Search for η′(958)-nucleus bound states by (p,d) reaction at GSI and FAIR

Hiroyuki Fujioka (Kyoto Univ.)
on behalf of the η-PRiME collaboration

京都大学
KYOTO UNIVERSITY

η-PRiME Collaboration

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Technische Universitaet Darmstadt, Comenius University Bratislava,
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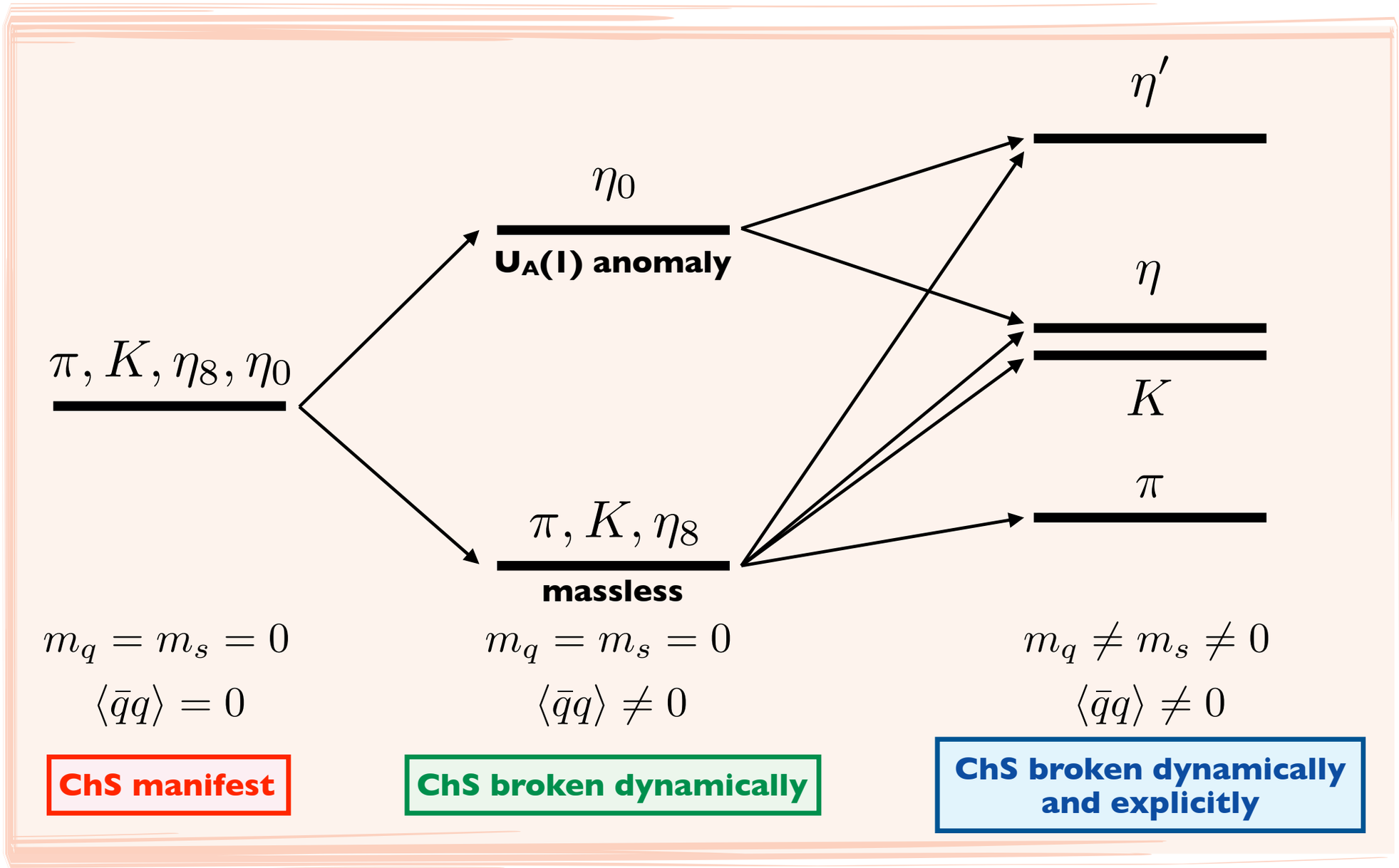
introduction

pseudoscalar mesons in broken chiral symmetry



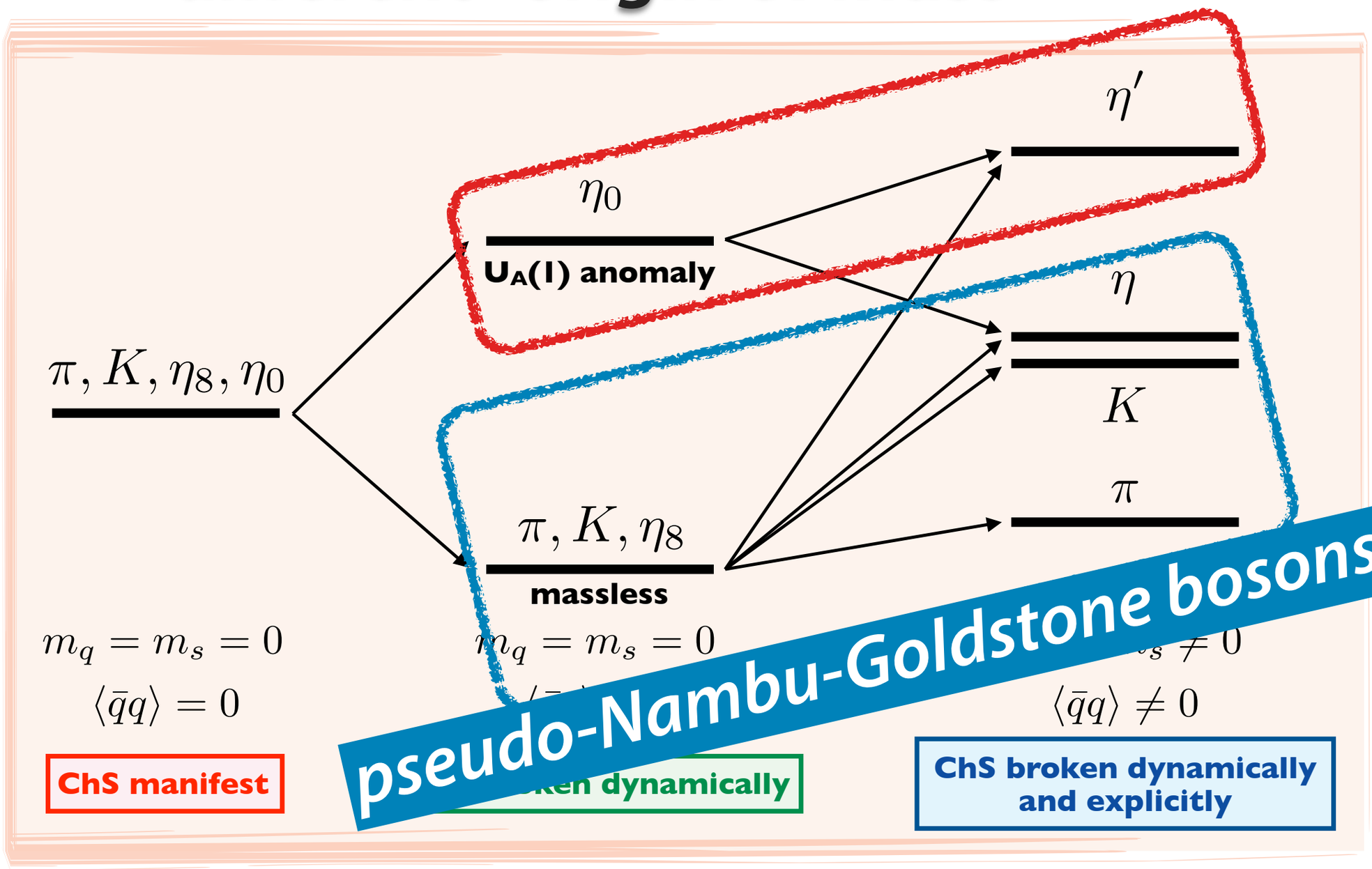
958 MeV

548 MeV
497 MeV

135 MeV

Nagahiro et al., PRC 87, 045201 (2013)

different "origin of mass"



958 MeV

548 MeV
497 MeV

135 MeV

Nagahiro et al., PRC 87, 045201 (2013)

η′ meson in medium

- At finite density/temperature,
  chiral symmetry will be partially restored
  - cf. deeply-bound pionic atom (talk by Ikeno-san)
- large mass reduction, as a consequence of
  suppression of the anomaly effect?
- optical potential: $V(r)=(V_0+iW_0)\rho(r)/\rho_0$
  - $|V_0|$= (mass reduction), $2|W_0|$= (absorption width)

η′ meson in medium

in vacuum

mass = 958 MeV/c^2

in medium (nucleus)

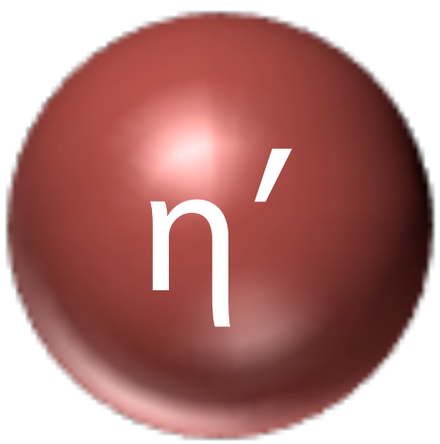
< 958 MeV/c^2 ?

<u>O(10) MeV</u> or even larger mass reduction?

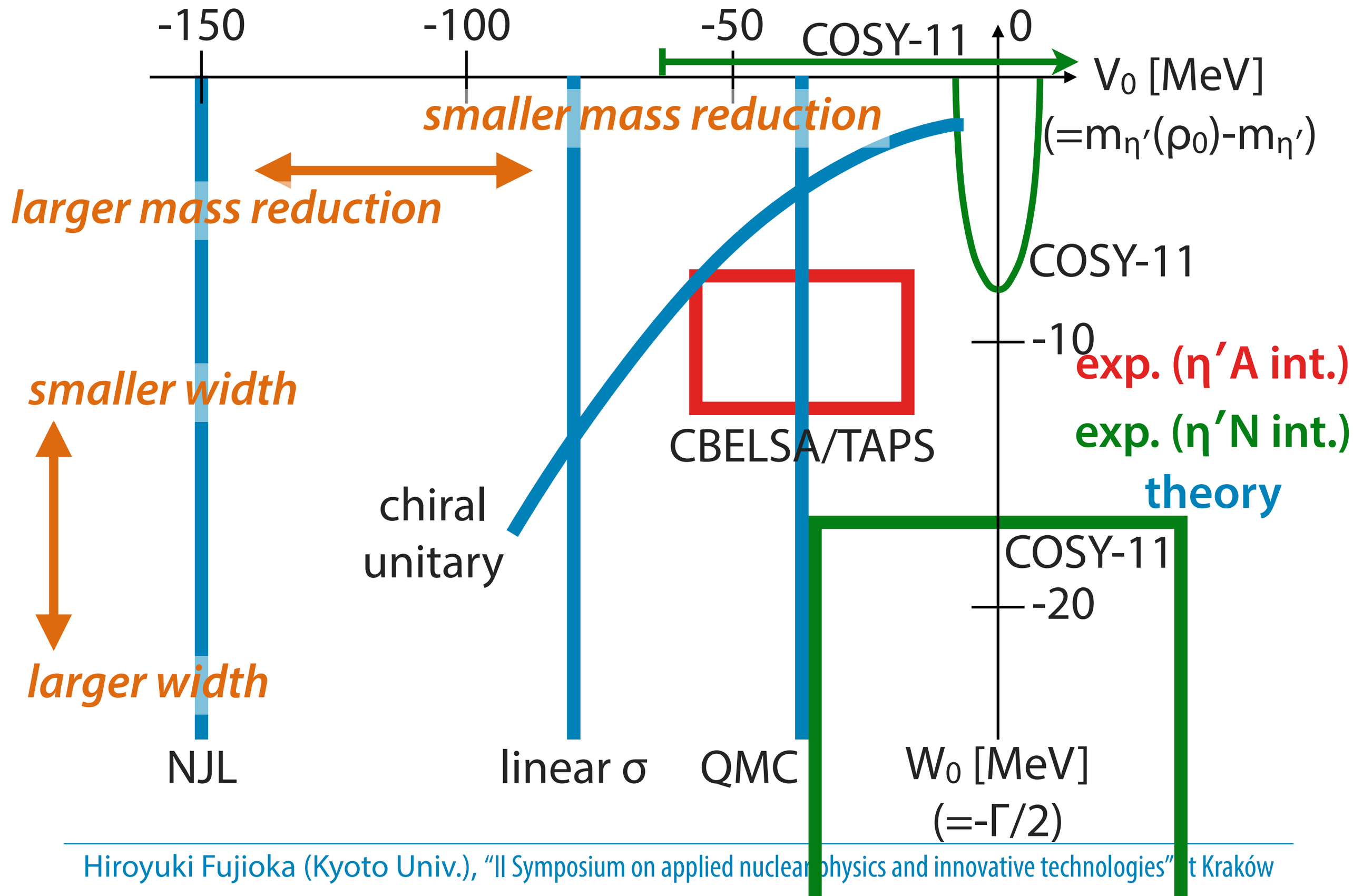
decay width = 0.2 MeV

absorption width = <u>O(10) MeV</u> ?

(free decay is largely suppressed)

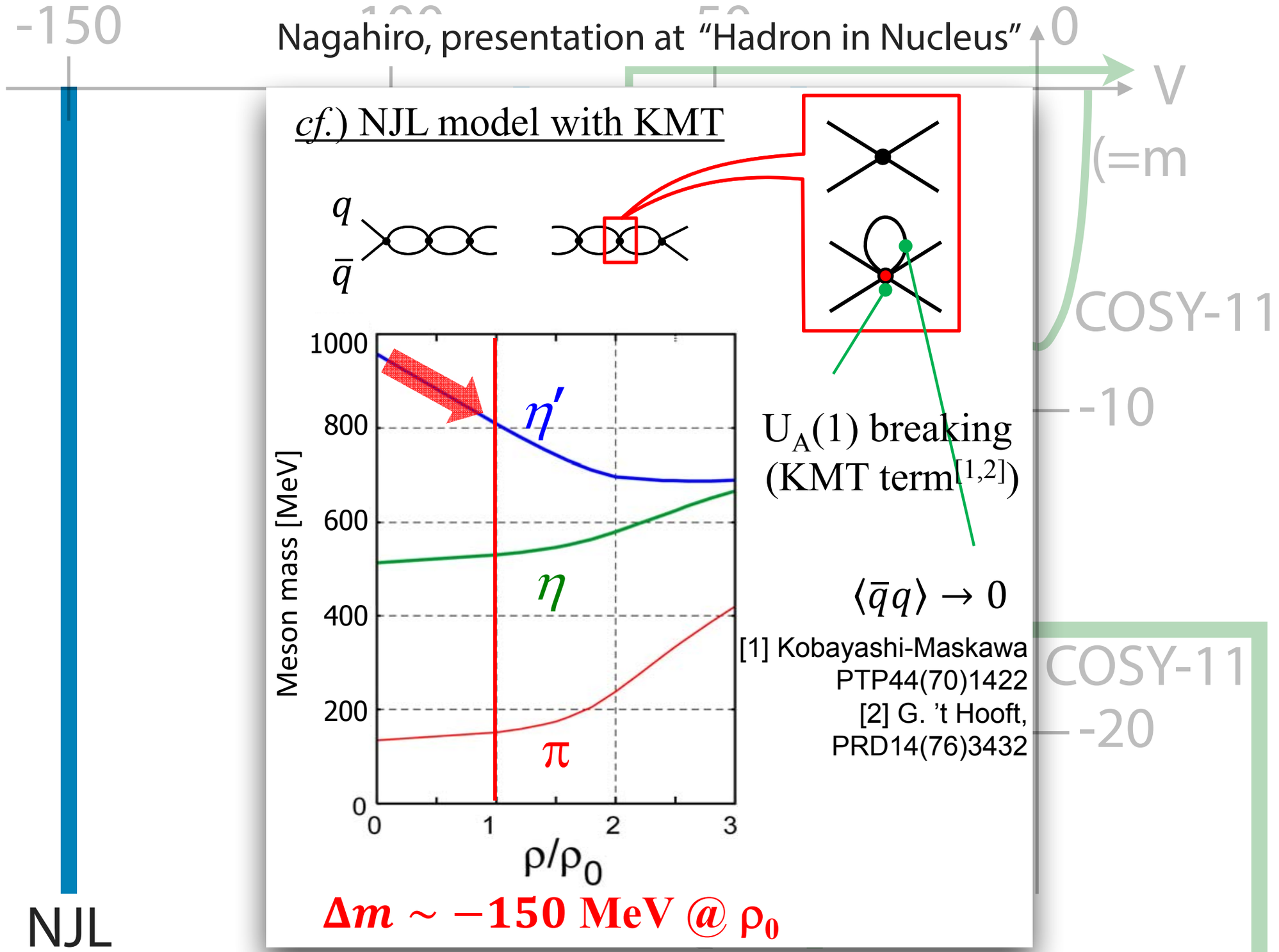


η′ optical potential: state of the art



Nambu–Jona-Lasinio model

Nagahiro, presentation at "Hadron in Nucleus"

