Doubly Strange System Physics with Antiprotons at PANDA

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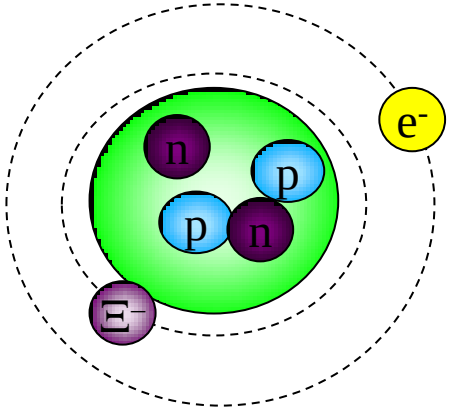
Summary

1. Overview of the physics of doubly strange systems
   a) Exotic atoms
   b) Doubly strange hypernuclei,
   c) Double hypernuclei
2. Strangeness in PANDA: $\Lambda\Lambda$ hypernuclei
   a) Production of S=-2 with antiprotons
   b) The 2-target technique
   c) Antiproton beam and expected rates
3. Work in progress
   a) Targets and detectors design, prototypes and tests
   b) Simulation and reconstruction
   c) Opportunities for simultaneous measurements

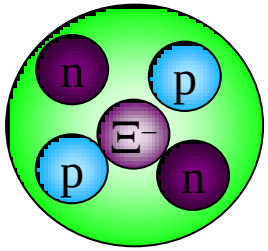
New Frontiers in Strangeness Physics: S=-2 Systems

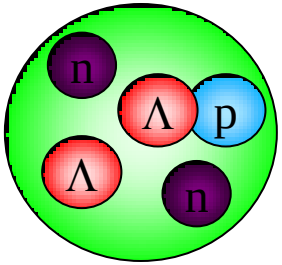
3 different systems contain double strangeness (S = -2)



Exotic Hyperatom:
a Ξ^- hyperon is captured in an atomic orbit

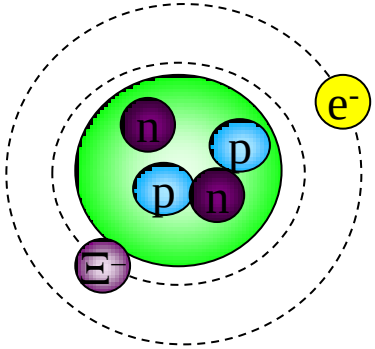
Doubly Strange Hypernucleus:
a Ξ^- hyperon is captured inside a nucleus
(Ξ^- hypernucleus)





Double Hypernucleus:
a nucleus is made by nucleons and 2 Λ's
(ΛΛ hypernucleus)

What is new in Ξ^- hyper-atom?



Hadronic atom, sensitive to **E.M. + strong forces**

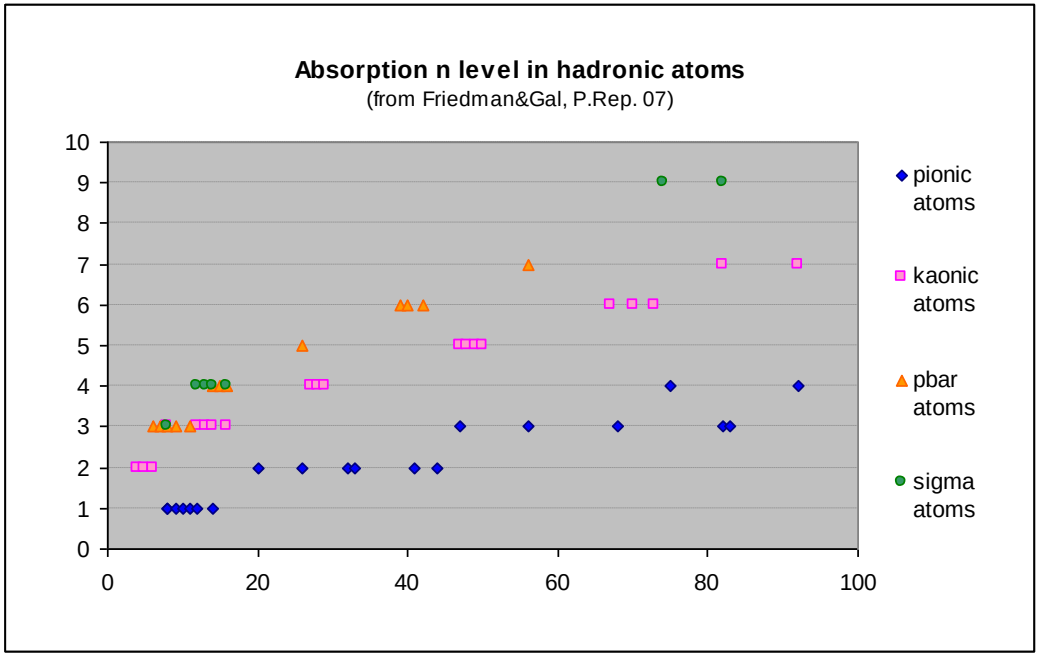
Formation of Ξ^- atom

- Ξ^- captured in a high atomic level ($\approx n_0\sqrt{(m_\Xi/m_e)}$)
- Atomic cascade → X rays emission → precise mass measurements
- In a low level $\mathbf{n_{abs}}$:
  - atomic orbit overlaps periphery of nucleus,
  - nuclear interaction shifts and broadens the level,
  - due to broadening, Ξ^- is absorbed into the nucleus

Only shift and width of the **last level** ($\mathbf{n_{abs}}$) of the cascade can be measured

- Test of models
- parameters for (Optical) Potential

Status of art of Ξ^- hyper-atom data



DATA: π^-, K^-, p, and Σ^- data cover the whole periodic table

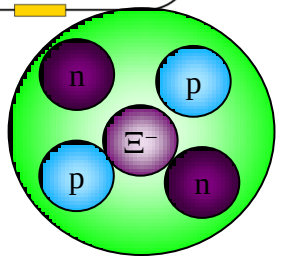
(n_{abs} *increases with Z & mass*)

Ξ^- and Ω^- are completely missing

Why?

Difficult Ξ^- production followed by stop

What is new in Ξ^- hyper-nucleus?



Physics with Ξ^- Hypernuclei:

- ***Nuclear structure*** : **spectroscopy → nuclear potential**

Ξ-N strong interaction

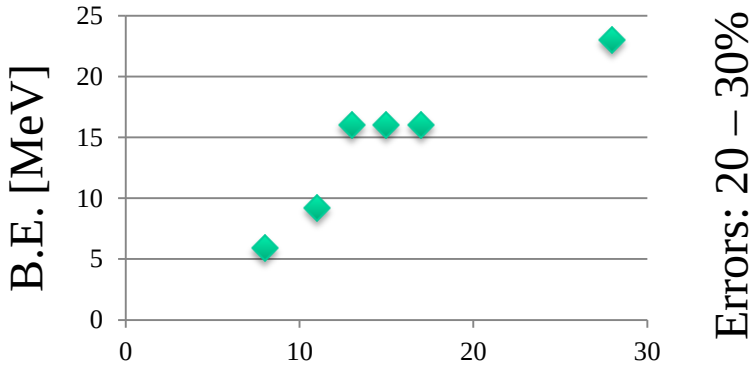
- **short range: 2s-quarks come into play**
- **long range: bosons exchange (Remarks: in OBE:**
  Ξ N → Ξ N : no *strange* (I=1/2) *meson*, all I=0,1 exchanged (ω, η , π, ρ ...)
  Ξ N → $\Lambda\Lambda$ coupling: only *strange meson* exchange (κ ...)

- ***In medium effects:*** **change of Y-mass , effects on magnetic moment …**
- ***Ξ-N weak interaction***
  - **Non Mesonic Weak Decay:** **Ξ p → Λ n (E_Λ=95 [MeV], $p_{\Lambda,N}$=469):**
    Ξ N → Σ N (E_Σ =55 [MeV],$p_{\Sigma,N}$=366):

In nuclei: expected suppressed by strong interaction, **$\Gamma_{\Lambda N} \approx 0$, $\Gamma_{\Sigma N} \approx 0$**

What happens in neutron stars (Λ-rich matter)?
does "Pauli blocking" suppress strong interaction Ξ N → $\Lambda\Lambda$?

Status of art of Ξ^- hyper-nucleus data

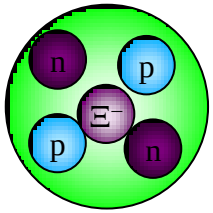


Dover&Gal:→ attractive well V_Ξ=21 24 MeV

$^{12}C(K^-,K^+)\ {}_\Xi B^{12}$ → $V_\Xi \approx 14$ MeV (AGS – E885,2000)
SCIFI$(K^-,K^+)\ {}_\Xi A^Z$ → $V_\Xi \approx 16$ MeV (KEK – E224)

Each point : single observation, no statistics

Other measurements:



- Ξ^- + N: $\sigma_{el} \leq 28$mb (Ξ^- produced in (K^-,K^+), with $p(K^-)$=1.66GeV/c) (Ahn06,PLB633)

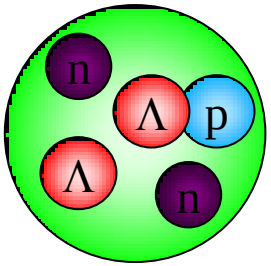
- Ξ^- + nucleus: mean free path in nucleus $\approx$ 4.7fm ($p(\Xi^-)$ = 0.6GeV/c) (Aoki98NPA644)

- $K^- + {}^{12}C \rightarrow K^+ + {}^{12}B_\Xi$: $\frac{d\sigma}{d\Omega}(\theta_K < 8^\circ) \approx 89[nb/sr]$ (Khaustov00,PRC61)

What is new in ΛΛ hyper-nuclei ?

Physics with ΛΛ Hypernuclei:

- ***ΛΛ strong interaction*** (only possible in double hypernuclei)
- **YY potential: attractive/repulsive?**
  - **short range: interaction of 2 s-quarks**
  - **long range: bosons exchange** (**Remarks: in OBE:**
    ΛΛ → ΛΛ : only non strange, I=0 mesons (ω, η...))
- **Hyper-fragments distribution:**
  dependence on YY potential and on Ξ nuclear level



- **Strong decay: ΛΛ → H particle? (H = uuddss, strongly bound)**
  If YES, dominant on weak decay?

- ***Weak interaction: several channels, mesonic and non mesonic***
- ***ΛΛ weak interaction*** (only possible in double hypernuclei)

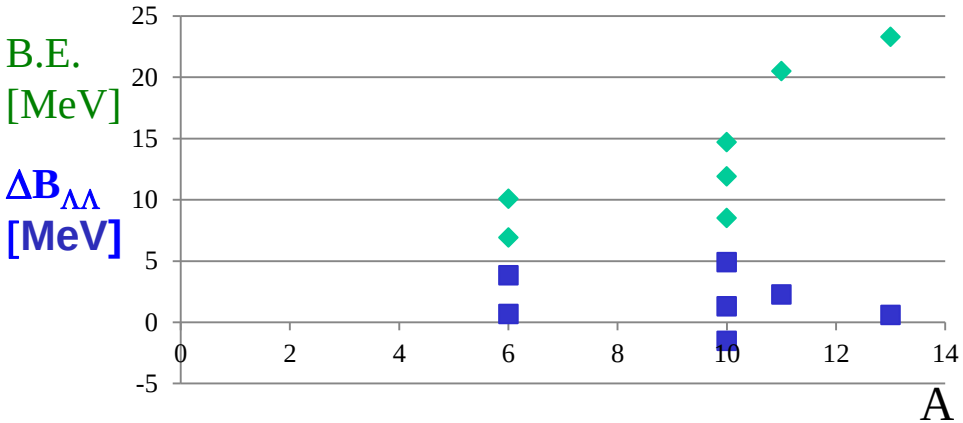
Hyperon Induced Non Mesonic Weak Decay

- **ΛΛ → Λ n : (expected $\Gamma_{\Lambda n}$ << Γ_{free}) ($p_{\Lambda/N}$ = 433 MeV/c)**
- **ΛΛ → Σ^-p : (expected $\Gamma_{\Sigma p}$ << Γ_{free}) ($p_{\Sigma/N}$ = 321 MeV/c)**

→ Important short-range interaction

Status of art of ΛΛ hyper-nucleus data

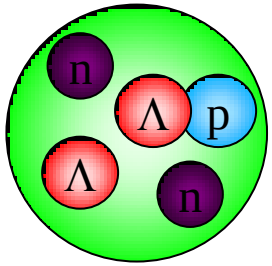
ΛΛ hypernuclei strong interaction



$$\Delta B_{\Lambda\Lambda} = \Delta B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) \equiv B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) - 2B_{\Lambda}({}^{A}_{\Lambda}Z)$$

Some questions:

- Coherent data ?
- $\Delta B_{\Lambda\Lambda}$ is constant with A? (Expected decreasing)
- $\Delta B_{\Lambda\Lambda}$ is attractive or repulsive?
- $B_{\Lambda\Lambda}$ is increasing with A?



