B01公募研究

K-ビームを用いた軽いハイパー核の寿命測定

1. ハイパートライトン研究の現状
2. 我々の実験手法
3. テスト実験/初期データ取得の状況
4. 今後のプランとまとめ

橋本直 (JAEA/ASRC)　2021/6/14

J-PARC E73/T77 collaboration

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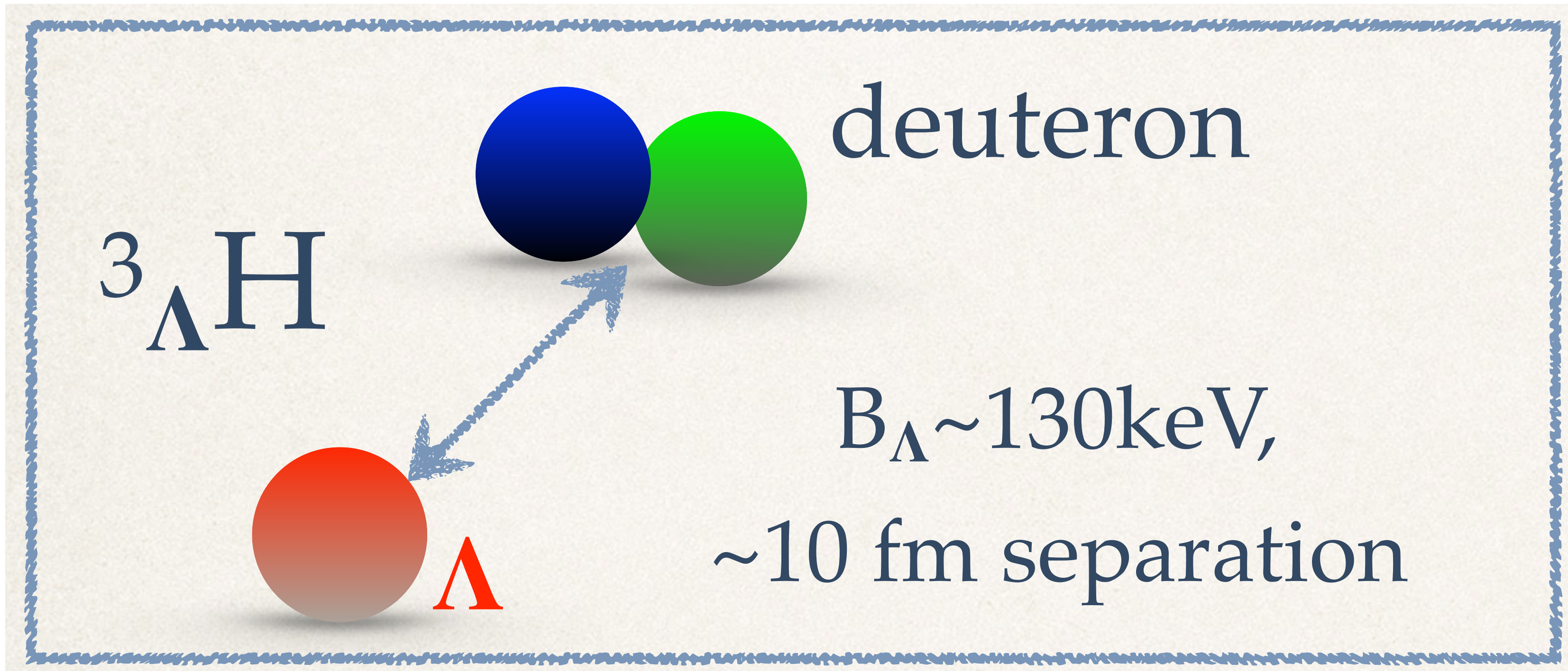
[10]RIKEN, Wako, 351-0198, Japan

- Main spokesperson: Y. Ma (RIKEN)
- Ph.D candidate: T. Akaishi (Osaka U.)

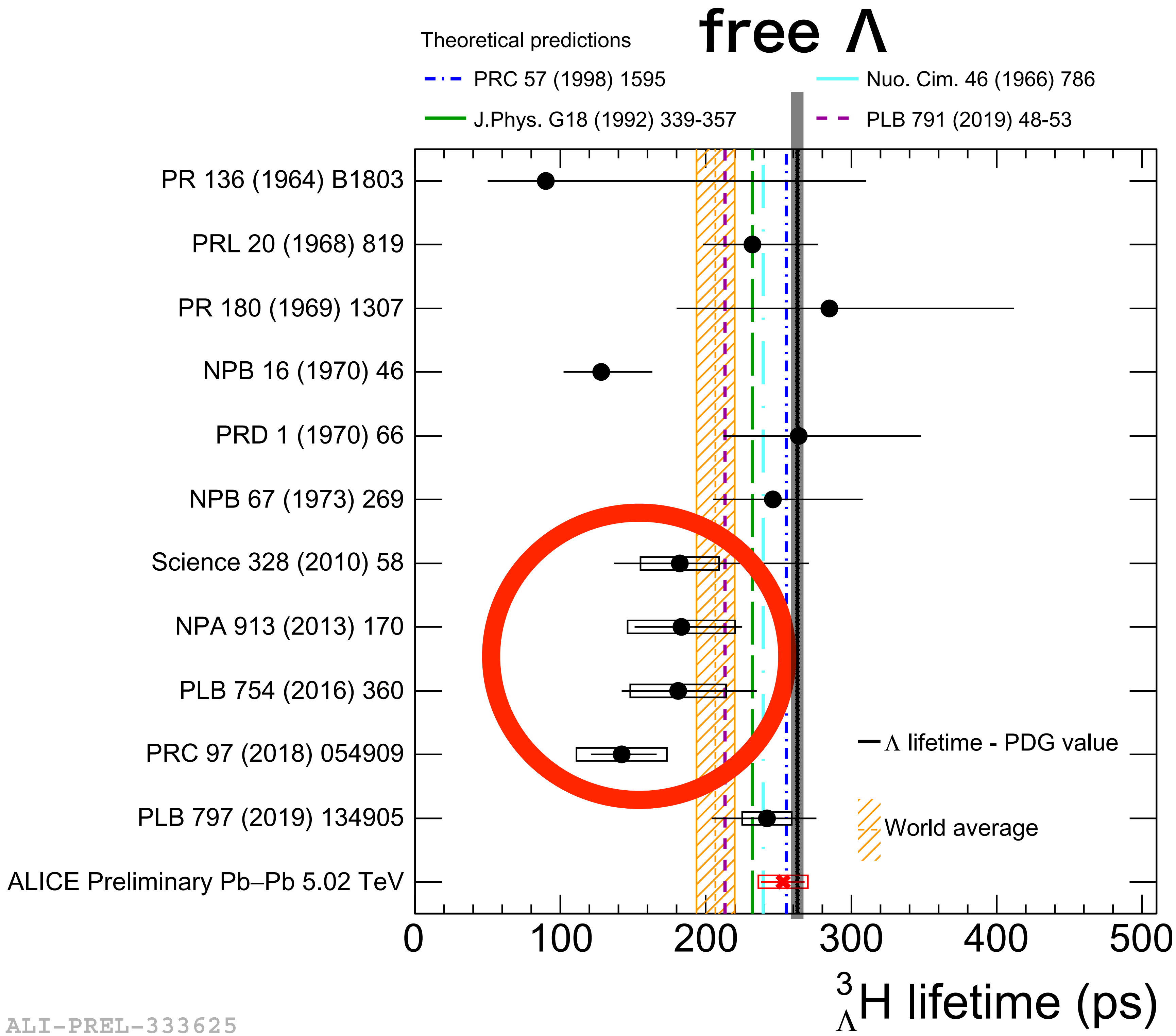
Hypertriton



- Lightest hyper nucleus: bench mark for ΛN(ΛNN) interaction models.
- Important input to determine the ΛN spin-singlet strength

- Small binding energy by emulsion data was generally accepted.
- Small B_Λ → large spacing between Λ & d
  → lifetime should be ~ free Λ (263 ps)
  - for example 256 ps by H. Kamada, et al, Phys. Rev. C Nucl. Phys. **57**, 1595 (1998).
- Spin 1/2 determined by the two-body decay ratio R_3 (G. Keyes et al., NPB67, 269, 1973).

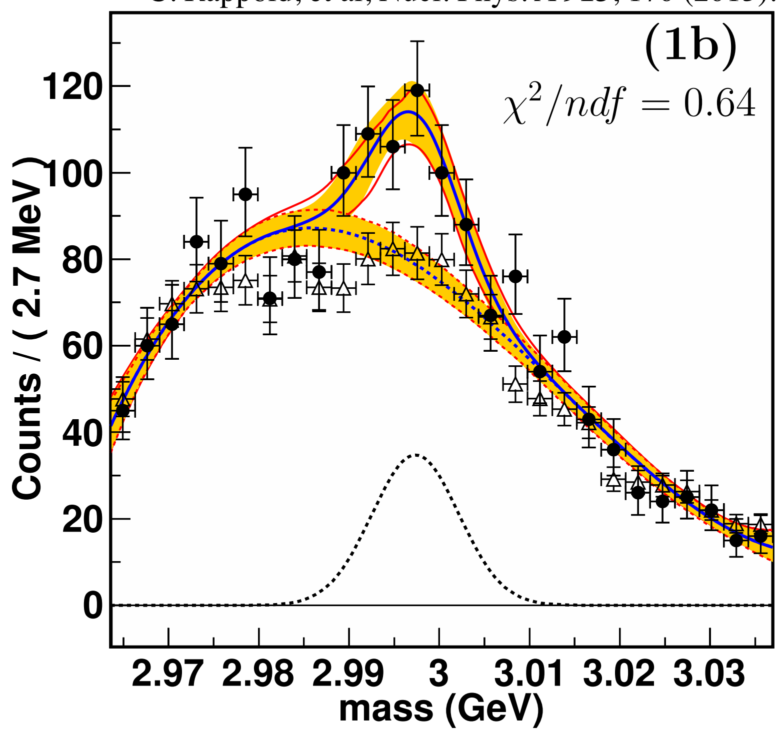
Hypertriton lifetime puzzle



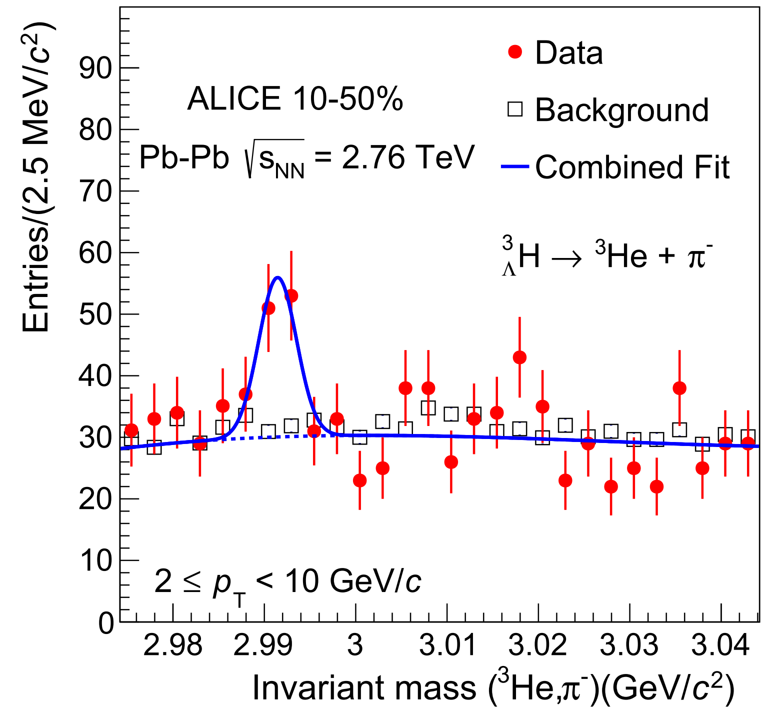
- Short lifetimes from HI experiments in 2010's

Hypertriton lifetime puzzle

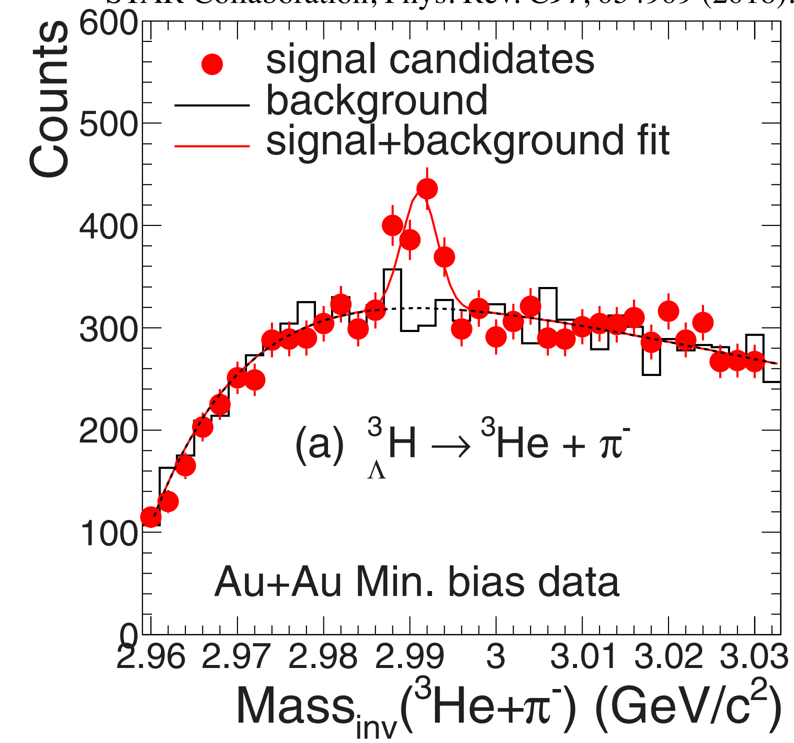
C. Rappold, et al, Nucl. Phys. A **913**, 170 (2013).

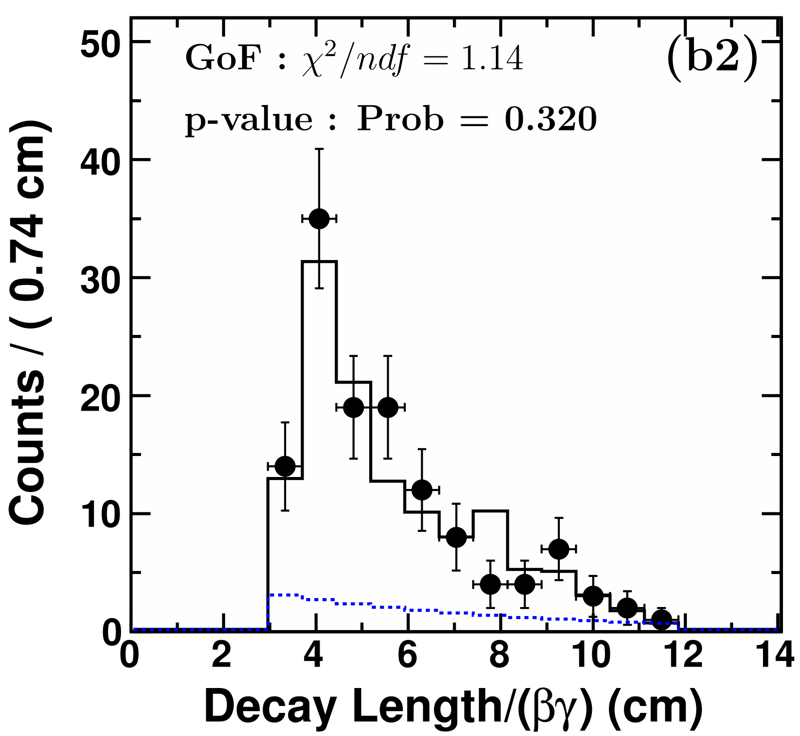


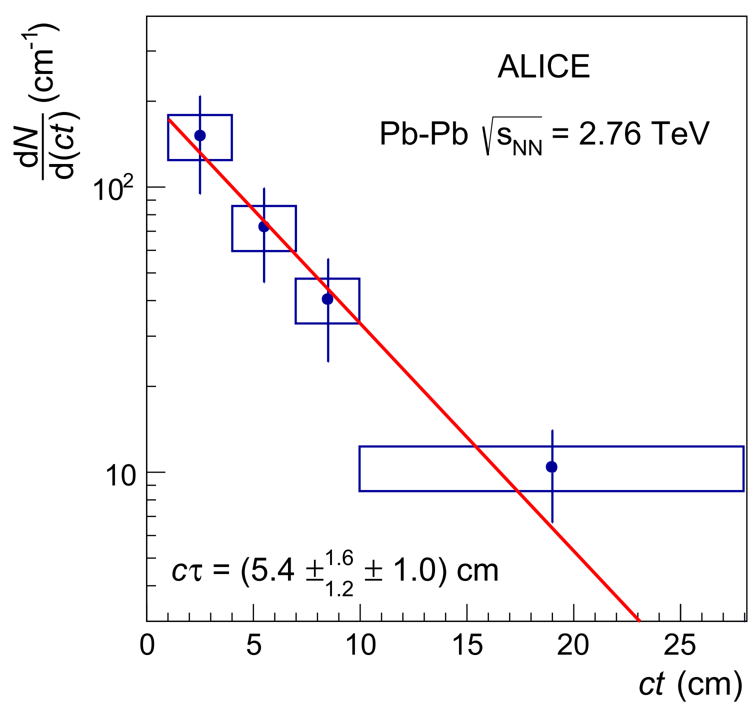
ALICE, Phys. Lett. B **754**, 360 (2016).

