Search for η′ mesic nuclei in GSI/FAIR

Kenta Itahashi

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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

Nagahiro, Jido, Fujioka, KI, Hirenzaki, PRC87(13)045201.
KI, Fujioka et al., PTP 128 (12) 601.

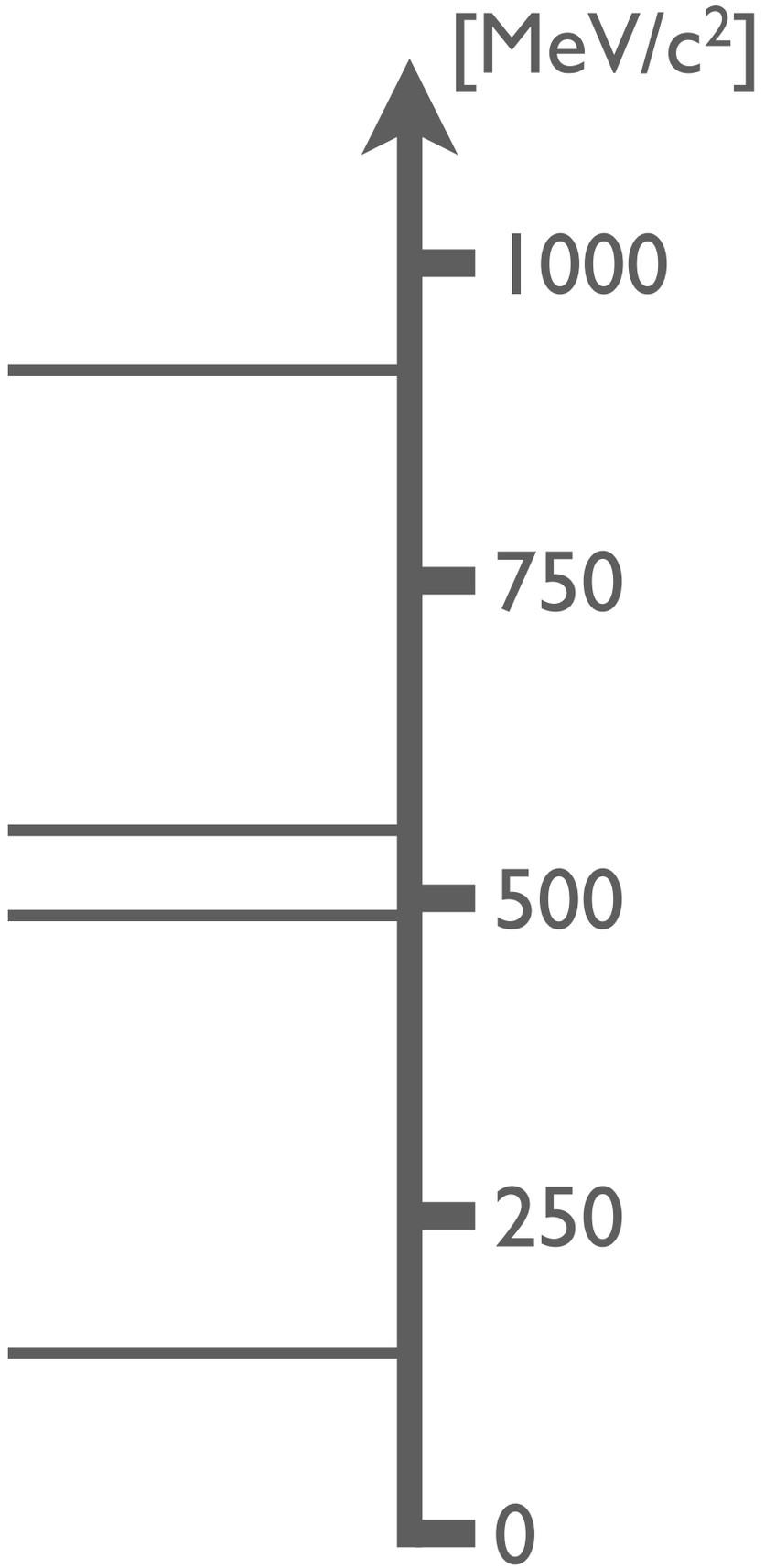
η′ and other PS mesons

η′ M=958 MeV/c^2

η M=548 MeV/c^2

K M=498 MeV/c^2

π M=140 MeV/c^2



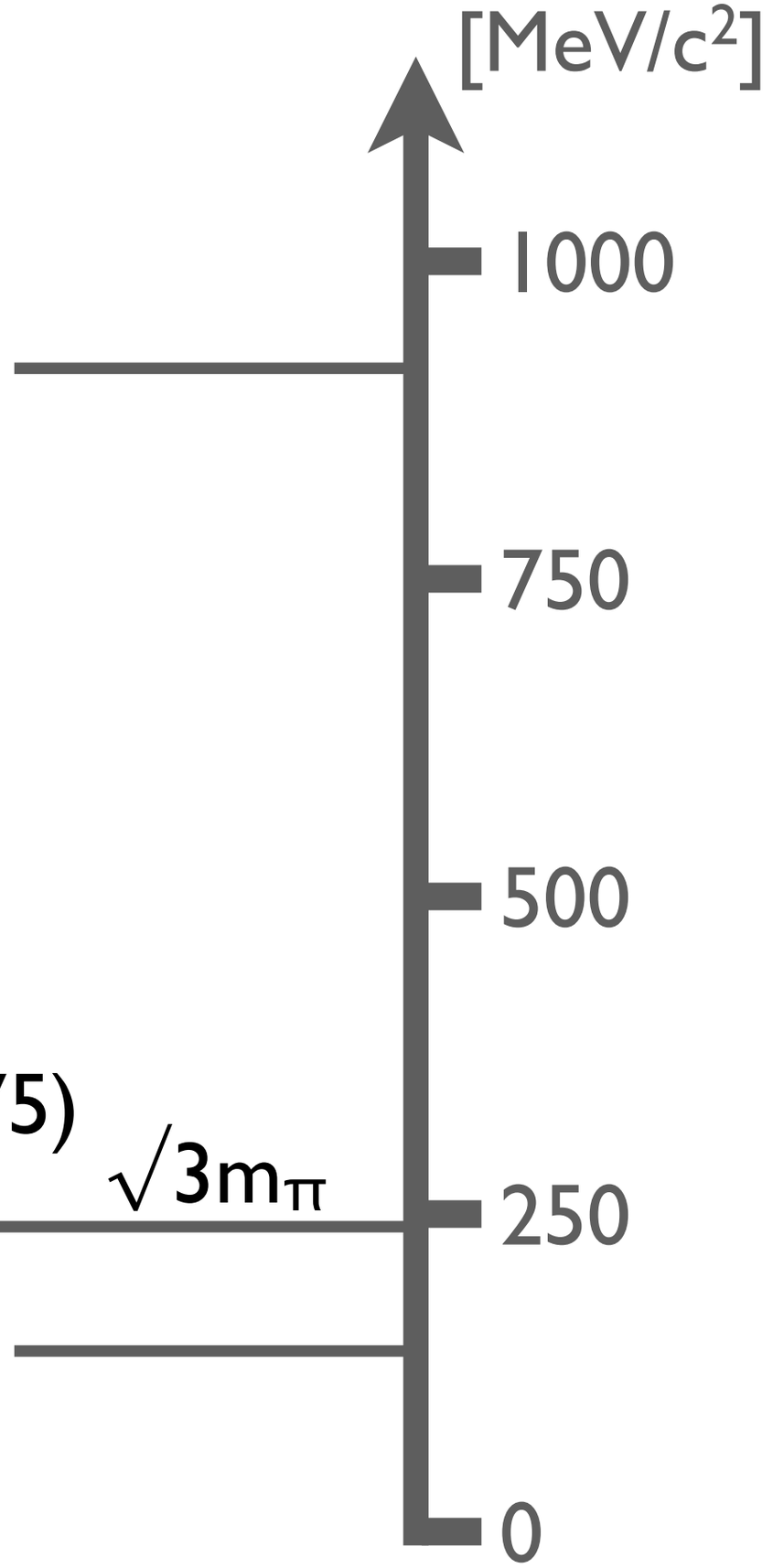
η′ and other PS mesons

η′ M=958 MeV/c^2

η problem

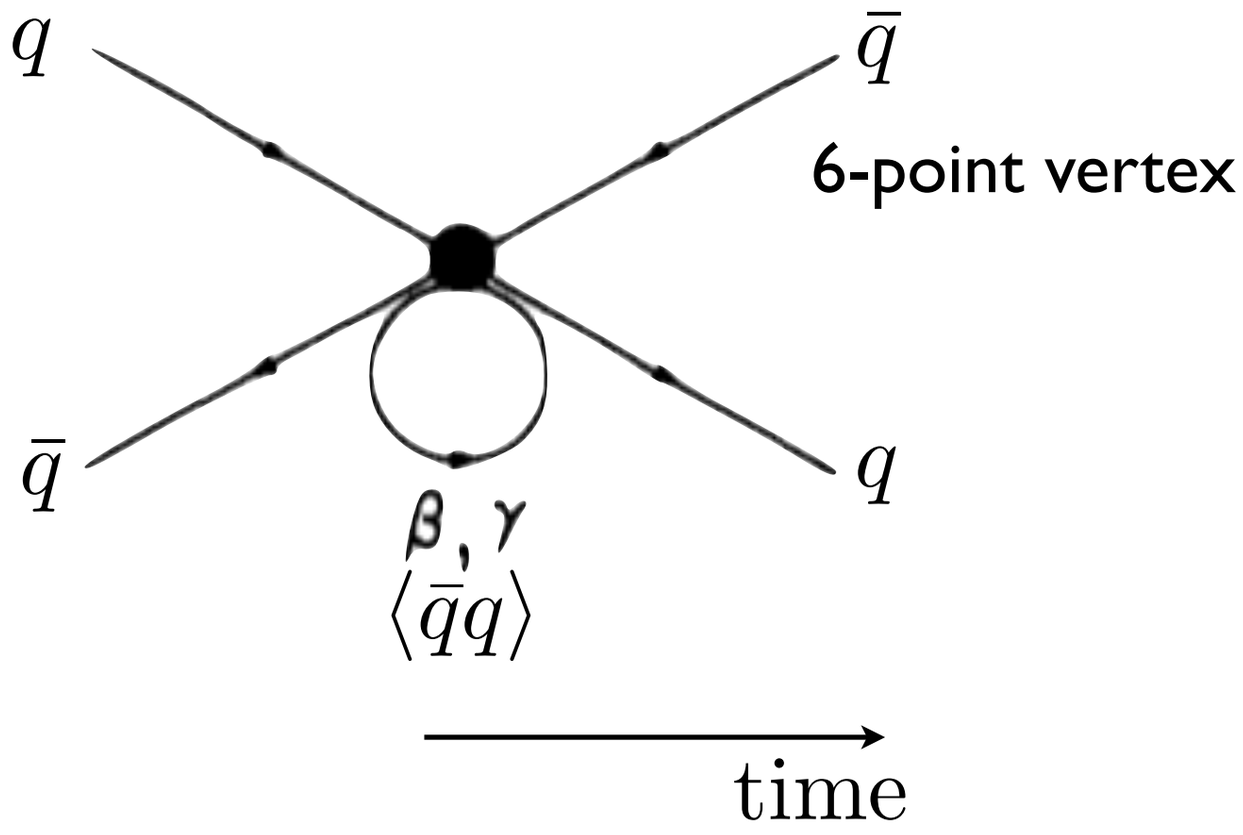
$m_{\eta'} < \sqrt{3}m_\pi$
(Weinberg, 1975)

π M=140 MeV/c^2



Large η′ mass can be explained

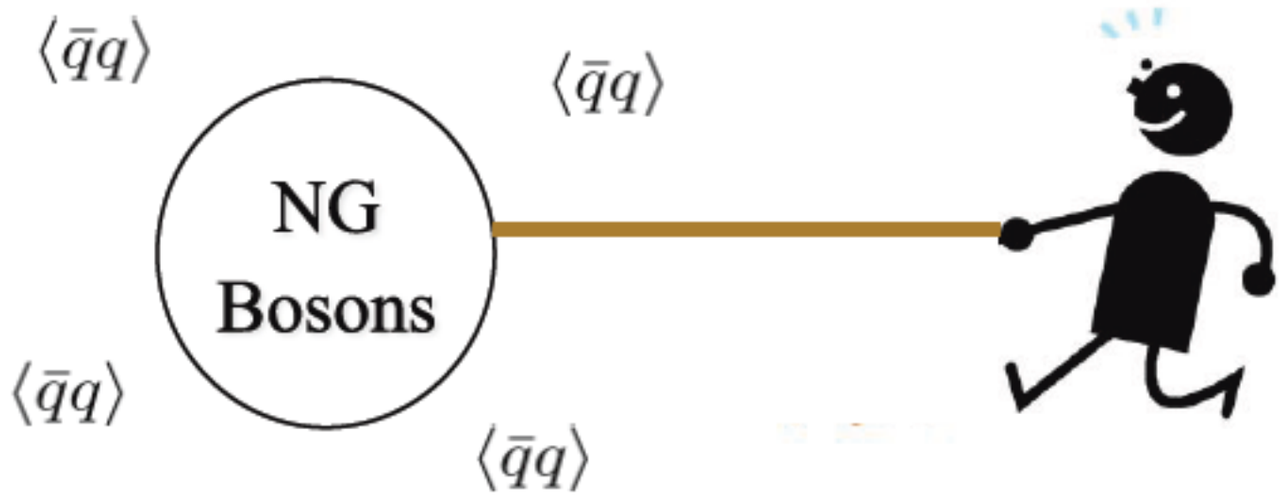
$U_A(1)$ quantum anomaly × χ-symmetry breaking

