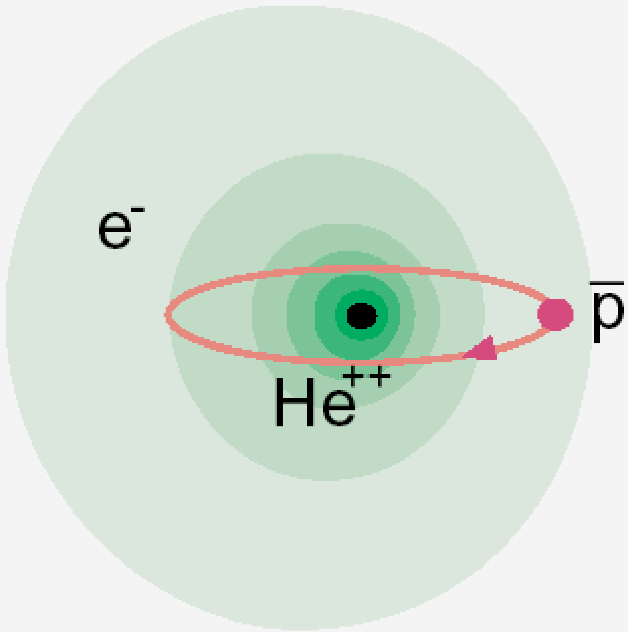
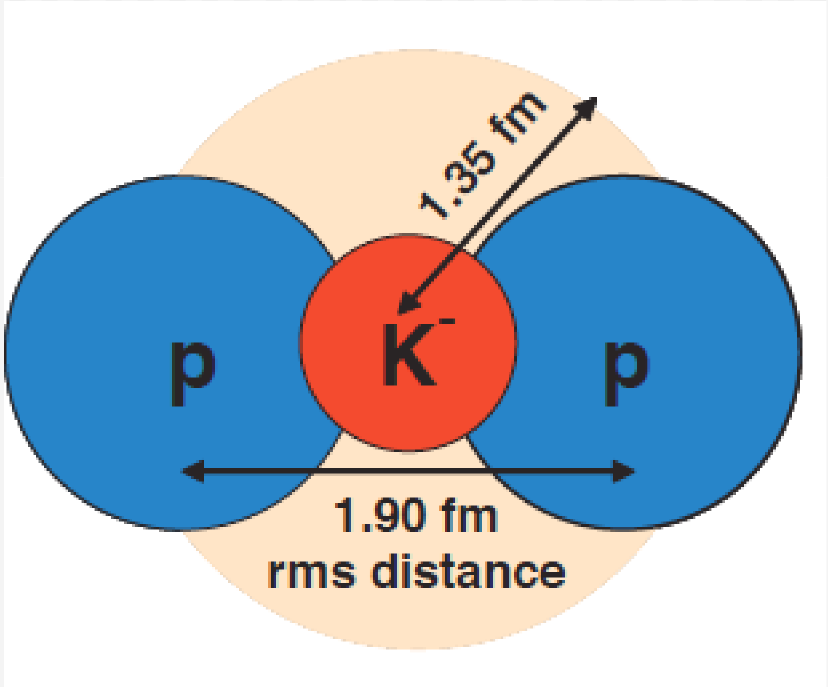
Friends of μCF



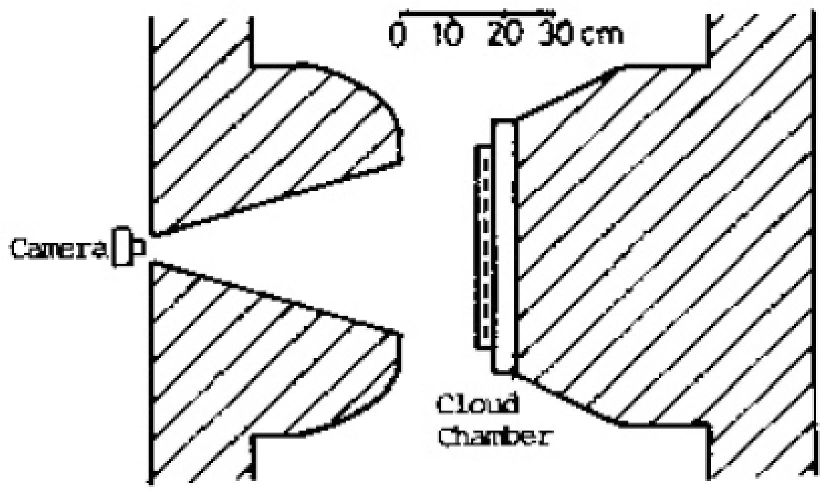


muCF2007 Lucky Seven !!

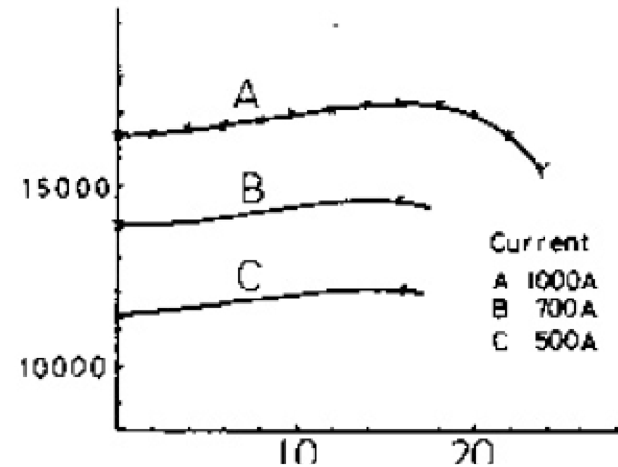
- Hydrogen molecule Heitler-London (1927)
- Nuclear force and nuclear structure Heisenberg (1932)
- Yukawa's meson prediction (1935)
- Discovery of the muon (1937)
- Prediction of muon catalyzed fusion (1947)
- Observation of muCF (1957); Parity-non-conservation
- Observation of the resonant ddmu formation (1967)
- Prediction of the high efficiency of muCF in D/T mixtures (1977)
- Discovery of long-lived antiprotonic helium (1991)
- High precision spectroscopy vs high precision theory
  Korobov muCF1995 --> talks follow
- Kaonic nuclear hydrogen molecule K^-pp predicted (2002)
- Super strong nuclear force (2007)

Discovery of MESOTRON (1937)

Cloud chamber with strong magnetic field



The cloud chamber apparatus in Nishina Laboratory,



- Cloud chamber in high magnetic field
- 1st track: p_X
- Thick Pb absorber
- 2nd track: p_X' --> Energy loss: ΔE
- ΔE vs p_X relation

QuickTimeý Ç²
TIFFÅiLZWÅj êLí£ÉvÉçÉOÉâÉÄ
Ç™Ç±ÇÃÉsÉNÉ`ÉÉÇ¾å©ÇÈÇžÇ½Ç…ÇÕïKóvÇ-ÇÅB

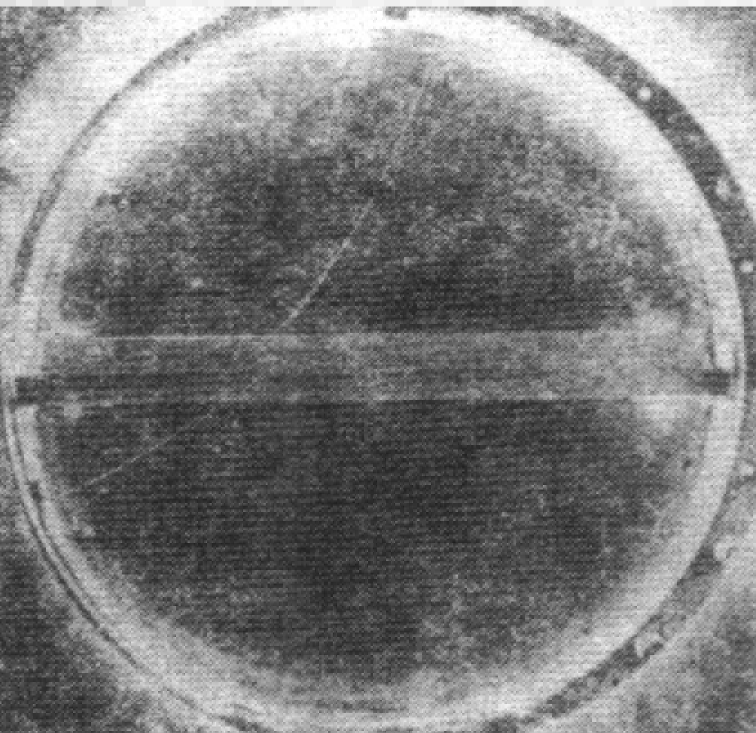
DECEMBER 1, 1937 PHYSICAL REVIEW VOLUME 52

On the Nature of Cosmic-Ray Particles

Y. NISHINA, M. TAKEUCHI, AND T. ICHIMIYA
Institute of Physical and Chemical Research, Tokyo

(Received August 28, 1937)

- Cloud ch
- 1st track
- Thick Pb



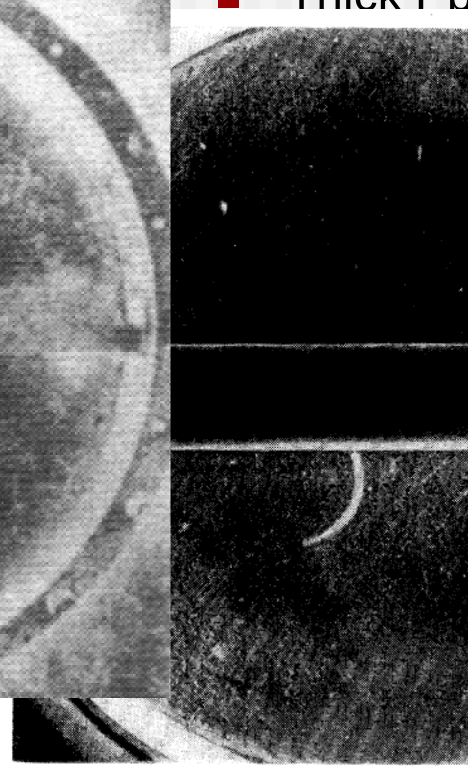
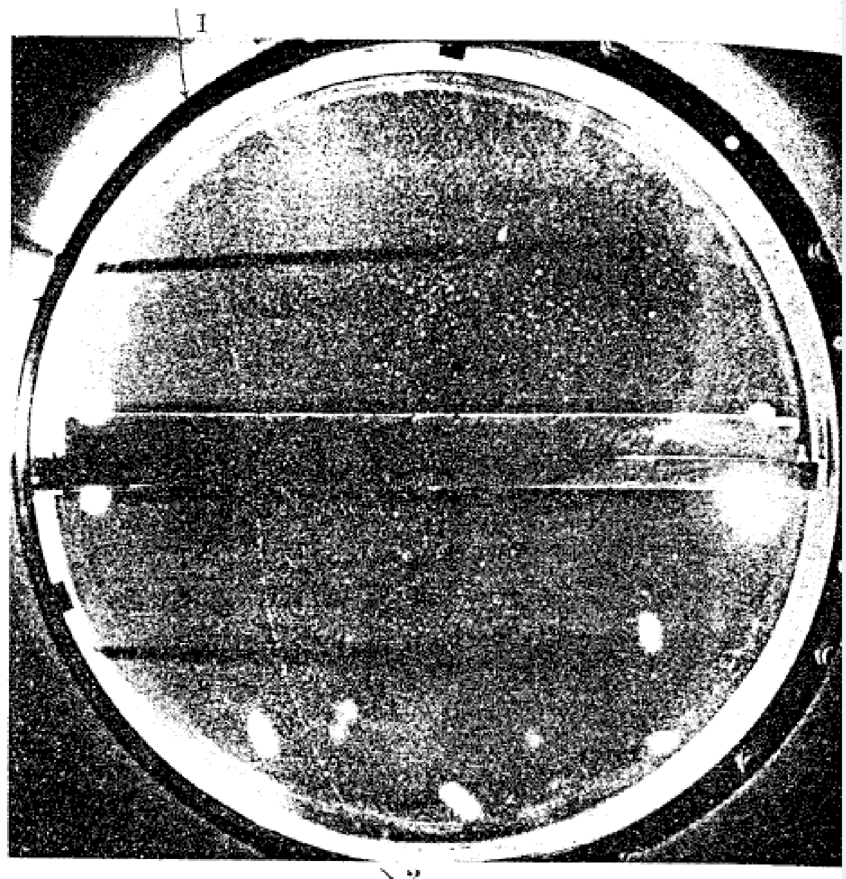


