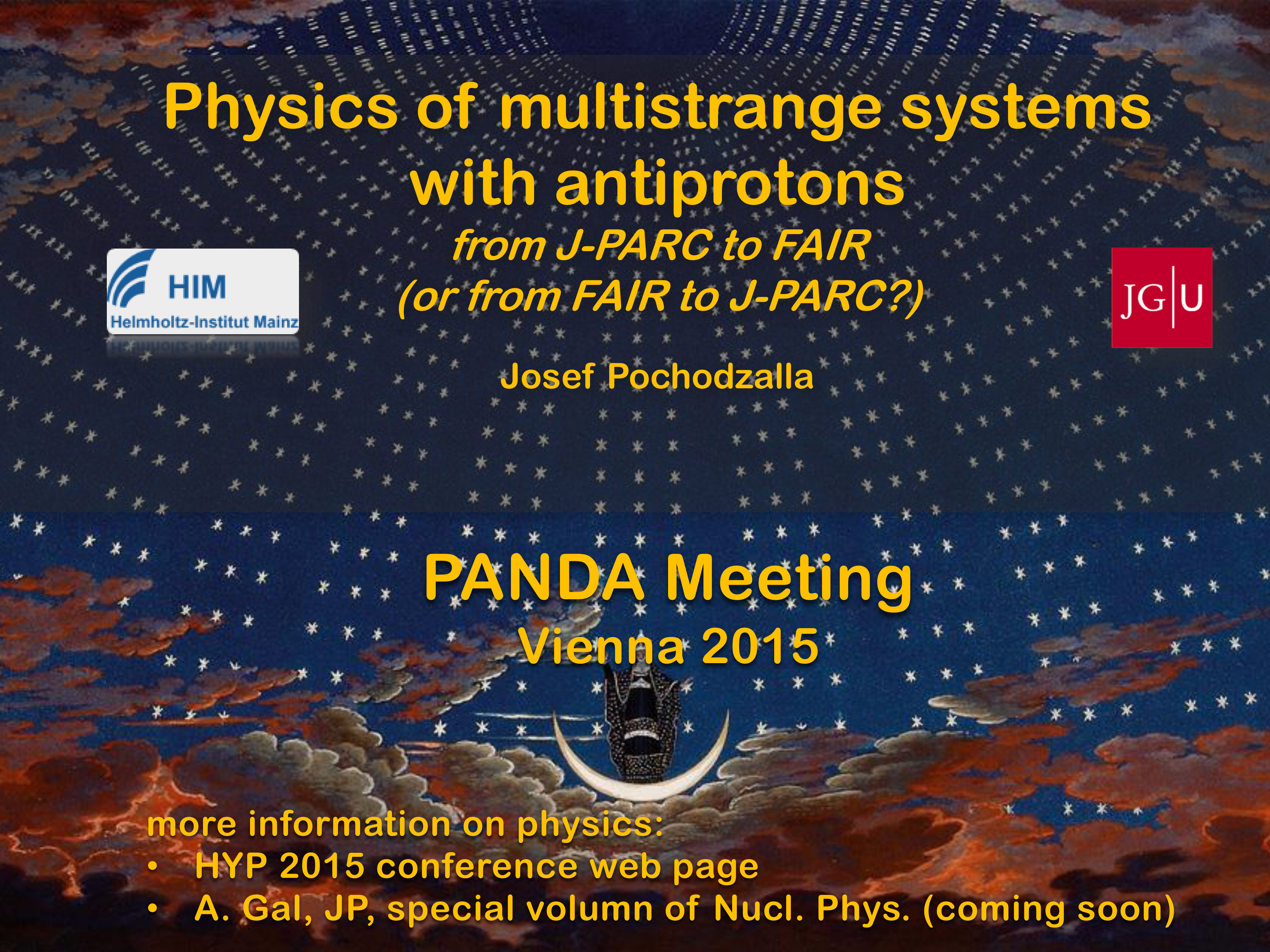


Physics of multistrange systems with antiprotons

from J-PARC to FAIR
(or from FAIR to J-PARC?)

Helmholtz-Institut Mainz

Josef Pochodzalla

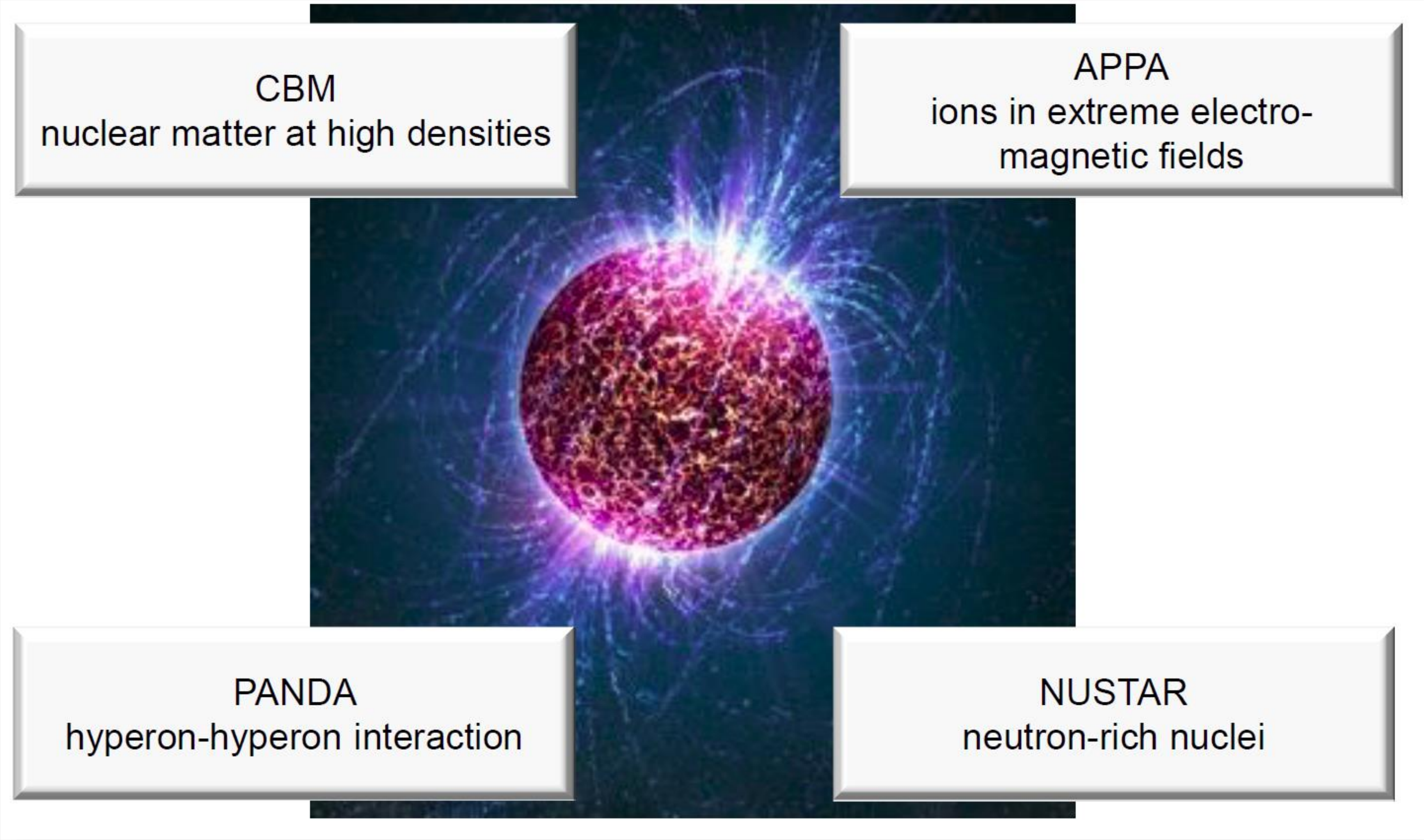
JG|U

PANDA Meeting
Vienna 2015

more information on physics:
- HYP 2015 conference web page
- A. Gal, JP, special volumn of Nucl. Phys. (coming soon)

P̄ANDA: a somewhat biased view

- Boris Sharkov, PANDA Meeting September 2015



CBM
nuclear matter at high densities

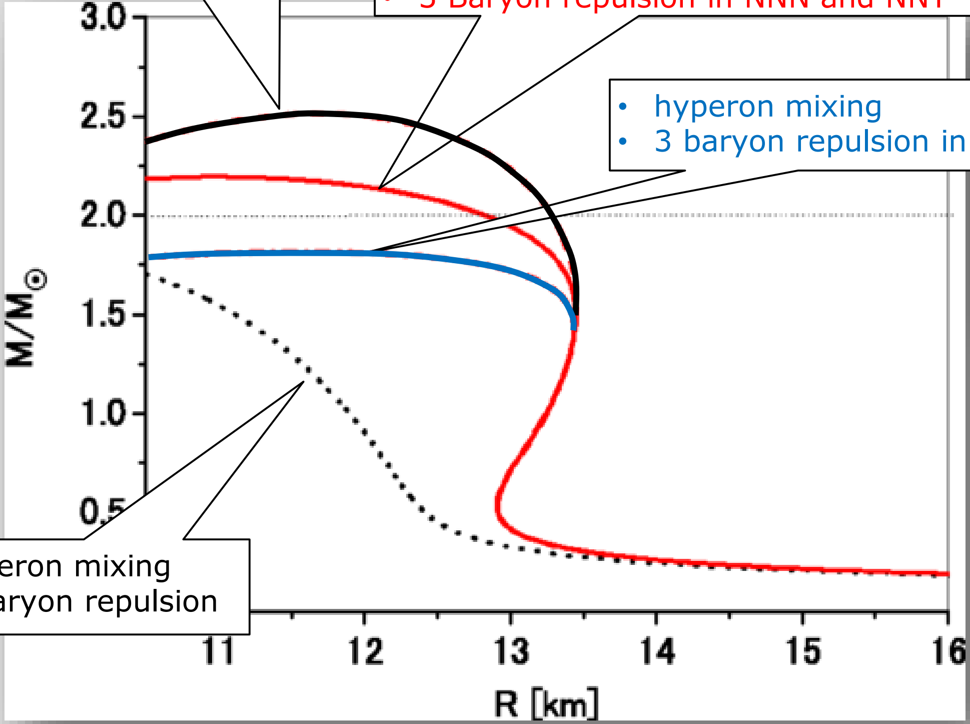
APPA
ions in extreme electro-magnetic fields