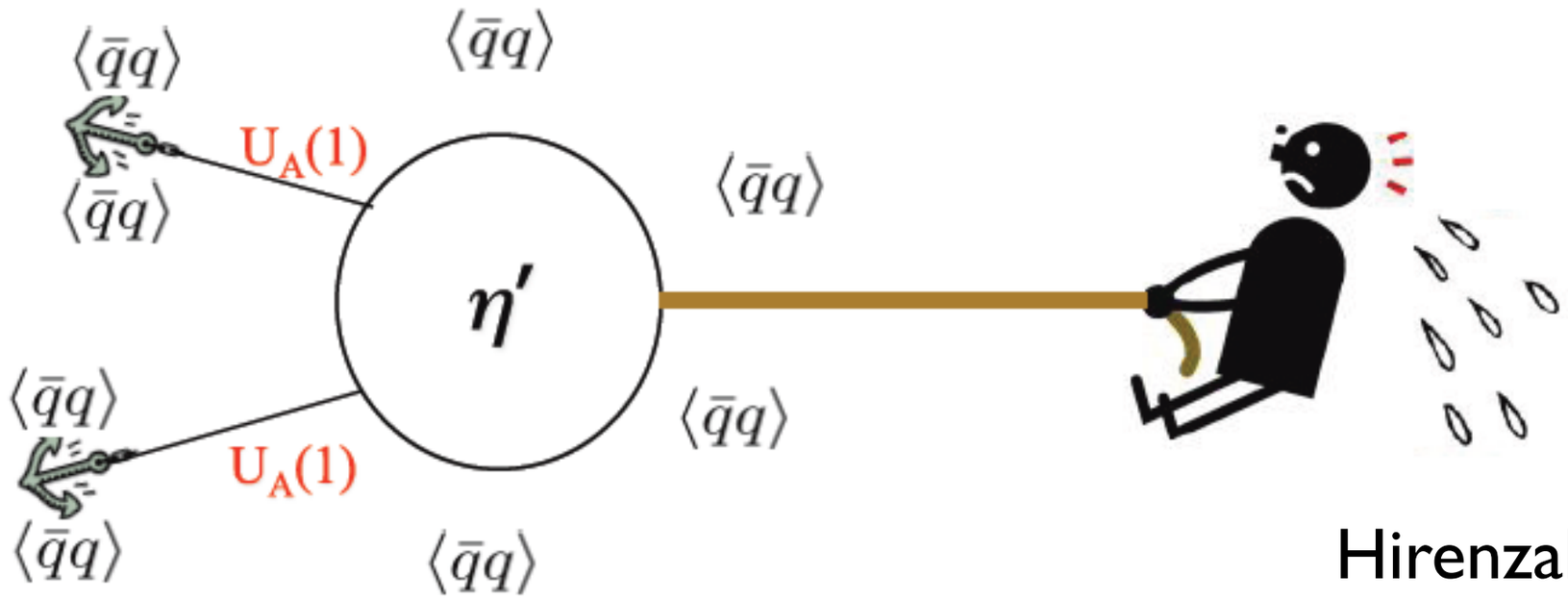


Kobayashi-Maskawa-'t Hooft-type interaction

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





Hirenzaki

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In-medium PS mesons

Partial restoration of dynamical breaking of χ symmetry

[MeV/c^2]

1000

750

500

250

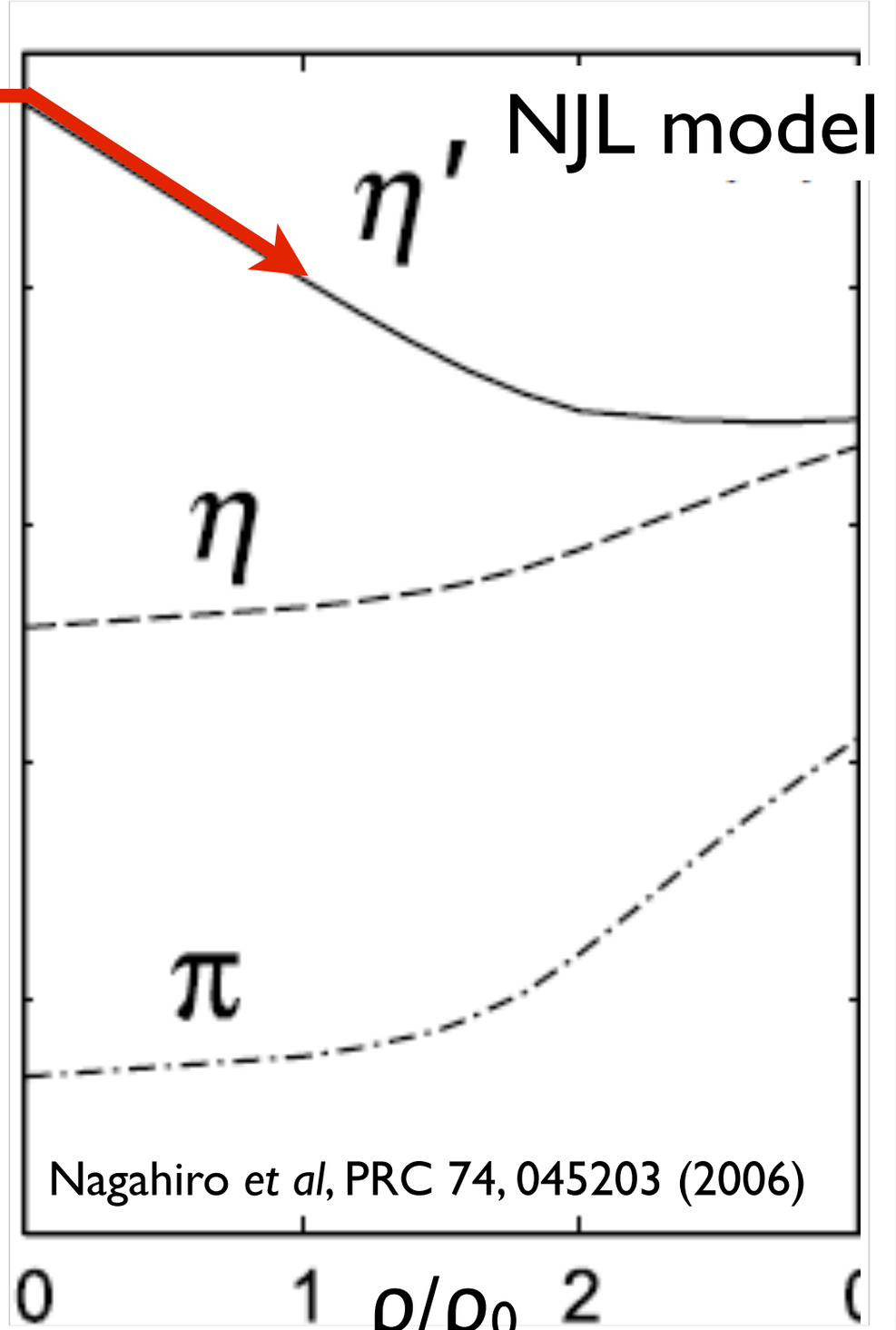
0

η′

η

K

π



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

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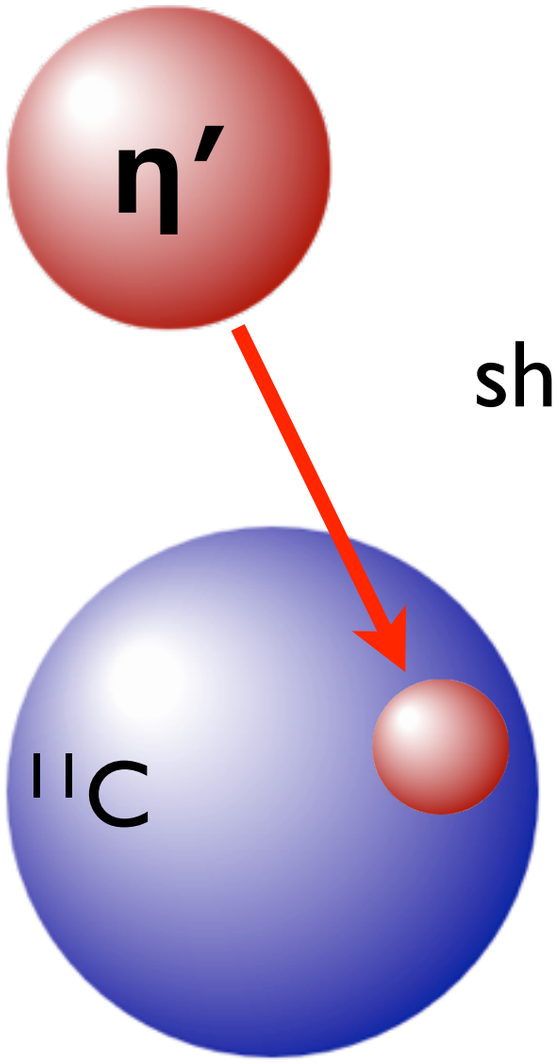
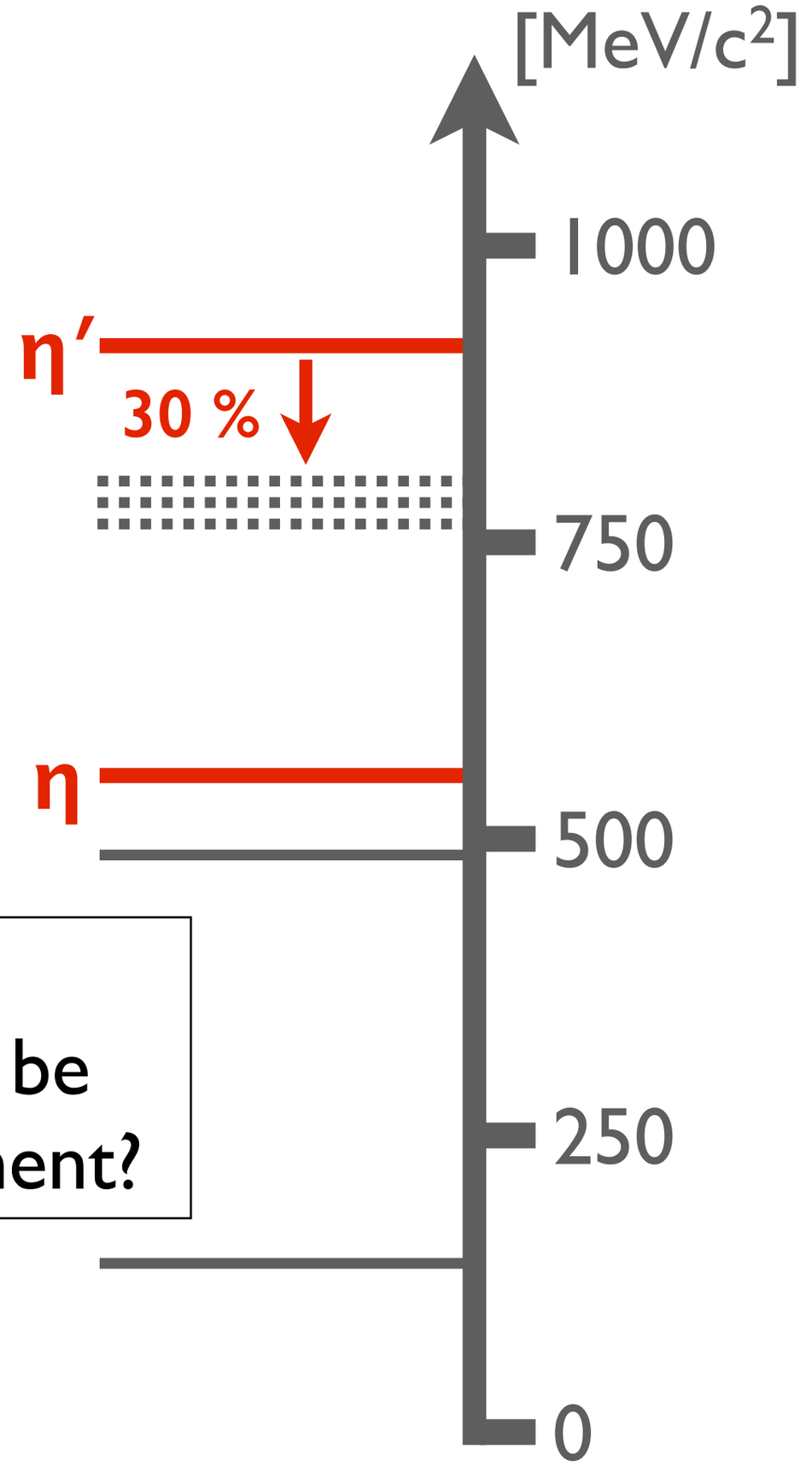
η′ mesic nuclei search



Naive estimation
shows 30% reduction
of $|m_{\eta'} - m_{\eta}|$



Q. Mass shift of
~ 150 MeV/c^2 can be
observed in experiment?

Jido, Nagahiro, Hirenzaki,
PRC85(2012)032201(R)

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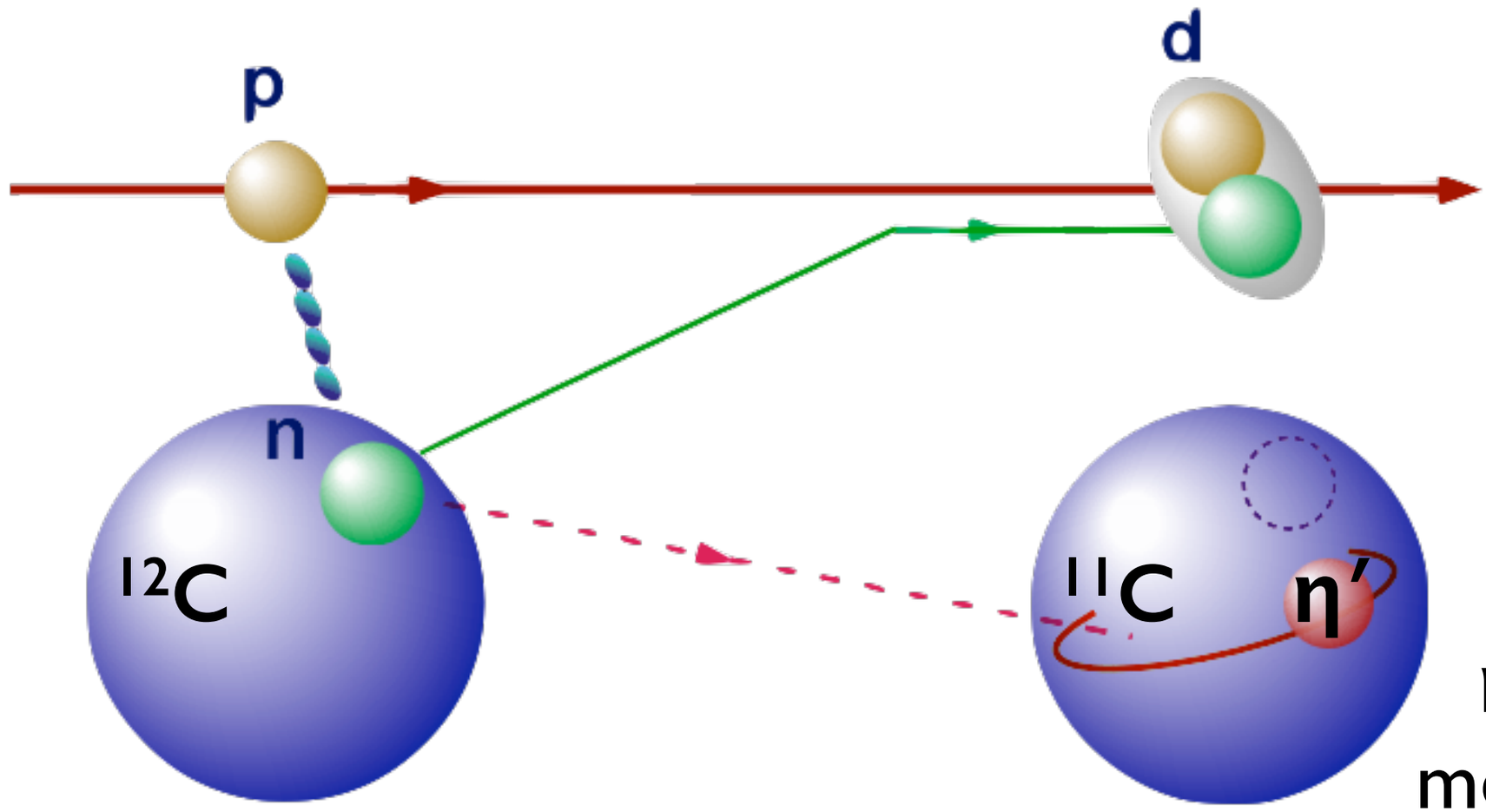
η′ Mesic Nuclei in (*p*,*d*) Reaction

