J. Pochodzalla

Perspectives for Hypernuclear Physics at the GSI Glue/Charm

Strange(ness) Matter(s)

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multi hypernuclei

Danysz (1963)

MEMO

metastable exotic multihypernuclear objects

Schaffner (1991)

strange stellar objects

Collins (1975)

strangelets

C. Greiner (1987)

QGP

'neutron' stars

Ambartsumyan & Saakyan (1960)

dark matter

YN and YY Interaction

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TOPIC

- **SU(2) → SU(3)** → SU(4)
- **strange matter** (e.g.H-search: ΛΛ nuclei as catalyst)
- **properties of strange baryons in nuclei**

LABORATORY

- single hypernuclei Λ, Ξ, Σ
- hyperon-atoms
- double hypernuclei

TOOLS

- γ-spectroscopy
  - better energy resolution
  - excited states not be populated by direct reactions
  - e.m. matrix elements, spin-parity
- decays of hypernuclei

present and future
hypernuclei studies at

BNL DAΦNE JLAB MAMIc

KEK GSI JHF HESR

goal: γ– and decay spectroscopy of double hypernuclei

→ YY interaction in nuclear medium

(ΛΛ correlations from HI probe free interaction)

OECD MEGASCIENCE FORUM

Final Report of the

WORKING GROUP on NUCLEAR PHYSICS

January 11, 1999

...

7. Future Facilities for Nuclear Physics

7.1 Radioactive Nuclear Beams

7.2 High-Energy Electron Facilities

7.3. Multi-Purpose Hadron Facilities

7.4 High-Energy Heavy Ion Collisions

7.3 Among the specific research topics that currently generate very high levels of interest among nuclear physicists are:

- hyperon-nucleon interactions and hypernuclear physics,
- hadron properties and interactions in nuclear matter,
- antiproton physics,
- light and heavy quark spectroscopy,
- kaon decays and other processes to measure CP parameters,
- flavour mixing and other topics beyond the Standard Model,
- accelerator-based neutrino oscillation experiments,
- other topics in hadron physics (hadron spectroscopy, physics with polarised protons, physics with heavy ion beams, etc.),
- other specific experiments in fundamental symmetries (neutron dipole moment, g-2, etc.).

Double Hypernucleus Production by Ξ^- Capture

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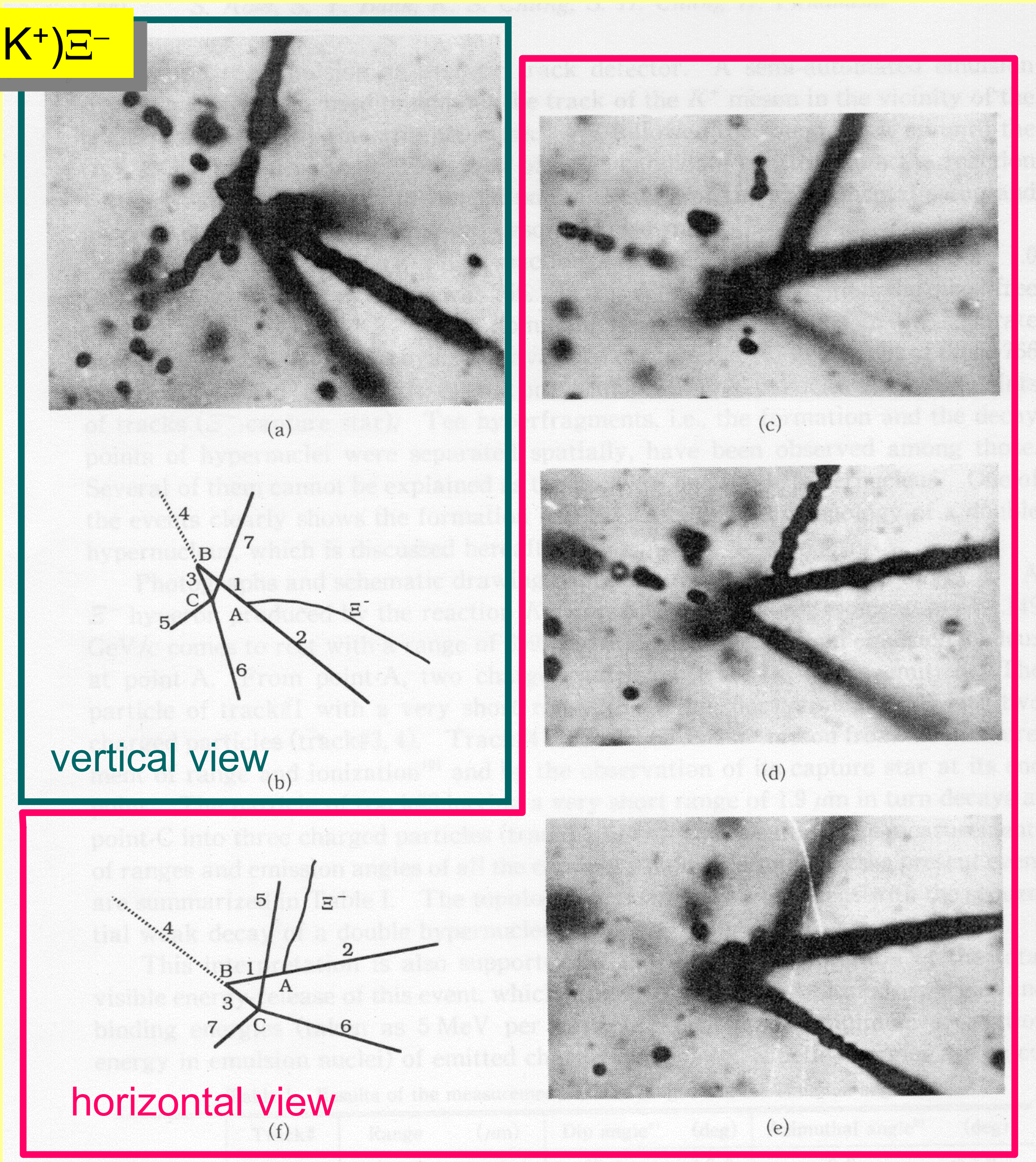
"cool" production: energy release $\Delta E = 28$ MeV for $\Xi^- p \rightarrow \Lambda\Lambda$

$(K^-,K^+)\Xi^-$



at point A: $\Xi^- \; {}^{14}N \rightarrow p \; n \; {}^{13}_{\Lambda\Lambda}B$

at point B: ${}^{13}_{\Lambda\Lambda}B \rightarrow \pi^- \; {}^{13}_{\Lambda}C$

at point C: ${}^{13}_{\Lambda}C \rightarrow {}^{3}He \; {}^{4}He \; {}^{4}He \; 2n$

KEK-E176
S. Aoki *et al.*,
Prog. Theor.Phys.
85, 1287 (1991)

The Darmstadt Secondary Beams Facility

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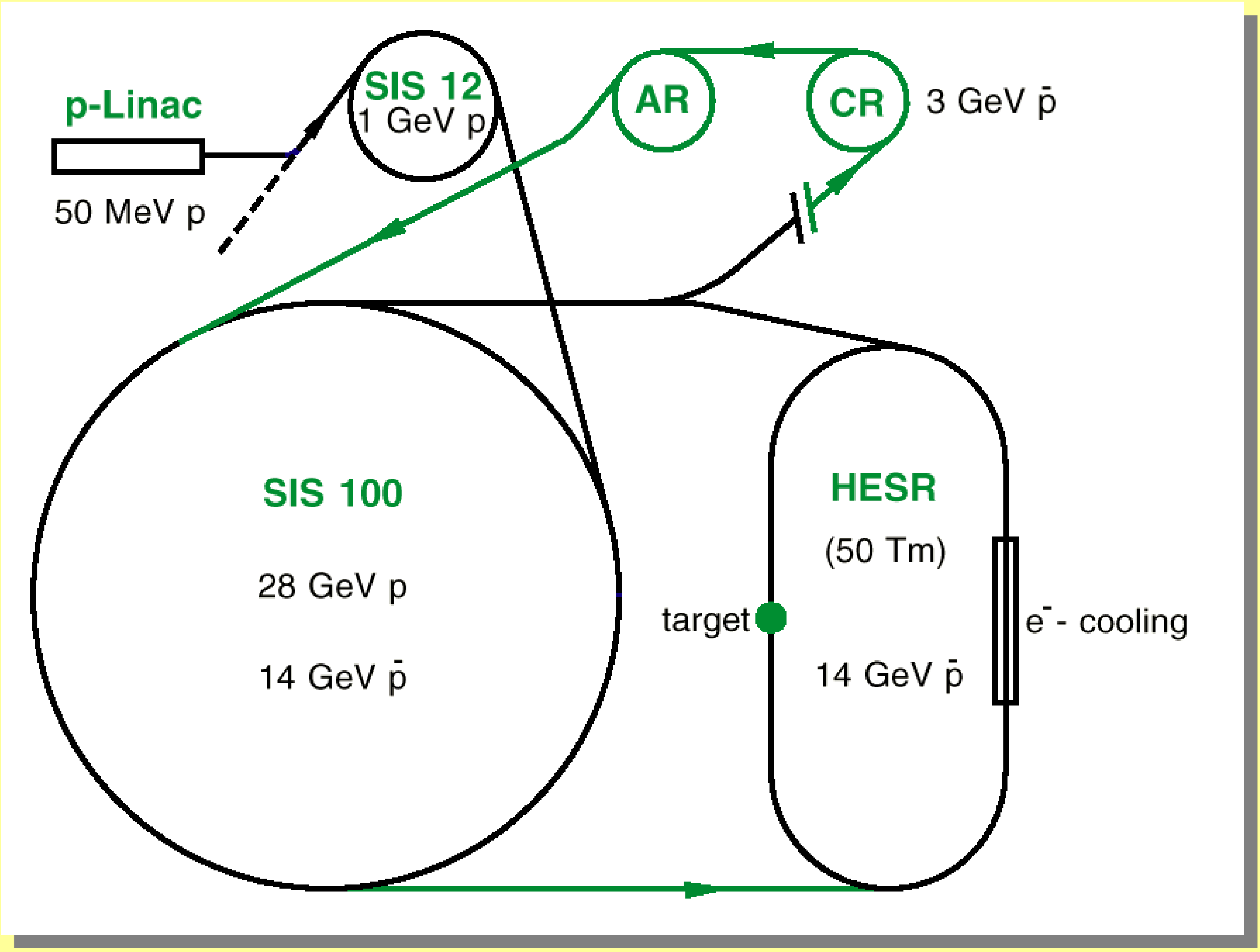

3 Key Experiments:

- *CP*-violation
- Exotic QCD states (e.g. qqg)
- Spectroscopy of multi-hypernuclei

http://www.ep1.ruhr-uni-bochum.de/gsi

Hadron-Antihadron Production in p̄p Collisions

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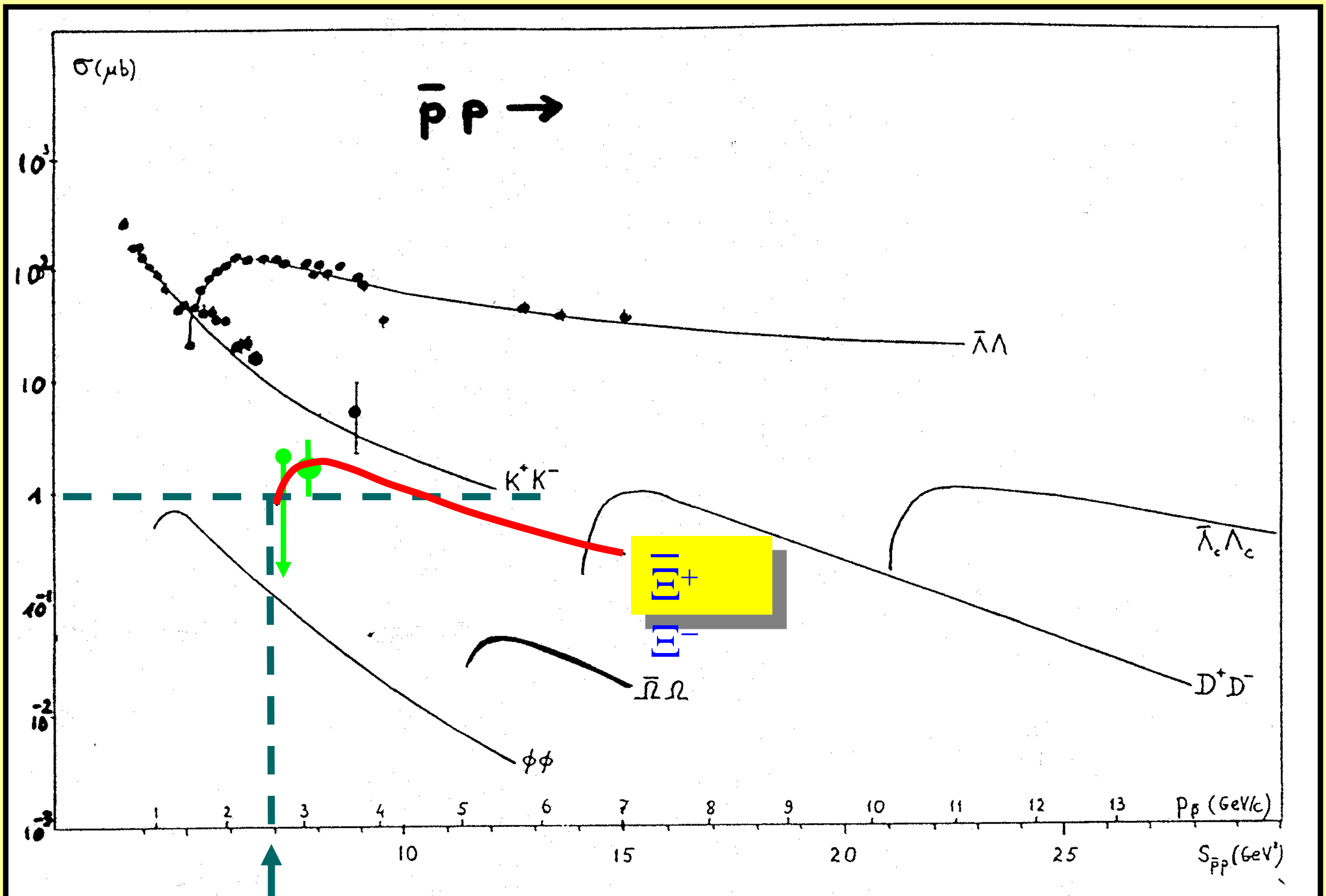
Kaidalov & Volkovitsky

quark-gluon string model



2.6 GeV/c

data:

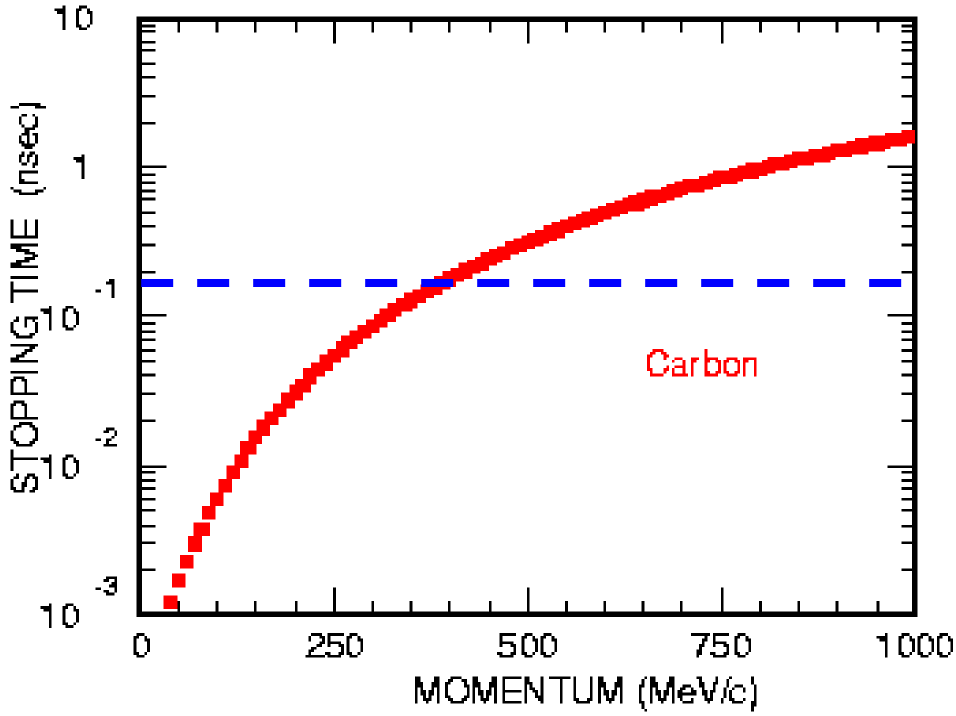
B. Musgrave *et al.*, il Nuovo Cimento **35**, 735 (1965)

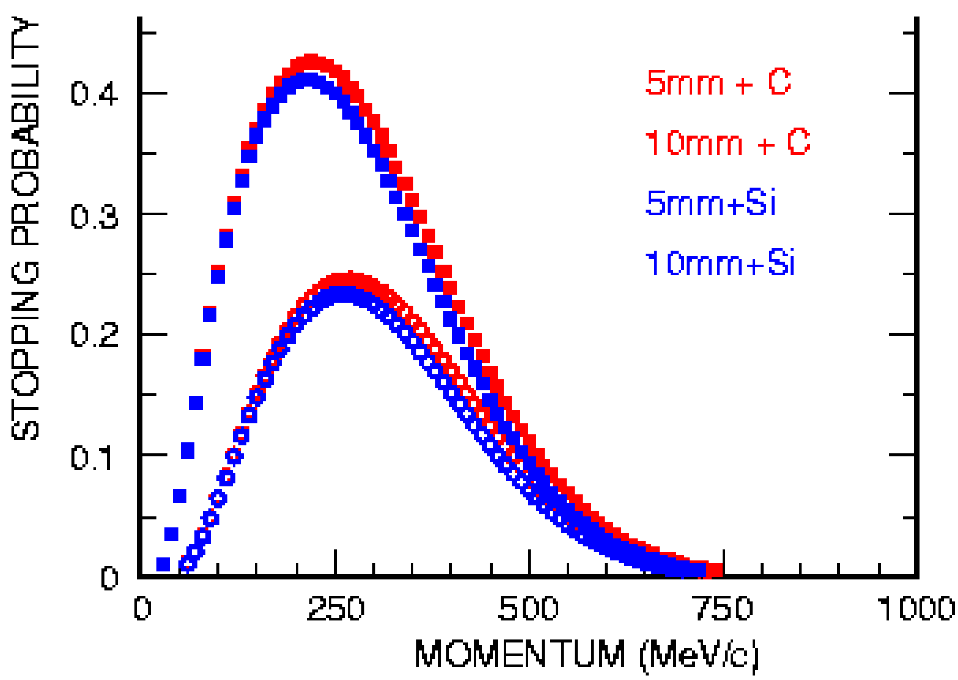
G.P. Fisher *et al.*, Phys. Rev. **161**, 1335 (1967)

