The Next Generation of Hypernucleus and Hyperatom Experiments

GSI, 18.10.2000

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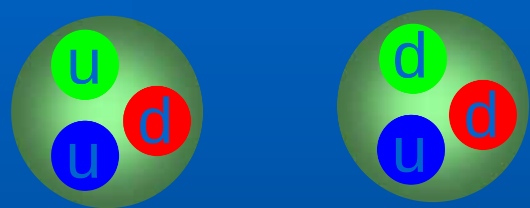
Quark Structure of Hyperons

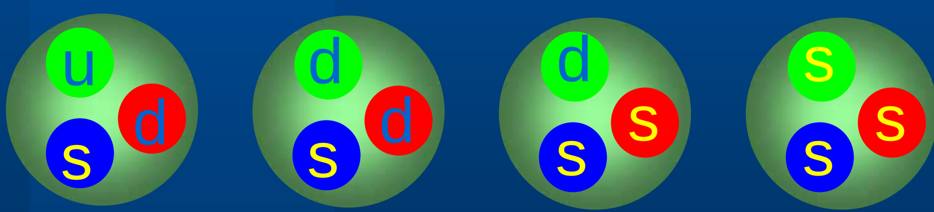
Nucleons

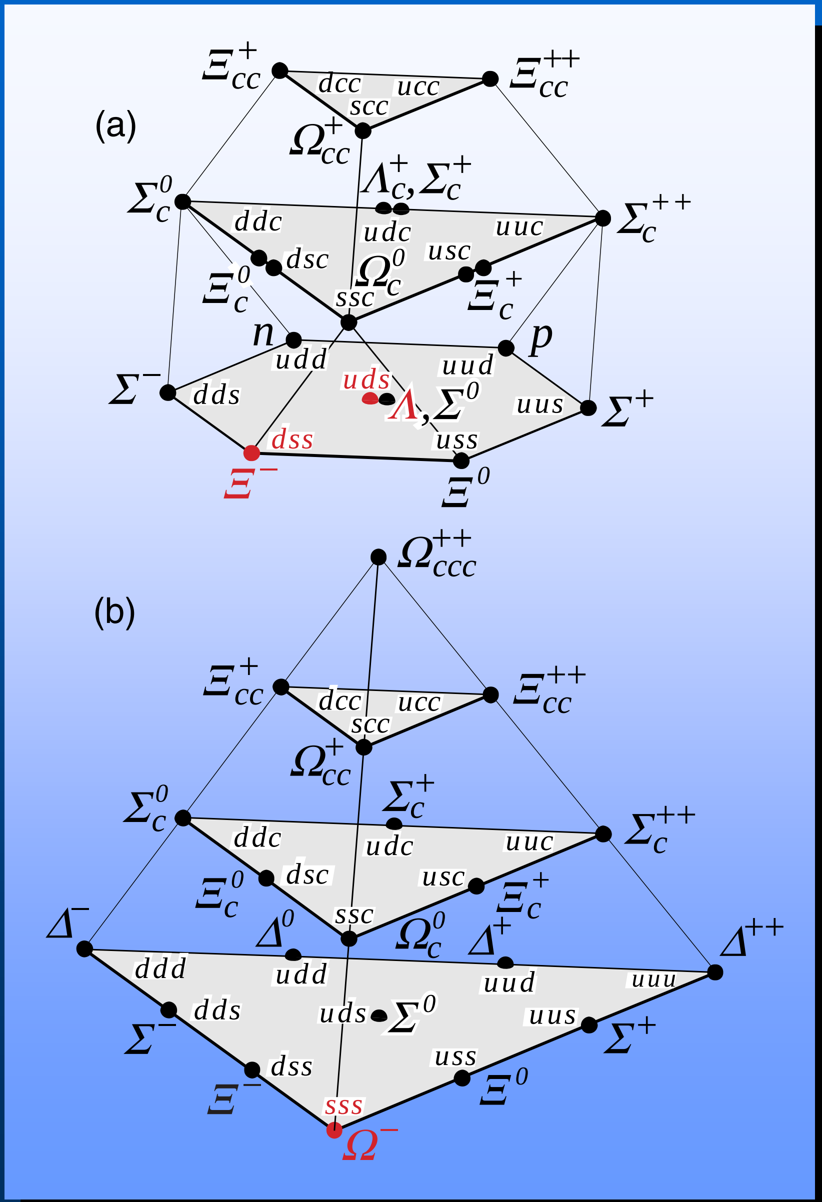
Proton Neutron



Hyperons

Λ^0 Σ^- Ξ^- Ω^- ...





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Present Status of s=-1 Nuclei

- Until few years ago hypernuclear studies focused on (π^+,K^+) or (K^-,π^-) reaction
- New tools
  - $e^+e^- \rightarrow \Phi_{1020} \rightarrow$ KK tagging (FINUDA @ DAΦNE)
  - γ-spectroscopy with Ge (BNL, KEK, GSI)
  - $(e,e'K^+)YX$ (TJNAF, MAMI-c)
- Topics
  - YN interaction
  - non-mesonic weak decay

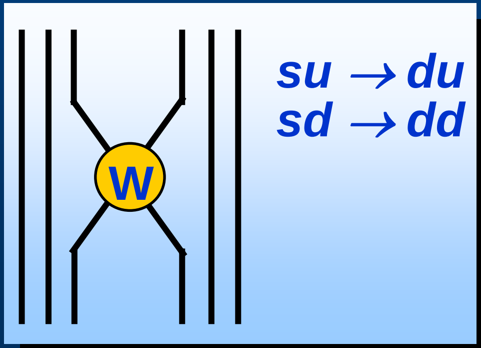
    $\Lambda p \rightarrow pn$

    $\Lambda n \rightarrow nn$

$$\sqrt{m_N(m_\Lambda - m_N)}c \approx 400 MeV/c$$

Weak decays...

