

# Analysis Status of S490

## Experimental Search for $\eta'$ -mesic Nuclei

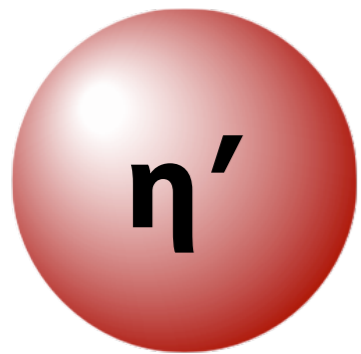
Kenta Itahashi

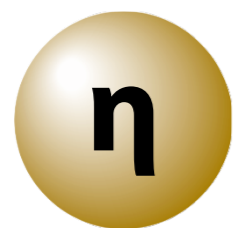
on behalf of

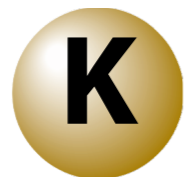
EtaPrime Collaboration



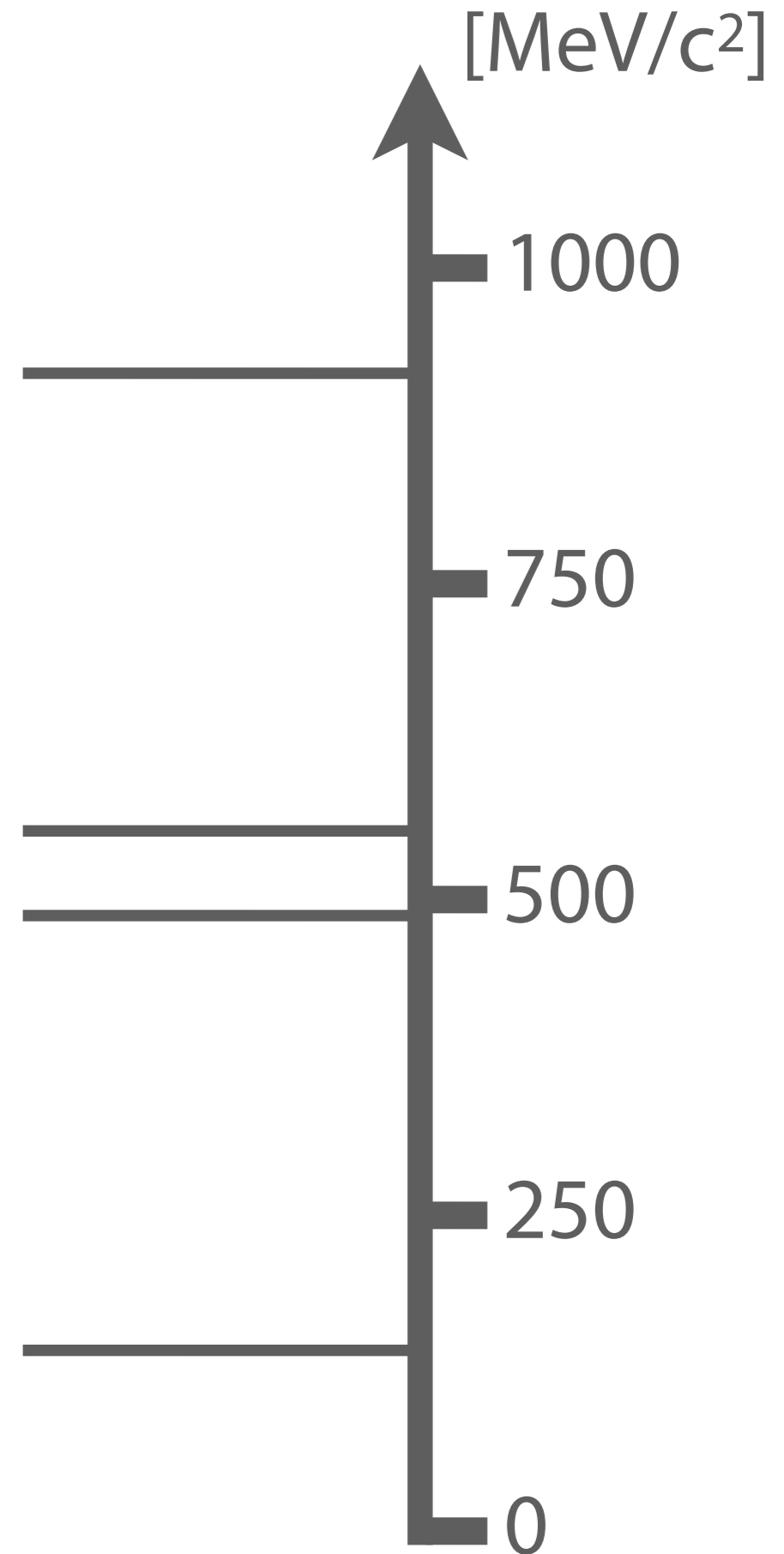
# $\eta'$ and other PS mesons

  $\eta'$   $M=958 \text{ MeV}/c^2$

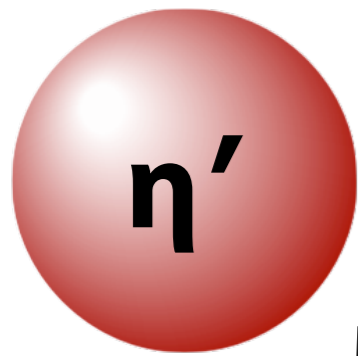
  $\eta$   $M=548 \text{ MeV}/c^2$

  $K$   $M=498 \text{ MeV}/c^2$

  $\pi$   $M=140 \text{ MeV}/c^2$

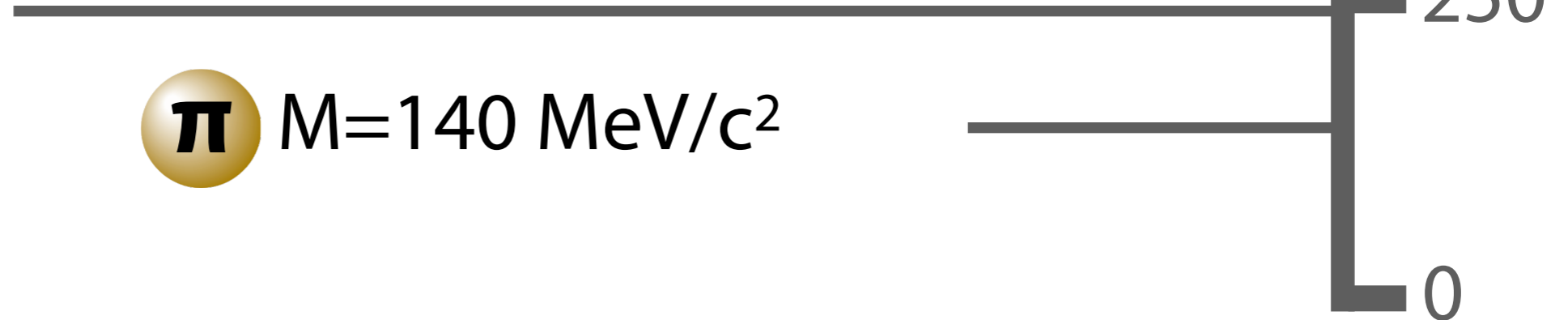


# $\eta'$ and other PS mesons



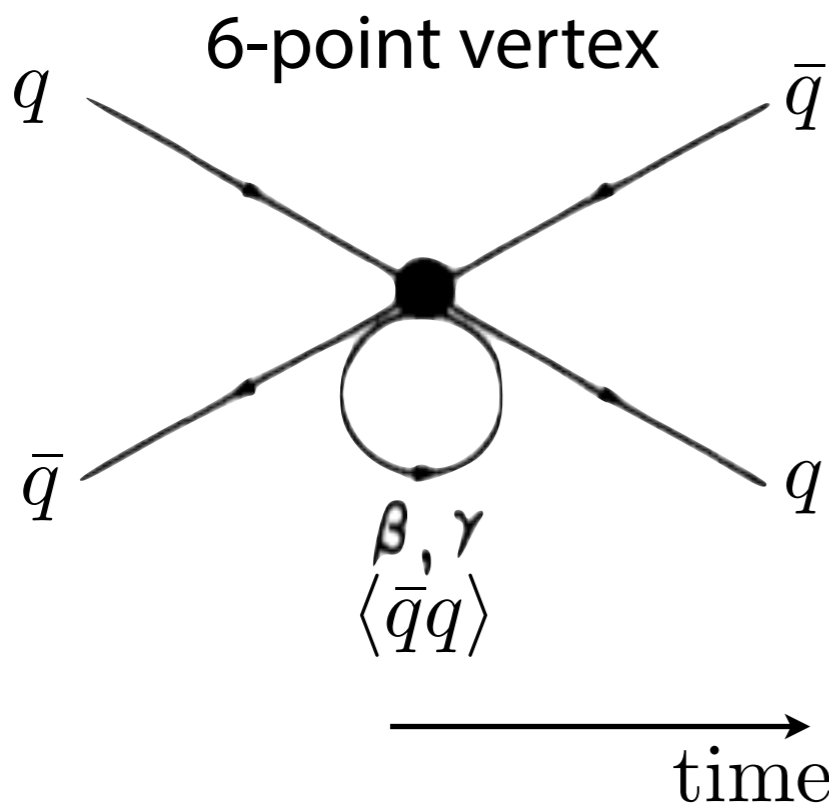
$M=958 \text{ MeV}/c^2$

**$\eta$  problem**  
Peculiarly large mass  
 $m_{\eta'} \gg \sqrt{3}m_{\pi}$   
(Weinberg, 1975)



# Large $\eta'$ mass = $U_A(1) \times$ chiral condensate

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



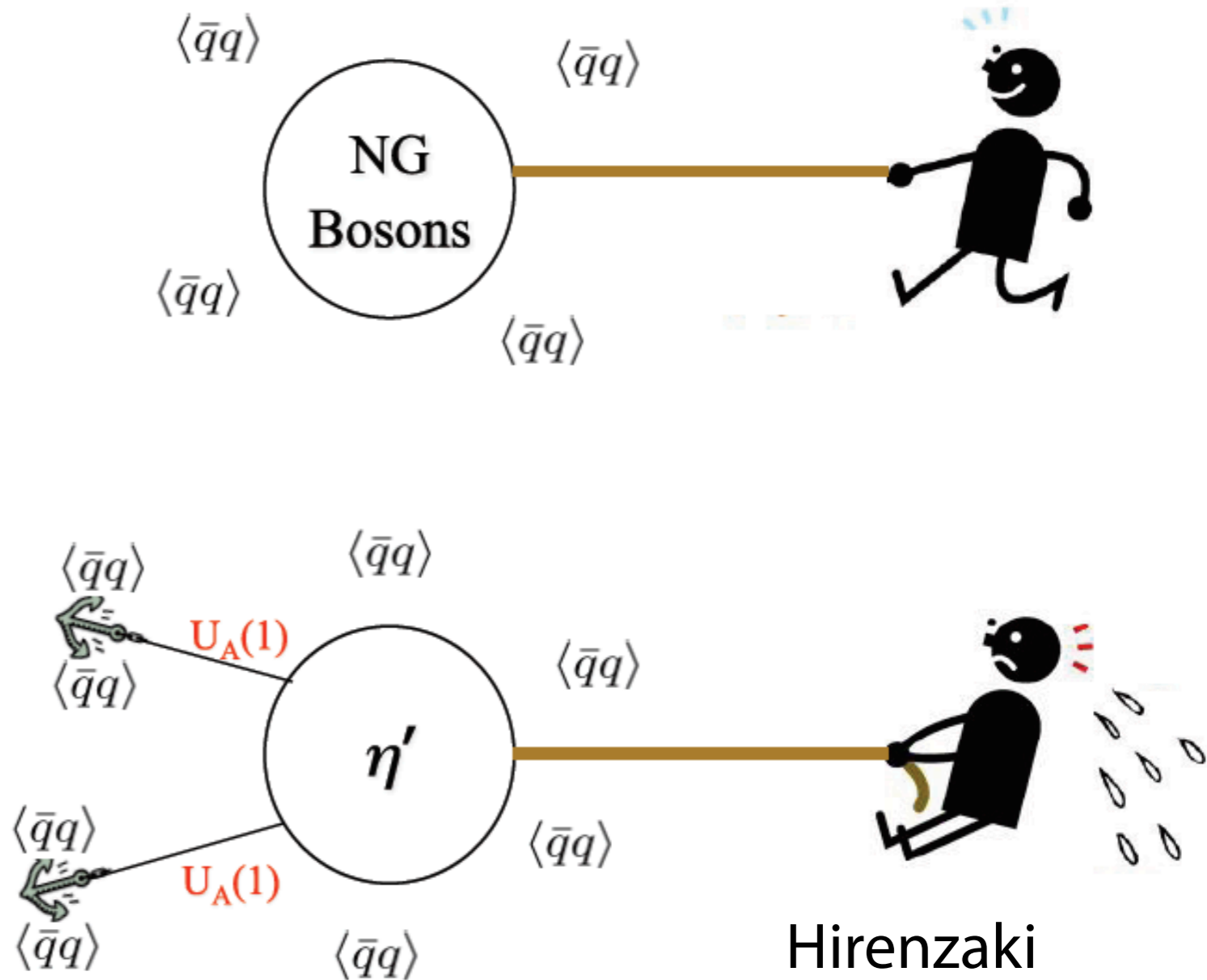
Kobayashi-Maskawa-'t Hooft interaction

Kobayashi, Maskawa, PTP44(70)1422

't Hooft, PRD14(76)3432.

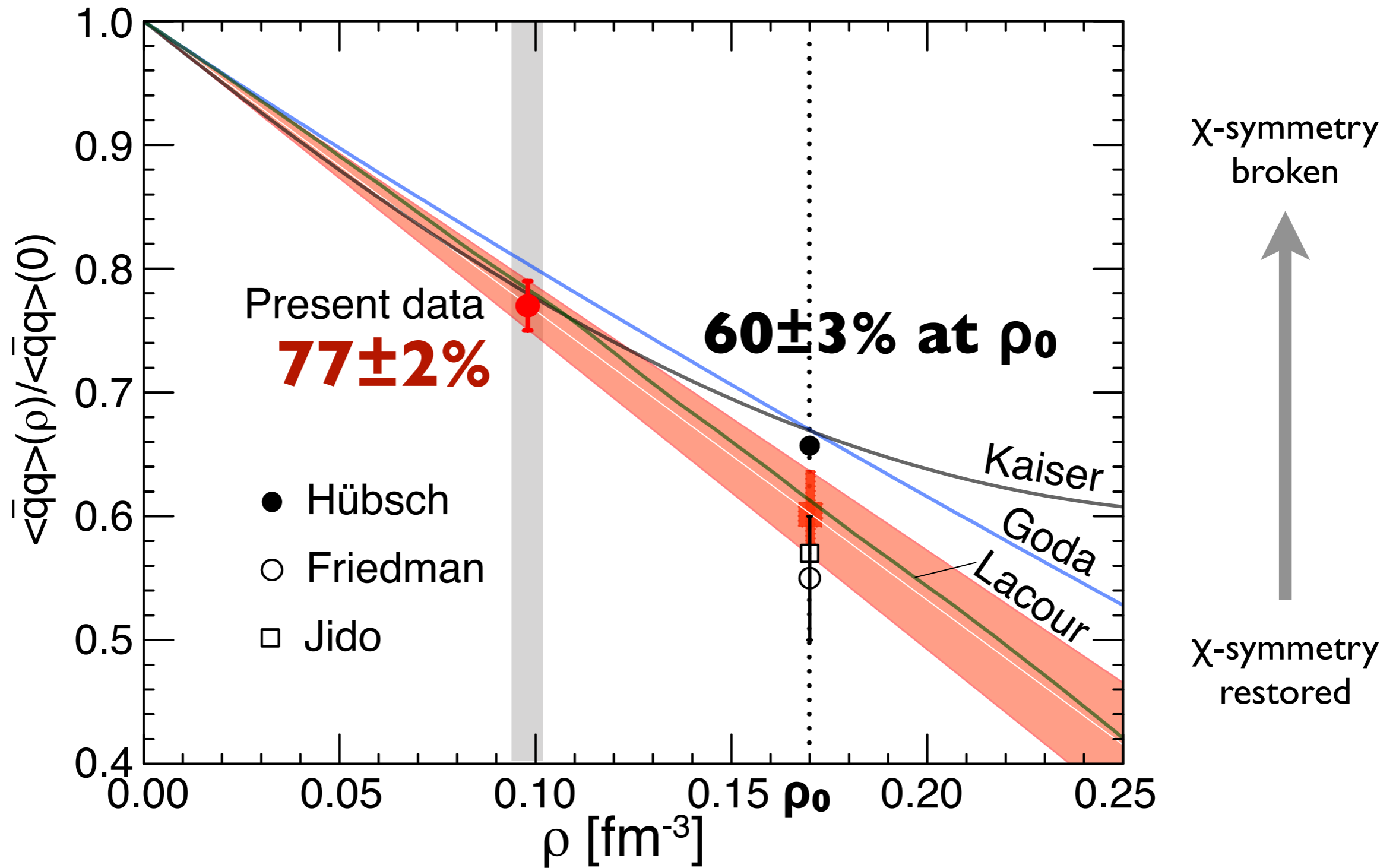
T. Kunihiro, Phys. Lett. B219(89)363.

