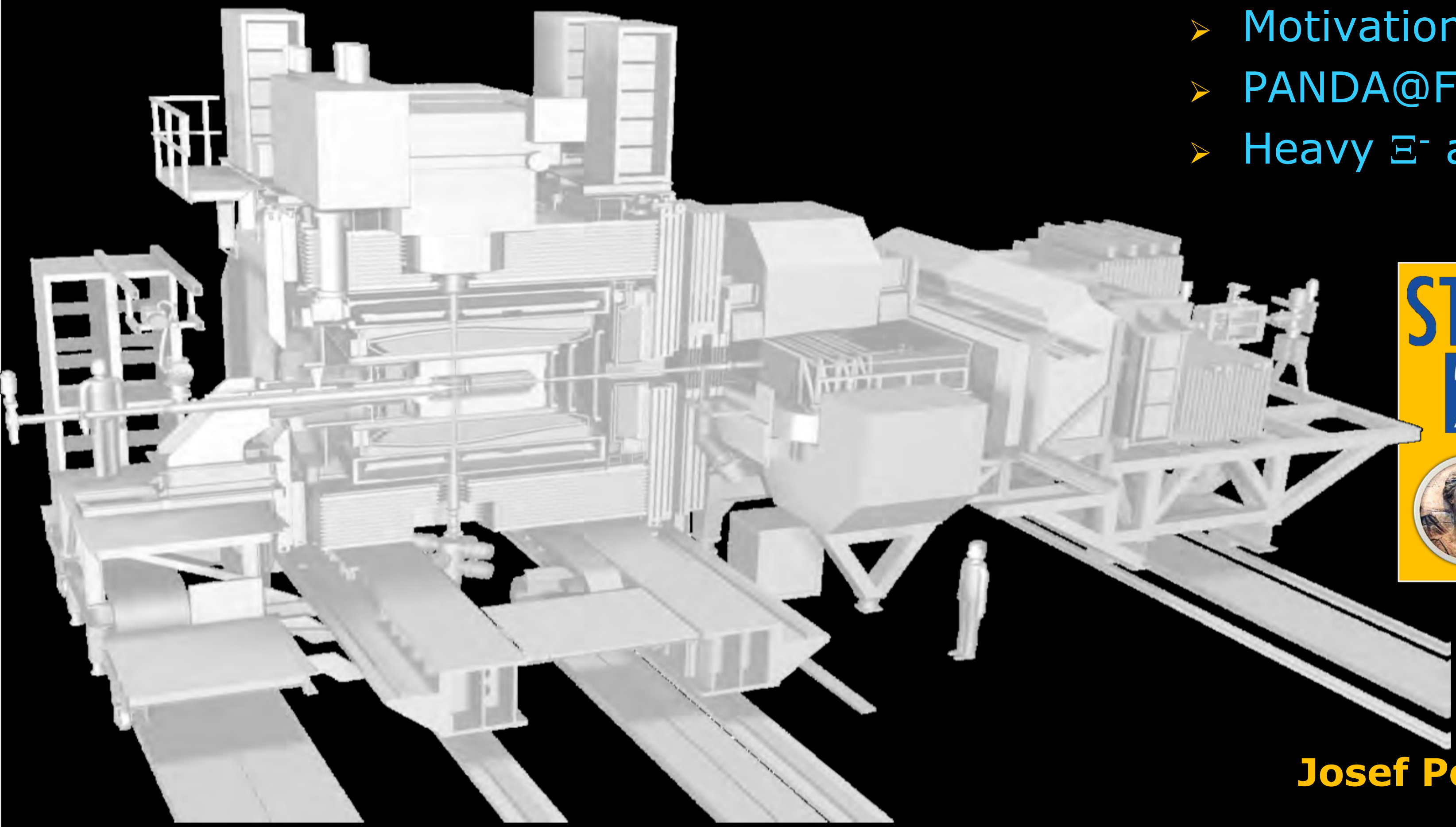
Hadron In Nucleus 2020 (HIN20)

8-10 March 2021

Yukawa Institute for Theoretical Physics, Kyoto University

Strange nuclear systems at panda

- Motivation
- PANDA@FAIR
- Heavy Ξ^- atoms



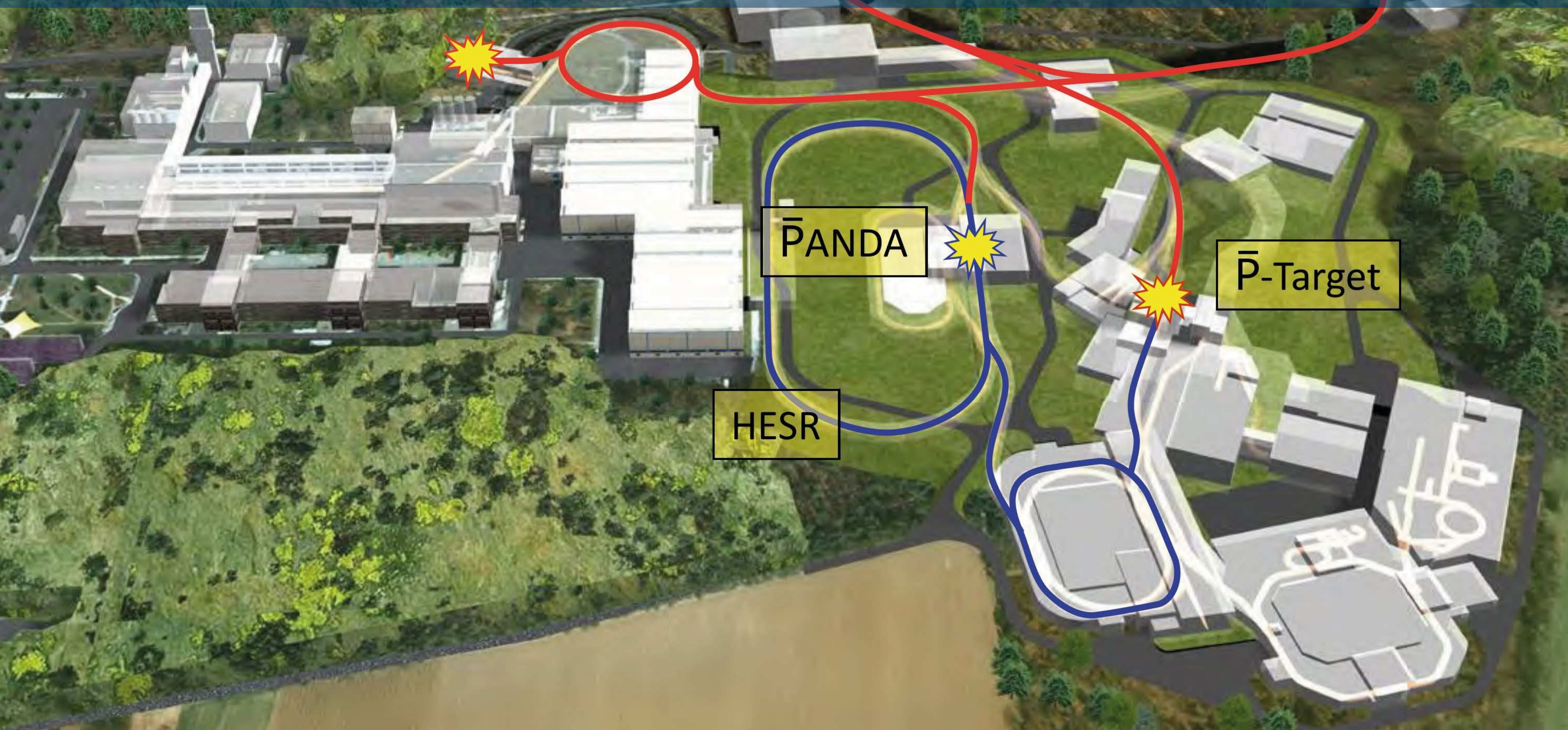
Josef Pochodzalla

JGU Mainz & Helmholtz-Institut – Mainz – European Union

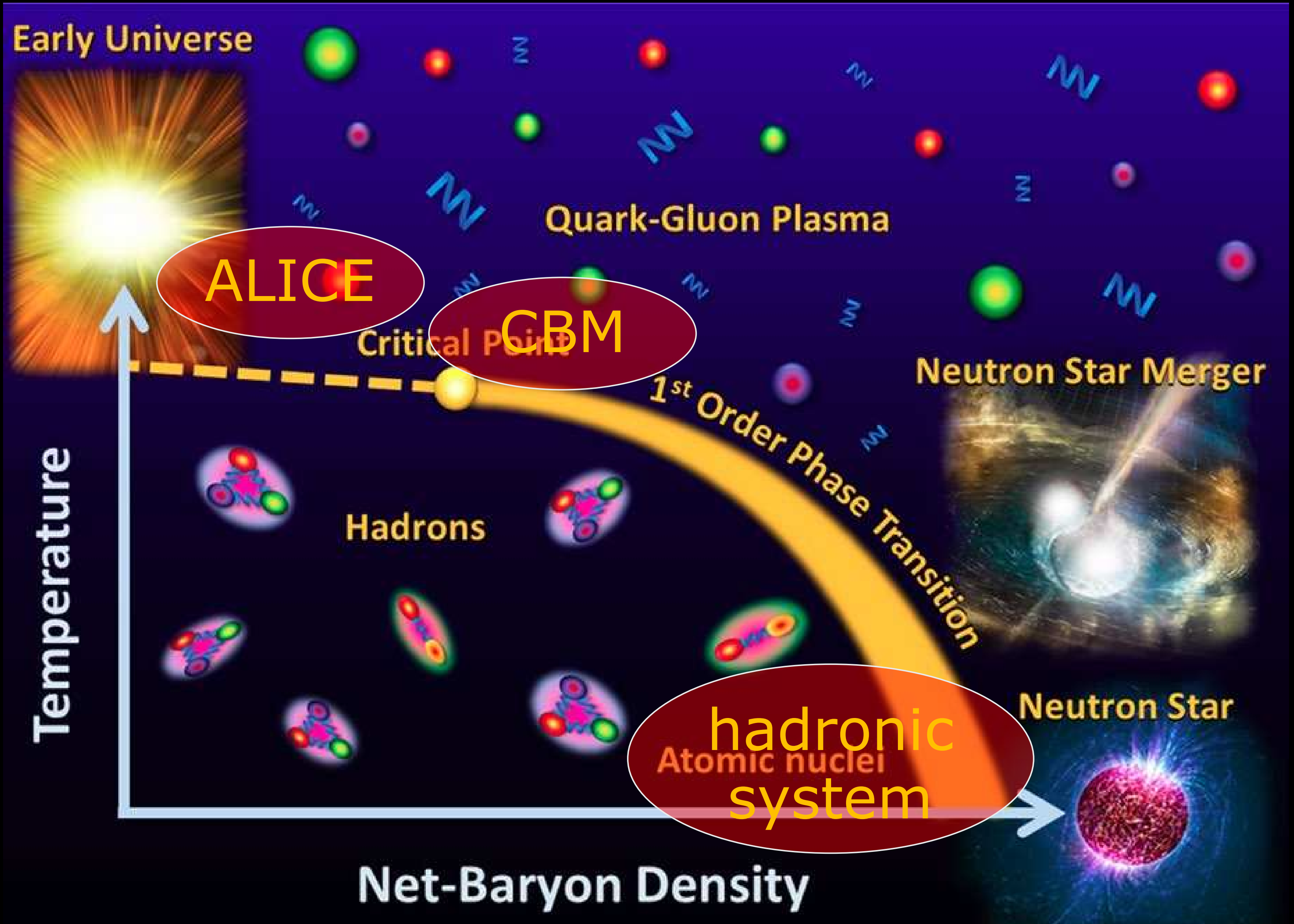
FAIR strongly interacting matter on all scales

- Nuclear Structure & Astrophysics (rare isotope beams)
- QCD-Phase Diagram (HI beams 2 to 45 GeV/u)
- Fundamental Symmetries & Ultra-High EM Fields (anti-protons & highly stripped ions)
- Hadron Physics (stored and cooled 15 GeV/c anti-protons)

- Dense Bulk Plasmas (ion beam bunch compression & petawatt-laser)
- Materials Science & Radiation Biology (ion & anti-proton beams)



