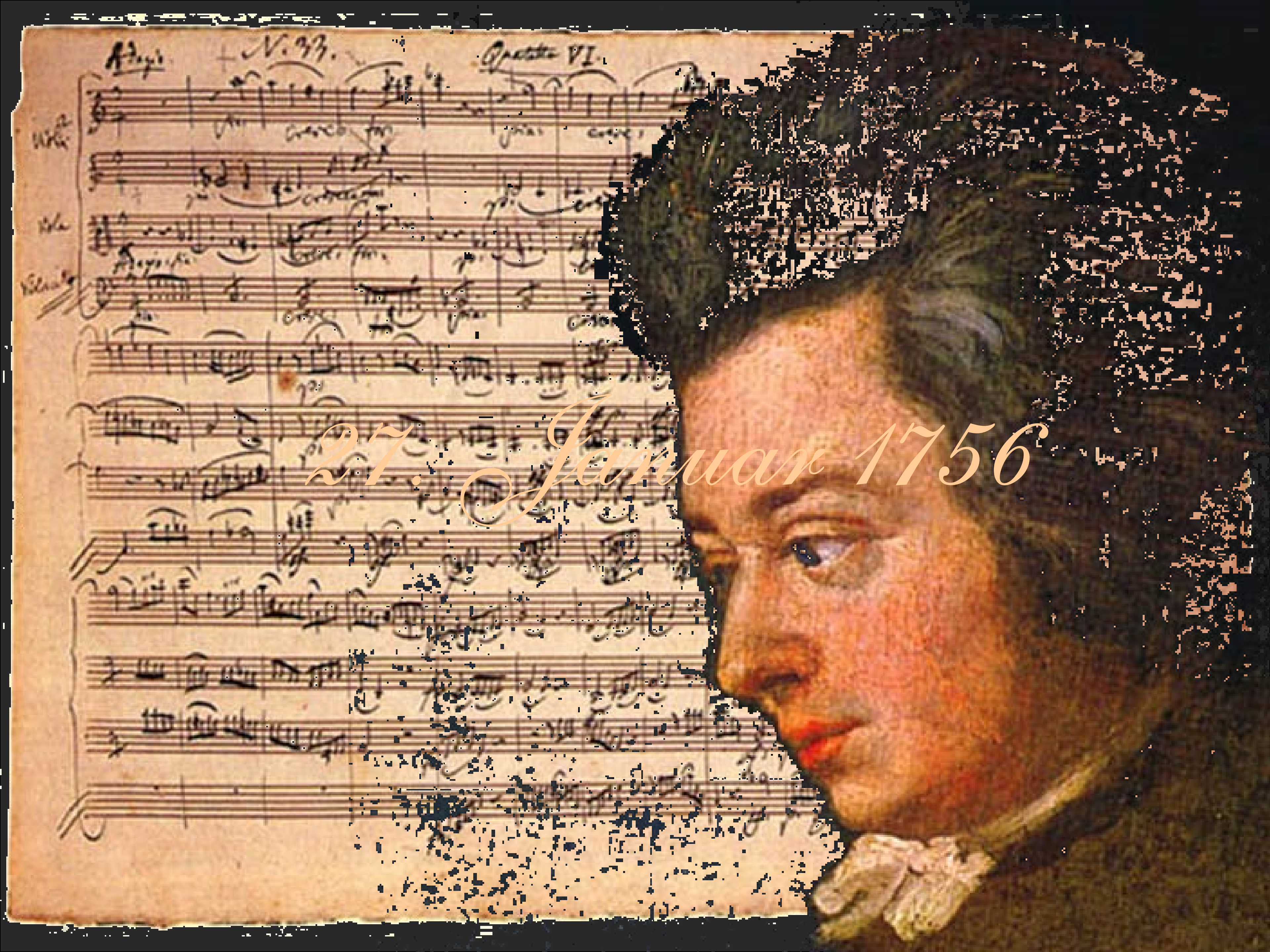
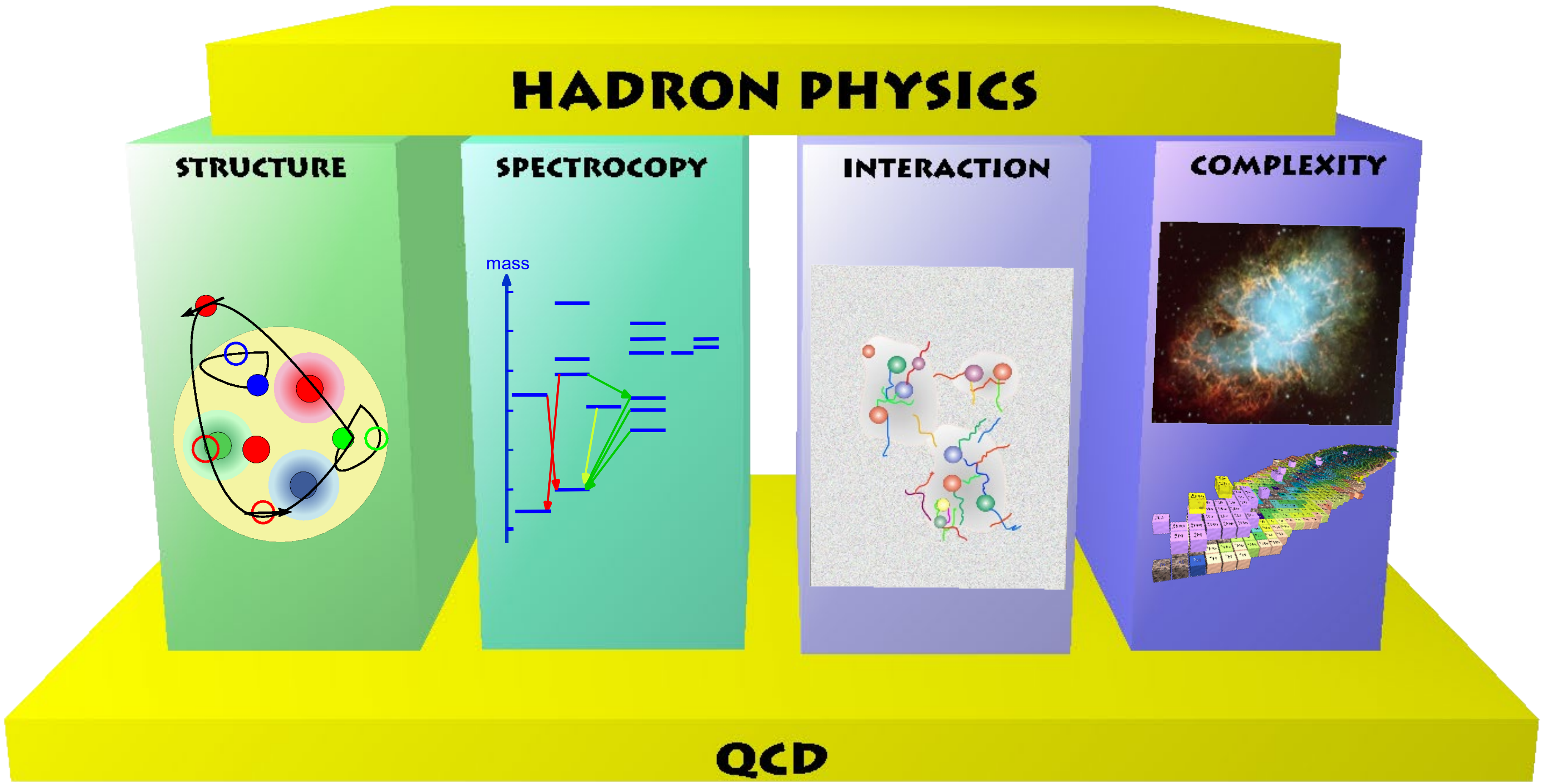

27. Januar 1756

Pillars of Hadron Physics



HADRONS:
Bridge BETWEEN
QUARKS And StARS

- MOtivation
- HADRONS in COLD NUCLEI
  - ANTIKAONS
  - ANTIBARYONS
  - EXOTIC HYPERNUCLEI
- conclusion

Bundesministerium für Bildung und Forschung

Motivation

Chi a una sola è fedele verso l'altre è crudele

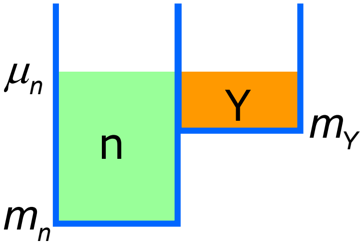
Wer nur einer treu ist, ist gegen die anderen grausam

Don Giovanni

The Core of a Neutronstar

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

picture: Fridolin Weber



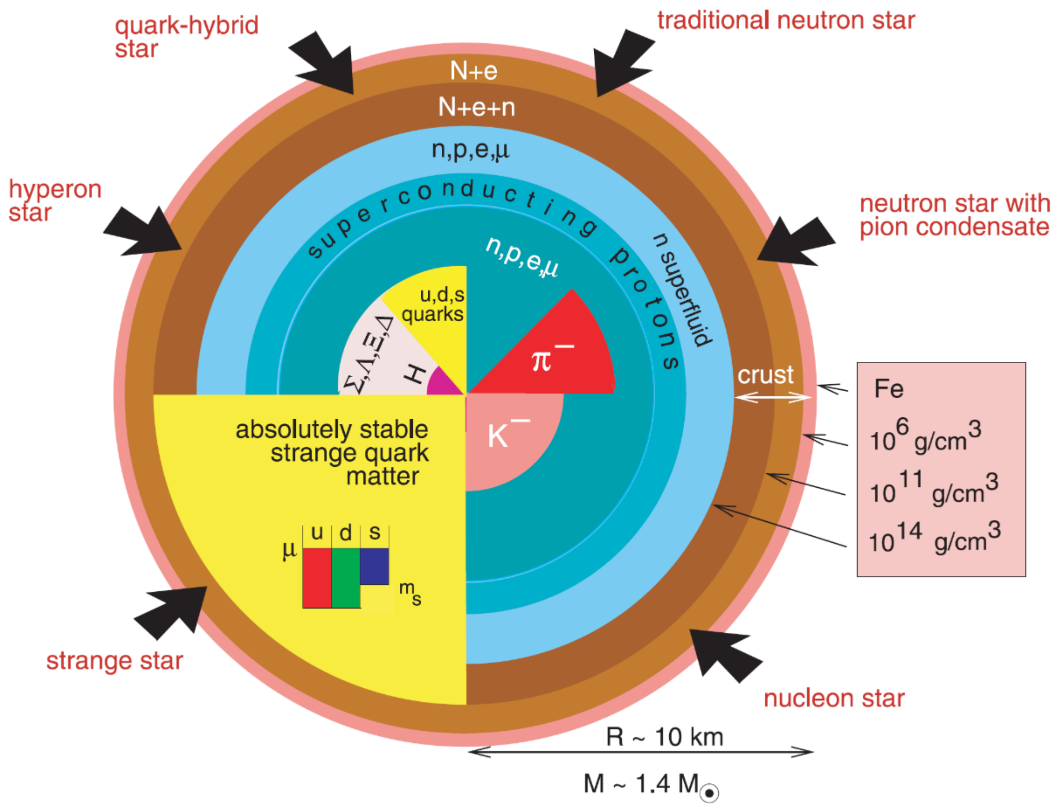
$$e^- + p \to \nu_e + \Sigma^-$$

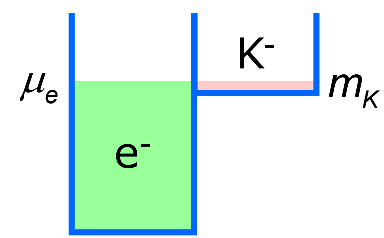
$$e^- + n \to \nu_e + \Lambda$$

$$p_F \geq \sqrt{m_\Lambda^2 - m_N^2} \approx 3fm^{-1}$$

$$\Rightarrow \rho > 2\rho_0$$

Cameron 1959,
Ambartsumyan &
Saakyan 1960





$$e^- \to K^- + \nu_e$$

$$n \to p + K^-$$

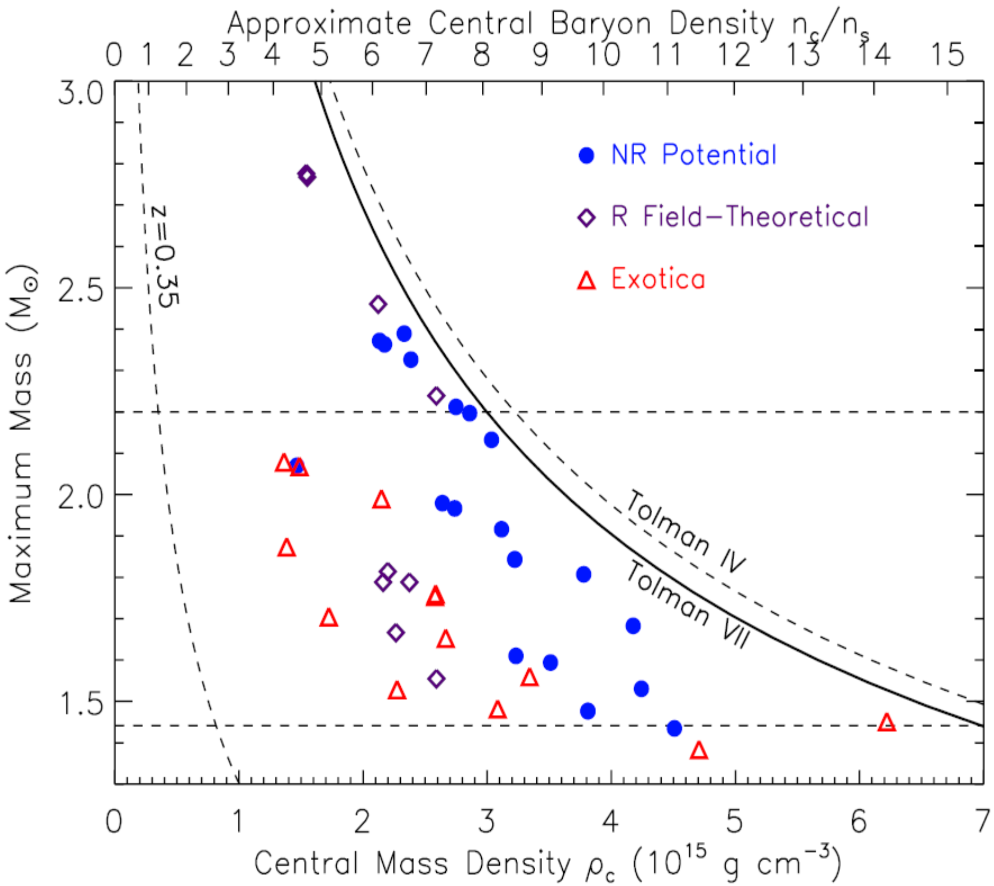
Kaplan & Nelson 1986

- …even more speculations: supersymmetric baryons

S. Balberg *et al.*, The Astrophysical Journal, 548:L179–L182 (2001)b

Observable Consequence

- Main consequence of hyperons and other exotica in neutron stars: softer EOS $\Rightarrow$ lower mass and smaller central density