- unique chance to study baryon-baryon weak interaction !



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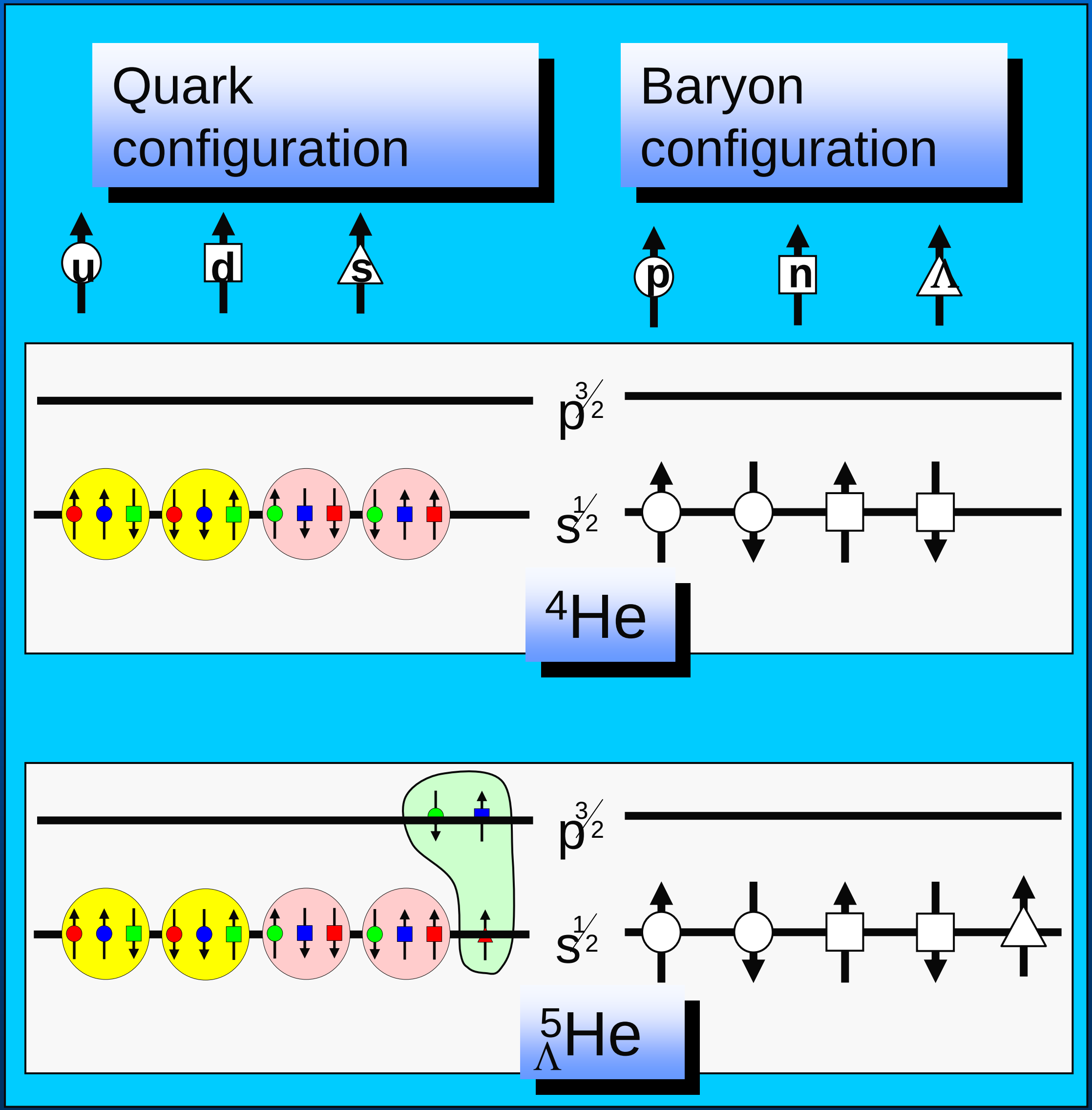
Hypernuclei and Deconfinement



Question...

- **Manifestation of the Pauli priciple on the quark ?**

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Status of Multi - Hypernuclei

- **Multi-Hypernuclei are a *terra incognita*...**
- **...but they exist !**

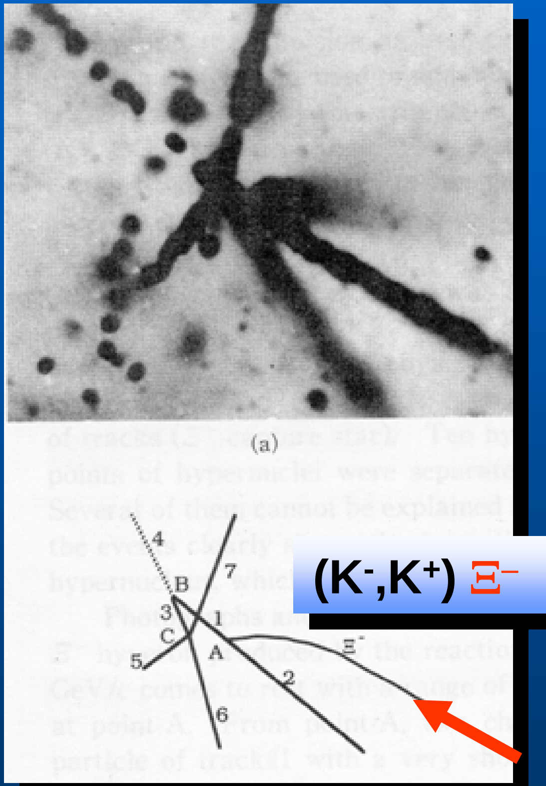
6 candidates for ΛΛ-hypernuclei are observed

