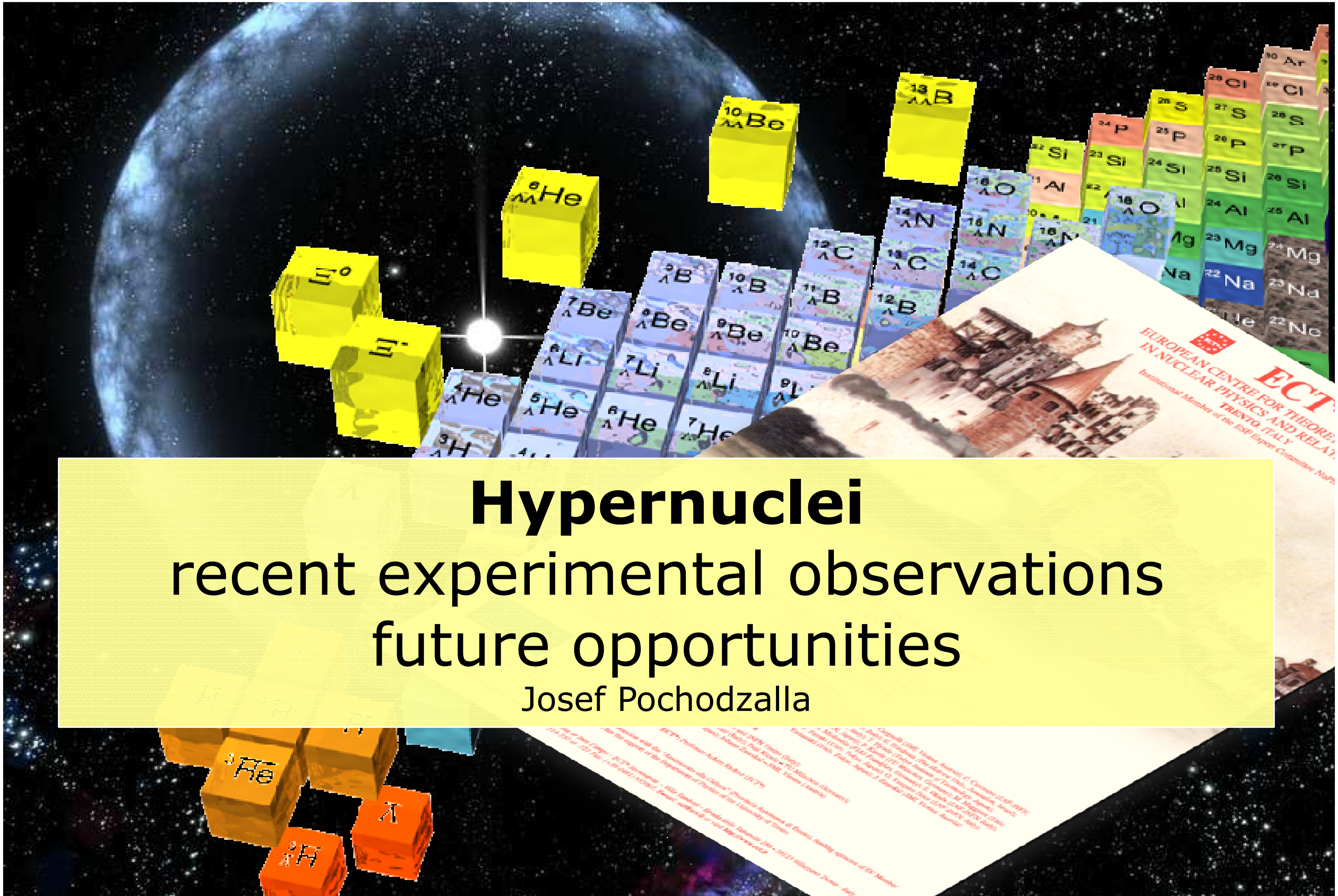


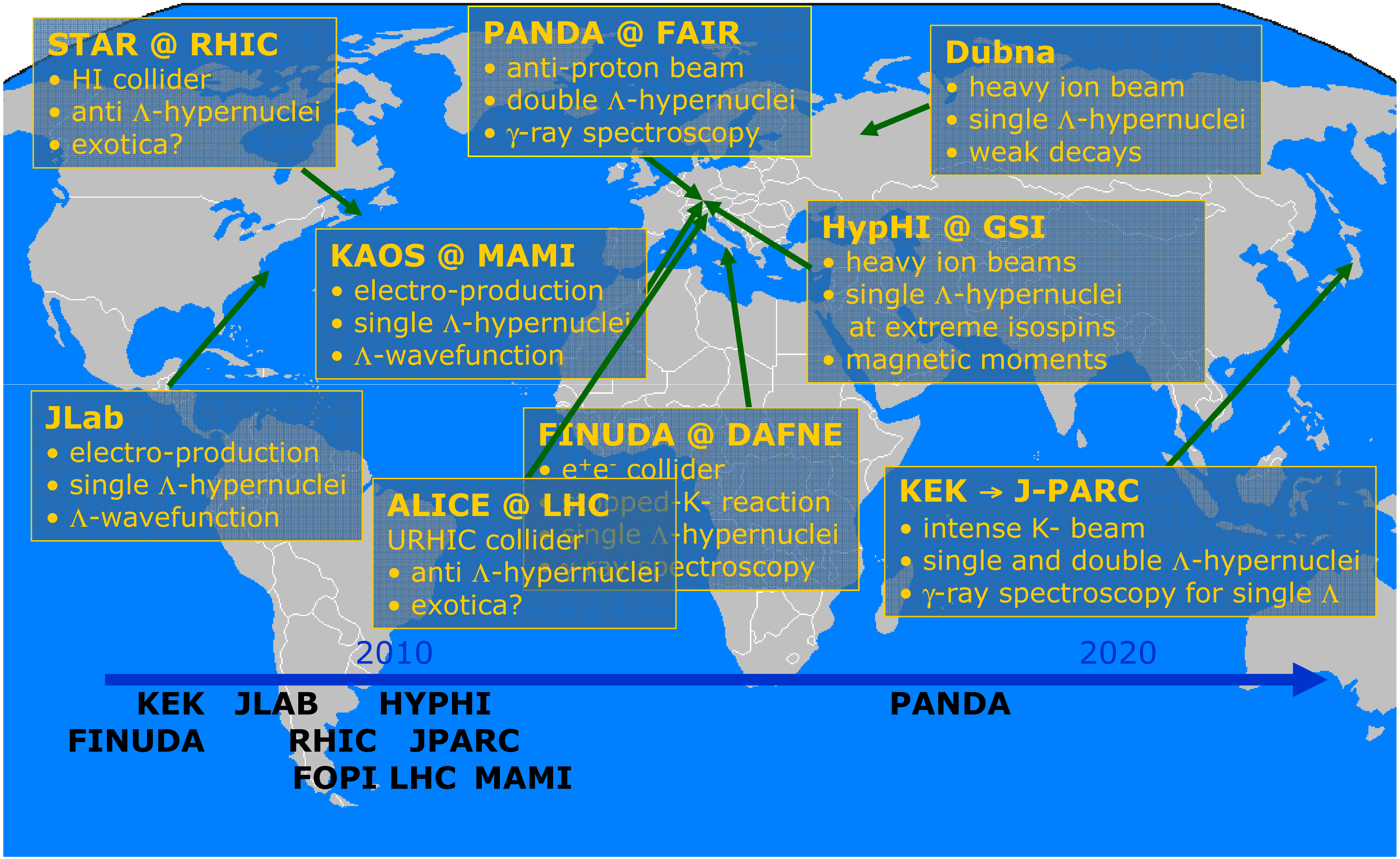
Hypernuclei

recent experimental observations
future opportunities

Josef Pochodzalla

HadronPhysics2
Study of Strongly Interacting Matter
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
mami MAINZER MIKROTRON
Bundesministerium für Bildung und Forschung

Global Hypernuclear Network

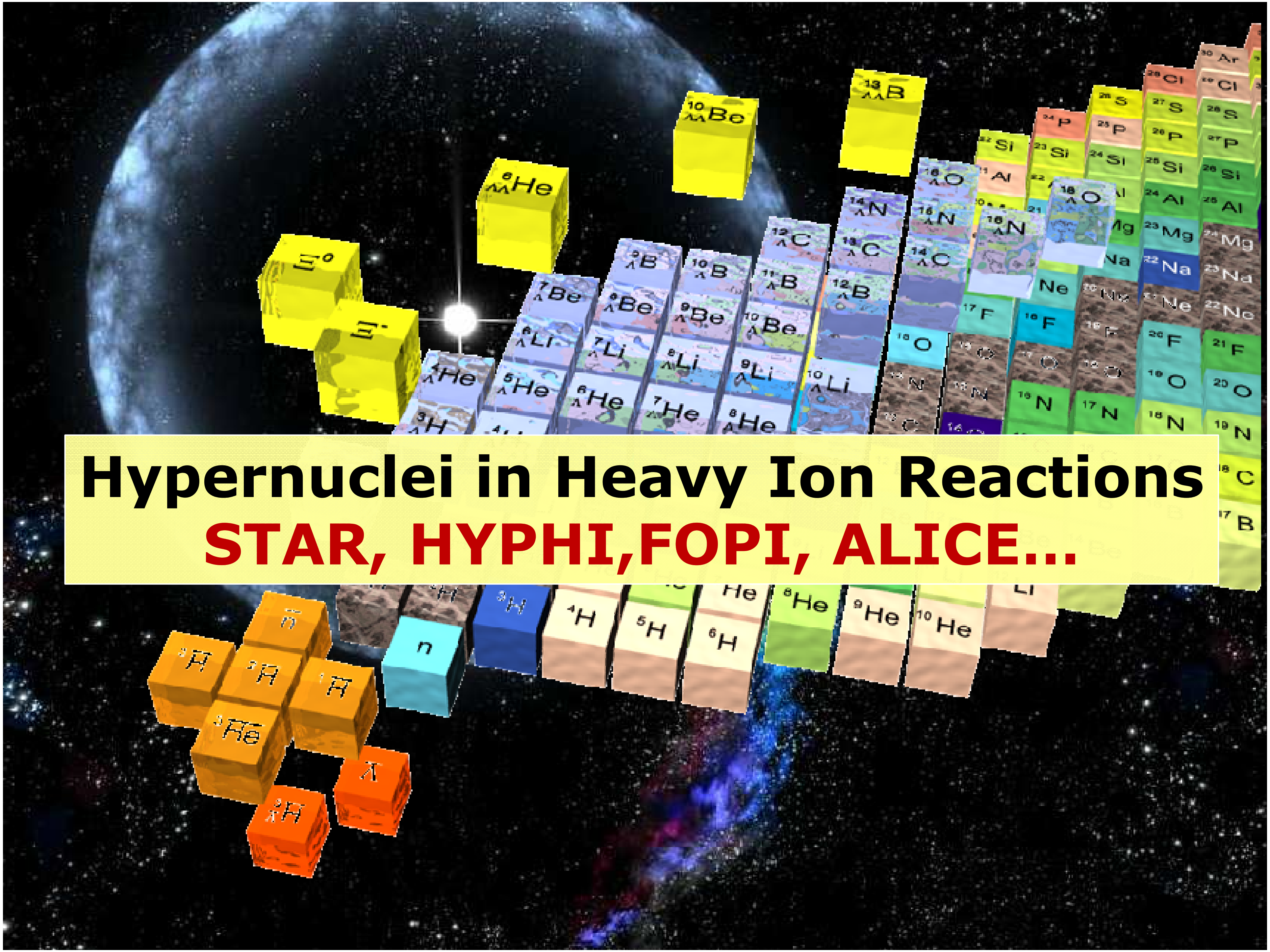


Individual Strengths

Experiment @Facility	Experimental tool & status	Methods & topics
JPARC	low mometum meson beams (π,K) setup ready, K beam intensity still limited (2011 aprox. 10% of design goal expected)	• Λ hypernuclei excited states (Δm~few keV) by γ-spectroscopy • Ξ-hypernuclei by missing mass • ground state masses of light double hypernuclei by hybrid emulsion (Δm~ few 10keV)
JLAB	electro production until 2012 upgrade of CEBAF	• Precission ground state masses by π^--spectroscopy (after 2012) • medium-heavy Λ-hypernuclei (after 2012)
A1@MAMI	electro production	• Precission ground state masses by π^--spectroscopy (Δm~10keV) • Λ-wave function by K angular distribution • Σ hyperon in light nuclei
HypHI@GSI&FAIR	projectile fragmentation 2AGeV - 15AGeV two experiments performed, data analysis ongoing	• ground state masses (Δm~few MeV) • lifetimes • exotic hypernuclei by radioactive beams
FOPI@GSI **STAR@AGS** **ALICE@LHC**	(symmetric) heavy ion collisions Signal seen by FOPI and STAR, analysis ongoing; ALICE started	• antihypernuclei and hypernuclei yields and ground state masses (Δm~few MeV) of S=-2 nuclei • lifetimes
PANDA@FAIR	antiproton beam in design and R&D stage; run after 2017	• level scheme of double $\Lambda\Lambda$ hypernuclei by γ-spectroscopy (Δm<10keV)

Hypernuclei in Heavy Ion Reactions

STAR, HYPHI,FOPI, ALICE...



