Status and perspectives of

η′-mesic nuclei spectroscopy

RIKEN Nishina Center
Kenta Itahashi

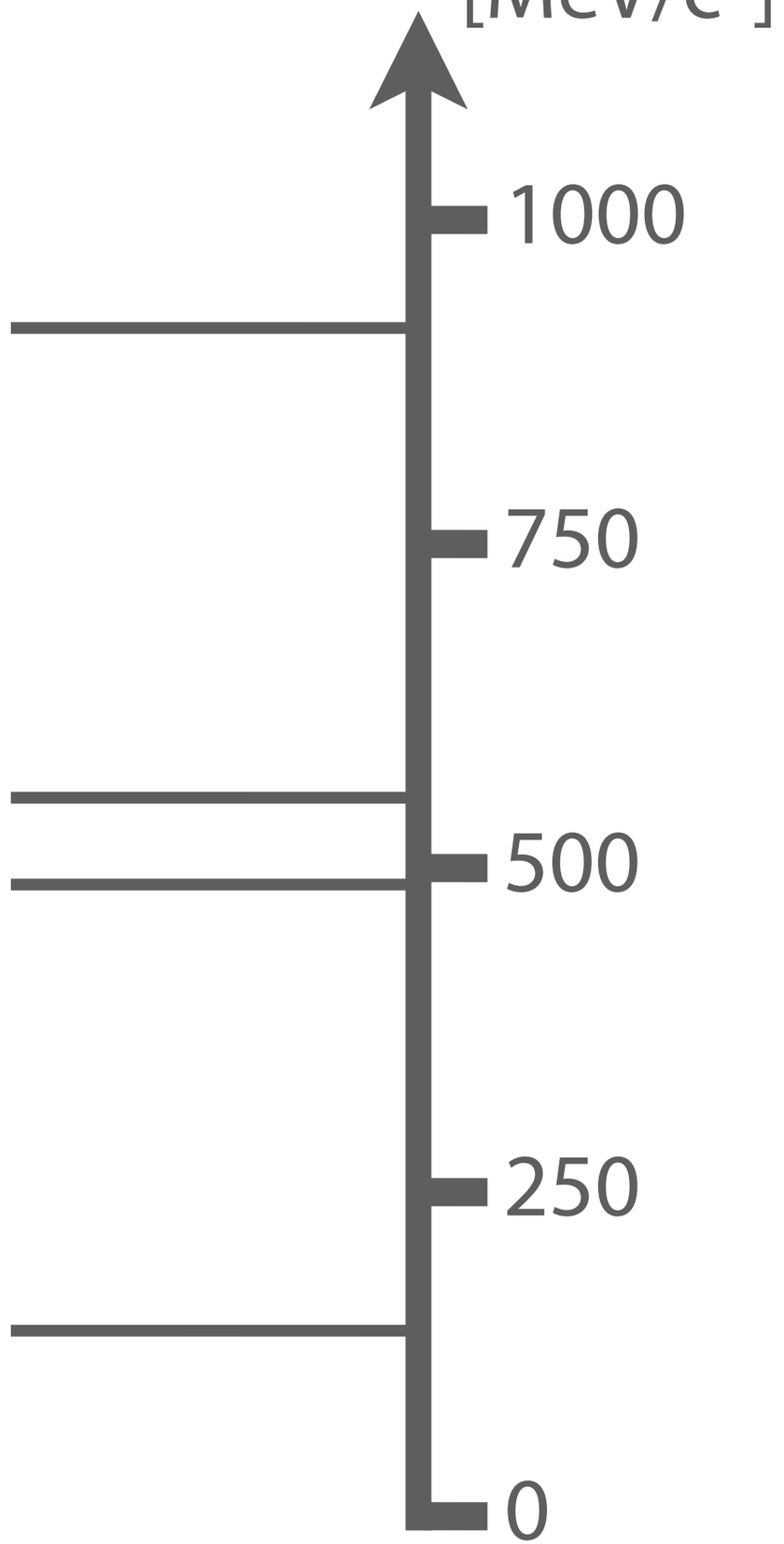
η′ and other PS mesons

η′ M=958 MeV/c²

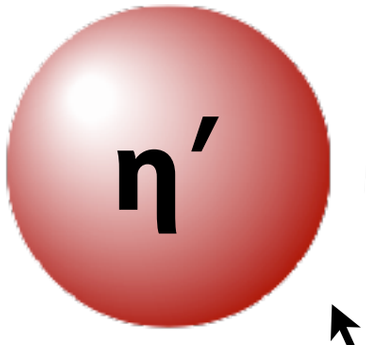
η M=548 MeV/c²

K M=498 MeV/c²

π M=140 MeV/c²



η′ and other PS mesons



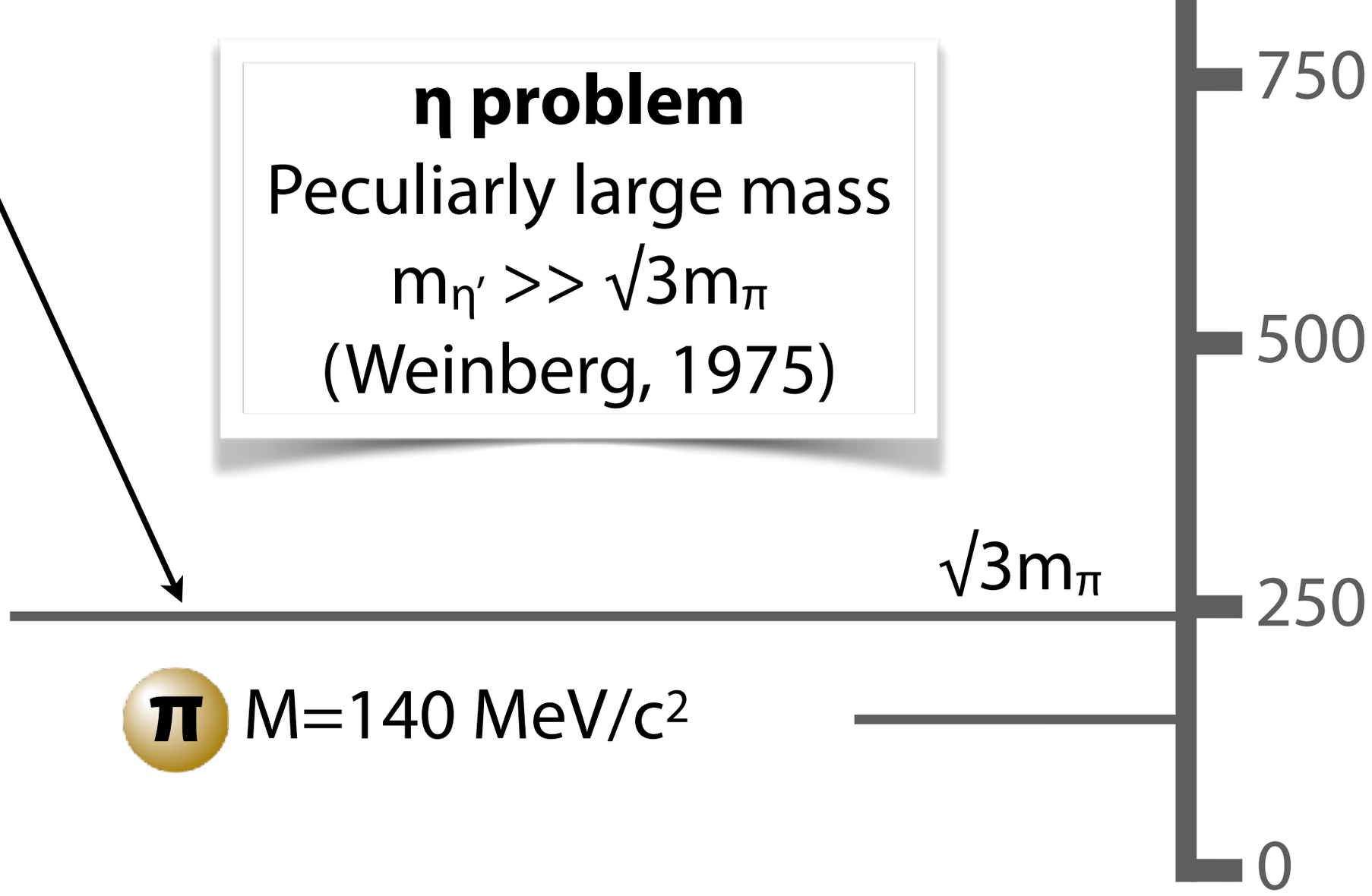
M=958 MeV/c²

η problem

Peculiarly large mass

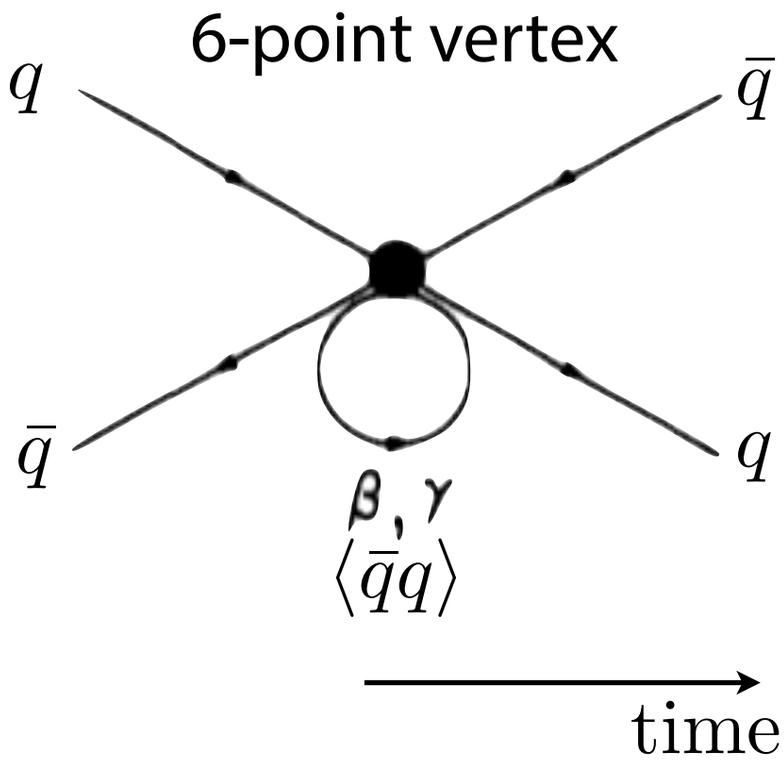
$m_{\eta'} >> \sqrt{3}m_\pi$

(Weinberg, 1975)

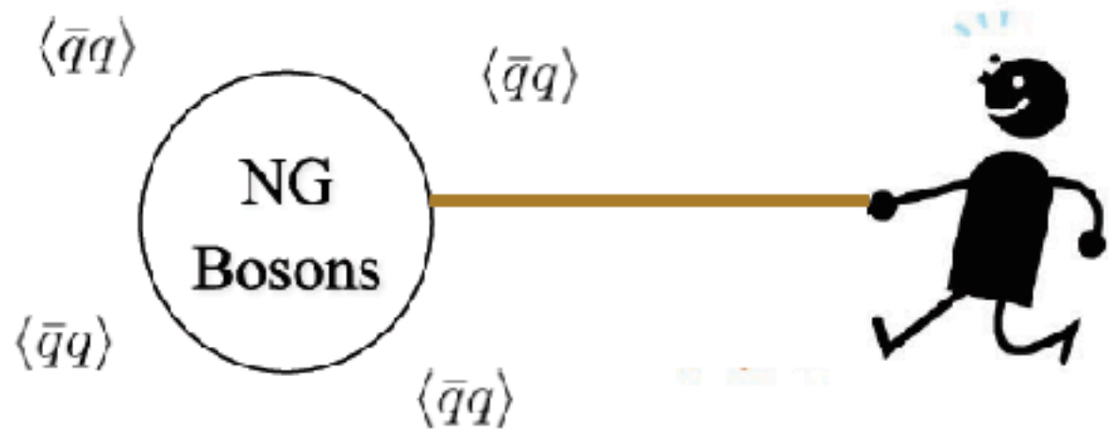


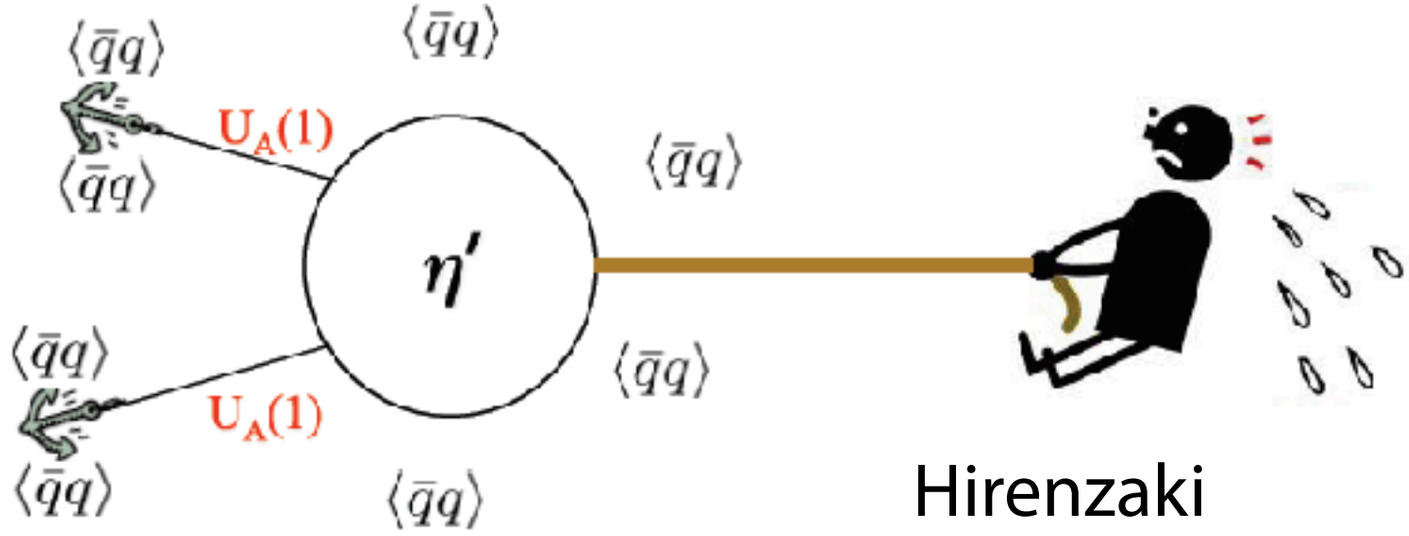
Large η' mass = $U_A(1)$ × chiral condensate

$U_A(1)$ symmetry breaking term of effective Lagrangian



Kobayashi-Maskawa-'t Hooft interaction





Hirenzaki

Kobayashi, Maskawa, PTP44(70)1422
't Hooft, PRD14(76)3432.
T. Kunihiro, Phys. Lett. B219(89)363.
Klimt, Lutz, Vogl, Weise, NPA516(90)429.

Large η' mass = $U_A(1)$ × chiral condensate

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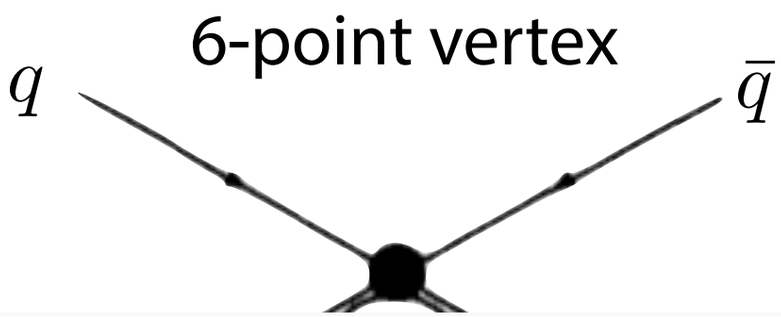
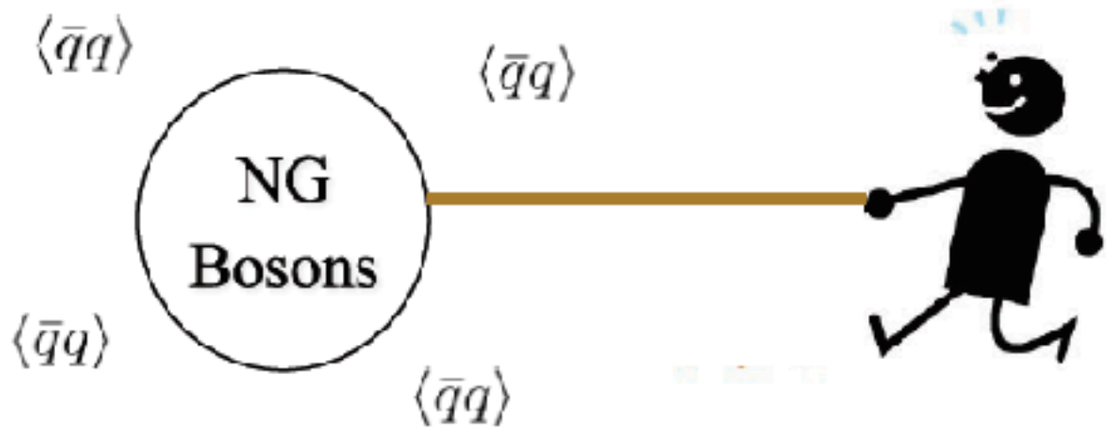


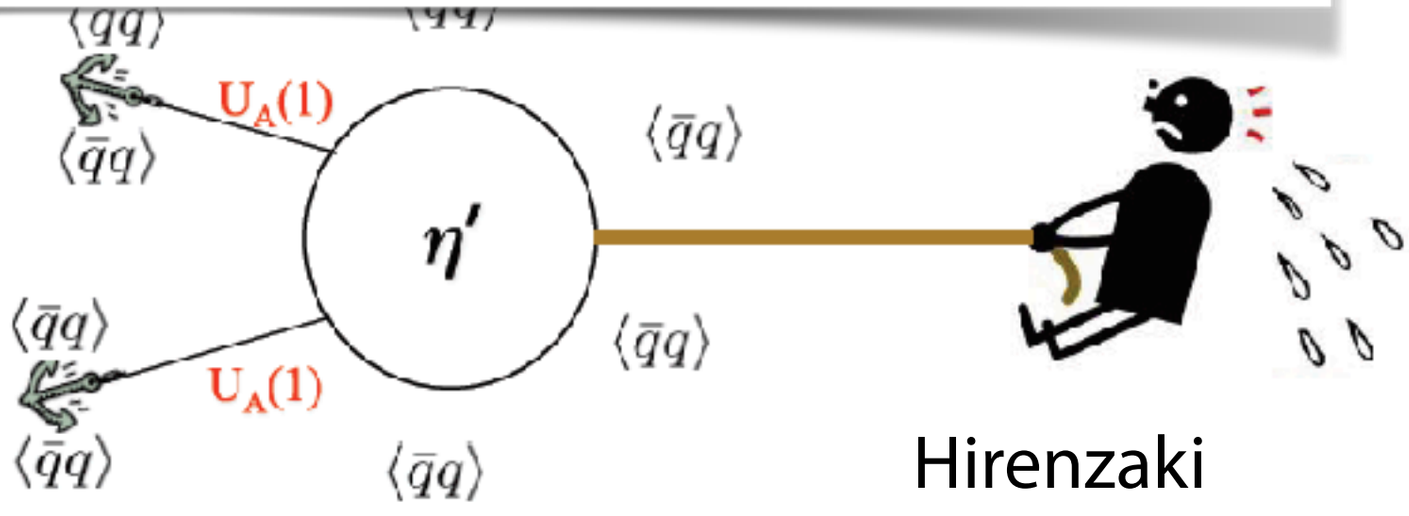


The question is "What happens if <qq> is smaller?"