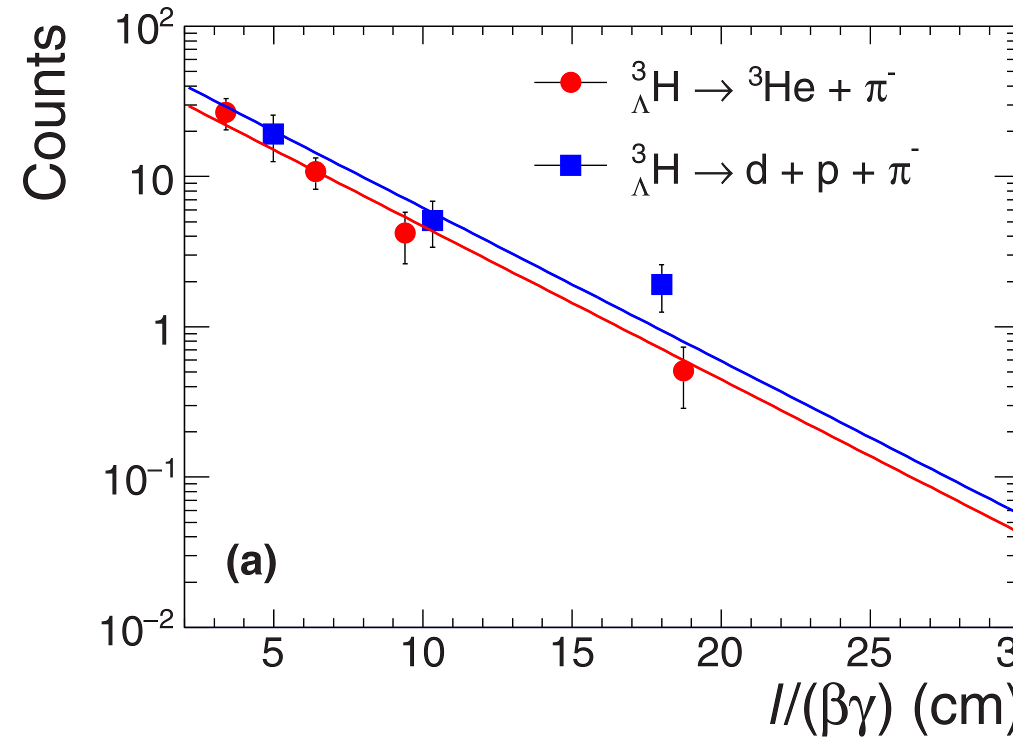


STAR Collaboration, Phys. Rev. C**97**, 054909 (2018).





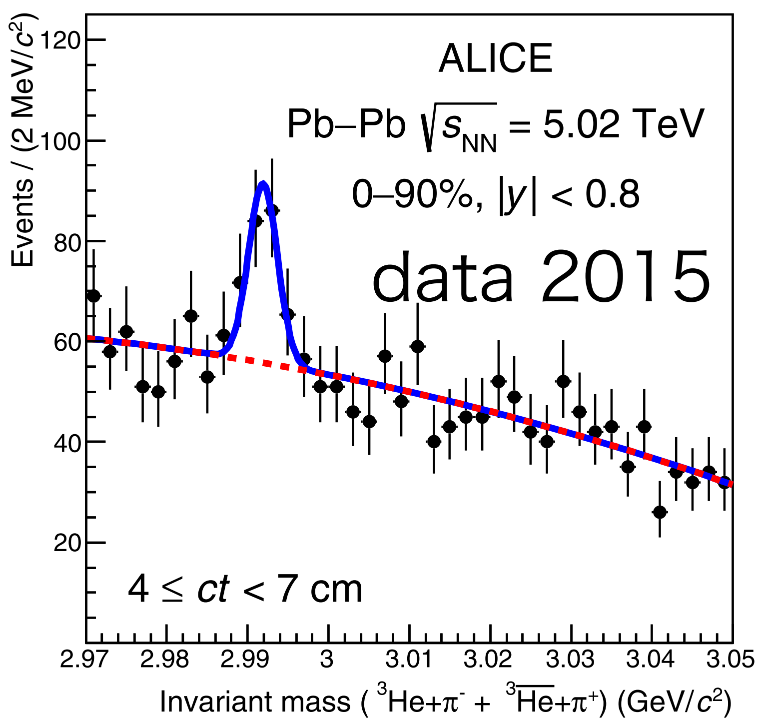




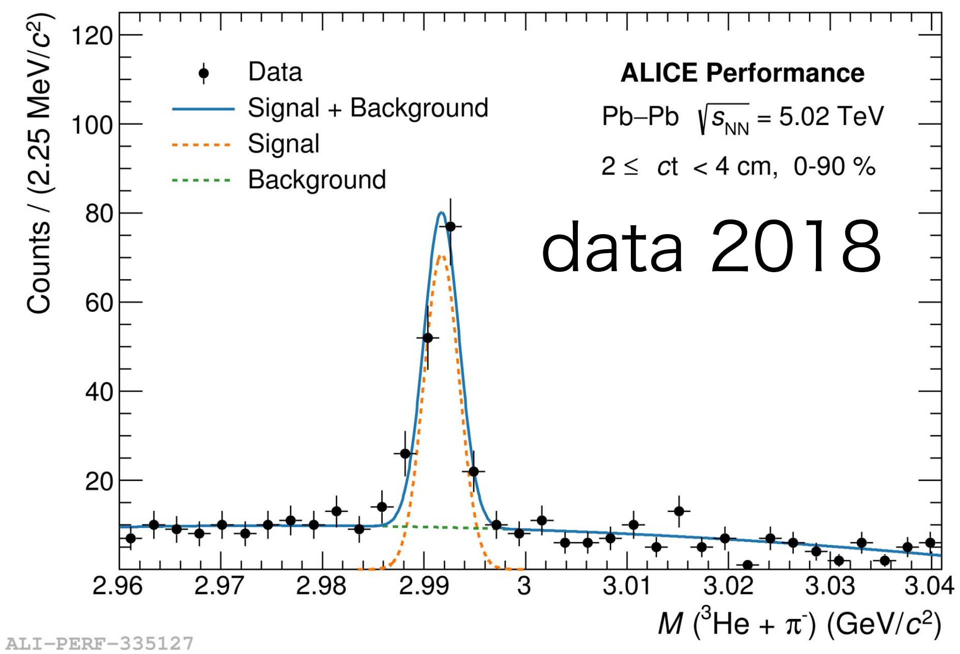
- Data quality is not good. limited counts, bad S/N
- Indirect measurement using decay length.

Recent progress in experiment

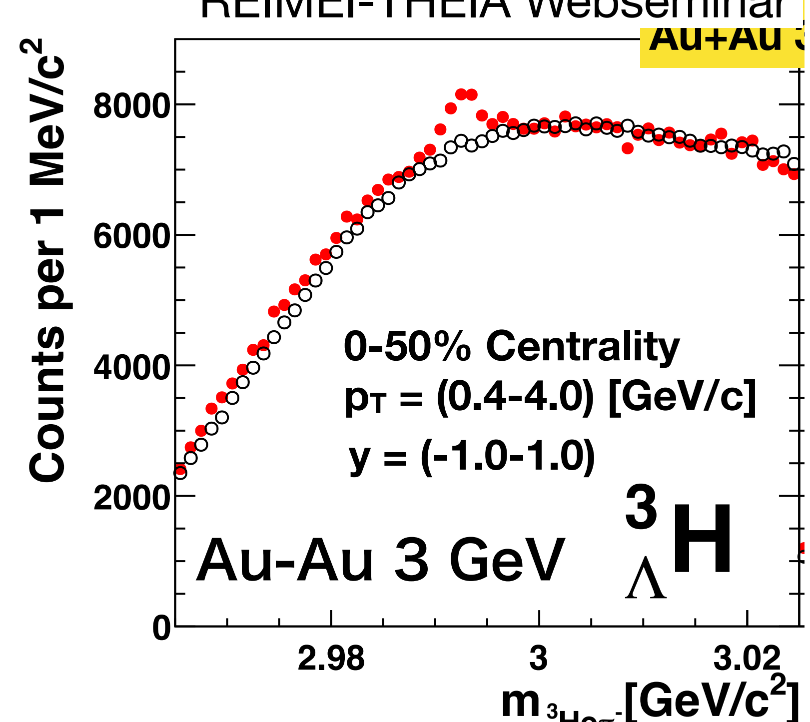
ALICE, Phys. Lett. B **797**, 134905 (2019).



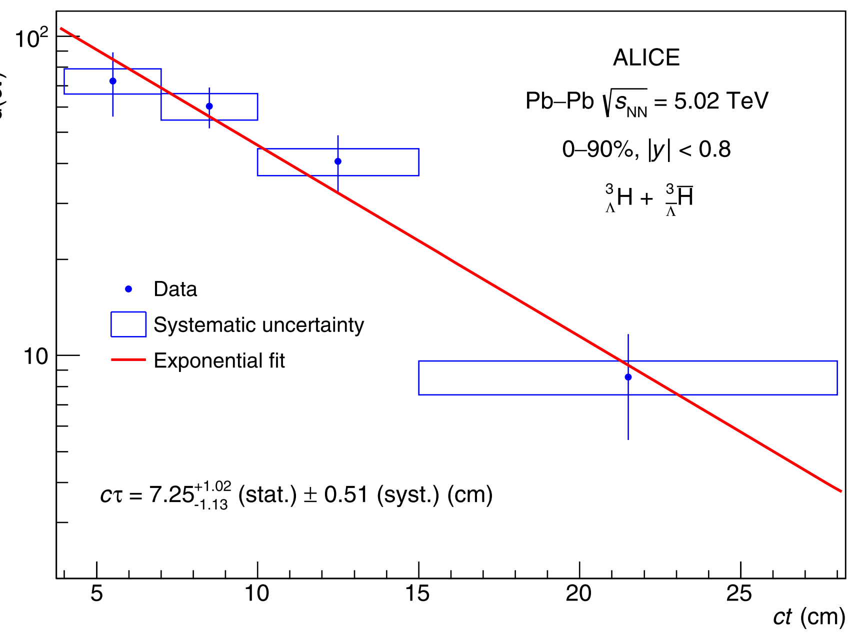
E. Bartsch, et al., Nucl. Phys. A **1005**, 121791 (2021).
Francesco Mazzaschi, THEIA-STRONG 2020

