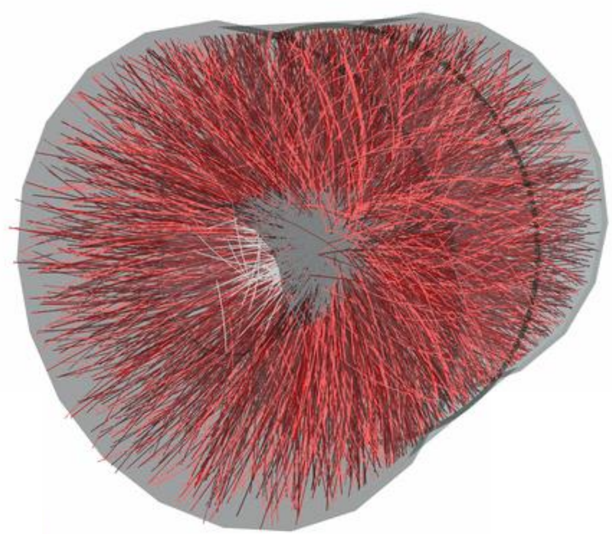
Search for exotic hyper-matter and measurement of nuclei with ALICE at the LHC



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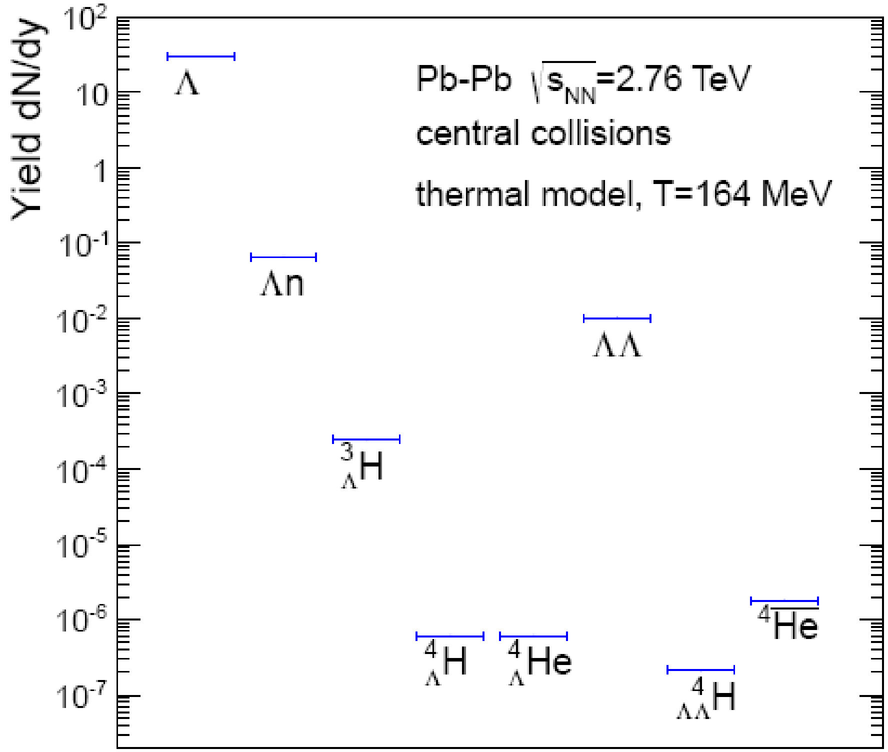
- Motivation
- ALICE performance
- Anti-Alpha
- Deuterons
- Search for Λn bound state
- Summary

Motivation



Andronic, private communication, model described in Andronic et al., PLB 697, 203 (2011) and references therein

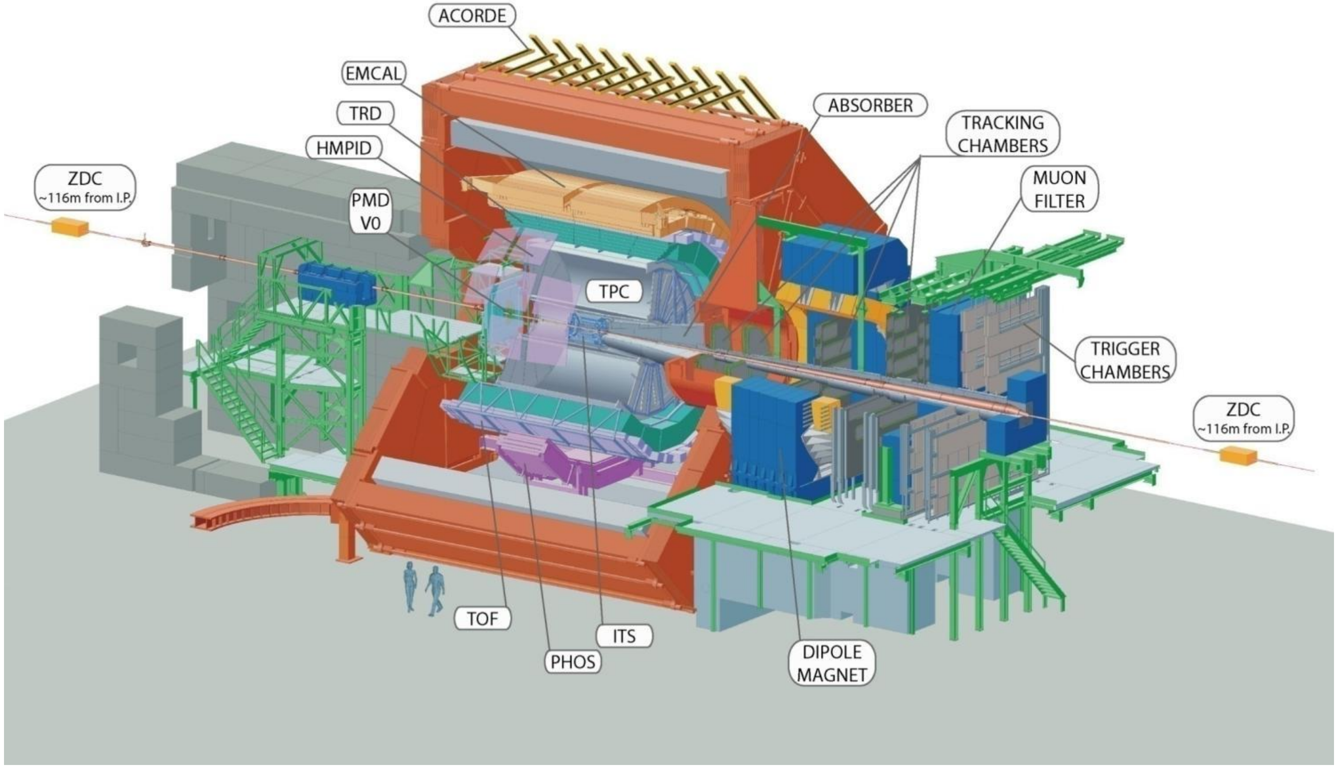
- Explore QCD predictions for unusual multi-baryon states
- Search for rarely produced anti- and hyper-matter
- Test model predictions, e.g. thermal and coalescence

ALICE

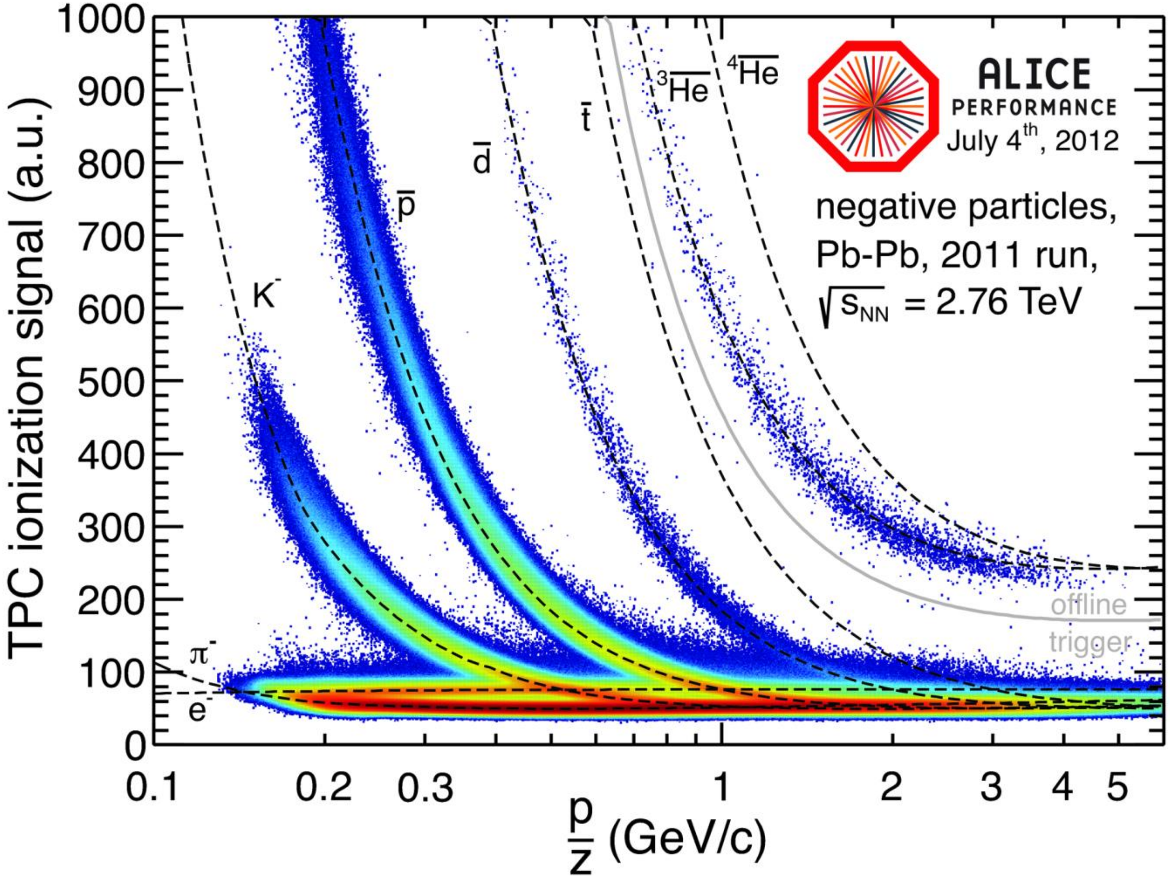
A Large Ion Collider Experiment

Particle identification techniques involved:

- Energy loss (dE/dx)
- Time-Of-Flight
- Topological



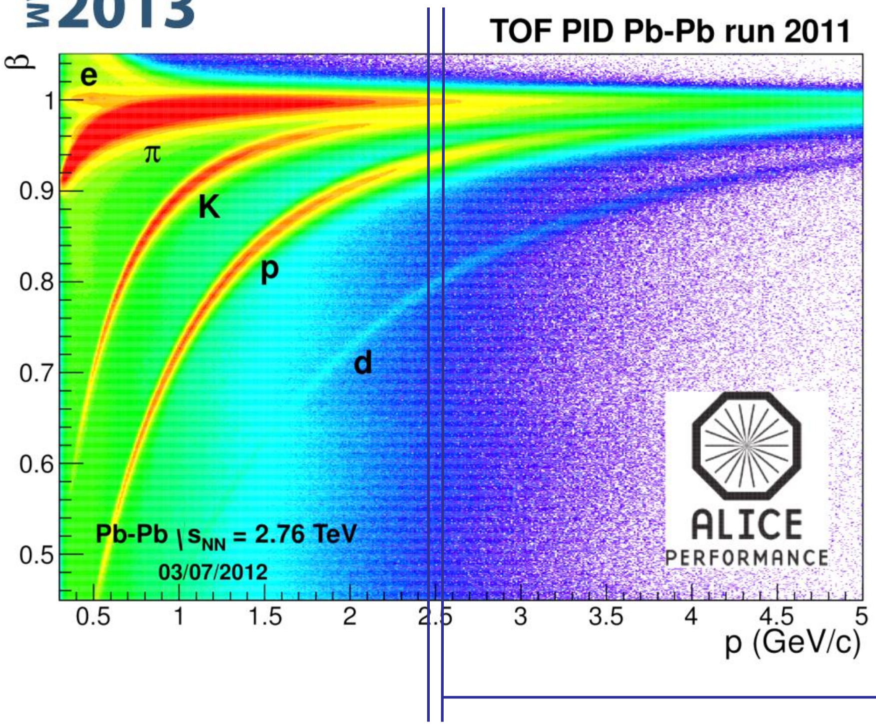
Time Projection Chamber (TPC)



Excellent dE/dx performance of TPC (~7% resolution in central Pb-Pb collisions)

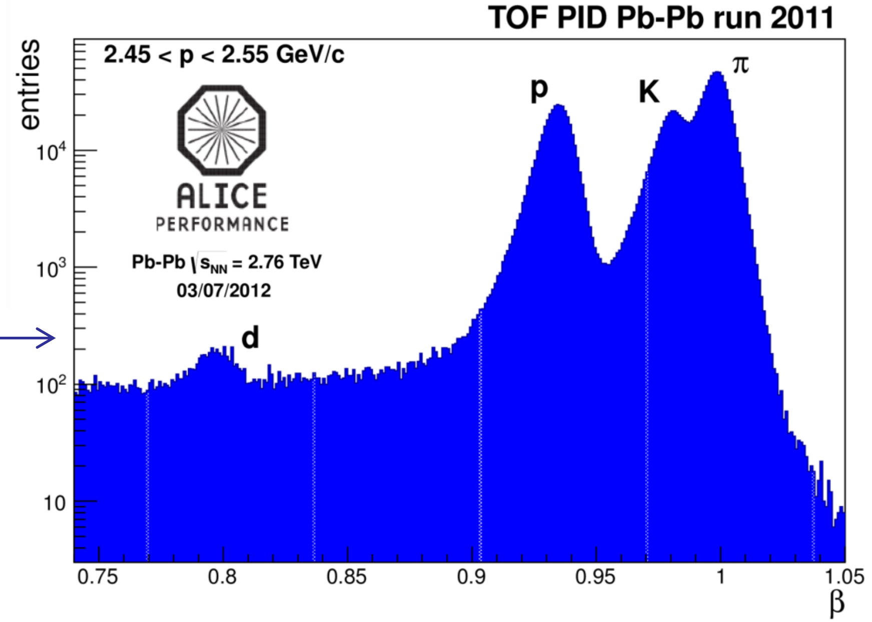
An offline trigger selects events with at least one $^3\overline{He}$/$^4\overline{He}$ candidate

Time-Of-Flight (TOF)



Excellent TOF performance

σ_{TOF} = 85 ps

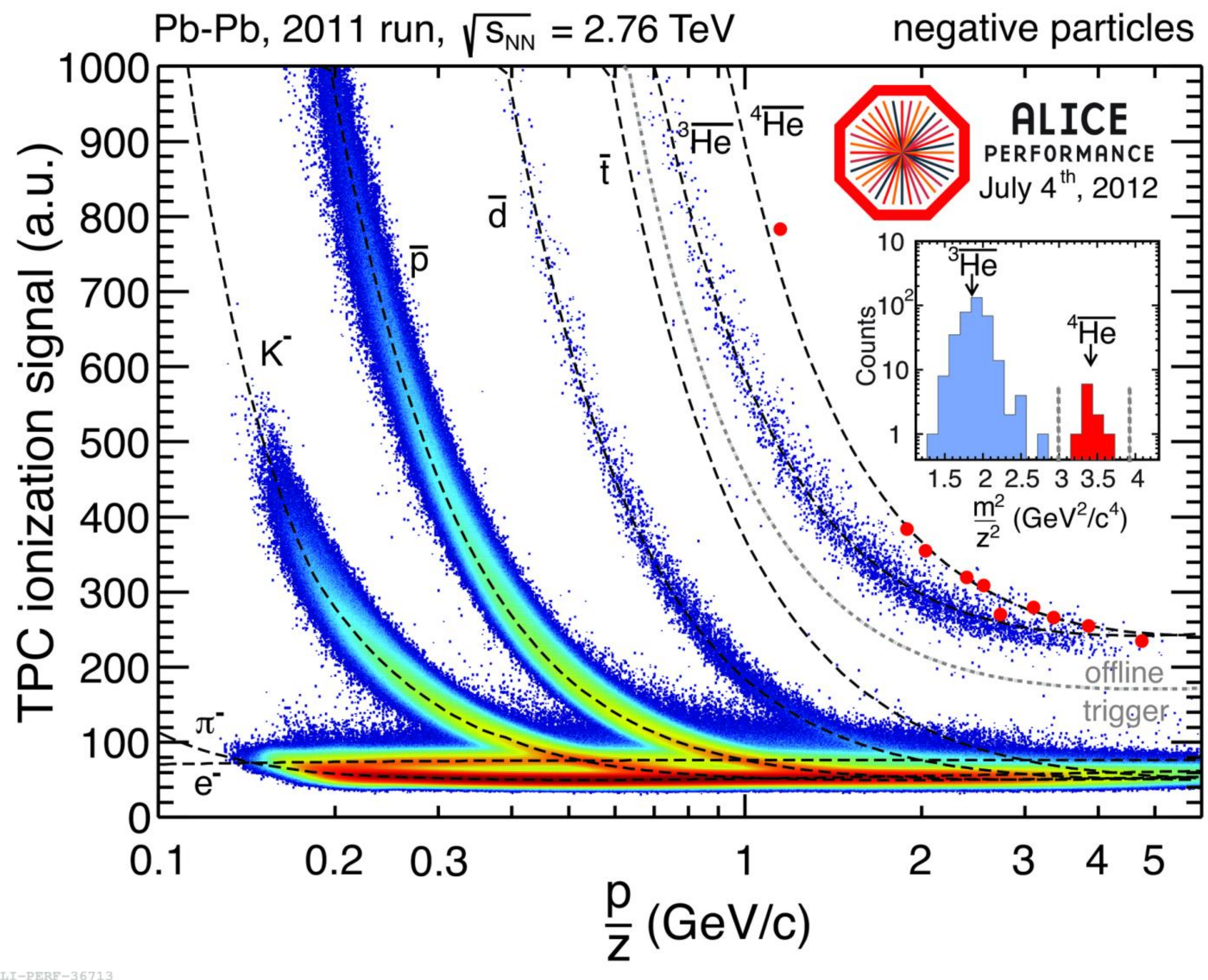


TOF performance is allowing a 2σ p/K-separation up to 5 GeV/*c*

Anti-Alpha

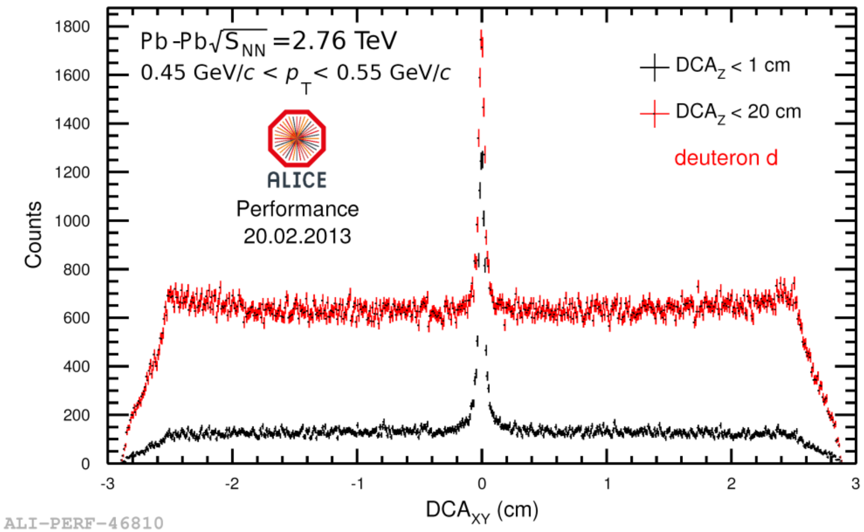
For the full statistics of 2011 we identified 10 Anti-Alphas using TPC and TOF

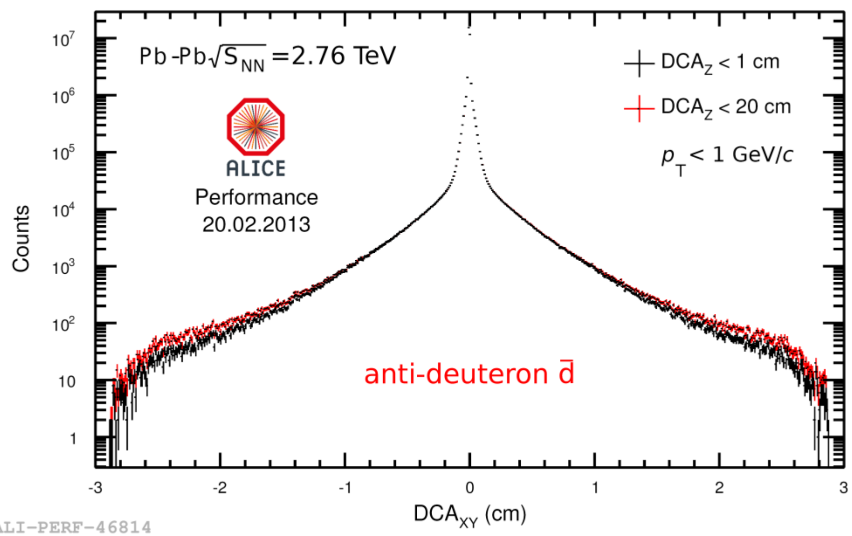
Corresponds to $23x10^6$ events of a trigger mix (central, semi-central and min. bias)



Secondaries

The measurement of nuclei is affected by a background coming from knockout from material (not relevant for anti-nuclei)





