SIMULATIONS AND AGENDA

R^3B Collaboration Meeting, Budapest, 2023

Hector Alvarez Pol, Yassid Ayad, Meytal Duer, Alexandre Obertelli, Yelei Sun, Simone Velardita

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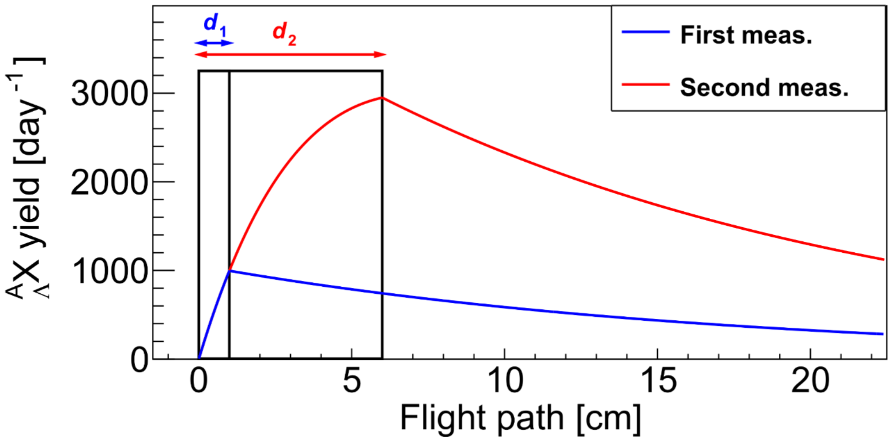
The two-target method

First experiment with the HYDRA prototype in Feb. 2025 (G-073):

- ➔ measure of the **hypertriton interaction cross section** and from this deduce its **matter radius**
  - ◆ direct measurement is difficult due to the short lifetime (237 ps)

- ➔ extract the interaction cross section by measuring the mesonic **decay vertex distribution**
  - ◆ two measurements with two targets of thicknesses, d_1=1 cm and d_2=6 cm



$$\frac{N_\Lambda(d_1)}{N_\Lambda(d_2)} \cdot \frac{N_{0,d_2}}{N_{0,d_1}} \cdot \left(1 - e^{B\,d_2}\right) \cdot e^{-n\sigma_R(d_2-d_1)} - 1 + e^{-B\,d_1} = 0$$

where

$$B = n\,\sigma_{\Lambda R} + \frac{1}{\gamma\beta c\,\tau} - n\,\sigma_R$$

$$N_{0,d_1} = I\,t\,\alpha \quad \text{and} \quad N_{0,d_2} = I\,t\,(1-\alpha)$$

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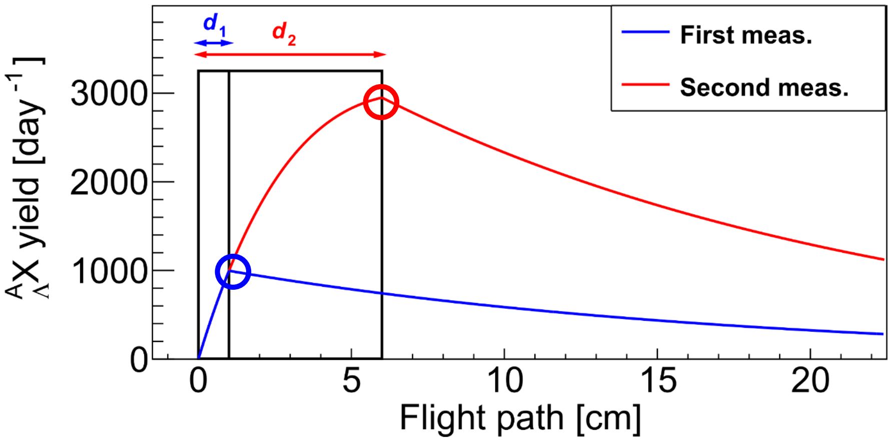

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Accepted experiment:

- ^{12}C beam @1.9 GeV/A
- ^{12}C targets max thickness 6 cm
- Total beam time, t=8 days
- Beam intensity, I=(1-5)·10^6 pps

Radius (rms) [fm]	$\sigma_{\Lambda R}$ [mb]	$\delta\sigma_{\Lambda R}/\sigma_{\Lambda R}$[%]
2.8 (no halo)	645 ± 106	17
4.9	861 ± 129	15
7.9	1062 ± 134	13

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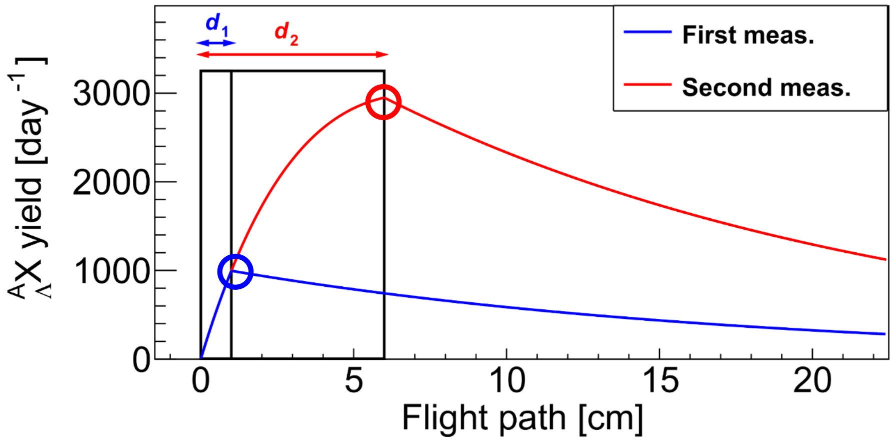

Paper submitted to **EPJA, in review**

Method to evidence hypernuclear halos from a two-target interaction cross section measurement

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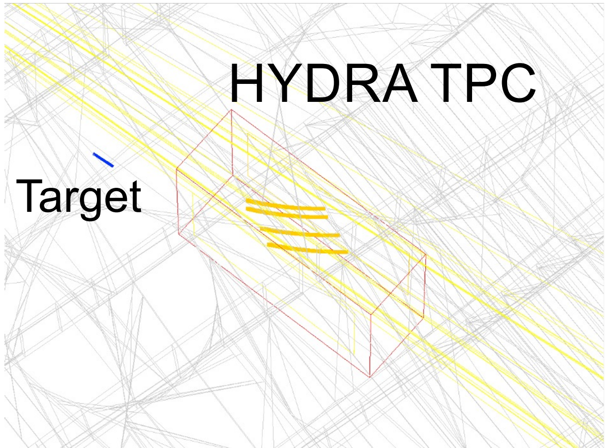
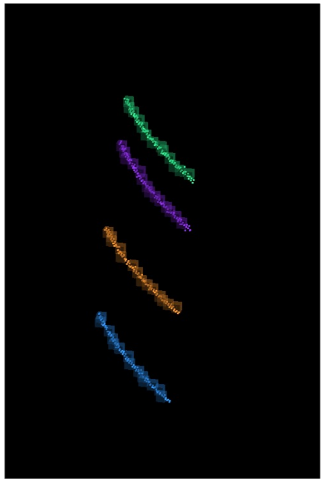
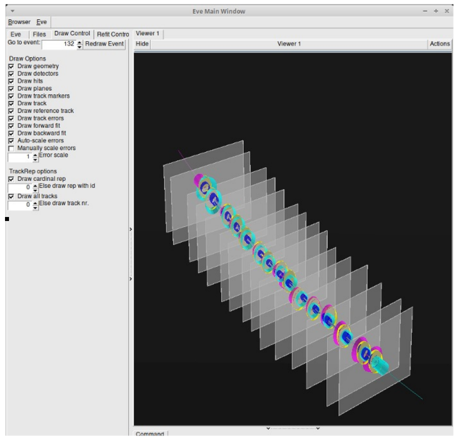
PION TRACKING

