Considerations of Meson Physics at FMF2 of Super-FRS

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1. **η' or η mesic nuclei**
2. **Double kaonic nuclei search**
3. **$\Delta Z = \pm 2$ p/n-rich nuclear spectroscopy**

Advantages
Dispersion matching
Pion beams
Pbar induced spectroscopy

Super-FRS secondary beam intensities

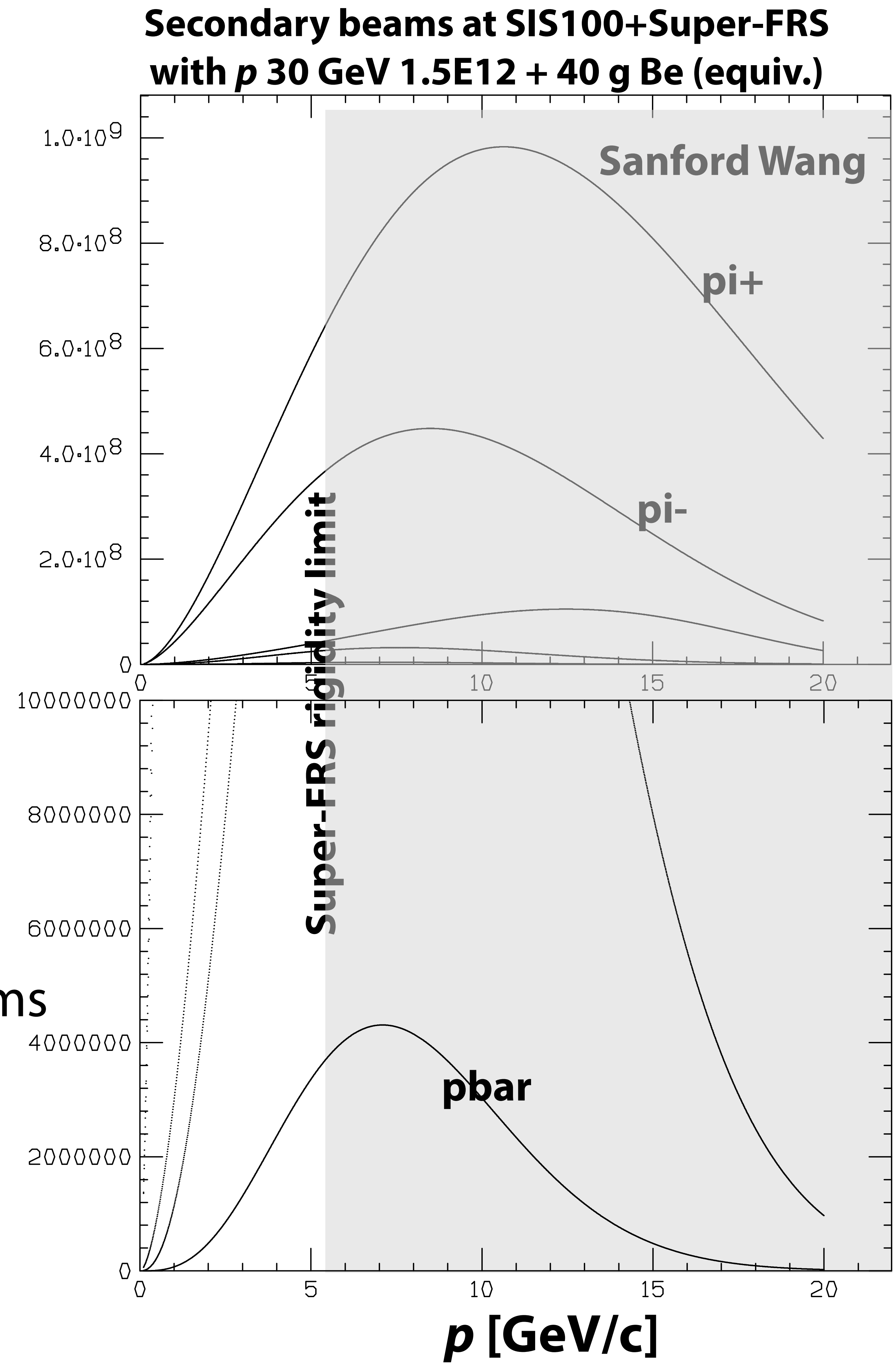
Max. proton energy of SIS100 is the same as J-PARC MR

