

Femtoscopic study at J-PARC facility

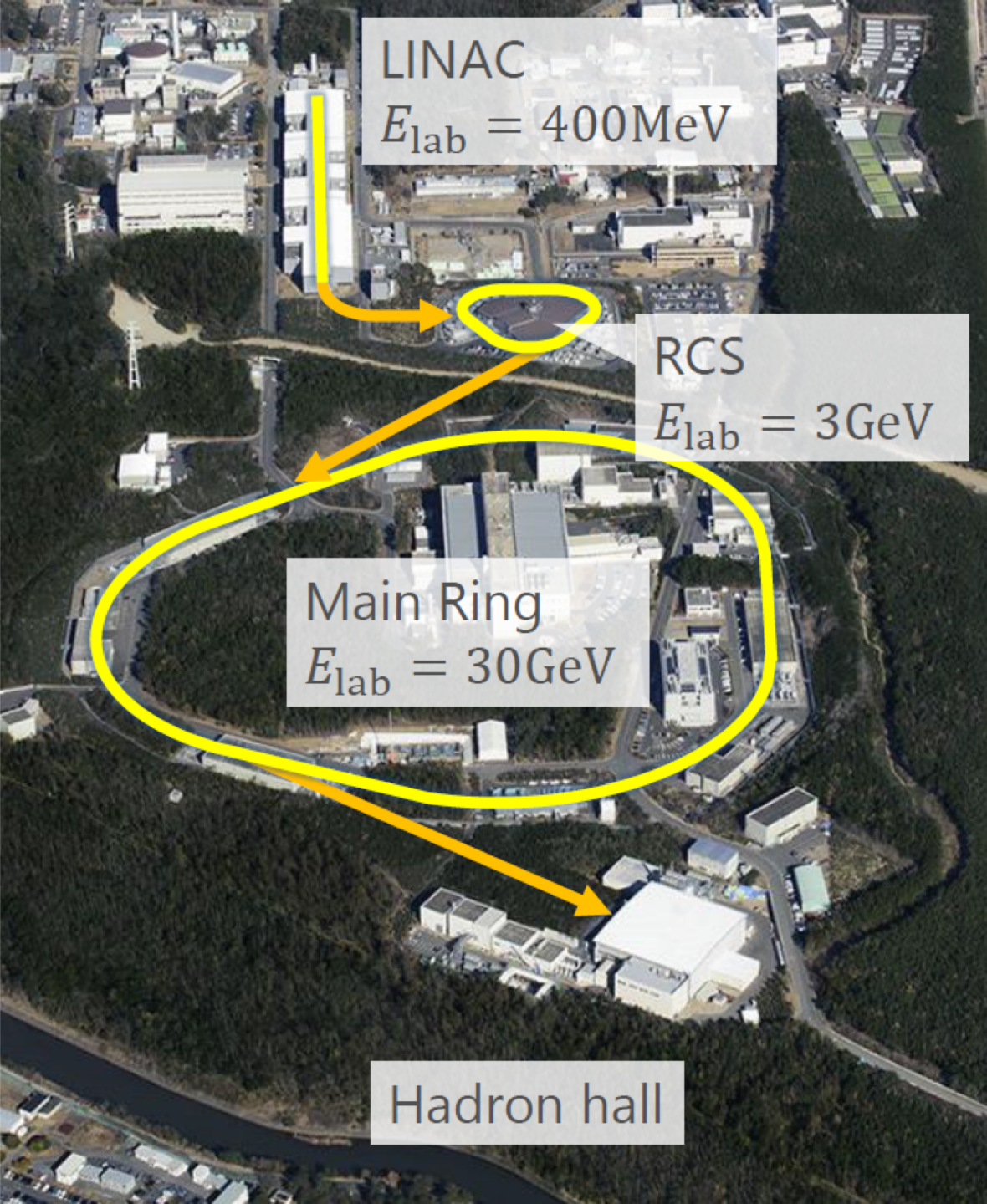
*pA: Based on the theoretical study by Asanosuke Jinno et al.,
PRC 110, 014001 (2024).*

AA: Y. Ichikawa et al., Journal of Subatomic Particles and Cosmology, 3, 100040 (2025).

Yudai Ichikawa (Tohoku University)

The 2nd International Workshop on Physics at High Baryon Density

2025/10/16-18

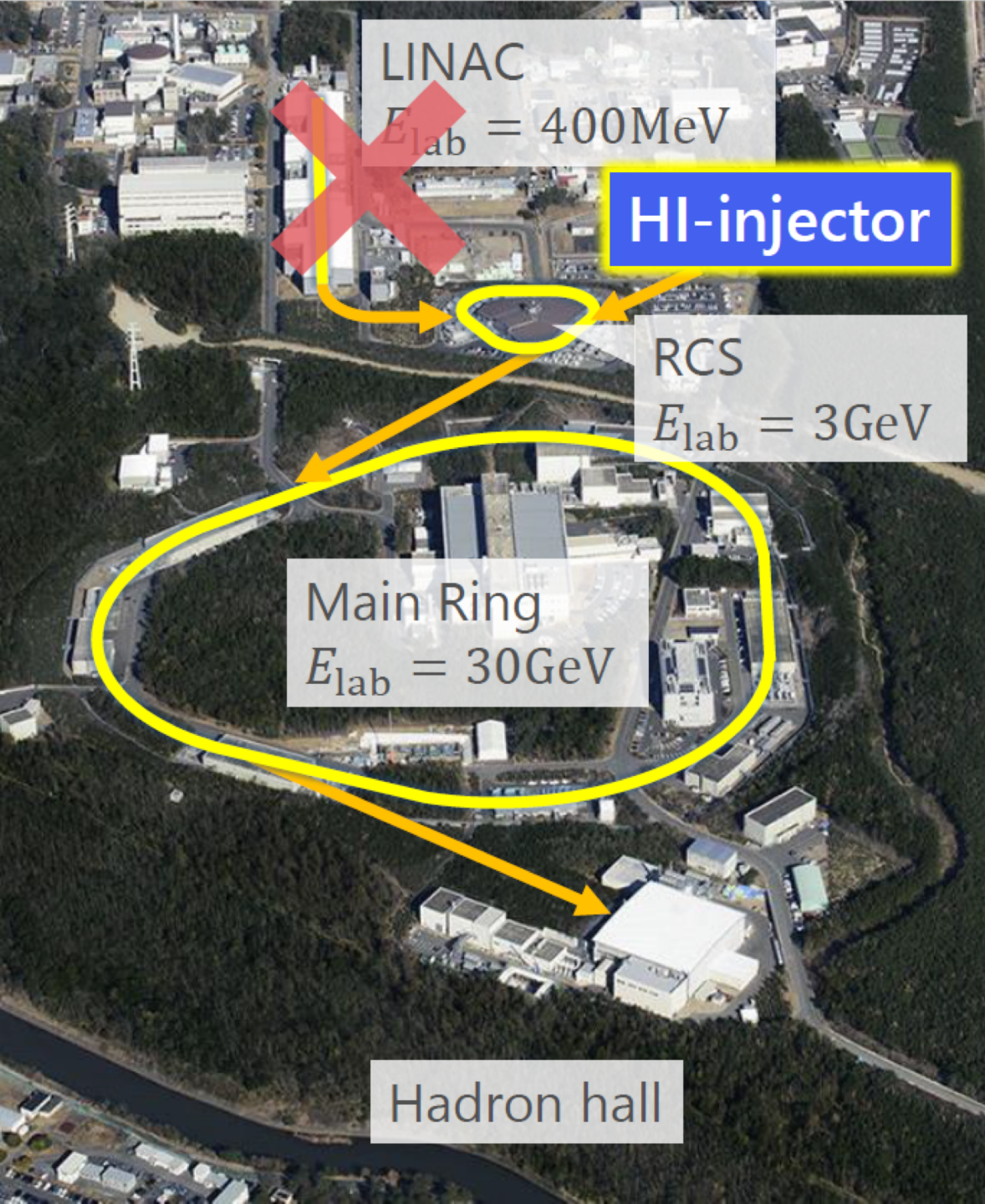


Accelerators

- LINAC
- RCS
- Main Ring
- High intensity

Purposes

- Hadron/Nuclear physics
- Neutrino physics
- Material/Life science



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J-PARC-HI

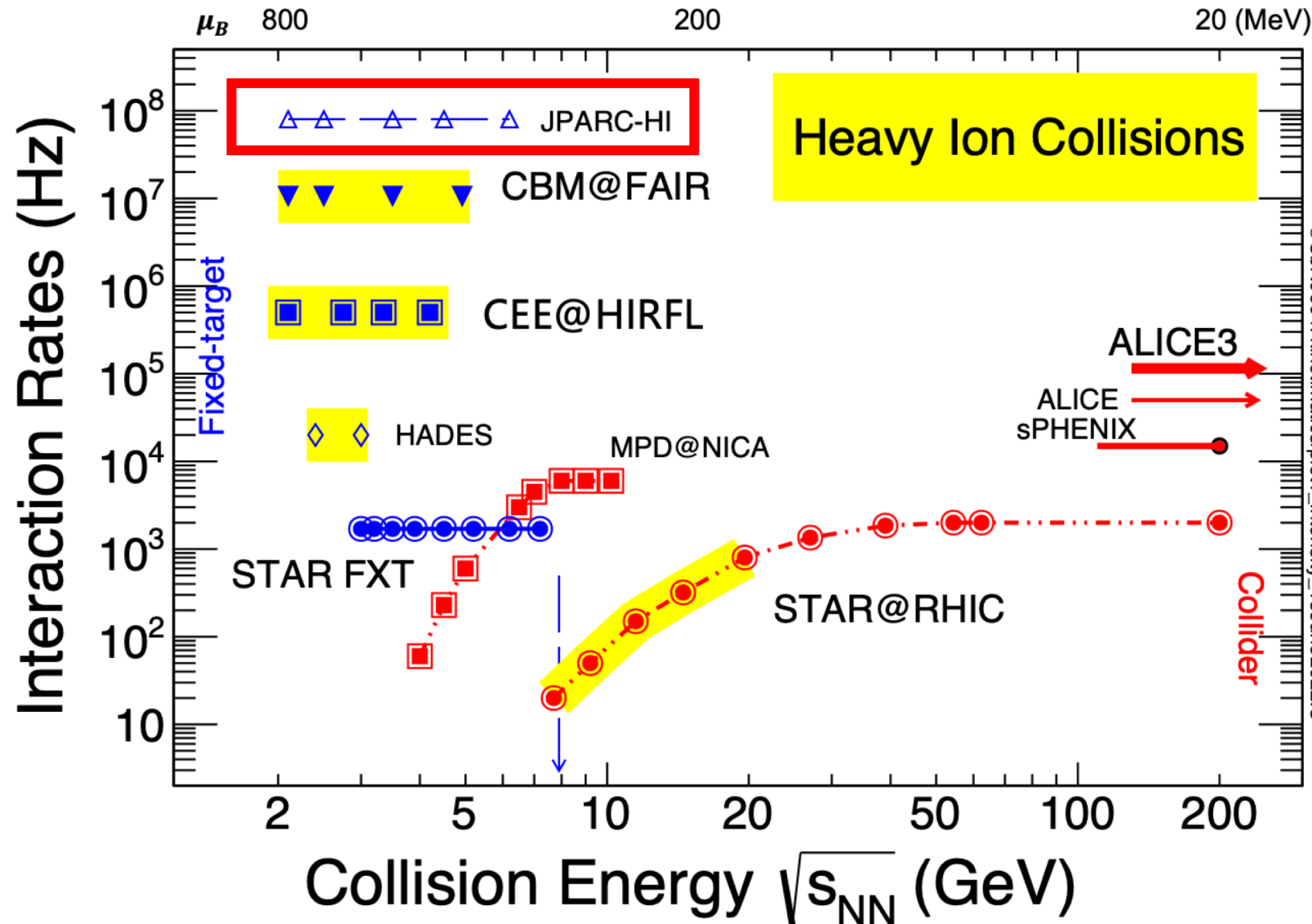
J-PARC Heavy Ion

High intensity



Intermediate energy

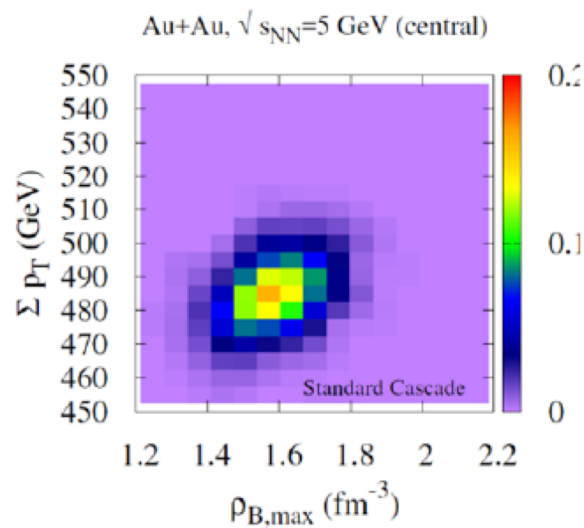
Collision Energy and Interaction Rate of HI-Accelerator in the World