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

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

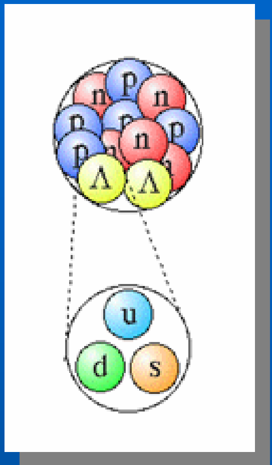
1991: KEK-E176 ${}^{10}_{\Lambda\Lambda}$**Be or** ${}^{13}_{\Lambda\Lambda}$**Be**

1991: KEK-E176 **3 non-mesonic decays**

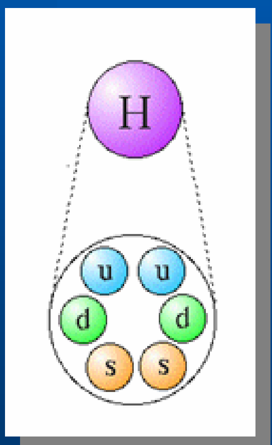


Hypernucleus	$B_{\Lambda\Lambda}$ [MeV]	$\Delta B_{\Lambda\Lambda}$ [MeV]
${}^{6}_{\Lambda\Lambda}$He	10.9 ± 0.6	4.7 ± 0.6
${}^{10}_{\Lambda\Lambda}$Be	17.7 ± 0.4	4.3 ± 0.4
${}^{13}_{\Lambda\Lambda}$B	27.6 ± 0.7	4.8 ± 0.7

ΛΛ-Nuclei as a Laboratory

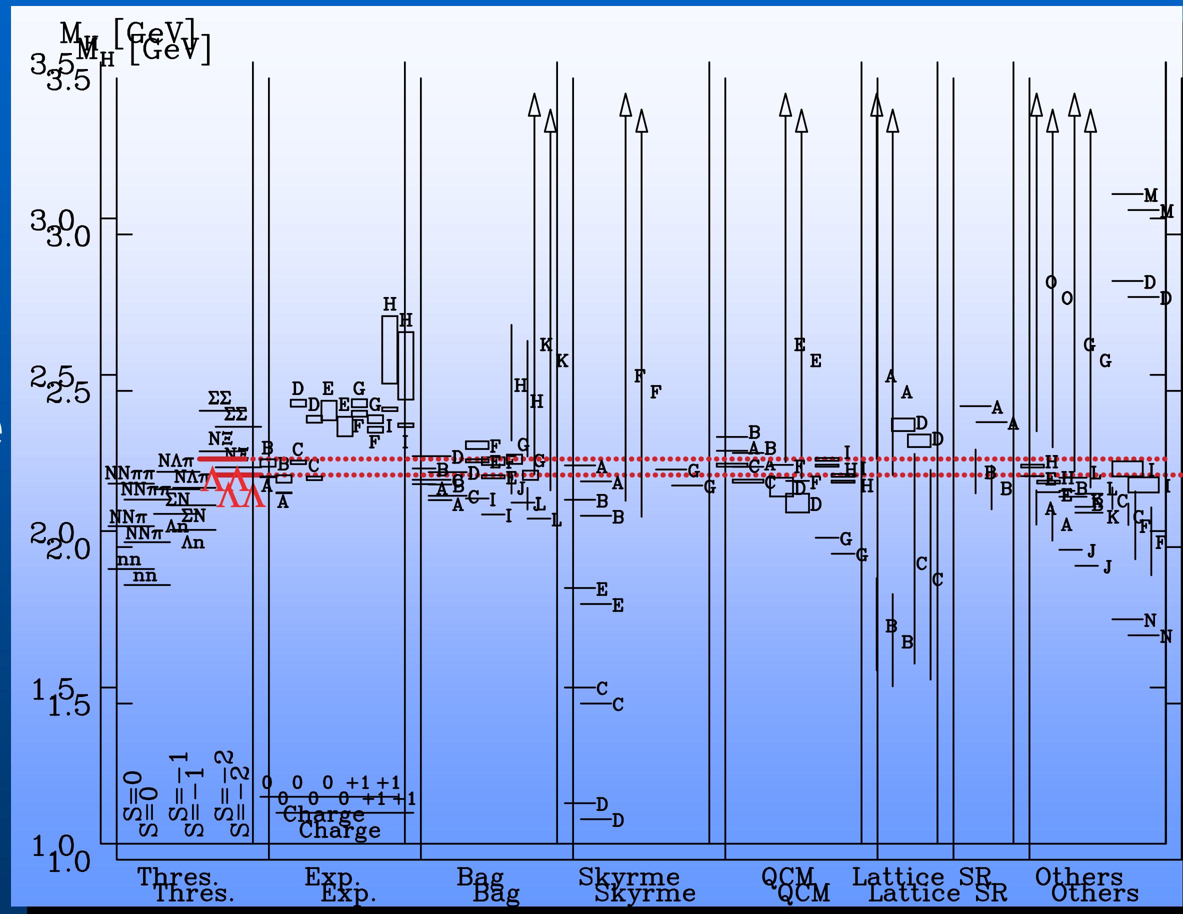


- **Hyperon-hyperon interaction**



- **H-particle**

R.L. Jaffe (1977)



Sakai *et al (nucl-th/9912063)*...