International Hypernuclear Network

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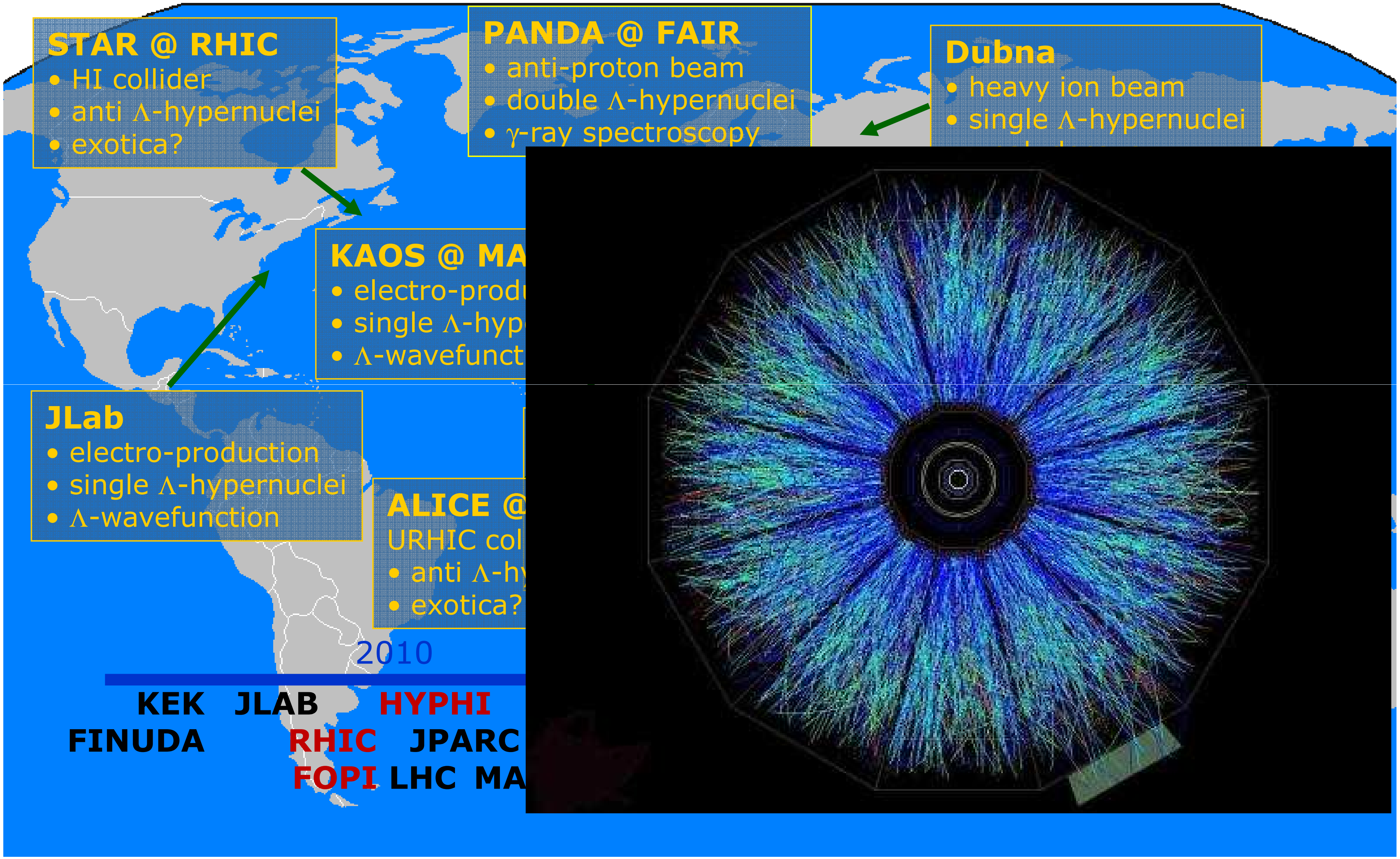
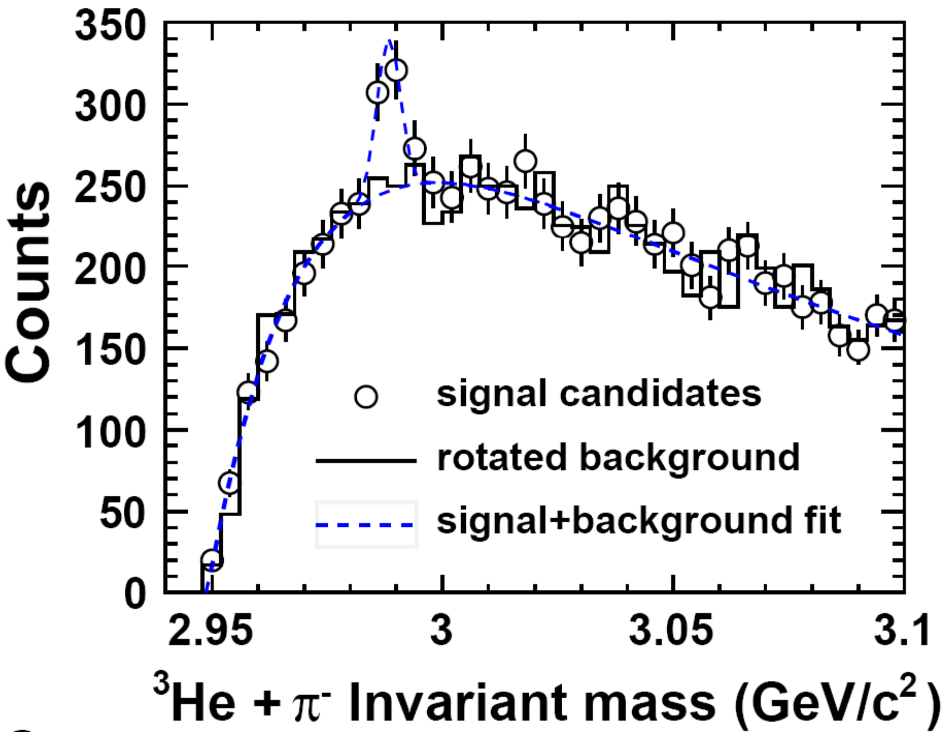
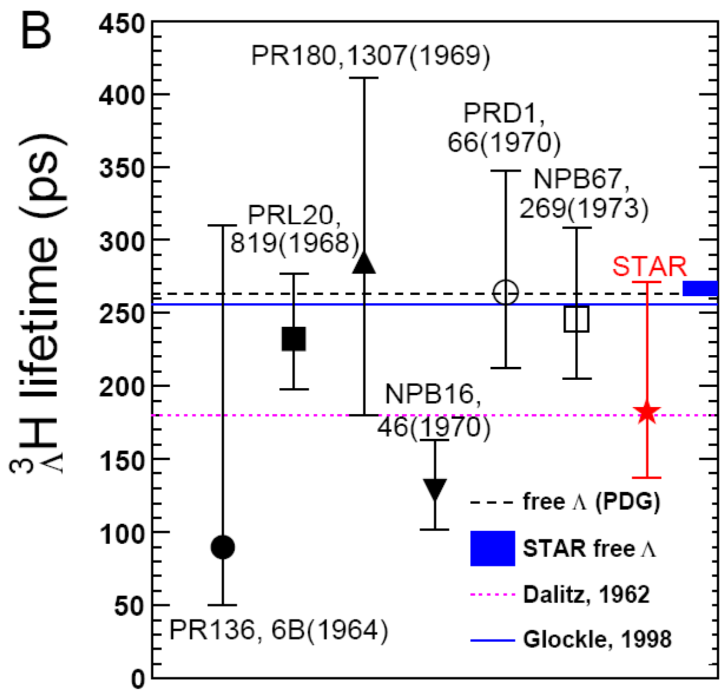


$^{3}_{\Lambda}$H at STAR

- STAR@RHIC : Au+Au at 200AGeV
  - ~10^8 minimum bias events, ~$2\cdot10^7$ central events
  - 157±30 hypertritons   70±17 antihypertritons

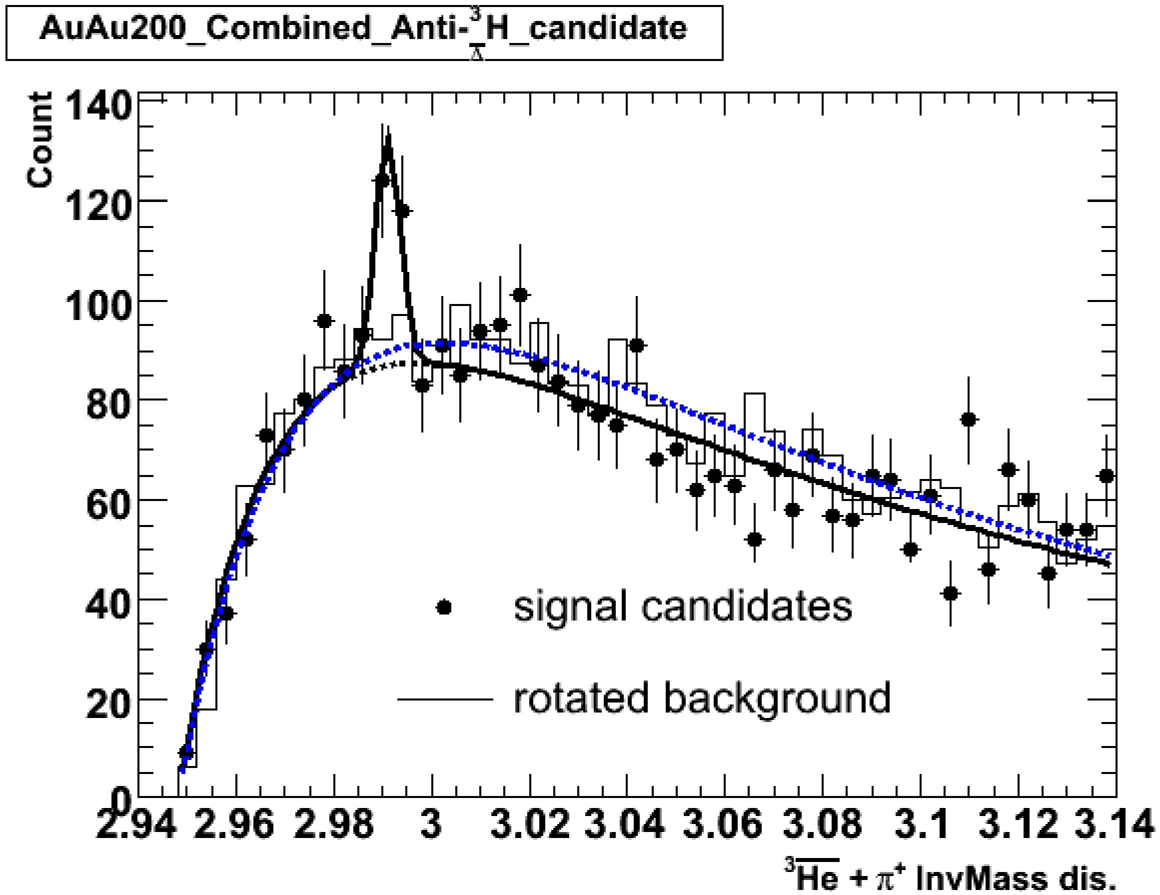
STAR collaboration, NATURE **328** (2010)





- background shape determined from rotated background analysis
- Mass: 2.990 ± 0.001 GeV; Width (fixed): 0.0025 GeV.

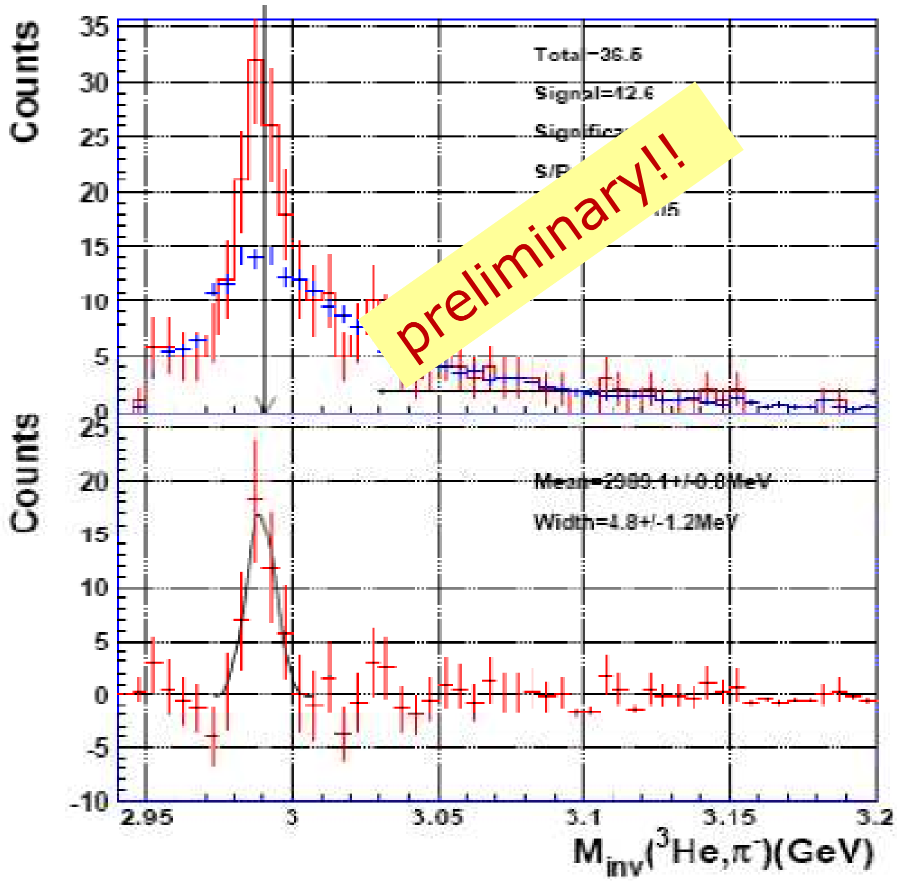
The first antihypernucleus: ${}^{3}_{\bar{\Lambda}}\bar{H}$ @ STAR



- Mass: 2.991$\pm$0.001 GeV; Width (fixed): 0.0025 GeV

Hypernuclei at FOPI

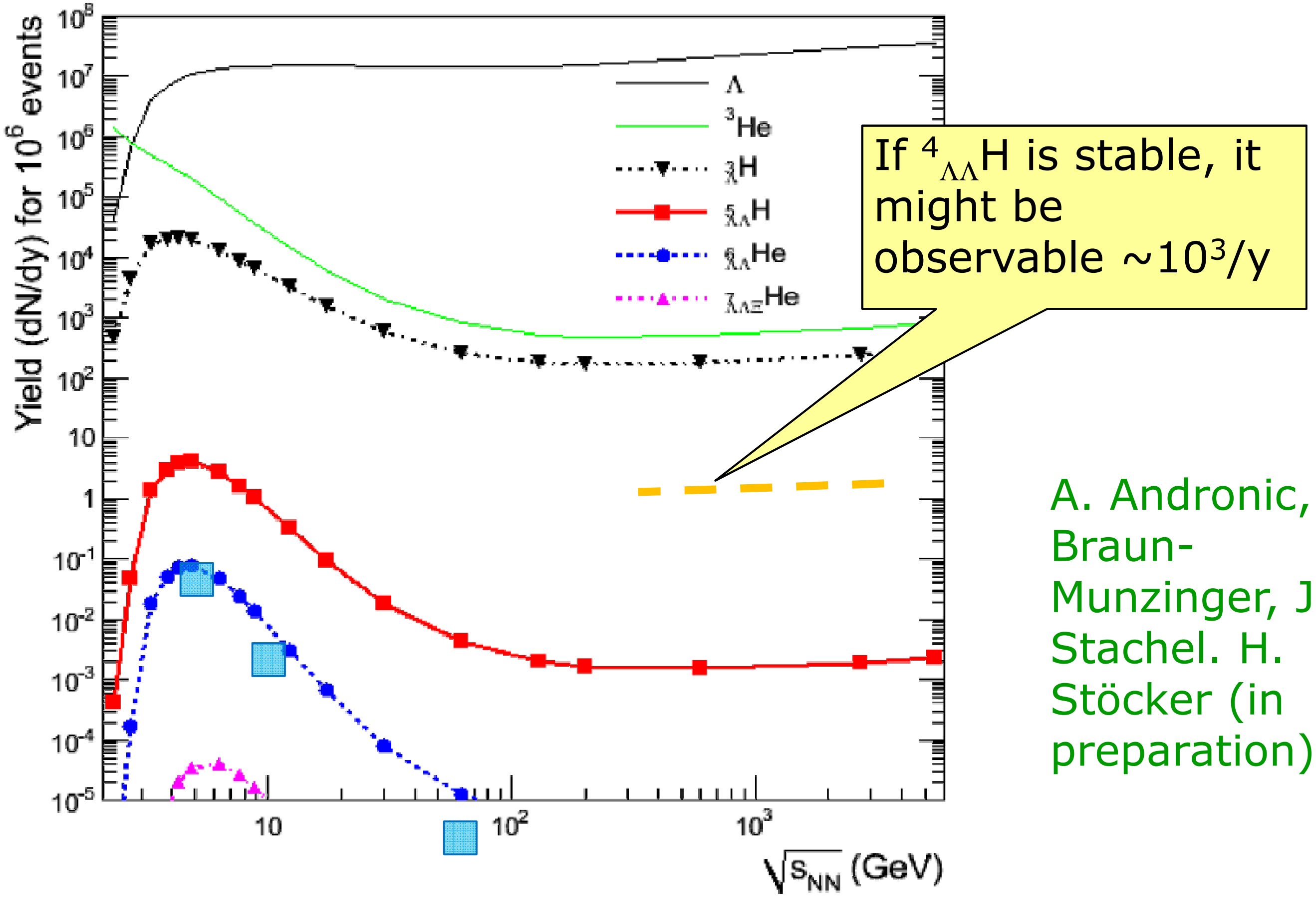
- Ni+Ni at 1.91AGeV ~$6\cdot10^7$events
- K^+ candidate tagged
- $0.05 < y_t < 0.35$.



