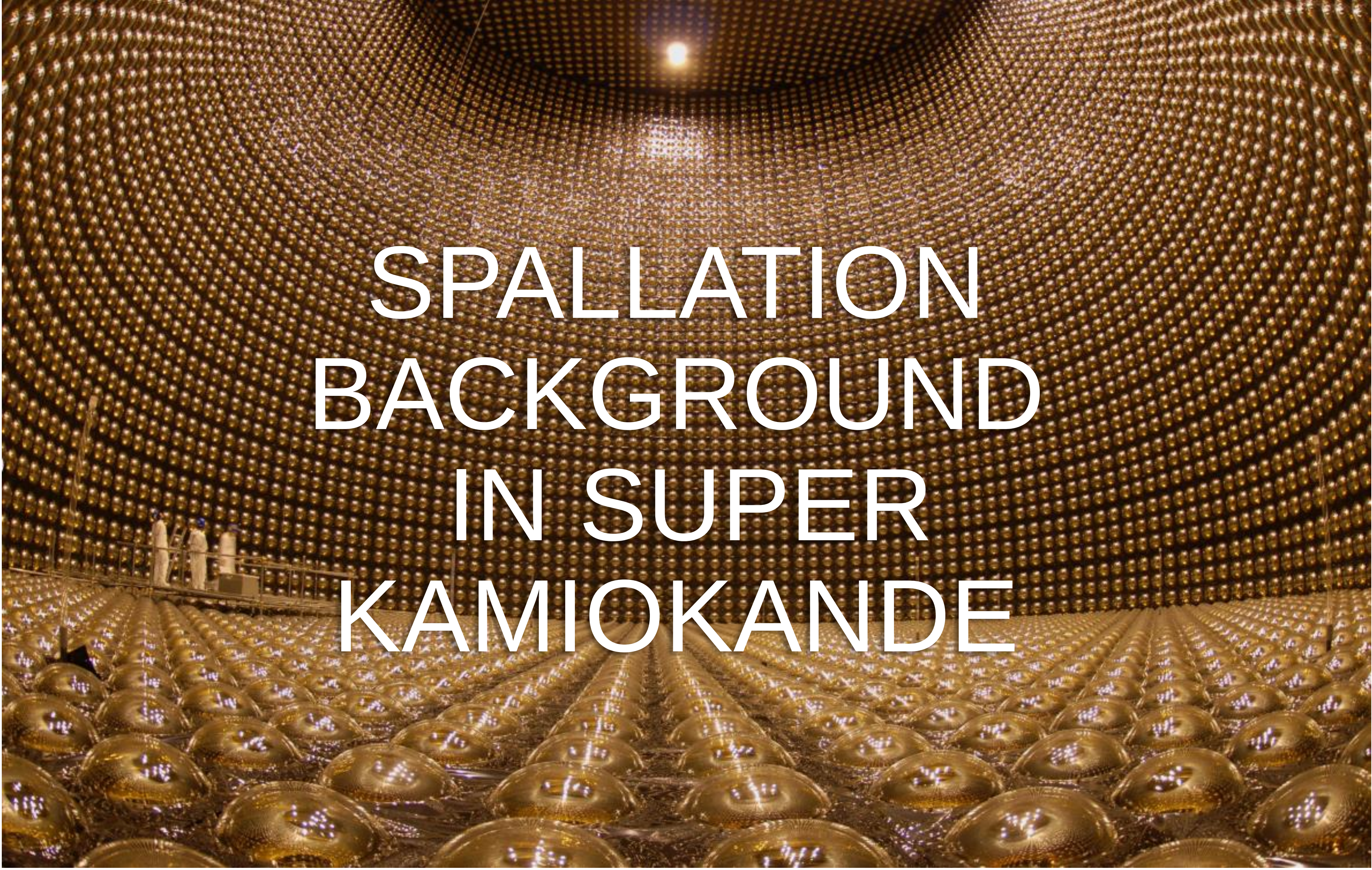


SPALLATION BACKGROUND IN SUPER KAMIOKANDE

XIX International Workshop on Neutrino Telescopes 24-02-021

Alice Coffani - LLR Ecole polytechnique

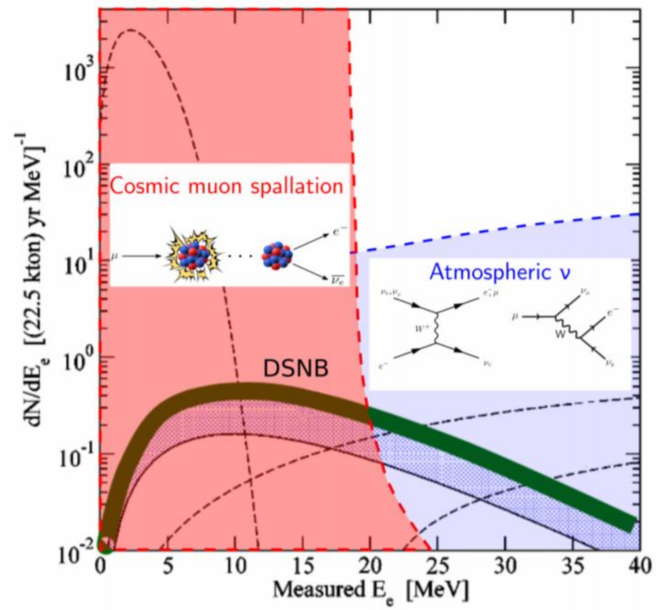
MOTIVATION

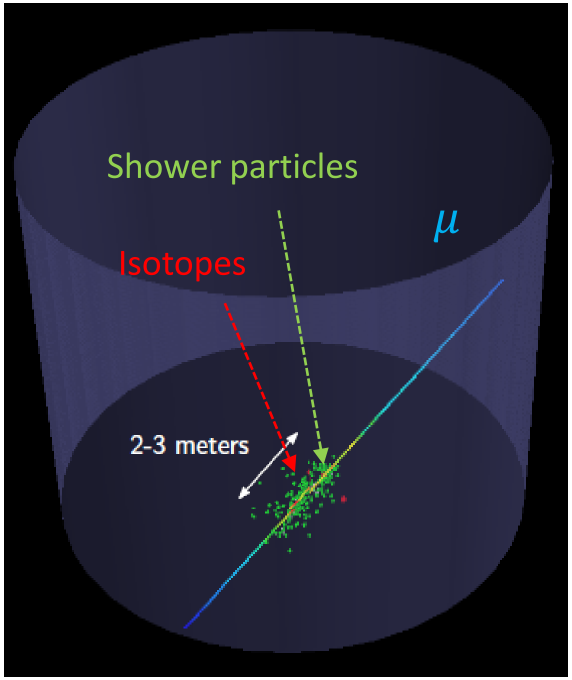
The Super-Kamiokande experiment has played a major role in astrophysics by investigating low energy O(10) MeV neutrinos, notably :

- **Solar neutrinos**
- **Supernova relic neutrino**

Currently the most critical background at SK in 6-20 MeV region are cosmic-ray muon spallation events.

Cosmic-ray muons in water can lead to nuclear breakup and initiate EM or hadronic showers containing spallation isotopes.





- **2 Hz muon rate**: about 1 μ every 2 minutes causes spallation in SK