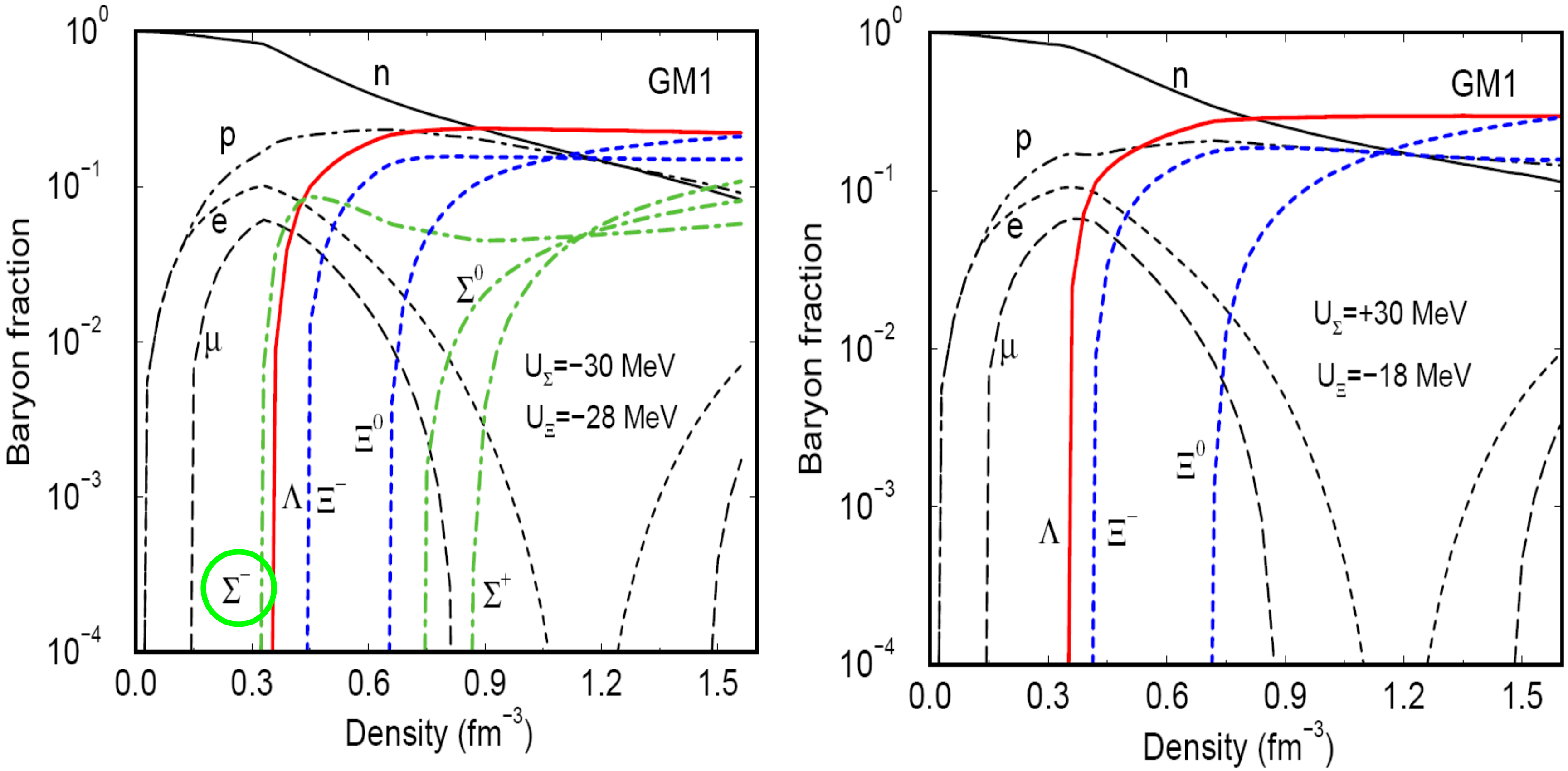


James M. Lattimer and Madappa Prakash
Phys. Rev. Lett. **94**, 111101 (2005)

- present data on neutron star masses do not exclude exotic cores
- simultaneous treatment of all possible ingredients (K,Y,q…) missing

Baryon stars

- Input: Baryons in chemical Equilibrium, conservation laws, interaction



N. K. Glendenning, Phys. Rev. C **64**, 025801 (2001)

  - beyond $2\rho_0$ Hyperons may play a significant role in neutron stars
  - in the core hyperons may even be more abundant than neutrons

- needed: BB interaction at high density= at small distances

AntiKAONS IN NUCLEI

Glücklich preis ich, wer erfasset
alles von der guten Seite,
der bei Stürmen niemals erblasset,
wählt Vernunft als Führerin.

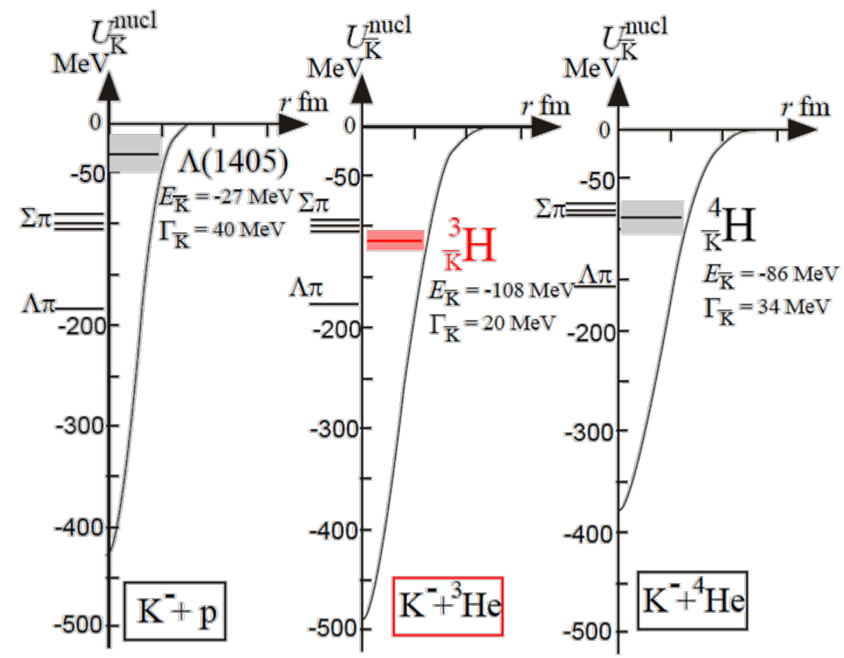
Cosi fan tutte

K^--nucleus bound systems

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

- relevance
  - hadron masses in nuclear medium
  - astronomical objects
- starting point: $\Lambda(1405)$ as K^-p system

  $\Rightarrow$ K-nucleus bound states may be
  - deeply bound (~100MeV)
  - narrow (~20MeV)
  - dense (~$5\rho_0$)



Y. Akaishi and T. Yamazaki, PRC65, 044005 (2002)

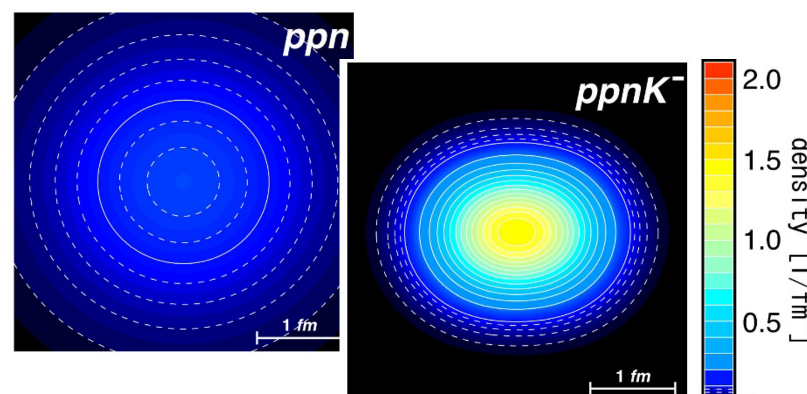
- detection
  - missing mass (KEK,Jlab,MAMI-C)

$$\left.\begin{array}{l} ^{(3)4}He(_{stopped}K^-,N)X \\ ^{(3)4}He(e,e'K^+)X \end{array}\right\} \quad X=(N)NNK^-$$

  - invariant mass (FINUDA,FOPI,WA89)

$$ppK^- \to \Lambda + p + 263\text{MeV}$$

$$ppnK^- \to \Lambda + d + 208\text{MeV}$$

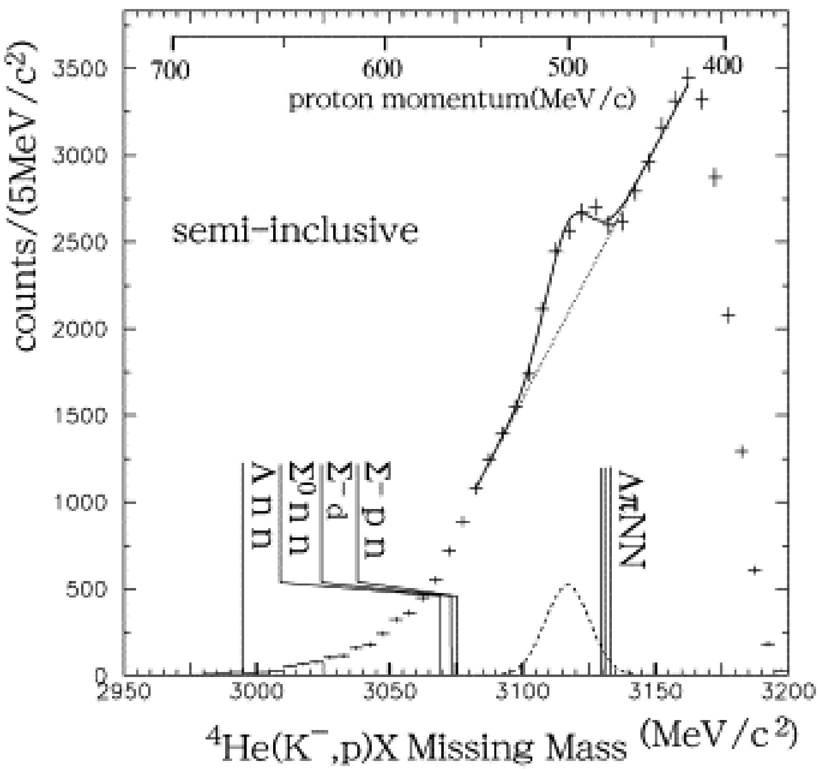


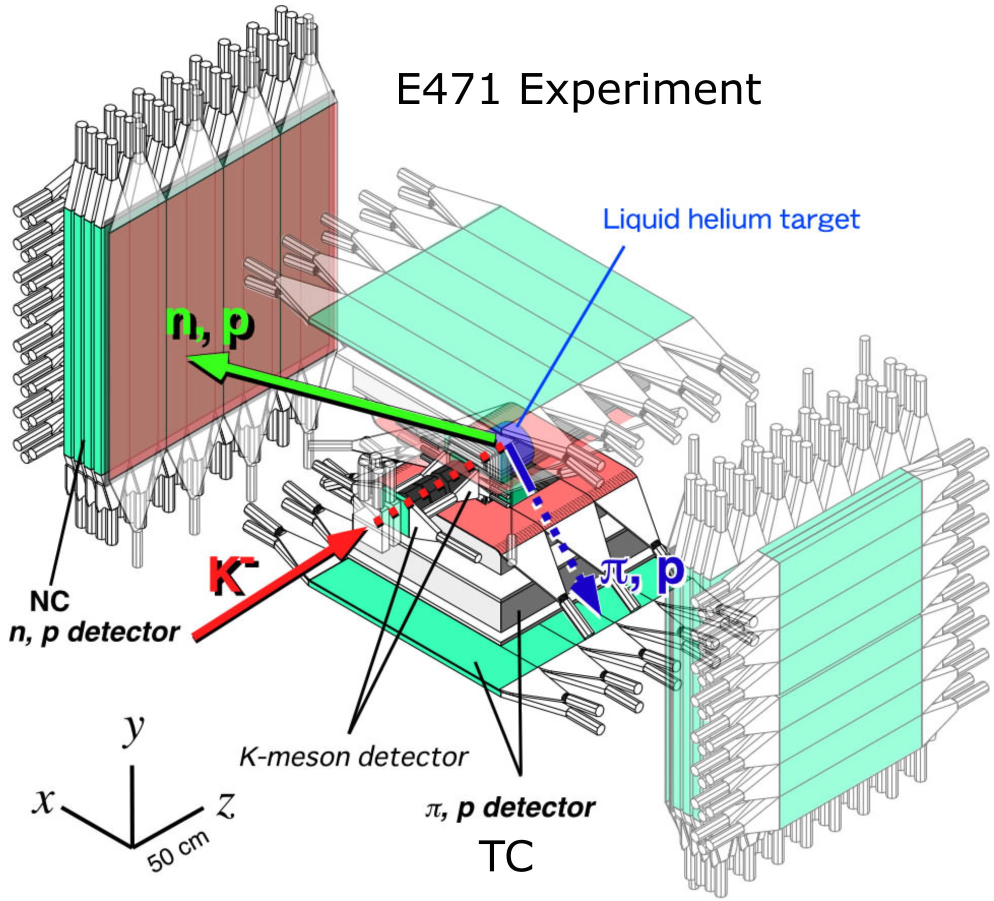
A. Dote et al., PLB 590, 51 (2004)

