# FINUDA: Physics Perspectives

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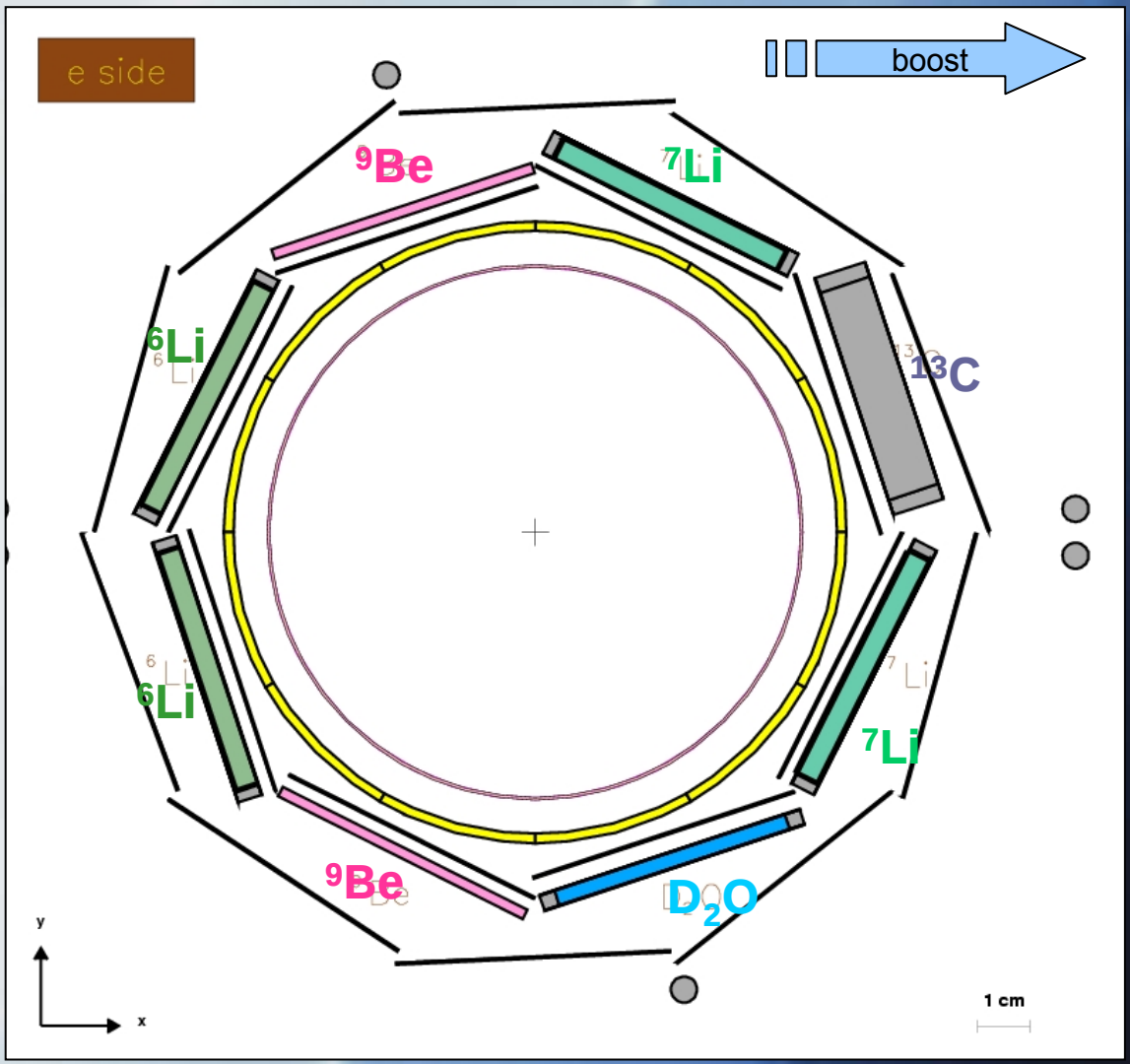
33rd LNF Scientific Committee Meeting, Nov 27 2006

# New FINUDA target setup

- Boost side:
  - 2x $^{7}$Li
    - + mylar degraders
  - 1x $^{13}$C
    - Must get the most of the kaon boost momentum
  - 1x $D_2O$
    - lowest position!
- Antiboost side:
  - Symmetric layout with respect to the median plane
    - 2x $^{6}$Li
    - 2x $^{9}$Be



# Physics items for FINUDA with the new target setup

- Study of Deeply Bound Kaon-Nuclear states
  - All targets
    - Invariant mass analysis: ($K^-pp$), ($K^-pn$), ($K^-ppn$) aggregates, effects of FSI's
    - Missing mass analysis: study of $K^-$ absorption on two nucleons
      - Free deuterons ($D_2O$)
      - Quasi deuterons inside the nuclei
- Hypernuclear spectroscopy
  - $^{13}C$, $^{16}O$, $^{9}Be$, $^{7}Li$
- Hypernuclear decays
  - Non mesonic decays
    - All targets + $^{6}Li$ (decay of $^{5}_{\Lambda}He$)
  - Rare channels
    - $^{6}Li$, $^{7}Li$: hyperfragments ($^{4}_{\Lambda}He$) decays
- Neutron Rich Λ-Hypernuclei
  - All targets
- Σ-Hypernuclei searches
  - All targets
- Study of the $K^+N$ Charge EXchange reaction
  - $^{13}C$, $^{7}Li$, $^{2}H$

