K^-pp bound-state search via the ^{3}He(K^-,n) reaction at 1 GeV/c

- Introduction / physics
- Setup & performance
- Latest results: ^{3}He(K^-,n), ^{3}He(K^-,p), ^{3}He(K^-,Λp)n

Tadashi Hashimoto for the J-PARC E15 collaboration

J-PARC E15 collaboration

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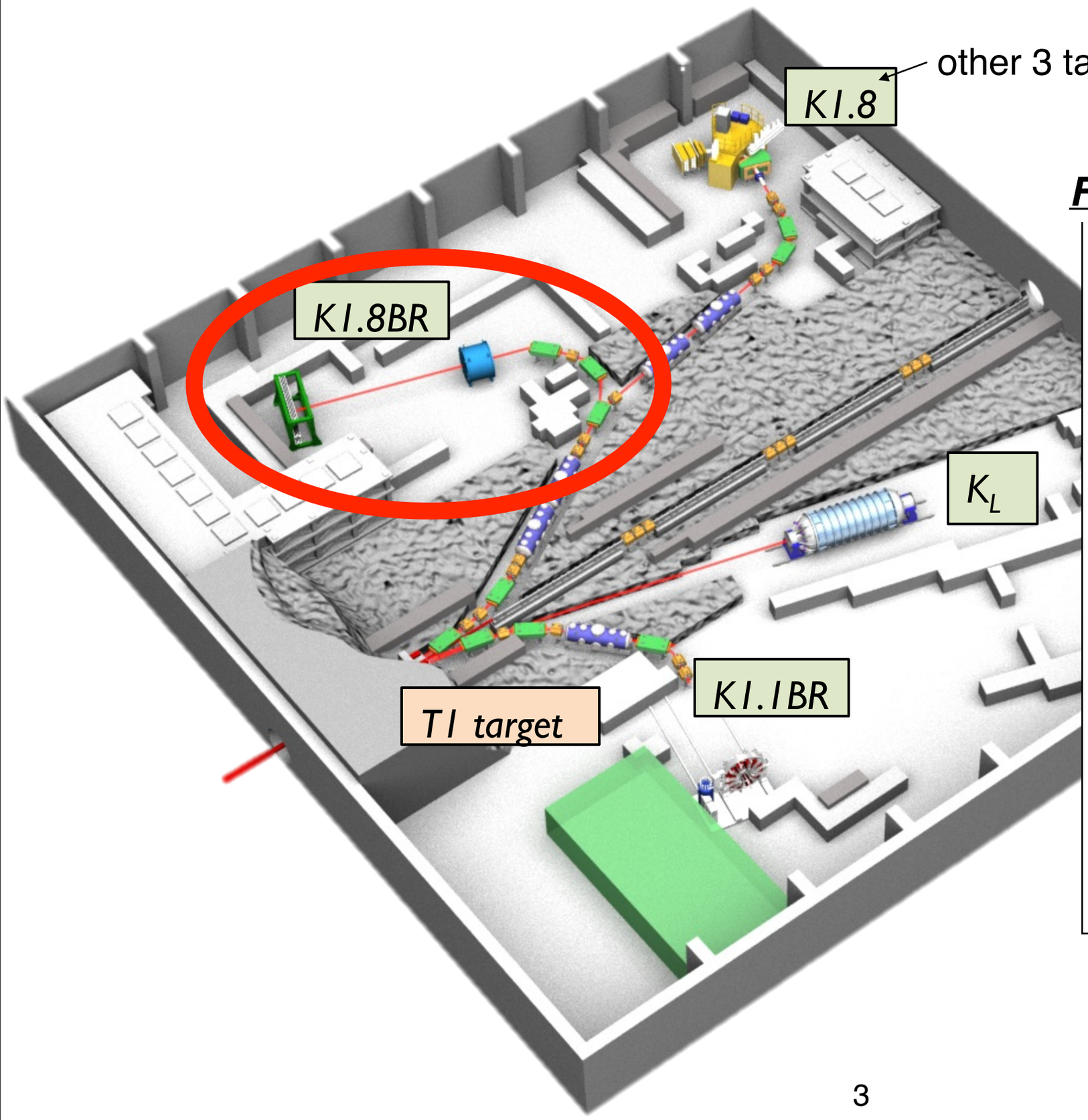
K1.8BR beam-line & experimental area



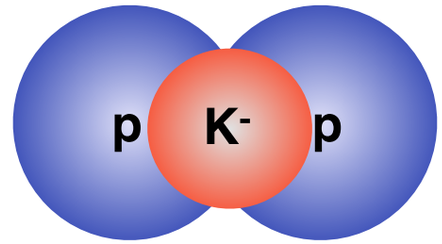
Features of K1.8BR

- **Low *p* kaon beam**
  - **< 1.1 GeV/c**
  - **stopped K**
- **Multi-purpose detector system**
  - **Neutron TOF counter**
  - **Beam analyzer**
  - **CDS**
  - **Cryogenic target (liquid H_2 / D_2 / $^{3/4}$He)**

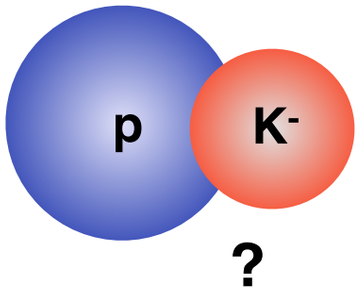
Experiments at K1.8BR

- **Three stage-2 approved experiments to investigate the $K^{bar}N$ interaction**

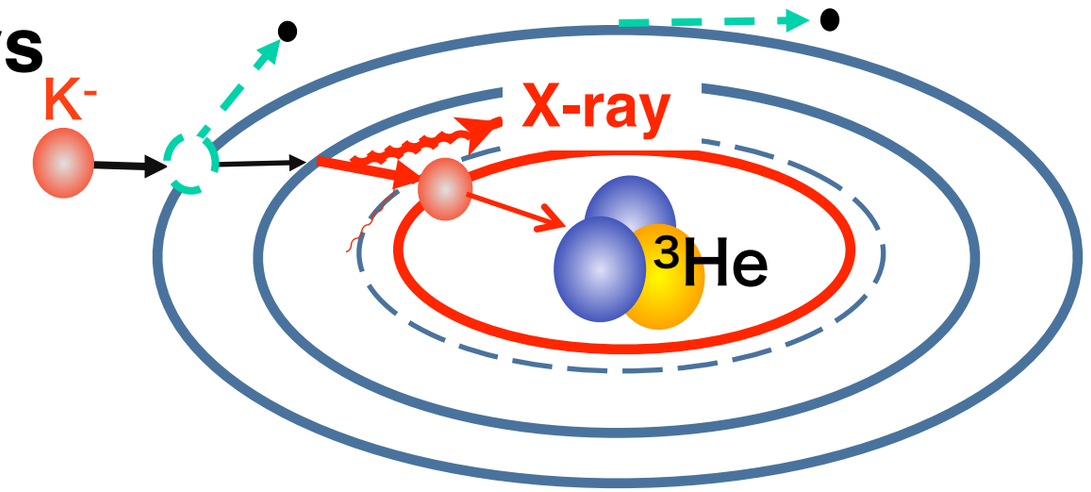
- **E15: Search for K^-pp via $^3He(K^-, n)$**



- **E31: Spectroscopic study of Λ(1405) via $d(K^-,n)$**

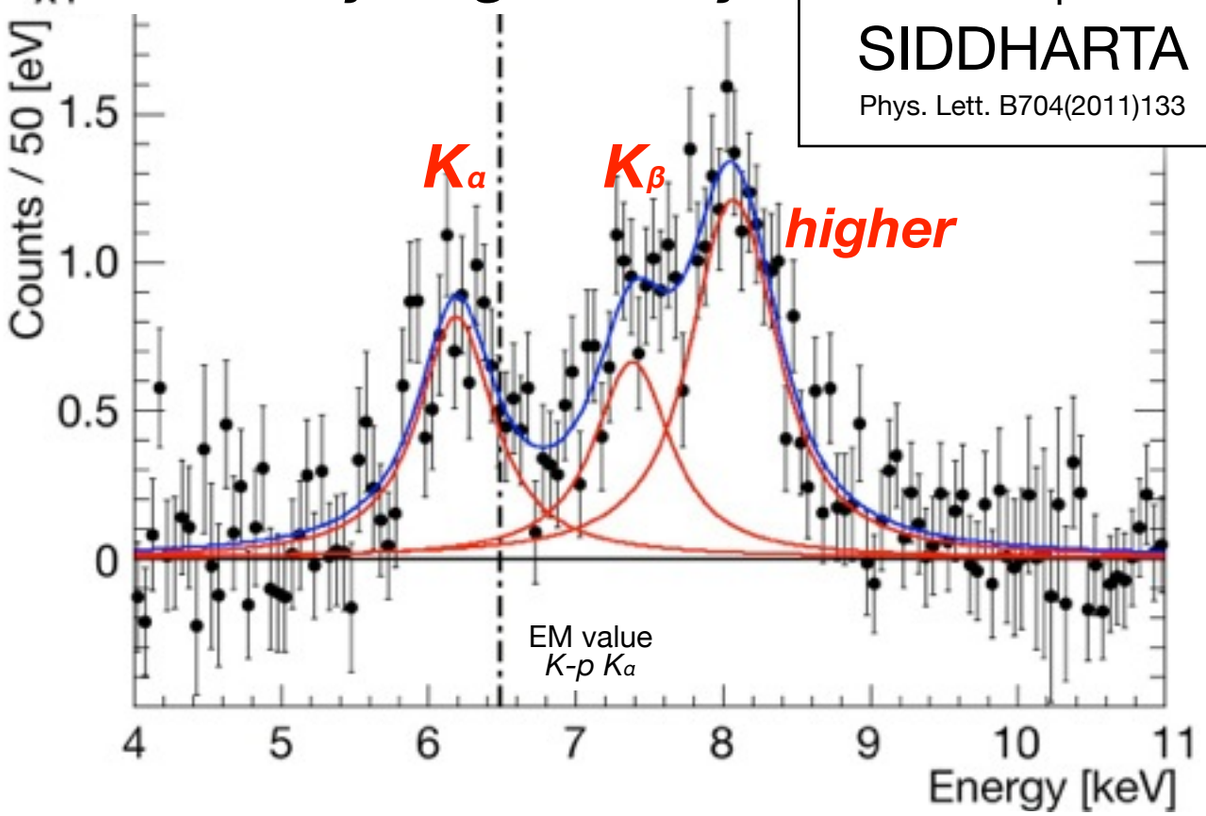


- **E17: Kaonic $^3He/^4He$ atom X-rays**



K^{bar}N interaction

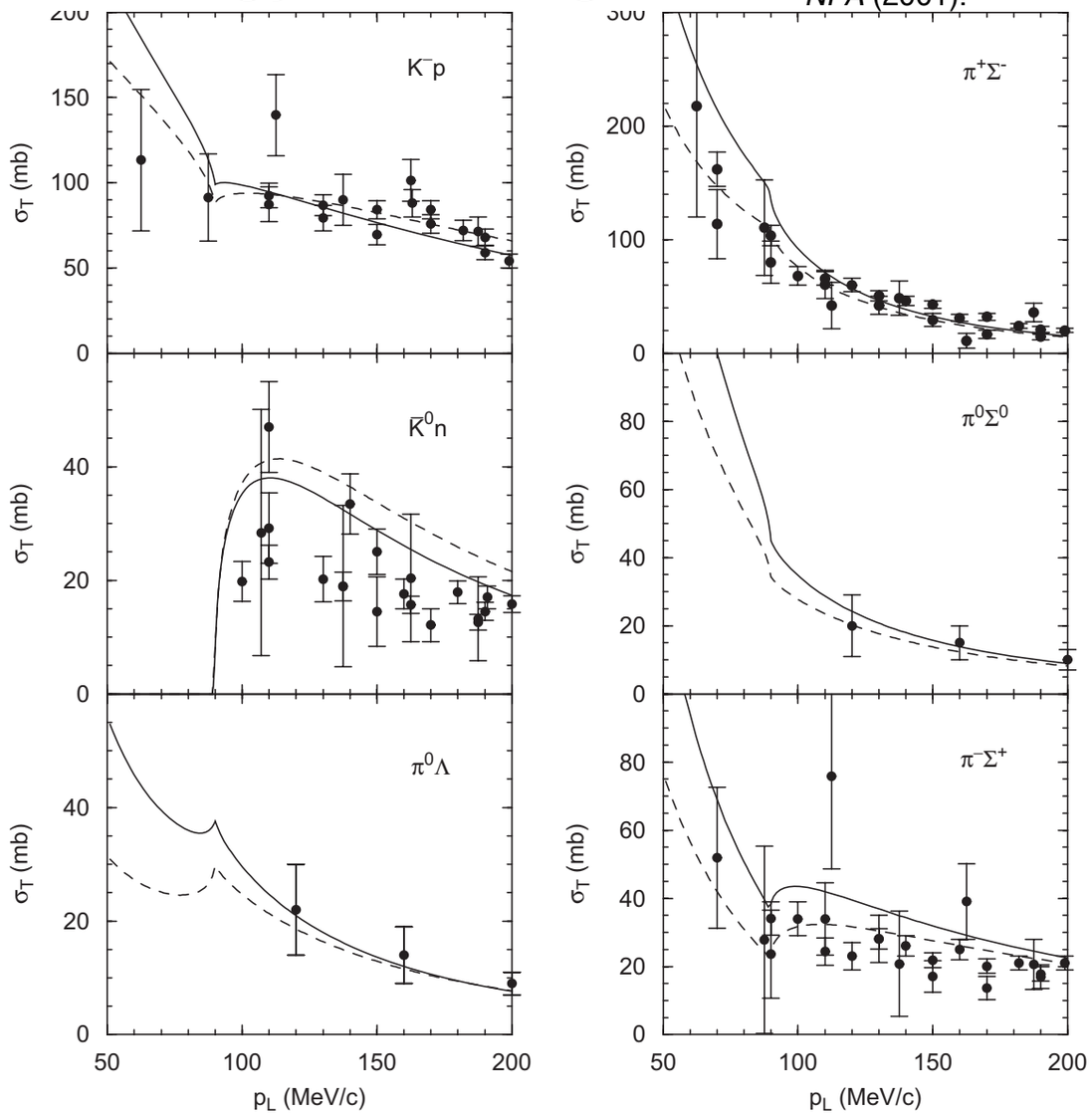
Kaonic hydrogen X-ray



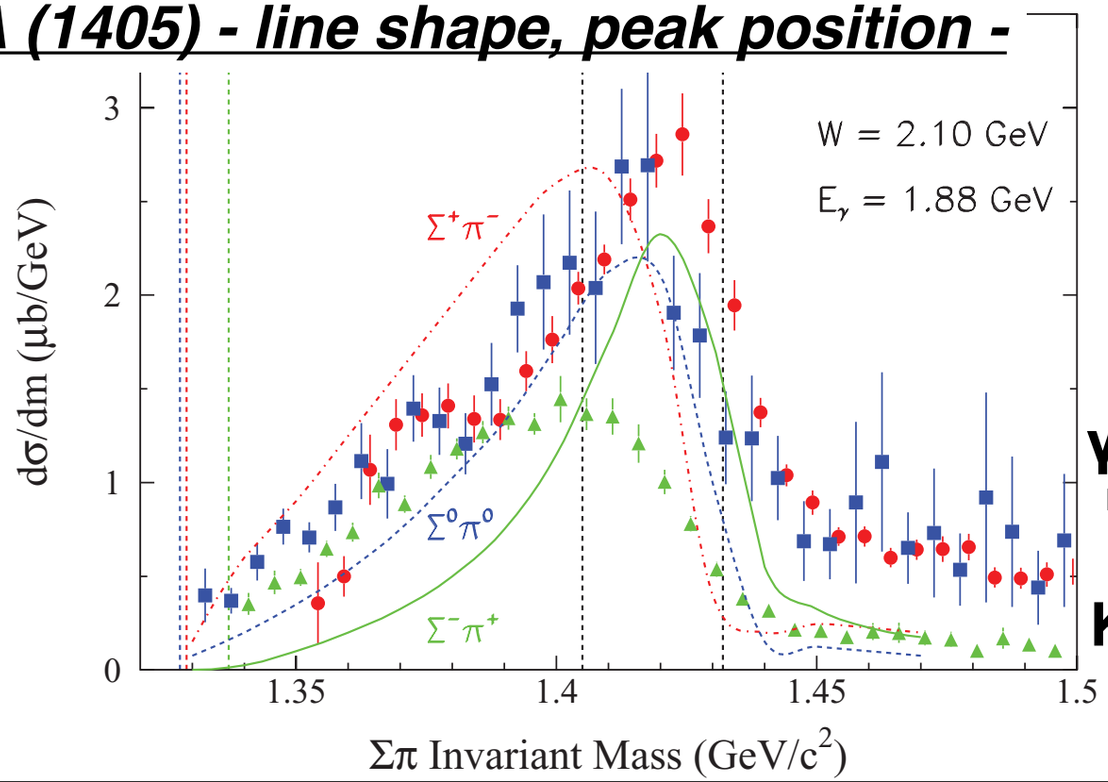
the latest experiment
SIDDHARTA
Phys. Lett. B704(2011)133

Low-energy scattering data

A. Cieplý *et al.* *NPA* (2001).



Λ (1405) - line shape, peak position -



γ-induced

K. Moriya et. al., Phys. Rev C87, 035206 (2013).

K-induced by E31

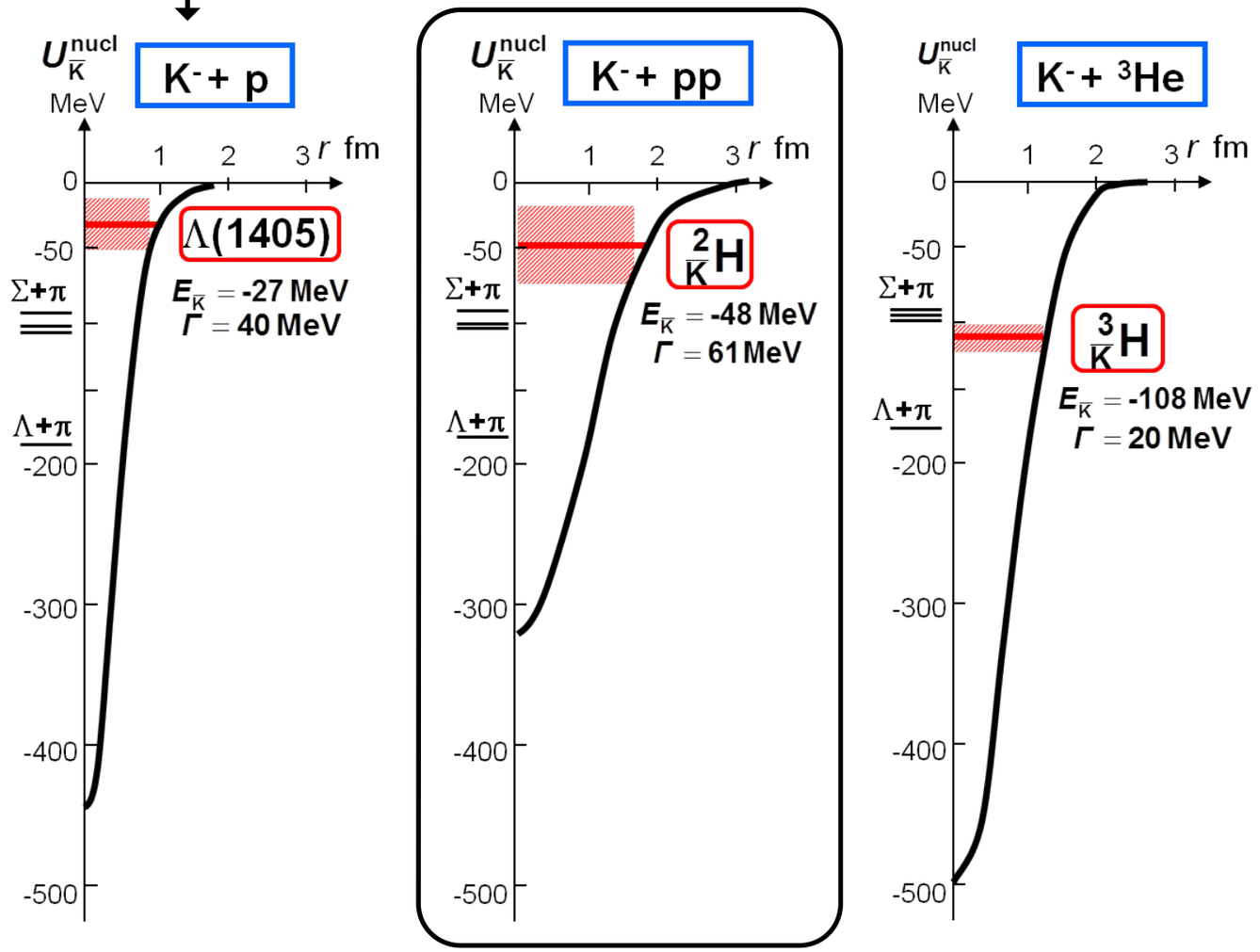
Attractive interaction (I=0) has been established.

But how strong??

Kaonic nuclear bound state

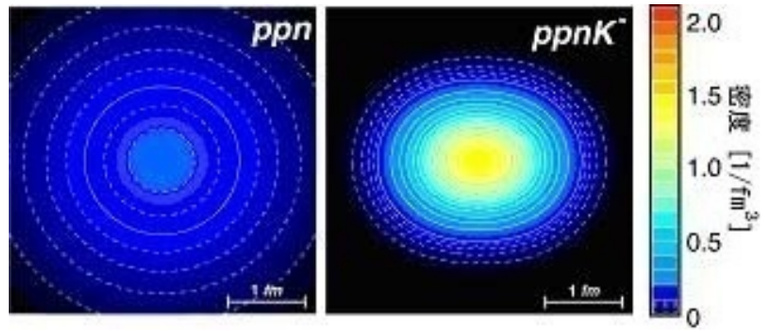
What will happen when anti-kaon is embedded in nucleus?

Assumption !



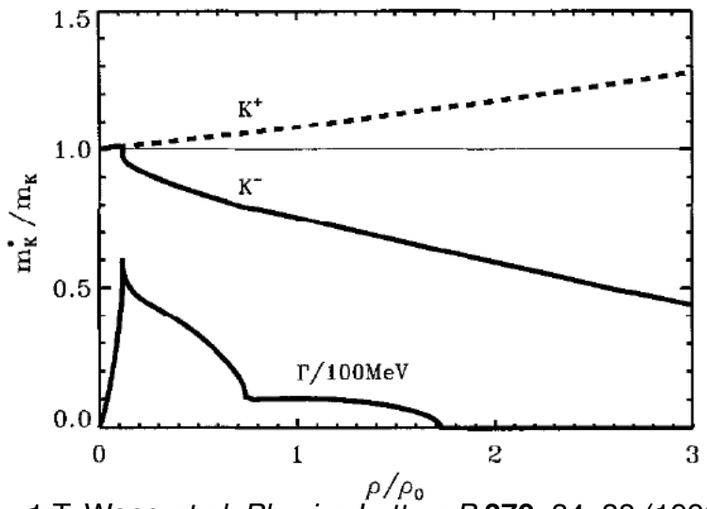
1.Y. Akaishi and T. Yamazaki. *Phys. Rev. C* **65,** 044005 (2002).
2.T. Yamazaki and Y. Akaishi. *Physics Letters B* **535,** 70–76 (2002).

dense matter ?



