Recent results on hypernuclear production at SIS energies

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for the HypHI collaboration

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EMMI workshop 2015:
Anti-Matter, hyper-matter and exotica production at the LHC
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Outline

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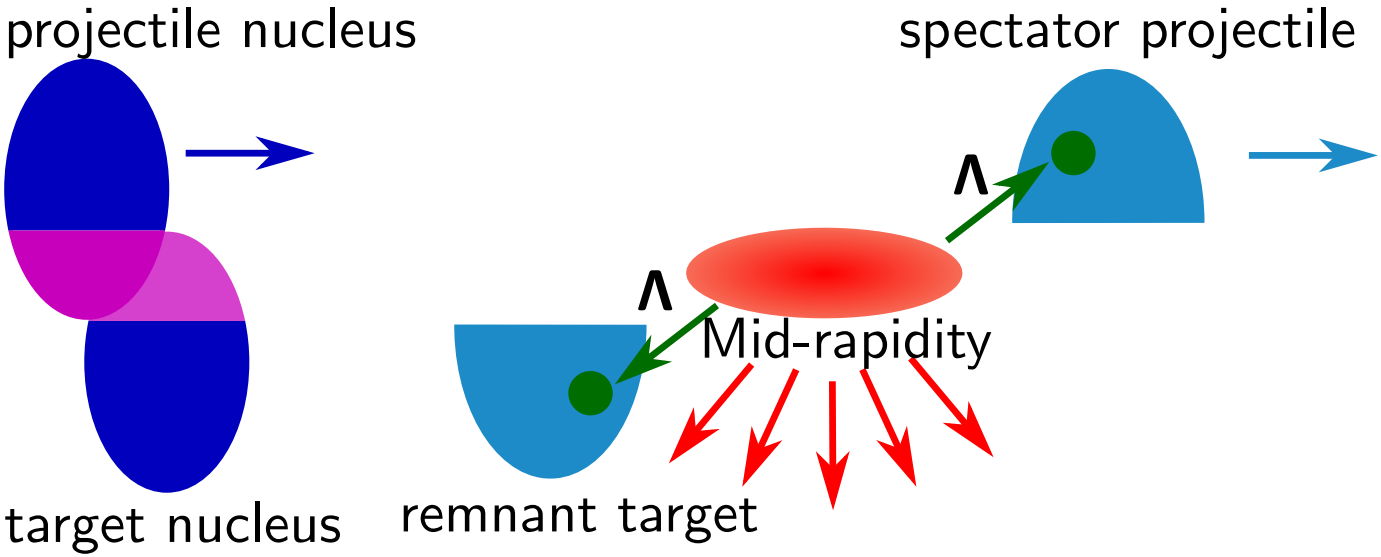
Properties of the production mechanism



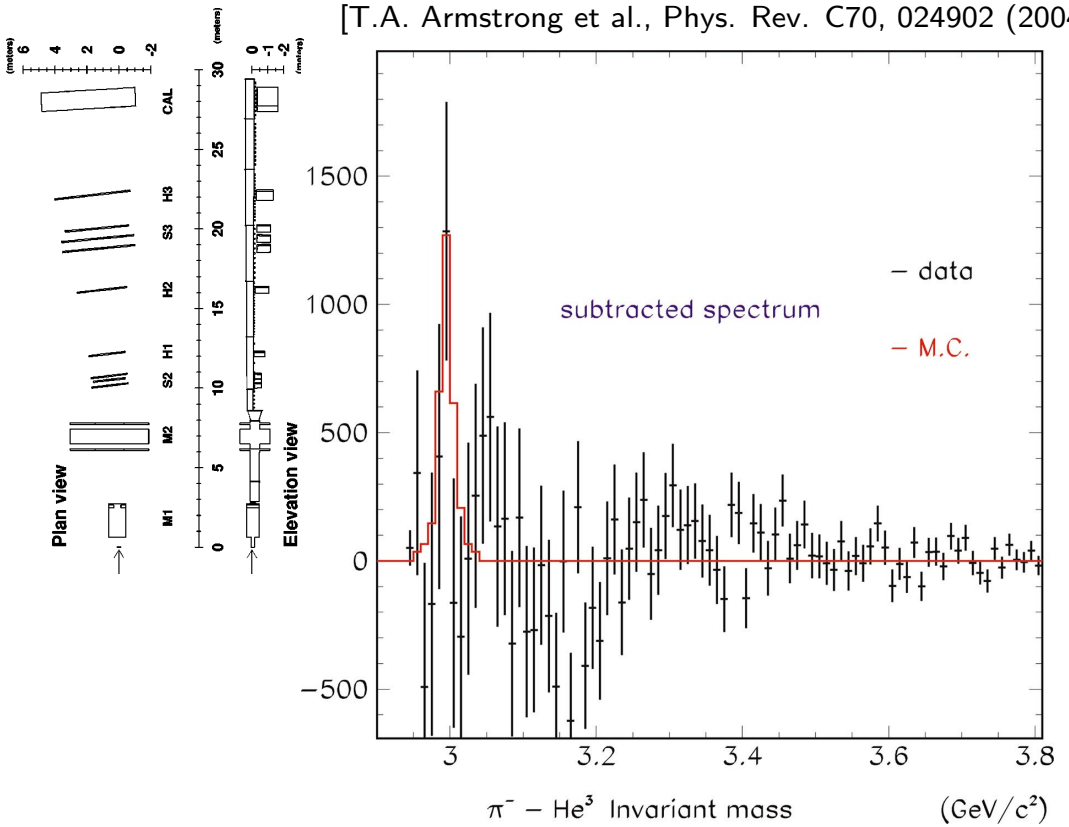
- $NN \rightarrow \Lambda KN$ Energy threshold $\sim$ 1.58 GeV.
- Beam energy $>$ E_{th}: available at GSI - SIS (2 A GeV)
- Coalescence of Λ or (π^+, K^+) reaction in spectator fragment :
  $\Rightarrow$ Can produce high isospin and heavy hypernuclei.
- Coalescence within the participant region :
  $\Rightarrow$ Can produce light hypernuclei (penalty factor).