Y.P.Zhang SPHERE & JSPS Meeting, Prague, Czech 04.09.2010-06.09.2010

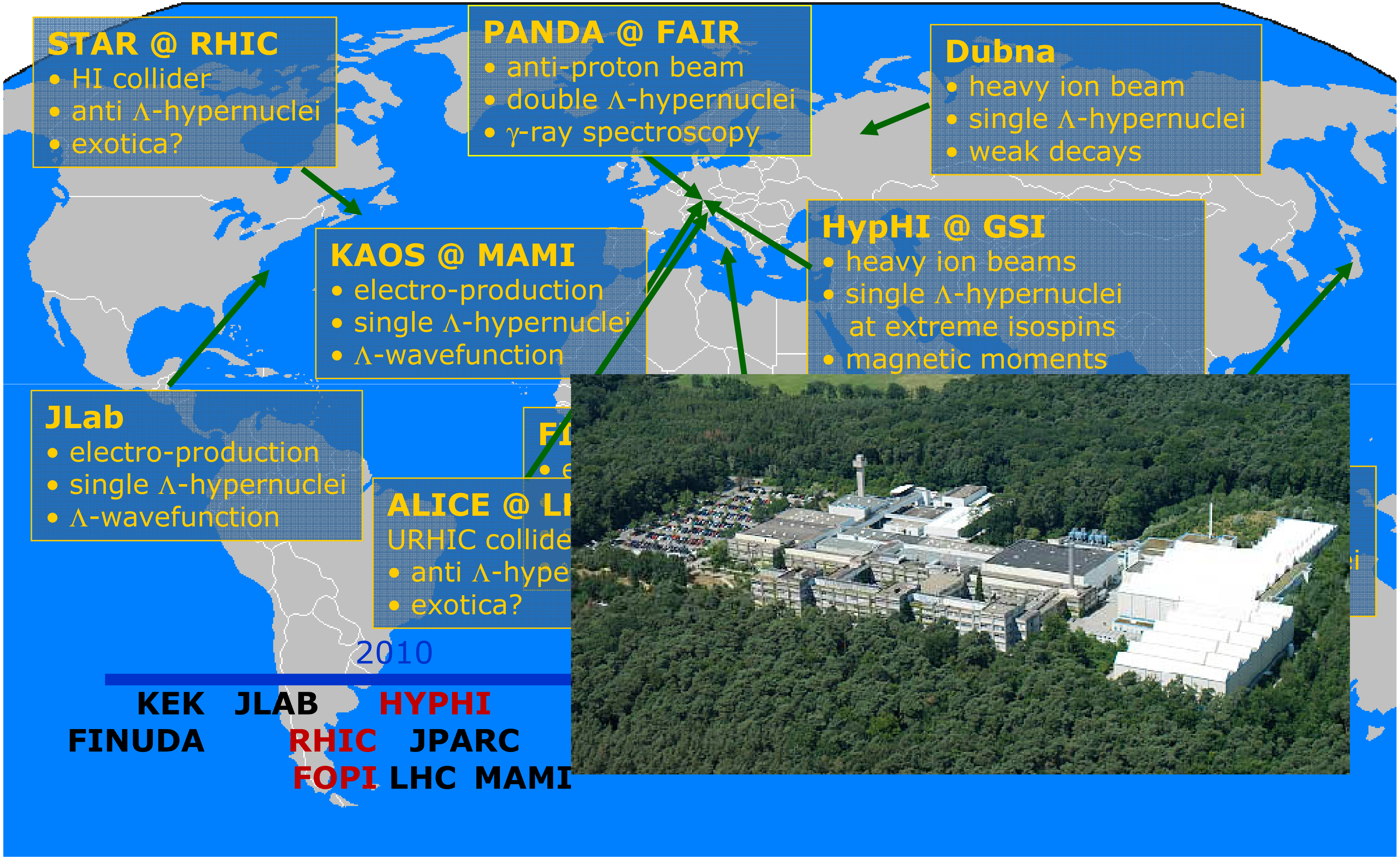
Pb+Pb at ALICE

- Expected luminosity $5 \cdot 10^{26} cm^{-1}s^{-1}$
- Minimum bias interaction rate 4kHz
- Running time per year $\sim 10^6$s



A. Andronic, P. Braun-Munzinger, J. Stachel. H. Stöcker (in preparation)

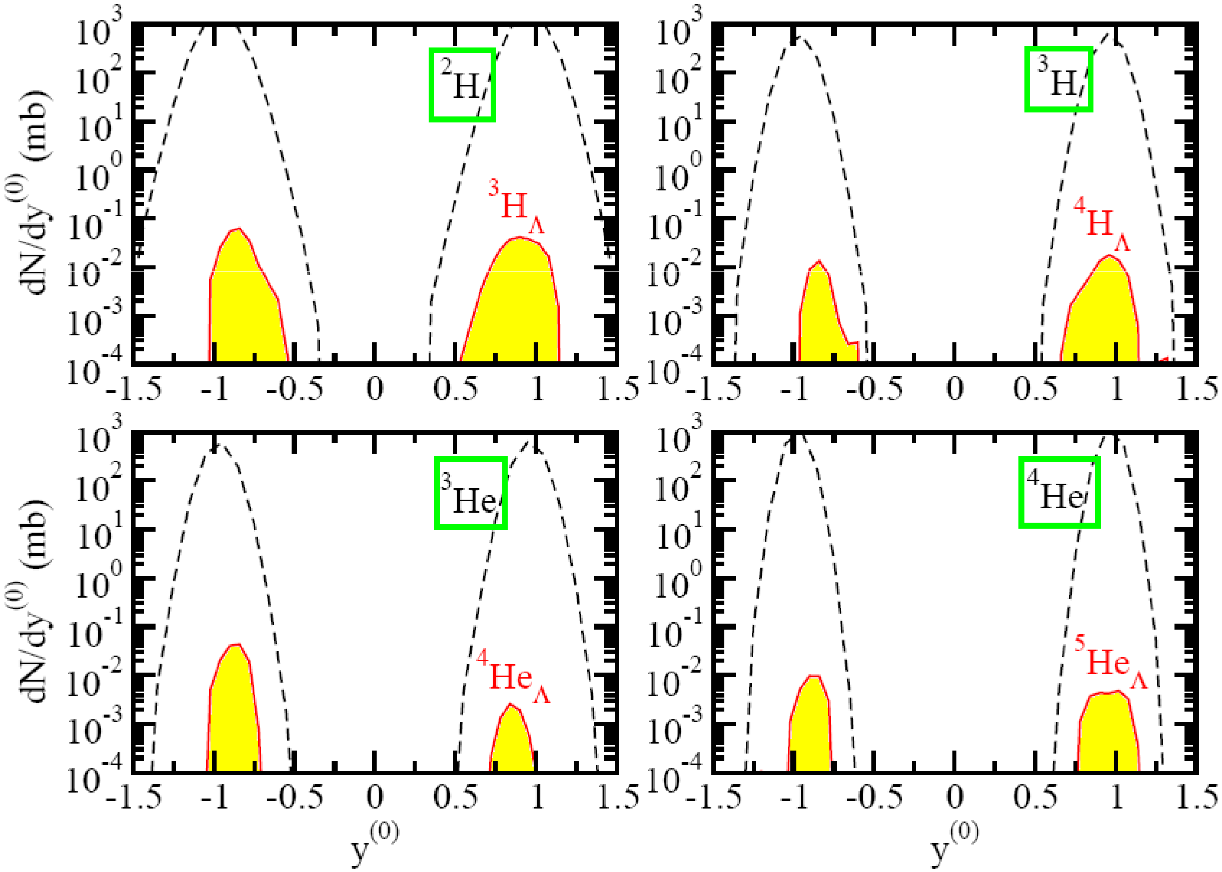
International Hypernuclear Network



Prediction

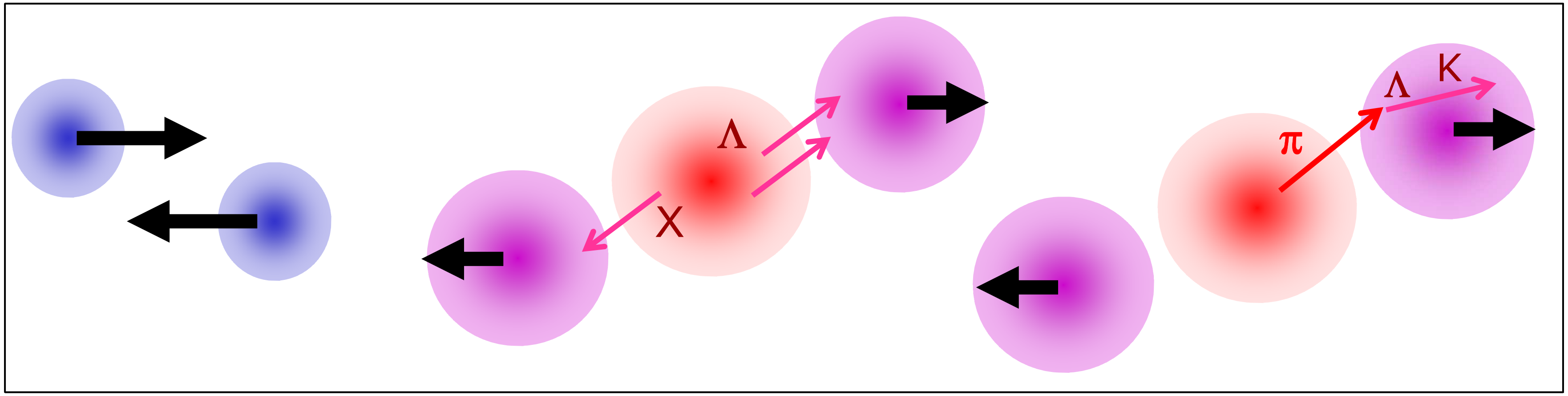
- combination of a dynamical transport model and a statistical approach of fragment formation: GiBUU+SMM

