



J-PARC Symposium 2019

26th September 2019



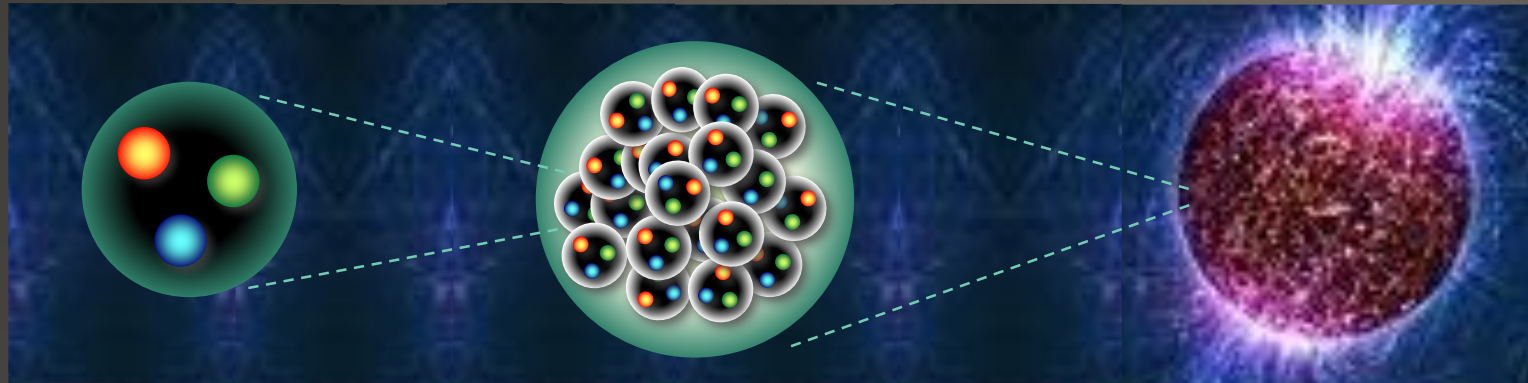
Spectroscopic Study of Lambda Hypernuclei at JLab

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Tohoku University

Baryon

(Hyper)
Nucleus

Neutron Star



10^{-15} m

10^4 m

Baryon Interaction

$SU_f(3)$ Symmetry

Nuclear Force

NN scattering data

Hyperon Force

Limited YN scattering data

Hypernuclei

Reliable Experiments on Hypernuclei

Precise Spectroscopy
Light hypernuclei

Precise Spectroscopy
Medium – Heavy hypernuclei

Meson Beams
Electron Beams
RI Beams
 γ spectroscopy
Decay pi
Emulsion

Hyperon
Scattering

Cluster Calc.
Faddeev
NCSM

Shell Model
Quantum MC
Hyper AMD
Rel. MF ...

Baryonic Interaction Potentials

Reliable 2BF potential

Various 3BF models

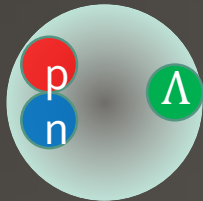
Lattice QCD

NS EOS
Solution of Hyperon Puzzle

Current problems on Λ hypernuclei

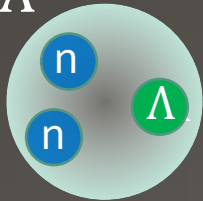
Hypertriton Puzzle

Shallow bound
short lifetime

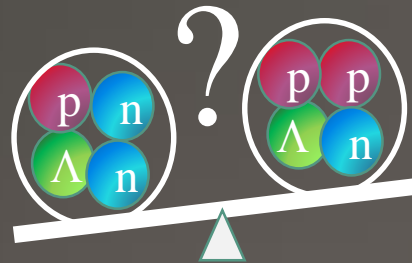


Bound?
Resonance?
Not Exist?

${}^3_{\Lambda}n$ Puzzle



CSB of Λ Hypernuclei

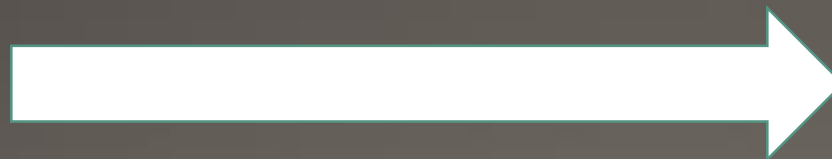


Hyperon Puzzle



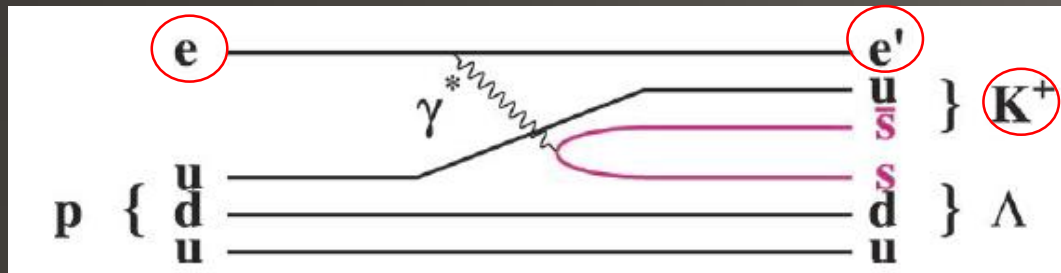
Why massive
NS exists?

$A=3$
 10^{-15} m



$A \sim 10^{57}$
 10^4 m

Electron beam vs. meson beams



$(e, e'K^+)$

Excellent mass resolution

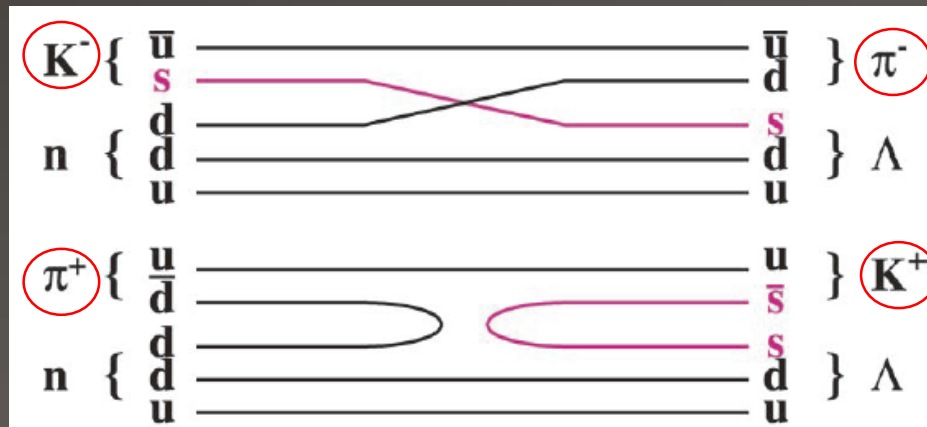
(~ 0.5 MeV)

Absolute energy calibration

$p(e, e'K^+) \Lambda, \Sigma^0$

Thin target (isotopically enriched)

eg. $^{40,48}\text{Ca}$, ^3H



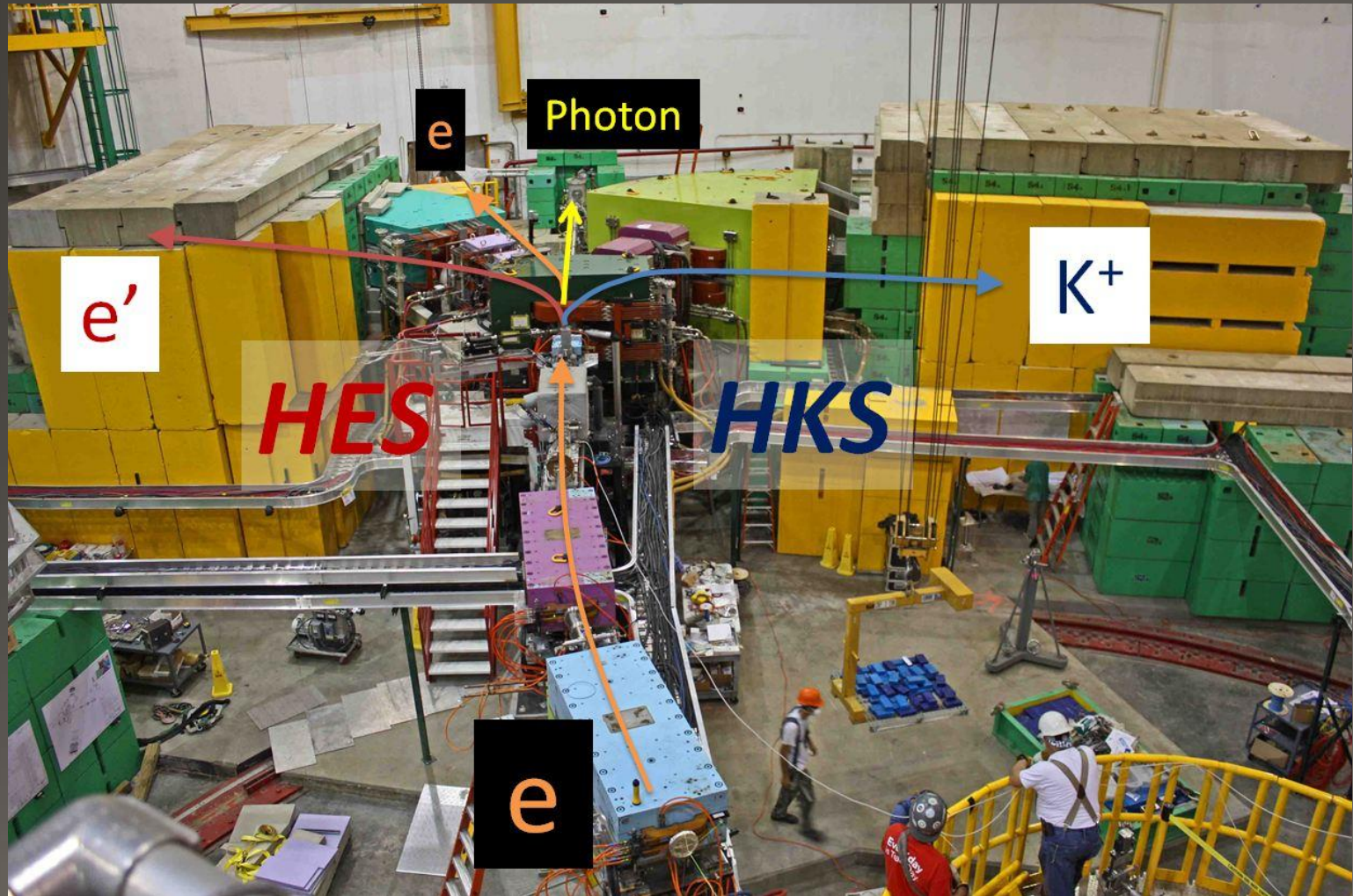
(K^-, π^-)