Klimt, Lutz, Vogl, Weise, NPA516(90)429.



Hirenzaki

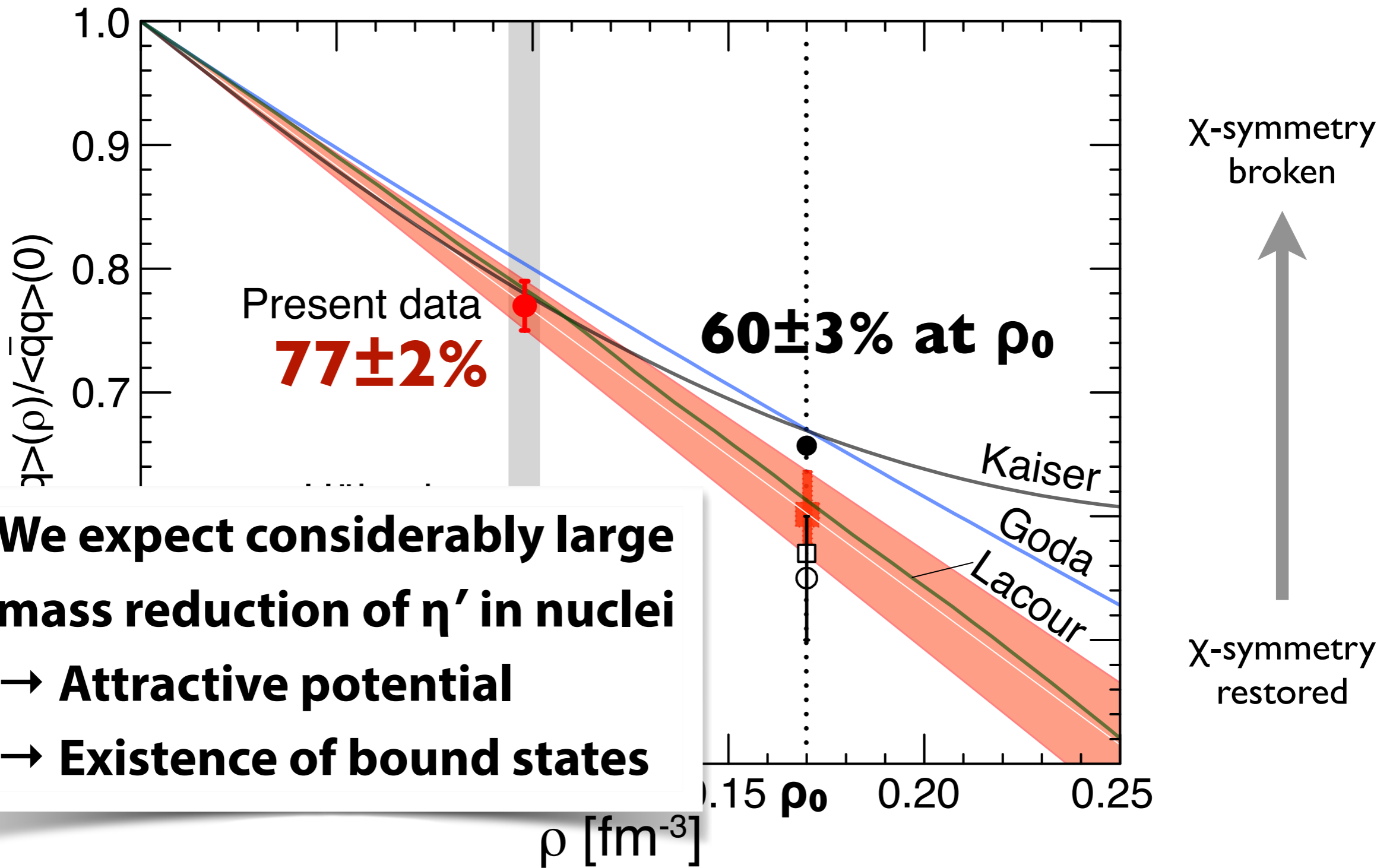
# Chiral condensate in nuclear matter decreases ~pionic atom spectroscopy~



T. Nishi, Kl et al., Nature Physics **19**, 788 (2023)

Article DOI: 10.1038/s41567-023-02001-x

# Chiral condensate in nuclear matter decreases ~pionic atom spectroscopy~



**We expect considerably large mass reduction of  $\eta'$  in nuclei**

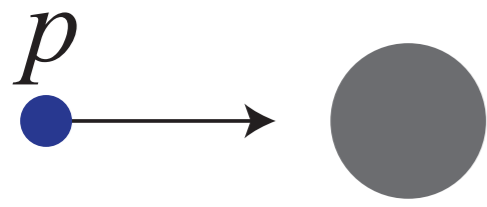
- **Attractive potential**
- **Existence of bound states**

T. Nishi, KI et al., Nature Physics **19**, 788 (2023)

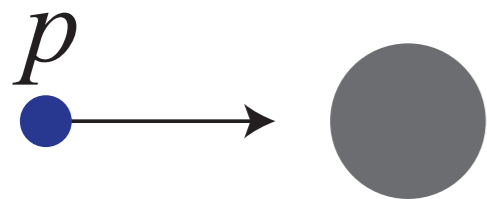
**Article DOI:** 10.1038/s41567-023-02001-x

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

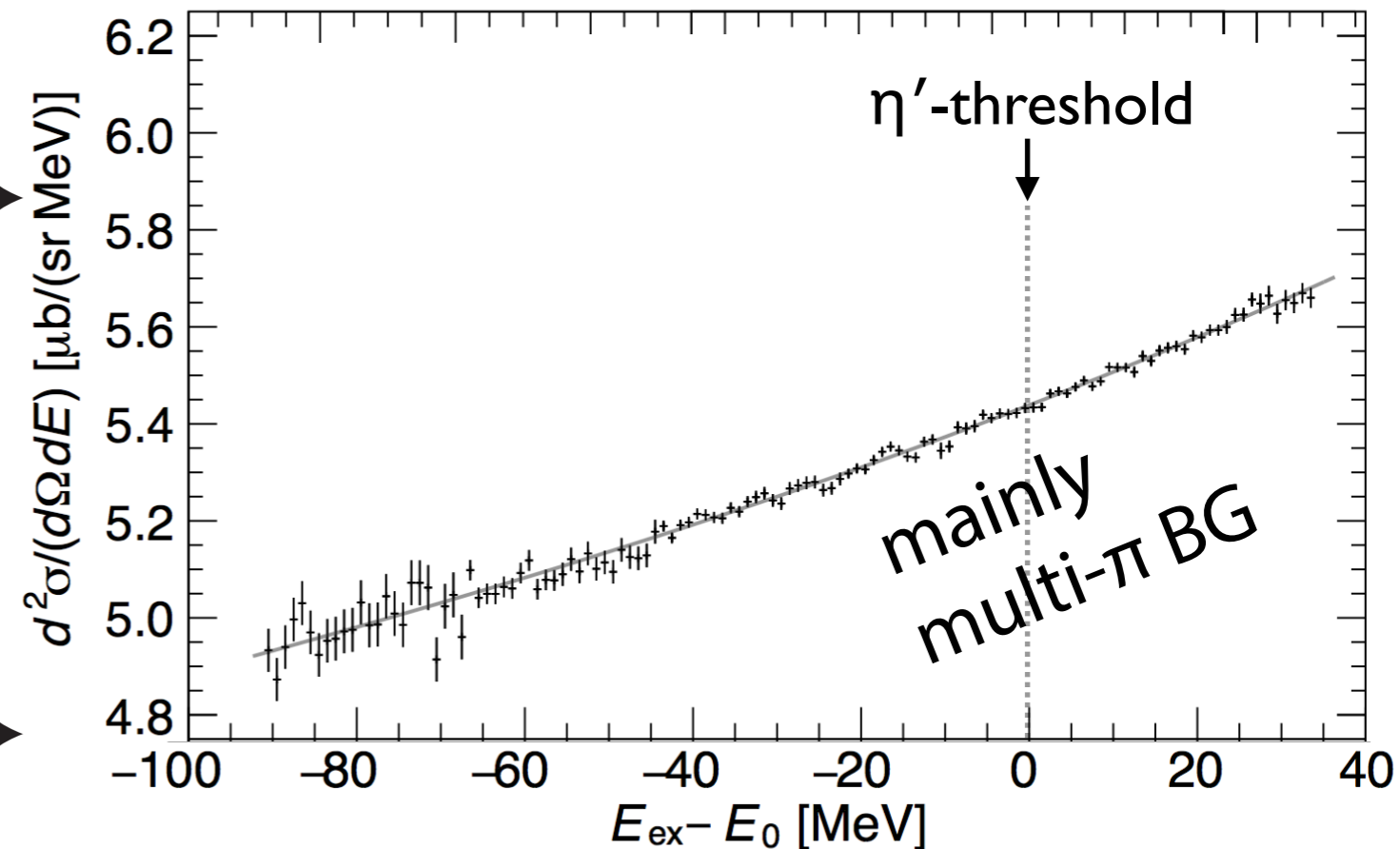
Signal



Background



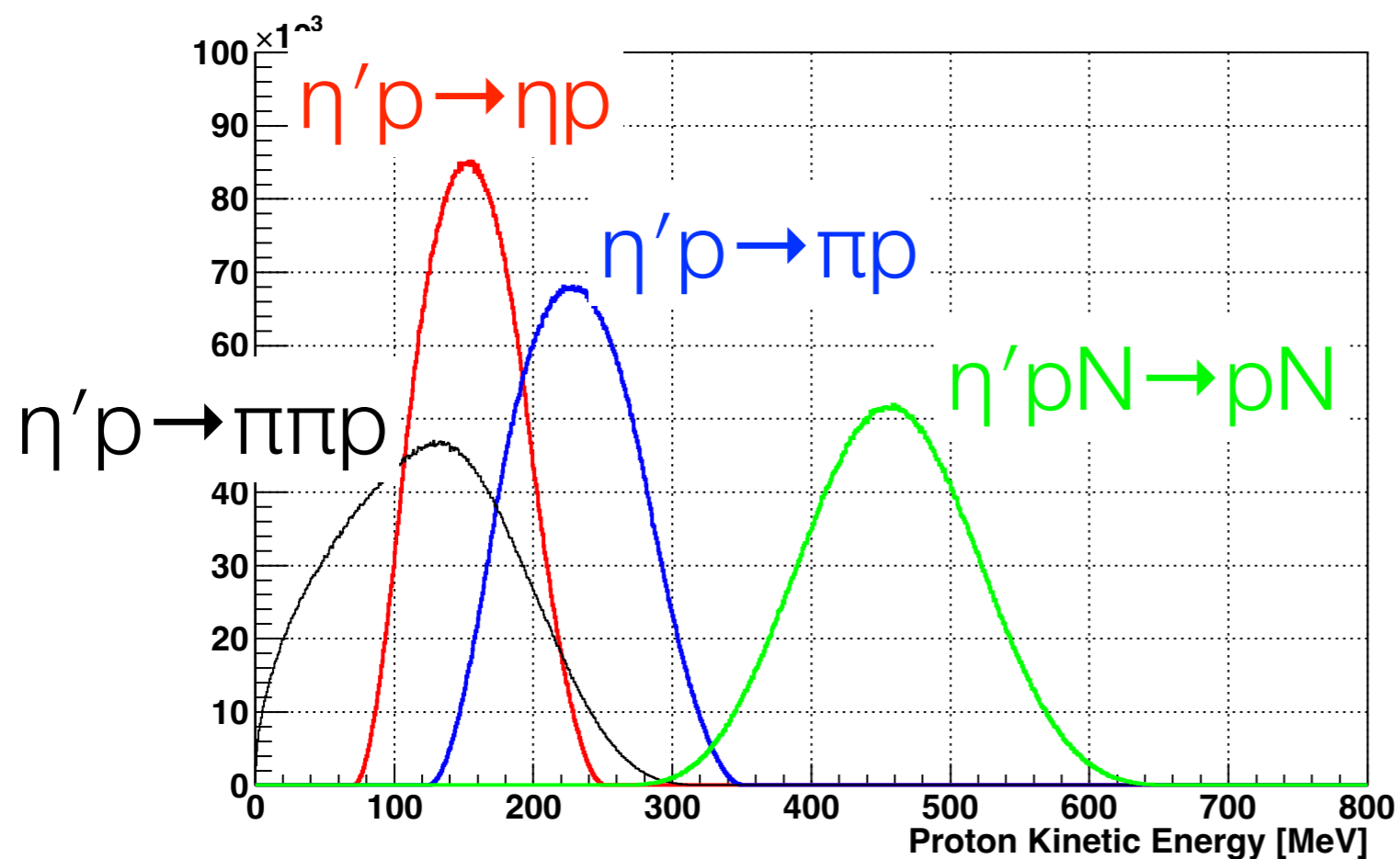
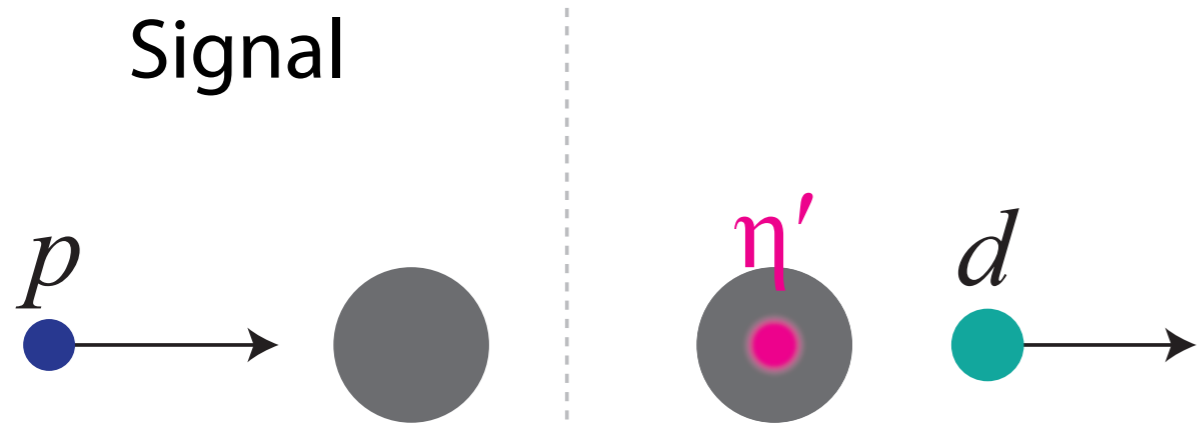
S437: $^{12}\text{C}(p,d)$  in 2014 at FRS/GSI



