Neutron Identification with Plastic Scintillators

Sebastian Ritter
CALICE Collaboration Meeting - 30.03.23
sebastian.ritter@uni-mainz.de
on behalf of: Antoine Laudrain, Asa Nehm and Asma Hadef

PRISMA+ DETECTOR LAB

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

OUTLINE

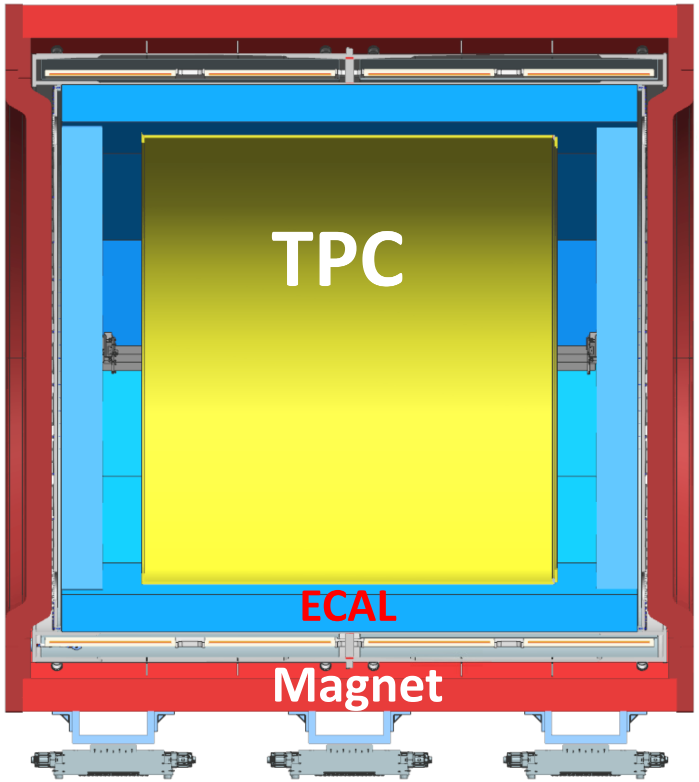
- Motivation
- What is Neutron ID?
- Methodology
- Old setup + Results
- Improved setup + first Results
- Summary

MOTIVATION

- Can we use AHCAL-style design with pulse shape discrimination (PSD) to identify gammas and neutrons?

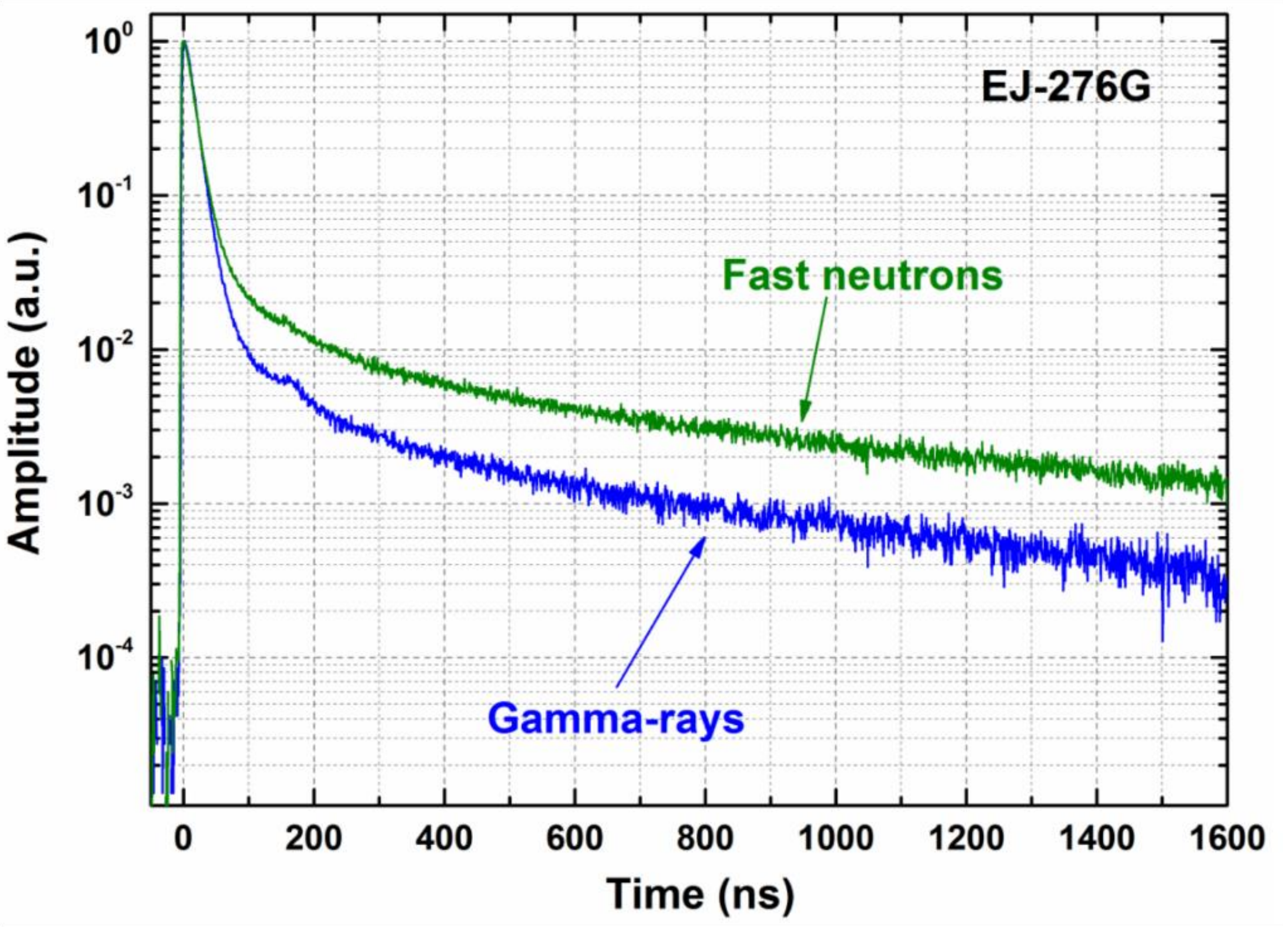
- Case study: DUNE ND-GAr
  - TPC measures charged particles
  - ECAL can detect neutral particles but not identify (**so far**)

- Special plastic scintillators are optimized for Neutron ID (e.g. EJ-276G)