Rejection possible restricting DCA_Z and fitting the DCA_{XY} distribution

Deuterons

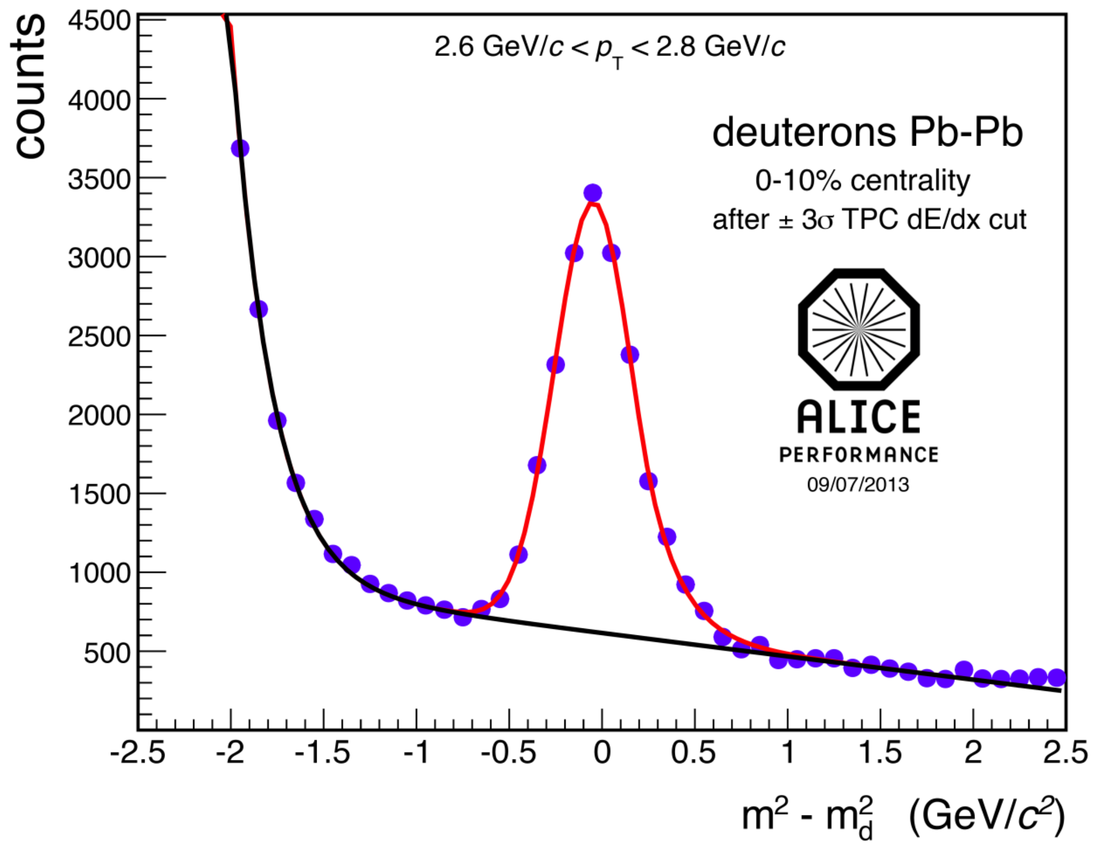
Deuterons are identified combining d*E*/d*x* and TOF

After cut on 3σ of d*E*/d*x* the m^2-distribution

is fitted with a

Gaussian function

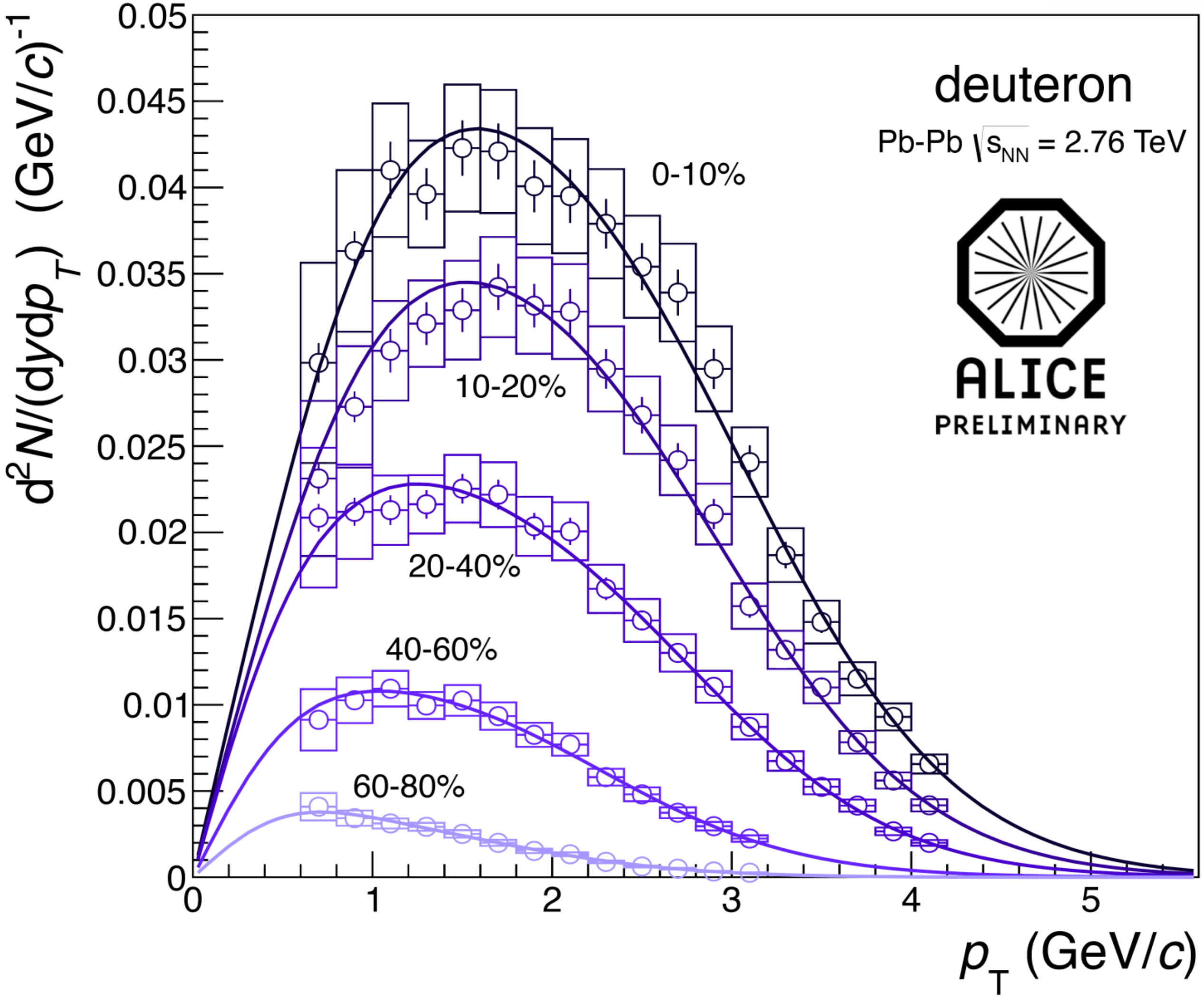
+ exponential tail



Deuterons: spectra

Characteristic hardening of the spectrum with increasing centrality qualitatively similar to proton spectra

Lines shows individual Blast-Wave fits

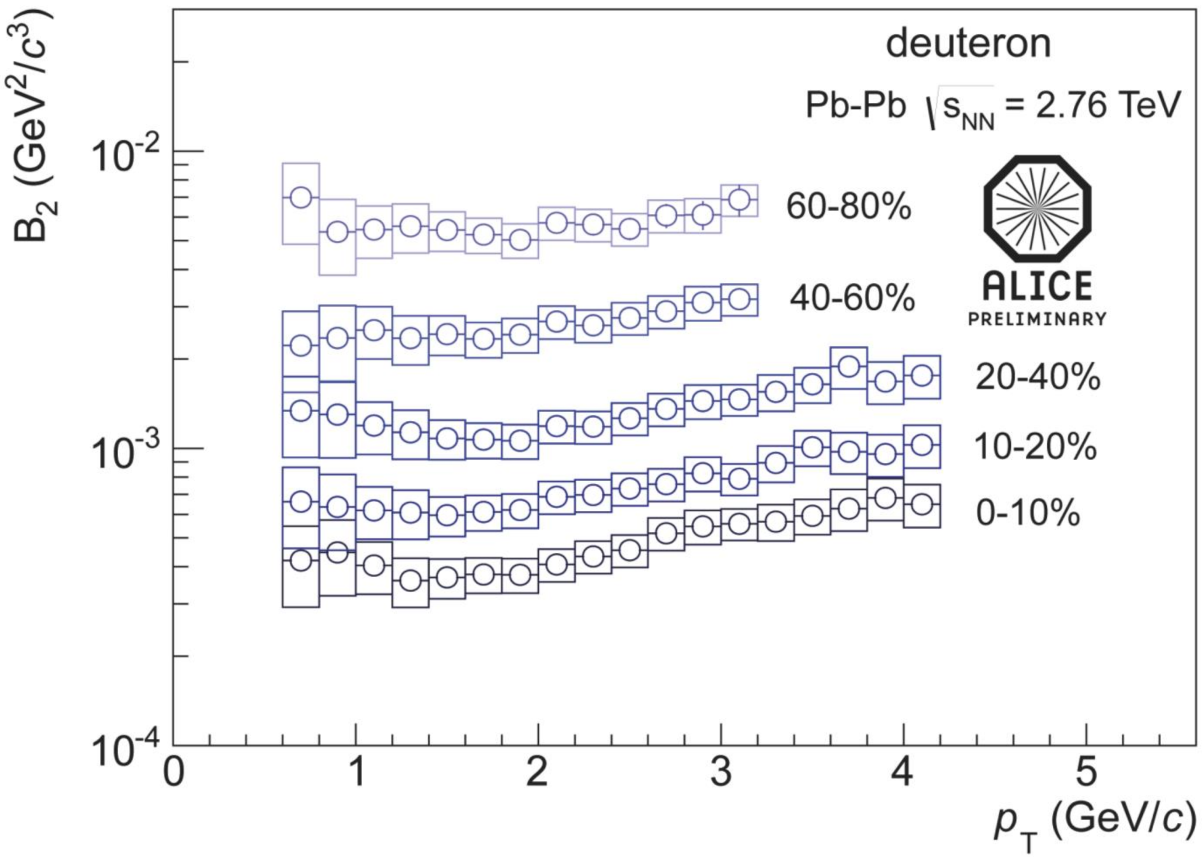


Deuterons: B_2

The formation probability of nuclei can be quantified through the coalescence parameter B_A