- Main signatures: > 99% **β decays**
- Wide range of isotopes' half-lives (**10 ms up to 13 s**) : cuts have to be further improved to not overly discard signal events: 90% is cut leads to about 20% dead time

Reduction strategy:

- Identification of isotope clusters using neutrons from muon showers
- Investigate correlations between muons and candidate events

Need to characterize spallation background: SIMULATION

SPALLATION SIMULATION

The goal is to build a **FLUKA** based simulation for the calculation of cosmic-ray muon spallation backgrounds in SK: well characterized in liquid scintillators but not yet in water detectors.

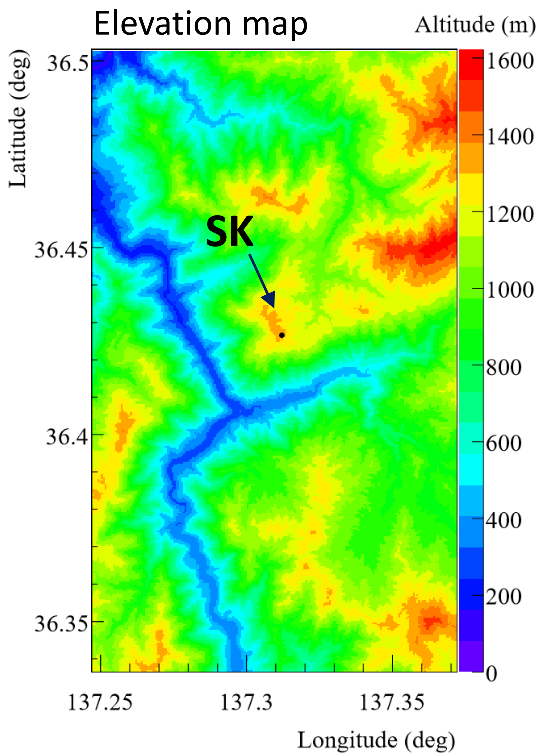
MUSIC
Generation of muons at surface and transport at SK depth

