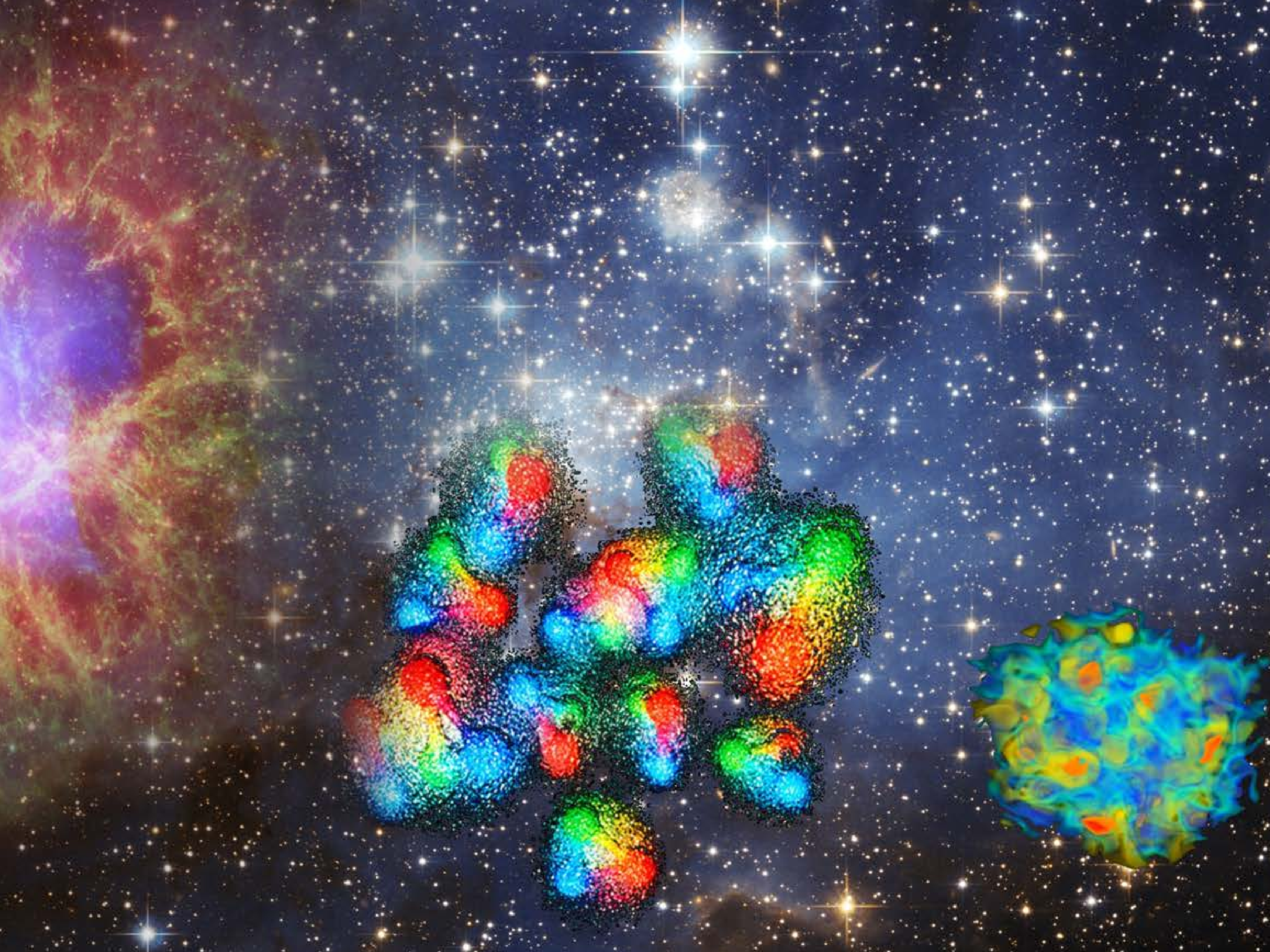


1997

Bemerkungen zu einem Hochenergie-Experimentierspeicherring Projekt bei GSI

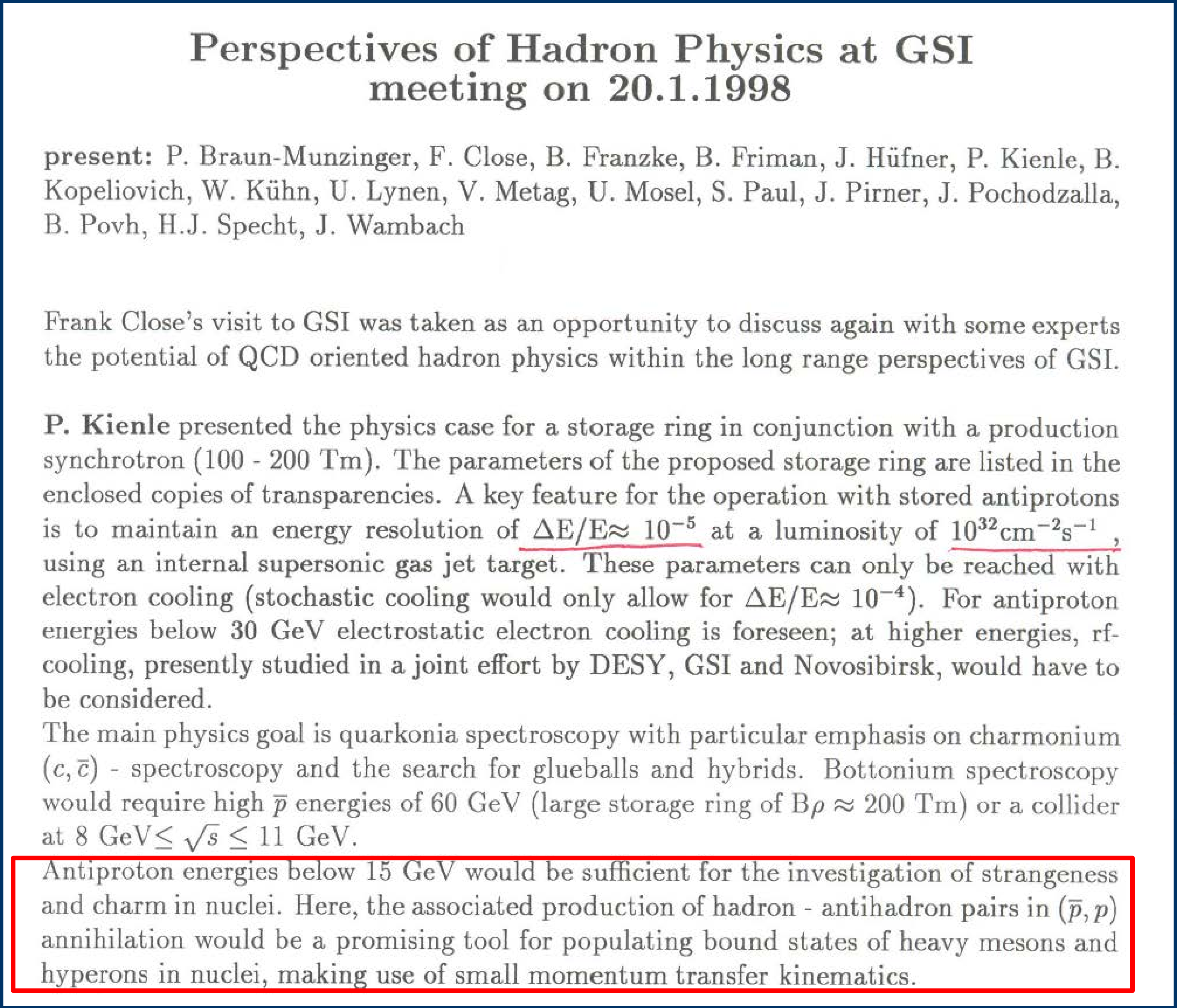
Paul Kienle, Physik-Department E12, TU München

Im Zusammenhang mit den Ausbauplänen der GSI wird ein 200 Tm Hochenergie-Experimentierspeicherring HESR vorgeschlagen, der zusammen mit einem 100 Tm Synchrotron SIS 100 eine neue Experimentiereinrichtung ergäbe, die einmalige Experimente zur Untersuchung der Struktur und Dynamik von Hadronen mit schweren Quarks (s,c), verdichteter und erhitzter hadronischer Materie und der Struktur von neutronenarmen und -reichen Kernen erlauben würde.

⋮

Zur Physik am HESR

Mögliche Physikprogramme schließen Experimente ein, die im Rahmen des LISS-Projekts und früher für SuperLEAR diskutiert wurden. Die höhere Energie des HESR im Vergleich zu LISS und SuperLEAR, die Hochenergie-Elektronenkühlerausstattung, die Verfügbarkeit von Schwerionenstrahlen und von SIS 100-Sekundärstrahlen lassen darüber hinaus ein wesentlich breiteres Experimentierprogramm zu.



Perspectives of Hadron Physics at GSI
meeting on 20.1.1998

present: P. Braun-Munzinger, F. Close, B. Franzke, B. Friman, J. Hüfner, P. Kienle, B. Kopeliovich, W. Kühn, U. Lynen, V. Metag, U. Mosel, S. Paul, J. Pirner, J. Pochodzalla, B. Povh, H.J. Specht, J. Wambach

Frank Close's visit to GSI was taken as an opportunity to discuss again with some experts the potential of QCD oriented hadron physics within the long range perspectives of GSI.

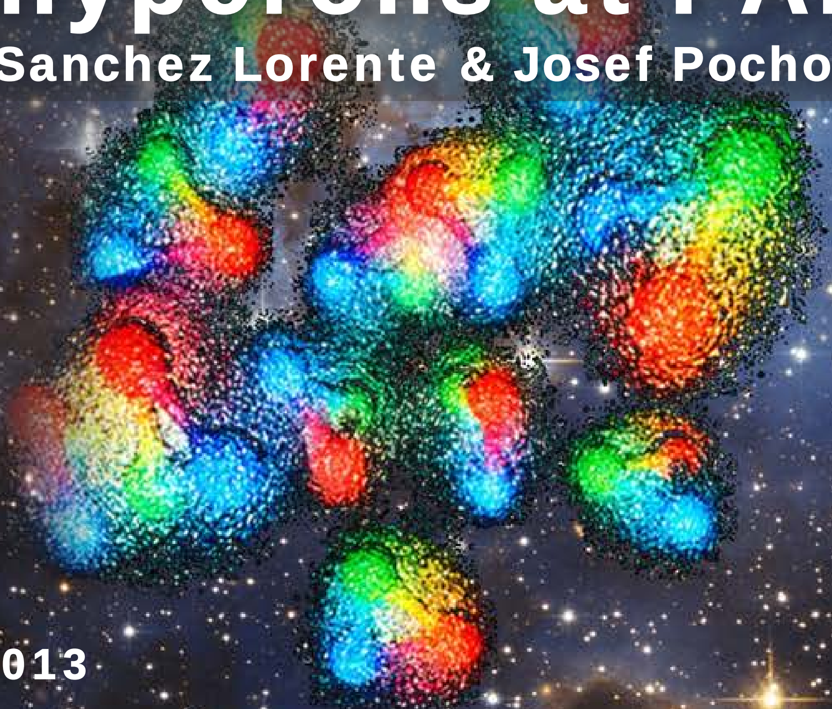
P. Kienle presented the physics case for a storage ring in conjunction with a production synchrotron (100 - 200 Tm). The parameters of the proposed storage ring are listed in the enclosed copies of transparencies. A key feature for the operation with stored antiprotons is to maintain an energy resolution of $\Delta E/E \approx 10^{-5}$ at a luminosity of $10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, using an internal supersonic gas jet target. These parameters can only be reached with electron cooling (stochastic cooling would only allow for $\Delta E/E \approx 10^{-4}$). For antiproton energies below 30 GeV electrostatic electron cooling is foreseen; at higher energies, rf-cooling, presently studied in a joint effort by DESY, GSI and Novosibirsk, would have to be considered.

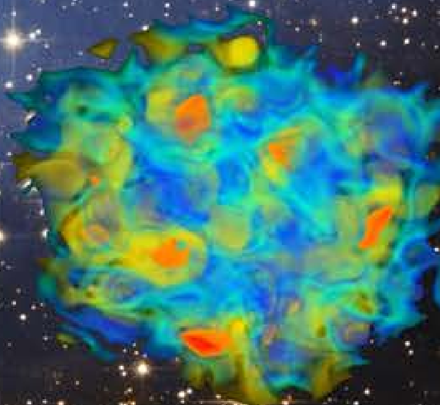
The main physics goal is quarkonia spectroscopy with particular emphasis on charmonium $(c, \bar{c})$ - spectroscopy and the search for glueballs and hybrids. Bottonium spectroscopy would require high $\bar{p}$ energies of 60 GeV (large storage ring of $B\rho \approx 200$ Tm) or a collider at 8 GeV$\leq \sqrt{s} \leq 11$ GeV.

Antiproton energies below 15 GeV would be sufficient for the investigation of strangeness and charm in nuclei. Here, the associated production of hadron - antihadron pairs in $(\bar{p}, p)$ annihilation would be a promising tool for populating bound states of heavy mesons and hyperons in nuclei, making use of small momentum transfer kinematics.

Physics Opportunities with Antihyperons at PANDA

Alicia Sanchez Lorente & Josef Pochodzalla

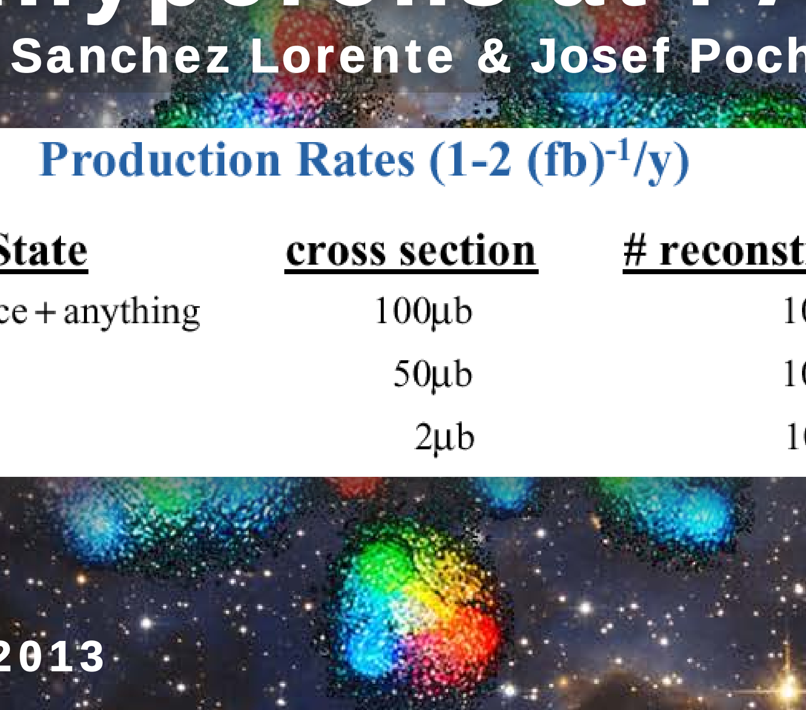




Trento October 21st 2013

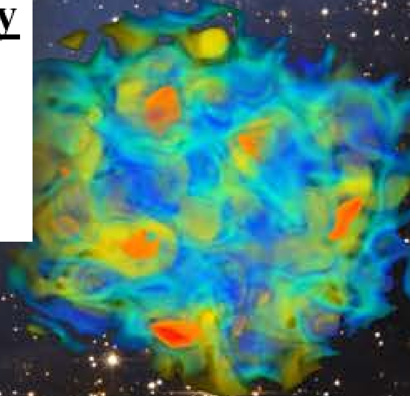
Physics Opportunities with Antihyperons at PANDA

Alicia Sanchez Lorente & Josef Pochodzalla



Production Rates (1-2 $(fb)^{-1}/y$)

Final State	**cross section**	**# reconstr. events/y**
Meson resonance + anything	100µb	10^{10}
$\Lambda\bar{\Lambda}$	50µb	10^{10}
$\Xi\bar{\Xi}(\rightarrow {}_{\Lambda\Lambda}A)$	2µb	10^{8} (10^{5})