***J-PARC is
intensity
frontier***

(Main) Topics with Higher Density

Search for critical point



T. Sakaguchi et al.,
PoS(CORFU2018) 189.

Measurement
of Higher order
Baryon fluctuation

Density
Selection
with Σp_T

Measurement
of Low mass
Enhancement
of e^+e^- spectrum

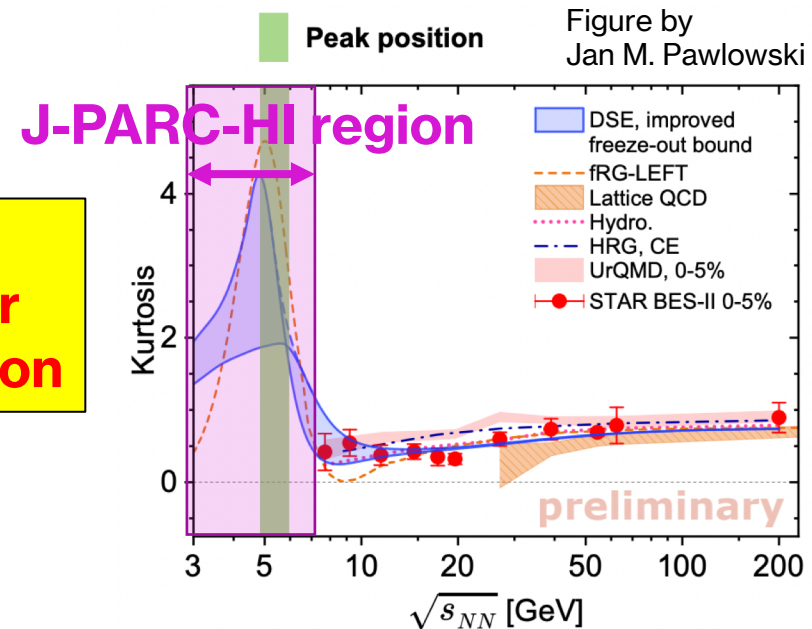
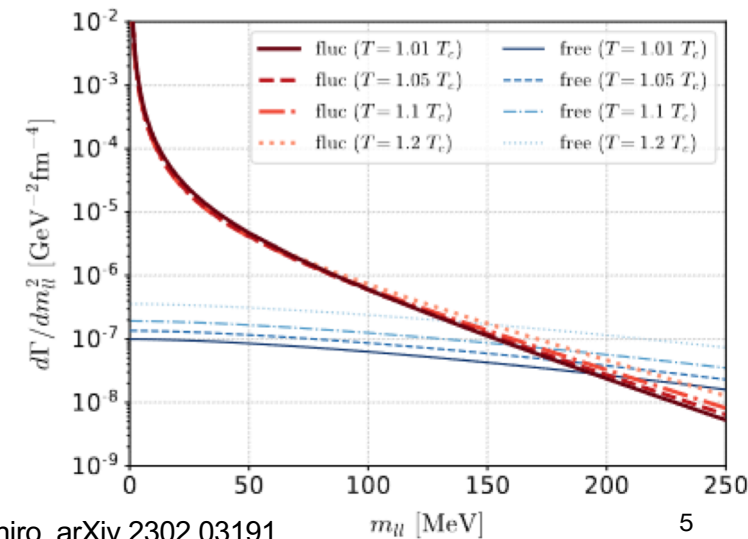


Figure by
Jan M. Pawłowski



T. Nishimura, M. Kitazawa, T. Kunihiro, arXiv 2302.03191

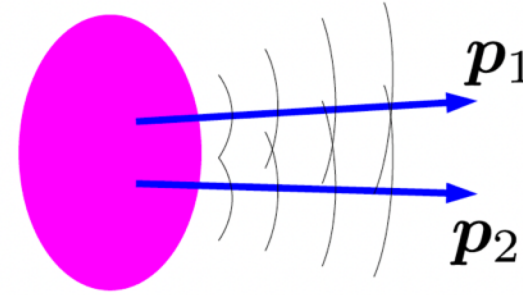
Femtoscscopy

Correlation Function

Koonin('77), Pratt+('86), Lednický+('82)

$$C(q) = \int d\mathbf{r} S(\mathbf{r}) |\varphi_q(\mathbf{r})|^2$$

$S(\mathbf{r})$ = source function, $\varphi_q(\mathbf{r})$ = relative w.f.



Experiment:

$$C(q) = N \frac{A(q)}{B(q)}$$

$A(q)$: "Signal"

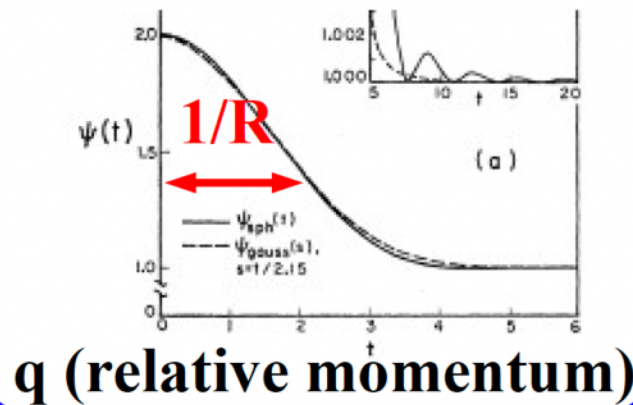
Same event sample

$B(q)$: "Uncorrelated"

Event mixing

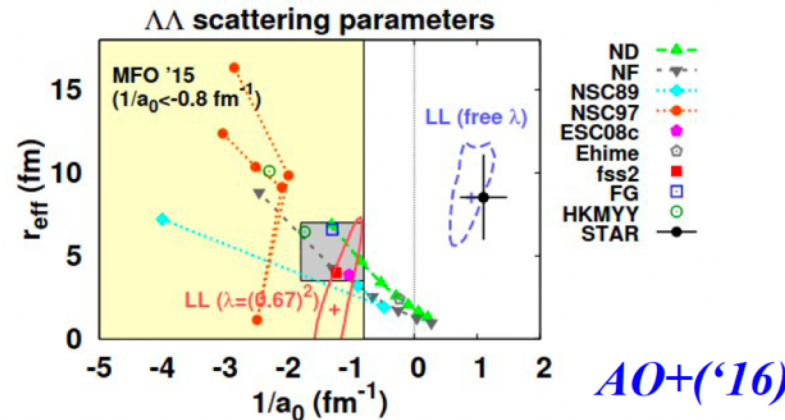
Source size (HBT)

*Hanbury Brown & Twiss, Nature 10 (1956), 1047;
Goldhaber, Goldhaber, Lee, Pais, Phys. Rev. 120 (1960), 300.*



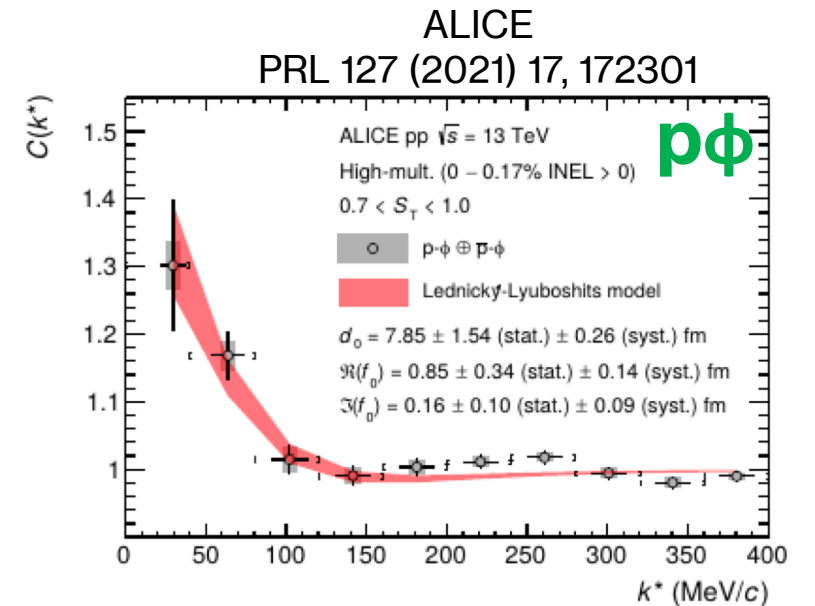
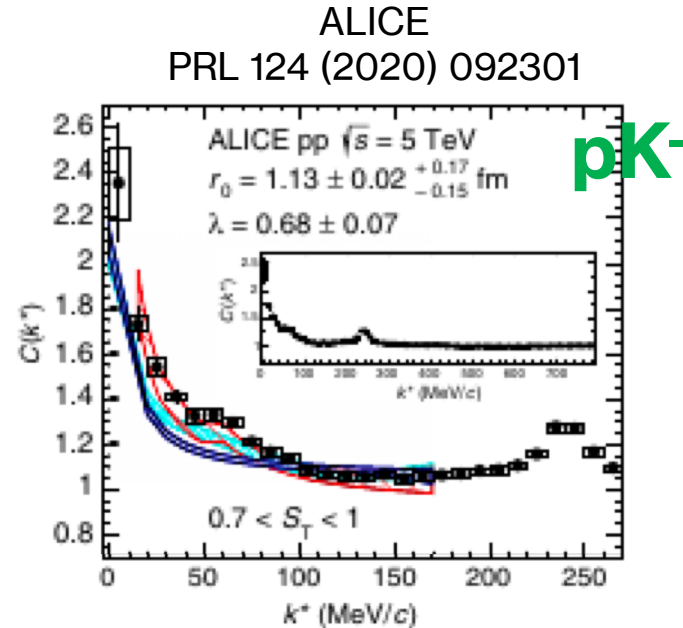
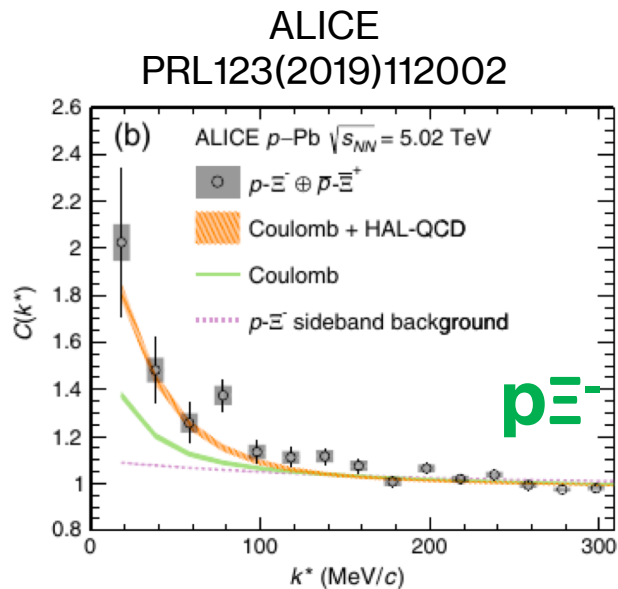
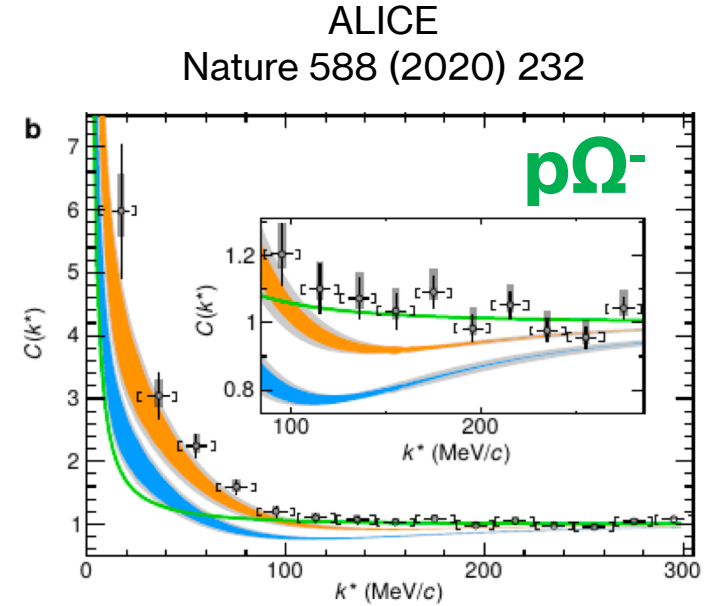
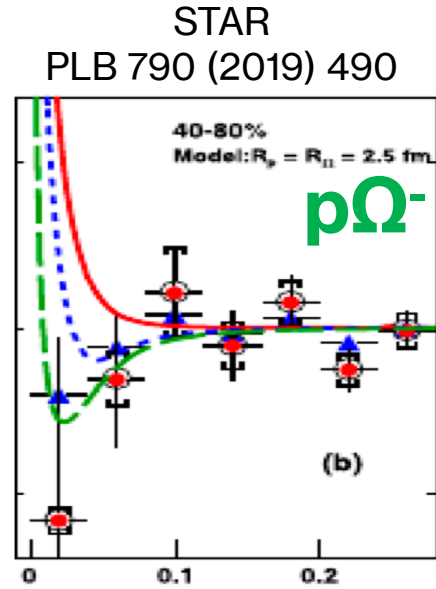
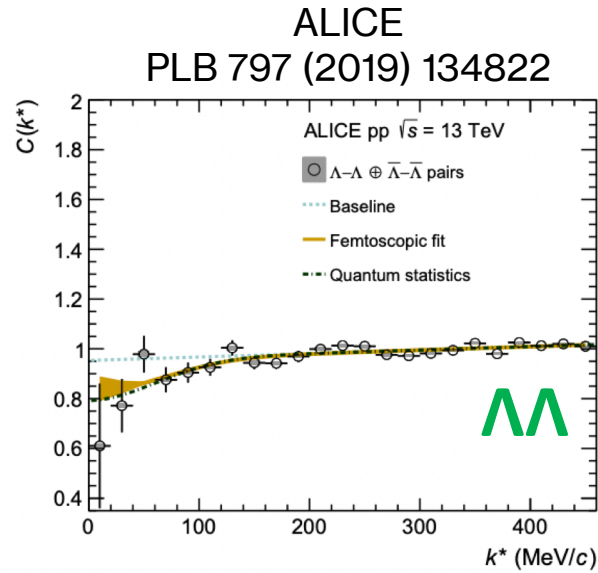
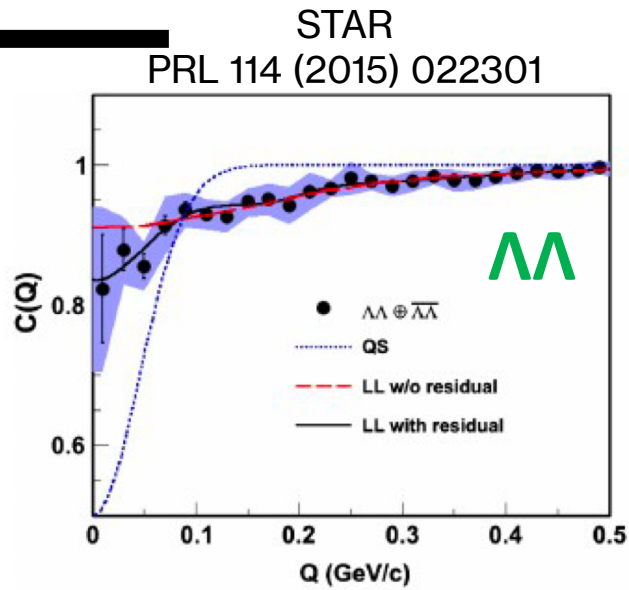
Hadron-Hadron Interaction