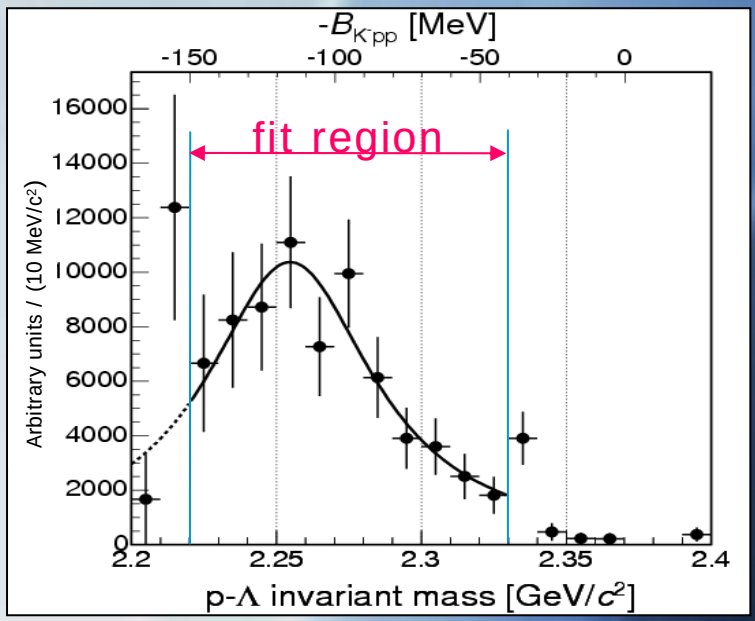
# Search for DBKS: invariant mass method

- In the last run data analysis, two approaches were used, based on two different pattern recognition procedures
  - **Reconstruction of events with well defined tracks (4 points each)**
    - Approach suitable for high resolution studies (hypernuclear spectroscopy)
      - Clean events can be picked up, full acceptance for DBKS events
      - Physical background contamination under control
      - EXCLUSIVE ANALYSIS
  - **Reconstruction of events with tracks with ≥3 points**
    - Short tracks included
      - Acceptance improvement (low momentum tracks)
      - Larger available statistics vs higher physical background contributions
        - **8 times more statistics available,** as compared with the exclusive analysis method
        - Study for each target feasible
      - Lower resolution for shorter tracks
      - INCLUSIVE ANALYSIS of ($\pi^-$pp) system

- Strategy
  - **Use of both methods to observe, if any, similar signals in the invariant mass spectra**

# Search for DBKS: di-baryon strange aggregates I

- Exclusive analysis ("high resolution tracks")
  - Last data taking: $K^-pp$ study
    - ~ 200 events on all lighter targets ($^6$Li, $^7$Li, $^{12}$C)
    - Bump observed in the $\Lambda p$ invariant mass spectrum at 2255 MeV, B = 115 MeV, $\Gamma$=67 MeV
    - Limited physical background feeding the experimental spectrum



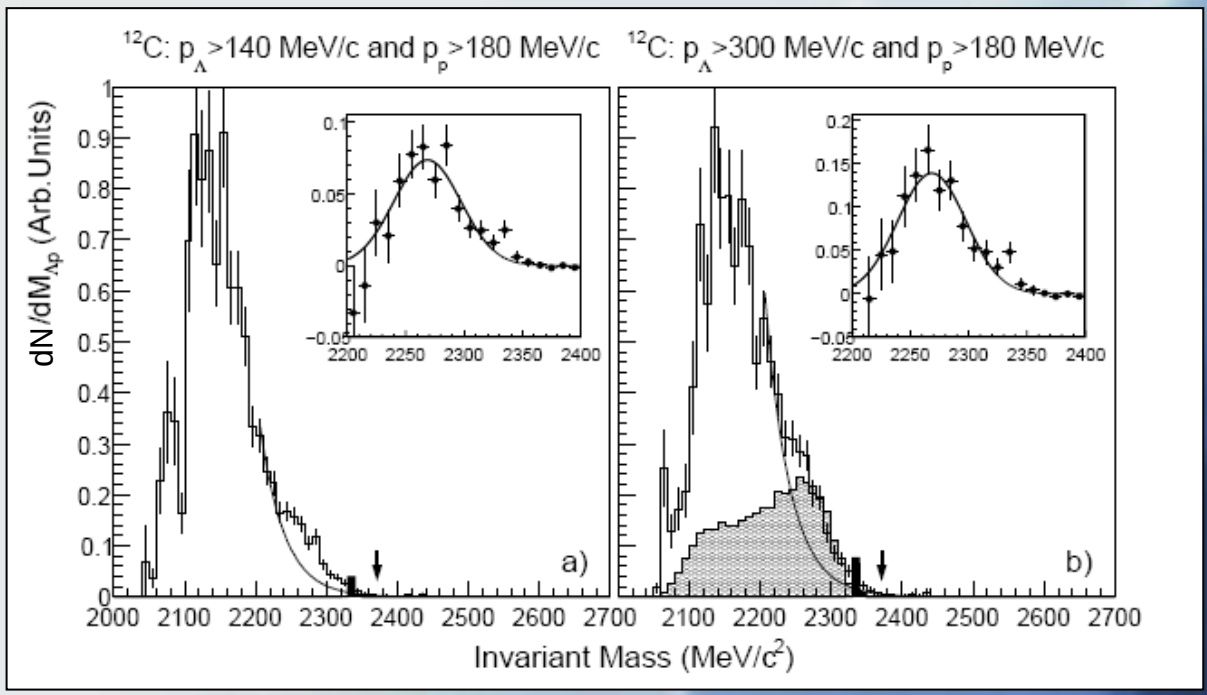

PRL 94 (2005), 212303

- New data taking
  - Expected a factor 10 more statistics AT LEAST
  - Possibile to track a dependence of the observations on the target nature
  - If a dependence is detected, the hypothesis of formation of a DBKS could be weakened

