

Plan of η' mesic nucleus spectroscopy with (p,d) reaction at GSI and FAIR

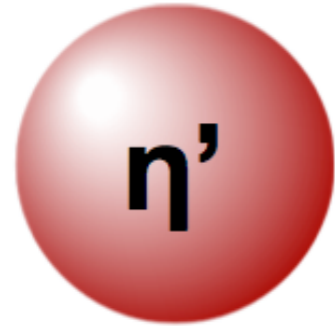
Yoshiki K. Tanaka (Univ. of Tokyo)
for the η -PRiME collaboration

η -PRiME collaboration

K.-T. Brinkmann, S. Friedrich, H. Fujioka, H. Geissel,
R.S. Hayano, Y. Higashi, S. Hirenzaki, Y. Igarashi, N. Ikeno,
K. Itahashi, S. Itoh, M. Iwasaki, D. Jido, V. Metag, T. Nagae,
H. Nagahiro, M. Nanova, T. Nishi, K. Okochi, H. Outa, K. Suzuki,
T. Suzuki, Y.K. Tanaka, Y.N. Watanabe, H. Weick, H. Yamakami

University Giessen, Kyoto University, GSI,
The University of Tokyo, Nara Women's University, KEK
RIKEN Nishina Center, Tokyo Metropolitan University, SMI

η' meson



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

$\Gamma=0.199 \text{ MeV}$

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

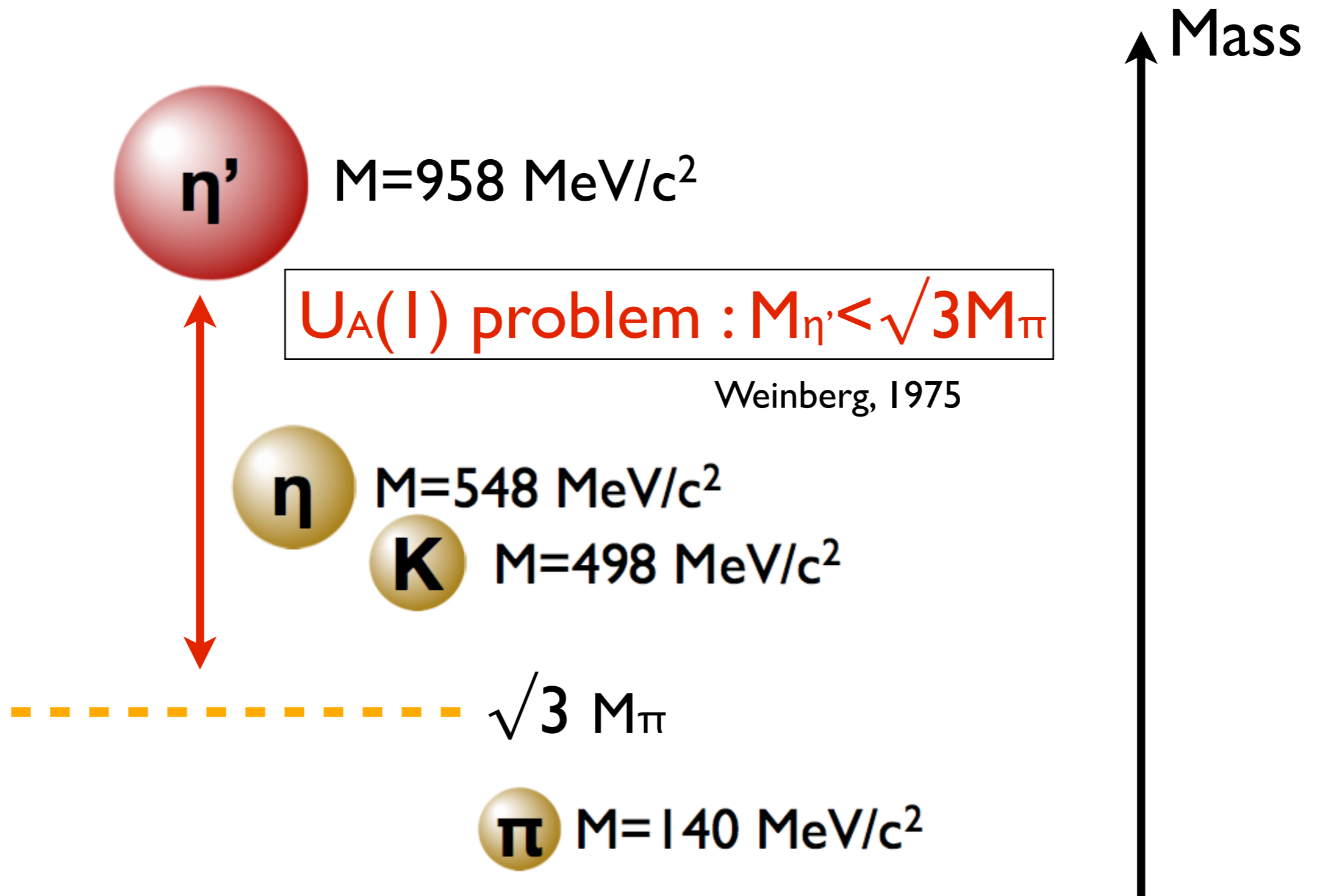
Decay mode

$\pi^+\pi^-\eta(43\%),$

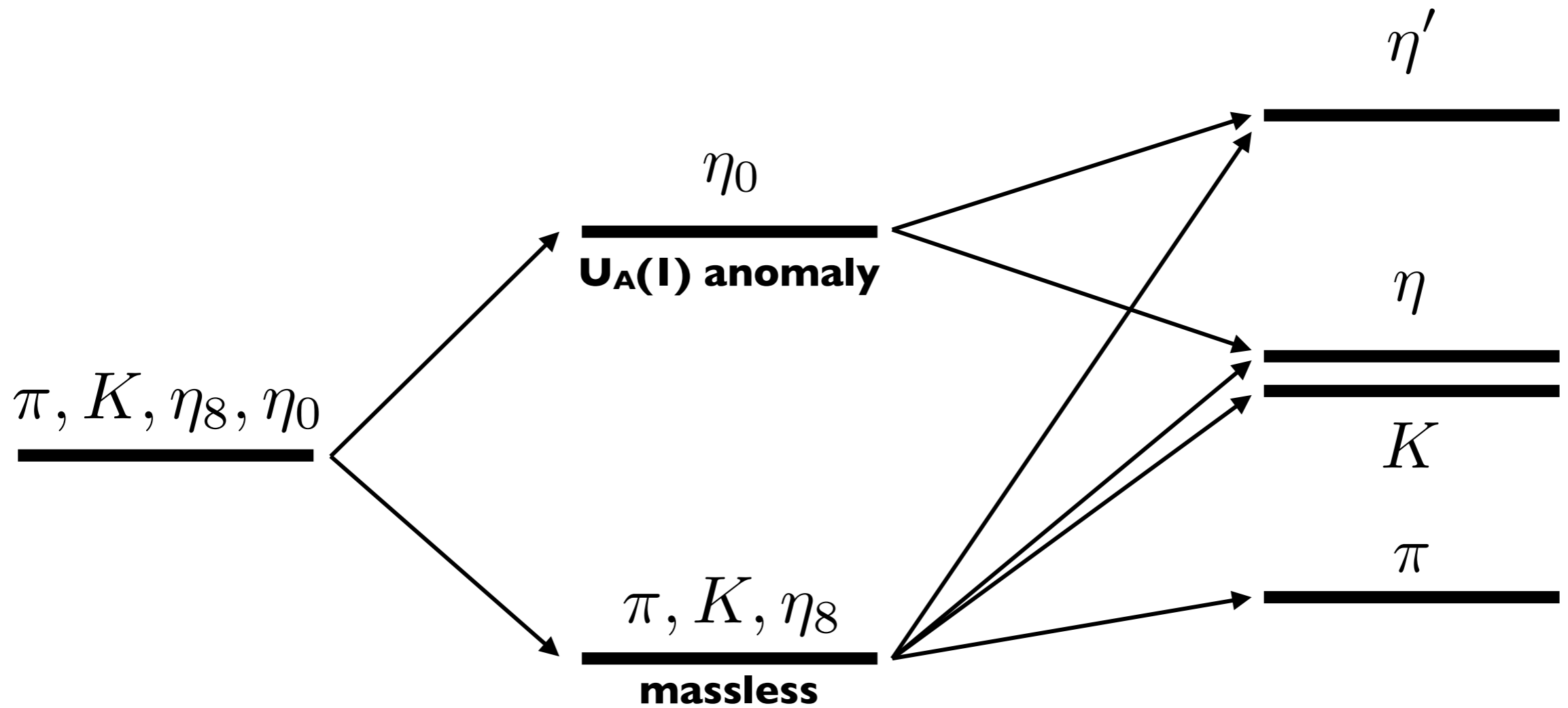
$\rho^0\gamma(29\%),$

$\pi^0\pi^0\eta(22\%)$

η' meson



η' meson



$$m_q = m_s = 0$$

$$\langle \bar{q}q \rangle = 0$$

ChS manifest

$$m_q = m_s = 0$$

$$\langle \bar{q}q \rangle \neq 0$$

ChS broken dynamically

$$m_q \neq m_s \neq 0$$

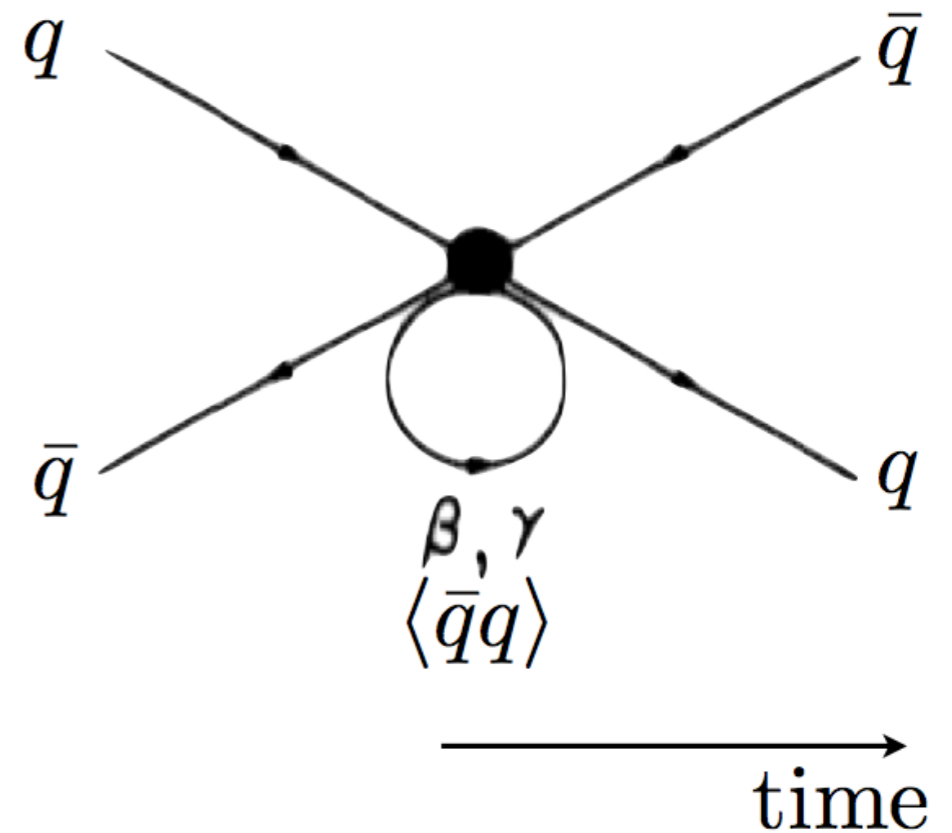
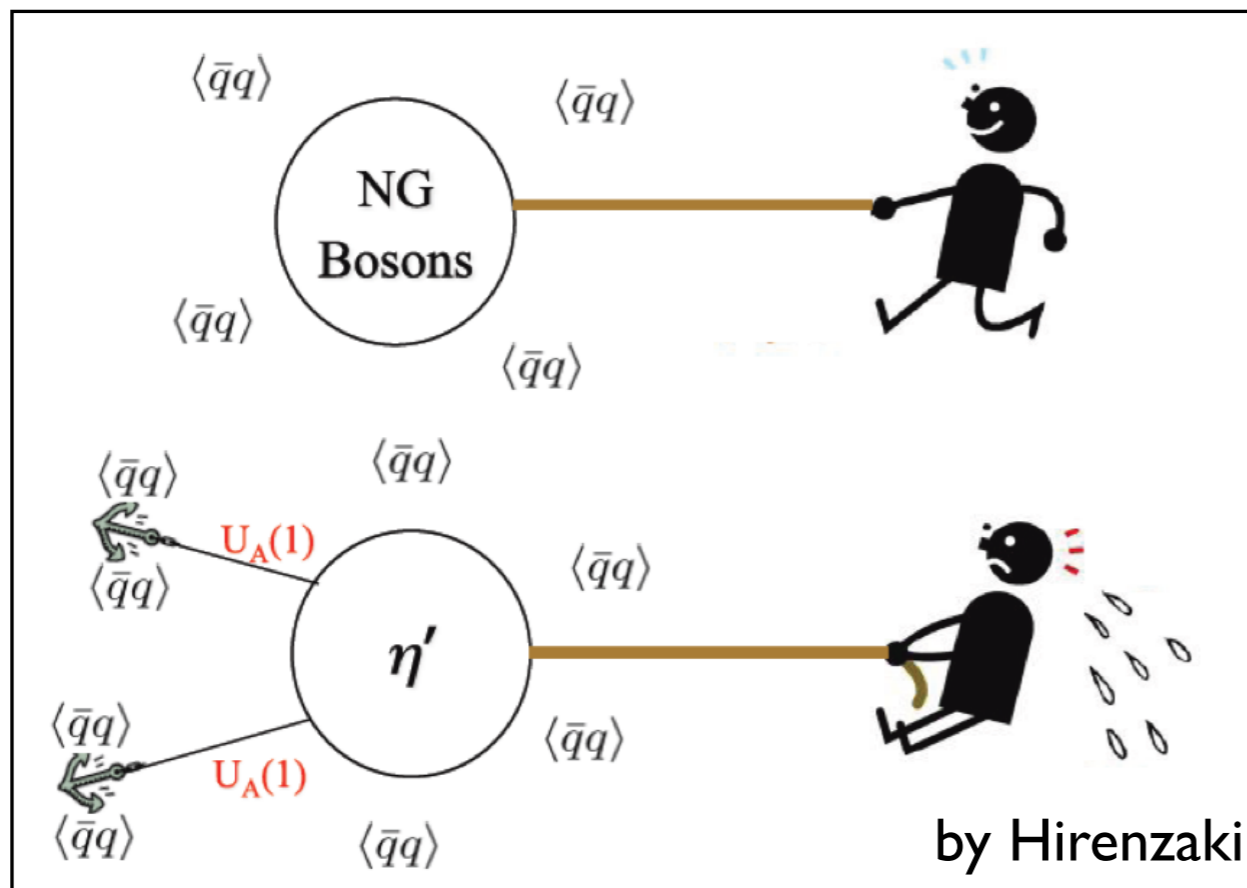
$$\langle \bar{q}q \rangle \neq 0$$

ChS broken dynamically and explicitly

η' meson

$U_A(1)$ anomaly effect on η' mass

- KMT interaction in NJL model
- related to the strength of chiral condensate $\langle \bar{q}q \rangle$