Lednickey, Lyuboshits ('82); Lednický, Lyuboshits, Lyuboshits ('98); Heidenbauer ('19); C. Greiner, B. Muller, PLB219('89)199; AO+ ('00); Morita+ ('15~); Kamiya+('20~); STAR ('15~); ALICE ('19~)



Led by
Prof. A. Ohnishi

Example of Femtoscopy



Issue of Femtoscopy and advantage at J-PARC(-HI)

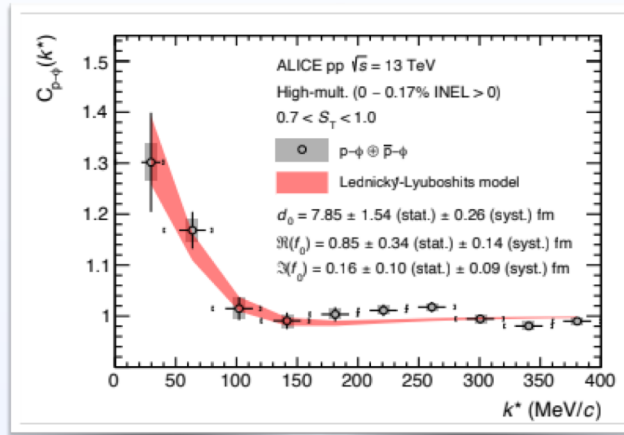
- Femtoscopy → Isospin and spin **averaged** interaction (f_0 , d_0)
- CF corresponds to **total cross section (σ)** in the scattering experiment.
 - Scattering experiment: PWA to decompose them using $d\sigma/d\Omega$ and spin observables
 - Can CF(Femtoscopy) be decomposed with spin observables?



$N\phi$ interaction

Slide by Dr. Kamiya

- $p\phi$ correlation data from pp collisions



ALICE, PRL 127 (2021) 17, 172301

- Enhancement in the low momentum region

- attractive $p\phi$ interaction

- Analysis with Lednický-Lyuboshits formula

$$\begin{aligned} \text{Re } a_0 &= 0.85 \pm 0.34(\text{stat.}) \pm 0.14(\text{syst.}) \text{ fm} \\ \text{Im } a_0 &= 0.16 \pm 0.10(\text{stat.}) \pm 0.09(\text{syst.}) \text{ fm} \end{aligned}$$

- Decomposition for spin channels?

$$C_{p\phi}(k^*) = \frac{2}{3}C_{3/2}(k^*) + \frac{1}{3}C_{1/2}(k^*)$$

use the latest lattice potential determine from data

Reanalyze data to extract spin 1/2 int.

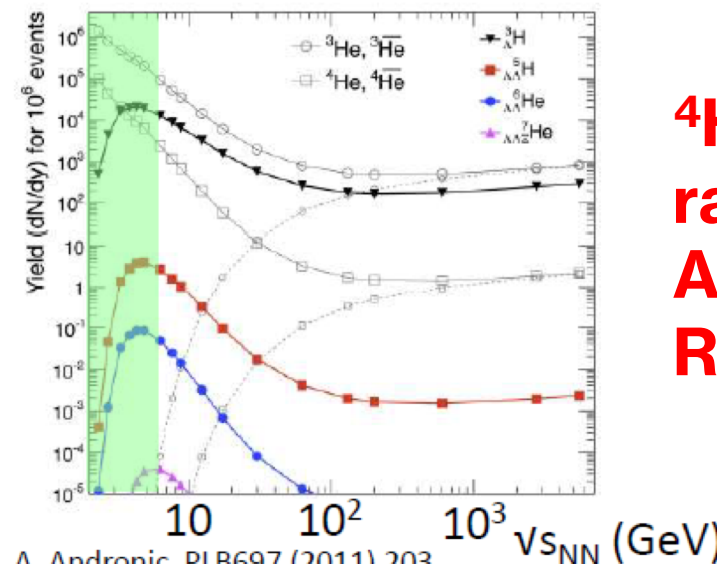
21

Key of J-PARC-HI Femtoscopy

^4He ($I=J=0$)

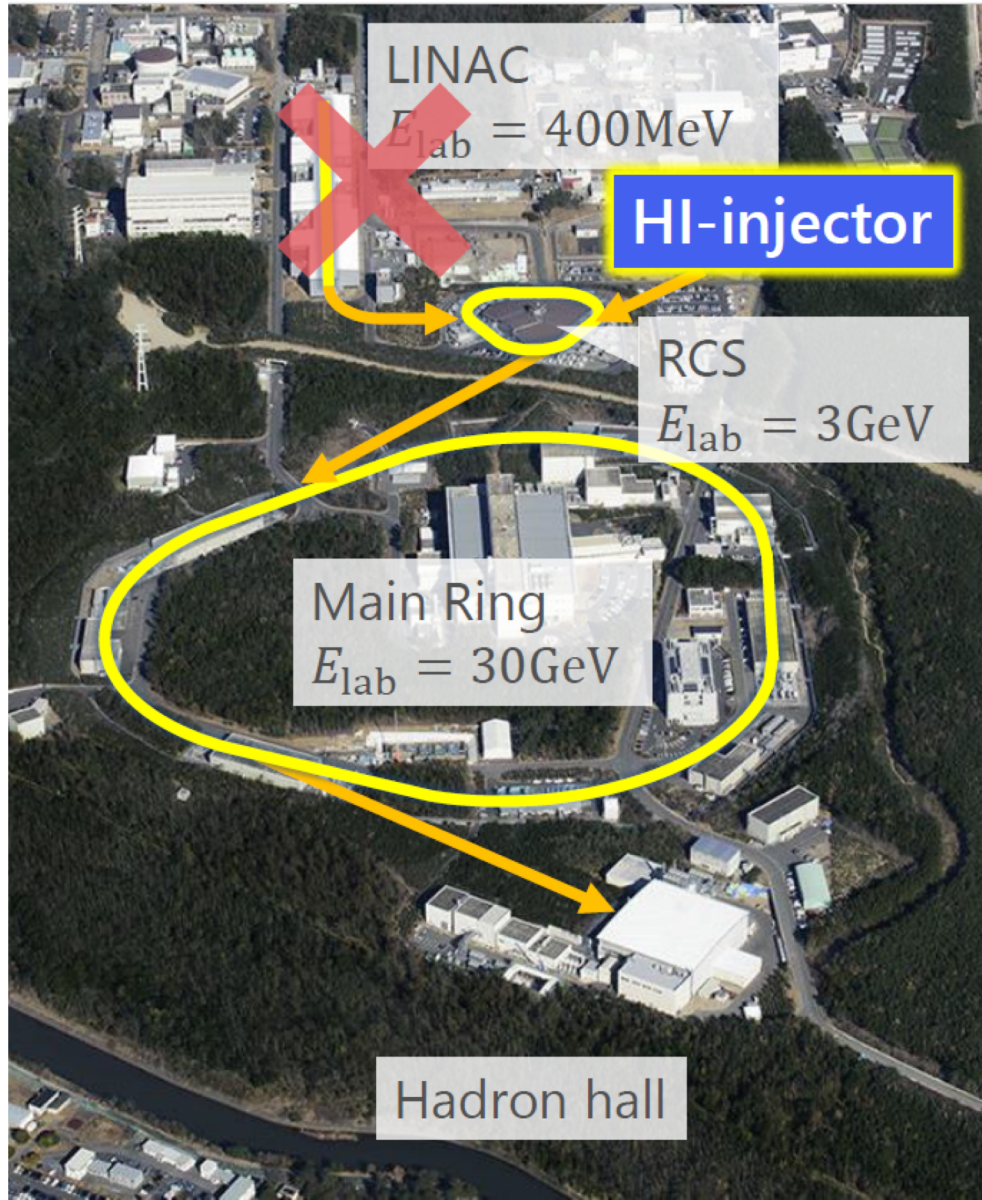
f_0 , d_0 will be determined uniquely

J-PARC-HI



^4He production rate is maximum. Advantage over RHIC and LHC!!

In order to construct J-PARC-HI, we need to show good results with existing J-PARC facility. (current J-PARC (pA, pp), J-PARC-HI (AA))



Accelerators

- LINAC
- RCS
- Main Ring
- High intensity $I = 1\text{MW}$

Purposes

- Hadron/Nuclear physics
- Neutrino physics
- Material/Life science

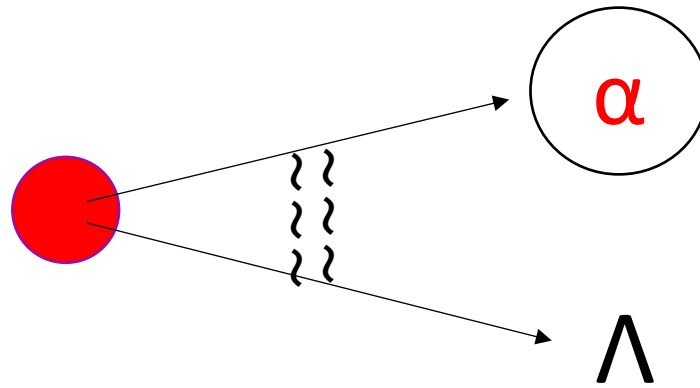
J-PARC-HI
J-PARC Heavy Ion

High intensity



Intermediate energy

$\alpha\Lambda$ Femtoscopy with pA collision (J-PARC E88) Key: Small system and α !!



Note: No pA measurement with STAR-BES.
STAR-BES only took AA and dAu data.
Statistics of dAu data at $\sqrt{s} = 20$ GeV is small.

Unique points of $\alpha\Lambda$ Femtoscopy with pA

- Density of α is high ($\sim 2\rho_0$) !
- Source size of pA collision is small !

Short range ΛN interaction !

Density effect !

Key to understand the neutron star

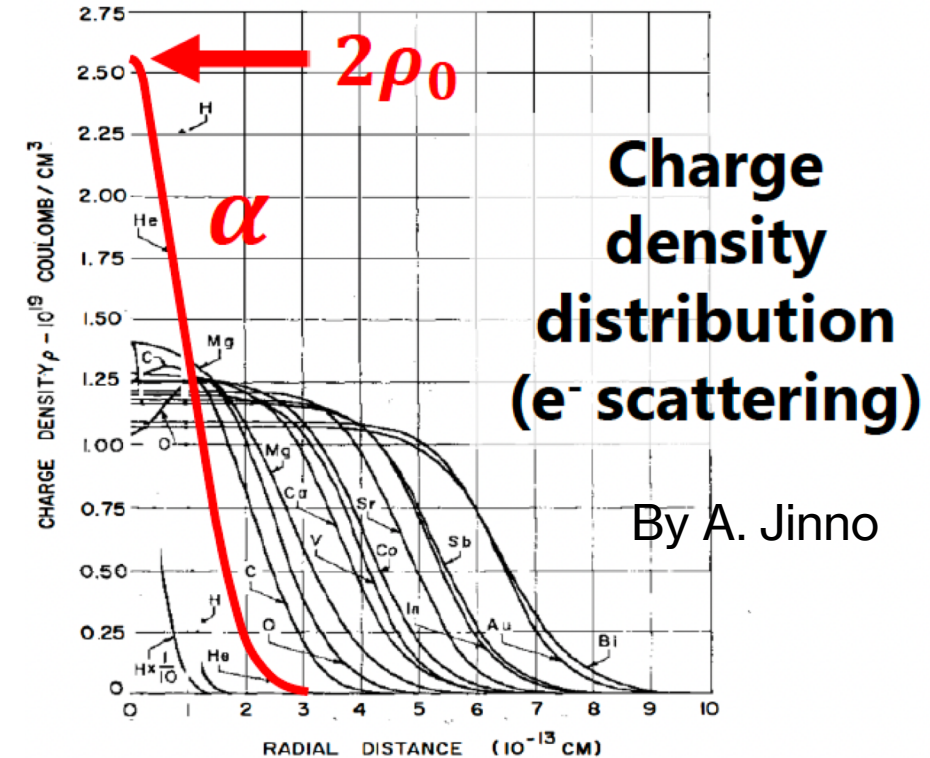


FIG. 32. This figure represents a summary of the charge distributions found for various nuclei by electron-scattering methods.