Advantages

Dispersion matching
Pion beams
Pbar induced spectroscopy

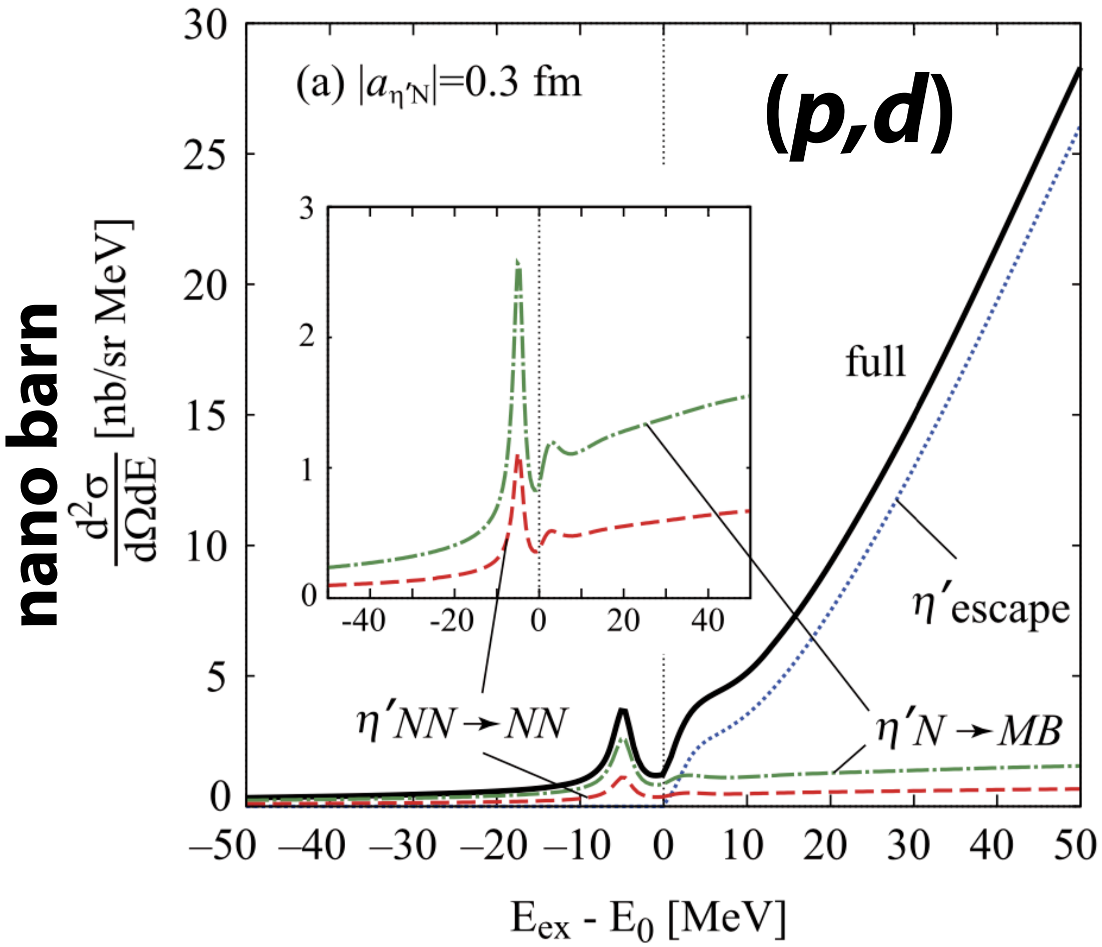
Competitors

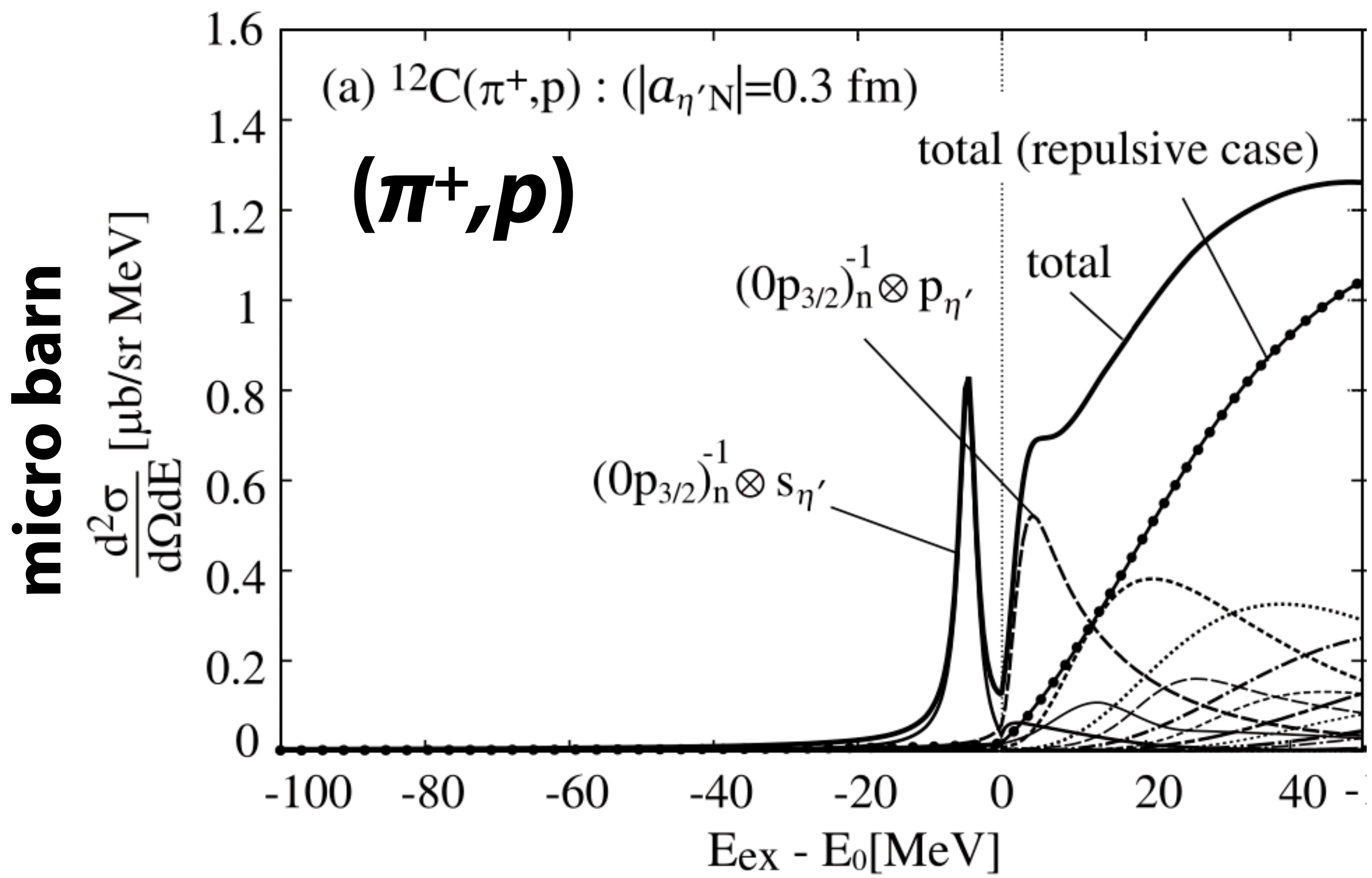
J-PARC K1.8(BR) for pion / K / pbar beams
J-PARC HIHR for DM pion / pbar beams
R[3]B for pbar with forward detectors