Outline

Mid-rapidity, freeze out : AGS E864 results

Fixed target, Reaction: Au+Pt @ 11.5 AGeV/c or $\sqrt{s_{NN}} = 4.84$ GeV

[T.A. Armstrong et al., Phys. Rev. C70, 024902 (2004)]



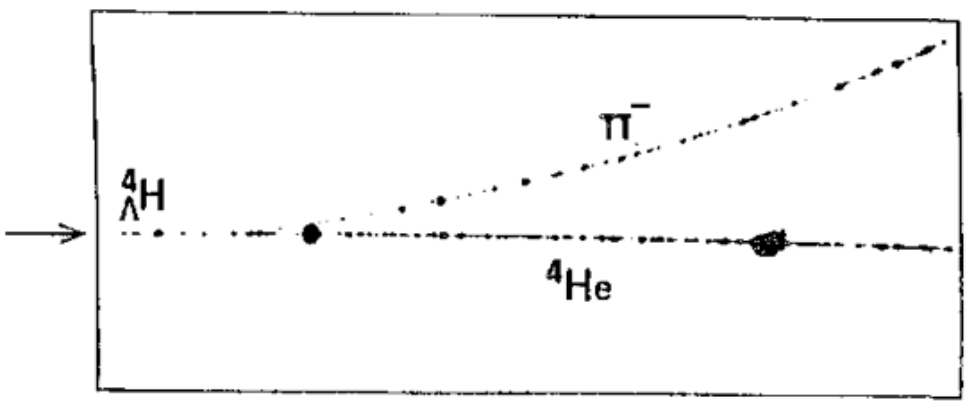
- ${}^{3}_{\Lambda}\mathrm{H}$ signal : 2σ in rapidity range :[1.6, 2.6] ($y_{cm} \sim 2.3$)
- ${}^{4}_{\Lambda}\mathrm{H}$: upper limit.
- First to use the ratio $S_3 = {}^{3}_{\Lambda}\mathrm{H}/{}^{3}\mathrm{He} \cdot \mathrm{p}/\Lambda$ and $S_4 = {}^{4}_{\Lambda}\mathrm{H}/{}^{4}\mathrm{He} \cdot \mathrm{p}/\Lambda$
- $S_3 = 0.36 \pm 0.26$
- $S_4(upperLimit) < 0.225$

Projectile region : Before HypHI

- First experiments provided first hints of feasibility :
  - At LBNL Bevatron ^{16}O+polyethylene @ 2.1AGeV or $\sqrt{s_{NN}}$ =2.73 GeV

    [K. Nield et al., Phys.Rev. C13, 1263 (1976)]
  - At JINR Dubna, ^{4}He @ 3.7 AGeV ($\sqrt{s_{NN}} = 3.2$ GeV)& ^{7}Li @ 3.0 AGeV ($\sqrt{s_{NN}} = 3$ GeV)+ polyethylene

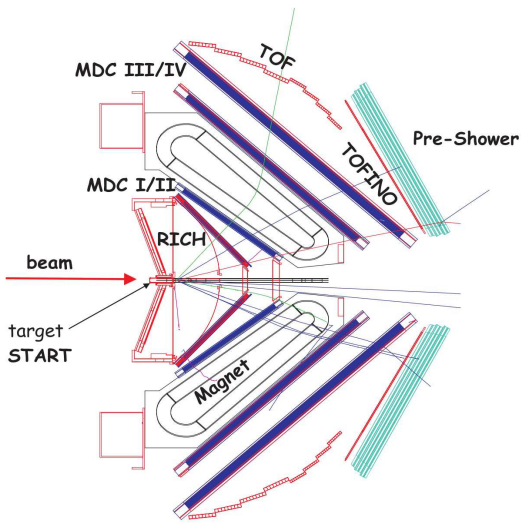
    [A. U. Abdurakhimov et al., N.Cimento A102, 645 (1989)]

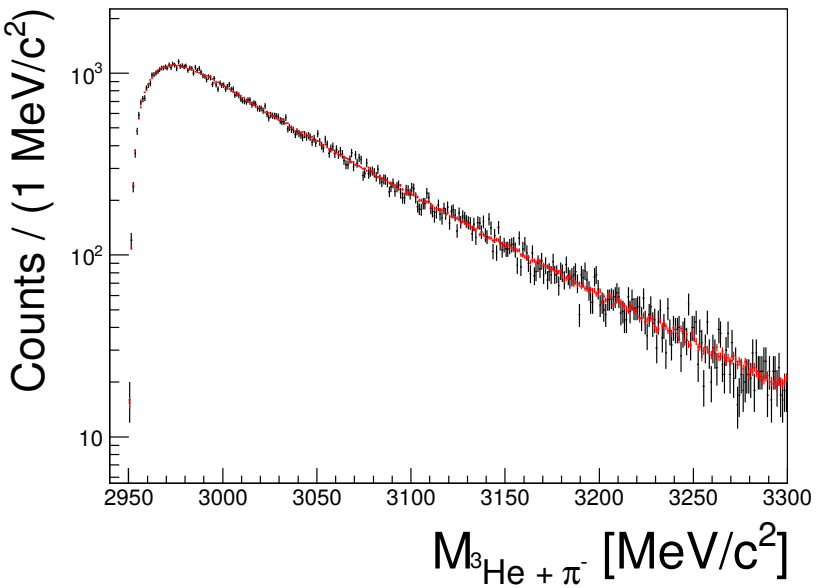


Outline

Spectator region (target) : HADES results

HADES: Ar+KCl @ 1.76AGeV or $\sqrt{s_{NN}} = 2.61$ GeV



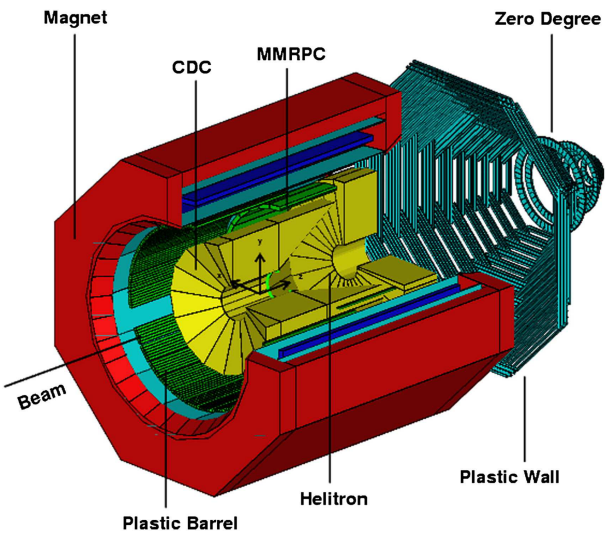


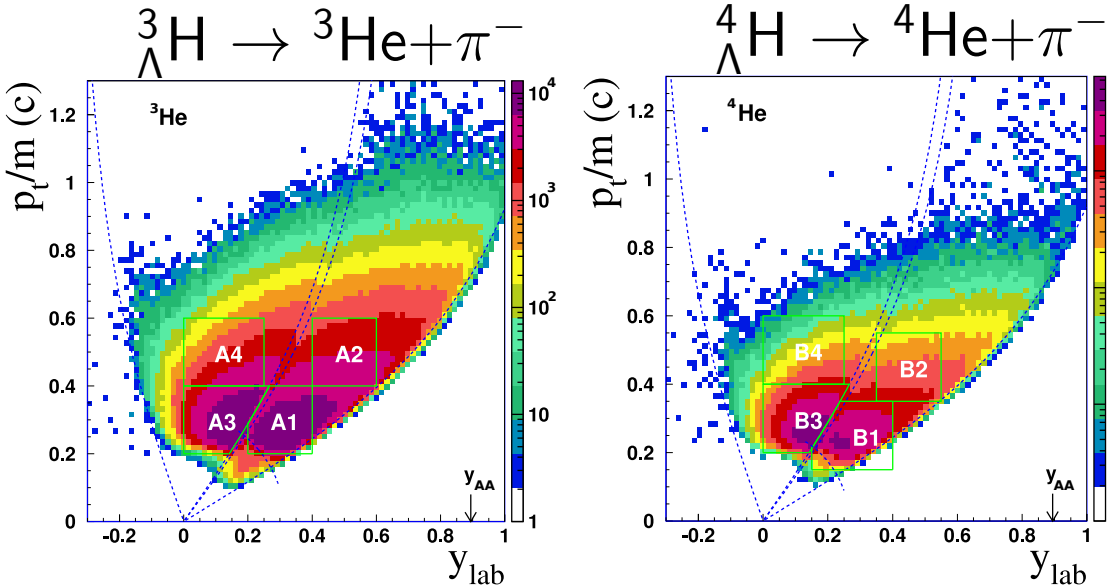
[HADES Collaboration, Eur.Phys. J. A 49 (2013) 146]

