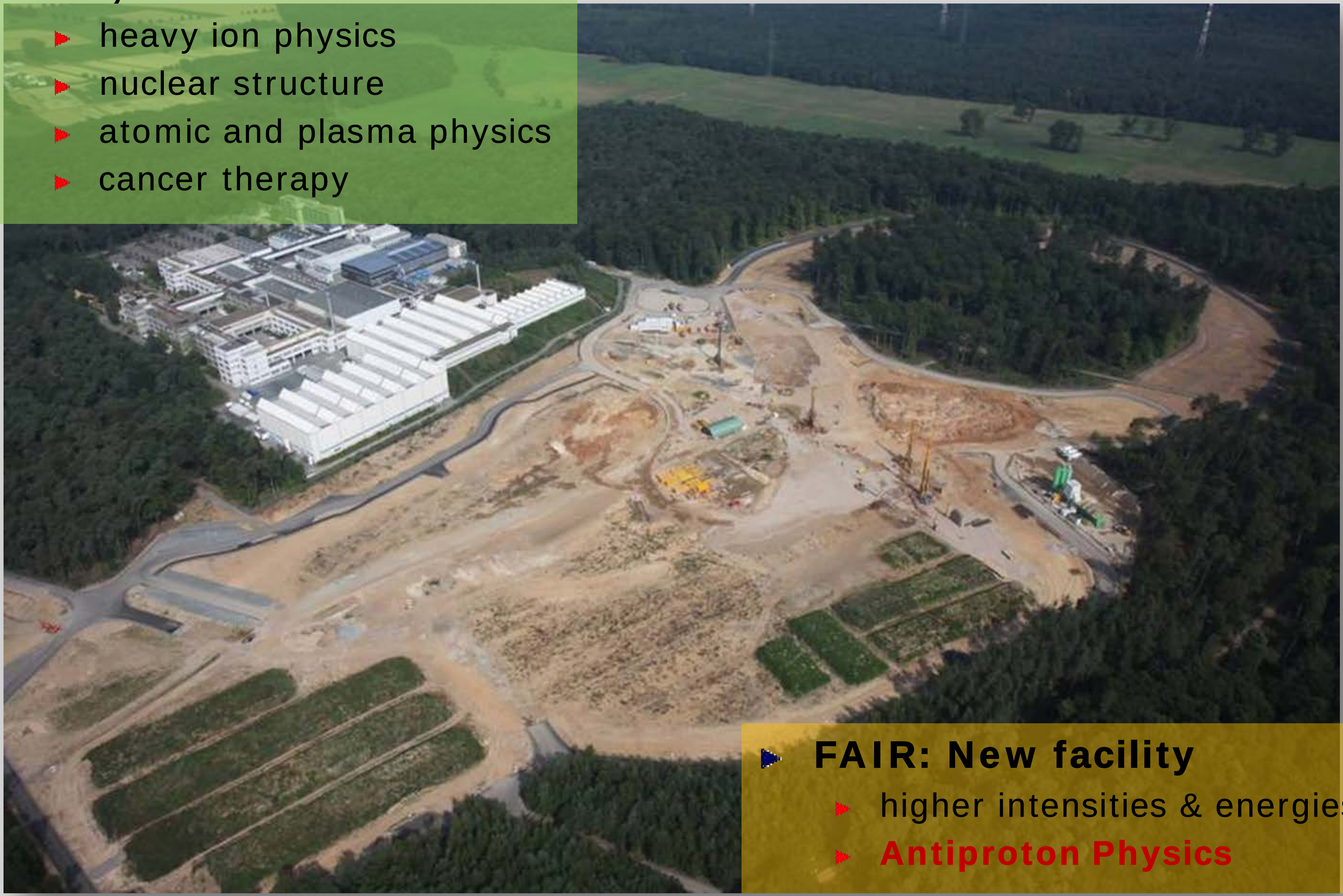
Stars … Nuclei … Baryons … Quarks

STRANGENESS IN NUCLEI UNIQUE OPPORTUNITIES at FAIR

Josef Pochodzalla

Facility for Antiproton and Ion Research

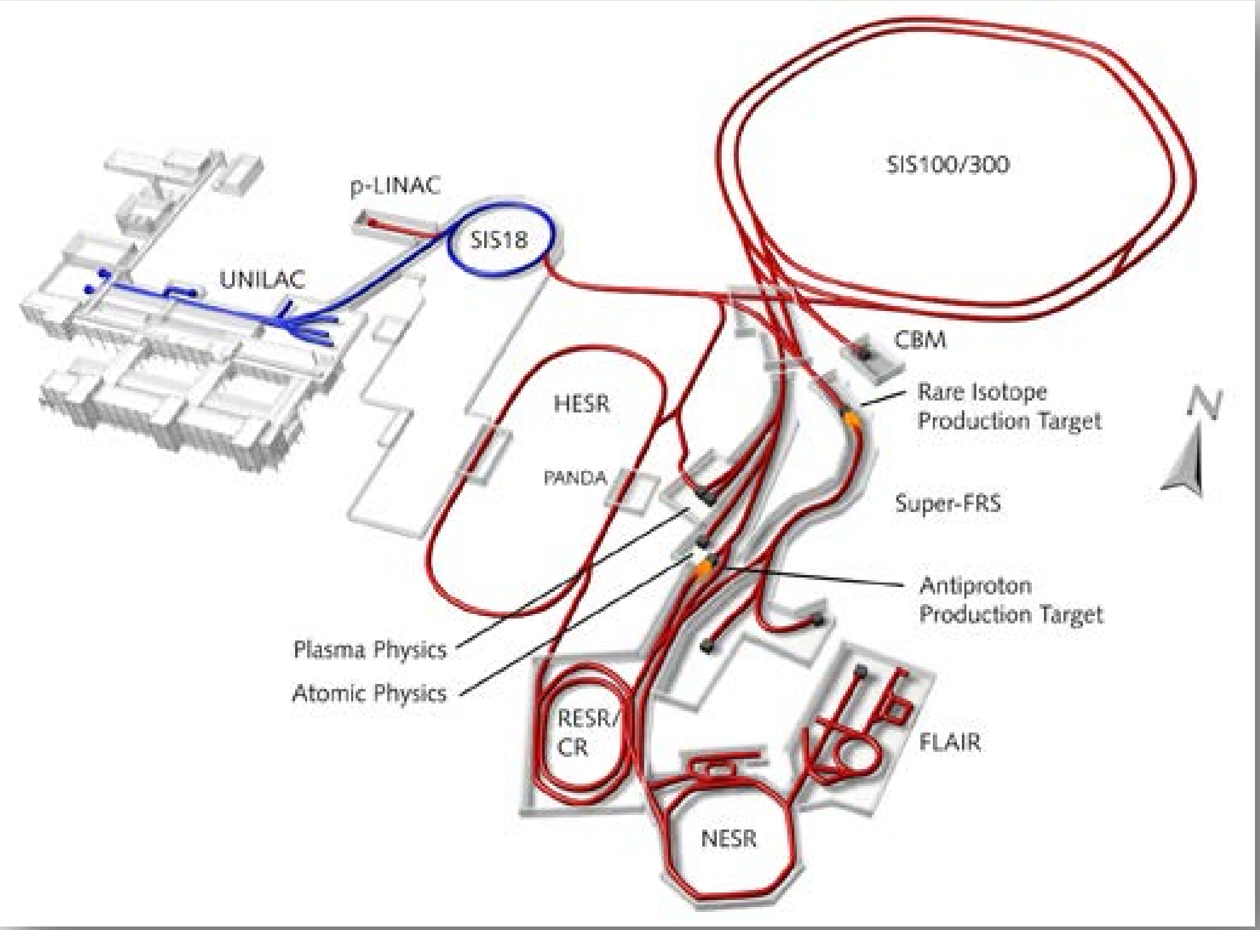
- **GSI, Darmstadt**
  - heavy ion physics
  - nuclear structure
  - atomic and plasma physics
  - cancer therapy



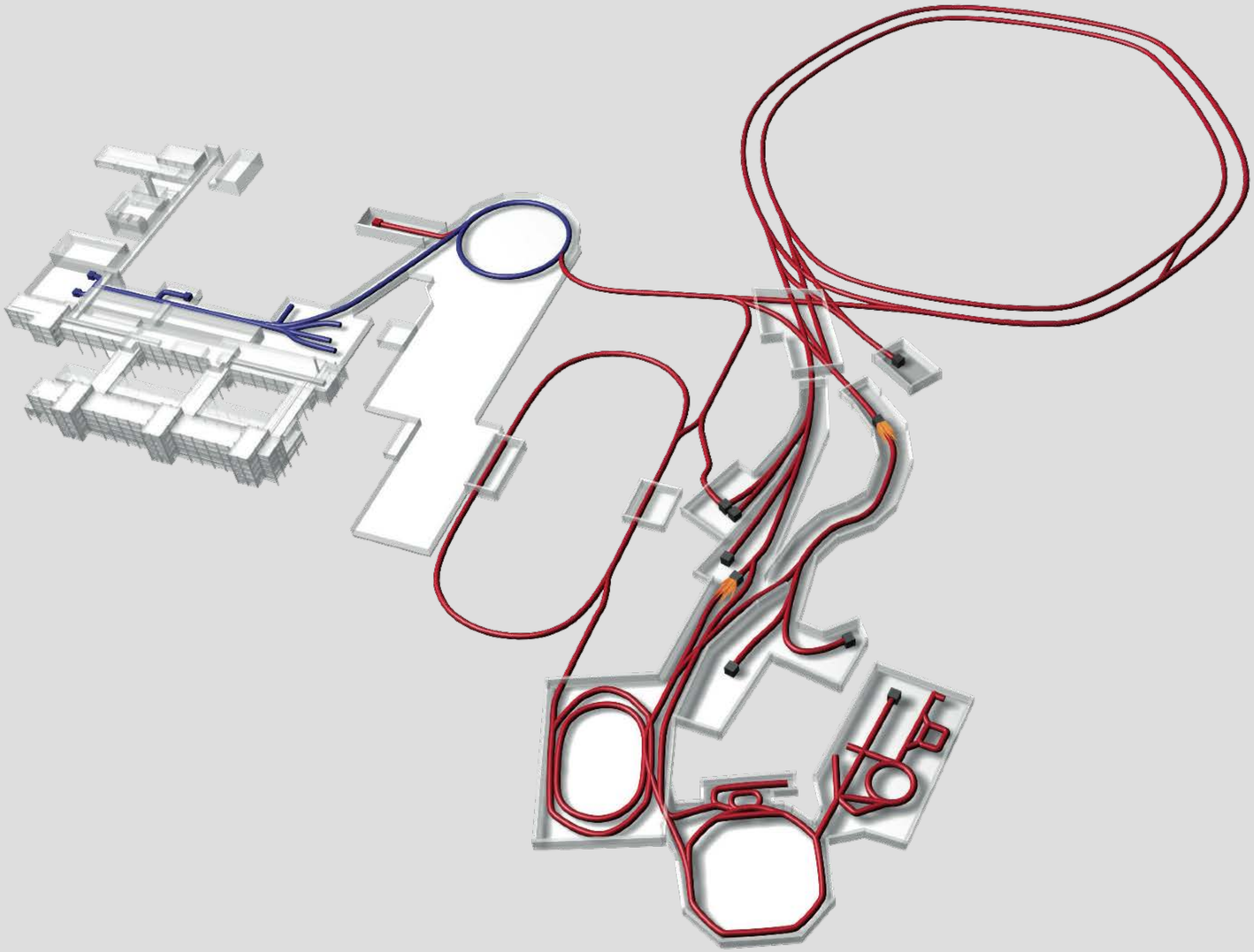
- **FAIR: New facility**
  - higher intensities & energies
  - **Antiproton Physics**

The FAIR Facility

- Uranium up to 35 AGeV
- Protons up to 30 GeV/c
- Broad range of secondary radioactive beams, up to 10000 more
- Antiprotons 0 - 15 GeV/c