- Possibility to study the $K^-pn$ cluster in the following decay channels (a few tens events only available from the first data taking):
  - $K^-pn \rightarrow \Lambda n$
  - $K^-pn \rightarrow \Sigma^- p$

# Search for DBKS: di-baryon strange aggregates II

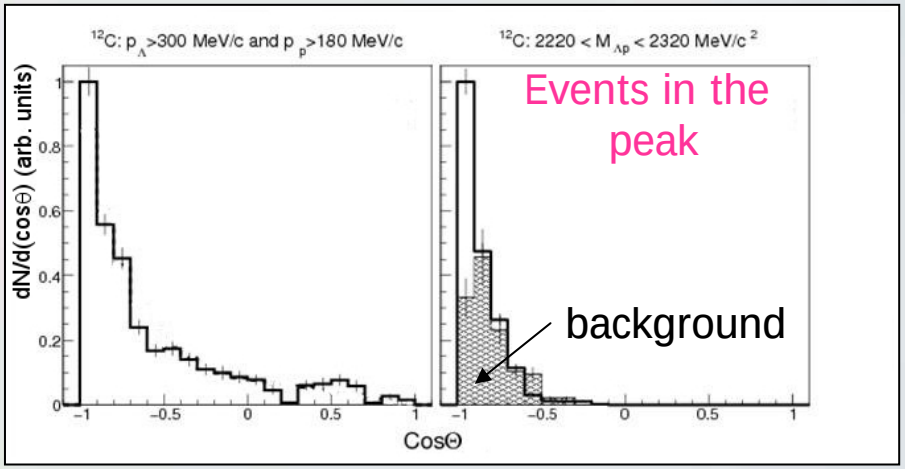
- Inclusive analysis (shorter tracks included)
  - **Last data taking: $K^-pp$ study**
    - Confirmed the presence of a bump below the mass threshold for the unbound $K^-pp$ system: m=2274 MeV, $\Gamma$= 56 MeV (slightly narrower)
      - Good agreement with the first approach
      - 750 events in the bump
    - The structure appears without angular cuts as well
    - LARGER ACCEPTANCE, LARGER PHYSICAL BACKGROUND



# Search for DBKS: di-baryon strange aggregates III

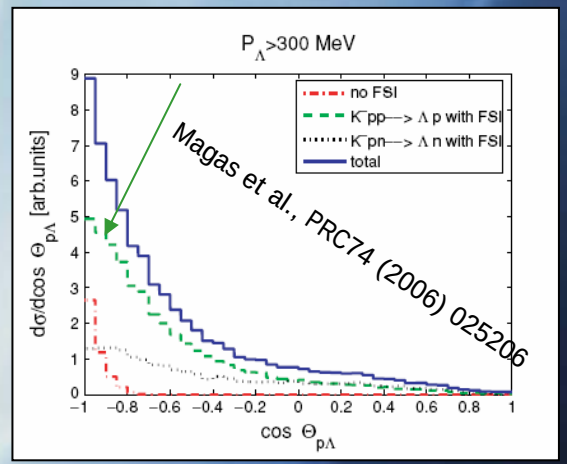
- Inclusive analysis
- Angular correlations:

**Back-to-back trend with a sensible strenght over the whole interval**




**Selected events: true back-to-back**

Narrow distribution unlikely to be fed just by FSI's




- **New data taking**: $K^-pp$ study
  - **8x statistics available on each target**
  - **Selection cuts may be strenghtened:**
    - Powerful cut to reject background (FSI reactions occurring inside the nucleus): distance from the $K^-$ stopping point and the $\Lambda$ decay vertex
      - excellent signal/noise ratio for the $\Lambda$ selection: ~20
      - Severe reduction of the statistics: factor 4 at least
  - **Selections in angular intervals and momentum slices can be made**
    - Effects of FSI interactions, dependent on angles and target nature

# Search for DBKS: tri-baryon strange aggregate formation on deuteron in $^6$Li

- The $^6$Li nucleus is a well-known $\alpha$+d cluster
  - Study with the missing mass analysis technique
  - First purpose: to reproduce the $^4$He($K^-$,p) reaction observed by E471, that led to the claim for the $S^0(3115)$

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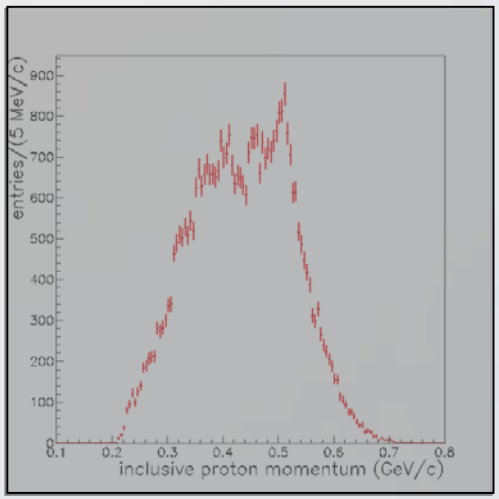
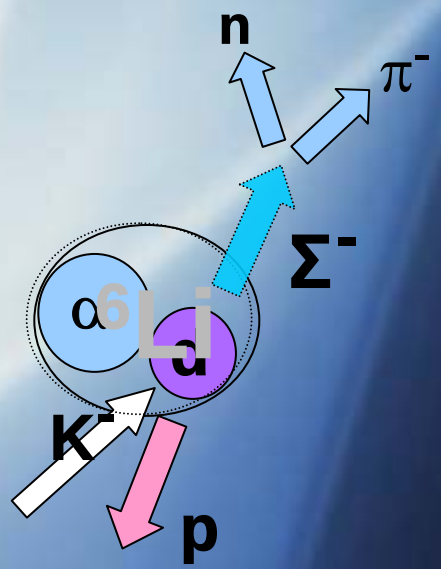