$\langle\bar{q}q\rangle$

time

Kobayashi-Maskawa-'t Hooft interaction



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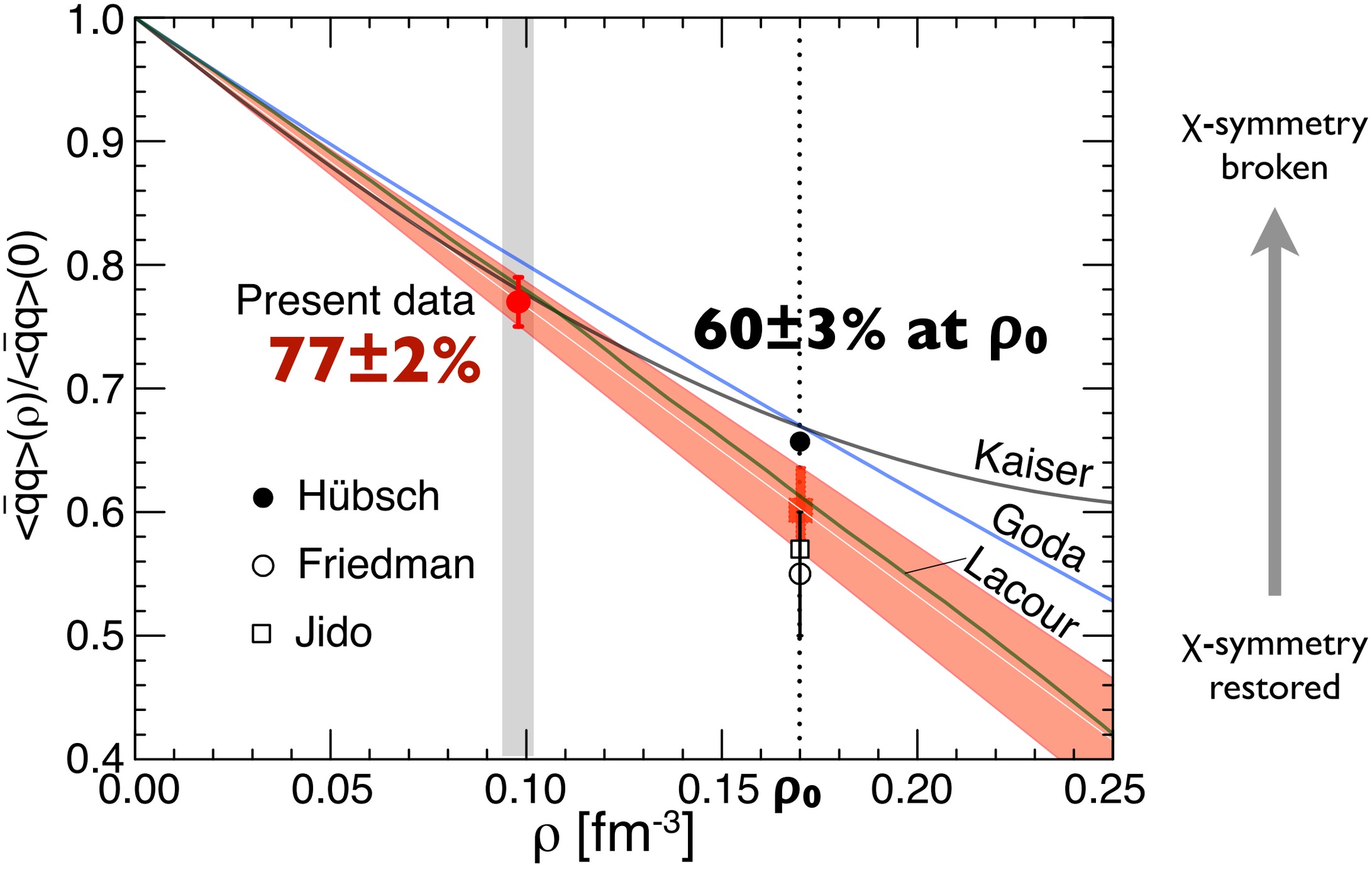
Chiral condensate decreases in nuclear matter
~pionic atom spectroscopy~



T. Nishi, KI et al., Nature Physics **19**, 788 (2023)
Article DOI: 10.1038/s41567-023-02001-x

Chiral condensate decreases in nuclear matter
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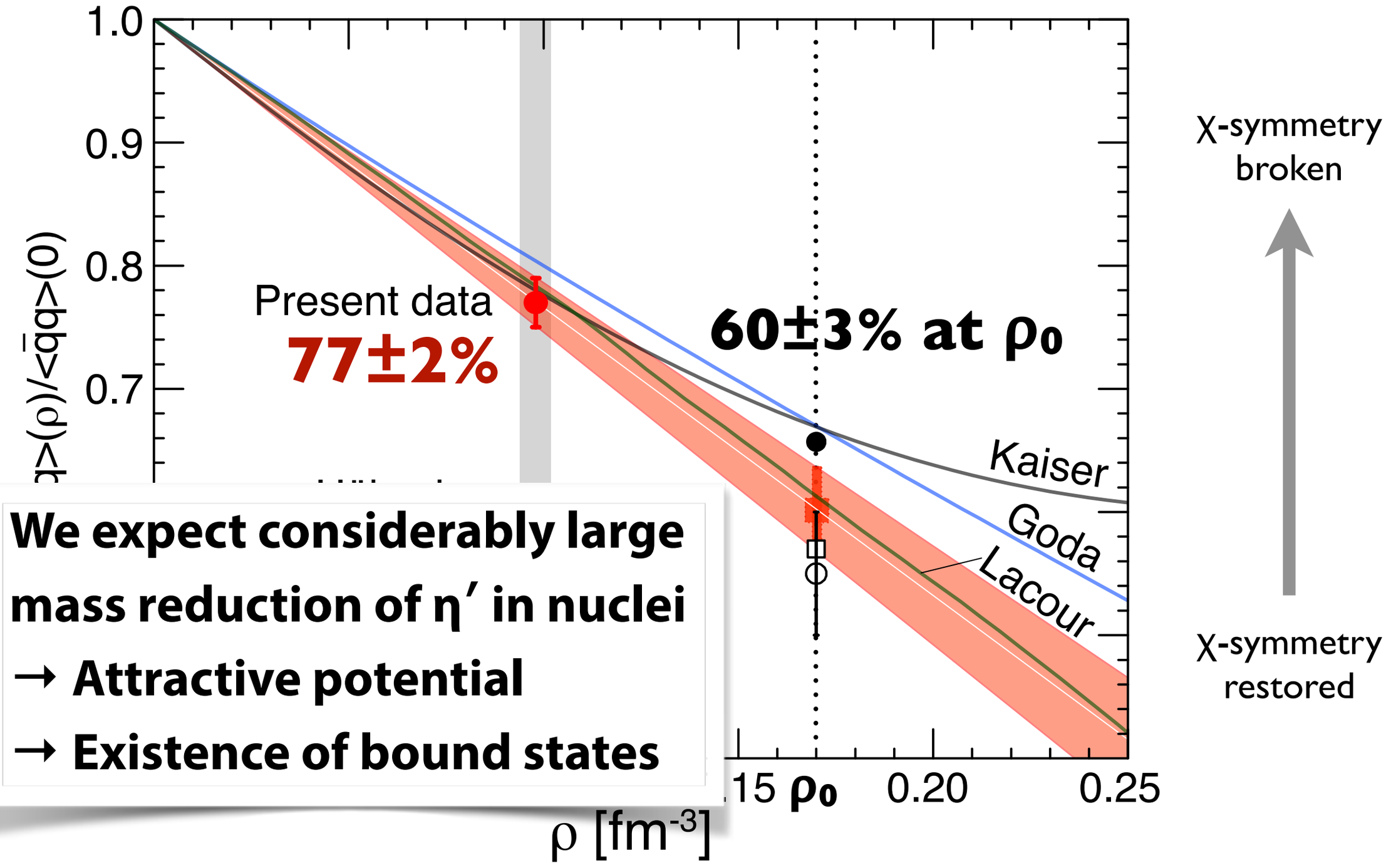


We expect considerably large mass reduction of η′ in nuclei

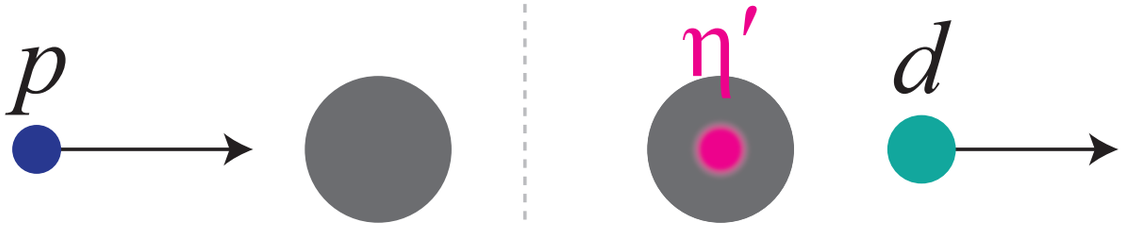
→ Attractive potential

→ Existence of bound states

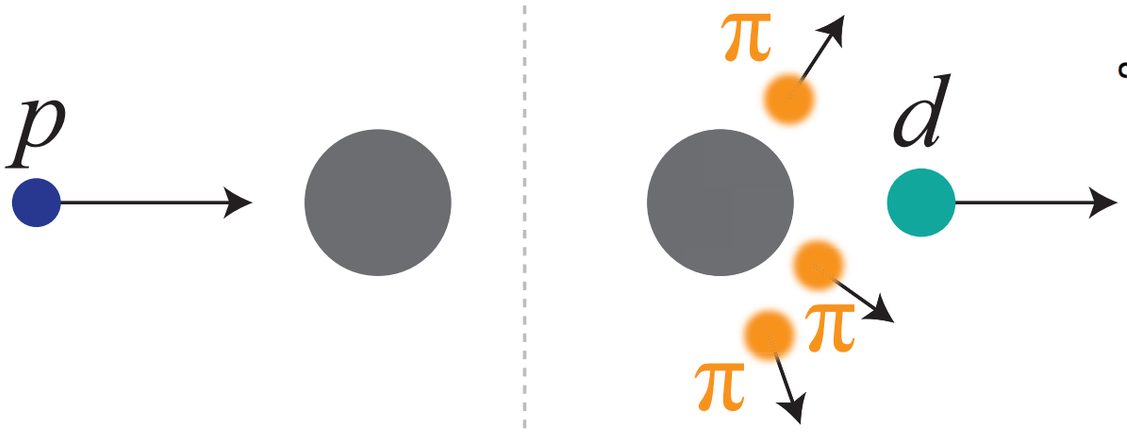
T. Nishi, KI et al., Nature Physics **19**, 788 (2023)
Article DOI: 10.1038/s41567-023-02001-x

Missing-mass of $^{12}C(p,d)$ inclusive measurement

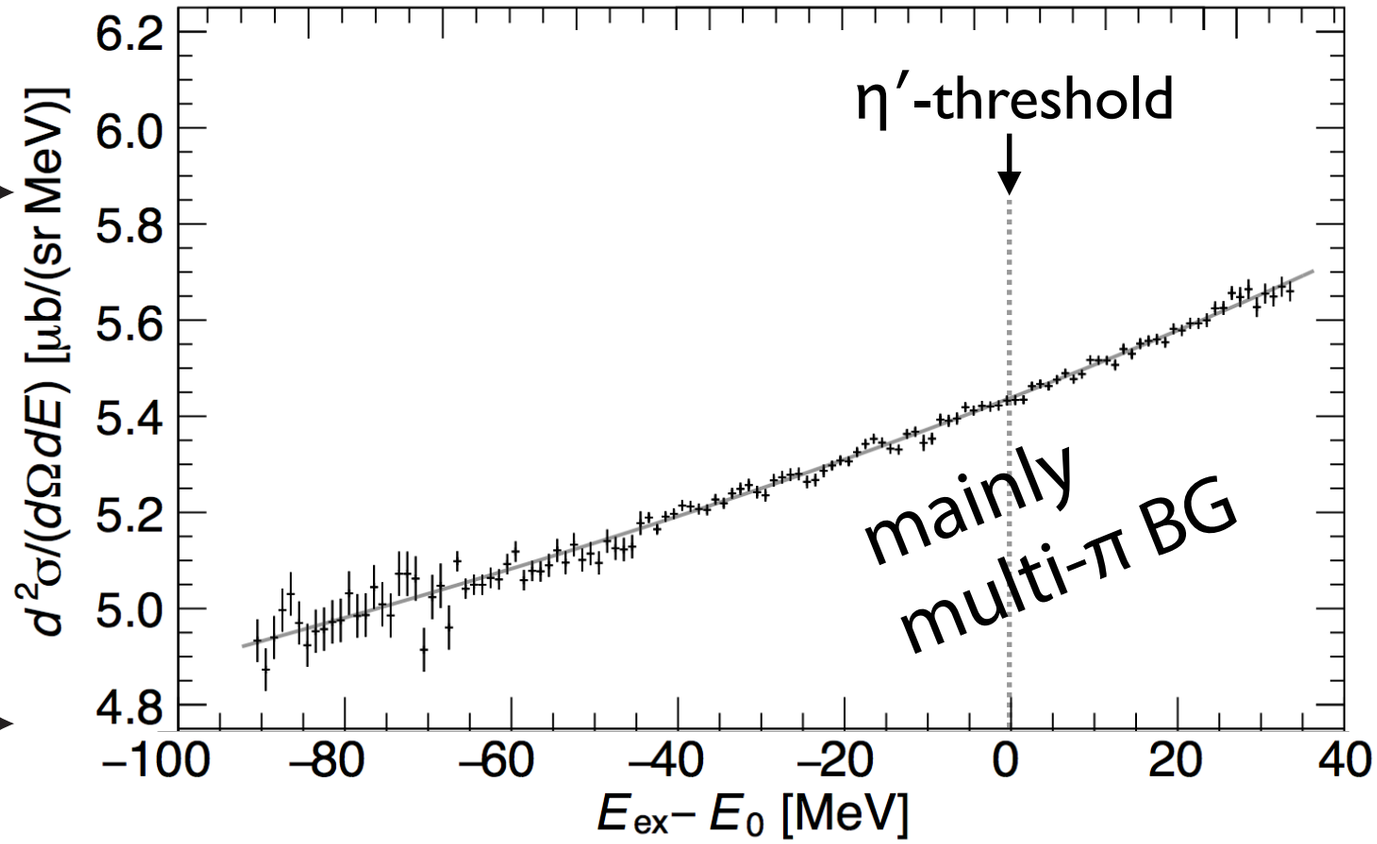
Signal



Background



S437:$^{12}C(p,d)$ in 2014 at FRS/GSI



Y.K. Tanaka et al., Phys. Rev. Lett. **117**, 202501(2016)

We achieved extremely high statistical sensitivity demonstrating very good performance of FRS. But, no peak was observed. Major BG=multi π. S/BG cross sections must be < 1/100

