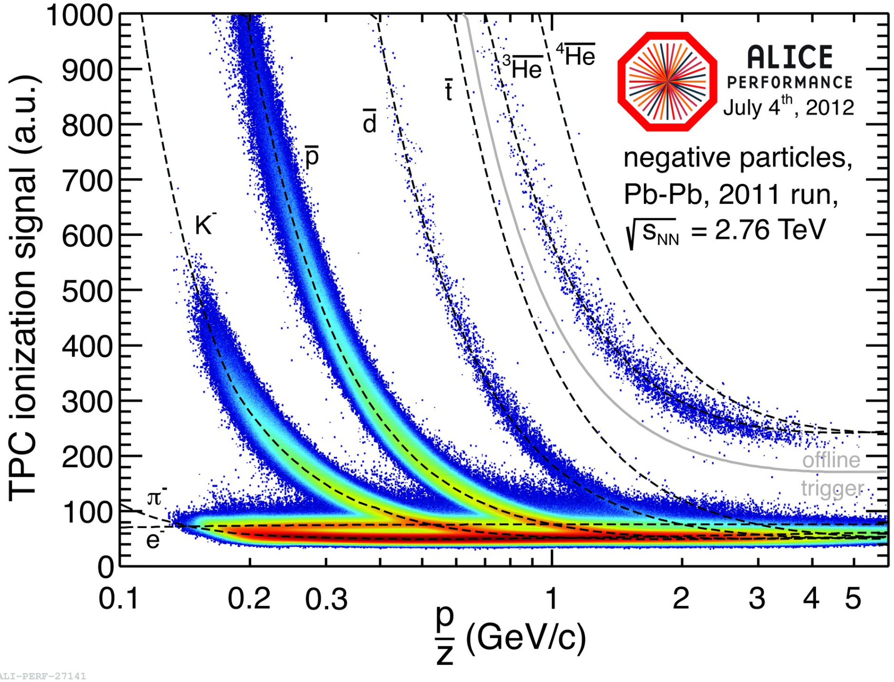
TOF performance is allowing a 2σ p/K-separation up to a momemtum of 5 GeV/*c*



Particle Identification - TPC

- Unique speciality of the ALICE experiment: continuous and precise particle identification and tracking from very low (100 MeV/*c*) to very hight p_T (20 GeV/*c*).

- Identification from the lightest (electron) to the heaviest (anti-nuclei) particles



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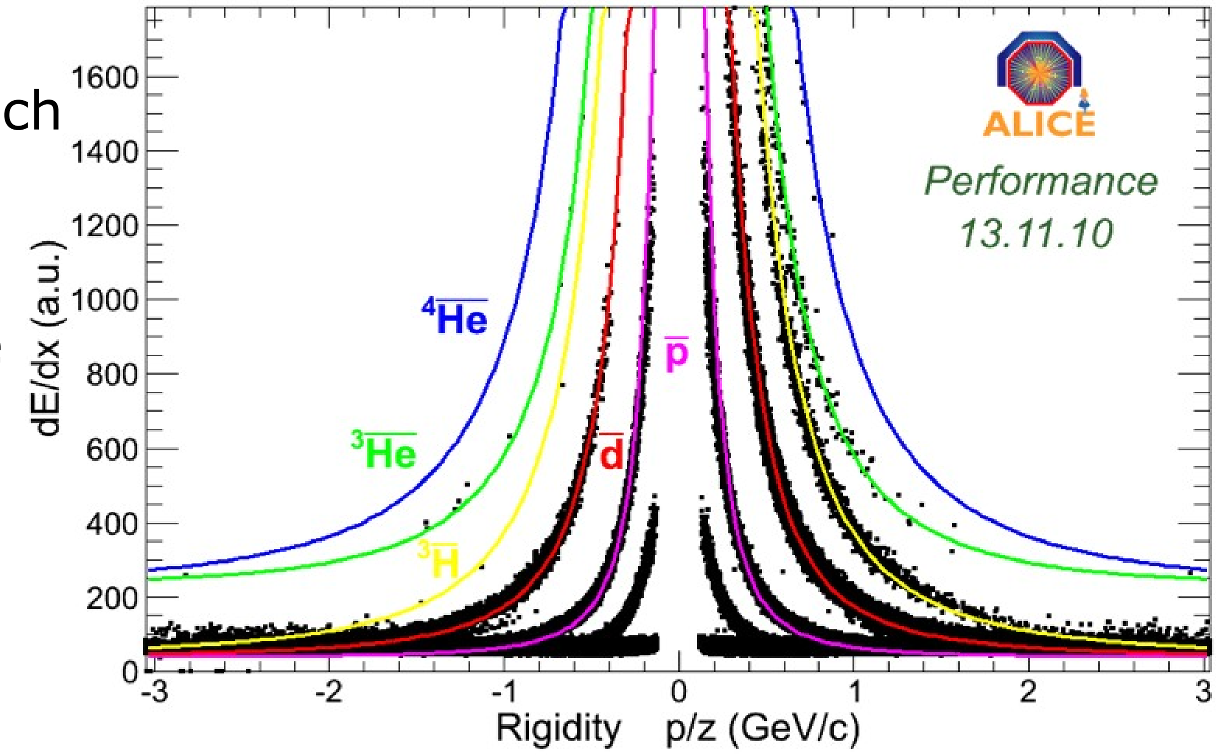
Anti-nuclei

Anti-particles in pp

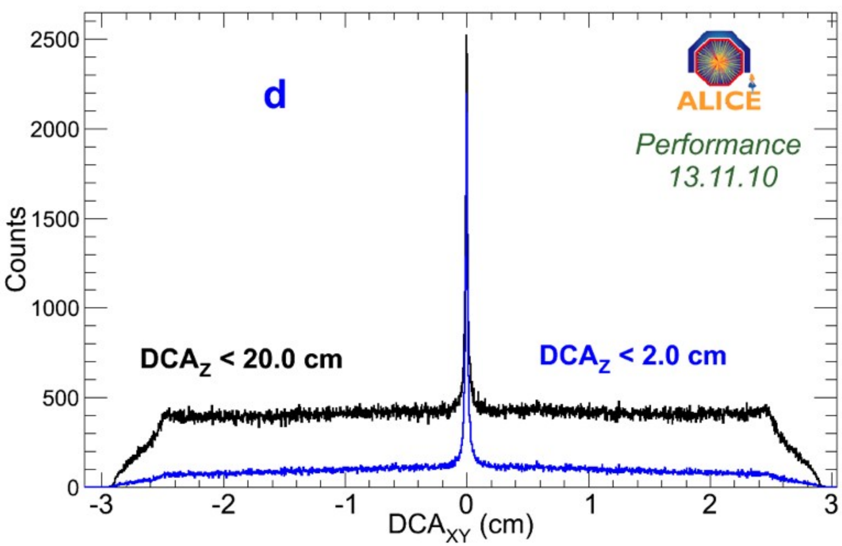
Light anti-particles such as anti-protons, -deuterons, -tritons up to anti-^{3}He are produced in pp collisions in a significant amount