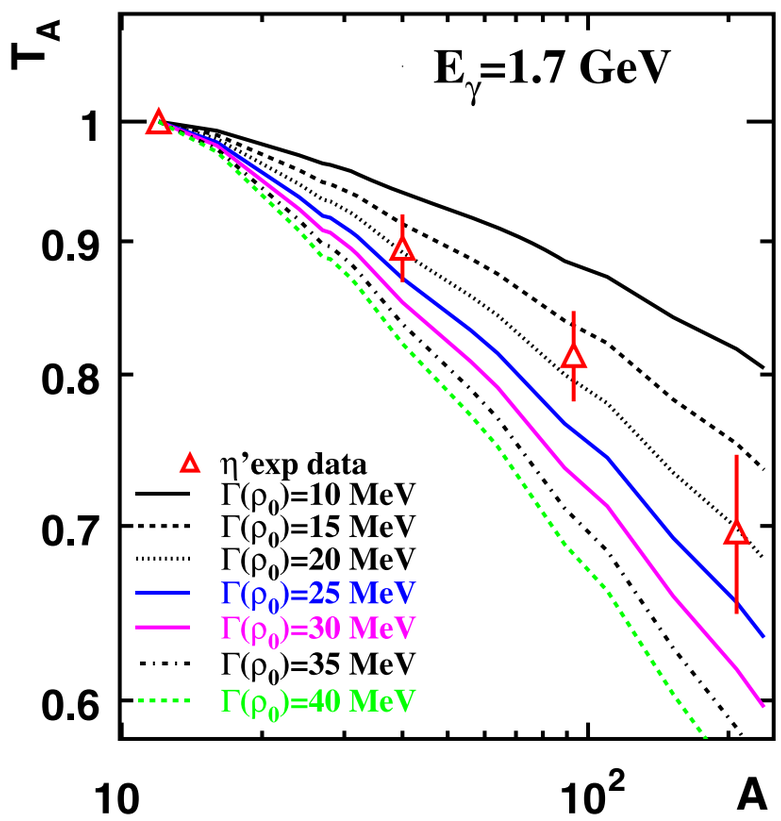


transparency ratio measurement

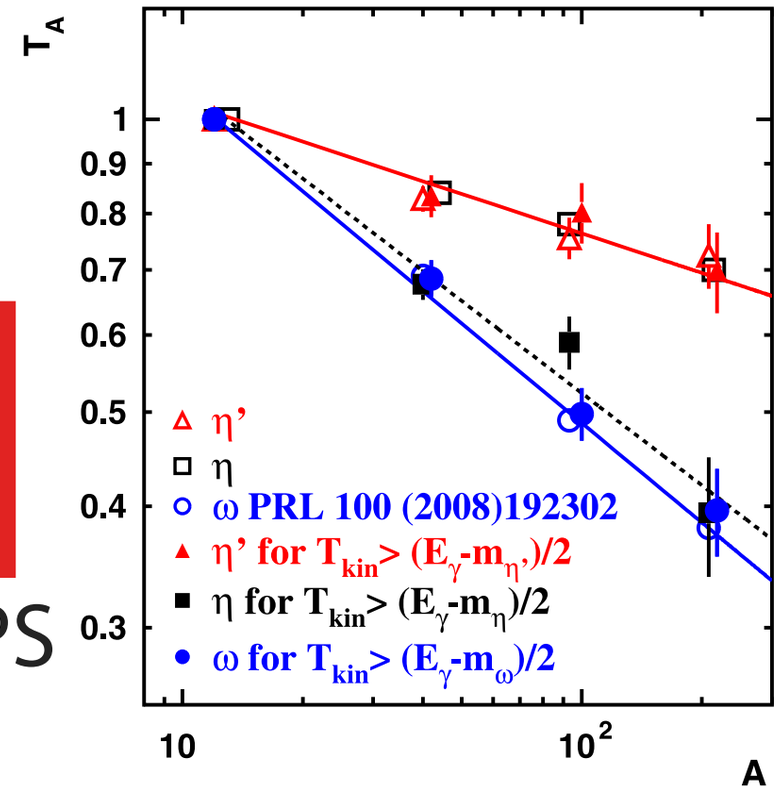
-150 -100 -50 COSY-11 0 V

transparency ratio

$$T_A = \frac{\sigma(\gamma A \to \eta' X)}{A \cdot \sigma(\gamma N \to \eta' X)}$$



CBELSA/TAPS

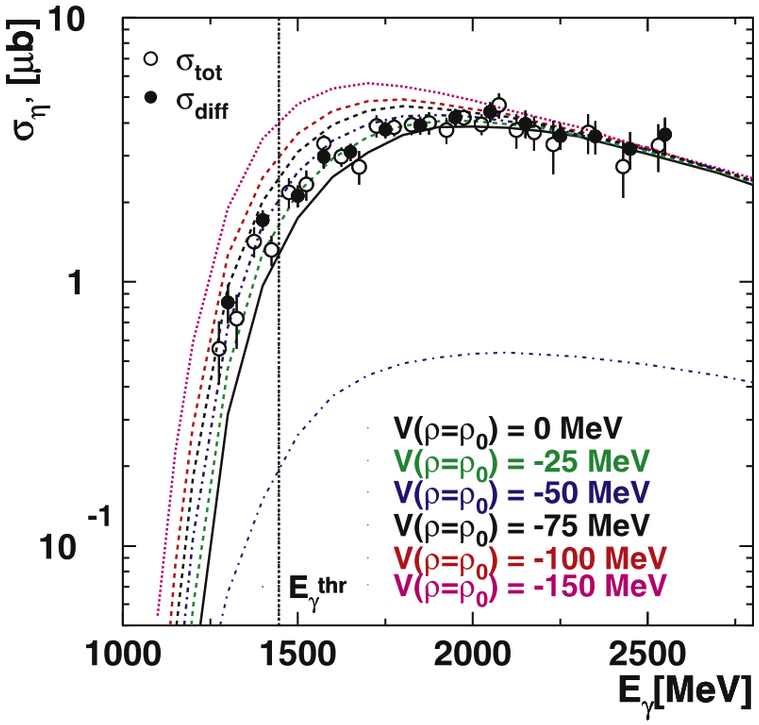


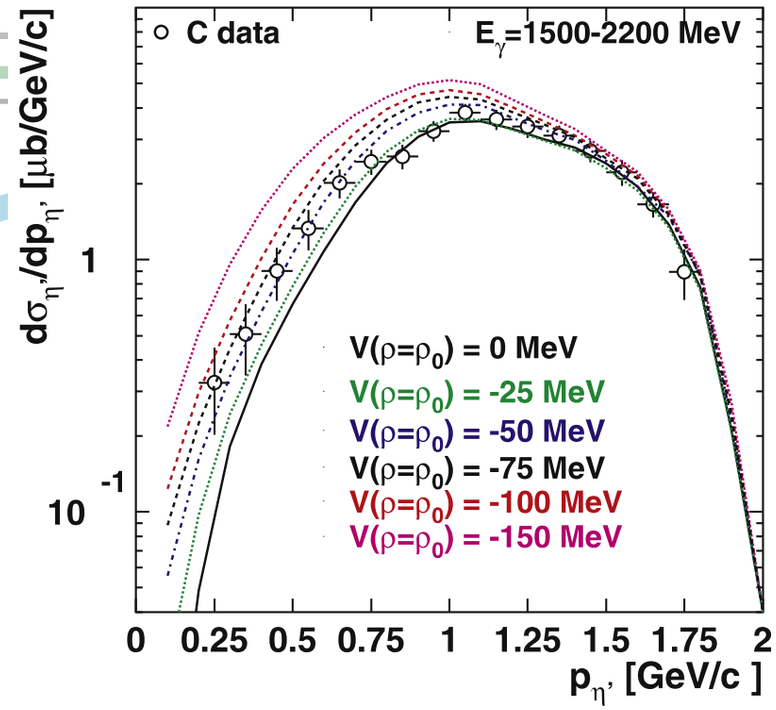
→ **Γ=15–25MeV at ρ=ρ0**

for <$p_{\eta'}$>~1.05GeV/c

Nanova et al., PLB 710, 600 (2012)

excitation function and momentum distribution





V_0=−(40±6) MeV

chiral unitary

CBELSA/TAPS

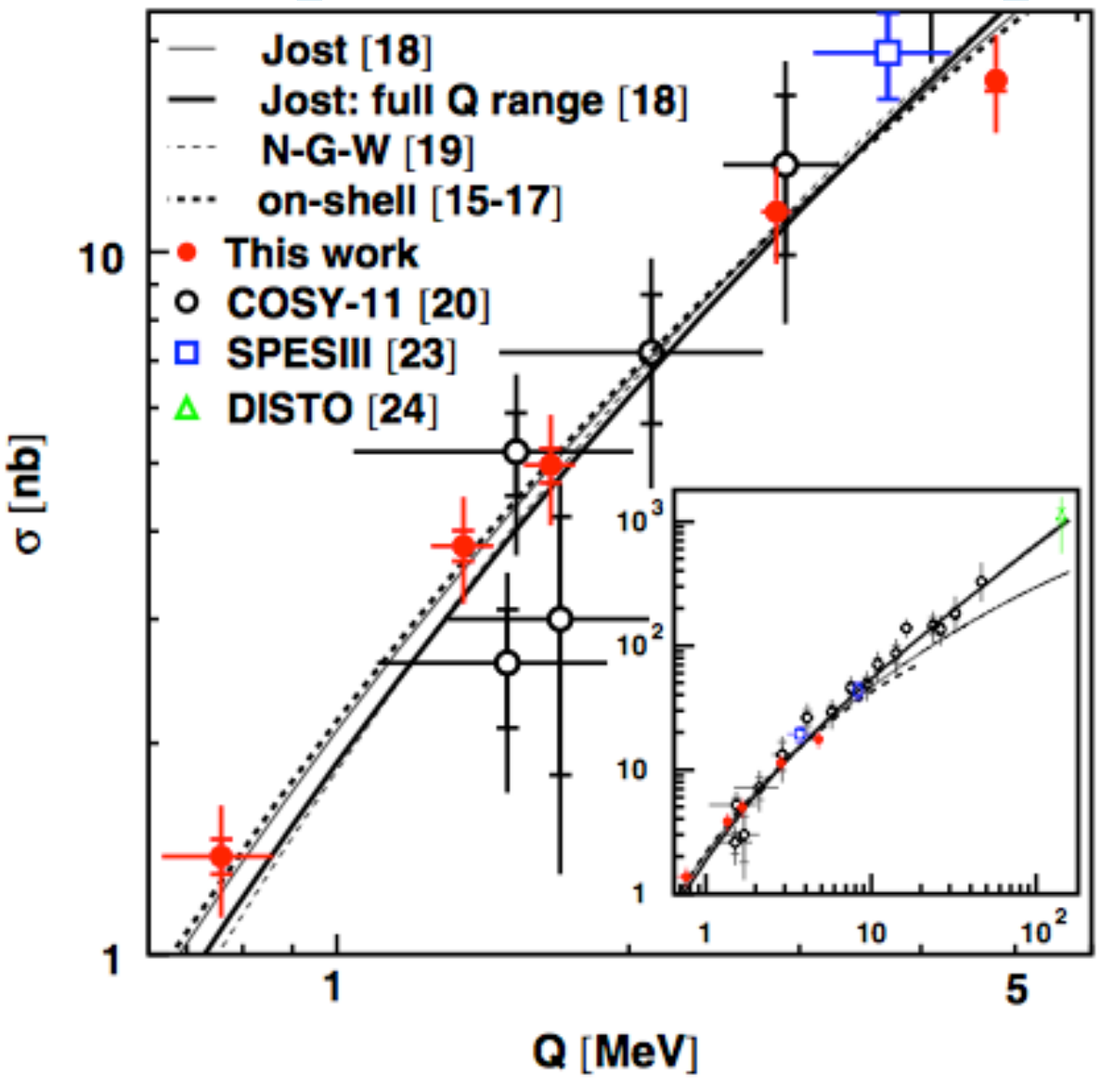
V_0=−(32±11) MeV

COSY-11

V_0=−(37±10$_{stat}$±10$_{syst}$) MeV

Nanova et al., PLB 727, 417 (2013)

elementary process : pp→ppη′

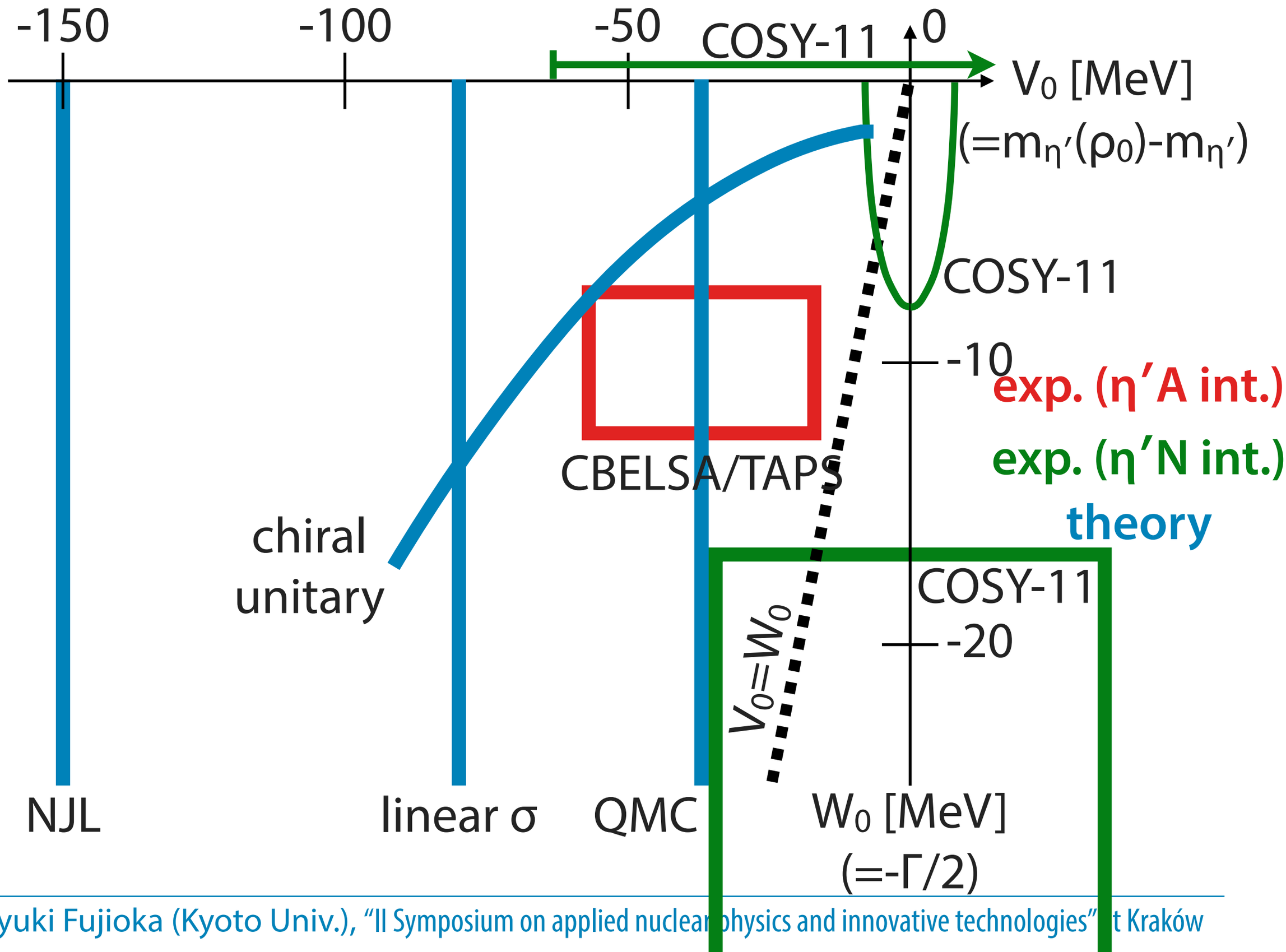


Czerwiński et al., PRL 113, 062004 (2014)