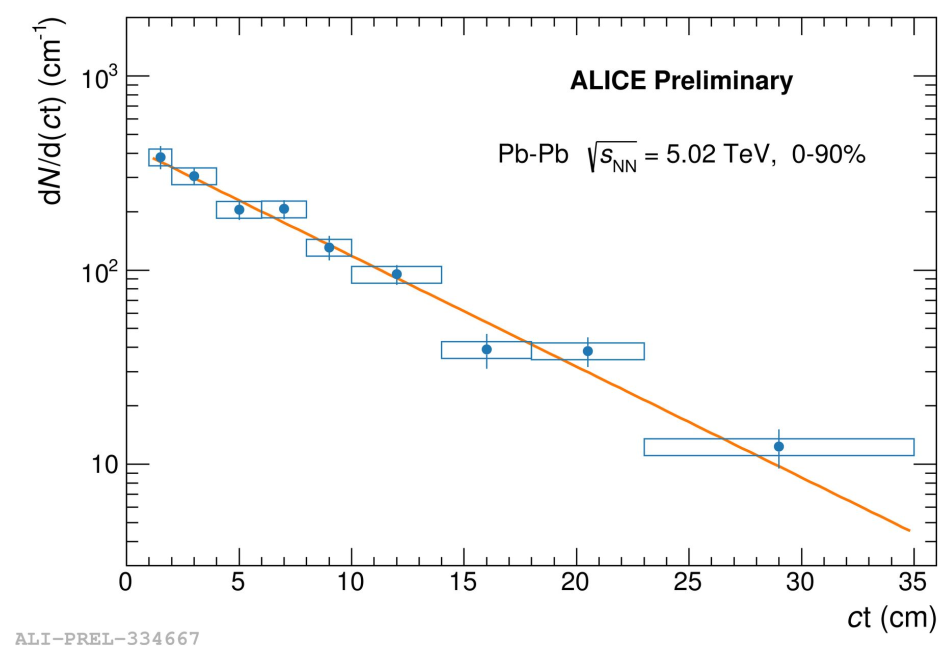


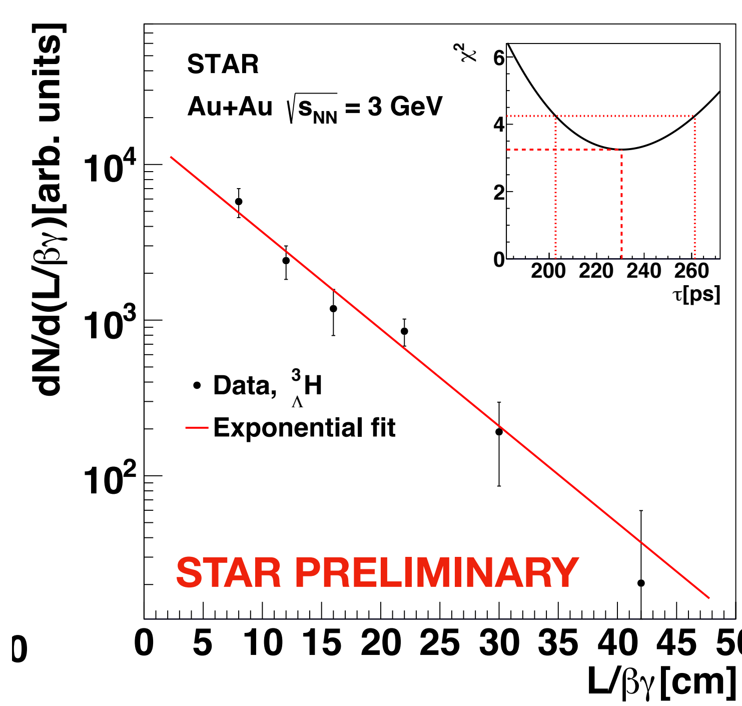
Yue-Hang Leung
REIMEI-THEIA Webseminar



$^3_\Lambda$H

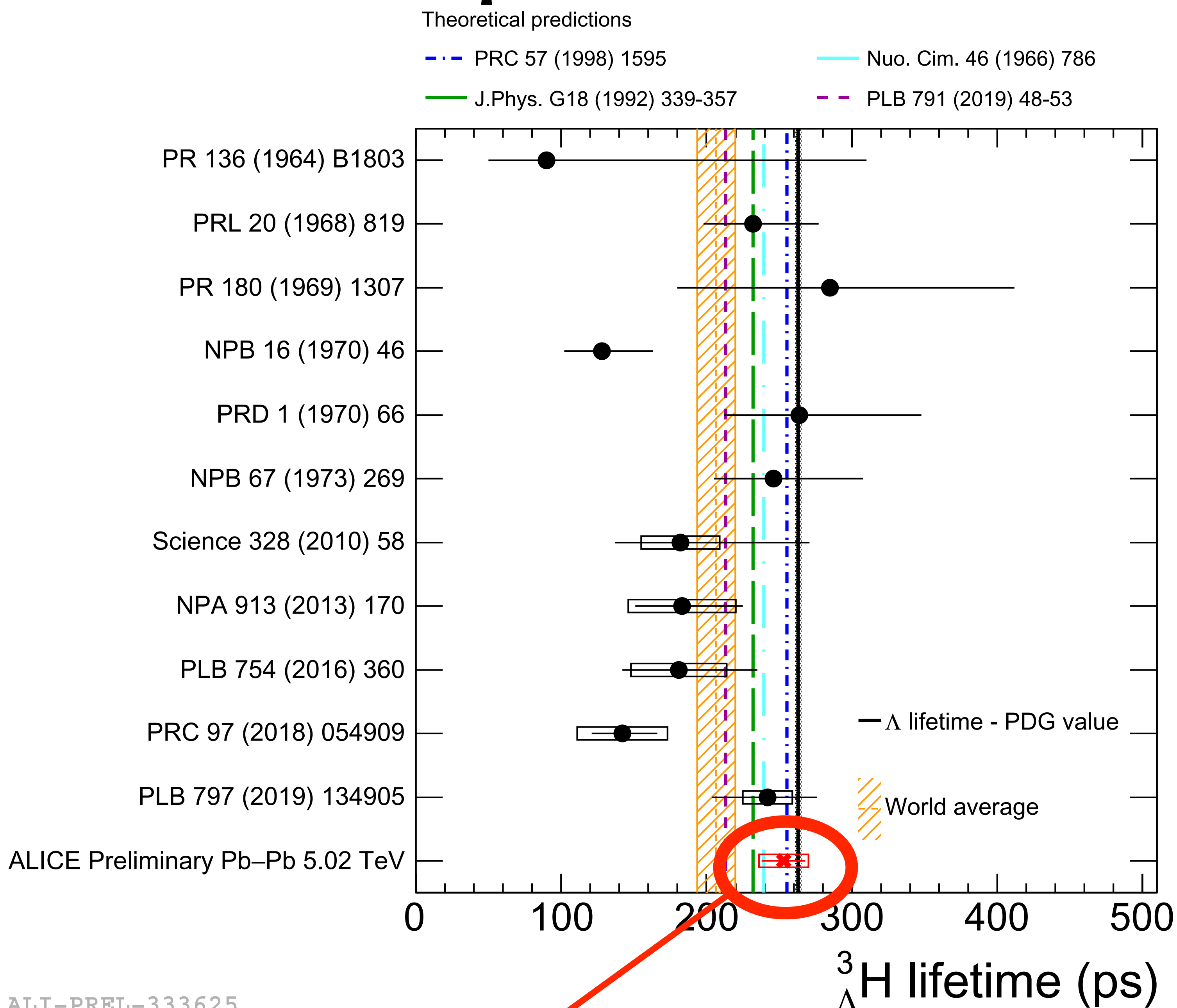






- More signals, better S/N (ALICE with ML), …

Is there still puzzle?



Lifetime value from the fit

- 254 ± 15 (stat.) ± 17 (syst.) ps

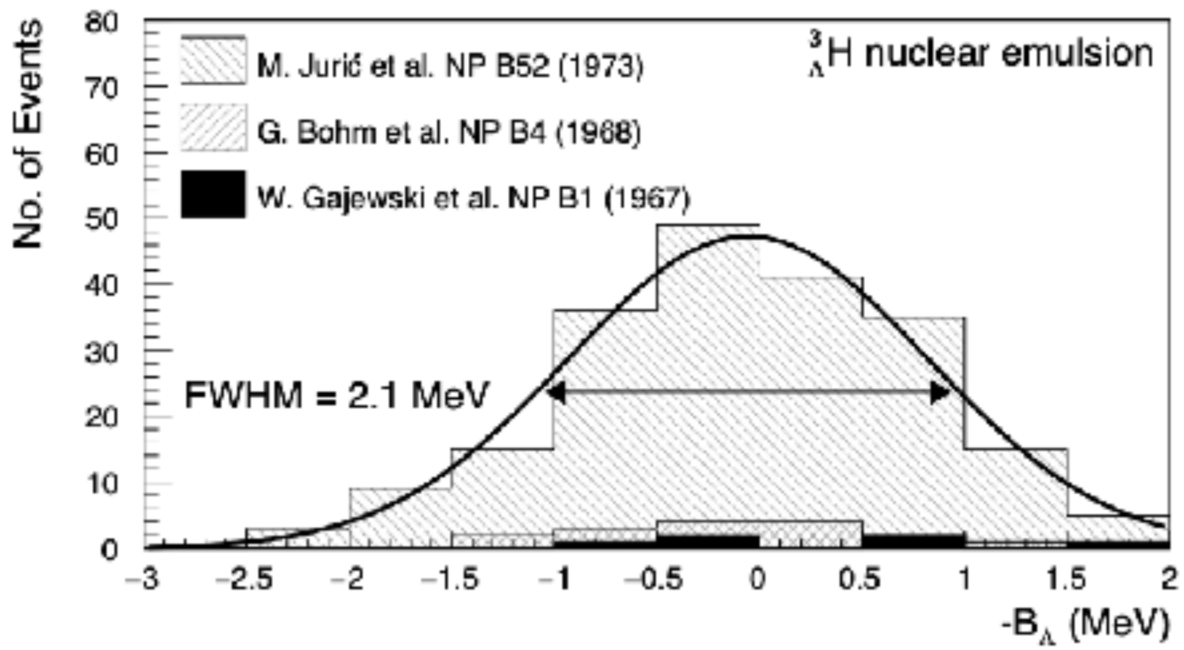
$^{3}_{\Lambda}H : \tau = 232.1 \pm 29.2(stat) \pm 36.7(syst)[ps]$

$^{4}_{\Lambda}H : \tau = 218.3 \pm 7.5(stat) \pm 11.8(syst)[ps]$

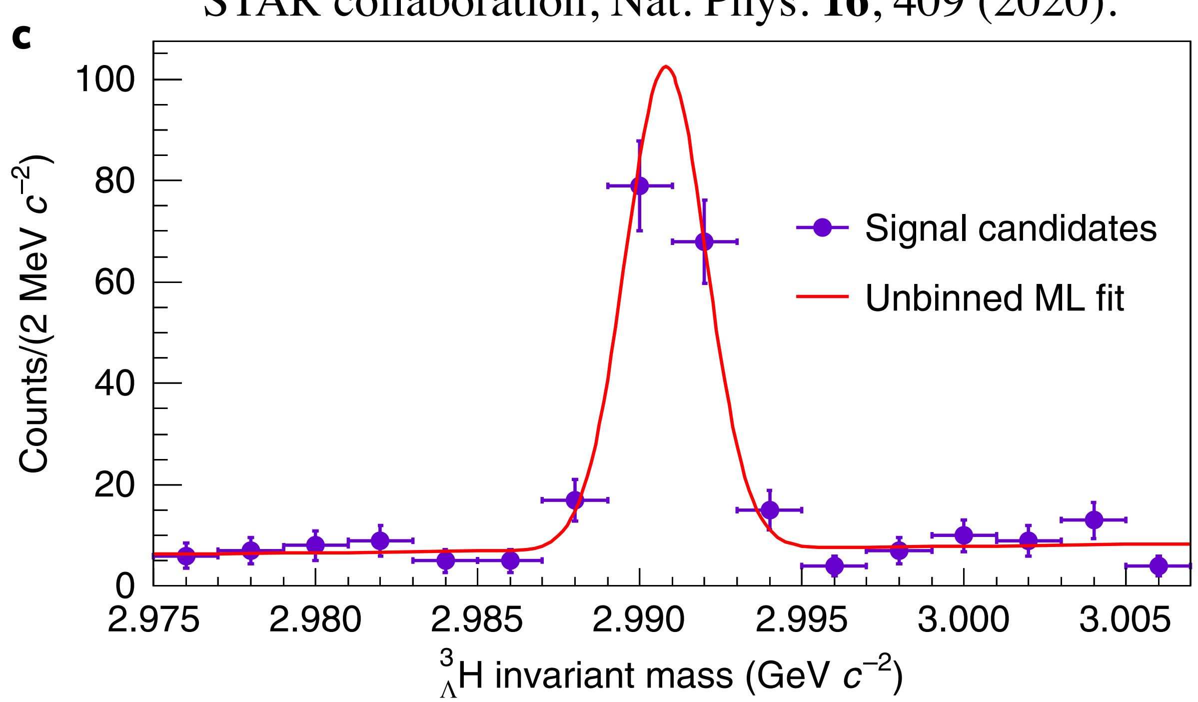
STAR Au+Au 3 GeV

Binding energy

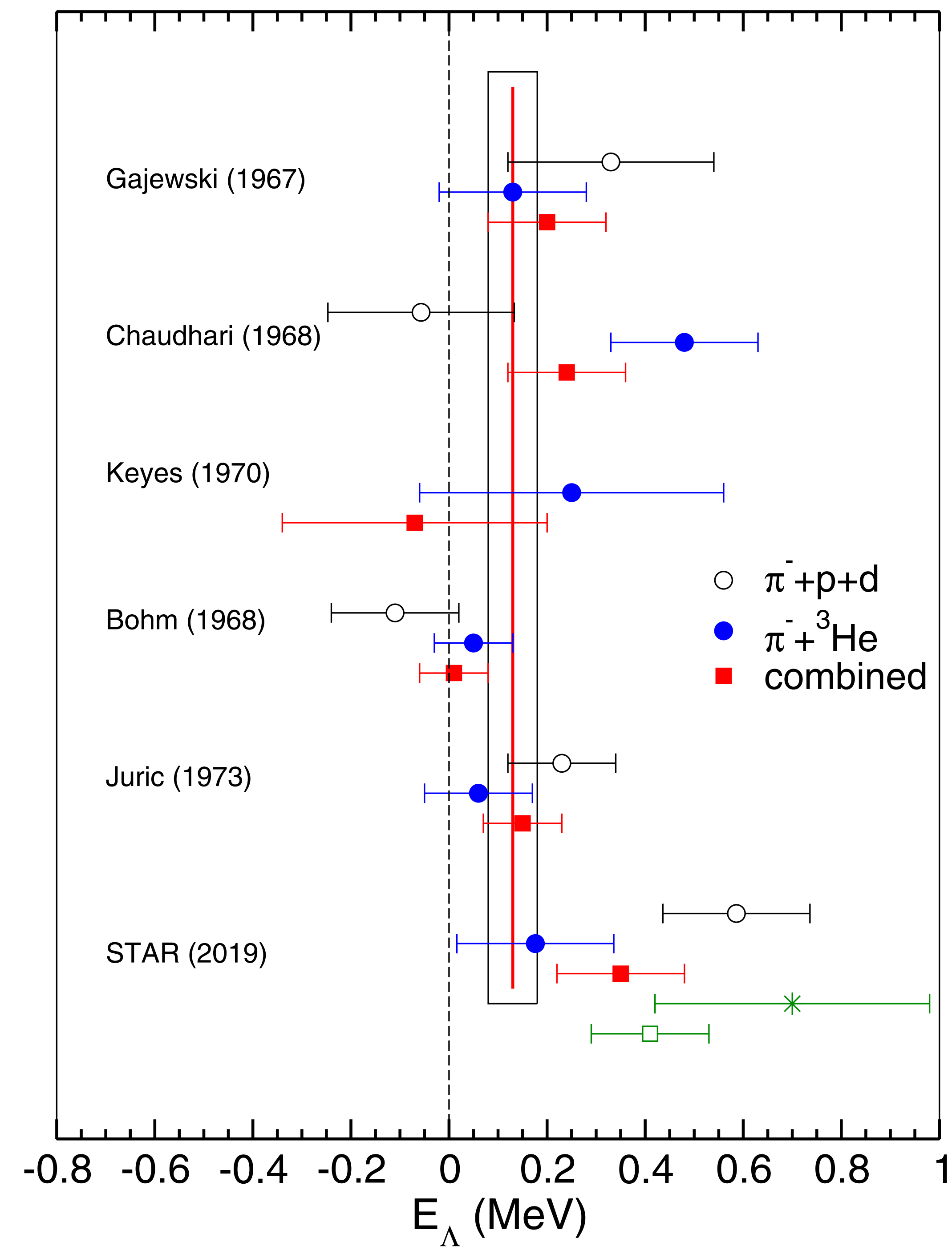
P. Achenbach, *et al*, *PoS(Hadron2017)*207.



STAR collaboration, Nat. Phys. **16**, 409 (2020).



H. Le, J. Haidenbauer, et al, Phys. Lett. B **801**, 135189 (2020).



- STAR 0.41(12)(11) MeV > Emulsion 0.13(5) MeV
- Need high precision data

(Part of) Recent progress in theory

- Pion FSI enhance the decay rate 10~20%
  A. Gal, et al, Phys. Lett. B **791**, 48 (2019).
- Σ admixtures reduce the decay rate ~10%
  Strong dependence on B_Λ
  A. Pérez-Obiol, et al, Phys. Lett. B **811**, 135916 (2020).
- Branching ratio depends on B_Λ
  F. Hildenbrand et al., Phys. Rev. C**102**, 064002 (2020).
- etc···

A. Pérez-Obiol, et al, Phys. Lett. B **811**, 135916 (2020).

Λ_{UV} (MeV)	B_Λ (keV)	$\Gamma_{^3_\Lambda H \to ^3He + \pi^-}$ (GHz)	$\tau(^3_\Lambda H)$ (ps)
800	69	0.975	234 ± 27
900	135	1.197	190 ± 22
1000	159	1.265	180 ± 21
–	410	1.403	163 ± 18

F. Hildenbrand, et al., Phys. Rev. C**102**, 064002 (2020).

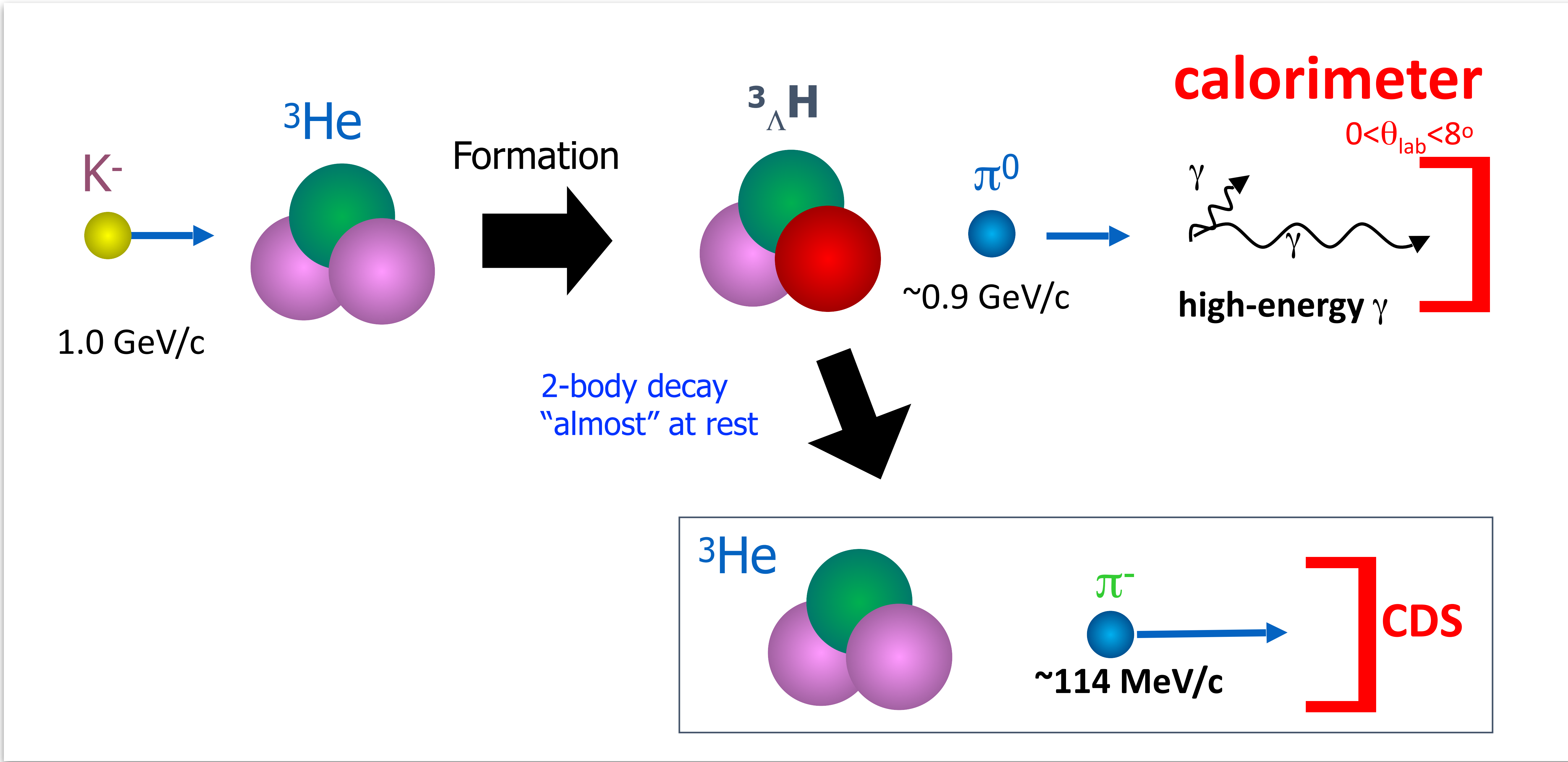
Observable	$B_\Lambda = 0.13$ MeV		$B_\Lambda = 0.41$ MeV	
α_-	0.642	0.732	0.642	0.732
$(\Gamma_{pd} + \Gamma_{nd})/\Gamma_\Lambda$	0.612	0.612	0.415	0.416
$(\Gamma_{^3He} + \Gamma_{^3H})/\Gamma_\Lambda$	0.382	0.363	0.569	0.541
$\Gamma_{^3_\Lambda H}/\Gamma_\Lambda$	0.992	0.975	0.984	0.956
$\Gamma_{^3He}/(\Gamma_{^3He} + \Gamma_{pd})$	0.384	0.373	0.578	0.566
$\tau_{^3_\Lambda H}$[ps]	264.7	269.8	267.6	275.0

