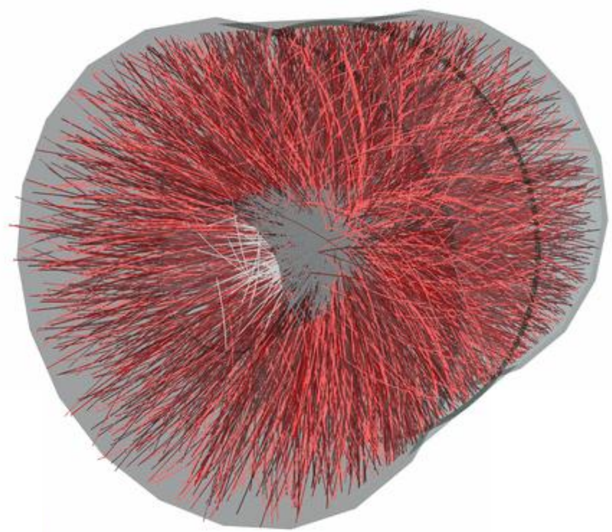
(Anti-) matter and hyper-matter production at the LHC with ALICE



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for the ALICE collaboration

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Quark Matter Studies

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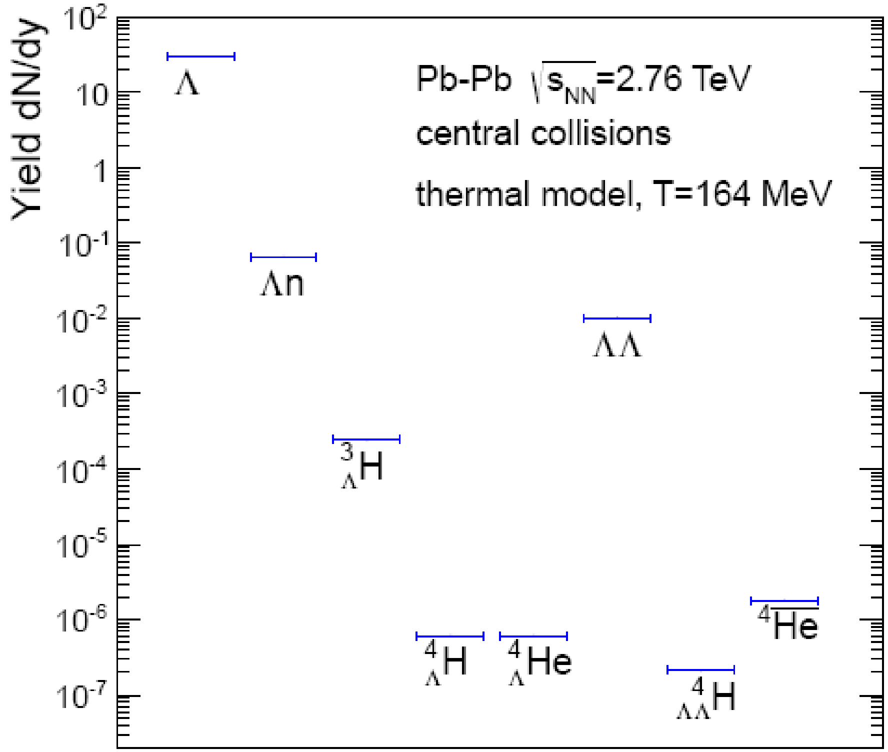
- Motivation
- ALICE performance
- Anti-Alpha
- Hypertriton
- Search for H-Dibaryon
- Search for Λn bound state
- Outlook

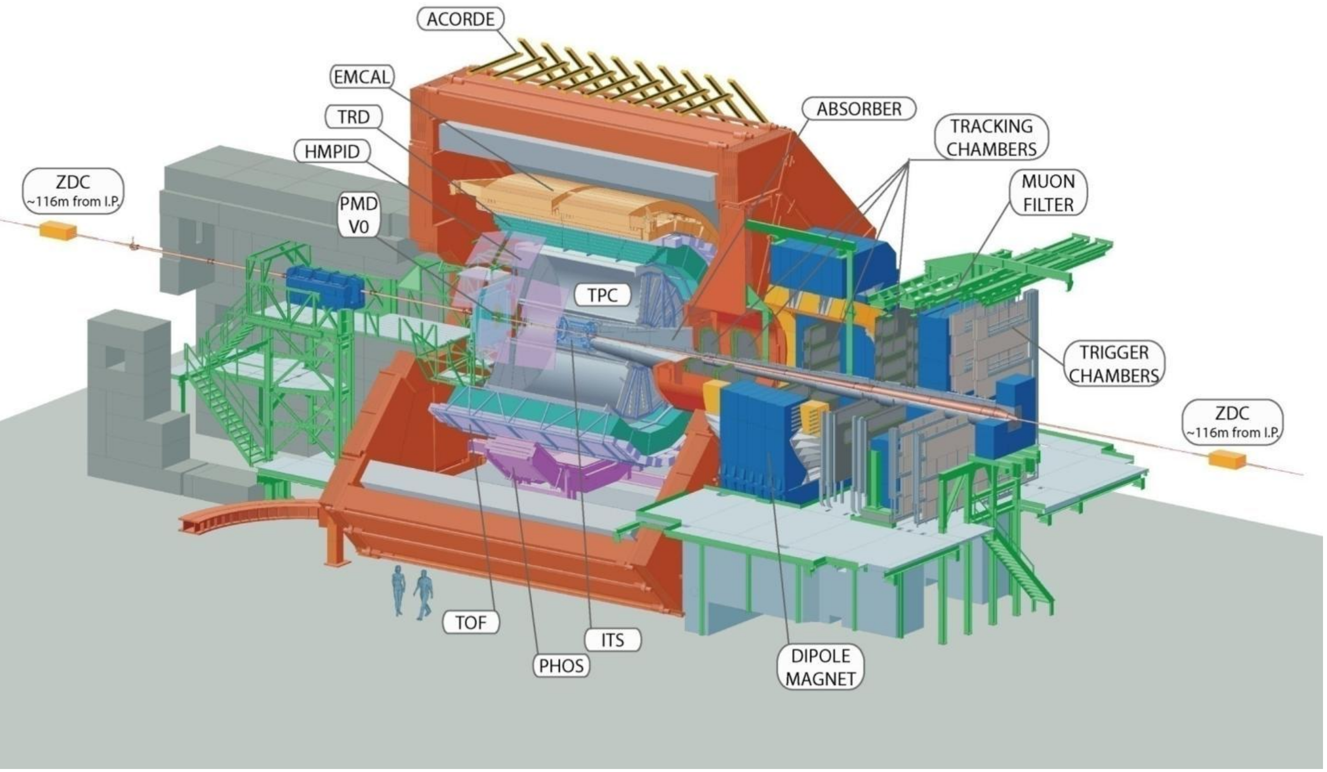
Motivation



A.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 thermal model predictions