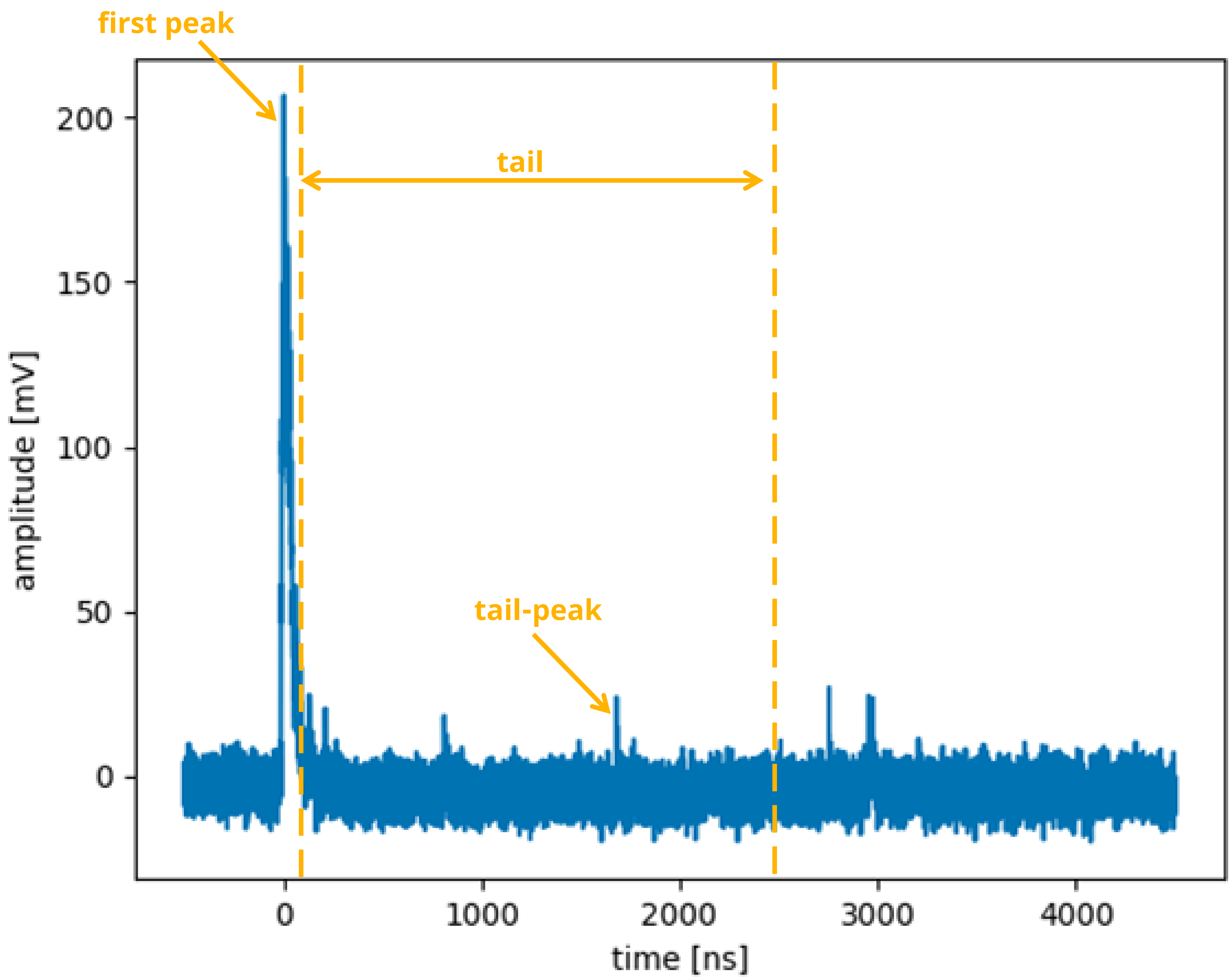


WHAT IS NEUTRON ID?

- Neutron ID: discrimination of incident neutrons by scintillation signature
- Classic process:
  1. Ionizing particles excite scintillator
  2. Light emission at deexcitation
- Neutron:
  1. Neutron scattering on nucleus
  2. Proton recoil
  3. Ionization
- Processes differ in photon timing



particle	Short component Decay const. [ns]	Long component 1 Decay const. [ns]	Long component 2 Decay const. [ns]
Gamma	13±1	110±10	800±80
Neutron	14±1	95±10	800±80



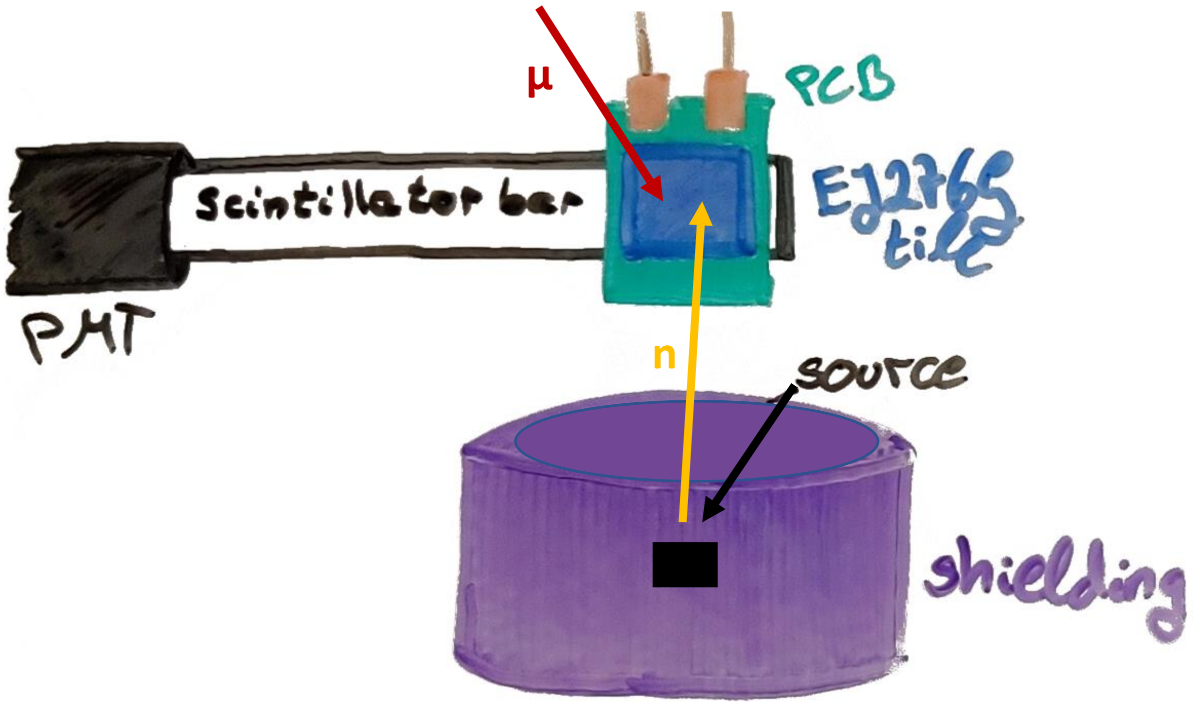
METHODOLOGY

- Compare immediate and delayed light output using full waveform
- In practice: compare
  - Height of initial peak
  - Number of tail peaks
  - Timing of tail peaks

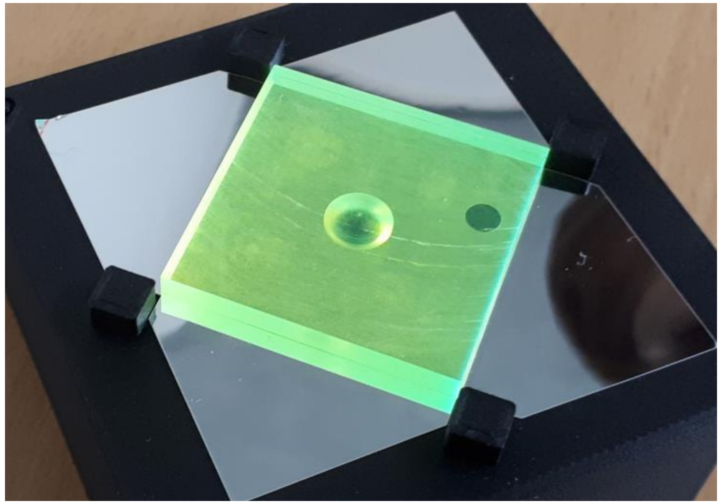
Tail Start:	4 x short component 4 x 15 ns = 60 ns
Tail Stop:	3 x long component 3 x 800 ns = 2400 ns

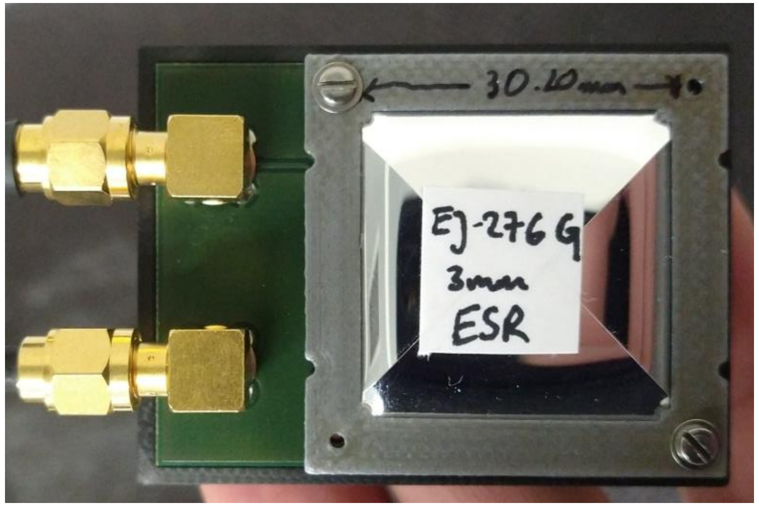
SETUP

- How do we get neutrons and gammas?
  - Neutrons from shielded AmBe source
  - Cosmic muons used to emulate gammas (similar scintillation signature expected)



- SiPM-on-tile configuration similar to tiles on HBU
  - 30 x 30 x 3 mm EJ-276G tile
  - S13660-1325PE SiPM
- Signal amplified externally and readout by oscilloscope
- Full waveform saved -500 ns to 4500 ns