η′ transfer reaction + missing mass measurement

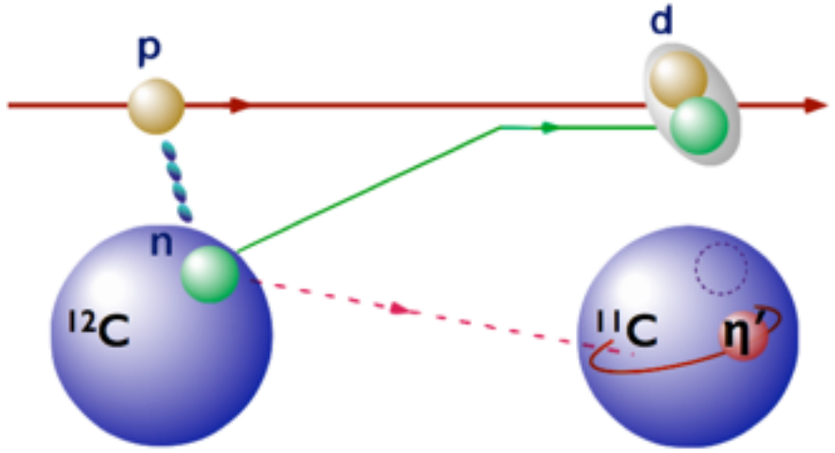


η′ × ^{11}C
mesic nuclei

T_p = 2.50 GeV → q ~ 400 MeV/c

KI, Fujioka et al., PTP 128 (12) 601.

Theoretical Prediction

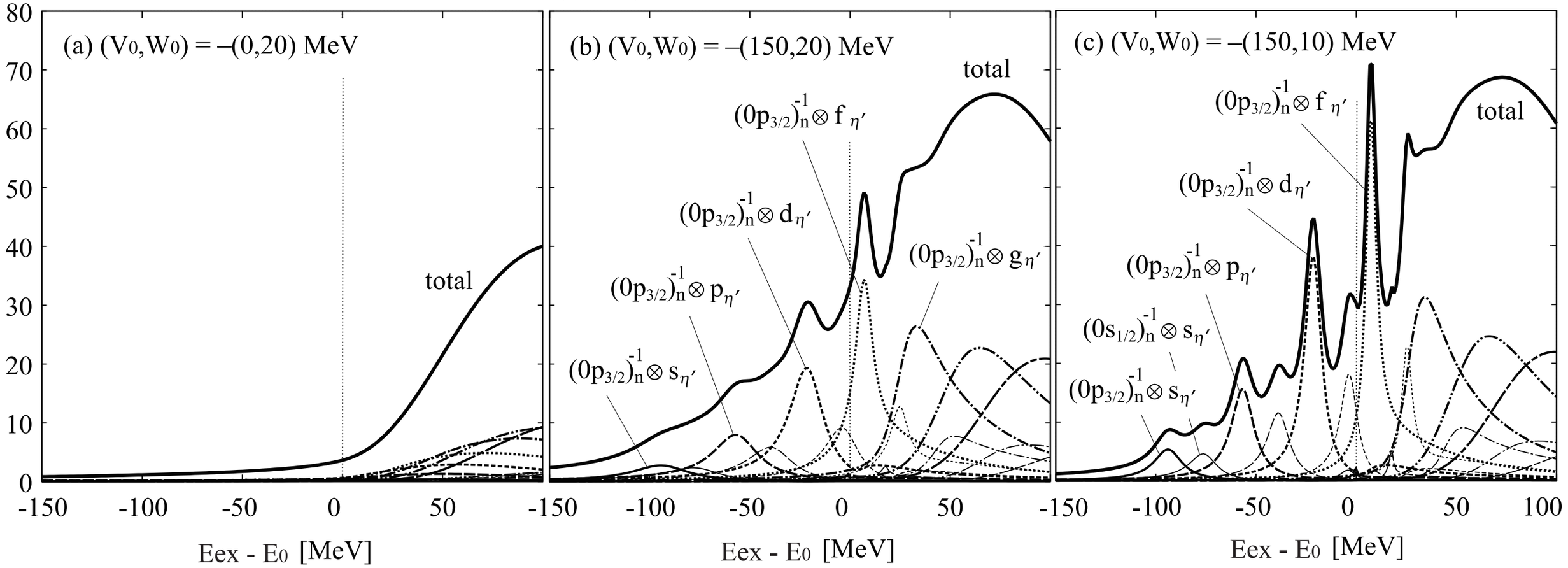


η′-nucleus potential:

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

ρ: nucleon density
V_0: Real potential depth
W_0: Imaginary potential depth

^{12}C(*p*,*d*) at T_p = 2.50 GeV



Nagahiro et al., PRC87(13)045201.

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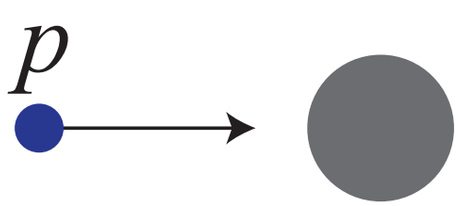
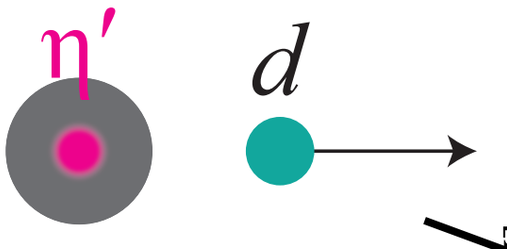
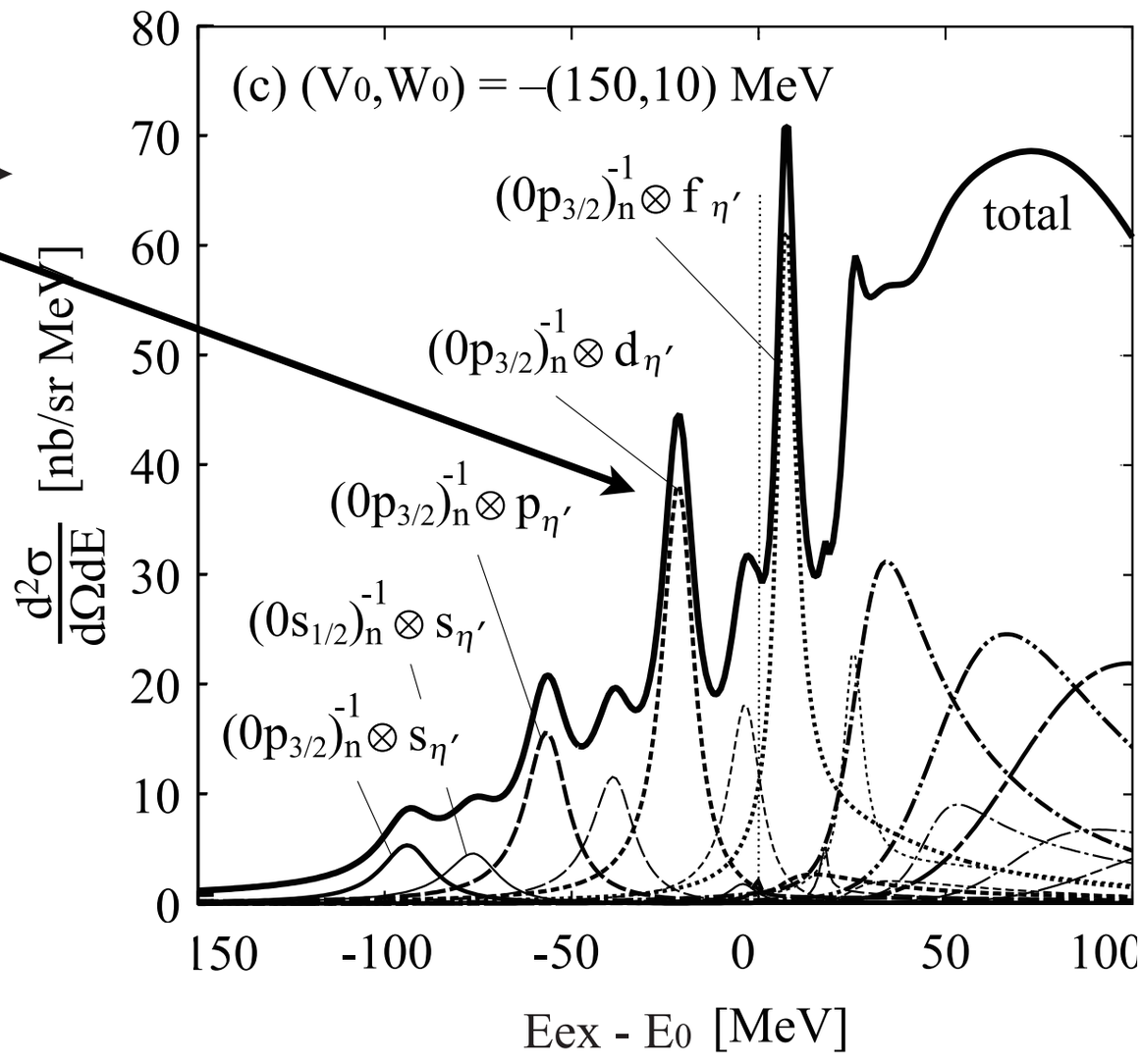
Spectrum in Inclusive Measurement at GSI

Signal





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



Nagahiro et al., PRC87(13)045201.

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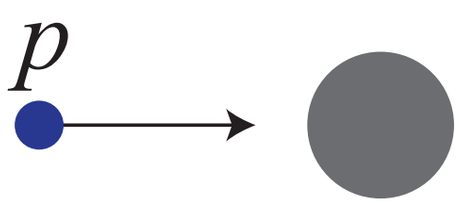
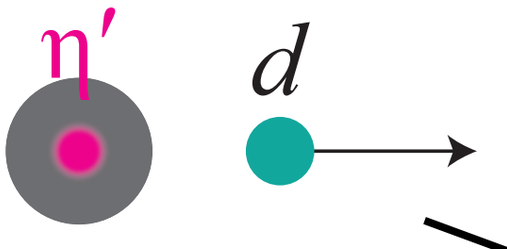
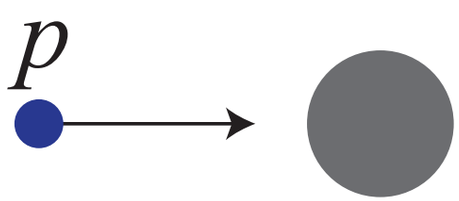
Spectrum in Inclusive Measurement at GSI

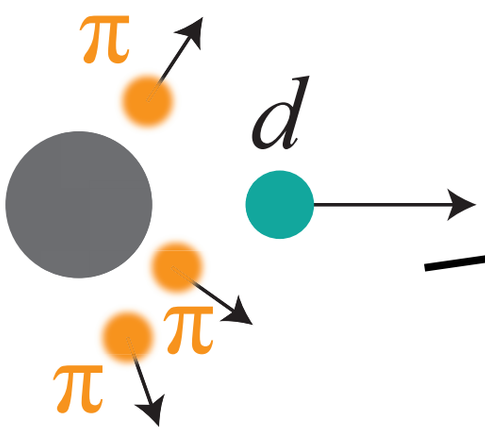
Signal

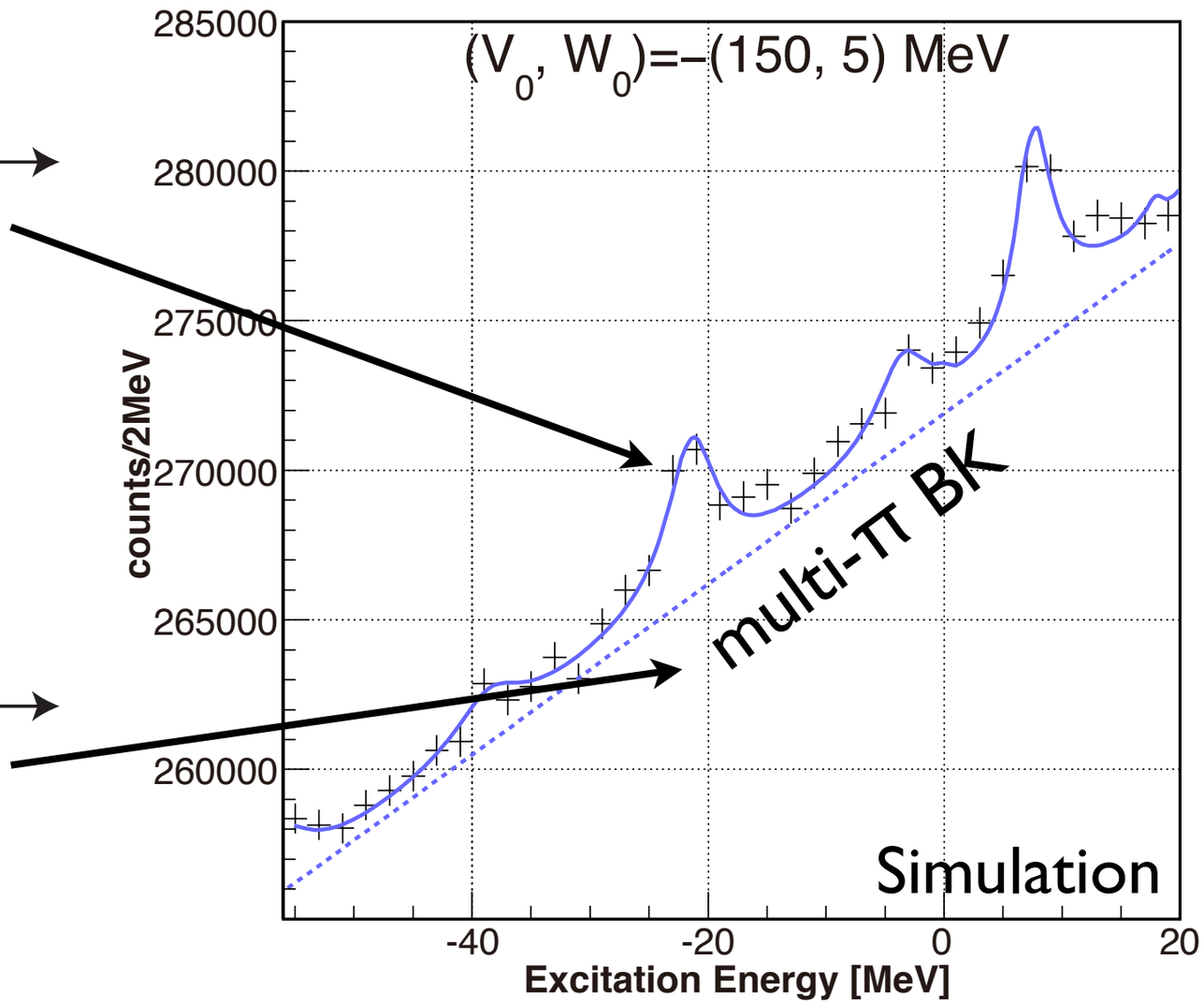




Background







KI, Fujioka et al., PTP 128 (12) 601.

