P10-1: Production of Neutron-Rich Λ-Hypernuclei with the Double Charge-Exchange Reaction

(update of P10: Study on Λ-Hypernuclei with the Charge-Exchange Reactions)

Ajimura → P10-2: on weak decay of Λ-hypernuclei

Collaboration:
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JAEA, Univ. Torino, INFN and INAF-IFSI

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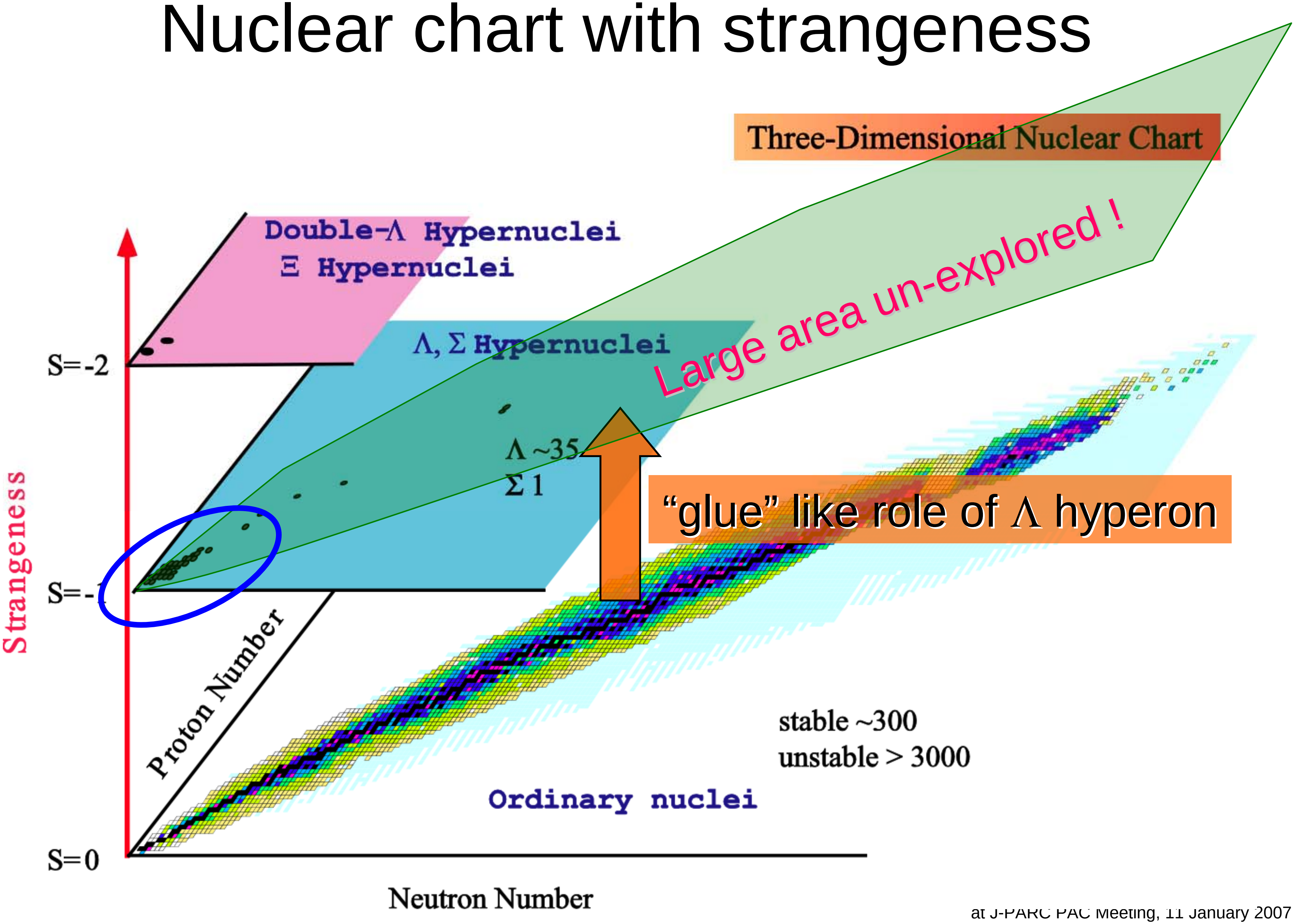
Subjects of proposal P10-1

- Production of neutron-rich Λ-hypernuclei
  - Λ-hypernuclei close to neutron drip-line
  - Quite exotic objects if mass number is small

- Λ-nucleus interaction in high isospin state
  - Structures of hypernuclei → Λ-N interaction in neutron-rich environment
  - ΛN-ΣN mixing is important if isospin≠0
  - Close connection to EoS in neutron stars

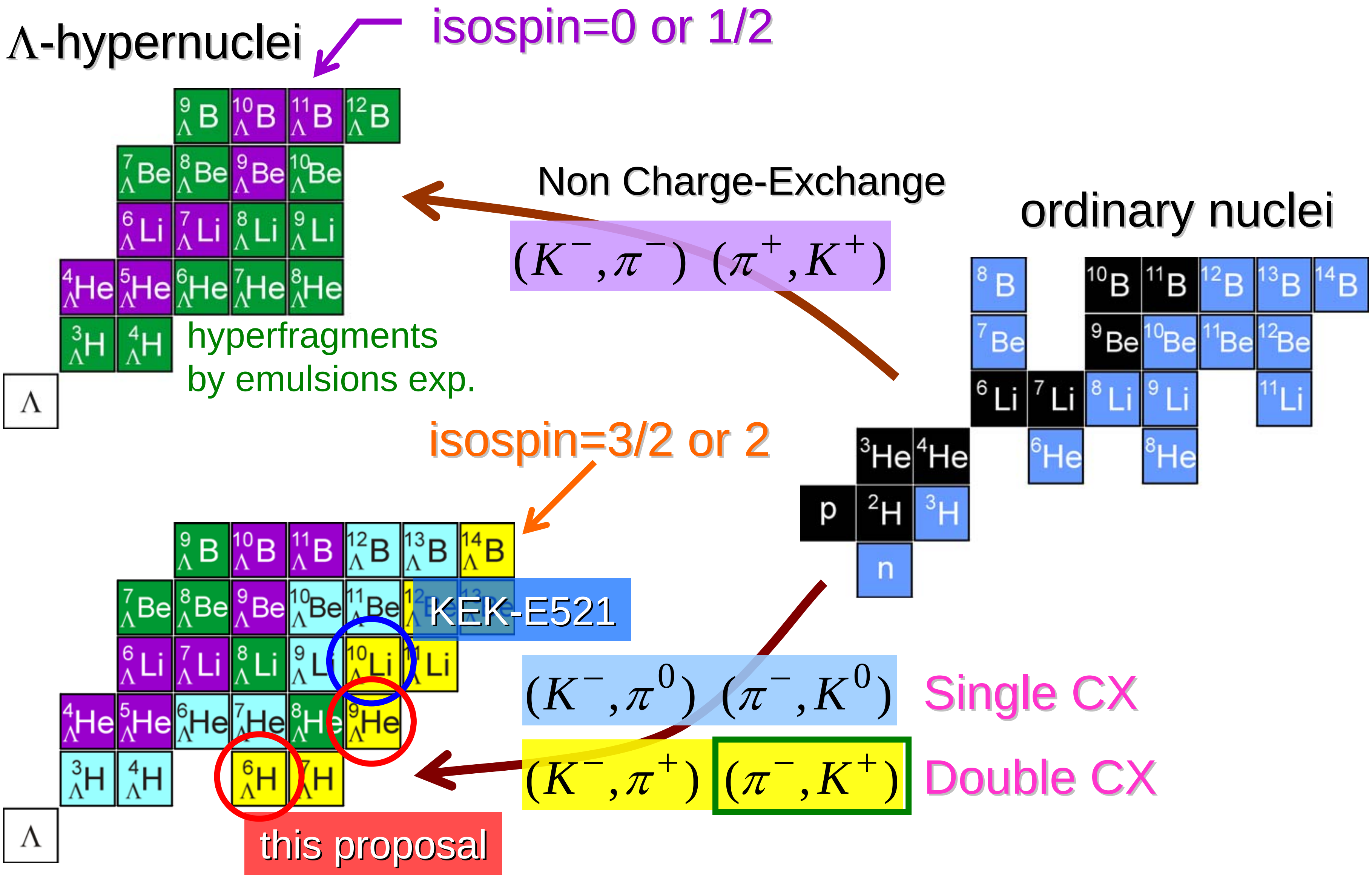
Nuclear chart with strangeness



Large area un-explored !

“glue” like role of Λ hyperon

Expand the hypernuclear chart



Λ-hypernuclei

isospin=0 or 1/2

Non Charge-Exchange

(K^-,π^-) (π^+,K^+)

ordinary nuclei

hyperfragments
by emulsions exp.

isospin=3/2 or 2

KEK-E521

(K^-,π^0) (π^-,K^0) Single CX

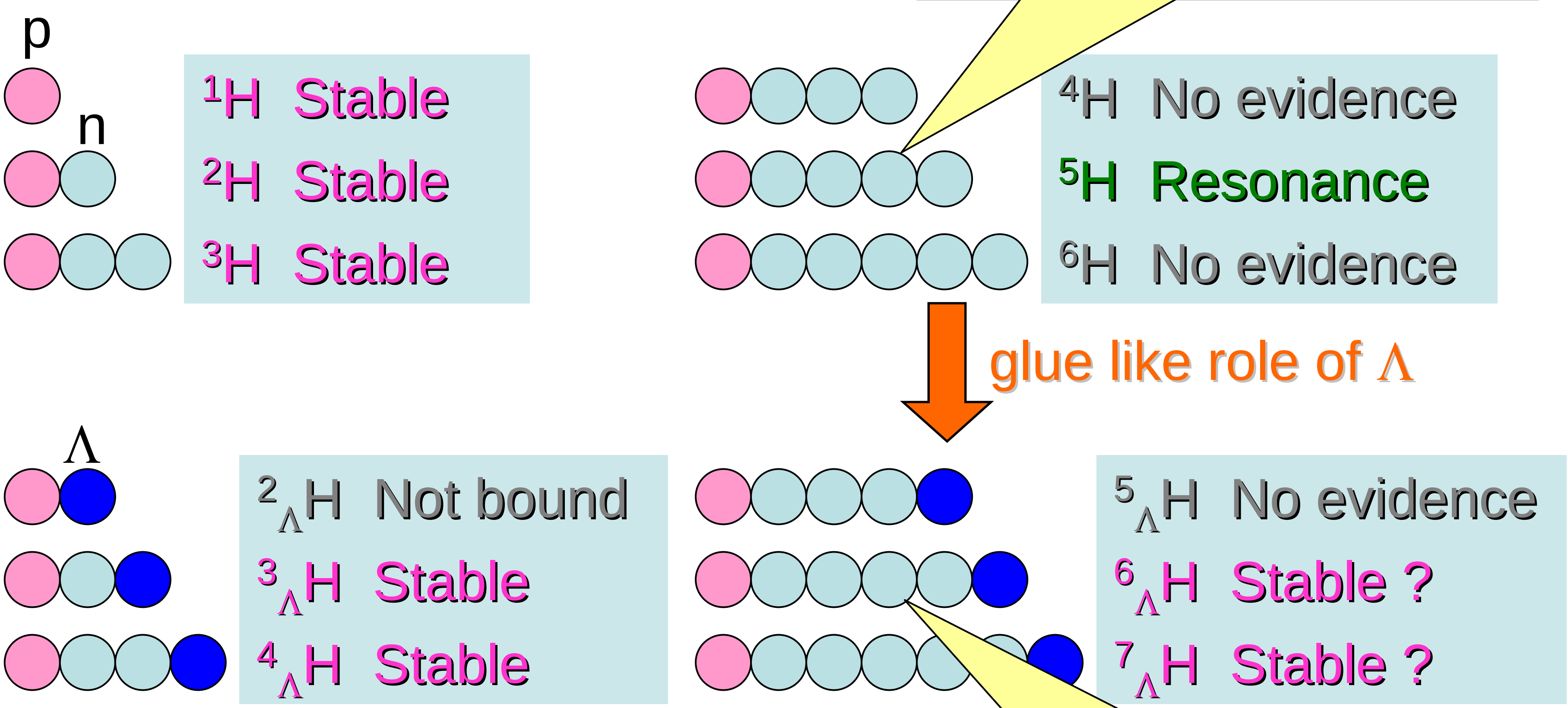
(K^-,π^+) (π^-,K^+) Double CX

this proposal

Exotic Λ-hypernuclei

- Example of "hydrogen"