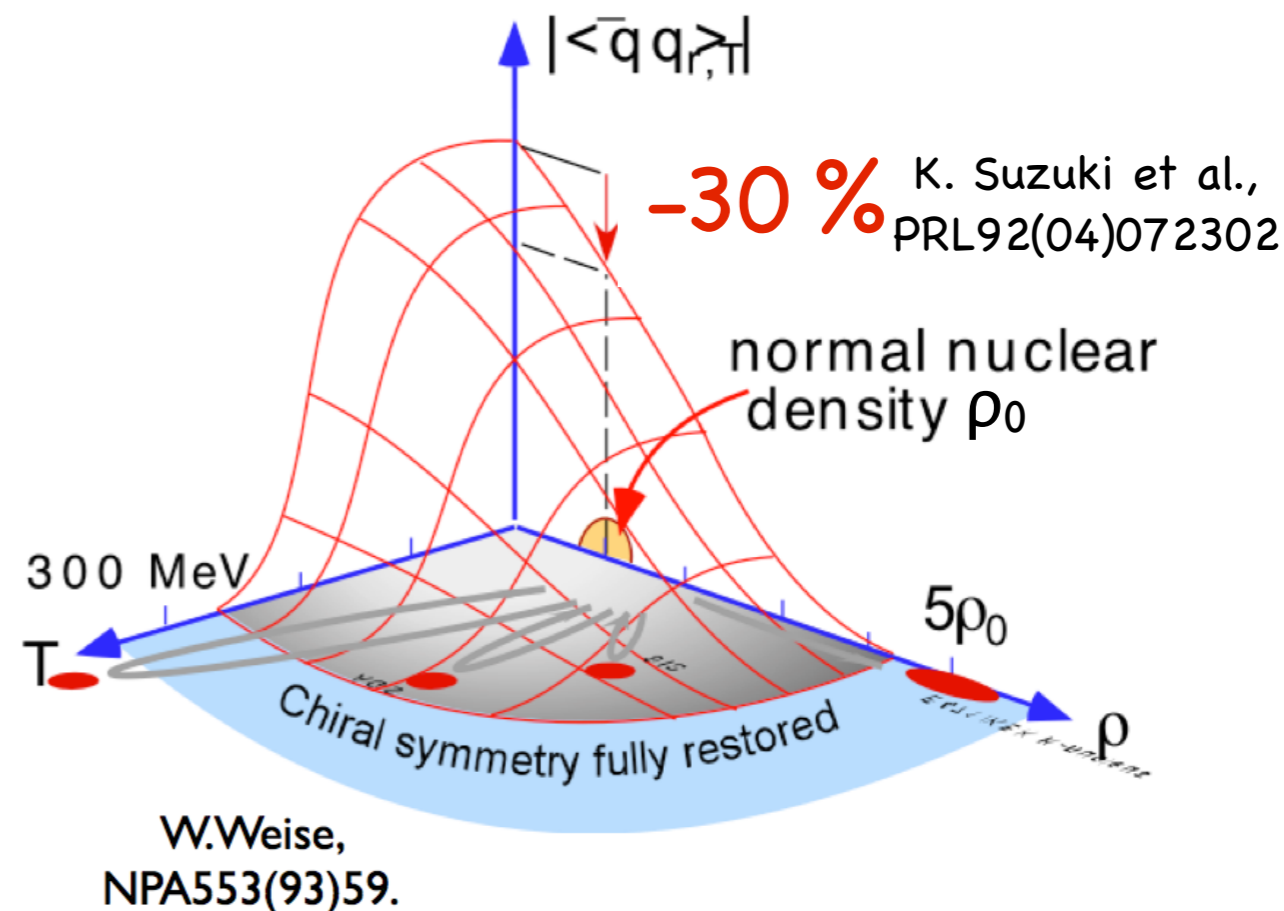
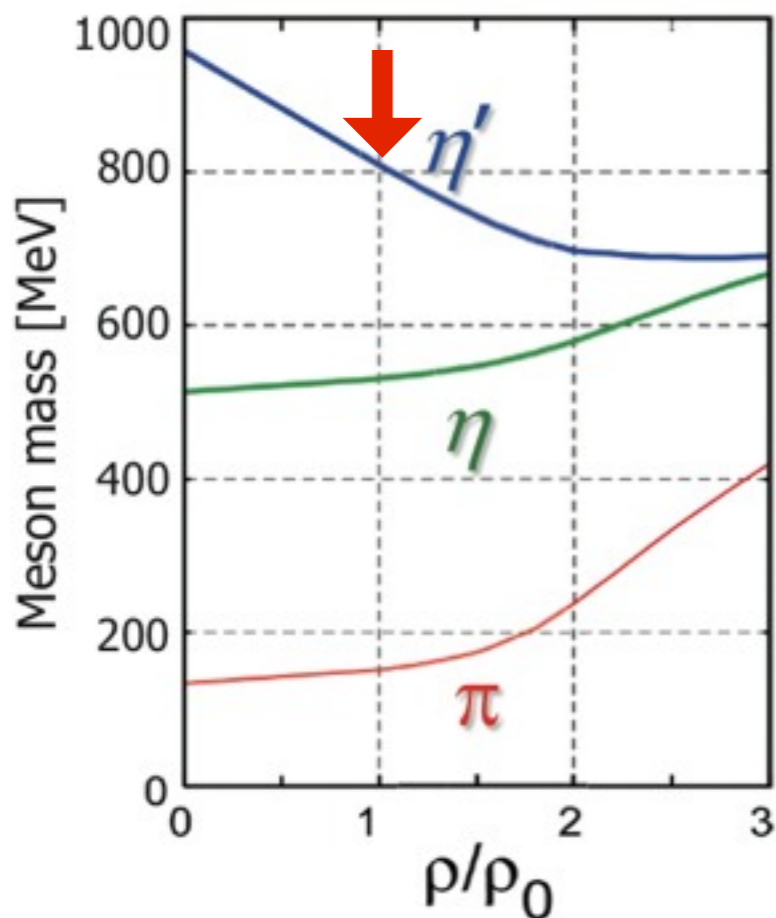
Kobayashi-Maskawa-'t Hooft
6-point vertex

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 mass

- Chiral condensate $\langle \bar{q}q \rangle$ decreases by $\sim 30\%$ at ρ_0 .
- Mass reduction expected e.g., NJL model calculation
 → **150 MeV/c²** mass reduction

partial restoration of chiral symmetry



P.Costa et al., PLB560, (2003) 171.
 H.Nagahiro et al., PRC 74, (2006) 045203.

in-medium mass

η' nucleus optical potential :

$$V_{\eta'} = (V_0 + iW_0) \frac{\rho(r)}{\rho_0}$$
$$V_0 = \Delta m(\rho_0), \quad W_0 = -\Gamma(\rho_0) / 2$$

- NJL model prediction
~ 150 MeV/c² reduction at ρ_0

strong attraction ?

in-medium mass

η' nucleus optical potential :

$$V_{\eta'} = (V_0 + iW_0) \frac{\rho(r)}{\rho_0}$$
$$V_0 = \Delta m(\rho_0), \quad W_0 = -\Gamma(\rho_0) / 2$$

- NJL model prediction
~ 150 MeV/c² reduction at ρ_0 **strong attraction ?**
- CBELSA/TAPS (talk by M. Nanova)
~ 40 MeV/c² reduction at ρ_0
- relatively small scattering length of the s-wave η' -proton interaction
 $|a_{\eta'p}| \sim 0.1$ fm P. Moskal et al., PLB482(00)356.
➔ ~ 8 MeV/c² mass reduction at ρ_0 H. Nagahiro et al.,
Phys. Lett. B 709 (2012) 87

in-medium width

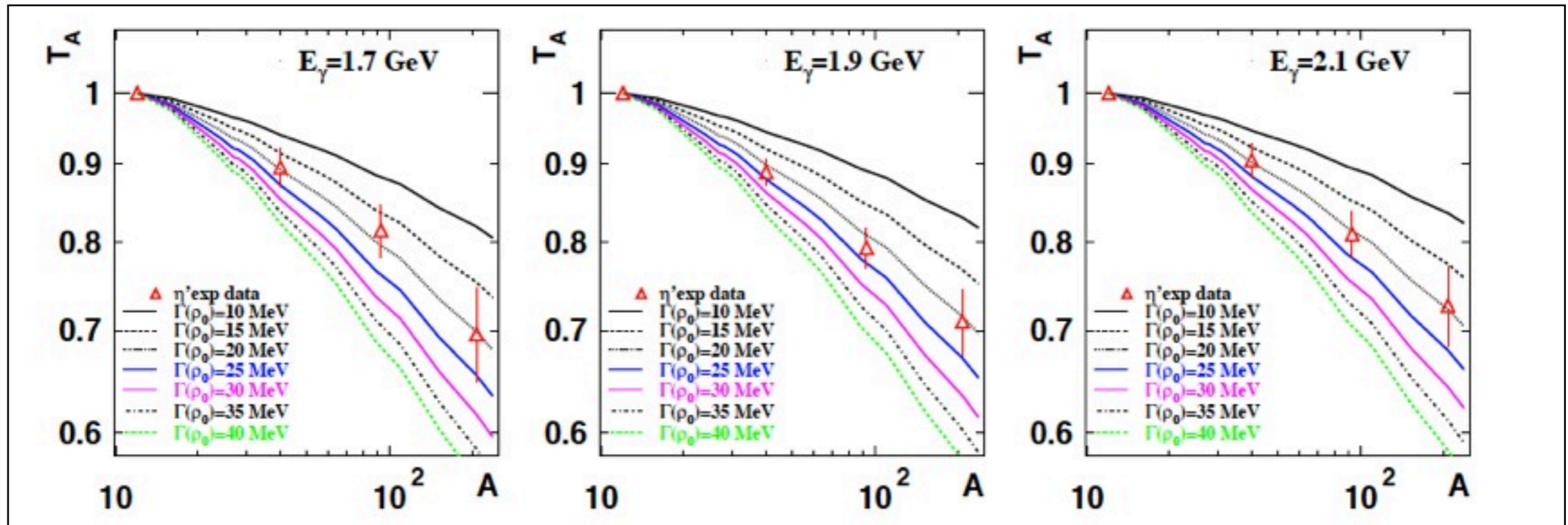
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- $\Gamma(\rho_0) \sim 15 - 25 \text{ MeV}$ deduced by CBELSA/TAPS transparency ratio measurement

M. Nanova et al., PLB710,600(2012)



in-medium width

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M. Nanova et al., PLB710,600(2012)

➔ $|W_0|$ smaller than possible mass reduction $|V_0|$

➔ η' mesic nuclei may exist !

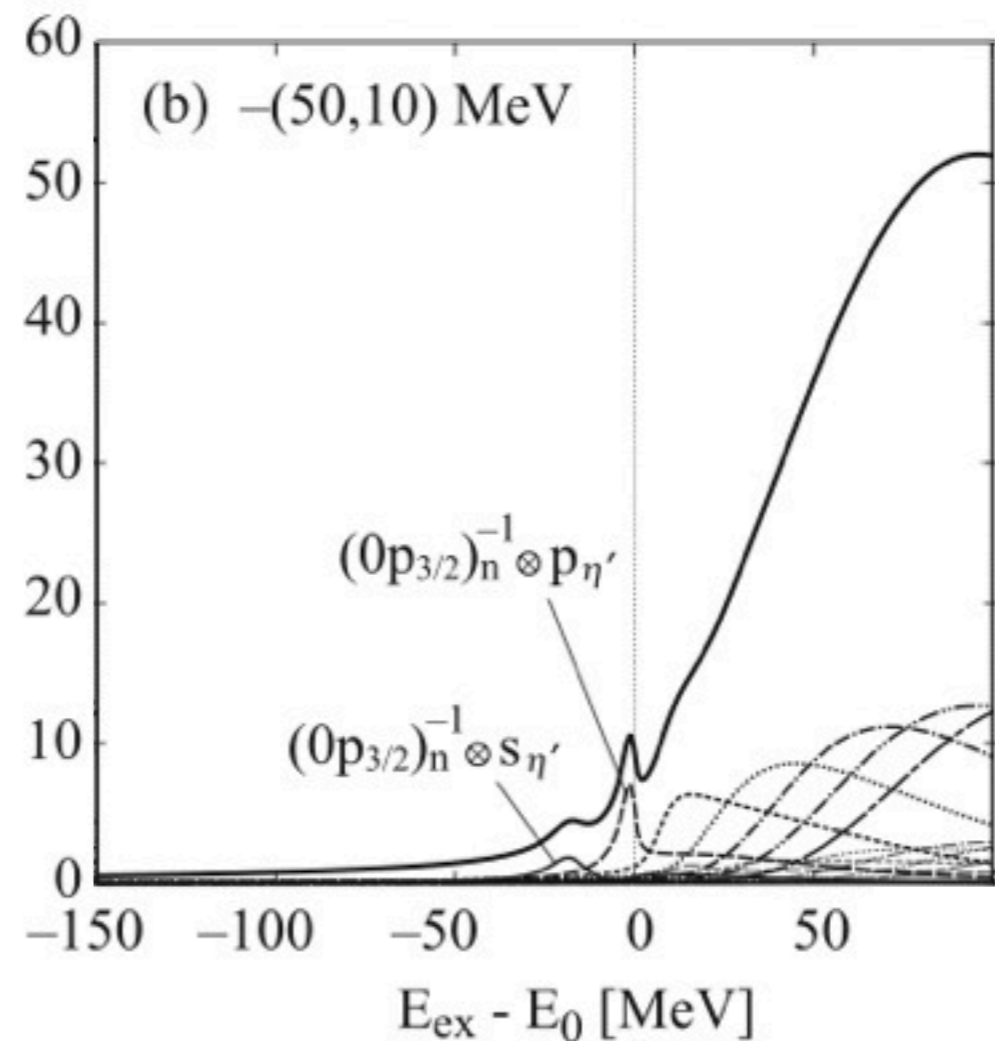
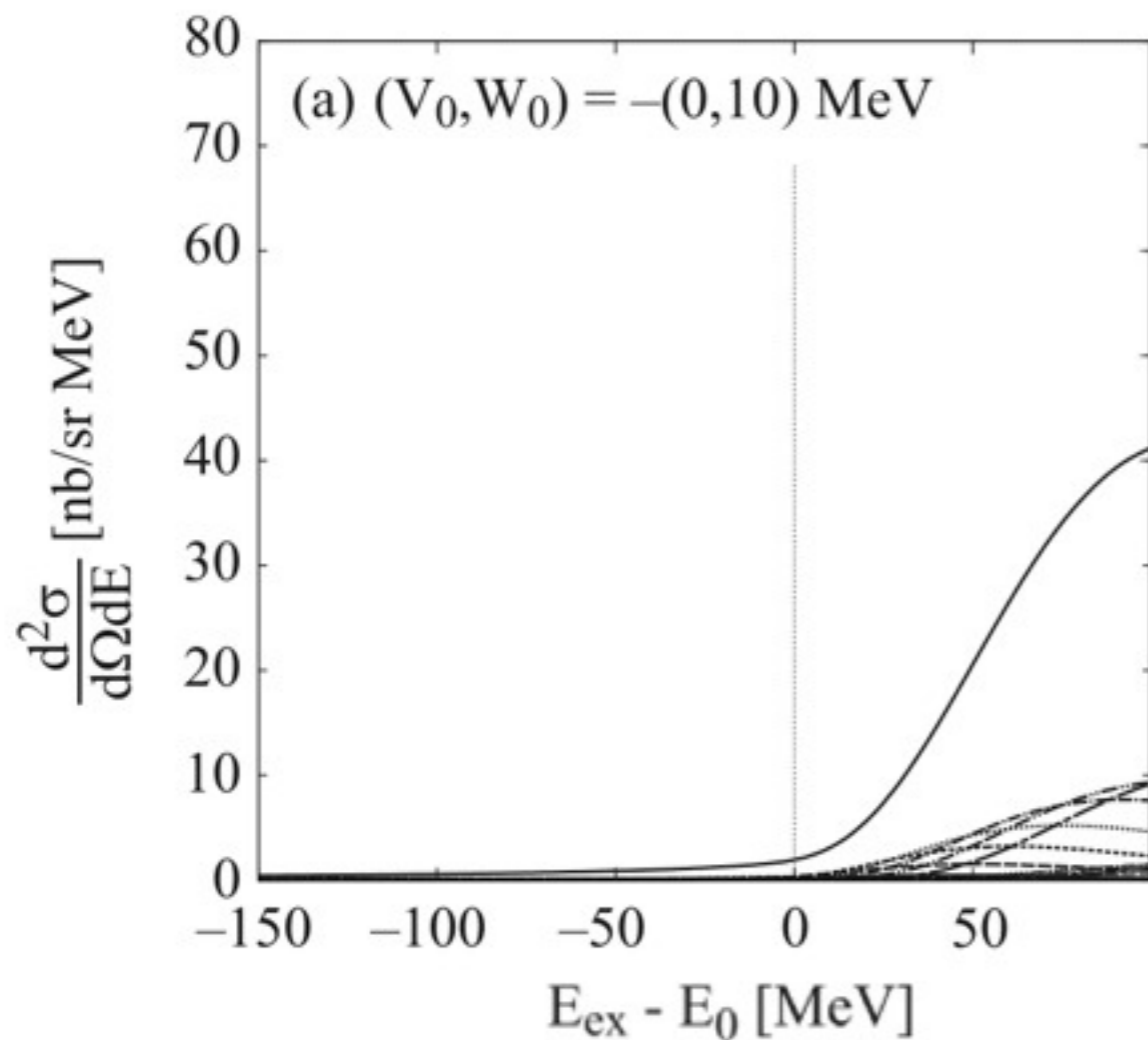
Theoretical spectra of $^{12}\text{C}(p,d)^{11}\text{C}\times\eta'$