„The situation in a finite nucleus will be that the low-lying states have the character of ΛΛ bound states, but that some of excited states may have strong admixture of the H-nuclear states.“

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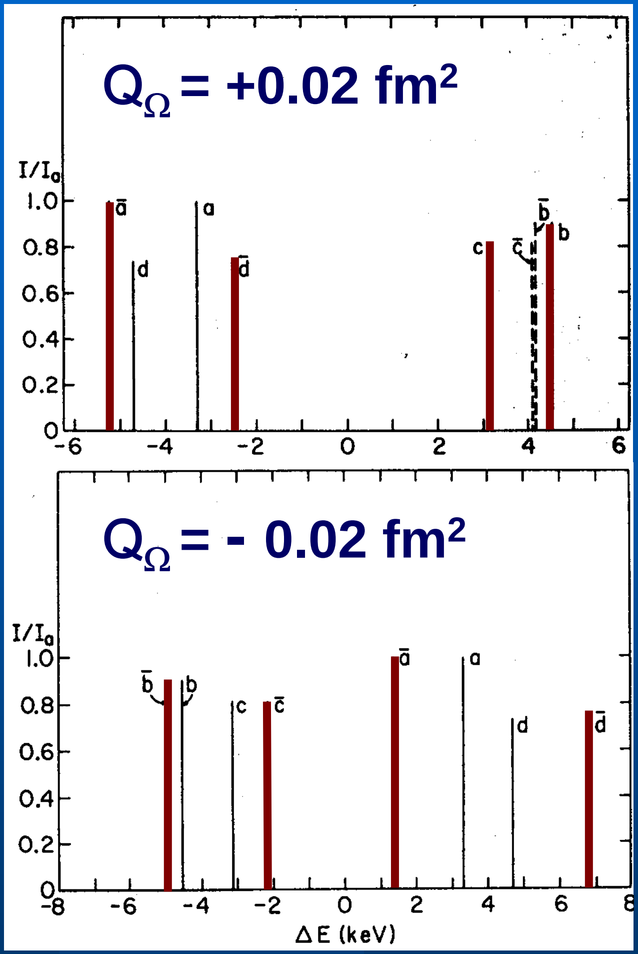
The s=-3 Challange



- Ω hypernuclei by $\Omega\bar{\Omega}$ production
- Electric quadrupole moment of the Ω by hyperfine splitting in Ω-atoms*)
  - tensor forces between quarks
  - expectation $Q_\Omega = (0 - 3.1)\ 10^{-2}\ \text{fm}^2$
  - $\Delta E(\ell=10 \rightarrow \ell=9) \sim 515$ keV
  - $\Delta E_Q \sim$ few keV for Pb

spin-orbit	$\Delta E_{\ell s} \sim (\alpha Z)^4\ \ell m_W$
quadrupole	$\Delta E_Q \sim (\alpha Z)^4 Q_{33} m^3_\Omega$

*) C.J. Batty (1995)...

"…The precision measurements of X-rays from Ω^- Pb atoms will certainly require a future generation of accelerators and probably also of physicists.“

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Production of s=-2 Hypernuclei

- **relativistic HI collisions**
  - **coalescence of hyperons**

    Bodmer (1971), Rufa *et al.* (1989), Schaffner *et al.* (1991)...

- **Ξ^- capture: Ξ^- p $\rightarrow \Lambda\Lambda$ + 28 MeV**
  - **(K^-,K^+)**

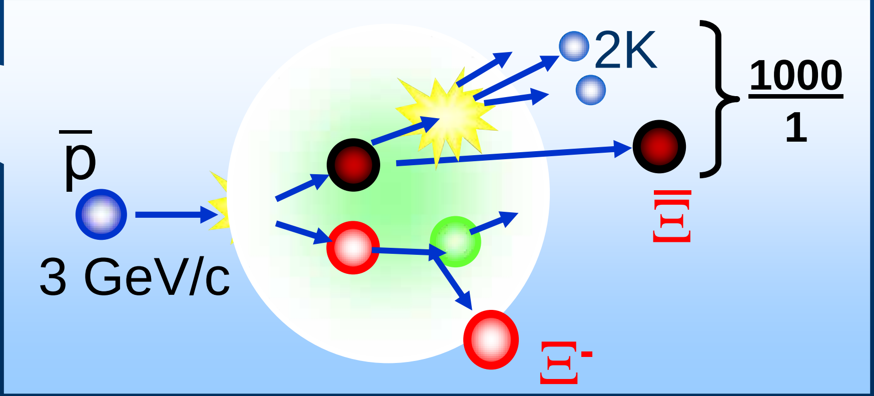
    KEK-PS E373, BNL-E906...
  - **$\bar{p}$p annihilation at rest**

