Trigger and Analysis methods for the HypHI phase 0 experiment

Christophe Rappold [1,2]

[1]IPHC/DRS, Université de Strasbourg, France

[2]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt

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Goals of the HypHI phase 0 experiment

The phase 0 experiment:

- aims to demonstrate the feasibility of hypernuclear spectroscopy by means of heavy ion collisions.
- focuses on the study of ${}^{3}_{\Lambda}H$, ${}^{4}_{\Lambda}H$, ${}^{5}_{\Lambda}He$

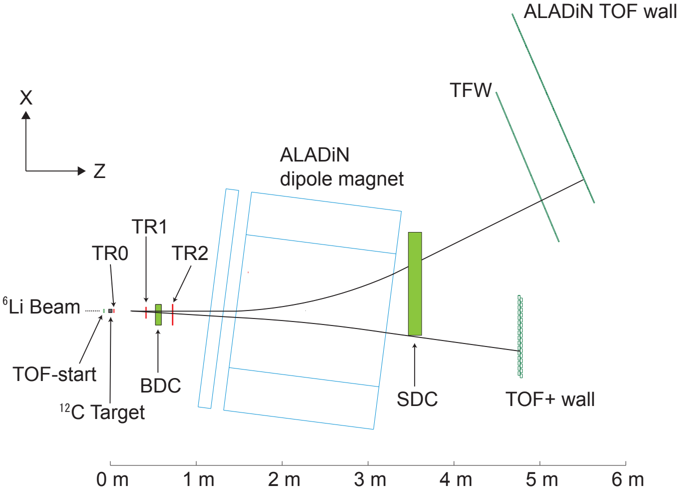
to measure:

- the production cross section.
- hypernuclear lifetime.
- polarization of produced hypernuclei.

By identifying them:

1. Invariant mass spectroscopy.
2. Secondary vertex selection.

Setup of Phase 0 experiment (October)



One of the challenges of the experiment

- To deal with the small hypernuclear production cross section ($\sim 0.1\mu$b). Compare the total reaction cross section (~ 1b).

Proposed solution:

- Online selection via the trigger system.
- To reject background signal.

After in the Offline Analysis

A Precise hypernuclear spectroscopy needs:

- Precise tracking reconstruction ($\delta p/p \sim 1\%$)
  $\Rightarrow$Precise secondary vertex reconstruction.
  $\Rightarrow$Invariant mass in few MeV resolution ($\leqslant 3$MeV).
- Several cut conditions can improve the S/B ratio.

Topology of the hypernuclear decay:

Decay

- ${}^{3}_{\Lambda}\mathrm{H} \longrightarrow \pi^{-} + {}^{3}\mathrm{He}$
- ${}^{4}_{\Lambda}\mathrm{H} \longrightarrow \pi^{-} + {}^{4}\mathrm{He}$
- ${}^{5}_{\Lambda}\mathrm{He} \longrightarrow \pi^{-} + {}^{4}\mathrm{He} + \mathrm{p}$

$\longrightarrow$ In common : π^{-} and Z=2 particle.

At 2 *A*GeV, hypernuclei are produced with a Lorentz boost $\gamma \sim 3$:

$\longrightarrow$ hypernuclei will decay outside the target.

$\Longrightarrow$ secondary vertex can be distinguished from primary vertex.

Trigger system:

Simultaneous requirement:

- Secondary vertex $\times$ Z=2 particle detection $\times$ π^{-} detection.

Tracking trigger: Template matching method

Track template built from simulation:

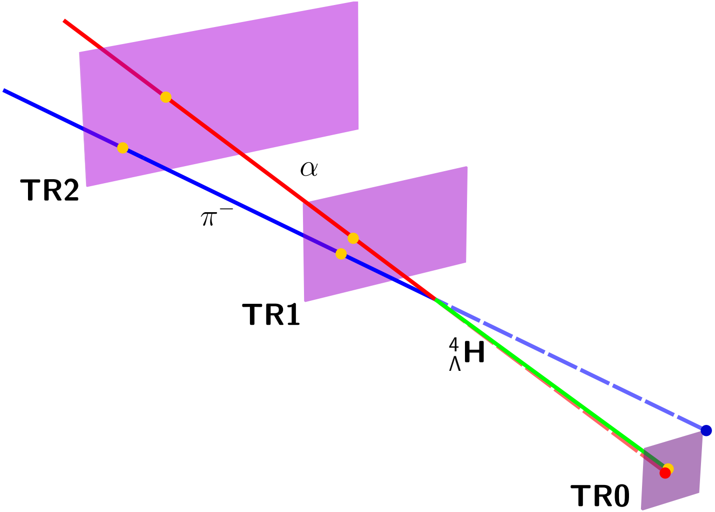
- a track template = collection of hits on TR0 & 1 & 2.
- all possible primary track originate from the target :
  $\longrightarrow$ veto matrix.
- remaining hit on TR1 & TR2 used to evaluate the secondary vertex.