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

- proton energy 2.5 GeV
- Green's function method



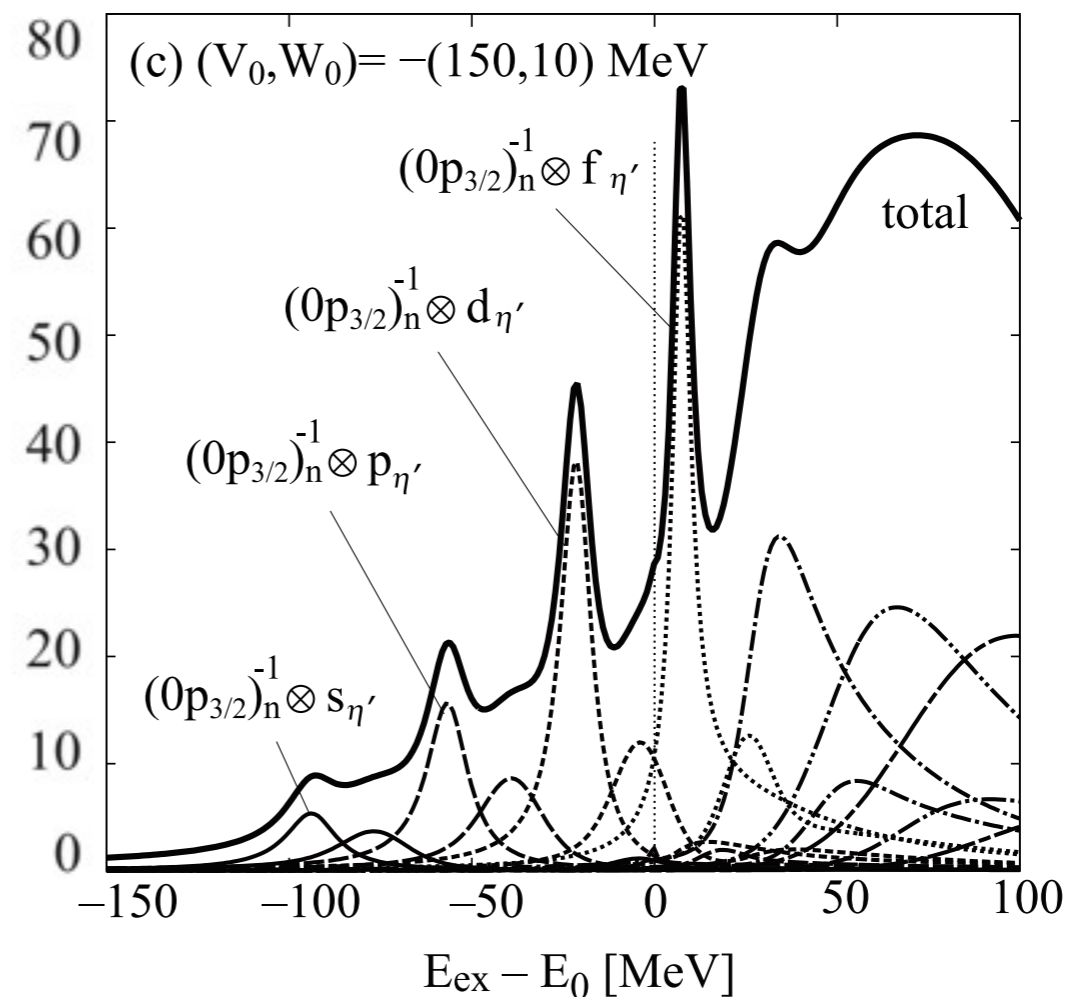
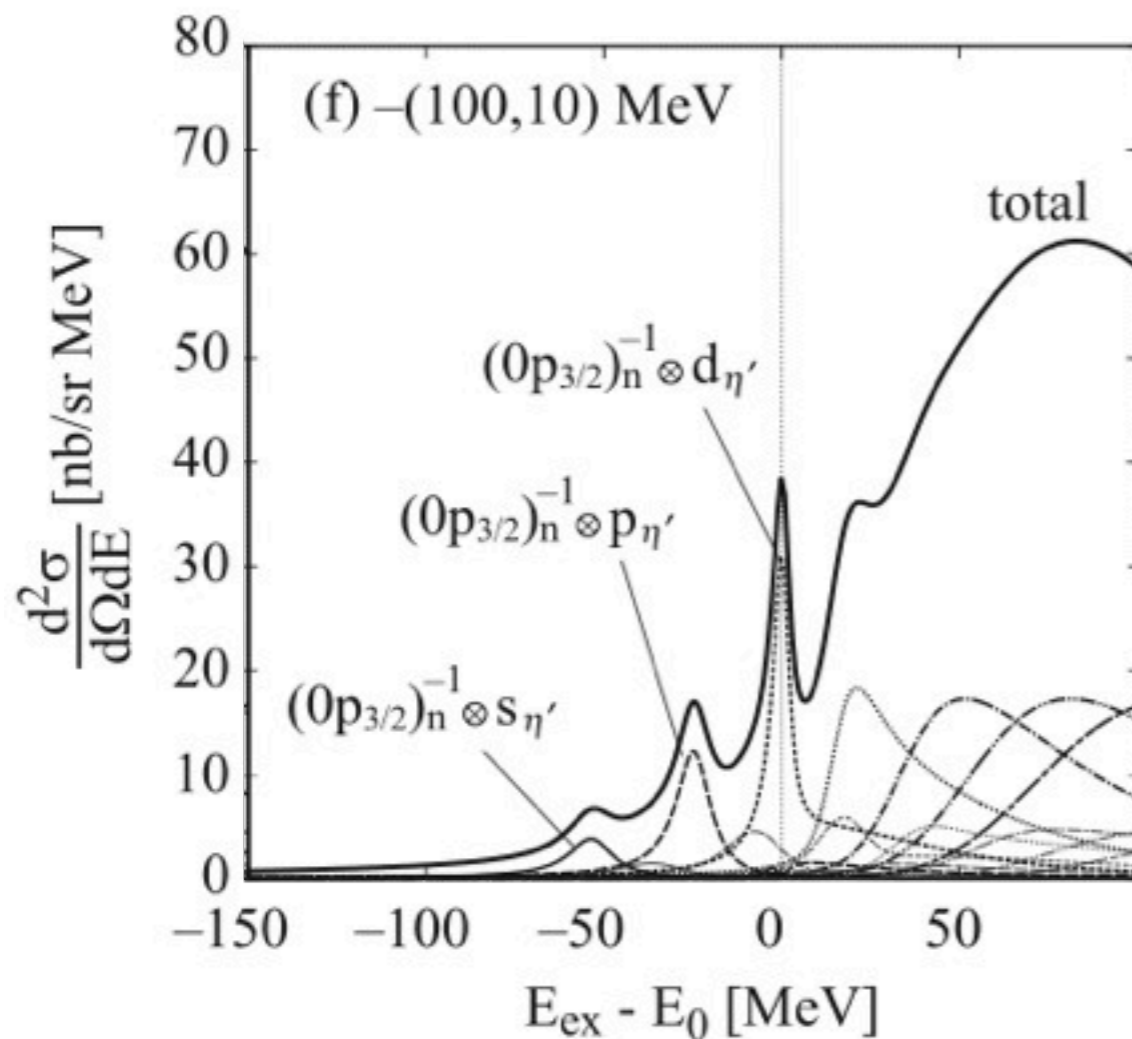
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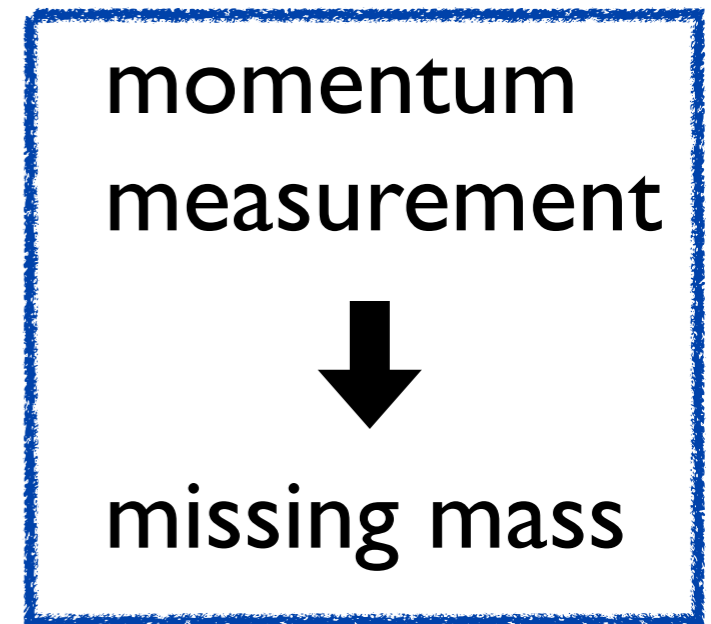
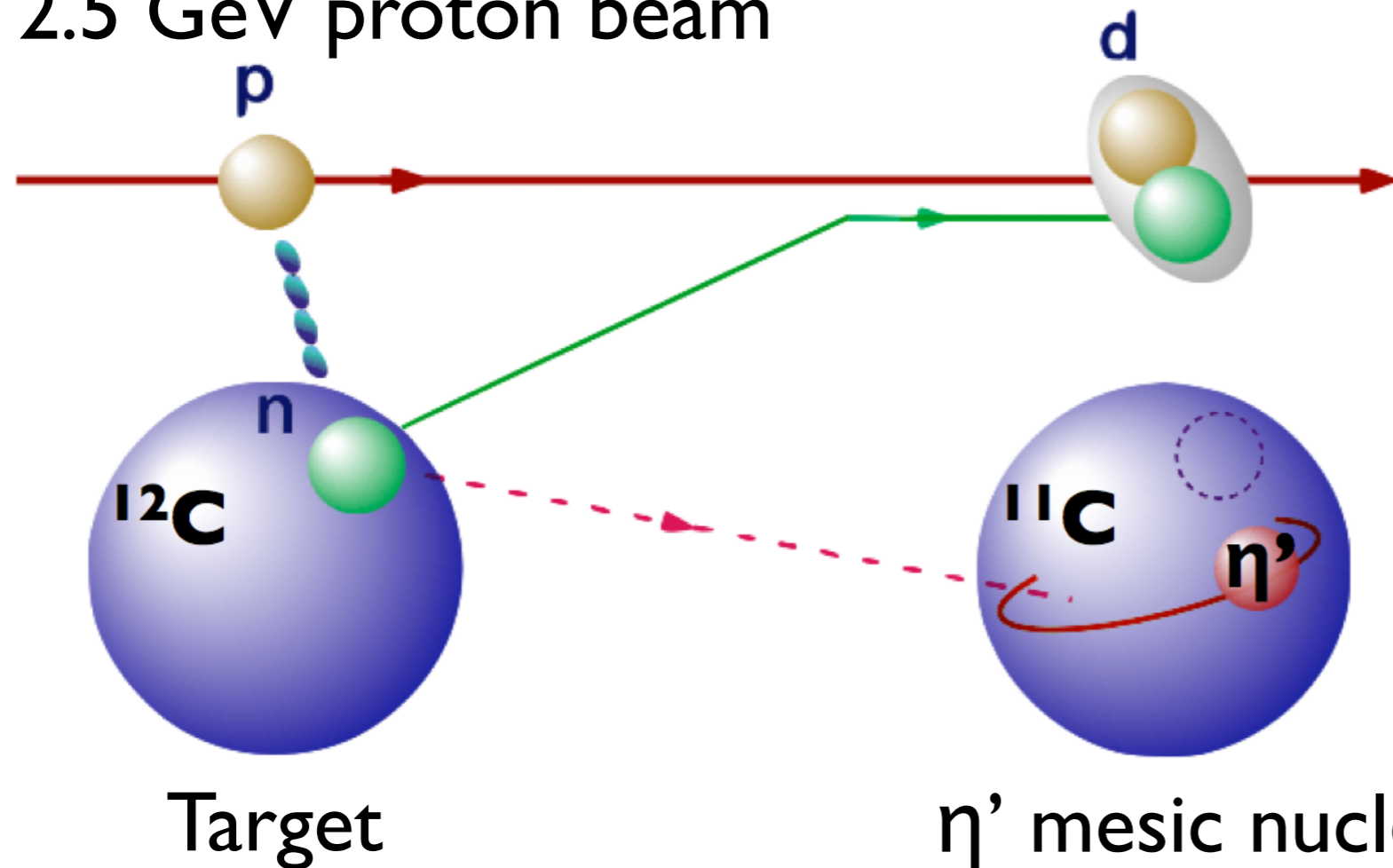




Experimental Plan at GSI

Missing mass spectroscopy of (p,d) reaction

2.5 GeV proton beam



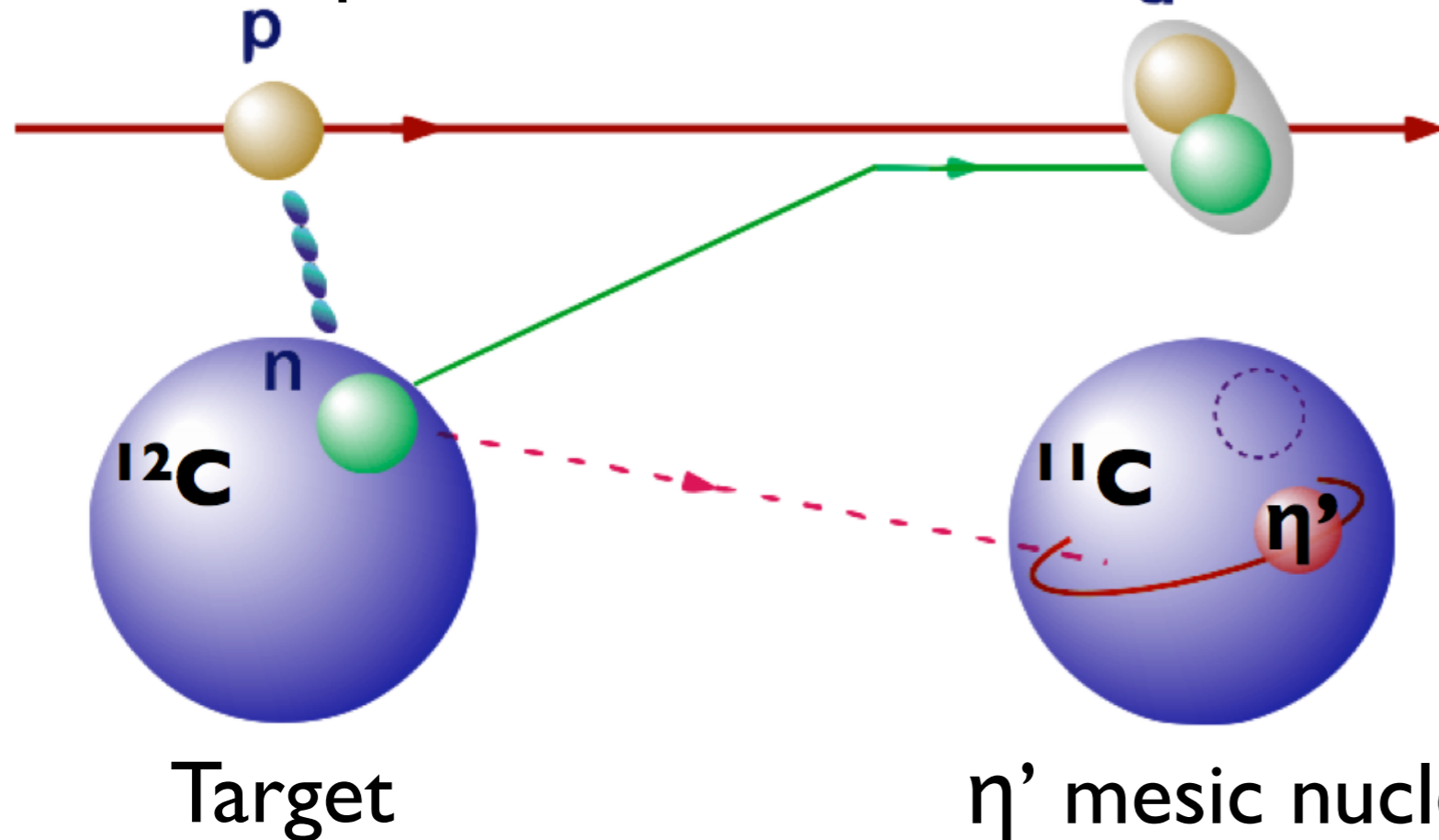
K. Itahashi et al.,
PTP 128,601(2012)

1st Step : Inclusive measurement of (p,d) reaction at GSI

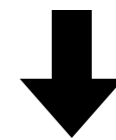
- no assumption on decay process
- small S/N ratio ← background processes (e.g., multi-pion production)

Missing mass spectroscopy of (p,d) reaction

2.5 GeV proton beam



momentum
measurement



missing mass

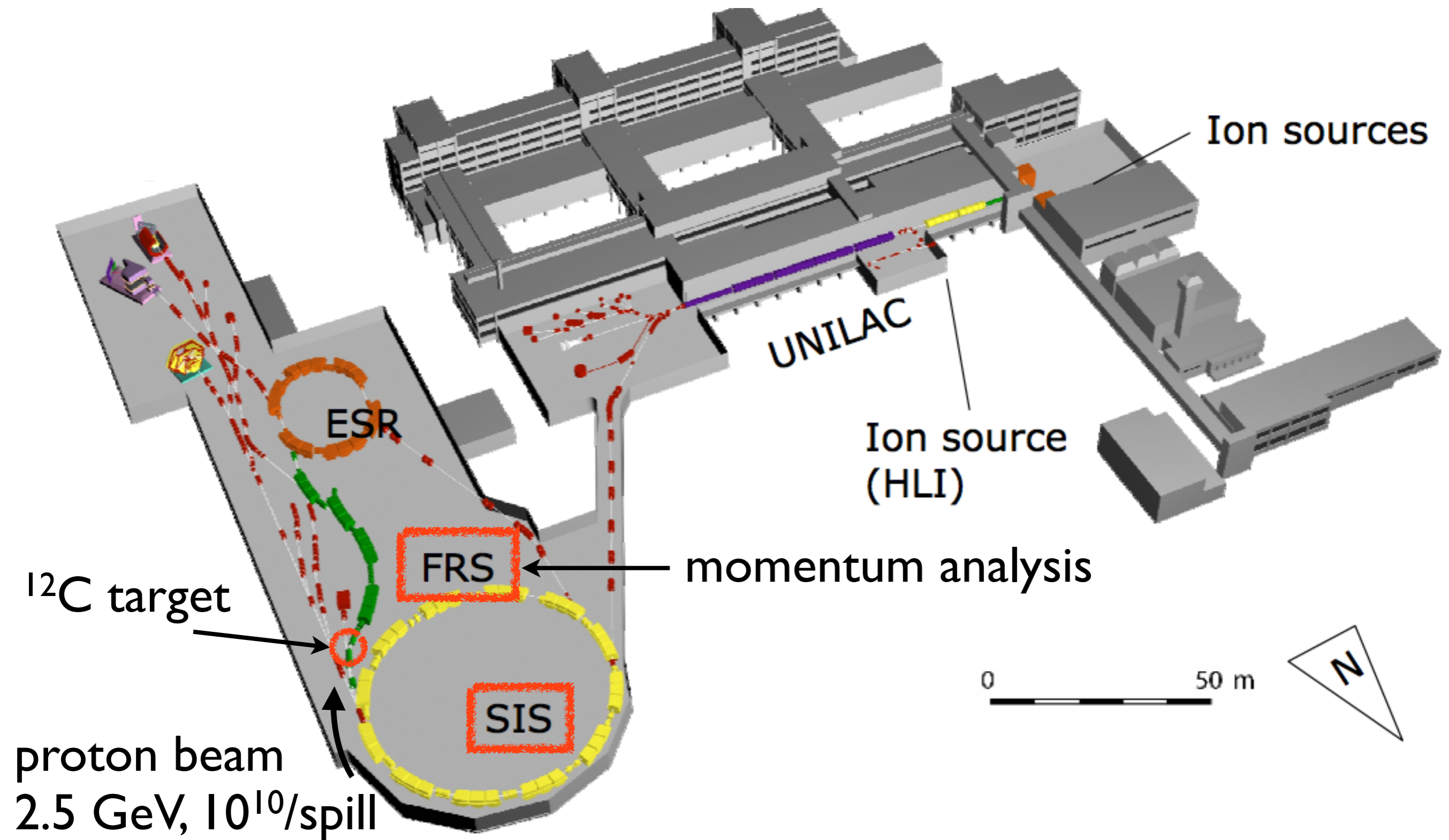
K. Itahashi et al.,
PTP 128,601(2012)

