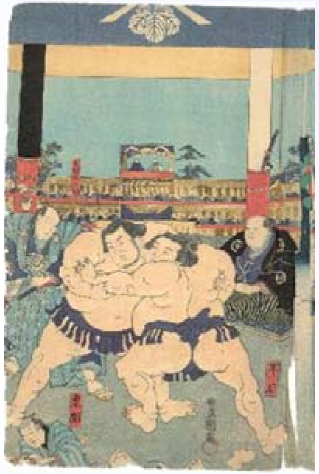
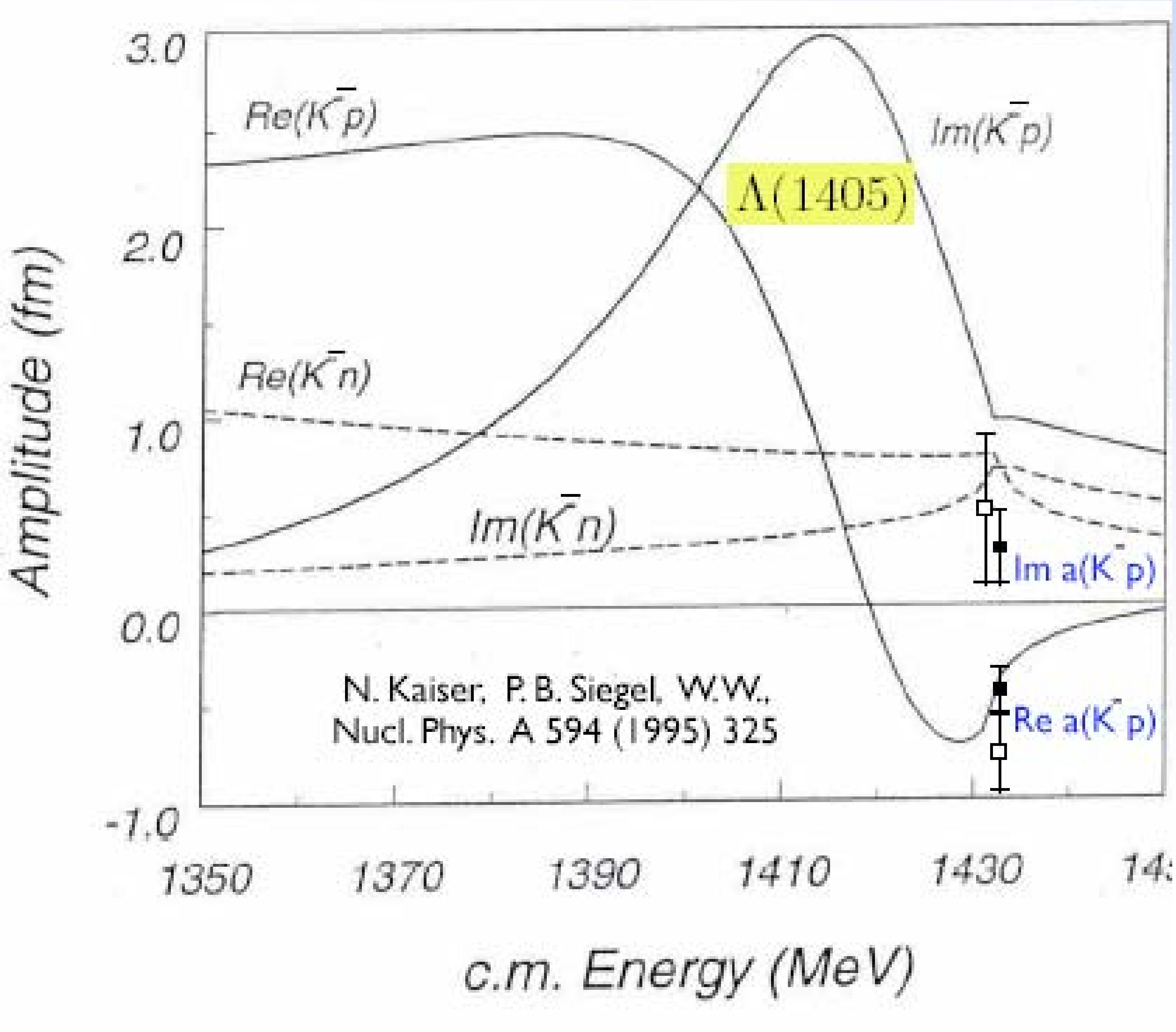
Experimental Studies of Antikaon Mediated Bound Nuclear Systems

- **Λ(1405), the doorway state to deeply bound, dense antikaonic nuclear clusters**
- **First experimental searches and results**
- **Heavy ion and proton induced reactions**
- **Size and density of kaonic nuclei**
- **Antiproton annihilation for double antikaonic nuclei**

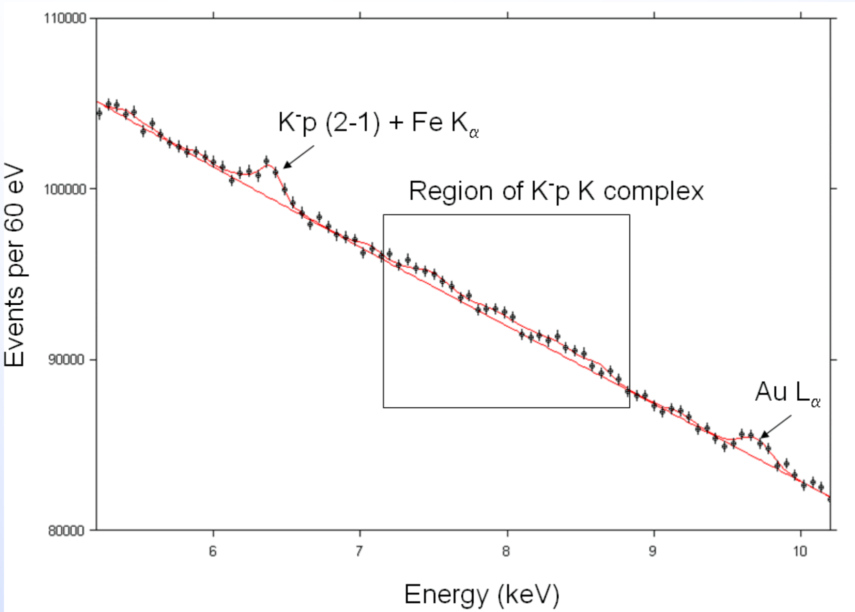


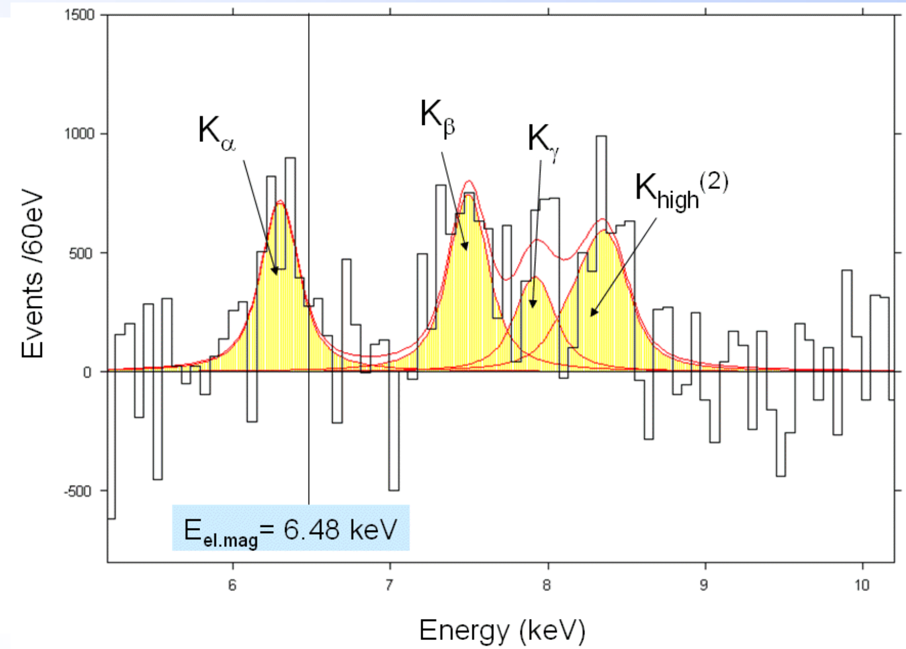
Λ(1405) the Doorway to Antikaonic Nuclei



Kaonic Hydrogen K-Lines (DEAR)

G. Beer et al. Phys. Rev. Lett. 94 (2005) 212302





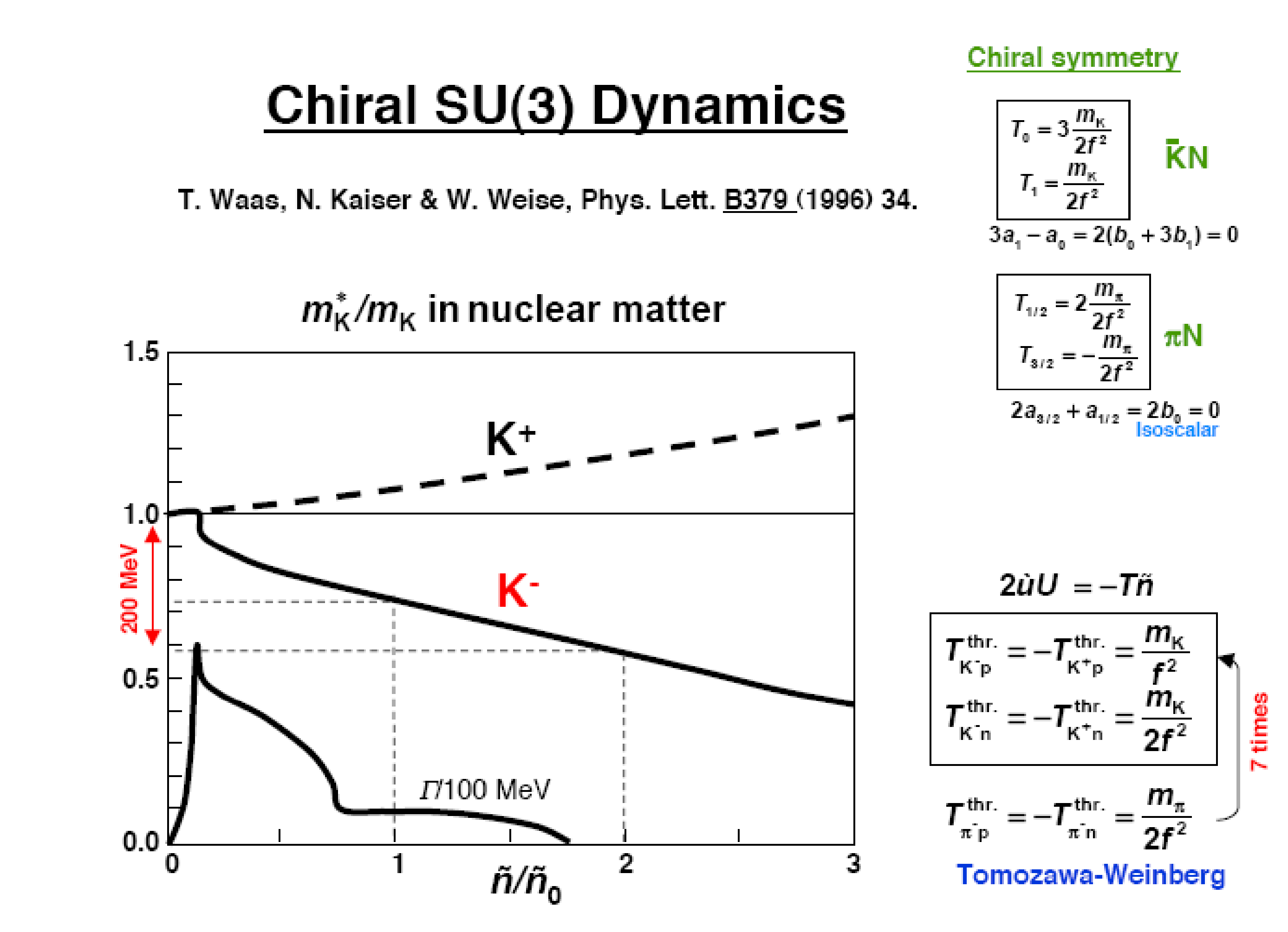
$$\epsilon_{1s} = -193 \pm 37\ (\text{stat.}) \pm 6\ (\text{syst.})\ \text{eV}.$$

