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.

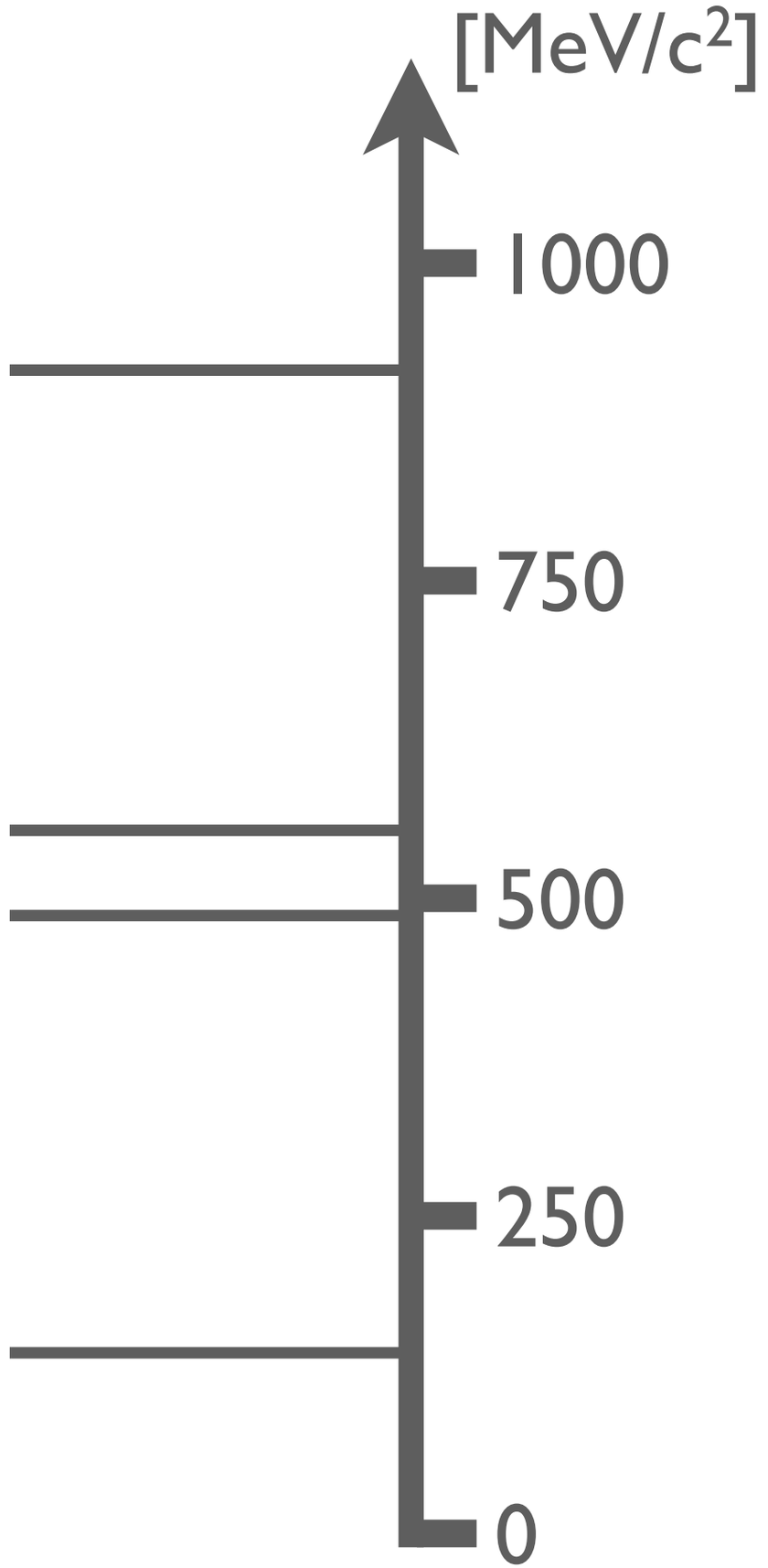
η′ and other PS mesons

η′ M=958 MeV/c^2

η M=548 MeV/c^2

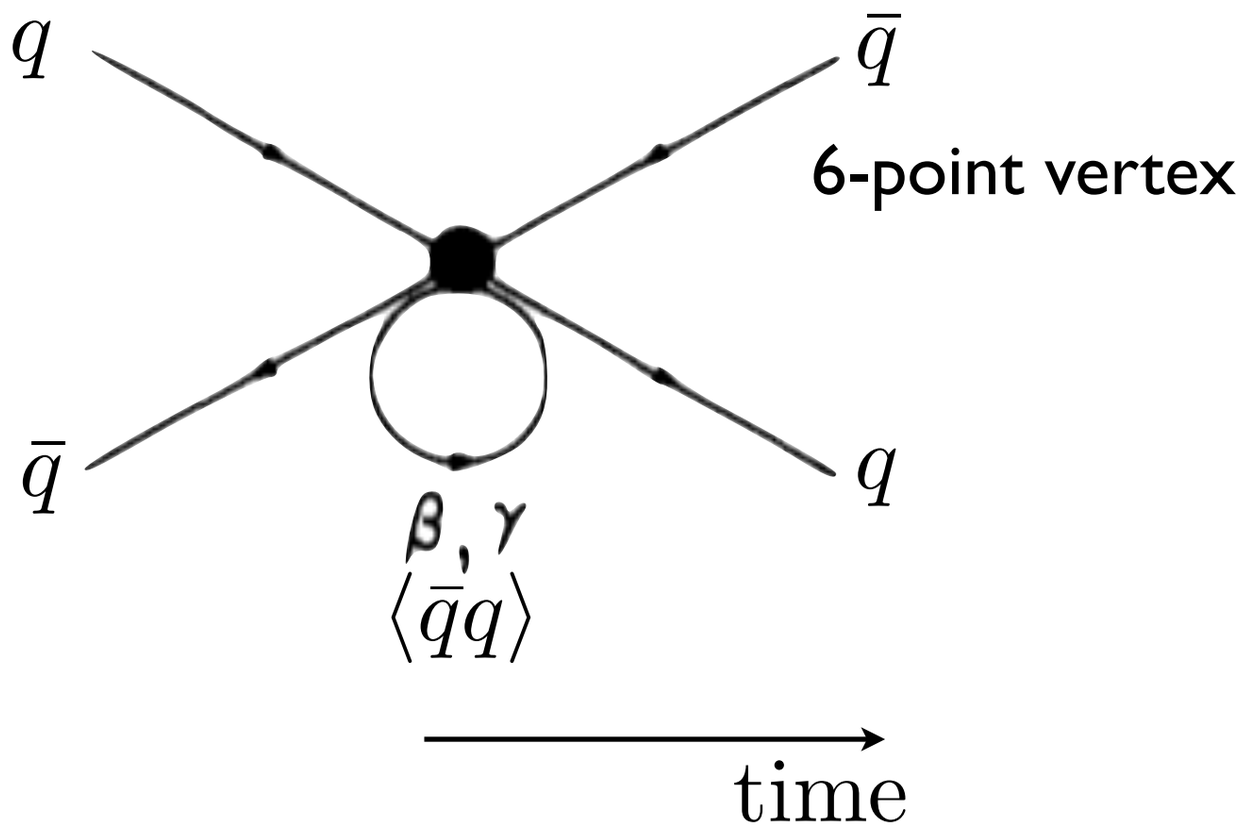
K M=498 MeV/c^2

π M=140 MeV/c^2



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.

In-medium PS mesons

Partial restoration of dynamical breaking of χ symmetry

[MeV/c²]