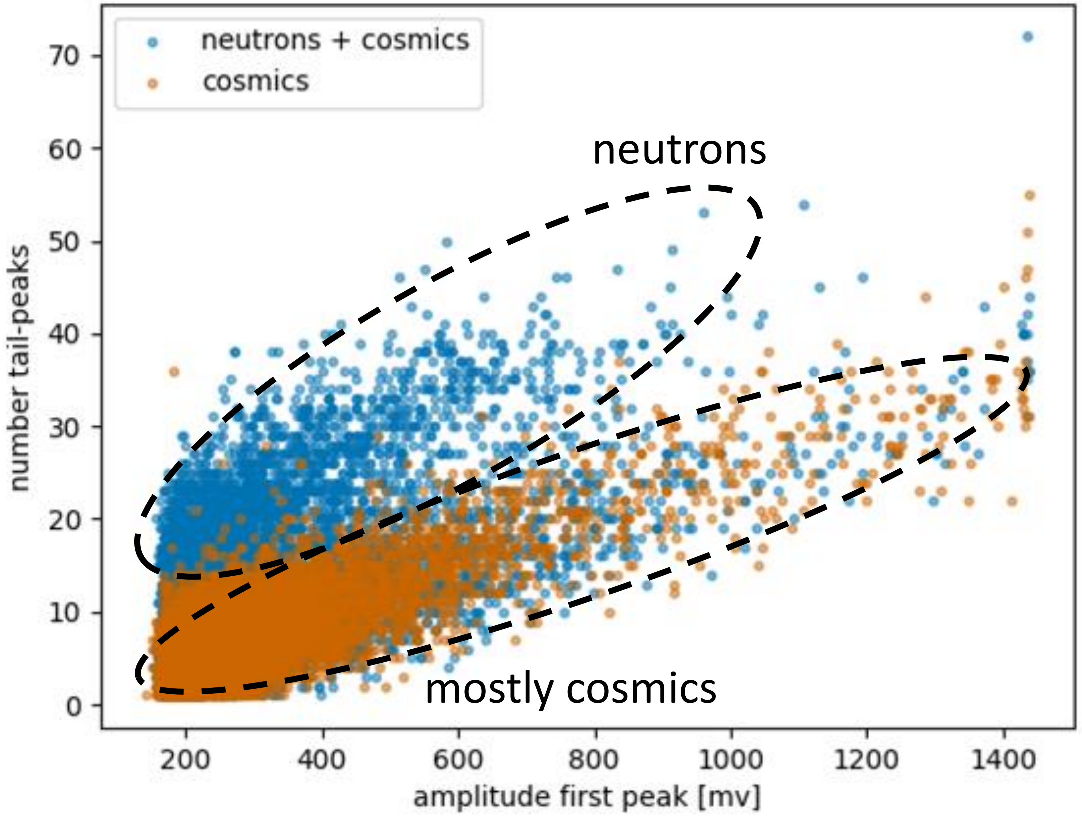


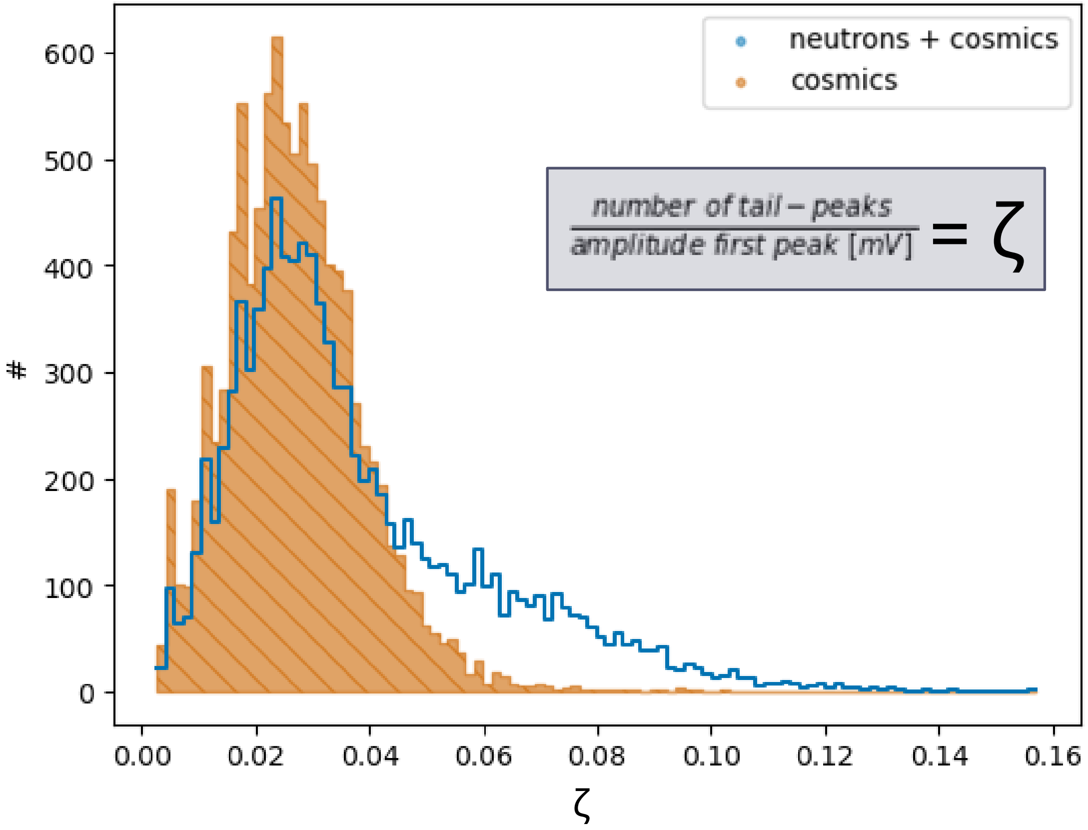


DATA

- Muon + neutron samples

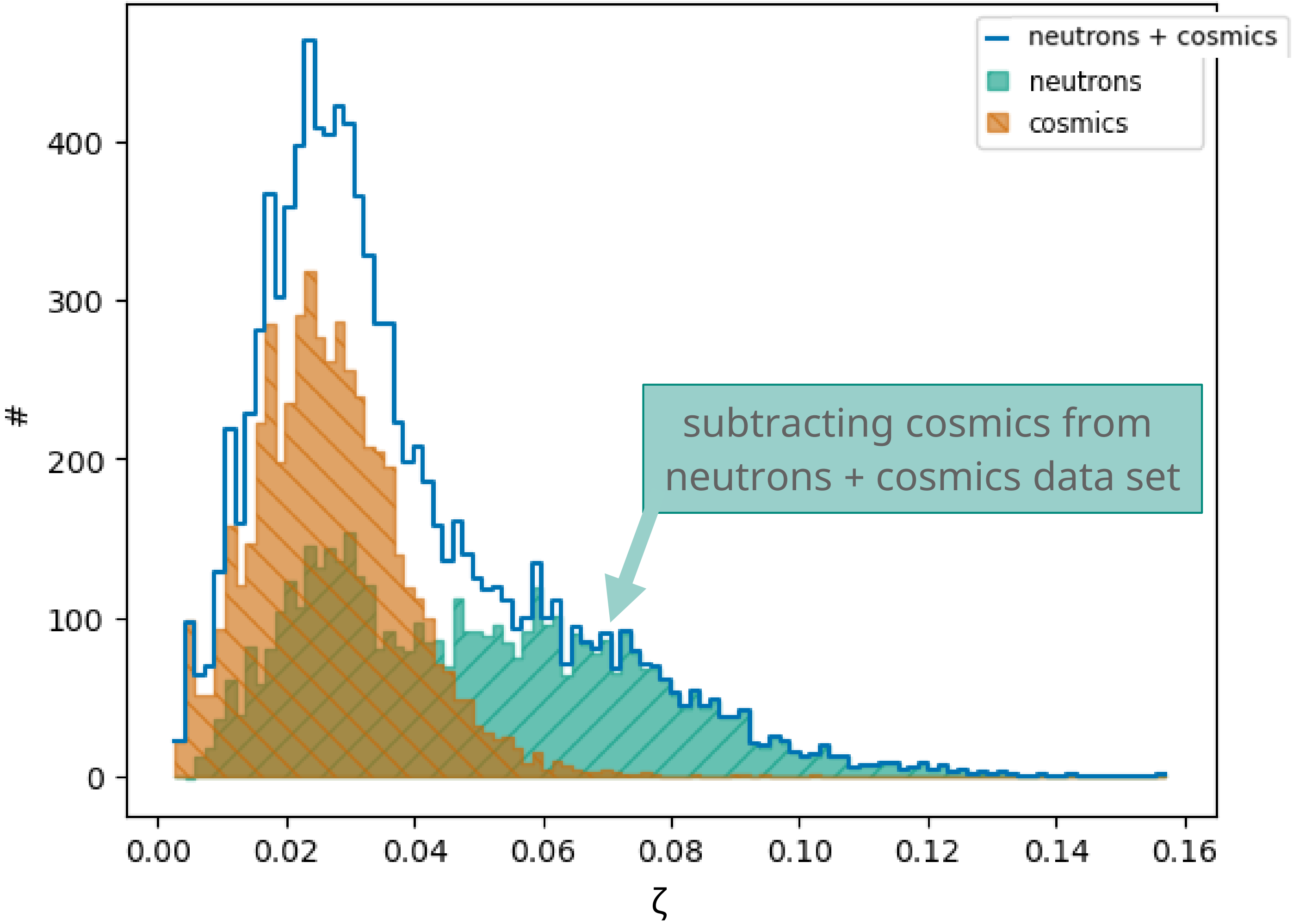
Peak height vs. number of tail peaks per event