$$\Gamma_{1s} = 249 \pm 111\ (\text{stat.}) \pm 30\ (\text{syst.})\ \text{eV}.$$

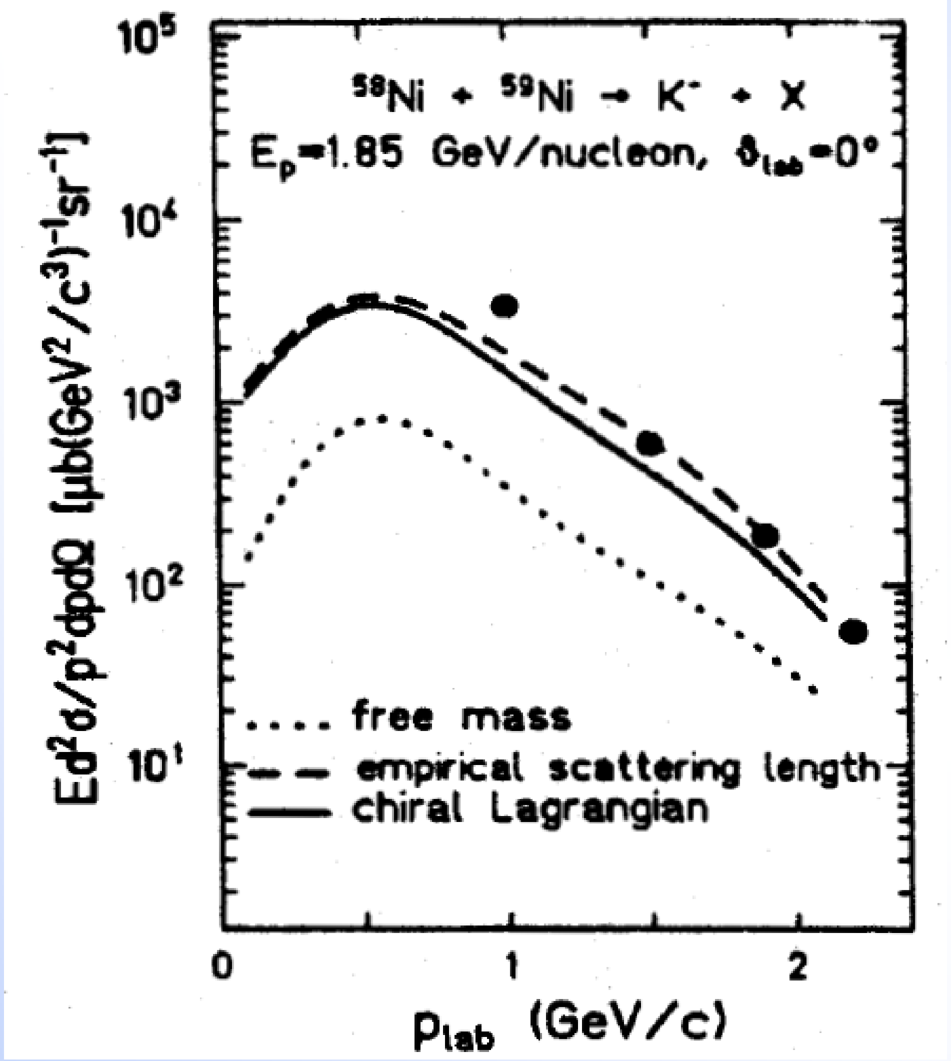
$$a_{K^-p} = (-0.468 \pm 0.090\ (\text{stat.}) \pm 0.015\ (\text{syst.})) + i(0.302 \pm 0.135\ (\text{stat.}) \pm 0.036\ (\text{syst.}))\ \text{fm}.$$

SIDDHARTA using **SDD's** triggered by kaons: **K^-H,K^-D** → KN iso-scalar and –vector scattering length with high accuracy @ **DAPHNE, LNF** in 2007-08.

Decrease of K- Mass in a Nuclear Medium → Strong Binding by Attractive K-N Force



Antikaon Production in Ni-Ni Collisions



P. Kienle, A. Gillitzer

Proc. Int. Conf. Nucl.Phys. (1996) Widerness,SA

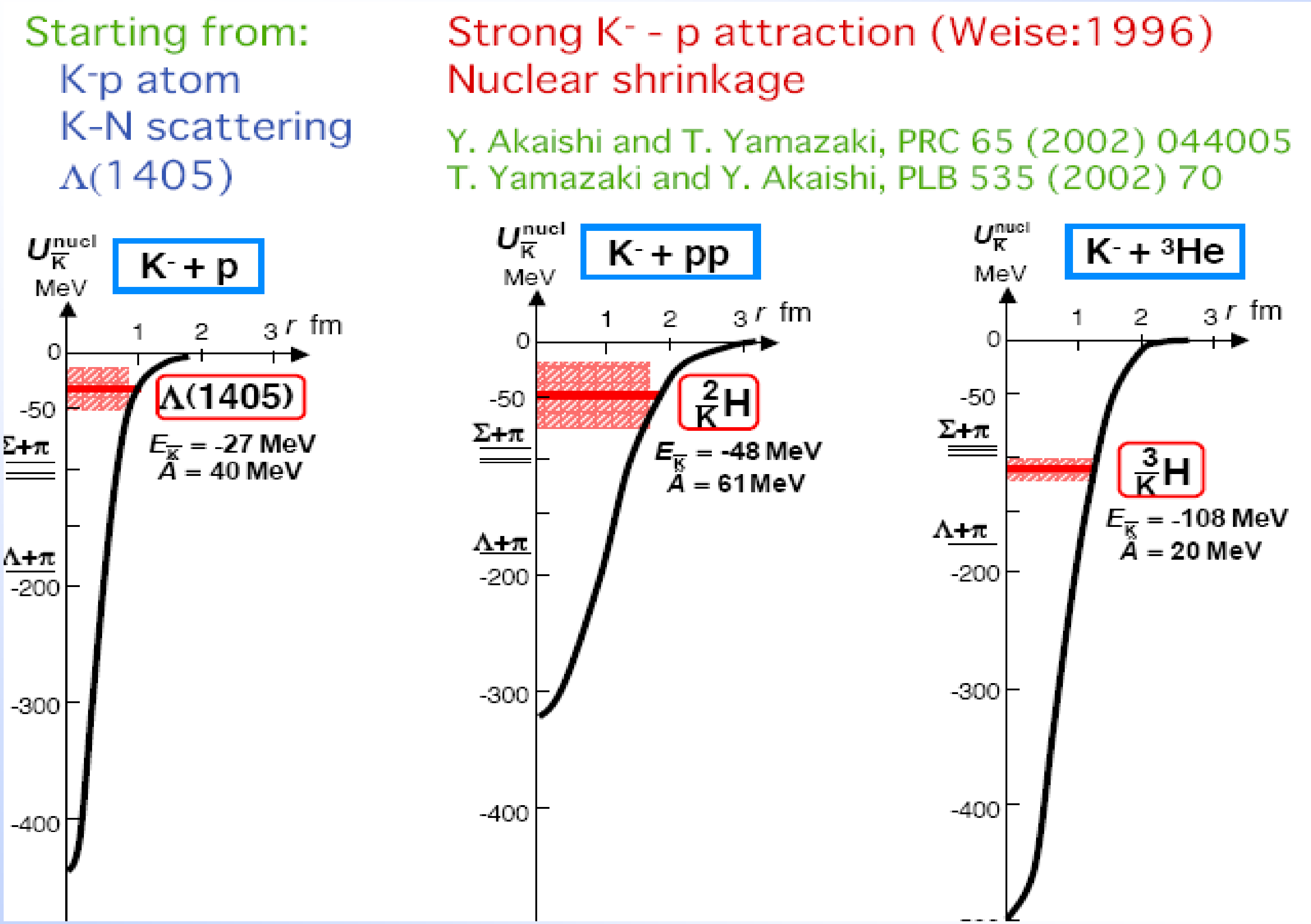
Ed,:Stöcker, Gallmann, ,Hamilton, World Scientific

G,Q. Li, C.M. Ko, X.S. Fang, Phys. Lett. **B329,** (!994) 149

Indication of a decrease of the K^- mass of ~200 MeV in a nuclear medium with n/n_0 ~ 2

Prediction of Lightest Kaonic Nuclear Systems

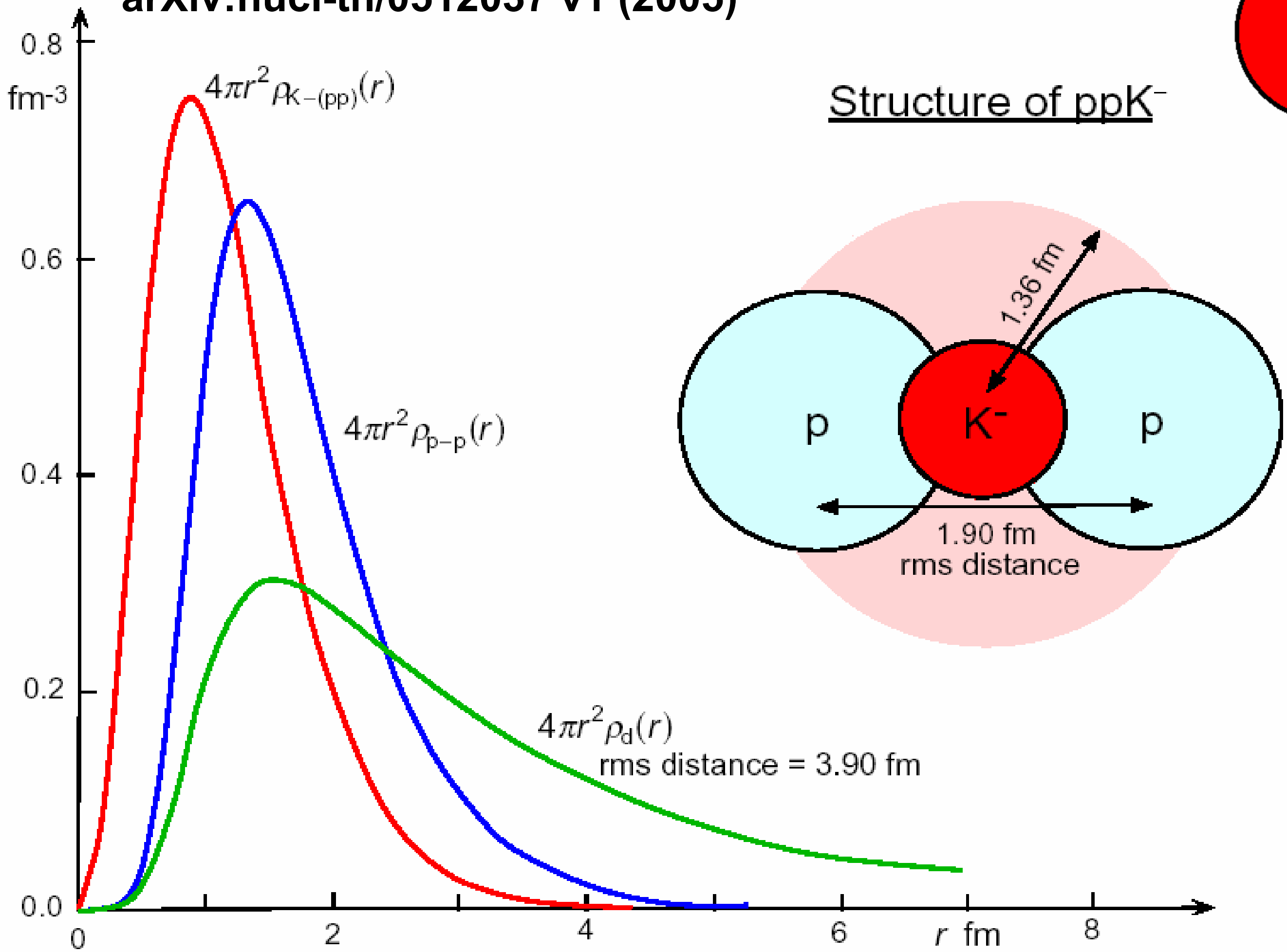
Strong K^- binding in a nuclear medium predicted by Wycech (1986) and p-wave contribution (EXA05)

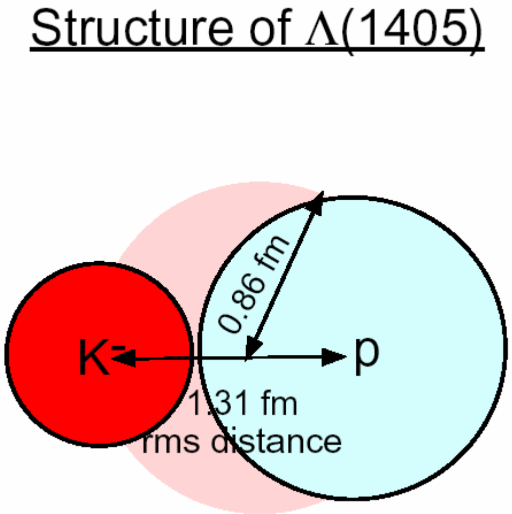


ppK⁻ Bound System

Antikaonic “hydrogen molecule”