Pion induced η/η′-mesic nuclei spectroscopy

η′-mesic nuclei





(π^+,*p*) has 100 times larger cross section

→ Using 10^8/s beams, we will have 100 times higher statistics

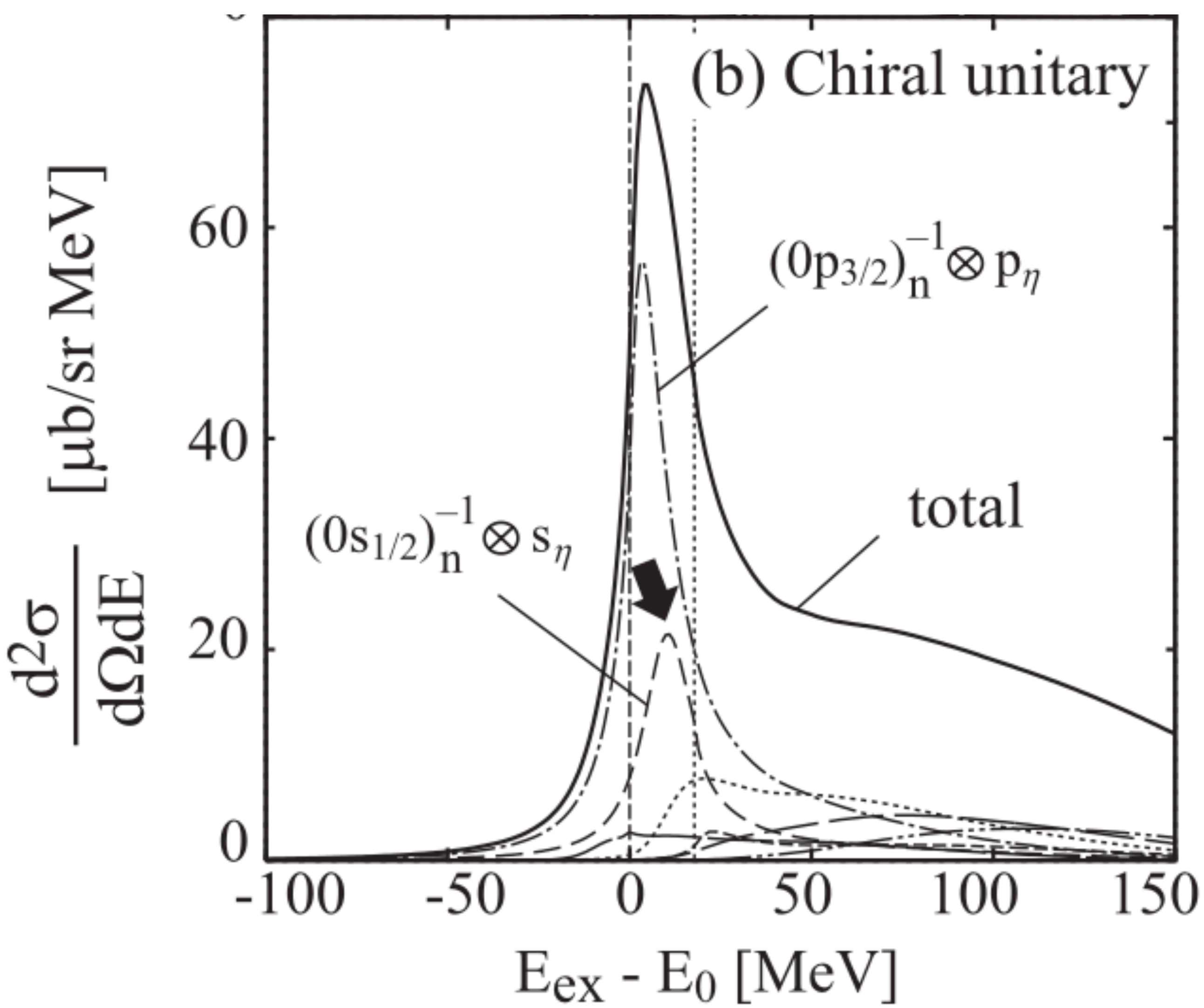
First step	(π,p)	DM inclusive measurement	Simple setup
Second step	(π,p) w. decay tagging	semi-exclusive	Large Ω tracker

Nagahiro, NPA914, 360 (2013)
Nagahiro et al., PRC80, 025205 (2009)

Pion induced η/η′-mesic nuclei spectroscopy

η-mesic nuclei

in (π^+,*p*) or (*d*,^{3}He)



η in nuclei couples to $J^\pi=1/2^-$

N*(1535) → Nπ

back-to-back Nπ tagging suppress BG

LETTER OF INTENT FOR J-PARC

SPECTROSCOPY OF η MESIC NUCLEI BY (π^-, n) REACTION AT RECOILLESS KINEMATICS

KI et al. (2007)

If we can place a forward neutron counter,
(π-,*n*) can also be a candidate

Nagahiro, NPA914, 360 (2013)
Nagahiro et al., PRC80, 025205 (2009)

Double Kaonic Nuclear Cluster

Antikaons in Nuclei by Antiproton Annihilation

$$\bar{p} + 3He \rightarrow ppK^{-} + K^{0}$$

Production of ppK⁻ cluste[…] the n in ^{3}He and creation [...]

Missing mass spectrosco[…]

Invariant mass of ppK⁻ → […]

Exclusive formation and […] a 4π-detector allowing K⁰ […]

First idea by late Prof. Em. P. Kienle

Double Antikaon Production in Nuclei by Antiproton Annihilation

- The process: $\bar{p} + p \rightarrow K^+ + K^+ + K^- + K^- - 0.098\ \mathrm{GeV}$
- The cross section: $\dfrac{\sigma(\bar{p}p \rightarrow K^+K^-\pi^+\pi^-)}{\sigma(\bar{p}p \rightarrow 2\pi^+2\pi^-)} \sim 0.1$ $\quad \sigma(\bar{p}p \rightarrow 2K^+2K^-) \sim 10\ \mu b$
- The kinematics $\sqrt{M^2 + \vec{p}_0^{\,2}} = 2m_K \qquad p_{0,lab} \simeq 652\ \mathrm{MeV/c}$
- Double kaon production in nuclei:

$$\bar{p}\,^4He \rightarrow K^+K^+ + [K^-K^-pnn]$$

$$\bar{p}\,^6Li \rightarrow K^+K^+ + [K^-K^-pp3n]$$

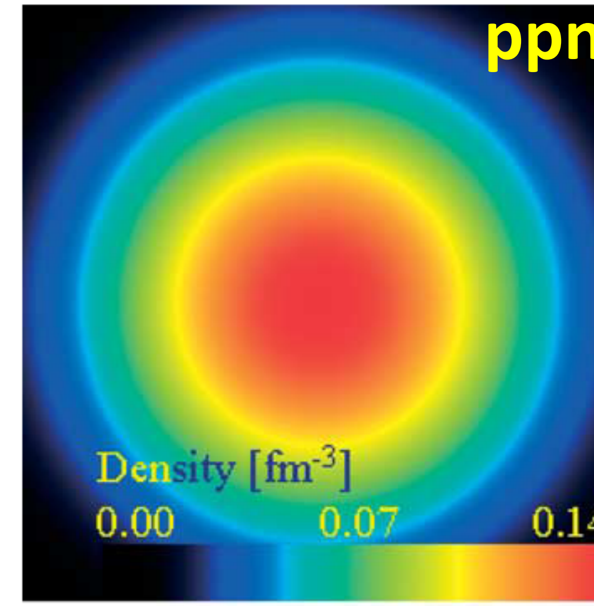
→ With the binding energy exceeding ~ 225 MeV, double kaonic nuclei can be produced even by stopped antiprotons.

