Feasibility of Production and Detection of Relativistic Hypernuclei

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- Status of Hypernuclear Physics
- Value of Relativistic Hypernuclei
- Considerations on Experiment at 50-GeV PS
- Prospects on Single-Λ Hypernuclei
- Possibility of Double-Λ Hypernuclei
- Summary

Status of Hypernuclear Physics

Structure of Single-Λ Hypernuclei

- Hypernuclei produced by various beams

  (K^-,π^-) reaction
  - Transfer strange-quark to nuclei
  - Small momentum transfer ⇒ Low-spin states (ΔL=0)

  (π^+,K^+) reaction
  - s and s-bar associate production ⇒ s-quark stays in nuclei
  - Larger momentum transfer ⇒ High-spin states (ΔL»1)

  (e,e'K) and (γ,K) reaction
  - s and s-bar associate production
  - Spin-flip amplitude ⇒ excite unnatural parity states

Classification of hypernuclear states

- Theoretical predictions are very helpful to identify states

Gross feature of Λ-nucleus and ΛN interaction

- High-resolution spectroscopy
  - High-resolution spectrometers
    - $\Delta Ex \sim 1$ MeV $\Rightarrow$ 100 keV
  - γ-ray spectroscopy
    - $\Delta E \sim 1$ keV

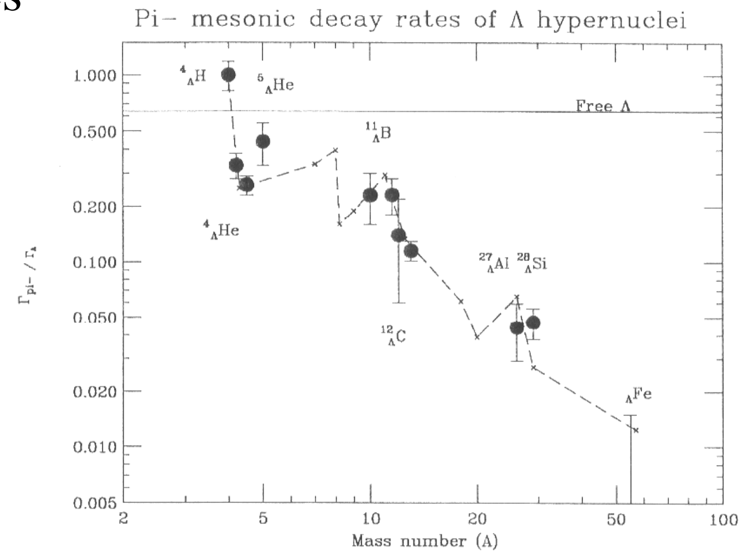
Precise measurement of nuclear structure

- Theoretical works are very helpful
  - Microscopic YN interactions based on NN interaction and $SU_F(3)$ symmetry
  - Effective interaction in hypernuclei

Details of Λ-nucleus and ΛN interaction

Baryon-Baryon Weak Interaction in Hypernuclei

Y. Sato, *in Hypernuclear Physics with Electromagnetic Probes*, 1999, Hampton



- Hypernuclei decay with weak processes

  Mesonic decay mode

  - π^- or π^0 emission

    $^{4}_{\Lambda}\mathrm{He} \rightarrow {}^{4}\mathrm{He} + \pi^0$

    $^{4}_{\Lambda}\mathrm{He} \rightarrow {}^{3}\mathrm{He} + p + \pi^-$

  - Analogous with Λ free decay

    "Λ" $\rightarrow n + \pi^0$ or $p + \pi^-$

  Non-mesonic decay mode

  - New decay mode only in hypernuclei
  - Weak ΛN interaction

    "Λ" + "N" $\rightarrow p + n$ or $n + n$

- Experimental data

  Lifetime measurement $\Gamma=\Gamma m+\Gamma nm$ <u>$\Delta\Gamma/\Gamma$~5%</u>

  Branching ratios Γnn, Γpn, etc. <u>still have large ambiguity</u>

Spin and isospin structure of ΛN weak interaction

Production of Double-Λ Hypernuclei

- S=−2 hypernuclei

  Double-Λ hypernuclei

  - ΛΛ interaction
  - Decay by weak interaction

  Ξ hypernuclei

  - Ξ bounds in nuclei
  - ΞN interaction
  - ΞN → ΛΛ conversion

Quite important to study BB interaction systematically

- Production of S=−2 hypernuclei

  (K^-,K^+) reaction

  - Direct production of Ξ^- hypernuclei and decay to ΛΛ
  - Quasi-free Ξ^- production goes to Ξ^- atom then ΛΛ