Simulation of inclusive measurement

Simulated spectra of inclusive measurement assuming 4.5 day DAQ

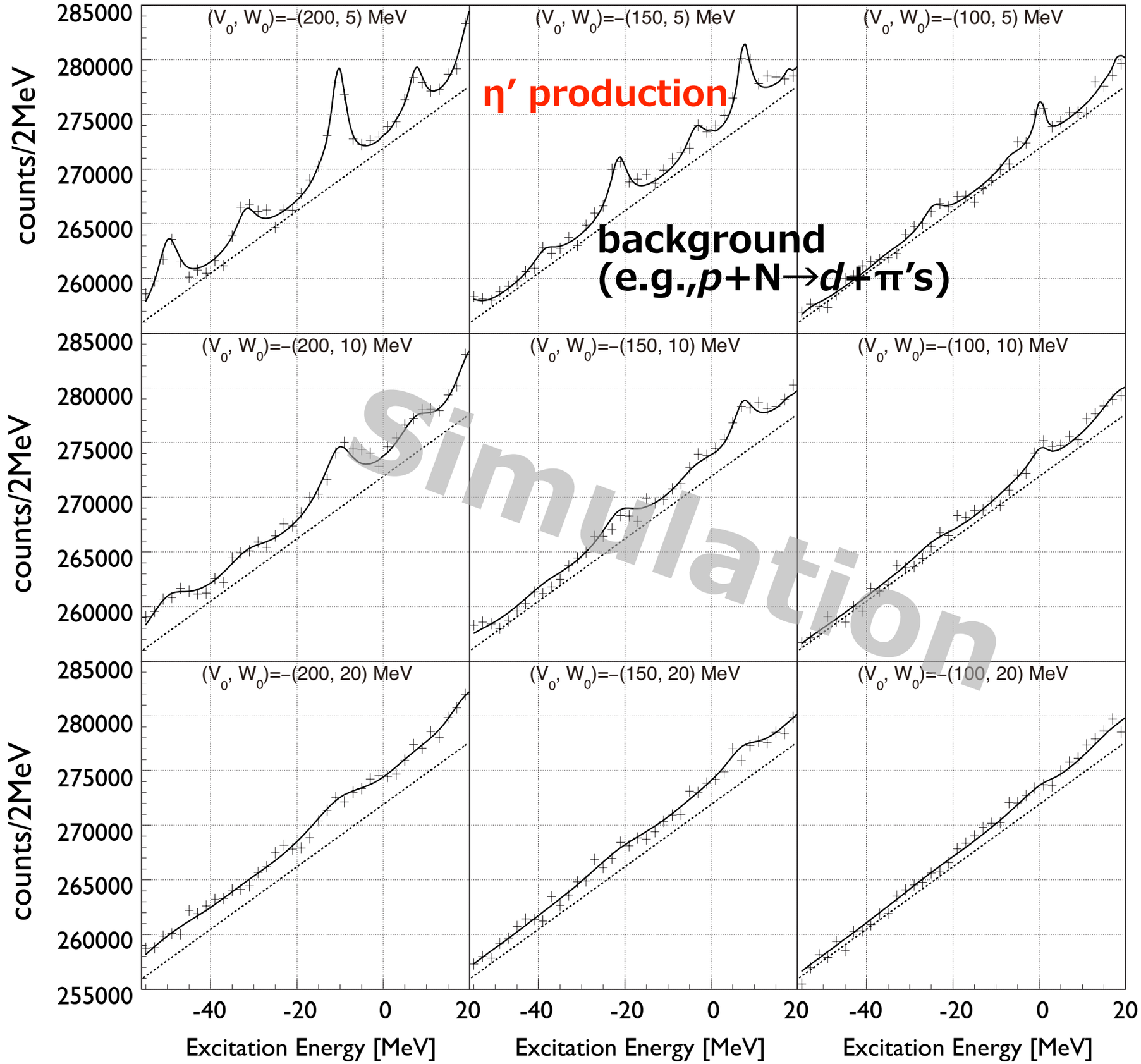
K. Itahashi et al.,
PTP 128,601(2012)

V_0, W_0 :
real, imaginary part
of optical potential

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

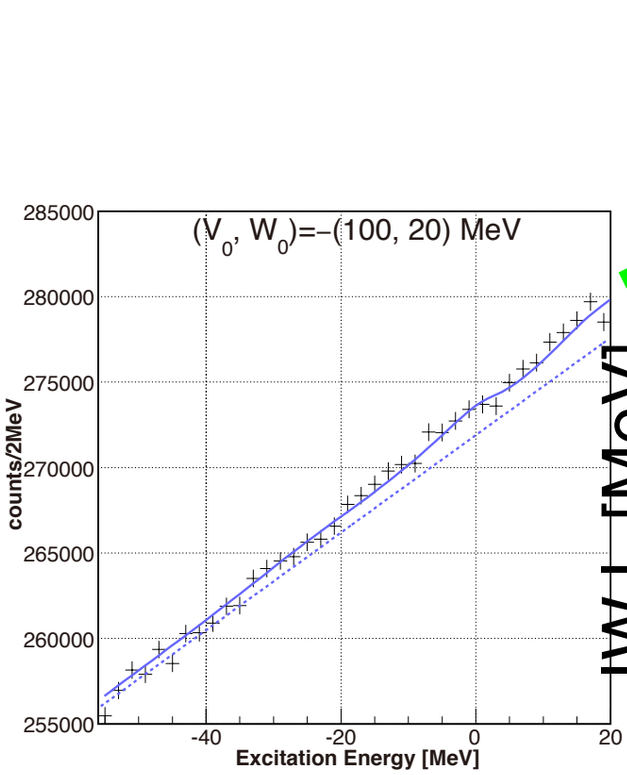
$(V_0 = \Delta m(\rho_0), W_0 = -\Gamma(\rho_0)/2)$

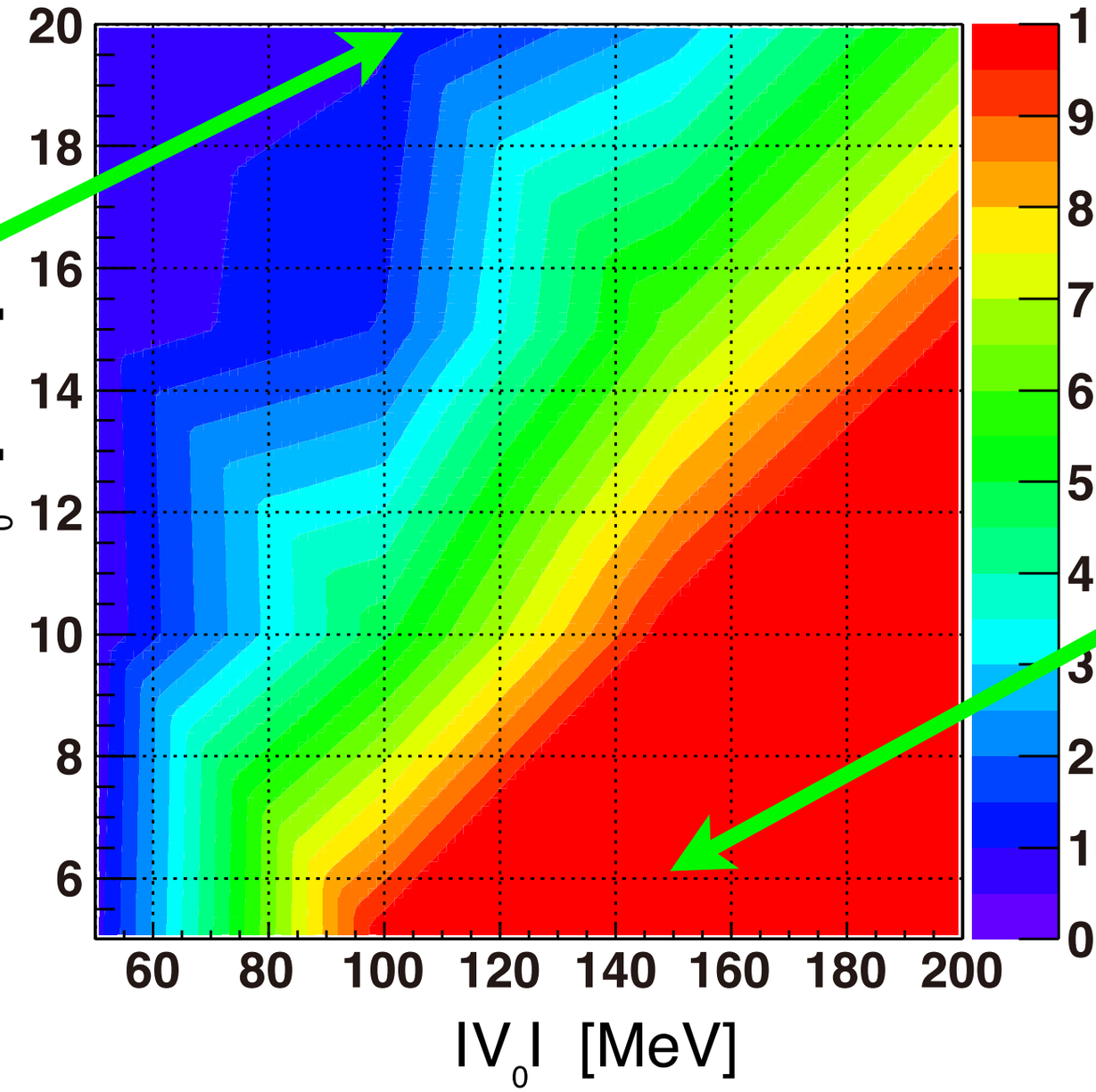
S/N ratio ~ O(1/100)
at most

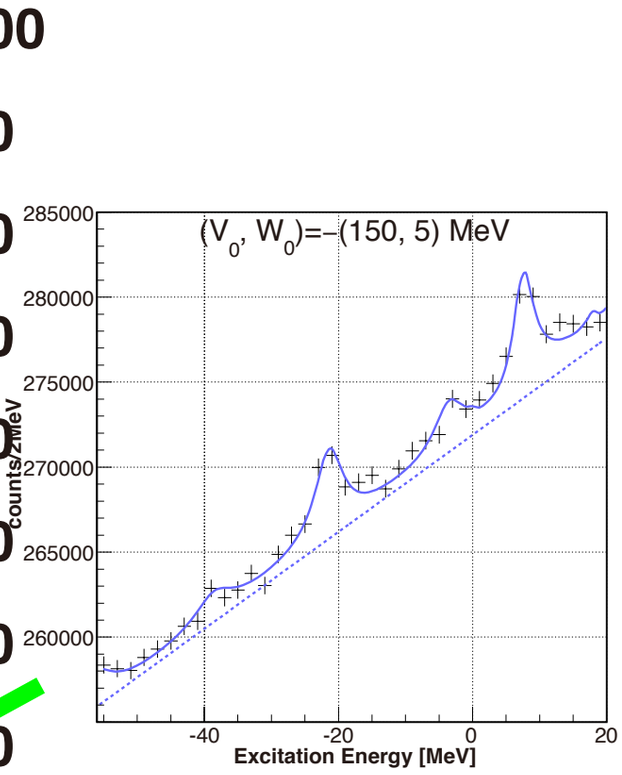


Structure-finding Probability

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







in 4.5 days DAQ

for 95 % C.L.