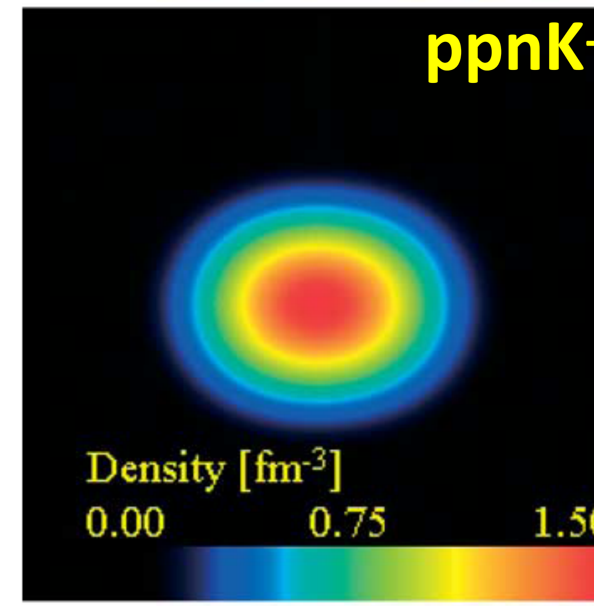
P.Kienle, ECT* 2006

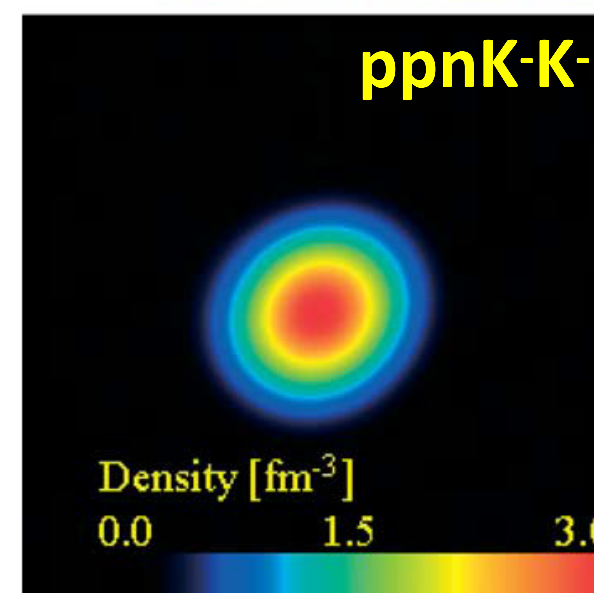
Double Kaonic Nuclear Cluster

AMD calculations show very large binding energies for double K clusters partly due to the very concentrated densities

$\bar{K}$ cluster	Mc^2 [MeV]	E_K [MeV]	Γ_K [MeV]	$\rho(0)$ [fm^{-3}]	R_{rms} [fm]	k_p [fm^{-1}]	k_K [fm^{-1}]
pK^-	1407	27	40	0.59	0.45	1.37	1.37
ppK^-	2322	48	61	0.52	0.99	1.49	1.18
$pppK^-$	3211	97	13	1.56	0.81		
$ppnK^-$	3192	118	21	1.50	0.72		
$ppppK^-$	4171	75	162	1.68	0.95		
$pppnK^-$	4135	113	26	1.29	0.97		
$ppnnK^-$	4135	114	34		1.12		
ppK^-K^-	2747	117	35				
$ppnK^-K^-$	3582	221	37	2.97	0.69		
$pppnK^-K^-$	4511	230	61	2.33	0.73		