$\mathrm{Re}\, a_{\eta' N} = 0 \pm 0.43$ fm

$\mathrm{Im}\, a_{\eta' N} = 0.37^{+0.40}_{-0.16}$ fm

η′ optical potential: state of the art

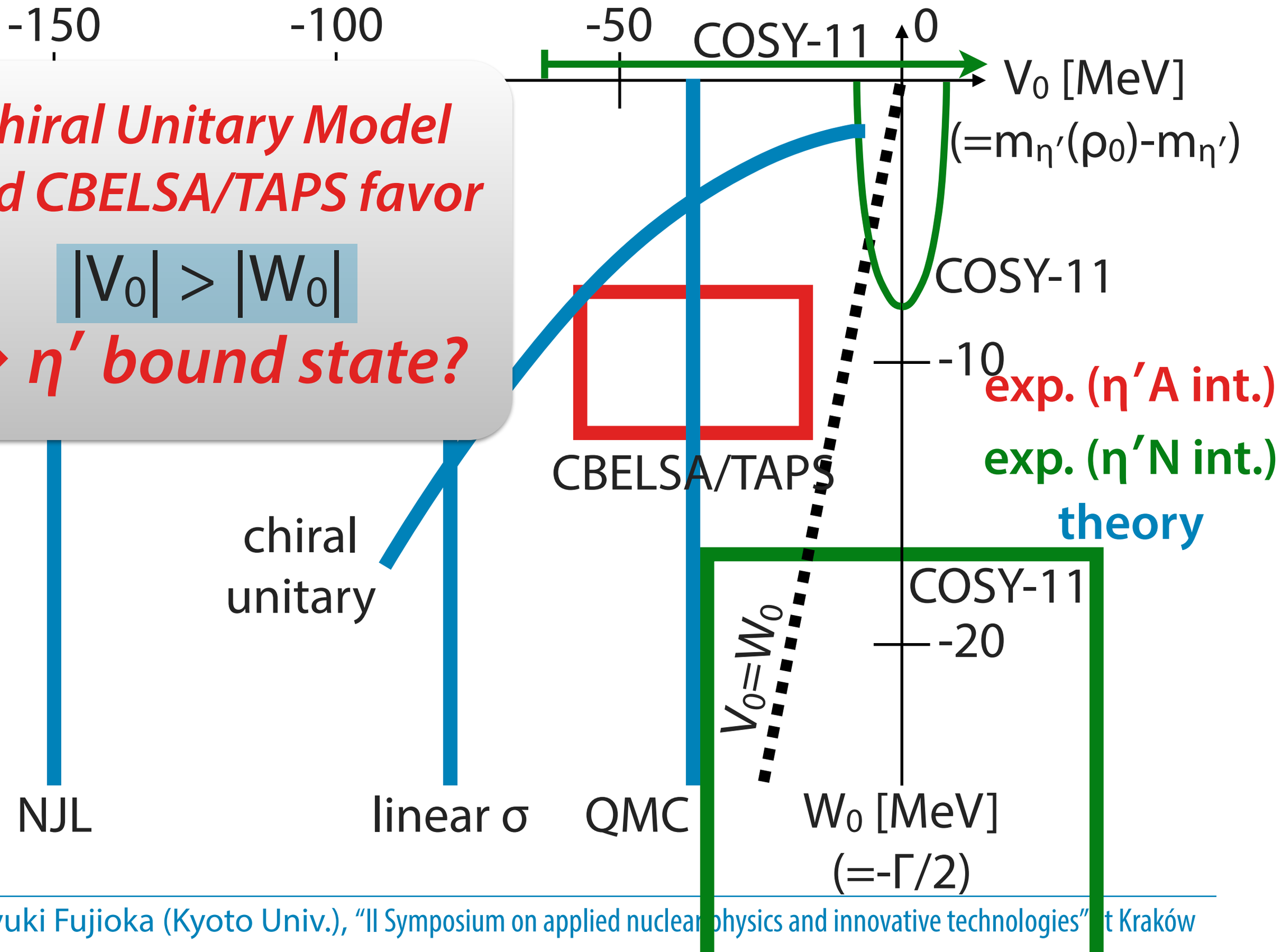


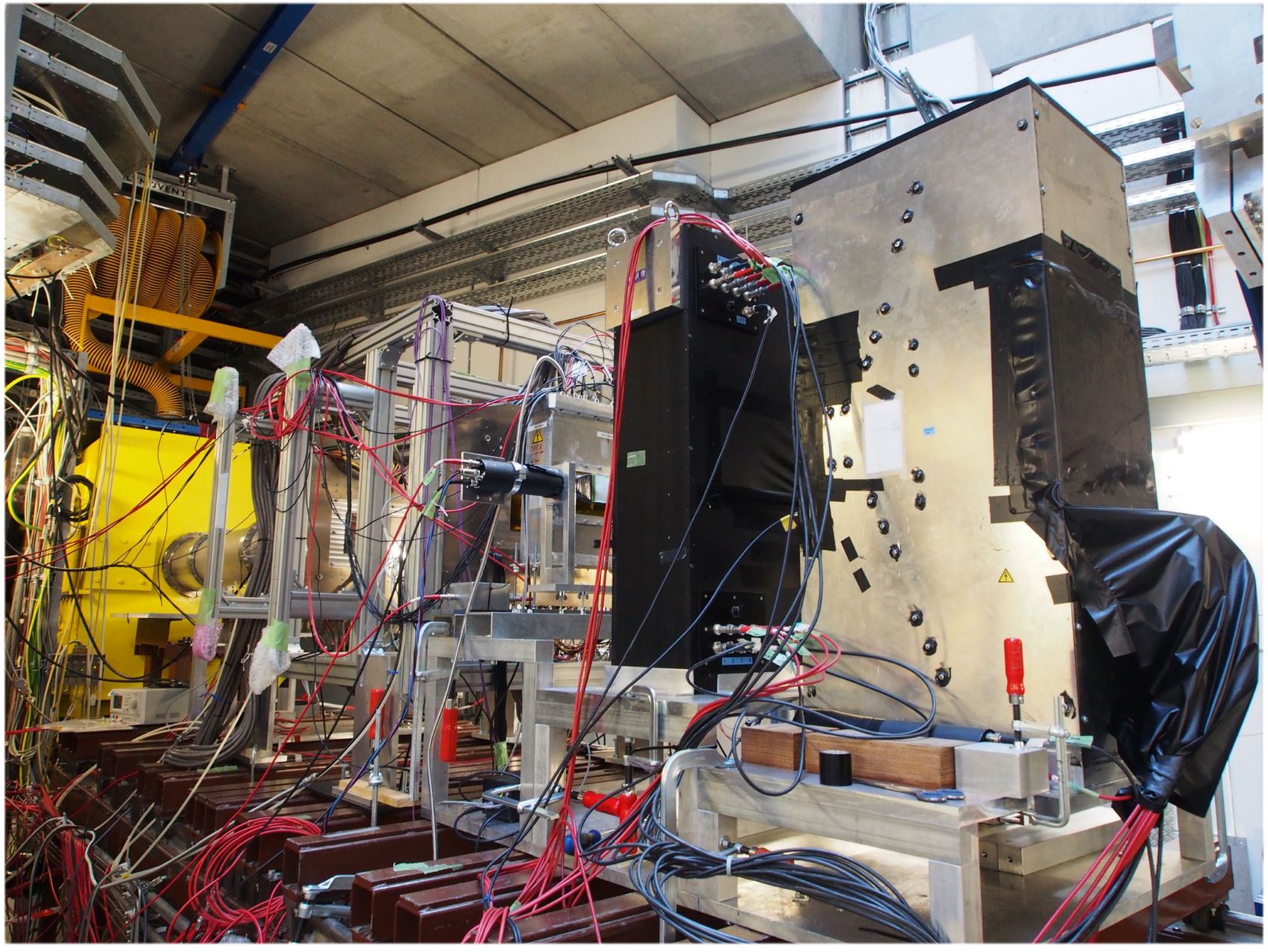
η′ optical potential: state of the art

Chiral Unitary Model and CBELSA/TAPS favor

$$|V_0| > |W_0|$$

→ η′ bound state?

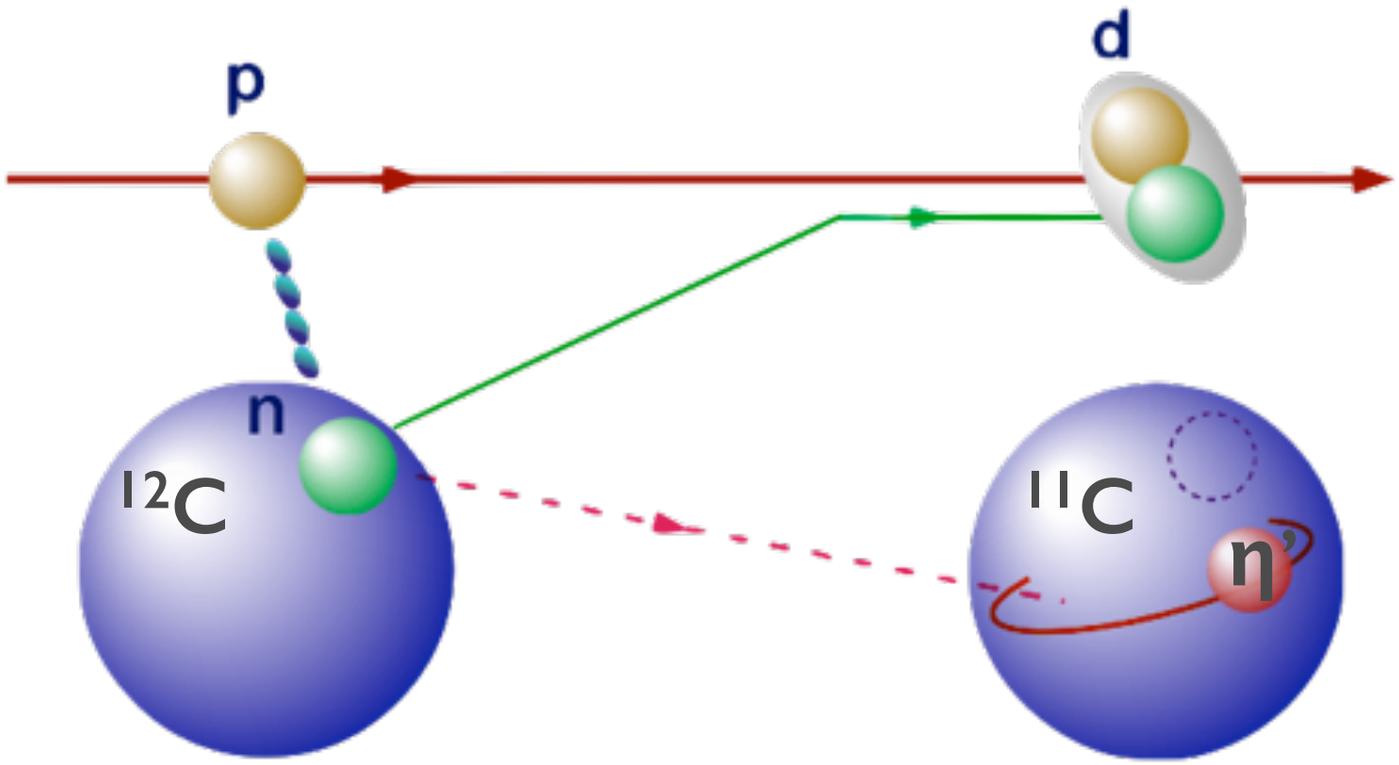


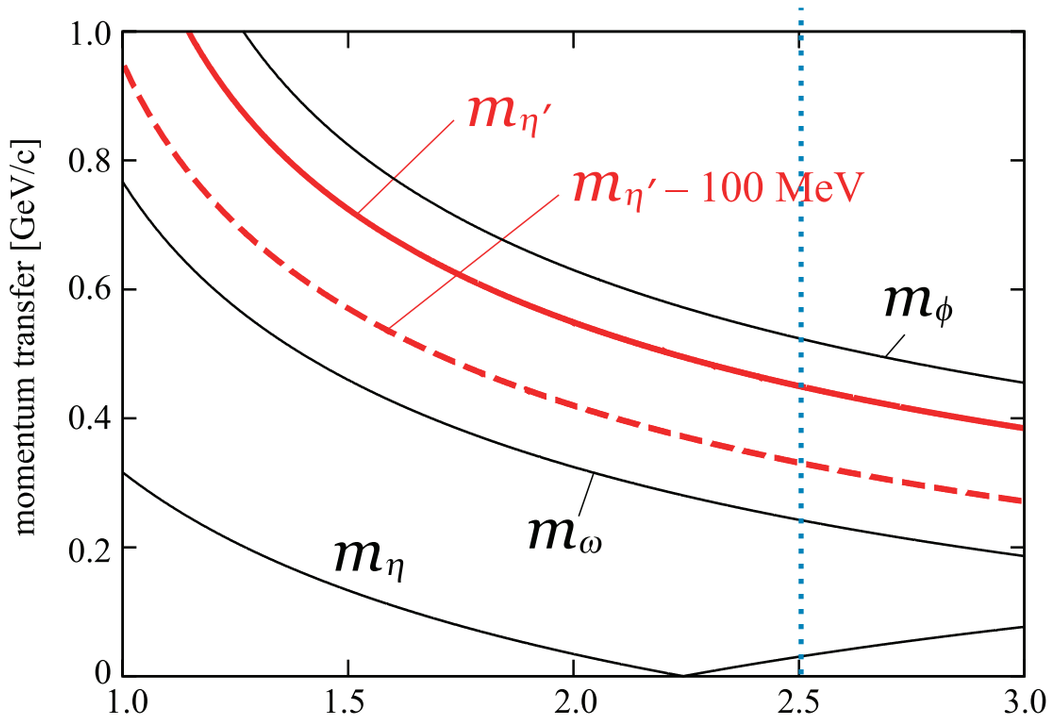


spectroscopy of η′ mesic nuclei at GSI

Hiroyuki Fujioka (Kyoto Univ.), “II Symposium on applied nuclear physics and innovative technologies” at Kraków

^{12}C(p,d) reaction

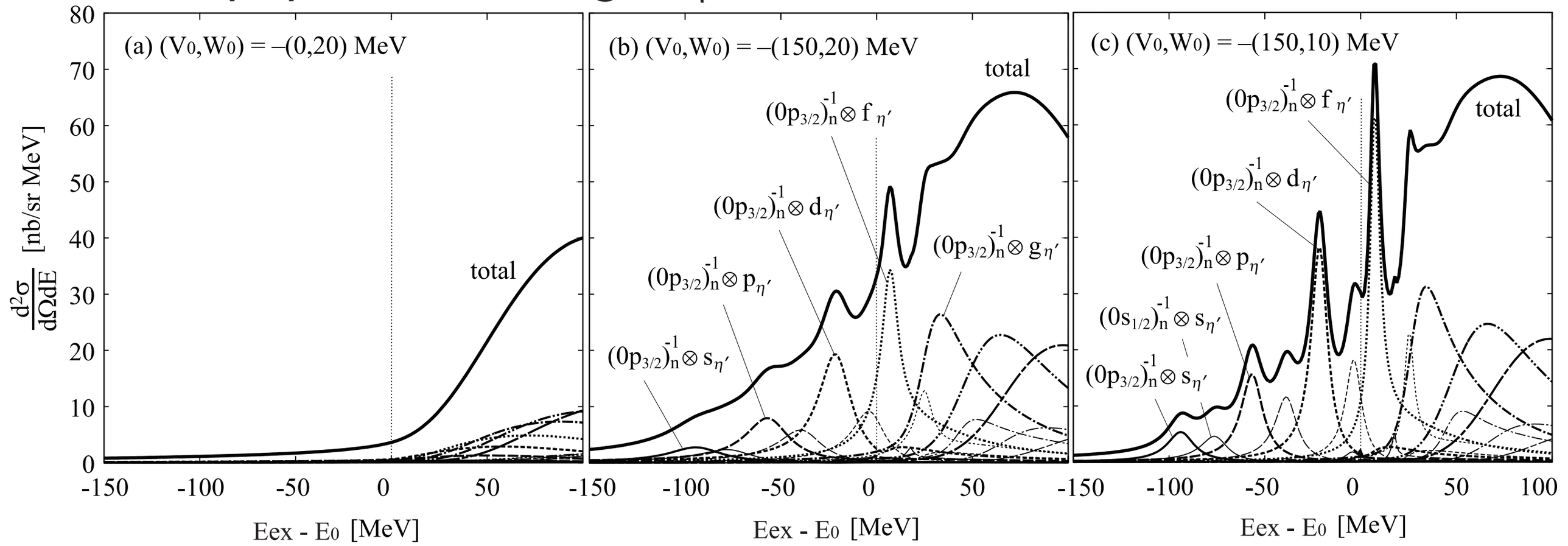




- intense proton beam available
- relatively large momentum transfer
  - population of large $\ell_{\eta'}$ states near threshold
  - different rigidities between protons and deuterons (from an experimental point of view)

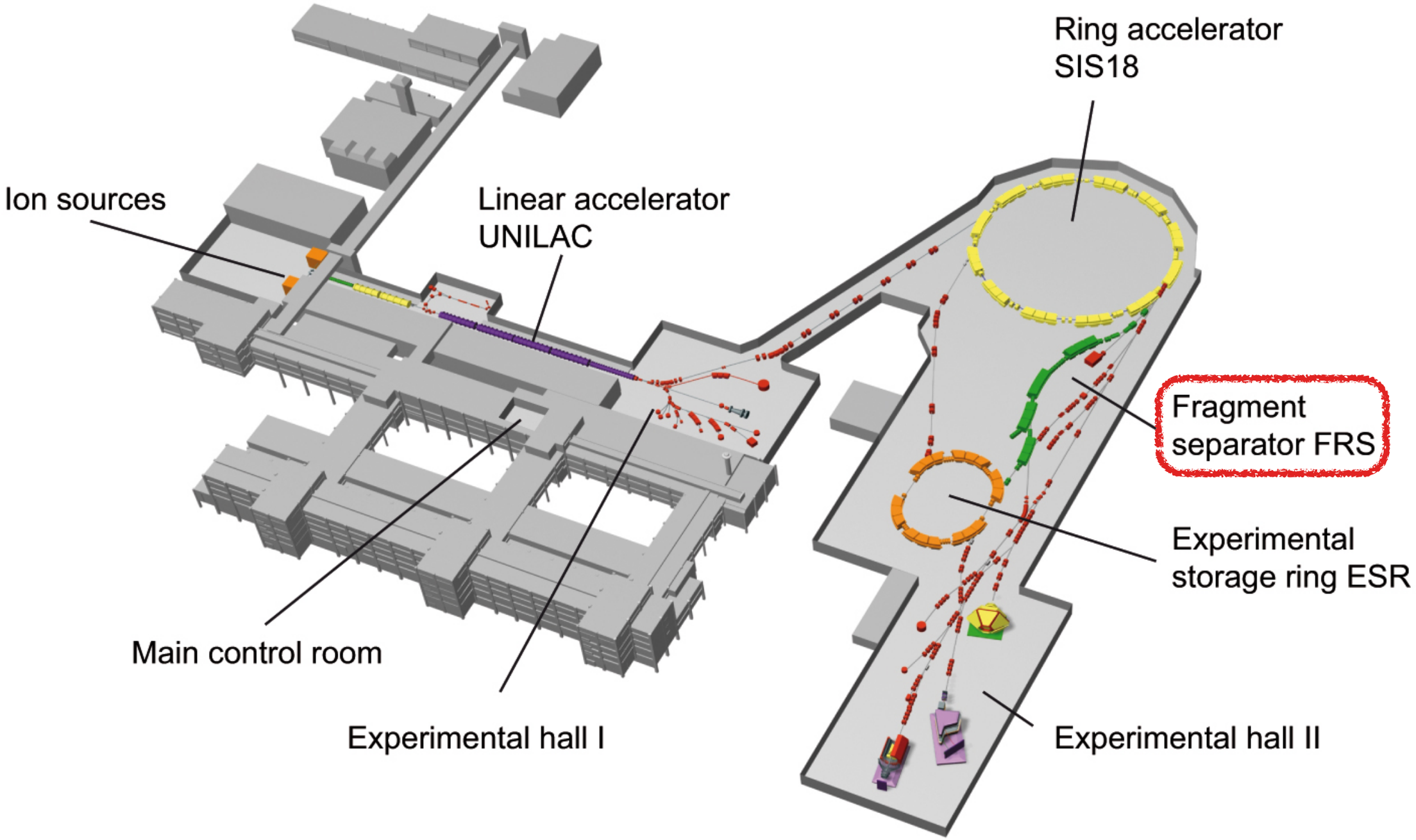
theoretical calculation

- elementary cross section : $d\sigma/d\Omega(pn \rightarrow d\eta') = 30 \mu b/sr$
- relatively large momentum transfer
  - population of large $\ell_{\eta'}$ states near threshold



Nagahiro et al., PRC 87, 045201 (2013)

GSI accelerator facility



GSI S437 experiment (*)