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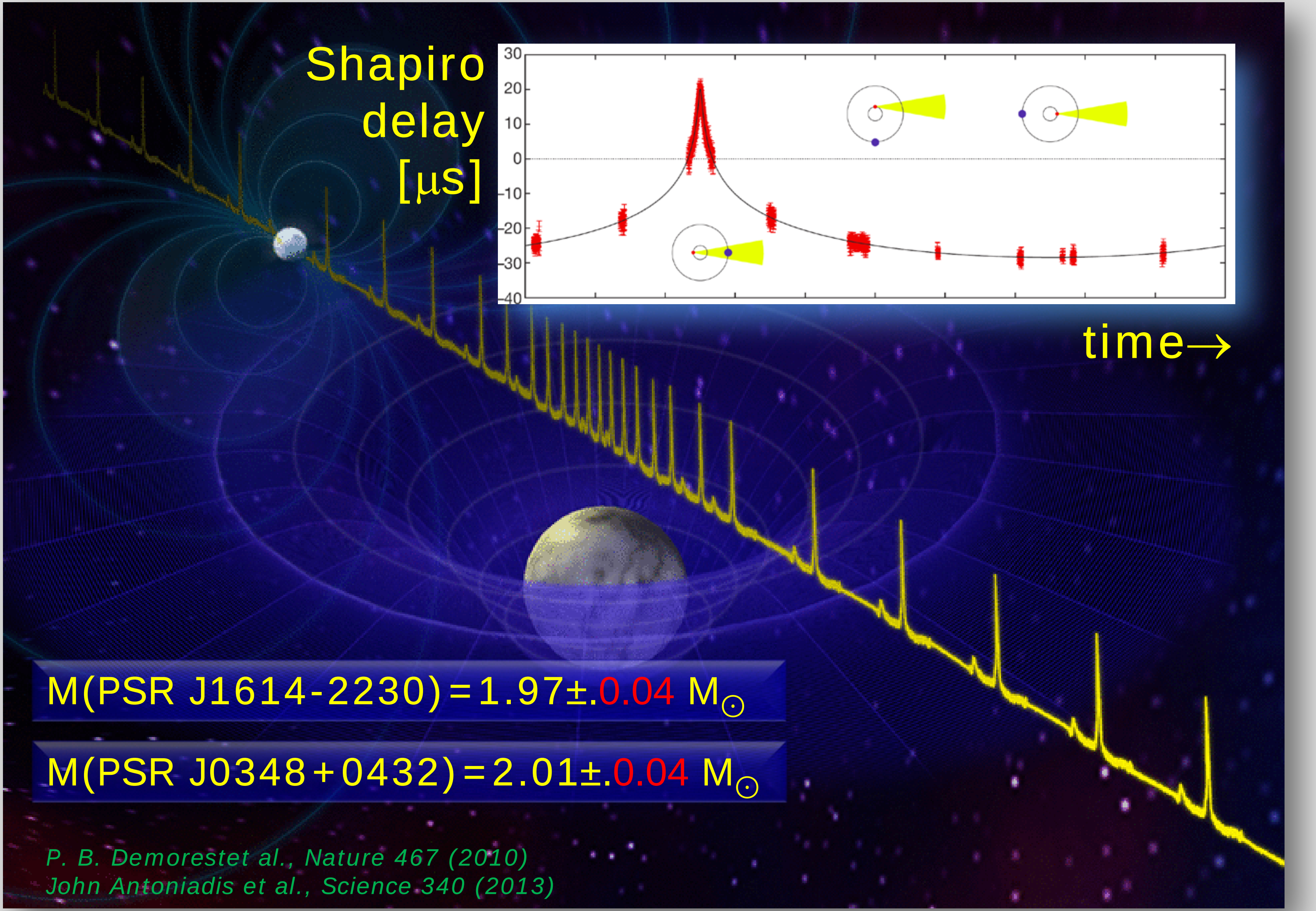
Heavy Neutron Stars

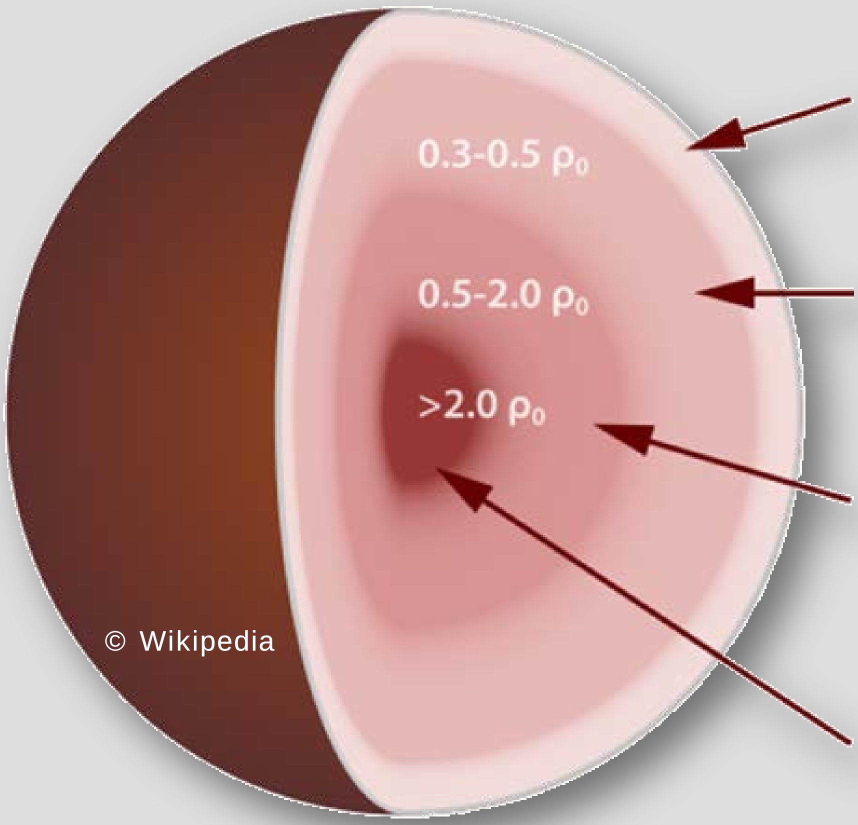


M(PSR J1614-2230) = 1.97±0.04 $M_\odot$

M(PSR J0348+0432) = 2.01±0.04 $M_\odot$

P. B. Demorest et al., Nature 467 (2010)
John Antoniadis et al., Science 340 (2013)

Neutron star in an onionskin



© Wikipedia

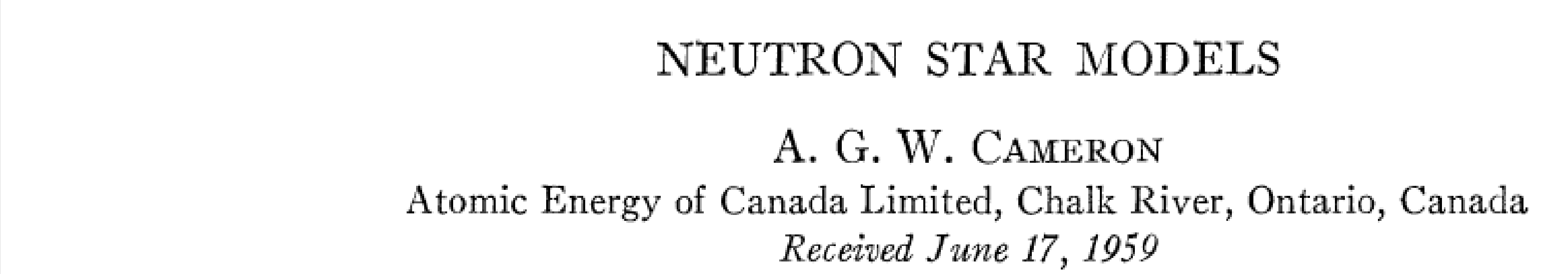
- outer crust
  - Ions, electrons
  - Few hundret meters thick
  - $\rho \leq 4\cdot10^{11}\,\mathrm{g/cm^3} = 2\cdot10^{-3}\rho_0$
  - $m/m_{NS} \approx 10^{-5}$
- inner crust
  - neutrons, protons
  - Thickness 1-2 km
  - $\rho \leq 0.5\rho_0$
- outer core
  - Mostly neutrons
  - Thickness ~8 km
  - $\rho \leq 2\rho_0$
- Inner core
  - Composition ?
  - Thickness 0-3 km ?
  - ρ_{max} = ?

Fragmentation reactions
Liqid-gas phase transition

Central heavy ions collisions

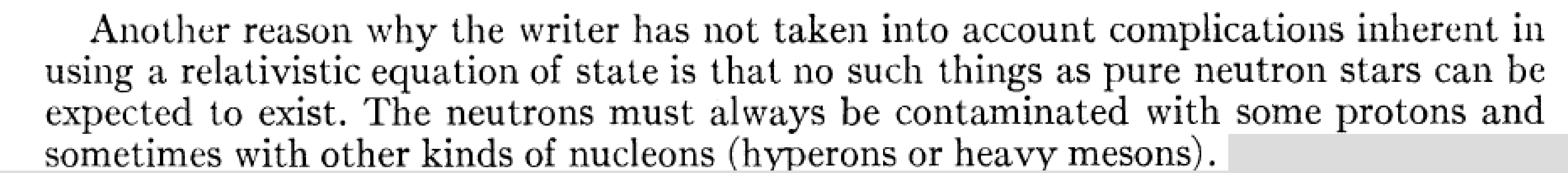
The composition of the inner core determines the maximum mass of a neutron star

hyperons in neutron stars – an old (fairy)story



NEUTRON STAR MODELS

A. G. W. Cameron
Atomic Energy of Canada Limited, Chalk River, Ontario, Canada
Received June 17, 1959

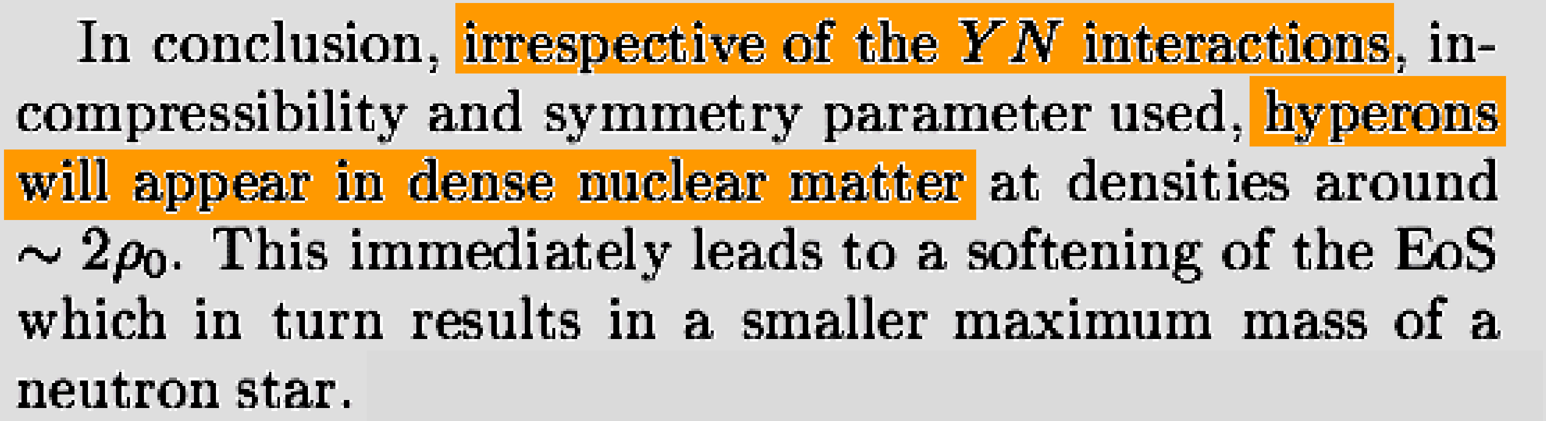


Another reason why the writer has not taken into account complications inherent in using a relativistic equation of state is that no such things as pure neutron stars can be expected to exist. The neutrons must always be contaminated with some protons and sometimes with other kinds of nucleons (hyperons or heavy mesons).

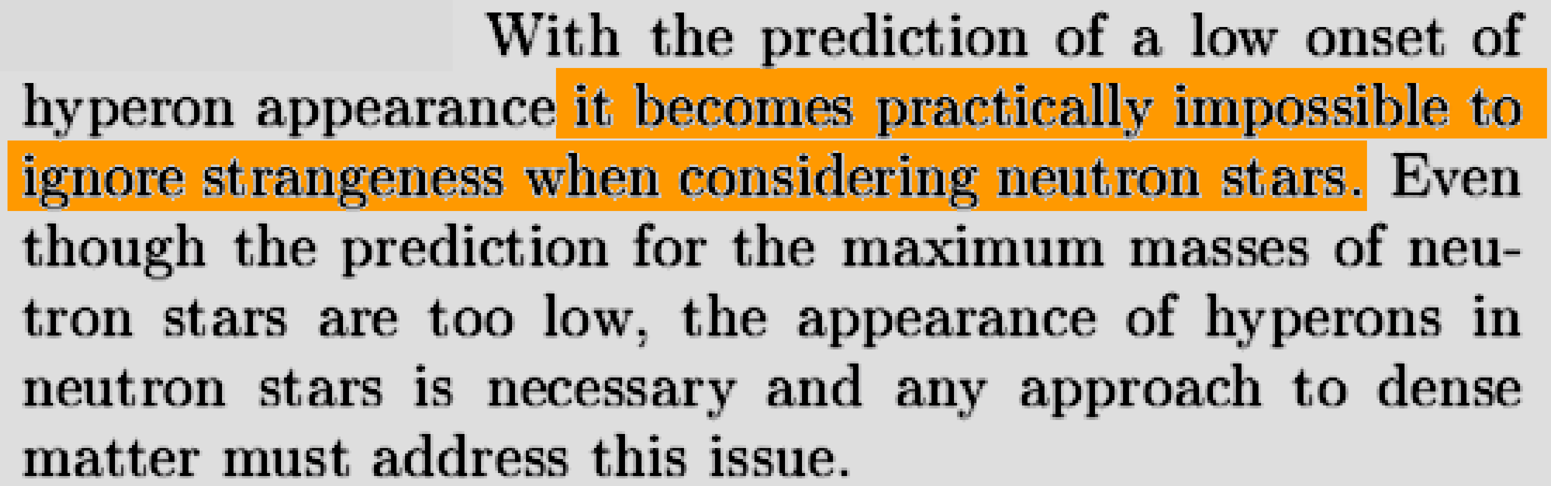
- Alastair G.W. Cameron, Astrophysical Journal, vol. 130, p.884 (1959)

hyperons in neutron stars – an old (fairy)story

- Haris Djapo, Bern-Jochen Schäfer and Jochen Wambach
  arXiv:0811.2939v1 [nucl-th] 18 Nov 2008



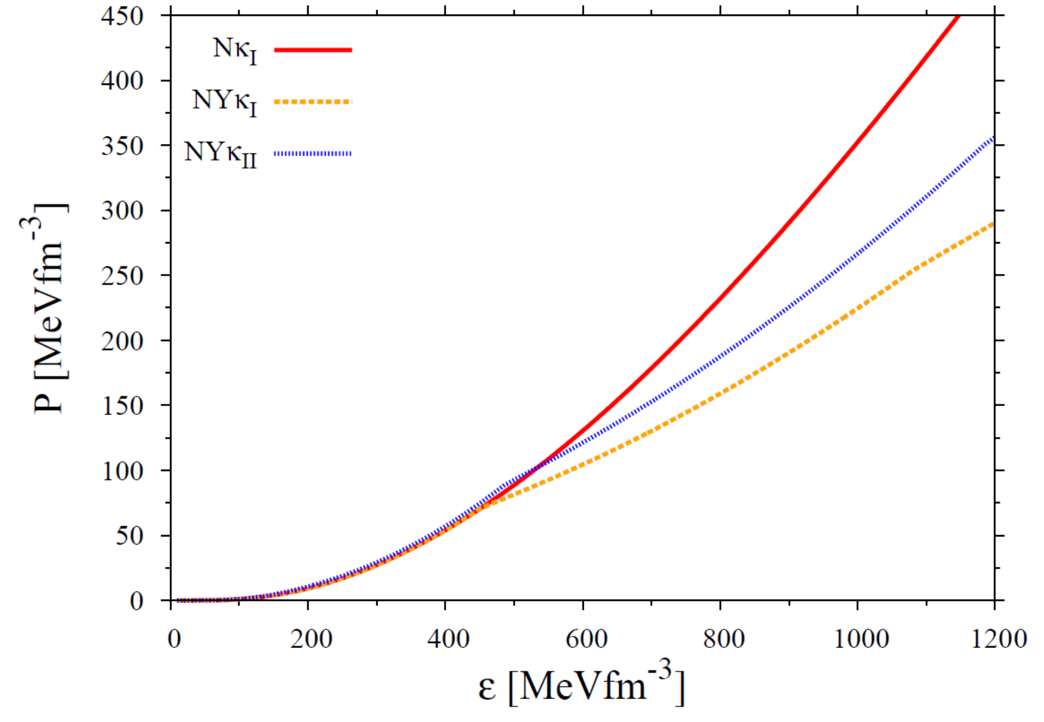
In conclusion, irrespective of the YN interactions, incompressibility and symmetry parameter used, hyperons will appear in dense nuclear matter at densities around $\sim 2\rho_0$. This immediately leads to a softening of the EoS which in turn results in a smaller maximum mass of a neutron star.