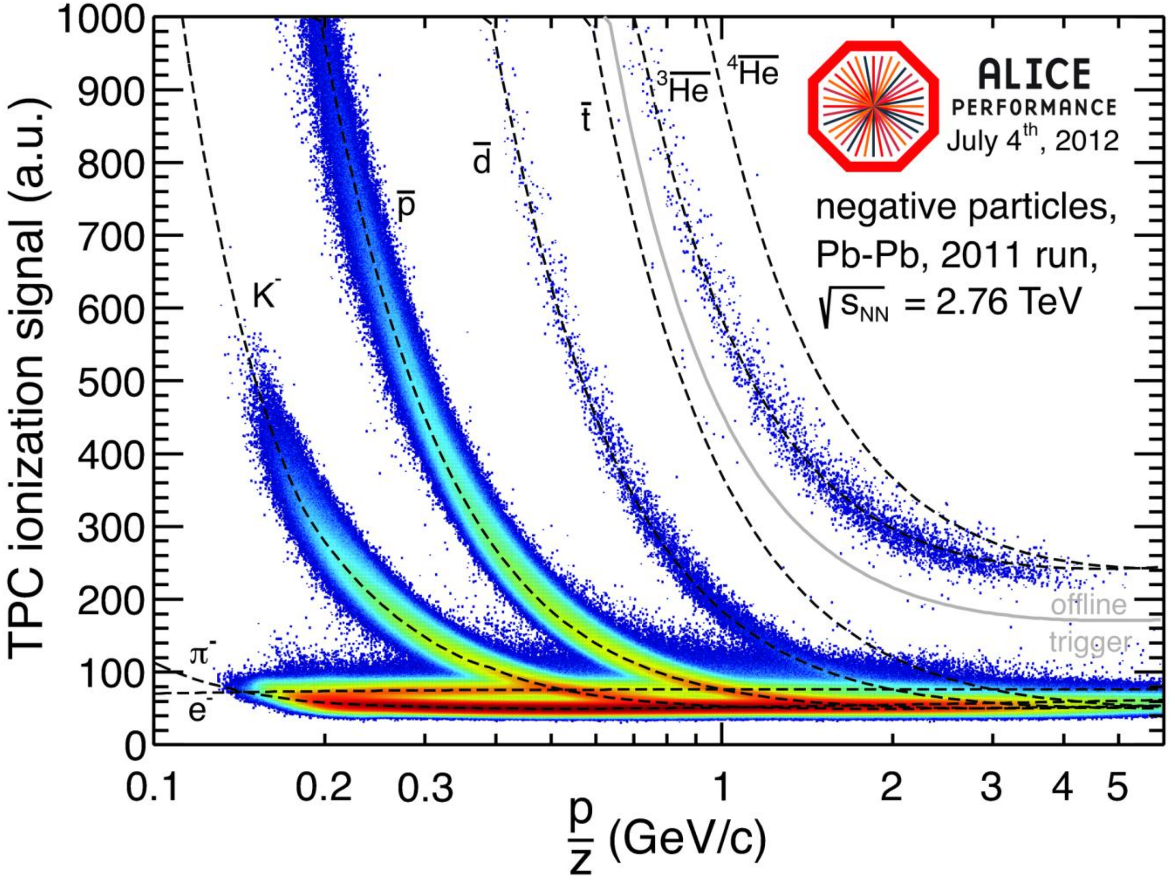
ALICE
A Large Ion Collider Experiment



Particle identification techniques involved:

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

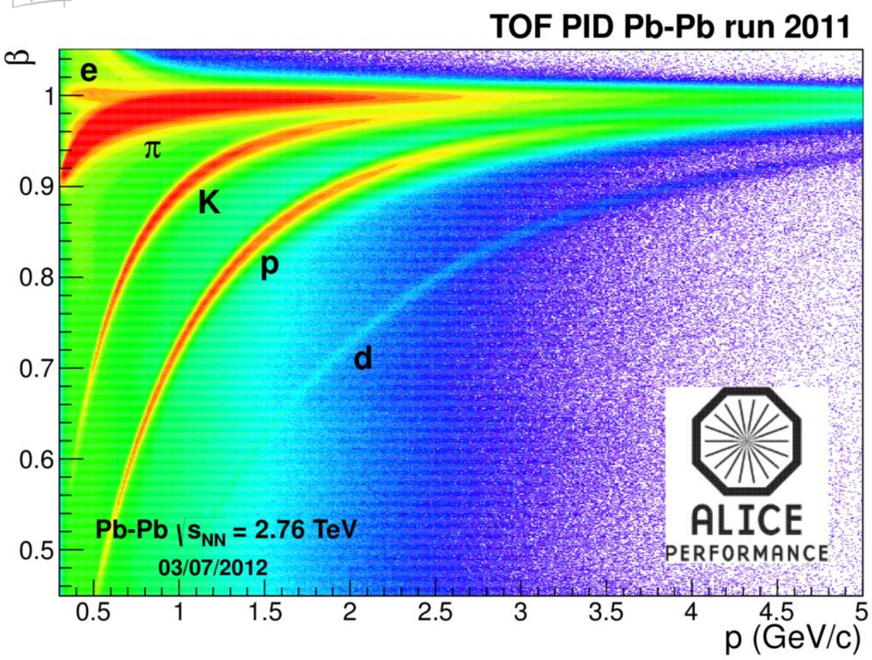
Time Projection Chamber (TPC)



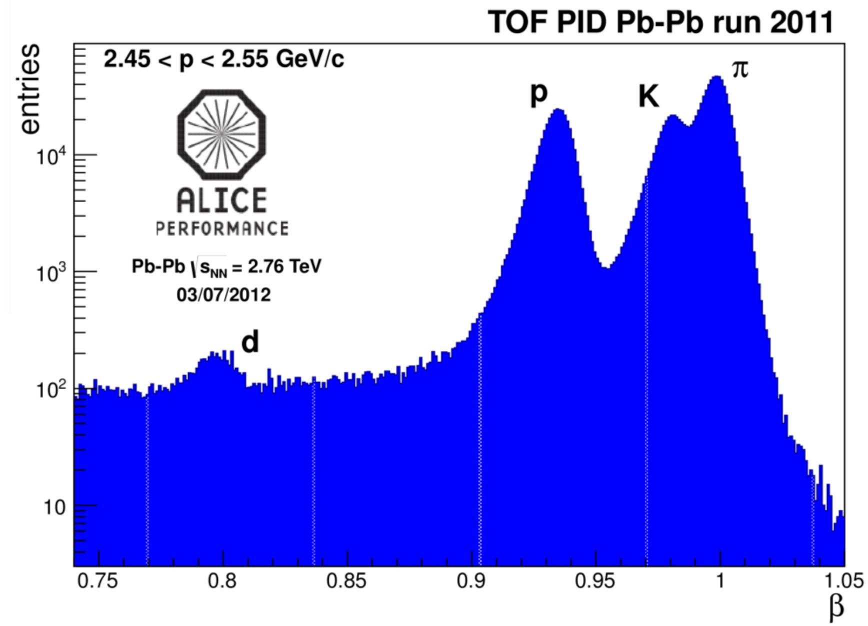
Excellent d*E*/d*x* performance of TPC (6.5% (2010) and 7.2% (2011) resolution in central Pb-Pb collisions)