Super Heavy Hydrogen



^{1}H	Stable
^{2}H	Stable
^{3}H	Stable

^{4}H	No evidence
^{5}H	Resonance
^{6}H	No evidence

glue like role of Λ

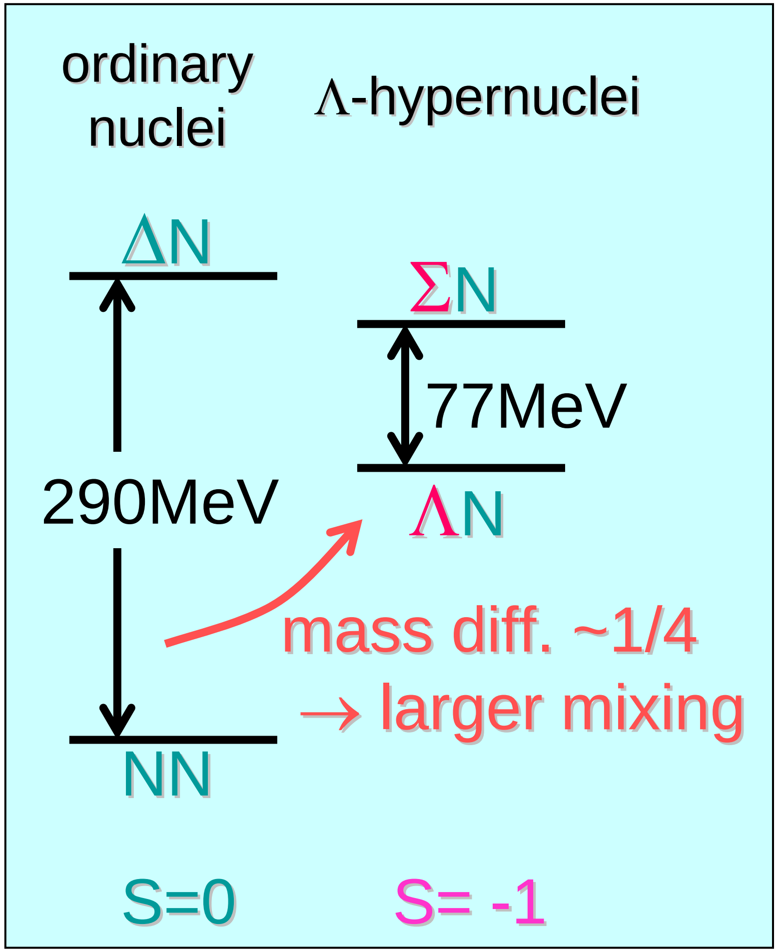
$^{2}_{\Lambda}$H	Not bound
$^{3}_{\Lambda}$H	Stable
$^{4}_{\Lambda}$H	Stable

$^{5}_{\Lambda}$H	No evidence
$^{6}_{\Lambda}$H	Stable ?
$^{7}_{\Lambda}$H	Stable ?

We can produce at J-PARC

Hyper Heavy Hydrogen

ΛN-ΣN mixing effect



ordinary nuclei

Λ-hypernuclei

ΔN

ΣN

77MeV

290MeV

ΛN

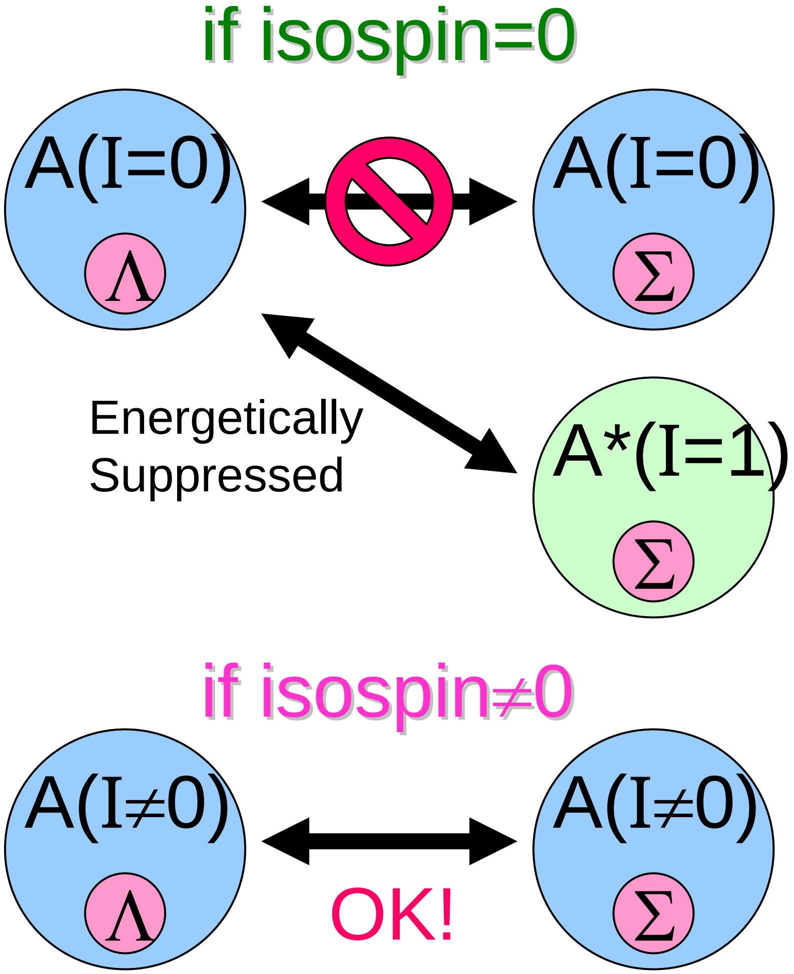
mass diff. ~1/4

→ larger mixing

NN

S=0

S= -1



if isospin=0

A(I=0)

Λ

A(I=0)

Σ

Energetically Suppressed

A*(I=1)

Σ

if isospin≠0

A(I≠0)

Λ

OK!

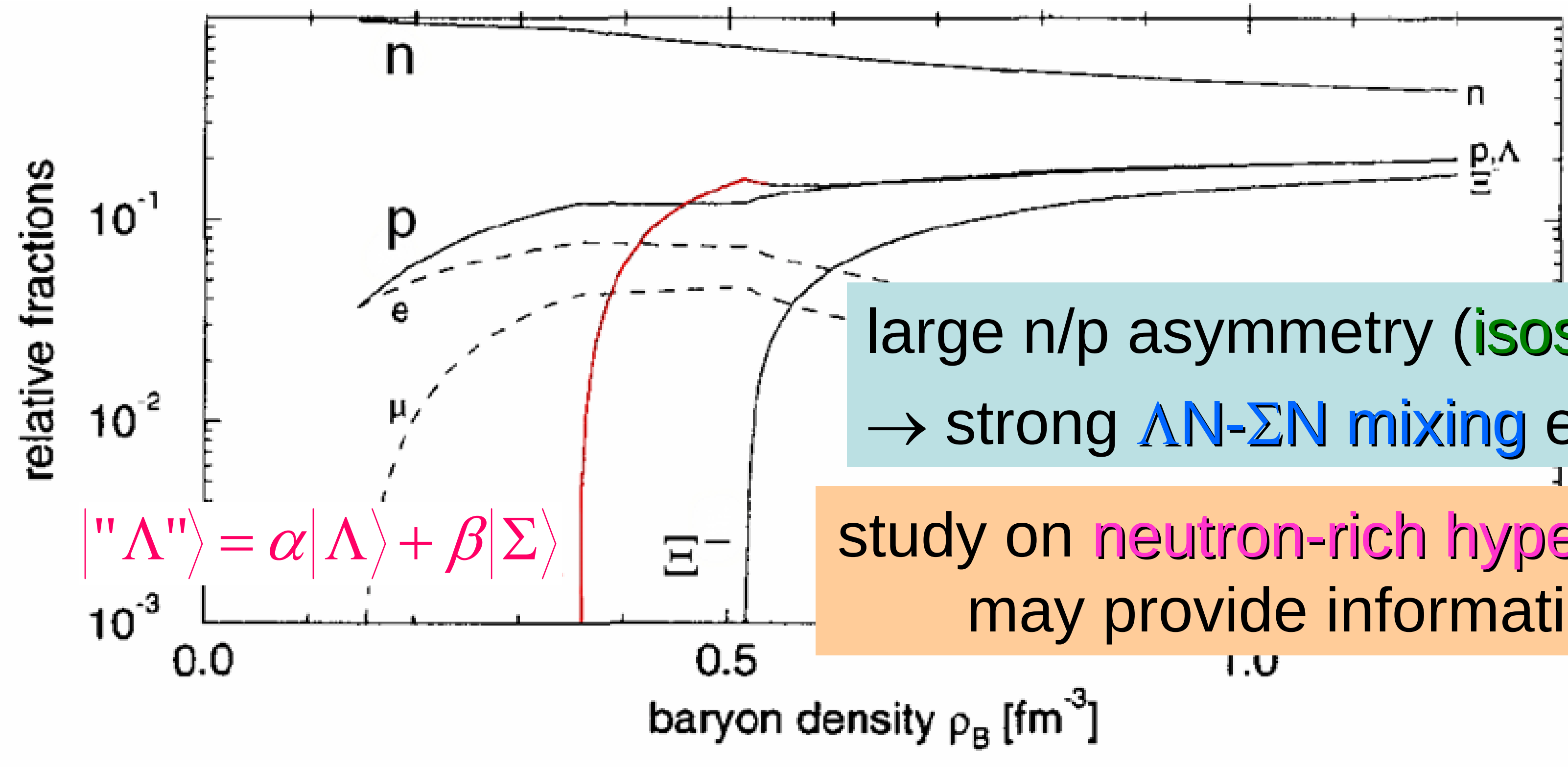
A(I≠0)