- rapidity: [-0.7, 0.1] ($y_{cm} = 0.86$)
  - Upper limit : ${}^{3}_{\Lambda}\mathrm{H}/\Lambda = 2.5 \pm 0.3 \cdot 10^{-2}$

Spectator region (target) : FOPI results

FOPI : Ni+Ni @ 1.91 AGeV or $\sqrt{s_{NN}} = 2.67$ GeV





[Y. Zhang, PhD Thesis (2013)]

Spectator region (target) : FOPI results

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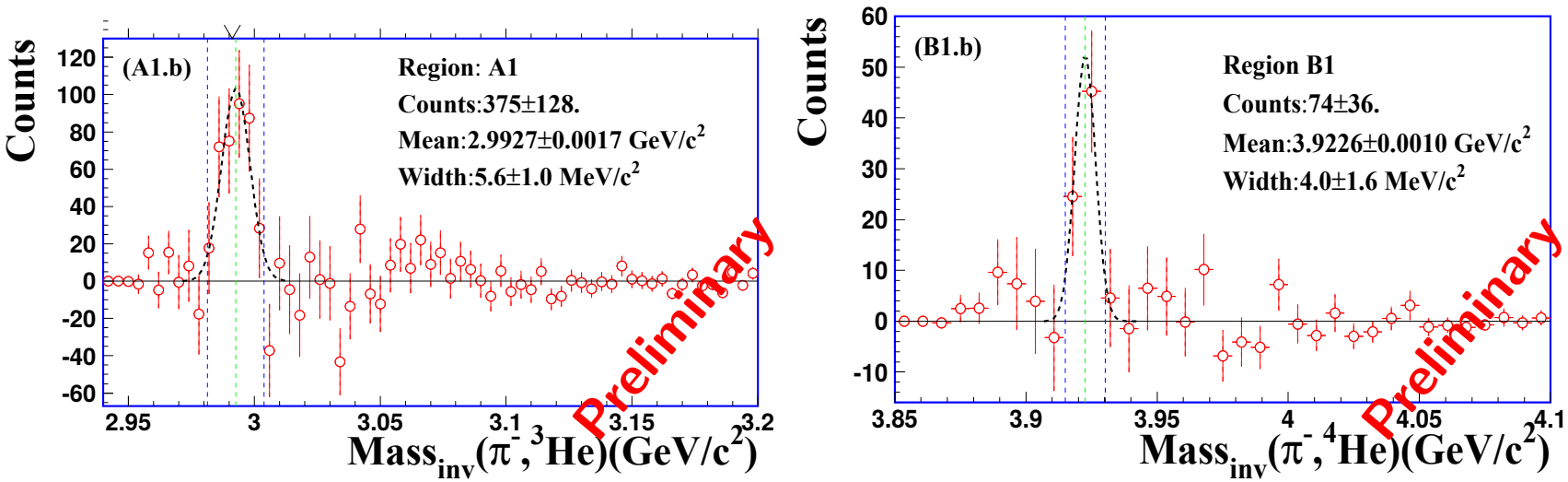
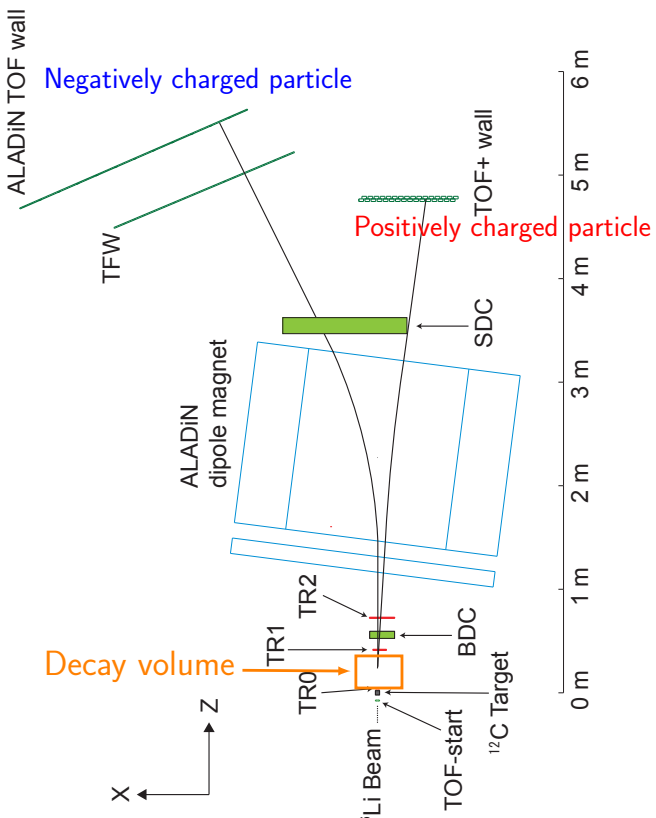


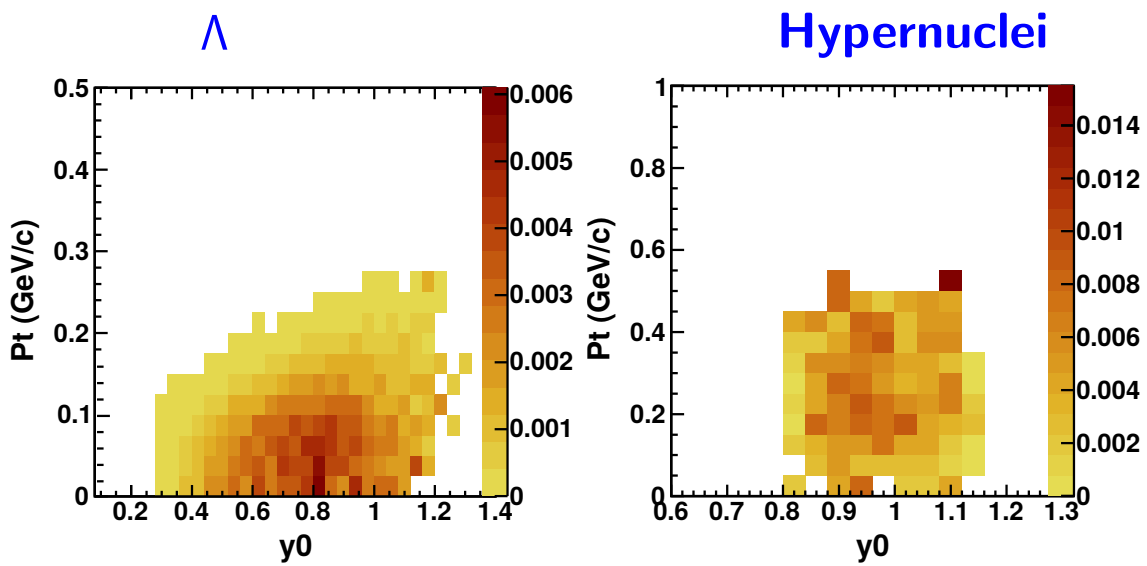
[Y. Zhang, PhD Thesis (2013)]