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

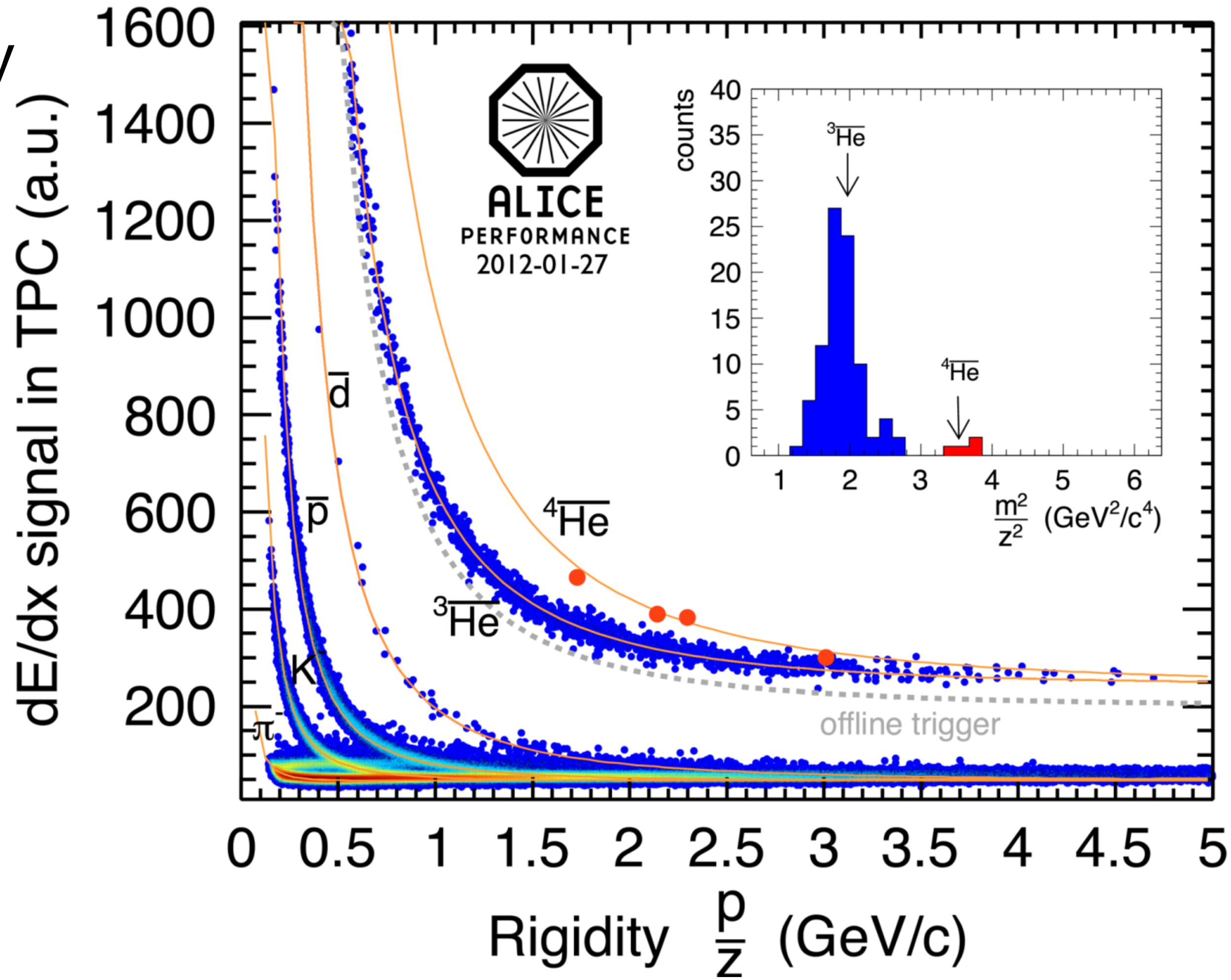


TOF performance is allowing a 2σ p/K-separation up to 5 GeV/*c*

Anti-Alpha

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

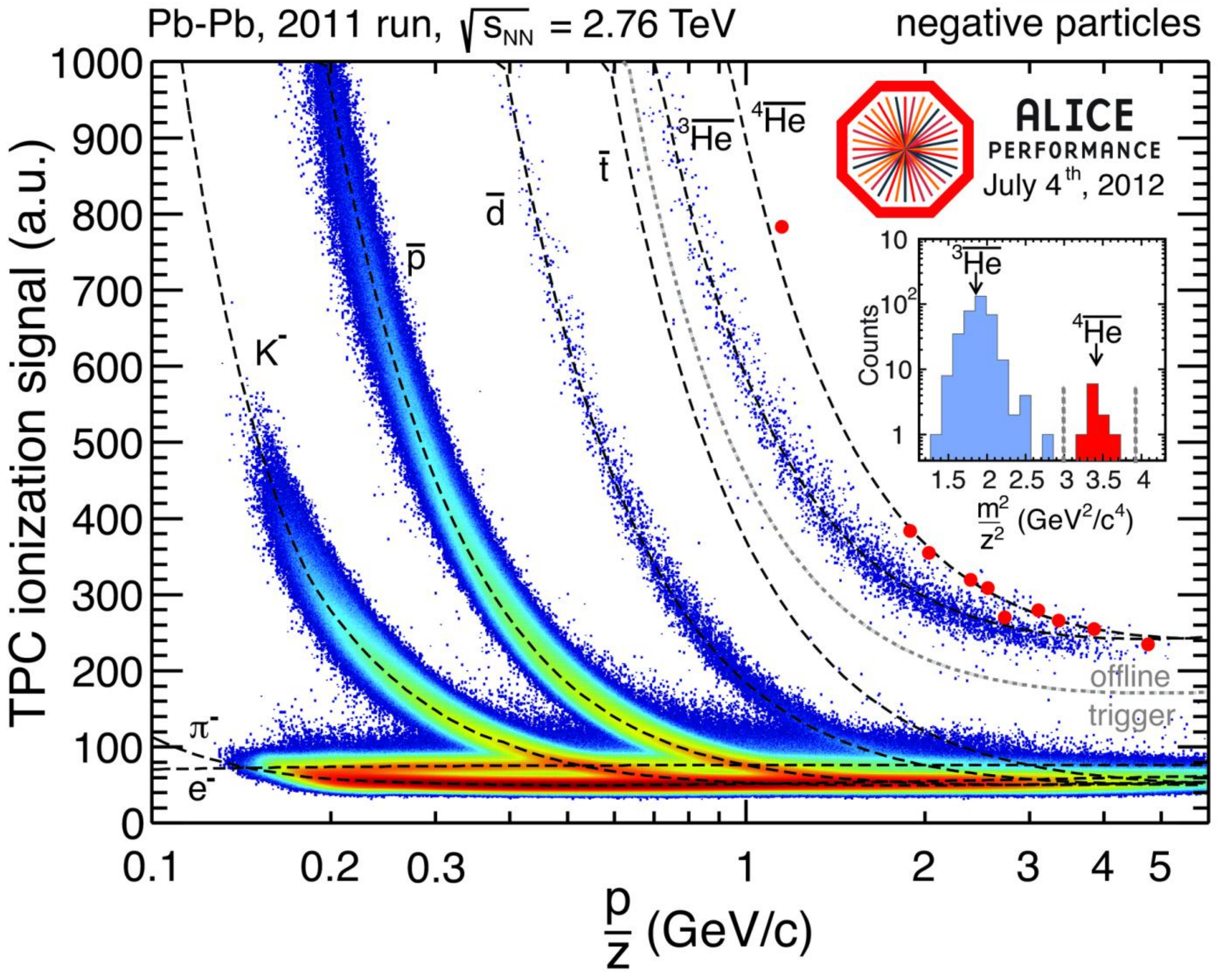
Full statistics 2010 ($13.8x10^6$ min. bias events)



Anti-Alpha

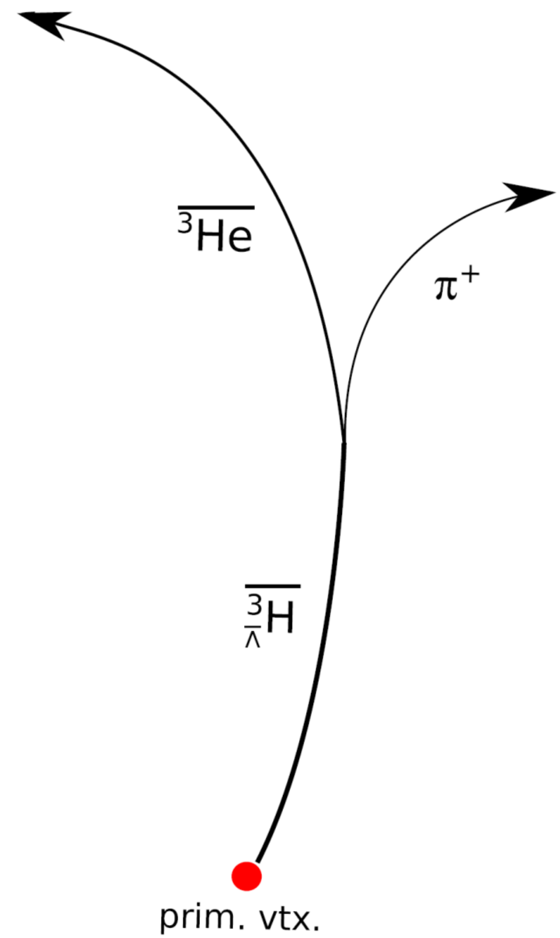
For the full statistics of 2011 we identified 10 Anti-Alphas using TPC and TOF

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



Hypertriton

- Decay topology is similar to a V0 decay
- Identification of light nuclei which are daughter tracks originating from decay vertices



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

decay lenght $c\tau = 5.5^{+2.7}_{-1.4} \pm 0.8$ cm

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

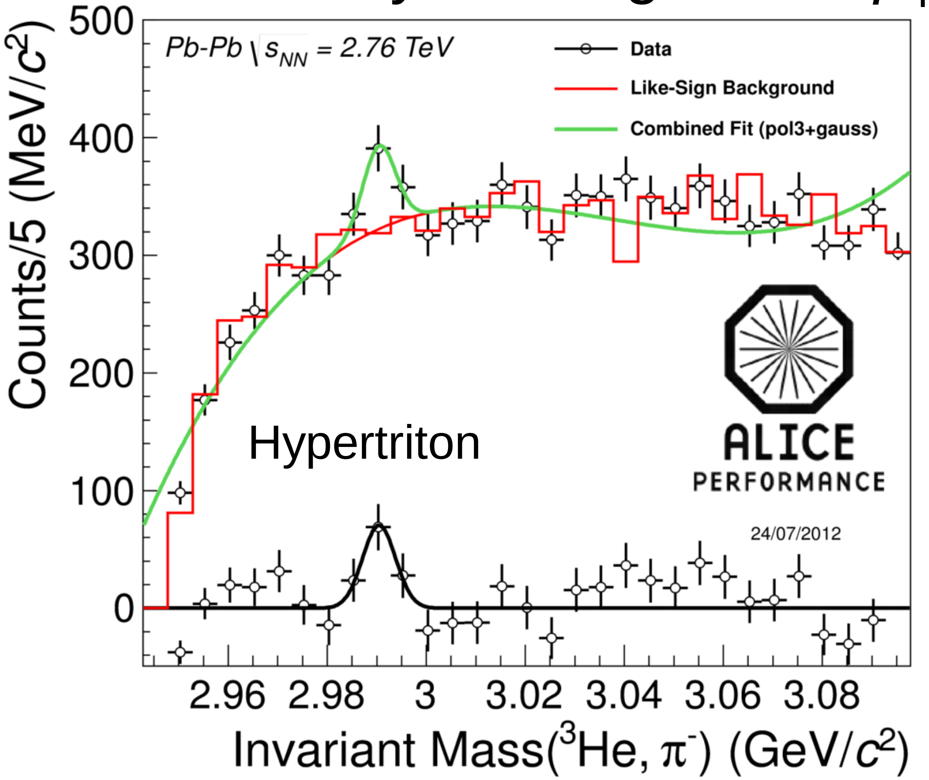
$\overline{^{3}_{\Lambda}\mathrm{H}} \longrightarrow \overline{^{3}\mathrm{He}} + \pi^{+}$