PANDA
hyperon-hyperon interaction

NUSTAR
neutron-rich nuclei

The Hyperon Puzzle…

Y. Yamamoto, T. Furumoto, N. Yasutake, Th. A Rijken,
Phys. Rev. C 90, 045805 (2014)

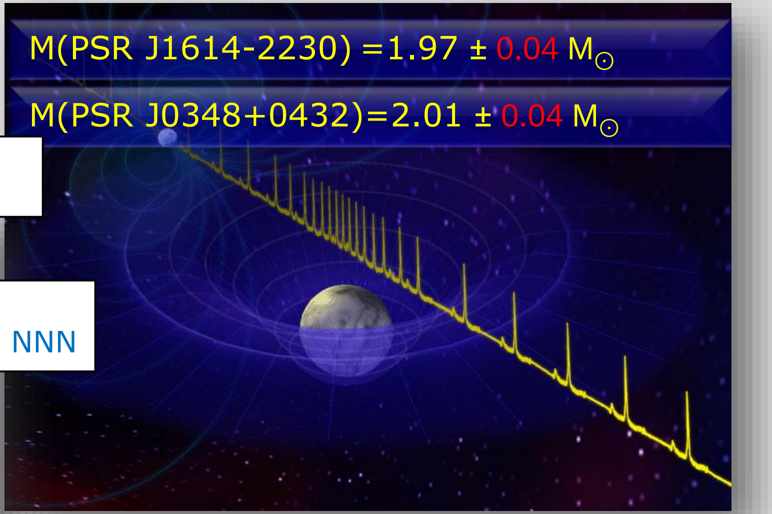


- no hyperon mixing
- 3 Baryon repulsion

- hyperon mixing
- 3 Baryon repulsion in NNN and NNY

- hyperon mixing
- 3 baryon repulsion in NNN

- no hyperon mixing
- no 3 baryon repulsion



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

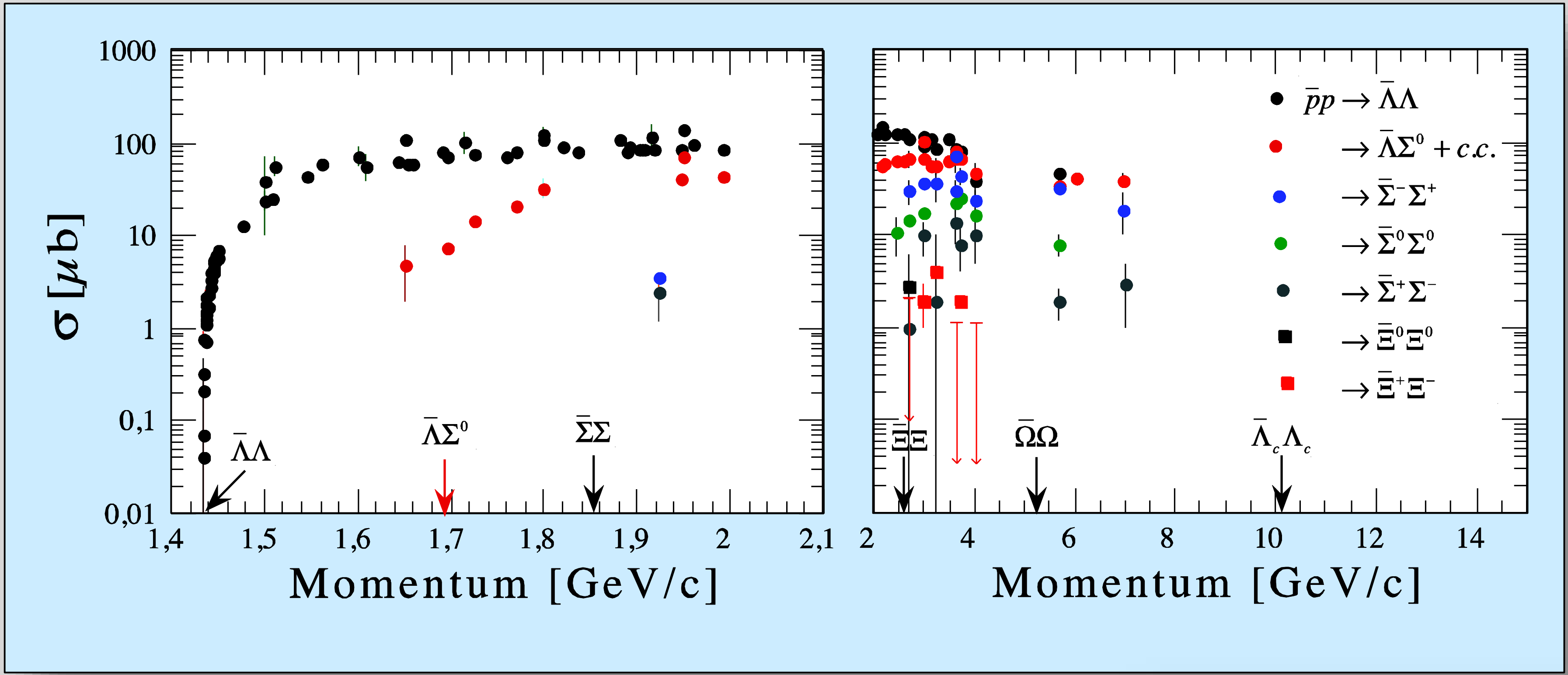
M(PSR J0348+0432)=2.01 ± 0.04 $M_\odot$

- model constrained by terrestrial experiments
- universal many-body repulsion
- no ad hoc parameter to stiffen EOS

Yamamota (HYP2015):
"Including 3- and 4-body repulsions leads to massive neutron stars with 2$M_\odot$ in spite of significant softening of EOS by hyperon mixing"….
"Hyperon puzzle is a quantitative problem"

Once solved, we may look at the interaction between baryonic matter and dark matter in compact stars

$\bar{\text{P}}$ANDA – a Factory for strange *and* charmed $Y\bar{Y}$-Pairs



- Note: in nuclei secondary processes possible

$$\bar{p} + n \rightarrow \bar{\Xi}^- + \Xi^0 \qquad \Xi^0 + X \rightarrow \Omega^- + K^+ + X$$

$$\bar{p} + p \rightarrow \bar{\Xi}^- + \Xi^- \qquad \Xi^- + X \rightarrow \Omega^- + K^0 + X$$

…seen in emulsions ~10 years prior to the „discovery" at Brookhaven

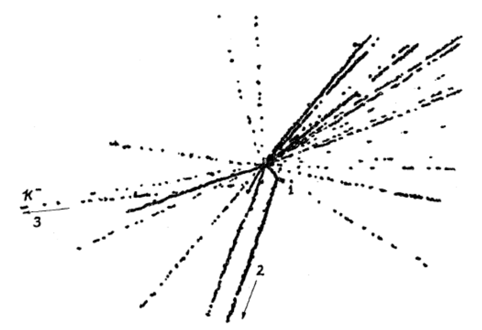
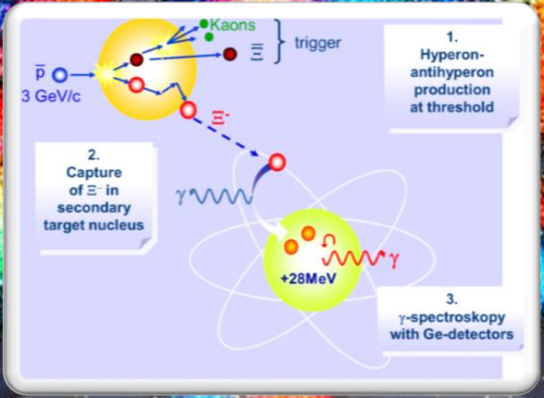


FIG. 1. A projection drawing of the *K*-mesonic decay of a slow particle is shown above. Track 1 is a short recoil. Track 2 was produced by a particle of $Z=1$. Track 3 was produced by a negative *K*-meson. A few tracks of particles from the primary star which are in the same direction as the connecting track, but at a different depth, were omitted from the drawing for the sake of clarity.

EXAMPLE 1

Approaching the hyperonization puzzle

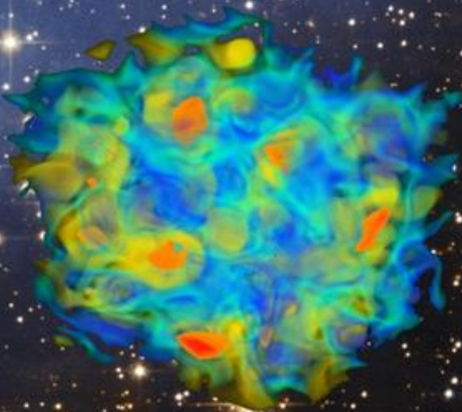
$\Lambda\Lambda$ HYPERNUCLEI at PANDA



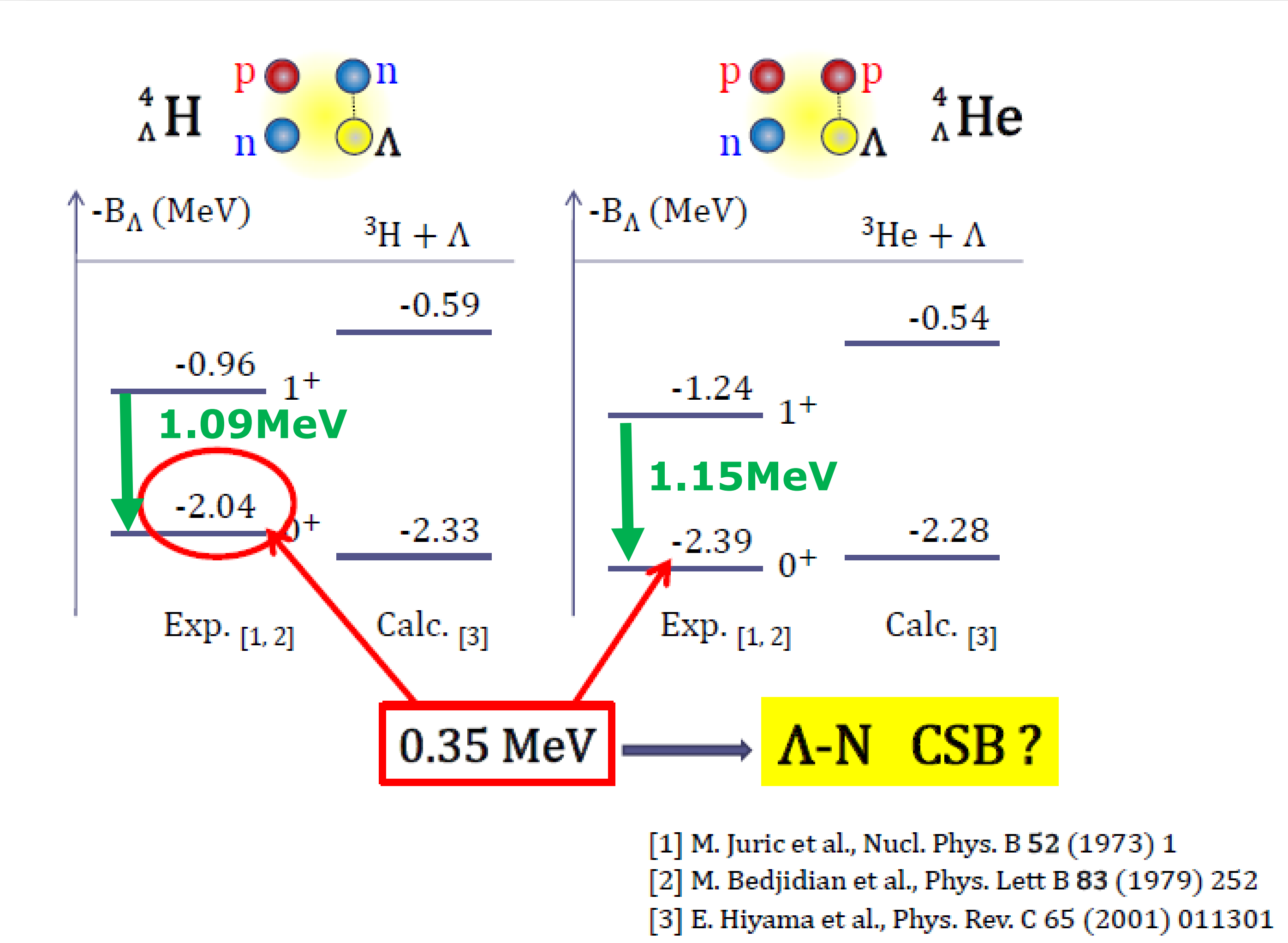
1. Hyperon-antihyperon production at threshold

