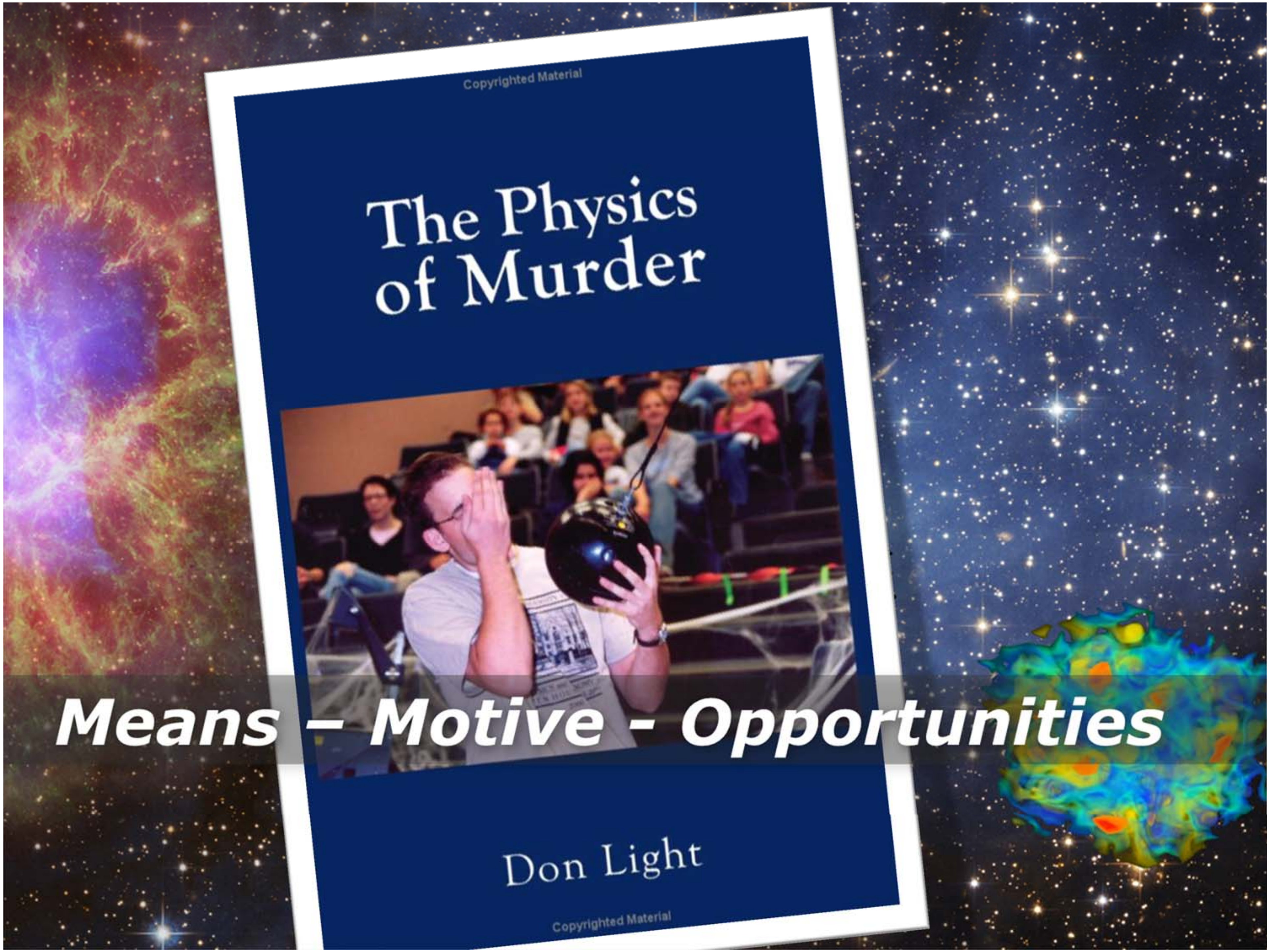
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The Physics of Murder
Don Light
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Means – Motive - Opportunities

Prospects for Hypernuclear Physics at Mainz:

from KAOS@MAMI to PANDA@FAIR

HYP 2012 BARCELONA

Josef Pochodzalla

The means

Collaborative Research Centre 1044

- *The Low-Energy Frontier of the Standard Model*

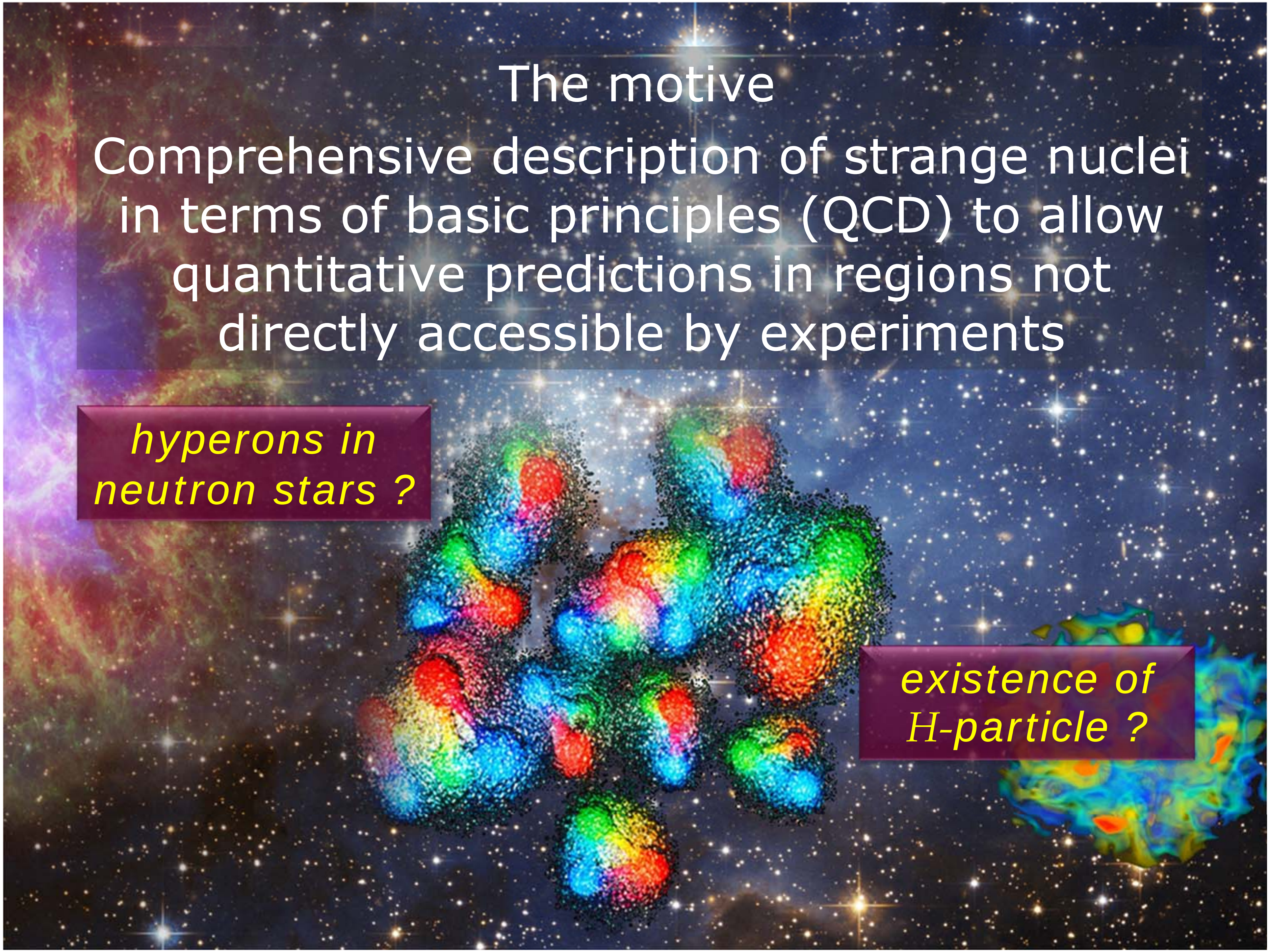
From Quarks and Gluons To Hadrons and Nuclei

- Funding for MAMI and BES activities
- Sub-Project N (assoc. PI O.Hashimoto, L. Tang)
- 4 (+4+4) years

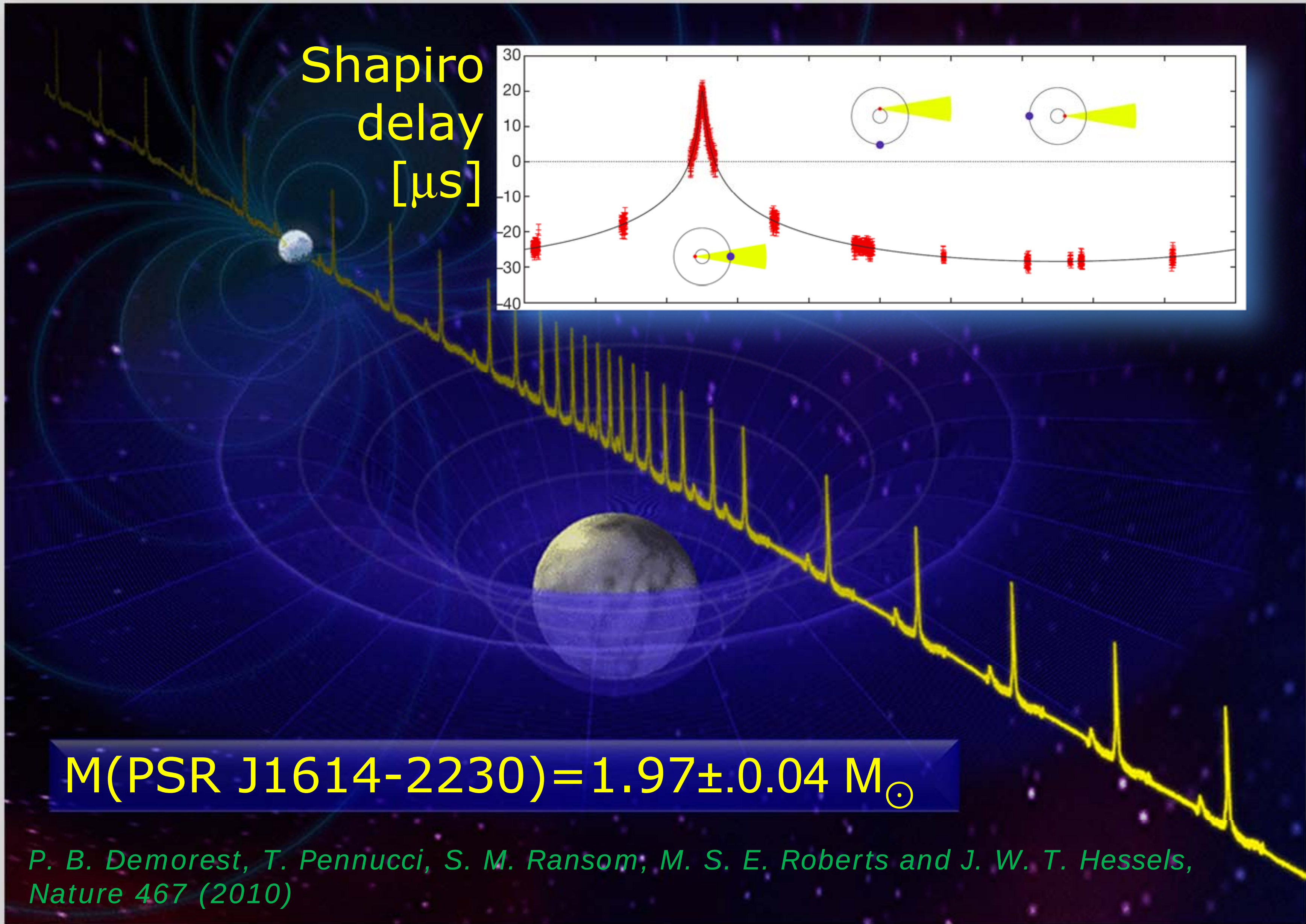
Helmholtz-Institute Mainz HIM

- *Structure, Symmetry und Stability of Matter and Antimatter*
- 6 Sections : SPECF Hadron spectroscopy and Flavor
- Funding for only FAIR activity
- Permanent

- Cluster of Excellence PRISMA
  - *Precision Physics, Fundamental Interactions and Structure of Matter*
  - 4 research fields, 3 structural measures
  - Research field C: Structure of Matter
  - 5 (+5) years


The motive
Comprehensive description of strange nuclei in terms of basic principles (QCD) to allow quantitative predictions in regions not directly accessible by experiments
hyperons in neutron stars ?
existence of H-particle ?