Planned experiments

- Heavy ion collision
  - ALICE Run 3(2021~2024), Run 4 (2027~2030)
    - ~50 times yield expected
  - GSI (2022?)
    - FRS+WASA
- Binding energy measurement
  - MAMI (e, e'K) decay pion spectroscopy
  - JLab (e, e'K) C12-19-002
  - J-PARC E07: Emulsion full scan
- Counter experiments for lifetime
  - ELPH: (γ, K+)
  - J-PARC P74: (π-, K^0) at K1.1
  - **J-PARC E73: (K-, π^0) at K1.8BR**

Our approach

Hypertriton寿命測定(J-PARC E73/T77)



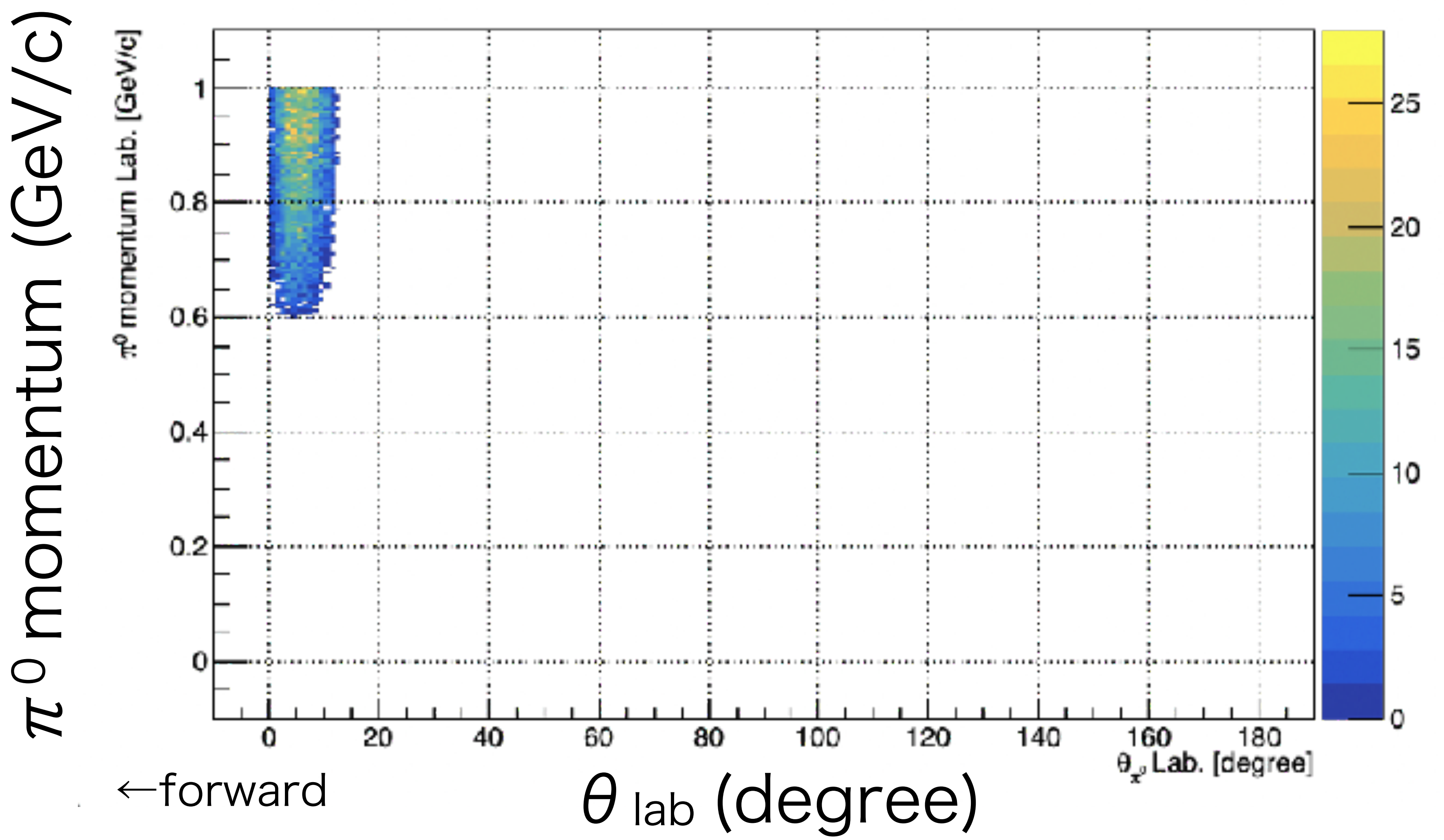
- detect forward high-energy gamma to tag (K-, π^0) reactions
- $^4{}_\Lambda$H measurement as feasibility demonstration (T77)

Forward gamma tag

Simulation

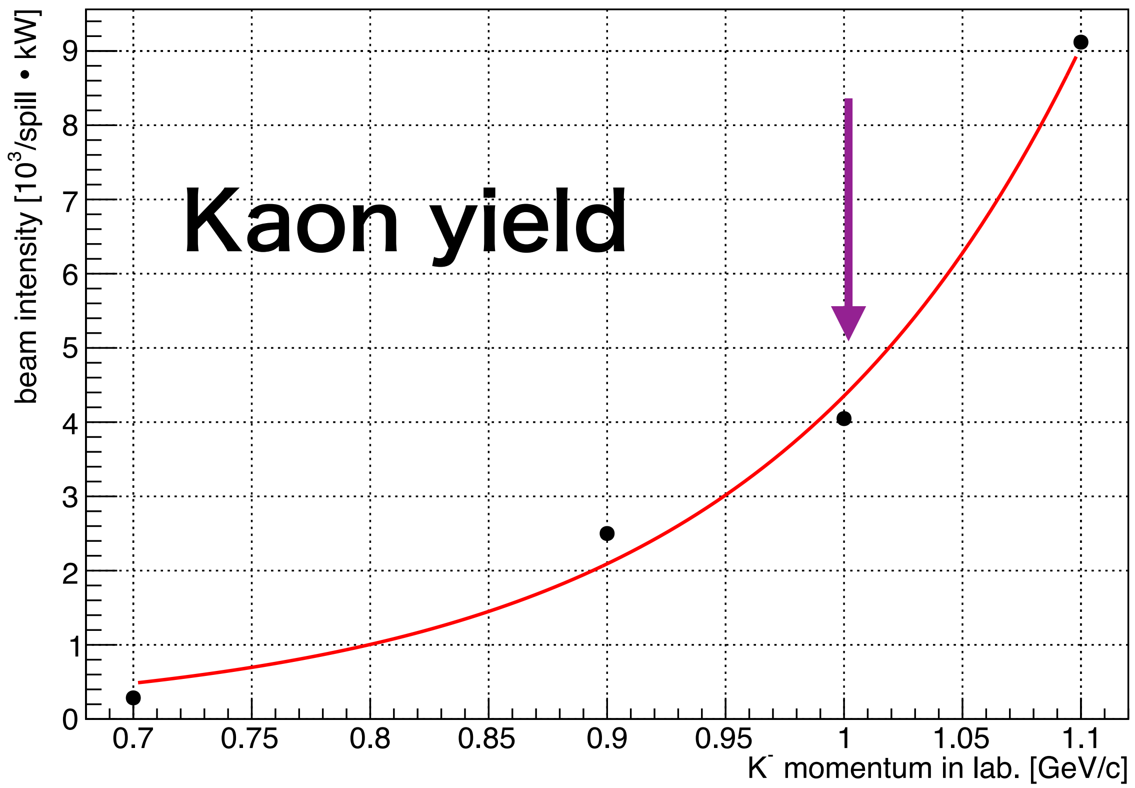
Generate: π^0 uniformly 0~1 GeV/c, 0~180 deg

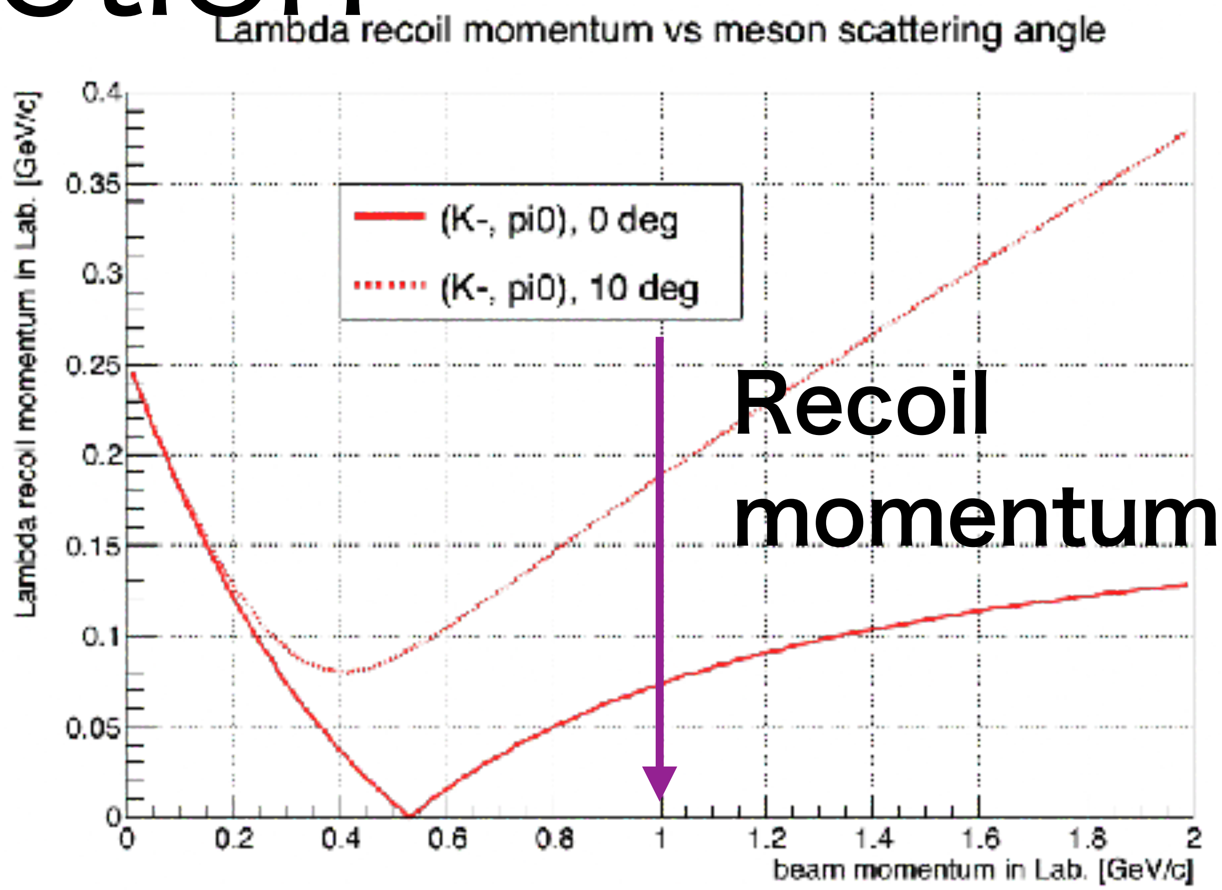
Accept: >0.6 GeV/c gamma in the calorimeter

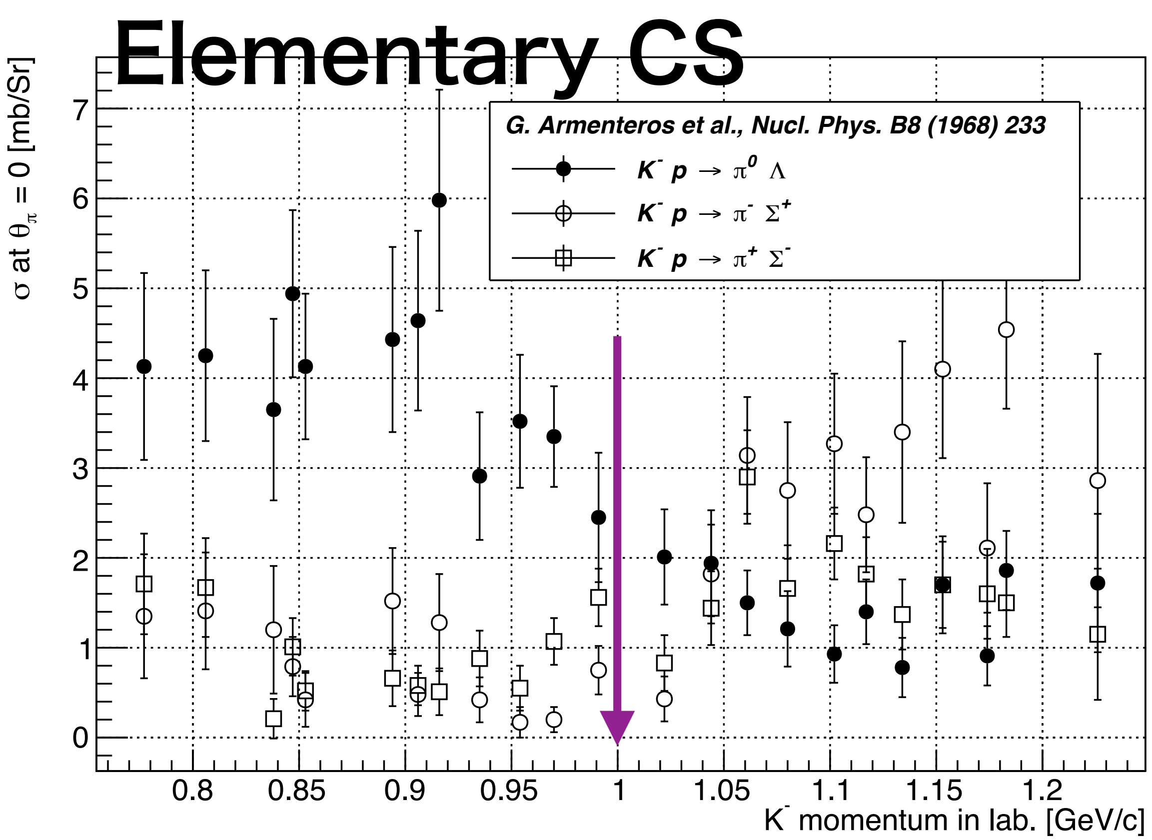


- forward high-energy π^0 can be selected by detecting 1 gamma
- low-energy π^0 from hyperon decays can be removed.

