

# First measurement of $\phi$ meson production in 30 GeV proton-nucleus reactions via di-electron decay at J-PARC

Based on Prog. Theor. Exp. Phys. **2026**, 043D03

Satomi Nakasuga (RIKEN) for the J-PARC E16 collaboration

MESON2026, Krakow, Poland

June 26, 2026

# Overview

- **Introduction:**
  - Newly constructed beamline at J-PARC
  - J-PARC E16 experiment
  - Strangeness production at J-PARC energy
- **Experimental Setup**
- **Results**
- **Summary & Prospects**

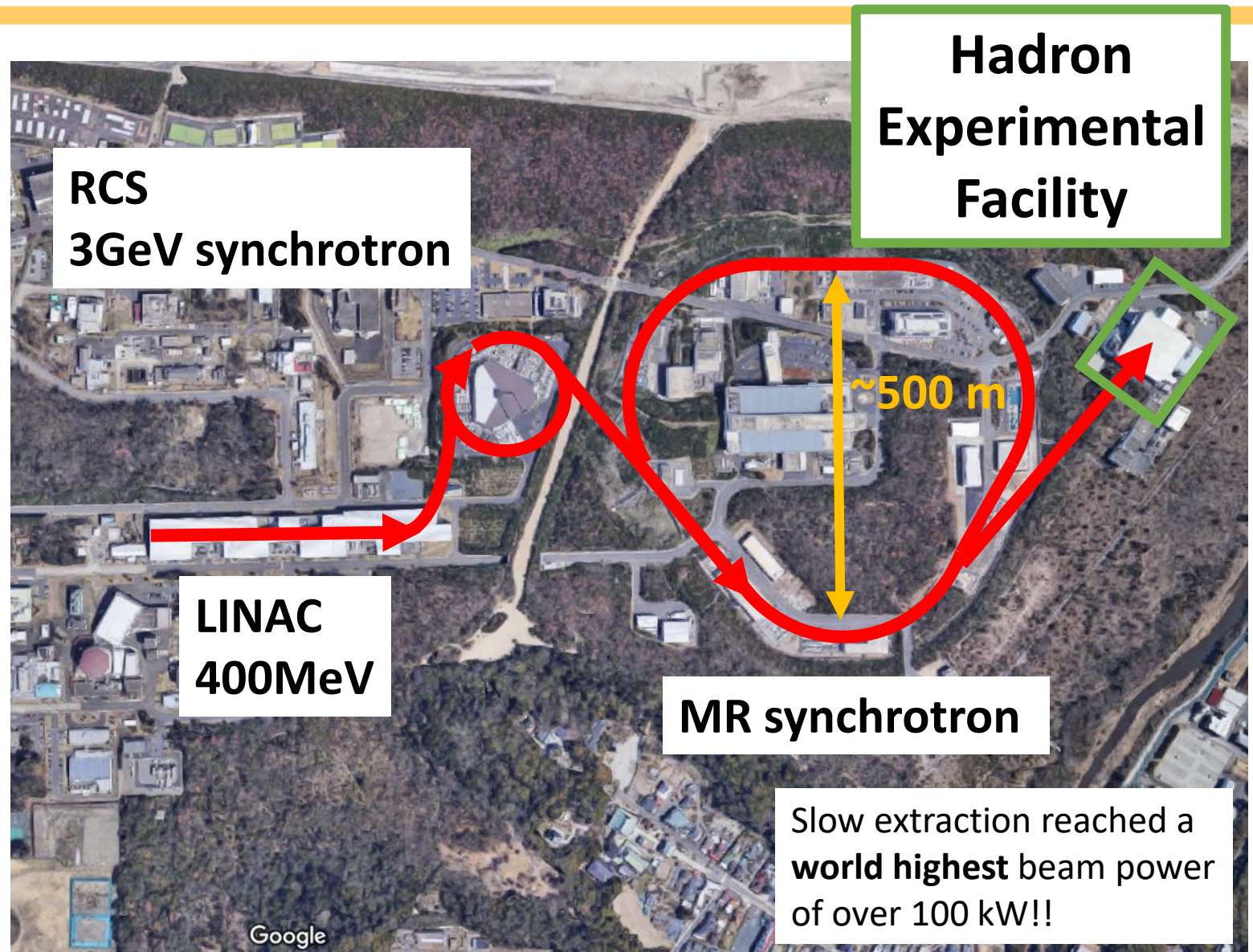


E16 spectrometer and High-momentum beamline (constructed in 2020, commissioned in 2020-2024)

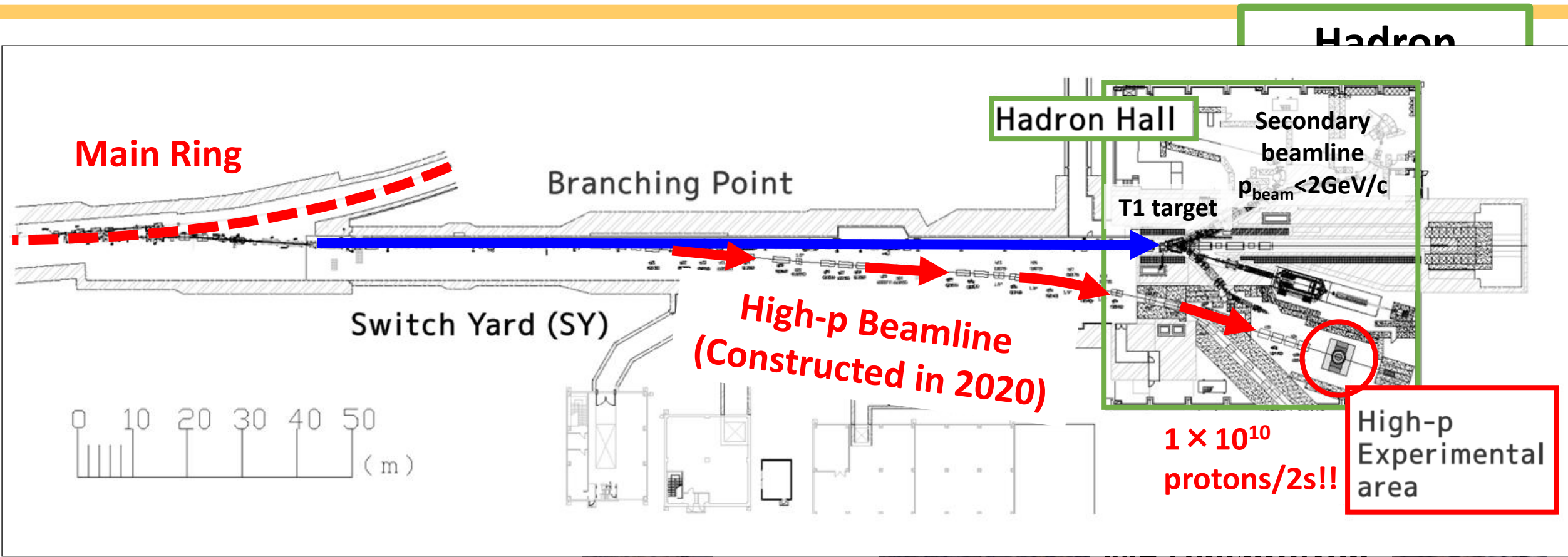
# J-PARC: Japan Proton Accelerator Research Complex 3



- **proton beam** is accelerated to a **kinetic energy of 30 GeV**
- $\sim 8.8 \times 10^{13}$  protons/2 sec. are extracted to HEF.



# J-PARC: Japan Proton Accelerator Research Complex



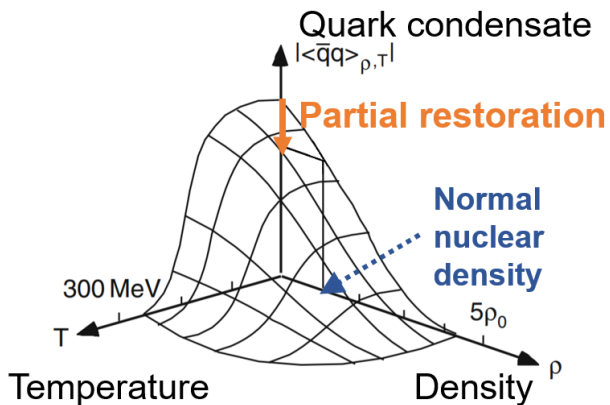
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  - a
- New physics opportunities**
- with intermediate-energy (2–30 GeV) & high-intensity beams**
- Referred by Sakuma-san in today's plenary session

