Accelerator-Based Measurement of Muon-Induced Neutron Background for Underground Science

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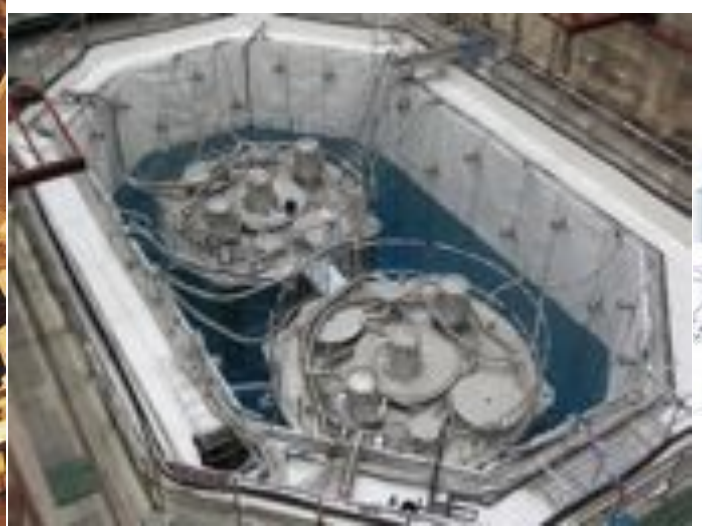
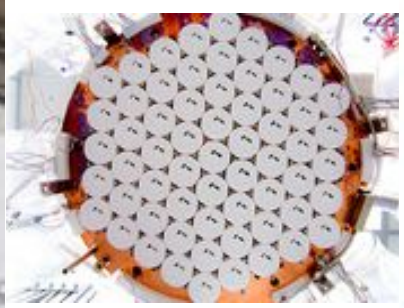
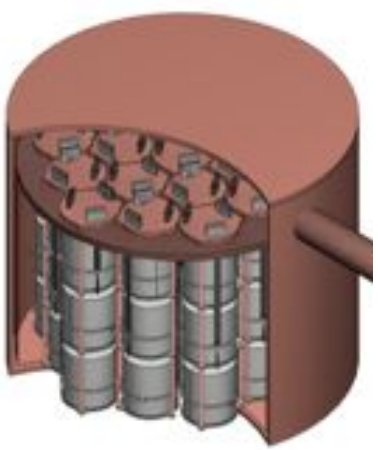
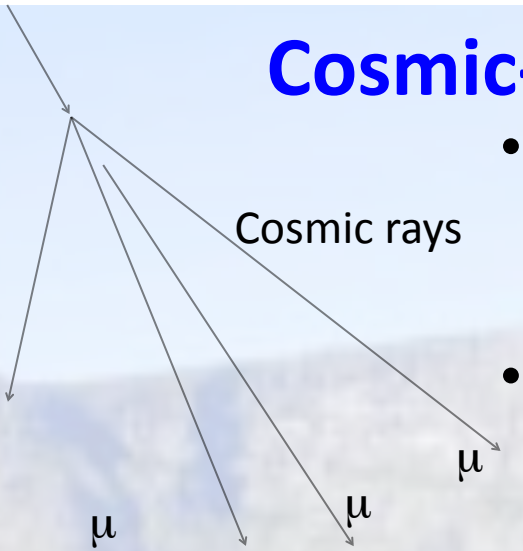






Cosmic-Ray Muon-Induced Backgrounds



- Rare searches need to go deep underground to shield detectors from cosmogenic backgrounds
- Mean muon energy at some of the deep underground labs is around 300 GeV

- Two categories of "problematic" muon-induced backgrounds:
  - Fast neutrons
  - Radioactive isotopes, such as ^{9}Li, ^{8}He, ^{11}C, ^{7}Be, etc. (isotope production is linked to neutron flux)

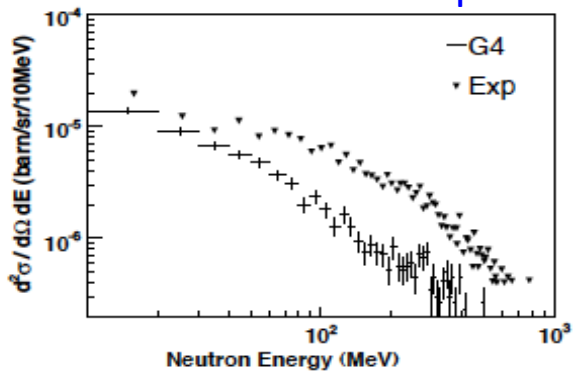
- Fast neutron is difficult to shield and is one of the most serious backgrounds for dark matter, $0\nu\beta\beta$, and other searches

- Modeling of these backgrounds has proven to be very challenging

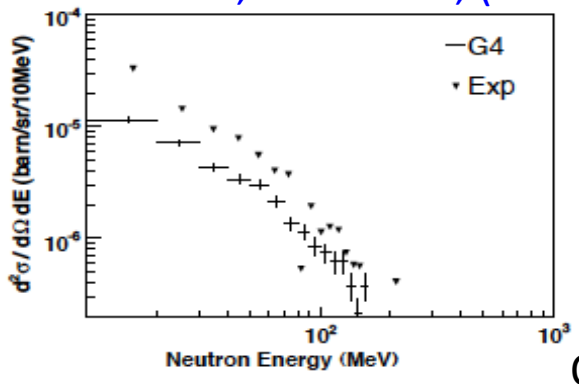
- Underground sciences would greatly benefit from more comprehensive set of muon-induced neutron production data