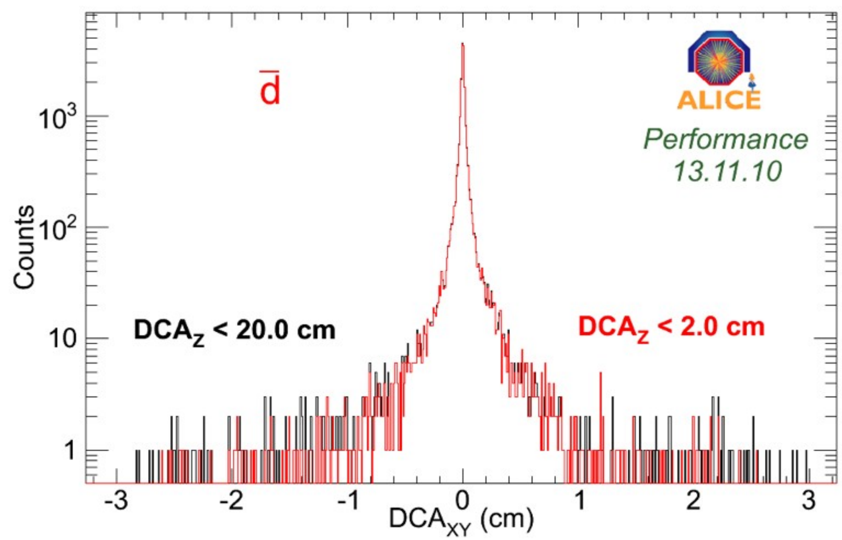


380 million events of pp @ 7 TeV collisions

Knock-out from material

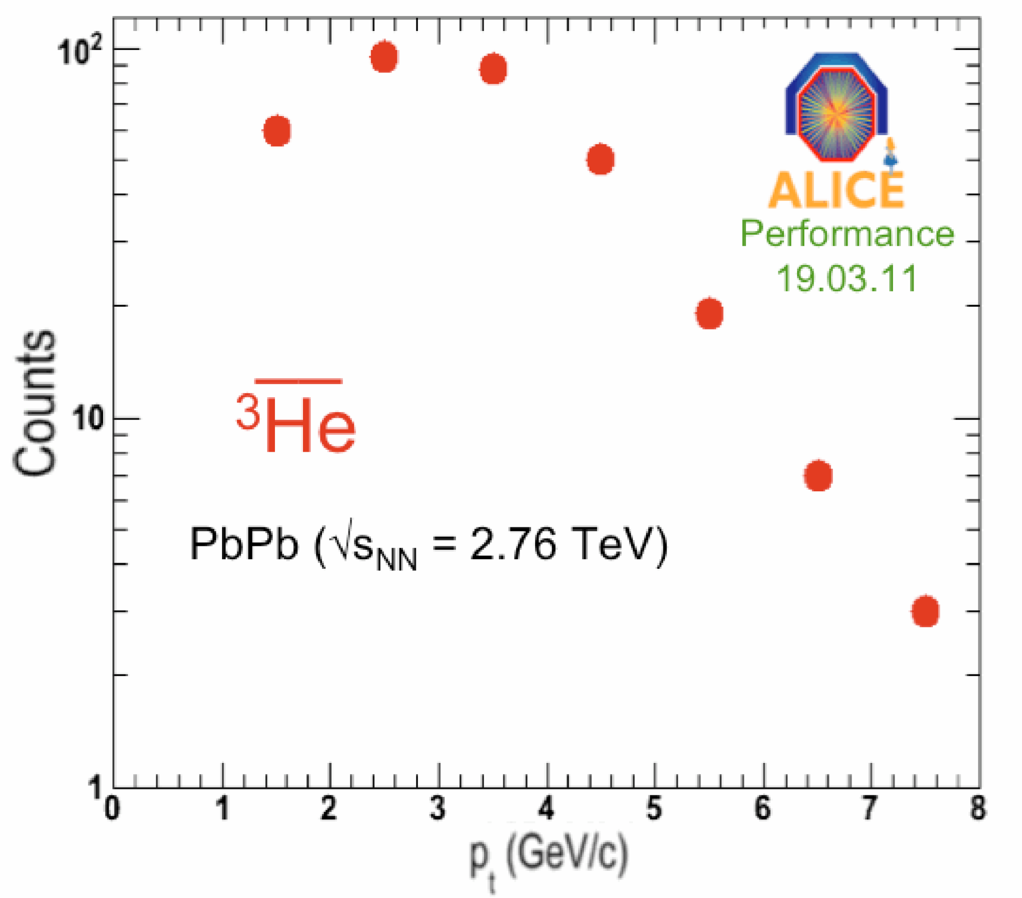
Search for anti-nuclei is often easier than the search for the corresponding nuclei for which knock-out from material is a significant problem at low p_T