# First Program @High-p: E16 experiment

## ■ Physics Motivation

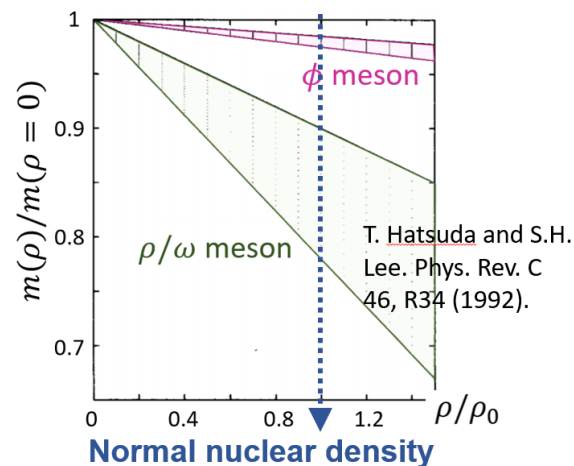
- Spontaneous Breaking of Chiral Symmetry
  - Origin of the hadron mass
  - Quark condensate  $\langle \bar{q}q \rangle$ : order parameter of chiral symmetry
  - In vacuum,  $\langle 0 | \bar{q}q | 0 \rangle \neq 0$
- Restoration in Extreme Environment

by the NJL Model

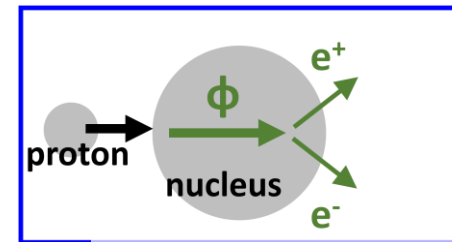
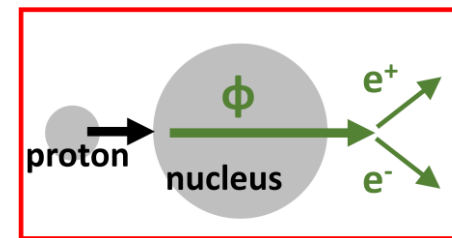
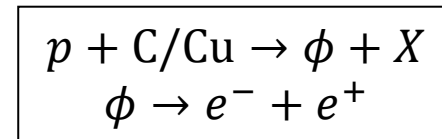


W. Weise, Nucl. Phys. A 553, 59(1993).

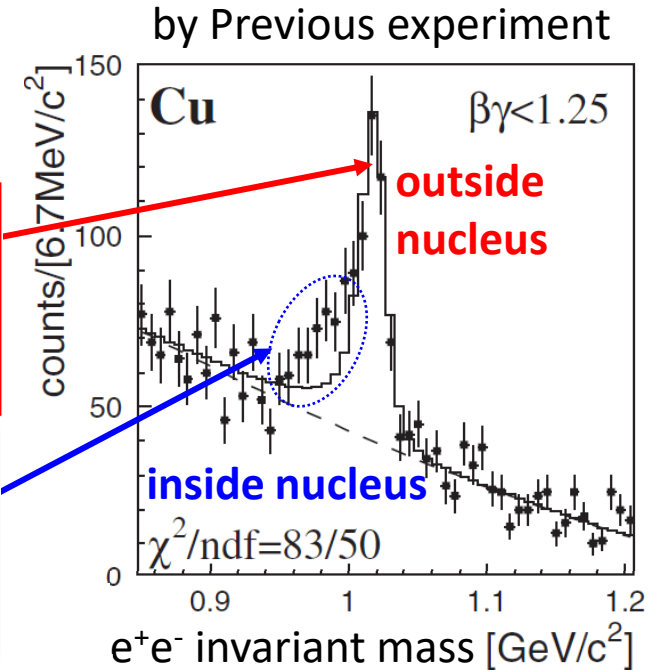
by the QCD sum rule



## ■ Experimental Approach



Electron: No final state interaction with nucleus



R. Muto *et al.*, Phys. Rev. Lett. 98, 042501 (2007).

→ **E16: much higher statistics & resolution!**  
 Commissioning was finished (today's topic),  
 Physics data taking is ongoing.

# First Program @High-p: E16 experiment

## Related Talks:

Details of E16 physics data taking:

→ Ngafusa-san's talk

C3, 15:25-15:45, June 26 (in parallel)

Complemental study of  $\phi \rightarrow K^+K^-$  decays:

→ WooSeung-san's talk

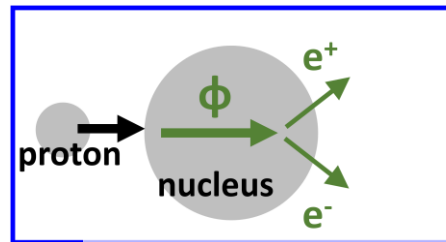
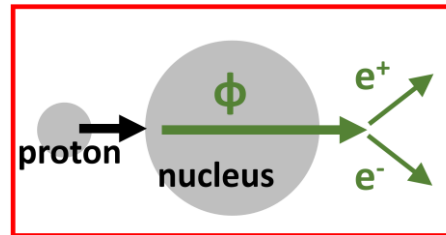
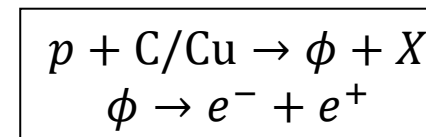
C3, 15:45-16:05, June 26 (after this talk)

Re-analysis of spectral modification in previous experiment:

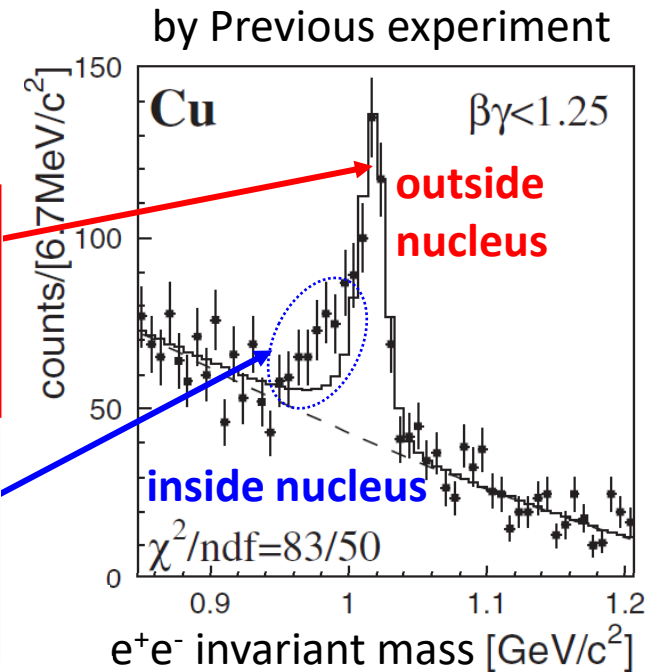
→ Ichikawa-san's talk

B3, 15:45-16:05, June 26 (after this talk)

## ■ Experimental Approach



Electron: No final state interaction with nucleus



R. Muto *et al.*, Phys. Rev. Lett. 98, 042501 (2007).

→ **E16: much higher statistics & resolution!**  
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# Strangeness production at intermediate energies (1) 7

Strangeness production in 30-GeV p–A collisions ( $\sqrt{s} = 7.7$  GeV) is considered to be dominated by  $s\bar{s}$  pair creation from the vacuum via **string fragmentation**.

Schwinger mechanism (the basis of the Lund string model)

$$P(q\bar{q}) \propto \exp\left(-\pi \frac{m_q^2}{2K}\right)$$

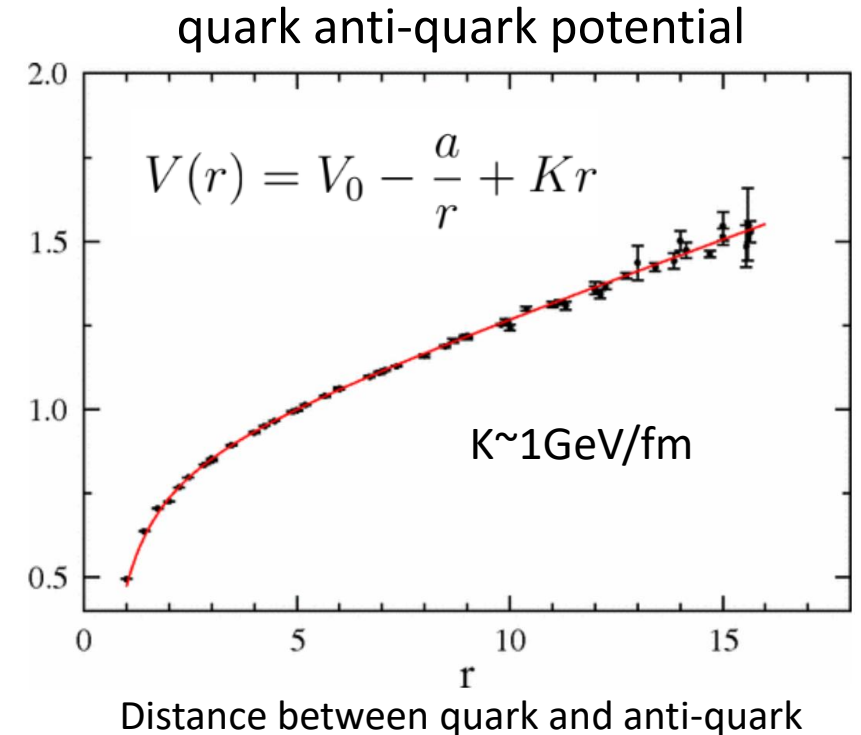
(K is string tension,  $m_q$  is effective quark mass)

The production ratio of u,d quarks to s quarks is

$$\frac{P(s\bar{s})}{P(u\bar{u})} = \frac{P(s\bar{s})}{P(d\bar{d})} = \gamma_s = \exp\left(-\pi \frac{m_s^2 - m_{u,d}^2}{2K}\right)$$