8 with L=2·10^{32} cm^{-2}s^{-1} à 1300 s^{-1} for a C target

Ξ⁻ Properties

- Ξ⁻ mean life 0.164 nsec





8 minimize distance *production à capture*

initial momentum 100-500 MeV/c

Hyperon Production

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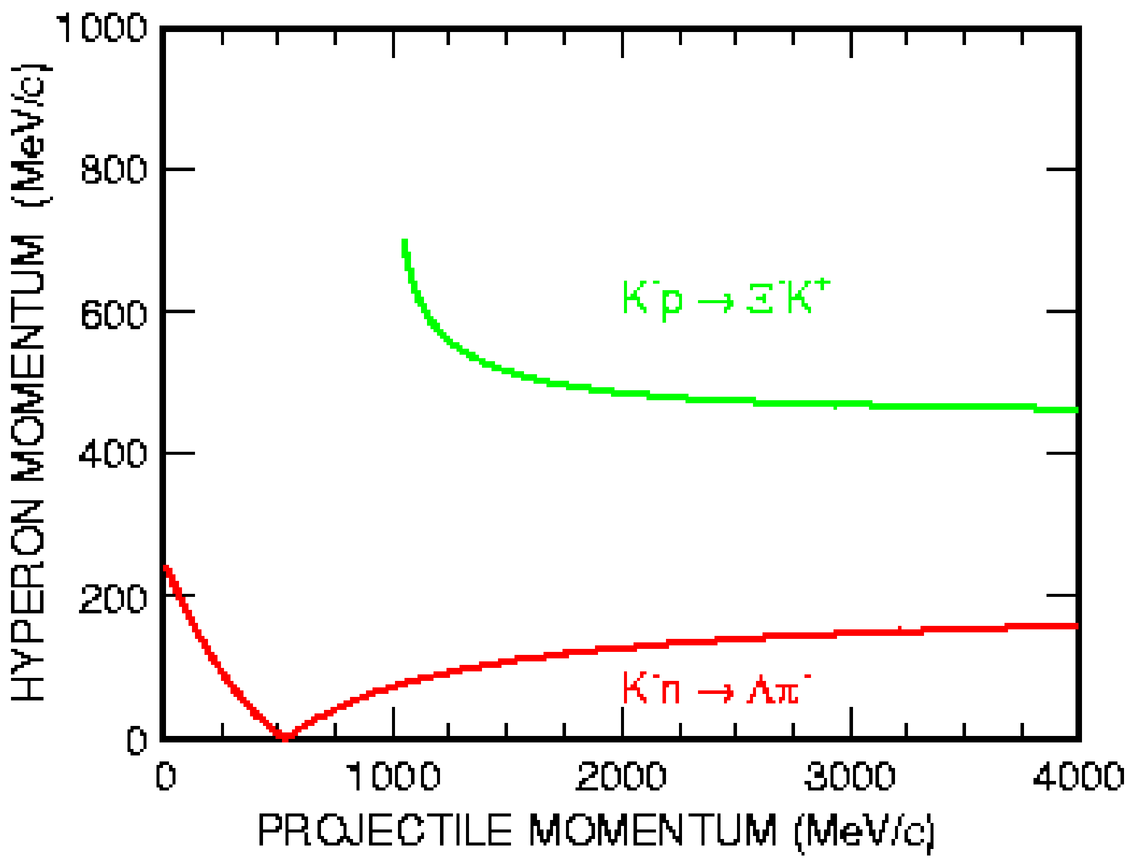
- strangeness exchange



8 typical Ξ recoil momentum > 460 MeV/c

storage of K^- not possible ($c\tau$ = 3.7 m)

KEK-E176:	80 stopped Ξ
ß E373:	1000 stopped Ξ
AGS-E885:	9000 stopped Ξ

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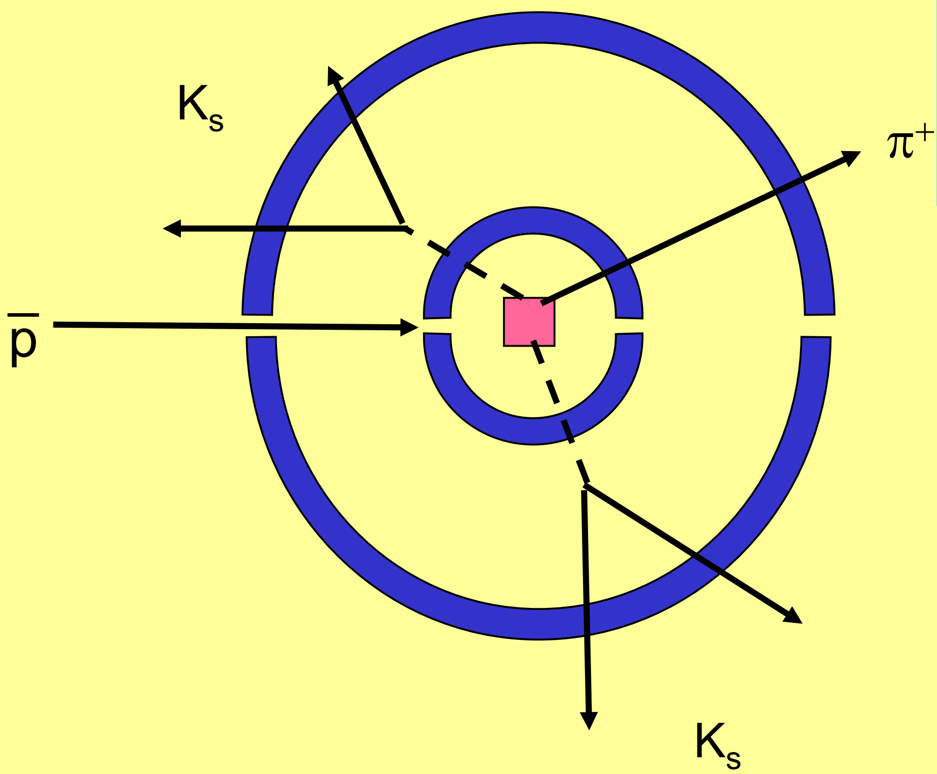
Double Hypernuclei in $\bar{p}$ Annihilation at Rest

K. Kilian (1987)

$p\bar{p} \rightarrow K^{*}\bar{K}^{*}$ p(K^{*}) = 285 MeV/c

å $\bar{K}^{*}pn \rightarrow \pi^{+}$ K H

p ^{3}He $\rightarrow KK\pi^{+}H$



multiplicity jump

trigger 1 $\rightarrow$ 5

$p\bar{p} \rightarrow K^{*}\bar{K}^{*}$ p(K^{*}) = 285 MeV/c

å $\bar{K}^{*}N \rightarrow K\ \Xi$

p d $\rightarrow \{KK\pi\}^{+}\ \Xi^{-}$

Production of low-momentum Ξ^-

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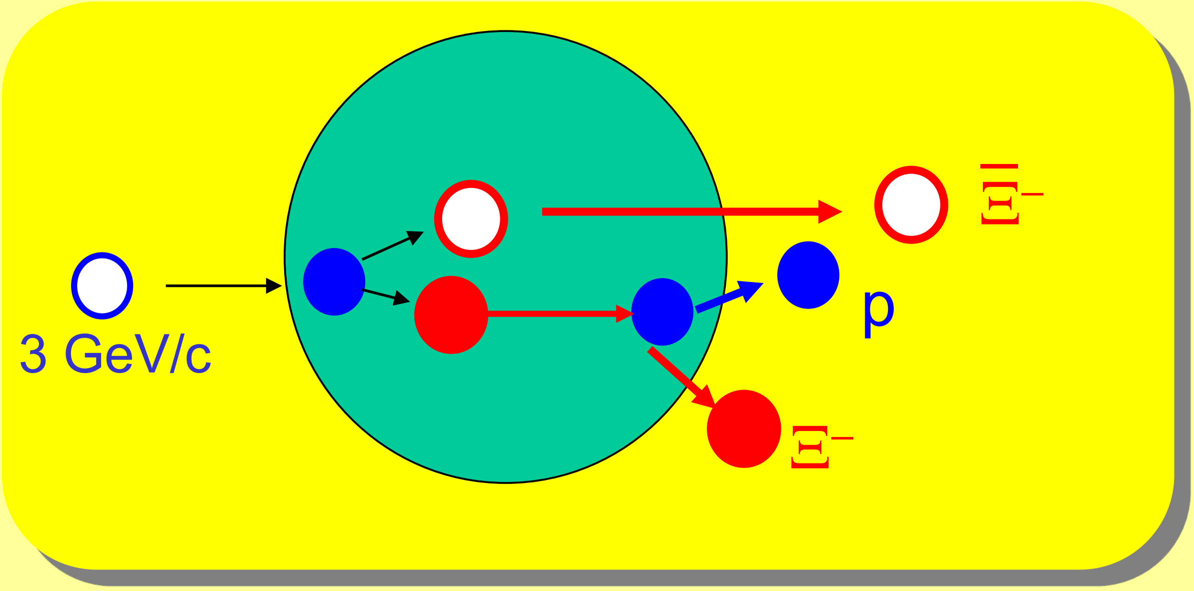
- $\Xi^- \bar{\Xi}^+$ production close to threshold (p_{TH} = 2.62 GeV/c)
- de-accelerate Ξ^- by Ξ^- p elastic scattering



signature:

- $\bar{\Xi}^-$ with large momentum
- Ξ^- capture and secondary decay

Schematic Setup & Technical Challenges

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beam: 3 GeV/c, Ø ≈1mm

internal target (gas-jet e.g. Ne) width 1mm

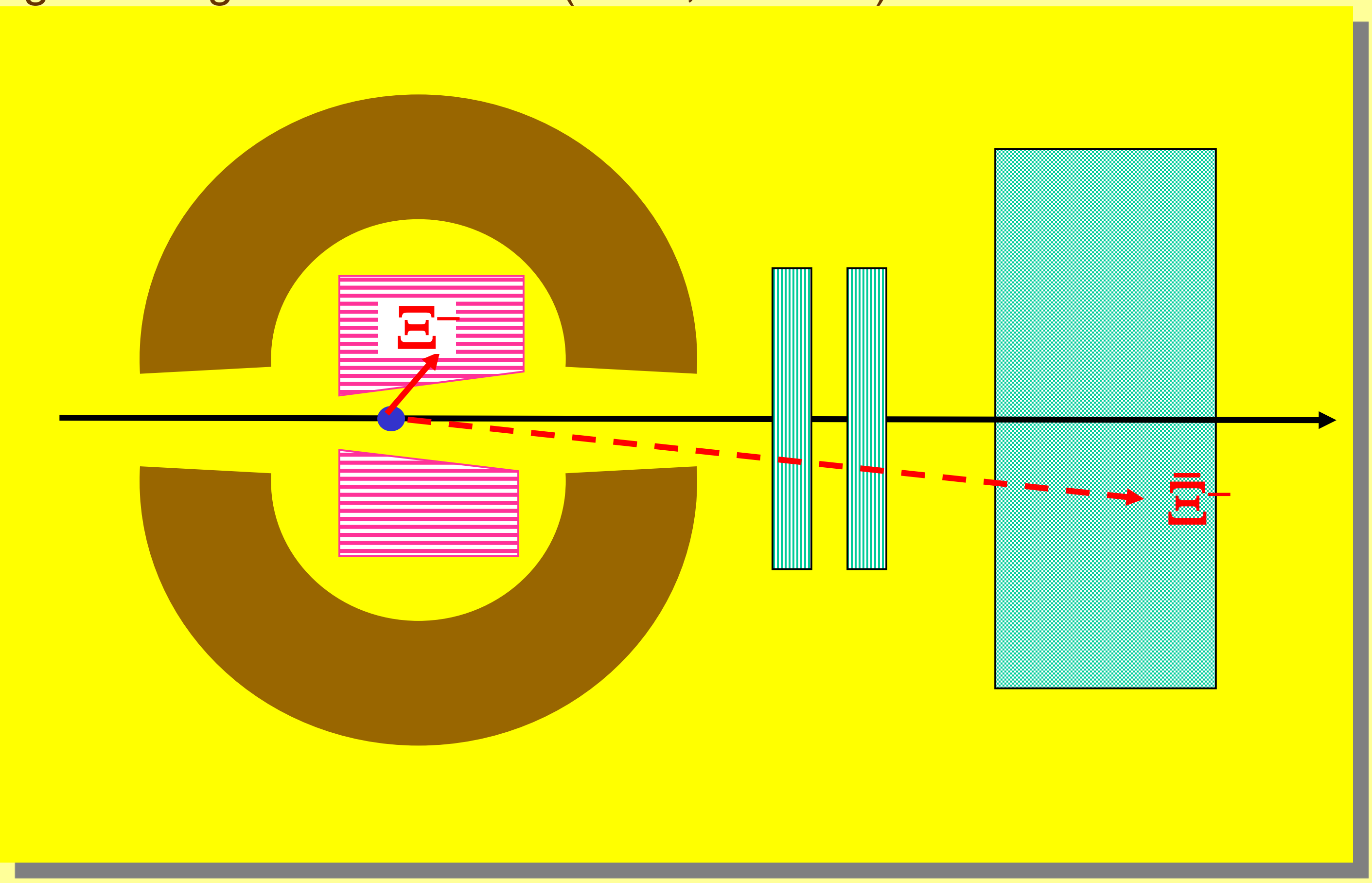
diamond strip detector block: 26 mm thick; $\theta_{LAB} > 20^o$

forward tracking detectors: $\theta_{LAB} \leq 20^o$

(e.g. GEM, szintillators for stopped anti-protons with 1GeV/c)

"4π" Germanium array

granular gamma-detector (CdTe, CdZnTe) ?



...additional tracking detectors for secondary decay products

Expected Count Rate

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- luminosity $2\cdot10^{32}\,cm^{-2}s^{-1}$
- $\bar{\Xi}^{+}\Xi^{-}$ cross section 2μb for $\bar{p}p$ Þ 1300 Hz
- p(100-500 MeV/c) $p_{500}\approx 0.0005$
- Ξ^{+} reconstruction probability 0.5
- stopping and capture probability $p_{CAP}\approx 0.20$

8 total stopped Ξ^{-} 5600 / day

- total ΛΛ conversion probability $p_{\Lambda\Lambda}\approx 0.05$

8 total ΛΛ hyper nucleus production 8400 / month

- gamma emission/event, $p_{\gamma}\approx 0.5$
- γ-ray peak efficiency $p_{GE}\approx 0.1$

8 total γ–rate ≈ 0.4/ hour

8 30 days beam time:

77000 stopped Ξ^{-} (KEK-E176: 80 ß E373: 1000)

3800 ΛΛ - hyper nuclei produced

~400 pionic decays

300 γ-transitions detected

Two-Kaon trigger for Ξ^- production

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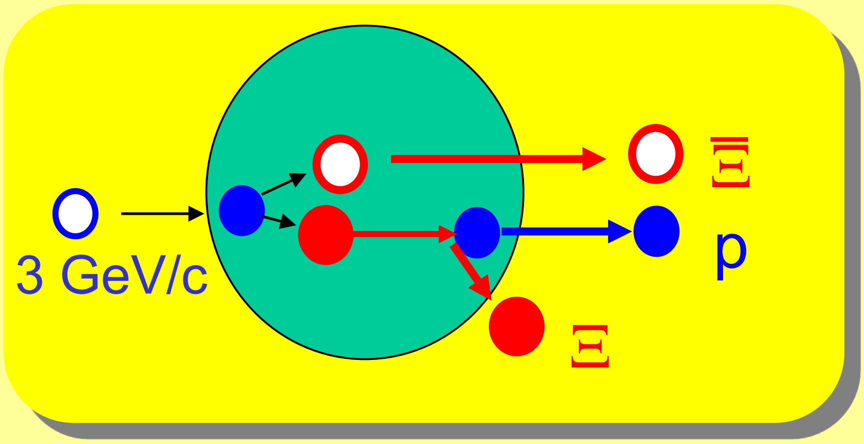
- $\overline{\Xi}$ absorption dominant ($\sigma=0.8\cdot\sigma_{ABS}(\overline{p}p)$)
- $\overline{\Xi}$NÞ KKπ^n strong



8 2K trigger may increase yield by about 2 orders of magnitude

facility	*reaction*	*cross section*	*device*	*beam/ target*	*stopped Ξ^- per day*
JHF	$(K^-,K^+)\Xi$	10 μb	spectrome-ter, $\Delta\Omega$ =30 msr	$8\cdot10^6$/sec 5 cm ^{12}C	7000
cold anti-protons	$p\overline{p} \rightarrow K^*\overline{K}^*$ $K^*N \rightarrow \Xi\overline{\Xi}$	$p \approx 10^{-7}$	vertex detector	10^6 stopped $\overline{p}$ per sec	5000
GSI	$p\overline{p} \rightarrow \Xi\overline{\Xi}$	2 μb	vertex detector + spectrom.	$L=2\cdot10^{32}$ thin target	5600 „golden events“ 500000 KK trigger

The VEGA Detector

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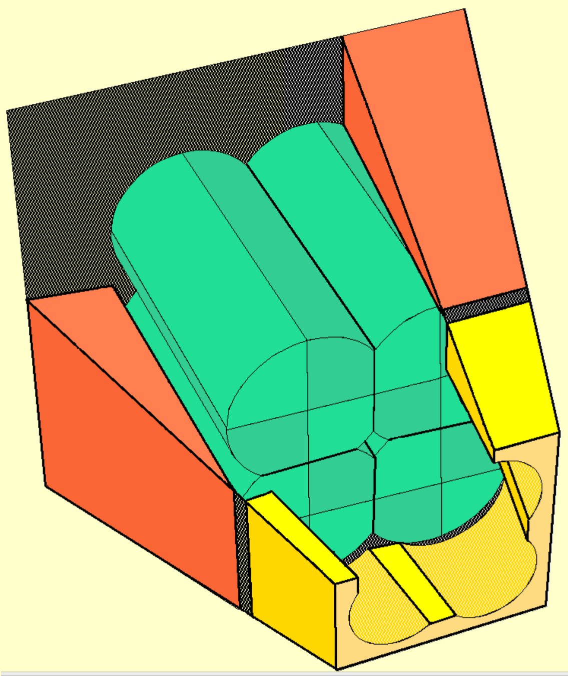
Versatile and **E**fficient **GA**mma –detectors

Segmented Clover

7 cm Æ, 14 cm long

ε_{ph} (1.3 MeV)	0.38
ε_{ph} (10 MeV)	0.11
P/T (1.3 MeV)	D 0.7
N_{gr}	4w4



Status

- 1 seg. clover delivered
- 2 seg. clover ordered, delivery 5/2000
- fast readout electronics in development