(π^+, K^+)

1-2 MeV resolution

Normalized to $^{12}_\Lambda\text{C}$ mass

$(e, e'K^+)$ reaction spectroscopy



$$(e,e'K^+)^{12}_{\Lambda}B$$

0.5 MeV (FWHM)

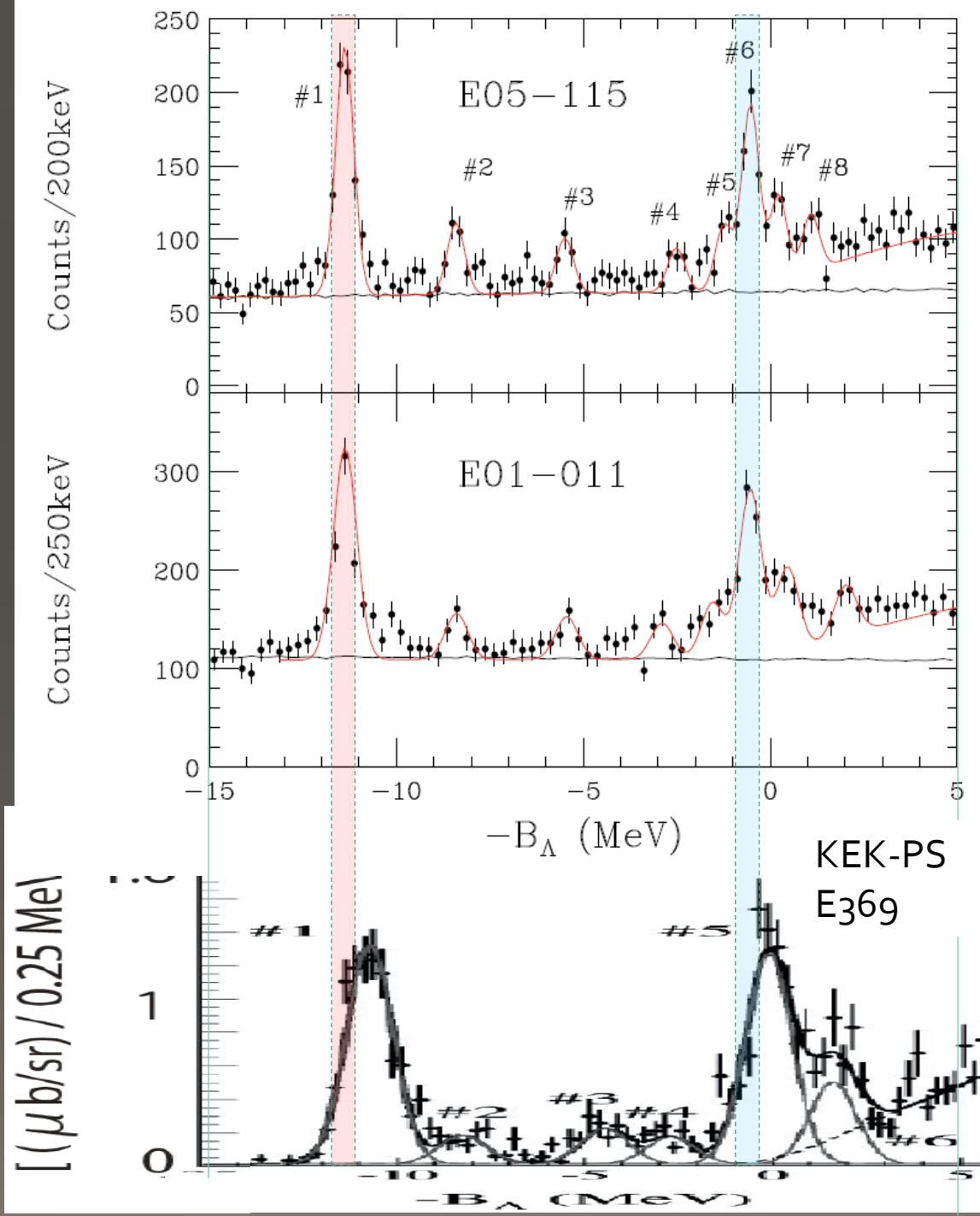
0.7 MeV (FWHM)

Absolute MM calibration

$$^{12}C(\pi^+,K^+)^{12}_{\Lambda}C$$

1.45 MeV (FWHM)

$^{12}_{\Lambda}C_{gs}$ energy
from emulsion



$^{12}\text{C}(e,e'K^+)^{12}_{\Lambda}\text{B}$

0.5 MeV (FWHM)

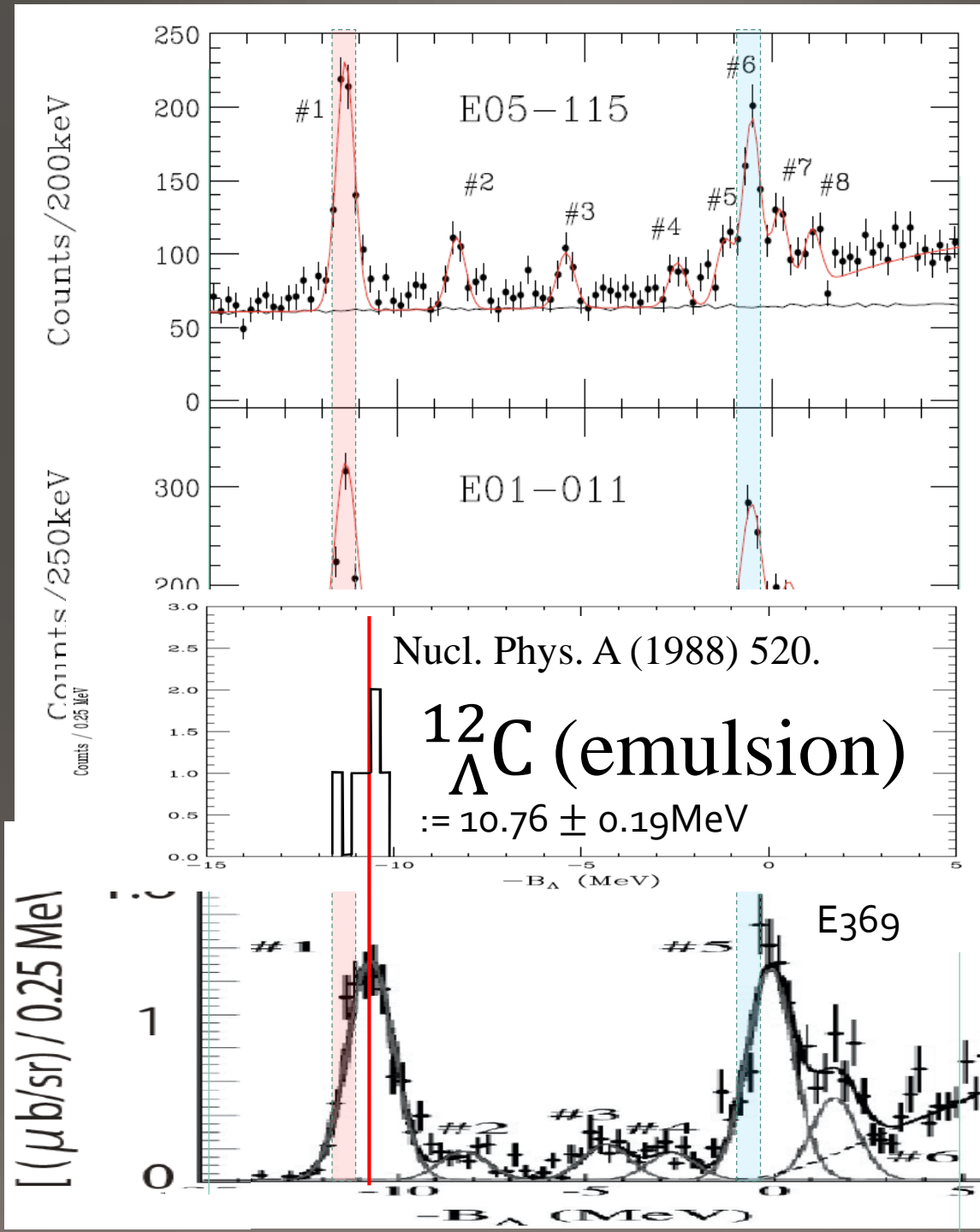
0.7 MeV (FWHM)