T.Yamazaki, A.Dote, Y.Akiaishi, PLB587, 167 (2004).

Kaon in nuclear medium?



1.T. Waas *et al. Physics Letters B* **379,** 34–38 (1996).

K⁻pp : [K^bar(NN)_I=1]_I=1/2
the lightest kaonic nucleus

K^-pp few-body calculations

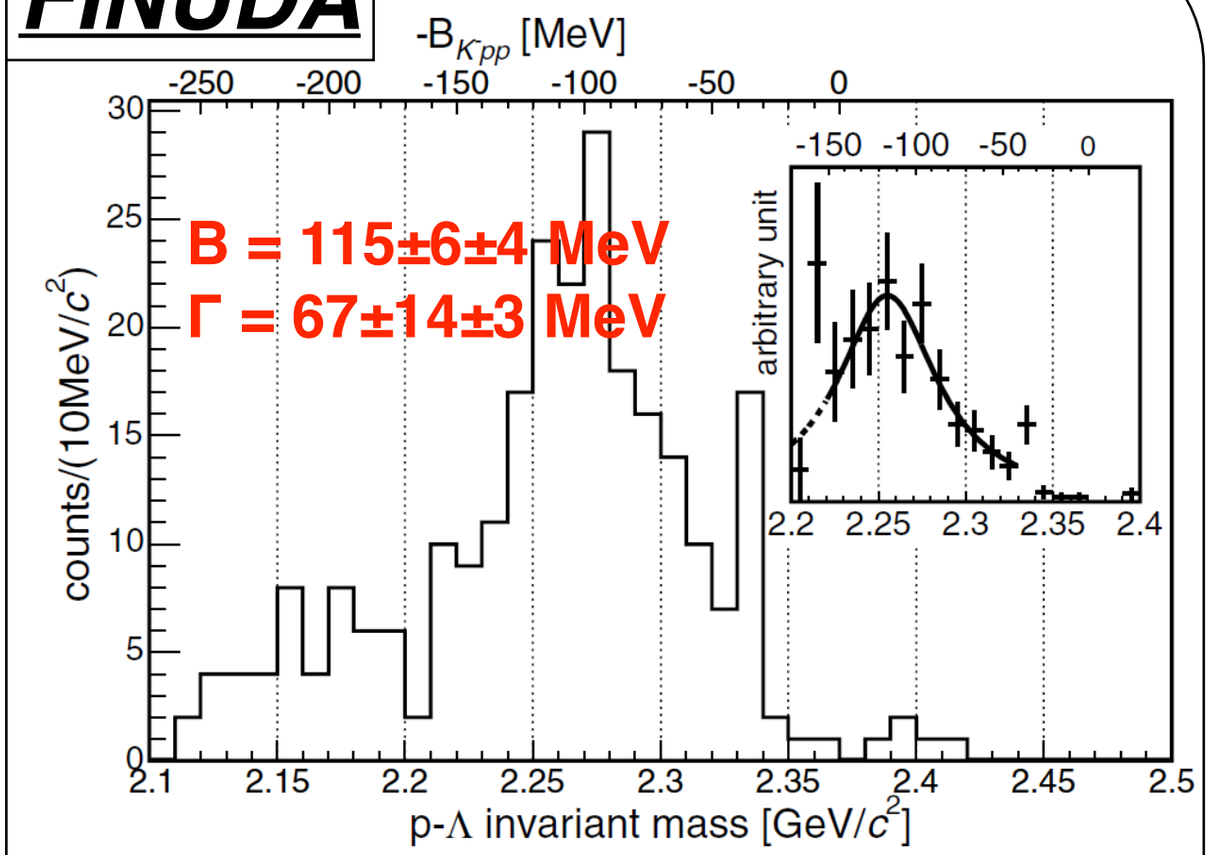
chiral & energy dependent	Method	B.E.[MeV]	Γ[MeV]
N. Barnea, A. Gal, E.Z. Liverts(2012)	var.	16	41
A. Dote, T. Hyodo, W. Weise(2008,09)	var.	17-23	40-70
Y. Ikeda, H. Kamano, T. Sato(2010)	Fad.	9-16	34-46

Λ(1405) ansatz	Method	B.E.[MeV]	Γ[MeV]
T. Yamazaki, Y. Akaishi(2002)	var.	48	61
N.V. Shevchenko, A. Gal, J. Mares(2007)	Fad.	50-70	90-110
Y. Ikeda, T. Sato (2007,2009)	Fad.	60-95	45-80
S. Wycech, A.M. Green (2009)	var.	40-80	40-85

- **All calculations agree on the existence of the bound state**
- **Model of the $K^{bar}N$ interaction makes large difference**

Claims of K⁻pp candidates

FINUDA



1.M. Agnello *et al. Phys. Rev. Lett.* **94,** 212303 (2005).

back-to-back Λp pair
from stopped K⁻ on ^{6}Li, ^{7}Li, ^{12}C

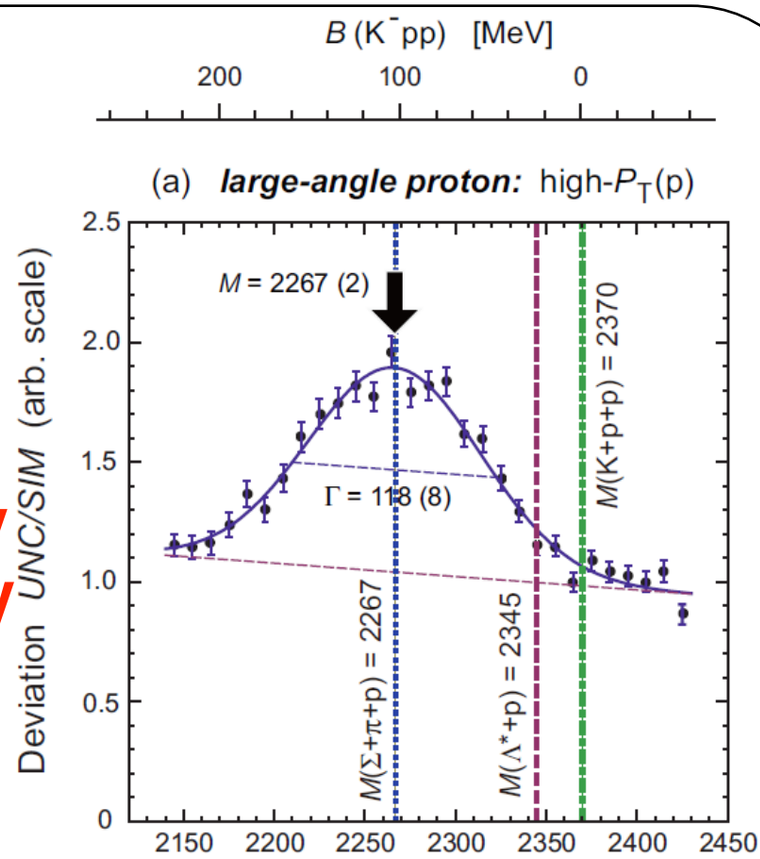
2NA contributions?

$$K^-"NN" \to \Sigma^0 p, \quad \Sigma^0 \to \Lambda\gamma \qquad K^-"NN"N \to \Sigma NN, \quad \Sigma N \to \Lambda N$$

DISTO

@T_p=2.85 GeV

B = 105±2±5 MeV
Γ = 118±8±10MeV



1.P. Kienle *et al. Eur. Phys. J. A* **48,** 183 (2012).
2.T. Yamazaki *et al. Phys. Rev. Lett.* **104,** 132502 (2010).

Exclusive pp→("K⁻pp"K⁺)→ΛpK⁺ channel

T_p dependence?

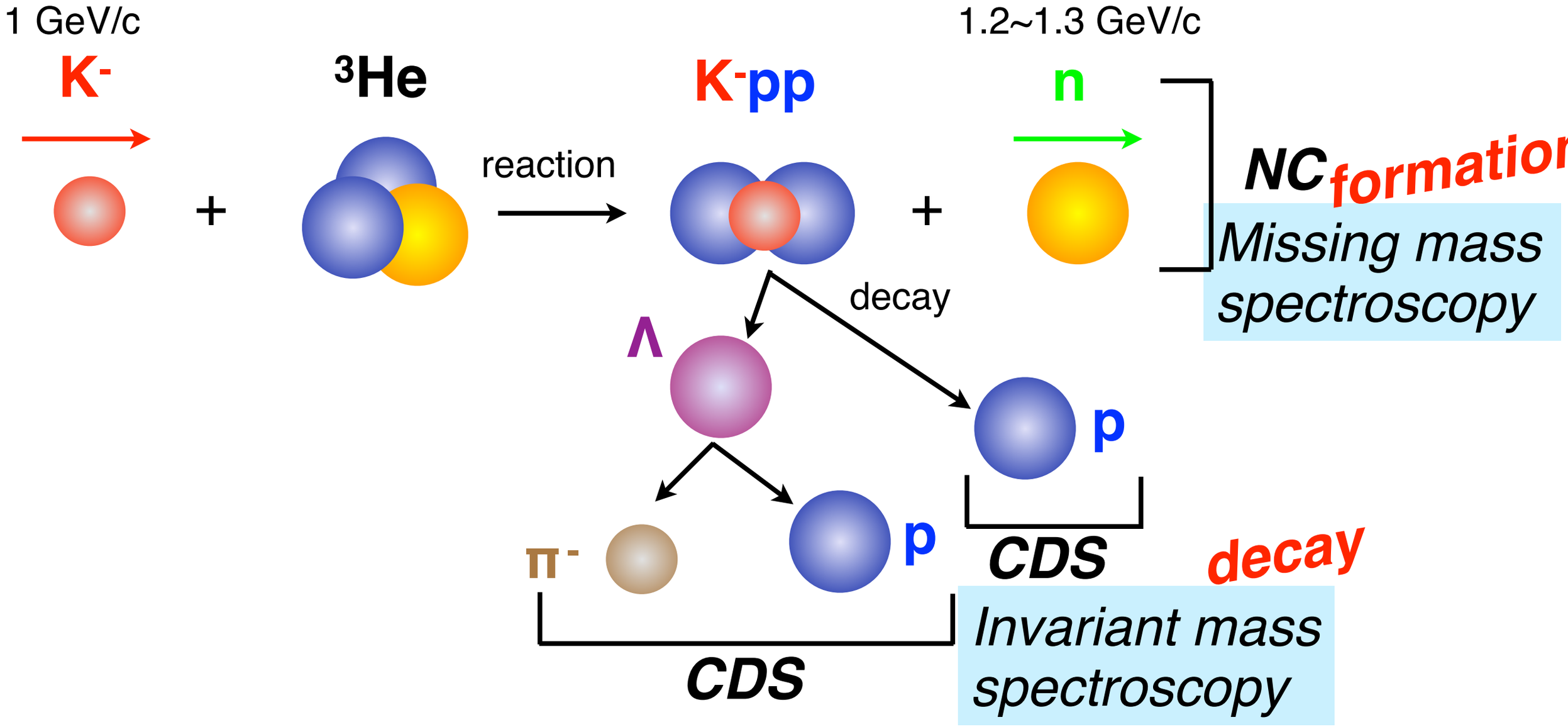
Consistency with HADES@T_p=3.5 GeV ?

N* contribution? $p + p \to p + N^*, \quad N^* \to K^+\Lambda$

Interpretations are still arguable…

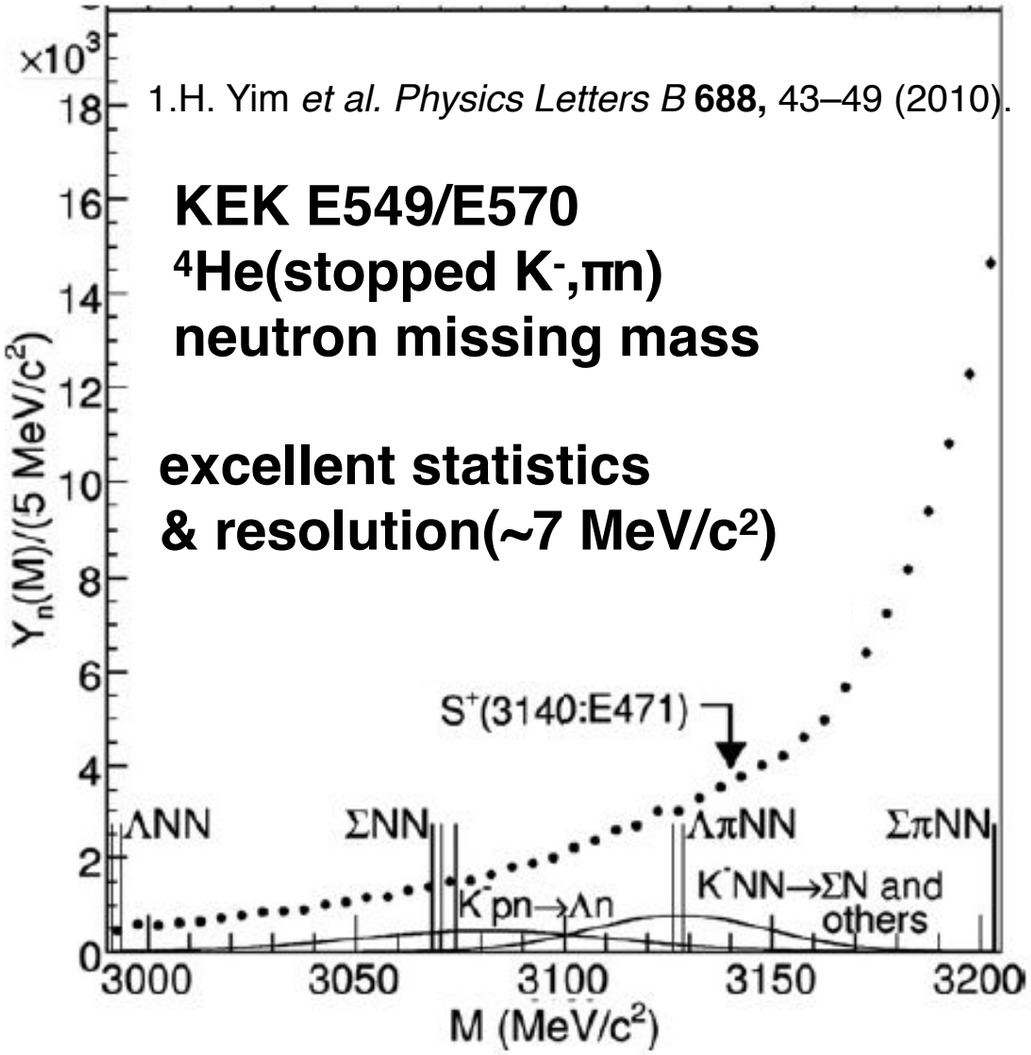
J-PARC E15 experiment

A search for the simplest kaonic nucleus K^-pp

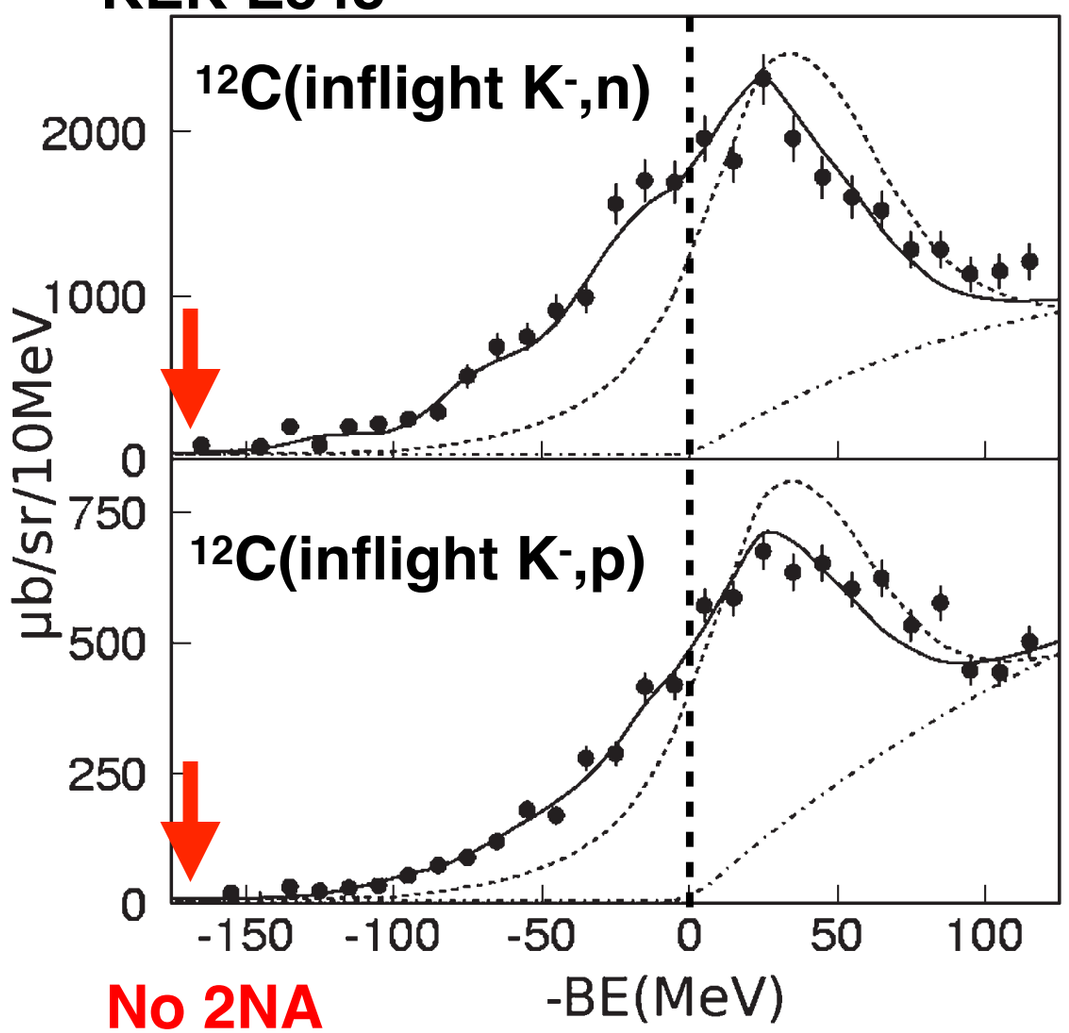


A kinematically complete experiment with J-PARC intense beam

in-flight vs. stopped kaons



1.T. Kishimoto *et al. Progress of Theoretical Physics* **118,** 181–186 (2007).

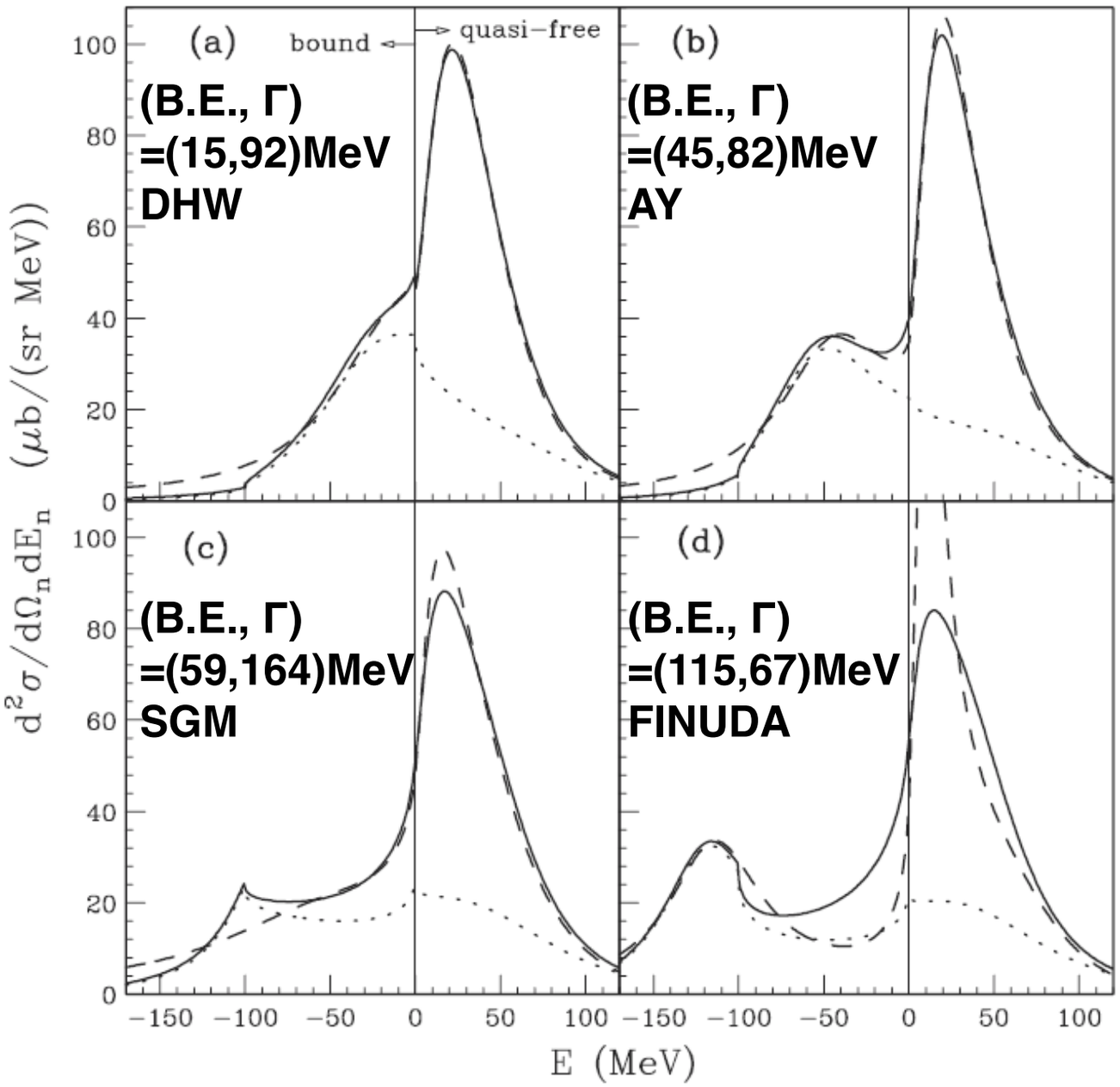


- **In-flight reaction**
  - **suppresses multi-nucleon absorption reactions**
  - **kinematically separates multi-NA & hyperon decay**

Low background condition is expected !!