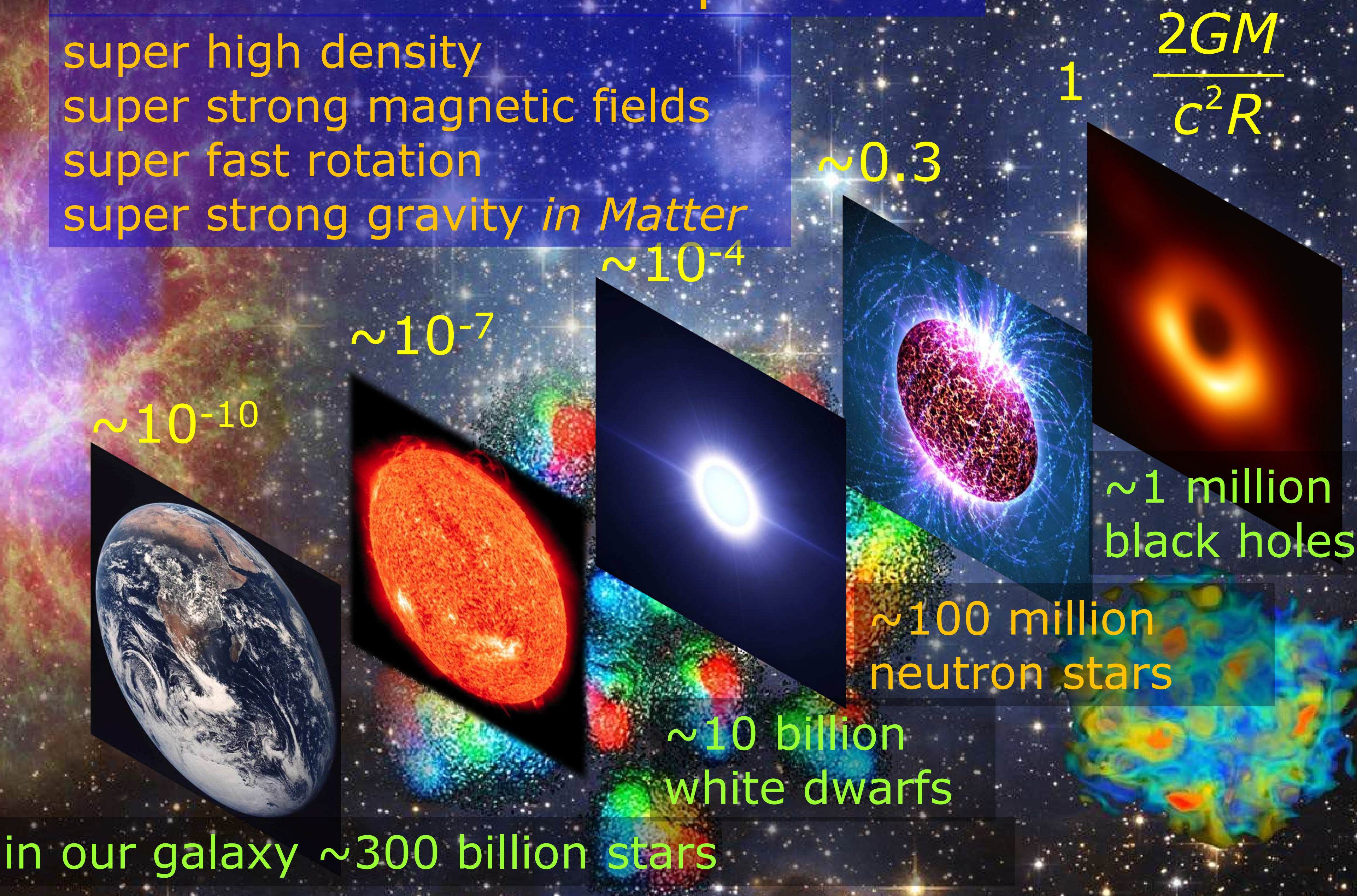
The Holy Grail of QCD Matter

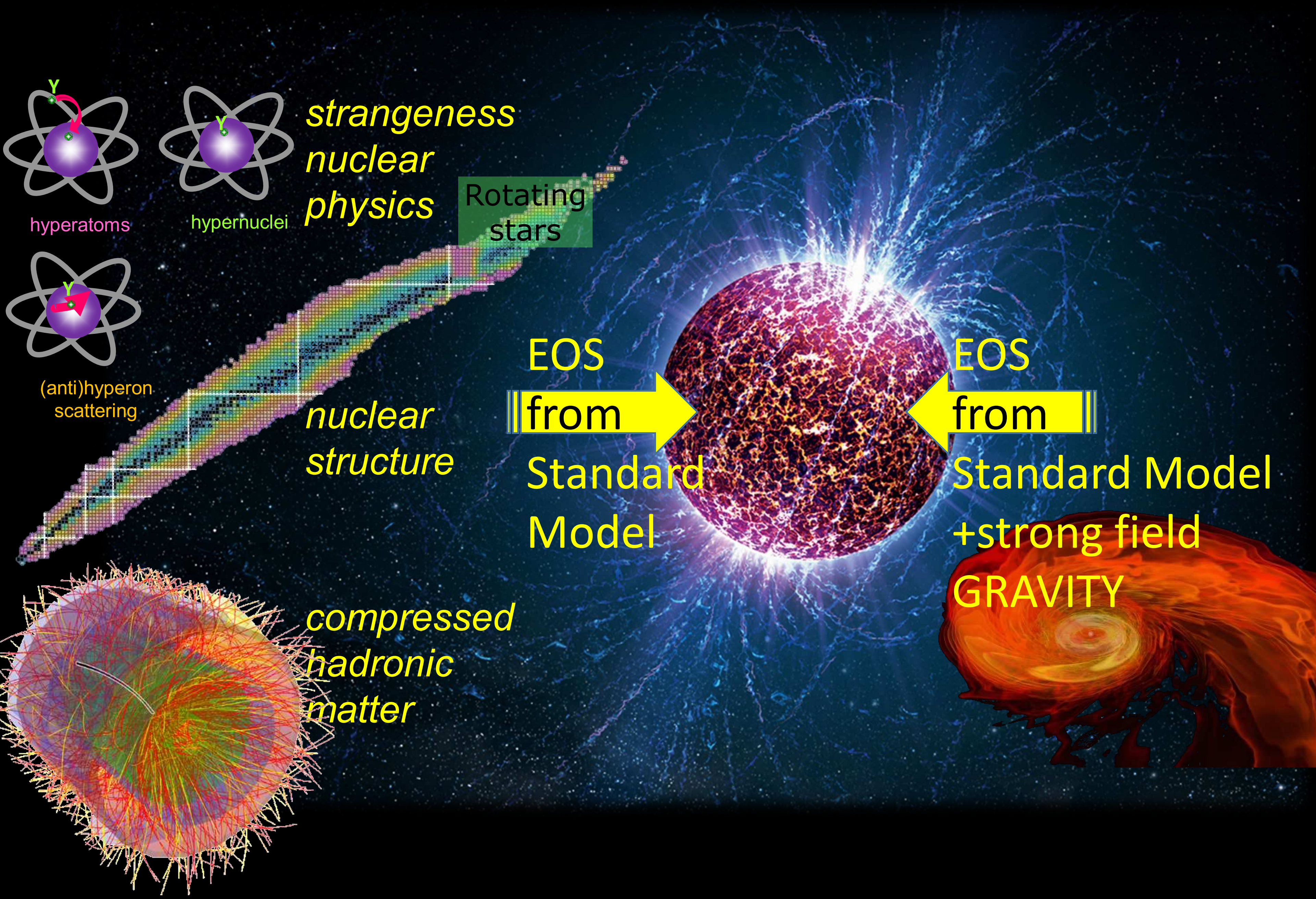


courtesy of Peter Senger and Norbert Herrmann

Neutron stars are Superstars

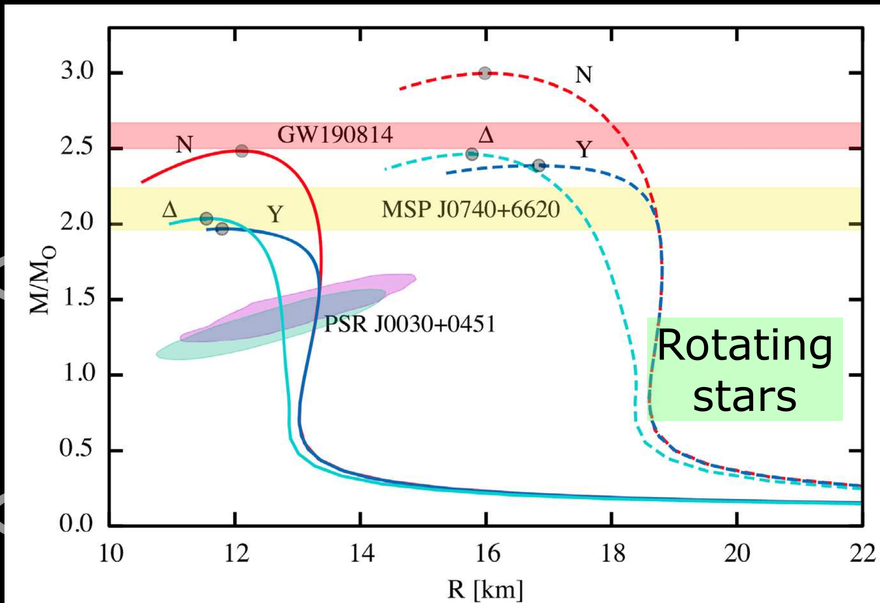
super high density
super strong magnetic fields
super fast rotation
super strong gravity *in Matter*



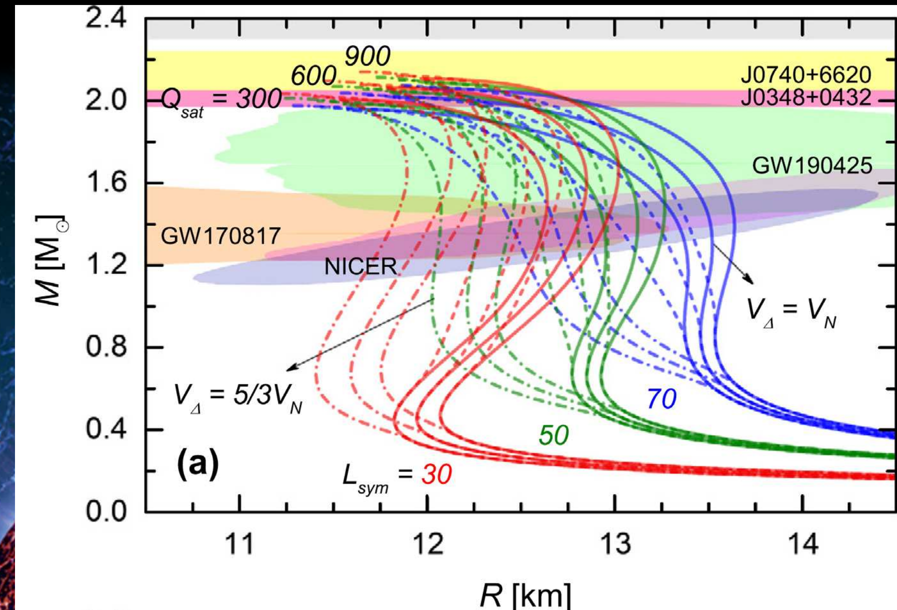


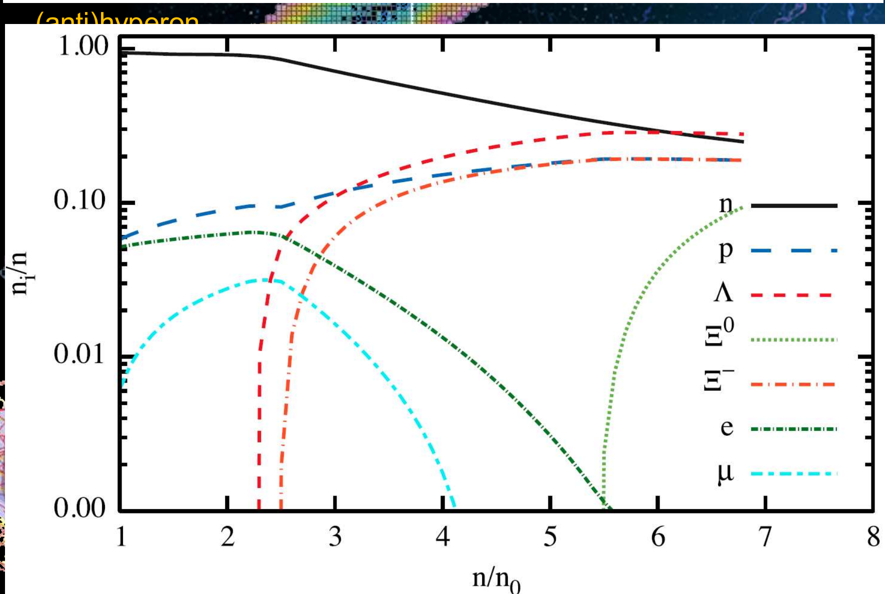
hyperatoms
hypernuclei
strangeness
nuclear
physics
Rotating
stars
(anti)hyperon
scattering
nuclear
structure
compressed
hadronic
matter
EOS
from
Standard
Model
EOS
from
Standard Model
+strong field
GRAVITY

Sedrakian, Weber, Li, Phys. Rev. D 102, 041301(R) (2020)



Li, Sedrakian, Weber, Phys. Lett. B 810, 135812 (2020)