Absolute MM calibration

$^{12}\text{C}(\pi^+,K^+)^{12}_{\Lambda}\text{C}$

1.45 MeV (FWHM)

$^{12}_{\Lambda}\text{C}_{\text{gs}}$ energy
from emulsion



Hyperon Puzzle

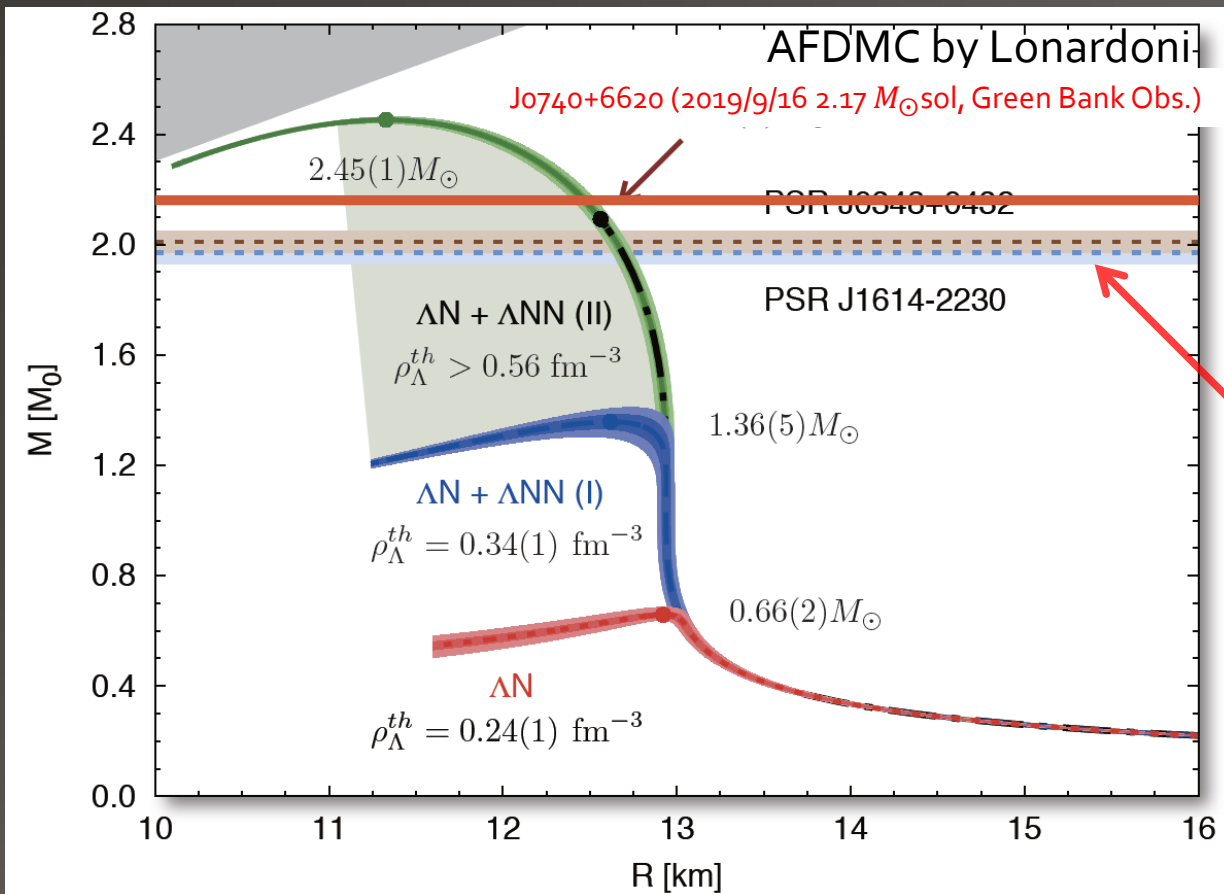


Two solar mass neutron stars

Hyperon Puzzle

Based on our knowledge on Baryonic Force:

Hyperon naturally appear at high density ($\rho = 2 \sim 3\rho_0$)



Too Soft EOS

Contradict
to
observation

$2 M_\odot$ Neutron Stars

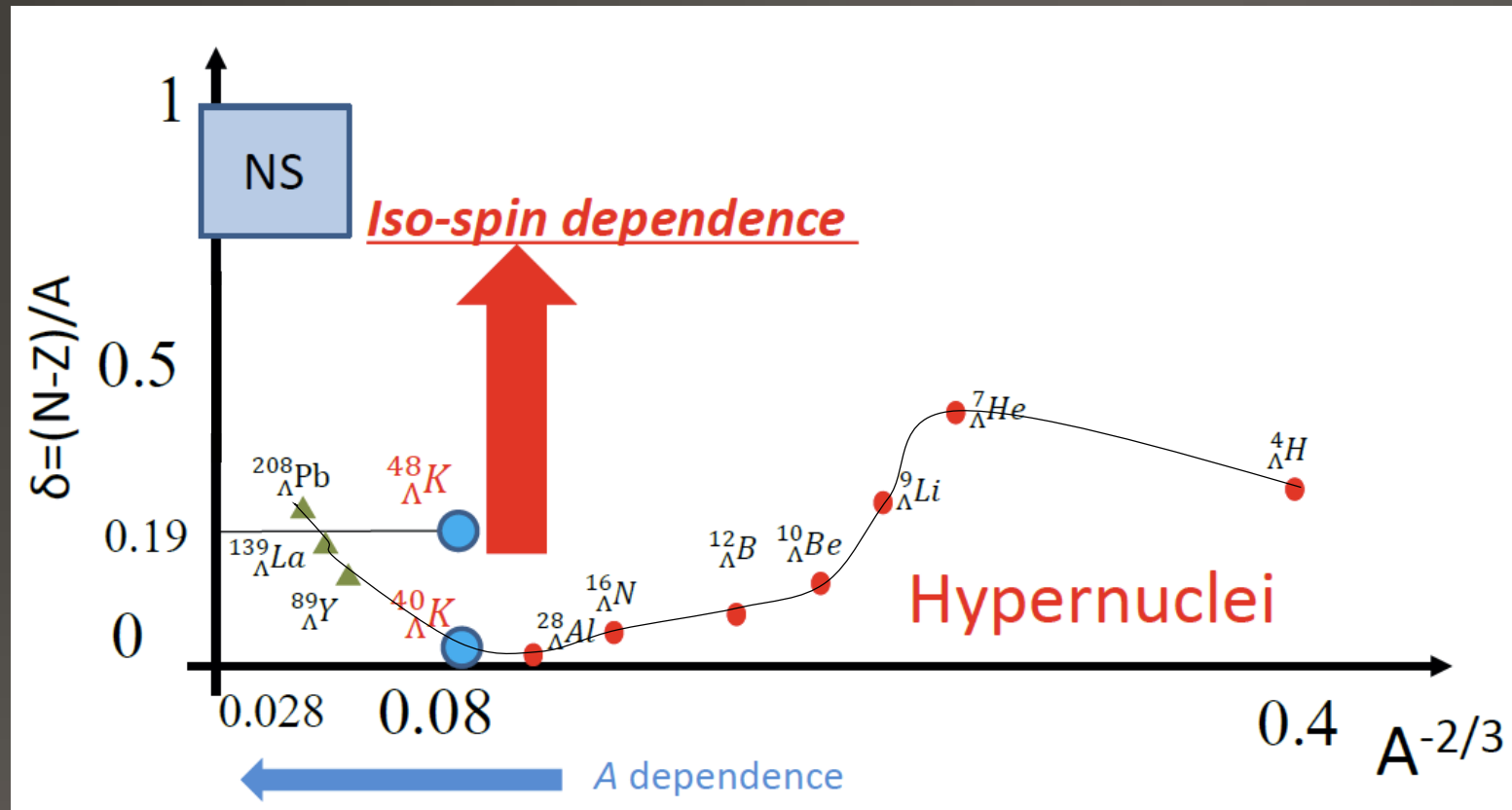
Additional Force
to make EOS stiff

AFDMC by Lonardoni et al. PRL114 (2015) 092301, updated (2016)

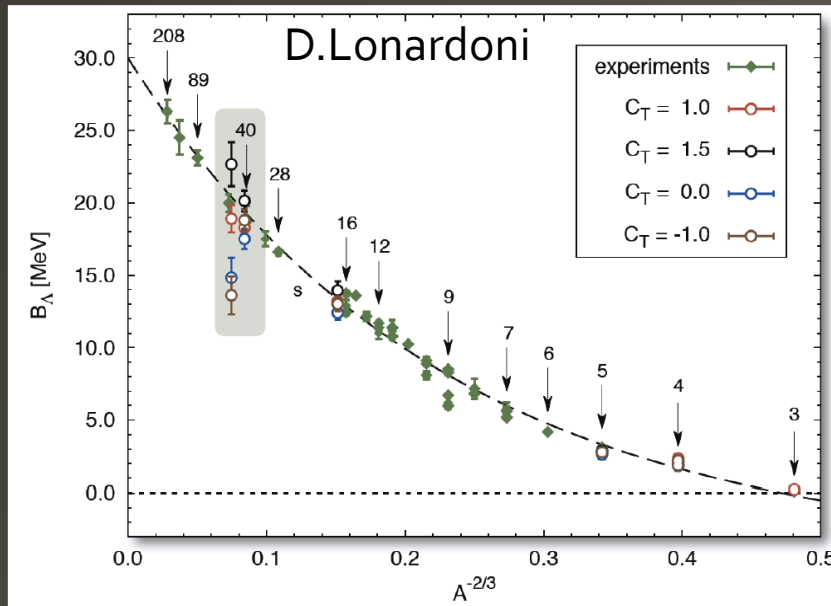
ESCo8c + $3B/4B$ RF : G-Matrix Calc. by Yamamoto et al., PRC 90 (2014) 045805.