Spectral calculation by Koike&Harada

$K^- + {}^3He \rightarrow$ "K^-pp" + n @ P_K=1GeV/c, θ_{lab}=0°



- **DWIA using Green's function method**
- **Phenomenological potential**

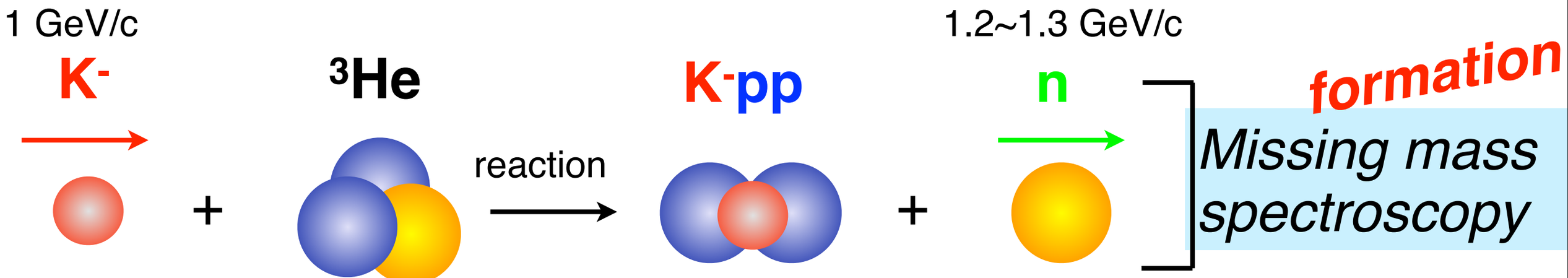
$$U^{\mathrm{opt.}}_{K^- - pp}(r) = (V_0 + i\, W_0\, f(E))\ \exp\left[-(r/b)^2\right]$$

phase space factor

- **~mb/sr cross section in bound region**
- **observed as a distinct peak in the DISTO/FINUDA case.**

1.T. Koike and T. Harada. *Phys. Rev. C* **80,** 055208 (2009).
2.T. Koike and T. Harada. *Physics Letters B* **652,** 262–268 (2007).

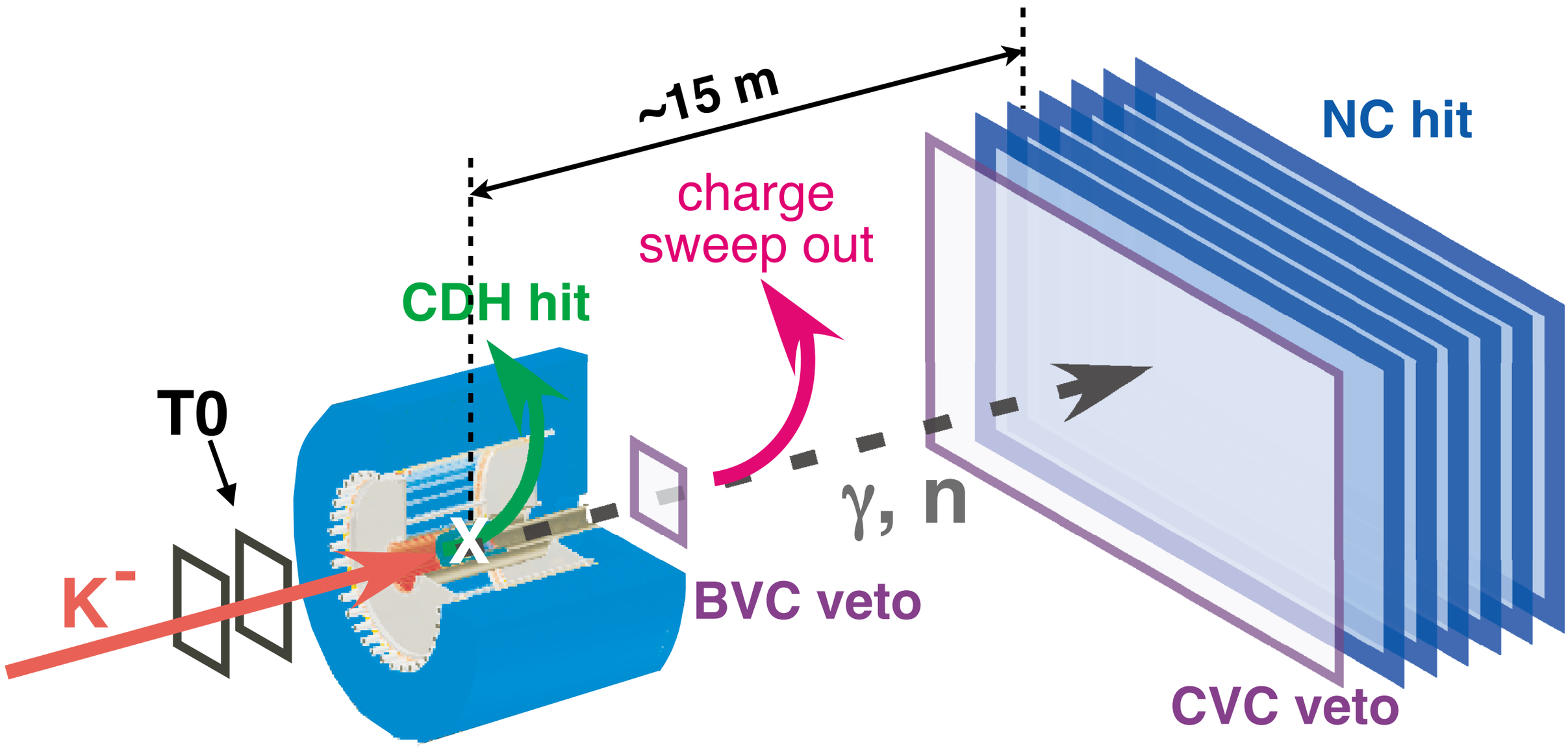
J-PARC E15 1st stage physics run



- Focus on the missing-mass measurement
  - ^{3}He(K$^-$,n)X semi-inclusive analysis
  - ^{3}He(K$^-$,p)X semi-inclusive analysis
  - Hint of exclusive ^{3}He(K$^-$,Λp)n events
- First physics data taking in May, 2013
  - 24 kW x 4 days, ~ 5 x 10^9 kaons on ^{3}He
  - < 1% of full proposal (270 kW x 40 days)

Setup & Performance

Principle of the $^{3}He(K^{-},n)$ measurement



- **Kaon beam** analysis :
  select single-beam events & reconstruct beam momentum
- **Neutron** analysis:
  T0-NC TOF with vertex information provided by the **CDS**

J-PARC K1.8BR spectrometer

beam dump

beam sweeping magnet

liquid ^{3}He-target system

CDS

beam line spectrometer

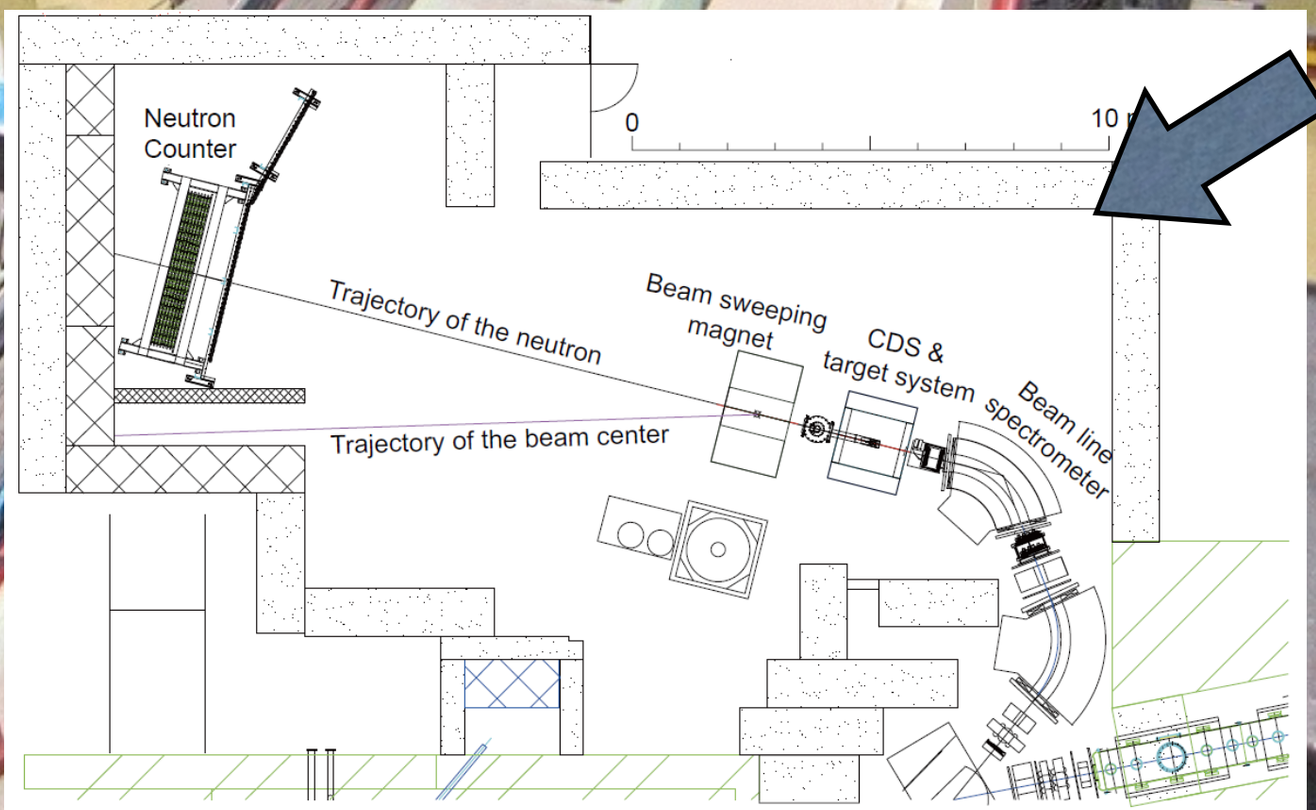
K-

γ, n

p

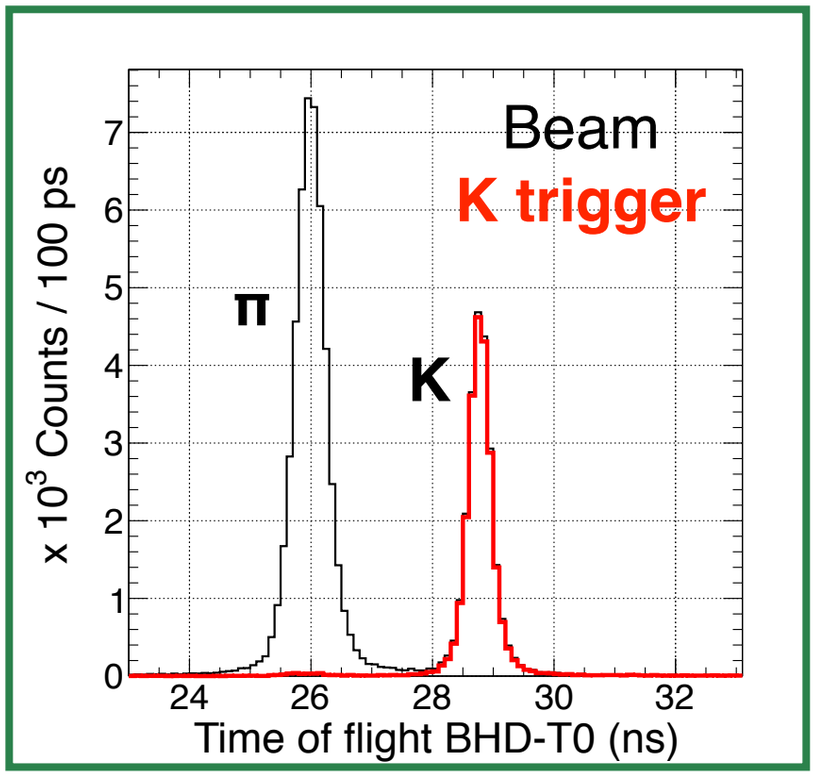
15m

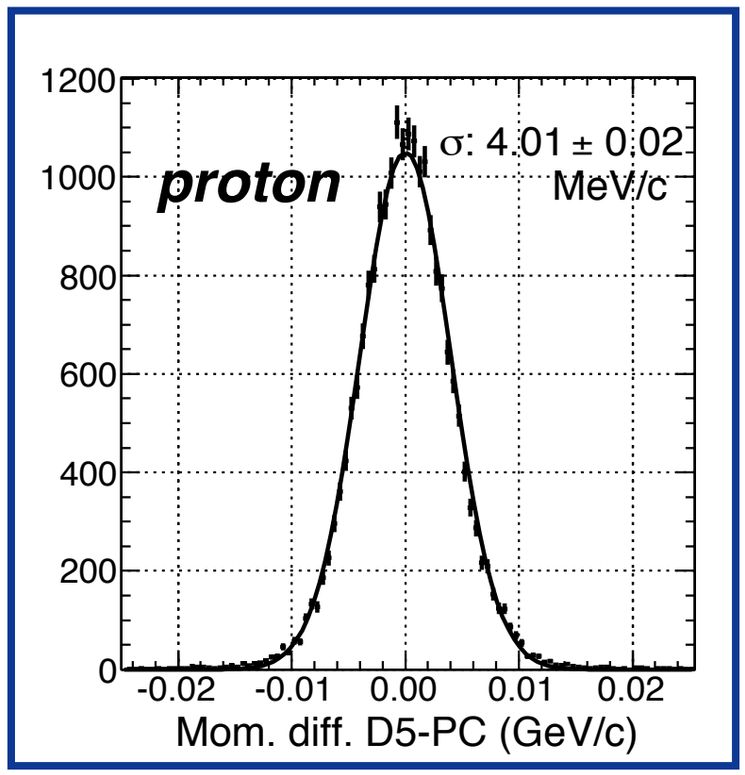
neutron counter
charge veto counter
proton counter



K. Agari et. al., PTEP 2012, 02B011

Kaon beam line

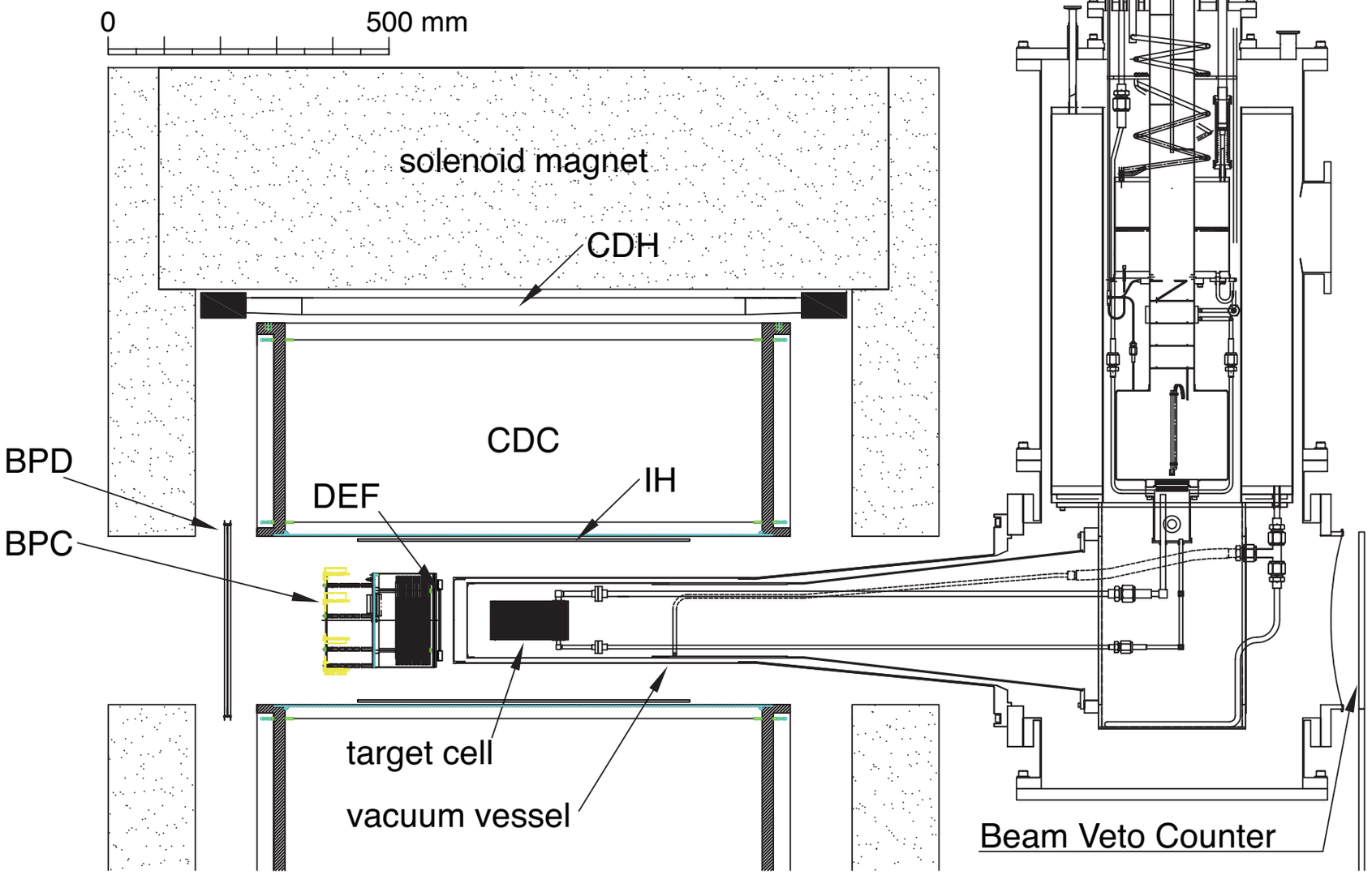


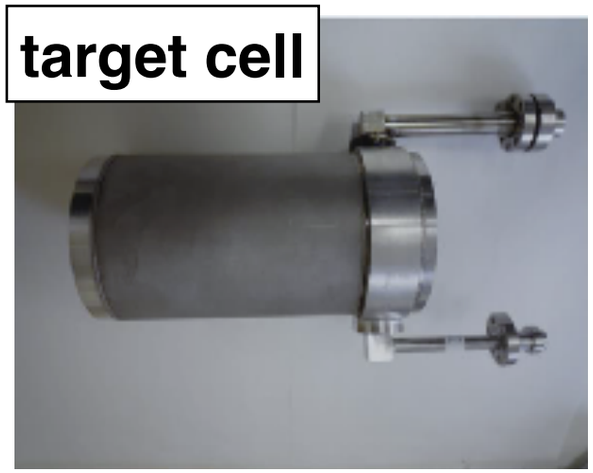


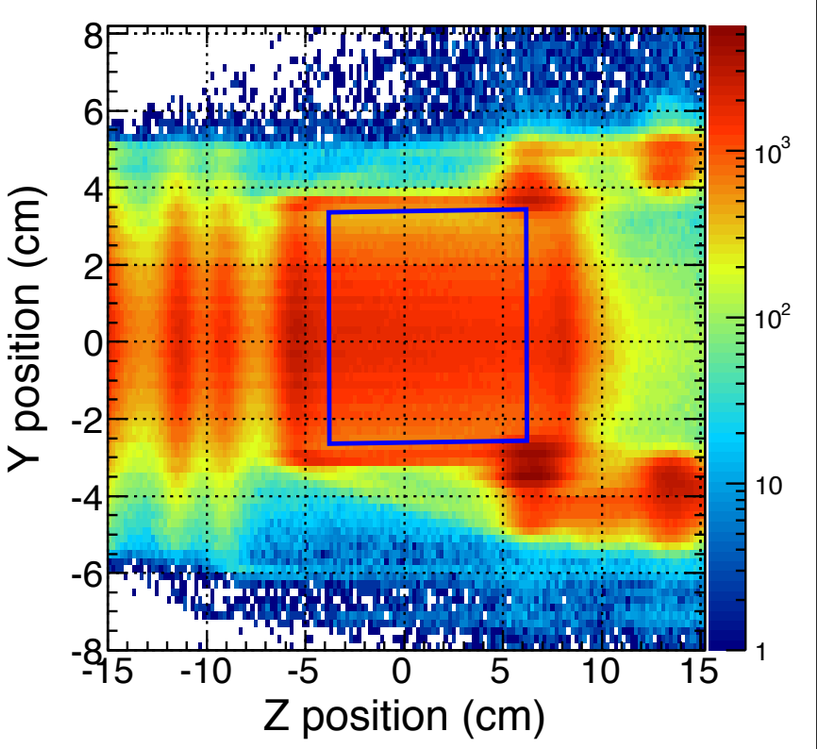
$\sigma_{p\_beam} \sim 2$ MeV/c @ 1 GeV/c

@ 24 kW
kaon/spill : 150k
K/π ratio : 0.45

Cylindrical Detector System (CDS)