2. Capture of Ξ^- in secondary target nucleus

3. γ-spectroskopy with Ge-detectors



Spin dependent CSB of ΛN interaction

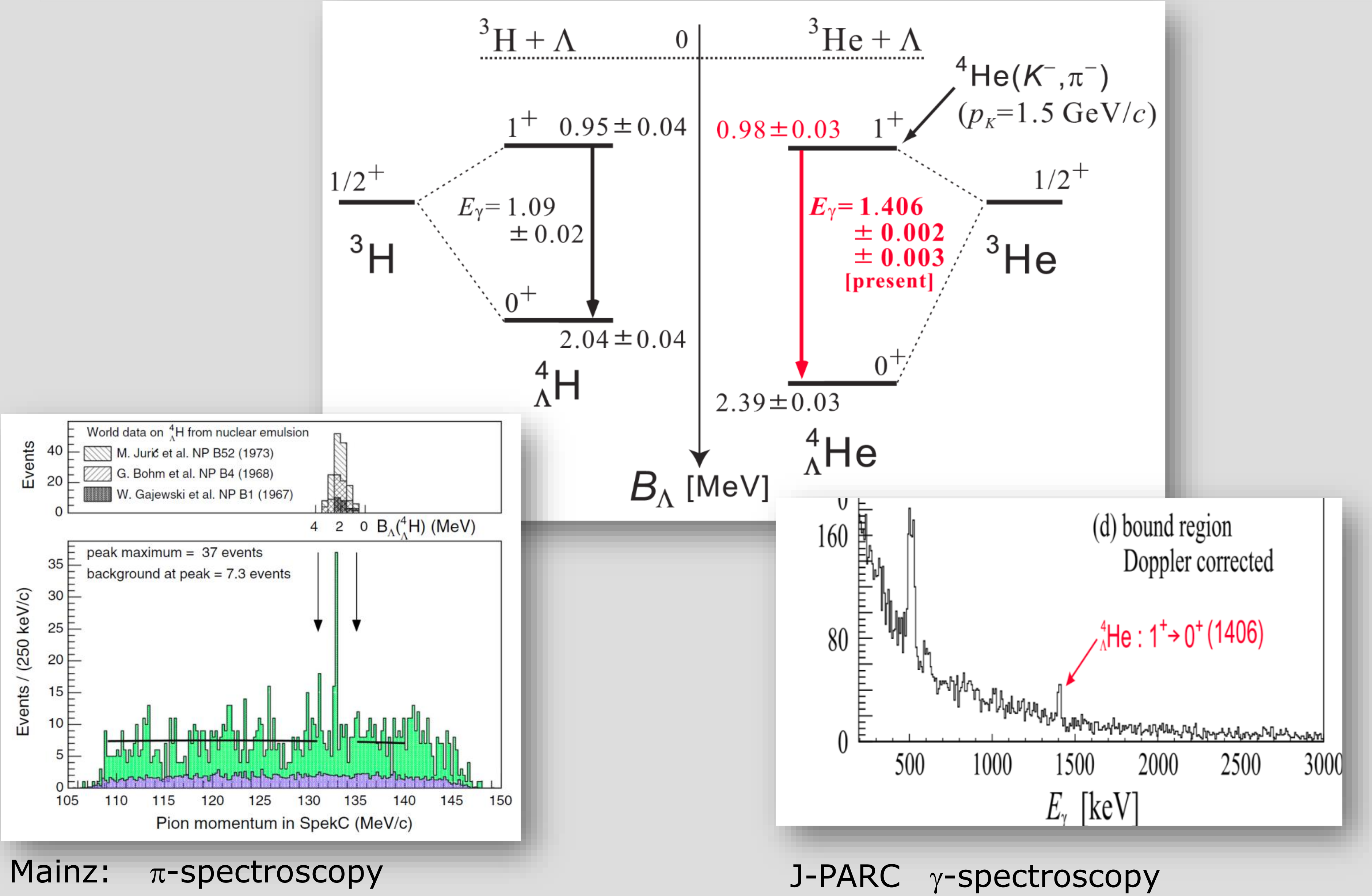


[1] M. Juric et al., Nucl. Phys. B **52** (1973) 1

[2] M. Bedjidian et al., Phys. Lett B **83** (1979) 252

[3] E. Hiyama et al., Phys. Rev. C 65 (2001) 011301

Spin dependent CSB of ΛN interaction

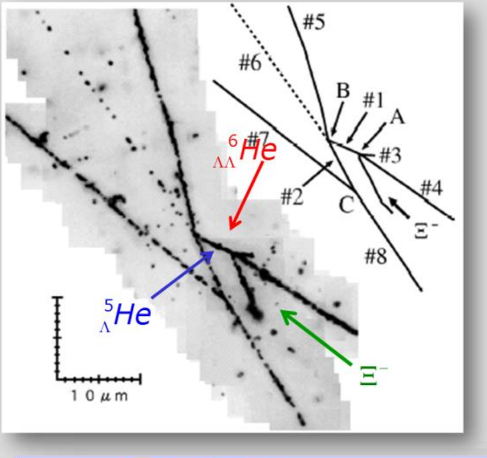


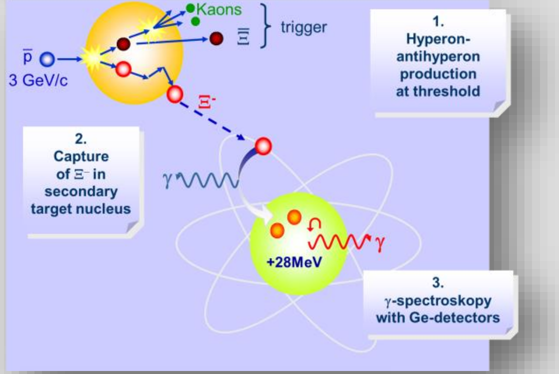
Mainz: π-spectroscopy
PRL 114, 232501 (2015)

J-PARC γ-spectroscopy
PRL 115, 222501 (2015)

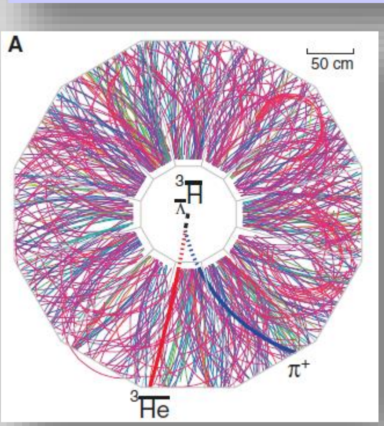
Many ways to double hypernuclei

- Ground state masses
  - Hybrid-emulsion technique
  - J-PARC E07
  - Goal: factor of 10 („overall scanning“ 100) compared to existing data





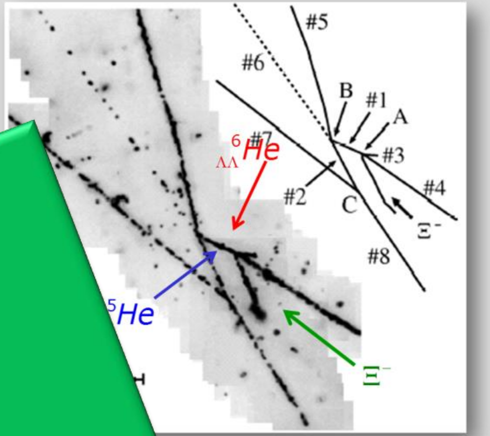
- Excited particle stable state spectroscopy
  - γ-spectroscopy
  - PANDA@FAIR



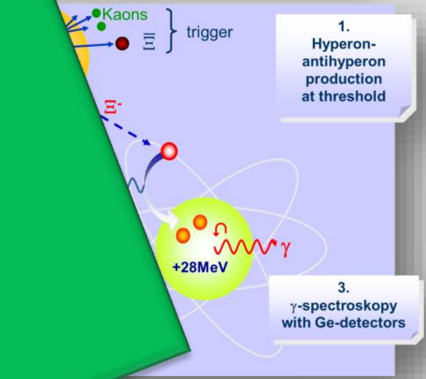
- Excited unstable resonances, exotic single hypernuclei, lifetime
  - Invariant mass; hypernuclei-Λ correlations
  - CBM and NuSTAR
  - STAR, ALICE

Many ways to double hypernuclei

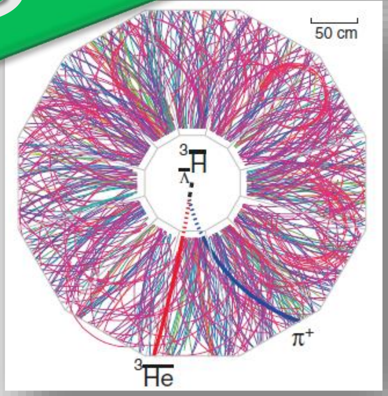
- Ground state masses
  - Hybrid-emulsion technique
  - J-PARC E07
  - Goal: factor of 10 („overall scanning“
    compared to existing data