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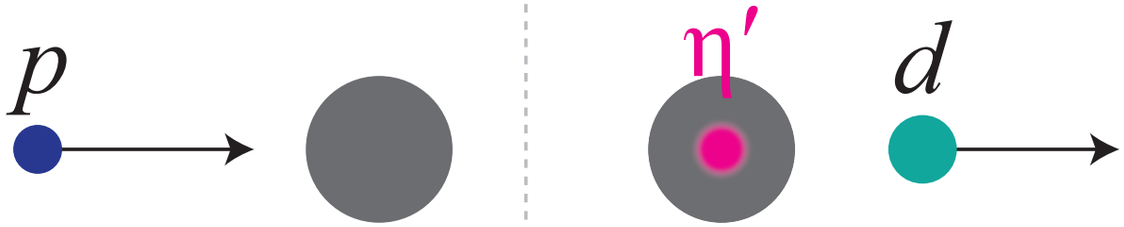
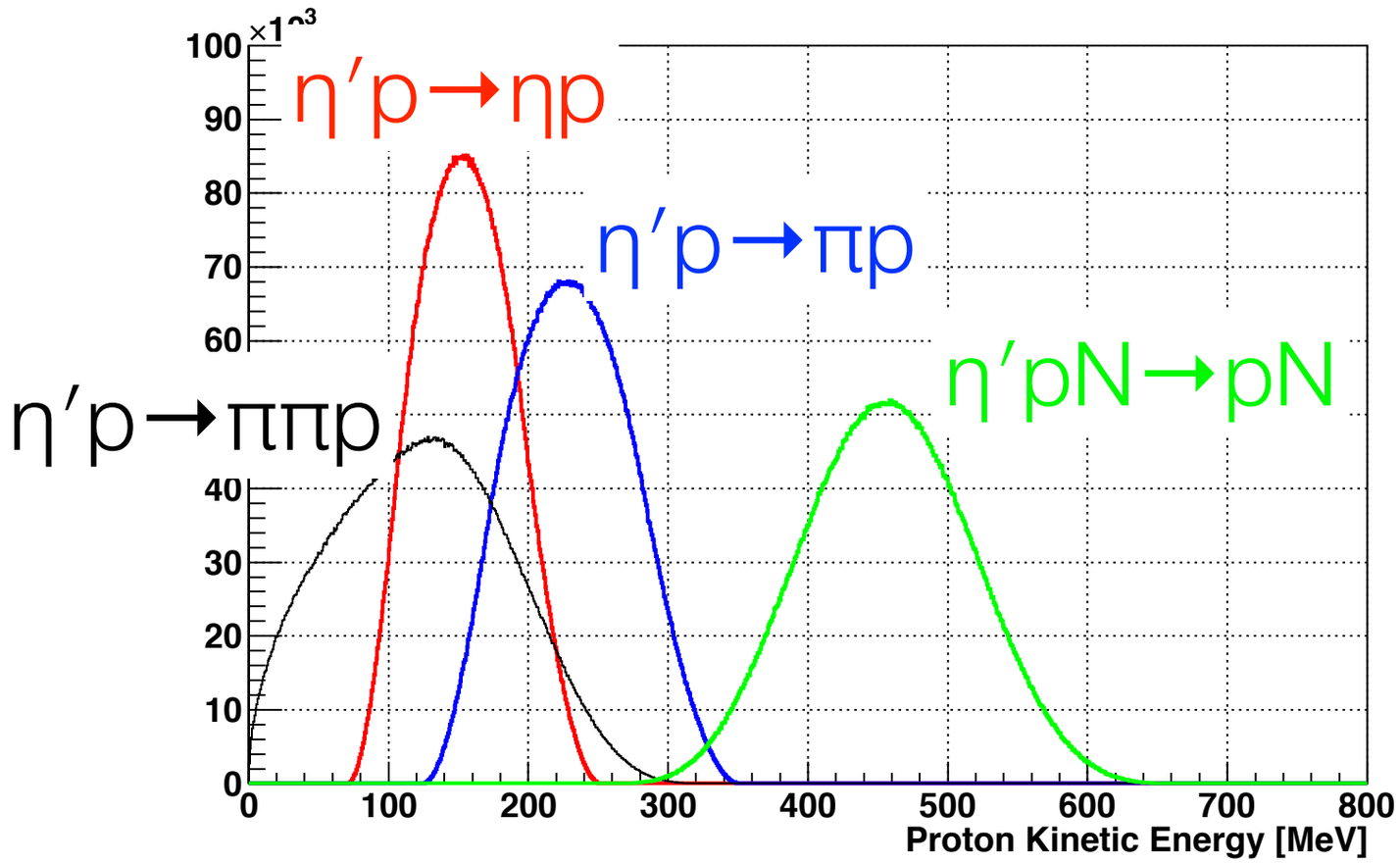
How to select signals

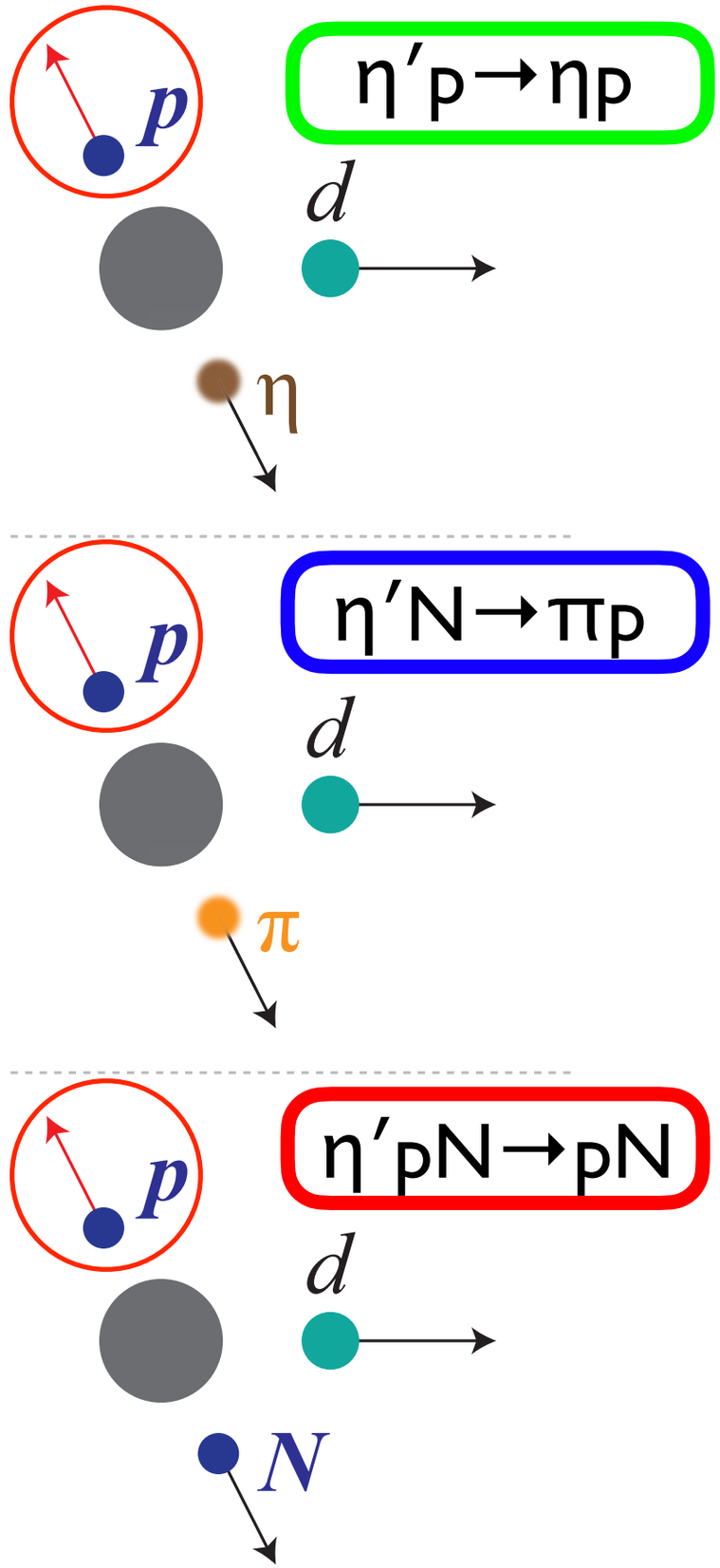
Signal





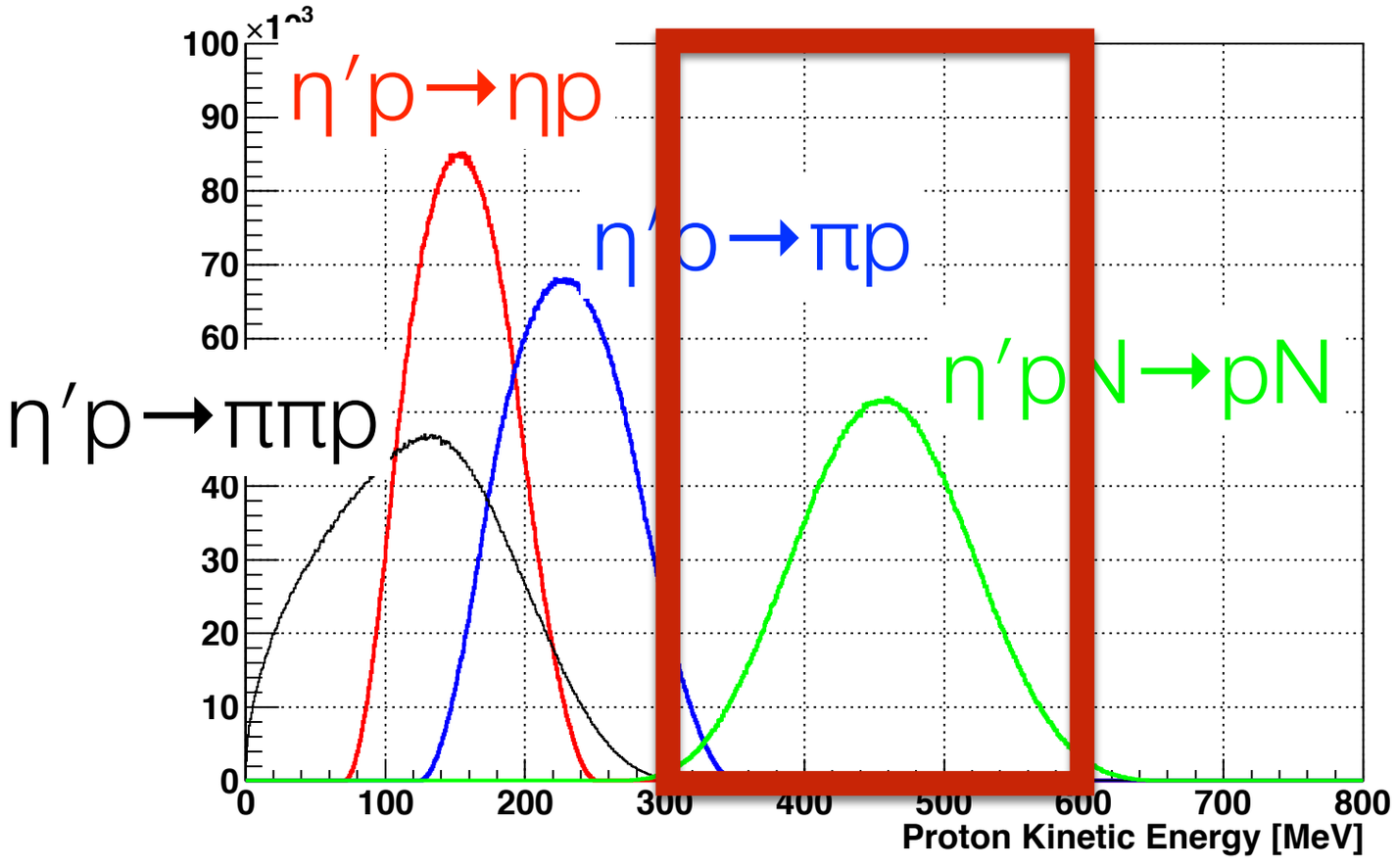
Y.K. Tanaka and Y. Higashi

3 major decay modes of η′-mesic nuclei



How to select signals

Detect *p* (800-1200 MeV/*c*) emitted in the decay of η′-nuclei for **semi-exclusive** measurement.
f ~ 100 improvement in S/BG



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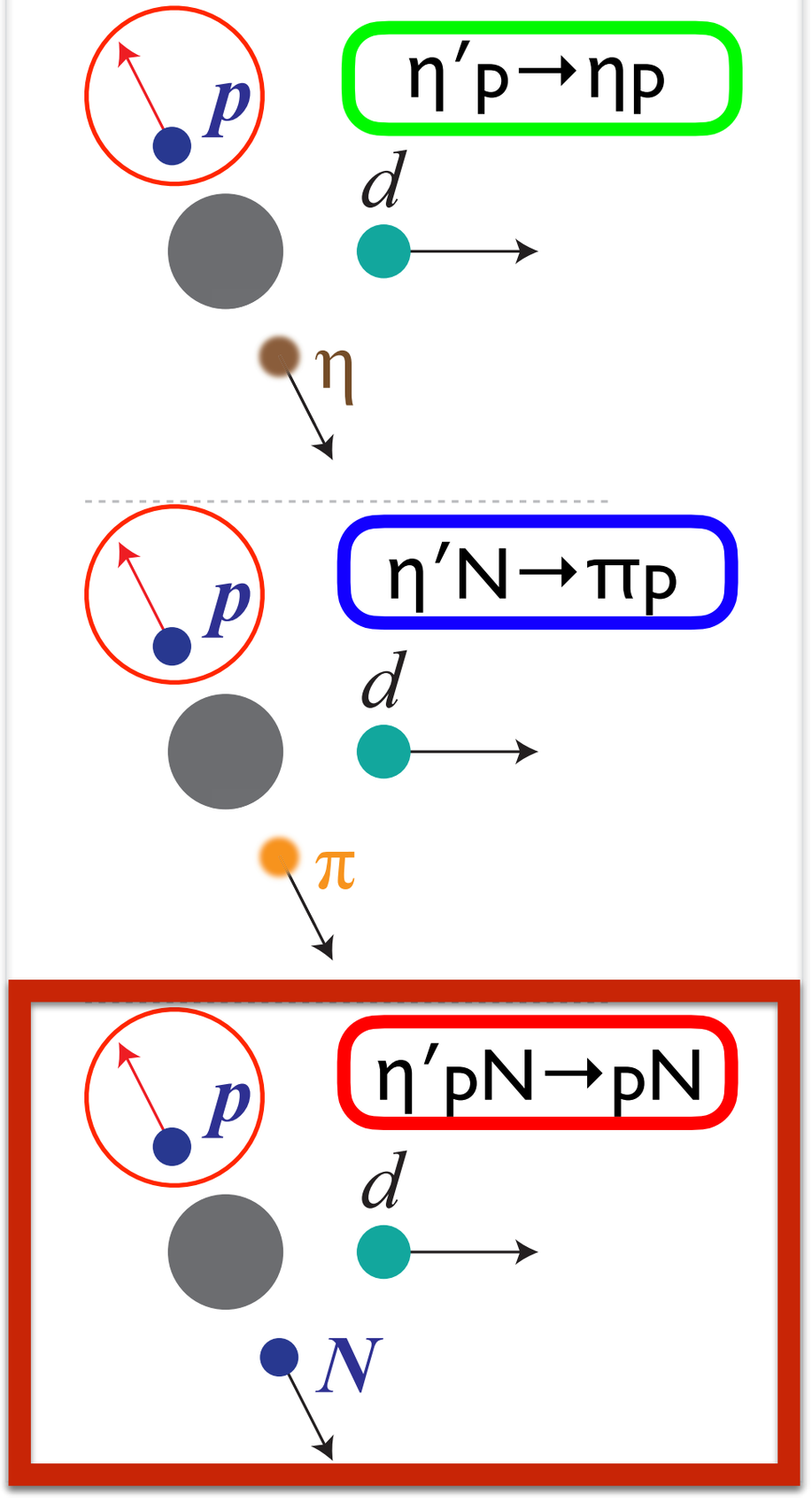
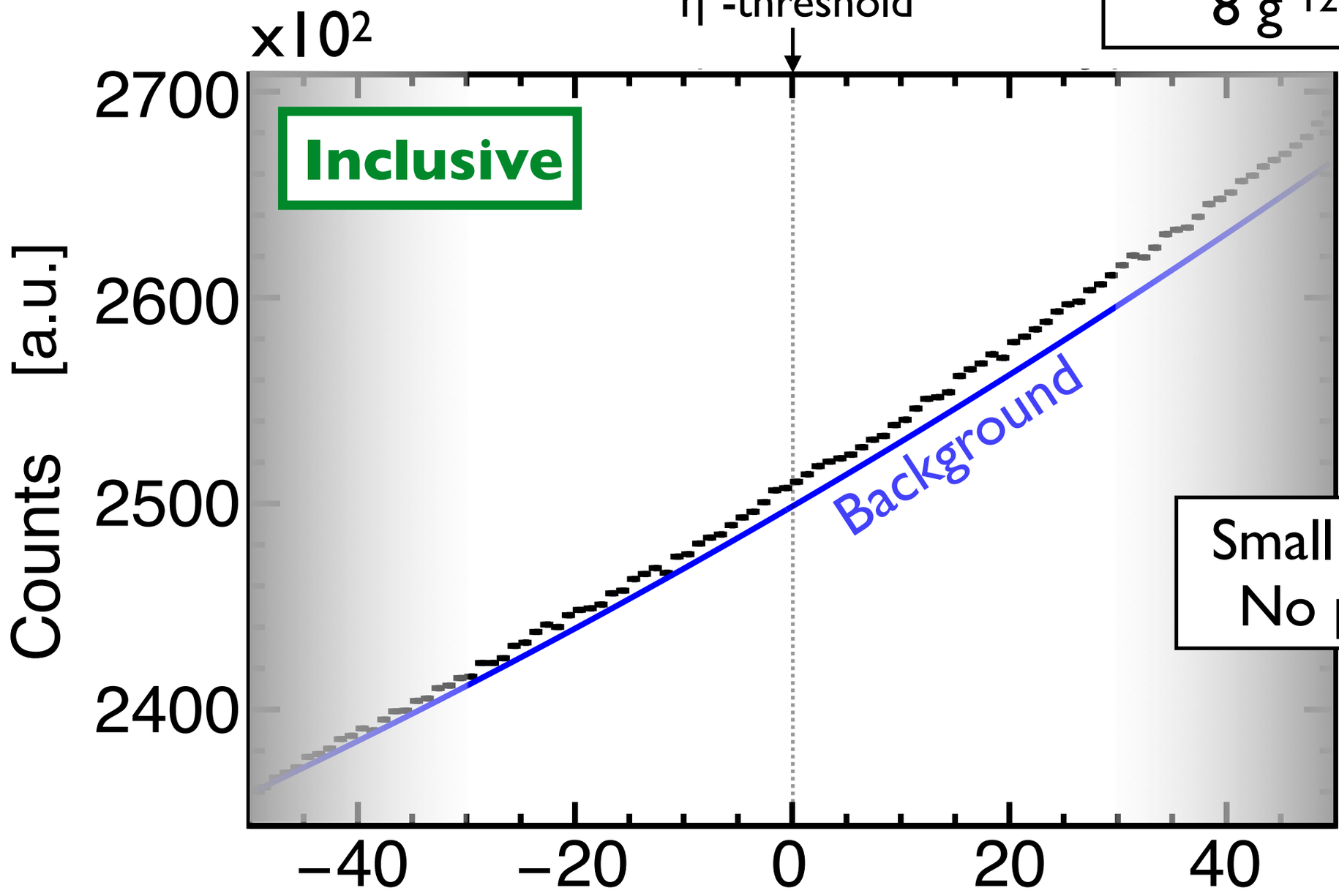