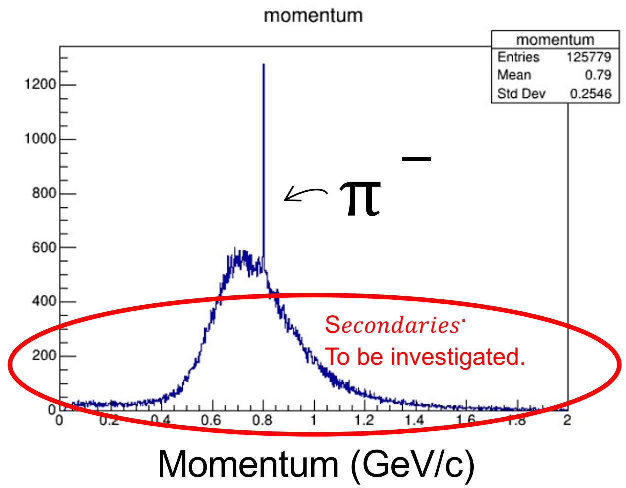




Simulation: 0.8 GeV π^- and secondaries $(0-2\ \mathrm{GeV})$

- Detecting and separating curves in 3D point clouds.
- Clustering point triplets instead of the original points.
- Clustering process can be controlled by several parameters.
- Light-weight and efficient C++ code ported into R3BROOT.





- Kalman Filter adapted to HYDRA geometry (virtual planes).
- Provides an estimate of the momentum with 0.1% of precision.
- Position reconstructed with about few mm of precision.
- GLAD inhomogeneous magnetic field taken into account.
- Next steps: origin of secondaries / rejection

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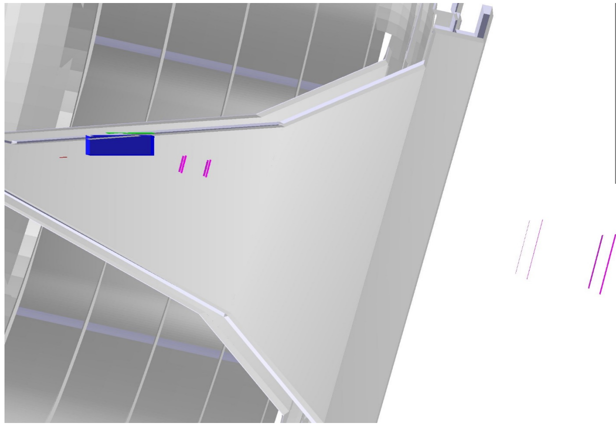
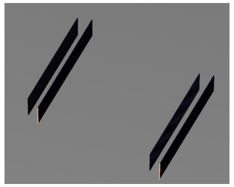
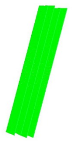
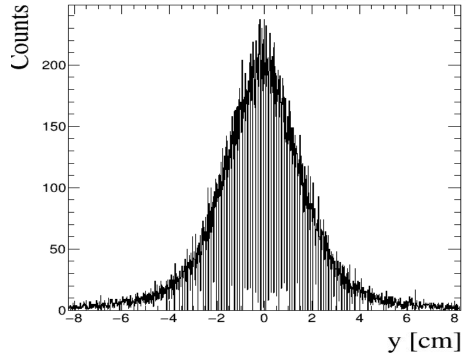




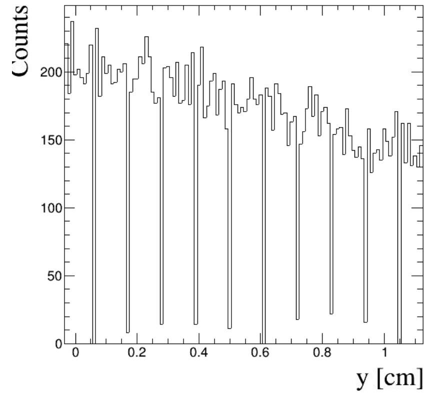
Fibers inside GLAD – new (to be built)
2 double planes (x,y) of 0.1 cm thick fibers
Air gap between fibers 0.01 cm
X layers 15x15 cm², Y layers 15x15 cm²