- NA55 took data at M2 ~15 years ago was the last expt that measured fast neutron productions at a muon beamline
- However, they used a “thin” target for spallation studies and only one muon beam energy (190 GeV)
- After all these years, differences between data and simulation (GEANT4, FLUKA) are still not fully understood ☹

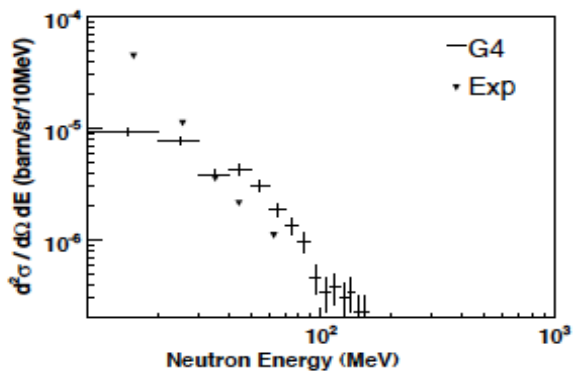
GEANT4 and NA55 Comparisons (Marino *et al.*, NIM A582, (2007), 611)



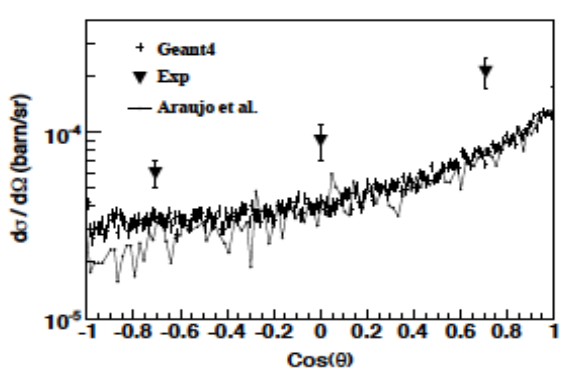
(a) θ =45°



(b) θ =90°



(c) θ =135°



(d) Angular distribution.

Other references:
NIM A545 (2005), 398
Astropart. Phys. 31 (2009) 366

Proposal

- Once and for all, provide a more comprehensive set of neutron production data that can be used to benchmark GEANT4 and FLUKA with minimal assumptions

- Modest scale fixed target experiment to measure:

  - neutron production rates, angular distributions, multiplicity, and energy spectrum

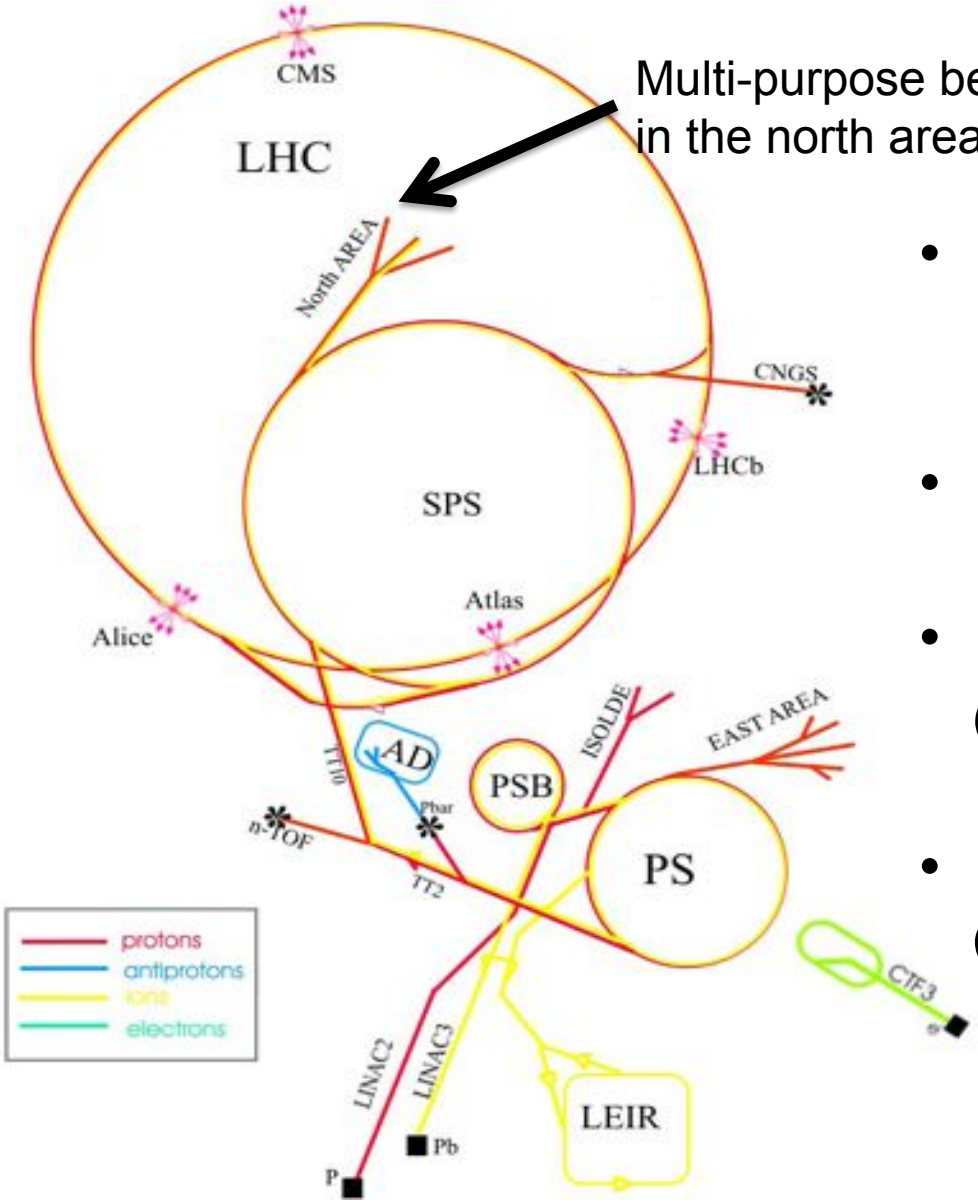
  - for different targets (low *Z* to high *Z*, solids and liquids?)