Expected spectrum in 4 days of DAQ at FRS

T_p = 2.5 GeV, ^{12}C(*p*,*d*)

p 2.5 GeV, 2.5x10^8/s,
8 g ^{12}C target



U(r=0) = −90−17i MeV

microscopic transport simulation

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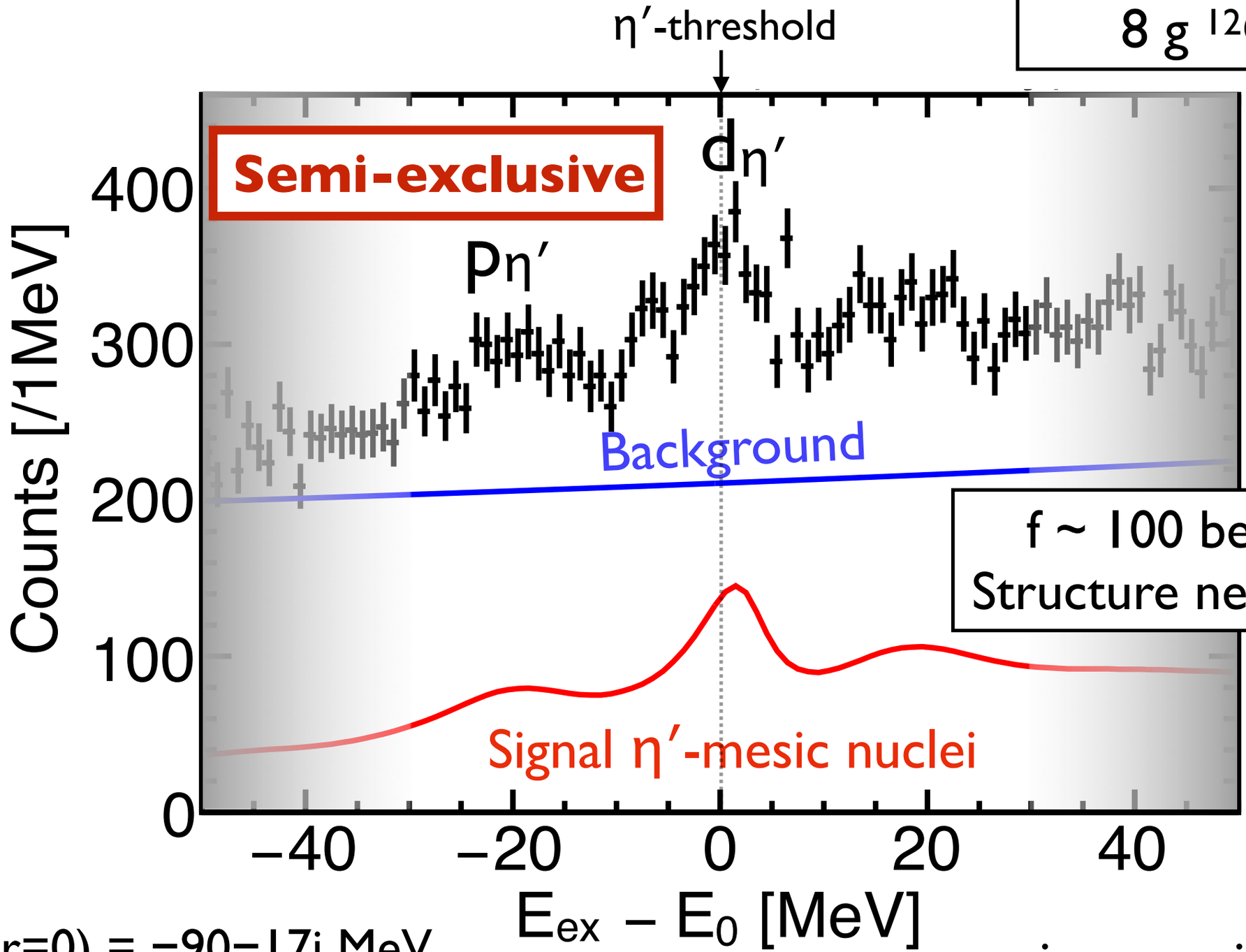
S490-η′

Expected spectrum in 4 days of DAQ at FRS

T_p = 2.5 GeV, ^{12}C(*p*,*dp*)

p 2.5 GeV, 2.5x10⁸/s,
8 g ^{12}C target



f ~ 100 better S/BG
Structure near threshold

U(r=0) = −90−17i MeV

microscopic transport simulation

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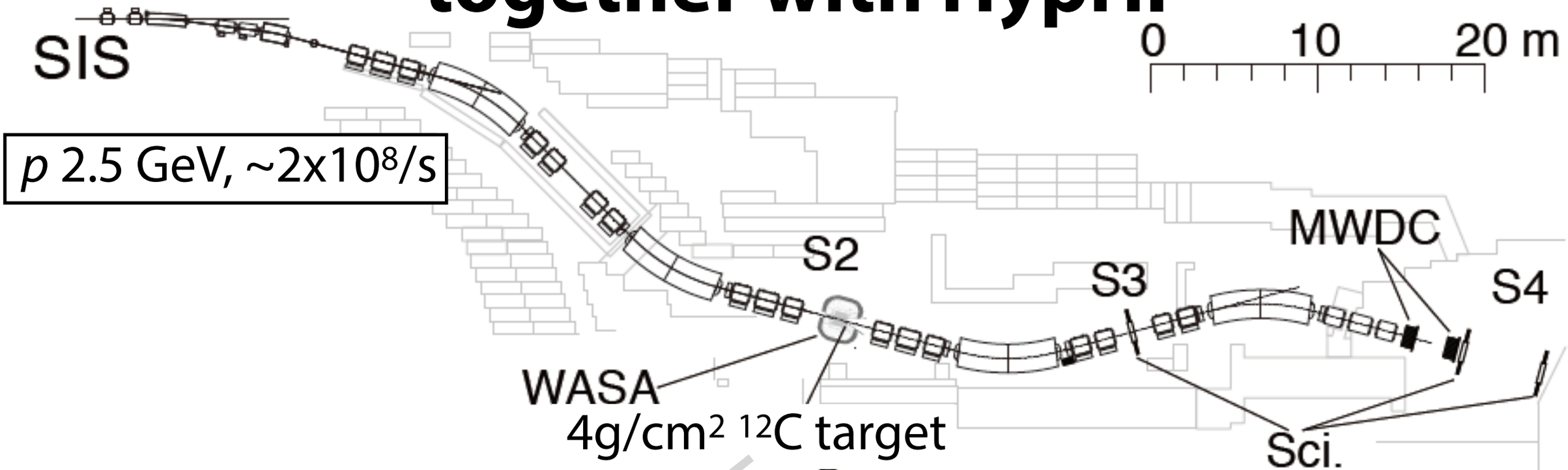
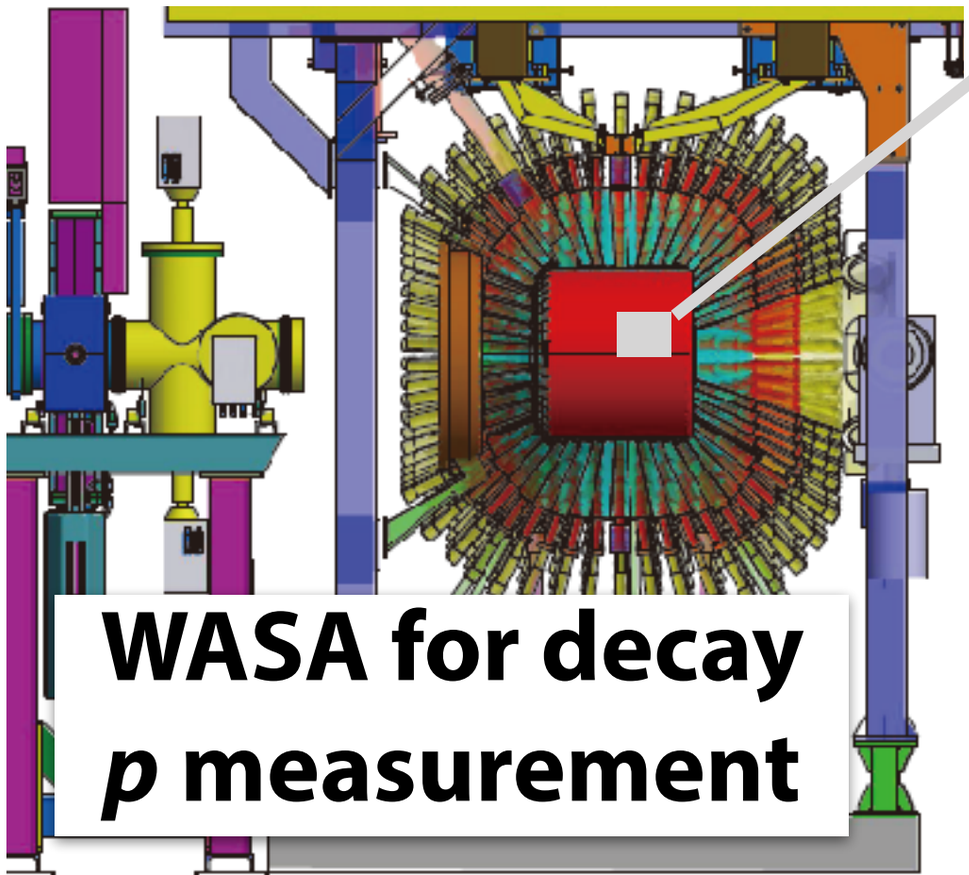
Experimental setup : ^{12}C(*p,dp*) in Feb. 2022 together with HypHI



Momentum analysis of (*p,d*) for Missing Mass Spectroscopy

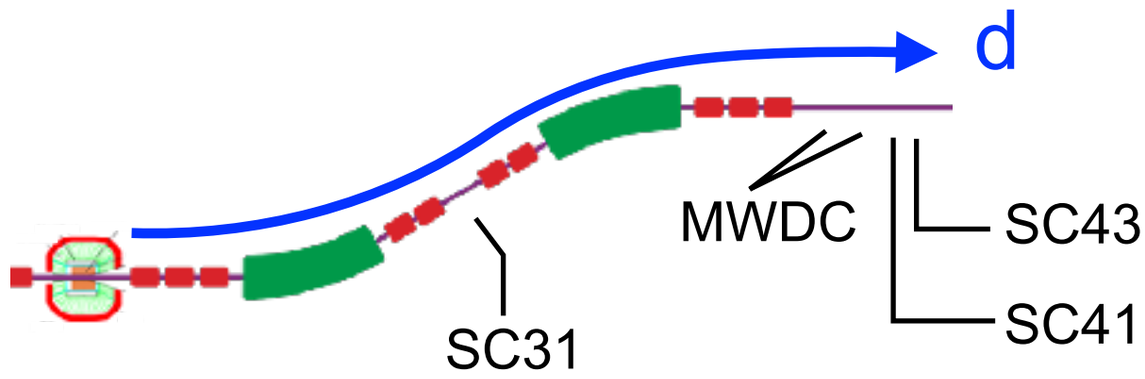


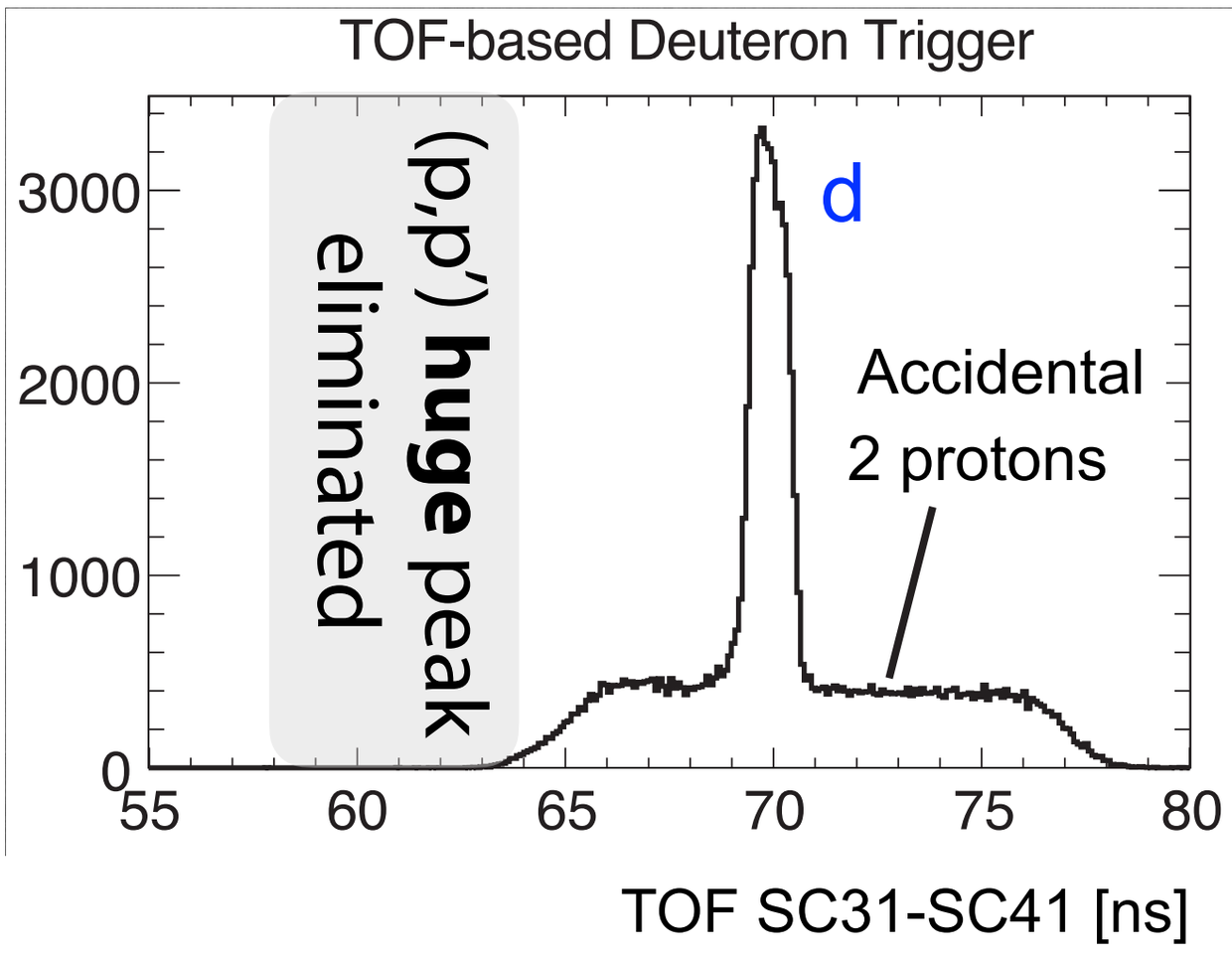
WASA for decay *p* measurement

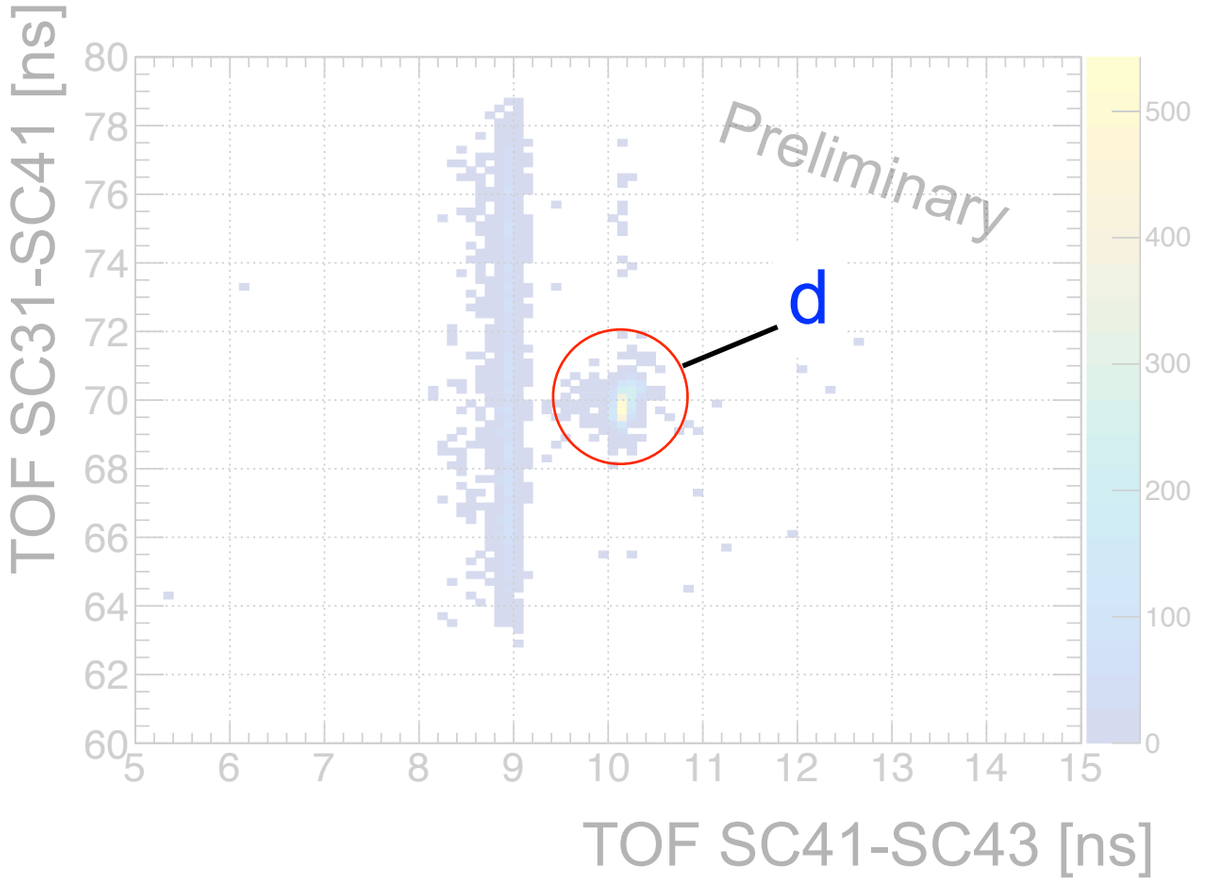
Combination of forward high-res. spectrometer and large solid angle detector