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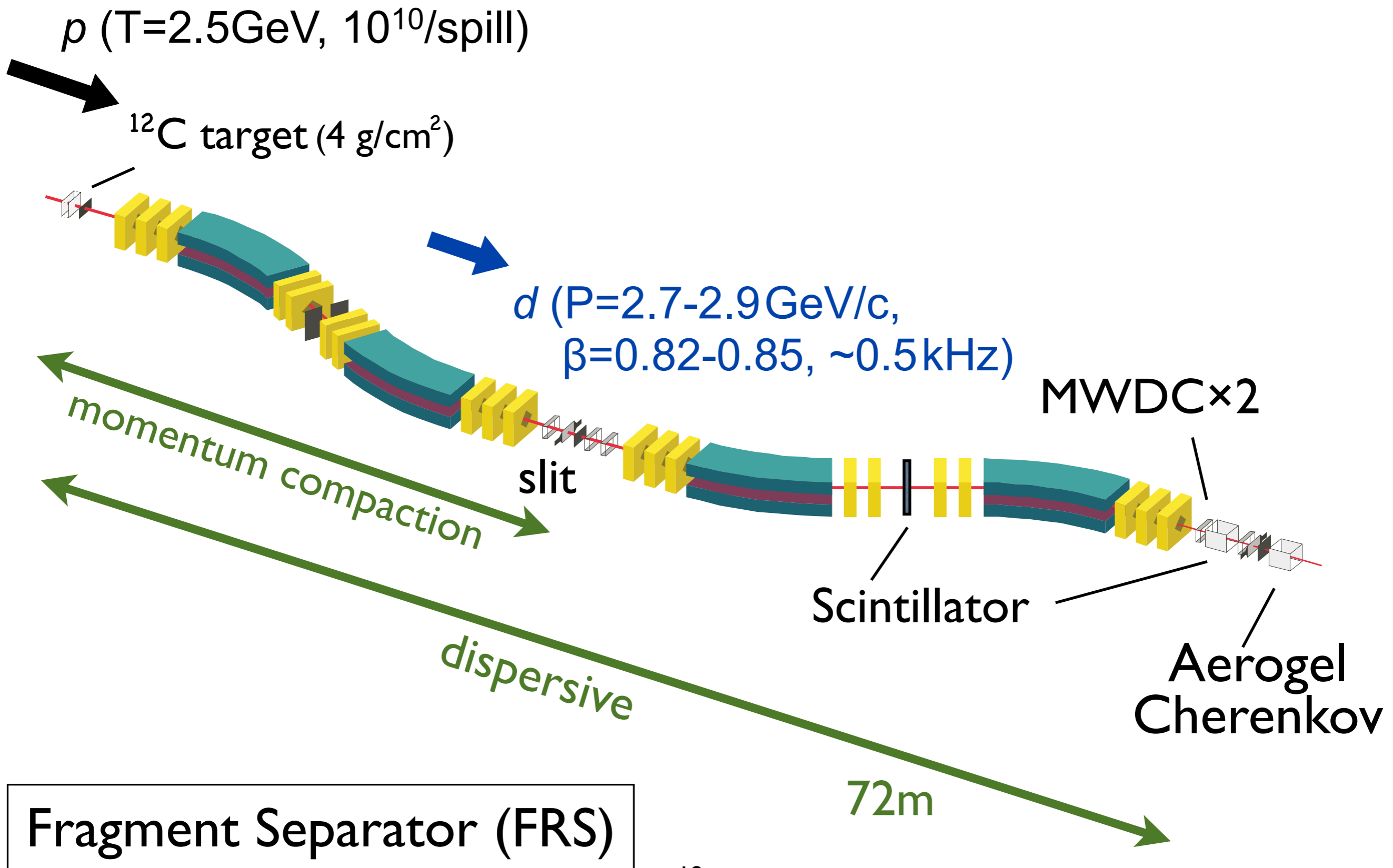
- no assumption on decay process
- small S/N ratio \leftarrow background processes (e.g., multi-pion production)

