Status of hypertriton reconstruction in BM@N

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16th Collaboration Meeting of the BM@N Experiment at NICA

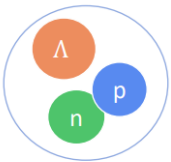
13 May 2026

Outline

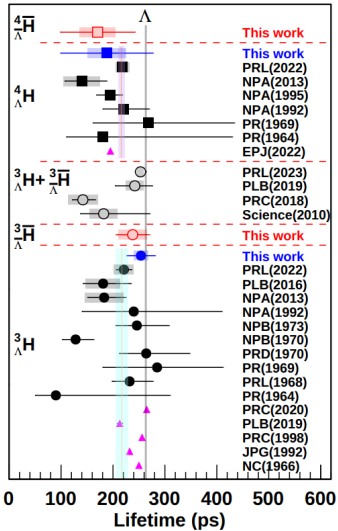
1. Hypertriton
2. Event selection and signal extraction from invariant mass spectrum
3. Dependence of signal and background on geometrical cuts
4. Lifetime reconstruction methods
   - Ratio method
   - Efficiency correction method
5. Results and comparison of different MC statistics
6. Plans and ideas

Hypertriton ($^{3}_{\Lambda}$H)

- The lightest hypernucleus: a bound state of Λ, p and n.
- Unique probe for ΛN interaction in the strangeness sector.
- Decay channel used: $^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$.
- Lifetime puzzle.



$^{3}_{\Lambda}$H



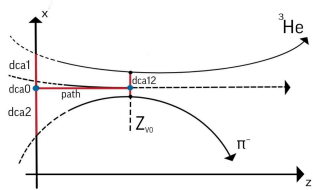
STAR-2024:
https://arxiv.org/pdf/2310.12674

Statistics

- Experimental data: runs A and B
- Three MC sets: 1M, 2M and 4M events, ${}^{3}_{\Lambda}\mathrm{H}$ presented in each event

Selection list

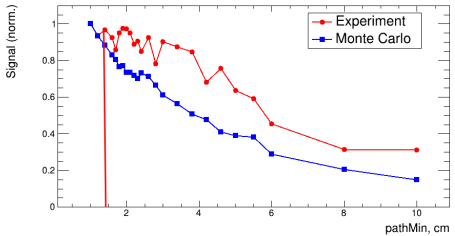
- Vertex cuts: 2+ tracks & $-0.5\ \mathrm{cm} < V_x < 0.5\ \mathrm{cm}$ & $\sqrt{(V_x - 0.4)^2 + (V_y - 0.15)^2} < 1.2\ \mathrm{cm}$
- 4+ hits per track & 3+ GEM hits per positive track (for dE/dx)
- Parabolic cut on m^2 (TOF-700) for ${}^{3}\mathrm{He}$
- Parabolic cut on m^2 (TOF-400) for K^+ - only events with associated K^+ are taken into account
- dE/dx cut for ${}^{3}\mathrm{He}$
- TMVA cut to reduce fake tracks
- Momentum corrections for ${}^{3}\mathrm{He}$
- Geometric cuts for two particle decay

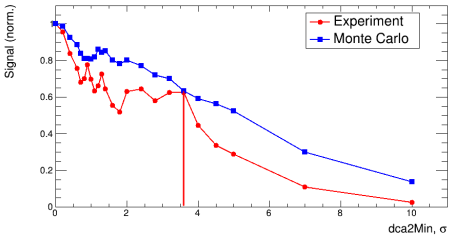


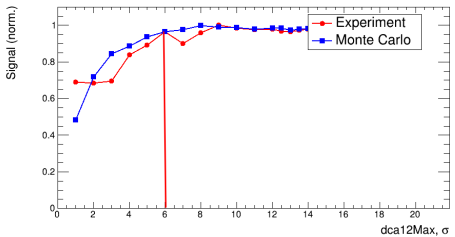
Signal extraction from invariant mass spectrum

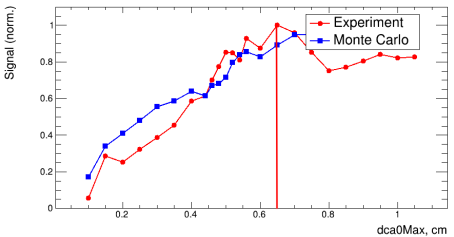
- Background on mass distribution of $^3\mathrm{He} + \pi^-$ pairs is fitted with a Chebyshev polynomial of 3rd order using data outside the signal region.
- Signal evaluation: $S = T - B$, where T is the total integral of data in the signal region.
- Statistical uncertainty: $\Delta S = \sqrt{S + 2B}$ (accounts for both signal and background fluctuations).