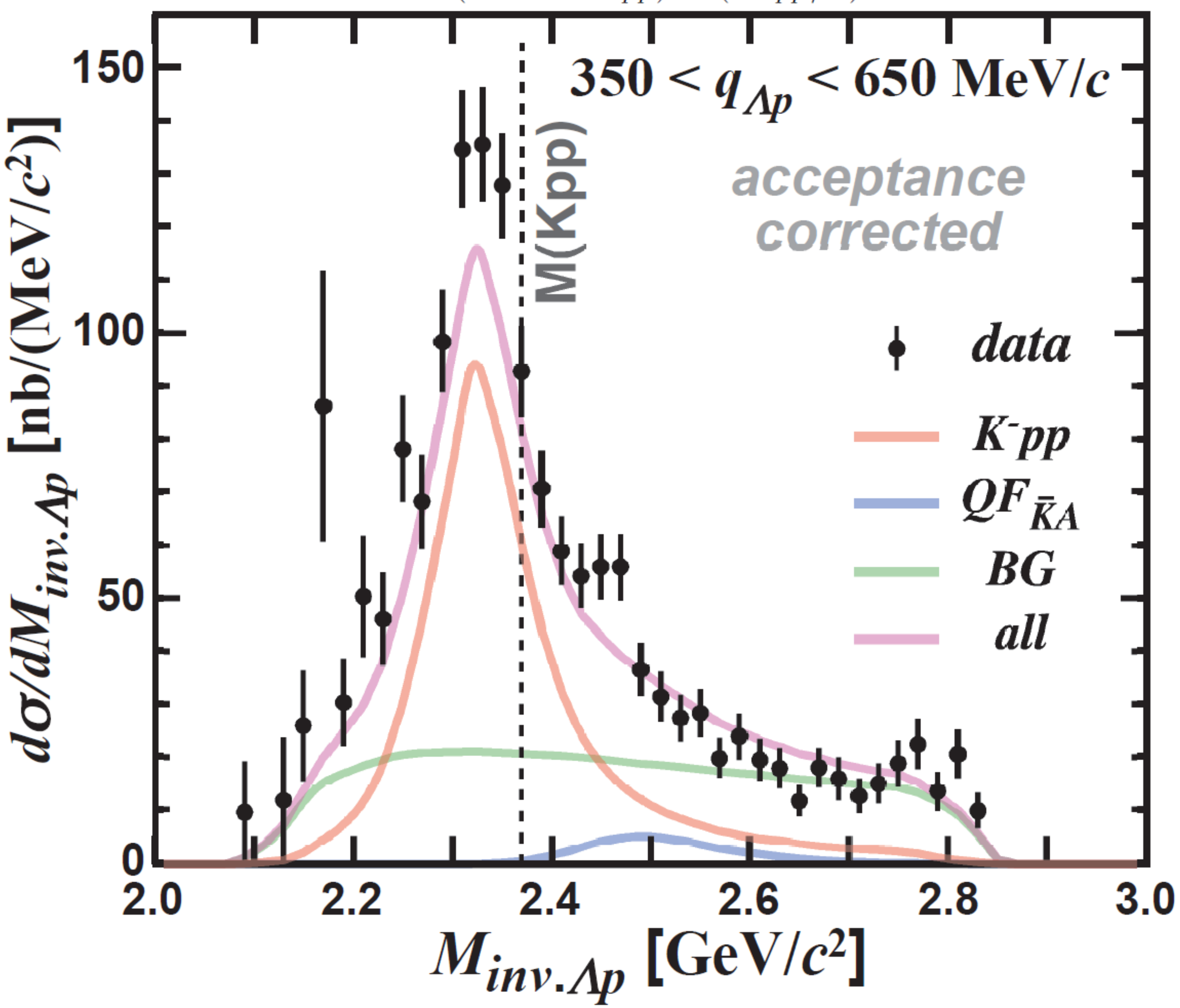
PL,B587,167 (2004)

J-PARC E15 Discovered $K^{-}pp$ Bound-State

$$f_{\{Kpp\}}(M,q) = \frac{A_{Kpp}\,(\Gamma_{Kpp}/2)^2}{(M - M_{Kpp})^2 + (\Gamma_{Kpp}/2)^2}\, e^{-\left(\frac{q}{Q_{Kpp}}\right)^2},$$

$B = 47 \pm 3\ ^{+3}_{-6}$ MeV

$\Gamma = 115 \pm 7\ ^{+10}_{-9}$ MeV



Yamaga et al., PhysRevC.102.044002 (2020)

K^-K^-pp search by stopped K at J-PARC

Experimental Principle

- We search for S=-2 dibaryon with p^{bar}+^{3}He annihilation at rest (3N absorption):

$$\bar{p} + {}^3He \rightarrow K^+ + K^0 + X, \quad X \rightarrow \Lambda\Lambda$$

final state: $K^+ + K^0 + \Lambda + \Lambda$ ($K^0 \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\pi^-$, $\Lambda \rightarrow p\pi^-$)

  - if K^-K^-pp state exists with deep bound energy:

$$\bar{p} + {}^3He \rightarrow K^+ + K^0 + K^-K^-pp + B.E. - 109 MeV$$

  - if H-dibaryon (resonance) exists:

$$\bar{p} + {}^3He \rightarrow K^+ + K^0 + H$$

We can investigate S=-2 dibaryon with inclusive *or* exclusive measurement

Sakuma, LoI for J-PARC (2009)

Not easy…because

- **Absorption at rest has not enough energy to populate shallow bound states.**
- **In-flight events can contaminate easily.**
- **Number of stopped pbar is limited.**

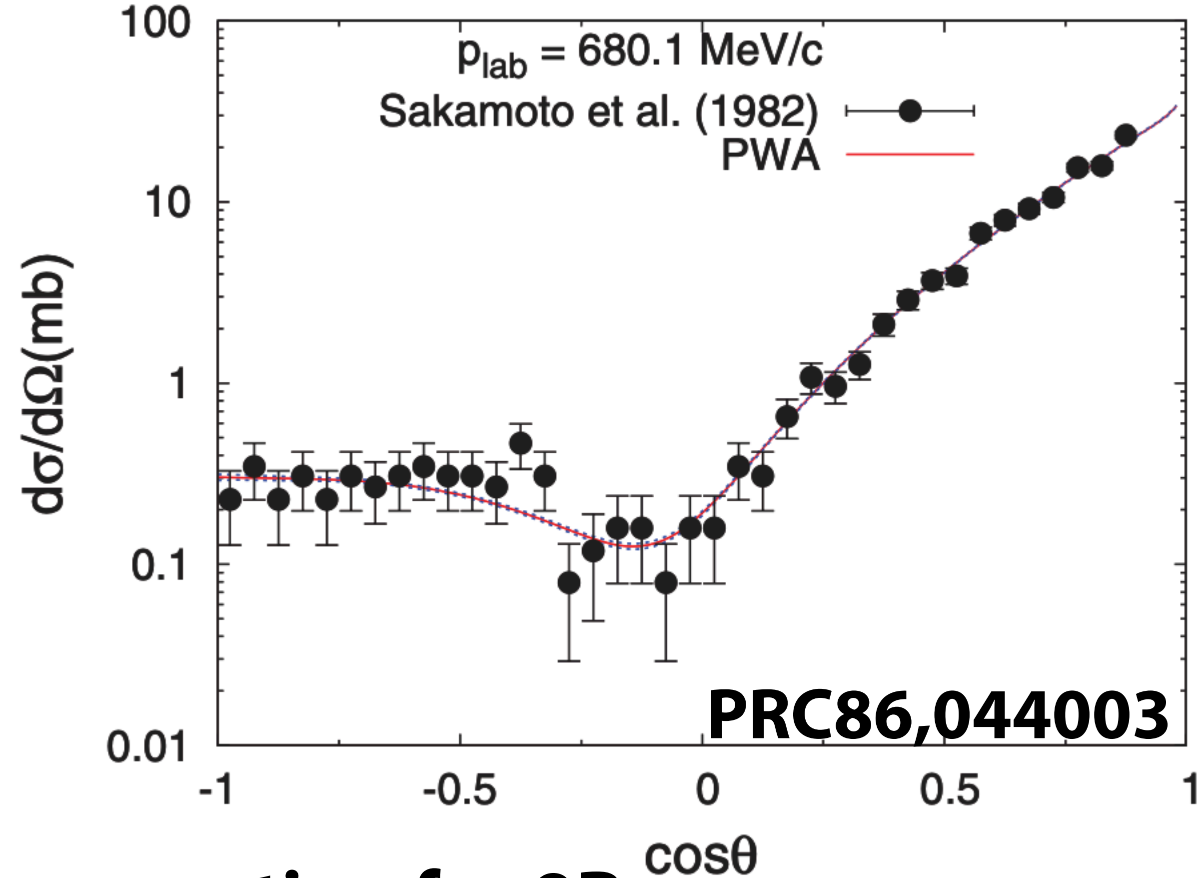
^{9}Be(pbar,p) reaction for DKNC search at Super-FRS