Anti-3He in Pb-Pb

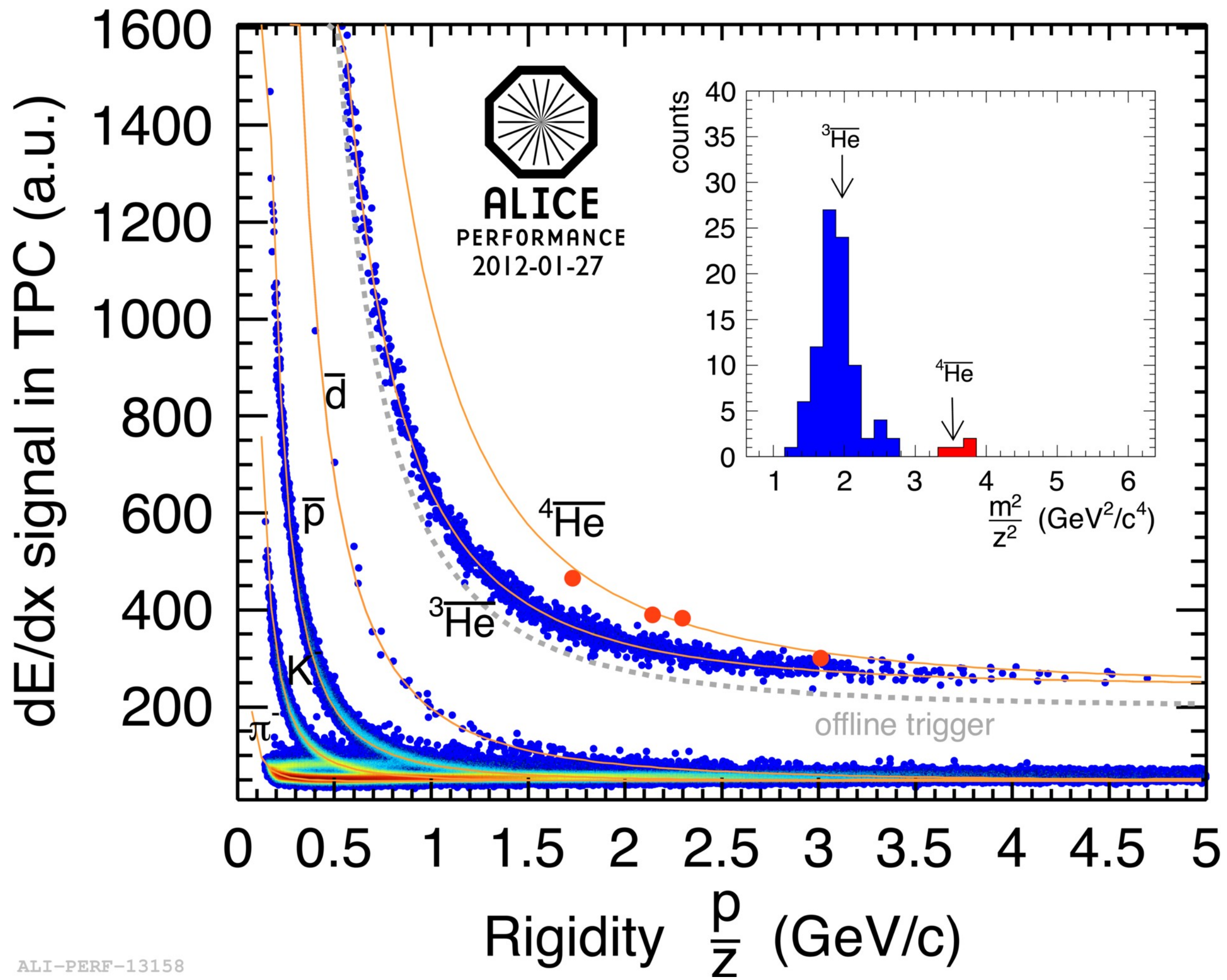
- Raw spectrum of anti-^{3}He reaches up to 8 GeV/c
- 2010 (13.8×10^6 min. bias events): ~ 330 anti-^{3}He
- expected from the data taking in 2011: ~ 5000 anti-^{3}He



Anti-Alpha in Pb-Pb

In 2010 data we clearly identified four Anti-Alphas by combining TPC and TOF information

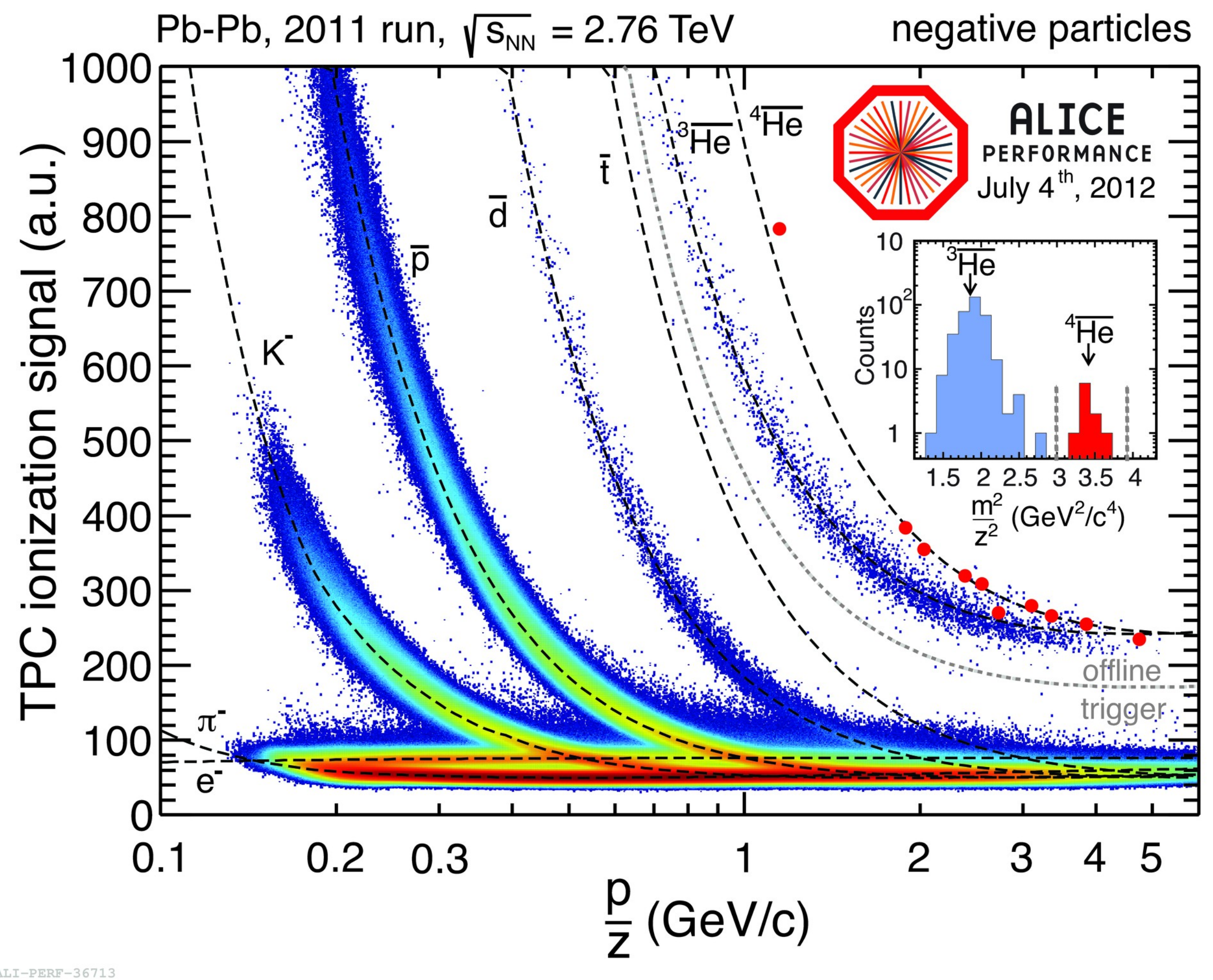
Full statistics 2010 ($13.8x10^6$ min. bias events)