    K. Kilian (1987), DIANA coll.
  - **$\Xi\bar{\Xi}$ threshold**

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

➥ $\bar{K}^*N \rightarrow K\,\Xi^-$

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



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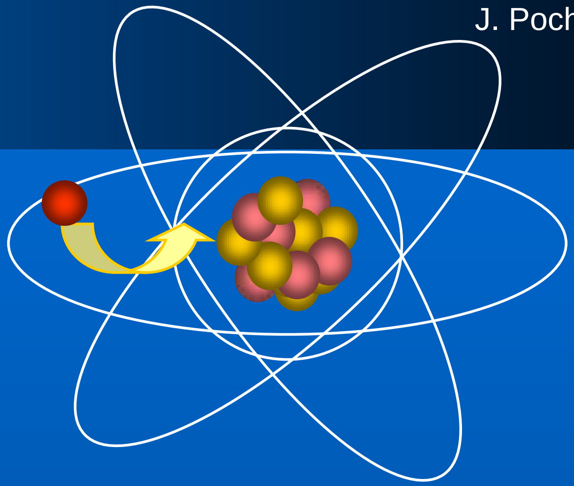
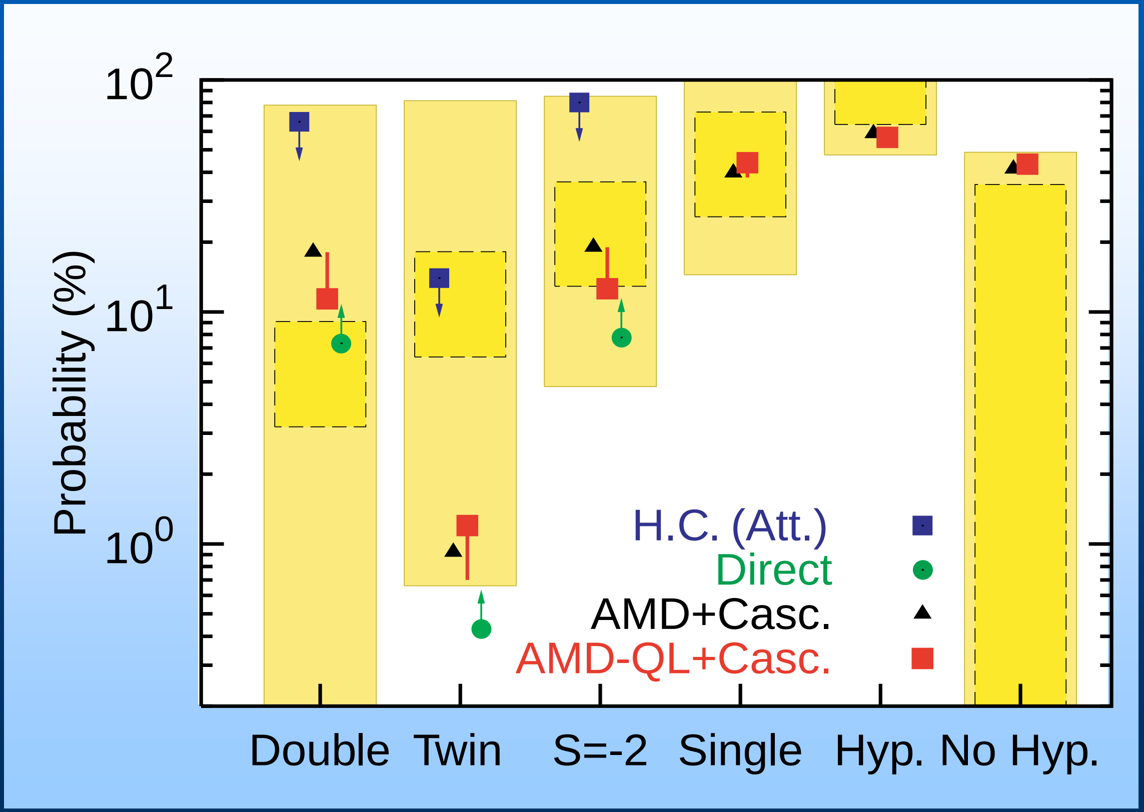
Ξ⁻ capture



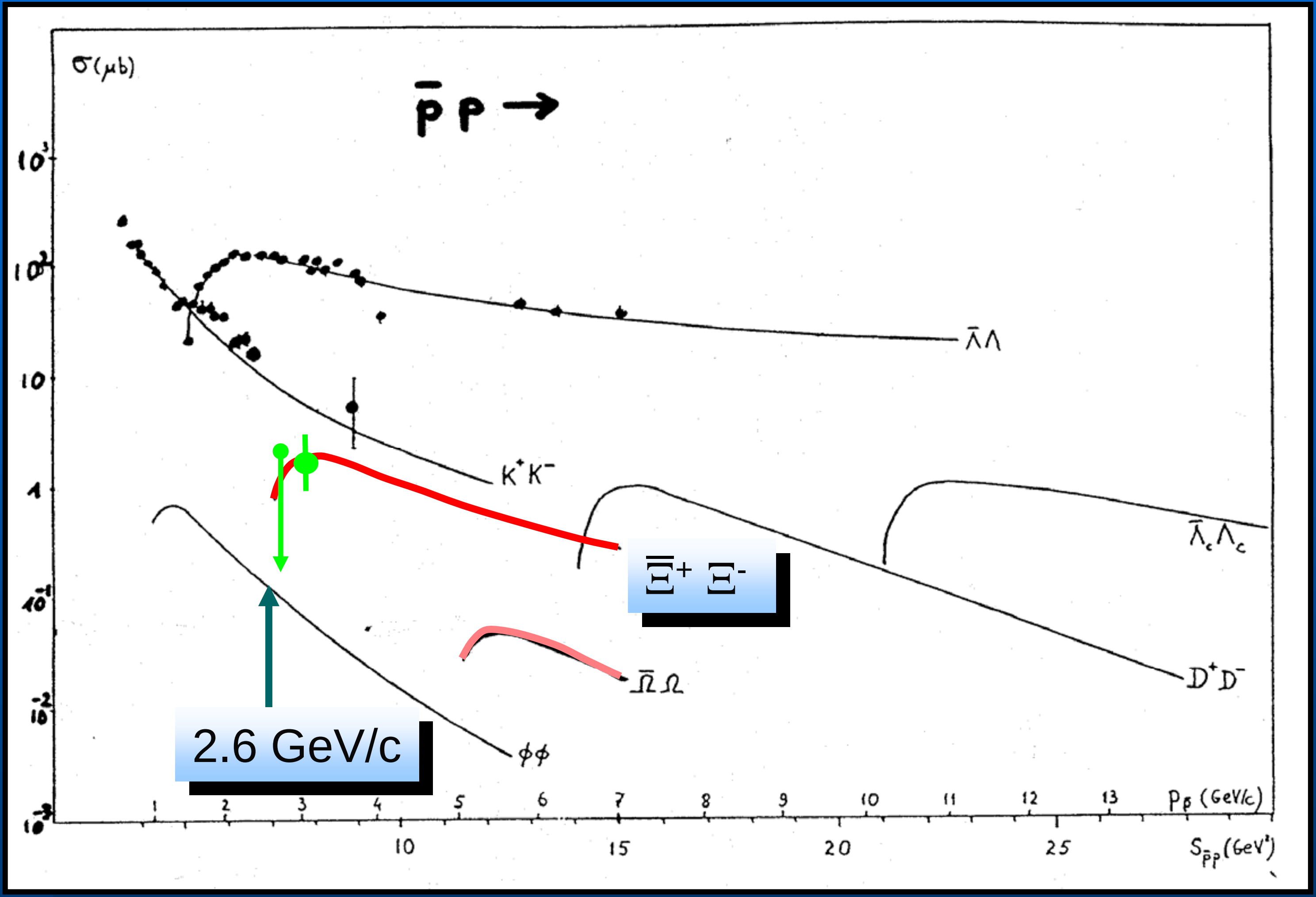
- Ξ-atoms: x-rays
- conversion
  - Ξ⁻(dss) **p**(uud) → Λ(uds) Λ(uds)
  - **ΔQ = 28 MeV**



Conversion probability...