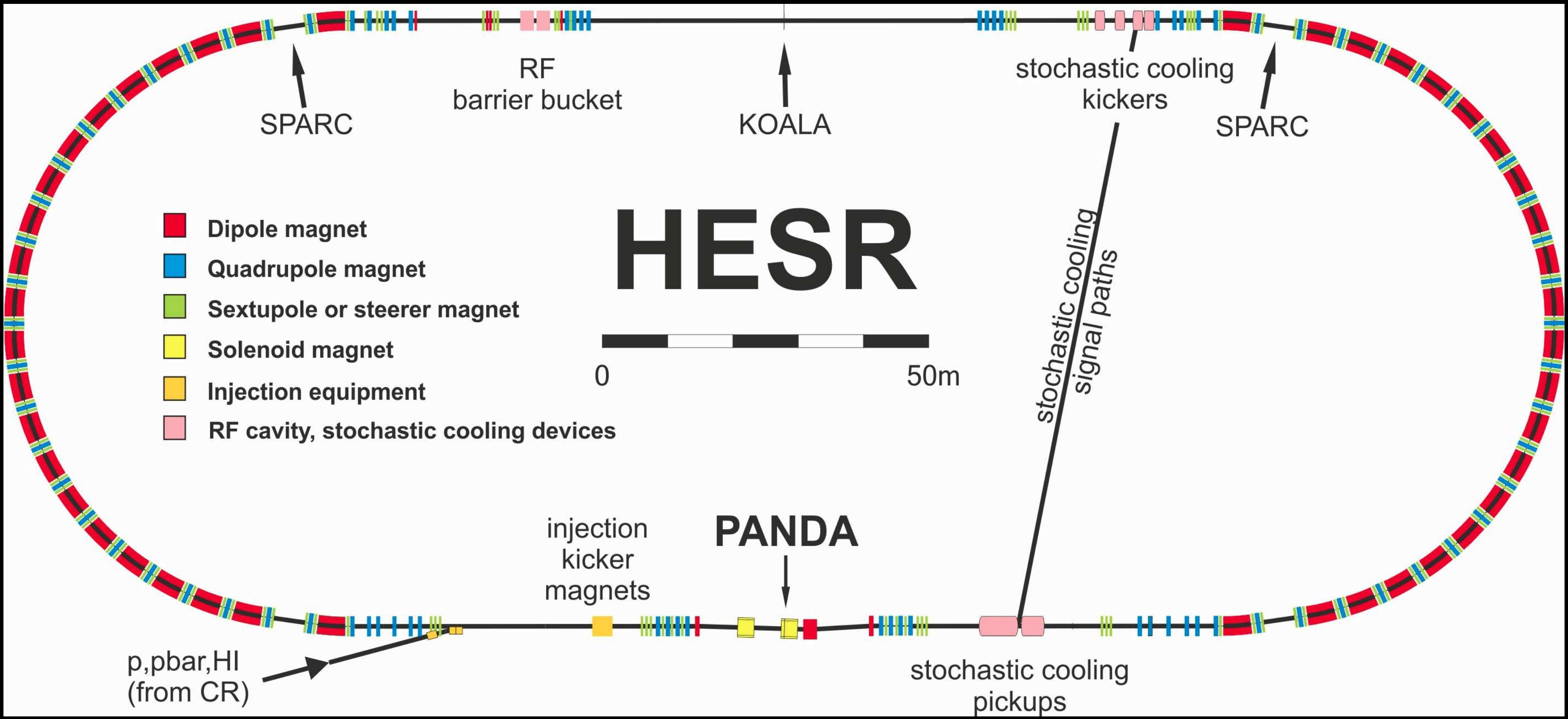




Although the hadronic EOS is related to many other branches in nuclear or hadronic physics, the focus on the strangeness aspect guarantees specific, unique and important contributions by PANDA.

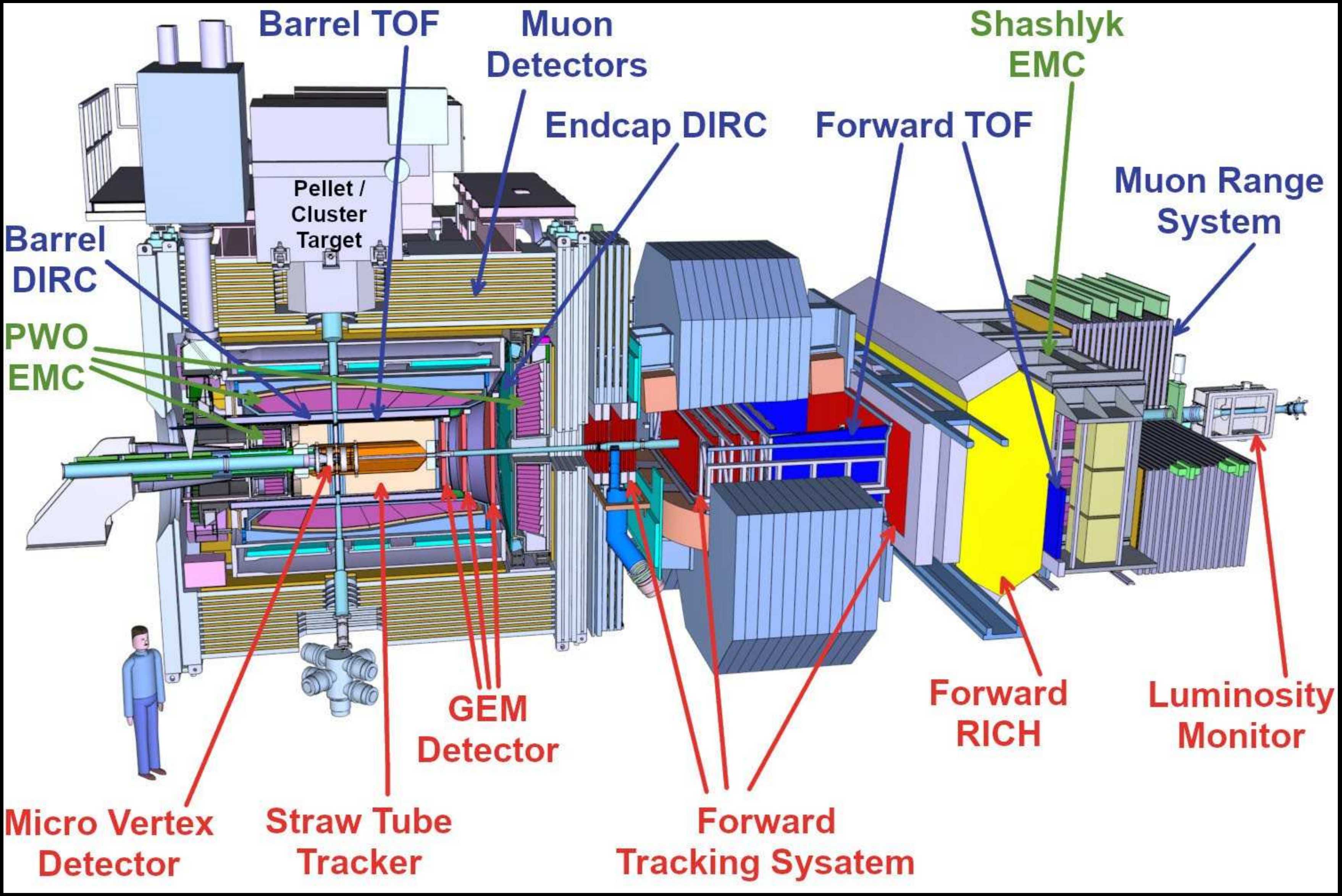

PANDA @ FAIR

High Energy Storage Ring HESR

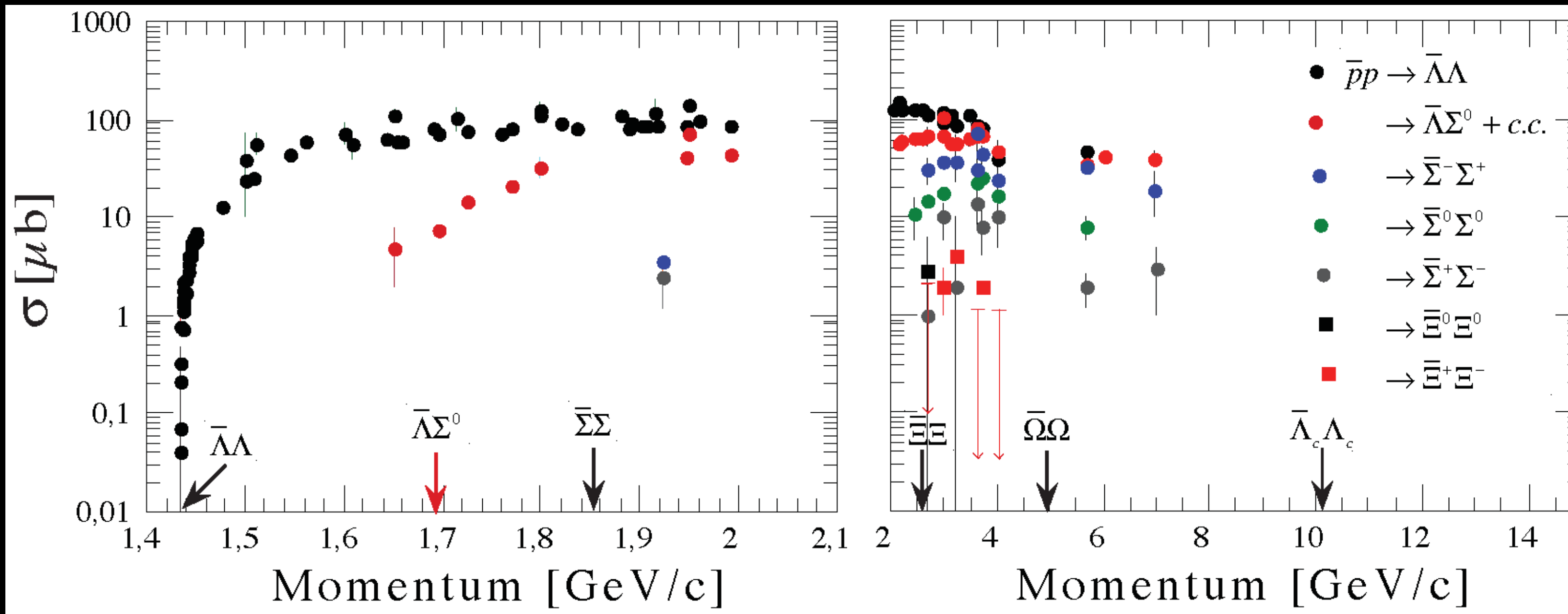


- Circumference 575 m
- Momentum 1.5 – 15 GeV/c
- Stochastic cooling
- 10^{11} antiprotons stored
- Luminosity up to $2\cdot10^{32}$ $cm^{-2}s^{-1}$
- $\Delta p/p \leq 2\cdot10^{-4}$