H(pbar,p) at 180 degree
0.3mb/sr -> 40 counts/s
(pbar 1.0E6 beam, 1 mol target

$$\overline{p} + {}^{9}\mathrm{Be} \rightarrow p + \overline{p}^{*} + {}^{8}\mathrm{Li}$$

$$\overline{p}^{*} + {}^{8}\mathrm{Li} \rightarrow K^{+}K^{+} + K^{-}K^{-} + {}^{7}\mathrm{He}$$

$$\overline{p}^{*} + {}^{8}\mathrm{Li} \rightarrow K^{+}K^{0} + K^{-}K^{-} + {}^{7}\mathrm{Li}$$



PRC86,044003

If we assume similar cross section for 9Be,
we have 40 pbar/s with small *q* in the nucleus
which may form double K nuclear clusters
(or Λ, ΛΛ or Ξ hypernuclei…)

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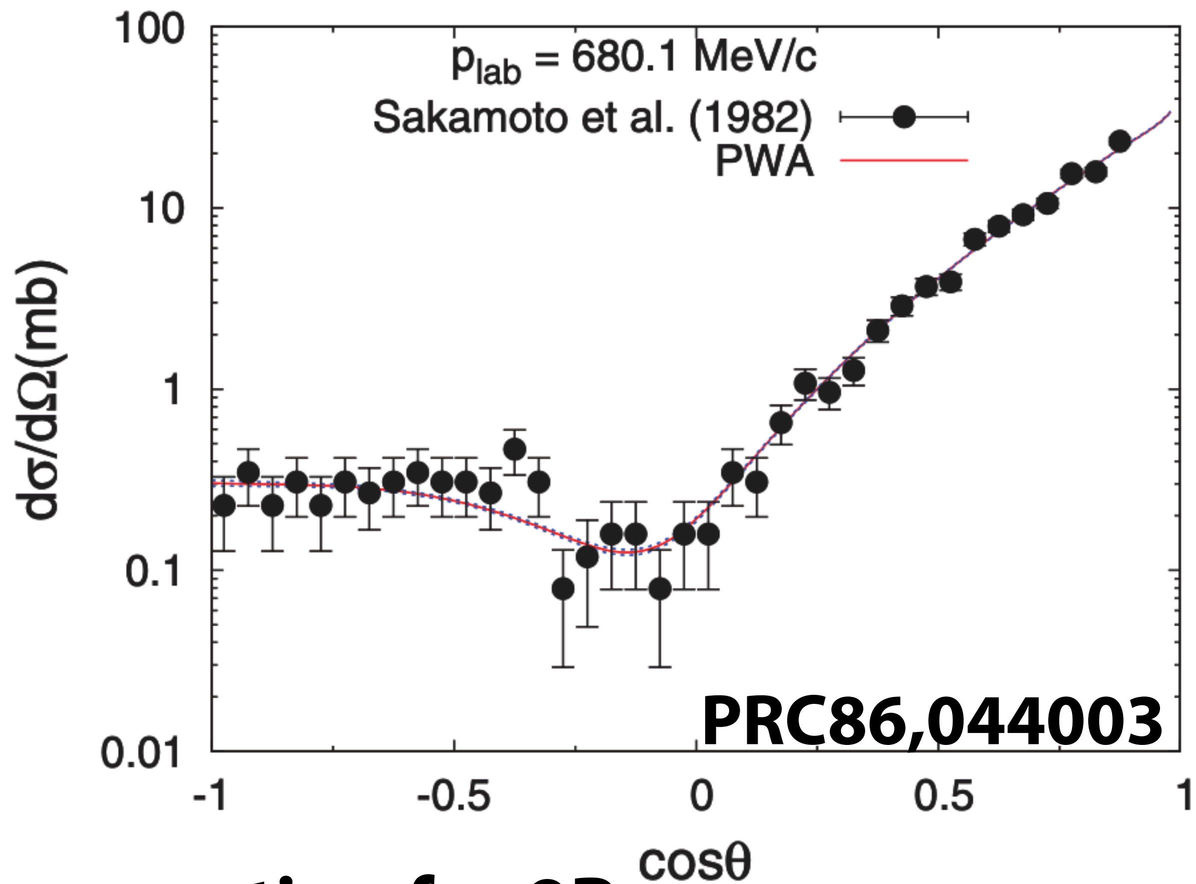