Σ

important in neutron-rich Λ-hypernuclei (large isospin)

EoS of matter in neutron star

- Strangeness degree of freedom inevitable
  - – What kinds of strangeness appear ?
  - – Controlled by mass, charge and interaction.



$$|"\Lambda"\rangle = \alpha|\Lambda\rangle + \beta|\Sigma\rangle$$

large n/p asymmetry (isospin≫1)

→ strong ΛN-ΣN mixing expected

study on neutron-rich hypernuclei may provide information

How to produce n-rich Λ-hypernuclei

- KEK-E521 experiment established
  - $^{10}B\left(\pi^-,K^+\right)^{10}_{\Lambda}Li$ reaction
  - Clean reaction

K6 beamline @KEK-PS

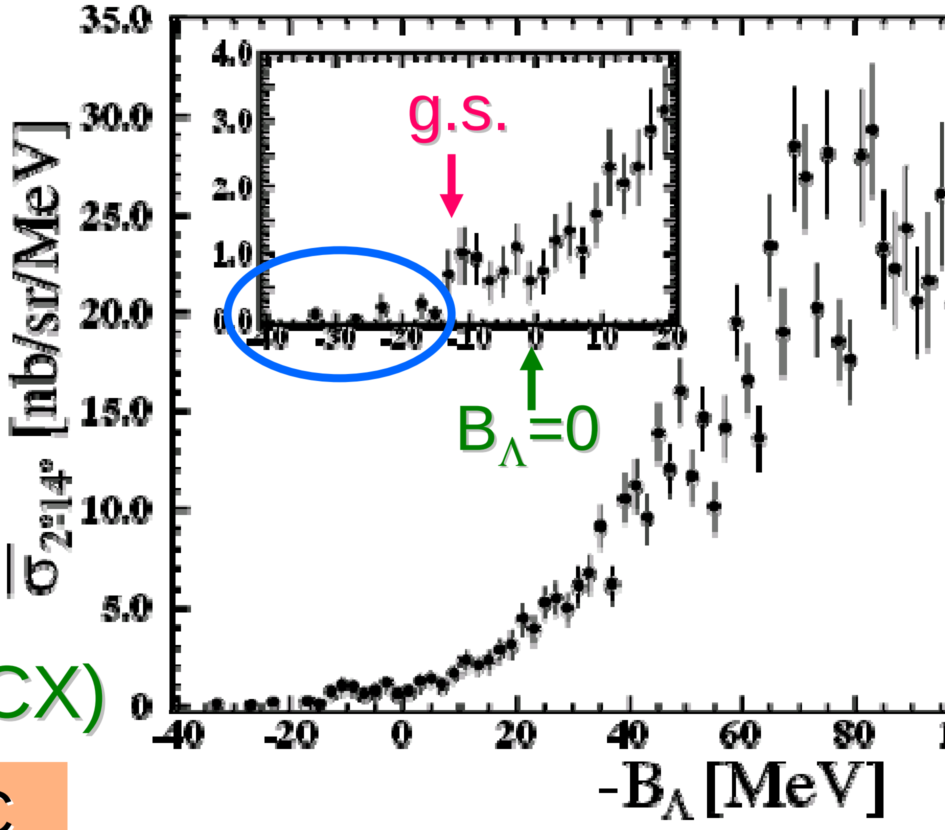
SKS spectrometer

good energy resolution

ΔB_Λ = 2.5MeV (FWHM)

~45 events in bound region

dσ/dΩ~10nb/sr (1/1000 of NCX)



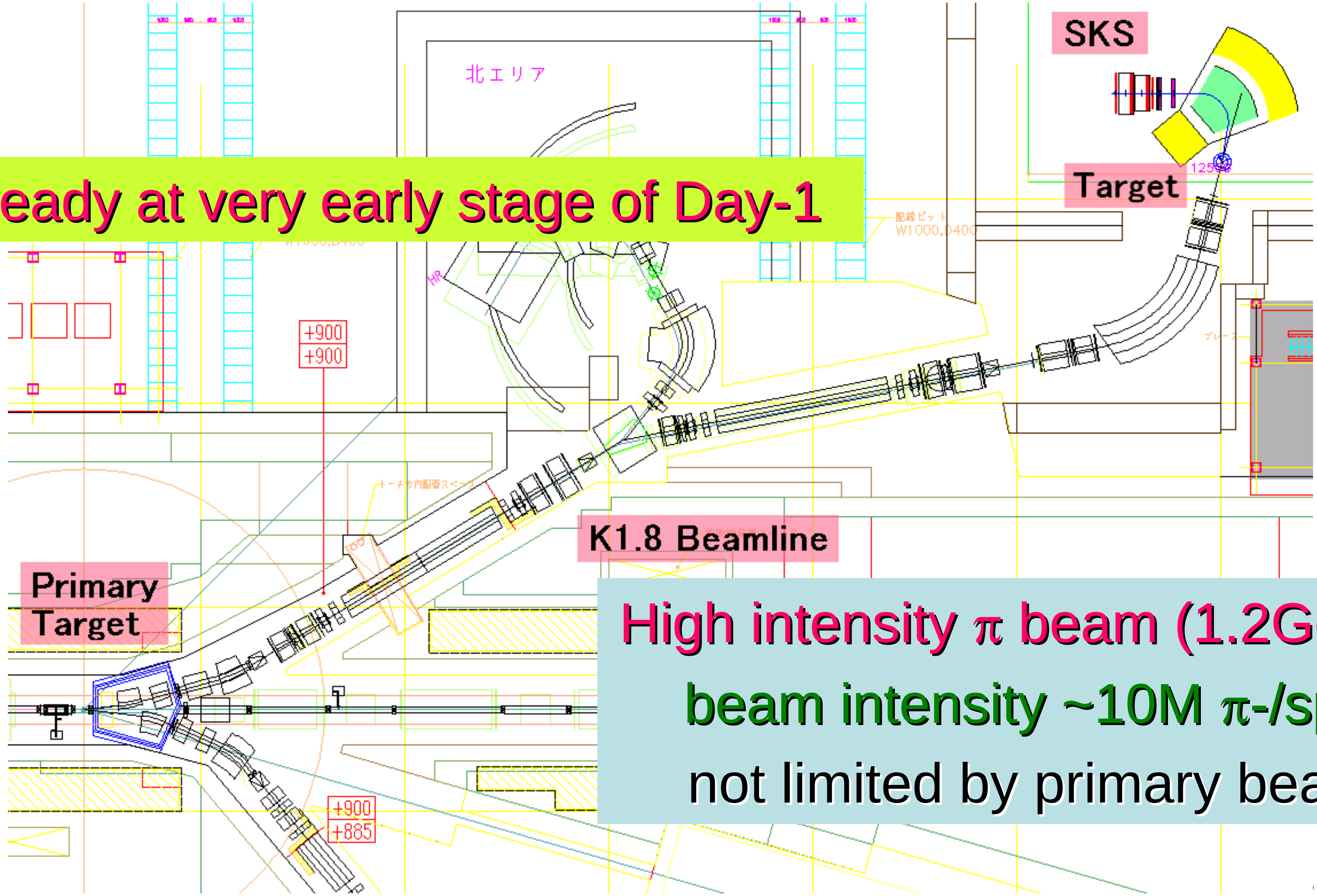
Increase yield ×10 at J-PARC

Experimental setup at J-PARC

- K1.8 beamline + SKS

Excellent resolution

Large acceptance



ready at very early stage of Day-1

High intensity π beam (1.2GeV/c)

beam intensity ~10M π-/spill

not limited by primary beam

Yield: ${}^{9}_{\Lambda}$He production

– Particle bound → clear observation of g.s.

Parameters	Values
π^- beam momentum	1.20 GeV/c
π^- beam intensity	1×10^7 /spill
PS acceleration cycle	3.4 sec
^{9}Be target thickness	3.5 g/cm^2
Reaction cross section	10 nb/sr
Spectrometer solid angle	0.1 sr
Spectrometer efficiency	0.5
Analysis efficiency	0.5

← High beam intensity

← Large acceptance

– dσ/dΩ=10nb/sr is assumed (same order as ${}^{10}_{\Lambda}$Li hypernucleus)

– 310 events in 3 weeks

– 7 times larger ← KEK-E521

if beam spill longer (3sec) → ×2

– Discussion on level structure possible

Yield: $^{6}_{\Lambda}H$ production

- – Simple estimation tells binding is marginal
  - May be bound or may not
  - May observe even unbound g.s. if width is narrow
- – Yield estimation has large ambiguity
  - Exotic nature of $^{6}_{\Lambda}H$: overlap of w.f. smaller ?
  - Production cross section may be smaller ?
- – Yield vs. information

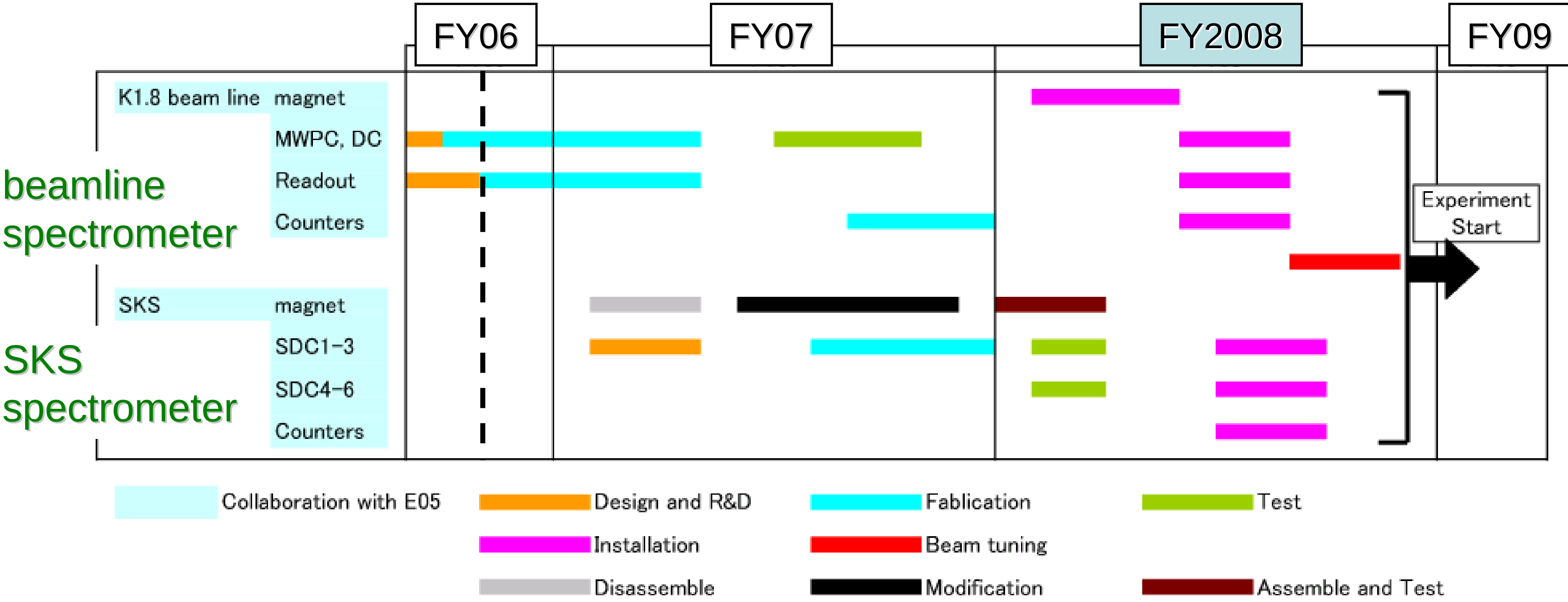
Pessimistic estimation

- ~50 events: discuss “bound” or “not bound”