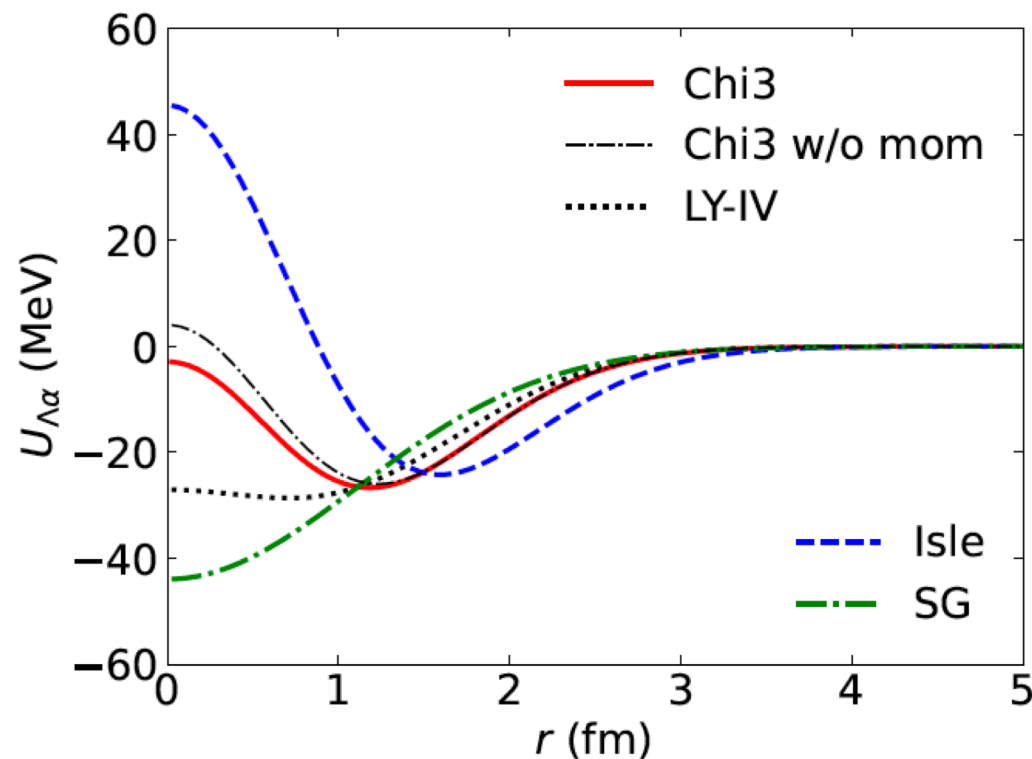
* B_Λ of $^5_\Lambda\text{He}$ ($^4\text{He} + \Lambda$) was measured as 3.12 ± 0.02 MeV
→ Overall interaction is known.

M. Juric et. al., NPB52, 1 (1973).

$\alpha\Lambda$ potential

[A. Jinno et al., *PRC* 110, 014001 (2024).]

$U_{\Lambda\alpha}$: ($\Lambda\alpha$ potential)



**Overall interaction is constraint by B_Λ of ${}^5_\Lambda\text{He}$.
Short range part has large difference!!**

TABLE III. Λ binding energy of ${}^5_\Lambda\text{He}$, scattering length a_0 , and effective range r_{eff} for five $\Lambda\alpha$ potential models. B_Λ^{ERE} represents the binding energy estimated by the effective-range expansion (16).

	Isle	SG	Chi3	LY-IV	Chi3 w/o mom
B_Λ (MeV)	-3.10	-3.09	-3.12	-3.12	-3.12
a_0 (fm)	4.24	3.79	4.01	3.89	3.95
r_{eff} (fm)	2.07	1.56	1.84	1.70	1.77
B_Λ^{ERE} (MeV)	-3.79	-3.13	-3.41	-3.26	-3.33

$$B_\Lambda (\text{Experiment}) = 3.12 \pm 0.02 \text{ MeV}$$

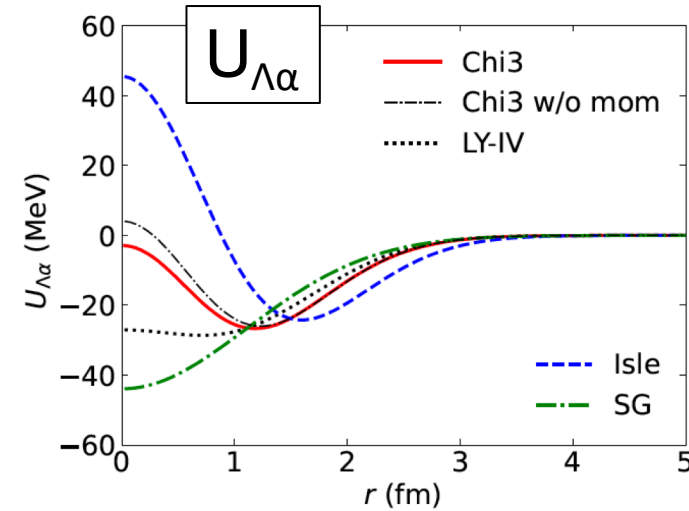
M. Juric et. al., NPB52, 1 (1973).

$\alpha\Lambda$ Correlation function ($C_{\Lambda\alpha}$)

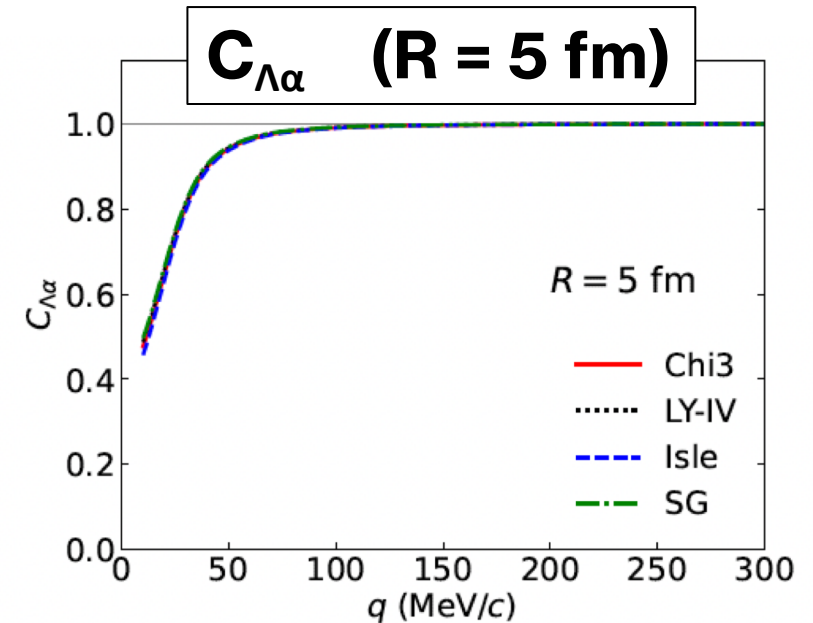
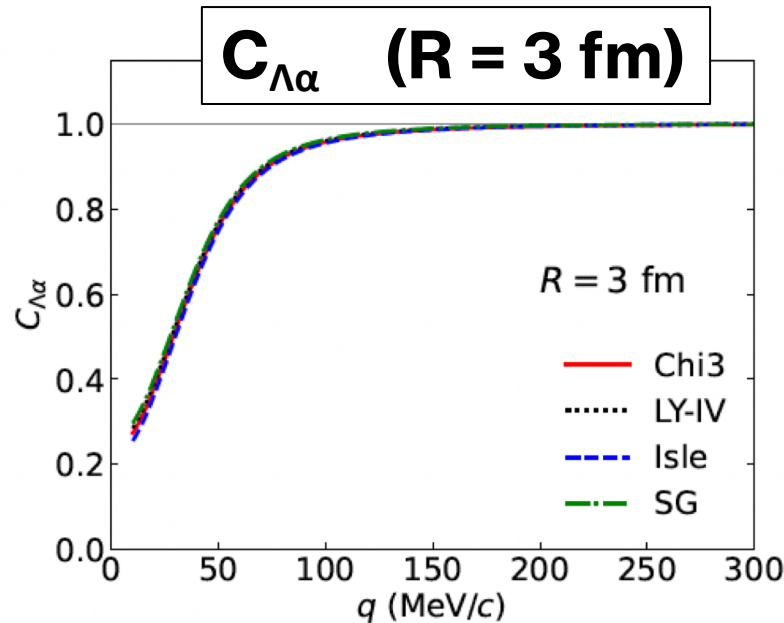
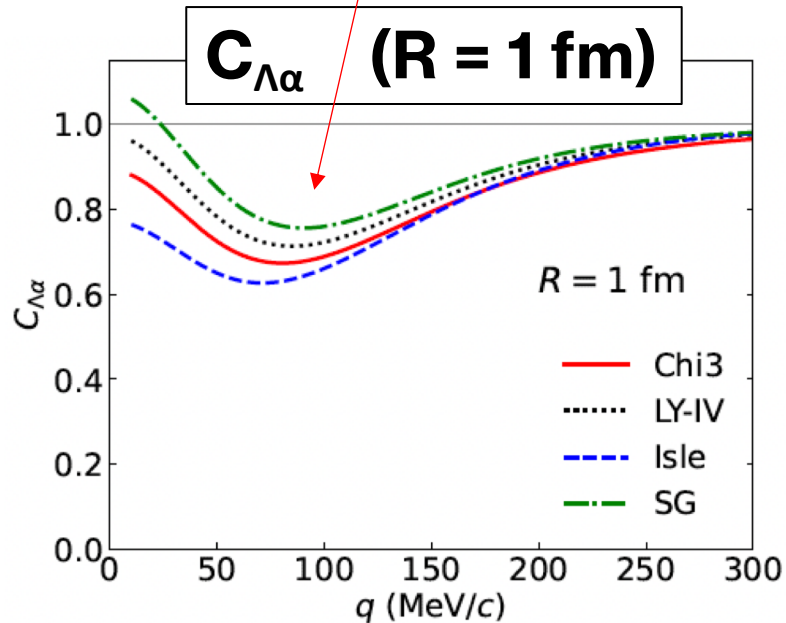
[A. Jinno et al., *PRC* 110, 014001 (2024).]

When source size is large, $C_{\Lambda\alpha}$ are almost same because overall interaction is constrained by ${}^5_\Lambda\text{He}$.

We can discuss the short range part of $U_{\Lambda\alpha}$ with small size !!

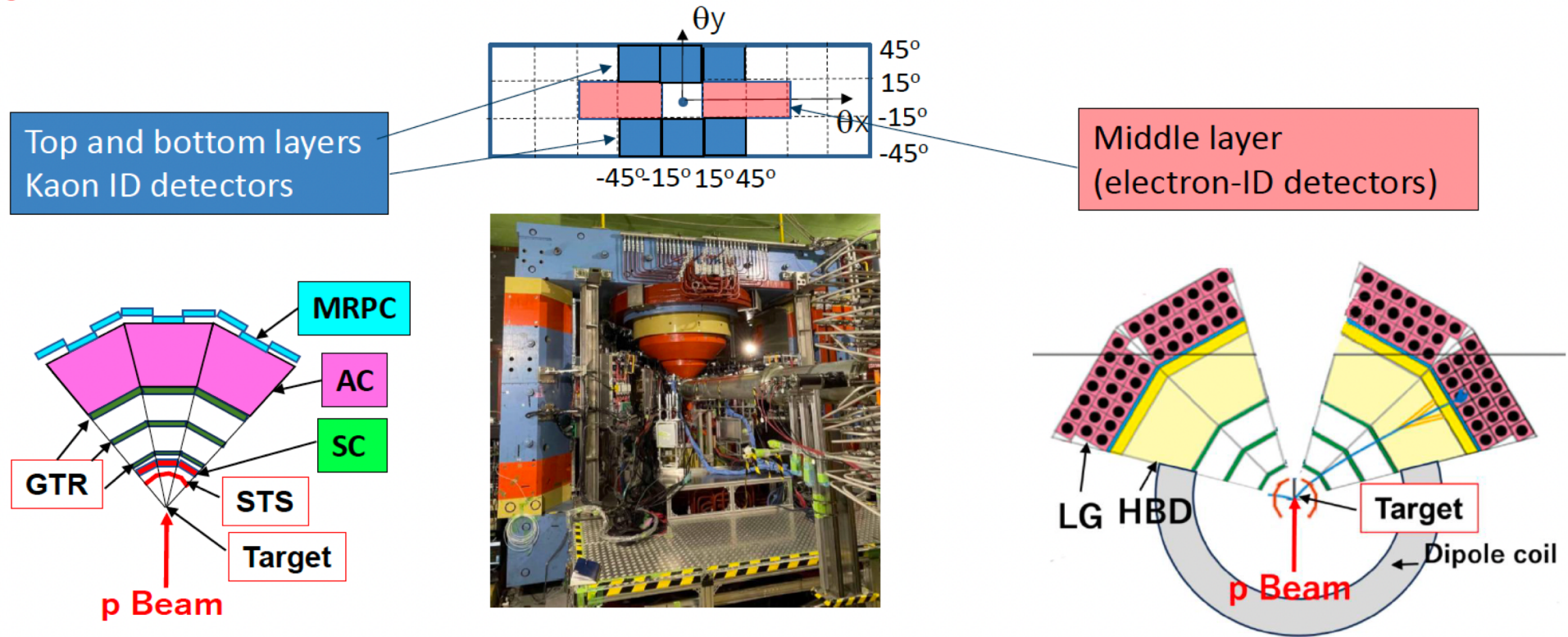


Difference can be seen !!