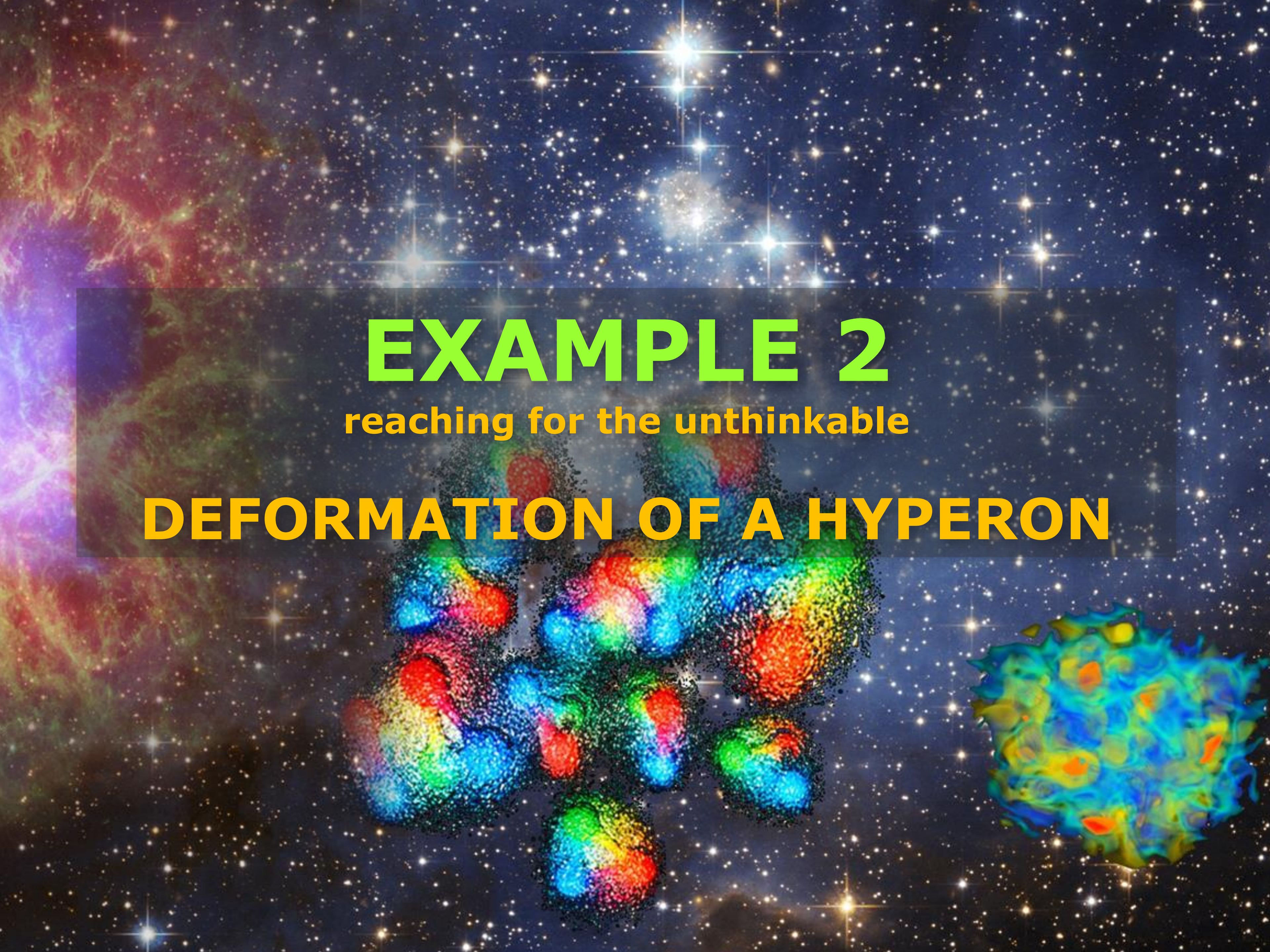
- Exci
  - γ-
  - PA



- Excited u
  single hyp
  - Invariant ei-Λ correlations
  - CBM and
  - STAR, ALIC



P̄ANDA is unique and complements worldwide activities



EXAMPLE 2

reaching for the unthinkable

DEFORMATION OF A HYPERON

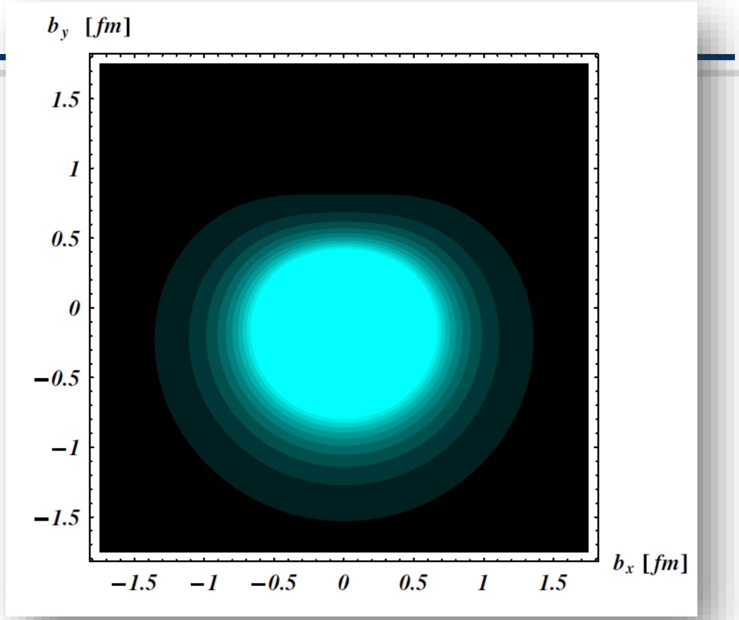
Proton vs. Omega

PRL **100,** 032004 (2008) PHYSICAL REVIEW LETTERS week ending 25 JANUARY 2008

Empirical Transverse Charge Densities in the Nucleon and the Nucleon-to-Δ Transition

Carl E. Carlson[1] and Marc Vanderhaeghen[1,2]

FIG. 1 (color online). Quark transverse charge densities in the *proton*. The upper panel shows the density in the transverse plane for a proton polarized along the x axis. The light (dark) regions correspond with largest (smallest) values of the density. The

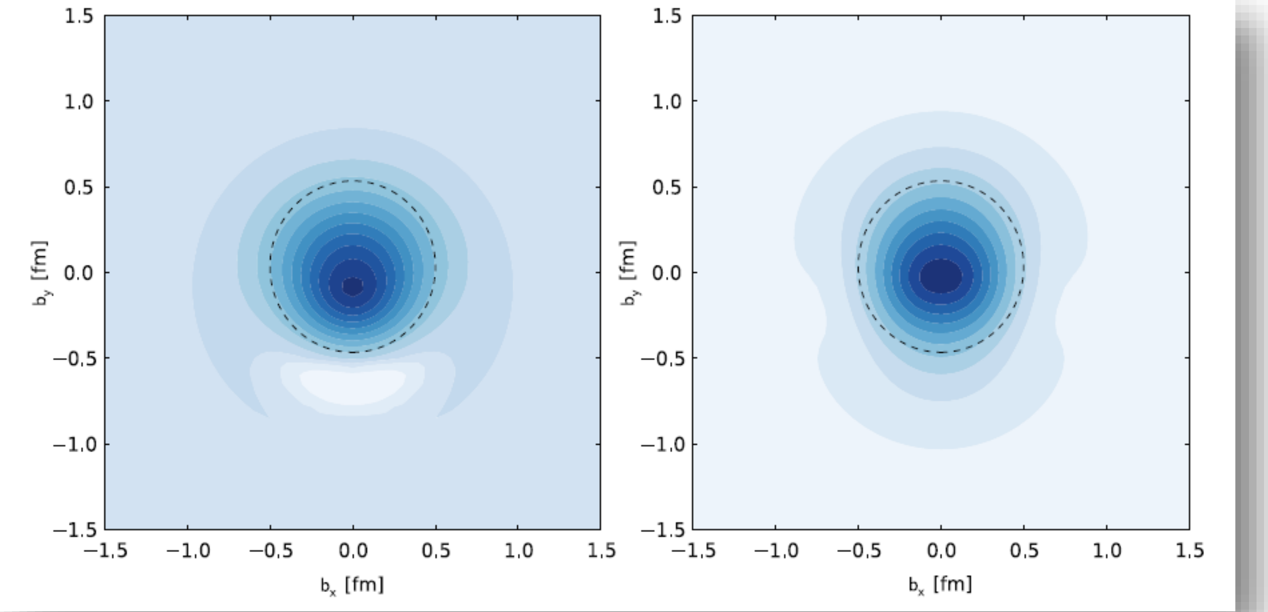


PHYSICAL REVIEW D **82,** 034504 (2010)

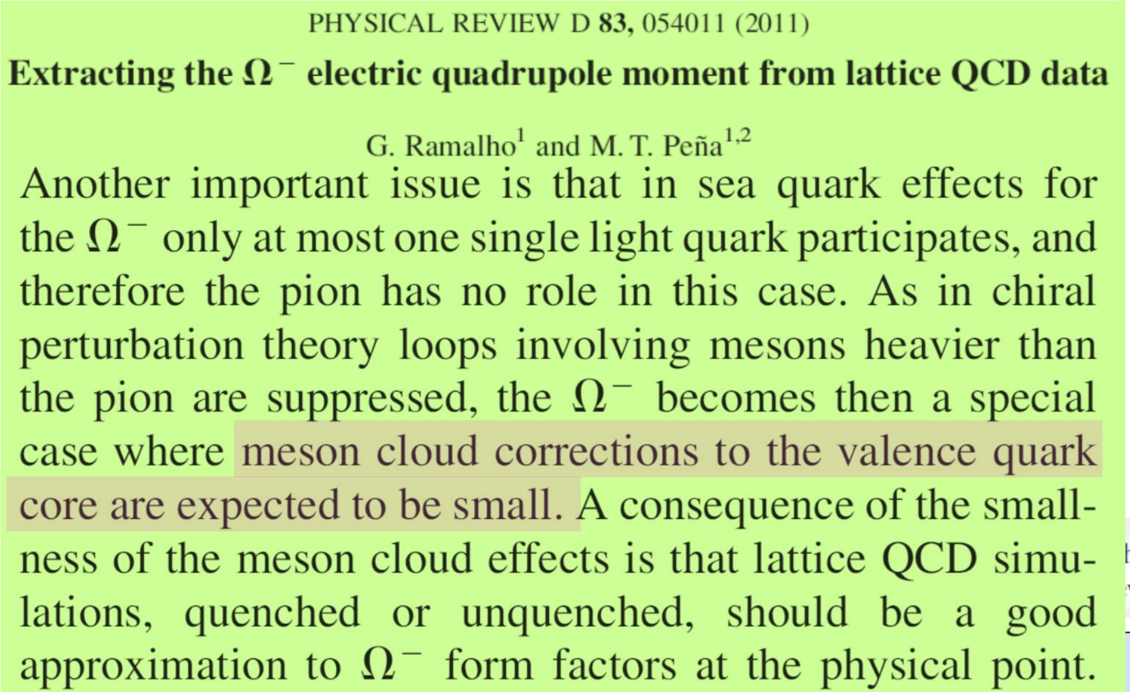
Electromagnetic form factors of the Ω^- in lattice QCD

C. Alexandrou,[1,2] T. Korzec,[3] G. Koutsou,[4,5] J. W. Negele,[6] and Y. Proestos[2]

FIG. 8 (color online). Transverse charge densities in the Ω^- with polarization along the x axis. Left: $\rho^{\Omega}_{T3/2}(\vec{b})$. Right: $\rho^{\Omega}_{T1/2}(\vec{b})$. A circle of radius 0.5 fm is drawn in order to clearly demonstrate the deformation. For the evaluation of the densities we used the dipole parametrization of the form factors.