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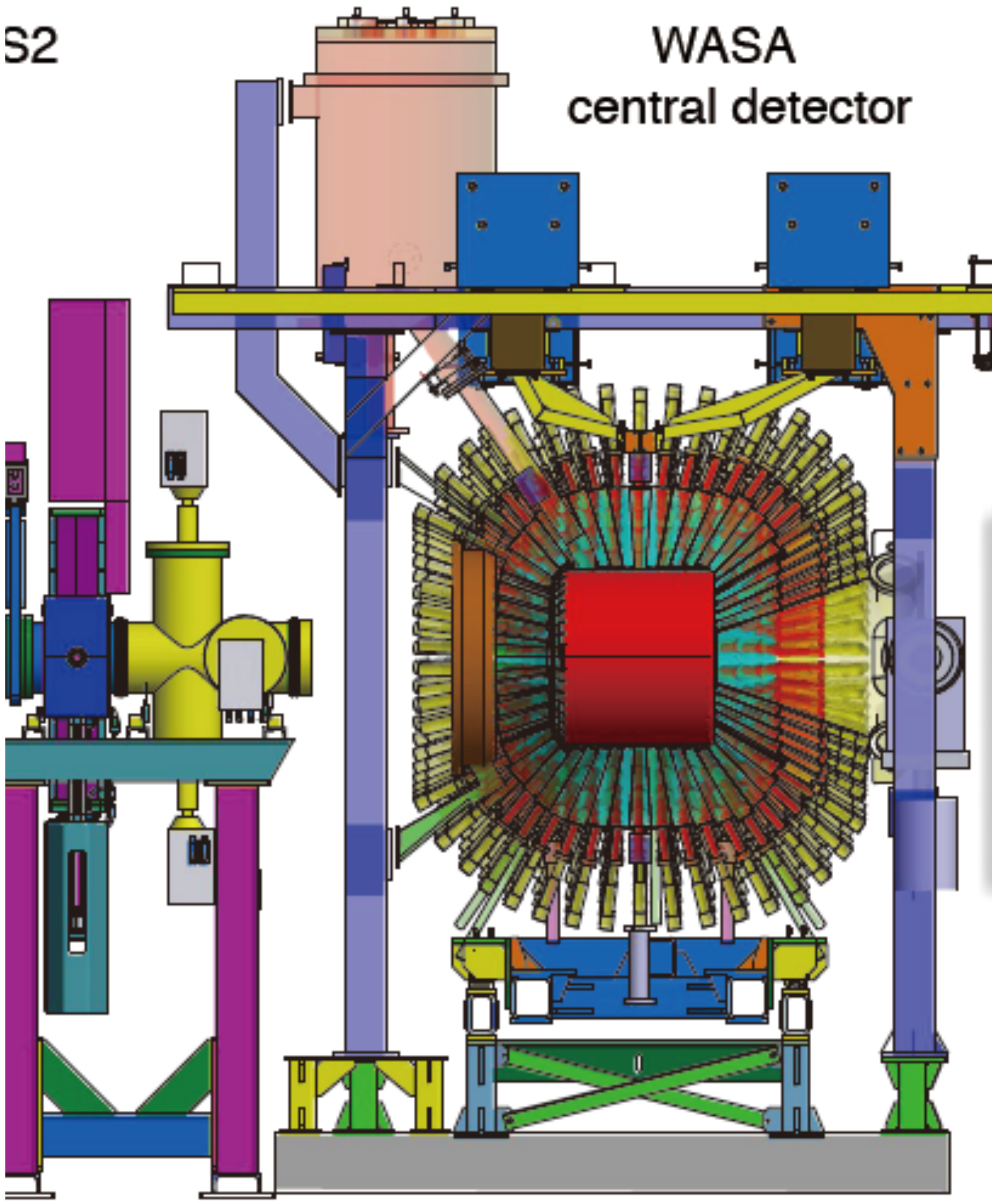
Comments

- **We still need theoretical calculations for cross sections.**
- **Identifying K+K- leads to φ in nucleus**
- **Experiment may be feasible with ~4pi detector at FMF2 such as smaller WASA**

Large Ω charged particle detector at FMF2

Large Ω charged particle detector at FMF2

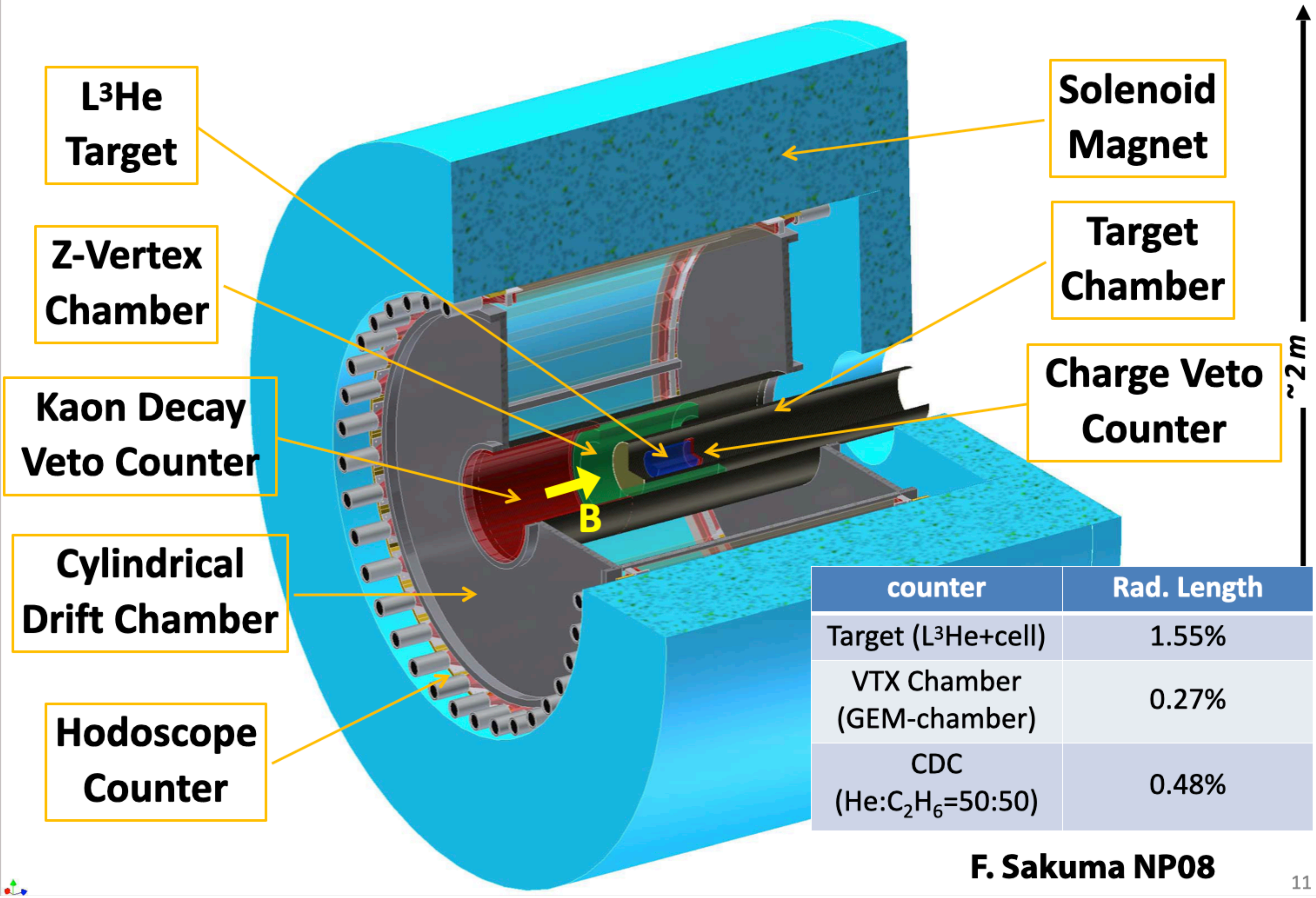


WASA is too big…

We do **not** need neutral detectors for the first moment. We need charged particle identification and momentum analysis only