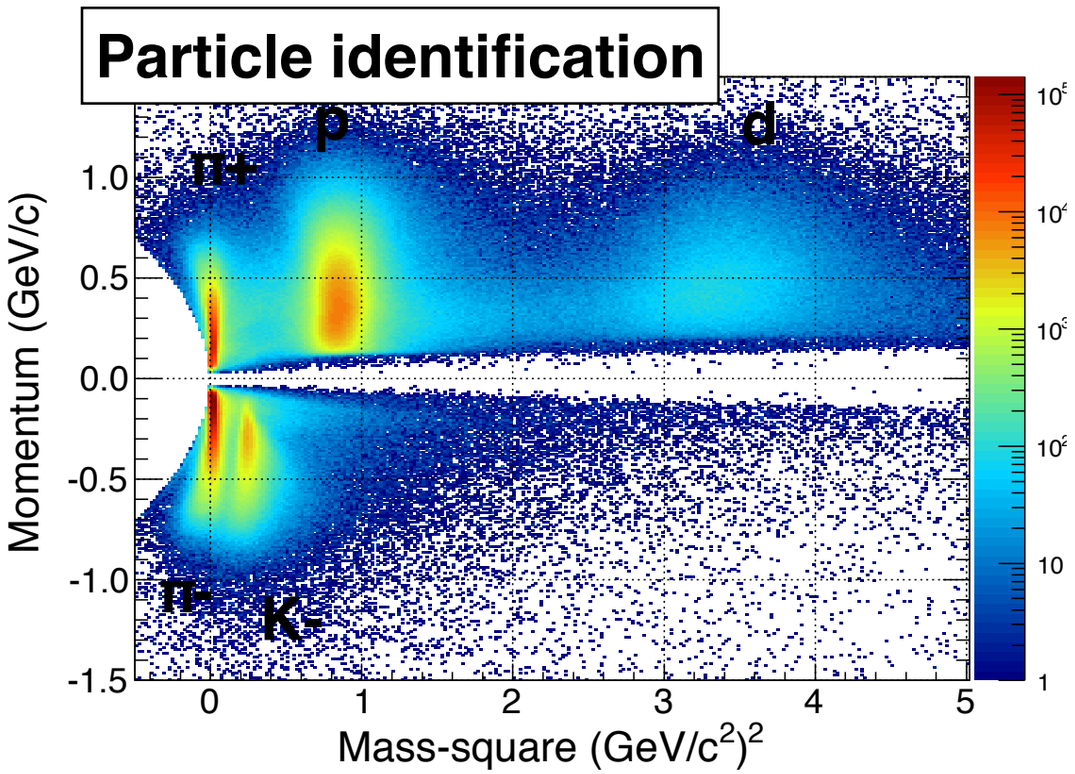


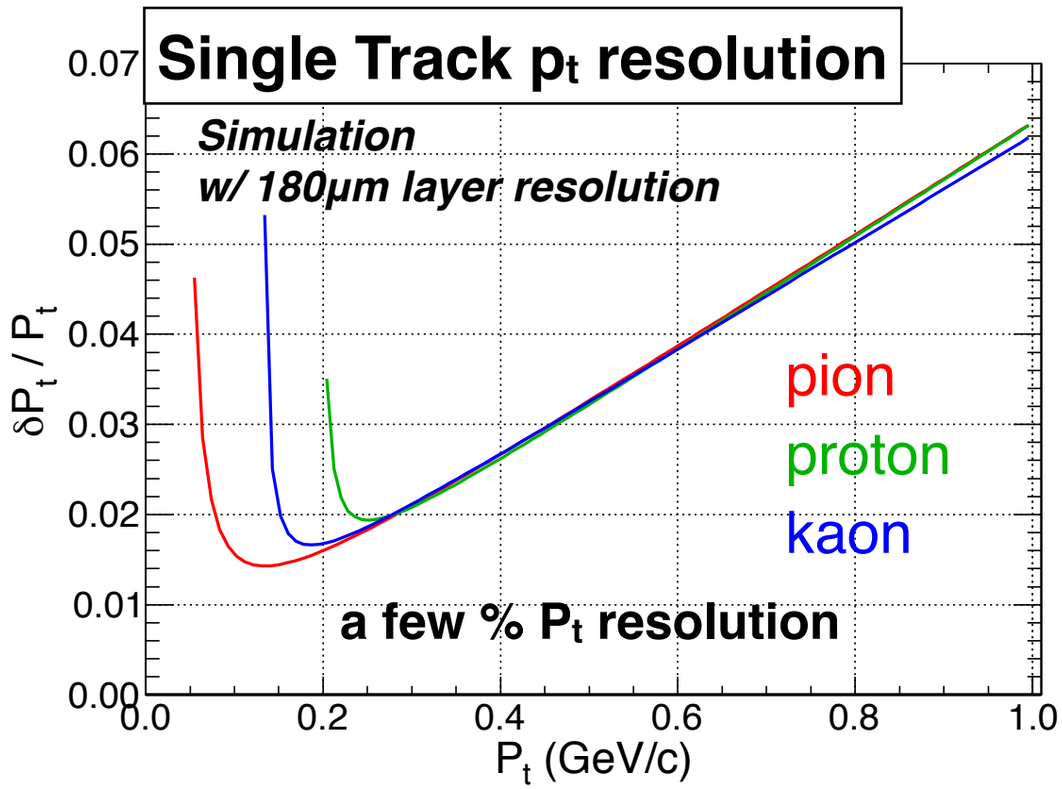


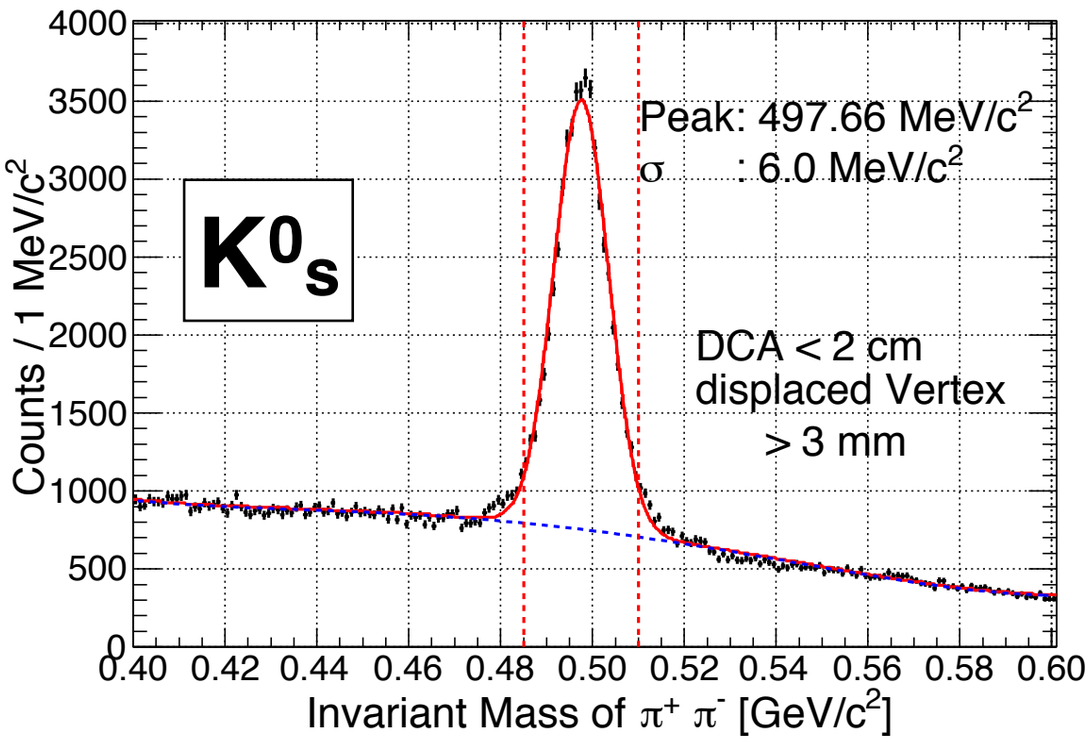


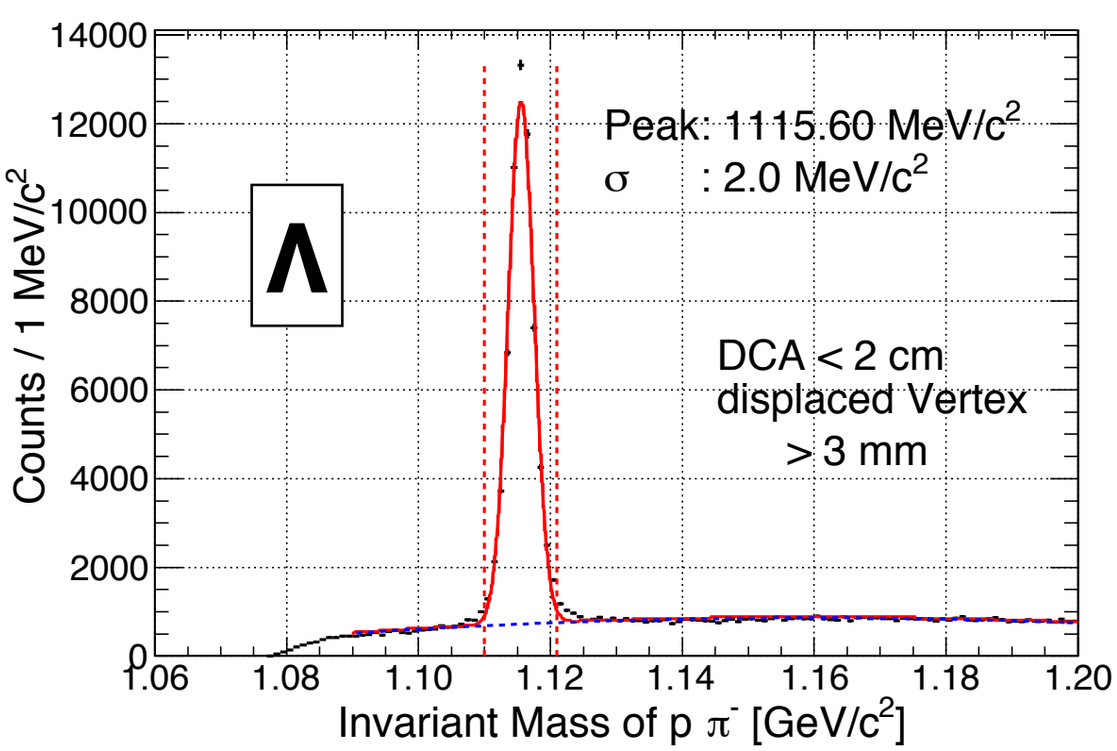
- **CDC : Vertex reconstruction with BPC track**
- **CDH : Trigger & PID, 54°<θ <126°**

CDS performance

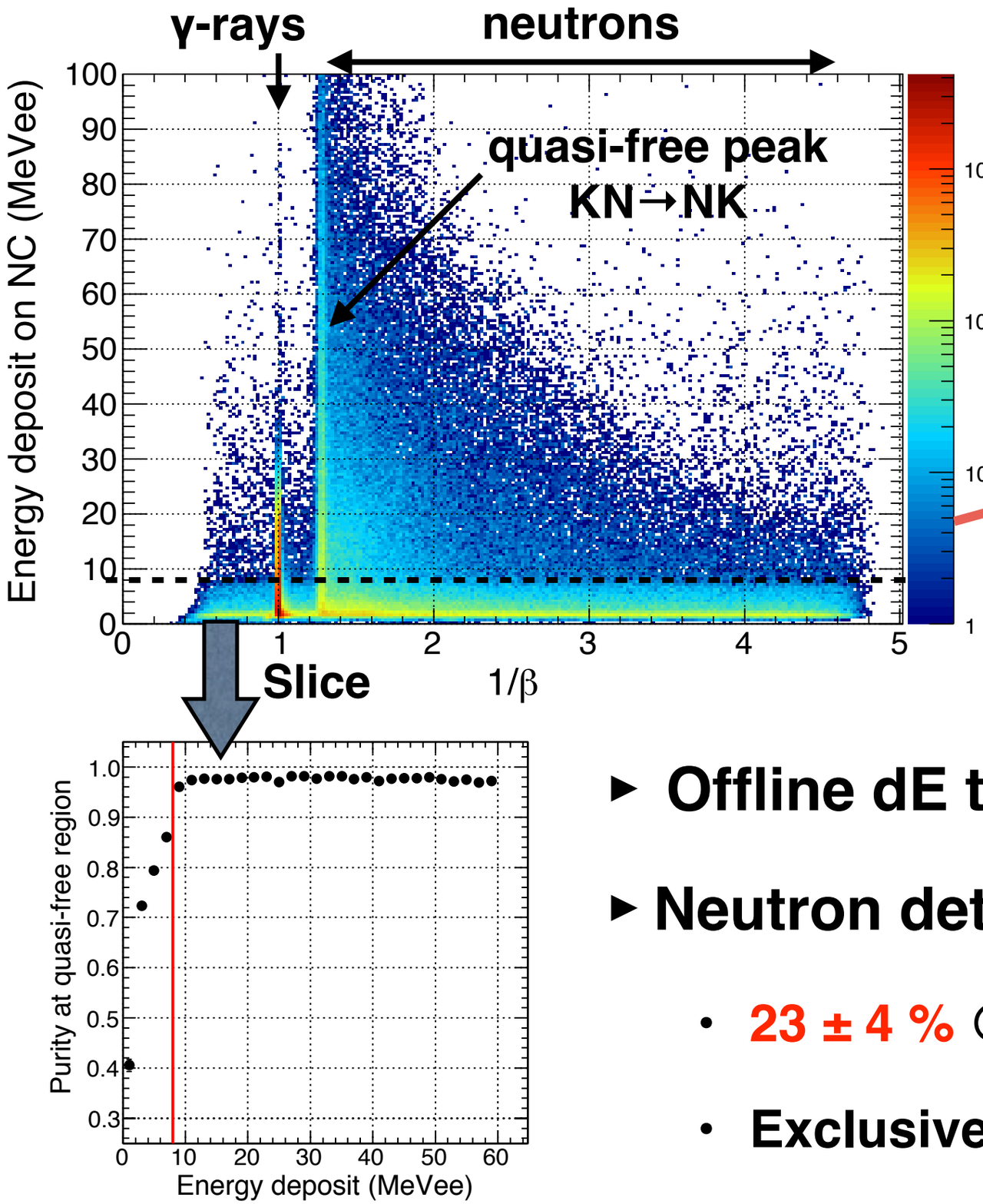


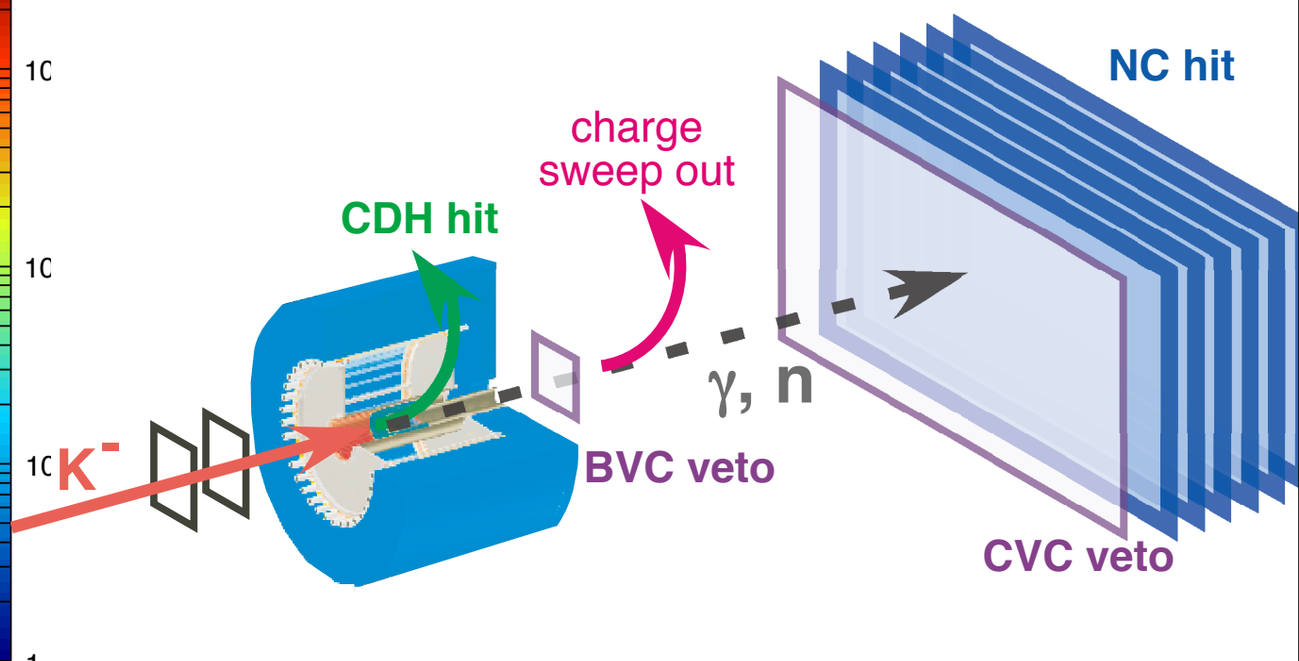






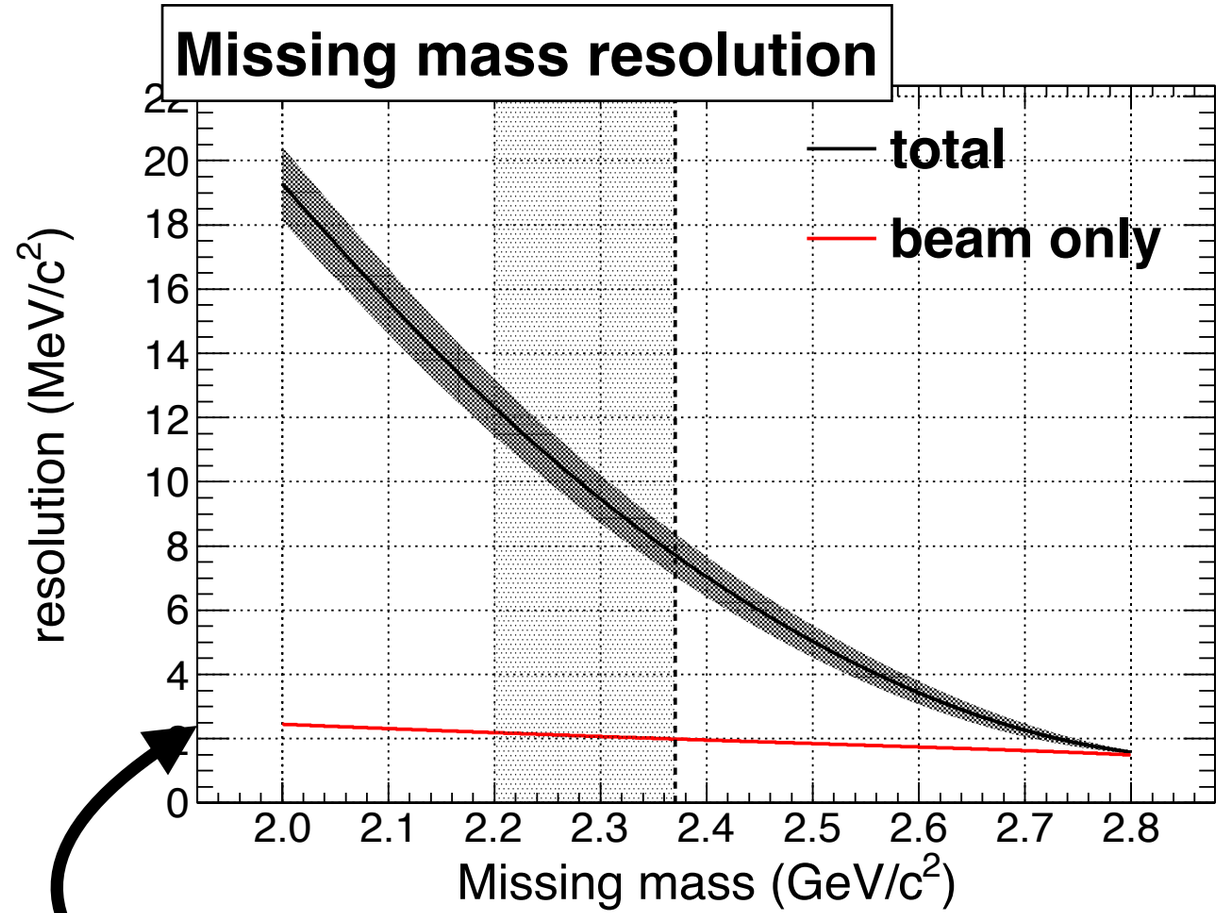
Neutron analysis

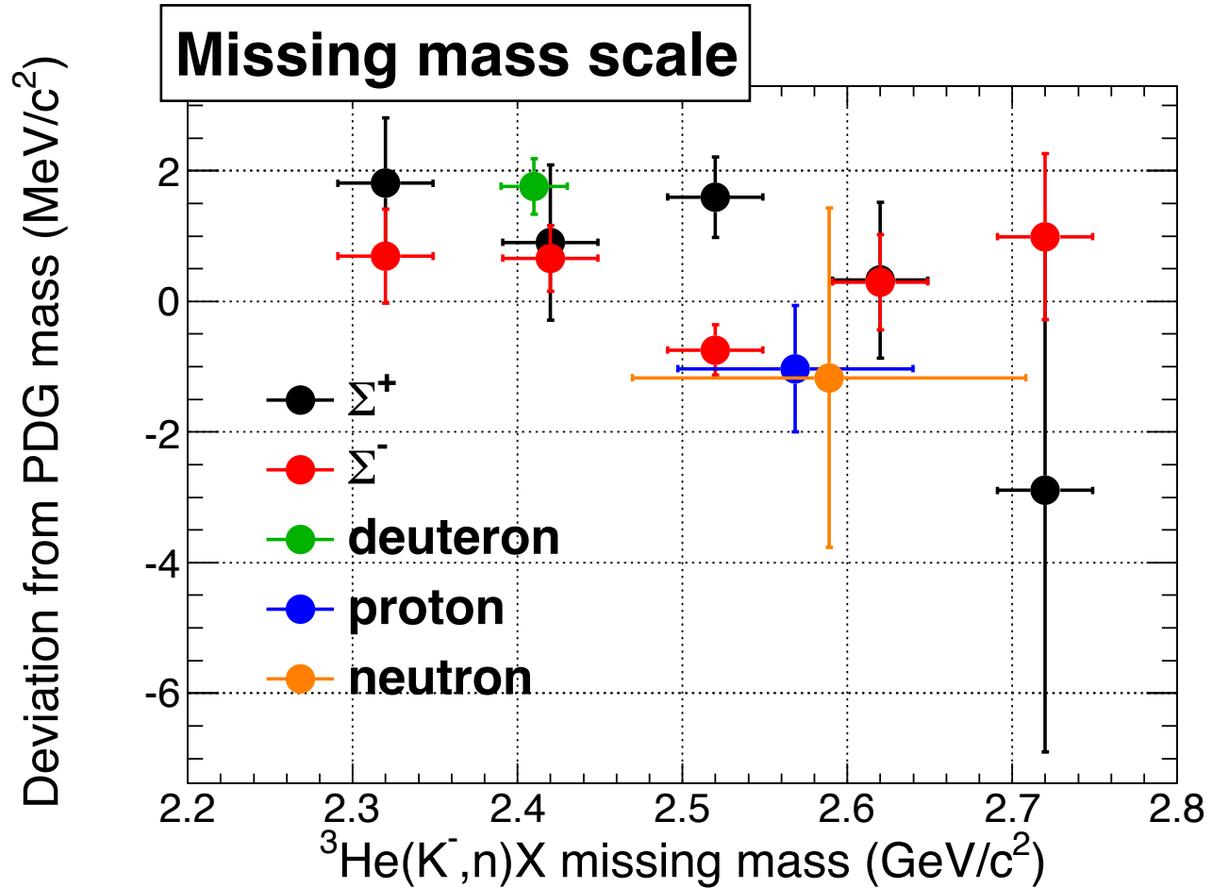




- **Offline dE threshold to reduce accidentals**
- **Neutron detection efficiency**
  - **23 ± 4 % @ quasi-free**
  - **Exclusive analysis of ^{3}He(K^{-},$K^{0}_{s}n$)d events**

Missing mass resolution & scale





~ 10 MeV/c² resolution achieved !!

