University of Messina
Department of Mathematical and Computer Science, Physical Sciences and Earth Sciences
PhD in Physics

Opportunities beyond hadron physics @ JLab: infrastructures

Mu and Nu beams using Hall-A Beam Dump

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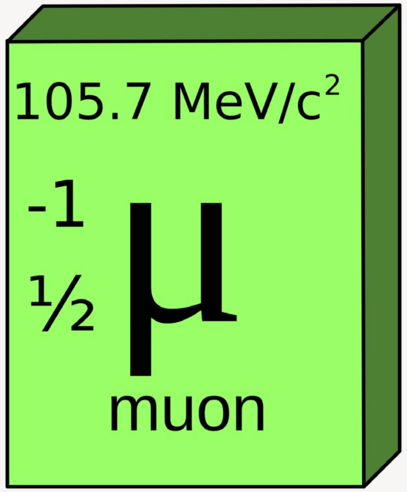
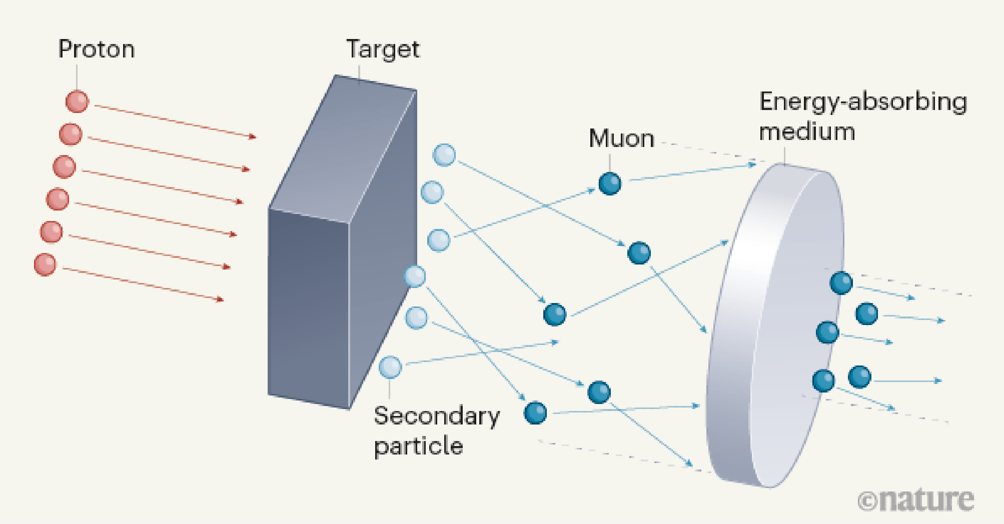
Outline

1. Muon beam
    - The experimental setup of the simulation
    - Results of the simulations
    - Muon tagging system
    - Muon beam momentum measurement
2. Neutrino beam
    - Results of the simulations
3. Conclusions

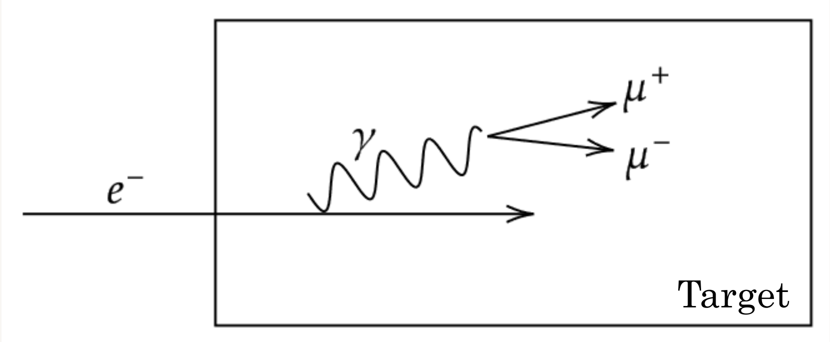
Muon beam





Muon beams can be obtained from:

1. Proton beams (decay)
2. Electron beams (radiation $\rightarrow \mu^+\mu^-$)

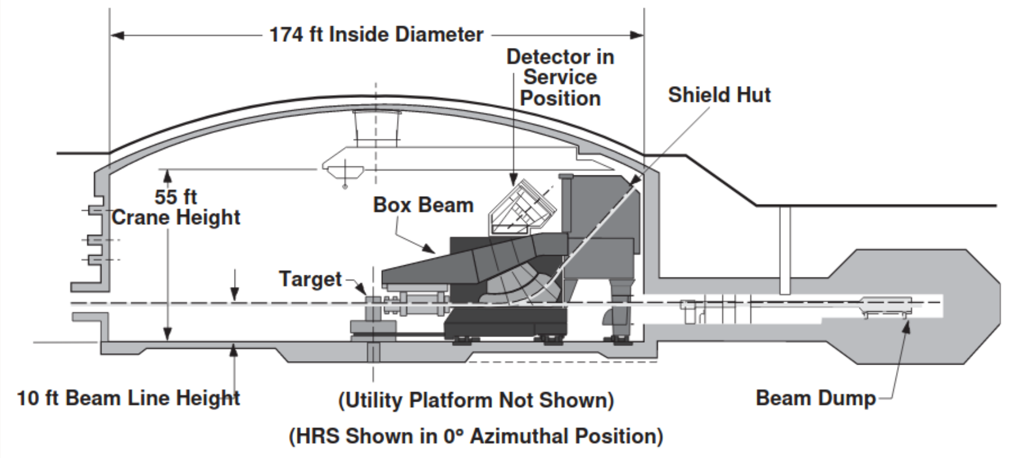


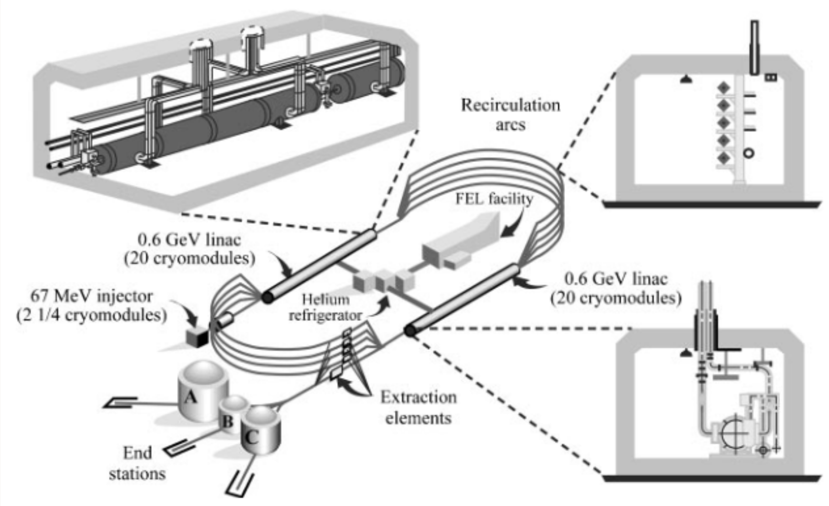
Jefferson Lab

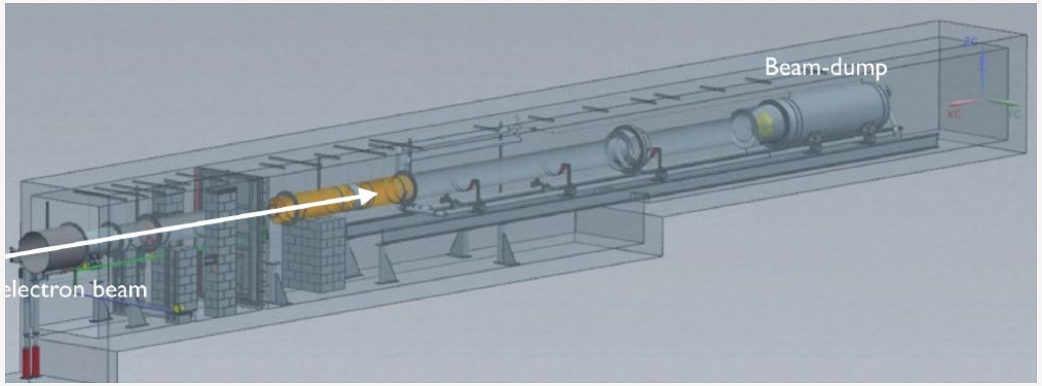
The simulated muon beam is obtained from the JLab electron beam

- $E \approx 11\ GeV$
- $I \approx 100\ \mu A \rightarrow 6.25 \times 10^{14}\ e/s$
- Continuous beam

