

Search for η' mesic nuclei in GSI/FAIR

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 for η -PRiME collaboration

Y. Ayyad, J. Benlliure, K.-T. Brinkmann, S. Friedrich, H. Fujioka**, H. Geissel, J. Gellanki, C. Guo, E. Gutz, E. Haettner, M. N. Harakeh, R. S. Hayano, Y. Higashi, S. Hirenzaki, C. Hornung, Y. Igarashi, N. Ikeno, K. Itahashi*, M. Iwasaki, D. Jido, N. Kalantar-Nayestanaki, R. Kanungo, R. Knoebel, N. Kurz, V. Metag, I. Mukha, T. Nagae, H. Nagahiro, M. Nanova, T. Nishi, H. J. Ong, S. Pietri, A. Prochazka, C. Rappold, M. P. Reiter, J. L. R. Sánchez, C. Scheidenberger, H. Simon, B. Sitar, P. Strmen, B. Sun, K. Suzuki, I. Szarka, M. Takechi, **Y. K. Tanaka**, I. Tanihata, S. Terashima, Y. N. Watanabe, H. Weick, E. Widmann, J. Winfield, X. Xu, H. Yamakami, J. Zhao

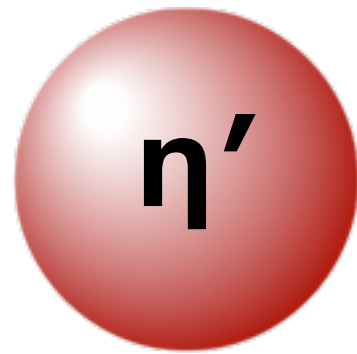
*spokesperson, ** co-spokesperson



for Super-FRS collaboration

Osaka University, Universidade de Santiago de Compostela, Universitaet Giessen, Kyoto University, GSI, University of Groningen, Beihang University, The University of Tokyo, Nara Women's University, KEK, RIKEN, Tokyo Metropolitan University, Saint Mary's University, Technische Universitaet Darmstadt, Comenius University Bratislava, Stefan Meyer Institut, Niigata University

η' Meson



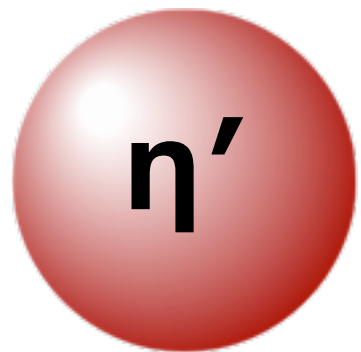
Pseudo scalar meson ($J^{\pi}=0^{-}$)

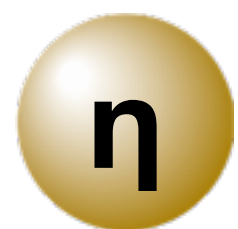
$$M=958 \text{ MeV}/c^2$$

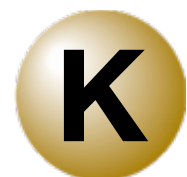
$$\Gamma=0.199 \text{ MeV}$$

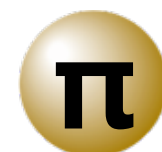
Decay: $\pi^+\pi^-\eta(43\%)$,
 $\rho\gamma(29\%)$, $\pi^0\pi^0\eta(22\%)$

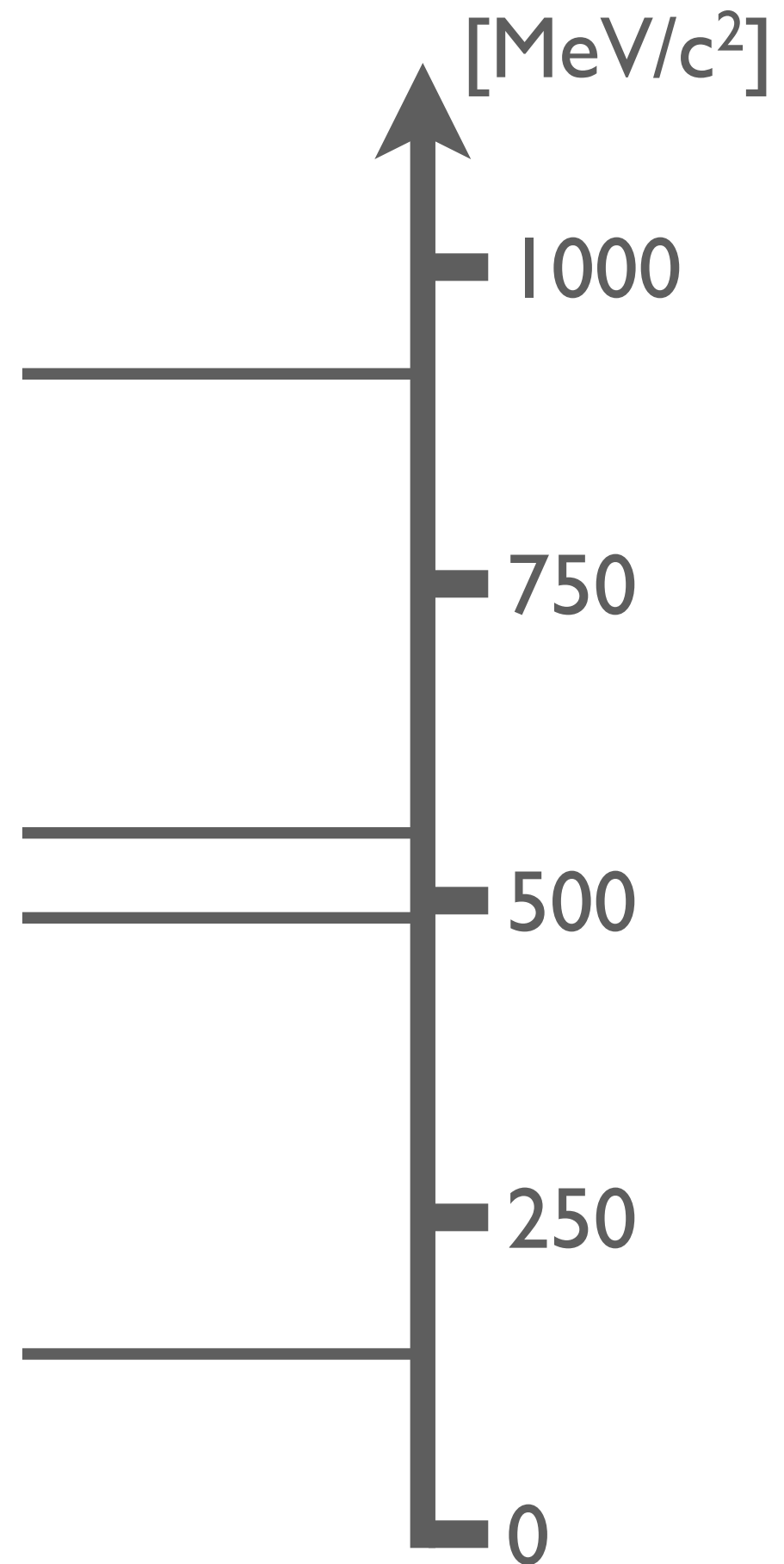
η' and other PS mesons

 η' $M=958 \text{ MeV}/c^2$

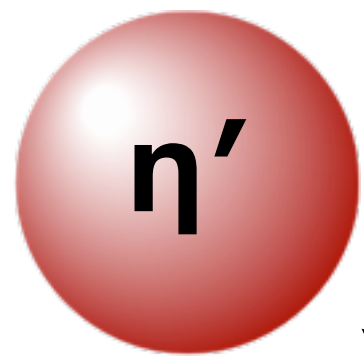
 η $M=548 \text{ MeV}/c^2$

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

 π $M=140 \text{ MeV}/c^2$



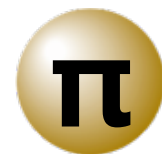
η' and other PS mesons



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

η problem

$m_{\eta'} < \sqrt{3}m_{\pi}$
(Weinberg, 1975)



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

$\sqrt{3}m_{\pi}$

[MeV/c²]

1000

750

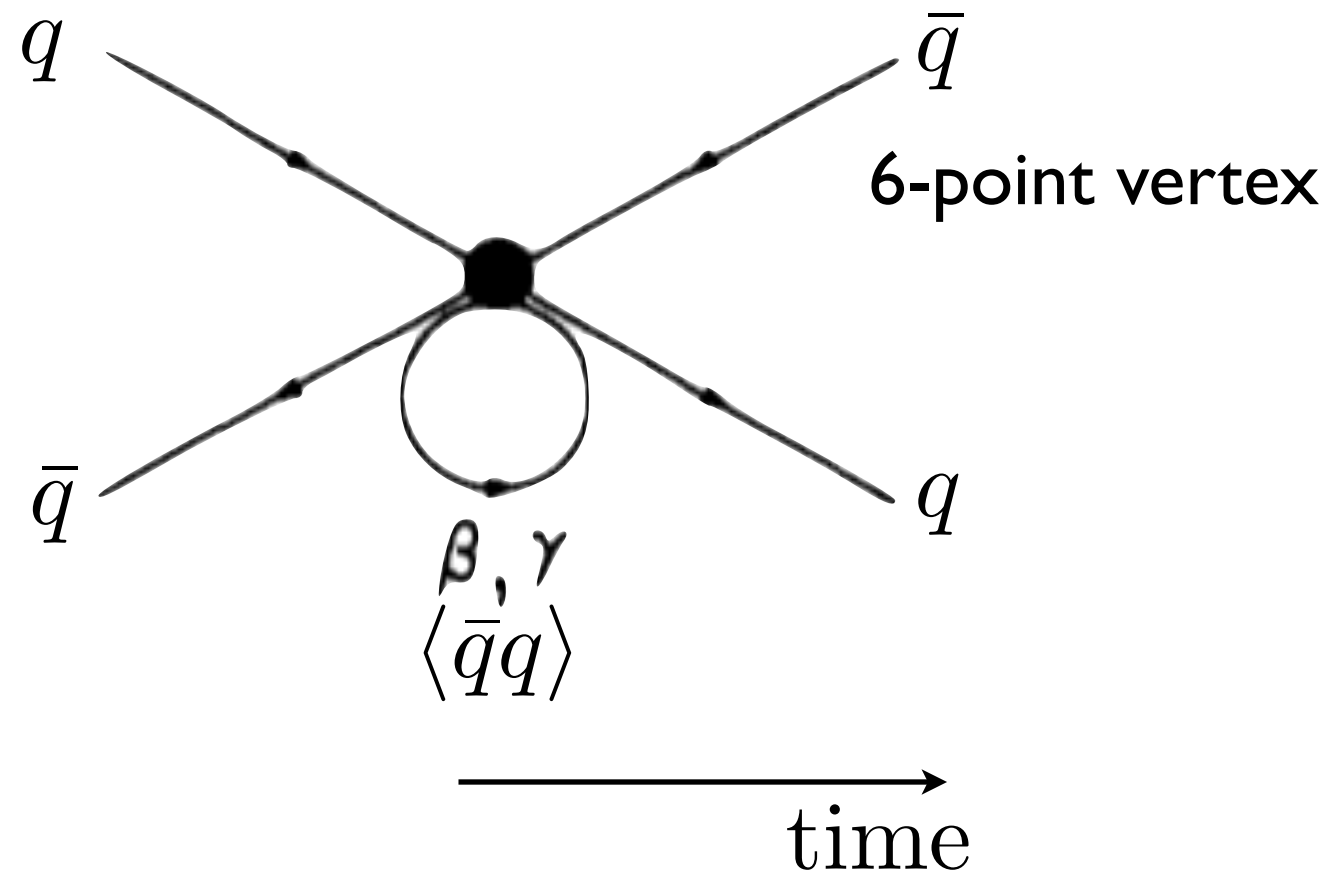
500

250

0

Large η' mass can be explained

$U_A(1)$ quantum anomaly $\times$ χ -symmetry breaking



Kobayashi-Maskawa-'t Hooft-type interaction

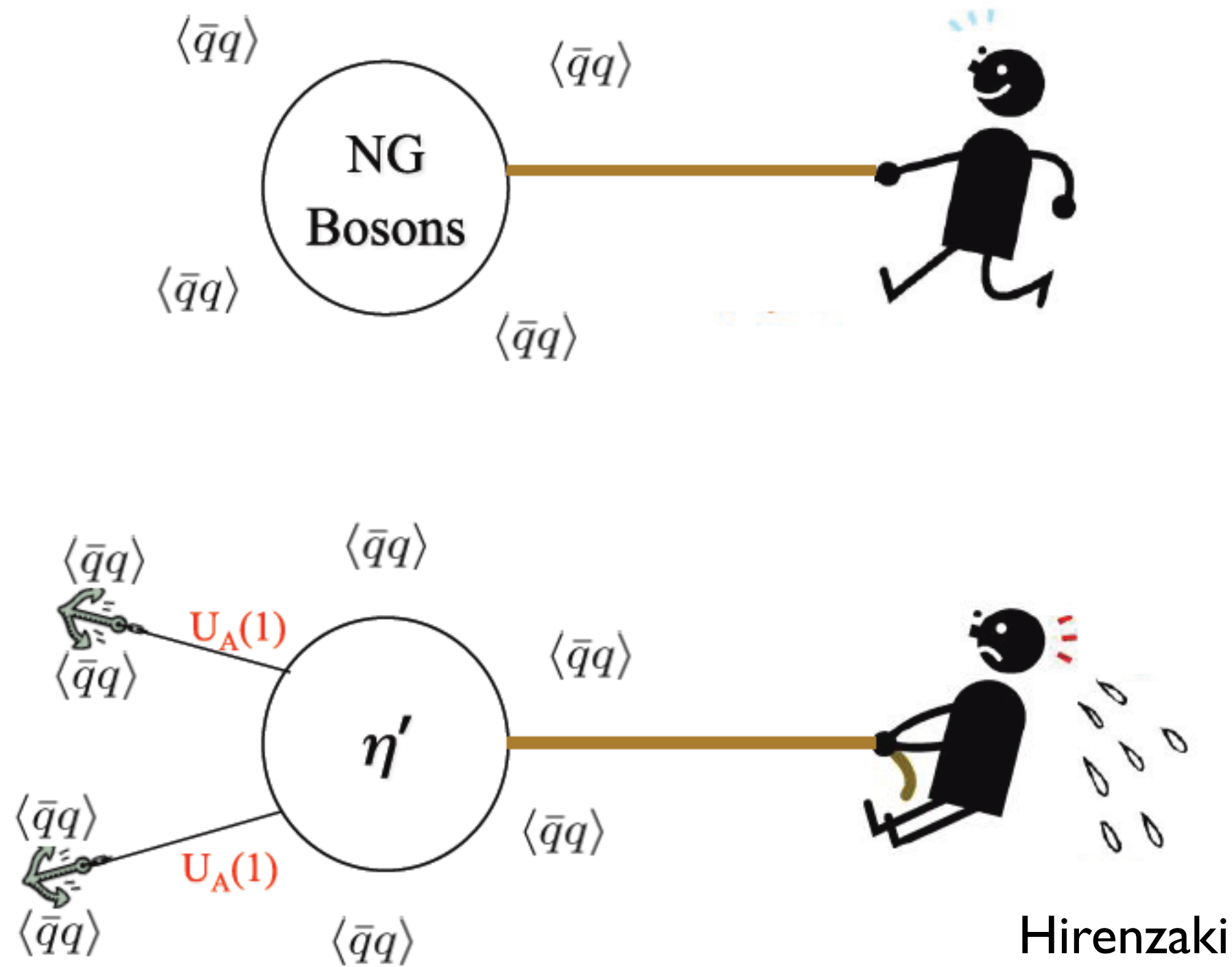
Kobayashi, Maskawa, PTP44(70)1422

't Hooft, PRD14(76)3432.