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

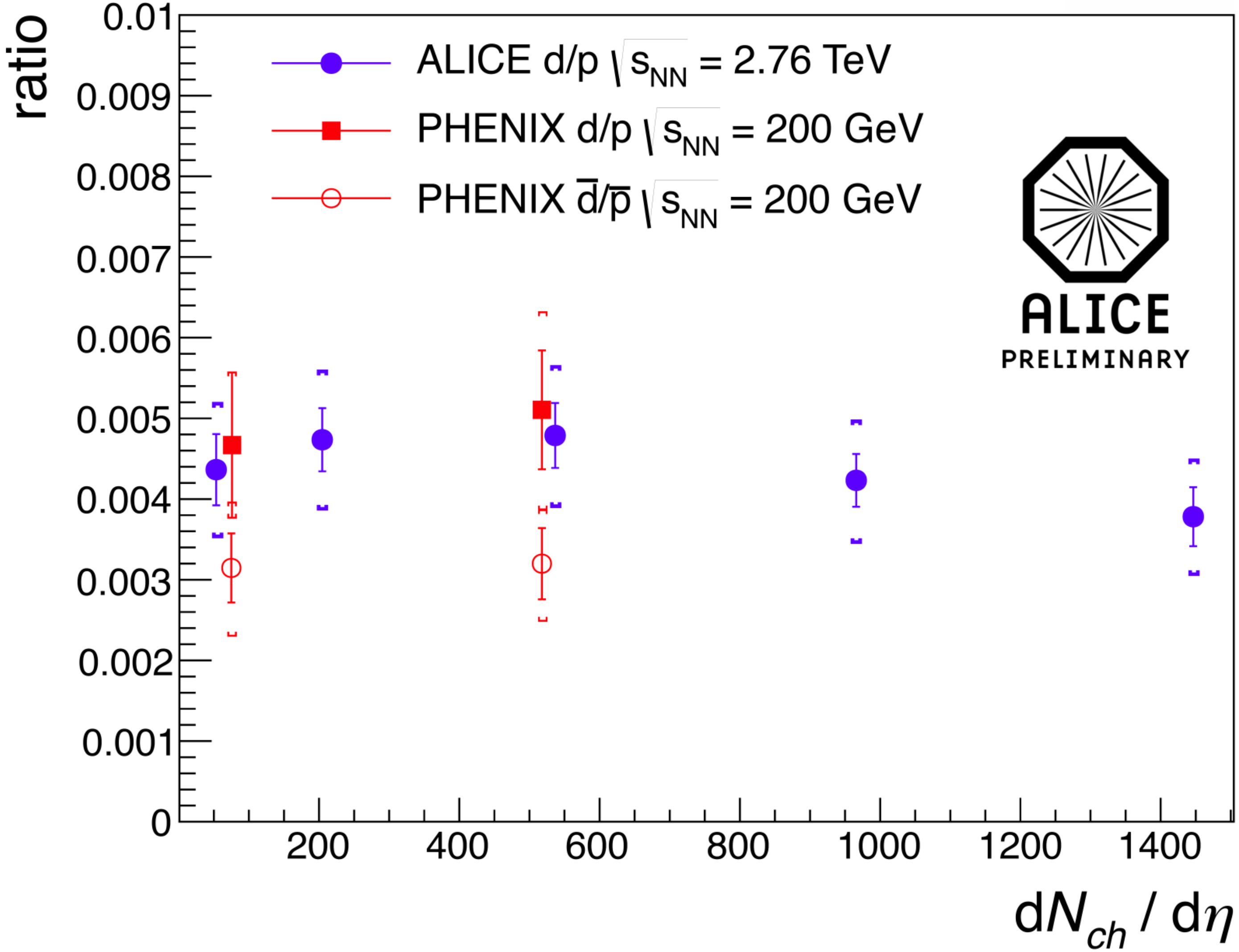
B_2 goes down with centrality, because d/p is constant and the overall proton multiplicity is increasing



Deuterons: d/p ratio

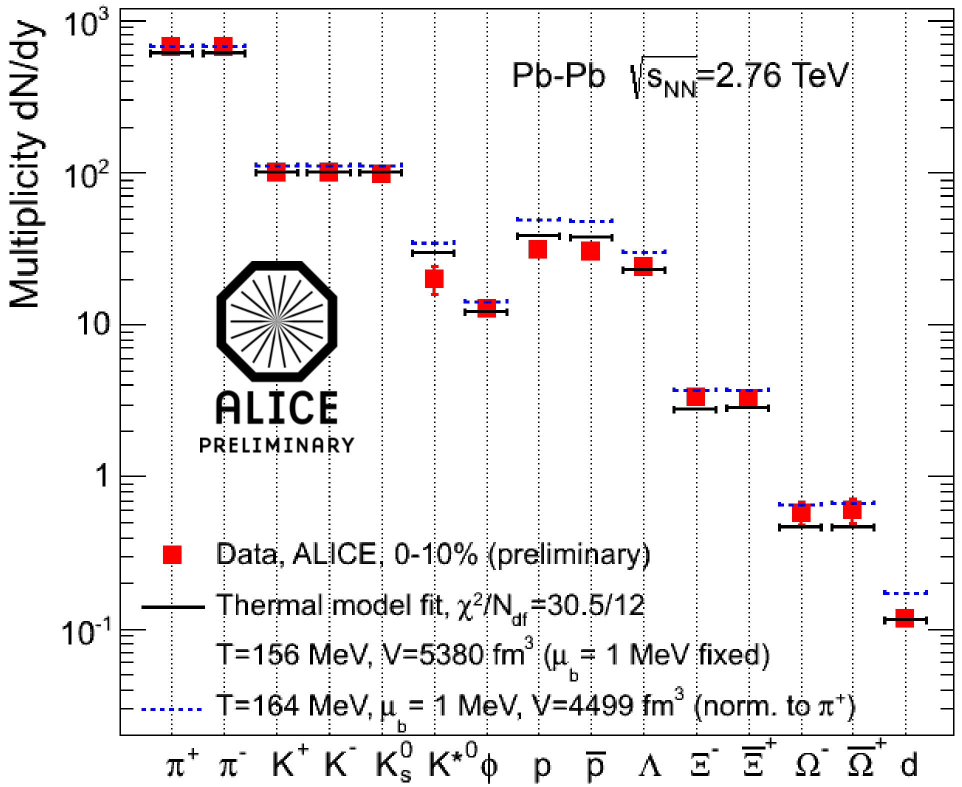
Deuteron-to-proton ratio for different centralities and energies

ALICE measurement agrees with the average of PHENIX results



Thermal model fit to ALICE data

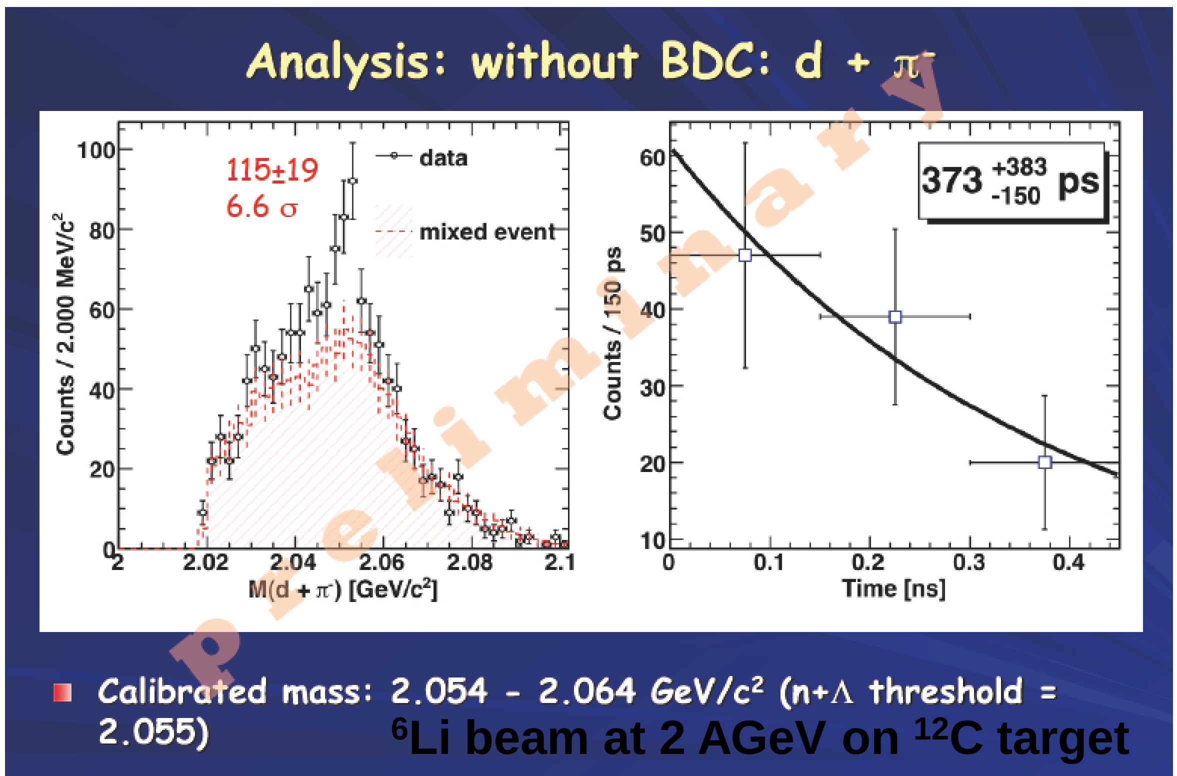
The measured deuteron yield is in good agreement with a equilibrium thermal model fit with a temperature of $T \approx 156$ MeV



Andronic et al., Nucl. Phys. A 772, 167 (2006)
Andronic et al., PLB 697, 203 (2011) and references therein

Λn bound state

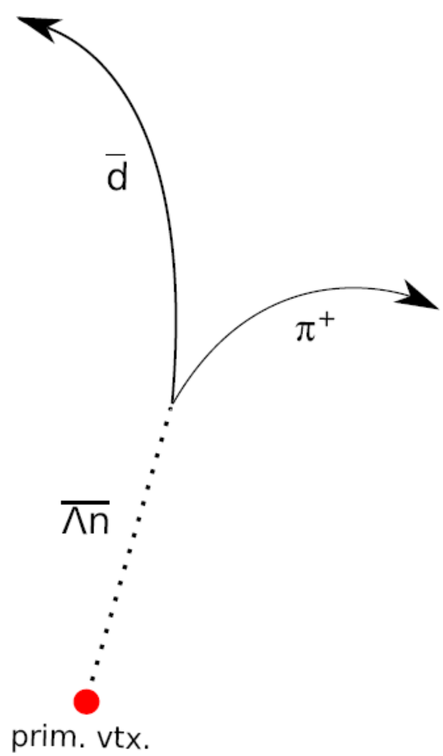
- HypHI experiment at GSI sees evidence of a new state: $\Lambda n \rightarrow d\, \pi^-$