Momentum selection



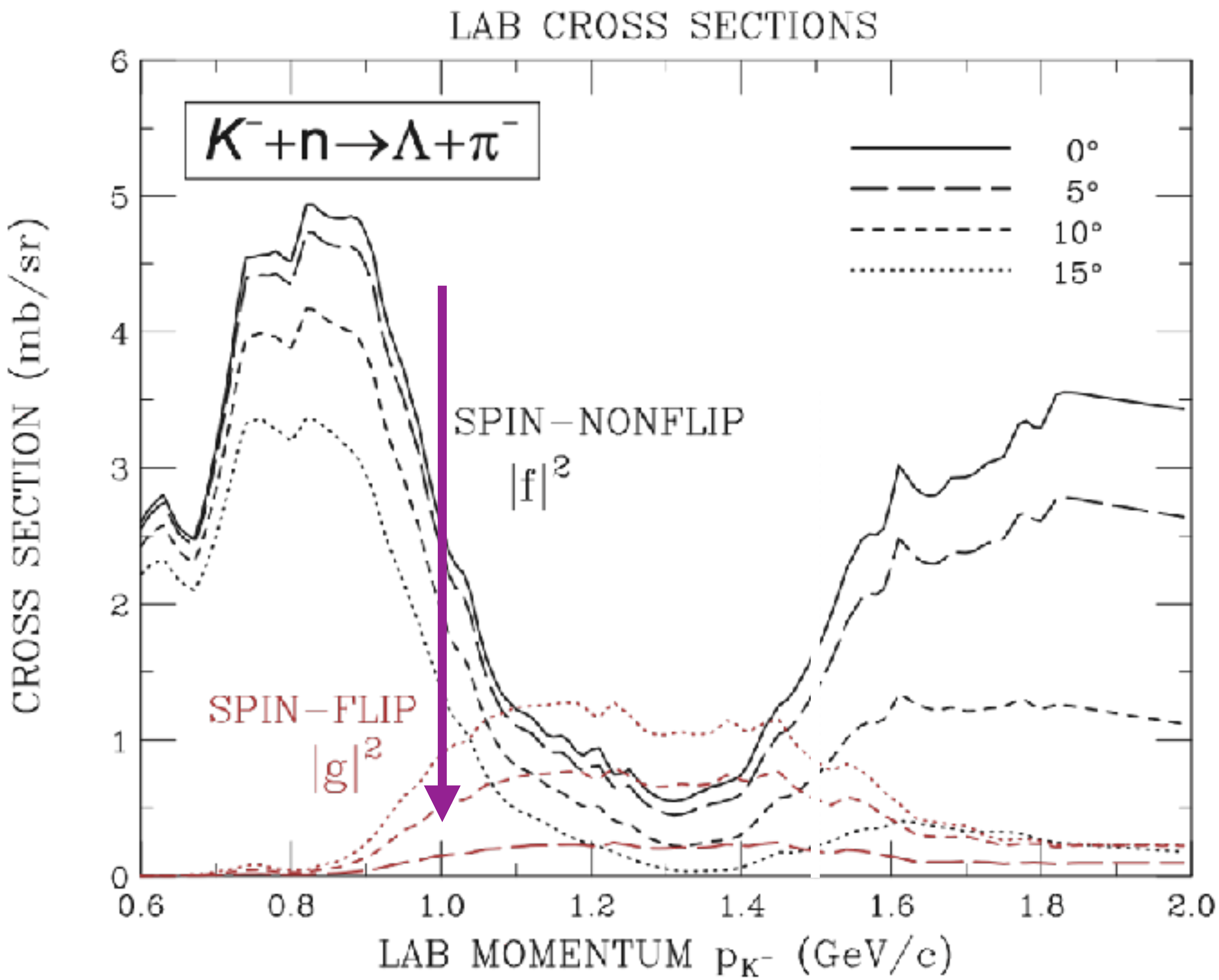




At higher momentum

- Slight increase of recoil momentum
- Higher kaon yield
- Lower elementary CS
- 1.0 GeV/c (or 0.9 GeV/c)

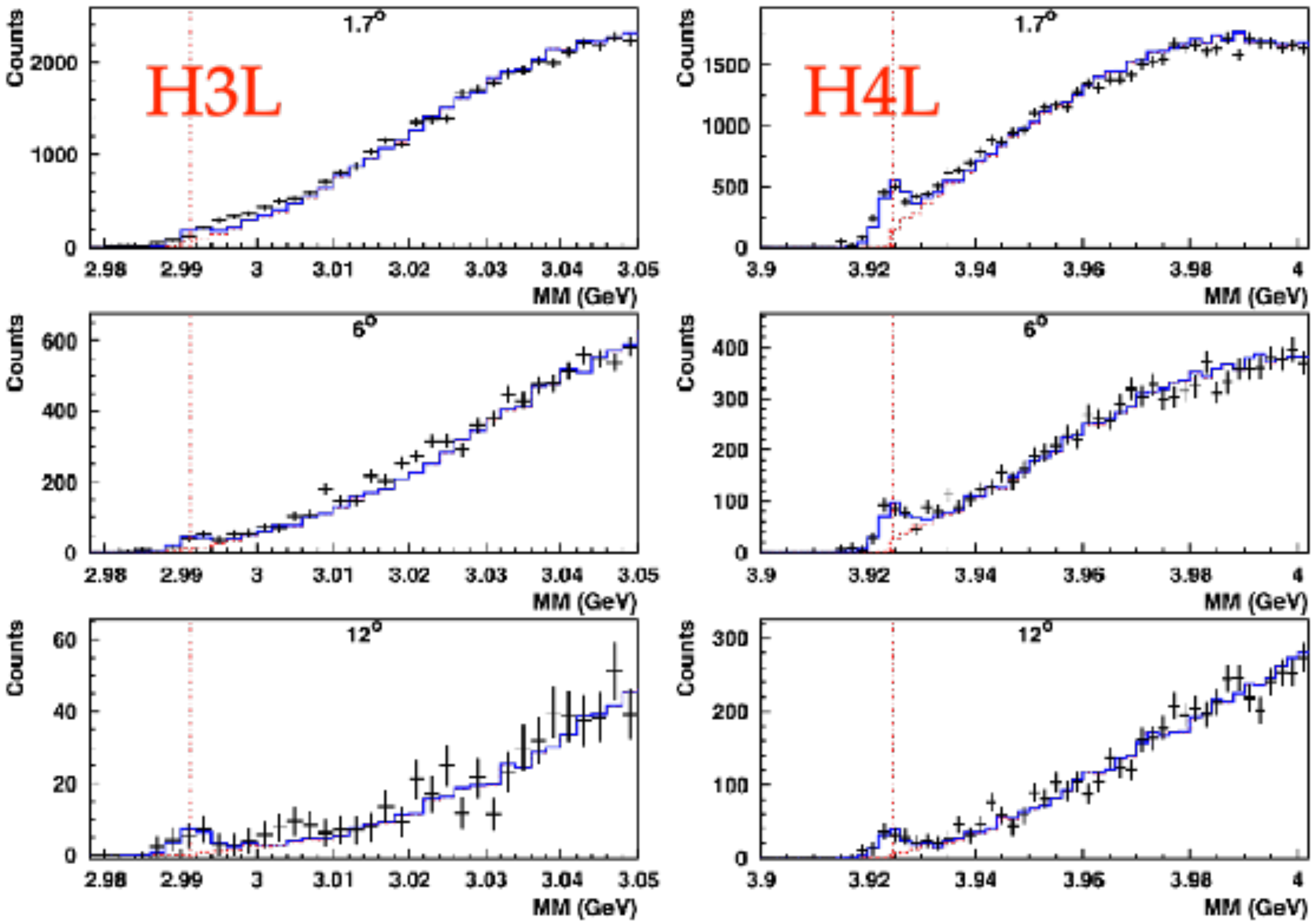
Spin non-flip nature of the reaction



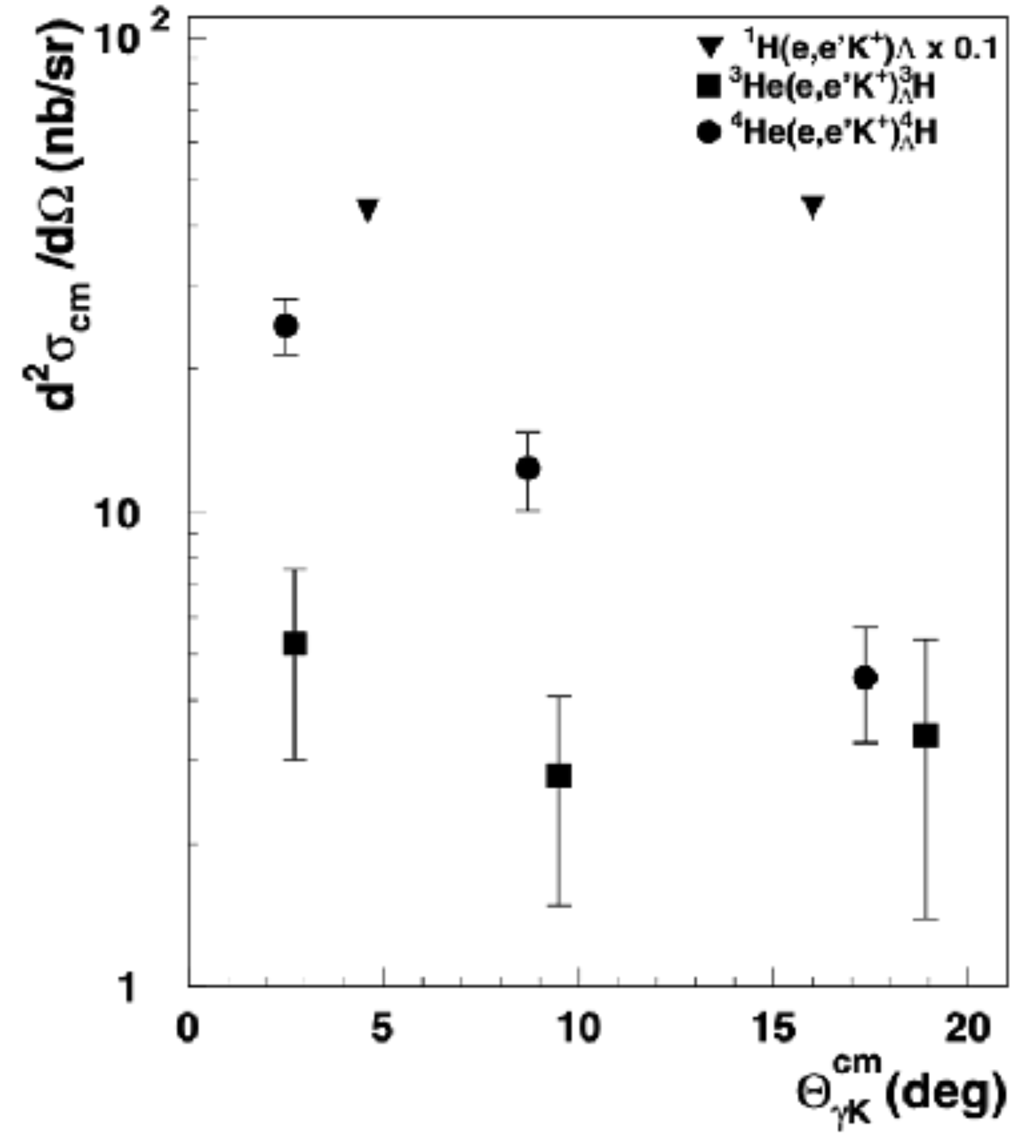
- Spin-nonflip reaction is dominant at 1.0 GeV/c or lower
- Selectively produce ground states ${}^{4}_{\Lambda}H(0^+)$, ${}^{3}_{\Lambda}H(1/2^+)$

Cross section ratio $R = \sigma_{\rm lab}({}^3_\Lambda{\rm H})/\sigma_{\rm lab}({}^4_\Lambda{\rm H}).$