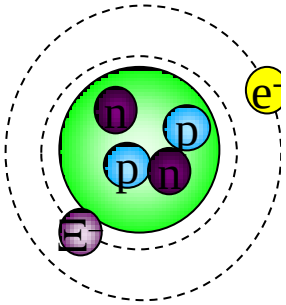
ΛΛ hypernuclei weak interaction

- a lot of channels: mesonic, non mesonic, hyperon induced, mixed, but:

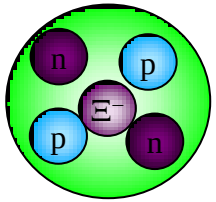
NO DATA

Needs of: high statistics, several nuclei

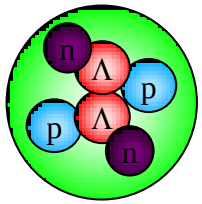
S= -2 Systems Physics: Summary



- **Ξ^- Hyper-atom → interplay between Coulomb and nuclear potential in the peripheral nuclear matter**



- **Ξ^- Hyper-nucleus → peculiar aspects of the strong and weak interaction: Ξ^- N potential, Non Mesonic Weak Decay…**



- **ΛΛ Hyper-nucleus → peculiar aspects of the strong and weak interaction: ΛΛ potential, H-Dibaryon, Hyperon Induced Non Mesonic Weak Decay of ΛΛ …**

PANDA aims to investigate: ΛΛ Hyper-nuclei

by Intense Antiproton Beam to get High Statistics in Several Nuclei

Production of ΛΛ Hypernuclei

Ξ^- hyperon is produced by antiproton in:

$p_{bar} + p \rightarrow \Xi^+ + \Xi^-$ $\quad$ $p_{bar} + n \rightarrow \Xi^0_{bar} + \Xi^-$

Threshold @ $\approx$ 2.65 GeV/c

If a nuclear target is used:

quasi free reactions

Ξ^- can re-scatter in residual nucleus, strongly decelerating

Ξ^- exits from the nucleus:

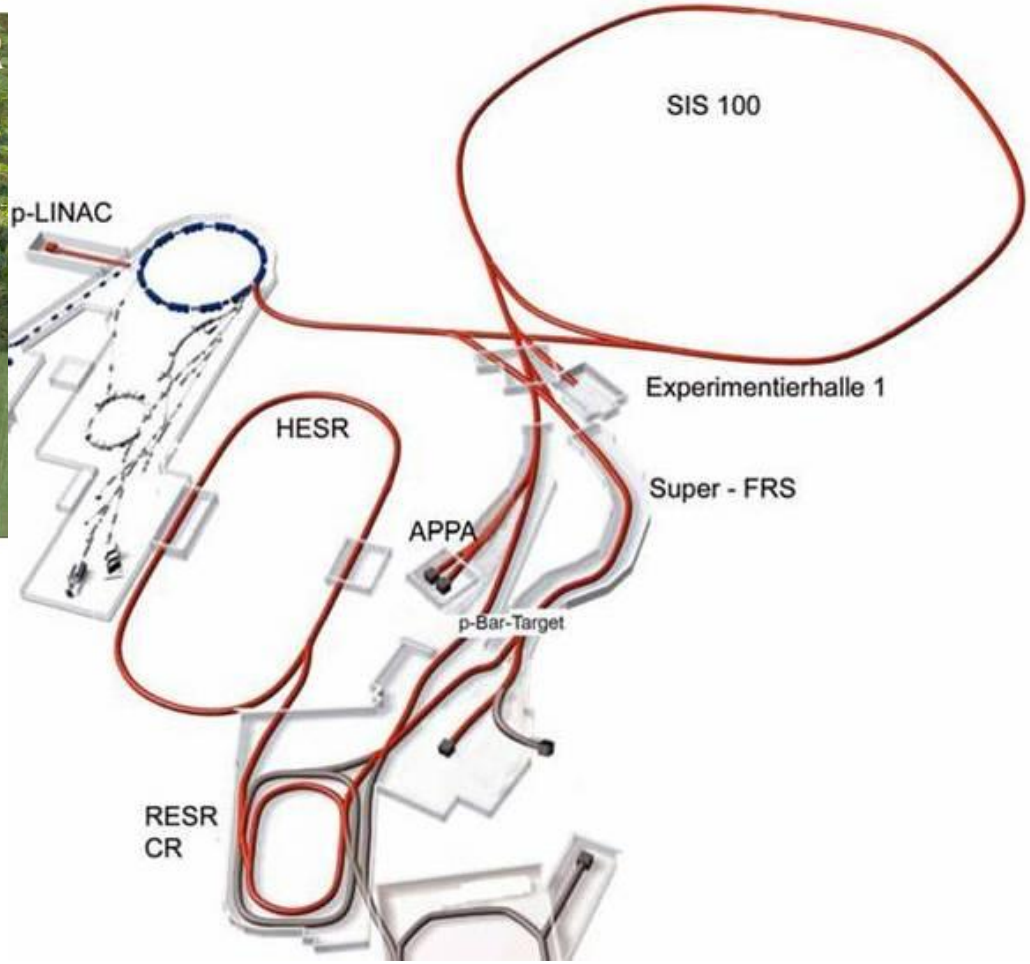
goes to stop in ordinary matter (if doesn't decay!)

is absorbed in a nucleus

interacts with a proton: **$\Xi^- p \rightarrow \Lambda\Lambda$**

If ΛΛ stick to the nucleus: ΛΛ hypernucleus is formed

Antiprotons @FAIR



- Proton acceleration in LINAC to 70 MeV
- Multi-turn injection into SIS18
- Transfer of 4 SIS pulses to SIS100
- Acceleration to 29 GeV and extraction of single bunch

- Antiproton target and separator for 3GeV (3.7 GeV/c) antiprotons
- Collection and precooling in the Collector Ring (CR): rate=10^7 pbar/s
- Transfer to users (HESR)
- Storage and acceleration of antiprotons in the range: 1.5 15 GeV/c

Momentum range: 1.5 – 15 GeV/c
Production rate: $1x10^7$antiproton/s

Choosing Antiproton Momentum for Ξ^-

σ(3 GeV/c) = Max (very few data)

⊕

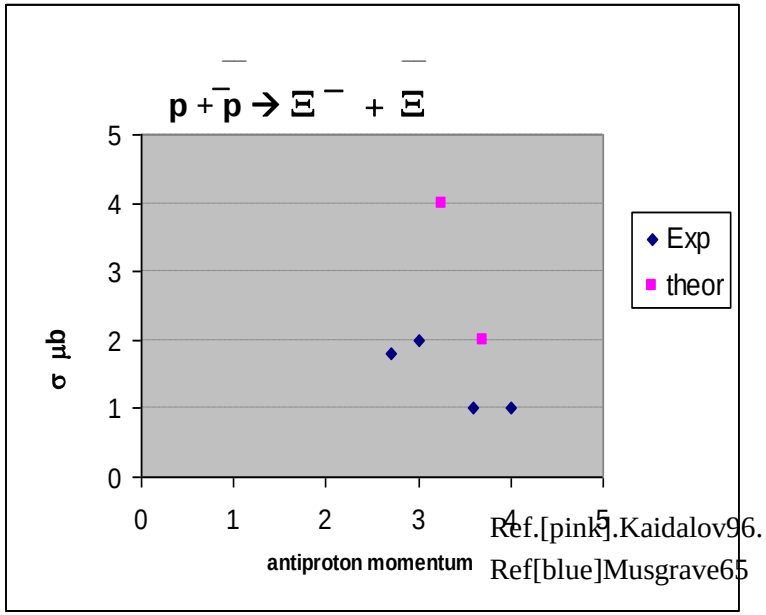
$\Xi^- \bar{\Xi}^+$ threshold = 2.65 GeV/c

⊕

π production threshold = 3.1 GeV/c

⇩

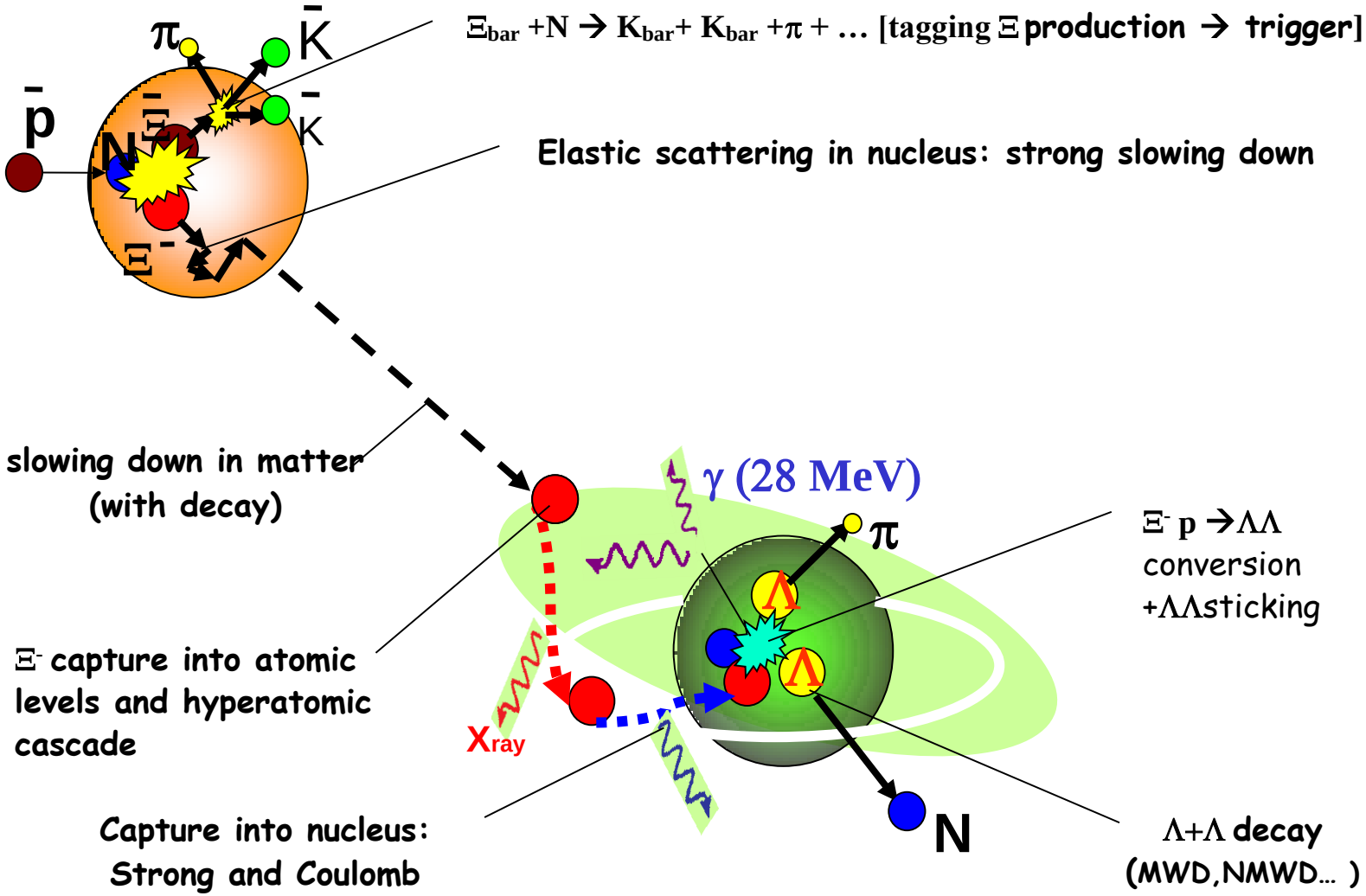
antiproton momentum = 3 GeV/c



Ξ^- production rate depends also on:

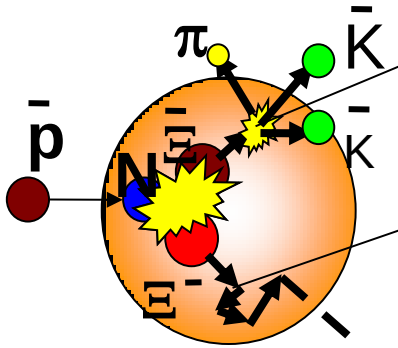
- Experimental setup : target sizes and material
- Antiproton beam: intensity, antiproton production rate, beam cycle

S = -2 Systems Production by Antiprotons



Two-target Technique at PANDA

I Target

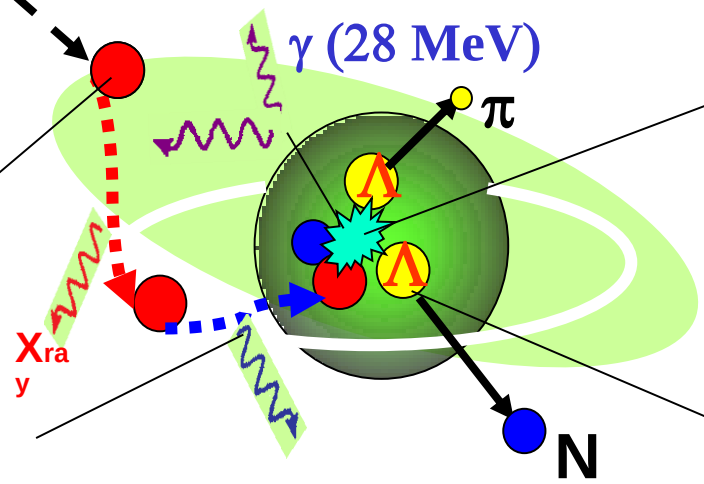


Ξ_{bar} +N → K_{bar}+ K_{bar} +π + … [tagging Ξ production → trigger]