Optimistic estimation

- ~300 events: some discussion on level structure

Time schedule



- Need only K1.8 beamline and SKS
- Beamline and detectors will be ready in FY08
- Collaboration with E05

Summary of proposal

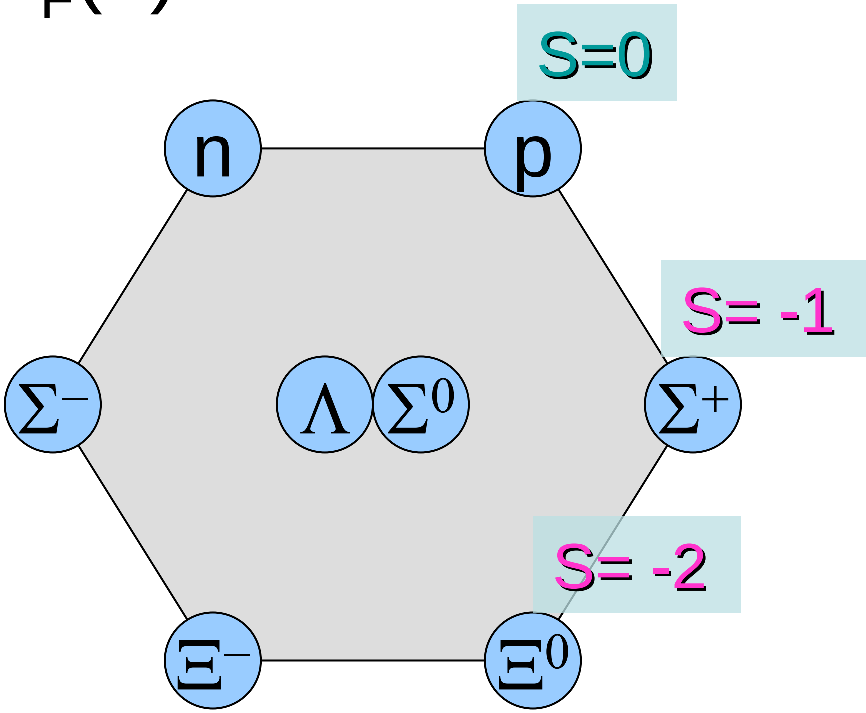
- Double CX: New spectroscopic tool
  - Hypernuclei close to neutron drip-line: ${}^{9}_{\Lambda}\mathrm{He}$
  - Exotic Λ-hypernuclei: ${}^{6}_{\Lambda}\mathrm{H}$
  - Expect higher statistics than KEK-E521

- Information from neutron-rich Λ-Hypernuclei
  - Λ-N interaction in neutron-rich environment
  - ΛN-ΣN mixing effects
    - Small Λ-Σ mass difference
    - Important if core nucleus has non-zero isospin
  - Close connection to the EoS of matter in neutron stars (isospin$\gg$1)

Backup Slides

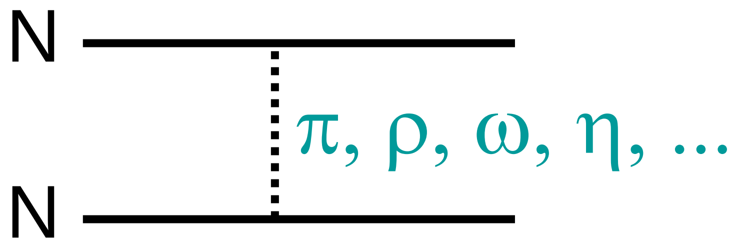
Flavor SU(3) symmetry

- u and d quarks $SU_F(2)$
- → u, d and s quarks $SU_F(3)$
  - – proton and neutron
  - – and hyperons
- Lightest hyperon (Λ)
  - – Λ-hypernuclei
    - Another stable "nuclei"
- Other hyperons
  - – ΛN-ΣN mixing occur
    - Affect to Λ-nucleus interaction

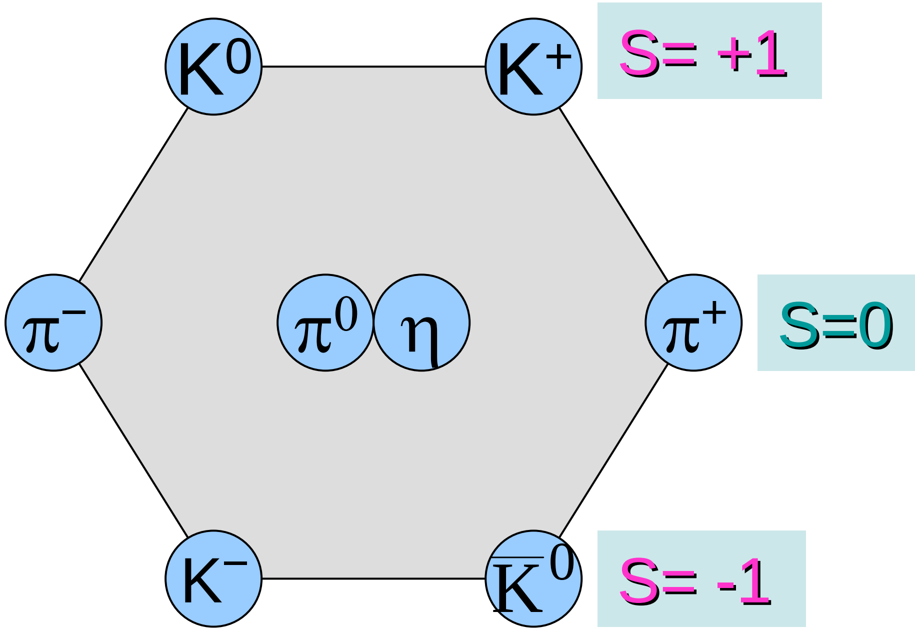


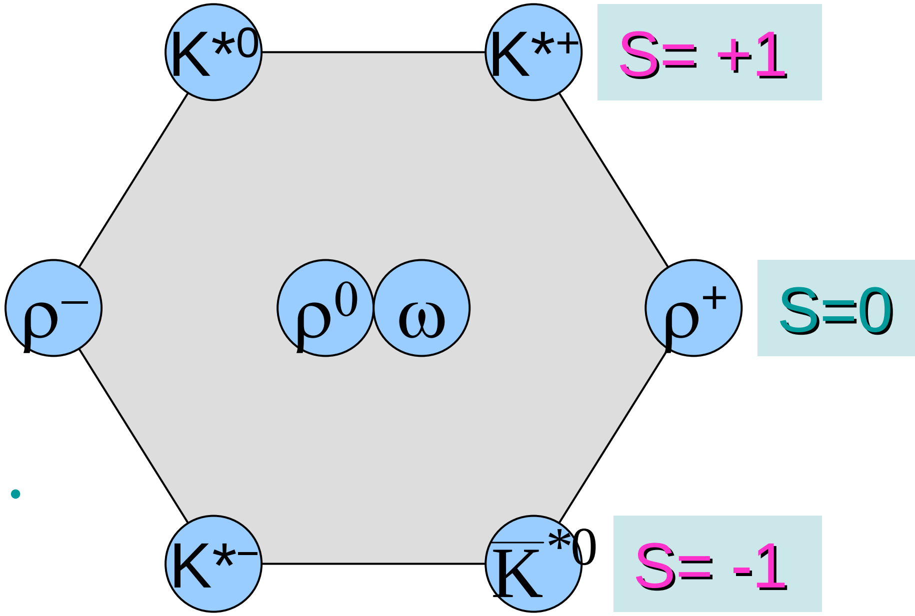
- NN and YN int.
  - – $SU_F(2) \rightarrow SU_F(3)$