1000

750

500

250

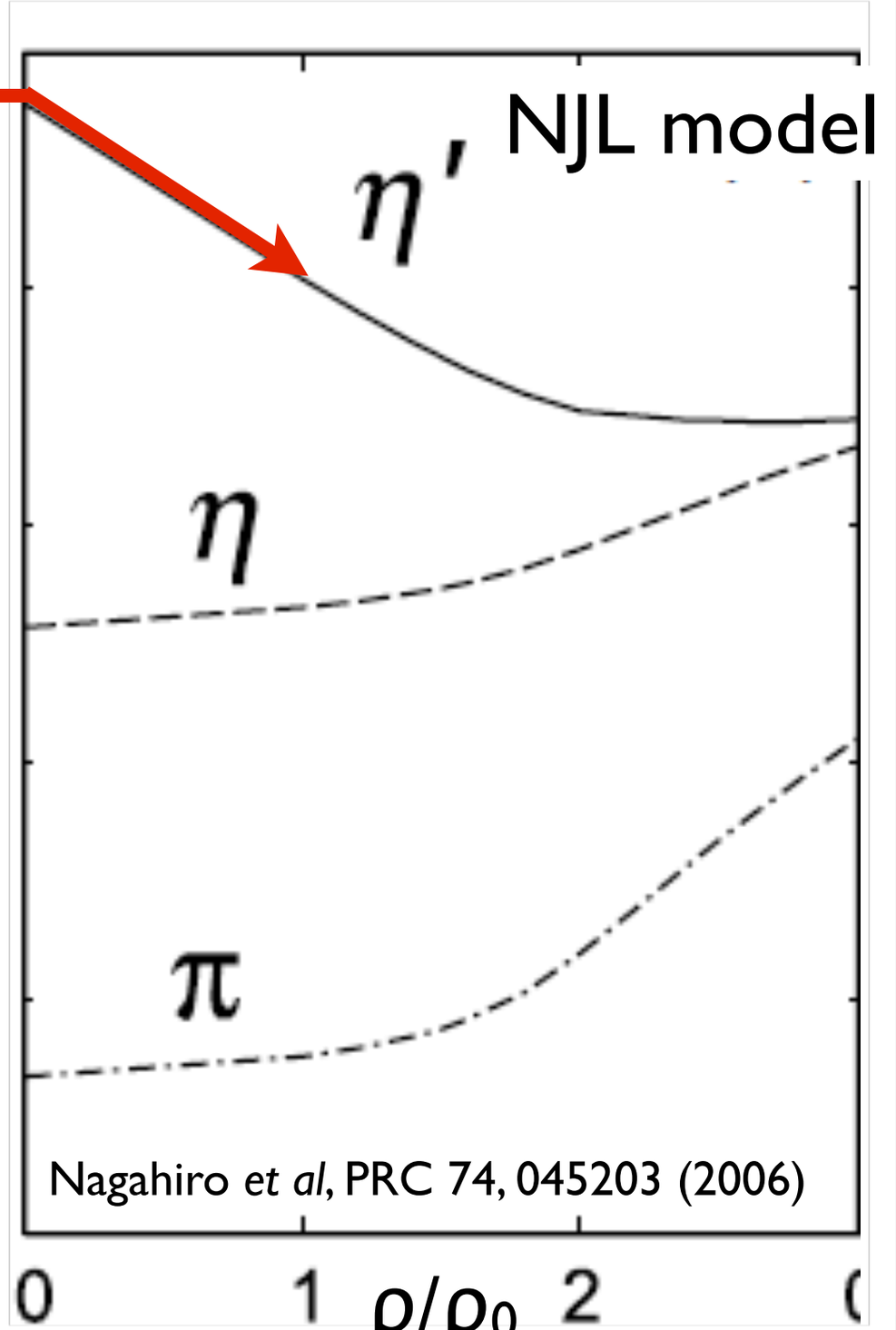
0

η′

η

K

π



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

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In-medium PS mesons

Partial restoration of dynamical breaking of χ symmetry

[MeV/c^2]

1000

750

500

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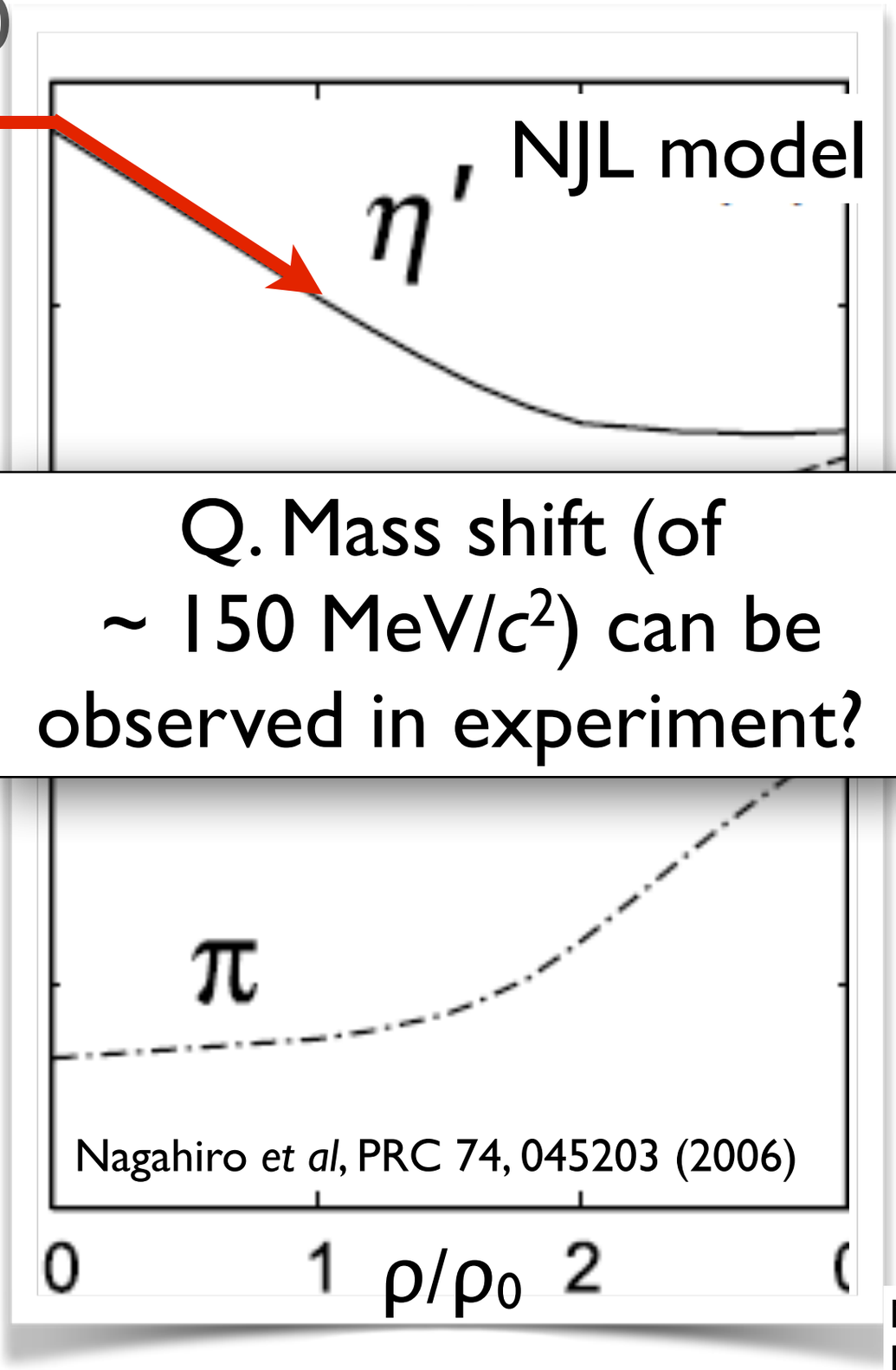
η′

η

K

π



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

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

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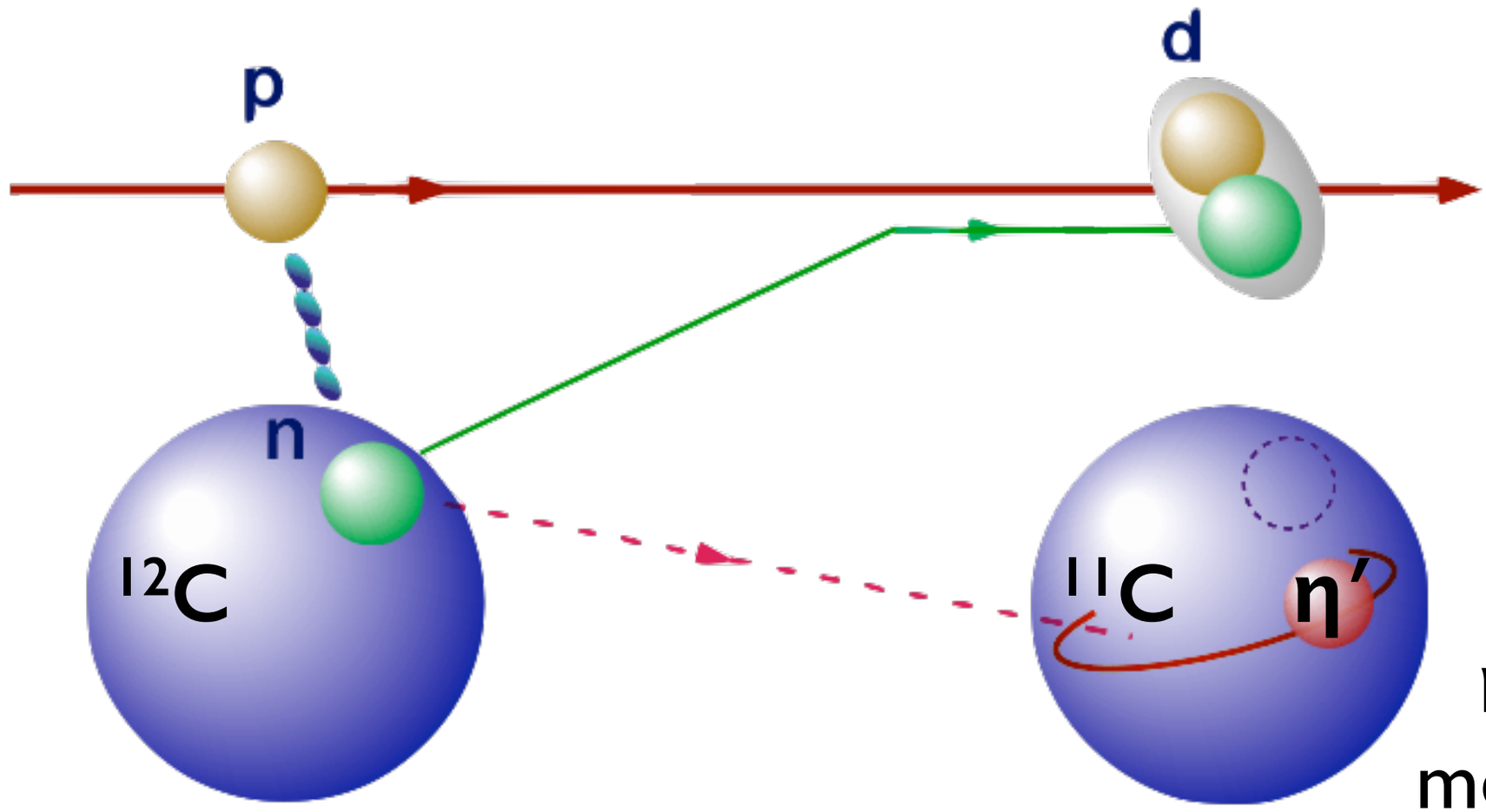
η′ Mesic Nuclei in (*p*,*d*) Reaction