FAIR Experiments



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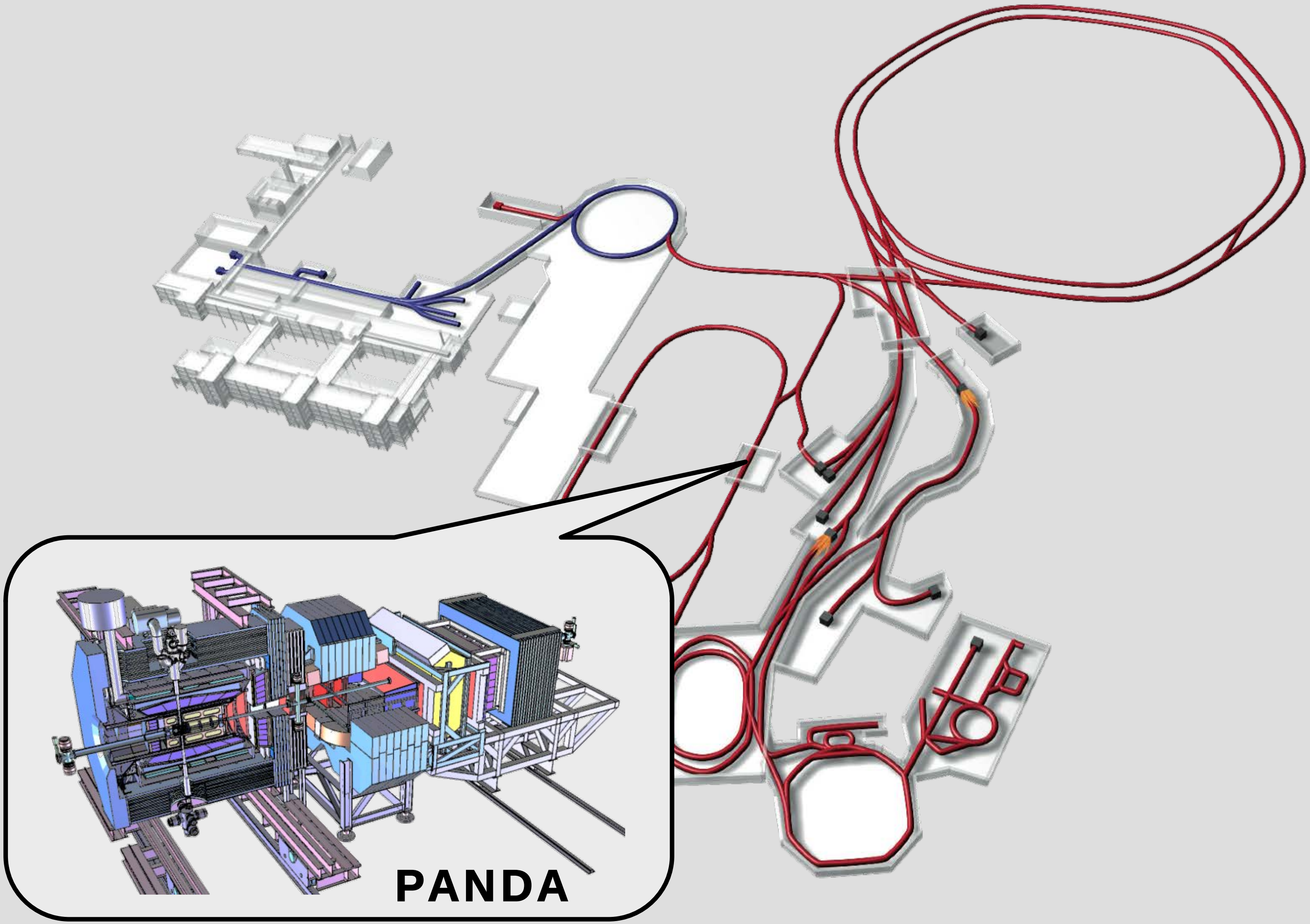
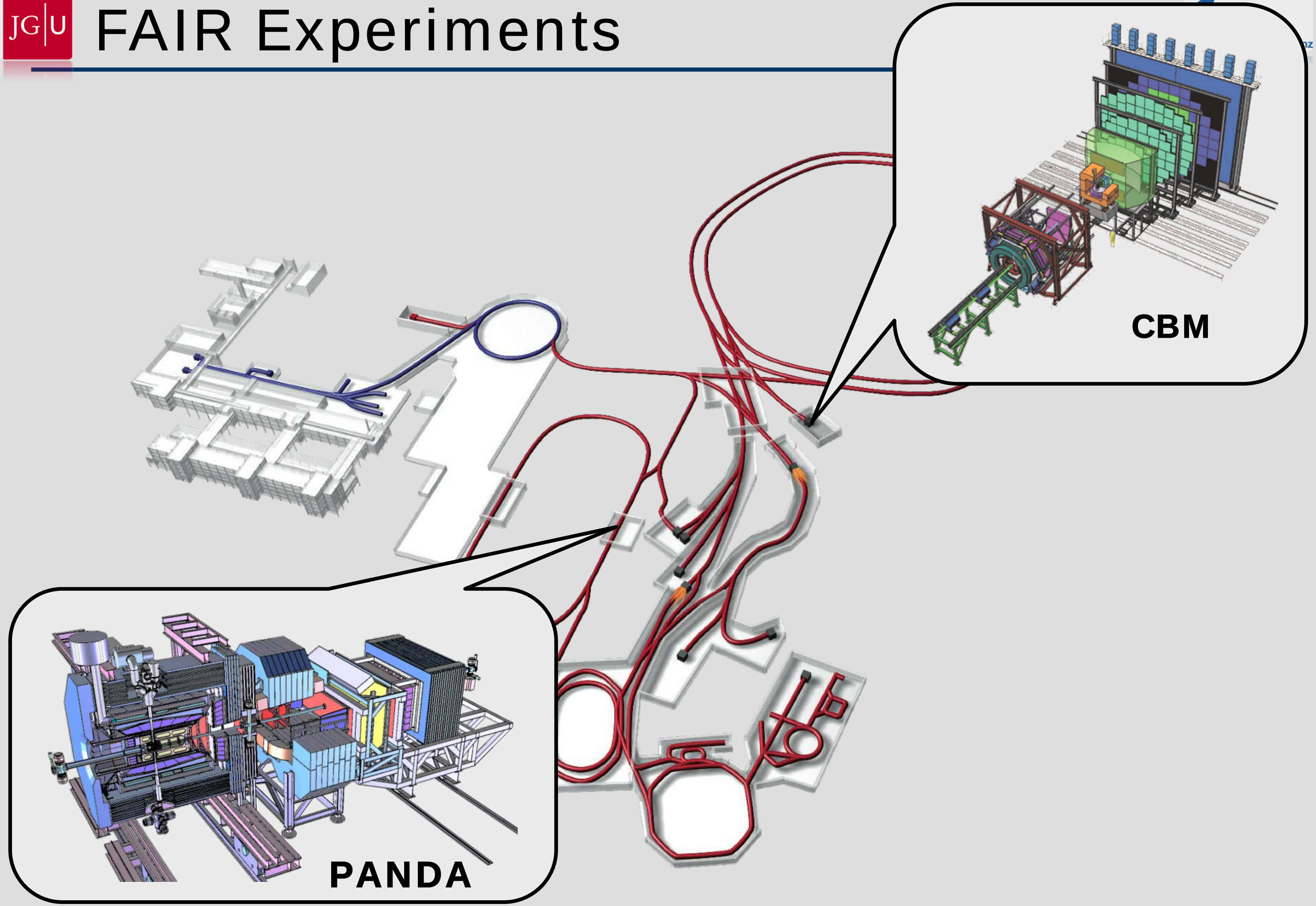
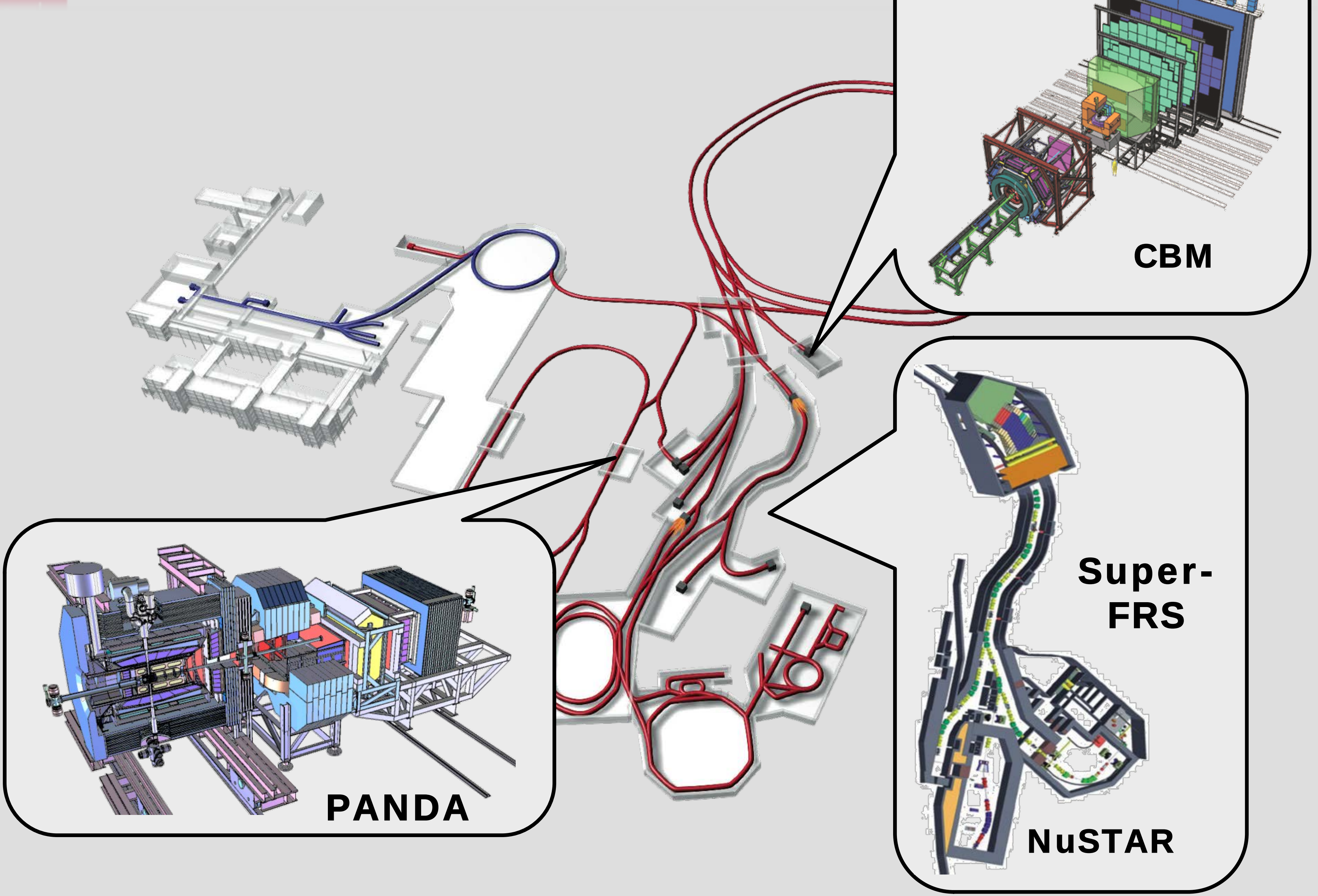


FAIR Experiments



FAIR Experiments



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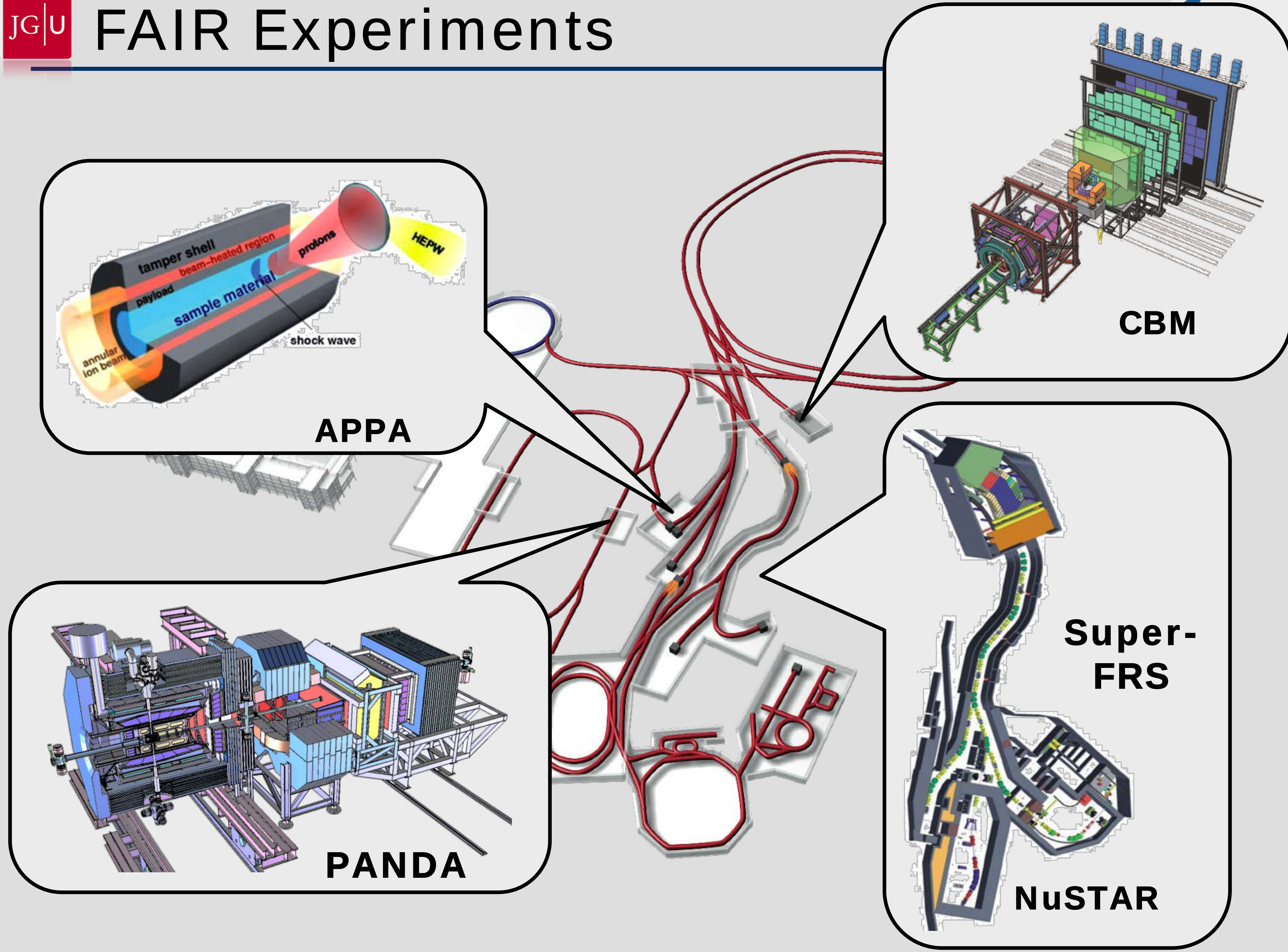
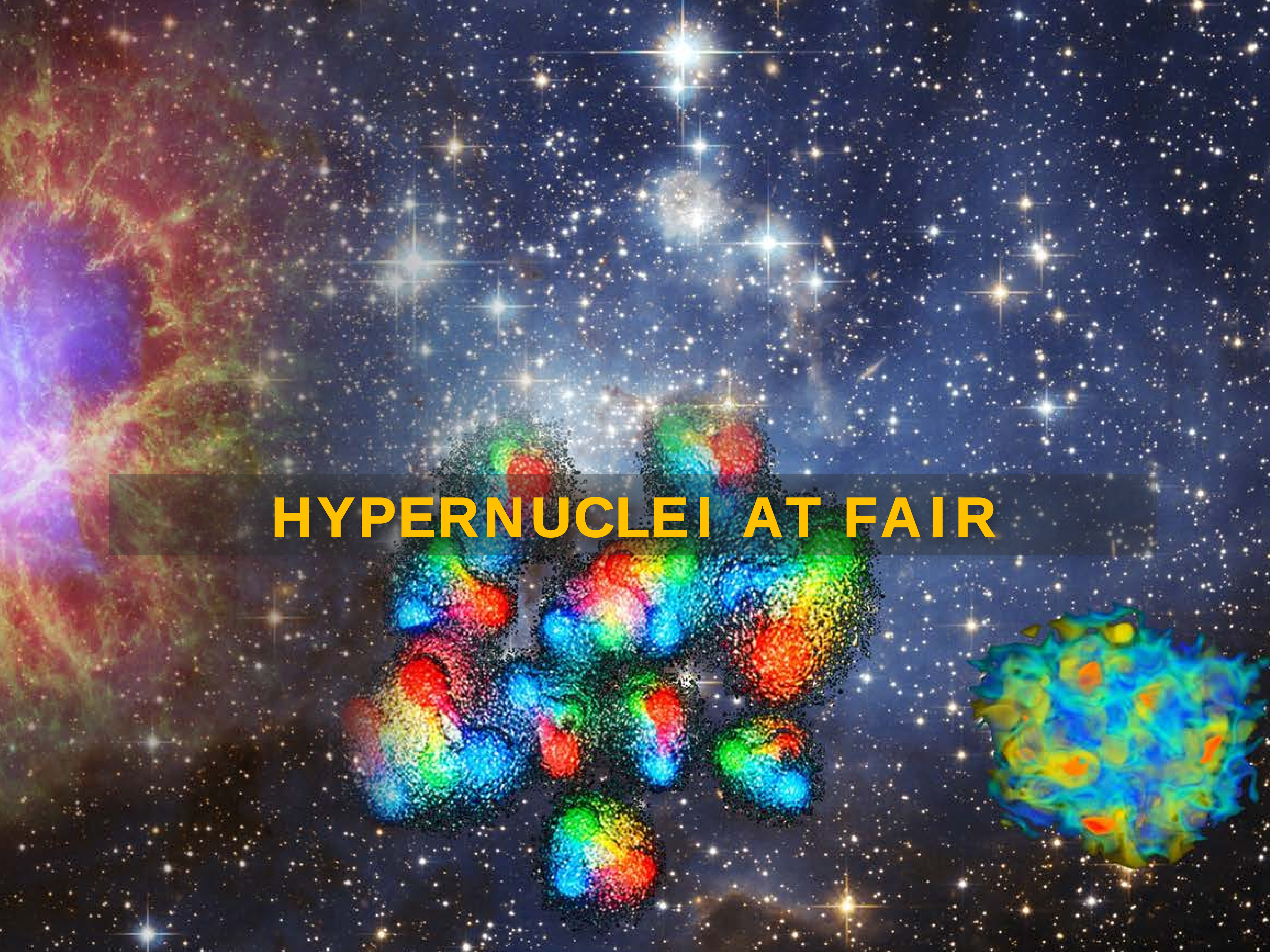
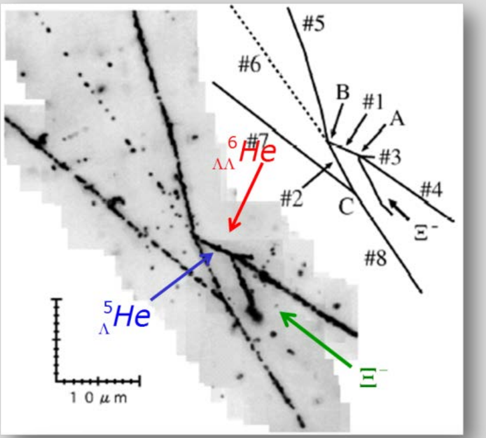


hypernuclear activities

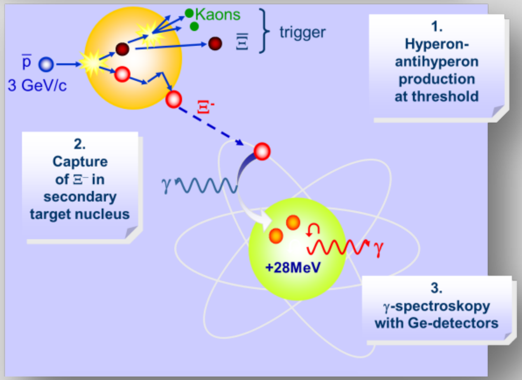

HYPERNUCLEI AT FAIR

Many ways to double hypernuclei

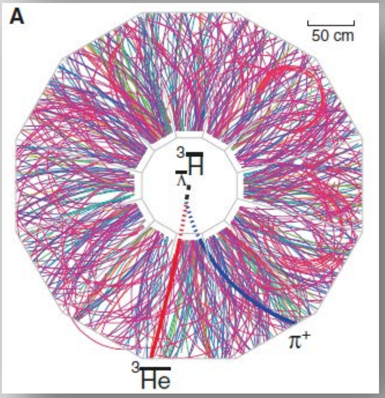
- Ground state masses
  - Hybrid-emulsion technique
  - J-PARC