FRS S2-S4 PID Analysis

***p/d* ratio at S4 >1000**
SC31-SC41 TOF trigger
→ *p/d* ratio ~10







Y.K. Tanaka

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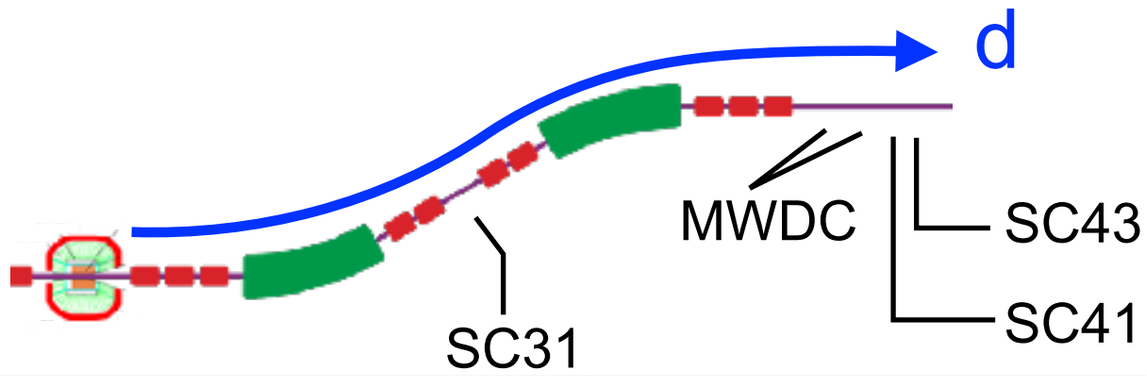
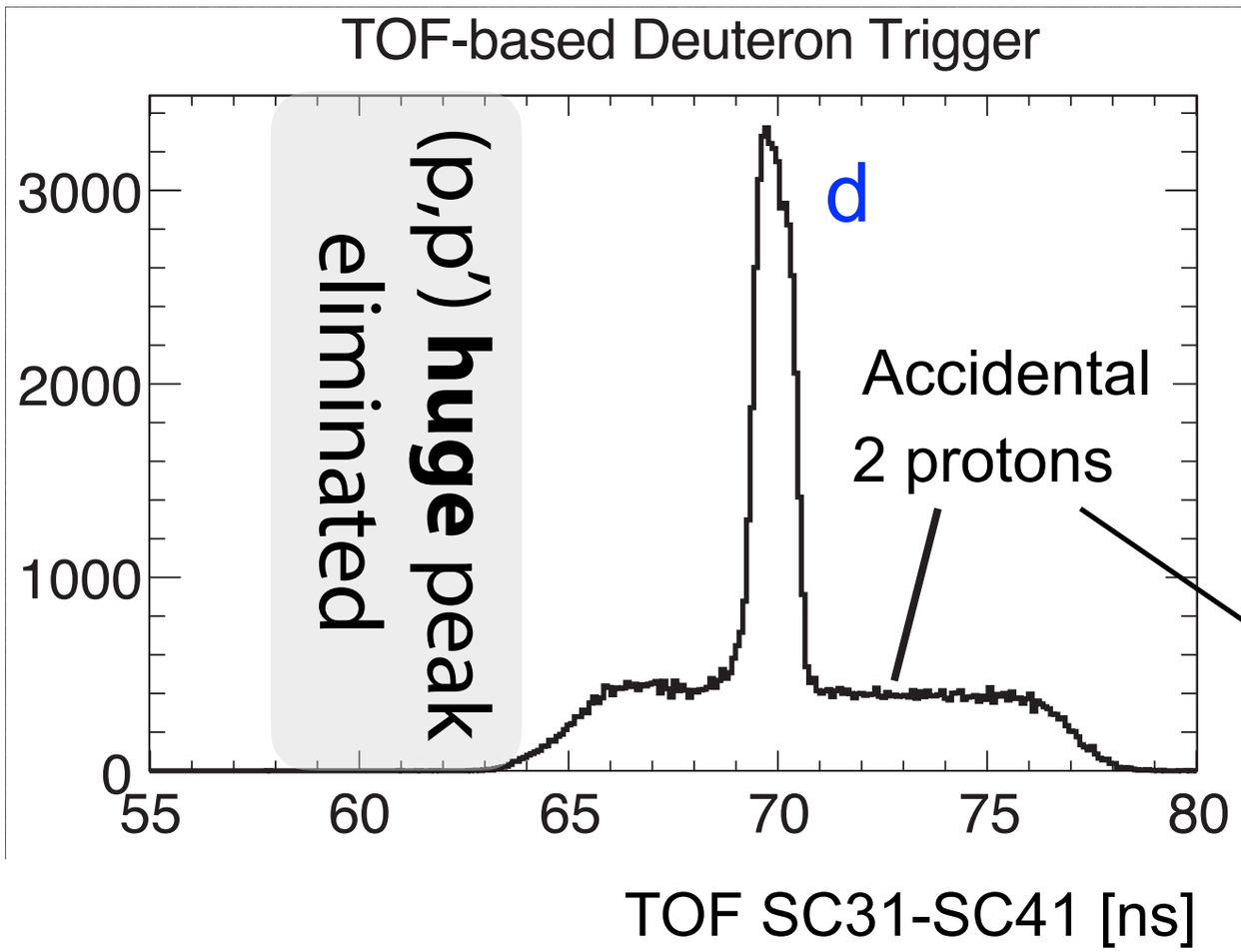
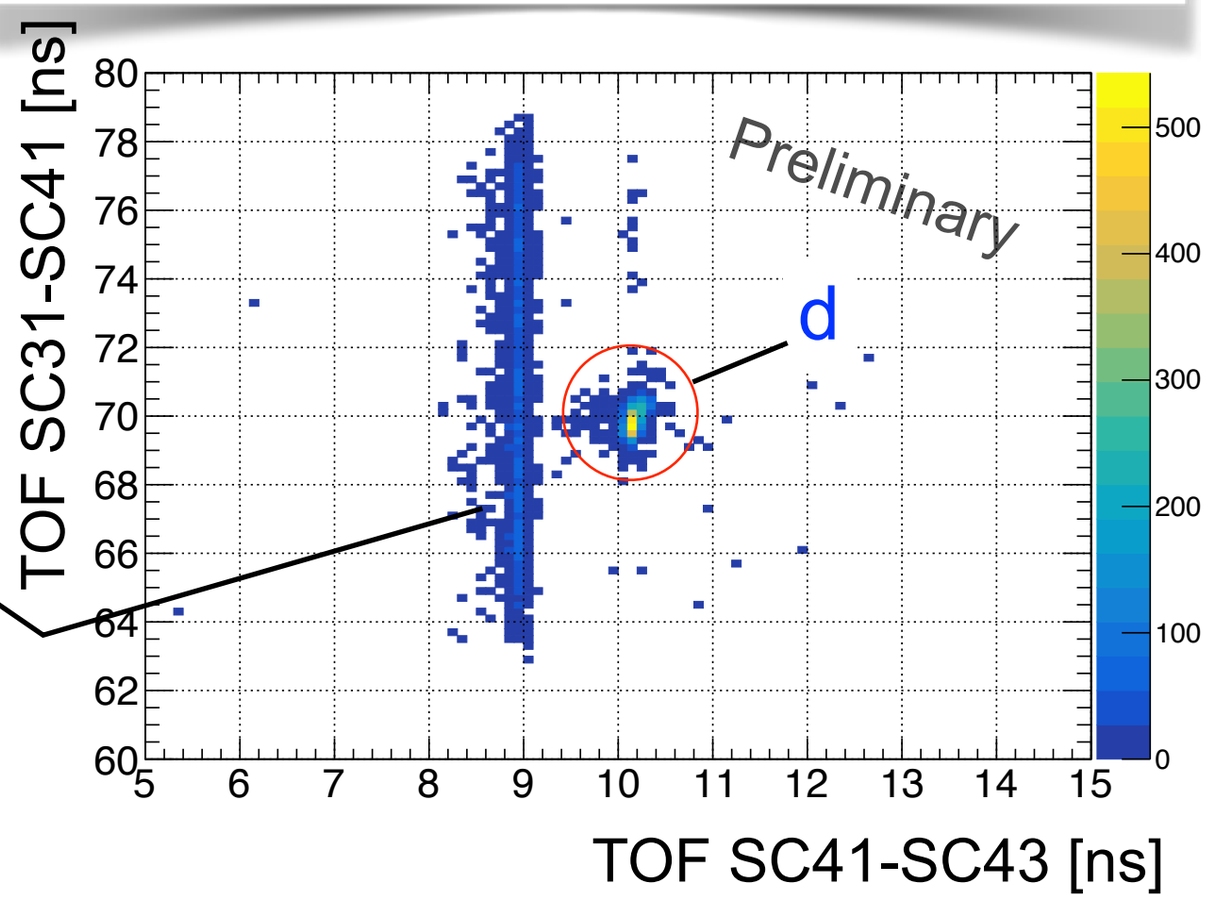


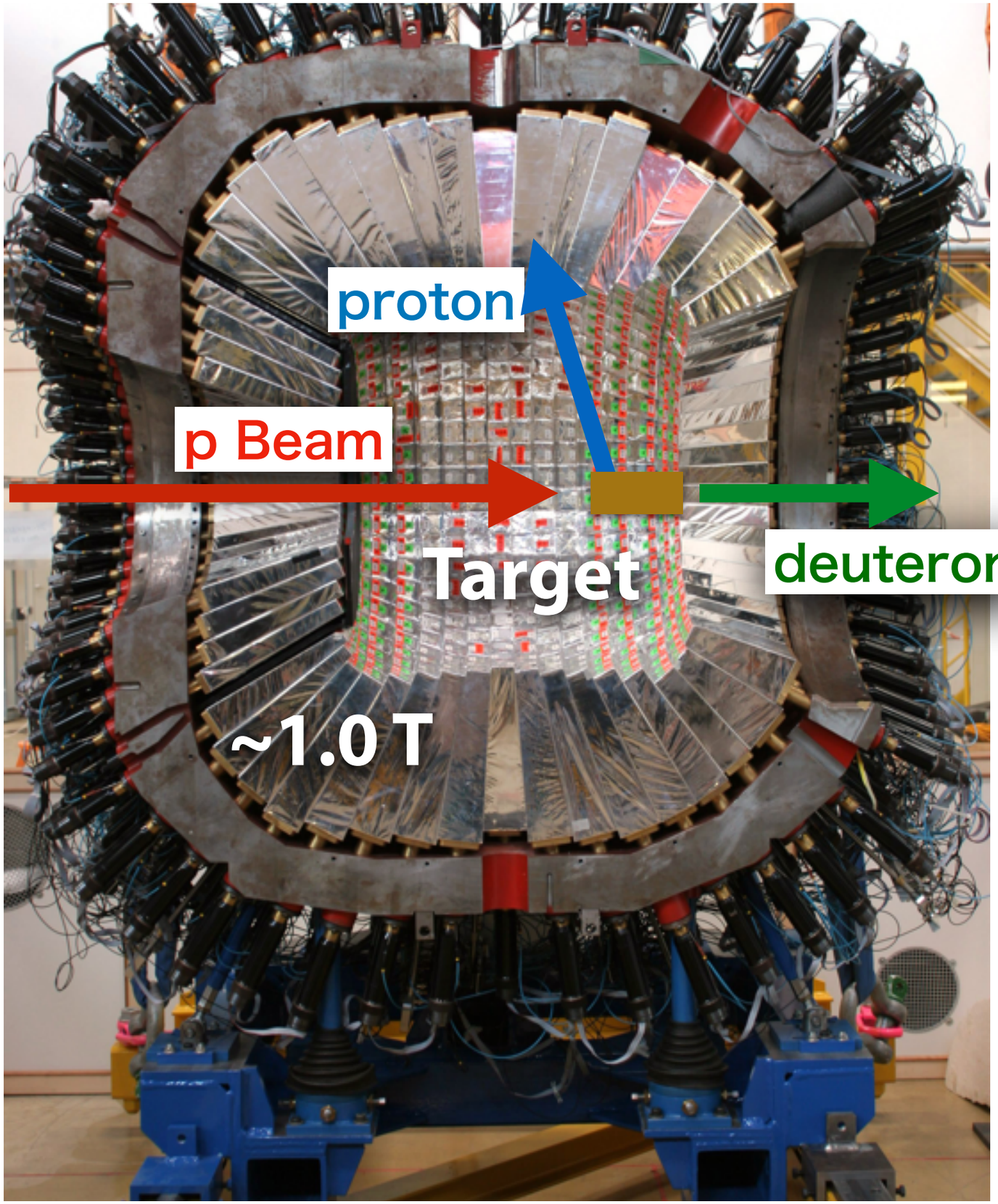
SC31-SC41-SC43 TOF made perfect offline PID