η′ transfer reaction + missing mass measurement

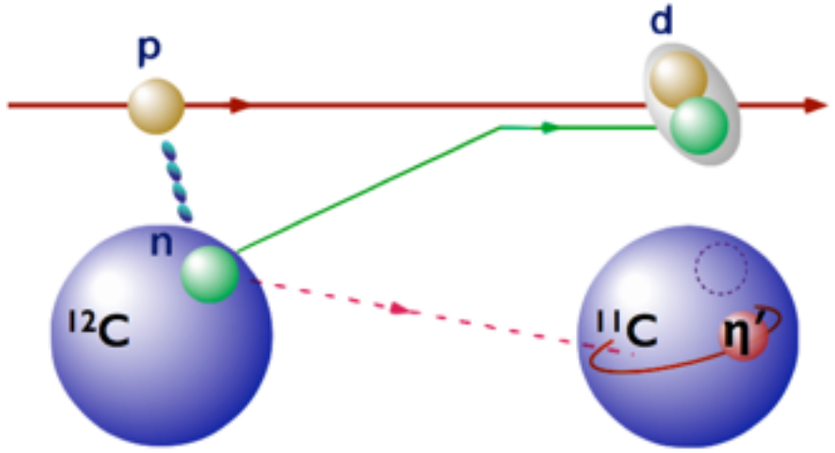


η′ × ^{11}C
mesic nuclei

T_p = 2.50 GeV → q ~ 400 MeV/c

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

Theoretical Prediction

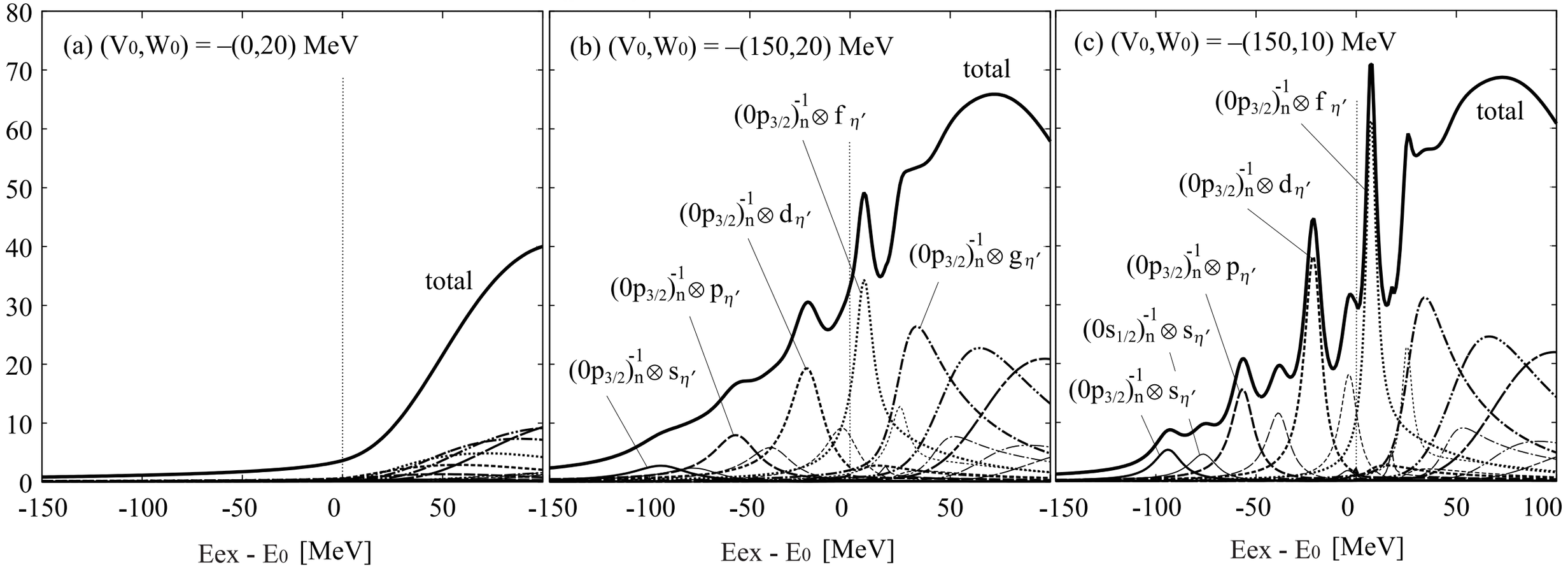


η′-nucleus potential:

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

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

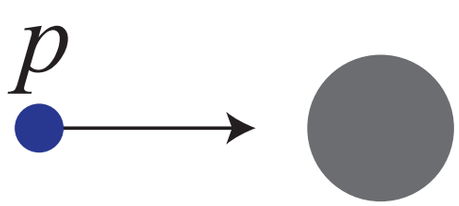
^{12}C(*p*,*d*) at T_p = 2.50 GeV

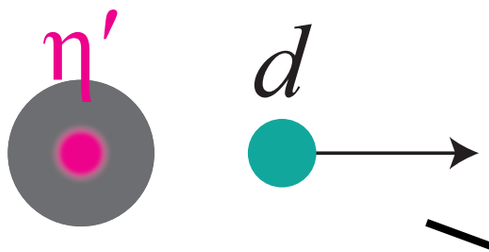


Nagahiro et al., PRC87(13)045201.

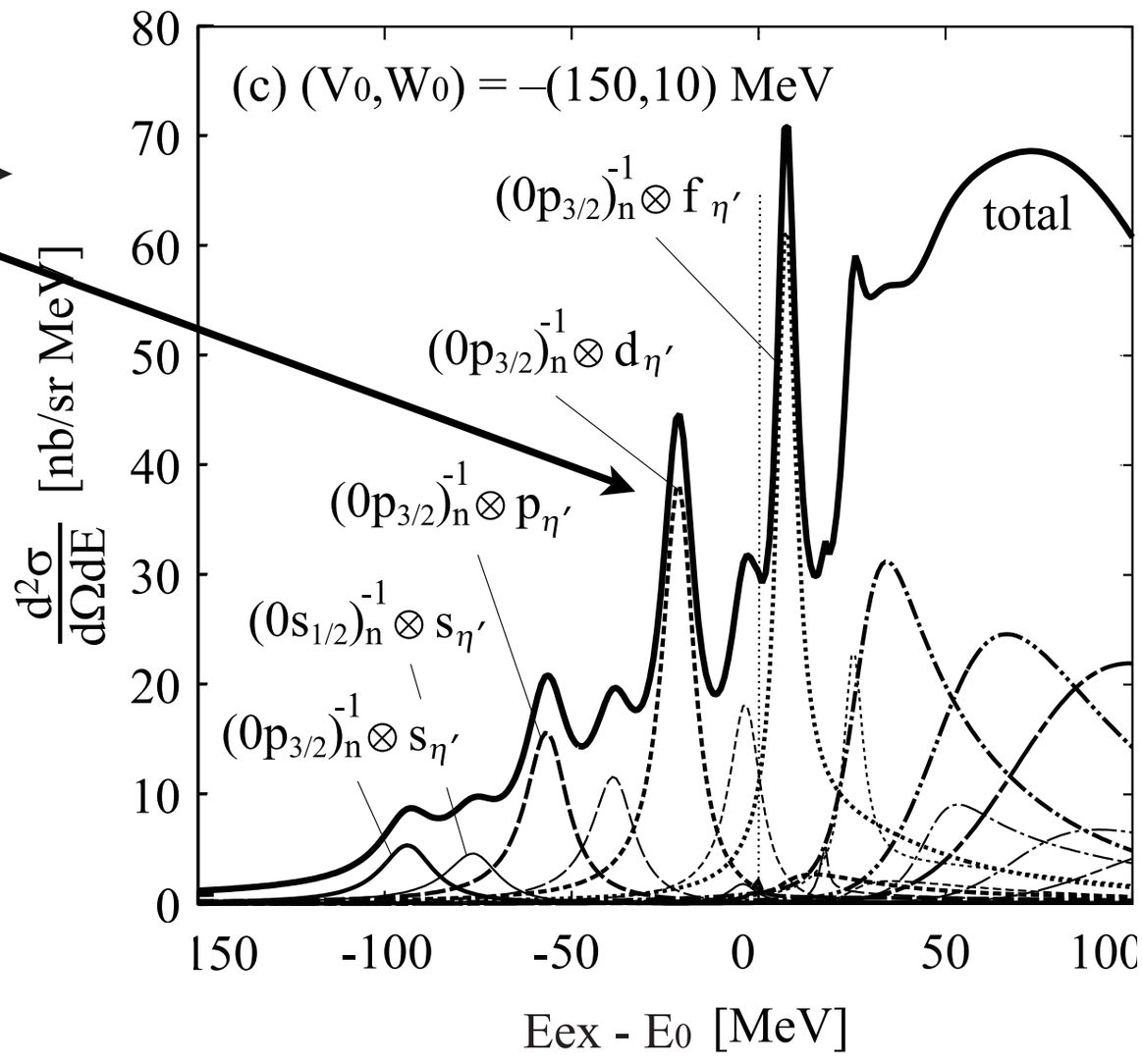
Spectrum in Inclusive Measurement at GSI

Signal





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



Nagahiro et al., PRC87(13)045201.