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

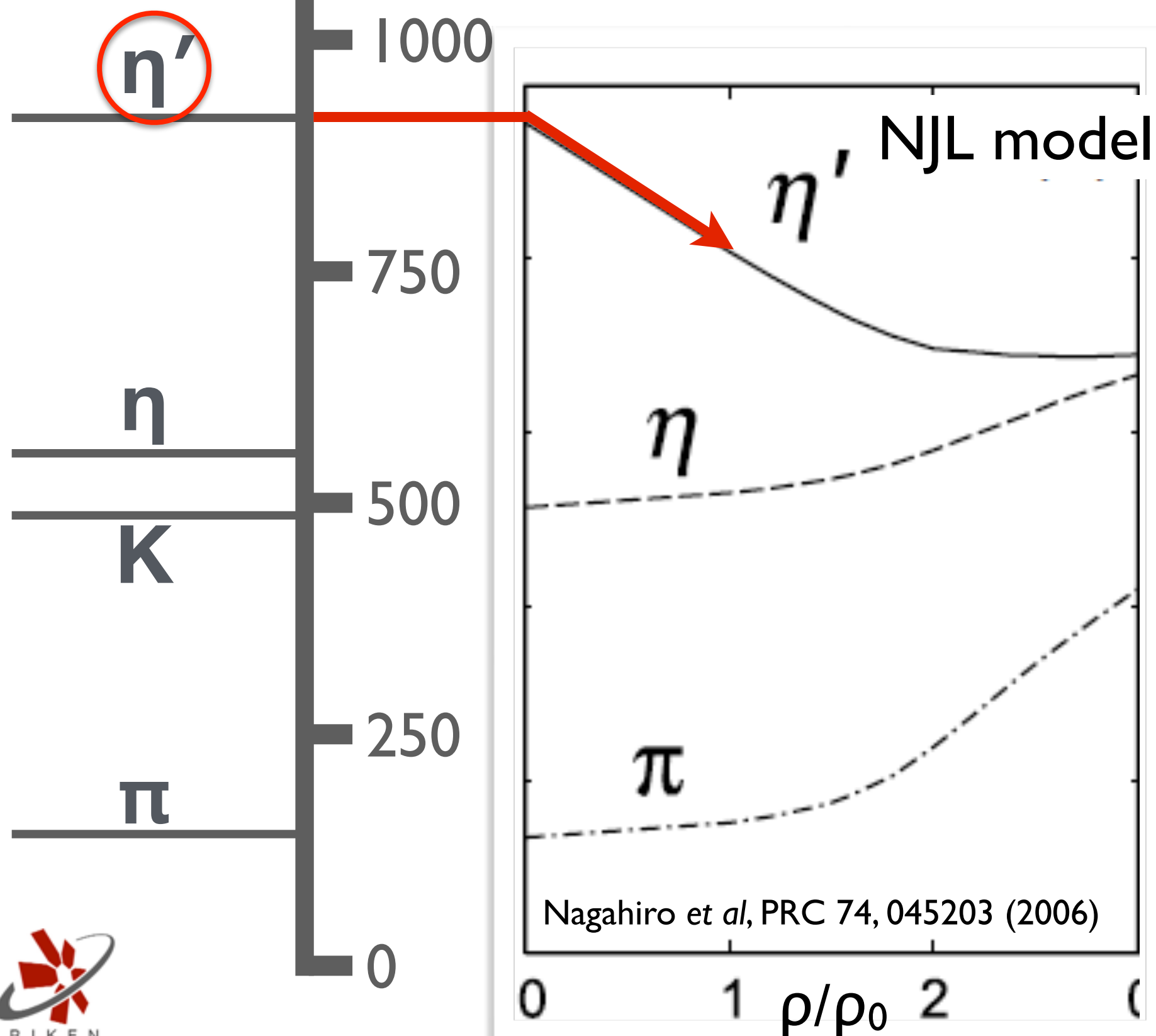
Klimt, Lutz, Vogl, Weise, NPA516(90)429.

η' Meson



[MeV/c²]

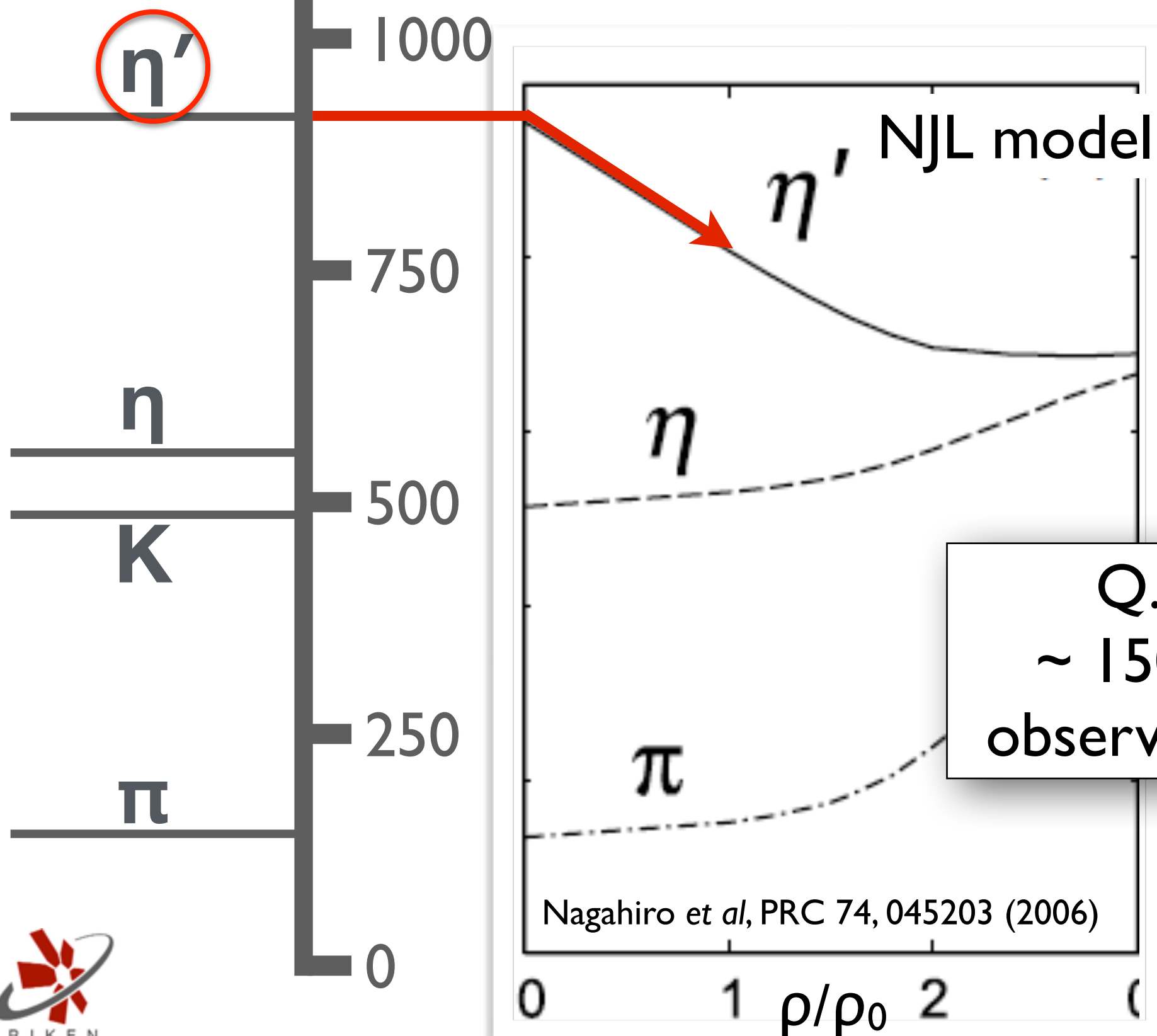
In-medium PS mesons

Partial restoration of dynamical breaking of χ symmetry

Nagahiro et al., PRC 87 (2013) 045201
 Jido et al., NPA 914 (2013) 354

[MeV/c²]

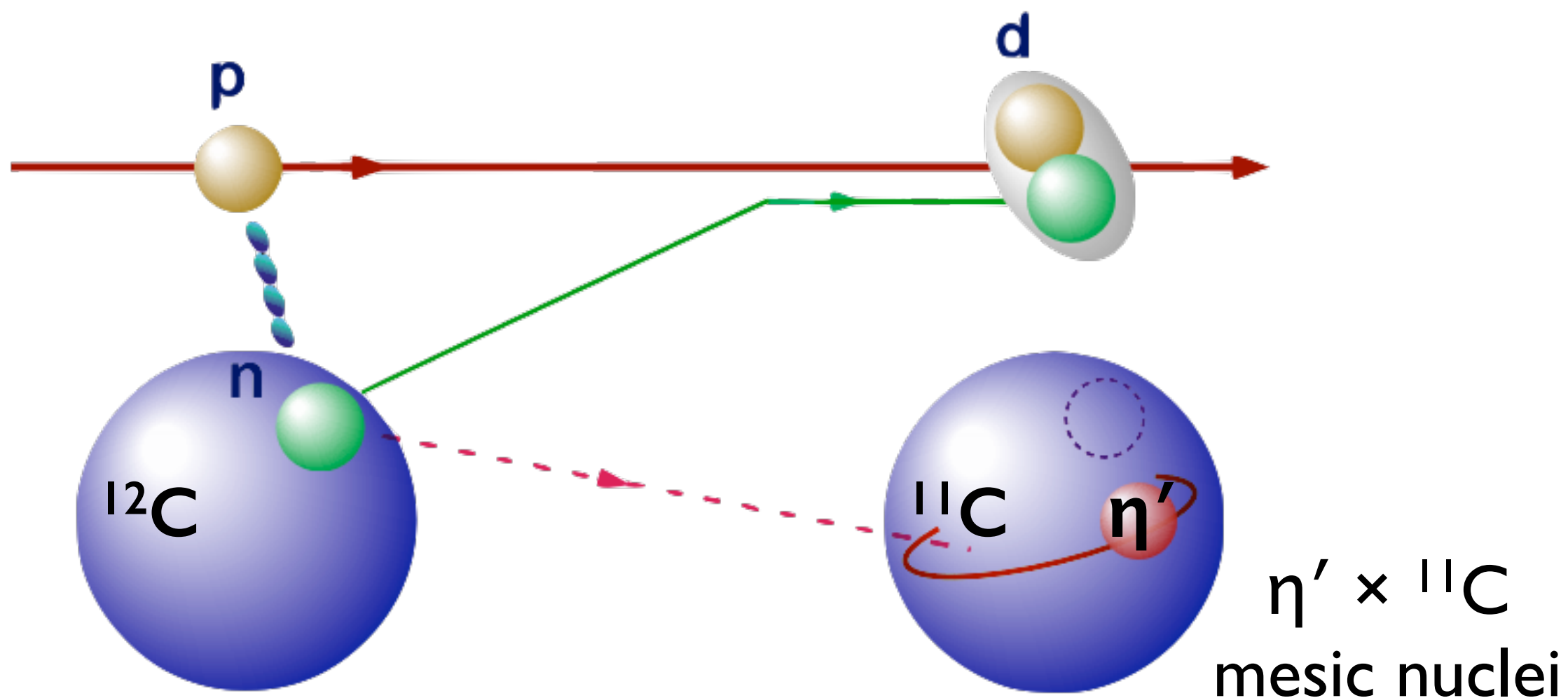
In-medium PS mesons

Partial restoration of dynamical breaking of χ symmetry

Q. Mass shift (of
~ 150 MeV/c²) can be
observed in experiment?

η' Mesic Nuclei in (p,d) Reaction

η' transfer reaction + missing mass measurement



$$\underline{T_p = 2.50 \text{ GeV} \rightarrow q \sim 400 \text{ MeV}/c}$$

Theoretical Prediction

η' -nucleus potential:

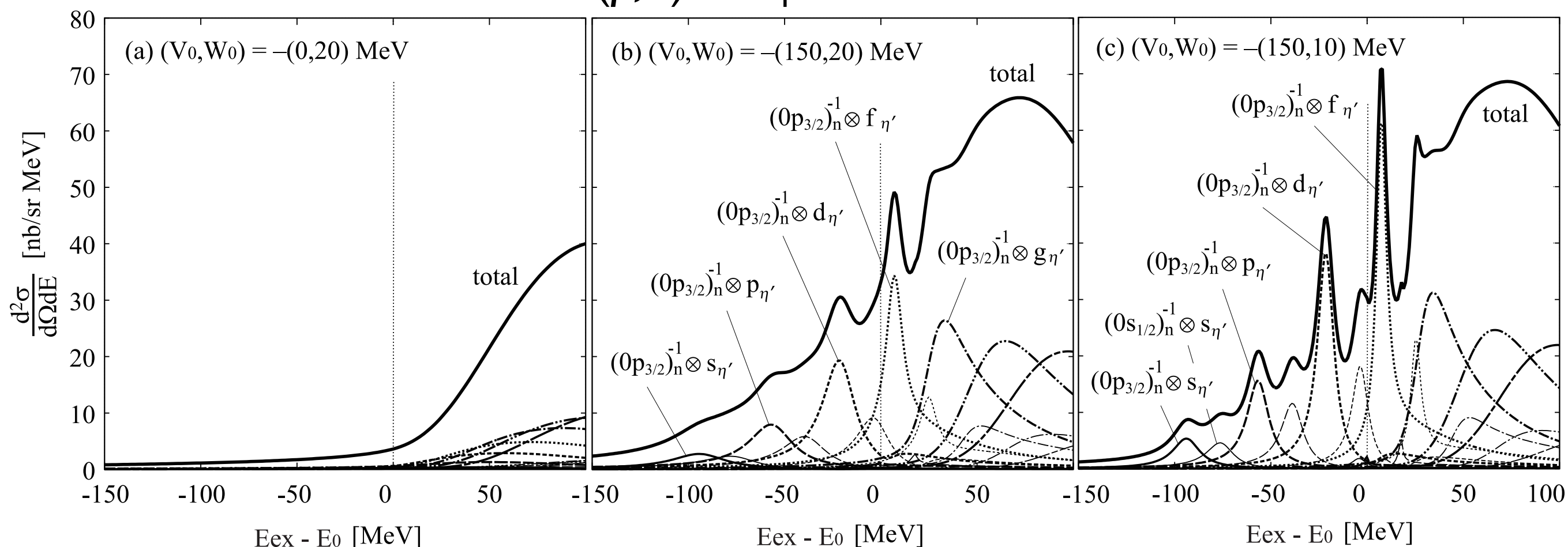
$$V_{\eta'}(r) = (V_0 + iW_0) \frac{\rho(r)}{\rho_0}$$