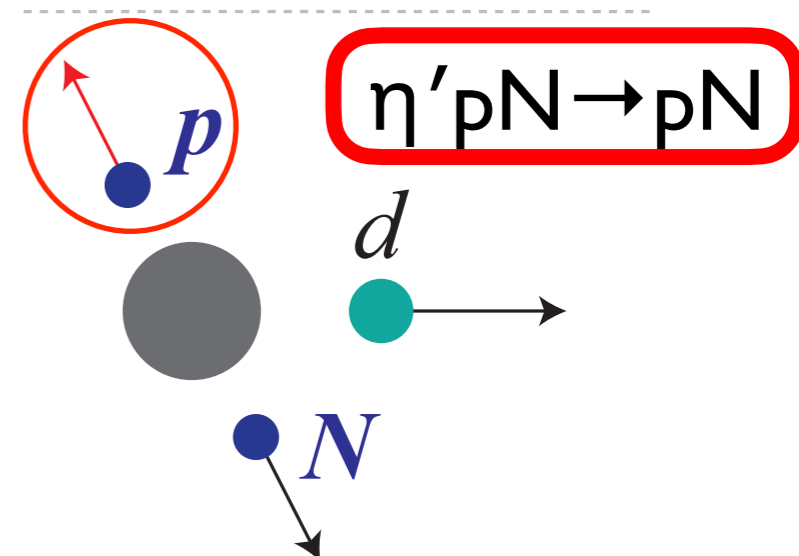
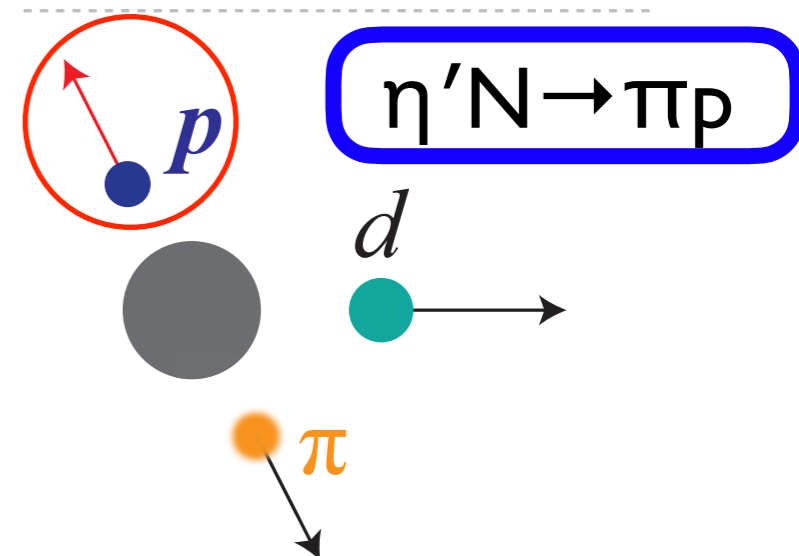
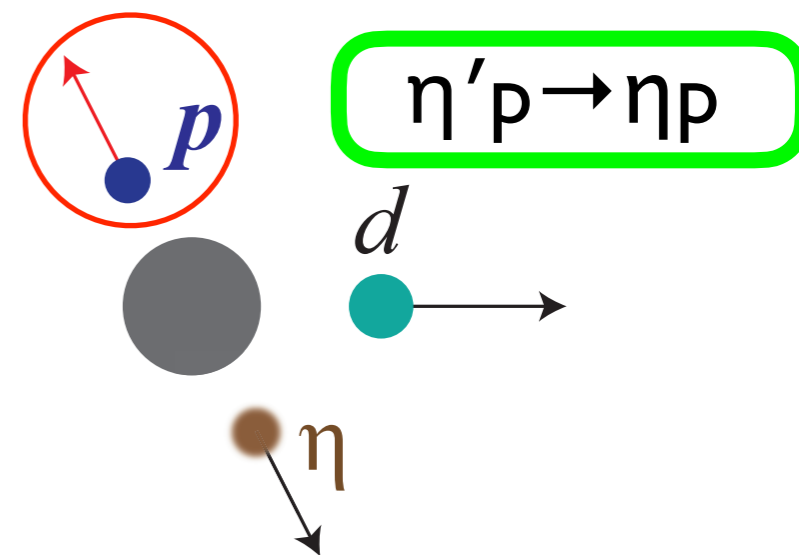
Y.K. Tanaka et al., Phys. Rev. Lett. **117**, 202501(2016)

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

# How to select signals



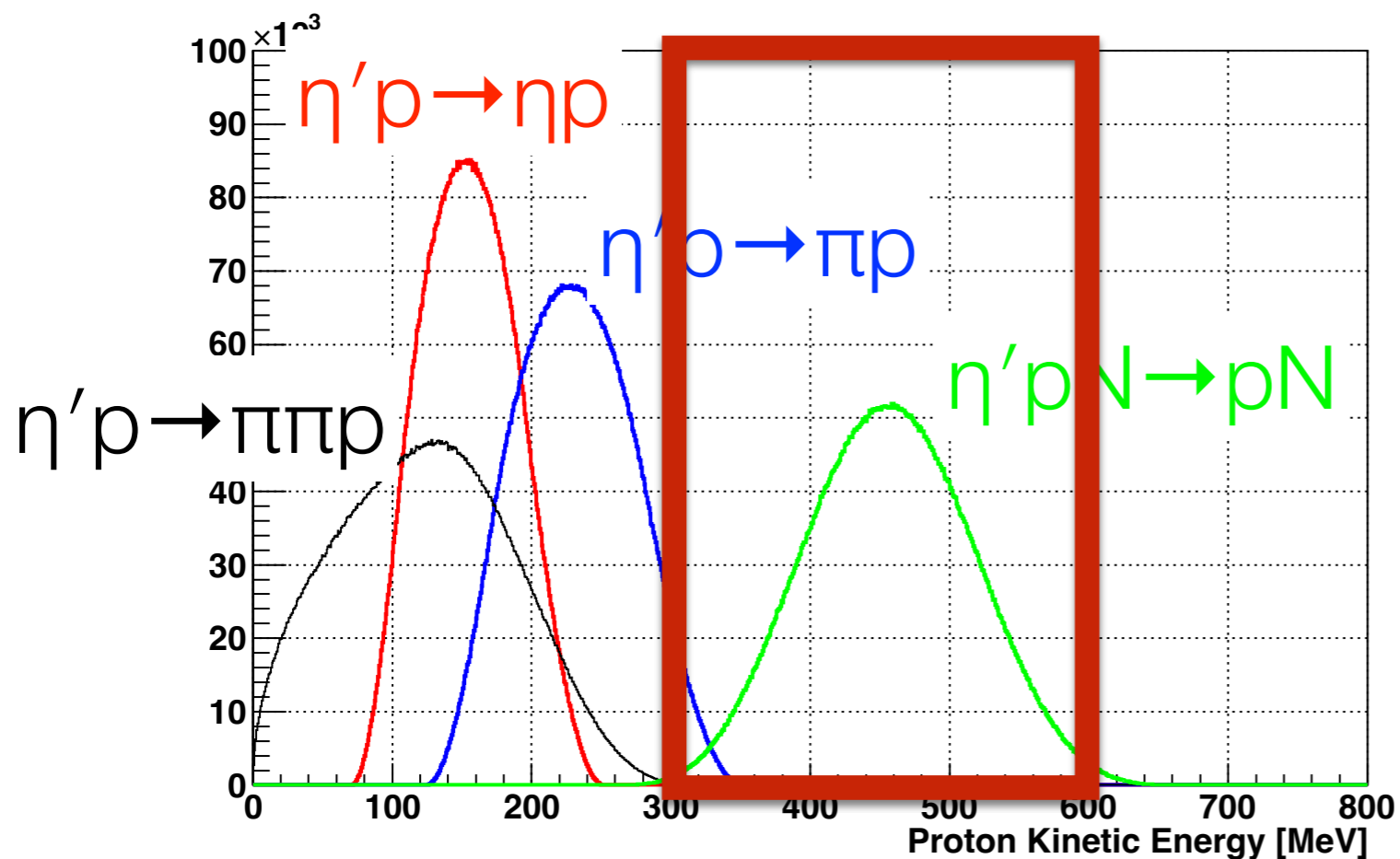
3 major decay modes of  $\eta'$ -mesic nuclei



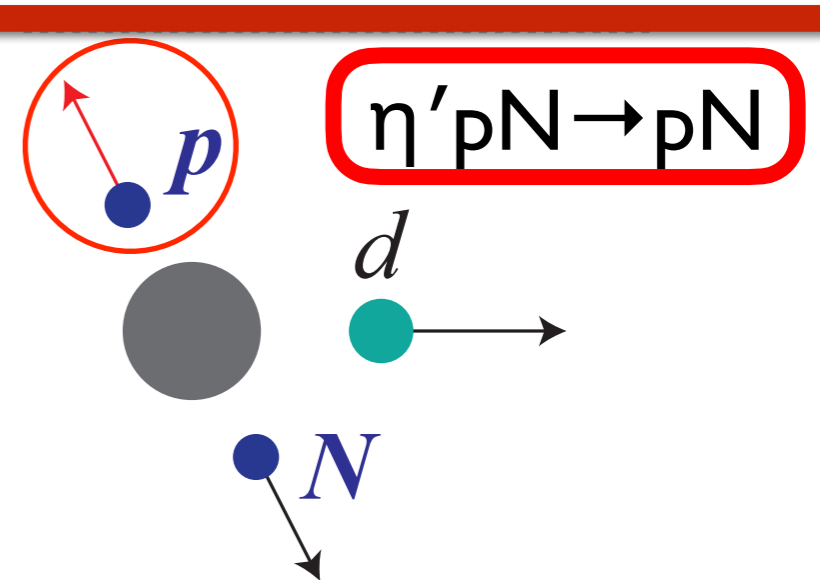
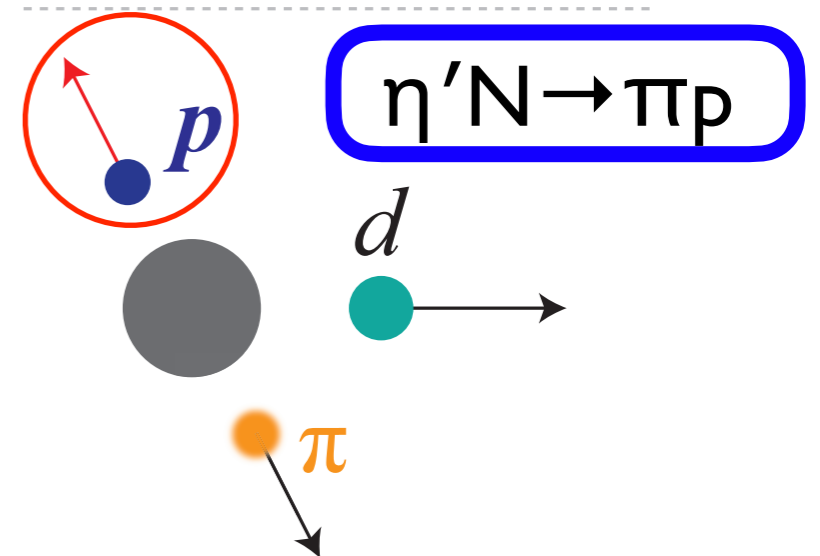
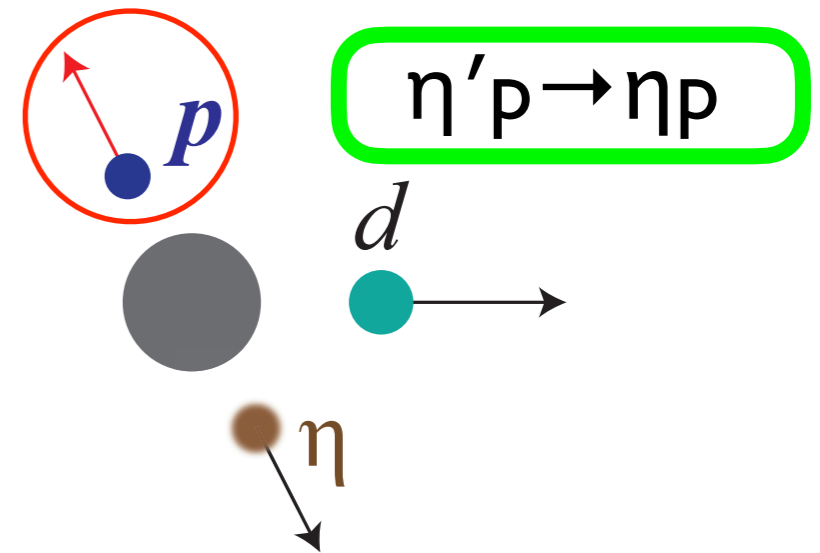


# How to select signals

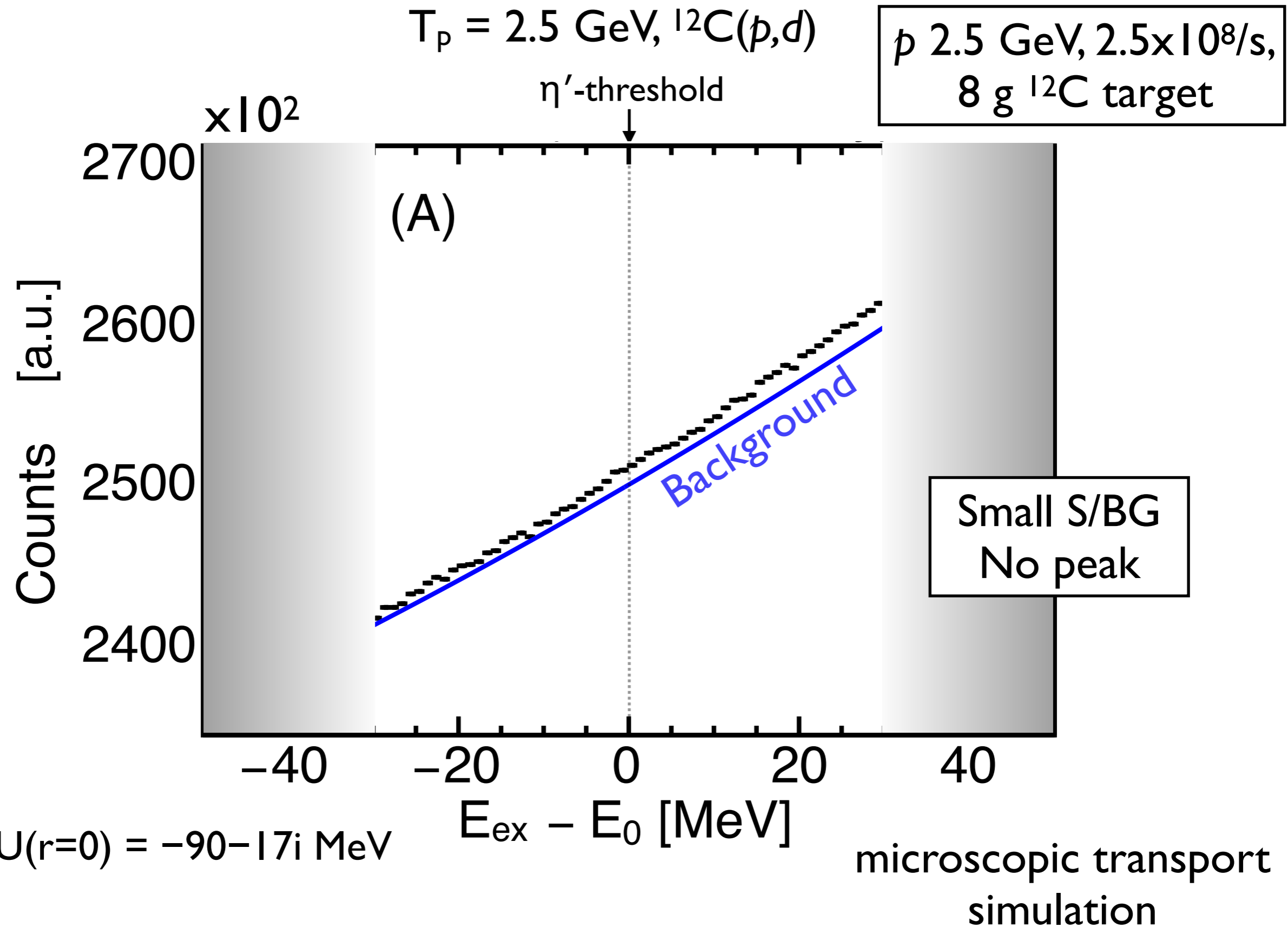
Detect  $p$  (800-1200 MeV/c) emitted in the decay of  $\eta'$ -nuclei for **semi-exclusive** measurement.  
 $f \sim 100$  improvement in S/BG