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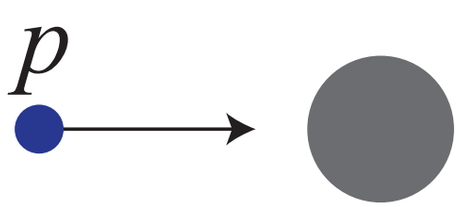
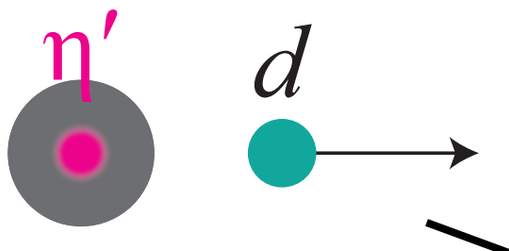
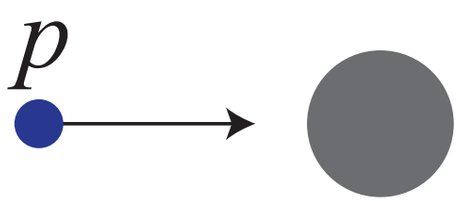
Spectrum in Inclusive Measurement at GSI

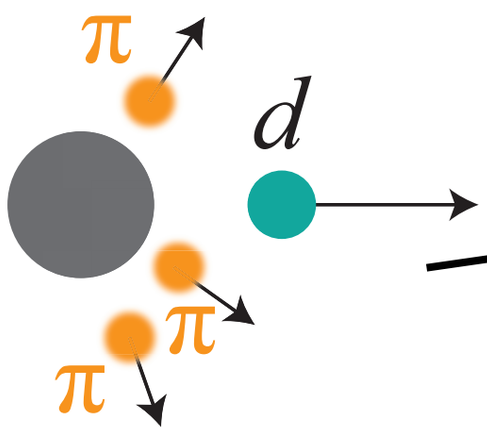
Signal



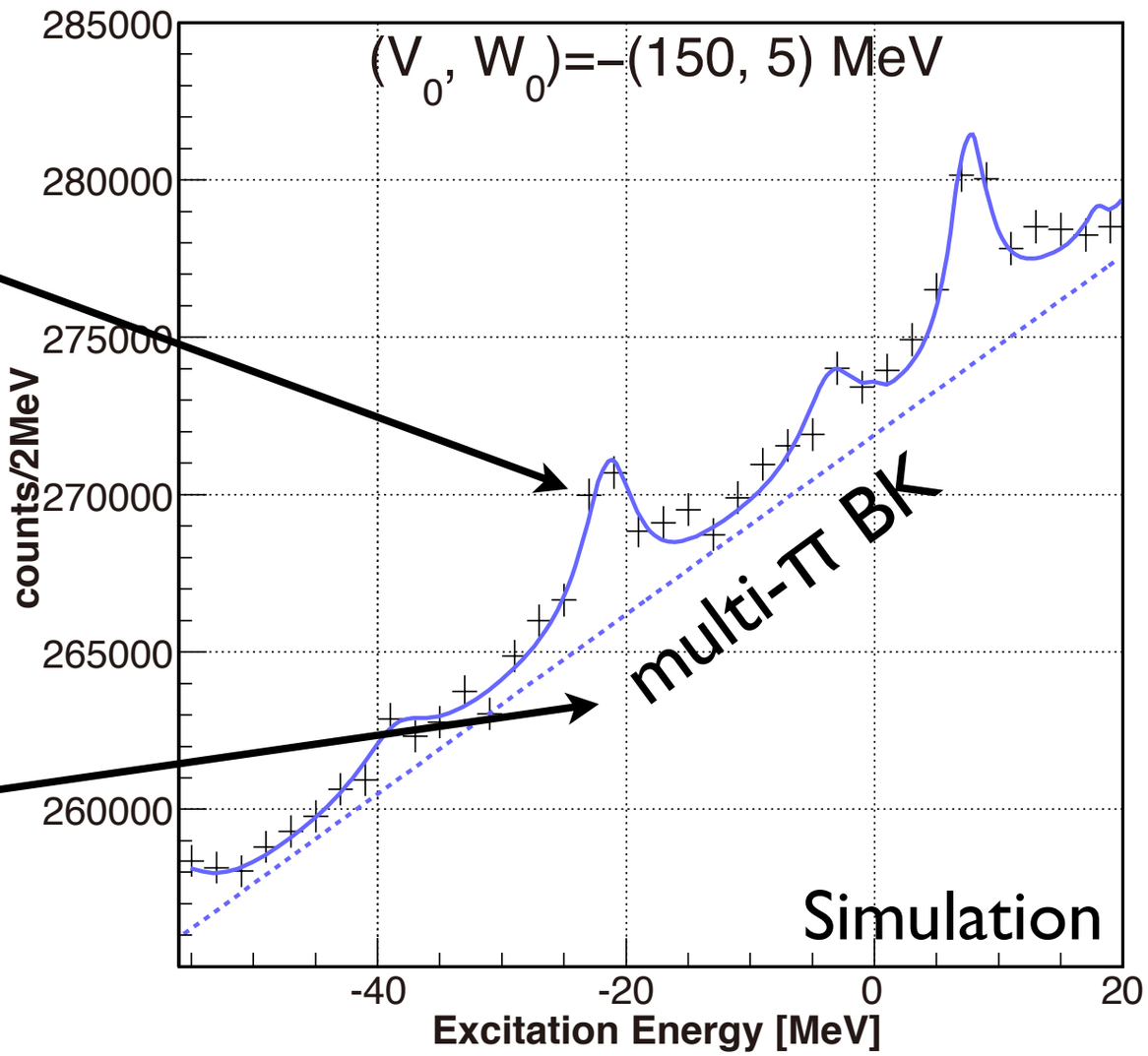


Background





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



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

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Step-by-step approach

	Measurement	Objectives	S/N
GSI	(*p*,*d*) inclusive	extremely good statistics for overall structure + BK study	poor
GSI/FAIR Day 1	(*p*,*dp*) exclusive*	extended sensitivity for excited + ground states	good
FAIR Day≧1	(*p*,*dx*) exclusive*	exclusive + decay mode studies	good

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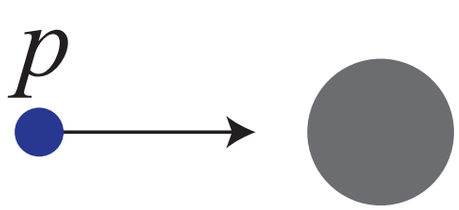
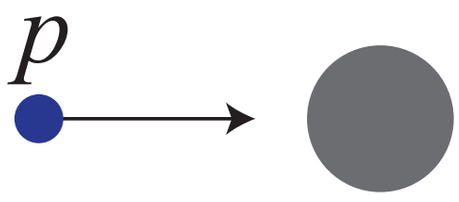
Principles of Exclusive Measurement at GSI/FAIR