Variational Meth. + AV18+UIX by Togashi et al., PRC 93 (2016) 035808

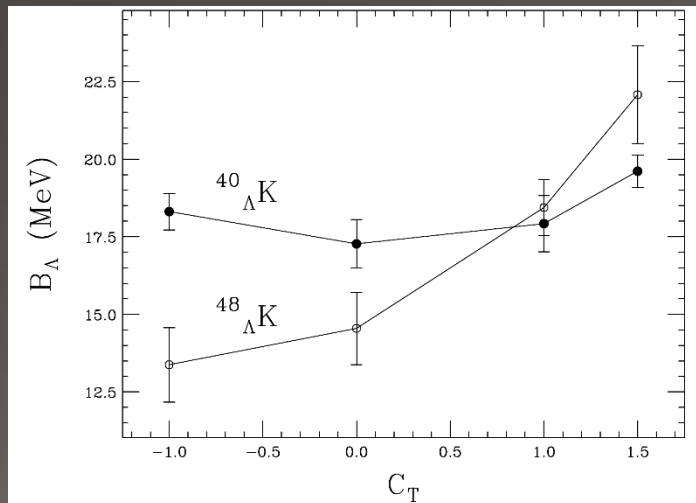
From Hypernuclei to NS



Phenomenological ${}^3\text{BRF}+\text{AFDMC}$



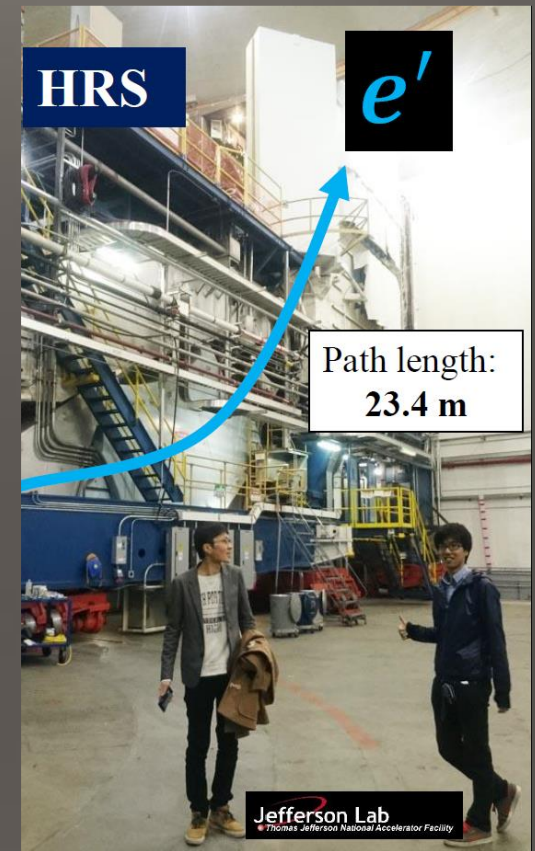
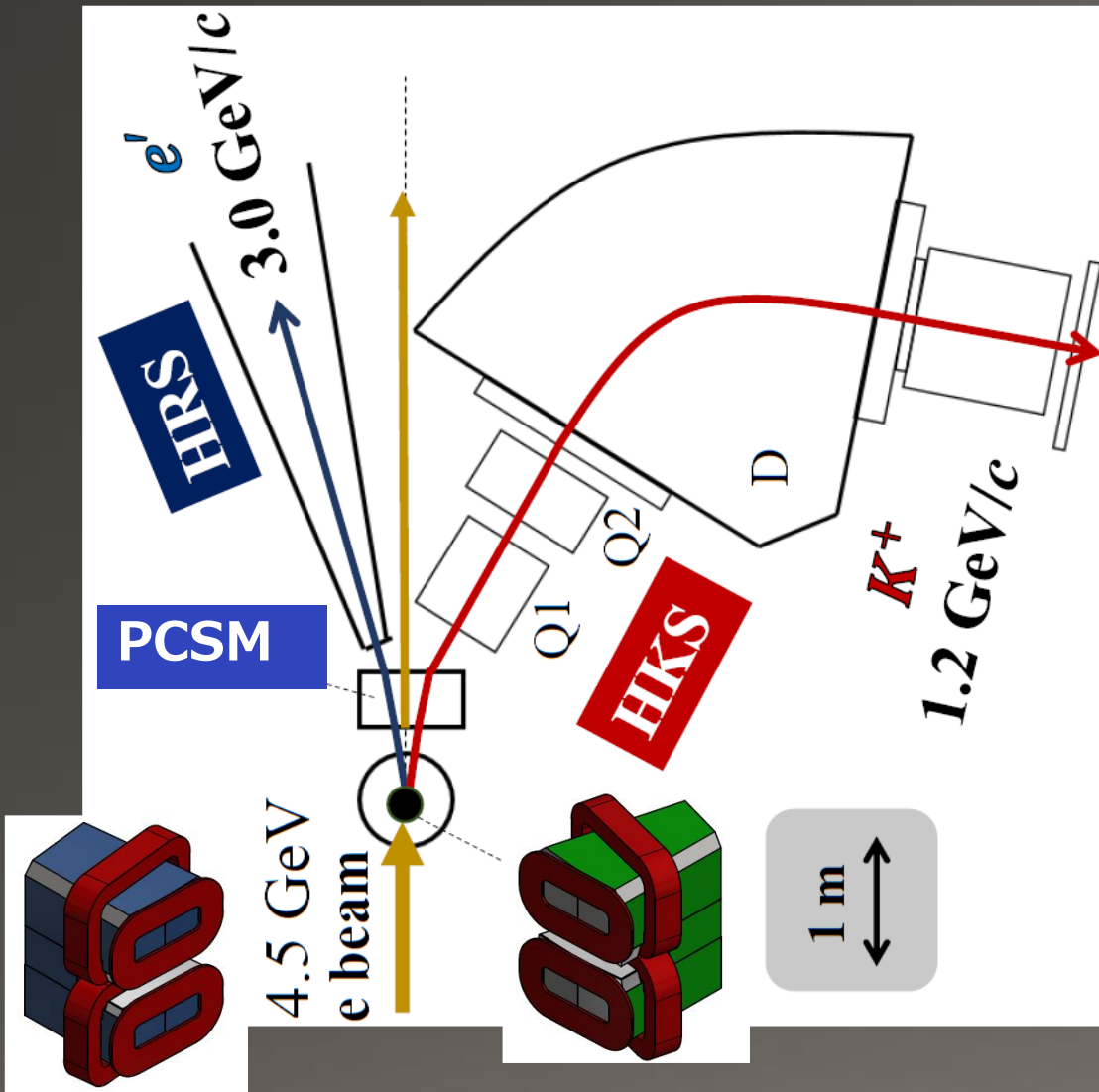
C_T : Parameter to gauge Λ nn contribution in Λ NN potential



${}^{40}\text{Ca}(e, e'K^+){}^{40}\Lambda\text{K}$ and ${}^{48}\text{Ca}(e, e'K^+){}^{48}\Lambda\text{K}$

E12-15-003
accepted with GRADE A.

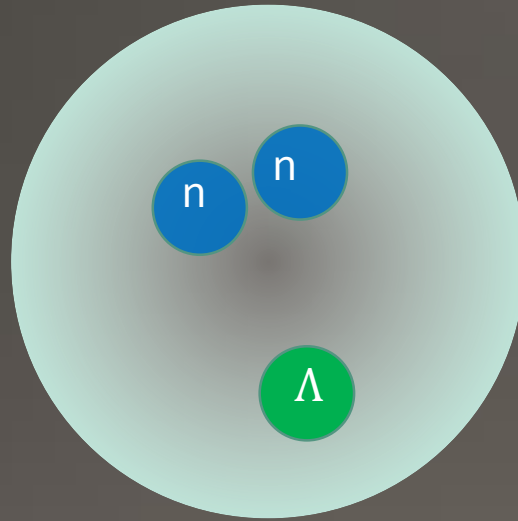
New setup for E12-15-008



New Pair Charge Sep. Mag.
Ca targets holder
under construction

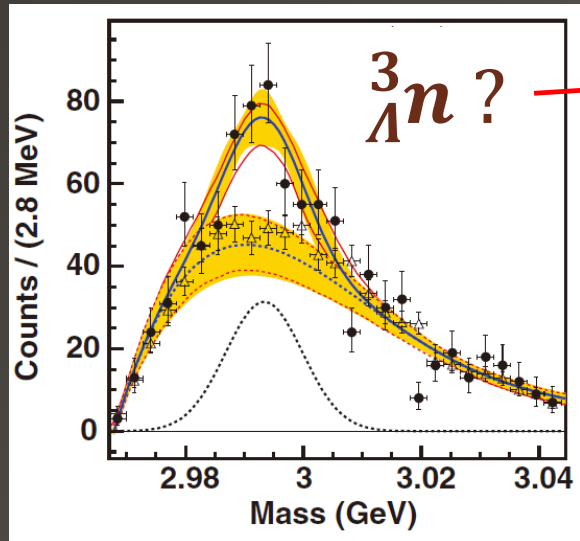
E12-15-008
(ready for beam, 2021)

${}^3_{\Lambda}n$ Puzzle



$nn\Lambda$ state exists?