Masses of Neutron Stars

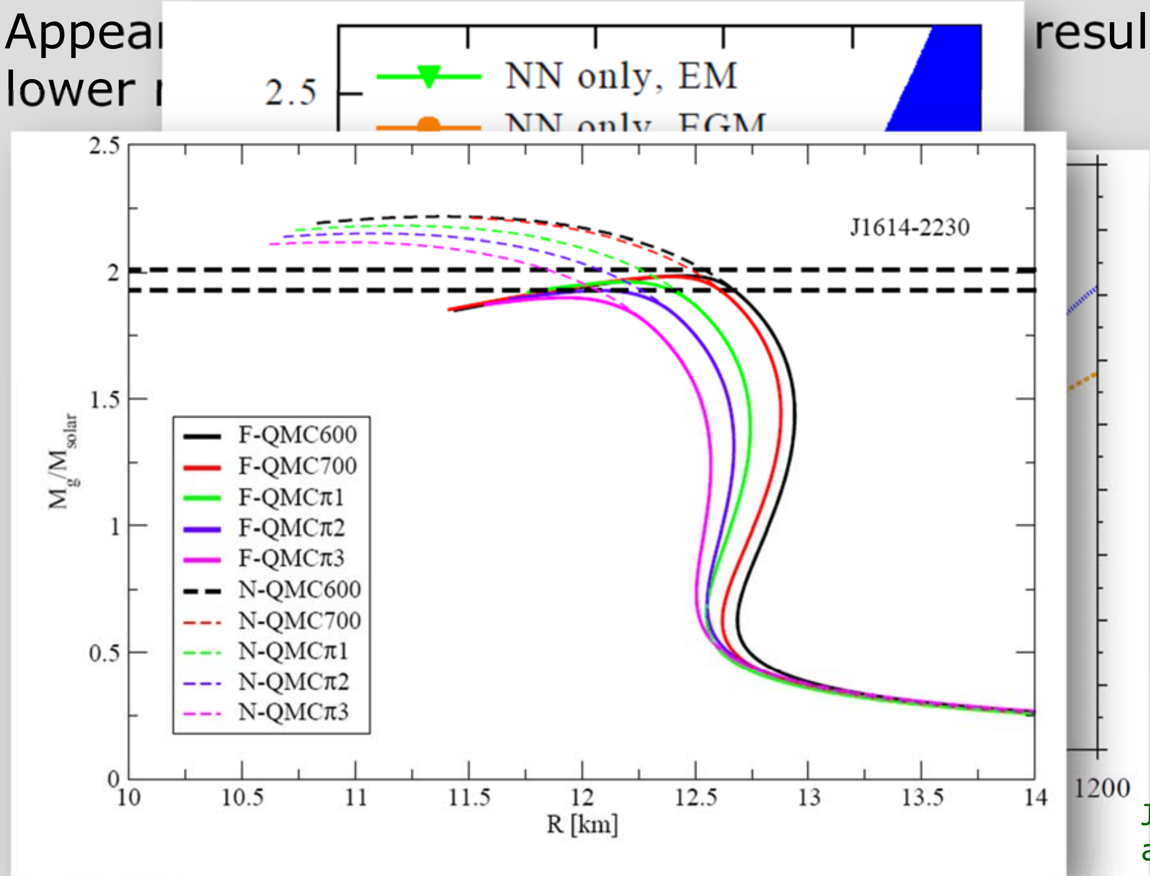


M(PSR J1614-2230)=1.97±.0.04 $M_\odot$

P. B. Demorest, T. Pennucci, S. M. Ransom, M. S. E. Roberts and J. W. T. Hessels, Nature 467 (2010)

The Hyperon Puzzle in Neutron Stars

- Three (and four) baryon forces are essential for understanding the EOS at high density
- Appear… result in lower …



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

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

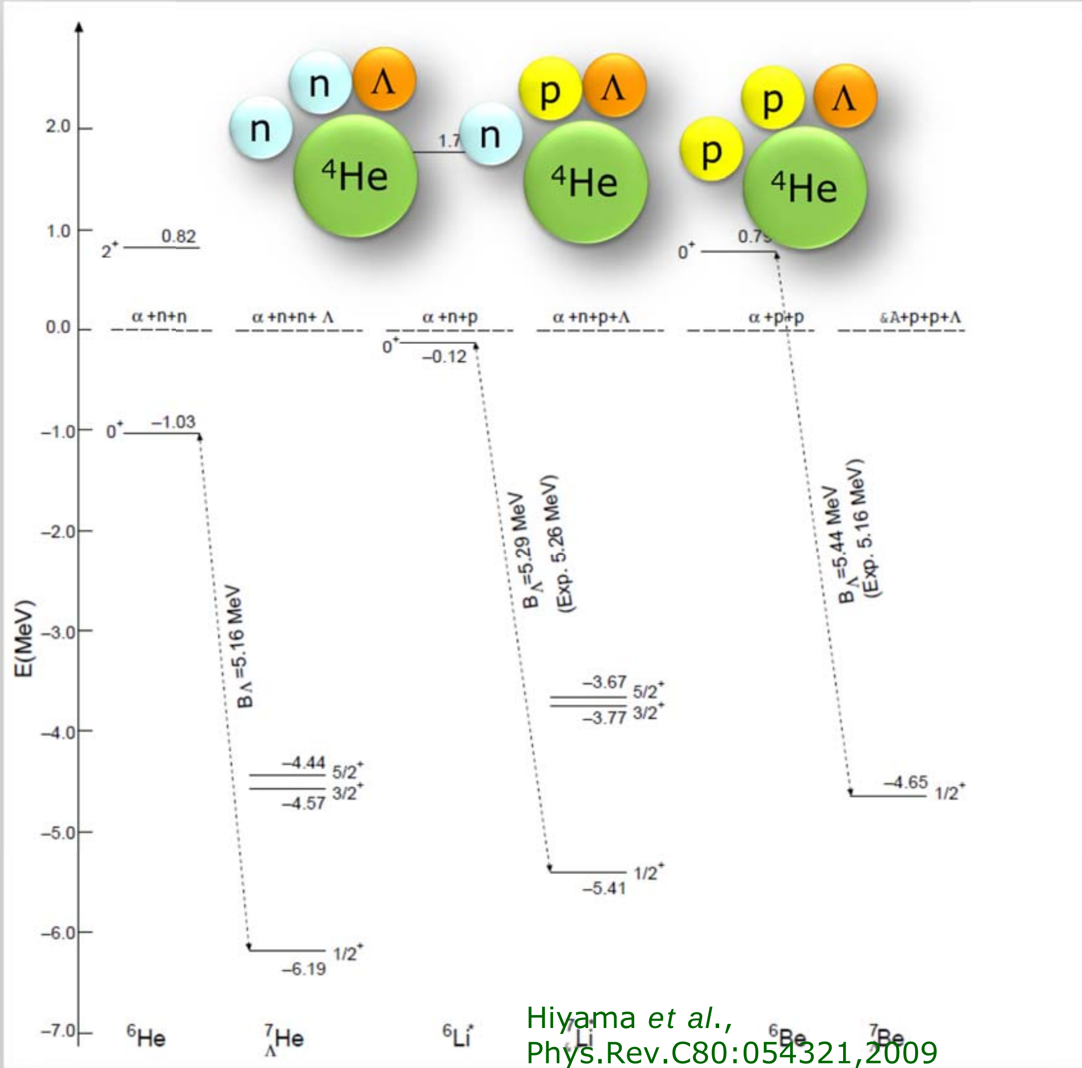
- A two solar mass neutron star is compatible with the presence of hyperons

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

CSB, 3BF …

- *A. Nogga, E. Hiyama "CSB is a puzzle"*
- CSB $|\Delta E| \sim 100\text{keV}$
- 3 baryon force: YNN ?

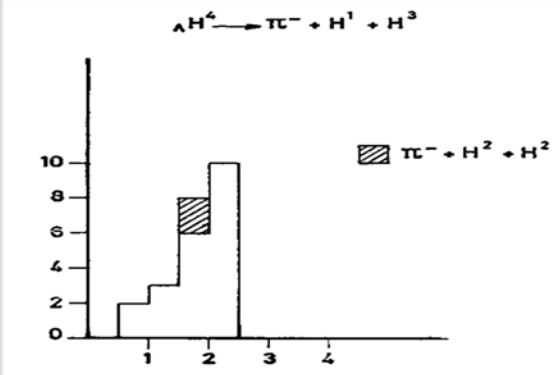
- Precise <100keV information on ground state masses can serve as an extremely valuable input

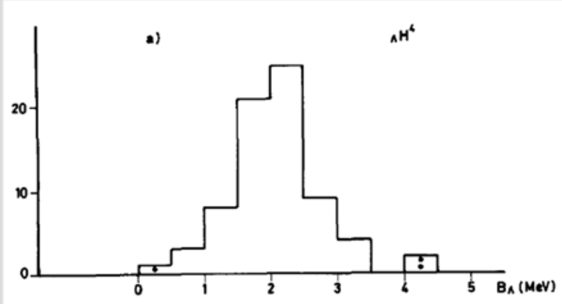


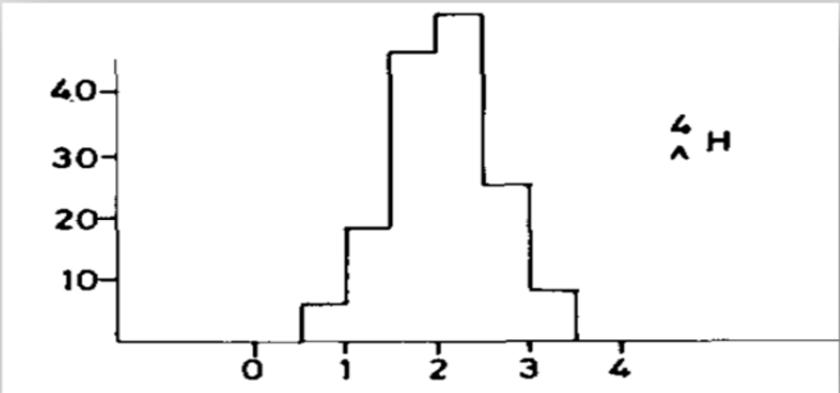
Hiyama *et al.*, Phys.Rev.C80:054321,2009

The $^{4}_{\Lambda}$H case

- W. Gajewski *et al*,
  - Nucl. Phys. B1, 105 (1967)
  - 208 (π^- 4He) B_Λ= 2.26±0.07
  - 21 (π^- pt)+2 (π^-dd) B_Λ= 1.86±0.10
- G. Bohm *et al*.,
  - Nucl. Phys. B4, 511 (1968)
  - 552 (π^- 4He) B_Λ= 2.29±0.04
  - 63 (π^- pt)+7 (π^-dd) B_Λ= 2.08±0.06
- M. Juric *et al*., Nucl. Phys. B52, 1 (1973)
  - 56 (π^- pt) B_Λ= 2.14±0.07
  - 11 (π^-ppd) B_Λ= 1.92±0.12







The A=7 Hypernuclei

Table 4
$^{7}_{\Lambda}He$ candidates

Event number	$^{7}_{\Lambda}He \rightarrow \pi^- + {}^3H + {}^4He$ $B_\Lambda \pm \Delta B_\Lambda$ (MeV)	χ^2_3
38.234	5.47 ± 0.58	0.6
199.036	3.92 ± 0.63	1.0
199.090	2.81 ± 0.63	0.1
210.063	4.78 ± 0.57	2.5
258.101	4.33 ± 0.65	1.8
271.014	5.06 ± 0.62	1.5
298.301	5.05 ± 0.59	0.8
298.805	2.38 ± 0.71	0.8
304.810	5.16 ± 0.54	2.6
294.107 a)	5.48 ± 0.67	6.5
329.107 a)	5.03 ± 0.69	5.1

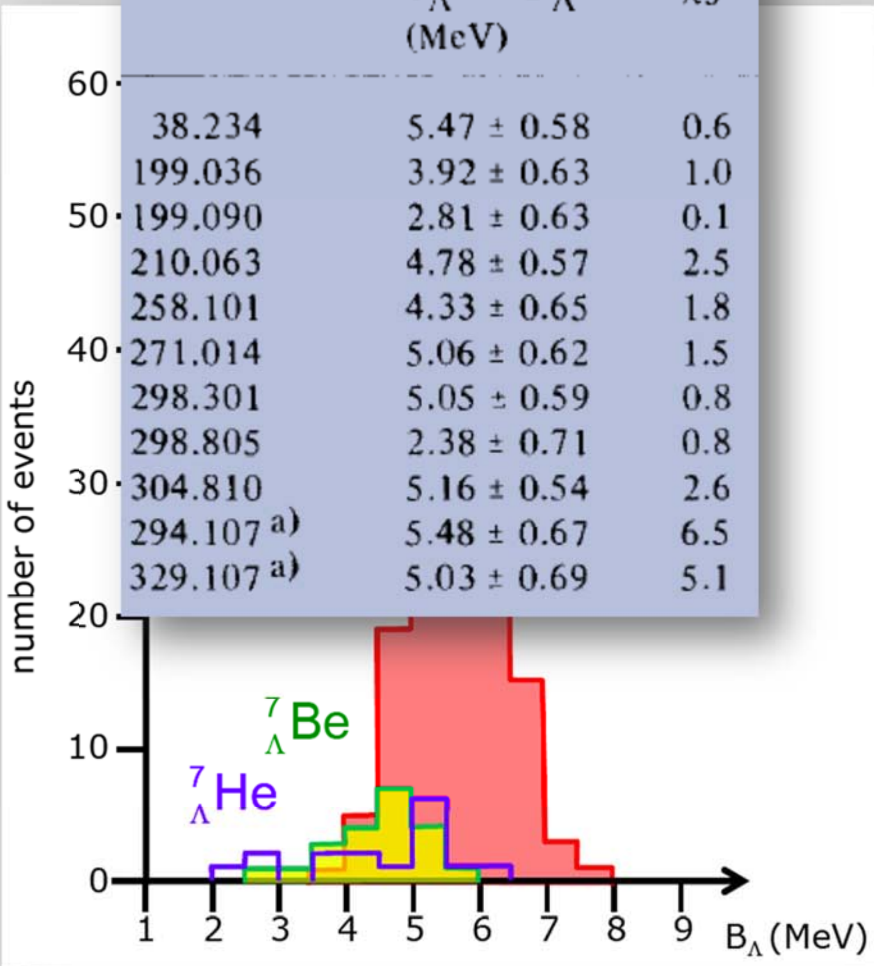
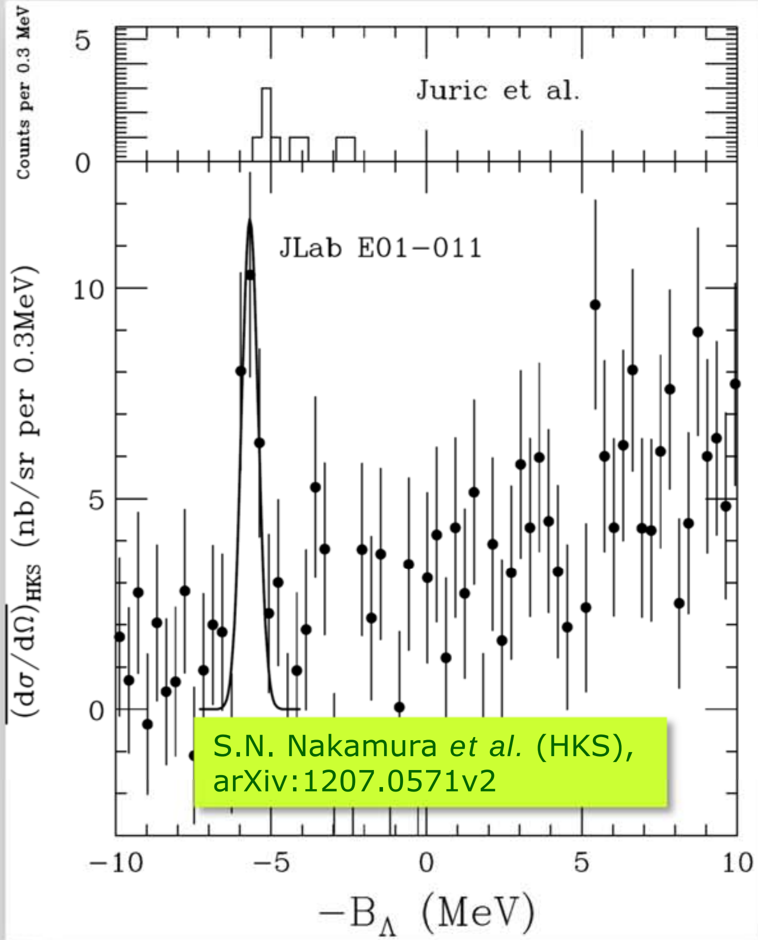


TABLE II. Binding energies of $A = 7, T = 1$ iso-triplets Λ hypernuclei. Errors of E01-011 are statistical and systematic errors.