HYP 2015

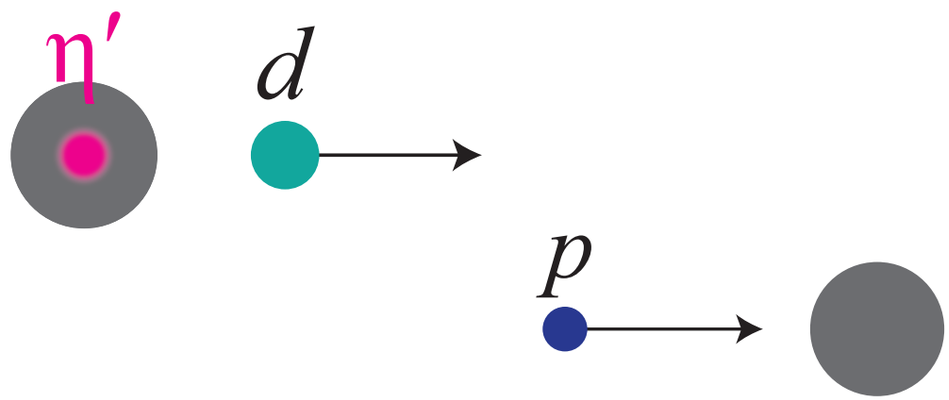
Signal

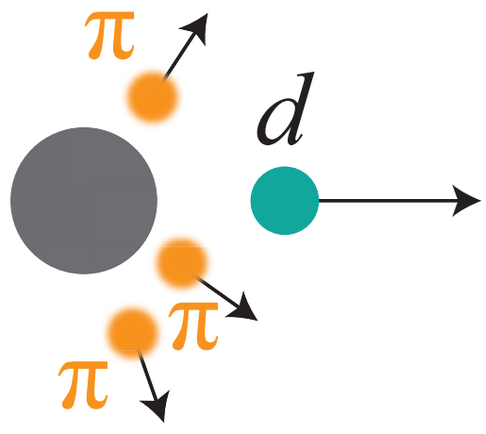


Background

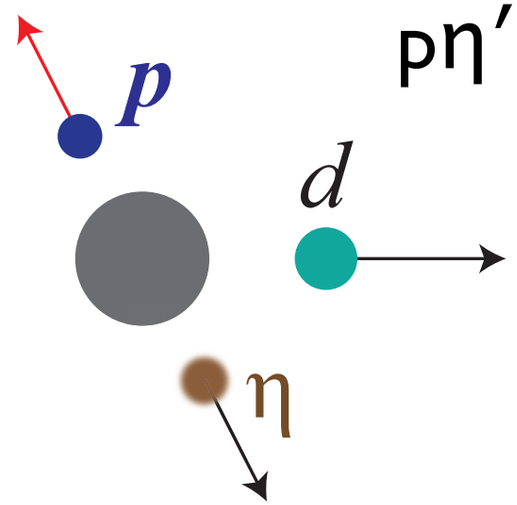


Signals

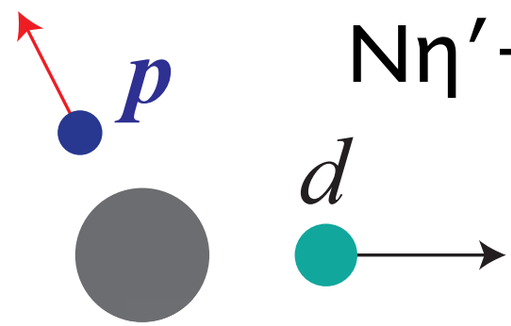




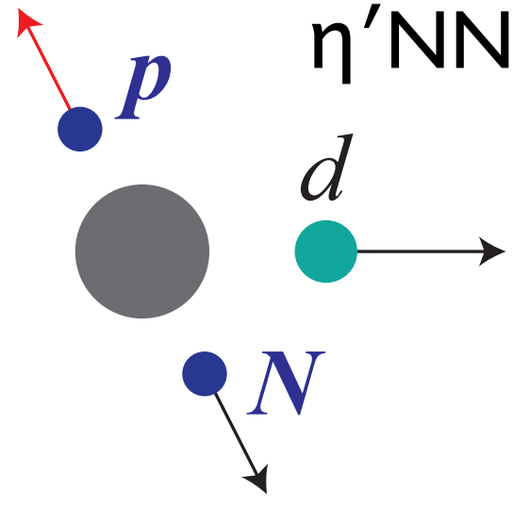
pη′→pη



Nη′→pπ



η′NN→pN



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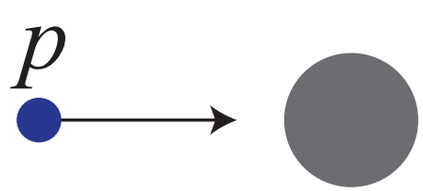
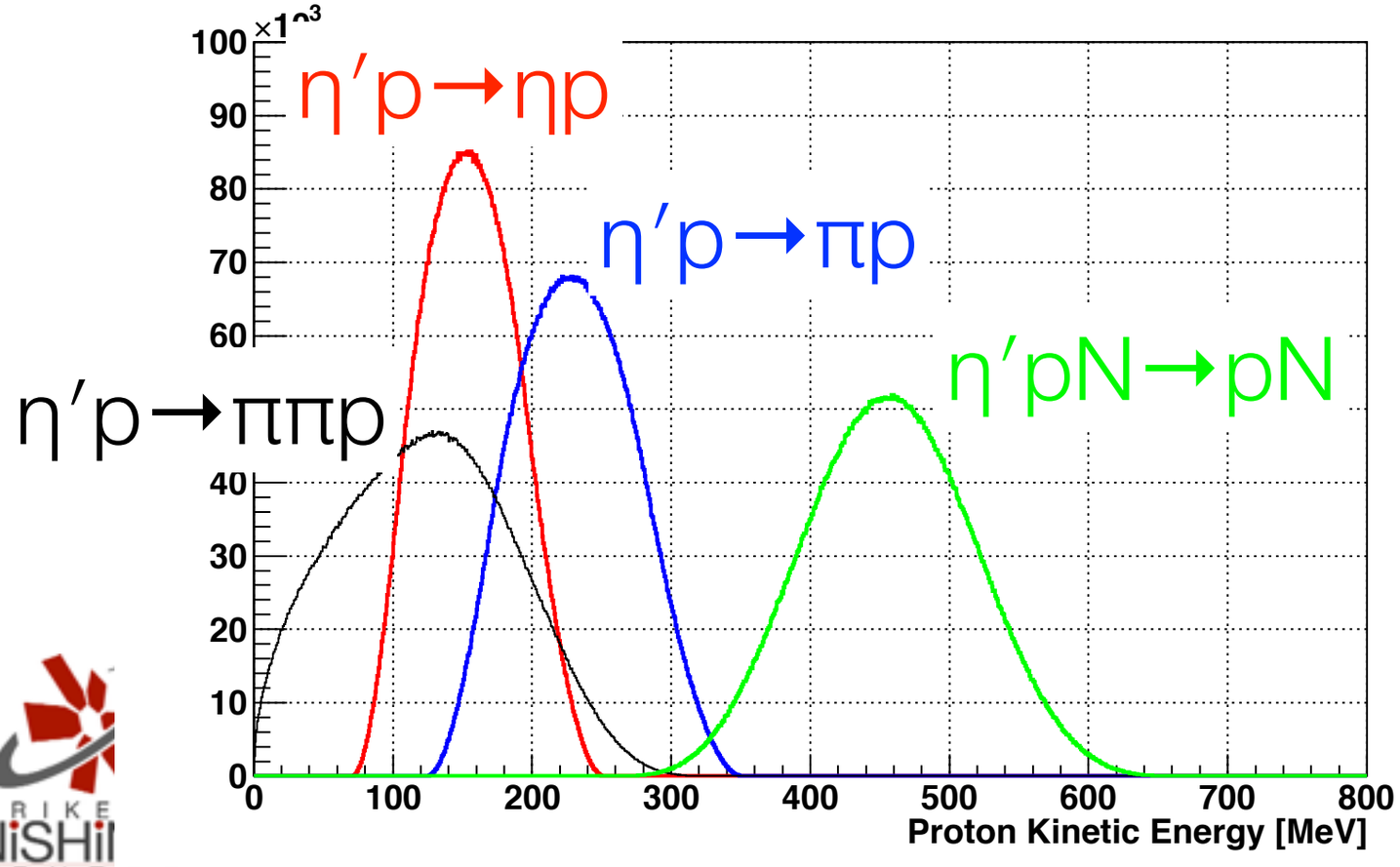
Principles of Exclusive Measurement at GSI/FAIR

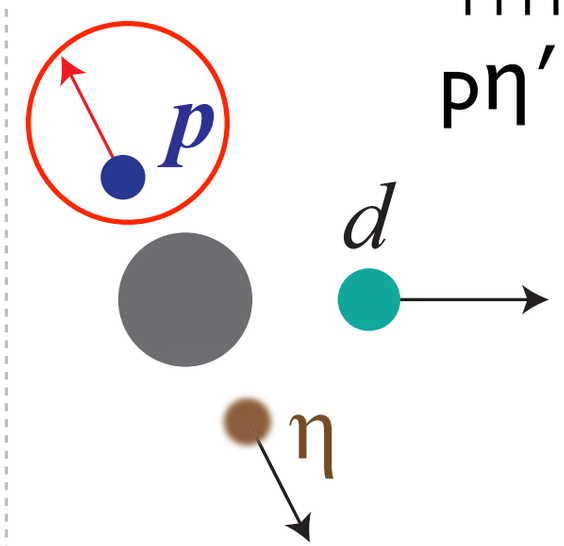
Signals

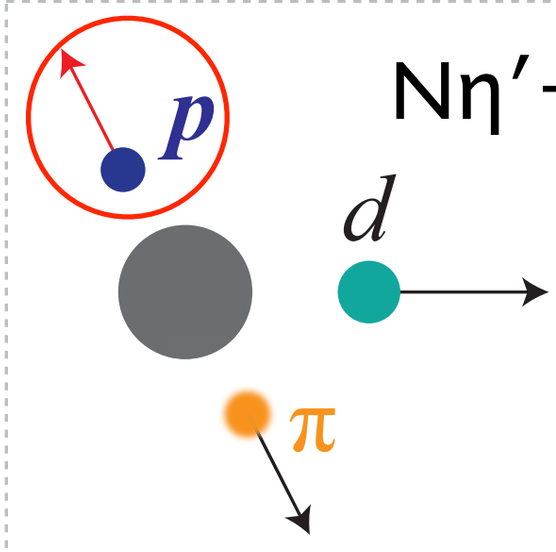
Tagging high-momentum protons
(300-600 MeV)

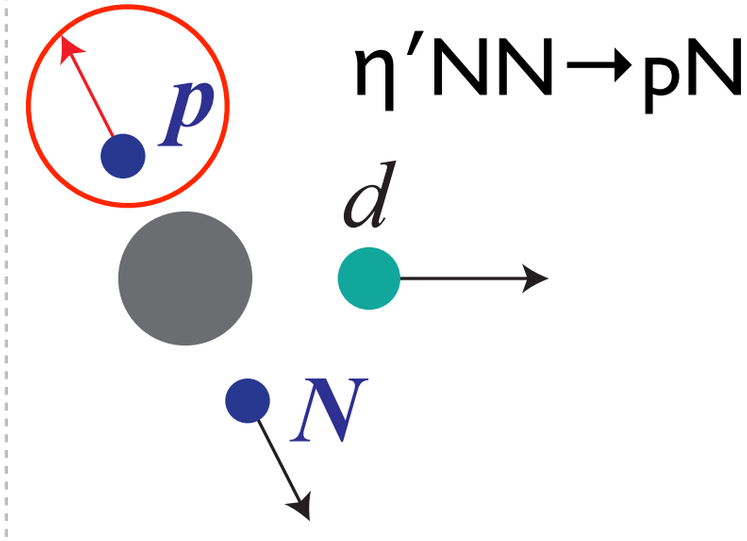
Y.K. Tanaka and Y. Higashi











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FAIR Day≧1	(*p*,*dx*) exclusive*	exclusive + decay mode studies	good