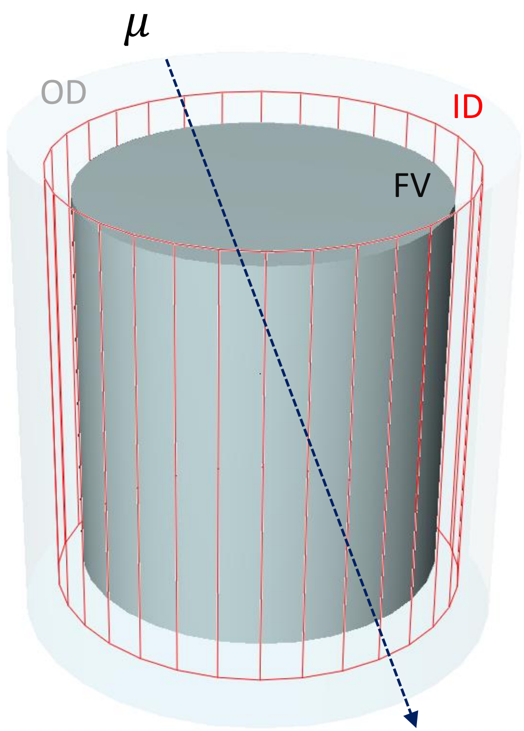
→

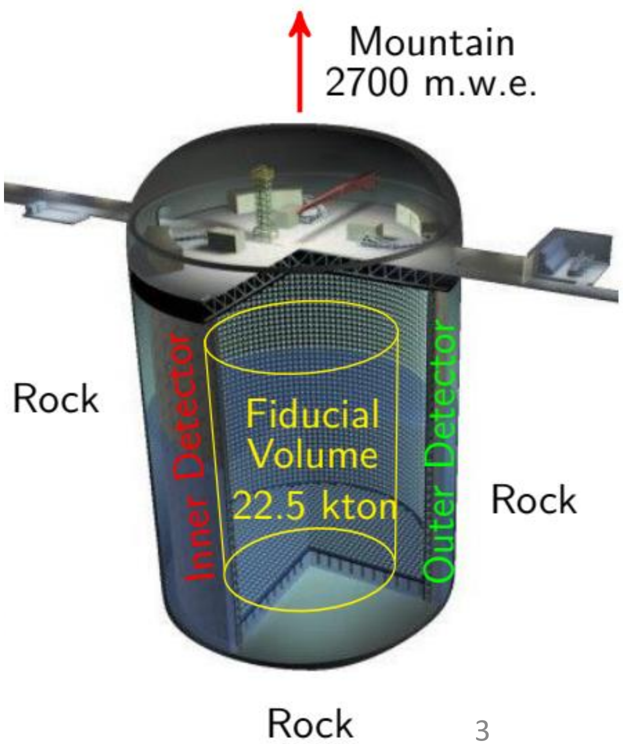
FLUKA
Simulation of spallation induced showers in water