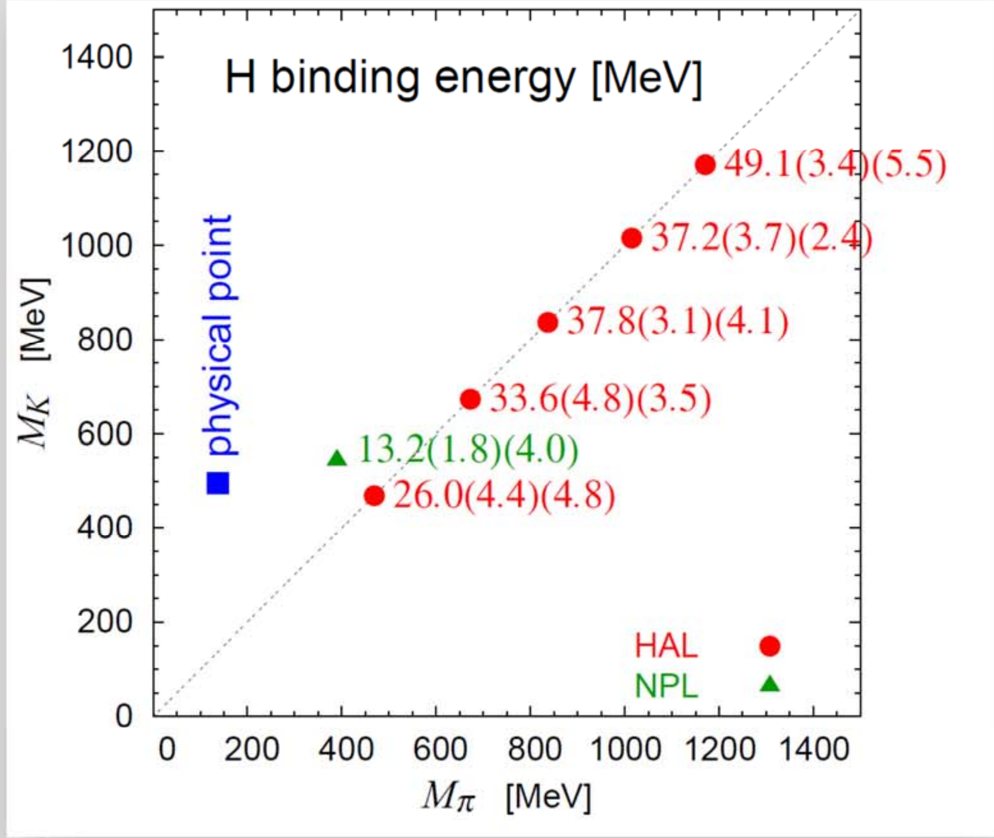
	$^{7}_{\Lambda}$He (E01-011)	$^{7}_{\Lambda}$Li* [2, 13]	$^{7}_{\Lambda}$Be [2]
B_Λ (MeV)	5.68 ± 0.03 ± 0.25	5.26 ± 0.03	5.16 ± 0.08



S.N. Nakamura *et al.* (HKS), arXiv:1207.0571v2

LQCD puts the *H*-Particle on the agenda

R.L. Jaffe (1977)



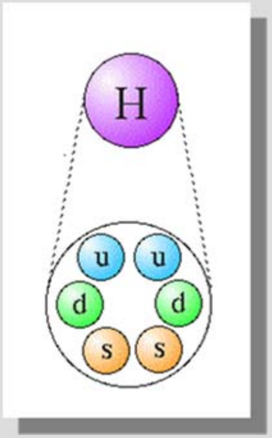
Takashi Inoueet al., Nucl. Phys A 881, 28 (2012)

- Recent lattice QCD calculations predict possibly a bound or a slightly unbound H-dibaryon
- Being so close to the threshold will undoubtedly spur investigations into the consequences for doubly strange hypernuclei as well as the equation of state of dense matter.

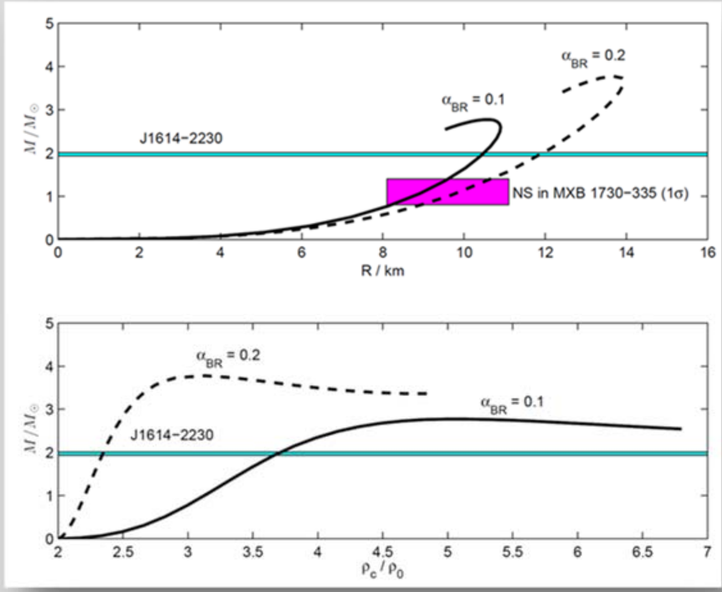
Where can the H be seen?

- Neutron stars → H cluster stars

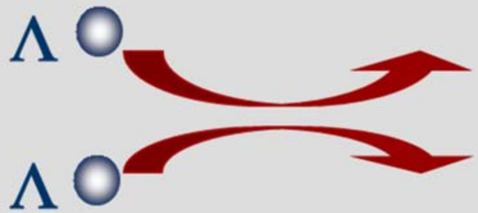
  X. Y. Lai, C. Y. Gao and R. X. Xu, arXiv:1107.0834v3



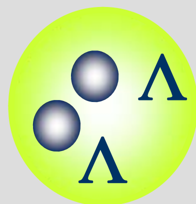
$$m_M^* \simeq m_M \left(1 - \alpha_{BR} \frac{\rho}{\rho_0}\right)$$



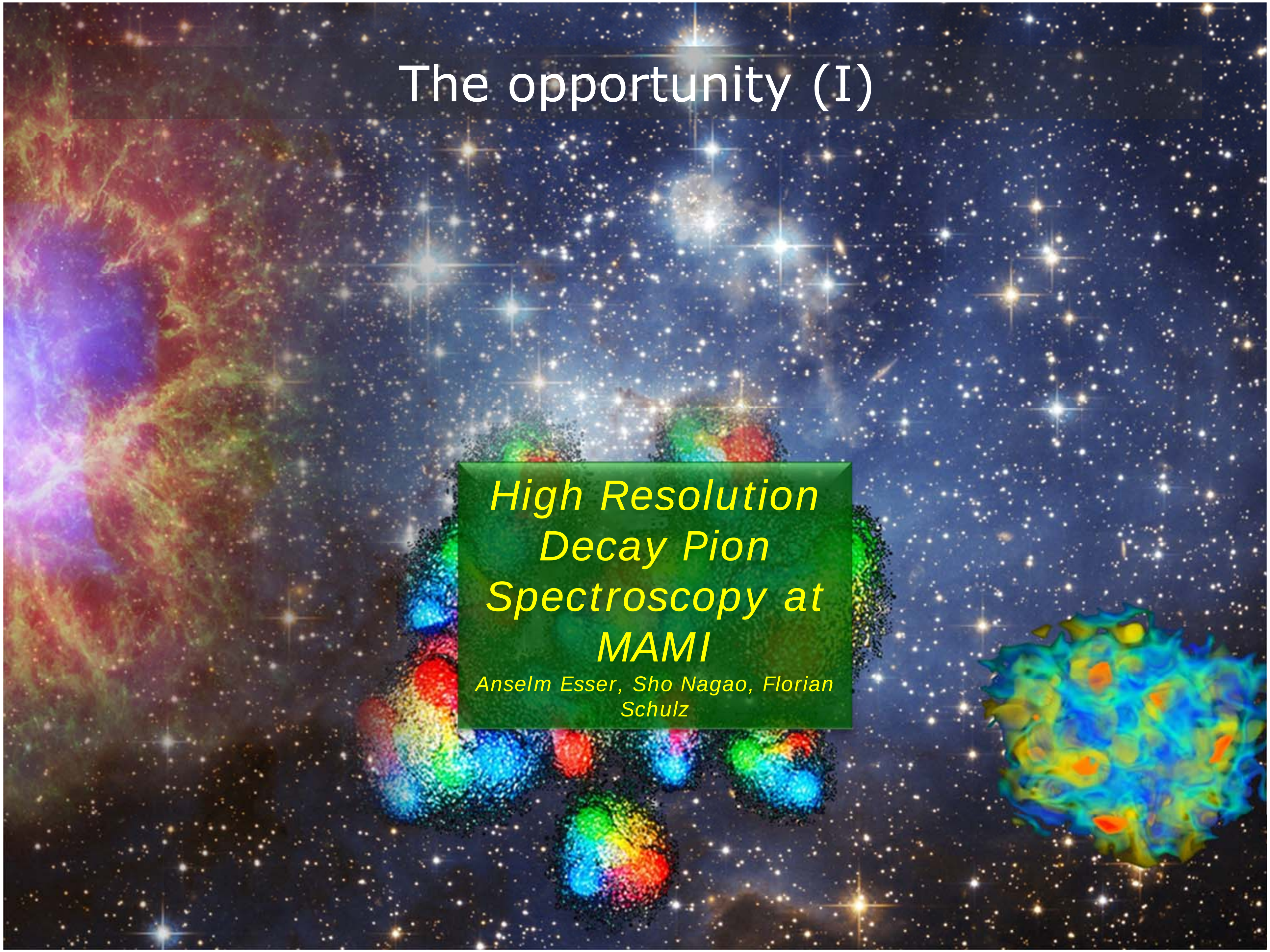
- free coalescence/FSI in energetic HI collisions
  - Time scale t ~ 10^{-23}s
  - JPARC, HI reactions at RHIC, ALICE, FAIR



- Double hypernuclei as doorway state/mixing
  - Time scale ~ 10^{-10}s
  - JPARC, FAIR
  - note: in this situation we are dealing with an H at non-zero density!



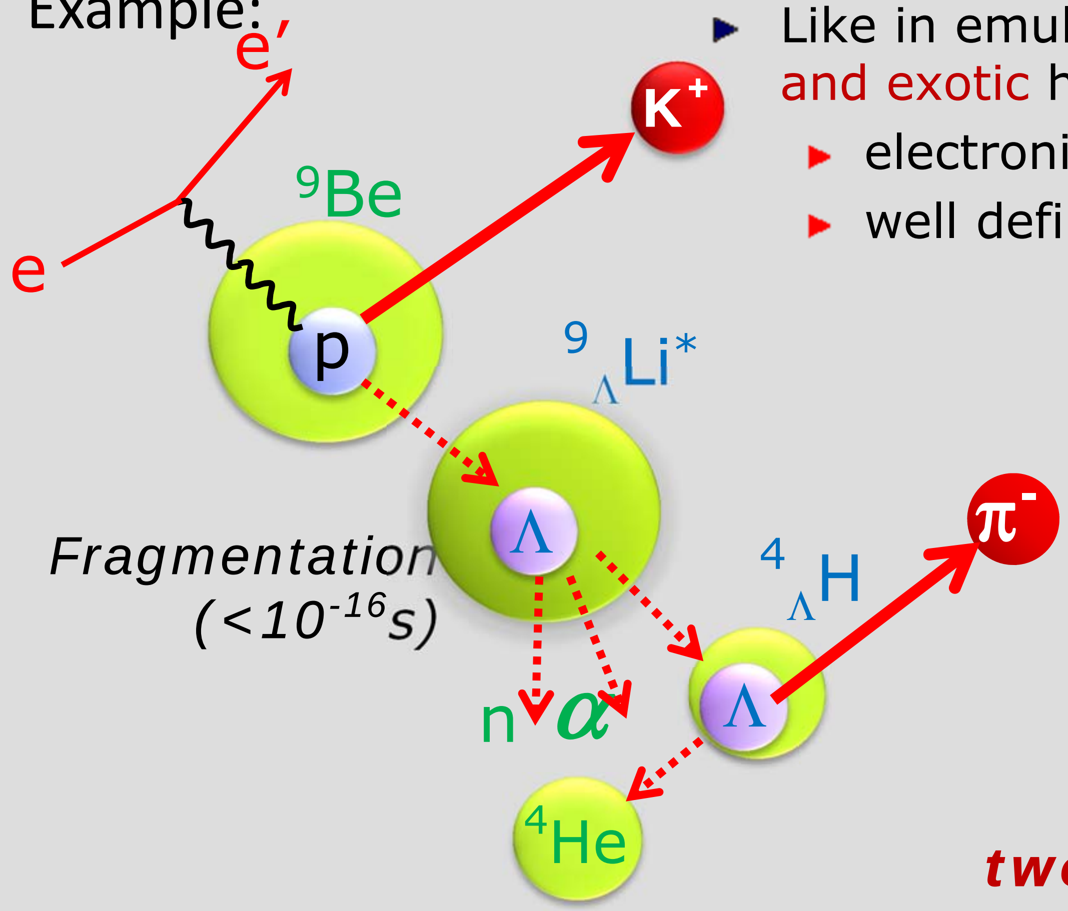
The opportunity (I)