FIG. 1. Wilson track of a mesotron. $H=12$,
oersted·cm. Observed range



第 4 圖 新粒子の飛跡. $H=8000$ oersteds, $H\rho_1=7{\cdot}0\times10^5$, $H\rho_2=2{\cdot}43\times10^5$ これより新粒子の質量は陽子の約 1/10 と推定される

Competition in "mesotron" discovery (1937)

Yukawa meson (1935)

S.H. Neddermeyer and C. Anderson, PR 51 (1937) 884

Received March 30, 1937; Published May 15, 1937

Note on the Nature of Cosmic-Ray Particles

1cm Pt: electrons + protons, and some intermediate with anomalous energy loss

J.C. Street and E.C. Stevenson, PR 52 (1937) 1003

Received October 6, 1937; Published November 1, 1937

New Evidence for the existence of a particle of intermediate mass

32 MeV/c : m_X/m_e = 130 +- 25% error

M.M. Jean Crussard and L. Leprince-Ringuet, Compt. Rend. 204 (1937) 240

Y. Nishina, M. Takeuchi and T. Ichimiya, PR 52 (1937) 1198

Received August 28, 1937; Published December 1, 1937

On the Nature of Cosmic-Ray Particles

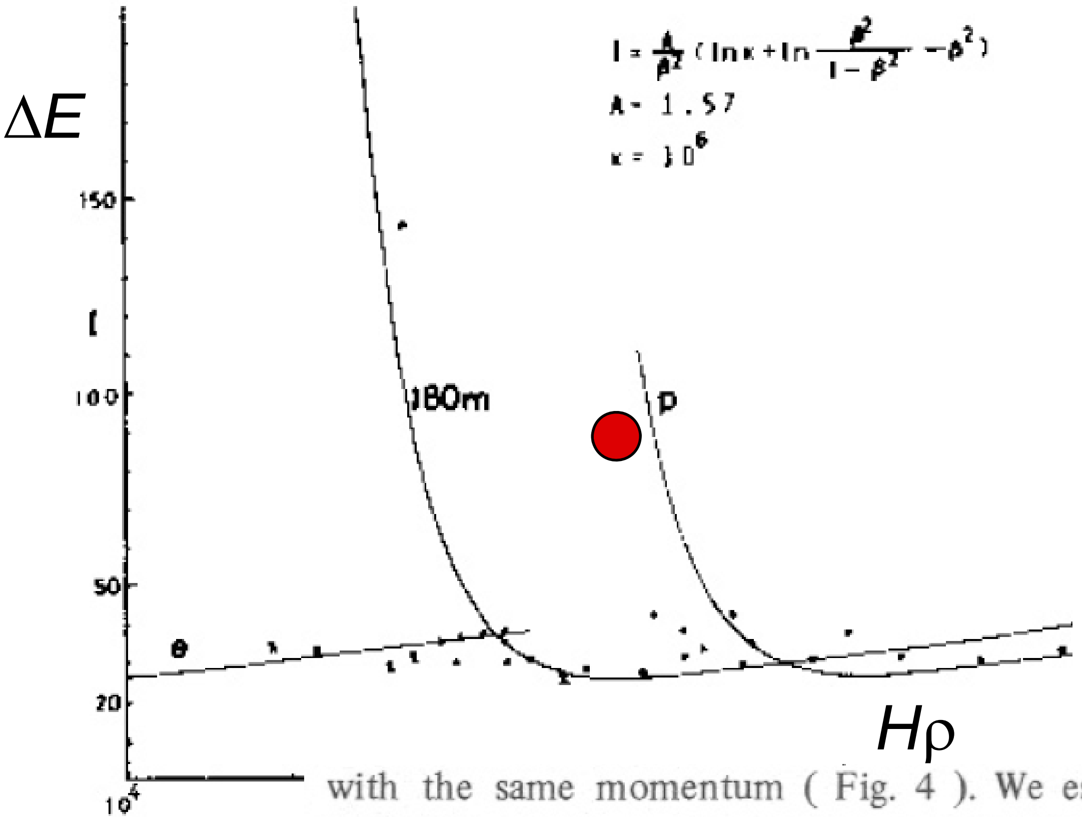
250 MeV/c : m_X/m_p = 1/7 ~ 1/10 m_X/m_e = 180 ~ 260 later = 180 +- 20

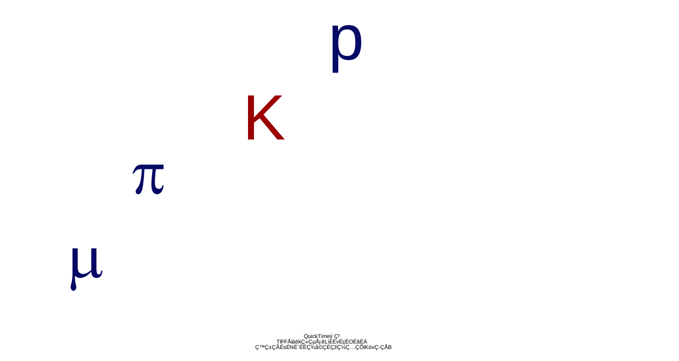
First conclusive identification of the mesotron

Not only mesotron but also ….!!!

ΔE-*p* particle identification in modern era

M. Takeuchi





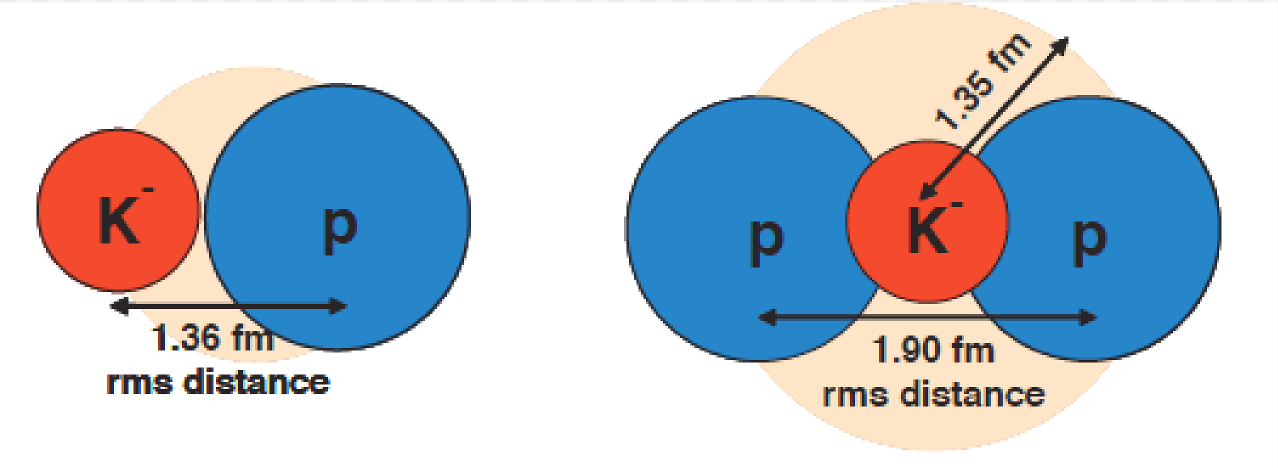
sult of observations

with the same momentum (Fig. 4). We estimated the mass of this particle to be a half of that of a proton, and reported this result at the meeting of I.P.C.R. However the existence of such a particle was not predicted at that time, and furthermore some people had doubts about the accuracy of our measurement of ionization density. As we observed only one such event, we did not publish it.

Super strong nuclear force caused by migrating $\bar{K}$ mesons
- Revival of the Heitler-London-Heisenberg scheme in kaonic nuclear clusters

By Toshimitsu YAMAZAKI, M.J.A.,[*1,*2] and Yoshinori AKAISHI[*2,*3]

The most fundamental kaonic nuclear cluster K^- pp



Toshimitsu Yamazaki and Yoshinori Akaishi
RIKEN

Kpp : basic building block
Test of Kbar nuclear physics

- Predicted 2002

  TY and Y. Akaishi, PLB 535 (2002) 70

  strange di-baryon, kbar cluster,

  kaonic nuclear hydrogen molecule

- Natural extension of

  K^-p as $\Lambda(1405)$

  K^-pp, K^-ppn, ,

based on the Akaishi-Y KN Interactions

PRC 65 (2002) 044005

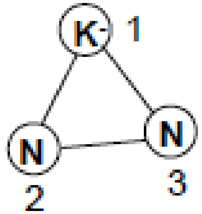
Akaishi's ATMS variational method: with elementary KN and NN interactions

Variational wave function of K-pp

ATMS

$$\Psi = \left[\left\{f^{I=0}(r_{12})\hat{P}_{12}^{I=0} + f^{I=1}(r_{12})\hat{P}_{12}^{I=1}\right\} f_{NN}(r_{23}) f(r_{31}) + f(r_{12}) f_{NN}(r_{23}) \left\{f^{I=0}(r_{31})\hat{P}_{31}^{I=0} + f^{I=1}(r_{31})\hat{P}_{31}^{I=1}\right\}\right] \left| T = 1/2 \right\rangle$$

$$\hat{P}_{12}^{I=0} = \frac{1 - \vec{\tau}_K \vec{\tau}_N}{4}, \quad \hat{P}_{12}^{I=1} = \frac{3 + \vec{\tau}_K \vec{\tau}_N}{4}$$