Elastic scattering in nucleus: strong slowing down

II Target

slowing down in matter (with decay)



Ξ^- p →ΛΛ conversion +ΛΛsticking

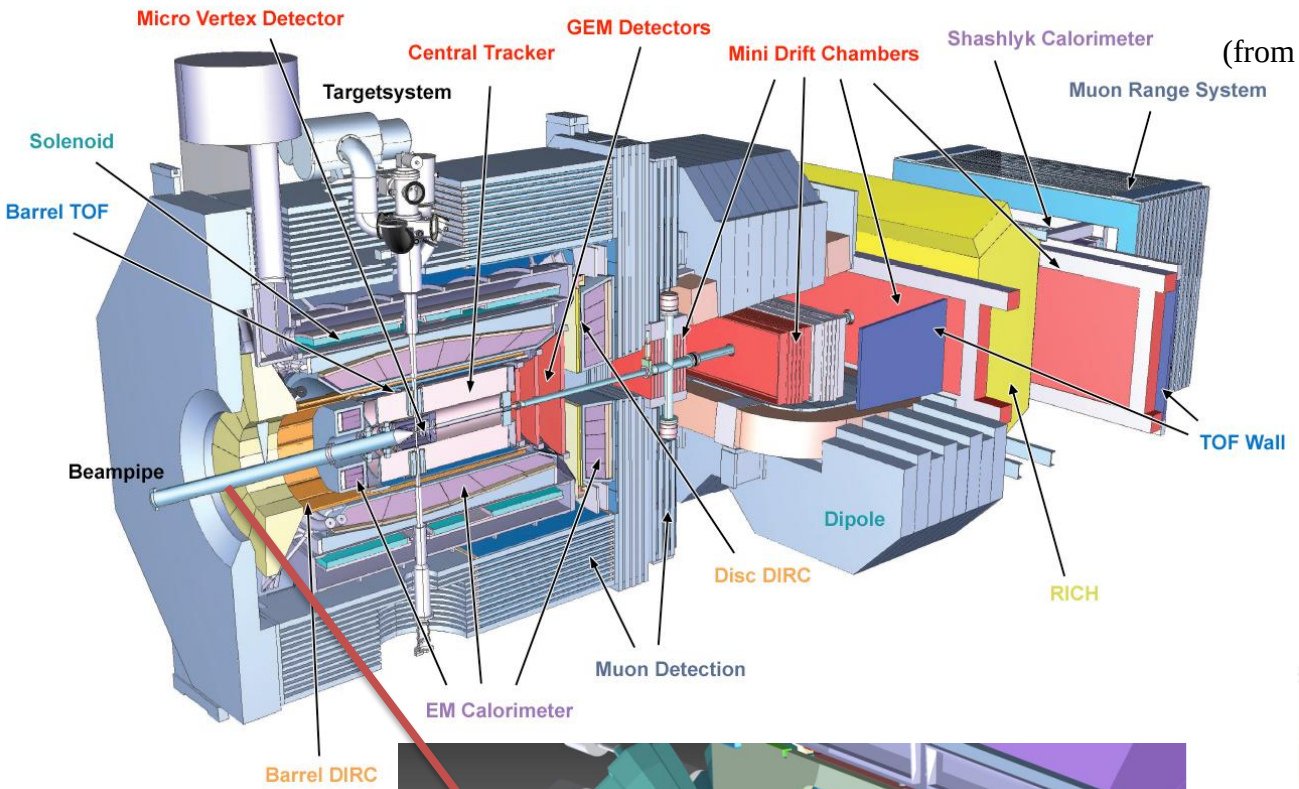
Ξ^- capture into atomic levels and hyperatomic cascade

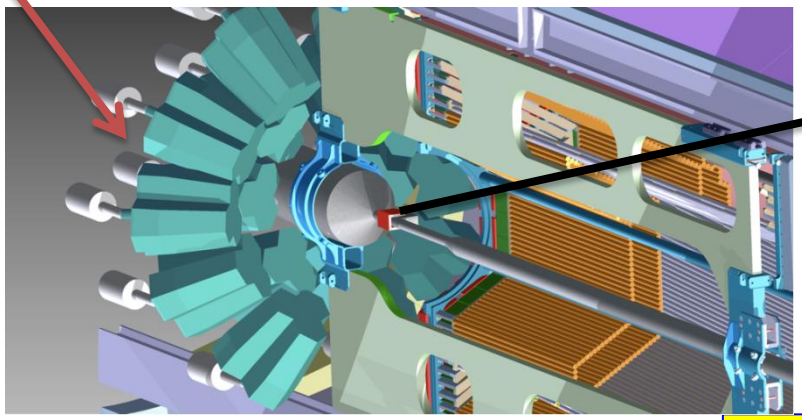
Capture into nucleus: Strong and Coulomb forces

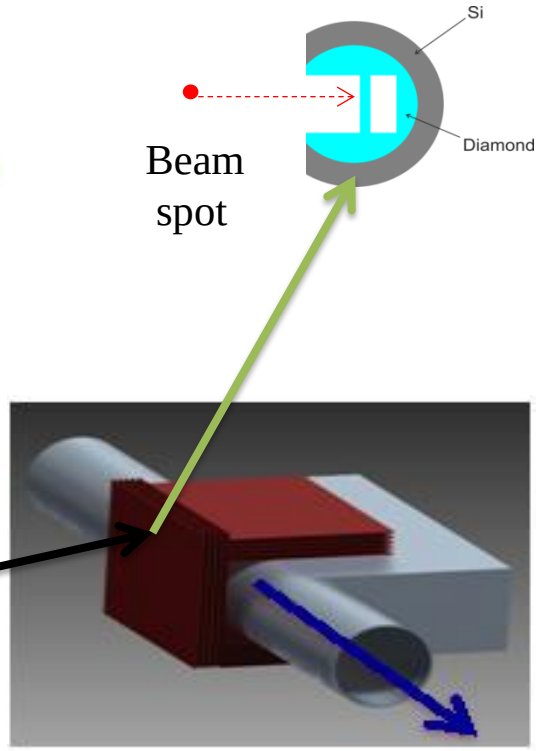
Λ+Λ decay (MWD,NMWD…)

Set-up for Hypernuclei @ PANDA

(from A. Sanchez, PANDA Meeting, Sept. 2012)







To detect:

- $\pi^{\pm}$, $K^{\pm}$,
- γ, p, X,
- fragments (?)

3 Basic Problems of Hypernuclear Set-up

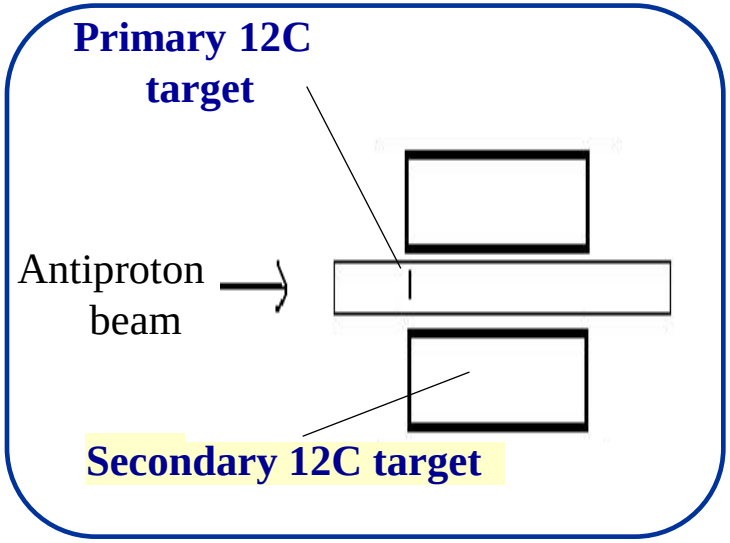
1. Efficiency of the Slowing down of Ξ^- in nuclear matter:
   - expected rates of stopped Ξ^-
   - expected $\Lambda\Lambda$ hypernuclei
2. HPGe performances in fringing magnetic field:
   - Resolution
   - Stability in long time operation
3. Interaction between internal "solid" target and antiproton beam:
   - Beam structure
   - Primary target features

1: Ξ^- Slowing down in nuclear matter

Efficiency calculated by MC

Ingredients:

- Very thin wire as primary)target
- Homogeneous ^{12}C as secondary target)
- Slowing down inside the residual nucleus by nuclear scattering (INC-like model)
- Slowing down and stop by ionization
- Atomic capture + Atomic cascade



The ratio R_Ξ of stopped to produced Ξ^- has been evaluated:

$$R_\Xi \approx 2.2 \cdot 10^{-3}$$

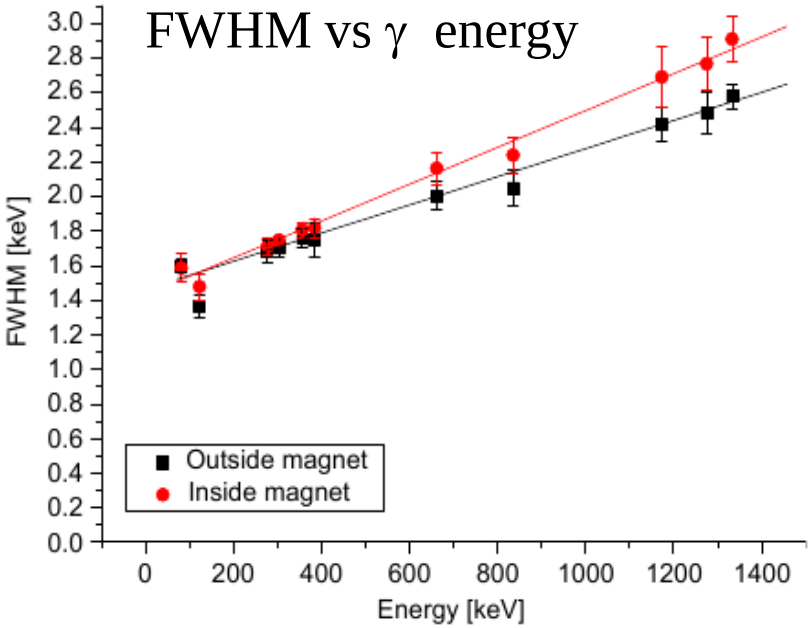
(In the real set-up (smaller and inhomogeneous secondary target, slightly larger beam pipe, ...) a ≈ 40% reduction is expected)

A fraction (roughly 5%) of stopped Ξ^- produce $\Lambda\Lambda$ (from old experiments):

$$R_{\Lambda\Lambda/\Xi} \approx 5 \cdot 10^{-2}$$

2: HPGe inside the fringing field

High precision γ and X ray spectroscopy require good performances of HPGe assembly even inside the fringing magnetic field (<0.5 T)



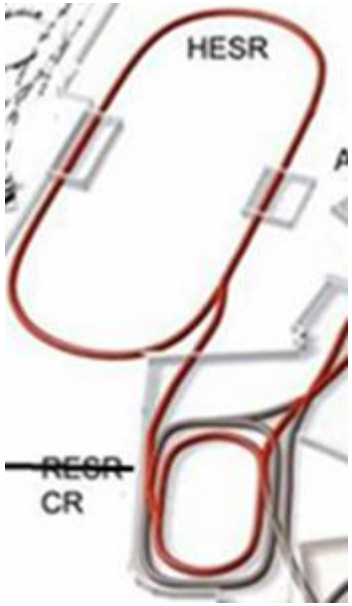
Test performed on HPGe in 0.8T magnetic field with different γ's energy showed:

* resolutions : variation within 10%
* efficiency : no variation
* performances : stable along 1 year

HPGe crystals can operate inside the fringing field safely and with high performance

3: Time structure of the antiproton beam

Beam cycle of HESR

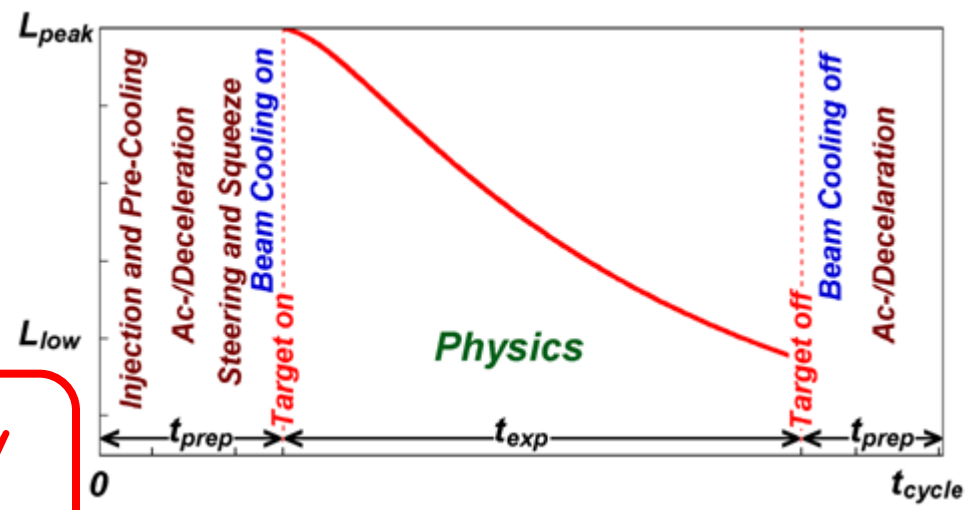


1. injection of 10^2 bunches (10^8 *pbar* each) into *HESR* from *CR*, *without target*, in *1000 s* : 10^{10} *pbar's* total bunch
2. preparation of the beam : *10-15* s
3. Target insertion , data taking , bunch depletion
4. Target switched off, inverse preparation : *10-15* s
5. Refilling *HESR* in 10^3*s* (→ 1.)