Decay pion spectroscopy

- Two-body decay ⇒ mono-energetic pions
- high resolution: Λ binding energy resolution limited by π^- momentum resolution
- Like in emulsion access to variety of light and exotic hypernuclei, but
  - electronic experiment
  - well defined initial target nucleus

Example:



Weak mesonic
***two-body** decay ($\sim10^{-10}$s)*
at rest

The prospects

PROTON NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
12		^{12}C	Target				$^{20}_{\Lambda}$Mg	$^{21}_{\Lambda}$Mg	$^{22}_{\Lambda}$Mg	$^{23}_{\Lambda}$Mg	$^{24}_{\Lambda}$Mg	$^{25}_{\Lambda}$Mg	$^{26}_{\Lambda}$Mg	$^{27}_{\Lambda}$Mg	$^{28}_{\Lambda}$Mg	$^{29}_{\Lambda}$Mg	$^{30}_{\Lambda}$Mg	$^{31}_{\Lambda}$Mg	$^{32}_{\Lambda}$Mg	$^{33}_{\Lambda}$Mg
11		^{9}Be						$^{20}_{\Lambda}$Na	$^{21}_{\Lambda}$Na	$^{22}_{\Lambda}$Na	$^{23}_{\Lambda}$Na	$^{24}_{\Lambda}$Na	$^{25}_{\Lambda}$Na	$^{26}_{\Lambda}$Na	$^{27}_{\Lambda}$Na	$^{28}_{\Lambda}$Na	$^{29}_{\Lambda}$Na	$^{30}_{\Lambda}$Na	$^{31}_{\Lambda}$Na	$^{32}_{\Lambda}$Na
10		^{7}Li				$^{17}_{\Lambda}$Ne	$^{18}_{\Lambda}$Ne	$^{19}_{\Lambda}$Ne	$^{20}_{\Lambda}$Ne	$^{21}_{\Lambda}$Ne	$^{22}_{\Lambda}$Ne	$^{23}_{\Lambda}$Ne	$^{24}_{\Lambda}$Ne	$^{25}_{\Lambda}$Ne	$^{26}_{\Lambda}$Ne	$^{27}_{\Lambda}$Ne	$^{28}_{\Lambda}$Ne	$^{29}_{\Lambda}$Ne	$^{30}_{\Lambda}$Ne	$^{31}_{\Lambda}$Ne
9						$^{16}_{\Lambda}$F	$^{17}_{\Lambda}$F	$^{18}_{\Lambda}$F	$^{19}_{\Lambda}$F	$^{20}_{\Lambda}$F	$^{21}_{\Lambda}$F	$^{22}_{\Lambda}$F	$^{23}_{\Lambda}$F	$^{24}_{\Lambda}$F	$^{25}_{\Lambda}$F	$^{26}_{\Lambda}$F	$^{27}_{\Lambda}$F	$^{28}_{\Lambda}$F	$^{29}_{\Lambda}$F	$^{30}_{\Lambda}$F
8				$^{13}_{\Lambda}$O	$^{14}_{\Lambda}$O	$^{15}_{\Lambda}$O	$^{16}_{\Lambda}$O	$^{17}_{\Lambda}$O	$^{18}_{\Lambda}$O	$^{19}_{\Lambda}$O	$^{20}_{\Lambda}$O	$^{21}_{\Lambda}$O	$^{22}_{\Lambda}$O	$^{23}_{\Lambda}$O	$^{24}_{\Lambda}$O	$^{25}_{\Lambda}$O	$^{26}_{\Lambda}$O	$^{27}_{\Lambda}$O		
7				$^{12}_{\Lambda}$N	$^{13}_{\Lambda}$N	$^{14}_{\Lambda}$N	$^{15}_{\Lambda}$N	$^{16}_{\Lambda}$N	$^{17}_{\Lambda}$N	$^{18}_{\Lambda}$N	$^{19}_{\Lambda}$N	$^{20}_{\Lambda}$N	$^{21}_{\Lambda}$N	$^{22}_{\Lambda}$N	$^{23}_{\Lambda}$N	$^{24}_{\Lambda}$N				
6			$^{10}_{\Lambda}$C	$^{11}_{\Lambda}$C	$^{12}_{\Lambda}$C	$^{13}_{\Lambda}$C	$^{14}_{\Lambda}$C	$^{15}_{\Lambda}$C	$^{16}_{\Lambda}$C	$^{17}_{\Lambda}$C	$^{18}_{\Lambda}$C	$^{19}_{\Lambda}$C	$^{20}_{\Lambda}$C	$^{21}_{\Lambda}$C						
5			$^{9}_{\Lambda}$B	$^{10}_{\Lambda}$B	$^{11}_{\Lambda}$B	$^{12}_{\Lambda}$B	$^{13}_{\Lambda}$B	$^{14}_{\Lambda}$B	$^{15}_{\Lambda}$B	$^{16}_{\Lambda}$B	$^{17}_{\Lambda}$B	$^{18}_{\Lambda}$B								
4		$^{7}_{\Lambda}$Be	$^{8}_{\Lambda}$Be	$^{9}_{\Lambda}$Be	$^{10}_{\Lambda}$Be	$^{11}_{\Lambda}$Be	$^{12}_{\Lambda}$Be	$^{13}_{\Lambda}$Be	$^{14}_{\Lambda}$Be	$^{15}_{\Lambda}$Be										
3		$^{6}_{\Lambda}$Li	$^{7}_{\Lambda}$Li	$^{8}_{\Lambda}$Li	$^{9}_{\Lambda}$Li	$^{10}_{\Lambda}$Li	$^{11}_{\Lambda}$Li	$^{12}_{\Lambda}$Li												
2	$^{4}_{\Lambda}$He	$^{5}_{\Lambda}$He	$^{6}_{\Lambda}$He	$^{7}_{\Lambda}$He	$^{8}_{\Lambda}$He	$^{9}_{\Lambda}$He														
1	$^{3}_{\Lambda}$H	$^{4}_{\Lambda}$H	$^{5}_{\Lambda}$H	$^{6}_{\Lambda}$H	$^{7}_{\Lambda}$H	$^{8}_{\Lambda}$H														
0	ΛN																			

NEUTRON NUMBER

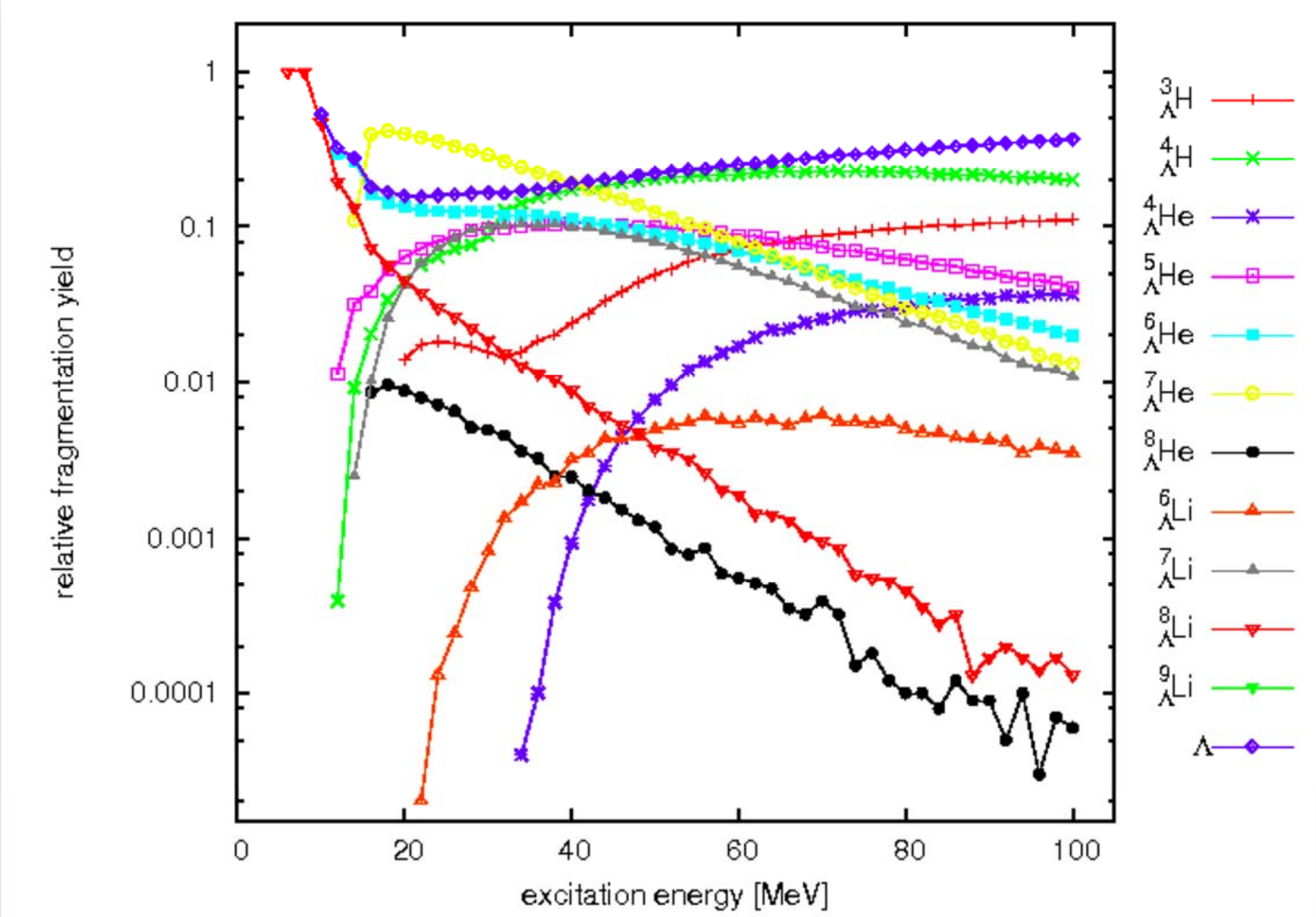
$n \rightarrow \Lambda$: (K^-,π^-), (K^-_{stop},π^-), (π^+,K^+)

$p \rightarrow \Lambda$: $(e,e'K^+)$, (K^-_{stop},π^0)

$pp \rightarrow n\Lambda$: (π^-,K^+)

Fermi breakup of excited hypernuclei

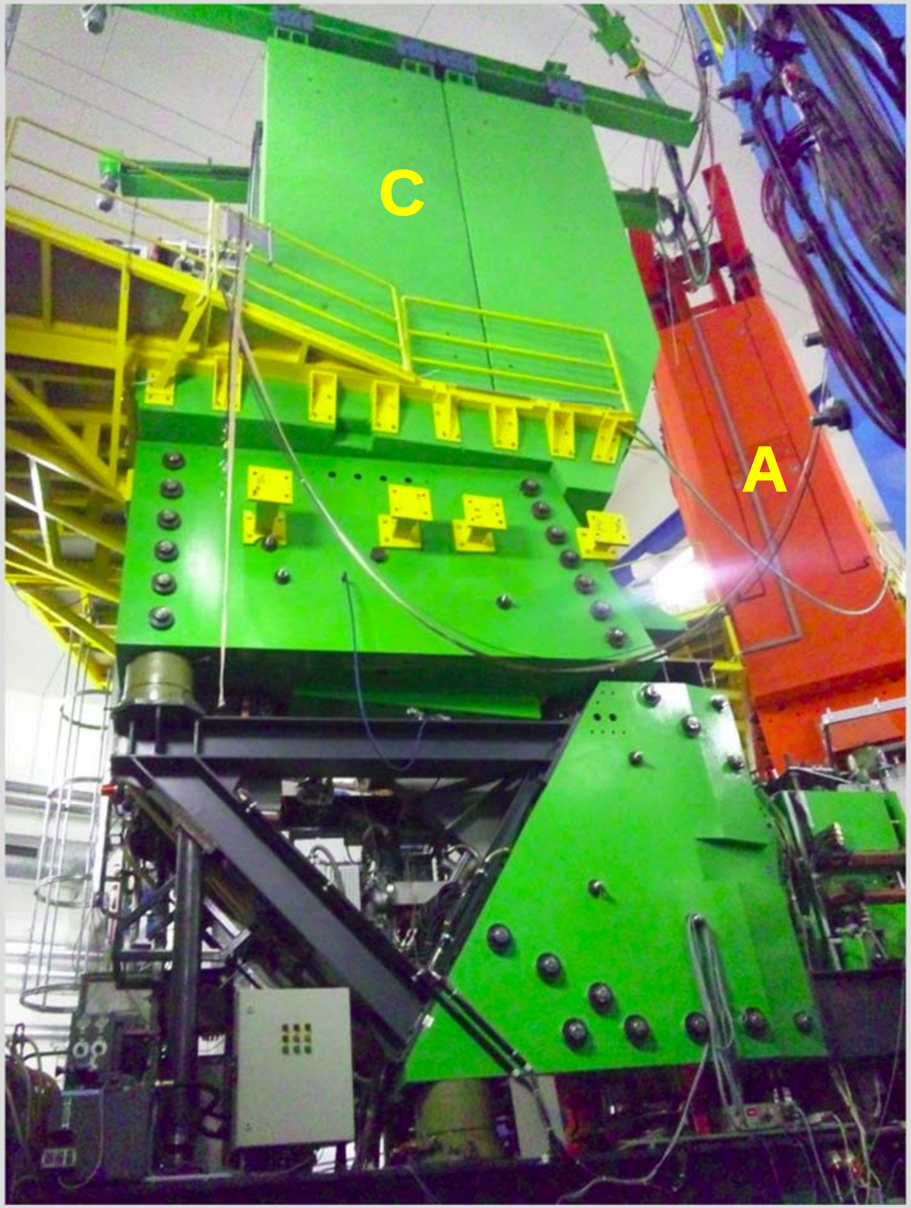
- Decay of $^{9}_{\Lambda}Li^*$ (A. Botvina, A. Sanchez, J. P., Physics Letters B 697 (2011) 222)