- ...approximatly 5-10%

Hyperon Production

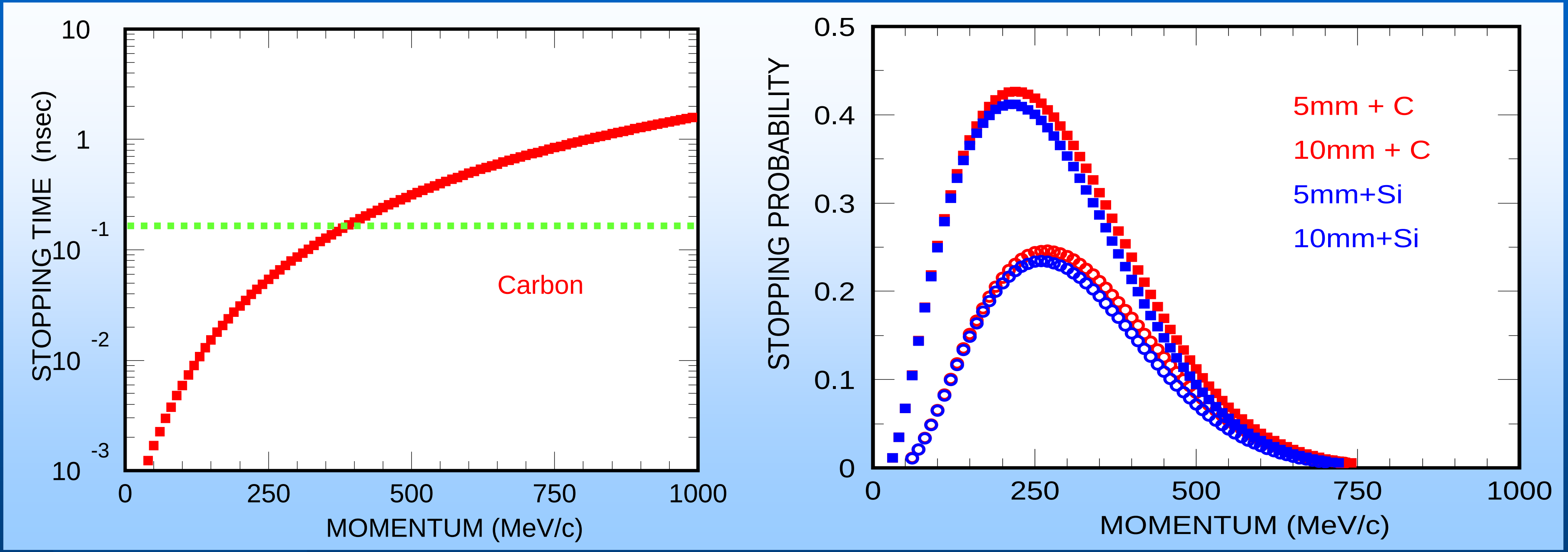


For example...

- **with L=2·10^{32} cm^{-2}s^{-1} ➠ 700 s^{-1} for a C target**

Ξ⁻ Properties

- Ξ⁻ mean life 0.164 ns

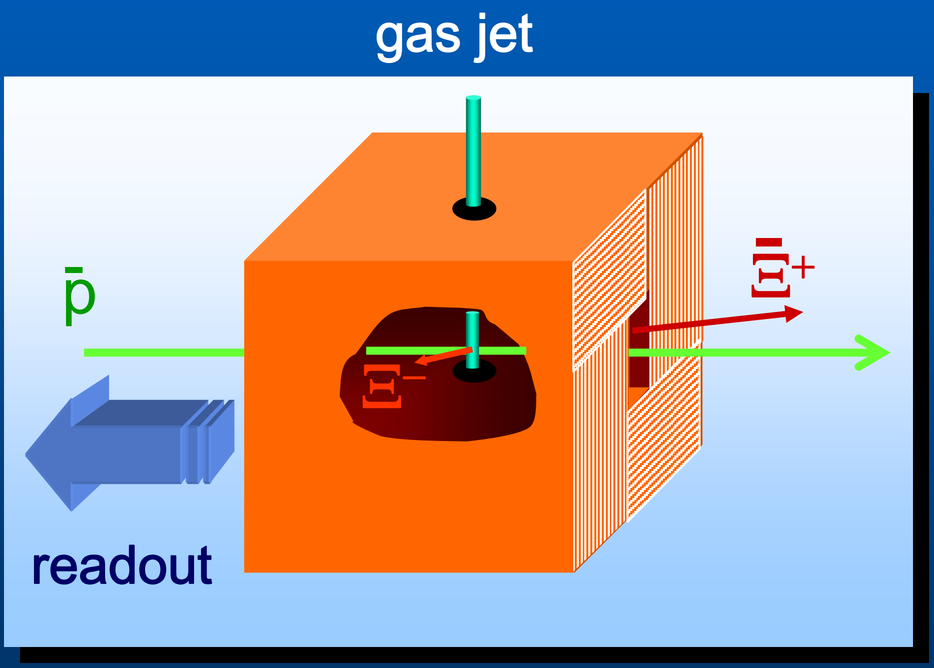


Consequence...