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

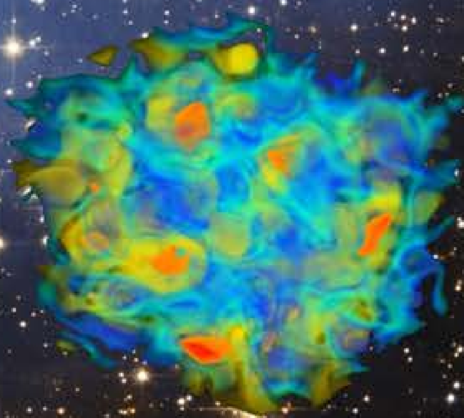


- Excited unstable resonances, exotic hypernuclei, lifetime
  - Invariant mass; hypernuclei-Λ correlations
  - CBM and Super-FRS @ FAIR
  - STAR, ALICE



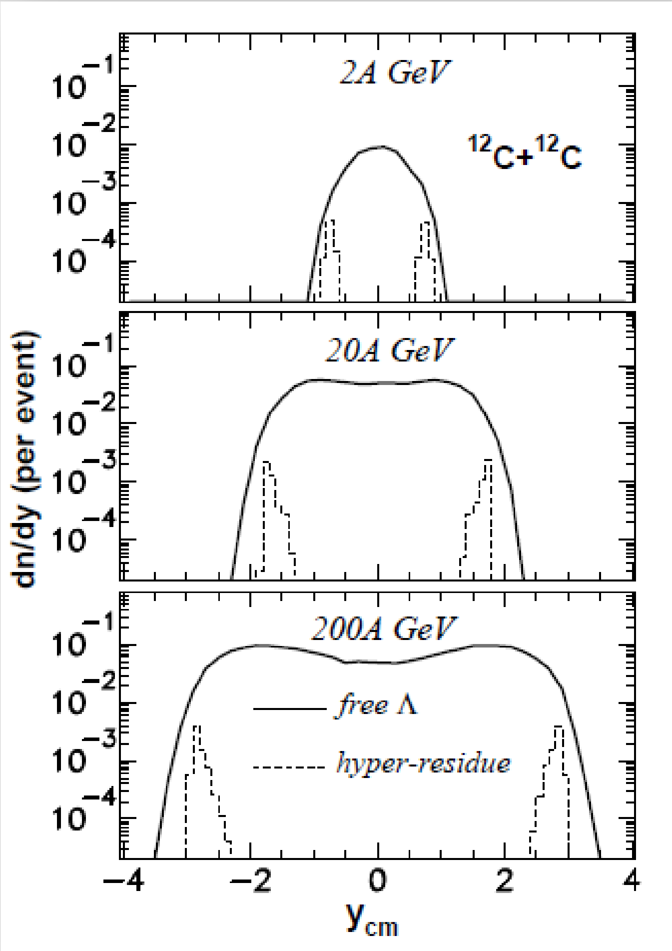
PROJECTILE FRAGMENTATION at SUPER-FRS

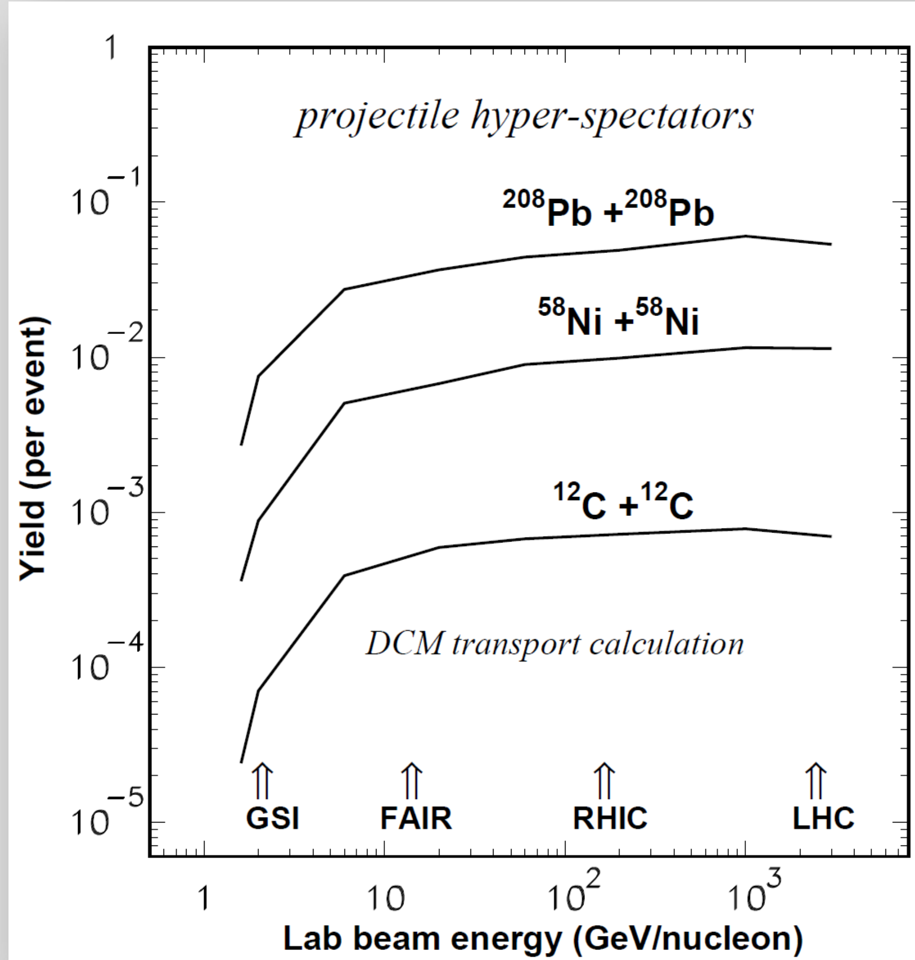
CENTRAL PRODUCTION at CBM



Light hypernuclei in HI collisions

- Dubna Cascade Model (DCM) transport calculations





A.S.Botvina, KK.Gudima, J.Pochodzalla, PRC 88, 054605, 2013

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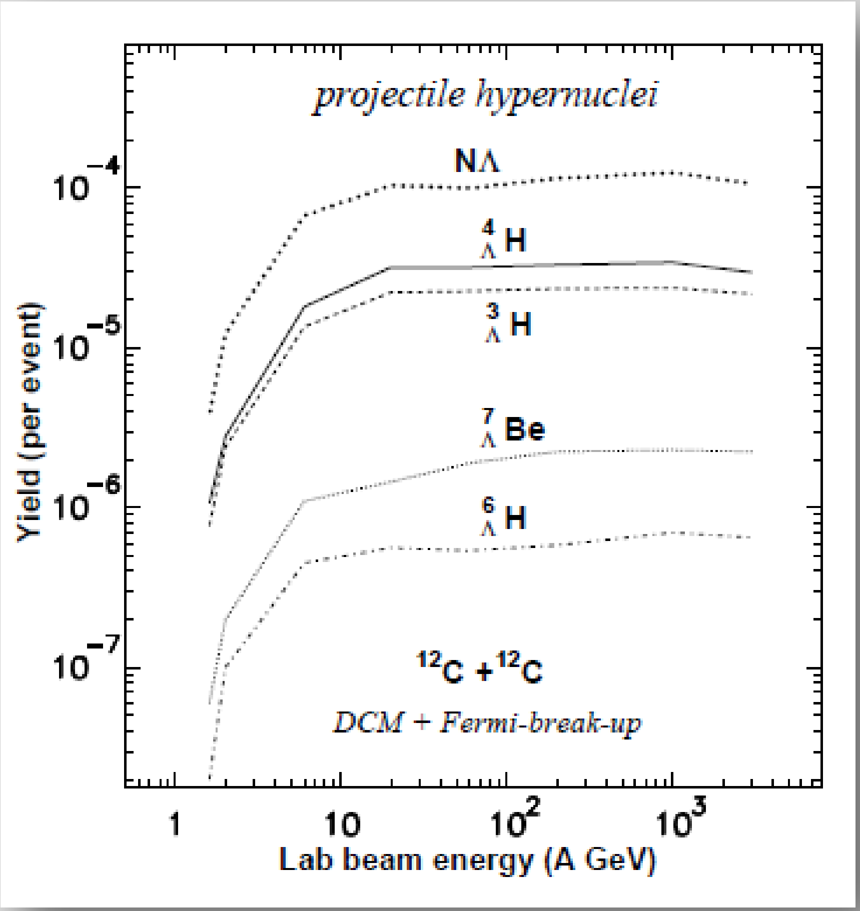
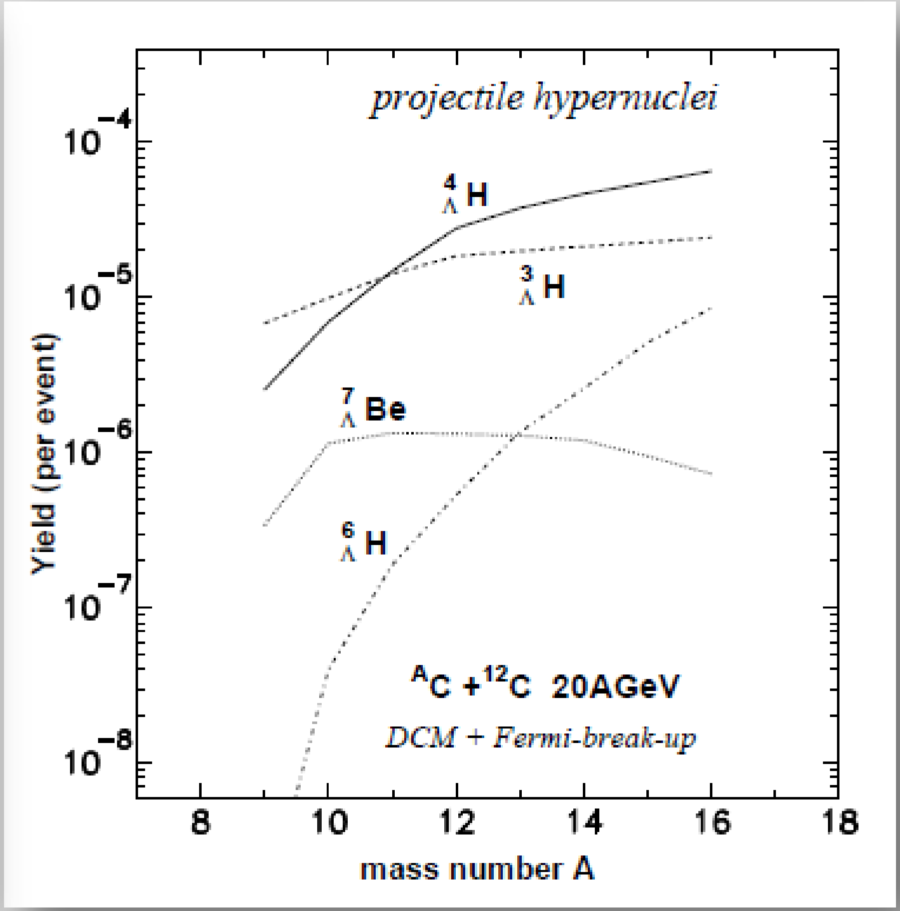
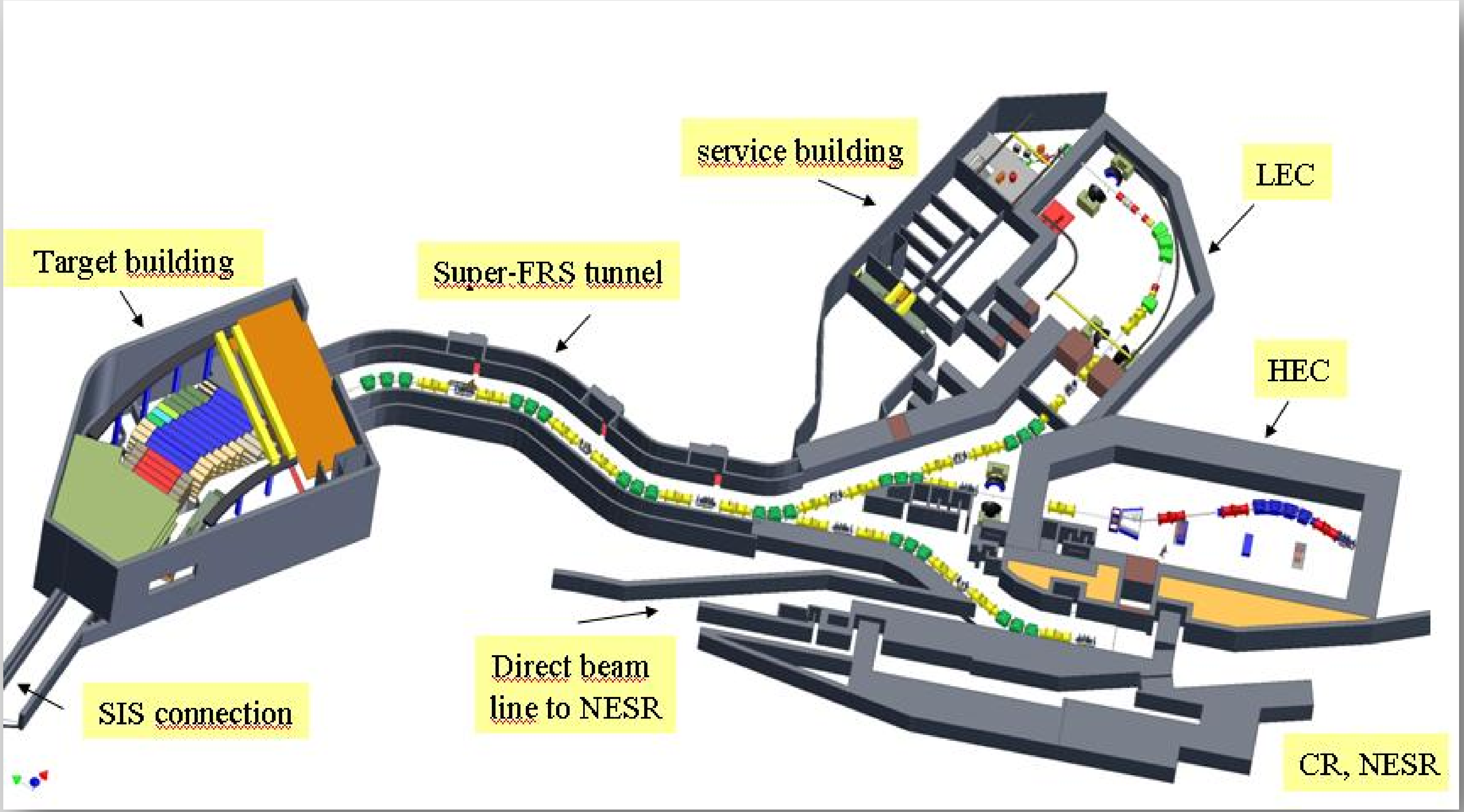