Implementation

- Total collection of channels to evaluate: 900k.
- Fast and parallel : FPGA chips.
- 38 VUPROM2 logic module used (GSI home development).

Illustration on a typical hypernuclear event

Vetoing all tracks from primary vertex (inside target) :

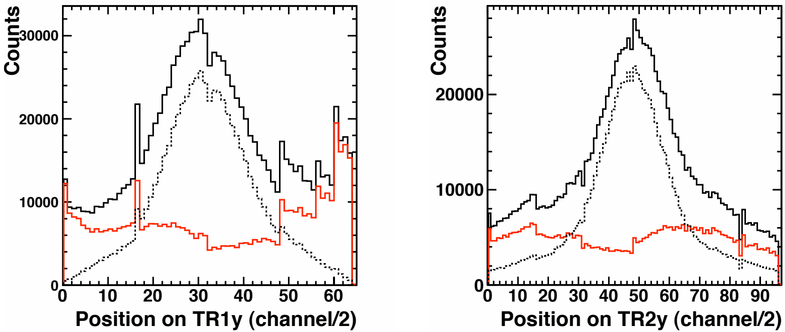


Achieved performances

Comparison between the decisions taken:

- during the experiment
- by an offline analysis which simulate trigger system.

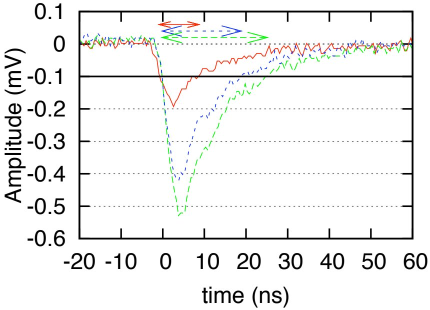
$\Longrightarrow$ Consistence over TR1x, 1y, 2x, 2y > 98 %.

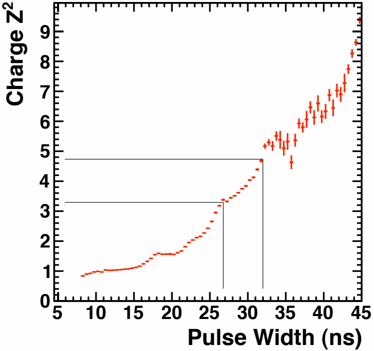


Time over threshold method

Z=2 particle discrimination

Measuring the pulse width and correlated it with the charge of the particle:

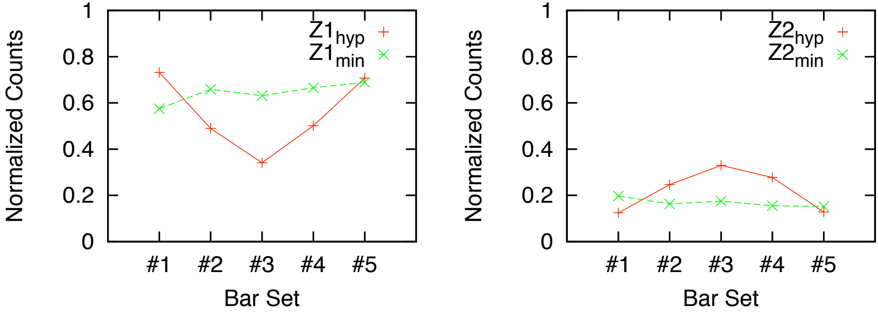




Achievements

Comparison between minimum bias and hypernuclear trigger.

Normalized Counts of Z=1 and Z=2 particles per bar set (4 neighboring bars):



Full trigger system efficiency

Monte Carlo study

- Secondary vertex trigger: 14% background reduction: 1.7%
- Z=2 trigger: 99% with reduction factor: 14%
- π^- trigger: 20% with reduction factor: 15%

⇒ All together

efficiency 7% with a background reduction of 0.017%.

Goals & Features

Goals

Handle only particles and their behaviour (decay/tracking).

From Hits to Tracks

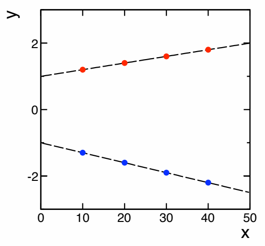
- Give a representation of particle, quadrivector **P**.
- Compute the momentum of each possible particule.