ρ : nucleon density

V_0 : Real potential depth

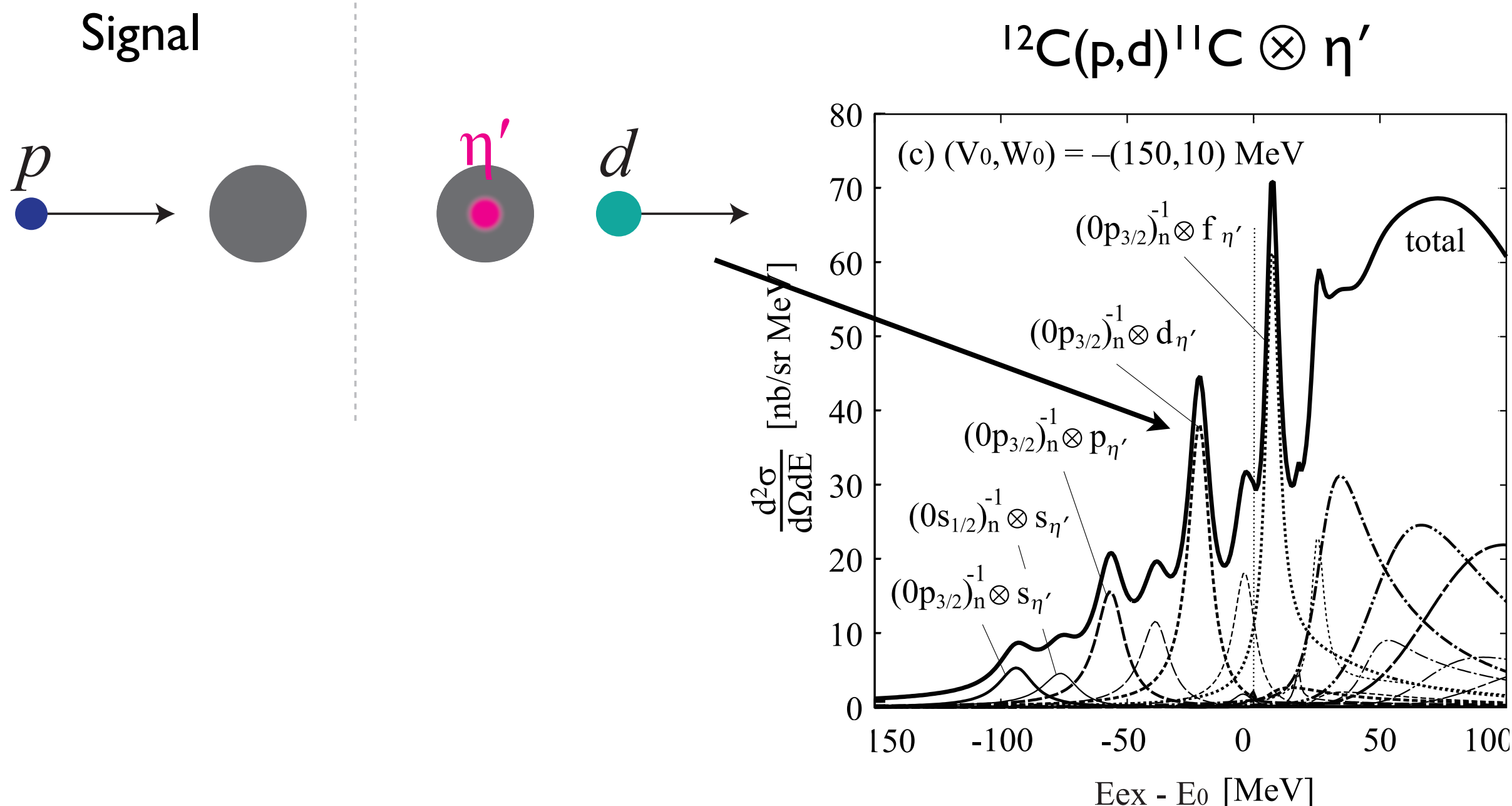
W_0 : Imaginary potential depth

$^{12}\text{C}(p,d)$ at $T_p = 2.50$ GeV



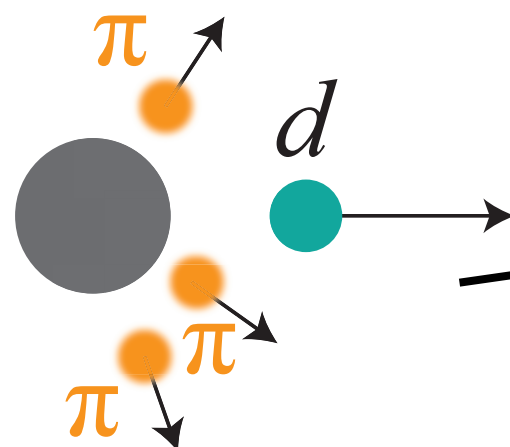
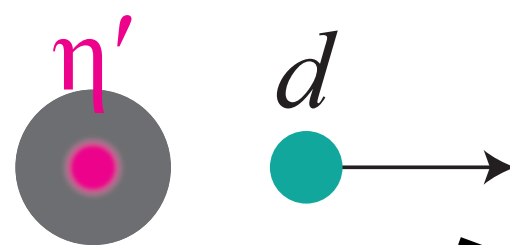
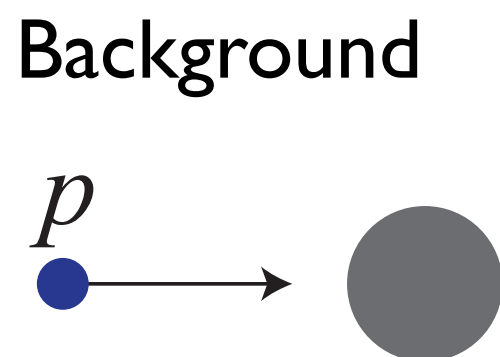
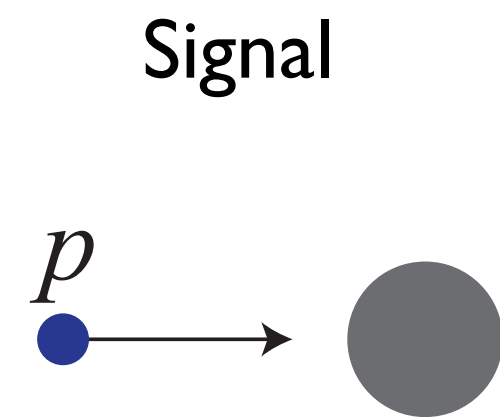
Nagahiro et al., PRC87(13)045201.

Spectrum in **Inclusive** Measurement at GSI

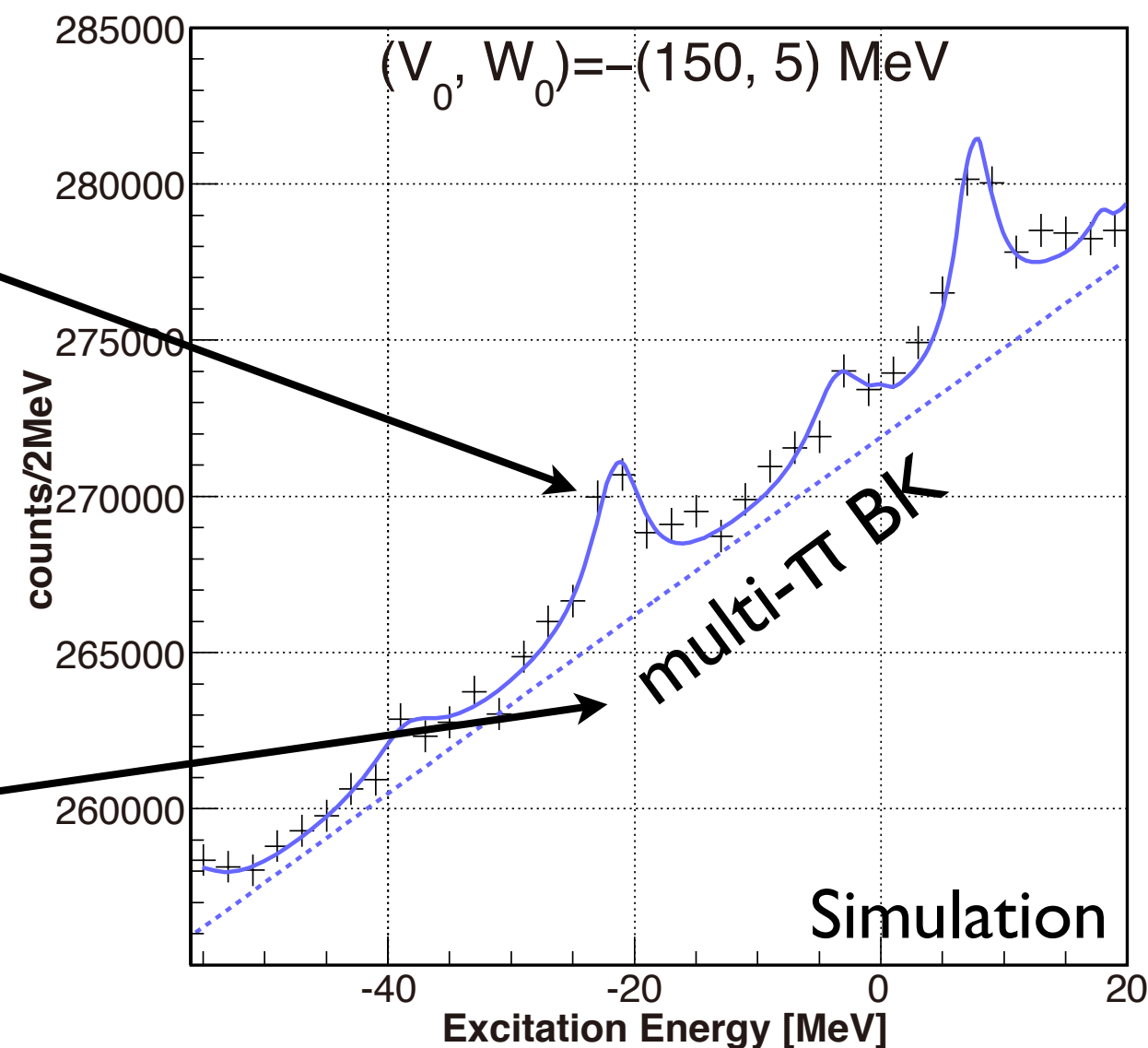


Nagahiro et al., PRC87(13)045201.

Spectrum in **Inclusive** Measurement at GSI



$$^{12}\text{C}(p,d)^{11}\text{C} \otimes \eta'$$



Step-by-step approach

	Measurement	Objectives	S/N
GSI step 1	(p,d) inclusive	extremely good statistics for overall structure + BK study	poor
GSI/FAIR step 2	$(p,d\textcolor{red}{p})$ exclusive*	extended sensitivity for excited + ground states	good
FAIR step ≥ 2	$(p,d\textcolor{red}{x})$ exclusive*	exclusive + decay mode studies	good

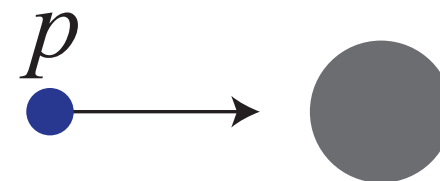
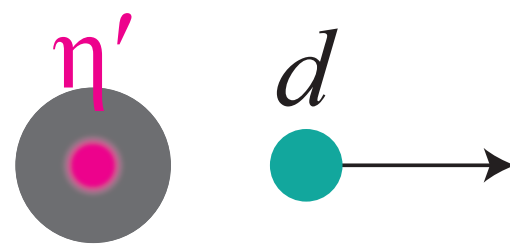
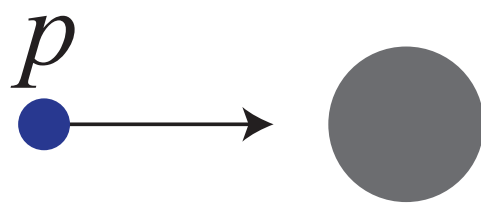
Principles of **Exclusive** Measurement at GSI/FAIR

NUSTAR 2015

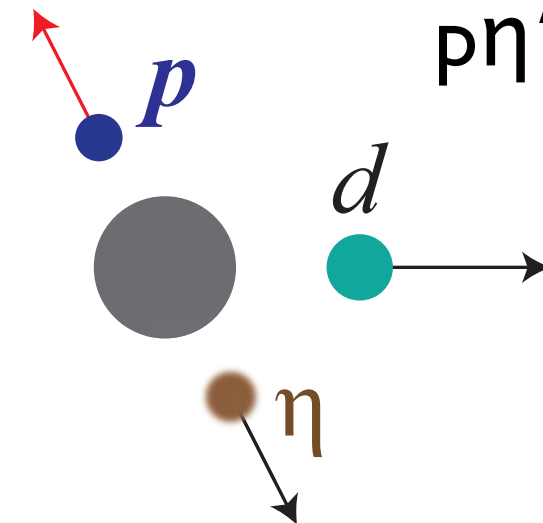
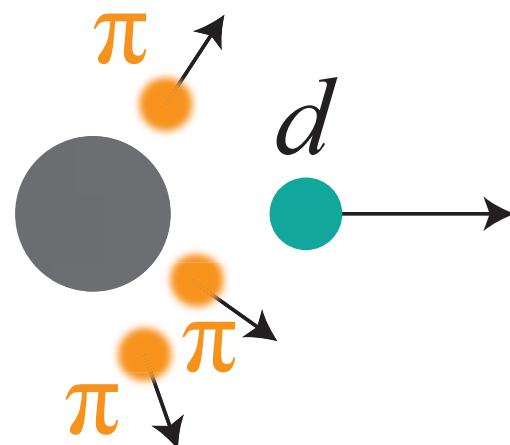
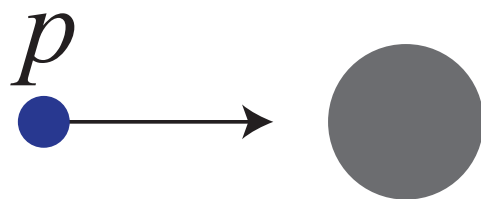
$$p\eta' \rightarrow p\eta$$