The PANDA Detector

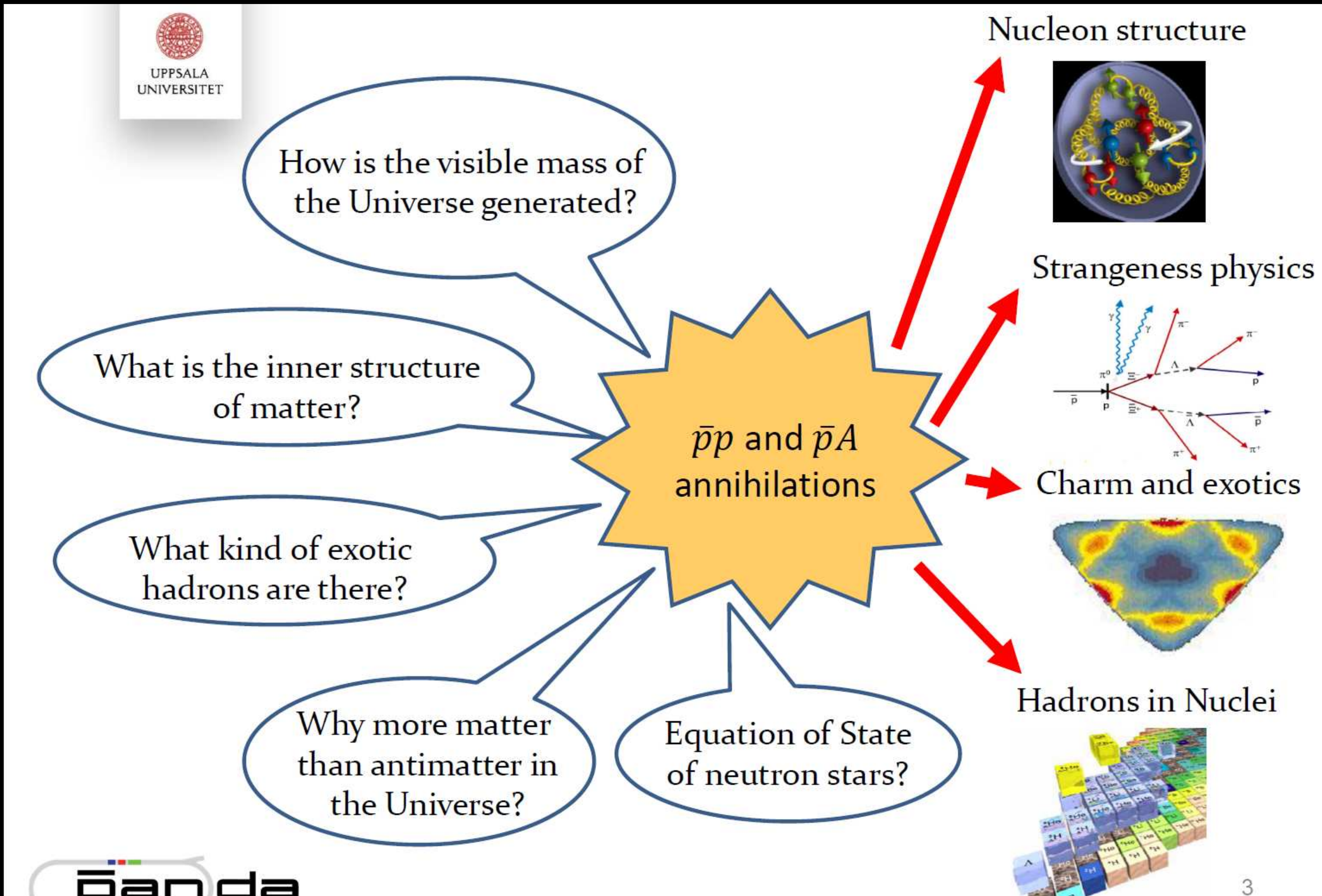


PANDA – a Factory for strange *and* charmed $Y\bar{Y}$-Pairs



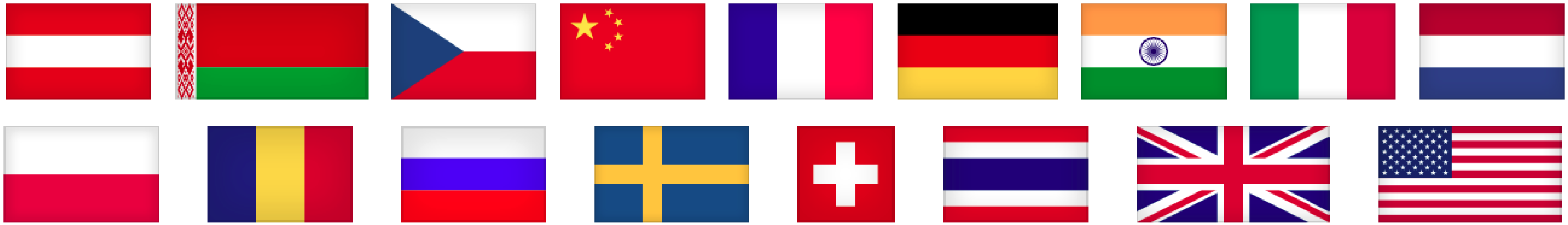
Momentum (GeV/c)	Reaction	σ (μb)	Efficiency (%)	Decay	Rate PHASE1 $10^{31}cm^{-2}s^{-1}$
1.64	$\bar{p}p\to\bar{\Lambda}\Lambda$	64	15.7	$\Lambda\to p\pi^-$	44
1.77	$\bar{p}p\to\bar{\Sigma}^0\Lambda$	10.9	5.3	$\Sigma^0\to\Lambda\gamma$	2.4
6.0	$\bar{p}p\to\bar{\Sigma}^0\Lambda$	20.0	6.1	$\Sigma^0\to\Lambda\gamma$	5.0
4.6	$\bar{p}p\to\bar{\Xi}^+\Xi^-$	1.0	8.2	$\Xi^-\to\Lambda\pi^-$	0.3

Physics at PANDA



Courtesy Karin Schönning

PANDA members

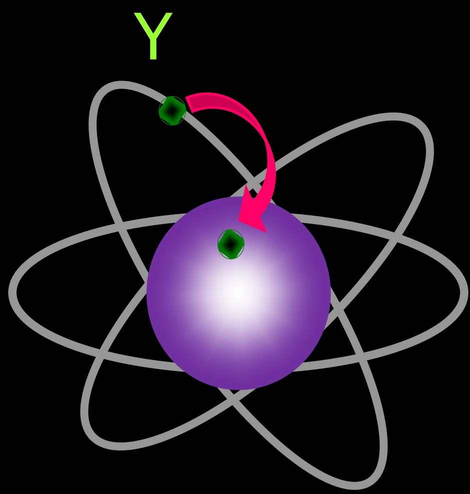


UP Marche Ancona
U Basel
IHEP Beijing
U Bochum
Abant Izzet Baysal
U Golkoy, Bolu
U Bonn
U Brescia
IFIN-HH Bucharest
AGH UST Cracow
IFJ PAN Cracow
JU Cracow
Cracow UT
FAIR Darmstadt
GSI Darmstadt
JINR Dubna
U Erlangen
NWU Evanston
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Gießen
Giresun U
U Glasgow
KVI Groningen
Gauhati U, Guwahati
USTC Hefei
URZ Heidelberg
Doğuş U, Istanbul
Okan U, Istanbul
FZ Jülich
IMP Lanzhou
INFN Legnaro
Lund U
HI Mainz
U Mainz
RINP Minsk
ITEP Moscow
MPEI Moscow
U Münster
BINP Novosibirsk
Novosibirsk State U
IPN Orsay
U Wisconsin, Oshkosh
U & INFN Pavia
PNPI St. Petersburg
Wet Boh. U, Pilzen
Charles U, Prague
Czech TU, Prague
IHEP Protvino
Irfu Saclay
KTH Stockholm
Stockholm U
SUT, Nakhon Ratchasima
SVNIT Surat-Gujarat
S Gujarat U, Surat-Gujarat
FSU Tallahassee
U & INFN Torino
Politecnico di Torino
U Uppsala
SMI Vienna
NCBJ Warsaw
U York

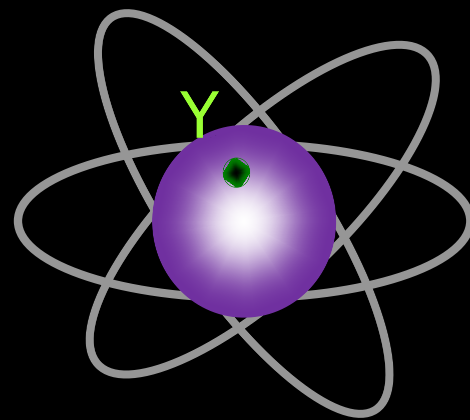
Progress @ FAIR

Strangeness Nuclear Physics

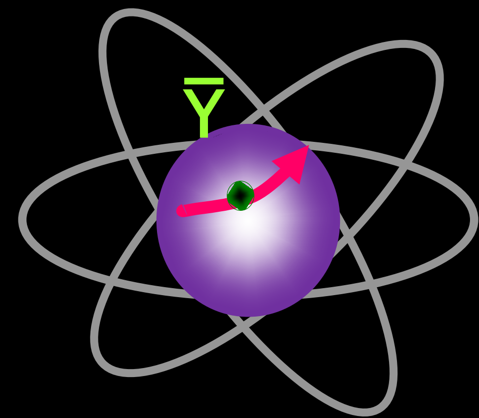
= Strangeness in cold nuclei



hyperatoms



hypernuclei



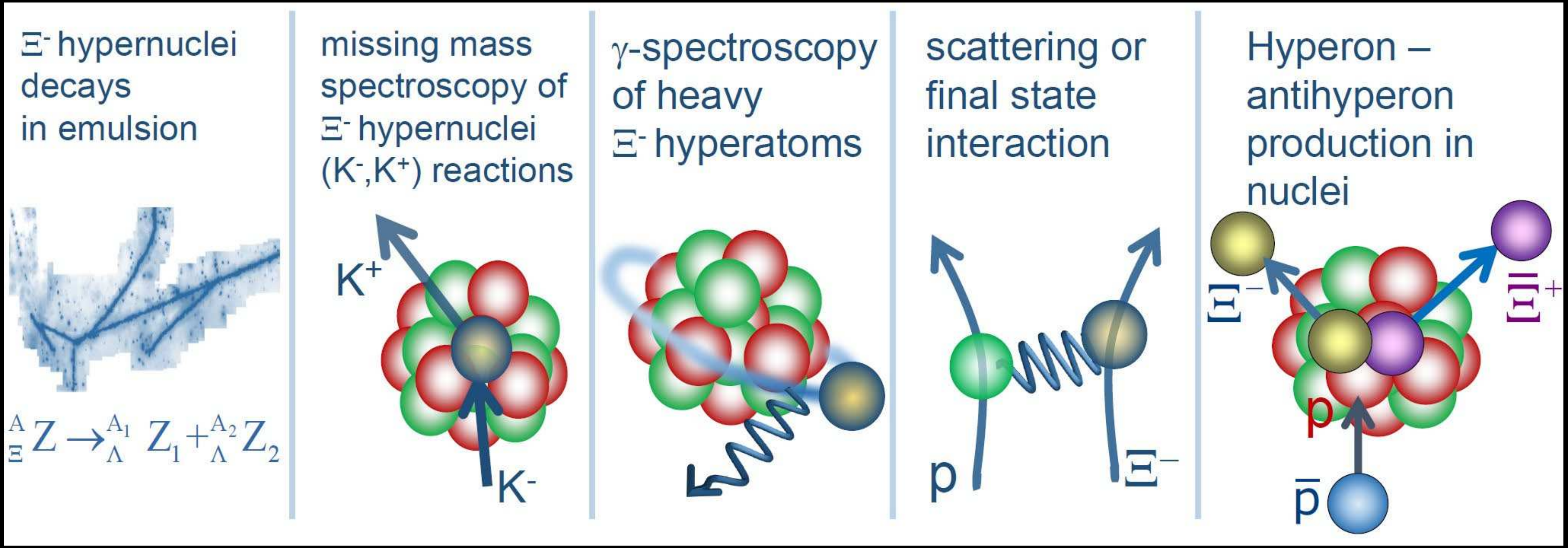
(anti)hyperon „scattering“

Recent Progress in Strangeness and Charm Hadronic and Nuclear Physics
Edts. A. Gal and JP
Nucl. Phys. A **954**, 1–2 (2016)

JP PLB **669**, 306 (2008)
Sanchez *et al*., PLB 749, 421 (2015)

Theoretical considerations for HI:
PRC **86**, 011601(R) (2012)
PRC **88**, 054605 (2013)
PLB **742**, 7 (2015)
Eur. Phys. J. **52**, 242 (2016)
PRC **94**, 054615 (2016)
PRC **95**, 014902 (2017)