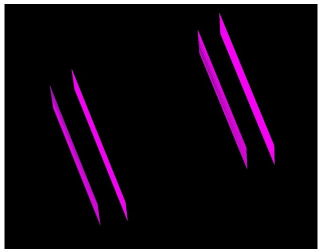


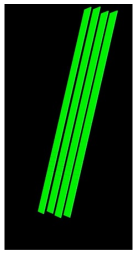


Fibers outside GLAD (Fib. 30-33)
2 double planes (x,y) of 0.1 cm thick fibers
Air gap between fibers 0.01 cm
X, Y layers 50x50 cm²

TOFD
4 planes 44 paddles: 2.7x100x0.5 cm³
Air gap between paddles 0.04 cm
Air gap between planes 5 cm
Plane 2 (4) shifted by half paddle compared to 1 (3)







RECOIL TRACKING

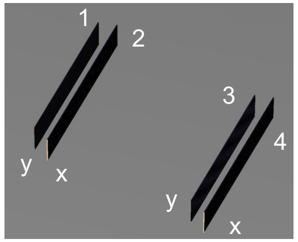
SIMULATIONS | RECOIL FRAGMENT

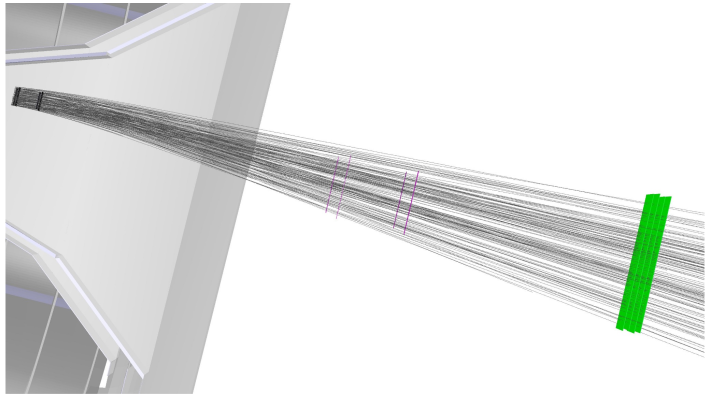
- Generate ^{3}He in large phase-space
  - ➔ Bρ~uniform(8.8,14.1)
  - ➔ ang_x~uniform(-0.22,0.07), ang_y~uniform(-0.08,0.08)
  - ➔ vertex: just before the first fiber inside (uniformly covers fiber area)

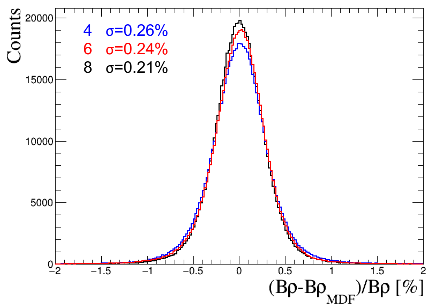
- Run the sample through the simulation
  - ➔ vacuum conditions: r3b_cave.vacuum.geo
  - ➔ new field map: R3BGladMap_Bxyz_X-3to3_Y-1to1_Z-4to13_step10mm.root
  - ➔ physics list: QGSP_BERT_EMV

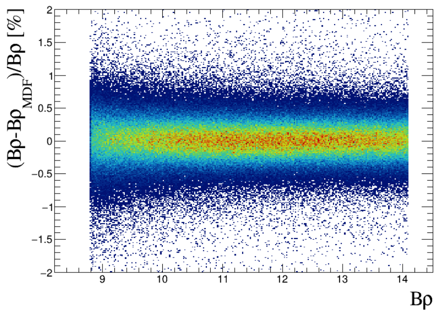
- Using multi-dimensional fit (8 variables) to create functions for Bρ, angx, angy, x, y.
- ***f***(fib1x,fib1T_x,fib1y,fib1T_y,fib2x,fib2T_x,fib2y,fib2T_y)
  - ➔ fib1x = x pos. at FibIN_2
  - ➔ fib1T_x = (FibIN2_X-FibIN4_X)/(FibIN2_Z-FibIN4_Z)
  - ➔ fib1y = y pos. at FibIN_1
  - ➔ fib1T_y = (FibIN1_X-FibIN3_X)/(FibIN1_Z-FibIN3_Z)
  - ➔ and the same for ‘2’ with IN→OUT