Signals

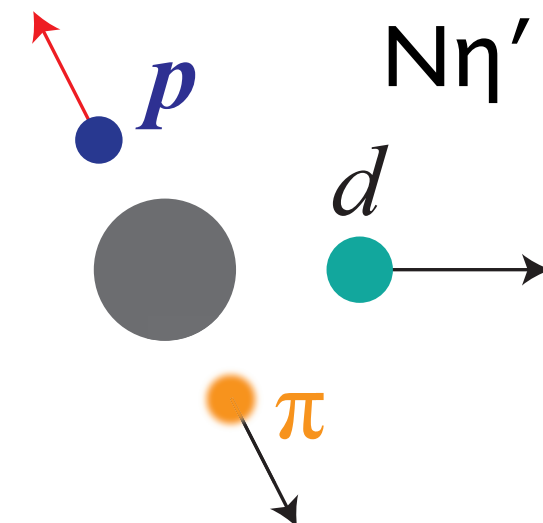
Signal



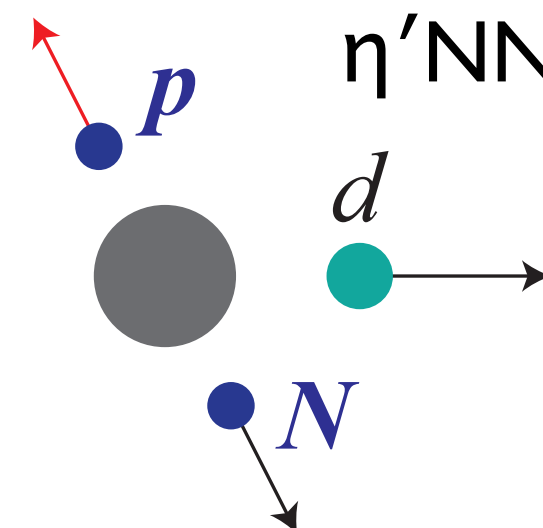
Background



$$N\eta' \rightarrow p\pi$$



$$\eta'NN \rightarrow pN$$

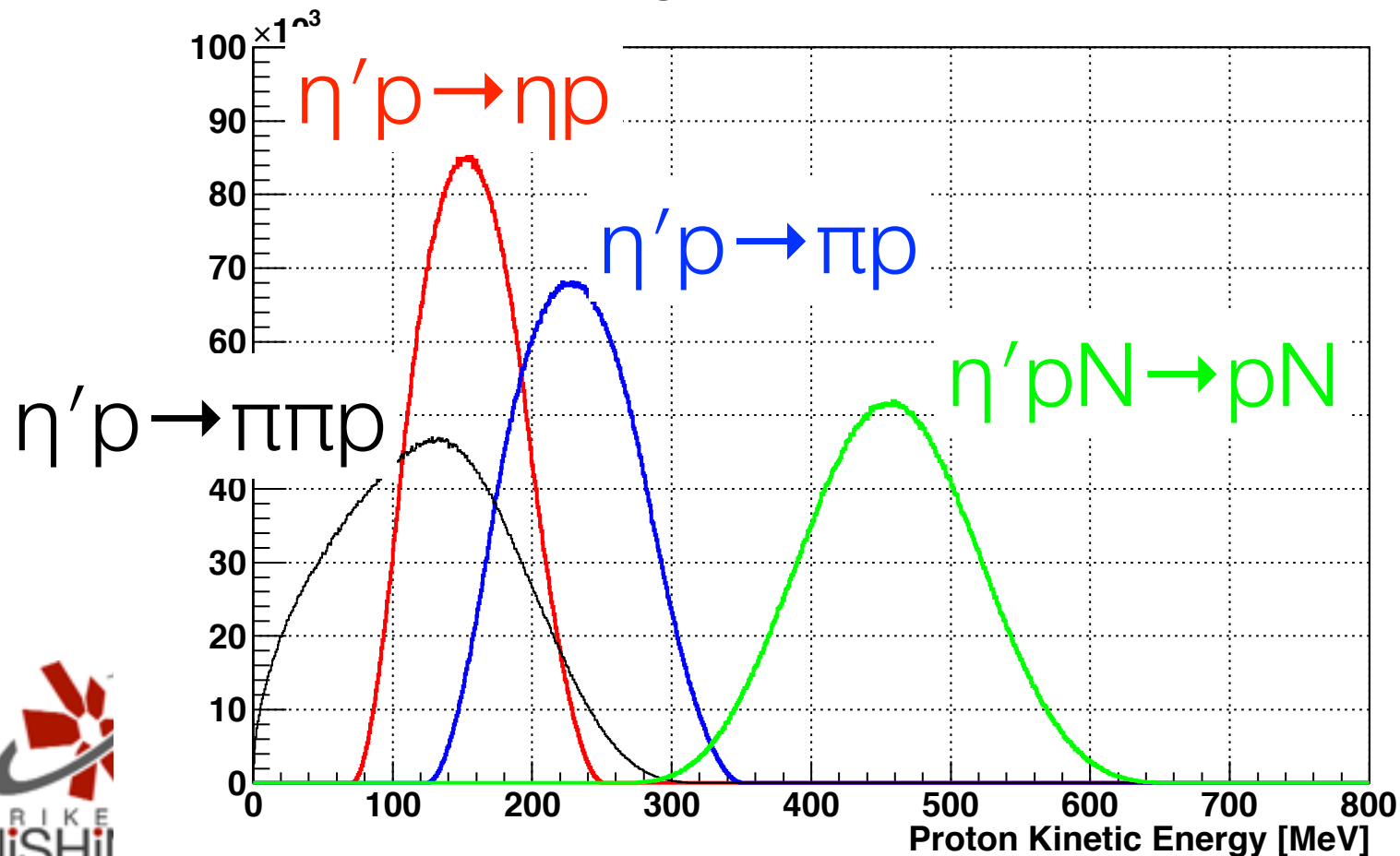


Principles of **Exclusive** Measurement at GSI/FAIR

Tagging high-momentum protons
(300-600 MeV)

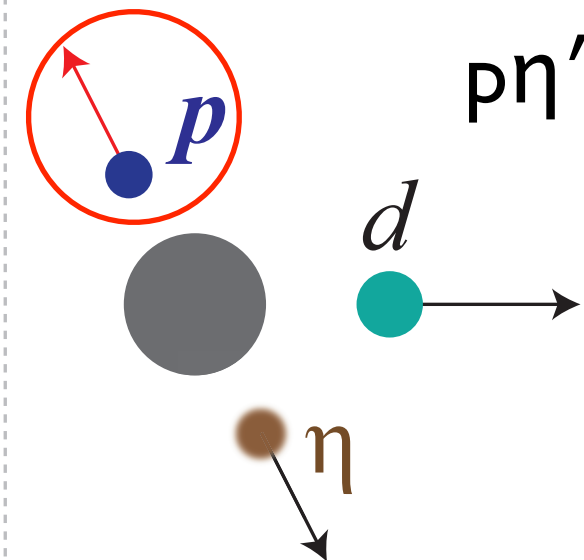
Signals

Y.K. Tanaka and Y. Higashi

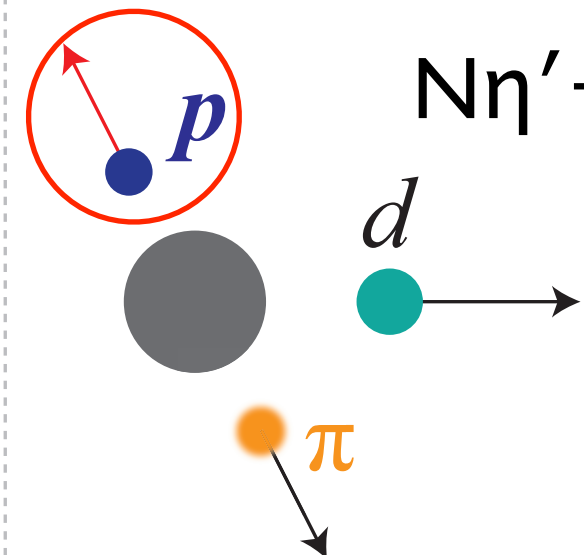


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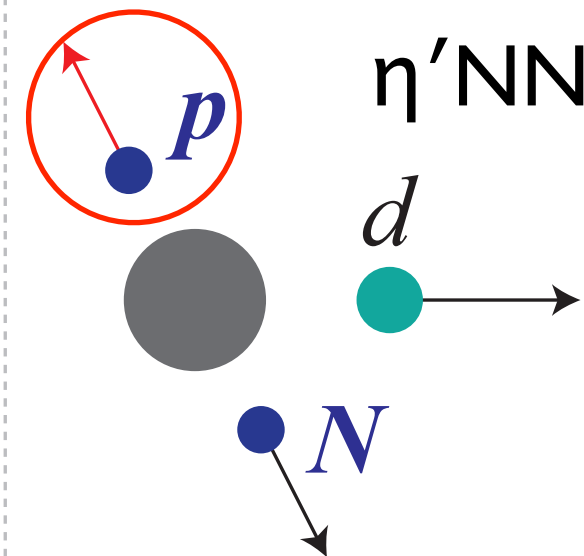
$p\eta' \rightarrow p\eta$



$N\eta' \rightarrow p\pi$



$\eta'NN \rightarrow pN$

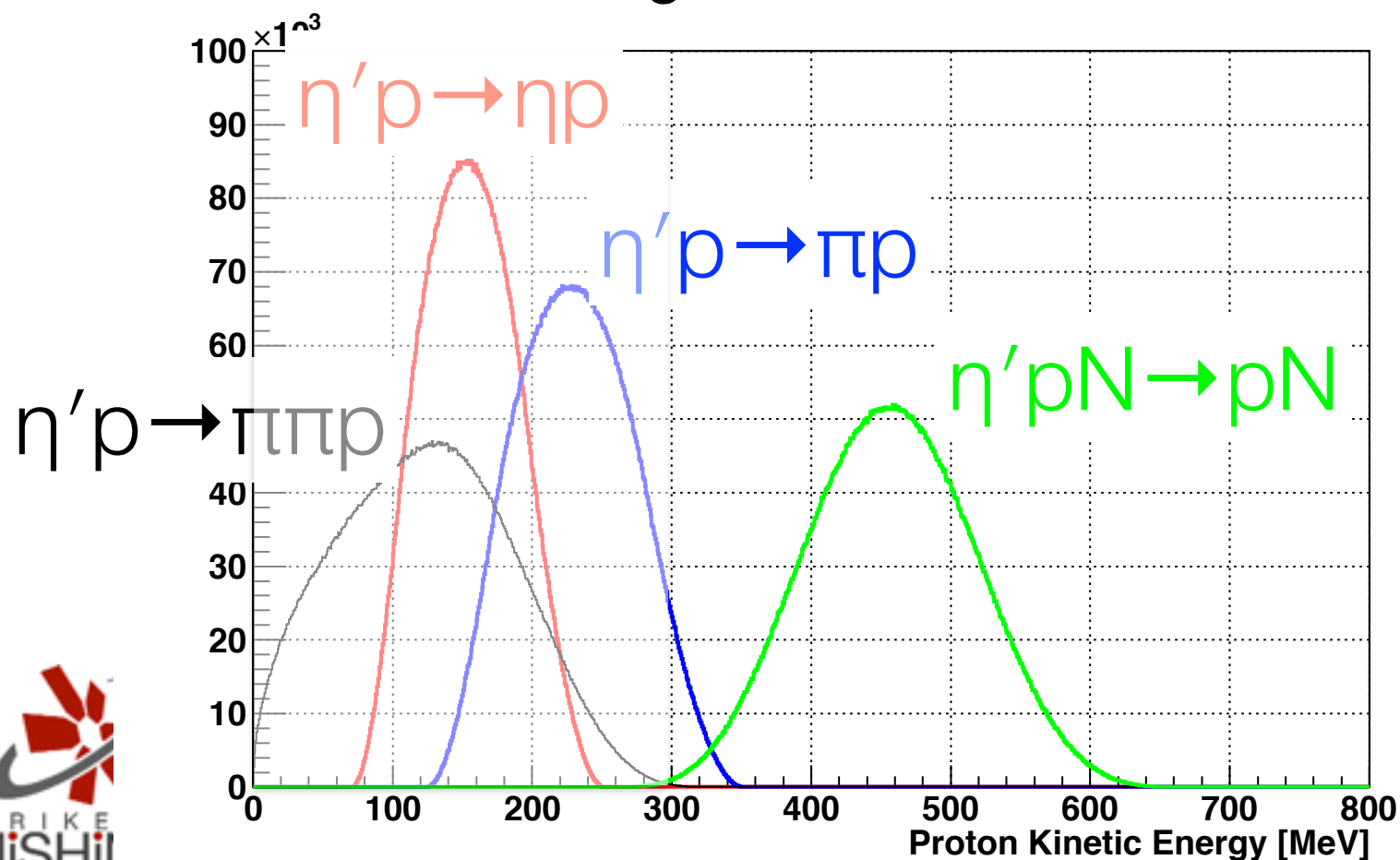


Principles of **Exclusive** Measurement at GSI/FAIR

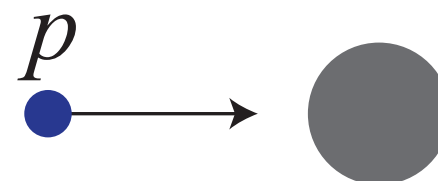
Tagging high-momentum protons
(300-600 MeV)

intra-nuclear cascade code $\rightarrow$
S/N improves by $f \sim 100$

Y.K. Tanaka and Y. Higashi

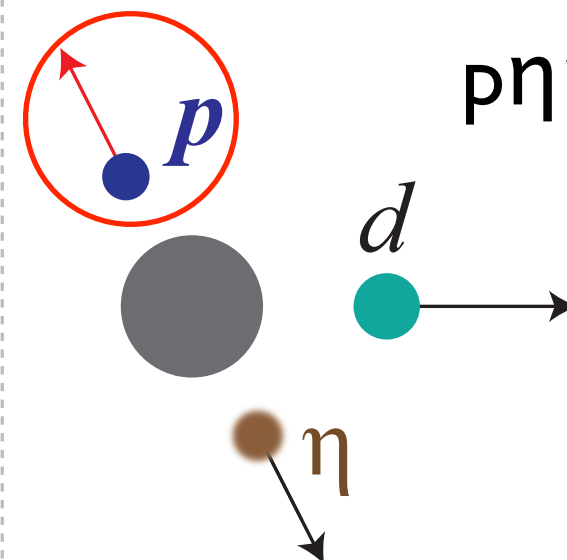


Signals

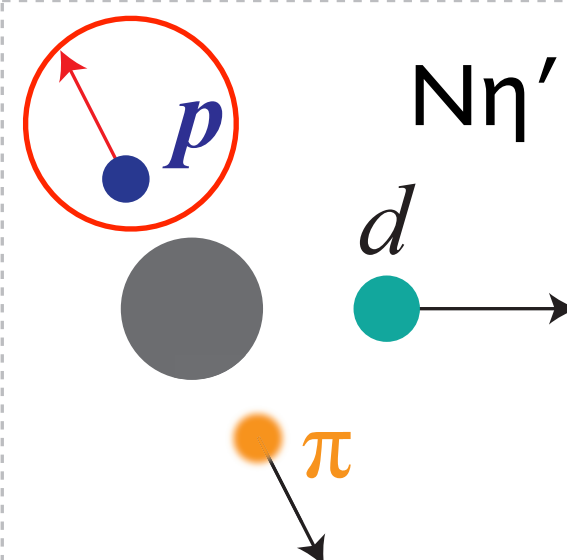


NUSTAR 2015

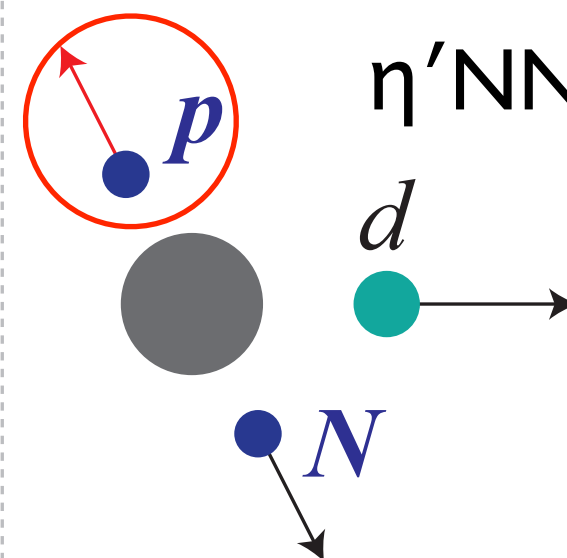
$p\eta' \rightarrow p\eta$



$N\eta' \rightarrow p\pi$



$\eta'NN \rightarrow pN$

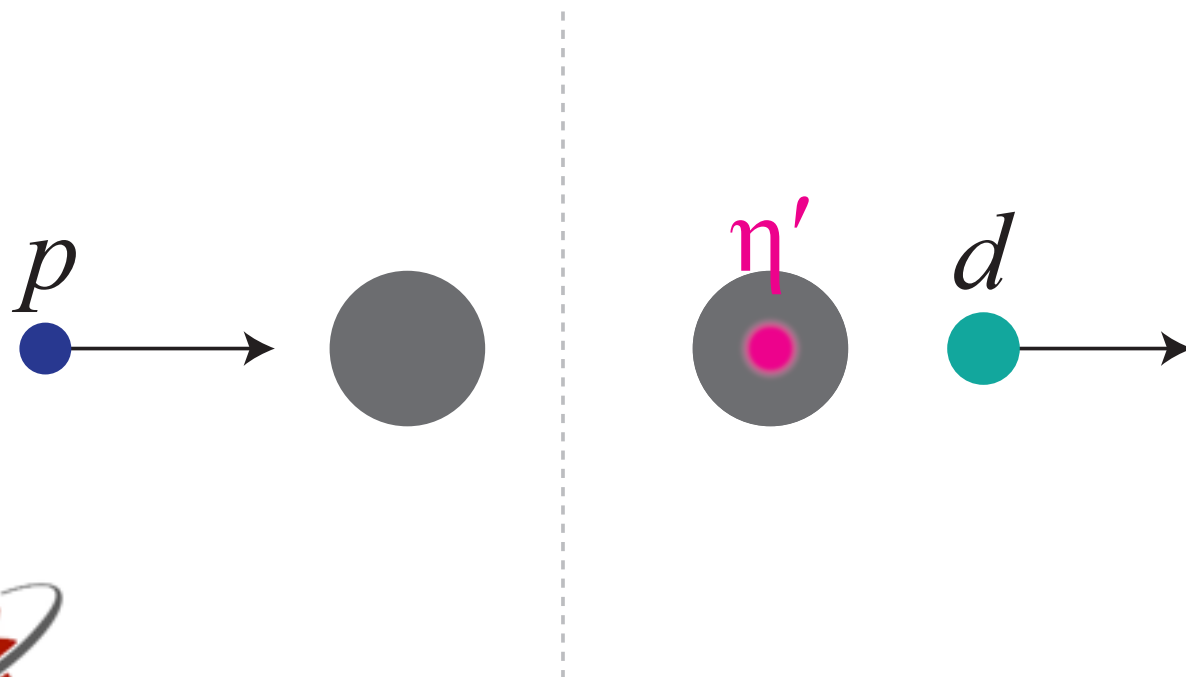


Step-by-step approach

	Measurement	Objectives	S/N
GSI step 1	(p,d) inclusive	extremely good statistics for overall structure + BK study	poor
GSI/FAIR step 2	$(p,d\textcolor{red}{p})$ exclusive*	extended sensitivity for excited + ground states	good
FAIR step ≥ 2	$(p,d\textcolor{red}{x})$ exclusive*	exclusive + decay mode studies	good

