

# Muon rates in DUNE

**Vitaly Kudryavtsev,  
Matt Robinson<sup>\*</sup>, Martin Richardson<sup>\*\*</sup>, Karl  
Warburton<sup>\*\*\*</sup>**

University of Sheffield

<sup>\*</sup> Now at the University of Loughborough

<sup>\*\*</sup> Graduated in 2016

<sup>\*\*\*</sup> Now at Iowa State University / Fermilab

# Muon generator for DUNE

- MUSUN – a muon generator for DUNE,
  - fully implemented into LArSoft,
  - tested, see the talk by Karl Warburton at the DUNE Collaboration meeting at Arlington.
- Muons were transported from the surface to the underground site with MUSIC and stored.
- Then muons are sampled from their angular and energy distributions.
- Very quick and reliable.
- Assumes 10 kt detector and the cavern design as in the CDR (-refresh).

# Muon sampling and rates

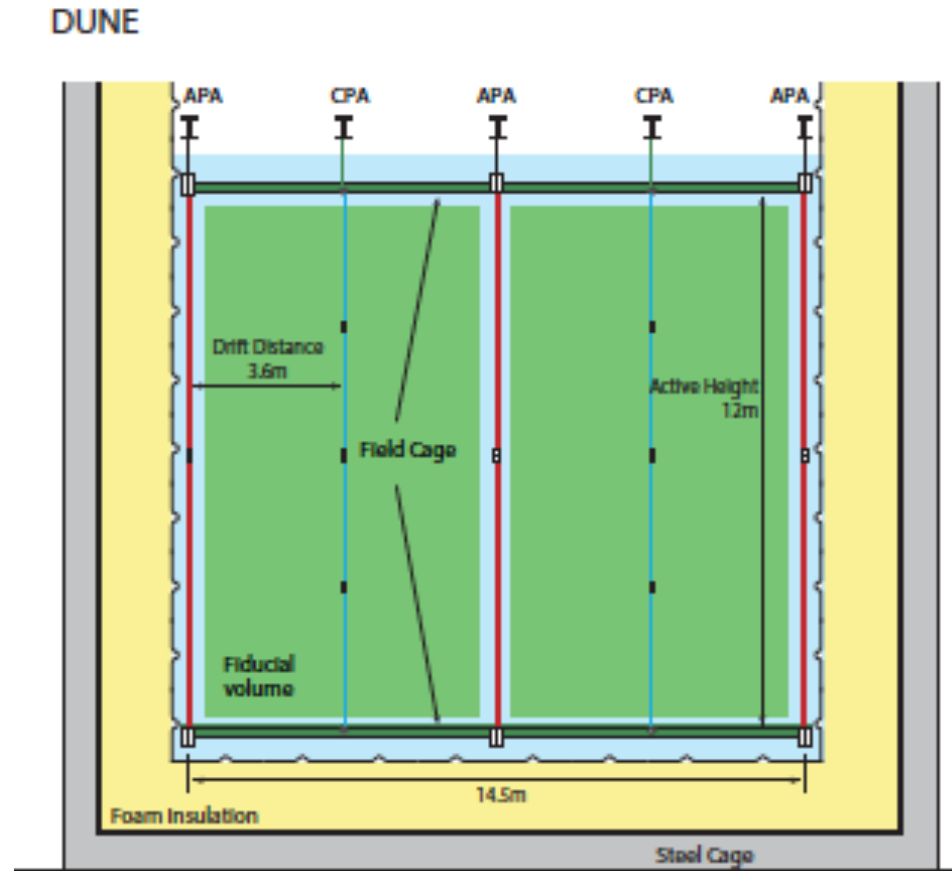
- Muons are sampled on the surface of a box that encompasses the cryostat, the cavern and 5-7 metres of rock:
- Box size:  $29.54 \times 30.18 \times 74.43 \text{ m}^3$ .
- Muon rate through the box: 0.1579 Hz.
- Muons rate through the 10 kt active volume: 0.0530 Hz or 4580 per day. This includes any energy deposition from a muon or its secondaries.
- Uncertainties probably about 20%:
  - Mean density and composition.
  - Assumption of constant flux at any place in the cavern.
  - Good to have some measurements of muon flux at the site.
- Muon bundles (groups) are not taken into account.
- Total flux (no detector):  $5.66 \times 10^{-9} \text{ cm}^{-2} \text{ s}^{-1}$ , mean energy 283 GeV.