Letter of Intent for GSI-SIS

Spectroscopy of η' mesic nuclei with $(p,\ d)$ reaction

— Interplay of $U_A(1)$ anomaly and chiral restoration in η' mass —

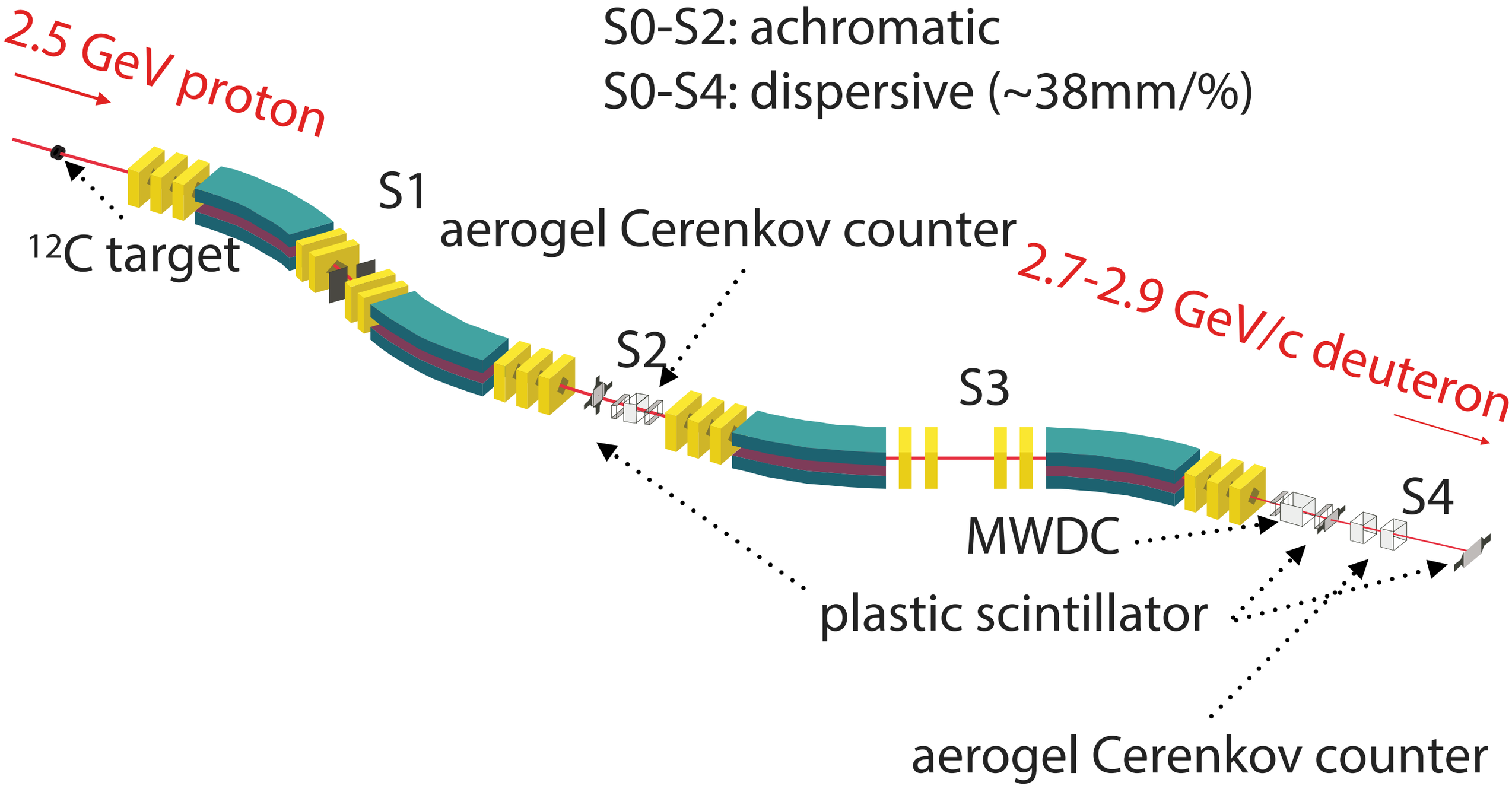
(2011)

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

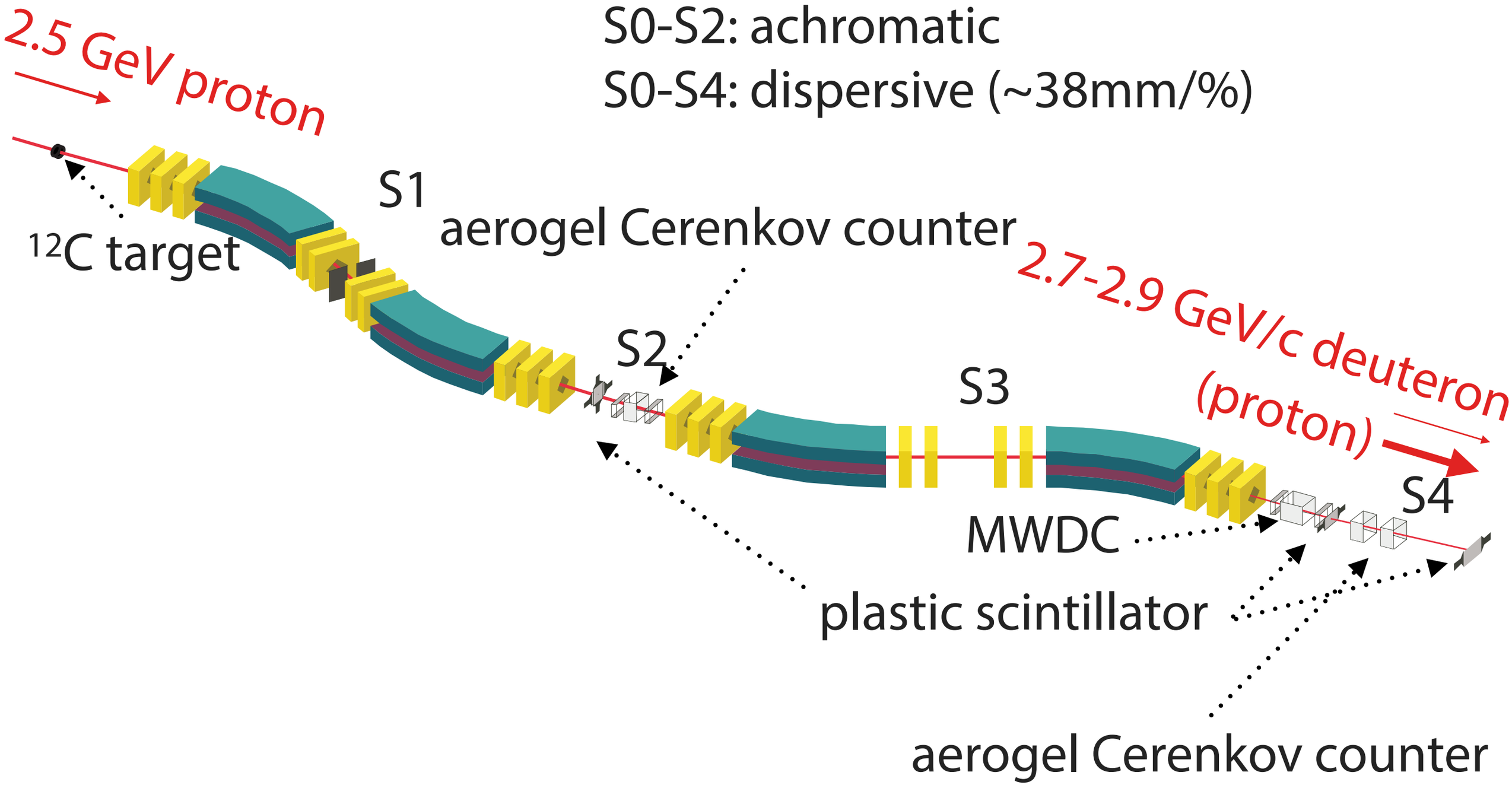
- intense proton beam from SIS-18 (~10^{10}/spill)
- 4g/cm^2-thick ^{12}C target
- high resolution measurement of deuteron by FRS
- overall missing-mass resolution : $\sigma < 2$MeV/c^2

(*) under the framework of the Super-FRS collaboration

experimental setup

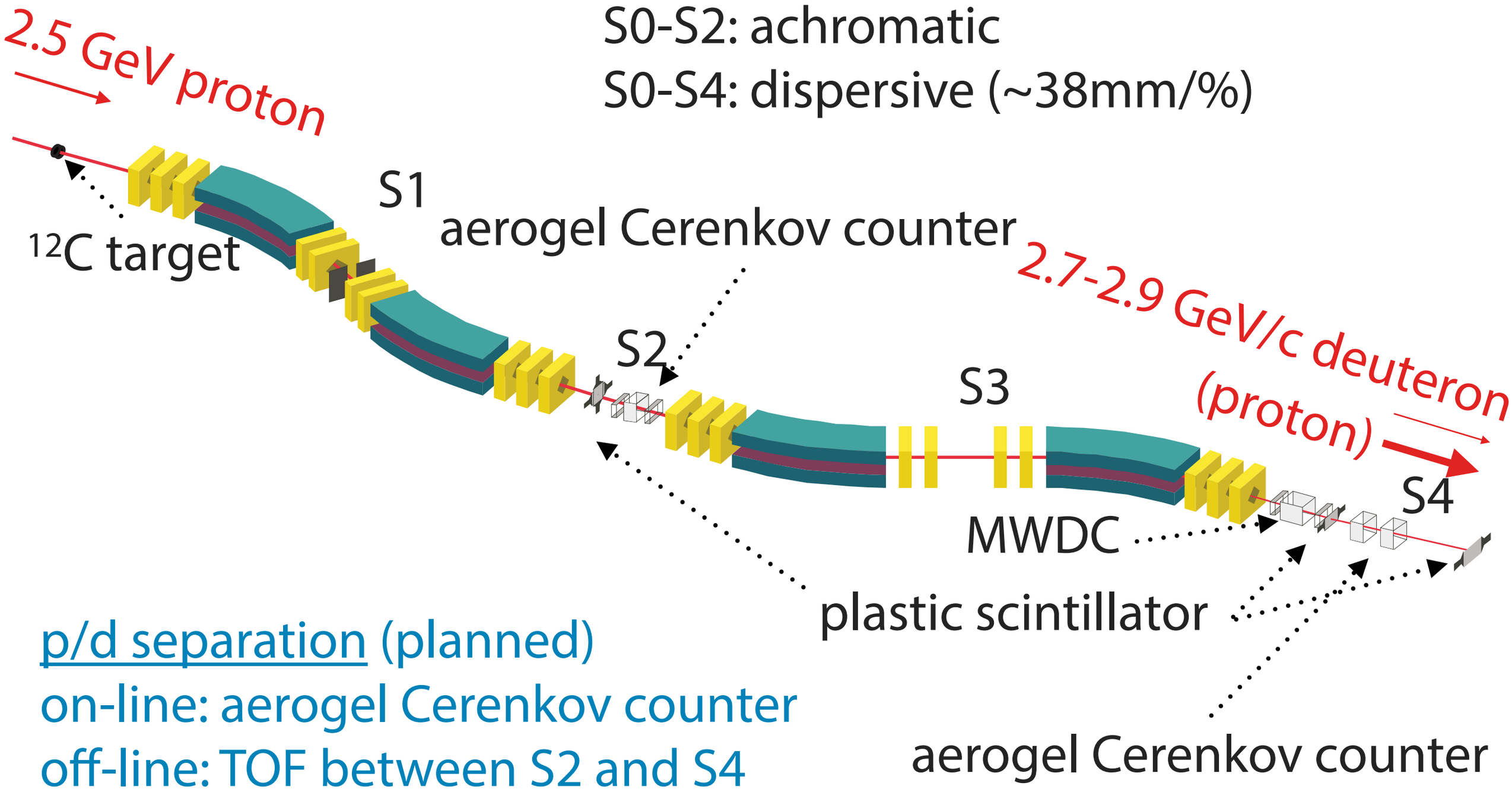


experimental setup



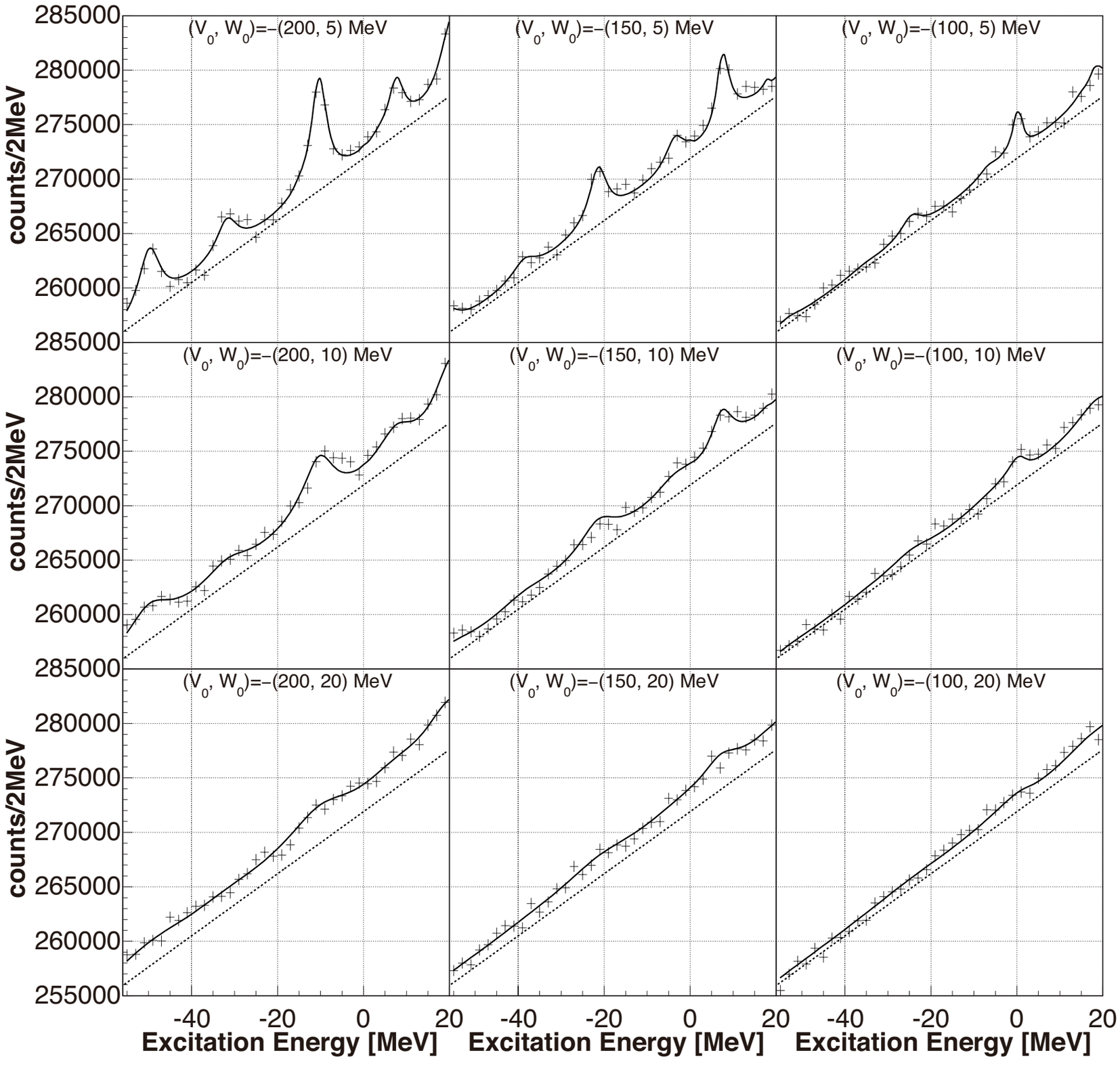
experimental setup

S0-S2: achromatic
S0-S4: dispersive (~38mm/%)



p/d separation (planned)
on-line: aerogel Cerenkov counter
off-line: TOF between S2 and S4
(diff. by ~20ns)