  - from thin to thick targets

  - production properties as a function of muon energy

- See talks from Monday's AARM collaboration meeting for more physics motivations for this measurement

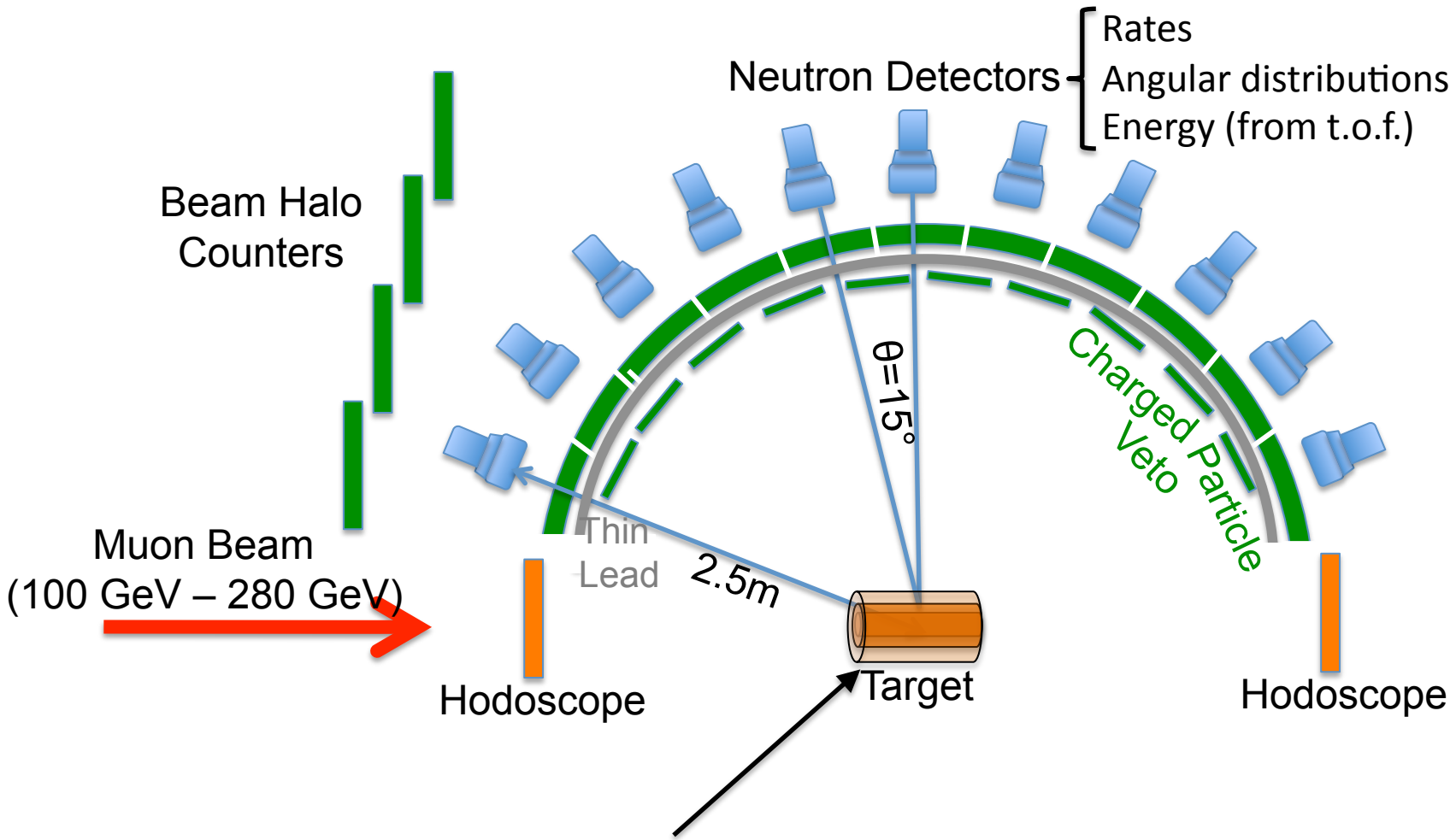
CERN ACCELERATOR COMPLEX



Multi-purpose beamlines in the north area

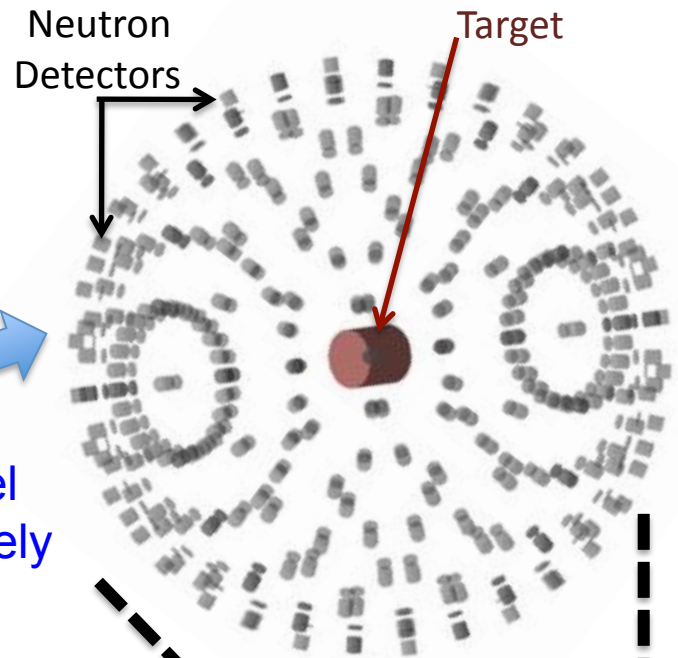
- M2 beamline in the North Area provides high intensity muons
- Muon energy up to 280 GeV