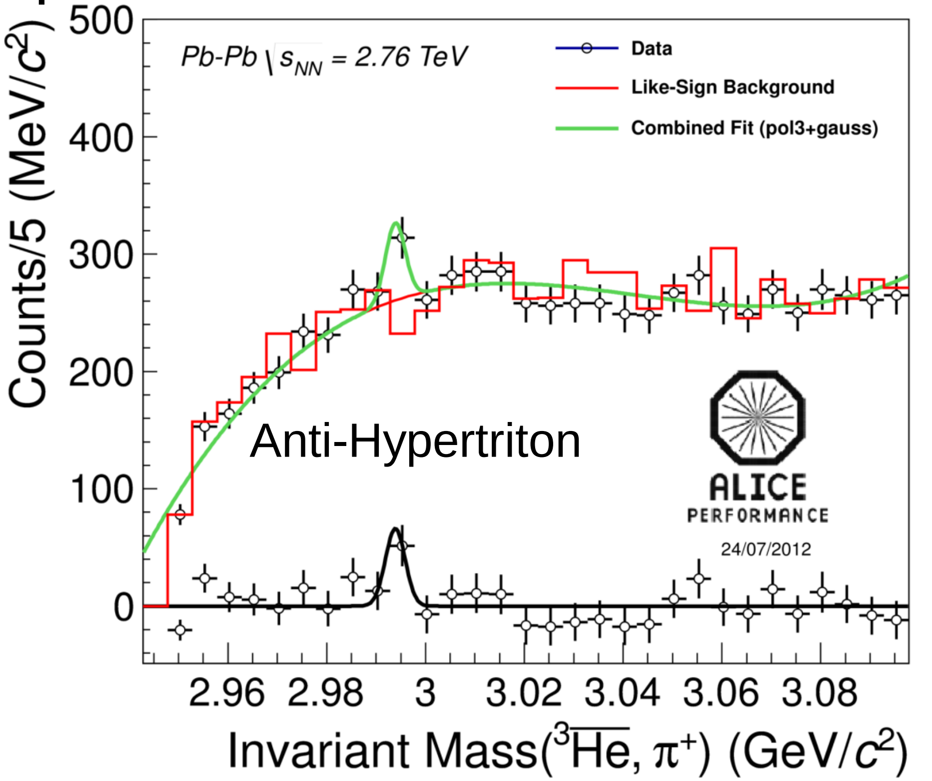
$^{3}_{\Lambda}\mathrm{H} \longrightarrow {}^{3}\mathrm{He} + \pi^{-}$

STAR Collaboration, Science 328, 58 (2010)

Hypertriton

Signal of the hypertriton from the 2011 run
→ currently working on the p_T spectra extraction





$\mu = (2.990 \pm 0.001)$ GeV/c^2
$\sigma = (3.35 \pm 0.7) \times 10^{-3}$ GeV/c^2

$\mu = (2.993 \pm 0.001)$ GeV/c^2
$\sigma = (2.00 \pm 1.2) \times 10^{-3}$ GeV/c^2

H-Dibaryon

- Hypothetical bound state of uuddss ($\Lambda\Lambda$)
- 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$\pm$14 MeV/c^2, respectively lies close to the Ξp threshold

→ Renewed interest in experimental searches

H-Dibaryon

Two cases:

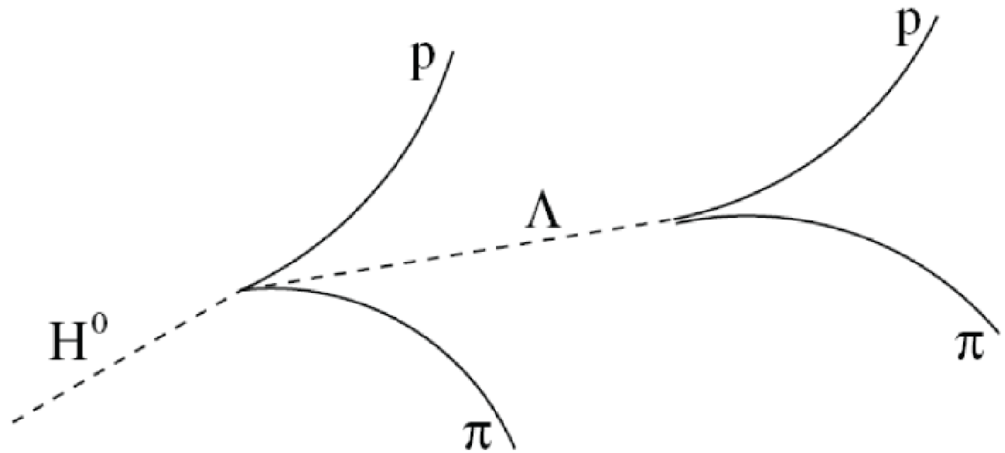
- $m_H < \Lambda\Lambda$ threshold

→ weakly bound

measurable channel

$H \rightarrow \Lambda p \pi$

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



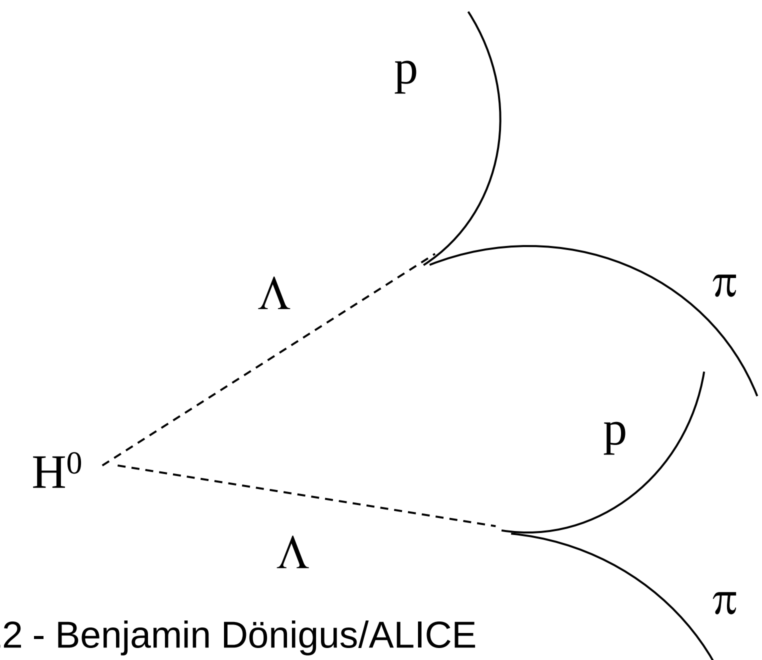
- $m_H > \Lambda\Lambda$ threshold

→ resonant state

measurable channel

$H \rightarrow \Lambda\Lambda$

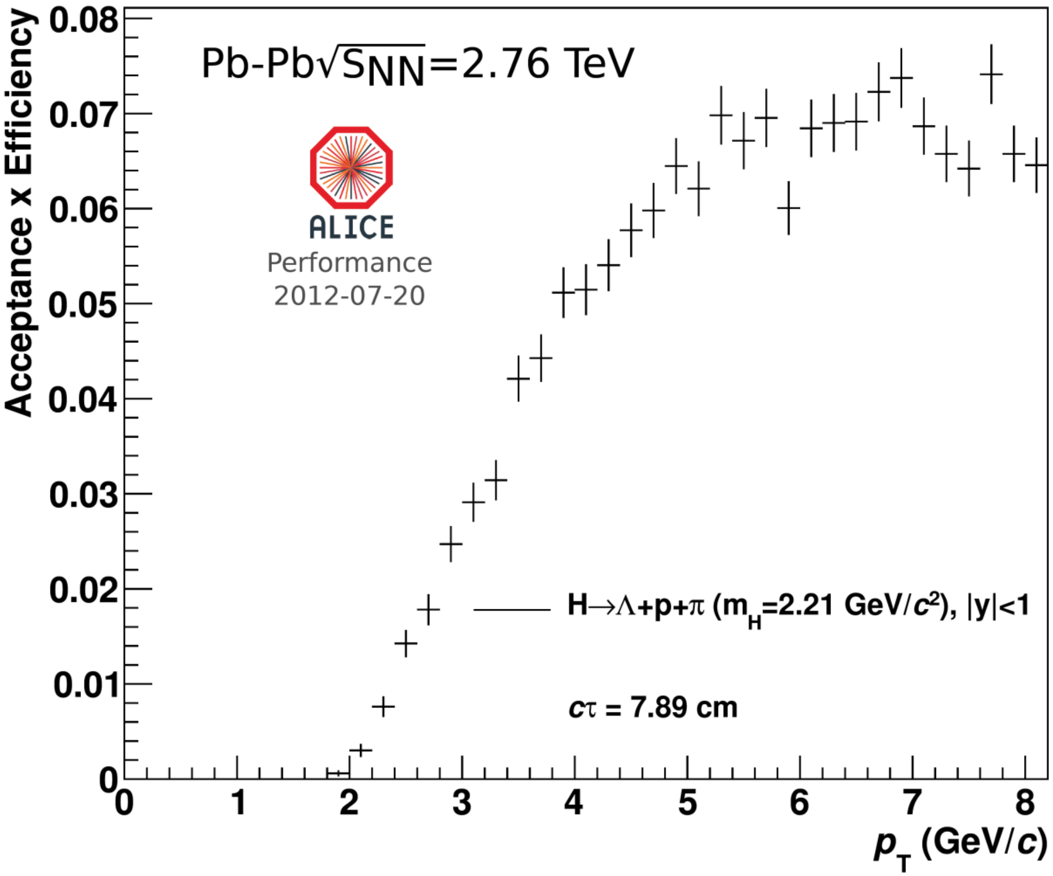
m_H > 2.231 GeV/c^2



H-Dibaryon

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

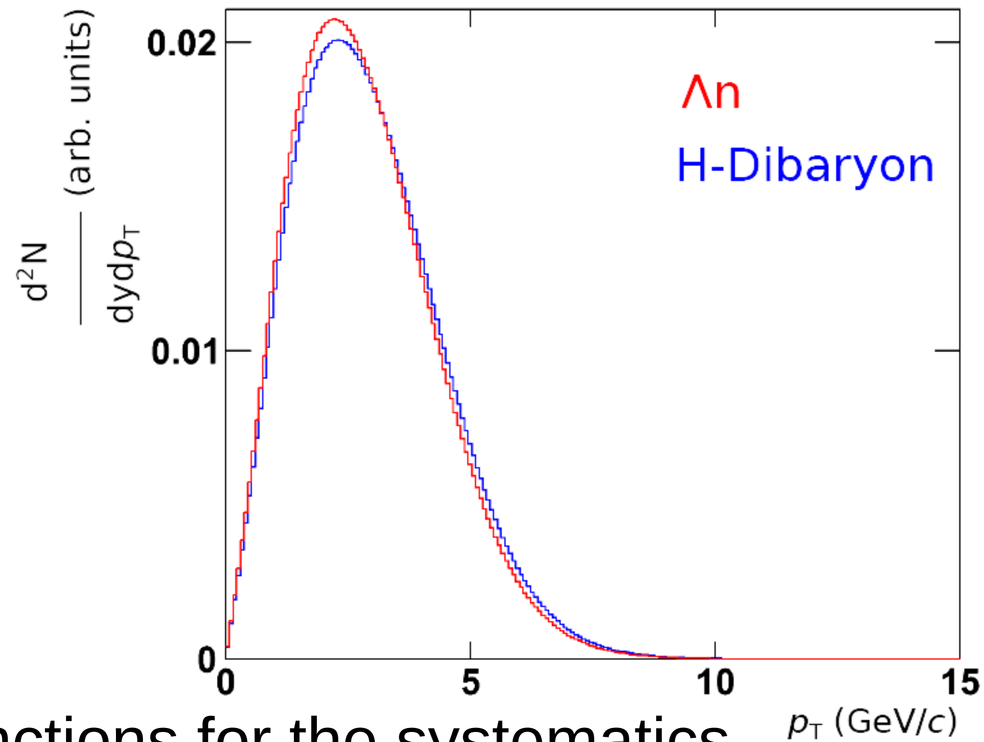
Assuming the lifetime to be that of the Λ



H-Dibaryon

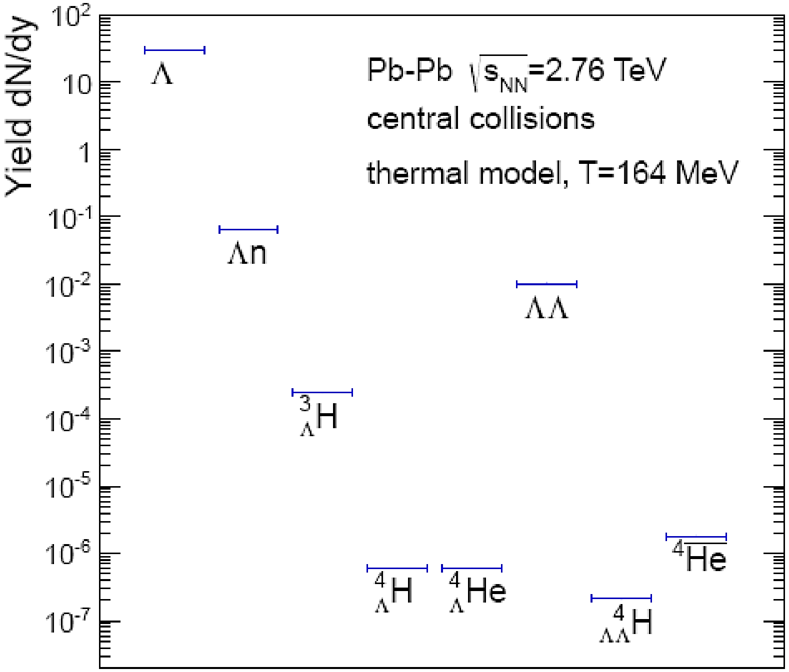
p_T-shape of the H-Dibaryon (and Λn bound state) estimated from the extrapolation of blast-wave fits for p,K,π

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

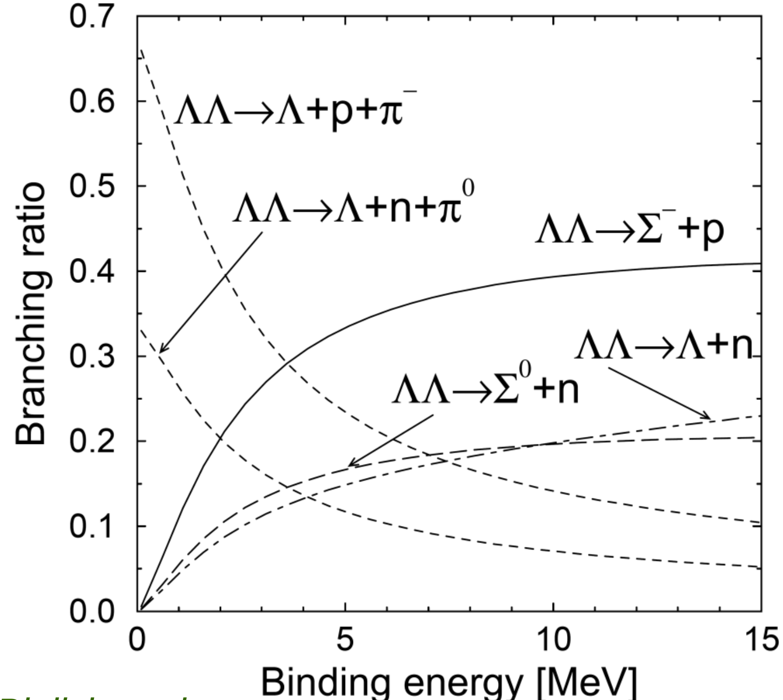


Unknown p_T-shape is the main source of uncertainty: Therefore used different functions for the systematics (limiting cases: blast-wave of deuteron and helium-3)

H-Dibaryon



A.Andronic, private communication



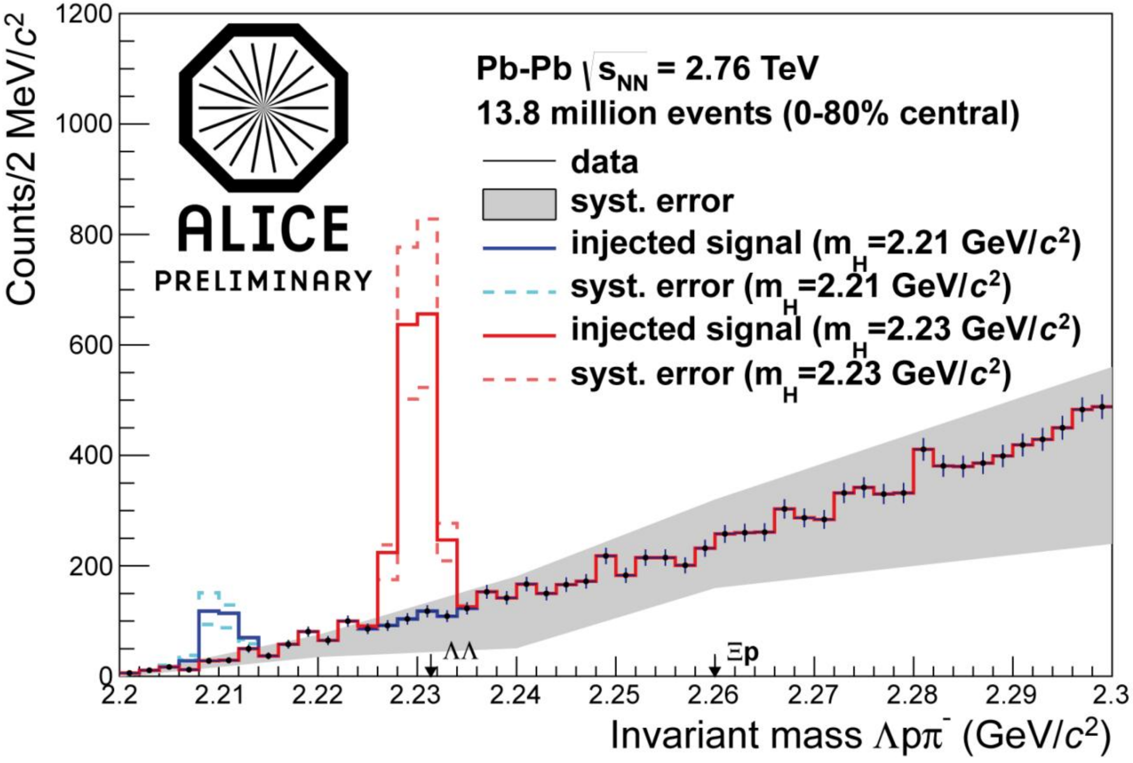
Schaffner-Bielich et al., PRL 84, 4305 (2000)