high-statistics measurement needed!
w/ high-intensity beam + thick target

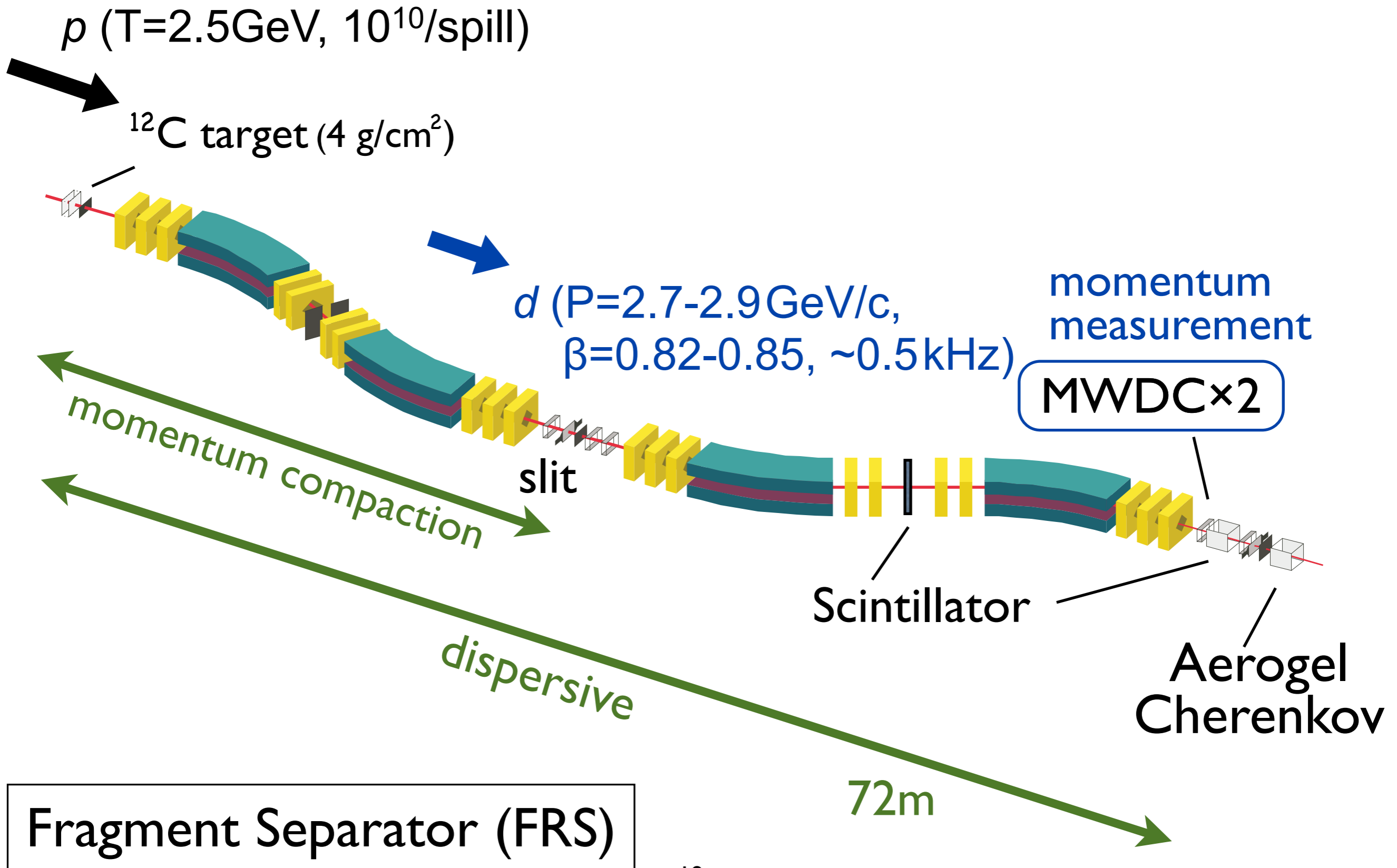
GSI facilities



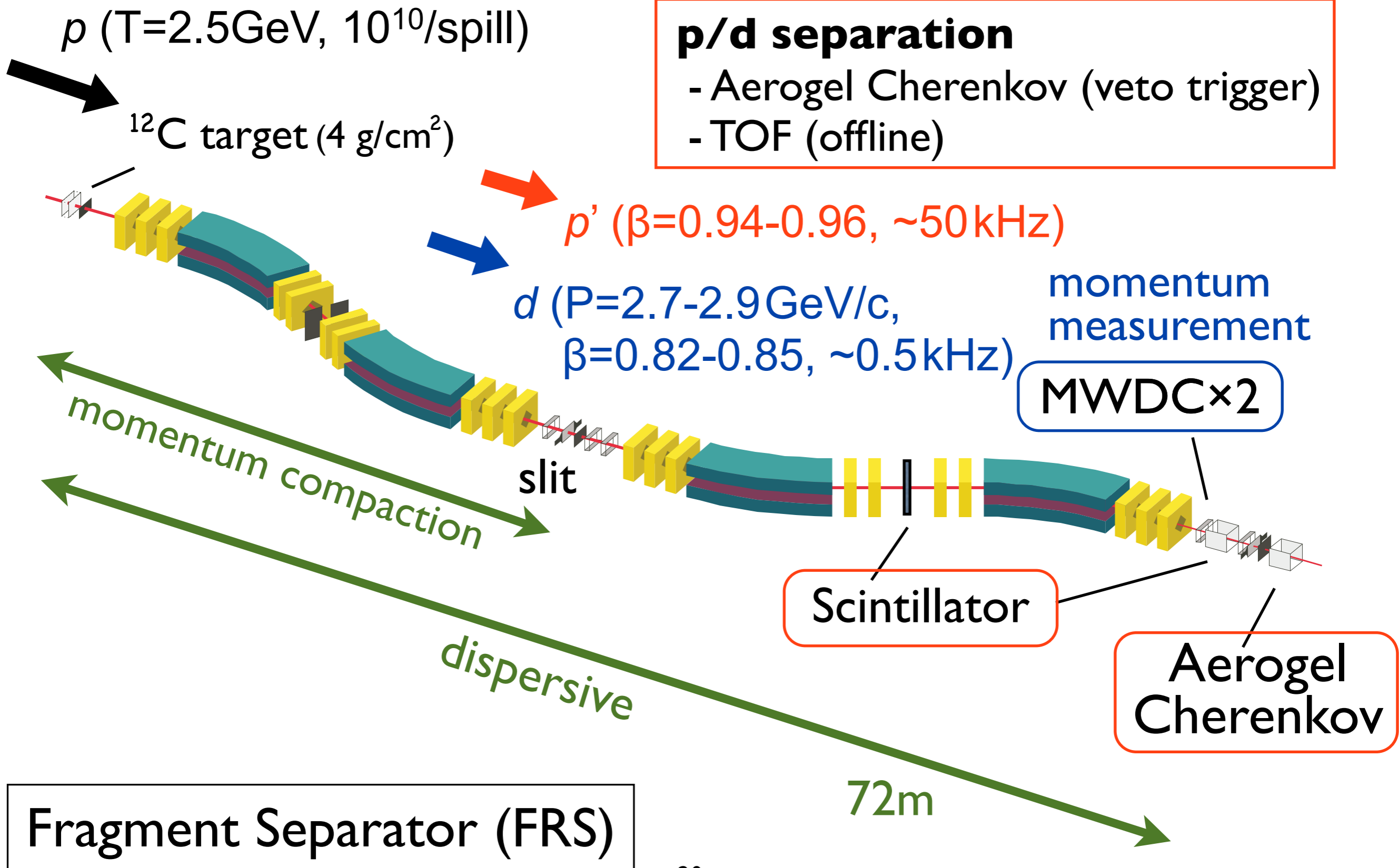
Experimental setup at FRS



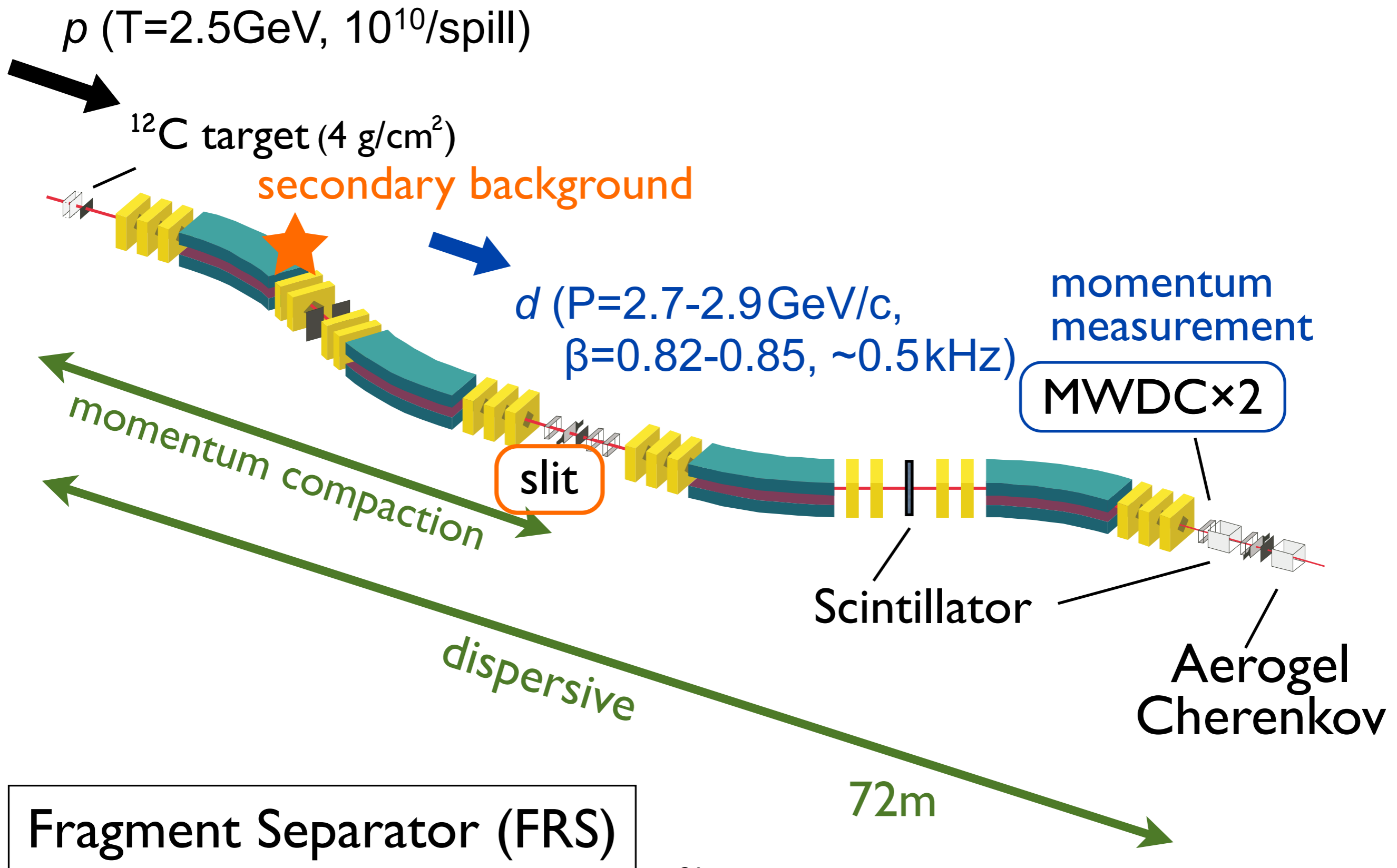
Experimental setup at FRS



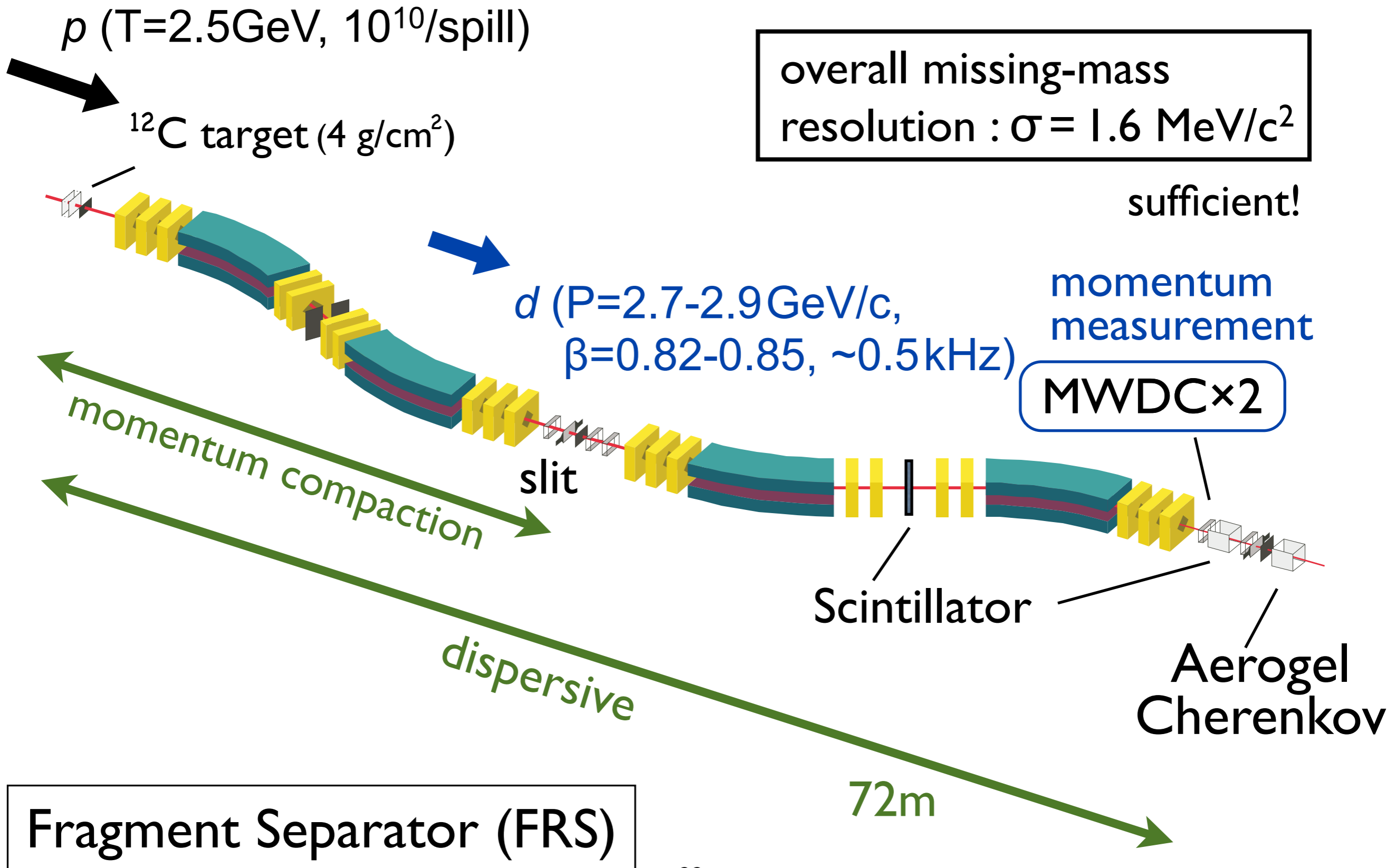
Experimental setup at FRS



Experimental setup at FRS



Experimental setup at FRS



Simulated spectrum in 4.5 days DAQ

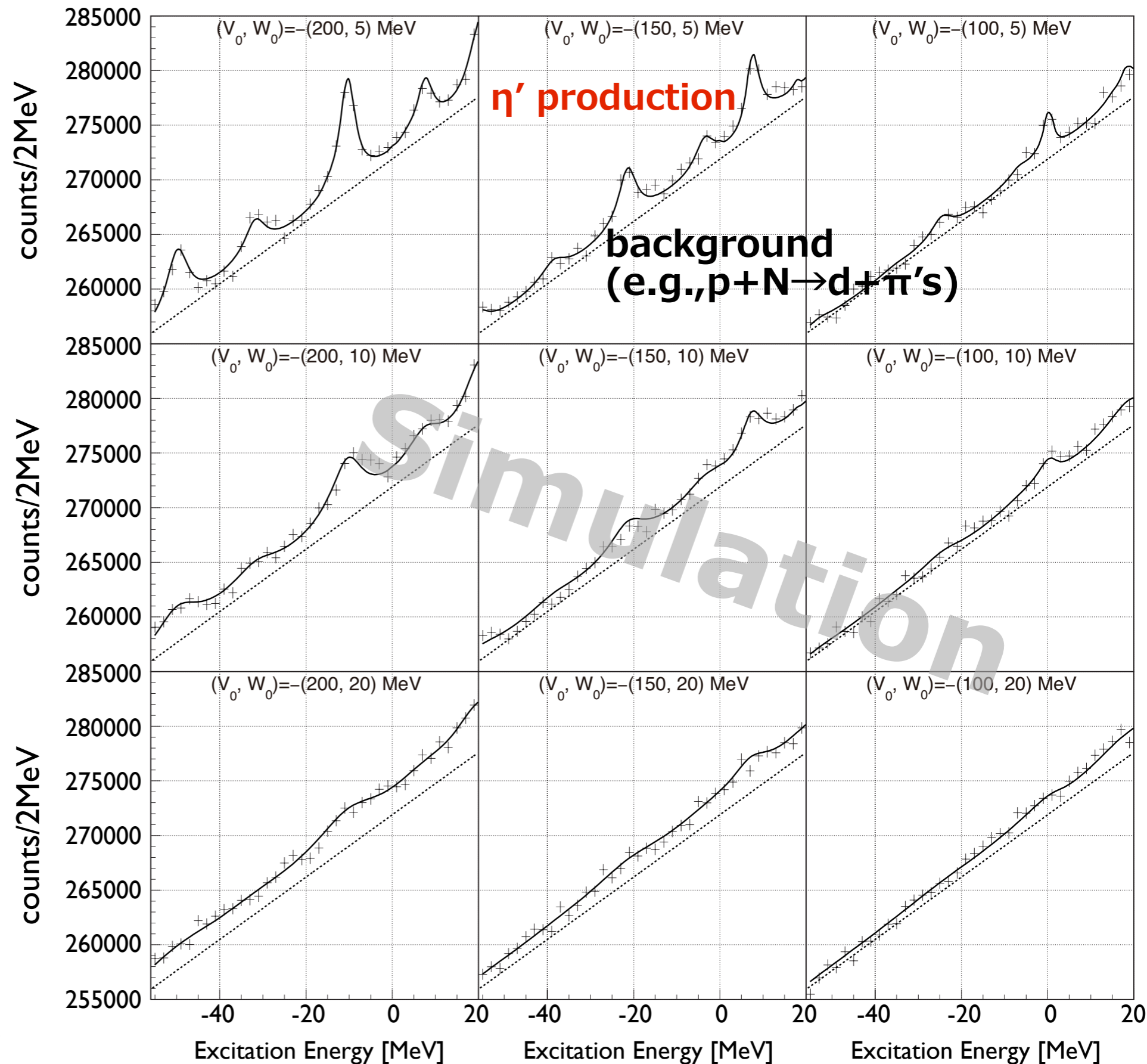
Inclusive spectrum
assuming 4.5 day DAQ

V_0, W_0 :
real, imaginary part
of optical potential

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

- background processes
based on COSY-ANKE
data/simulation [2]

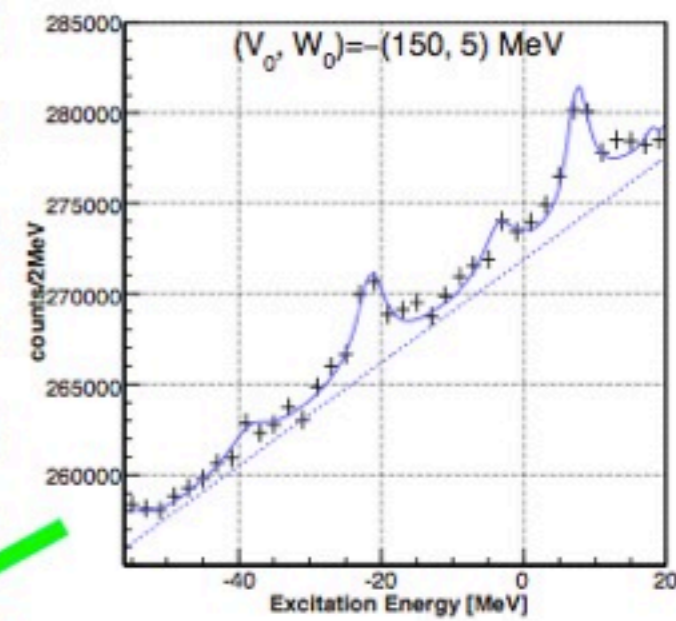
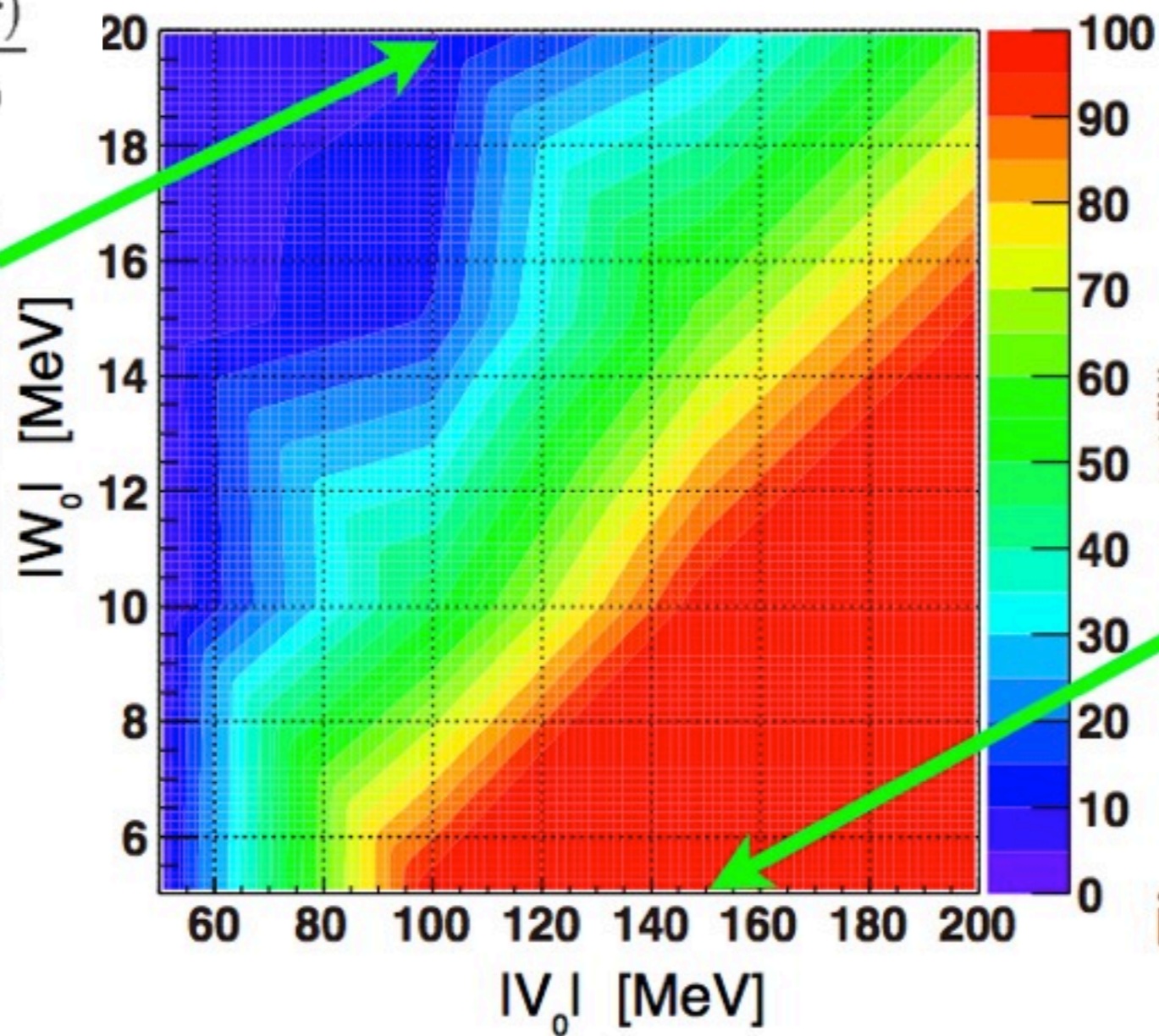
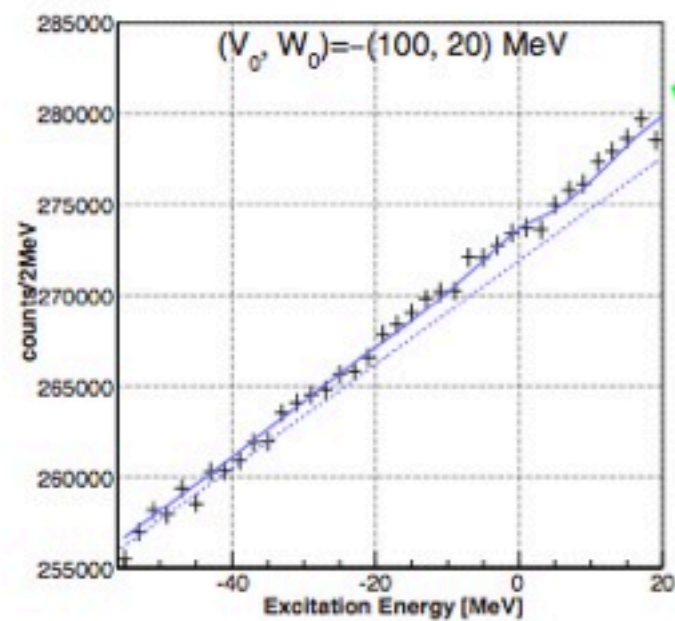
- S/N ratio
 $\sim O(1/100)$ at most



[2] S. Barsov et al., EPJ A21, 521 (2004);
I. Lehmann, Ph.D thesis (2003)

Structure-finding sensitivity

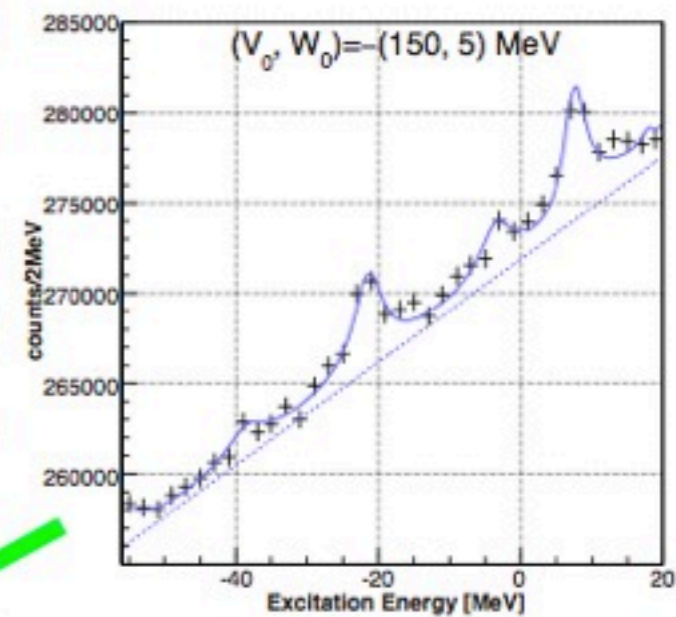
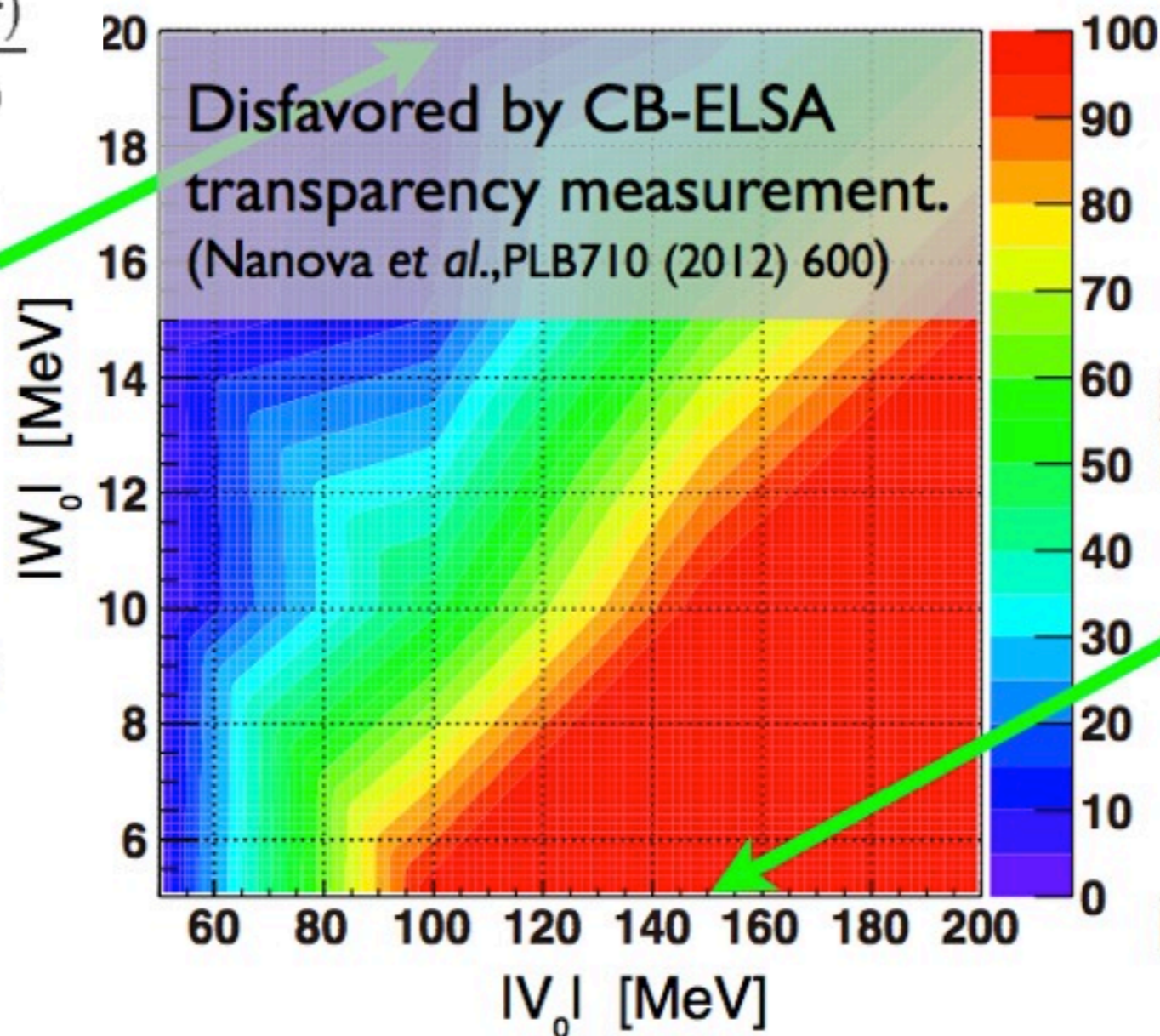
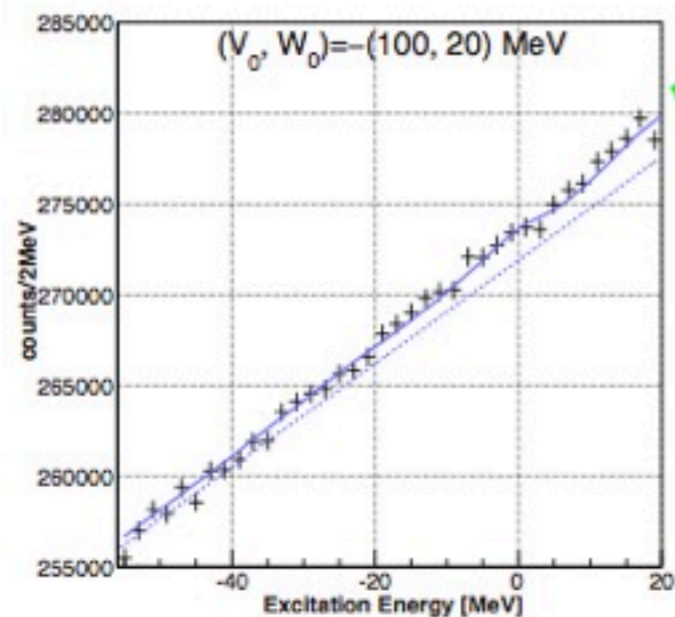
$$V_{\eta'}(r) = (V_0 + iW_0) \frac{\rho(r)}{\rho_0}$$



in 4.5 days DAQ
for 95 % C.L.