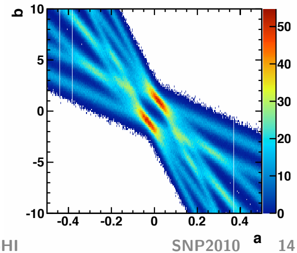
How ?

- Track finding algorithm : to handle high hit multiplicity.
- Track fitting algorithm : to compute goodness of tracking.

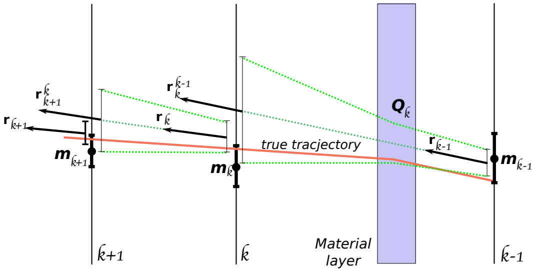
Track finding: Hough Transform

- Recognition of tracks $y = a \cdot x + b$ from a hit pattern.
- For each point (x_i, y_i) : $y_i = a \cdot x_i + b \sim$ new variable : (a, b)
- transpose each hit to a curve : Cartesian or polar parameters





Track fitting: Kalman Filter



An iterative fitting algorithm :

- prediction step : extrapolation of the position of the next hit from the last hit considered.
- filter step : correction of the prediction by comparing with the real measured hit.
- smoothing step : propagate backward to update all hits.

Systematic procedure : efficiency study

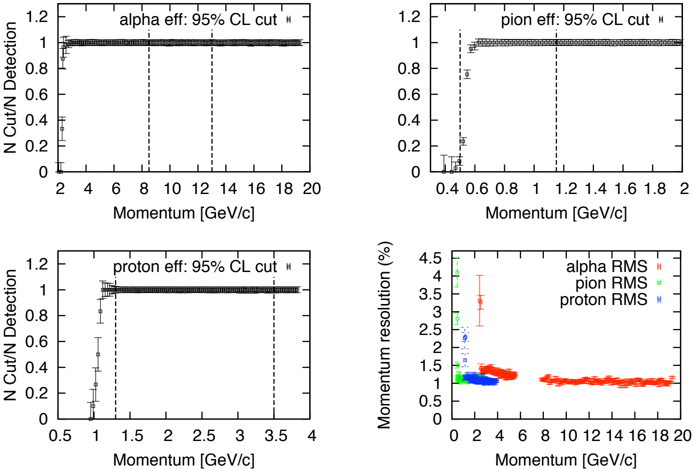
Procedure of the efficiency study

- After the Hough transform in the analysis : found tracks.
- Track Fitting with this Kalman Filter implementation.
- χ^2 test for rejection of bad tracks.
- Mass calculation of each involved particles.

Efficiency study : results

proton eff : 97 % / α eff : 99 % / π^- eff : 85% - 93%

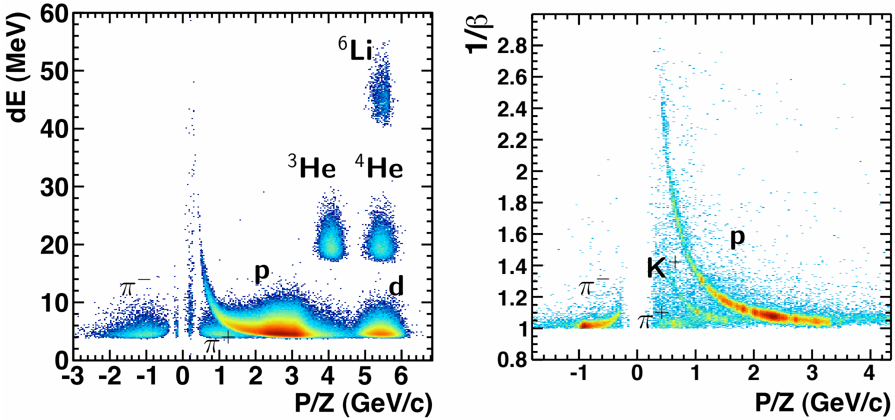
Momentum resolution $\delta p/p \sim 1\%$



The phase 0 analysis

1. Track finding:
   I. Pre tracking in upstream part (Fiber/DC) : Combinatorial track following.
   II. Track finding between upstream & downstream.
2. Track fitting:
   I. Compute seed for Kalman Filter (analytic calculation of momentum).
   II. Association of the charge from PID in TOF walls.
   III. Track fitting of each submitted tracks.
3. Particle Identification
   I. With: dE/dx vs P/Z or $1/\beta$ vs P/Z.
   II. χ^2 test for selection of good tracks of decay particles.
4. hypernuclear reconstruction:
   I. pair or triplet of tracks used for invariant mass of hypernuclei.
   II. secondary vertex reconstruction for selecting best hypernuclei candidates.