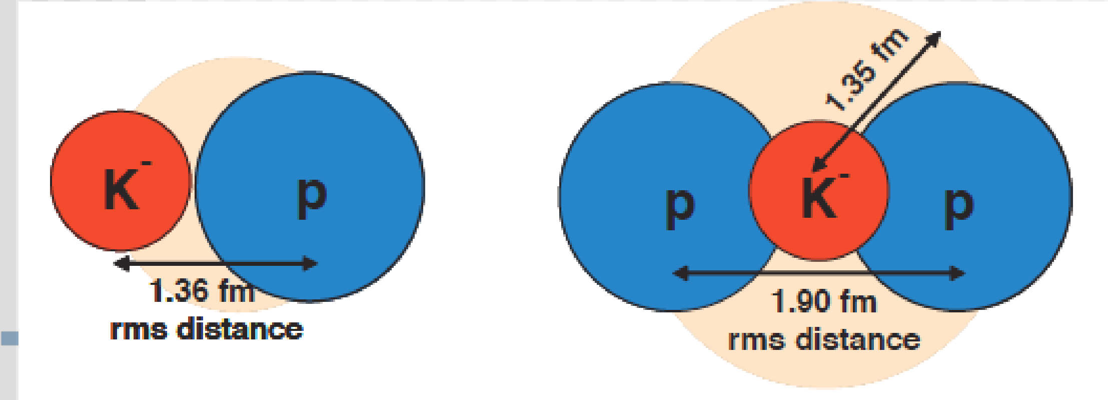
$$\left| T = 1/2 \right\rangle = -\frac{1}{2}\sqrt{\frac{1}{3}} \left(\bar{K}_1 N_2\right)^{1,0} p_3 + \sqrt{\frac{1}{6}} \left(\bar{K}_1 N_2\right)^{1,1} n_3 + \boxed{\frac{3}{2}\sqrt{\frac{1}{3}} \left(\bar{K}_1 N_2\right)^{0,0} p_3}$$

$\Lambda^* p$

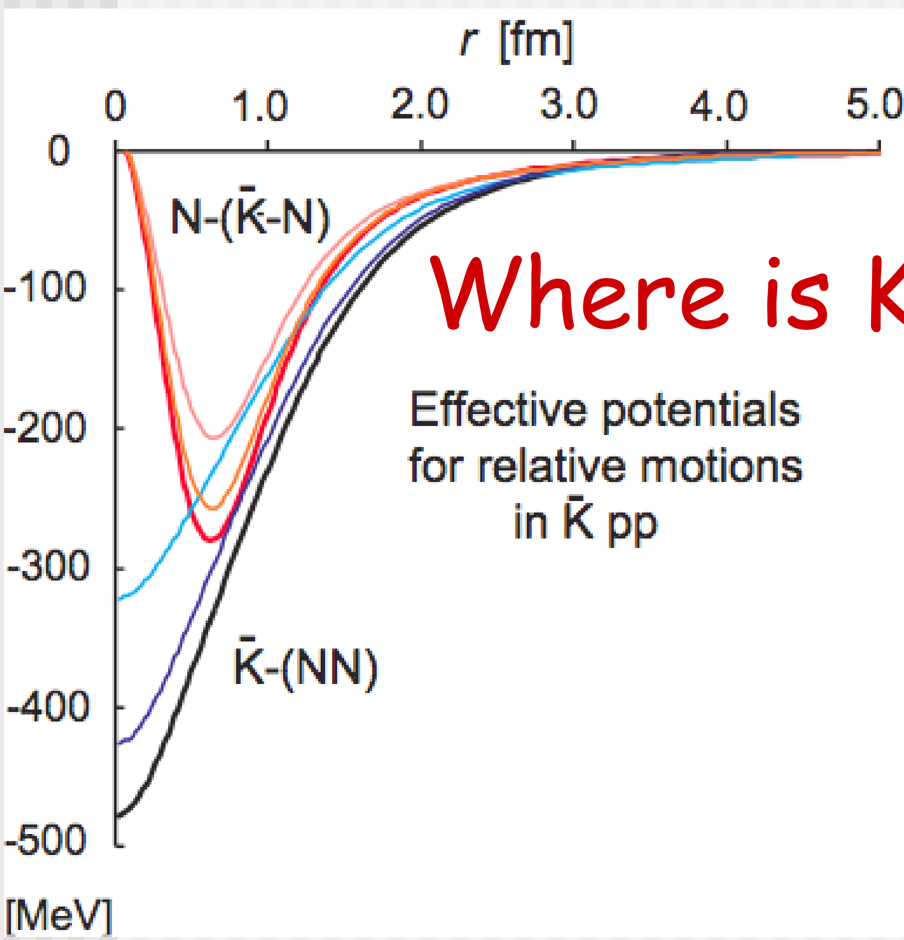
$$v_{\bar{K}N}^{T=0}(r) = \{-595 - i83\}_{\text{MeV}} \exp\{-(r/0.66_{\text{fm}})^2\}$$
$$v_{\bar{K}N}^{T=1}(r) = \{-175 - i105\}_{\text{MeV}} \exp\{-(r/0.66_{\text{fm}})^2\}$$

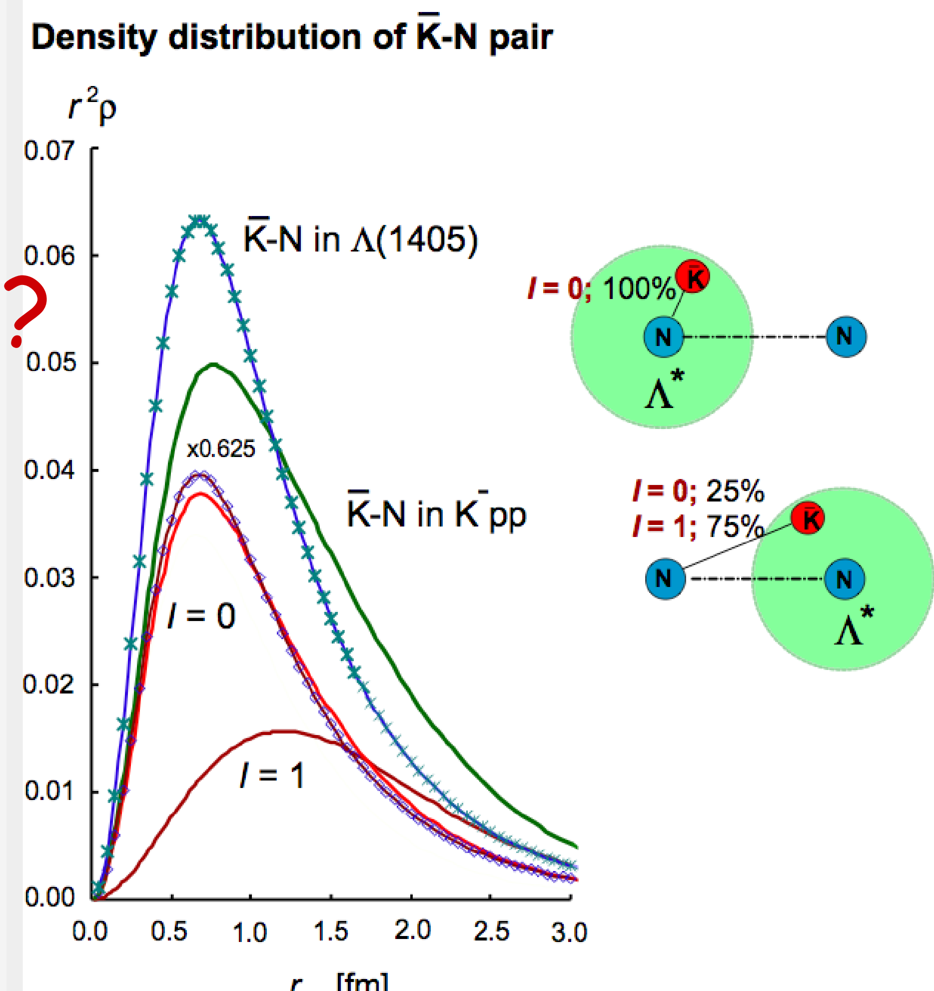
$$v_{NN}(r) = 2000_{\text{MeV}} \exp\{-(r/0.447_{\text{fm}})^2\} - 270_{\text{MeV}} \exp\{-(r/0.942_{\text{fm}})^2\} - 5_{\text{MeV}} \exp\{-(r/2.5_{\text{fm}})^2\}$$

K^-p (Λ*) "atom" persists in K^-pp ! --> molecule



Where is K-?

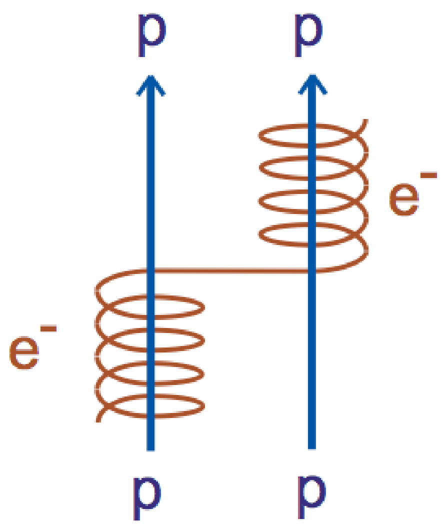




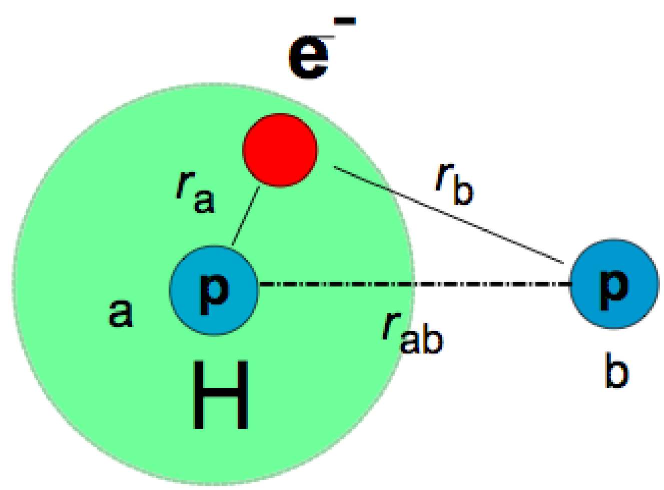
Heitler-London-Heisenberg
real migrating particle

Molecular

Heitler-London (1927)
Heisenberg (1932)