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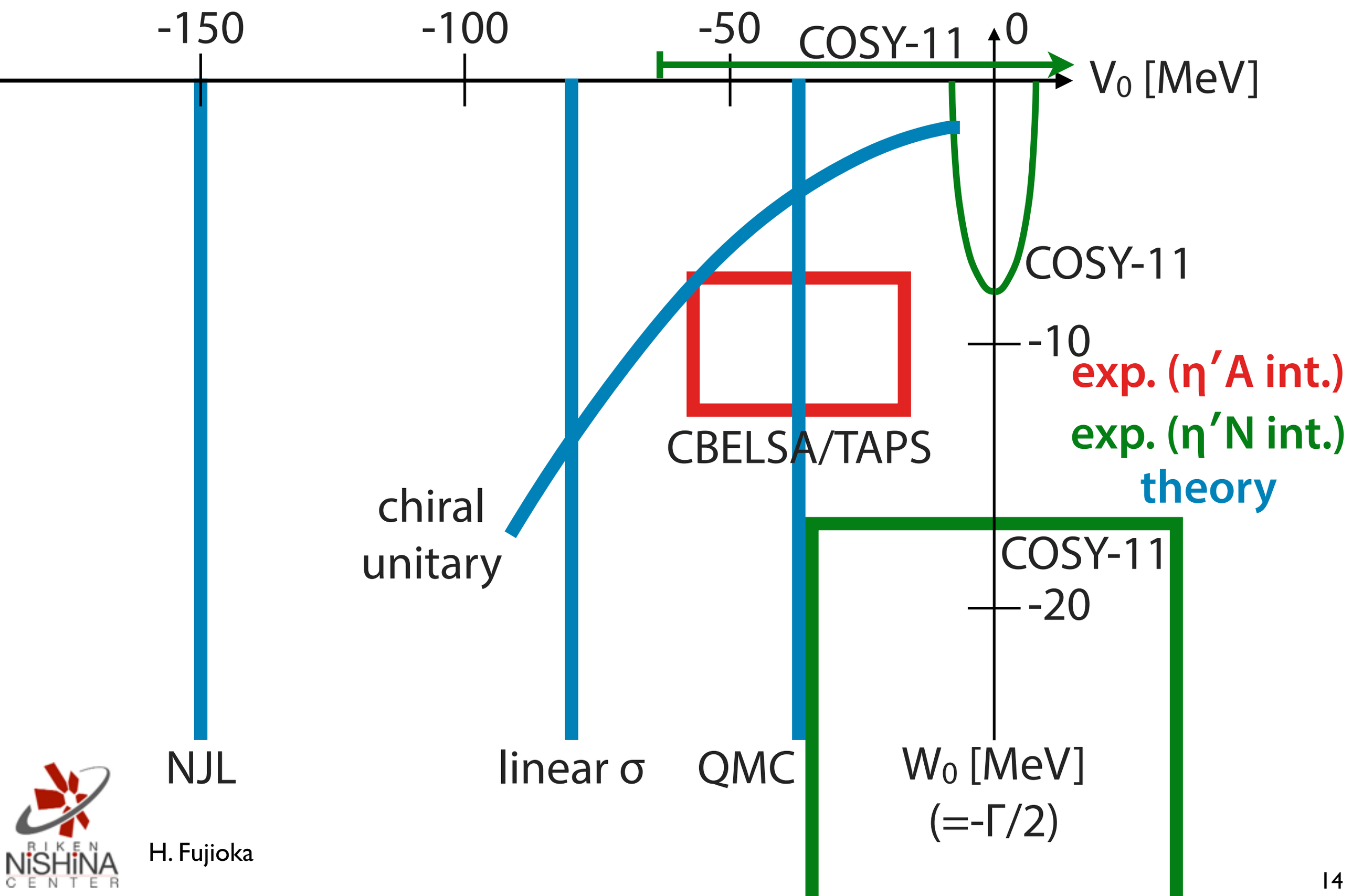
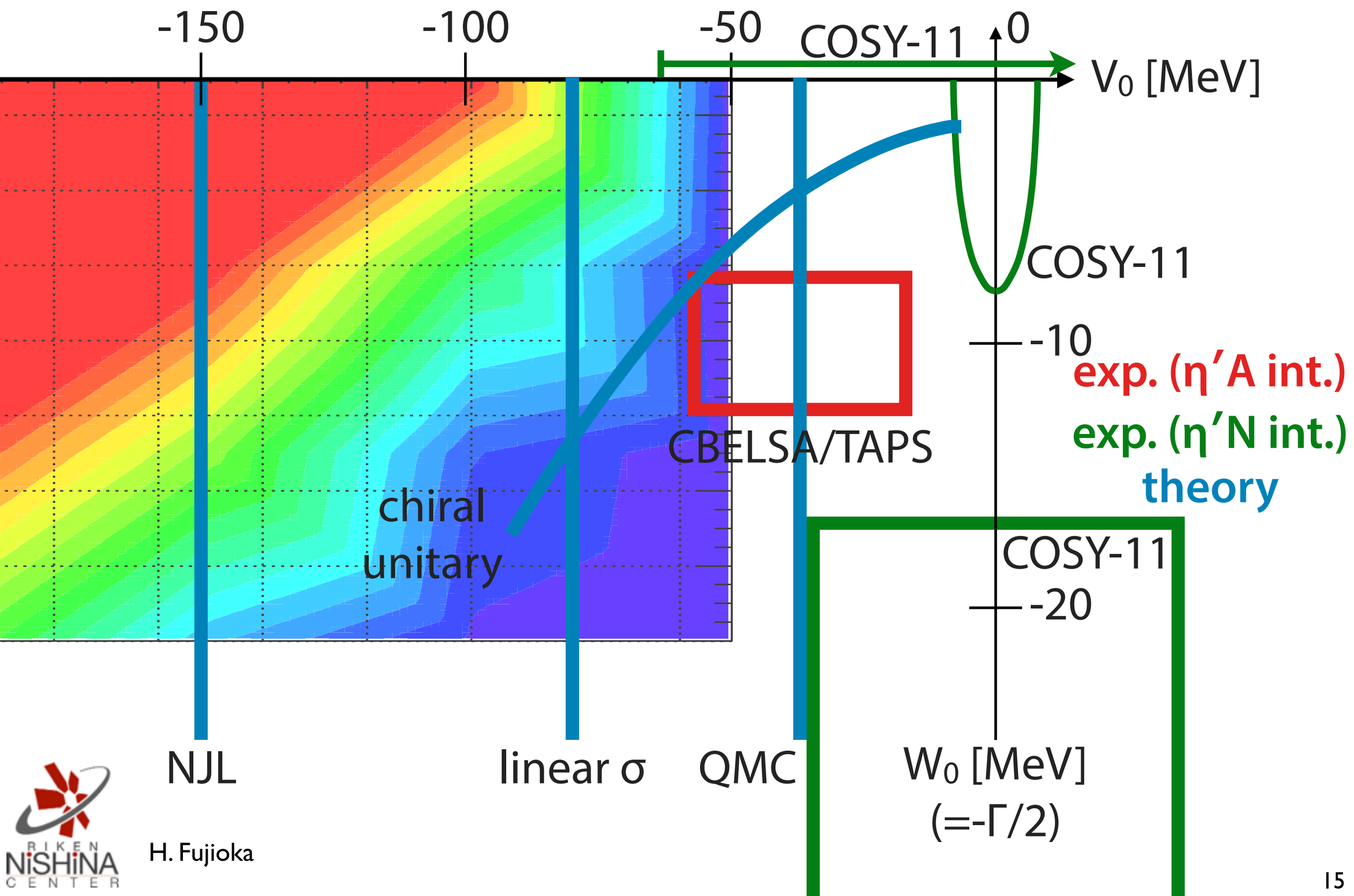
Structure-finding Probability for First Step (GSI)



Structure-finding Probability for First Step (GSI)



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*,*dp*) exclusive*	extended sensitivity for excited + ground states	good
FAIR step≧2	(*p*,*dx*) exclusive*	exclusive + decay mode studies	good

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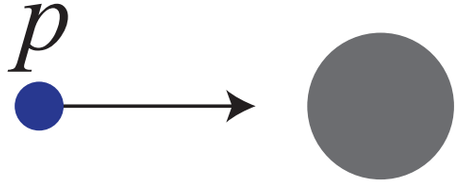
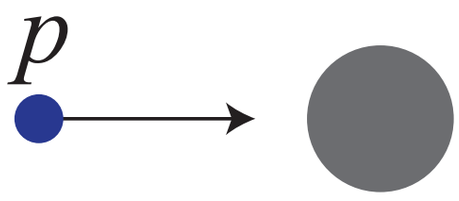
Principles of Exclusive Measurement at GSI/FAIR

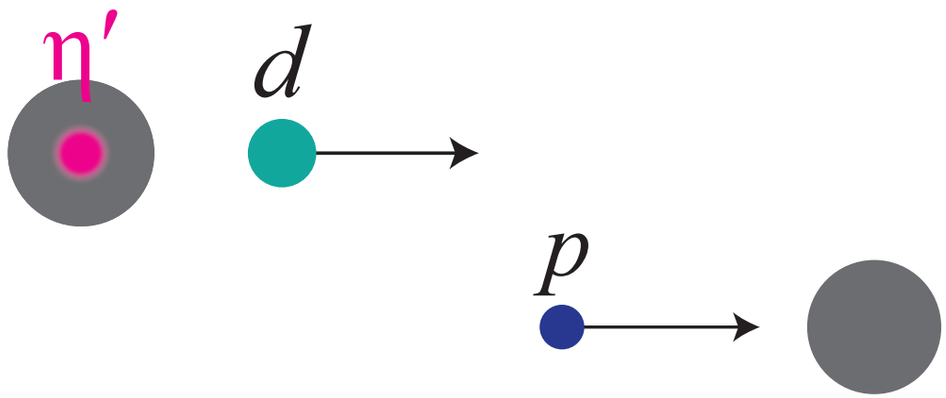
Signal

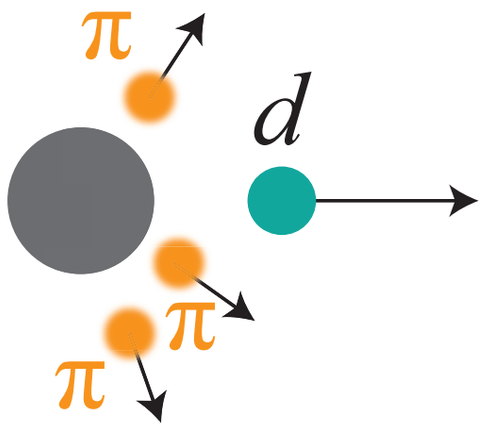


Background

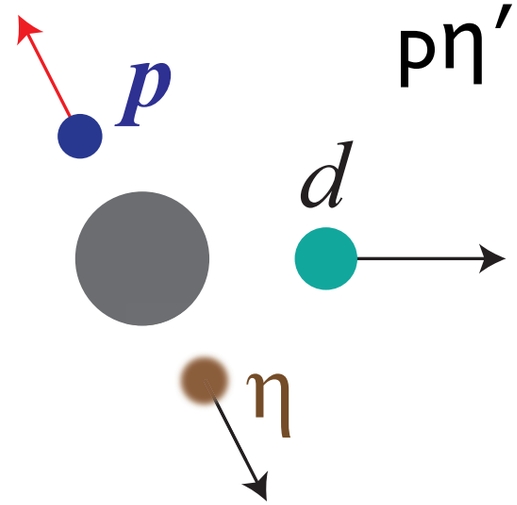


Signals

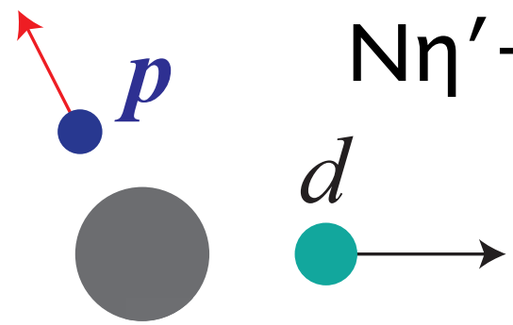




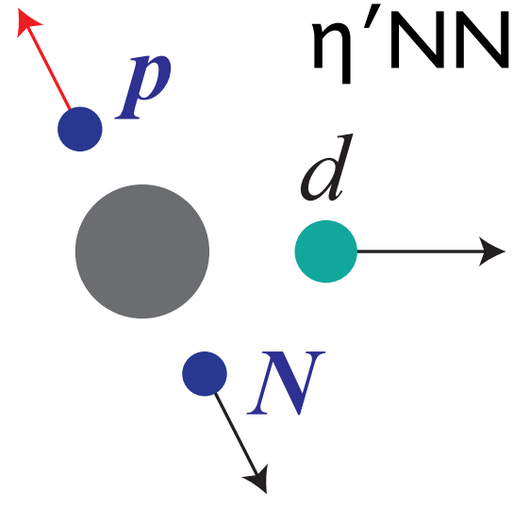
pη′→pη



Nη′→pπ



η′NN→pN



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First step

Inclusive measurement GSI SIS-S437 in 2014/Aug

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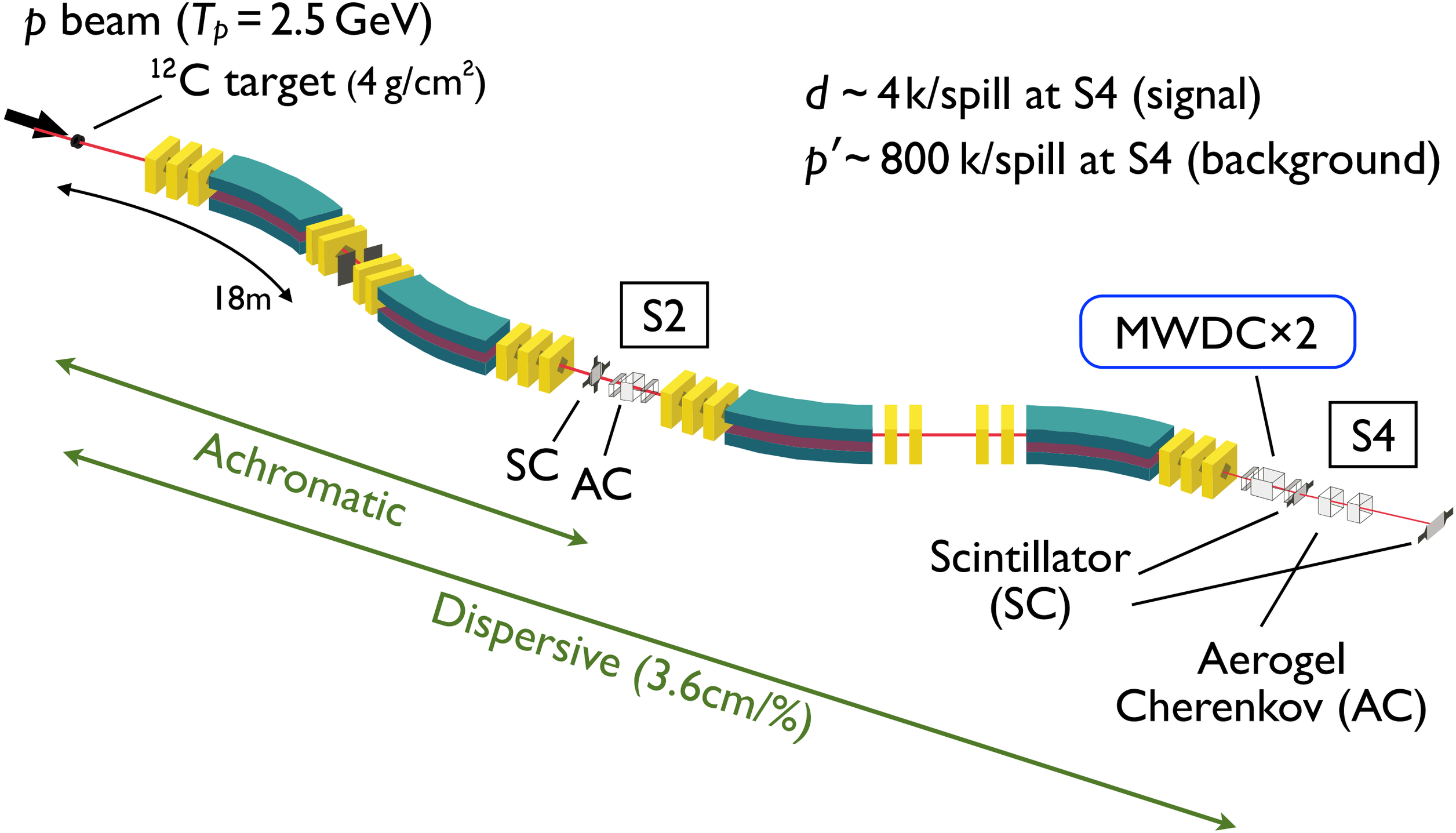
Production setup at FRS