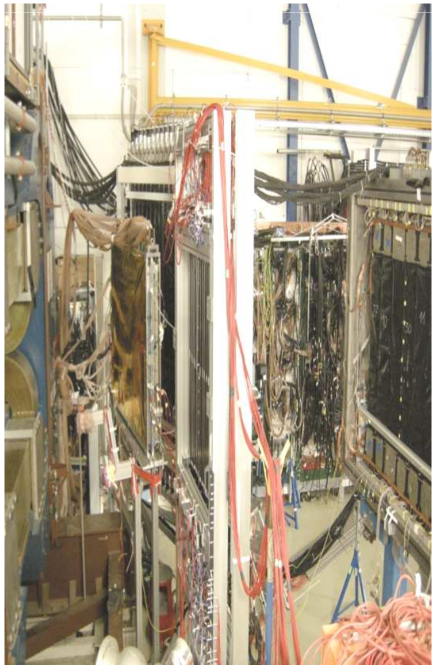
$^{12}C+^{12}C$ at 2AGeV

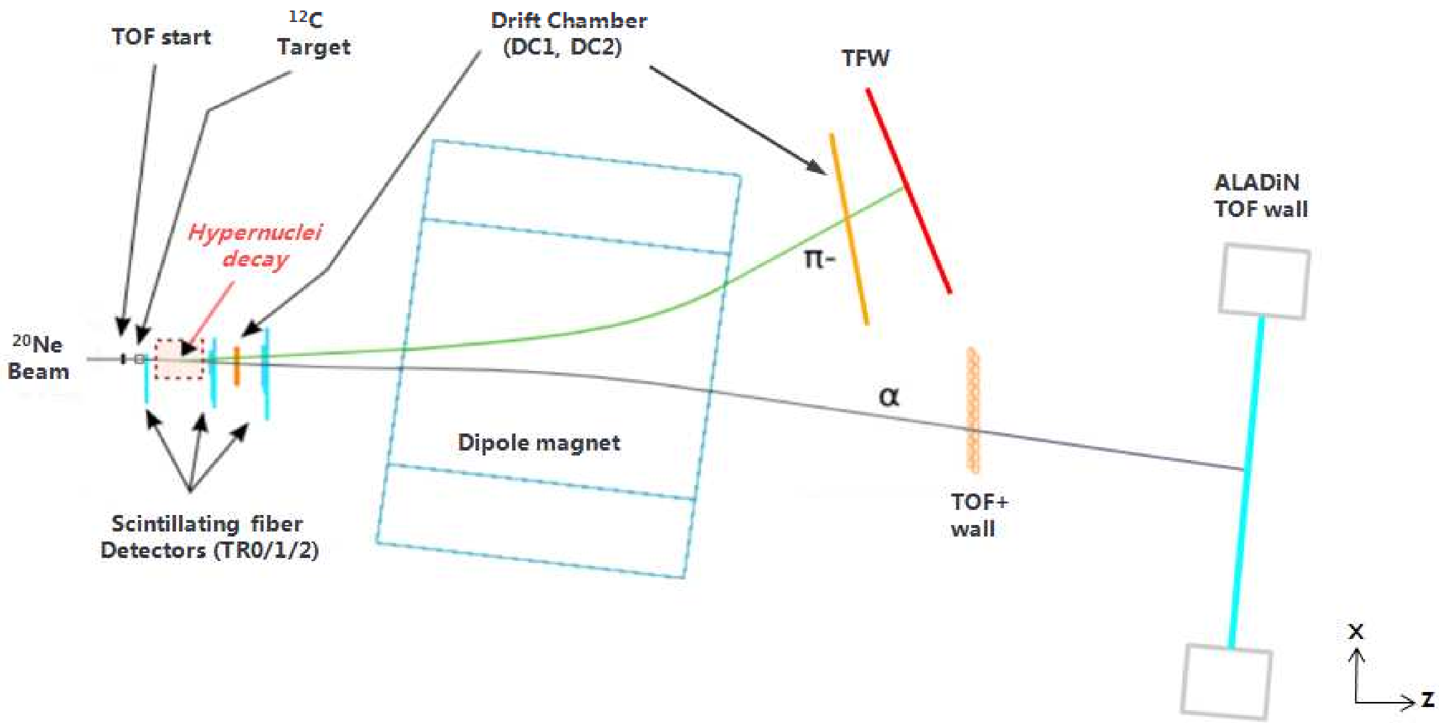


HYPHI @ GSI/FAIR

- October 2009: 2AGeV $^{6}Li+^{12}C$ March 2010: 2AGeV $^{20}Ne+^{12}C$

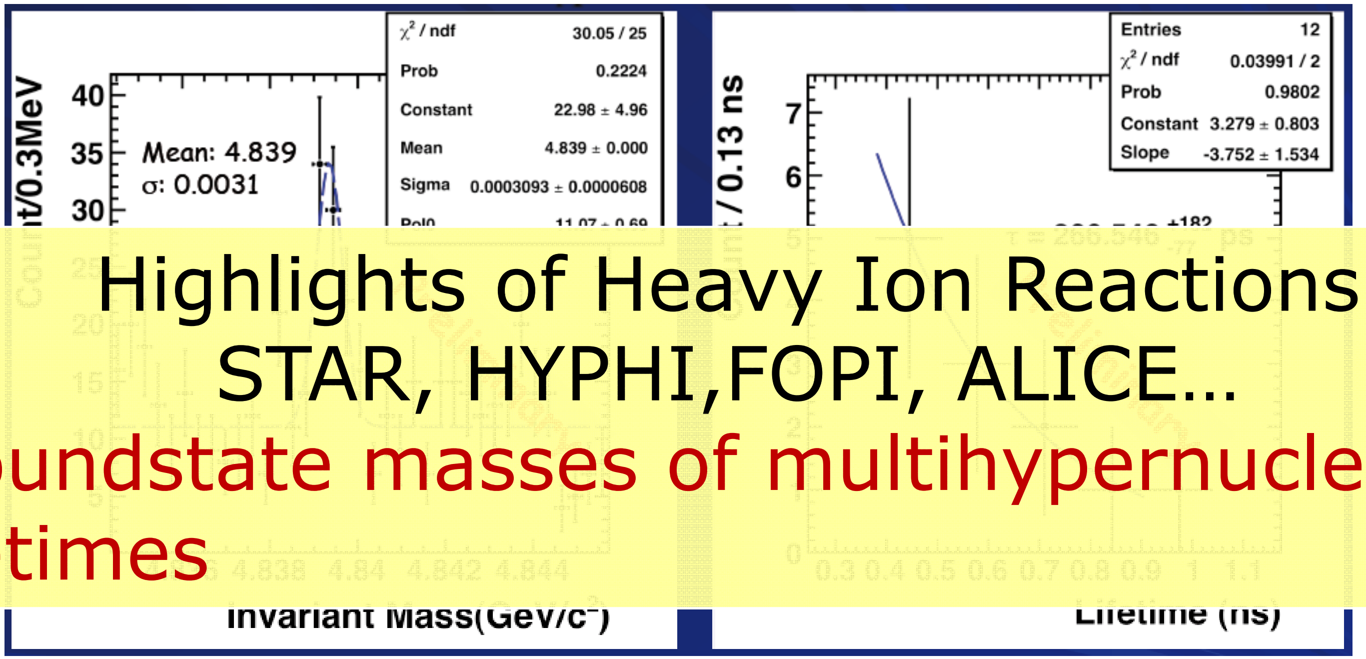






Preliminary Results

- First decays of Λ-hyperons and a first indication of ${}^{5}_{\Lambda}He$ are found which are compatible with known mass of 4.840GeV and lifetime of 256 (20) ps



Highlights of Heavy Ion Reactions
STAR, HYPHI,FOPI, ALICE…

Groundstate masses of multihypernuclei

Lifetimes

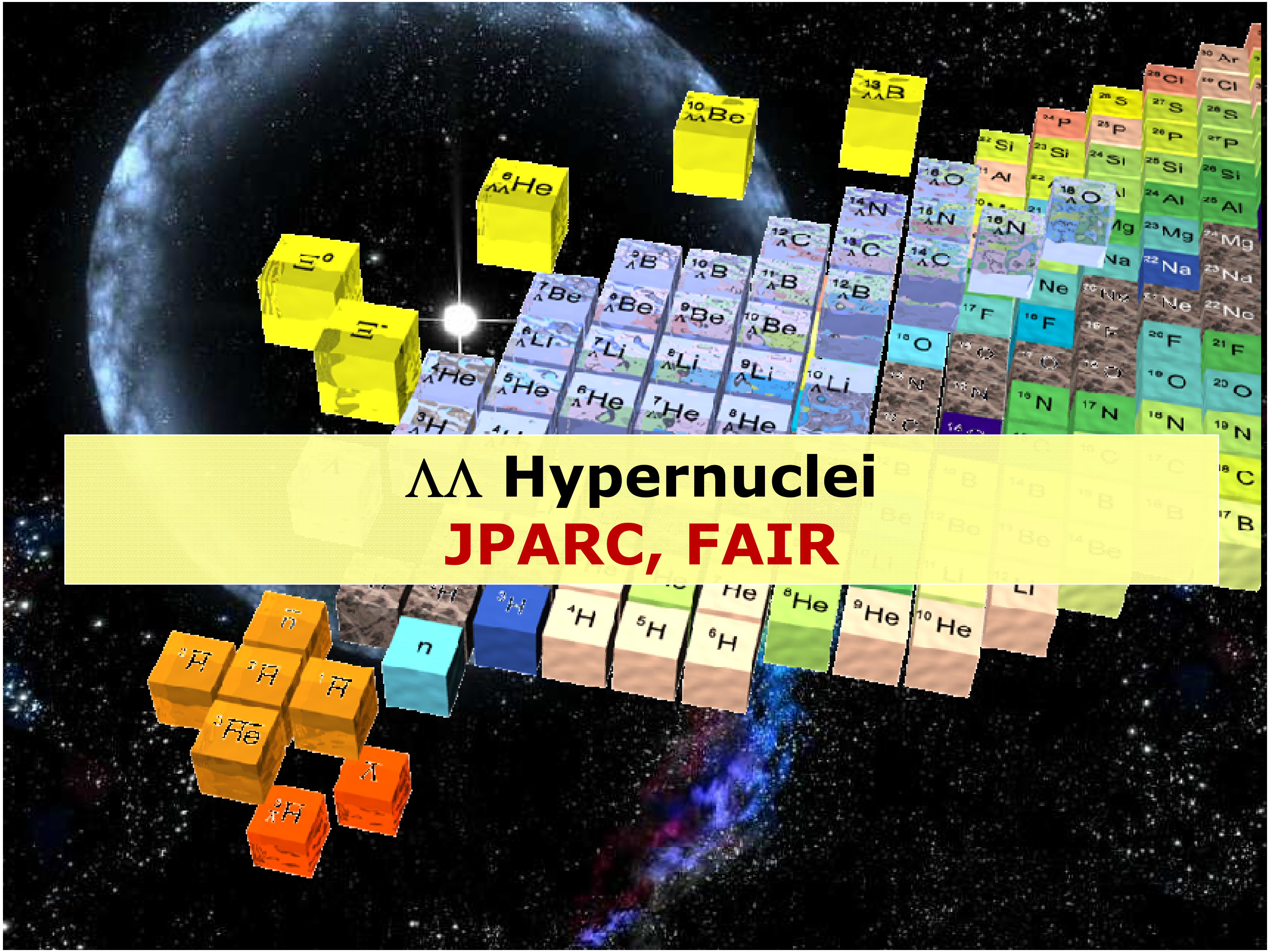
~1% of available data !

T. Saito, SPHERE & JSPS Meeting, Prague, Czech 04.09.2010-06.09.2010

D. Nakajima, PhD thesis
C. Rappold, PhD thesis

ΛΛ Hypernuclei

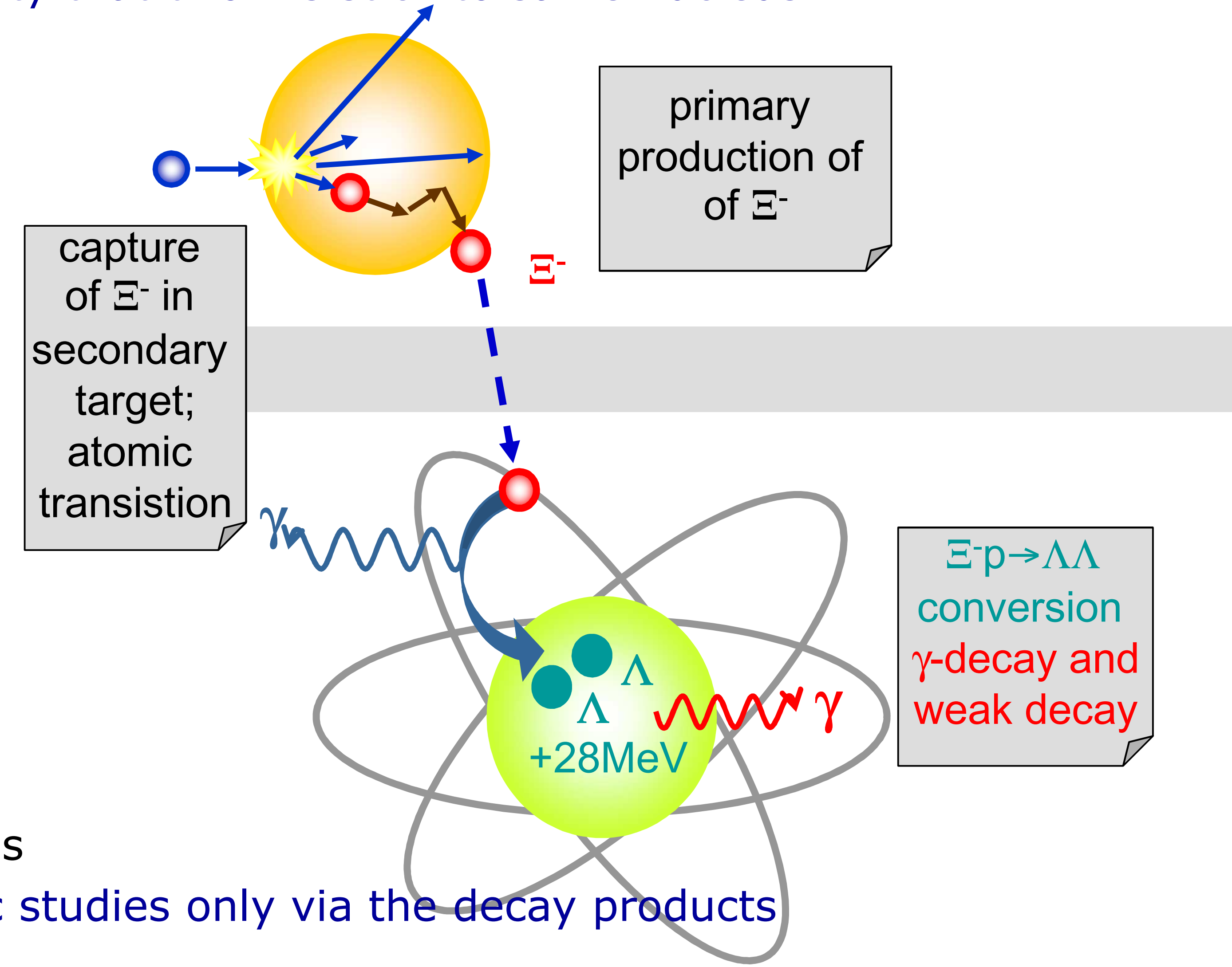
JPARC, FAIR



Production of ΛΛ Hypernuclei

- simultaneous implantation of two Λ's impossible
- Ξ⁻ conversion in 2Λ: $\Xi^- + p \rightarrow \Lambda + \Lambda$ + 28MeV

  ⇒large probability that two Λ's stick to same nucleus

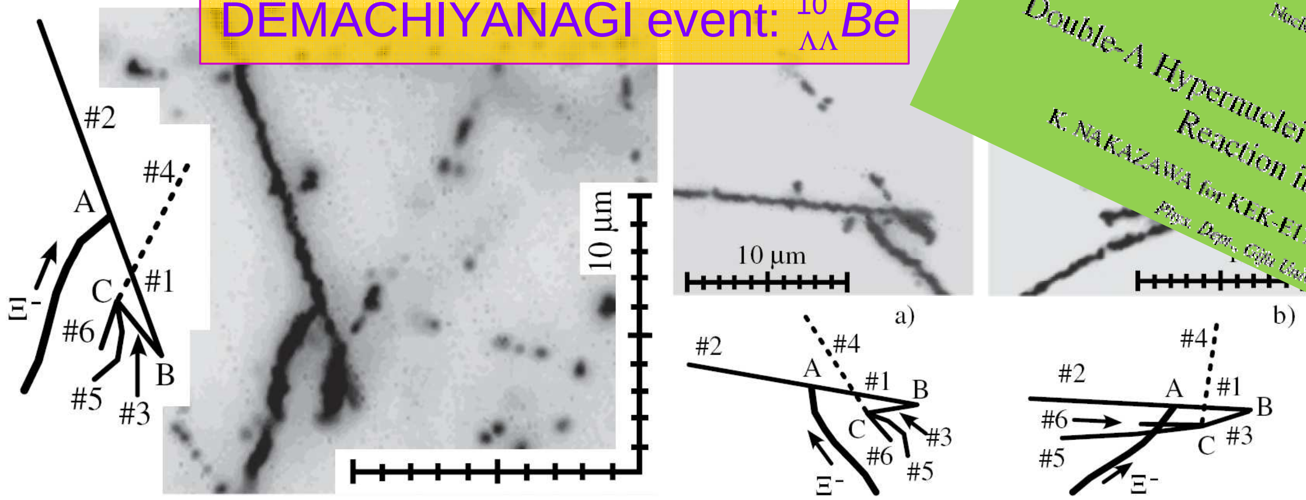


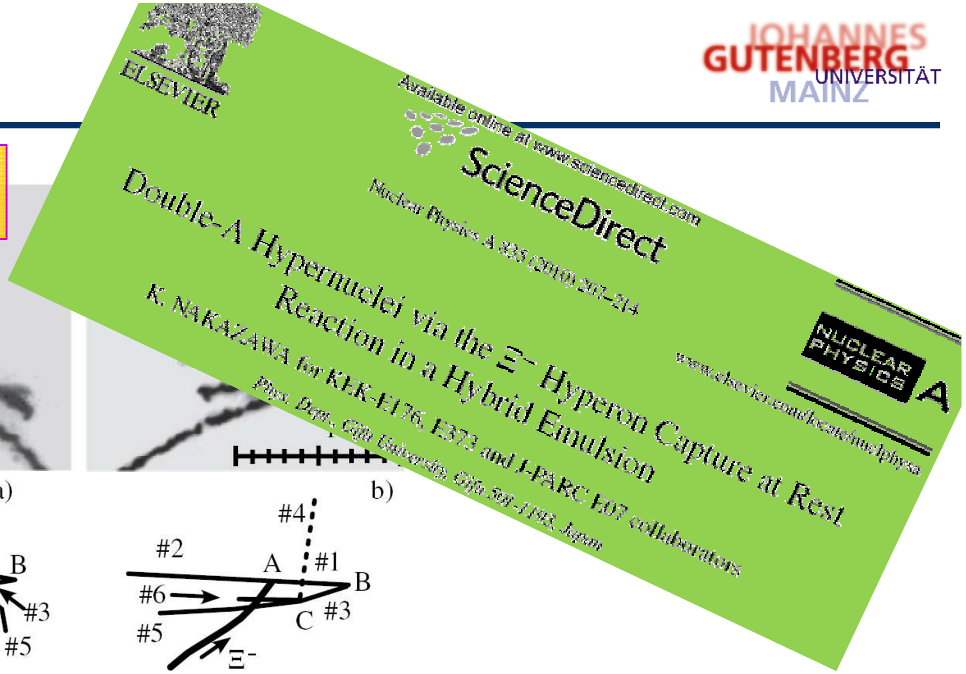
- two-step process

  ⇒ spectroscopic studies only via the decay products

After HYP-X 2009

DEMACHIYANAGI event: $^{10}_{\Lambda\Lambda}Be$

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Nuclear Physics A 835 (2010) 207–214