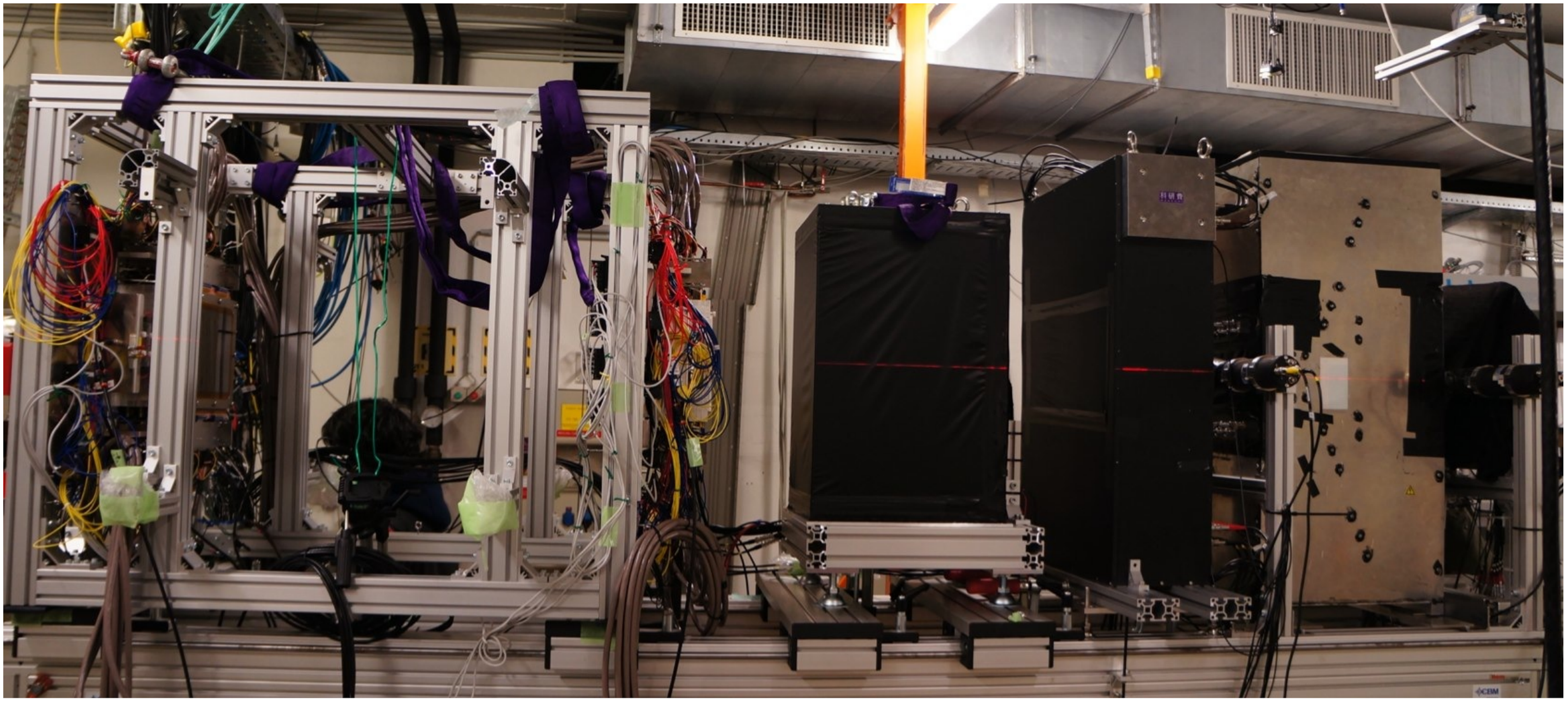
expected spectrum w/ 4.5-day DAQ



integrity test @ COSY-JESSICA, Jülich

1.5, 2.7GeV/c proton

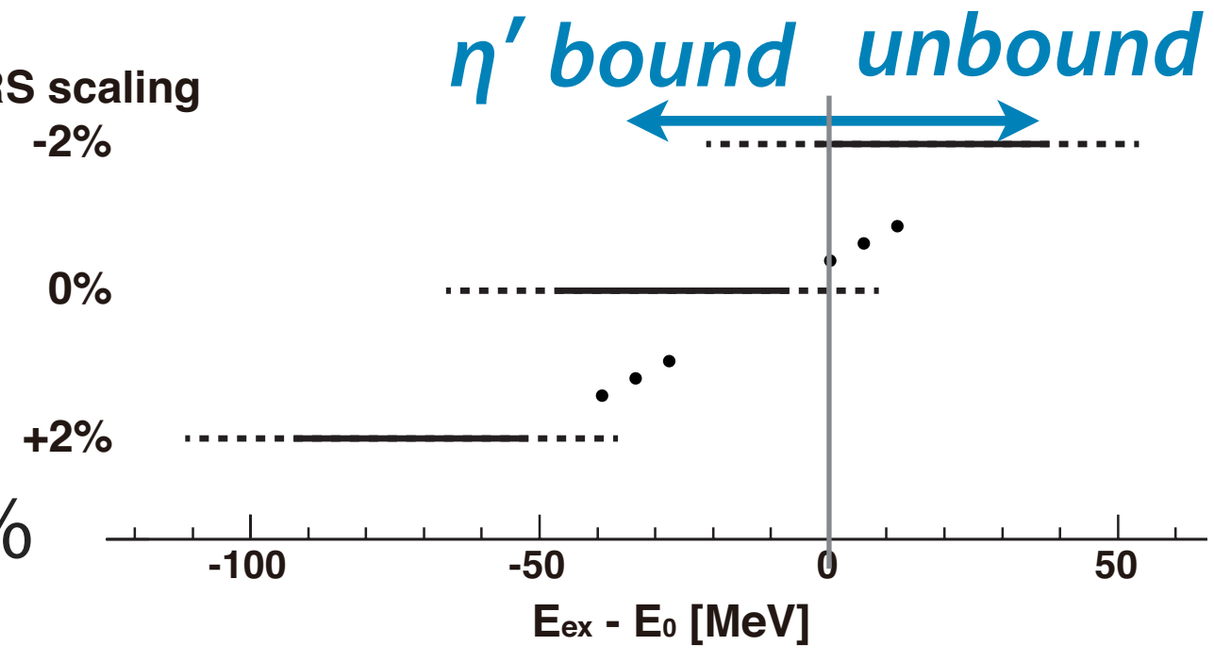
27th Jan. - 10th Feb. 2014



special thanks to: F. Goldenbaum, O. Felden, R. Maier, D. Prasuhn

S437 Exp. : 1st-8th August 2014

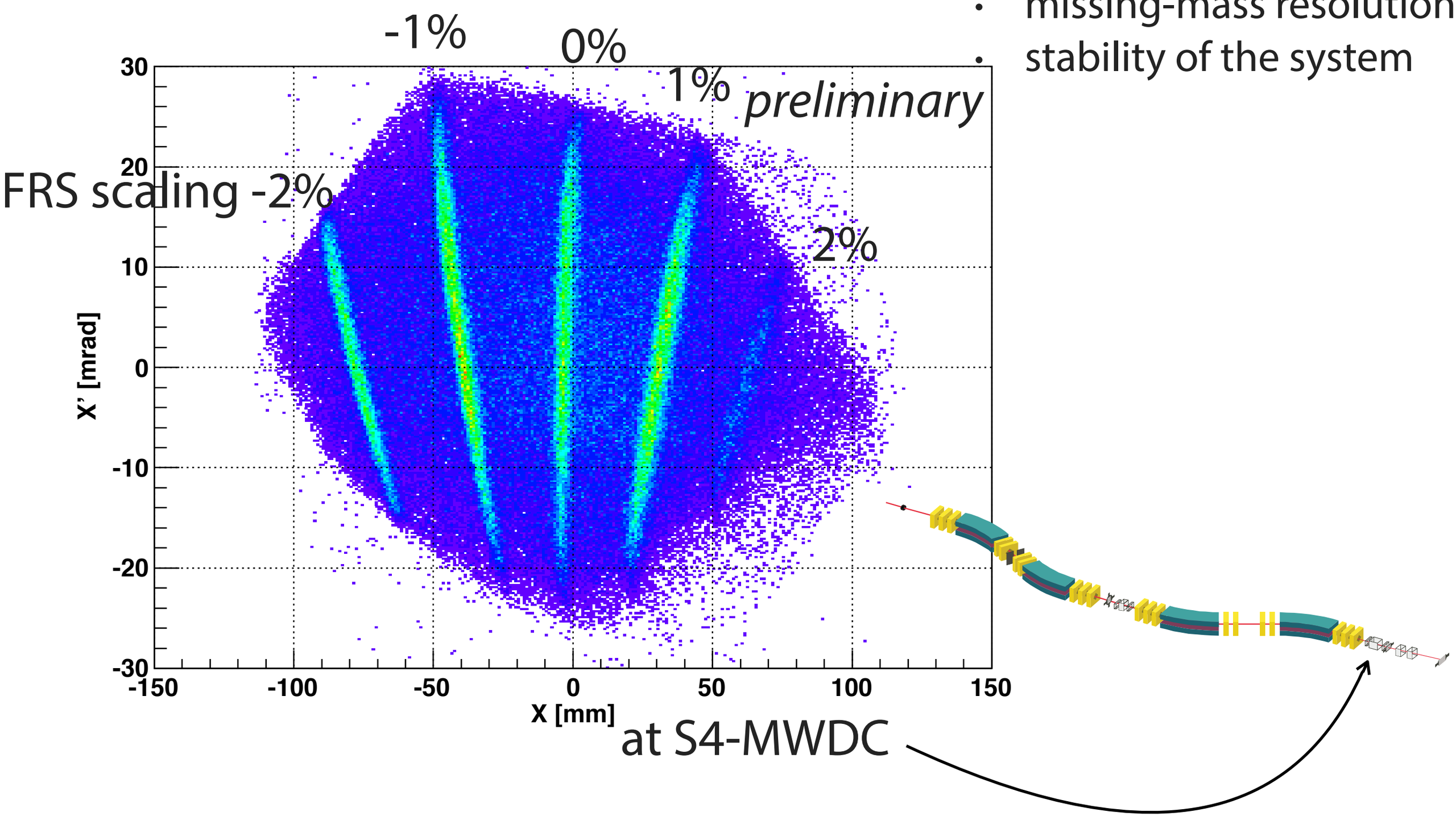
- Production Run (~5 days) : C(p,d) @ T_p=2.5 GeV
  - intensity (3–4)×10^{10} /spill
  - target thickness 4g/cm^2
  - FRS scaling from -2% to 2%
    - (5–10)×10^6 deuterons in each scaling mode



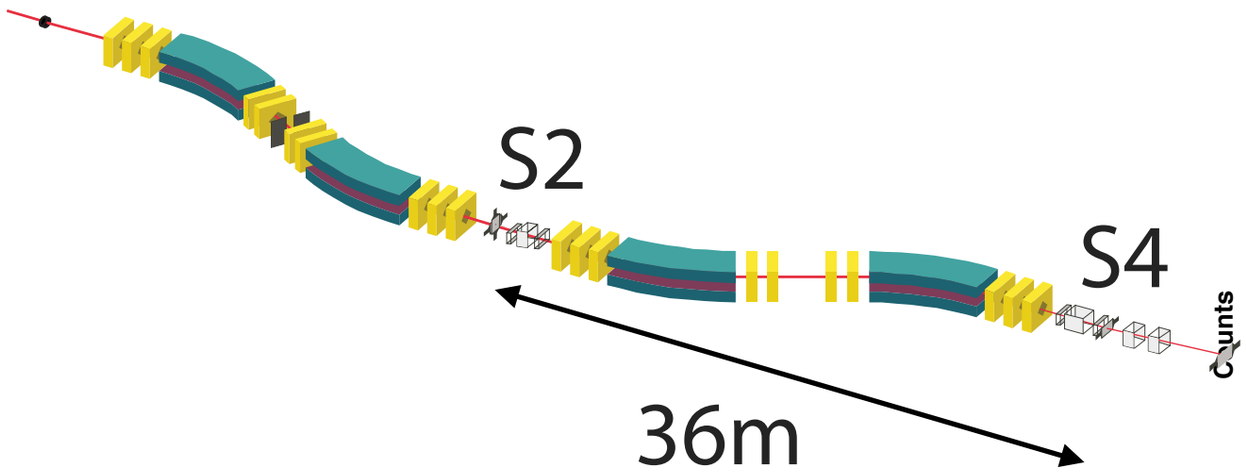
- Calibration Run : D(p,d)p @ T_p=1.6GeV
- Reference Run : D(p,d) @ T_p=2.5 GeV
  - background measurement (p+(p/n)→d + multi π's)

Calibration Run: D(p,d)p

- information on optics
- missing-mass resolution
- stability of the system



particle identification

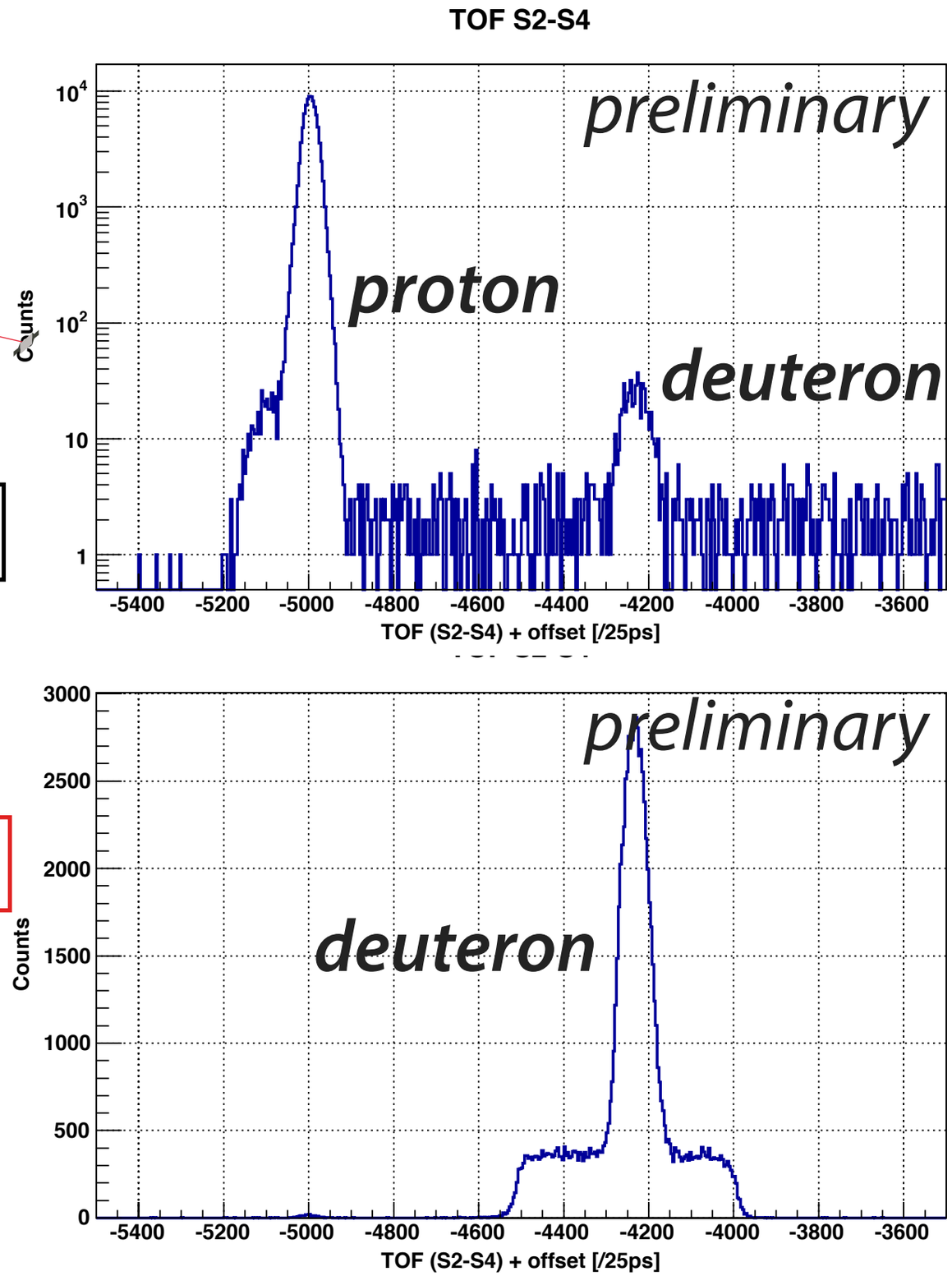


unbiased p/d ratio ~ **200**

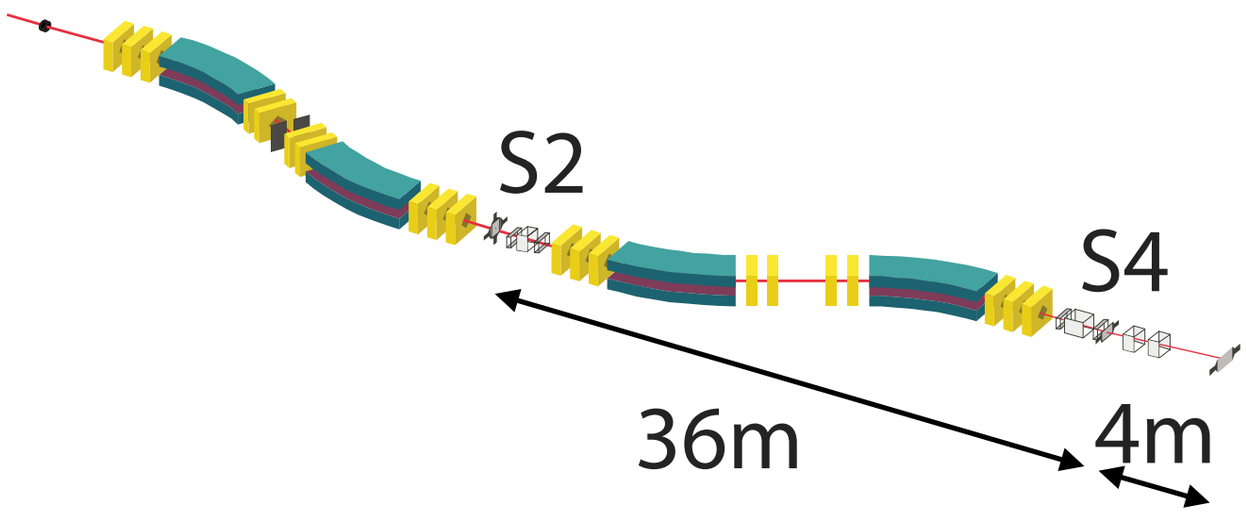
proton: 99.5% rejection

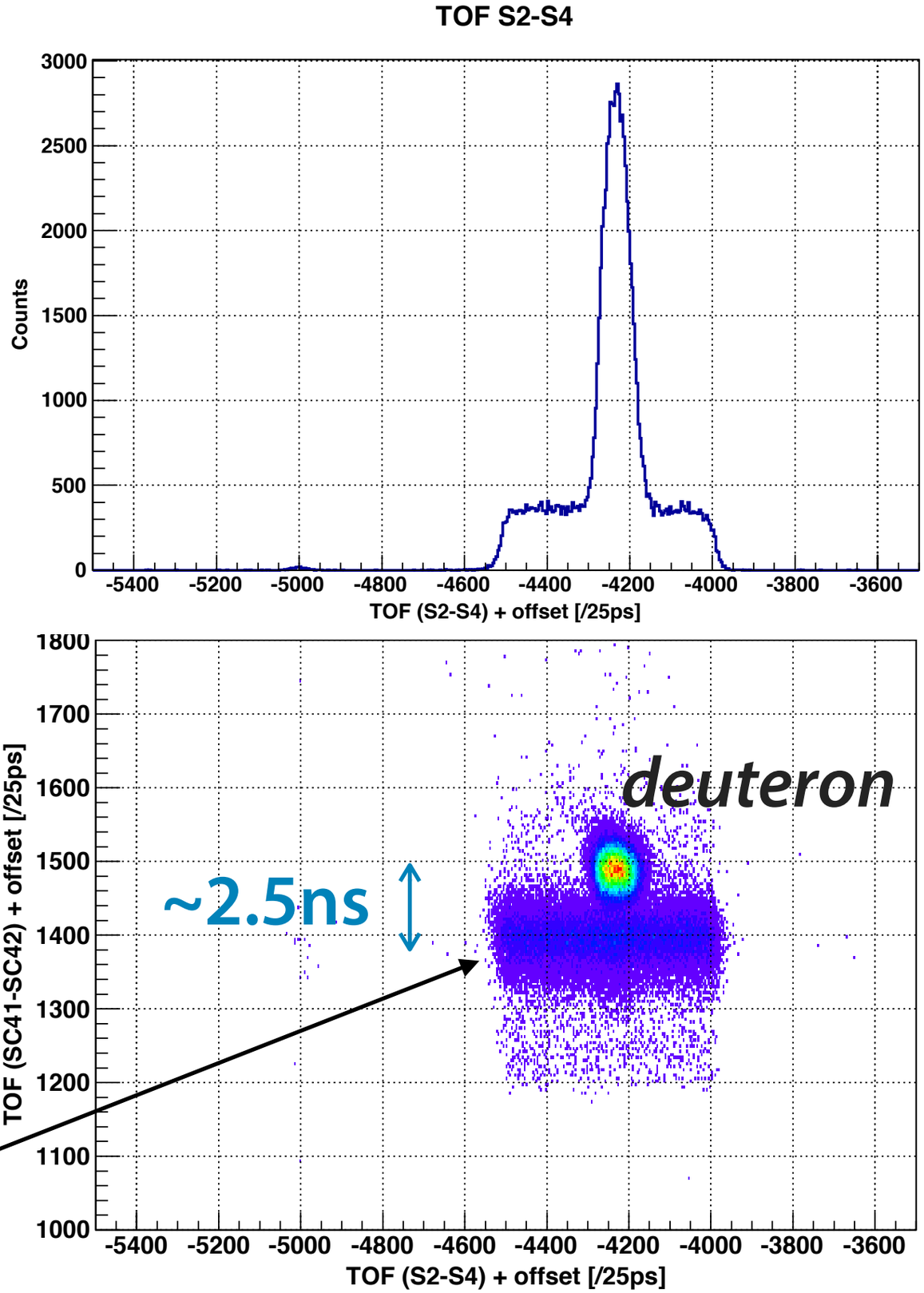
TOF trigger p/d ratio ~ 1

note: Cerenkov counters were *not* used for triggering purpose.