- ~10^8 muons per spill @ 160 GeV (45 sec duty cycle)
- Currently being used by the COMPASS experiment

Cartoon Sketch of the Neutron Production Experiment



- Target radius is varied to measure neutron production vs. target thickness.
- Potential targets: graphite, copper, lead, H_20, liquid scintillator, etc.

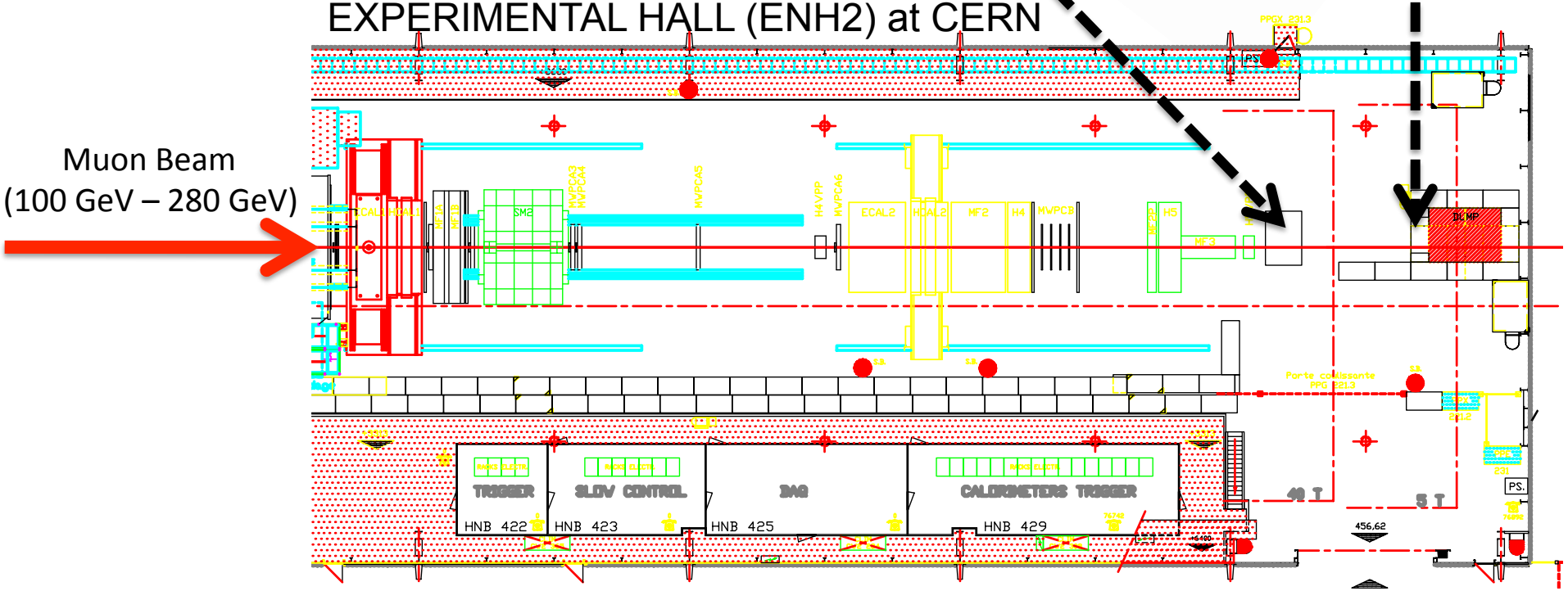
Proposed location of the neutron production setup is down stream of the COMPASS spectrometer
In EHN2 experimental area at CERN