A.N. Ivanov et al. Model of the ppK- in the groundstate arXiv:nucl-th/0512037 v1 (2005)

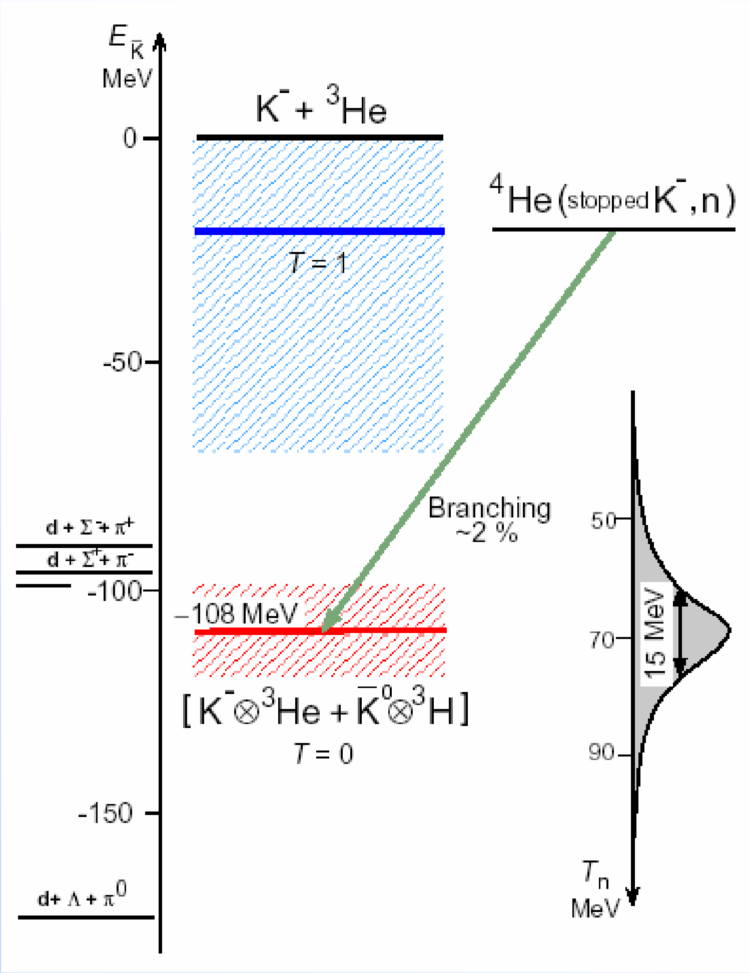




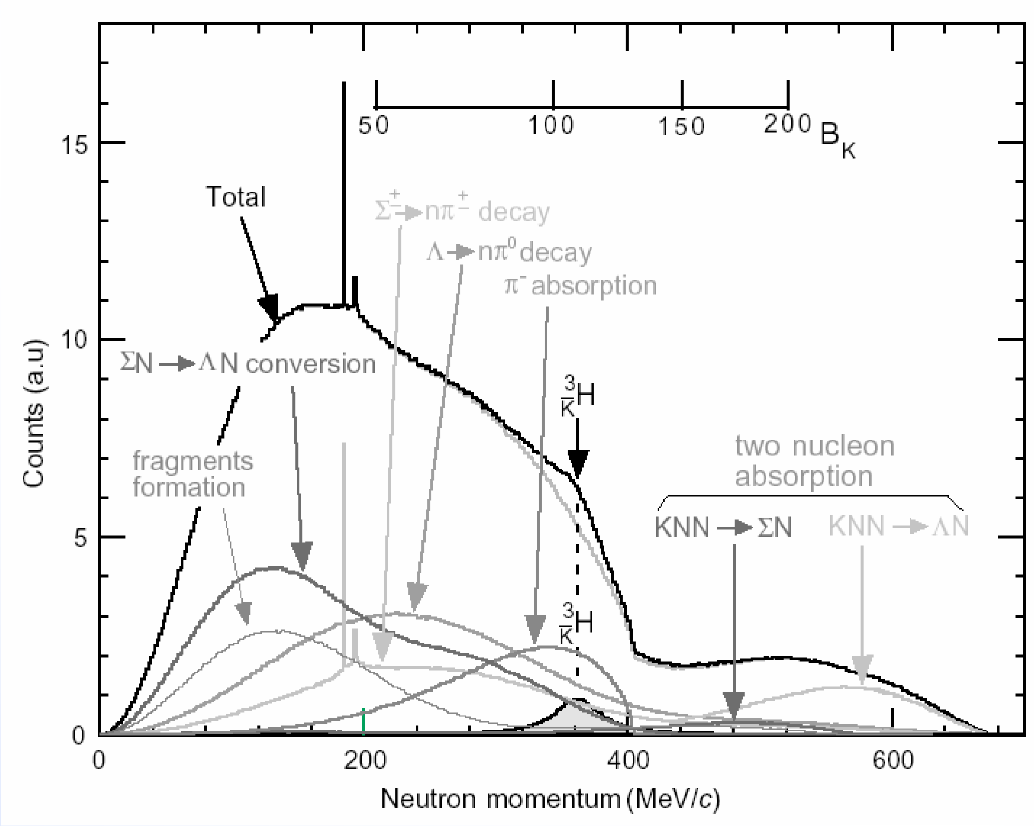
Experimental Search K⁻ppn @ KEK

M. Iwasaki et al., NIM . A473 (2001) 286

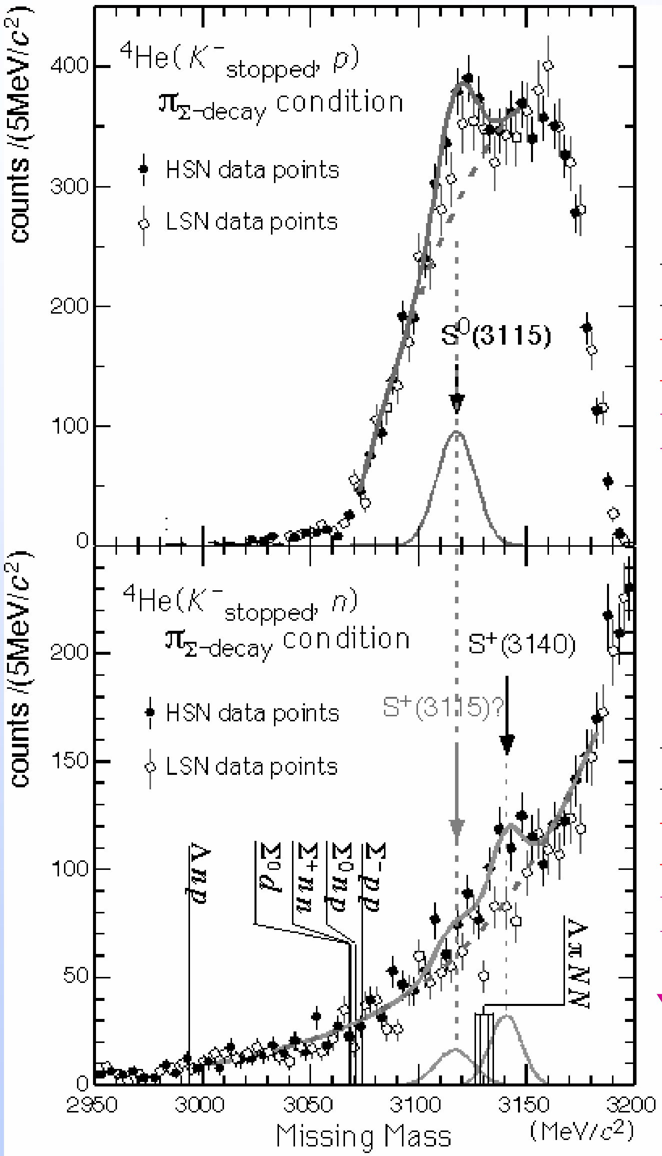
^{4}He (stopped K$^-$, n)K$^-$ ^{3}He



expectation



First Experimental Results of KEK E471



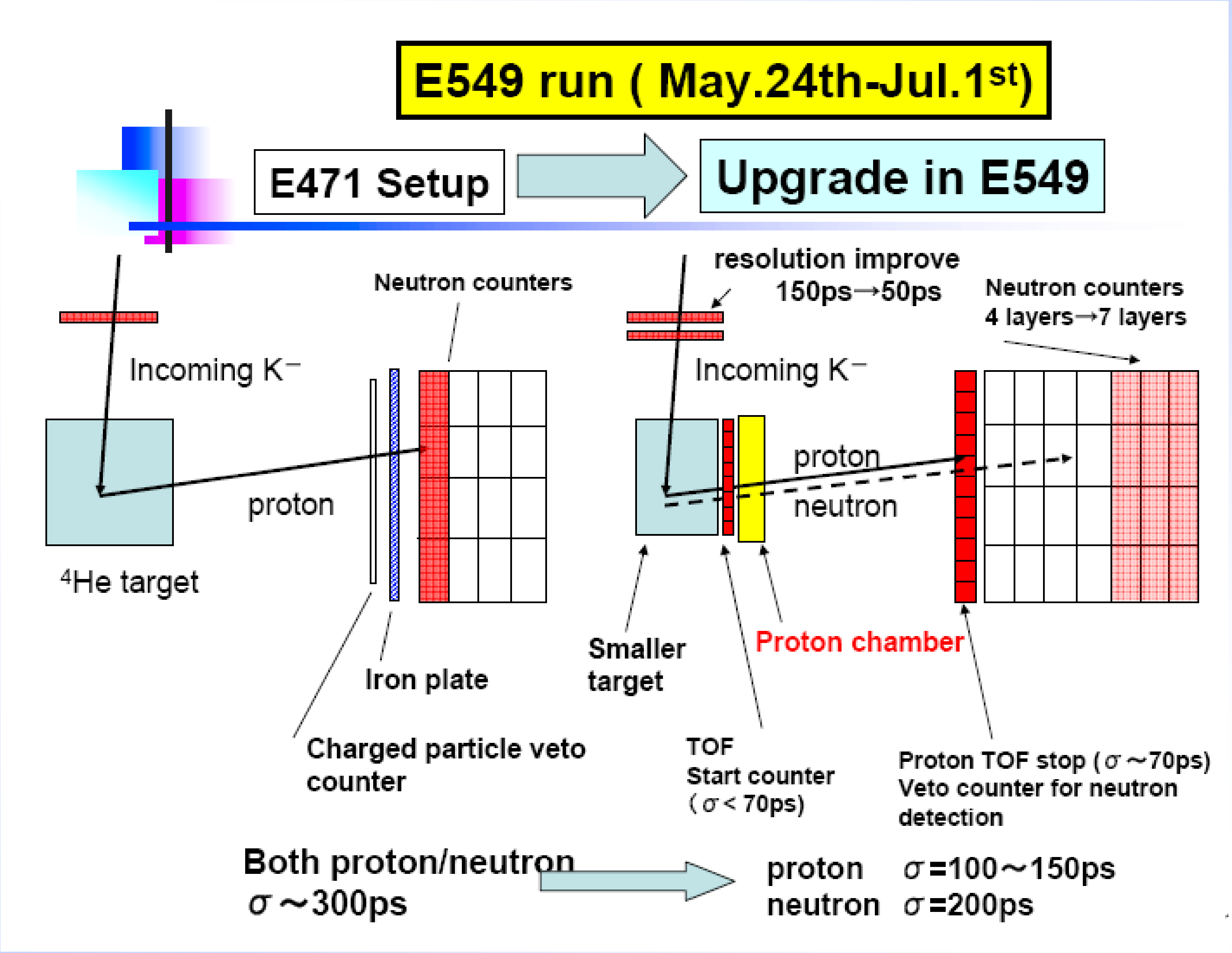
(M. Iwasaki *et al.*, nucl-ex/0310018 v2,
T. Suzuki *etal.*, *Phys. Lett. B 597* (2004), 263)

S^0(3115): M = 3117 $^{+3.8}_{-2.0}$(sys)+/-0.9 (stat)
Γ< 21.6 MeV,
B= -194 MeV with respect to K$^-$+p+n+n rest mass
Predicted NOT to exist! (B~20 MeV; Γ~100 MeV)