→

SKDETSIM
Inject FLUKA results in the full SK detector simulation

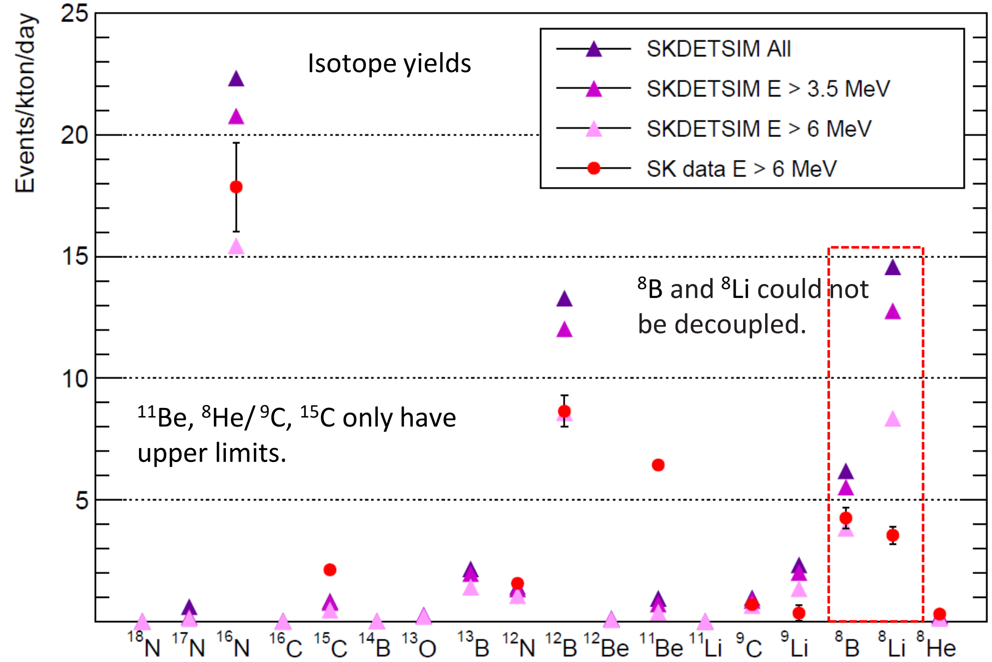






DATA-MC COMPARISON FOR ISOTOPES

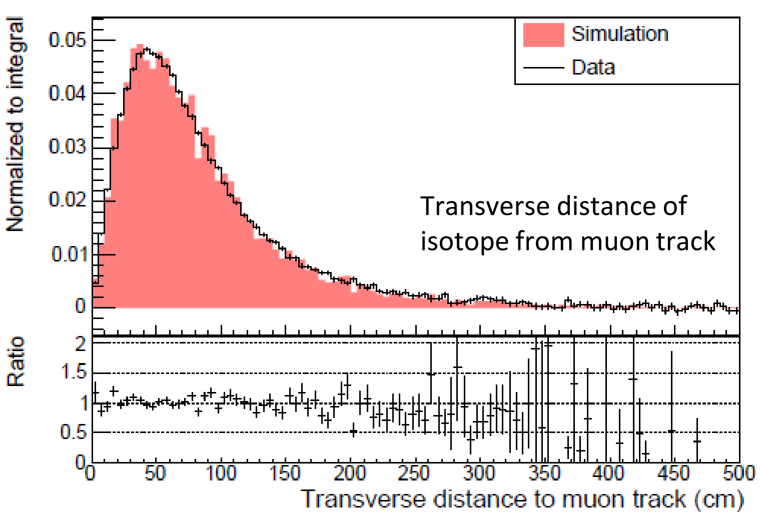
Comparison with data from *Y. Zhang et al. (Super-Kamiokande Collaboration) Phys. Rev. D* ***93****, 012004*.
The dominant error from the simulation: hadronic uncertainties could be of the order of 100%.

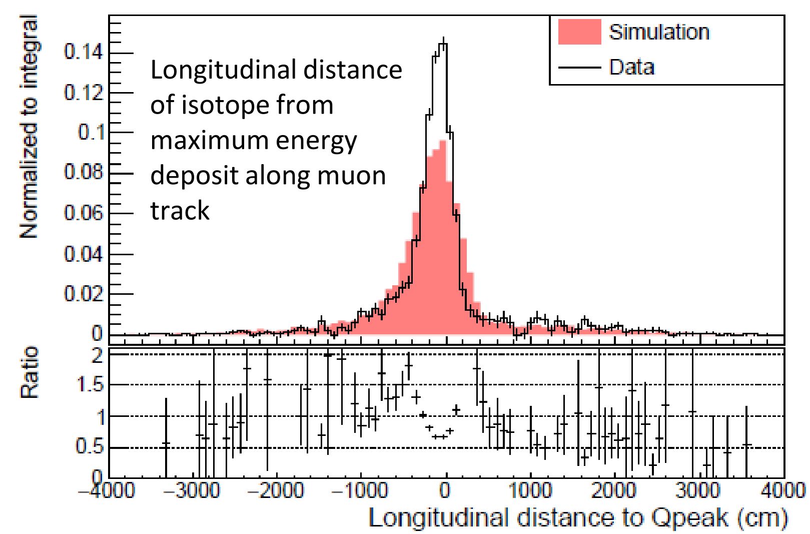


Overall good agreement:

- Isotope yields
- Pure geometrical variables

Misreconstruction of energy deposition along muon track possibly due to implementation in SKDetSim or intrinsic problems of the modelization: **Under study!**





NEUTRON CLOUDS

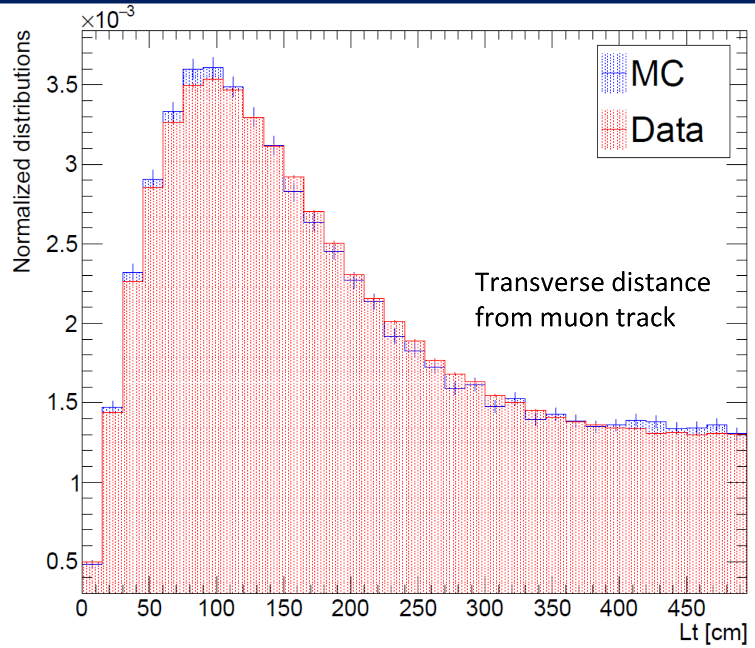
Why are neutrons so important?

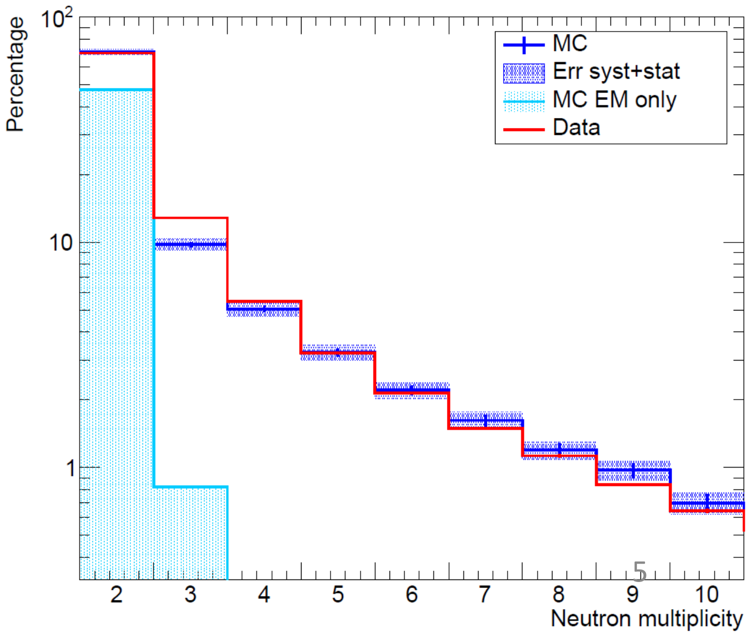
It is possible to directly see the hadronic shower, specifically looking for the neutrons produced:

- Most abundant particle in showers, more than 85% of spallation inducing muons produce at least 1 neutron
- Neutron events are tightly correlated to each other and the preceding muon → "Neutron clouds"
- Neutrons from showers capture on H emitting a 2.2 MeV photon → Use **WIT (Wideband Intelligent Trigger)** system
- Identification of isotopes created far form muons: ^{16}N
- Efficiency of n capture on H is one of the biggest limiting factors → enhanced with Gd (90% capture efficiency with 0.1% Gd) → **n-cloud will be a powerful tool for SK-Gd**

Overall good agreement between simulation and data:

- Geometrical properties on neutron clouds
- Neutron multiplicity





SUMMARY AND PERSPECTIVES

Decays of spallation isotopes represent a major background for low energy analysis in Super-Kamiokande:

- ✓ Built a FLUKA-based simulation to study spallation processes in SK induced by cosmic –ray muons:
  - FLUKA simulations cross-checked with existing results
  - Interfacing of FLUKA with SK detector simulation
- ✓ Comparison with data distributions were presented:
  - Good agreement for neutron cloud ;
  - Full understanding of the differences requires deeper study on the model incertitude.

