Spectroscopy of η′-nucleus bound states at GSI-SIS

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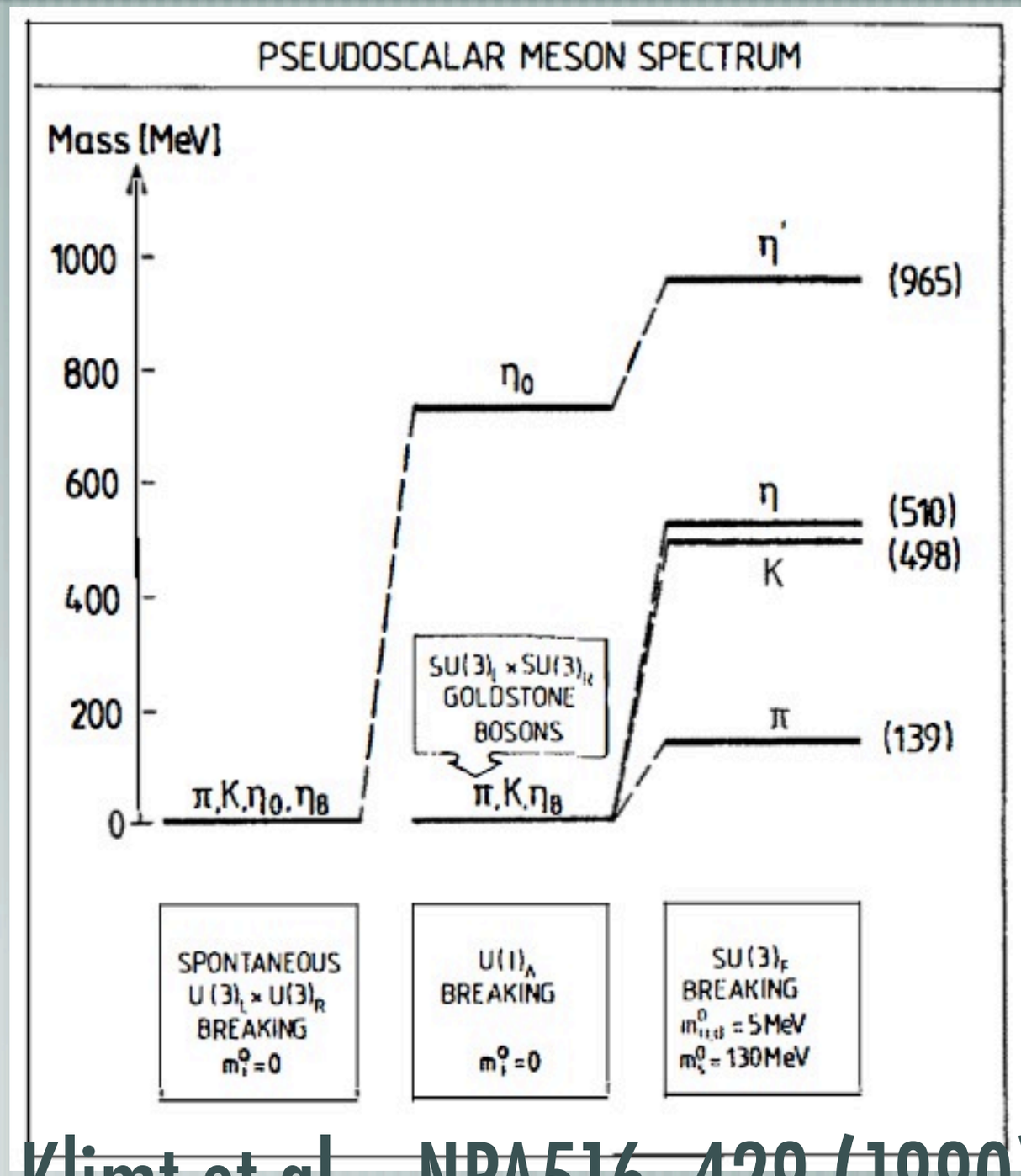
for the η-PRiME collaboration

京都大学 KYOTO UNIVERSITY

MESON 2012

η′ meson

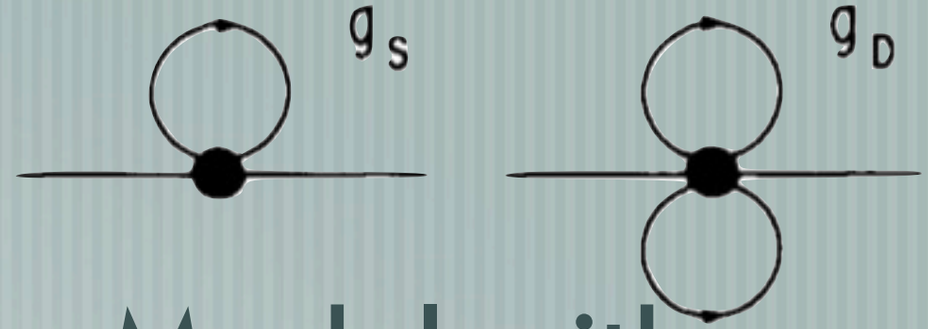
- peculiarly large mass (958MeV) because of $U_A(1)$ anomaly in QCD
- Anomaly effect is related to quark condensate
  - Jido, Nagahiro, and Hirenzaki, PRC85, 032201(R) (2012)
  - Lee and Hatsuda, PRD 54, 1871 (1996)



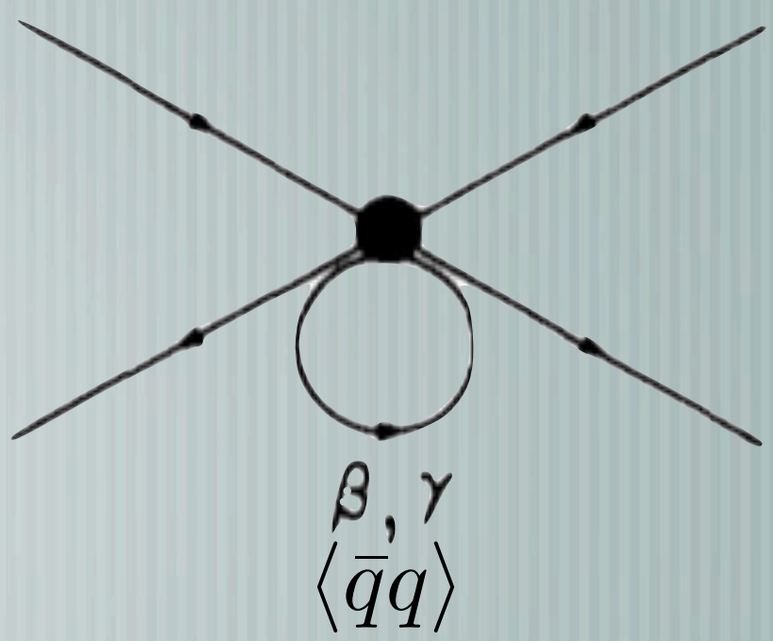
Klimt et al. , NPA516, 429 (1990)

in-medium η′ mass

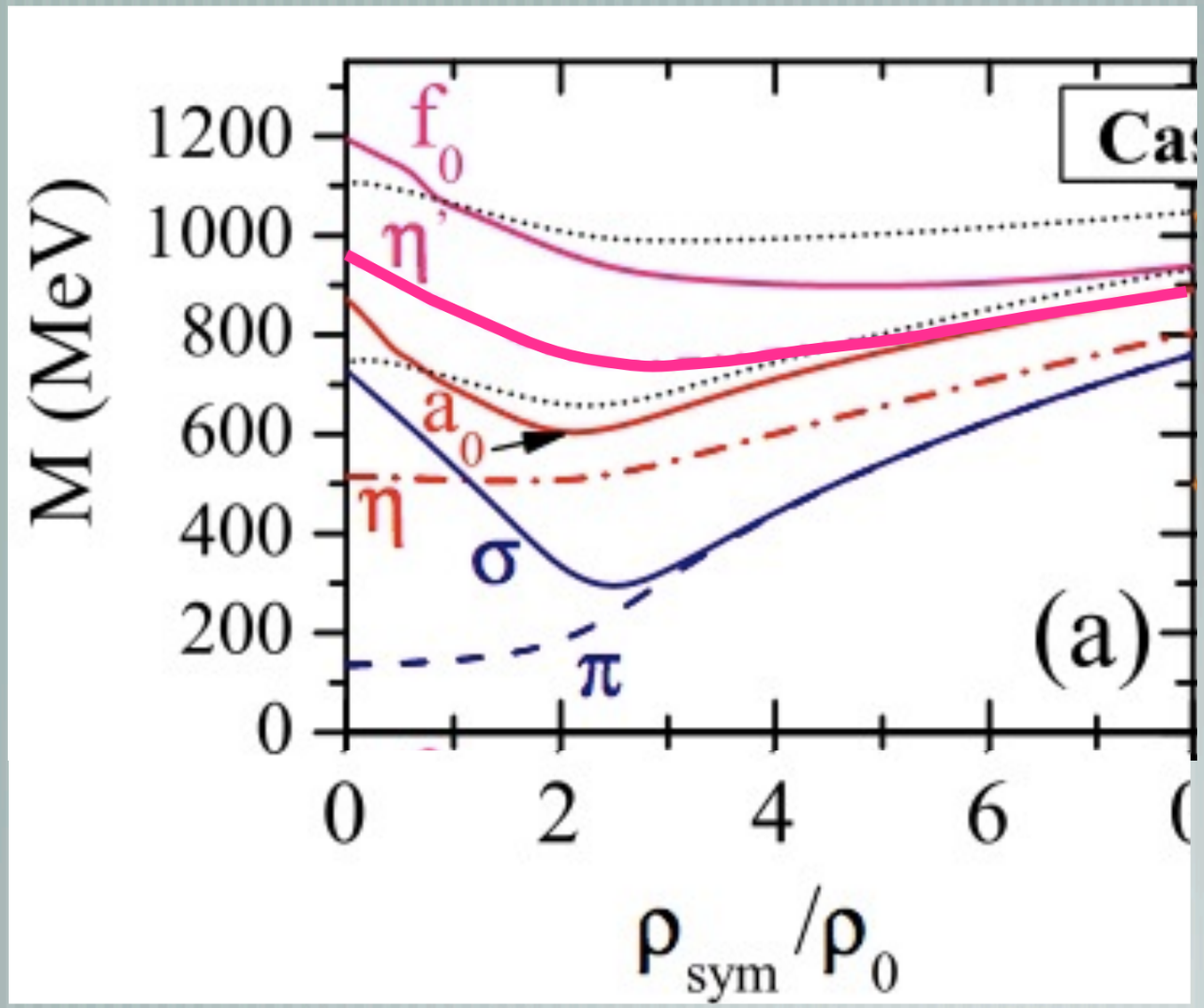
- calculated by the Nambu–Jona-Lasinio Model with the Kobayashi–Maskawa–'t Hooft term