# Stopping muons

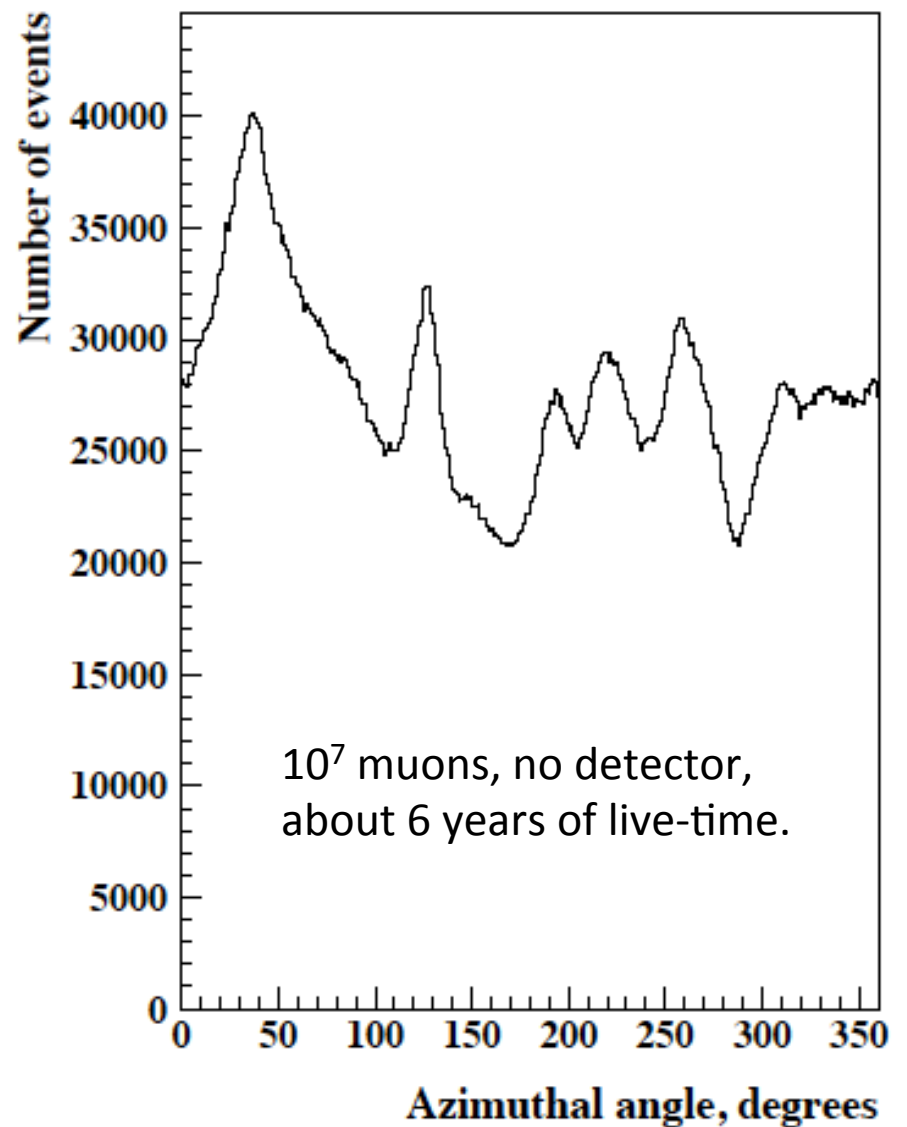
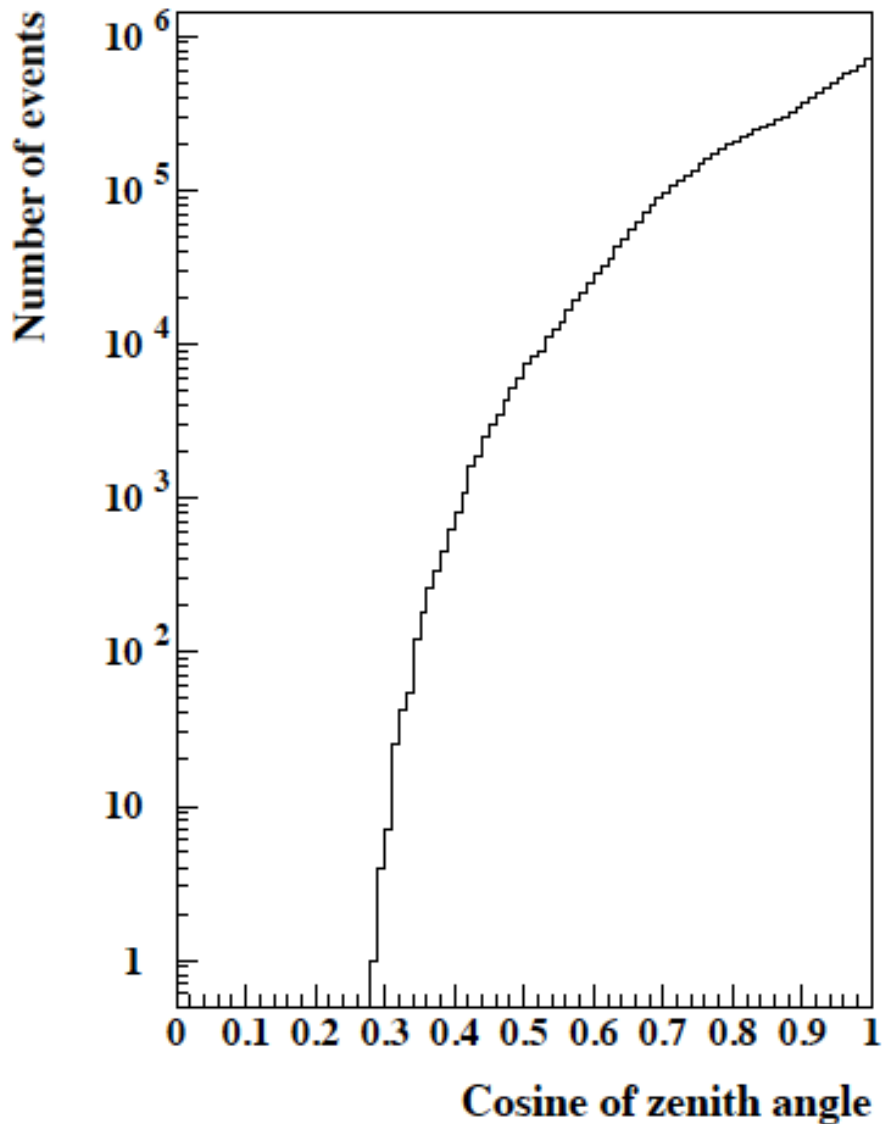
- Stopping muons: up to 2% or up to  $10^{-3}$  Hz.
- Depends on:
  - Track orientation,
  - Event selection and reconstruction (i.e. two TPC?).
- Realistically should be about  $5 \times 10^{-4}$  Hz, 40-45 per day.
- $\mu^+/\mu^-$  ratio is about 1.38 at these energies.
- 24%-25% of negative muons decay in LAr.
- 68% of muons will decay.
- No muons at zenith angles  $>75^\circ$ .