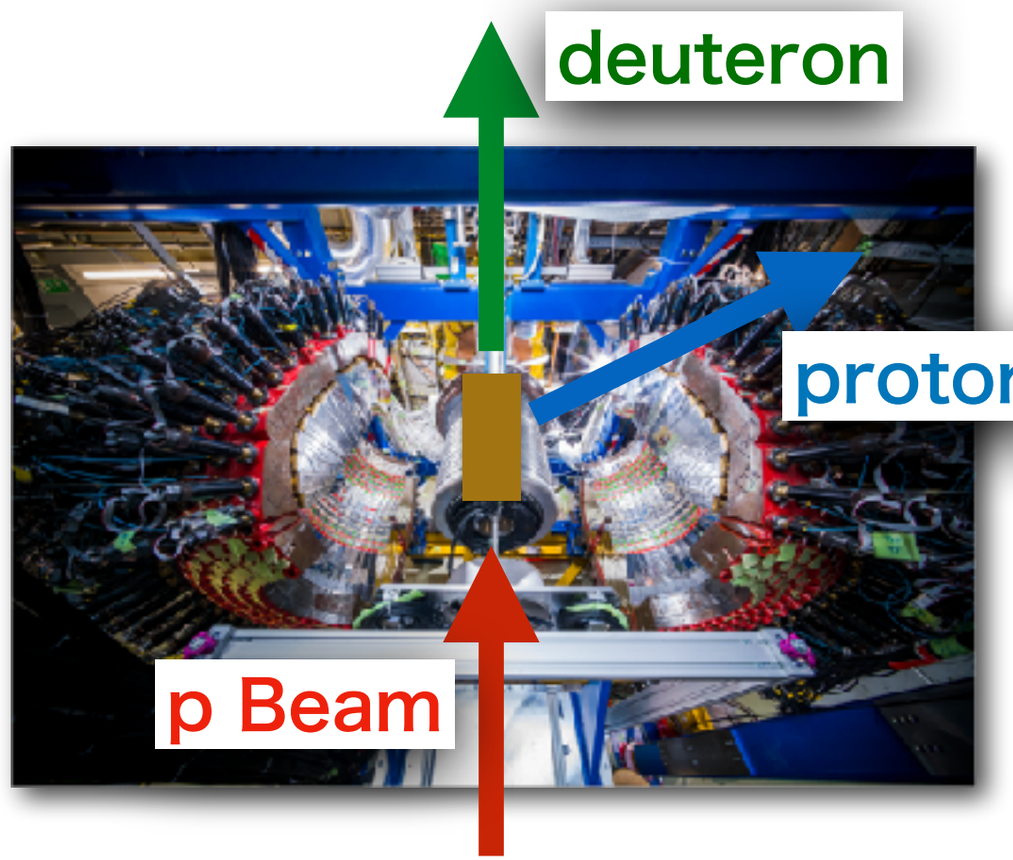




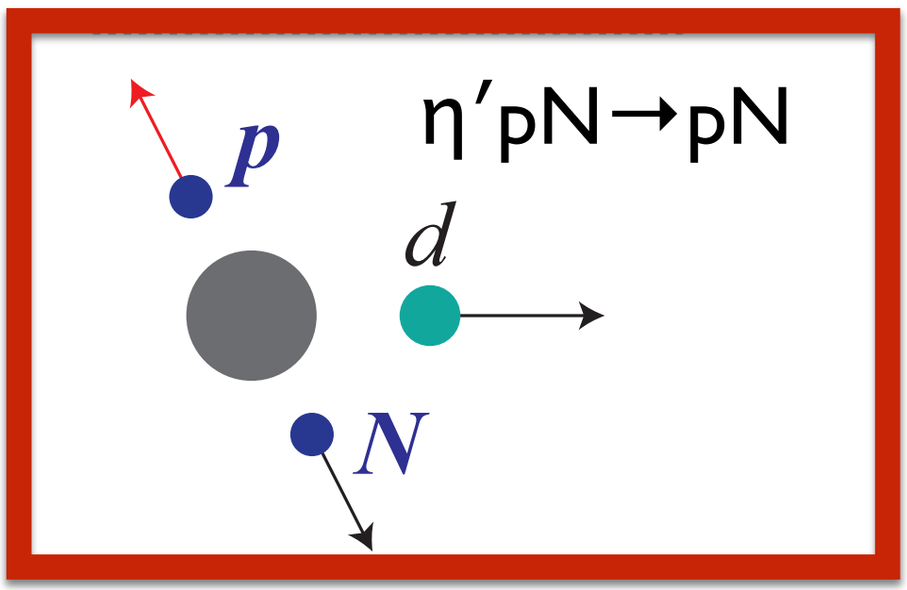
Y.K. Tanaka

Detectors in WASA



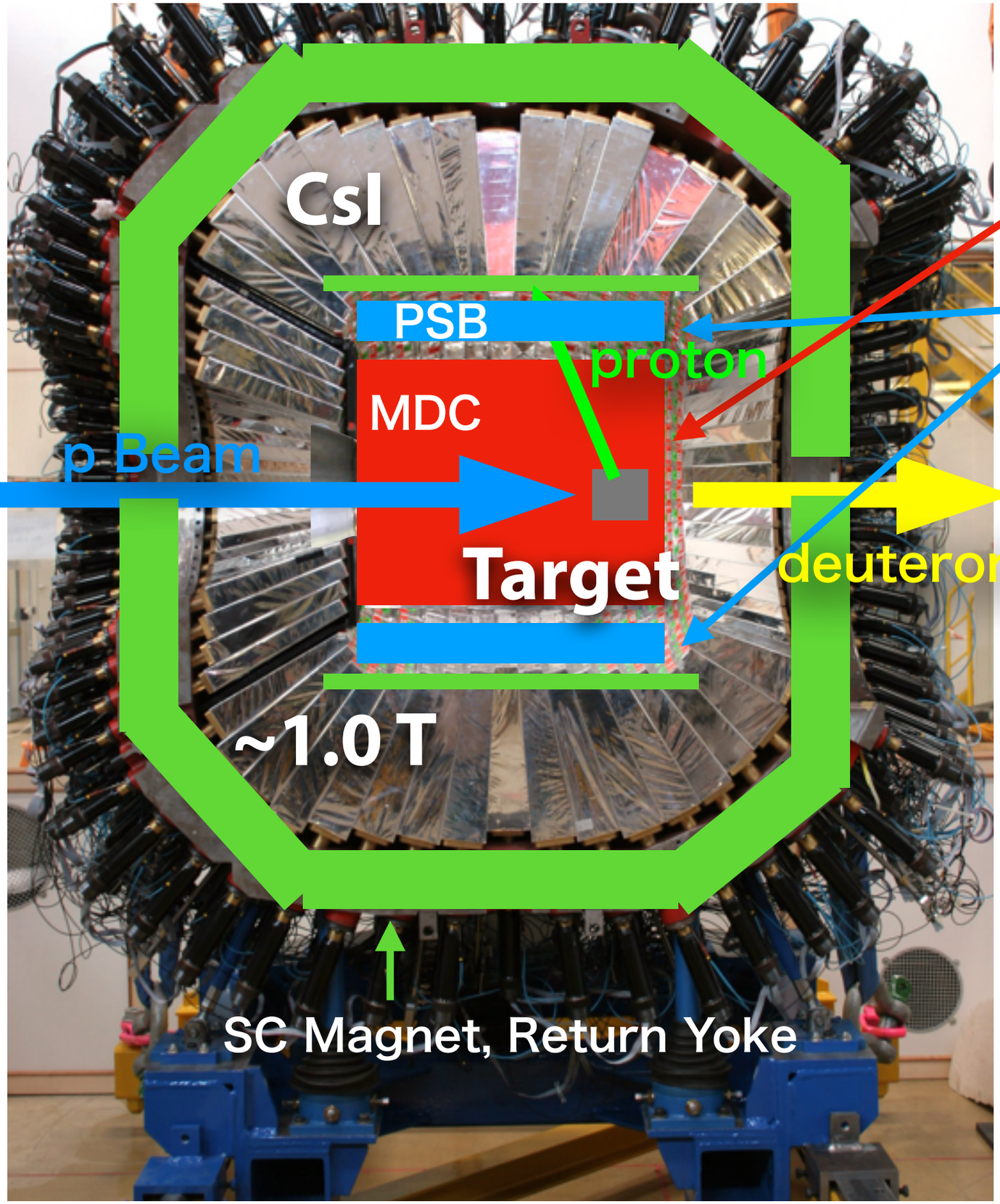


High energy proton tagging
in coincidence with forward *d*

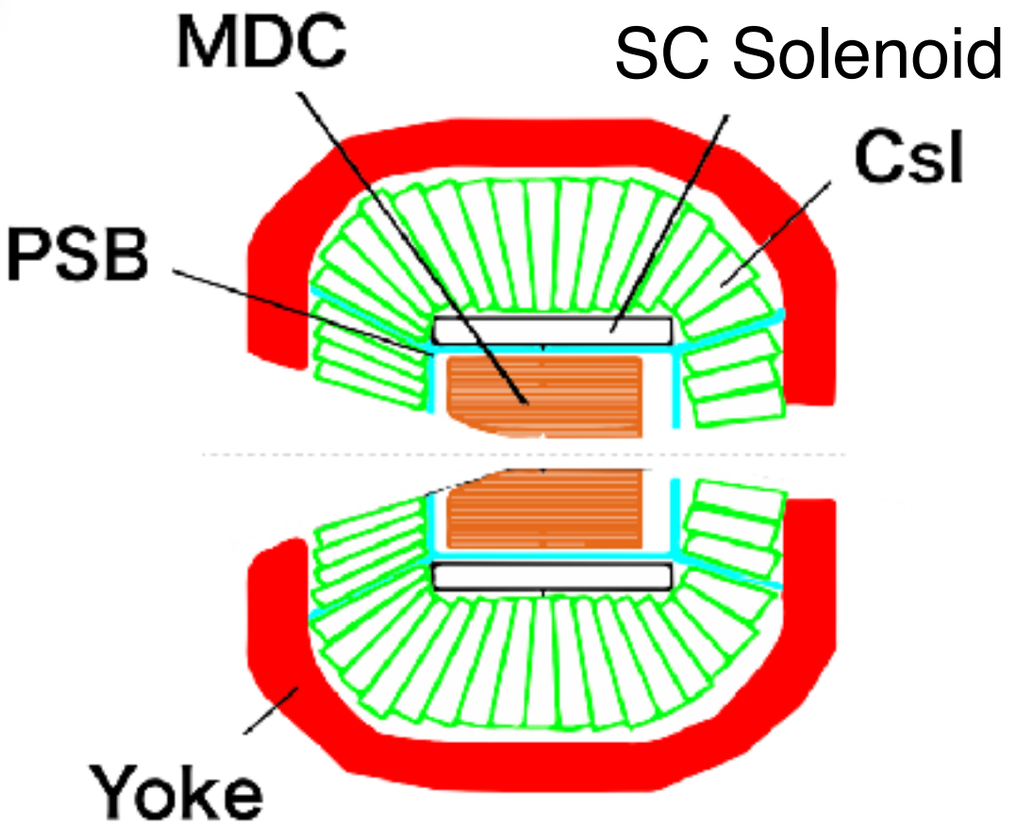


Cooperation with COSY-WASA collaboration

Detectors in WASA



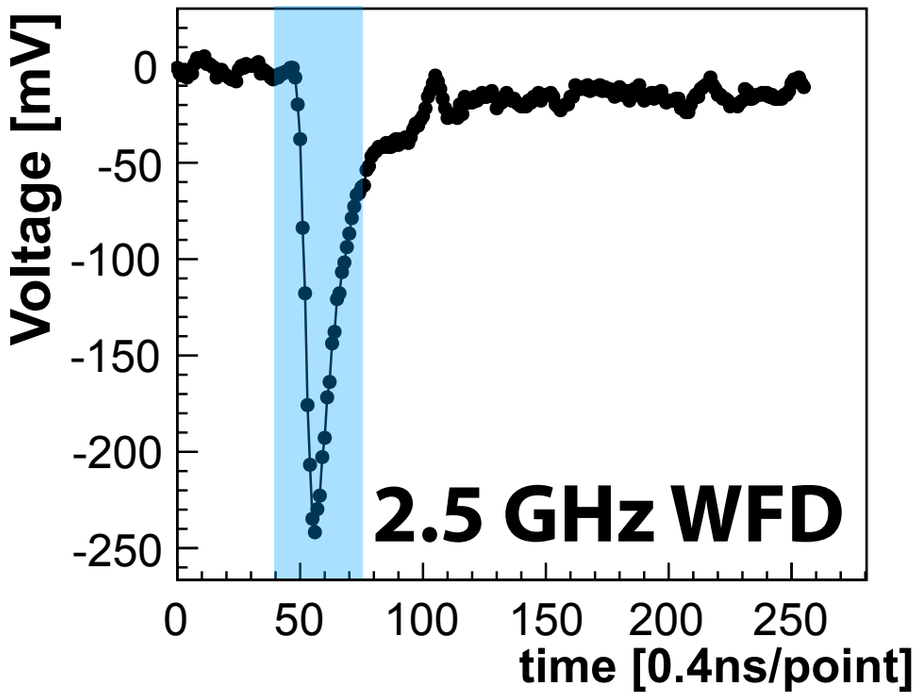
- **MDC (Mini Drift Chamber)**
  Charged particle tracking
- **PSB (Plastic Scintillator Barrel)**
  ΔE + Timing measurement
- **CsI**
  γ detection for calibration



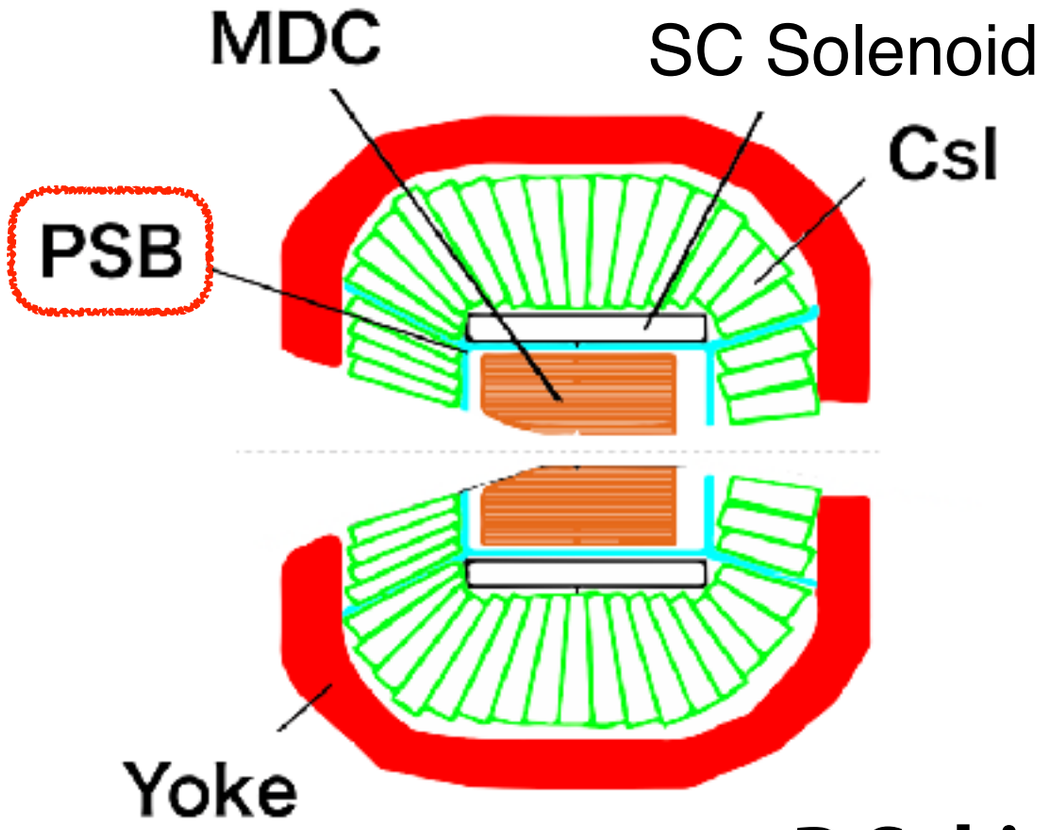
Cooperation with COSY-WASA collaboration

Plastic Scintillator Barell

Charged particle trigger
TOF, ΔE information for PID
Charge veto for CsI detector