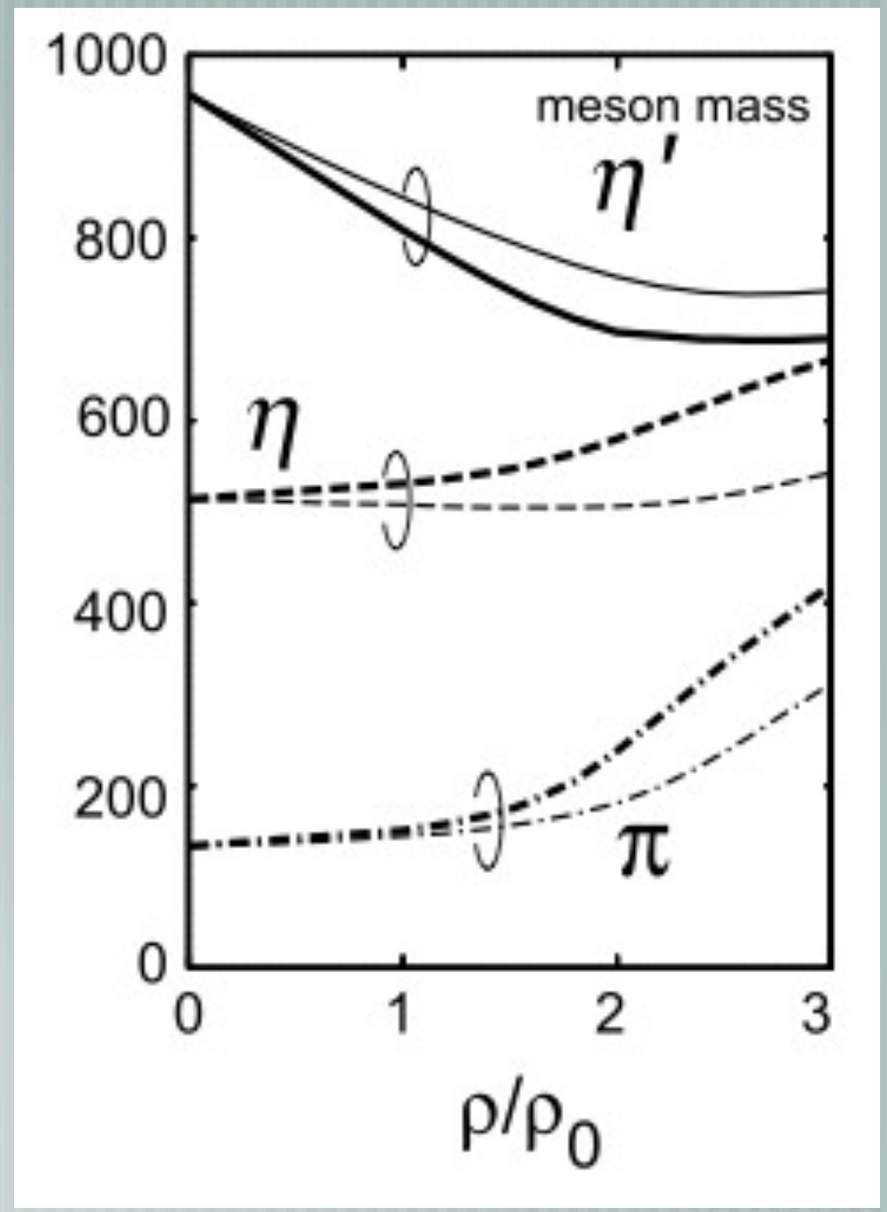
- The effect of KMT term is related to the strength of the quark condensate.



in-medium η′ mass



Costa et al., PRD 71, 116002 (2005)



Nagahiro et al., PRC 74, 045203 (2006)

η′-nucleus interaction

→ Hirenzaki's talk on Thursday

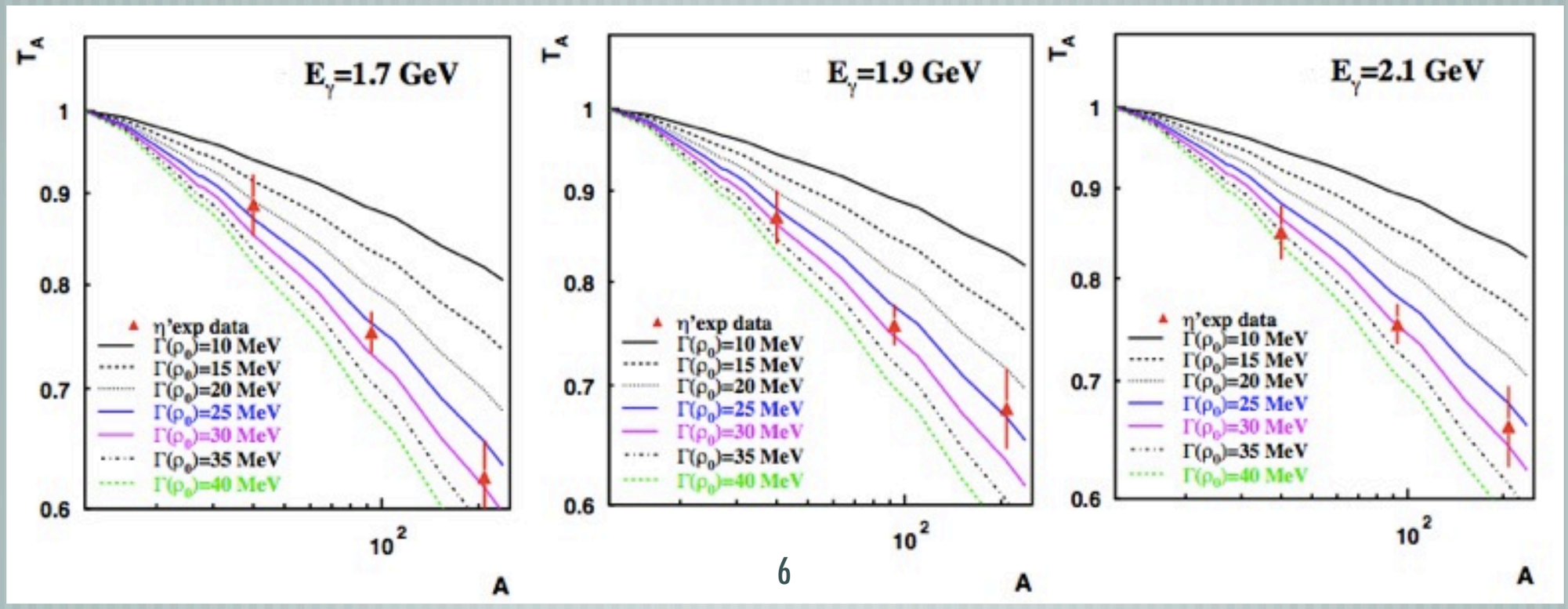
→ Jido's poster on Saturday

- in-medium mass reduction (15%@ρ_0)
  → attractive interaction between η′ and nucleus
- η′-nucleus bound state?

Decay width

Nanova et al., PLB 710, 600 (2012) → Nanova's talk on Monday

- Narrow decay width (<25MeV) indicated by CBELSA/TAPS
  - transparency ratio: $T_A = \frac{\sigma(\gamma A \to \eta' X)}{A \cdot \sigma(\gamma N \to \eta' X)}$



PRiME η′

Experiment at GSI-SIS

Itahashi et al., arXiv:1203.6720 [nucl-ex]
(submitted to Prog. Theor. Phys.)