With the prediction of a low onset of hyperon appearance it becomes practically impossible to ignore strangeness when considering neutron stars. Even though the prediction for the maximum masses of neutron stars are too low, the appearance of hyperons in neutron stars is necessary and any approach to dense matter must address this issue.

The Hyperon Puzzle in Neutron Stars

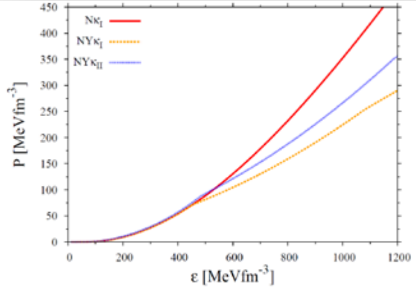
- Appearance of hyperons weaken EOS and result in lower maximum mass

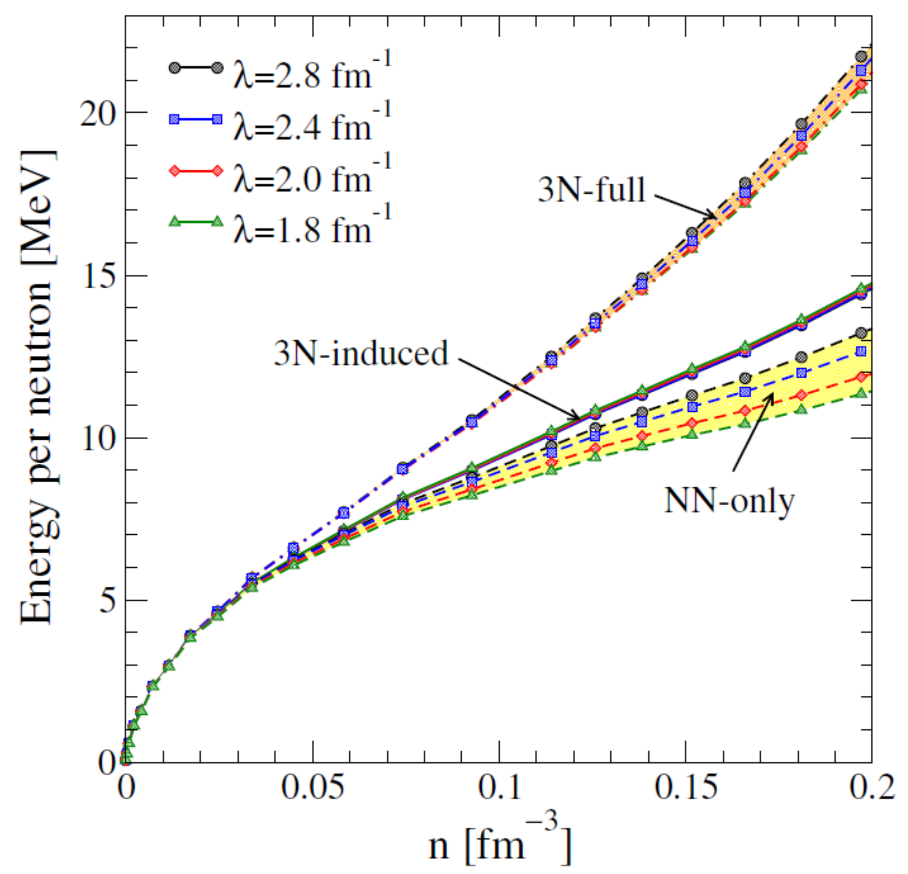


D.L.Whittenbury *et al.*, arXiv:1204.2614

The Hyperon Puzzle in Neutron Stars

- Appearance of hyperons weaken EOS and result in lower maximum mass
- Three baryon forces are essential for the EOS at high density, though it does not ensure $2M_\odot$ NS with hyperons (e.g. Vidana *et al.*)





K. Hebeler *et al.*, arXiv: 1301.7467

The Hyperon Puzzle in Neutron Stars

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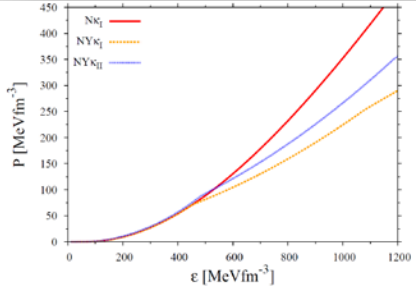
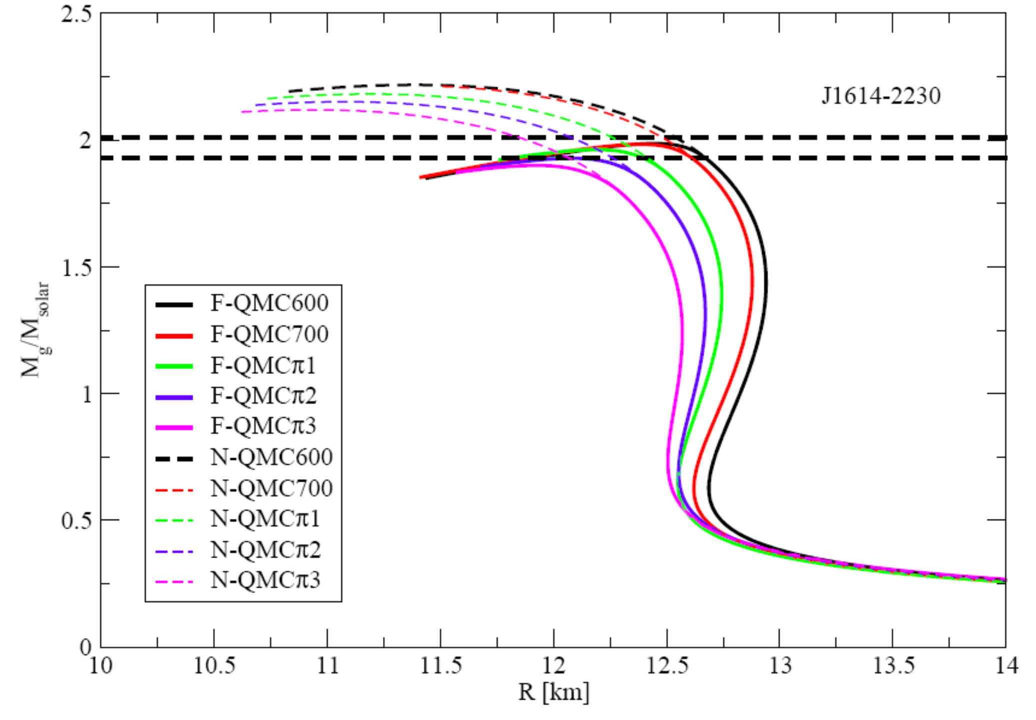
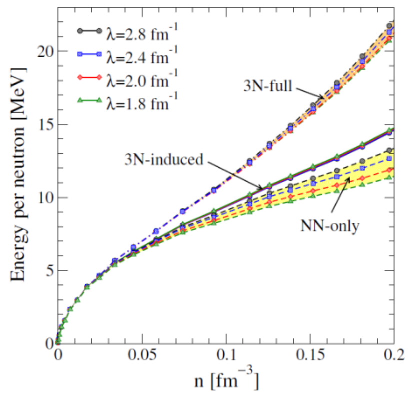




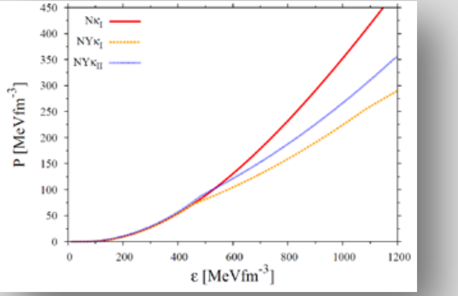


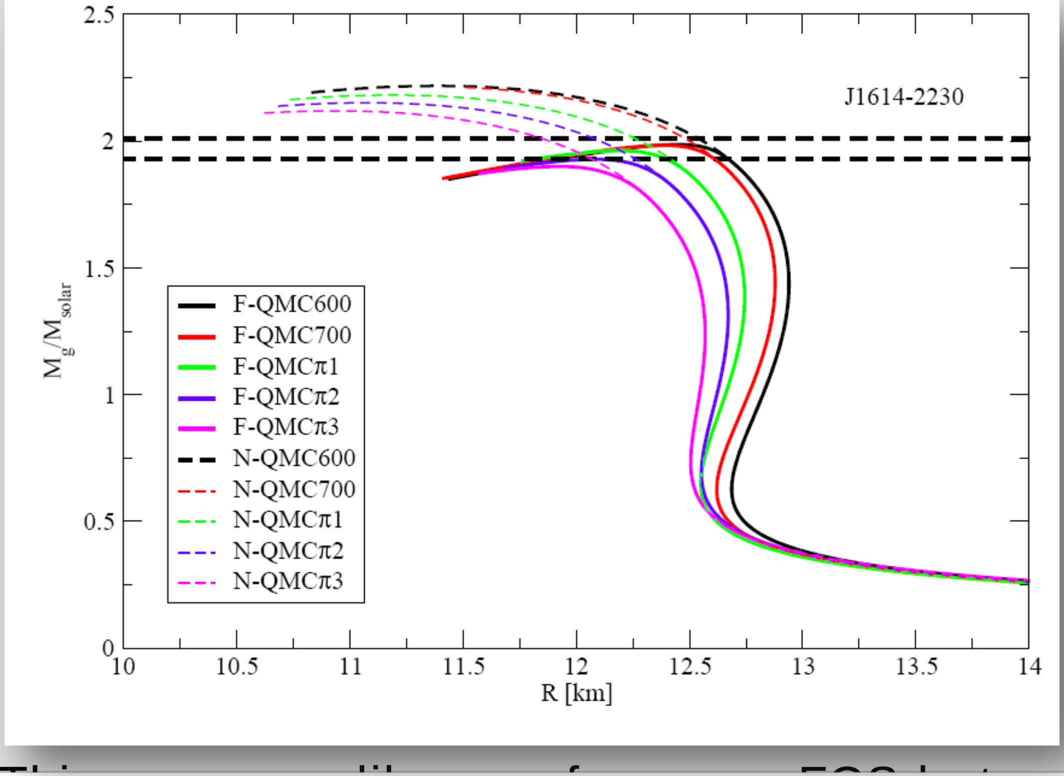
J. R. Stone et al.,
arXiv:1012.2919v1

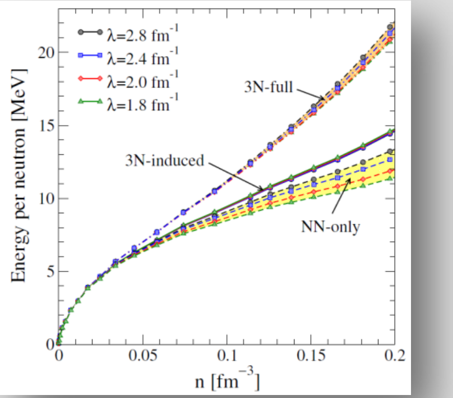
- This causes a dilemma for many EOS but a two solar mass neutron star may still be compatible with the presence of hyperons

The Hyperon Puzzle in Neutron Stars

- Appearance of hyperons weaken EOS and result in lower maximum mass
- Three baryon forces are essential for the EOS at high density, though it does not ensure $2M_\odot$ NS with hyperons (e.g. Vidana *et al.*)





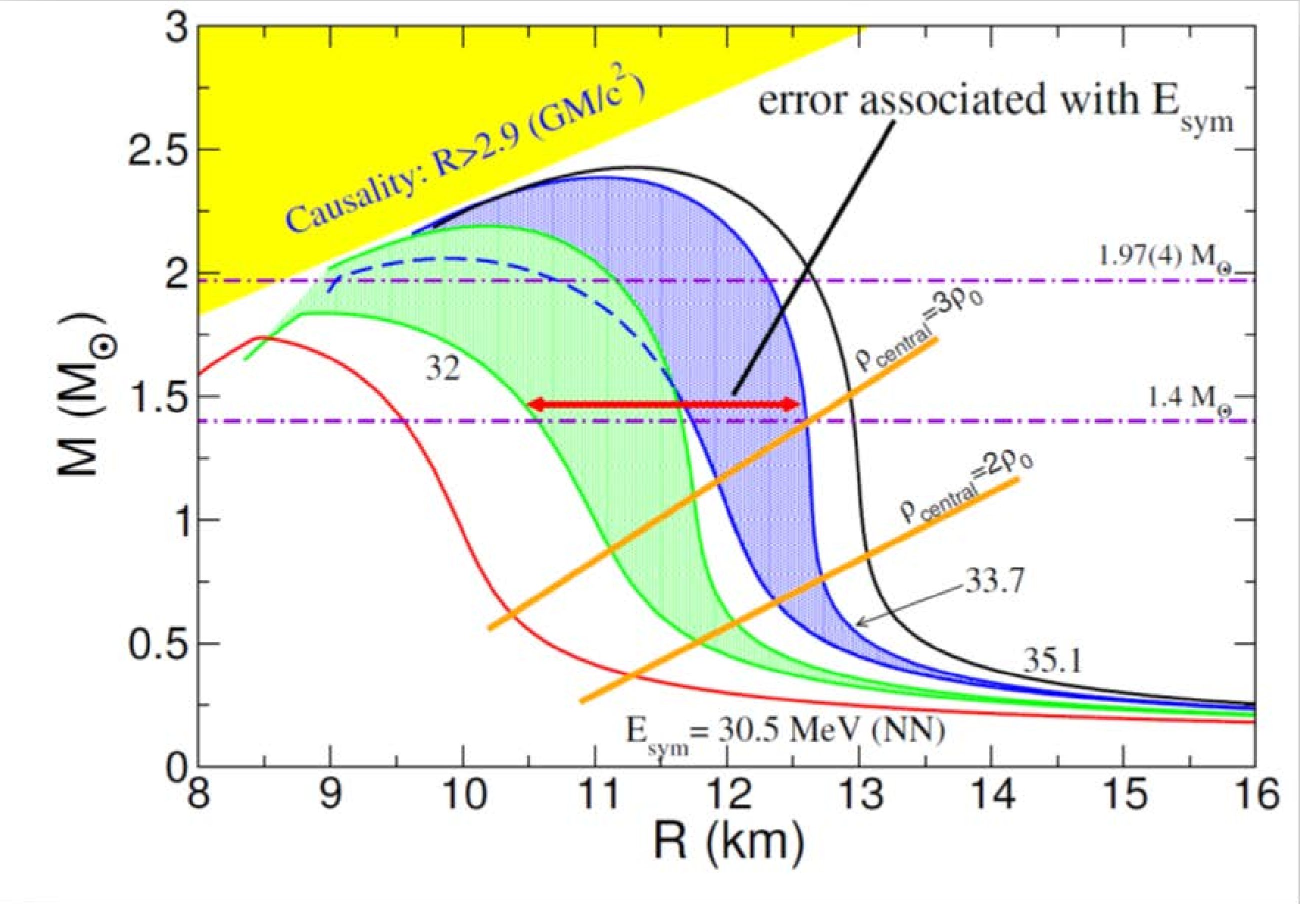


J. R. Stone et al.,
arXiv:1012.2919v1

But even if hyperons do *not* appear in neutrons stars, why so ?
⇒ Need a precise understand Y-N, Y-Y, Y-N-N, … interactions !