Bunch is depleted by:

a) Single Coulomb Scattering ($\sim Z^2$)
b) Hadronic interactions ($\sim A^{2/3}$)
c) Energy Straggling (*negligible*)
d) Touschek Effect (*negligible*)

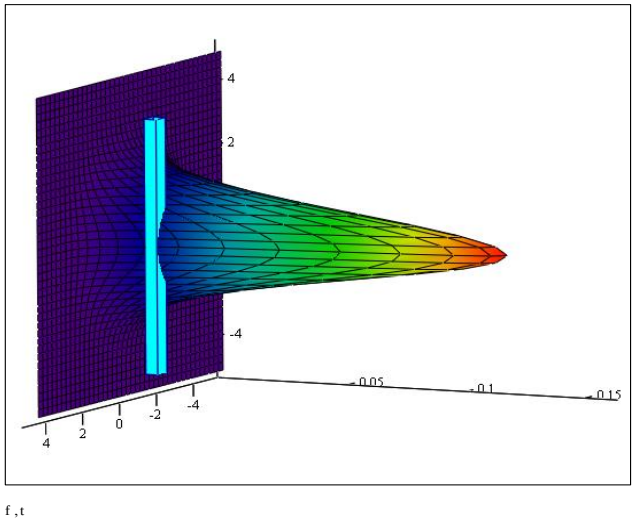
H pellet target density: 4×10^{15} at/cm^2
Diamond target density: 5×10^{18} at/cm^2



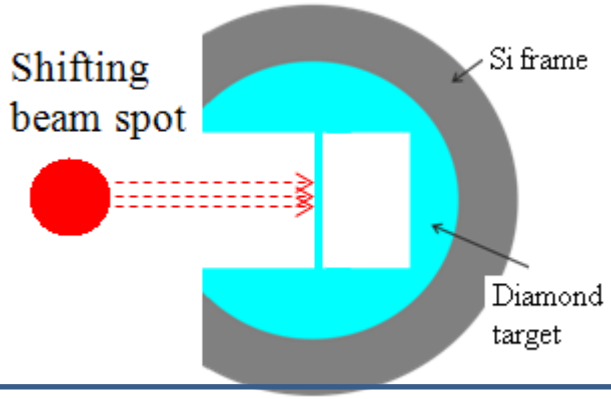
Solid target quickly destroys the beam

3: Antiproton beam spot and target

Radial Gaussian distribution of pbars in the bunch



Upstream-downstream view of the target



Slowly steering the spot tail onto the wire target

- *the rate of interacting pbar is maintained constant*
- *the rate of produced Ξ^- remains constant*

Overlapping target with beam spot tail:

- *small bunch fraction interacts with target*
- *bunch is slightly consumed*
- *this fraction determined by max ann. rate*

Beam steering technique → Ξ^- production rate ≈ 100 /s →
→ $\Lambda\Lambda$ production rate ≈ 10^{-2} /s (≈2.5 x10^4/m)

[Efficiency/channel ≈10^{-3}/ch → 50-100 detected 1-channel -$\Lambda\Lambda$ in 4m]

Work in progress

Set-up construction & software:

Work is in progress

Work in progress: Internal Target &Shifter

Prototype of internal target
(sizes: 13mm x 100μm x 3μm)

Tests under proton beam

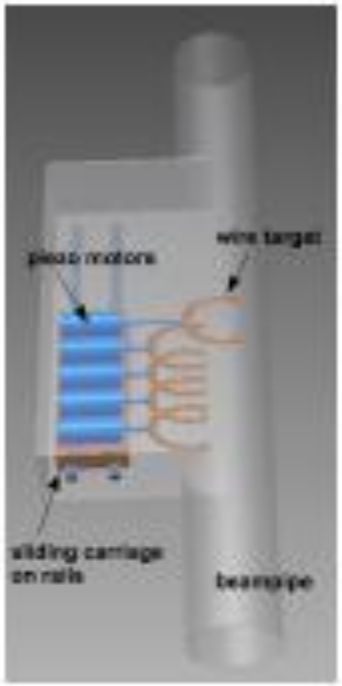
- Homogeneity and purity (B.S.)
- No phase modification (μR.S.)
- Good mechanical resistance
- Good thermal and electric conductivity

Problems

- Cutting into C-shape
- Brittleness for asymmetry

Storage of spare targets
(shifter: under study)

Courtesy of A.Sanchez&S.Bleser

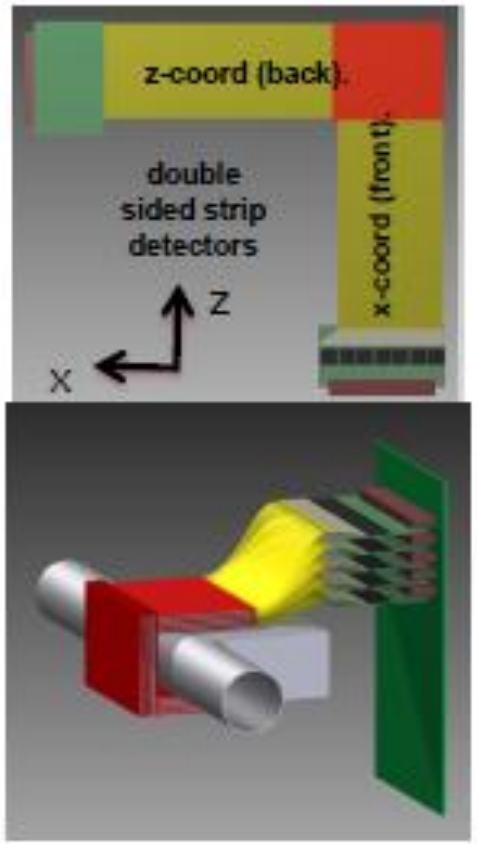


Problems

- Vacuum leakage
- Lubricant sublimation (piezo-motor?)

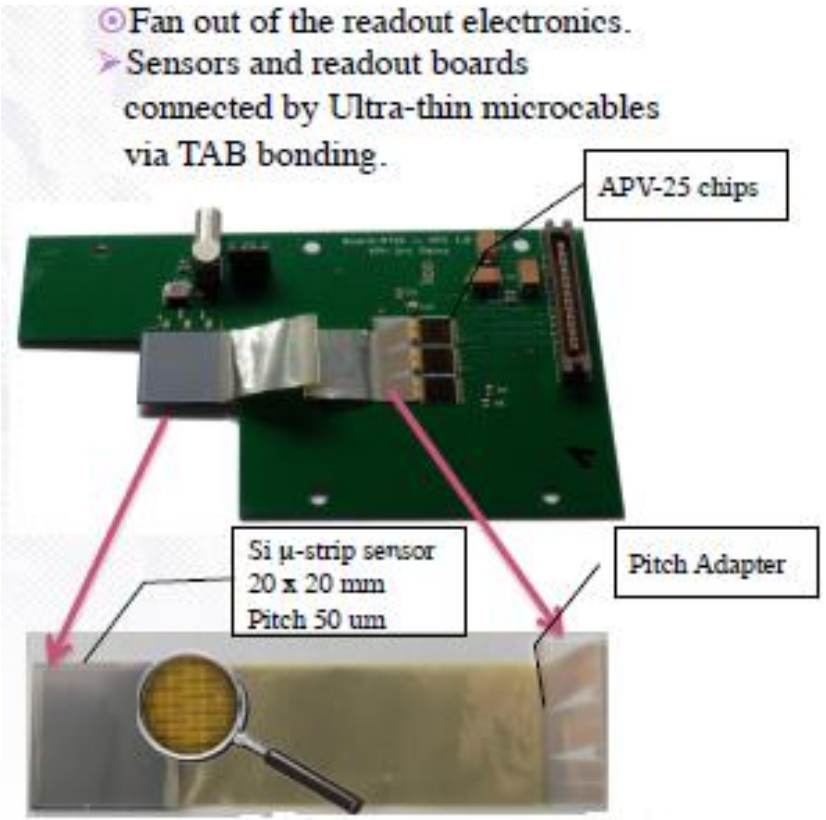
Work in progress: Secondary Active Target

Design of Active Target (MC)



Courtesy of A.Sanchez&S.Bleser &SERSTII

1 Sector prototype



3 side sectors, made of:

- Alternate layers absorber-μstrip
- 3 absorbers: ^{9}Be, ^{10,11}B, ^{12,13}C

Under test:

- Read-out space
- Minimizationof material budget

Work in progress: HPGe

Single crystal performances in magnetic field: OK

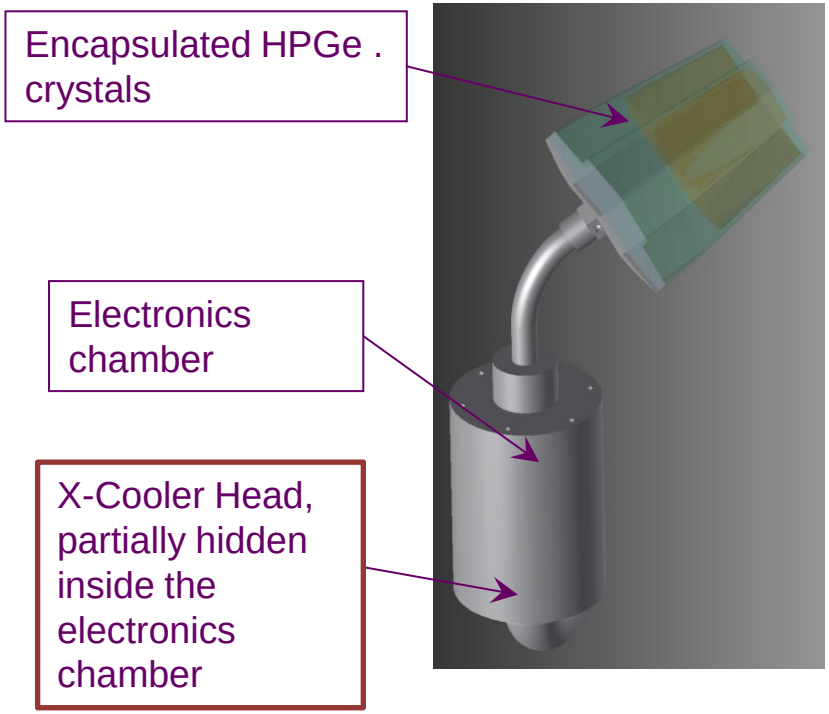
Activities toward a prototype of HPGe Cluster Array

MC study of the cluster geometry for:

- Tests on radiation damage
- Tests on pile-up
- Analysis of the pulse shape

ElectroChemical Cooler system (under study, to save space)

Courtesy of A.Sanchez,M. Steiner&I.Kojouharov



Work in progress: final state reconstruction

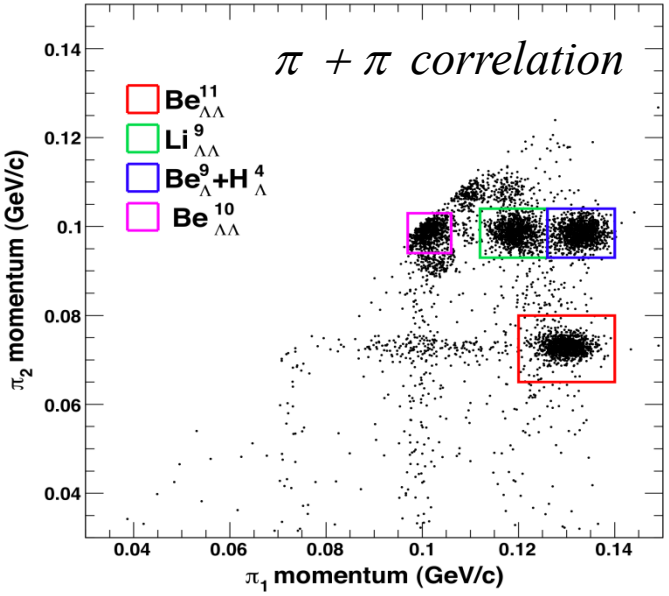
Reconstruction mainly consists of :

(Courtesy of A. Sanchez)

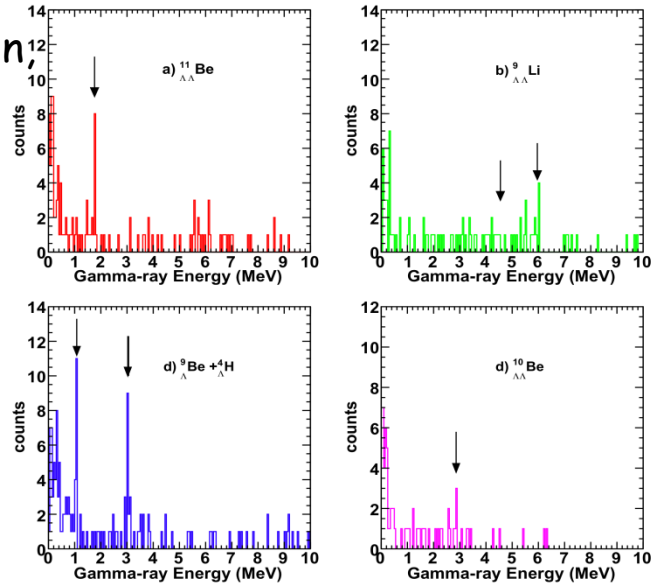
- Track finding&Tracking:(Kalman & GEANE)
- PID: Energy loss in: Si μ-strips (pions, protons, ligth fragments) in STT& SciTil, (Kbar's for trigger)