Hard to discuss structure only from formation process

Detection of double-Λ hypernuclei

- Sequential mesonic decay

  ${}^{4}_{\Lambda\Lambda}H \rightarrow {}^{4}_{\Lambda}He + \pi^-$

  ${}^{4}_{\Lambda}He \rightarrow {}^{3}He + p + \pi^-$

- Emulsion technique is quite powerful

  High position resolution and high efficiency

  Only 3(4) events obtained in 40 years

> Need more data and clear identification of created hypernuclei

Σ Hypernuclei

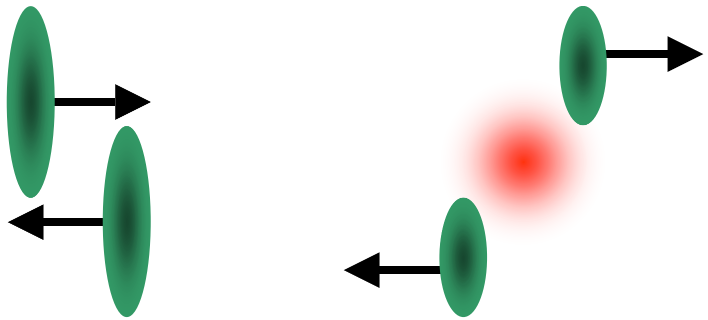
Σ-N Interaction

K^- Nuclei

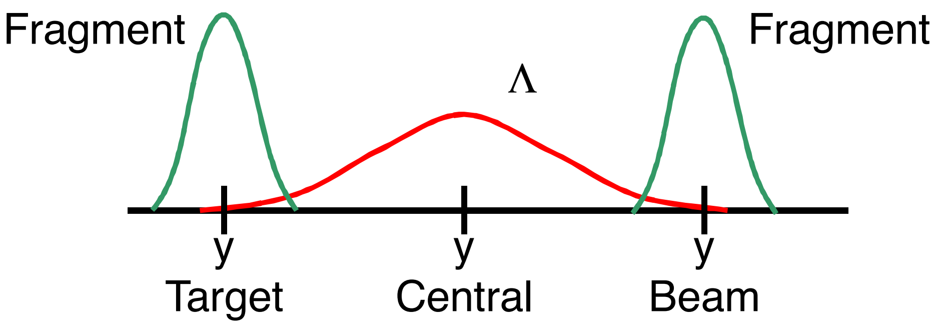
Value of Relativistic Hypernuclei

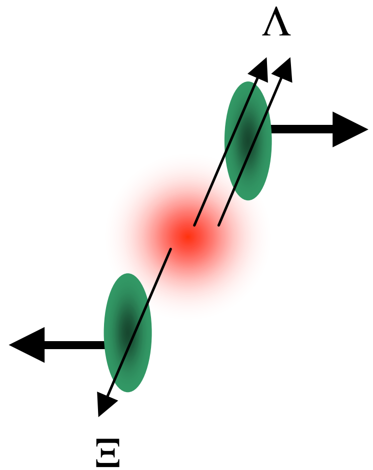
Production of Hypernuclei in Relativistic Heavy-Ion Collisions

- Originally proposed to produce multi-Λ hypernuclei
  - Relativistic heavy-ion collisions
    - See projectile fragment region



  - Coalescence of fragment and Λ particles
    - No limit on number of Λ to coalesce





- Theoretical predictions

M. Sano and M. Wakai, Prog. Theor. Phys. Suppl. 117 (1994) 99

Primary process

- Λ particle coalescence with fragment
- (^{4}He, ^{8}Be, ^{12}C, …)+Λ → $^{5}_{\Lambda}$He, $^{9}_{\Lambda}$Be, $^{13}_{\Lambda}$C, …

  Typical cross section is 1μb
- (Other fragments)+Λ, typically 0.1μb

Fragment 1b
↓
Single-Λ 1μb
↓
Double-Λ 1pb
??