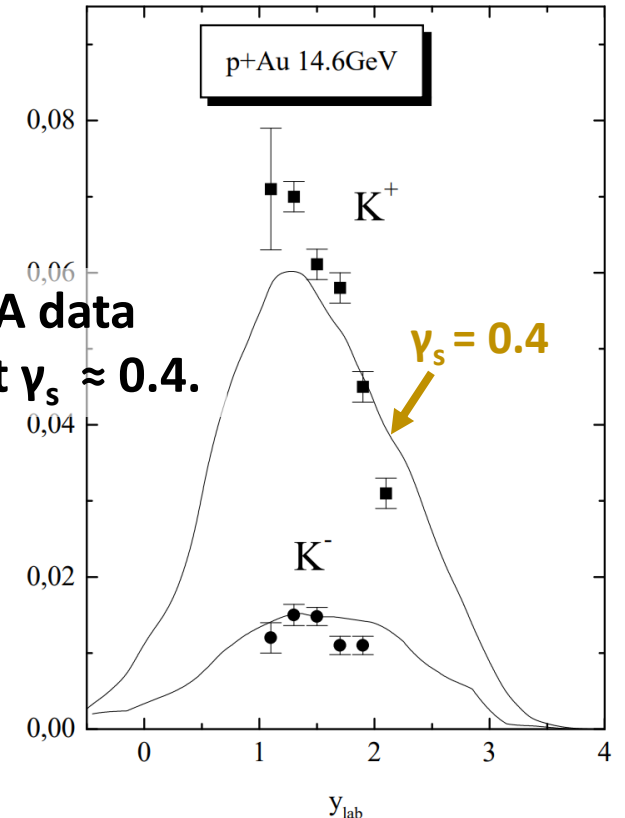
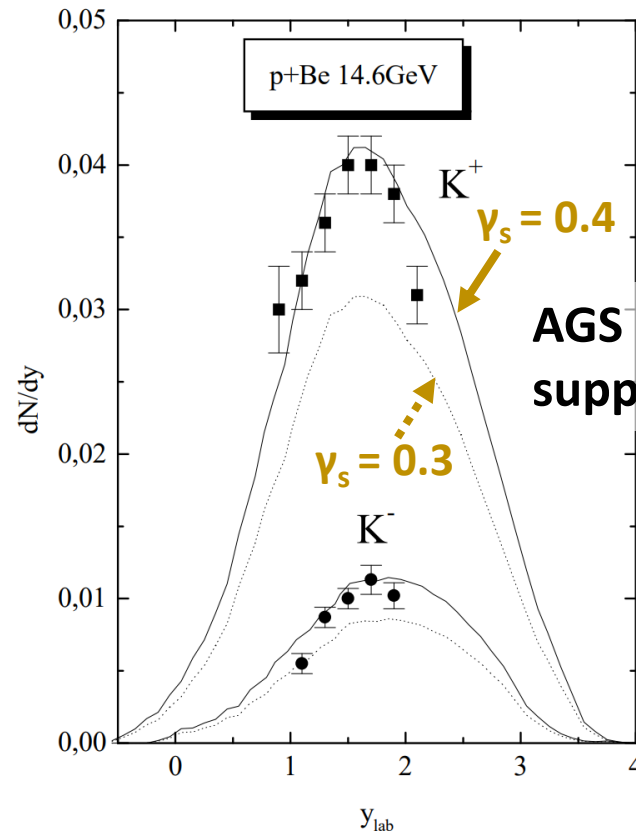
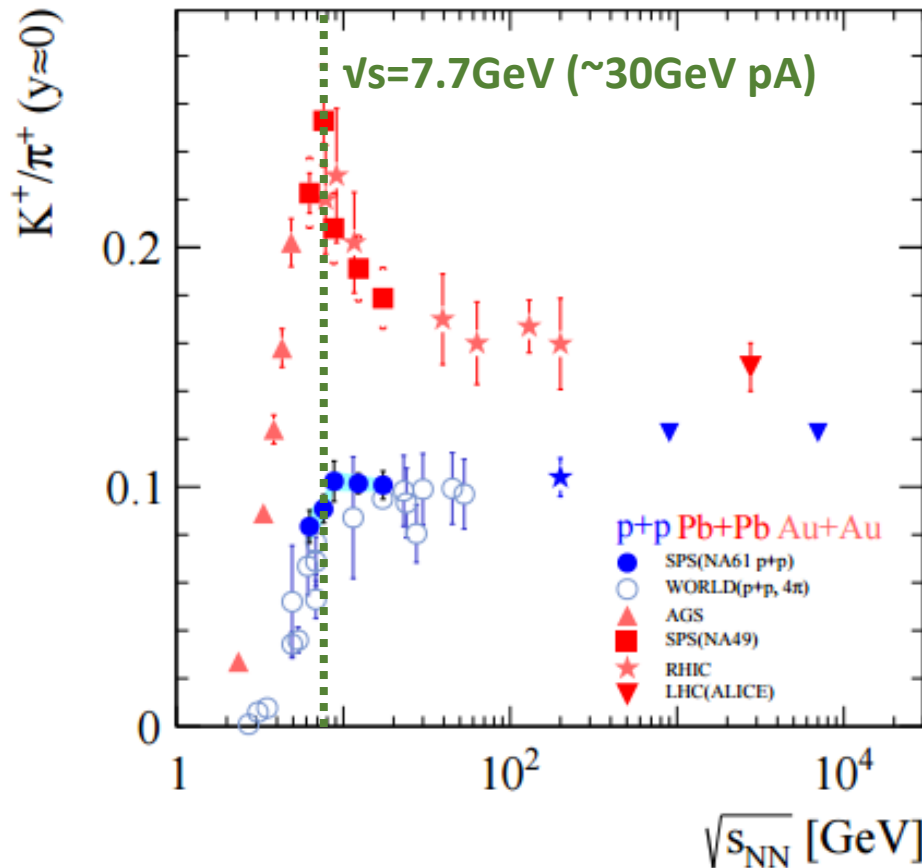
Using  $m_{u,d} \approx 300$  MeV and  $m_s \approx 500$  MeV gives  $\gamma_s \approx 0.3$ .

Hadron production from  $e^+e^-$  collisions support  $\gamma_s = 0.3$  (or 0.2).



# Strangeness production at intermediate energies (2) 8

On the other hands, at only intermediate energy, A+A and p+A data suggests the strangeness enhancement. → **Underlying picture??**



Nucl. Phys. A **644**, 107 (1998).

# Interpretation with chiral symmetry re

Phys. Rev. C **93** 014902(2016), Phys. Rev. C **94** 044912(2016)

## Concept:

chiral symmetry restoration at finite density



reduced effective quark masses



enhanced  $\gamma_s$

**Modeling:** the effective (dressed) quark mass decreases in response to the reduction of the quark condensate

$$m_s^* = m_s^0 + (m_s^V - m_s^0) \frac{\langle \bar{q}q \rangle}{\langle \bar{q}q \rangle_V}$$

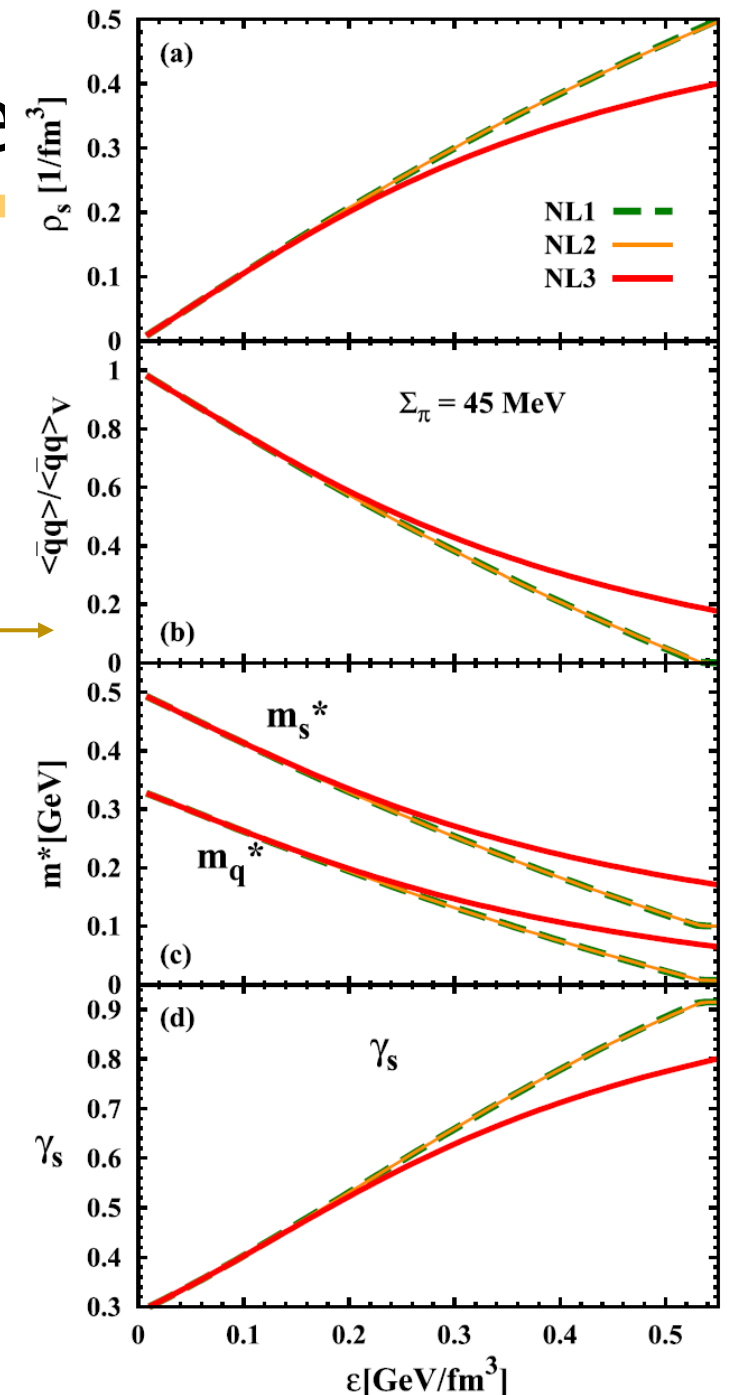
$\leftarrow \bar{q}q$  in medium  
 $\leftarrow \bar{q}q$  in vacuum