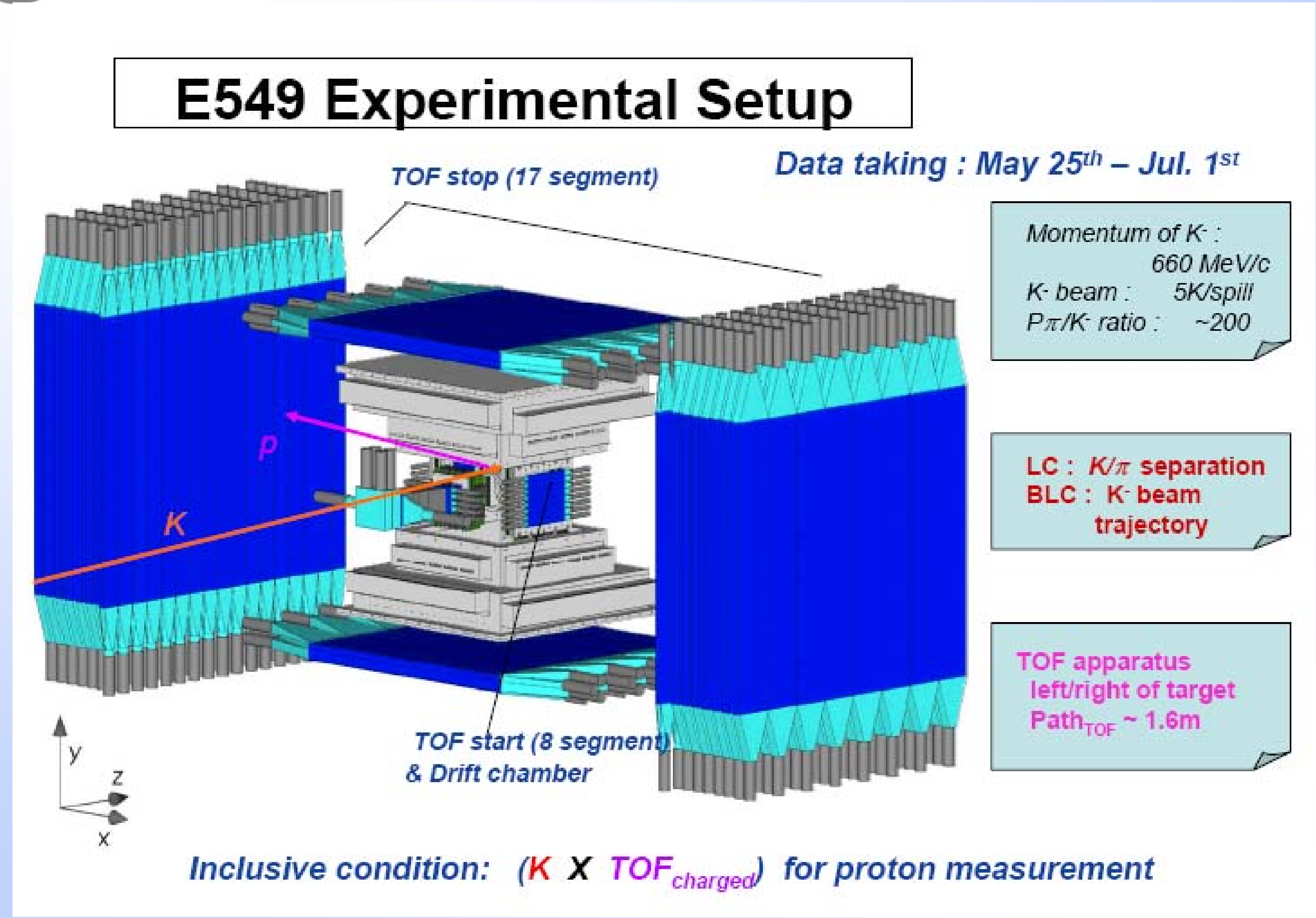
S$^+$(3140): M = 3117 $^{+3.8}_{-2.0}$(sys)+/-2.3 (stat)
Γ< 21.6 MeV,
B= -169 MeV with respect to K$^-$+p+p+n rest mass
Predicted with B ~ 110 MeV

Y. Akaishi & T. Yamazaki, Phys. Rev. C 65 (2002) 044005

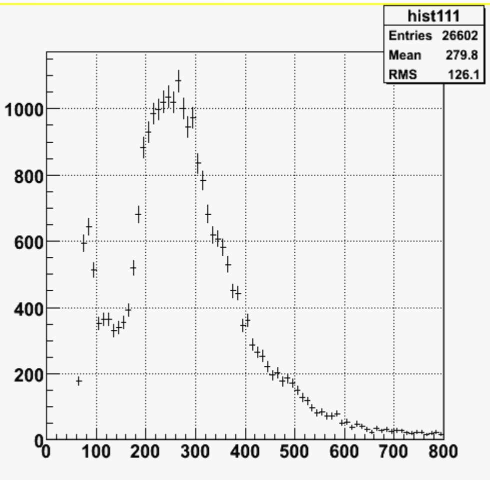
Schematic Experimental Setups



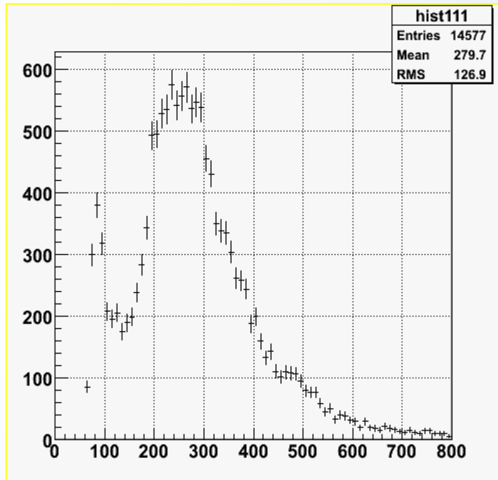
Detector Arrangement for $K^-(^4He,n/p)$ Reactions



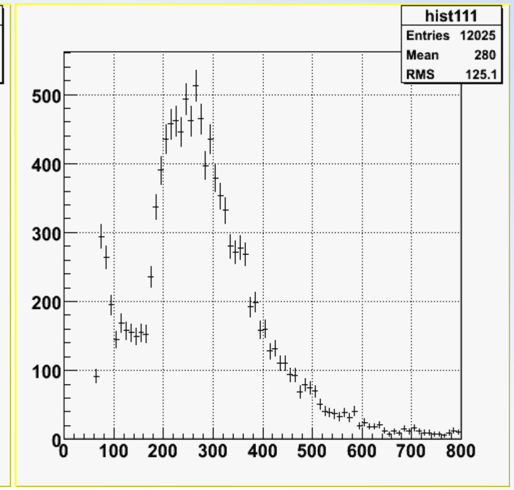
Fast Pion Triggered Neutron Momentum Spectra with Various Conditions **Preliminary**