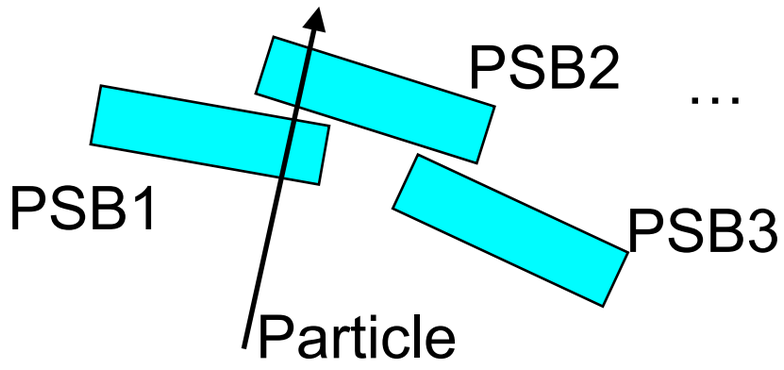


Software QDC/CFD for ΔE and timing

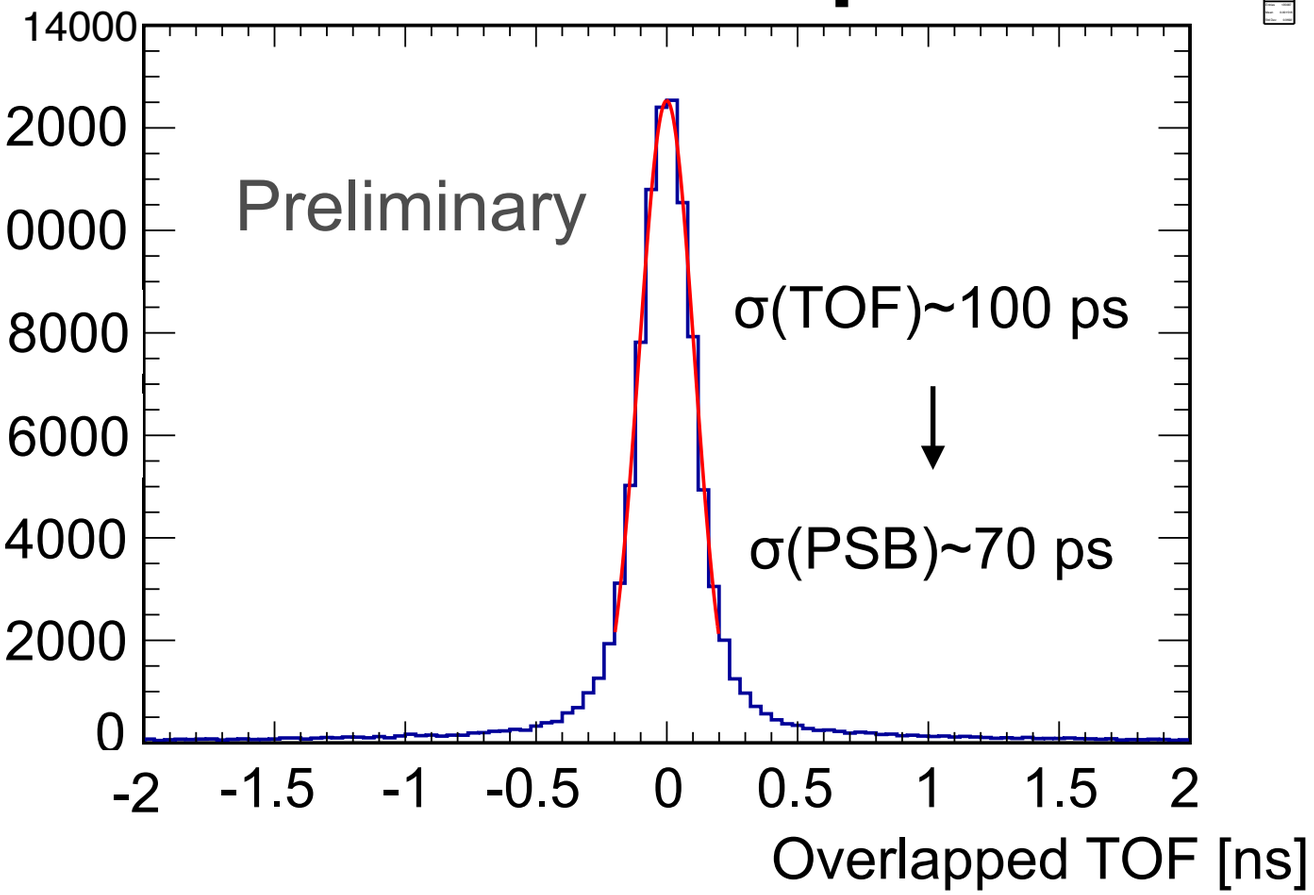


R.Sekiya

Plastic Scintillator Barell



TOF btw. overlap PSBs



PSB time resolution
~ 70 ps σ
for Z=1 particles

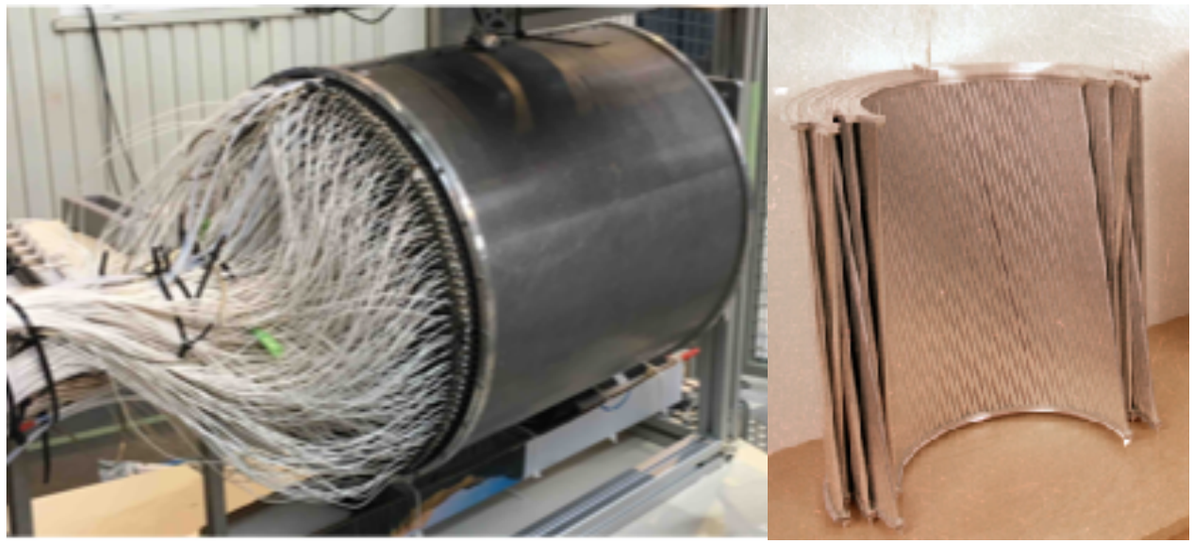
R.Sekiya

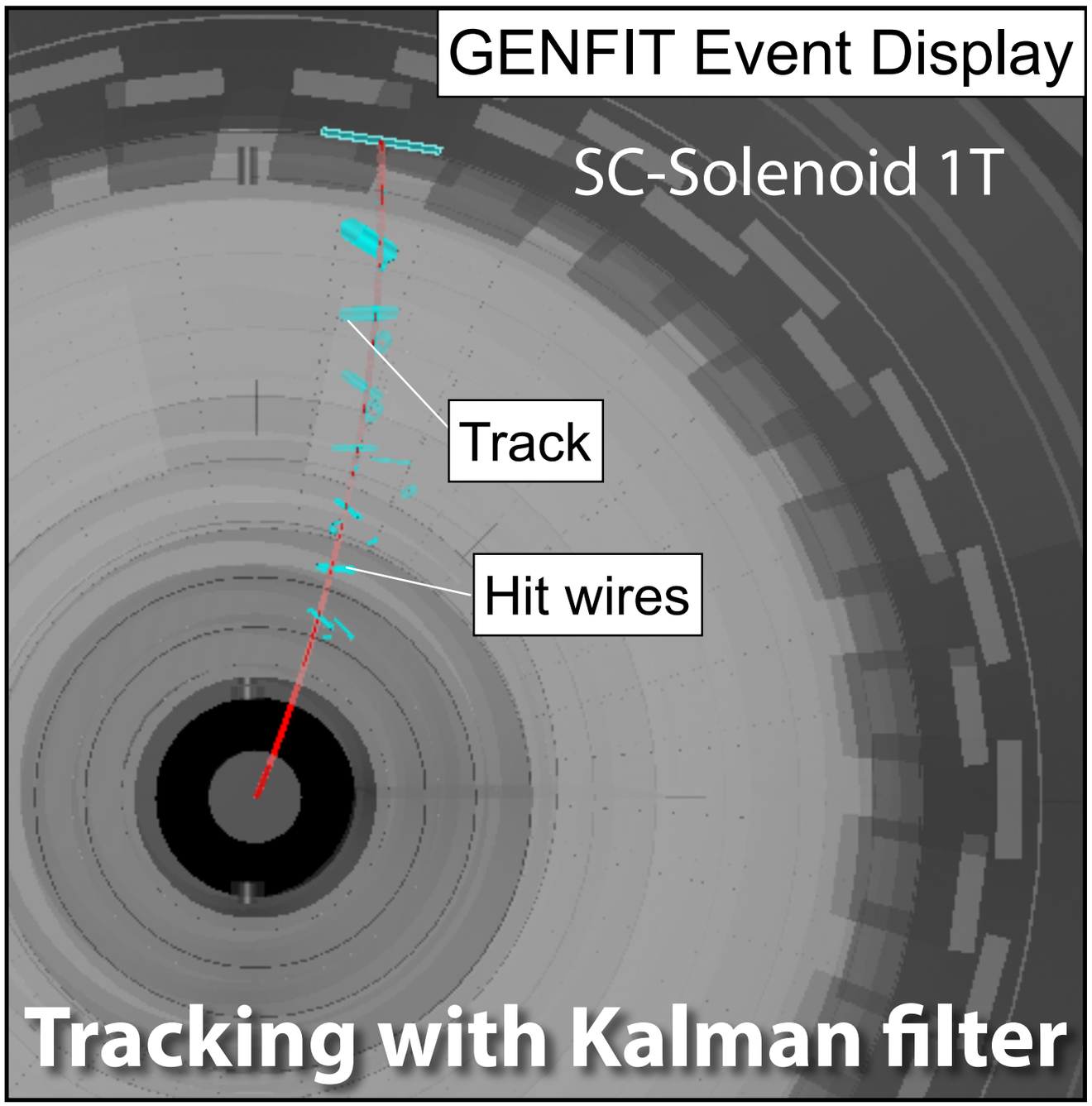
Mini Drift Chamber MDC

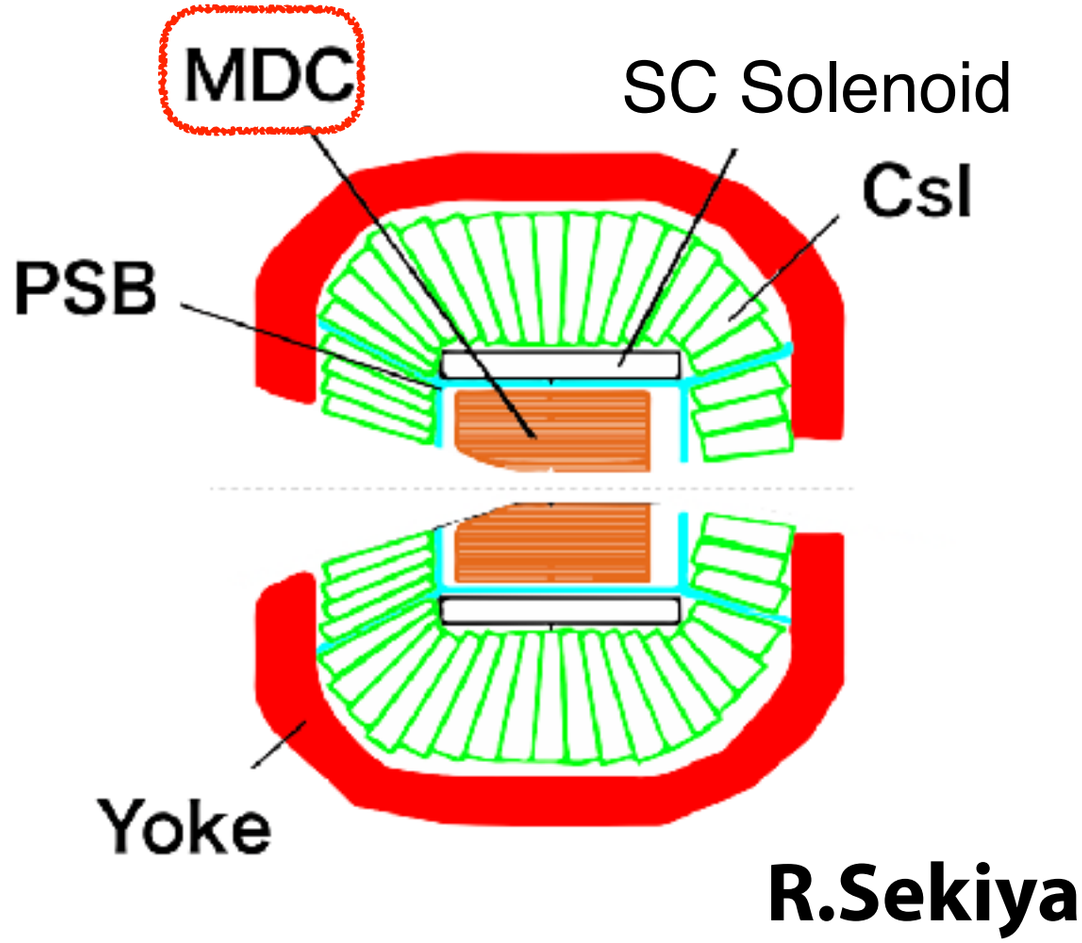
17 layers ~2K straw tube detectors

Tracking resolution 250-500 μm

→ $\Delta p/p$ ~ 40-45% at 1 GeV/c



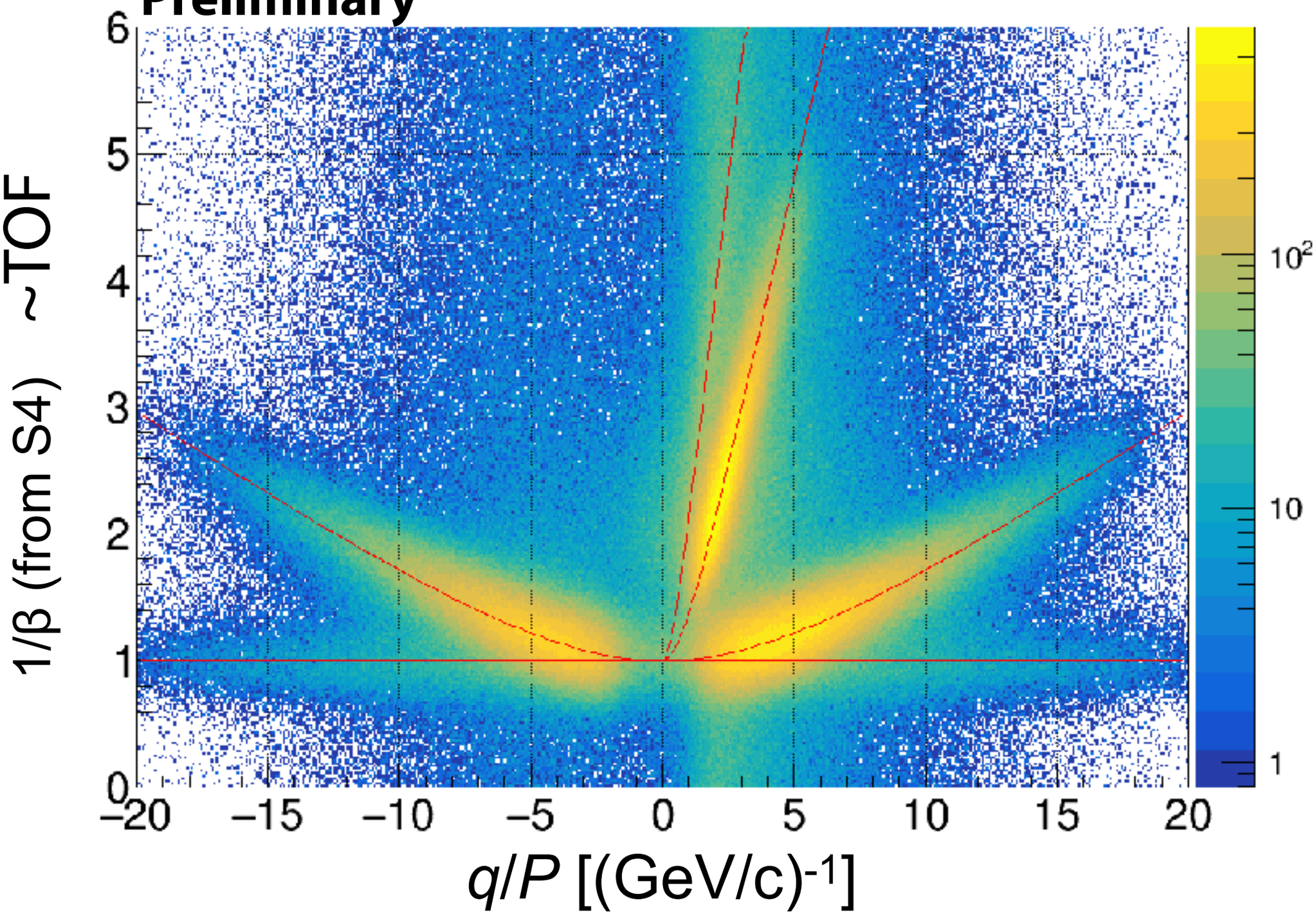




R.Sekiya

WASA Combined PID with TOF and *q/p*

TOF start ~ 200 ps computed based on S4 + track information in FRS



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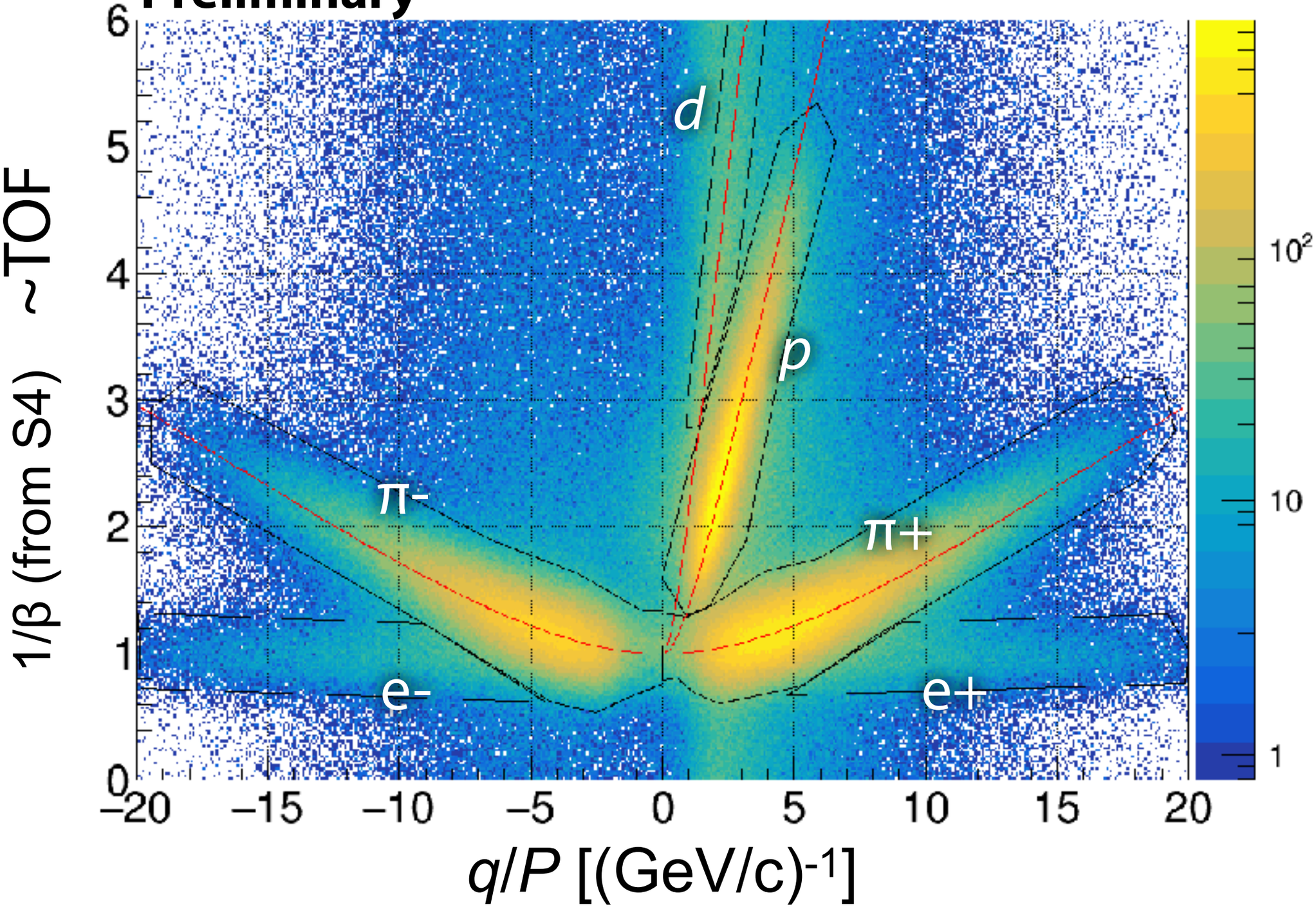
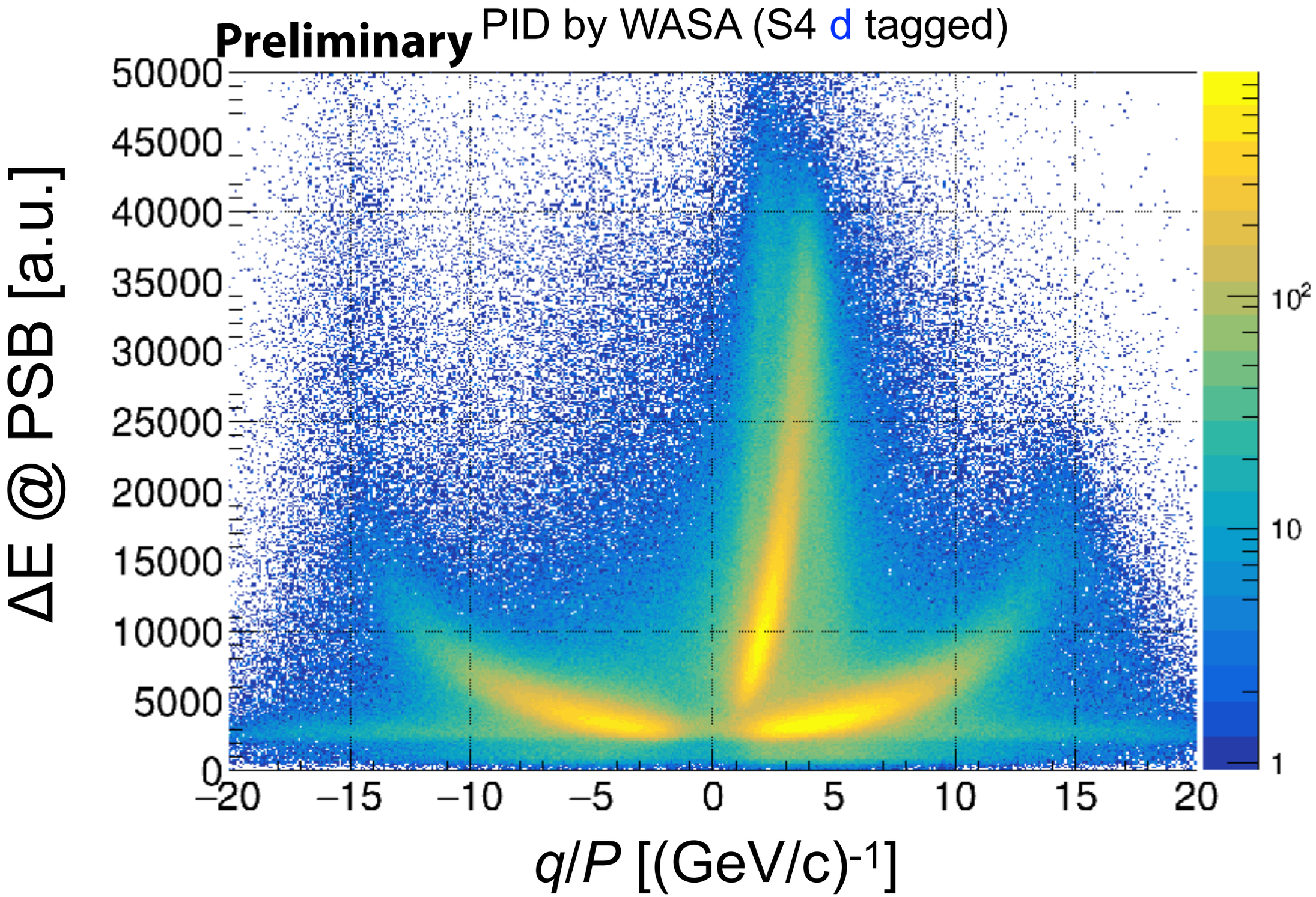