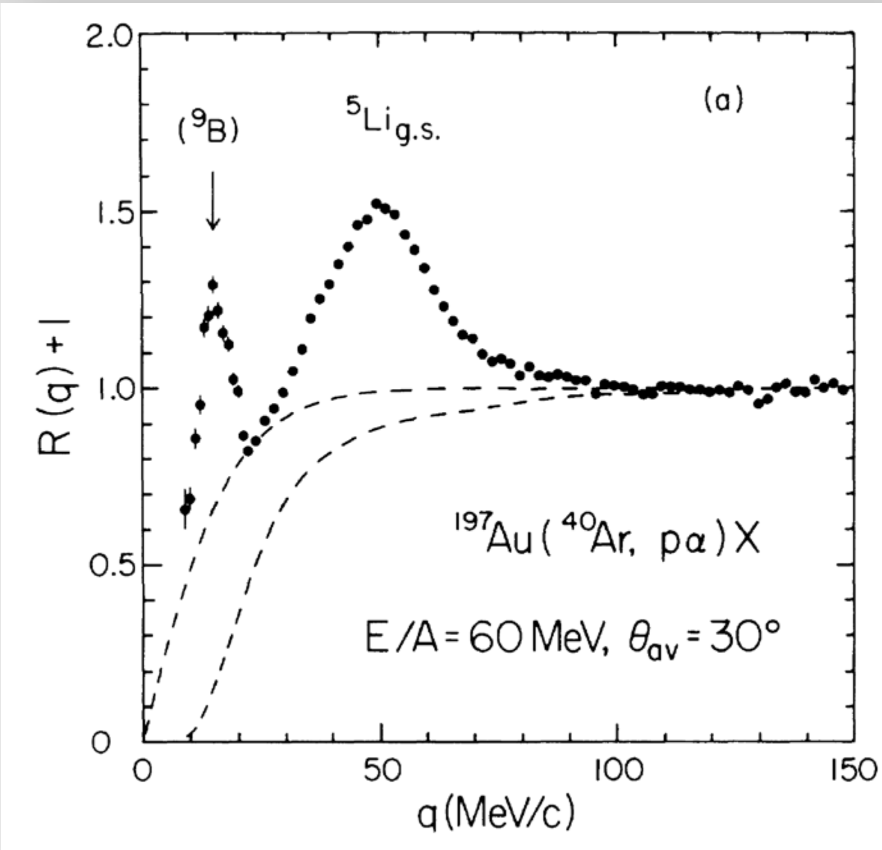
A.S.Botvina, KK.Gudima, J.Pochodzalla, PRC 88, 054605, 2013

With super-FRS at FAIR

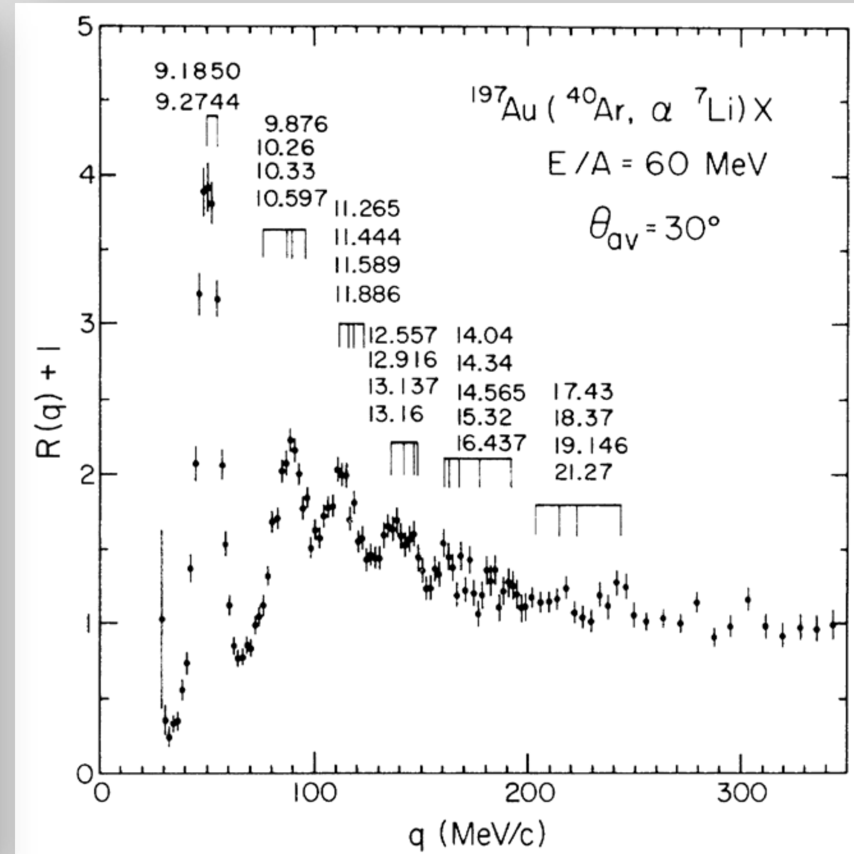


Small relative momentum correlation

- Well established method for conventional nuclei

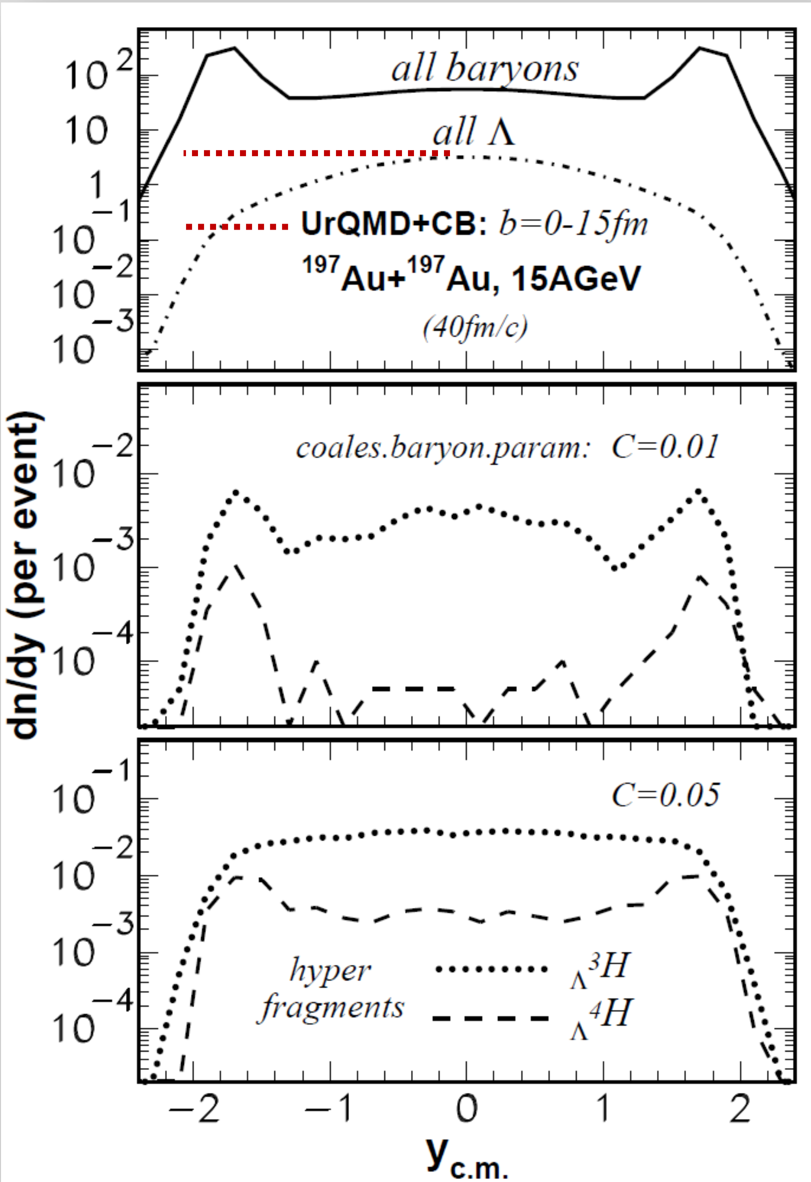


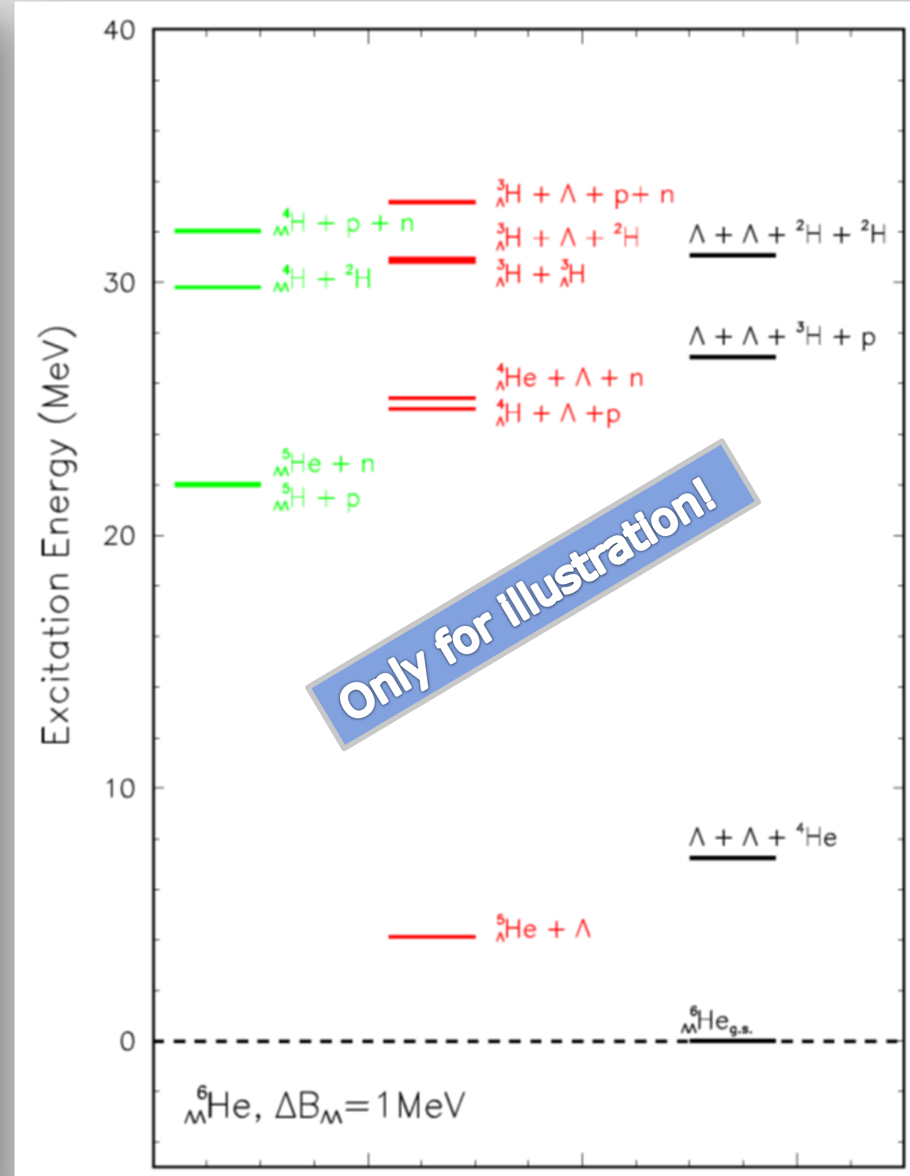
J.P *et al*, PLB 161B, 256 (1985)



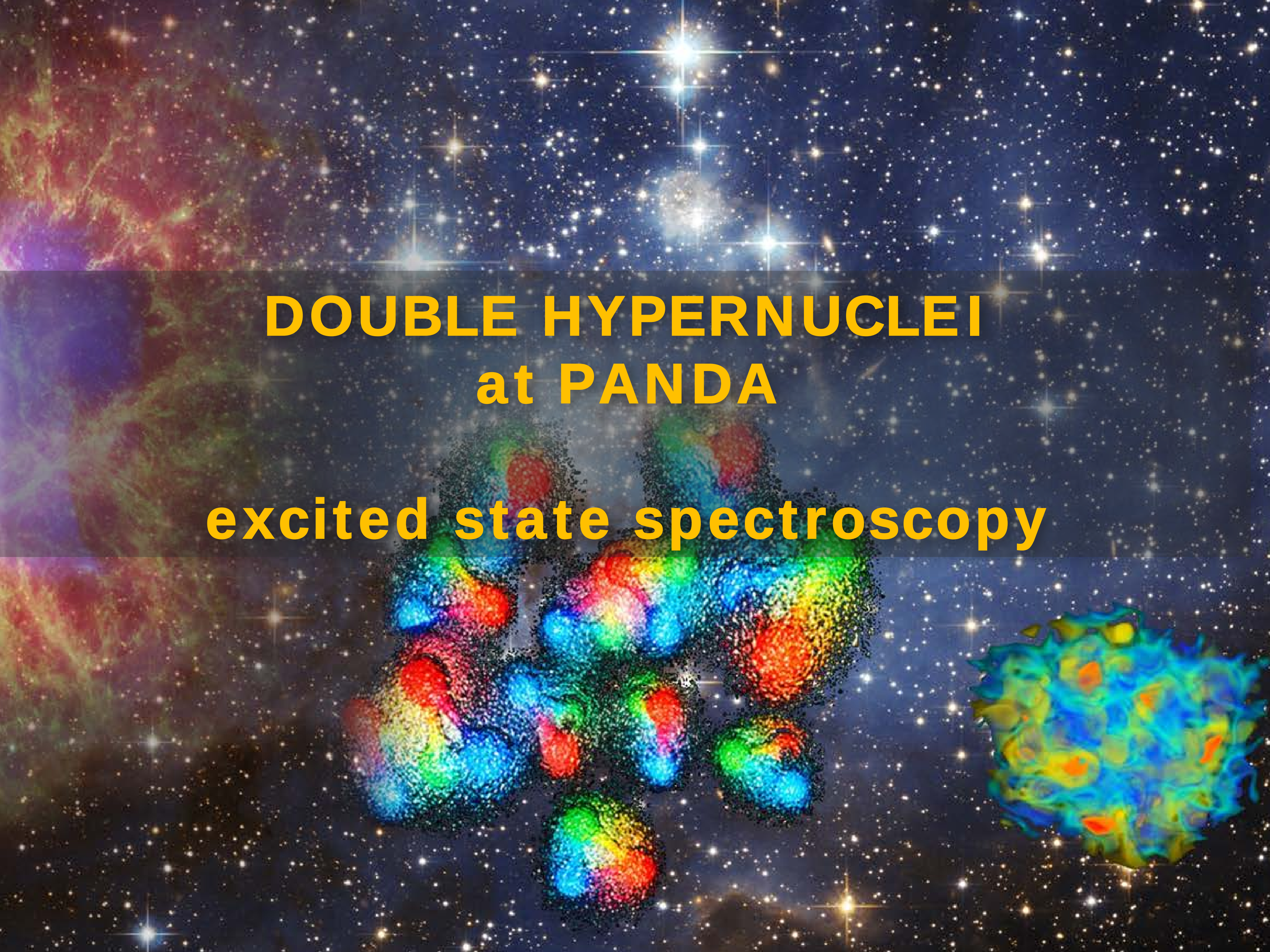
J.P *et al*, PRC 35, 1695 (1987)

Search for particle unbound states ?