First step

Inclusive measurement GSI SIS-S437 in 2014/Aug



Production setup at FRS

p beam ($T_p = 2.5$ GeV, $I_p = 4 \times 10^{10}$ /spill)

 ^{12}C target (4 g/cm²)

$d \sim 4\text{k/spill}$ at S4 (signal)

$p' \sim 800$ k/spill at S4 (background)

18m

S2

MWDCx2

S4

$$SC_{AC}$$

Scintillator (SC)

Aerogel Cherenkov (AC)

Achromatic

Dispersive (3.6cm/%)

Fragment Separator (FRS)

Production setup at FRS

p beam ($T_p = 2.5$ GeV, $I_p = 4 \times 10^{10}$ /spill)

 ^{12}C target (4 g/cm²)

$d \sim 4\text{k/spill}$ at S4 (signal)

~~$p' \sim 800$ k/spill at S4 (background)~~

perfect PID

18m

S2

MWDCx2

S4

$$SC_{AC}$$

Scintillator (SC)

Aerogel Cherenkov (AC)

Achromatic

Dispersive (3.6cm/%)

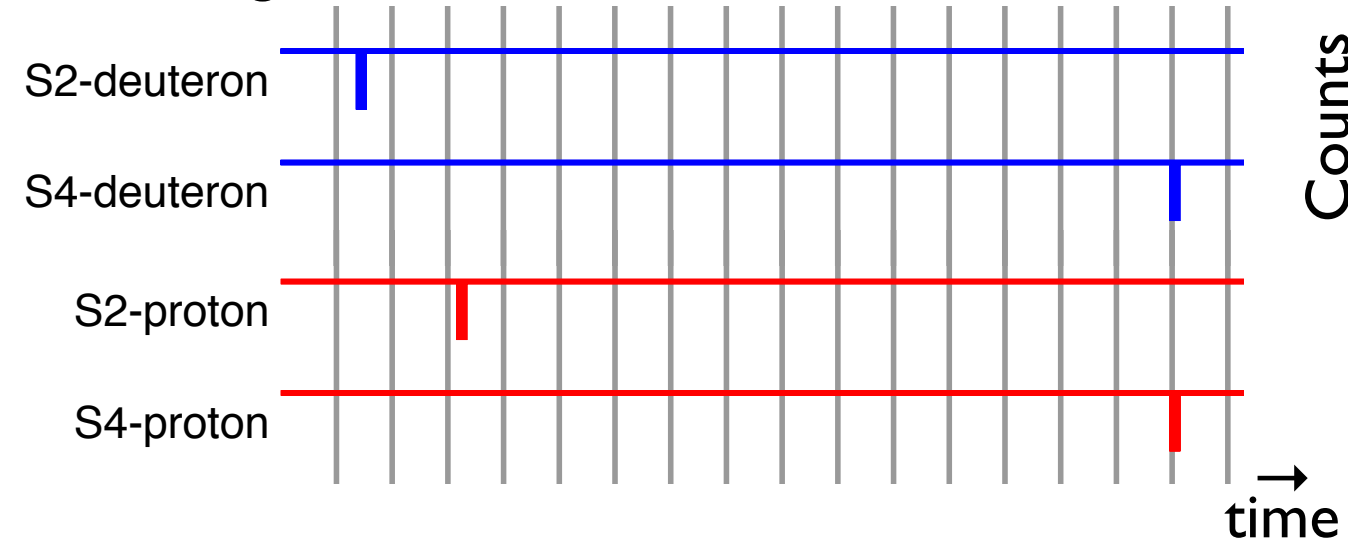
Fragment Separator (FRS)

Particle Identification

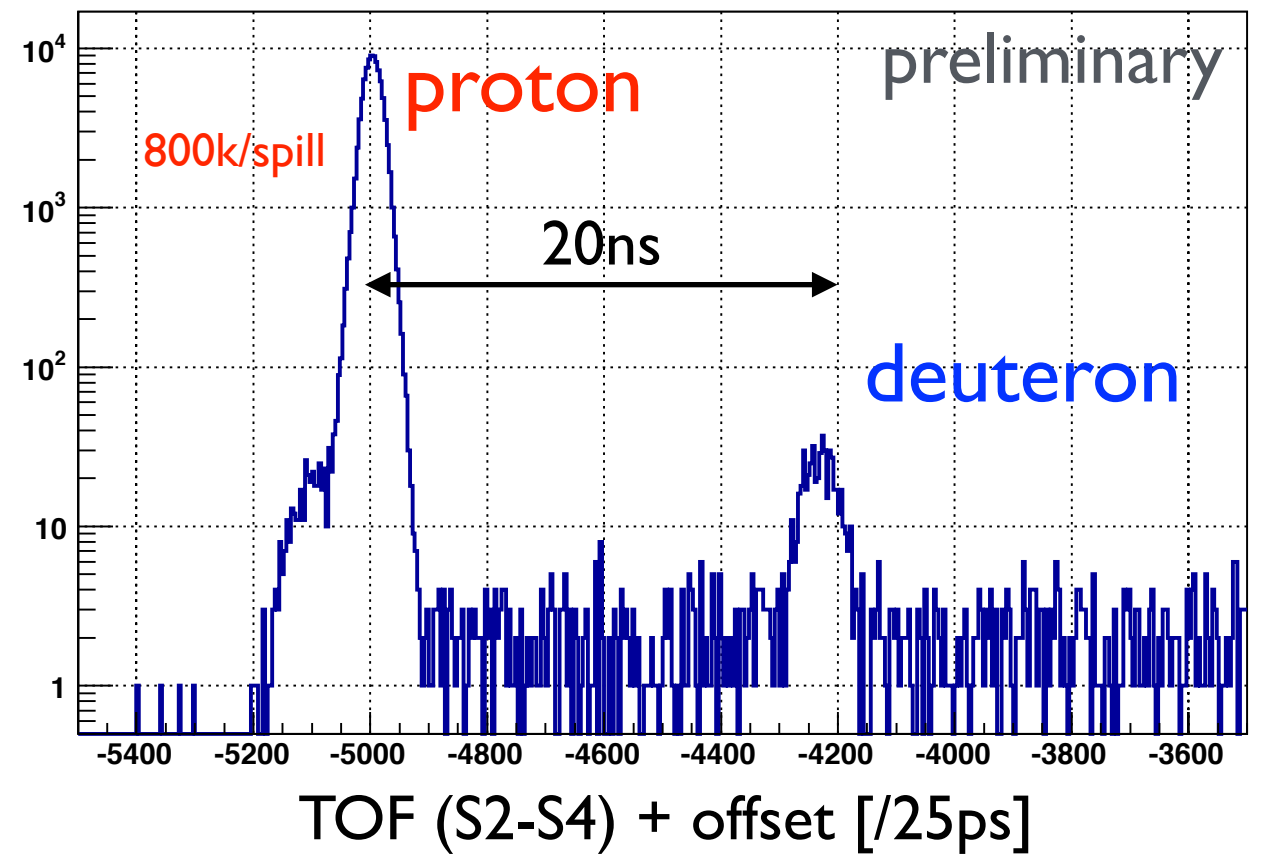
S2-S4 TOF (unbiased)

p/d ratio $\sim 200/1$

10ns/grid



Counts

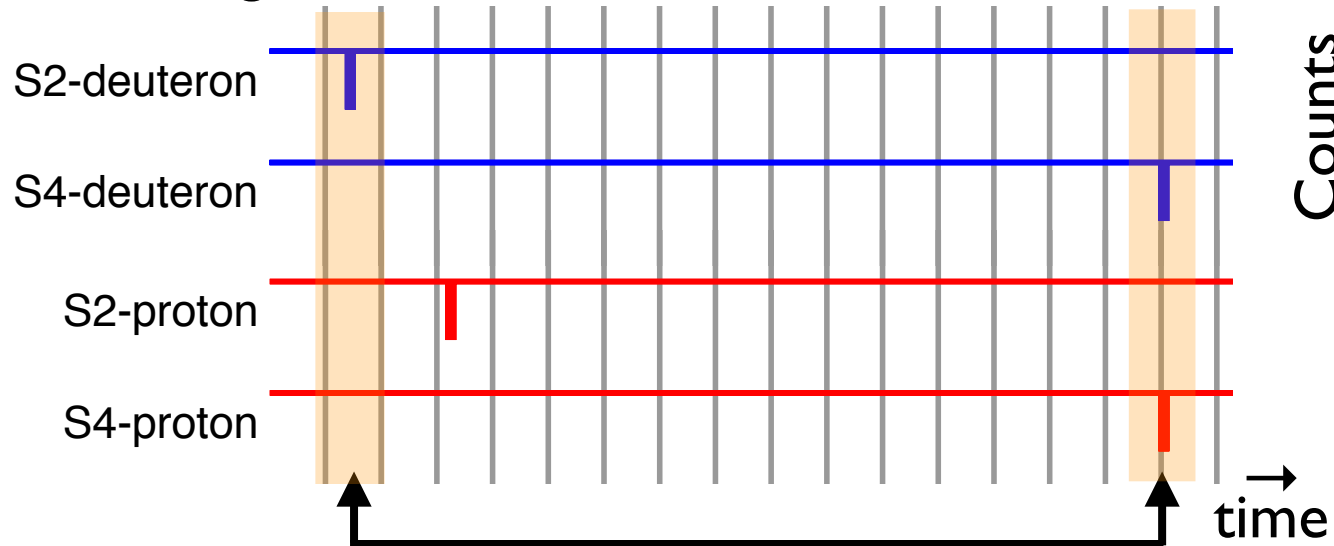


Particle Identification

S2-S4 TOF (unbiased)

p/d ratio $\sim 200/1$

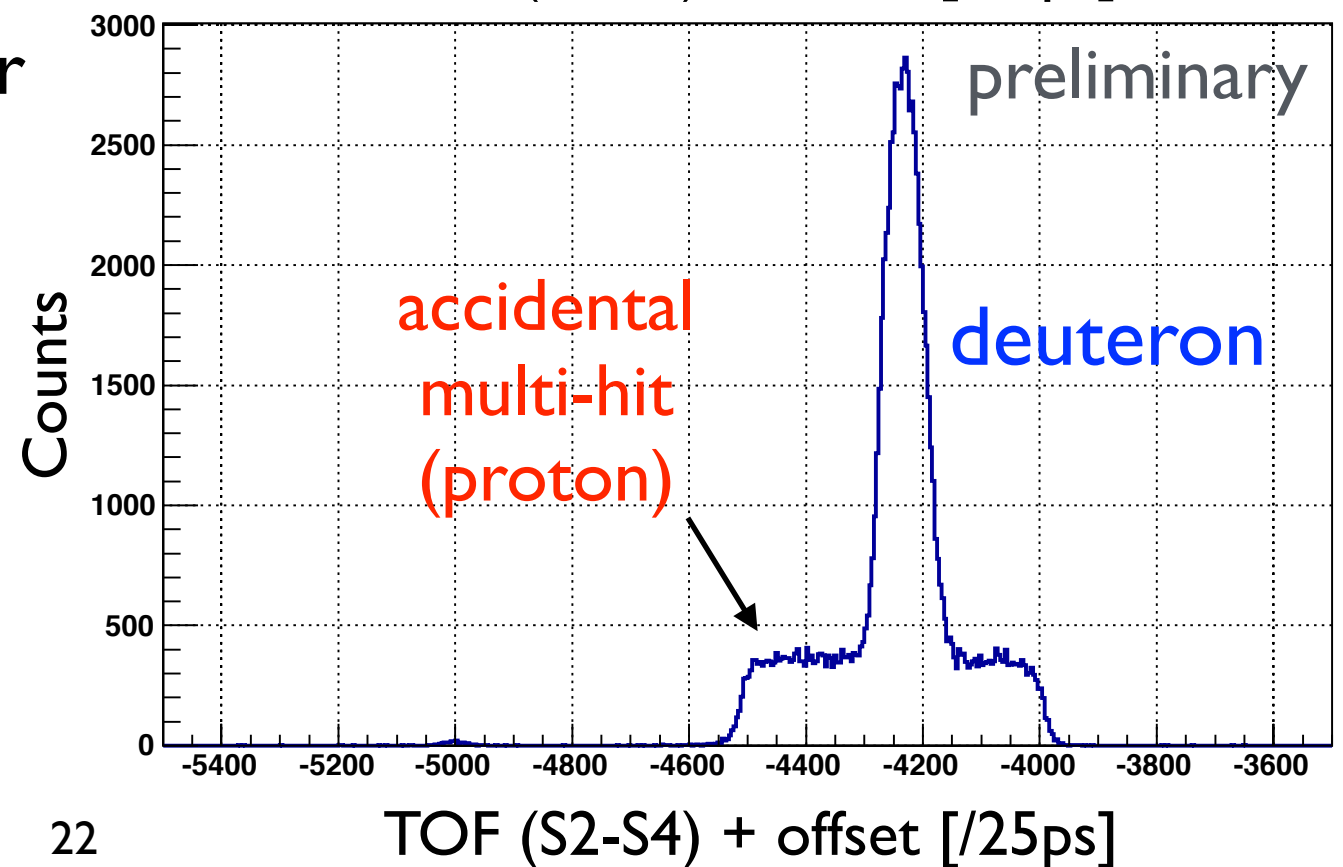
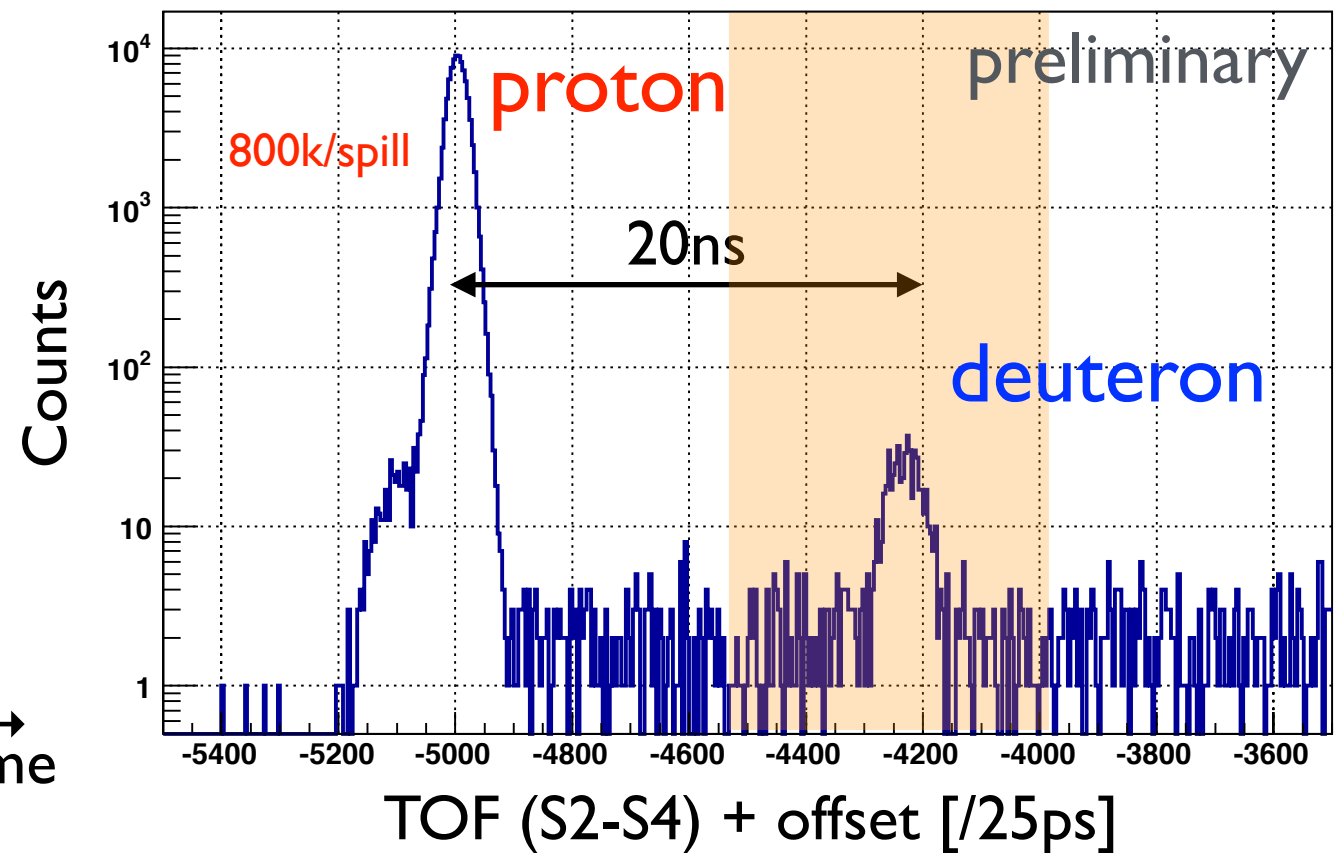
10ns/grid