Structure-finding sensitivity

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



in 4.5 days DAQ
for 95 % C.L.

Preparation status and Prospect

Aerogel Cherenkov detector

- high-index aerogel ($n=1.18$)
- developed and tested in 2012

MWDC

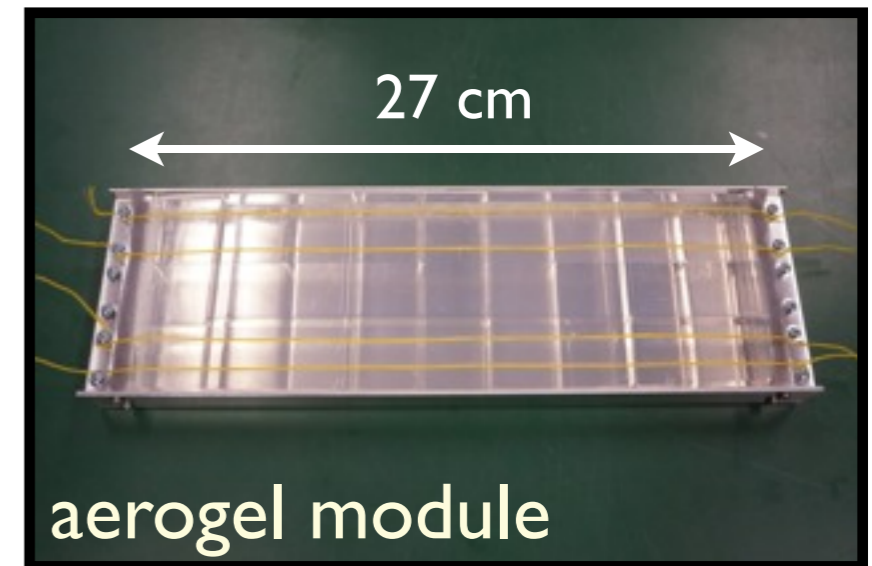
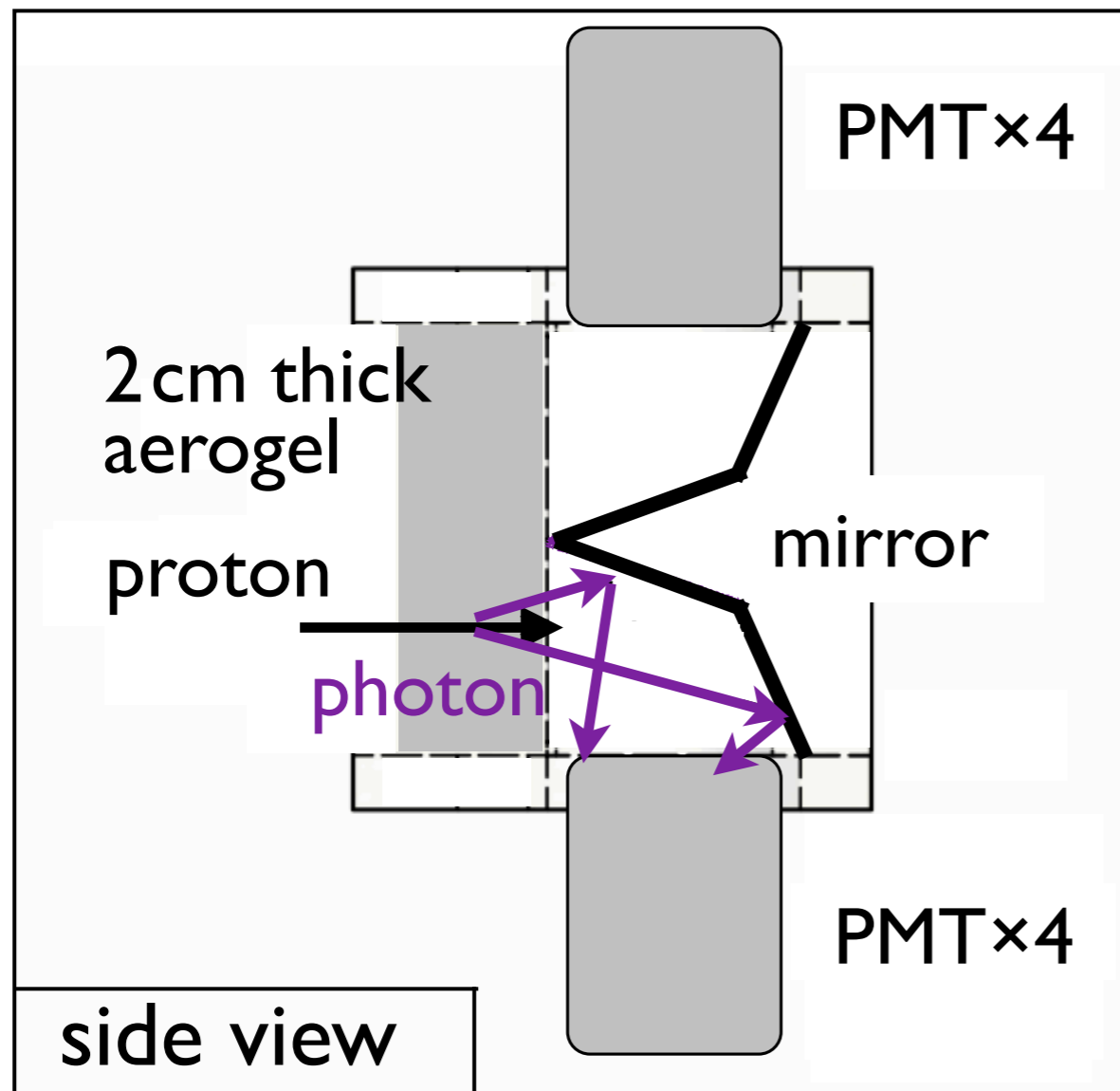
- use conventional type
- setting up on-going

FRS optics mode

- new optics mode of FRS has been developed.
- further improvement is in progress.

High index aerogel Cherenkov detector

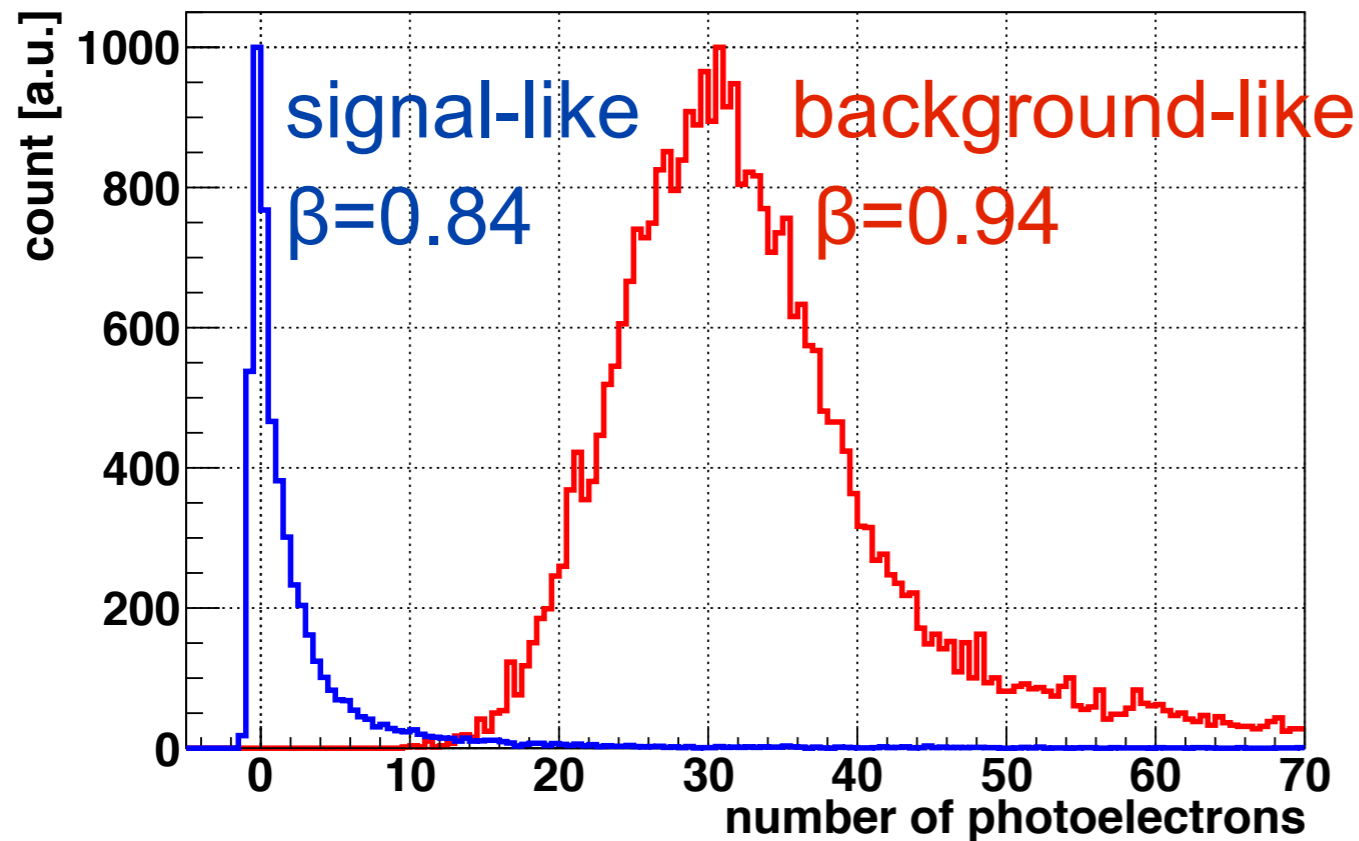
- $n=1.18$ high-refractive-index silica aerogel
- PID (p/d) at trigger level



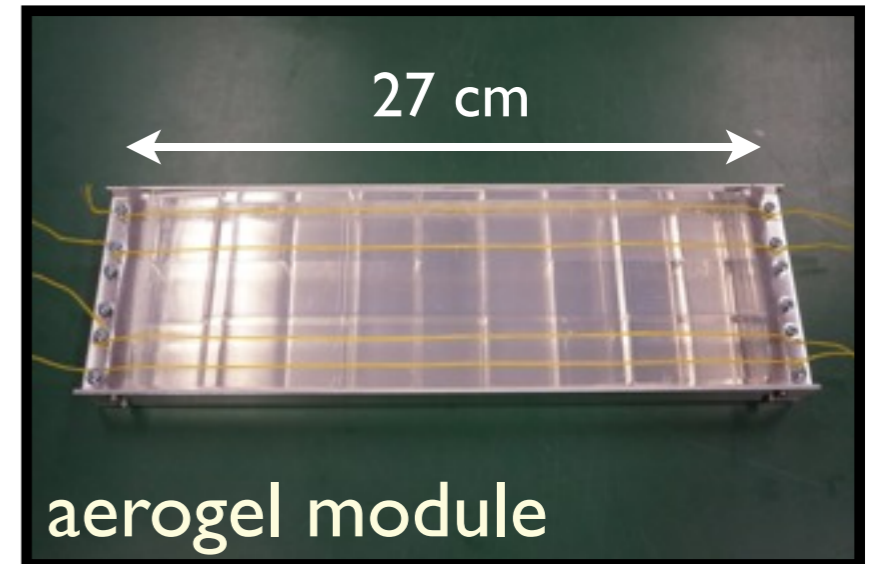
High index aerogel Cherenkov detector

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Test results with deuteron beam@GSI



We achieved $> 99.5\%$ BG rejection
w/ a few % signal overkill at online level



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FRS optics simulation with GICOSY

newly-developed mode
using GICOSY[1]

S2 : achromatic focus

S4 : dispersive focus

($D=4\text{cm}/\%$)