DISCRIMINANT

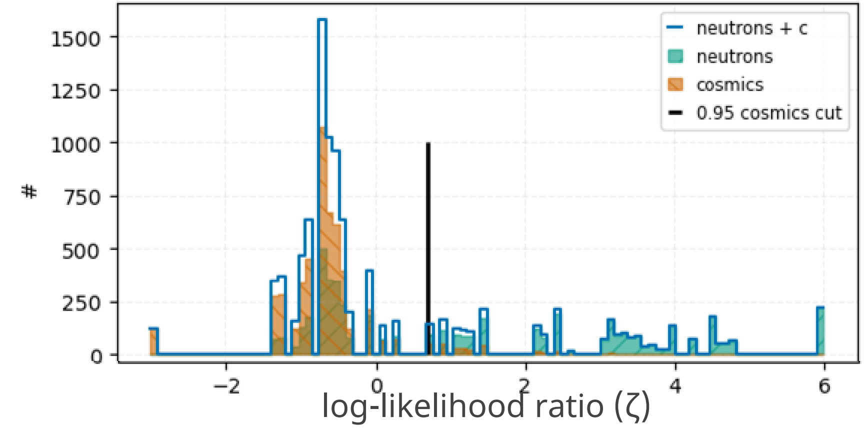
- Data runtime normalized
- Neutron data extracted by subtracting cosmics
- Discrimination efficiency determined based on resulting neutron shape

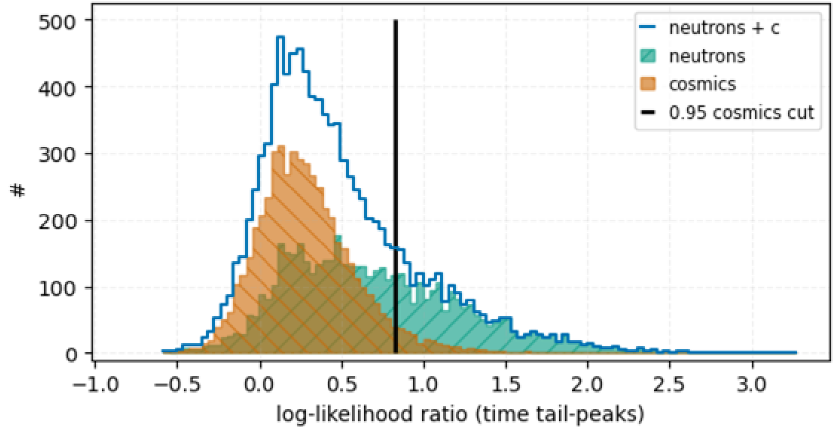


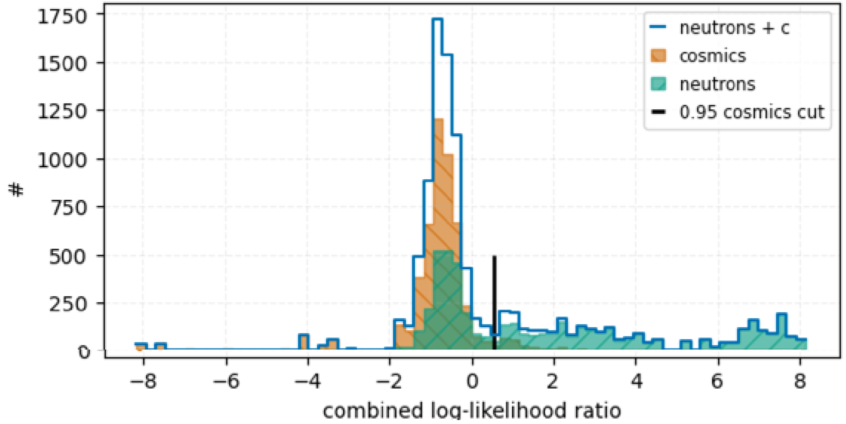
RESULTS

Three ways to perform Neutron ID:

- *Histogram bin height method*
  - Take log-likelihood for each ζ point
  - Bin height shows probability for each possibility
- *Time distribution Method*
  - Fit exponential to tail peak distribution
  - Log-likelihood based on time distribution fits
- *Combine both methods*
  - Good separation achieved





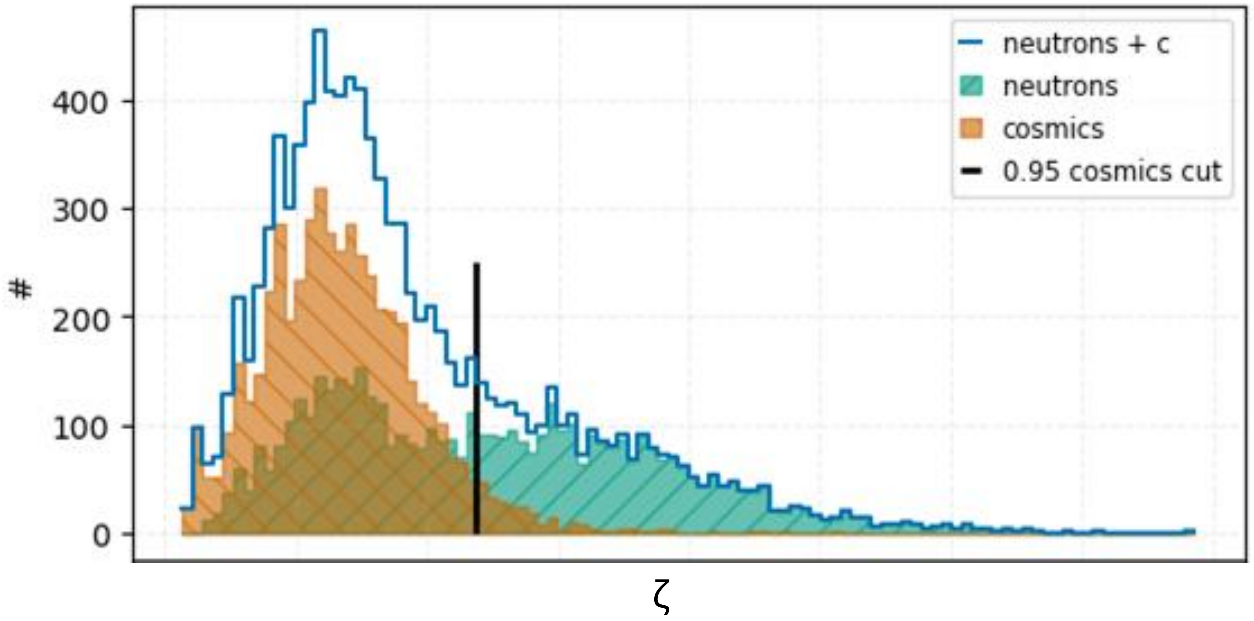


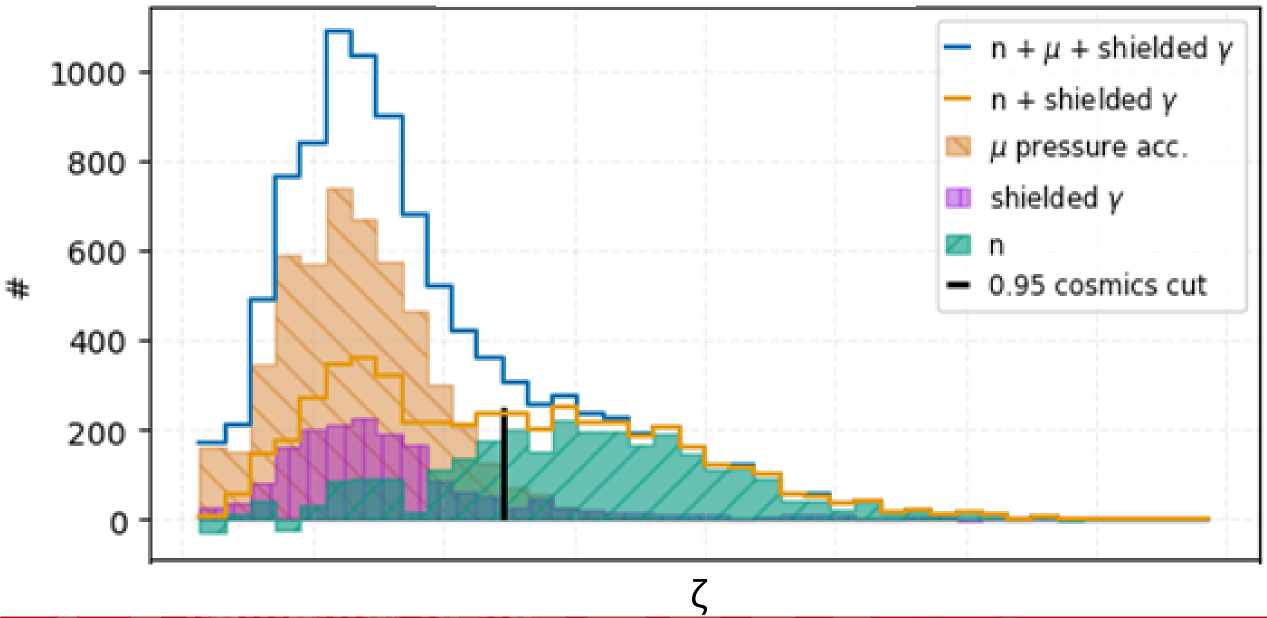
DISCUSSION

- What is the left peak in neutron distribution?
  - Suspicion: gammas penetrating shielding
  - Validation: measurement without shielding
- ➢ Neutron distribution corrected
  - Looks good
- ➢ Muons indeed look like gammas
  - Which is also good!