PRiME η′ Collaboration

RIKEN: K. Itahashi (spokesperson), H. Outa

Kyoto U.: H. Fujioka (co-spokesperson)

GSI: H. Geissel, H. Weick

U. Gießen: V. Metag, M. Nanova

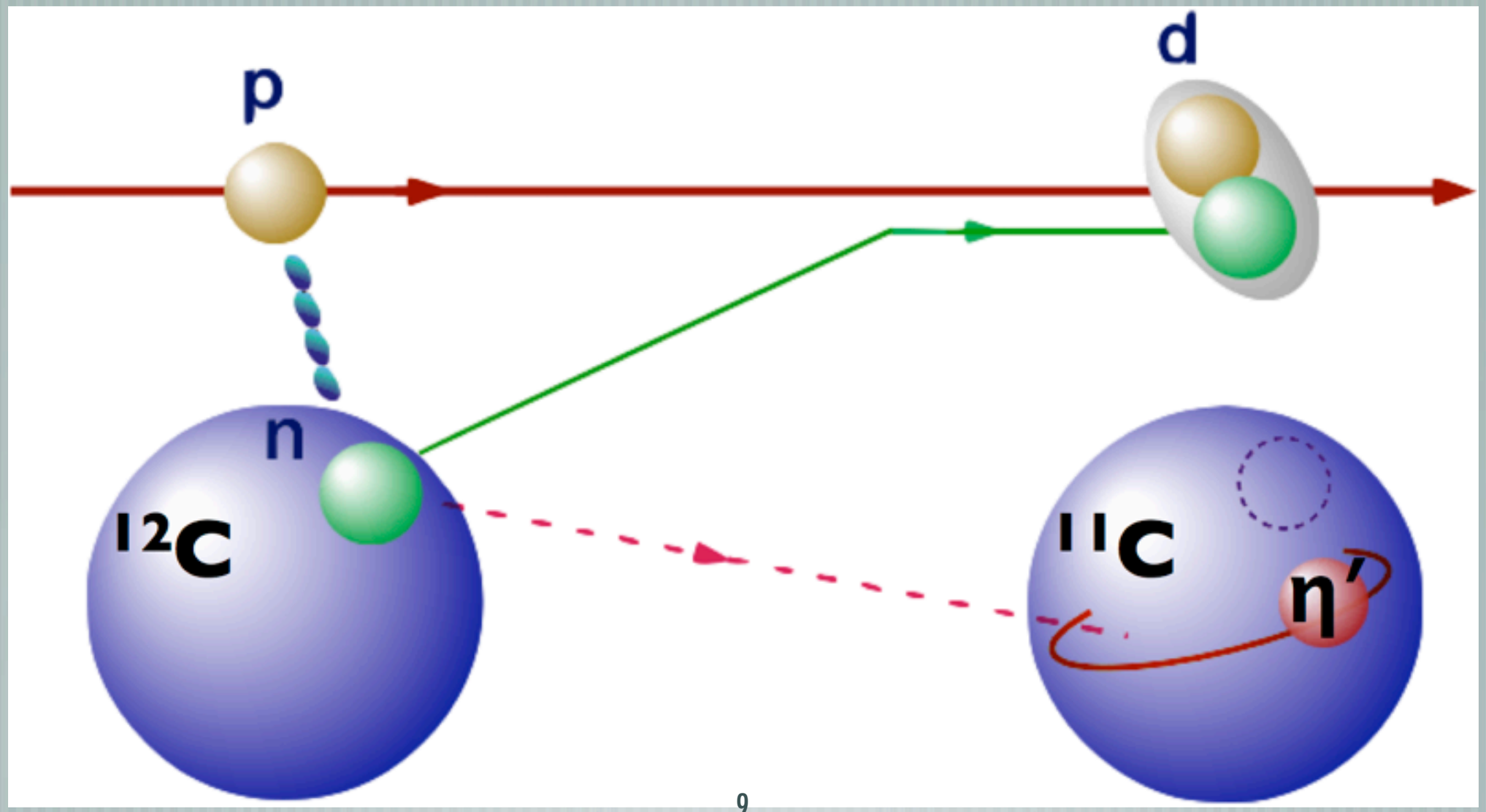
U. Tokyo: R.S. Hayano, S. Itoh, T. Nishi, K. Okochi,
T. Suzuki, Y.K. Tanaka