with hardware TOF trigger

p/d ratio $\sim 1/1$

99.5% of BG protons were rejected by TOF trigger without using Aerogel Čerenkov detector



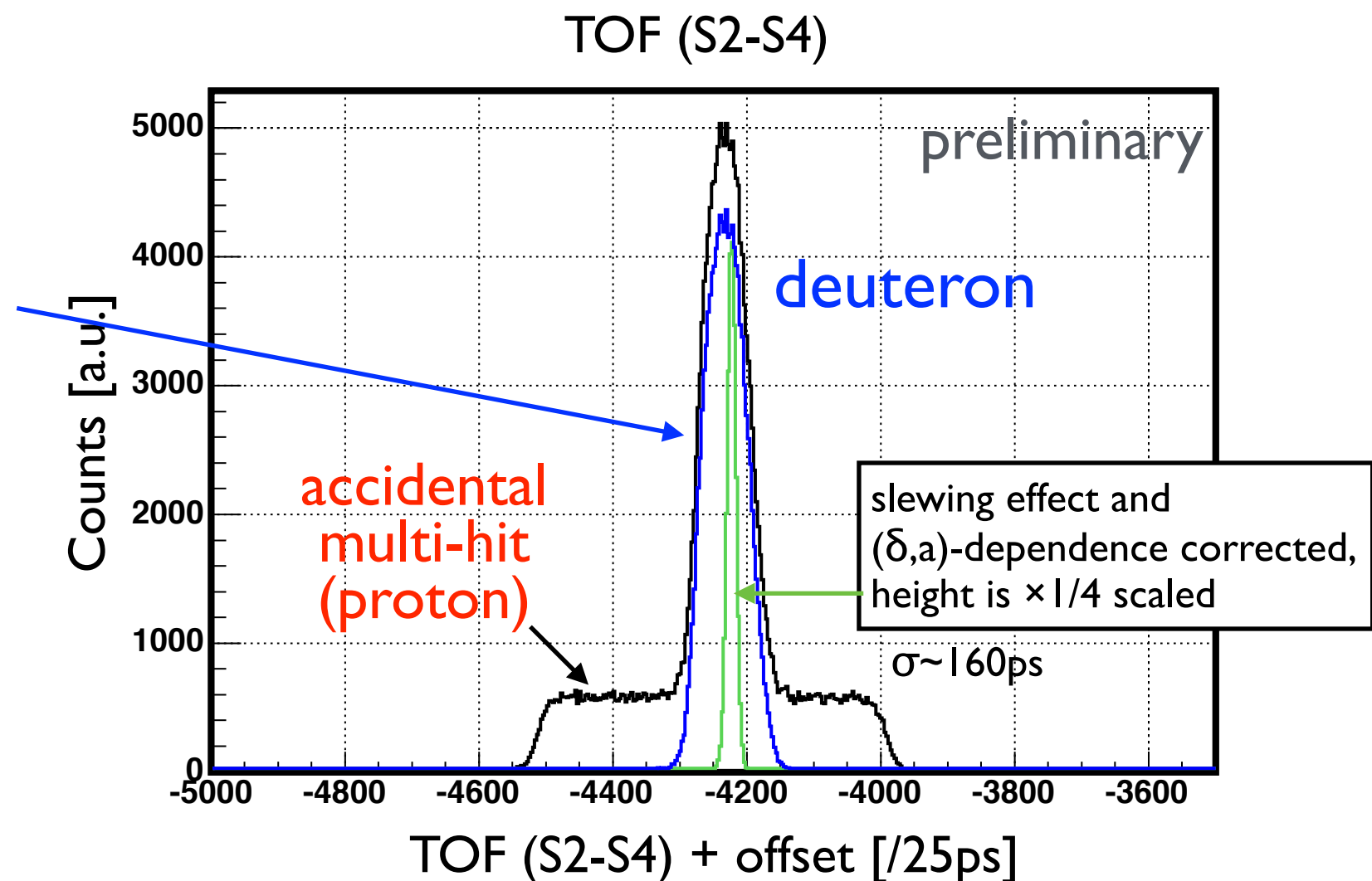
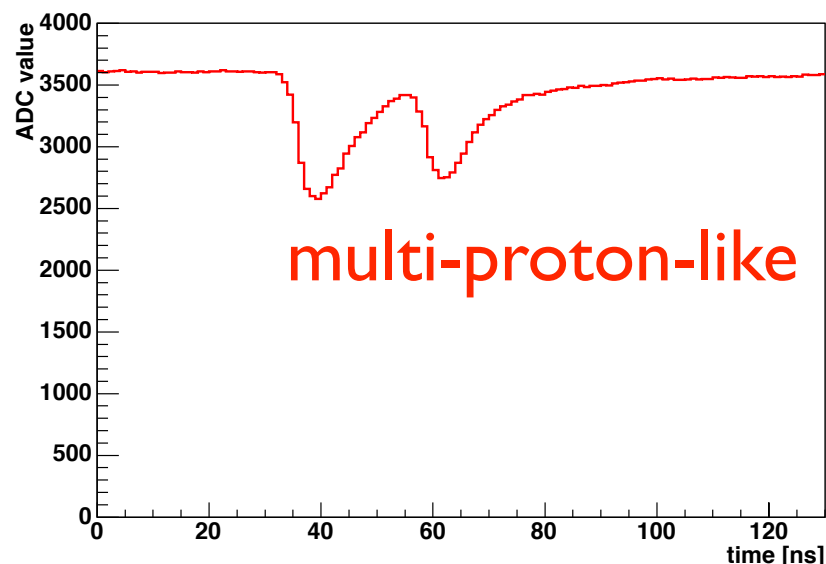
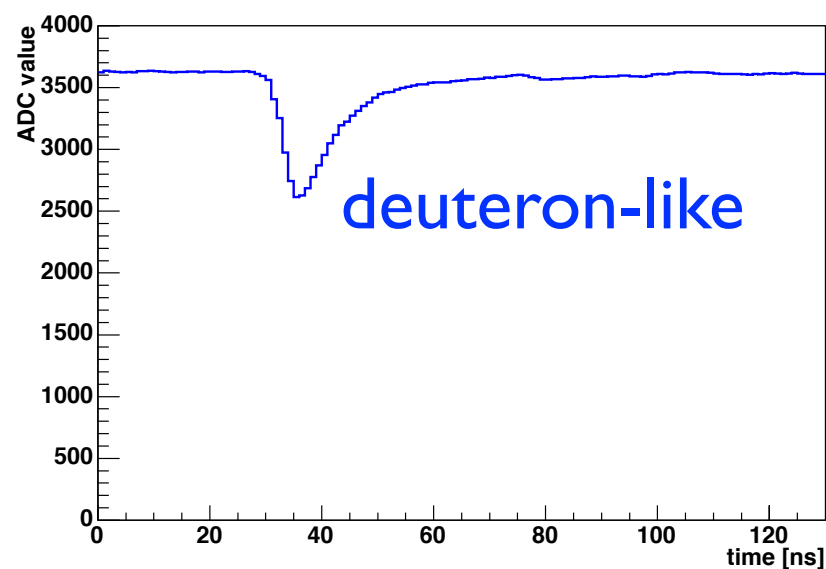
Particle Identification

Further rejection of the accidental multi-proton in offline analysis

- Single pulse selection by waveform analysis
- Cut condition for corrected TOF (S2-S4)

→ proton contamination is sufficiently small = PID perfect

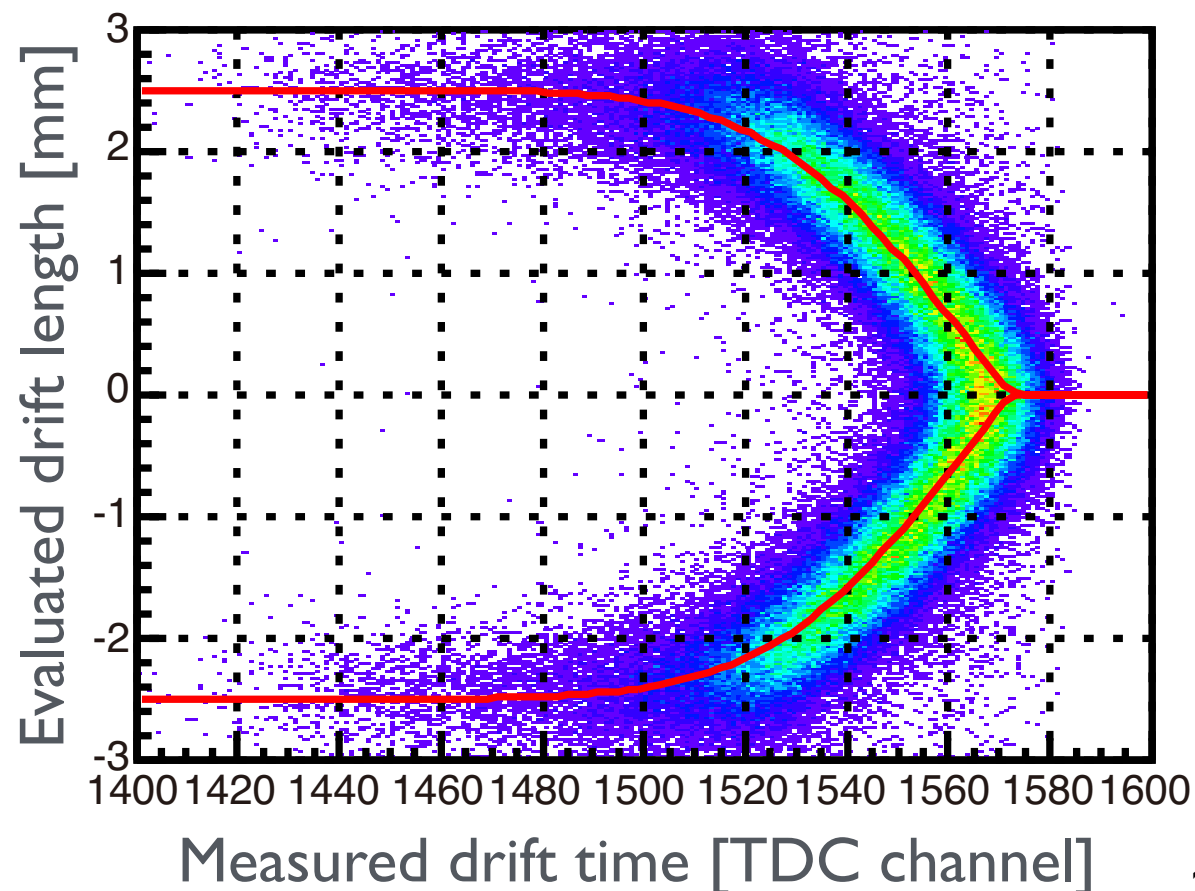
Examples of waveform of SC at S2



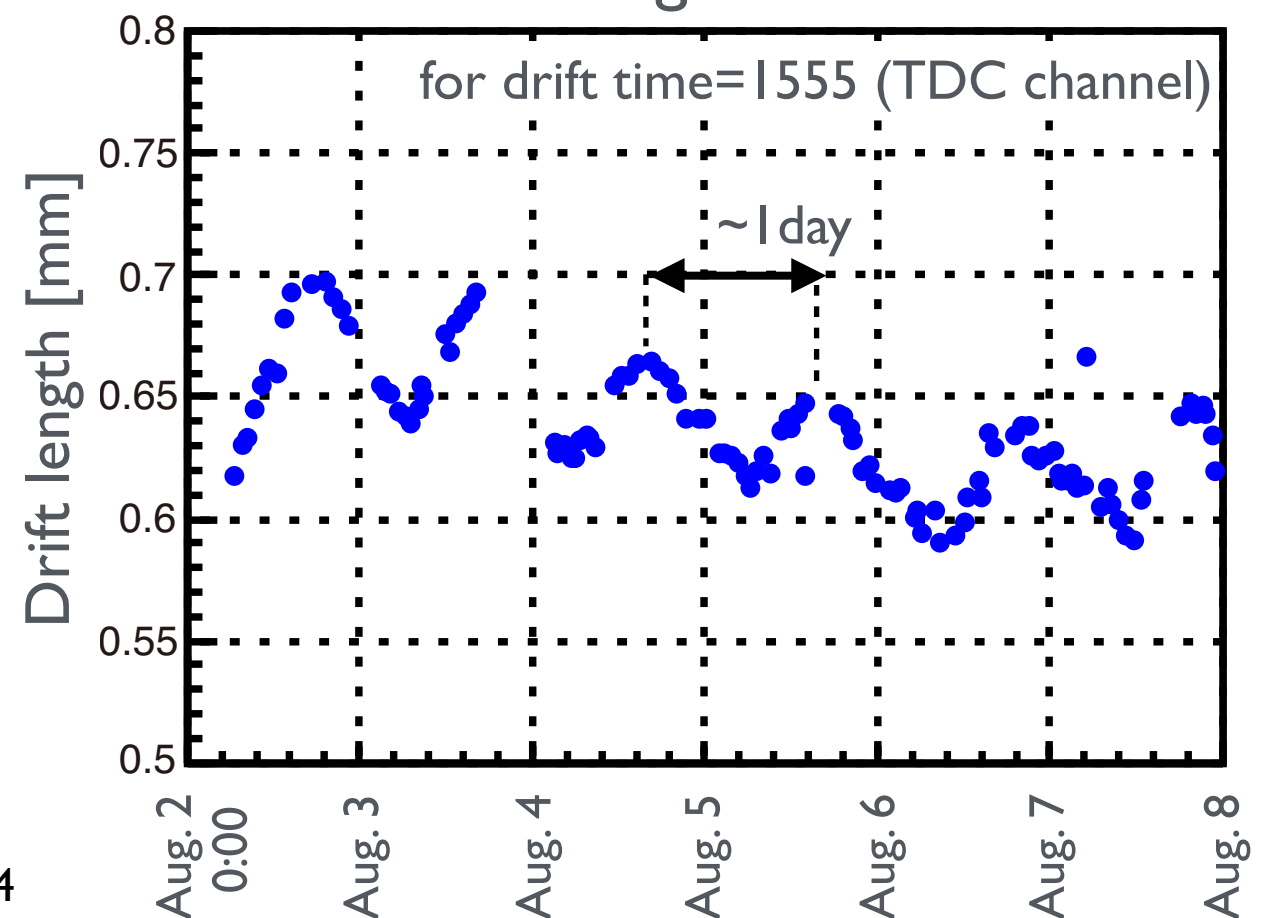
MWDC Analysis

- MWDC(XX'XX'UU'VV') $\times 2$ were used.
- Tracking :
drift time (measured) $\rightarrow$ drift length $\rightarrow \chi^2$ fitting for 2 MWDCs
- Iterative analysis for calibration :
temporary drift length $\rightarrow$ tracking $\rightarrow$ evaluate and update drift length
- Time dependence of relation between drift time and drift length