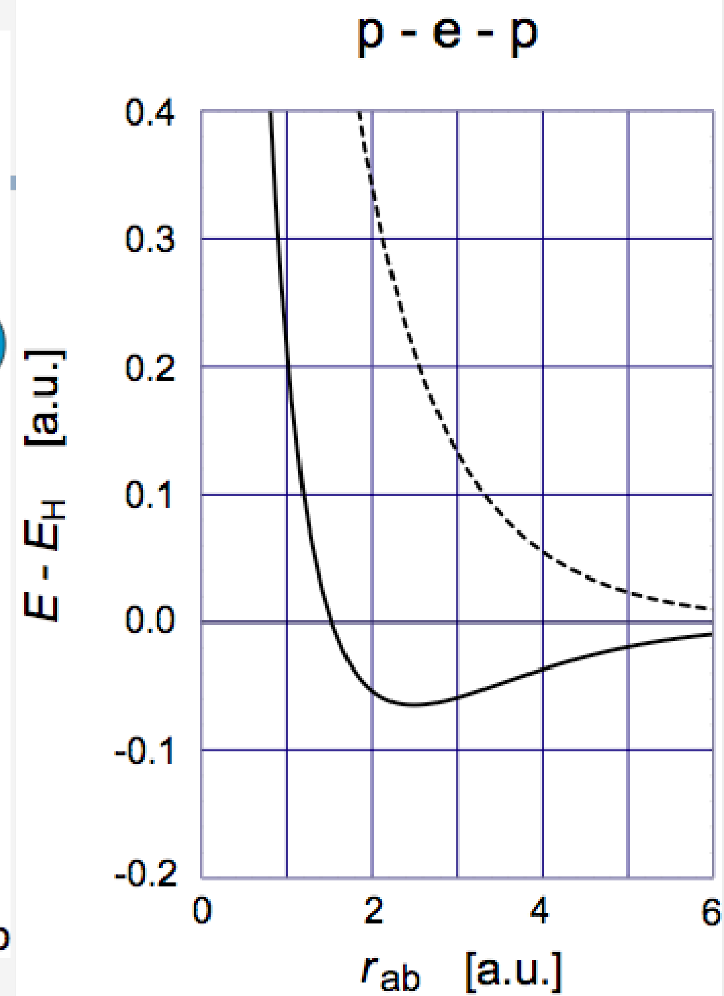
migrating
real
fermion



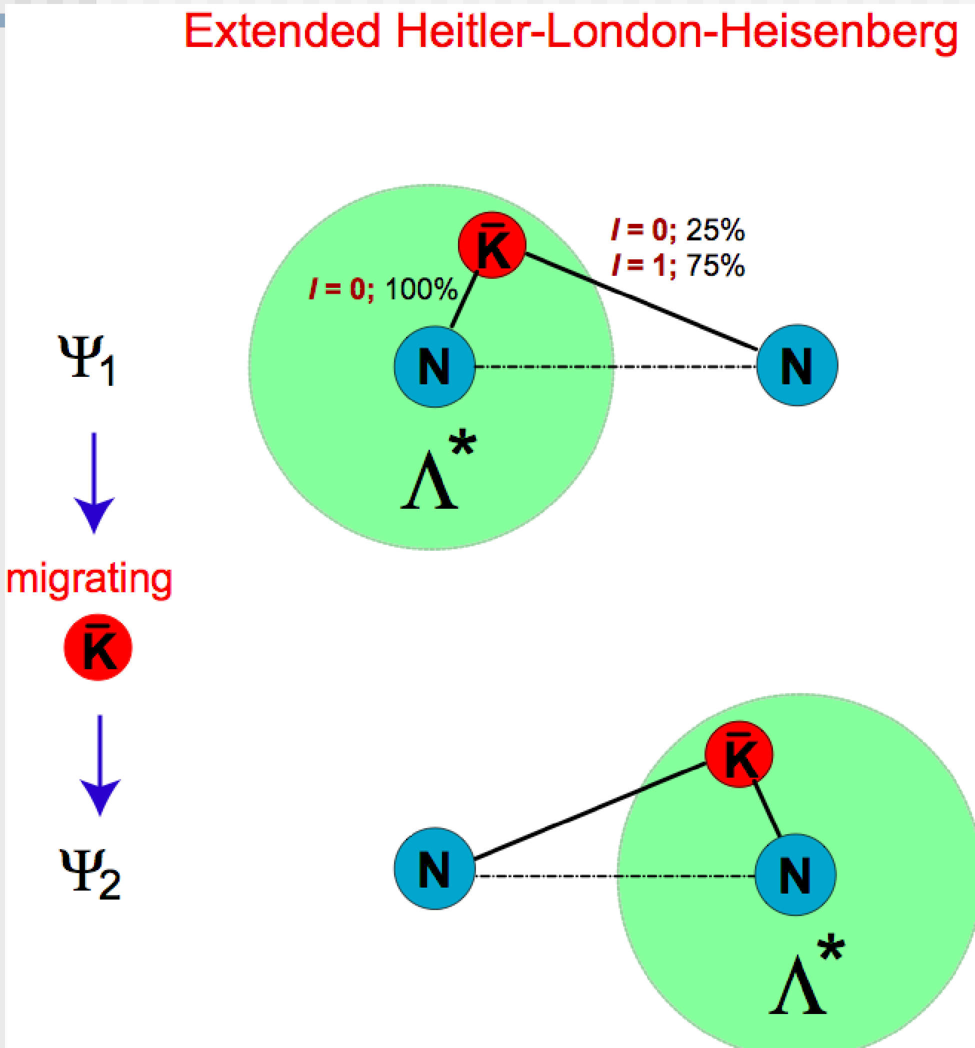
$$[\phi_a(r_a) + \phi_b(r_b)] / \mathrm{Sqrt}[2S+2]$$

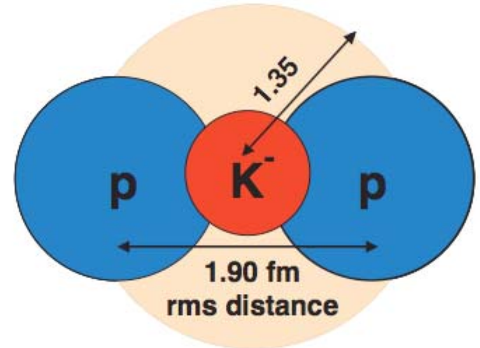
$$S = \langle \phi_a | \phi_b \rangle$$

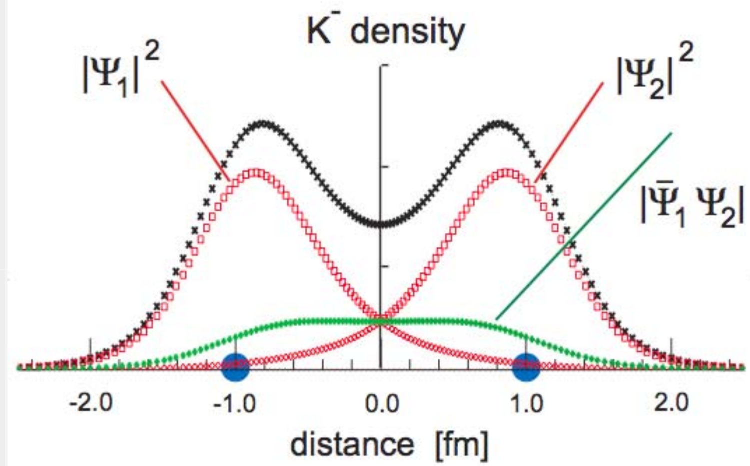
$$H = KE - e^2/r_a - e^2/r_b + e^2/r_{ab}$$

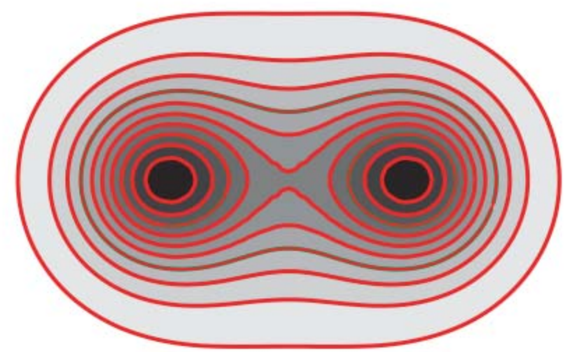


Heitler-London (1927) for H-H
Heisenberg (1932) for p-n
He atom *vs* H_2 molecule









p-p distance = 2.0 fm

ATMS prediction for Kpp quite robust:

consistent with

N.V. Shevchenko, A. Gal and J. Mares, arXiv:nucl-th/0610022.

Y. Ikeda and T. Sato, HYP2006 contribution.

Kpp beyond the present approach

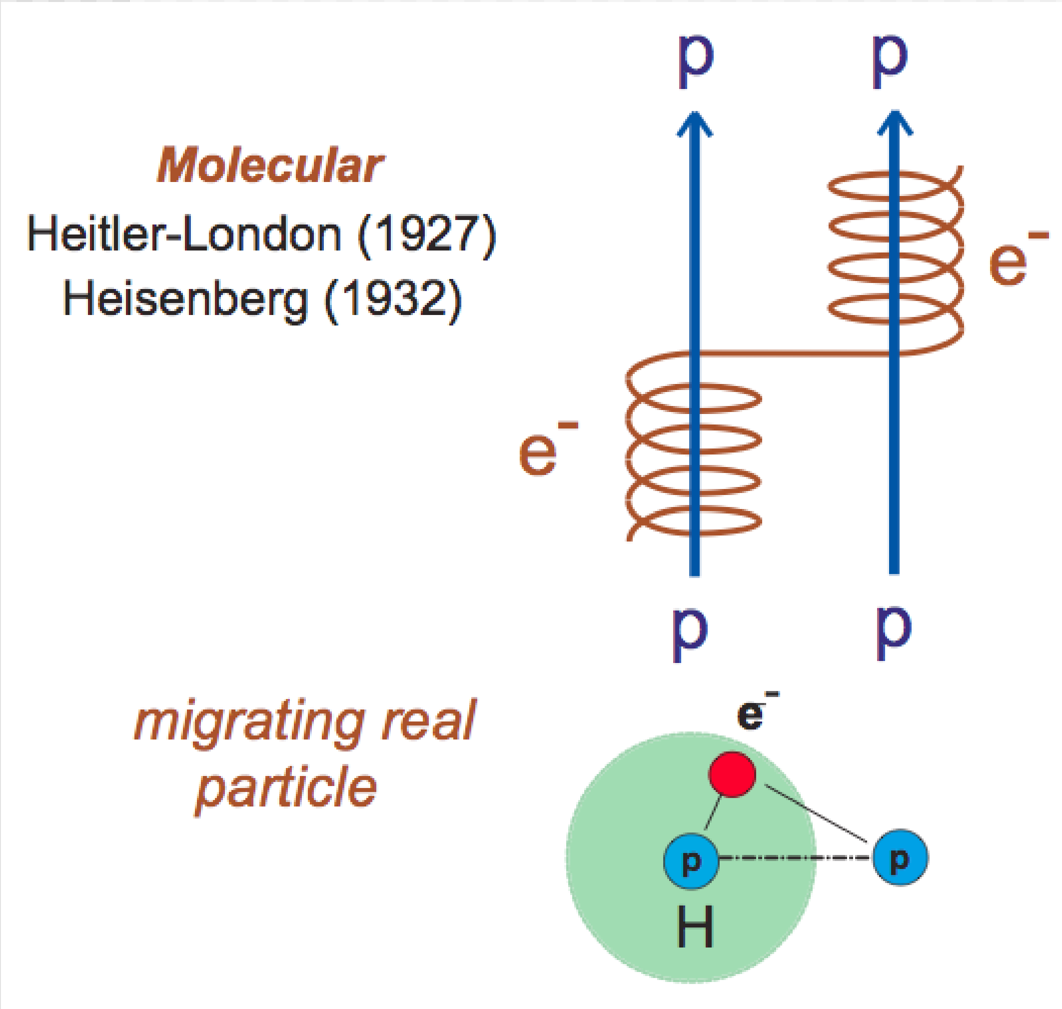
1. Validity of the Λ(1405) Ansatz
2. Unknown interactions pertinent to 3-body systems; p-wave, , ,
3. KN interaction modified

   by chiral symmetry restoration, quark structure, , ,

NN barrier weakened by Kbar ?