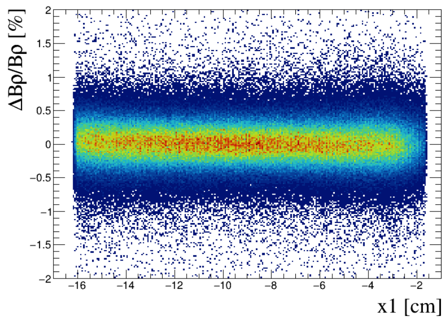
- ***f*** is fitted up to 8th order Monomials











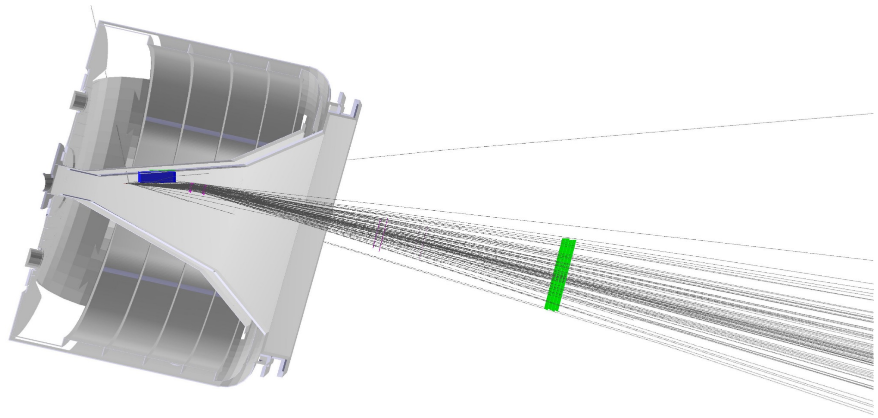
HYPERTRITON DECAY GENERATOR

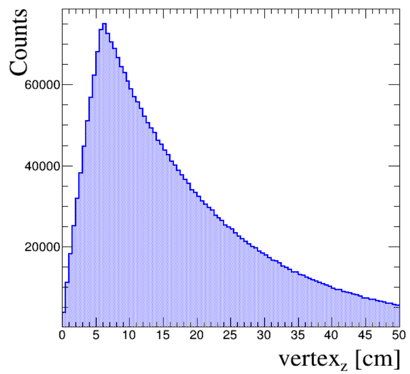
- Energy ~ Gaus(1.555,0.1344)AGeV
- Production vertex
  - ➔ tgt_z ~ uniform(0,6)cm
  - ➔ $tgt_{x,y}$ ~ Gaus (0, FWHM 0.4) cm & inside tgt. radius of 0.25 cm

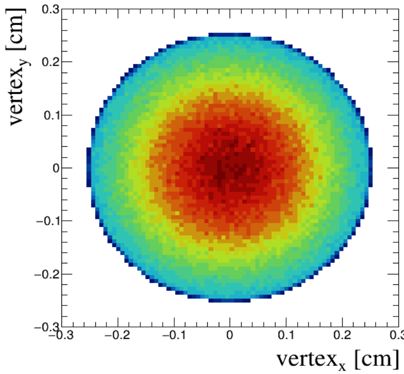
- Angular spread (Dubna cascade model+Fermi breakup)
  - ➔ angx ~ Landau(0.016,0.006)
  - ➔ angy ~ Landau(-0.29,0.8)