Nara Women's U.: S. Hirenzaki, H. Nagahiro

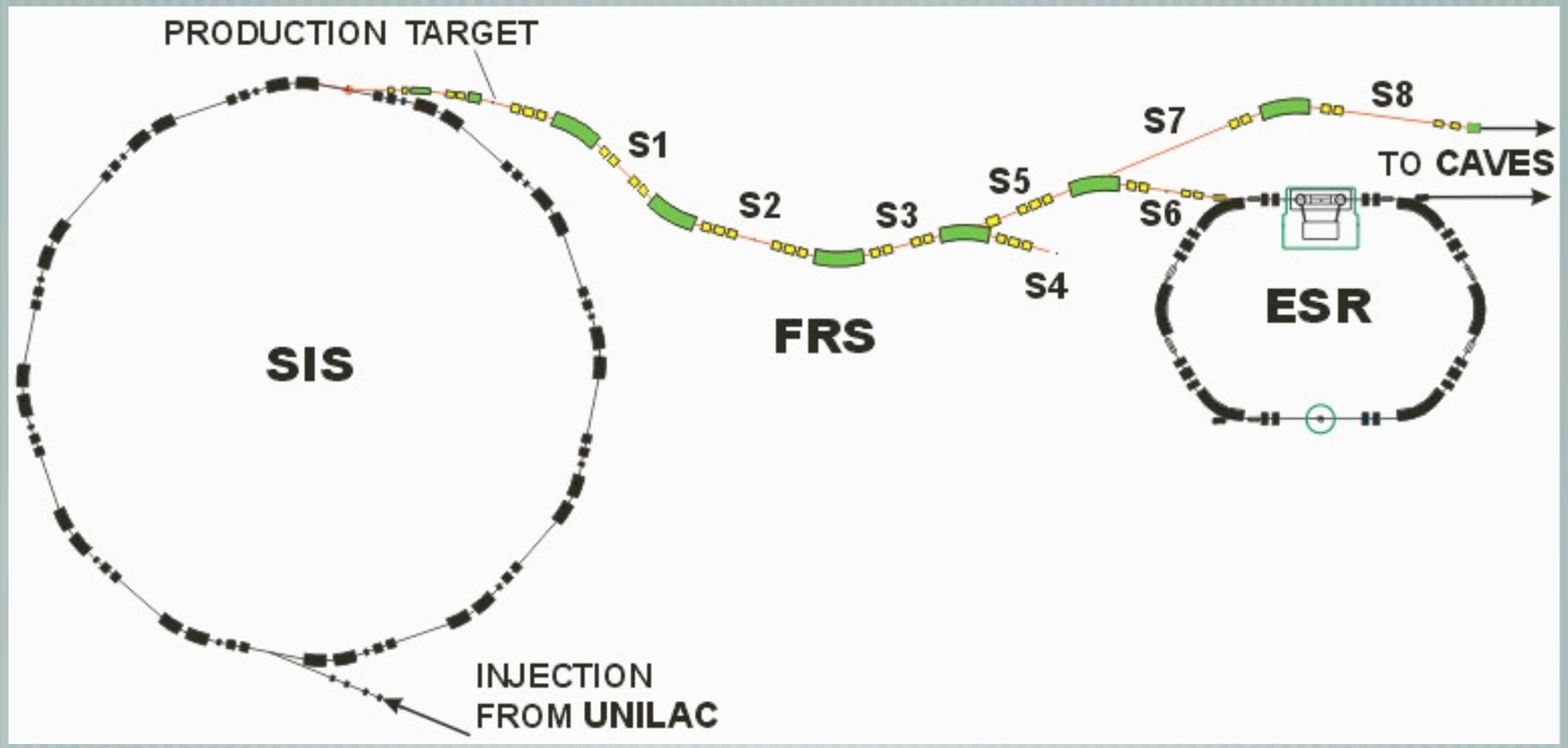
YITP, Kyoto U.:D. Jido

SMI: K. Suzuki

(p,d) reaction



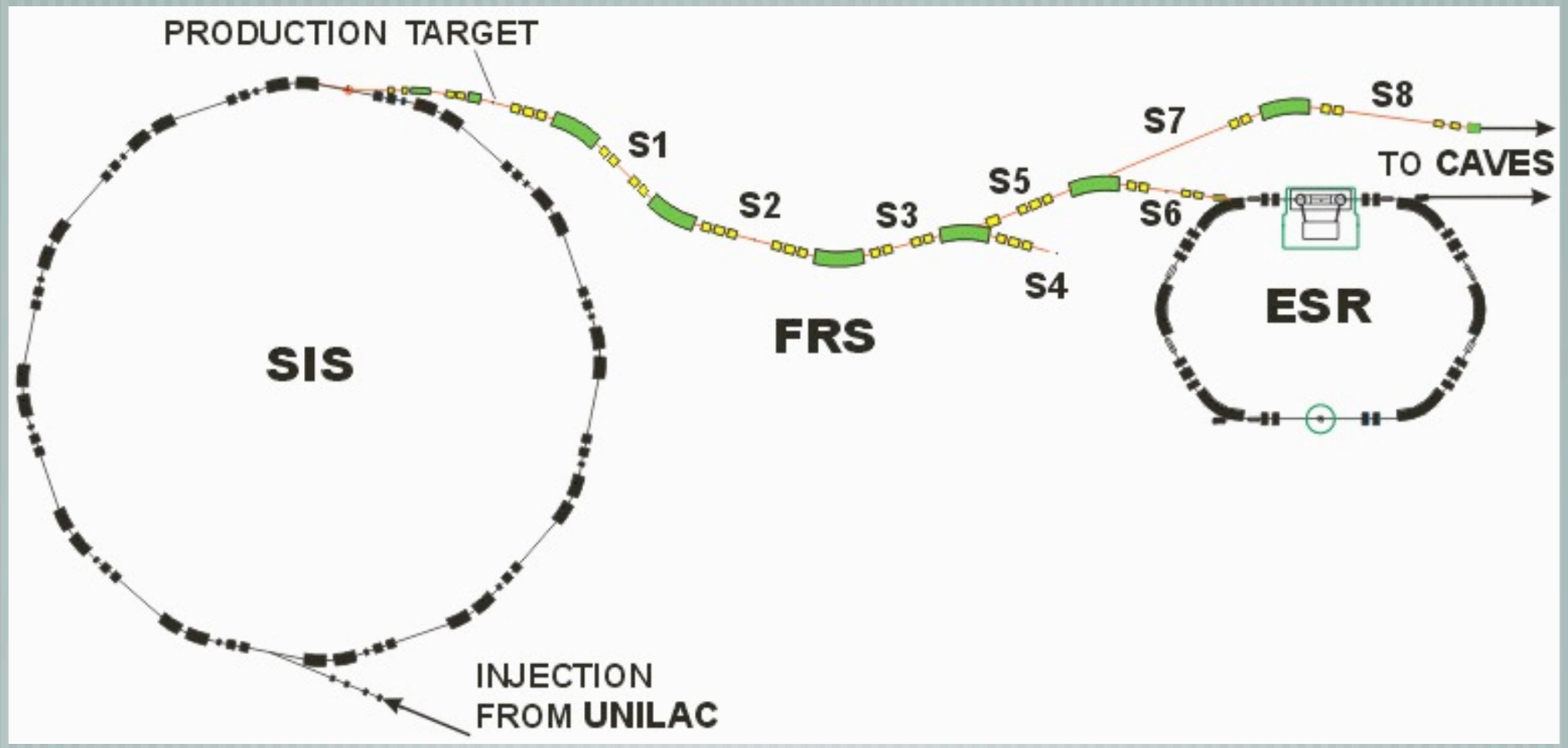
(p,d) reaction


PRODUCTION TARGET
S1
S2
S3
S4
S5
S6
S7
S8
TO CAVES
FRS
ESR
SIS
INJECTION
FROM UNILAC

(p,d) reaction

intense proton beam (2.5GeV, ~10^{10}Hz)

deuteron analyzed by FRS (FRagment Separator)



Cross section

- Elementary process: $pn \to d\eta'$
  - NO DATA!
  - Estimated with η production data as:
    - $$\frac{\sigma(pn \to d\eta')}{\sigma(pp \to pp\eta')} = \frac{\sigma(pn \to d\eta)}{\sigma(pp \to pp\eta)} \Rightarrow 3\mu b$$
  - Calculation by Grishina et al. ⇒3μb

Grishina et al., PLB475, 9 (2000)

Cross section

- Elementary process: pn→dη′
  - NO DATA!

$$\left(\frac{d\sigma}{d\Omega}\right)^{(\mathrm{Lab.})} = 30\mu\mathrm{b/sr}$$

  - Estimated with η production data as:
    - $\frac{\sigma(pn \to d\eta')}{\sigma(pp \to pp\eta')} = \frac{\sigma(pn \to d\eta)}{\sigma(pp \to pp\eta)}$ ⇒3μb
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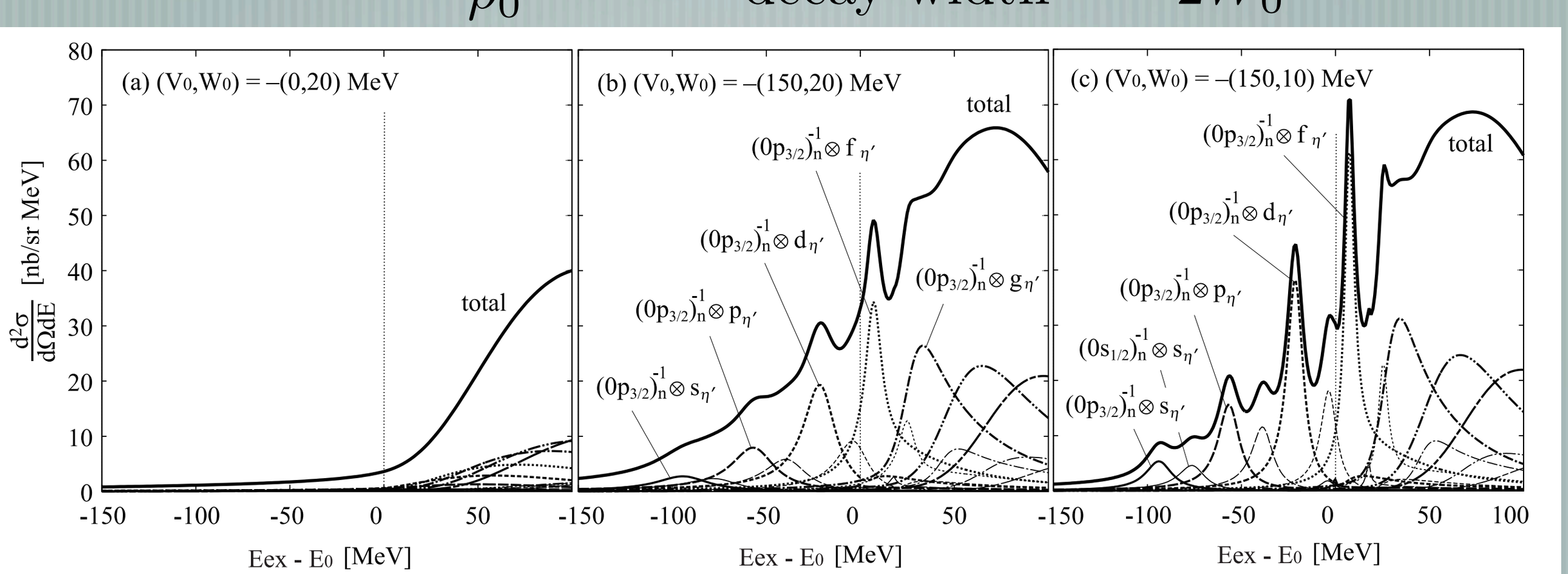
Theoretical spectra

Green's Function Method

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

$$V_0 = \Delta m_{\eta'}(\rho_0) = m_{\eta'}(\rho_0) - m_{\eta'}$$

$$\text{decay width} = -2W_0$$



Nagahiro et al., in preparation

Inclusive measurement

In general:

$^{12}C(p,d)X$ → A+B+...; → C+D+...

$^{12}C(p,d)X'$ → A′+B′+...

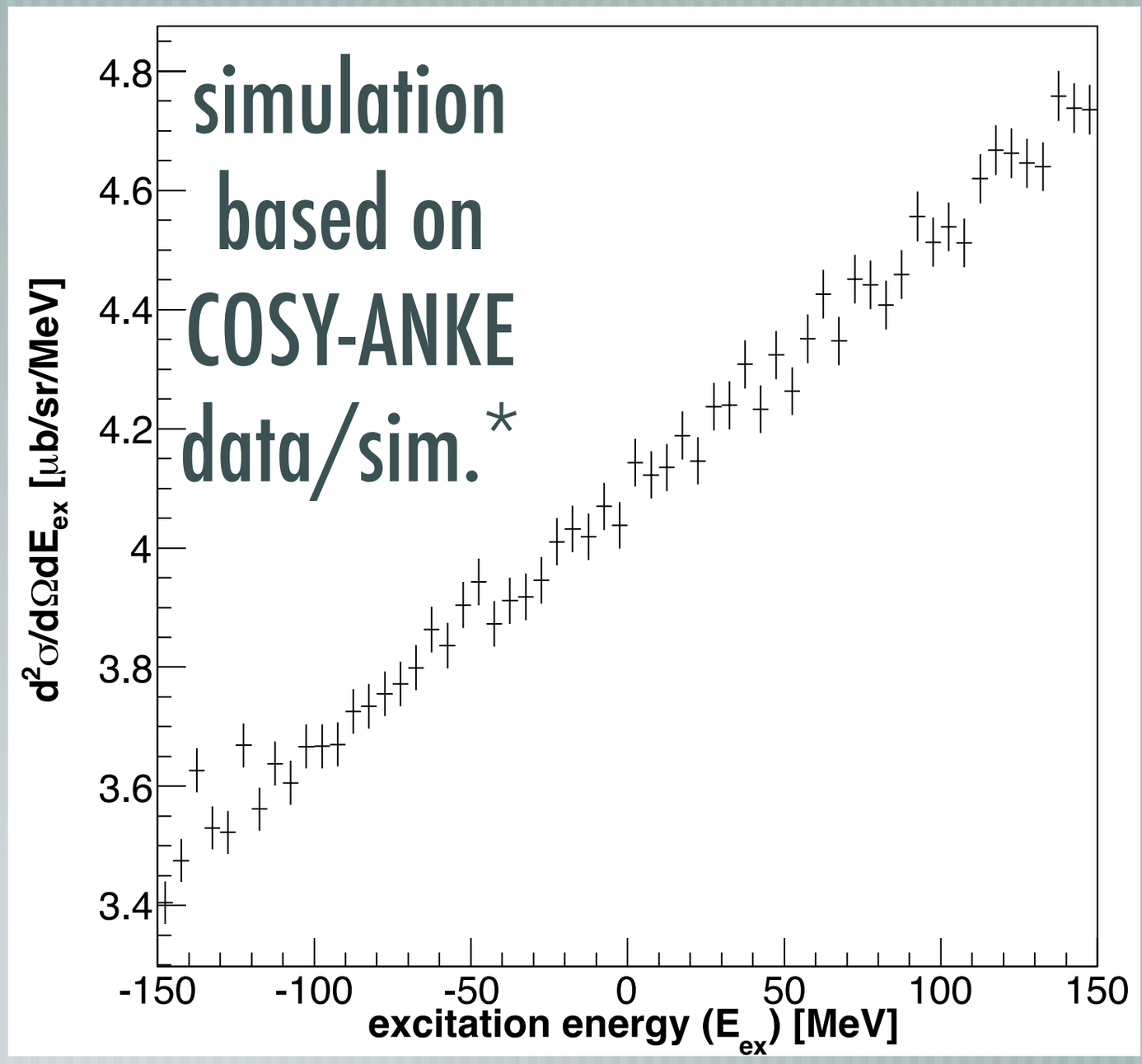
- the exclusive measurement, to detect the "decay particles", is adopted.
- the inclusive measurement is very difficult because of large decay width

Inclusive measurement @ GSI being proposed, as η′ mesic nuclei may have a narrow width.