# Muons crossing APA and CPA

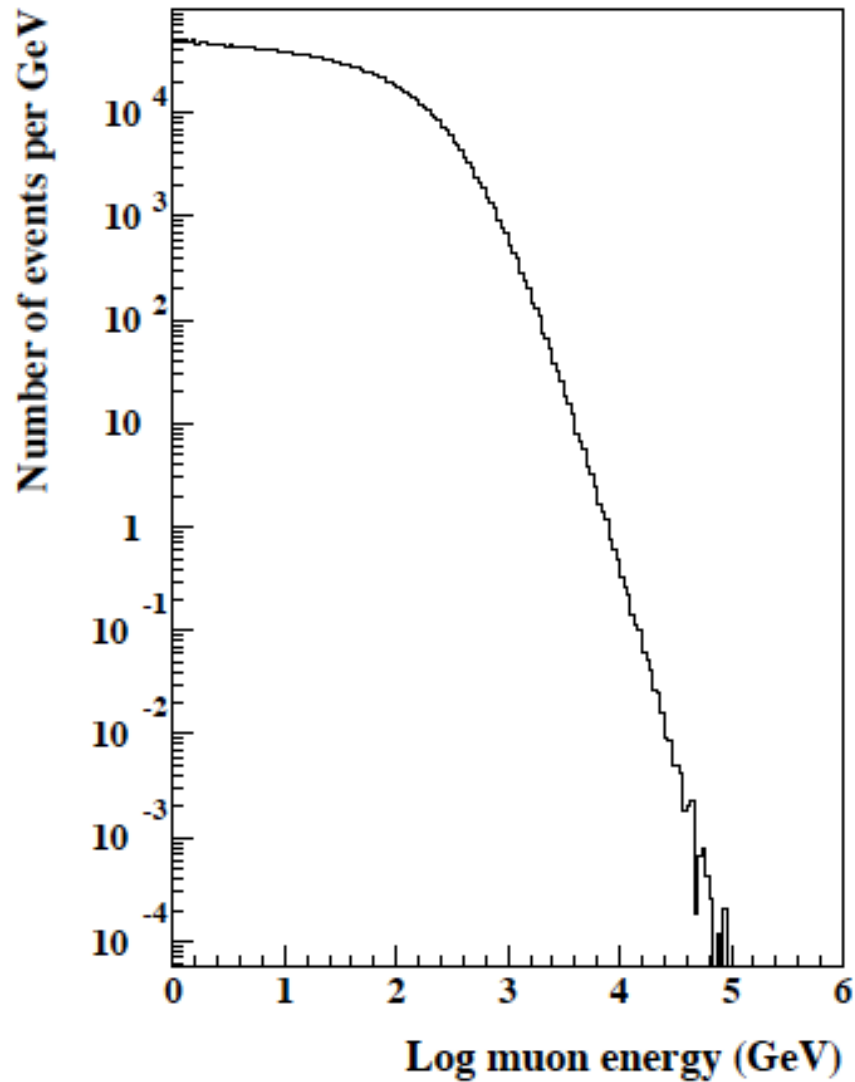
- Assume the size of one TPC module:
  - 2.3 m long (beam direction),
  - 3.6 m wide (drift direction) and
  - 6 m high.
- Minimum zenith angle for muon crossing APA and CPA of the same module:  $\arctan(3.6/6) = 31^\circ$ ,  $\cos(\theta) = 0.86$ .
- Maximum azimuthal angle for crossing APA and CPA of the same module:  $\arctan(2.3/3.6) = 33^\circ$ .
- Crude estimate: 5%-10% muons will cross CPA and APA of the same module or 200-500 per day.