The short distance challenge (I)

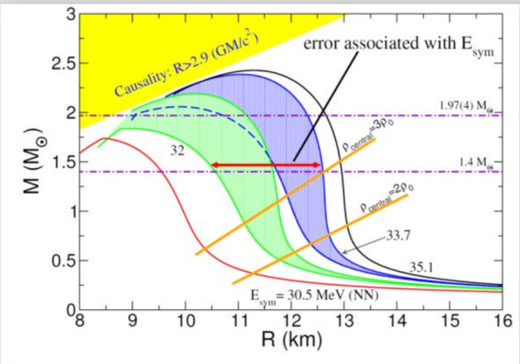
- Understanding neutron stars requires understanding of baryon-baryon force in SU(3) at short distances

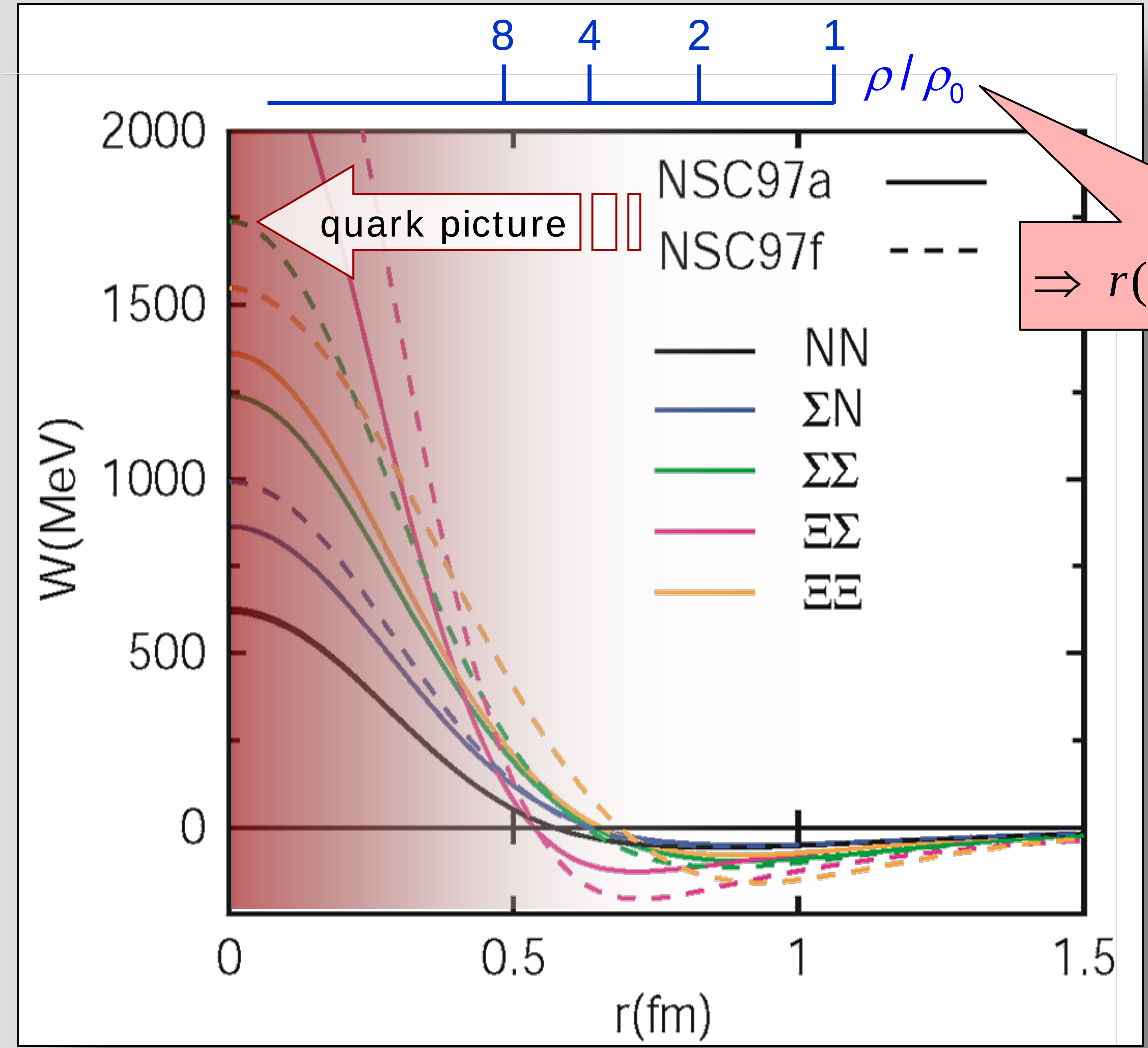


Stefano Gandolfi and Andrew W. Steiner arXiv:1308.6002

The short distance challenge (I)

- Understanding neutron stars requires understanding of baryon-baryon force in SU(3) at short distances

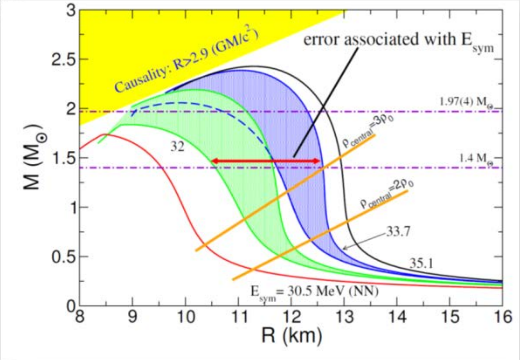


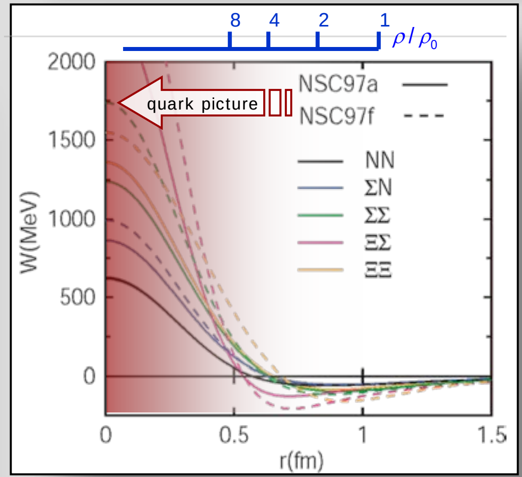


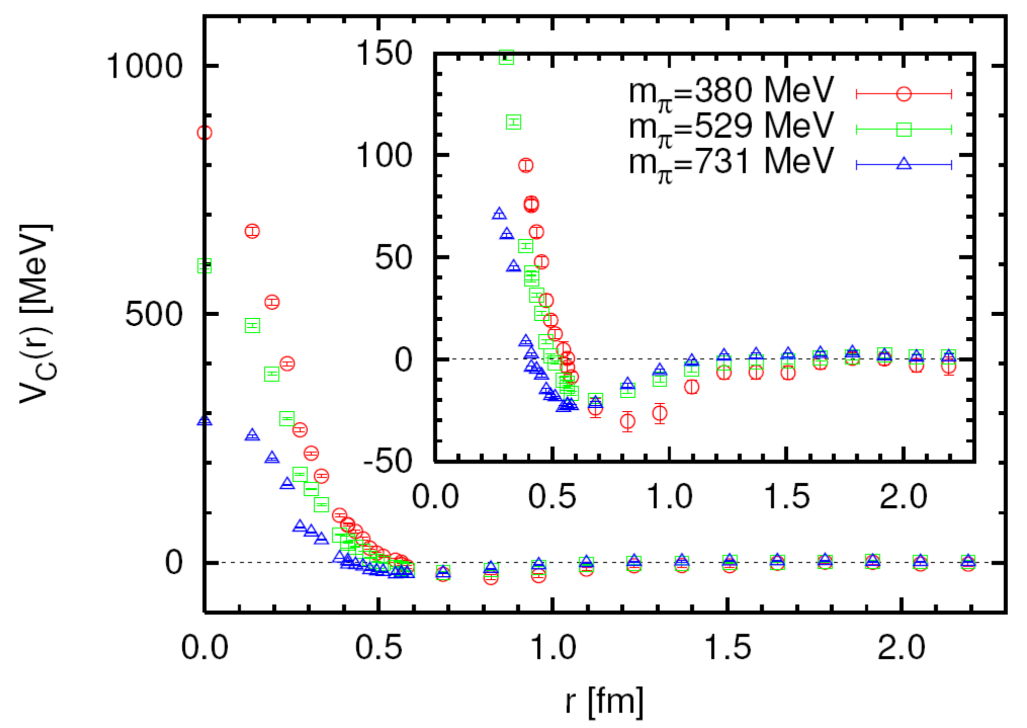
$$\Rightarrow\ r(\rho) = \left\langle \min(d_{ij})\ \ \forall i \neq j \right\rangle$$

The short distance challenge (I)

- Understanding neutron stars requires understanding of baryon-baryon force in SU(3) at short distances
- Lattice simulations might eventually provide a comprehensive description of B-B interactions and nuclei in terms of basic principles (QCD) to allow quantitative predictions in regions not directly accessible by experiments





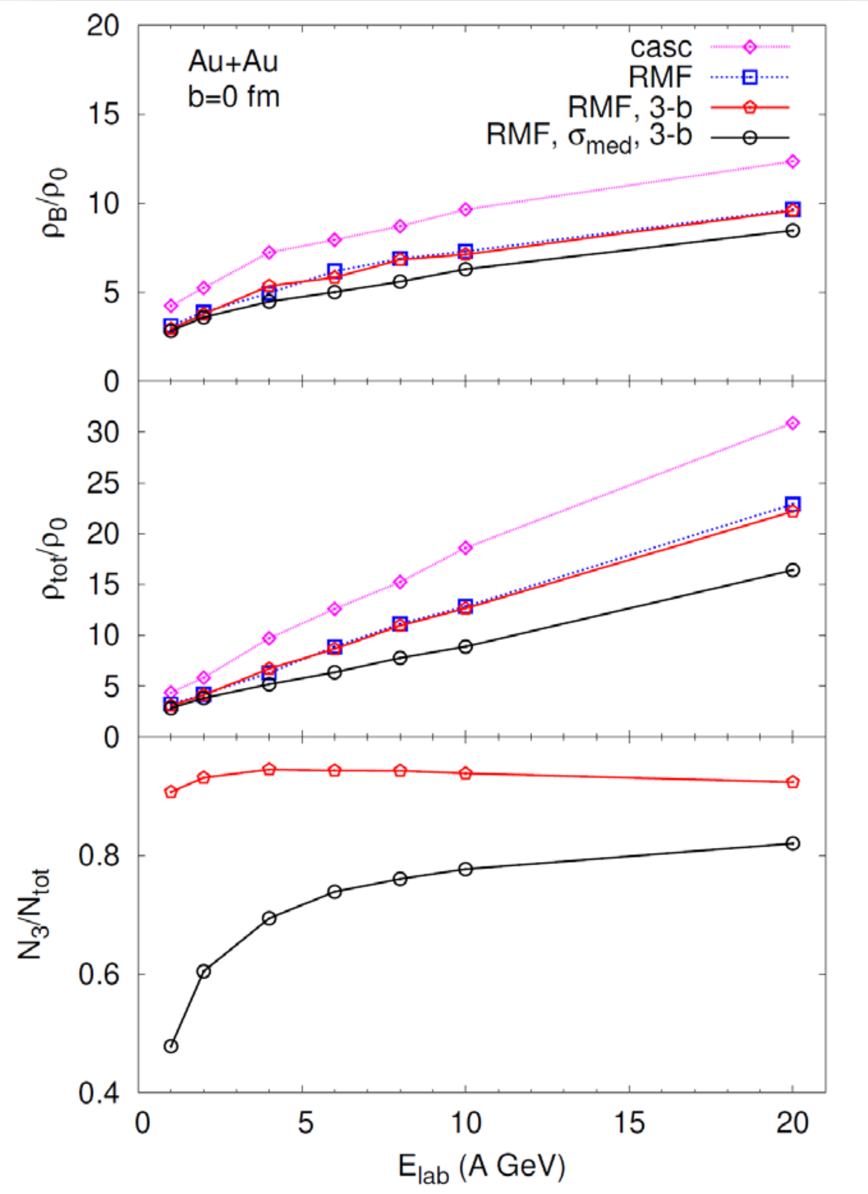


S. Aoki, T. Hatsuda and N. Ishii, Prog. Theor. Phys. 123 (2010) 89

The short distance challenge (I)

- Central heavy ion collisions are the usual tool to probe high densities
- But...
  - Central collisions → hot hadronic finite matter with mesons and baryons
  - Neutron stars → Cold baryonic infinite matter

⇒ Let us try a different approach



GiBUU code, Phys. Rep. 512, 1 (2012)

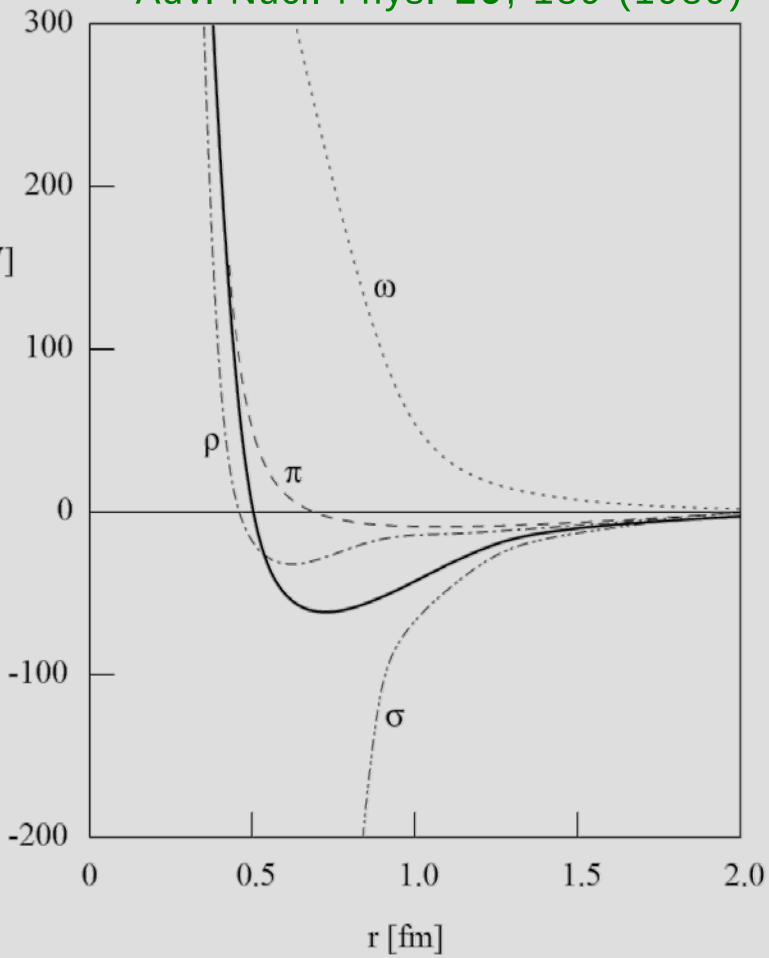
Traditional View of the N-N Interaction

- Experimental observation
  - short range (r<0.5fm) repulsion
  - intermediate (r≈1fm) 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≈2fm
  - $R = \hbar c/mc^2 \Rightarrow m \approx 100\,\mathrm{MeV}/c^2 \Rightarrow$ pion