Background

- quasi-free $pN \to d+n\pi$ (n=2,3,4)
- S/N=O(1/100) at most

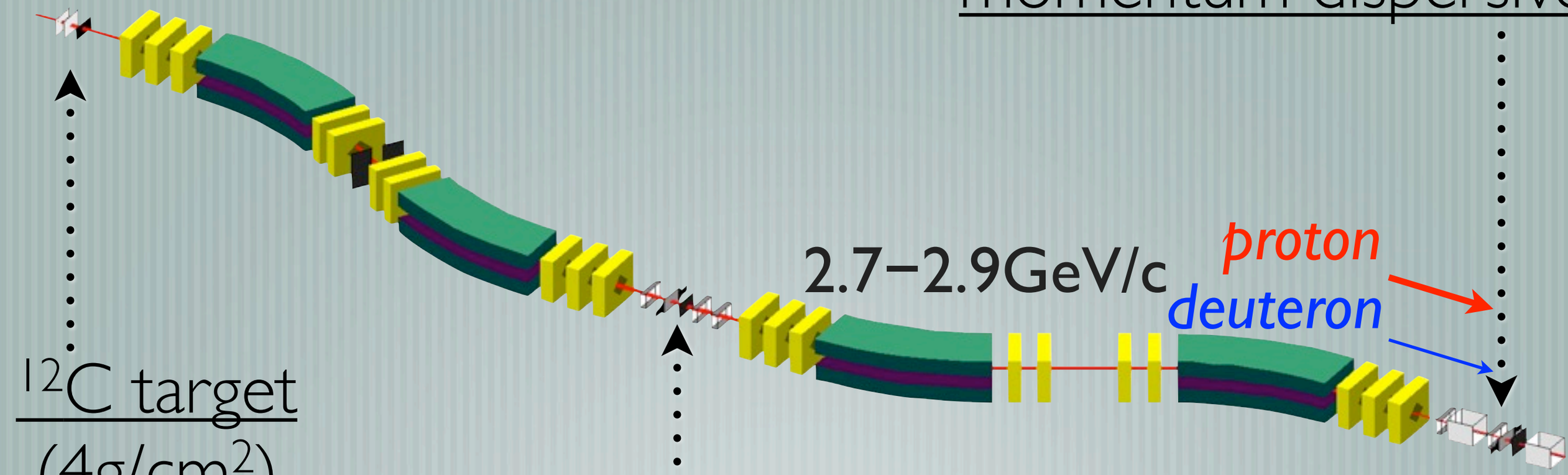
*Barsov et al., EPJ A21, 521 (2004); Lehmann, PhD thesis



Experimental Setup

FRS as spectrometer

2.5GeV (3.3GeV/c)
proton [10^{10}/spill]

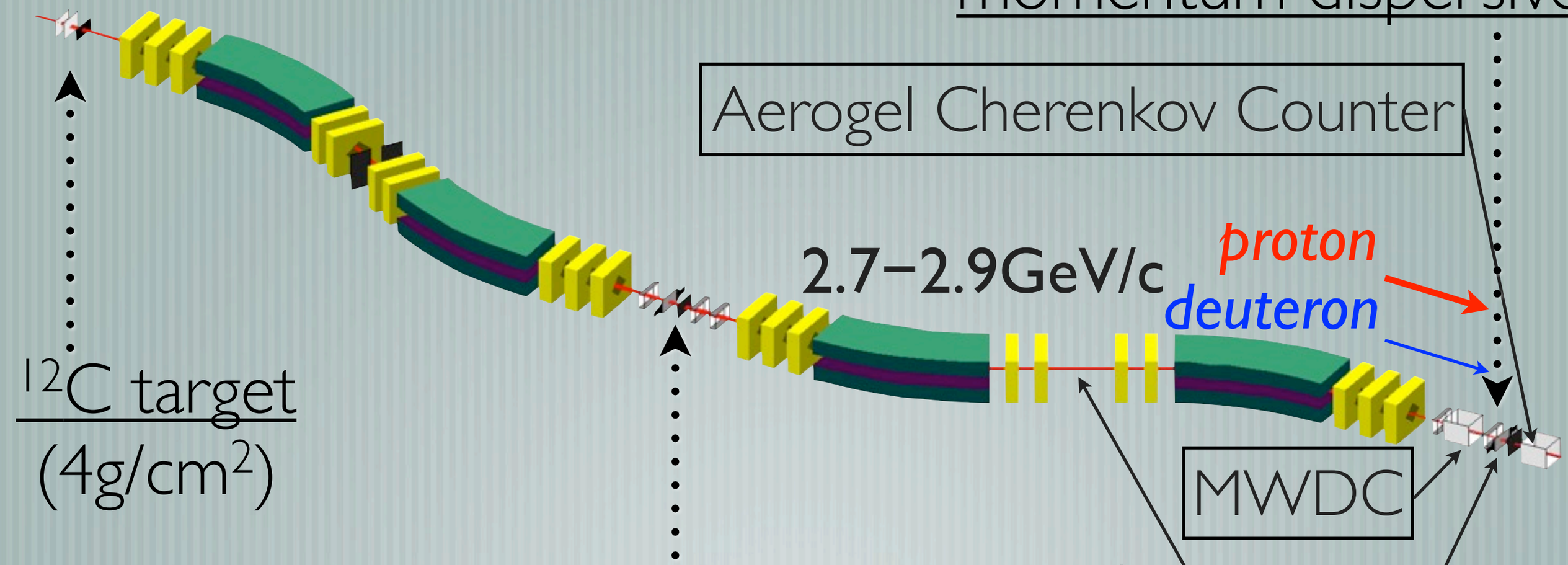


FRS as spectrometer

2.5GeV (3.3GeV/c)
proton [10^{10}/spill]

momentum dispersive

Aerogel Cherenkov Counter



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

momentum compaction

FRS as spectrometer

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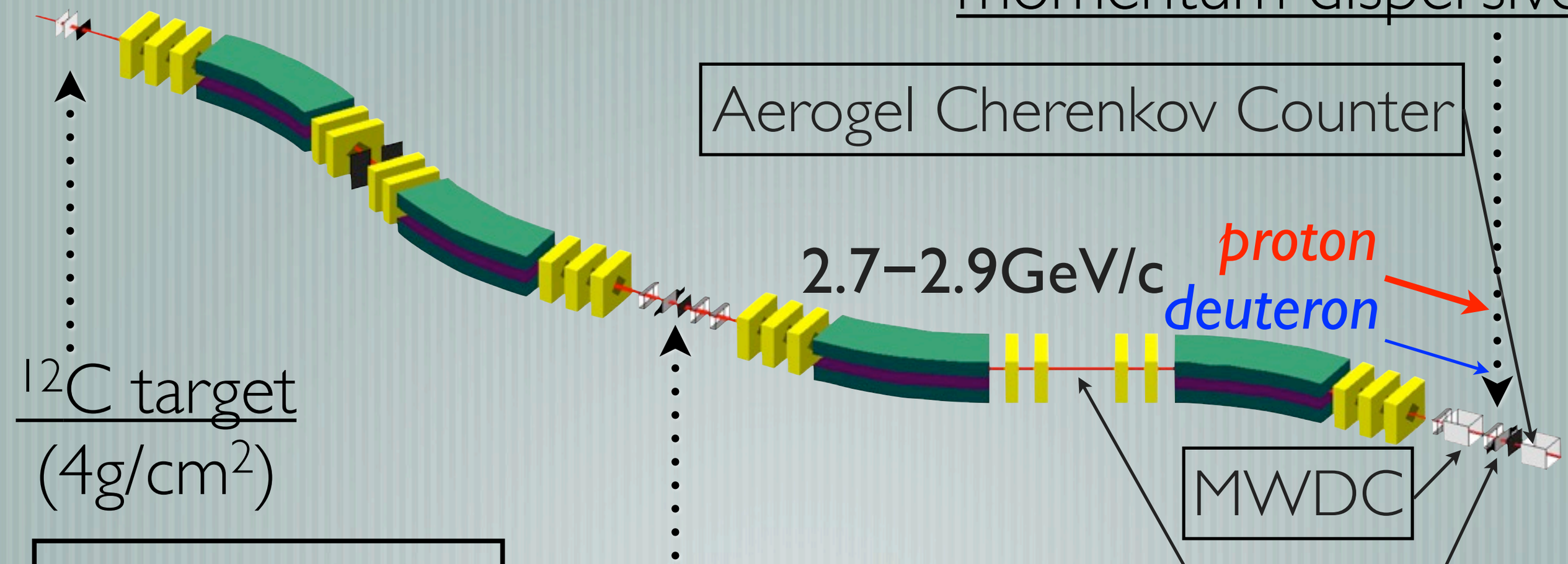