Segmented Clover Box

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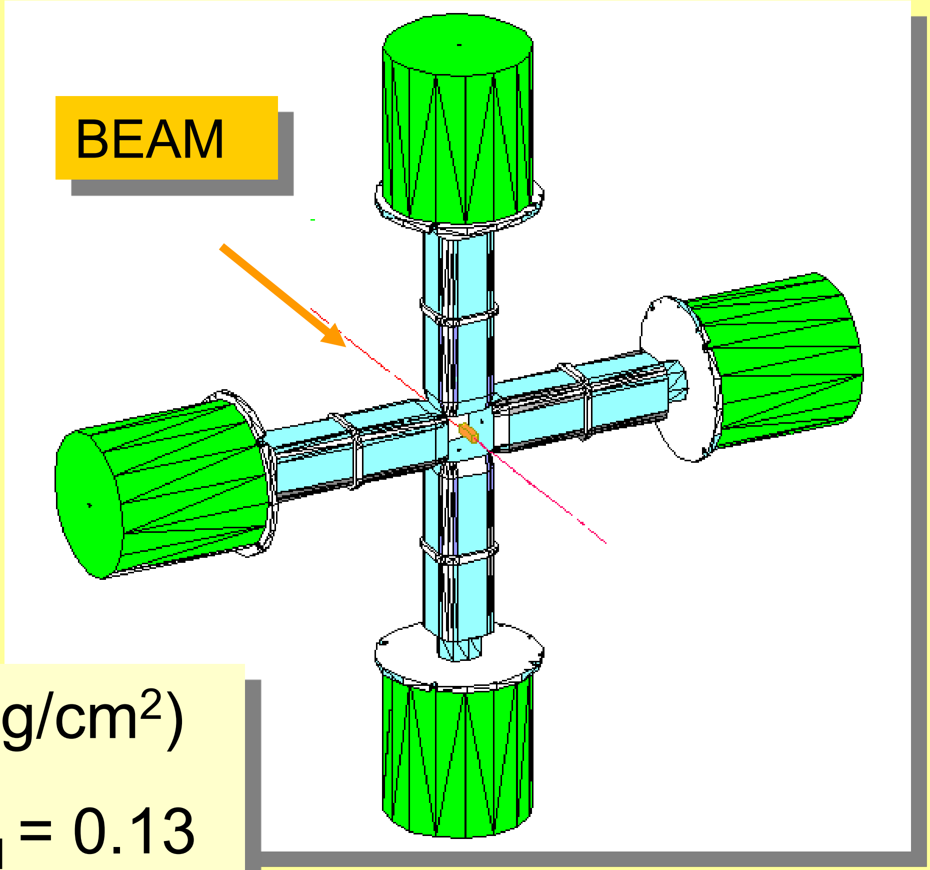
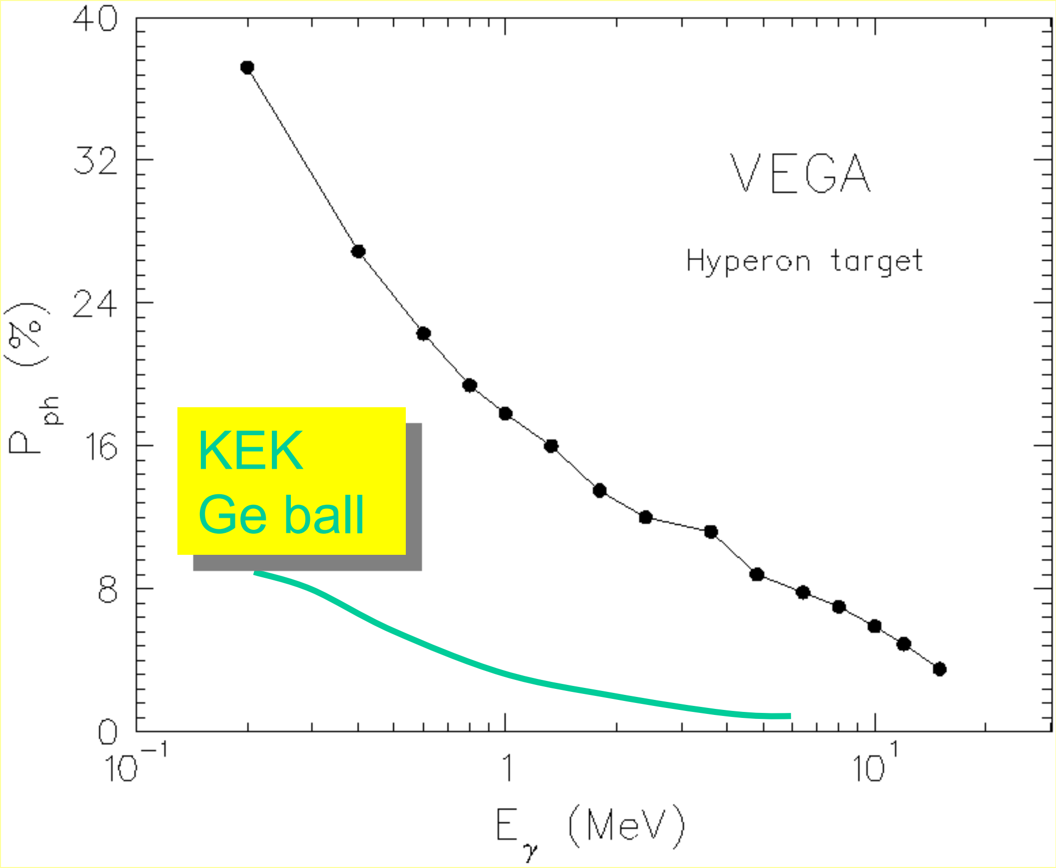


- pencil target (10 g/cm^2)
- 4 seg. clover, $\varepsilon_{PH} = 0.13$
- resolution ~ 0.5 %



Hypernuclei and Deconfinement

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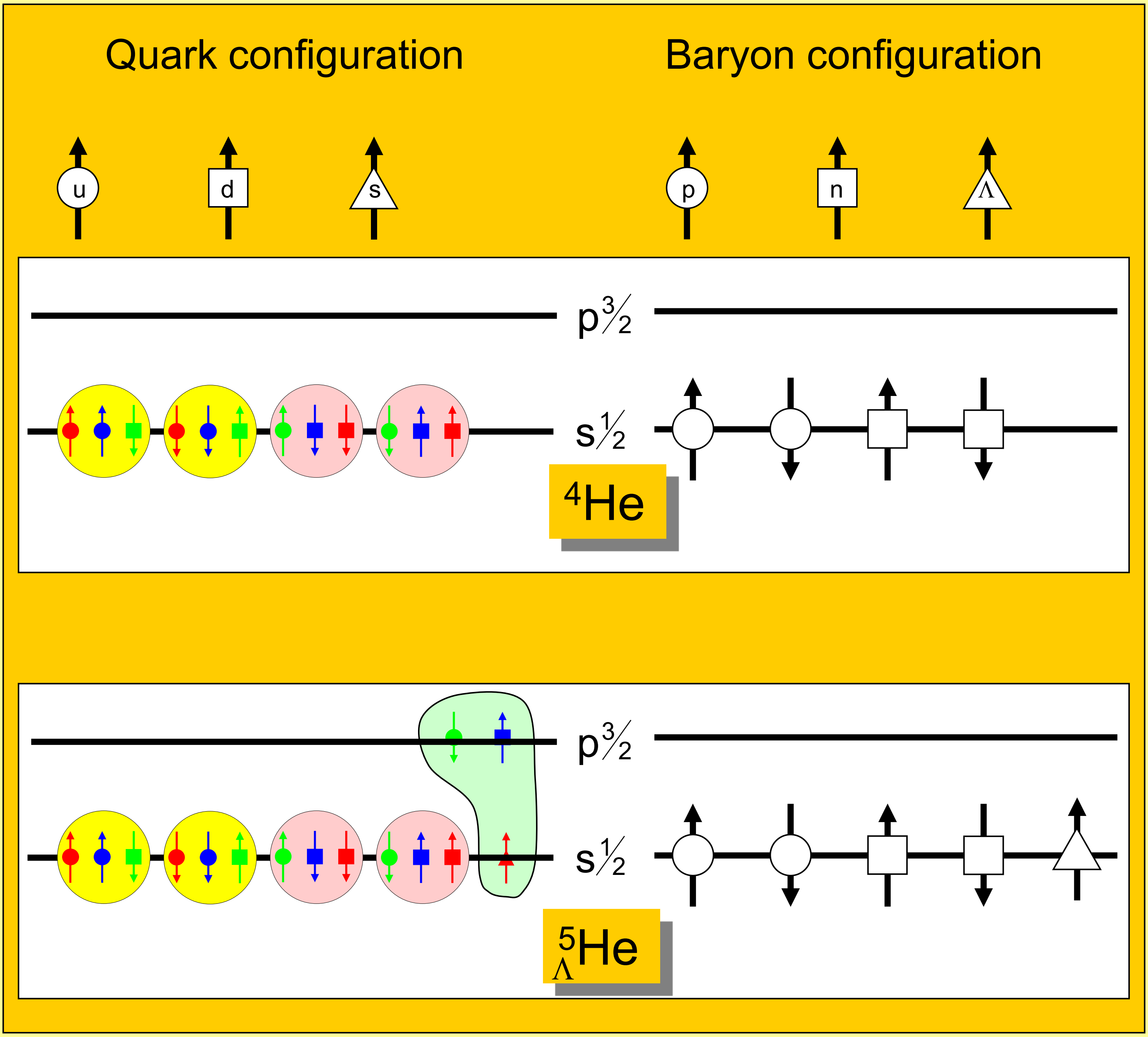

- ➢ overbinding of light Λ hypernuclei
- ➢ pionic decay width of A=4 hypernuclei

suggest *central repulsive potential*

? manifestation of the Pauli principle on the quark level ?

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What Do We Know about Single Hypernuclei ?

< 100 bound states of Λ-hypernuclei are observed;
typical resolution of (K,π) reactions 1-2 MeV

< 10 Λ-hypernuclei have a spin assigned

5 hypernuclear γ -transitions are established;
NaI: ΔE ~ 100 keV

For comparison: spin-dependent ΛN interaction results in a „hypernuclear fine structure“ Ô100 keV

Only 1 Σ-hypernucleus ($^{4}_{\Sigma}$He) is clearly established.

Narrow states observed previously are questionable.

Information on Ξ - hypernuclei is scarce (<10).

Only 2 events are clearly identified (KEK E176).

Phenomenological Wood-Saxon potential V^{Ξ} < 20 MeV

Present Status of Multi-Strange Hypernuclei

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Only 6 candidates for multi-hypernuclei are observed

1963: Danysz *et al.* $^{10}_{\Lambda\Lambda}$Be

1966: Prowse $^{6}_{\Lambda\Lambda}$He

1991: KEK-E176 $^{10}_{\Lambda\Lambda}$Be or $^{11}_{\Lambda\Lambda}$Be

1991: KEK-E176 3 non-mesonic decays

but...

1989: Dalitz *et al.*

8 Danysz event o.k. but double mesonic decay surprising

8 Prowse event questionable

1991: Dover *et al.*

8 KEK event most likely $^{13}_{\Lambda\Lambda}$B

$$B_{\Lambda\Lambda}(^{A}_{\Lambda\Lambda}Z) = B_{\Lambda}(^{A}_{\Lambda\Lambda}Z) + B_{\Lambda}(^{A-1}_{\Lambda}Z)$$

$$\Delta B_{\Lambda\Lambda}(^{A}_{\Lambda\Lambda}Z) = B_{\Lambda}(^{A}_{\Lambda\Lambda}Z) - B_{\Lambda}(^{A-1}_{\Lambda}Z)$$

Hypernucleus	$B_{\Lambda\Lambda}$ [MeV]	$\Delta B_{\Lambda\Lambda}$ [MeV]
$^{6}_{\Lambda\Lambda}$He	10.9 ± 0.6	4.7 ± 0.6
$^{10}_{\Lambda\Lambda}$Be	17.7 ± 0.4	4.3 ± 0.4
$^{13}_{\Lambda\Lambda}$B	27.6 ± 0.7	4.8 ± 0.7

Spectroscopy of Double Hypernuclei

A Possible Experiment for HESR

STRANGENESS

THE THIRD DIMENSION OF THE NUCLEAR CHART

Rauischholzhausen, April 8, 1999

J. Pochodzalla

MPI für Kernphysik Heidelberg

Why Strageness?

8 hadronic stellar objects

8 „exotic“ multi-quark systems (H-particle)

8 hyperon-hyperon interaction

⋮

Baryon Stars

A Strange Matter

Baryon Stars

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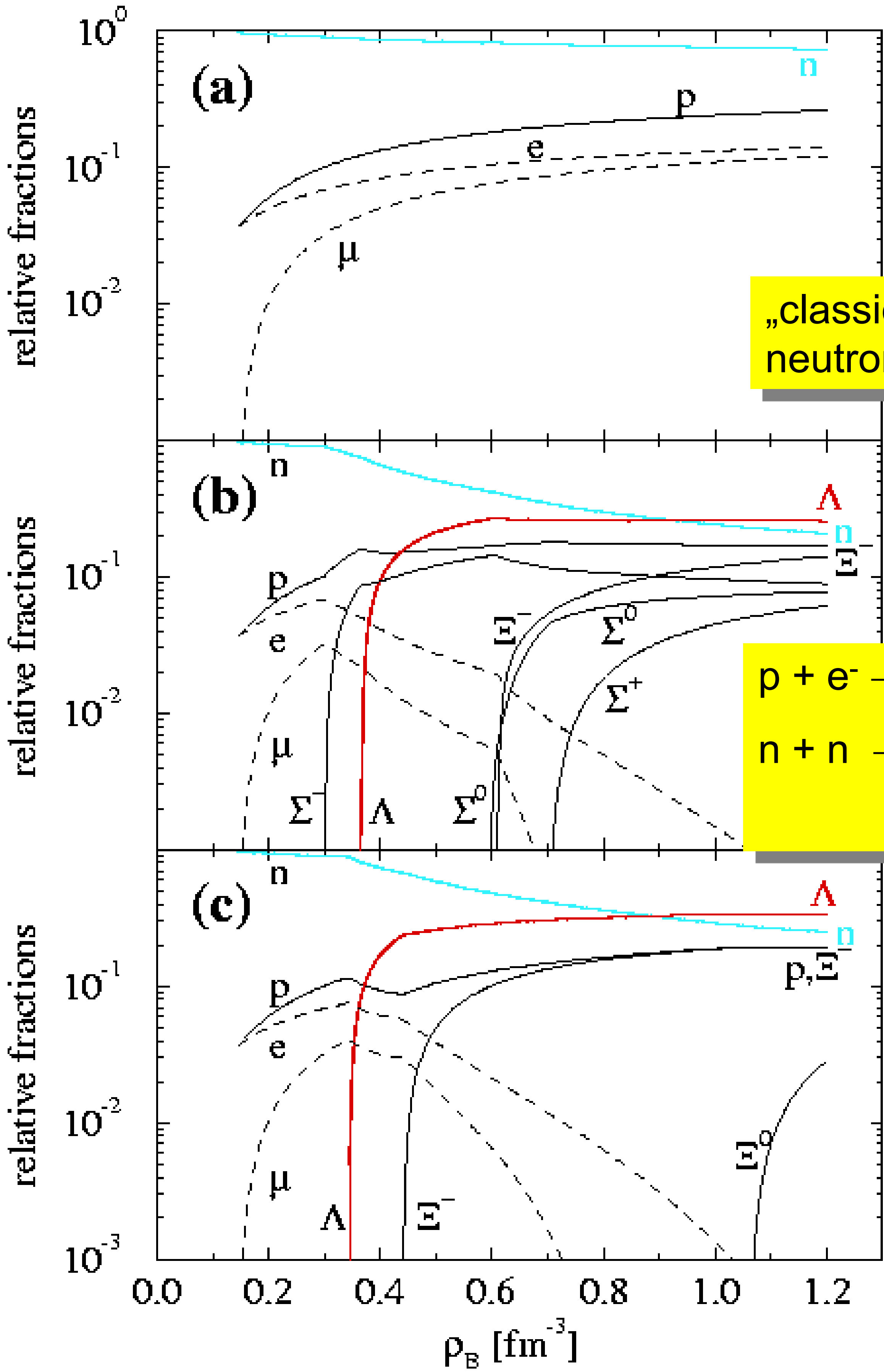

„classic“
neutron star

$p + e^- \rightarrow \Lambda + \nu_e$

$n + n \rightarrow \Lambda + n$

⋮

S. Balberg *et al.*, astro-ph/9810361

Maximum Mass of Baryon Stars

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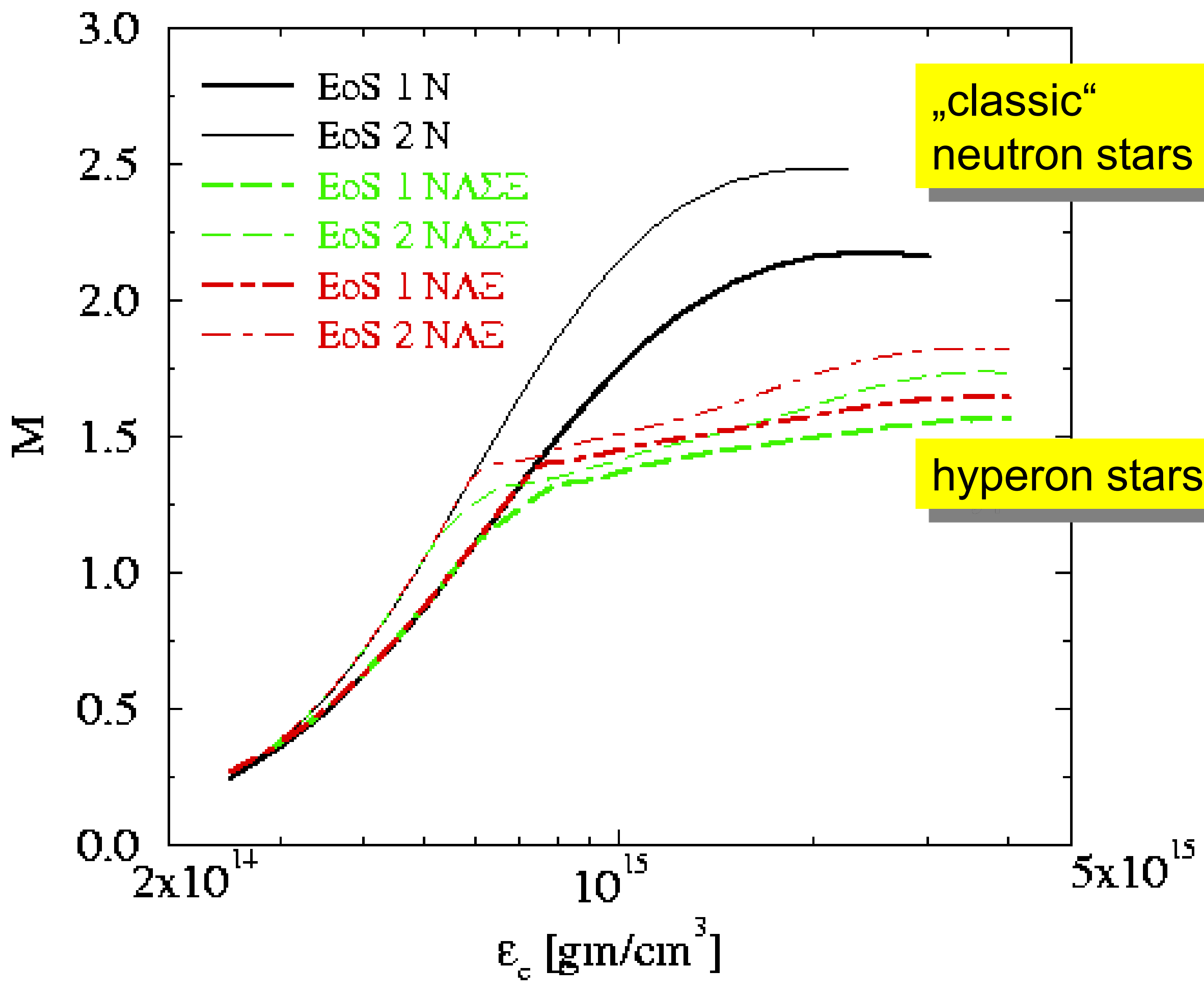
EOS 1: k=240 MeV