- Rapidity : [0.2, 0.4] ($y_{cm} = 0.9$) & Pt/m [0.2, 0.4]
  - ${}^{3}_{\Lambda}\mathrm{H}/\Lambda = 0.52 \pm 0.04$
    $\rightarrow$ Not compatible with the HADES upper limit
- Rapidity : [0.15, 0.4] ($y_{cm} = 0.9$) & Pt/m [0.15, 0.35]
  - ${}^{4}_{\Lambda}\mathrm{H}/\Lambda \sim 0.09$

Spectator region (projectile) : HypHI results

Fixed target, Reaction : ^{6}Li+^{12}C @ 2 AGeV or $\sqrt{s_{NN}} = 2.7$ GeV

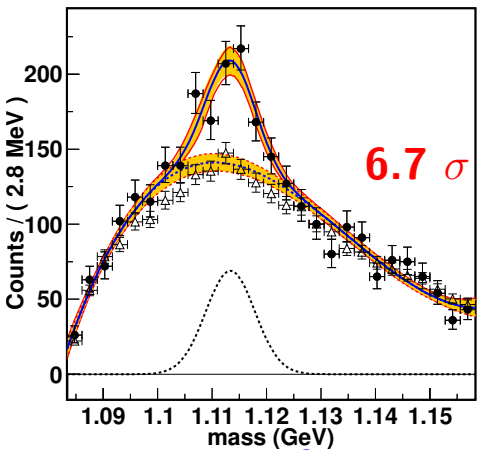




[C. Rappold *et al.*, Phys. Lett. B**747** (2015) 129]

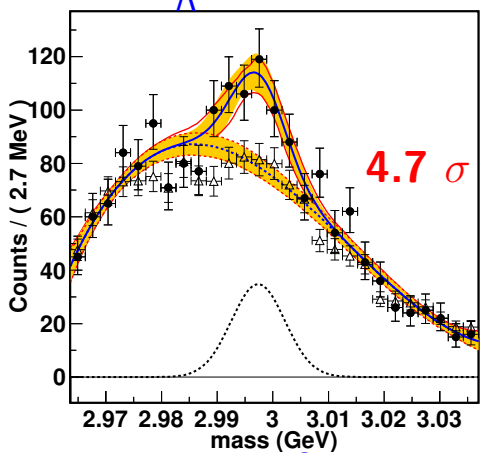
Spectator region (projectile) : HypHI results

$\Lambda \rightarrow p+\pi^-$



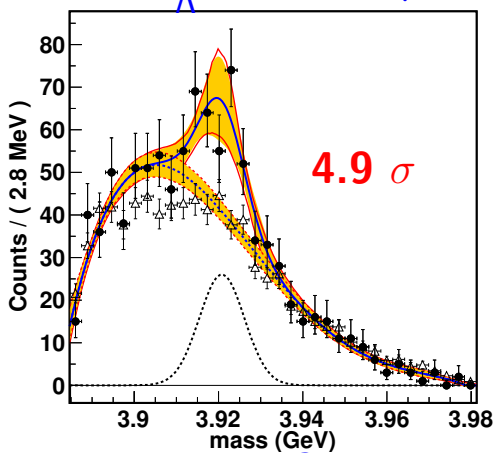
$\tau = 262^{+56}_{-43} \pm 45$ps

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



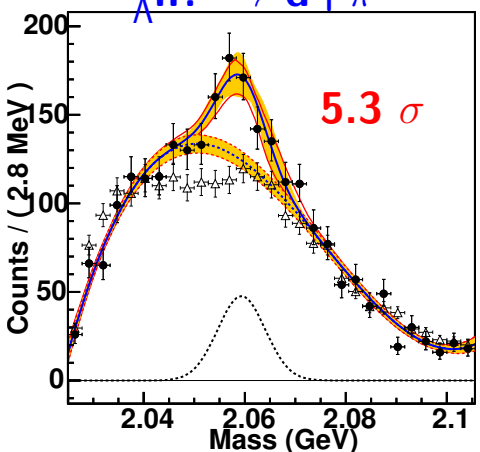
$\tau = 183^{+42}_{-32} \pm 37$ps

$^4_\Lambda H \rightarrow {}^4He+\pi^-$



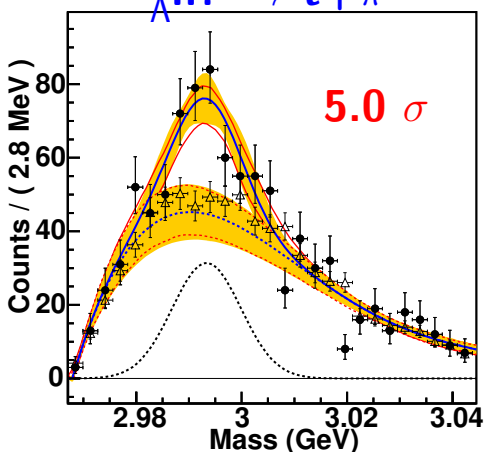
$\tau = 140^{+48}_{-33} \pm 35$ps

$^3_\Lambda n? \rightarrow d+\pi^-$



$\tau = 181^{+30}_{-24} \pm 25$ps

$^3_\Lambda n? \rightarrow t+\pi^-$



$\tau = 190^{+47}_{-35} \pm 36$ps

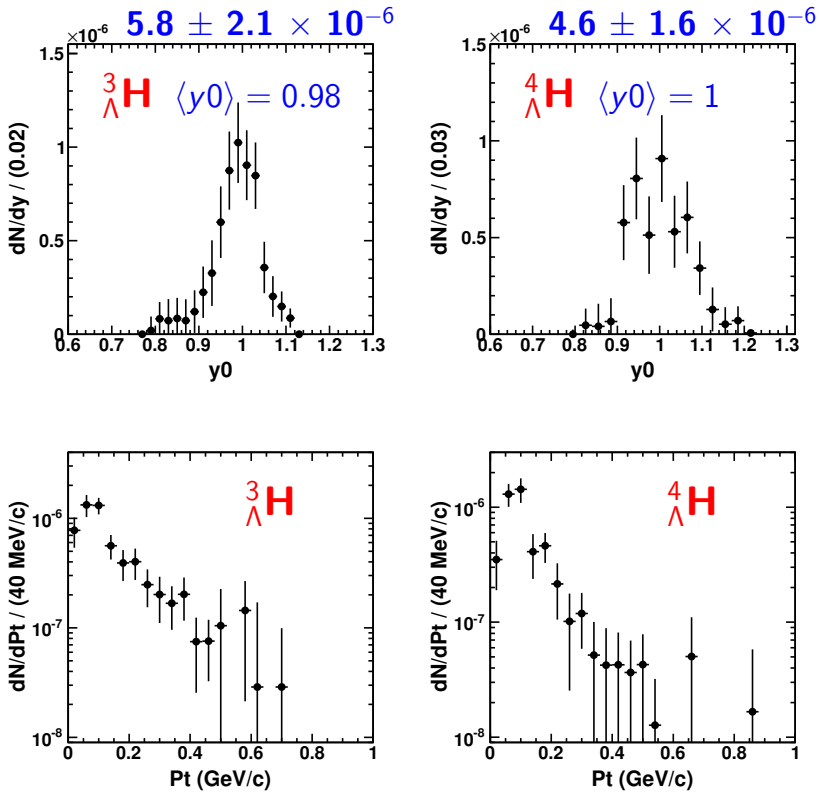
[C. Rappold *et al.*, Nucl. Phys. A. **913**, 170 (2013)]