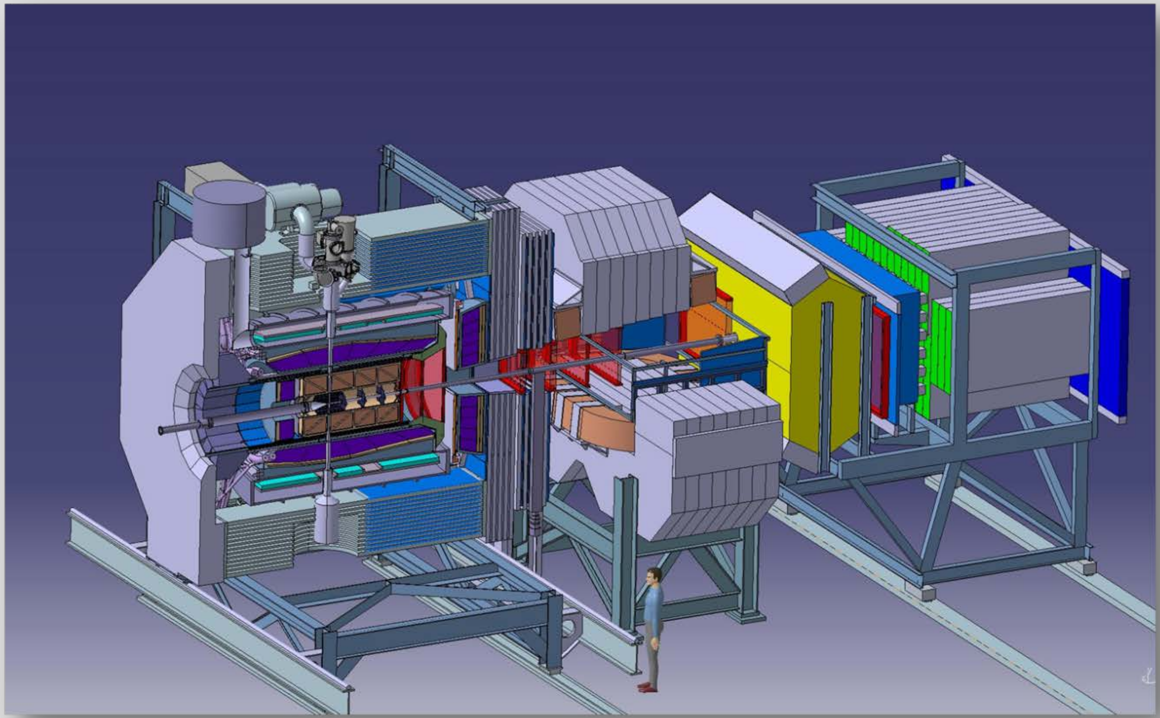


A. Botvina, J. Pochodzalla *et al.*


DOUBLE HYPERNUCLEI
at PANDA
excited state spectroscopy

Properties of the PANDA Detector

▸ 4π coverage	partial wave analysis
▸ high rates	2×10^7 annihilations/s
▸ good PID	γ,e,μ,K,p
▸ momentum resolution	~1%
▸ Vertexing for D,K^0_s,Λ,..	$c\tau$=123μm for D0 at p/m≈2
▸ efficient trigger	e,μ,K,D,Λ
▸ no hardware trigger	raw data rate~ TB/s



PANDA – a factory for tagged hyperons

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}
$\Xi\bar{\Xi}$	2µb	10^{8}
$D\bar{D}$	250nb	10^{7}
$J/\psi(\rightarrow e^+e^-, \mu^+\mu^-)$	630nb	10^{9}
$\chi_2(\rightarrow J/\psi+\gamma)$	3.7nb	10^{7}
$\Lambda_c\bar{\Lambda}_c$	20nb	10^{7}
$\Omega_c\bar{\Omega}_c$	0.1nb	10^{5}

- Low multiplicity events
- Moderate particle energies
- Close to threshold: exclusive conditions
  - effective capture of hyperons in nuclei (Ξ^-)
  - re-scattering of tagged hyperons and and even charmed baryons
  - (anti)hyperon potentials (see e.g. PLB 669 (2008) 306)

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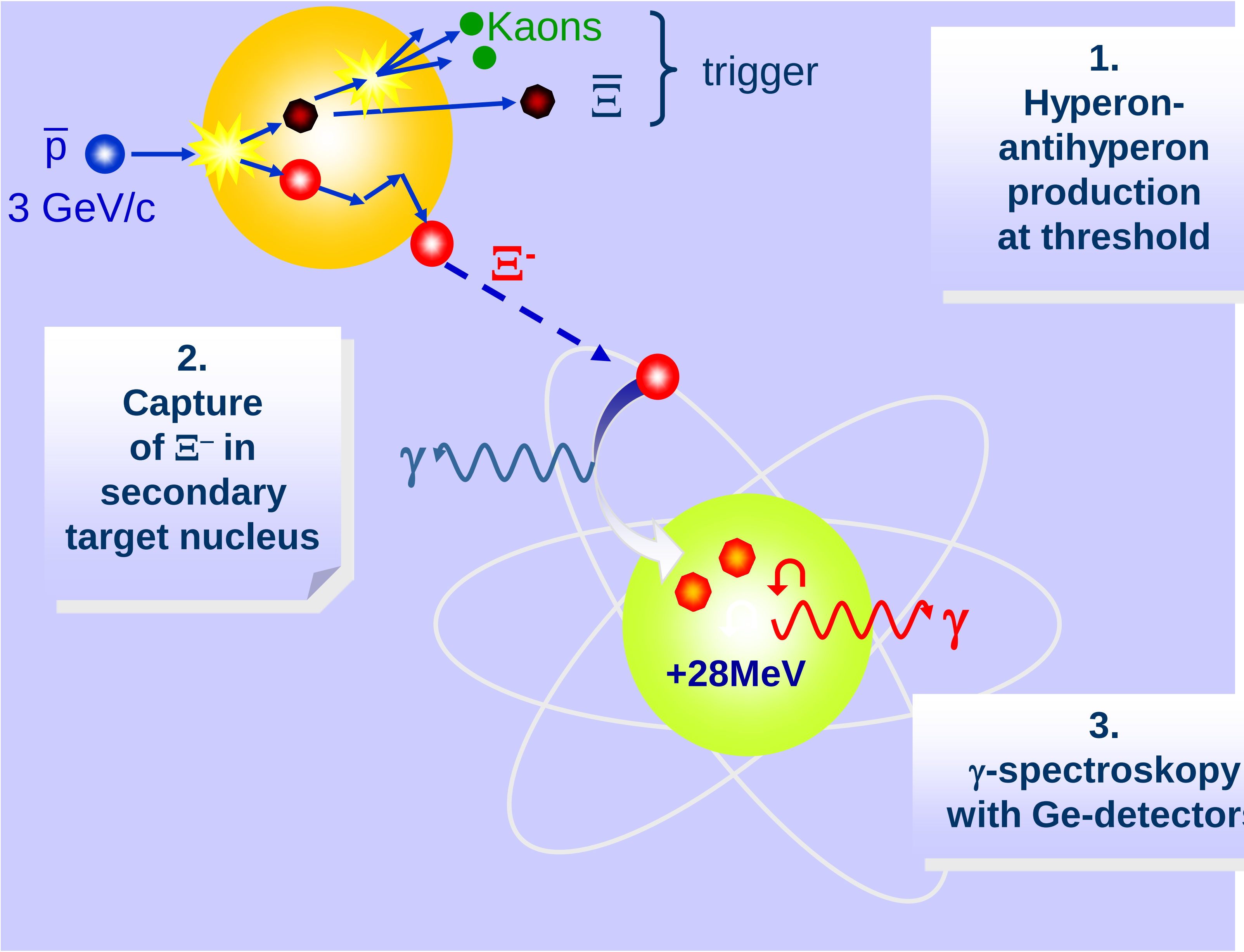
Production of Double Hypernuclei

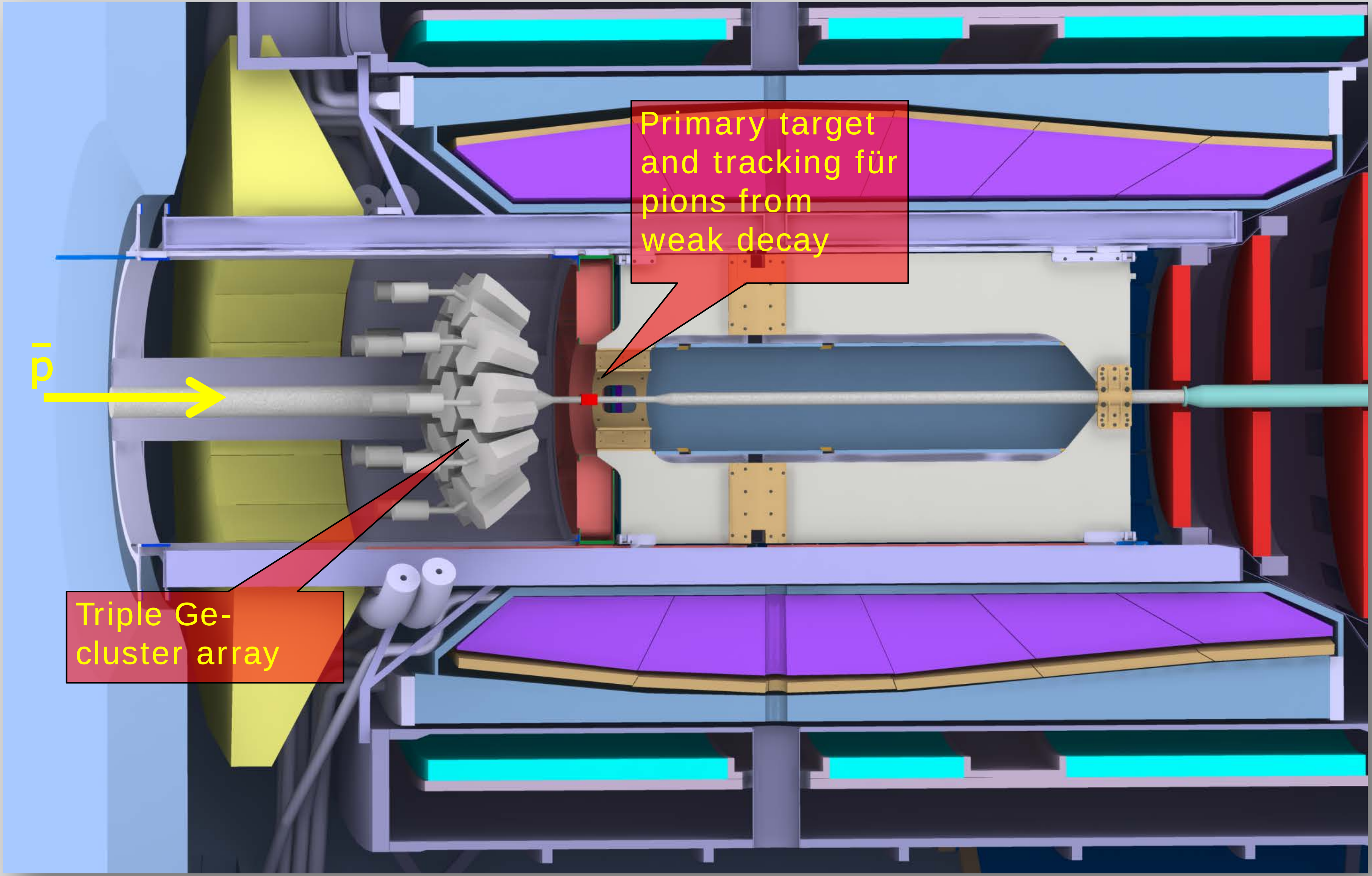


1. Hyperon-antihyperon production at threshold

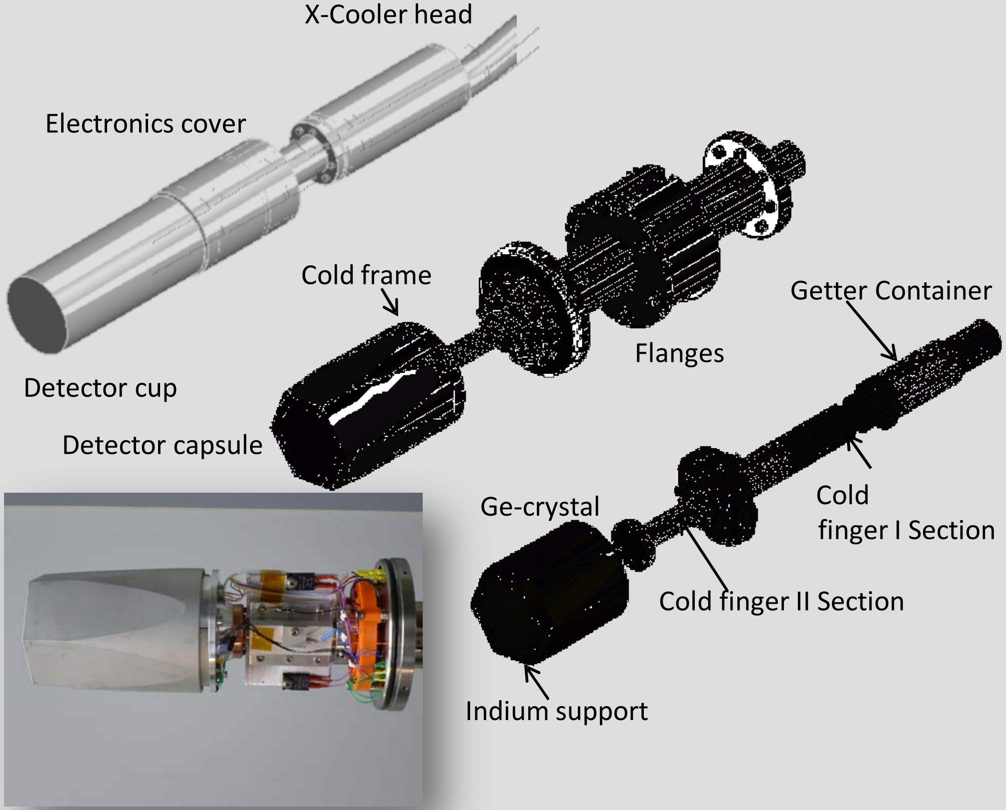
2. Capture of Ξ^- in secondary target nucleus