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First step

Inclusive measurement GSI SIS-S437 in 2014/Aug

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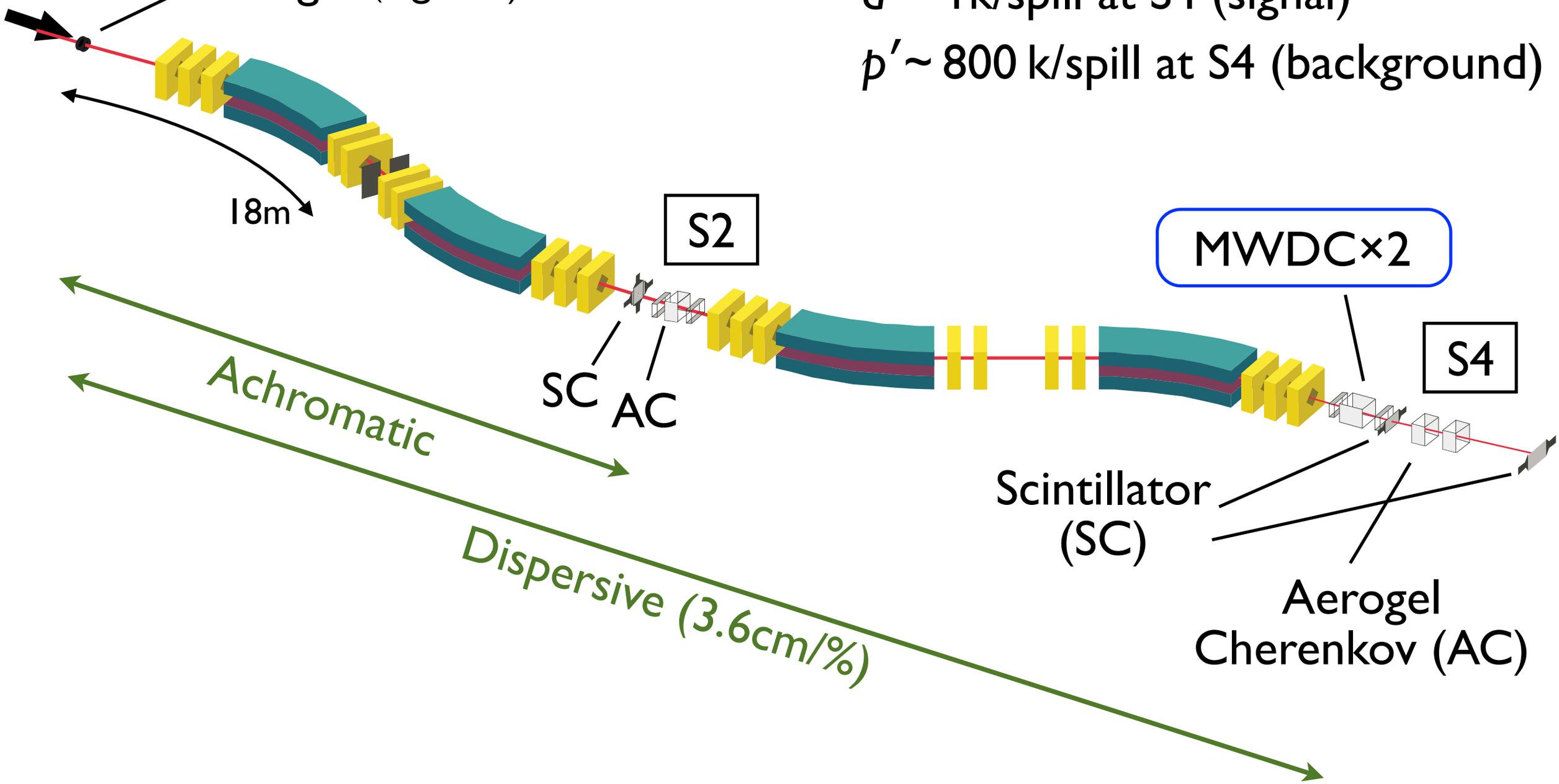
Production setup at FRS

p beam (T_p = 2.5 GeV)

^{12}C target (4 g/cm^2)

d ~ 4 k/spill at S4 (signal)

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



Fragment Separator (FRS)

Production setup at FRS

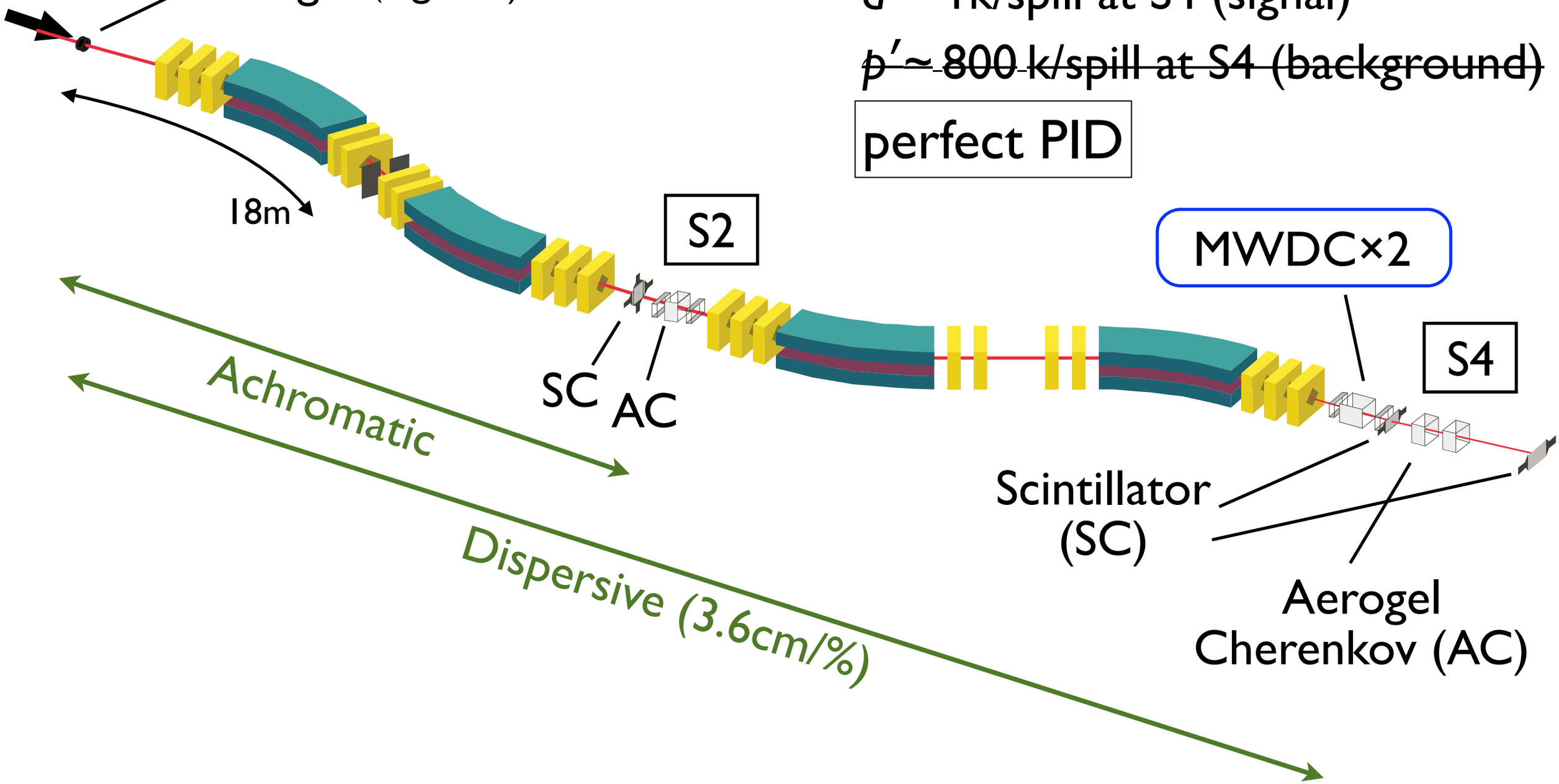
p beam (T_p = 2.5 GeV)

^{12}C target (4 g/cm^2)

d ~ 4 k/spill at S4 (signal)