} Intense beam

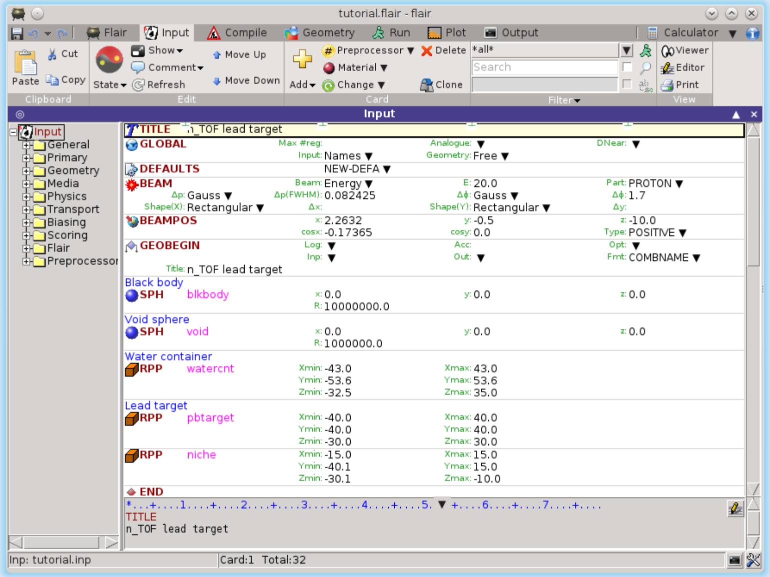




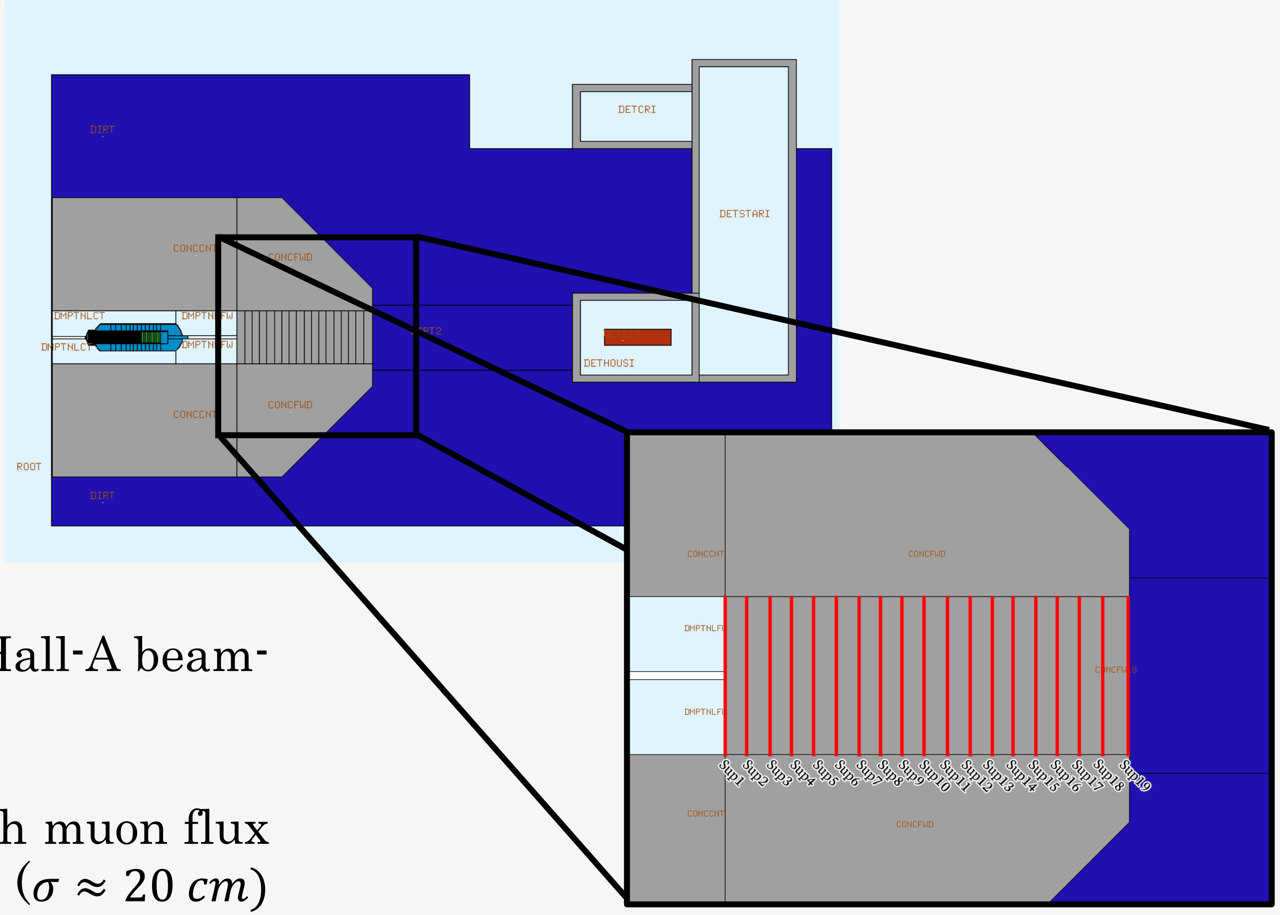


The experimental setup of the simulation

The simulations were performed using FLUKA



FLUKA geometry courtesy of A. Celentano & L. Marsicano



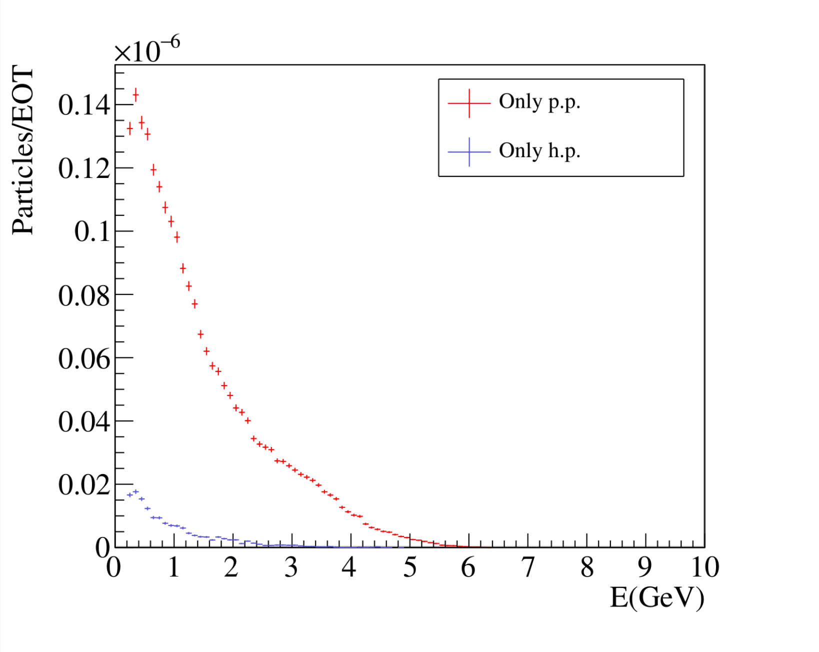
For the simulations, a simplified geometry of Hall-A beam-dump provided by RadCon was used.