- **minimize distance *production – capture***
- ***initial* momentum 100-500 MeV/c → range ~ few g/cm²**

Setup

- **beam: 3 GeV/c, ∅ ≈ 1mm; no halo (roman pots?)**
- **internal gas target e.g. Ne, width 1mm**
- **Tracking detector for Ξ^-**
  - **2-3 cm thick**
  - **diamond strip**
  - **Si strip**
  - **capillary fiber**



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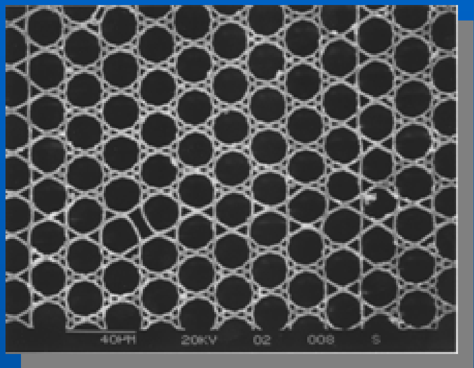
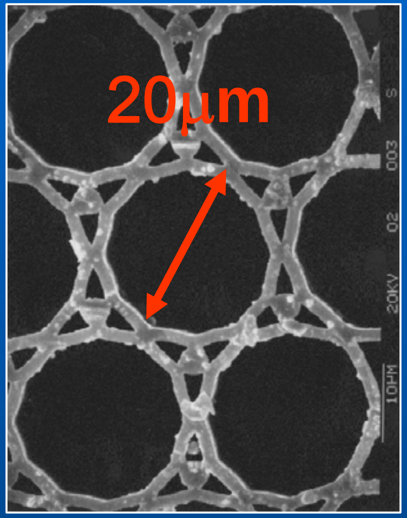
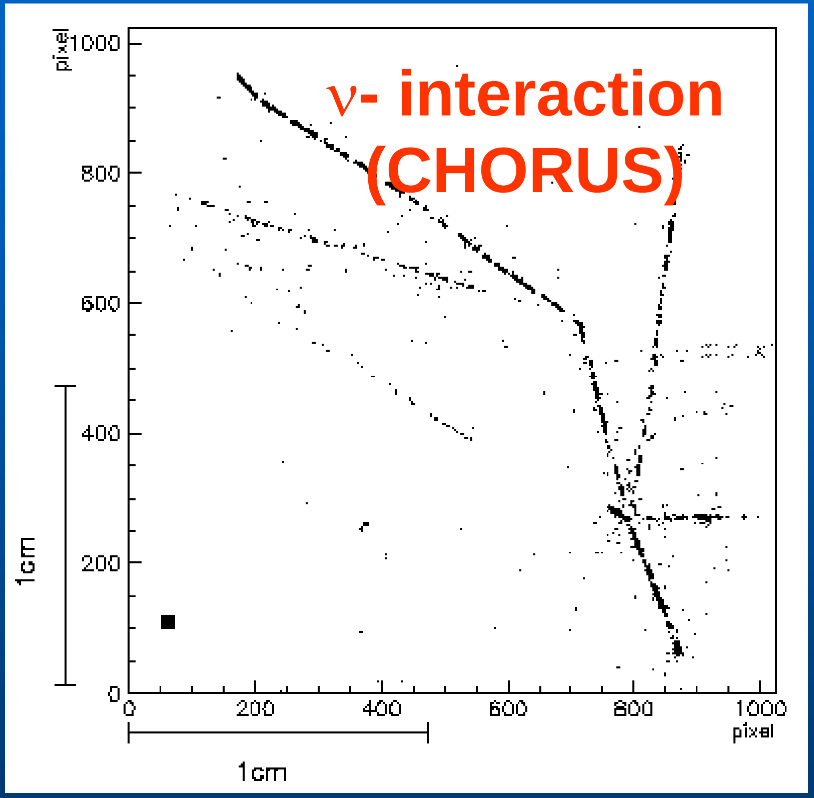
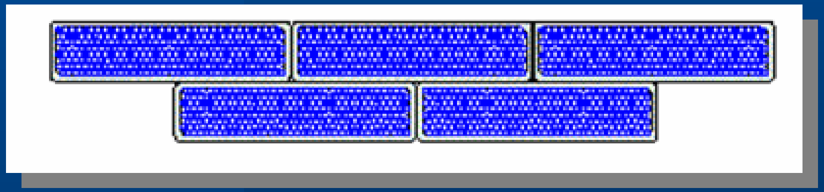
Capillary Detector

- **Glascapillaries filled with szintillator**









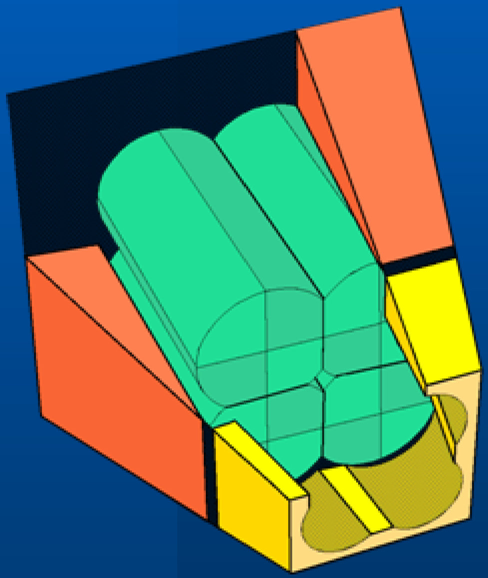
Problem...