Our current GEANT4 model for studies. Final design likely to have fewer detectors

EXPERIMENTAL HALL (ENH2) at CERN

Muon Beam
(100 GeV – 280 GeV)



Feasibility Study at CERN*

- Conducted a beam test at CERN recently to study the feasibility of using the CERN M2 beamline to measure neutron production properties

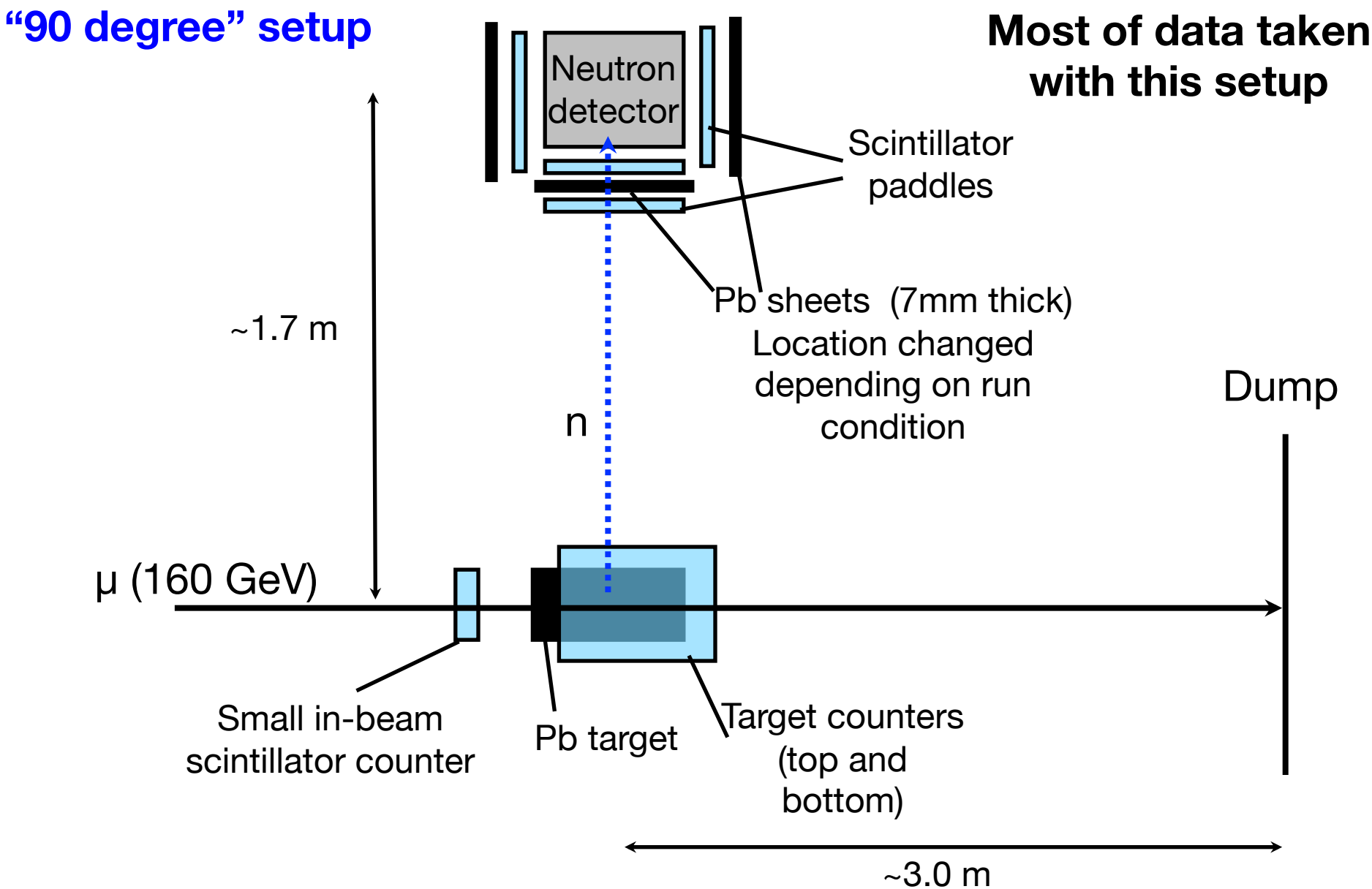
- Surveyed beam backgrounds and evaluated Sandia Lab's neutron detector (thanks to Erik Brubaker) performance in beam environment

- CERN accelerator division also conducted a short test on our behalf to demonstrate the feasibility and stability of running M2 at the maximum energy of 280 GeV

- The beam tests were very successful and addressed many technical concerns. Initial goal was just a feasibility study, but now trying to extract some physics results from the data