Ordinary nuclear force



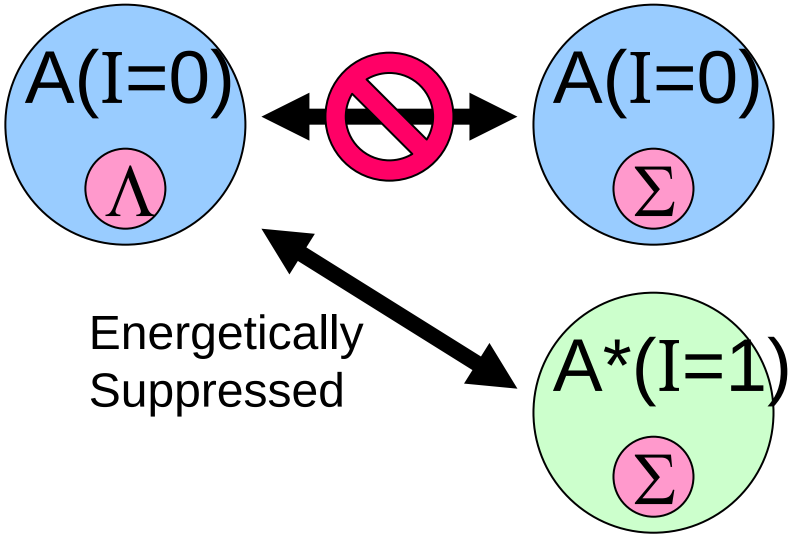
Extension to YN interaction





ΛN-ΣN mixing effect

if core isospin=0



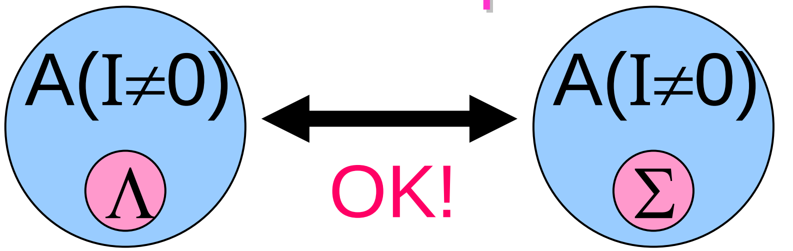
A(I=0) Λ

A(I=0) Σ

Energetically Suppressed

A*(I=1) Σ

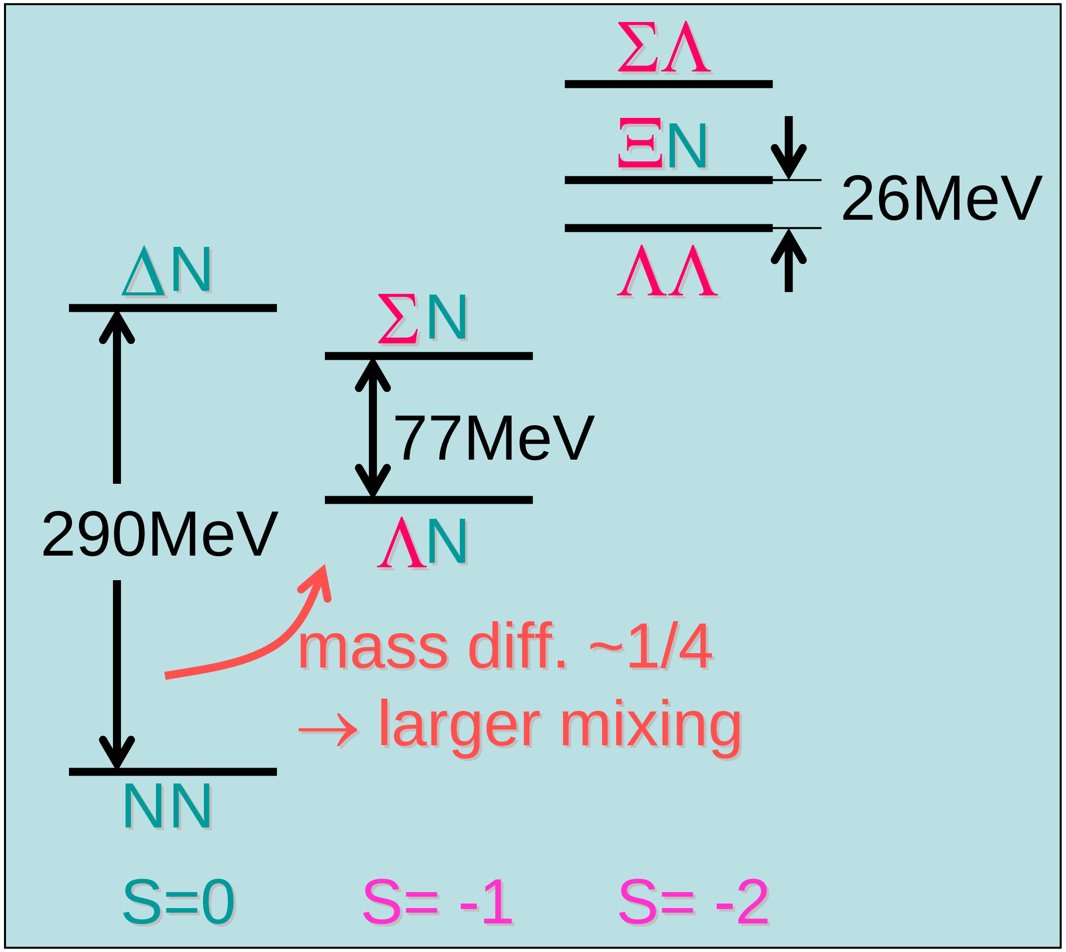
if core isospin≠0



A(I≠0) Λ

OK!

A(I≠0) Σ



ΣΛ

ΞN

26MeV

ΛΛ

ΔN

ΣN

77MeV

290MeV

ΛN

mass diff. ~1/4

→ larger mixing

NN

S=0

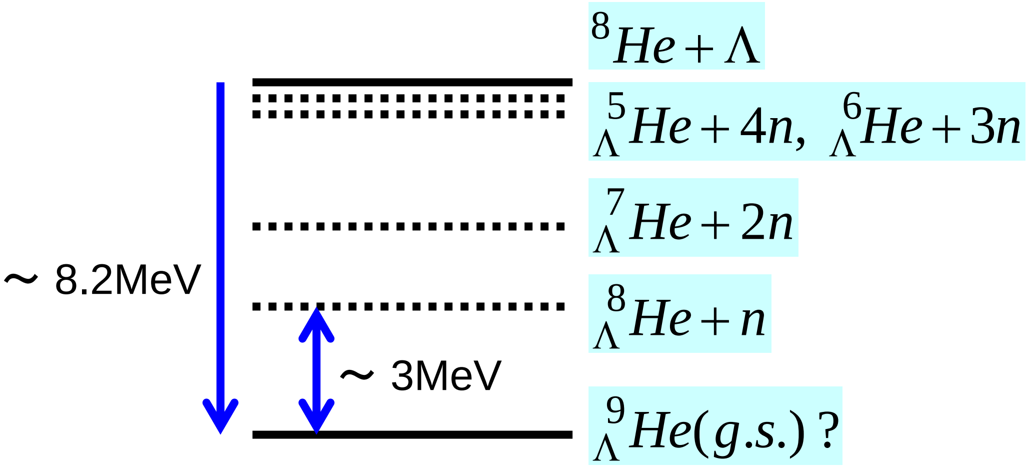
S= -1

S= -2

Important in n-rich (or p-rich) Λ-hypernuclei

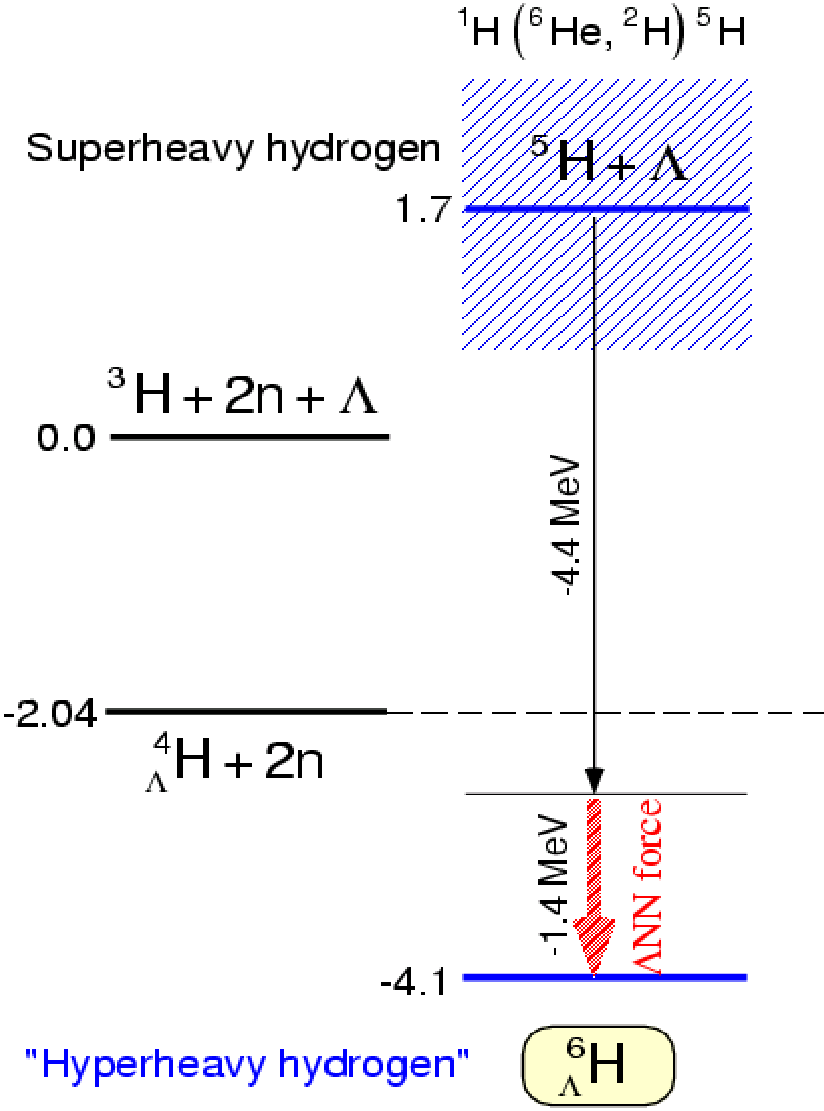
Structure of ${}^{9}_{\Lambda}$He hypernucleus

- Expected to be particle stable
  - Core nucleus ^{8}He is particle bound
- Practical decay thresholds
  - Naive extrapolation of B_{Λ} tells B_{Λ}~8MeV
  - → 3 MeV more bound than ${}^{8}_{\Lambda}$He+n threshold



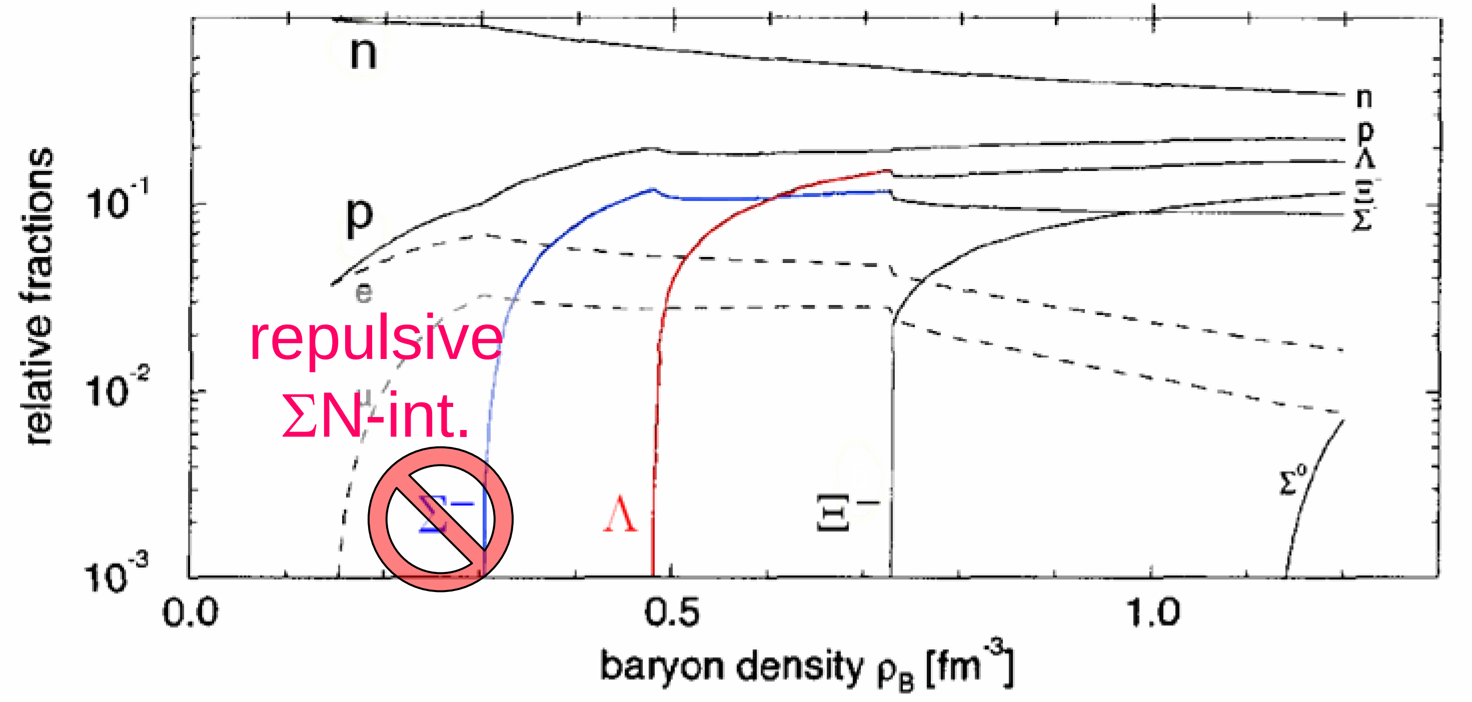
Structure of $^{6}_{\Lambda}$H hypernucleus