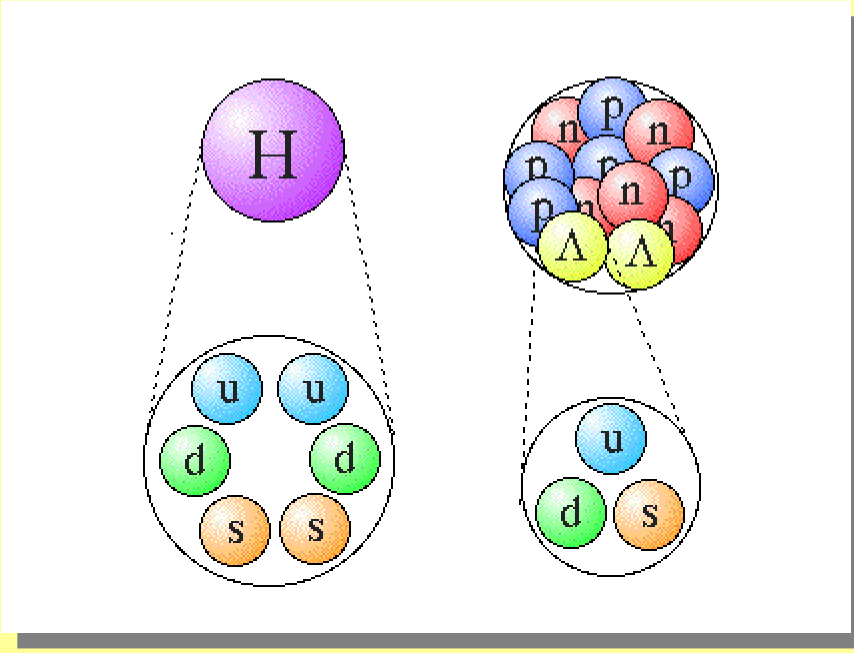
EOS 2: k=320 MeV



S. Balberg *et al.*, astro-ph/9810361

Searching for the H-Particle

A Strange Object



The H - Particle

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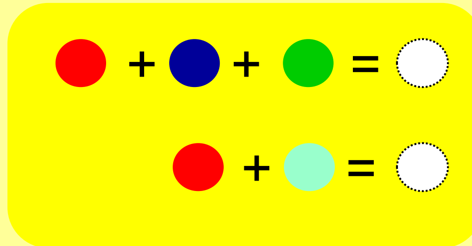
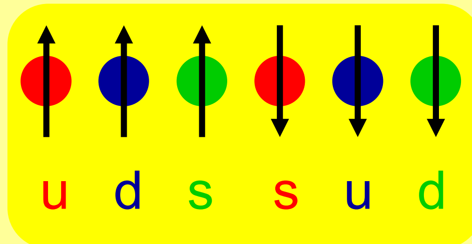
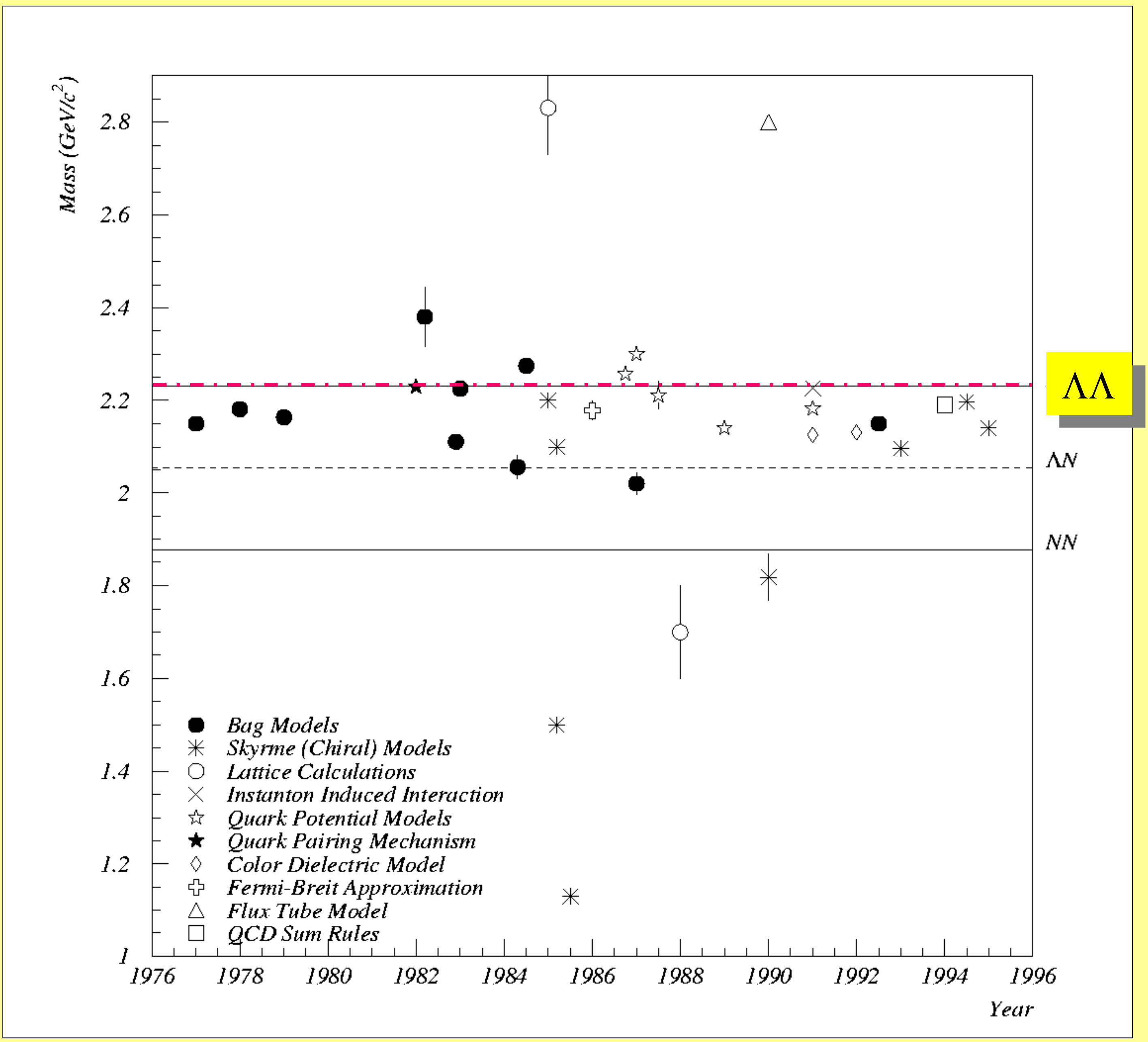
QCD rule: observed free particles are colorless



R.L. Jaffe (1977): color-magnetic binding may produce a metastable hexa-quark **H**





H -Particle and Double Hypernuclei

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Strong, strangeness conserving decay $\Lambda\Lambda N \rightarrow$ H N
possible if $m_H\ \Lambda\Lambda)$ - B(H) < $2 \cdot m_\Lambda$ - B $\Lambda\Lambda)$

ï Observation of weak decay of a double hypernucleus limits mass of H

$$B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) = B_\Lambda({}^{A}_{\Lambda\Lambda}Z) + B_\Lambda({}^{A-1}_{\Lambda}Z)$$

$$2\ M(\Lambda) = 2231.4\ MeV/c^2$$

Hypernucleus	$B_{\Lambda\Lambda}$ [MeV]	m_H [MeV/c^2]
${}^{6}_{\Lambda\Lambda}He$	10.9 ± 0.6	> 2220.5 + B(H)
${}^{10}_{\Lambda\Lambda}Be$	17.7 ± 0.4	> 2213.7 + B(H)
${}^{13}_{\Lambda\Lambda}B$	27.6 ± 0.7	> 2203.7 + B(H)

but...

decay of bound H $\rightarrow \Lambda p \pi^-$ may mimic a decay of a double hypernucleus

8 double hypernuclei events can be reinterpreted as H hypernuclei

Searching the H

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M(H) > 2 M(Λ) à strong decays

M(H) < 2 M(Λ) à weak decays

(2 M(Λ) = 2231.4 MeV/c²)

Direct searches:

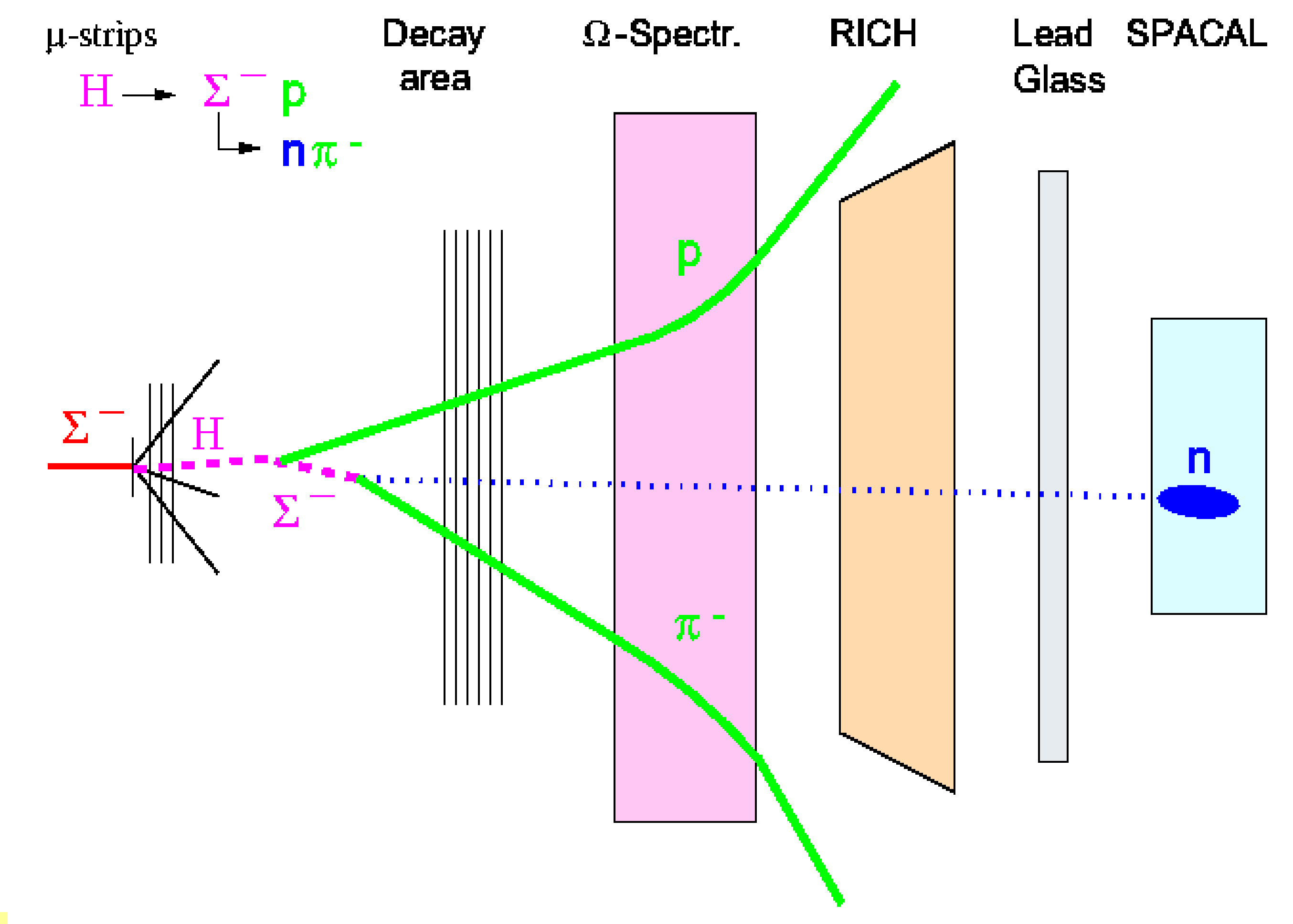
(K⁻,K⁺)	BNL E836	^{3}He (K⁻,K⁺)H n, ^{6}Li (K⁻,K⁺)H X
		Δm<-50 MeV: σ_H < 0.1 $\sigma_{COAL}(\Lambda\Lambda)$
	BNL E885	^{12}C (K⁻,K⁺)H X
	KEK E224	^{12}C (K⁻,K⁺)H X; $\Theta_{K+} \approx$ 00
		Δm<-16 MeV: σ_H < 0.04-0.6 μb/sr
stopped Ξ⁻	BNL E813	$(\Xi^{-}d)_{atom} \rightarrow$ H n; monoenergetic n
p+A	BNL E888	weak decay
		2 candidates: background
Σ⁻ +A	WA89	weak and strong decays
		σ_H Ô $\sigma_{COAL}(\Lambda\Lambda)$
relativistic HI	BNL E810, E896	

Weak Decays

- weakly bound H -dibaryon ê weak decay $\Delta S = 1$

H Þ $\Sigma^- p$	50 %		40 %
H Þ $\Sigma^0 n$	30 %		45 %
H Þ $\Lambda^0 n$	20 %		15 %
	Jaffe (1977)		Donoghue (1986)

event topology



- Calorimetry very important

"H" Mass Spectra

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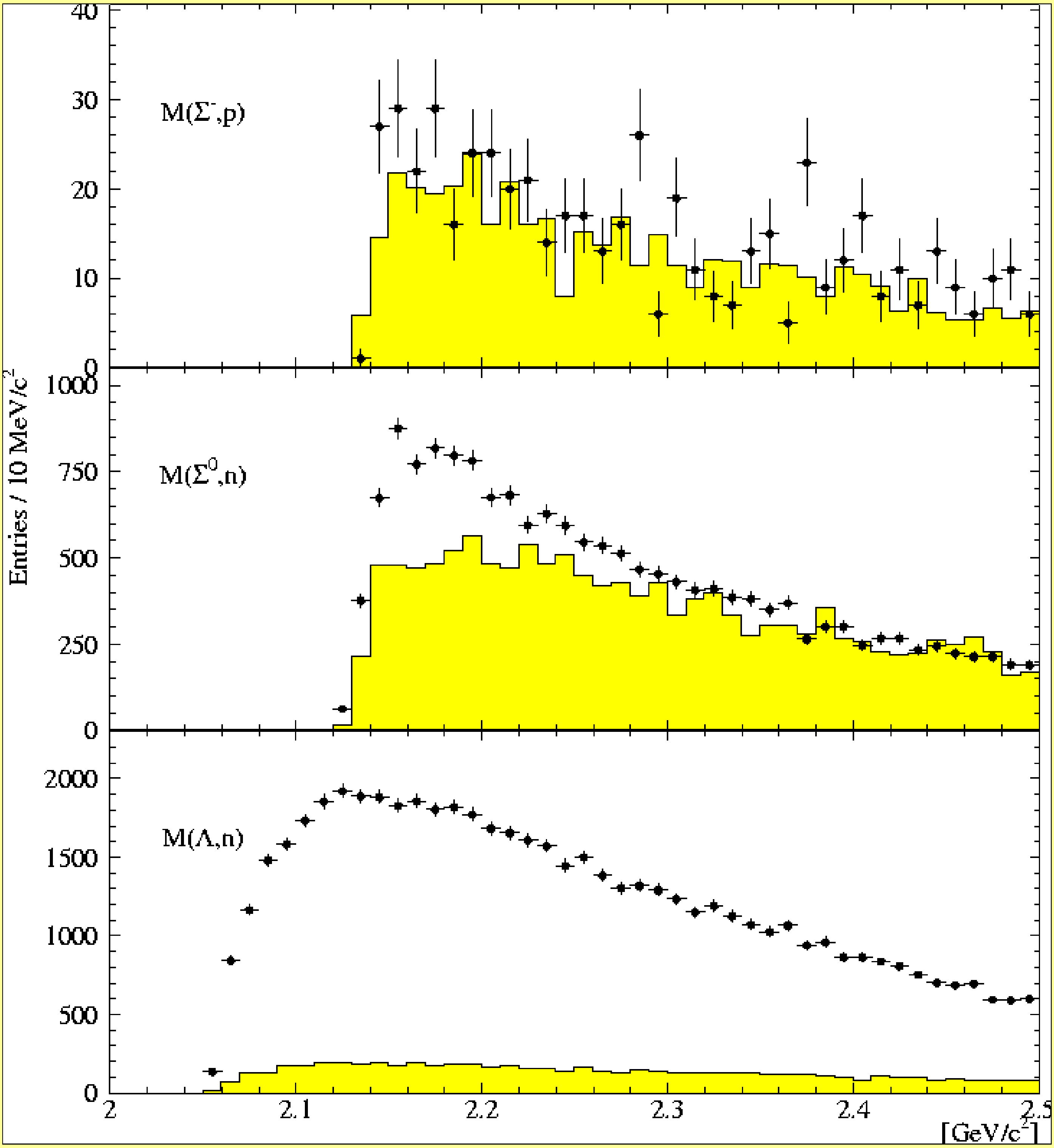
M. Beck (thesis, Heidelberg 1997)



background due to misidentified hyperons

8 no significant signal of a H -particle is observed

Σ-A Reaction (WA89)
H Production Limits

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M. Beck (thesis, Heidelberg 1997)

- weak decays [$\tau(H) = \tau(\Lambda)$]

H Þ Σ^- p : σ. BR < 0.8 ± 0.2 ± 0.2 μb/N
H Þ Σ^0 n : σ. BR < 3.4 ± 1.0 ± 0.9 μb/N
H Þ Λ^0 n : σ. BR < 5.0 ± 1.5 ± 1.3 μb/N

- strong decays M(H) > 2 M(Λ)

Ý no significant structure with $\Gamma \approx 100$ MeV/c²

H Þ Ξ^- p : σ. BR < 1.7 ± 0.3 ± 0.5 μb/N
H Þ $\Lambda^0\Lambda^0$: σ. BR < 0.2 ± 0.017 ± 0.042 μb/N

- predictions based on coalescence

Sano	5 GeV/c p+Ne	10 nb
Cousins & Klein	24 GeV/c p+Pt	20 nb
Cole	28 GeV/c p+Ca	420 nb
Rotondo	400 GeV/c p+Be	170 nb
Moinester	350 GeV/c Σ+p	~ 1μb

8 H production limits are of the order of predictions within coalescence scenarios

Enhanced Production of ΛΛ Pairs (E224)