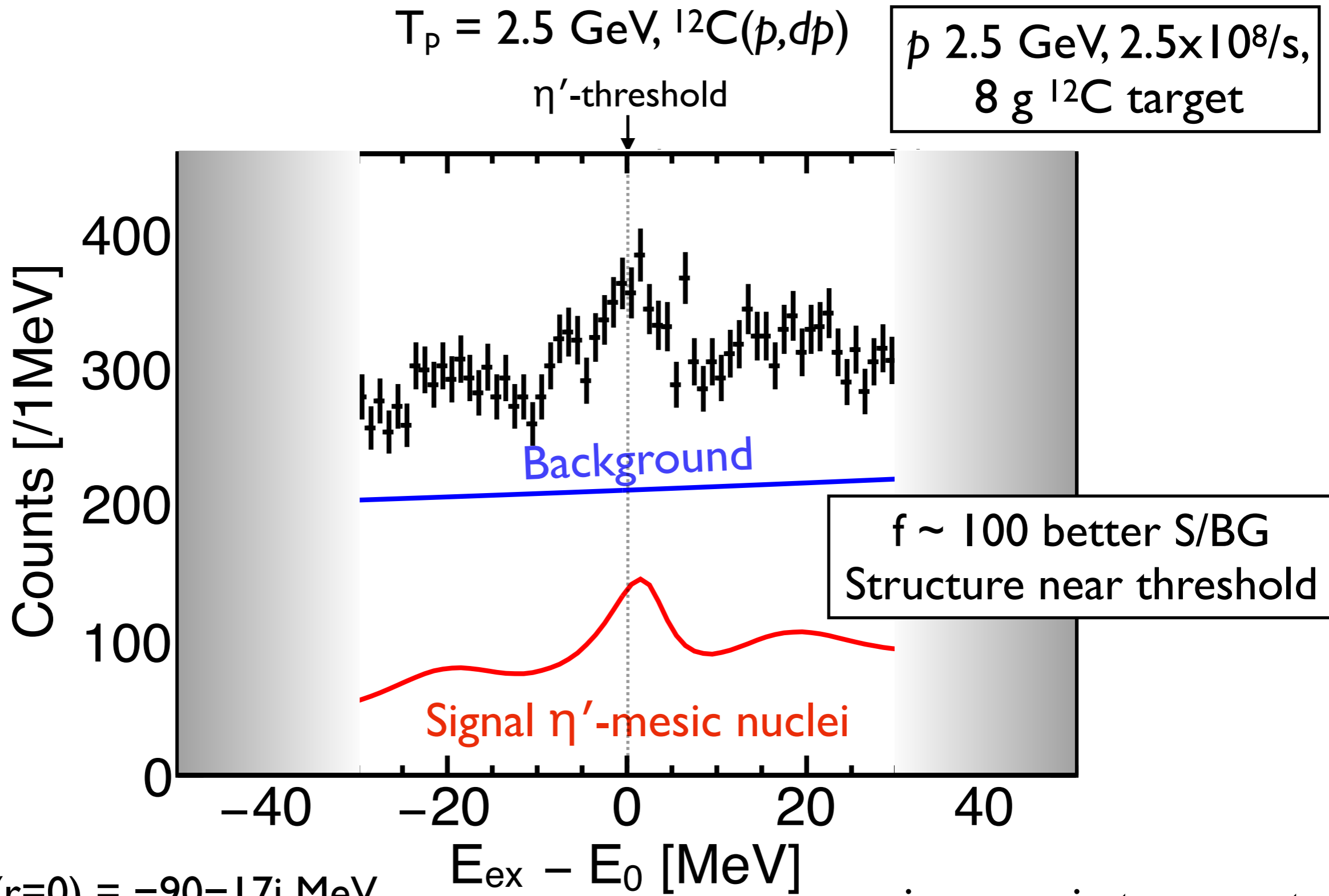
3 major decay modes of  $\eta'$ -mesic nuclei



# Expected spectrum in 4 days of DAQ at FRS



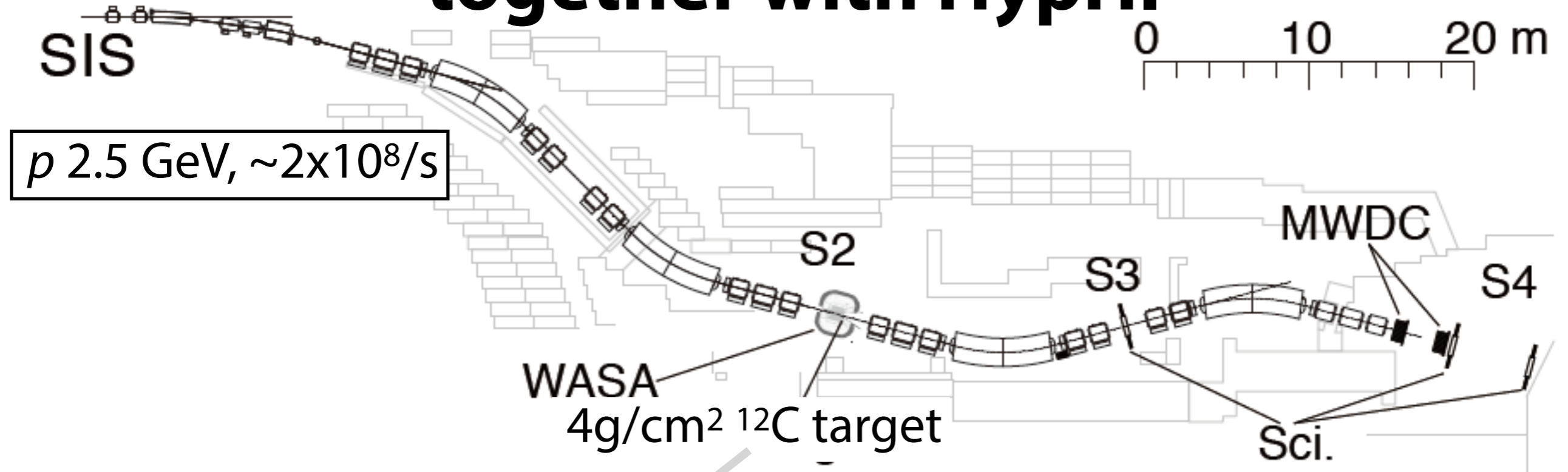
# Expected spectrum in 4 days of DAQ at FRS



$$U(r=0) = -90 - 17i \text{ MeV}$$

microscopic transport  
simulation

# Experimental setup : $^{12}\text{C}(p,d)$ in Feb. 2022 together with HypHI



←—————→  
**Momentum analysis of ( $p,d$ )  
for Missing Mass Spectroscopy**

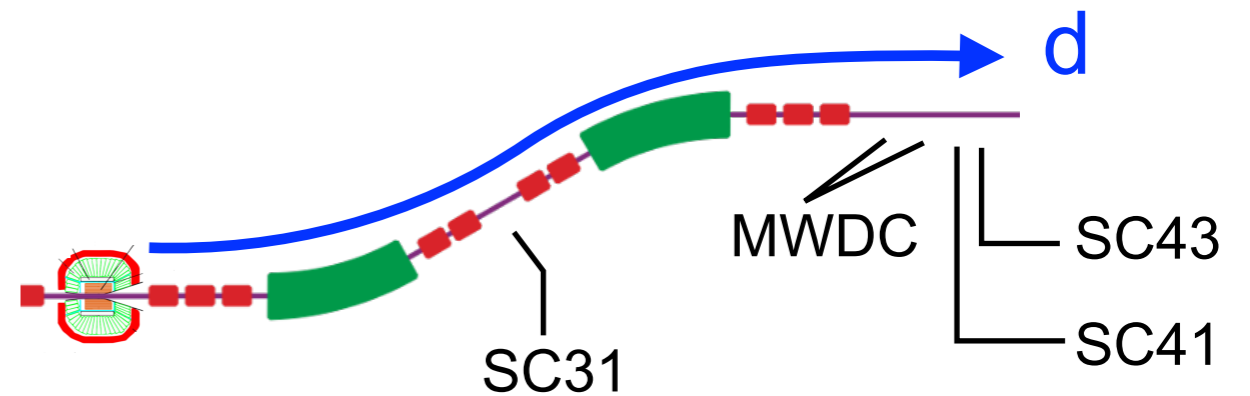
**Combination of forward  
high-res. spectrometer and  
large solid angle detector**

**WASA for decay  
 $p$  measurement**

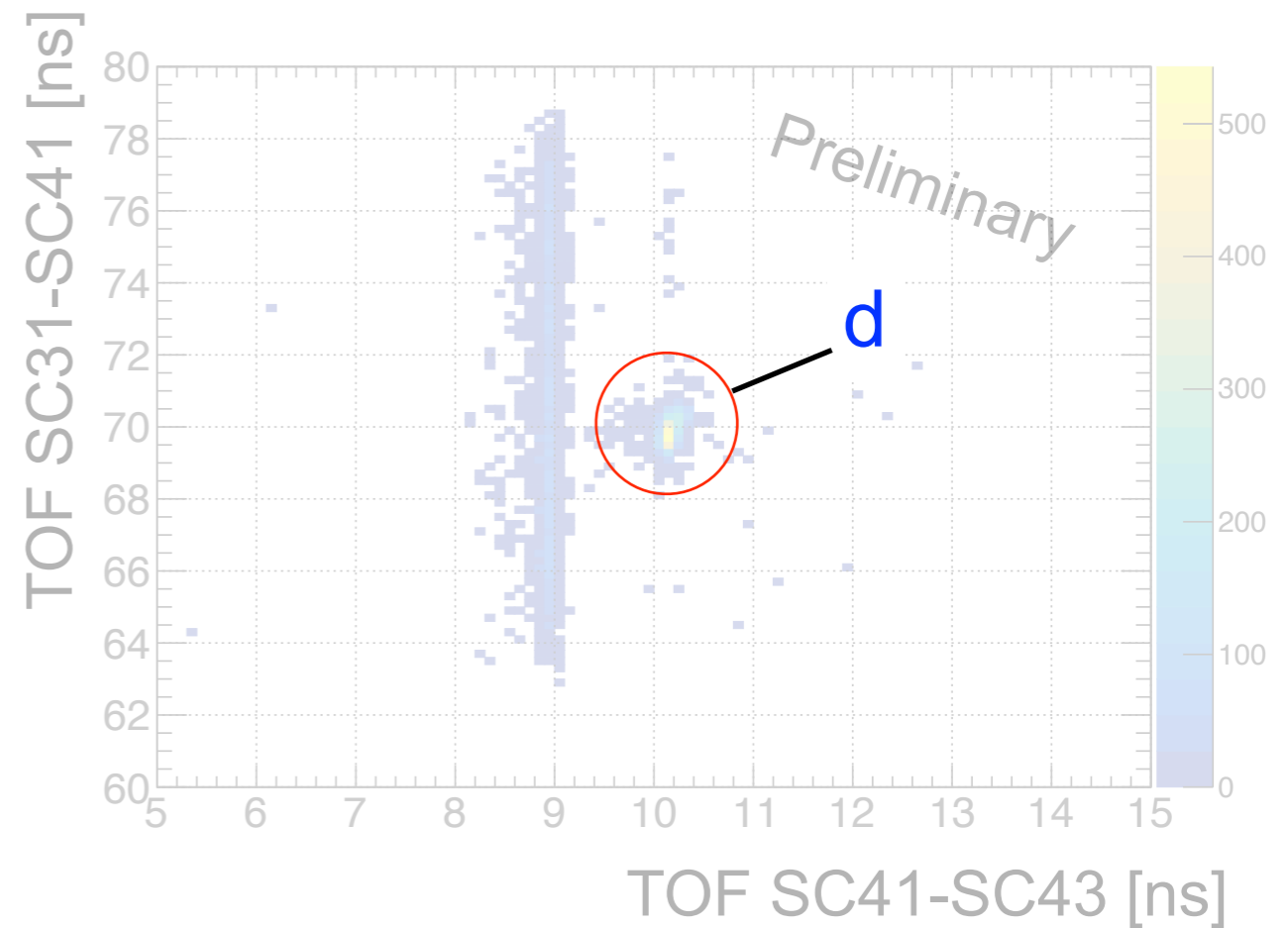
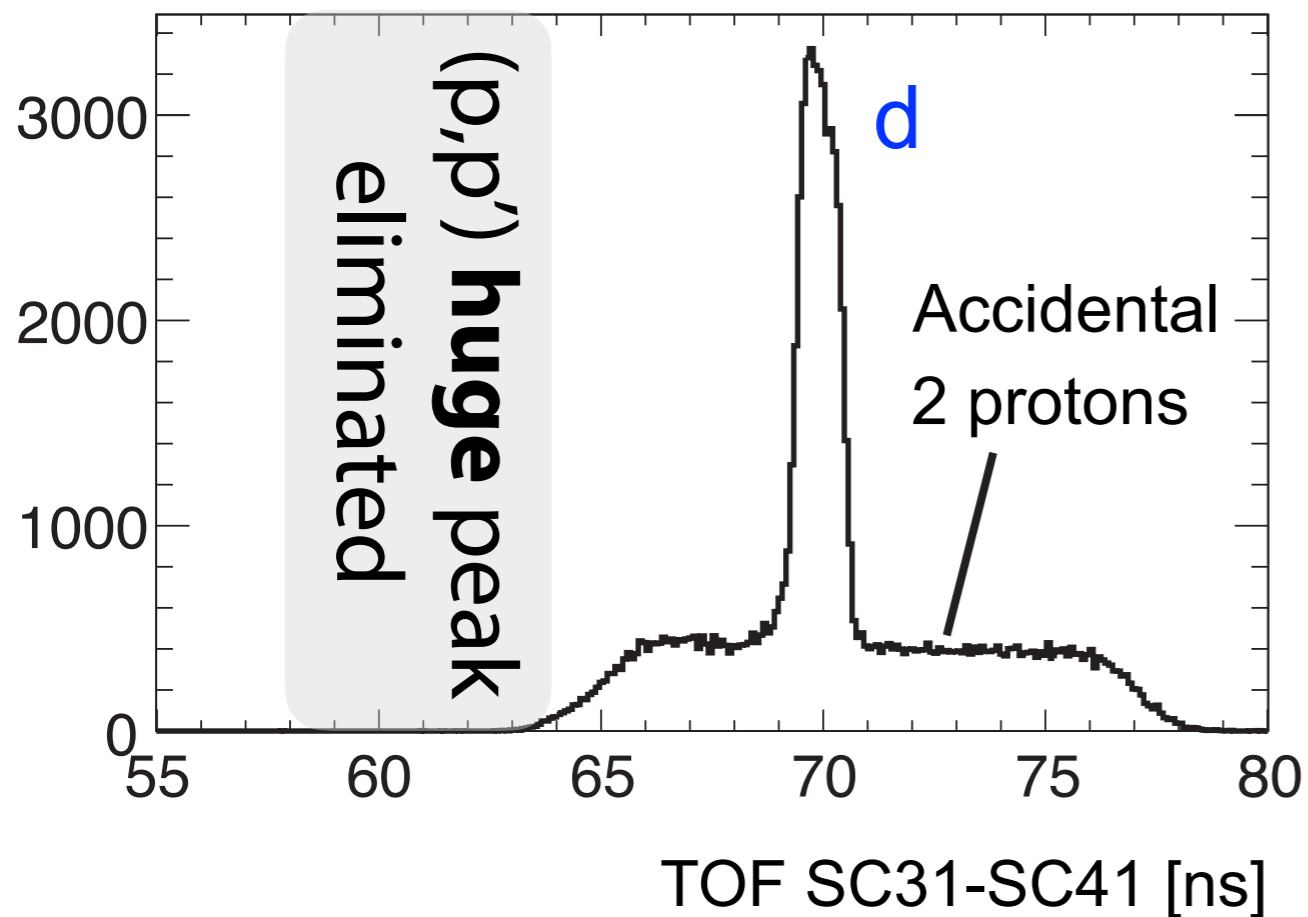
The image shows a detailed cross-sectional view of the WASA detector. It features a central red square target area surrounded by a dense array of multi-layered detector modules in various colors (yellow, blue, green, purple). The detector is mounted on a complex mechanical structure with support beams and various components.