Small dispersion kept
throughout FRS

→ $\pm 3\%$ $B\rho$ acceptance

$\pm 65\text{ MeV}$ in $E_{\eta'}$

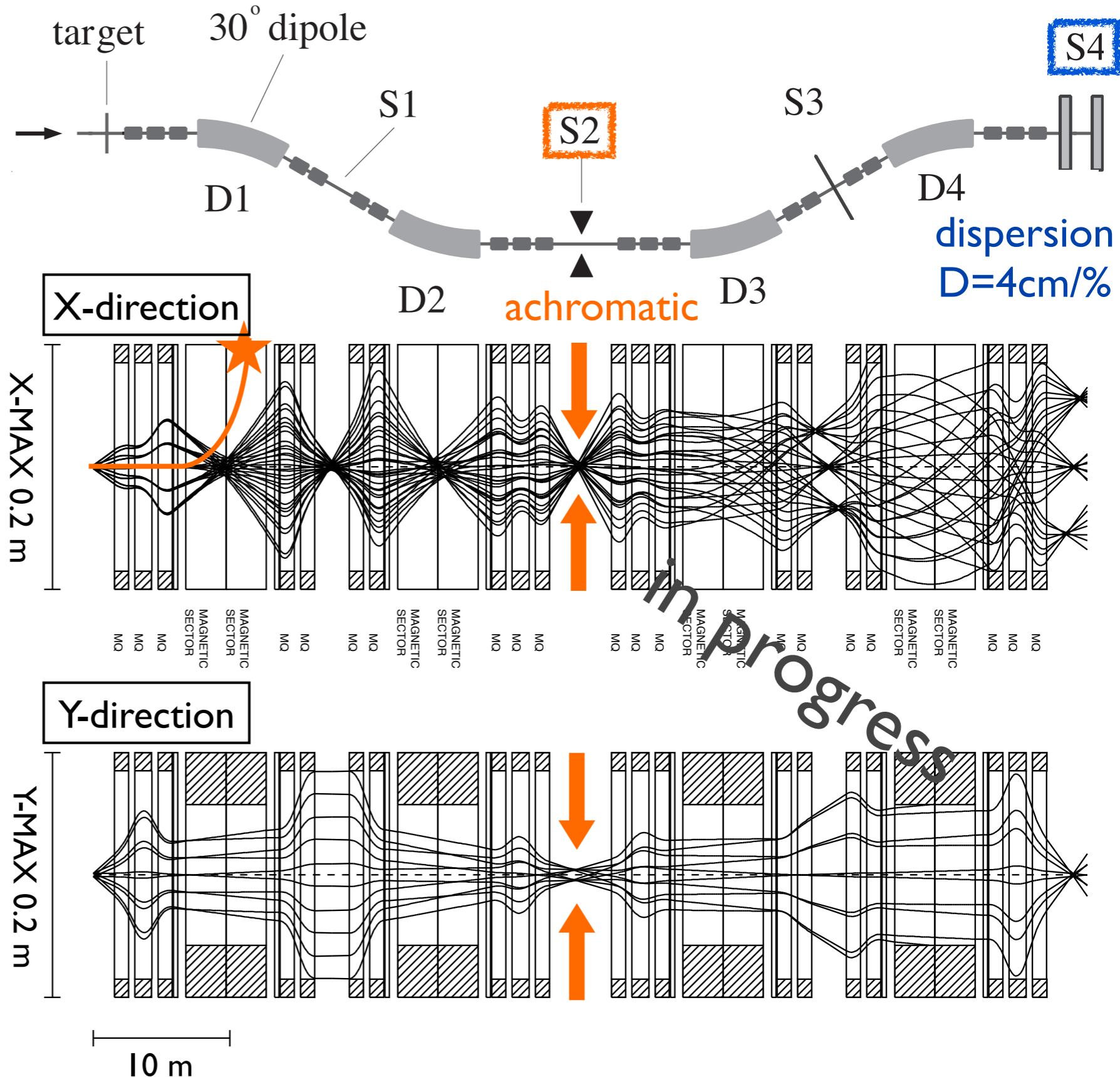
beam plot for

$X, Y = \pm 1.5\text{ mm}$

$X' = \pm 8\text{ mrad}$

$Y' = \pm 10\text{ mrad}$

$\delta = \delta p/p_0 = \pm 1.5\%$



[1] <http://web-docs.gsi.de/~weick/gicosy/>

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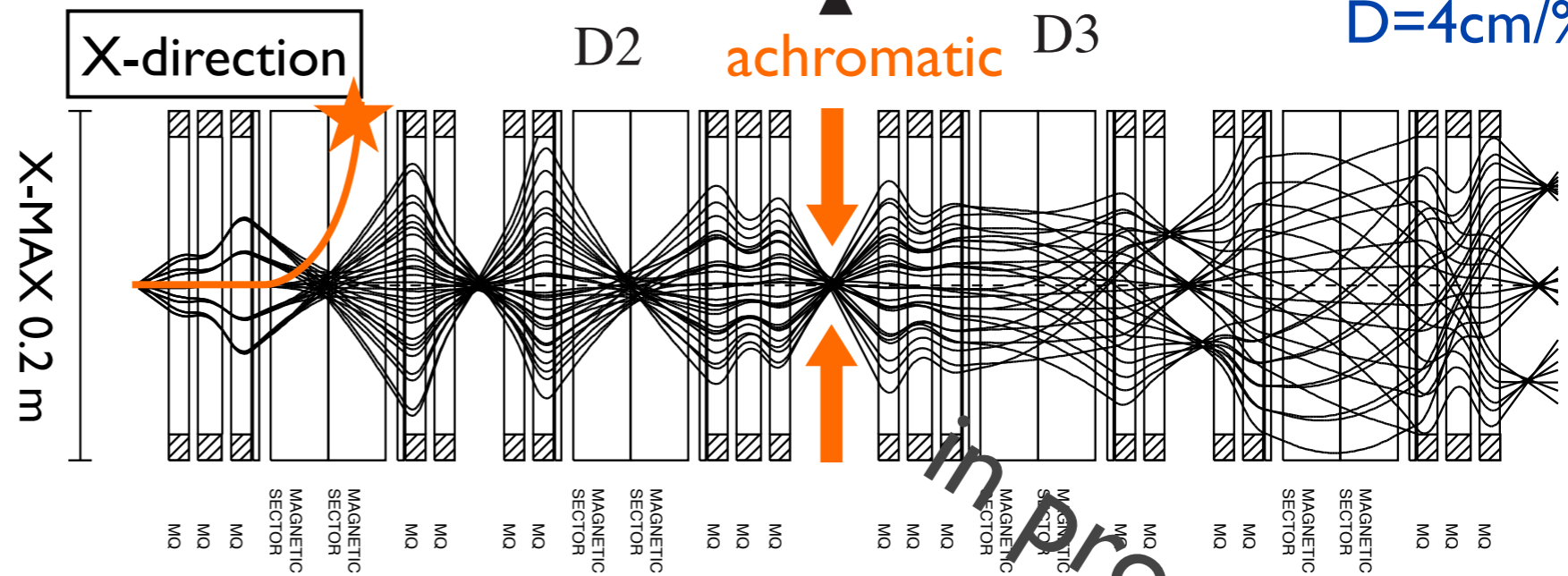
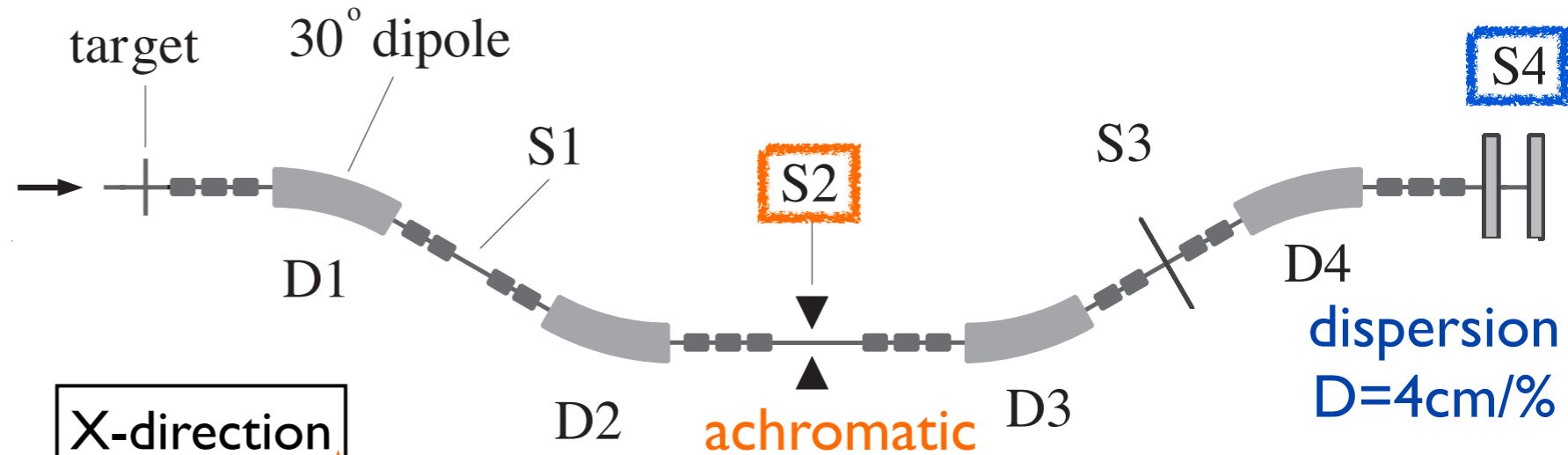
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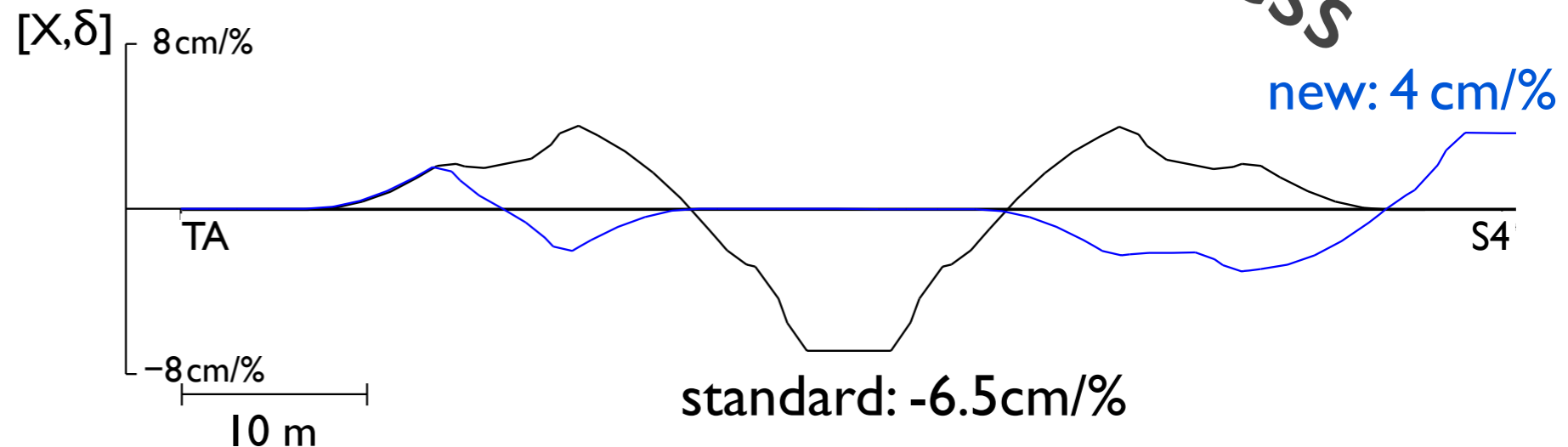
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Dispersion



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- **Experiment is now almost ready.**
Integrity test at COSY is scheduled in Jan. 2014.
- **First pilot experiment at GSI is expected in 2014.**

An aerial photograph of a large industrial or research facility. The facility consists of several large, white, rectangular buildings with flat roofs, arranged in a cluster on the left side. A central area is under construction, with a large, circular dirt clearing and several smaller structures. The surrounding area is mostly green, with dense forests and some open fields. A road or path curves around the construction site. The text "Future Plan at FAIR" is overlaid in the center of the image, enclosed in a red dashed border.

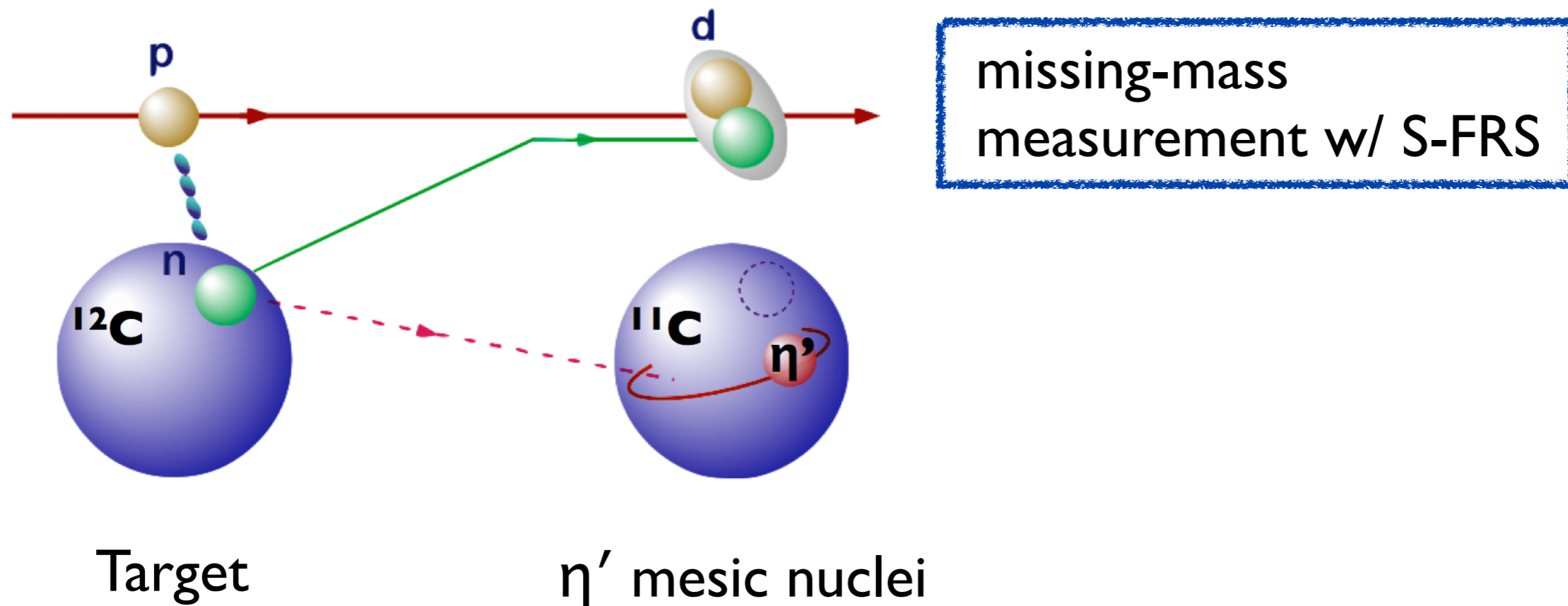
Future Plan at FAIR

Future plan at FAIR

1st Step : Inclusive measurement of (p,d) reaction with FRS at GSI



2nd Step : Semi-exclusive measurement of (p,dp) with Super-FRS at FAIR

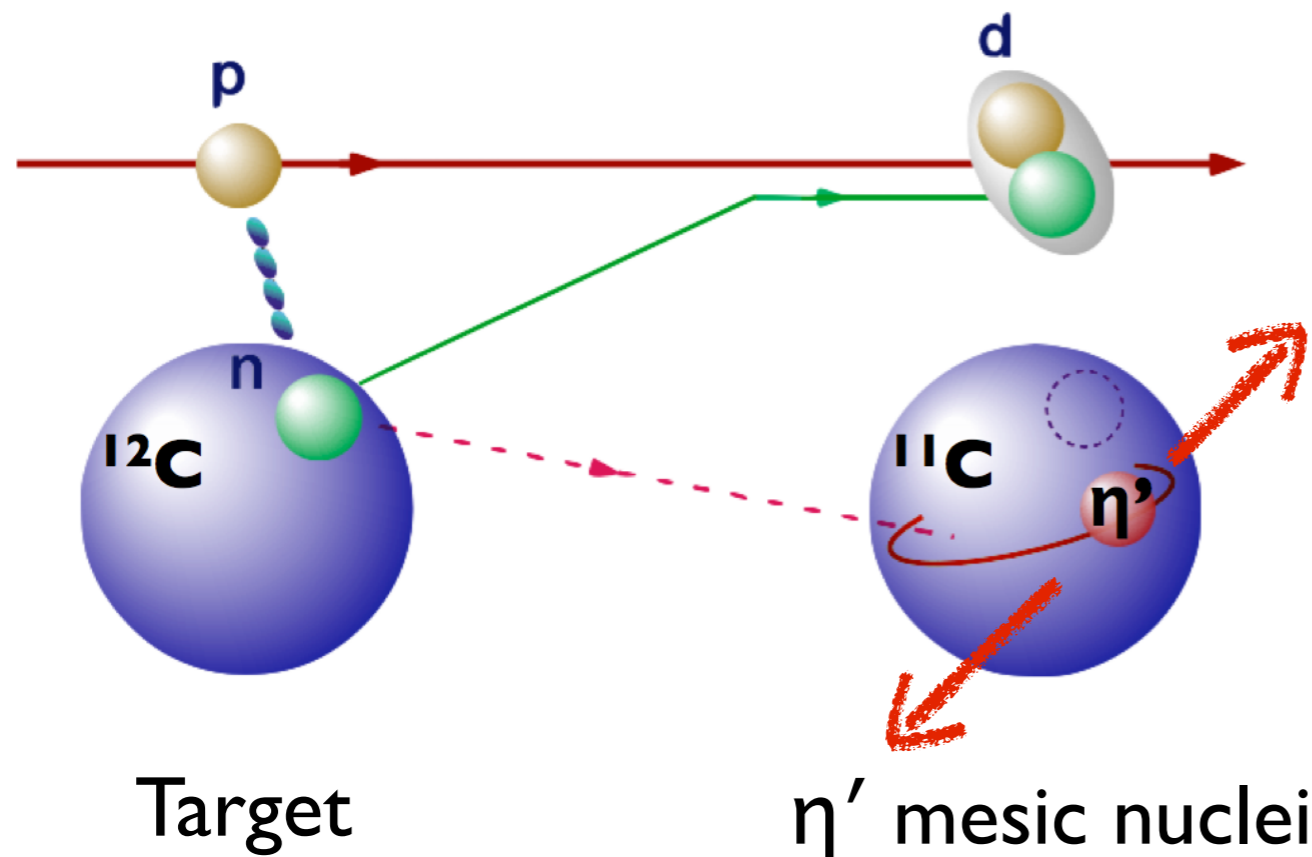


Future plan at FAIR

1st Step : Inclusive measurement of (p,d) reaction with FRS at GSI



2nd Step : Semi-exclusive measurement of (p,dp) with Super-FRS at FAIR



missing-mass
measurement w/ S-FRS

decay of η' mesic nuclei :

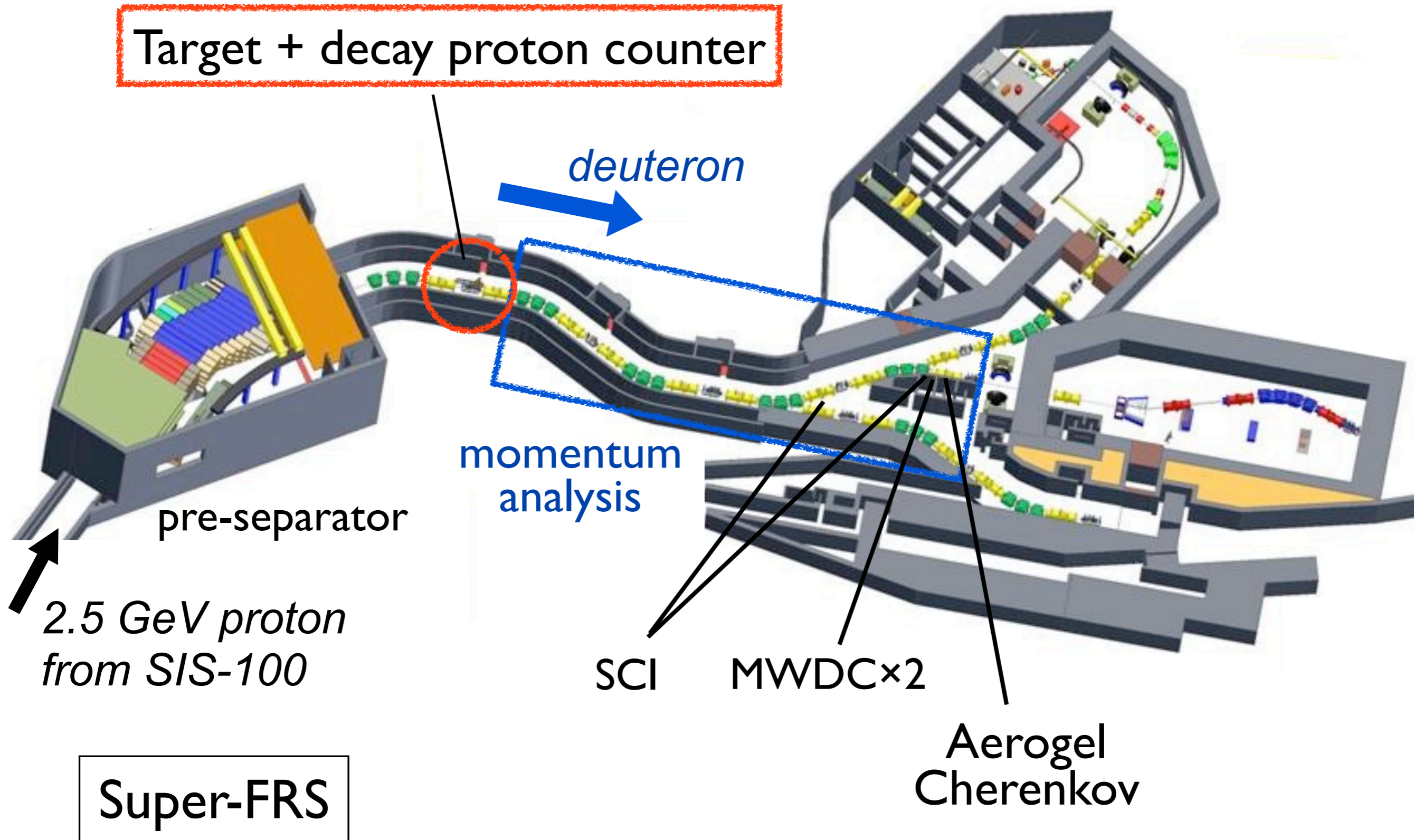
- $\eta'N \rightarrow \eta N$ or πN
- $\eta'NN \rightarrow NN$