- Unbound ^{5}H
  - 1.7 MeV unbound
  - Exist as resonance
  - "Superheavy Hydrogen"
- Bound $^{6}_{\Lambda}$H ?
  - glue-like role of Λ
  - B_{Λ}= 0.5~2 MeV ?
  - "Hyperheavy Hydrogen"

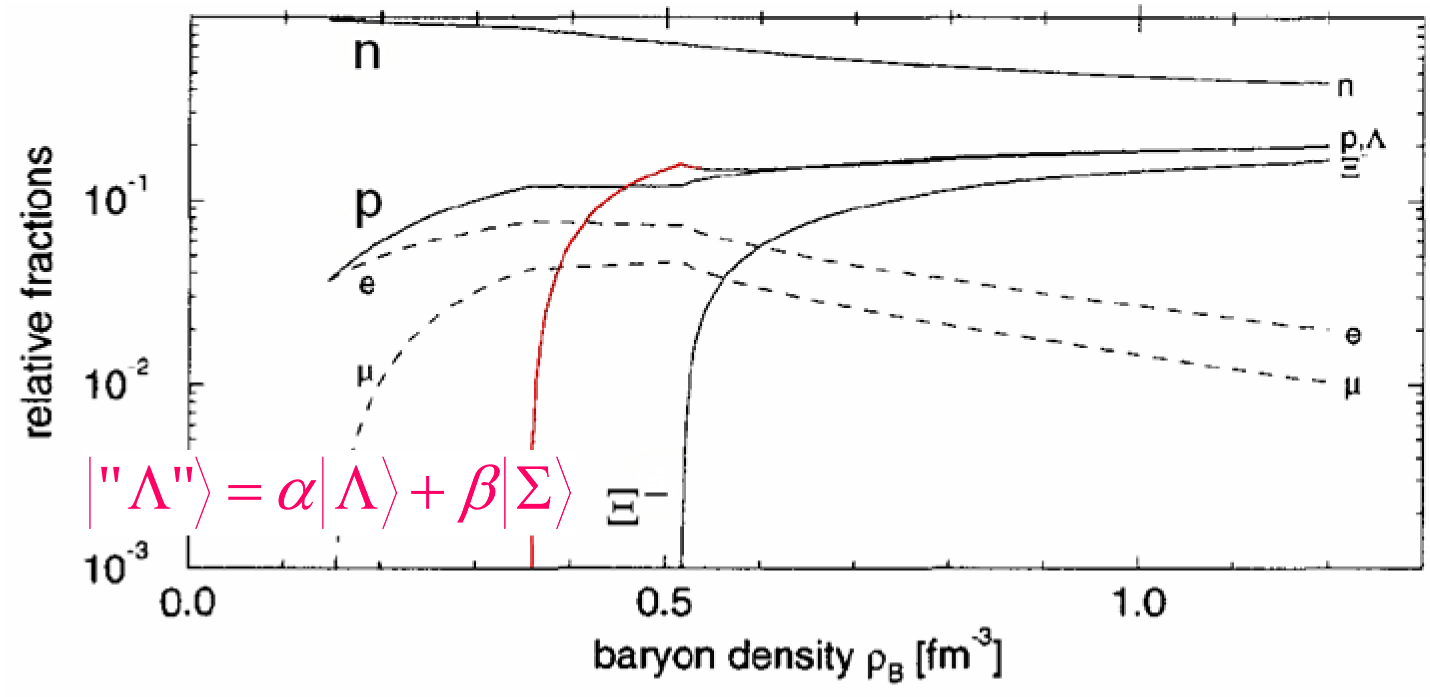


Ingredients of neutron stars

- Core of neutron stars
  - – Need strangeness degree of freedom
  - – What kinds of strangeness appear ?
  - – Controlled by mass, charge, interaction, etc.



ΛN-ΣN mixing in neutron star

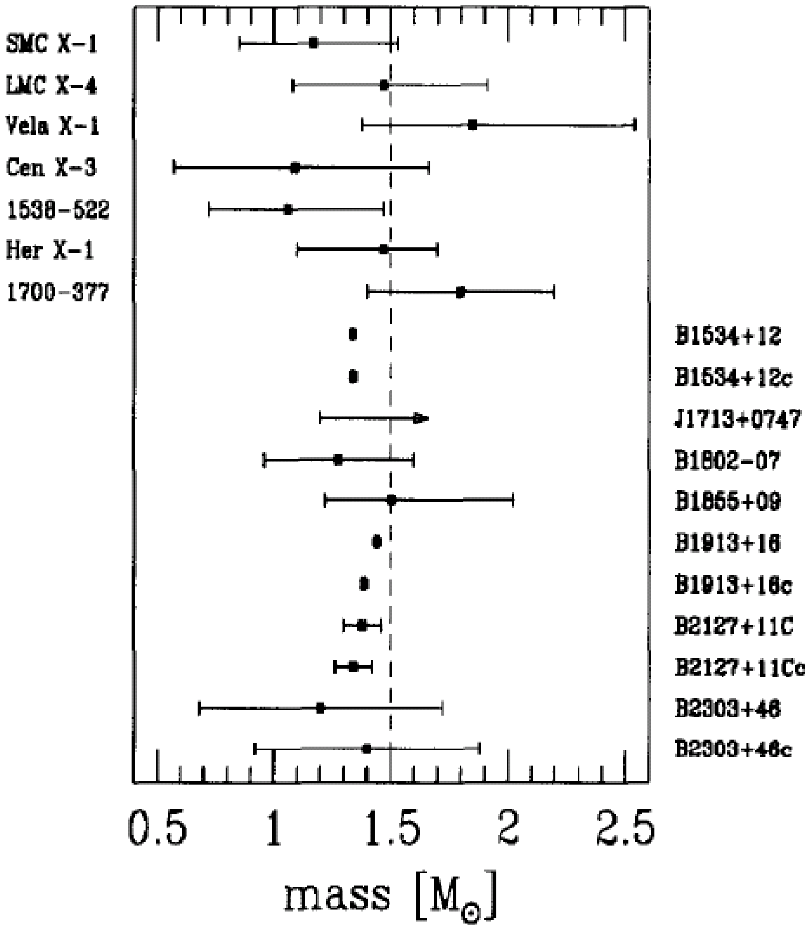


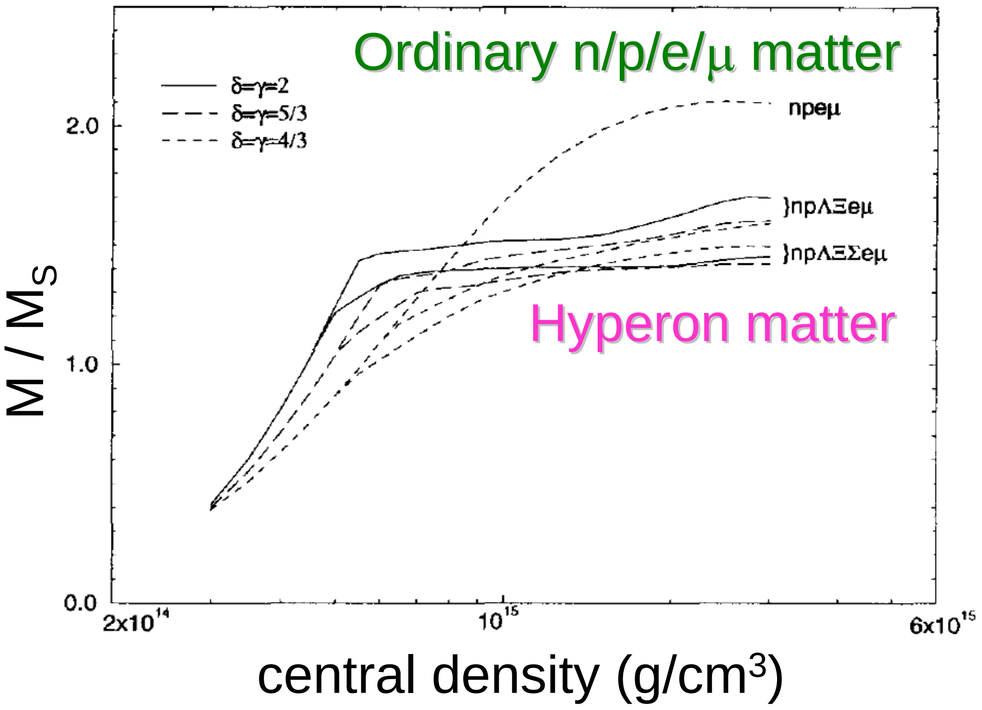
$$|"\Lambda"\rangle = \alpha|\Lambda\rangle + \beta|\Sigma\rangle$$

- Large n/p asymmetry (isospin$\gg$1)
  - ΛN-ΣN mixing is quite natural
  - Information on mixing for EoS discussion
  - Study of neutron-rich hypernuclei may provide

EoS and mass of neutron stars

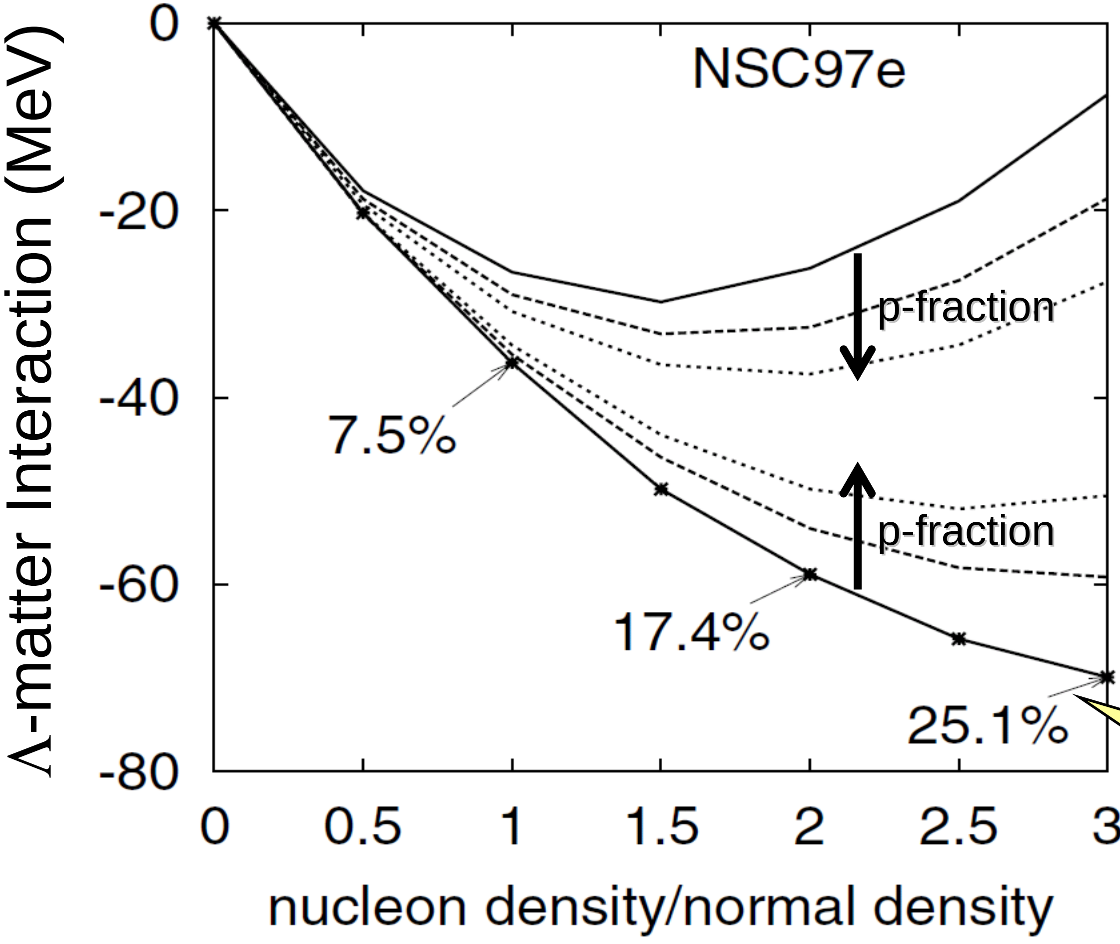
- Upper bound of neutron star mass $<1.5M_S$