# FRS S2-S4 PID Analysis

**$p/d$  ratio at S4  $> 1000$**   
**SC31-SC41 TOF trigger**  
 **$\rightarrow p/d$  ratio  $\sim 10$**

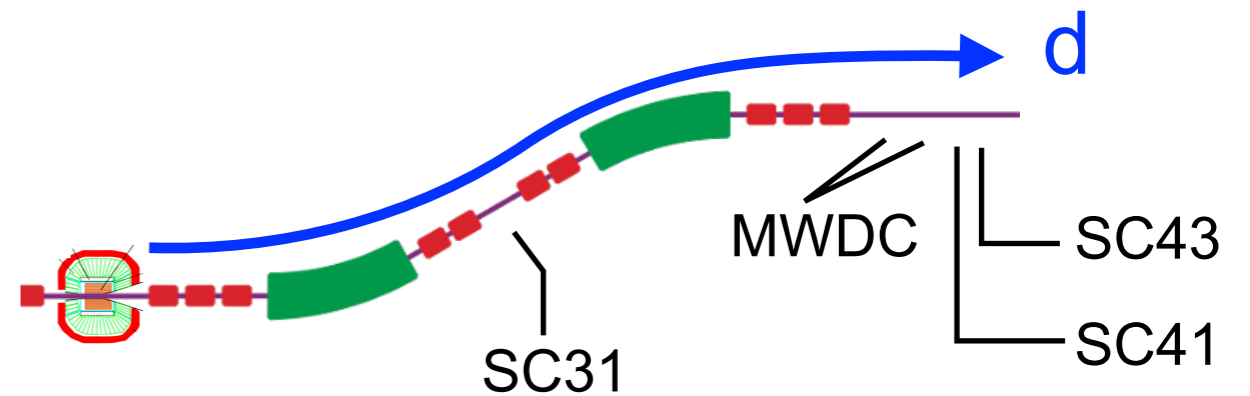


TOF-based Deuteron Trigger



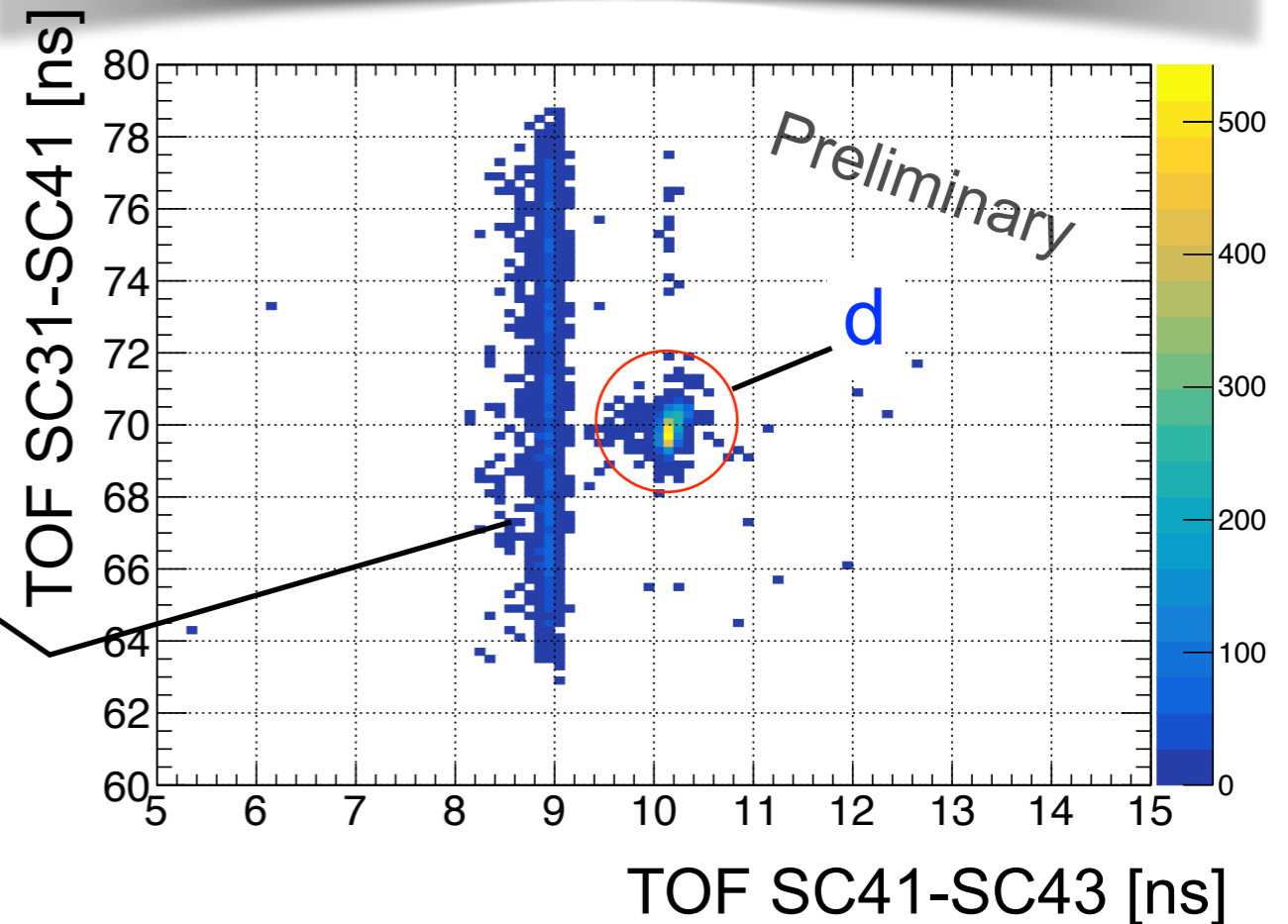
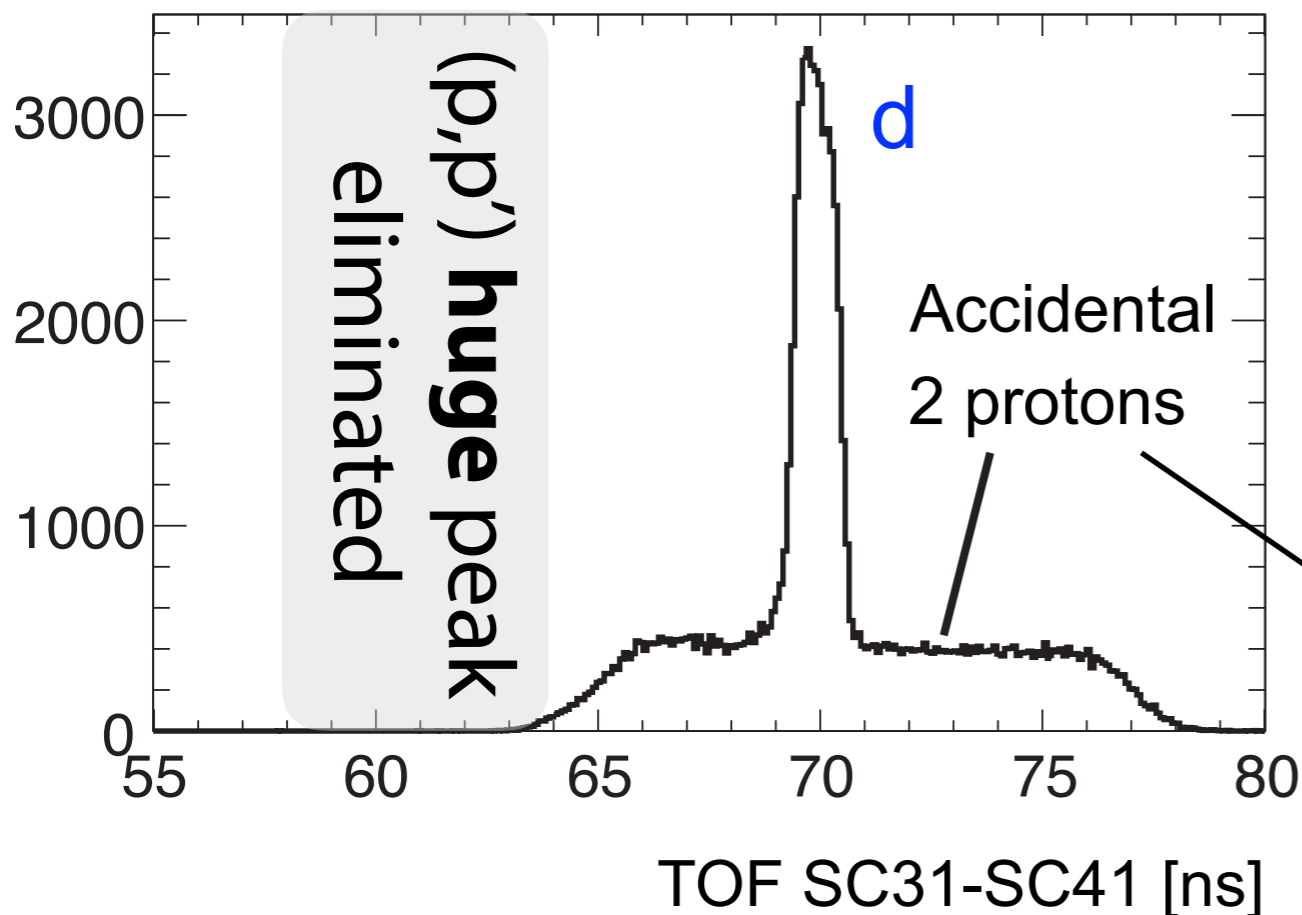
# FRS S2-S4 PID Analysis

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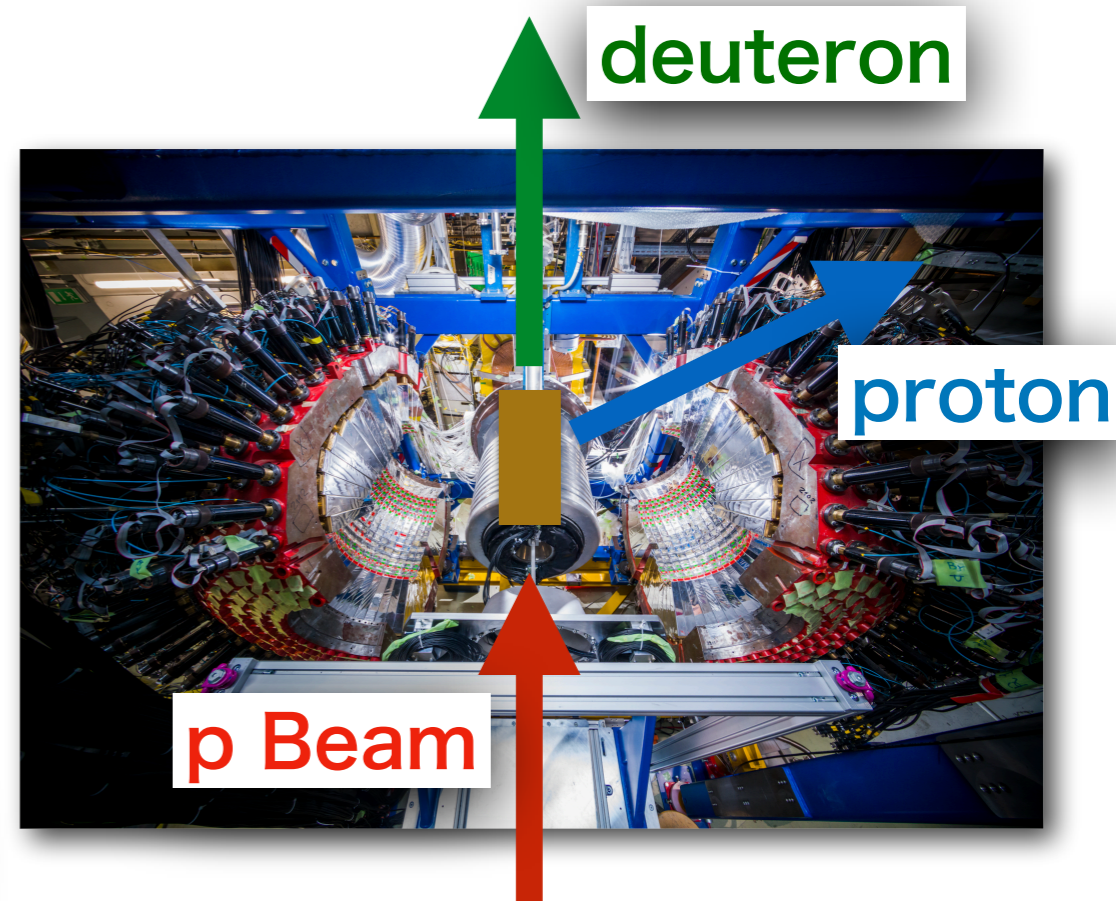
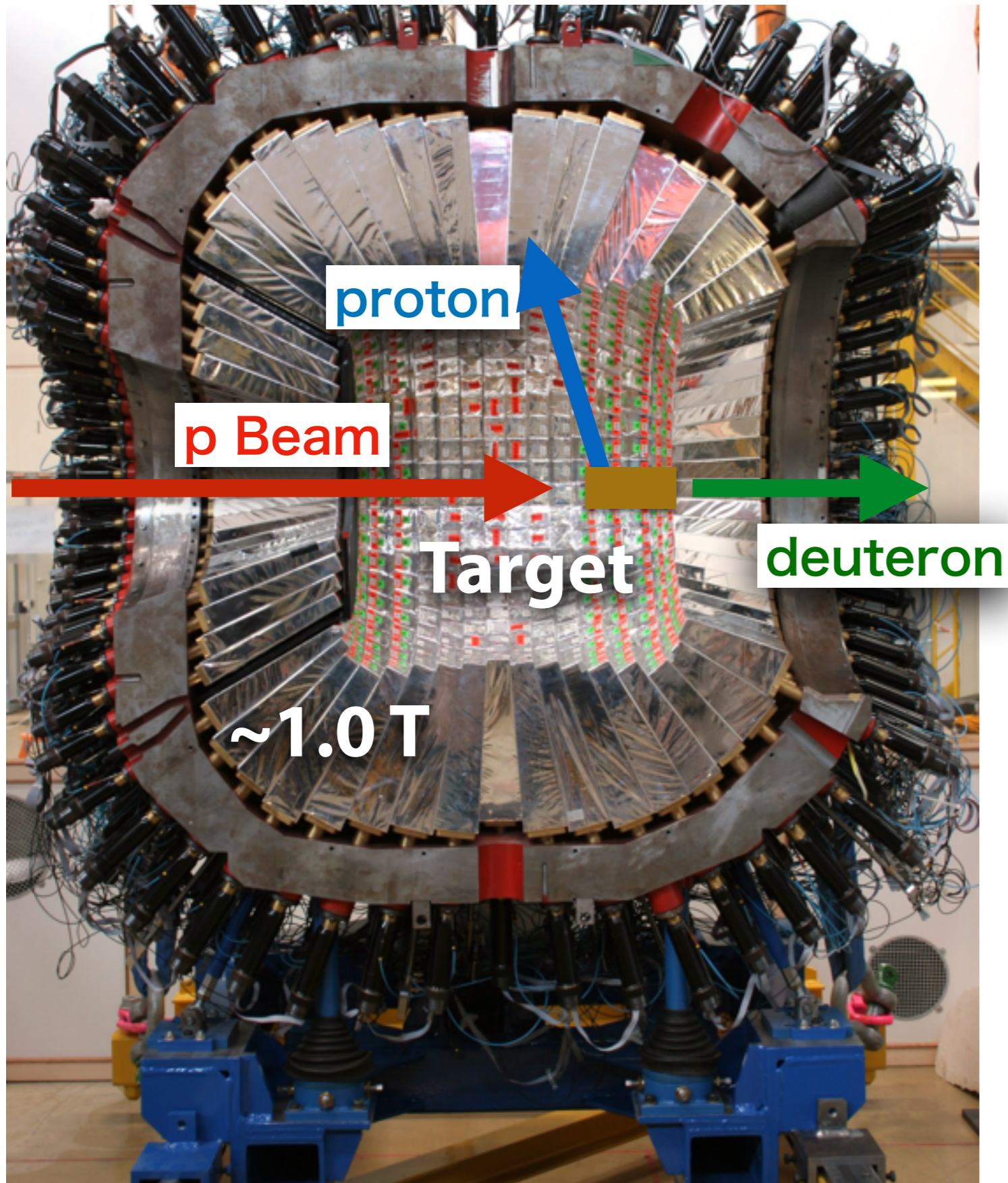