(p,d) event selection





further analysis

- Cerenkov signal
- waveform analysis of S2, S4 scintillators

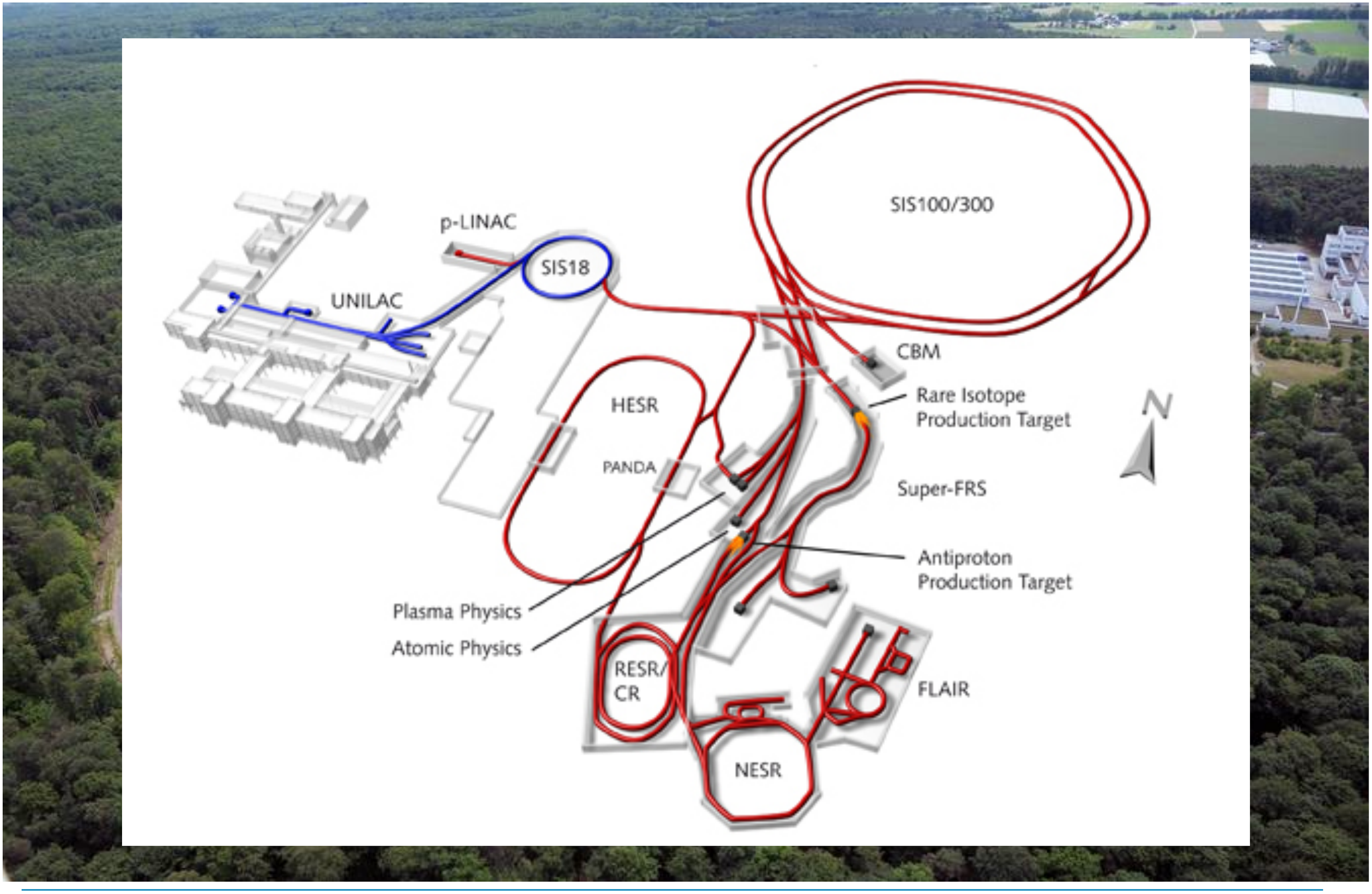
➡ (p,d) event selection

"proton traveling through S2-S4 plus a preceding proton"

FAIR under construction

Hiroyuki Fujioka (Kyoto Univ.), “II Symposium on applied nuclear physics and innovative technologies” at Kraków

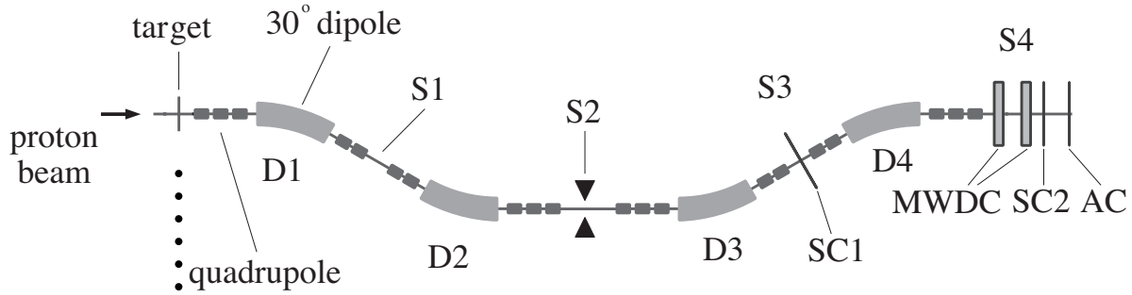
FAIR under construction



inclusive measurement at FAIR

from FRS to Super-FRS

FRS



Super-FRS

more intense beam (10^{11-13}/spill?)
and larger aperture of Super-FRS

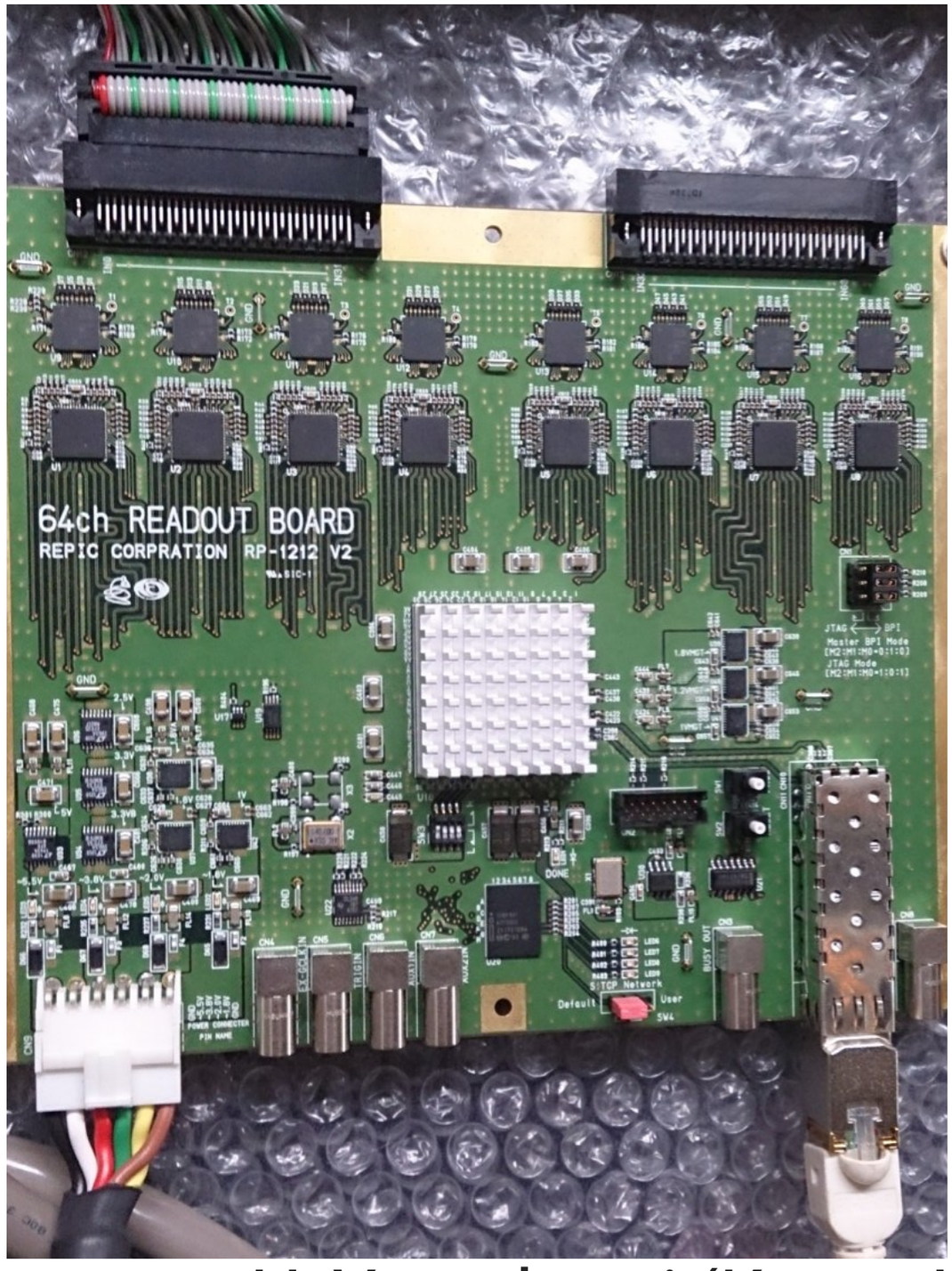
→ rejection of BG from beam dump

→ rate capability of detectors

→ faster DAQ

all-in-one readout board

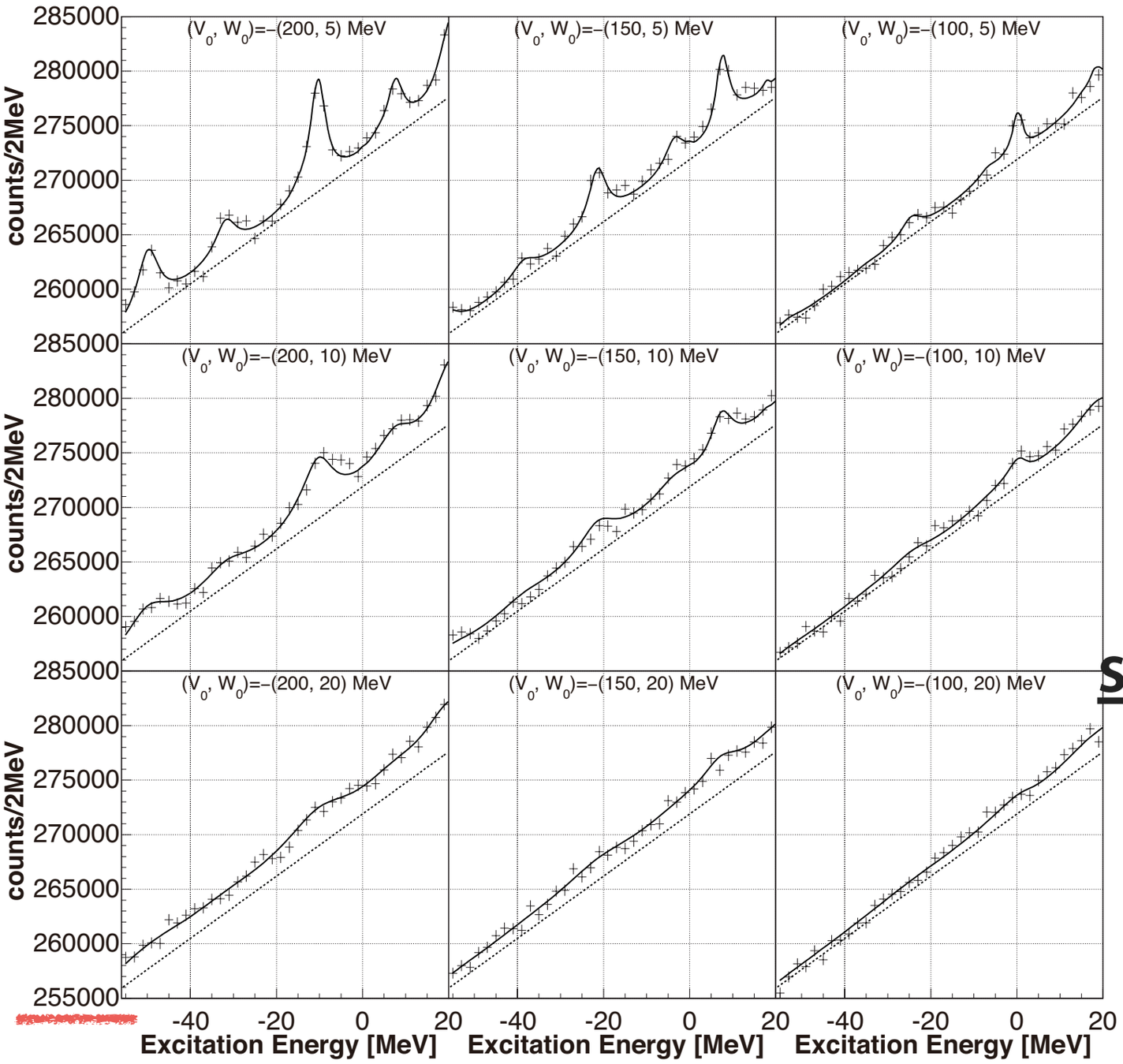
- one order of magnitude higher trigger rate
- R&D of 64ch readout board for MWDC
  - ASD + FlashADC + TDC
  - originally developed for Belle-II CDC
  - sub-trigger module for trigger distribution



H. Yamakami (Kyoto Univ.)
Taniguchi et al., NIM A732, 540 (2013)

semi-exclusive measurement at FAIR

Why semi-exclusive measurement?