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



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

- G=charge conjugation + 180° rotation around 2nd axis in isospin (Lee und Yang 1956, L. Michel 1952 „Isoparität“) $G = C \cdot e^{i\pi I_2}$
- G-parity of particle-antiparticle multipletts

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

$$G\left|\pi^{\pm 0}\right\rangle = (-1)^1 C\left|\pi^{\pm 0}\right\rangle = -\left|\pi^{\pm 0}\right\rangle$$

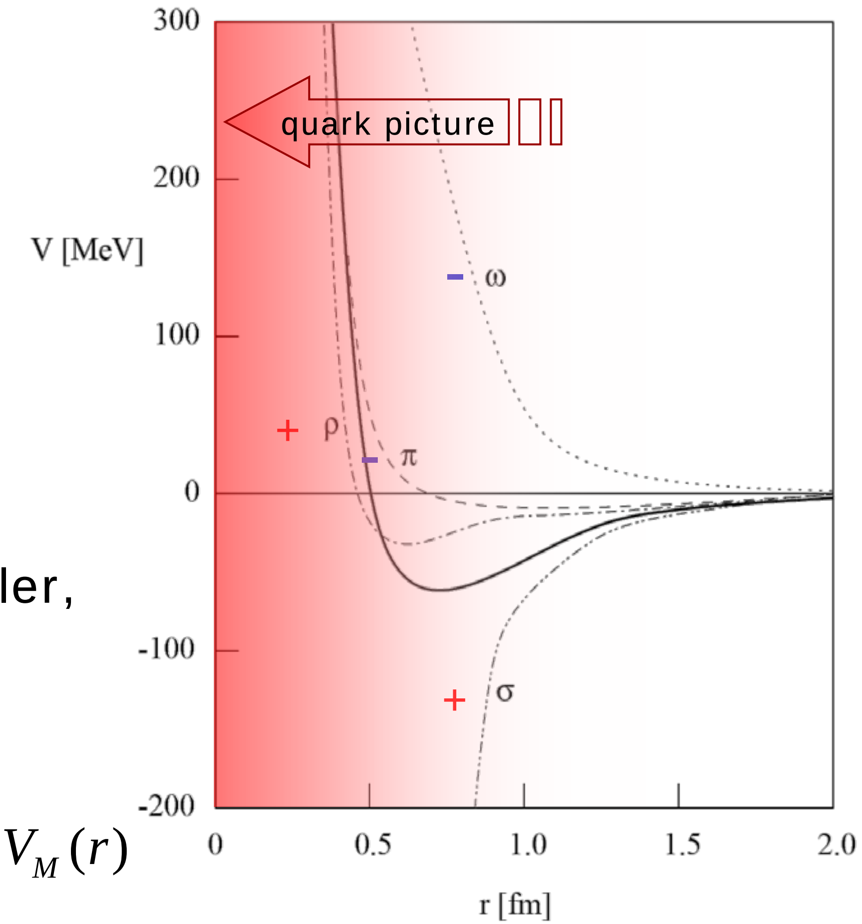
$$G\left|\rho\right\rangle = (-1)^1 C\left|\rho\right\rangle = +\left|\rho\right\rangle$$

$$G\left|\omega\right\rangle = (-1)^0 C\left|\omega\right\rangle = -\left|\omega\right\rangle$$

$$G\left|\sigma\right\rangle = (-1)^0 C\left|\sigma\right\rangle = +\left|\sigma\right\rangle$$

- Hans-Peter Dürr and Edward Teller, Phys. Rev. **101**, 494 (1956)
  - sign change in coupling constant when going from NN to N$\bar{\text{N}}$

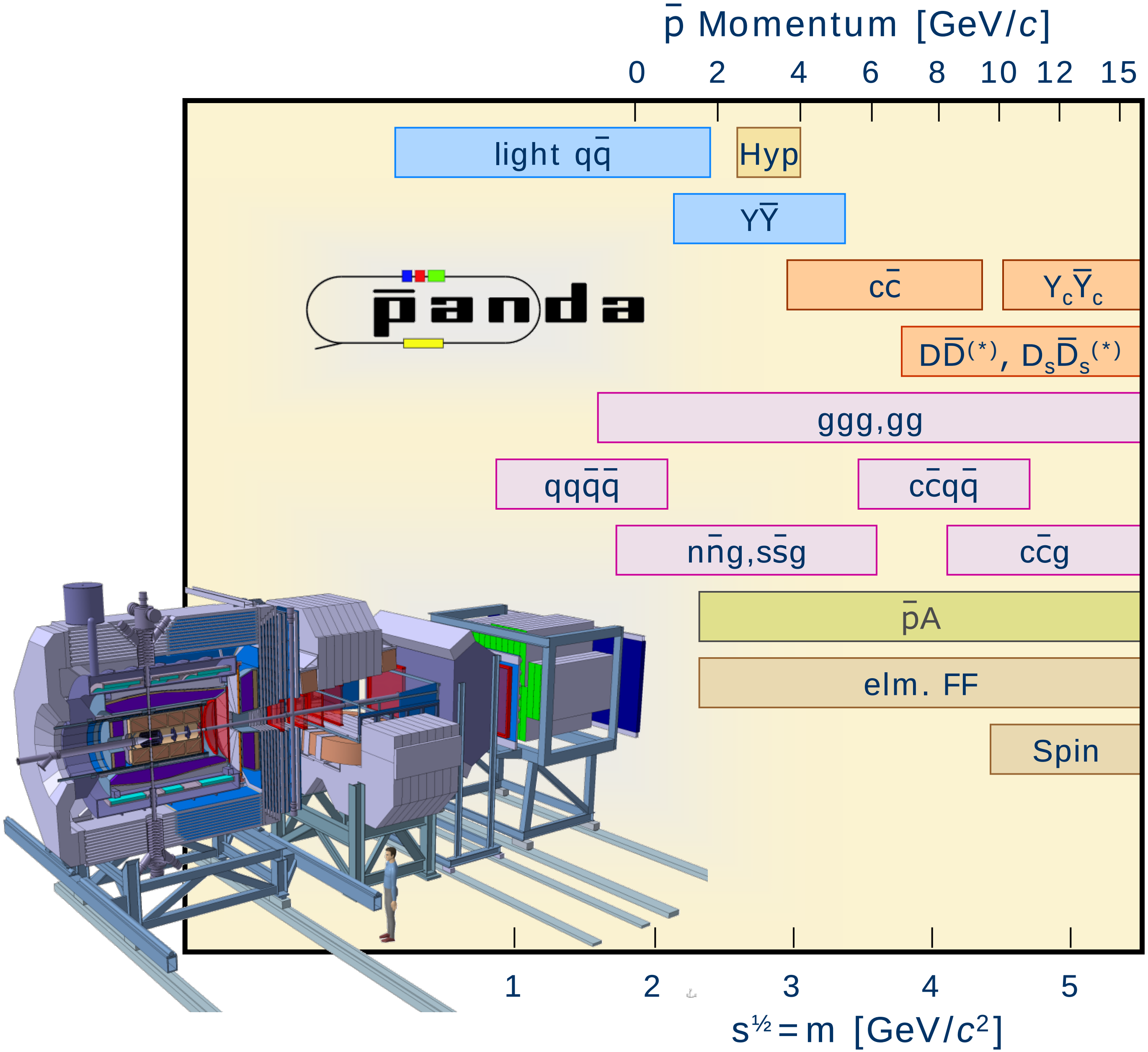
$$V(NN)(r) = \sum_M V_M(r) \rightarrow V(N\bar{N})(r) = \sum_M G_M V_M(r)$$



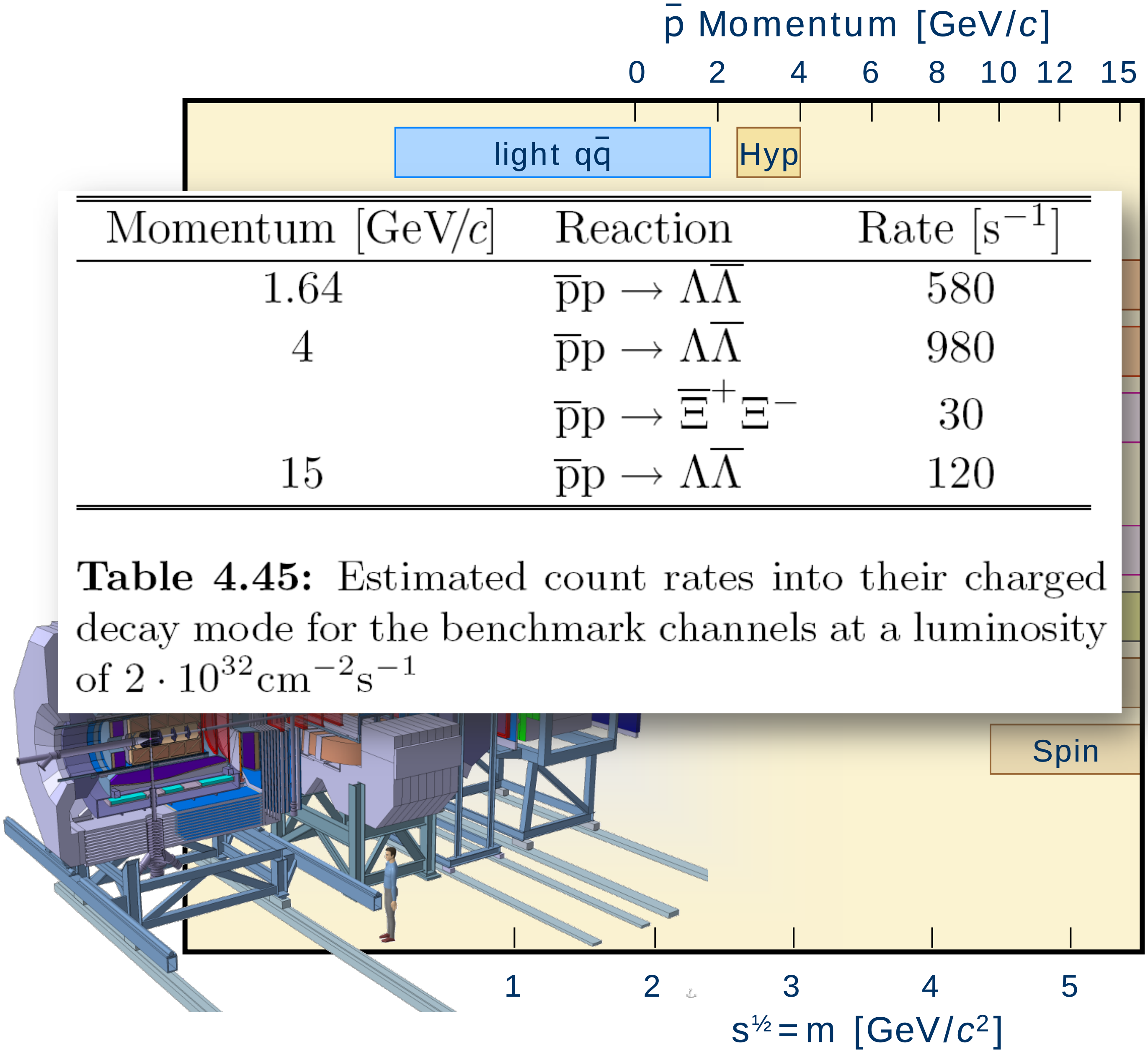
- Caveat: meson picture will probably not work at small distance
- Chance to study transition from meson to quark-gluon regime

Antihyperons at $\bar{\text{P}}$ANDA

$Y\bar{Y}$ at PANDA



$Y\bar{Y}$ at PANDA

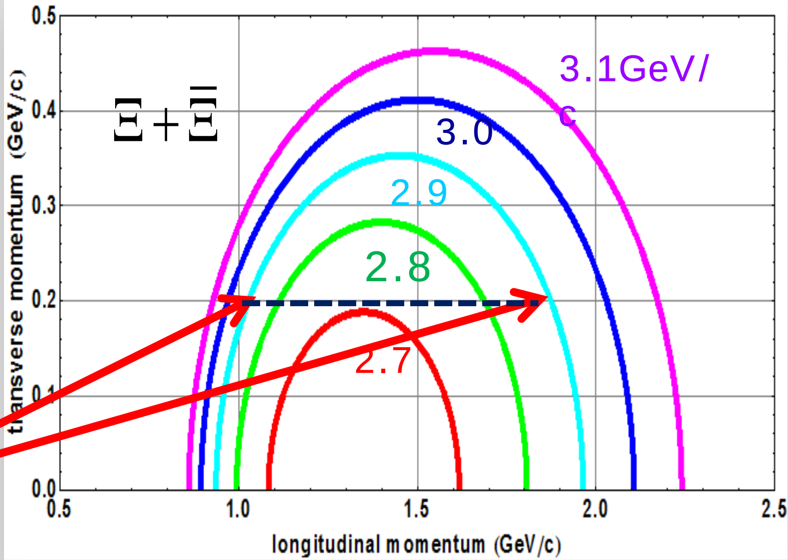


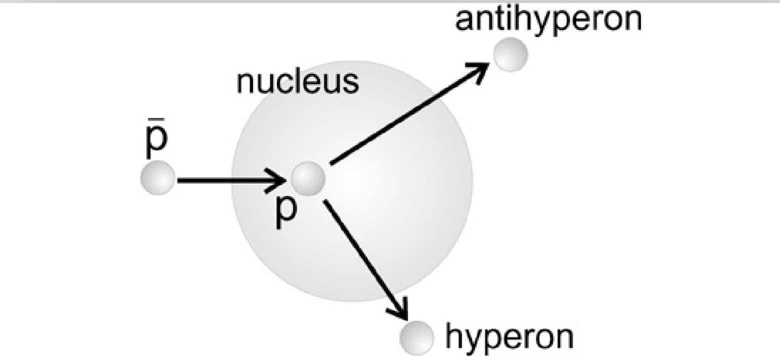
Momentum [GeV/c]	Reaction	Rate [s^{-1}]
1.64	$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	580
4	$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	980
	$\bar{p}p \rightarrow \bar{\Xi}^{+}\Xi^{-}$	30
15	$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	120

Table 4.45: Estimated count rates into their charged decay mode for the benchmark channels at a luminosity of $2 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Possibilities for studying YN, YNN,YY

- Hypernuclei !
  - Advantage: YN,YNN,...,YY interaction accessible
- Scattering of hyperons and antihyperons → JPARC, PANDA
  - $\bar{p}+p \to \bar{Y}+Y$ provides momentum tagged hyperon *or* antihyperon beams
- $\bar{p}+A \to \bar{Y}+Y+X$: (anti)hyperon nuclear potentials from $\bar{Y}+Y$ pair correlations → PANDA
  see e.g. PLB 669 (2008) 306