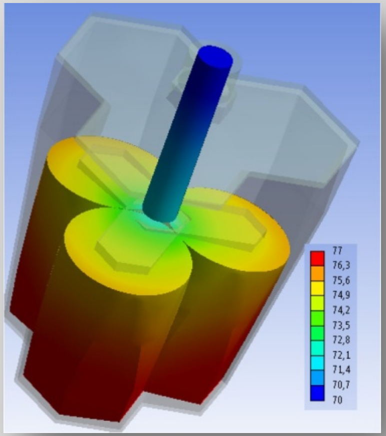
3. γ-spectroskopy with Ge-detectors

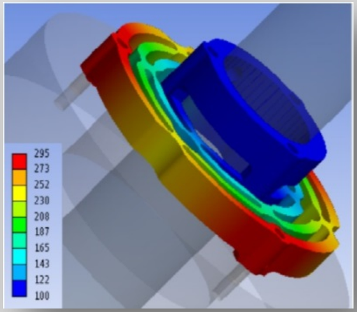
The HYP setup at PANDA

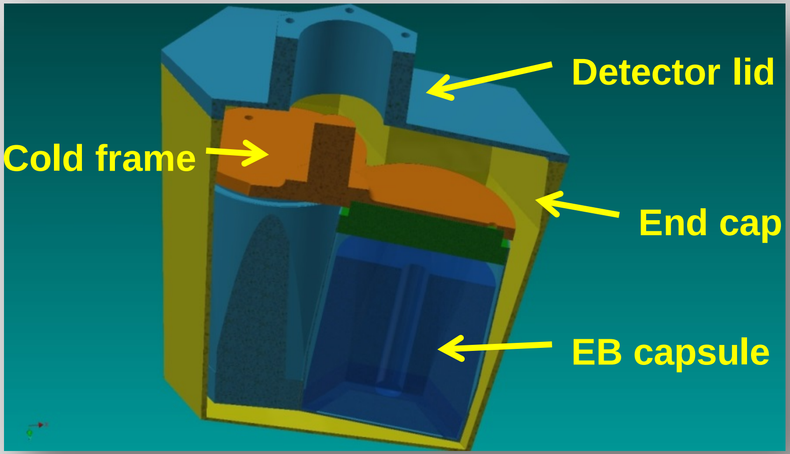


NUSTAR-PANDA Cooperation

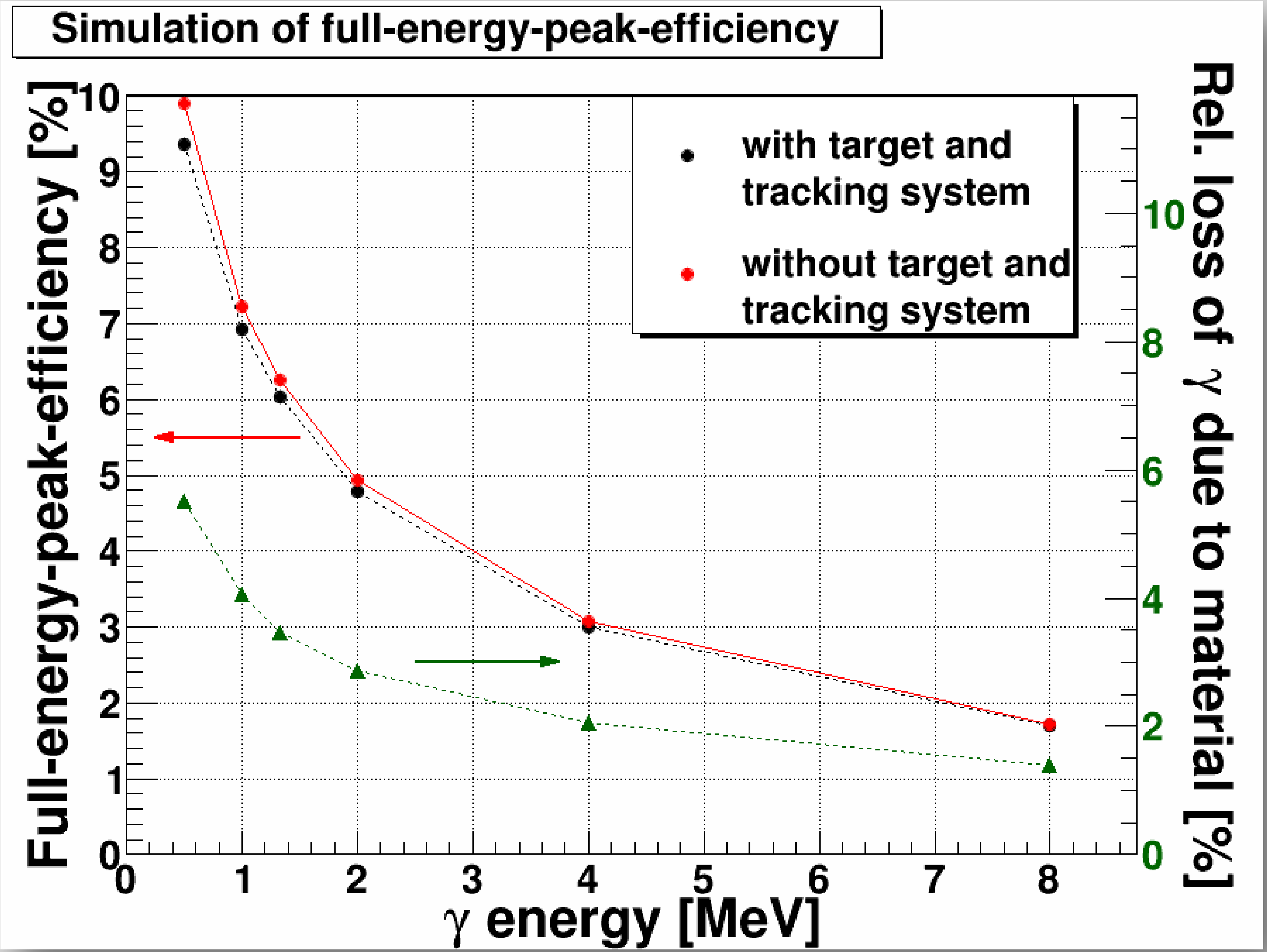






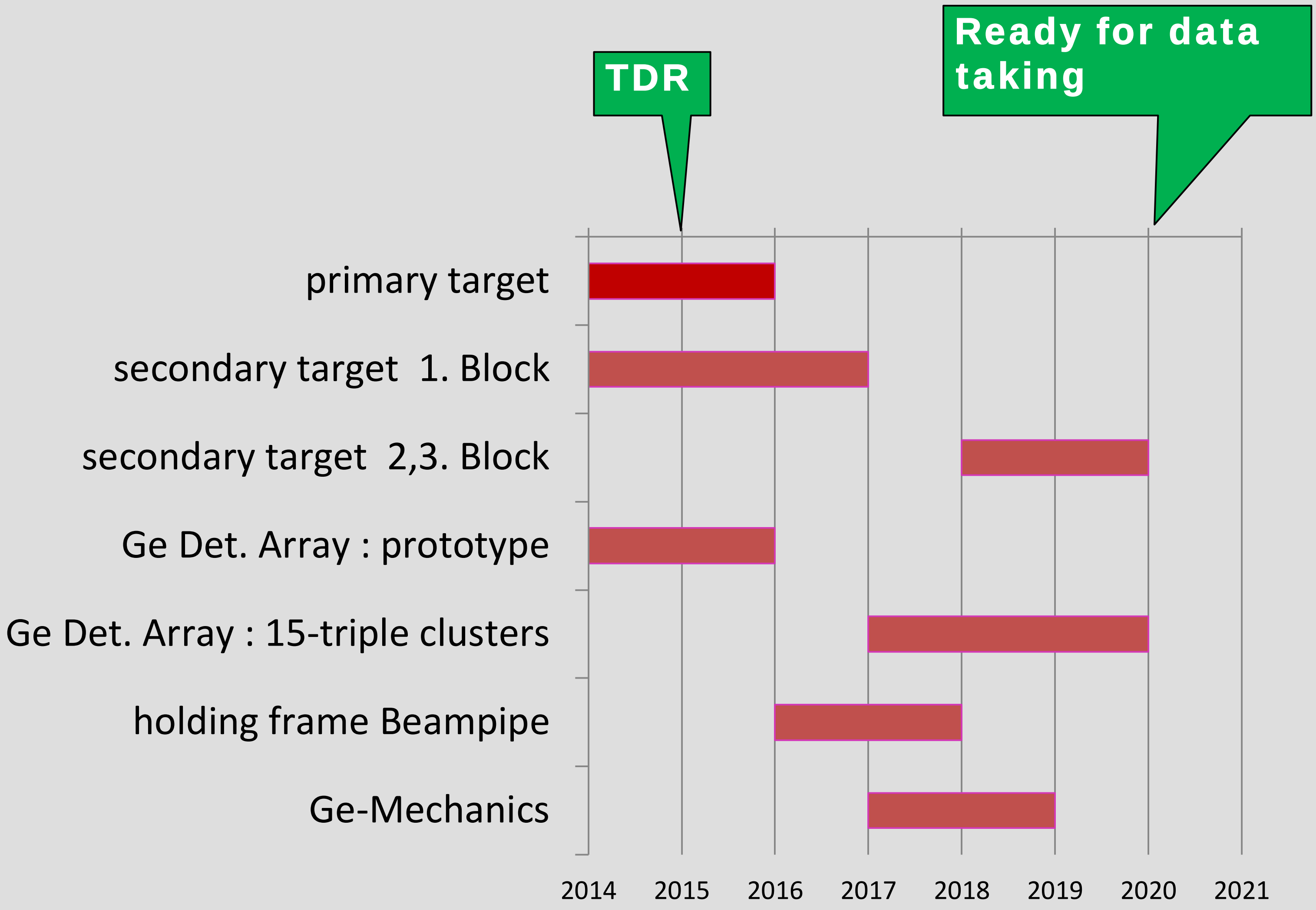


- Single detector undergoing intensive tests (e.g. COSY)
- First triple cluster under construction



Simulation of full-energy-peak-efficiency
Full-energy-peak-efficiency [%]
Rel. loss of γ due to material [%]
γ energy [MeV]
with target and tracking system
without target and tracking system
0
1
2
3
4
5
6
7
8
9
10

Envisaged Timeline



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 $10^{32} cm^{-2} s^{-1}$, 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.

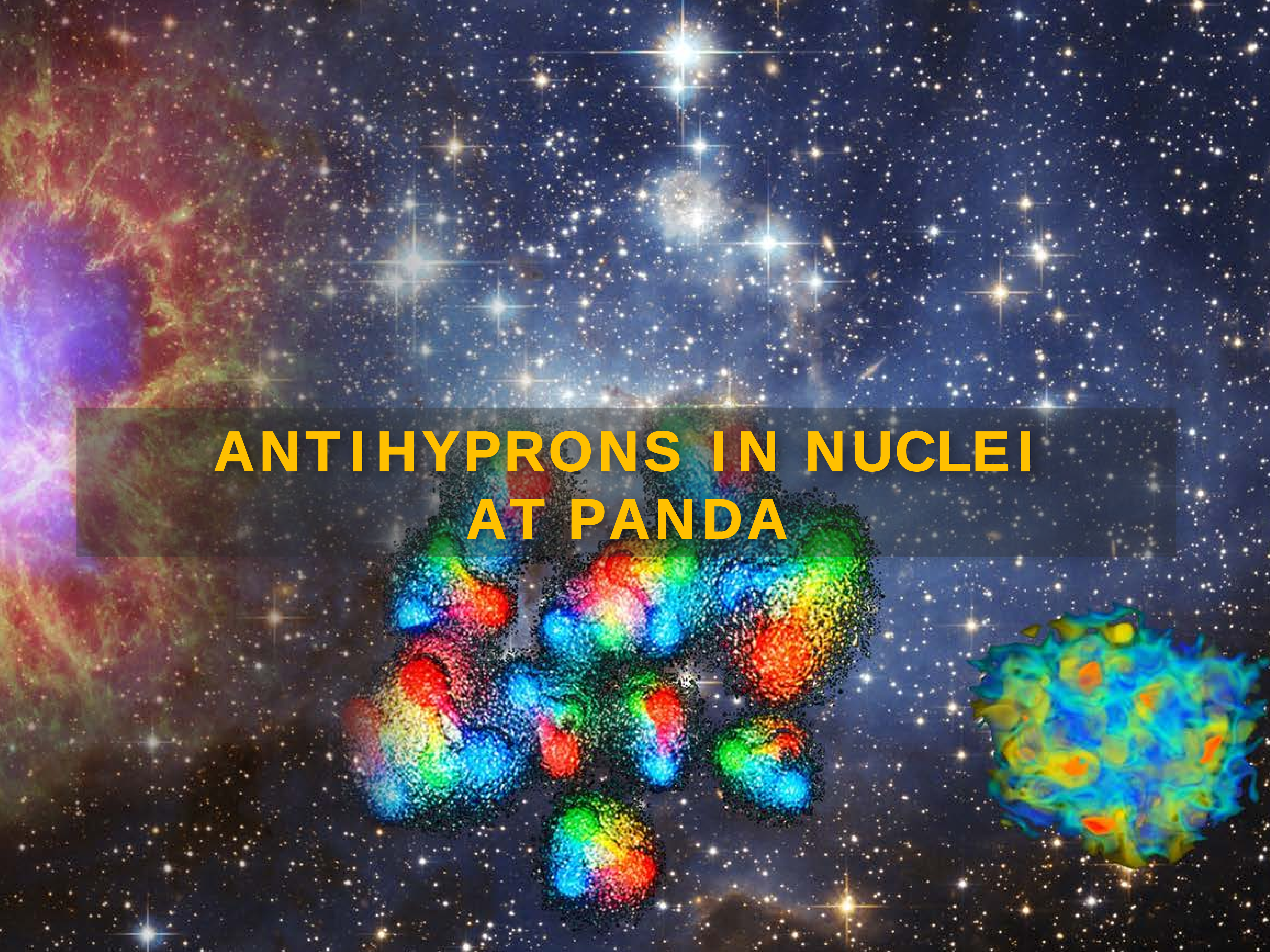
Antiproton energies below 15 GeV would be sufficient for the investigation of strangeness and charm in nuclei. Here, the associated production of hadron - antihadron pairs in $(\bar{p}, p)$ annihilation would be a promising tool for populating bound states of heavy mesons and hyperons in nuclei, making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

PANDA in 2018/2019/2020

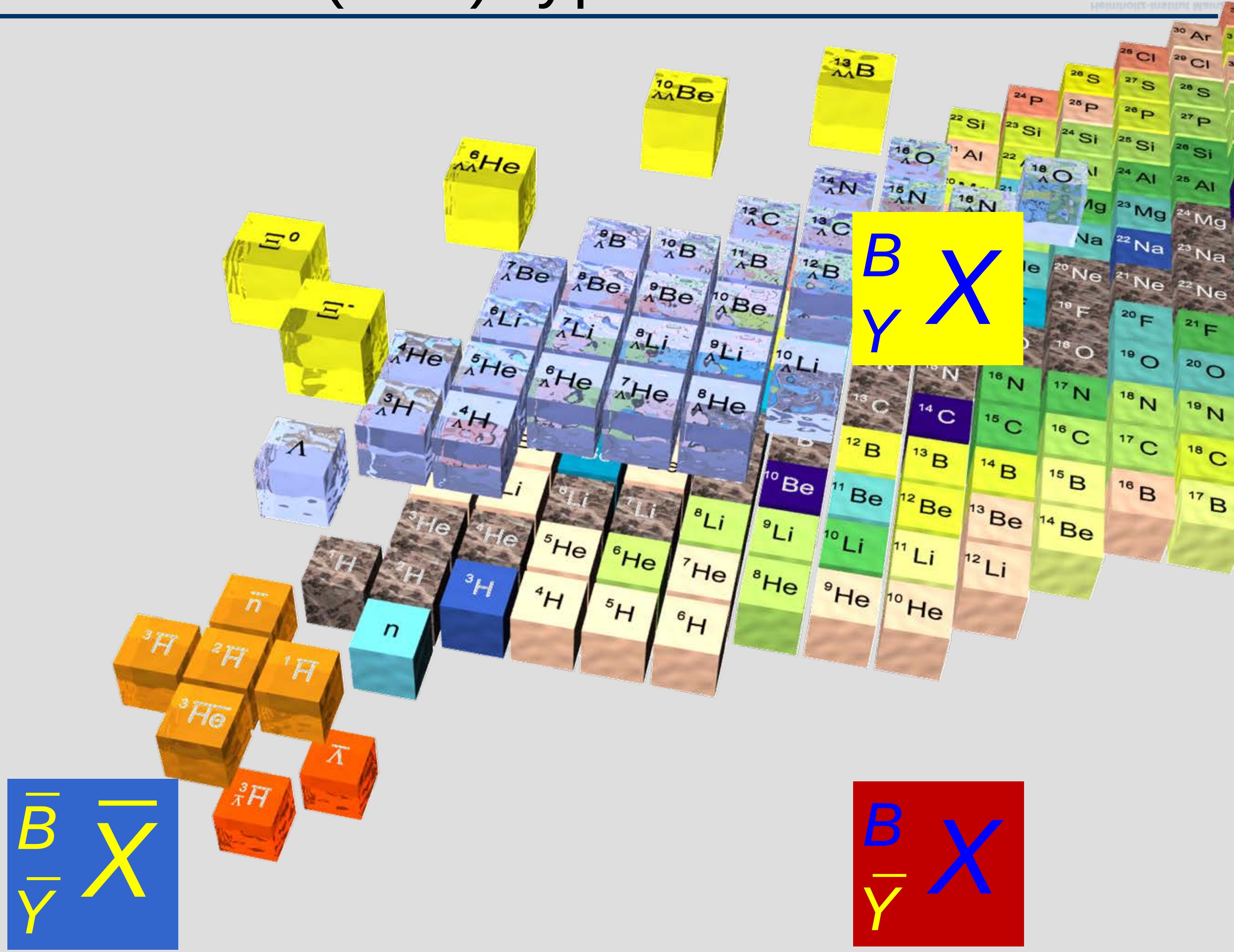
- Luminosity ?
- PANDA detector fully completed ?
- Running periods of HESR ?