**SC31-SC41-SC43 TOF**  
**made perfect offline PID**

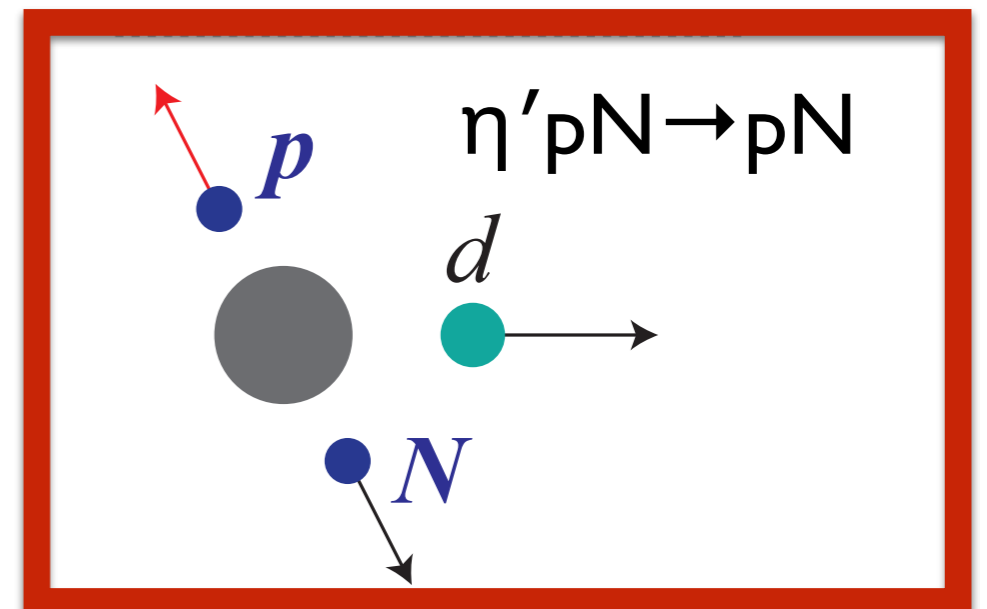
TOF-based Deuteron Trigger



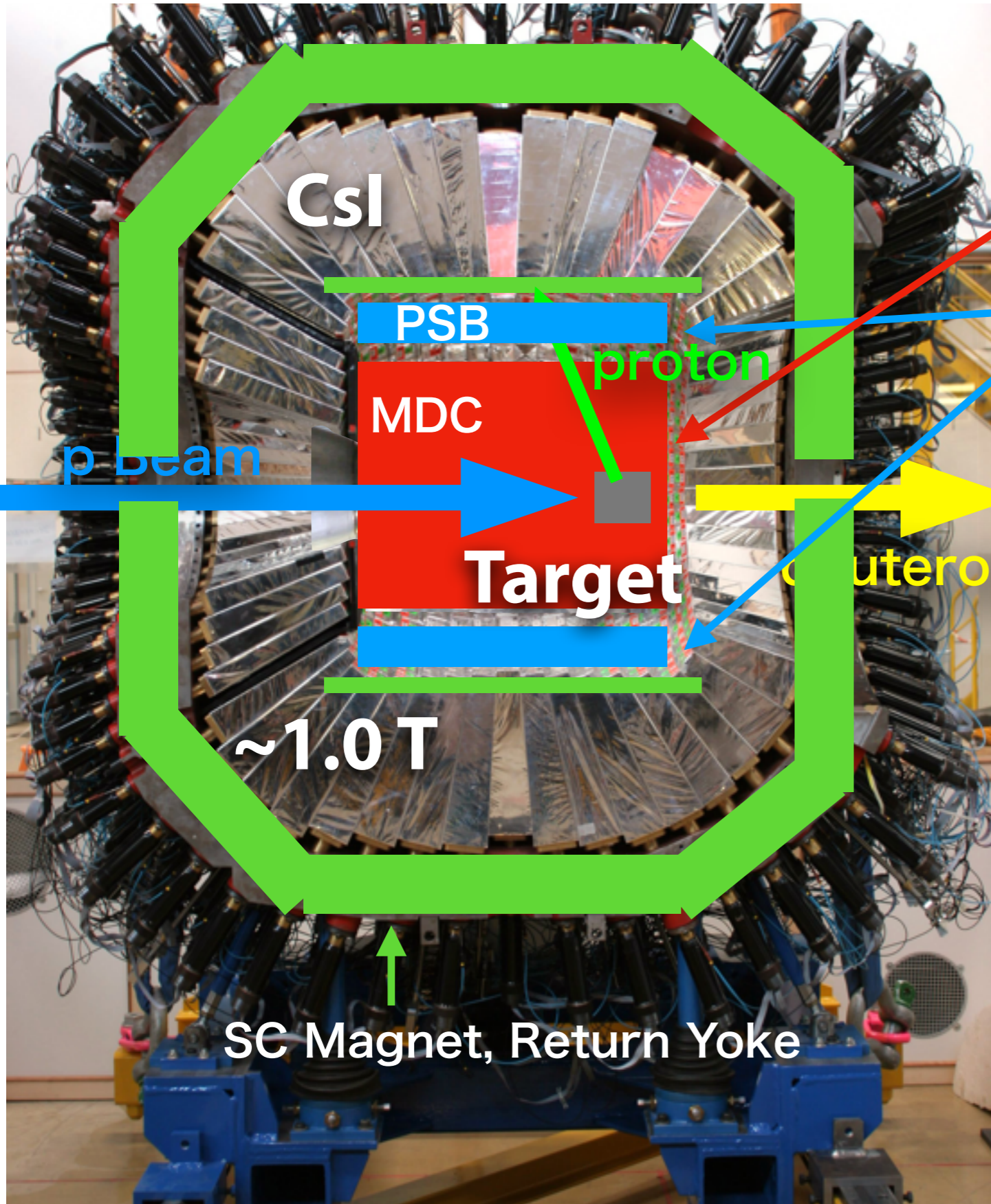
# Detectors in WASA



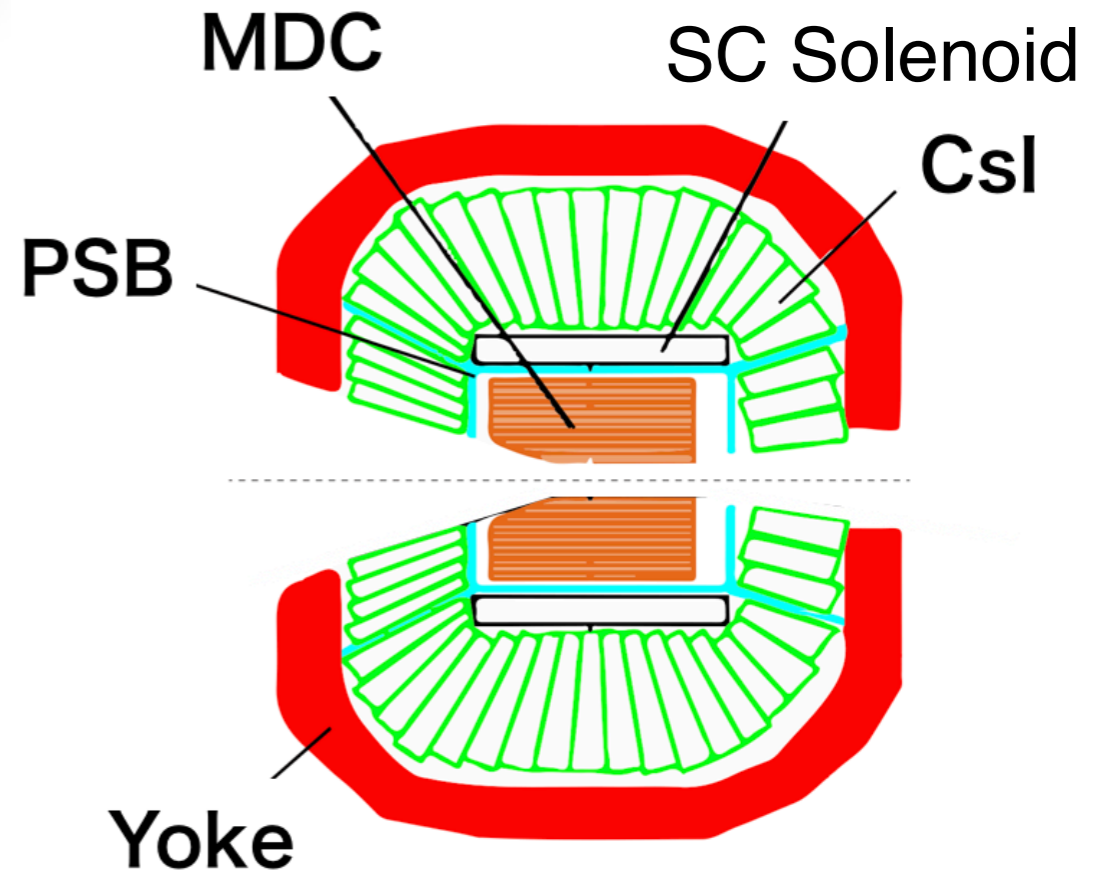
High energy proton tagging  
in coincidence with *forward d*



# Detectors in WASA



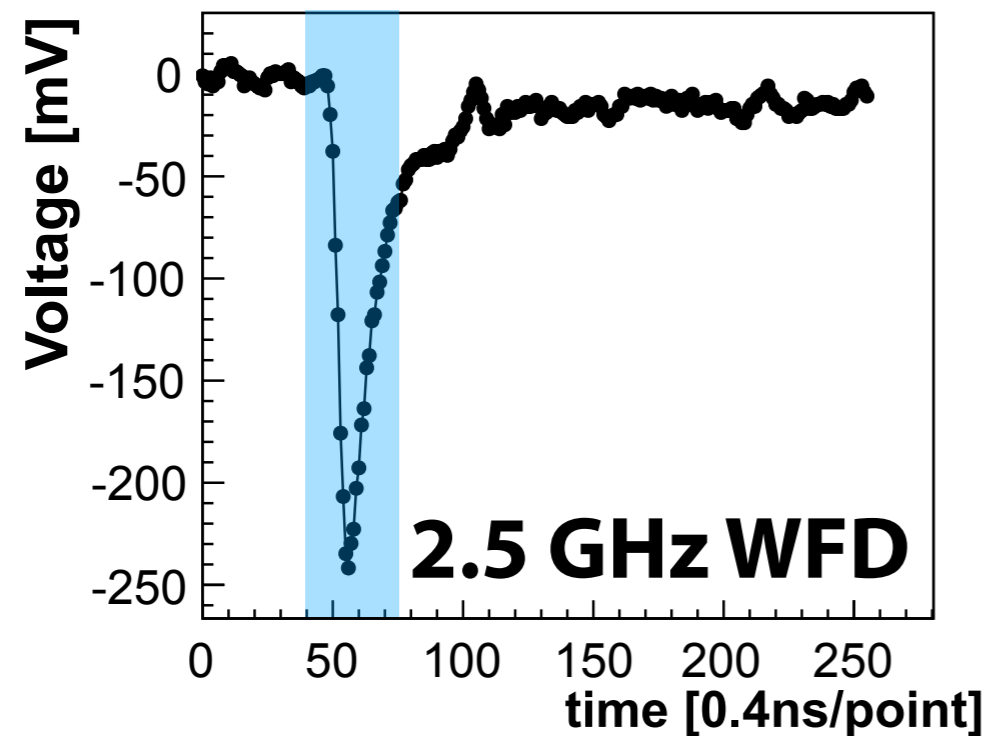
- MDC (Mini Drift Chamber)  
Charged particle tracking
- PSB (Plastic Scintillator Barrel)  
 $\Delta E$  + Timing measurement
- Csl  
 $\gamma$  detection for calibration