$$m_q^* = m_q^0 + (m_q^V - m_q^0) \frac{\langle \bar{q}q \rangle}{\langle \bar{q}q \rangle_V}$$

dressed quark mass in medium

dressed quark mass in vacuum

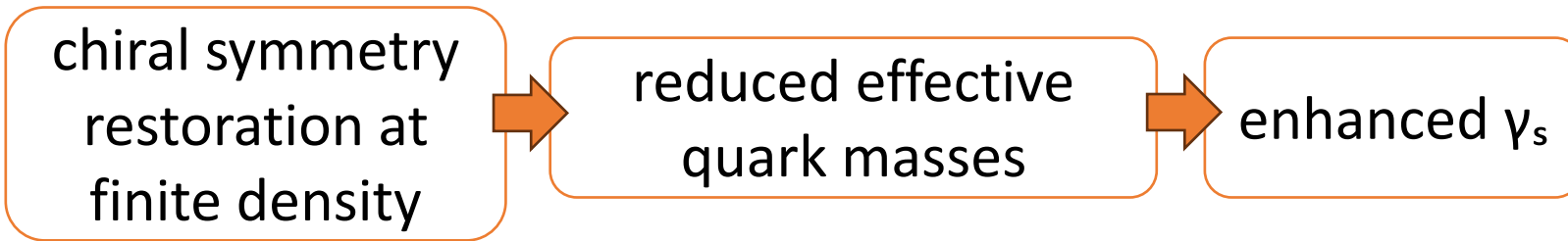
current quark mass



# Interpretation with chiral symmetry restoration

Phys. Rev. C **93** 014902(2016), Phys. Rev. C **94** 044912(2016)

## Concept:



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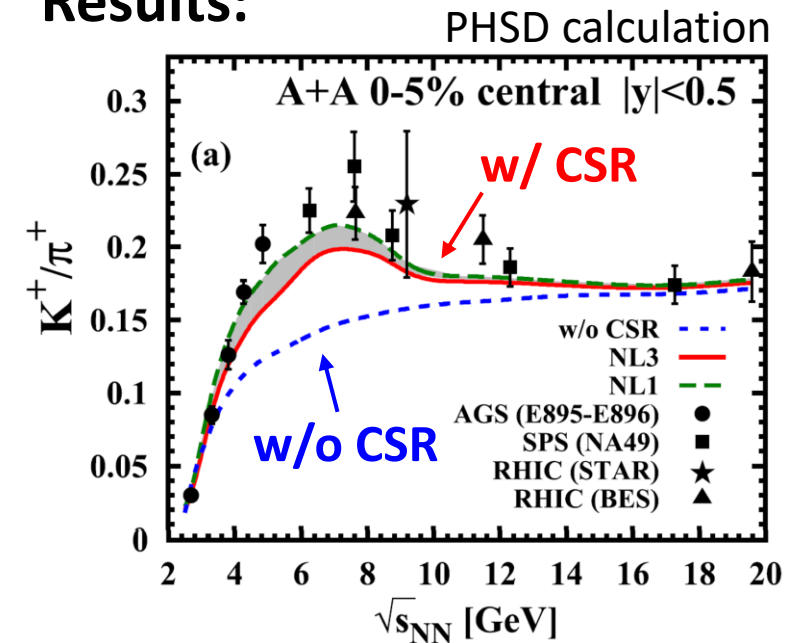
$$m_q^* = m_q^0 + (m_q^V - m_q^0) \frac{\langle \bar{q}q \rangle}{\langle \bar{q}q \rangle_V}$$

dressed quark mass in medium

dressed quark mass in vacuum

current quark mass

## Results:



It reproduces the observed strangeness enhancement.

# Interpretation with chiral symmetry restoration

Phys. Rev. C **93** 014902(2016), Phys. Rev. C **94** 044912(2016)

## Concept:

chiral sy  
restora  
finite c

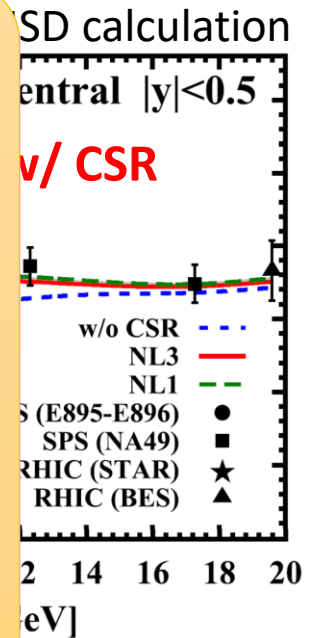
Modeling  
in respon

### Advantage of our (future precise) data

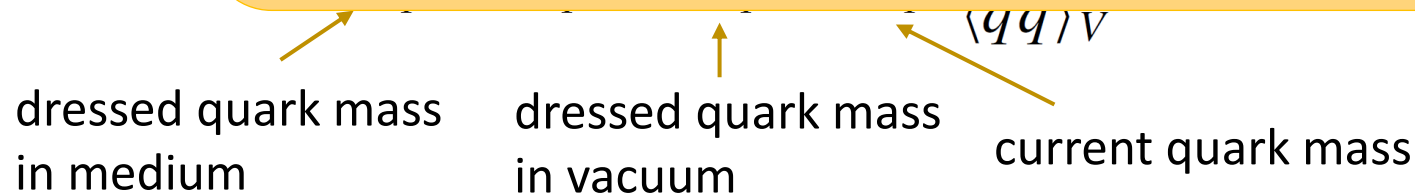
- No existing data of  $\phi$ -meson at  $\sqrt{s}=7.7$  GeV in pA
- pA reactions: a simple system of zero temperature and normal nuclear density
- Di-electron measurement: No final state interaction

### Today's report

- First measurement was achieved!
- We established the experimental technique



the observed strangeness enhancement.