[C. Rappold *et al.*, Phys. Rev. C (Rapid Comm.) **88**, 041001 (2013)]

Spectator region (projectile) : HypHI results

Production cross section & multiplicity :

	CS
Λ	1.7 ± 0.8 mb
${}^{3}_{\Lambda}\mathrm{H}$	3.9 ± 1.4 µb
${}^{4}_{\Lambda}\mathrm{H}$	3.1 ± 1.0 µb
${}^{3}_{\Lambda}\mathrm{H}/{}^{4}_{\Lambda}\mathrm{H}$	1.4 ± 0.8
${}^{3}_{\Lambda}\mathrm{H}/\Lambda$	$2.6 \pm 1.4 \times 10^{-3}$
${}^{4}_{\Lambda}\mathrm{H}/\Lambda$	$2.1 \pm 1.1 \times 10^{-3}$
${}^{3}_{\Lambda}\mathrm{H}/{}^{3}\mathrm{He} \cdot \mathrm{p}/\Lambda$	0.28 ± 0.14
${}^{4}_{\Lambda}\mathrm{H}/{}^{4}\mathrm{He} \cdot \mathrm{p}/\Lambda$	0.08 ± 0.04

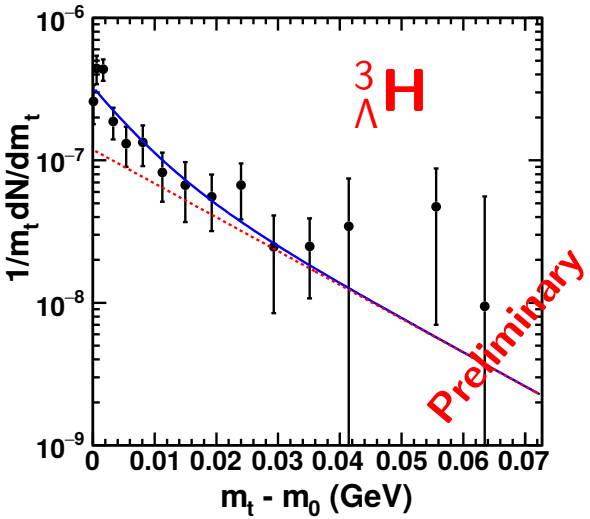


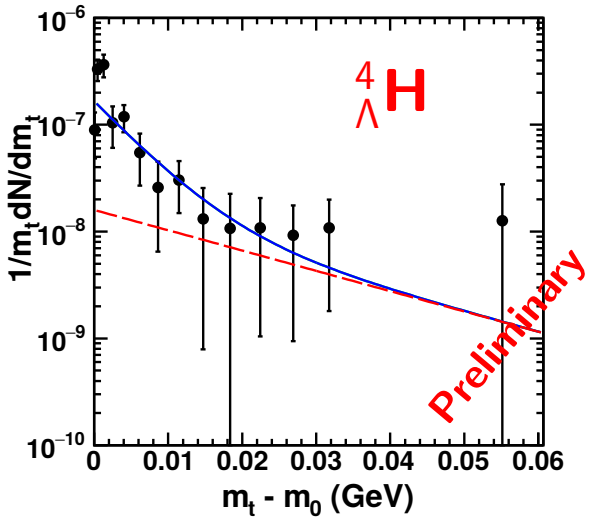
[C. Rappold *et al.*, Phys.Lett. B**747** (2015) 129]

Spectator region : HypHI results

Inverse slope T, m_t spectrum :