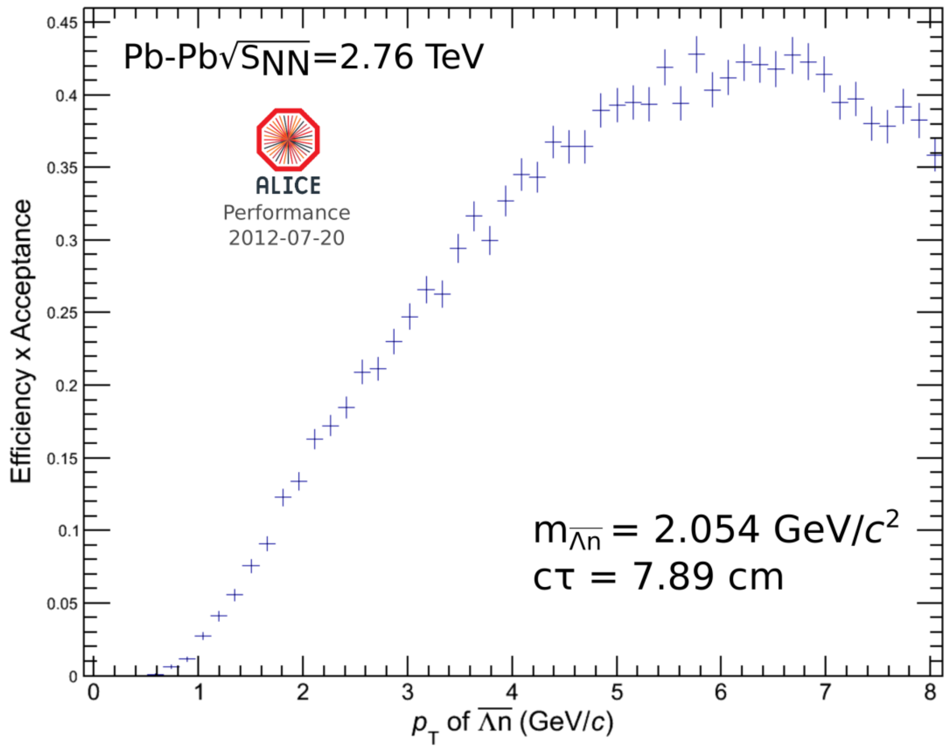


http://www.bnl.gov/hhi/files/talks/TakehikoSaito.pdf, as shown 1.3.2012

Λn bound state

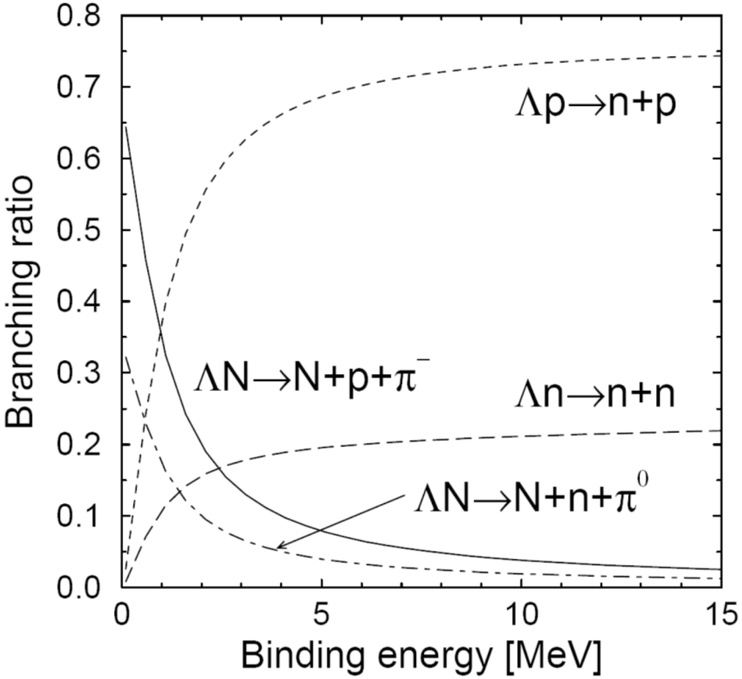
Assuming a V0
type decay topology



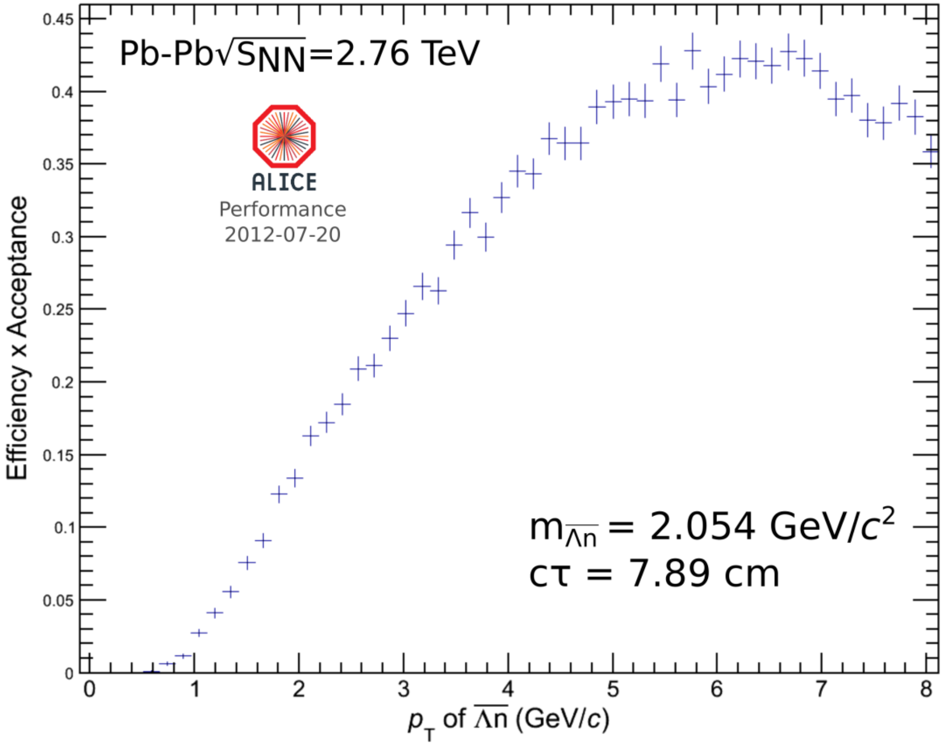


Efficiency estimation from
Monte Carlo simulation

Λn bound state



Schaffner-Bielich, private communication



$$N_{\overline{\Lambda n},\,rec} = \underbrace{1.38\cdot 10^{7}}_{events}\cdot\underbrace{0.0255}_{eff.}\cdot\underbrace{0.35}_{BR}\cdot\underbrace{0.01625}_{\frac{dN}{dy}}\cdot\underbrace{2}_{dy} = 4003$$

Λn bound state: results

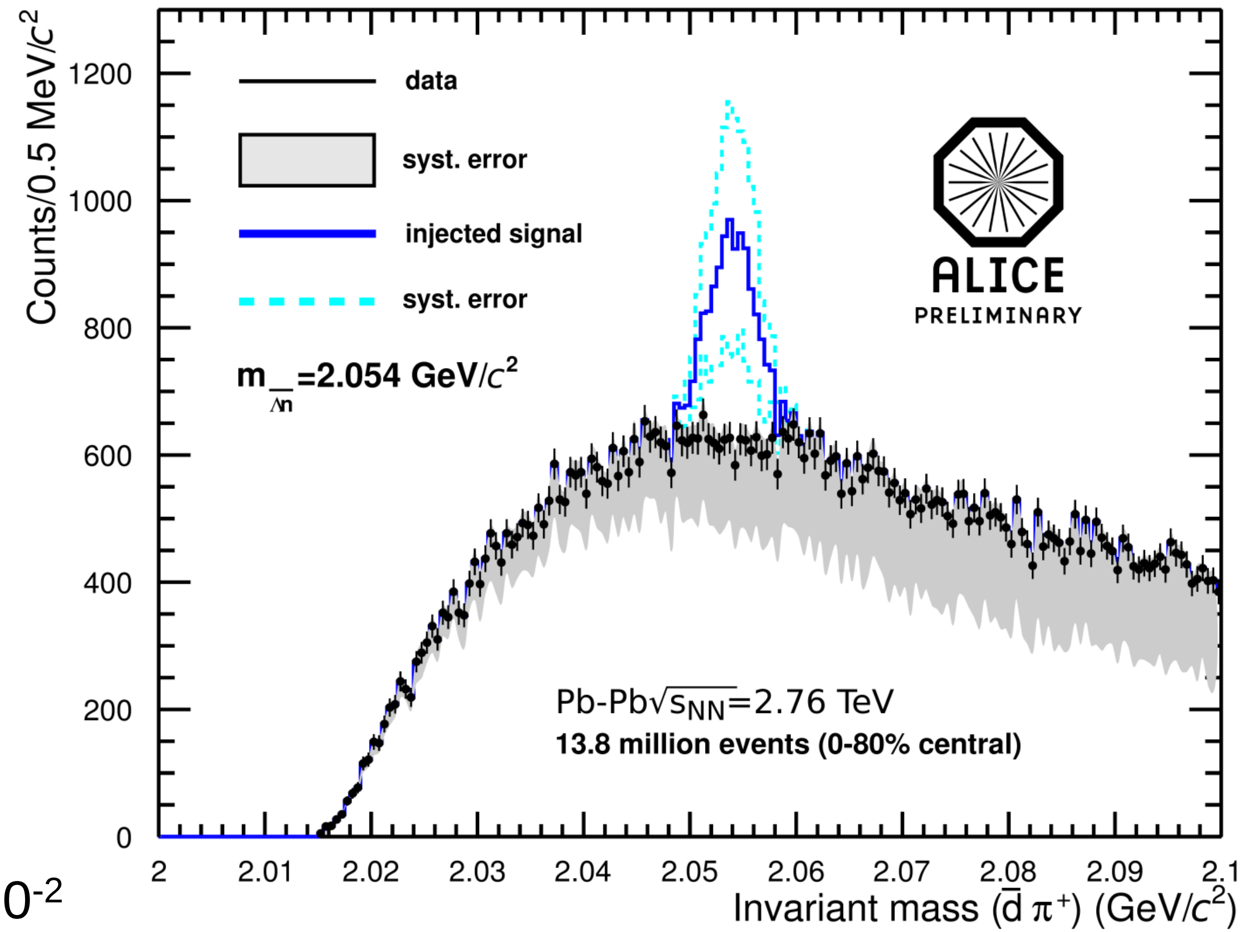
- No visible signal

From the non observation we can set an upper limit:

dN/dy ≤ 1.5x10^{-3} (99% CL)