Using detectors:

- Si μ-strips in secondary target: tracking (+ energy loss for PID?)
- TOF system : time of track (improvements under study)
- STT : Energy loss →PID (K's)
- HPGe's : γ's, X-rays

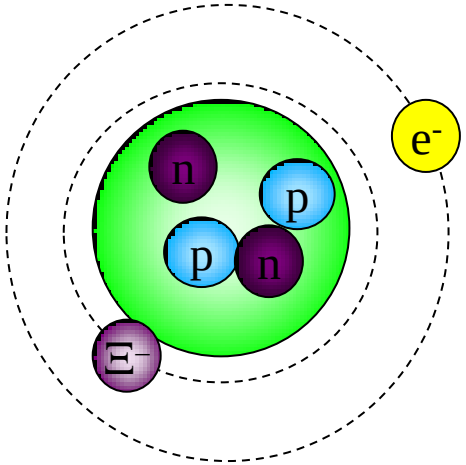


Event reconstruction, also using γ in coincidence



Simultaneous measurements: exotic atoms

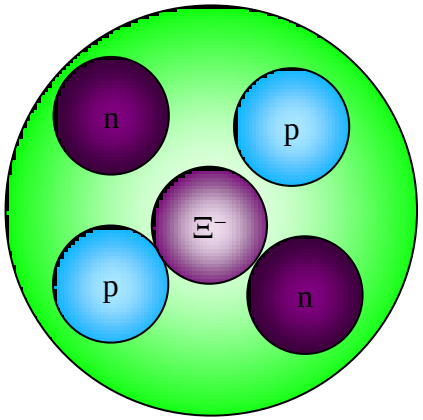
Ξ^- Hyper-atoms are formed as intermediate state of the ΛΛ formation process



In PANDA: X-ray emission from Ξ^- atom can be measured (**for free**) by HPGe

- **$\Xi N \rightarrow \Xi N$: final state reconstruction (needs high statistics)**

Ξ^- Hypernuclei too are formed as intermediate state of the ΛΛ formation process



- In PANDA: **$\Xi N \rightarrow \Xi N$: final state reconstruction? (needs high statistics)**

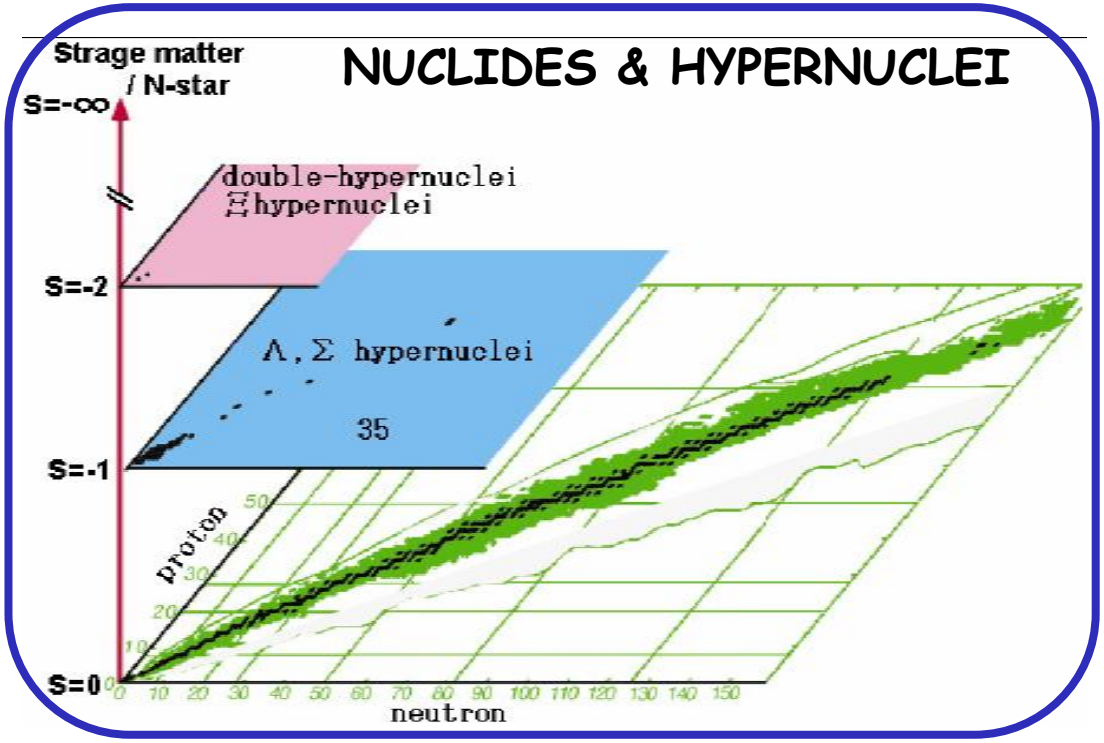
Conclusions

- *The physics of doubly strange systems presents interesting aspects concerning:*
  - the strong interaction (YY, Ξ-nucleus)
  - the weak interaction (mesonic and non-mesonic decay)
- *The present world data collection is very poor:*
  - few units of ΛΛ and Ξ hypernuclei and no Ξ hyper-atoms
- *PANDA: set-up dedicated to ΛΛ hyper-nuclei*
- *Highlights of PANDA:*
  - Hyperon production by antiprotons @ 3 GeV/c
  - Intense antiproton beam together with the "steering technique"
  - Double target system (→ flexible choice of hyper-nuclear targets)
  - High resolution γ detection in coincidence with π detection
- *Expected results:*
  - High statistics in single channels for different hyper-nuclei
  - Ξ-hyper-nuclei and hyper-atoms could be investigated too

Reference slides

New Frontiers in Strangeness Physics: S=-2 Systems

- Danysz & al claim double hypernucleus in '63
- Jaffe proposes H, a system of deconfined uuddss, in'77



Exotic Ξ^- atoms

Neutron Stars

ΛΛ Hypernuclei & Astrophysics

Hypernuclear data provide valuable input to nuclear astrophysics

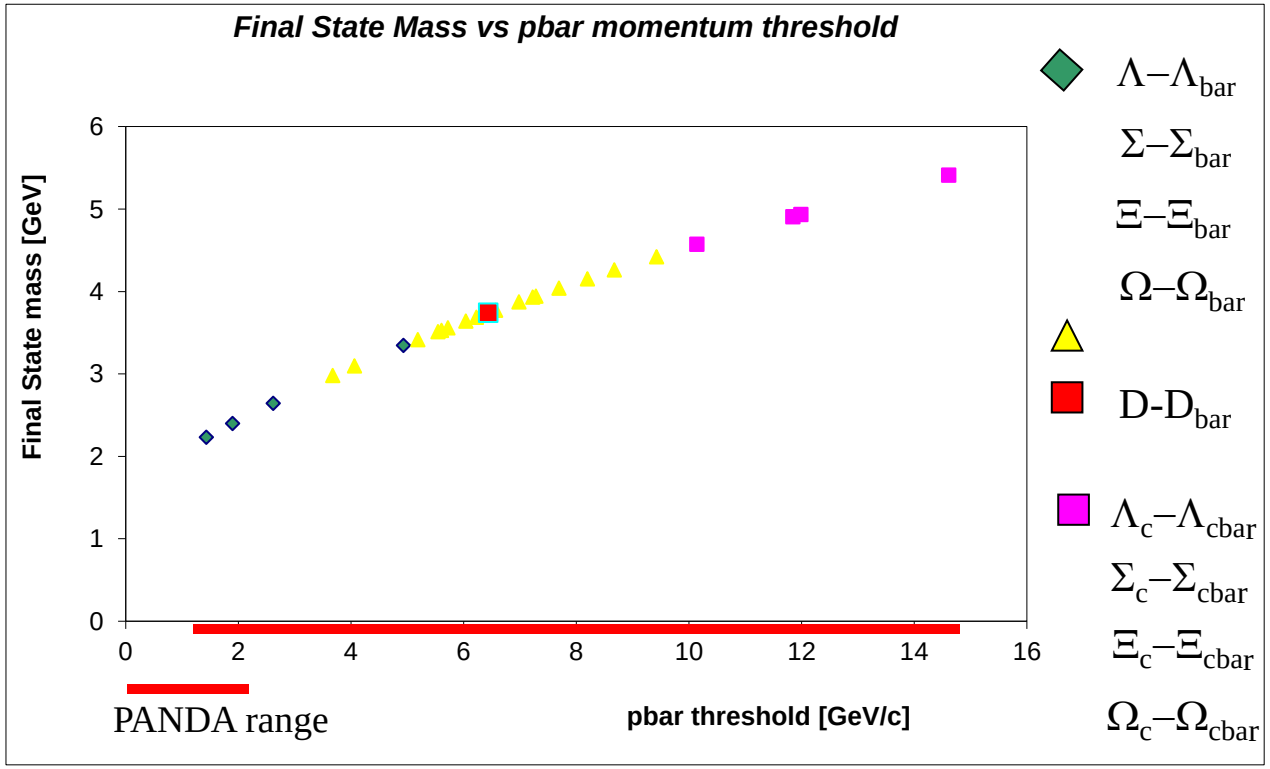
I. YN &YY couplings give information → emergence of Y's
   - in the core of neutron stars
   - in the cooling behaviour of massive neutron stars

II. Non-mesonic weak decays of hyperons in a dense medium control the bulk viscosity of neutron star matter, regulating the *r*-modes instability of pulsars and their emission of gravitational waves

III. if the hyperon-hyperon potential is suitably attractive: new class of hyperon stars can be formed

Strange Particle Production in the PANDA energy range

@ HESR: pbar + p → Bbar + B

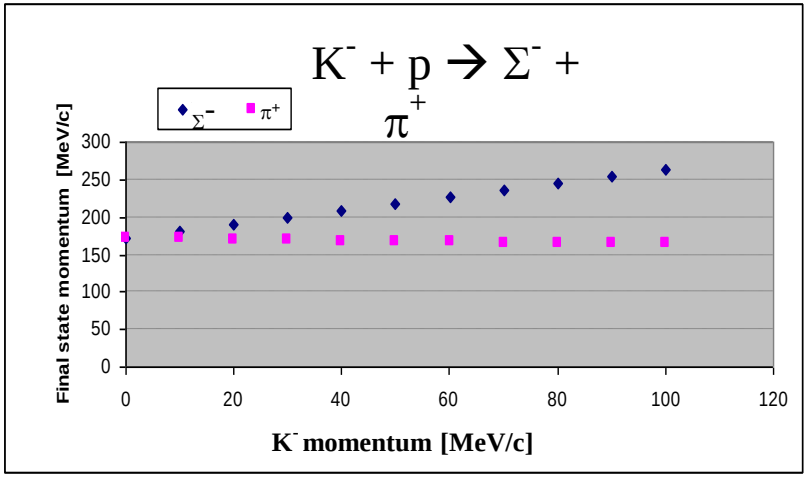


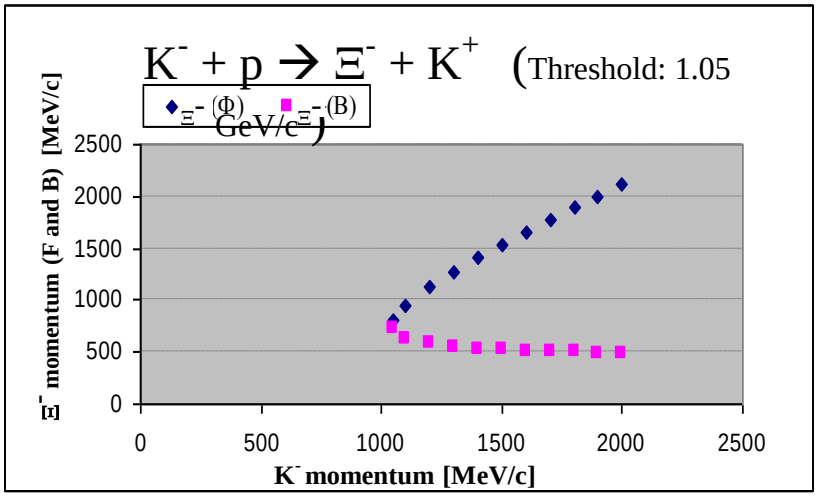
All strange baryons can be produced in PANDA

Hyperonic atoms production: HA1

Σ⁻: M = 1.19734 [GeV/c²]; τ = 14.82·10⁻¹¹ [s]; **S = -1**

Ξ⁻: M = 1.32132 [GeV/c²]; τ = 16.39·10⁻¹¹ [s]; **S = -2**





Σ stopping time at p_k =50 MeV/c:

- In Pb:≤ 2.5 10^{-11} [s]
- In Fe:≤ 2.0 10^{-11} [s]
- In C: ≤ 5.9 10^{-11} [s]

Ξ stopping time at p_k =1.8 GeV/c:

- In Pb:≤ 13.3 10^{-11} [s]
- In Fe:≤ 12.7 10^{-11} [s]
- In C: ≤ 33.2 10^{-11} [s]