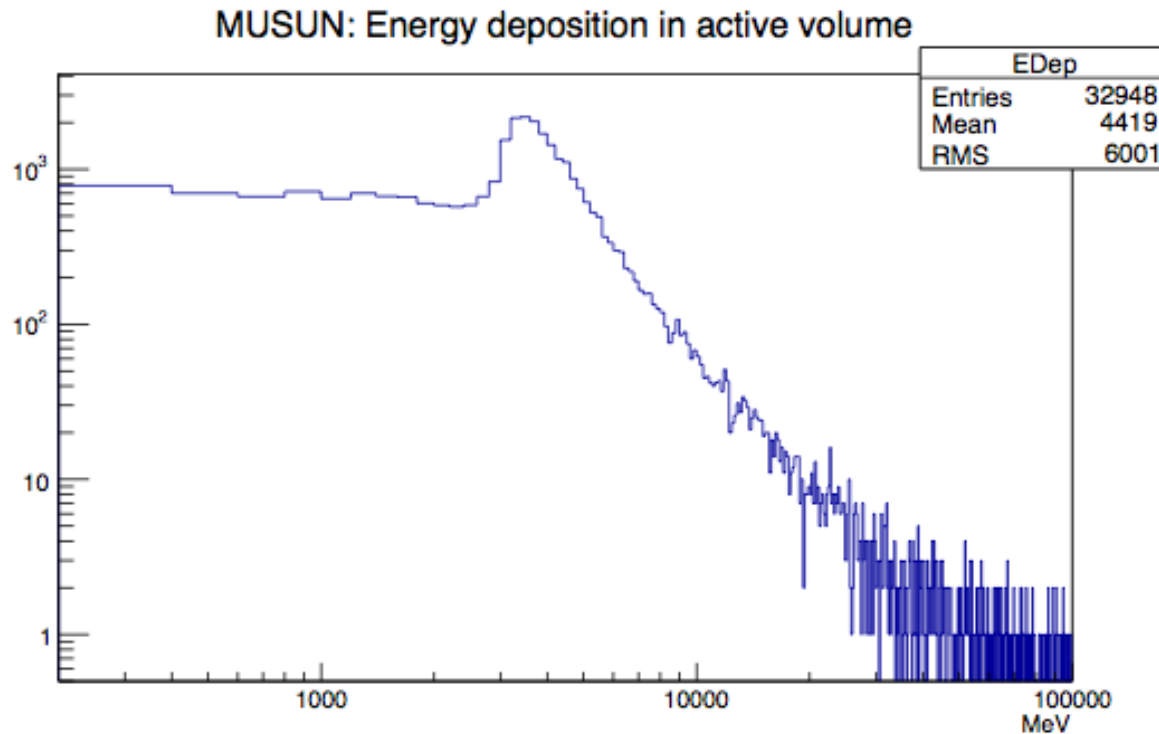
# Angular distributions



# Energy spectrum



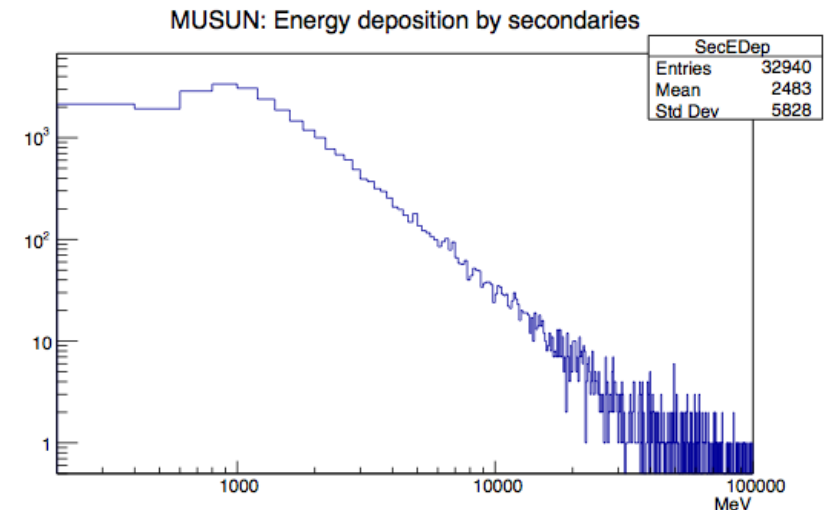
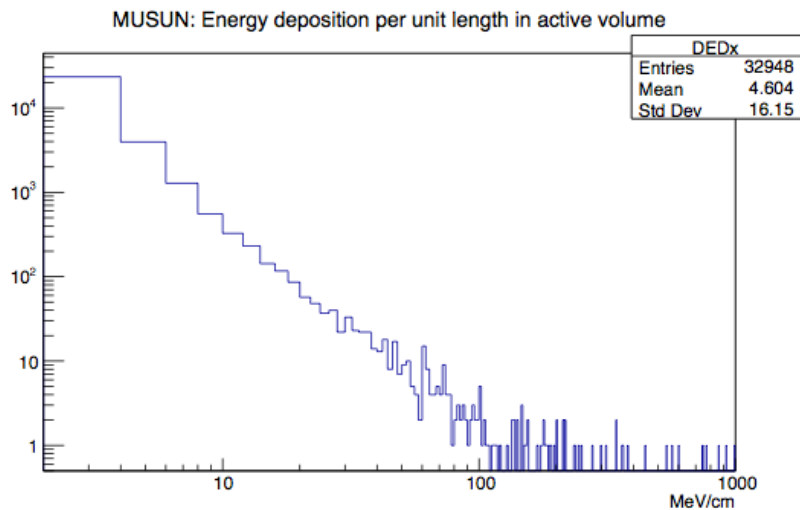