- ➢ Running new simulations with Gadolinium doping in the water;
- ➢ Comparison with Geant4-based simulation.

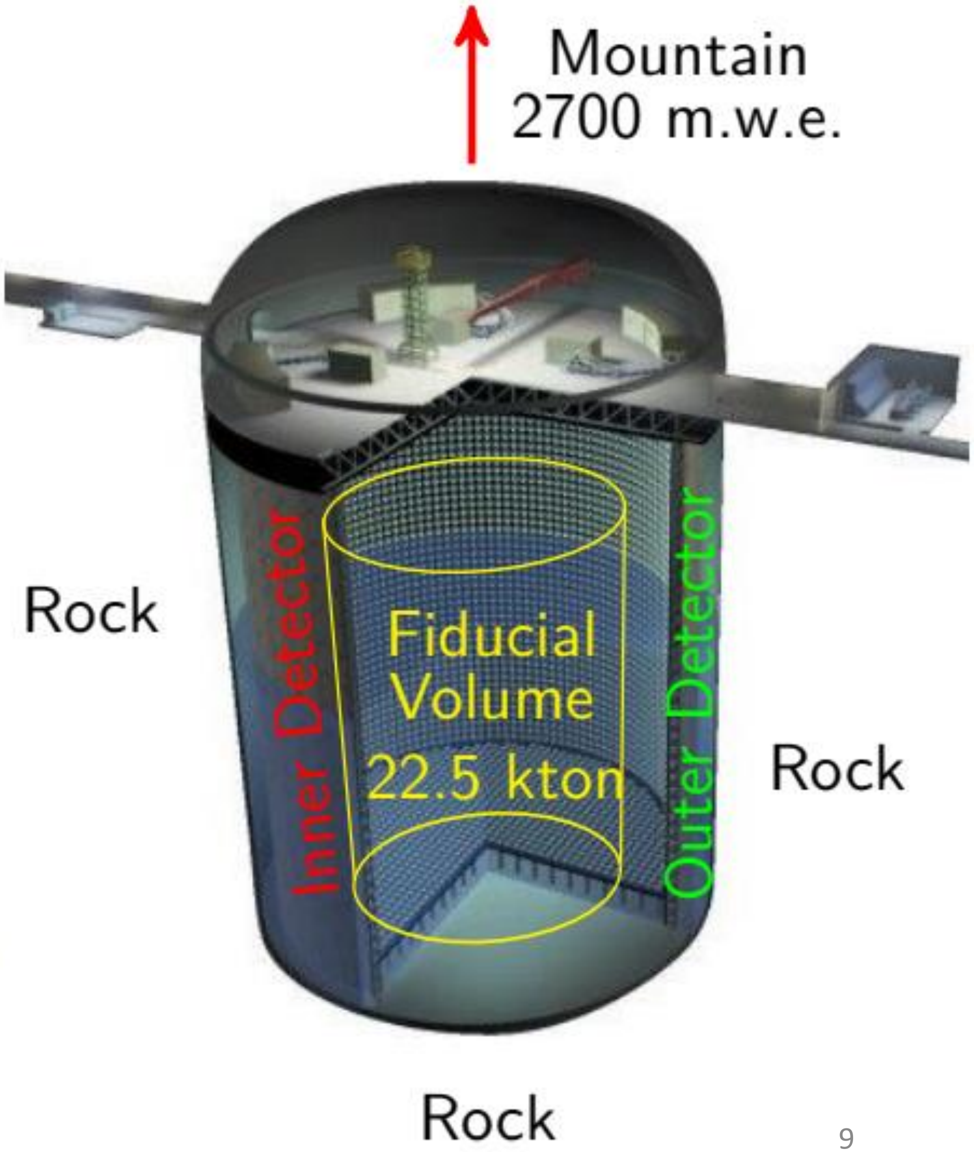
THANK YOU FOR YOUR ATTENTION

THANK YOU

BACKUP

SUPER KAMIOKANDE DETECTOR

- Located in the Kamioka Mine, Japan
- 1000 m underground (~ 2 Hz muon rate)
- 50 kton Water Cerenkov detector
- 11129 ID PMTs (3 ns, 50 cm resolution)
- Energy coverage : 4 MeV to ~ TeV
- Operational since 1996
- Gd loading just finished!