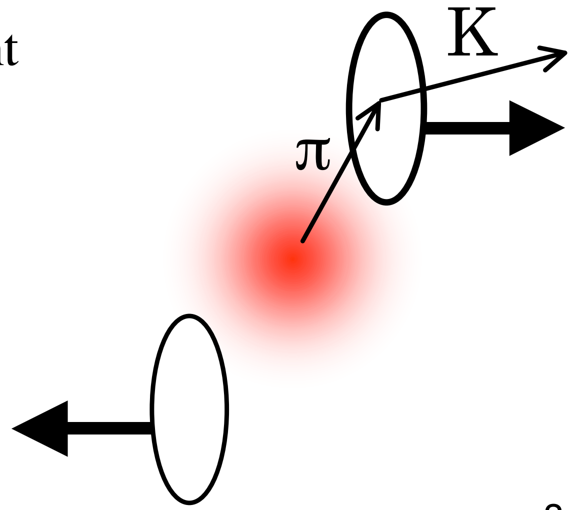
Originally proposed mechanism works fine, but …

Secondary process

- (π,K) and (K,π) reactions on fragment

  (π,K) reaction dominant

  Typical cross section is 0.1μb
- (K^-,K^+) creates Ξ^- in nuclei



Similar boundary condition with meson-beam experiment

Energy dependence of cross section

- Primary coalescence process stay constant
- Secondary process increase with beam energy
- Change over around 10 GeV/u

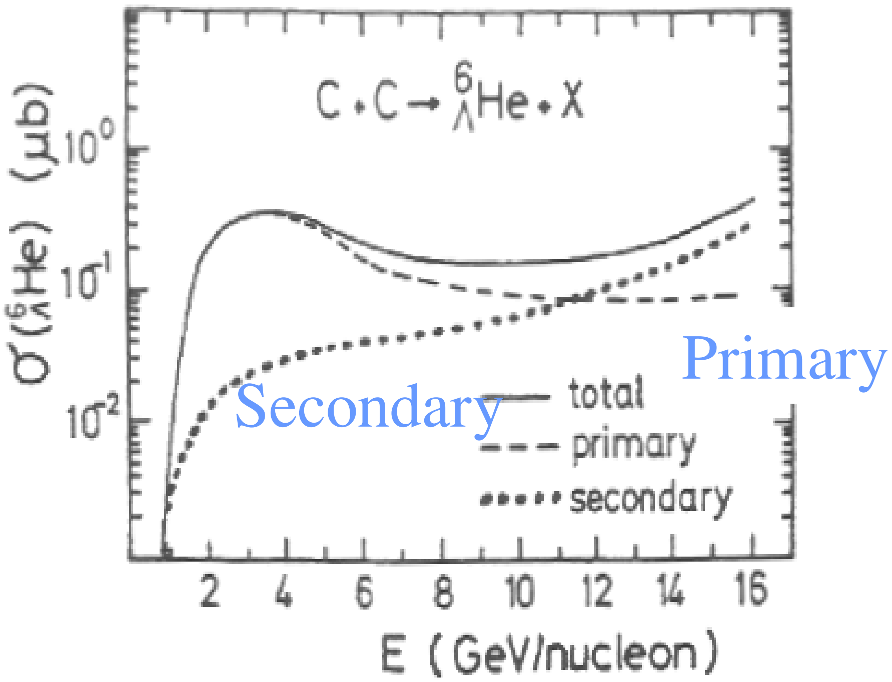
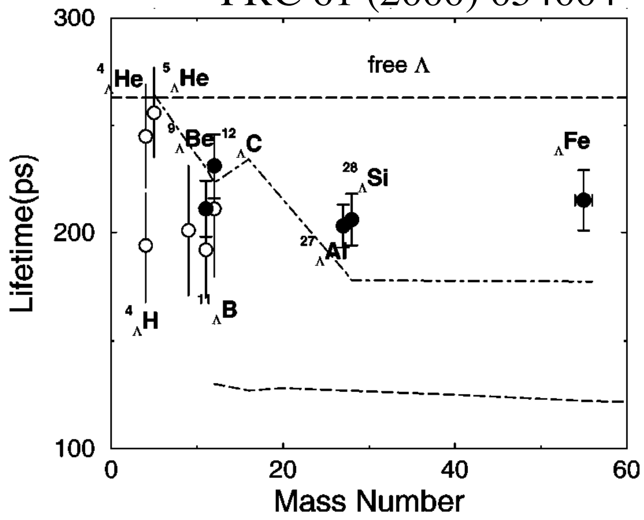


Fig. 6. Beam energy dependence of $^{6}_{\Lambda}$He production cross section in $^{12}C + ^{12}C$ collisions.

PRC 61 (2000) 054004



- Really new experiment possible ?