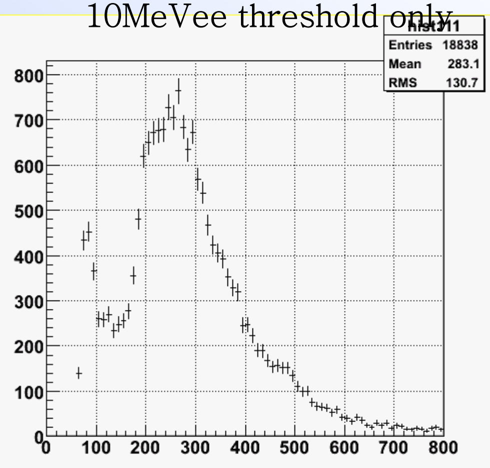
10MeVee threshold only



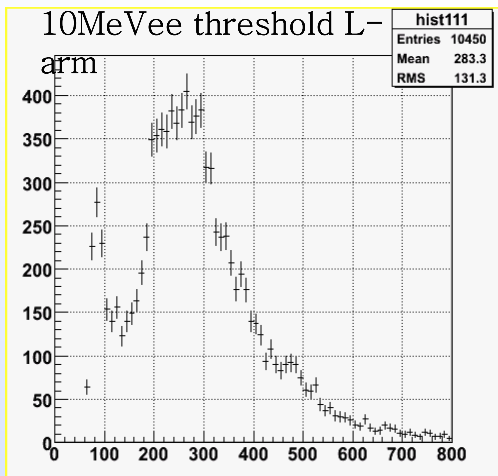
10MeVee threshold L-arm



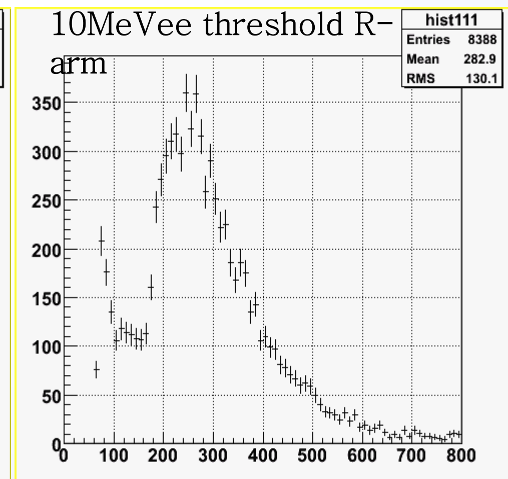
10MeVee threshold R-arm



10MeVee threshold with software veto

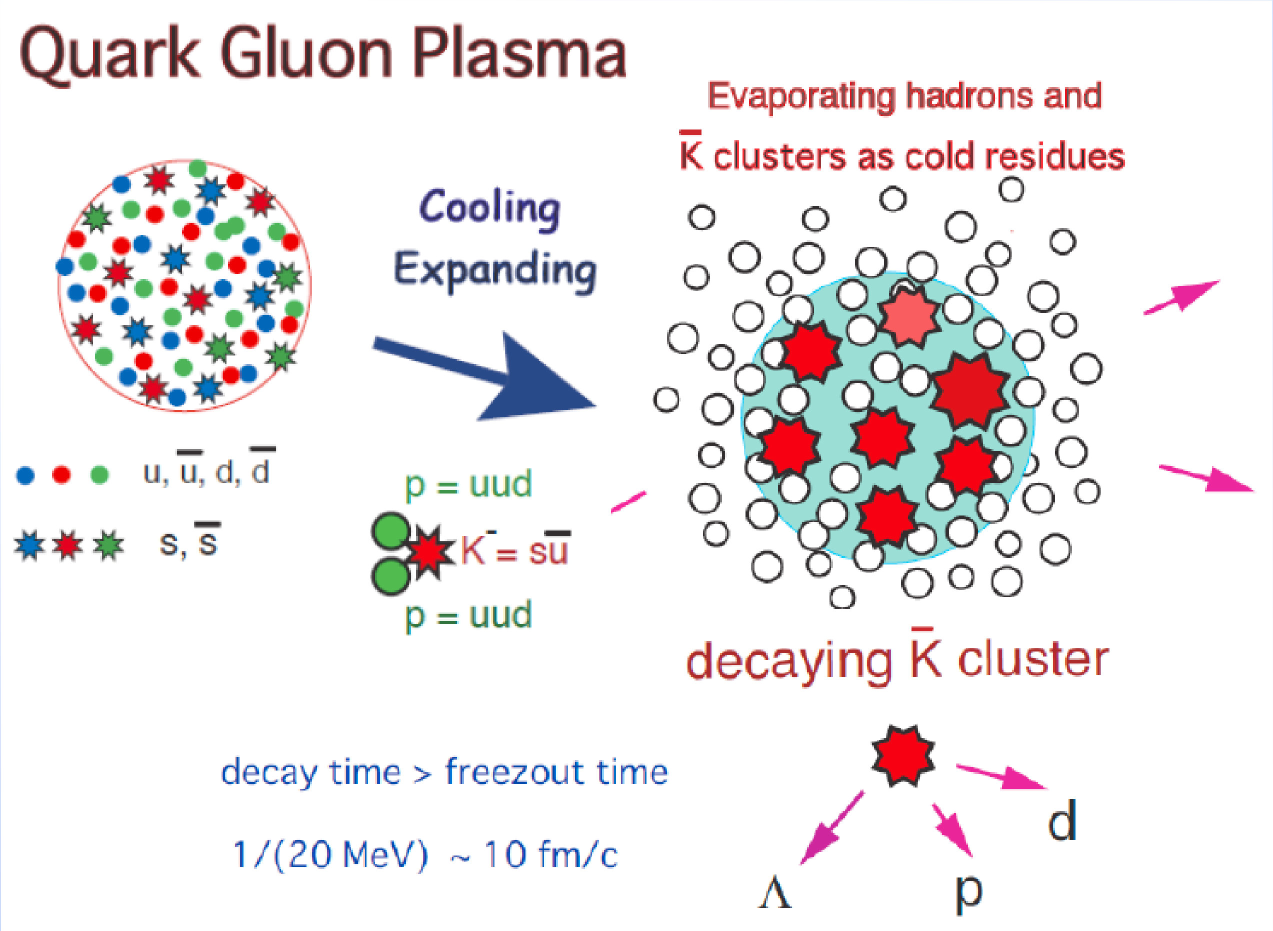


10MeVee threshold L-arm with software veto



10MeVee threshold R-arm with software veto

Production of Antikaon Nuclear Clusters in High Energy Heavy Ion Collisions



Search for K^- Clusters as Residues in Heavy Ion Reactions

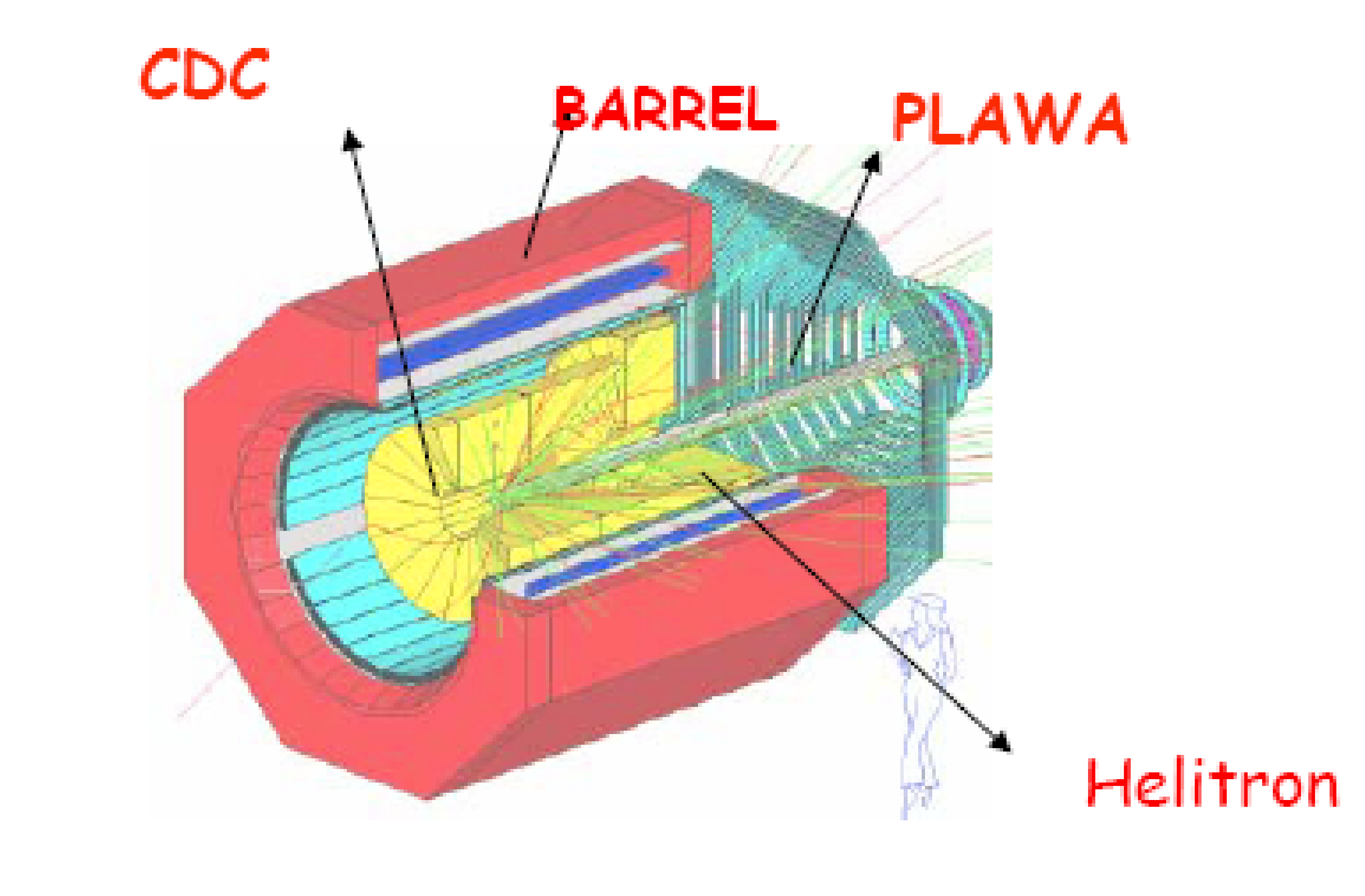
- **High density medium accommodated in fire balls**
- **Deep self-trapping centers in fire balls**
- **Freeze-out phase**
- **Invariant mass spectroscopy of fragments → freeze out.**

$ppK^- \rightarrow \Lambda + p$

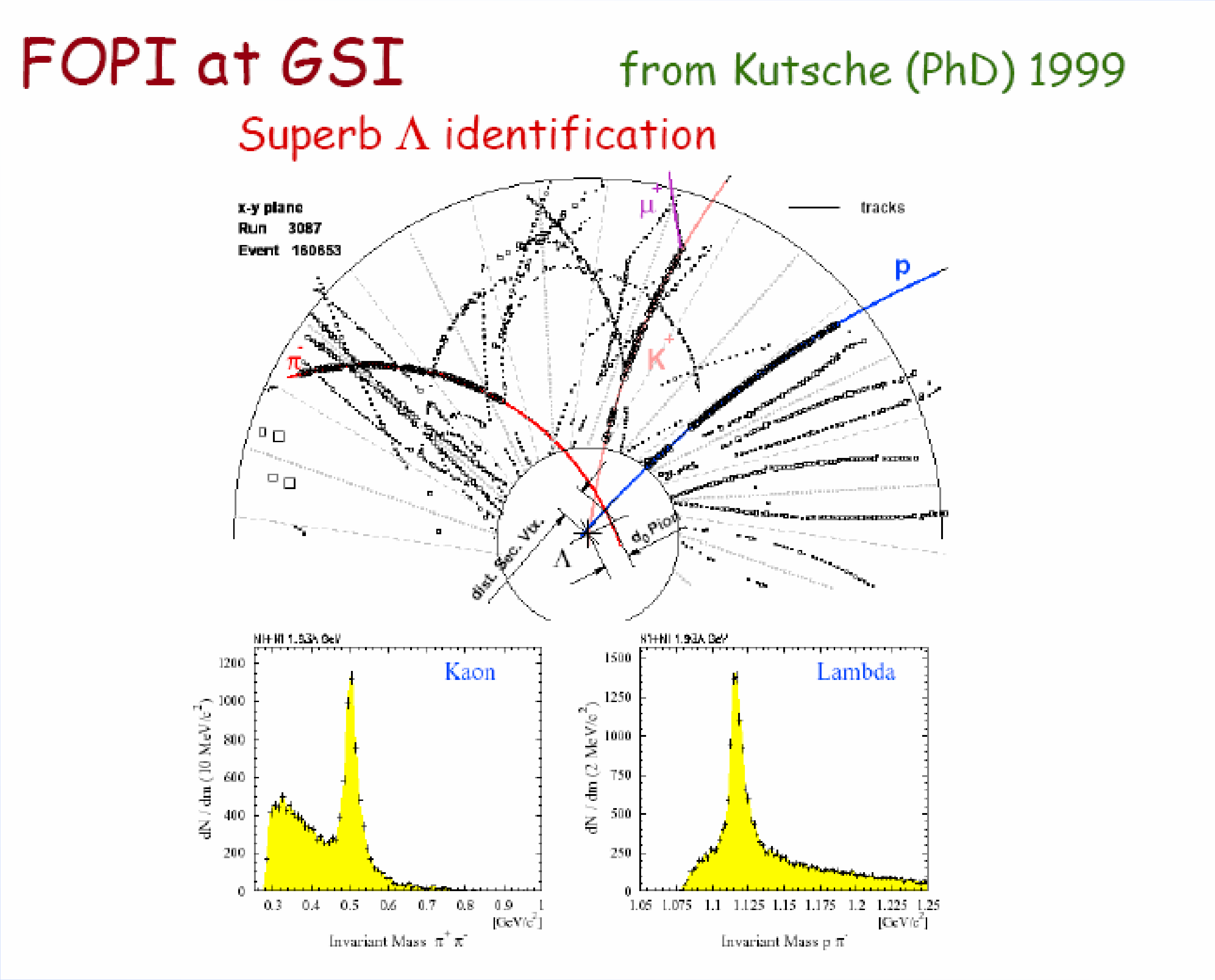
$ppnK^- \rightarrow \Lambda + d$

$pppK^- \rightarrow \Lambda + p + p$

FOPI @ GSI

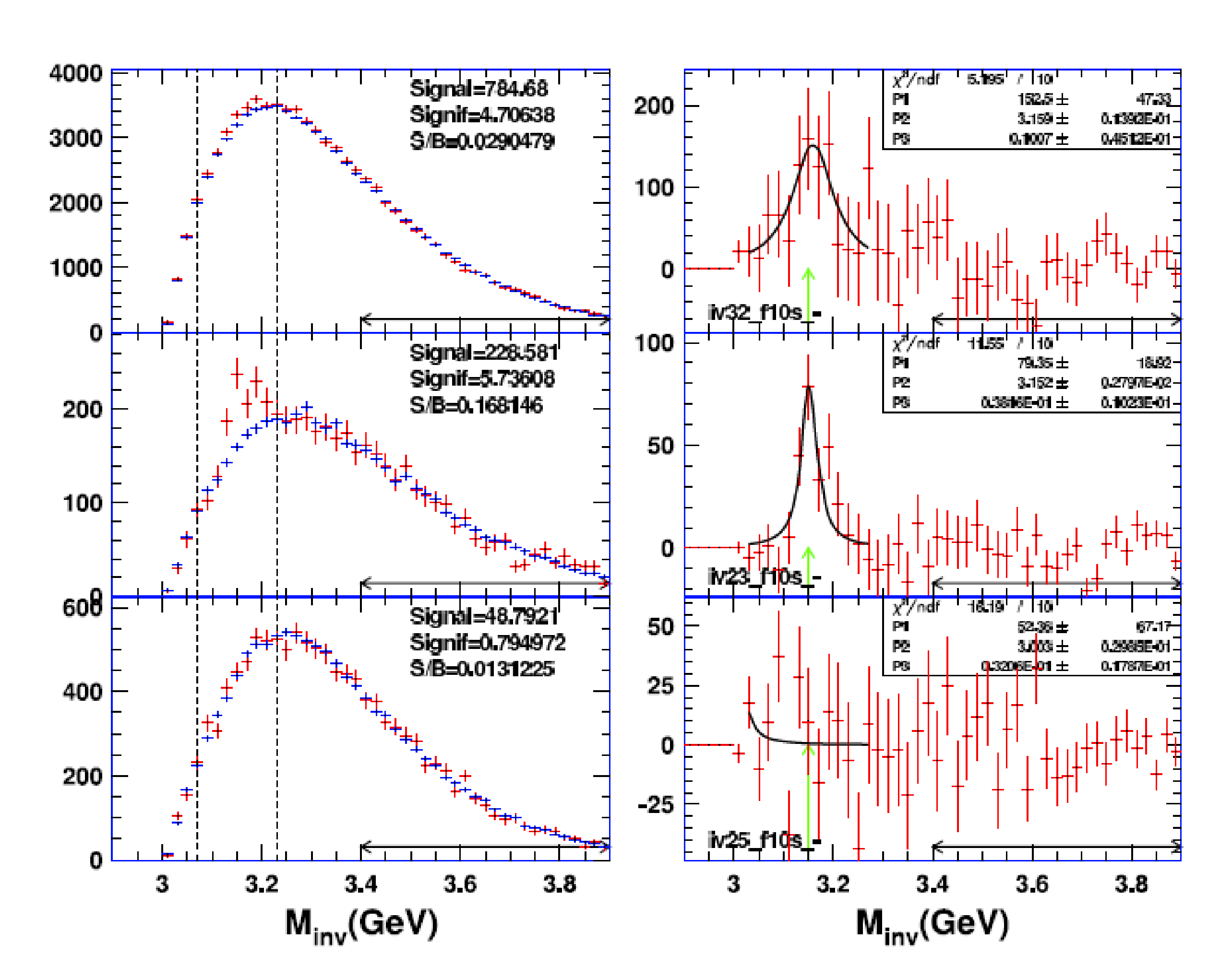


Use of 4π-Detector for Strangeness Identification in Heavy Ion Reactions



Ni-Ni Collisions @ 1.9A GeV (FOPI)
Λ-d Correlation

N. Herrmann, Proc. EXA 05, Vienna 2005



M > M(KEK)

Γ > Γ(KEK)

Origin:Collision effects?