J-PARC E88 experiment (ϕ mass shift with $\phi \rightarrow K^- K^+$)

AC will be joined to trigger for $K^- K^+$ selection $\rightarrow \alpha\Lambda$ will be killed in the trigger level
 $\rightarrow$ **Streaming DAQ system will be necessary to measure $\alpha\Lambda$.**

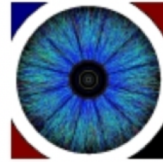
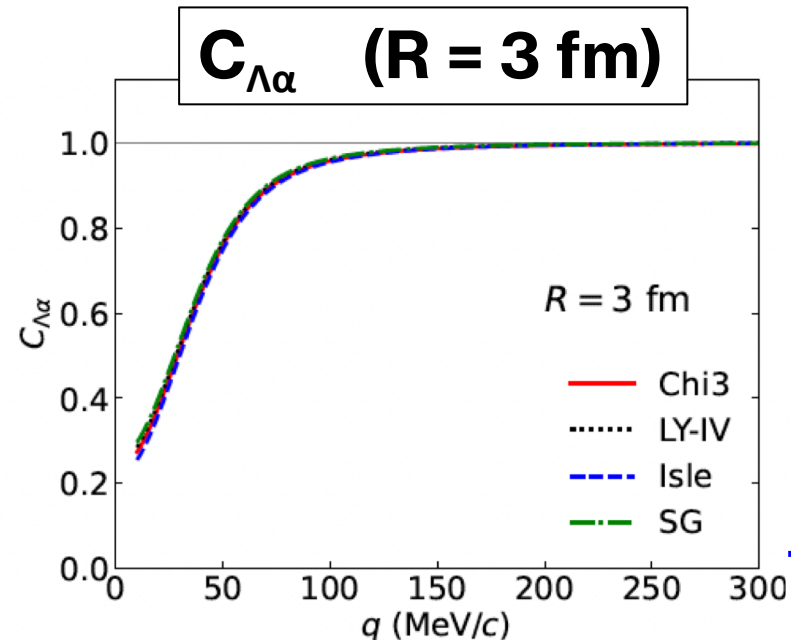
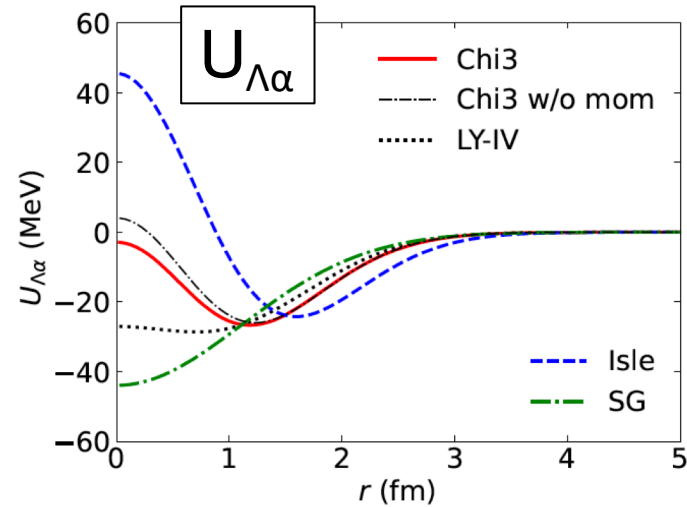


- 6 forward modules for $K^\pm$ identification in top and bottom layers
- **MRPC** (Multit-gap Resistive Plate Chamber) and **SC** (Start timing counter) for Time-of-Flight measurement
- **AC** (Aerogel Cherenkov counter) for pion rejection
- **STS** (Silicon Tracking System) and **GTR** (GEM Trackers) for track reconstruction

How to determine the source size of $\alpha\Lambda$?

- Combining the measurement the source of αp , pp , $p\Lambda$
 αp , pp : Interaction is well known.
 $p\Lambda$: already measured with ALICE and STAR with high statistics.
→ we can fix the interaction.
- From this measurement, can we determine the α , p , Y source size?

$C_{\Lambda\alpha}$ measurement with STAR BES



The STAR experiment

at the Relativistic Heavy Ion Collider, Brookhaven National Laboratory

Collaboration

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[Institutions](#)

[Organization](#)

[Funding agencies](#)

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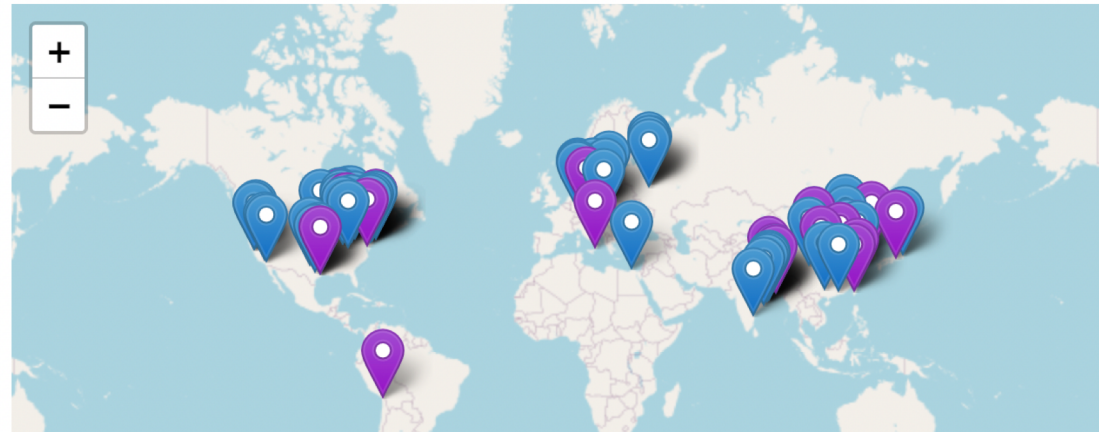
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★ star member institutions

STAR is composed of 76 institutes from 14 countries, with a total of 741 collaborators.



<https://www.star.bnl.gov/>

University of Tsukuba ([www](http://www.tsukuba.ac.jp))"

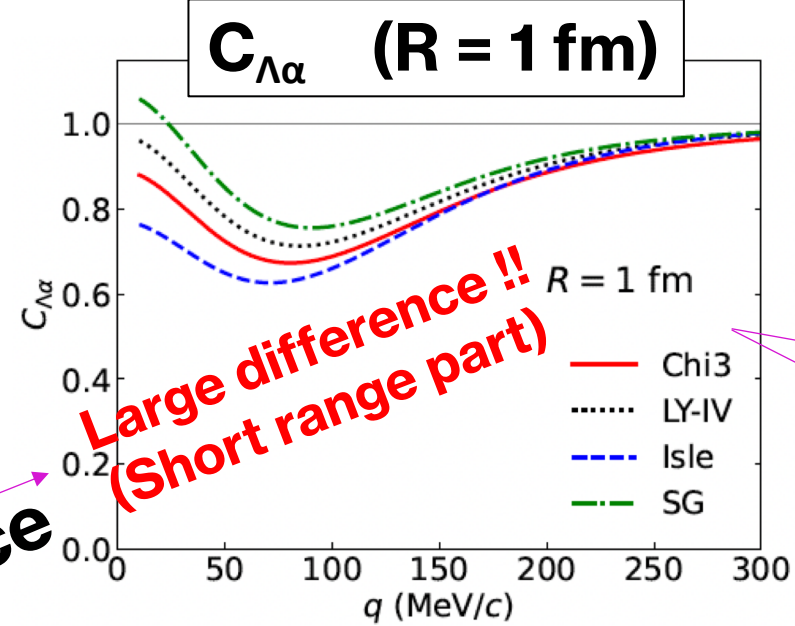
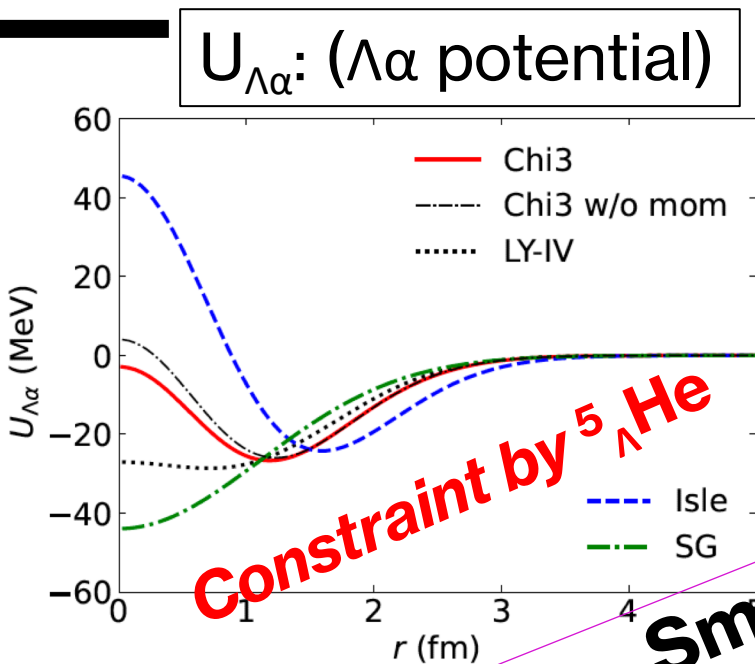
Shinichi Esumi, Takumi Furuya, Yudai Ichikawa, Moe Isshiki, Rurika Kajihara, Esaka Narito, Takafumi Niida, Toshihiro Nonaka, Orii Noritaka, Kosuke Okubo, Fumiya Oura, Hiroyuki Sako, Susumu Sato, Kondo Taiki

CBM Collaboration Board Meeting

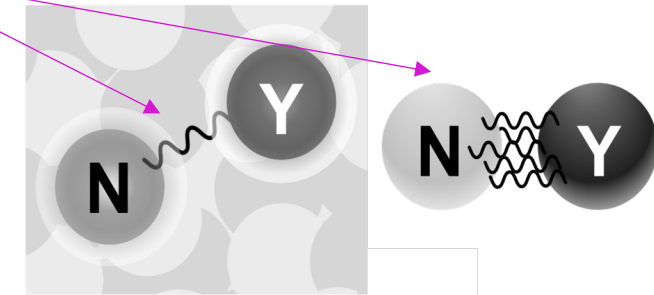
Wednesday, 22nd October 2025, 15:00 – 18:00 h CST (China Standard Time)
hybrid by ZOOM and in Lanzhou, China

- Adoption of the Agenda
- Minutes of the last meeting
- Spokesperson report – Tetyana Galatyuk
- Technical Coordinator Report – Piotr Gasik
- Resource Coordinator Report – Jürgen Eschke
 - Status preparation CBM M&O MoU
- Physics Coordinator Report – Krzysztof Piasecki
- Computing Coordinator Report - Volker Friese
- Run Coordinator Report – Christian Sturm
- Report from the Editorial Board – Rudi Schmidt
- Report on CBM Juniors Status – Pavish Subramani
- Applications for CBM membership
 1. Indian Institute of Technology Madras, India - Prabhat R. Pujahari (application for full membership)
 2. Tohoku University, Japan - Yudai Ichikawa and Kkoji Miwa (application for associate membership)
- Next Collaboration meetings
- AoB