Discovery of a strange tribaryon S(3115)

T. Suzuki et al., Phys. Lett. B. 597, 263 (2004)

$^4He(_{stopped}K^-,p)X+$ 1charged particle in TC



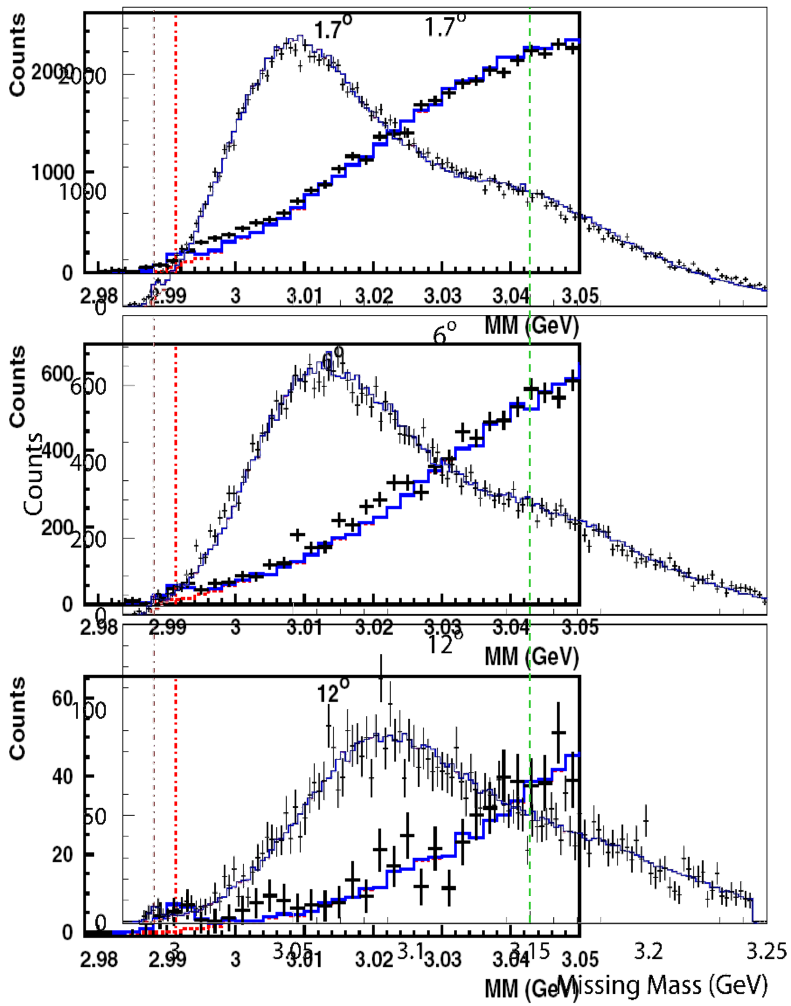


- supported by FOPI, Ni+Ni@1.93AGeV, N. Herrmann, EXA05
  - m=3159±20 MeV/c², Γ=100±45 MeV/c²

What about electroproduction?

- JLAB Experiment, E91016, Hall C
  - $^3He(e,e'K^+)X$ at 3.245GeV

ppnK⁻ ?



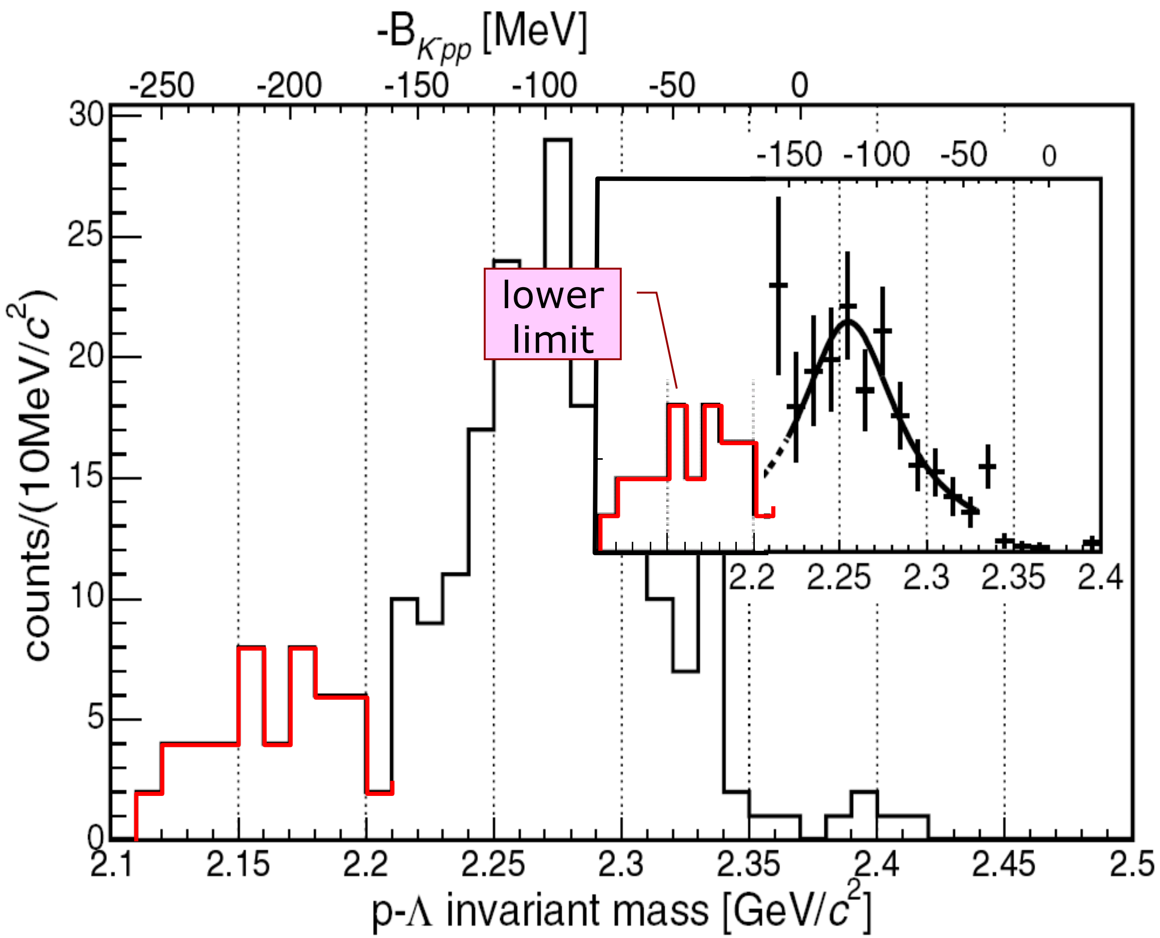
F. Dohrmann et al.,

PRL 93, 242501 (2004)

and priv. com.

ppK⁻→pΛ

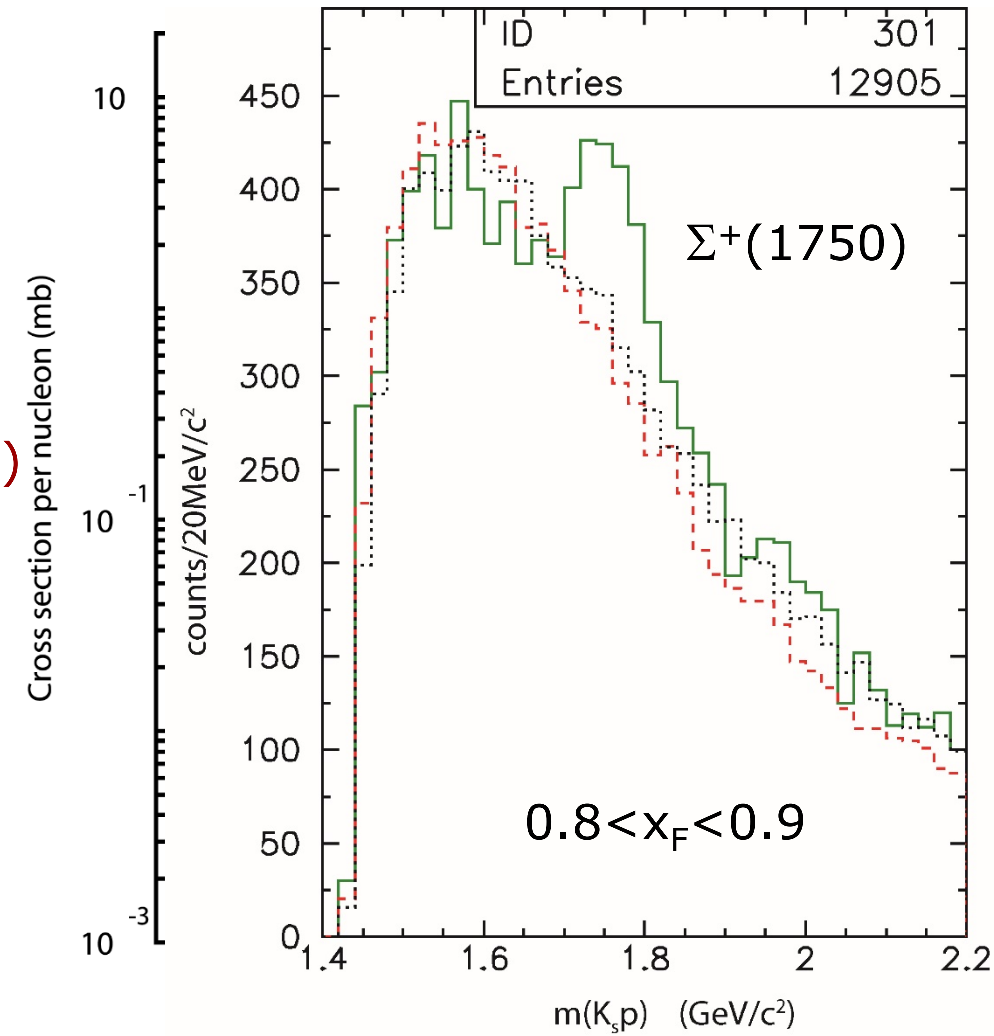
- FINUDA, PRL **94**,212303(2005)
  - $M=2.255GeV/c^2$, $\Gamma=67MeV$



- FOPI@GSI (N. Herrmann, Workshop Donnersberg 05)
  - $M_{FOPI}=2.165\pm0.007GeV/c^2 \neq M_{FINUDA}=2.255\pm0.009GeV/c^2$