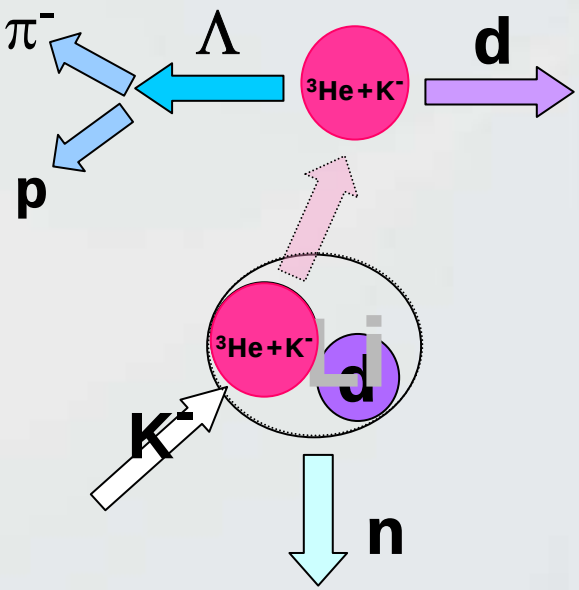



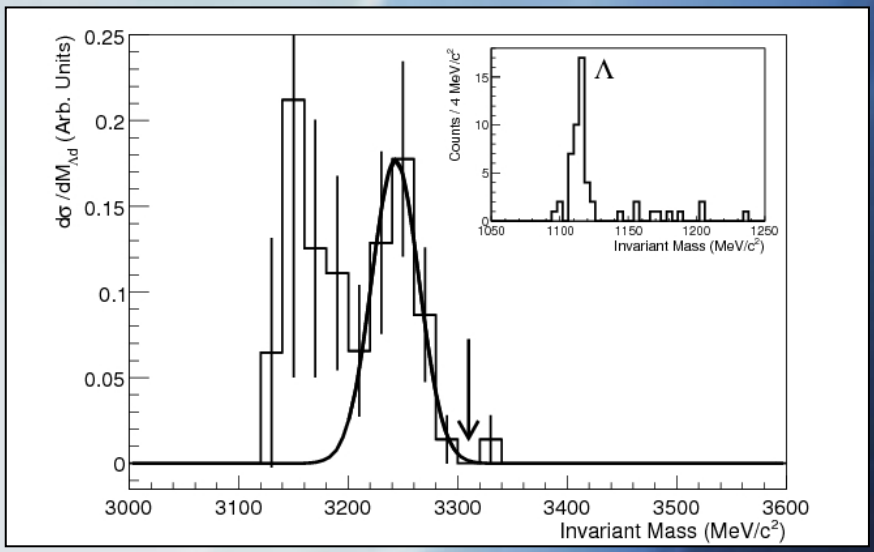

- The $K^-$ interacts with a deuteron and the observed signal (in coincidence with a fast $\pi^-$) comes from a simple two nucleon absorption reaction

New data taking: study of the $K^-$ absorption dynamics on several targets, and on free deuterons

# Search for DBKS: tri-baryon formation on $^6$Li: $^4$He

- Study of the Λd system invariant mass



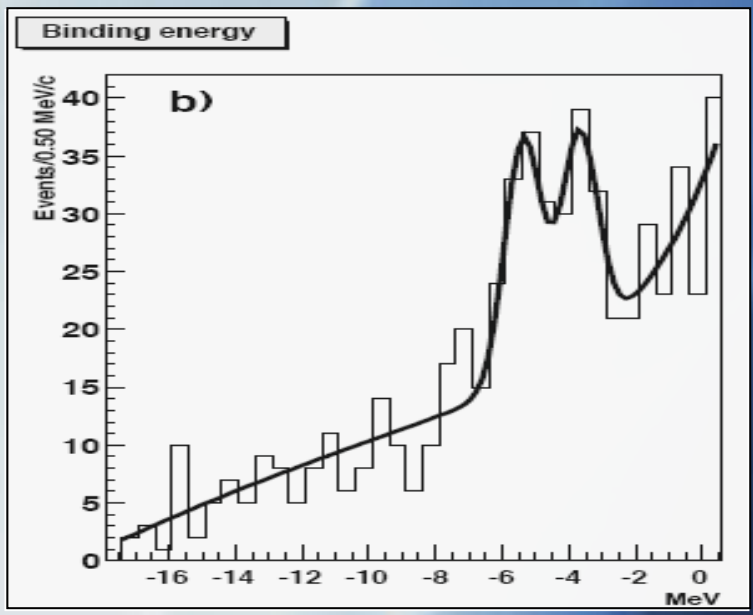




- **Last data taking:**
  - Enhancement observed at 3243 MeV, with $\Gamma_{\Lambda d}$=37 MeV on $^6$Li targets
  - 25 events in the peak, background mainly on its left side → ~3σ
  - The kinetic energy spectrum can reproduced only in the hypothesis of $^6$Li($K^-_{stop}$, Λd)nd with a spectator deuteron and the neutron carrying away the whole momentum