* **Many thanks to the COMPASS collaboration and CERN accelerator group**

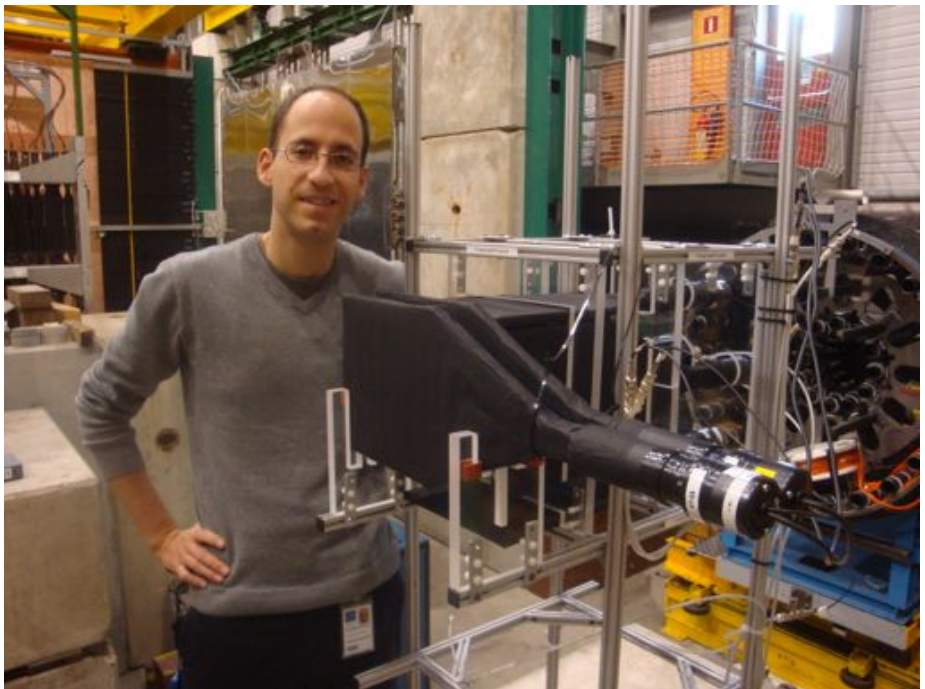
Beam Test Setup

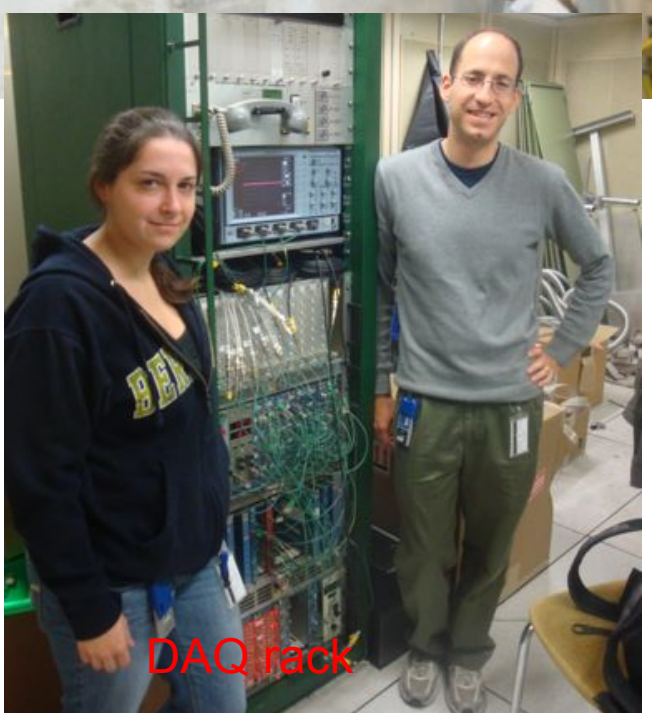


Beam Test Installation and Commissioning Photos

Installing the Neutron Detector Assembly