ΛN-ΣN mixing effect on EoS

- Degree of ΛN-Σ^0N mixing and EoS



no mixing

Hard EoS

with mixing

Soft EoS

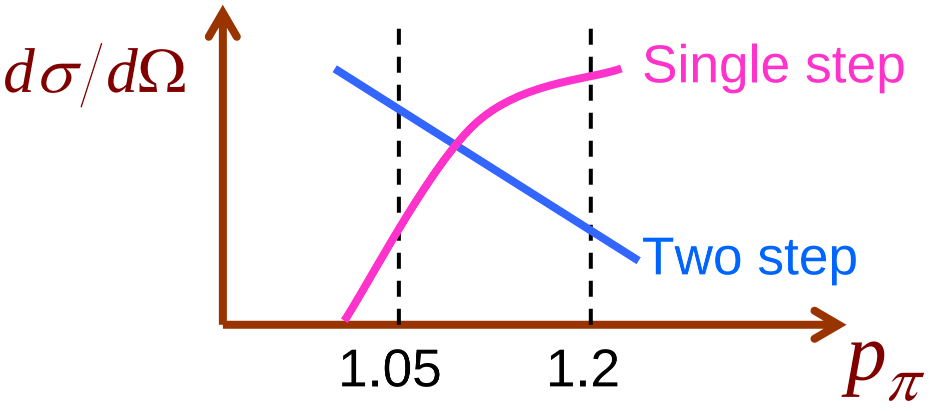
large mixing

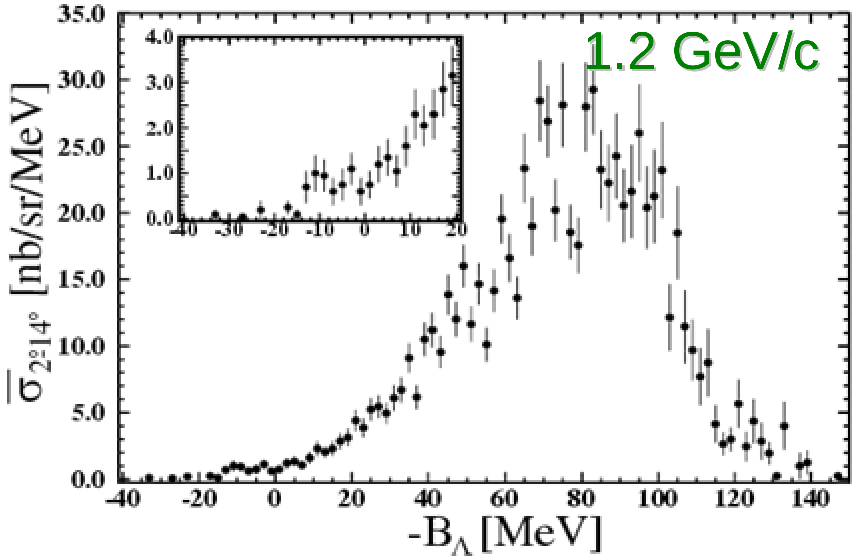
Results of KEK-PS-E521 experiment

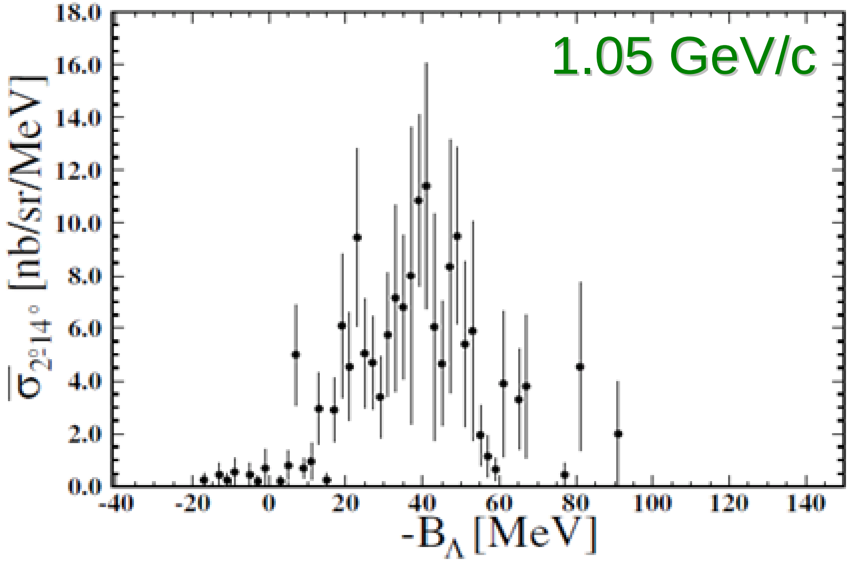
- Cross section
  - – p_π=1.2 GeV/c

    $$d\sigma/d\Omega \approx 11\,\mathrm{nb/sr}$$
  - – p_π=1.05 GeV/c

    $$d\sigma/d\Omega \approx 6\,\mathrm{nb/sr}$$
- Reaction mechanism

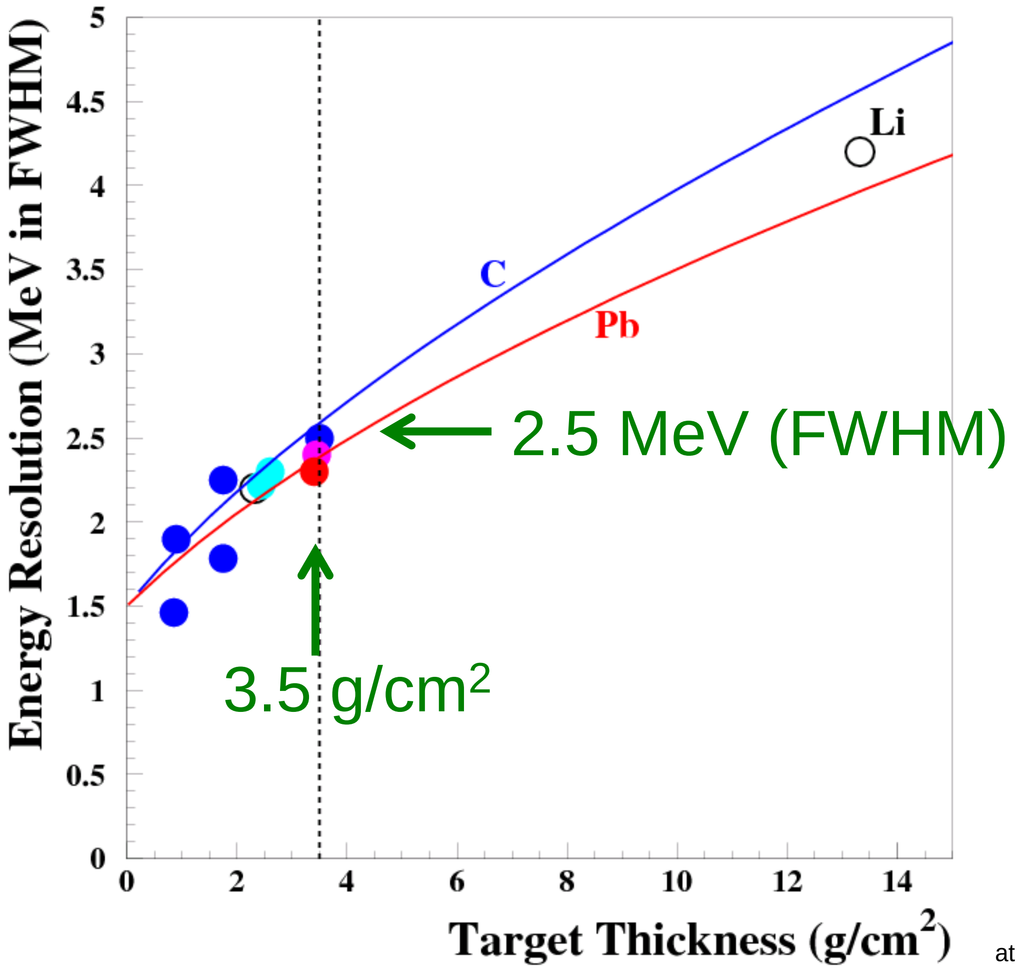






SKS energy resolution

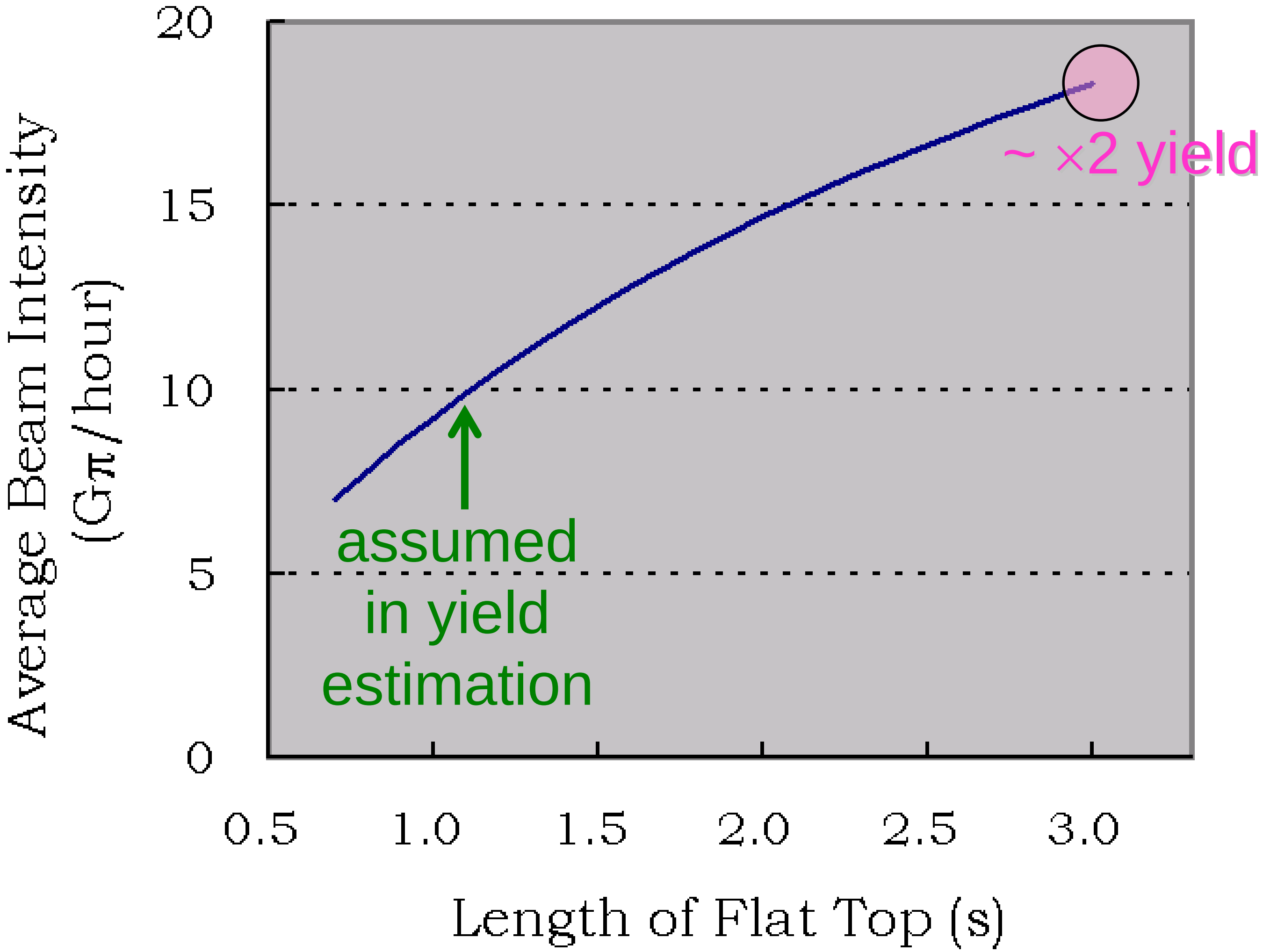
- Summary of experimental resolution



Calibration

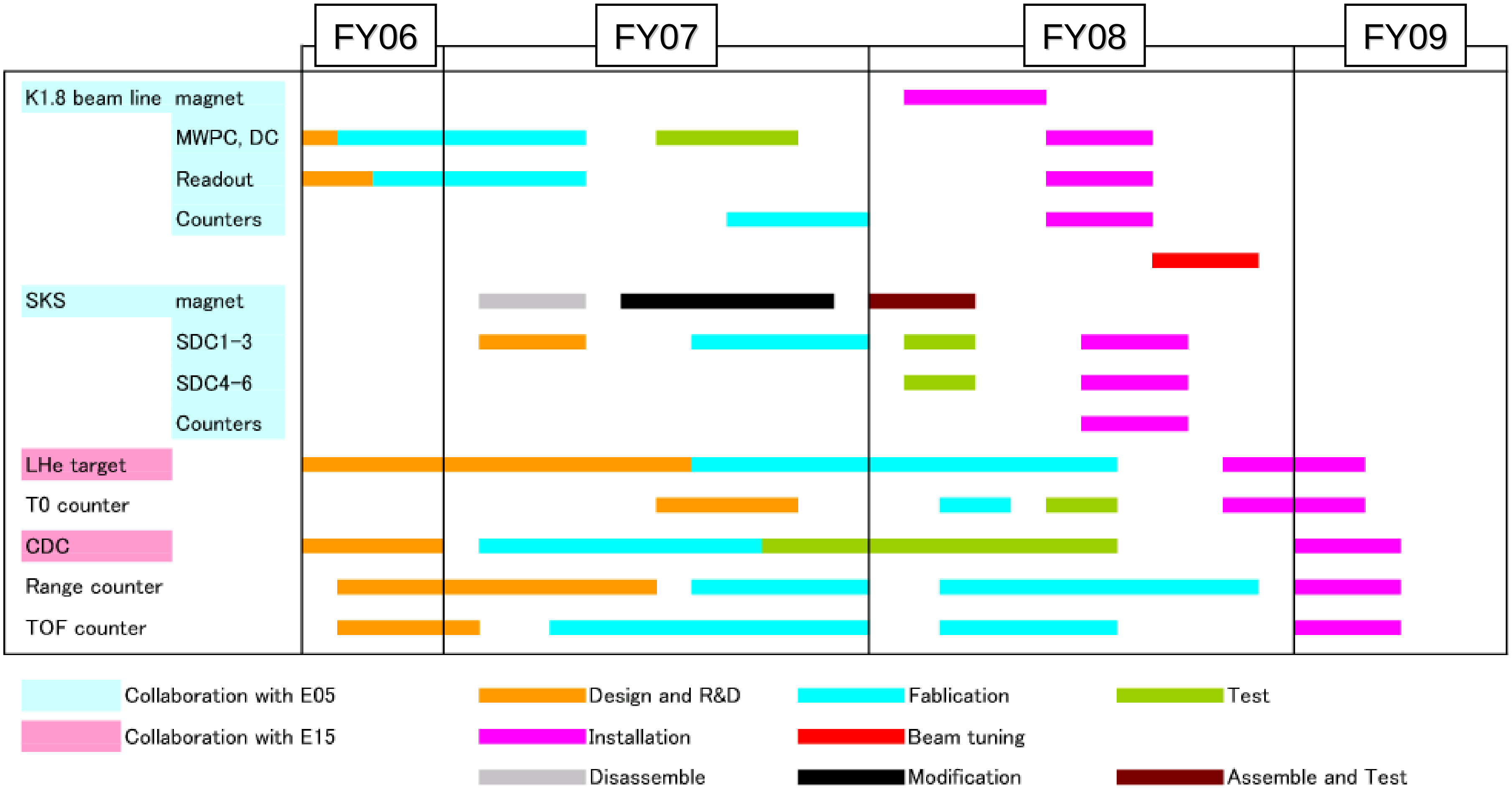
- B_Λ and Ex calibration