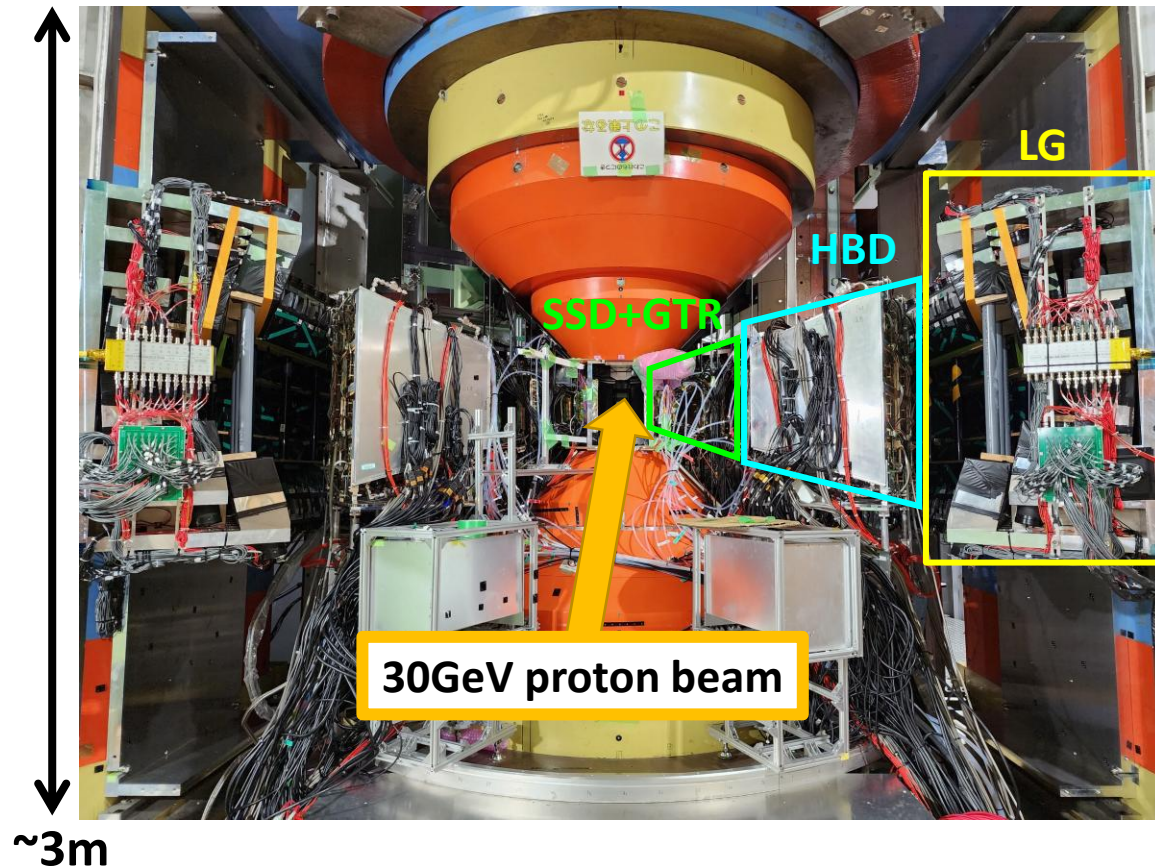


# Experimental Setup

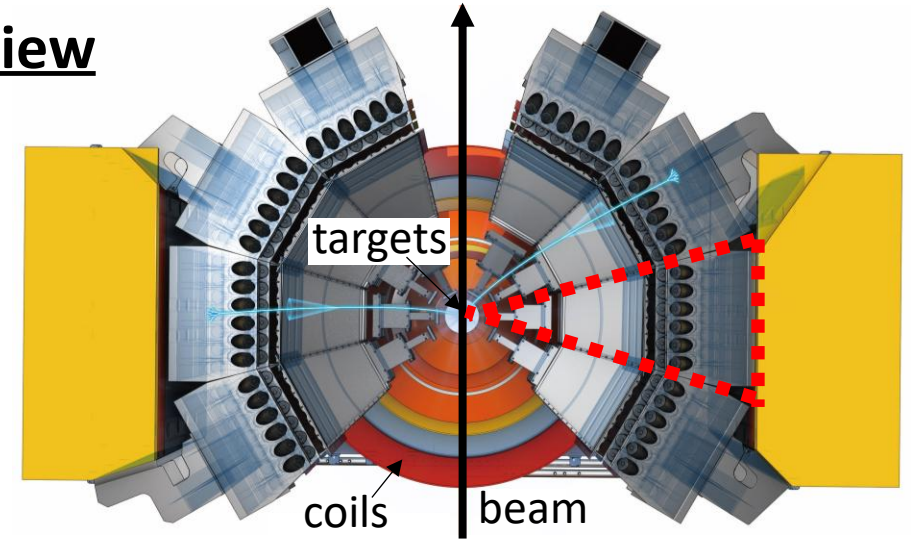
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# E16 Spectrometer

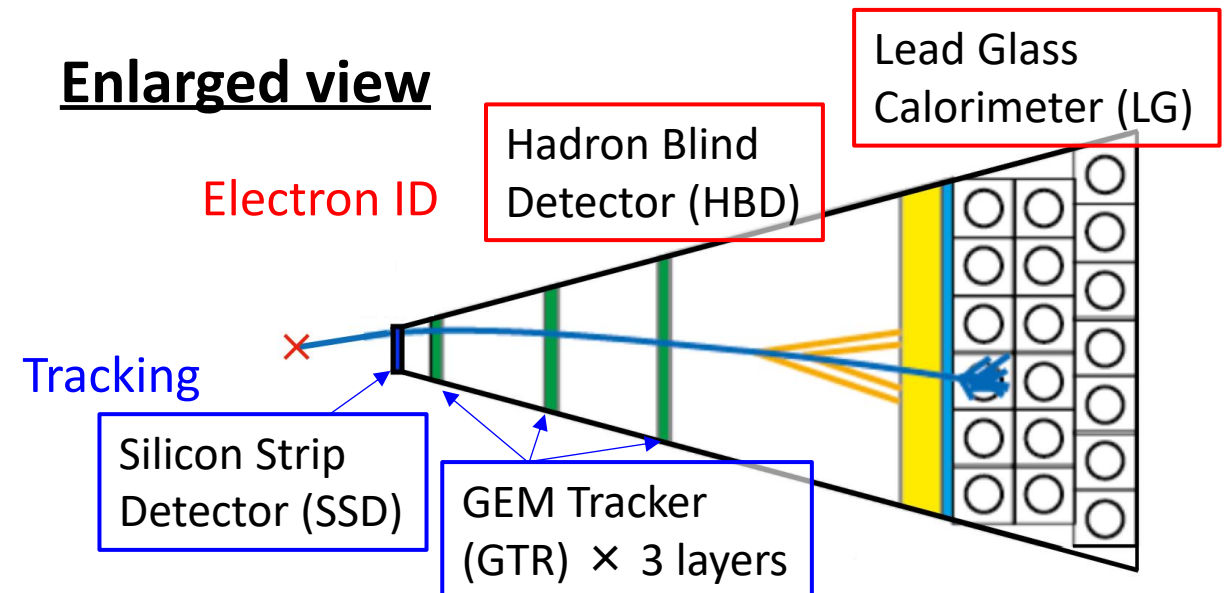
FM magnet: Normal-conducting electromagnet, up to 1.77 T