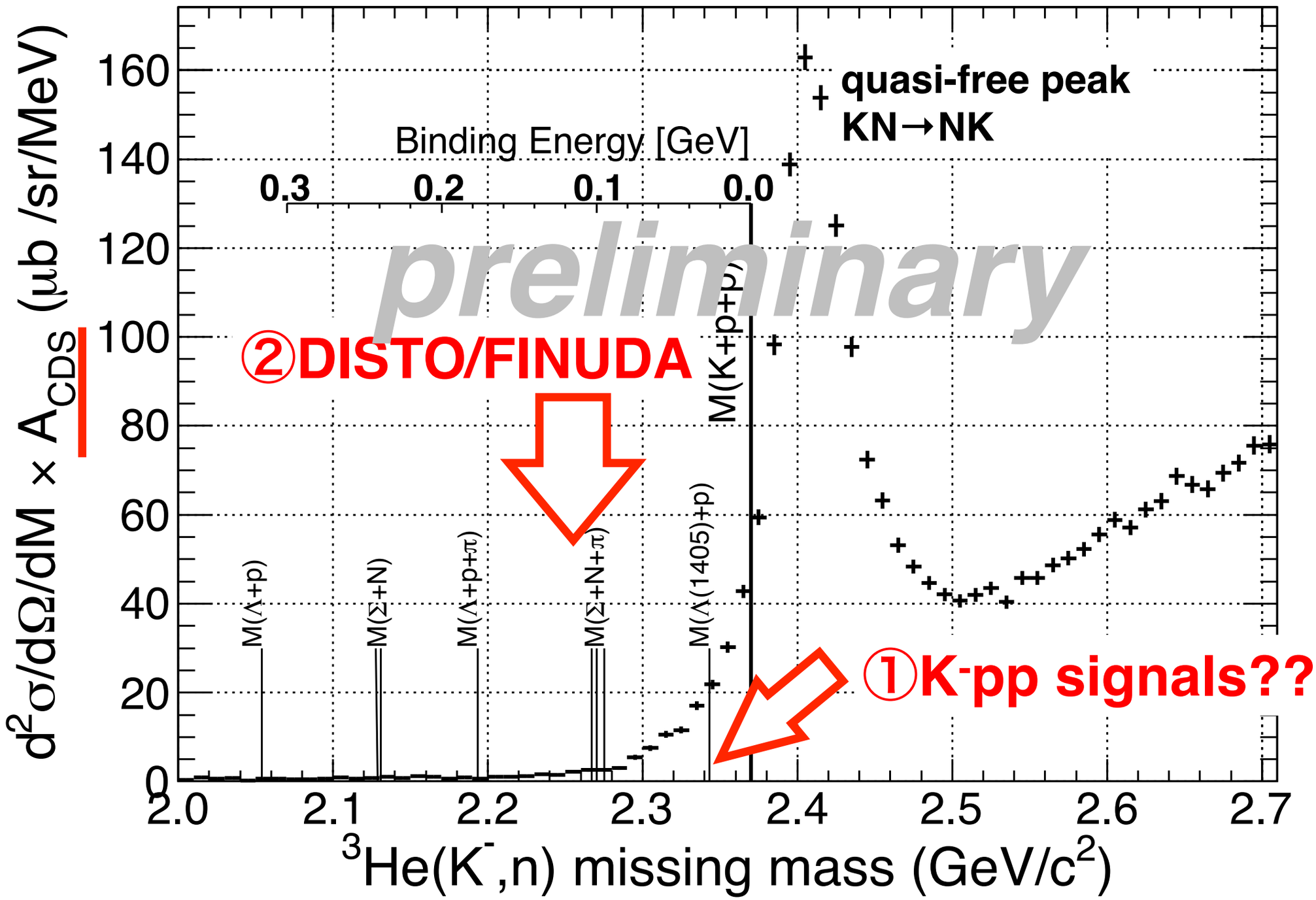
similar for ^{3}He(K$^-$,p)

3 MeV/c² systematic error in abs. scale.

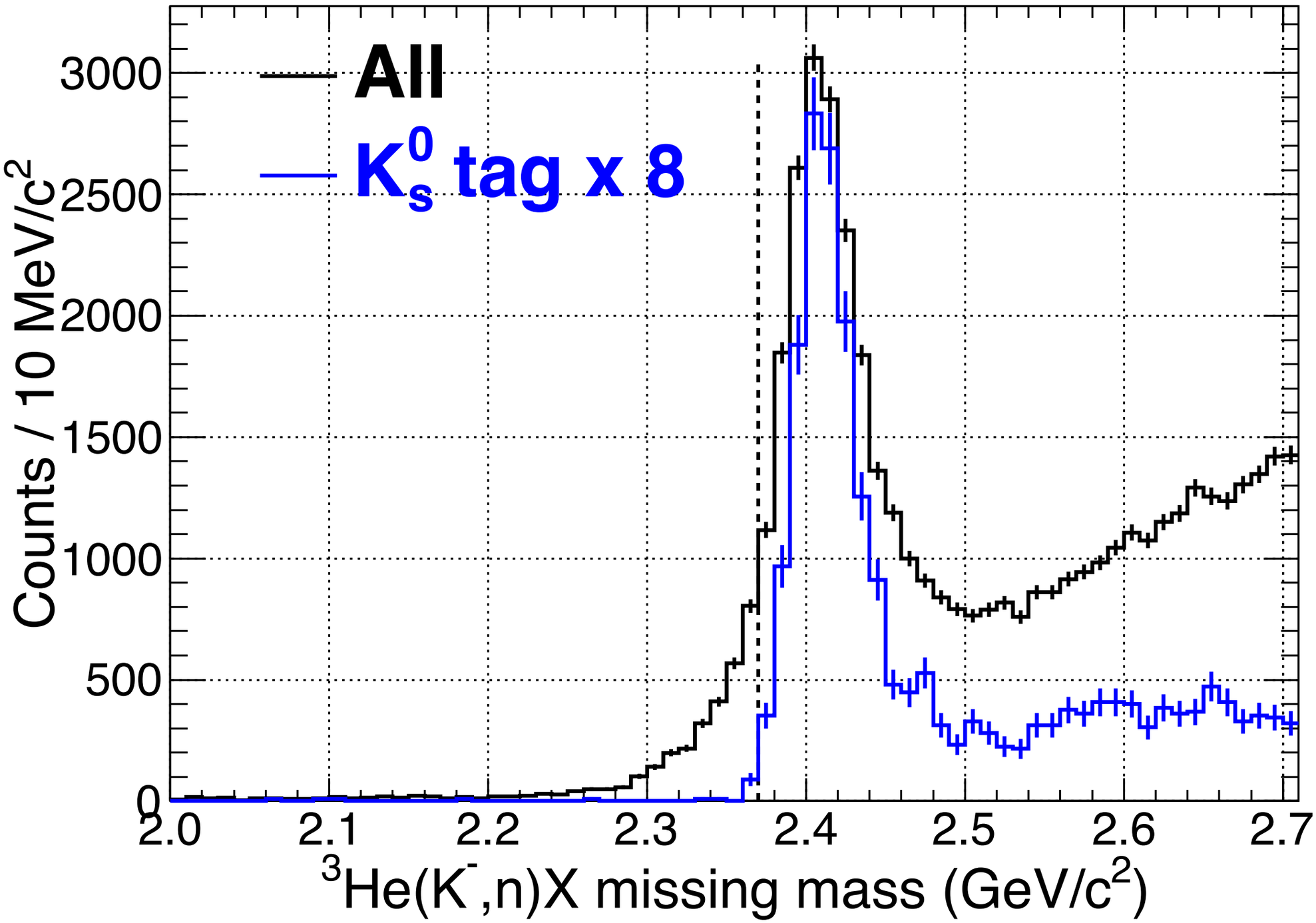
Results(1) : ^{3}He(K^{-}, n)X

Semi-inclusive spectrum

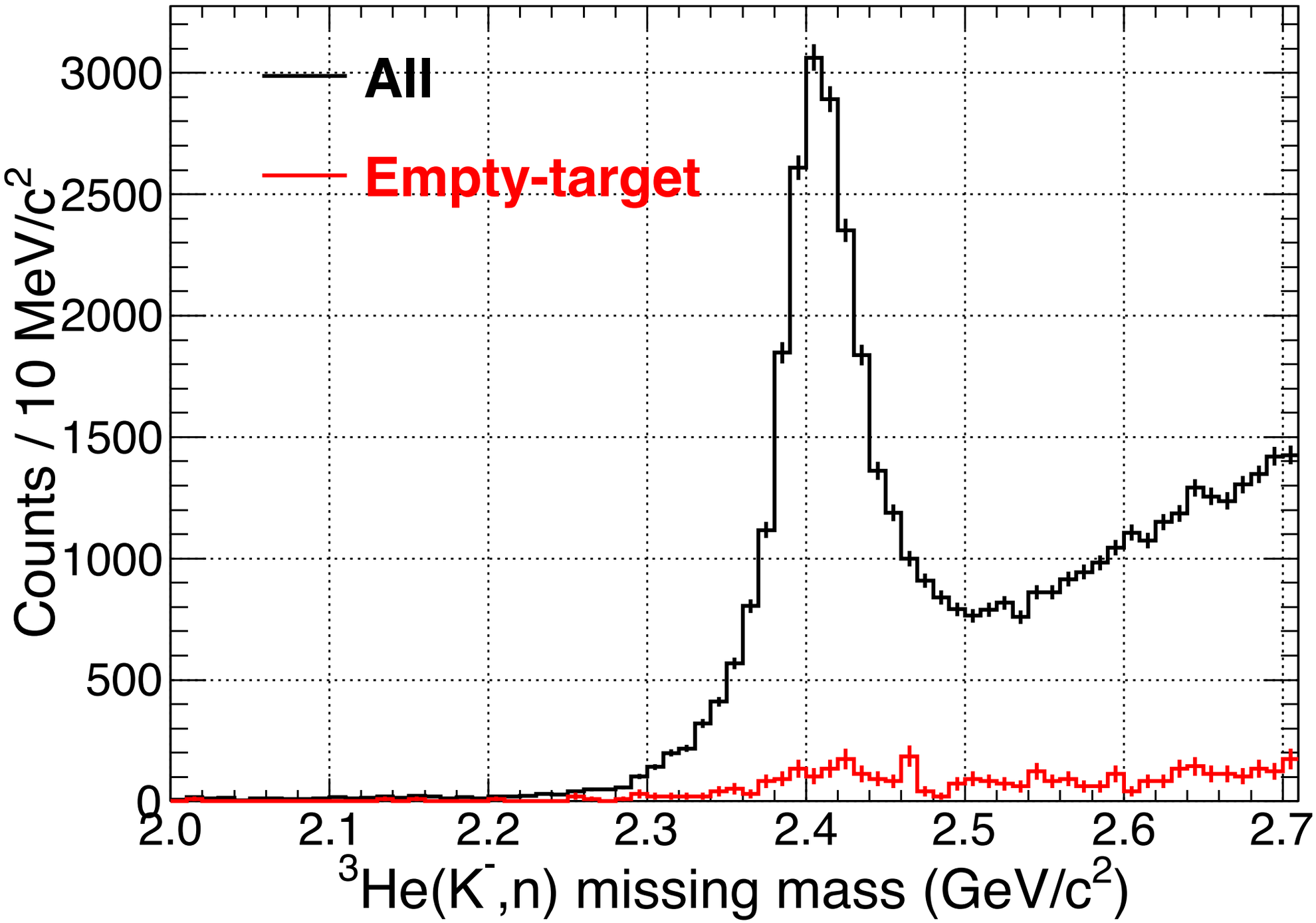
biased by the request of charged track(s) in the CDS



Experimental effect - resolution -



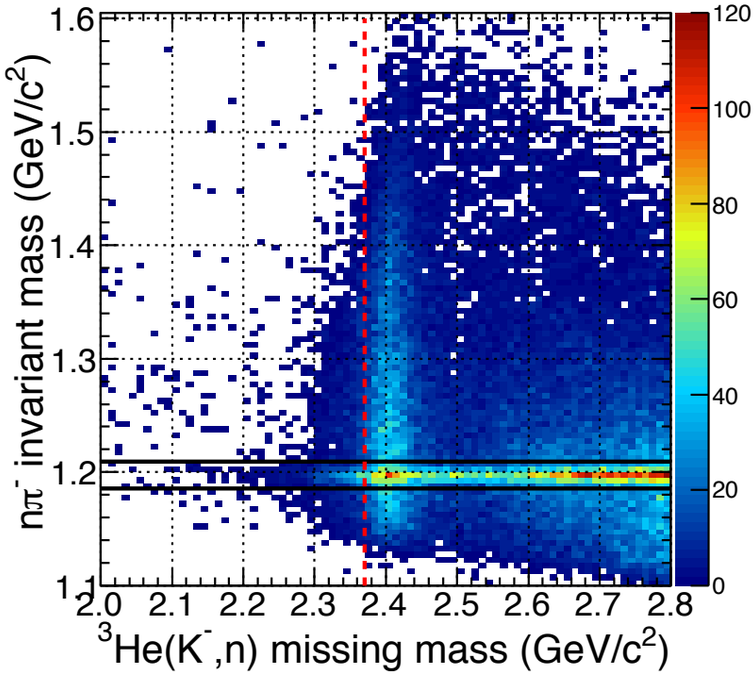
Experimental effect - Empty-target -

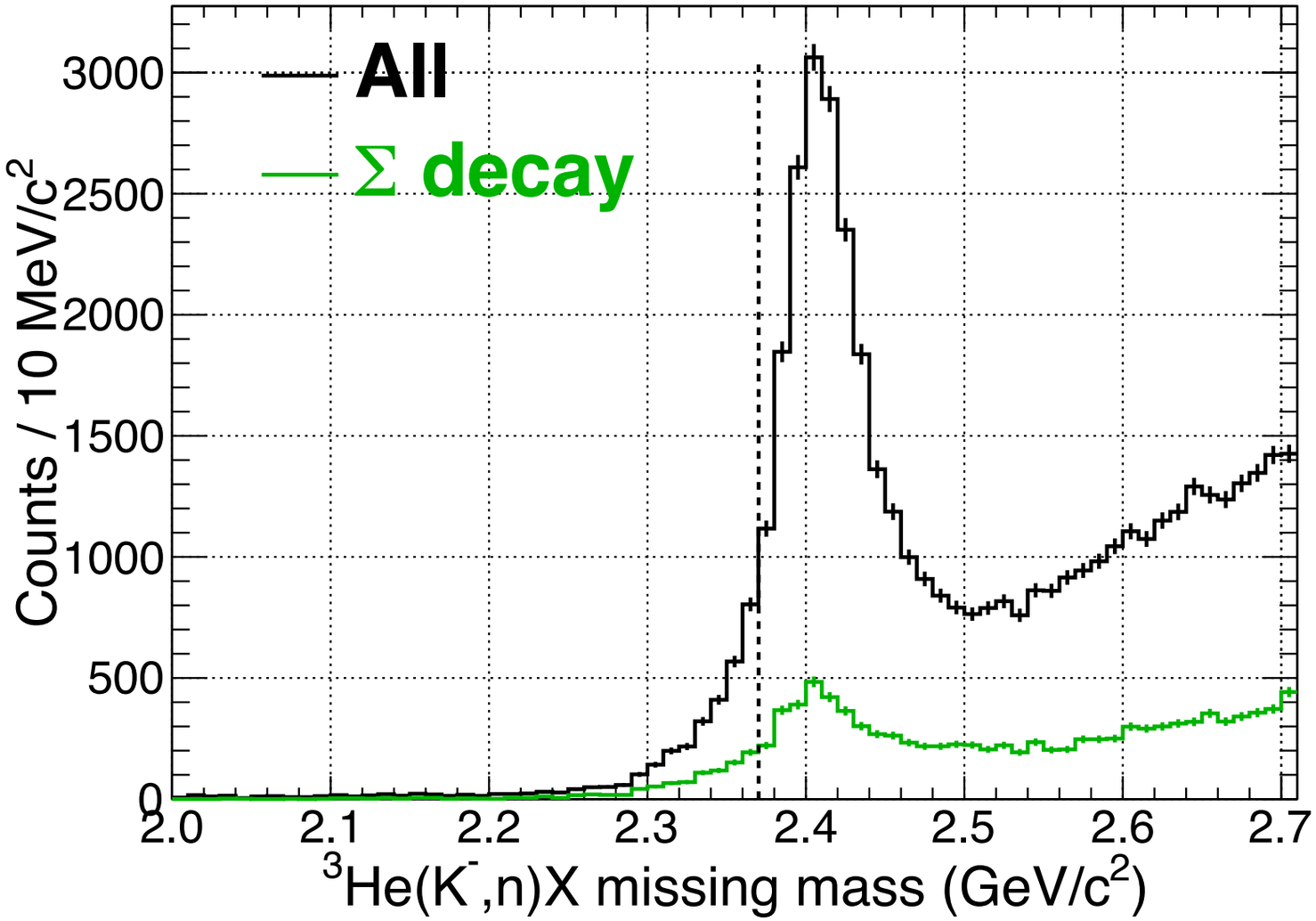


Single-nucleon processes

$$K^- + {}^3\mathrm{He} \rightarrow \Sigma^{\pm} + \pi^{\mp} + d_s$$
$$K^- + {}^3\mathrm{He} \rightarrow \Sigma^{-} + \pi^{0} + p_s + p_s$$
$$\Sigma^{\pm} \rightarrow n + \pi^{\pm},$$

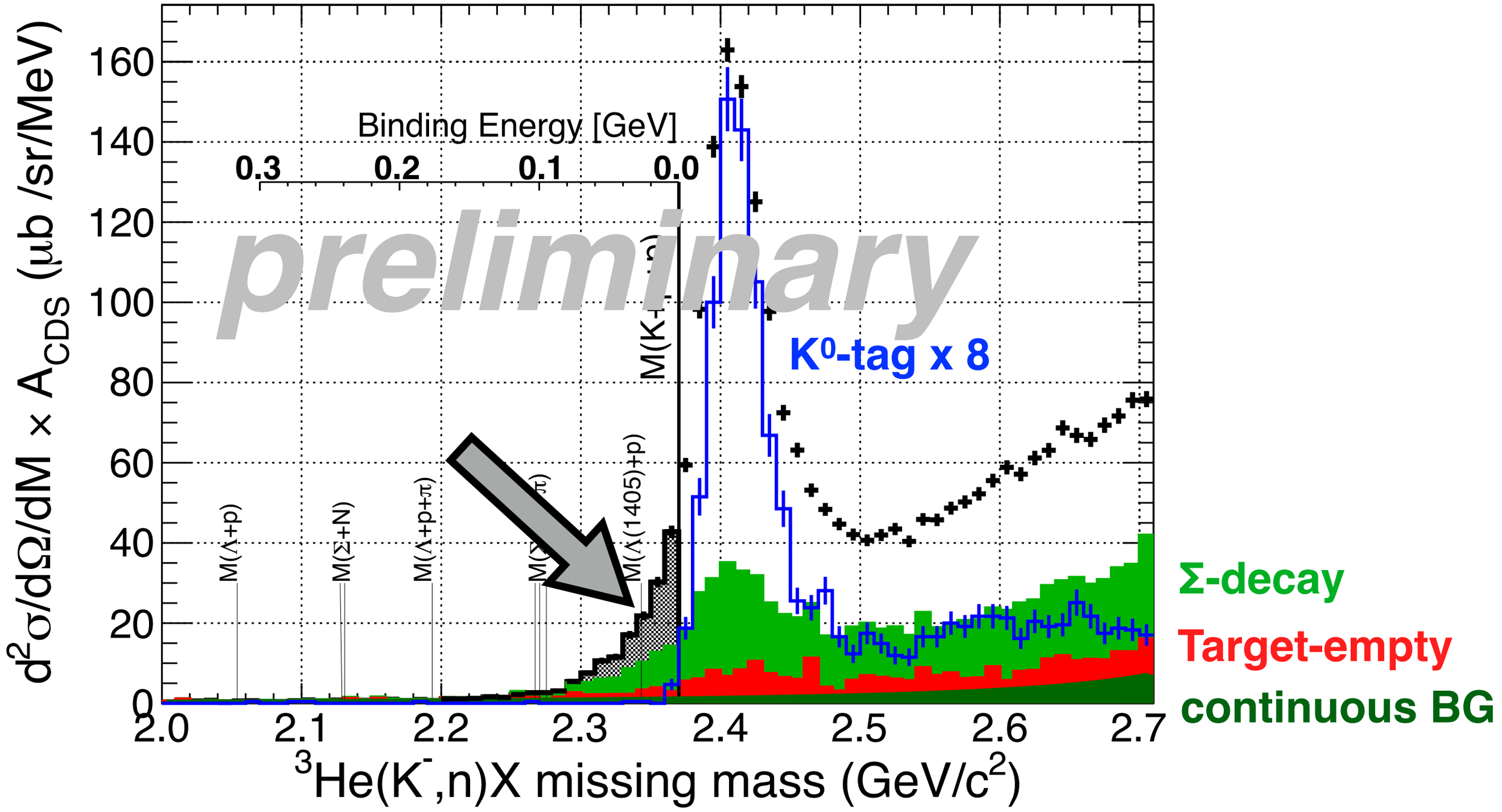
NC **CDS**





- **Only KN→Σπ, Σ→nπ can contribute to the bound region**
  - **~90% can be removed event by event**
  - **KN→Λπ, Λ→nπ is not triggered**

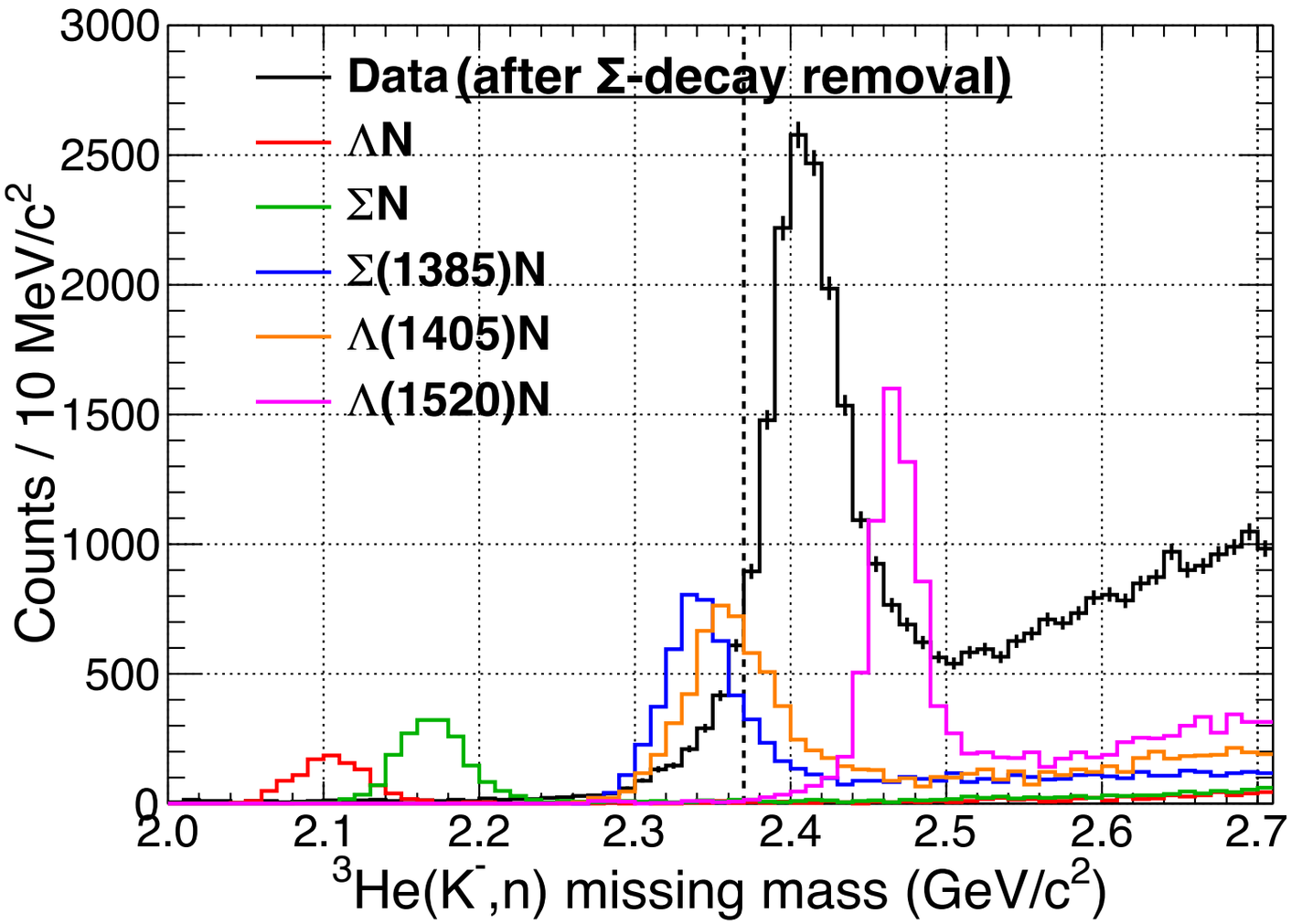
Unknown excess



There remains a statistically significant excess !!