C. Rappold et al. (HypHI Collaboration),
Phys. Rev. C 88, 041001(R) (2013).



$t + \pi$ decay with $\tau = 190^{+47}_{-35}\text{ps}$

Bound ${}^3_{\Lambda}n$ cannot be reproduced:

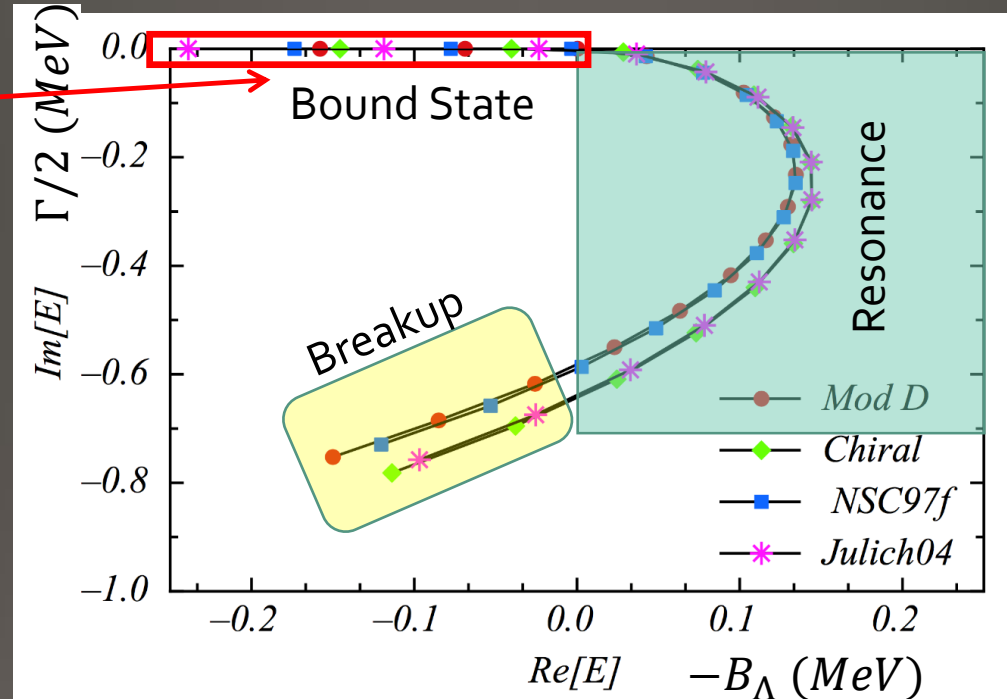
E. Hiyama et al., Phys. Rev. C 89, 061302(R) (2014)

A. Gal et al., Phys. Lett. B 736, 93–97 (2014)

Resonance $nn\Lambda$ may exist:

I.R.Afnan, B.F.Gibson, PRC 92, 054608 (2015)

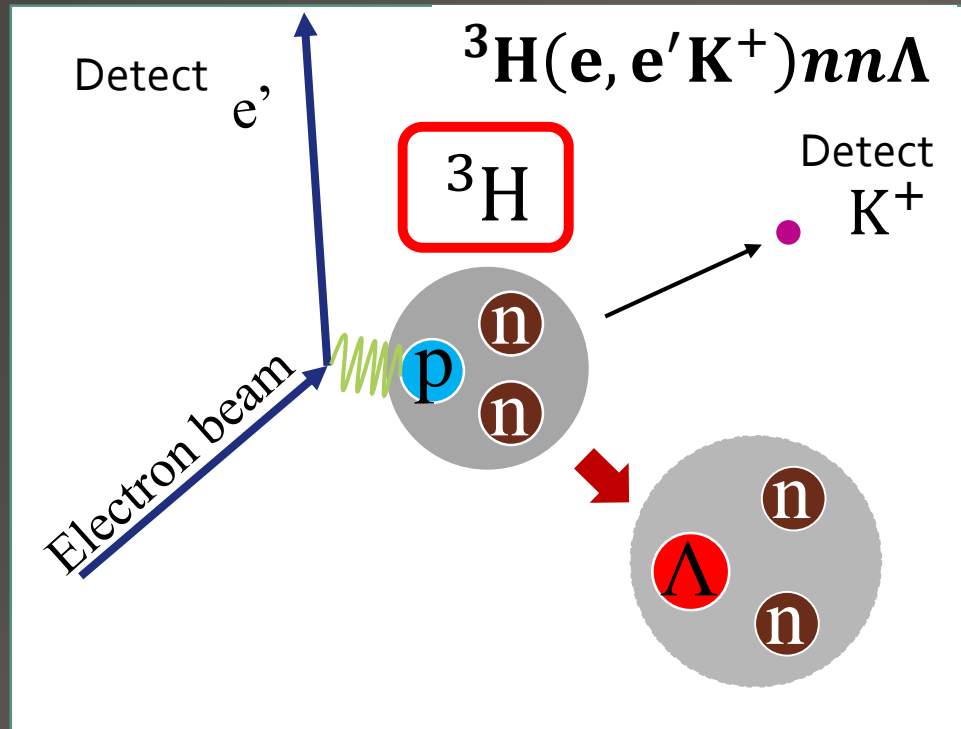
H. Kamada et al., EPJ Web Conf. 113, 07004 (2016)



I.R.Afnan, B.F.Gibson., PRC 92, 054608 (2015)

Additional binding energy from ${}^3\text{BF}$?
Lack of knowledge on Λn ${}^2\text{BF}$?

Electroproduction of $nn\Lambda$ resonance or ${}_{\Lambda}^3n$



${}_{\Lambda}^3n, nn\Lambda ?$

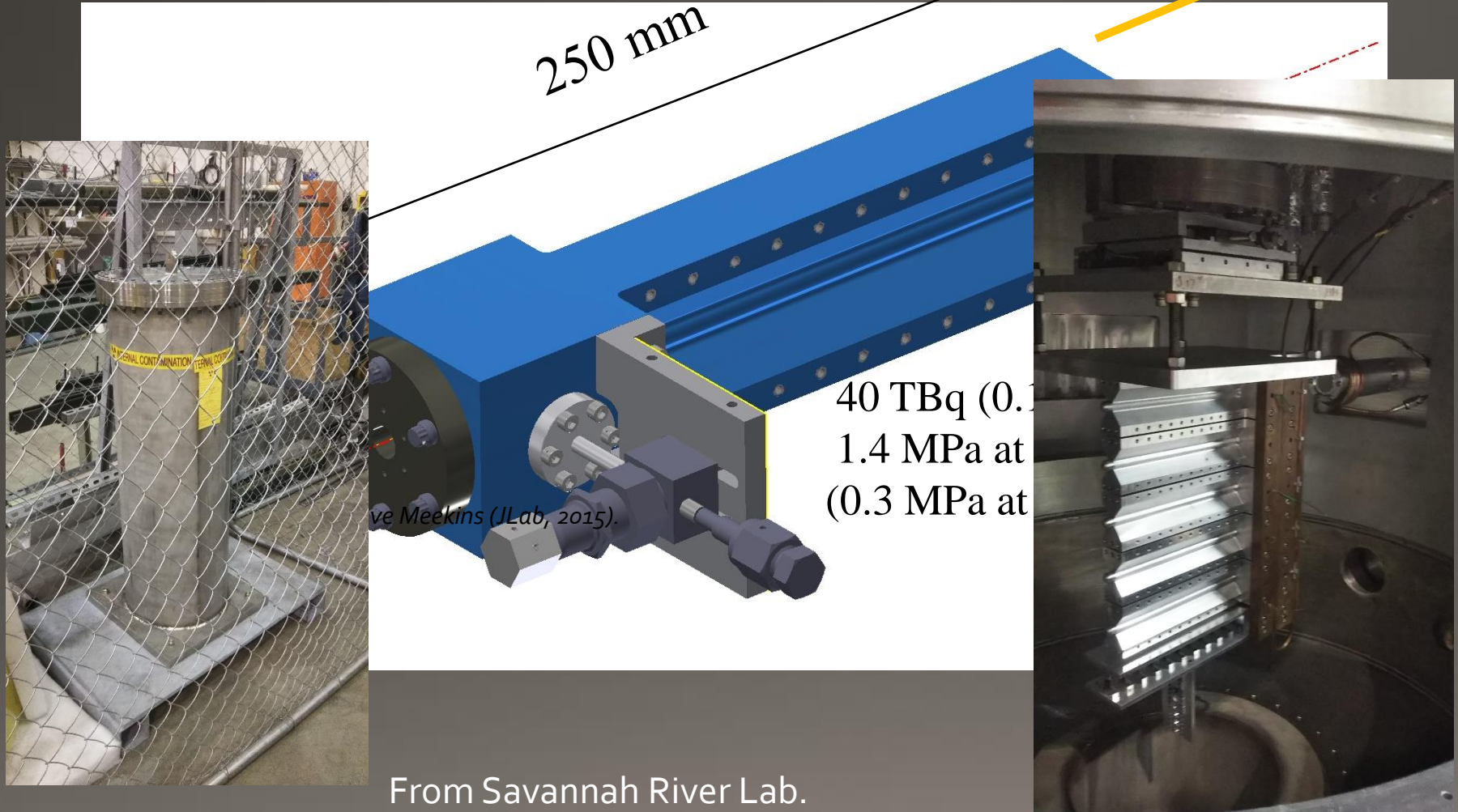
Missing Mass Spectroscopy

E12-17-003; Data taking successfully finished!