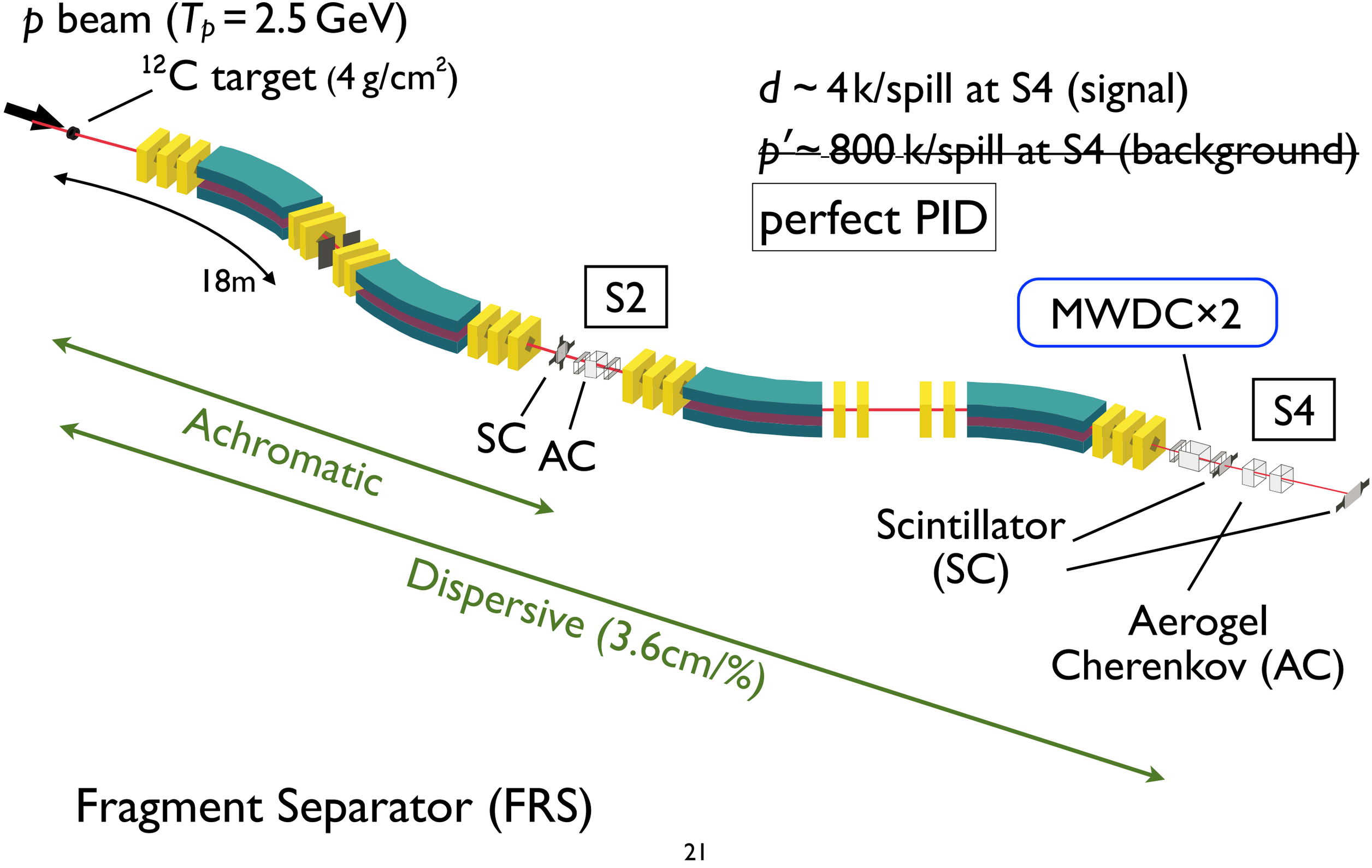


d ~ 4 k/spill at S4 (signal)

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

Fragment Separator (FRS)

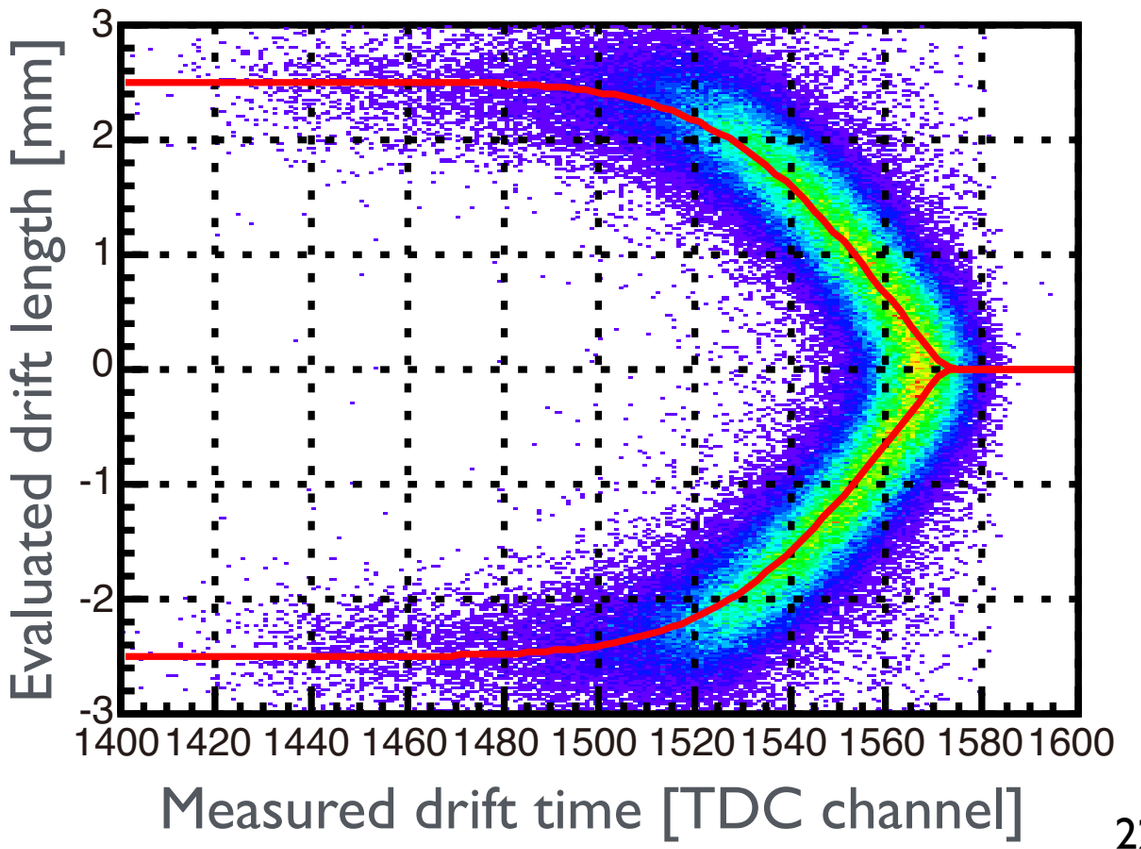
Production setup at FRS



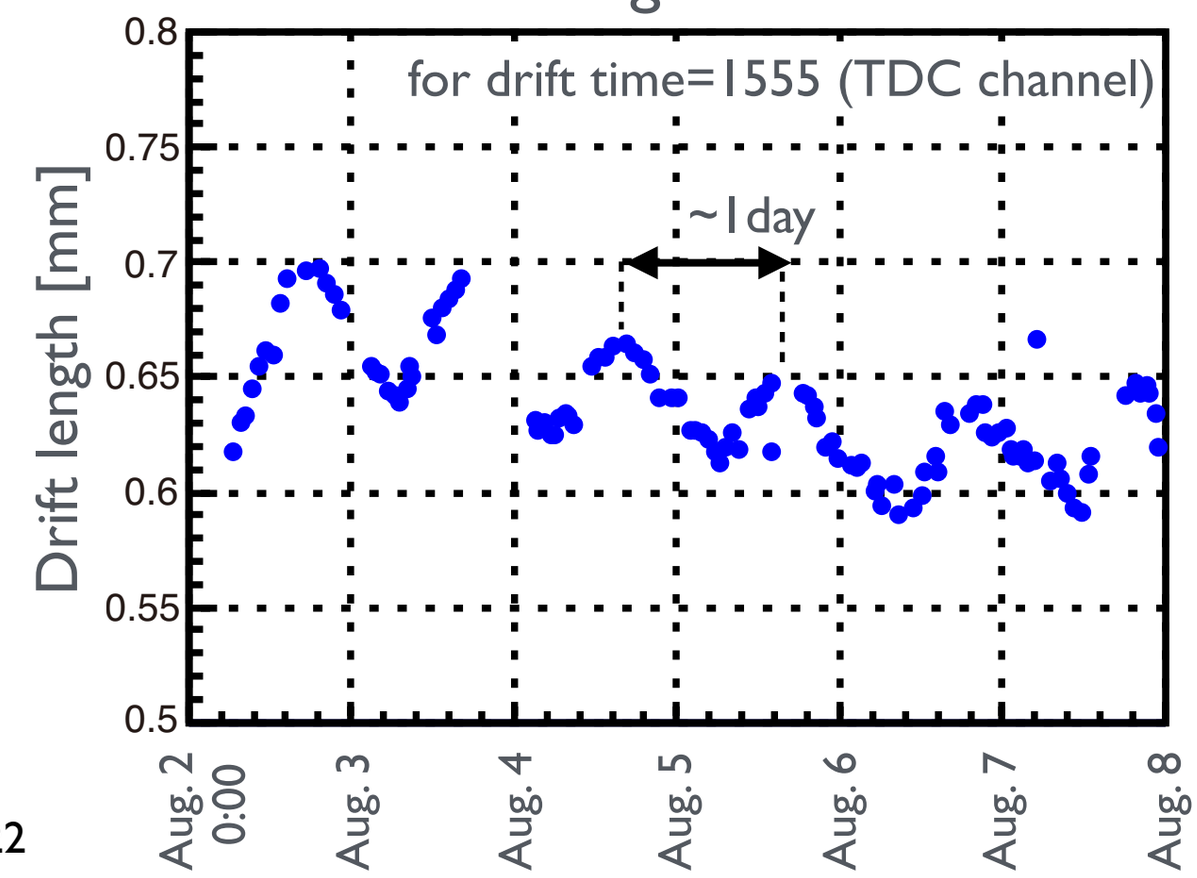
MWDC Analysis

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

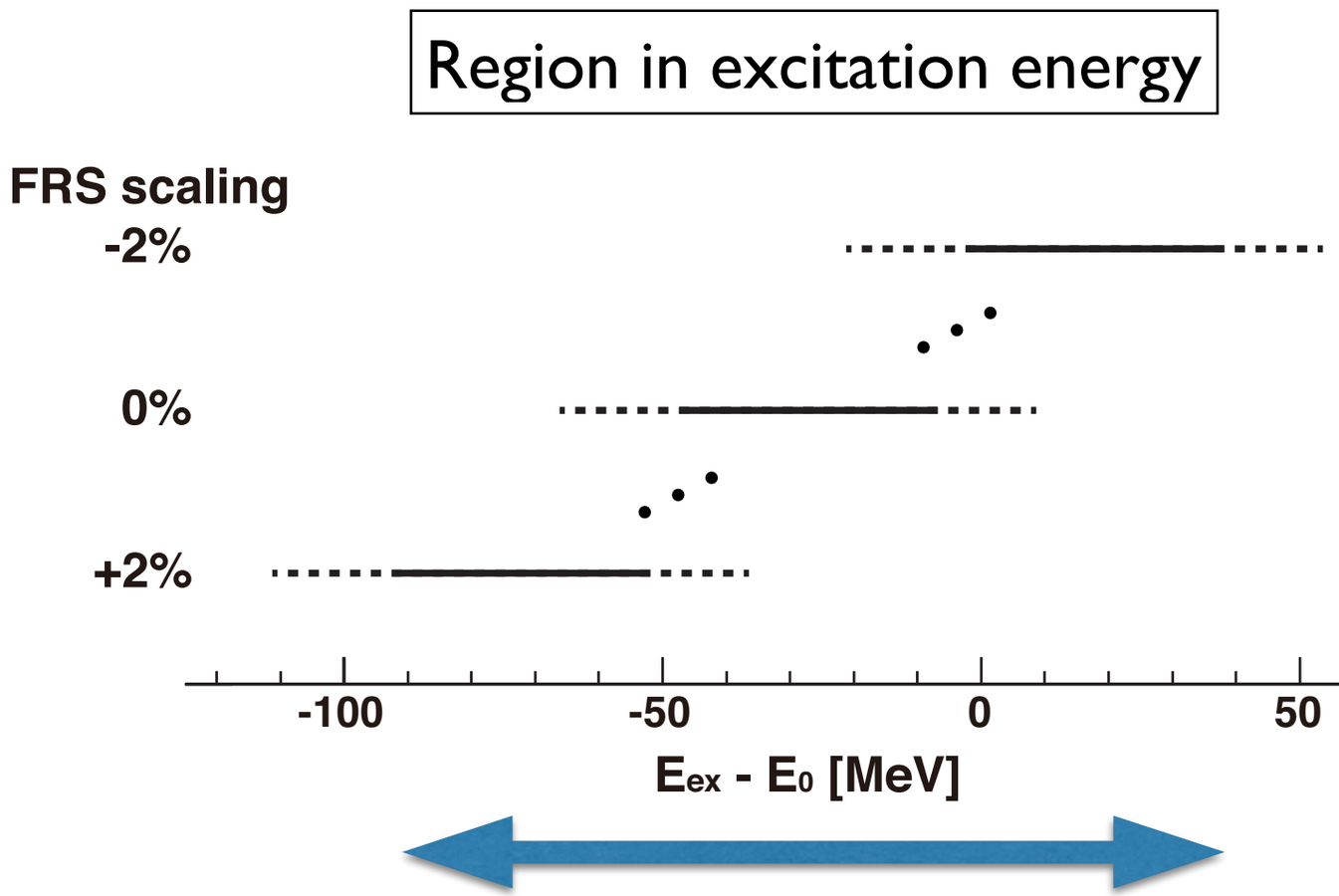
Drift length calibration



Time dependence of drift time to drift length relation



Spectrometer settings for wide mass region



Production run (~ 5 days)