$f(m_t - m_0) = K_1/T_1\ e^{-(m_t-m_0)/T_1} + K_2/T_2\ e^{-(m_t-m_0)/T_2}$

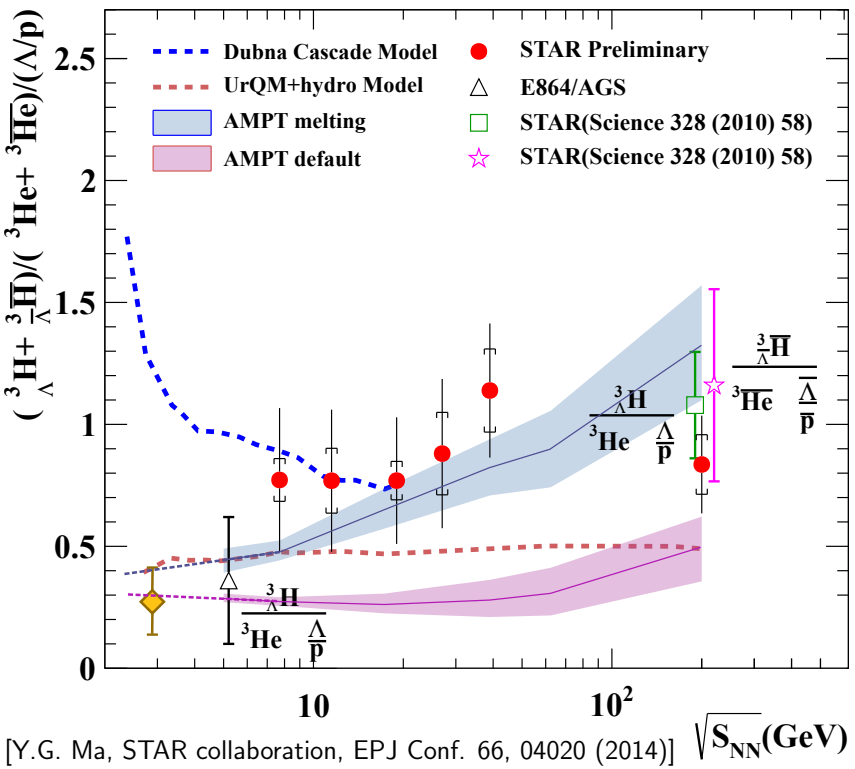




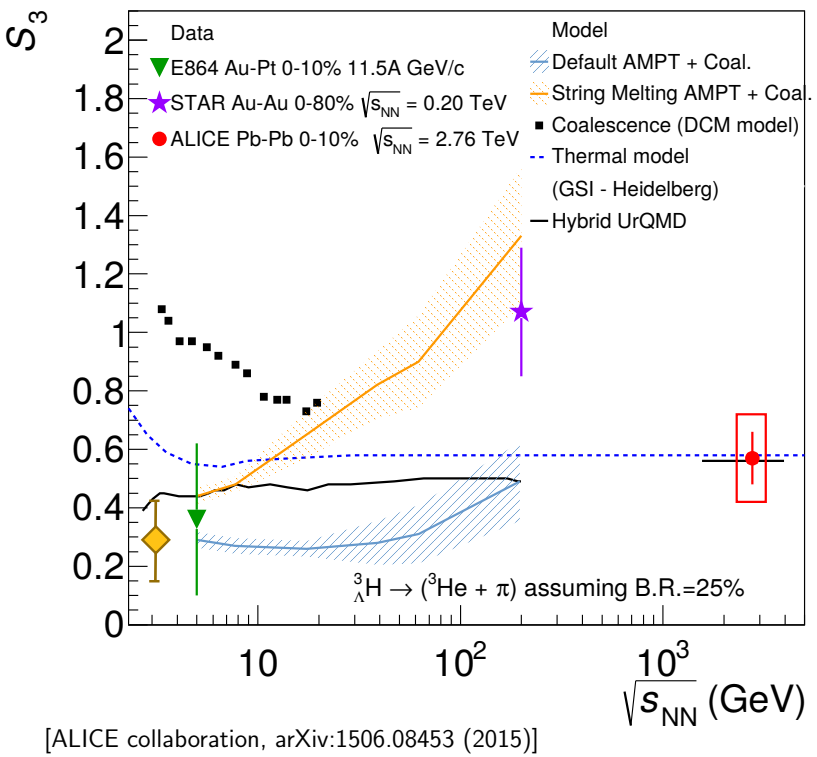
- for $^3_\Lambda$H : $T_1 \sim 7 \pm 2$ MeV & $T_2 \sim 18 \pm 7$ MeV
- for $^4_\Lambda$H : $T_1 \sim 6 \pm 2$ MeV & $T_2 \sim 13 \pm 6$ MeV
- very similar to multi-fragmentation ALADIN results

  [T. Odeh et al., Phys. Rev. Lett. 84 (2000) 4557]
- and Goldhaber model :[A.S. Goldhaber, Phys. Lett. B 53 (1974) 306]

Comparison S3 factor : HypHI results



[Y.G. Ma, STAR collaboration, EPJ Conf. 66, 04020 (2014)]



[ALICE collaboration, arXiv:1506.08453 (2015)]

[T.A. Armstrong et al., Phys. Rev. C70, 024902 (2004)]
[C. Rappold et al., Phys.Lett. B747, 129 (2015)]
[STAR collaboration, EPJ Conf. 66, 04020 (2014)]
[STAR Collaboration, Science 328, 58 (2010)]
[ALICE collaboration, arXiv:1506.08453 (2015)]

AMPT + Coal. : S. Zhang et al., Phys.Lett.B684 (2010) 224.
DCM model : J. Steinheimer et al., Phys.Lett.B714 (2012) 85.
Thermal model : A. Andronic et al., Phys.Lett.B697 (2011) 203.
Hybrid UrQMD : J. Steinheimer et al., Phys.Lett.B714 (2012) 85

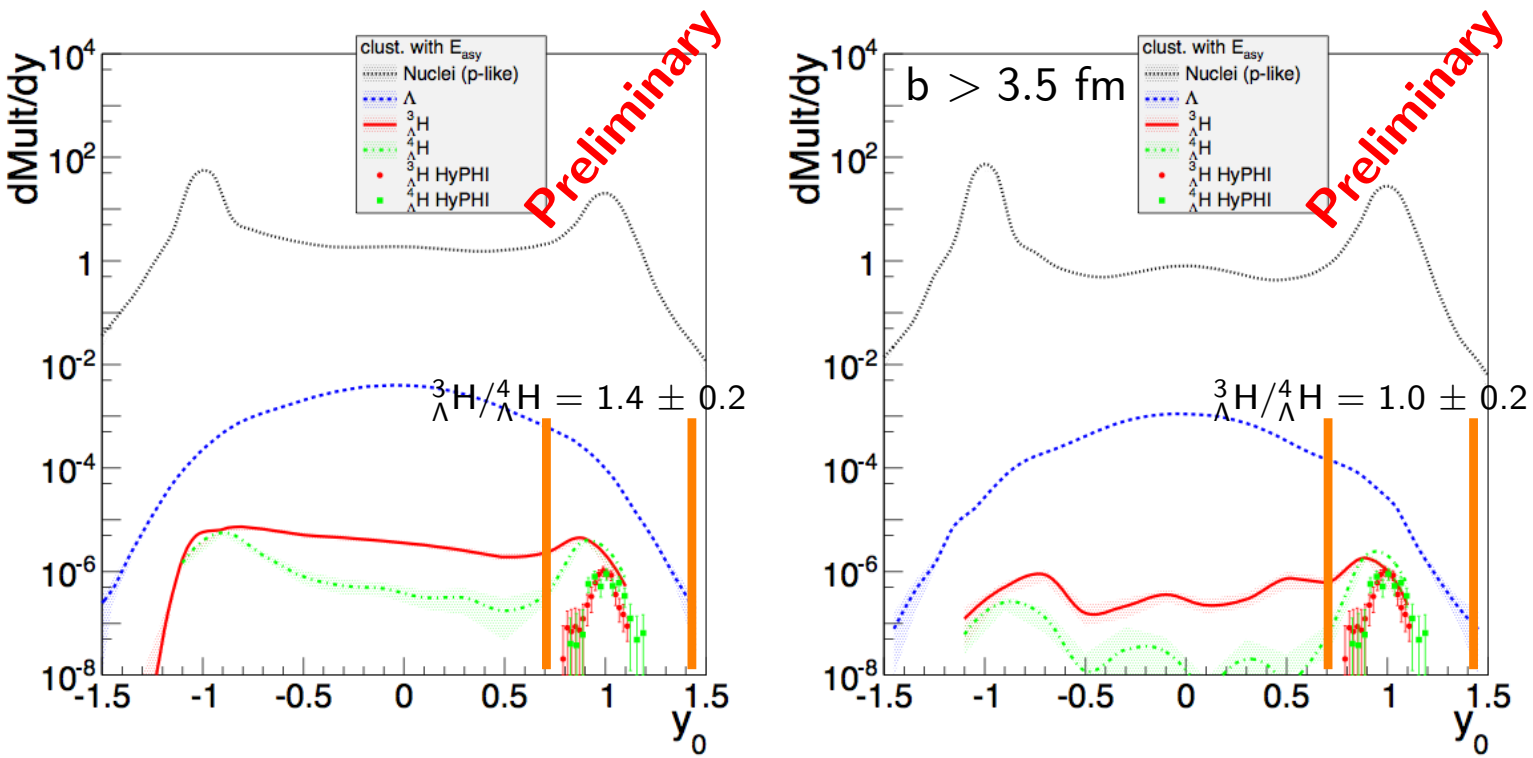
Comparison with transport model : HypHI results