3.5 GeV *pd* and *p*^{12}*C* Collision

The key elementary reactions are

$$p + "n" \rightarrow \Lambda^* + K^0 + p\,,$$

$$p + "p" \rightarrow \Lambda^* + K^+ + p\,,$$

In Deuterium

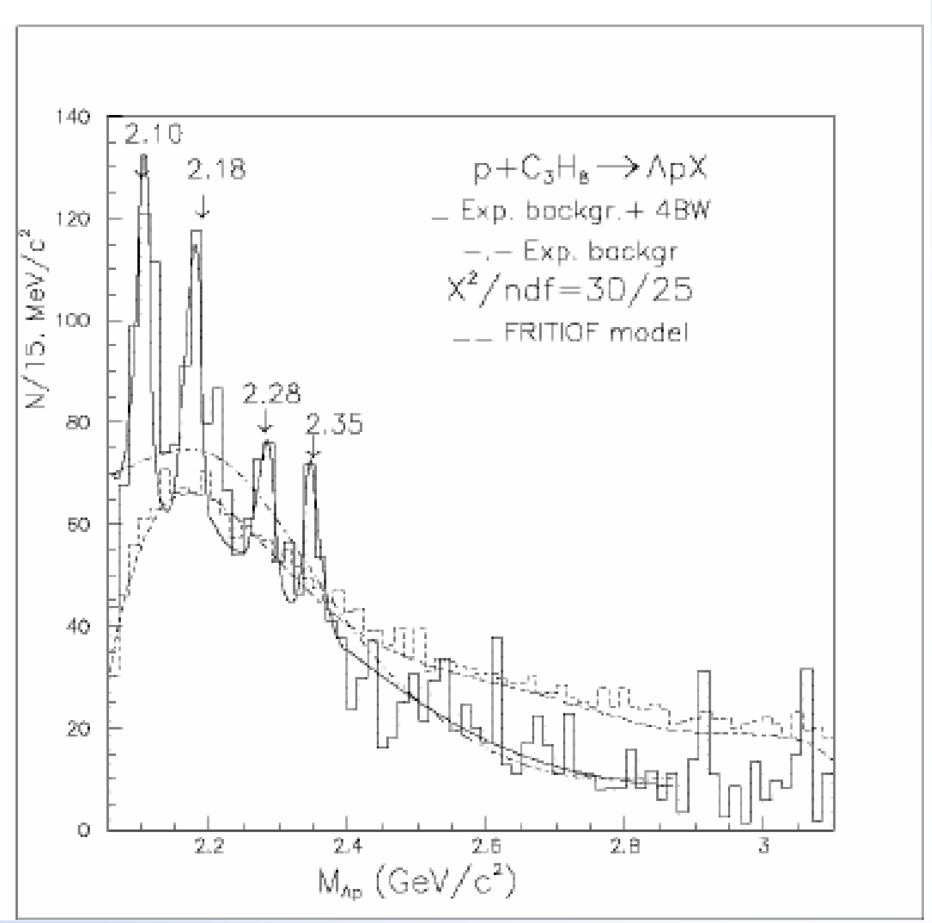
$$p + d \rightarrow [p + \Lambda^*] + K^0 + p_s \rightarrow ppK^- + K^0 + p_s$$

$$p + d \rightarrow [\,p + \Lambda^*\,] + K^+ + n_s \rightarrow ppK^- + K^+ + n_s$$

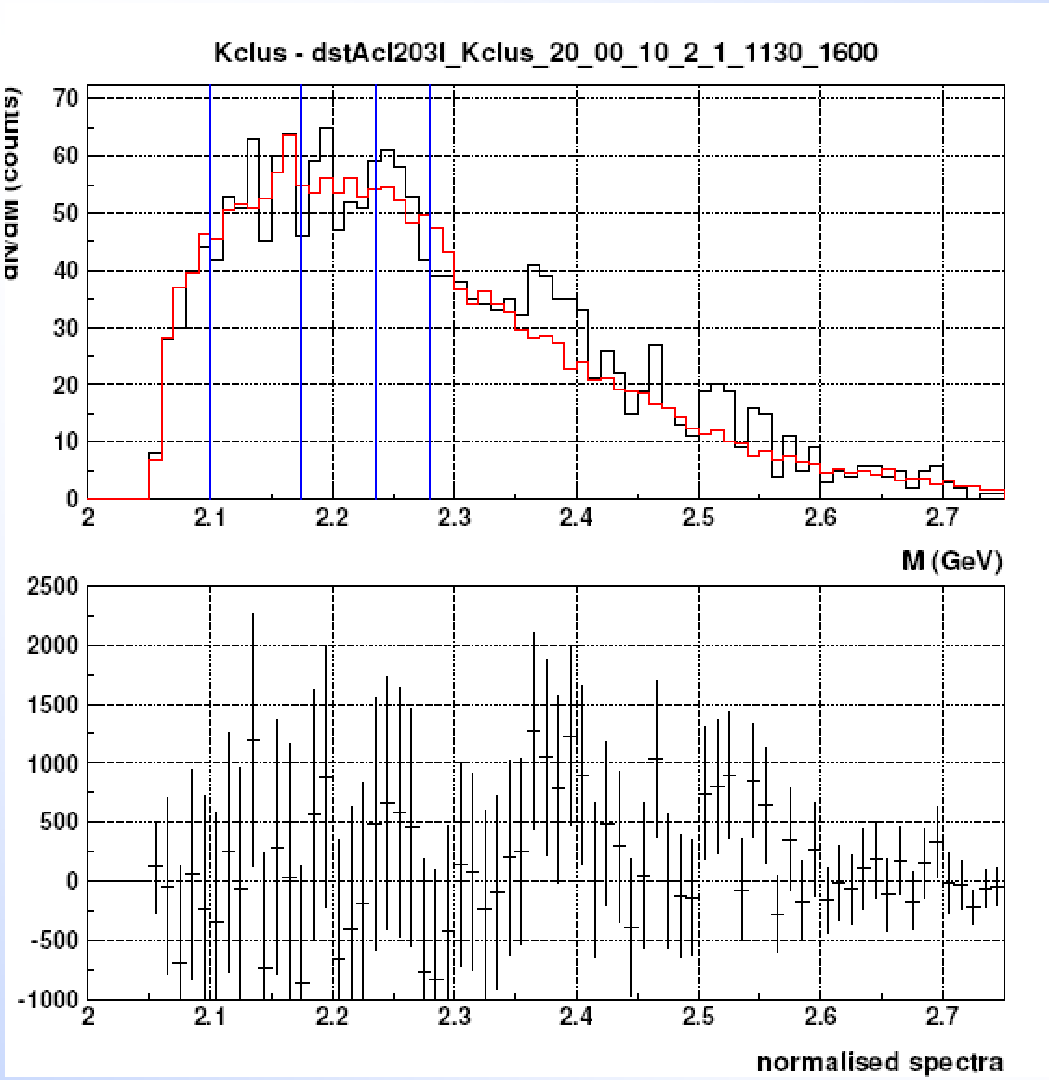
In Carbon similar processes may occur?

pΛ Invariant Mass Spectrum from 10 GeV/c $p^{12}C$ Collisions

P. Zh. Aslanyan, LEAP 05, AIP 0-7354-0248-1/05 p.197



3.5 GeV p-C Collisions @ FOPI
Λp-Invariant Mass Spectrum- Preliminary

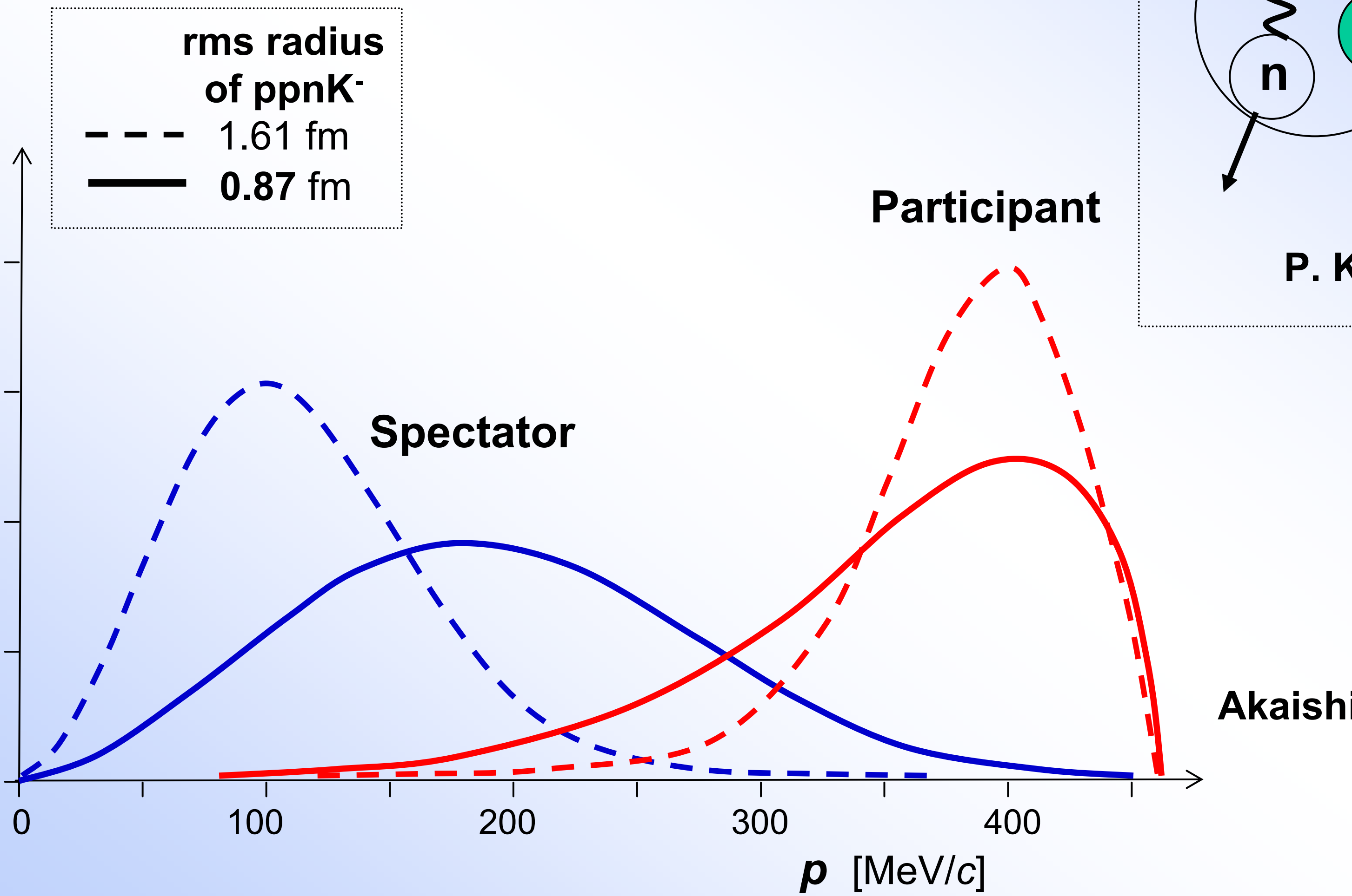


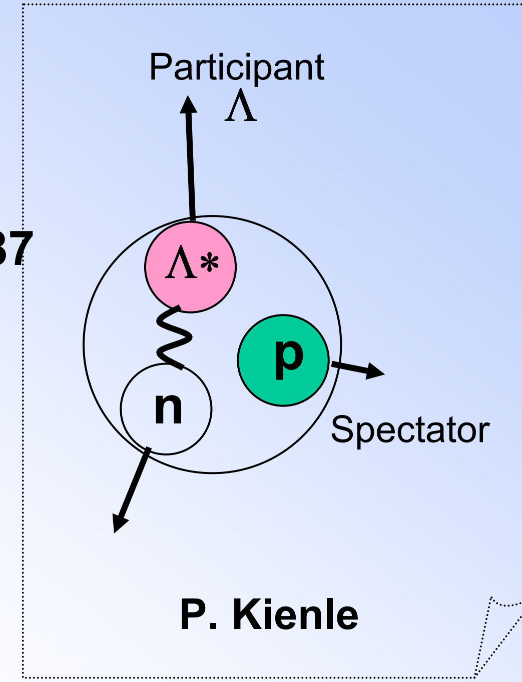
Methods to Determine the Size, Density and Angular Momentum of Kaonic Nuclear Clusters

- Measurement of the Coulomb energy displacement in the T=1 isospin triplet states.Splitting of ~4 MeV ~> <r²> of cluster.
- Spin-orbit splitting of p3/2-p1/2 in T=1 state is expected ~ 60 MeV and measures ∂V/∂r of cluster.
- Three body decays:[ppnK$^-$)$_{(T=0)}$ → Λ+p+n and [pppK$^-$]$_{(T=1)}$ → Λ+p+p a tool to measure momentum distribution of cluster and decay angular momentum.