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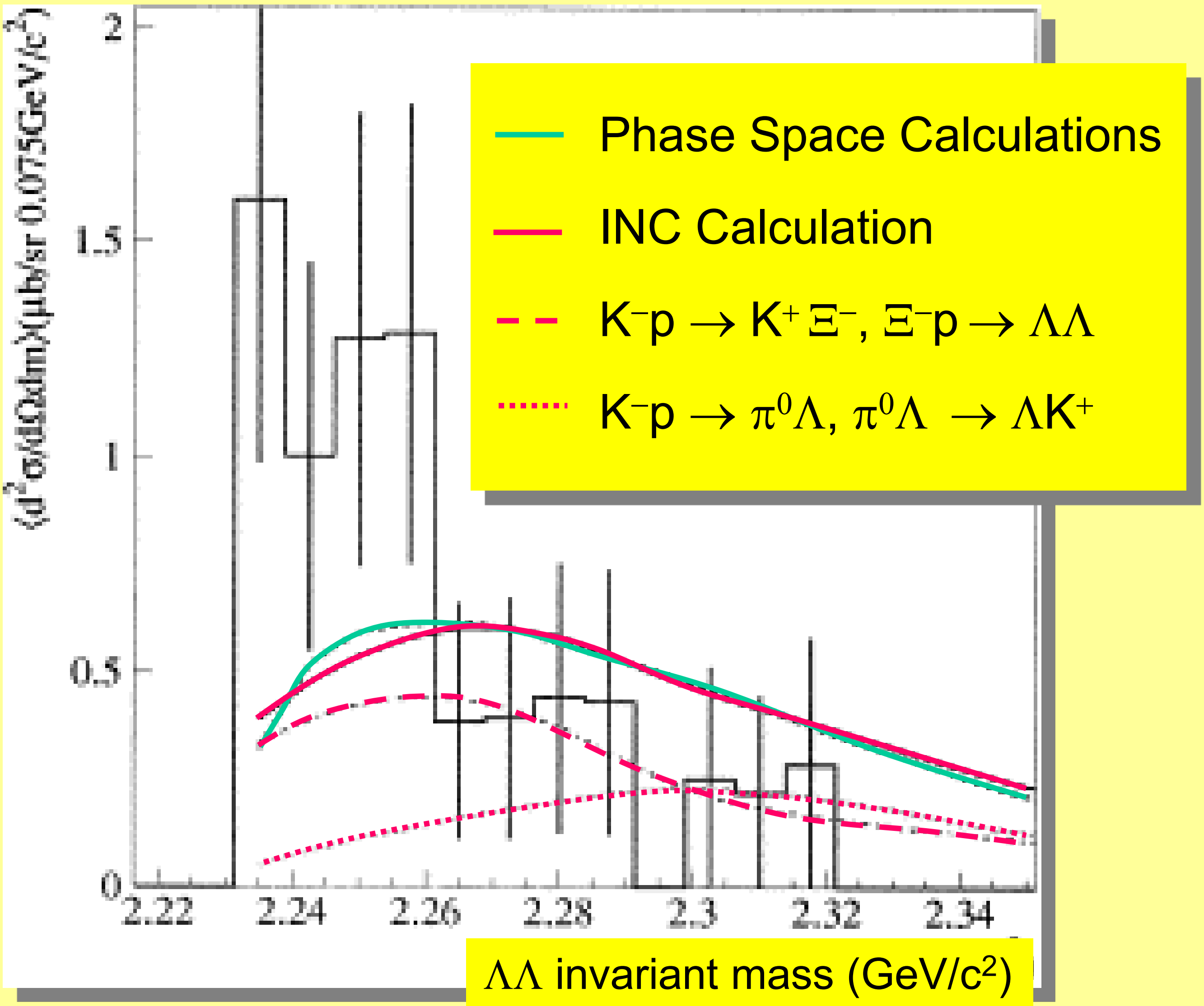
Phys. Lett. B**444**, 267 (1998)

$^{12}C\ (K^-,K^+)\Lambda\Lambda X$,
p_{K^-} = 1.66 GeV/c



• enhanced cross section: 3 μb/sr

Enhanced Production of ΛΛ Pairs (KEK-E224)

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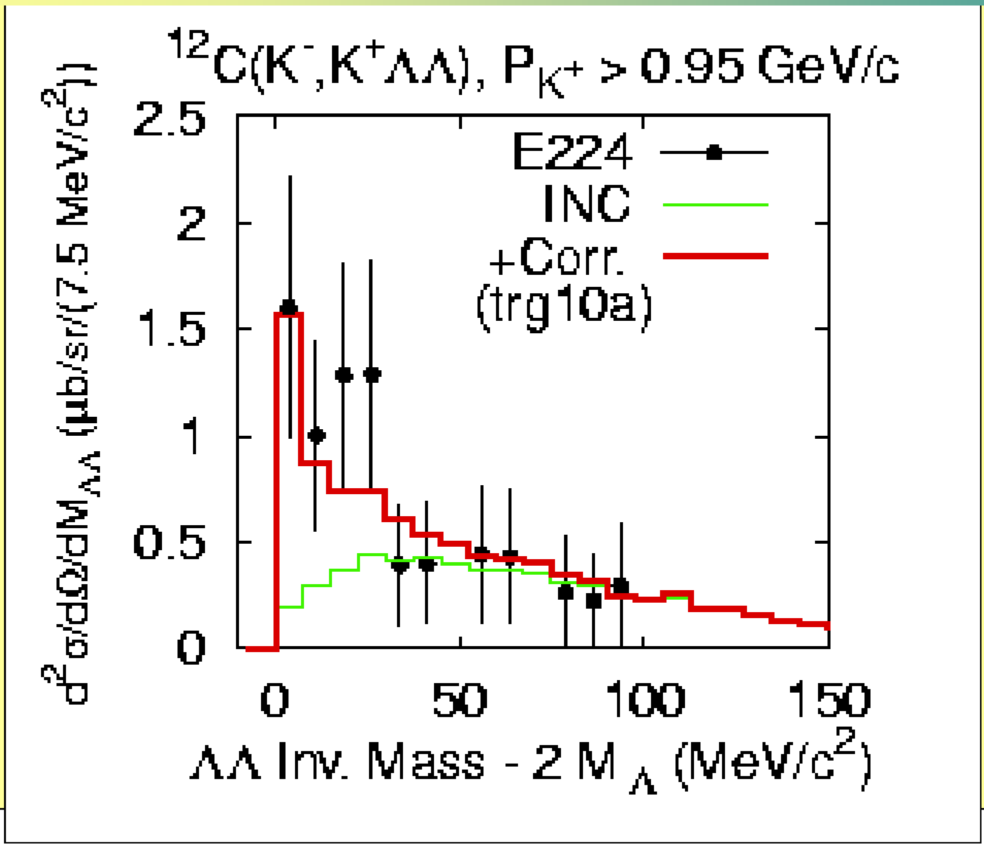

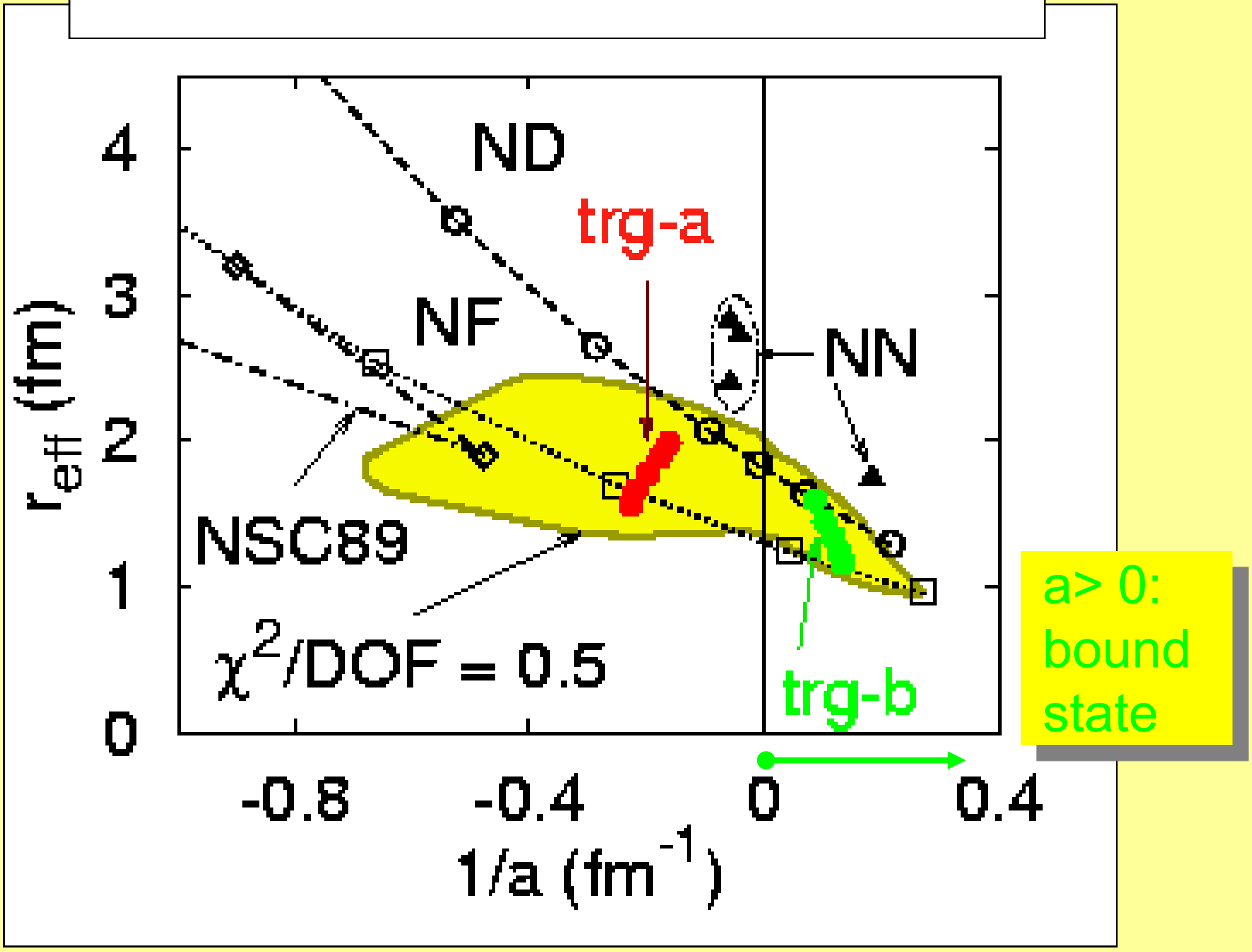

A. Ohnishi *et al.*, nucl-th/99xxx

Status of Double Hypernuclei

Needed: strangeness S=-2 transfer

8 Ξ^- capture

8 Relativistic Heavy Ion collisions

8 Antiproton annihilation at rest

Double Hypernuclei in Relativistic HI Collisions

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In relativistic HI Collisions many Λ's are produced

example: AGS central Au+Au ~20

central Si+Au ~5

Coalescence may produce Λ^n hypernuclei

example: AGS central Au+Au

$p({}^{6}_{\Lambda\Lambda}He) \approx 1.6\cdot 10^{-5}$ per reaction

more general: $p(A,S) \sim 10^{3 - A - |S|}$

possibility to produce multi-strange hypernuclei

Bodmer (1971), Rufa *et al.* (1989)

MEMOs

Schaffner *et al.* (1992)

...

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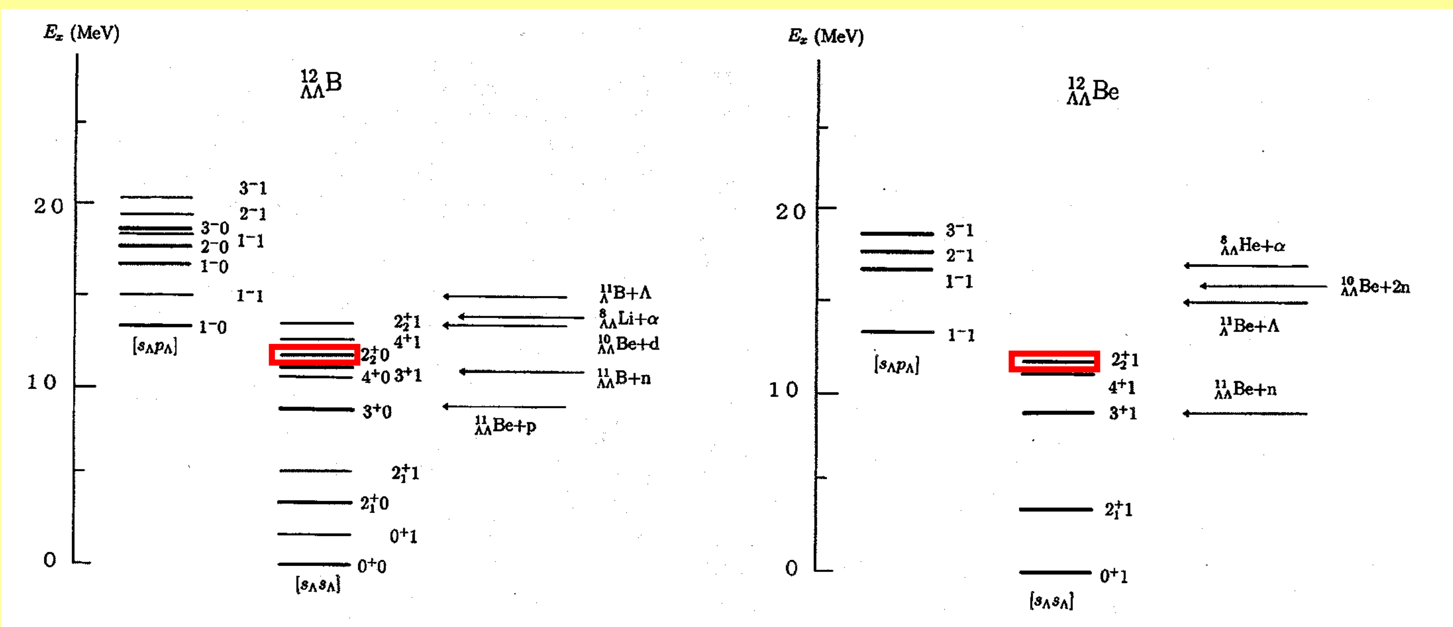
Ξ^-(dss)**p**(uud) Þ Λ(uds)Λ(uds)

- “cool” production: energy release ΔE= 28 MeV
- Ξ^-+^{12}C: T. Yamada and K. Ikeda, PRC **56**, 3216 (1997)

TABLE VIII. Calculated production rates per Ξ (R/Ξ) averaged over the absorption rates in the case of $V_{0\Xi}=16$ MeV.

Channel	R/Ξ (%)
$^{12}_{\Lambda\Lambda}$B$+n$	1.48
$^{12}_{\Lambda\Lambda}$Be$+p$	0.99
$^{11}_{\Lambda\Lambda}$Be$+d$	1.81
$^{10}_{\Lambda\Lambda}$Be$+t$	0.02
$^{9}_{\Lambda\Lambda}$Li$+\alpha$	0.02
$^{6}_{\Lambda\Lambda}$He$+^{7}$Li	0.23
$^{5}_{\Lambda\Lambda}$H$+^{8}$Be	0.20
$^{9}_{\Lambda}$Be$+^{4}_{\Lambda}$H	0.07
$^{8}_{\Lambda}$Li$+^{5}_{\Lambda}$He	0.04
$^{12}_{\Lambda}$B$+\Lambda$	1.08



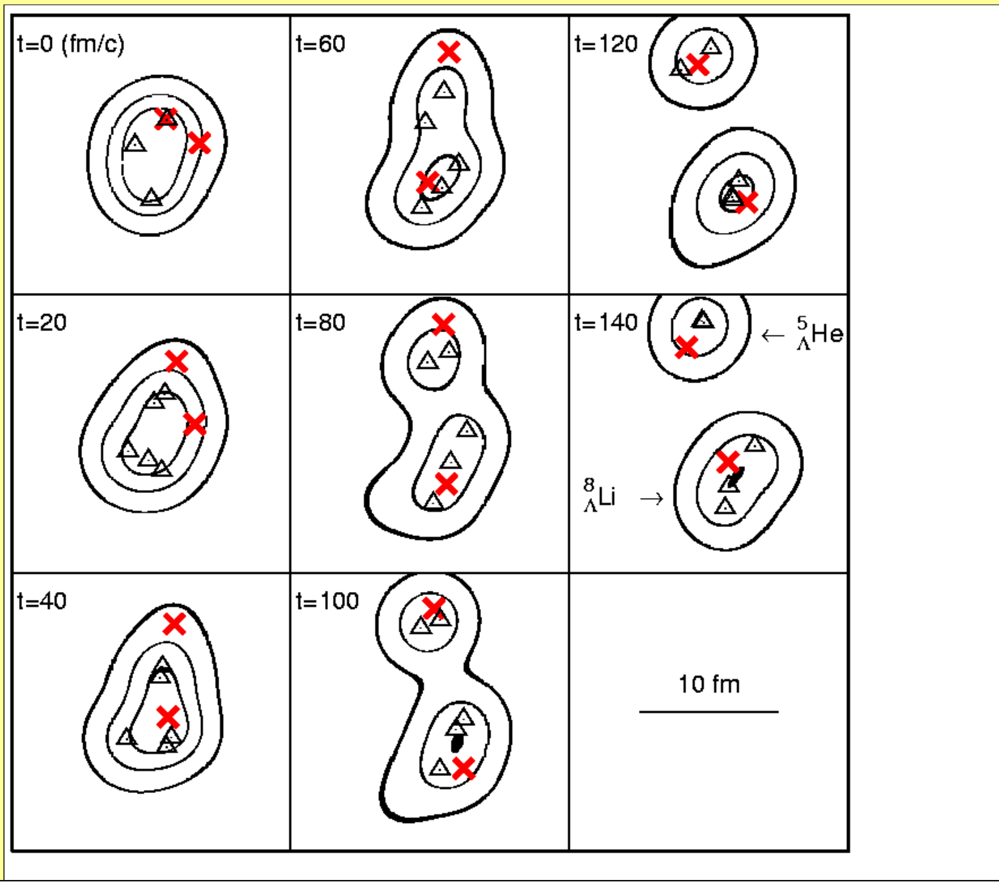
8 total probability $p_{\Lambda\Lambda} \approx 0.05$

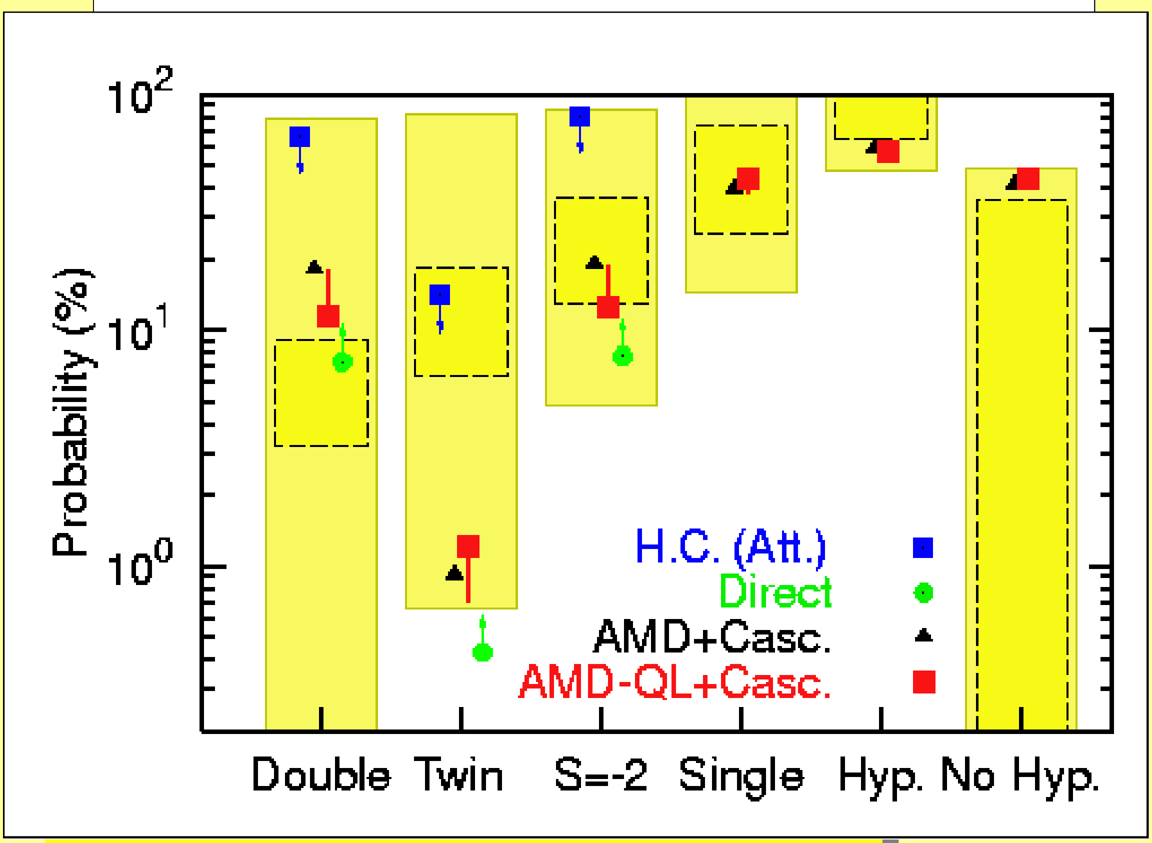
individual states a factor of $\approx$10 lower