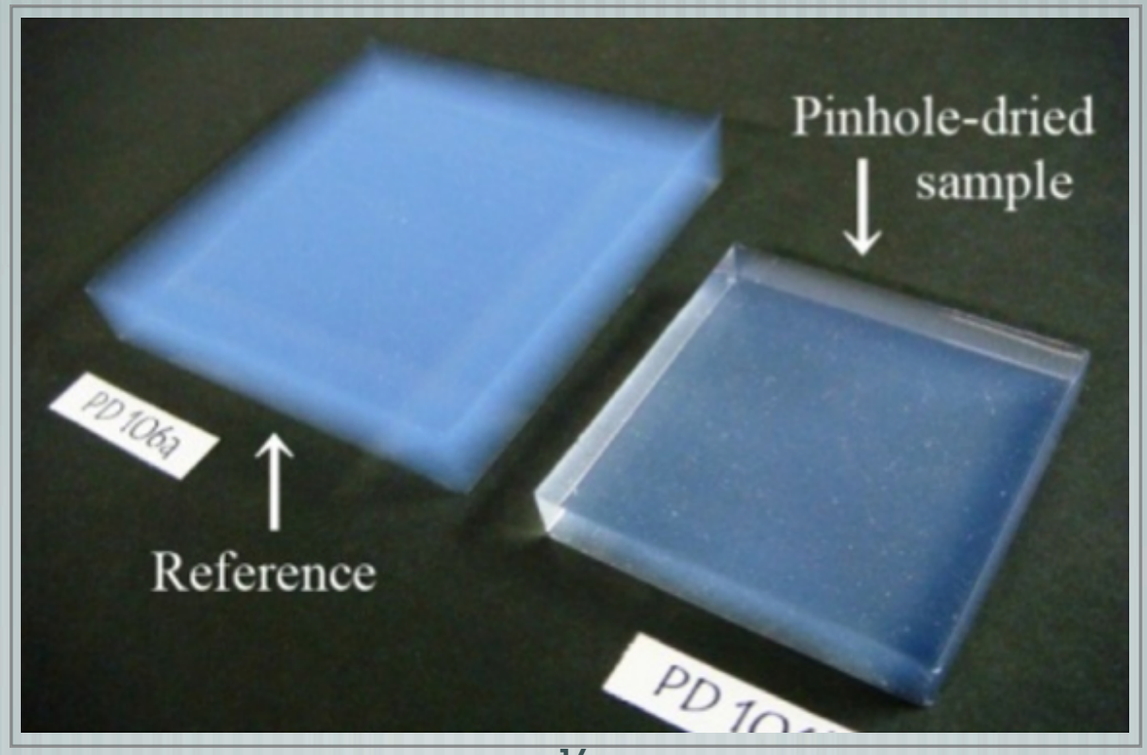
^{12}C target
($4g/cm^2$)

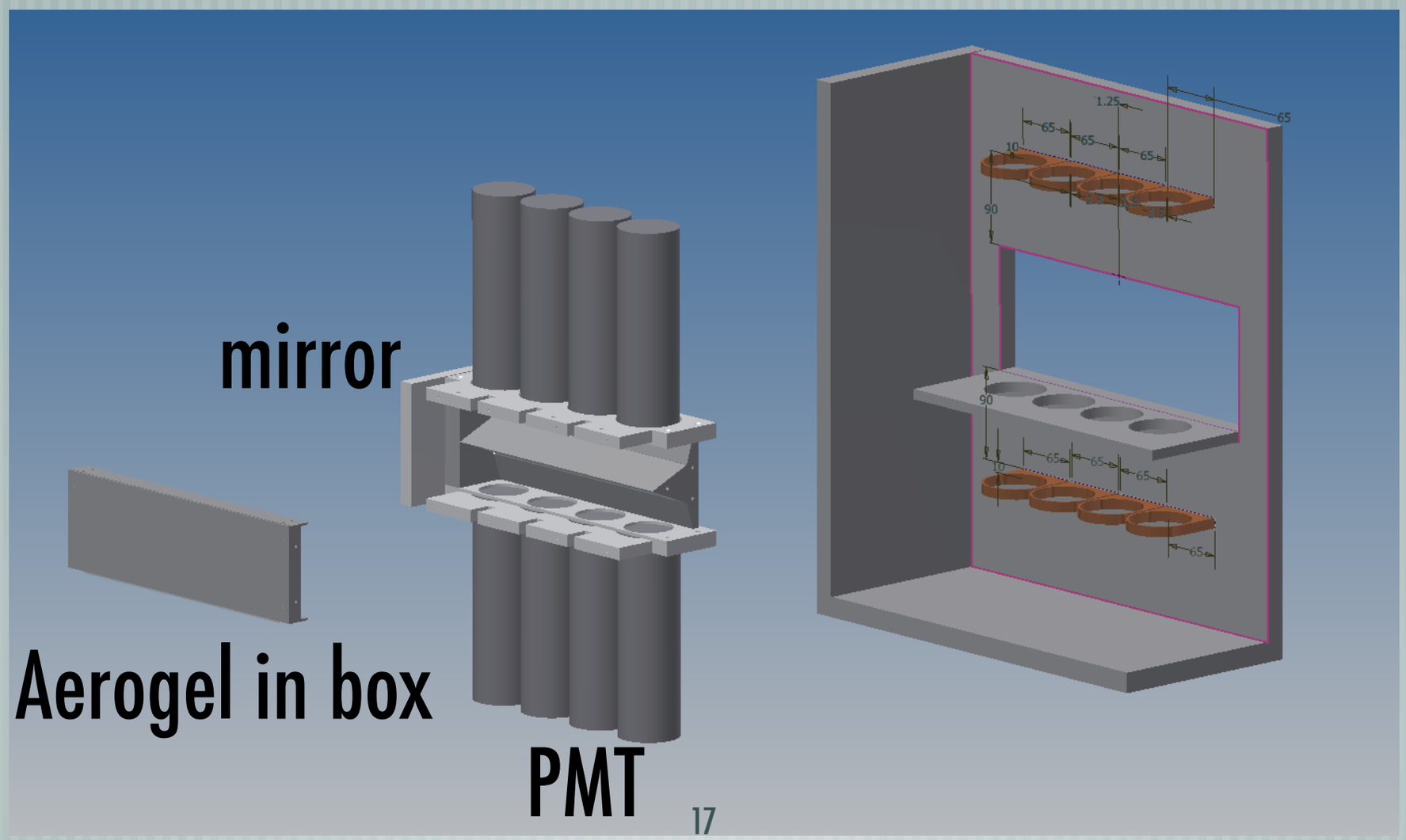
mass resolution
σ=1.6MeV/c^2

momentum compaction

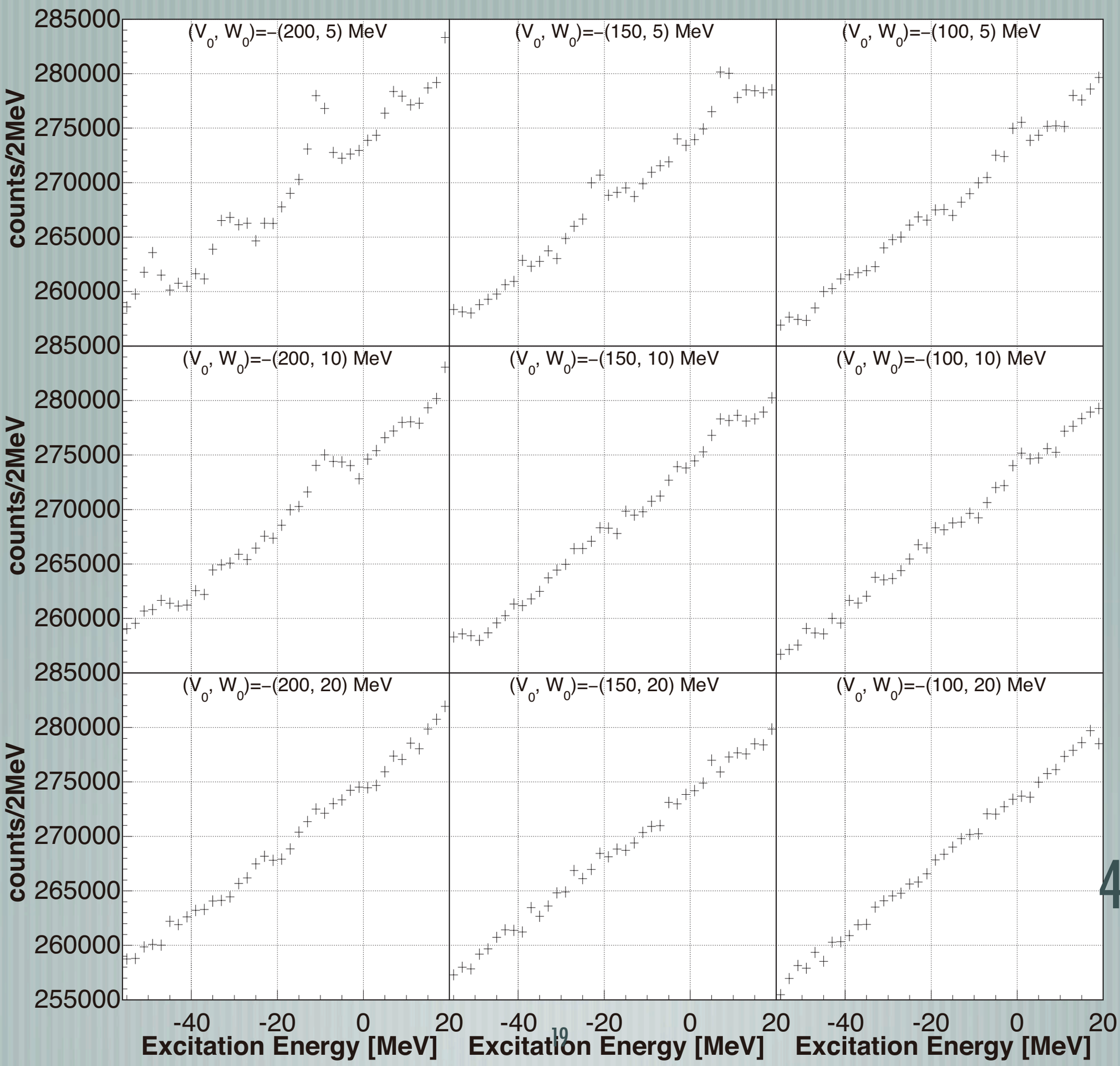
AC for p/d separation

- aerogel w/ high refractive index (n=1.18) developed at Chiba Univ.
  - Adachi et al., NIM A639, 222 (2011)