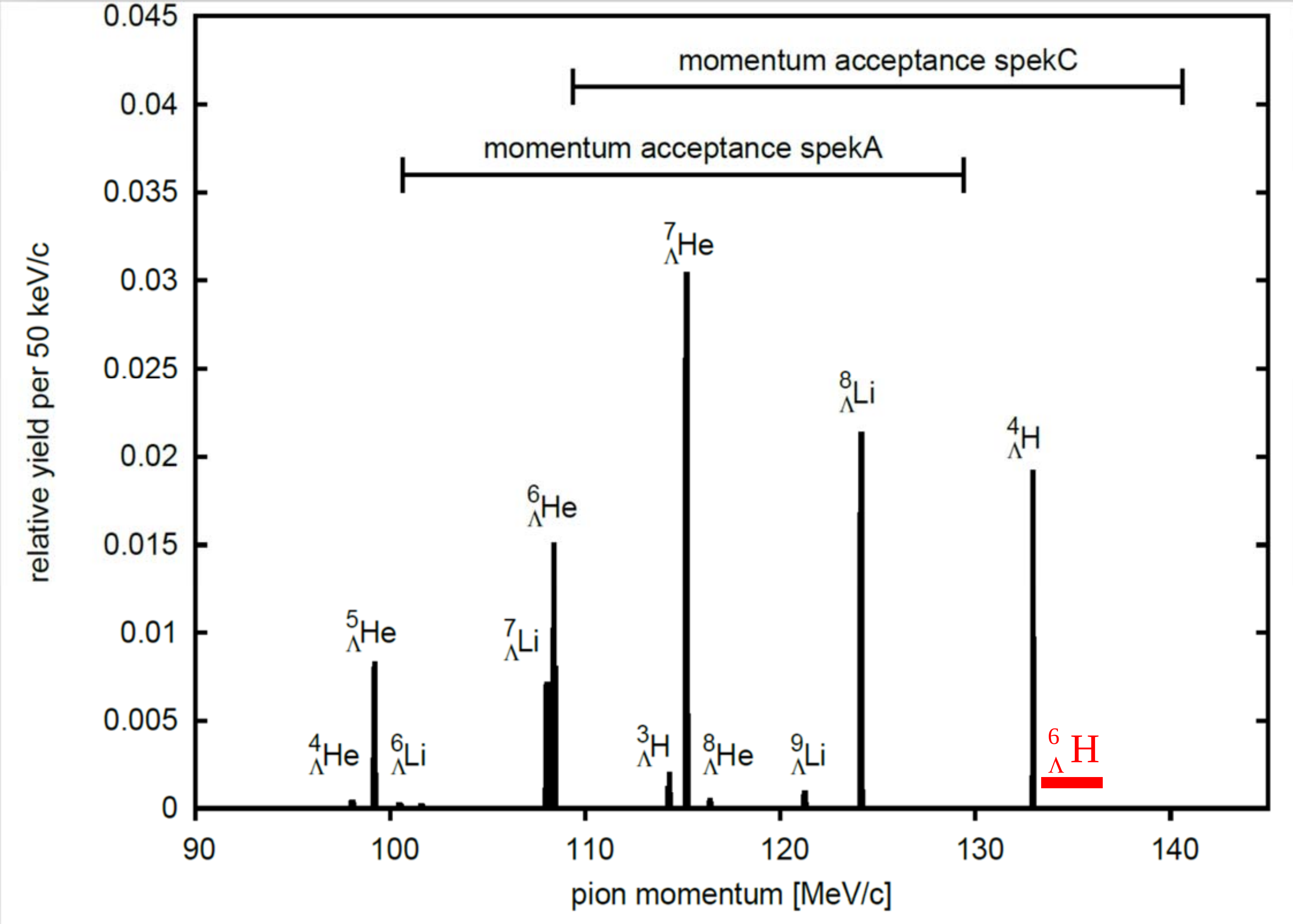
- See also poster of Majling

Pion detection

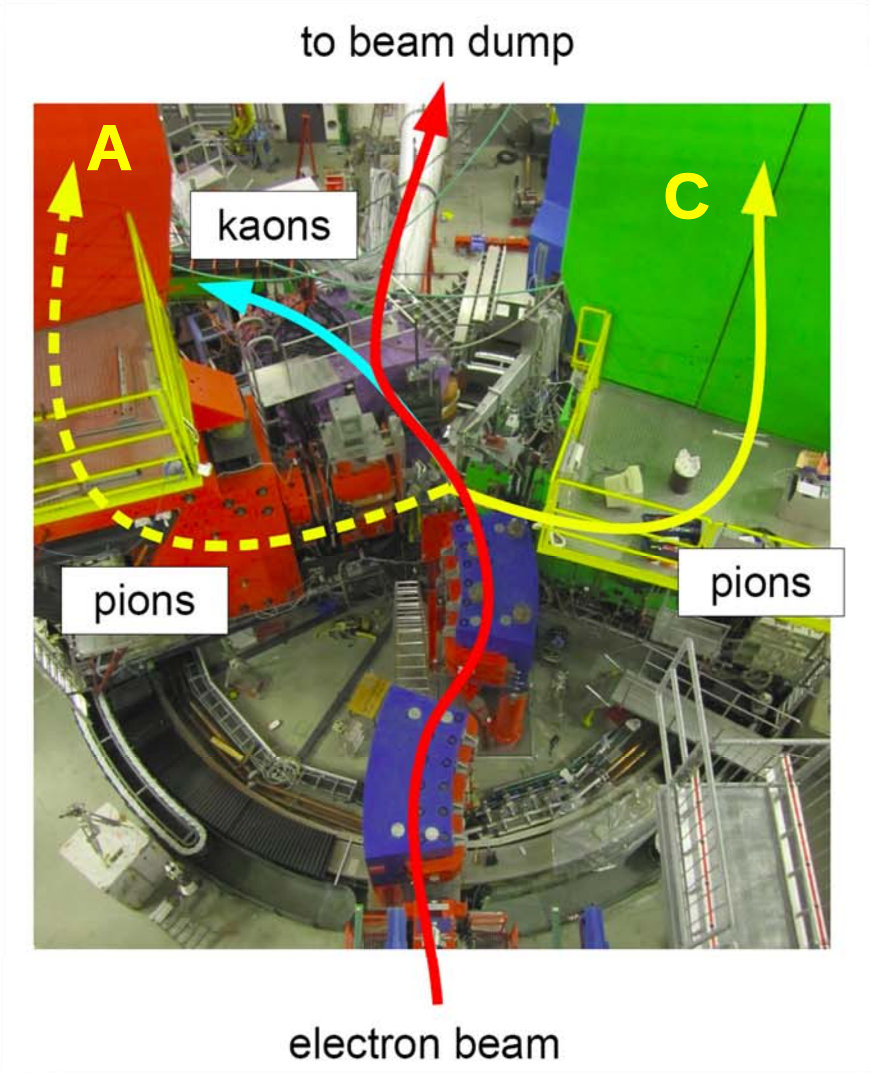
- Spectrometer A (red)
- Spectrometer C (green)
- Momentum resolution $\Delta p/p = 10^{-4} \Rightarrow \Delta m < 30$keV/c
- Solid angle: 28 msr
- Momentum acceptance
  - Spek A: 20%
  - Spek C: 25%
- Length of trajectories
  - Spek A:10.75m
  - Spek C: 8.53m
- Gas threshold Cherenkov detectors for pion/electron separation

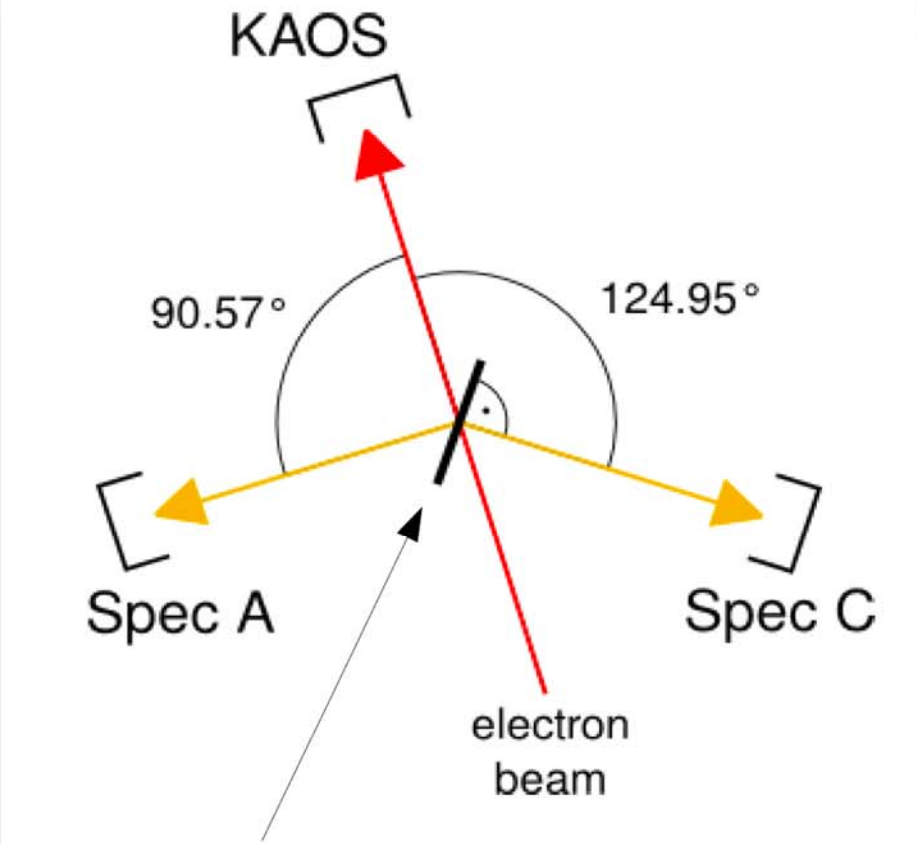


What can be expected



Setup of the Pilot run 2011

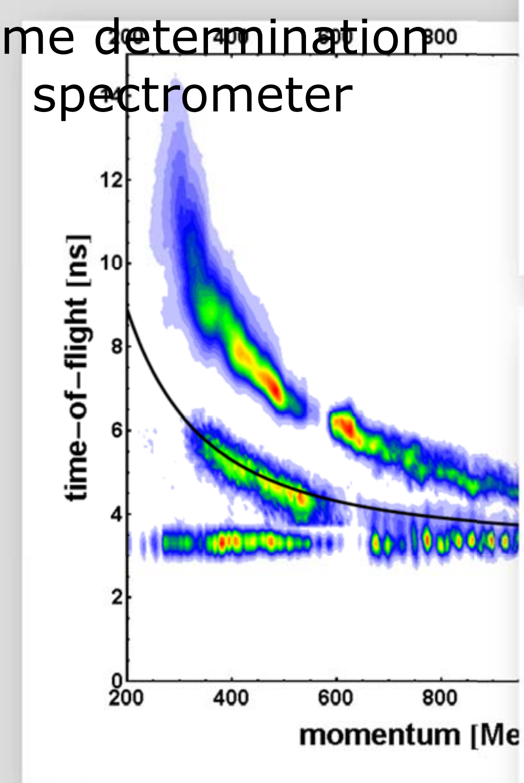


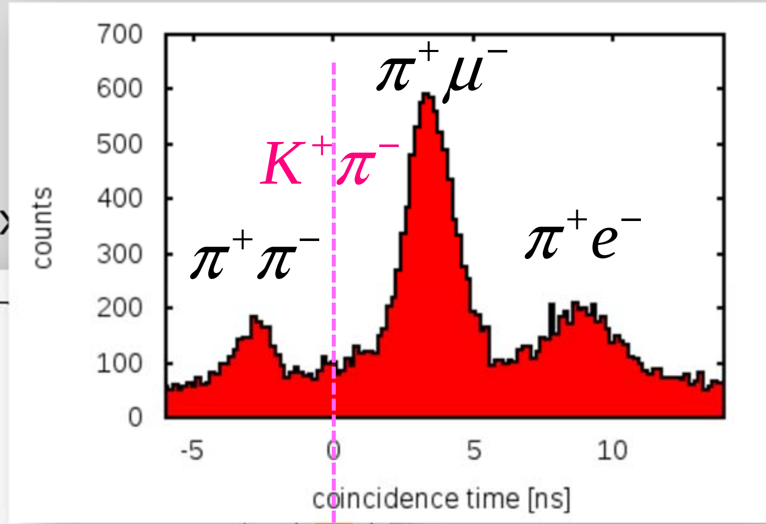


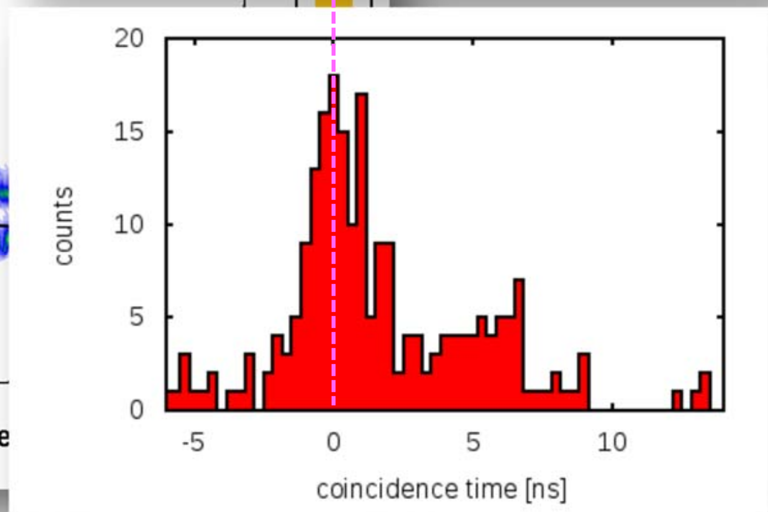
Target rotated 54° wrt beam:
→ Reduced energy loss variation for pions