Next steps:

- Separation not good enough
  - ➢ SiPM upgrade to increase LY
    - S13660-1325 to -3050 (active area increase x5.3)
- Tag neutrons with coincidence measurement of γ and n

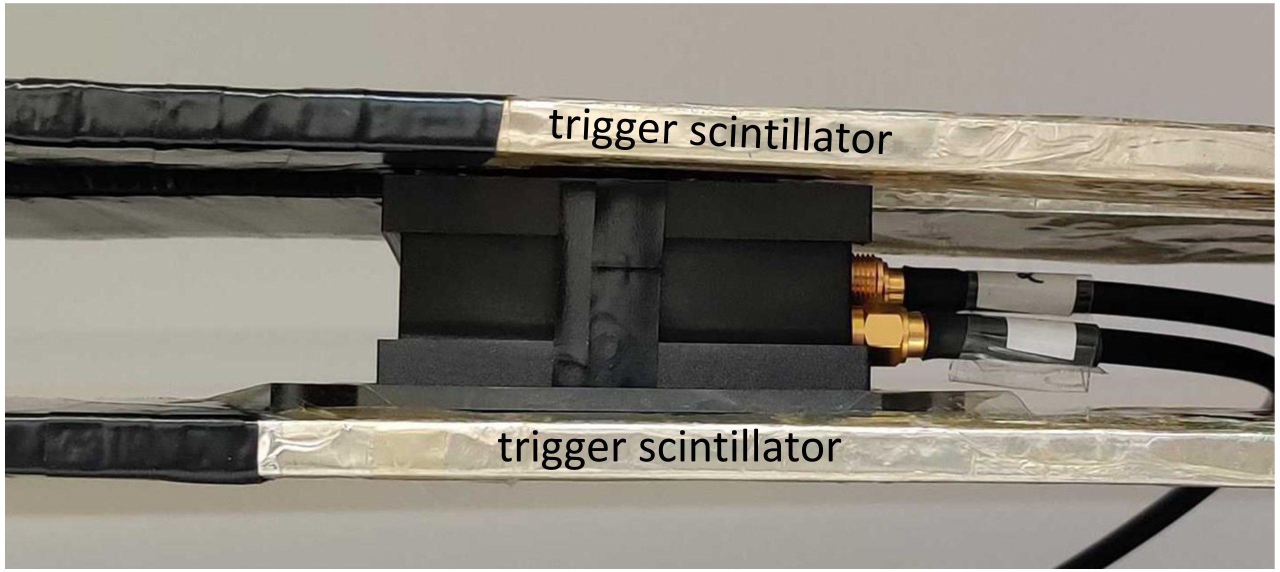


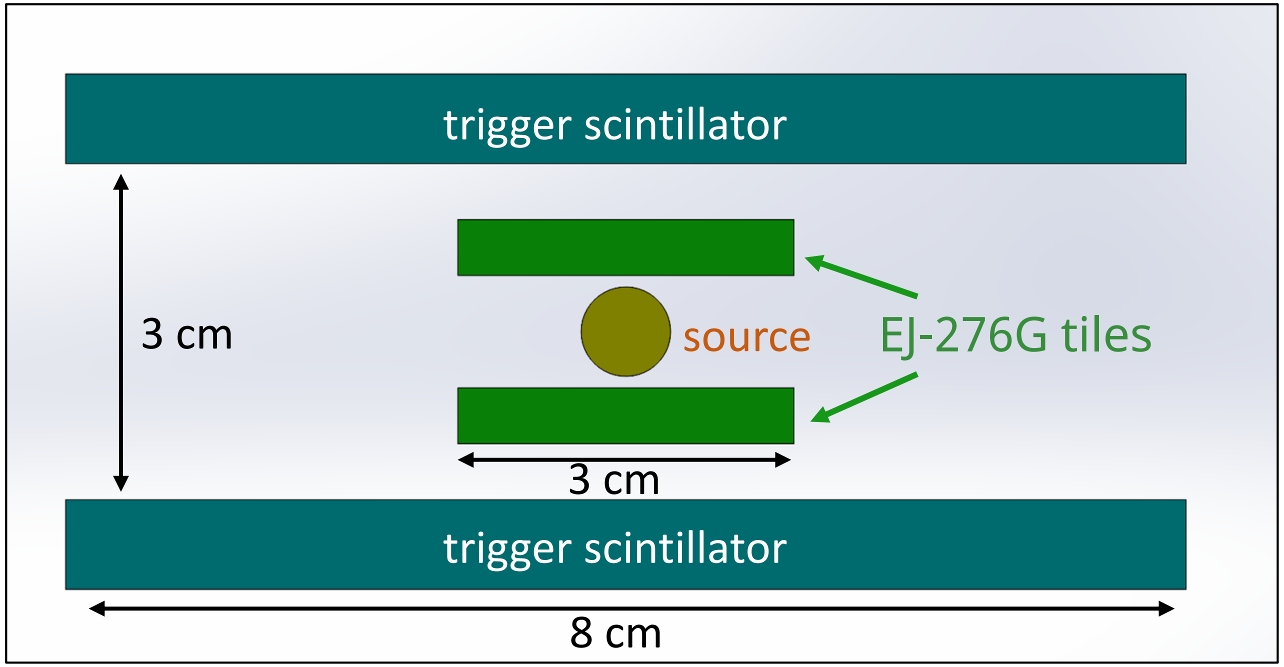


NEW SETUP

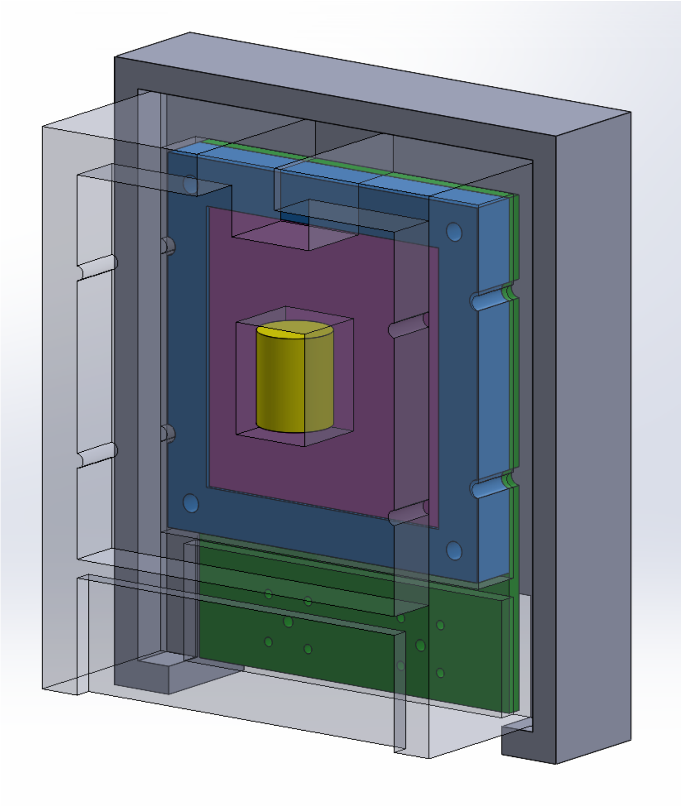
- Two PID scintillator tiles on both sides of source to cover large solid angle to maximize coincidences
- Tile thickness increased to 5 mm to boost interaction rate
- Large muon veto on top and bottom