(e, e′K+) reaction @ J-Lab

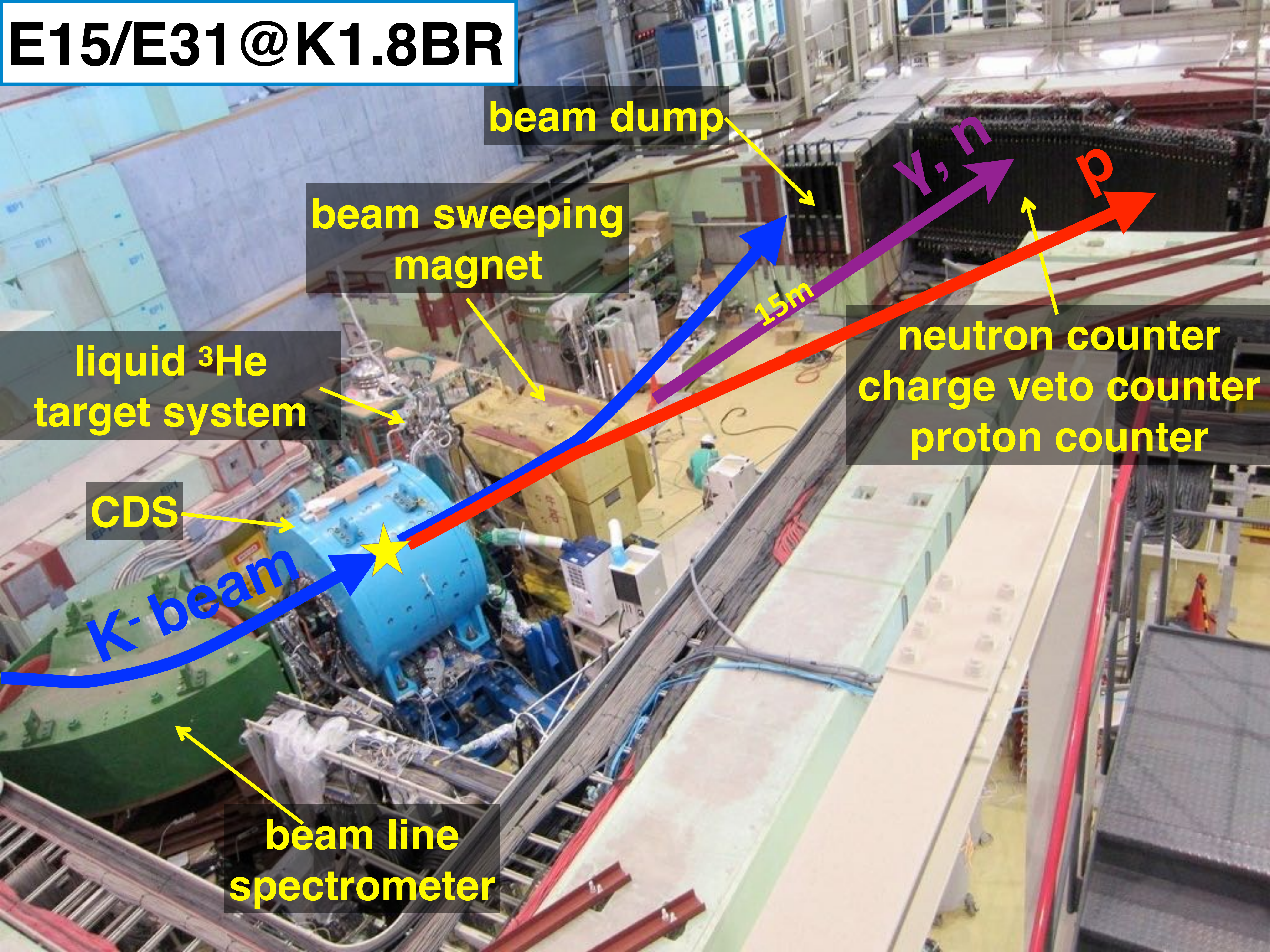


DOI: 10.1103/PhysRevLett.93.242501



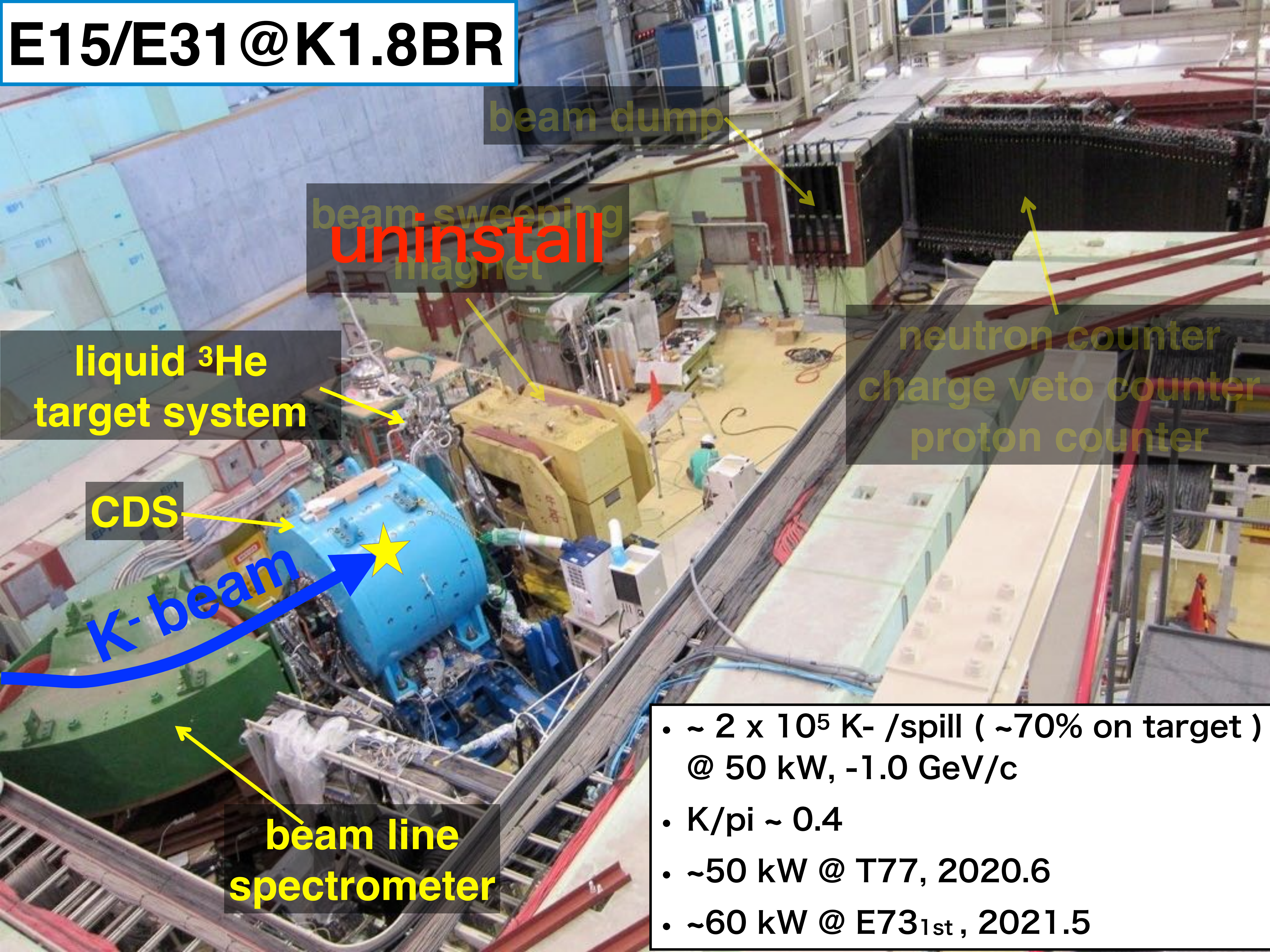
- Harada-san predict T. Harada and Y. Hirabayashi, http://arxiv.org/abs/2106.04256.
  - R=0.3~0.4 for B_Λ=0.13, R = 0.65 for B_Λ=0.41
- Hint for 3/2+ state combining J-Lab data (spin-flip favored)

Experiment



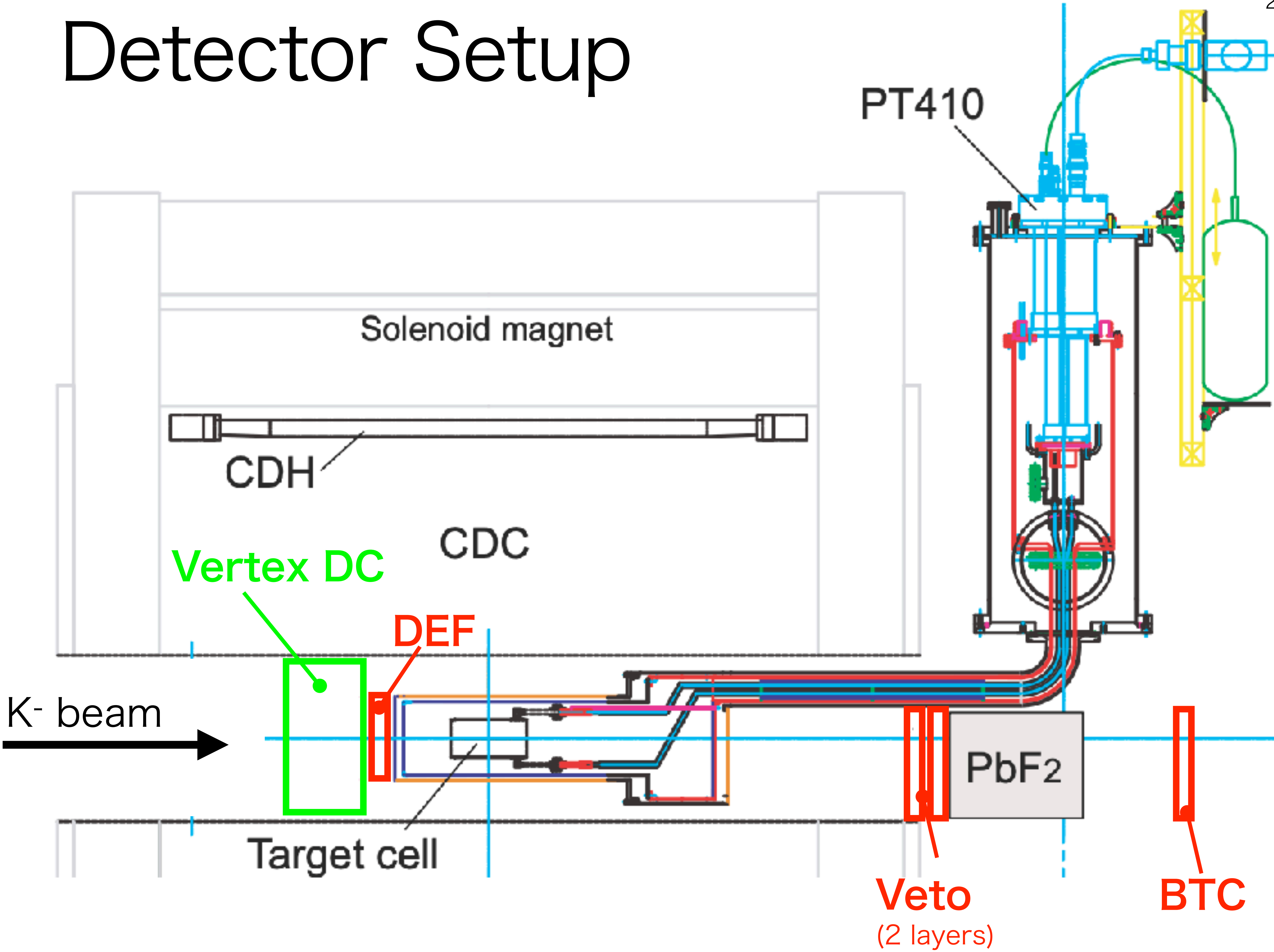
E15/E31@K1.8BR
beam dump
γ, n
p
beam sweeping magnet
15m
liquid ³He target system
neutron counter
charge veto counter
proton counter
CDS
K- beam
beam line spectrometer

E15/E31@K1.8BR

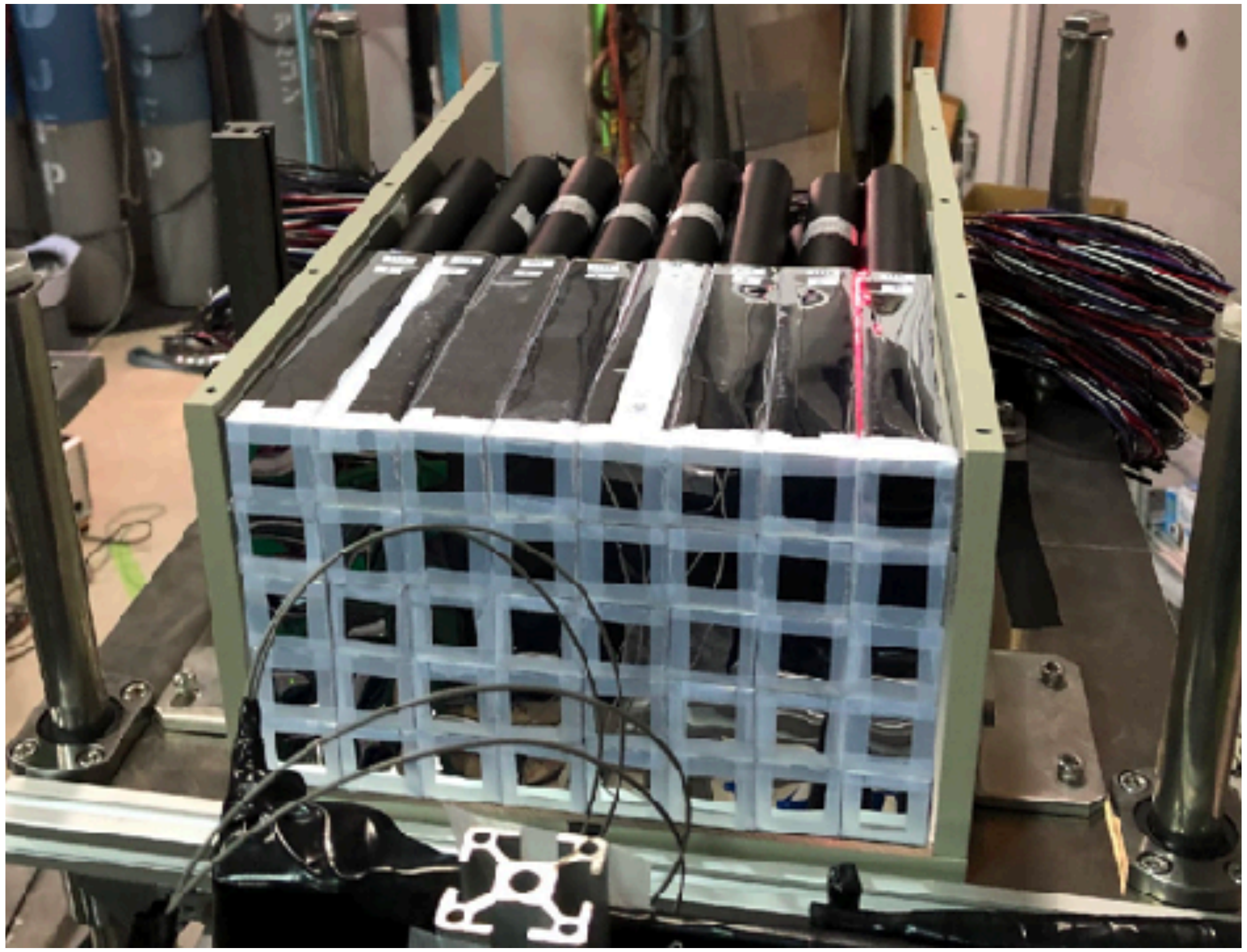


- ~ 2 x 10^5 K- /spill (~70% on target) @ 50 kW, -1.0 GeV/c
- K/pi ~ 0.4
- ~50 kW @ T77, 2020.6
- ~60 kW @ $E73_{1st}$, 2021.5

Detector Setup



PbF2 calorimeter



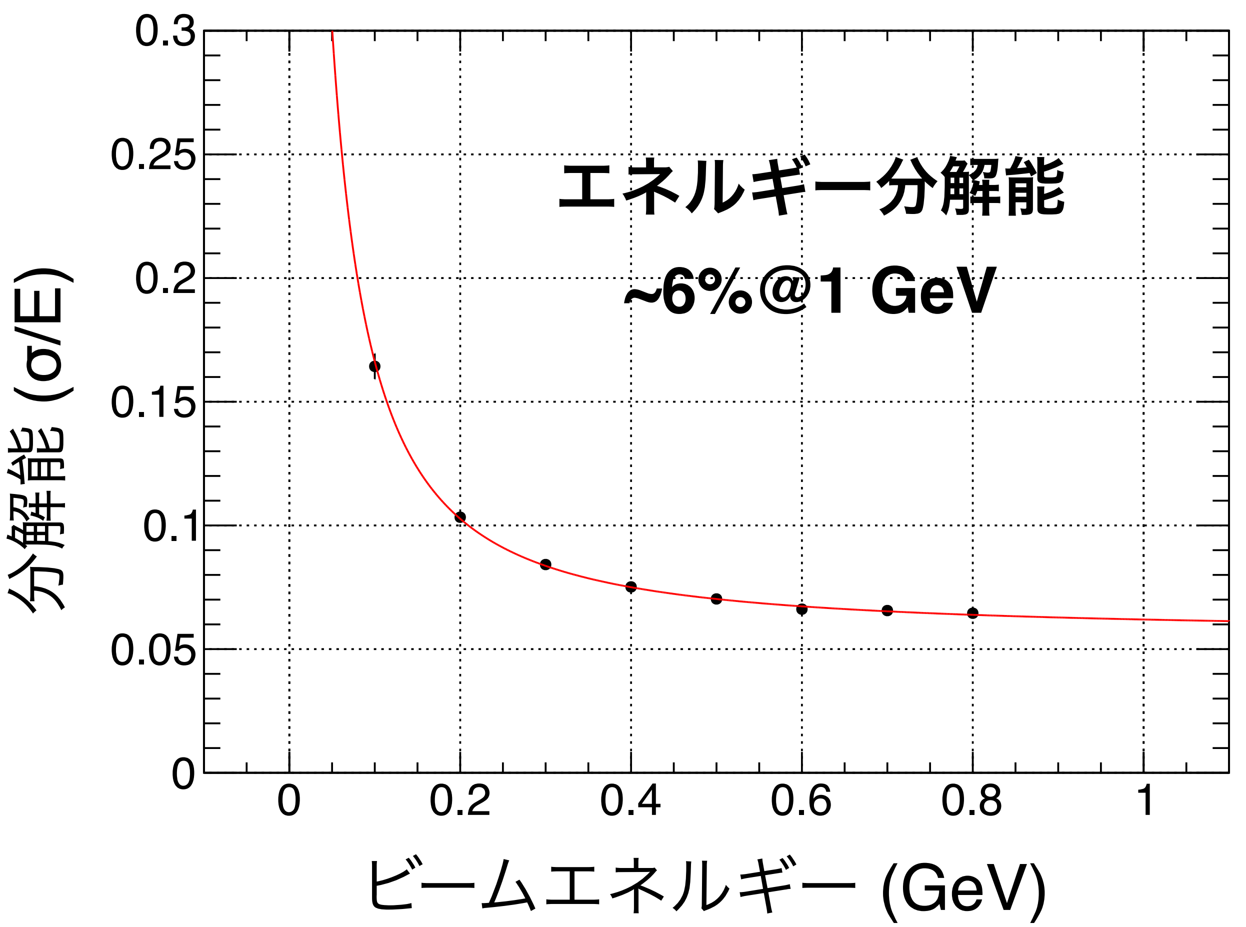
- PbF2 EM calorimeter
  - Cherenkov-type
  - Radiation hard
  - 25 x 25 x 140 mm
  - 40 segment
  - 1/4” PMT
  - Fe magnetic shield

Crystal	Radiation length	Moliere radius	Density	Cost	Resolution	Signal length
PbF_2	0.93 cm	2.22 cm	7.77 g/cm^3	12 USD/cc	5%	2ns