Yukawa's struggling in 1933

a la K. Nishijima



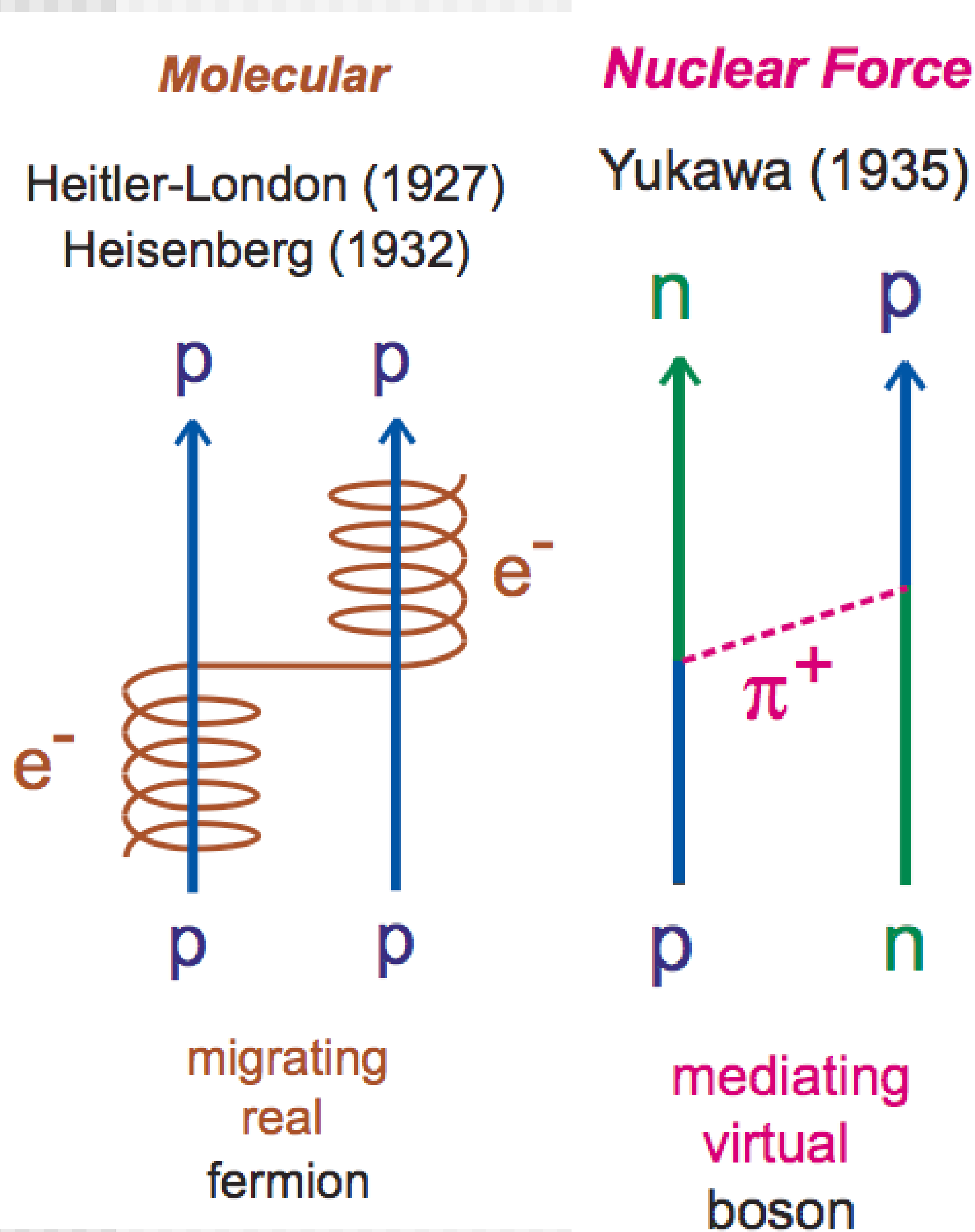
how can a migrating real particle exist in nuclei?

Bose electron ?

force range ?

$p + e^- = n$?

Finally, in 1935, Yukawa arrived at *virtual mediating* particle



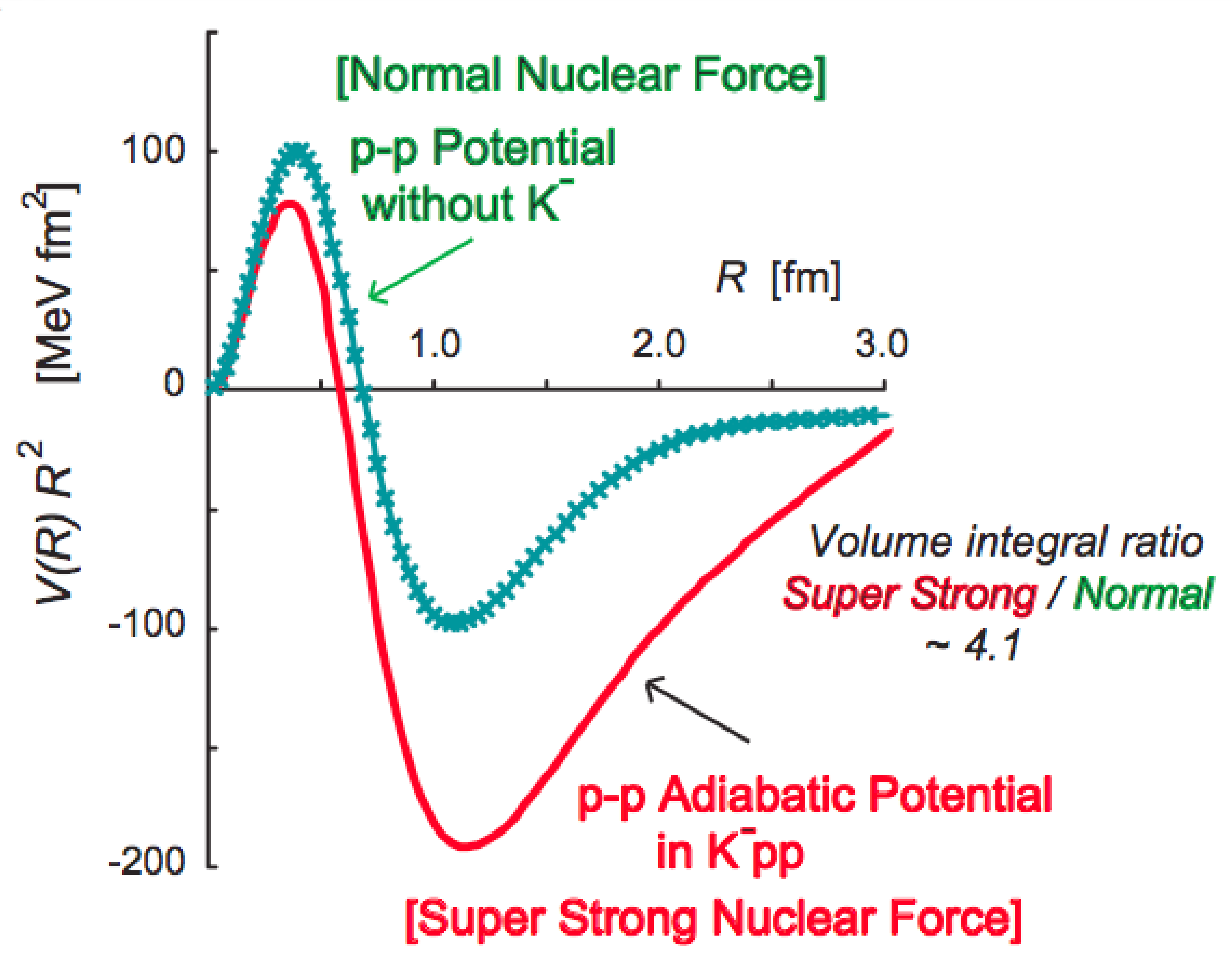
The Yukawa theory

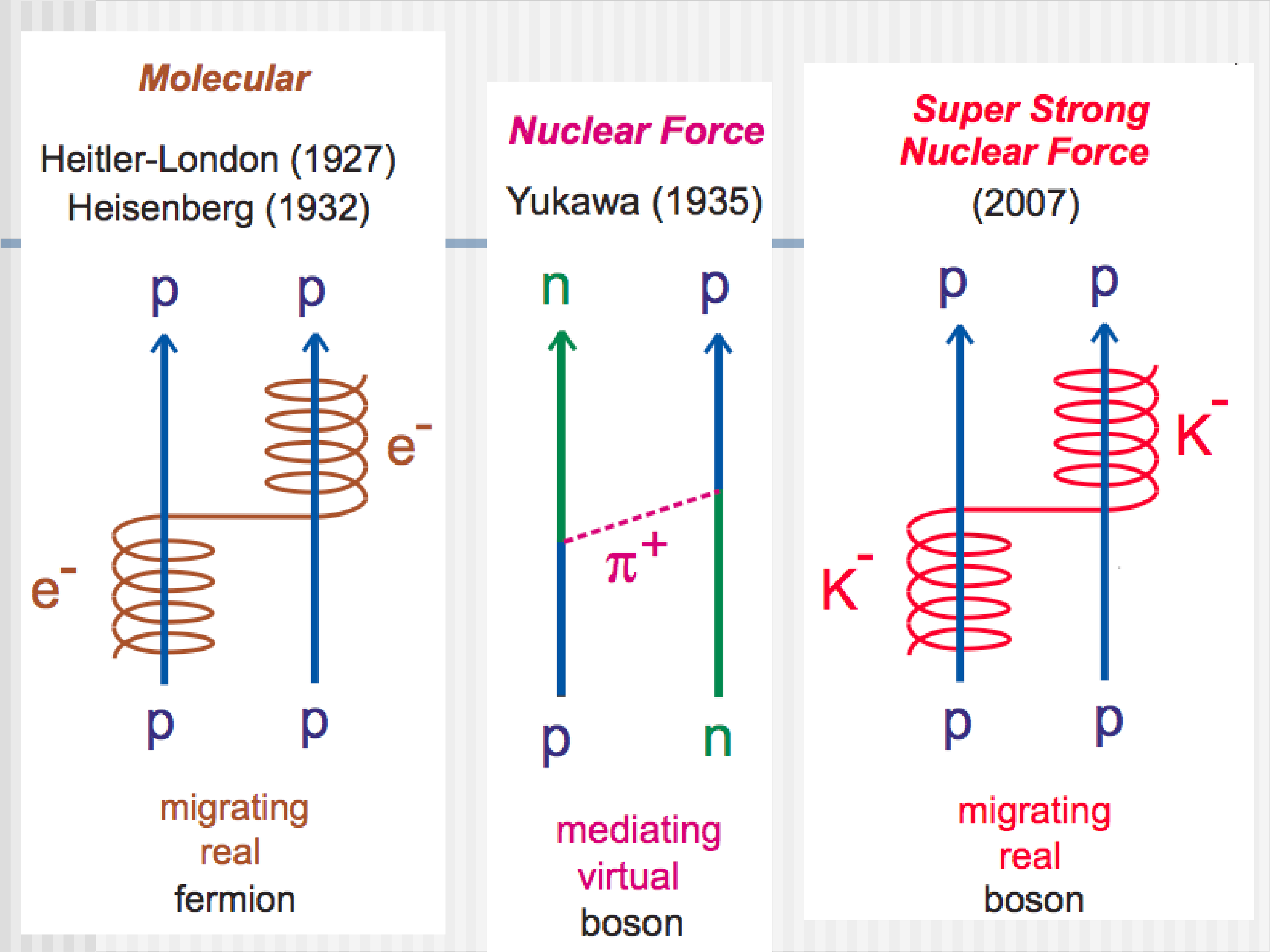
A virtual particle mediates strong interaction

- $m_U/m_e \sim 200$
- The mesons discovered
- Fundamental concept in physics

Heitler-London-Heisenberg scheme:

completely abandoned ?