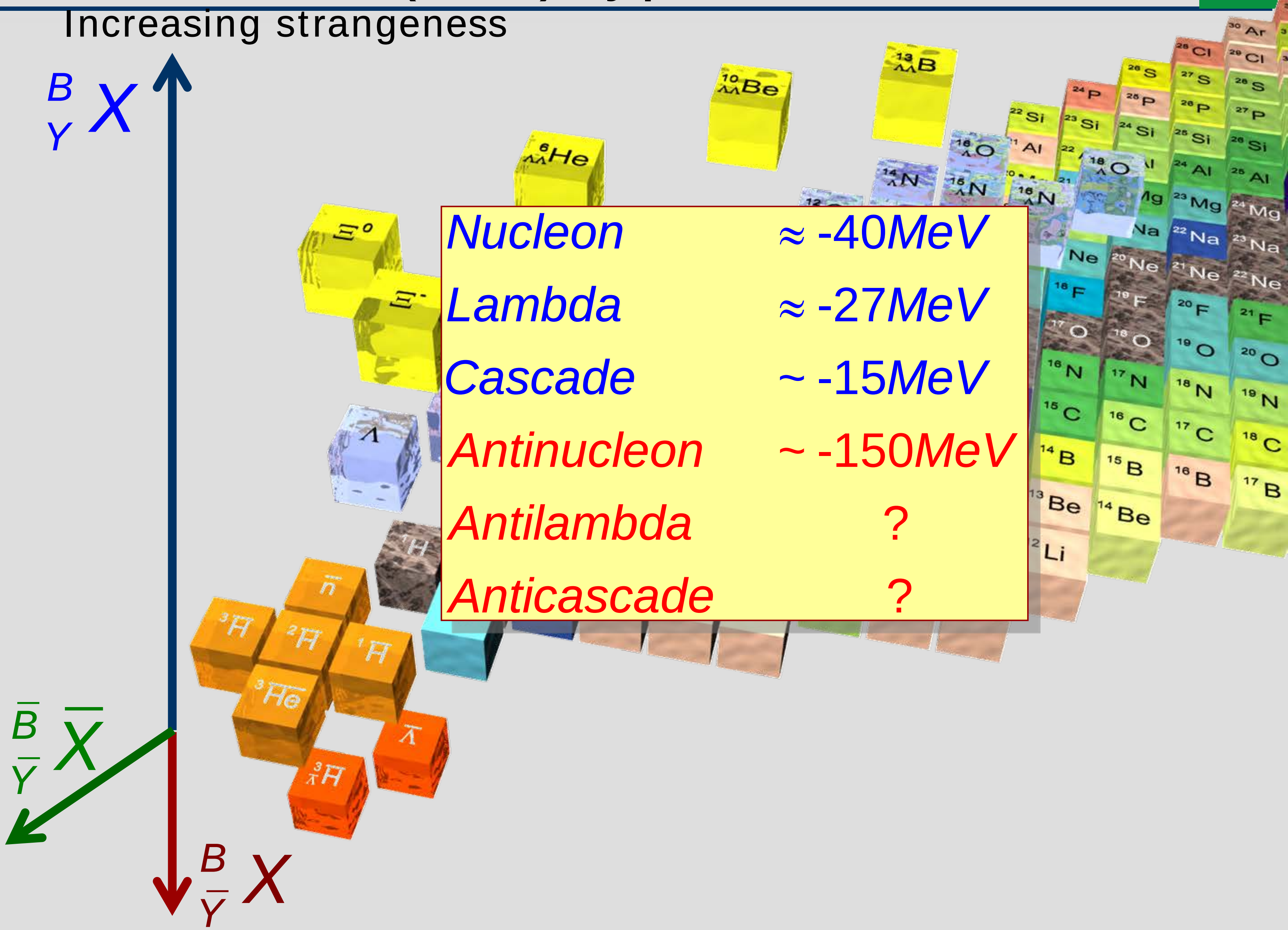




These topics are part of the “Update on the Physics Perspectives of PANDA”

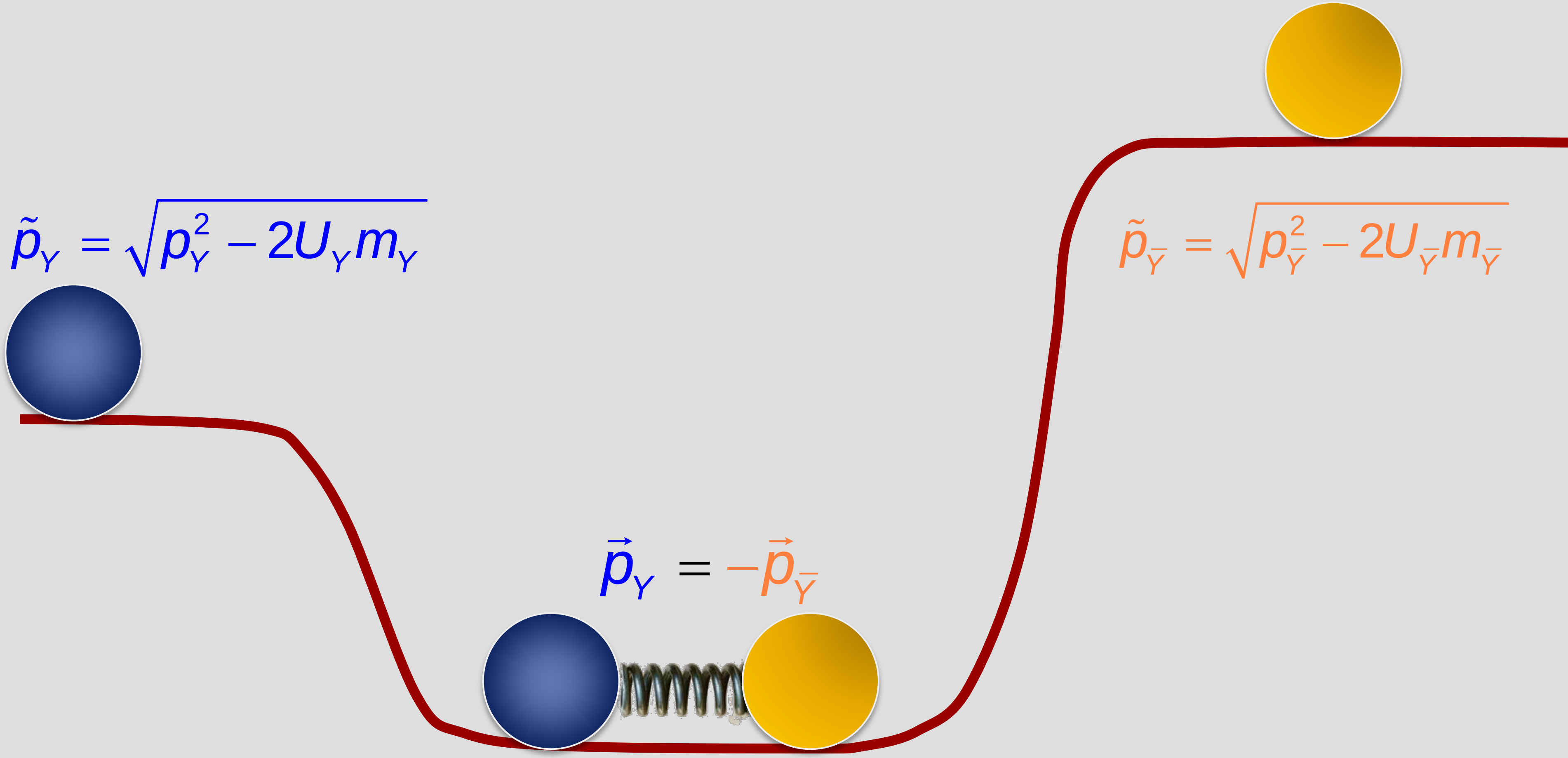
Nuclei with (anti)hyperons

Increasing strangeness



Nucleon	≈ -40*MeV*
Lambda	≈ -27*MeV*
Cascade	~ -15*MeV*
Antinucleon	~ -150*MeV*
Antilambda	?
Anticascade	?

How to measure a potential (difference)



$$\tilde{p}_Y = \sqrt{p_Y^2 - 2U_Y m_Y}$$

$$\tilde{p}_{\bar{Y}} = \sqrt{p_{\bar{Y}}^2 - 2U_{\bar{Y}} m_{\bar{Y}}}$$

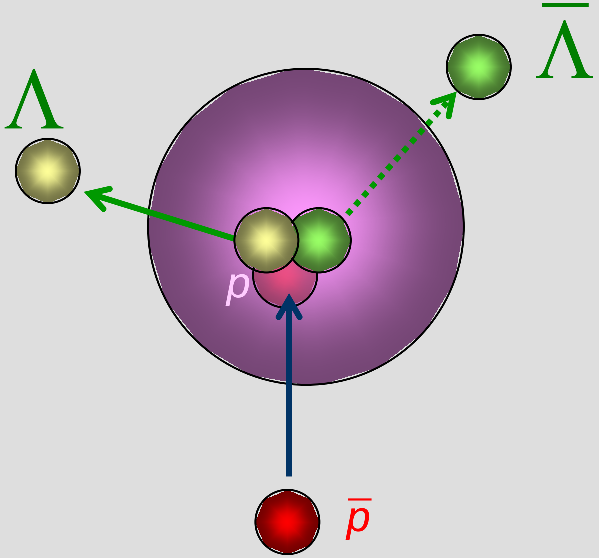
$$\vec{p}_Y = -\vec{p}_{\bar{Y}}$$

- If $m_Y \approx m_{\bar{Y}} \approx m$ and $U_Y \approx U_{\bar{Y}} \approx U \Rightarrow$

$$\alpha = \frac{\tilde{p}_Y - \tilde{p}_{\bar{Y}}}{\tilde{p}_Y + \tilde{p}_{\bar{Y}}} = \frac{\sqrt{p_0^2 - 2m_Y U_Y} - \sqrt{p_0^2 - 2m_{\bar{Y}} U_{\bar{Y}}}}{\sqrt{p_0^2 - 2m_Y U_Y} + \sqrt{p_0^2 - 2m_{\bar{Y}} U_{\bar{Y}}}} \approx \frac{U_{\bar{Y}} - U_Y}{4\left(\frac{p_0^2}{2m} - U\right)} \approx \frac{U_{\bar{Y}} - U_Y}{4E_{kin}}$$

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

- antiprotons are optimal for the production of mass without large momenta
- consider exclusive $\bar{p}+p(A) \rightarrow Y+\bar{Y}$ close to threshold within a nucleus
- Λ and $\bar{\Lambda}$ that leave the nucleus will have different asymptotic momenta depending on the respective potential

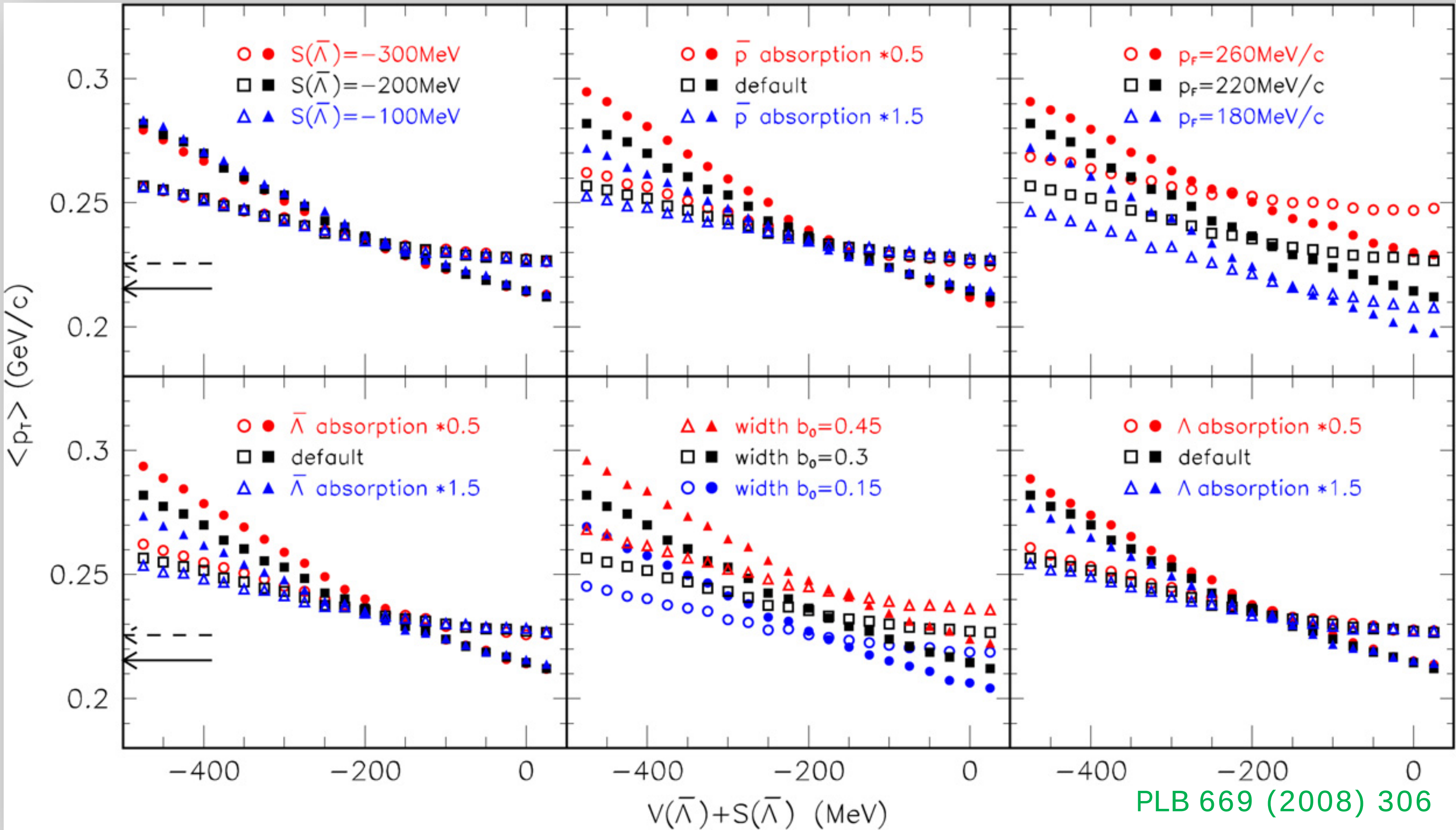


- experimental complications
  - Fermi motion of struck proton
  - Non-isotropic production
  - Density distribution U(ρ)
  - Exclusiveness

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

Sensitivity of p_t to model parameters

- Transverse momenta of $\bar{\Lambda}$ and Λ decrease with decreasing $\bar{\Lambda}$ potential
- Decrease for $\bar{\Lambda}$ (closed symbols) stronger than for Λ (open symbols)
- Major sensitivity to assumed Fermi motion and angular distribution
- $\langle p_t \rangle$ of inclusive distributions is not sufficient to determine the potential parameters unambiguously



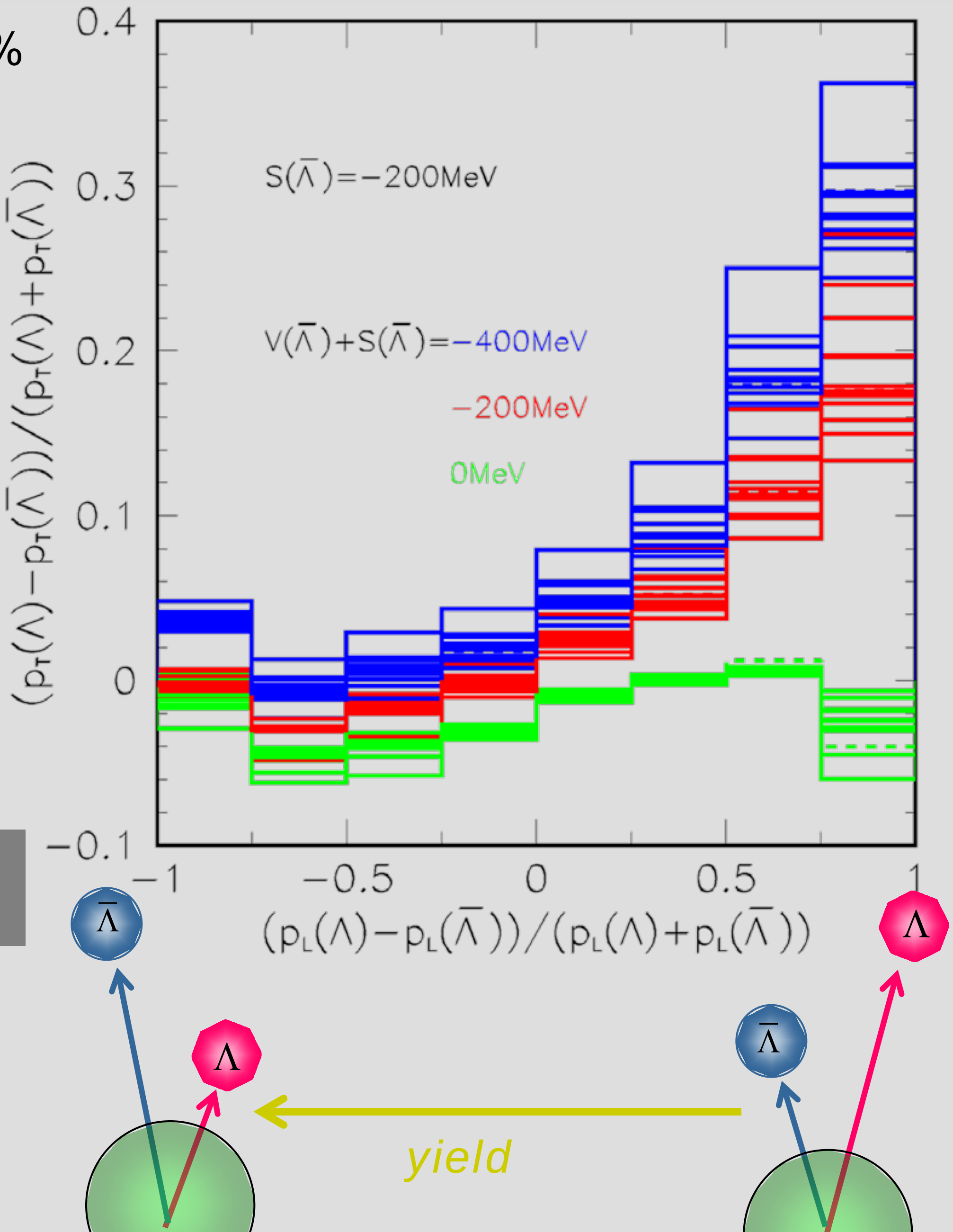
PLB 669 (2008) 306

Parameter Scan for transverse Asymmetry

- Parameter variation by ±50%
  - Other potentials ($p,\bar{p},\Lambda$)
  - absorption cross sections
  - angular distribution
  - diffuseness
- Transverse asymmetry mainly determined by total potential
- Effect largest for backward emitted $\bar{\Lambda}$
- α_T non-zero even if V+S=0

PLB 669 (2008) 306

What about state-of-the-art transport calculations?