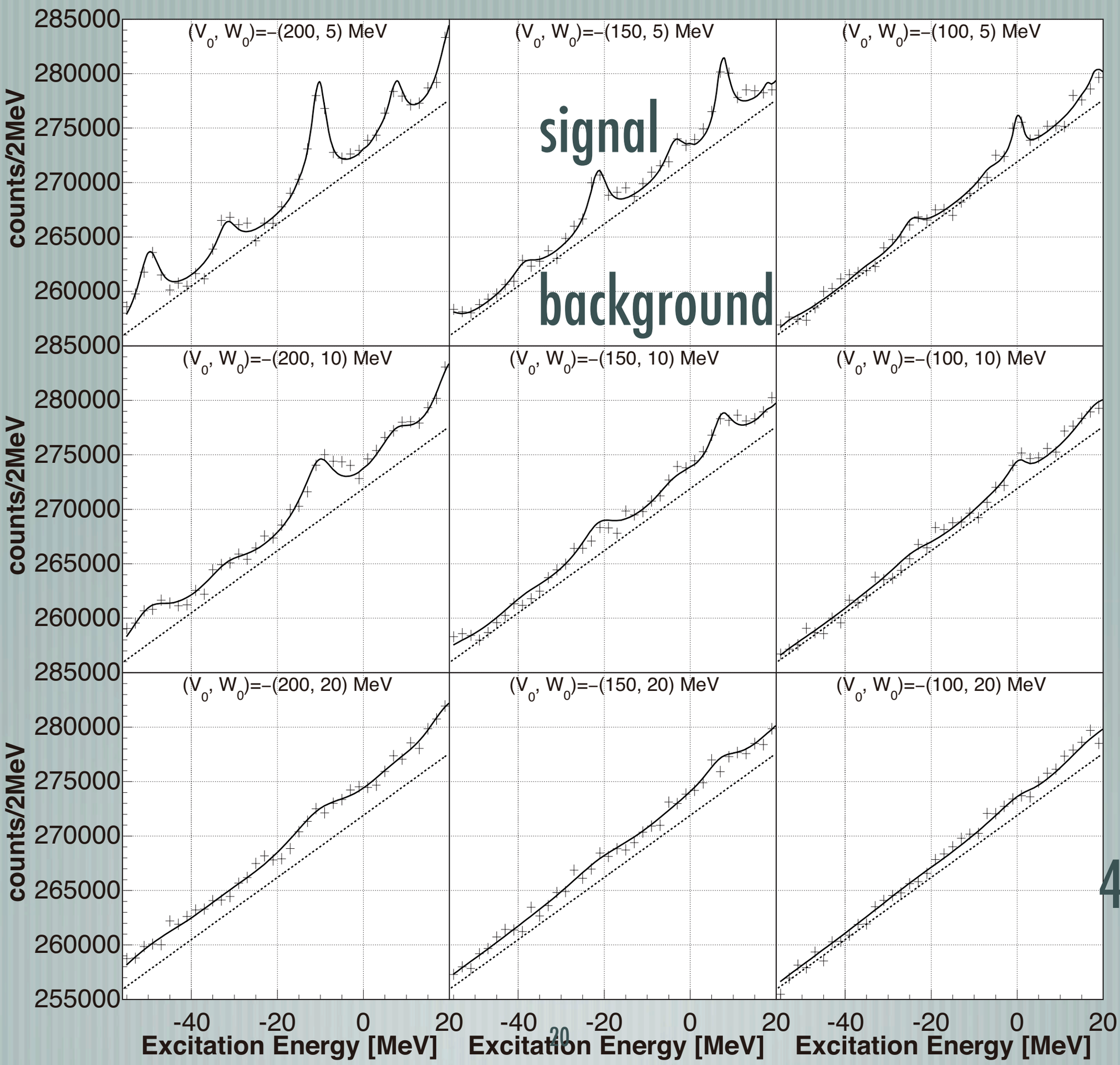



mirror
Aerogel in box
PMT
1.25
65
65
65
65
10
90
90
65
65
65
10
65

Simulation Result


(V0, W0)=−(200, 5) MeV
(V0, W0)=−(150, 5) MeV
(V0, W0)=−(100, 5) MeV
(V0, W0)=−(200, 10) MeV
(V0, W0)=−(150, 10) MeV
(V0, W0)=−(100, 10) MeV
(V0, W0)=−(200, 20) MeV
(V0, W0)=−(150, 20) MeV
(V0, W0)=−(100, 20) MeV
counts/2MeV
285000
280000
275000
270000
265000
260000
255000
-40
-20
0
20
Excitation Energy [MeV]