[Normal Nuclear Force]
p-p Potential
without K-
R [fm]
1.0
2.0
3.0
100
0
-100
-200
V(R) R2 [MeV fm2]
Volume integral ratio
Super Strong / Normal
~ 4.1
p-p Adiabatic Potential
in K-pp
[Super Strong Nuclear Force]


Molecular
Heitler-London (1927)
Heisenberg (1932)
p p
e-
e-
p p
migrating
real
fermion
Nuclear Force
Yukawa (1935)
n p
π+
p n
mediating
virtual
boson
Super Strong
Nuclear Force
(2007)
p p
K-
K-
p p
migrating
real
boson

Range and Coherency of Kbar bonding

Yukawa coupling (virtual meson)

range: short ~ 1/m

saturation, constant nuclear density

Kbar covalency (real Kbar: anti-u,d)

range: short - medium:

~ $1/B_K$ ~ Λ_{1405} size

higher density

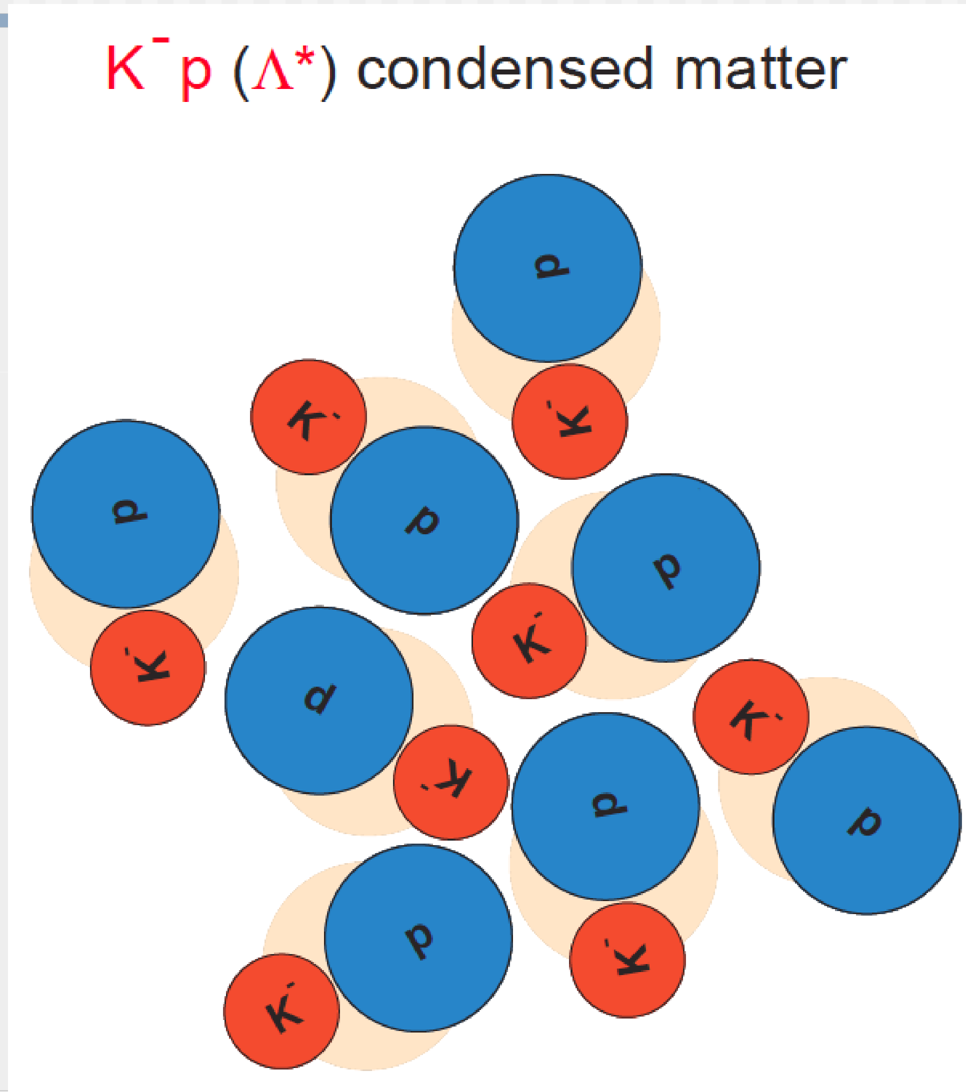
coherency range ?

Kpp Kppp Kpppp Akaishi, Dote

KKpp KKppp Akaishi, Dote

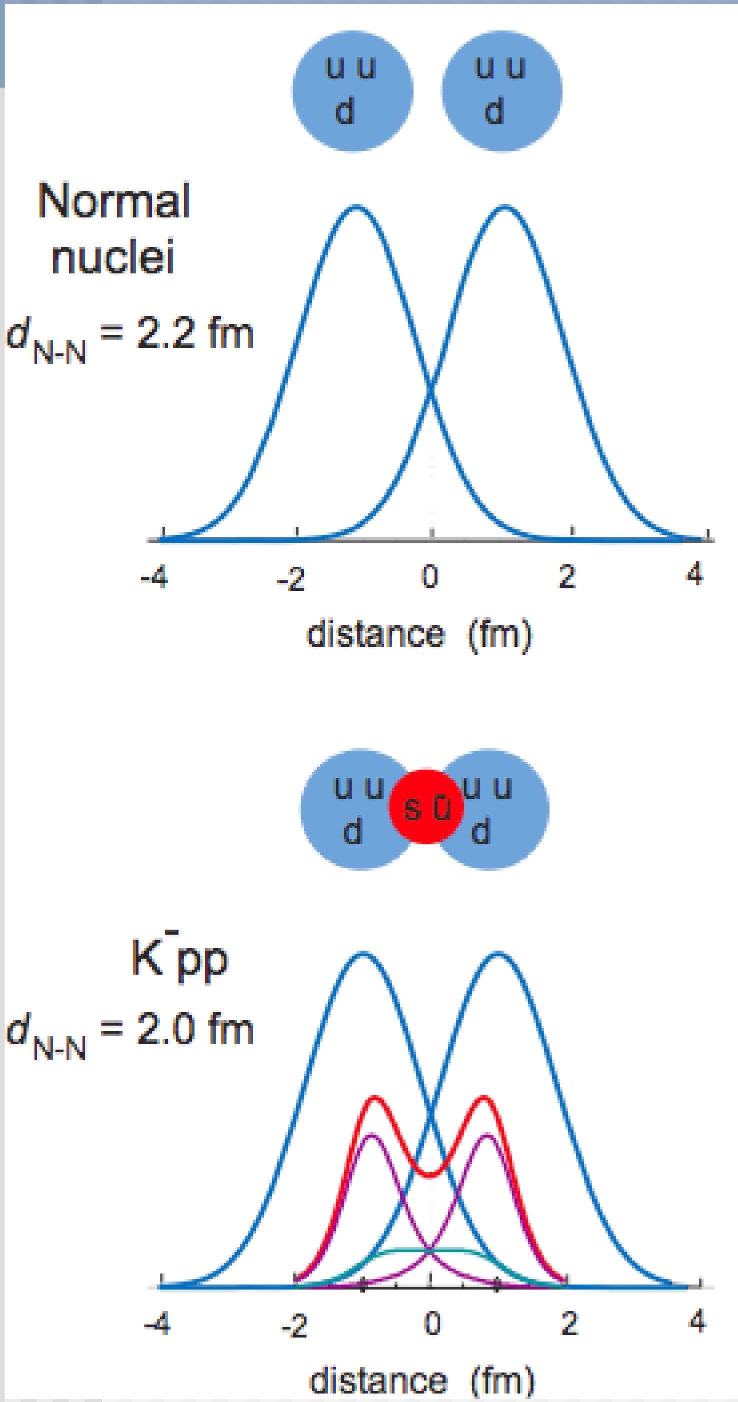
K-condensed matter:

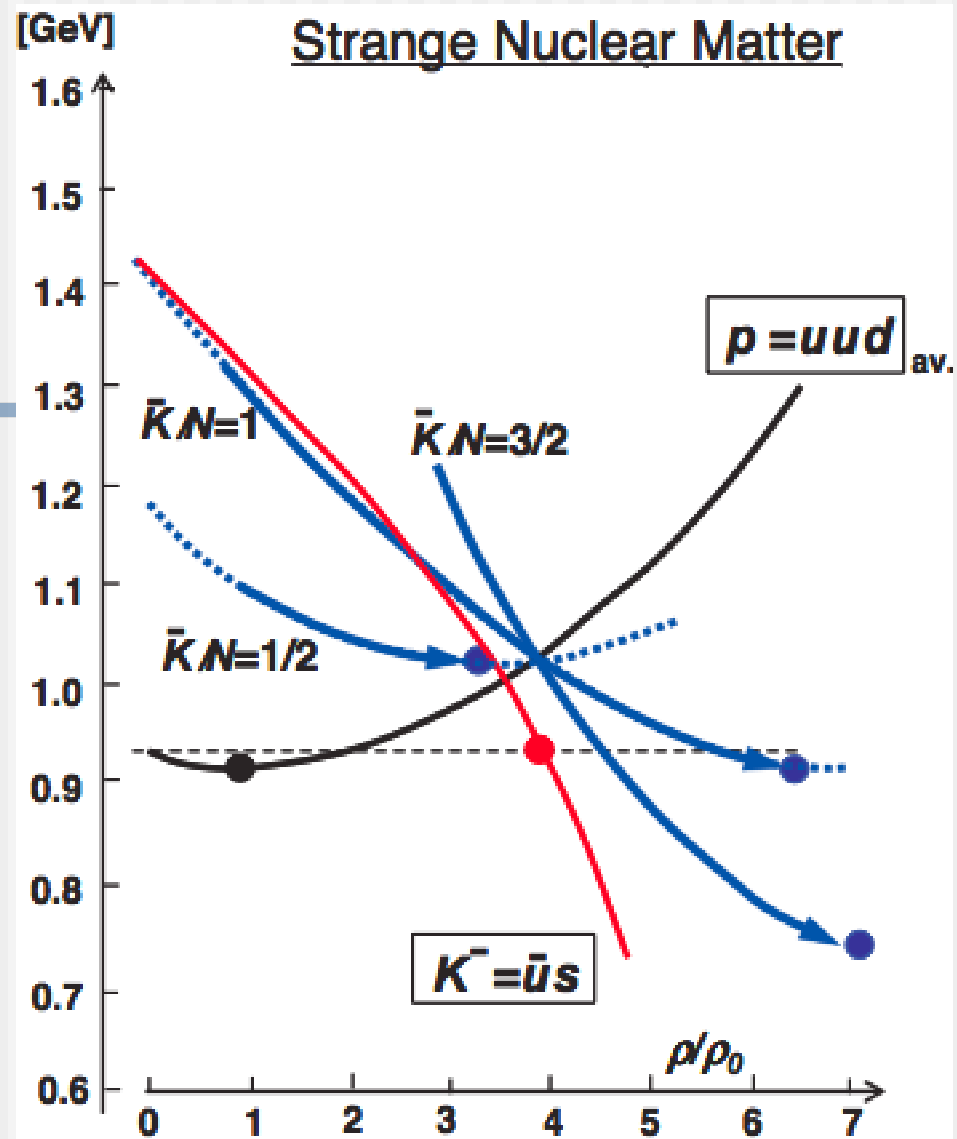
Λ^* matter by coherently migrating K^-



High density

Liquid, Solid?