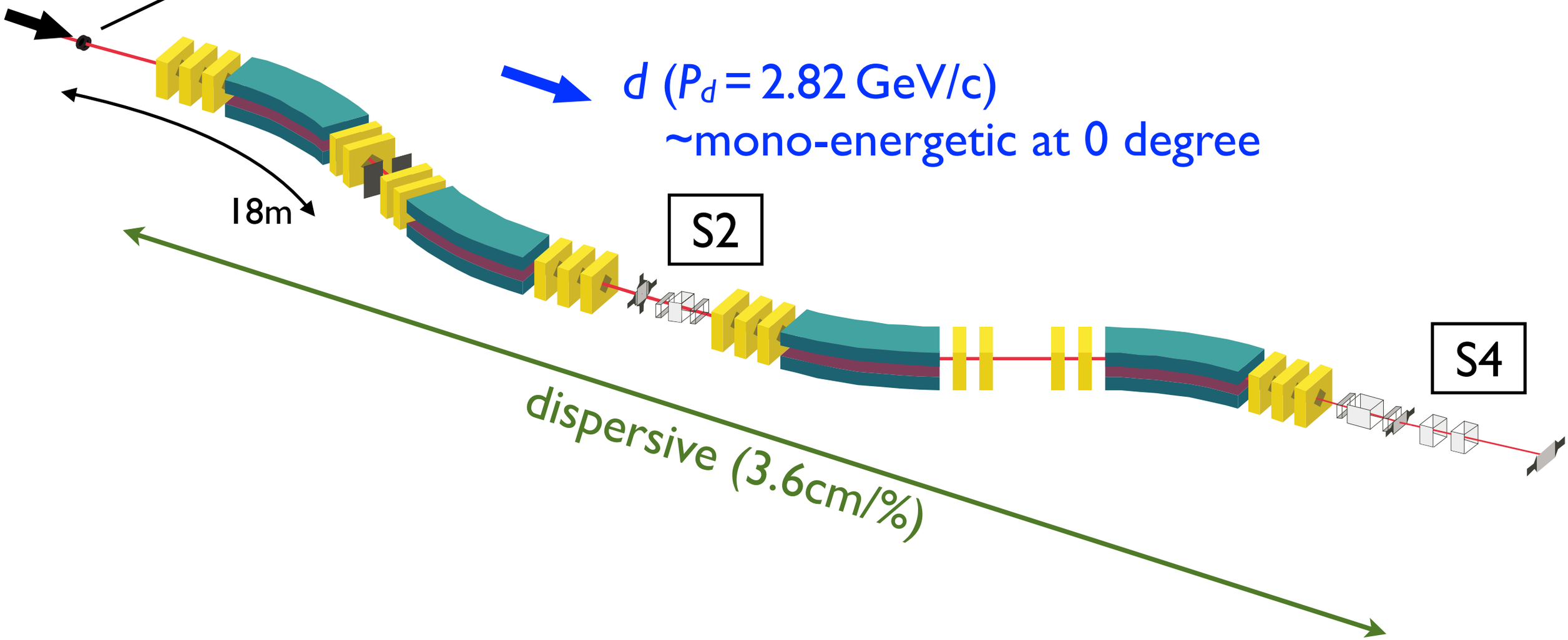
- 7 settings of FRS Bρ from -2% to 2% → -90 MeV < E_{ex}-E_0 < +40 MeV covered
- spectrometer calibration every 6 hours

Calibration Run

D(*p*,*d*)*p* **elastic** scattering
for ~mono-energetic *d*

p (T_p = 1.6 GeV)

CD_2 target (1 g/cm^2)

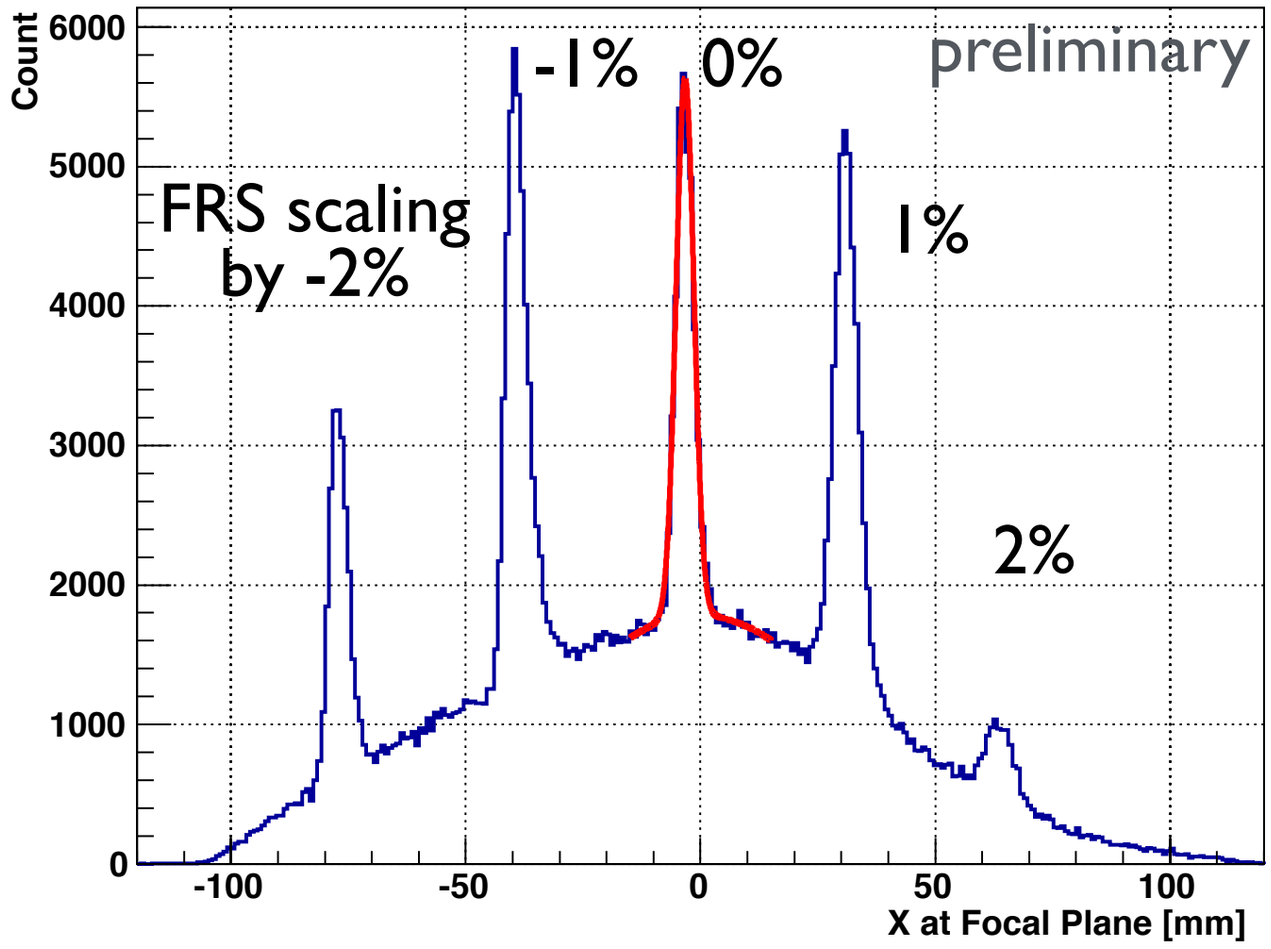


d (P_d = 2.82 GeV/c)
~mono-energetic at 0 degree

Fragment Separator (FRS)

Calibration Run

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



σ_X = 2.7 mm (CD_2 calibration run)

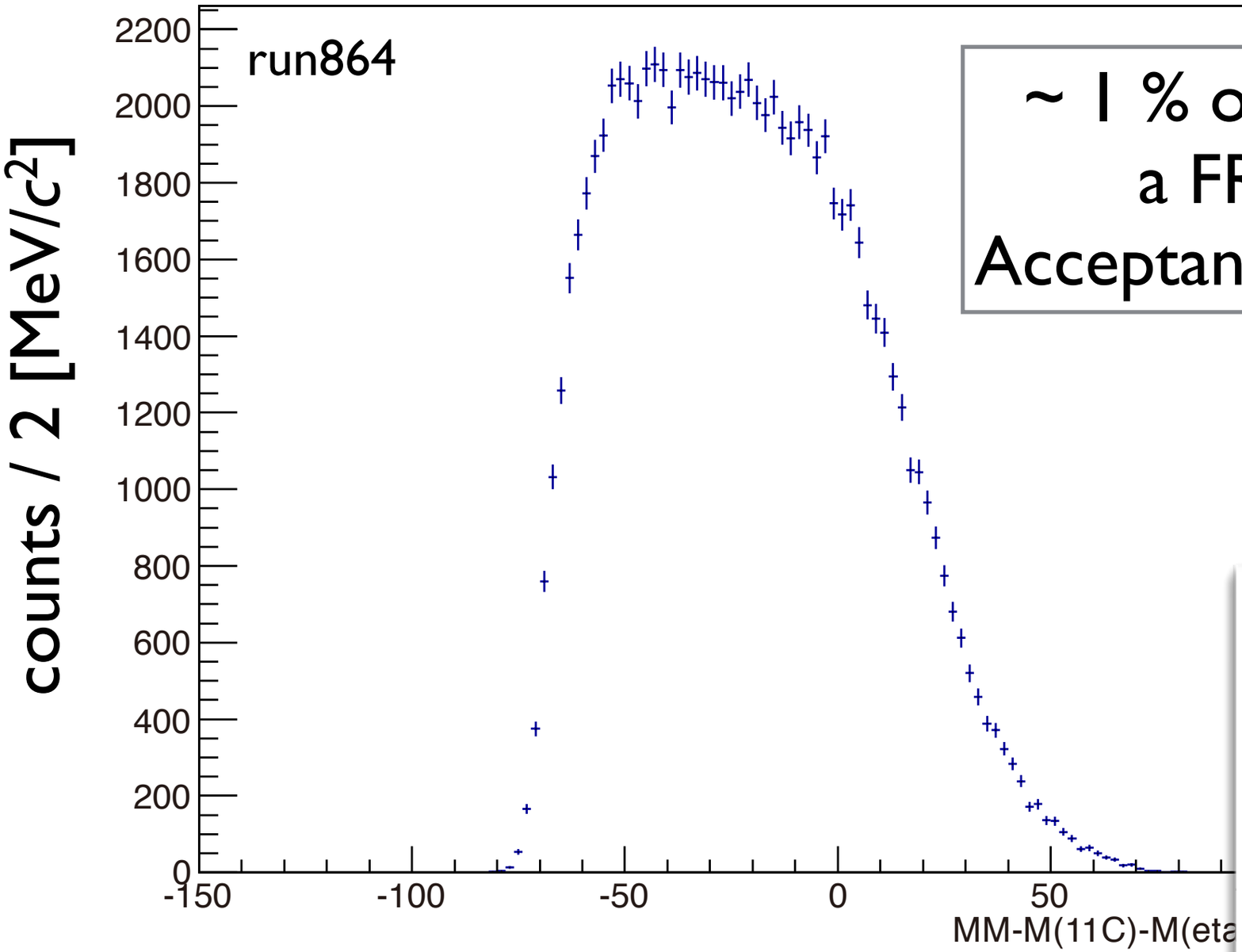
- energy loss and straggling calculation
- spectrometer momentum resolution
- beam momentum spread

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

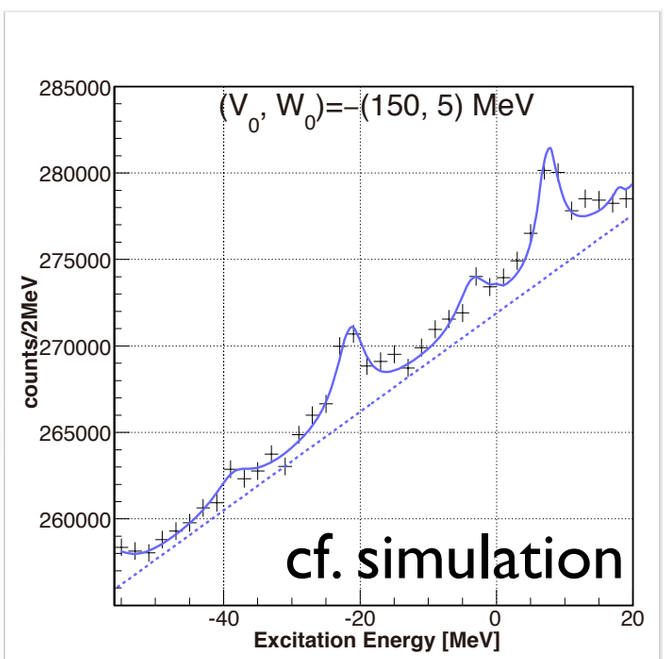
Sample spectrum of a very small part of accumulated data