Anti-Alpha in Pb-Pb

For the full statistics of 2011 we identified 10 Anti-Alphas using TPC and TOF

Corresponds to $23x10^6$ events of a trigger mix (central, semi-central and min. bias)



(Anti-)Hypertriton

Hypertriton

- Decay topology is similar to a V0 decay

- Identification of light nuclei which are daughter tracks originating from decay vertices

$$m\left(\overline{{}^{3}_{\Lambda}\mathrm{H}}\right) = 2.991 \pm 0.001 \pm 0.002\, GeV/c^{2}$$

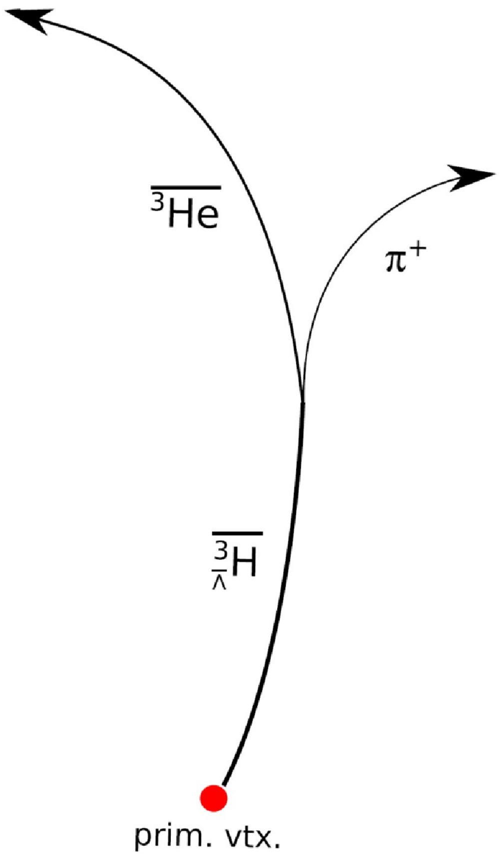
$$\text{decay length}\; c\tau = 5.5^{+2.7}_{-1.4} \pm 0.8\,\mathrm{cm}$$

$$\text{life time}\; \tau = 182^{+89}_{-45} \pm 27\,\mathrm{ps}$$

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

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

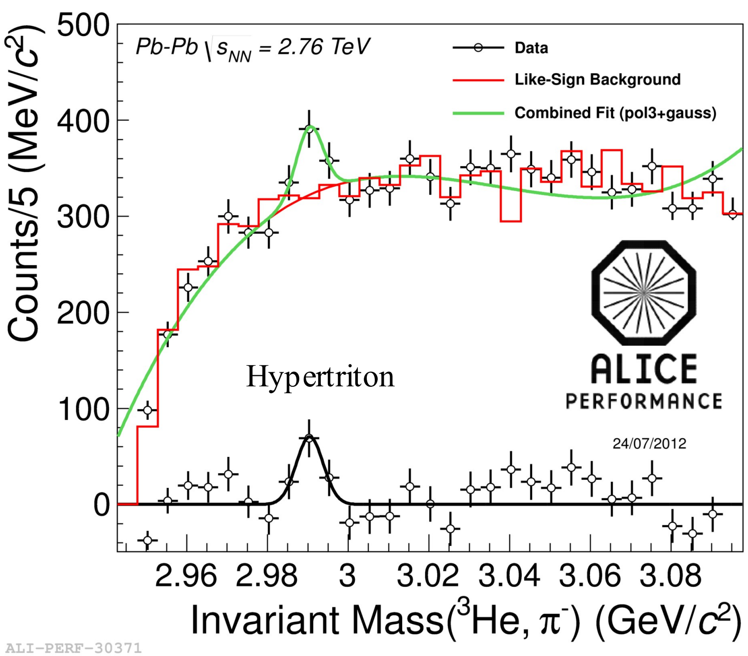
STAR Collaboration, Science 328, 58 (2010)