Top view



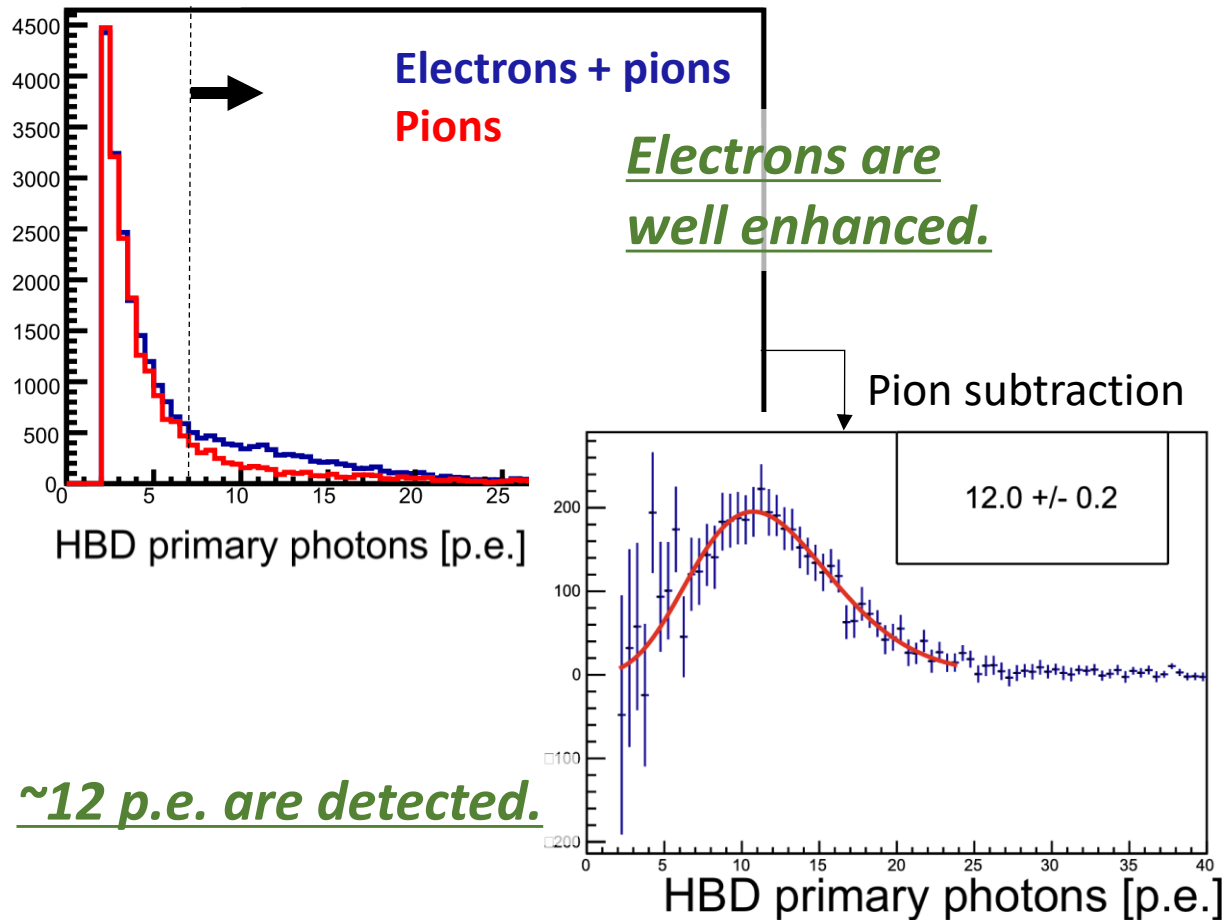
Enlarged view



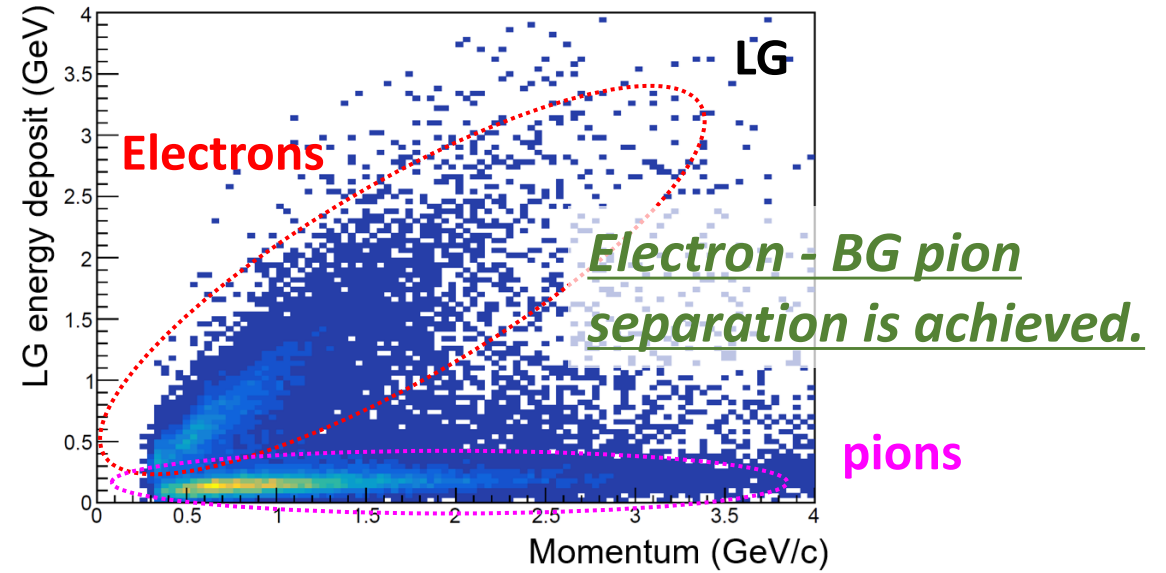
# Detector response: electron ID

## ■ Hadron Blind Detector

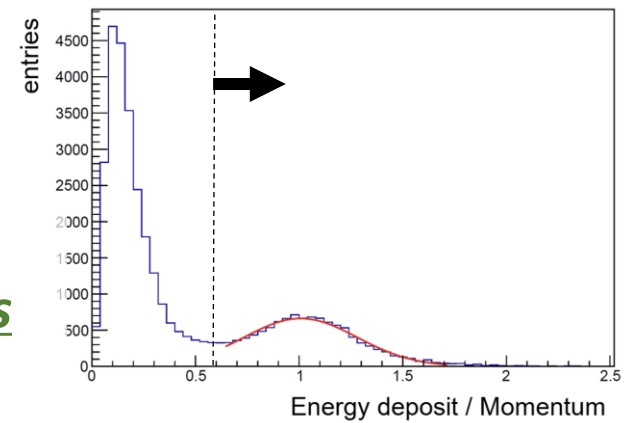
– Gas Cherenkov Detector



## ■ Lead-glass Calorimeter

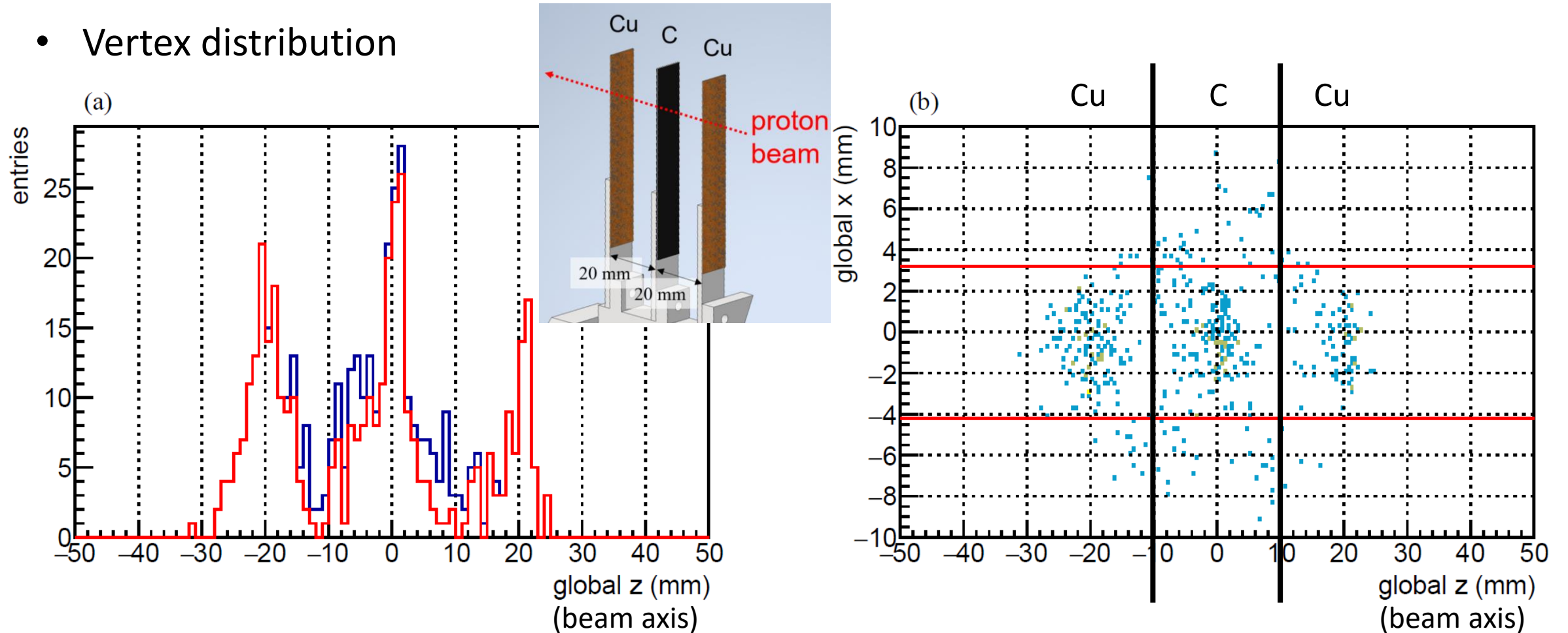


*95% efficiency for single tracks*



# Detector response: tracking

- Vertex distribution



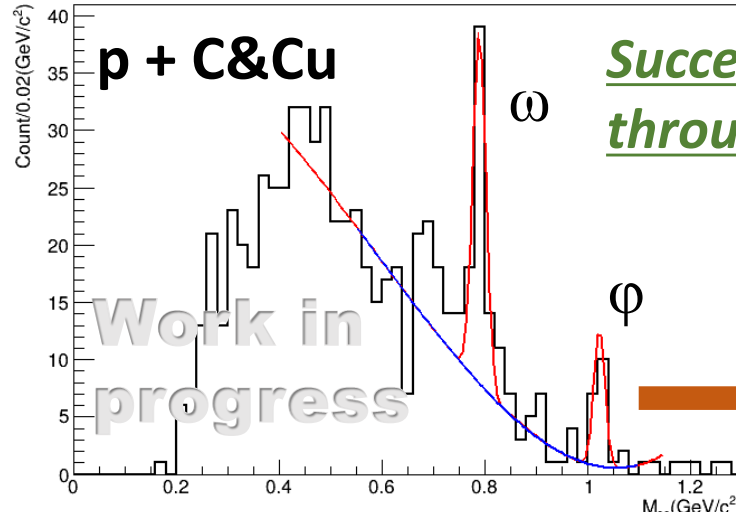
Successful reconstruction of target positions

# Results

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# $e^+e^-$ Invariant Mass Spectrum