Ξ^-(dss)**p**(uud) Þ Λ(uds)Λ(uds) in Microscopic Models

Y. Hirata, J. Randrup *et al.*,

nucl-th/9711063





8 total probability $p_{\Lambda\Lambda} > 0.1$

Tracking of Ξ^-

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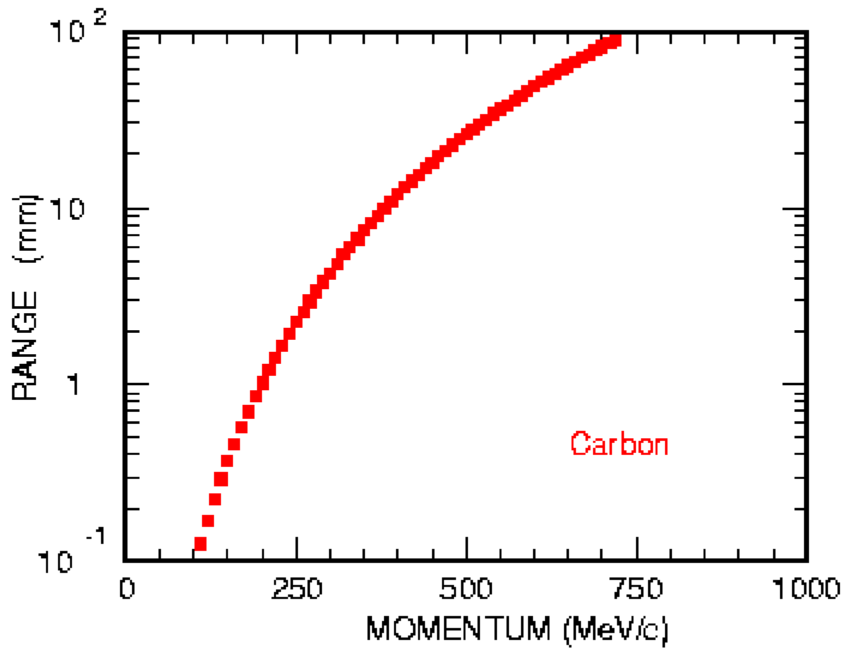
MPI -HD

• range a few mm



• several closely spaced layers of small micro-strip tracking detectors (diamond, Si) close (5mm) to the primary target resp. beam

• Ξ decay during cascading (~10^{-12}s) small (Batty 95)

8 tracking and capture probability of $p_{CAP} \approx 0.15$ feasible

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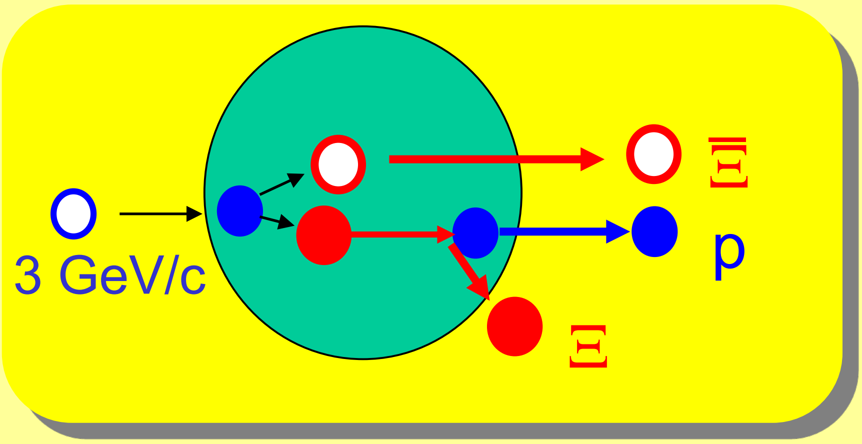
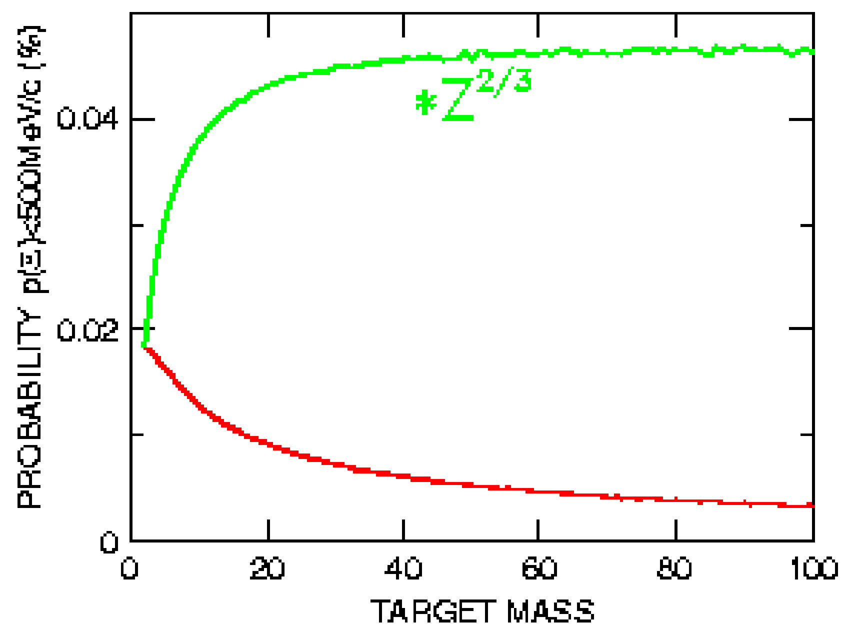
Production Probability for low-momentum Ξ^-



- Ξ $\bar{\Xi}$ cross section ~ $A^{2/3}$
- $\bar{\Xi}$ absorption $\sigma=0.8\cdot\sigma_{ABS}(\bar{p}p)$
- elastic scattering σ_{EL}=10mb

$\sigma(\Xi^- p$Þ $\Xi^- p)$ = 13±6mb, Dover & Gal; $\sigma(\bar{p}p$Þ $\bar{p}p)$=22mb

- $\sigma(\Xi^- p$Þ $\Xi^- p) \propto$ *exp*$(B\cdot t)$; B=5GeV^{-2}



8 event probability p_{500} = 0.0001

but: multiple scattering neglected

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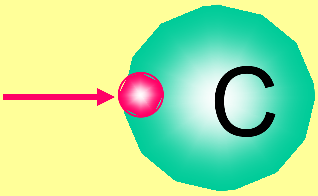
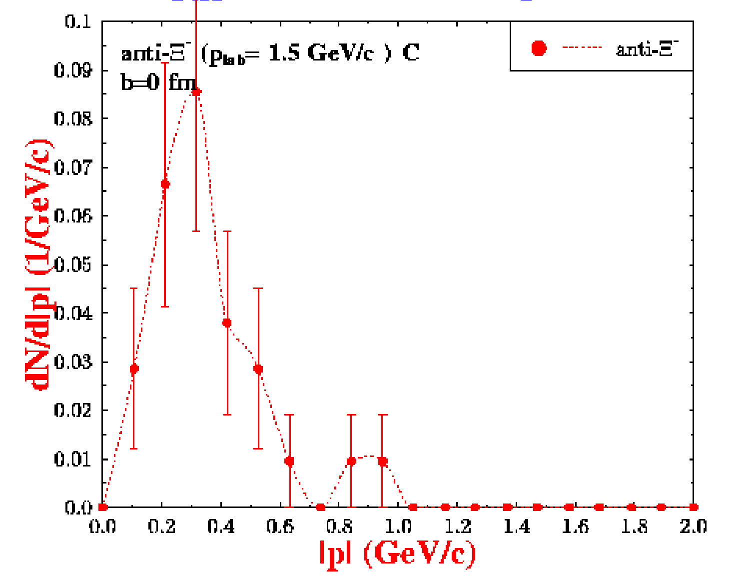
UrQMD



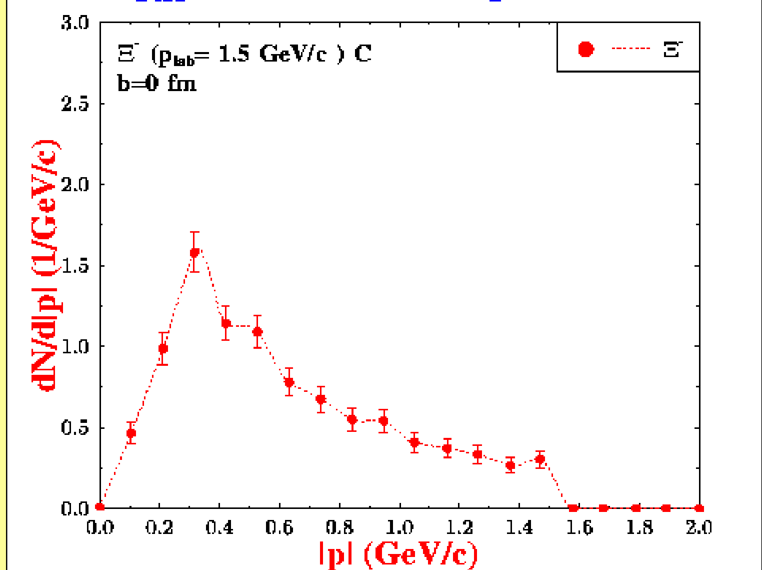
Sven Soff *et al.* (Frankfurt)

- 1000 $\bar{\Xi}$ or Ξ at b=0 with p=1.5 GeV/c

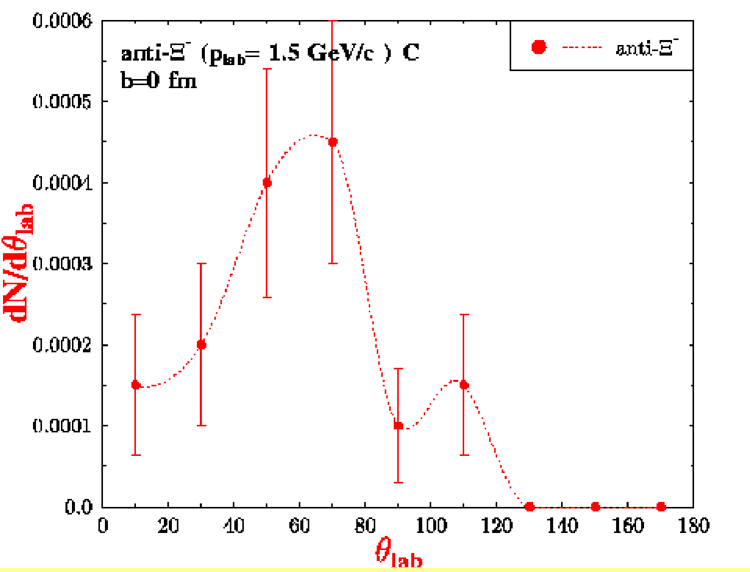
anti-Ξ^- (p_{lab}=1.5 GeV/c) C dN/d|p| distributions



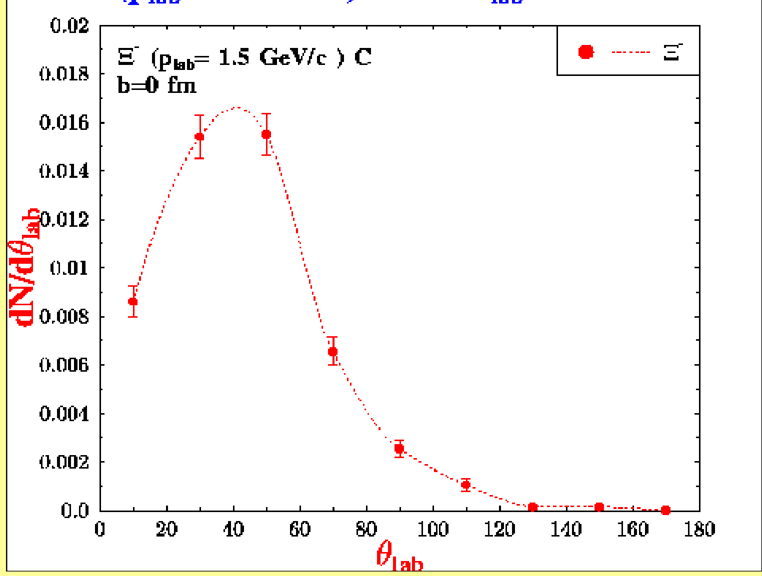
Ξ^- (p_{lab}=1.5 GeV/c) C dN/d|p| distributions



anti-Ξ^- (p_{lab}=1.5 GeV/c) C dN/dθ_{lab} distributions



Ξ^- (p_{lab}=1.5 GeV/c) C dN/dθ_{lab} distributions



emission probability of $\bar{\Xi}$ at forward angles
(⇔ large momenta) ≈ 0.2%

probability for low momentum Ξ ~ 40%

total probability p_{500}= 0.002 · 0.4 ~ 0.001

Decay Properties

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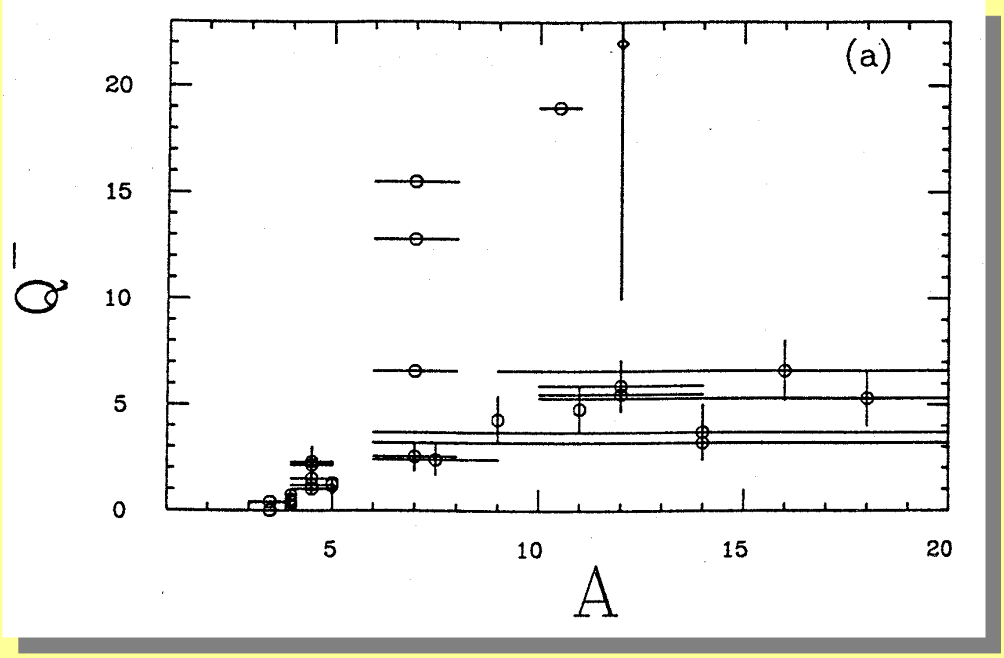
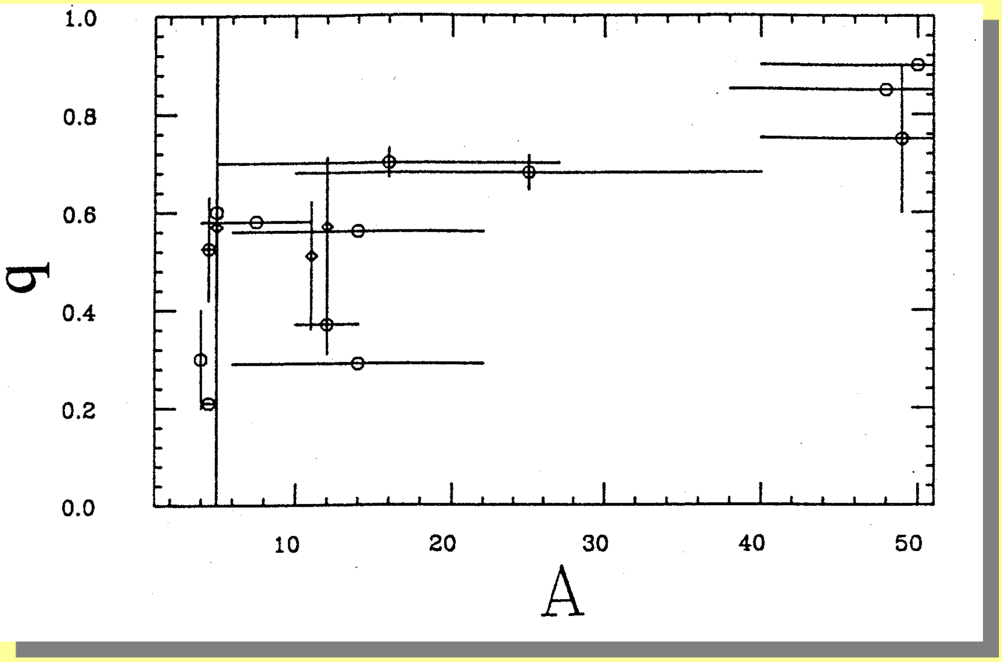
MPI -HD

- for heavy nuclei non-mesonic decay dominates

  non-mesonic: mesonic ≈ 5



- ΛN Þ NN   ΔQ= 176 MeV: energetic nucleon
- (Λn Þ nn) : (ΛN Þ NN) ≈ 0.5



8 non-mesonic decay with energetic proton has large probability in carbon $p_{NM} \approx 0.4$

Things To Do

J. Pochodzalla
MPI -HD

- complete microscopic calculation for anti-Ξ trigger
- detector studies (efficiencies...)
- background
- γ-spectrum
- ...

8 spectroscopy of double-strange hypernuclei may be feasible !

S=-1 Hypernuclei

High-Resolution Hypernuclear γ-Spectroscopy at GSI

J. Gerl, Ch. Schlegel, P. Senger
GSI Darmstadt
J. Pochodzalla
MPI für Kernphysik Heidelberg
D. Dehnhard, H. Juengst, Jinghua Liu
University of Minnesota, Minneapolis
B. Kohlmeyer
Universität Marburg
A. Wagner
Forschungszentrum Rossendorf e.V.
W. Korten
CEA Saclay
H. Lenske
Universität Giessen

Why Hypernuclei ?

J. Pochodzalla

8 deeply bound states are accessible

8 strange baryons in nuclear medium

- ➢spin-dependent interactions
- ➢hyperon states and collective motion
- ➢do narrow Σ, Ξ excitations exist?