Ξ interaction in hadronic systems

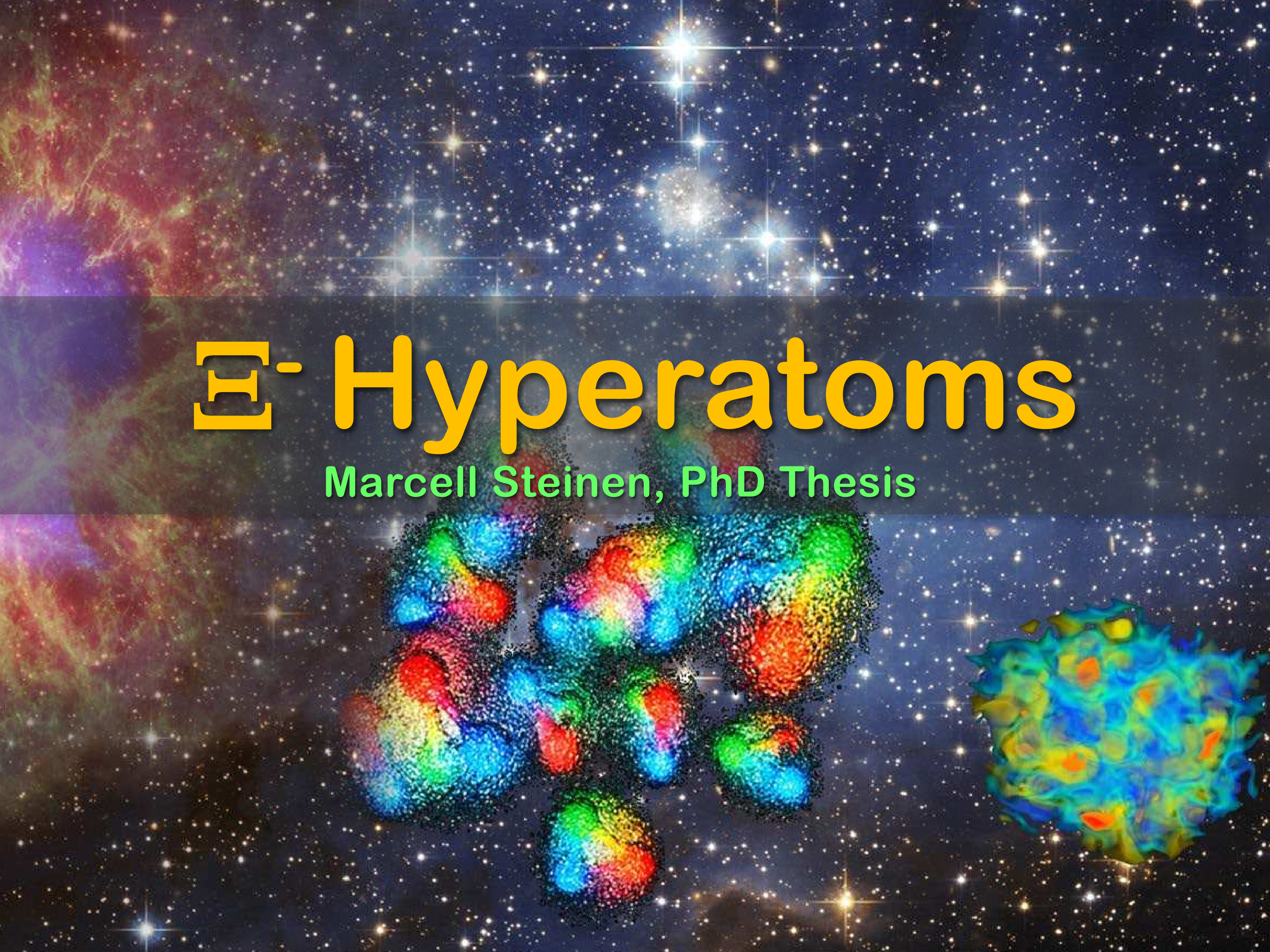


J-PARC E07

J-PARC E03
PANDA

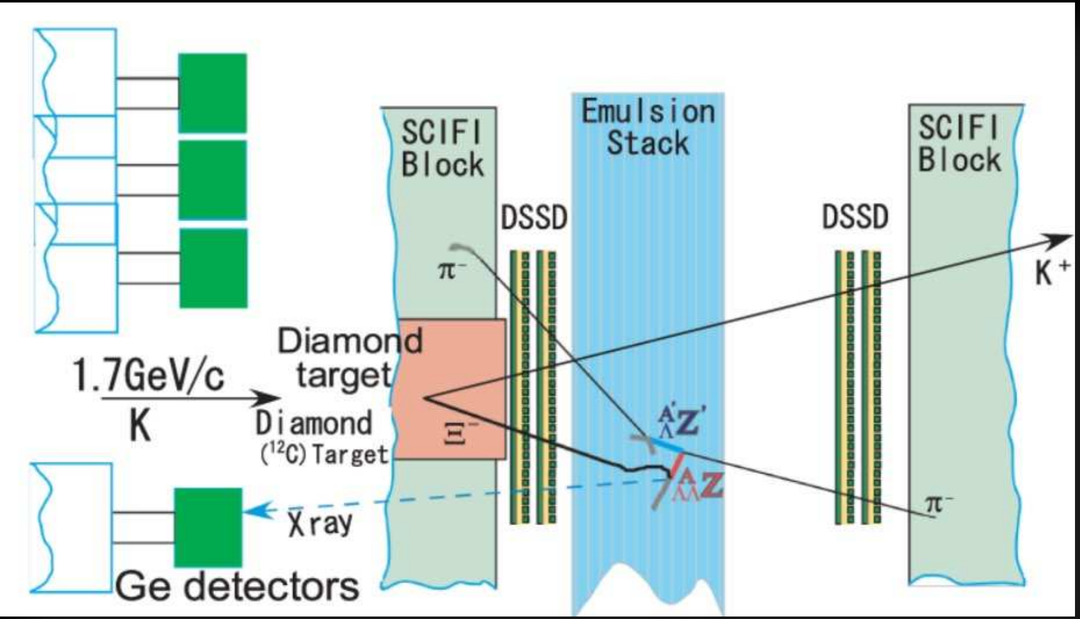
ALICE

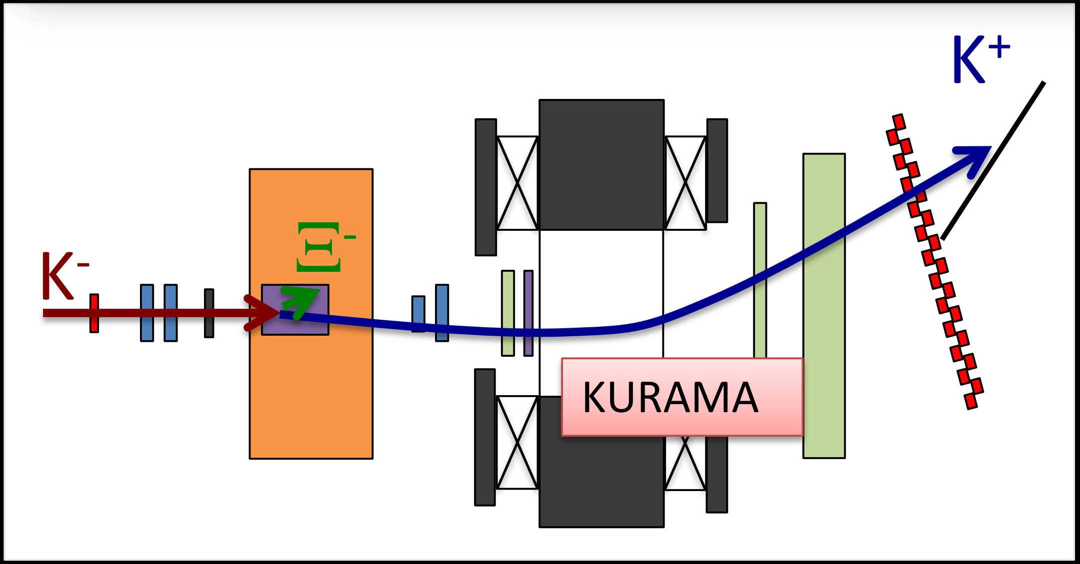
PANDA


Ξ- Hyperatoms
Marcell Steinen, PhD Thesis

E03 and E07 @ J-PARC

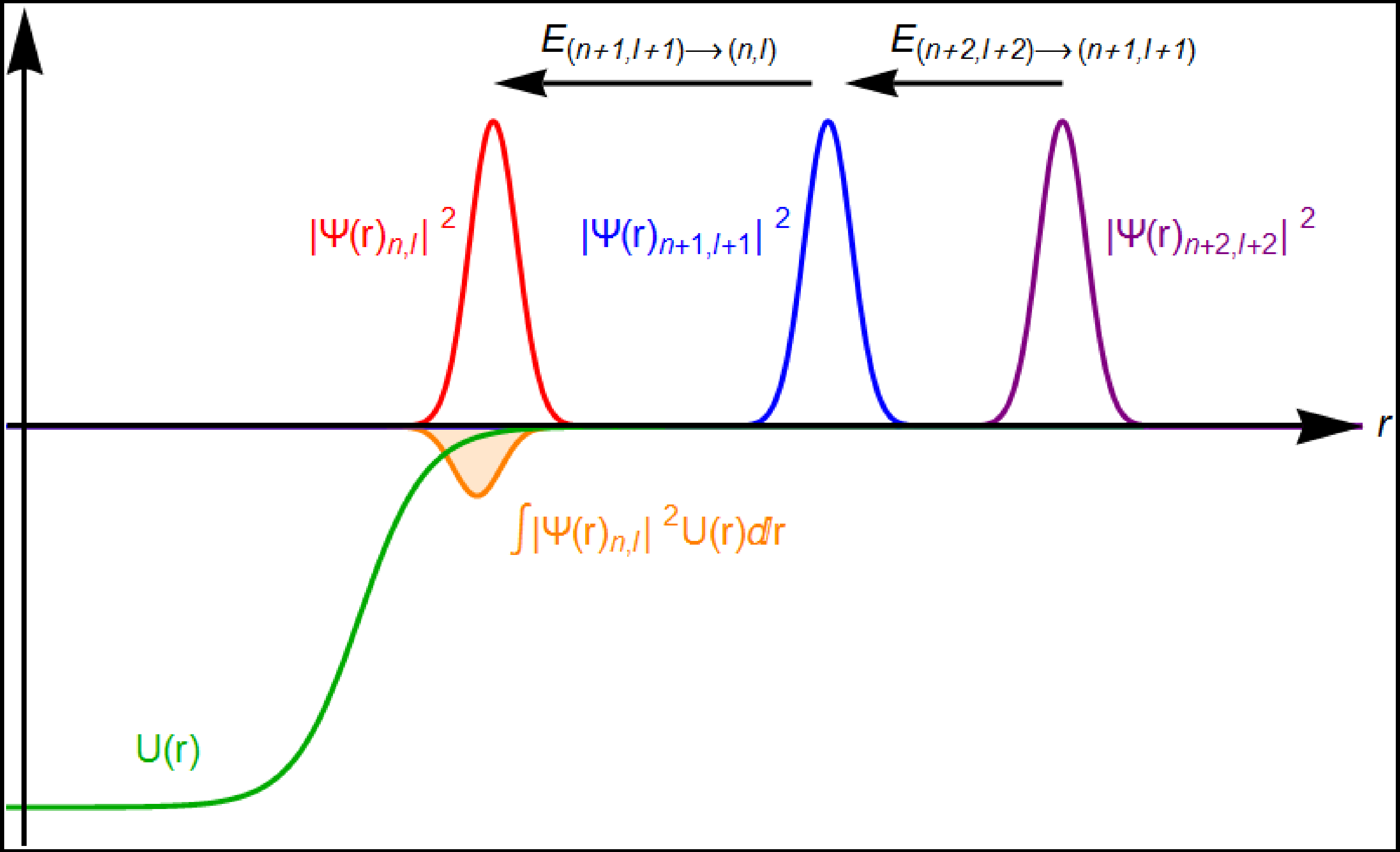
- E07
  - Beam exposure has successfully been performed for all emulsion stacks in 2016/2017
  - auto-scanning has started
  - ground state masses for $\Lambda\Lambda$-hypernuclei can be determined
  - Ξ^--Ag and Ξ^--Br X-rays
- E03
  - Ξ^--Fe X-rays (medium mass targets) running right now at J-PARC



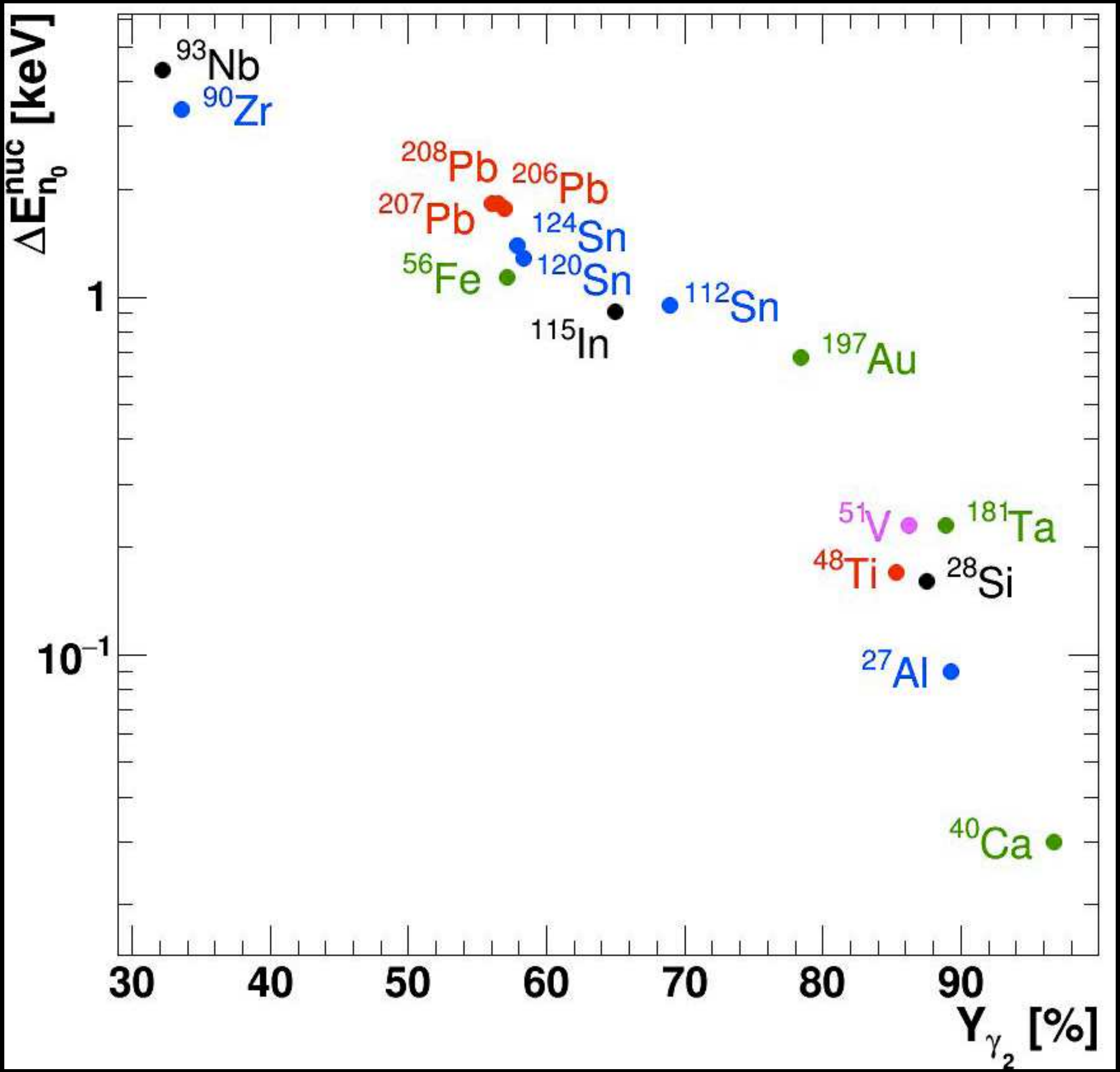


Ξ^- atom X-ray spectroscopy

- Shift of „lowest" atomic sensitive to Ξ^--nucleus interaction
- Interpretation requires knowledge on
  - the neutron and proton distribution
  - the isospin dependence of the baryon-baryon force