Obtained Particle identification from simulations



Cut conditions on the background reduction of ${}^{4}_{\Lambda}$H

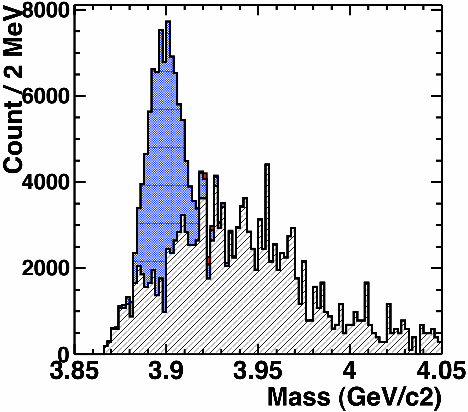
${}^{4}_{\Lambda}H \rightarrow \alpha + \pi^{-}$

Two type of background:

1. tracks from primary vertex (in gray)
2. Λ+α events: $\Lambda \rightarrow p + \pi^{-}$ (in blue)

- first: reduced by the trigger + secondary vertex cut.
- second: reject Λ event + TR0 energy cut.

After trigger (both background).
$S/B = 0.14 \cdot 10^{-3}$



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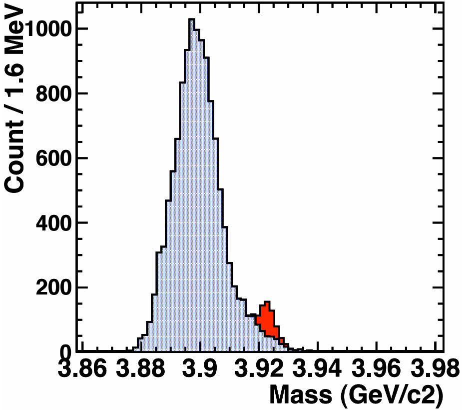
Secondary vertex cut.
$S/B = 0.57$



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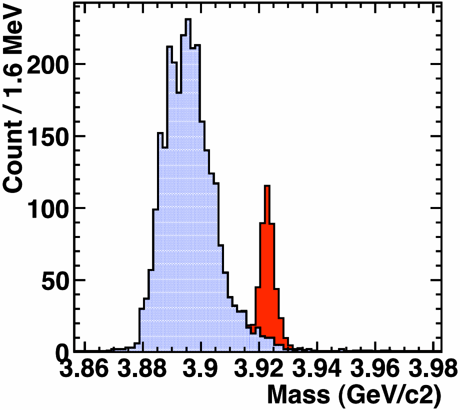
Vertex cut + Λ rejection.
$S/B = 3.20$



Cut conditions on the background reduction of ${}^4_\Lambda$H

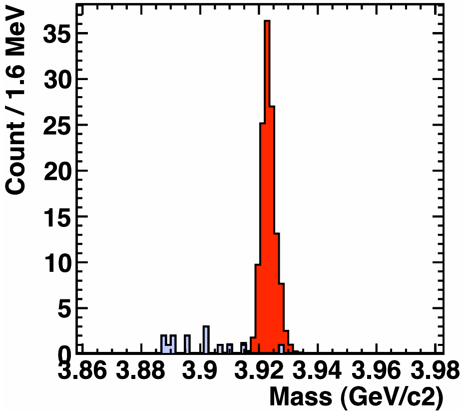
${}^4_\Lambda\mathrm{H} \to \alpha + \pi^-$

Two type of background:

1. tracks from primary vertex (in gray)
2. Λ+α events: $\Lambda \to p + \pi^-$ (in blue)

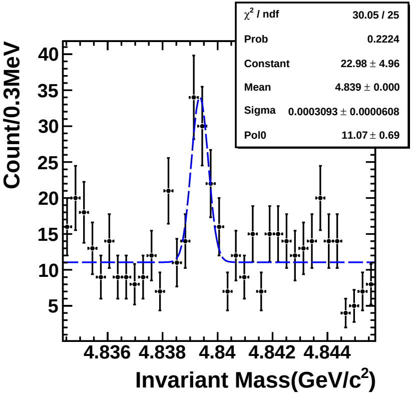
- first: reduced by the trigger + secondary vertex cut.
- second: reject Λ event + TR0 energy cut.