All mass region

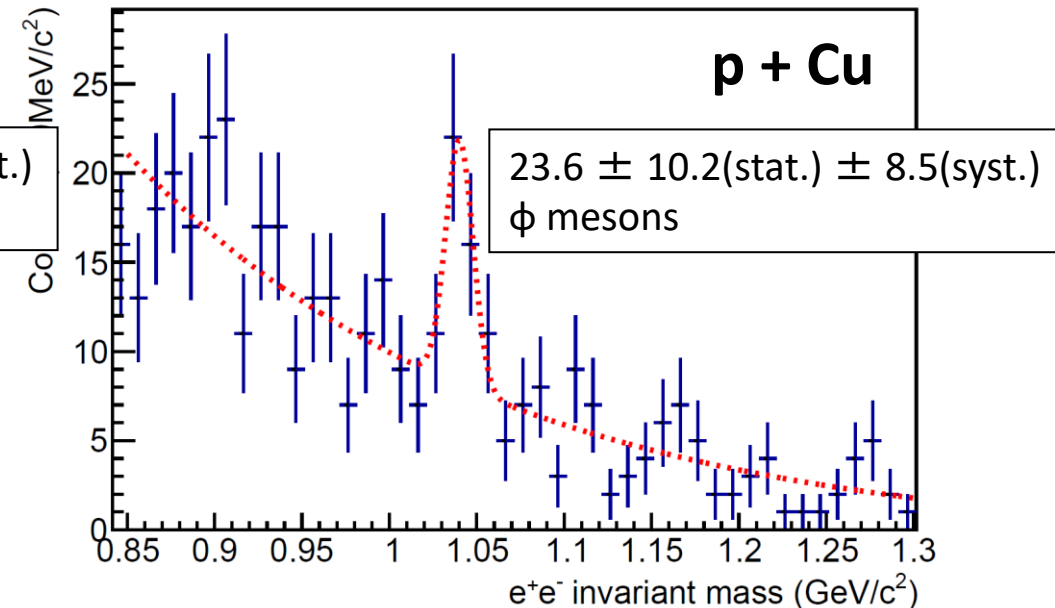
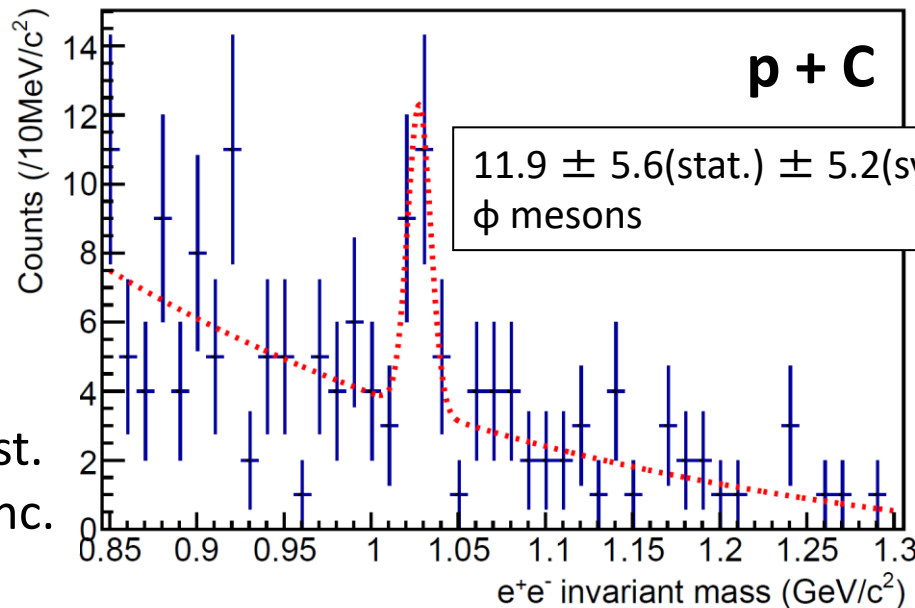


Successful measurement of vector mesons through di-electron decay

M. Naruki *et al.*, PoS HADRON2025 (2026) 184

Finalization of  $\phi$  Yields by improved method

$\phi$  mass region



..... Signal + BG  
Signal: Gaussian dist.  
BG: exponential func.

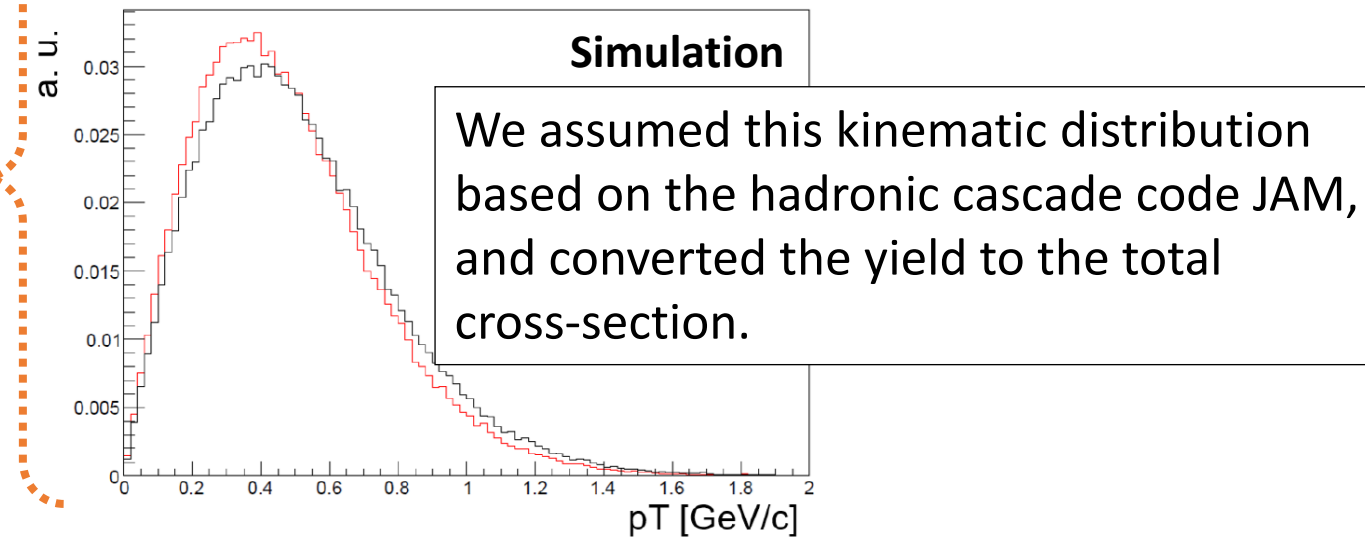
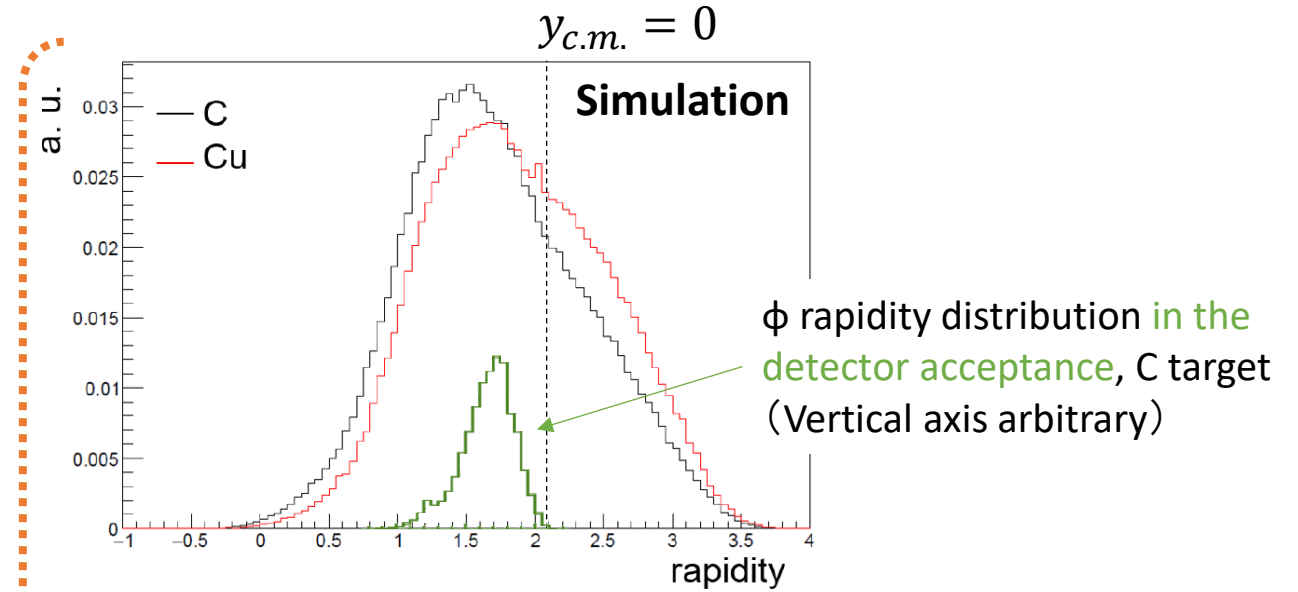
S. Nakasuga *et al.*, Prog. Theor. Exp. Phys. **2026**, 043D03

# Estimation of $\phi$ total cross section

$$\sigma^{C/Cu} = \frac{N_{\text{yield}}^{C/Cu}}{N_{\text{beam}} \cdot N_{\text{target}}^{C/Cu} \cdot \varepsilon^{C/Cu} \cdot R}$$

- $N_{\text{yield}}$ : Yield of  $\phi$  mesons
- $N_{\text{beam}}$ : The number of beam protons
- $N_{\text{target}}$ : The number of target nuclei
- $R$ :  $\phi \rightarrow ee$  branching ratio
- $\varepsilon$ : Efficiency, Detector Acceptance

	Total cross section (mb)	
➔ C	$2.0 \pm 0.9$ (stat.)	$\pm 1.0$ (syst.)
Cu	$10.3 \pm 4.4$ (stat.)	$\pm 4.4$ (syst.)