Dependence of signal on geometrical cuts

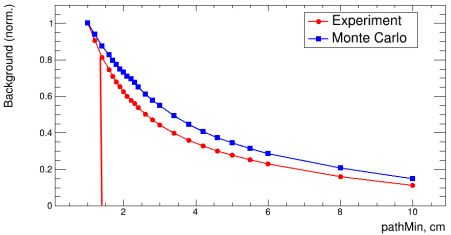


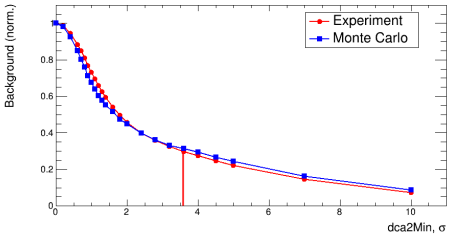


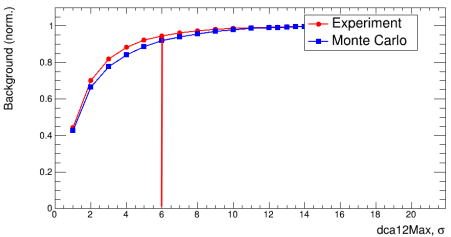


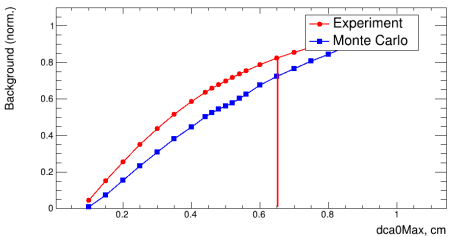


Dependence of background on geometrical cuts



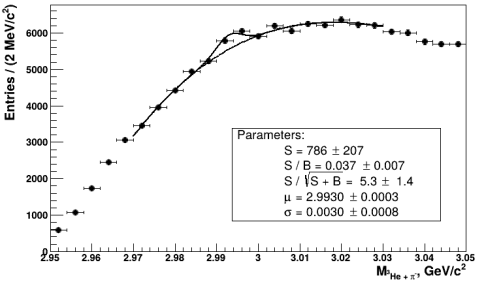




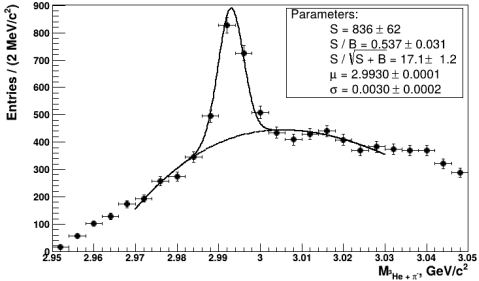


Optimized signals

EXP



MC



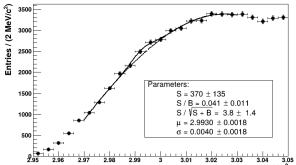
Signals in time bins

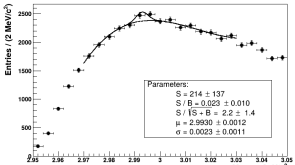
(0.02-0.07) ns

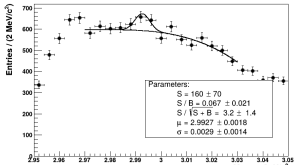
(0.07-0.18) ns

(0.18-0.50) ns

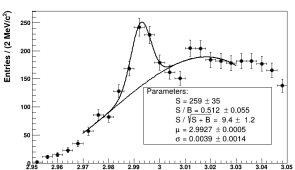
EXP

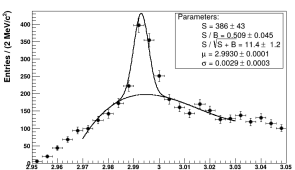


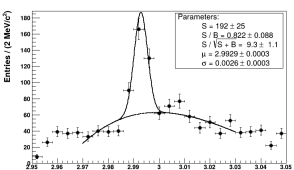




MC



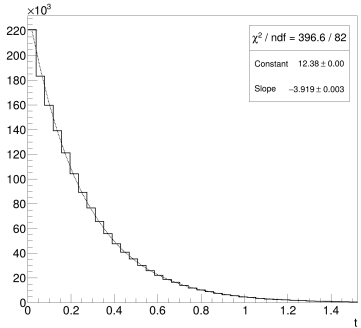




Lifetime reconstruction: Ratio method (I)

Key quantities:

- generated MC signal ($\tau_{gen} = 255$ ps)
  $S_{gen}(t) = N_0^{gen} \cdot e^{-t/\tau_{gen}}$
- reconstructed MC signal
  $S_{mc}(t) = \varepsilon(t) \cdot S_{gen}(t)$
- true experimental signal
  $S_{exp}^{true}(t) = N_0^{exp} \cdot e^{-t/\tau_{exp}}$
- reconstructed experimental signal
  $S_{exp}(t) = \varepsilon(t) \cdot S_{exp}^{true}(t)$

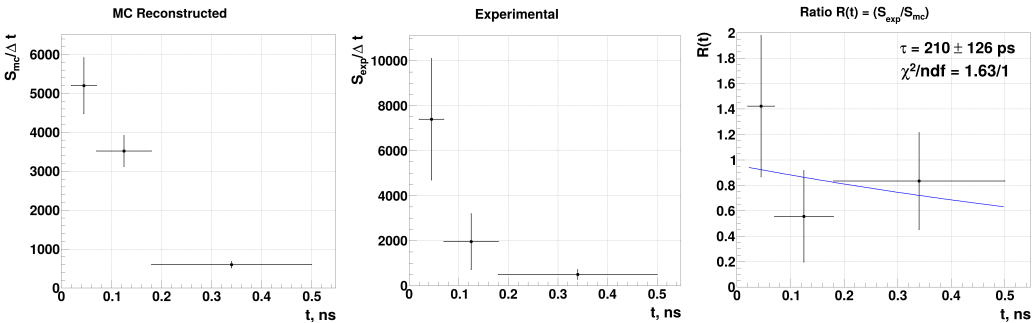


The ratio cancels the efficiency:

$$R(t) = \frac{S_{exp}(t)}{S_{mc}(t)} = \frac{\varepsilon(t) \cdot S_{exp}^{true}(t)}{\varepsilon(t) \cdot S_{gen}(t)} = \frac{N_0^{exp}}{N_0^{gen}} \cdot e^{-t\left(\frac{1}{\tau_{exp}} - \frac{1}{\tau_{gen}}\right)}$$

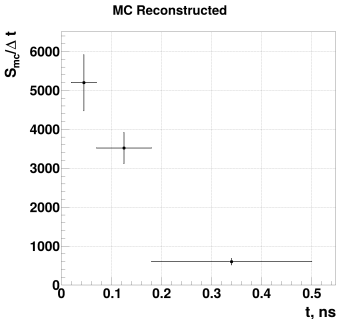
Lifetime reconstruction: Ratio method (II)

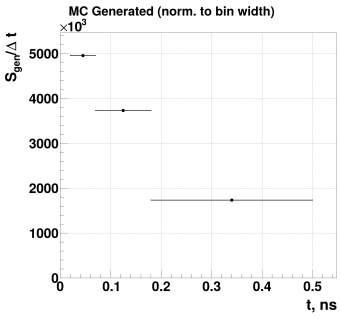
- Fit R(t) with $A \cdot e^{\alpha t}$.
- Evaluate $\tau_{exp} = \frac{1}{\frac{1}{\tau_{gen}} - \alpha}$.
- Error propagation: $\Delta\tau_{exp} = \tau_{exp}^2 \cdot \Delta\alpha$, where $\Delta\alpha$ - from fit.

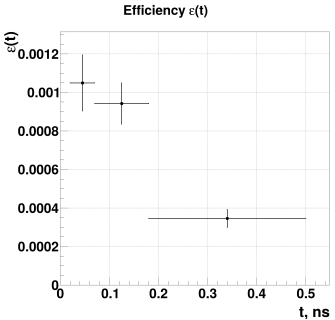


Lifetime reconstruction: Efficiency correction method (I)

- Compute efficiency from MC: $\varepsilon(t) = \frac{S_{mc}(t)}{S_{gen}(t)}$
- Correct experimental signal: $S^{corr}_{exp}(t) = \frac{S_{exp}(t)}{\varepsilon(t)} = N^{exp}_0 \cdot e^{-t/\tau_{exp}}$





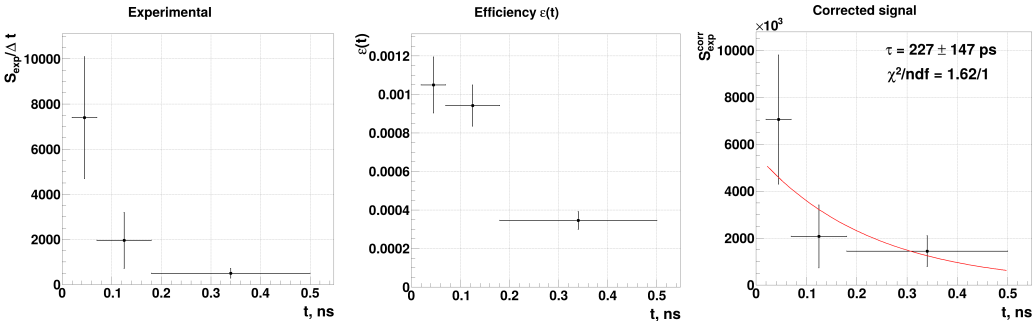


Lifetime reconstruction: Efficiency correction method (II)