Target cell of tritium gas

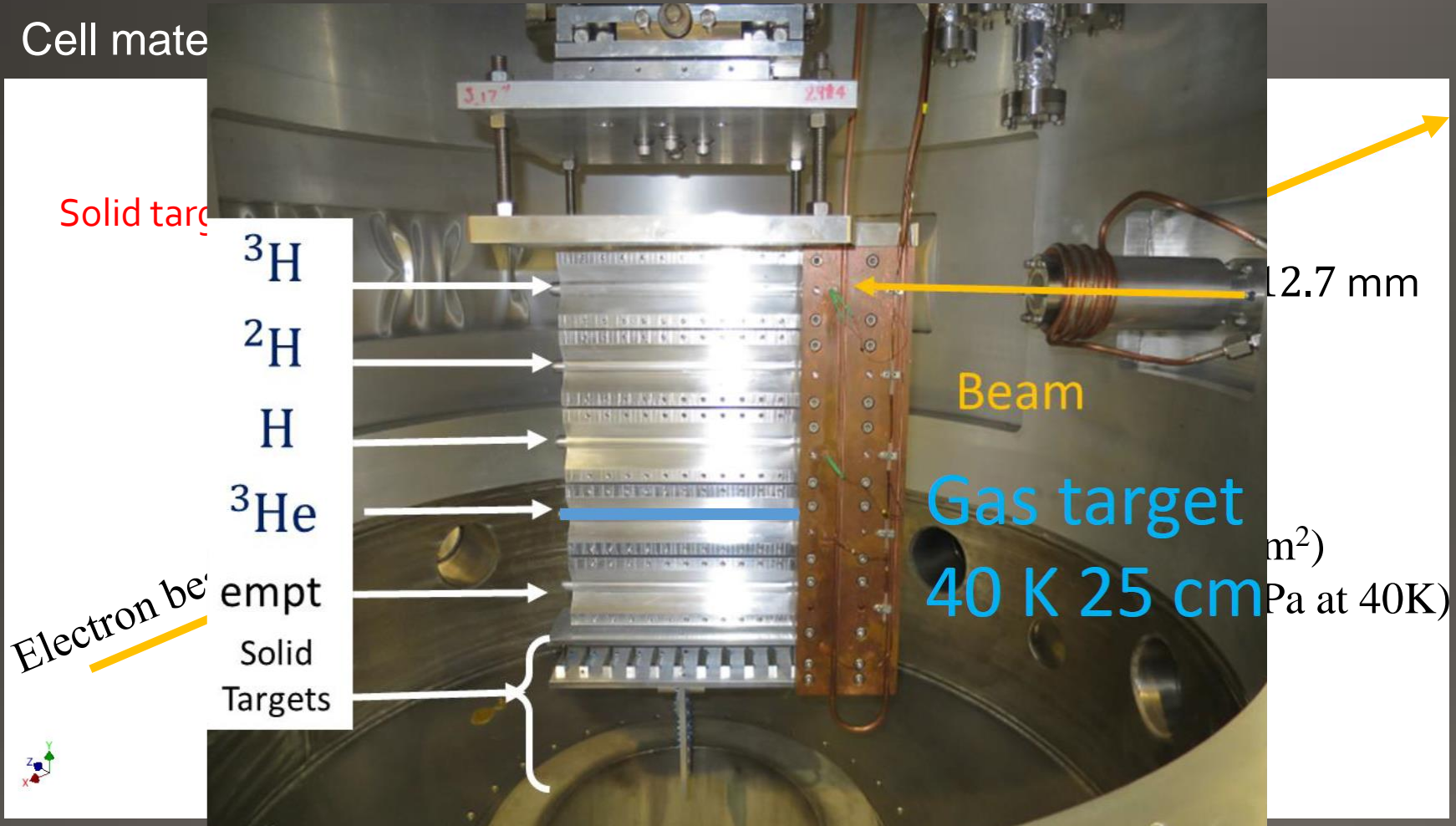
Cell material:

Al alloy (ASTM B209 AL 7075-T651)



Tritium Target

Cell mate

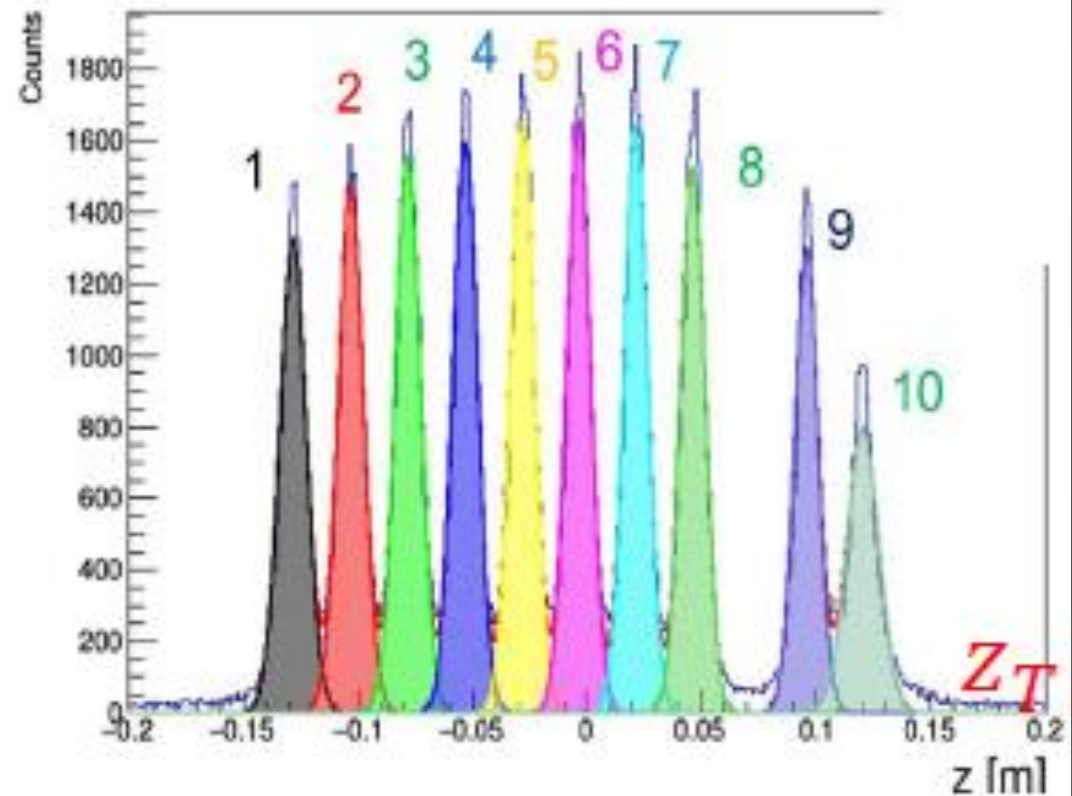
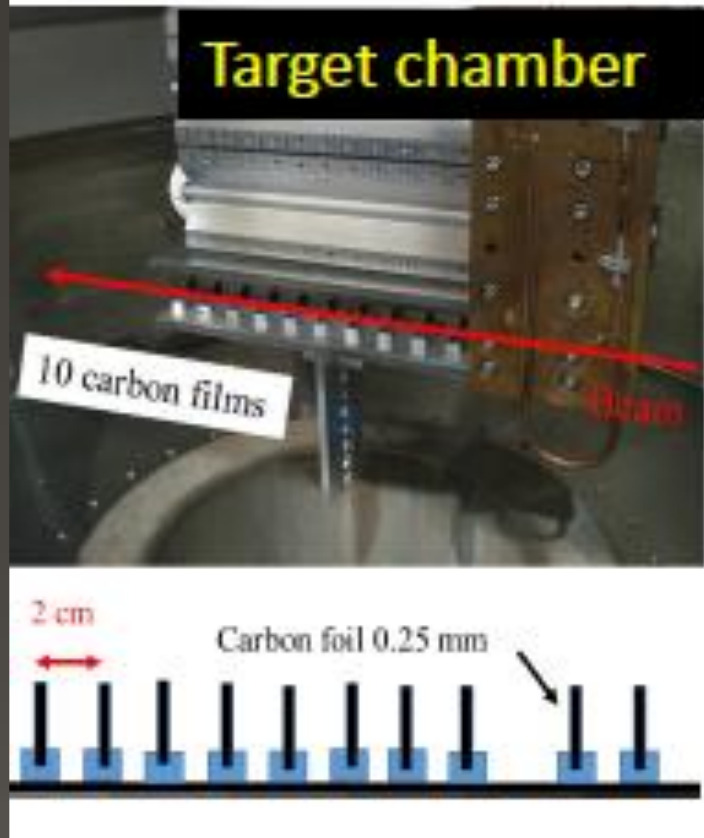


10 September : Refreshed T₂ target arrived (T_{1/2} = 12.3 y)

Beamtime 25Oct. - 25 Nov.

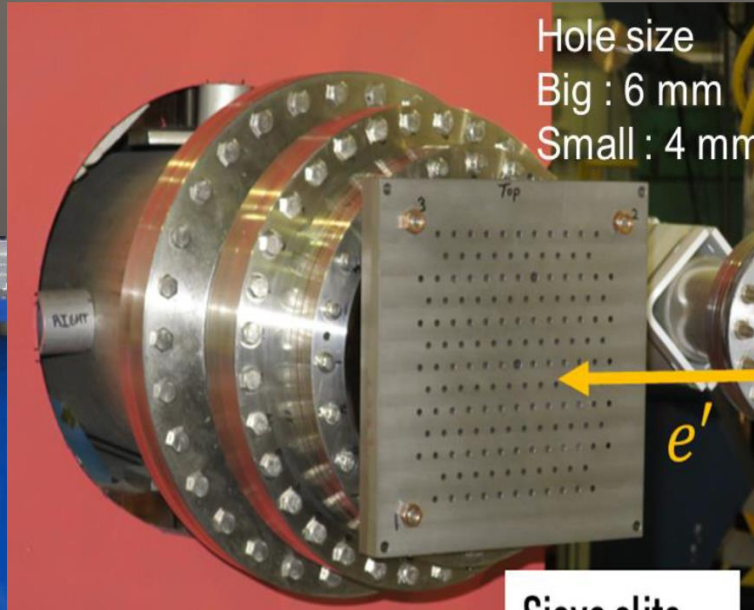
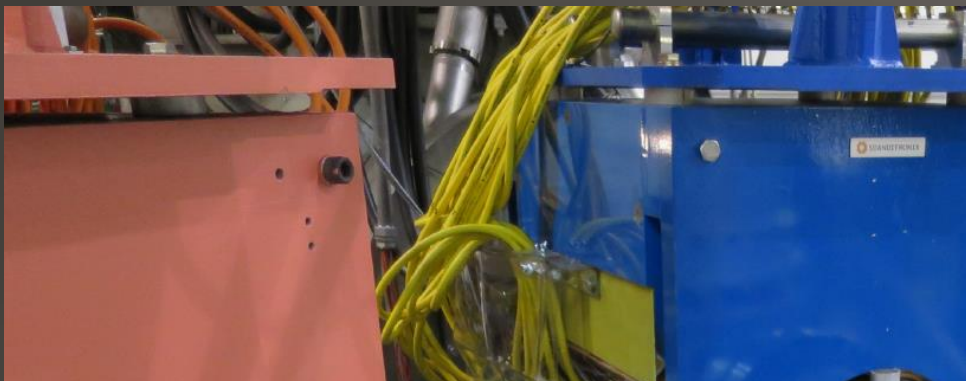
(³He decay 0.7% - 1.2%, H₂ contamination ~ 2% , Al wall)

Multi-foil target



New Analysis procedures are necessary.