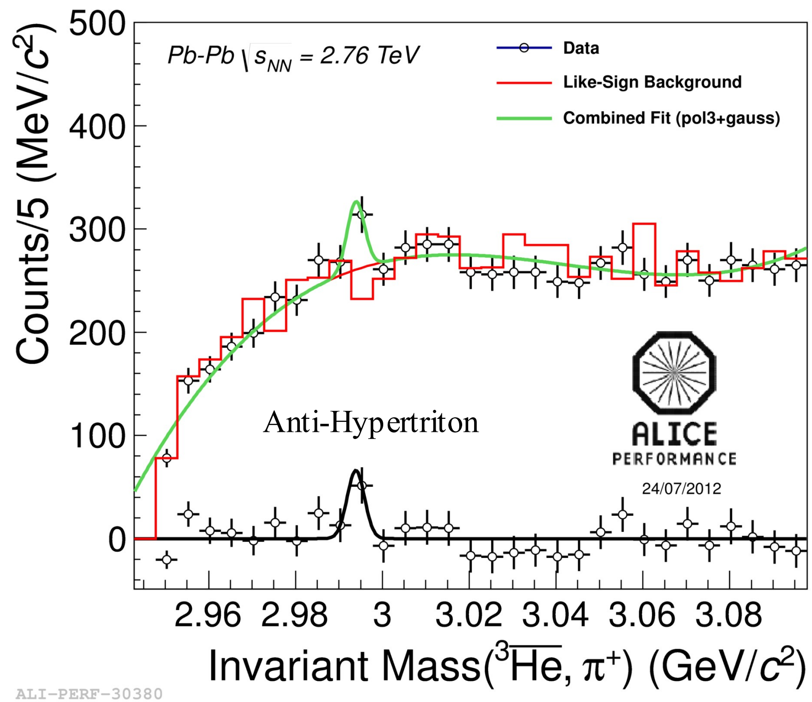
Hypertriton

Signal of the (anti-)hypertriton from the 2011 run

- currently working on the p_T spectra extraction



μ = (2.990 ± 0.001) GeV/c^2
σ = (3.35 ± 0.7)x10-3 GeV/c^2

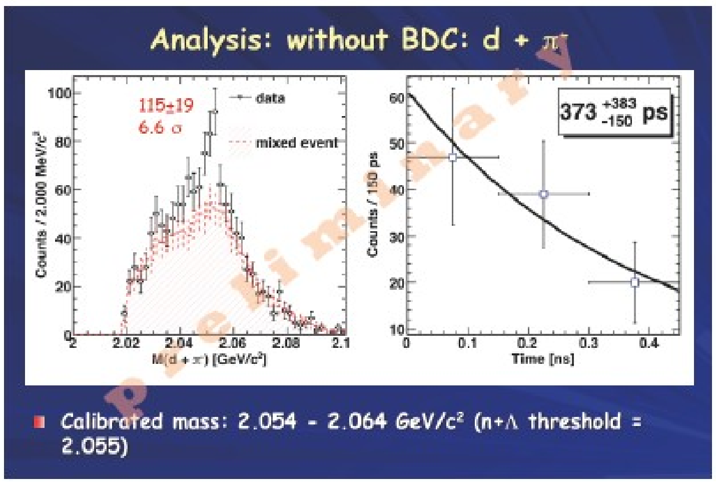


μ = (2.993 ± 0.001) GeV/c^2
σ = (2.00 ± 1.2)x10-3 GeV/c^2

Exotic bound states

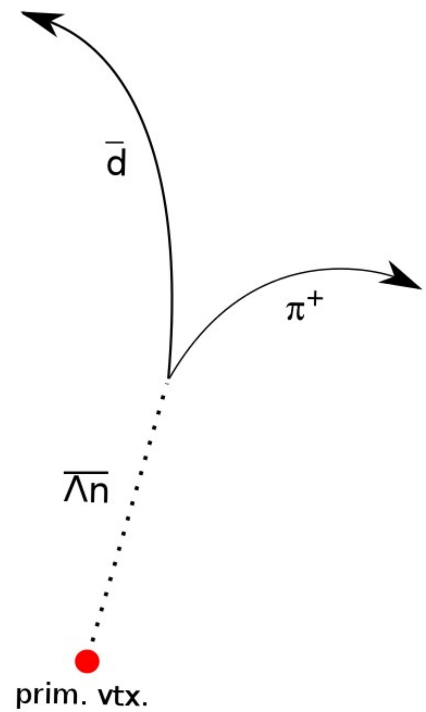
Λn bound state

HypHI experiment at GSI
see evidence of a new state:
Λn→ d π-



http://www.bnl.gov/hhi/files/talks/TakehikoSaito.pdf,
as shown 1.3.2012 at the Riken-BNL workshop on
"Hyperon-Hyperon Interactions and
Searches for Exotic Di-Hyperons in Nuclear Collisions"

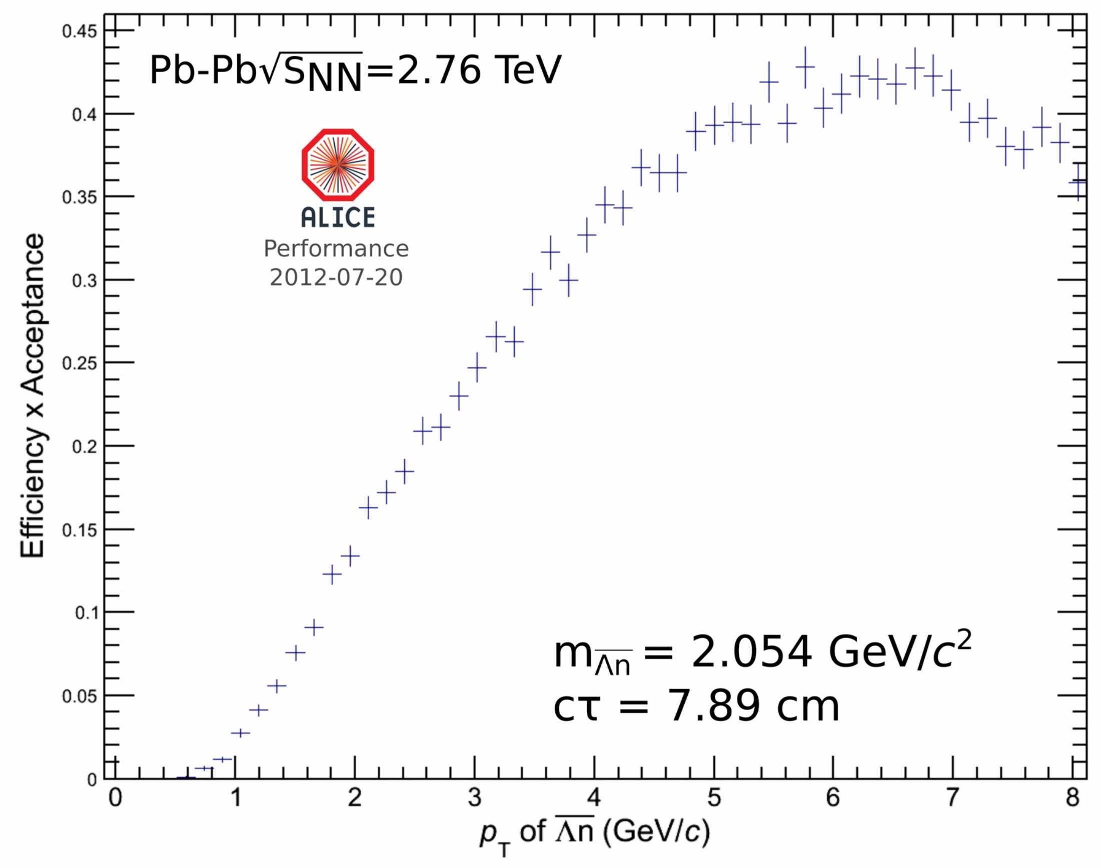
We assume a V0
type decay topology



Λn bound state

Efficiency estimation from Monte Carlo simulation (generated flat in y and p_T) for the detection of the Anti-Λn