Proton vs. Omega

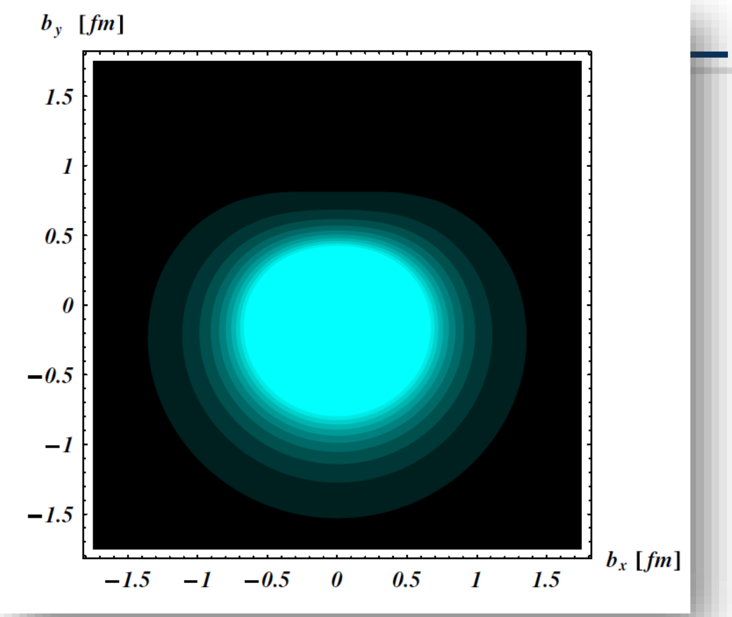


PHYSICAL REVIEW D **83,** 054011 (2011)

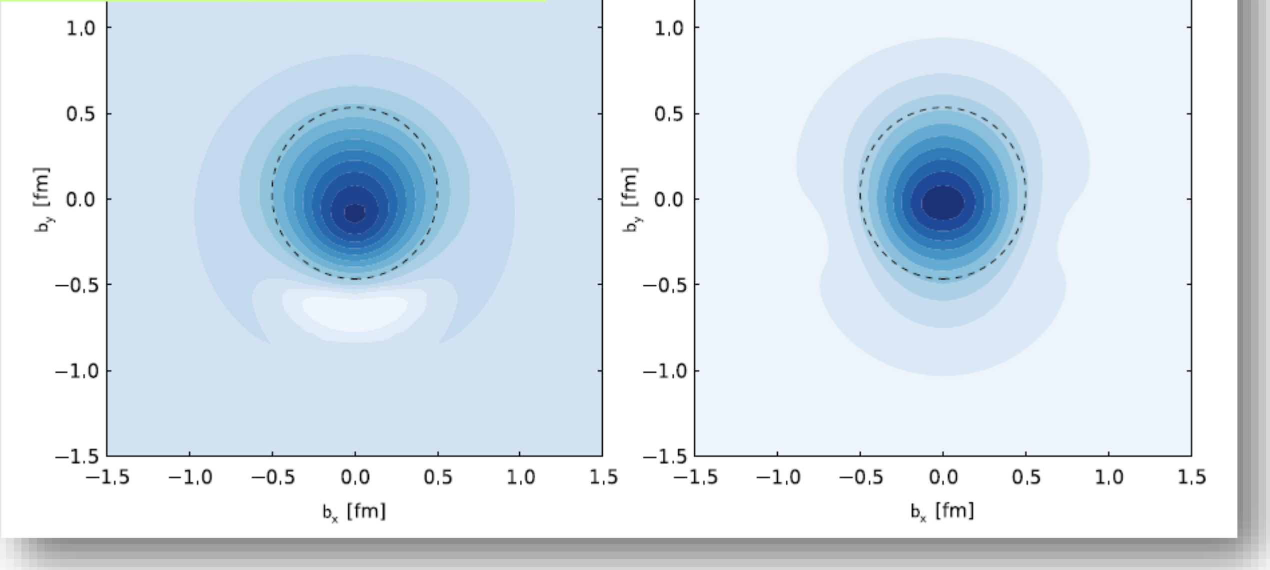
Extracting the Ω^- electric quadrupole moment from lattice QCD data

G. Ramalho[1] and M. T. Peña[1,2]

Another important issue is that in sea quark effects for the Ω^- only at most one single light quark participates, and therefore the pion has no role in this case. As in chiral perturbation theory loops involving mesons heavier than the pion are suppressed, the Ω^- becomes then a special case where meson cloud corrections to the valence quark core are expected to be small. A consequence of the smallness of the meson cloud effects is that lattice QCD simulations, quenched or unquenched, should be a good approximation to Ω^- form factors at the physical point.



he x axis. Left: $\rho^{\Omega}_{T3/2}(\vec{b})$. Right: $\rho^{\Omega}_{T1/2}(\vec{b})$. A
valuation of the densities we used the dipole



Ω^- Quadrupole Moment

Model	**Q [fm^2]**	**Reference**
NRQM	0.018	S.S. Gershtein,Yu.M., ZinovievSov. J. Nucl. Phys. 33, 772 (1981)
NRQM	0.004	J.-M. Richard, Z. Phys. C 12, 369 (1982)
NRQM	0.031	N. Isgur, G. Karl, R. Koniuk, Phys. Rev. D 25, 2395 (1982)
SU(3) Bag model	0.052	M.I. Krivoruchenko, Sov. J. Nucl. Phys. 45, 109 (1987)
QCD-SR	0.1	K. Azizi, Eur. Phys. J C 61, 311 (2009); T.M. Aliev, etal., arxiv: 0904.2485
NRQM with mesons	0.0057	W.J. Leonard, W.J. Gerace, Phys. Rev. D 41, 924 (1990)
NQM	0.028	M.I. Krivoruchenko, M.M. Giannini, Phys. Rev. D 43, 3763 (1991)
Lattice QCD	0.005	D.B. Leinweber, T. Draper, R.M. Woloshyn, Phys. Rev. D 46, 3067 (1992)
HBχPT	0.009	M.N. Butler, M.J. Savage, R.P. Springer, Phys. Rev. D 49, 3459 (1994)
Skyrme	0.024	J. Kroll, B. Schwesinger, Phys. Lett. B 334, 287 (1994)
Skyrme	0.0	Yoongseok Oh, ep-ph/9506308
QM	0.022	A.J. Buchmann, Z. Naturforschung 52a, 877 (1997)
χQM	0.026	G. Wagner, A.J. Buchmann, A. Faessler, J. Phys. G 26, 267 (2000)
GP QCD	0.024	A.J. Buchmann, E.M. Henley, Phys. Rev. D 65,073017 (2002)
χPT+qlQCD	0.0086	L.S. Geng, J. Martin Camalich, M.J. Vicente Vacas, Phys. Rev. D80, 034027 (2009)
Lattice QCD	0.0096±0.0002	G. Ramalho, M.T. Pena, Phys.Rev.D83:054011 (2011), arxiv:1012.2168

A very strange Atom

- hyperfine splitting in Ω-atom
  ⇒ electric quadrupole moment of Ω

spin-orbit $\Delta E_{ls} \sim (aZ)^4\, l\cdot m_{\Omega}$

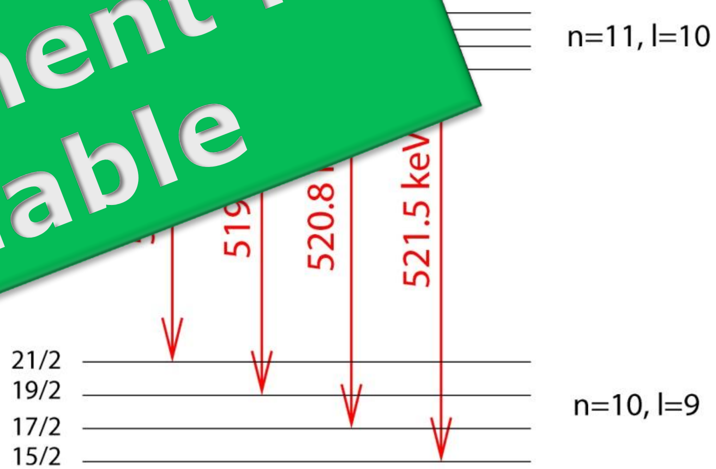
quadrupole $\Delta E_{\Theta} \sim (aZ)$

R.M. Sternh

M.M. Gia

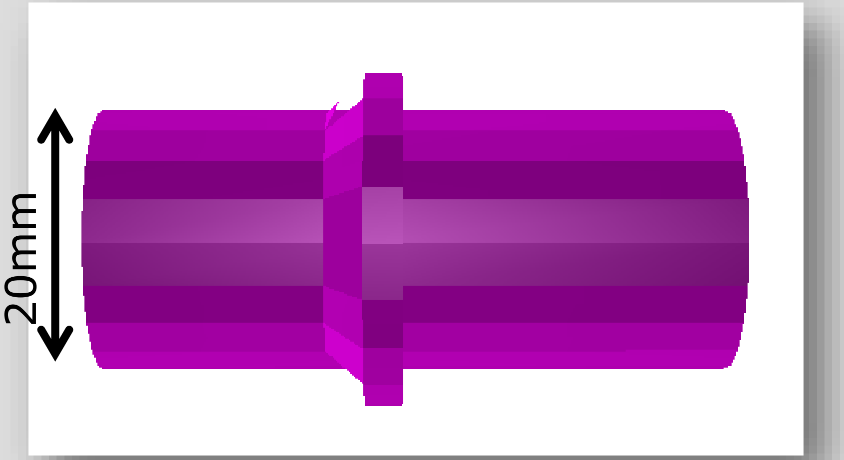
P̄ANDA is the only experiment where this measurement is imaginable

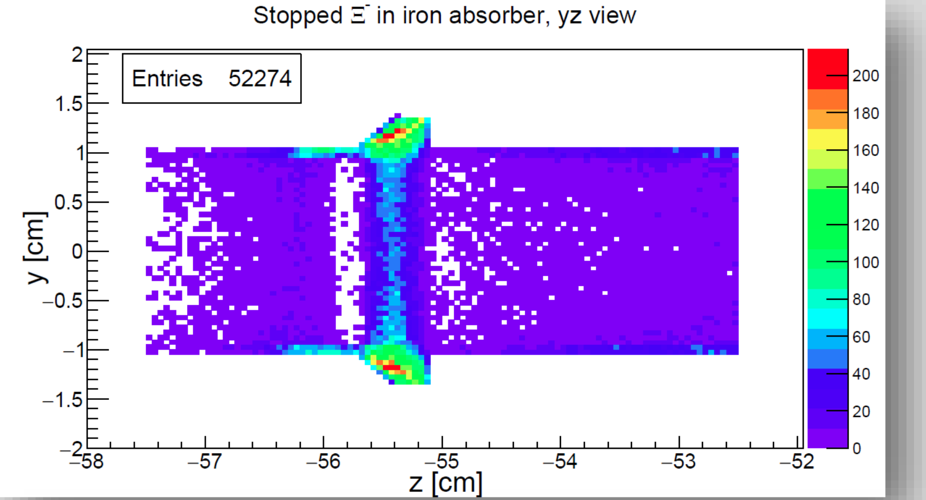
- predictio
  - E(n=1
    - cali
  - $\Delta E_{\Theta} \sim$ fe