  - $^{12}_{\Lambda}C$ production by the (π^+,K^+) reaction
    - Ground state ($s_{1/2,\Lambda}$): B_Λ=10.76±0.19 MeV
    - Excited state ($p_{3/2,\Lambda}$): Ex=11.00 ± 0.03 MeV
  - Obtain response function (peak shape)
  - No change in SKS, beamline polarity change
    - Symmetry of π^+/π^- beams
    - Narrow acceptance of beamline
- 1 shift for every 1 week
  - ΔB_Λ, ΔEx ~ 0.05 MeV (stat.)

Length of Flat Top vs Yield



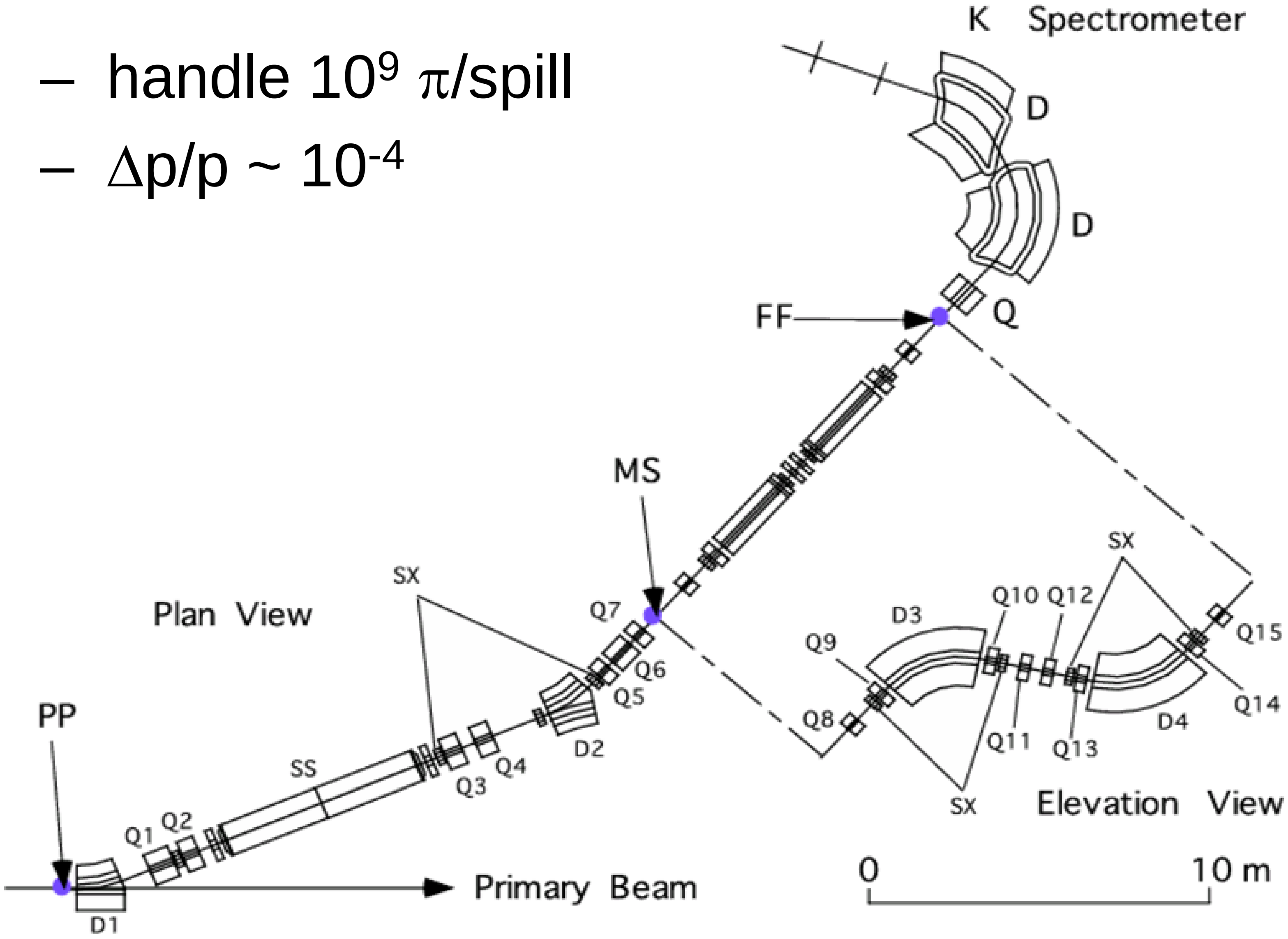
– 10MHz beam operation assumed

Time schedule of “weak decay” experiment



High Intensity and High Resolution beamline

- handle 10^9 π/spill
- $\Delta p/p \sim 10^{-4}$



High Intensity and High Resolution beamline (new configuration)