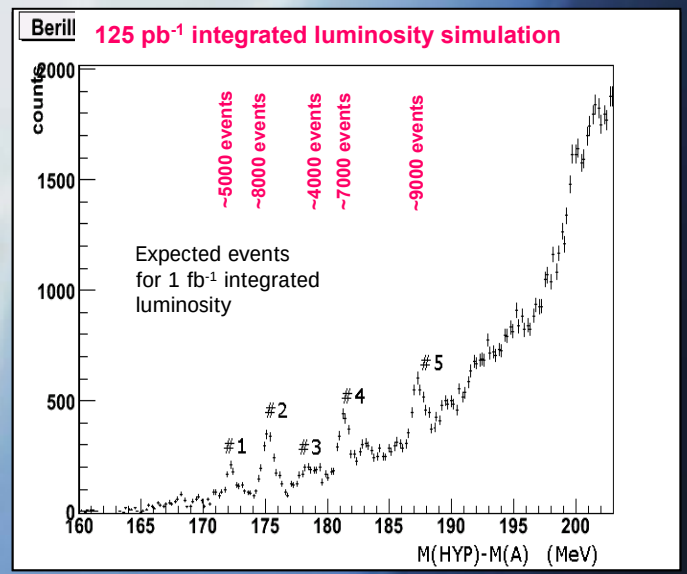
- **New data taking:**
  - 8x more statistics
  - Statistical significance of the bump can increase to 7.2σ
  - Possibility to study the left part of the spectrum with larger detail (physical background contributions)
  - Possibility to detect the neutron in coincidence

# Hypernuclear spectroscopy: $^{7}_{\Lambda}$Li, $^{9}_{\Lambda}$Be

- $^{7}_{\Lambda}$Li
  - First results obtained with one target in the last data taking, first results ever for $^{7}_{\Lambda}$Li production in a ($K^-_{stop}$, $\pi^-$) reaction
    - Two close peaks
    - In the bound region: S/N = 1:3
    - Capture rates: 0.04% for each
    - few tens of coincidence proton and neutrons for NMWD measurements
  - Tenfold statistics more expected with 1 fb$^{-1}$ integrated luminosity

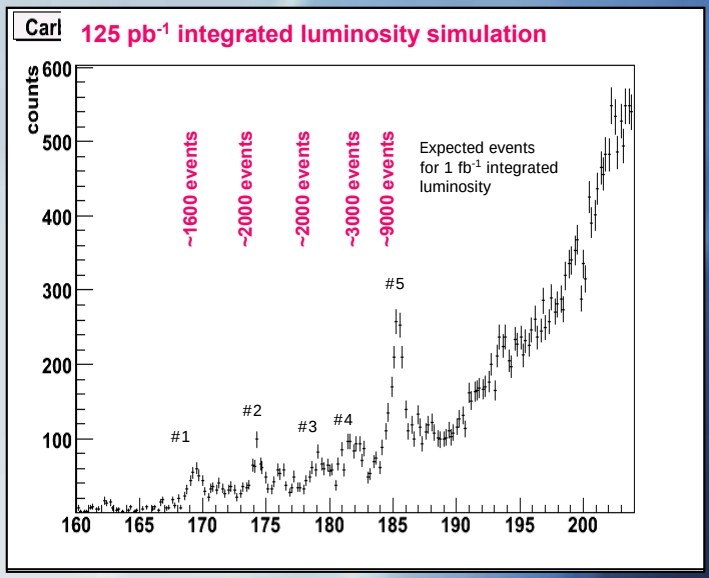



- $^{9}_{\Lambda}$Be
  - The Be nucleus has a particularly symmetric structure and can be understood as formed by a α+α+n cluster
  - Excitation spectrum measured with the ($\pi^+$,$K^+$) reaction at KEK with 2.2 MeV resolution
  - With FINUDA:
    - Expected capture rate of the order of $10^{-4}/K^-_{stop}$
    - Better resolution on the levels expected
      - The binding energy if $^{9}_{\Lambda}$Be requires a more refined measurement, existing values are in disagreement
    - Several thousand events expected with 1 fb$^{-1}$

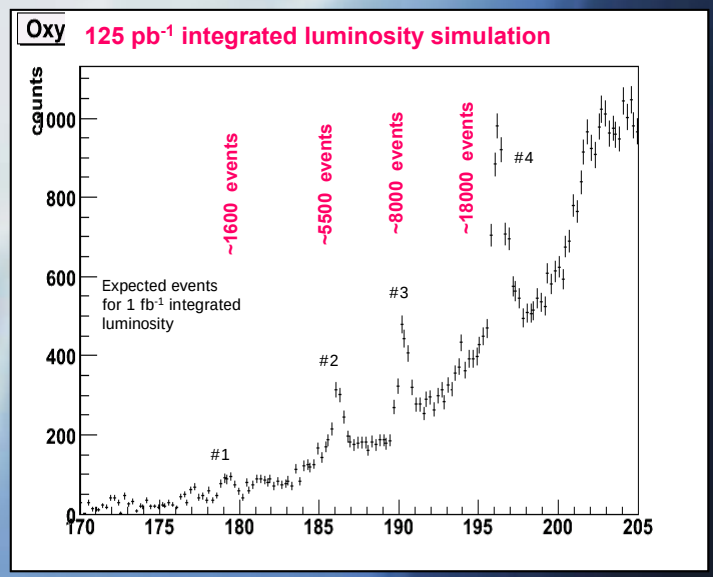


# Hypernuclear spectroscopy: $^{13}_{\Lambda}C$, $^{16}_{\Lambda}O$

- $^{13}_{\Lambda}C$
  - One neutron more than $^{12}C$: study differences with last run measurements Excitation spectrum measured by E336 in the $(\pi^+,K^+)$ with 2.2 MeV resolution
  - Expected capture rate in $(K^-_{stop}, \pi^-)$ reaction: $10^{-4}/K^-_{stop}$
  - Several thousand events expected in each level