Summary of $\alpha\Lambda$ femtoscopy

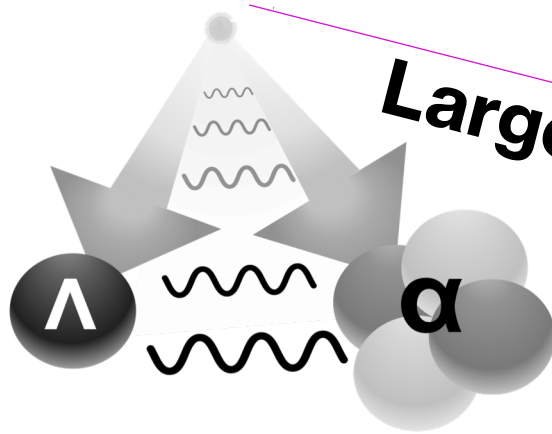
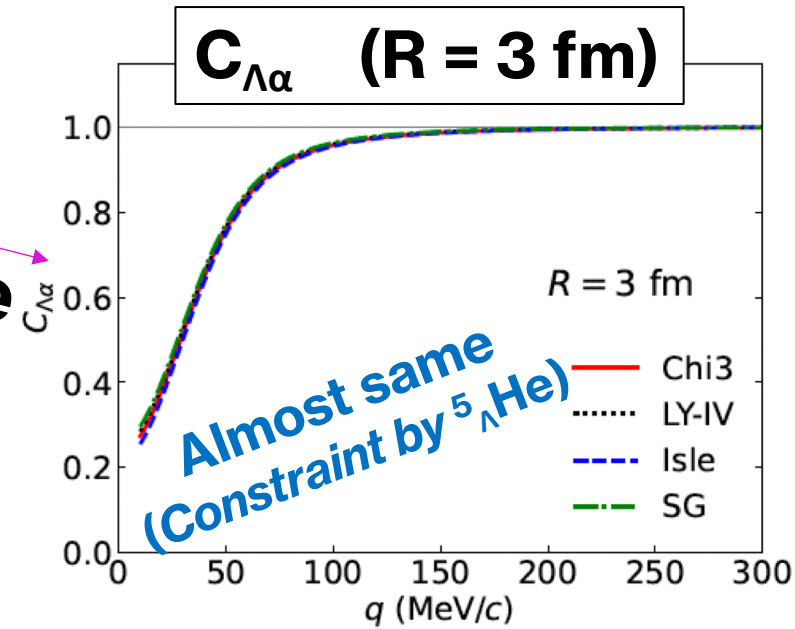


Interaction under high density **Short range ΛN interaction**

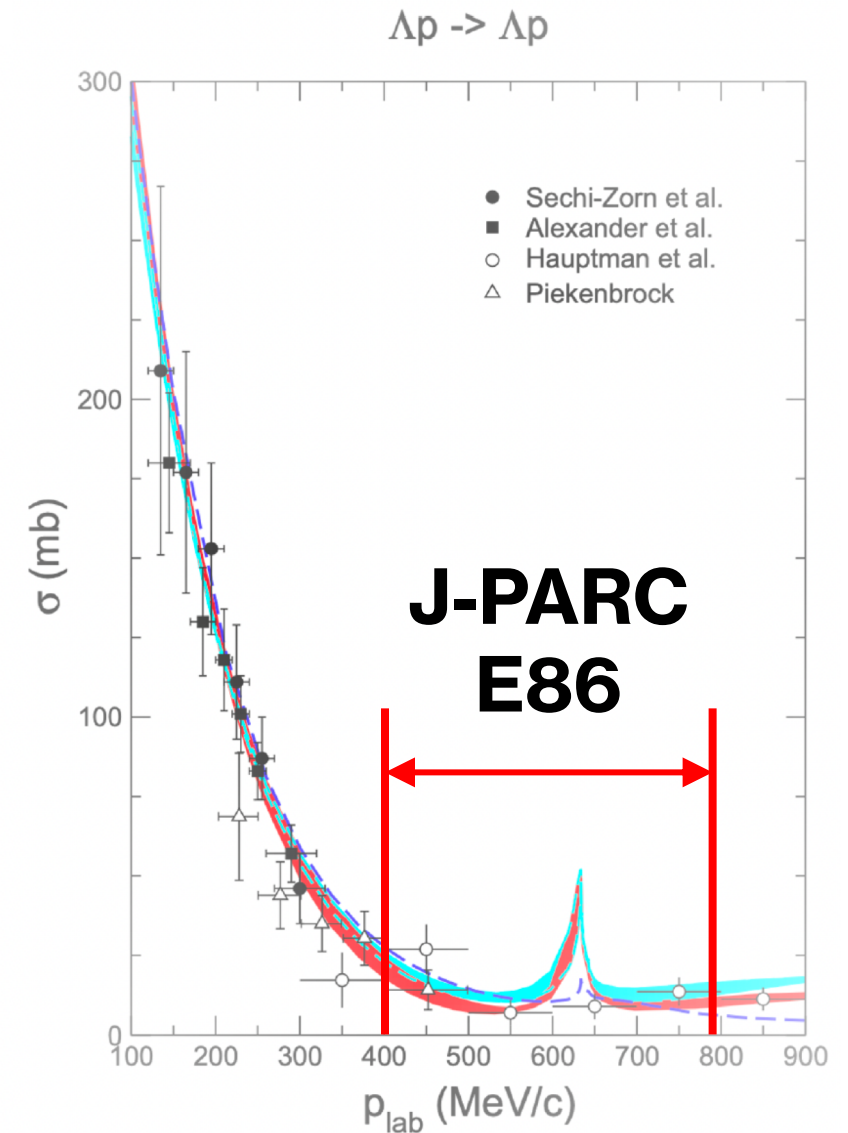
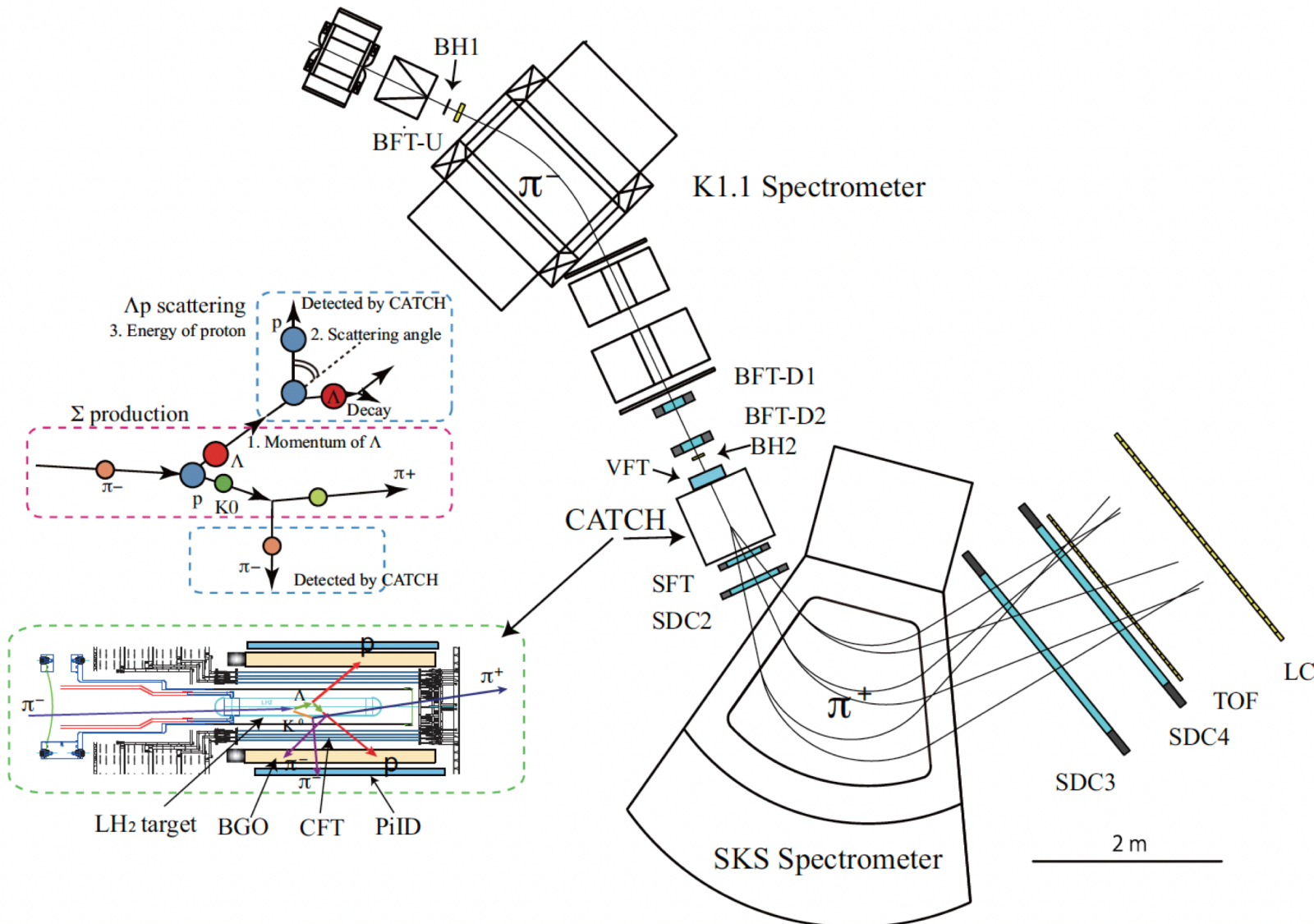


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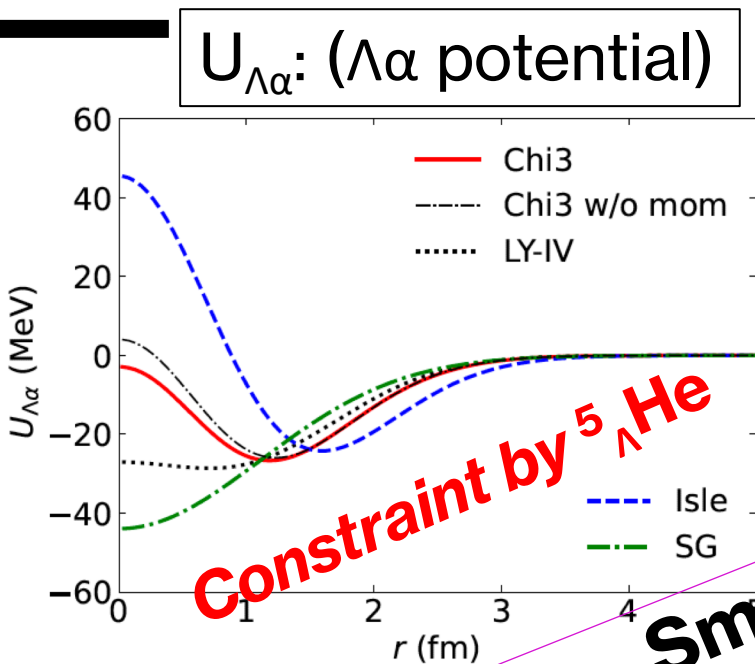
Large source



J-PARC E86 experiment

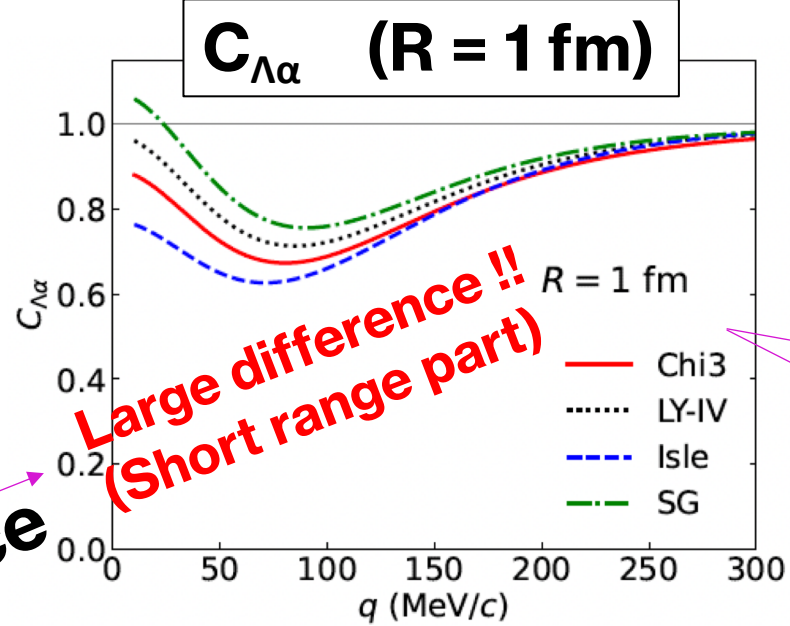
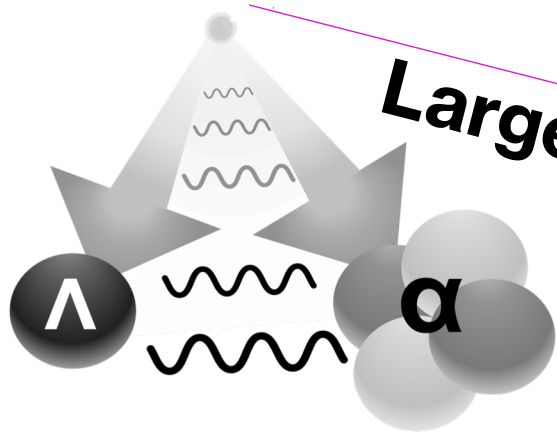