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

strongly bound: 2110 x 0.1 = 211

lightly bound: 2110 x 0.64 = 1350

H-Dibaryon



- No signal visible

From the non observation we obtain as upper limits:

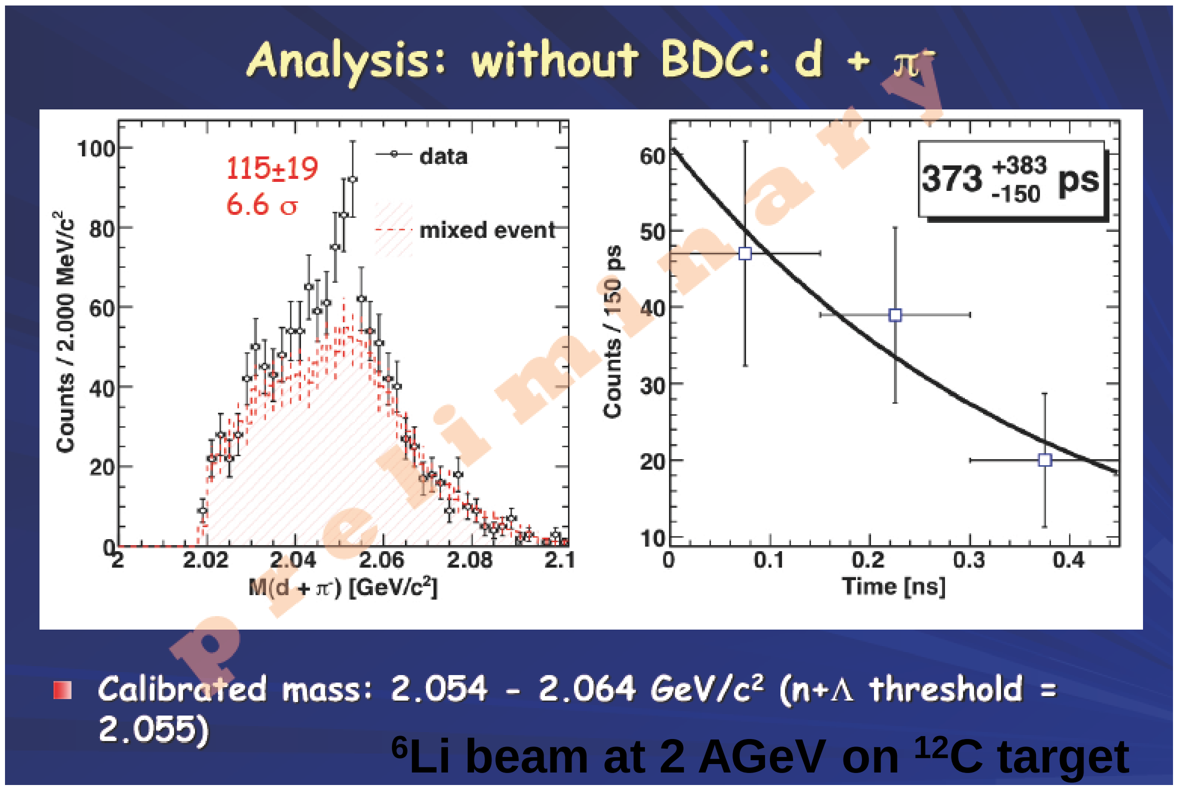
For a strongly bound H:
→ d*N*/d*y* ≤ 8.4×10^{-4} (99% CL)

For a lightly bound H:
→ d*N*/d*y* ≤ 2×10^{-4} (99% CL)

Thermal model prediction is d*N*/d*y*=3.1×10^{-3} → thermal model would need to be wrong by a factor ~10
But the model describes the hypertriton yields measured with STAR correctly within uncertainties *(Andronic et al., PLB 697, 203 (2011) and Cleymans et al., PRC 84, 054916 (2011))*

Λn bound state

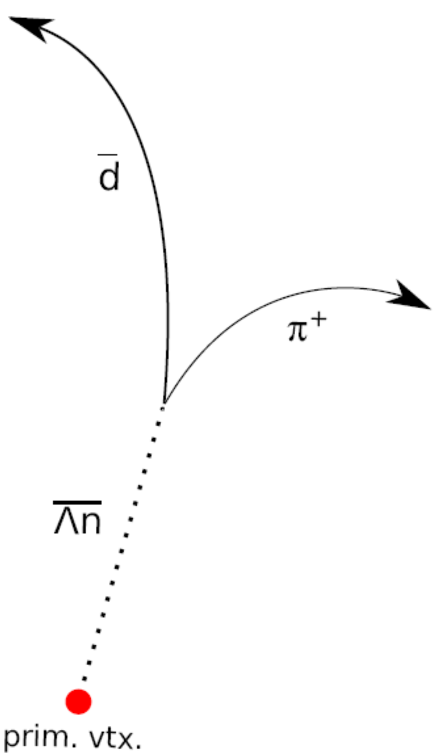
- HypHI experiment at GSI see evidence of a new state:
  Λn→d π^-