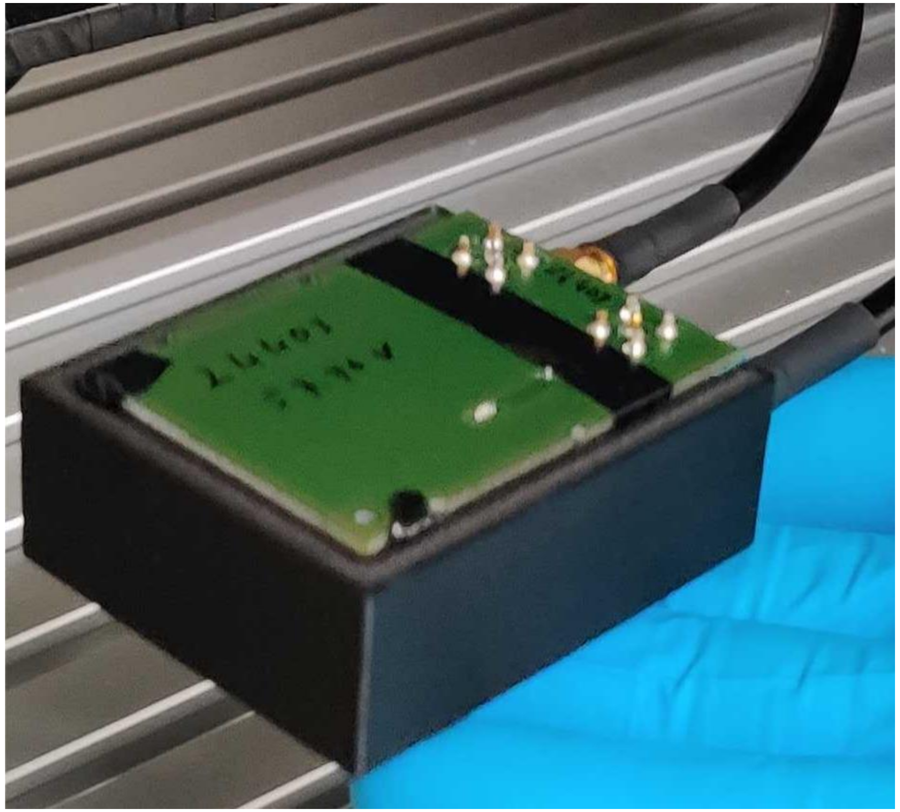
- Additional benefits:
  - Increase proton interaction rate
  - Tag muons with veto





NEW SETUP

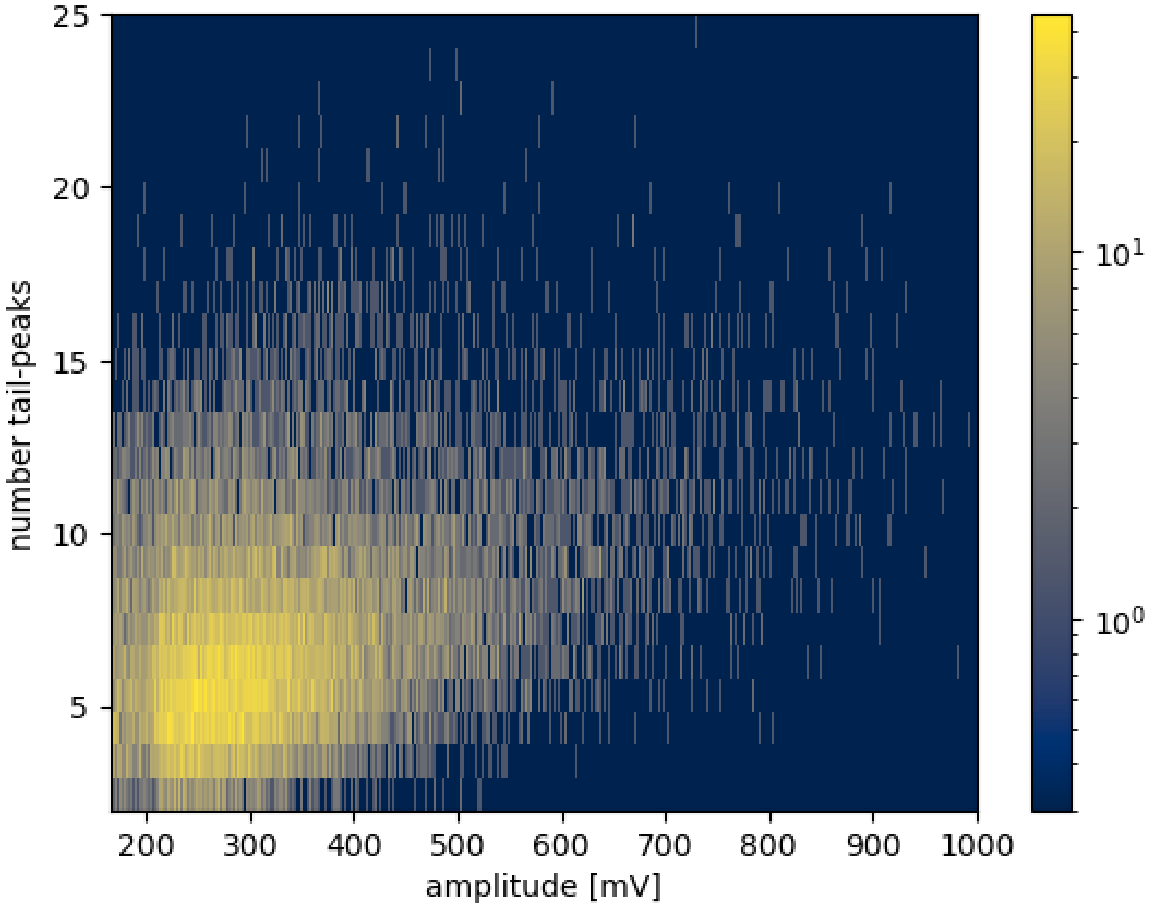




FIRST DATA

- Data taken for 20h with new setup
- About 2% coincidence events of γ and n

topPMT	x	x	x	–	x	–	–	–
topSiPM	x	–	x	x	–	–	x	–
bottomSIPM	x	x	x	x	x	x	x	x
bottomPMT	x	x	–	x	–	x	–	–
#hits	21	17	108	82	347	285	9424	591240