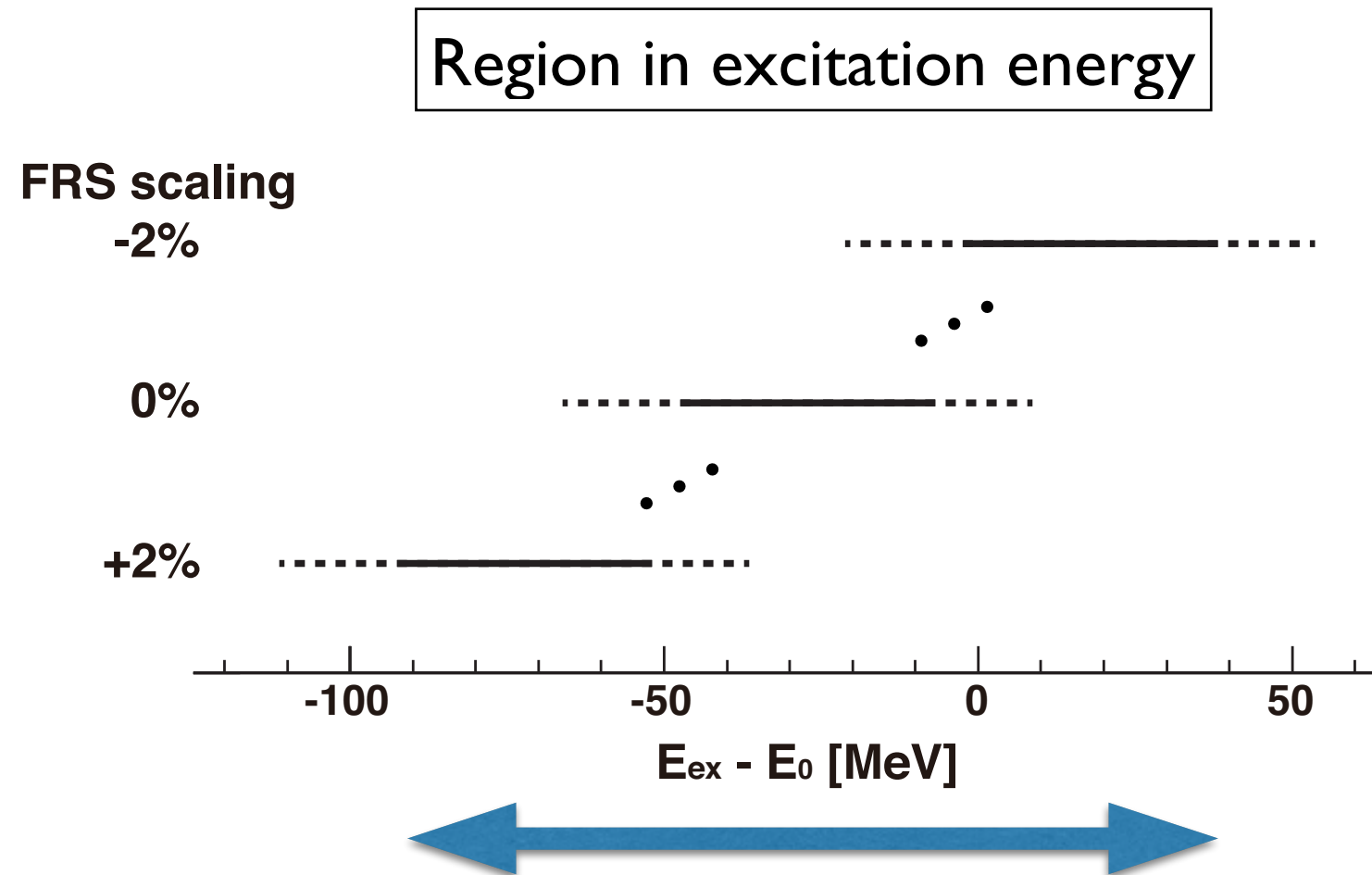
Drift length calibration



Time dependence of drift time to drift length relation

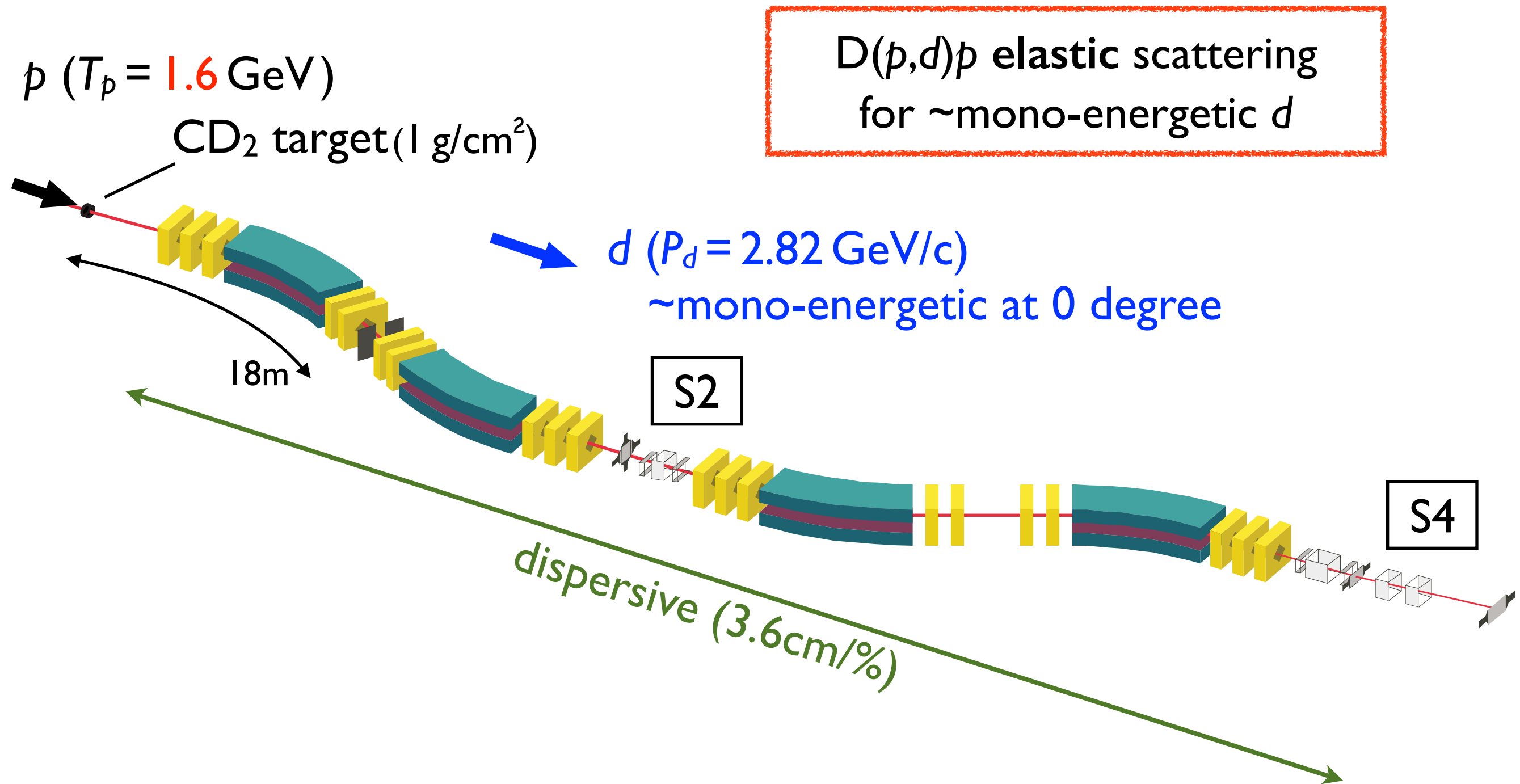


Spectrometer settings for wide mass region



- 7 settings of FRS Bp from -2% to 2%
→ $-90 \text{ MeV} < E_{\text{ex}} - E_0 < +40 \text{ MeV}$ covered

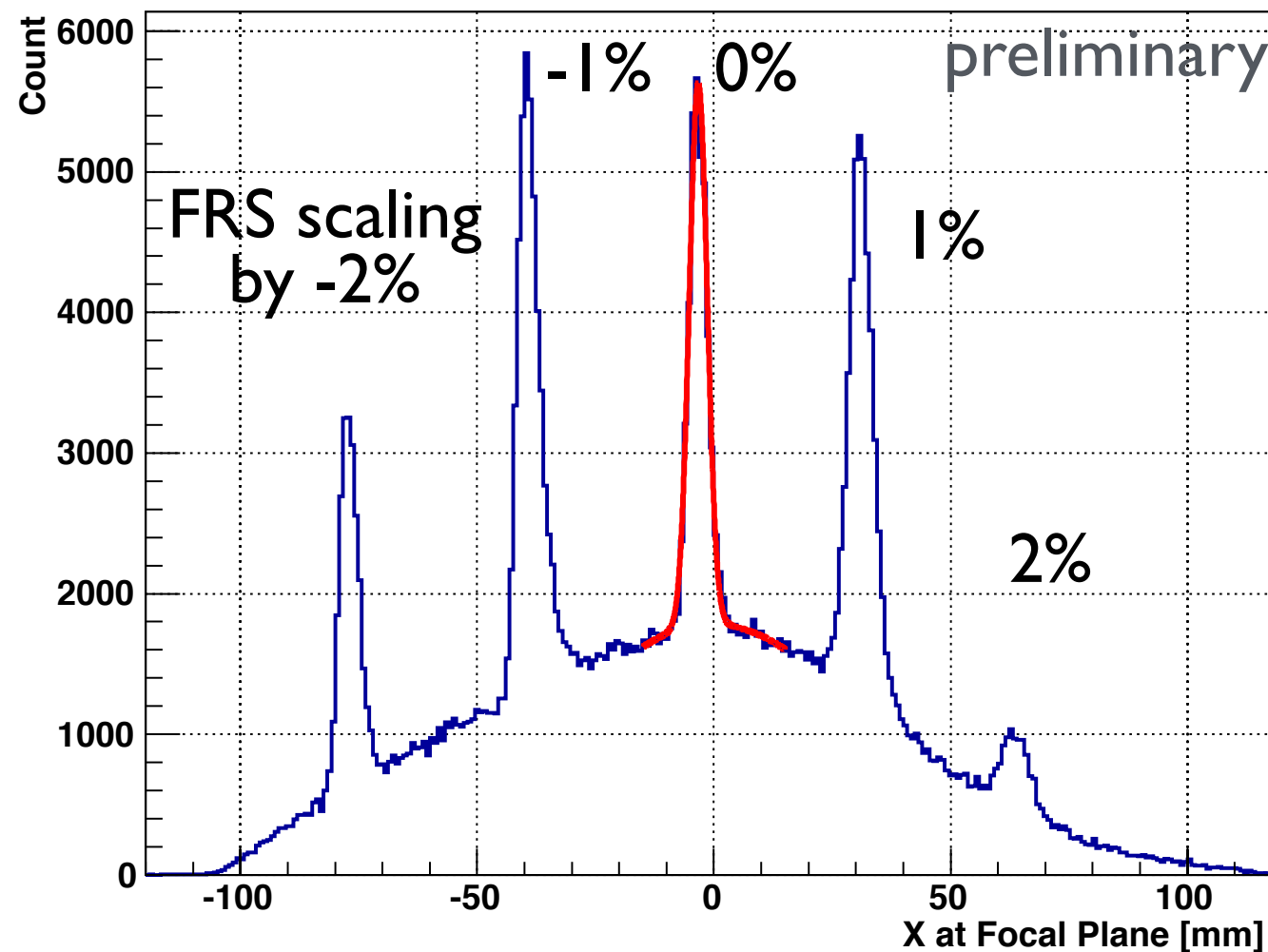
Calibration Run



Fragment Separator (FRS)

Calibration Run

Focal plane position (online, ion-optics roughly corrected)



$\sigma_X = 2.7$ mm (CD_2 calibration run)