Summary of $\alpha\Lambda$ femtoscopy



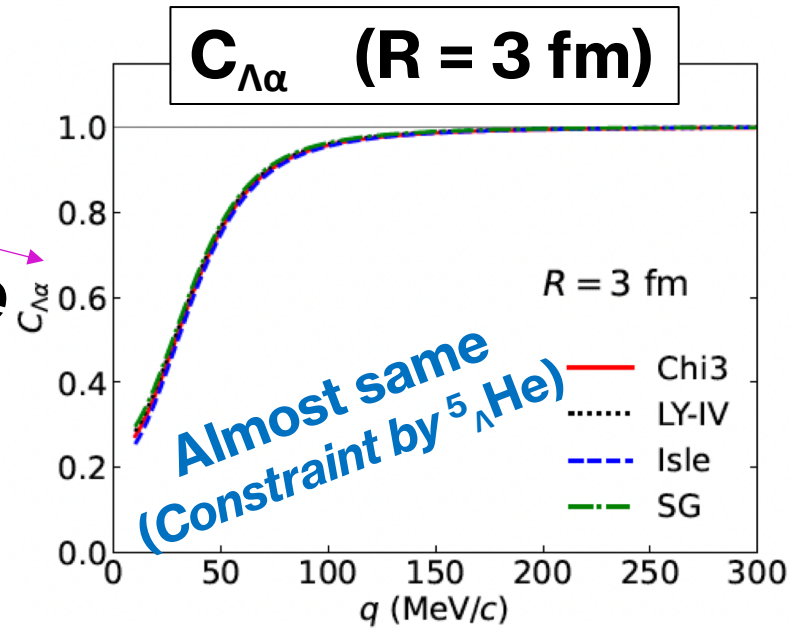
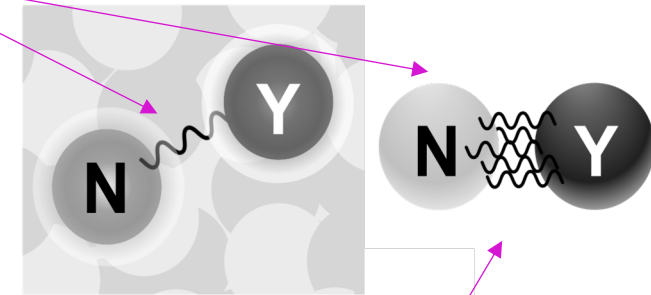
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Large source



Key for hyperon puzzle

Interaction under high density **Short range ΛN interaction**



**J-PARC E86
 Λp scattering
at $p = 0.4 - 0.8$ GeV/c**

Plan and Discussion for pA Femtoscopy

- We would like to submit a new proposal as a byproduct of E88.
- Not only $\alpha\Lambda$ but also various hadron-hadron Femtoscopy is possible!

Join us!!

- Considering the budget situation of J-PARC, J-PARC-HI (or HD extension) will be delayed.
- In order to encourage the J-PARC-HI, I think it is better to submit a lot of proposal related to J-PARC-HI physics with pA collision, while it is byproduct.
- Trigger and readout should be considered to measure αY in the final state.
- E88 measure not only lepton but also hadron, then a lot of physics can be output.

Femtoscopes with AA collision (J-PARC-HI)



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Journal of Subatomic Particles and Cosmology

Volume 3, June 2025, 100040



Full Length Article

Femtoscopic study in the J-PARC-HI project

Yudai Ichikawa ^{a d} , Kazuya Aoki ^b, Masakiyo Kitazawa ^c, Yuhei Morino ^b,
Hiroyuki Sako ^{d 1}, Kazuhiro Tanaka ^{b d}, J-PARC-HI Collaboration

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Issue of Femtoscopy and advantage of J-PARC-HI

- Femtoscopy $\rightarrow$ Isospin and spin **averaged** interaction (f_0, d_0)
- CF corresponds to **total cross section (σ)** in the scattering experiment.
 - Scattering experiment: PWA to decompose them using $d\sigma/d\Omega$ and spin observables
- **Can CF(Femtoscopy) be decomposed with spin observables?**

<Isospin decomposition>

e.g.

- $\Xi N : I = 0, 1 (S = 0, 1)$
 - $\Xi^- p : I = 0, 1$
 - $\Xi^0 p : I = 1$

$\rightarrow$ Neutral particle detection
will be necessary!!

<Spin decomposition>

e.g.

- $\Lambda N : S = 0, 1 (I = 1/2)$
(Total spin) $J_{\Lambda p} = L_{\Lambda p} \otimes S_{\Lambda p}$
(Parity) $P_{\Lambda p} = (-1)^{\{L_{\Lambda p}\}}$

In S-wave ($L_{\Lambda p} = 0$), $J_{\Lambda p} = 0$ or 1

$S_{\Lambda p}$ determination ($S_{\Lambda p} = 0$ or 1)

Reduction factor

$$N(\phi_{\Lambda p}) = N_0 (1 + \underline{r} \cdot S_{\Lambda p} \cos \phi_{\Lambda p})$$

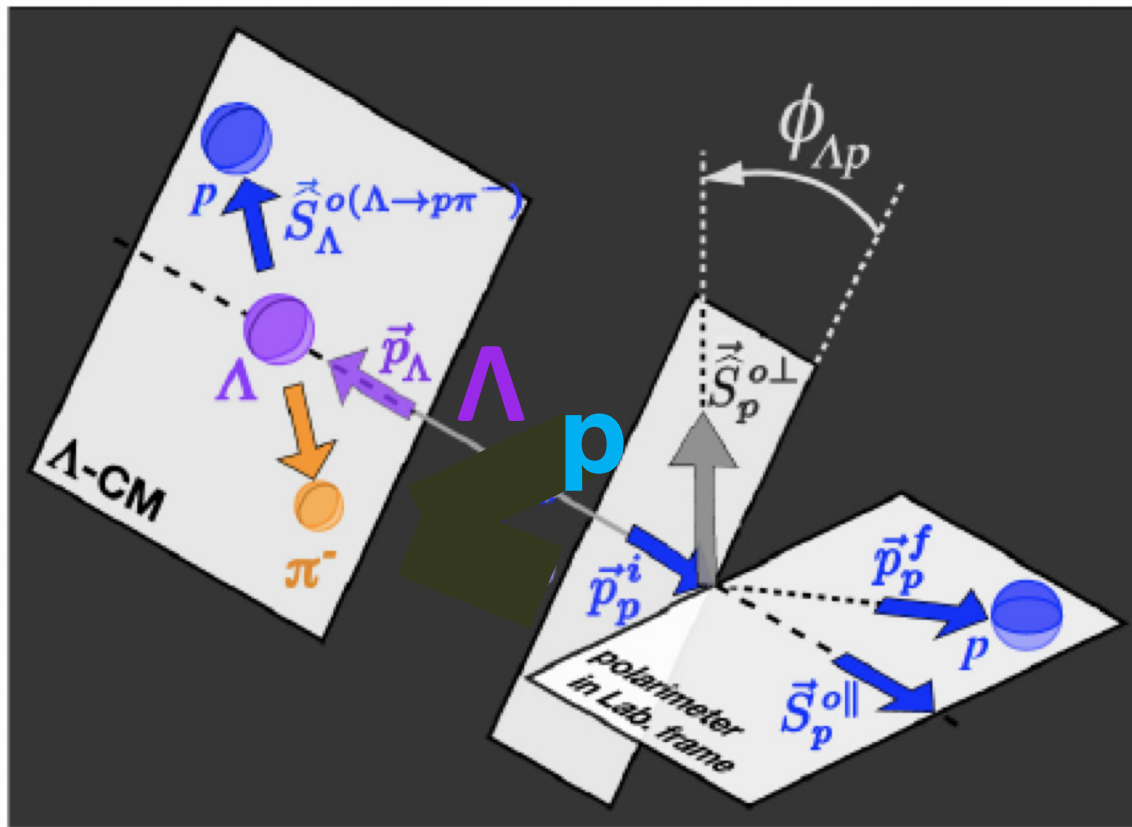
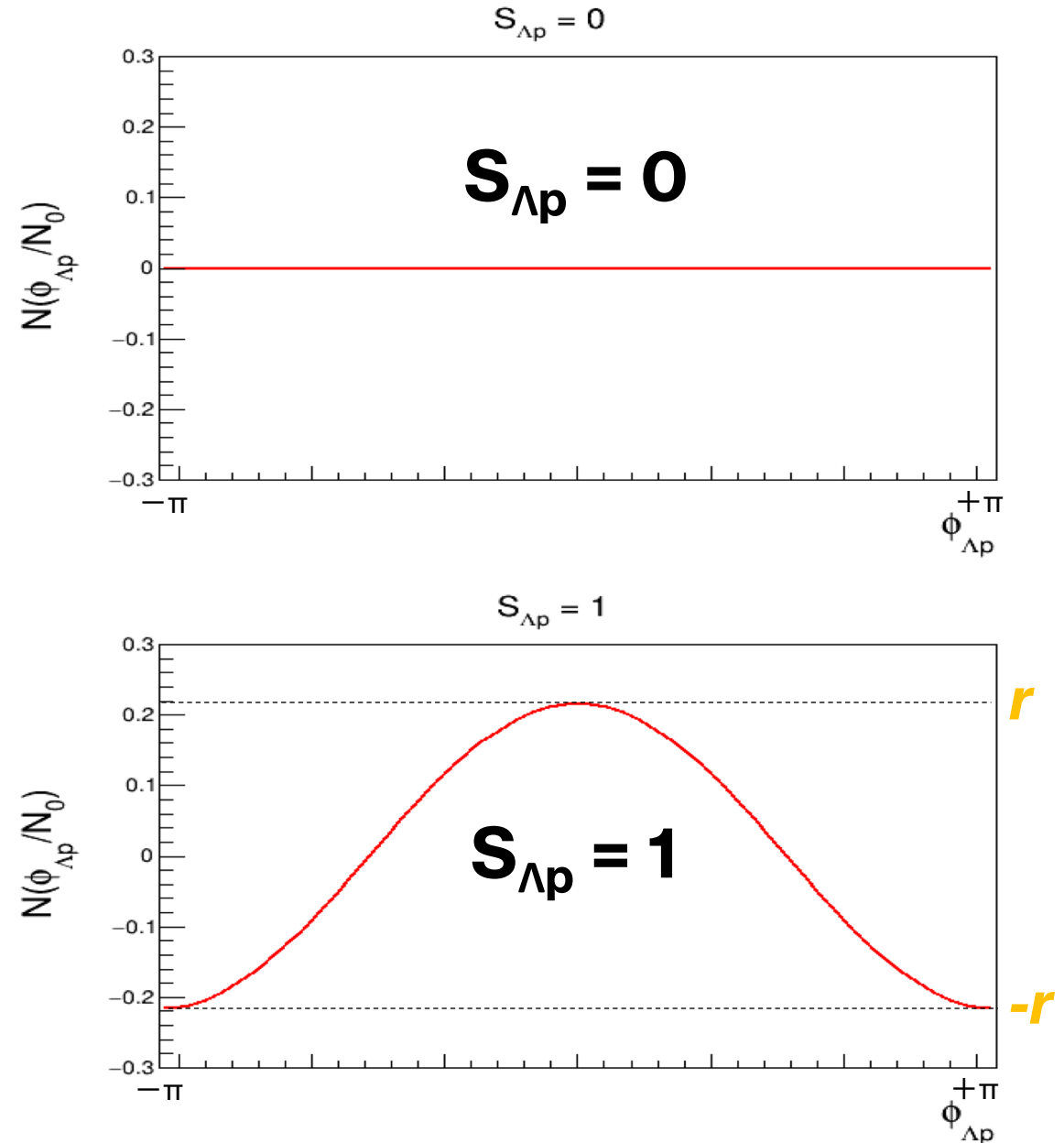


Figure is modified from J-PARC E89 proposal



$S_{\Lambda p}$ determination ($S_{\Lambda p} = 0$ or 1)

Reduction factor

$$r = \underline{\alpha_-} A_{pC}$$

$$N(\phi_{\Lambda p}) = N_0 (1 + \underline{r} \cdot S_{\Lambda p} \cos \phi_{\Lambda p})$$