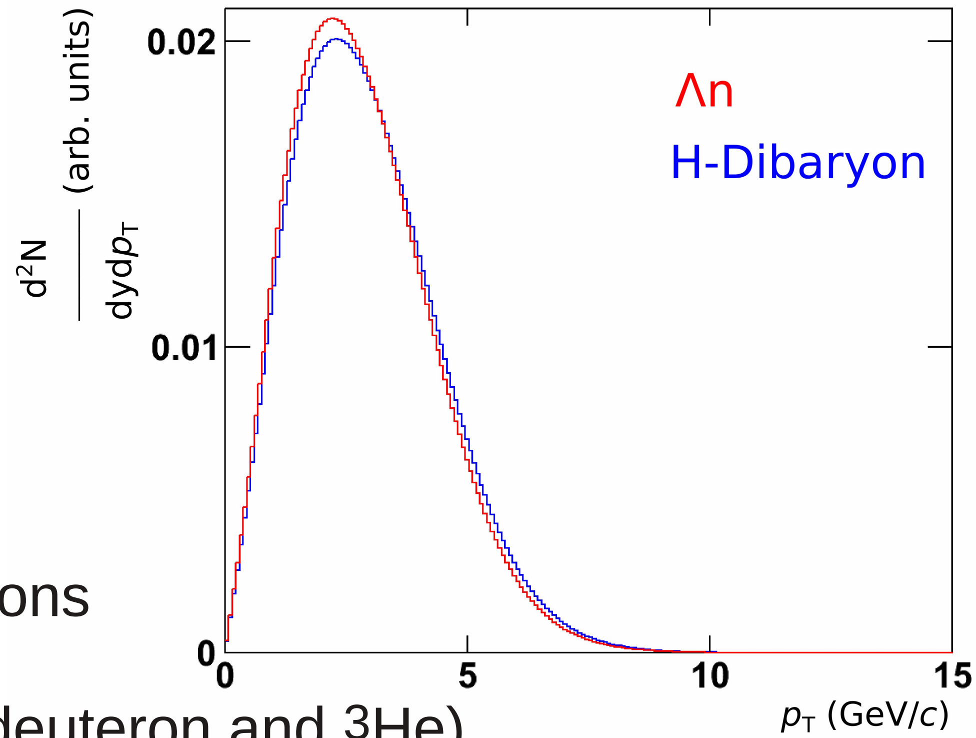
Assuming the lifetime to be that of the Λ



Λn bound state

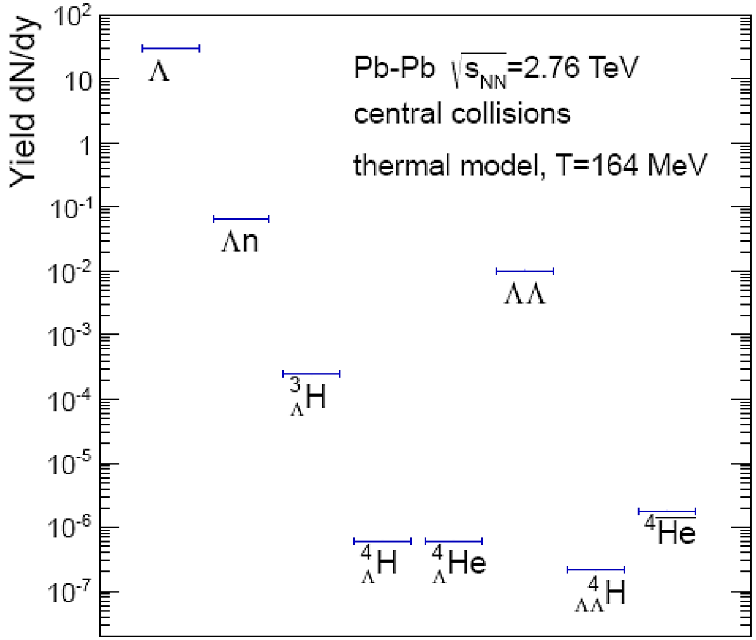
p_T-shape of the Λn bound state (and the H-Dibaryon) estimated from the extrapolation of blast-wave fits for π,K,p

Normalised to unity and convoluted with Acceptance x Efficiency to get a weighted efficiency

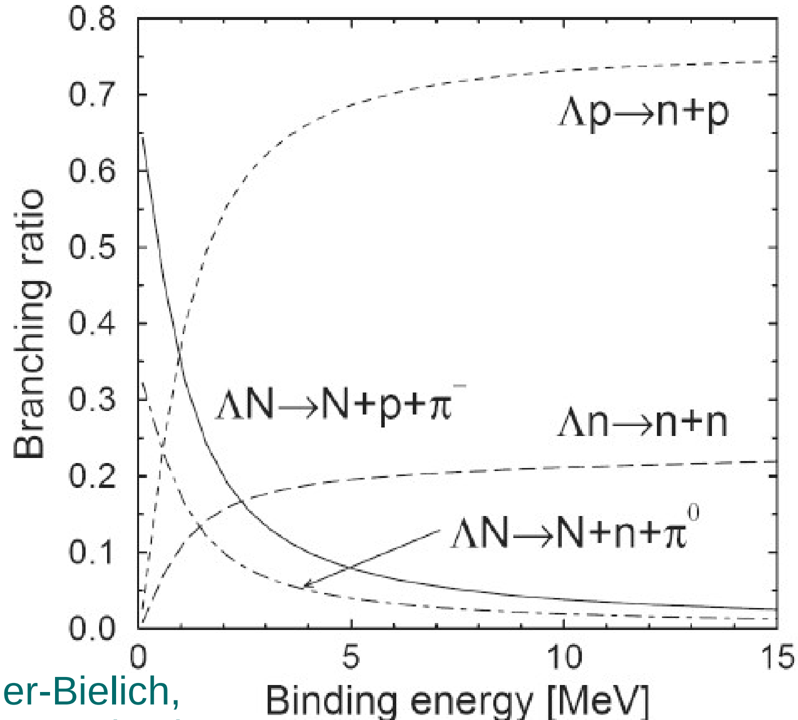


Unknown p_T-shape is the main source of uncertainty: Therefore used different functions for the systematics (limiting cases: blast-wave of deuteron and ^{3}He)

Λn bound state



A.Andronic, private communication



J. Schaffner-Bielich, private communication

$$N_{\overline{\Lambda n},\,rec} = \underbrace{1.38\cdot 10^{7}}_{events}\cdot\underbrace{0.0255}_{eff.}\cdot\underbrace{0.35}_{BR}\cdot\underbrace{0.01625}_{\frac{dN}{dy}}\cdot\underbrace{2}_{dy} = 4002.9$$