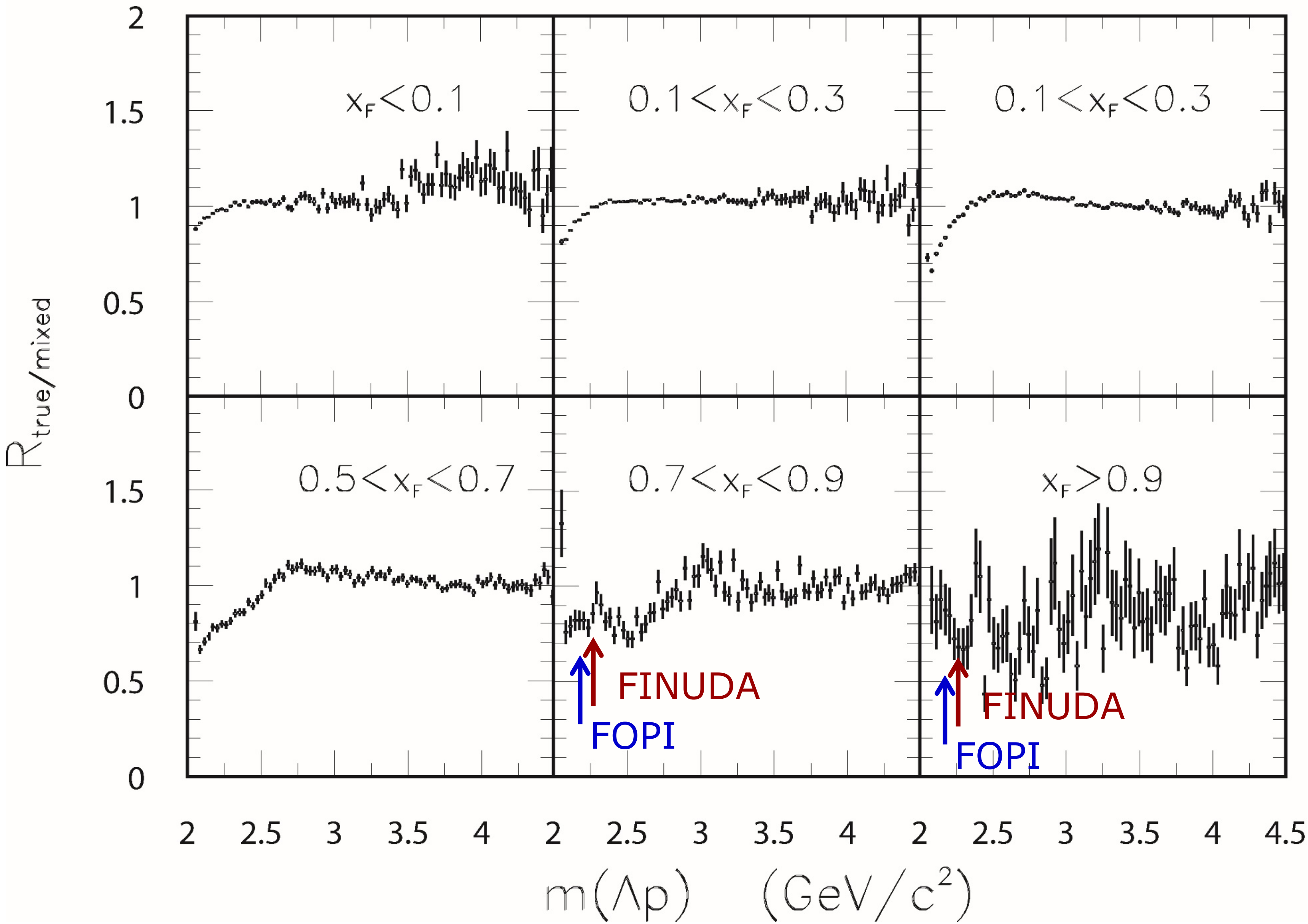
WA89@CERN

- more than 20 different strange and charmed hadrons are analyzed under identical conditions
- examples ($0<x_F<1$) $\sigma_0 = \sigma_A / A^{2/3}$
  - $\Xi^-(1320)$: $\sigma_0=1000\mu b$
  - $\Xi^0(1530)$: $\sigma_0=200\mu b$
  - $\Xi^-(1820)$: $BR \cdot \sigma_0=20\mu b$
  - $\Xi^-(1950)$: $BR \cdot \sigma_0 =12\mu b$
- Pentaquarks
  - $\Xi^{--}(1860)$:$BR \cdot \sigma_0 <3\mu b$
  - $\Theta^+(1530)$:$BR \cdot \sigma_0 <1.8\mu b$
- First observation of $\Sigma(1750)$ in a production experiment



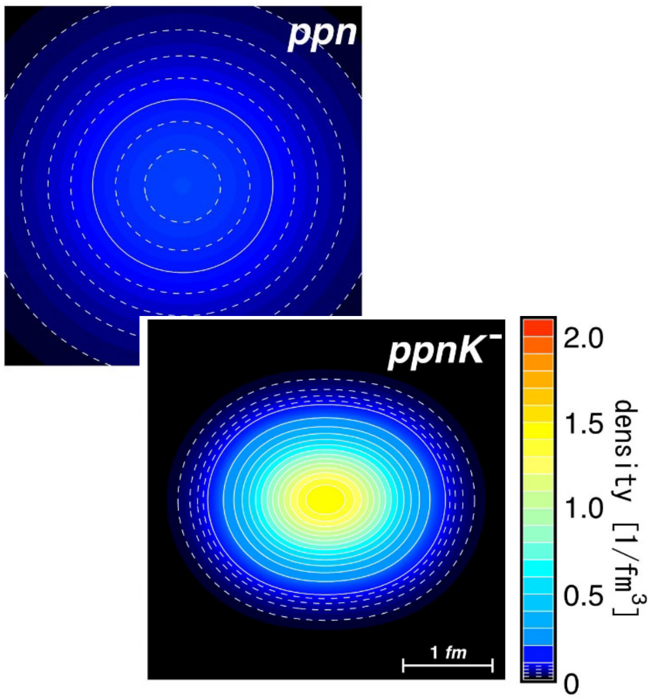
p-Λ Correlations @WA89: ppK⁻→pΛ

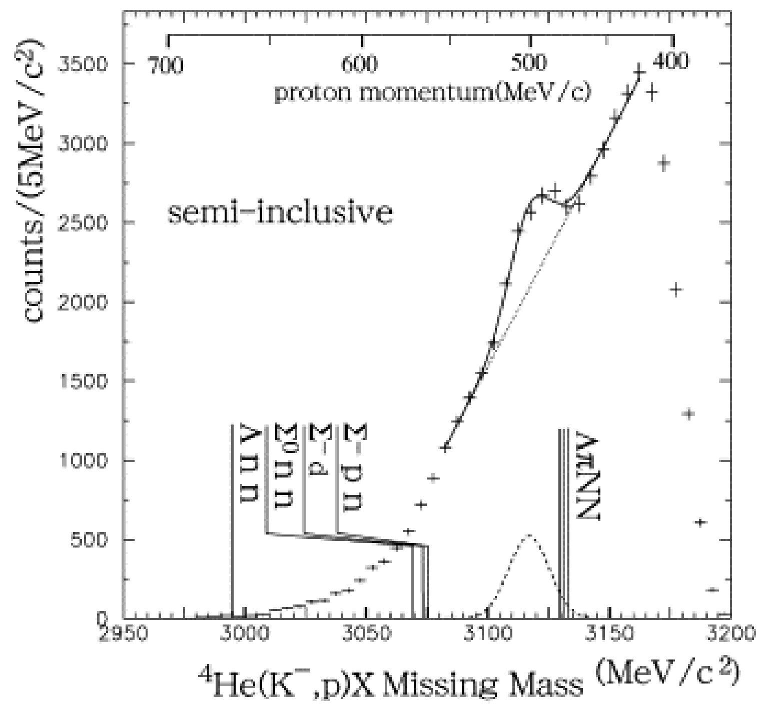
- 20MeV/c² bins



Intermezzo

- K-nucleus bound states may be an unique tool to explore the meson-baryon interaction at large densities $\sim 5\rho_0$
  - NNNK state looks promising but not yet settled
  - The NNK-states clearly needs further confirmation





- if the NNNK and (hopefully) also NNK confirmed without doubt, a new field studying cold, dense nuclear systems with many different experimental approaches will open up – including FAIR and perhaps MAMI-C

AntiBAryonS IN NUCLEI

Führt diese beyden Fremdlinge,
In unsern Prüfungstempel ein:
Bedecket ihre Häupter dann -
Sie müssen erst gereinigt seyn.

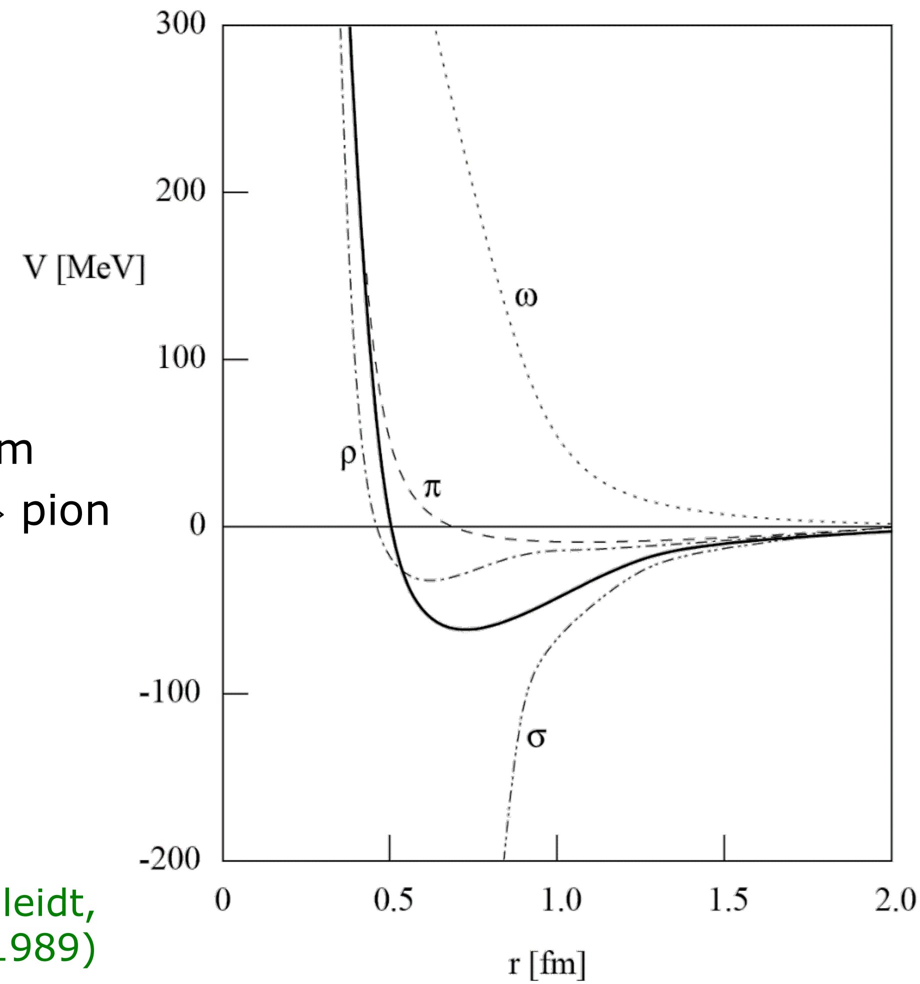
Zauberflöte

Traditional View of the N-N Interaction

- Experimental observation
  - short range (r<0.5fm) repulsion
  - intermediate ($r \approx 1$fm) strong attraction
  - long range (r>1.5fm) attraction
- Boson exchange model
  - Yukawa (1935)
  - Klein-Gordon equation

$$\left(\partial^2 + m^2\right)\varphi(x) = g\bar{\psi}\psi$$

  - range of N-N interaction $R \approx 2$fm
  - $R = \hbar c/mc^2 \Rightarrow m \approx 100\text{MeV}/c^2 \Rightarrow$ pion



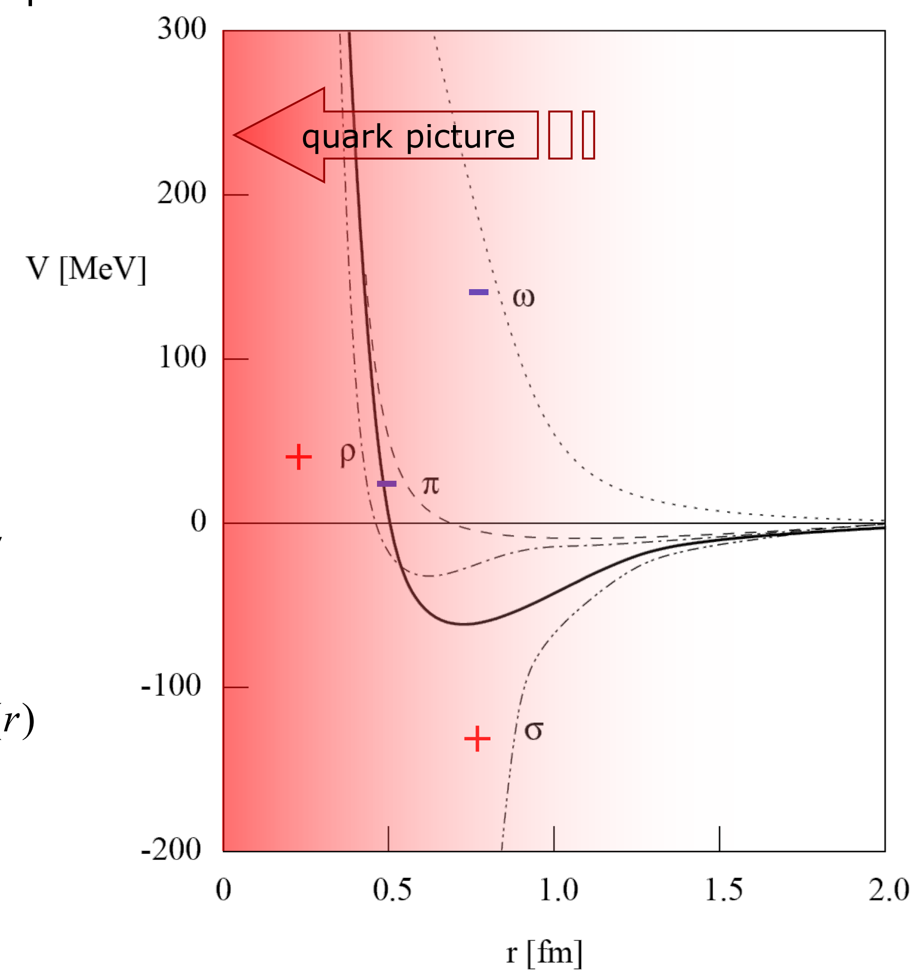
after R. Machleidt,
Adv. Nucl. Phys. **19**, 189 (1989)