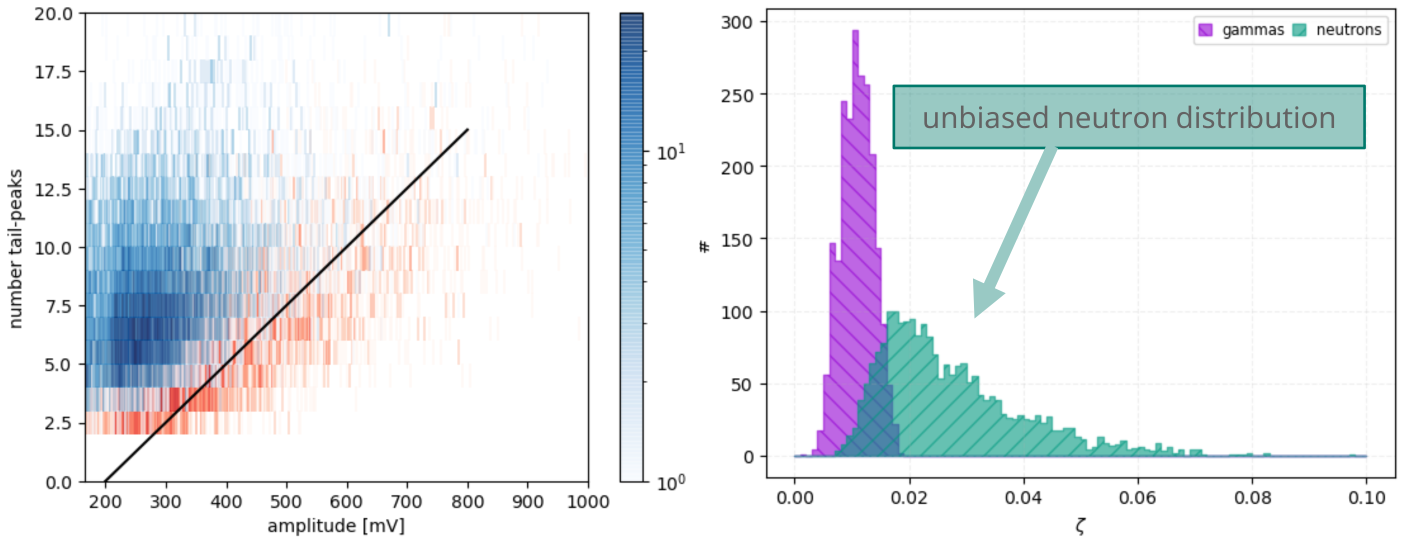


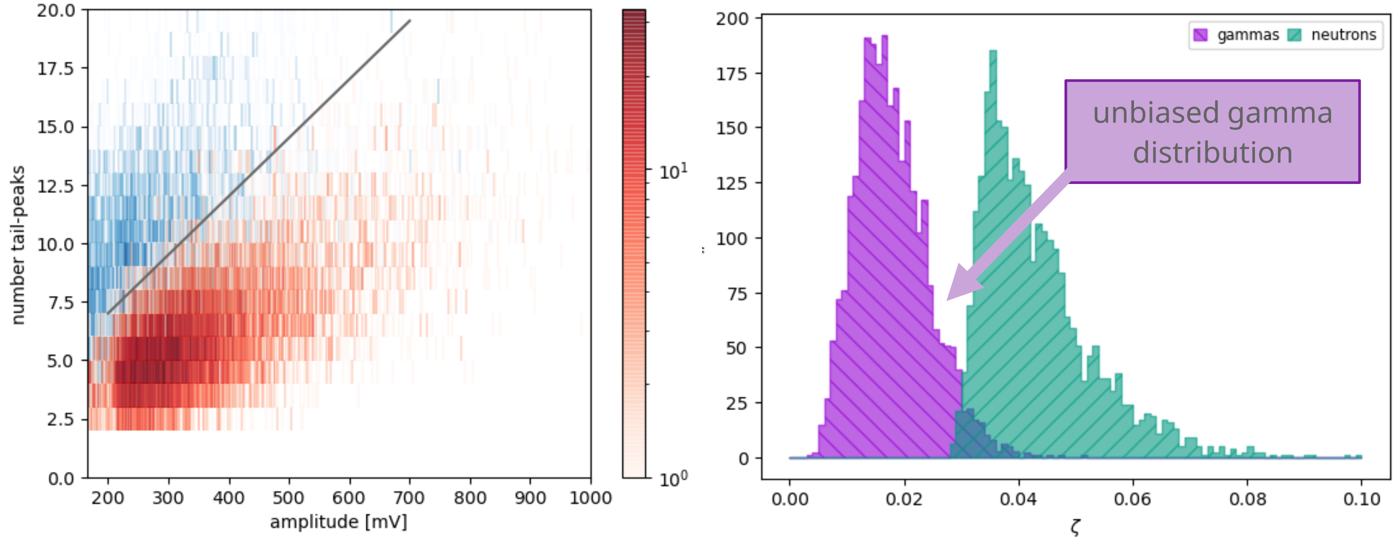
NEUTRON TAGGING IN ACTION

- Coincidence data used

- Top plots:
  - low cut
  - ➢ unbiased neutron sample
- Bottom plots:
  - high cut
  - ➢ unbiased gamma sample

➢ Tagging works
  - clean determination of n + γ shapes





SUMMARY

- Neutron ID with EJ-276G scintillator is a success
- Coincident photon + neutron emission from AmBe source can be used to determine neutron scintillation signal

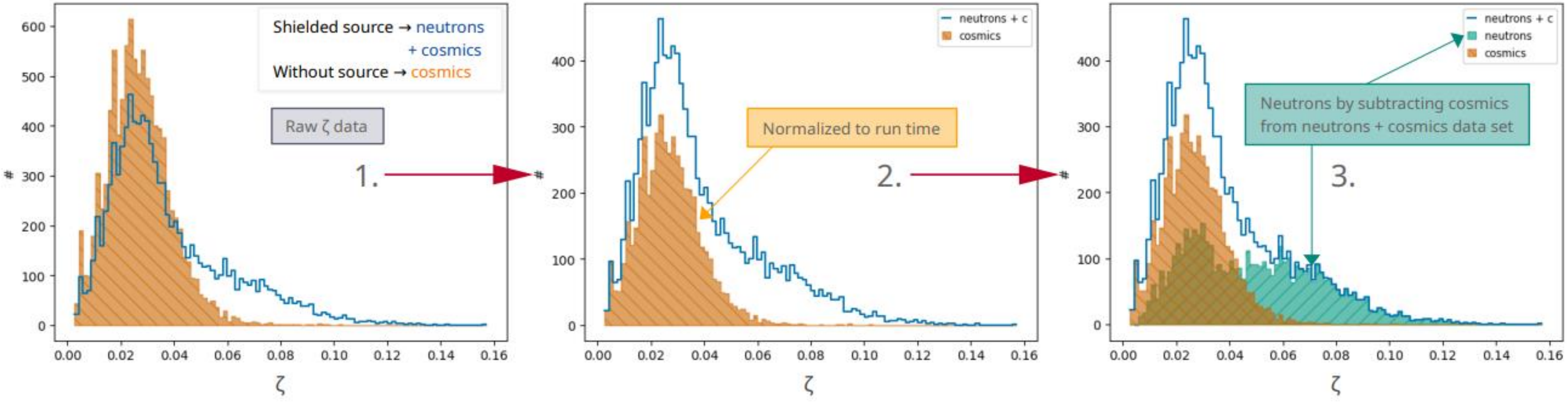
- Next step: Increase LY with larger SiPM to improve separation

- To be discussed: optimal realization in readout electronics (KLauS)

BACKUP

Defining a discriminant

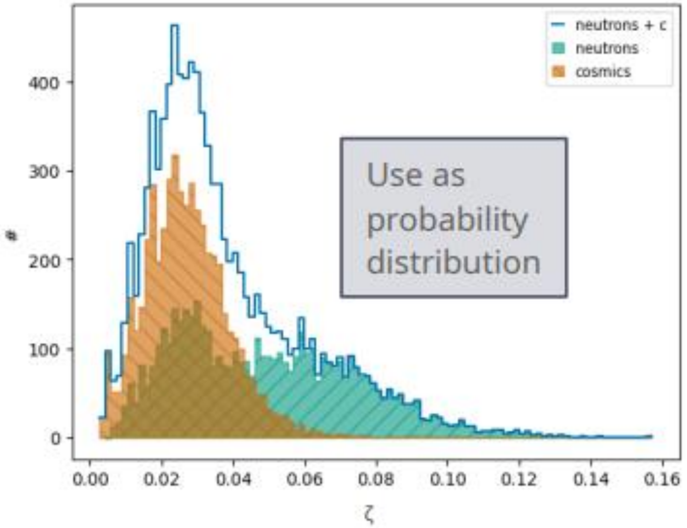
- Separate neutrons and cosmic muons first
  - Cosmic muons and gammas should have similar signal
- Information about amplitude of first peak and number of tail-peaks per event

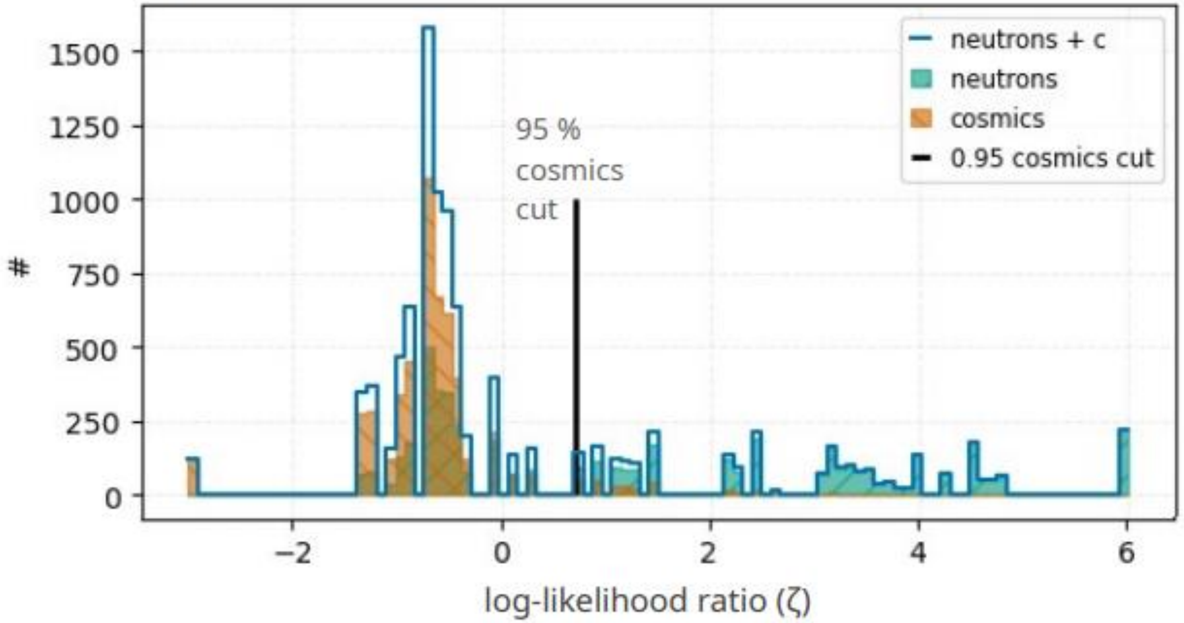


Distinguish with log-likelihood ratios

Histogram bin height method

- Take for each ζ point the respective bin
- Bin heights of neutrons and cosmics distribution as likelihoods to be either one
  - log(height neutron) – log(height cosmic)