Data analysis

- Main challenge: Huge positron background at 0° in KAOS produced by bremsstrahlung conversion: $10^6/\mu A$
- Determination of best parameters for kaon selection:
  - Single KAOS arm time-of-flight
  - Specific energy loss
  - Threshold Cherenkov light yield
  - Optimisation of K^+ selection in an ex
- Coincidence time determination from different spectrometer

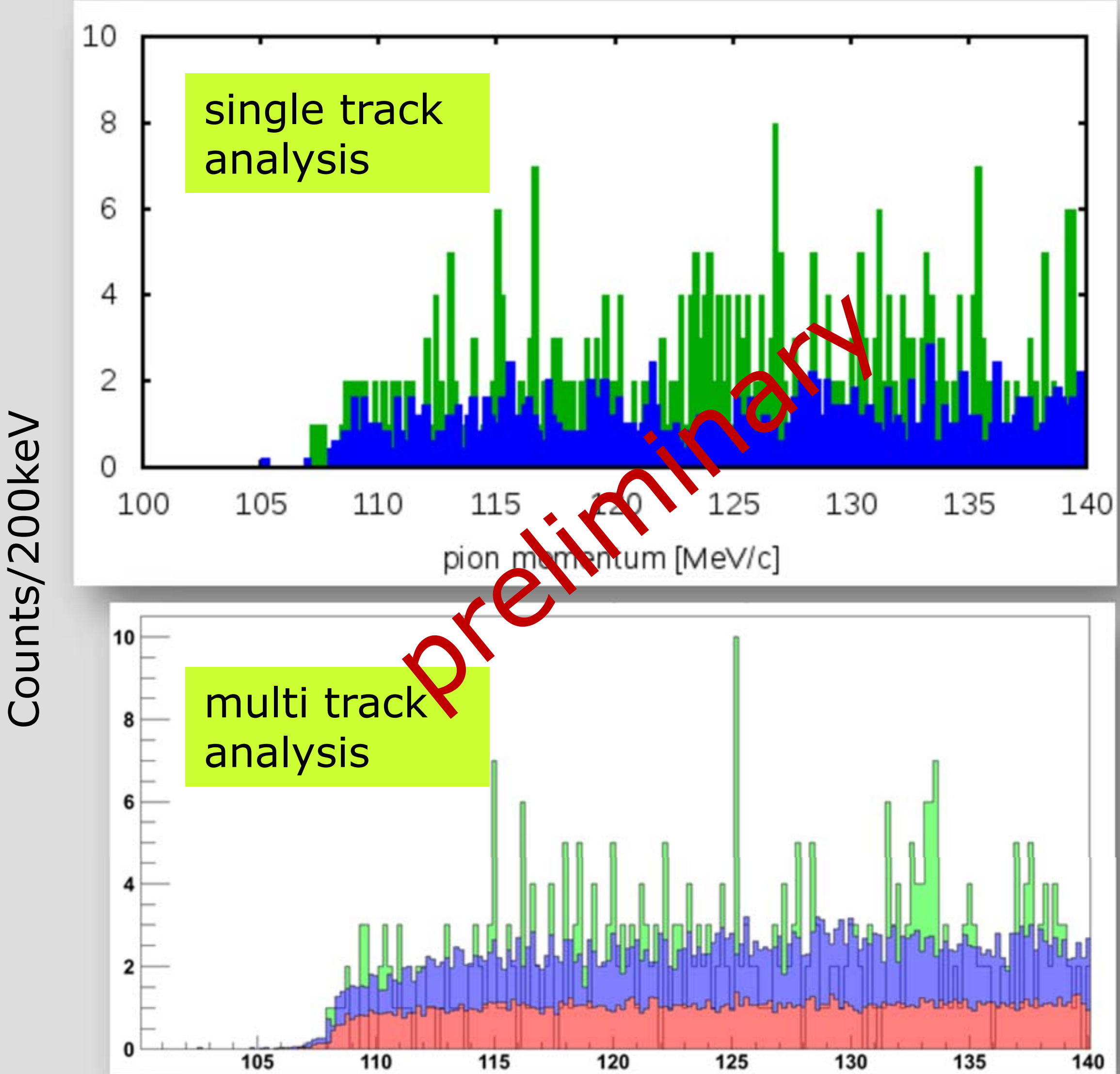






Anselm Esser (PhD Mainz)
Sho Nagao (PhD Sendai)
Florian Schulz (PhD Carl Zeiss fellow)

Decay pion spectroscopy

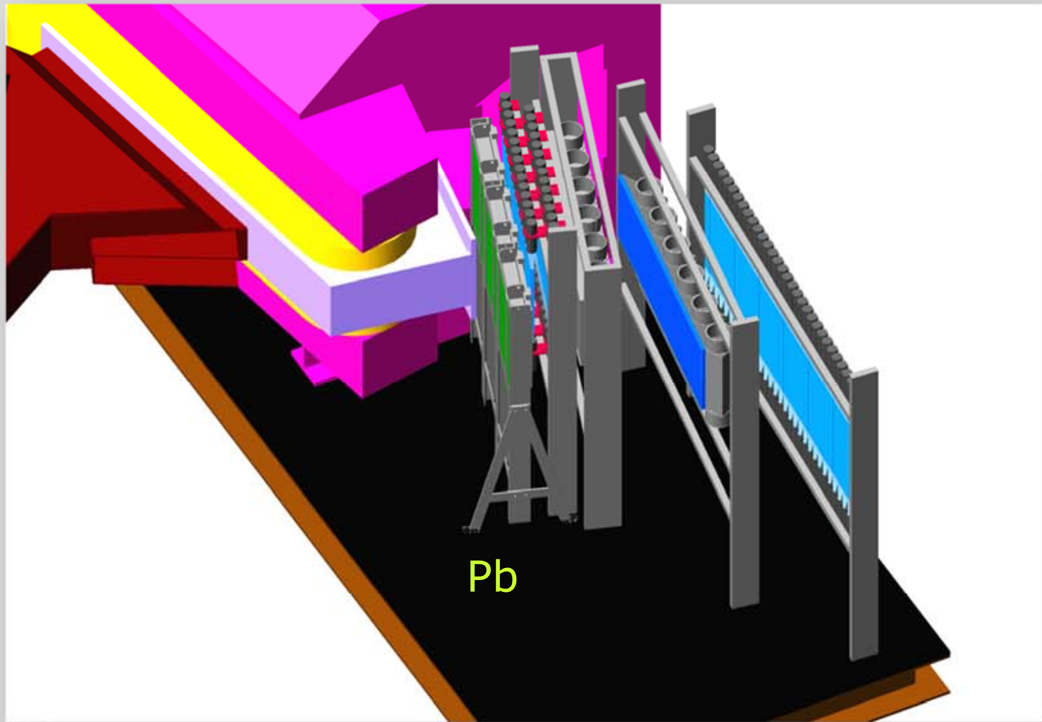


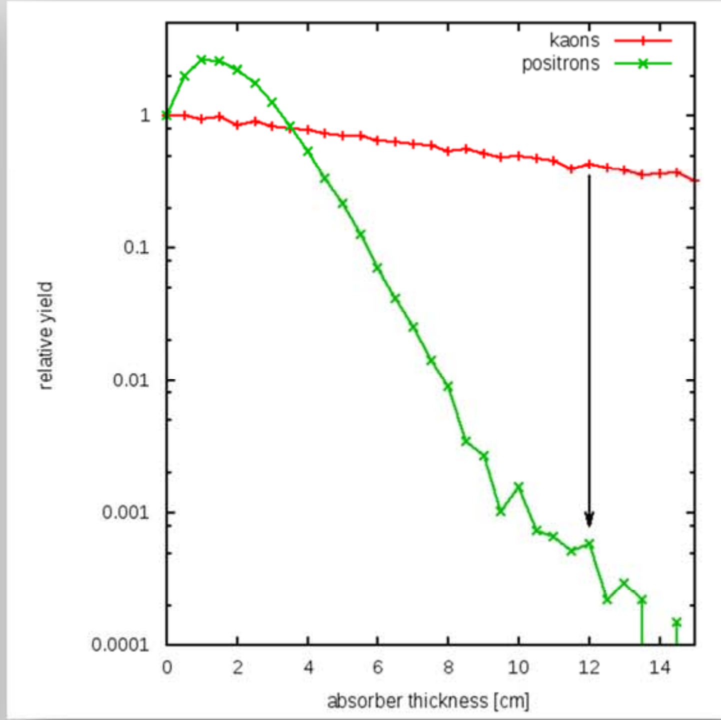
PhD projects Anselm Esser, Sho Nagao, Florian Schulz

- Promising but not yet conclusive!
- Need better statistics!!

Dedicated KAOS setup

- Lead ρ=11.35 g/cm^2
  - Nuclear interaction length 199.6 g/cm^2
  - Radiation length X0=6.37g/cm^2

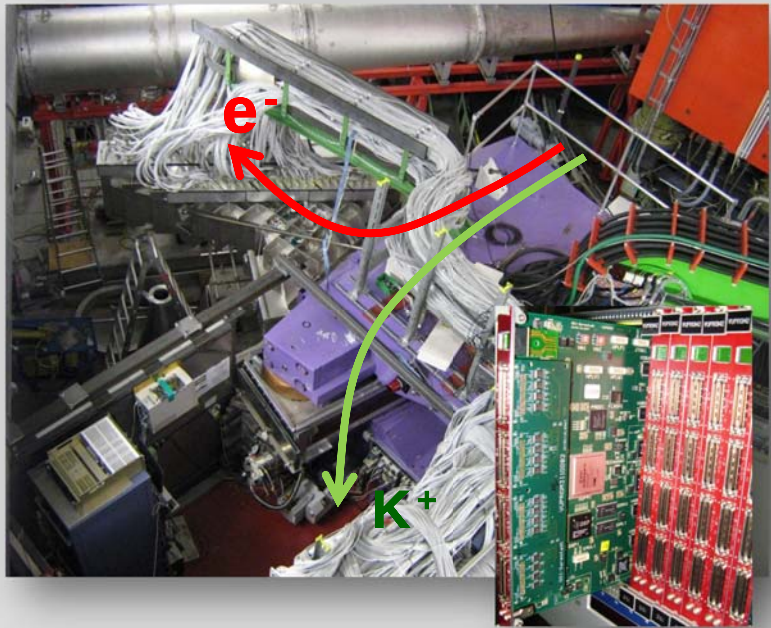


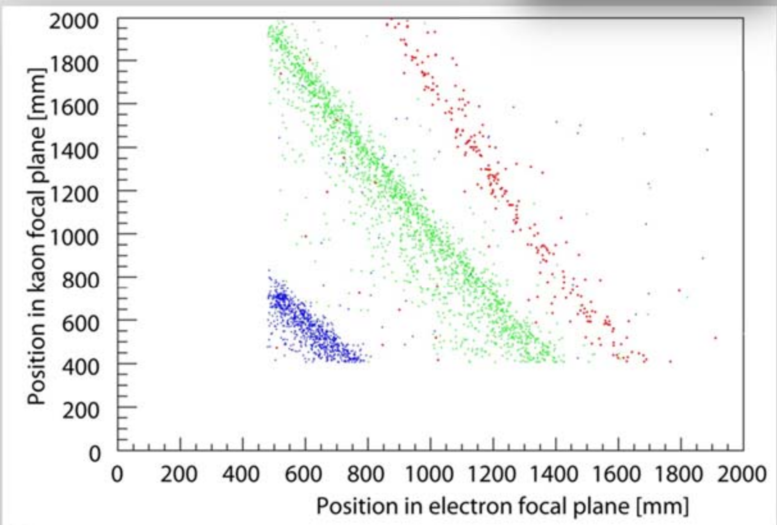


- Reduction of background at increased luminosity
- Optimized by GEANT simulations: I_e= 22μA d_{Pb}=10cm→14cm
- Improvements: 3 TOF walls, increased TOF path, 2 Č-detectors
- Experiment will start October 23rd 2012