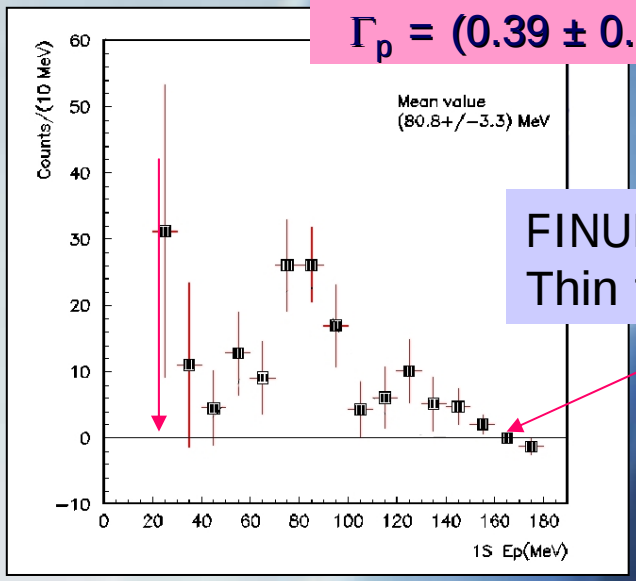

- $^{16}_{\Lambda}O$
  - Excitation spectrum measured by E336 in the $(\pi^+,K^+)$ with 2.2 MeV resolution
  - Expected capture rate in $(K^-_{stop}, \pi^-)$ reaction: $10^{-3}$-$10^{-4}/K^-_{stop}$
  - $^{15}O$ is a rather stable nucleus ($^{16}O$ is double magic)
  - With higher resolution a possible spin-orbit splitting of 1 MeV for the states #3-#4 could be observed



# Non Mesonic Weak Decay

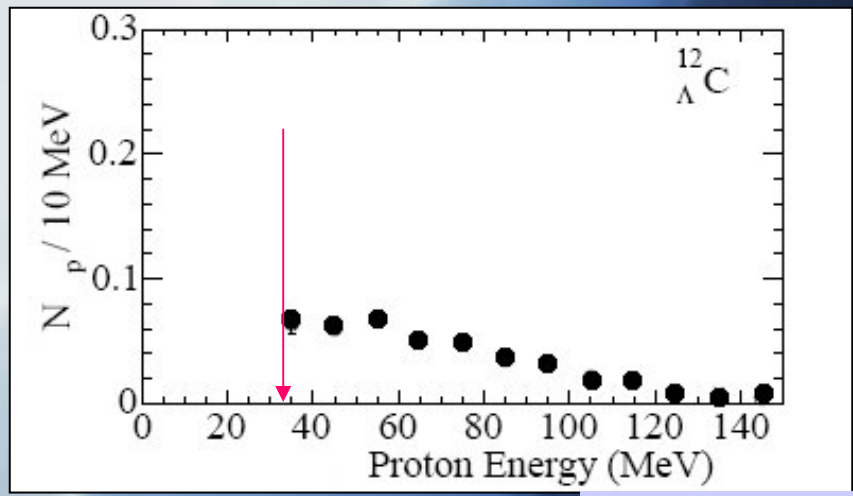
- First studies of NMWD in FINUDA with $^{12}C$ targets
  - First experiment detecting neutrons with p < 40 MeV/c
    - Interesting for the study of
      - FSI contributions
      - 2N induced NMWD (20% ?)
  - Shape of the proton momentum spectrum in the g.s. region different from earlier measurements at KEK

$\Gamma_p$ = (0.39 ± 0.10)




FINUDA: Thin target

- Strategy for the new data taking:
  - Measurement of the proton spectra with high resolution (1%) on several nuclei to test the possible distorting effect of FSI's
  - Useful tool as input for DBKS studies
    - Interplay between different analyses!!