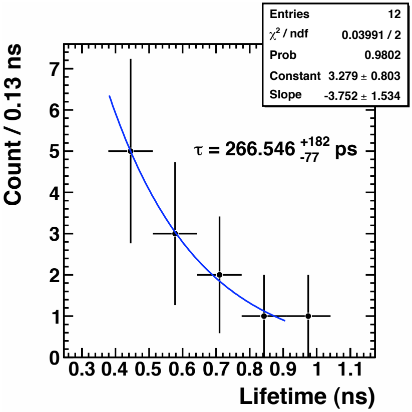
Vertex + Λ + TR0 energy cut.
$S/B = 124$



Invariant mass and lifetime measurement of ${}^{5}_{\Lambda}$He

Mass: 4.8394GeV width: 3.1MeV Significance $S/\sqrt{(S+B)}$: 5.6σ





Known mass: 4.8399 GeV

Known lifetime: 256 ±20 ps

[Bando et al., Int. J. Mod. Phys. A **5** (1990) 4021]

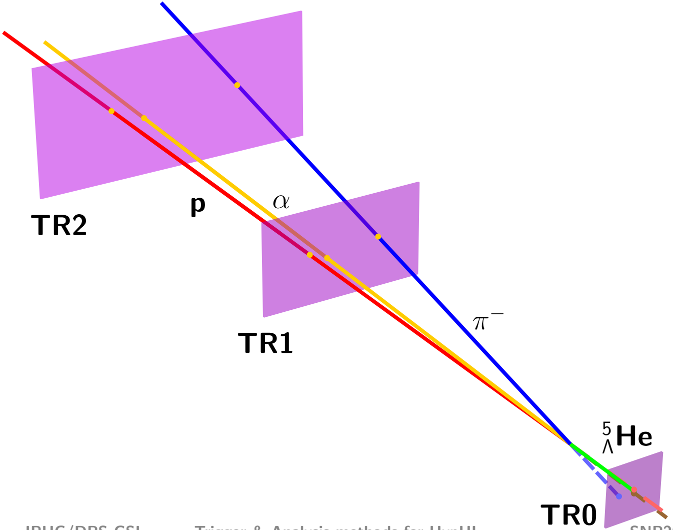
[Szymanski et al., Phys. Rev. C **43** (1991) 849]

Summary

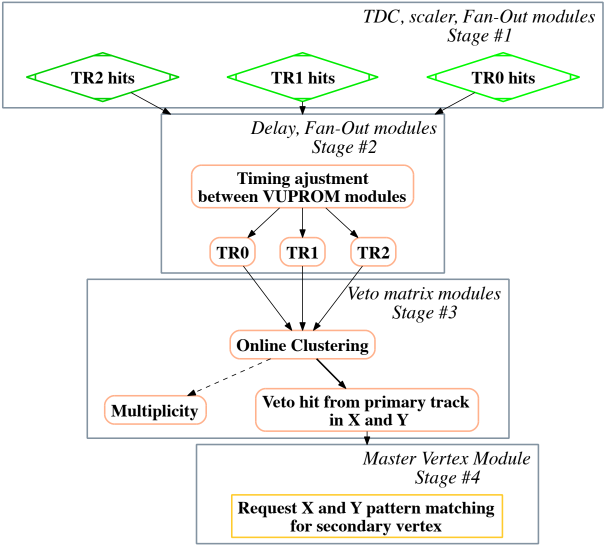
- Fast and efficient methods have been employed for online trigger system.
- Trigger analysis shows good performances for each subsystem.
- Advance method for track reconstruction have used.
- good efficiency and momentum resolution have been obtained.
- background reduction has been studied and cut conditions have been determined.
- Finally the first preliminary signature of ${}^{5}_{\Lambda}$He hypernuclei has been presented.

Illustration on a typical hypernuclear event: case $^{5}_{\Lambda}$He

Vetoing all tracks from primary vertex (inside target) :



Full algorithm in FPGA chips



Secondary vertex resolution

Species	x (mm)	y (mm)	z (mm)
${}^{4}_{\Lambda}H$	0.23	0.33	3.53
${}^{3}_{\Lambda}H$	0.22	0.35	3.61
${}^{5}_{\Lambda}He$	0.17	0.29	6.4

Secondary decay vertex resolutions within 95% CL

Rate expectations

Species	Expected cross section (μb)	event/week
${}^{3}_{\Lambda}$H	0.1	7.8×10^3
${}^{4}_{\Lambda}$H	0.1	7.2×10^3
${}^{5}_{\Lambda}$He	0.5	18.2×10^3