NUCLEAR PHYSICS A

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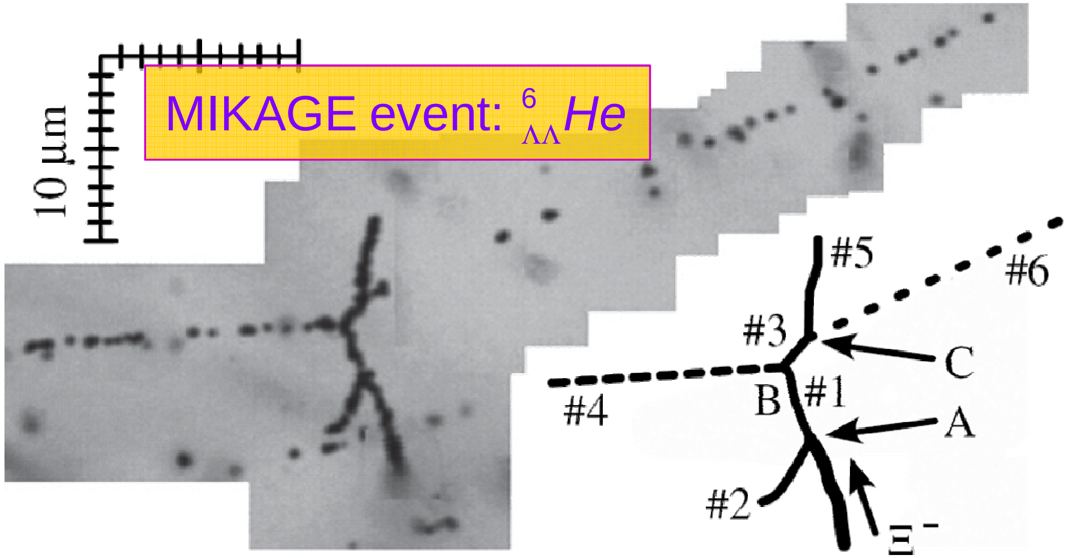
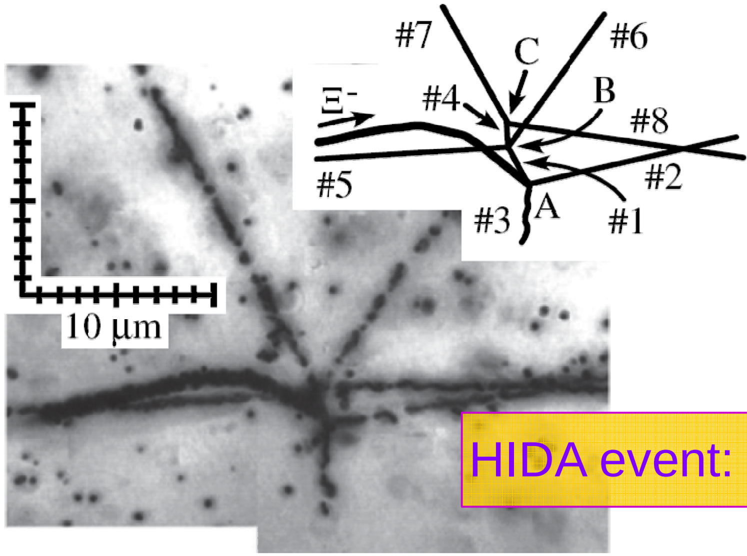
Double-Λ Hypernuclei via the Ξ⁻ Hyperon Capture at Rest Reaction in a Hybrid Emulsion

K. NAKAZAWA for KEK-E176, E373 and J-PARC E07 collaborators
Phys. Dept., Gifu University, Gifu 501-1193, Japan

MIKAGE event: $^{6}_{\Lambda\Lambda}He$



HIDA event: $^{11}_{\Lambda\Lambda}Be$ or $^{12}_{\Lambda\Lambda}Be$



Summary and perspective (1)

By checking consistency of $\Delta B_{\Lambda\Lambda}$ (NAGARA) within 3 STD. errors,

	$^{A}_{\Lambda\Lambda}Z$	Ξ^- Captured	$B_{\Lambda\Lambda} - B_{\Xi^-}$ [MeV]	$\Delta B_{\Lambda\Lambda} - B_{\Xi^-}$ [MeV]	Assumed level	$B_{\Lambda\Lambda}$ [MeV]	$\Delta B_{\Lambda\Lambda}$ [MeV]
NAGARA	$^{6}_{\Lambda\Lambda}He$	^{12}C	$B_{\Lambda\Lambda} = 6.79 + 0.91 B_{\Xi^-}$ (+/- 0.16) $\Delta B_{\Lambda\Lambda} = 0.55 + 0.91 B_{\Xi^-}$ (+/- 0.17) $B_{\Xi^-} < 1.86$		3D	6.91 +/- 0.16	0.67 +/- 0.17
MIKAGE	$^{6}_{\Lambda\Lambda}He$	^{12}C	9.93 +/- 1.72	3.69 +/- 1.72	3D	10.06 +/- 1.72	3.82 +/- 1.72
DEMACHI-YANAGI	$^{10}_{\Lambda\Lambda}Be^*$	^{12}C	11.77 +/- 0.13	-1.65 +/- 0.15 *cf.* *Ex* = 3.0	3D	11.90 +/- 0.13	-1.52 +/- 0.15 *cf.* *Ex* = 3.0
HIDA	$^{11}_{\Lambda\Lambda}Be$	^{16}O	20.26 +/- 1.15	2.04 +/- 1.23	3D	20.49 +/- 1.15	2.27 +/- 1.23
	$^{12}_{\Lambda\Lambda}Be$	^{14}N	22.06 +/- 1.15	------	3D	22.23 +/- 1.15	------
E176	$^{13}_{\Lambda\Lambda}B$ -> $^{13}_{\Lambda}C^*$		------ *Ex* = 4.9	-------	3D	23.3 +/- 0.7	0.6 +/- 0.8
	$^{10}_{\Lambda\Lambda}Be$ -> $^{9}_{\Lambda}Be^*$		------ *Ex* = 3.0	-------	not checked, yet.	14.7 +/- 0.4	1.3 +/- 0.4

M.Danysz et al., PRL.11(1963)29;
R.H.Dalitz et al., Proc. R.S.Lond.A436(1989)1

B_{Ξ^-} (atomic 3D) = 0.13 MeV [^{12}C- Ξ^-], 0.17 MeV [^{14}N- Ξ^-], 0.23 MeV [^{16}O- Ξ^-].

JPARC: E07 experiment

- 1.7GeV K- beam
- $3 \cdot 10^5$ K^-/4.8s
- 3 times larger emulsion volume
- Ξ atomic transisions?
- Factor of 10

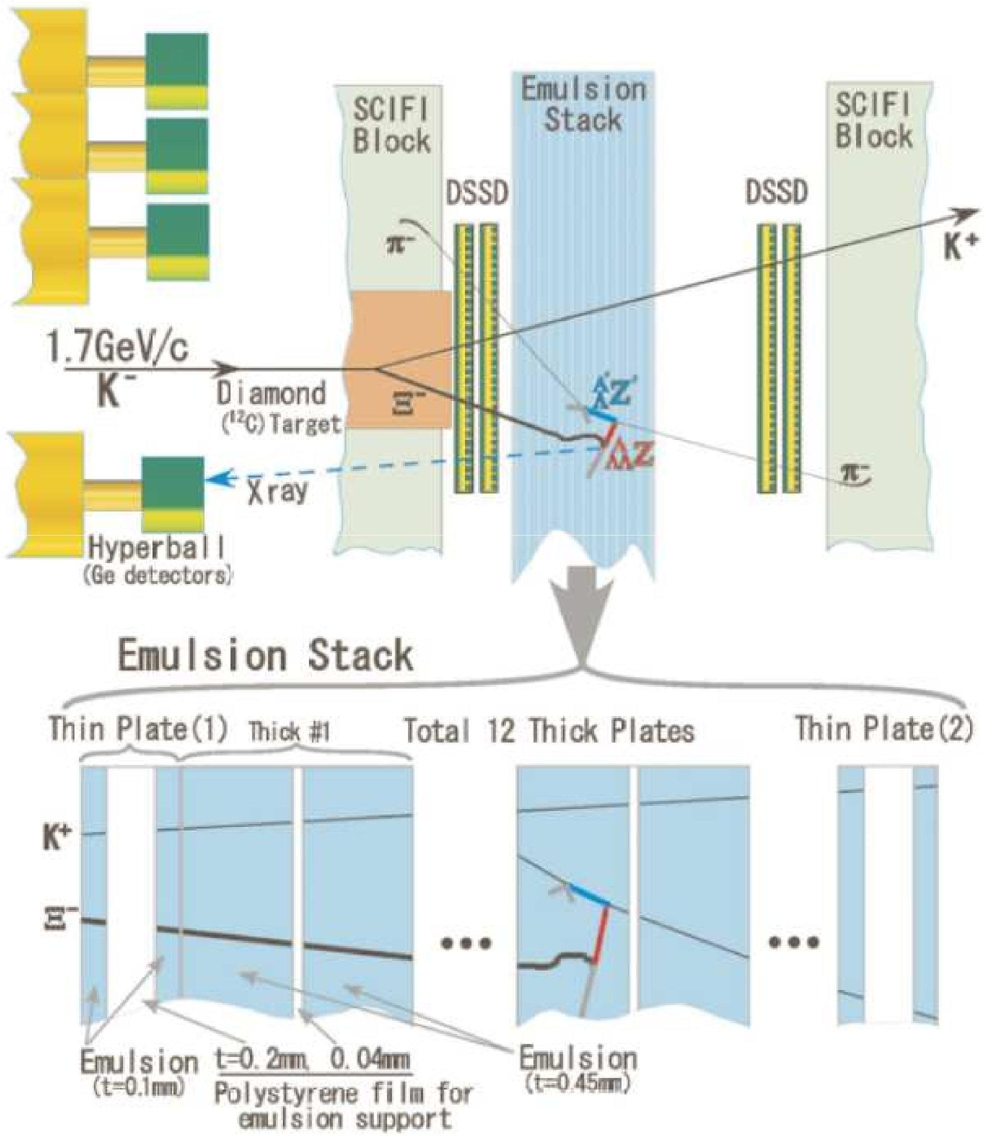
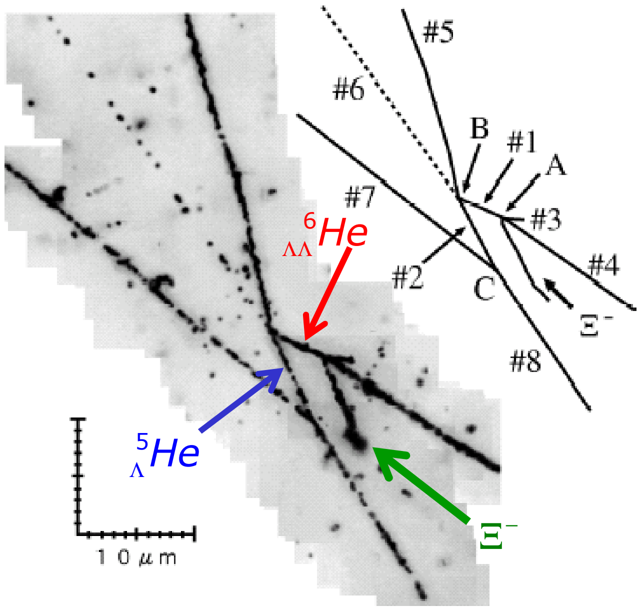
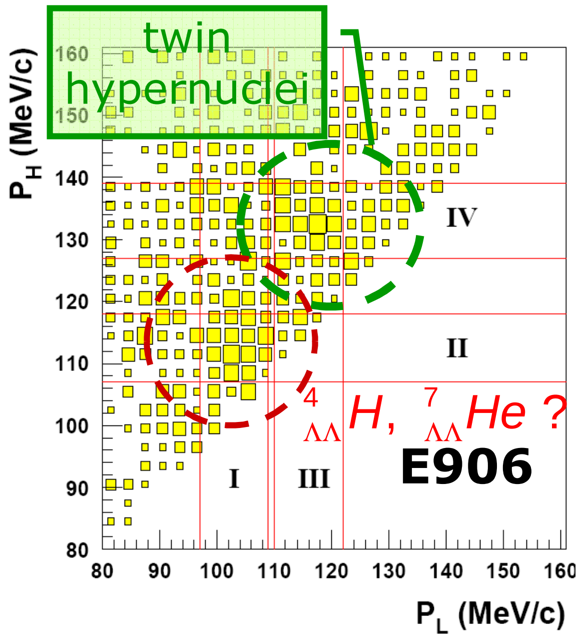


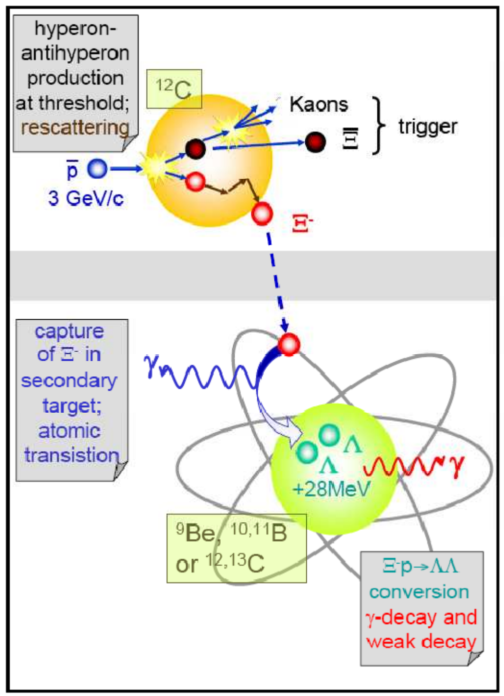
Figure 6: Setup of the E07 experiment at J-PARC.