CDS at J-PARC K1.8BR will be dismounted soon…

Cylindrical Detector System (CDS)



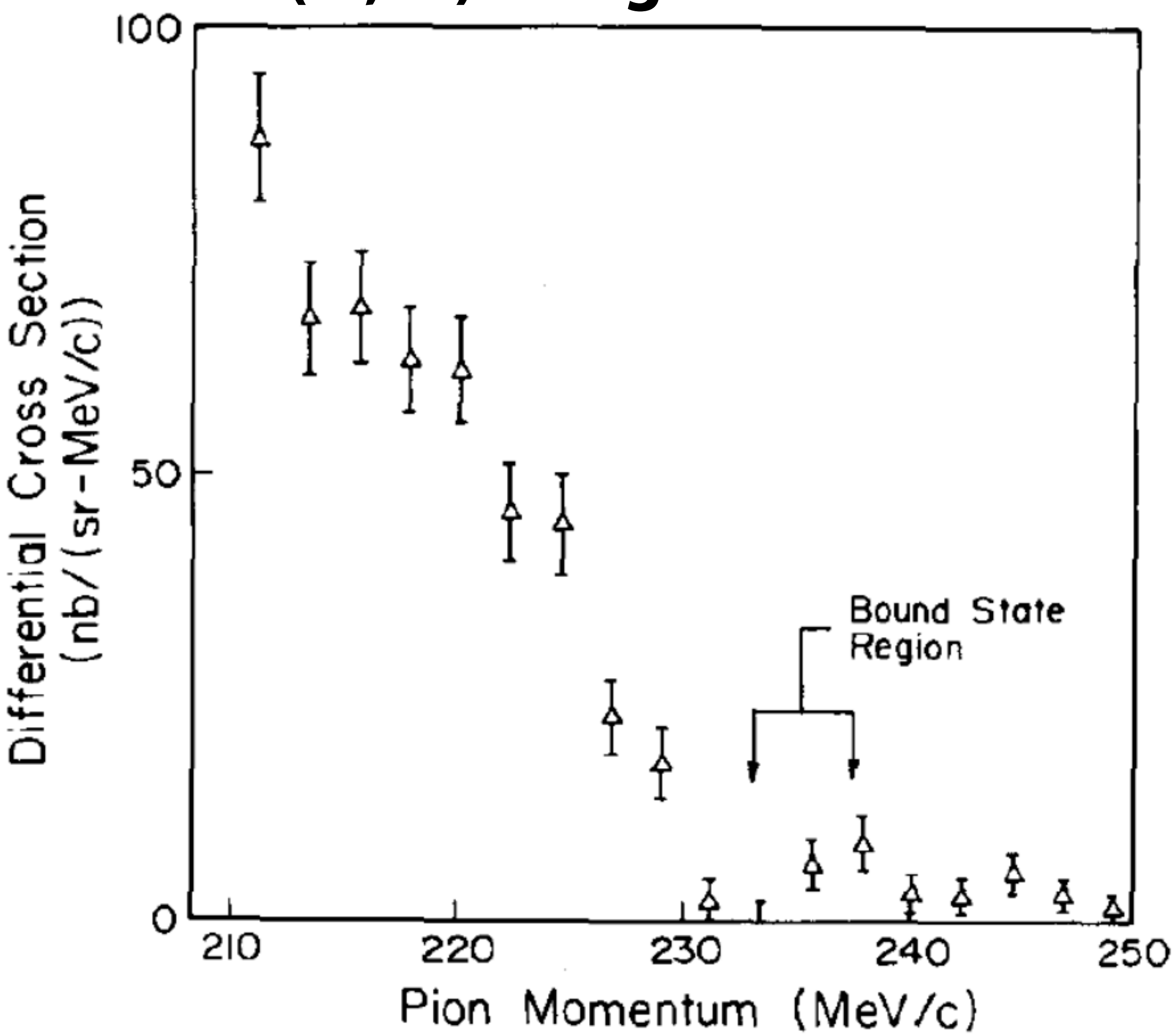
counter	Rad. Length
Target (L3He+cell)	1.55%
VTX Chamber (GEM-chamber)	0.27%
CDC ($He:C_2H_6$=50:50)	0.48%

F. Sakuma NP08

ΔZ=±2 spectroscopy in π induced reactions

ex. 4n in $^4He(\pi^-,\pi^+)$
or 3n in $^4He(\pi^-,p)$?

$^4He(\pi^-,\pi^+)$ 0 degree at 165 MeV



Preceding experiment at TRIUMF did not show clear structure

J.E. Ungar, PLB144,333(1984)

4n at Super-FRS…

- **850 MeV π^- beam ~2×10^8/spill**
- **q ~ 31 MeV/c**
- **2 g/cm^2 liq. ^4He target**
- **Assume c.s. 1nb/sr → 60 4n/week**

Spectroscopy of p/n-rich nuclei with ΔZ=±2 reactions of $\pi^\pm$ beam

Summary

- **Super-FRS provides unique opportunity for making high resolution spectroscopy experiments with pion / pbar beams with DM conditions**
- **A large Ω detector at FMF2 expands chances to make many experimental programs including η/η′-mesic nuclei in a similar way as in WASA at FRS.**
- **DKNC (KK in nuclei) search can also be conducted, which may generate nuclear matter with higher ρ.**
- **$\Delta Z=\pm 2$ reactions may enable study of p/n-rich nuclei including 4n or 3n**