Calculations from IQMD* transport + FRIGA clustering models

[A. Le Frevre, Y. Leifels, J. Aichelin, Ch. Hartnack]

[*: Ch.Hartnack et al., Eur. Phys. J. A 1(1998) 151]

Rapidity distribution with passing time 15 fm/c :



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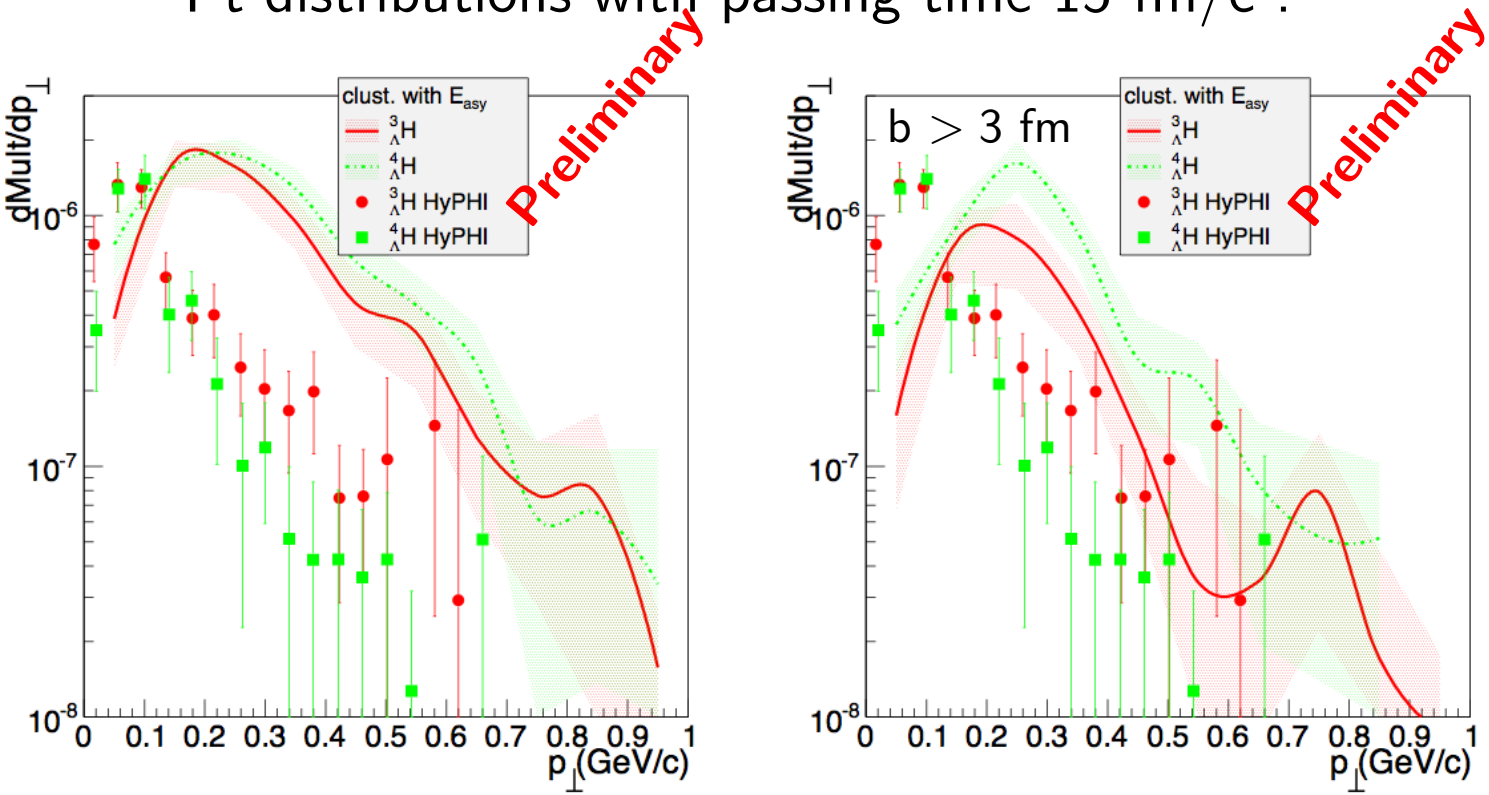
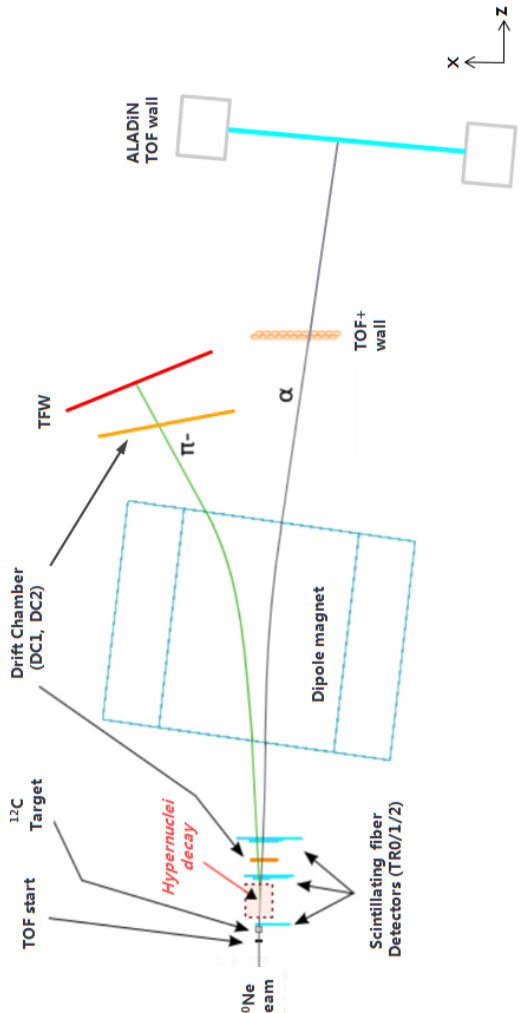
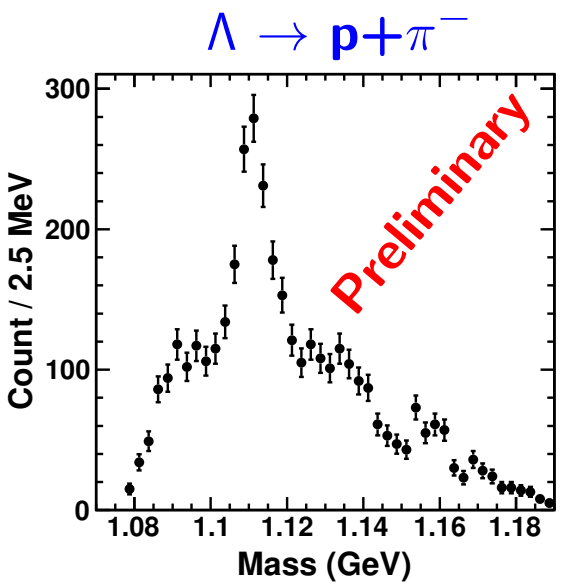
Pt distributions with passing time 15 fm/c :