Decay Products of ΛΛ Hypernuclei

- nuclear fragments ⇒ emulsion hadron+nucleus
  - detection of charged products only
  - limited to light nuclei
- weak decay products ⇒ BNL-AGS E906 $^{9}Be(K^{-},K^{+})X$
  - resolution limited
  - no information on excited states
  - interpretion not unique because π momenta are similar
- γ- spectroscopy ⇒ PANDA $\bar{p}$+A
  - no excited states observed yet, but theoretically predicted
  - How to identify the nucleus





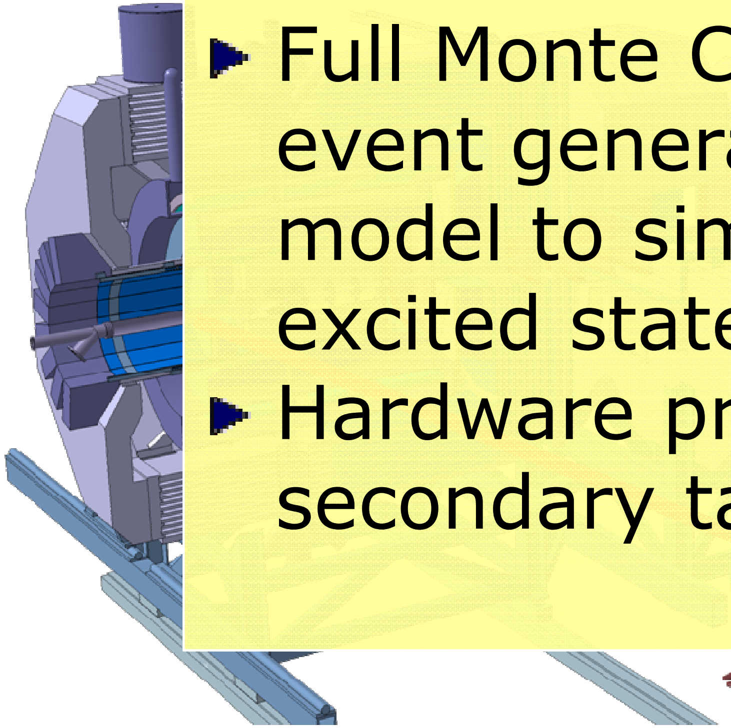


PANDA Setup

- θ_{lab}< 45°: $\bar{\Xi}^{-}$, K- trigger (PANDA)
- θ_{lab}= 45°-90°: Ξ-capture, hypernucleus formation
- θ_{lab}>90°: γ-detection Euroball at backward angles

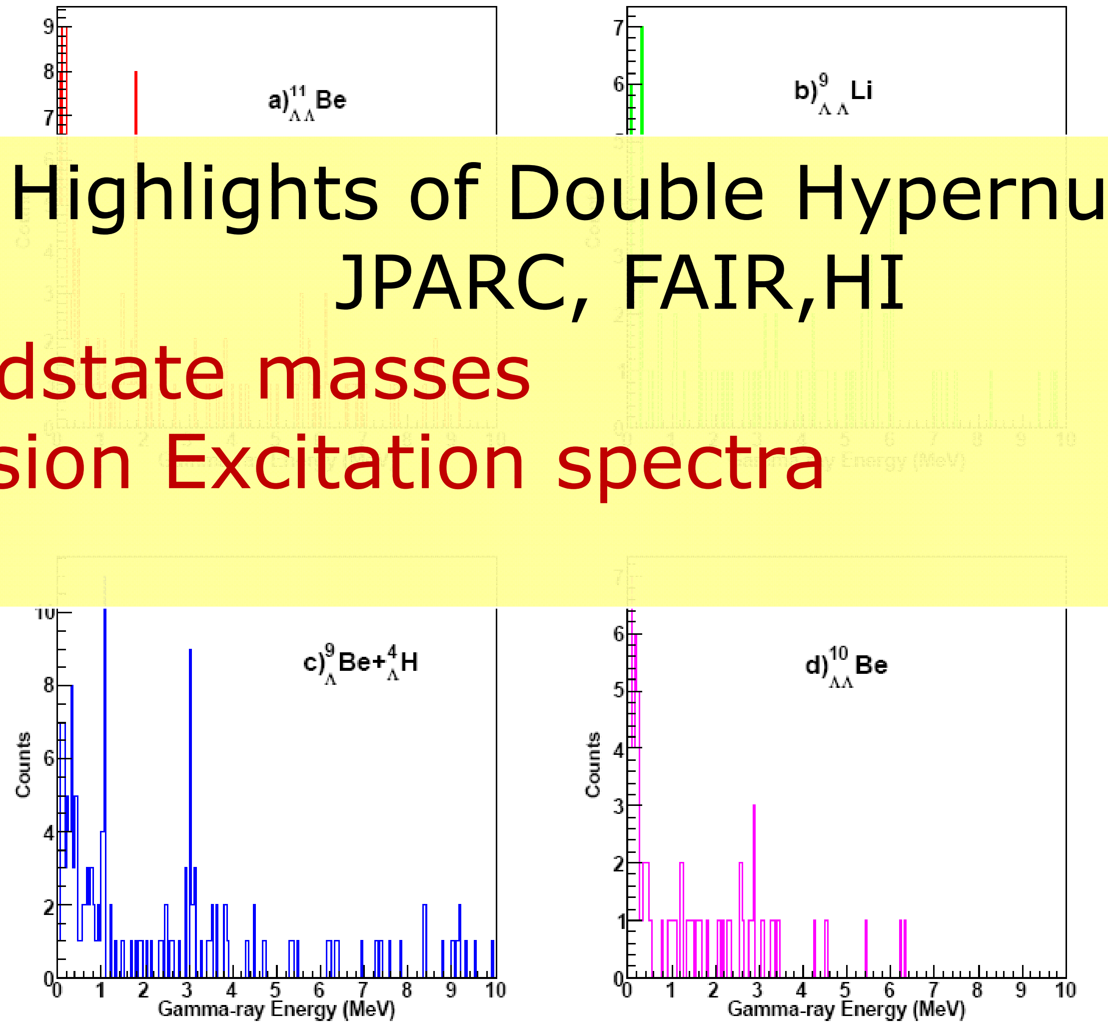
Milestones:

- Full Monte Carlo chain including event generator, new statistical model to simulate the population of excited states
- Hardware projects: Ge-detectors, secondary target, primary target…



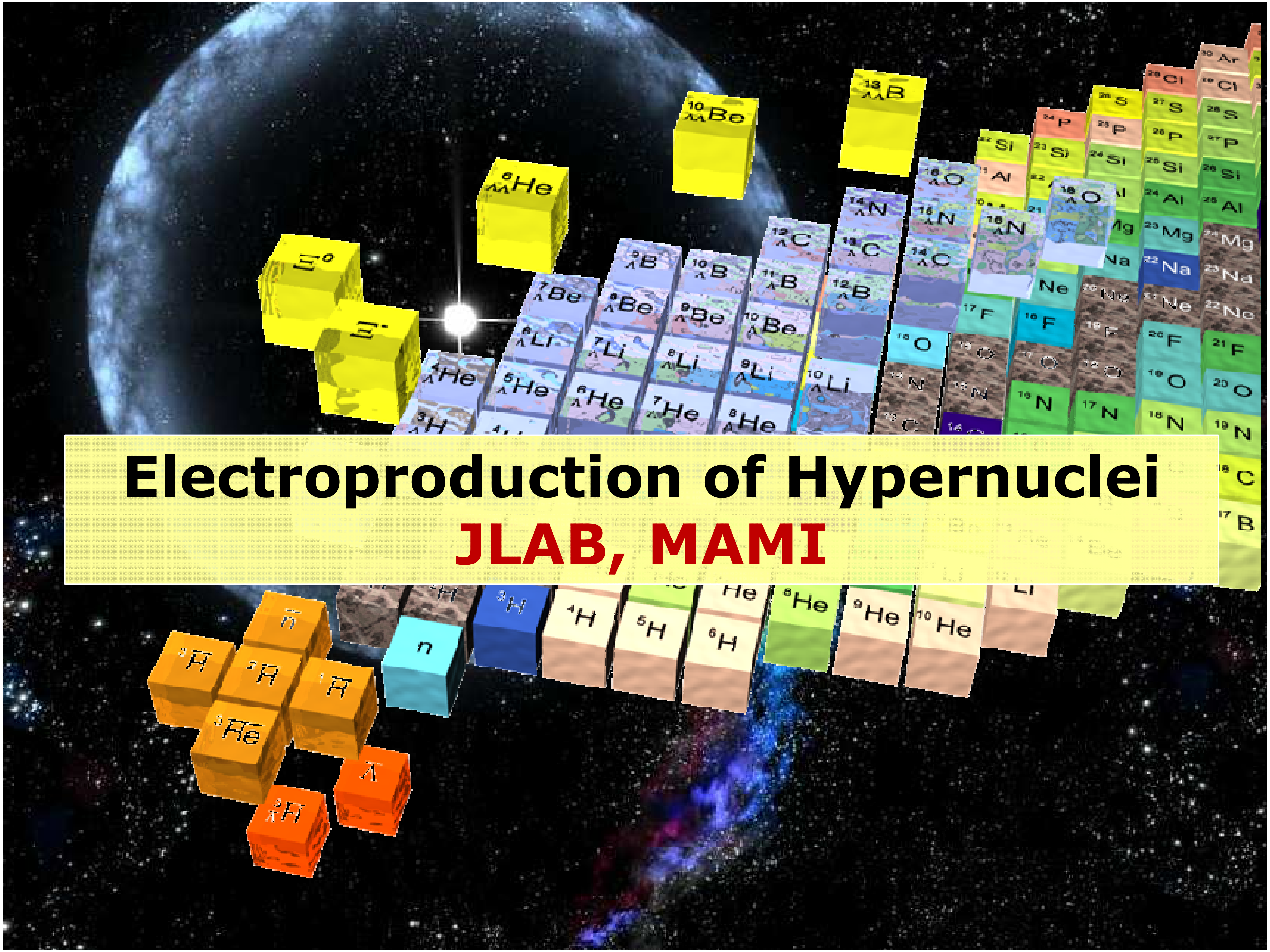
Simulation within PANDA_ROOT

- Example: secondary ^{12}C target (~2 weeks)