R.Sekiya

WASA Combined PID with ΔE and *q/p*



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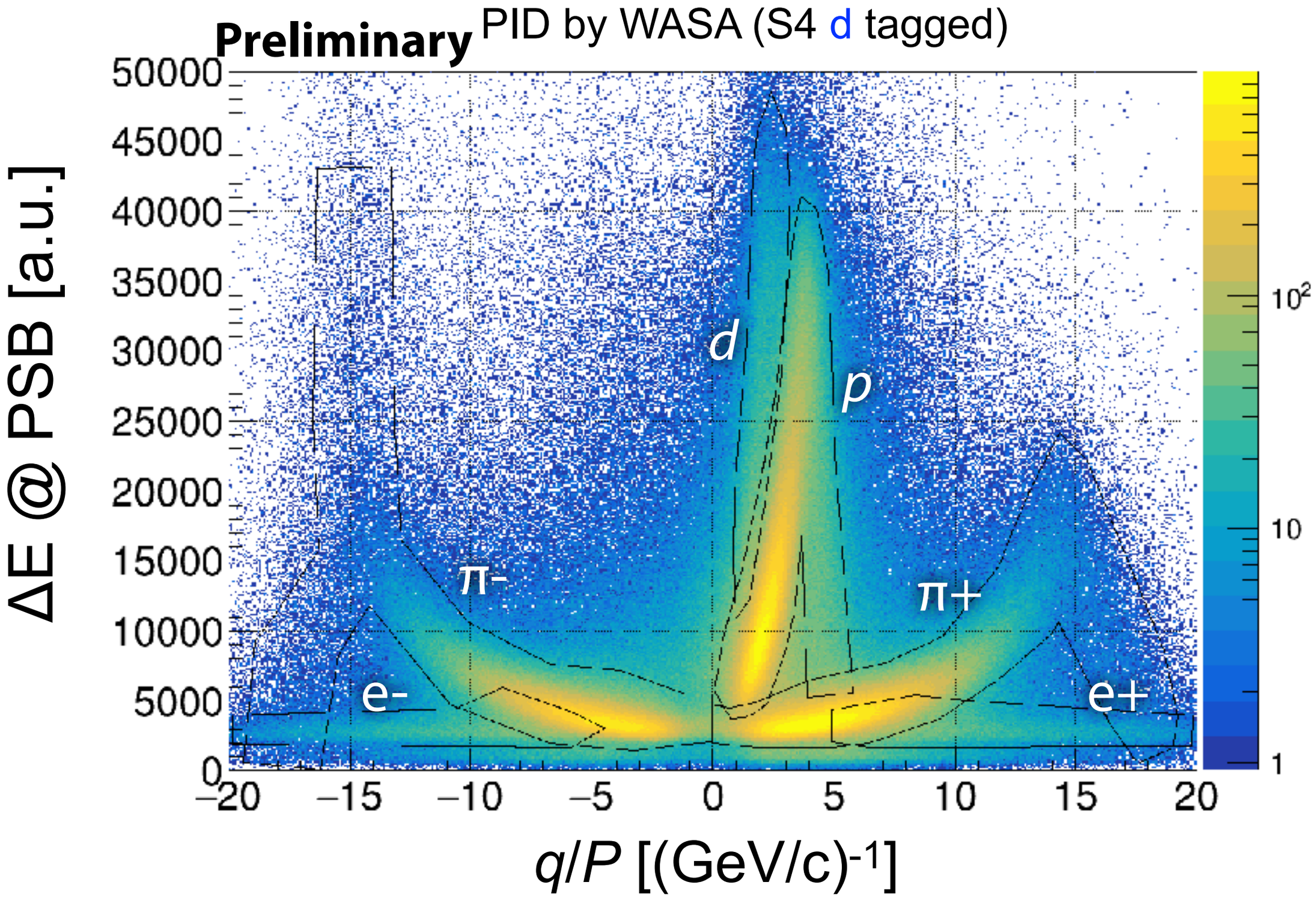
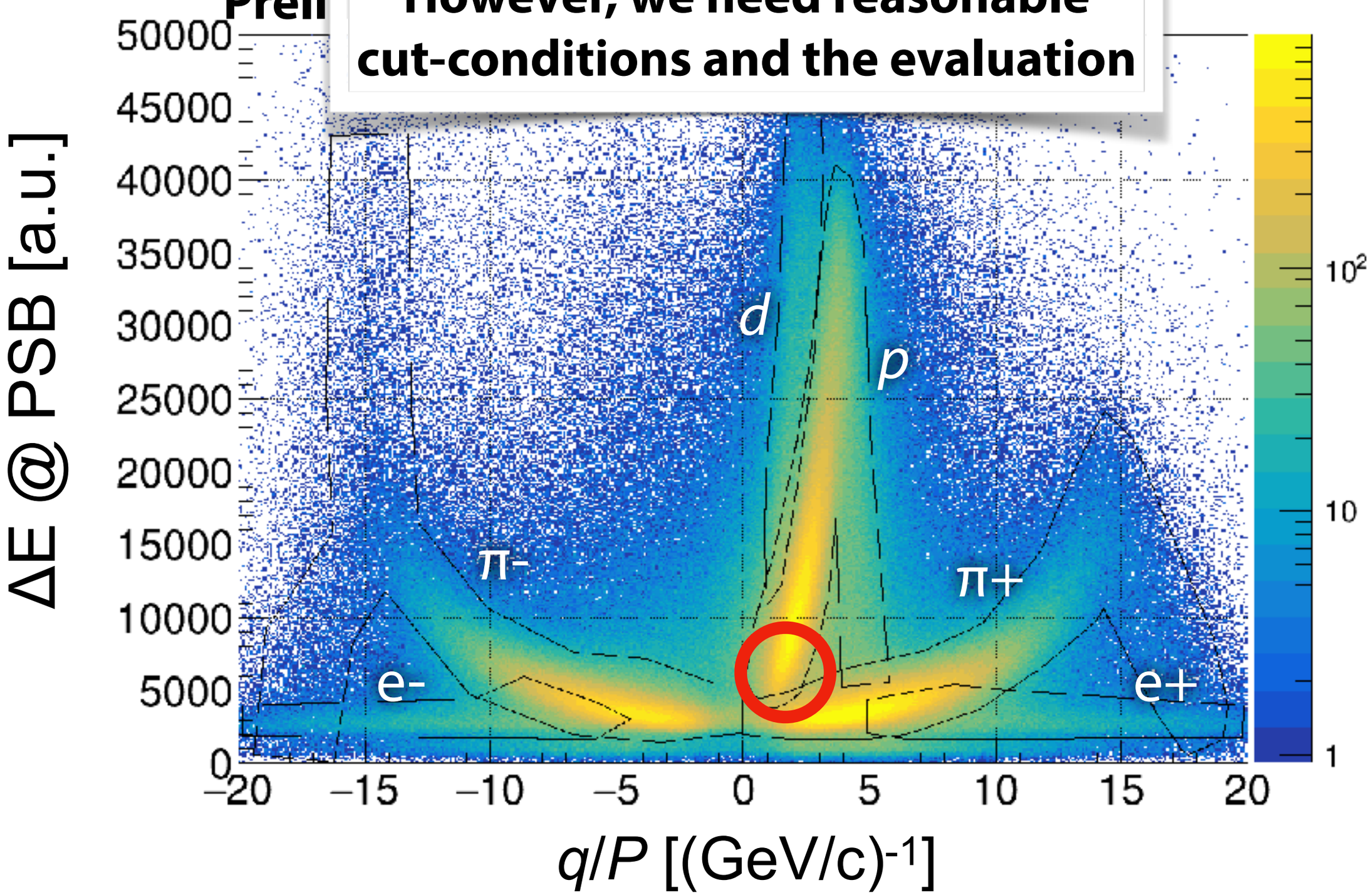


R.Sekiya

WASA Combined PID with ΔE and *q/p*

PID seems to work fine
However, we need reasonable cut-conditions and the evaluation



R.Sekiya

Future plans of eta'-mesic nuclei search

	Reaction	Facility	Measurement
GSI-S437	(*p*,*d*)	FRS	inclusive
GSI-S490	(*p*,*d*)	FRS+WASA	semi-exclusive
Next step	**(*p*,*d*)**	**FRS+WASA'**	**semi-excl., increased statistics**
Next next	**(π^+,*p*)**	**Super-FRS+WASA'**	**semi-excl., neutral decays**

Super-FRS secondary beam intensities

Max. proton energy of SIS100 is the same as J-PARC MR

Advantages

Dispersion matching

Pion beams

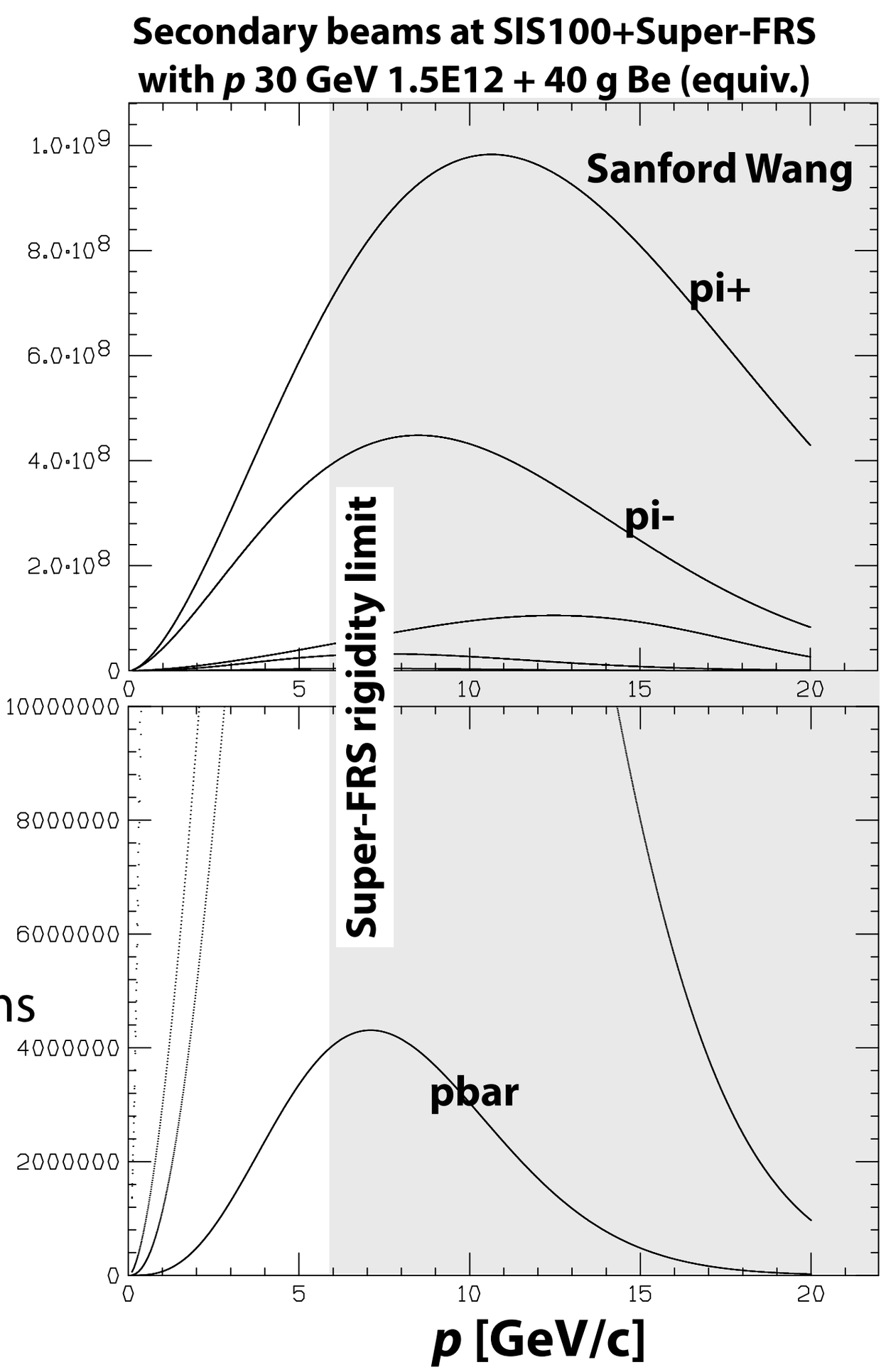
Pbar induced spectroscopy

Competitors

J-PARC K1.8(BR) for pion / K / pbar beams

J-PARC HIHR for DM pion / pbar beams

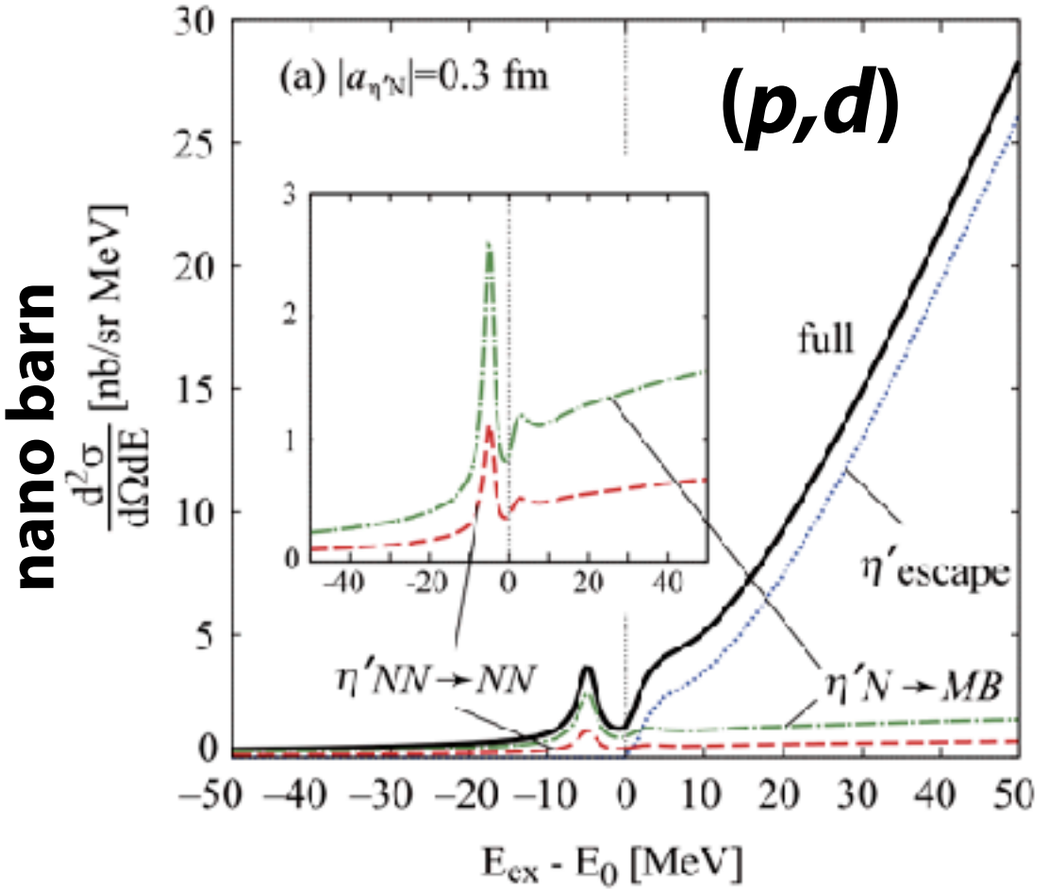
R³B for pbar with forward detectors



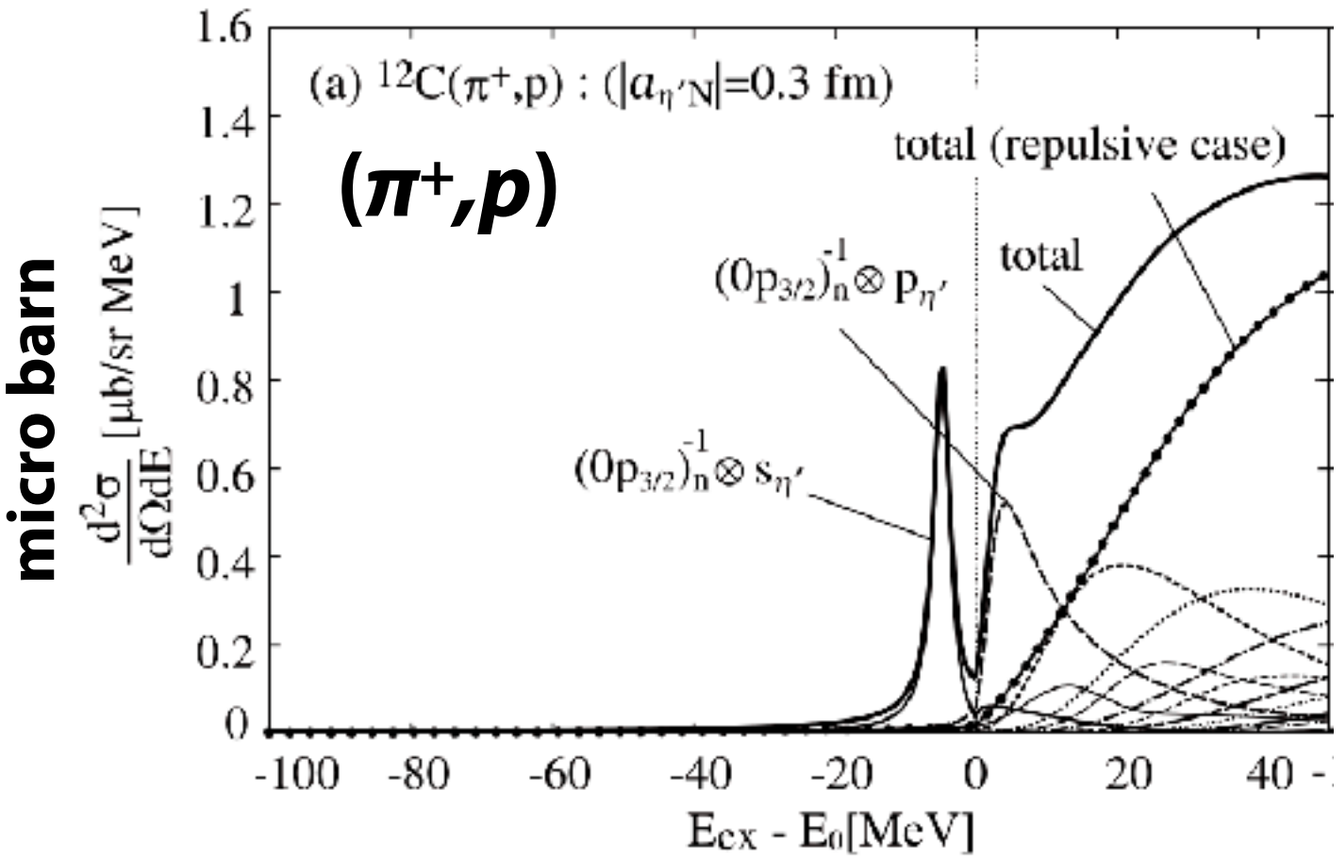
Pion induced η/η′-mesic nuclei spectroscopy

η′-mesic nuclei

nano barn



micro barn



(π^+,p) has much larger cross section

→ Using 10^7/s beams, we will have 10 times higher statistics

pbar+p→ηη′ is also a good candidate

Nagahiro, NPA914, 360 (2013)
Nagahiro et al., PRC80, 025205 (2009)

Summary

- **η′-mesic nuclei hold a key to understand origin of matter mass and non-trivial structure of QCD vacuum**
- **We have conducted S490 experiment to search for eta-prime mesic nuclei**
- **We have conducted missing-mass spectroscopy of ^{12}C(*p,d*) reaction with tagging of ~1 GeV/*c* proton emitted nearly isotropically for two nucleon absorption of η′**
- **We accumulated 1.1x10^{7} forward *d* in the inclusive measurement of (*p,d*) by FRS. Detected proton number with WASA in coincidence with forward *d* agrees with expectations → BG suppression as expected**
- **WASA PID works fine with TOF, tracking, and ΔE information. Cut conditions are to be finalized**
- **WASA momentum resolution is by a factor of 1.4-1.5 worse compared with simulation. We are investigating the reasons**
- **We combine ΔE, TOF, and tracking information to make "kinematical fitting" to achieve better momentum resolution**
  → Semi-exclusive spectra will be ready soon
- **We start considerations of next experiments using pion/pbar beams at Super-FRS.**

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