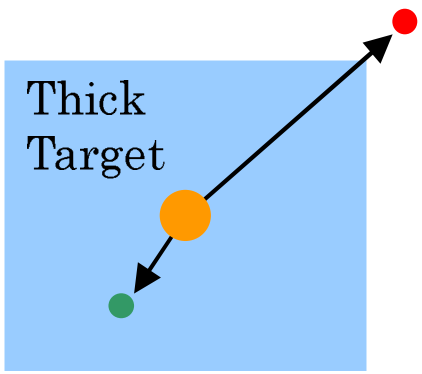
  Precise lifetime measurement

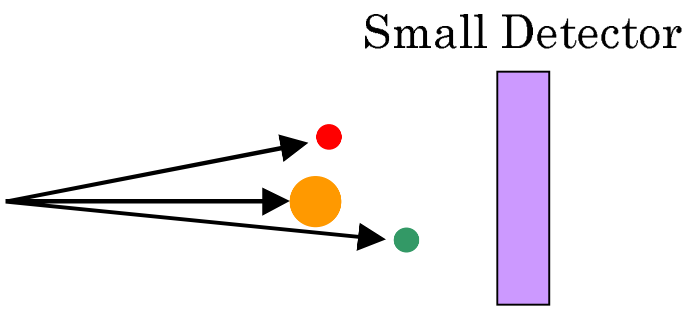
  - $\Delta Z_{VTX} \sim 1$ cm $\Rightarrow$ $\Delta\tau < 1$ %

    $\beta\gamma c\tau \sim 200$ cm

  Complete decay branch

  - Mesonic and non-mesonic modes at the same time
  - Detect decay particles efficiently





  Inverse kinematics

  - Size of hypernuclei

  n- or p-rich hypernuclei

  - Fragment (target) may be unstable

Considerations on Experiment at 50-GeV PS

Beam

- Light heavy-ion (say ^{12}C, ^{16}O, ^{28}Si, etc.)
  to be available in near future, I hope
- Energy: 25 GeV/u
  $\beta\gamma c\tau$ (Λ) ~ 2.1m
- Intensity: 10^9~10^{10} ion/burst (<200W)
- Good emittance
  assume 6π mm·mrad ⇒ a few mm and a few mrad

Production Target

- 5% reaction length for heavy-ion beam
  ^{12}C: about 1 g/cm^2
  Multiple scattering of fragment negligible (~0.05mrad)
- 50 ~ 500 hypernuclei/burst at production target

Separation of Hypernuclei from Beam

- Magnets and collimators

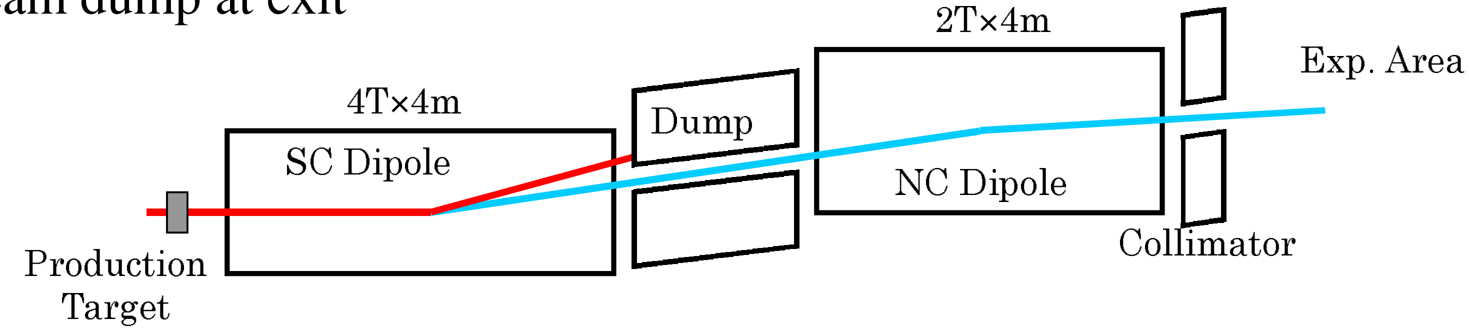
  Similar with hyperon beam-line or K^0 beam-line

  But, we have to see absolute 0 degree !