α_- : Asymmetry parameter

$\alpha_- = 0.748$

$$(1 - \alpha_- \cos \theta_p d\Omega)$$

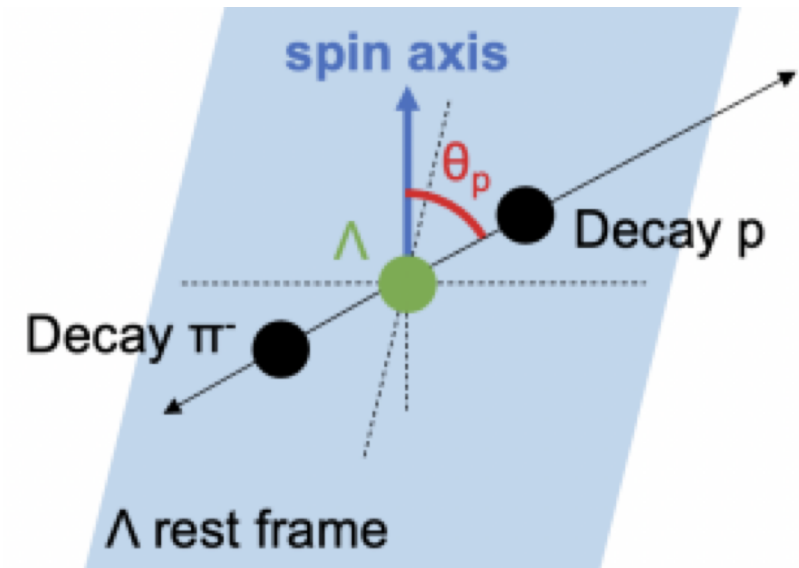
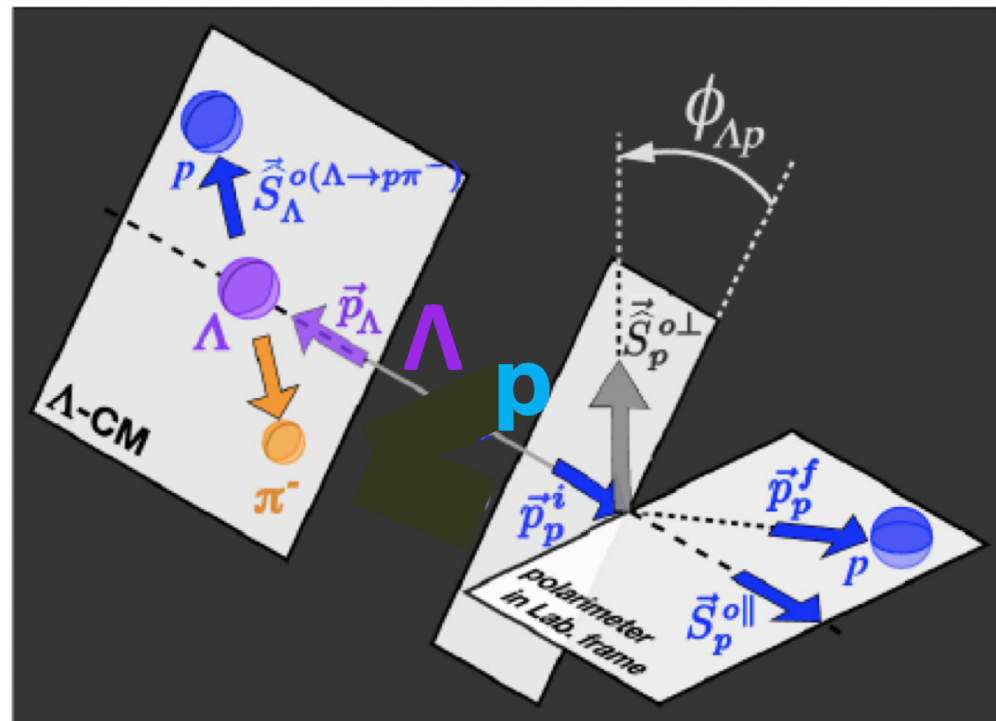


Figure is modified from J-PARC E89 proposal

$S_{\Lambda p}$ determination ($S_{\Lambda p} = 0$ or 1)

Reduction factor

$$r = \alpha \cdot A_{pC}$$

$$N(\phi_{\Lambda p}) = N_0 (1 + r \cdot S_{\Lambda p} \cos \phi_{\Lambda p})$$

A_{pC} : Analyzing power of pC scattering $\gtrsim 0.3$ at θ_{Max}

R.D. Ransome *et al.*, NIM 201, 315 (1982)

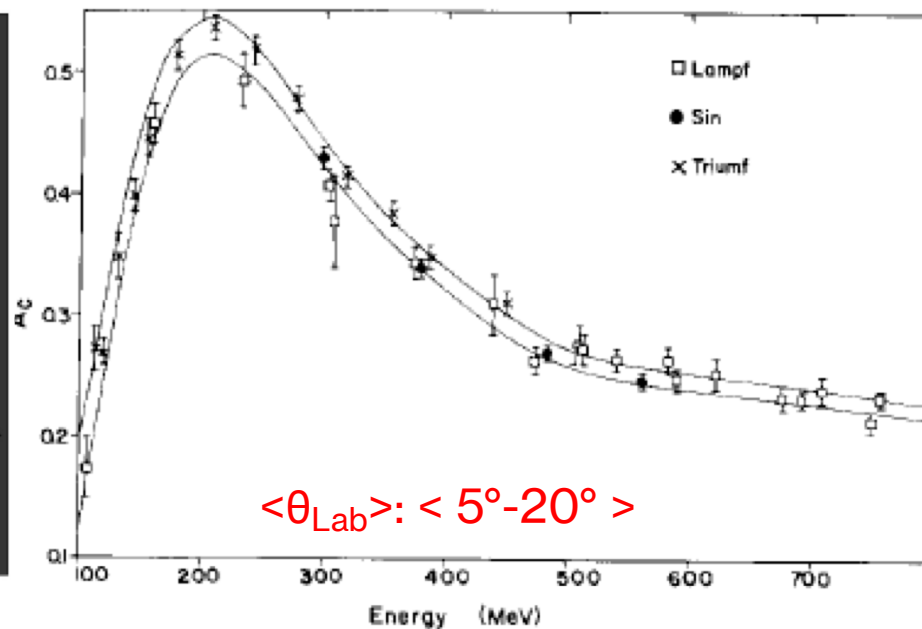
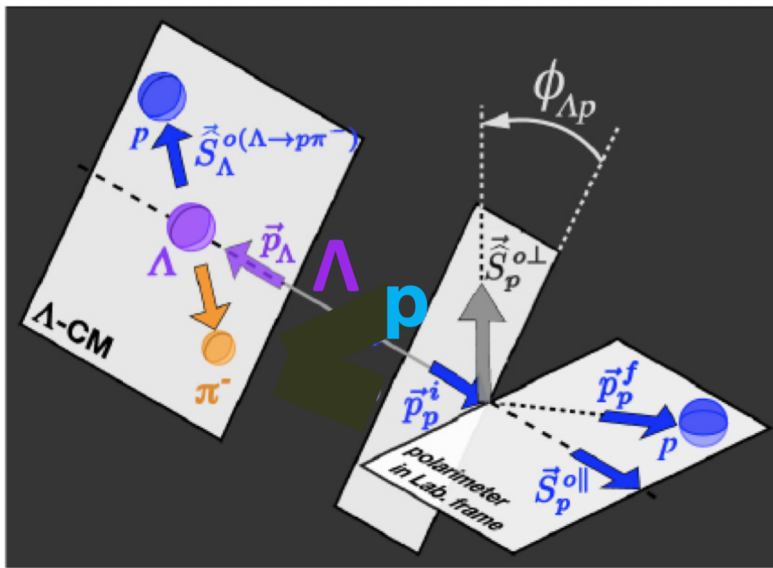


Fig. 6. Single energy and energy dependent averages from 5° to 20° lab (from tables 3 and 4). (Note that this is an unweighted average, see text.)

I.G. Alekseev *et al.*, NIM A434, 254 (1999)

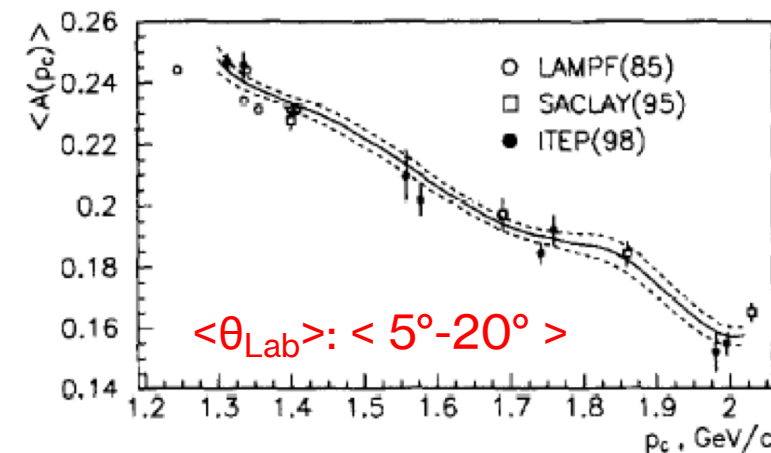
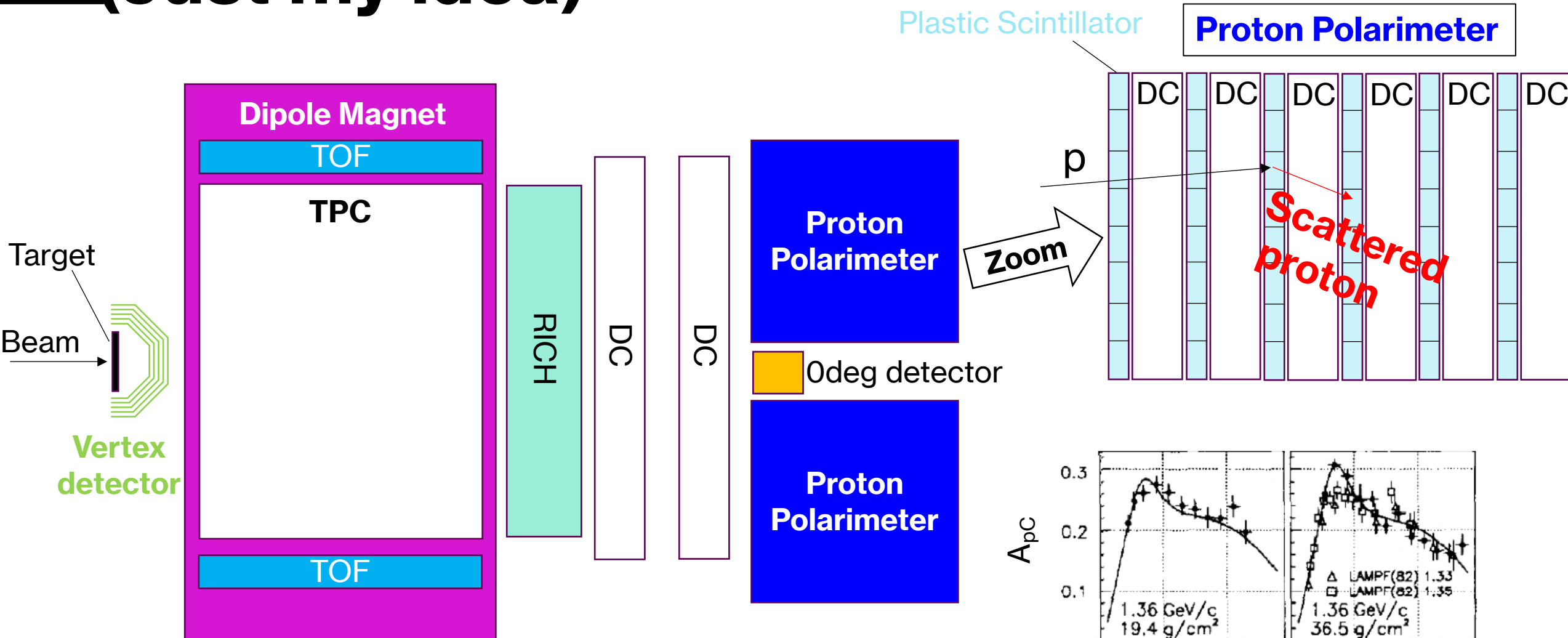


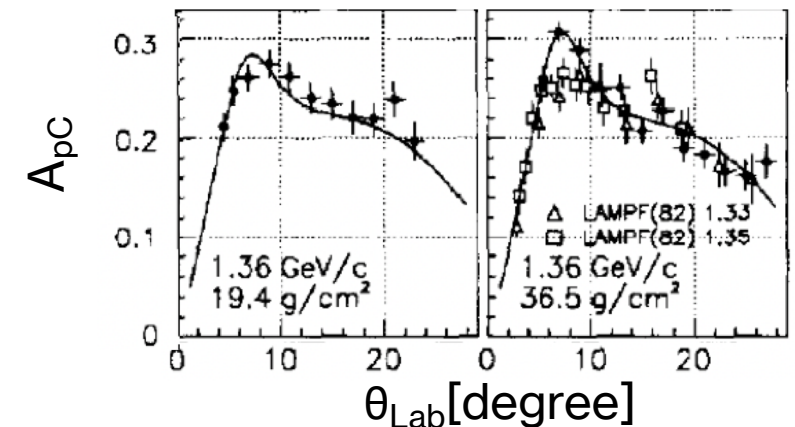
Fig. 7. Comparison of the parametrization results with the experimental data. Curve $\bar{A}(p_C)$, represented by the solid line, is average analyzing power for the angle region $5^\circ - 20^\circ$. $\bar{A}(p_C)$ and

Figure is modified from
J-PARC E89 proposal

Schematic view of J-PARC Femtoscopy (Just my idea)



S_p will be changed due to precession in B-Field
 $\rightarrow S_{\Lambda} \times S_p$ will be measured event by event



Summary

- We are proceeding the J-PARC-HI project.
- In order to implement J-PARC-HI, it is important to show the good result with current J-PARC facility.
- We will propose the new experiment to perform the $\alpha\Lambda$ Femtoscopy with pA collision as a byproduct of E88 (Mass modification of ϕ in pA collision).
- In this measurement, we can study the short range interaction between α and Λ .
→ Important Key to solve the hyperon puzzle in neutron star.
- In this experiment, not only $\alpha\Lambda$ but also various Femtoscopy is possible.

Join us!!