G-Parity and N$\bar{\text{N}}$ Potential

- strong interaction conserves isospin and C-parity
- *G*=charge conjugation + 180° rotation around 2nd axis in isospin
  - Lee und Yang 1956, L. Michel 1952 „Isoparity"
  - G-parity of particle-antiparticle multipletts

$$G|f\bar{f}\rangle = (-1)^I C|f\bar{f}\rangle = (-1)^{I+L+S}|f\bar{f}\rangle$$

$$G|\pi^{\pm 0}\rangle = (-1)^1 C|\pi^{\pm 0}\rangle = -|\pi^{\pm 0}\rangle$$
$$G|\rho\rangle = (-1)^1 C|\rho\rangle = +|\rho\rangle$$
$$G|\omega\rangle = (-1)^0 C|\omega\rangle = -|\omega\rangle$$
$$G|\sigma\rangle = (-1)^0 C|\sigma\rangle = +|\sigma\rangle$$



- Hans-Peter Dürr and Edward Teller, Phys. Rev. **101**, 494 (1956)
  - sign change in coupling constant

$$V(NN)(r) = \sum_M V_M(r) \rightarrow V(N\bar{N})(r) = \sum_M G_M V_M(r)$$

Elastic Antiproton-Nucleus Scattering

Elastic Scattering of Antiprotons from Complex Nuclei*

GERSON GOLDHABER† AND JACK SANDWEISS‡

Physics Department and Radiation Laboratory, University of California, Berkeley, California

(Received May 5, 1958)

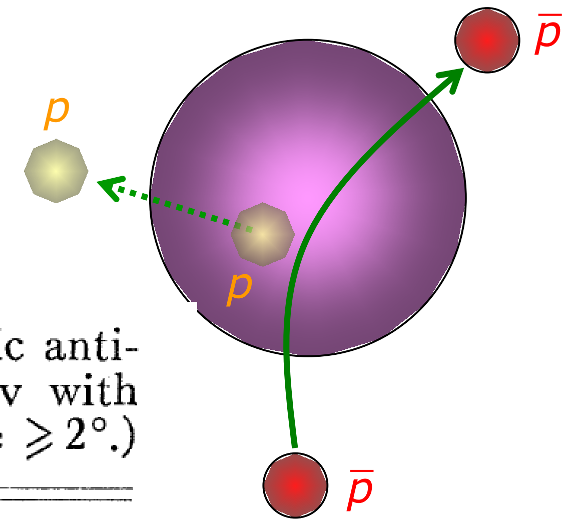


TABLE III. Comparison of experimental data for elastic antiproton-nucleus scattering of energy $T_{\bar{p}}=80$ to 200 Mev with Glassgold's calculations at $T_{\bar{p}}=140$ Mev. (Projected angle $\gtrsim 2°$.)

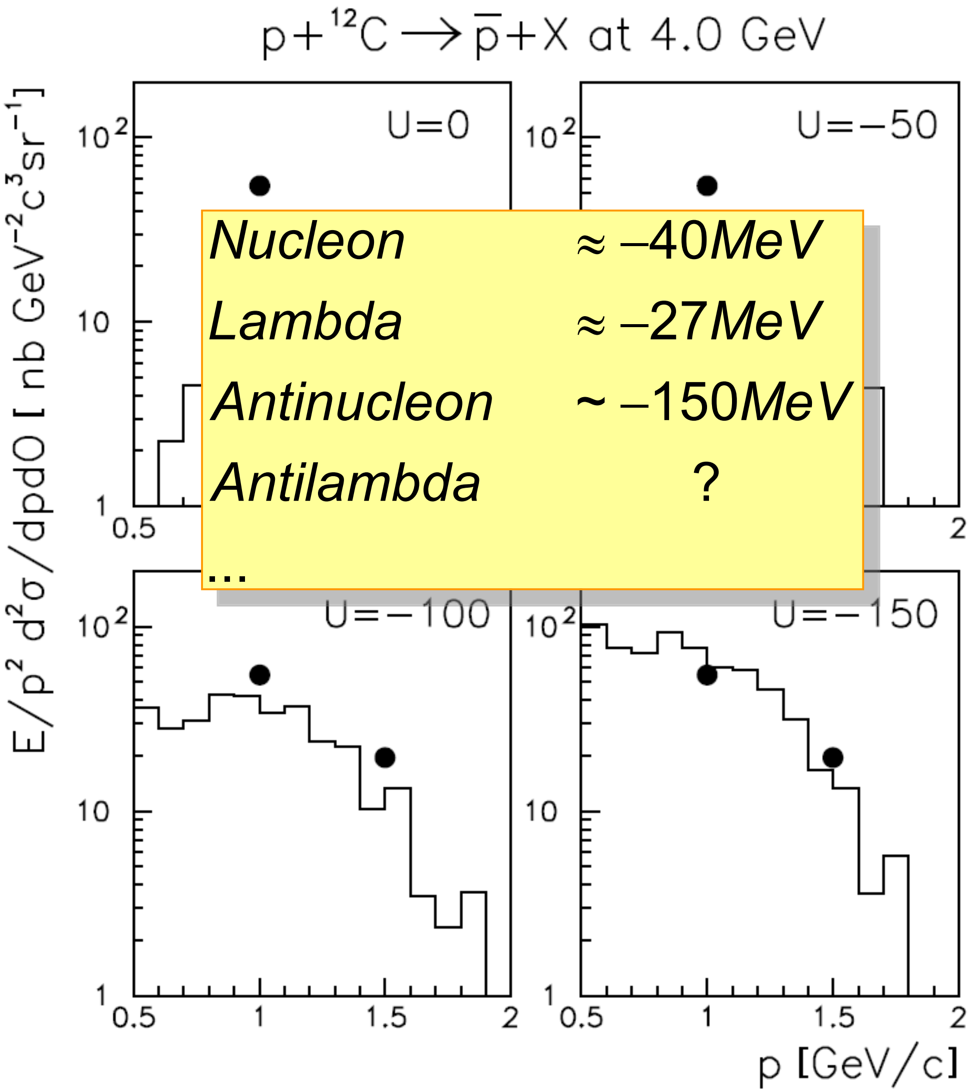
		Number of events	
Angular interval (degrees)	Experimental ($T_{\bar{p}}=80$ to 200 Mev)	Calculated for potential[a] $V=-15$ Mev $W=-50$ Mev	Calculated for potential[a] $V=-528$ Mev $W=-50$ Mev
2–6	54	56	71
6–12	20	17.1	24
12–24	5	4.3	10
24–180	1	1.4	9.5
2–180	80	78.8	114.5

Antiprotonproduction in HI Collisions

- see e.g.

  A. Sibirtsev, W. Cassing et al., Nucl. Phys. A **632**, 131 (1998)

  C. Spieles *et al*., Phys. Rev. C **53**, 2011-2013 (1996)

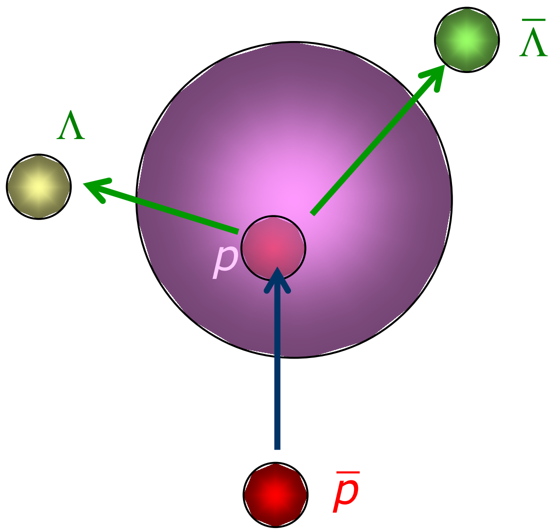


Nucleon	$\approx -40 MeV$
Lambda	$\approx -27 MeV$
Antinucleon	$\sim -150 MeV$
Antilambda	?
...	

Can we measure the potential for $\overline{Y}$?

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

- $p + \bar{p} \to \Lambda + \bar{\Lambda}$ close to threshold in complex nuclei
- Question: is the momentum of the Λ and anti-Λ equal?
- If yes, Λ and anti-Λ that leave the nucleus will have different asymptotic momenta
  - the momentum difference is sensitive to the potential difference



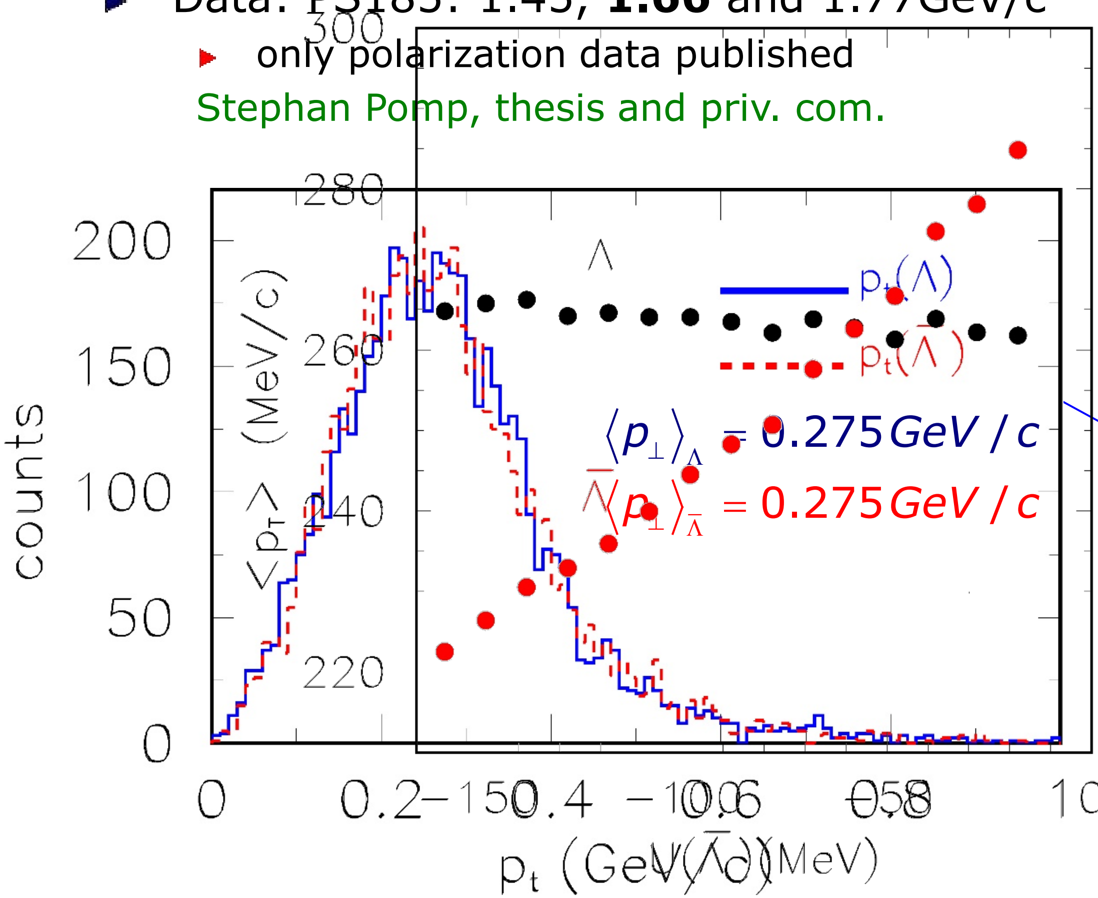
- experimental complications
  - need to average over Fermi motion
  - leading effect
  - exclusiveness

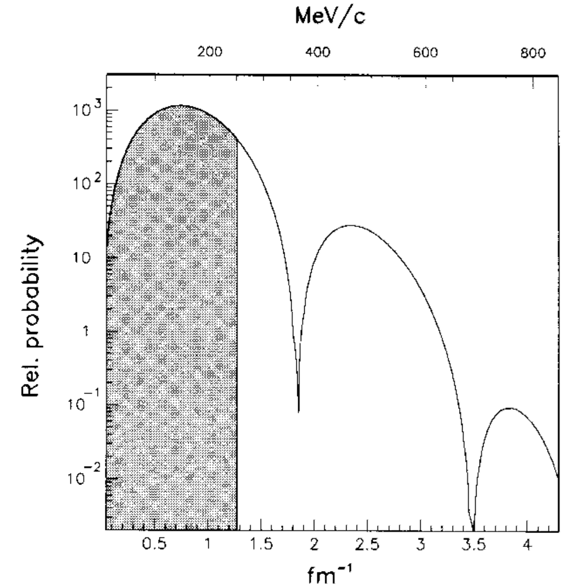
$\Rightarrow$ need to look at *average transverse momentum close to threshold of coincident* $\Lambda\bar{\Lambda}$ *pairs*

Pair production in Nuclei: $\bar{p}\,^{12}C \rightarrow \bar{\Lambda}\Lambda X$

- Simulations: Antiproton momentum: 1.66 GeV
  - Λ potential: -28MeV
  - Fermi motion ($1s_{1/2}$ and $1p_{3/2}$ single-particle wf)
  - angular distribution (leading effect)
  - absorption (still crude)
- Data: PS185: 1.45, **1.66** and 1.77GeV/c
  - only polarization data published