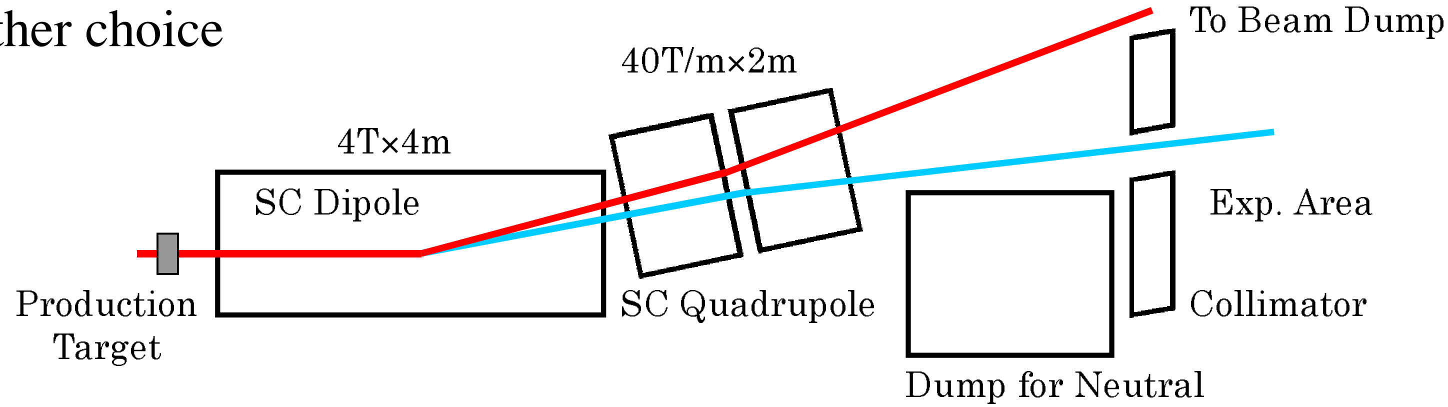
- Strong magnetic field and beam dump

  4T × 4m super-conducting magnet

  Beam dump at exit

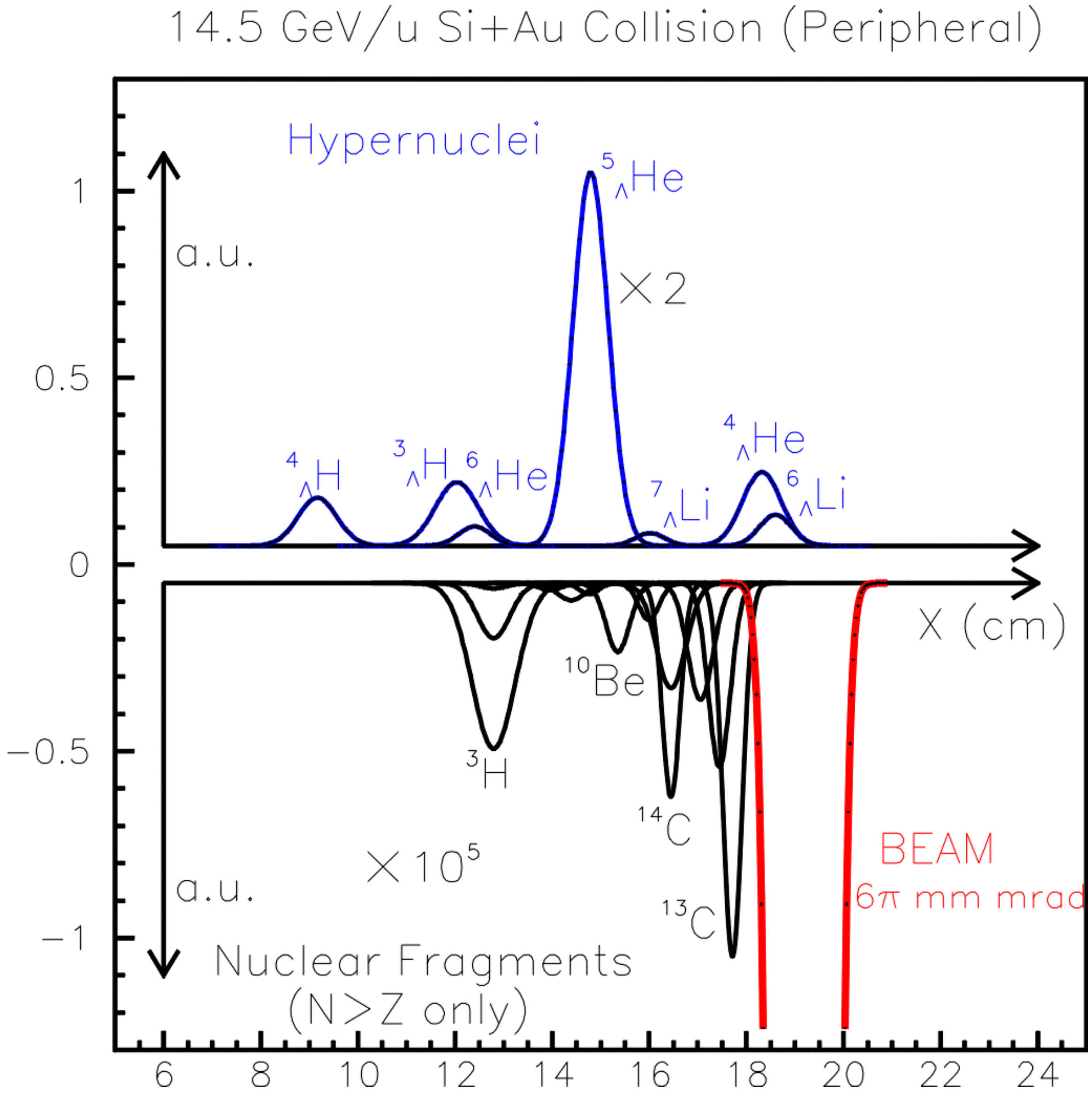


- Another choice



- Profile at exit of SC dipole

  A toy model calculation



Prospects on Single-Λ Hypernuclei

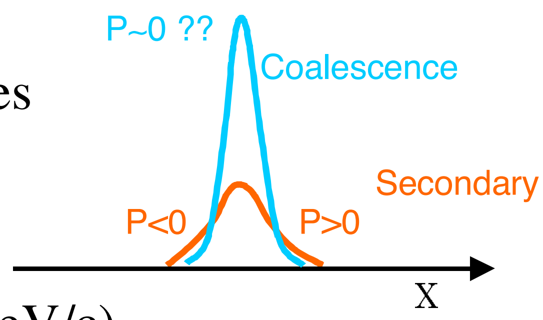
Relativistic Hypernuclei to Experimental Area

- 1/100 due to decay after 10 m separation line
  0.5~5 hypernuclei/burst
- Fragments/Hypernuclei ~ 10^7 (no collimation)
  About 1 hypernuclei/burst
- Fragments/Hypernuclei ~ 10^6 (with collimation)
  About 10 hypernuclei/burst

About 10^4 hypernuclei/day

- Not so huge, but enough to study decay processes