- Energy-loss of hypertriton in the target

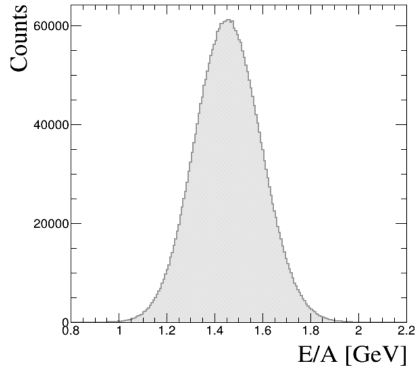
- Phase-space decay to π^-+^{3}He at the decay position
  - ➔ decay_vertex = tgt + decay_length(z-direction)
  - ➔ decay_length = β*c*t (β of hypertriton)
  - ➔ t ~ exp(-L/(ɣβcτ))=exp(-t/(ɣτ)) τ=0.237 ns







Generated ^{3}He distributions



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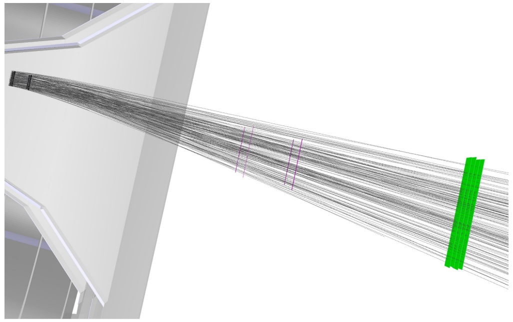
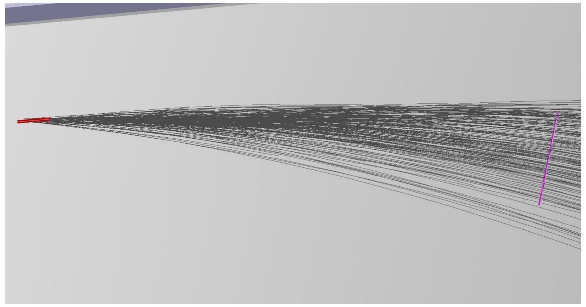
- Use functions to get $B\rho_1$, $angx_1$, $angy_1$, and x_1, y_1 at (I)
- Combine with pion track from TPC to get decay vertex
- Another simulated ^{3}He sample
  - → again large phase space
  - → vertex_z z_0~uniform(0,50)) (0 = target)
  - → MDF functions for $B\rho_0$, $angx_0$, $angy_0$ (II)
  - → $\boldsymbol{f}(B\rho_1, angx_1, angy_1, x_1, y_1, z_0)$
- Momentum at decay vertex

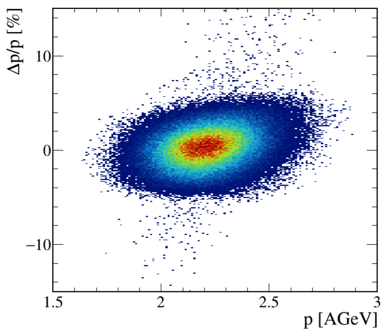
(I)

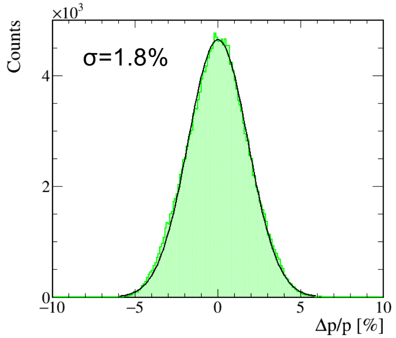


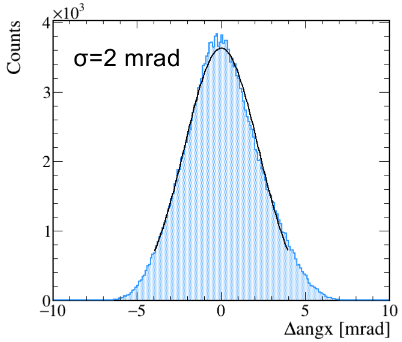
(II)