Expectations for $\bar{\text{P}}$ANDA

GiBUU 1.5

- https://gibuu.hepforge.org/trac/wiki

Institut für Theoretische Physik, JLU Giessen

GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

- G-parity used to estimate anti-baryons potential

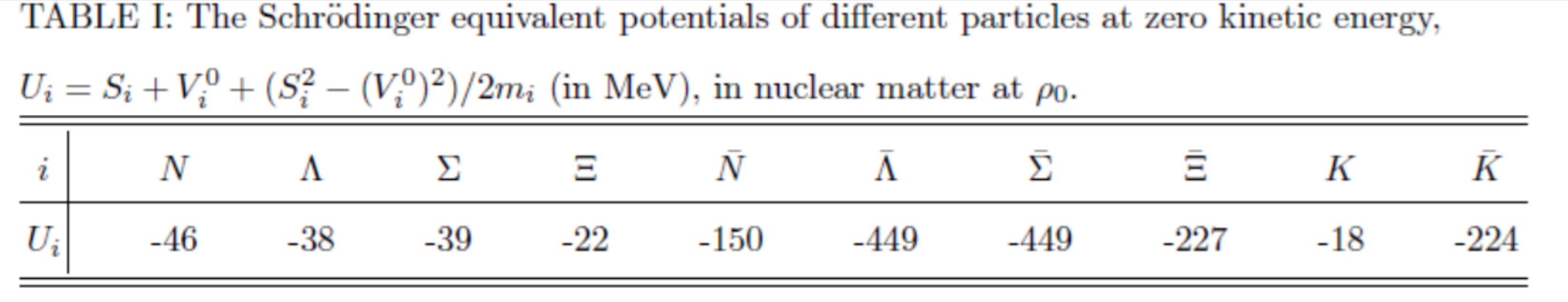


TABLE I: The Schrödinger equivalent potentials of different particles at zero kinetic energy, $U_i = S_i + V_i^0 + (S_i^2 - (V_i^0)^2)/2m_i$ (in MeV), in nuclear matter at ρ_0.

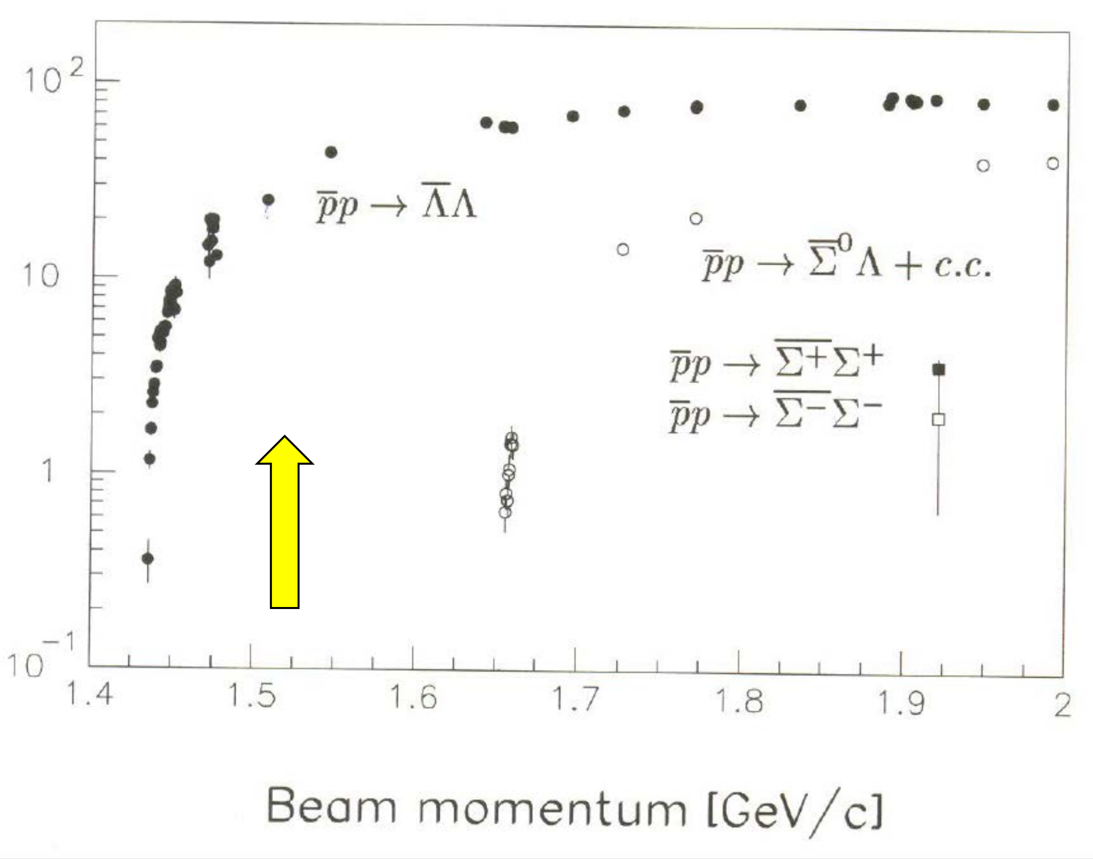
i	N	Λ	Σ	Ξ	$\bar{N}$	$\bar{\Lambda}$	$\bar{\Sigma}$	$\bar{\Xi}$	K	$\bar{K}$
U_i	-46	-38	-39	-22	-150	-449	-449	-227	-18	-224

- Drawbacks
  - Antiproton potential scaled by 0.22 to obtain -150MeV
  - Σ potential attractive
  - Kaon attraction

GiBUU Simulations $\bar{p}+{}^{20}\mathrm{Ne} \to \Lambda\bar{\Lambda}+X$

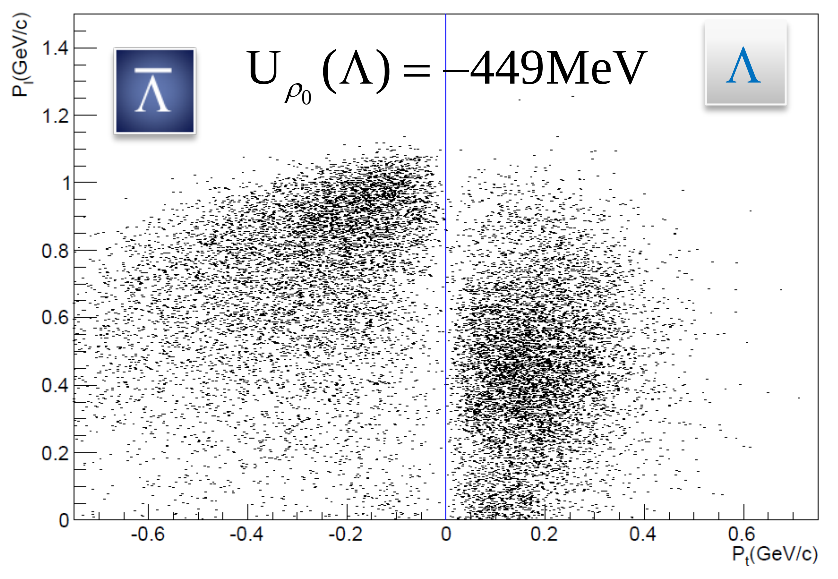
- $\bar{p}p$ threshold 1435MeV/c
- 27M inclusive events for each data set calculated at HIMster
- Approximately 10k exclusive $\Lambda\bar{\Lambda}$ pairs in each set

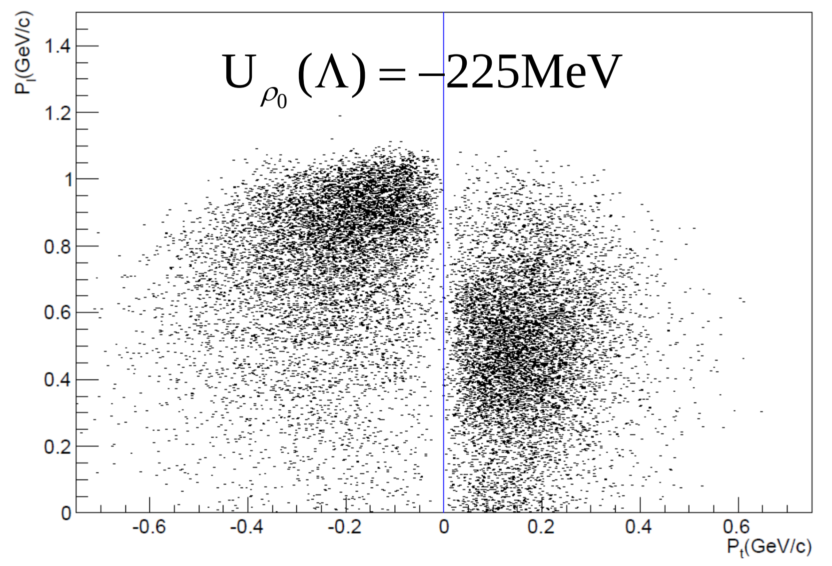
Energy (MeV)	**Momentum (MeV/c)**	**Excess energy (MeV)**
850	**1522**	**30.6**
900	1581	51.2
1000	1696	92.0

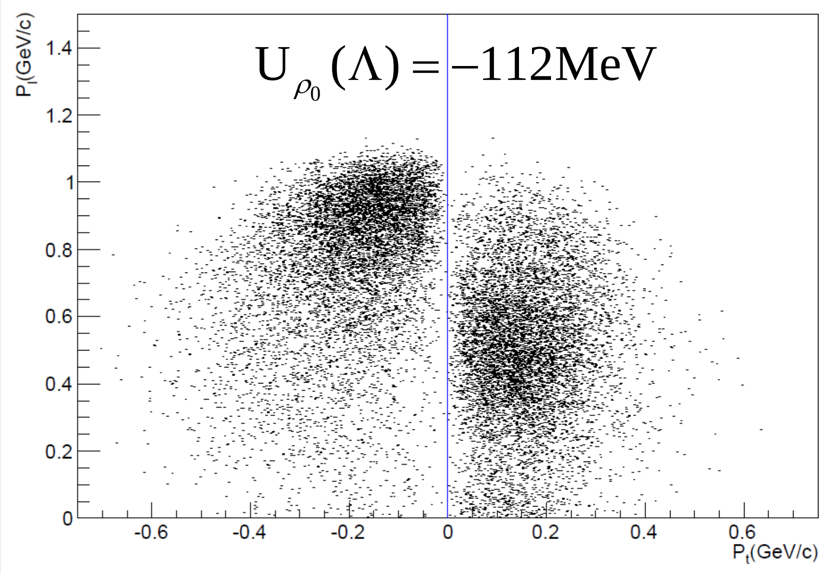


Scan of $\bar{\Lambda}$ potential

- Default parameters for RMF
  - $V(N) = -46$MeV
  - $V(\Lambda) = -38$MeV
  - $V(\bar{N}) = -150$MeV
  - $V(\bar{\Lambda}) = -449$MeV
- Most obvious change: transvere momenta of antilambdas





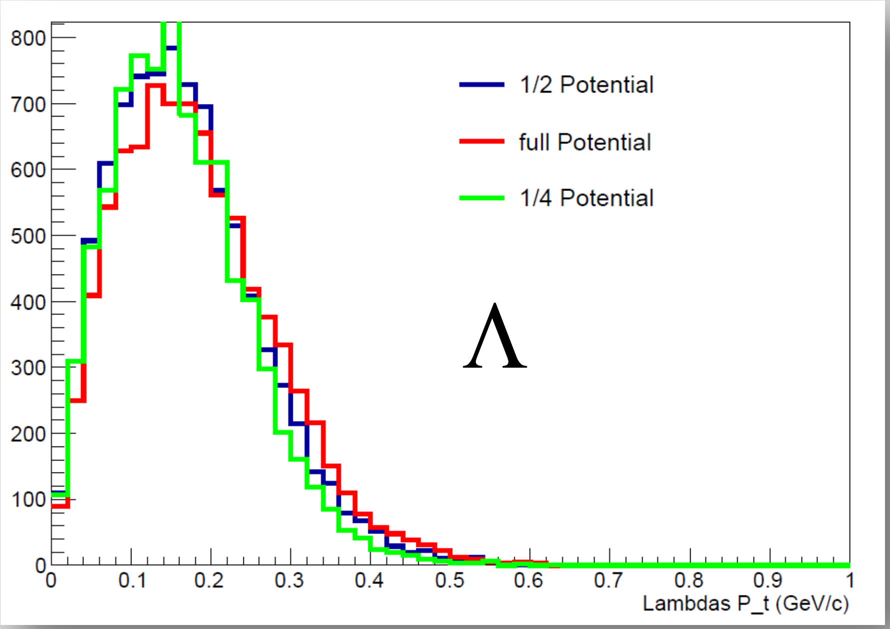


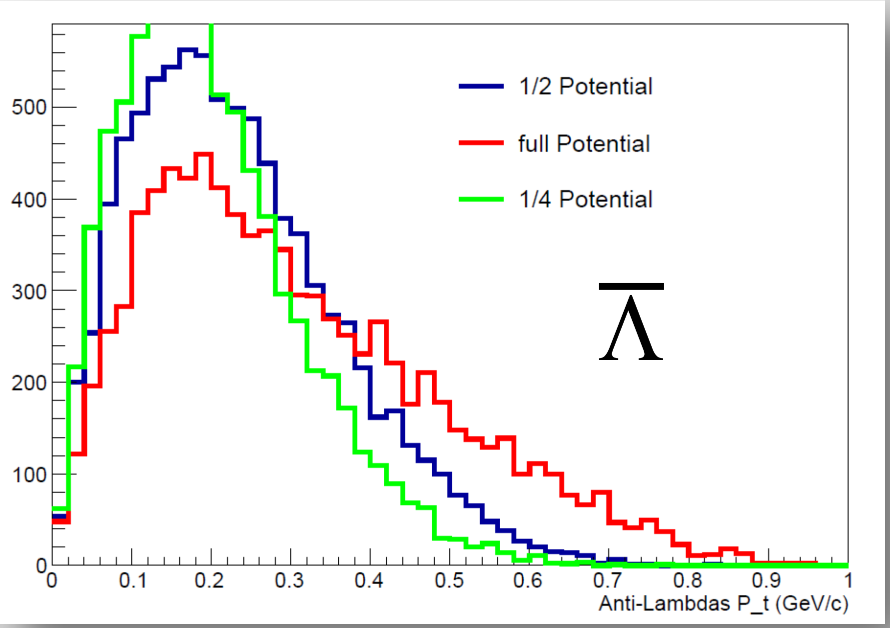
Transverse Momentum (GeV/c)