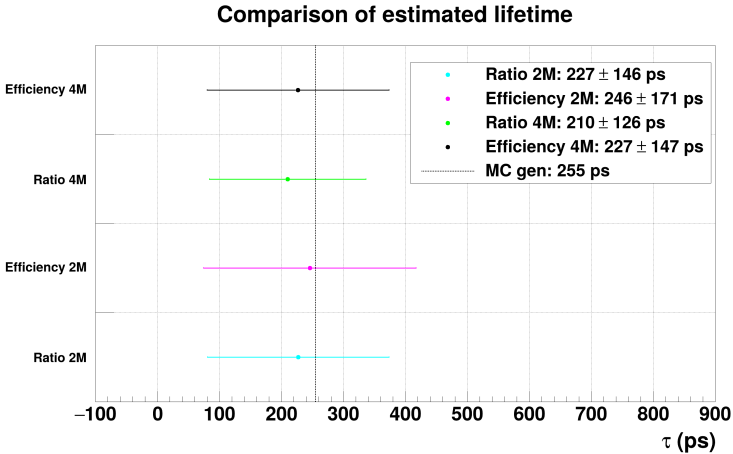
- Direct exponential fit gives τ_{exp}.
- Uncertainty includes contributions from S_{exp}, S_{mc}, and S_{gen}:

$$\frac{\Delta S_{exp}^{corr}}{S_{exp}^{corr}} = \sqrt{\left(\frac{\Delta S_{exp}}{S_{exp}}\right)^2 + \left(\frac{\Delta S_{mc}}{S_{mc}}\right)^2 + \left(\frac{\Delta S_{gen}}{S_{gen}}\right)^2}$$

- $\Delta S_{exp} = \sqrt{S_{exp} + 2B_{exp}}$, $\Delta S_{mc} = \sqrt{S_{mc} + 2B_{mc}}$, $\Delta S_{gen} = \sqrt{S_{gen}}$



Results: τ from different methods and MC statistics



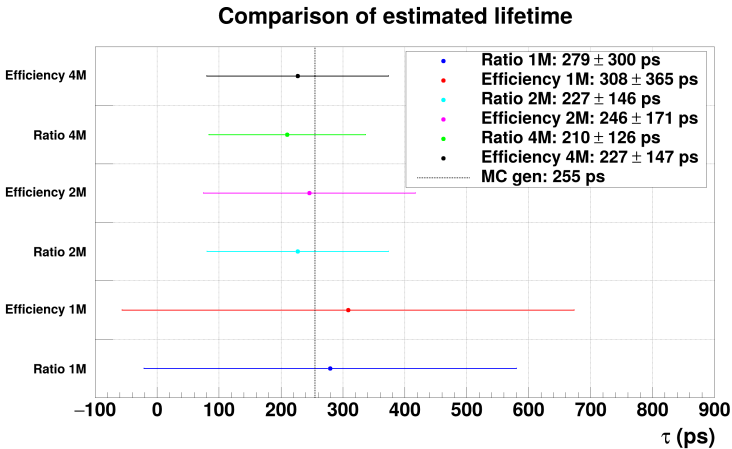
- Both methods give consistent results within errors
- Lack of statistics gives large error bars
- Lifetime values are systematically shifted

Plans and ideas for improving

- Increase MC statistics to reduce uncertainties.
- Study systematic effects by varying fit ranges and background models.
- In MC implement efficiency of TOF-400 (for K^+ selection), TOF-700 and dE/dx identification (for ^3He selection).
- Add runs of type C to increase experimental statistics.

Thank you!

Backup


Comparison of estimated lifetime
Efficiency 4M
Ratio 4M
Efficiency 2M
Ratio 2M
Efficiency 1M
Ratio 1M
Ratio 1M: 279 ± 300 ps
Efficiency 1M: 308 ± 365 ps
Ratio 2M: 227 ± 146 ps
Efficiency 2M: 246 ± 171 ps
Ratio 4M: 210 ± 126 ps
Efficiency 4M: 227 ± 147 ps
MC gen: 255 ps
−100
0
100
200
300
400
500
600
700
800
900
τ (ps)