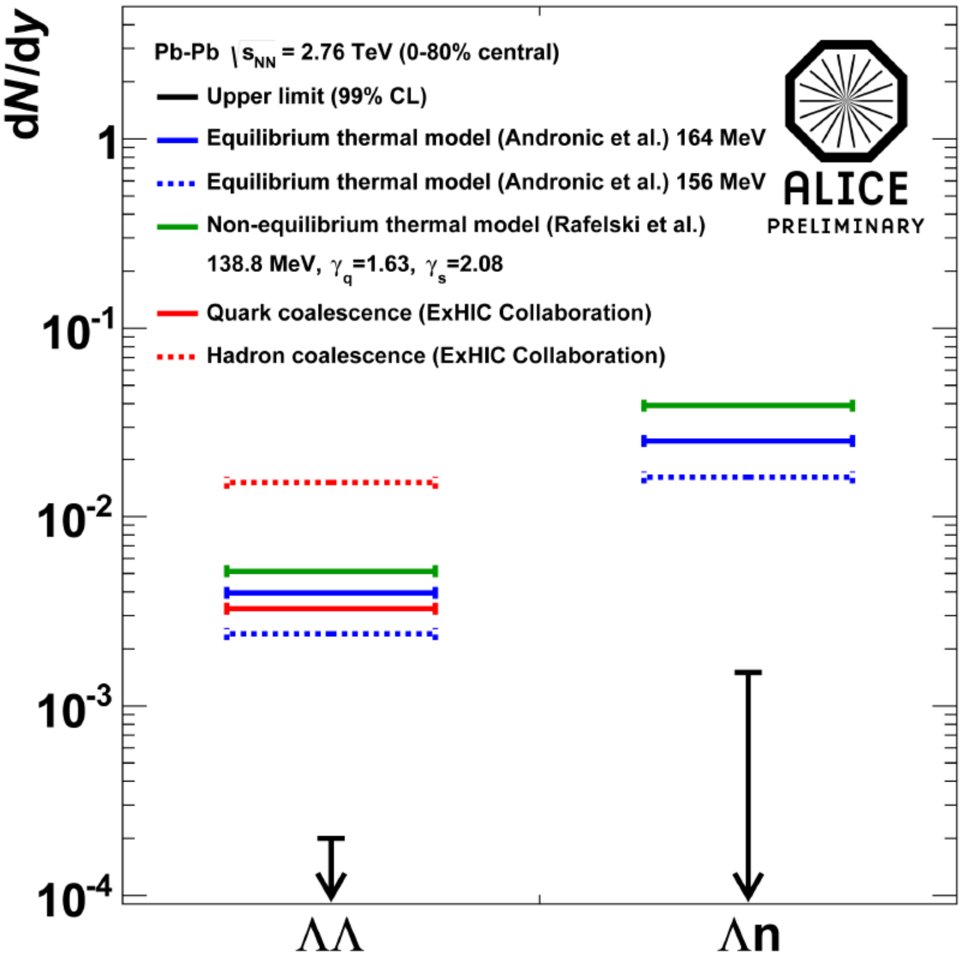
→ thermal model input at 164 MeV:

dN/dy = 1.65x10^{-2}



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

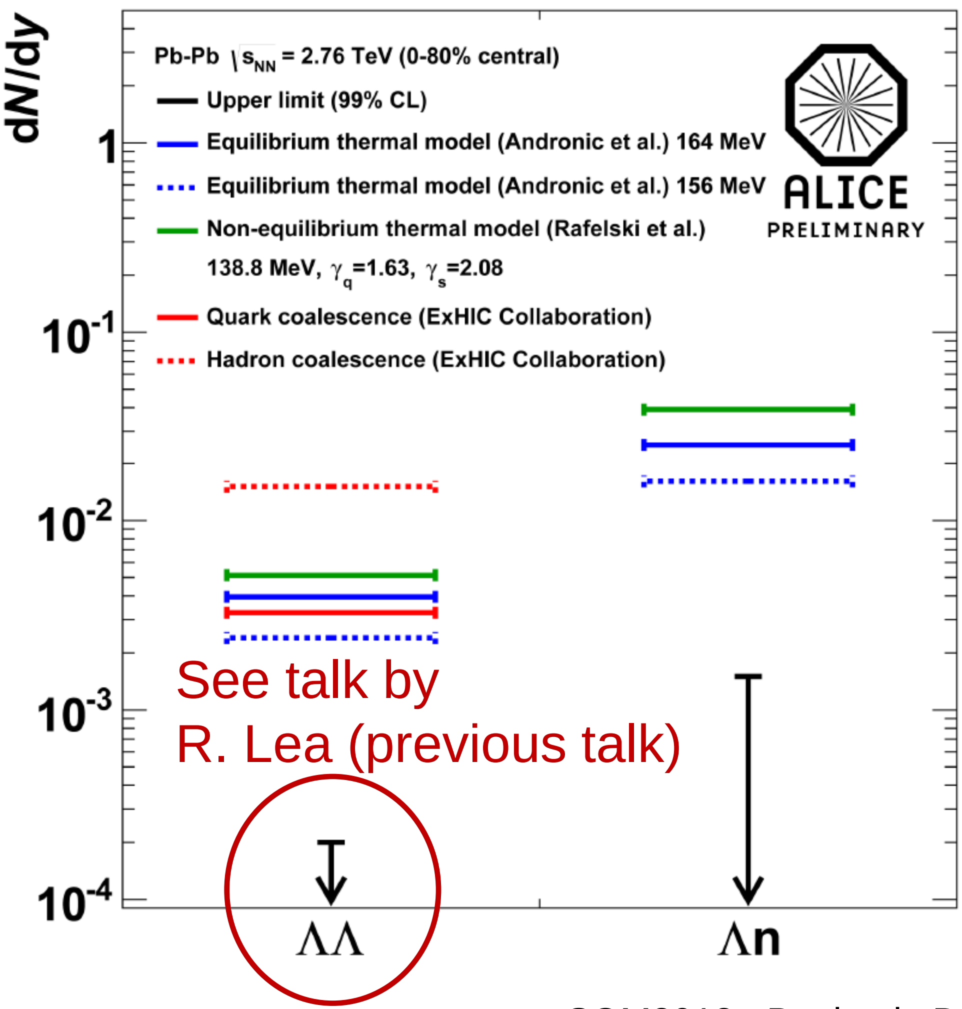
Comparison



Different predicting models are of the same order

At least factor 10 between models and estimated upper limit

Comparison



Different predicting models are of the same order

At least factor 10 between models and estimated upper limit

Conclusion

- ALICE has excellent capabilities
  for detecting different particle species (stable, weakly and strongly decaying)
- The combination of different particle identification techniques (TPC d*E*/d*x* and TOF) allows for measurement of (anti-)nuclei
  - Anti-Alpha
  - Deuterons
- Measured deuteron yields in agreement with current best thermal fit from equilibrium thermal model
- Upper limits for Λn bound state and H-Dibaryon are significantly lower than all predicting models (thermal and coalescence)

Backup

H-Dibaryon

Two cases:

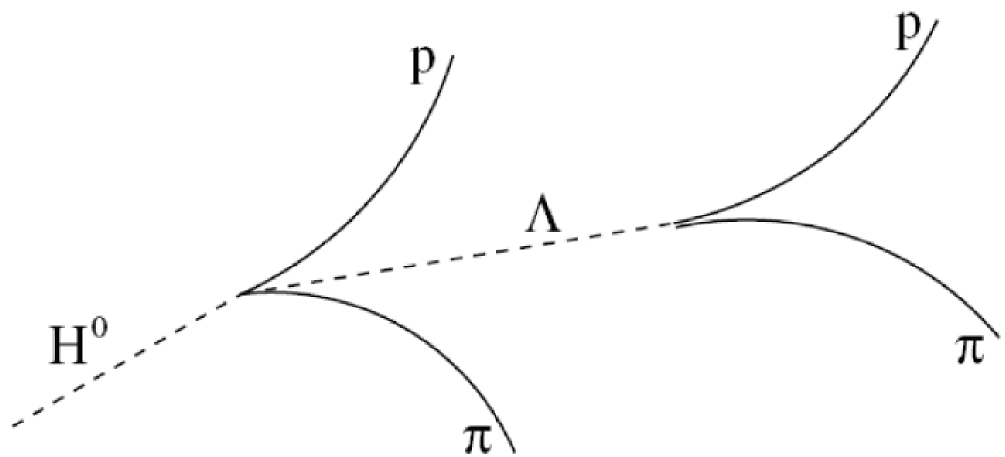
- $m_H < \Lambda\Lambda$ threshold

→ weakly bound

measurable channel

$H \rightarrow \Lambda p \pi$

$2.2\ \mathrm{GeV}/c^2 < m_H < 2.231\ \mathrm{GeV}/c^2$



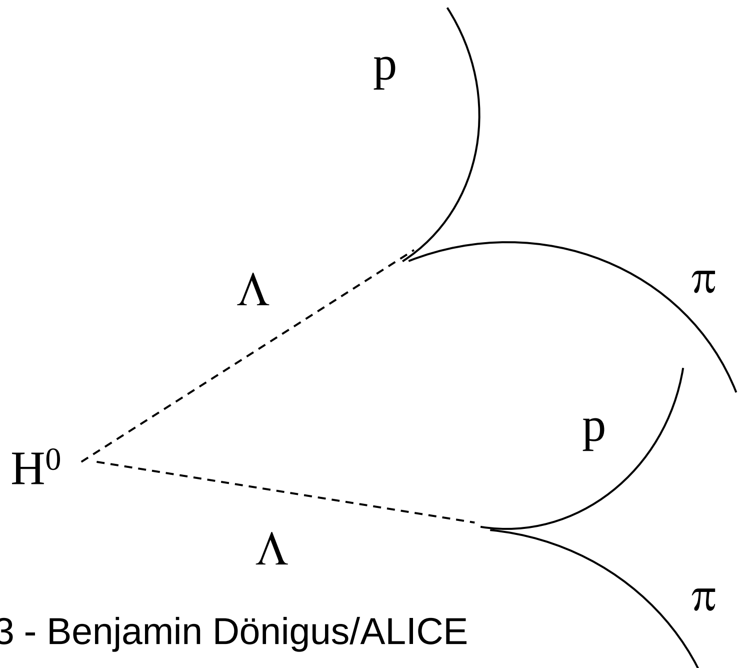
- $m_H > \Lambda\Lambda$ threshold

→ resonant state

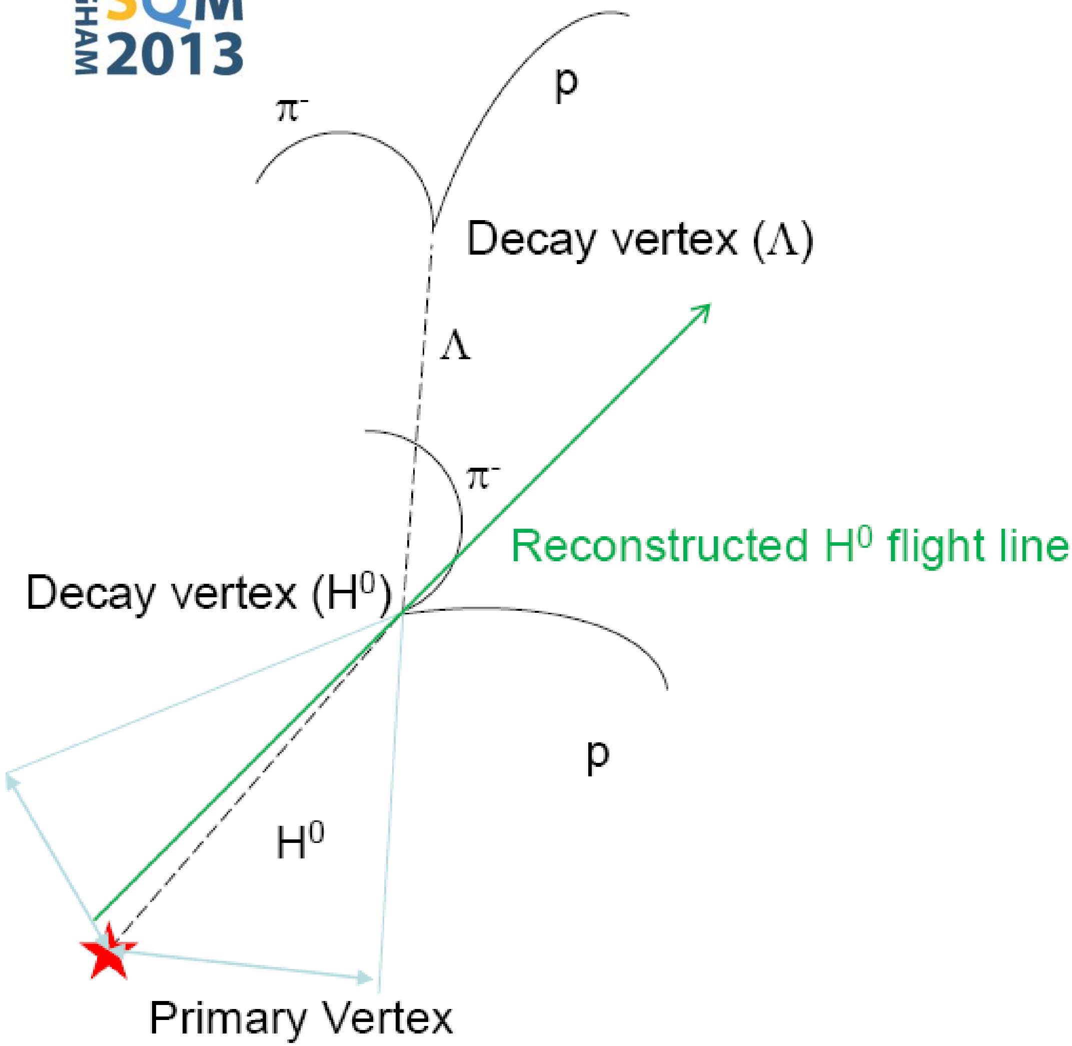
measurable channel

$H \rightarrow \Lambda\Lambda$

$m_H > 2.231\ \mathrm{GeV}/c^2$



H-Dibaryon

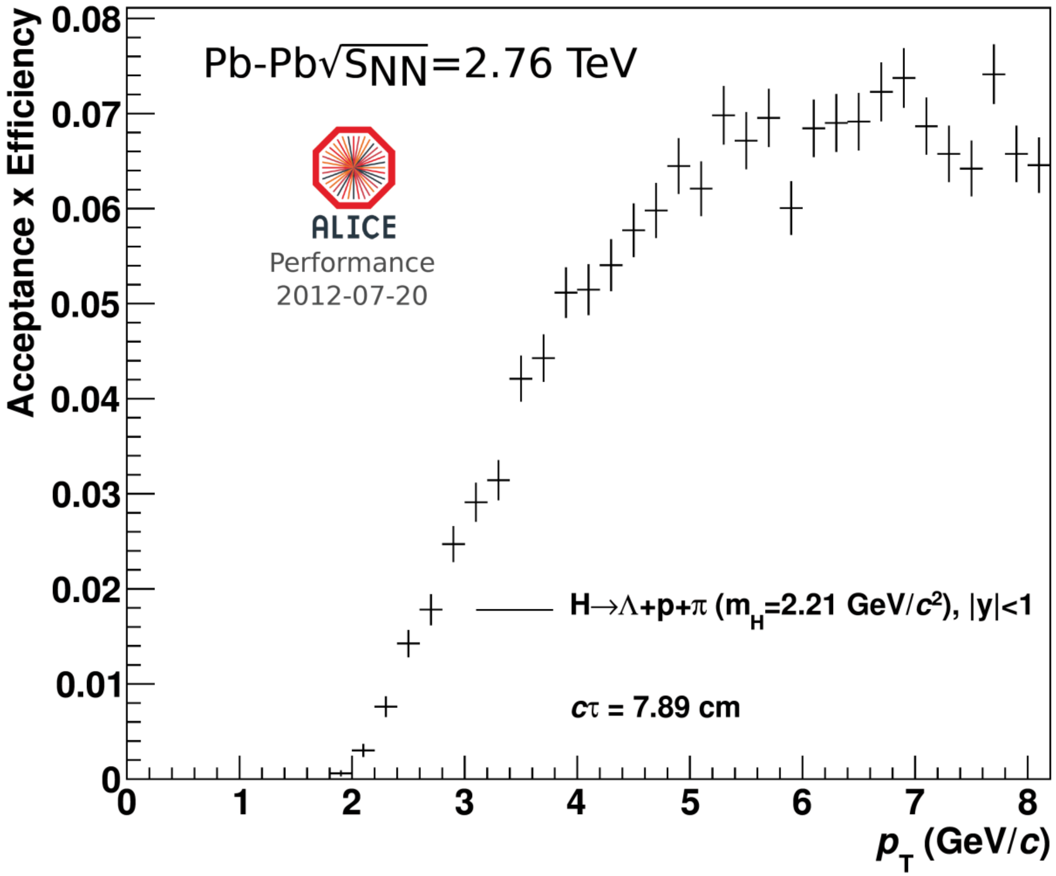


cut	value
Track cuts	
Kink daughters	rejected
TPC	refit
$n_{clusters}$(TPC)	> 80
χ^2/cluster	< 5
$\|\eta\|$	0.9
V0 cuts	
dca V0 daughters	< 1 cm
dca positive V0 daughter - Vertex	> 1 cm
dca negative V0 daughter - Vertex	> 1 cm
Kinematical cuts	
dca positive H^0 daughter - Vertex	> 1 cm
dca negative H^0 daughter - Vertex	> 1 cm
dca H^0 daughters	< 1 cm
Pointing angle of H^0	< 0.1 rad

H-Dibaryon

Efficiency estimation from Monte Carlo simulation (generated flat in *y* and p_T) for the detection of the H-Dibaryon

Assuming the lifetime to be that of the Λ

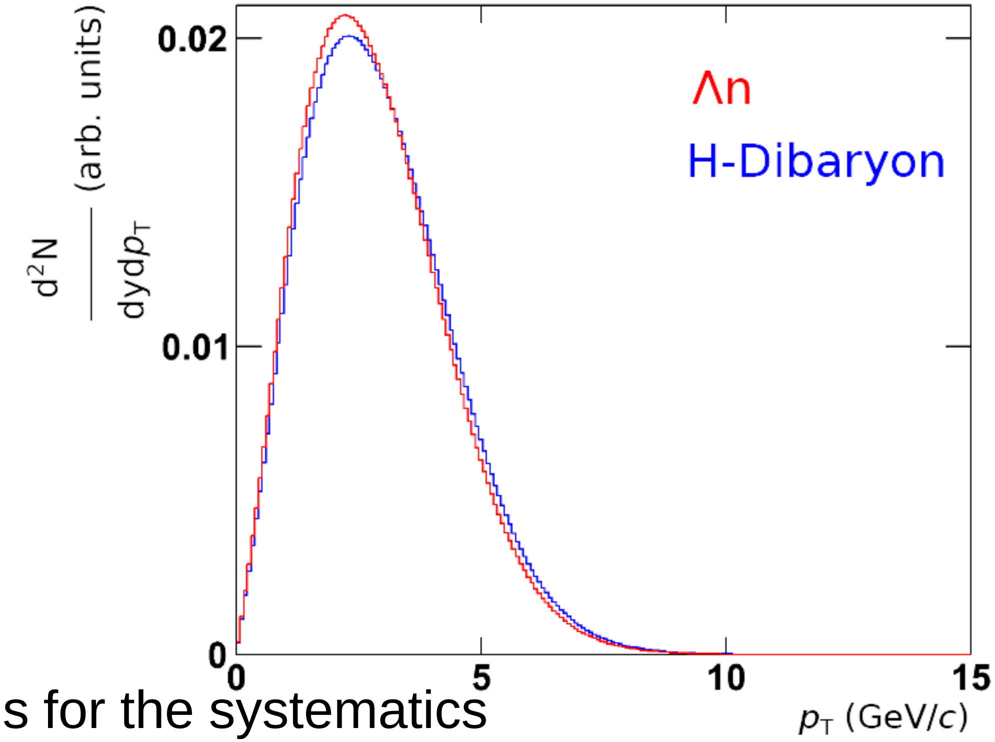


H-Dibaryon

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

Normalised to 1 and convoluted with Acceptance x Efficiency to get a weighted efficiency

Unknown p_T-shape is the main source of uncertainty:

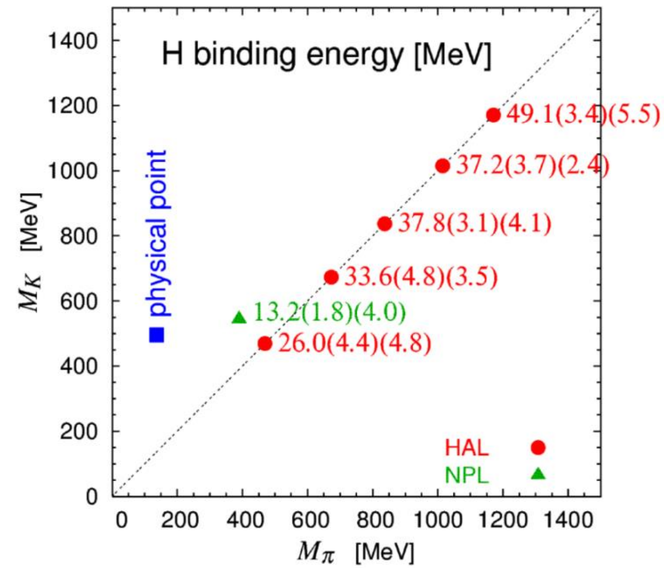


Therefore used different functions for the systematics (limiting cases: blast-wave of deuteron and helium-3)