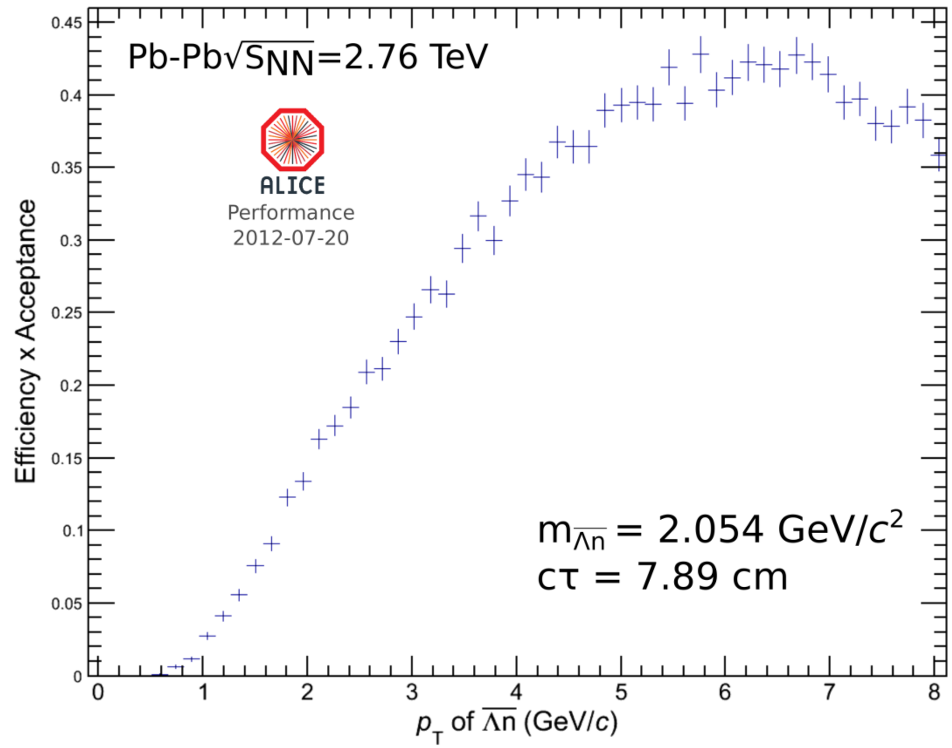


http://www.bnl.gov/hhi/files/talks/TakehikoSaito.pdf, as shown 1.3.2012

Λn bound state

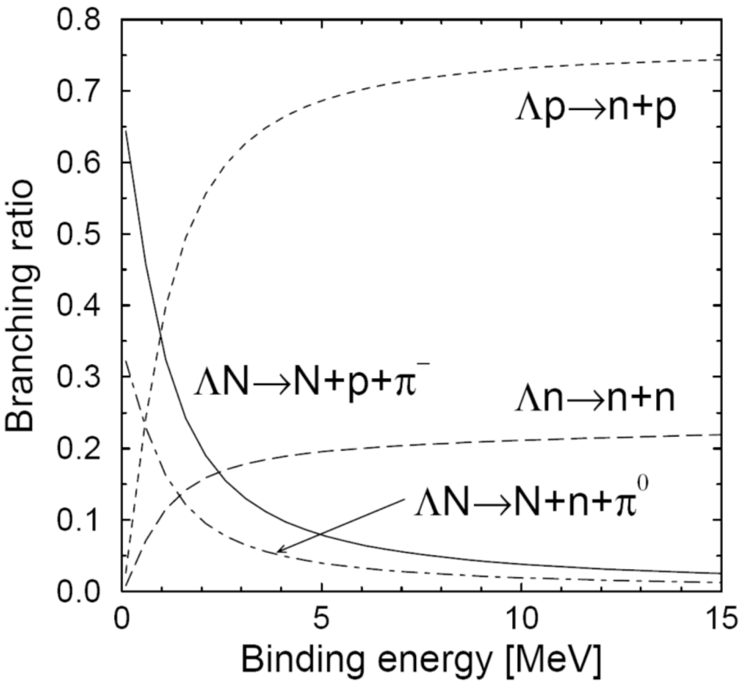
We assume a V0 type decay topology



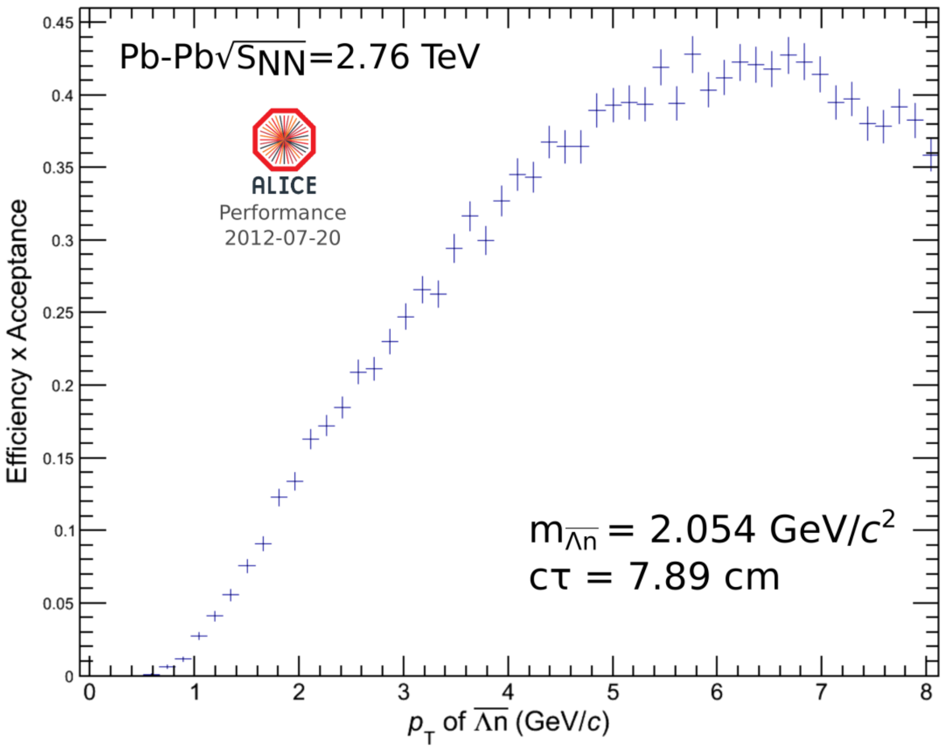


Efficiency estimation from Monte Carlo simulation

Λn bound state



Schaffner-Bielich, private communication



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

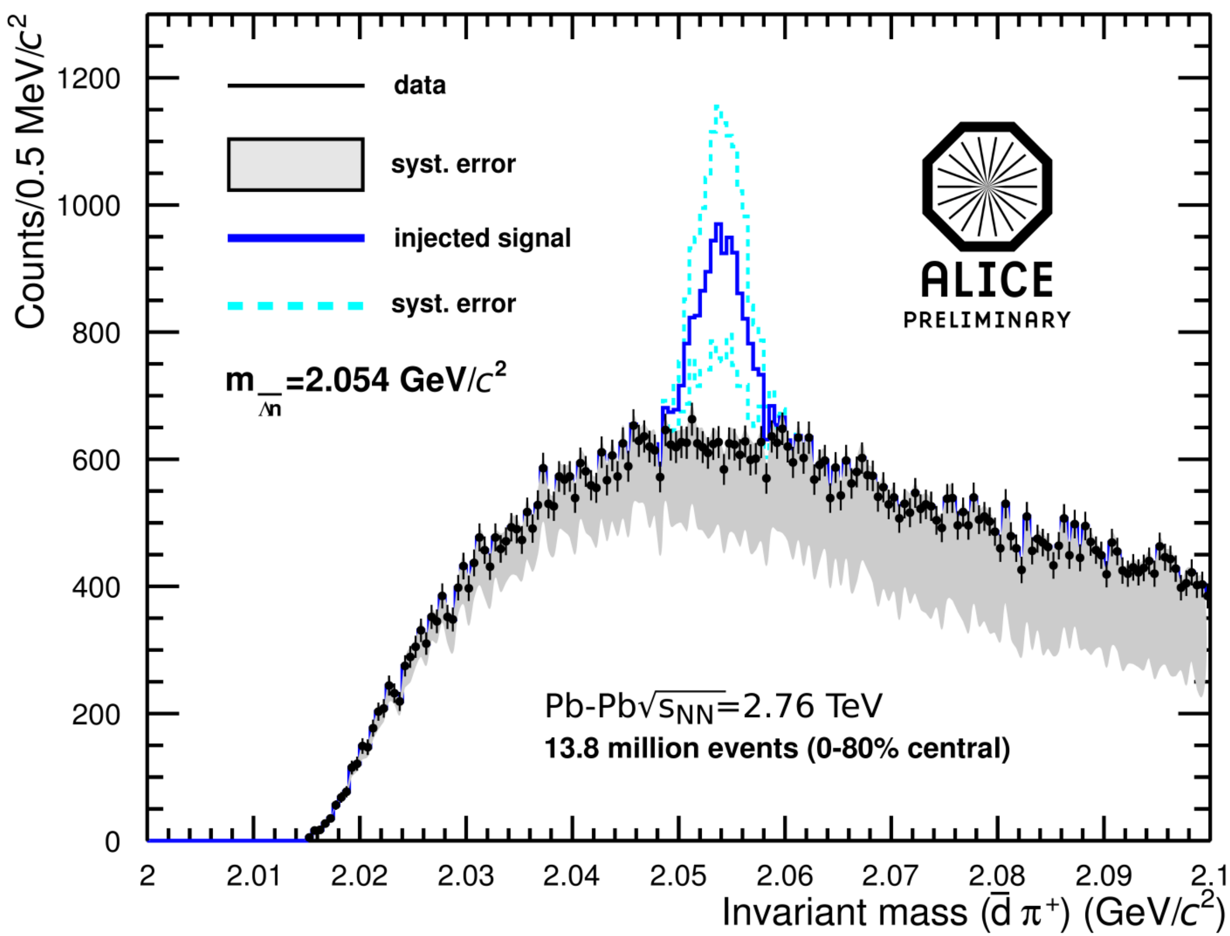
Λn bound state

- 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}

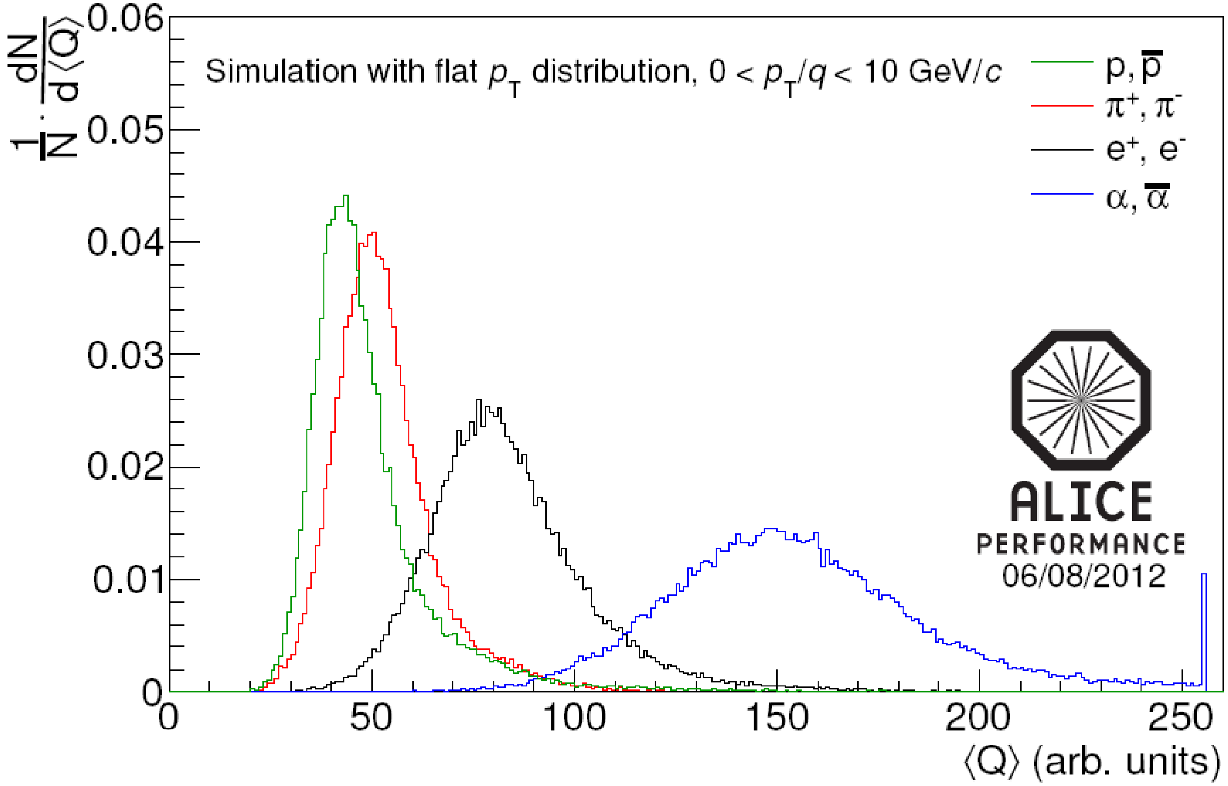


→ thermal model would need to be wrong by a factor ~10

Outlook: Trigger on nuclei

Clear separation of nuclei in d*E*/d*x* of the Transition Radiation Detector allows to trigger on them

→ Working on the efficiency and rejection estimation from data in pp and Pb-Pb



Conclusion

- ALICE is well suited for the detection of different particle species (stable, weakly and strongly decaying)
- By combining the different particle identification techniques (TPC dE/dx and TOF) we have
  - observed 10 Anti-Alphas in the run of 2011
  - observed hypertriton signal and work on the p_{T} spectra
  - set an upper limit for the H-Dibaryon for two bound cases