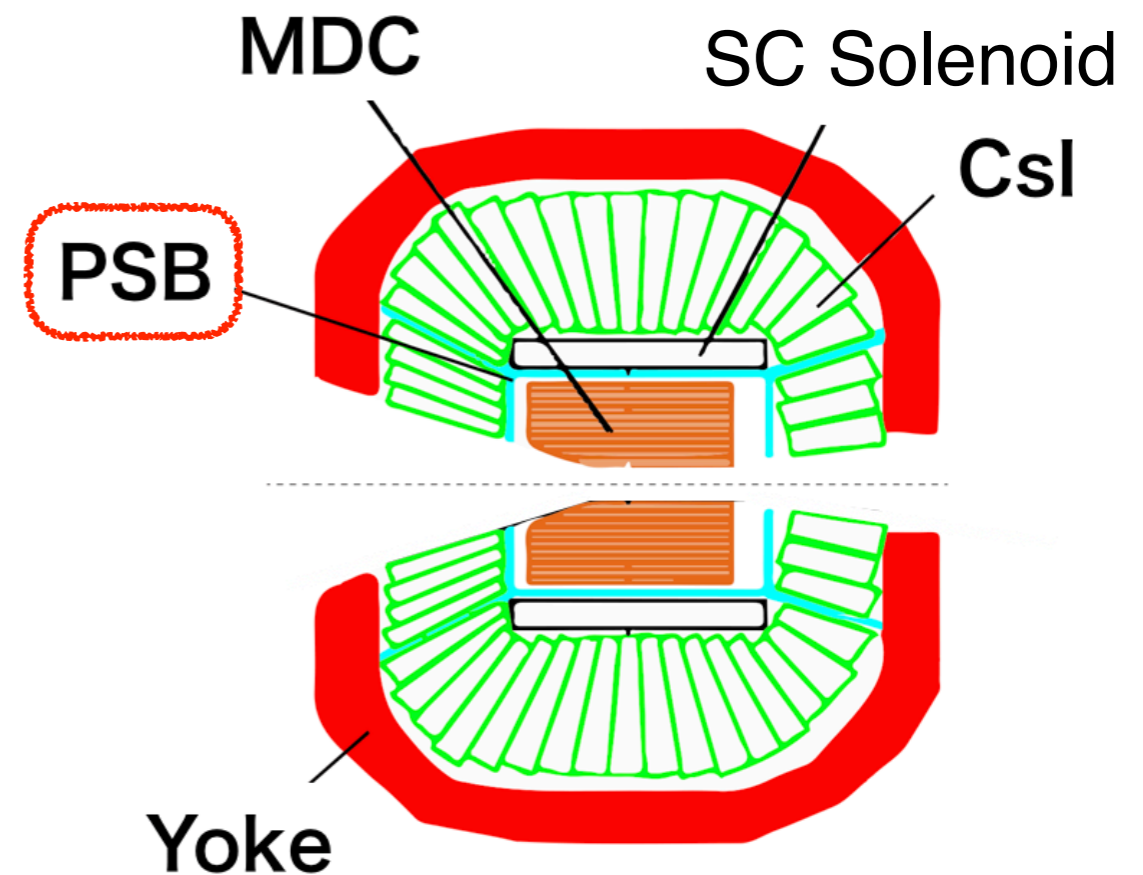


# Plastic Scintillator Barrel

**Charged particle trigger**  
**TOF,  $\Delta E$  information for PID**  
**Charge veto for CsI detector**

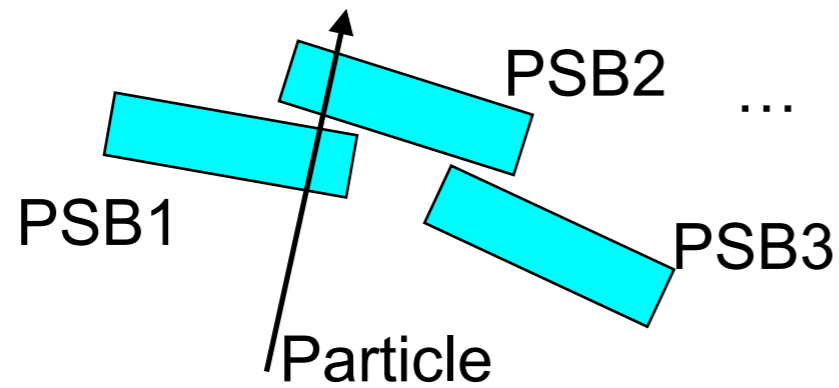


Software QDC/CFD for  $\Delta E$  and timing

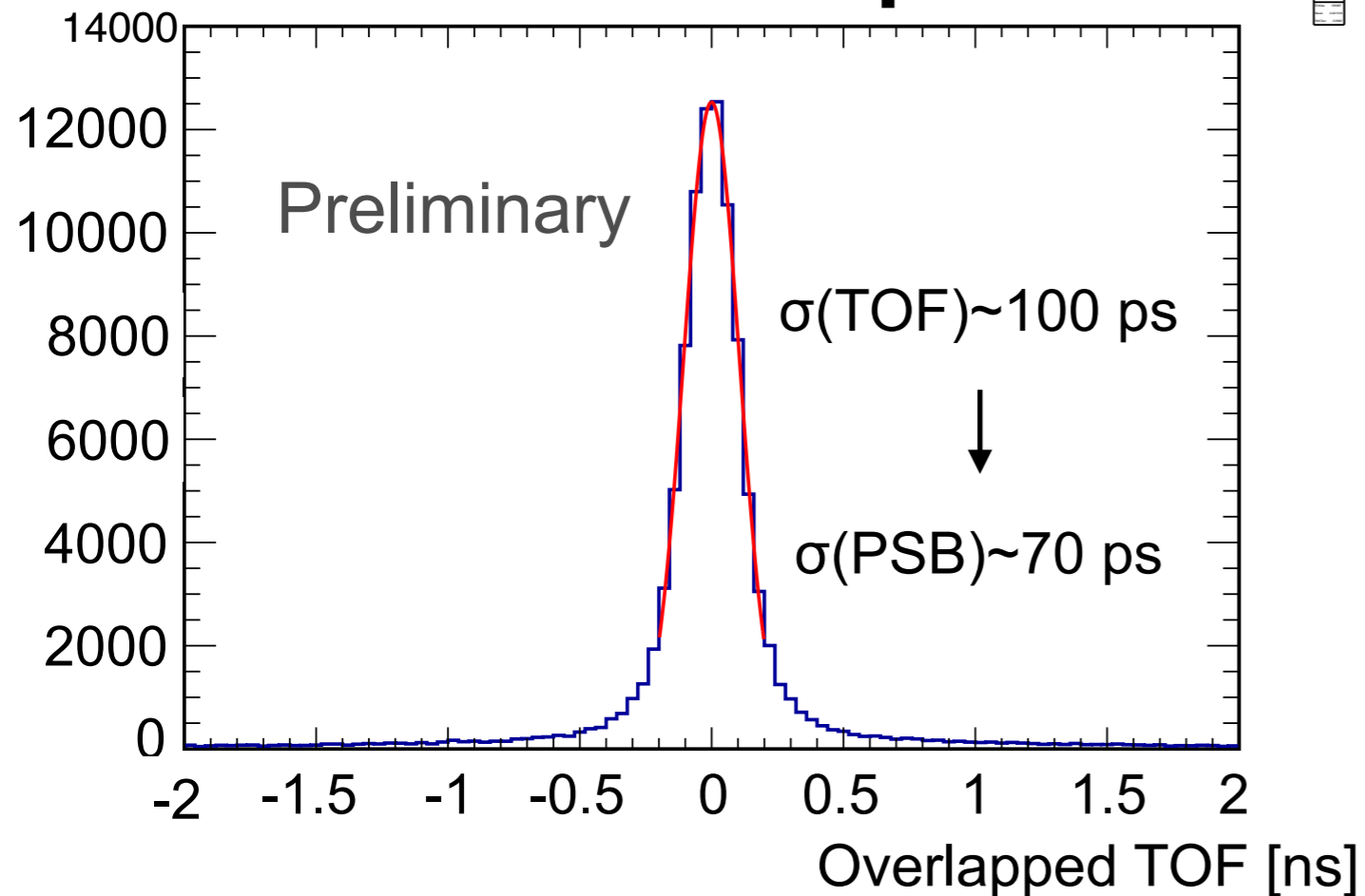


**R.Sekiya**

# Plastic Scintillator Barrel



## TOF btw. overlap PSBs

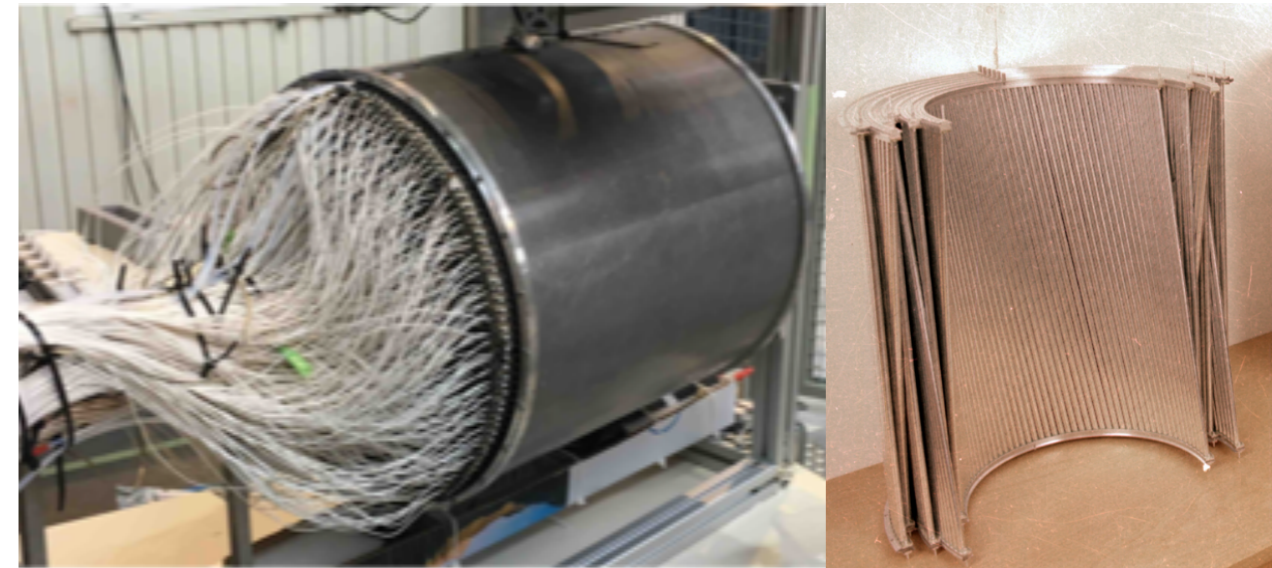


**PSB time resolution  
~ 70 ps  $\sigma$**

# Mini Drift Chamber MDC

17 layers  $\sim 2\text{K}$  straw tube detectors

Tracking resolution 250-500  $\mu\text{m}$   
 $\rightarrow \Delta p/p \sim 40\text{-}45\%$  at 1 GeV/c