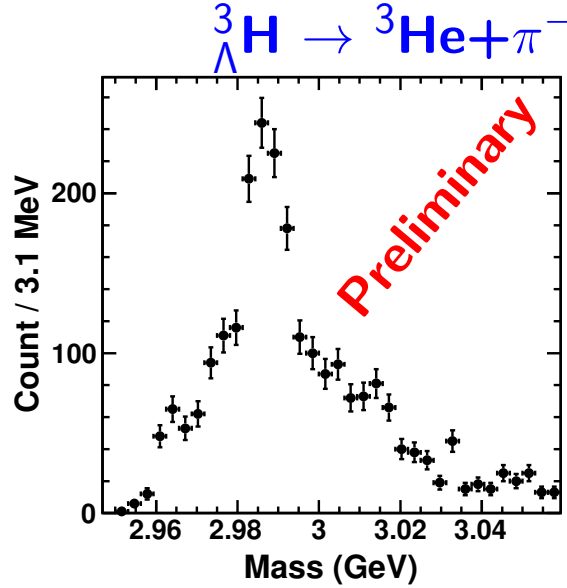


Second HypHI experiment : Phase 0.5

Fixed target, Reaction : ^{20}Ne+^{12}C @ 2 AGeV or $\sqrt{s_{NN}} = 2.7$ GeV







- good signals for Λ and $^{3}_{\Lambda}$H
- Analysis of d+π^- and t+π^- on-going
- Analysis of $^{7}_{\Lambda}$Li and $^{6}_{\Lambda}$He on-going

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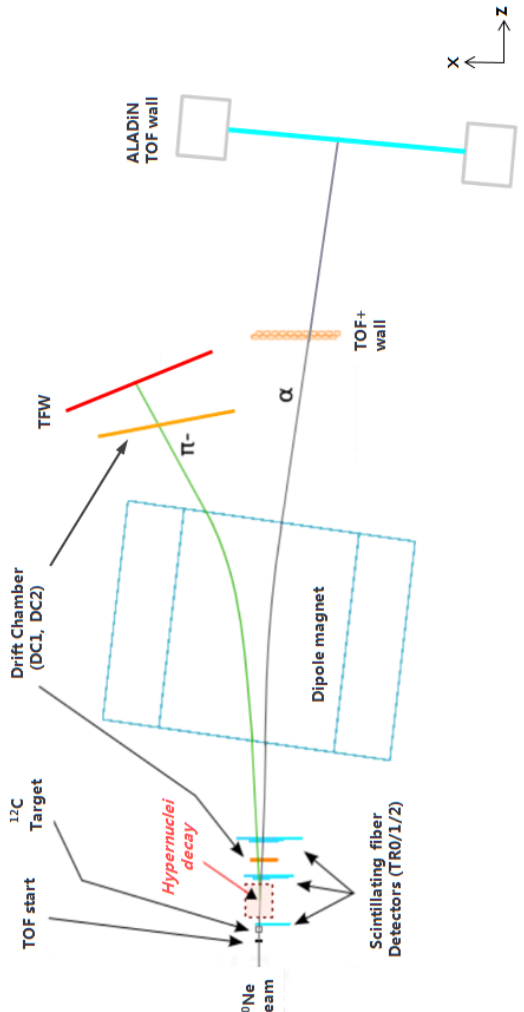
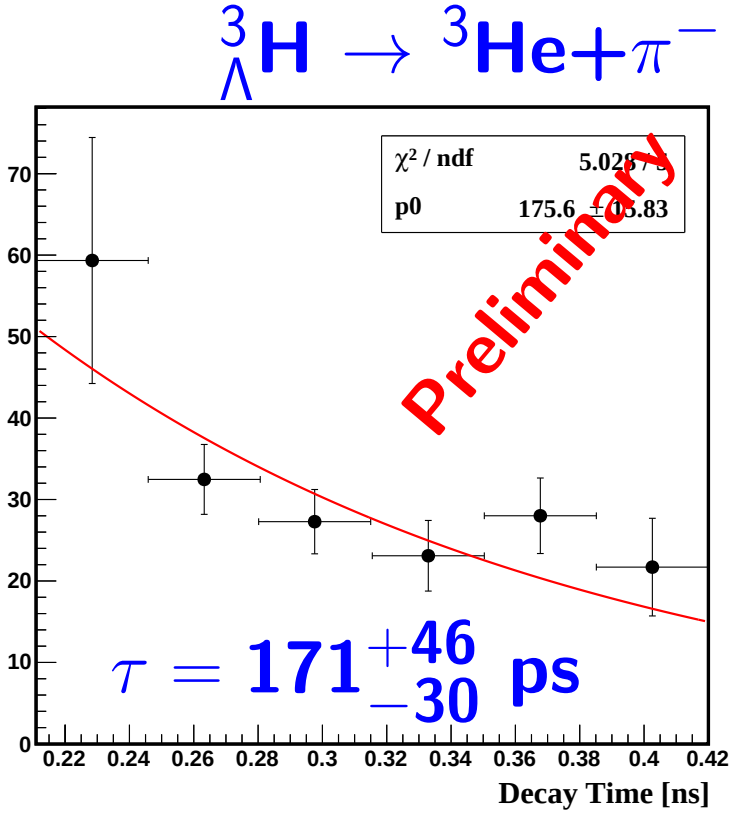
Fixed target, Reaction : ^{20}Ne+^{12}C @ 2 AGeV or $\sqrt{s_{NN}} = 2.7$ GeV





Outline

Conclusion

In relativistic regime :

- FOPI : $\sim$ target region / HypHI : spectator region
- mid-rapidity: freeze-out.
- spectators: different production mechanism
  - coalescence of mid-rapidity Λ with spectator fragments.
  - probe to what happen between the participants & spectator !
    - ex: Yield ratio sensitive to time interval of the interaction.
- Theoretical calculation : Preliminary results :
  - Reproduction of HypHI results.
  - interaction time : 15 fm/c & EoS with E_{asym}
  - Yield ratio ${}^{3}_{\Lambda}\mathrm{H}/{}^{4}_{\Lambda}\mathrm{H} = 1.4 \pm 0.2$ or 1.0 ± 0.2
  - Need impact factor cut b > 3.5 fm
  - Soon reproduction of FOPI results.

Conclusion

What next ?

- from ALICE & STAR :
  - Next hypernuclei, A=4 will be difficult to measure (penalty factor)
  - Might focus A=3 hypernuclei with different baryons.
- FOPI : work in progress for finalizing analysis.
- HypHI :
  - Second exp. performed ^{20}Ne+^{12}C @ 2 AGeV
    - spectroscopy: Λ analysis done ! $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H done !
    - $^{7}_{\Lambda}$Li and $^{6}_{\Lambda}$He analysis in progress.
    - reaction aspect: to be started.
  - Next experiment on proton rich hypernuclei :
    - Within fragment separator FRS @ GSI & SuperFRS @ FAIR