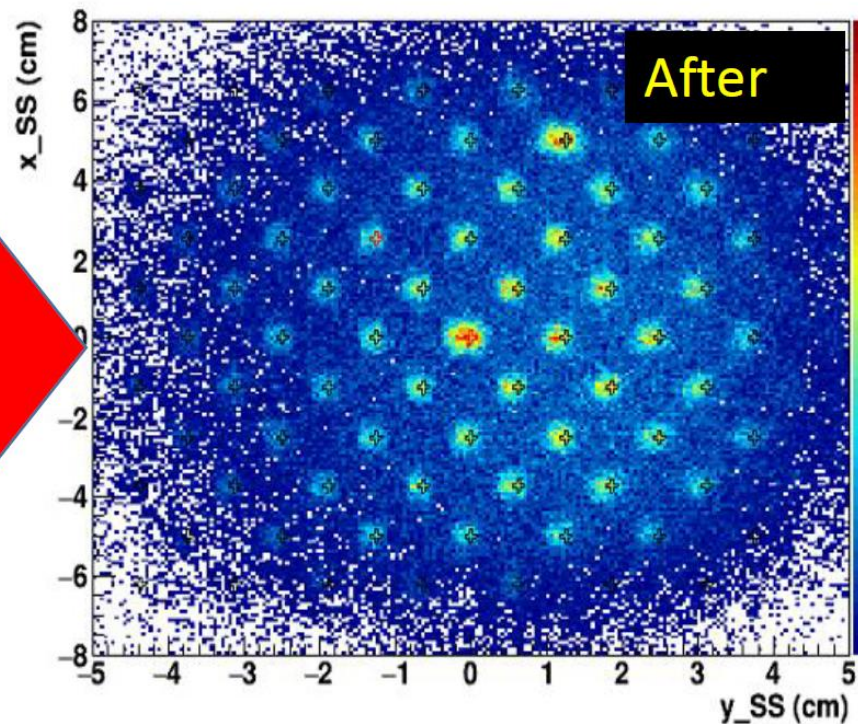
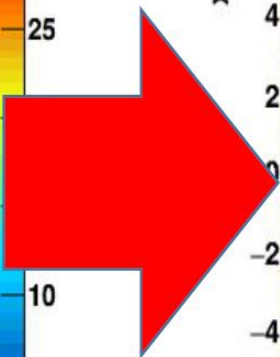
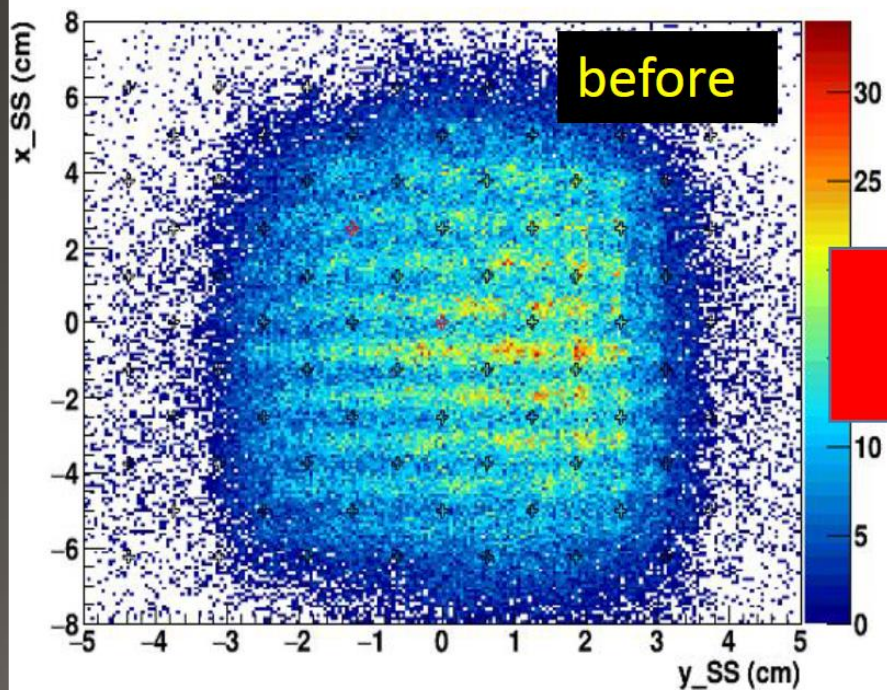
Sieve Slits



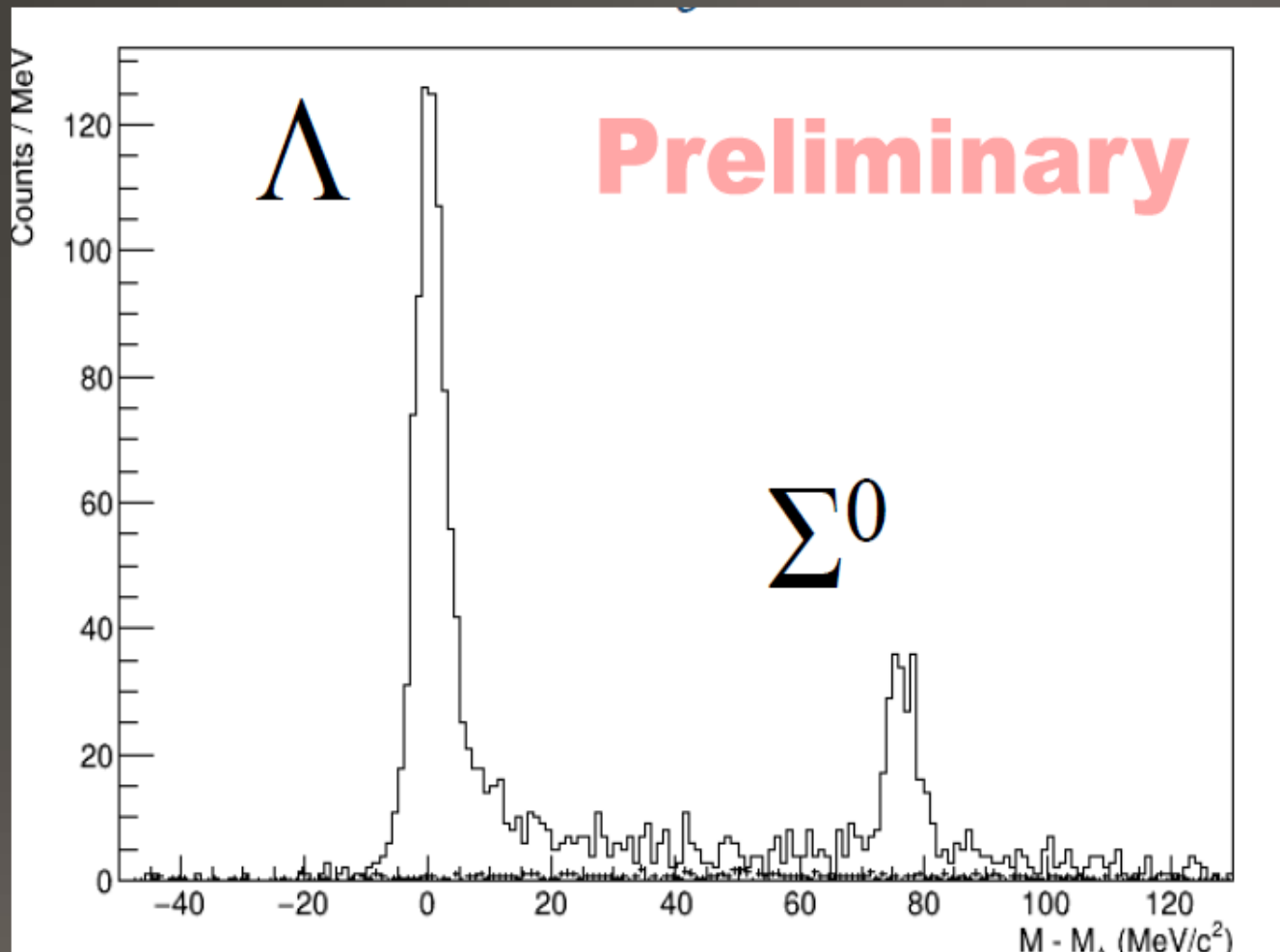
SS pattern w/o matrix tuning

SS pattern after matrix tuning

Sieve plate



Calibration Data (H target)