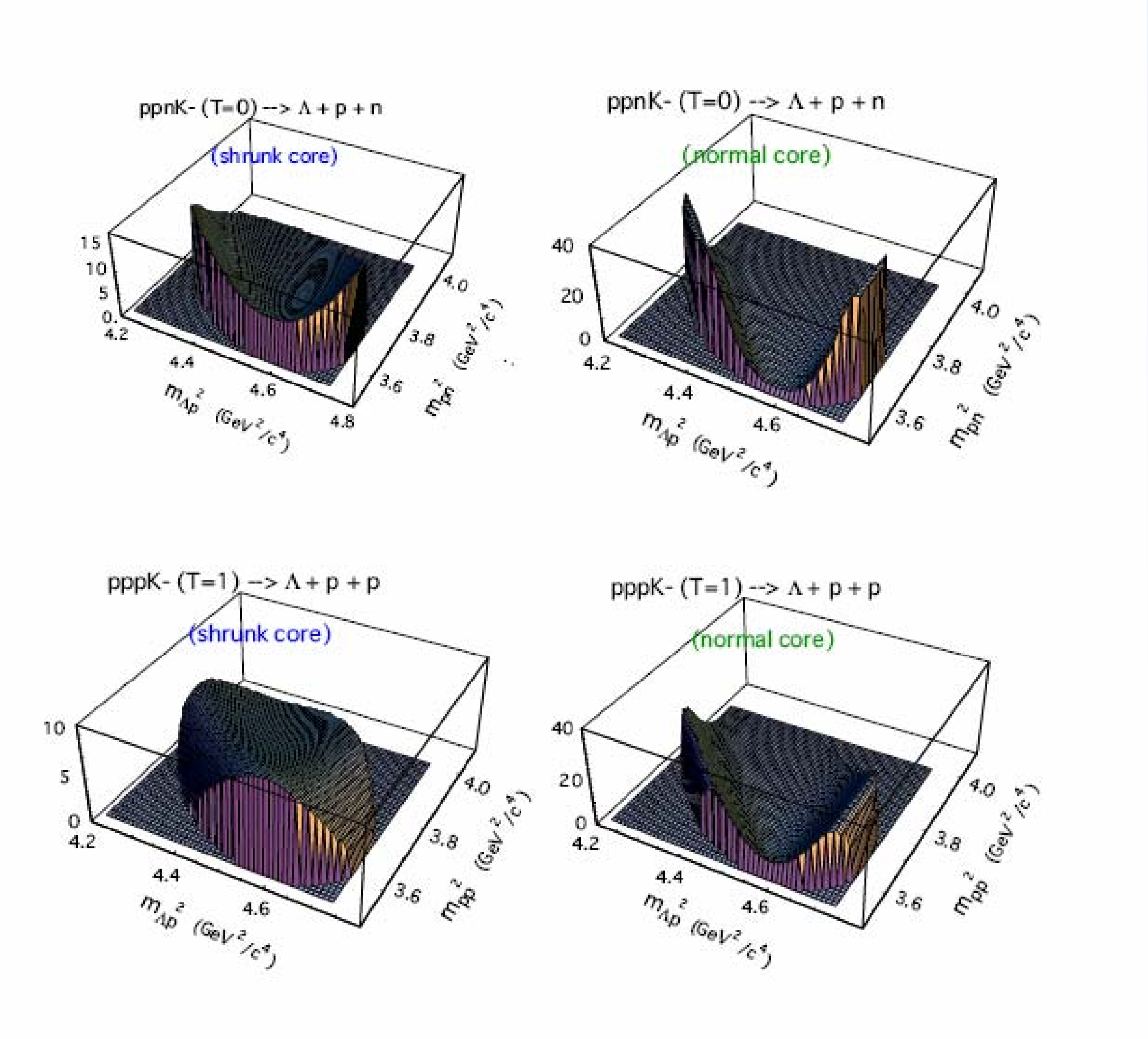
Momentum Correlation of the 3-Body Decay of ppnK$^-$

P.Kienle, Y.Akaishi, and T.Yamzaki PLB <u>632,</u> (2006) 187

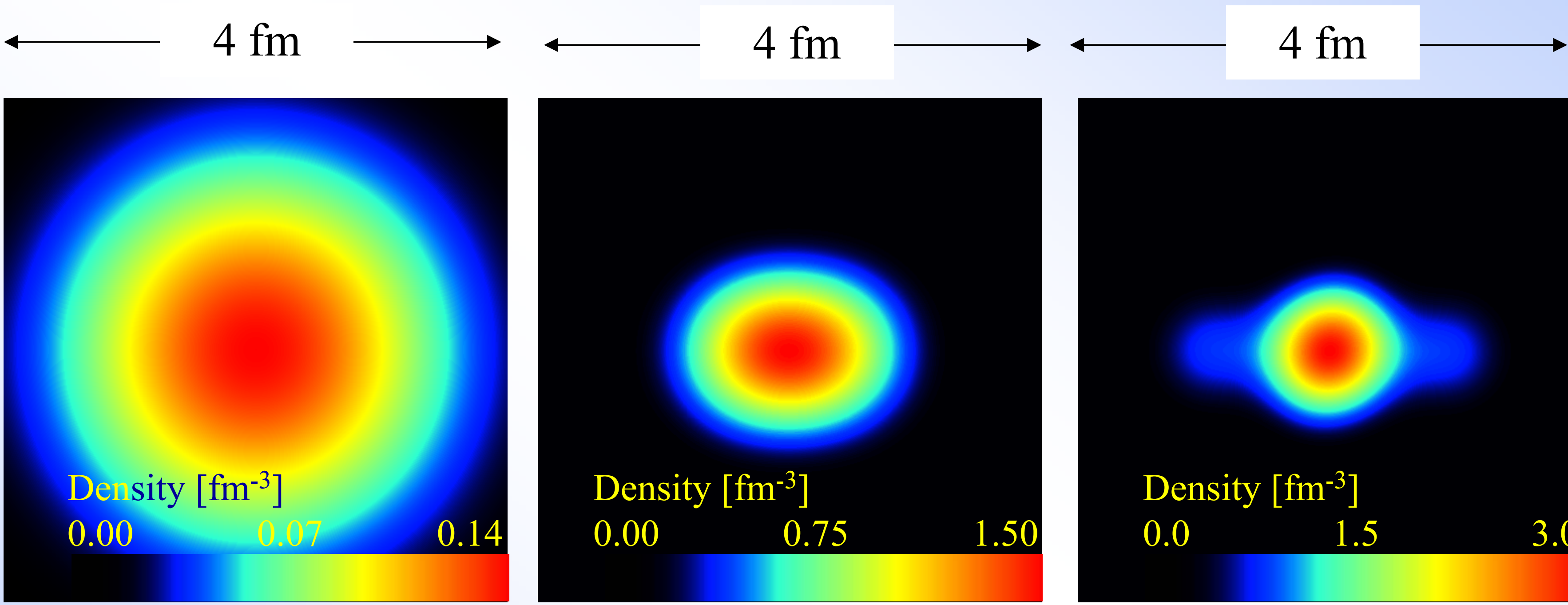




Density Distributions in the ppnK- and pppK- Decays with „shrunk“ and „normal“ Cores

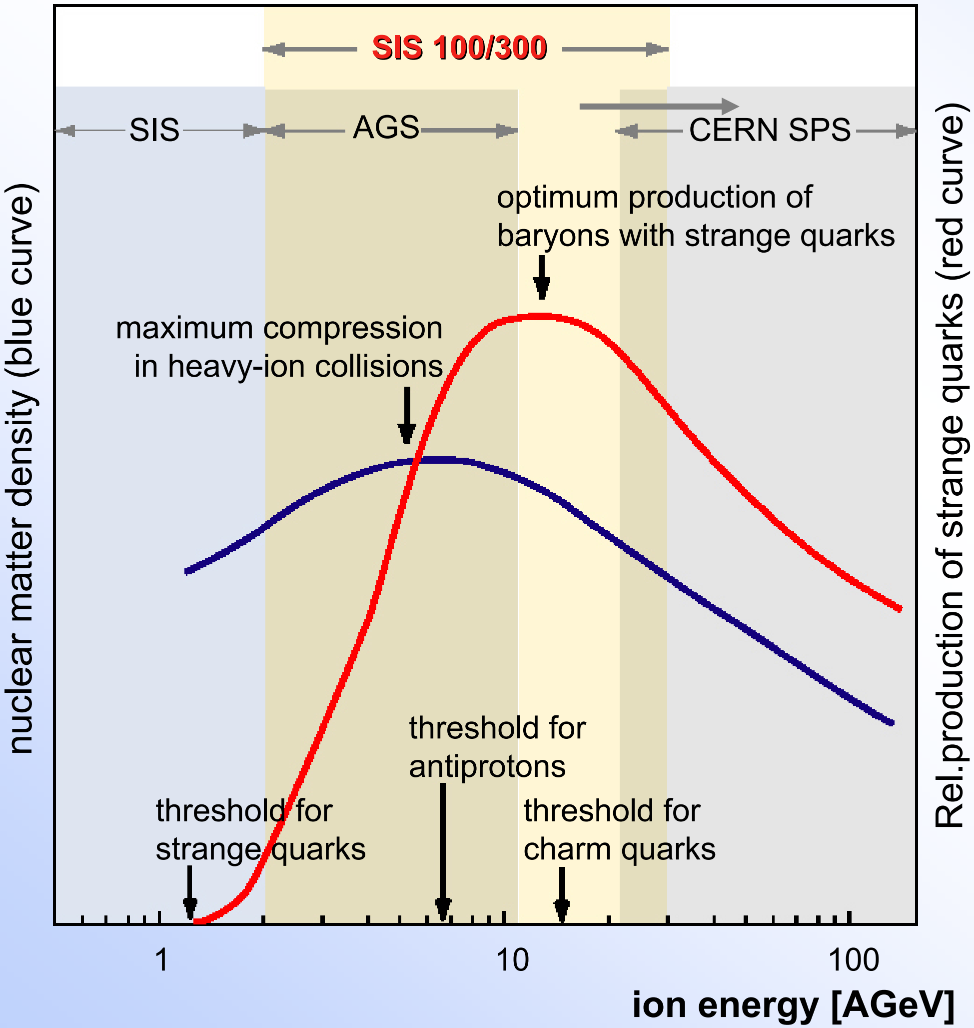


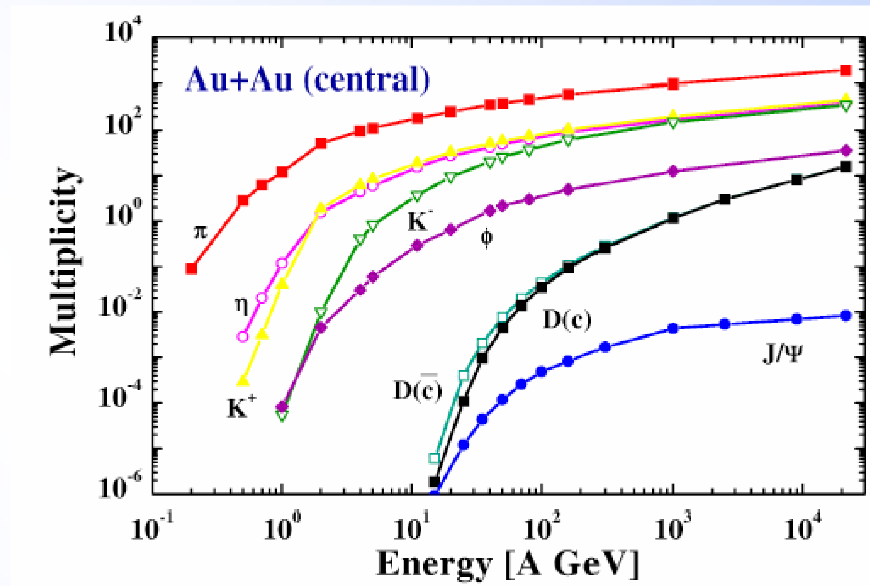
Double Kaonic Nucleus [$ppnK^-K^-$]



ppn	$ppnK^-$	$ppnK^-K^-$
total B.E. = 6.0 MeV	total B.E. = 118 MeV	total B.E. = 221 MeV
central density = 0.14 fm^{-3}	central density = 1.50 fm^{-3}	central density = 3.01 fm^{-3}
rmsR= 1.59 fm	rmsR= 0.72 fm	rmsR= 0.69 fm

GSI SIS100-300: Production of Double Kaonic Nuclear Clusters in Heavy Ion Collisions