Highlights of Double Hypernuclei
JPARC, FAIR,HI

Groundstate masses
Precission Excitation spectra

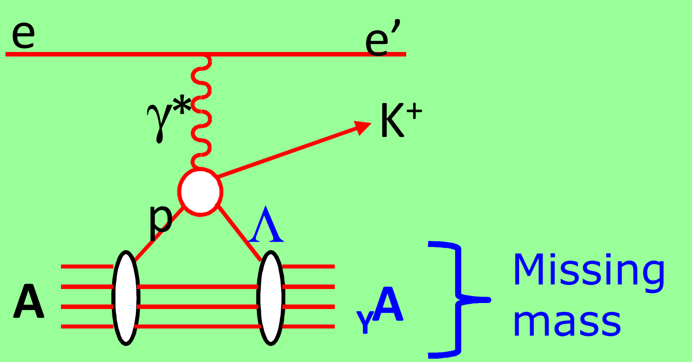


Electroproduction of Hypernuclei

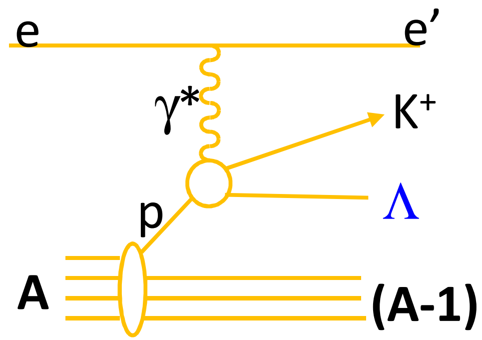
JLAB, MAMI

Electro-production of Hypernuclei

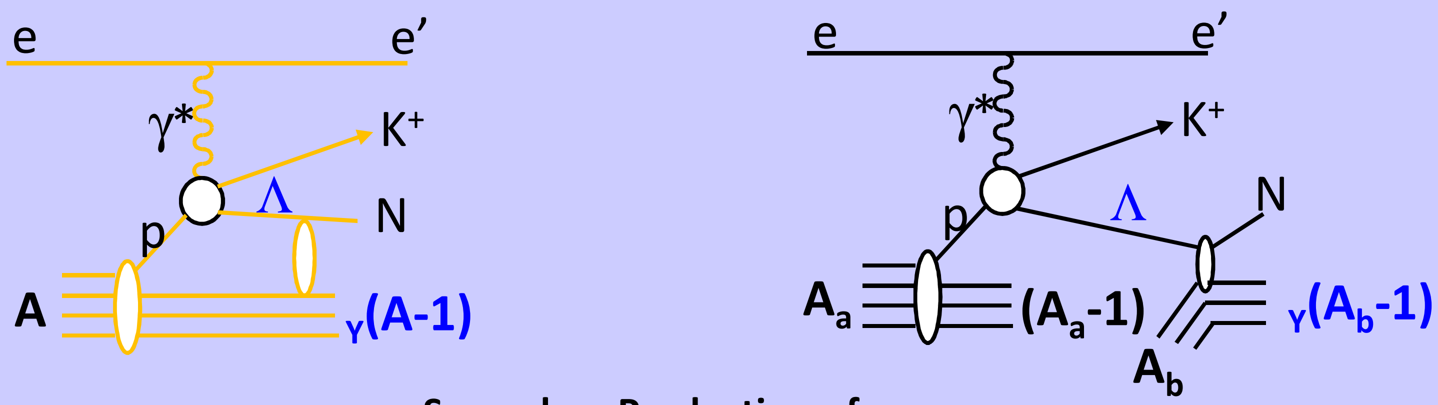
Courtesy
Liaung Tang



Direct production of Hypernuclei

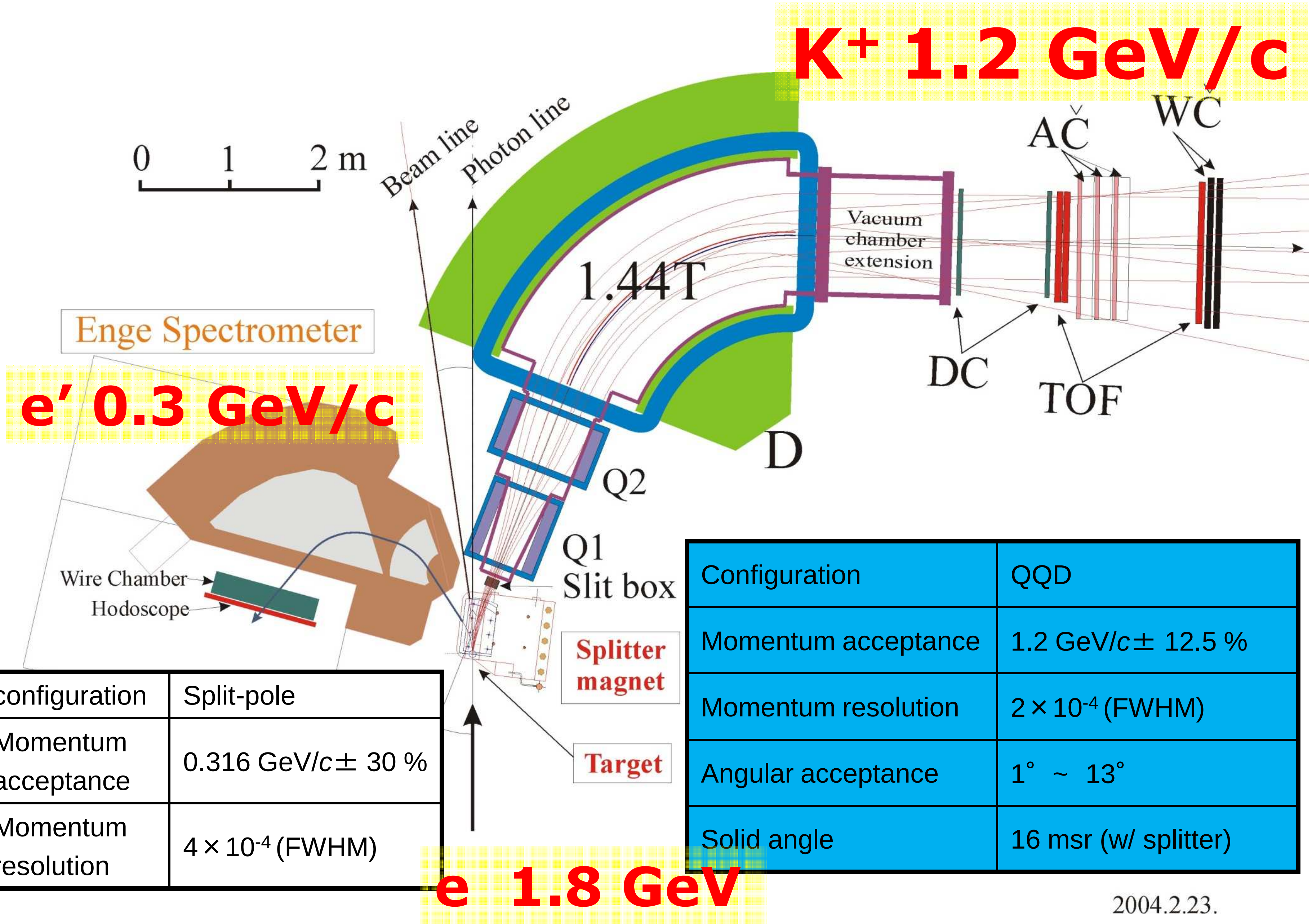


Quasi-free Λ production (Continuum)



Secondary Production of Hyperfragment (Continuum)

Hall A: 2nd Generation Exp. E01-011



configuration	Split-pole
Momentum acceptance	0.316 GeV/*c*± 30 %
Momentum resolution	4×10^{-4} (FWHM)

Configuration	QQD
Momentum acceptance	1.2 GeV/*c*± 12.5 %
Momentum resolution	2×10^{-4} (FWHM)
Angular acceptance	1° ~ 13°
Solid angle	16 msr (w/ splitter)

2004.2.23.

Charge Symmetry breaking

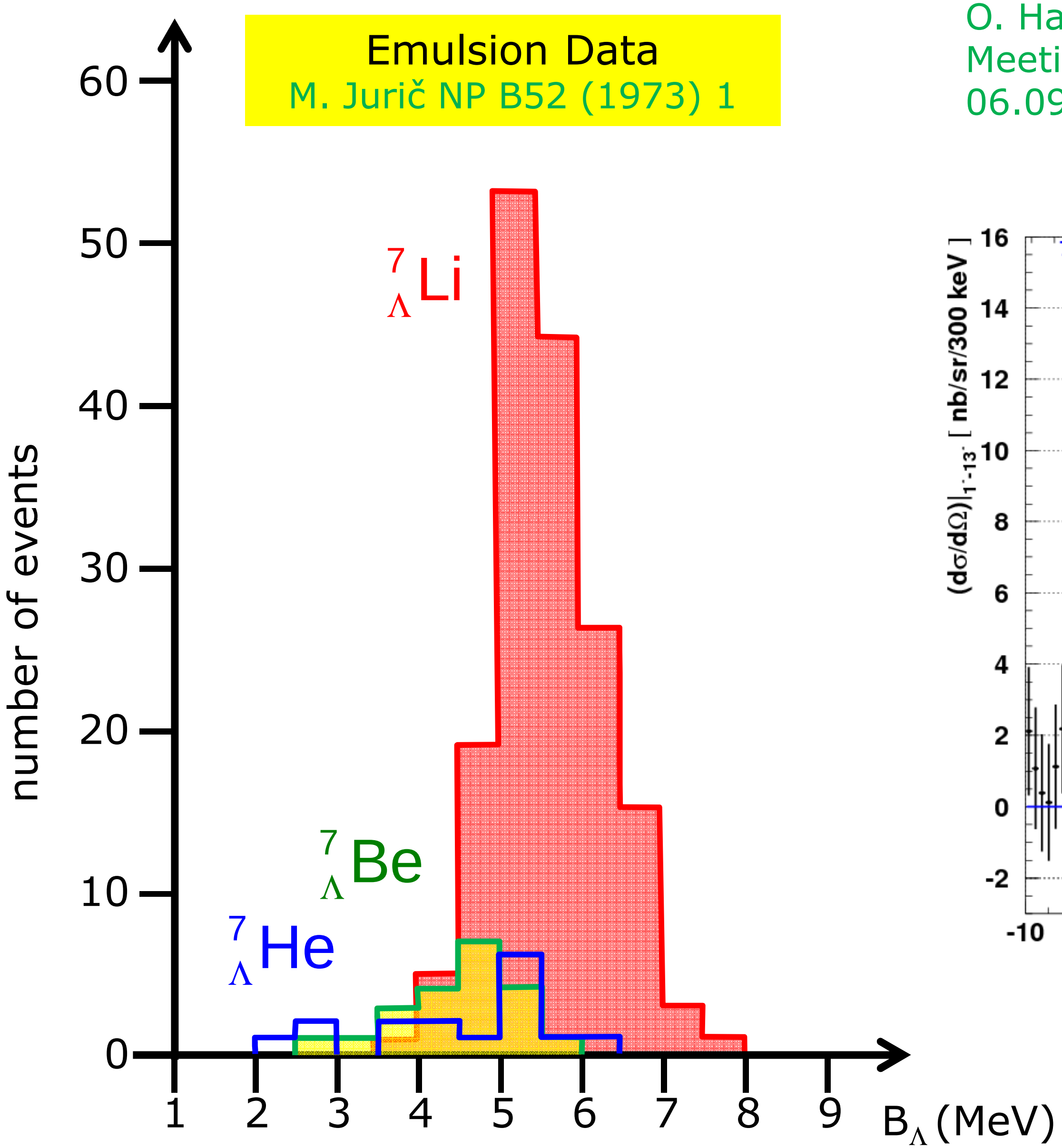
- If isospin is an exact symmetry and therefore also no ΛN charge symmetry breaking $\Rightarrow B_\Lambda$ of mirror nuclei identical

Z \ N	1	2	3	4	5	6	7	8	9	10
8				${}^{13}_{\Lambda}$O	${}^{14}_{\Lambda}$O	${}^{15}_{\Lambda}$O	${}^{16}_{\Lambda}$O	${}^{17}_{\Lambda}$O	${}^{18}_{\Lambda}$O	${}^{19}_{\Lambda}$O
7				${}^{12}_{\Lambda}$N	${}^{13}_{\Lambda}$N	${}^{14}_{\Lambda}$N	${}^{15}_{\Lambda}$N	${}^{16}_{\Lambda}$N	${}^{17}_{\Lambda}$N	${}^{18}_{\Lambda}$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
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
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								

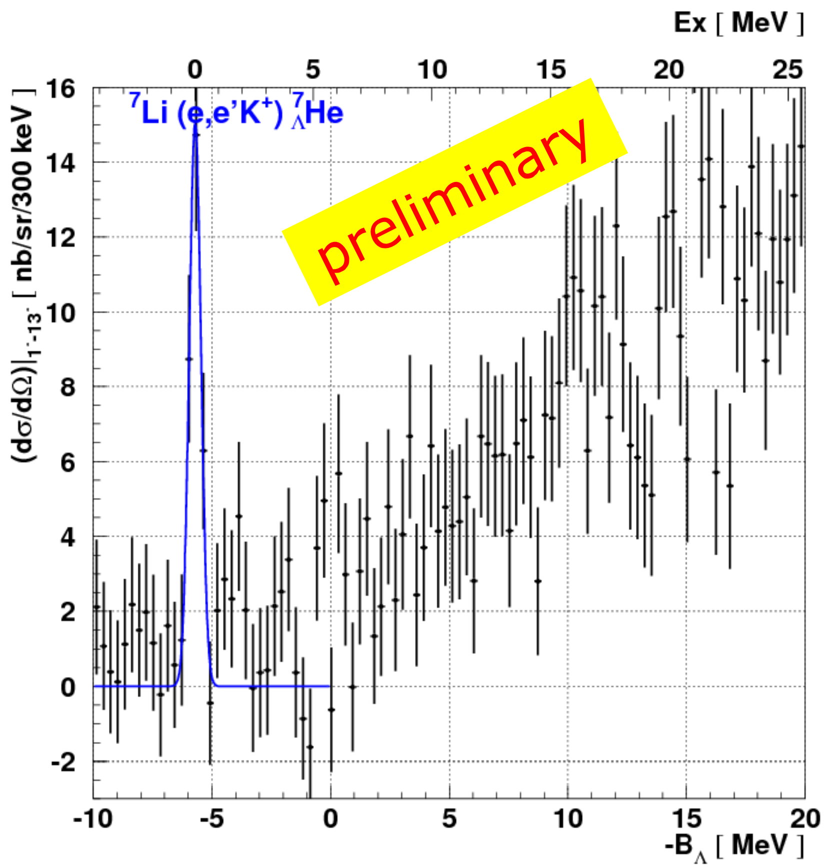
${}^{4}_{\Lambda}H$	2.04 ± 0.04	${}^{4}_{\Lambda}He$	2.39 ± 0.03
${}^{6}_{\Lambda}He$	4.18 ± 0.10	${}^{6}_{\Lambda}Li$	3.92 ± 0.37
	4.42 ± 0.13		
${}^{7}_{\Lambda}He$	3.69 ± 0.90	${}^{7}_{\Lambda}Be$	5.16 ± 0.08
${}^{8}_{\Lambda}Li$	6.80 ± 0.03	${}^{8}_{\Lambda}Be$	6.84 ± 0.05
${}^{9}_{\Lambda}Li$	8.53 ± 0.15	${}^{9}_{\Lambda}B$	7.88 ± 0.15
${}^{10}_{\Lambda}Be$	9.11 ± 0.22	${}^{10}_{\Lambda}B$	8.89 ± 0.12
${}^{12}_{\Lambda}B$	11.37 ± 0.06	${}^{12}_{\Lambda}C$	10.76 ± 0.19
			11.38 ± 0.09
${}^{16}_{\Lambda}N$	13.76 ± 0.16	${}^{16}_{\Lambda}O$	12.42 ± 0.05
			13.28 ± 0.36
			13.40 ± 0.40

- Differences could be caused by
  - Coulomb effects + other electromagnetic effects
  - nuclear CSB
  - ΛN CSB

$^{7}Li(e,e'K^{+})^{7}_{\Lambda}He$



O. Hashimoto, SPHERE & JSPS Meeting, Prague, Czech 04.09.2010-06.09.2010

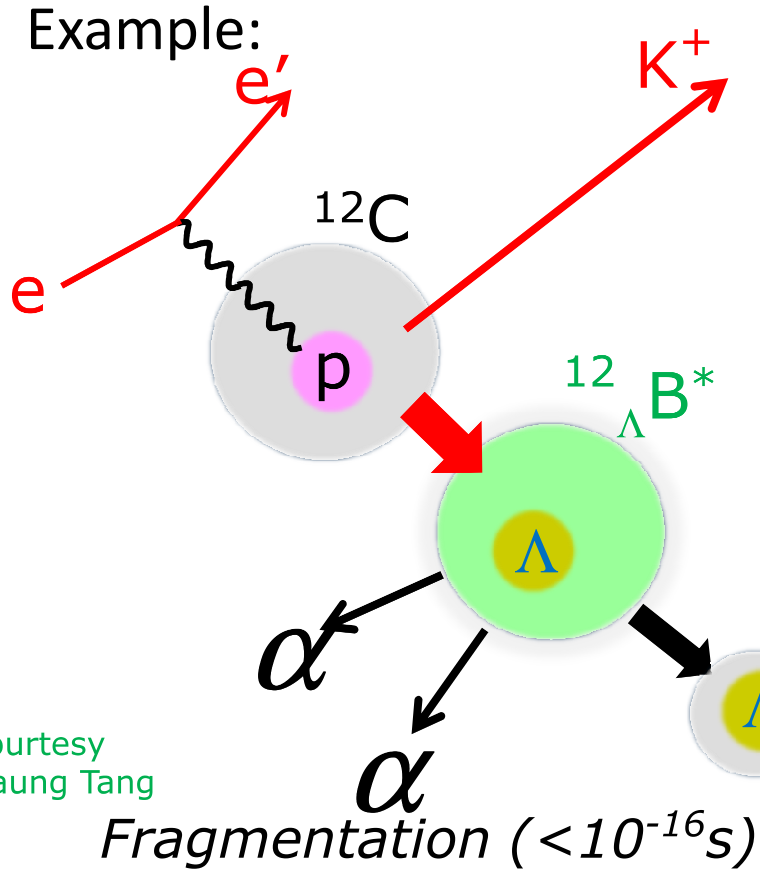


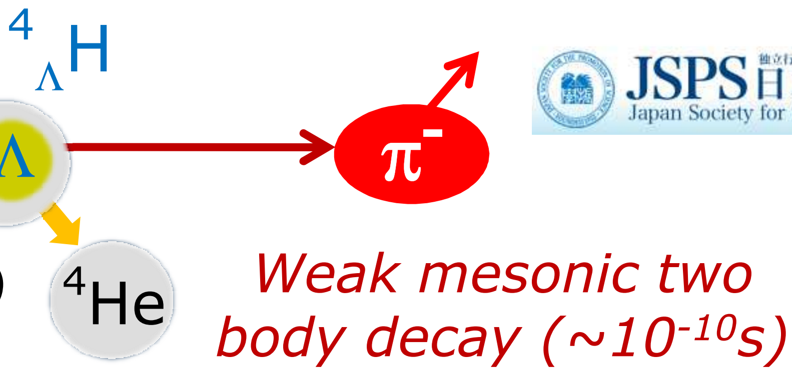
- FirstFirst reliable observation of $^{7}_{\Lambda}He$