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

preliminary



~ 1 % of statistics for a FRS setting. Acceptance uncorrected



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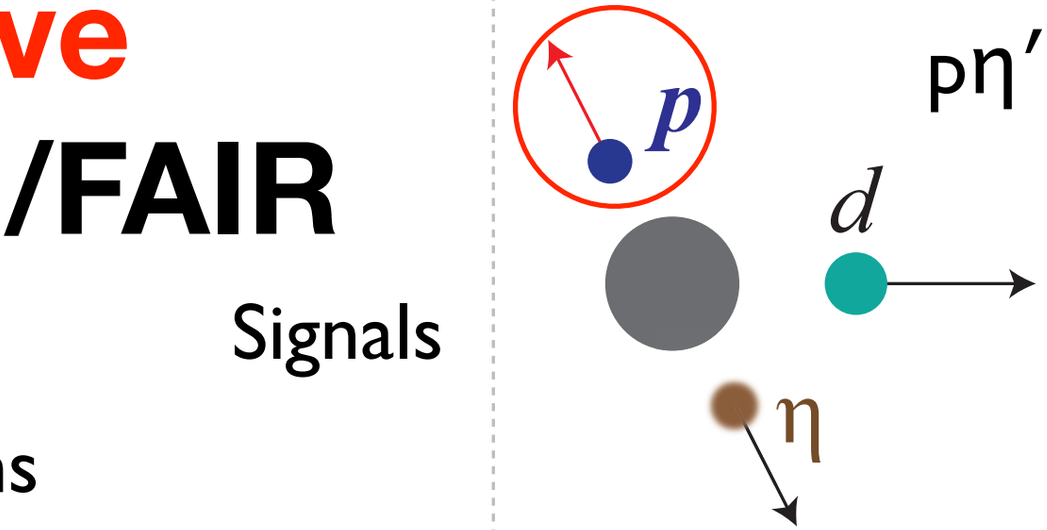
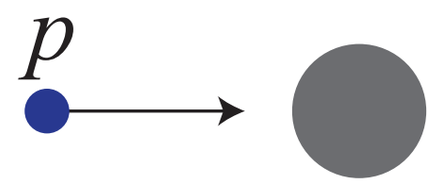
Principles of Exclusive Measurement at GSI/FAIR

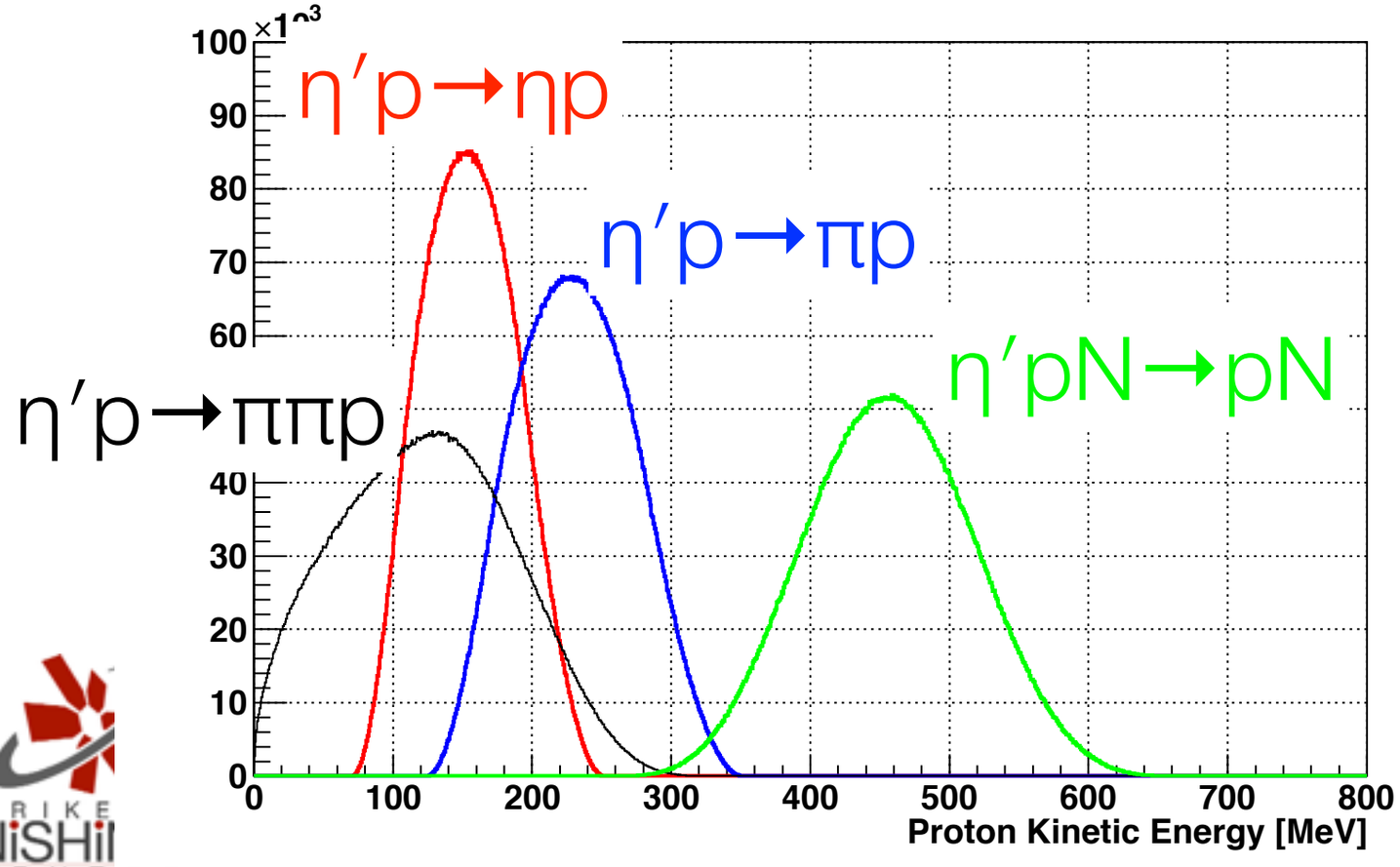
Signals

Tagging high-momentum protons
(300-600 MeV)

Y.K. Tanaka and Y. Higashi

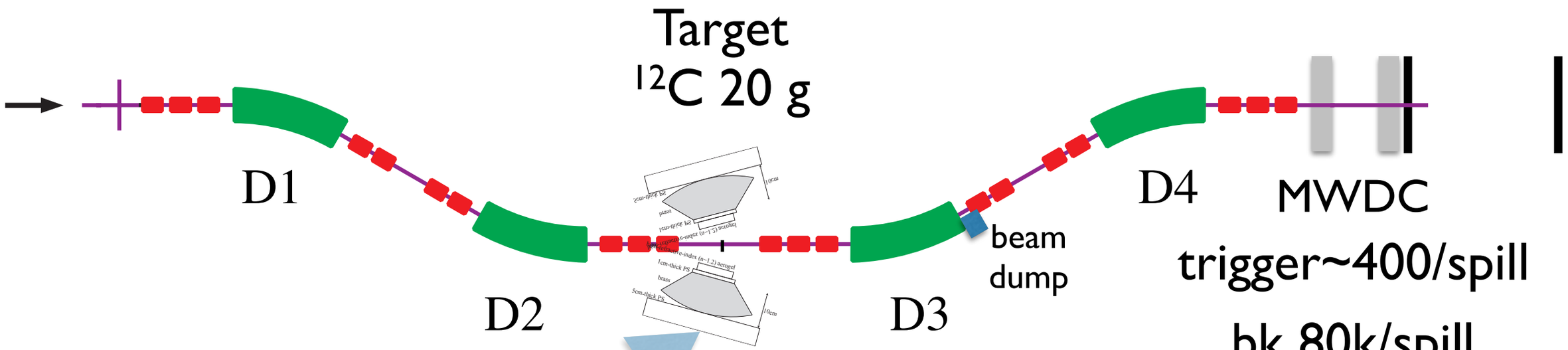






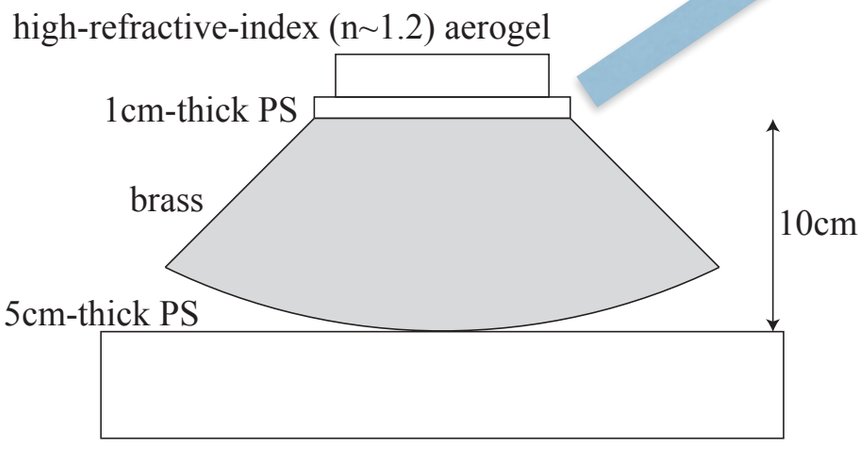
For next step

Pilot run for exclusive measurement at GSI

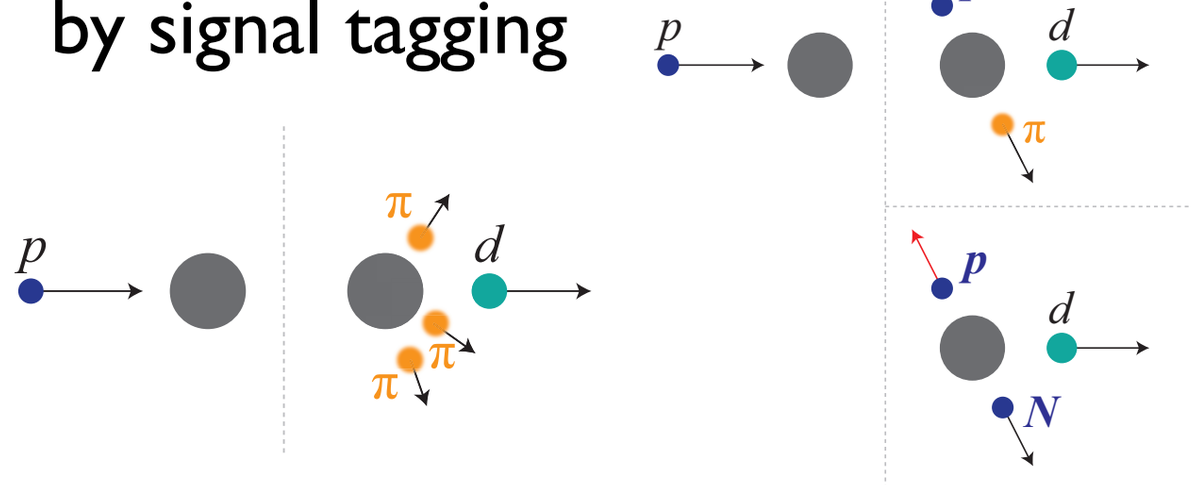


Beam T_p = 2.5 GeV

$I_p > 10^8$/spill



Background suppression by signal tagging



Roadmap for η′

FAIR
GSI

Construction of proton detector

Production exclusive measurement

Systematic study
Decay mode study

S437 analysis

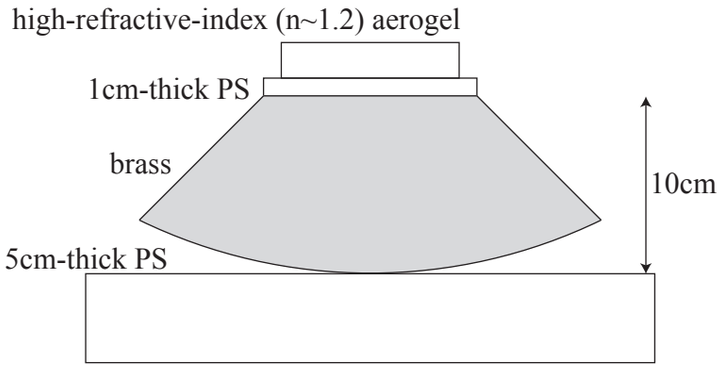
Better stat./Pilot exclusive measurement

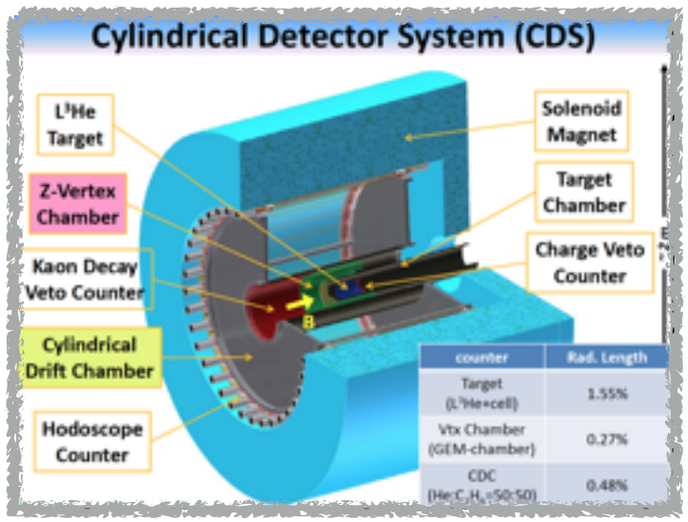
4pi installation

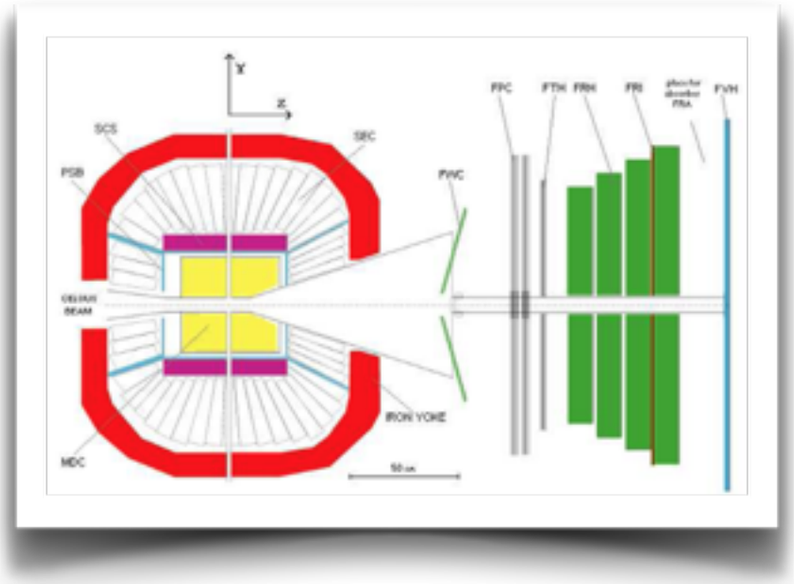
Detector test

4pi detector development

2015 2020 2025







unofficial roadmap (or wishes)

Summary

- Search for η′ meson bound states in ^{11}C by missing mass spectroscopy at GSI/FAIR
- η′ is interesting in relation to $U_A(1)$ anomaly × χ-symmetry
- Just finished first physics run for inclusive (*p*,*d*)
  - PID perfect
  - Successfully accumulated targeted statistics with good resolution ~ 2 MeV/c^2
  - Preparation for semi-exclusive measurement

RIKEN NiSHiNA CENTER