Downstream of the concrete vault there is a high muon flux ($\approx 10^9\ \mu/s$), with compact spatial distribution ($\sigma \approx 20\ cm$) and with an energy spectrum $\propto 1/E_\mu$.

Muon production: decay vs radiation

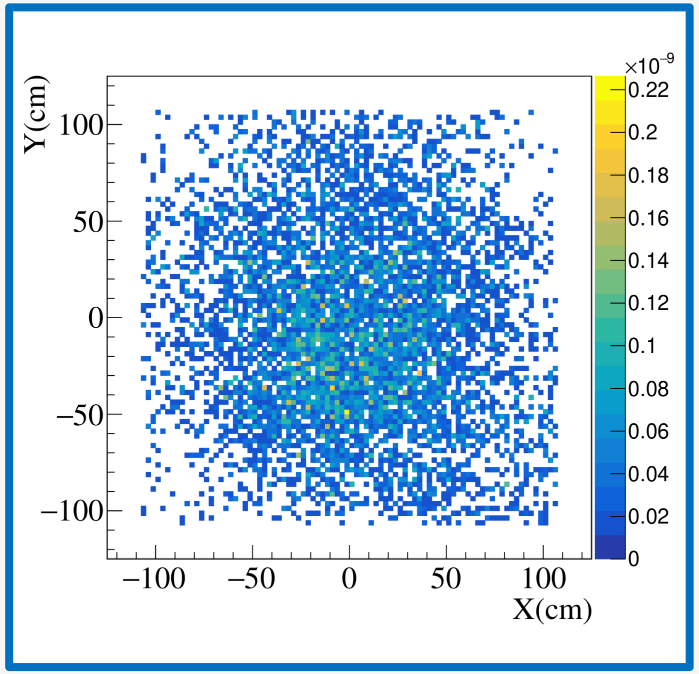
Muons are mainly generated by pair production and are more focused than muons produced by hadronic decays

Composition of the muon beam

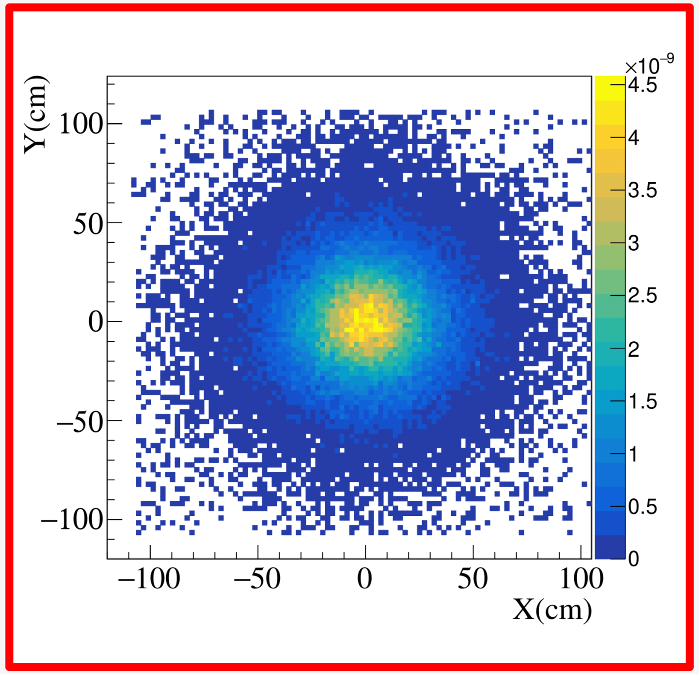


Muon energy spectrum:

- Muons produced by pair production
- Muons produced by hadronic decays



Spatial distribution of muons generated by hadronic decays



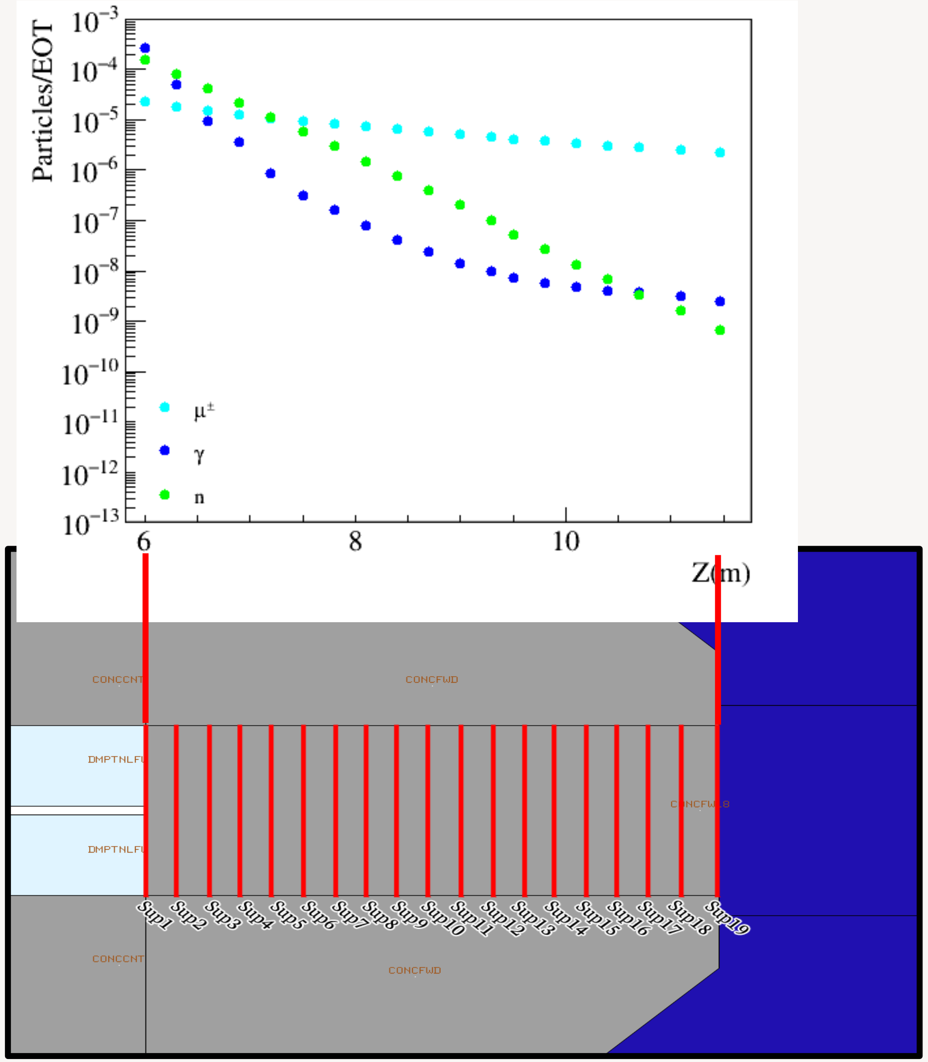
Spatial distribution of muons generated by pair production

Results for an 11 GeV electron beam

10^8 electrons on target (EOT) with a momentum $p_{e^-} = 11\ GeV$ were simulated

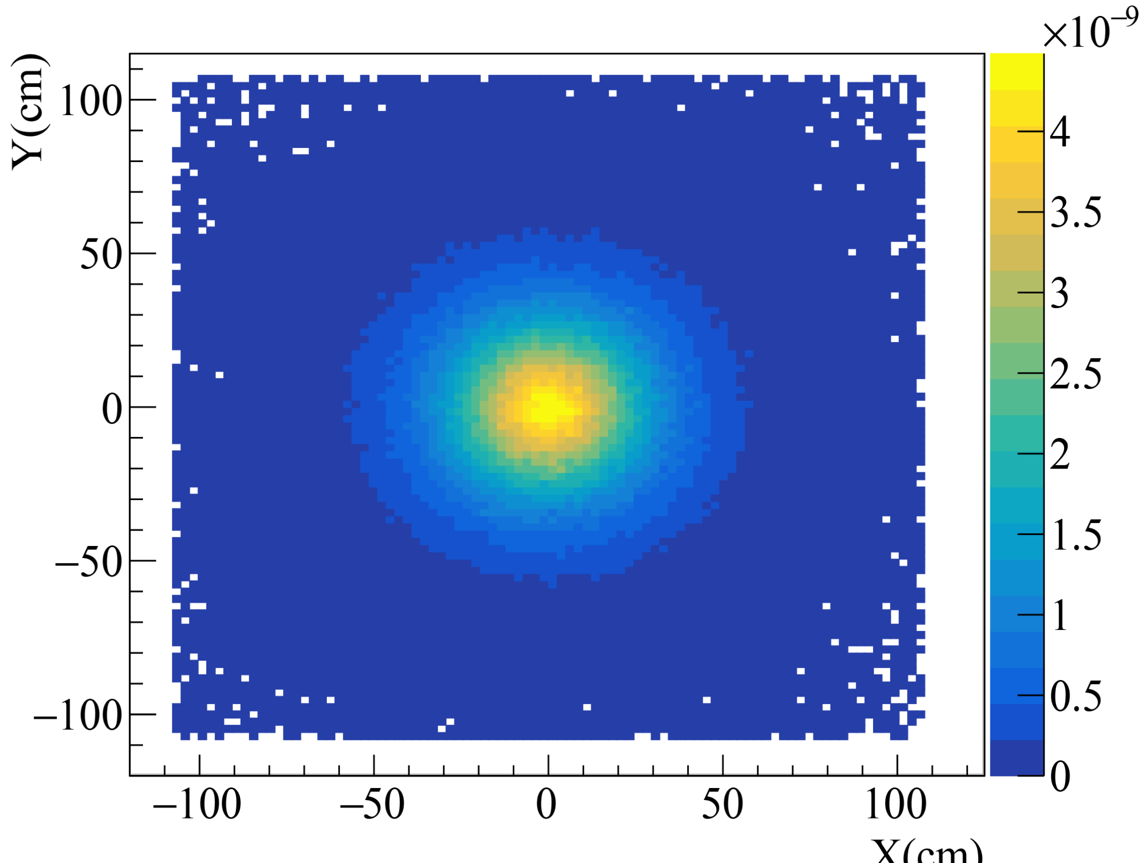
The particles were sampled in each surface only when:

$$T > 100\ MeV$$

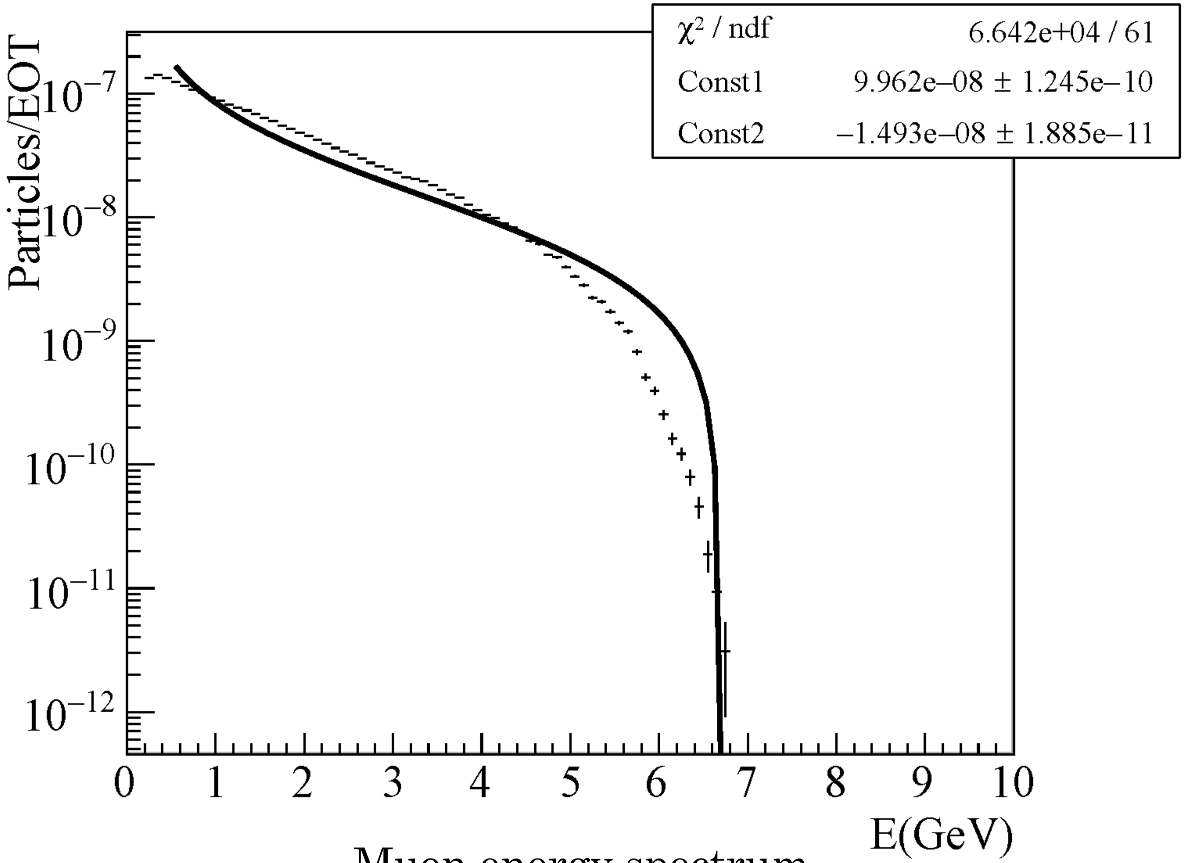


Results for an 11 GeV electron beam

Muon distributions and spectrum downstream of the concrete vault



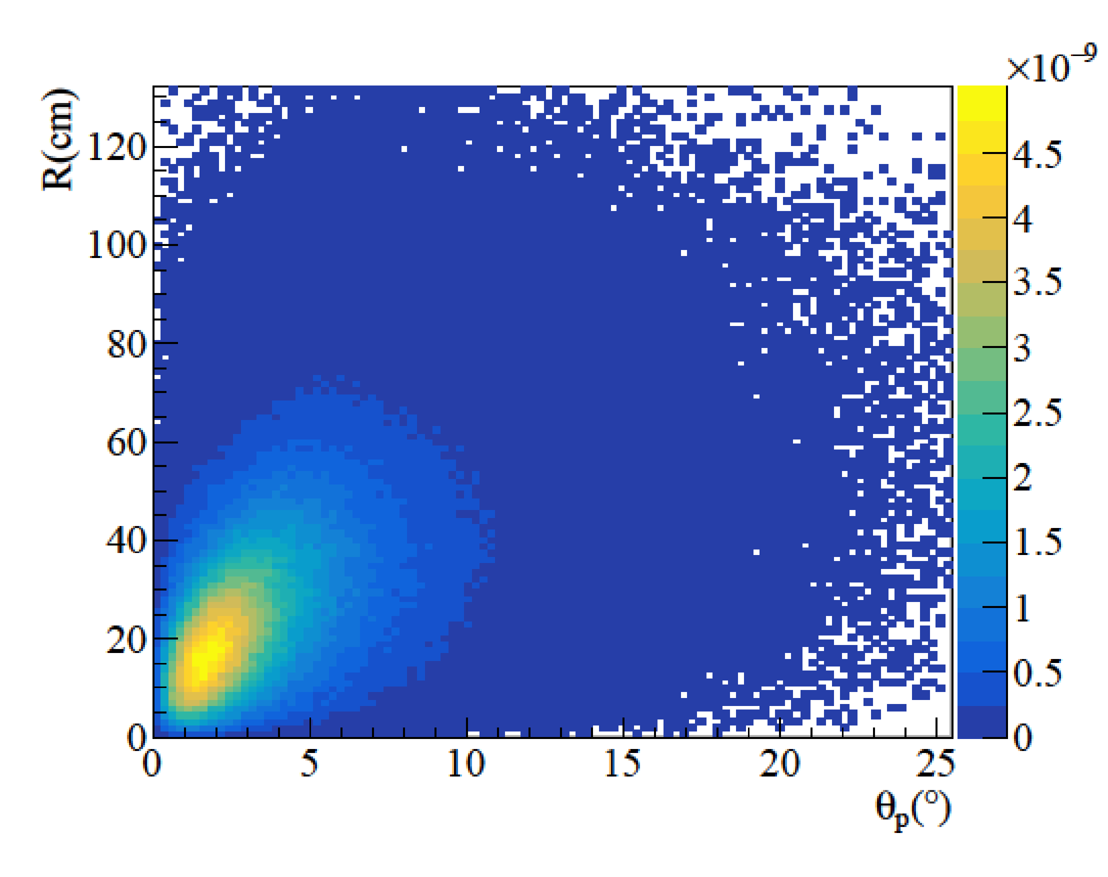
Muon spatial distribution

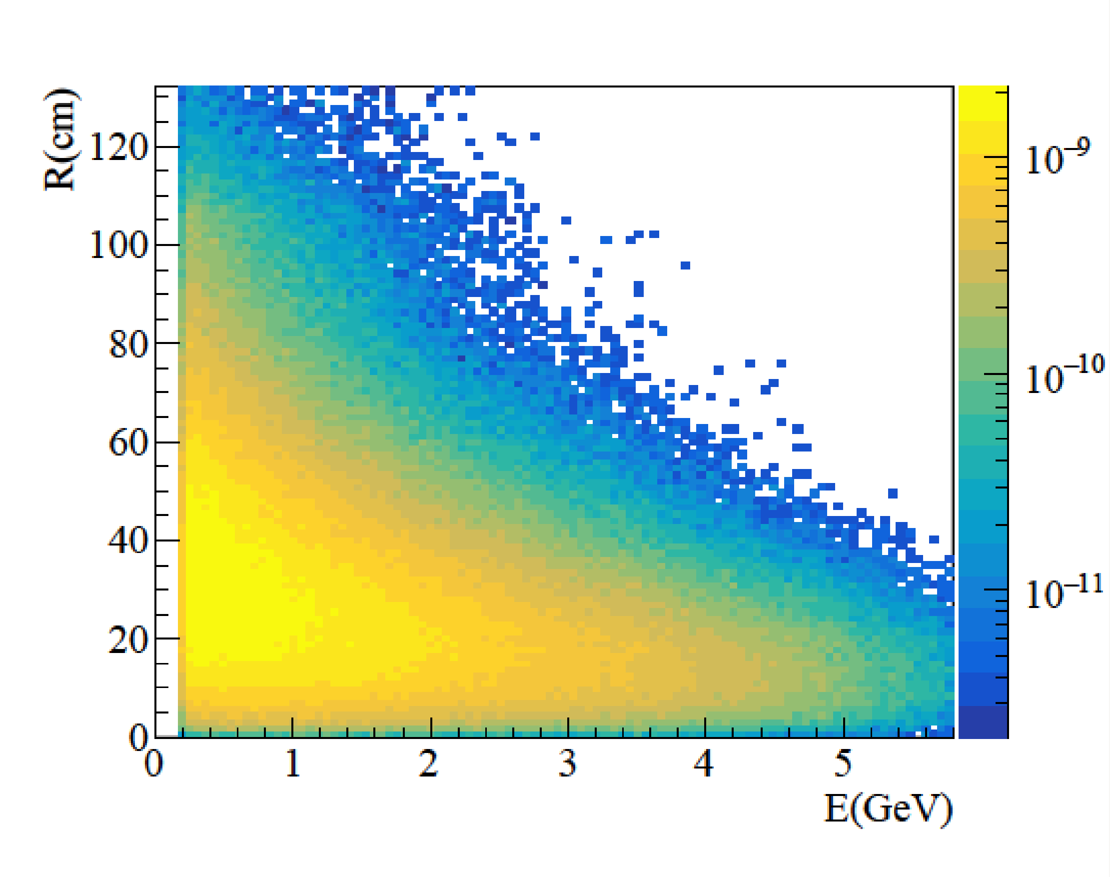


Muon energy spectrum

Results for an 11 GeV electron beam