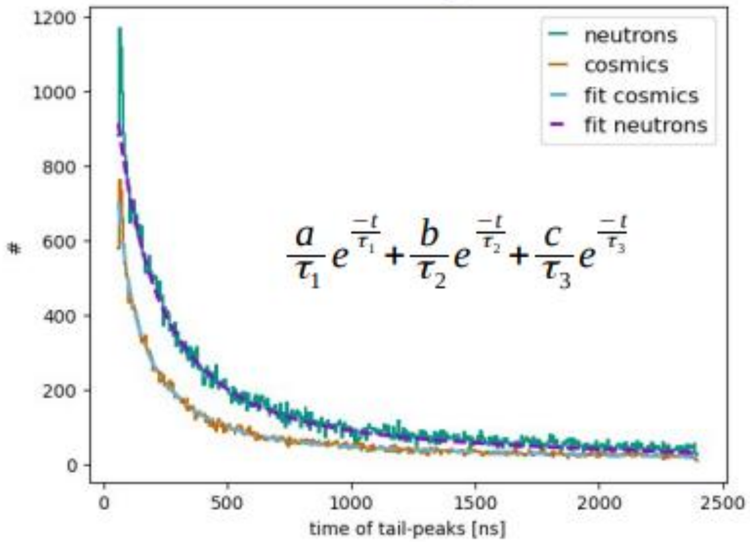


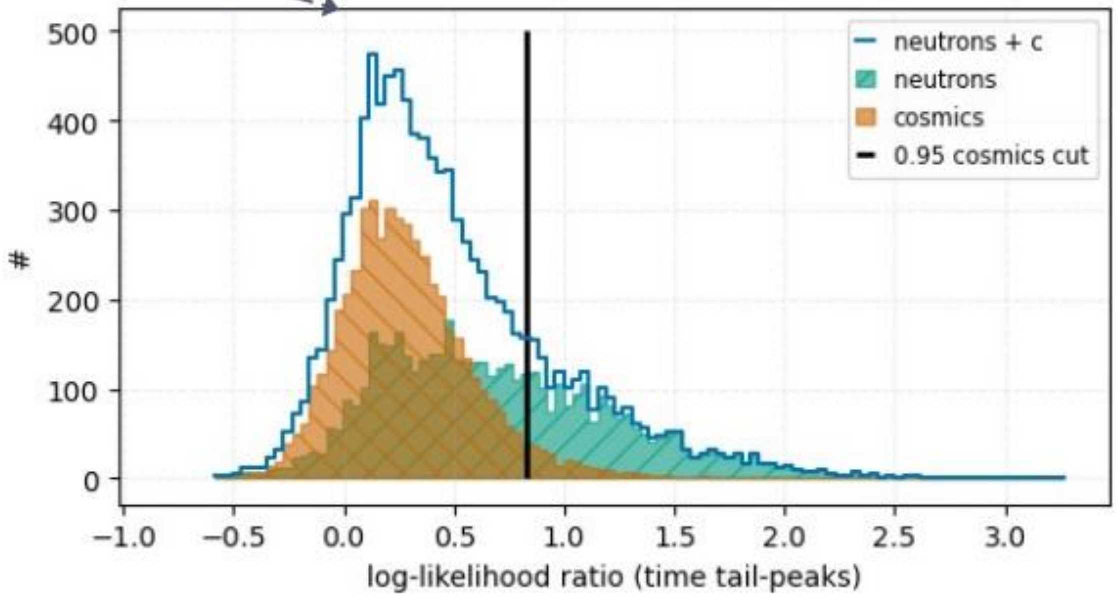
Distinguish with log-likelihood ratios

Time distribution method

- Fit to the time distribution of the tail-peaks of the events
- Calculate <u>log-likelihood ratio of event</u> being neutron or cosmic by comparing to the time distribution fits

$$\ln \mathscr{L} = \ln\left(\sum \frac{a_n}{\tau_{1,n}} e^{\frac{-t_i}{\tau_{1,n}}} + \frac{b_n}{\tau_{2,n}} e^{\frac{-t_i}{\tau_{2,n}}} + \frac{c_n}{\tau_{3,n}} e^{\frac{-t_i}{\tau_{3,n}}}\right) - \ln\left(\sum \frac{a_\mu}{\tau_{1,\mu}} e^{\frac{-t_i}{\tau_{1,\mu}}} + \frac{b_\mu}{\tau_{2,\mu}} e^{\frac{-t_i}{\tau_{2,\mu}}} + \frac{c_\mu}{\tau_{3,\mu}} e^{\frac{-t_i}{\tau_{3,\mu}}}\right)$$

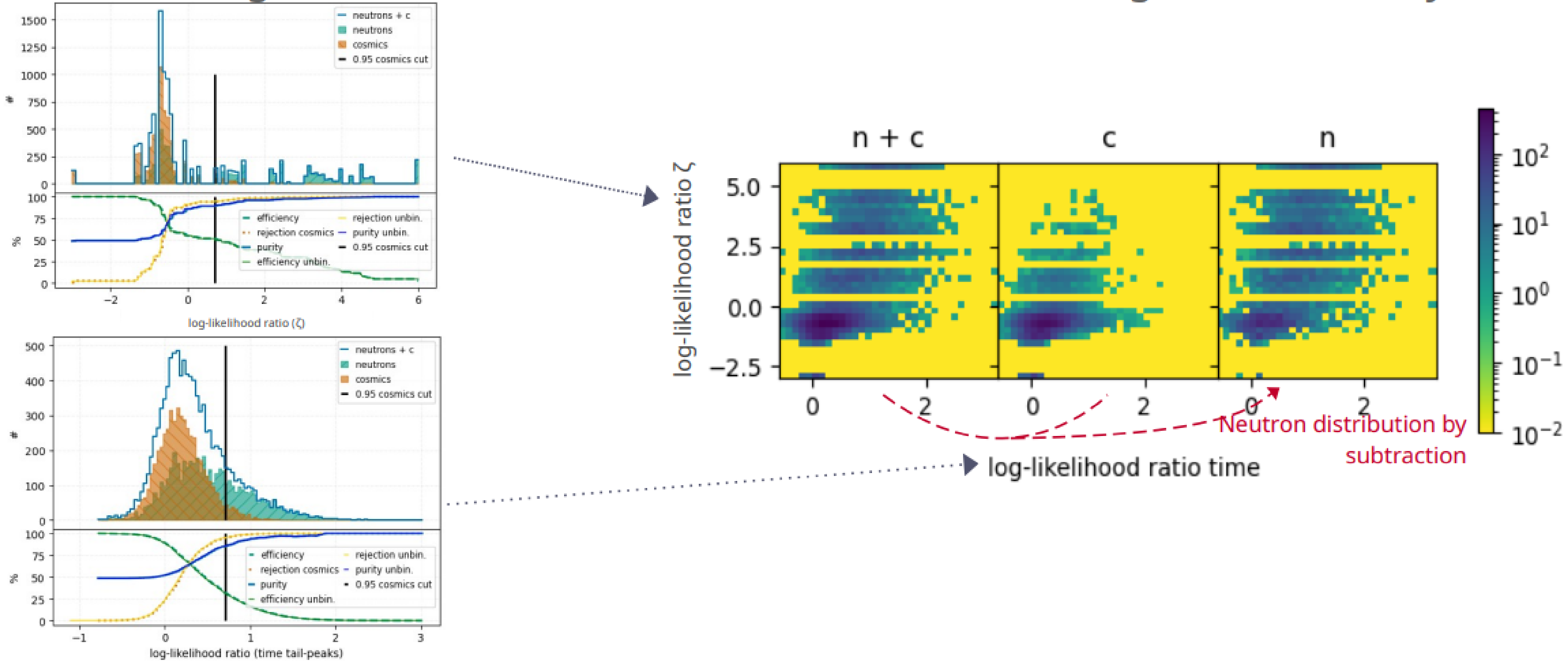




Combine log-likelihood ratio methods

2d combination

- 2d histograms with time information on x- and bin height method on y-axis



Combine log-likelihood ratio methods

2d combination

- 2d histograms with time information on x- and bin height method on y-axis
- Use 2d combination as new distributions for new log-likelihood ratio

method	Efficiency [%]
LLR ζ	49.60
LLR time tail-peaks	36.19
Combination LLR – LLR	54.03