Possibility of Polarized Hypernuclei



- Coalescence process
  Λ polarization is small due to small p_T (~50 MeV/c)
  Fragment may have polarization (unknown at such high energy)
- Secondary process
  Polarization due to (π,K) reaction may be large ~0.3

Background Events

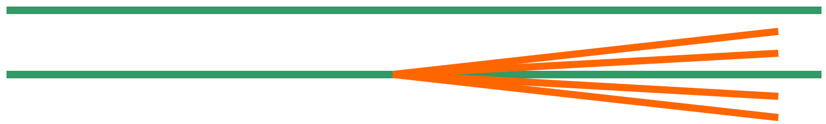
- Nuclear reactions of fragments

  Single track

  Track with multi-hadron (pion) vertex

  - Opening angle ~ 10 degrees (central rapidity)

  Can be reduced by vacuum decay volume



Signal Events

- Mesonic decay mode

  Track with single π^- vertex

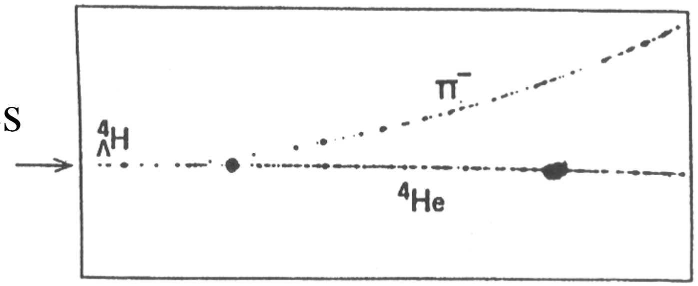
  4 GeV pion, opening angle ~ 1.5 degrees