  - set an upper limit for the Λn bound state (observed by the HypHI collaboration → different production mechanism?)
  - made first steps towards an online trigger on light nuclei

Backup

Hypertriton

LHC11h - ESDs Pass 2 reconstruction; 23 M events, trigger selection kAny
TRACK CUTS:
TPC refit;
No pure SA;
No SA tracks;
TPC cluster > 60;
chi2 < 5;
No kink daughter
PID:
3He tracks: asymmetric n-sigma band;
Negative tracks : symmetic 2-s band;
|DCAz| 3He track < 1cm;
He3 rigidity > 1.2 GeV/c && < 6 GeV/c
SECONDARY Vertex
DCA tracks < 0.7 cm;
Cos(Pointing angle)>0.99;
DCA neg to PV > 0.4 cm;
c*tau < 40 cm.

LHC11h - ESDs Pass 2 reconstruction; 23 M events, trigger selection kAny
TRACK CUTS:
TPC refit;
No pure SA;
No SA tracks;
TPC cluster > 60;
chi2 < 5;
No kink daughter
PID:
Anti-3He tracks: asymmetric n-sigma band;
Positive tracks : symmetic 2-s band;
|DCAz| Anti-3He track < 1cm;
Anti-He3 rigidity > 1.2 GeV/c && < 6 GeV/c
SECONDARY Vertex
DCA tracks < 0.7 cm;
Cos(Pointing angle)>0.99;
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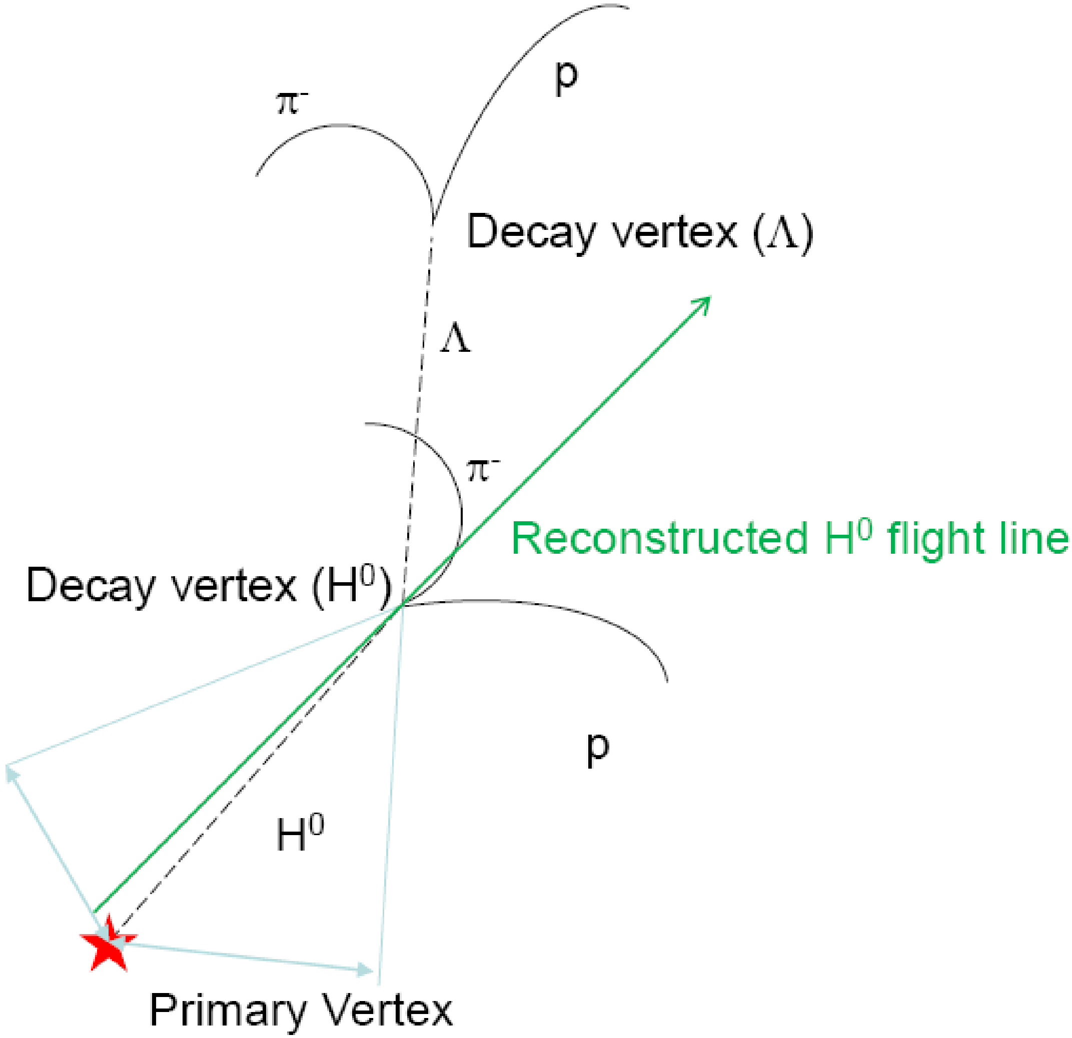
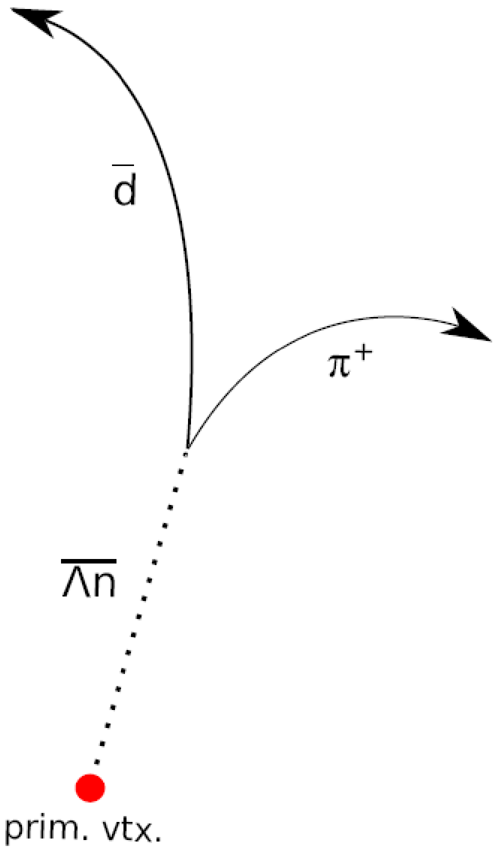
H-Dibaryon



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

$\overline{\Lambda n}$ 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

Minimum bias dE/dx