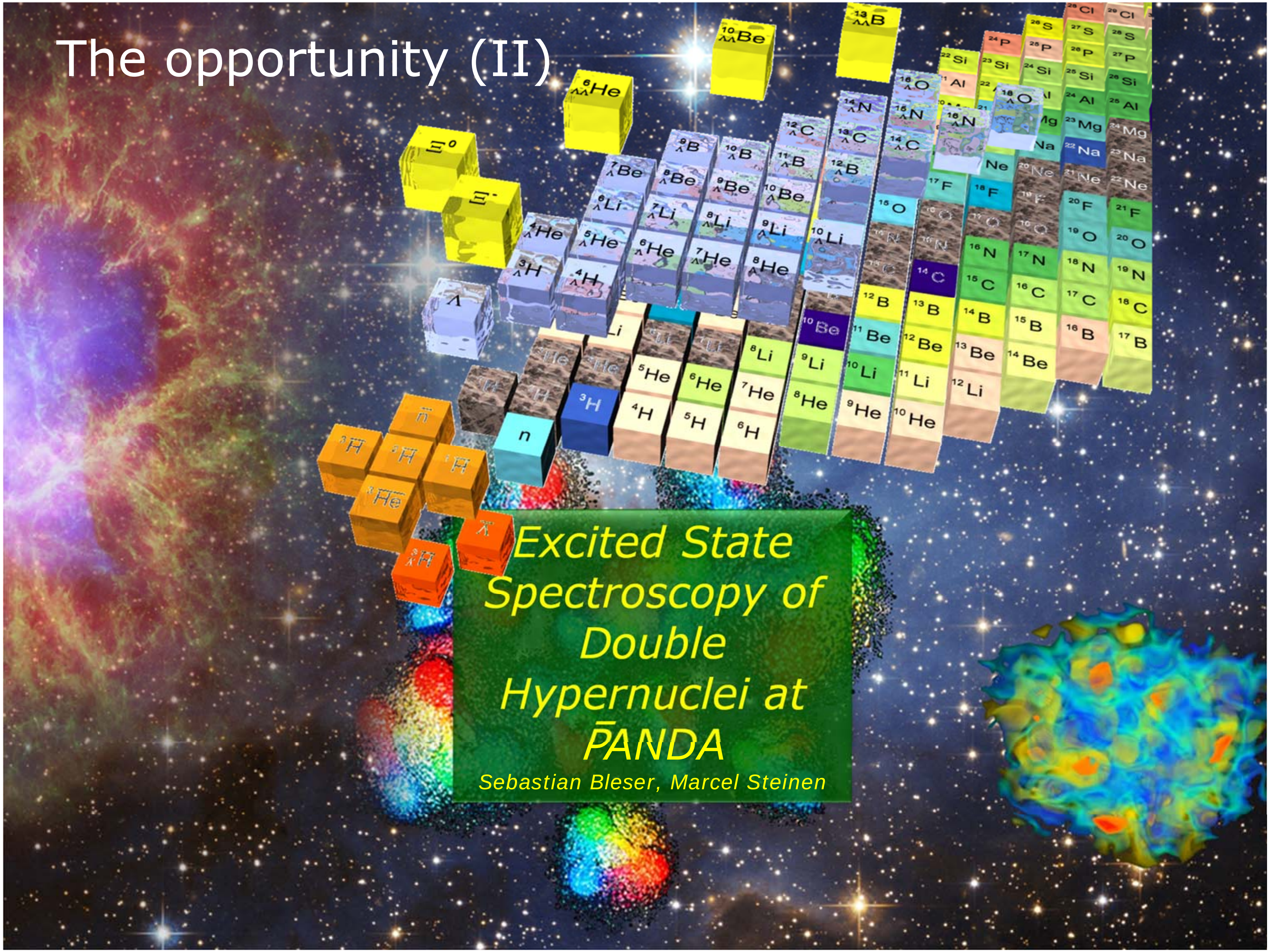
Missing Mass Studies of Hypernuclei

- Fiber detector planes are fully assembled, calibrated and installed
  Adrian Weber (Diploma thesis)
- Detector test scheduled for December 17th 2012
- Problem
  - huge e^{+} and e- single rate
  - pair conversion
- Solution
  - Online m.m.-trigger
    - correlate >30⊗2000 channels
    - use also track information
    - flexibility (different beams, magnet setting…) → programmable
  - Pb in front of last TOF wall ?
  - avoid bending plane ?
- First pilot run (d-target) early 2013





The opportunity (II)



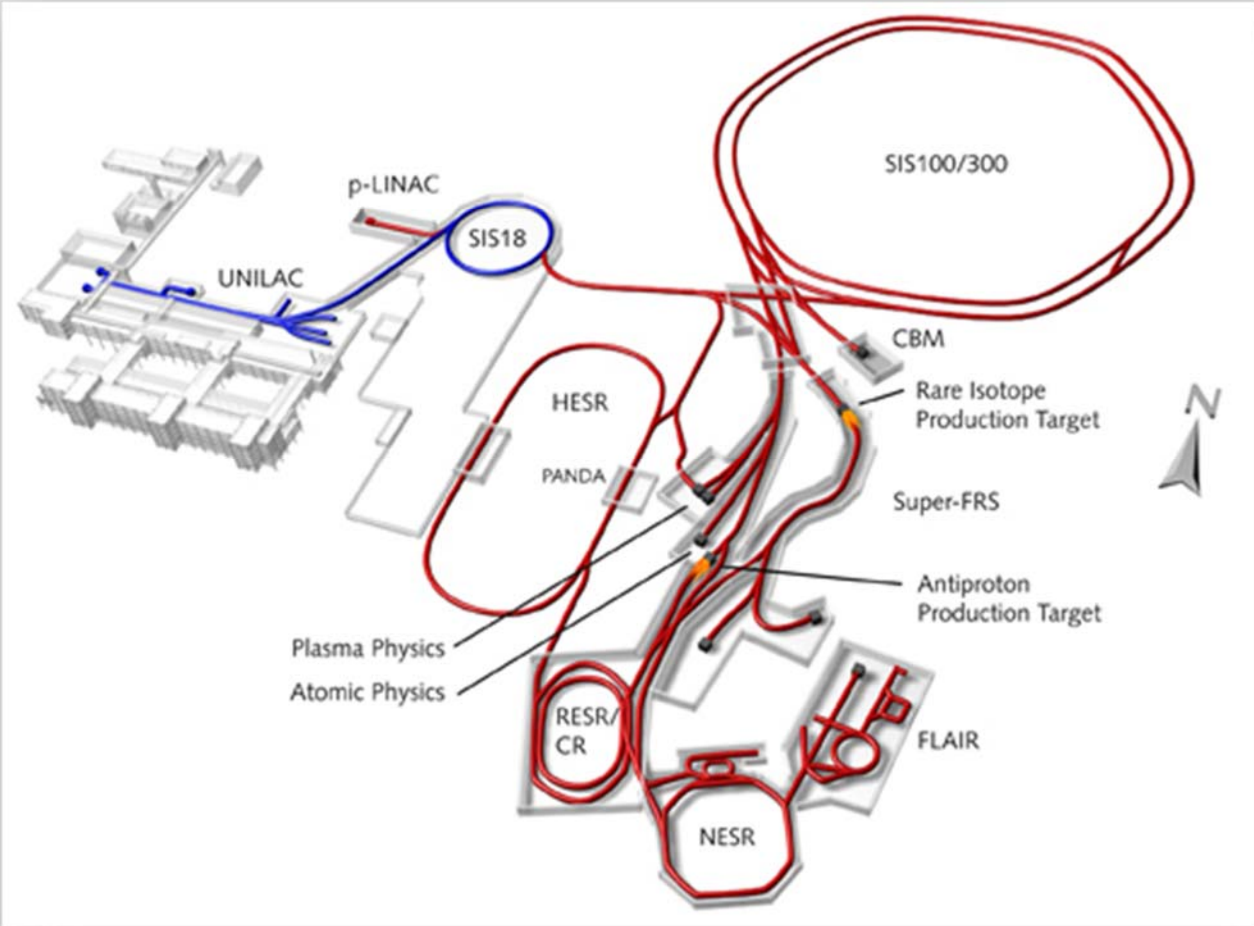
Facility for **A**ntiproton and **I**on **R**esearch

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

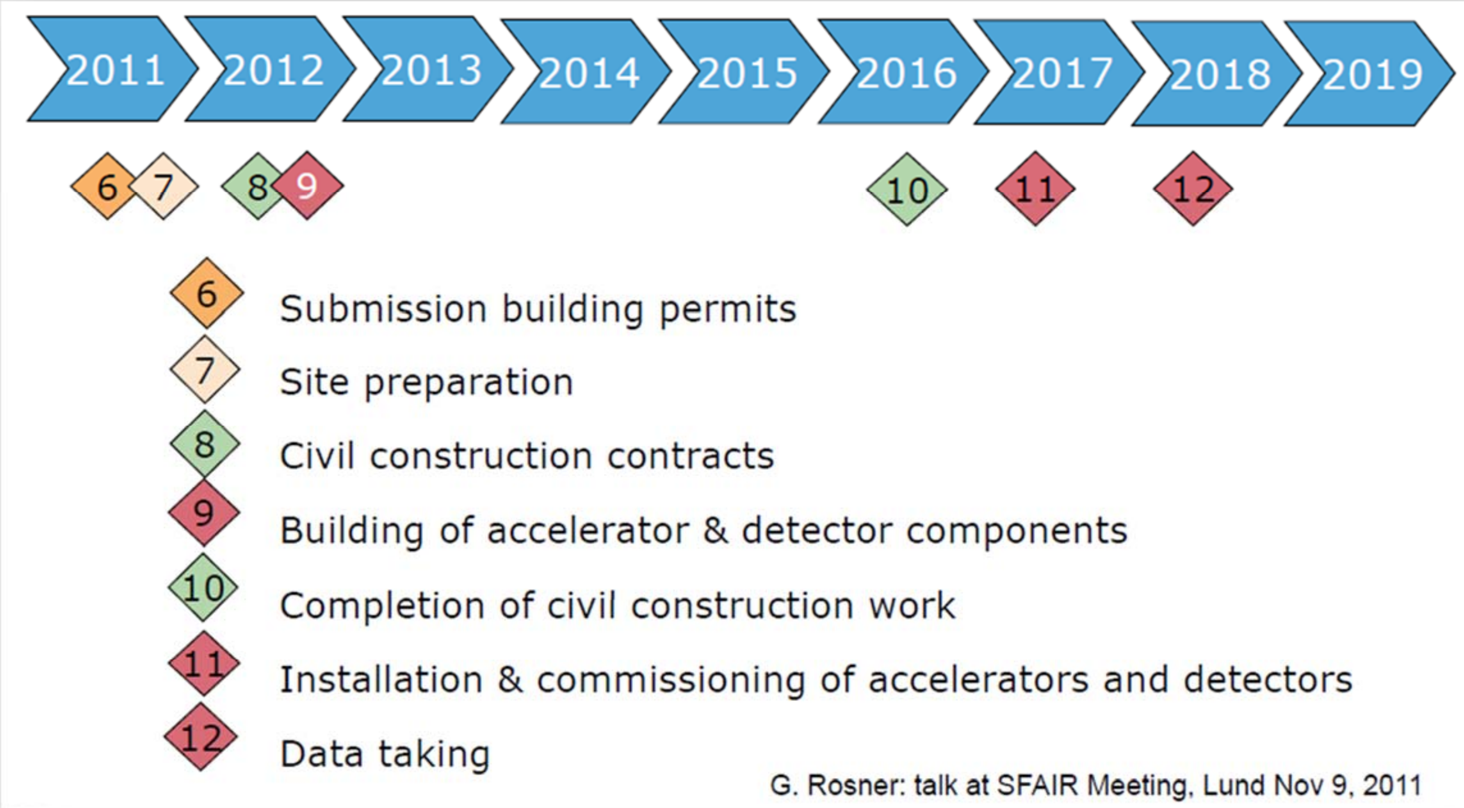
- **FAIR: New facility**
  - higher intensities & energies
  - **Antiproton Physics**