$\Rightarrow$ scrutiny process to define physics program for commissioning phase of PANDA

- Process with large cross section
- Unique $\Rightarrow$ experiment *only* possible with antiproton beam
- Interesting and timely physics

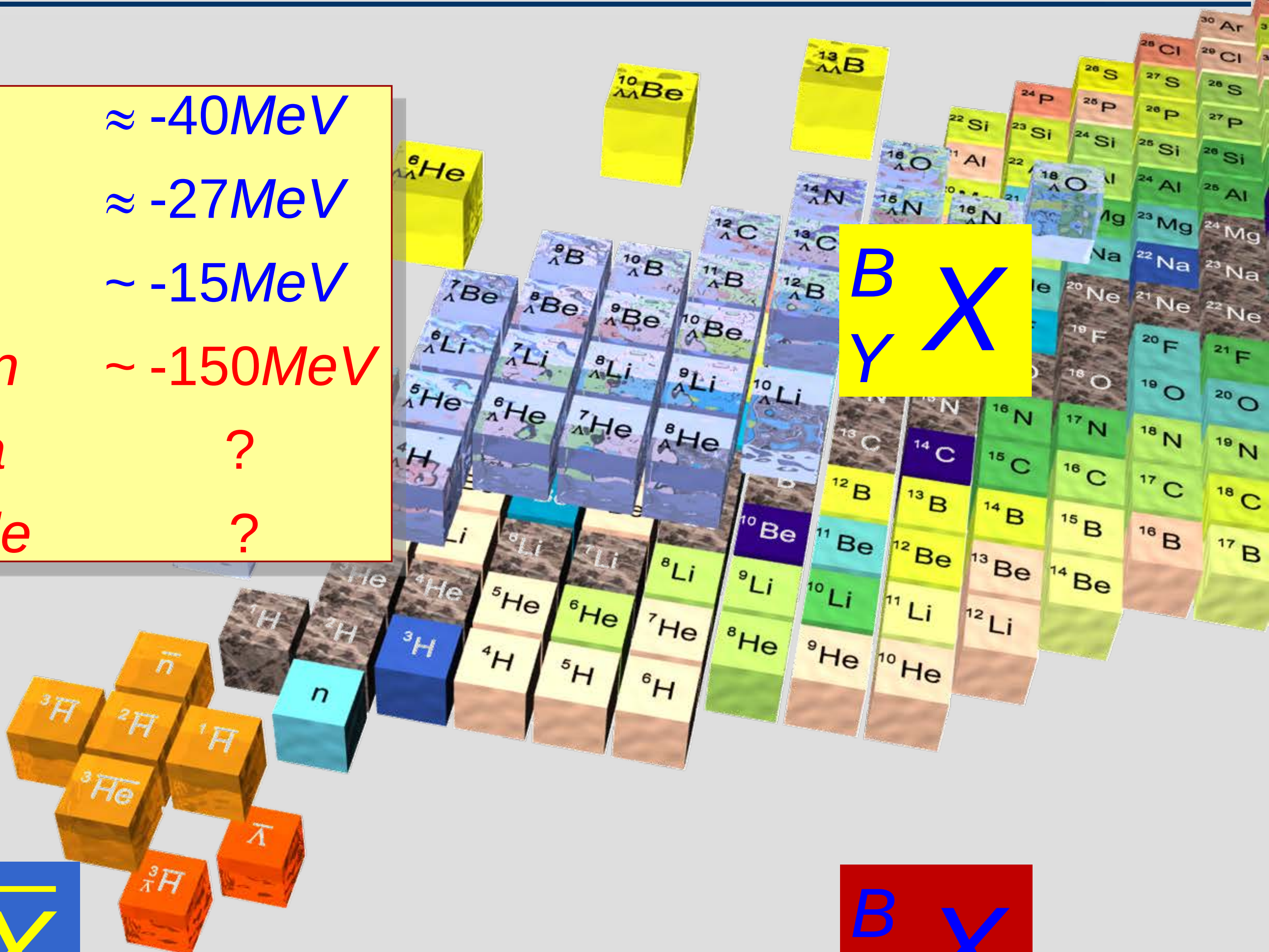

ANTIHYPRONS IN NUCLEI
AT PANDA

Nuclei with (anti)hyperons



Nuclei with (anti)hyperons

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



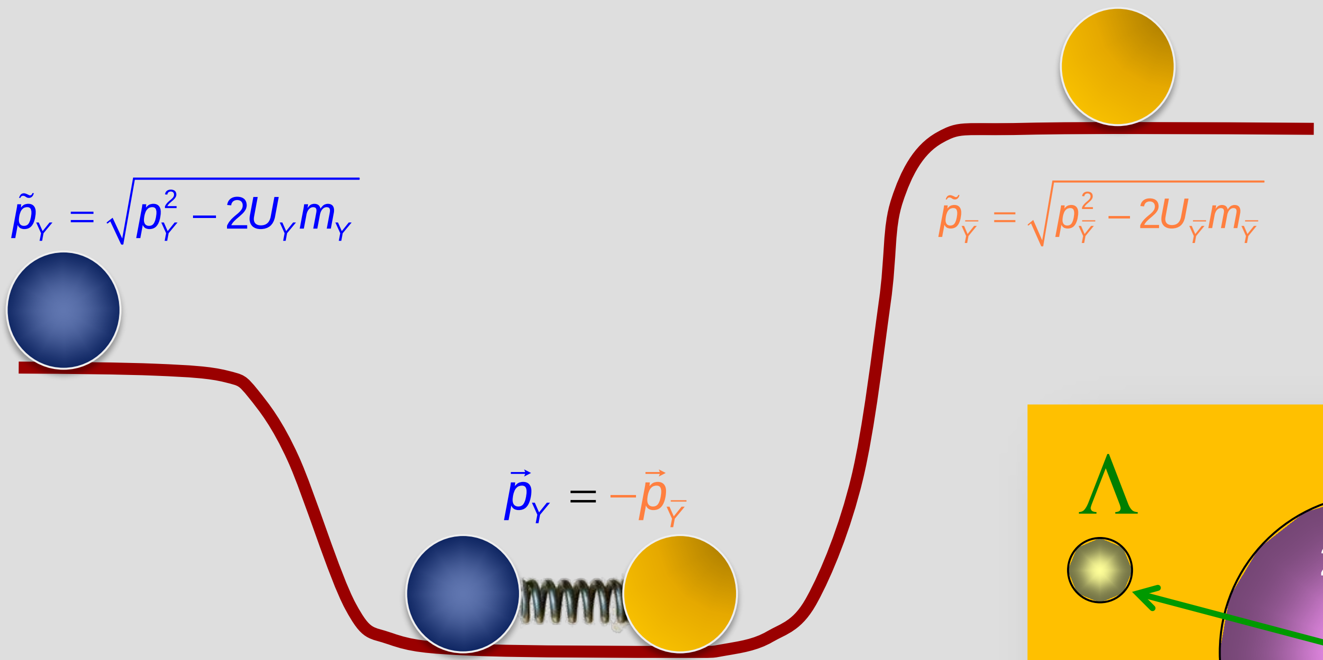
B X
Y

$\bar{B}$ $\bar{X}$
$\bar{Y}$

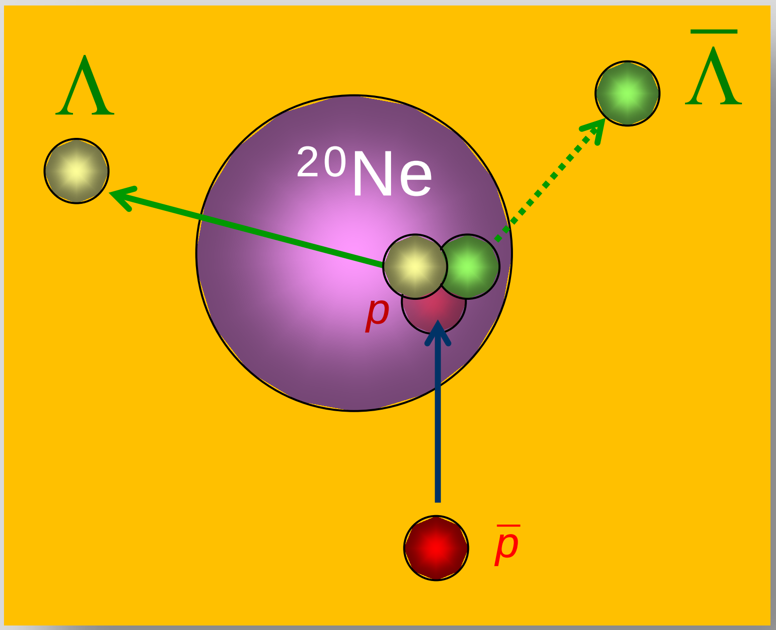
B X
$\bar{Y}$

$\overline{\Lambda}$ Potential (in neutron matter)

- exclusive $\bar{p}$+p(A) → Y+$\overline{Y}$ close to threshold within a nucleus
- Λ and $\overline{\Lambda}$ that leave the nucleus will have different asymptotic momenta depending on the respective potential



J.P., PLB **669** (2008) 306



- ⇒ *transverse* momentum close to threshold of *coincident* $Y\overline{Y}$ pairs

$$\alpha_\perp = \left\langle \frac{p_\perp(\Lambda) - p_\perp(\overline{\Lambda})}{p_\perp(\Lambda) + p_\perp(\overline{\Lambda})} \right\rangle$$

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.

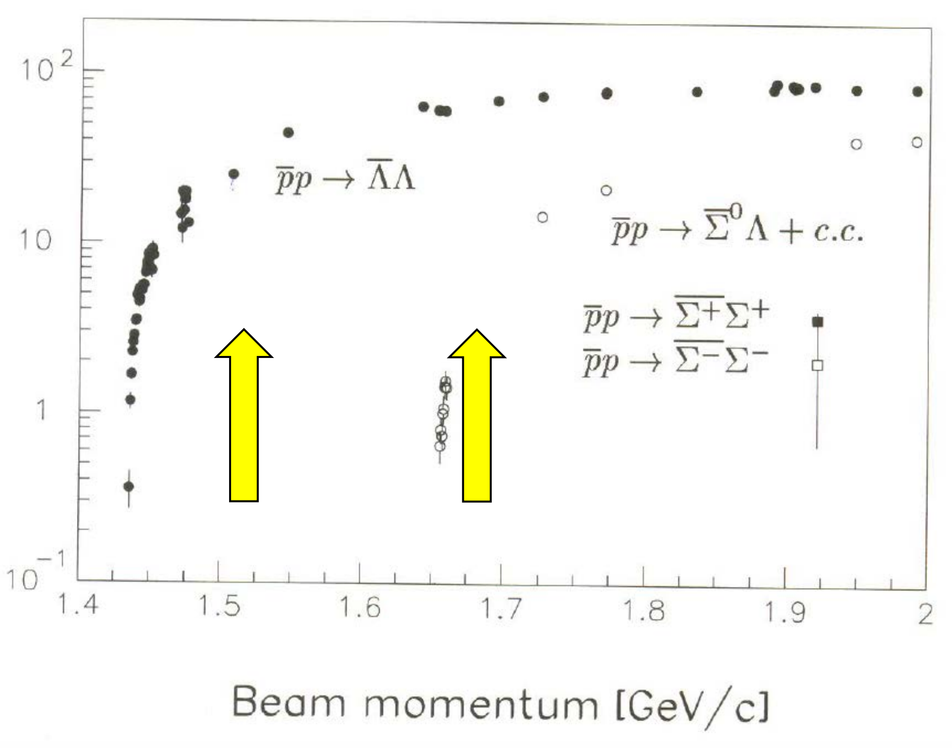
i	N	Λ	Σ	Ξ	$\bar{N}$	$\bar{\Lambda}$	$\bar{\Sigma}$	$\bar{\Xi}$	K	$\bar{K}$
U_i	-46	-38	-39	-22	-150	-449	-449	-227	-18	-224

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

GiBUU Simulations $\overline{p}+{}^{20}Ne \rightarrow \Lambda\overline{\Lambda}+X$

- $\overline{p}p$ threshold 1435MeV/c
- 27M inclusive events for each data set calculated at HIMster
- Cross section for $Y\overline{Y}$ production increased by factor of 10
- Approximately 10k exclusive $\Lambda\overline{\Lambda}$ pairs in each set

Energy (MeV)	Momentum (MeV/c)	Excess energy (MeV)
850	1522	30.6
1000	1696	92.0



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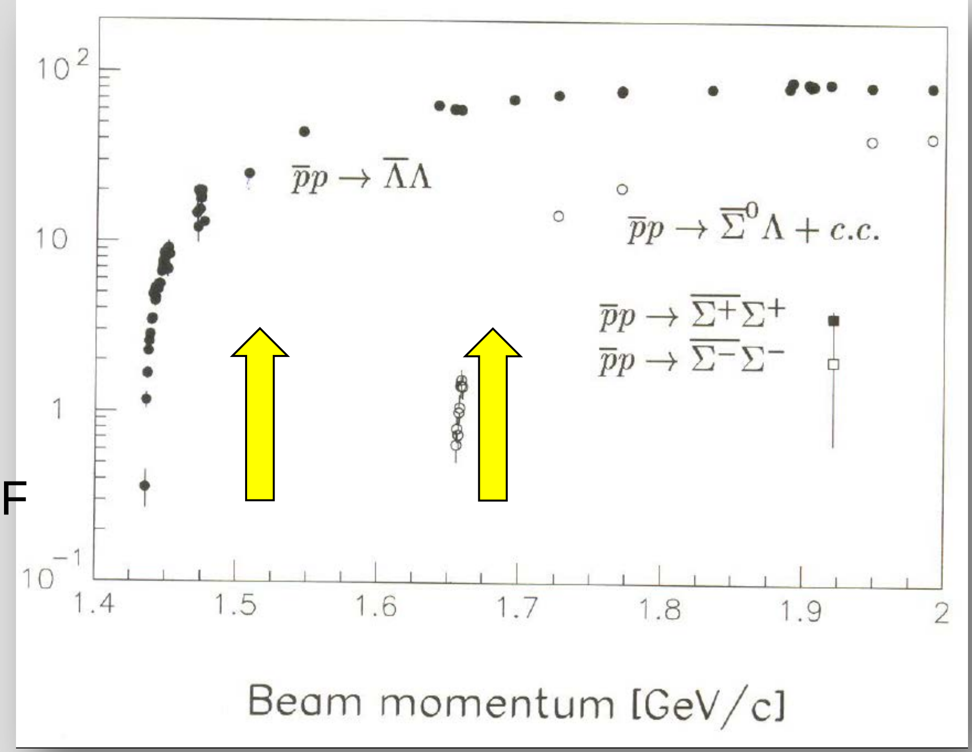
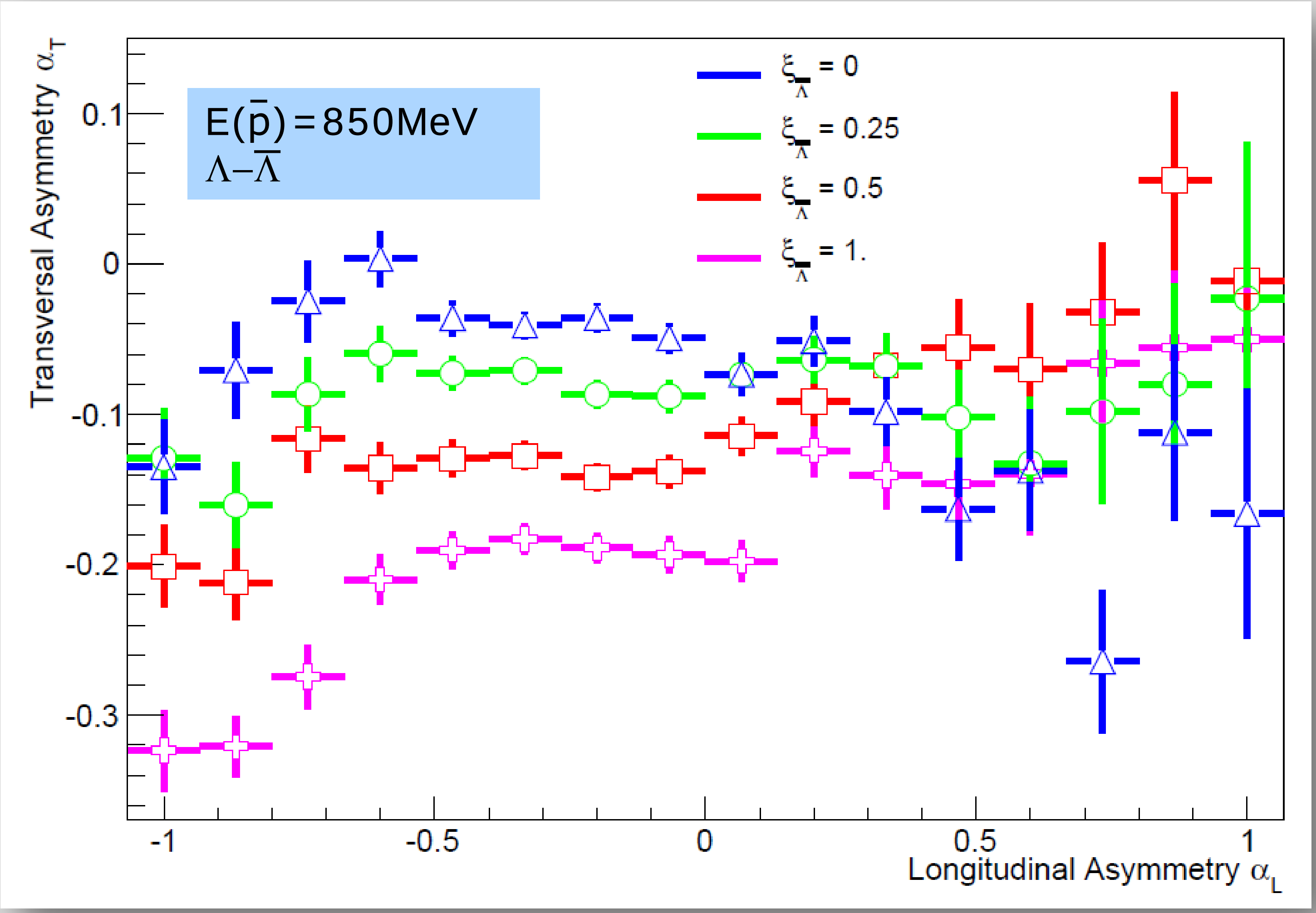