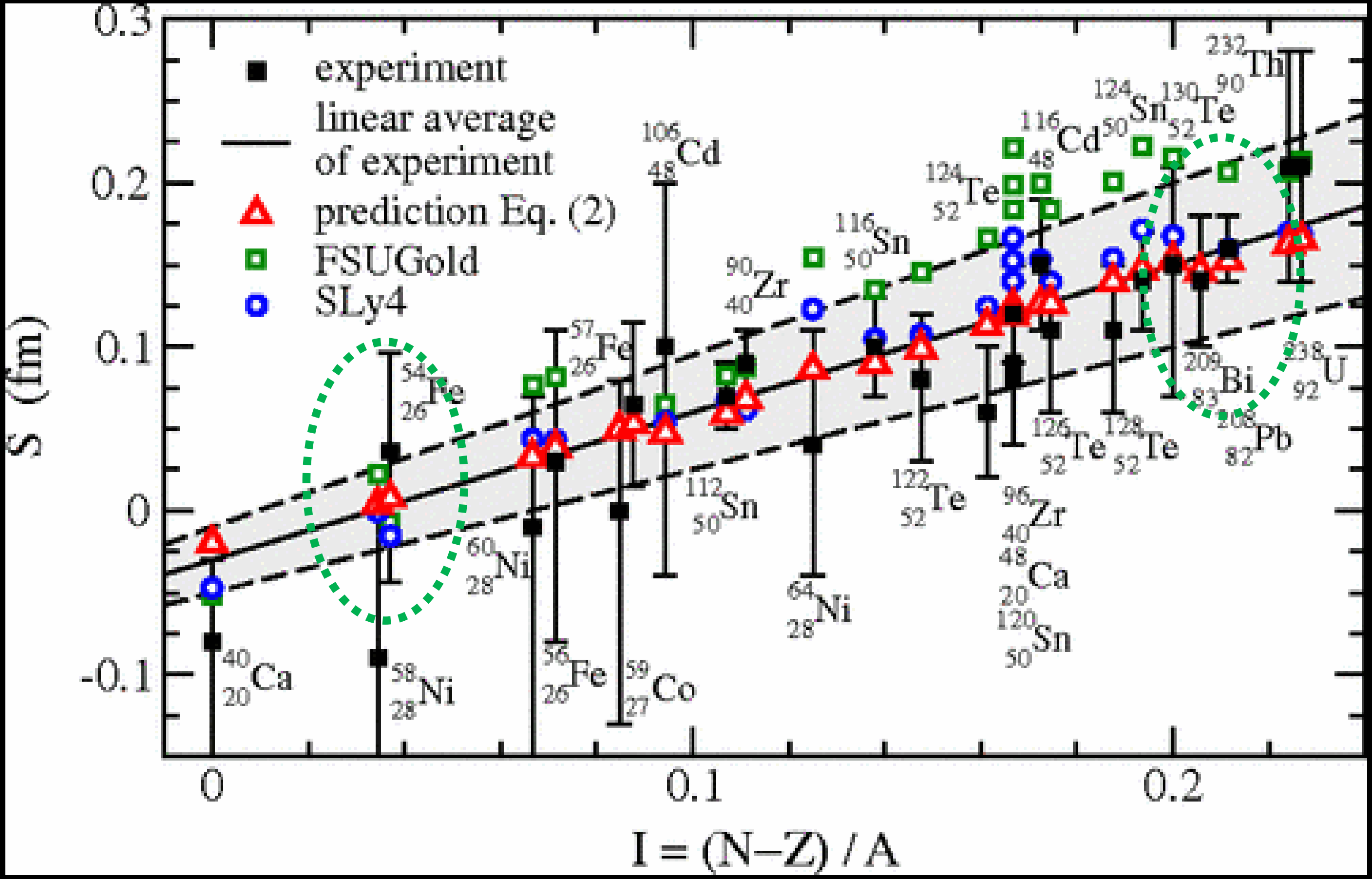


What is the best Target?



Isospin in Ξ^- atoms

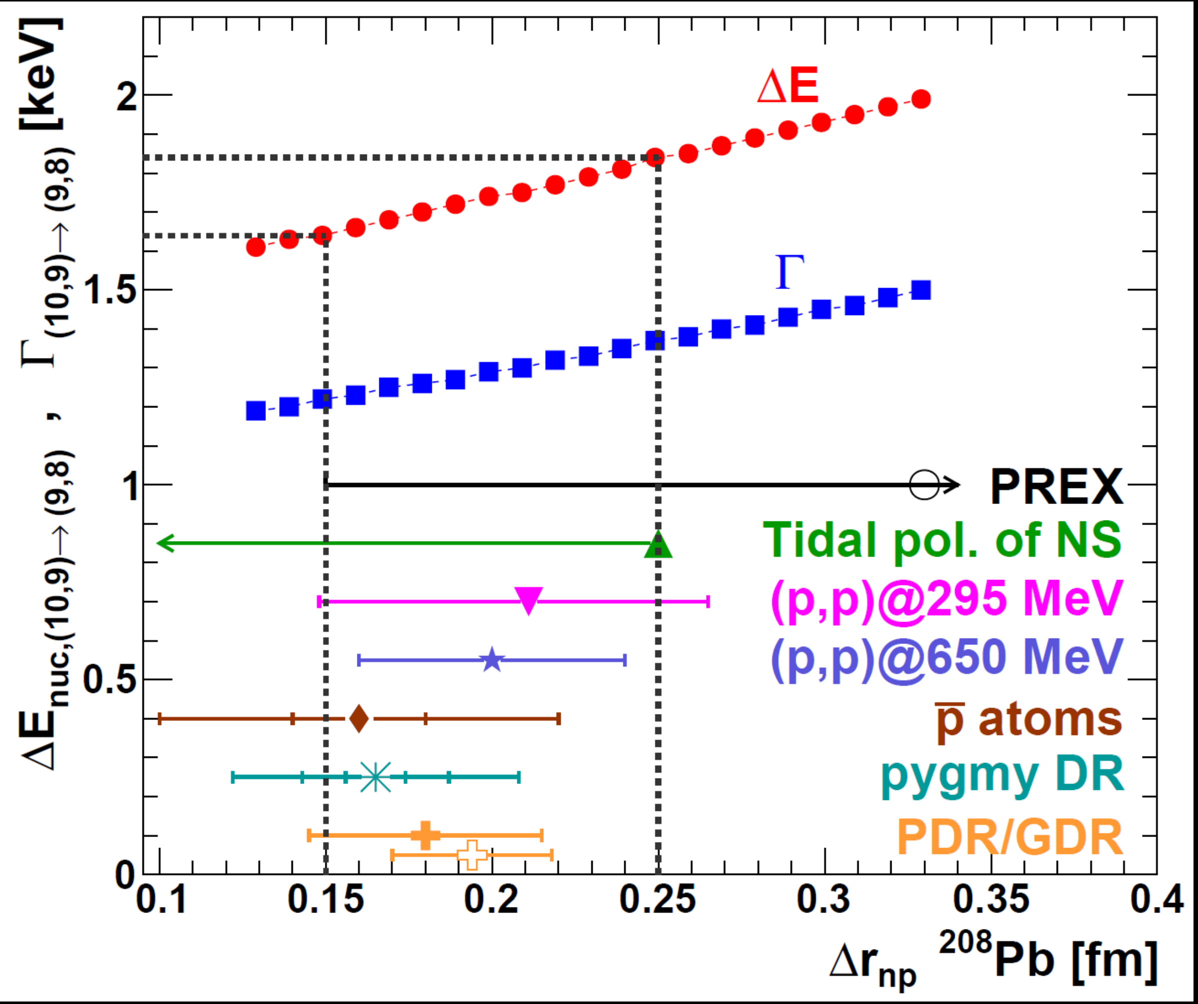
- It is important to measure both, light nuclei with I=0 (N=Z) and heavy nuclei (neutron skin)
- Goal at PANDA: study well known double-magic nuclei



M. Centelles, X. Roca-Maza, X. Viñas, and M. Warda
Phys. Rev. Lett. 102, 122502

Sensitivity to ^{208}Pb structure

- changing thickness of neutron skin artificially in calculation



Strange Systems at PANDA

X^- production

$\bar{p}N \rightarrow X^- + X$

rescattering in
primary target nucleus

deceleration in
secondary target

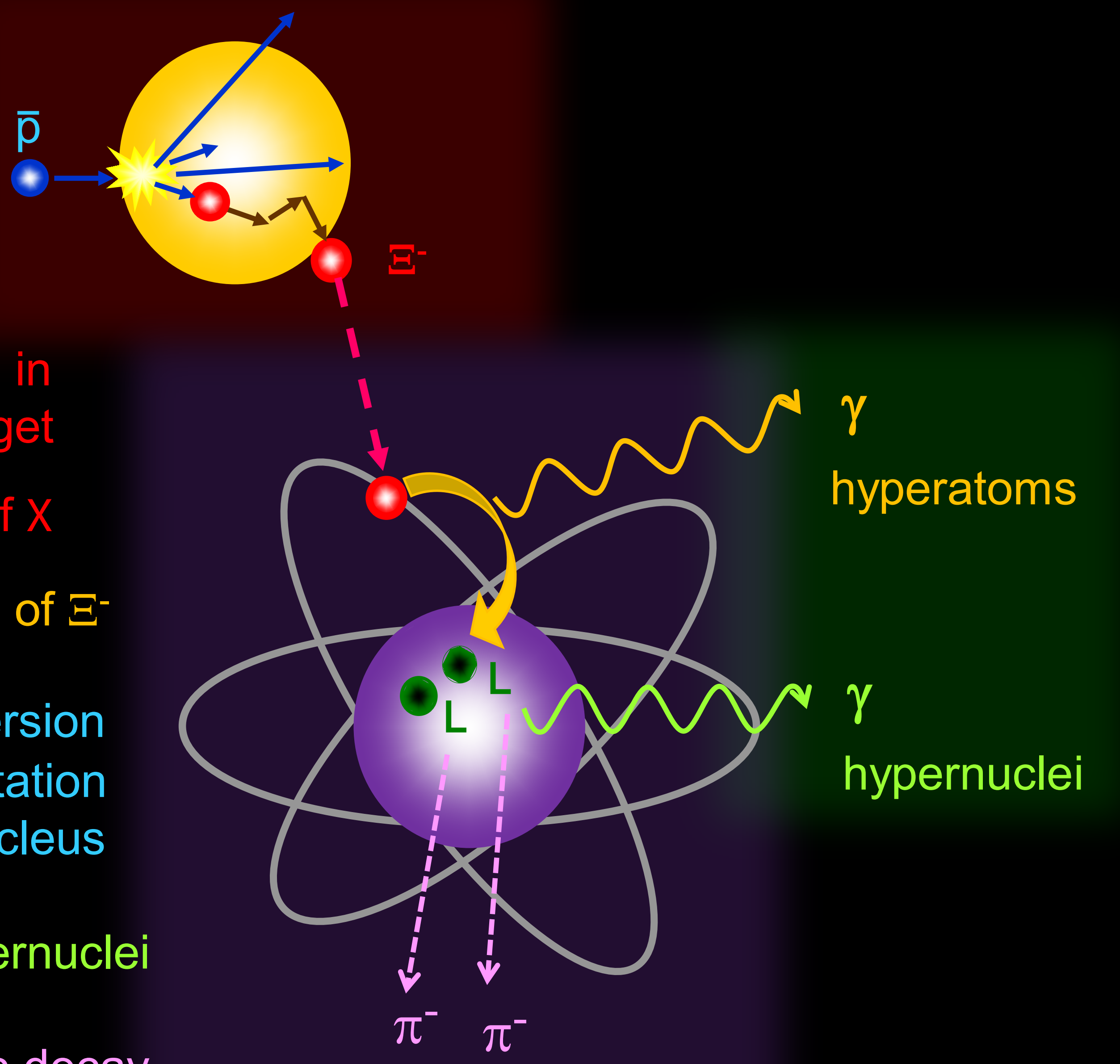
capture of X

atomic cascade of Ξ^-

Ξ^-p ⊠ $\Lambda\Lambda$ conversion
fragmentation
$\rightarrow$ excited $\Lambda\Lambda$-nucleus