# Mass number dependence

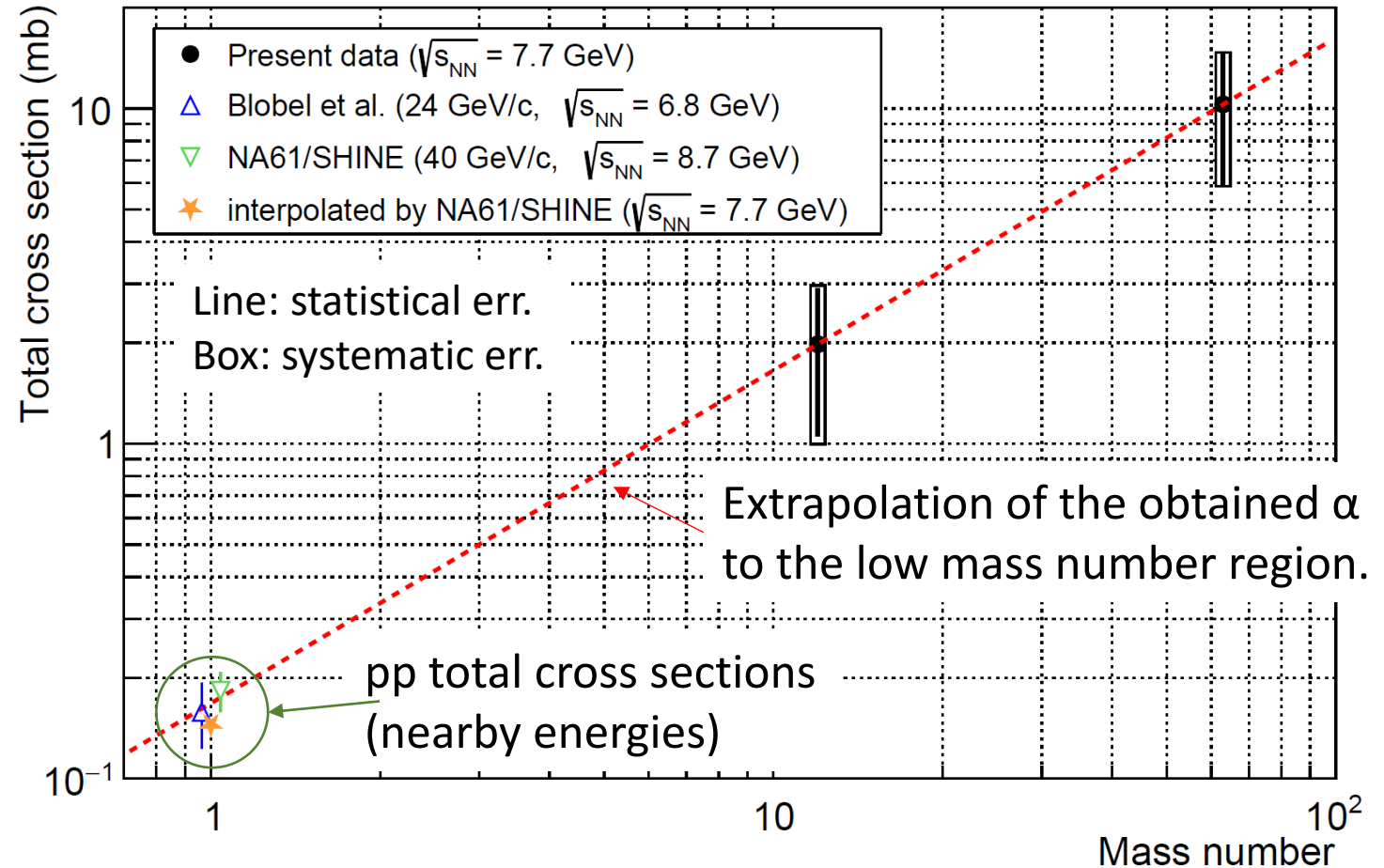
$\alpha$  parameter:  $\sigma_{pA}(A) \propto A^\alpha$

We obtained

$$\alpha = 0.99 \pm 0.38 \text{ (stat.)} \pm 0.34 \text{ (syst.)}$$

Our evaluation includes large uncertainties; however, a similar trend with  $\alpha \approx 1$  is observed across different energy regions.

Beam energy (GeV)	$\alpha$
12 (KEK-PS, ee)	$0.937 \pm 0.049 \pm 0.018$
30	$0.99 \pm 0.38 \pm 0.34$
400 (NA60, $\mu\mu$ )	$0.906 \pm 0.011 \pm 0.025$



S. Nakasuga *et al.*, Prog. Theor. Exp. Phys. 2026, 043D03

Our result may suggest  $\alpha \approx 1$ , namely,  $\sigma_{pA} \approx A \times \sigma_{pp}$

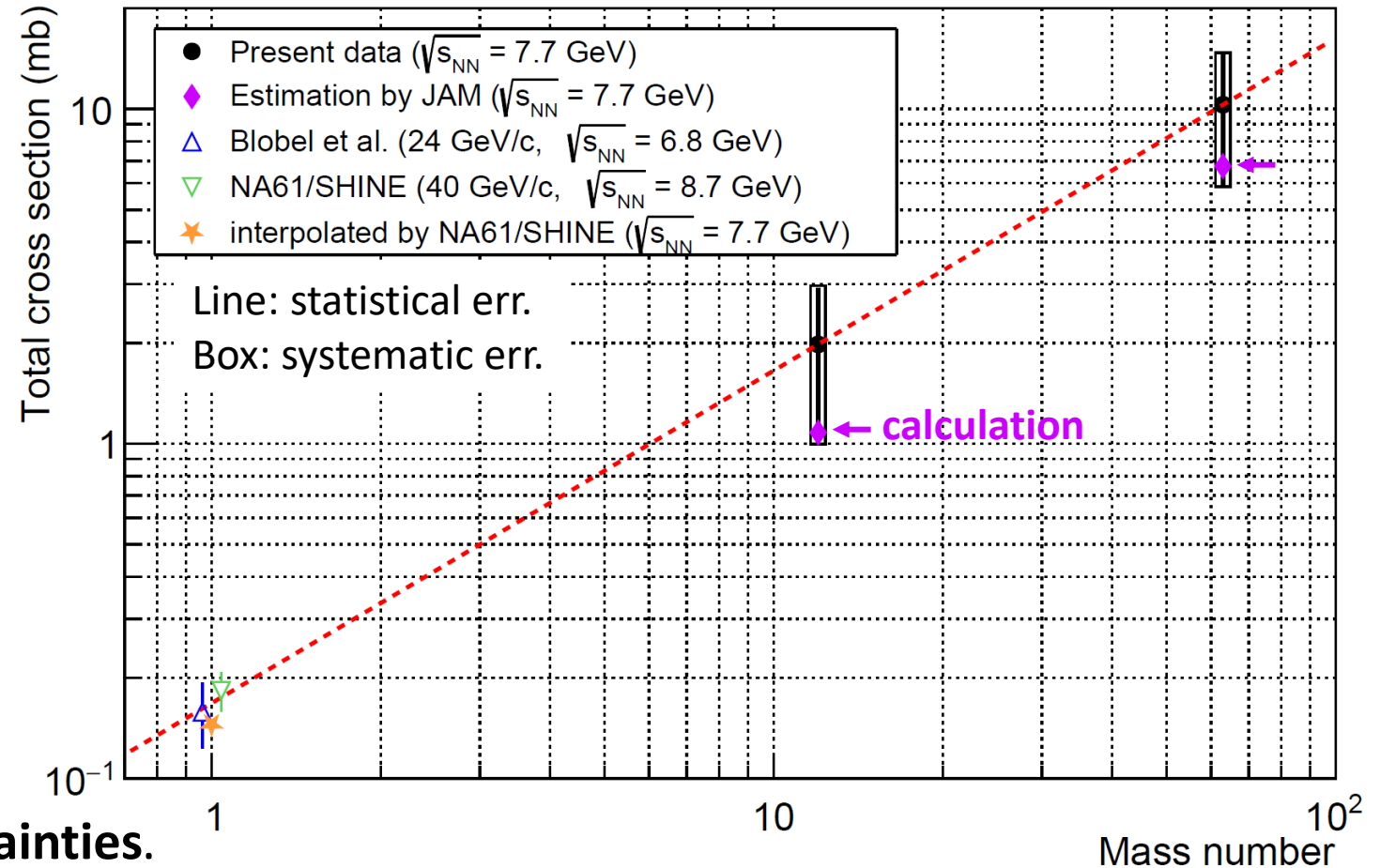
$\Rightarrow$  Are  $\phi$  mesons produced uniformly inside the nucleus and detected **with little absorption**?

# Comparison with calculation

✂ This is unpublished information, but it will be available in my Ph.D. thesis through the KURENAI repository of Kyoto University.

Compare the total cross-section estimated by the hadronic cascade code JAM with the data.

	Data	Simulation
Cross section for C (mb)	$2.0 \pm 0.9 \pm 1.0$	1.08
Cross section for Cu (mb)	$10.3 \pm 4.4 \pm 4.4$	6.75
$\alpha$	$0.99 \pm 0.38 \pm 0.34$	1.11



Data and calculation **agree within uncertainties.**

This result supports the production mechanism in JAM (string fragmentation).

However, the data tend to be larger than the calculation. Future high-statistics data and comparison with the PHSD result may help to determine  $\gamma_s$ , testing the scenario of chiral symmetry restoration.

- The high-p beamline provides new physics opportunities at J-PARC.
- First physics program at high-p is the E16 experiment, which precisely measure the  $\phi$  mass spectrum via di-electron decays.
- High-p beamline & E16 setup also enable us to study the strangeness production at intermediate energies.
- Mass spectrum of vector mesons are successfully reconstructed.
- Total production cross section of  $\phi$  meson is estimated.
- $\phi$  meson production and mass-number dependence are discussed.  
Future more precise data will improve our understanding of them.