Experiments with Σ⁻

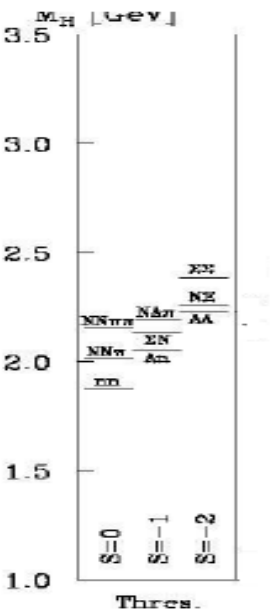
- K^- brought to stop in LH2
- Σ^- brought to stop in LH2 and solid target thin foils (W, Pb…)
- Sigma-onic atoms formed in solid targets

H-dibaryon mass

- **H particle** : *di-baryon (B=2) system (de-confined uuddss)*

- *Double Hypernuclei can decay by strong interaction*

$$ {}_{\Lambda\Lambda}^{A}Z \rightarrow H + {}^{A-2}Z $$



If M(H) << M(Λ), decay into H is strongly dominant with respect weak decay

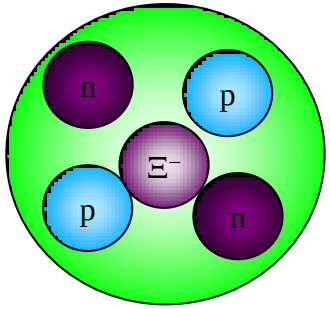
→ Observation of weak decay Puts strong limitations on M(H) (>2M(Λ)-B(ΛΛ))

${}_{\Lambda\Lambda}^{6}He$ lifetime ≈ 10^{-18} - 10^{-20} [s],
(Kerbikov,SJP,1984)

B(H) ≈ 30 -40 [MeV]
(Takahashi et al, ArX2011March)

Ξ^- hyper-nuclei (I)

Physics (II): Ξ-N weak interaction



Non Mesonic Weak Decay:

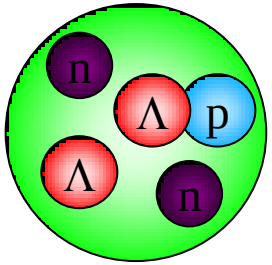
- **Ξ N → Λ N (E_Λ=95 [MeV],$p_{\Lambda,N}$=469): Λ sticking? Nucleon ejected: $\Gamma_{\Lambda N}$ =?**
- **Ξ N → Σ N (E_Σ =55 [MeV],$p_{\Sigma,N}$=366): Σ sticking? Nucleon ejected: $\Gamma_{\Sigma N}$ =?**

- **Mesonic Weak Decay: Ξ^- → Λ π^- (E_Λ =9.1[MeV] $p_{\pi,\Lambda}$=143): no Pauli blocking**

ΛΛ hyper-nuclei (I)

ΛΛ weak interaction

(only possible in double hypernuclei)



Hyperon Induced Non Mesonic Weak Decay

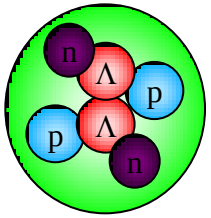
- **$\Lambda\Lambda \rightarrow \Lambda\, n$: (expected $\Gamma_{\Lambda n} << \Gamma_{free}$) ($p_{\Lambda/N}$ = 433 MeV/c)**
- **$\Lambda\Lambda \rightarrow \Sigma^- p$: (expected $\Gamma_{\Sigma p} << \Gamma_{free}$) ($p_{\Sigma/N}$ = 321 MeV/c)**

Calculations in absence of H : $\Gamma_{\Lambda N}$, $\Gamma_{\Sigma N}$ small

(TakahashiNP2003,ParrenosPR2002, ItonagaNP2001)

Physics with ΛΛ hypernuclei: status of art (II)

ΛΛ hypernuclei Weak decay: a lot of final states, new B.R.



MESONIC WEAK DECAY OF 1 Λ

momentum range is approximately calculated for Z=6,7;A=12;B_Λ=11[MeV];B.E(N)=8[MeV]

Neglecting: DB_{LL}

$$ {}_{\Lambda\Lambda}Z^{A} \rightarrow \begin{cases} {}_{\Lambda}Z^{A} + \pi^{0} \\ {}_{\Lambda}(Z+1)^{A} + \pi^{-} \end{cases} $$

$\Gamma^{(\Lambda)}_{\pi^0}$ $\quad 86.7 \leq p_{\pi^\circ} \leq 103.9$

$\Gamma^{(\Lambda)}_{\pi^-}$ $\quad 88.4 \leq p_{\pi-} \leq 100.6$

$\Gamma^{(\Lambda)}_{\pi^0} / \Gamma^{(\Lambda)}_{\pi^-} \approx 1/2\,?$

NUCLEON INDUCED NON- MESONIC WEAK DECAY OF 1 Λ

$$ {}_{\Lambda\Lambda}Z^{A} \rightarrow \begin{cases} {}_{\Lambda}Z^{A-2} + n + n \\ {}_{\Lambda}(Z-1)^{A-2} + n + p \end{cases} $$

$\Gamma^{(\Lambda)}_{n}$ $\quad 391.1 \leq p_p \leq 416.7$

$\Gamma^{(\Lambda)}_{p}$ $\quad 391.2 \leq p_n \leq 414.6$

$\Gamma^{(\Lambda)}_{\Lambda n}$

HYPERON INDUCED NON-MESONIC WEAK DECAY OF 1 Λ (HINMWD)

$$ {}_{\Lambda\Lambda}Z^{A} \rightarrow \begin{cases} Z^{A-2} + \Lambda + n \\ Z^{A-2} + \Sigma^{-} + p \end{cases} $$

$\Gamma^{(\Lambda)}_{\Lambda n}$ $\quad 402.2 \leq p_\Lambda \leq 433.0$

$\Gamma^{(\Lambda)}_{\Sigma p}$ $\quad 275.8 \leq p_{\Sigma-} \leq 318.9$

$\Gamma^{(\Lambda)}_{\Lambda n} / \Gamma^{(\Lambda)}_{\Sigma n} \approx ?$

SHWD

+ fragmentation

ΛΛ Hypernuclei Production using K^-

Up to now all DSS experiments used K^- beams (1.66, 1.8 GeV/c)

- Using reaction: K^- + p (in nucleus) → $K^+ + \Xi^-$
  threshold: $p_{K^-} \approx 1.1$ [GeV/c] ; $p_{\Xi} \approx 0.5$[GeV/c] (unlikely sticking Ξ^-)
- In the 1960's: first observations in bubble chambers, emulsions
  (measuring B.E. only)

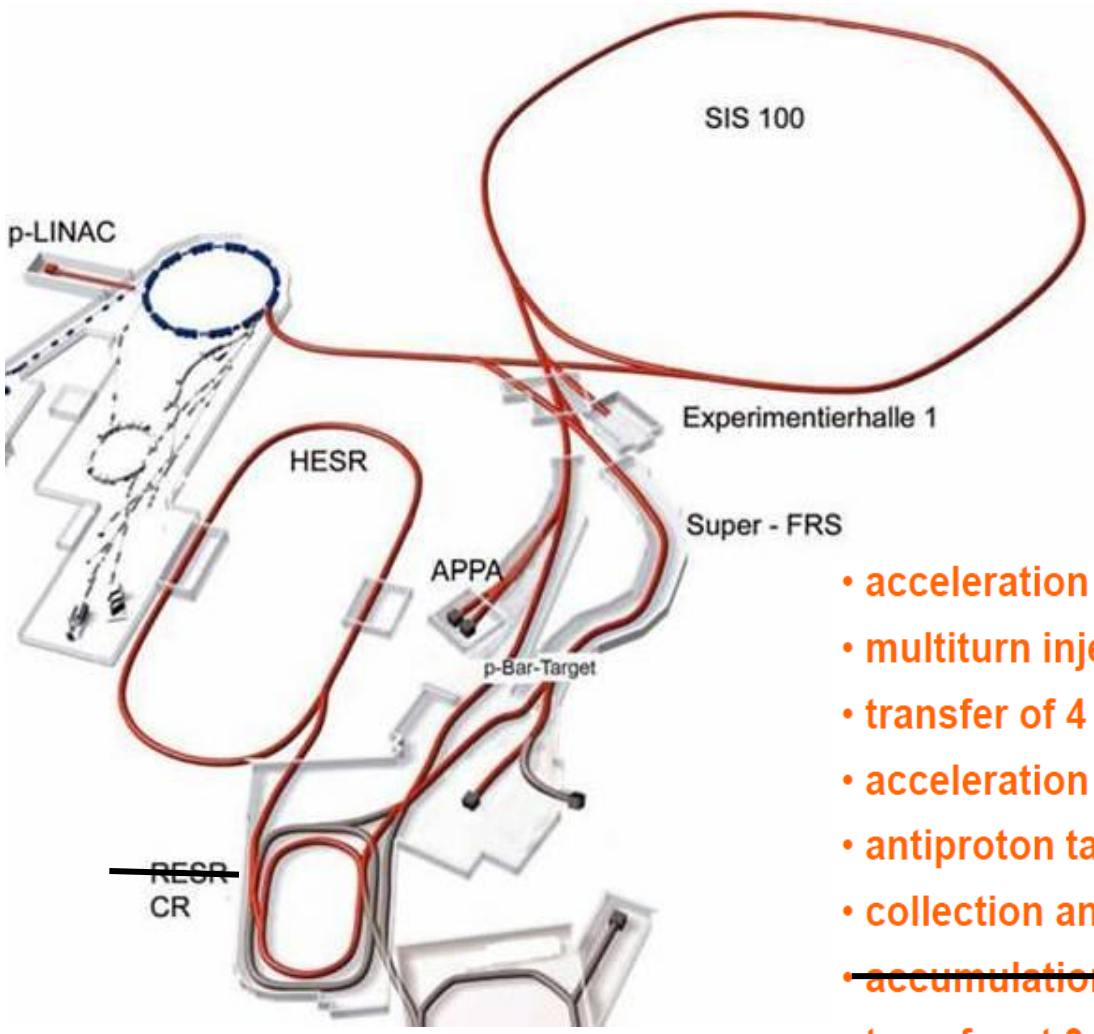
Recently: counter experiments

- KEK-E176: emulsion target (Ξ^- production&stopping) + spectrometer (K^+ tagging)
- KEK-E224: SCIFI active/passive target
- KEK-E373: SCIFI active/passive target. Still analyzing data

- AGS-E885: emulsion target (Ξ^- production)+ spectrometer (K^+ detection) for $C^{12}(K^-,K^+)\,{}_{\Xi}Be^{12}$ reaction
- AGS-E885, E906: diamond target (Ξ^- production&stopping) + scintillator array (n detection) for $C^{12}(K^-,K^+)\,{}_{\Lambda\Lambda}B^{12}$+n reaction, Ξ^- hyper-nuclei confirmation, ratio ΛΛ hyper-nuclei to stopped Ξ^-'s determined

Back up slides

Antiproton beam: @FAIR



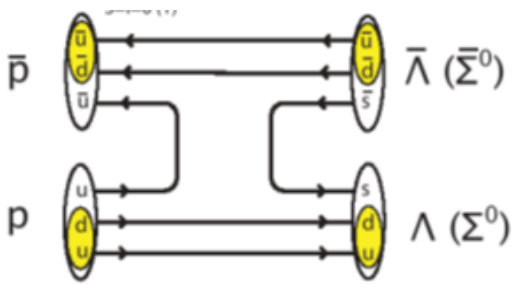
Expected performance @ HESR:

- Generation of intense antiproton beams
- Wide energy range:
  1.5 -15 GeV/c antiprotons

- acceleration in linac to 70 MeV
- multiturn injection into SIS18, acceleration to 4 GeV
- transfer of 4 SIS pulses to SIS100
- acceleration to 29 GeV and extraction of single bunch
- antiproton target and separator for 3 GeV antiprotons
- collection and pre-cooling in the Collector Ring CR
- ~~accumulation of up to 10^{11} antiprotons in RESR~~
- transfer at 3 GeV to users (HESR and NESR)
- storage of antiprotons in the HESR (0,8 - 14 GeV)

What is new in Ξ^- hyperon production ?

Pbar + N → Ξbar + Ξ^- : Cross sections

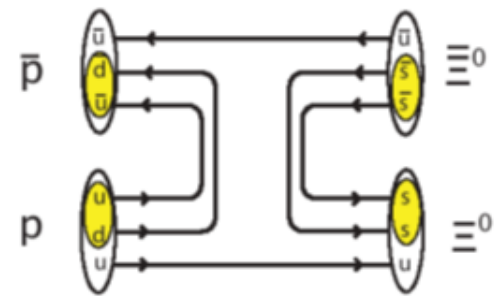


- Total: σ(ΛΛbar) > σ(ΞΞbar)

OZI rule for Hyperons?

- 2 s-sbar pairs creation:

flat angular distribution?