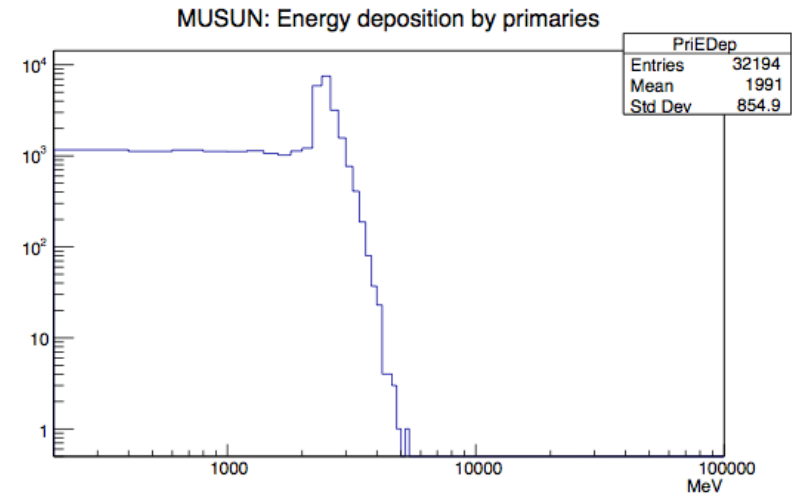
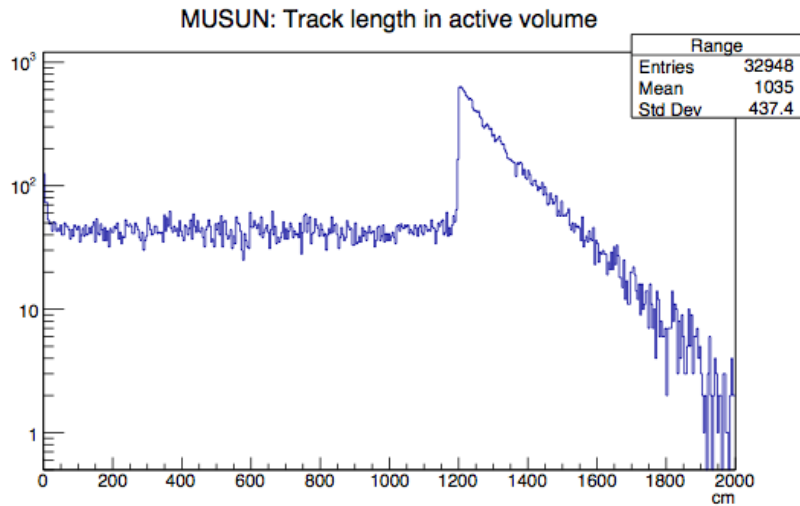
# Some results



- MC truth info.
- Energy deposition peaks at 3.5 GeV.
- Mean is 4.4 GeV.