What is the excess??

1. **non-mesonic 2NA : Y*N branches may contribute**
2. mesonic 2NA & 3NA :
3. K$^-$pp formation :



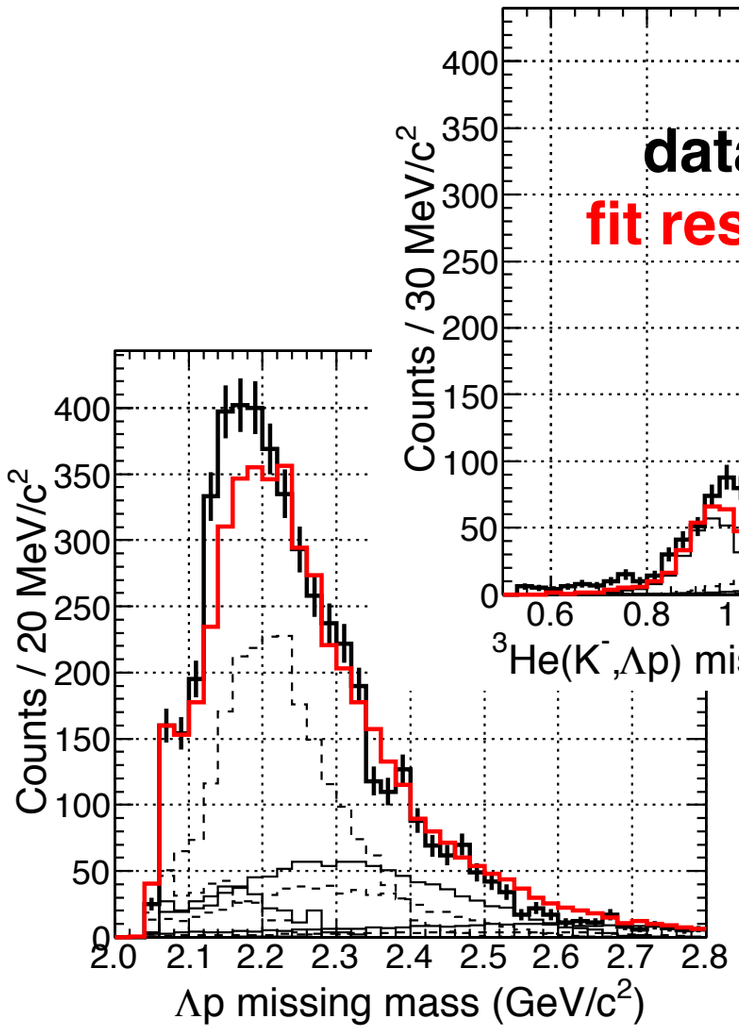
$$K^- + {}^3\mathrm{He} \rightarrow Y^{(*)} + N + N_s.$$

ΛN/ΣN branches : small

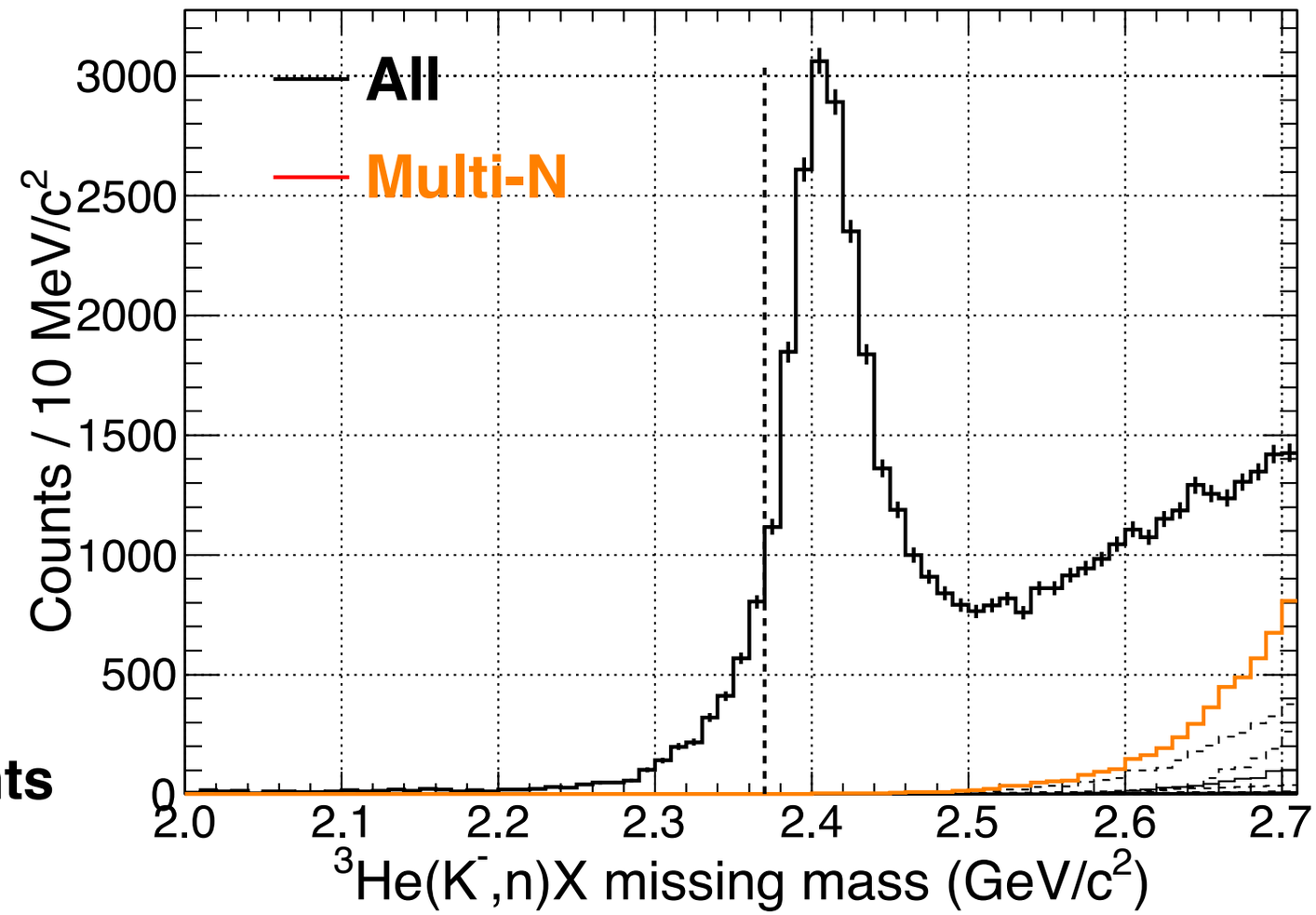
Y*N branches :
large cross section (~ 5mb/sr)
to fully explain the excess

What is the excess??

1. non-mesonic 2NA : Y*N branches may contribute
2. **mesonic 2NA & 3NA : little contribution**
3. K^-pp formation :

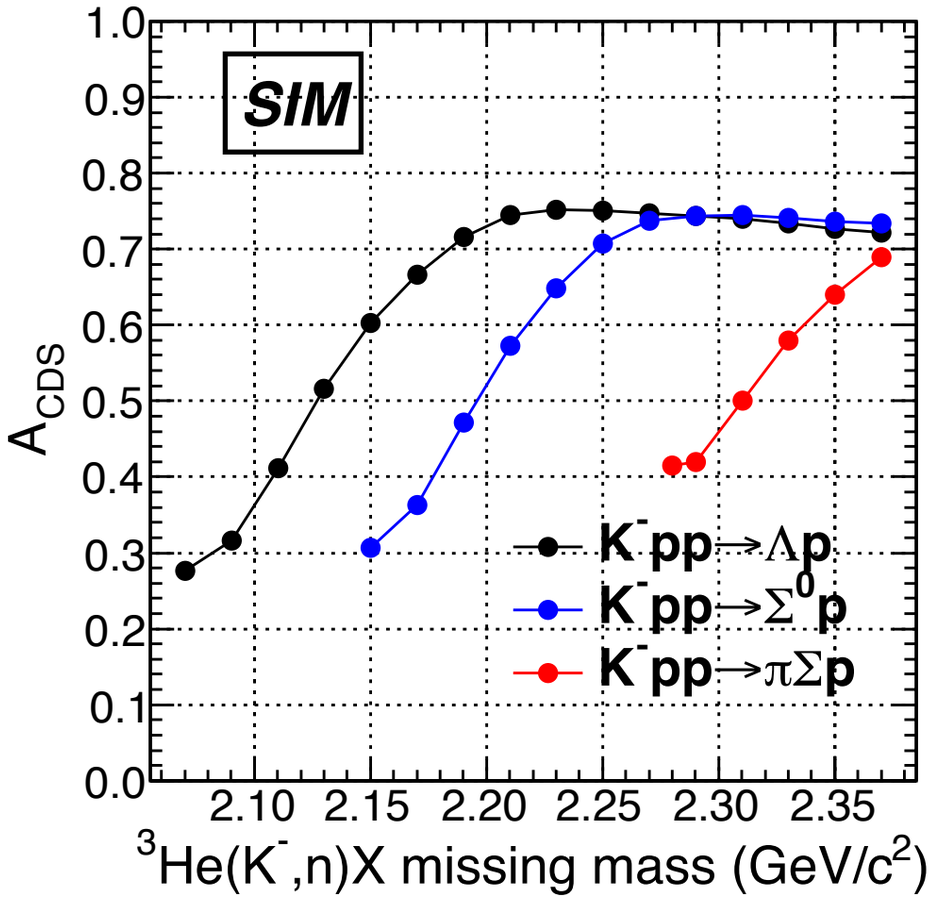


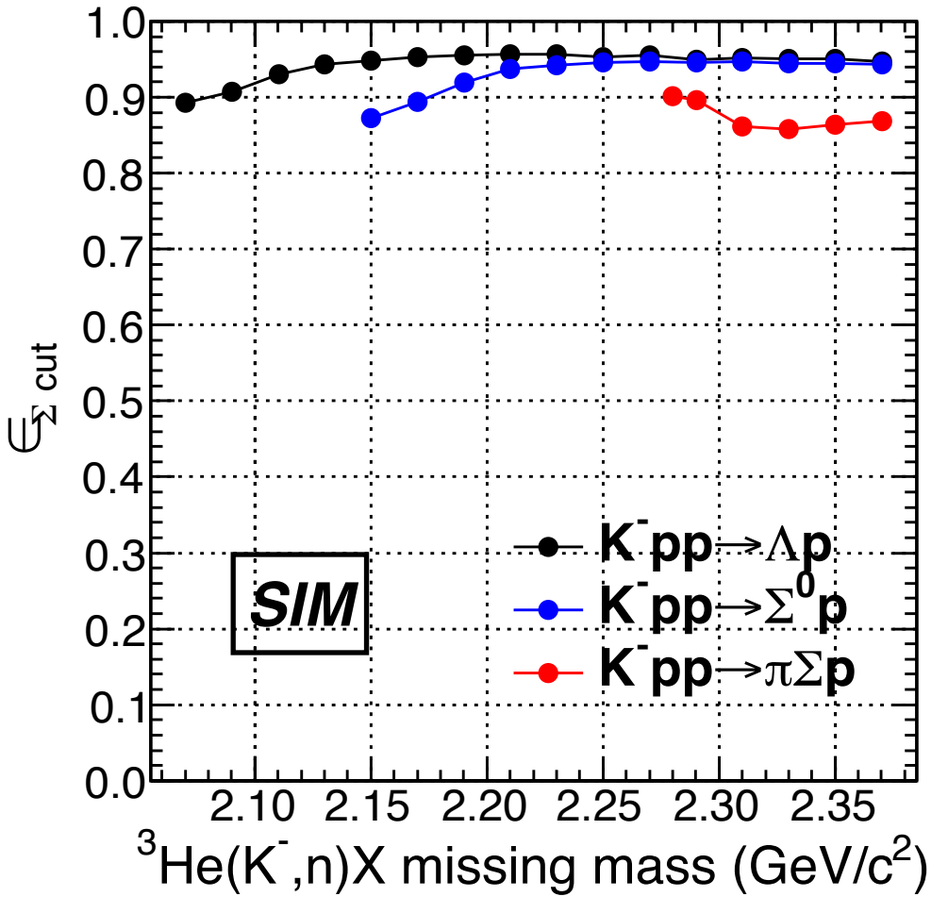
Constrain from Λp events



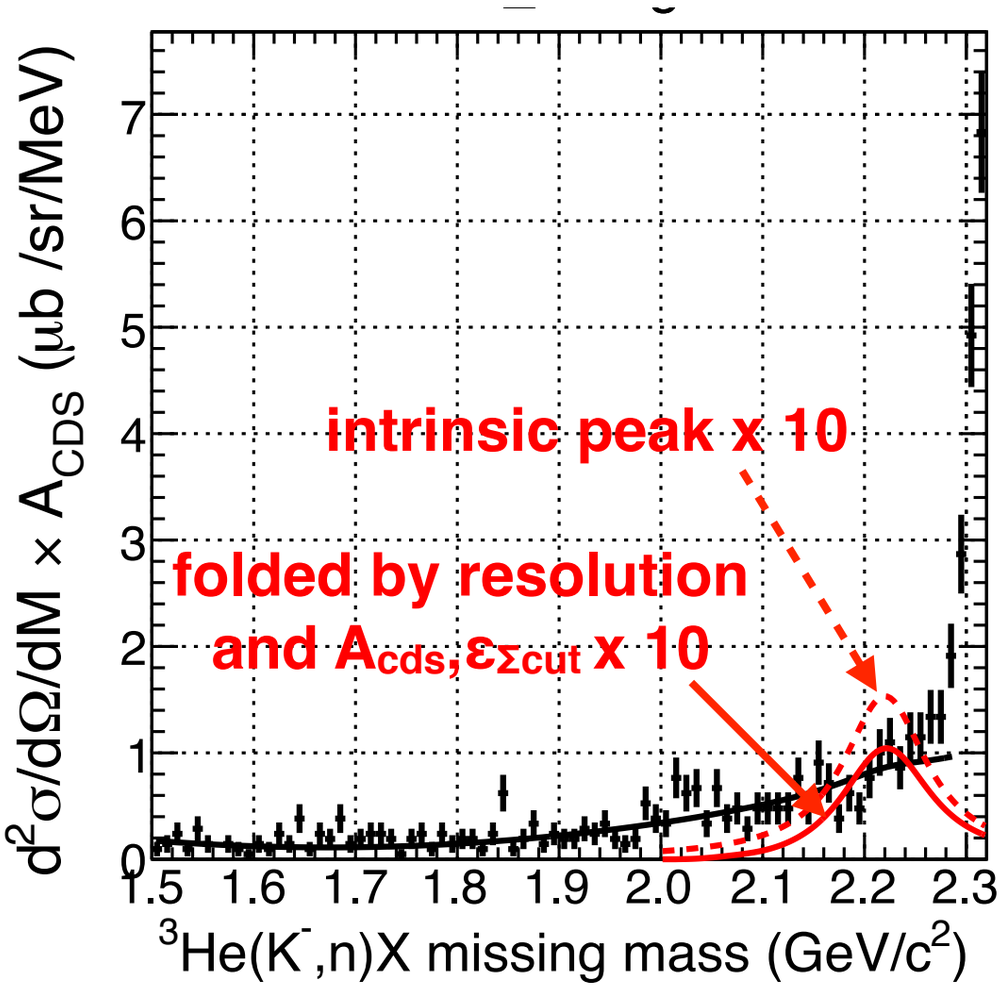
What is the excess??

1. non-mesonic 2NA : Y*N branches may contribute
2. mesonic 2NA & 3NA : little contribution
3. **K^-pp formation : 1.2~1.6 mb/sr**