8 hyperon-nucleon interaction

- ➢ baryon stars

8 first step towards multistrange objects

⋮

...and why γ-spectroscopy ?

better energy resolution 1 MeV → 10 keV

8 excited states, which can not be populated by direct reactions (e.g. if spin-flip necessary)

8 e.m. matrix elements, spin-parity

present and future hypernuclei studies at

BNL	DAΦNE	JHF
KEK	JLAB	MAMI C

Production of
Λ – Hypernuclei

J. Pochodzalla

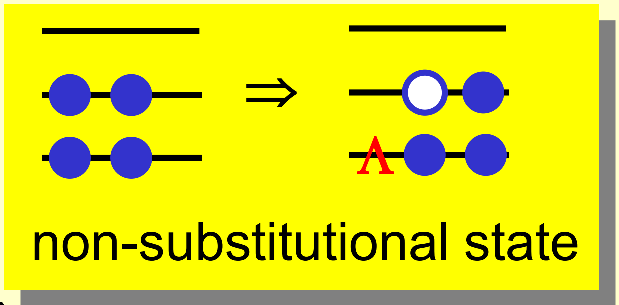
8 strangeness production (π^+, K^+)

$p_{BEAM} \approx 1$ GeV/c

high beam intensity

low cross section (1-10 μb/sr)

q > 200 MeV/c à large Δp, ΔL

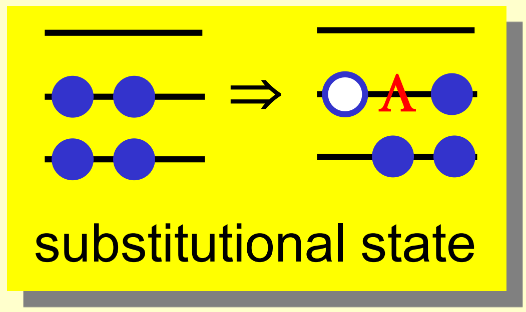


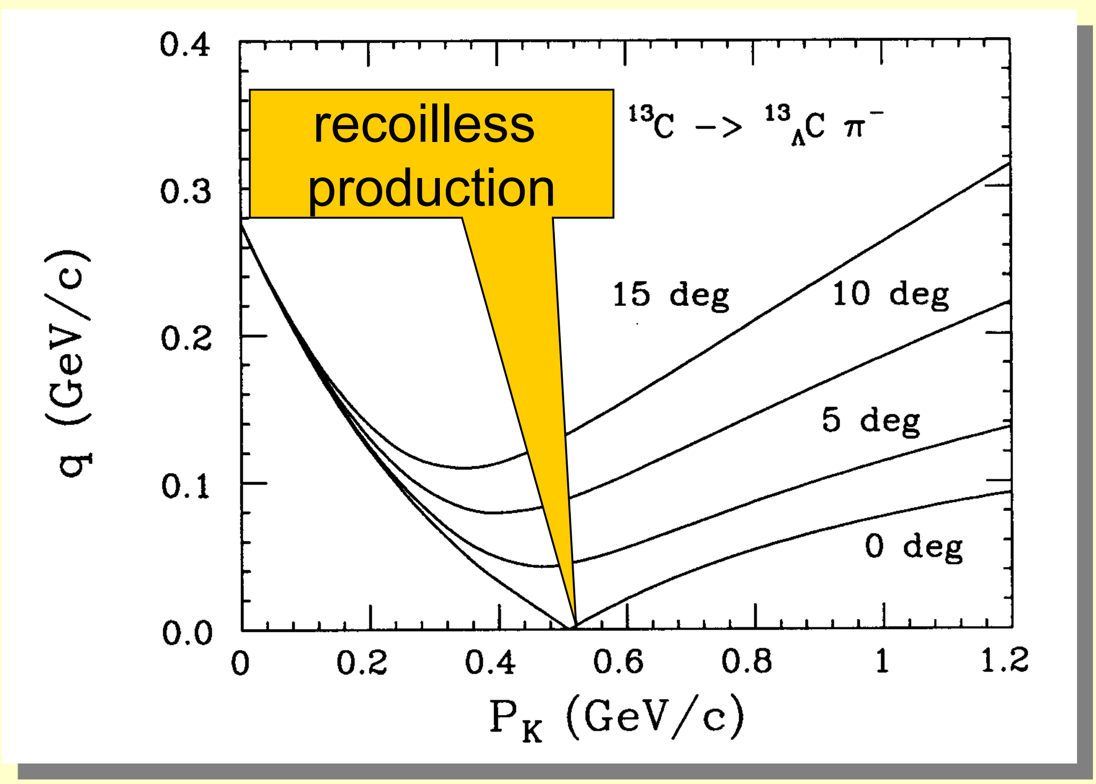
8 strangeness exchange (K^-, π^-)

low beam intensity

larger cross section (100 μb/sr)

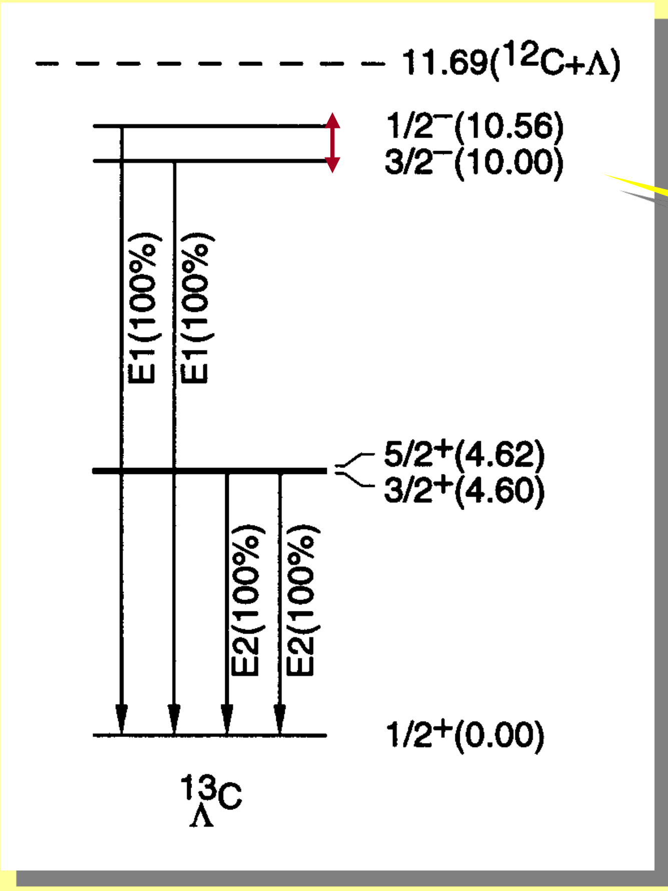
magic momentum low Δp, ΔL





ls - splitting of $^{13}_{\Lambda}C$

J. Pochodzalla

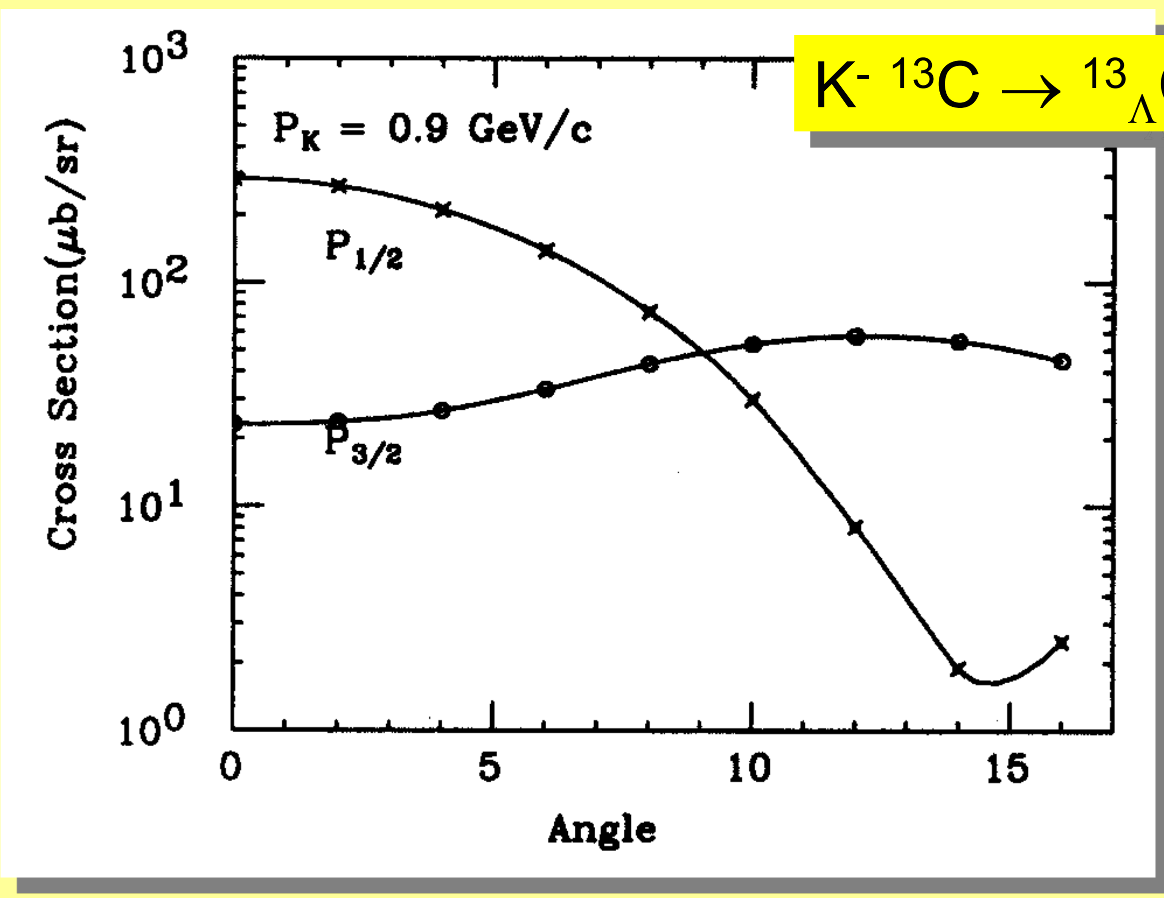


$^{12}C_{g.s.} + p_{1/2\Lambda}$ or $p_{3/2\Lambda}$

ΛN spin-orbit interaction

$^{12}C_{2+} + s_{1/2\Lambda}$

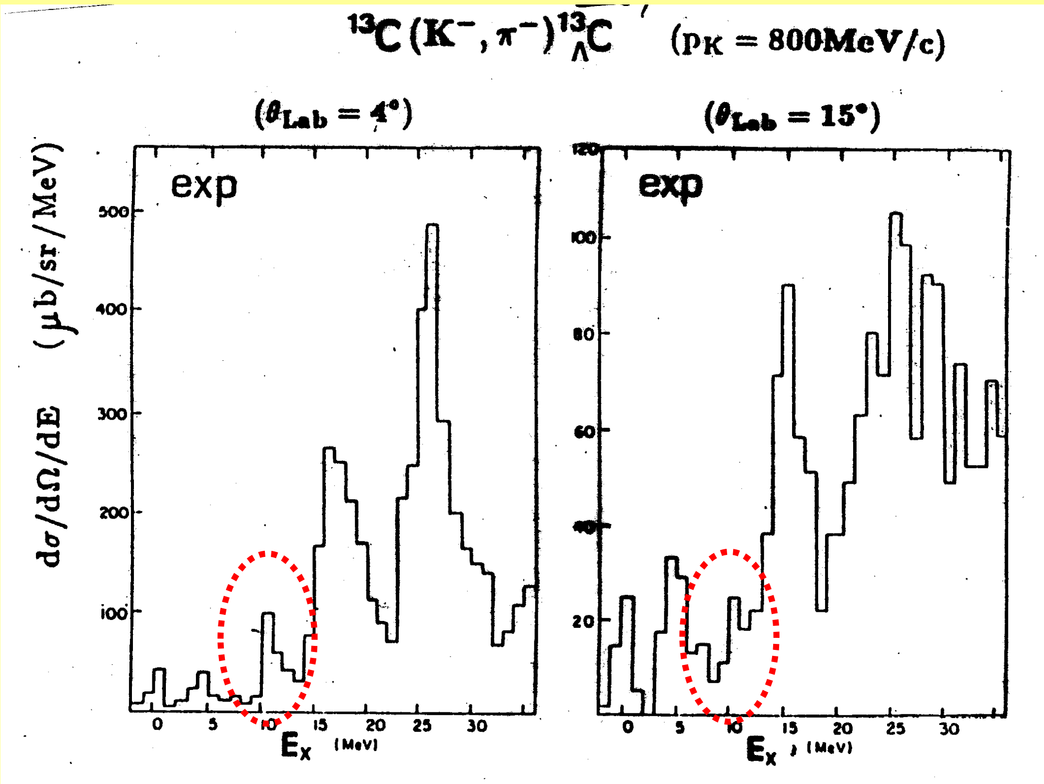
$^{12}C_{g.s.} + s_{1/2\Lambda}$



$K^- \, ^{13}C \rightarrow \, ^{13}_{\Lambda}C \, \pi^-$

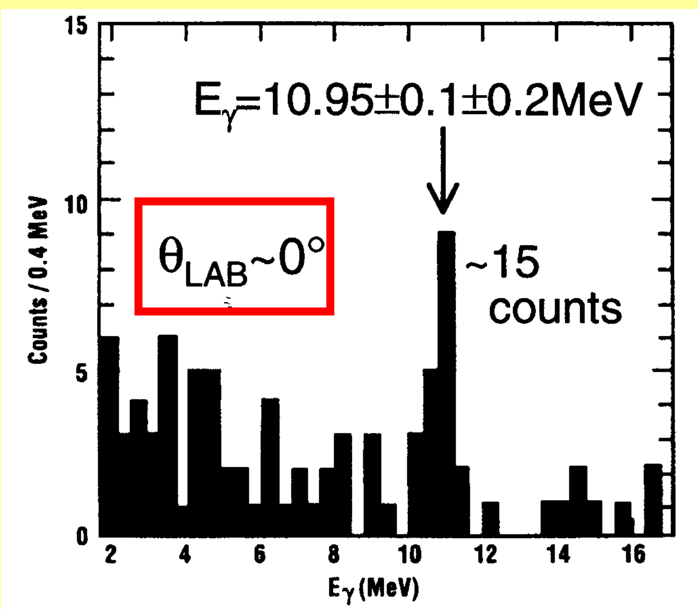
ls - splitting of $^{13}_{\Lambda}C$ experimental situation /

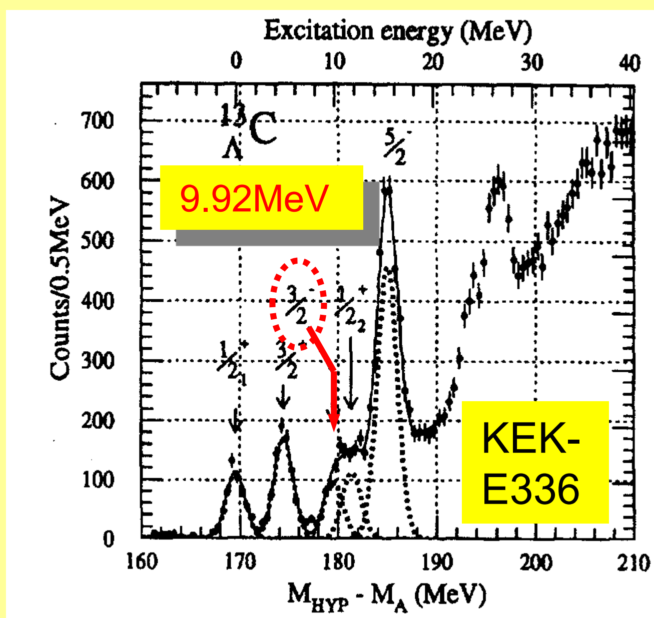
J. Pochodzalla



M. May et al., PRL **47**, 1106 (1981)

8 splitting small : ΔE = 0.36 ± 0.3 MeV





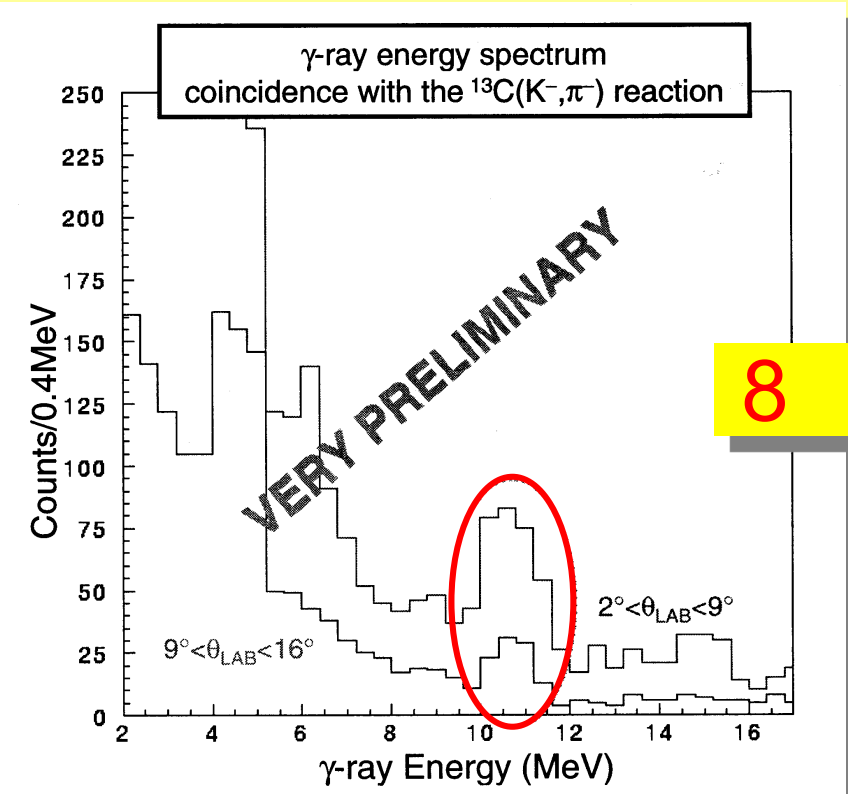
M. May *et al.*, PRL **78**, 4343 (1997)

S. Ajimura *et al.*, NP **A639**, 93c (1998)

8 splitting large : ΔE = 1.03 ± 0.6 MeV

ls splitting of $^{13}_{\Lambda}C$ experimental situation *II*

J. Pochodzalla

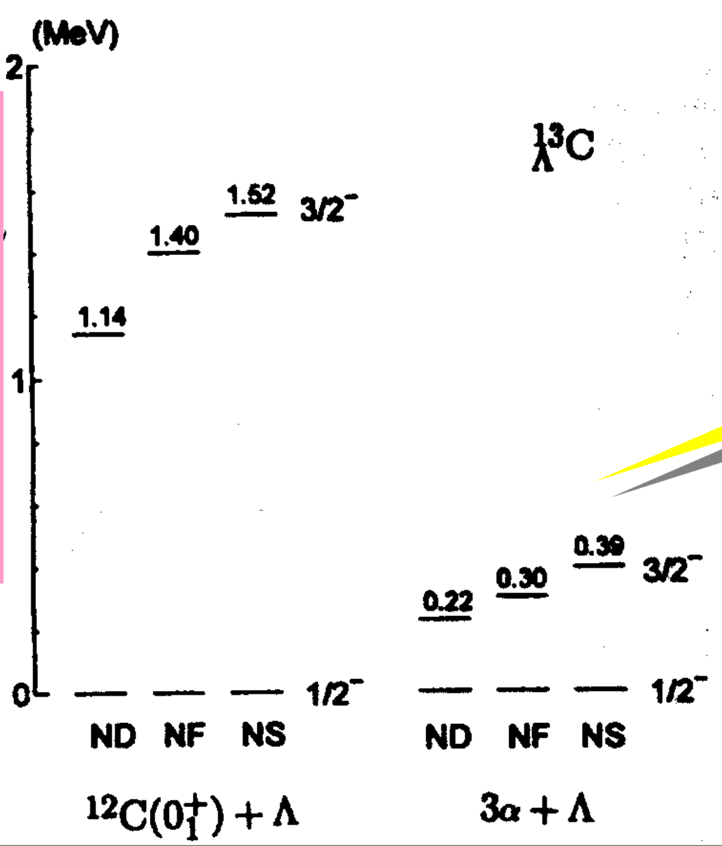


A. Sakaguchi (AGS/E929)

SNP99 (1999)

8 splitting small

but: is the spin orbit splitting really small ?