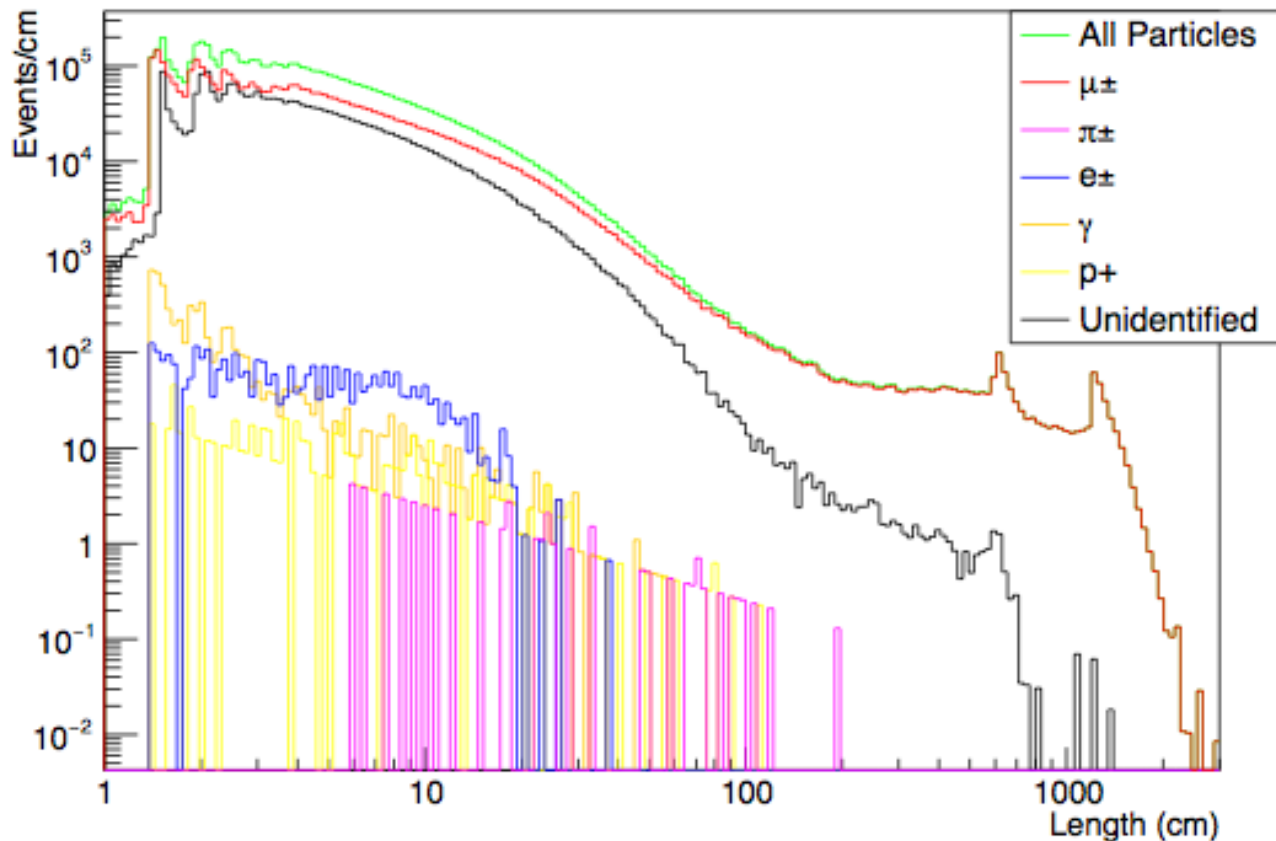


# More on energy depositions



# Reconstructed track length

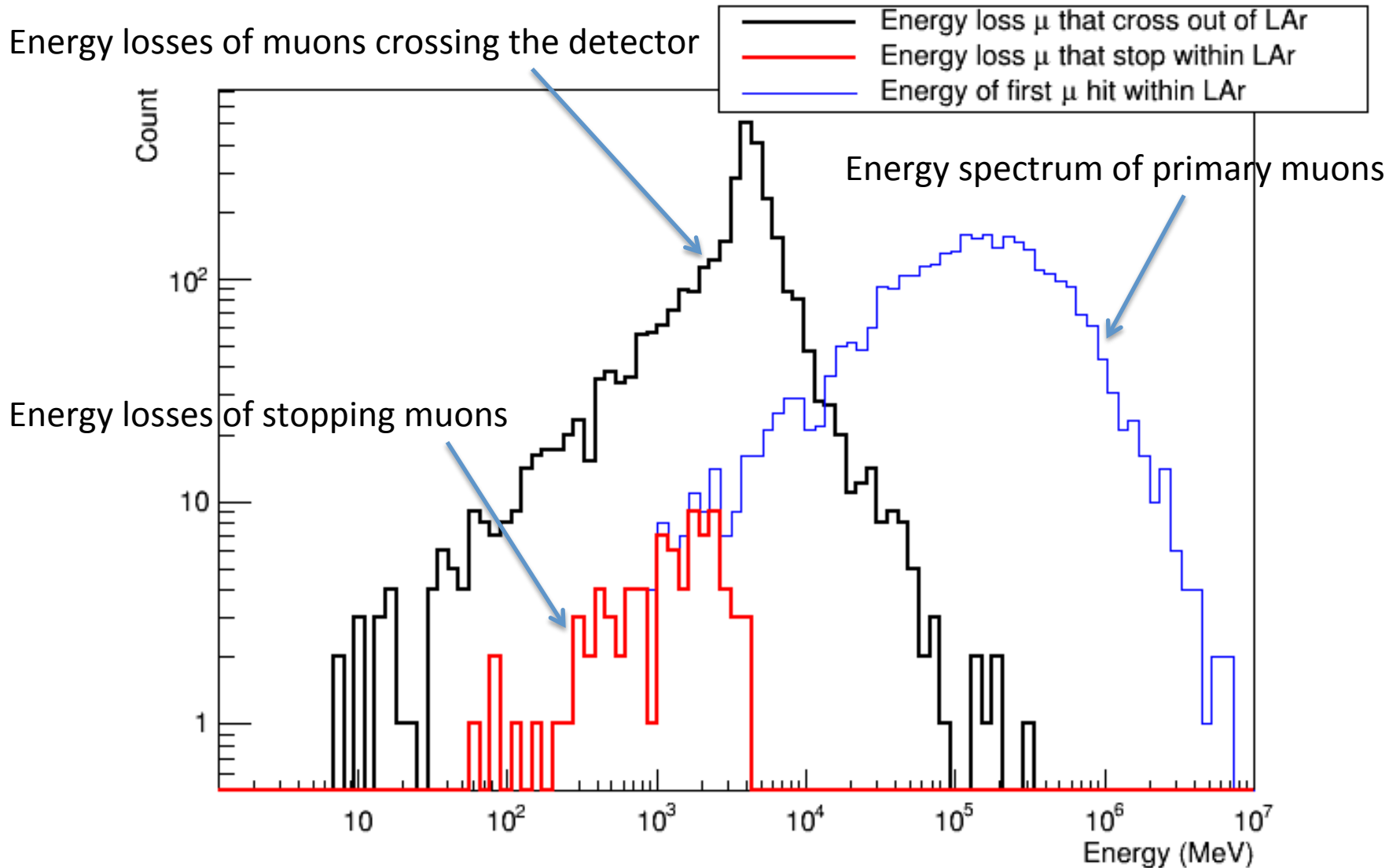
MUSUN: Reconstructed Track Length



This simulations were done in Autumn 2015

- Two peaks correspond to the full and half height of the detector (two or 1 cell).
- Many tracks consist of small segments treated as separate tracks.
- Reconstruction is not ready for high-energy muons.
- Many interactions (bremsstrahlung photons?) cause problems.

# Muon spectra (not for a designed geometry)



# Current status of simulations

- Limited resources.
- Main efforts on background for proton decay.
- Filter recorded events and information (events with long,  $> 1$  m muon tracks or without energy depositions are not recorded).
- Simulation of truth and development of simple cuts.
- Starting work on reconstruction.
- Requires lots of events.
- Muon events for calibration need to be generated without cuts.
- The main problem will be the disk space.