u u
d
u u
d
Normal
nuclei
d N-N = 2.2 fm
-4
-2
0
2
4
distance (fm)
u u
s ū
u u
d
d
K⁻pp
d N-N = 2.0 fm
-4
-2
0
2
4
distance (fm)

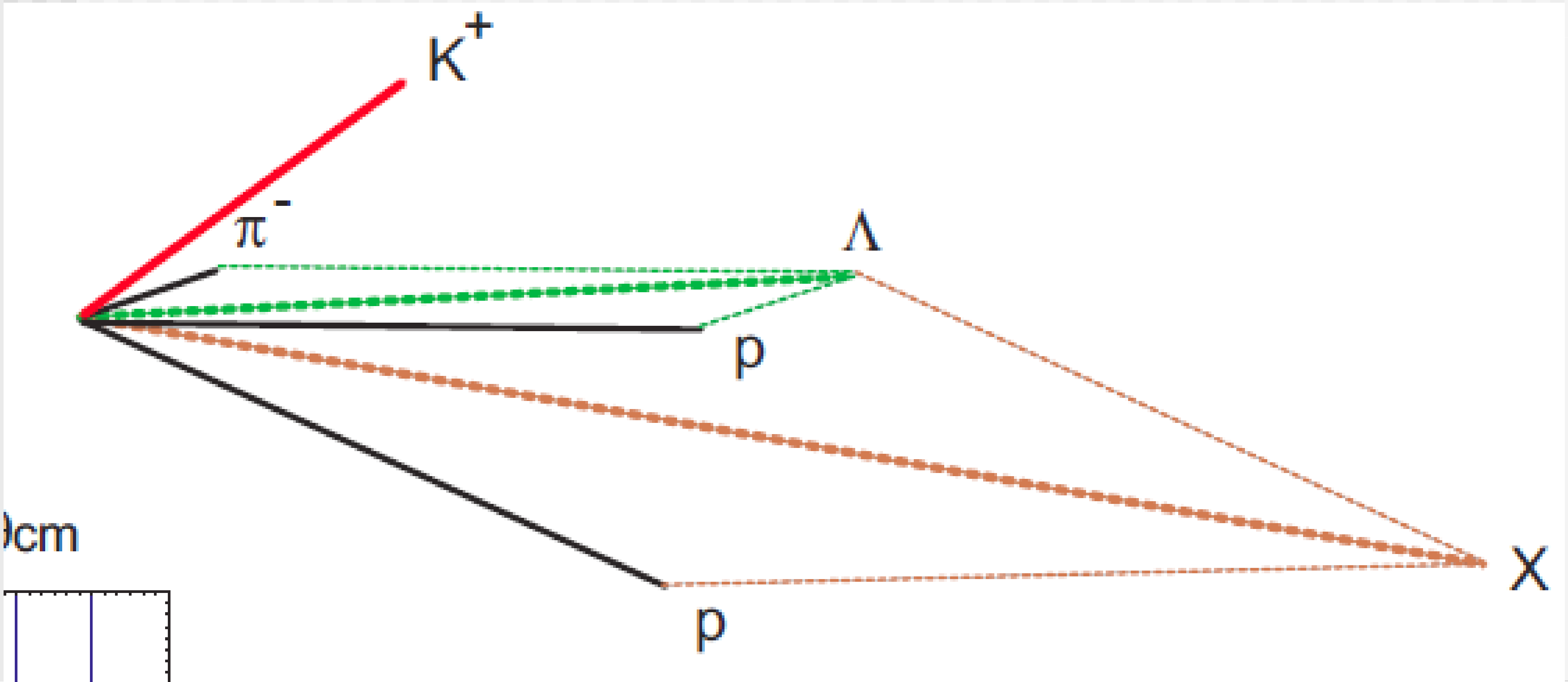

[GeV]
Strange Nuclear Matter
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
p =uud av.
K̄N=1
K̄N=3/2
K̄N=1/2
K⁻=ūs
ρ/ρ0
0
1
2
3
4
5
6
7

Kpp formation

How to prove the high density in Kbar nuclei ?