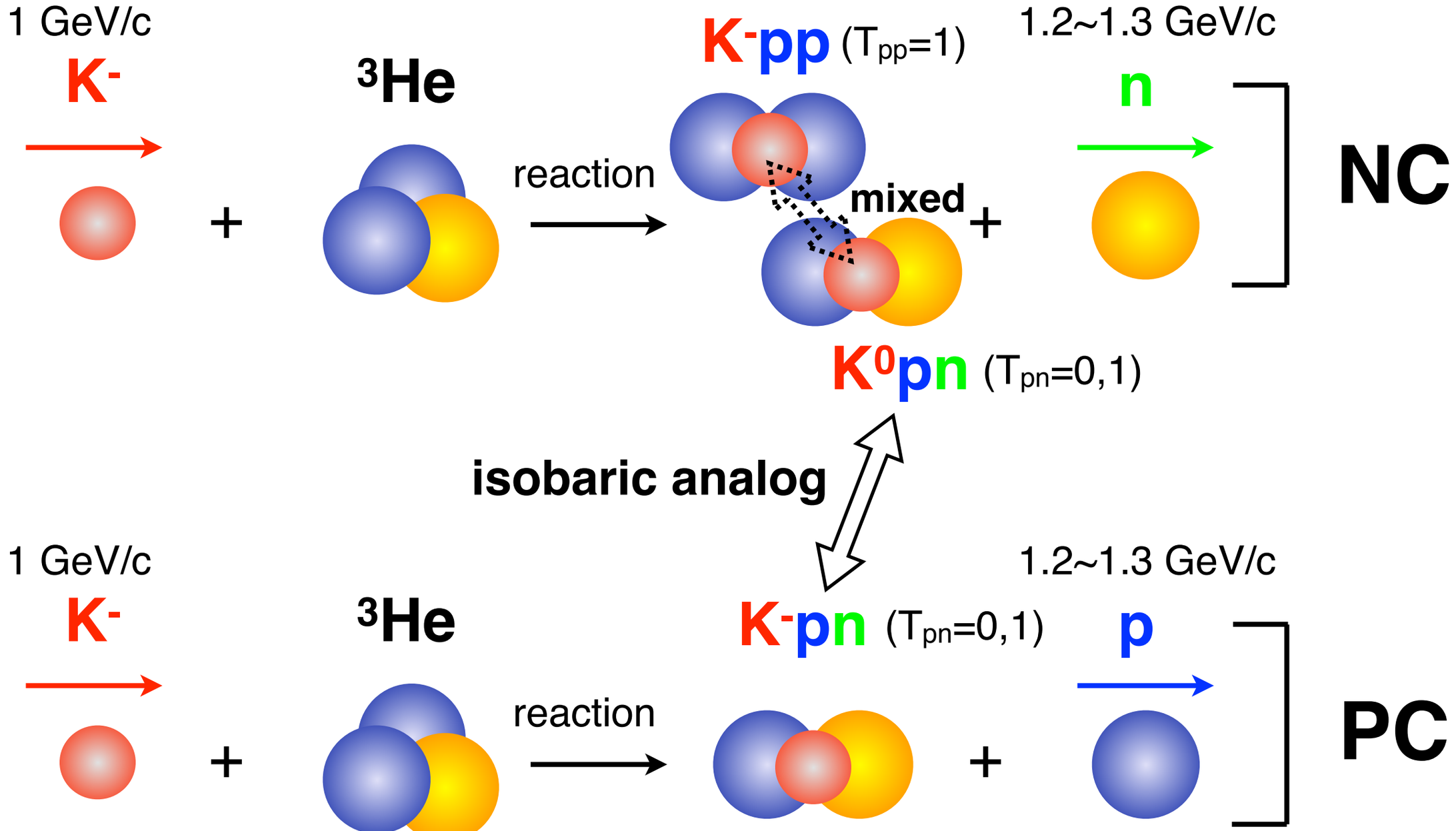
Upper limits for deeply-bound states



preliminary

Results(2) : ^{3}He(K^{-}, p)X

Isospin dependence of K^- NN reaction

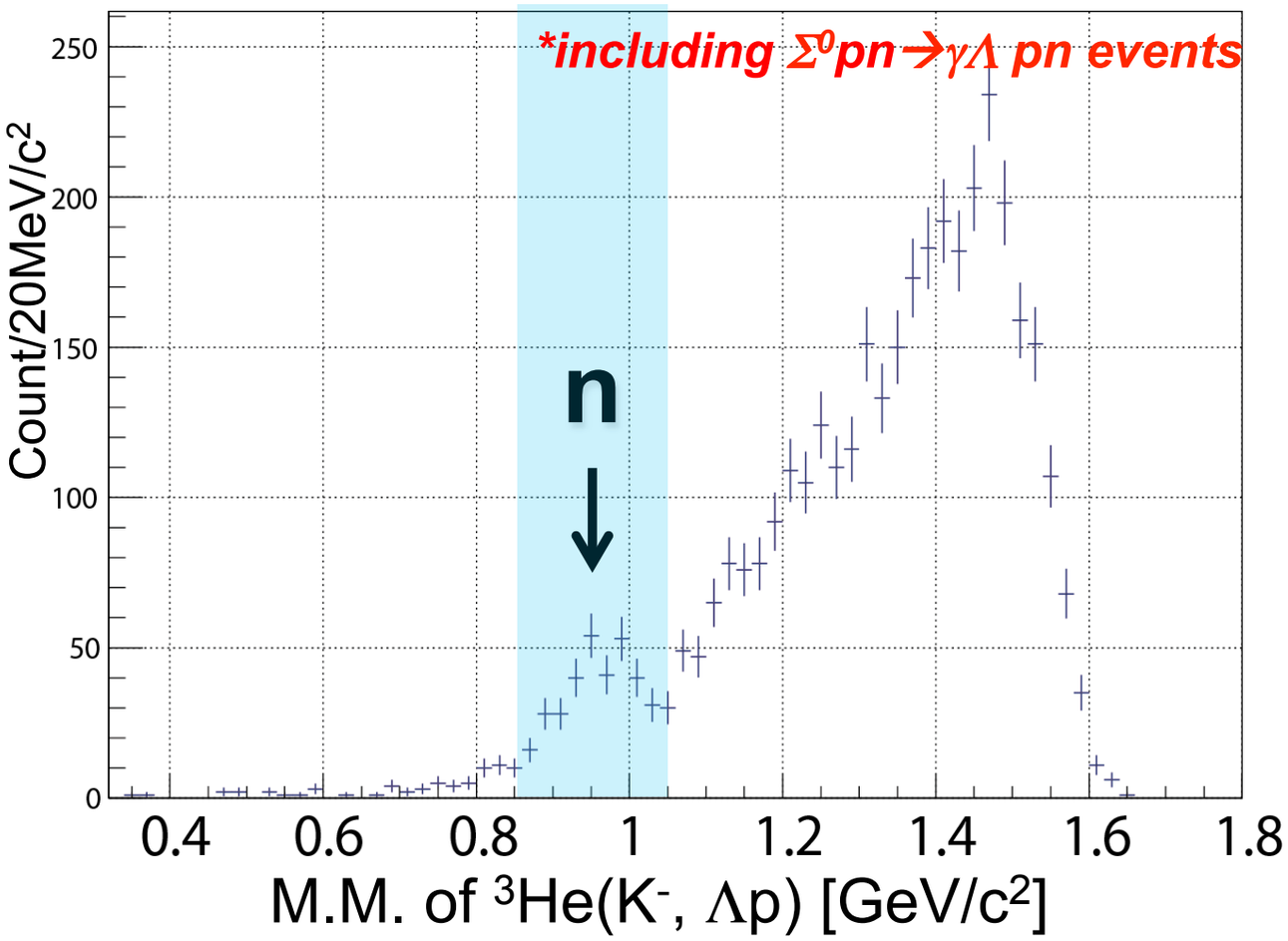


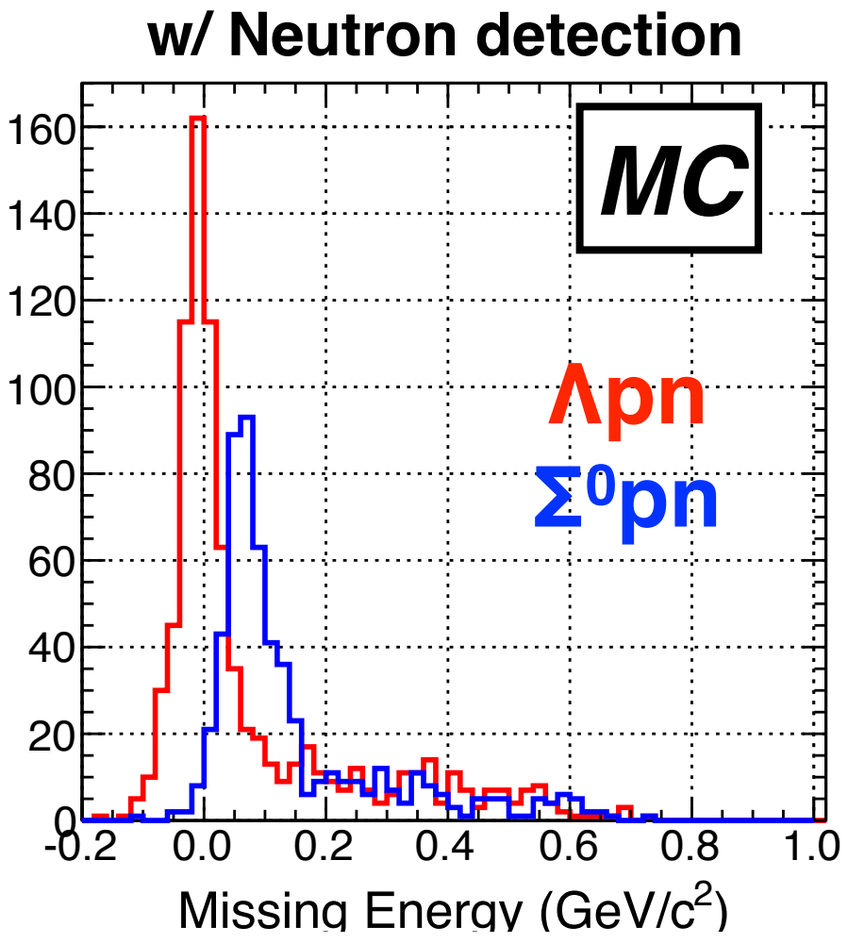
Semi-inclusive ^{3}He(K^{-},p) spectrum

preliminary

Results(3) : ^{3}He(K^{-}, Λp)n

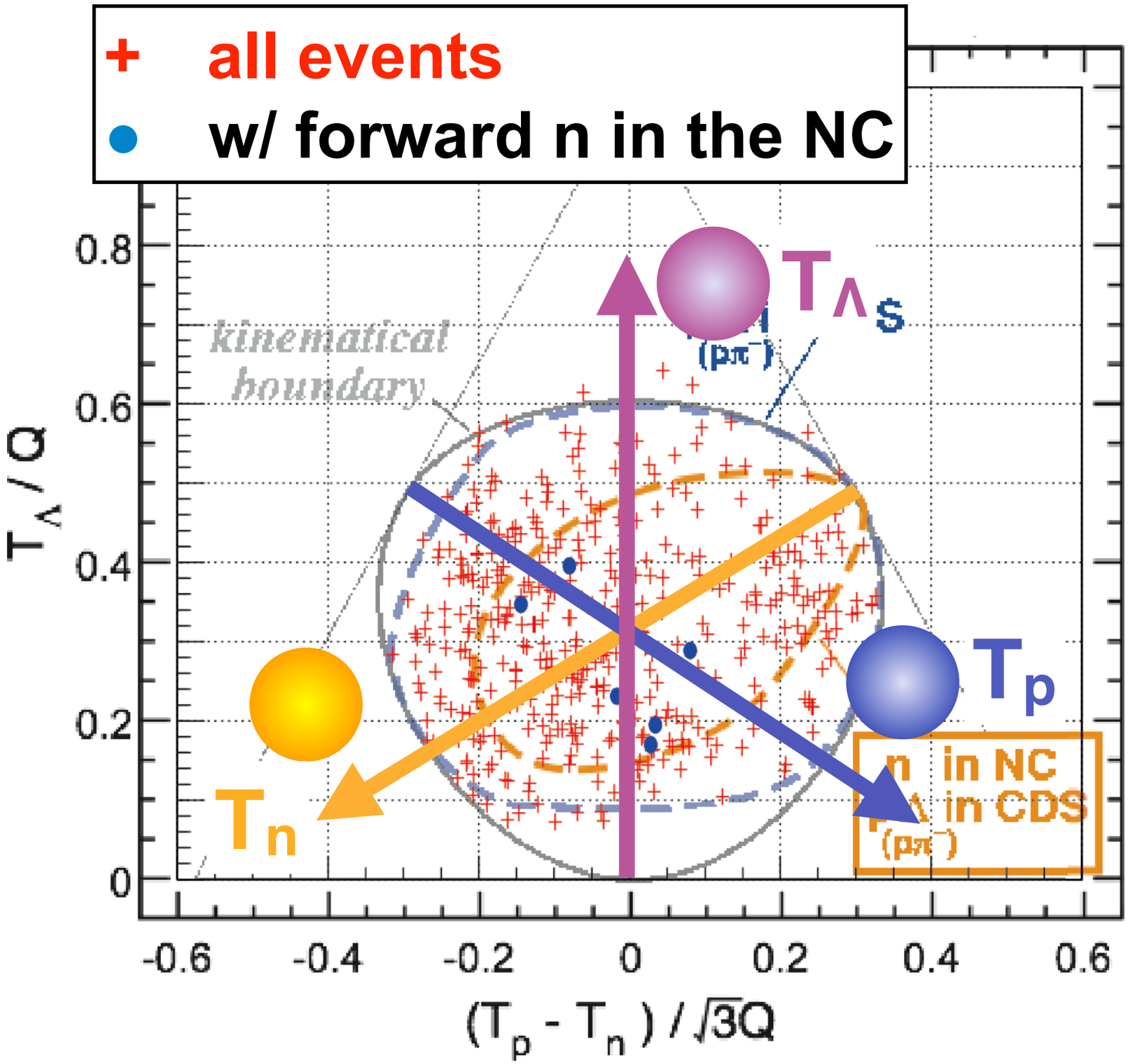
Λp distribution



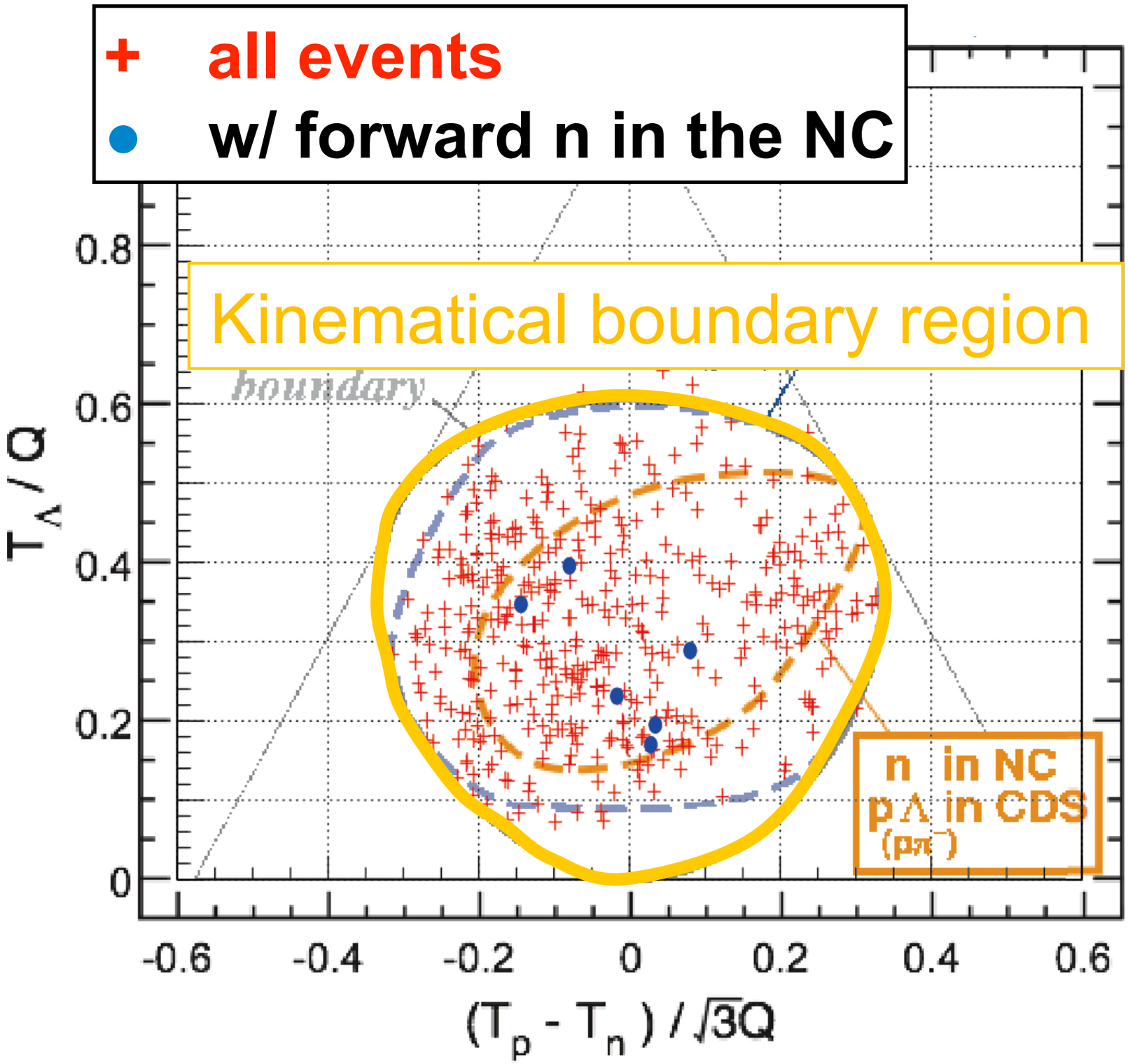


- **Λp reconstructed with the CDS**
  - **most events accompanied by pion(s)**
  - **missing-neutron ~ 400 events**
- **Σ⁰pn (Σ⁰→Λγ) separation is not easy…**