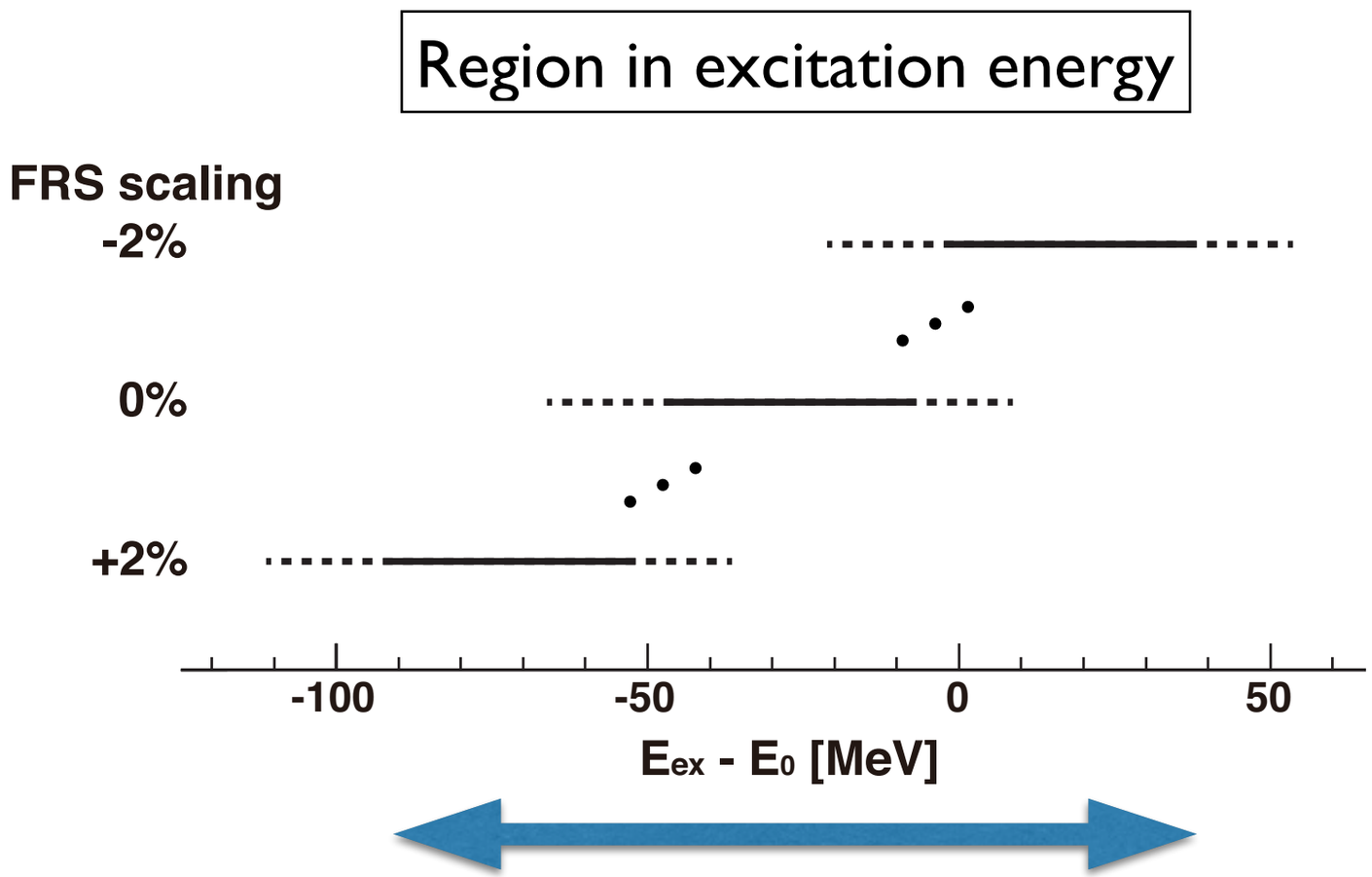
~~p' ~ 800 k/spill at S4 (background)~~

perfect PID



Fragment Separator (FRS)

Spectrometer settings for wide mass region



Production run (~ 5 days)

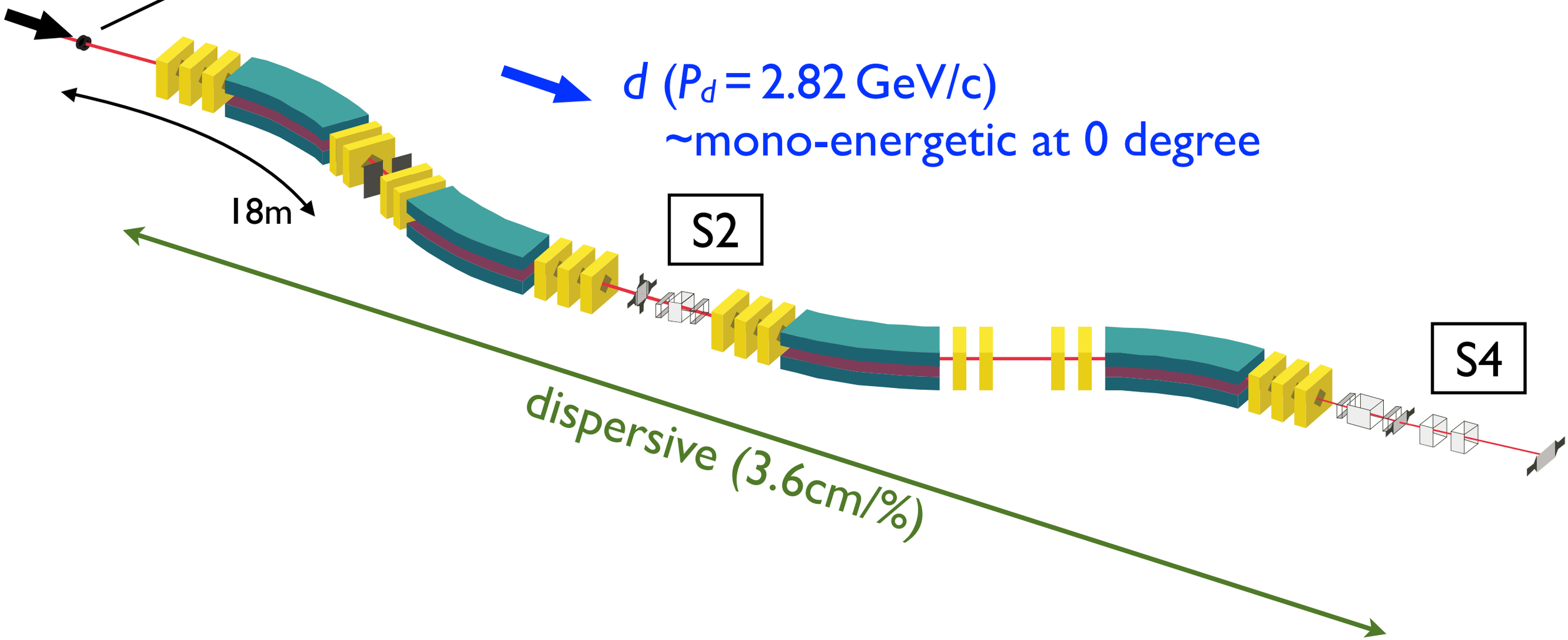
- 7 settings of FRS Bρ from -2% to 2% → -90 MeV < E_{ex}-E_0 < +40 MeV covered
- spectrometer calibration every 6 hours

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)

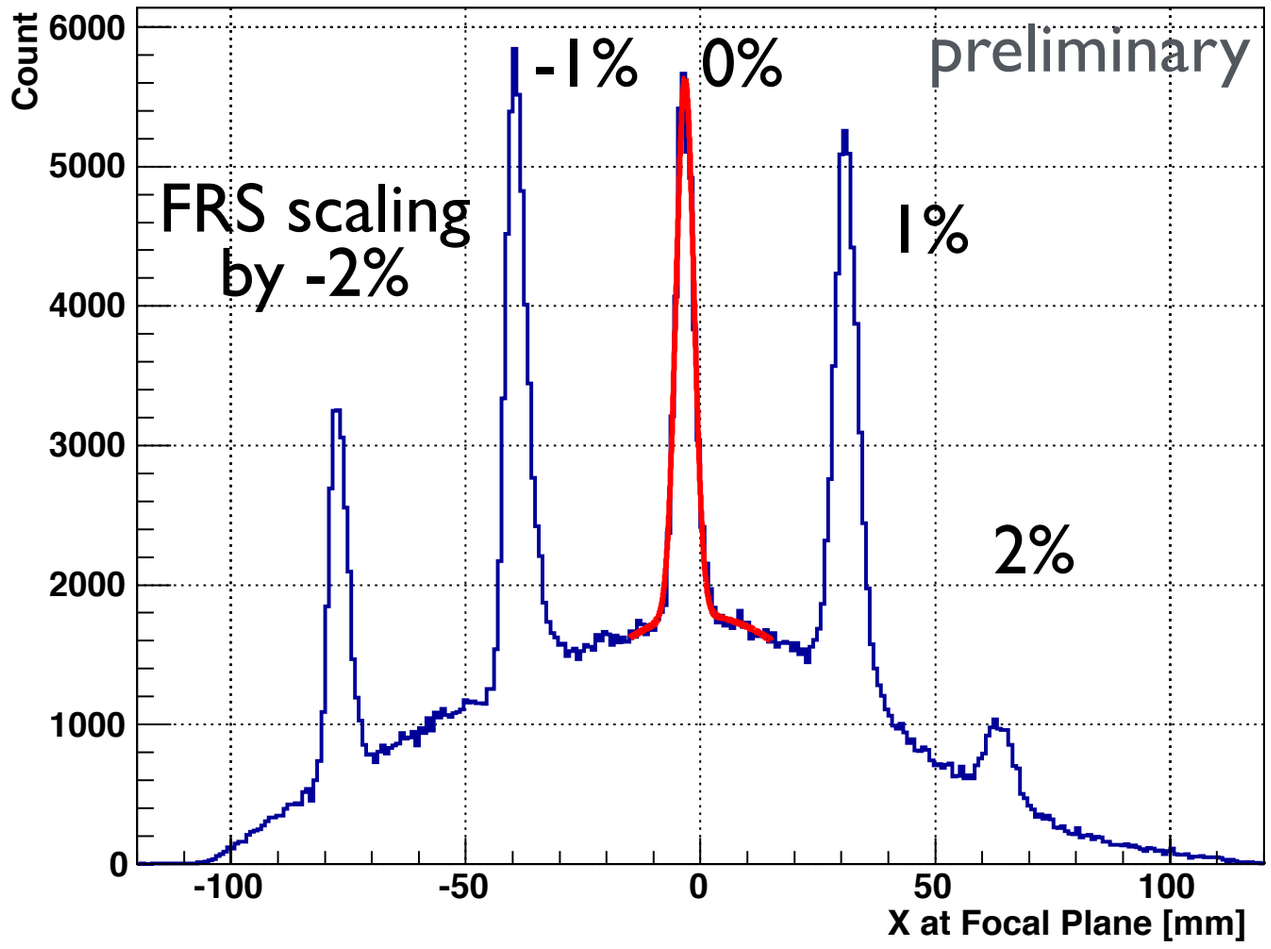


d (P_d = 2.82 GeV/c)
~mono-energetic at 0 degree

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)