Tagging proton in
coincidence with deuteron

- **drastically improve S/N ratio**
- **sensitivity to smaller $|V_0|$**

Experimental setup at Super-FRS

Target + decay proton counter



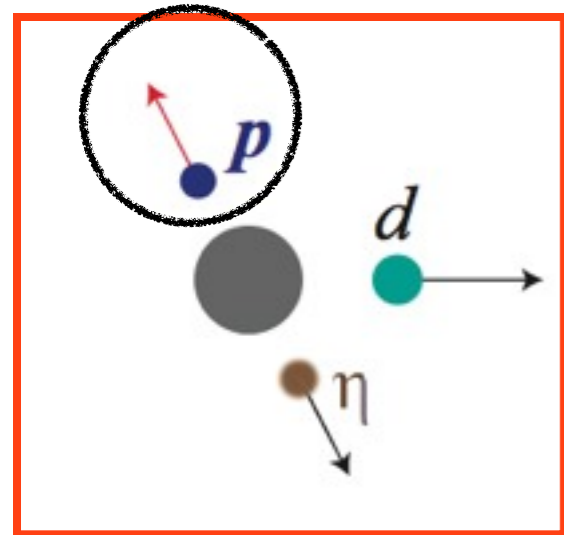
Tagging decay proton

signal

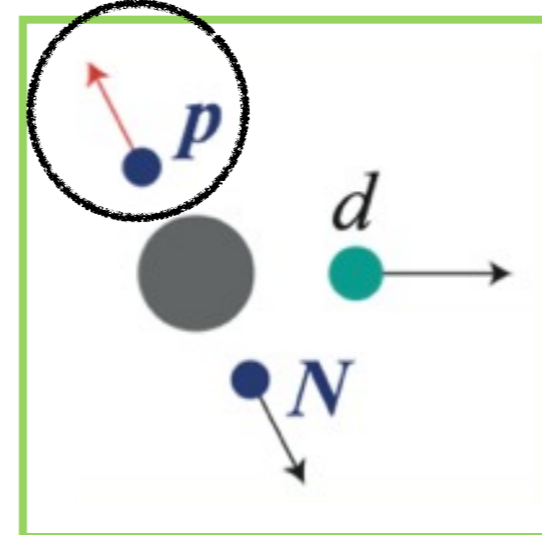
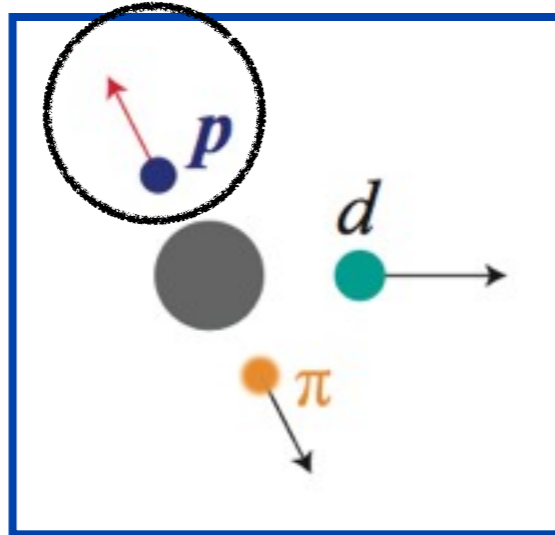
η' mesic nuclei

background

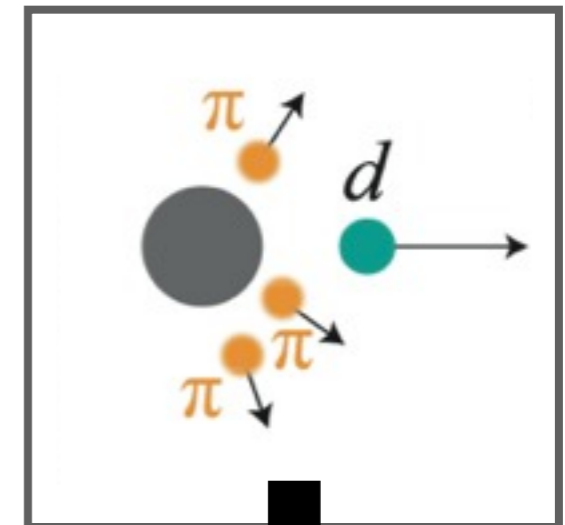
multi- π production



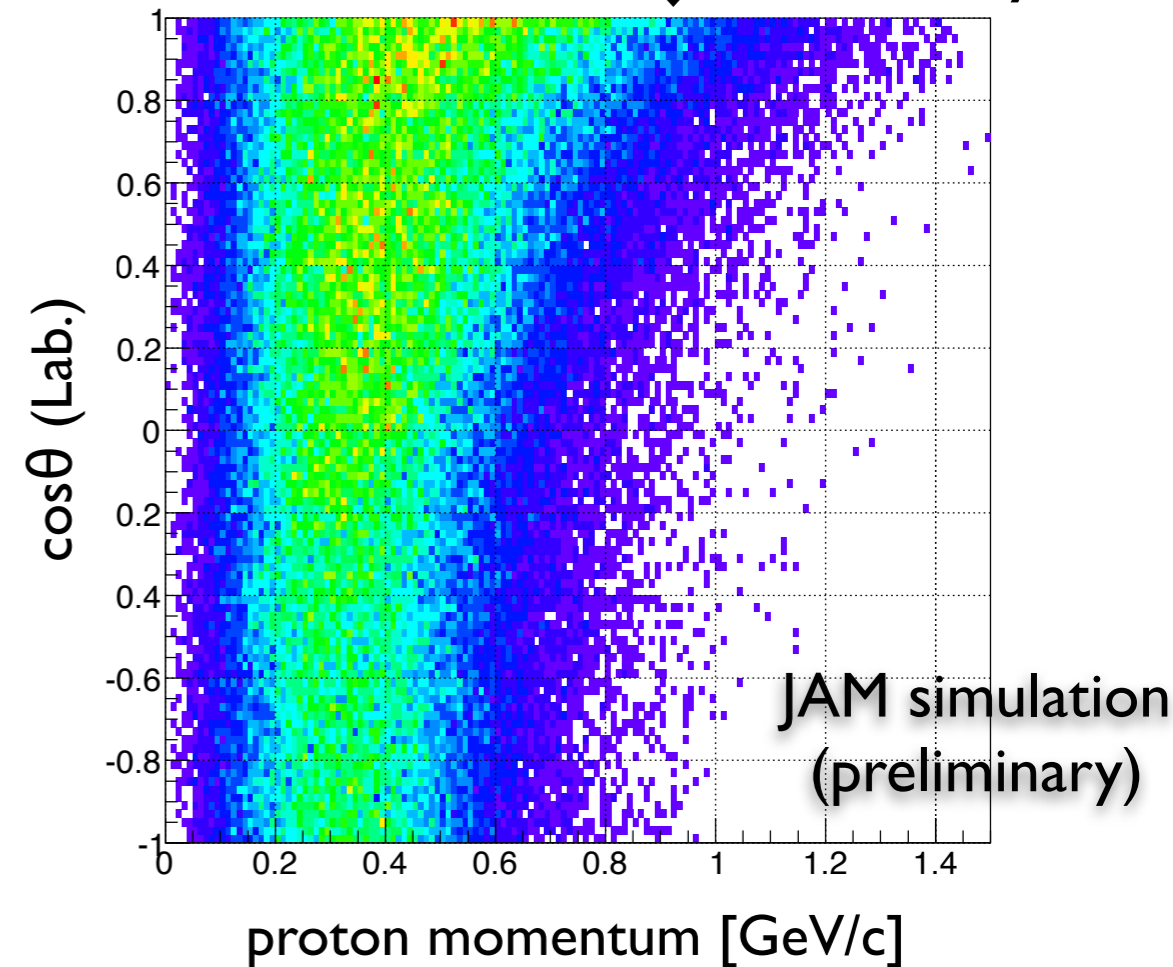
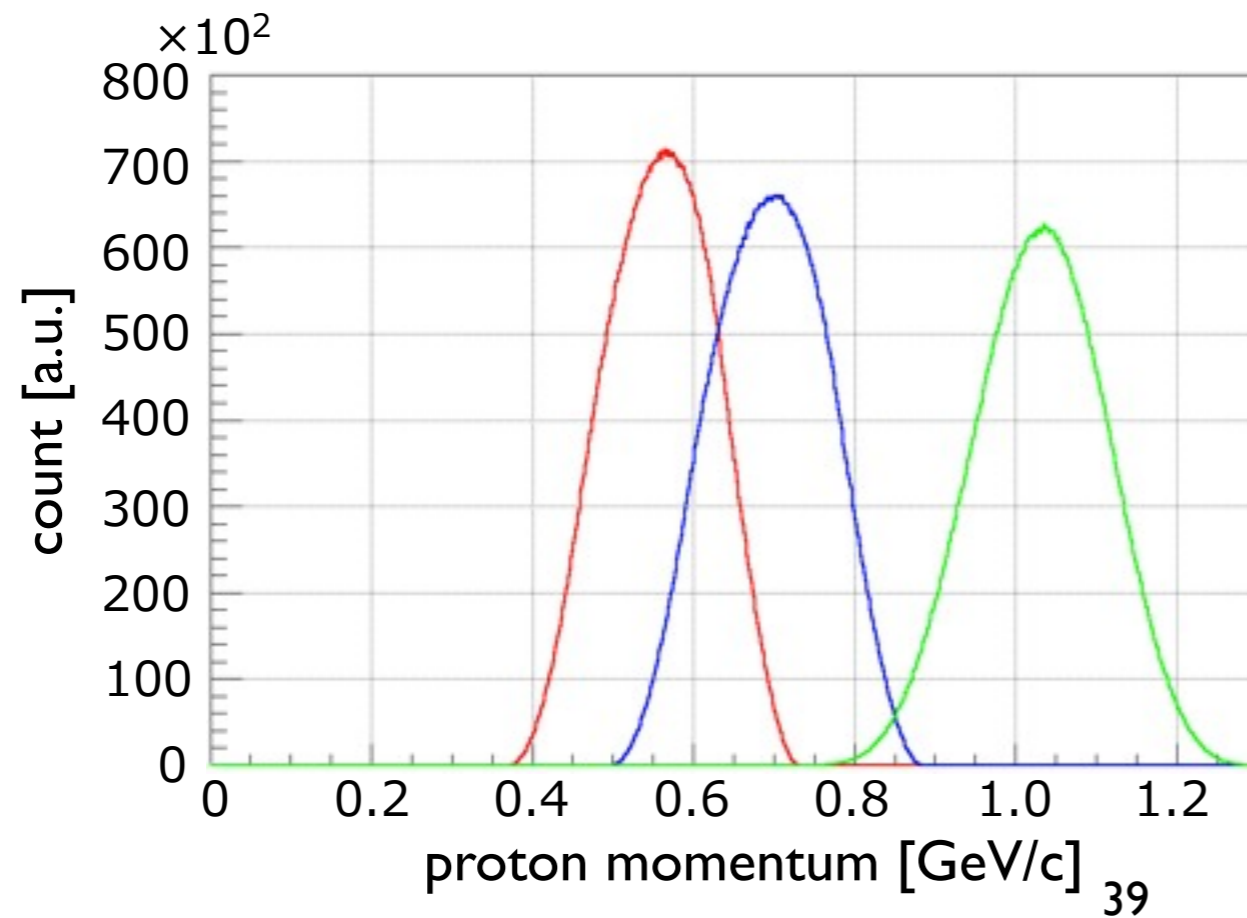
1 nucleon absorption



2 nucleon absorption



Proton by FSI



Decay proton counter

Requirements :

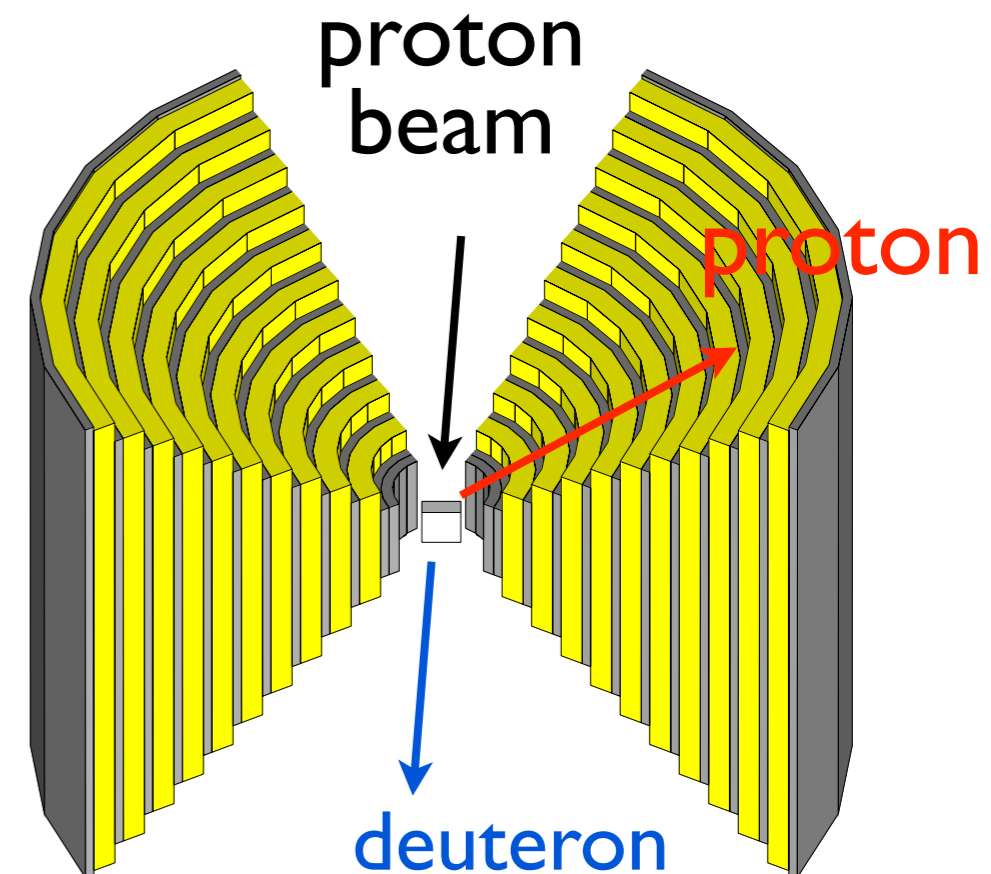
- π/p separation
- proton momentum of 0.4 – 1.2 GeV/c

Sampling calorimeter

- PID(π/p) by ΔE_i pattern and Range
- ~10 layers of Scintillator and Brass

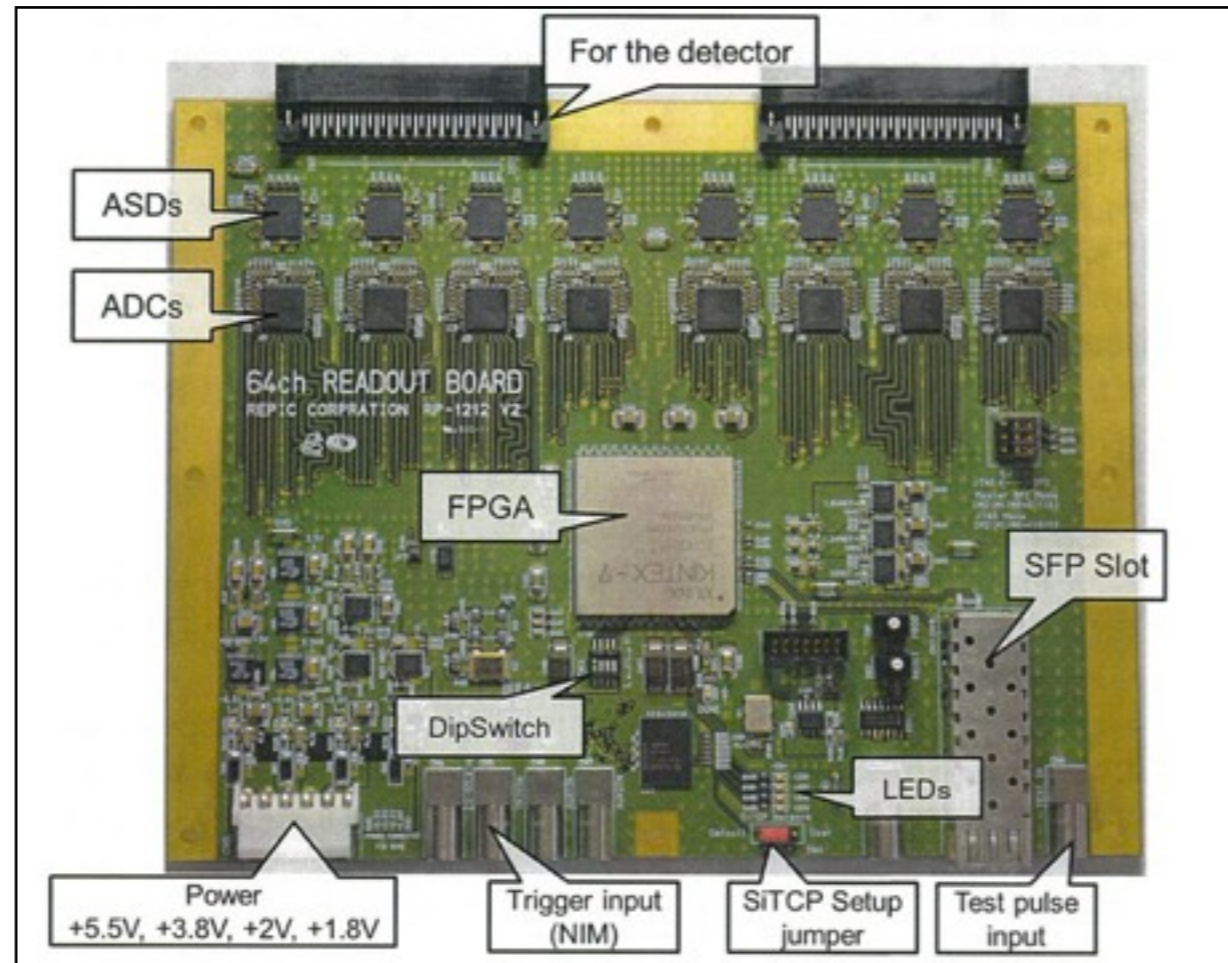
On-going study:

- optimization of detector configuration and algorithm of pattern recognition



Belle-II CDC readout board

- 64ch readout board (ASD+FADC+TDC)
- Dead time $\sim 0.5\%$ at 10 kHz trigger rate
(2012 Mar. JPS meeting, Taniguchi et al.)
- for readout MWDCs



On-going work:

- modification to fit general purposes (event matching etc.)
- testing data acquisition with MWDC

Summary

- We are planning missing-mass spectroscopy of η' mesic nuclei with (p,d) reaction to study in-medium properties of η' meson.
- With large mass reduction ($\sim 100\text{MeV}$) and narrow decay width ($\sim 20\text{MeV}$), η' mesic nuclei may be observed in inclusive spectrum.
- Inclusive measurement using FRS at GSI is almost ready. First pilot experiment is expected in 2014.
- At FAIR, we plan a semi-exclusive measurement of (p,dp) reaction with decay proton counter and Super-FRS. Tagging decay protons could improve S/N ratio drastically. R&D is presently on-going.