4.5 days
DAQ


(V0, W0)=−(200, 5) MeV
(V0, W0)=−(150, 5) MeV
(V0, W0)=−(100, 5) MeV
signal
background
(V0, W0)=−(200, 10) MeV
(V0, W0)=−(150, 10) MeV
(V0, W0)=−(100, 10) MeV
(V0, W0)=−(200, 20) MeV
(V0, W0)=−(150, 20) MeV
(V0, W0)=−(100, 20) MeV
counts/2MeV
285000
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-20
0
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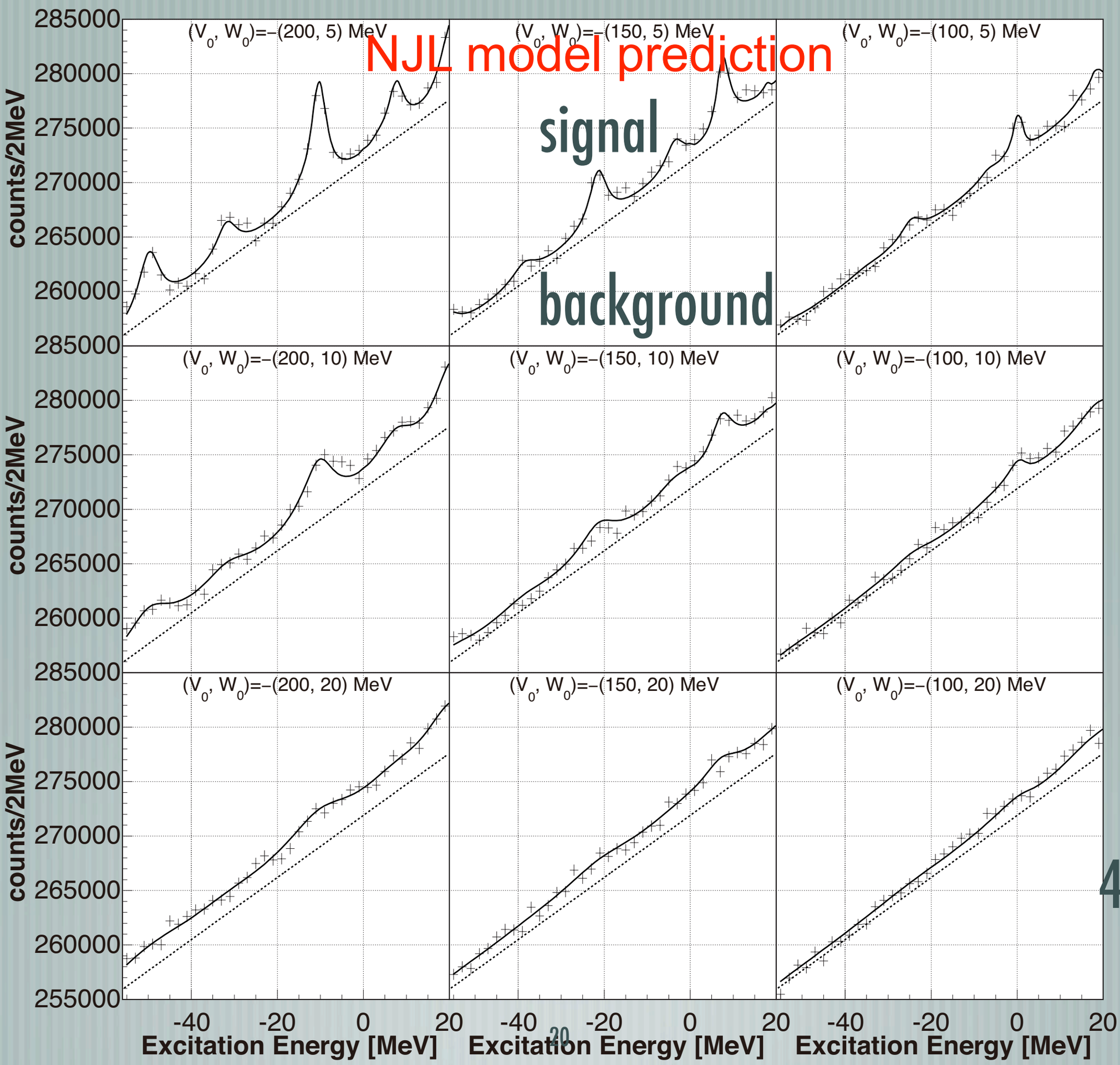
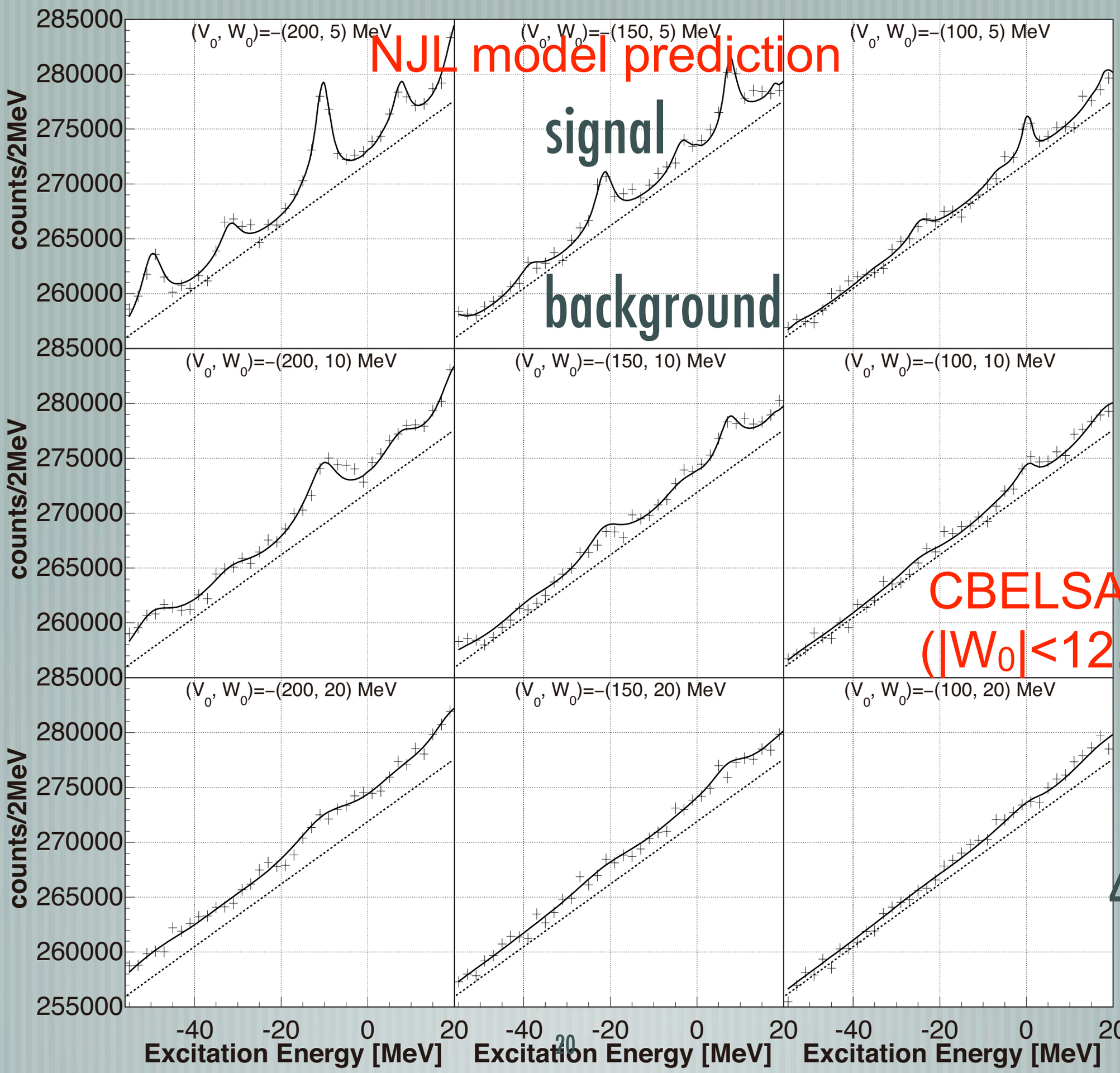
Excitation Energy [MeV]

4.5 days DAQ


NJL model prediction
signal
background
(V0, W0)=−(200, 5) MeV
(V0, W0)=−(150, 5) MeV
(V0, W0)=−(100, 5) MeV
(V0, W0)=−(200, 10) MeV
(V0, W0)=−(150, 10) MeV
(V0, W0)=−(100, 10) MeV
(V0, W0)=−(200, 20) MeV
(V0, W0)=−(150, 20) MeV
(V0, W0)=−(100, 20) MeV
counts/2MeV
Excitation Energy [MeV]
4.5 days
DAQ


NJL model prediction
signal
background
CBELSA/TAPS
(|W0|<12.5MeV)
4.5 days
DAQ
(V0, W0)=−(200, 5) MeV
(V0, W0)=−(150, 5) MeV
(V0, W0)=−(100, 5) MeV
(V0, W0)=−(200, 10) MeV
(V0, W0)=−(150, 10) MeV
(V0, W0)=−(100, 10) MeV
(V0, W0)=−(200, 20) MeV
(V0, W0)=−(150, 20) MeV
(V0, W0)=−(100, 20) MeV
counts/2MeV
Excitation Energy [MeV]
285000
280000
275000
270000
265000
260000
255000
-40
-20
0
20

Why (p,d)?

1. High Statistics

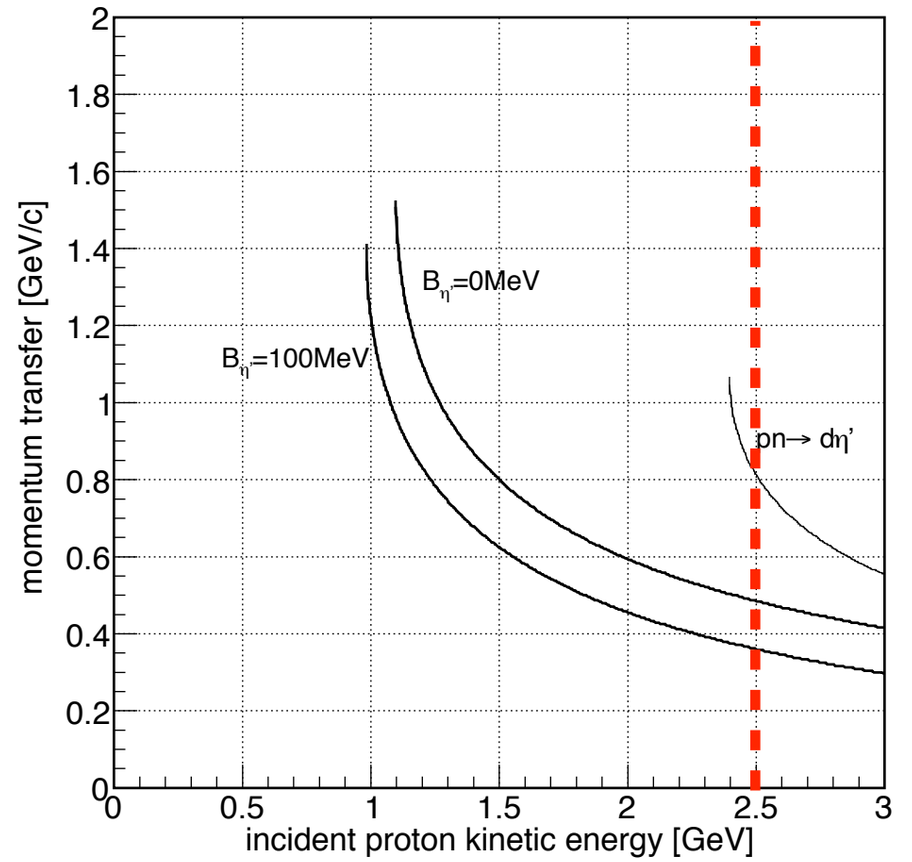
- intense proton beam on thick target
- BG not from target can be suppressed by the achromatic condition for the first stage of FRS

Why (p,d)?

- **2.** High Resolution
  - resolving power of FRS > 2000
  - energy loss in thick target predominantly worsens the resolution
  - σ=1.6MeV/c^2 much smaller than the expected decay width

Why (p,d)?

3. Relatively large momentum transfer



- many states populated
- near-threshold peak structure
- different rigidities between projectile and ejectile

Schedule

- test beam to be allocated in near future
  - FRS optics tuning
  - detector commissioning
  - background measurement
- physics run expected in 2013-2014

Present status

- Detectors
  - Aerogel Cherenkov Counter:
    - under R&D, to be ready in this summer
  - other detectors: existing
- Beam Optics Study : under way
- DAQ : ready in 2012

Summary

- η'(958) meson-nucleus system
  - can be bound ← NJL model ($-V_0=\Delta m=150$MeV)
  - can be narrow ← CBELSA/TAPS ($-2W_0=\Gamma<25$MeV)
- Experimental search at GSI-SIS
  - inclusive (p,d) spectroscopy
  - high statistics, high resolution
  - beamtime expected in 2013-2014