Close-up of detector assembly



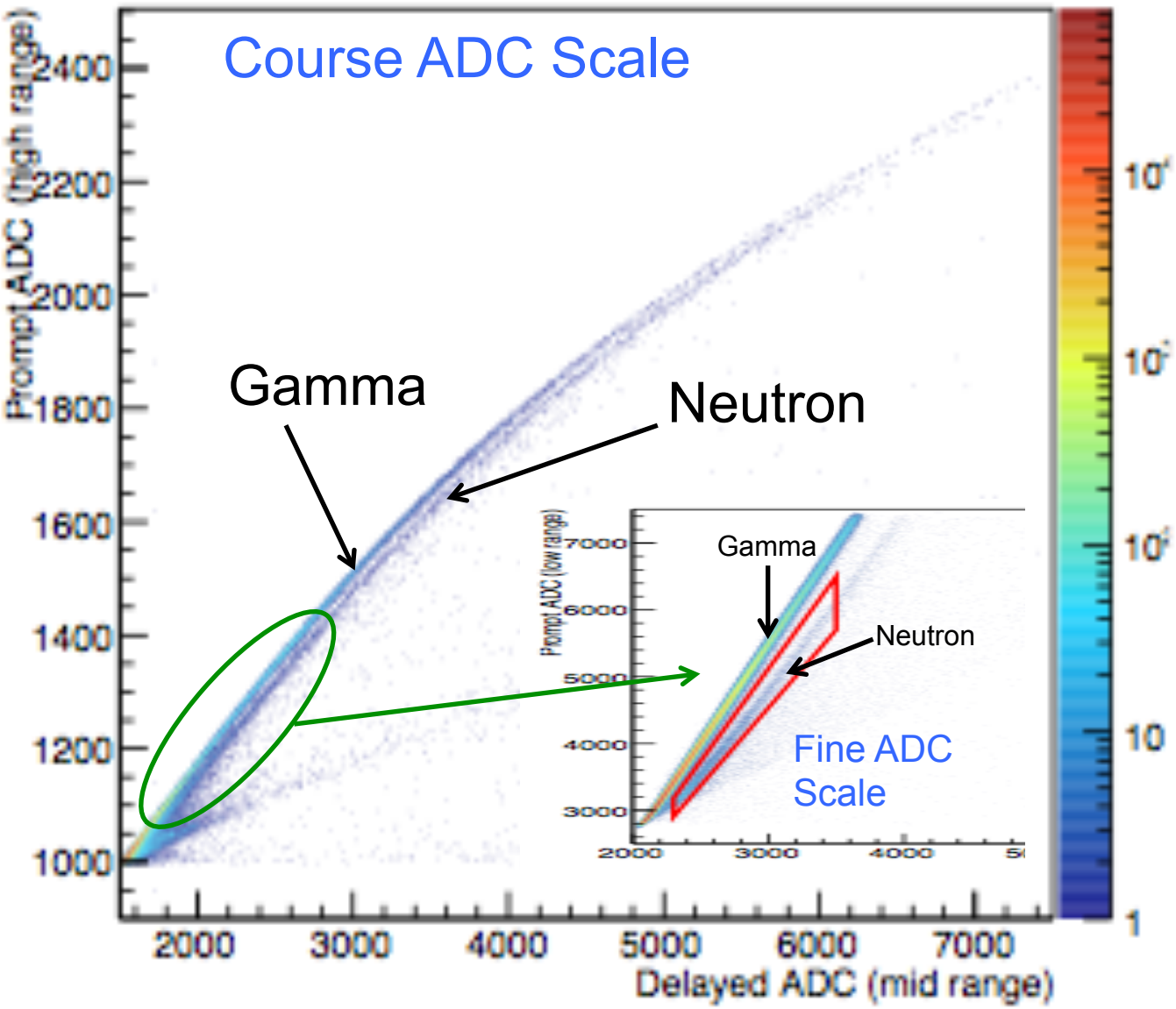


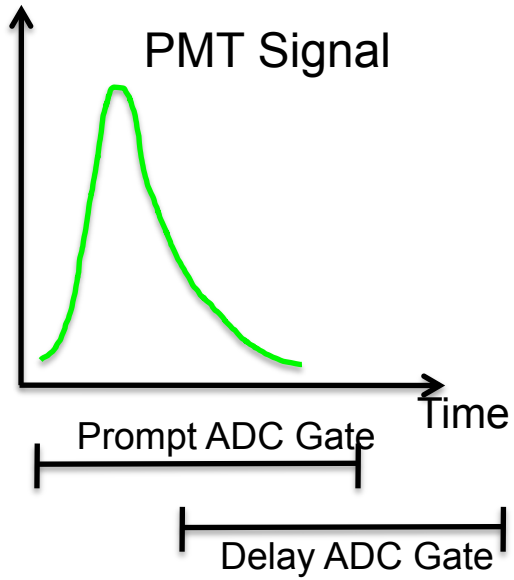
DAQ rack

Looking at initial beam data

Preliminary Results

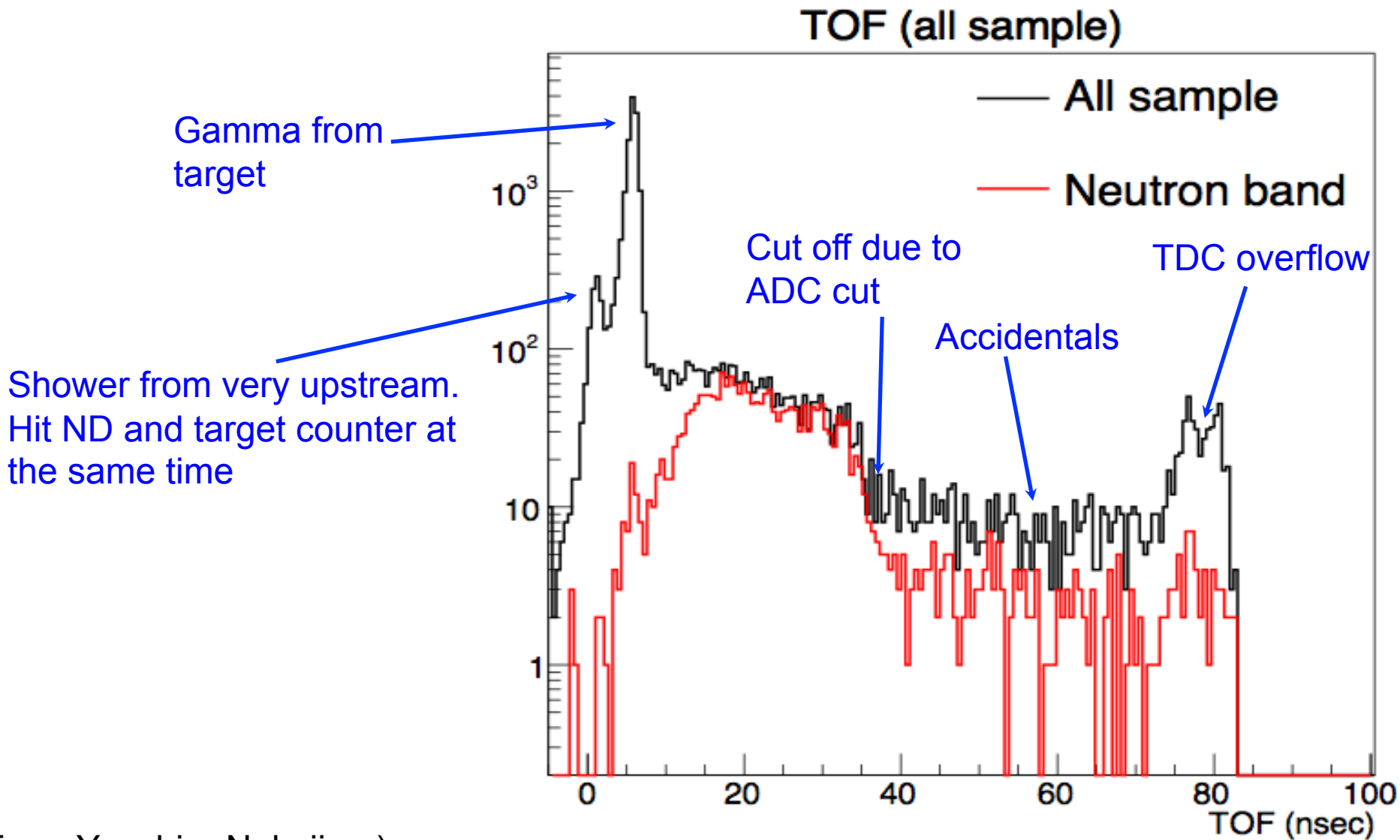
Data analysis is still ongoing, showing some highlights today