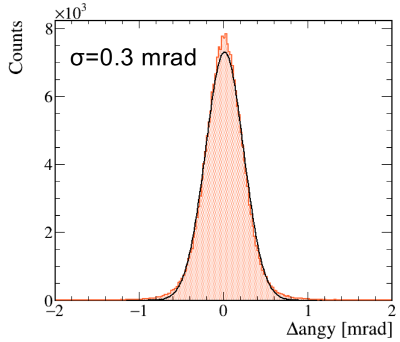


Resolutions extracted with simulated data from hypertriton decay treated as exp. data (see next slides):









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Signal amplitude in fibers

$A_{up/down} = \Delta E \times Y_s(\lambda) \times \varepsilon_{trap} \times \varepsilon_{att} \times \varepsilon_{PPE}$

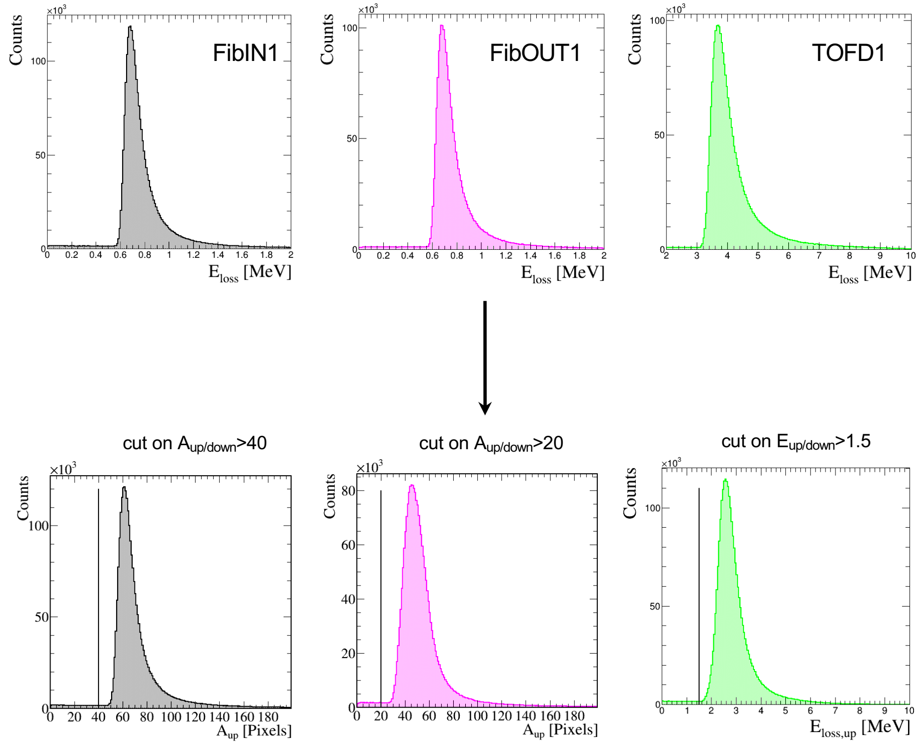
- ΔE = energy loss in fiber [MeV]
- $Y_s(\lambda)$ = light yield. SCSF78 (Kuraray fib.) Photons/MeV
- ε_{trap} = fraction of emitted light which falls into the two cones in which
- it undergoes total internal reflections. For square Kuraray fiber 4.2%.
- ε_{att} = attenuation in the fiber over a distance d:
- d = L/2+y(x) up, d=L/2-y(x) down L fiber length ∝ exp(-d/λ), λ=74 cm
- ε_{PPE} = photon detection efficiency: QE(λ)xε_{geo} :

QE(λ) quantum efficiency & ε_{geo} geometrical efficiency

- → SiPM MPPC S13360-3050 (for PW): QE(λ)=40%, ε_{geo}=74%
- → MAPMT H13700 (existing fibers): QE(λ)=33%, ε_{geo}=80%

TOFD light attenuation

- Attenuation length for EJ204 scintillator λ = 140 cm
- Bar length L = 100 cm
  - → $E_{up} \propto E_{loss}$ exp(-(L/2-y)/λ), $E_{down} \propto E_{loss}$ exp(-(L/2+y)/λ)