- Non-mesonic decay mode

  Track with a few protons vertex

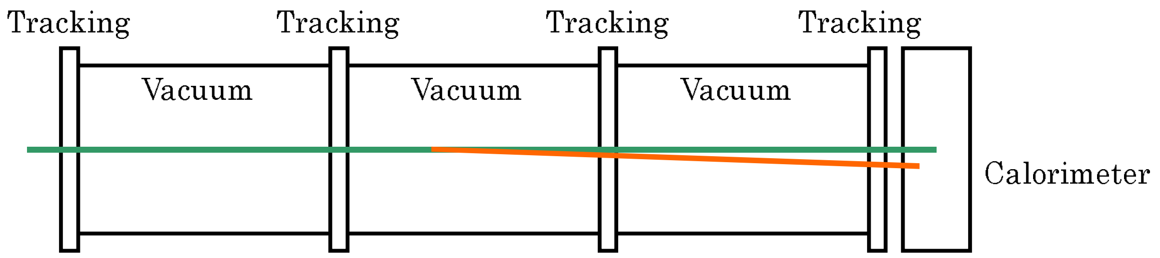
  25 GeV protons, opening angle ~ 1 degree

Dubna streamer chamber experiment

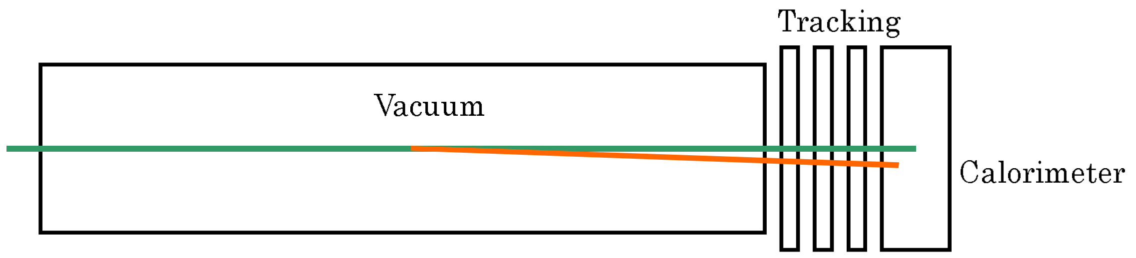


Detector Setup

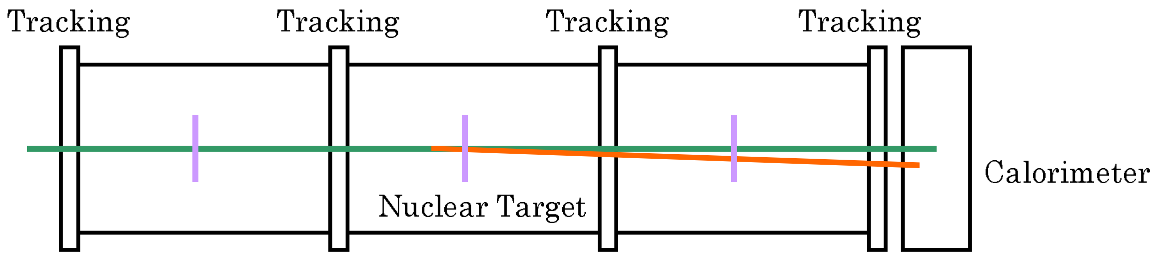
- Lifetime measurement



- Weak decay study



- Size of hypernuclei

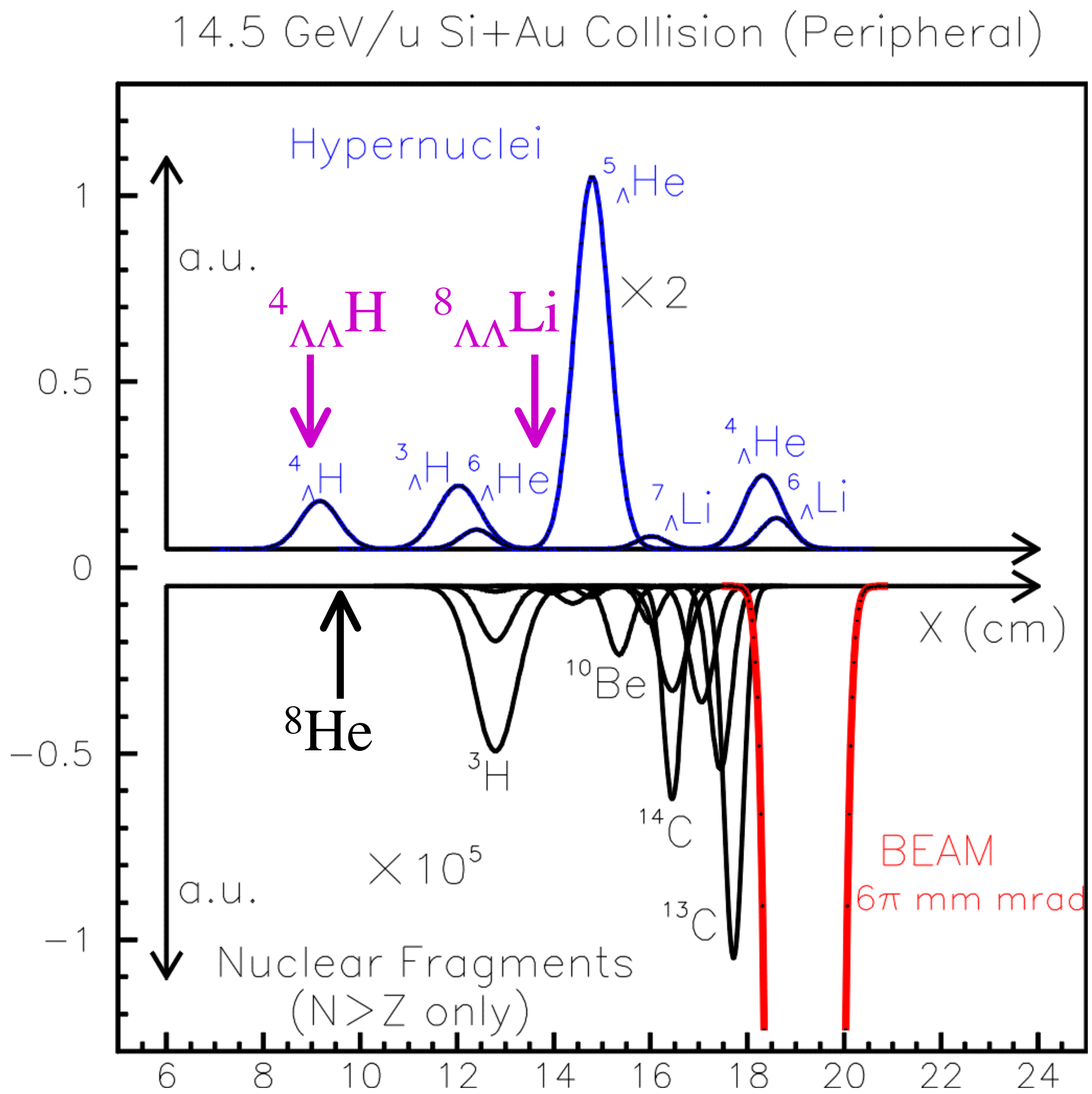


Possibility of Double-Λ Hypernuclei

Production Rates

- Direct double-Λ hypernuclei formation
  - Coalescence two Λ to a fragment
  - Cross section ~ 1 pb
- Through Ξ hypernuclei
  - Ξ hypernuclei formation ~ 5 nb
    - Mainly from Ξ coalescence with fragment
    - $(^{4}He, ^{8}Be, \ldots) + \Xi^{-}$
  - $\Xi N \rightarrow \Lambda\Lambda$ and ΛΛ stay in nuclei ~ 10 %
    - $^{4}He + \Xi^{-} \rightarrow {}^{5}_{\Lambda\Lambda}H^{*} \rightarrow {}^{4}_{\Lambda\Lambda}H + n$
  - 1/2000 of single-Λ hypernuclei
- If we detect 2000 single-Λ hypernuclei, we may see 1 double-Λ hypernuclei.
  - A few double-Λ hypernuclei in a day ? Life time effect ?
  - ${}^{4}_{\Lambda\Lambda}H \rightarrow {}^{4}_{\Lambda}He + \pi^{-} \Rightarrow {}^{4}_{\Lambda}He \rightarrow {}^{3}He + p + \pi^{-}$
  - Need magnetic field to estimate binding energy

- Profile at exit of SC dipole



Summary

- Production of relativistic hypernuclei by relativistic heavy-ion collisions was discussed. Production of relativistic light single-Λ hypernuclei amounts to 10000/day with a practical experimental condition.

- The relativistic hypernuclei are suitable to study decays of hypernuclei, and are valuable to study details of the ΛN weak interaction.

- Production of double-Λ hypernuclei was marginal. Configuration of the separation line should be optimized. Double-Λ hypernuclei like ${}^{4}_{\Lambda\Lambda}H$ reachable ??

- Comment: Production rate of light double-Λ hypernuclei is about 1000 times higher in the central rapidity region (about 1 in 10000 central collisions). Spectrometer like OMEGA at CERN may see it.