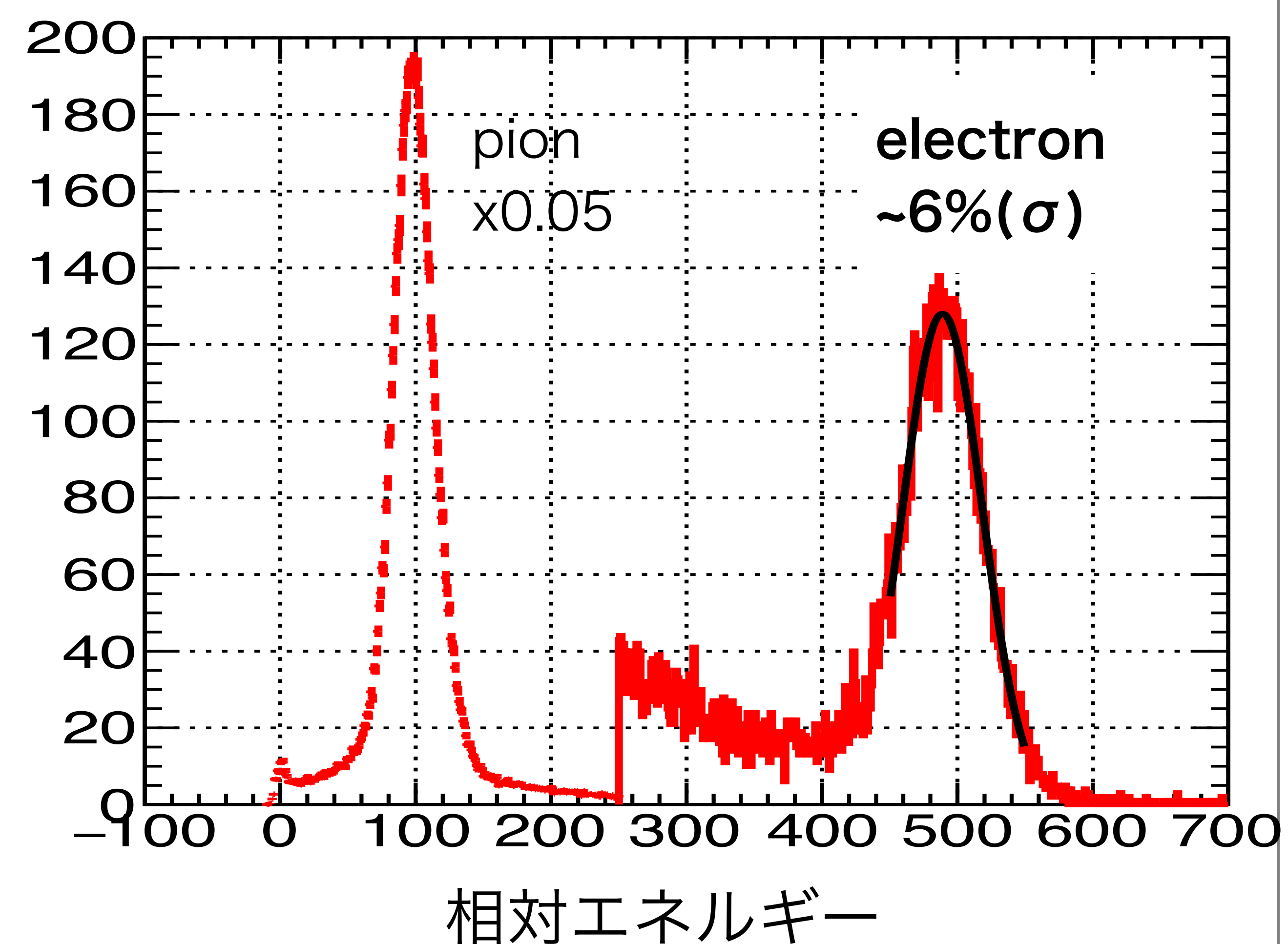
D.F. Anderson, *et al.*, Nucl. Inst. Meth. A290 (1990) 385
P. Achenbach, *et al.*, Nucl. Inst. Meth. A416 (1998) 357

PbF2 calorimeter performance

2019.12: Test experiment @ ELPH using 100~800 MeV e+ beam



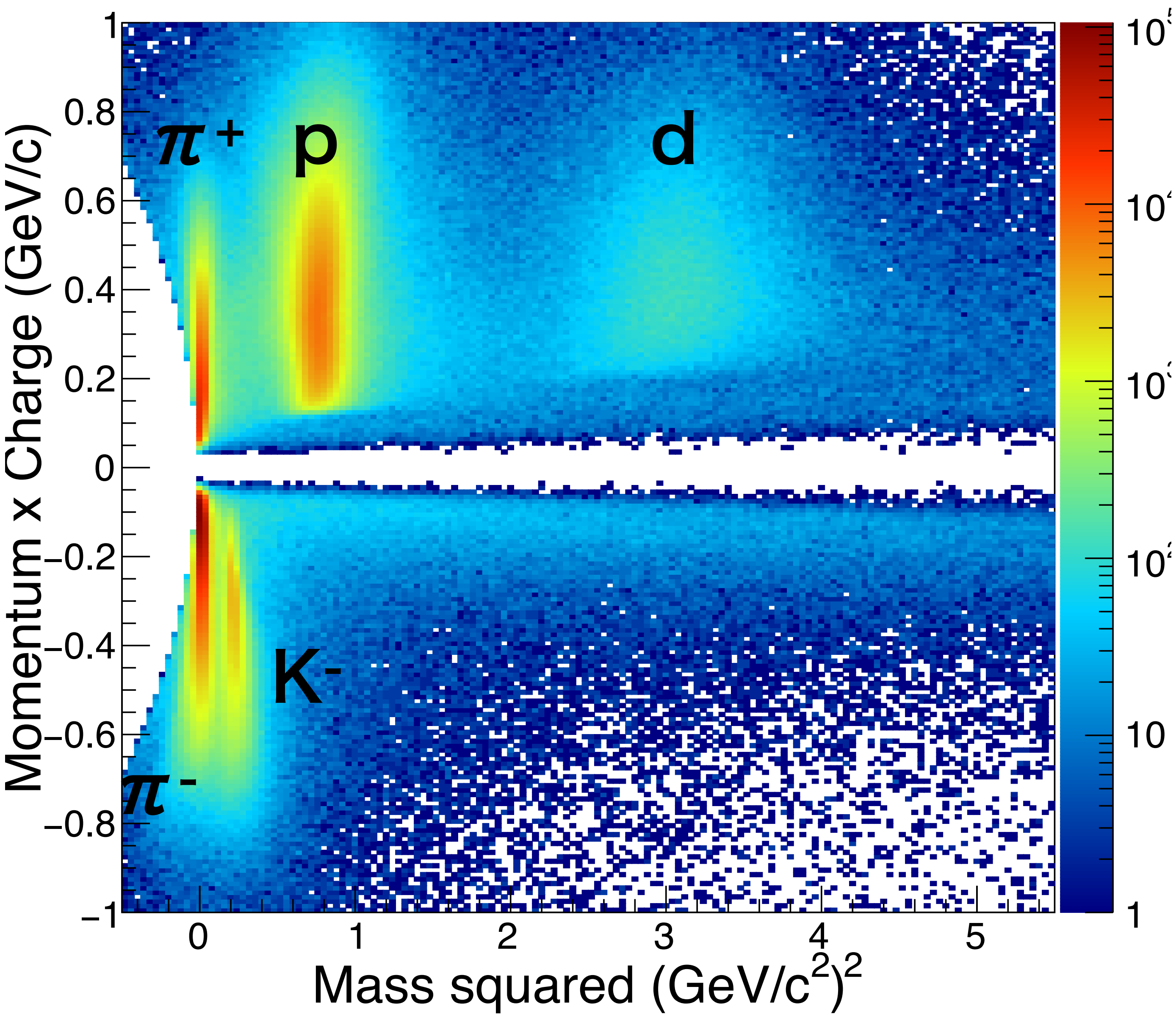
Response to 1 GeV/c π-/e- @ J-PARC



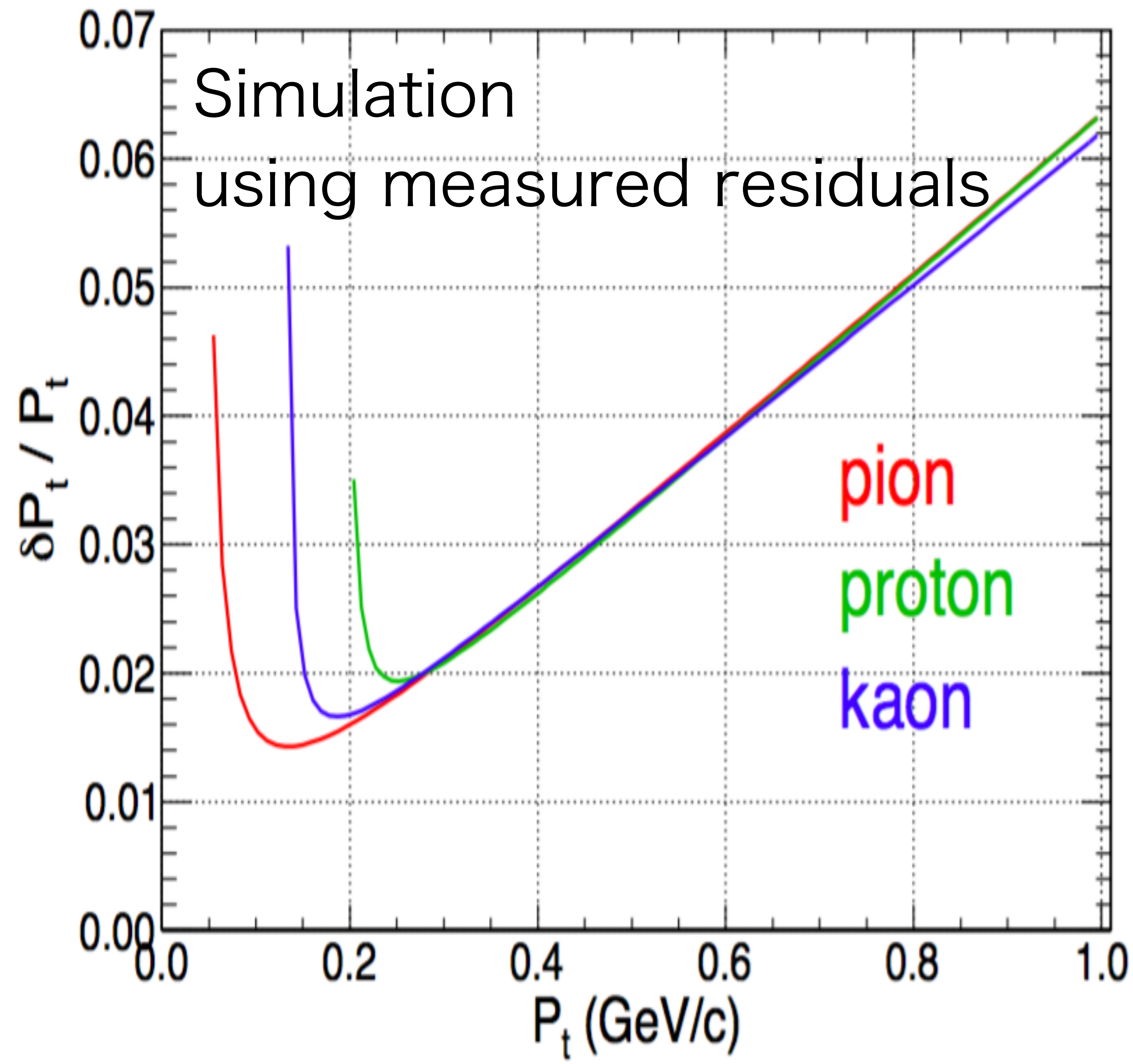
- good enough performance to tag high-energy gamma

Cylindrical detecter system

Particle ID

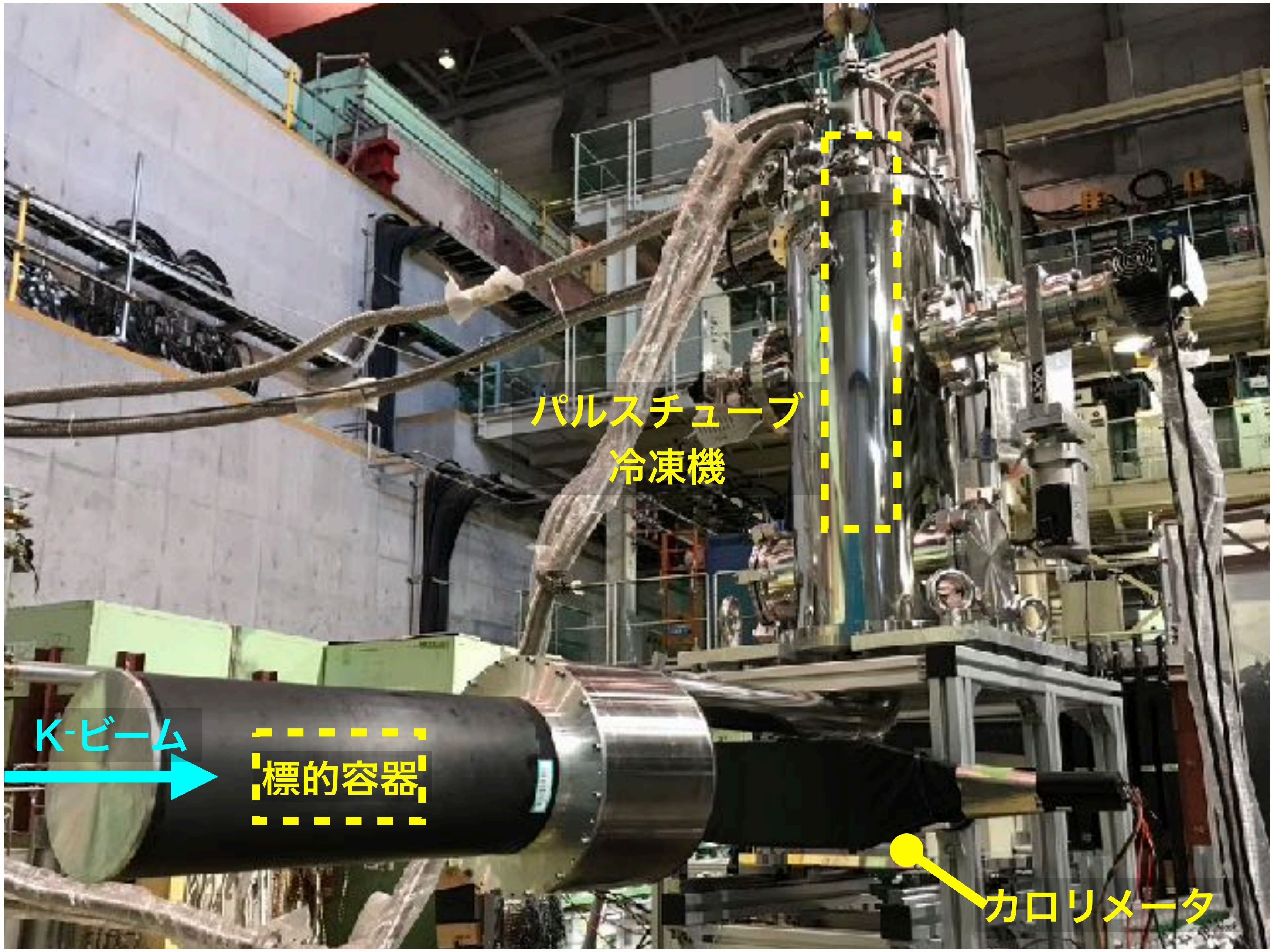


Single track resolution



- Well established system. used in E15(K-pp)/E31(L1405)
- Best resolution at around 0.1 ~ 0.15 GeV/c