$p + p \dashrightarrow K^+ + p + \Lambda^*$ $\Lambda^* p$ sticking

$\dashrightarrow K^+ + K^- pp$: $K^- pp \dashrightarrow \Lambda + p$



weakly coupled Λ*p doorway	strongly coupled Λ*p doorway

π^+ + "n" --> "Λ*" + K^+

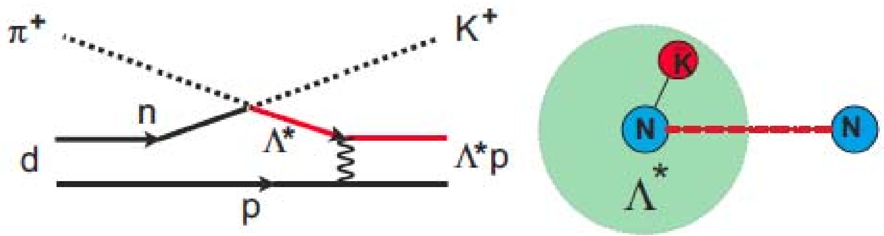
"Λ*" + "p" --> bound K^-pp ***minor***

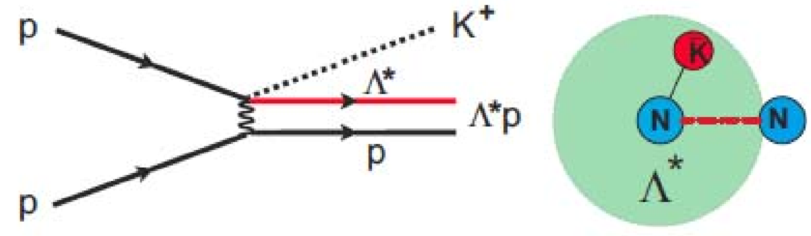
--> quasi-free Λ* ***dominant***

pp --> K^+ + Λ*p

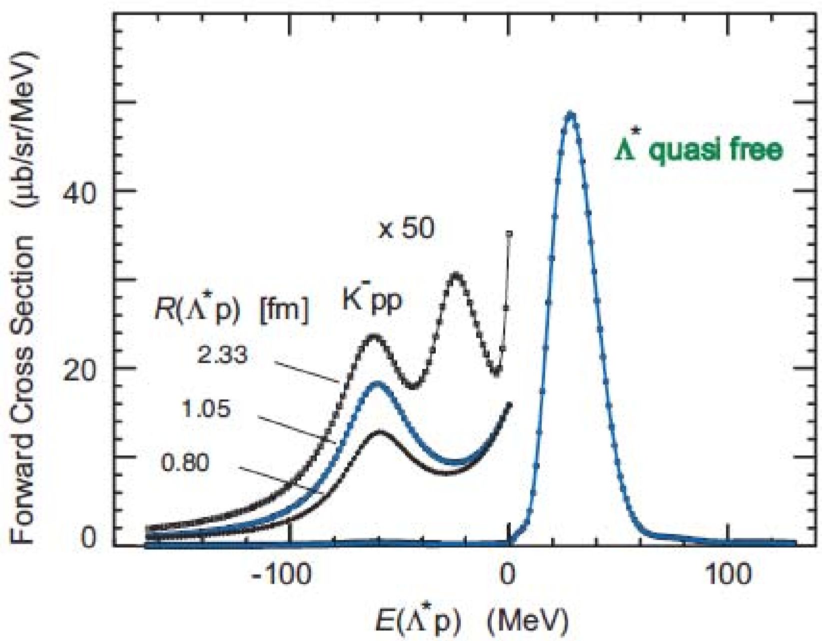
bare Λ*p --> bound K^-pp ***dominant***

--> quasi-free Λ*

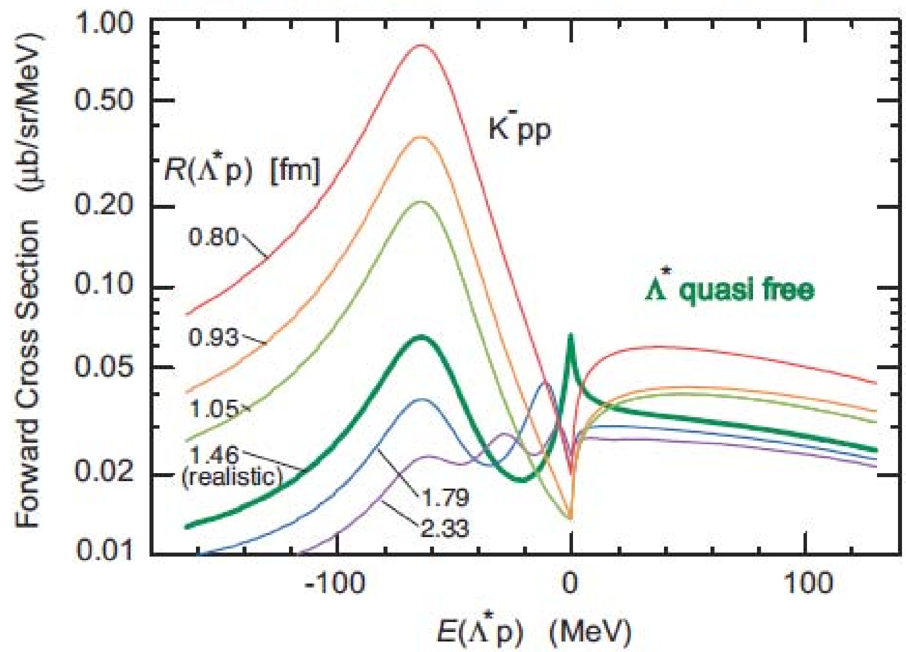


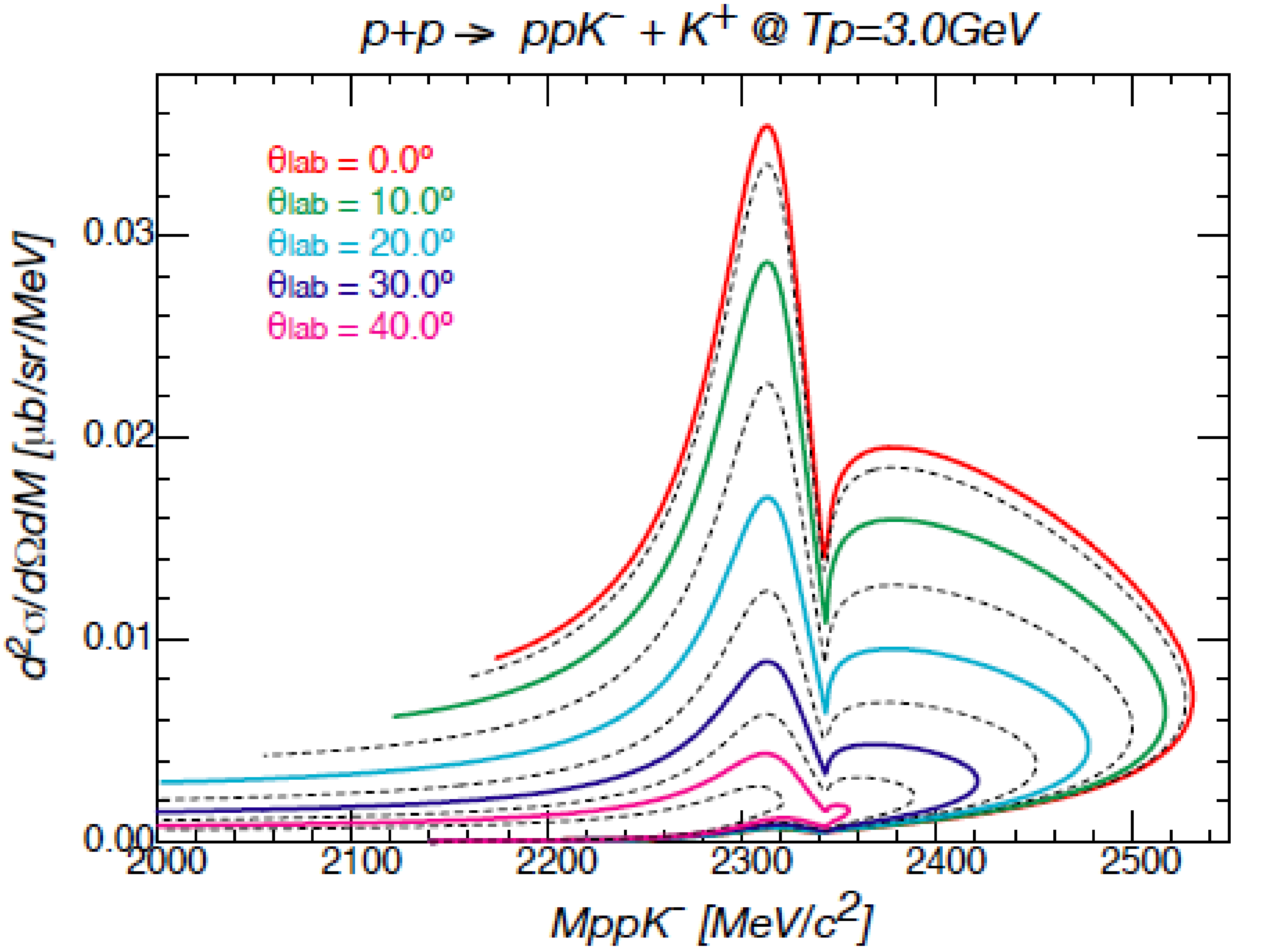


d + π^+, --> K^+ + p + Λ*



p + p --> K^+ + p + Λ* @4.0 GeV *Q* ~ 1.6 GeV/c





p+p → ppK⁻ + K⁺ @ Tp=3.0GeV
θlab = 0.0°
θlab = 10.0°
θlab = 20.0°
θlab = 30.0°
θlab = 40.0°
0.00
0.01
0.02
0.03
2000
2100
2200
2300
2400
2500
d²σ/dΩdM [μb/sr/MeV]
MppK⁻ [MeV/c²]

Aslanyan et al. DUBNA

Propane bubble chamber

p+p, p+^{12}C, n+p, n+^{12}C

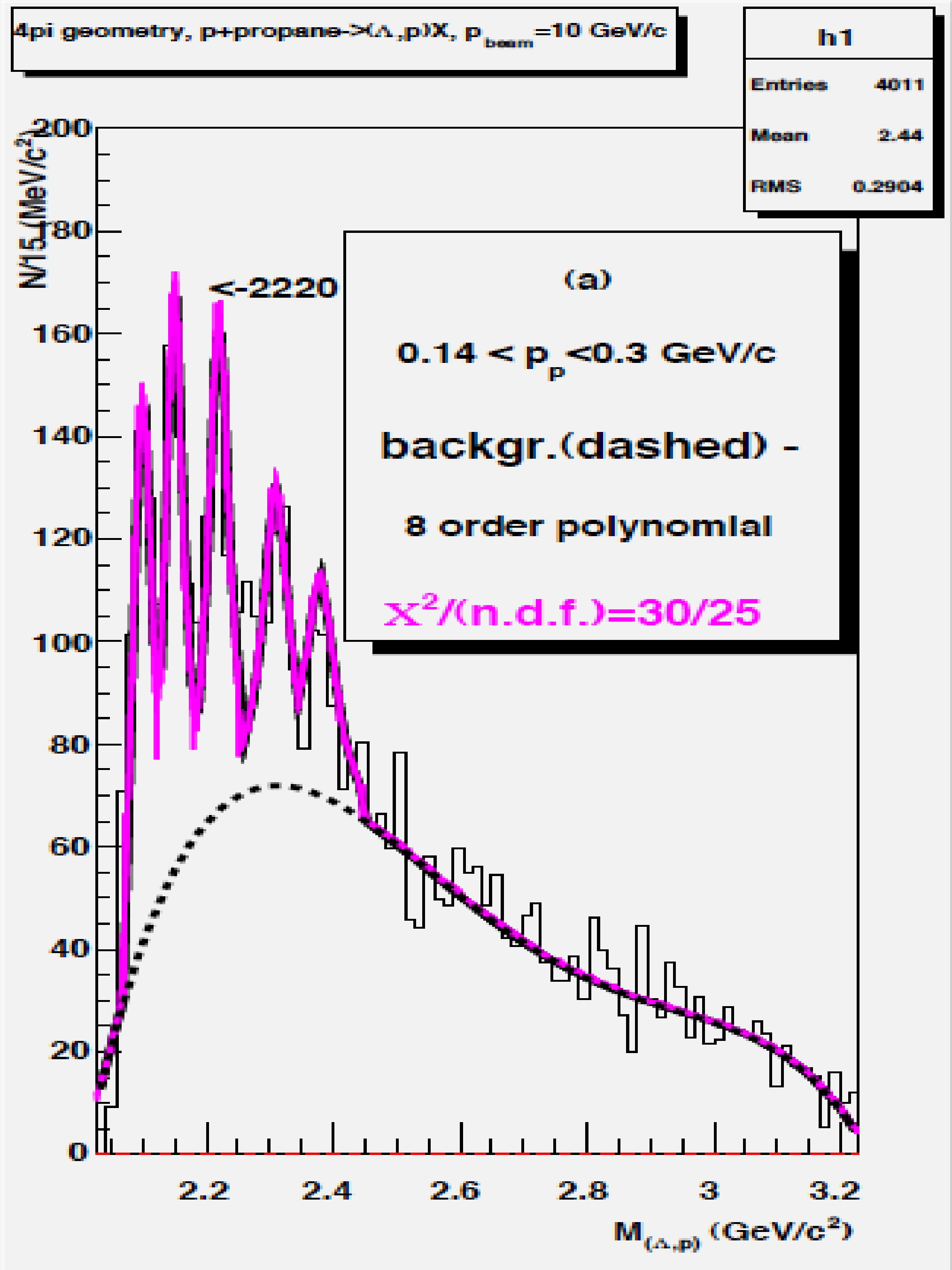
- Invariant mass

  $K^-pp \dashrightarrow \Lambda + p$

a significant peak at

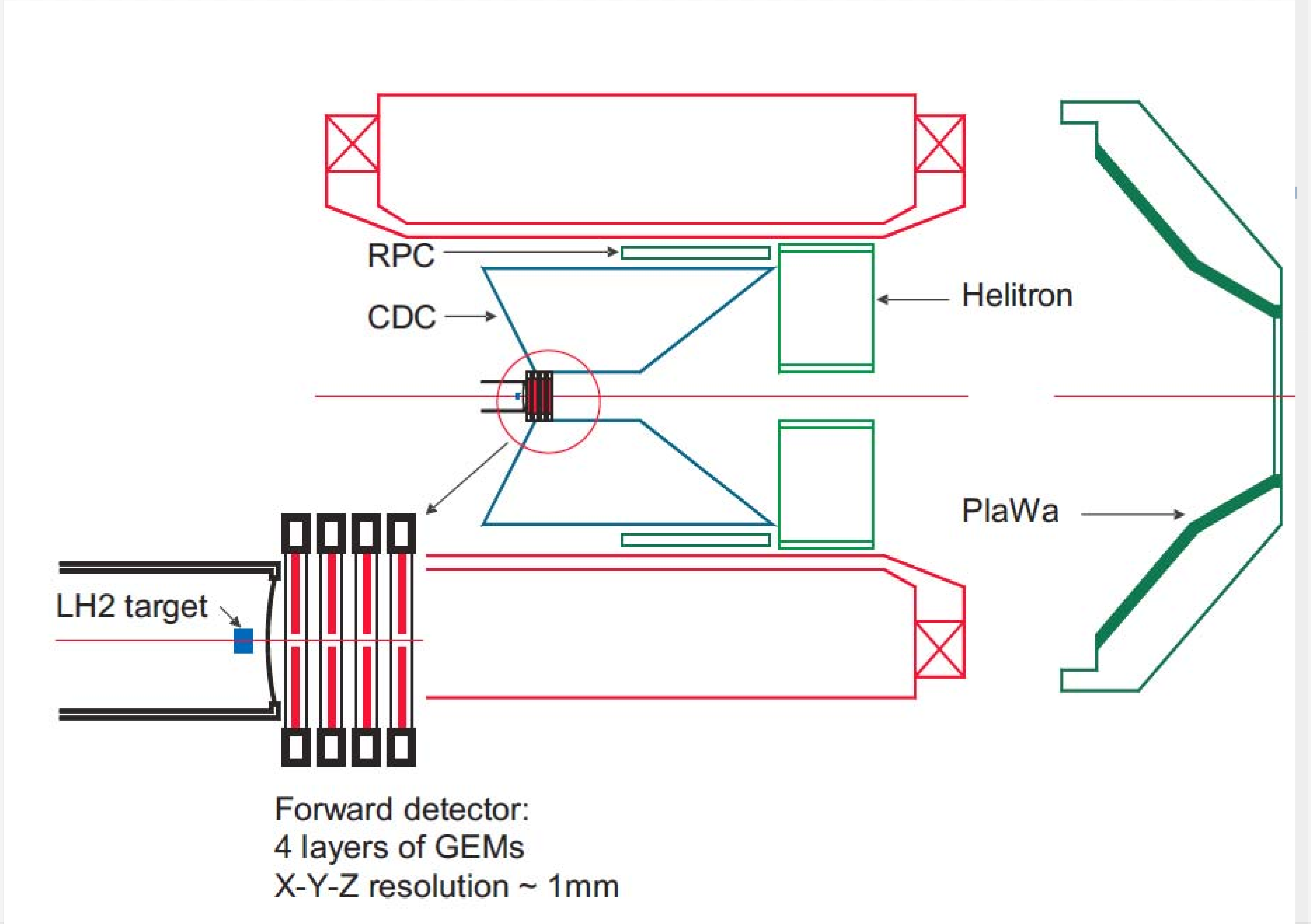
$M \sim 2220$ MeV/c^2

$B_K \sim 120$ MeV



FOPI pp -> K+X experiment

FOPI-GSI, SMI, TMU,,,



Thank you very much