H-Dibaryon

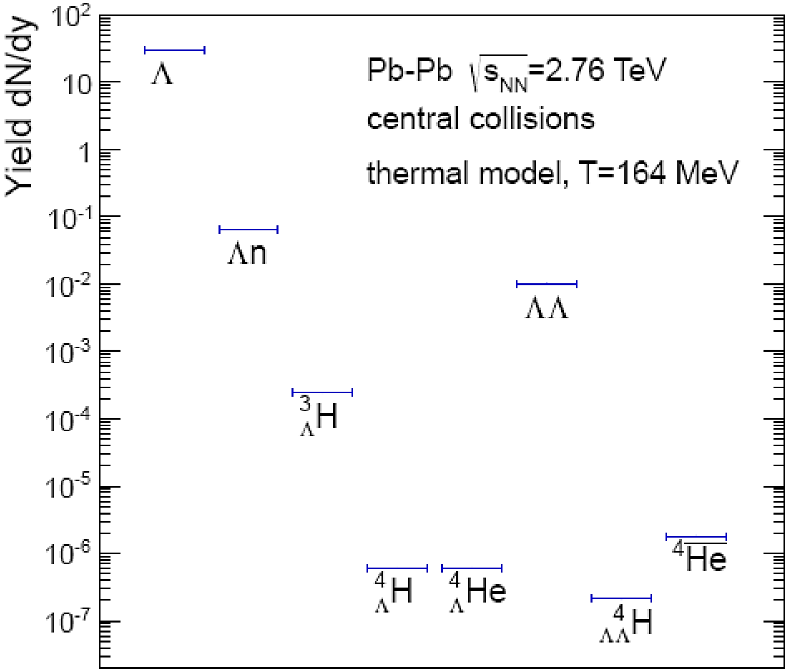
- Hypothetical bound state of *uuddss* ($\Lambda\Lambda$)
- First predicted by Jaffe in a bag model calculation (*Jaffe, PRL 38, 195 + 617 (1977)*)
- Recent lattice calculations suggest (*Inoue et al., PRL 106, 162001 (2011) and Beane et al., PRL 106, 162002 (2011)*) a bound state (20-50 MeV/c^2 or 13 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

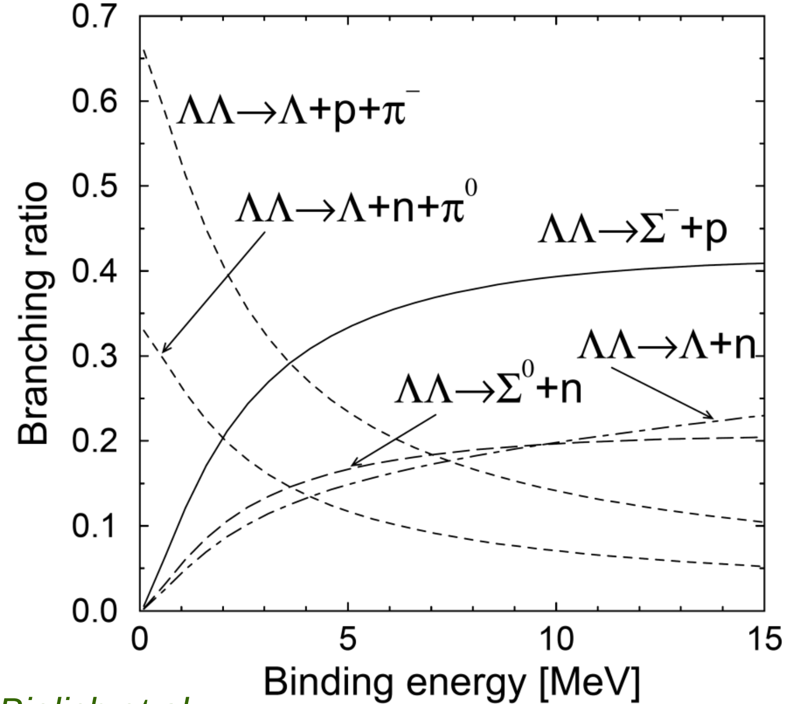


T. Inoue, private communication

H-Dibaryon



Andronic, private communication



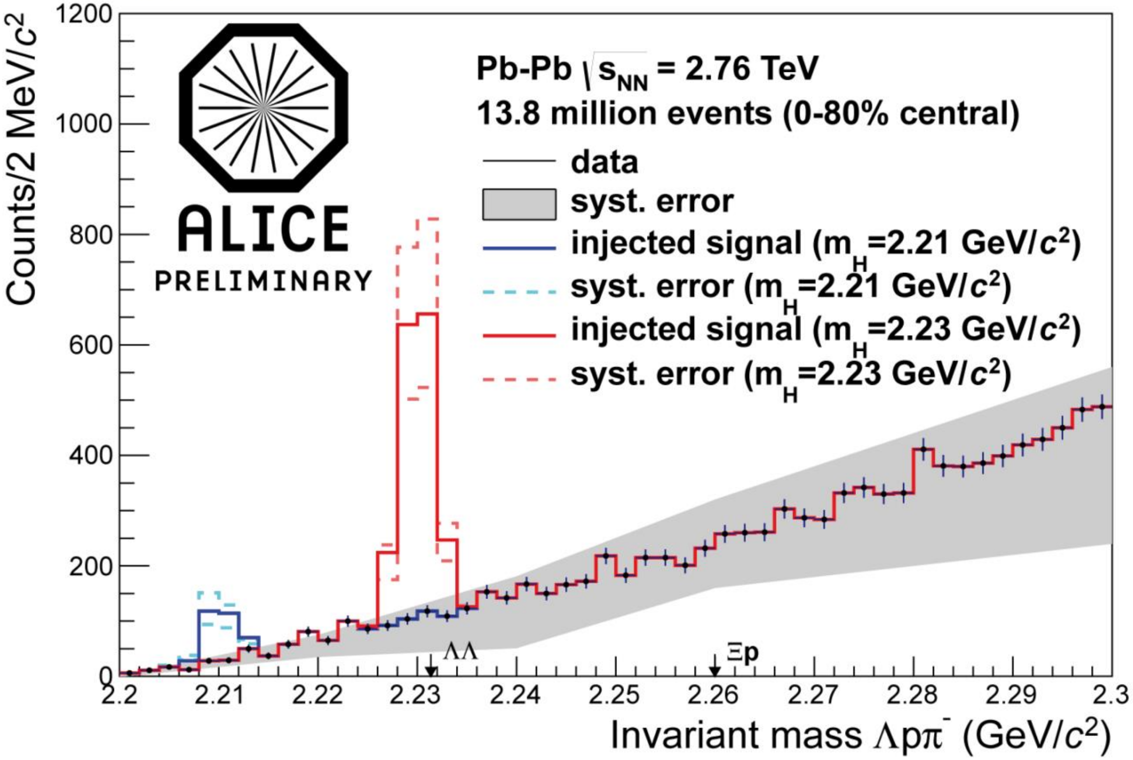
Schaffner-Bielich et al., PRL 84, 4305 (2000)

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

strongly bound: 2110 x 0.1 = 211

lightly bound: 2110 x 0.64 = 1350

H-Dibaryon: results



- No visible signal

From the non observation we obtain as upper limits:

For a strongly bound H:

→ d*N*/d*y* ≤ 8.4×10^{-4} (99% CL)

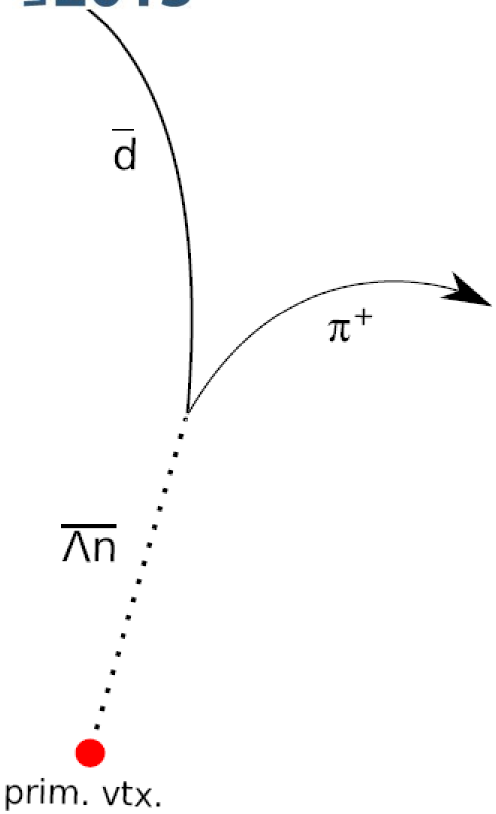
For a lightly bound H:

→ d*N*/d*y* ≤ 2×10^{-4} (99% CL)

Used thermal model prediction at 164 MeV is d*N*/d*y*=3.1×10^{-3}

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

$\overline{\Lambda n}$ bound state



cut	**value**
Track cuts	
Kink daughters	rejected
TPC	refit
$n_{clusters}$(TPC)	> 60
$\chi^2/cluster$	< 5
pseudo-rapidity $\lvert\eta\rvert$	$\lvert\eta\rvert < 0.9$
rapidity y	$\lvert y\rvert < 1$
V0 and kinematical cuts	
VO finder	online
Cosine of pointing angle	$\cos(\Theta) > 0.99$
DCA V0 daughters	$dca < 1$ cm
Momentum p_{tot} of the anti-deuteron	$p_{tot} > 0.2$ GeV/c
Energy loss dE/dx deuteron or anti-deuteron	$dE/dx > 110$

Lifetime dependency

H-Dibaryon

Lifetime (s)	Decay length (cm)	Efficiency	Upper limit dN/dy 99% CL
1.3×10^{-10}	3.95	0.0531	0.00061
2.63×10^{-10}	7.89	0.0385	0.00084
5.2×10^{-10}	15.8	0.0308	0.0011
1.4×10^{-9}	42	0.0154	0.0017

Λn bound state

Lifetime (s)	Decay length (cm)	Efficiency	Upper limit dN/dy 99% CL
1.3×10^{-10}	3.95	0.022	0.001708
2.63×10^{-10}	7.89	0.0255	0.001474
5.2×10^{-10}	15.8	0.032	0.001174
1.4×10^{-9}	42	0.044	0.000854

Comparison

Upper limits: Λn bound state: 1.5x10^{-3}

H-Dibaryon: 2x10^{-4} (8.4x10^{-4})

Thermal model (equilibrium) 164 MeV – *Andronic, private communication*:

Particle	Yield dN/dy	Yield scaled to 0-80%
Λn bound state	0.065	0.01625
H-Dibaryon ($\Lambda\Lambda$)	0.01016	0.00254

Thermal model (non-equilibrium) 138.8 MeV – *Petran, private communication*:

Particle	Yield dN/dy	Yield scaled to 0-80%
Λn bound state	0.086827	0.0391
H-Dibaryon ($\Lambda\Lambda$)	0.011396	0.00516

Coalescence model (only H-Dibaryon) – *ExHIC Collaboration, PRC 84, 064910 (2011):*

Model	Yield dN/dy	Yield scaled to 0-80%
Hadron coalescence	0.038	0.0095
Quark coalescence	0.0082	0.0021