PIPELINE

MUSIC
Generation of muons at surface and transport at SK depth

→

FLUKA
Simulation of spallation induced showers in water

→

SKDETSIM
Inject FLUKA results in the full SK detector simulation

MUSIC gives a detailed determination of flux and energy spectra at SK depth:

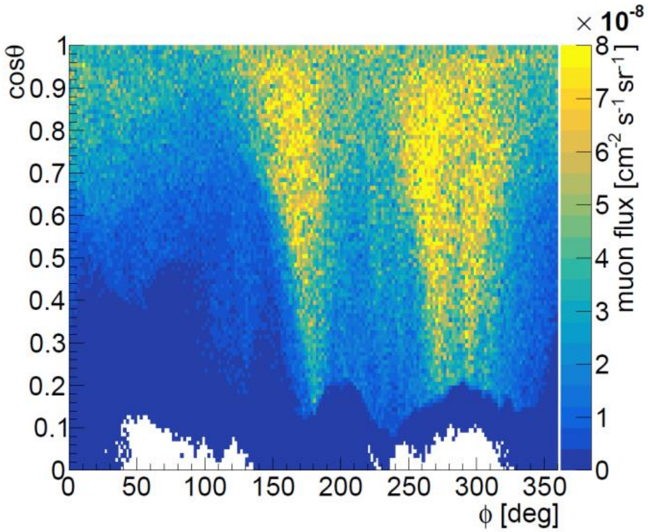
- Angle distributions
- Energy distribution (259 GeV mean E)

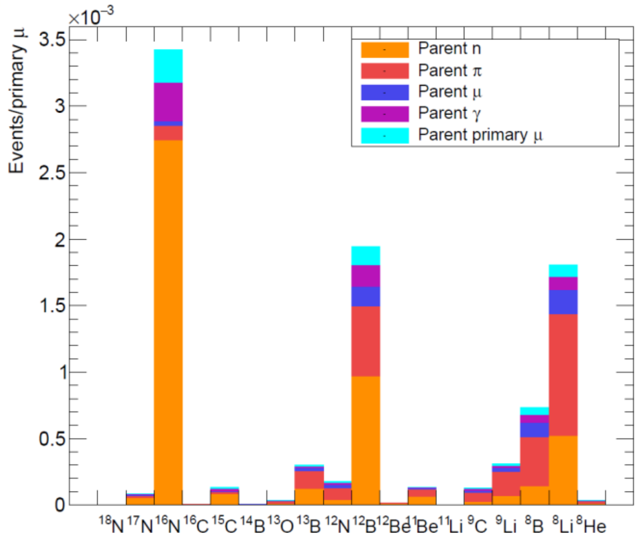
μ abundantly produce particles that initiate **electromagnetic** and **hadronic** showers leading to successive spallation processes.

- Shower properties
- Isotope production

Need to evaluate how to propagate the FLUKA events to SKDetSim.

- Unstable isotopes are mainly produced in showers → Need to save shower particles from FLUKA
- Turn off the creation of secondaries in hadronic processes
- Turn off muon nuclear interactions
- Let SKDetSim take care of the electromagnetic part → Production of light