Λn bound state

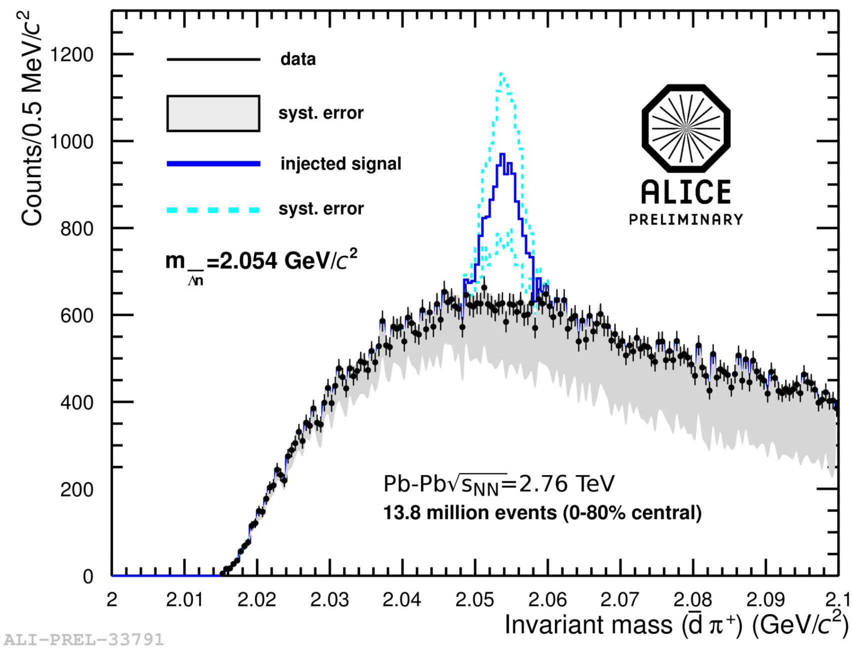
- No visible signal

From the non observation we can set an upper limit:

dN/dy ≤ 1.5x10^{-3} (99% CL)

→ thermal model input:

dN/dy = 1.65x10^{-2}



→ thermal model would need to be wrong by a factor ~10

However the model describes the hypertriton yields measured by STAR correctly within uncertainties

(Andronic *et al*., PLB 697, 203 (2011) and Cleymans *et al*., PRC 84, 054916 (2011))

H-Dibaryon

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- Hypothetical bound state of uuddss (ΛΛ)
- First predicted by Jaffe in a bag model calculation (Jaffe, PRL 38, 617 (1977))
- Recent lattice calculations suggest (Inoue *et al*., PRL 106, 162001 (2011) and Beane *et al*., PRL 106, 162002 (2011)) a bound state (20-50 MeV/c^2 or 13 MeV/c^2)
- Shanahan *et al*., PRL 107, 092004 (2011) and Heidenbauer, Meißner, PLB 706, 100 (2011) made chiral extrapolation to a physical pion mass and got as result:
  – the H is unbound by 13±14 MeV/c^2, respectively lies close to the Ξp threshold

➔ Renewed interest in experimental searches

H-Dibaryon

Two cases:

- $m_H < \Lambda\Lambda$ threshold

 → weakly bound

measurable channel

$H \rightarrow \Lambda p \pi$

2.2 GeV/c^2 < m_H < 2.231 GeV/c^2

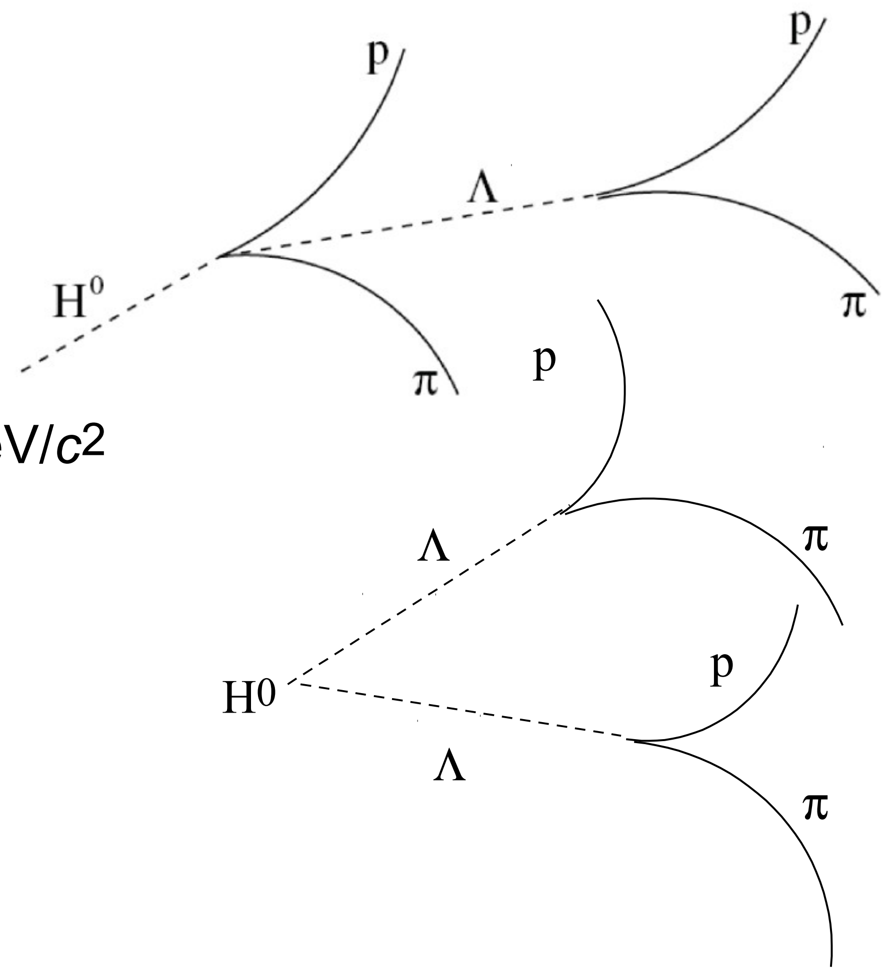
- $m_H > \Lambda\Lambda$ threshold

→ resonant state

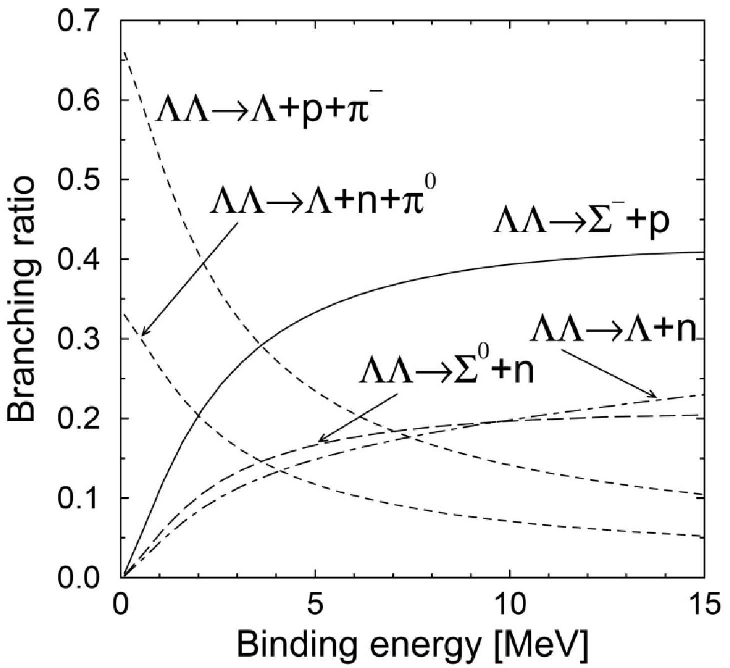
measurable channel

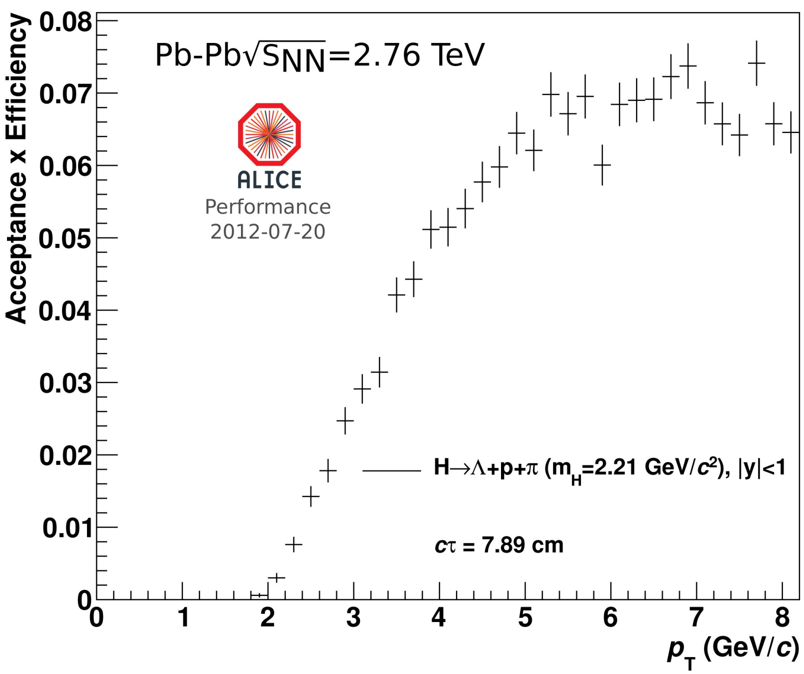
$H \rightarrow \Lambda\Lambda$

m_H > 2.231 GeV/c^2



H-Dibaryon





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

$$N_{H^0} = \underbrace{1.38 \cdot 10^7}_{events} \cdot \underbrace{0.0385}_{eff.} \cdot \underbrace{0.64}_{BR(\Lambda)} \cdot \underbrace{3.1x10^{-3}}_{\frac{dN}{dy}} \cdot \underbrace{2}_{dy} = 2110$$

strongly bound: 2110 x 0.1 = 211 lightly bound: 2110 x 0.64 = 1350

H-Dibaryon

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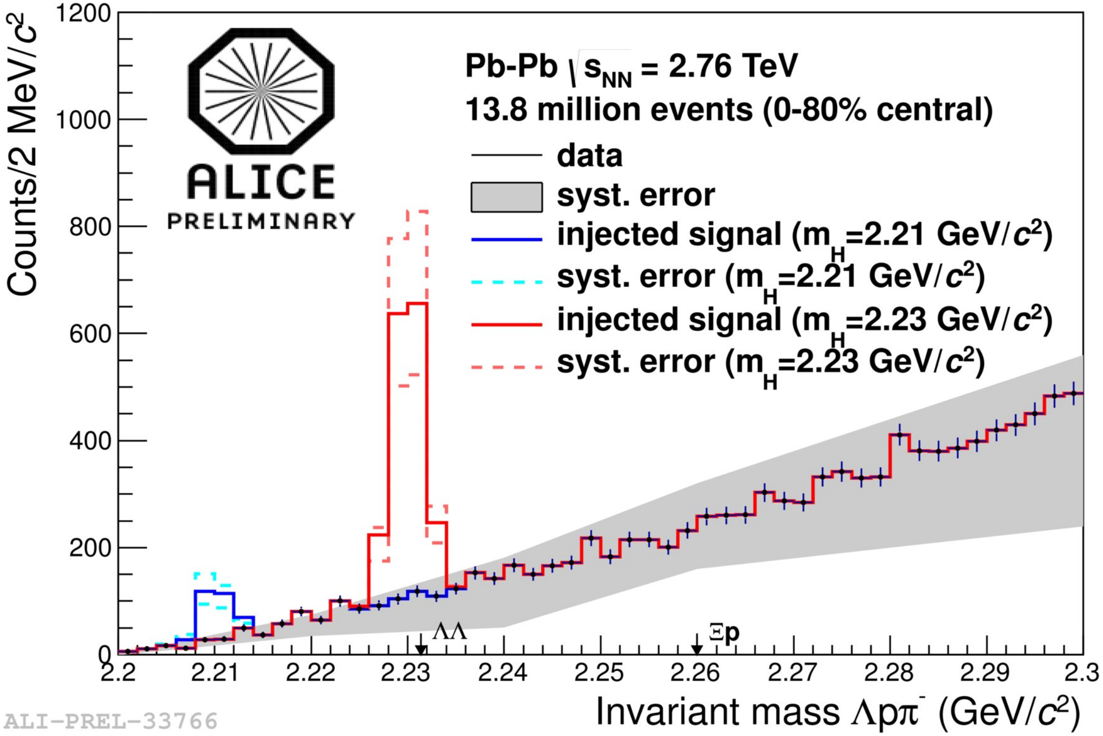
- No visible signal

From the non observation we obtain as upper limits:

For a strongly bound H:
→ dN/dy ≤ 8.4x10^{-4} (99% CL)

For a lightly bound H:
→ dN/dy ≤ 2x10^{-4} (99% CL)



Thermal model prediction is dN/dy=3.1x10^{-3} → thermal model would need to be wrong by a factor ~ 10

Summary

- ALICE is well suited for the detection of many particle species (stable, weakly and strongly decaying)
- By combining the different particle identification techniques (e.g. TPC dE/dx and TOF) we have
  - observed 10 Anti-Alphas in the run of 2011
  - observed (anti-)hypertriton signal and work on the p_T spectra
  - set an upper limit for the Λn bound state (observed by the HypHI collaboration → different production mechanisms?)
  - set an upper limit for the H-Dibaryon for two bound cases