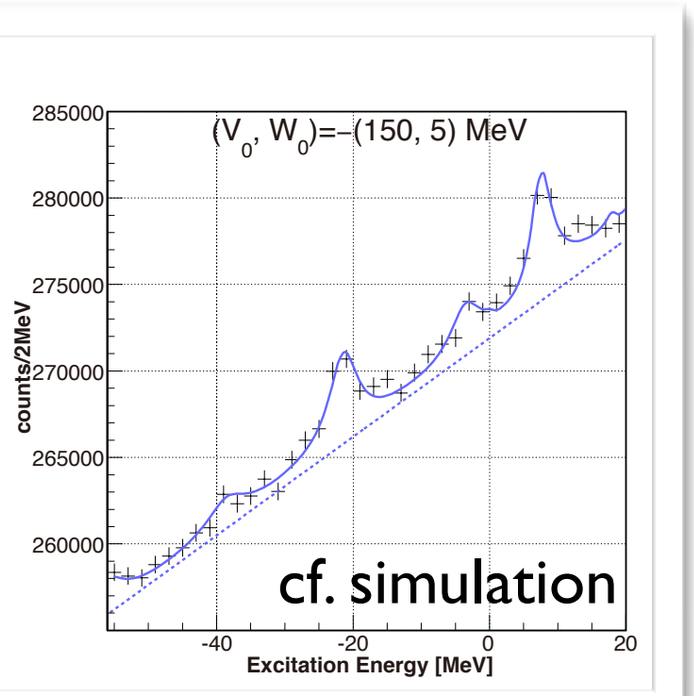
Sample spectrum of a very small part of accumulated data

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

run864

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

counts / 2 [MeV/c^2]



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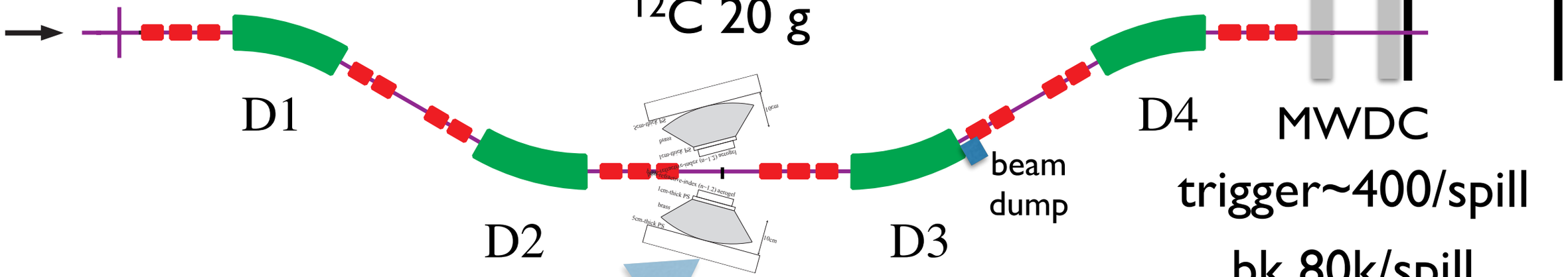
For next step

Pilot run for exclusive measurement at GSI

Scintillators

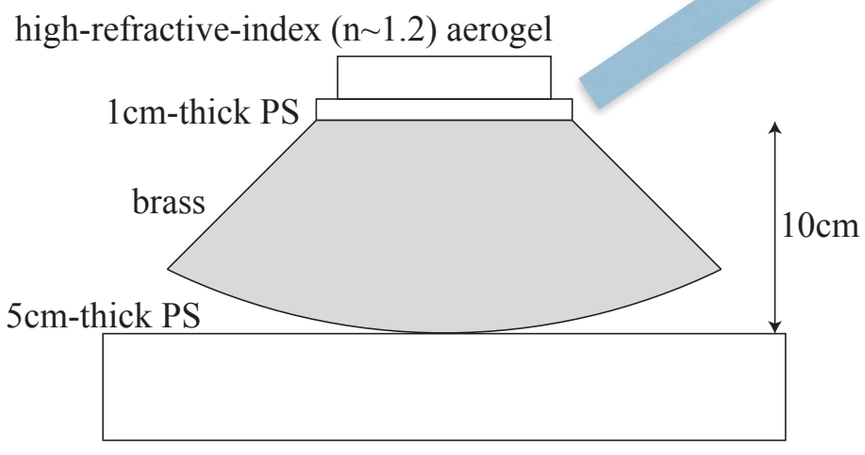
Target
^{12}C 20 g



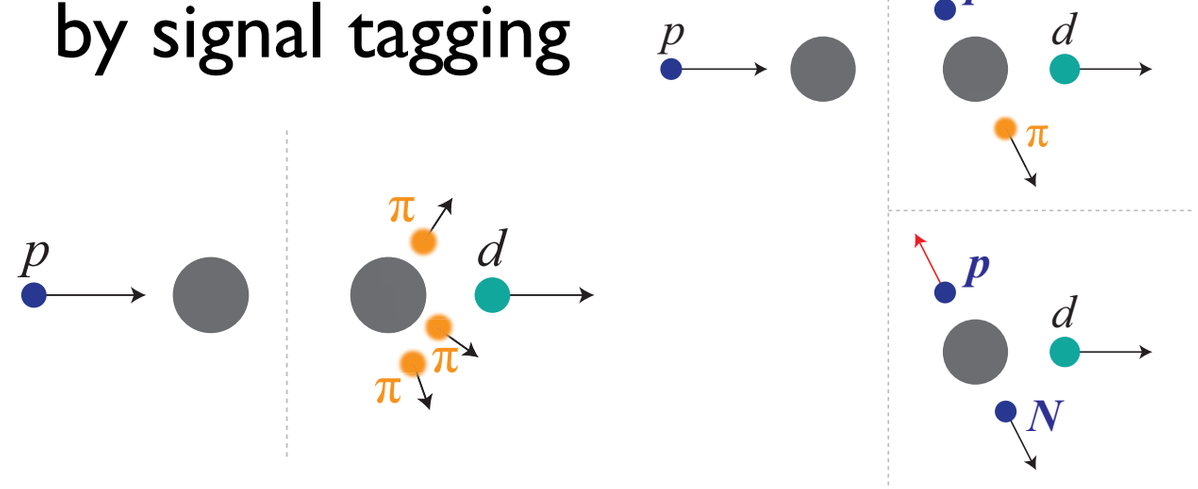
trigger~400/spill

bk 80k/spill

Beam T_p = 2.5 GeV
$I_p > 10^8$/spill



Background suppression
by signal tagging



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Roadmap for η′

HYP 2015

FAIR

GSI

Construction of proton detector

Production exclusive measurement

Systematic study
Decay mode study

S437 analysis

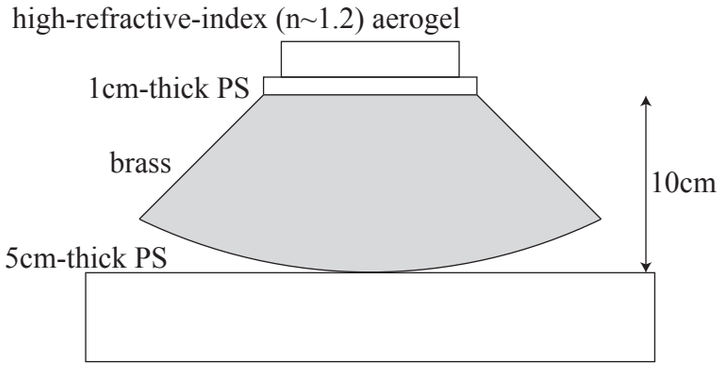
Better stat./Pilot exclusive measurement

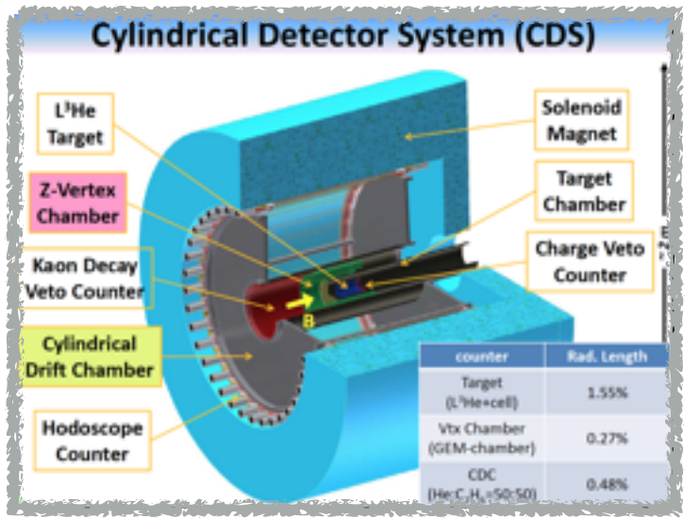
4pi installation

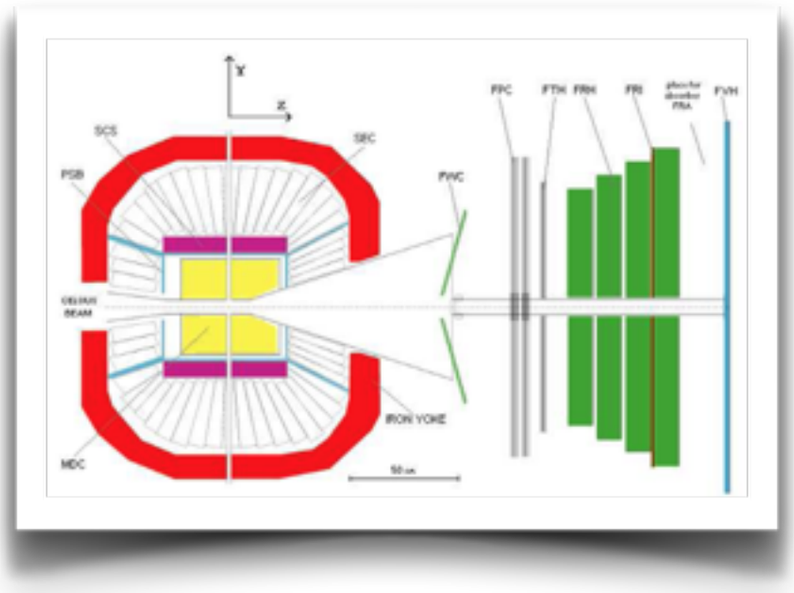
Detector test

4pi detector development

2015 2020 2025 2030







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

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