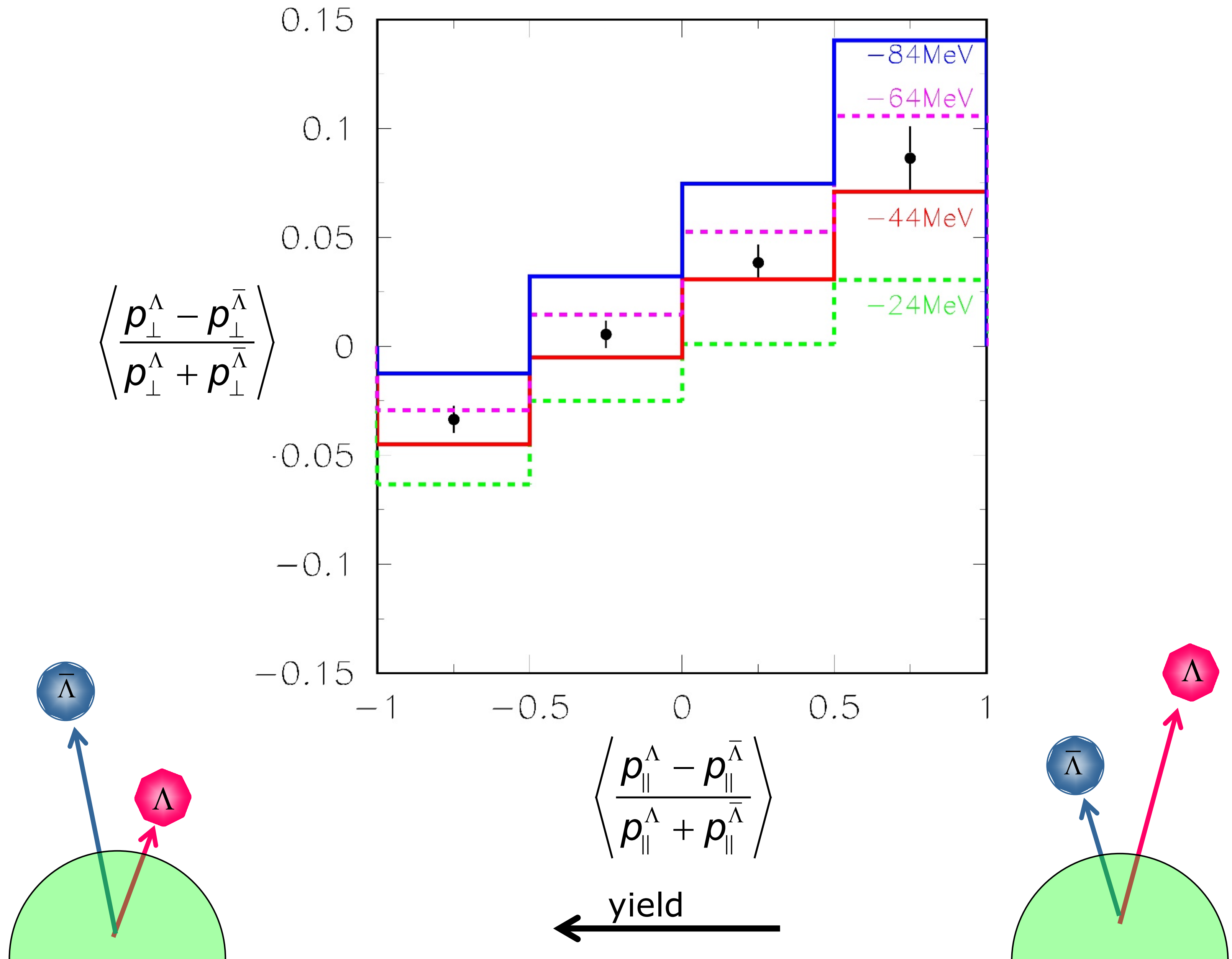
Stephan Pomp, thesis and priv. com.





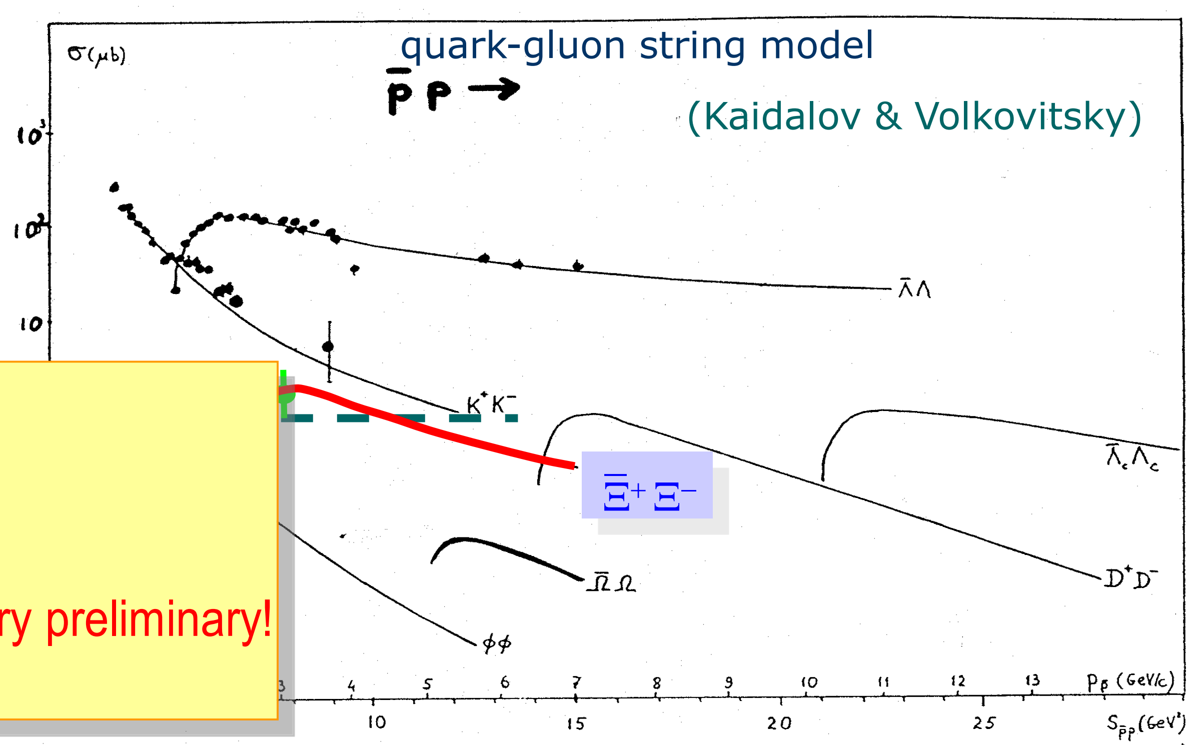
$\bar{\Lambda}$ have larger momenta $\Rightarrow$ less influenced by potential or Fermi motion

A Closer Look…



Intermezzo

- the (exclusive) production of B-$\bar{B}$ pairs in nuclei by antiproton beams may offer the possibility to study the behaviour of antibaryons in nuclei



Nucleon	≈ -40MeV	
Lambda	≈ -27MeV	
Antinucleon	~ -150MeV	
Antilambda	~ -50MeV	very preliminary!
...		

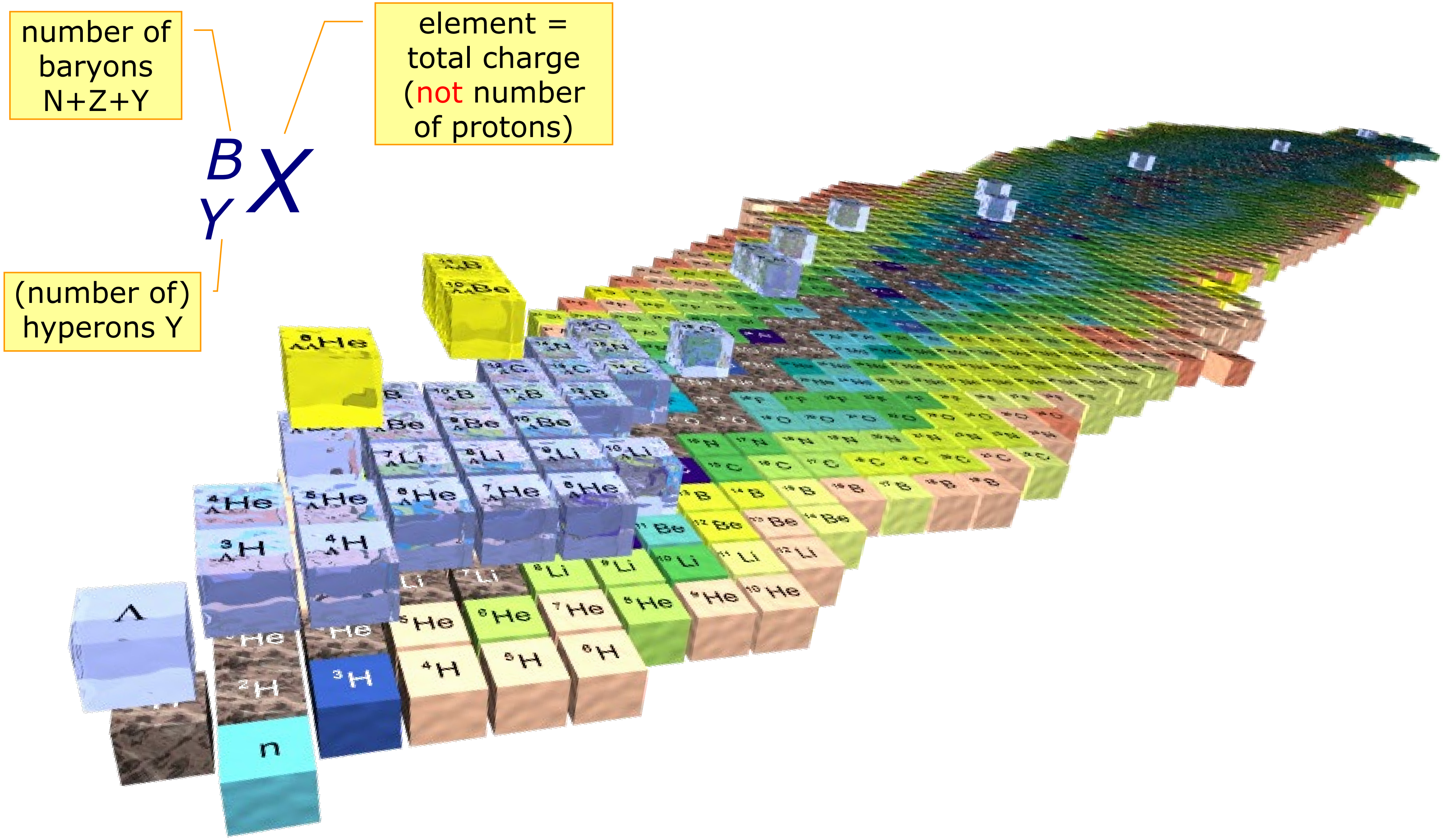
- it will be interesting to look for relations between B-$\bar{B}$ and B-B interactions on a more fundamental (quark) level

EXOTIC (Single) Hypernuclei

Das Meer ist friedlich, legen wir ab,
alle Zeichen stehen günstig,
ein glücklicher Ausgang ist uns
beschieden, ja, die Reise mag beginnen.

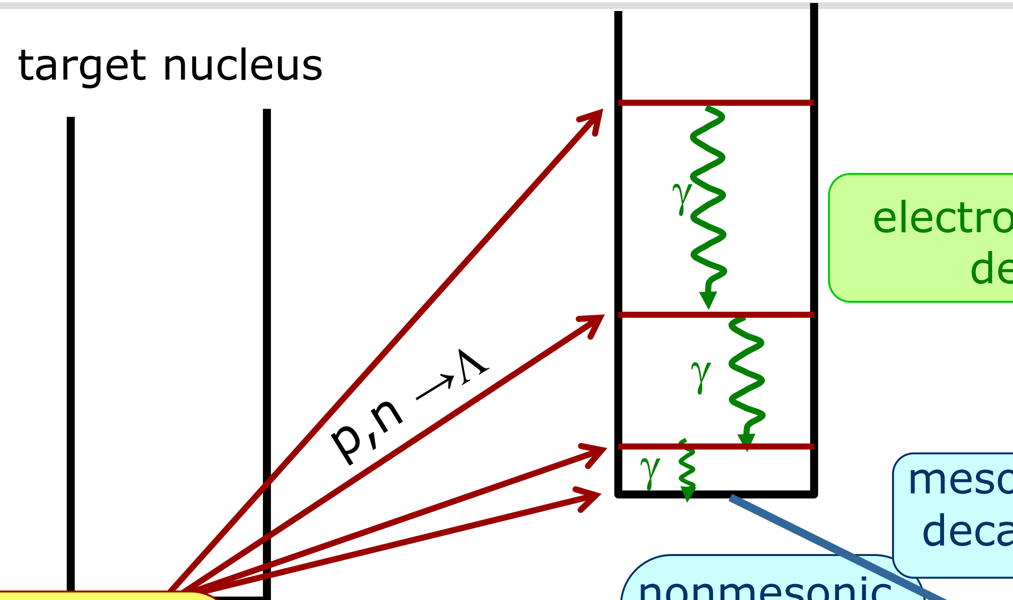
Idomeneo

Baryon-baryon interaction



- Isospin dependence of Y-N and Y-Y interaction?
  ⇒ Information on hyperons in neutron rich matter/nuclei needed