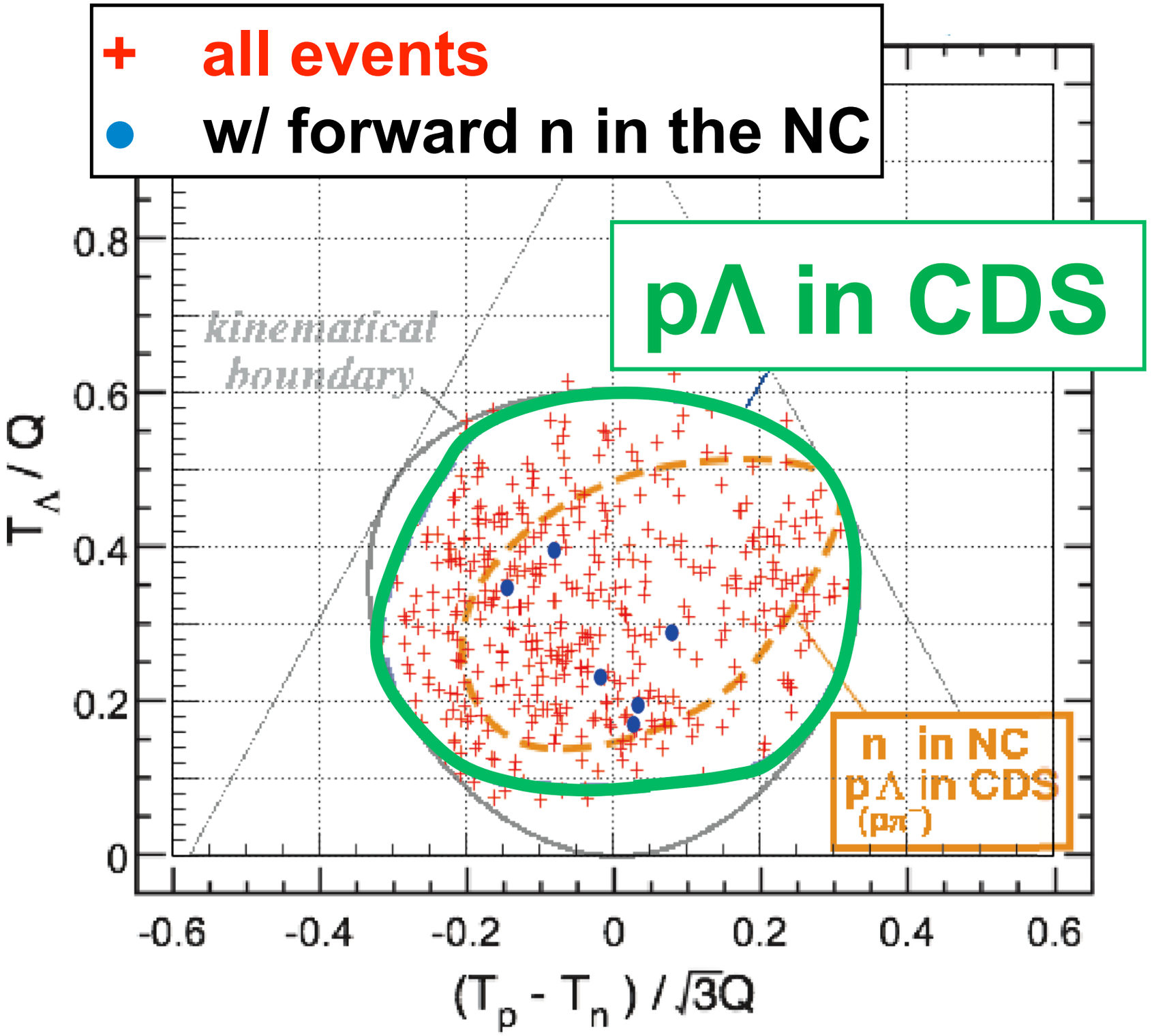
Λpn correlation



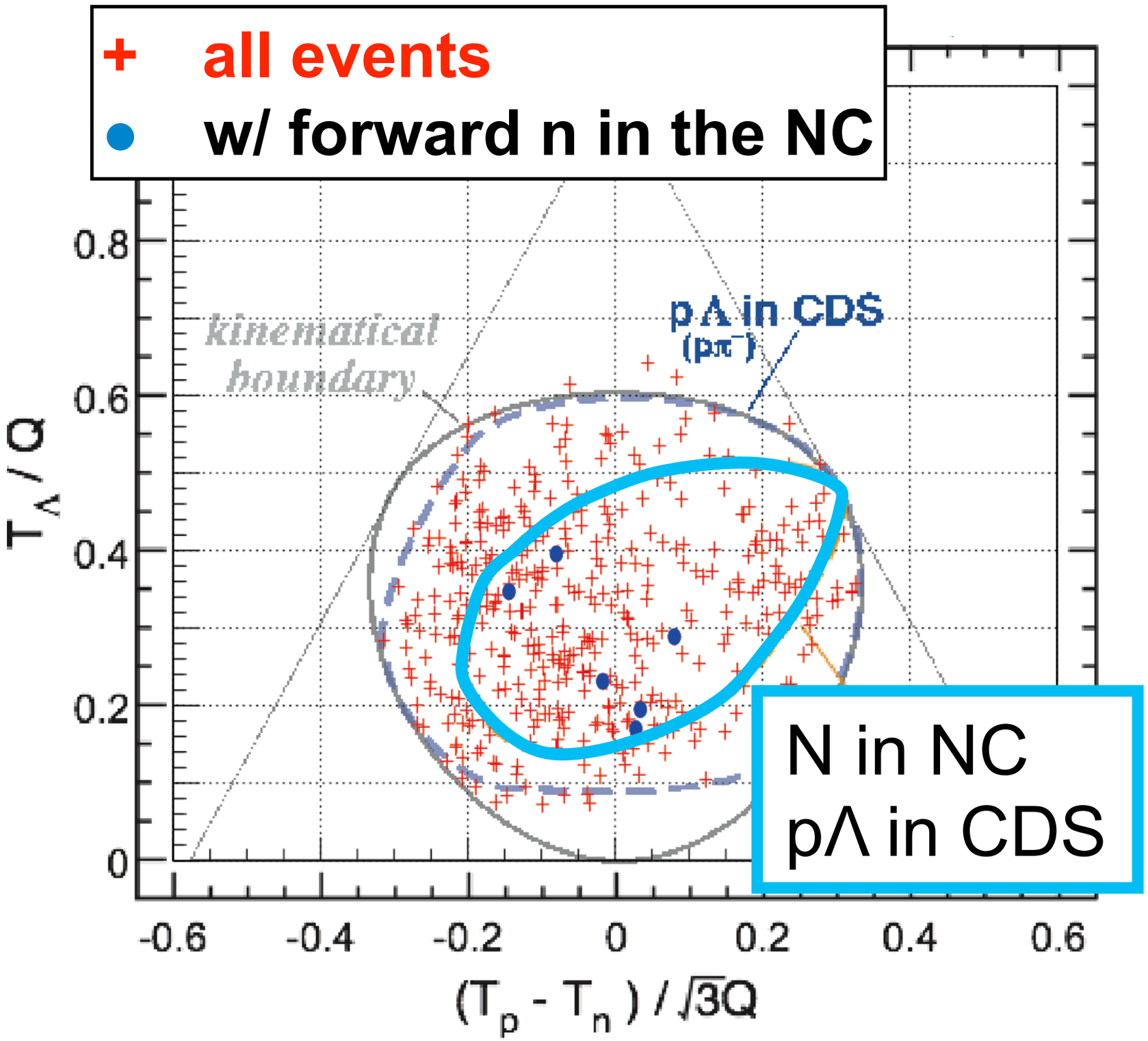
Λpn correlation



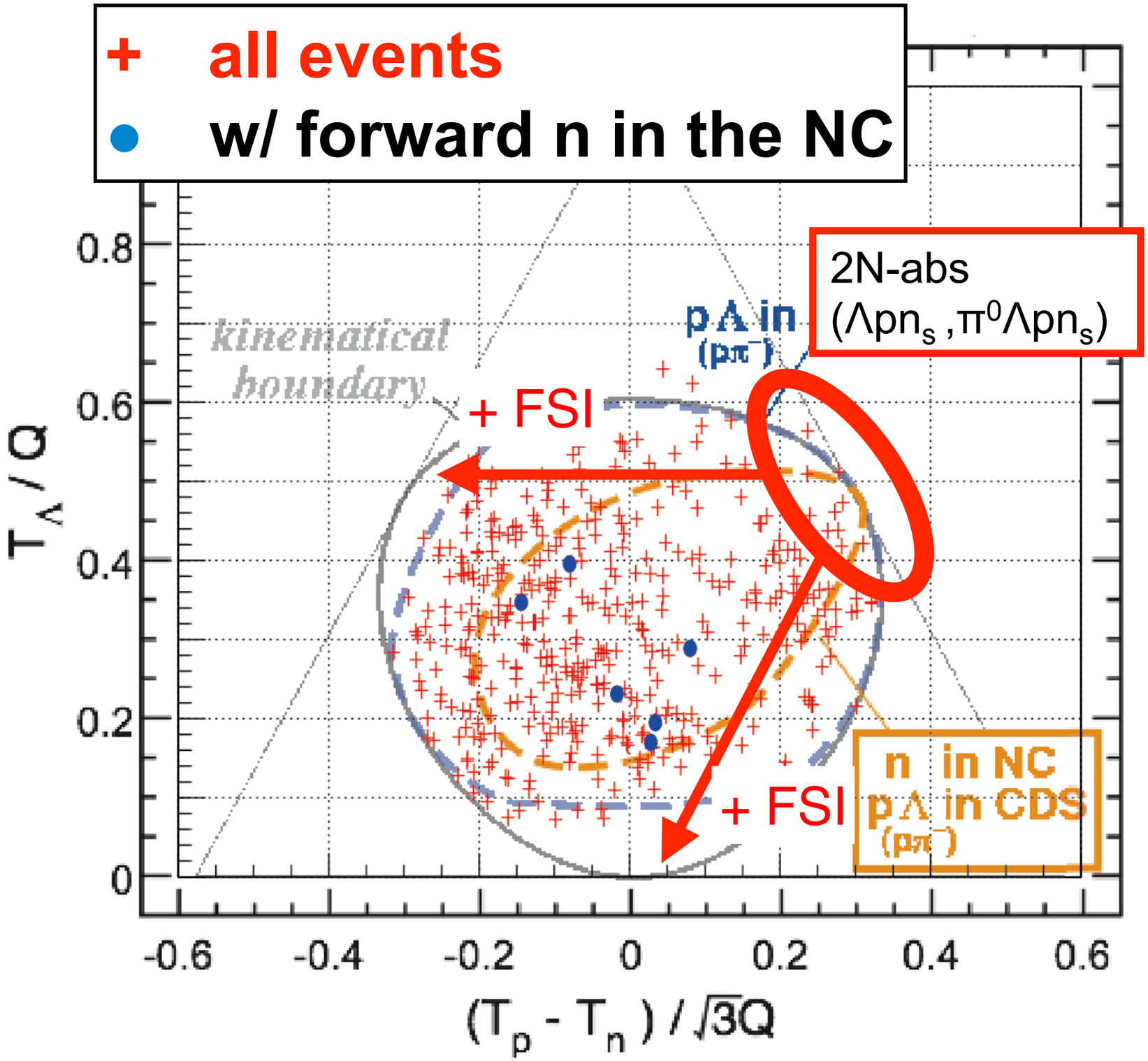
Λpn correlation



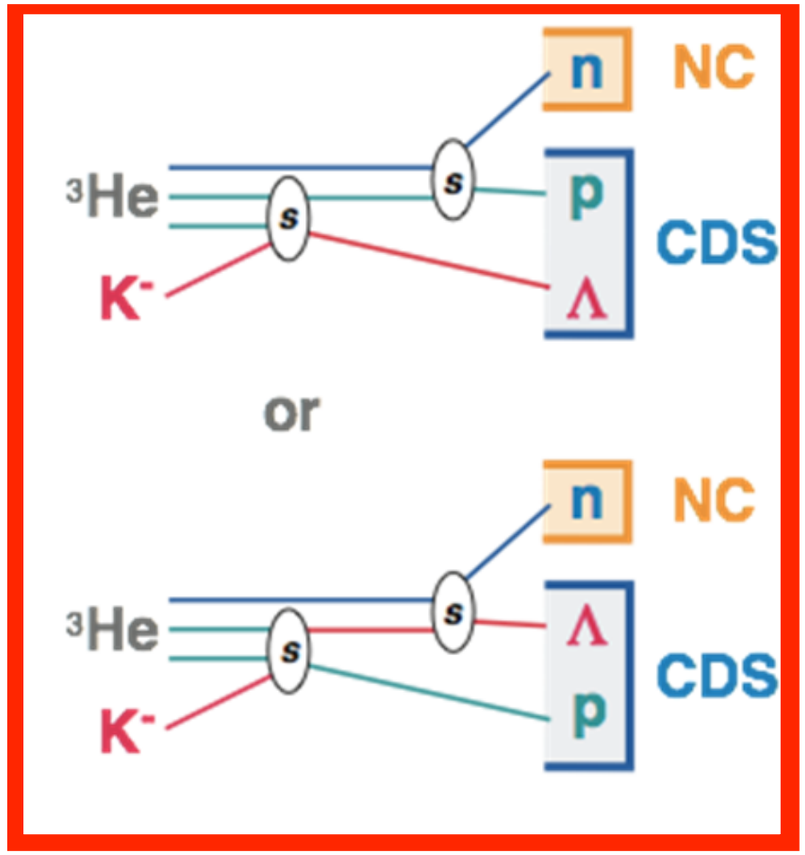
Λpn correlation



Λpn correlation

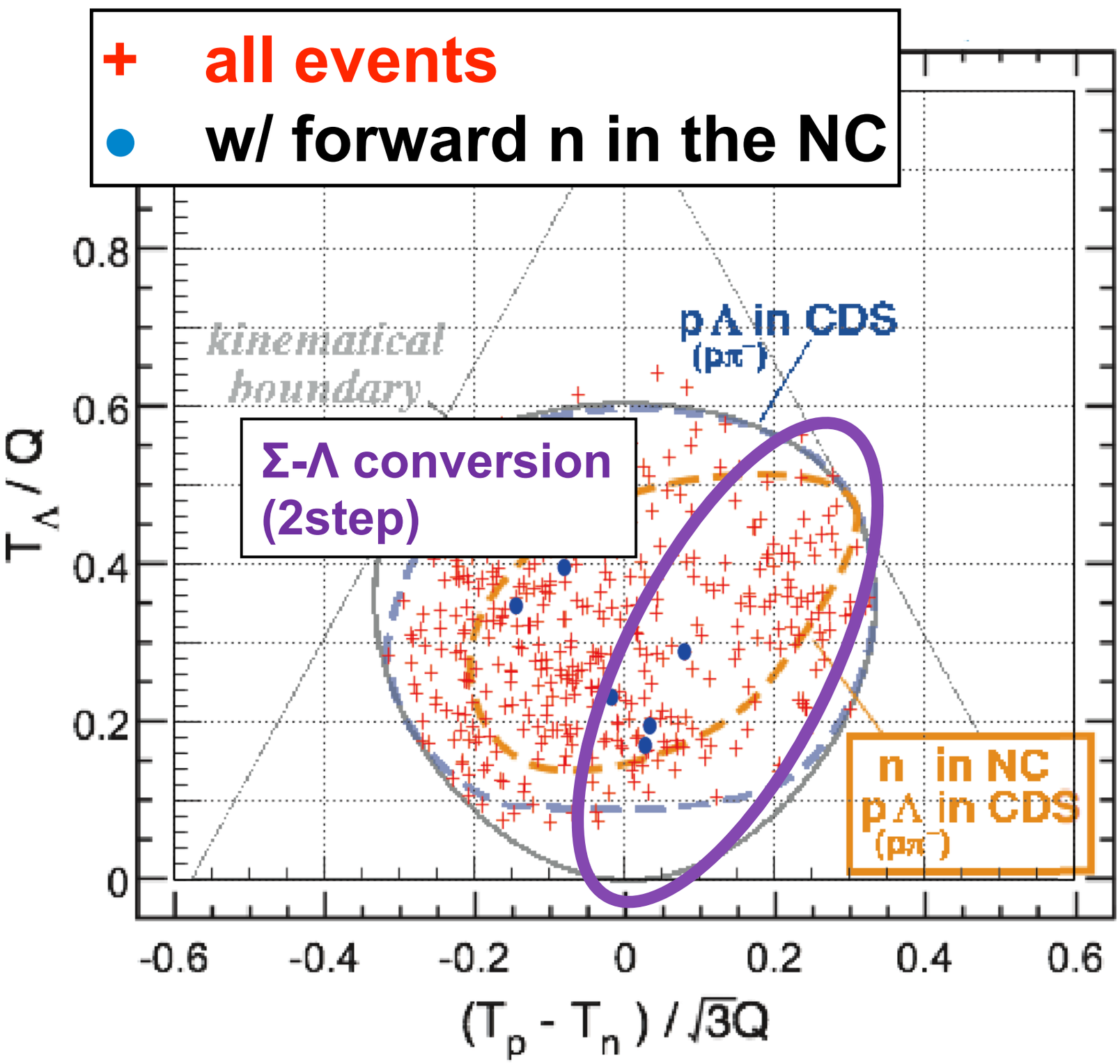


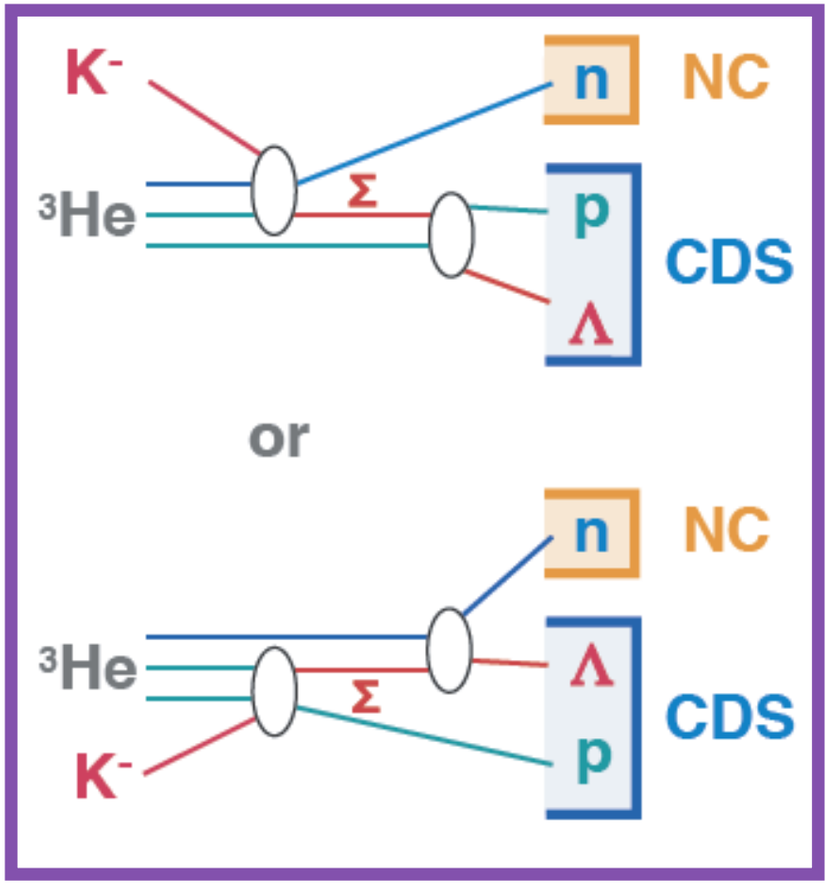
2NA + FSI

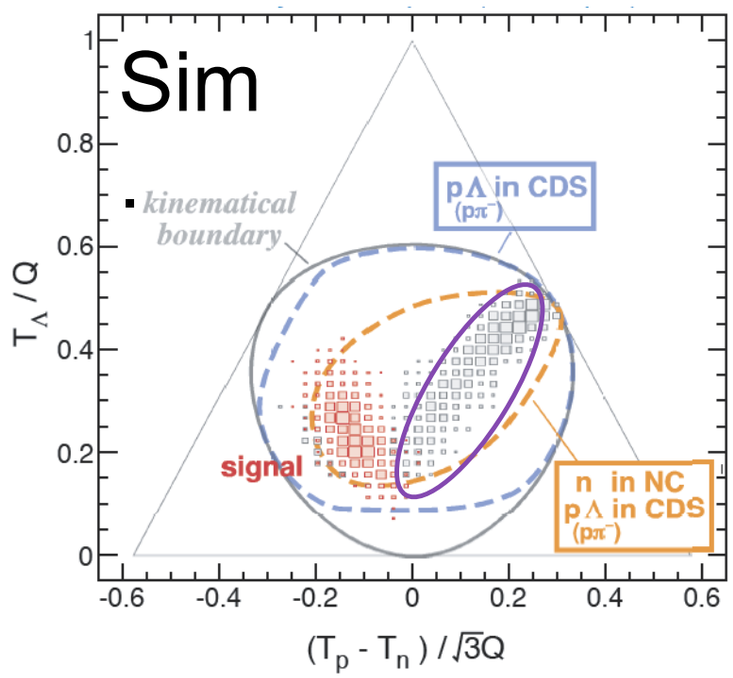


Λpn correlation

+ all events
● w/ forward n in the NC

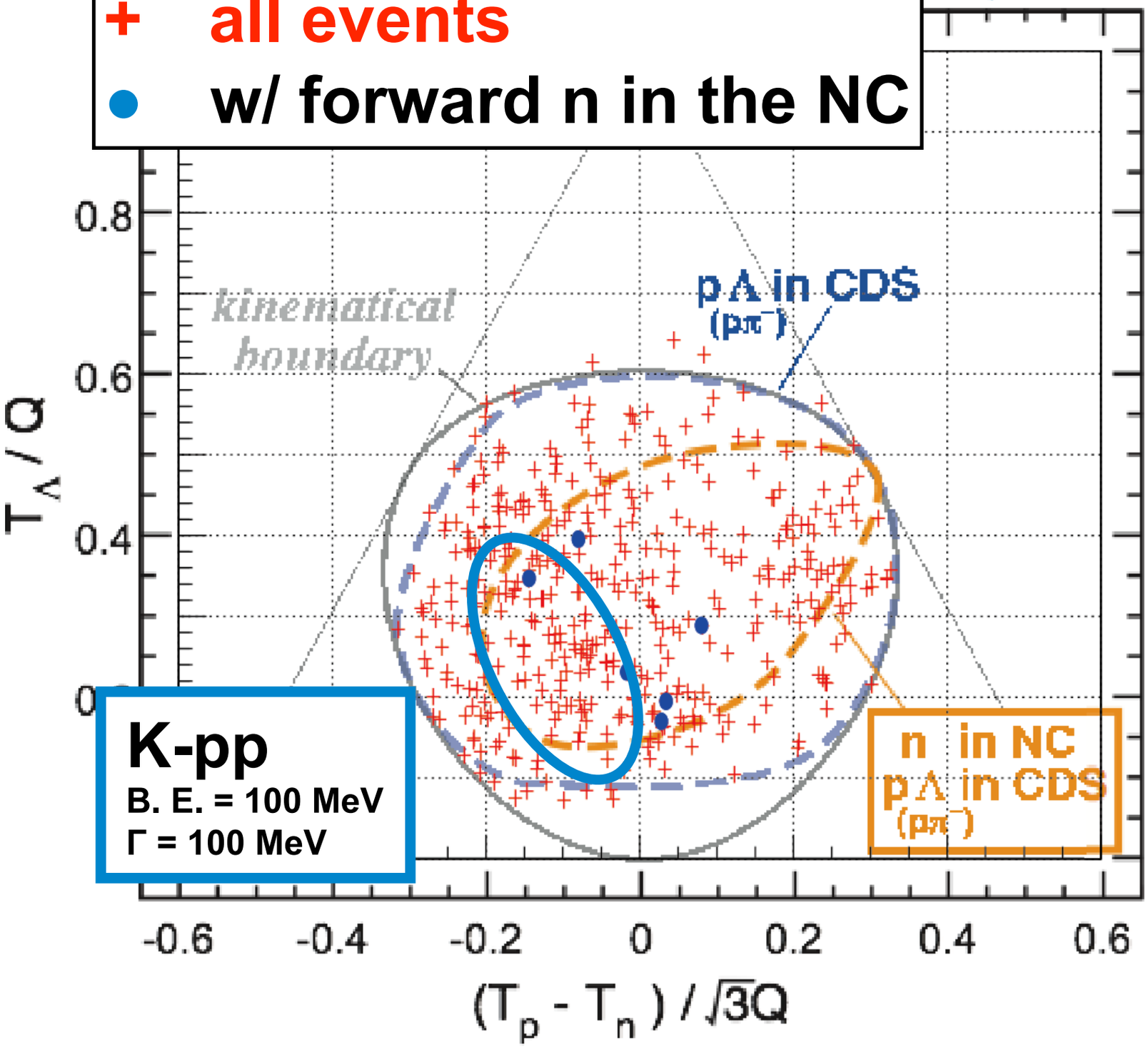


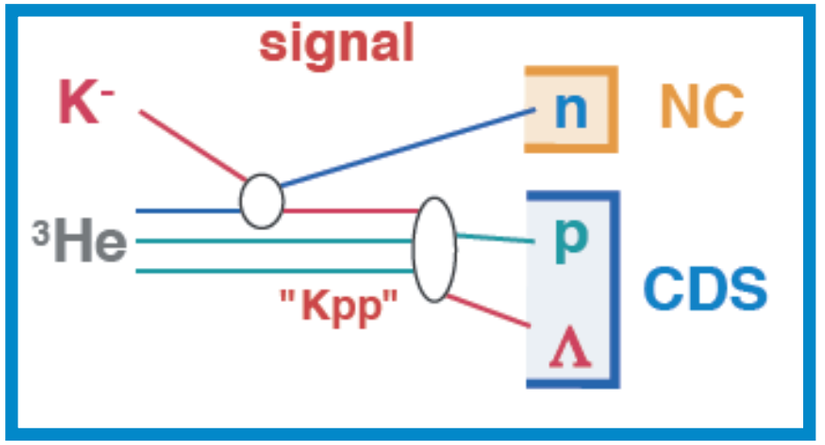


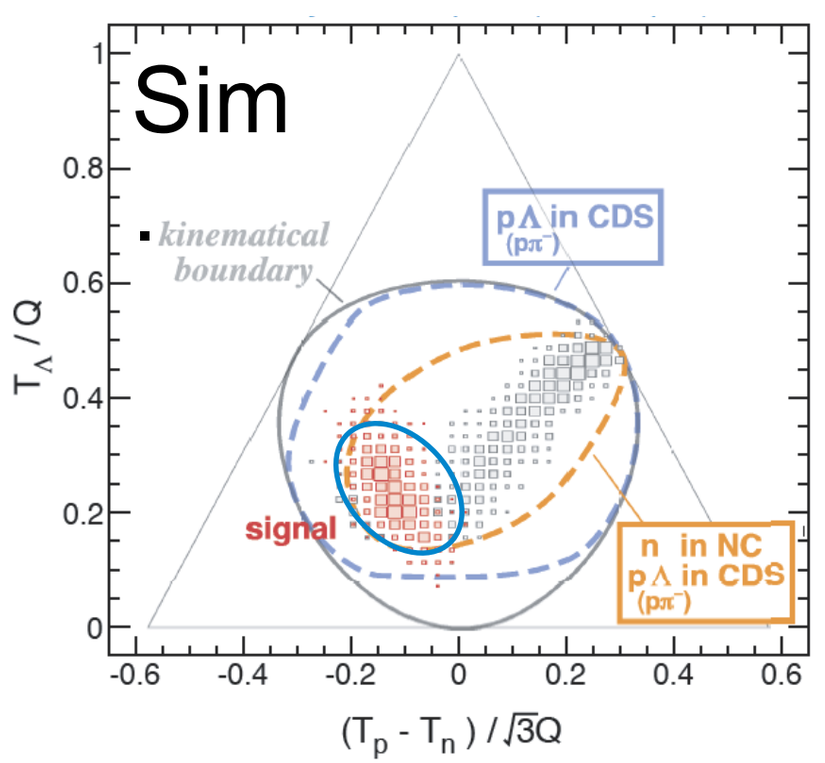


Λpn correlation

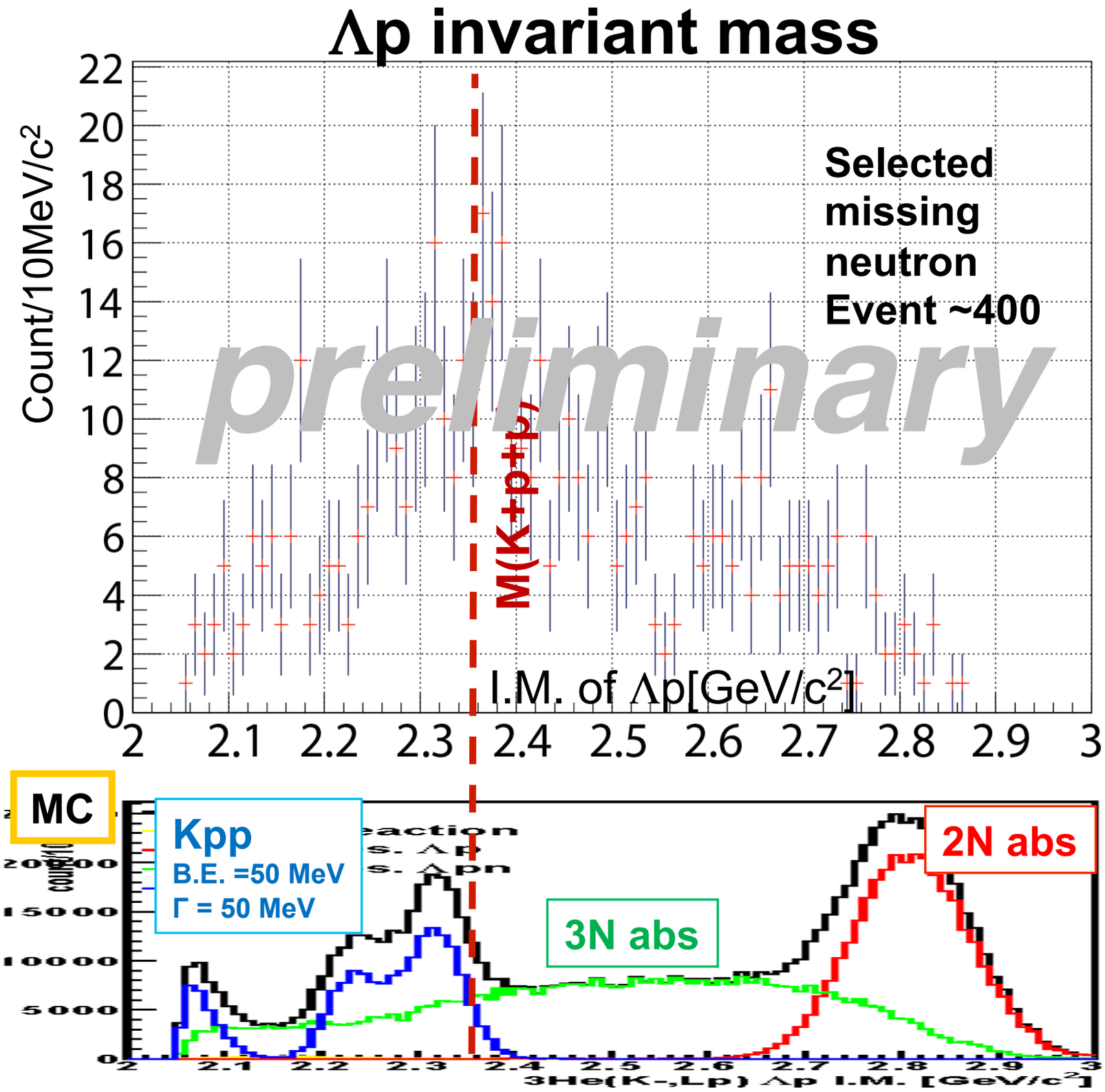
+ all events
● w/ forward n in the NC







Λp invariant mass (+ $n_{missing}$)



resolution ~ 10 MeV/c^2

- 2NA very weak
- 3NA dominant?
- structure around the threshold ??

need more data !!

Summary of J-PARC E15 status

- **J-PARC E15 1st stage physics run was performed**
  - **All the detector subsystems are working well with the good performance as designed**
  - **Unfortunately stopped at only 24 kW*4 day running (< 1% of full proposal)**

- **Semi-inclusive ^{3}He(K^{-},n)X spectrum have tail component in the K-bound region which is hard to be explained by ordinary processes**

- **^{3}He(K^{-},p)X spectrum looks very similar to (K^{-},n)**

- **Λ + p + n$_{(missing)}$ correlation analysis seems interesting when the statistics is much improved in the future run.**