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

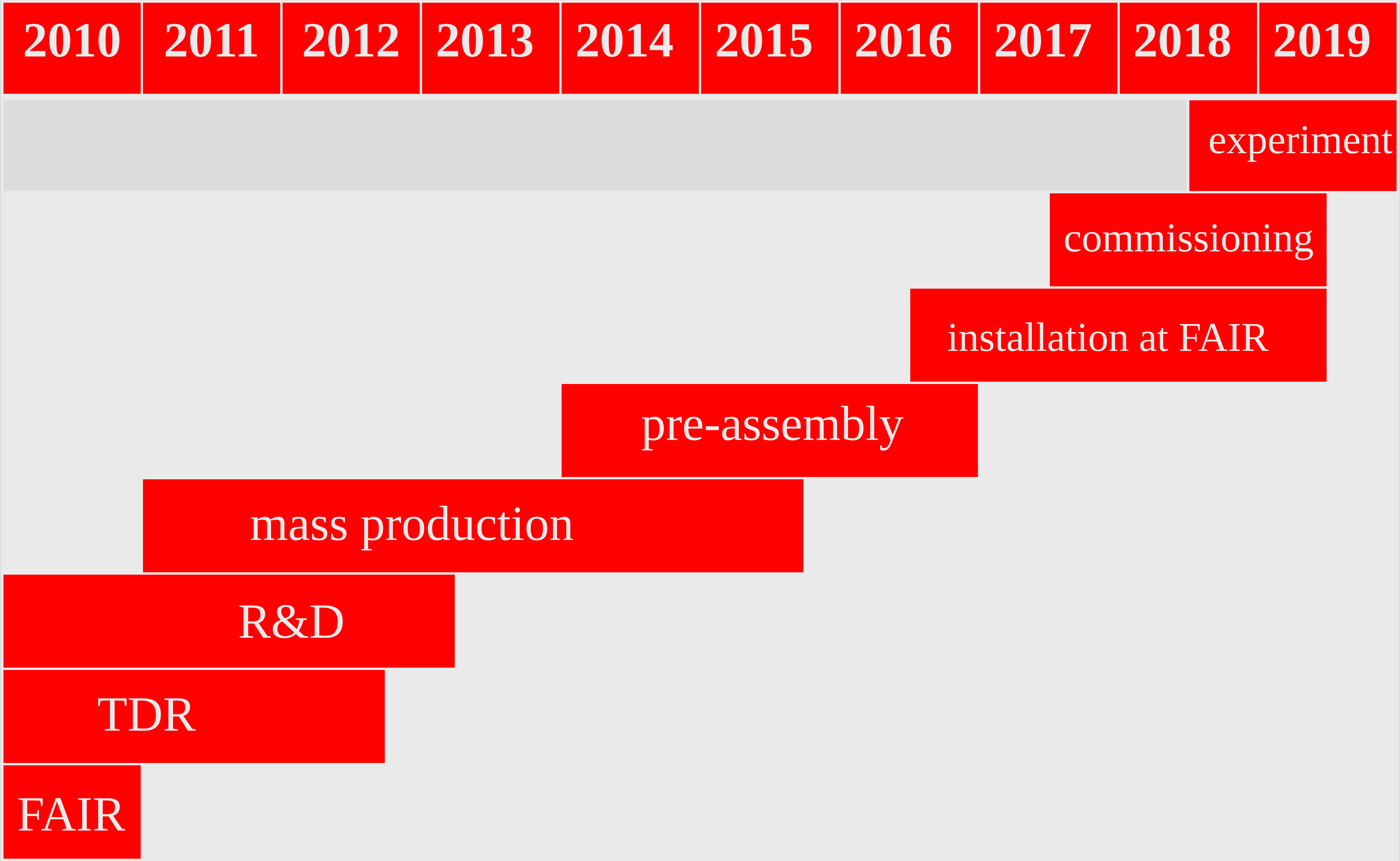


Timeline of FAIR



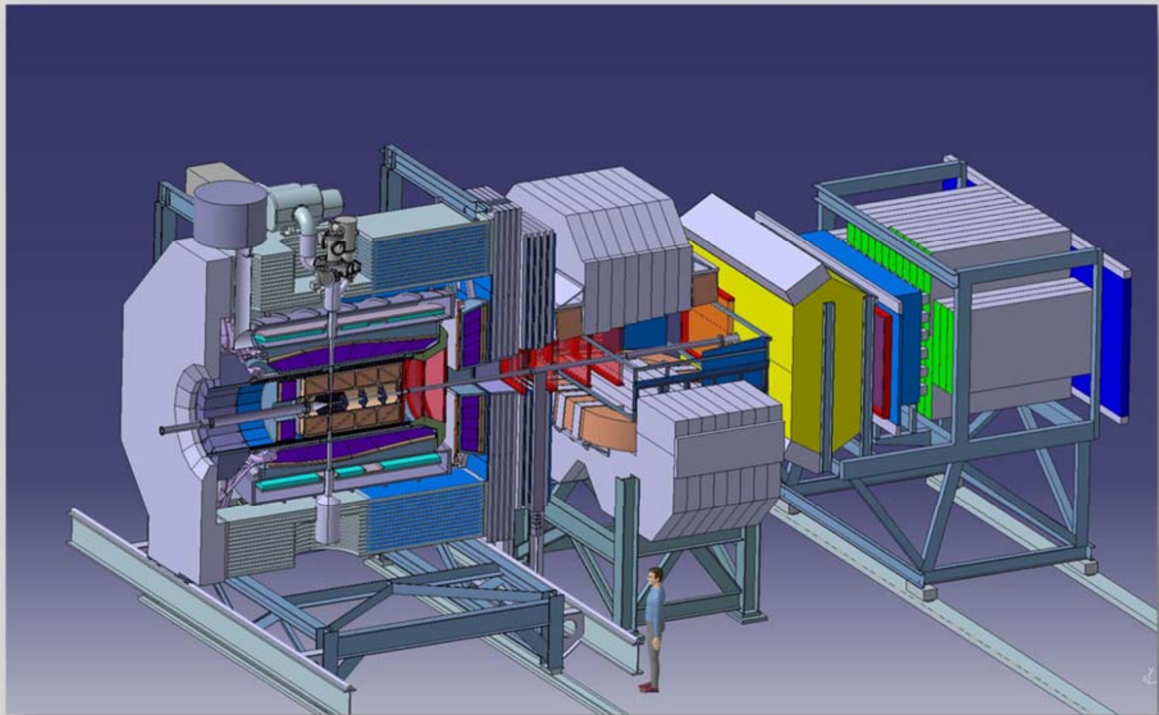
- At present only „**Modularized Start Version**" financed
  - SIS 100
  - Experimental halls for CBM and APPA
  - SUPER FRS for NuSTAR
  - Antiproton facility for PANDA

Schedule of P̄ANDA



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 facility for tagged hyperons

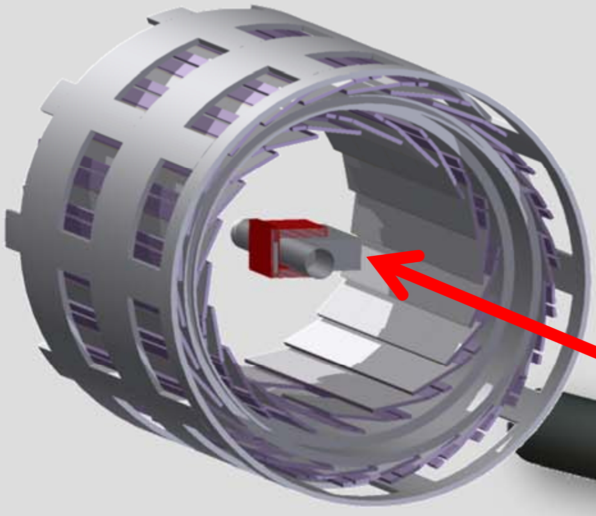
Production Rates (1-2 $(fb)^{-1}/y$)

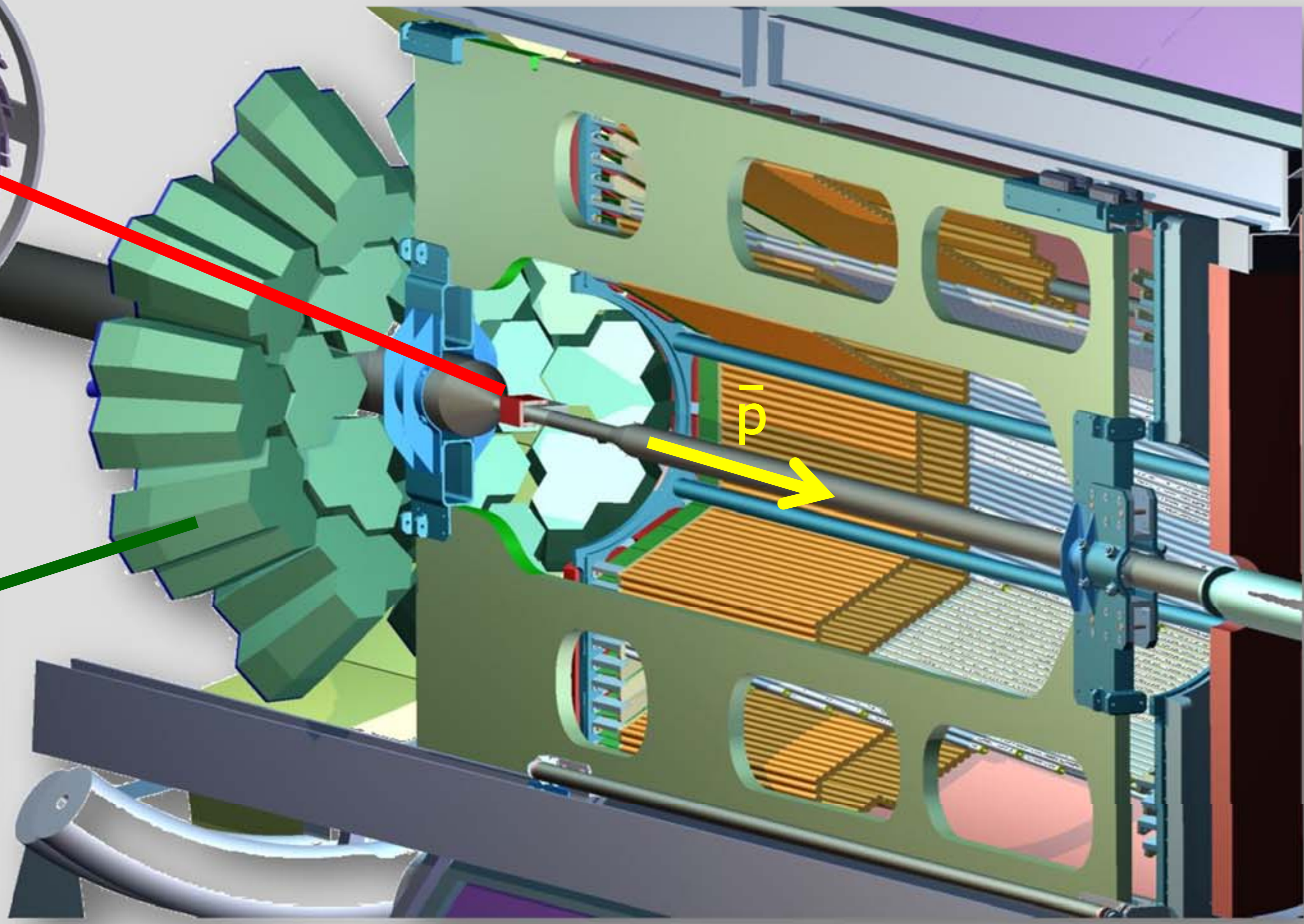
Final State	cross section	# reconstr. events/y
Meson resonance + anything	100μb	10^{10}
$\Lambda\bar{\Lambda}$	50μb	10^{10}
$\Xi\bar{\Xi}$	2μb	10^{8}
$D\bar{D}$	250nb	10^{7}
$J/\psi(\rightarrow e^+e^-, \mu^+\mu^-)$	630nb	10^{9}
$\chi_2(\rightarrow J/\psi+\gamma)$	3.7nb	10^{7}
$\Lambda_c\bar{\Lambda}_c$	20nb	10^{7}
$\Omega_c\bar{\Omega}_c$	0.1nb	10^{5}

- Common feature
  - Low multiplicity events
  - Moderate particle energies
  - For pairs: charge symmetric conditions: trigger on one, investigate the other one
    - re-scattering of tagged hyperons and charmed baryons
    - (anti)hyperon potentials (see e.g. PLB 669 (2008) 306)

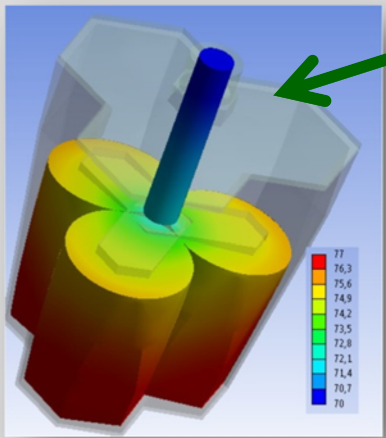
The HYP setup at PANDA

- Primary target and tracking für pions from weak decay



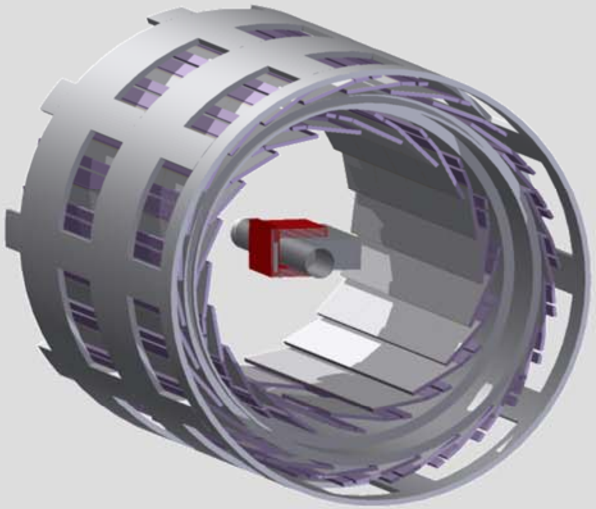


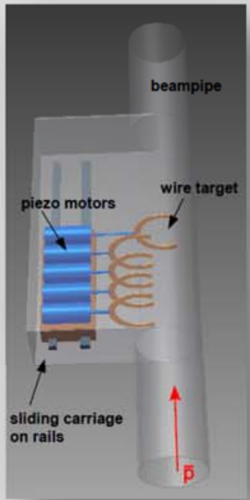
- Ge array

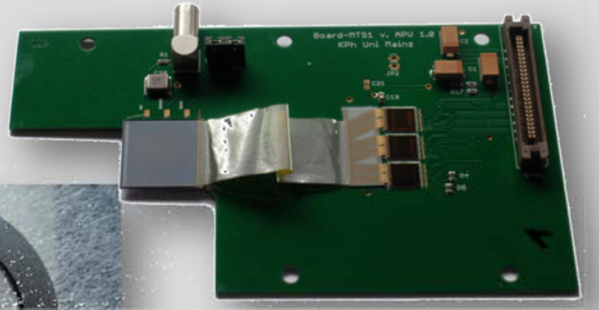


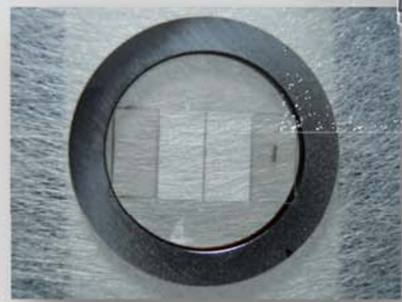
The HYP setup at PANDA

- Primary, secondary targets, tracking system for π from weak decay

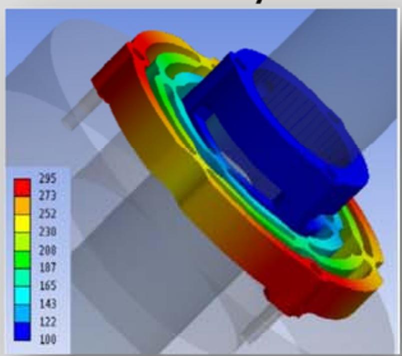


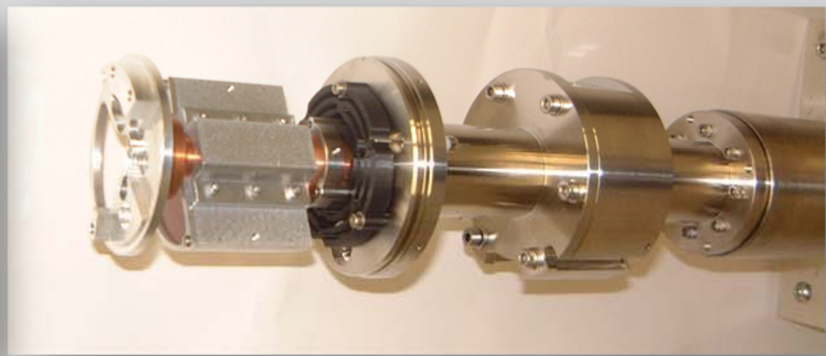


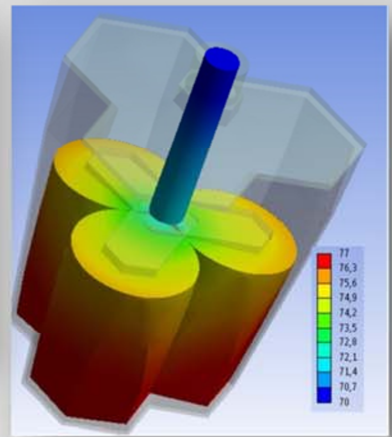




- Ge array







- Goal: TDR in 2013


Conclusions
• Hypernuclear program at MAMI has started and will hopefully soon present first physics results
• The construction of FAIR and PANDA has begun. HYP@PANDA is aiming at the required Technical Design Report