- Default parameters for RMF
  - $V(N)$ = -46MeV
  - $V(\Lambda)$ = -38MeV
  - $V(\bar{N})$ = -150MeV
  - $V(\bar{\Lambda})$ = -449MeV

Scan of $\overline{\Lambda}$ potential

- $U(\overline{\Lambda})$ = -449MeV, -225MeV, -112MeV, 0MeV
- All other potentials unchanged



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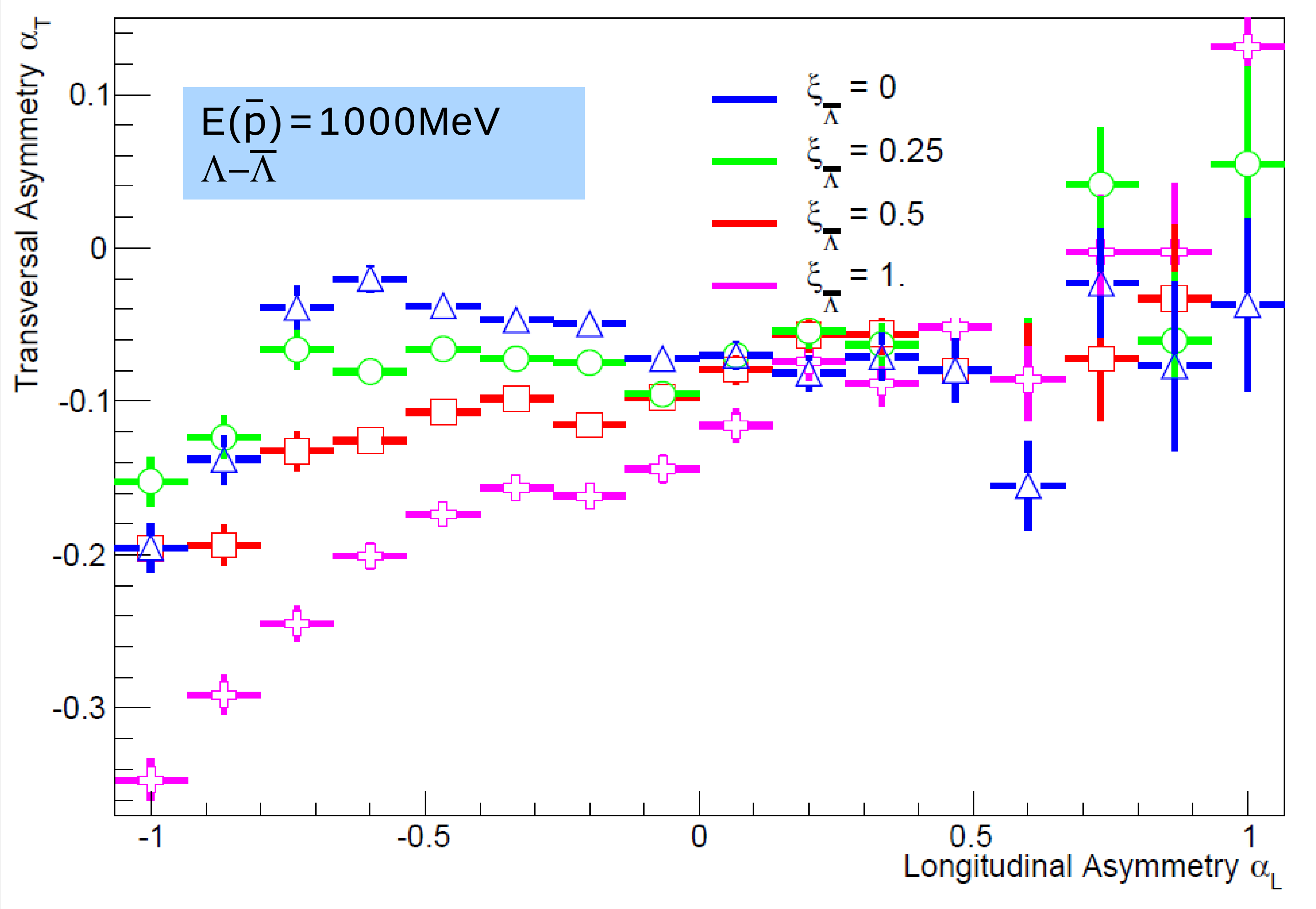
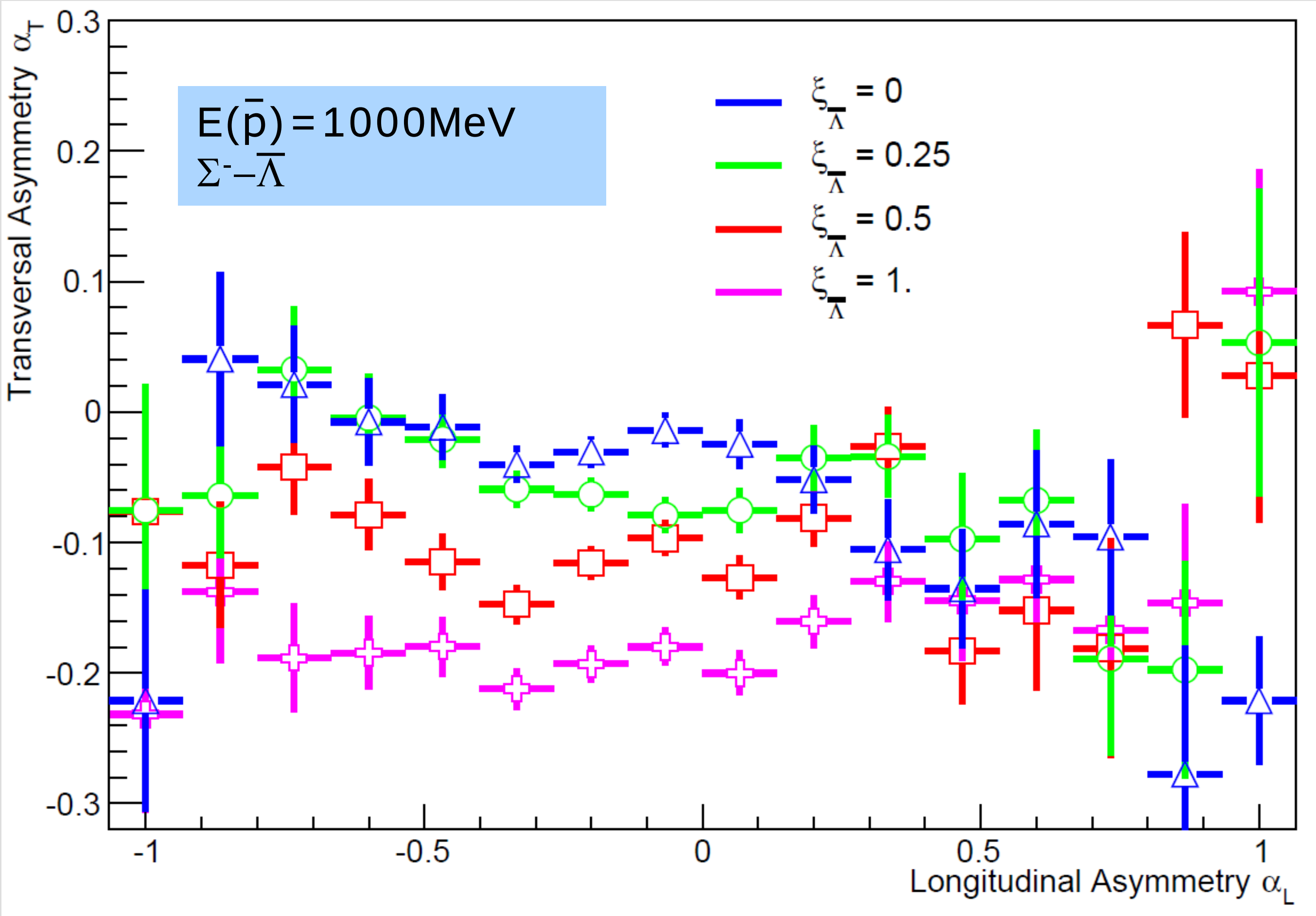


Other |s|=1 channels @ 1000MeV

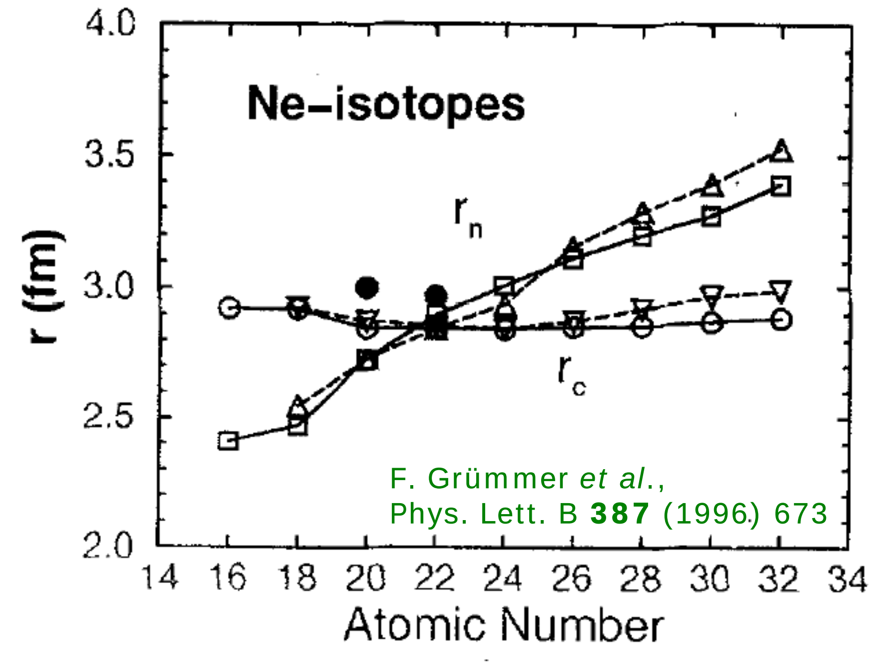
- $\bar{p}+p\to\bar{\Lambda}+\Lambda$ $\quad$ $\bar{p}+p\to\bar{\Sigma}^0+\Lambda$
- $\bar{p}+n\to\bar{\Lambda}+\Sigma^-$ $\quad$ $\bar{p}+n\to\bar{\Sigma}^++\Lambda$ ($\times$1/100)



Probing the neutron skin of nuclei

- $\bar{p}+p\rightarrow\bar{\Lambda}+\Lambda$ $\bar{p}+p\rightarrow\bar{\Sigma}^0+\Lambda$ $\bar{p}+n\rightarrow\bar{\Lambda}+\Sigma^-$ $\bar{p}+n\rightarrow\bar{\Sigma}^++\Lambda$
- Rare gas Isotopes are available
  - http://www.iconisotopes.com/Code/NobleGas.asp
  - other (also semi-magic) rare gases available like ^{38}Ar, ^{86}Kr

Neon				
Neon-20 (90.92%)	^{20}Ne	99.95	1 & 3	1000ml
Neon-21 (0.26%)	^{21}Ne	90	3	10ml
Neon-22 (8.82%)	^{22}Ne	99.9	1 & 3	1000ml

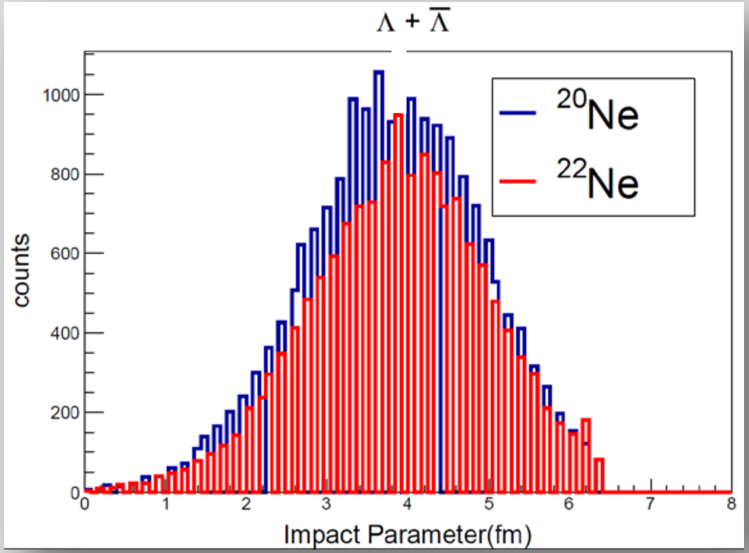


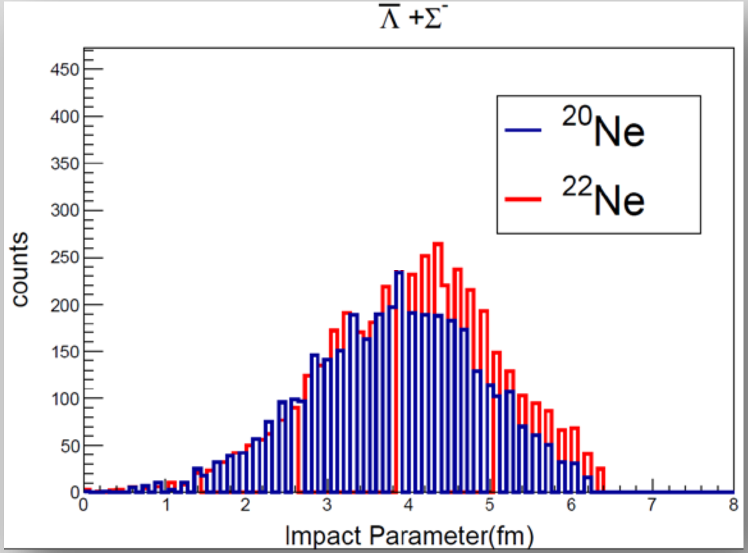
F. Grümmer *et al.*,
Phys. Lett. B **387** (1996) 673

Reactions within the neutron skin

- 1000MeV $p+^{20}Ne$ and $p+^{22}Ne$
- Scaling factor for potential $\xi(\bar{\Lambda}) = 0.25$

	$\bar{p}+p\to\bar{\Lambda}+\Lambda$	$\bar{p}+n\to\bar{\Lambda}+\Sigma^-$
^{20}Ne	18868	3667
^{22}Ne	15733	4516
$^{22}Ne/^{20}Ne$ =R	0.83	1.23
$R(\bar{\Lambda}+\Sigma^-)/R(\bar{\Lambda}+\Lambda)$	1.34	



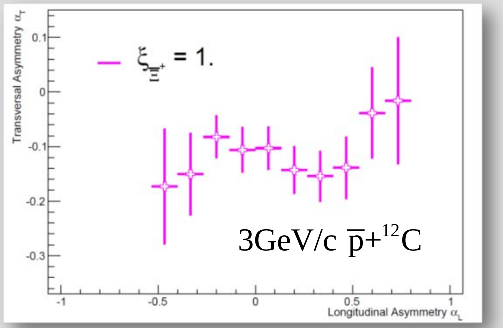


- the ratio $\bar{\Lambda}+\Sigma^-/\bar{\Lambda}+\Lambda$ may provide a measure of the neutron skin
- explore potentials in neutron-rich environment by neutron rich targets

Requirements

- ^{20}Ne, ^{22}Ne, H for calibration; later: ^{86}Kr, ...
- $\overline{\Lambda}+\Lambda$
  - ^{20}Ne target, H for calibration
  - only charged particle detection — *easy*
  - average interactions rate $10^5 s^{-1}$ — *1% of default luminosity*
  - 30 days of data taking
    $\Rightarrow 2.6\cdot10^{11}$ detected interactions
  - reconstruction efficiency 5% — *conservative*
    $\Rightarrow$0.5M detected $\overline{\Lambda}+\Lambda$ pairs — 40 $\times$ present GiBUU simulations
- $\overline{\Lambda}+\Sigma^-$
  - ^{20}Ne; ^{22}Ne, H for calibration; later: ^{86}Kr (36 Protons, 50 Neutrons)
  - Σ^- tracking, $\Sigma^-\rightarrow n\pi^-$
  - similar production rate (at least in light nuclei)

- Future options:
  - Neutron skin
  - Other pairs like Ξ-$\overline{\Xi}$
  - long lived resonances in nuclei



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

The antihyperon-hyperon production is an ideal experiment for the commissioning phase of PANDA

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THANK YOU