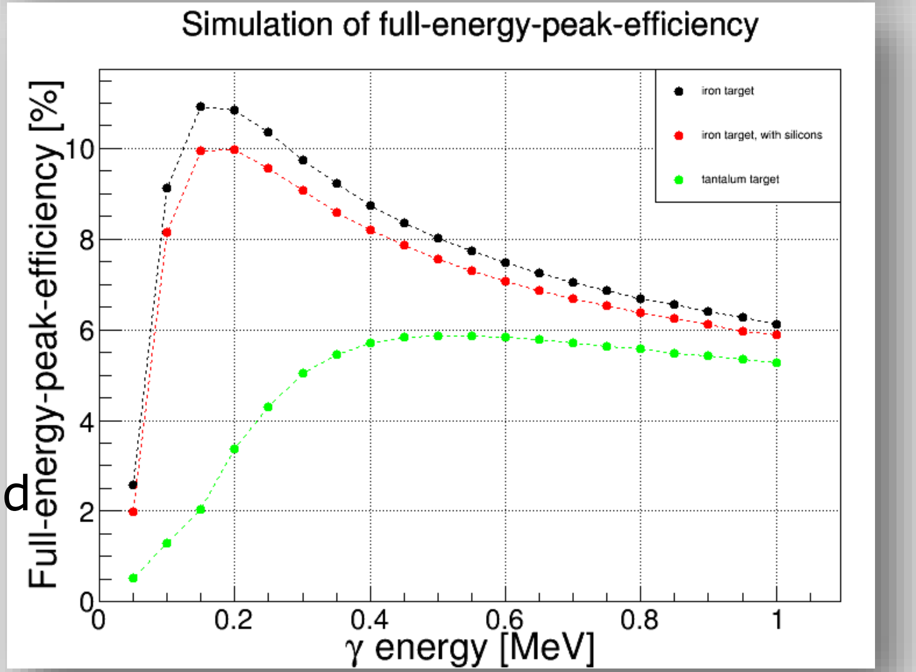
Q_{Ω}=0.02fm^2

PANDA Setup for Hyperatoms

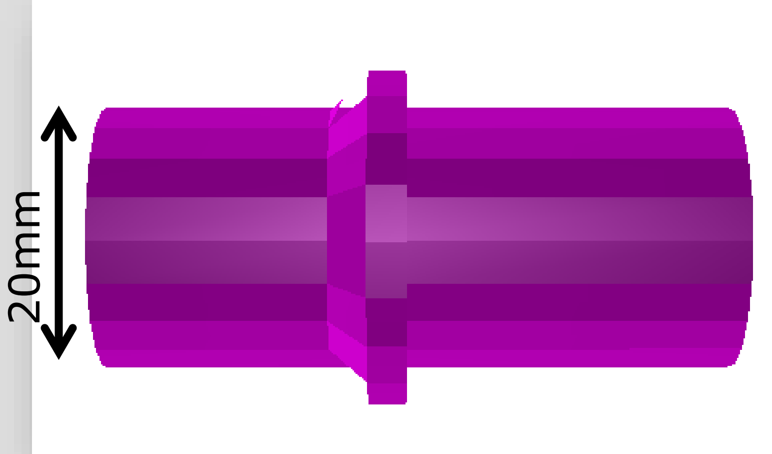


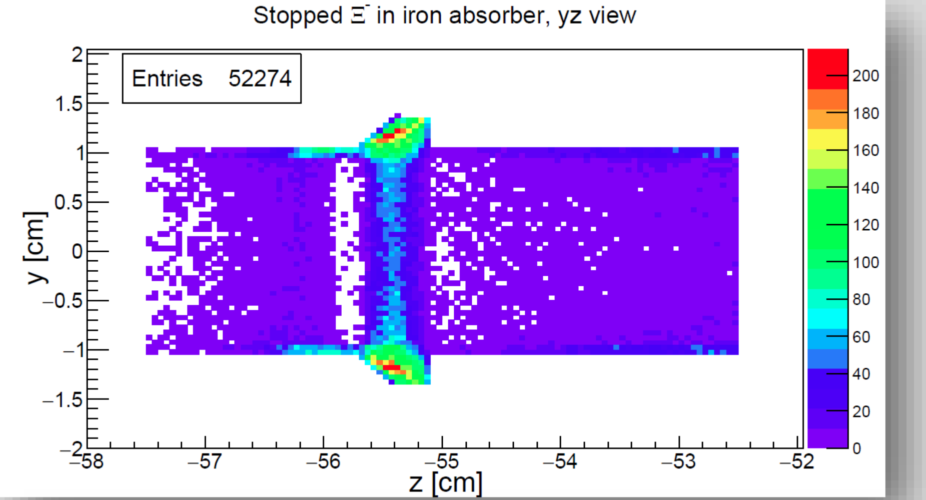

Stopped Ξ^- in iron absorber, yz view

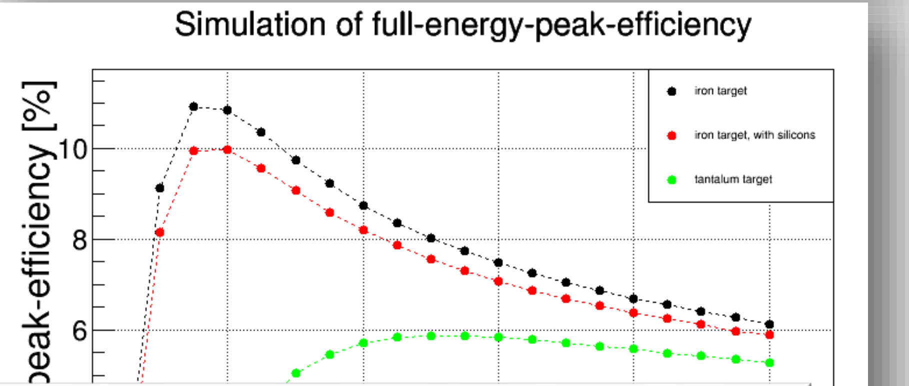
- Primary and secondary target separated
- very thin primary target
- relative thin secondary target ⇒ moderate x-ray absorption
- tracking secondary particles possible ⇒ reduced background


Simulation of full-energy-peak-efficiency

PANDA Setup for Hyperatoms







- Primary and secondary target separated
- very thin primary target
- relative thin secondary target
  ⇒ moderate x-ray absorption

For Fe absorber:

Single X-ray lines (6,5)→(5,4): ~3400/month

Cascade events (7,6)→(6,5)∧(6,5)→(5,4) ~100/month

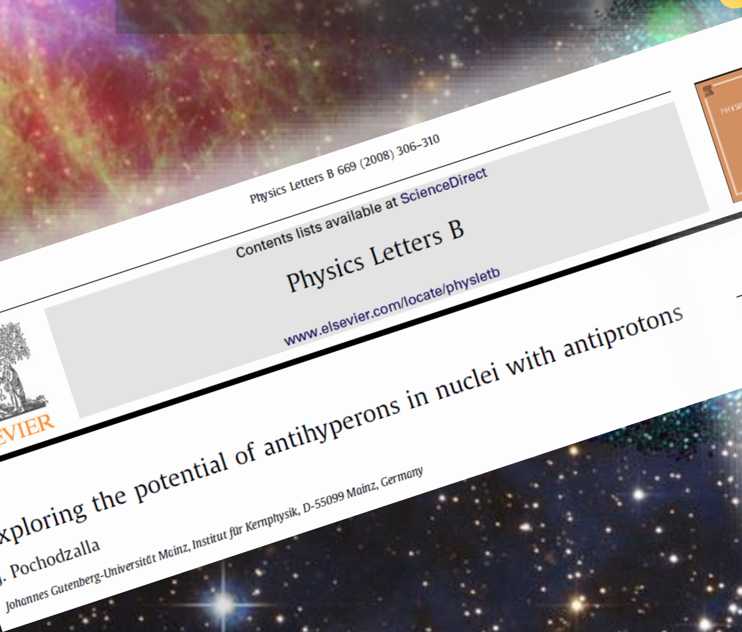
for Ta target FOM ~ 2.5 less

⇒ ideal for comissioning phase of hypernucleus setup

EXAMPLE 3

A one day day-one experiment

ANTIHYPRONS IN NUCLEI at PANDA



Physics Letters B 669 (2008) 306–310

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xploring the potential of antihyperons in nuclei with antiprotons

. Pochodzalla

Johannes Gutenberg-Universität Mainz, Institut für Kernphysik, D-55099 Mainz, Germany

Physics Letters B 749 (2015) 421–424

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Antihyperon potentials in nuclei via exclusive antiproton–nucleus reactions

Alicia Sanchez Lorente[a], Sebastian Bleser[a], Marcell Steinen[a], Josef Pochodzalla[a,b,*]

[a] Helmholtz Institut Mainz, Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany

[b] Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany

Probing the Neutron Skin of Nuclei

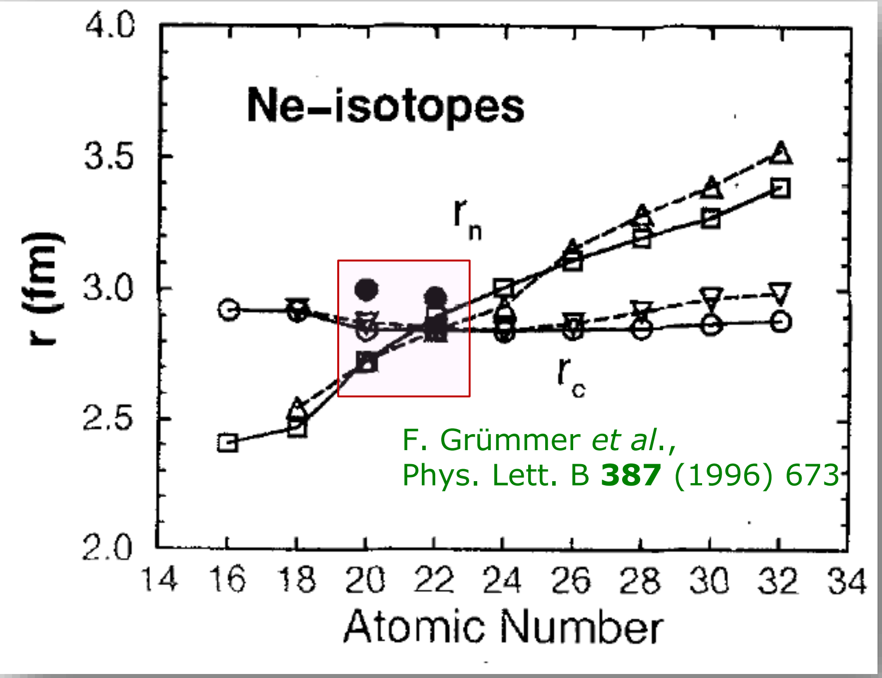
- $\bar{p}+p\rightarrow\bar{\Lambda}+\Lambda$ $\bar{p}+p\rightarrow\bar{\Sigma}^0+\Lambda$ $\bar{p}+n\rightarrow\bar{\Lambda}+\Sigma^-$ $\bar{p}+n\rightarrow\bar{\Sigma}^++\Lambda$

absorption length of $\bar{p}$ $$r_{abs} = \frac{1}{\sigma_{abs}\rho} \sim \frac{1}{100mb\cdot 0.17fm^{-3}} \approx \frac{\rho_0}{\rho}0.6fm$$