Decay pion spectroscopy

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

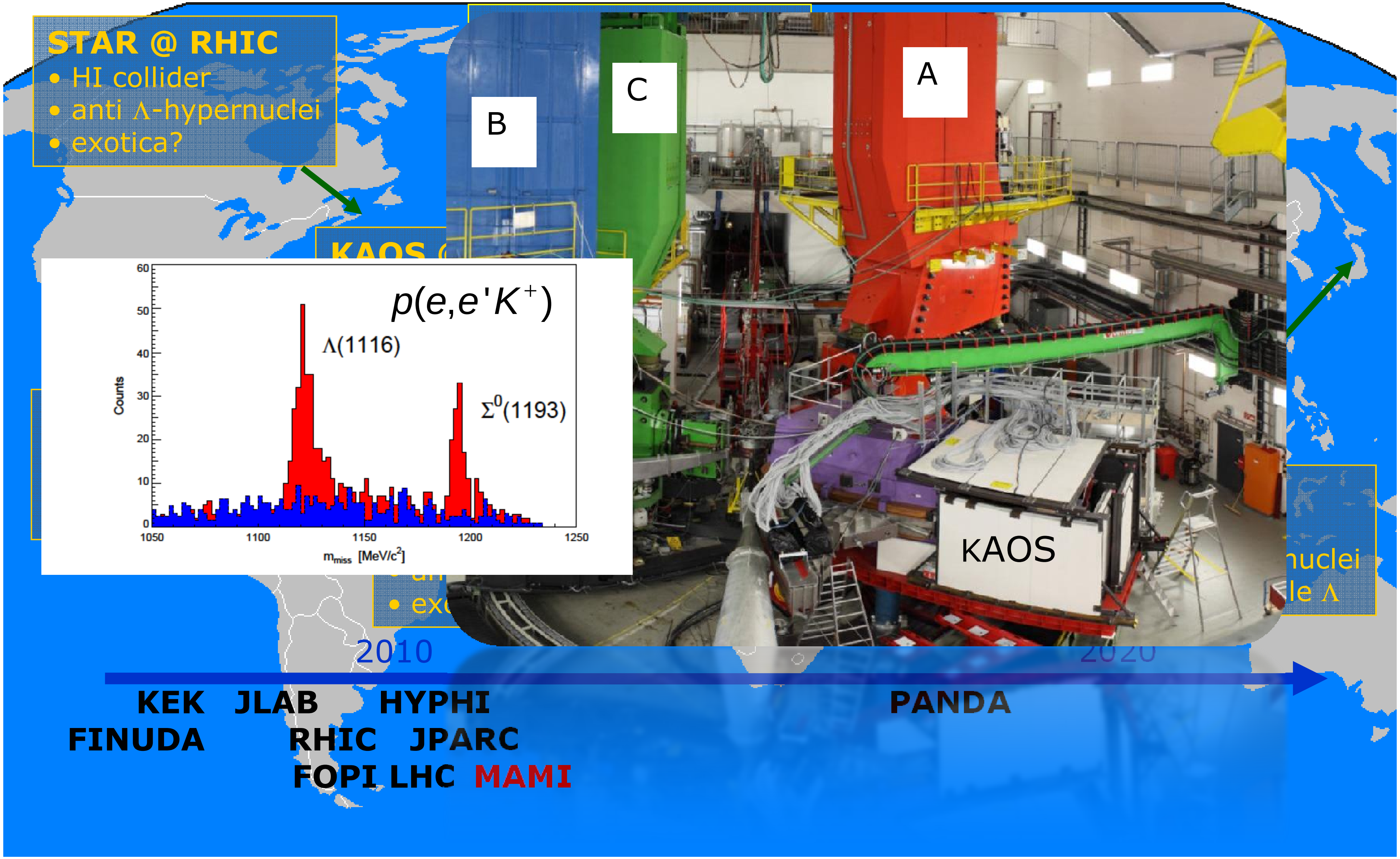
Example:



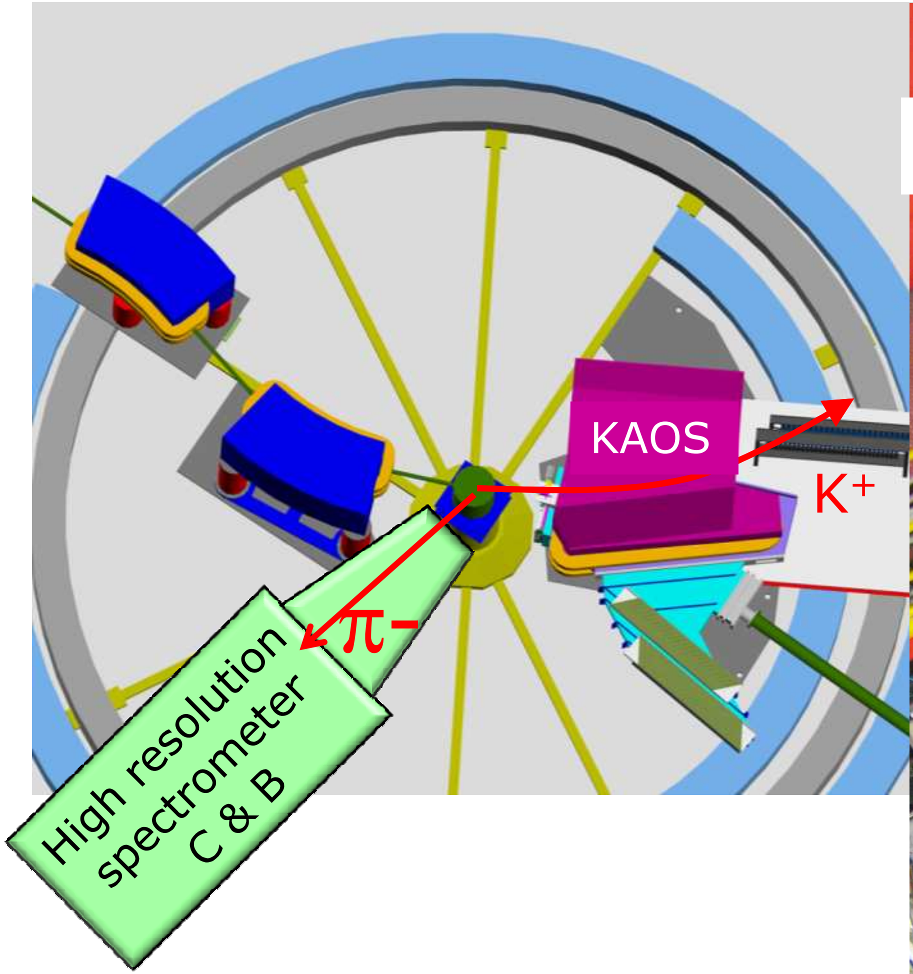


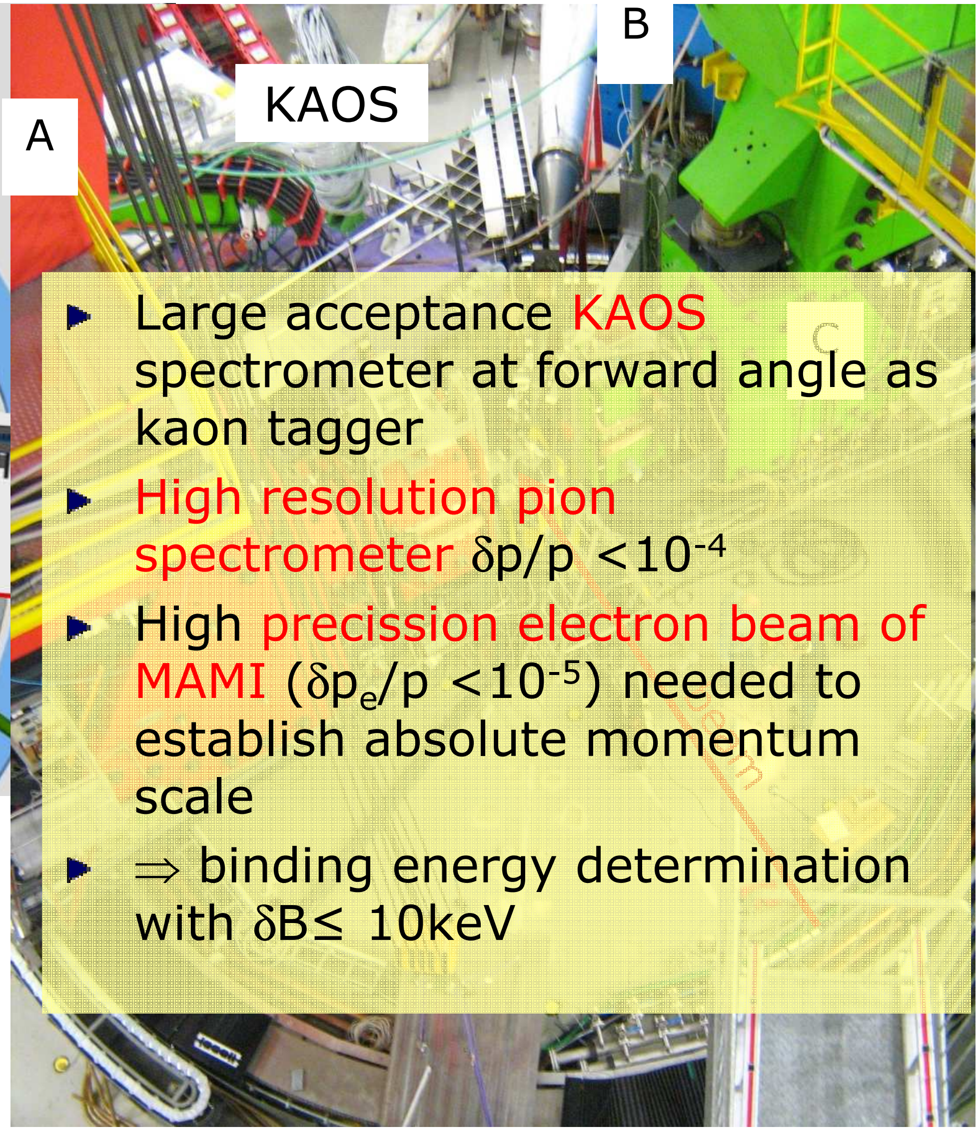
Courtesy Liaung Tang

International Hypernuclear Network



π–Spectroscopy at MAMI





- Large acceptance KAOS spectrometer at forward angle as kaon tagger
- High resolution pion spectrometer $\delta p/p < 10^{-4}$
- High precission electron beam of MAMI ($\delta p_e/p < 10^{-5}$) needed to establish absolute momentum scale
- $\Rightarrow$ binding energy determination with $\delta B \leq 10$keV

Expected Benefits ^{7}Li, ^{9}Be, ^{12}C targets

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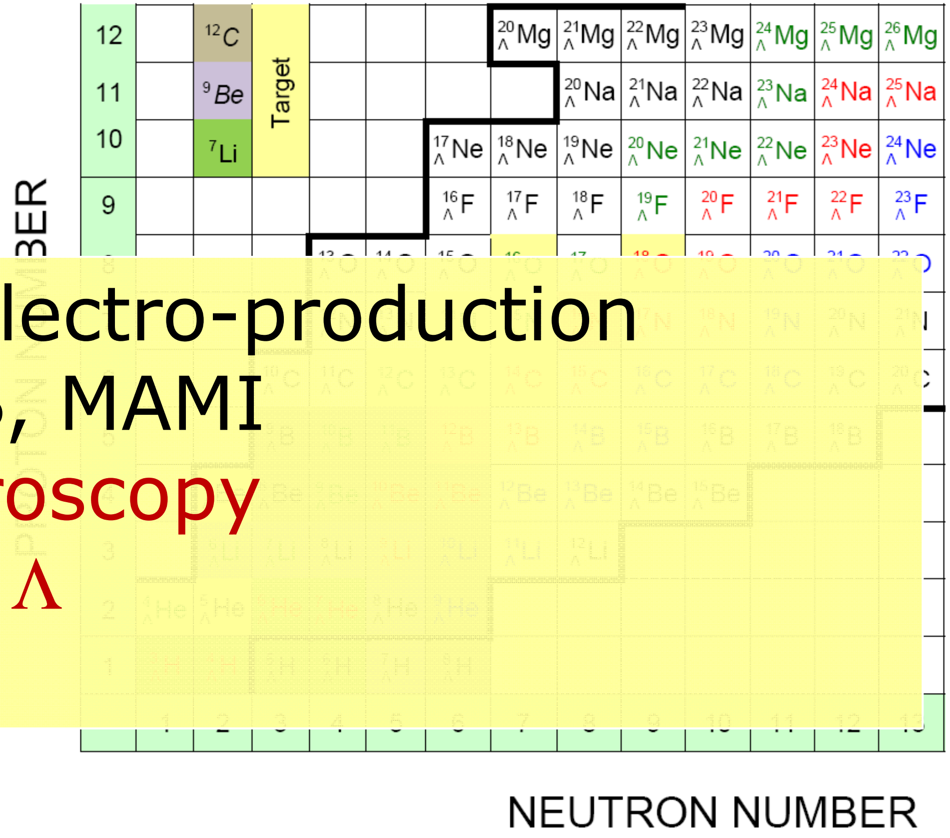
- High precision ground state mass of light hypernuclei
  - precise Λ binding energy < ±10 keV
  - Charge symmetry breaking
- Search for ... states
- Study the drip line limit on Λ-hypernuclei, ... hyper-hydrogen ... and $^8_\Lambda$H

Highlights of Electro-production JLAB, MAMI

Precission pion spectroscopy

Structure Function of Λ



JSPS 日本学術振興会 Japan Society for the Promotion of Science

Jefferson Lab Exploring the Nature of Matter

Summary

Experiment @Facility	Experimental tool & status	Methods & topics
JPARC	low mometum meson beams (π,K) setup ready, K beam intensity still limited (2011 aprox. 10% of design goal expected)	• Λ hypernuclei excited states (Δm~few keV) by γ-spectroscopy • Ξ-hypernuclei by missing mass • ground state masses of light double hypernuclei by hybrid emulsion (Δm~ few 10keV)
JLAB	electro production until 2012 upgrade of CEBAF	• Precission ground state masses by π^--spectroscopy (after 2012) • medium-heavy Λ-hypernuclei
A1@MAMI	electro production	• Precission ground state masses by π^--spectroscopy (Δm~10keV) • Λ-wave function by K angular distribution • Σ hyperon in light nuclei
HypHI@GSI&FAIR	projectile fragmentation 2AGeV - 15AGeV two experiments performed, data analysis ongoing	• ground state masses (Δm~few MeV) • lifetimes • exotic hypernuclei by radioactive beams
FOPI@GSI **STAR@AGS** **ALICE@LHC**	(symmetric) heavy ion collisions Signal seen by FOPI and STAR, analysis ongoing; ALICE started	• antihypernuclei and hypernuclei yields and ground state masses (Δm~few MeV) of S=-2 nuclei • lifetimes
PANDA@FAIR	antiproton beam in design and R&D stage; run after 2017	• level scheme of double ΛΛ hypernuclei by γ-spectroscopy (Δm<10keV)


THANK YOU