<u>inclusive measurement</u>

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

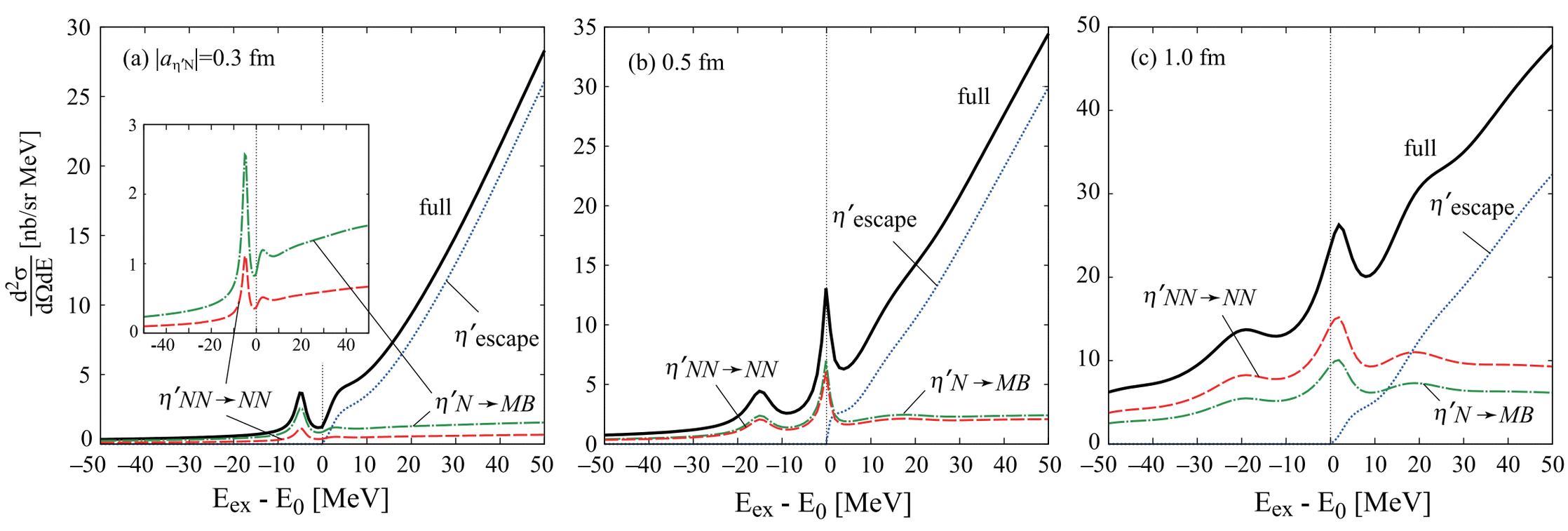
BG: multi-π production

<u>semi-exclusive measurement</u>

(w/ improved S/N)
more sensitivity in case of
shallow potential

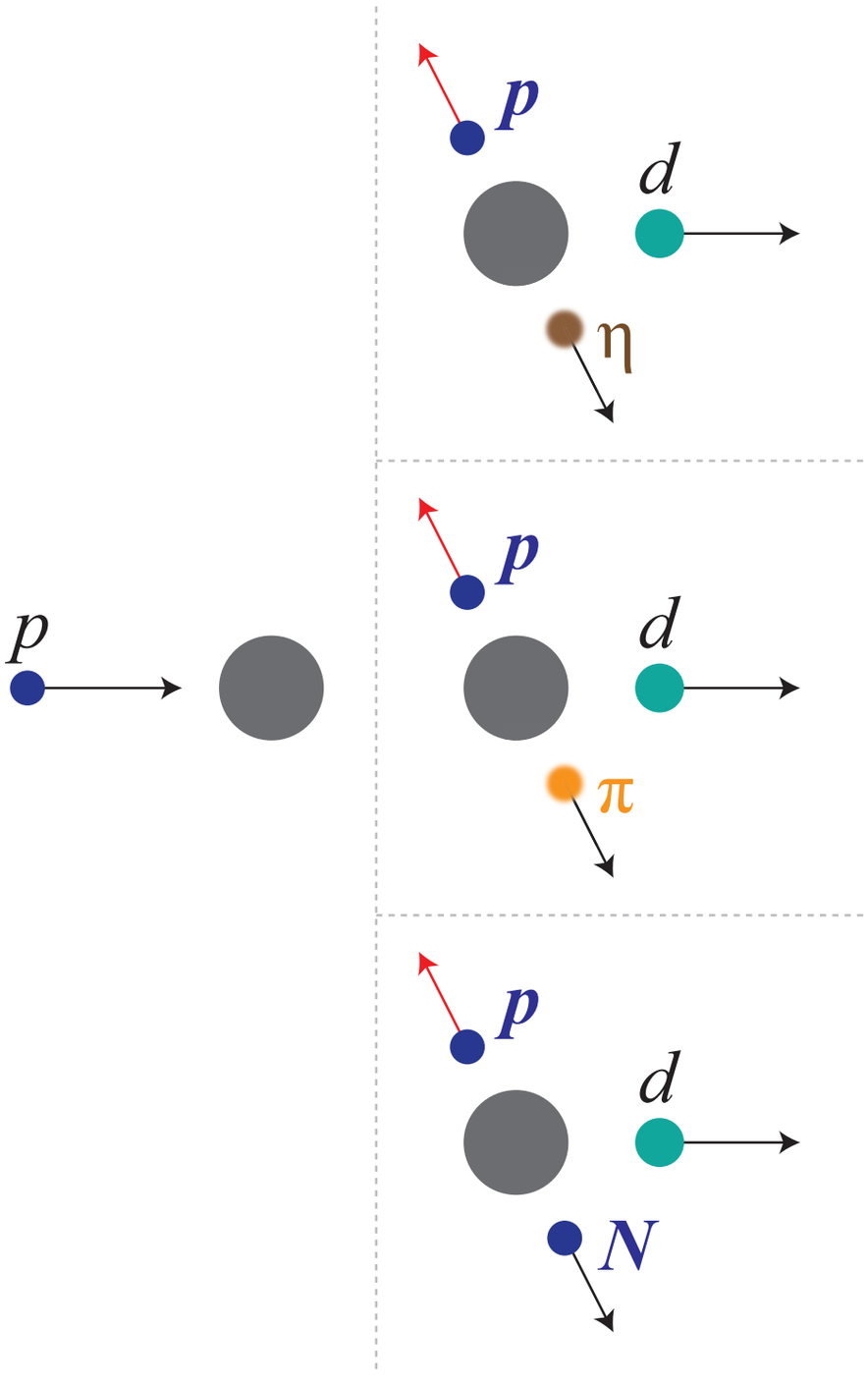
coincidence of decay particles

- one-nucleon absorption: $\eta' N \rightarrow \eta N, (\pi N)$
- two-nucleon absorption: $\eta' NN \rightarrow NN$
  - higher energy than in any mesonic processes

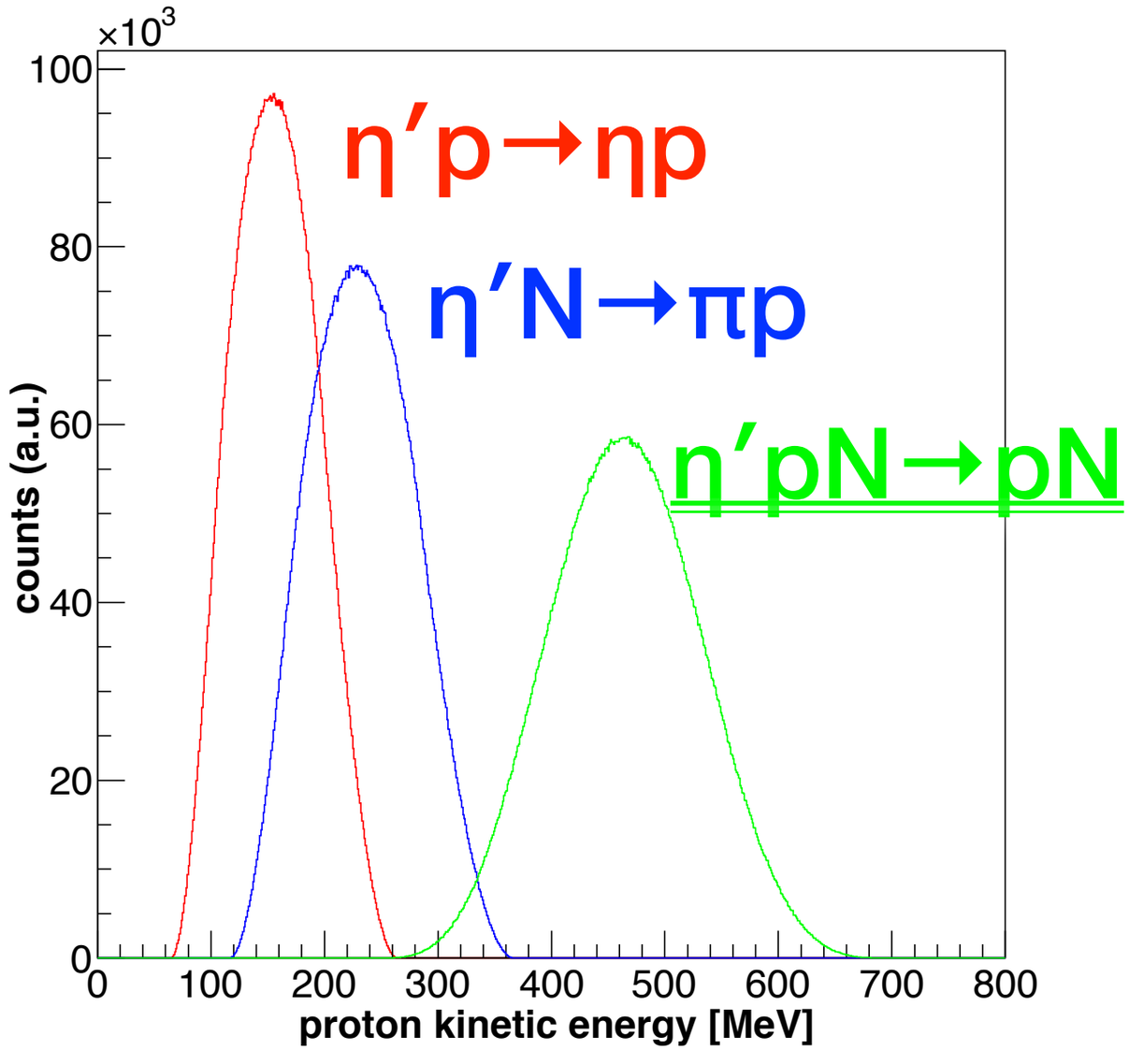


Nagahiro et al., PRC 87, 045201 (2013)

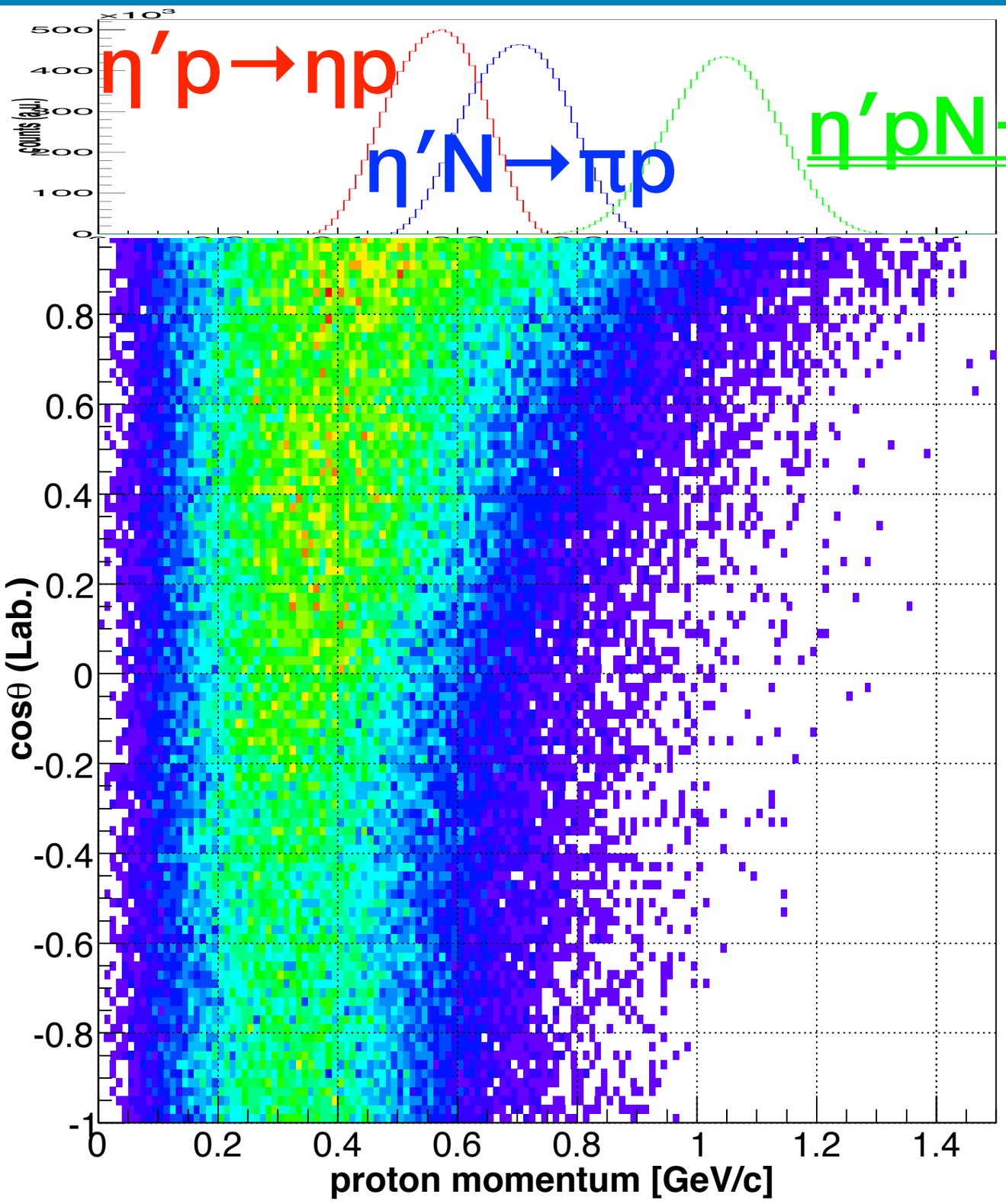
high-energy protons from η′ mesic nuclei



Detection of high energy protons
(T_p= 300–600 MeV)



high-energy protons from BG (multi π)

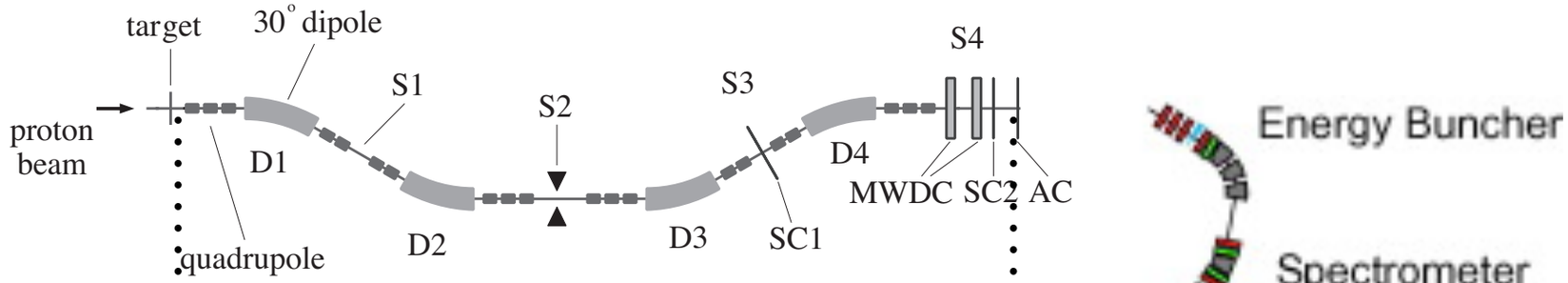


simulation by a microscopic transport model (JAM)