survival probability $$p_{survival} = \exp(-\Delta r / r_{abs})$$

- going from ^{20}Ne vs. ^{22}Ne

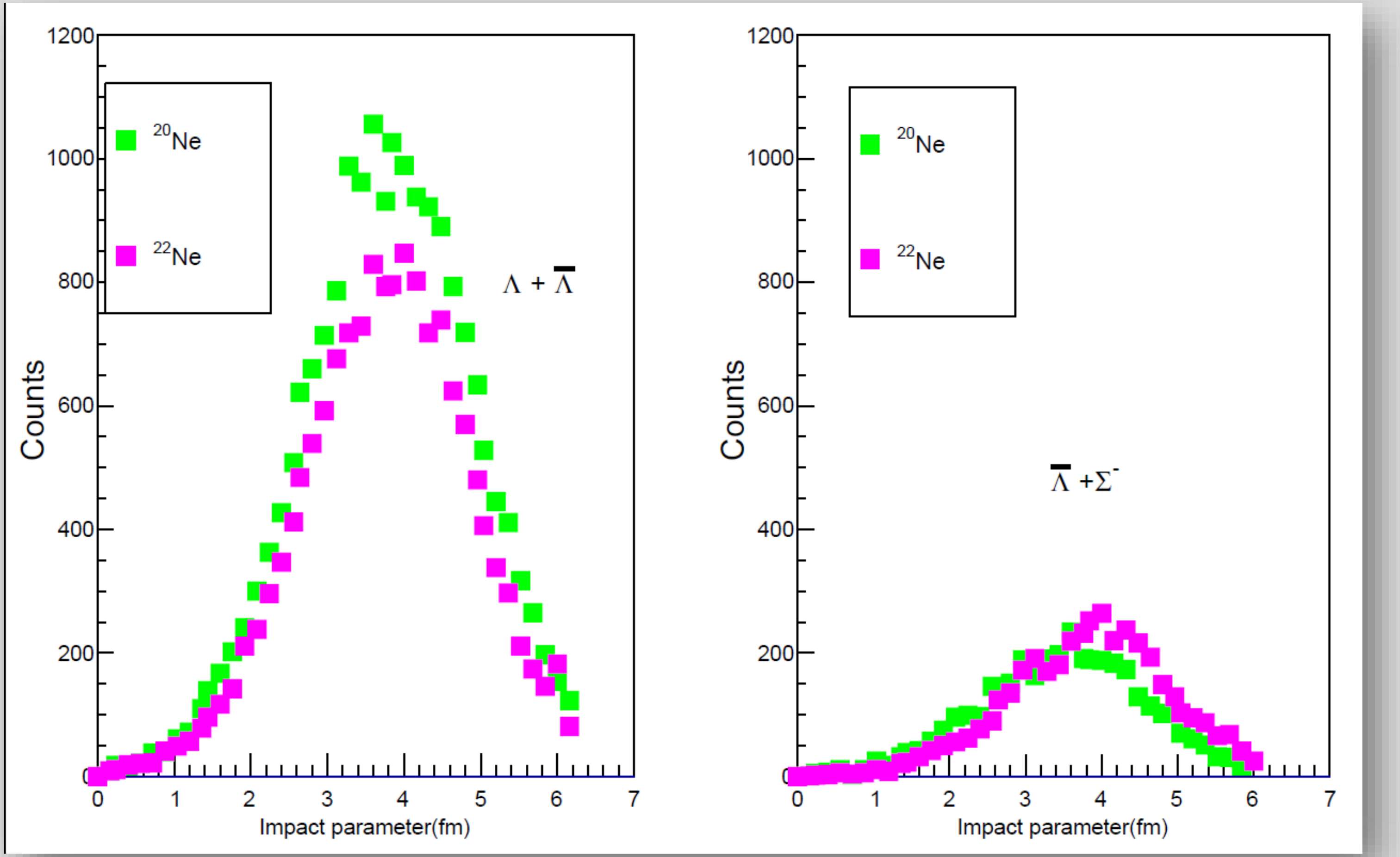
$$p_{survival}(\rho / \rho_0 = 0.3) \approx 0.89$$



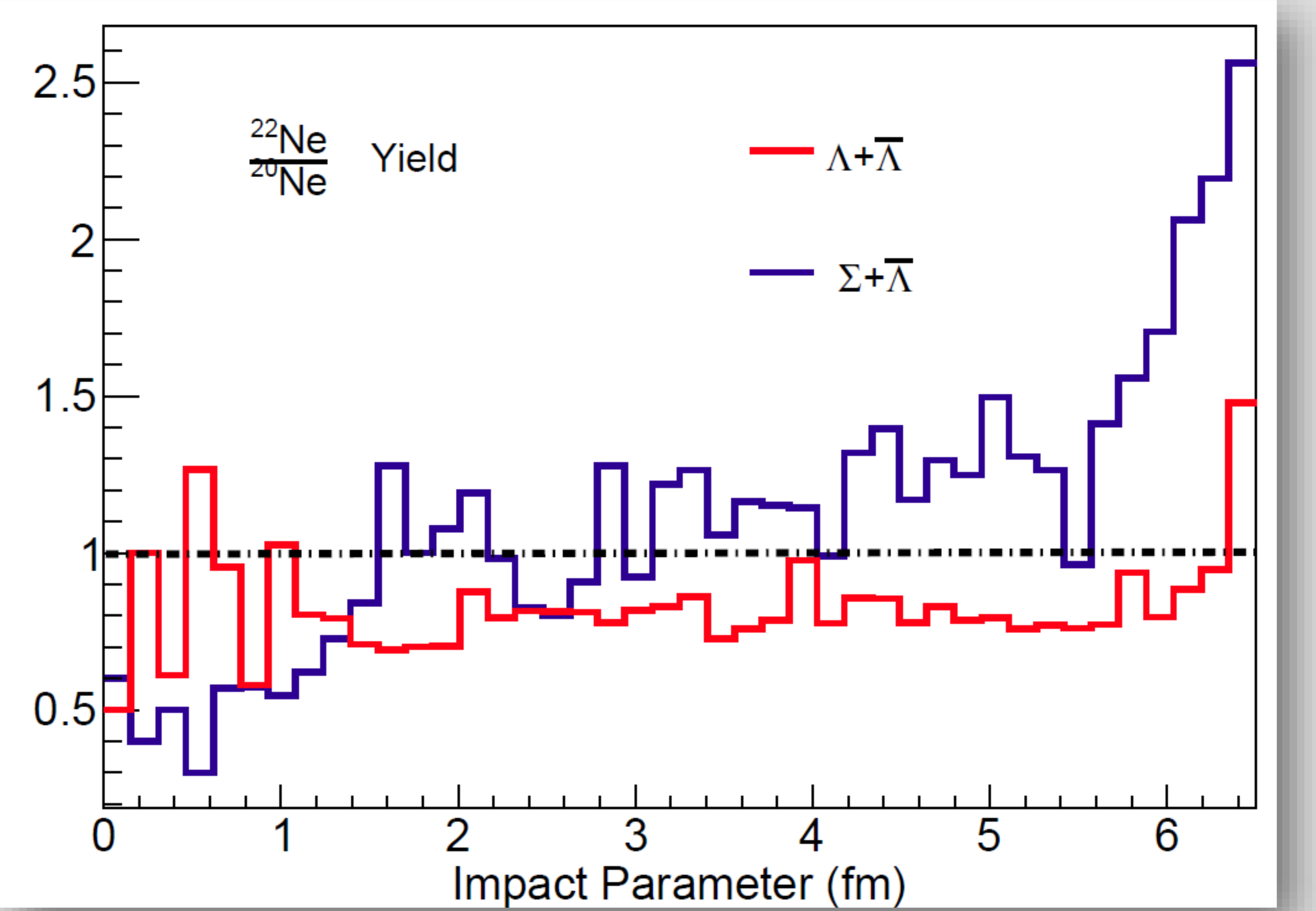
F. Grümmer *et al.*,
Phys. Lett. B **387** (1996) 673

- additional absorption of antiprotons in neutron skin:
  - $\bar{\Lambda}+\Sigma^-$ will increase and $\bar{\Lambda}+\Lambda$ will decrease
- additional absorption of *outgoing* Λ
  - $\bar{\Lambda}+\Sigma^-$ will decrease and $\bar{\Lambda}+\Lambda$ will decrease

- additional absorption of antiprotons in neutron skin:
  - $\bar{\Lambda}+\Sigma^-$ will increase and $\bar{\Lambda}+\Lambda$ will decrease
- additional absorption of *outgoing* Λ
  - $\bar{\Lambda}+\Sigma^-$ will decrease and $\bar{\Lambda}+\Lambda$ will decrease



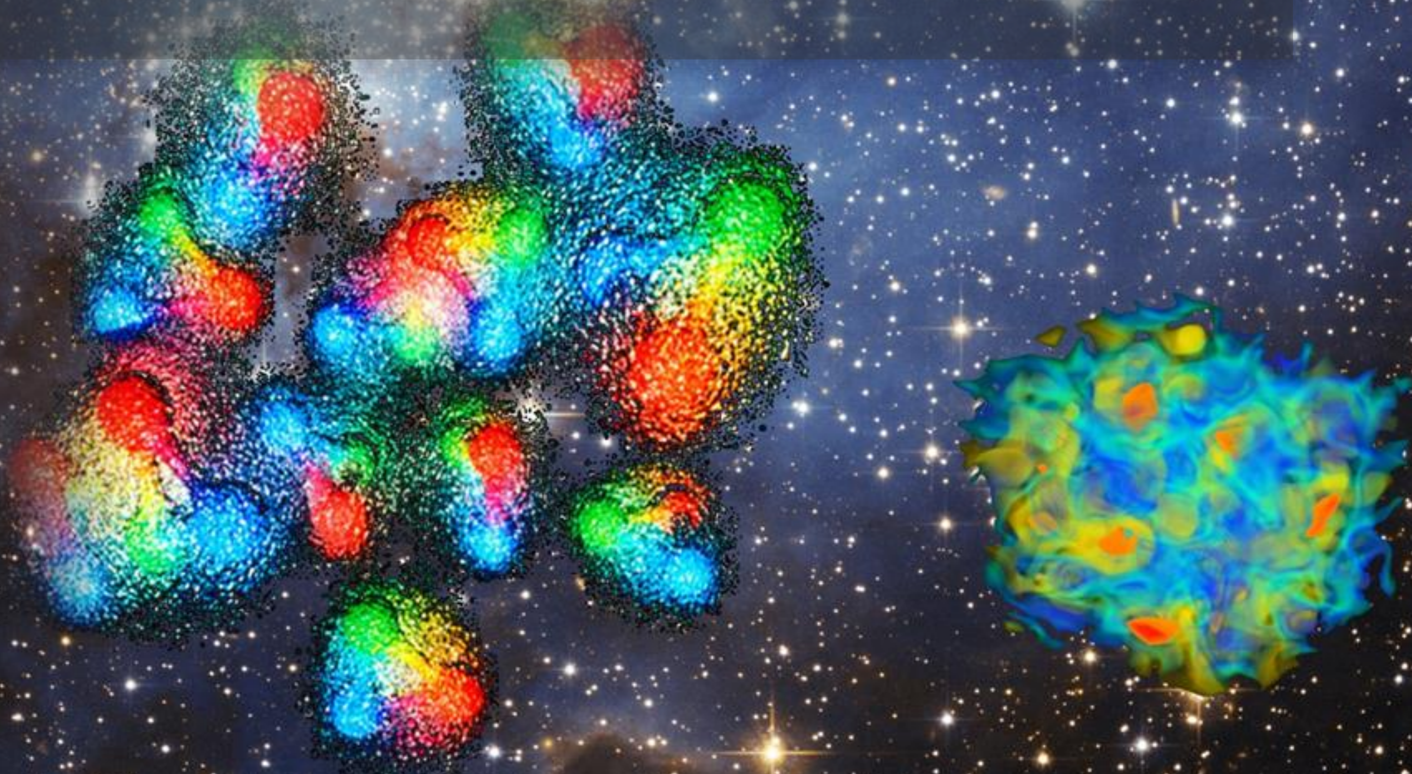
- additional absorption of antiprotons in neutron skin:
  - $\overline{\Lambda}+\Sigma^-$ will increase and $\overline{\Lambda}+\Lambda$ will decrease
- additional absorption of *outgoing* Λ
  - $\overline{\Lambda}+\Sigma^-$ will decrease and $\overline{\Lambda}+\Lambda$ will decrease