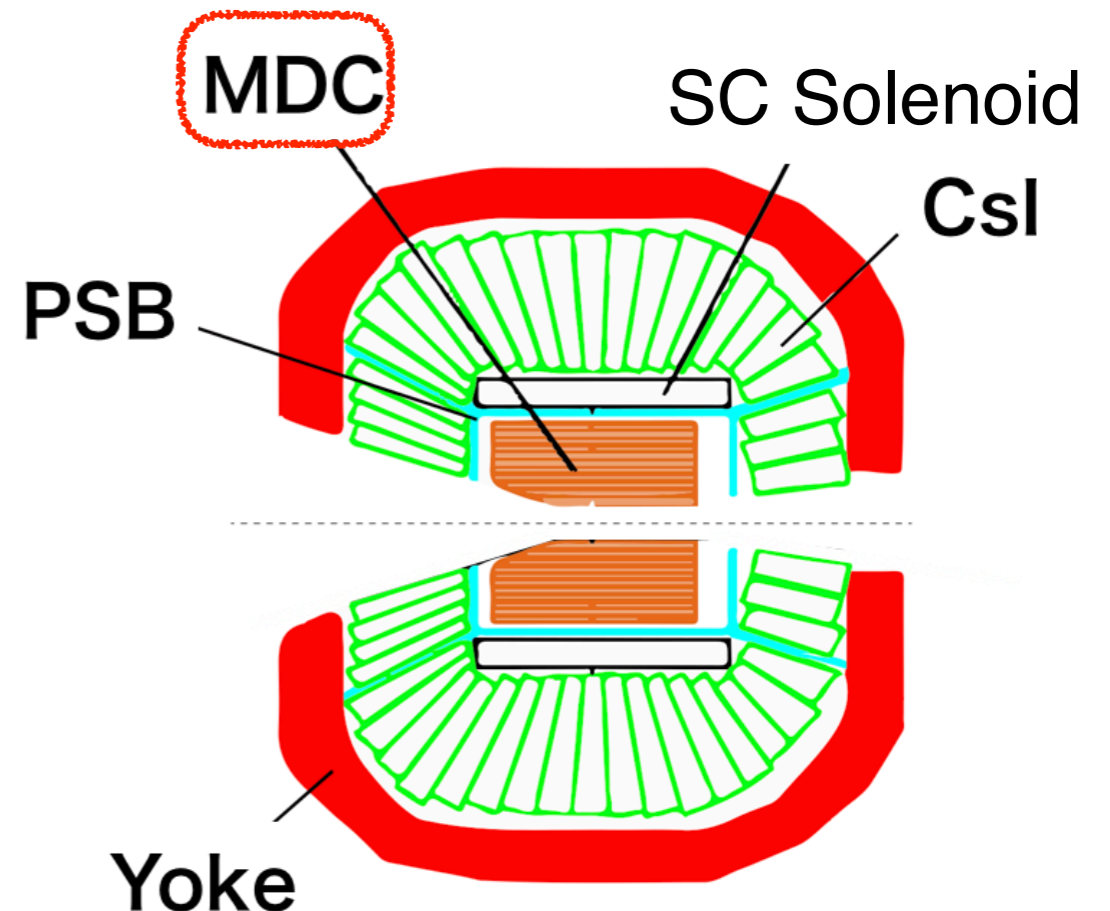
GENFIT Event Display

SC-Solenoid 1T

Track

Hit wires

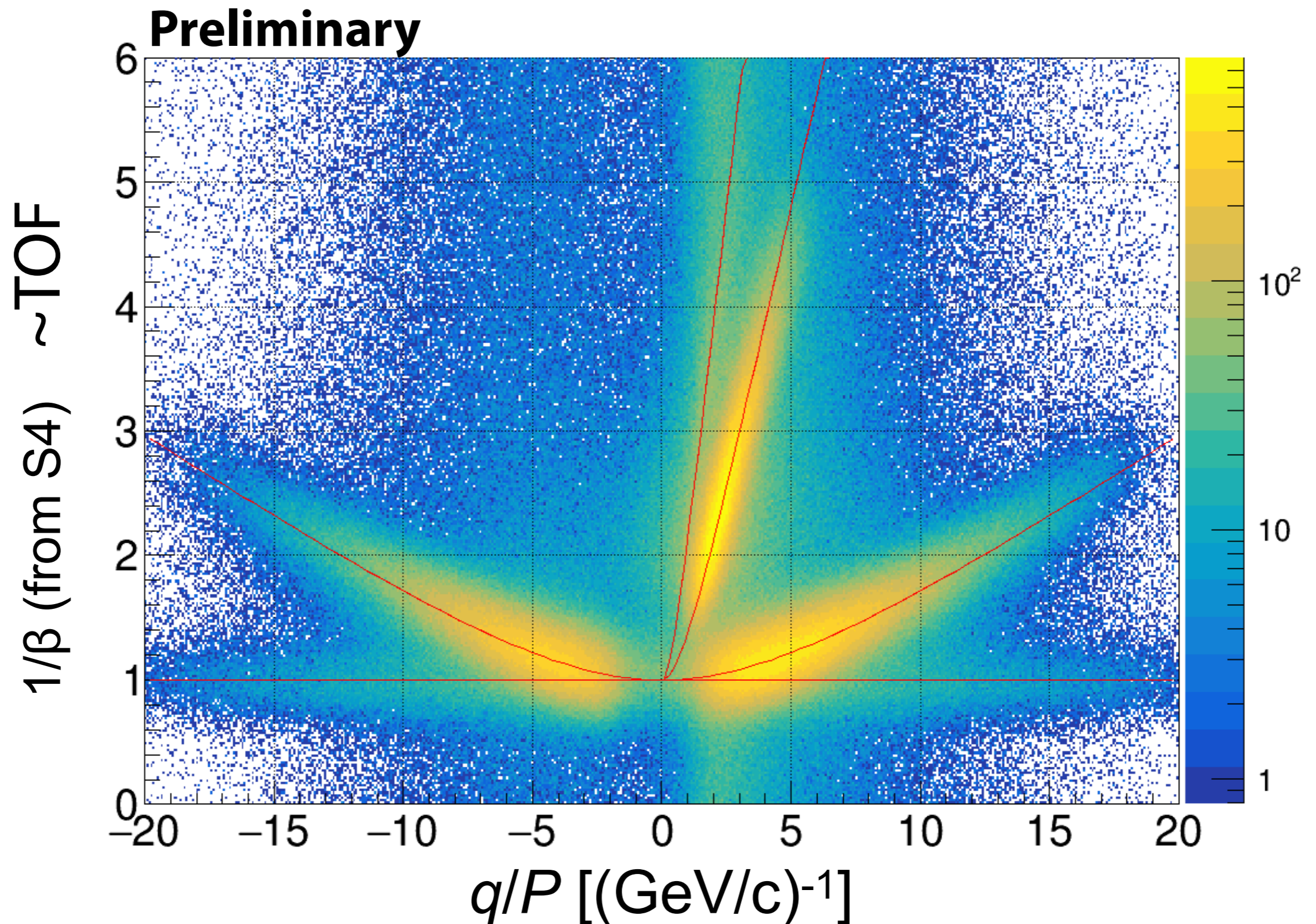
Tracking with Kalman filter



R.Sekiya

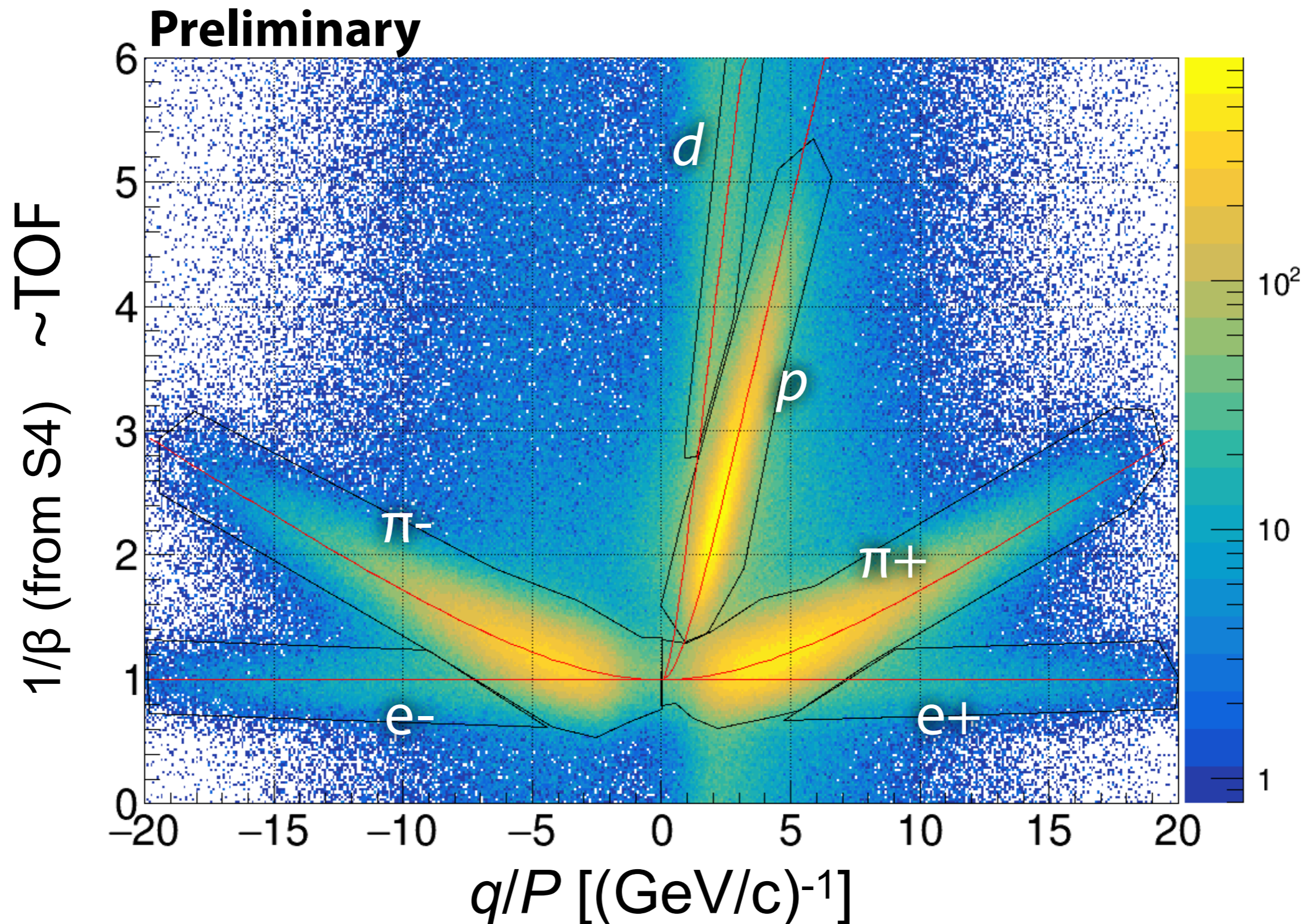
# WASA Combined PID with TOF and $q/p$

TOF start  $\sim 200$  ps computed based on S4 + track information in FRS

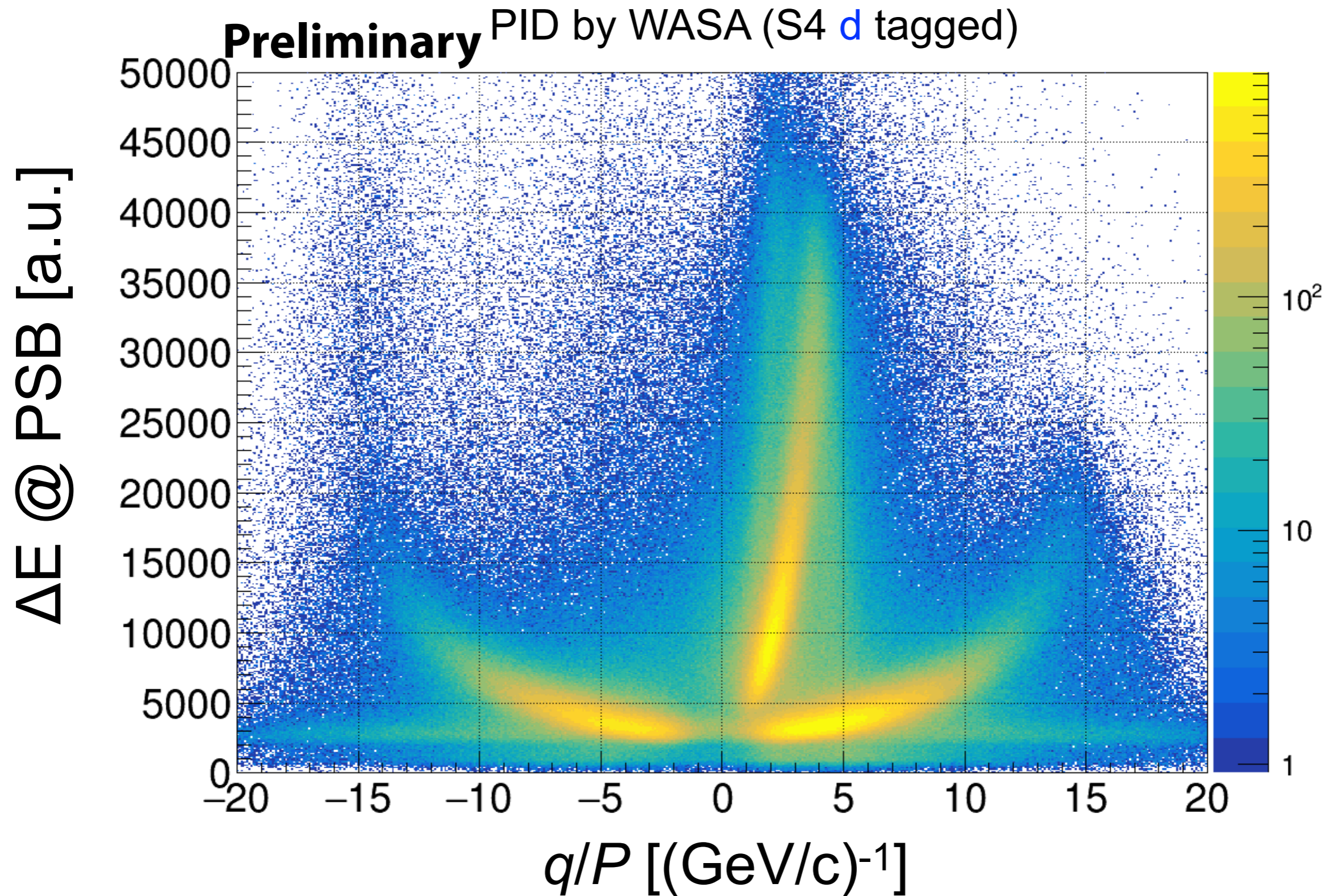


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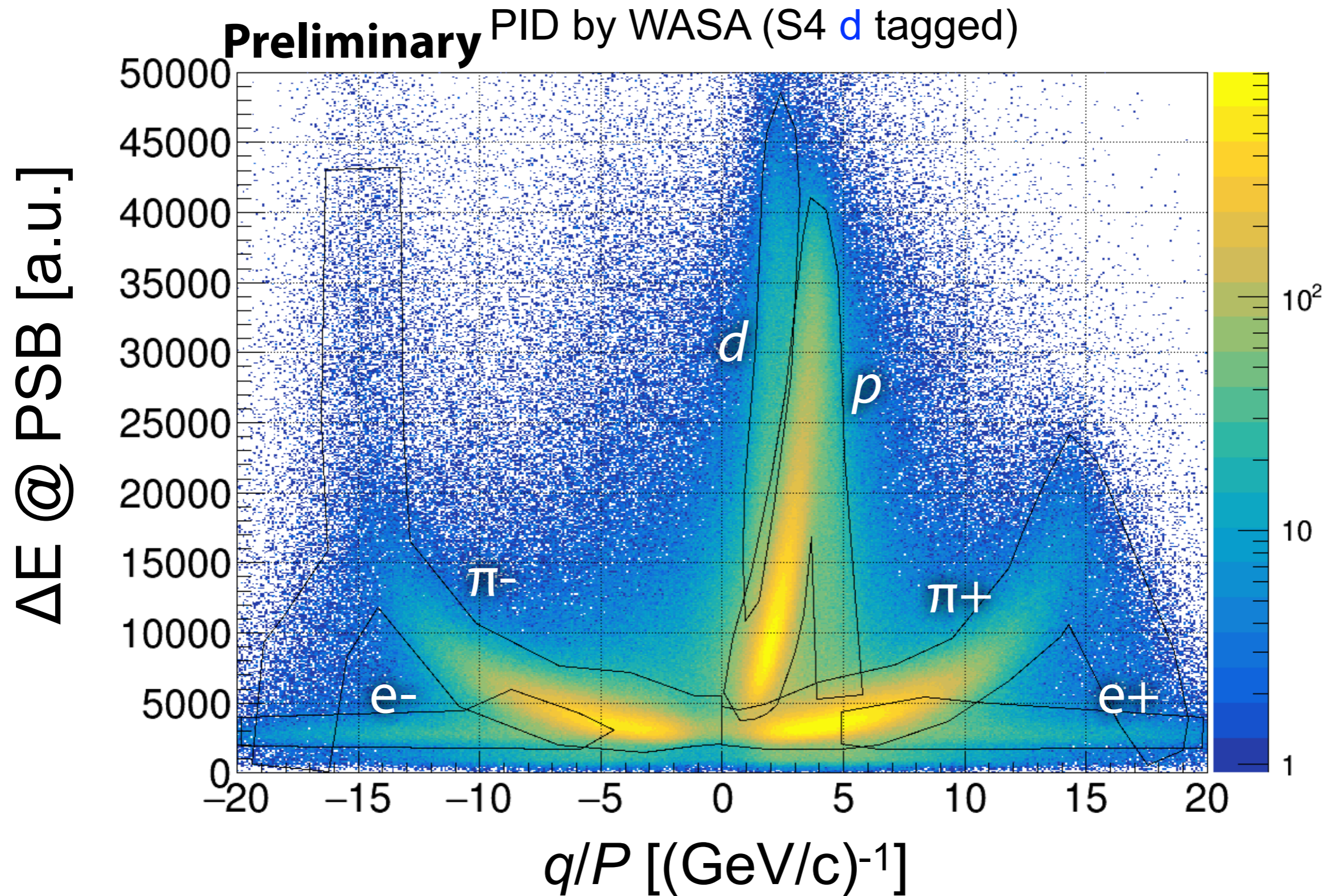
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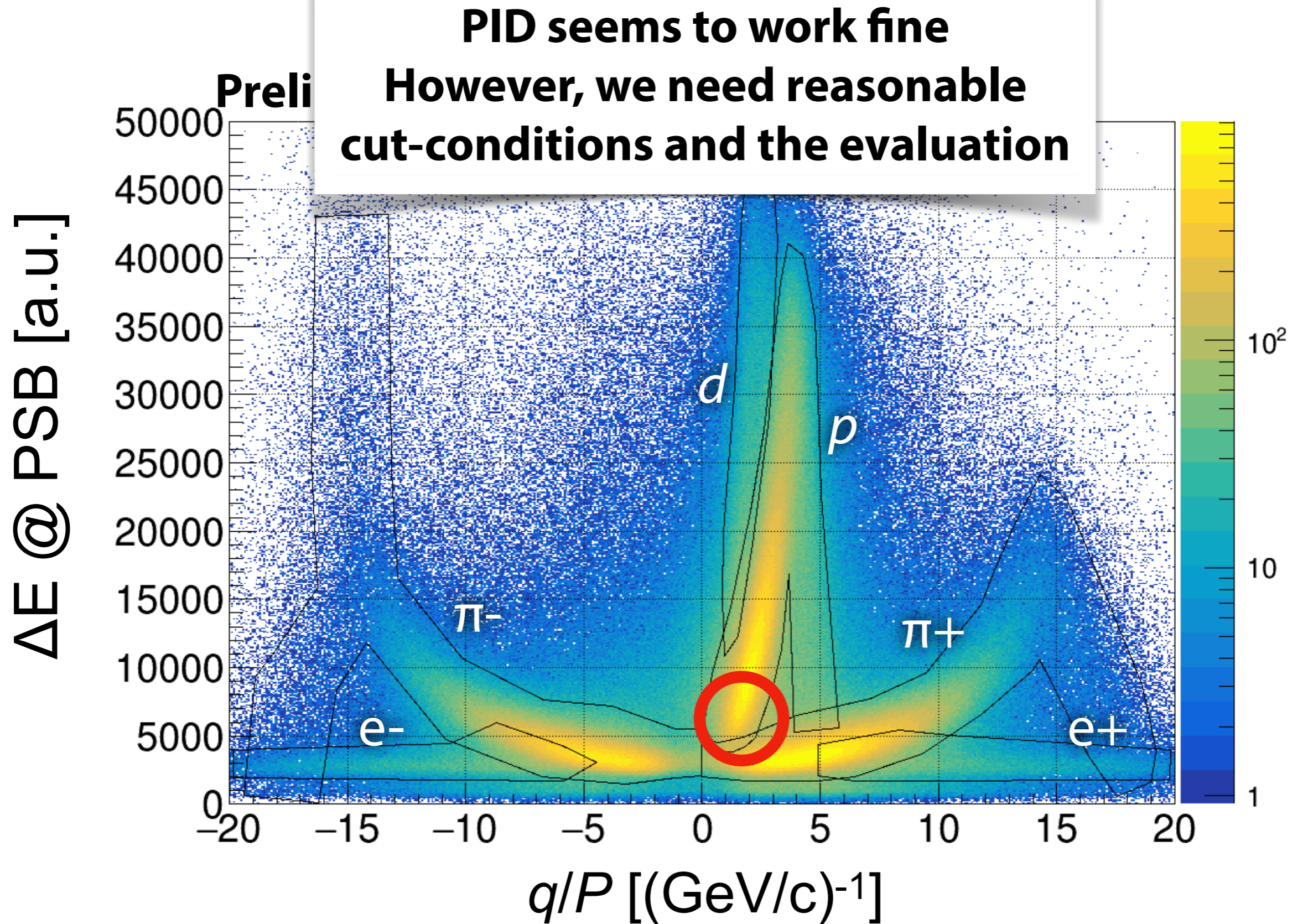
# WASA Combined PID with $\Delta E$ and $q/p$



# WASA Combined PID with $\Delta E$ and $q/p$



# WASA Combined PID with $\Delta E$ and $q/p$





# Summary

- **Thank you for your cooperation**
- **We have conducted S490 experiment to search for eta-prime mesic nuclei**
- **We have conducted missing-mass spectroscopy of  $^{12}\text{C}(p,d)$  reaction with tagging of  $\sim 1$  GeV/c proton emitted nearly isotropically for two nucleon absorption of  $\eta'$**
- **We accumulated  $1.1 \times 10^7$  forward  $d$  in the inclusive measurement of  $(p,d)$  by FRS. Detected proton number with WASA in coincidence with forward  $d$  agrees with expectations  $\rightarrow$  BG suppression as expected**
- **WASA PID works fine with TOF, tracking, and  $\Delta E$  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  $\Delta E$ , TOF, and tracking information to make “kinematical fitting” to achieve better momentum resolution**  
 **$\rightarrow$  Semi-exclusive spectra will be ready soon.**
- **We start considerations about next experiment**

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