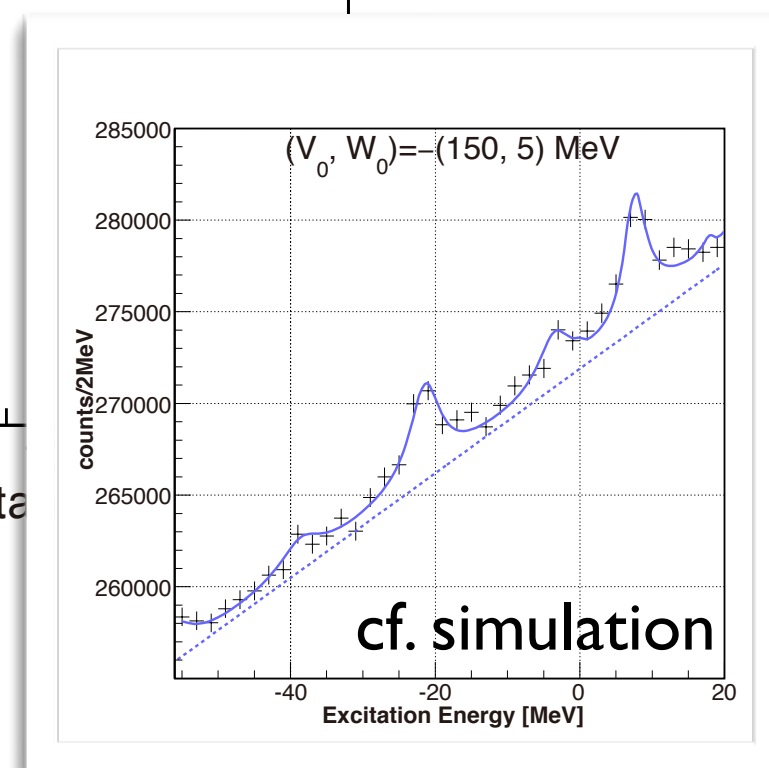
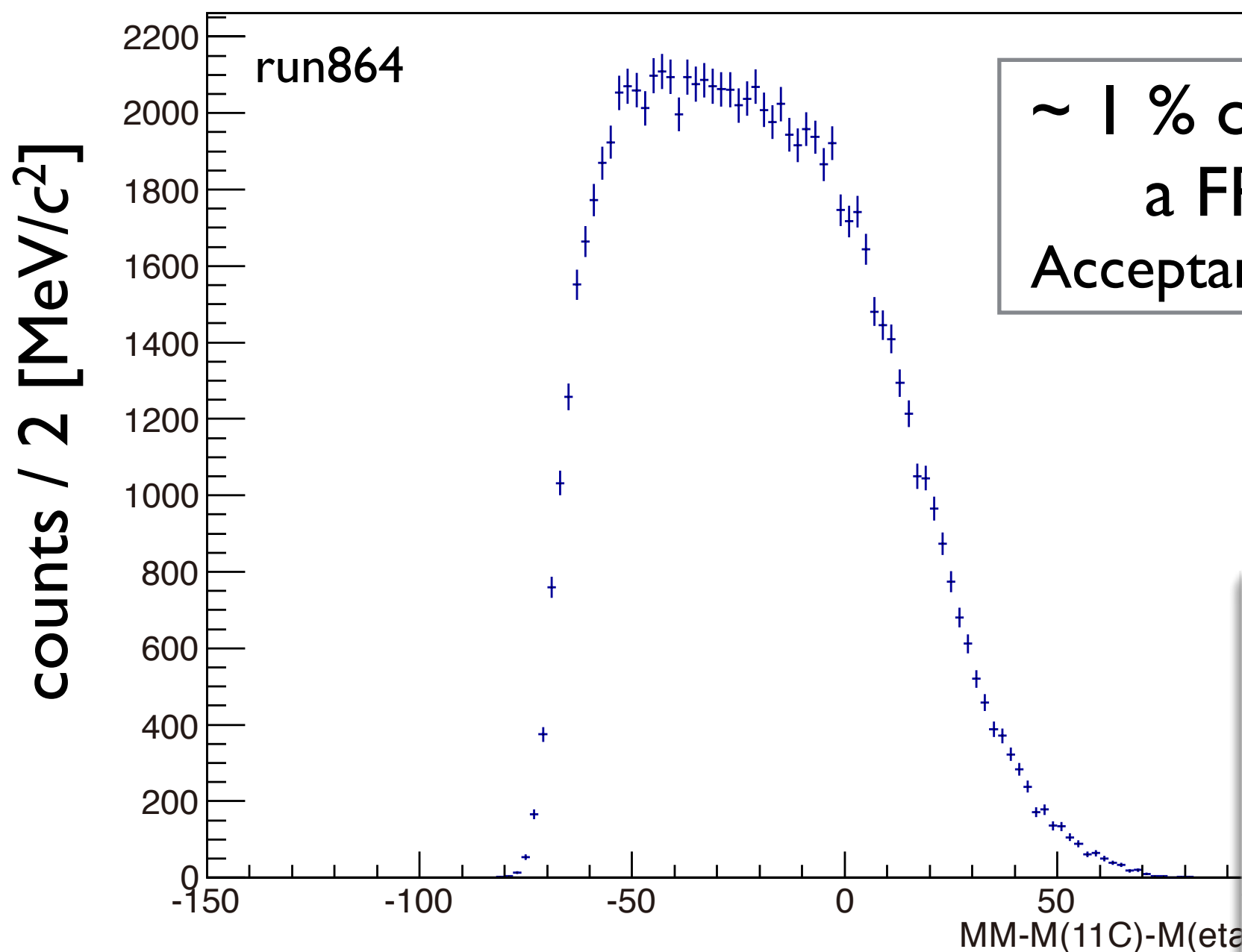
- energy loss and straggling calculation
- spectrometer momentum resolution
- beam momentum spread

Expected mass resolution : $\sigma \sim 2$ MeV/ c^2 (production run)

Sample spectrum of a very small part of accumulated data

$^{12}\text{C}(p,d)$ $T_d = 2.5$ GeV

preliminary

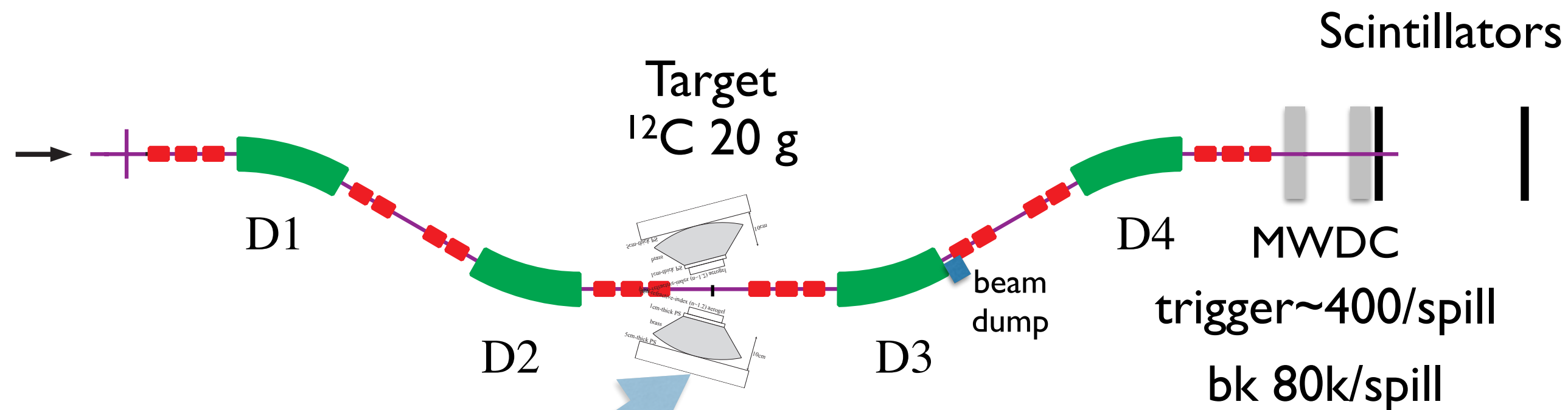


7 settings cover estimated statistics

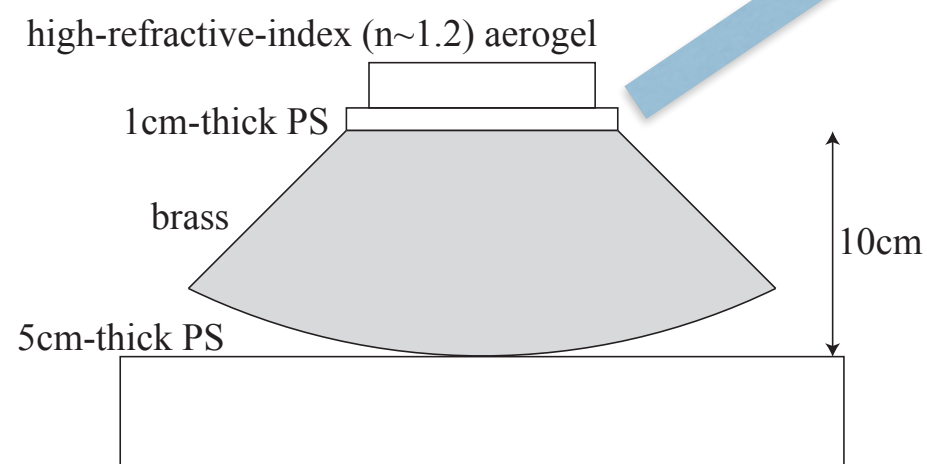
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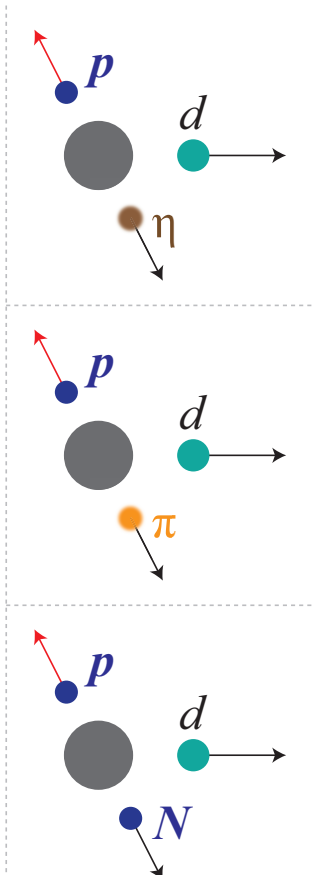
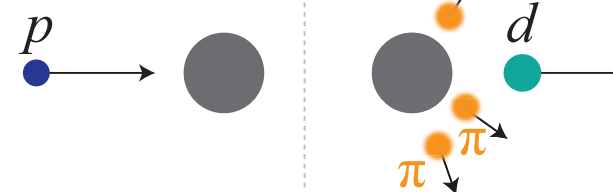
Second step

Pilot run for exclusive measurement at GSI

Beam $T_p = 2.5 \text{ GeV}$
 $I_p > 10^8/\text{spill}$



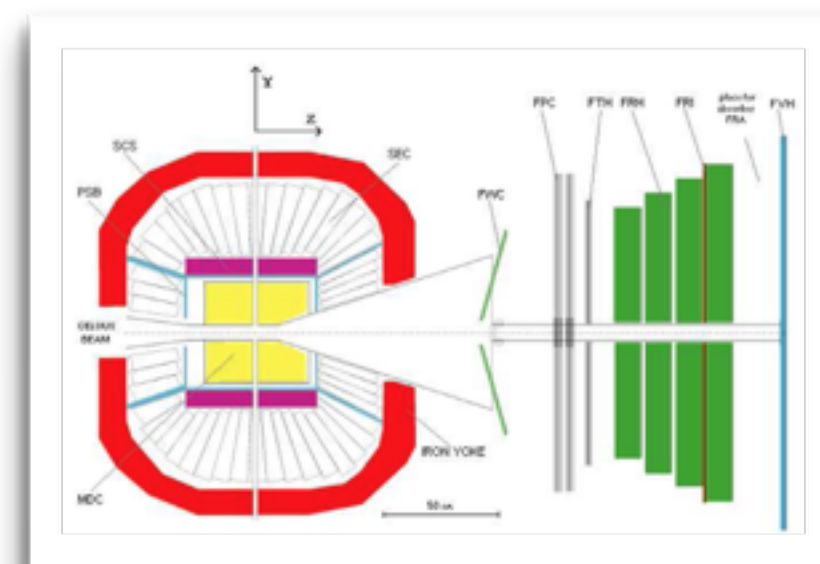
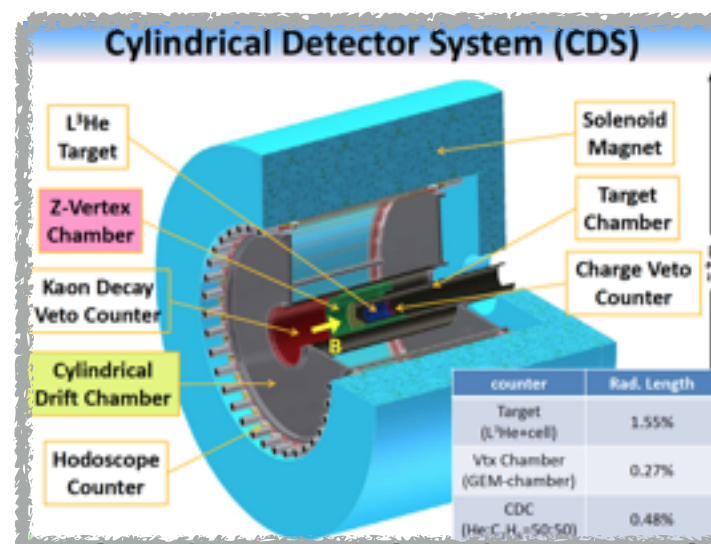
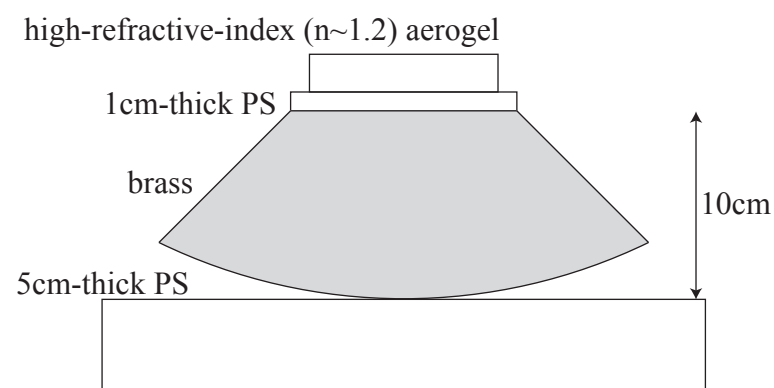
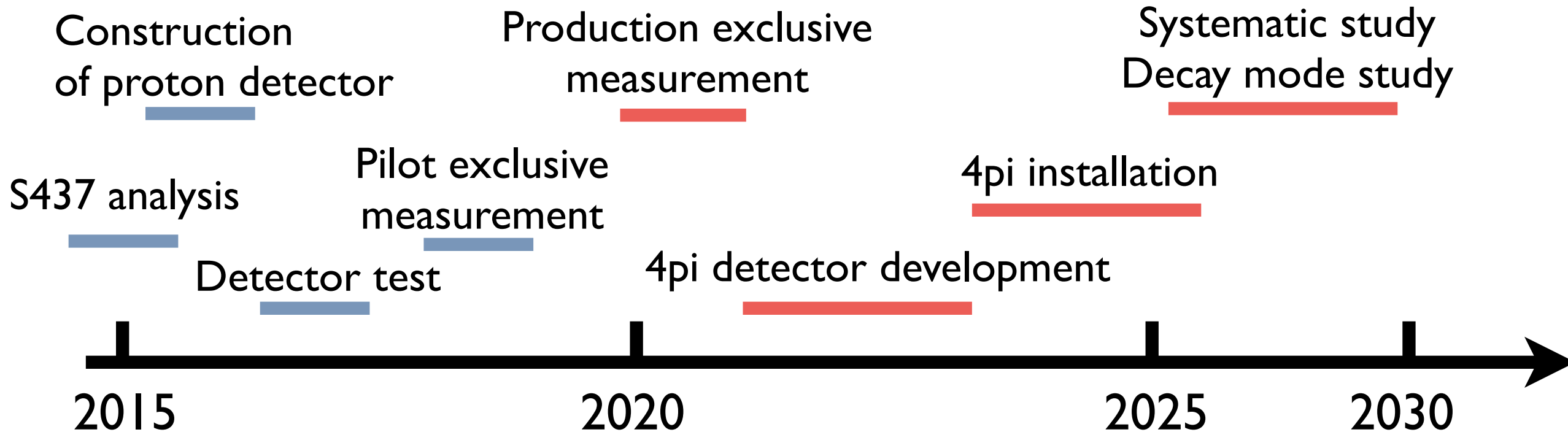
Background suppression
by signal tagging



Roadmap for η'

NUSTAR 2015

FAIR —
GSI —



Summary

- Search for η' meson bound states in ^{11}C by missing mass spectroscopy at GSI/FAIR in framework of SuperFRS
- η' is interesting in relation to $U_A(1)$ anomaly $\times$ χ -symmetry
- Just finished first physics run for inclusive (p,d)
- PID perfect
- Successfully accumulated targeted statistics with good resolution $\sim 2 \text{ MeV}/c^2$
- We will soon start writing the first paper
- Preparation for semi-exclusive measurement