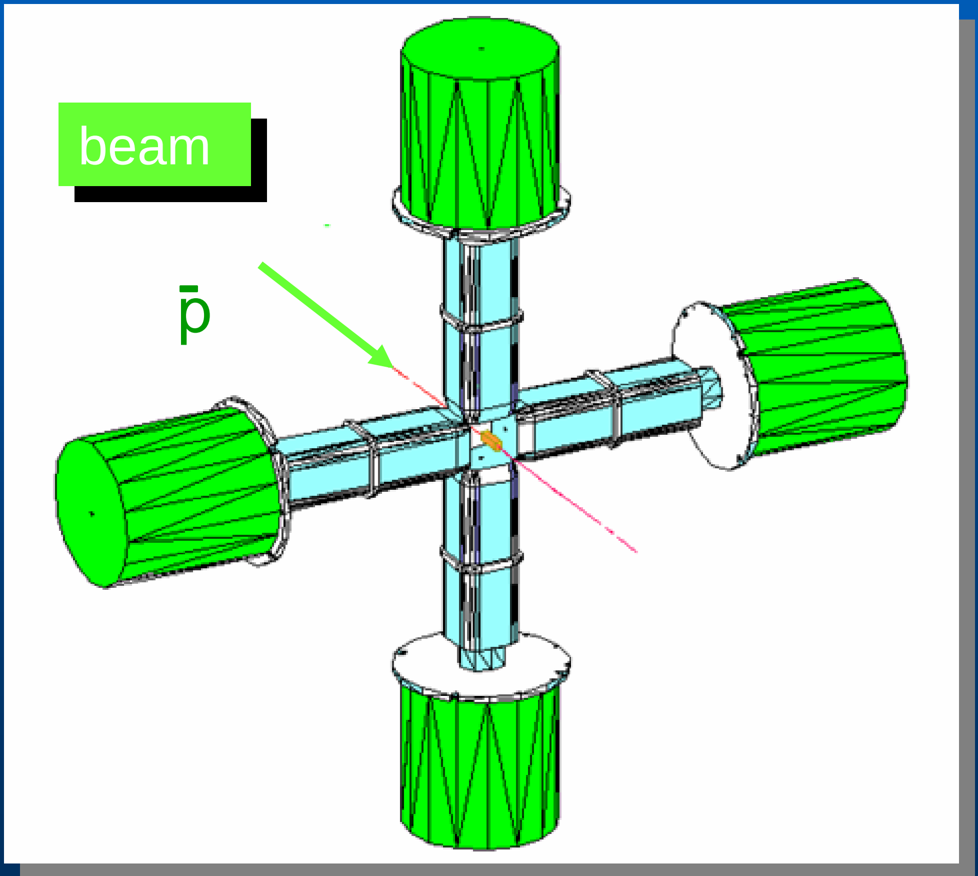
- **fast readout**
- **possible solution :Hybrid Phototube + ALICE pixel chip**

Needs R&D !

Gamma Spectroscopy

- **Ge box based on VEGA type detectors**
- **segmented Clover**
- **7 cm ∅, 14 cm long**
- **4 seg. clover, ε_{PH} = 0.13 @ 1.33 MeV**
- **resolution ~ 0.5 %**





crucial point...

- **fast electronics under development**

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Count Rate

• luminosity $2 \cdot 10^{32}\ cm^{-2}s^{-1}$		
• $\Xi^+\Xi^-$ cross section 2μb for pp	→	700 Hz
• p(100-500 MeV/c)		$p_{500} \approx 0.0005$
• Ξ^+ reconstruction probability		0.5
• stopping and capture probability		$p_{CAP} \approx 0.20$
• *total stopped* Ξ^-	→	*3000 / day*
• Ξ^- to $\Lambda\Lambda$ conversion probability		$p_{\Lambda\Lambda} \approx 0.05$
• *total* $\Lambda\Lambda$ *hyper nucleus production*	→	*4000 / month*
• gamma emission/event,		$p_\gamma \approx 0.5$
• γ-ray peak efficiency		$p_{GE} \approx 0.1$

total single line γ–rate

- ~ 5/day „golden events“ (Ξ^+ trigger)
- ~ 500/day with *KK* trigger

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Competition

experiment	*reaction*	*device*	*beam/ target*	*status*
BNL-AGS E885	$(\Xi^{-},{}^{12}C) \to {}^{12}_{\Lambda\Lambda}B + n$	neutron detector arrays	K^{-} beam, diamond target	20000 stopped Ξ^{-}
BNL-AGS E906	2π decays	Cylindrical Detector System	K^{-} beam line	few tens 2π decays of ${}^{4}_{\Lambda\Lambda}H$
KEK-PS E373	$(K^{-},K^{+})\Xi$	emulsion	(K^{-},K^{+})	several hundreds stopped Ξ^{-}
facility	*reaction*	*device*	*beam/ target*	*Observed captured Ξ^{-} per day*
JHF	$(K^{-},K^{+})\Xi$	spectrometer, $\Delta\Omega$ =30 msr	$8 \cdot 10^{6}$/sec 5 cm ${}^{12}C$	<7000
cold anti-protons	$p\,\bar{p} \to K^{*}\bar{K}^{*}$ $\bar{K}^{*}N \to \Xi\,K$	vertex detector	10^{6} stopped $\bar{p}$ per sec	2000
GSI-HESR	$p\,\bar{p} \to \Xi\,\bar{\Xi}$	vertex detector + γ–spectrometer	$L=2 \cdot 10^{32}$, thin target, production vertex $\neq$ decay vertex	3000 „golden events“ ~ 300000 KK trigger

Conclusion

- **The anti-proton storage ring HESR @ GSI can provide a unique facility to study strange hyperatoms and hypernuclei.**
- **Key points**
  - **highest luminosity possible**
  - **moderate beam quality**
  - **micro tracking device**
  - **high rate Germanium array**
- **Detailed spectroscopic studies of multi-strange systems will be possible.** ***"hyperon laboratory"***