Birth, life and death of a hypernucleus



electromagnetic decays

mesonic decays $\Lambda \rightarrow p\pi^{-}$ $\Lambda \rightarrow n\pi^{0}$

nonmesonic weak decay
$\Lambda p \rightarrow np$
$\Lambda n \rightarrow nn$
$\Lambda\Lambda \rightarrow YN$

hadronic decay in emulsion

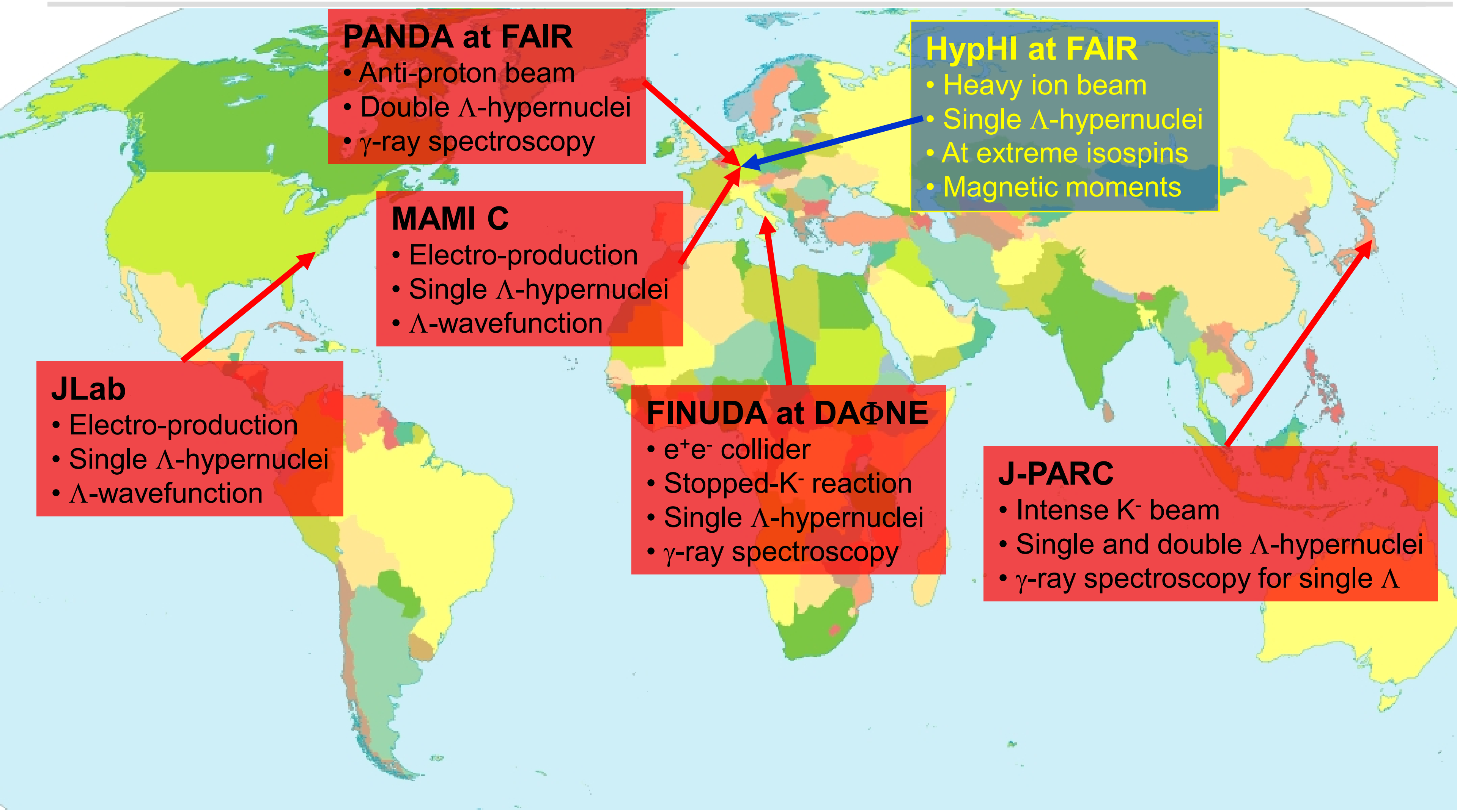
strangeness deposition
$e^{+} + e^{-} \rightarrow \Phi \rightarrow K^{+} + K^{-}$
$K^{-}_{stopped} + {}^{A}Z \rightarrow {}^{A}_{\Lambda}Z + \pi^{-}$
FINUDA

strangeness production
(π^{+}, K^{+}), (π^{-}, K^{0})
BNL,KEK

strangeness exchange
(K^{-}, π^{-}) , (K^{-}, π^{0})
BNL,KEK,JPARC

electroproduction
(e,e´K+) , (γ,K+)
Jlab, MAMI-C

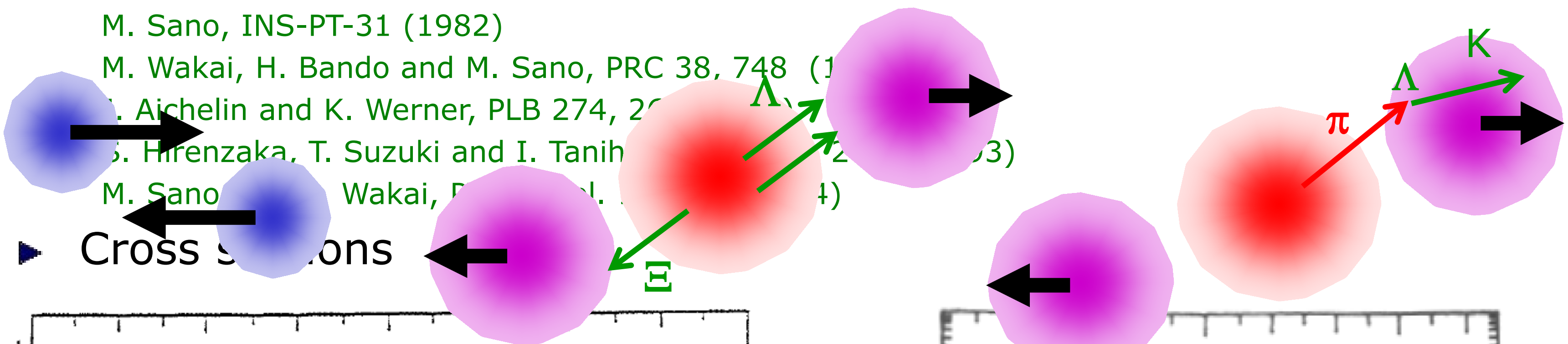
International Hypernuclear Network



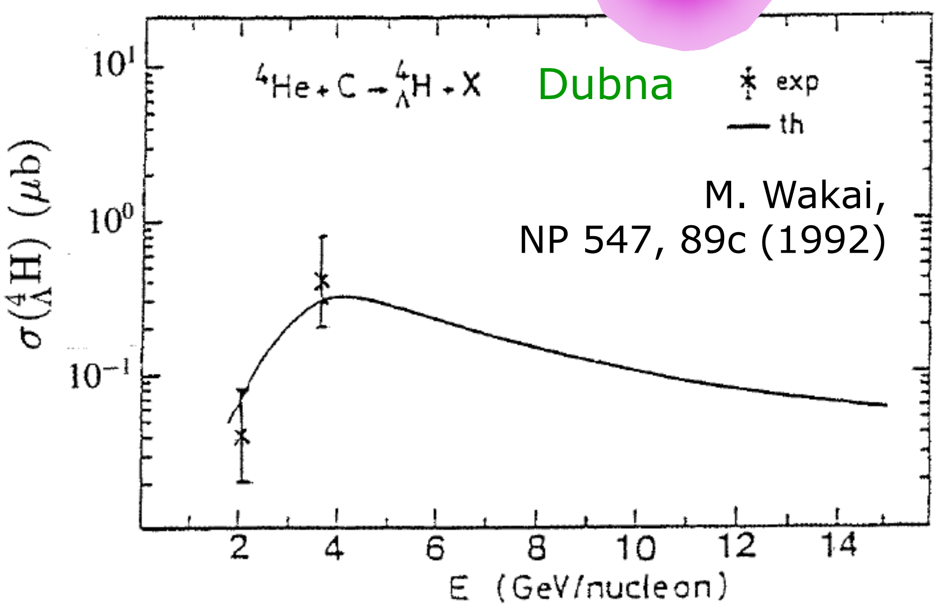
Relativistic Hypernuclei

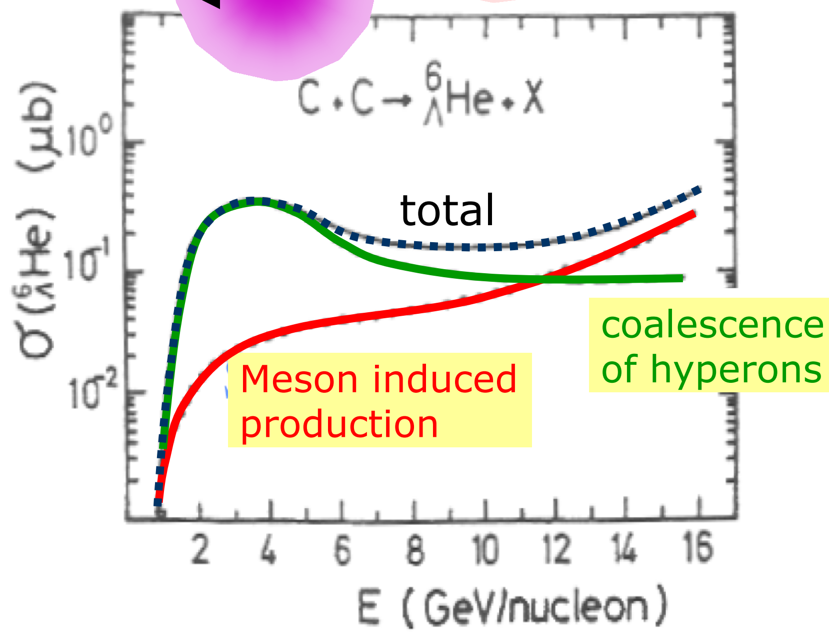
- Production of hypernuclei in relativistic heavy ion collisions
  - Production of many hyperons
  - Multiple Coalescence of hyperons with fragments
  - (π,K), (K,π) and (K^-,K^+) reactions on fragments
- Many predictions based on coalescence model

  M. Sano, INS-PT-31 (1982)
  M. Wakai, H. Bando and M. Sano, PRC 38, 748 (1
  . Aichelin and K. Werner, PLB 274, 2
  . Hirenzaka, T. Suzuki and I. Tanih 2 3)
  M. Sano Wakai, 4)



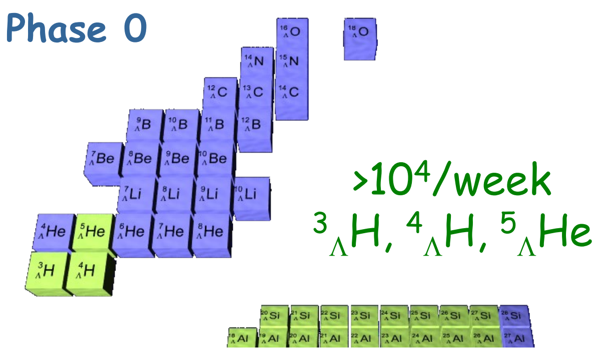
- Cross s ons

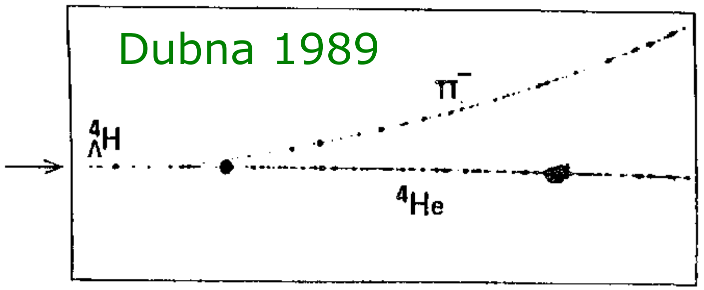


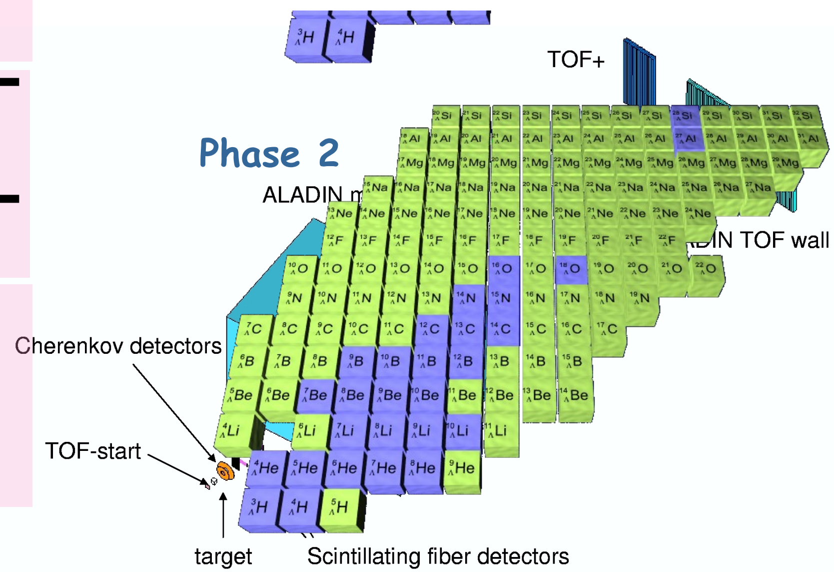


The HYPHI Project T. Saito

2004	▶ HypHI project started ▶ LOI and progress report to the GSI PAC, Design study
2005	
2006	▶ Design study, preparation for the phase 0 experiment
2007	▶ Phase 0: experiment with $^{3}_{\Lambda}H$, $^{4}_{\Lambda}H$ and $^{5}_{\Lambda}He$
2008	▶ Design study for the setup for hypenuclear non-mesonic weak decay measurements
2009	▶ Phase 1: Experiments for proton rich hypernuclei
2010	
~2011	▶ Phase2: Experiment for neutron rich hypernuclei at NuSTAR/FAIR
	▶ Phase 3: Hypernuclear separator ▶ Hypernuclear magnetic moments ▶ Hypernuclear driplines