Transverse Momentum (GeV/c)

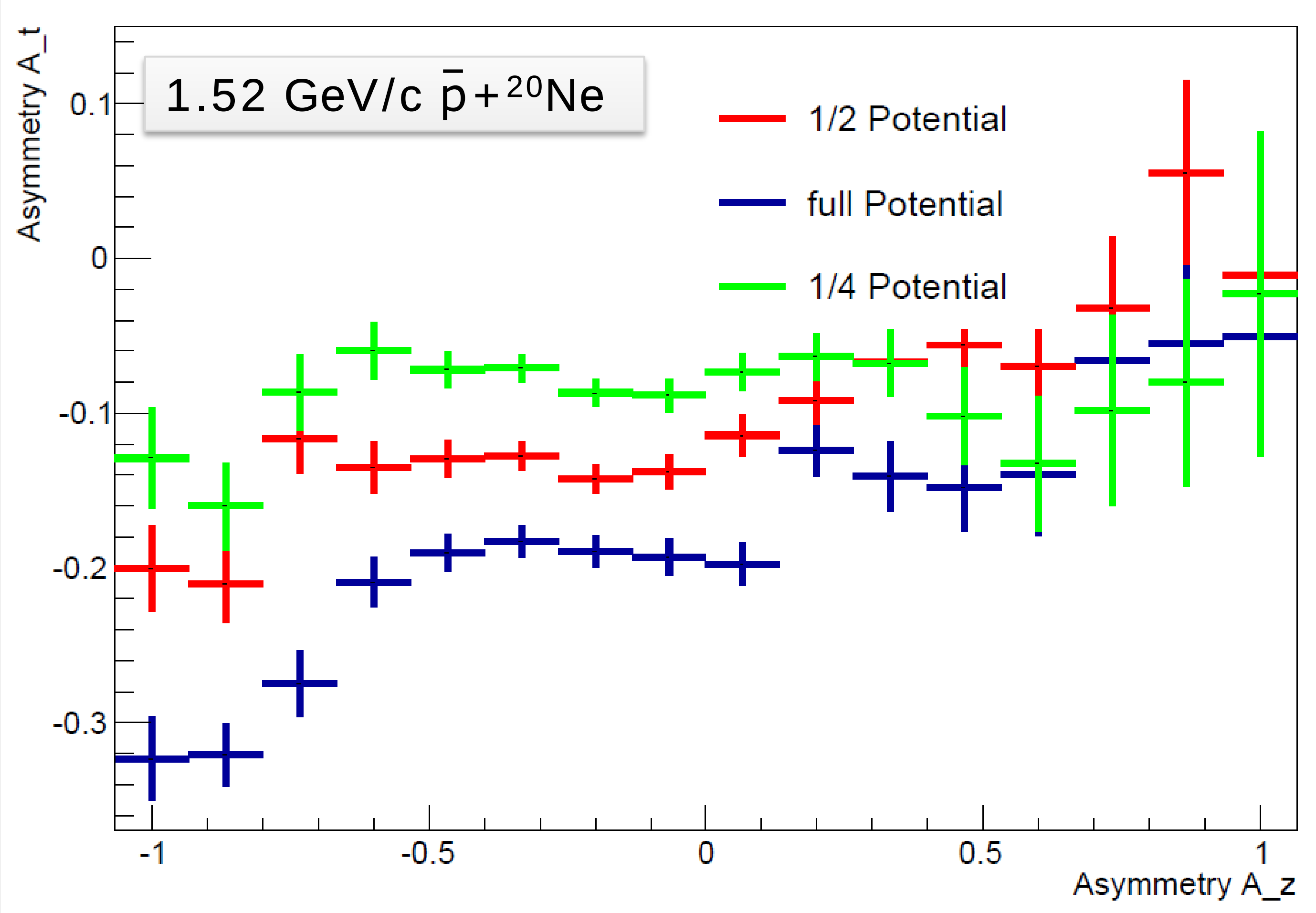
p_t distributions

- Change of transverse momenta in qualitative agreement of schematic simulations



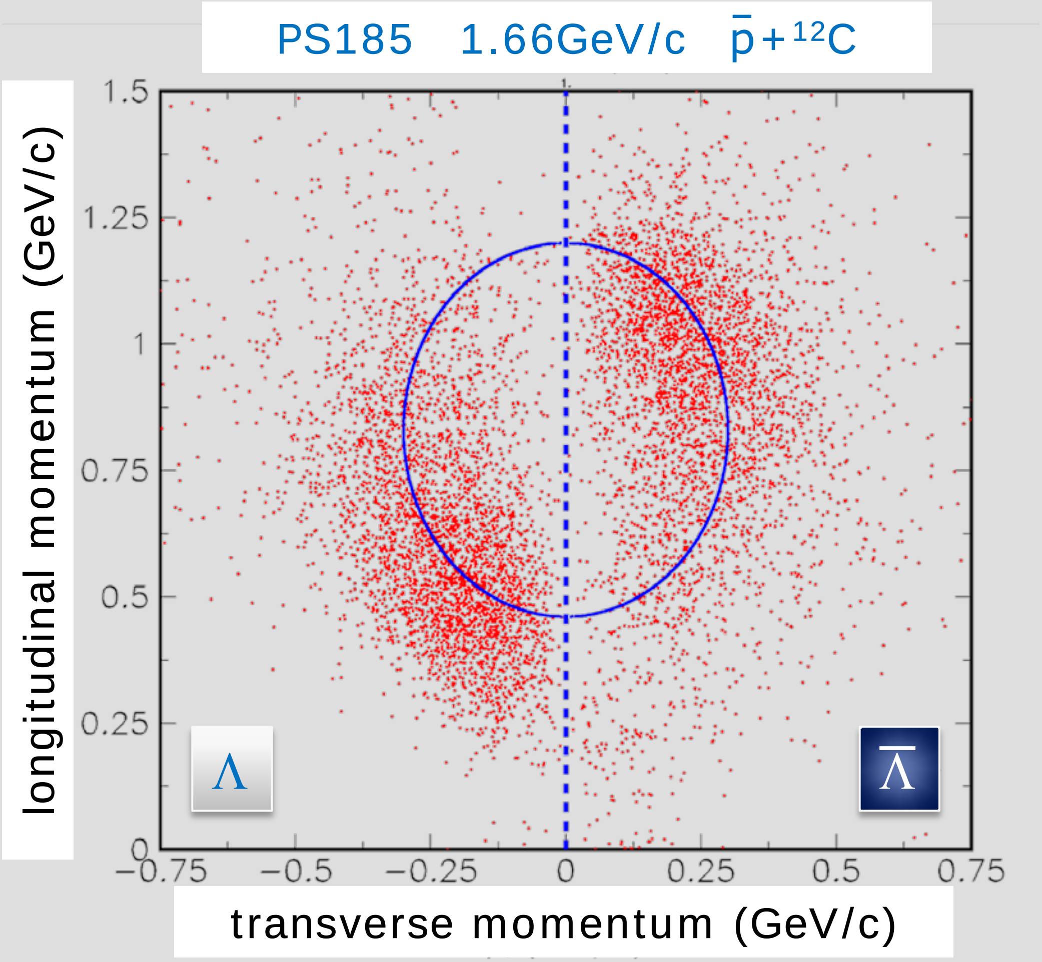


Transverse Asymmetry from GiBUU



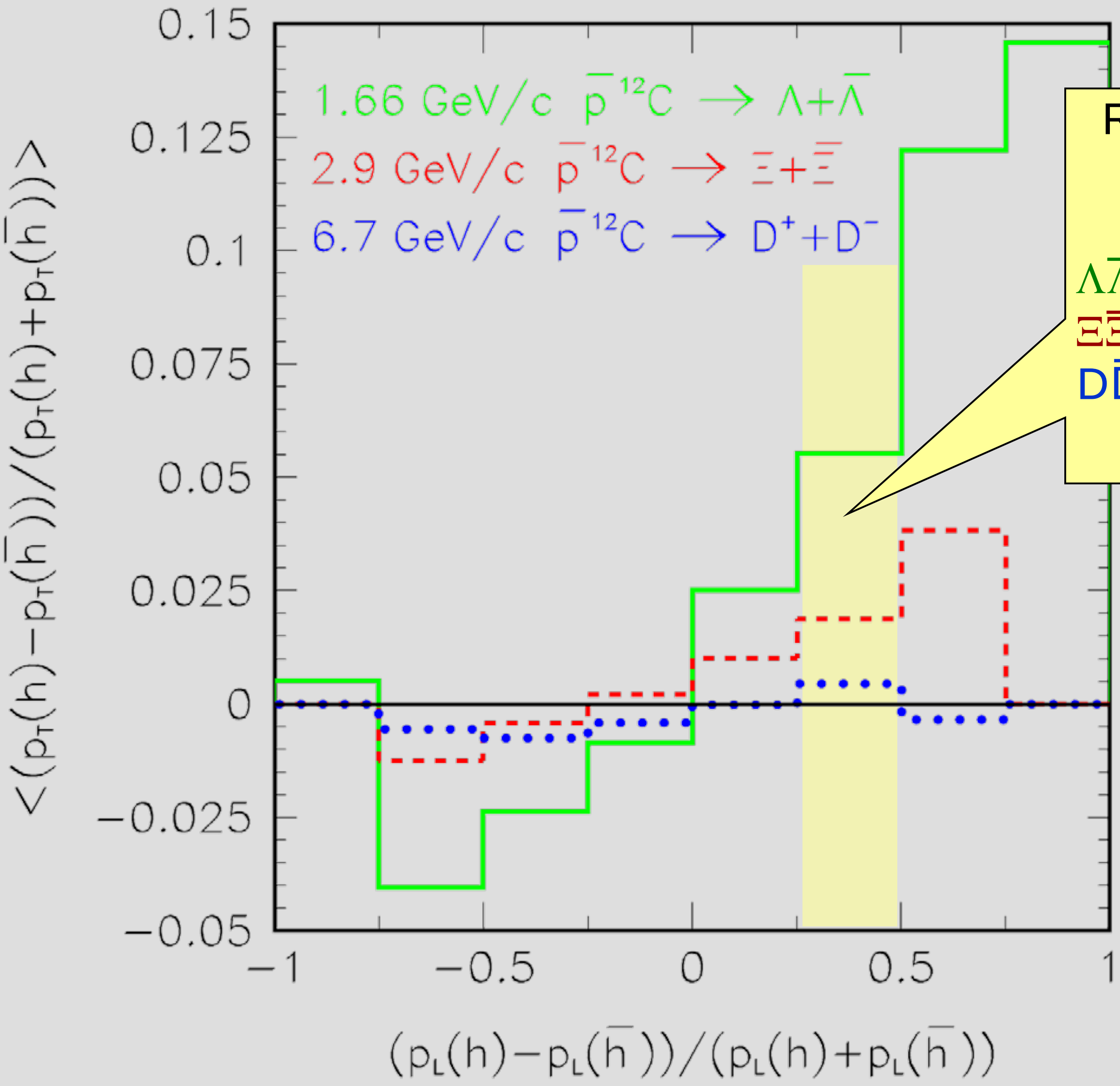
- What‘s next?
  - improve statistics
  - further parameter scan to check sensitivities
  - energy scan
  - Other $Y\bar{Y}$ pairs ($\Xi\bar{\Xi}$,...)

PS185: 1.66 GeV/c $\bar{p}+{}^{12}C \rightarrow \Lambda\bar{\Lambda}$



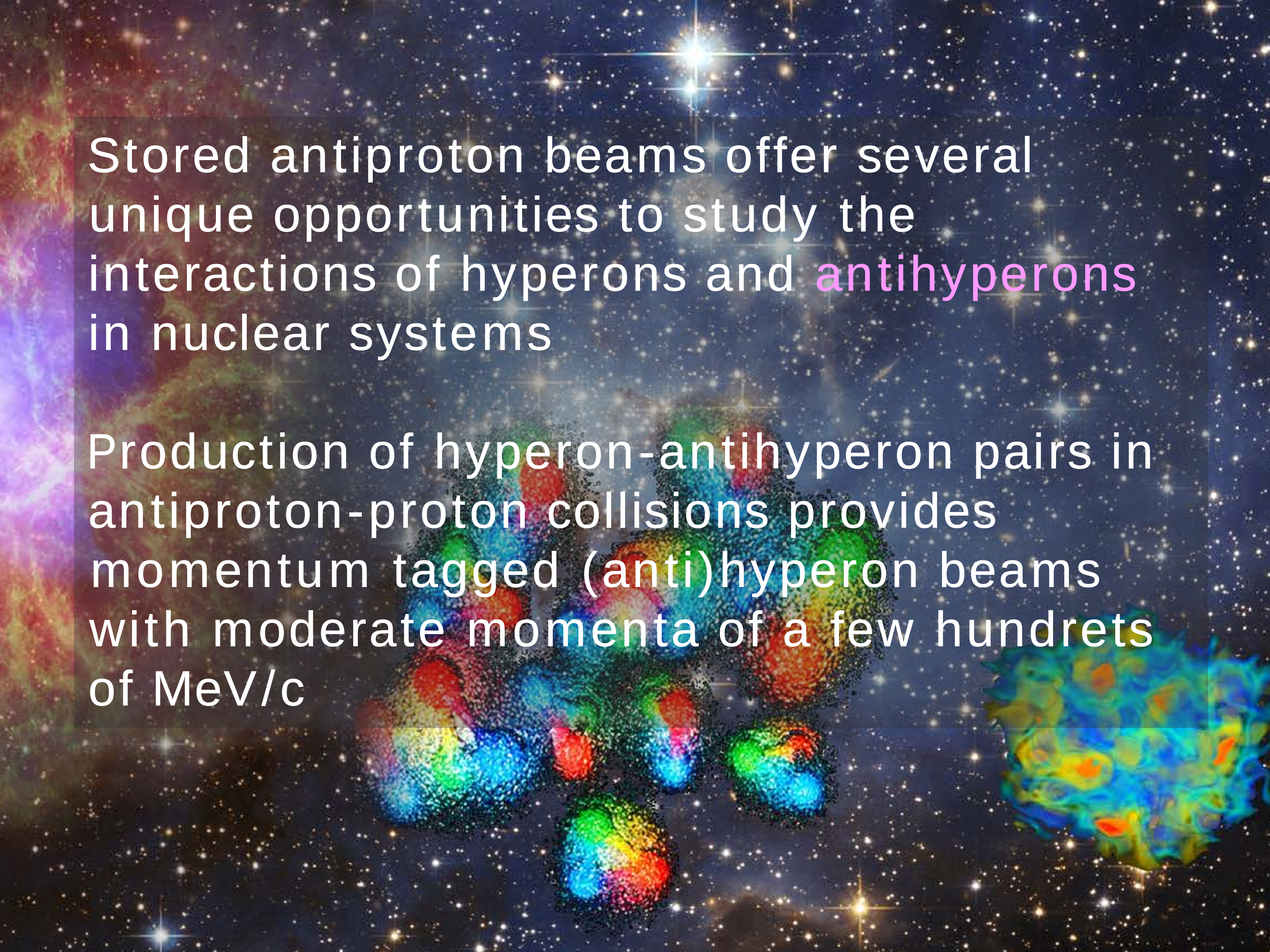
- The experiment is doable
- At PANDA similar statistics like in the present simulations can be reached in about 5 minutes

Other hadron-antihadron pairs



Required running time
for $\delta a/a = 10\%$:

$\Lambda\bar{\Lambda}$: few minutes
$\Xi\bar{\Xi}$: several h
$D\bar{D}$: several months
at PANDA



Stored antiproton beams offer several unique opportunities to study the interactions of hyperons and antihyperons in nuclear systems

Production of hyperon-antihyperon pairs in antiproton-proton collisions provides momentum tagged (anti)hyperon beams with moderate momenta of a few hundrets of MeV/c

THANK YOU

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