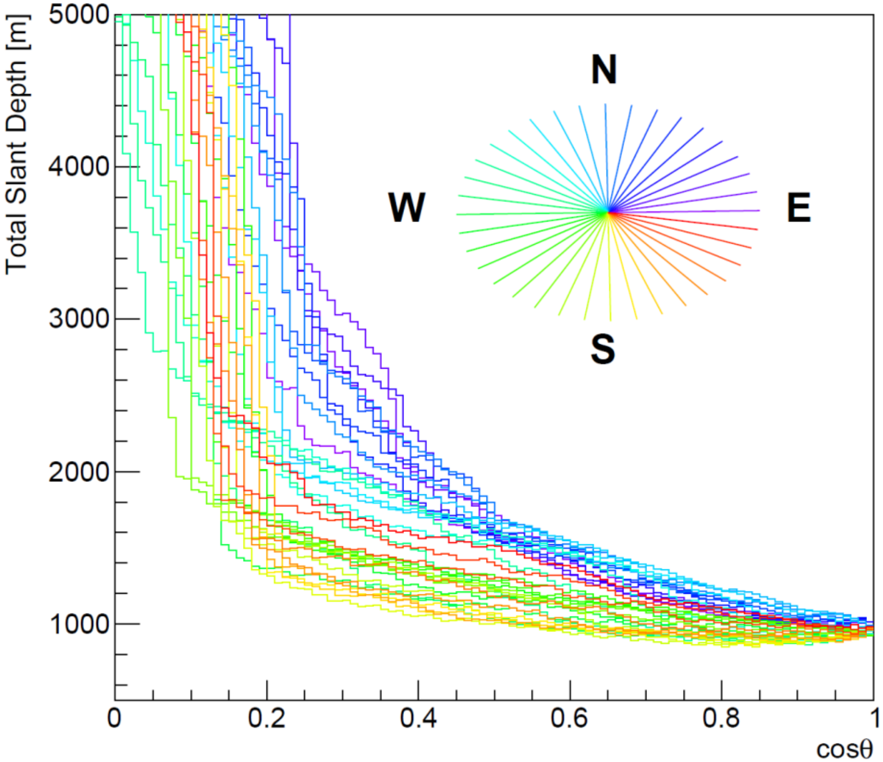


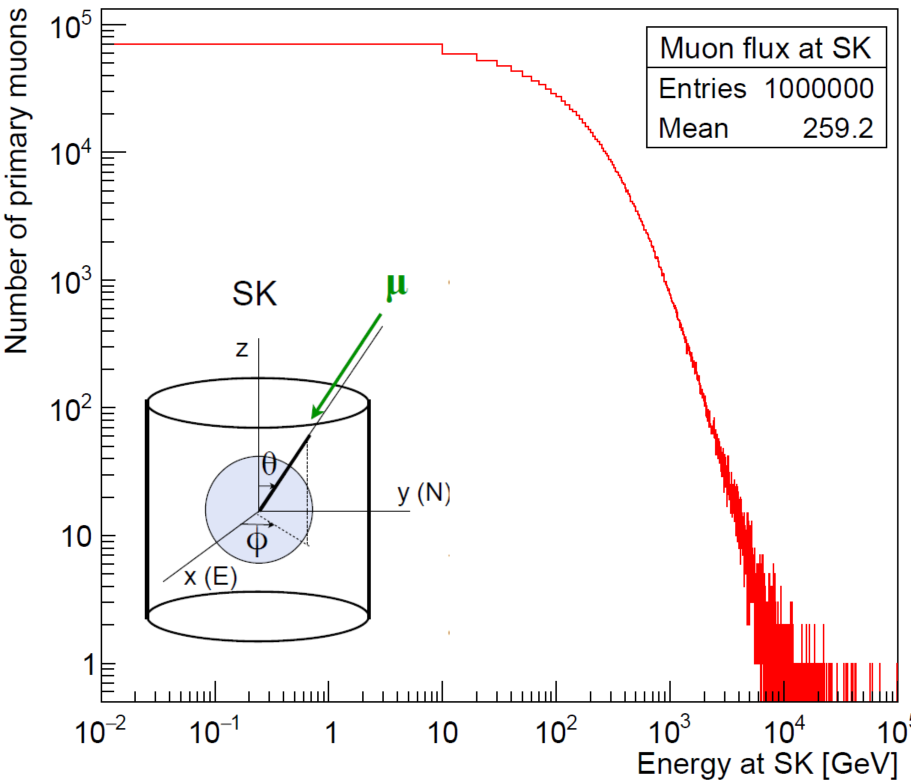
MUSIC: MUON FLUX CALCULATION

Elevation data to reconstruct the Ikenoyama topological profile were derived from the Geographical Survey Institute of Japan.

MUSIC muon simulation code generates muons at surface, transports them through the digital profile of Ikenoyama and gives a detailed determination of flux and energy spectra at SK depth.

Production yields of radioactive isotopes from muon initiated spallation are energy dependent: SK does not measure the muon energy → Estimated by simulation.





NEUTRON CLOUD: DEFINING PARAMETERS

How do we parametrize the neutron cloud:

- Transverse distance (Lt):

  Distance of closest approach of event to track

- Longitudinal distance (Ll):

  Distance along track direction

  Taken as $(Ll_i - Ll_{avg})$ for neutrons

- Time difference (dt):

  Time from muon to candidate

- Multiplicity:

  Number of candidate events per muon