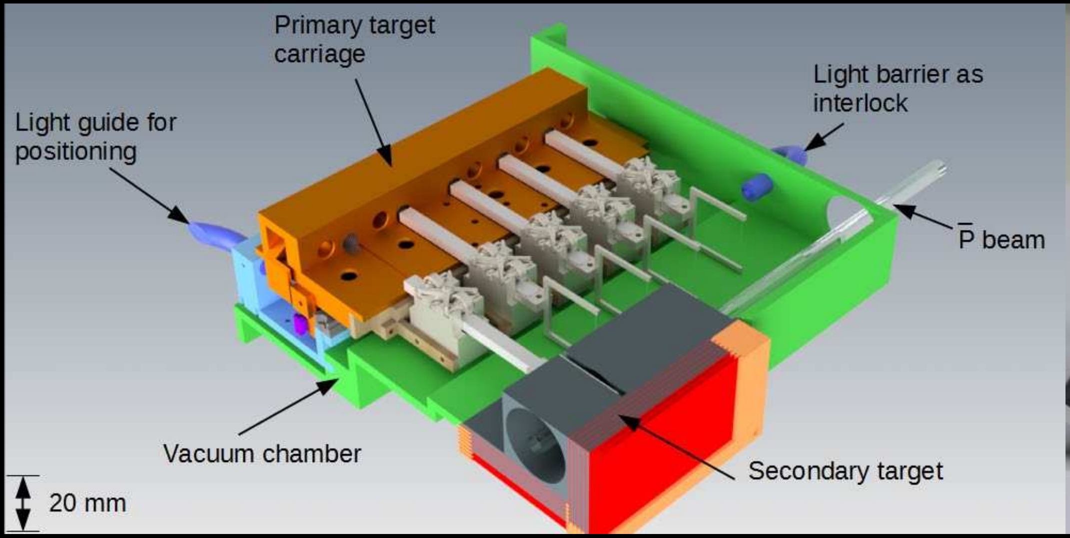
γ-decay of $\Lambda\Lambda$ hypernuclei

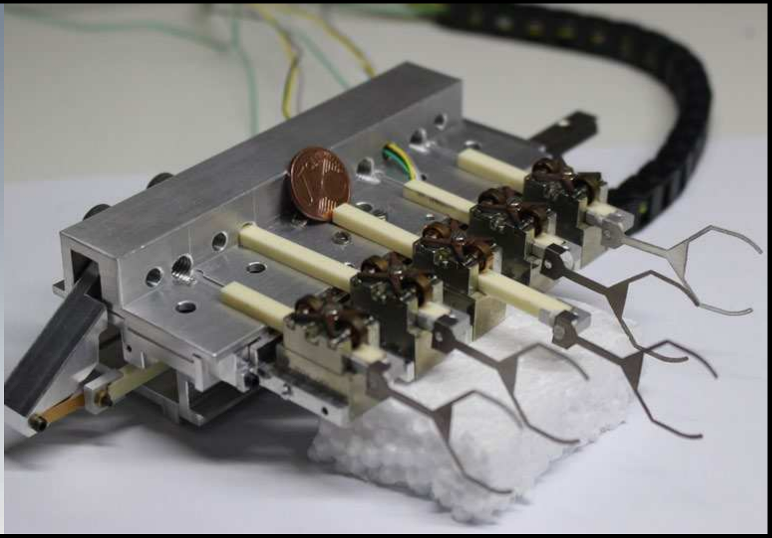
weak pionic decay



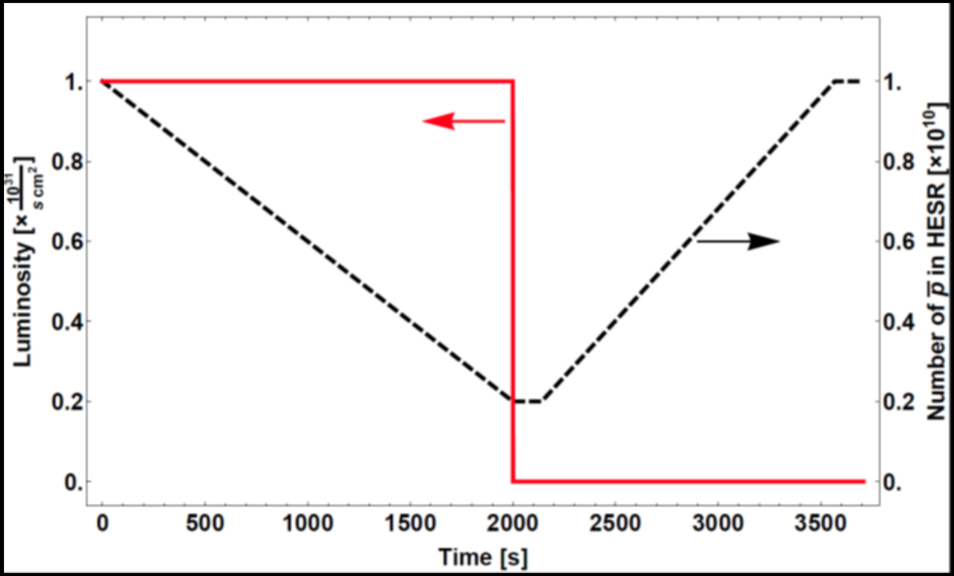
Primary Target

- Task: maximize slow Ξ^- production

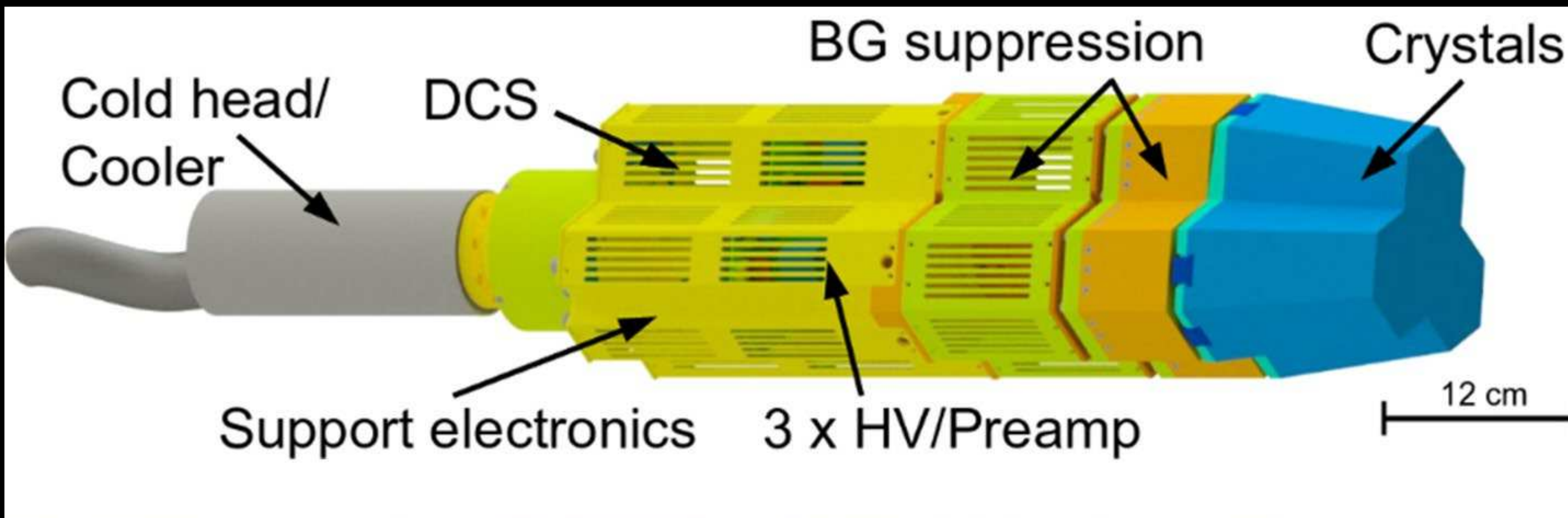


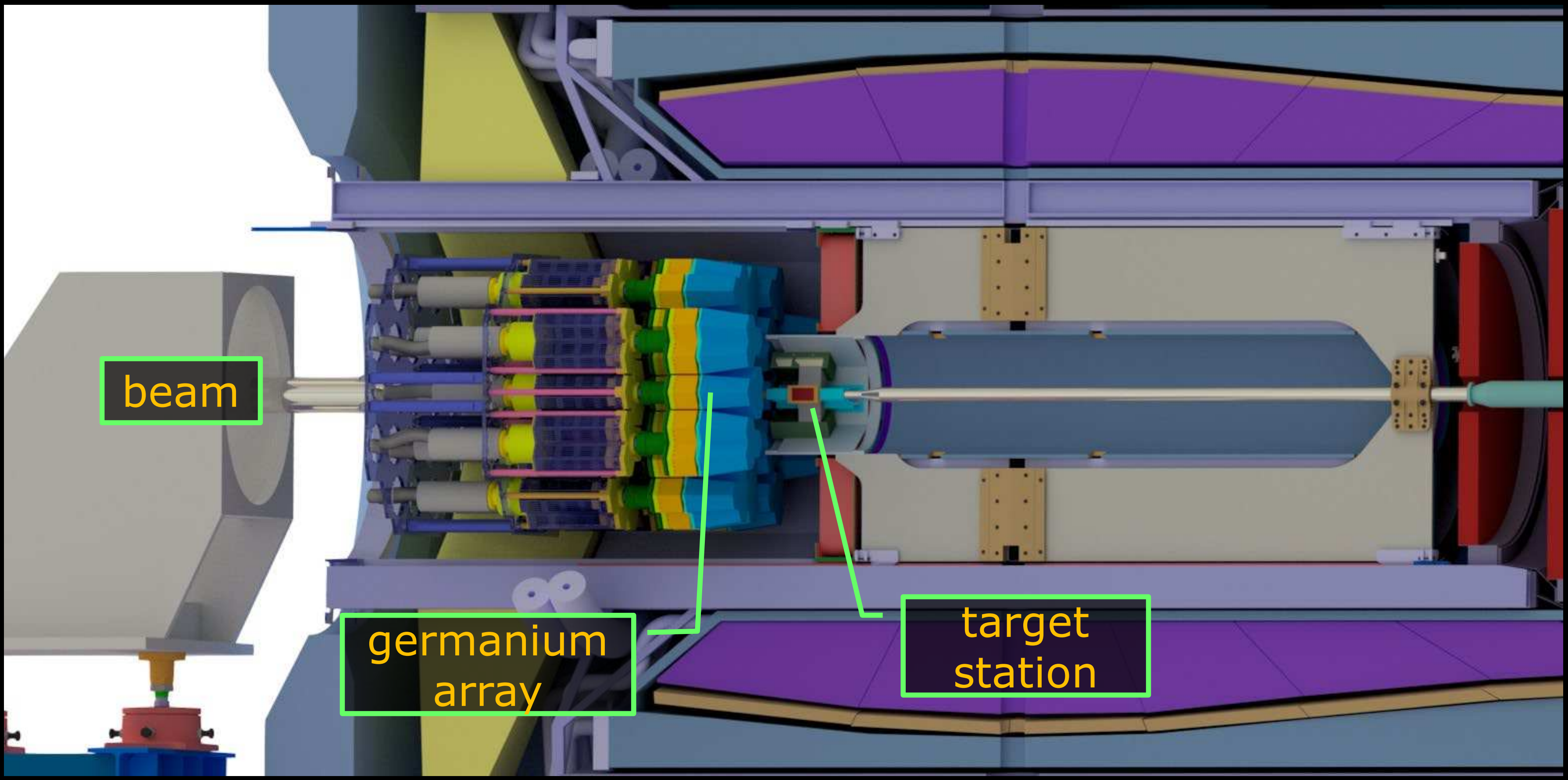


- Target material: C filament 5μm
  - production cross section
  - slow down process
  - beam losses…
- ultra high vacuum
- magnetic field
- radiation hardness
  e.g. passive position control
- …



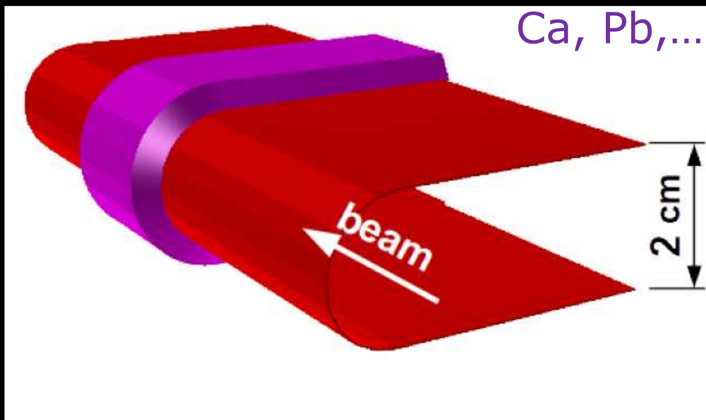
PANGEA

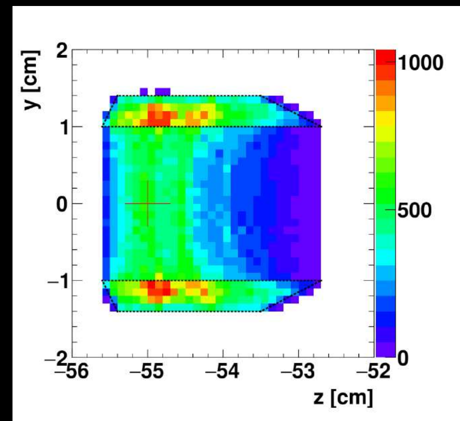

BG suppression
Crystals
Cold head/
Cooler
DCS
Support electronics
3 x HV/Preamp
12 cm