Ξ^- + N: Scattering in flight

- Ξ^- in nuclei: mean free path 5fm (Aoki98,NP), (compatible with cross section of the same order of the N+N (Ferro,NP07))
- $\sigma(\Xi^- + p \rightarrow \Xi^- + p) <$ 24mb (@ $p_{\Xi^-} \approx 0.5$ GeV/c (Ahn06,PLB633)

Reactions

- $\sigma(\Xi^- + p \rightarrow \Xi^0 + n) \approx$ 10 nb (@ $p_{\Xi^-} \approx 0.5$ GeV/c (Ahn97,NP231)
- $\sigma(\Xi^- + p \rightarrow \Lambda + \Lambda) \approx$ 5mb (@ $p_{\Xi^-} \approx 0.5$ GeV/c (Ahn06,PLB633)

Products from the Doubly Strange Systems

Hyper-atom and Hypernuclei formation

- X rays from Ξ^- capture into atomic orbit and Ξ^- cascade in hyper-atom
- γ's from Ξ^- absorption in nucleus
- γ's from Ξ^- p → ΛΛ + 28 MeV

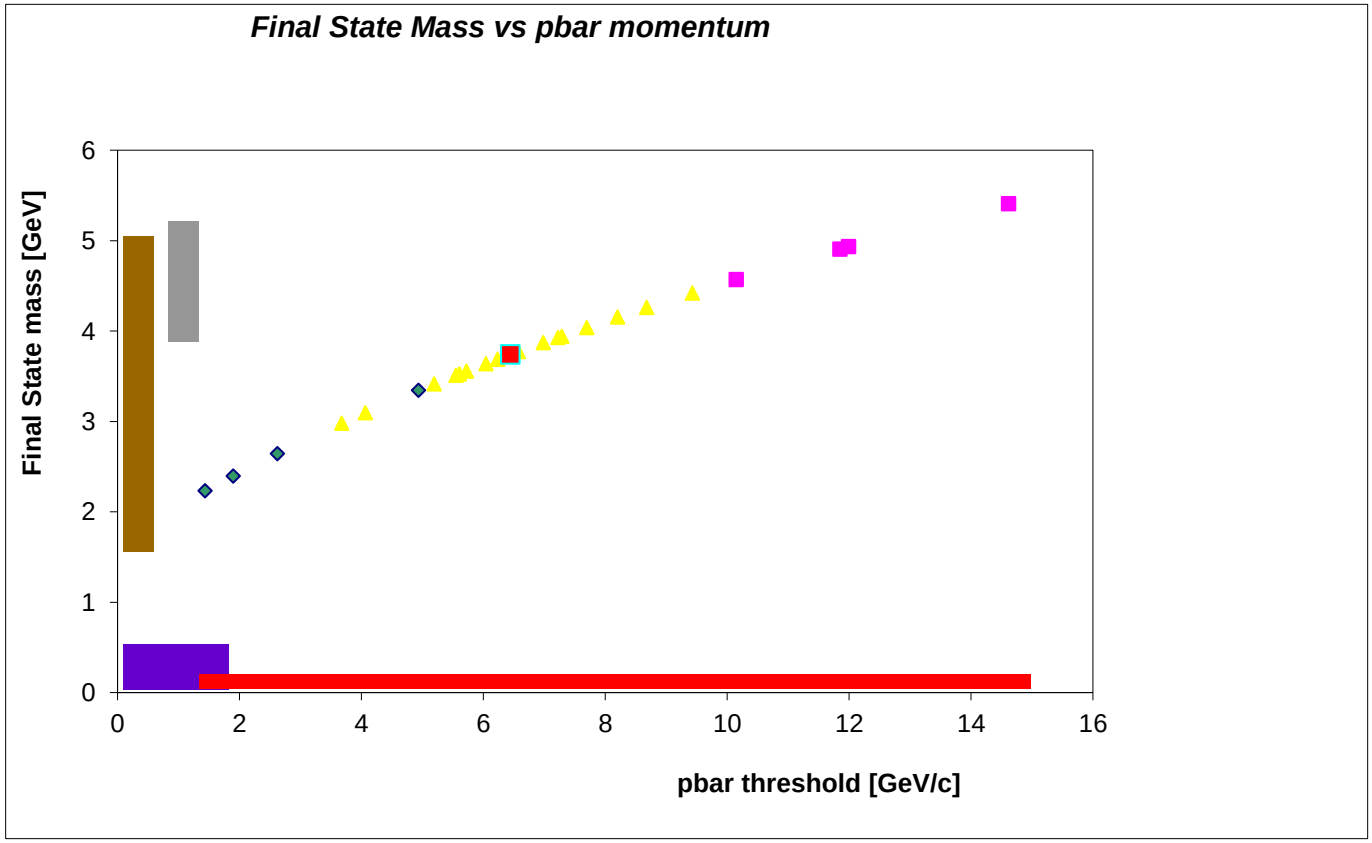
Weak Decay of Doubly Strange Hypernuclei

Ξ^- mesonic	$\Xi^- \rightarrow \pi\Lambda \rightarrow \pi\,\pi\,N$
Ξ^- non mesonic	$\Xi^- N \rightarrow NN$
Both ΛΛ mesonic:	$\Lambda\Lambda \rightarrow \pi N + \Lambda \rightarrow \pi N + \pi N$
Both ΛΛ non mesonic:	$\Lambda\Lambda + NN \rightarrow \Lambda N + NN \rightarrow NN + NN$
Mixed mesonic & non mesonic:	$\Lambda\Lambda N \rightarrow \pi N + \Lambda N \rightarrow \pi N + NN$
Hyperon induced + Non Mesonic	$\Lambda\Lambda \rightarrow \Lambda N \rightarrow NN$
Hyperon induced + Mesonic	$\Lambda\Lambda \rightarrow \Lambda N \rightarrow N\pi N$
Hyperon induced + Non Mesonic	$\Lambda\Lambda \rightarrow \Sigma N \rightarrow NN$
Hyperon induced + Mesonic	$\Lambda\Lambda \rightarrow \Sigma N \rightarrow N\pi N$

Hyperfragments: excited ΛΛ-Hypernucleus → breakup channels

- $\Lambda + {}^{A}Z_{\Lambda}$ + others
- ${}^{A1}Z_{1\Lambda} + {}^{A2}Z_{2\Lambda}$ + others
- ${}^{A}Z_{\Lambda\Lambda}$ + others

Physics in the PANDA Energy range



p + pbar →

$\Lambda_s \Lambda_s$ bar
$\Sigma_s \Sigma_s$ bar
$\Xi_s \Xi_s$ bar
$\Omega_s \Omega_s$ bar

c cbar

D Dbar

$\Lambda_C \Lambda_C$ bar
$\Sigma_C \Sigma_C$ bar
$\Xi_C \Xi_C$ bar
$\Omega_C \Omega_C$ bar

PANDA range

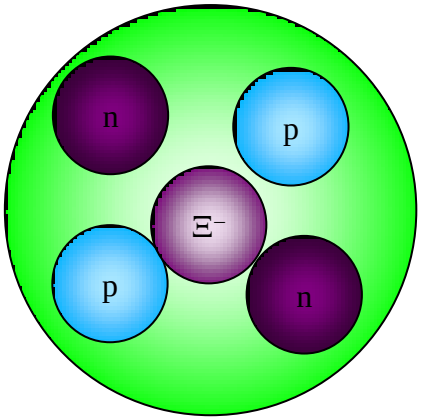
Charmed hybrids mass range

LEAR range

Glueballs mass range

Simultaneous measurements: Ξ^- hypernuclei

Ξ^- Hypernuclei are formed as intermediate state of the $\Lambda\Lambda$ formation process



Physics: Ξ-N strong interaction

- **Ξ N → Ξ N : final state reconstruction (needs high statistics)**
- **Distribution of $\Lambda\Lambda$, twin single Λ and free Λ's in hyper -fragments (*correlation with the Ξ level of the conversion*)**

•Very high statistics is required, but
•No dedicated measurements

Production of ΛΛ Hypernuclei

Starting point: Ξ^- hyperon production

With kaons:

$K^- + p \rightarrow K^+ + \Xi^-$
$K^- + n \rightarrow K^0 + \Xi^-$

(uû) annihilation + (sŝ) creation

(KEK, BNL-AGS, JPARC)

With antiprotons:

$p_{bar} + p \rightarrow \Xi^+ + \Xi^-$
2(uû) annihilation +2 (sŝ) creation

$p_{bar} + n \rightarrow \Xi^0_{bar} + \Xi^-$
(uû)+(dđ) annihilation +2 (sŝ) creation

(FAIR : **PANDA**, FLAIR)

Both reactions have high threshold

Using a nuclear target: quasi free reactions

$K^- + {}^{Z}A \rightarrow K^{+0} + \Xi^- + X$

$p_{bar} + {}^{Z}A \rightarrow \Xi_{bar} + \Xi^- + X$

X = A-1,fragments → Ξ^- nearly free inside nucleus

Direct production of S= -2 Hypernuclei

In nuclei: direct reactions

(hyper-nucleus created inside the same nucleus where Ξ^- is created)

$K^- + {}^{A}Z \rightarrow$ *(p(K-,K+)Ξ^- , re-scattering in nucleus)* $\rightarrow K^+ + {}^{A}(Z-1)_{\Xi} \rightarrow K^+ + {}^{A}(Z-2)_{\Lambda\Lambda}$

➢ $K^- + {}^{12}C \rightarrow K^+ + {}^{12}B_{\Xi}$: $\frac{d\sigma}{d\Omega}(\theta_K < 8^\circ) \approx 89 nb/sr$ (Khaustov00,PRC61)

p_{bar} *(rest)* + N $\rightarrow$ K* + K^*_{bar} ($p_{K^*} \approx 290$ [MeV/c])

$\rightarrow$*(in same nucleus)* K*(≈ 200)+N' $\rightarrow K_{bar} + \Xi^-$ *(≈ at rest)* **(FLAIR)**

Two-step process in 1 nucleus Production rates to be estimated

$K^- + {}^{A}Z \rightarrow$ *(through: $\pi^0 + {}^{A}(Z-1)_{\Lambda}$)* $\rightarrow K^+ + {}^{A}(Z-2)_{\Lambda\Lambda}$

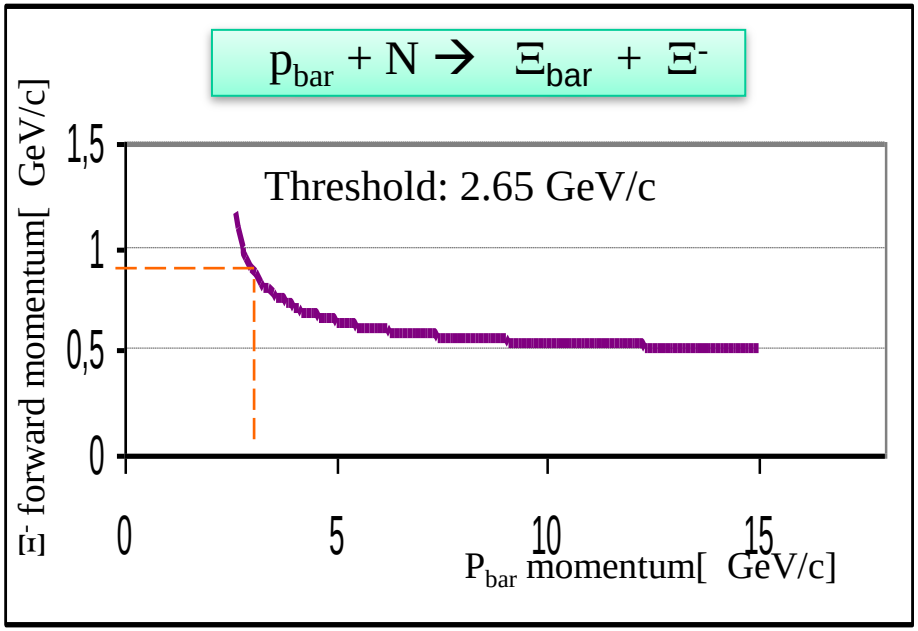
➢*No observation (AGS): ($\sigma(\theta) < 10$[nb/sr],May,NP2001);*

No Hyper-atom production

Indirect production of S= -2 Hypernuclei

In nuclei: indirect reactions

- Ξ^- is created in a nucleus ($p_{bar} + {}^{Z}A \rightarrow \Xi_{bar} + \Xi^- + A_{res}$)
- exits from the nucleus ($c\tau = 4.9\ cm$),
- hyper-nucleus is created in another nucleus

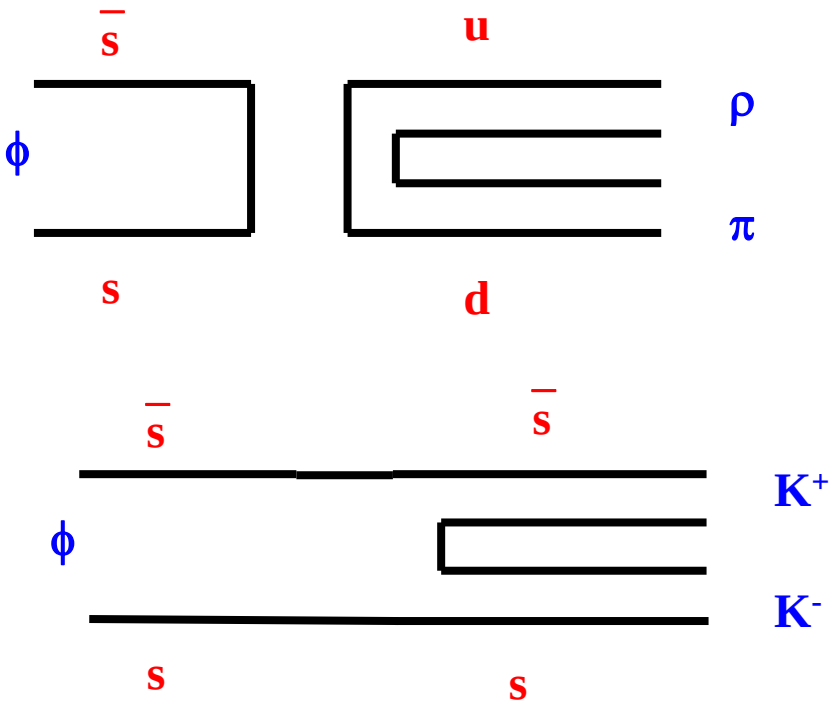


Kinematical features:

- Minimum Ξ^- recoil > 500 MeV/c > p_F
- High momentum → long path to stop
- <u>Re-scattering in highly dense residual nucleus can help to slow down Ξ^-</u>

Nuclei are suggested as targets

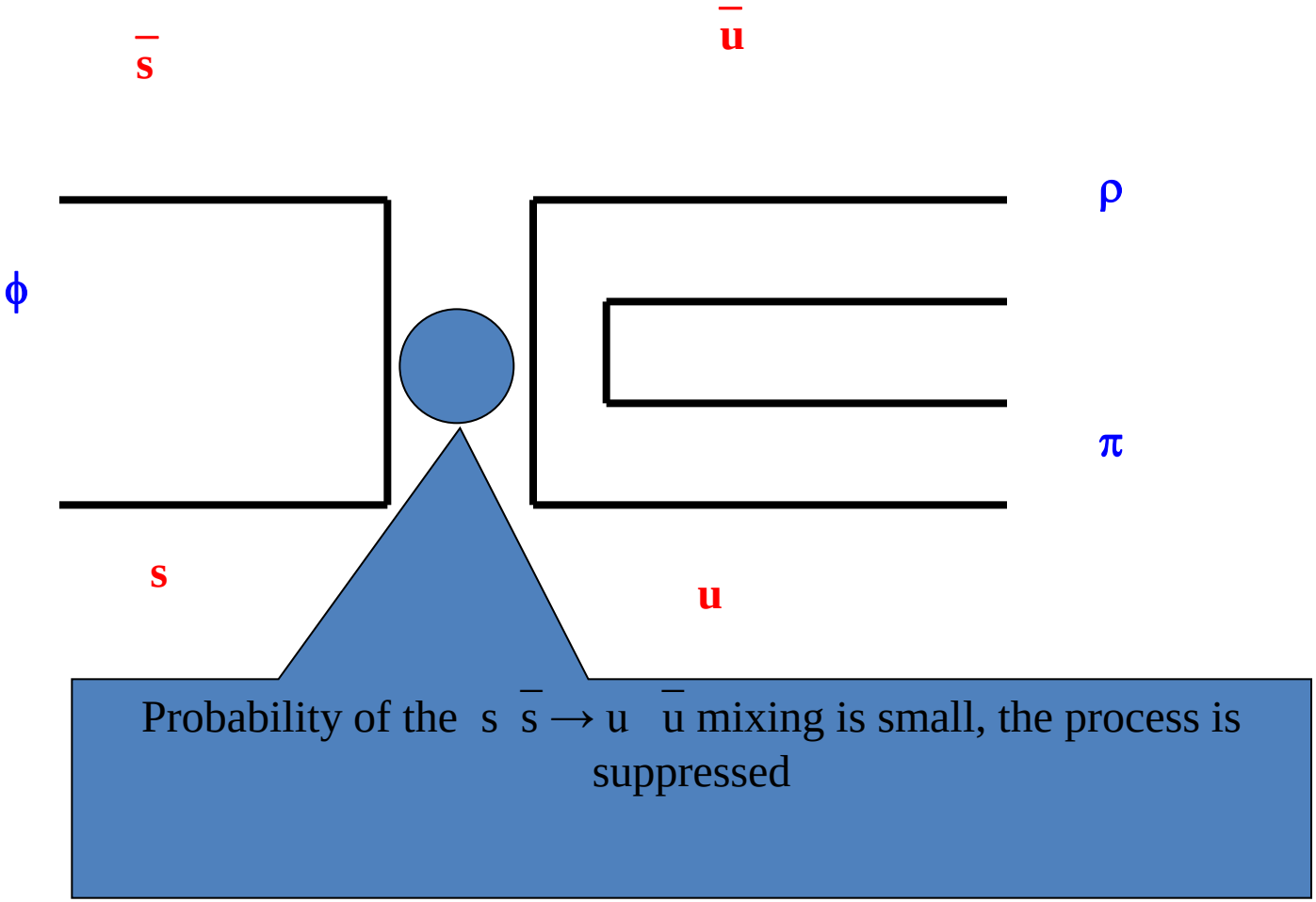
The OZI-rule



$\phi(1020) \rightarrow K + \bar{K}$ BR= 83%

$\phi(1020) \rightarrow \rho + \pi$ BR= 15%

The processes with disconnected quarks lines are suppressed



$$\phi = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\sin(\theta_i - \theta) - s\bar{s}\cos(\theta_i - \theta)$$

$\delta = \theta - \theta_i = 3.7^0$

The OZI rule predictions

$$\frac{\sigma(A+B\to C+\phi)}{\sigma(A+B\to C+\omega)} = \tan^2(\theta-\theta_i) \cong 4\cdot 10^{-3}$$

$$\frac{\sigma(A+B\to C+f_2'(1525))}{\sigma(A+B\to C+f_2(1270))} = 16\cdot 10^{-3}$$

$$\frac{\sigma(A+B\to C+\eta)}{\sigma(A+B\to C+\eta')} = 1.25$$

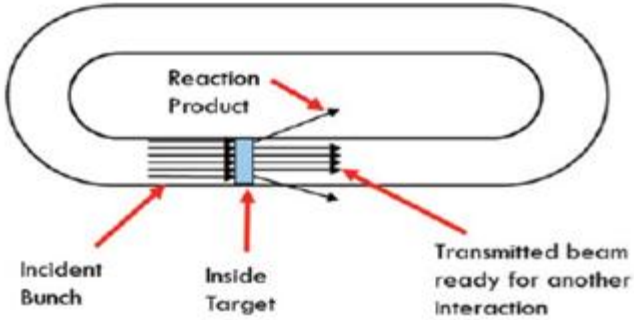
- Universal, does not depend on energy or other properties of the initial state.
- Depends on the masses of the meson in the nonet

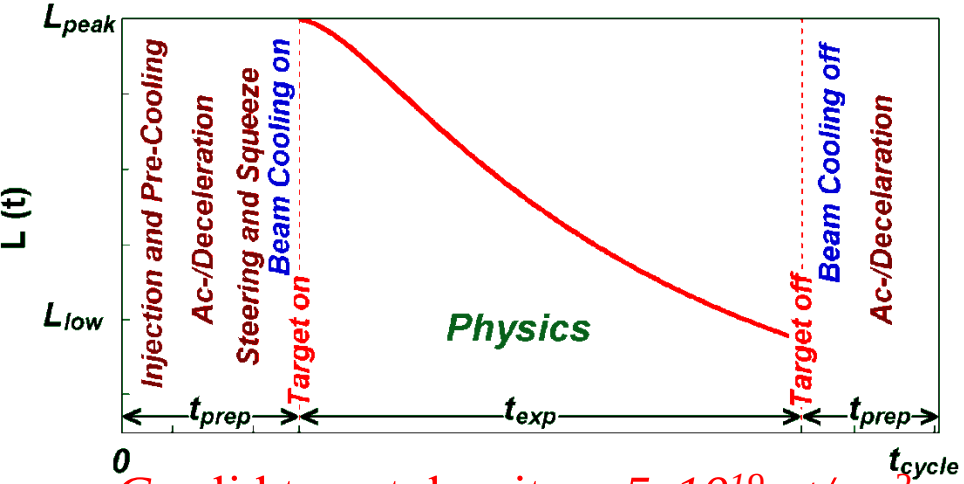
non flavoured mesons (ssbar):
σ(ϕϕ)/σ(ωω) = 1.6 10^-5 (OZI prediction)
σ(ϕϕ) = 4 nb (measured)
→ σ(ωω) should be too large

Needs a measurement of both with same apparatus to check the OZI violation

Time structure of the antiprotons beam at PANDA-HESR

Internal target option allows to avoid wasting antiprotons





- *100* bunches of 10^8 *pbar* each are injected in *1000 s*: 10^{10} *pbar's* total
- few seconds (*10-15*) are spent for preparation of the beam without target
- Target is inserted , data taking starts, bunch is consumed for t_{exp}
- Target is switched off, inverse preparation (cooling off…) for few sec.
- After that, *1000 s* are needed to refill the bunch from CR

C solid target density ≈ $5x10^{19}$ *at/cm*^{2};

Full bunch onto *C* target → all detectors blinded by annihilation products

2. The (new) other experiment(s): @ J-PARC

In 2007, 3 experiments approved for S=-2 Nuclear Physics:

E03 : Measurement of X rays from Ξ^- atom (S.P.– K. Tanida)

E05: Spectroscopic study of Ξ-hypernucleus, $^{12}_{\Xi}$Be, via the ^{12}C(K^-,K^+) reaction (Day 1 – 1st priority) (S.P. – T. Nagae)

E07: Systematic study of double strangeness system with an emulsion-counter hybrid method (S.P. K. Imai, K. Nakazawa, H. Tamura)

Choice of Fe-atom in Fe(K^-,K^+) to stop Ξ^- , but X-ray absorption is significant

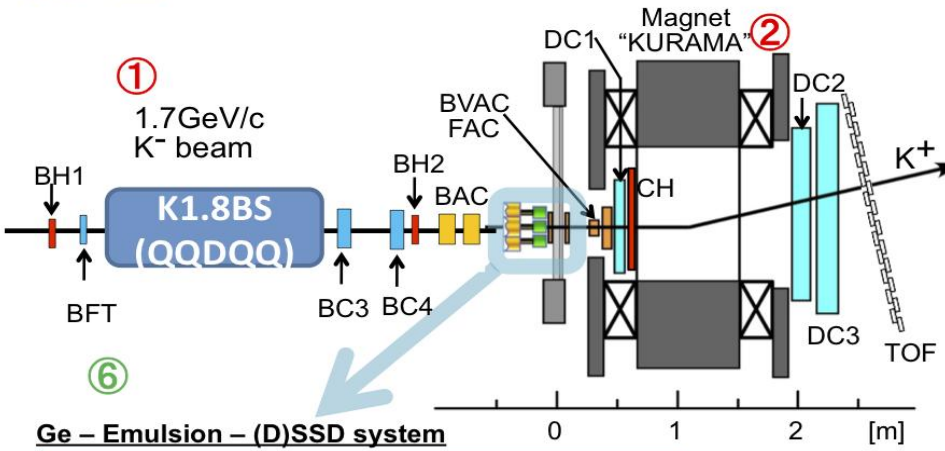
- Total number of K^-: 1.0×10^{12} for 800 hours.
- Yield of Ξ: 3.7×10^6 produced : 7.5×10^5 stopped
- X-ray yield : 2500 for n=6→5 transition, 7200 for n=7→6

First experiment (E05) expected in 2009

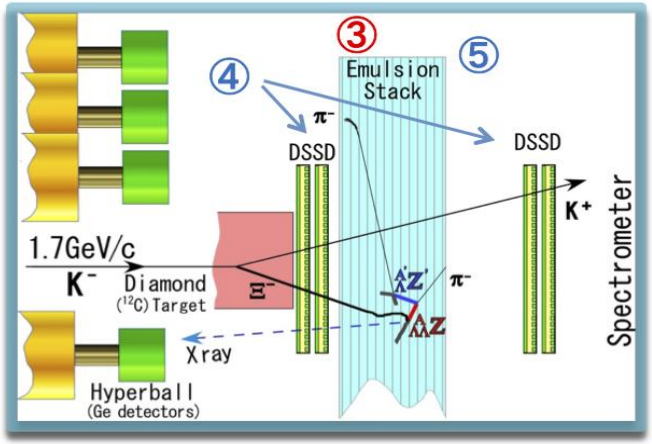
(From: K. Tanida, Talk at PANDA meeting, GSI 2008)

2. J-PARC: upgrade & plan after 2014

E07: Study on S=−2 system by Emulsion-Counter Hybrid Method



Ge – Emulsion – (D)SSD system



Improvements from KEK-E373

① High purity K⁻ beam
② KURAMA gap extension
③ Emulsion ×3
④ fiber tracker→ (D)SSD
16μm resolution for Ξ⁻
⑤ Position calib. of emulsion layers
~20μm → 1.4±0.8μm
→ Automatic scan w/ & w/o counters
⑥ Ge detectors to measure X-rays from Ξ⁻-atom
→ Ξ−Nucleus potential (in surface region)

Previous KEK experiments ended

E03 + E07 merged

10 times events as those of the previous exp.!

10^4 Ξ⁻ stopped events
10^2 double-Λ nucl. w/ counters
10^3 double-Λ nucl. w/o counters

Expected rates reduced by ≈10^2

Commissioning & physics RUN
2014～ @ K1.8

2012/10/5 HYP11 19

From: T. Takahashi, HYP 2012, Barcelona: "Overview of Hypernuclear program … @JPARC