Good gamma-neutron separation over a wide energy range

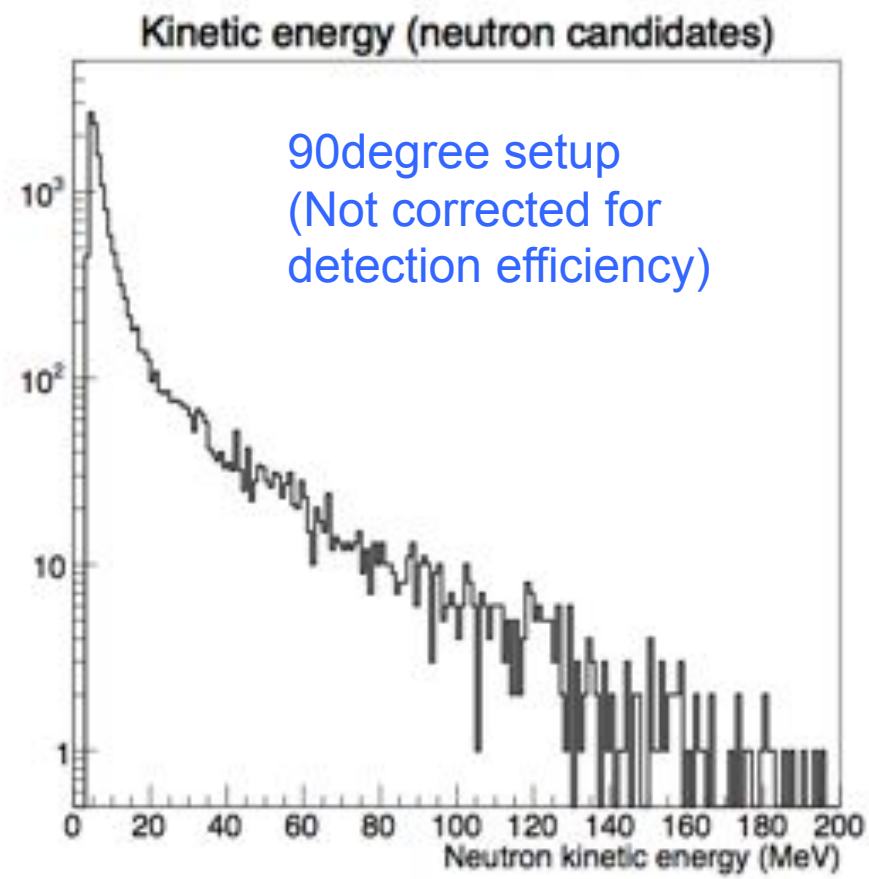
TOF Distribution



(From Yasuhiro Nakajima)

CERN Feasibility Study

Reconstruct kinetic energy assuming neutron mass



- Plan to complete data analysis (90deg, +45deg, -45deg) by this summer
- One of the main systematic uncertainty is neutron detection efficiency. Plan to use 88" cyclotron at LBNL to constrain the efficiency
- Plan to compare GEANT4 and FLUKA predications with our data

Summary

- We propose to carry out an experiment to systematically measure muon-induced neutron production at CERN
- Results would greatly benefit many current and future underground experiments → having a robust understanding of backgrounds is an essential step to any claim of discovery!
- Feasibility study at CERN was very successfully. Have addressed technical concerns of the "full experiment" (e.g. design choice, experimental space, beam time, CERN approval, etc.)
- This is a small scale experiment, but in the era of tight budget, will need broad community support to go forward
- We welcome more collaborators!

BACKUP SLIDES

TOF vs. Energy Deposit

Clear correlation between TOF and energy deposit