Y. Higashi
(Nara Women's Univ)
work in progress

from FRS to Super-FRS

FRS

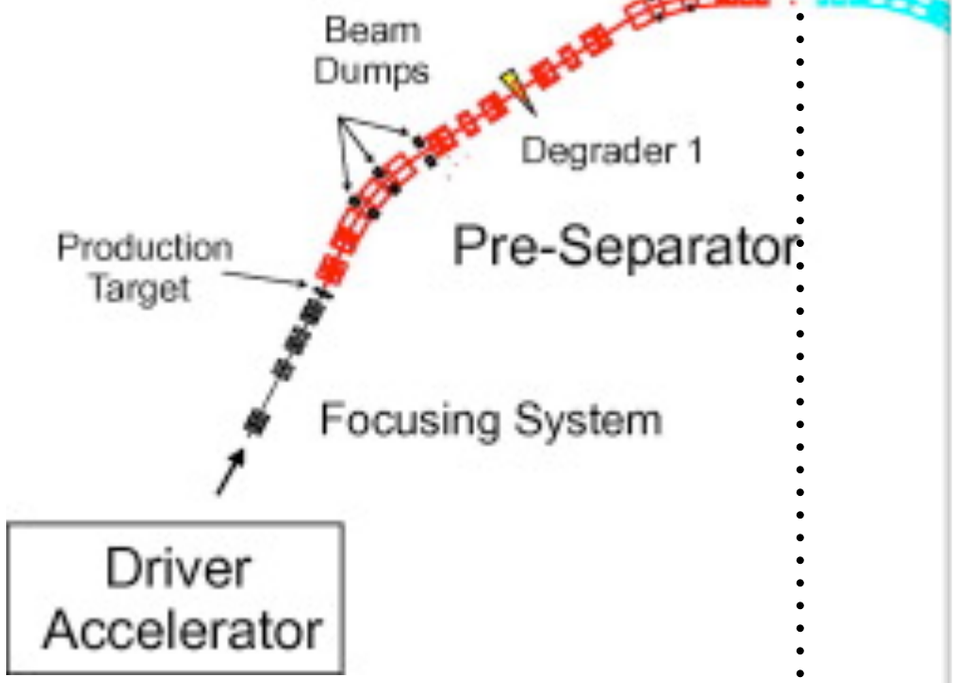


Super-FRS

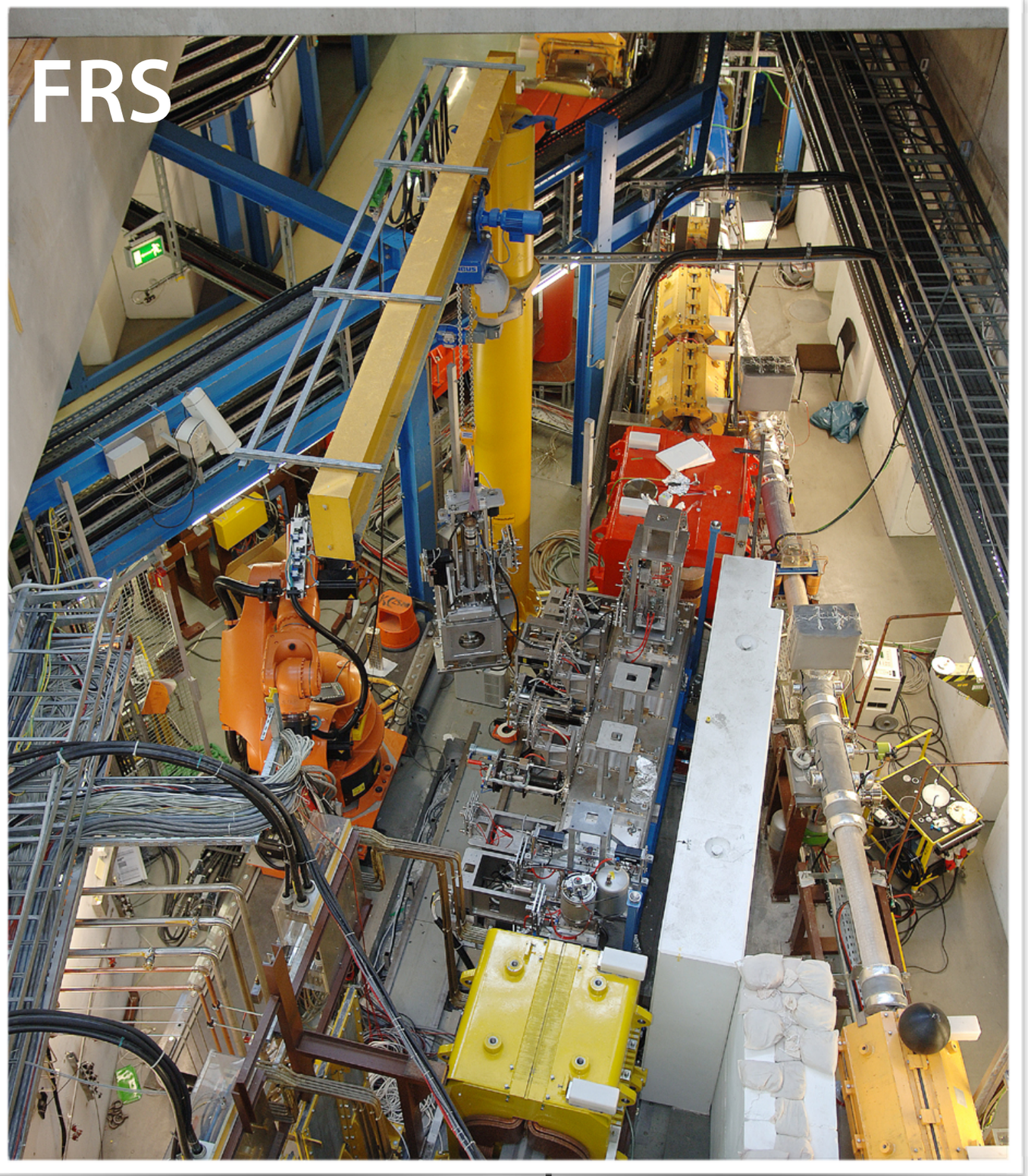
from FRS to Super-FRS

FRS

Super-FRS

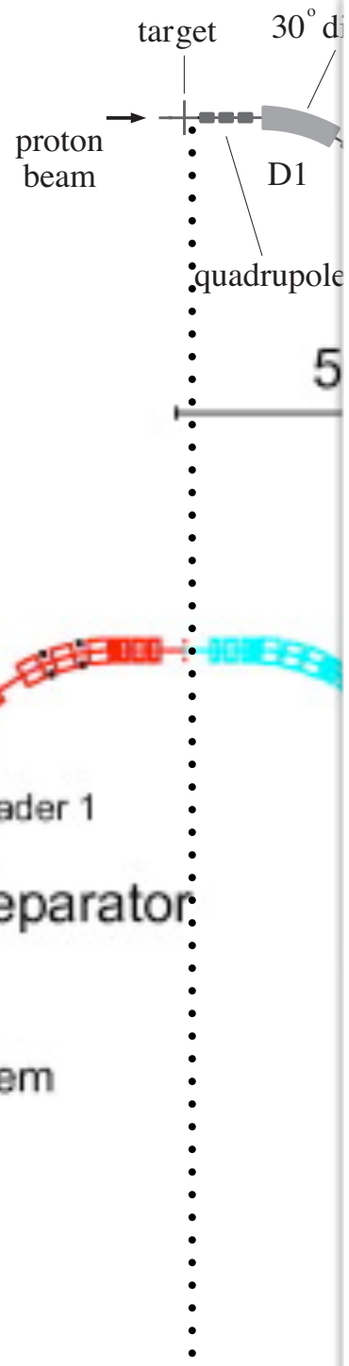


target



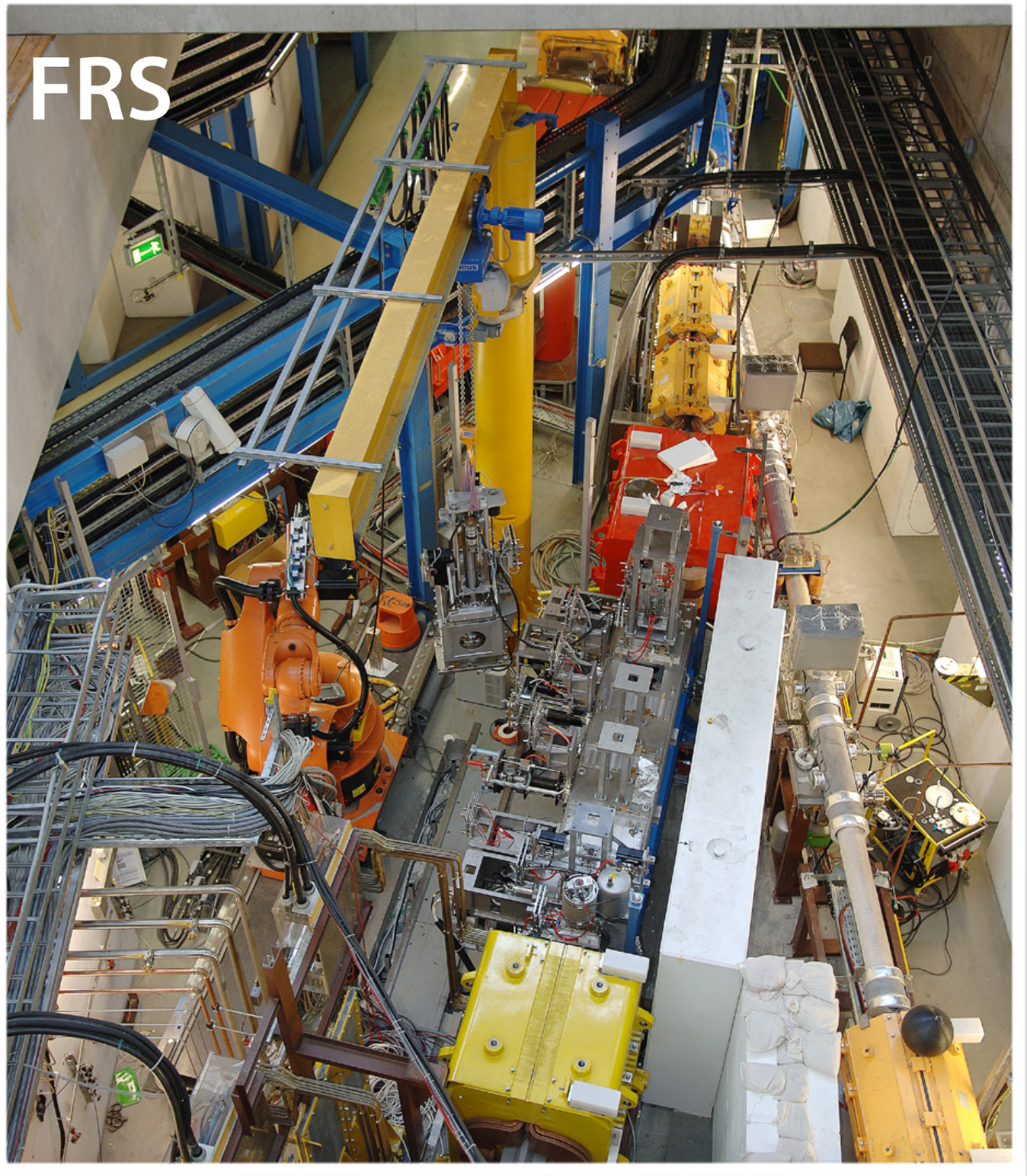
from FRS to Super-FRS

FRS



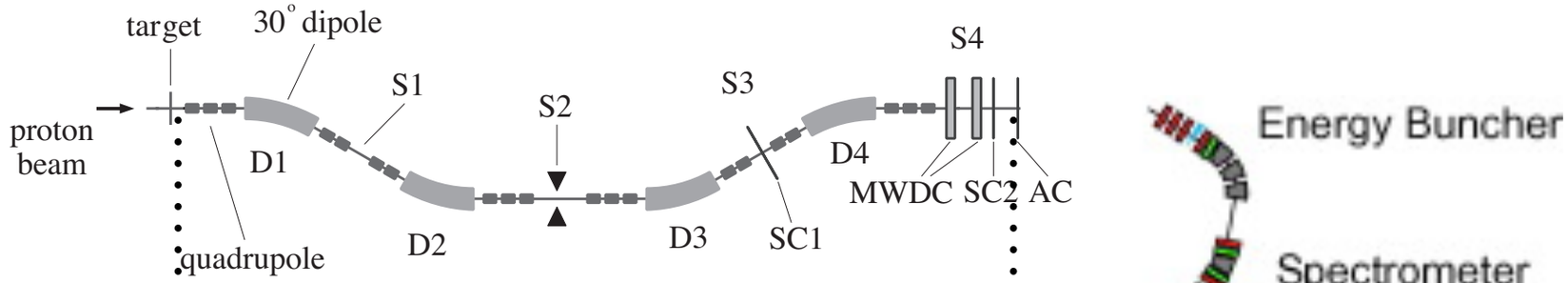
Super-FRS

target



from FRS to Super-FRS

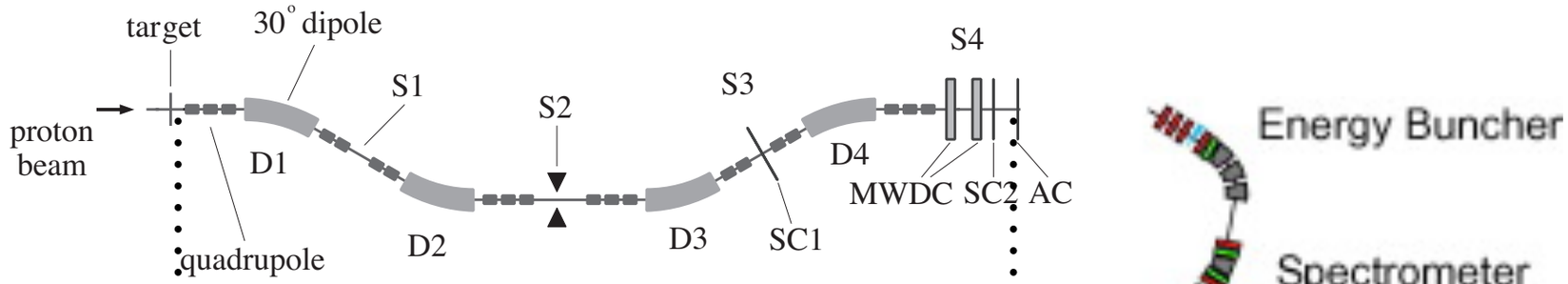
FRS



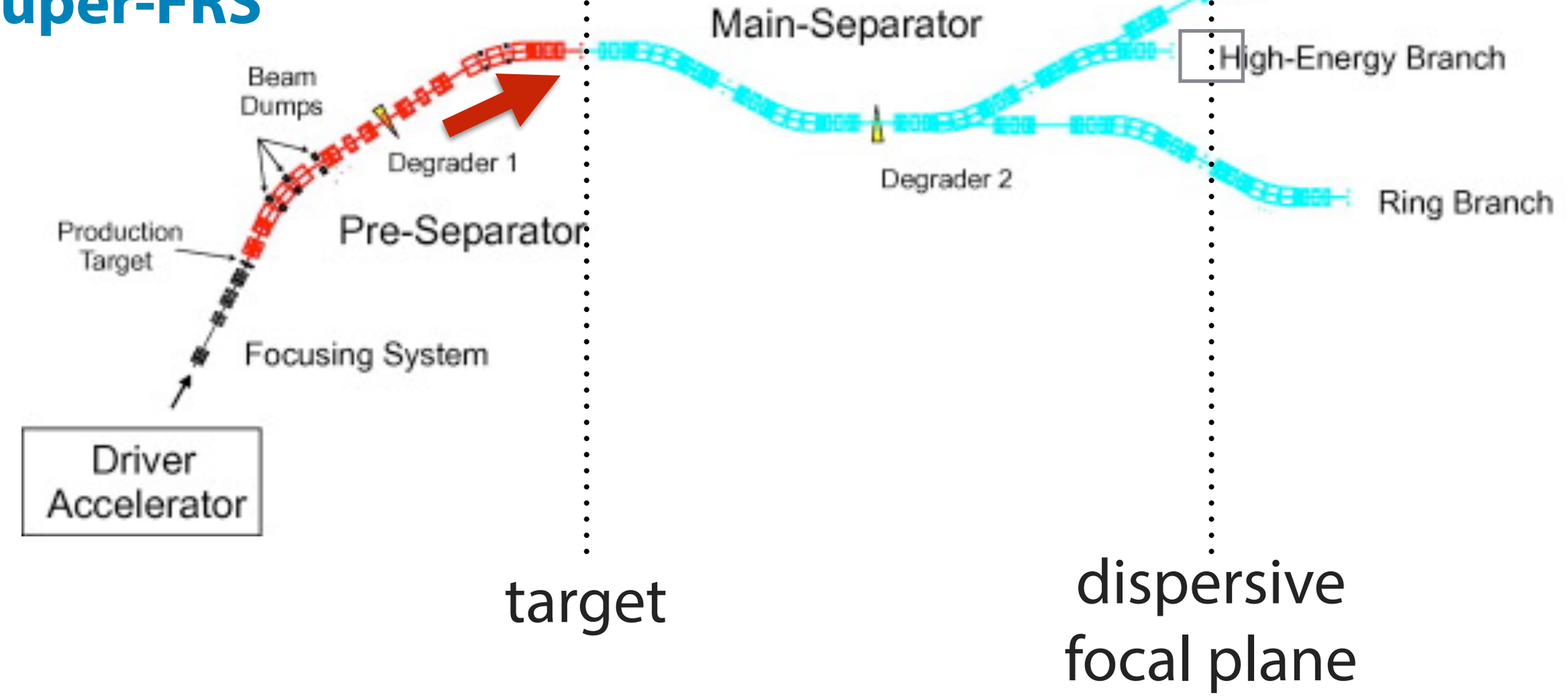
Super-FRS

from FRS to Super-FRS

FRS

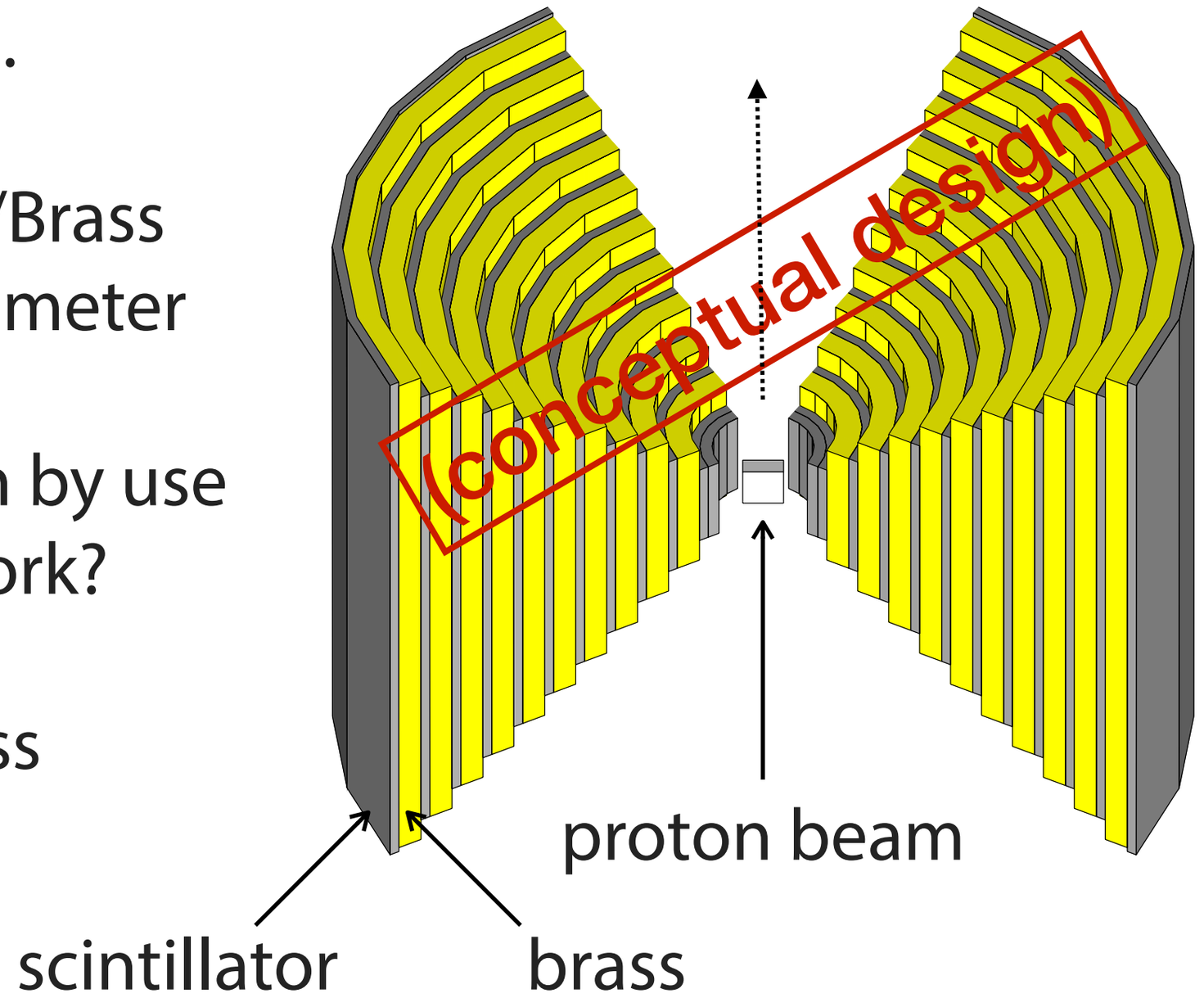


Super-FRS



range counter for proton detection

- just conceptual…
  - 10 layers of Sci/Brass sampling calorimeter
  - p/$\pi^{\pm}$ separation by use of neural network?
  - work in progress



conclusion

- possible existence of η′-nucleus bound state, due to partial restoration of chiral symmetry in medium
- inclusive measurement of (p,d) reaction at GSI/FAIR
  - high statistics and high resolution
  - near-threshold structure = signature of attractive int.
    - First experiment S437 carried out in August 2014
      - verified experimental feasibility
    - DAQ upgrade in progress for higher statistics at FAIR
- semi-exclusive measurement planned at FAIR
  - high-energy proton from η′pN→pN in coincidence