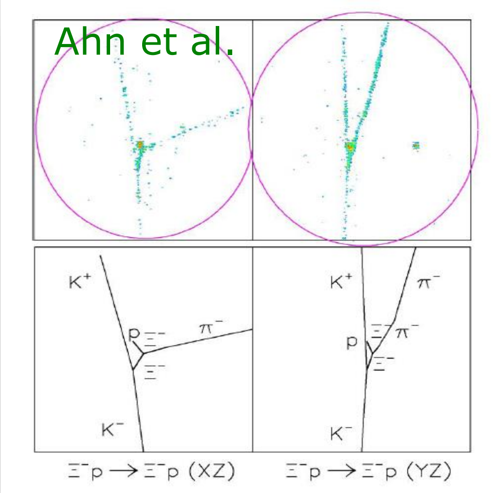
EXAMPLE 4

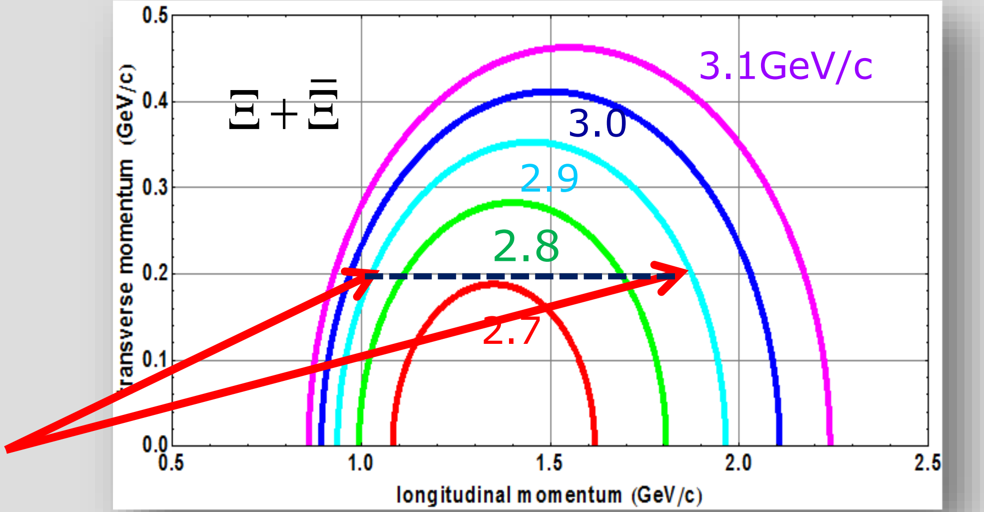
A unique tool to study elementary (anti)hyperon-nucleon interactions

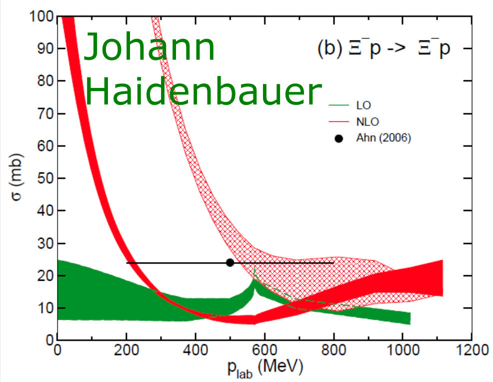
polarized Y and $\overline{Y}$ scattering

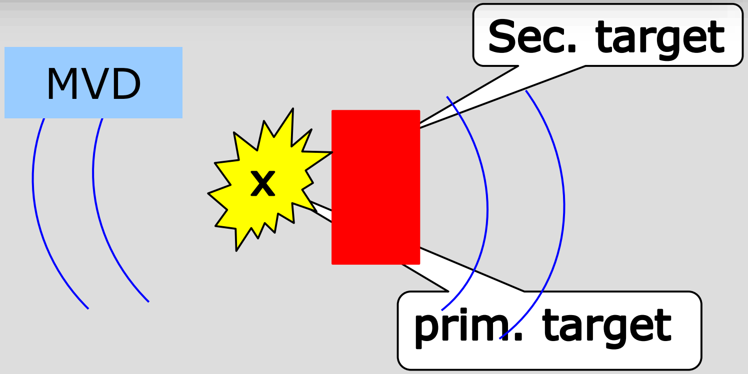


Ξ^- scattering

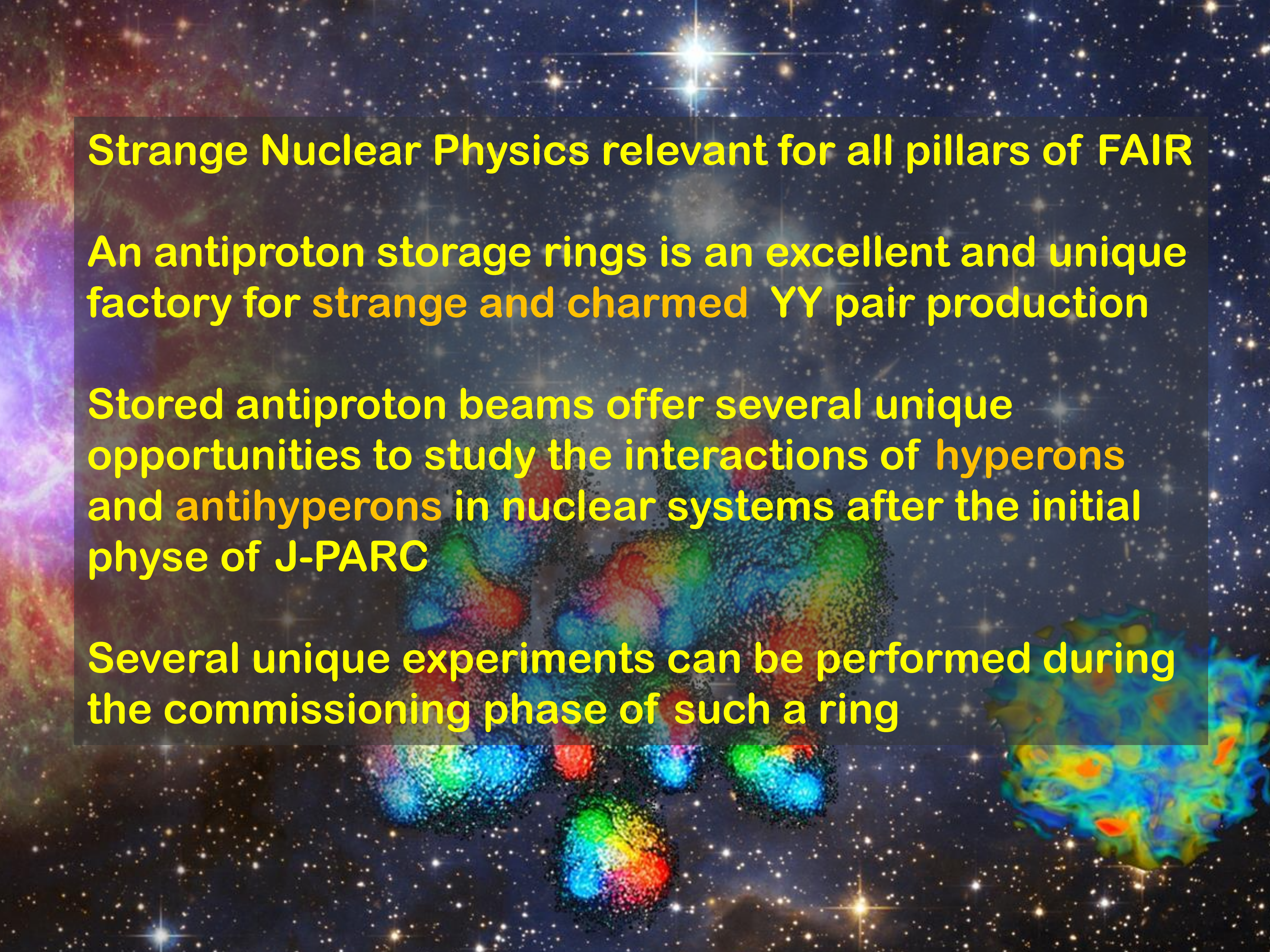








- $\bar{p}$+p→ $\bar{Y}$+Y provides momentum tagged (low) momentum, polarized hyperon *or* antihyperon beams
- scattering experiment with low momentum (anti)hyperons possible
- *long term future:low energy p-$\bar{p}$ collider*



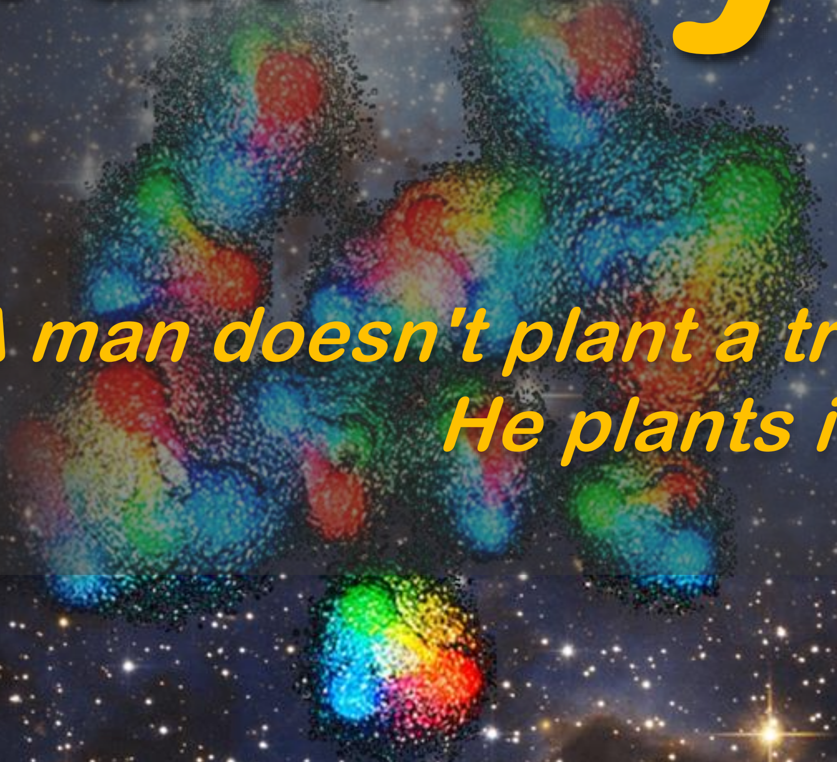
Strange Nuclear Physics relevant for all pillars of FAIR

An antiproton storage rings is an excellent and unique factory for strange and charmed YY pair production

Stored antiproton beams offer several unique opportunities to study the interactions of hyperons and antihyperons in nuclear systems after the initial physe of J-PARC

Several unique experiments can be performed during the commissioning phase of such a ring

Thank you



A man doesn't plant a tree for himself.
He plants it for posterity.
Alexander Smith