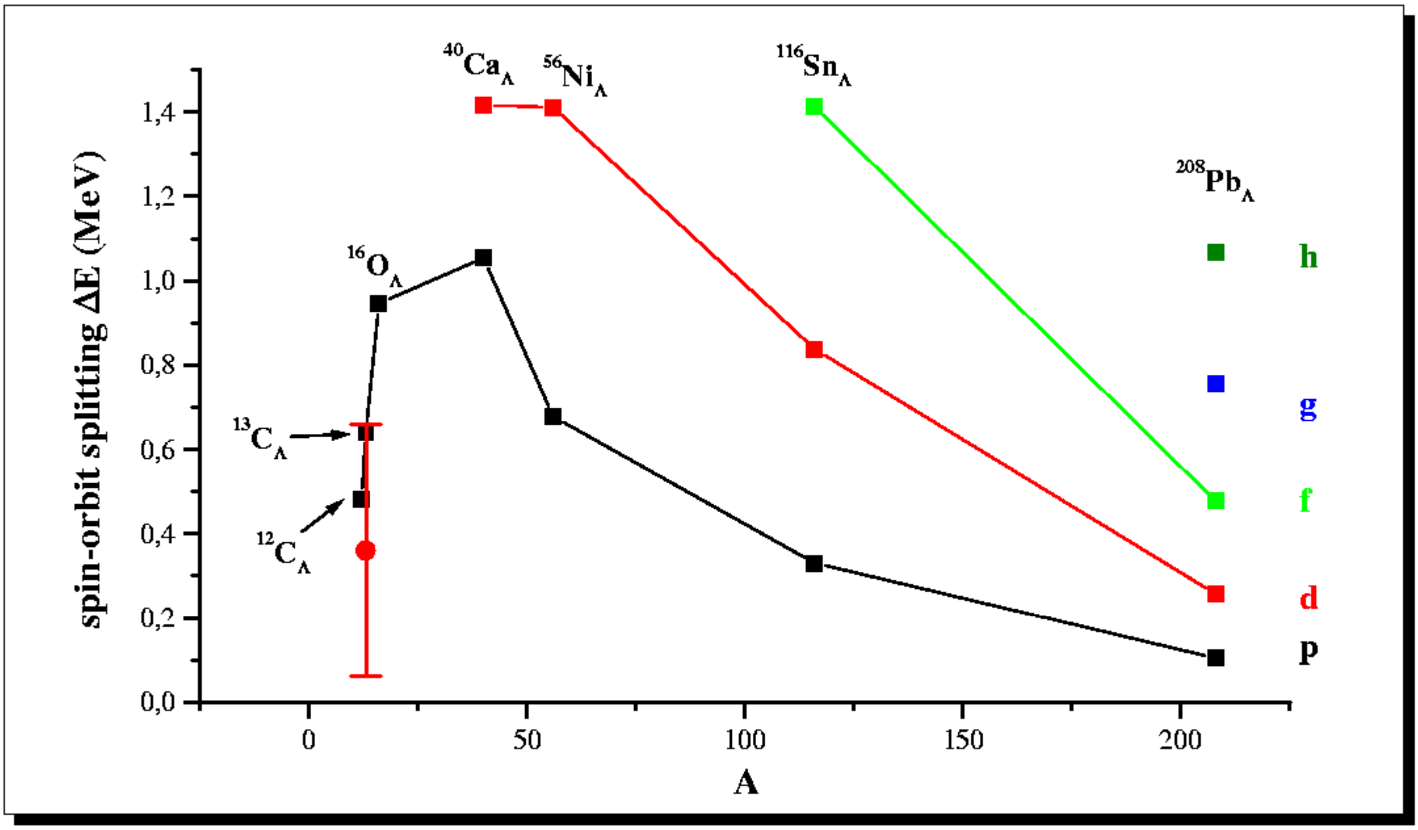
1/2- - 3/2- splitting

E. Hiyama *et al.*, NP **A639**, 173c (1998)

rearrangement of ^{12}C core

Spin-Orbit Splitting in Hadron Field Theory

J. Pochodzalla
MPI -HD



Density dependent relativistic hadron field theory

- in-medium Dirac-Brückner meson-baryon vertices
- ratio of $\Lambda-\sigma$ to N-σ coupling strength chosen as $R_\sigma = 0.49$

Inner-Shell Transitions

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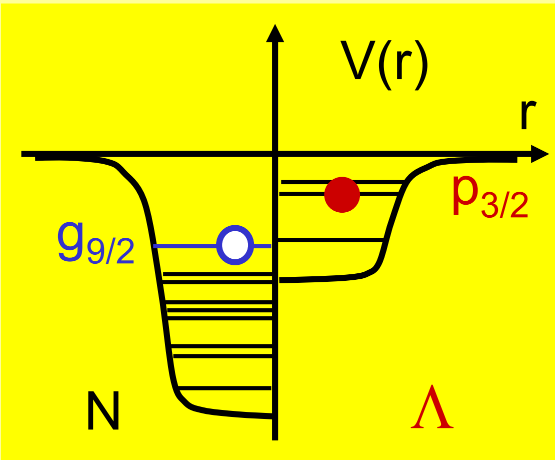
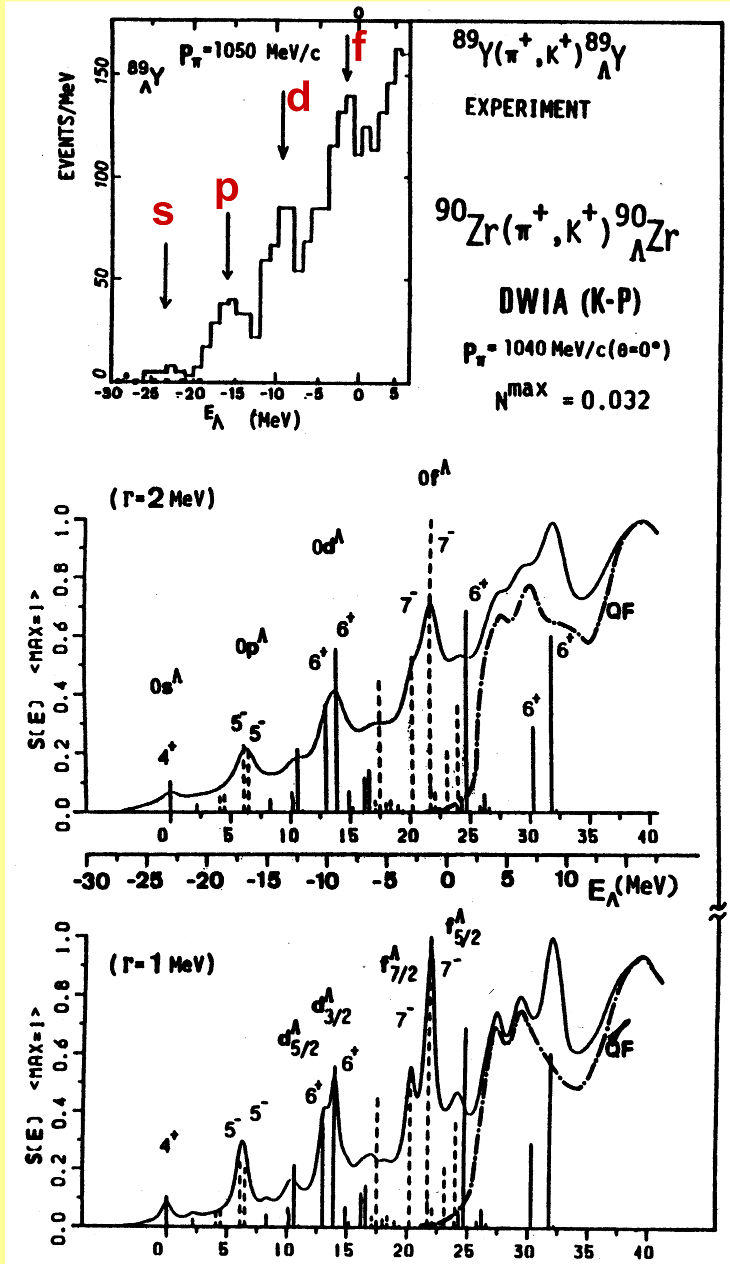
MPI -HD

(π^+,K^+) reaction

resolution ~ 2 MeV





inner shell transitions in heavy nuclei explore the properties of the Λ "deep inside" the nucleus.

- p_Λ states expected to decay via γ-emission
- e.g. in ^{90}Zr: $[g_{9/2}]^{-1} \otimes [p_{3/2}]_\Lambda$ at 10° $\sigma \approx 4$ μb/sr

(D.J. Millener 1999)

γ- Spectroscopy of Hypernuclei

J. Pochodzalla
MPI -HD

- production (π^+,K^+)

  $p_{BEAM} \approx 1$ GeV/c

  $5 \cdot 10^5$ sec^{-1} @ Cave C

GSI
pion beam

- trigger π, K tracking
- bound state selection

  $\Delta M = 8$ MeV (FWHM)

  diff. energyloss, straggling

KAOS
spectrometer

- high resolution γ - spectroscopy

VEGA
Ge-array

KEK vs. GSI

J. Pochodzalla
MPI -HD

	KEK	GSI
primary beam	12 GeV (p)	2 AGeV (^{12}C)
π^+ flux on target	$3\cdot10^6$/s	$0.5\cdot10^6$/s
momentum resolution	10^{-3}	$3\cdot10^{-3}$
typical momentum	1 GeV/c	1 GeV/c
magnetic spectrometer	SKS	KAOS
resolution	$2\cdot10^{-3}$	$5\cdot10^{-3}$
ΔE_x	2 MeV	5 MeV
$\Delta\Omega$	100 msr	35 msr
γ-detector	Ge-ball	VEGA
photo peak efficieny	3 % @ 1 MeV	20 % @1.3 MeV
	0.6% @ 5 MeV	5-6% @10 MeV

Program

J. Pochodzalla
MPI -HD

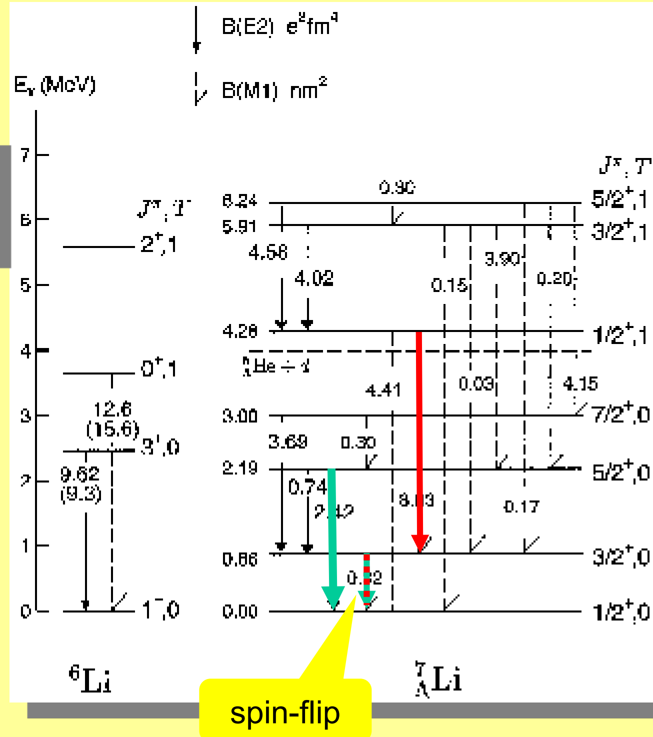
8 $^{7}{}_{\Lambda}$Li: first γ-γ coincidence

E. Hiyama et al.,
PRC **59**, 2351 (1999)

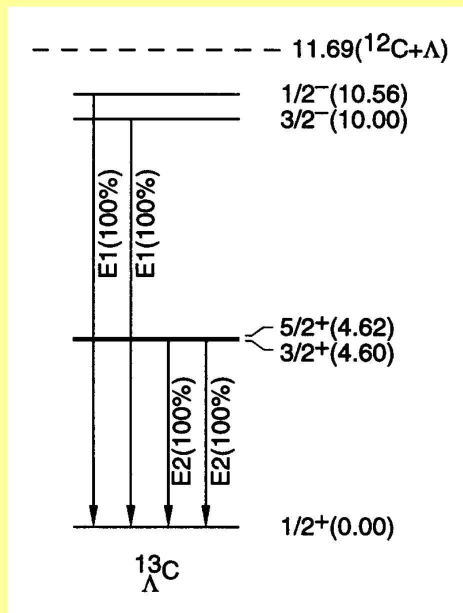
KEK E419 (prel.):

$5/2^{+} \rightarrow$ g.s. @ 2050 ± 2 keV

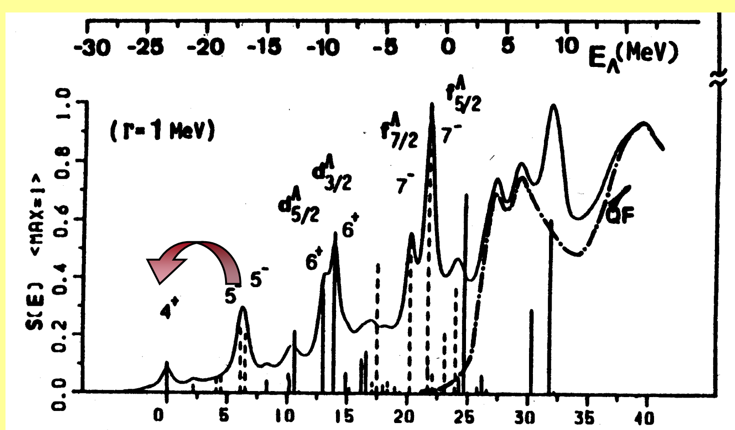
$3/2^{+} \rightarrow$ g.s. @ 689 ± 4 keV



8 $^{13}{}_{\Lambda}$C: $p_{1/2} - p_{3/2}$ spin-orbit splitting



8 $^{90}{}_{\Lambda}$Zr: search for inner-shell transitions



Rate Estimate

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MPI -HD

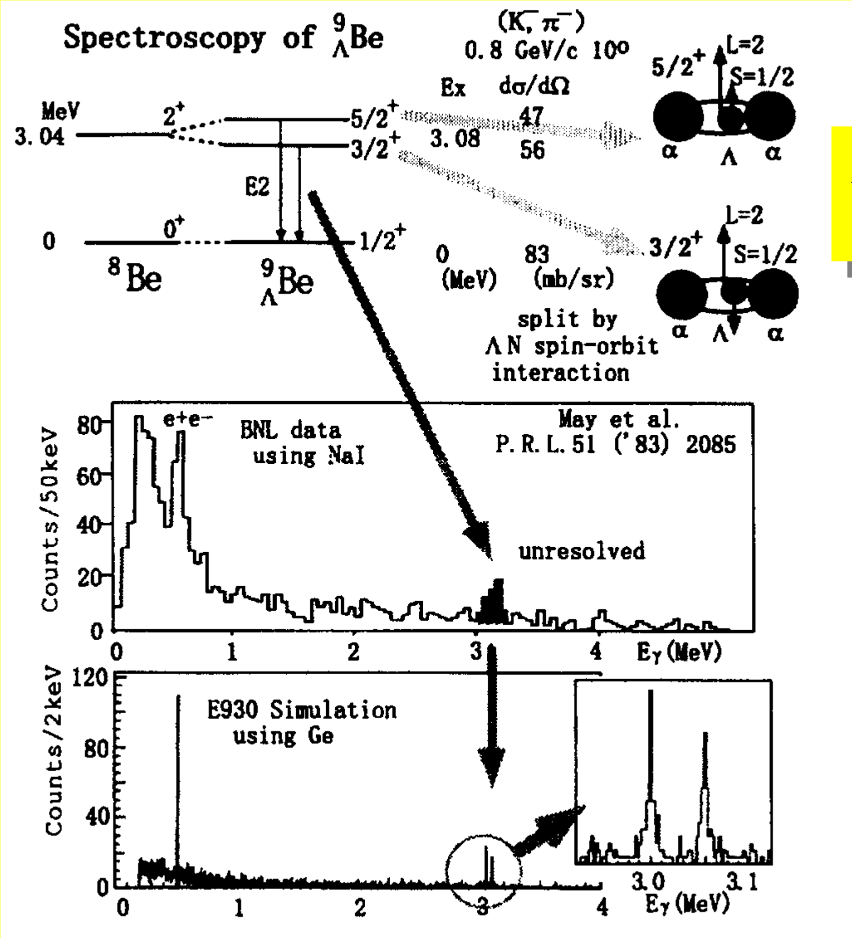
- beam flux at the KAOS target of $5 \cdot 10^5$ π^+/sec
- KAOS solid angle $\Delta\Omega$ = 35 msr
- K^+ survival probability for 5 m flight path SF = 0.36
- analysis efficiency 80%
- live time 80%

target	^{7}Li	^{13}C	^{90}Zr
target thickness [g/cm^2]	5	10	13
$N_T/10^{23}$	4.2	5	0.66
σ [μb/sr]	3	1.7	4
γ –energy [MeV]	3.42 $\wedge$ 0.86	10	6.1
ε_γ [%]	1.1	5.9	8.0
N_γ per day	5	18	7

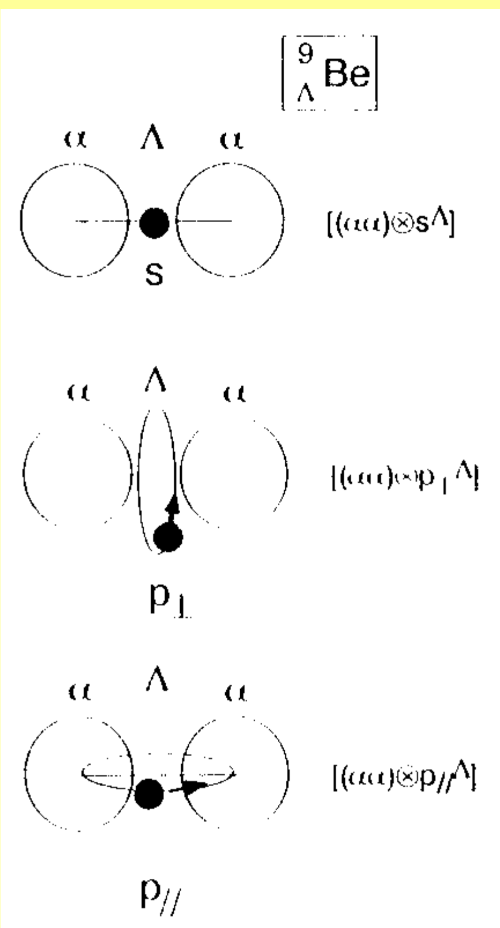
- 5 days of parasitic beam in cave C prior to scheduling the proposed experiment (*halo, background...*)
- 4 days prior main run for *test and calibration*
- 4 weeks of beam on target (1+1+2)

The $^{9}_{\Lambda}Be$ case

J. Pochodzalla



ΛN spin-orbit interaction



^{8}Be - analog

^{9}Be - analog

genuine hypernuclear state

J. Pochodzalla
MPI -HD

- ξξξ