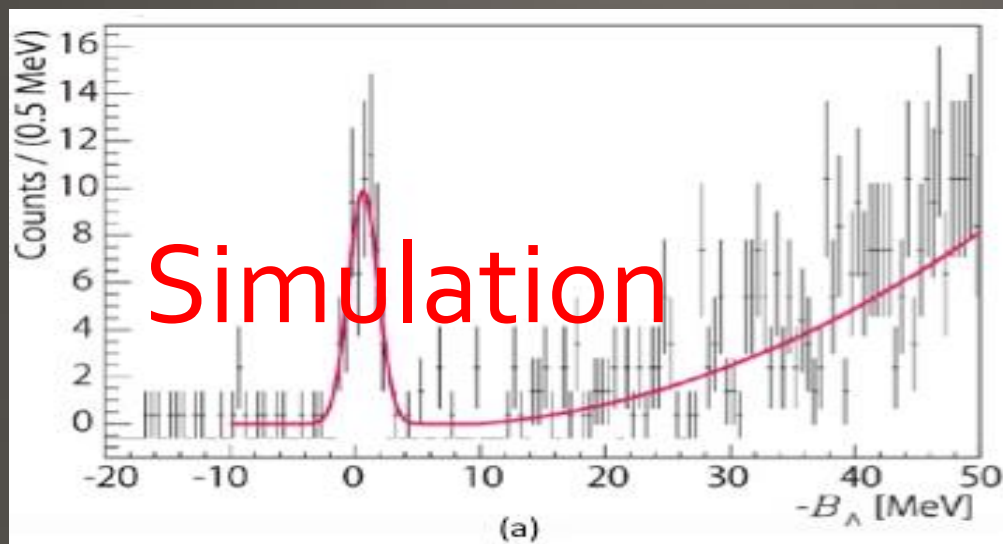
Missing Mass Spectrum

$${}^3T(e, e'K^+)nn\Lambda$$

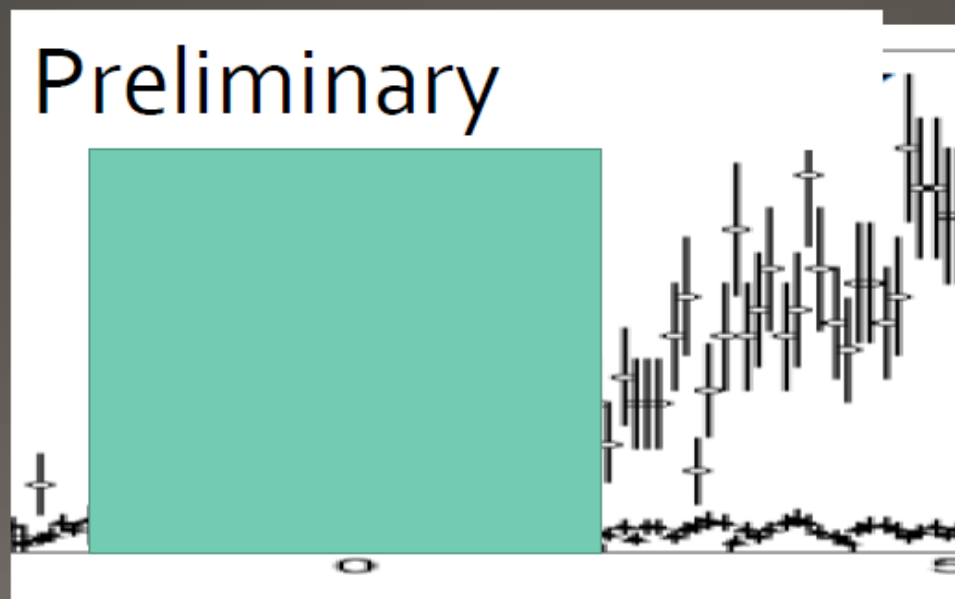
Assum:

$$B_{\Lambda} = -0.5 \text{ MeV}$$

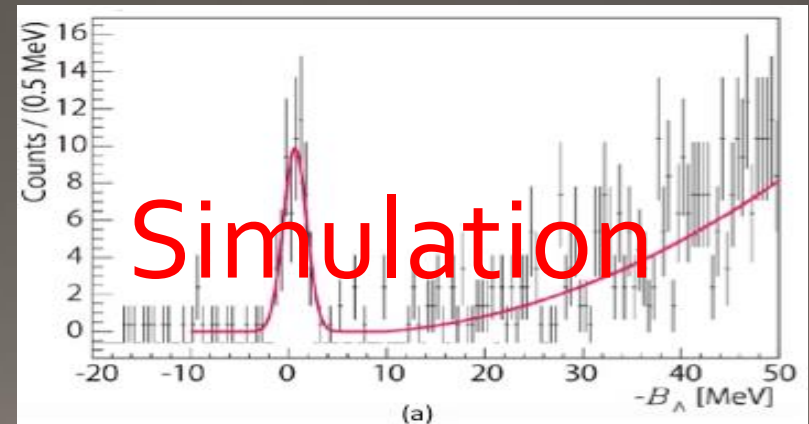
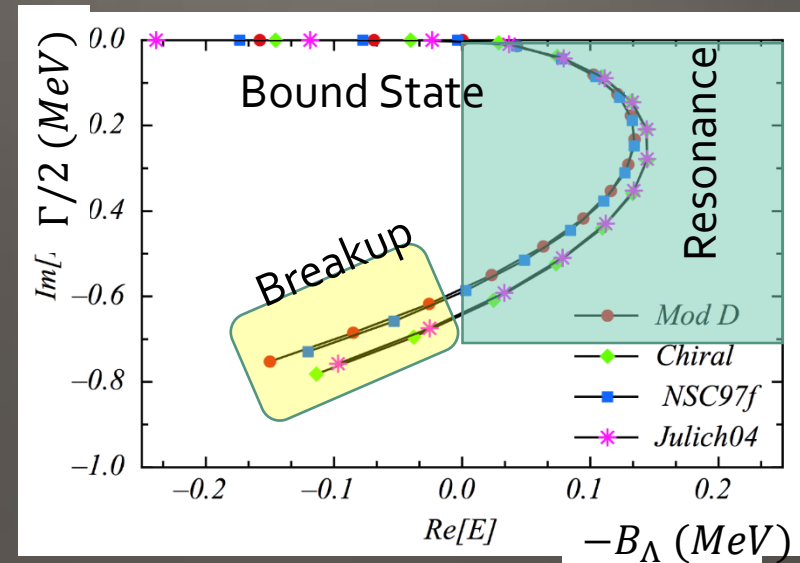
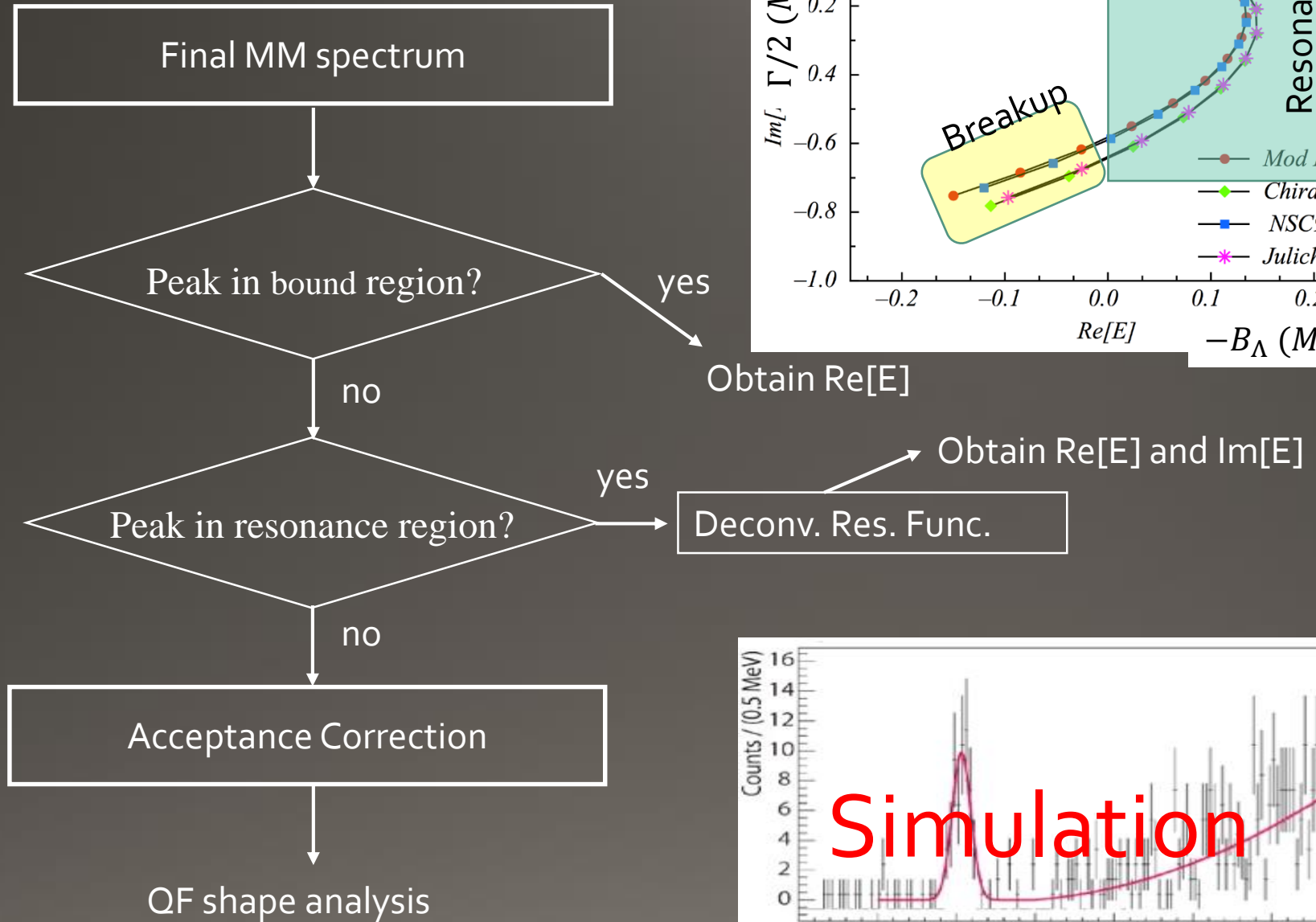
$$\Gamma = 0.5 \text{ MeV}$$



E12-17-003 :
Analysis in progress



Aft. MM Spectrum



Summary

Established $(e,e'K^+)$ spectroscopy of Λ hypernuclei at JLab

Study isospin dependence of Λ hypernuclei
(approved, will be ready in 2021)

New magnets are under construction.

Study wide A (light:C2 approval; heavy: working)

Search for bound/resonance state of $nn\Lambda$
Analysis is in progress.

**JLab hypernuclear programs are complimentary to
HIHR programs in J-PARC HD Ex.**