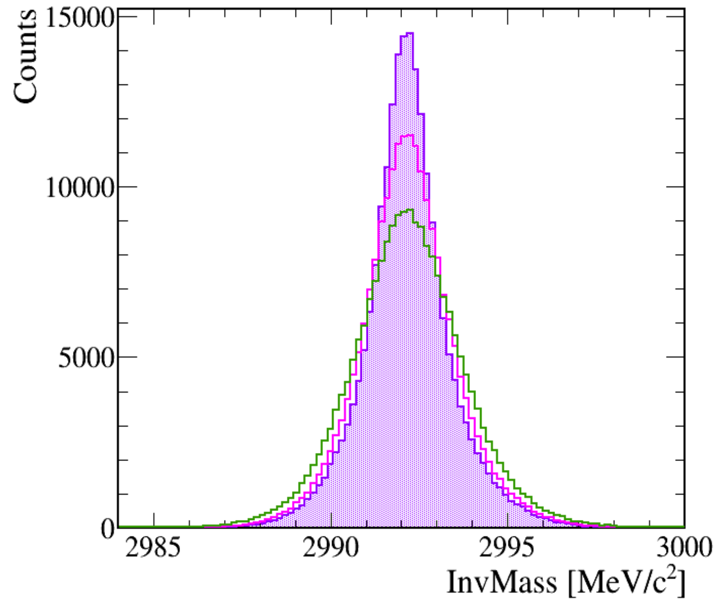
SIGNAL AMPLITUDES

Efficiency x acceptance

N_{acc}/N_{gen}	[%]
FibIN_1	86
FibIN_1+2	80
FibIN_1+2+3	71
FibIN_1+2+3+4	64
FibIN + FibOUT_1	57
FibIN + FibOUT_1+2	53
FibIN + FibOUT_1+2+3	48
FibIN + FibOUT_1+2+3+4	44
FibIN + FibOUT + TOFD	**42**

(in proposal: 60%)

- From tracking of both pion+^{3}He the decay vertex is reconstructed
  - → use different resolutions: 5, 10, 15 mm
  - → smear generated vertex z with Gauss(z_0,σ)
- Simulated sample includes both pion+^{3}He
  - → Pion acceptance: track length>1 cm in TPC + PW (E_{loss}>0.5 MeV)
  - → smear generated vertex z with Gaussian(z_0,σ)
  - → smear momentum with resolution of 1%
- Reconstruct invariant mass



vtx_z=5 mm → σ=1.4 MeV
vtx_z=10 mm → σ=1.6 MeV
vtx_z=15 mm → σ=1.8 MeV

(in proposal: 1.5 MeV)

RESULTS

- Finalize **pion tracking** simulations

- **Merge of fragment and TPC simulations** for hypertriton decay events
  ⟹ optimize and validate detector geometry and positions

- Add **small fiber detector** in front of production target (beam position)

- **Background** event simulations with final geometry
  ⟹ ion back flow and confirm primary beam intensity llimit
  ⟹ fine tune topological cuts for data analysis

- **Laser ionization** in simulations
  ⟹ compare to measurements in GLAD to extract spacial resolution

SIMULATION NEXT STEPS

- **June 2023**: detailed drawings and procedure for installation and dismounting at R3B
- **End of July 2023**: Full TPC characterized with source and cosmic rays (GET electronics)
- **August-September 2024**: implementation of laser system, operation with TPC @ TUDa
- **October or November 2024:** laser operation in GLAD, with / without B field (**1 week**)
  Time necessary for full installation: 2 days + 1 day tuning and flushing
  Tests duration: 1 day + 1 day spare
  Time necesary for removing TPC from GLAD: < 1 day
- **December 2023-January 2024:** operation tests with SRS + VMM3 continuous readout
- **February 2024**: tests of TPC inside GLAD (1 day in parasitic)
- **Around July 2024:** option for additional tests at CERN (if found necessary, within RD51 collaboration)
- **February 2025:** experiment at R3B

AGENDA