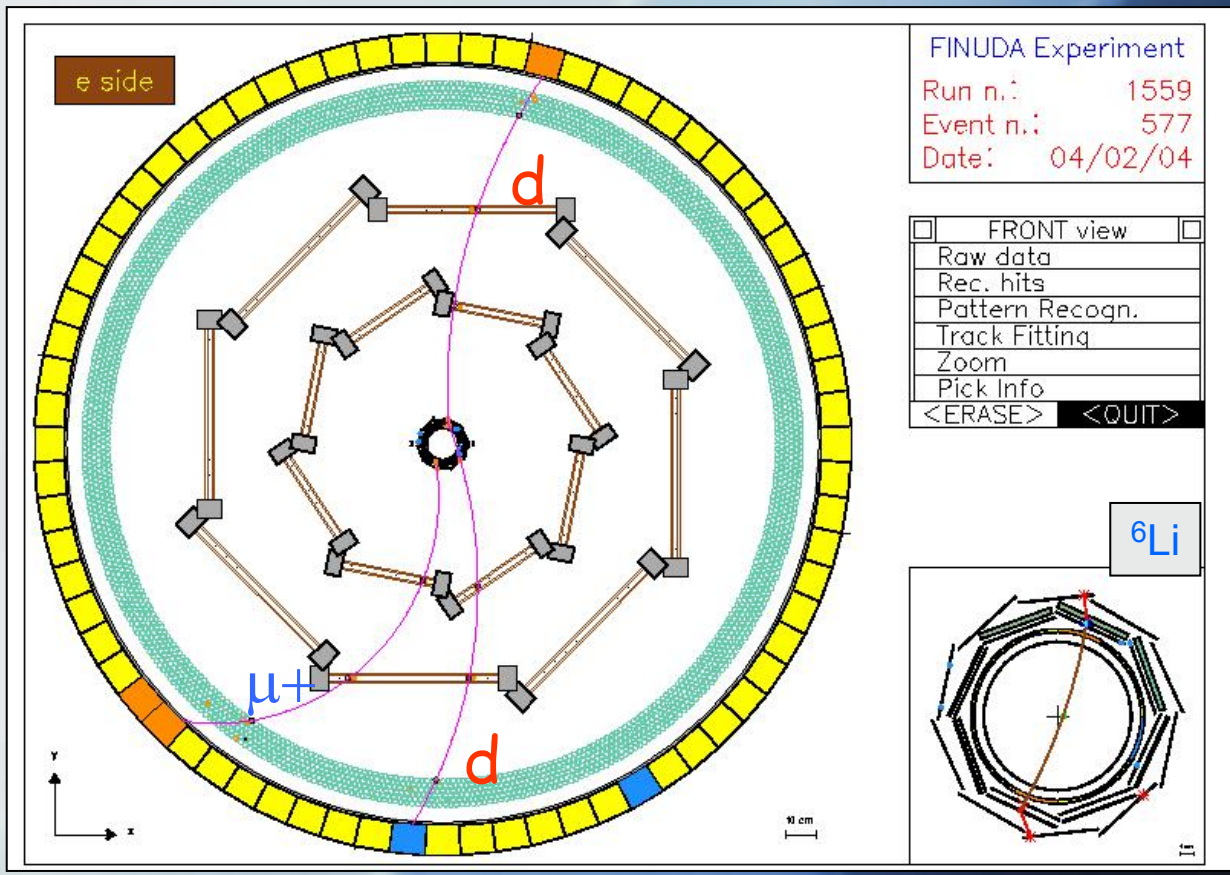

Thick target

# Study of rare decay of hyperfragments

- Exclusive non mesonic decay channels can be studied in FINUDA: rare two body decays of s-shell hypernuclei, produced as *hyperfragments* from heavier targets (e.g: hyperhelium from $^{6}$Li, $^{7}$Li)

$$ {}^{4}_{\Lambda}\mathrm{He} \rightarrow \begin{cases} \mathrm{d}+\mathrm{d} \\ \mathrm{p}+\mathrm{t} \\ \mathrm{d}+\mathrm{p}+\mathrm{n} \end{cases} $$

- Very clean signature: two monochromatic deuterons of 570 MeV/c
- Two events observed in the first data taking
- 15 events expected from $^{6}$Li and $^{7}$Li targets in the new data taking

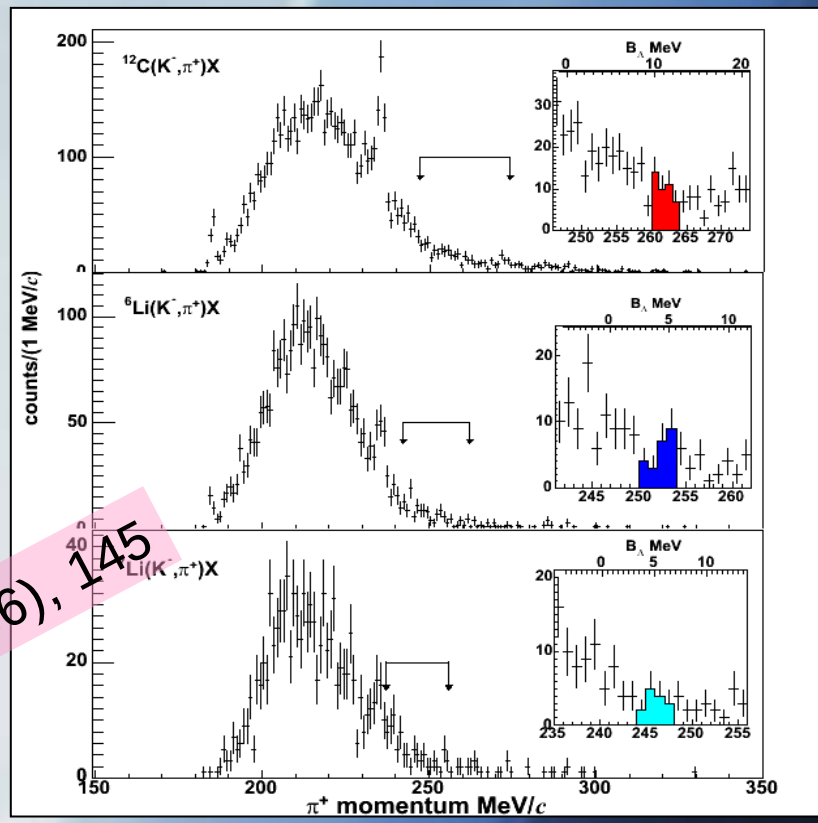


# Neutron Rich Λ-Hypernuclei on new targets

- Λ Hypernuclei with neutron eccess, more stable than ordinary nuclei because of the presence of the glueing Λ