無冷媒液体ヘリウム標的システム

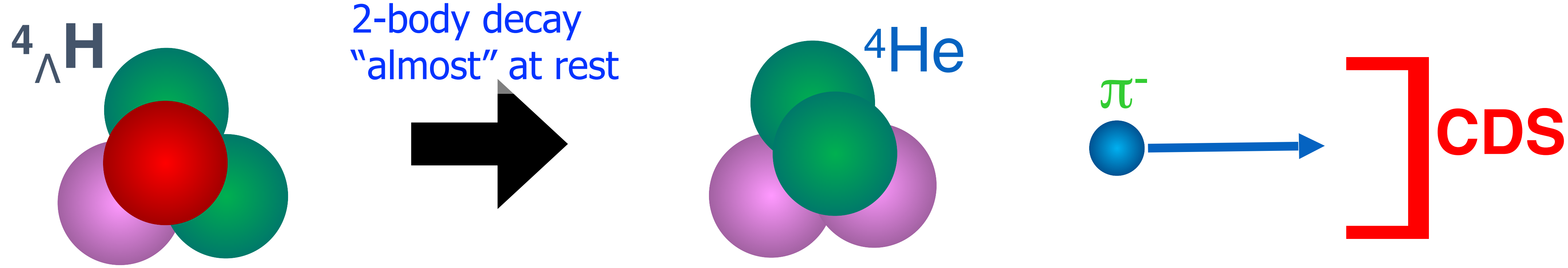


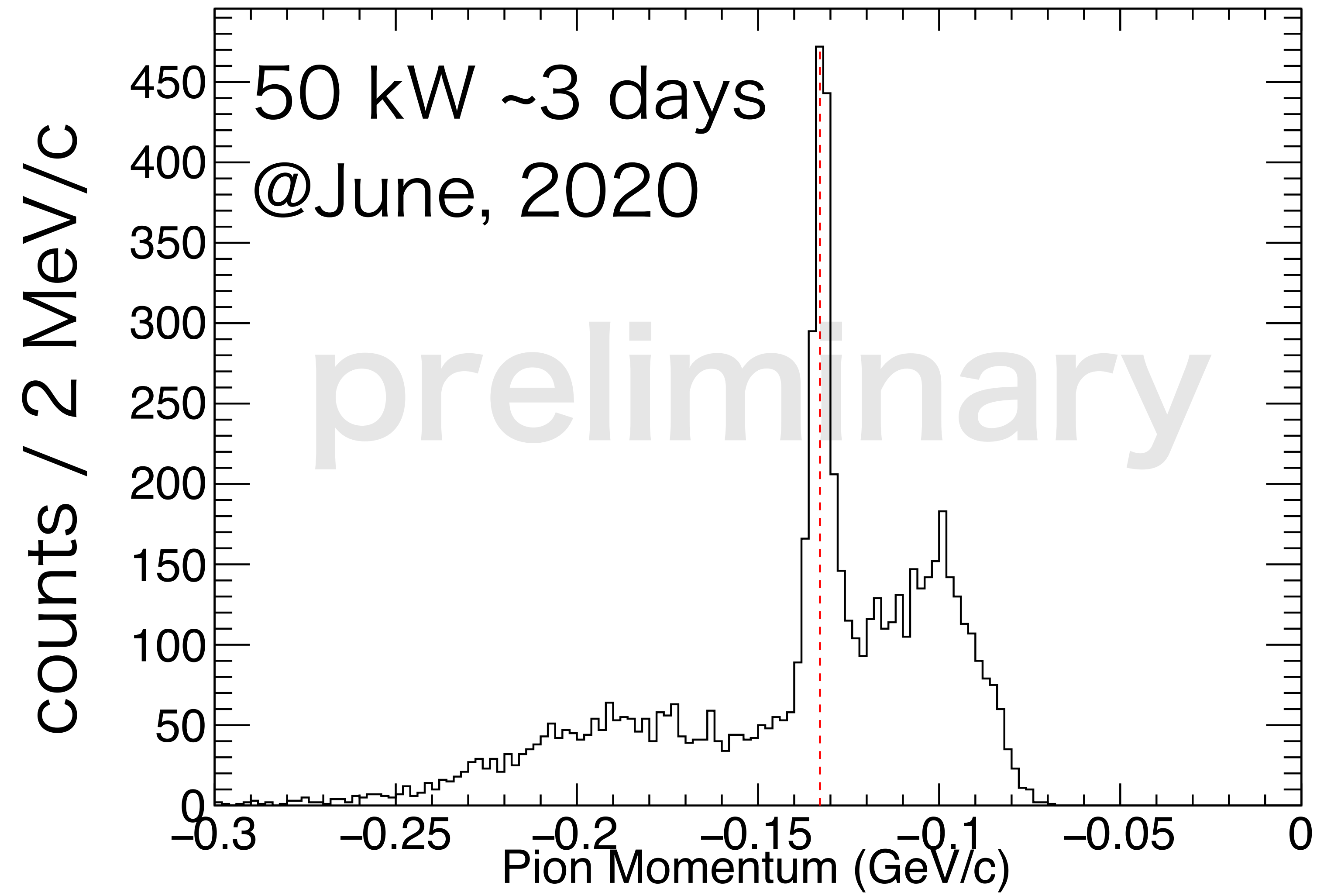
✓ 液体N_2/Heを用いたE15システム→パルスチューブ冷凍機を用いた無冷媒システムへ

✓ 到達温度 2.5~2.7K, 冷却開始から<48時間で^{3}He液化可能

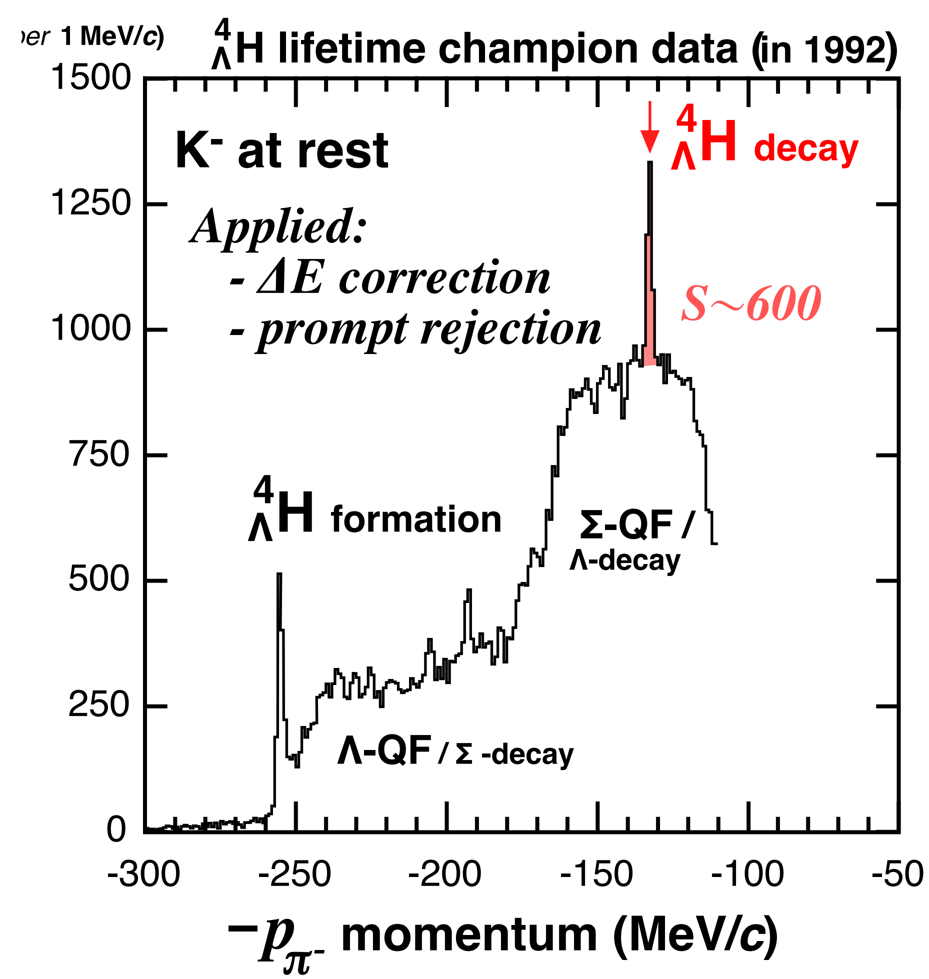
✓ T77/ E73 1stで実際に運用に成功

^{4}He data: Pion momentum spectrum





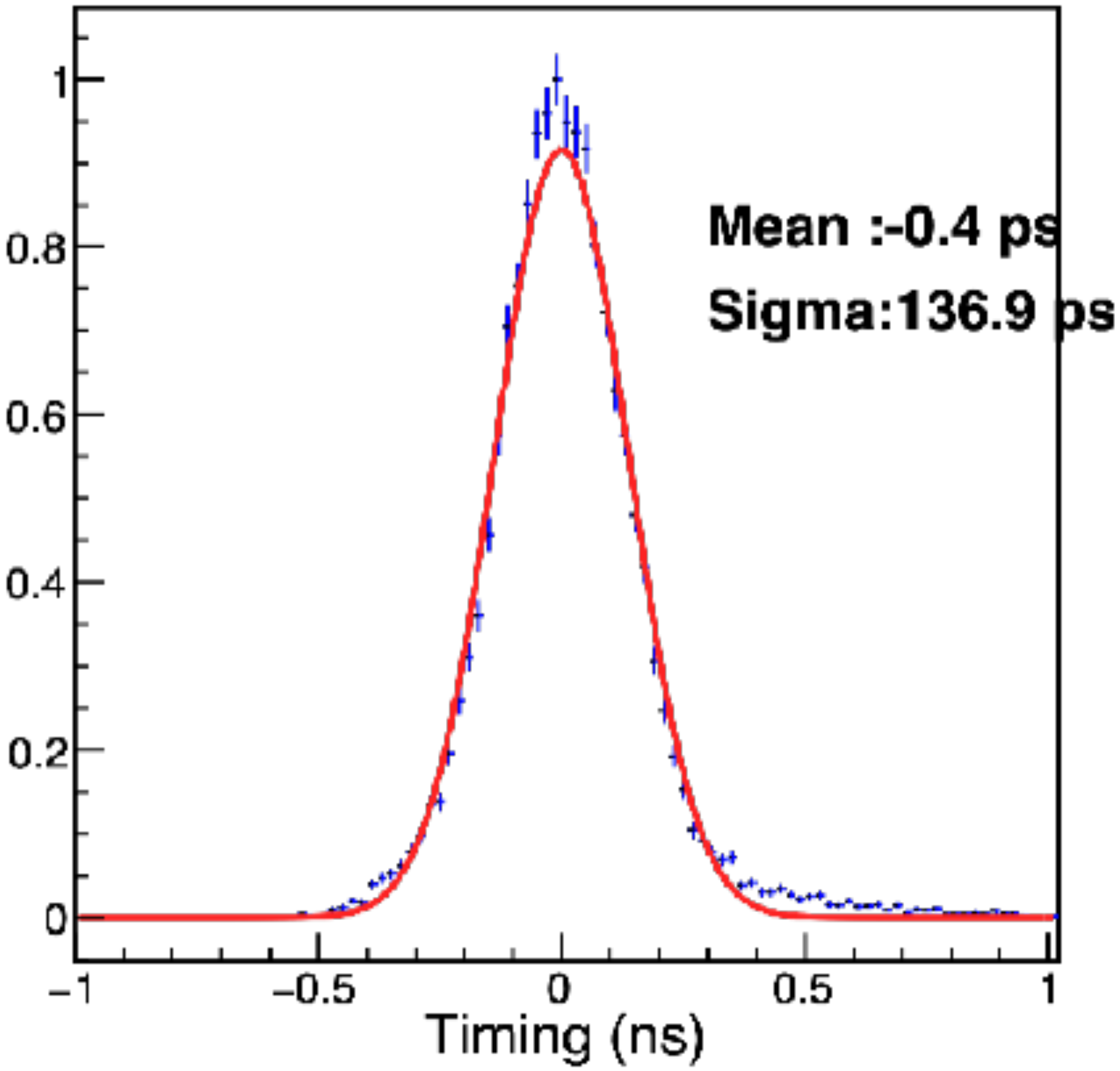
H. Outa, Nucl. Phys. A **585**, 109 (1995).



- H4L peak was clearly observed with expected background from quasi-free Y.
- x2 peak count, x10 S/N compared with the KEK experiment

^{4}He data: Timing spectrum

π scattering



H4L after sideband subtraction

statistical error < 10 ps

preliminary

- Detector timing response is well understood by π-scat. data.
- Need more study for the background subtraction.

^3He data

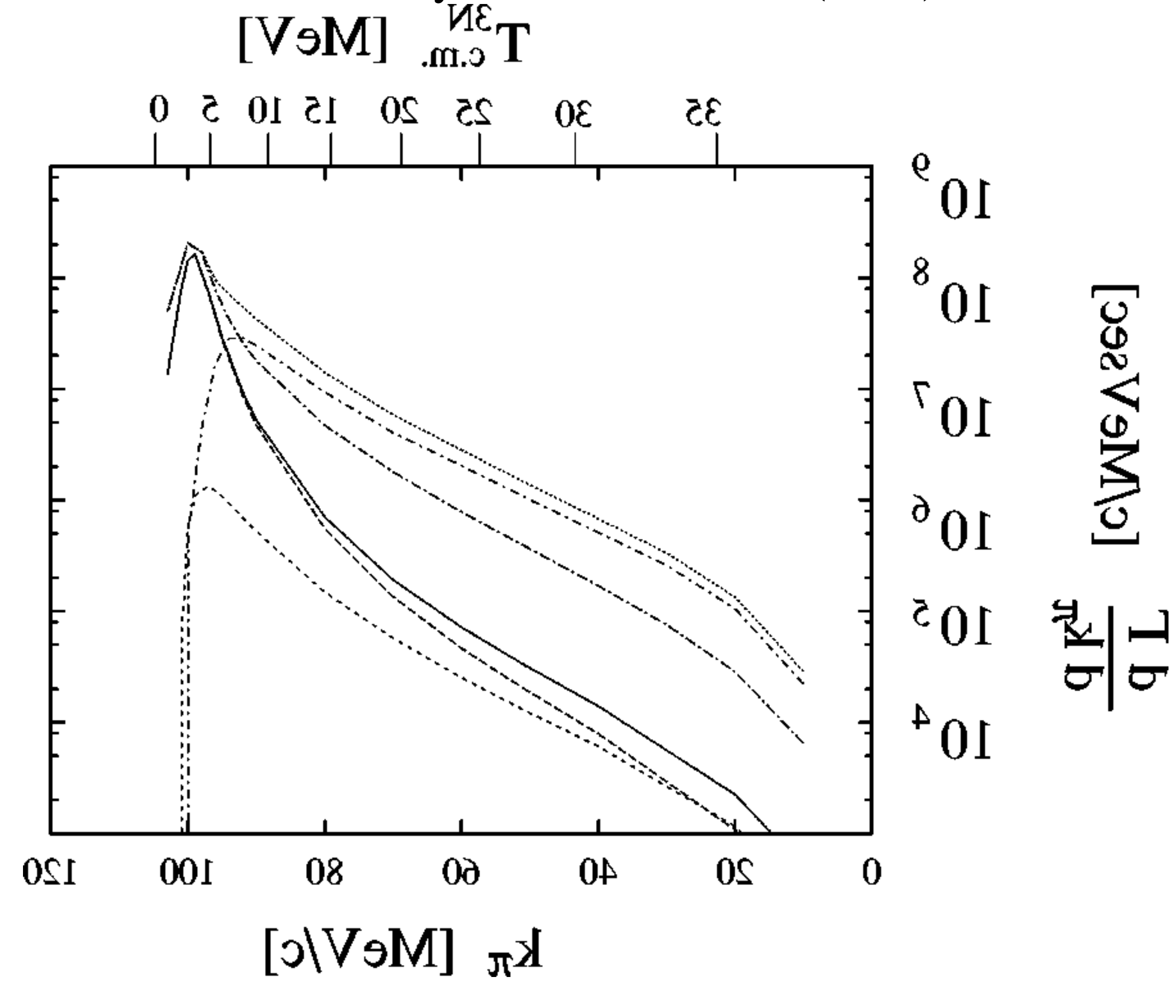
60 kW ~4 days beam
@May, 2021

Very preliminary

- Successfully observed the peak from 2 body decays.
- First direct confirmation of spin 1/2

^{3}He data

H. Kamada, *et al*., Phys. Rev. C**57**, 1595 (1998).



Very preliminary

QF-Σ-

QF-Λ/Σ0 just eye guides…

- 3-body decays are also observed. could be used for the life time evaluation
- We need careful study of the background shape

Plan for 2 years

- 2020.6: Feasibility demonstration with Helium-4 **done**
- 2021.5/6: Cross section measurement with Helium-3 **done**
    - Analysis (Ph.D thesis for T. Akaishi)
    - (necessary modifications of the setup (not all):
        - beam-line trigger counter
        - PbF2 readout
        - vertex fiber tracker
        - target radiation shield
        - etc…)
- 2022.10 or later (after long shutdown):
    - Lifetime measurement of ${}^{3}_{\Lambda}H$ (> 1000 events)

Summary

- Hypertriton provides a benchmark for hypernuclear physics.
- We have explored a new method to investigate the neutron-rich hypernuclei by K- beam & gamma-ray tagging
- We will provide unique information
  - Cross section (x Branching ratio) of ${}^{4}_{\Lambda}H$, ${}^{3}_{\Lambda}H$ in (K^{-}, π^{0})
  - Lifetime with highest precision and different systematics
    ${}^{4}_{\Lambda}H$: < 10 (stat.), < 10 (syst.) ps
    ${}^{3}_{\Lambda}H$: ~20 (stat.), < 20 (syst.) ps
  - (two-body decay ratio)