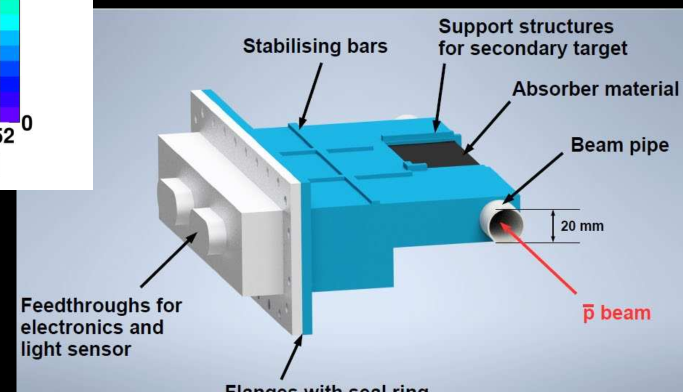

beam
germanium array
target station

PANDA Setup for Hyperatoms

- Shape of absorber optimized by GiBBU+GEANT4 simulations





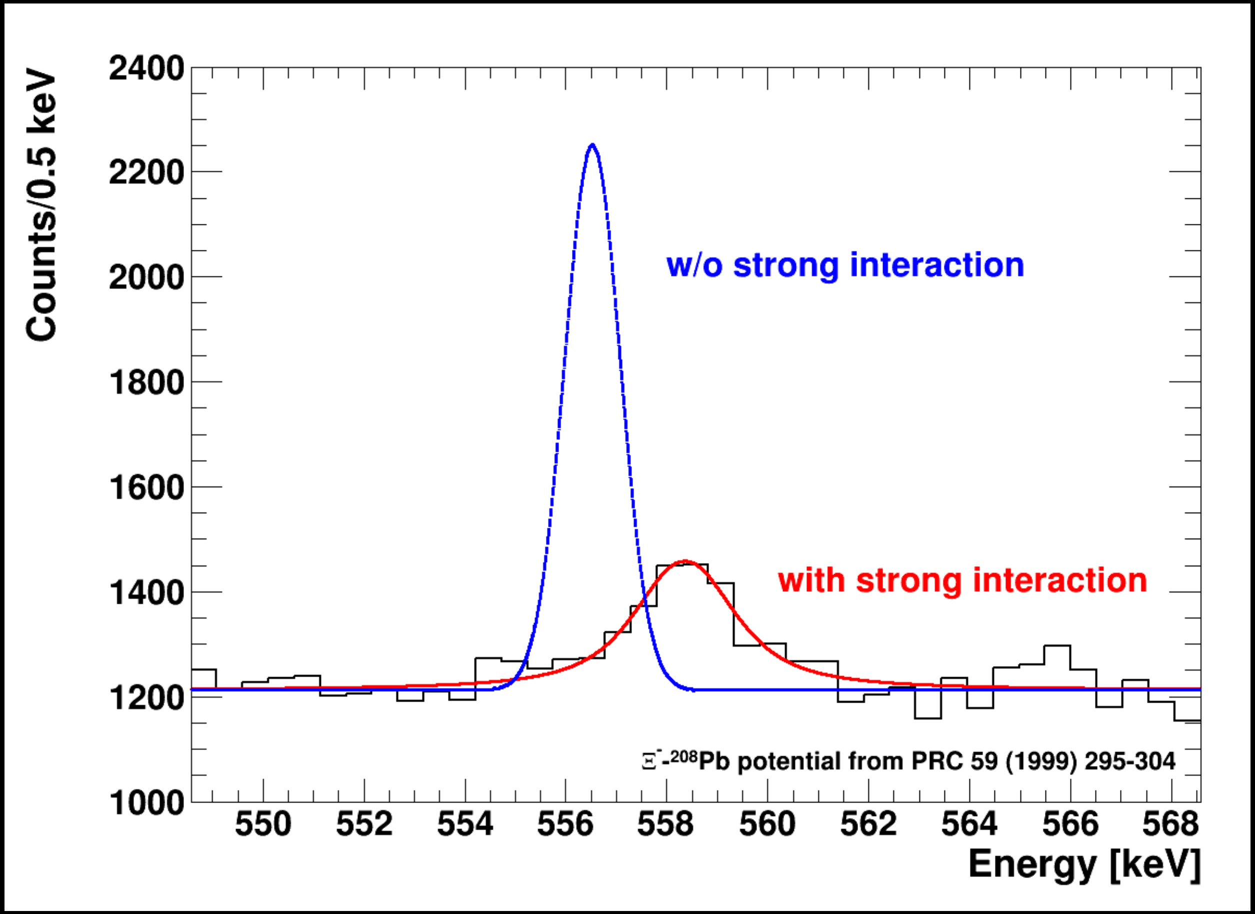


- very thin primary target
- primary and secondary target separated
- Sec. Target in or ouside of vacuum
- relative thin secondary target
  - ⇒ moderate X-ray absorption
  - ⇒ detection of cacades possible
  - ⇒ heavy targets possible
- tracking secondary particles also possible ⇒ reduced background

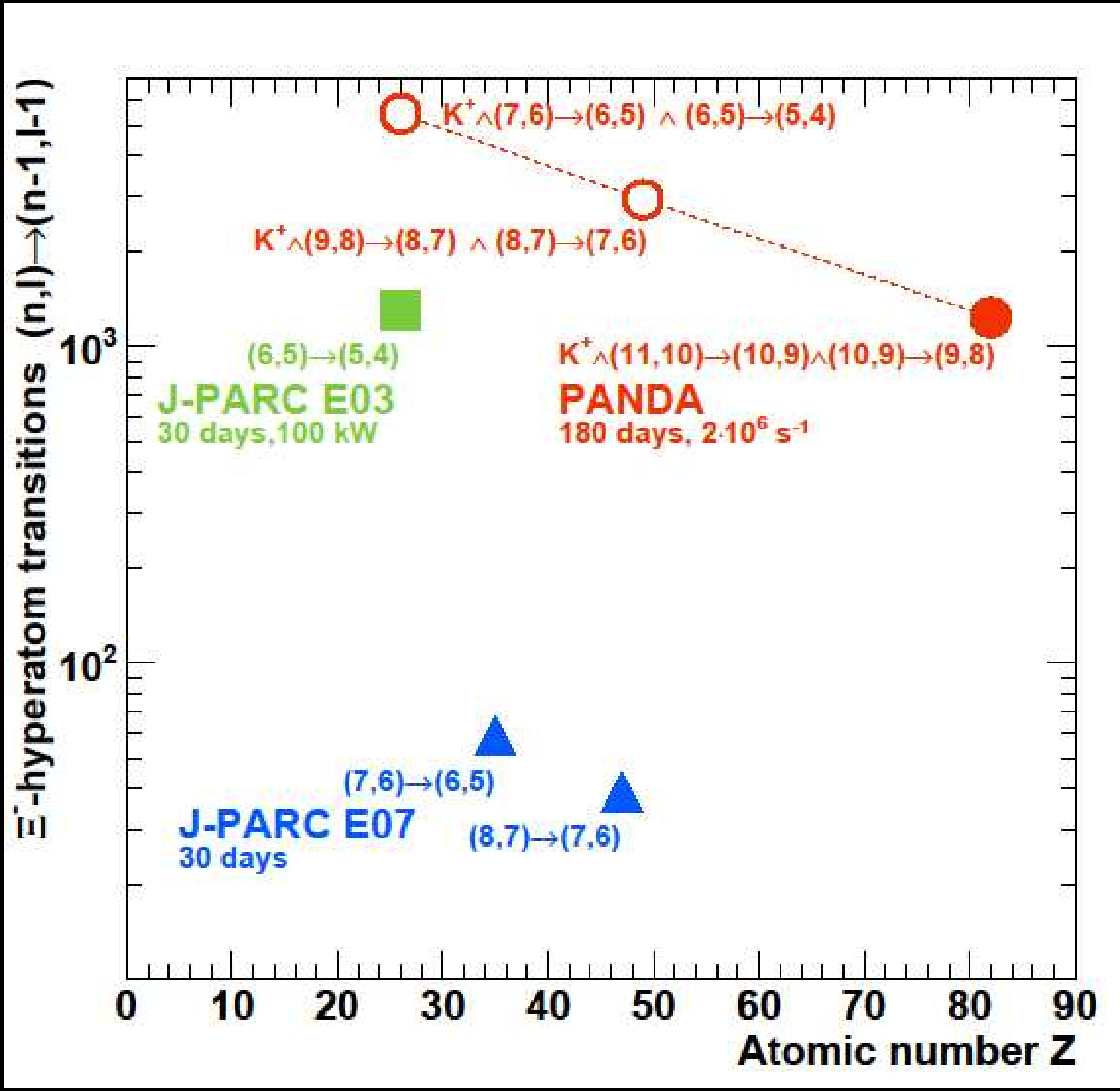
Count rate: □100 double hypernuclei ⇒ ideal as first step

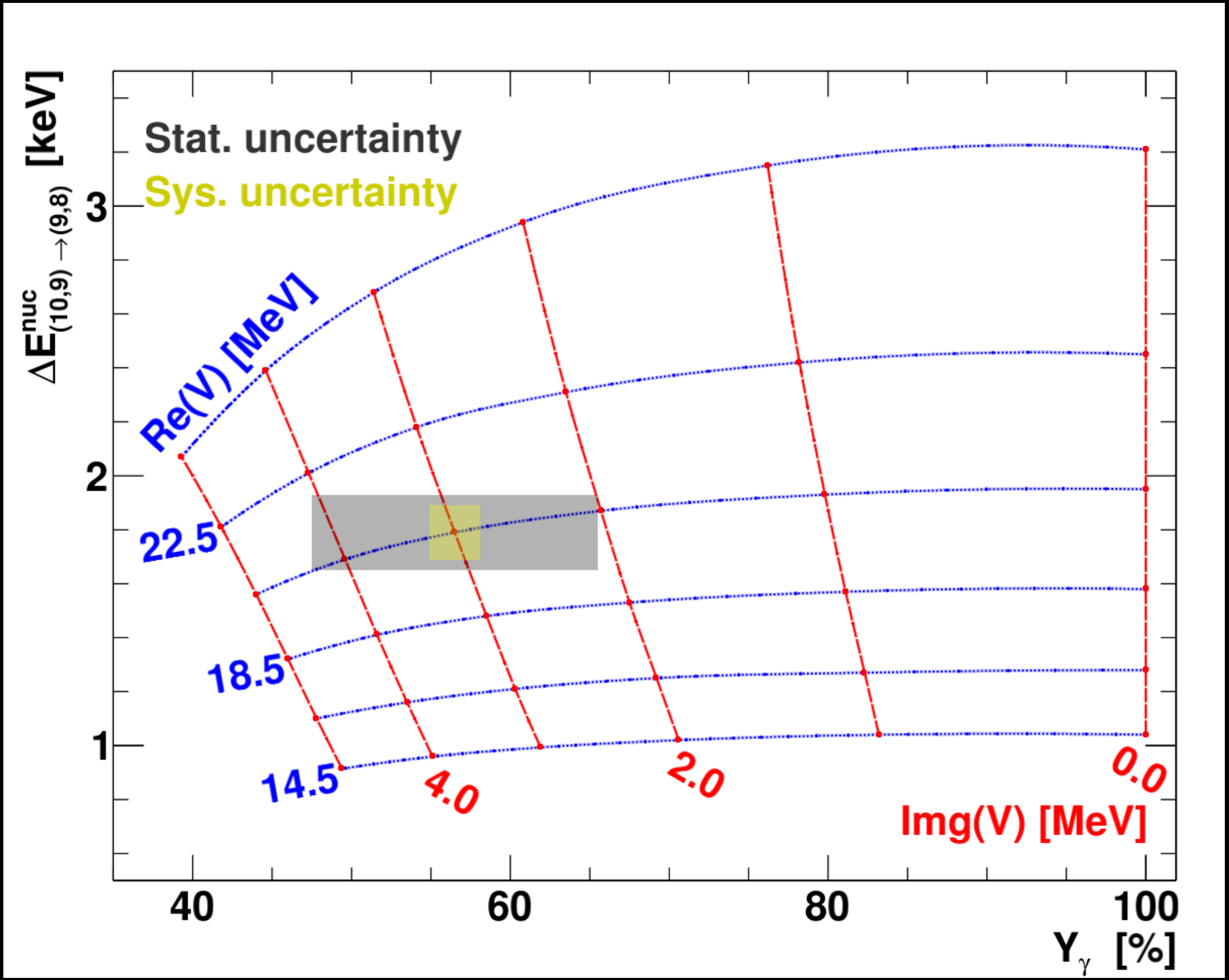
Expected result

- Full GEANT simulation of setup
- Background, pile-up,…



Expected rate




Stat. uncertainty
Sys. uncertainty
Re(V) [MeV]
22.5
18.5
14.5
4.0
2.0
0.0
Img(V) [MeV]
$\Delta E^{nuc}_{(10,9)\rightarrow(9,8)}$ [keV]
3
2
1
40
60
80
100
Y_γ [%]

Take-home message

- Strangeness nuclear physics is embedded in the quest to determine the EOS of dense stellar systems
- Hypernuclei and hyperatoms are femto-laboratories for Y^nN^m interaction
- After 60 years still many puzzles: hypertriton, existence of neutral hypernuclei $nn\Lambda$, $nn\Lambda\Lambda$, …hyperon puzzle of NS…
- Several complementing studies at different laboratories using different techniques
- Coming generation of experiments focus on precision studies


Thank you
for your attention