- Produced in two step reactions:
  Expected capture rate: $O(10^{-5}/K^-_{stop})$
  - Double charge exchange:
    - $K^- + p \rightarrow \Lambda + \pi^0$; $\pi^0 + p \rightarrow n + \pi^+$
  - Strangeness exchange & Σ-Λ coupling:
    - $K^- + p \rightarrow \Sigma^- + \pi^+$; $\Sigma^- + p \leftrightarrow \Lambda + n$
  - Upper limits given for their capture rate

- First FINUDA data taking: fixed upper limits
  - $^{12}_{\Lambda}$Be: $2 \times 10^{-5}/K^-_{stop}$
  - New measurements:
    - $^{6}_{\Lambda}$H: $2.5 \times 10^{-5}/K^-_{stop}$
    - $^{7}_{\Lambda}$H: $4.5 \times 10^{-5}/K^-_{stop}$

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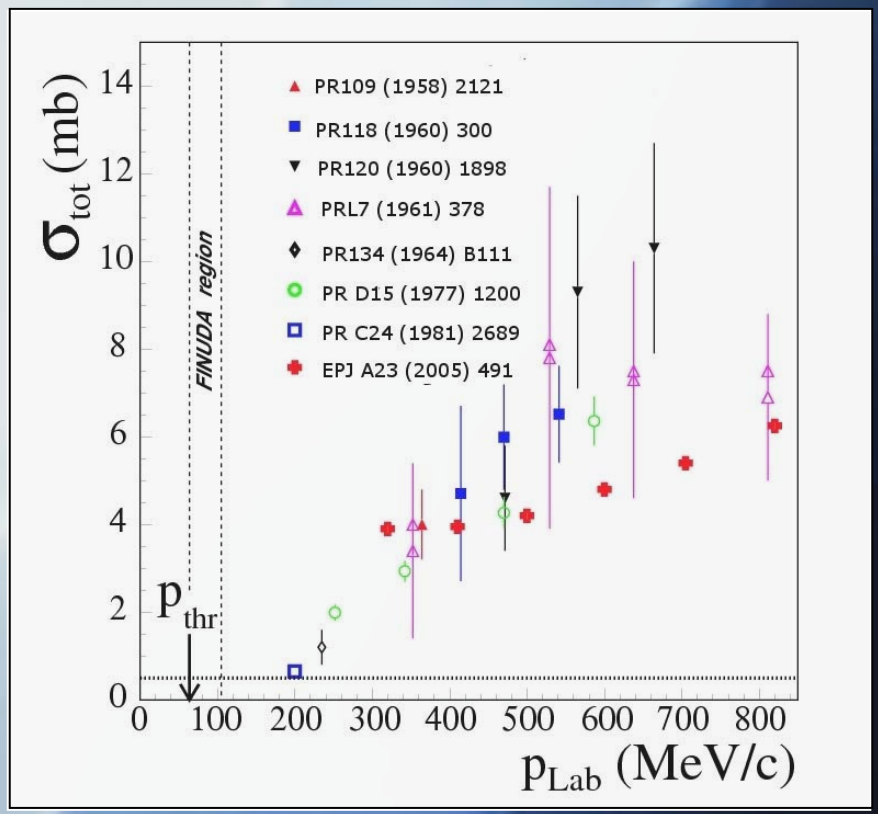
- New FINUDA data taking: possible to search for
  - $^{6}_{\Lambda}$H on $^{6}$Li targets, $^{7}_{\Lambda}$H on $^{7}$Li targets (more statistics: 450 events each in the ROI)
  - $^{9}_{\Lambda}$He on $^{9}$Be targets (600 events expected)
  - $^{13}_{\Lambda}$Be on $^{13}$C (100 events expected)
  - $^{16}_{\Lambda}$C on $^{16}$O (400 events expected for two levels)
  - Σ-Λ Coupling sensitive to the target nuclei

# Study of $K^+N$ Charge Exchange reactions

- Very few measurements exist, none close to threshold
  - **Is the process really featureless?**
- The reaction can be observed in FINUDA as a by-product (same trigger)
- Threshold reaction: only possible on selected targets:
  - **$^7$Li, $^{13}$C, $^2$H (all placed on the boost side)**
- In the last data taking: upper limit fixed for $^7$Li
  - **$\sigma \leq 2$ mb**
- New data taking expected sensitivities:
  - **0.1 mb/event $^7$Li**
  - **0.2 mb/event $^{13}$C, $^2$H**

$$K^+ + n \rightarrow K^0_s + p$$



# Conclusions

- A wide program of physics topics will be addressed by FINUDA in the next data taking

- The collection of 1 $fb^{-1}$ integrated luminosity will allow
  - To study with better detail possible target related effects, that may shed light on the dynamics of several mechanisms, such as
    - Kaon-nuclear aggregates formation
    - Final State Interaction effects
    - Kaon absorption by many nucleons
  - To study with unprecedented resolution the spectroscopy of several light hypernuclei and hyperfragments and their non-mesonic decay in rare channels as well
  - To study the existence of new, never observed, species of neutron rich hypernuclei (and, possibly, Σ hypernuclei as well)
  - To perform cross section measurements of $K^+$ induced reactions close to threshold, never measured before