Double Kaon Nuclear State Production

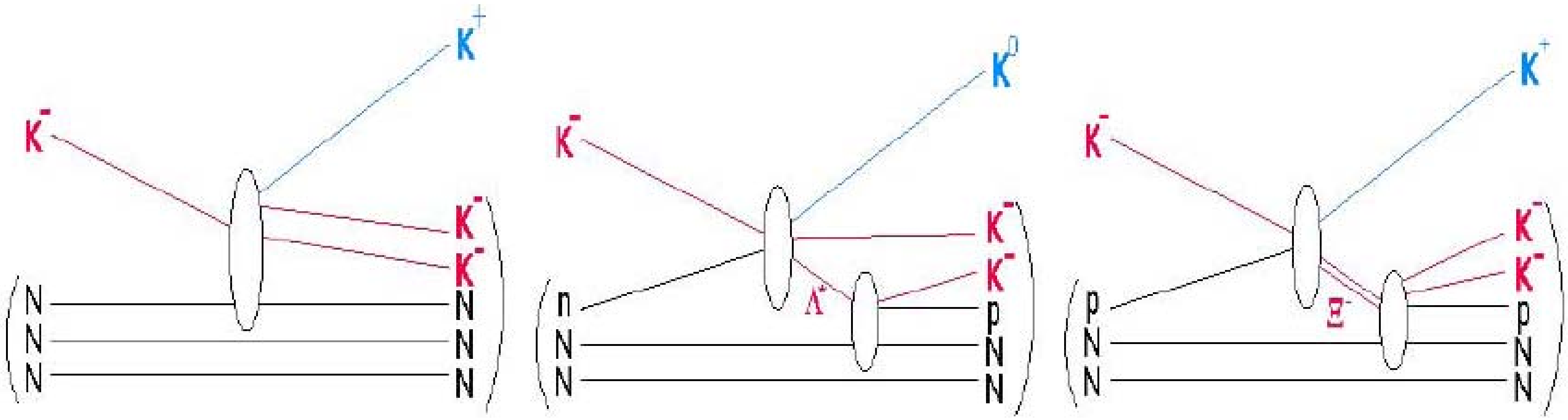


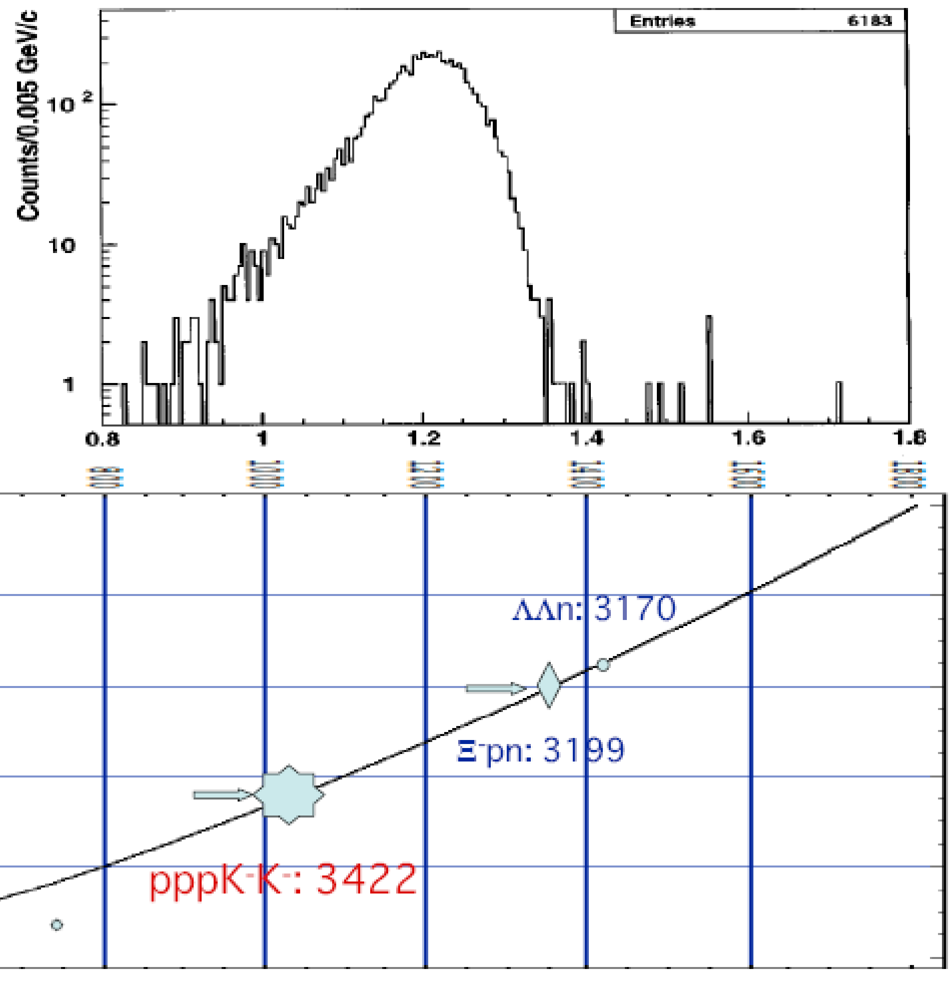
Fig. 13. Production processes of double-kaon nuclear states.

K^- momentum required:~2.1- 2.5 GeV/c, depending on B
J-PARC: K1.8 beamline?

Strangeness Exchange Reaction

$^3He(K^-,K^+)X$
@ 1.8 GeV/c
AGS E836

ΛΛn: 3170
Ξ^-pn: 3199
pppK$^-$K$^-$: 3422
Λ*Λ*n: 3752



Double Antikaon Production in Nuclei by Antiproton Annihilation

- The process: $\bar{p} + p \rightarrow K^+ + K^+ + K^- + K^- - 0.098 \text{ GeV}$
- The cross section: $\frac{\sigma(\bar{p}\,p \rightarrow K^+K^-\pi^+\pi^-)}{\sigma(\bar{p}\,p \rightarrow 2\pi^+2\pi^-)} \sim 0.1$

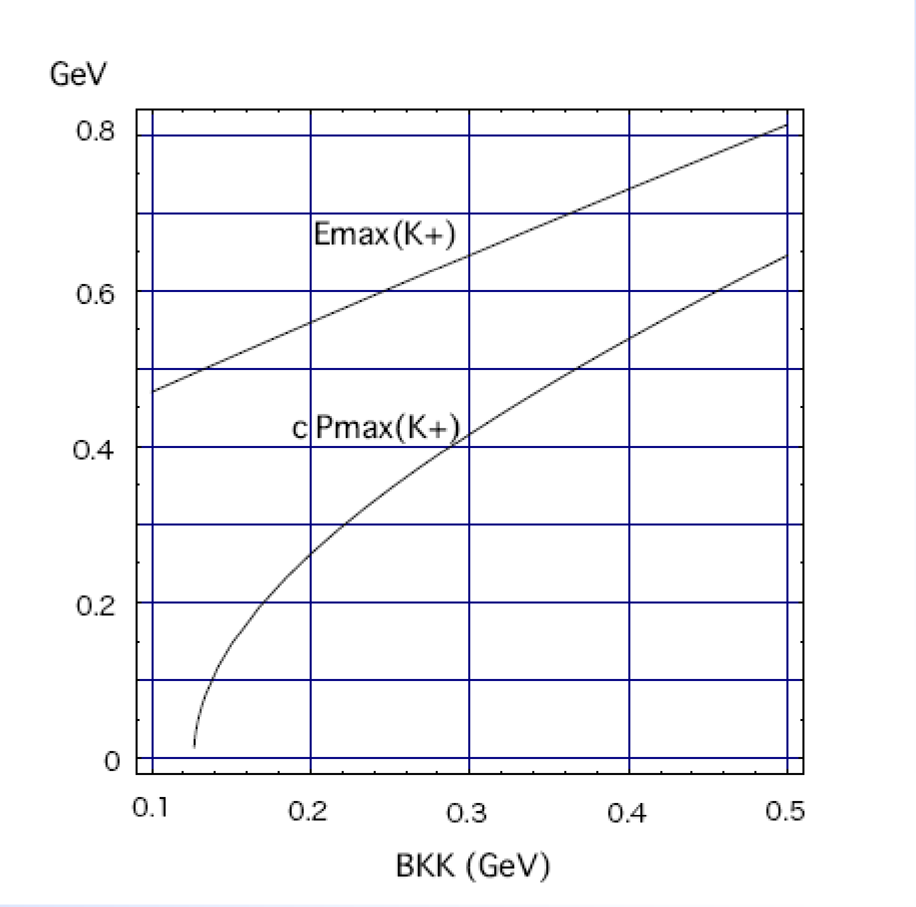
  $\sigma(\bar{p}\,p \rightarrow 2K^+\,2K^-) \sim 10\ \mu b$
- The kinematics $\sqrt{M^2 + \vec{p}_0^{\,2}} = 2m_K \qquad p_{0,lab} \simeq 652 \text{ MeV/c}$
- Double kaon production in nuclei:

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

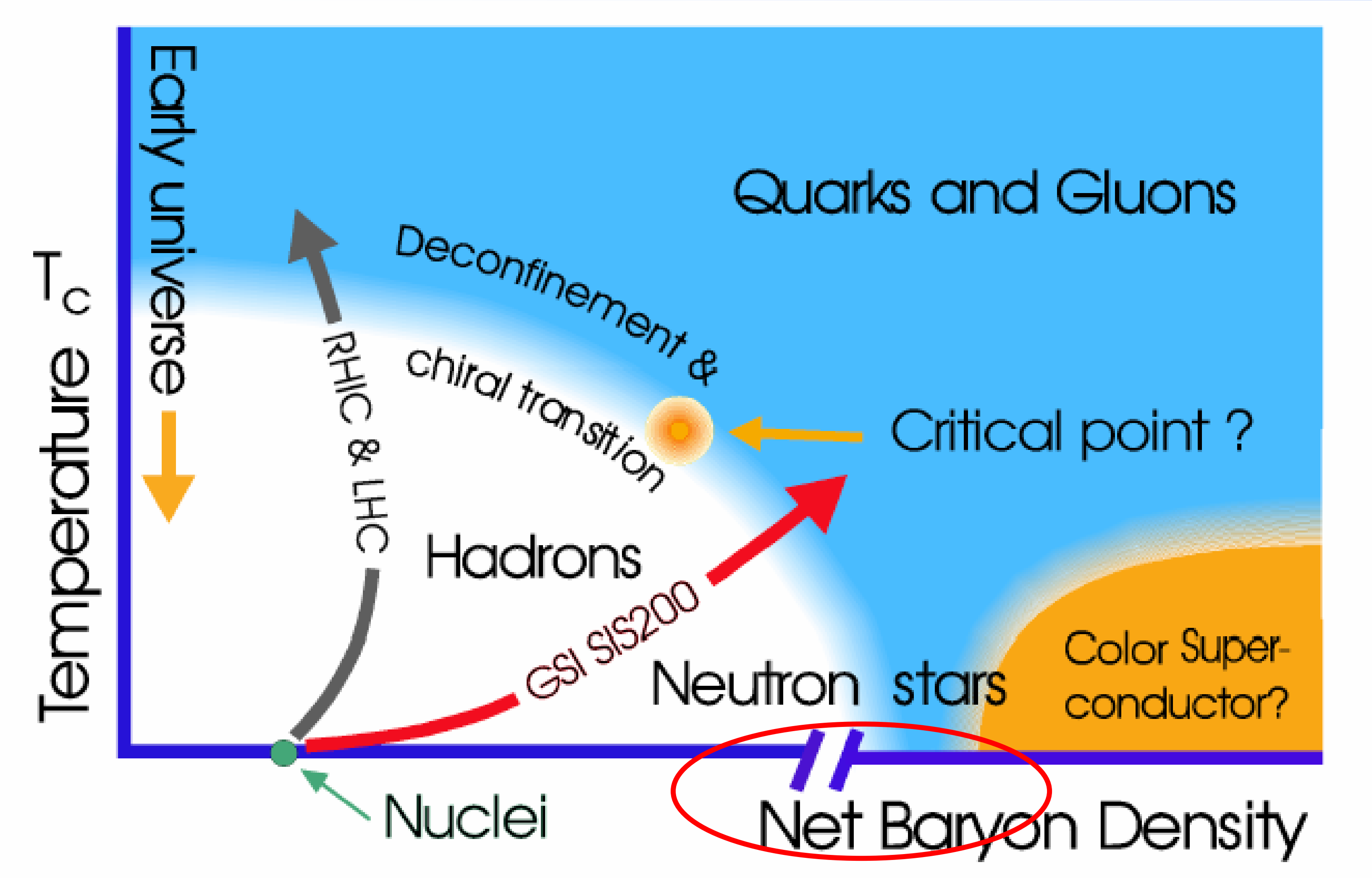
$$\bar{p}\ {}^6Li \rightarrow K^+K^+ + [K^-K^-pp3n]$$

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

Maximum Energy and Momentum of K^+ as Function of the Binding Energy B_{KK}



Exploring Dense Nuclei with K^- Bound States



Phase Transitions: Kaon Condensation – Color Superconductivity

Signature: Gap in the excitaion spectrum?