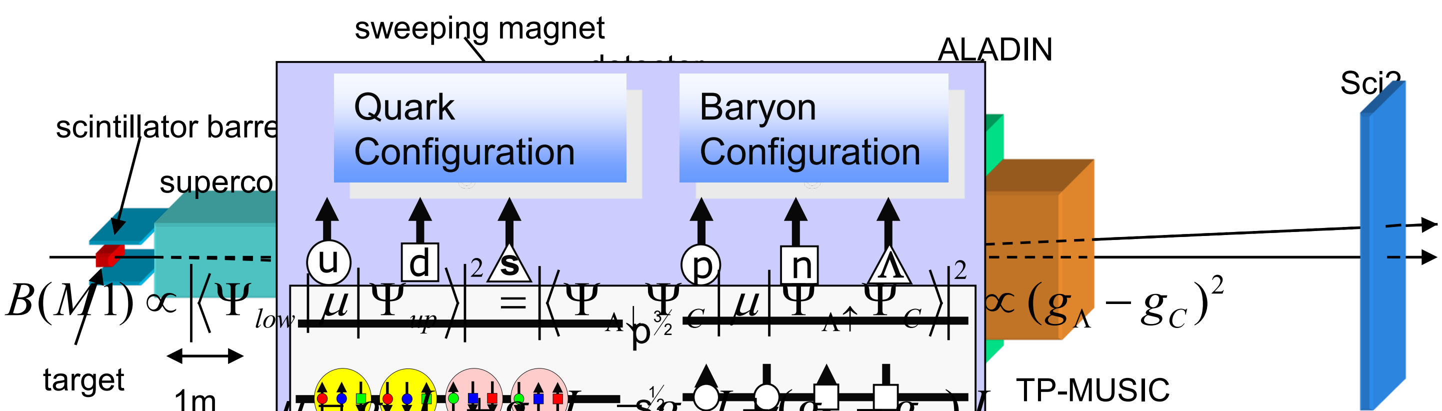


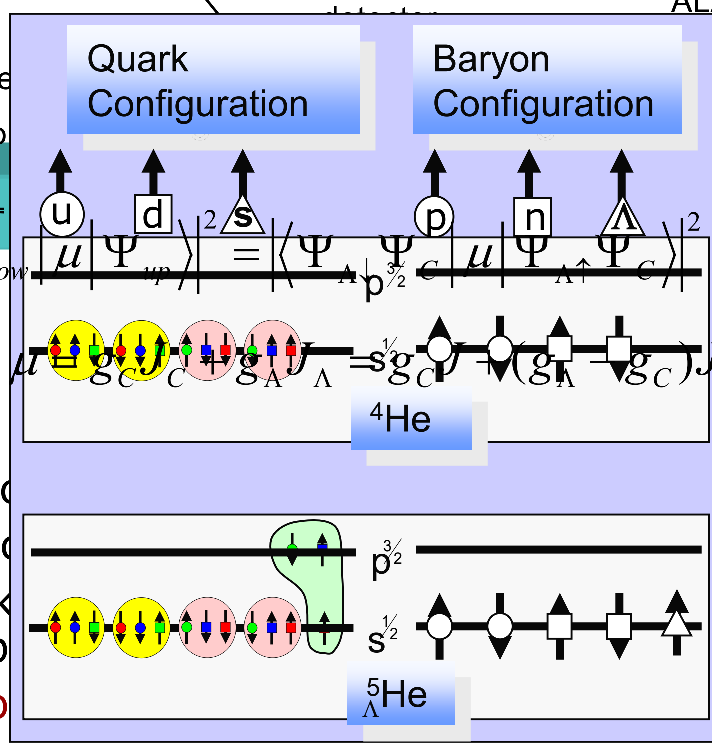




Magnetic moment of Λ in nuclei

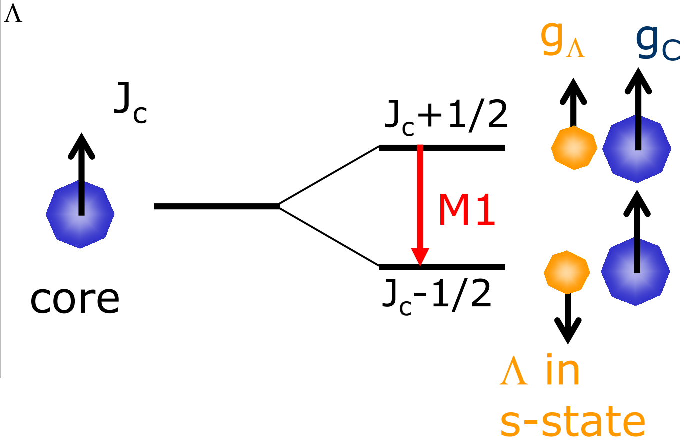
- Baryons do not „melt" in nuclei: quark effects are small
- EMC-effect: Whether there is any change in nucleon properties in nuclei remains controversial.
  - If mass and size of a baryons changes inside nuclei, also it's magnetic moment might change
  - If so, why? Meson current, $\Lambda\Sigma$ mixing, partial deconfinement…?





- Spin prec
  - Λ dec
  - Work
    doub

g_Λ do



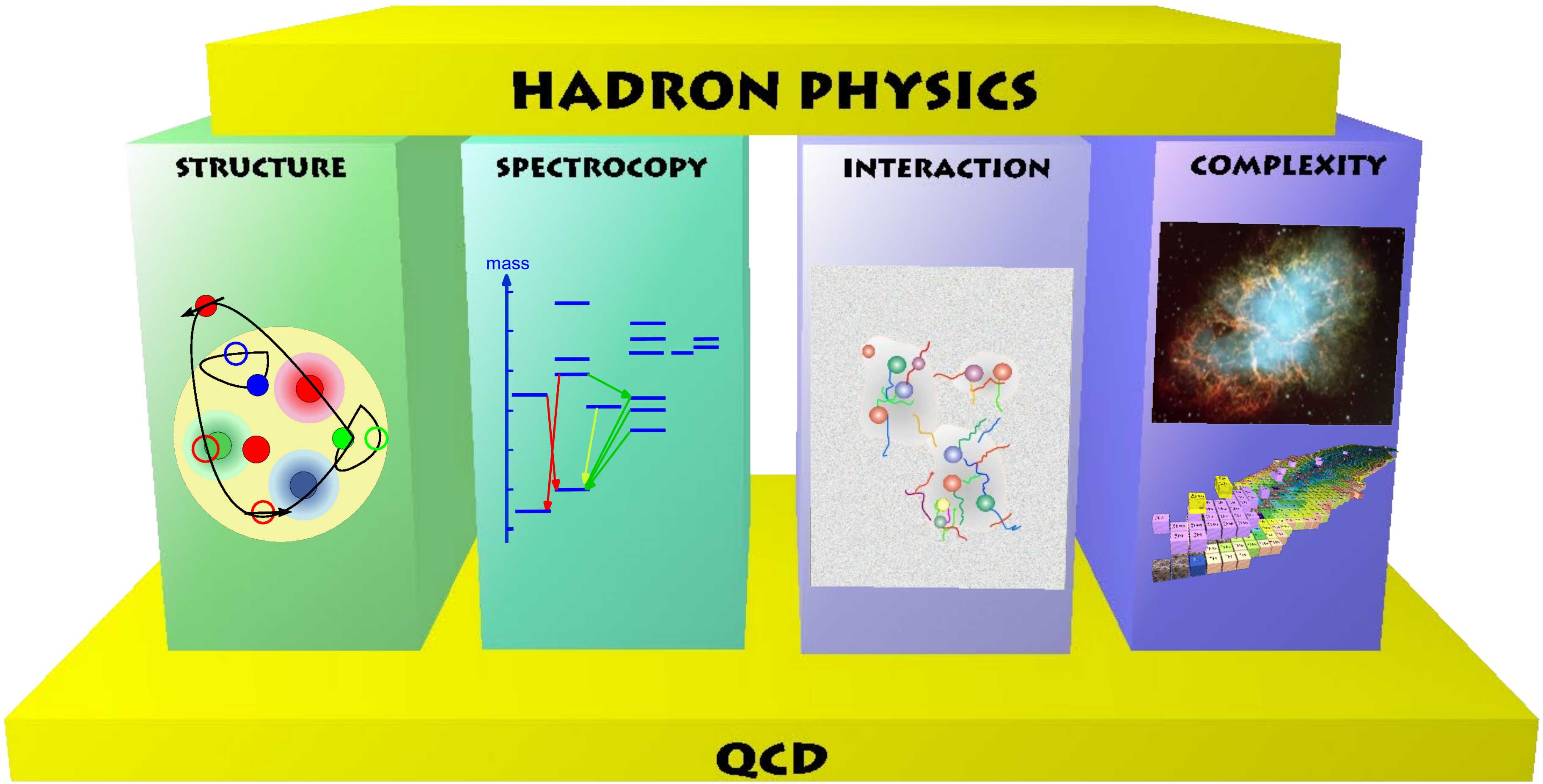
CONCLUSION

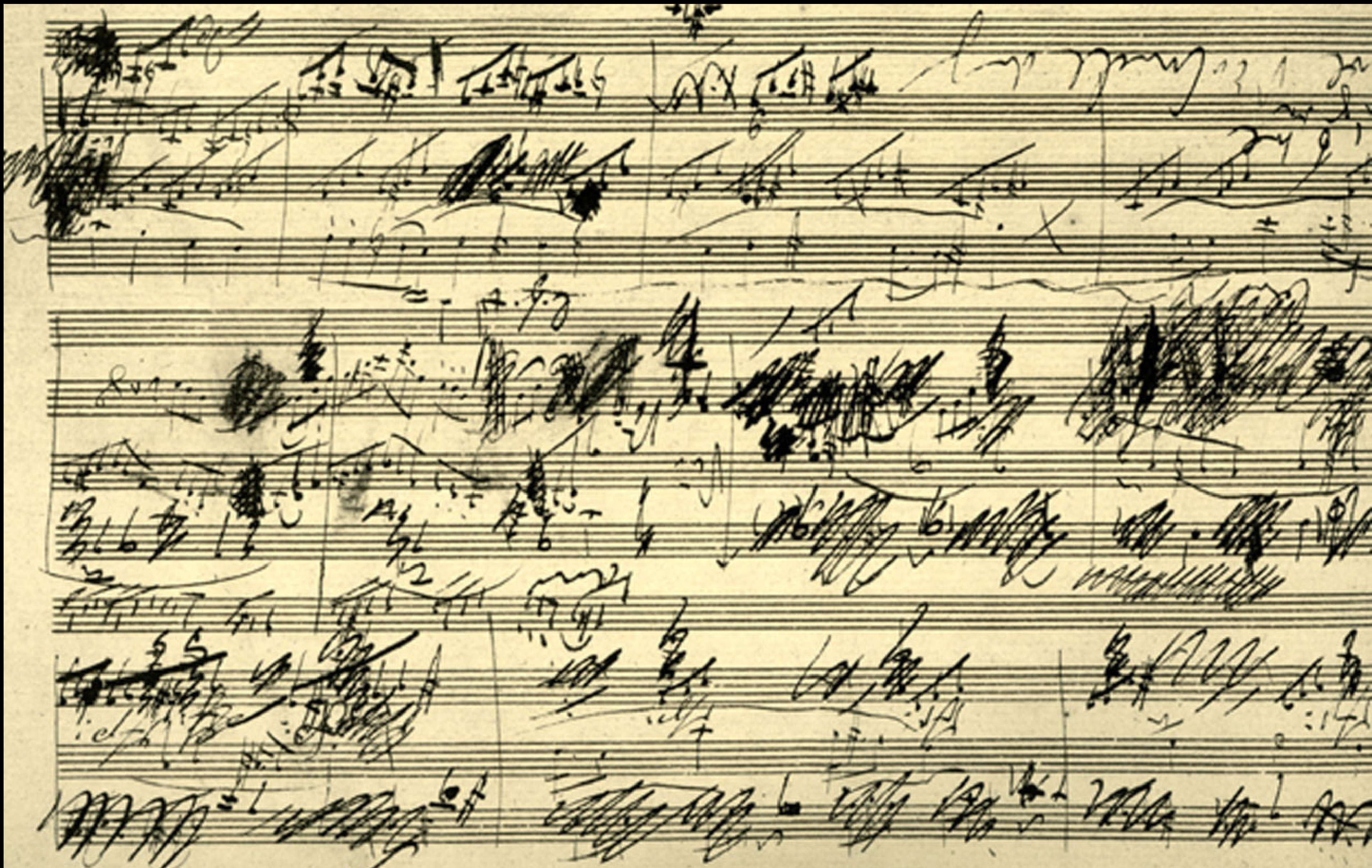
Und nun genug des schmeichelnden Lobes,
Säumt euch nicht mit dem Werke der Liebe,
Geht, und vollzieht eures Herzens Wünsche.

La Clemenza di Tito

Pillars of Hadron Physics

JOHANNES GUTENBERG UNIVERSITÄT MAINZ





Beethoven Op 69i for Cello and Piano

Richard (Dick) Dalitz

(1925-2006)

Wer nur einer treu ist, ist gegen die anderen grausam

Don Giovanni

The END

Thank you for your attention