Muon distributions downstream of the concrete vault

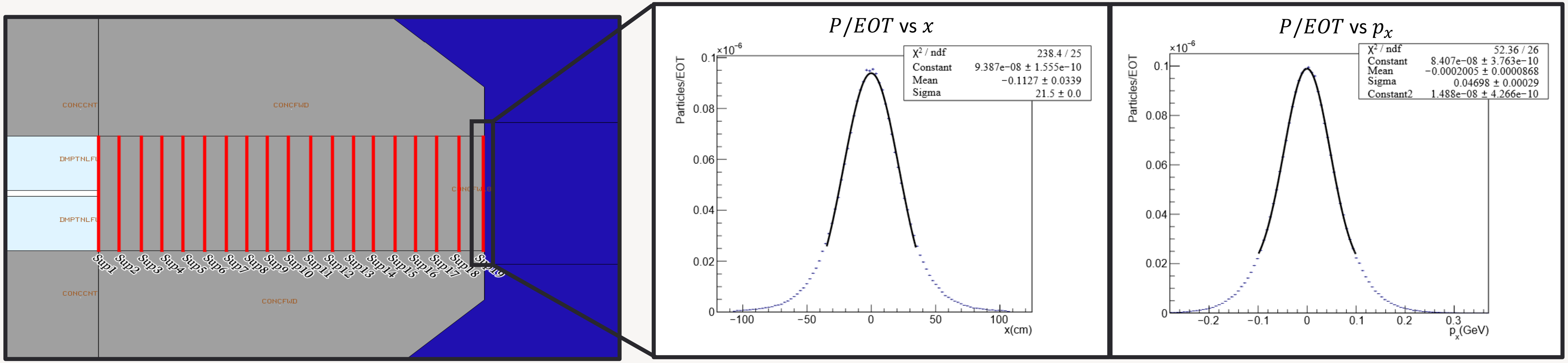




Results for an 11 GeV electron beam

Spatial and momentum distributions were fitted to a Gaussian: $f(x) = c_1 e^{-\frac{1}{2}\left[\frac{(x-\mu)}{\sigma}\right]^2} + c_2$

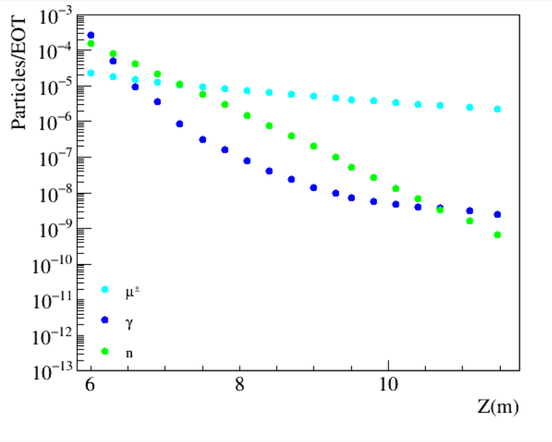
Surface position	Energy cut (GeV)	No. of μ/EOT		σ_x (cm)	σ_y (cm)	σ_{p_x} (MeV)	σ_{p_y} (MeV)
		213,36x213,36 cm^2	20x20 cm^2				
$z = 600$	$T_\mu > 0.1$	2.33×10^{-5}	2.36×10^{-6}	12.46 ± 0.04	12.55 ± 0.04	51.06 ± 0.2	53.96 ± 0.3
	$T_\mu > 1$	0.84×10^{-5}	1.96×10^{-6}	11.77 ± 0.02	11.91 ± 0.02	80.53 ± 0.1	80.64 ± 0.1
$z = 1146.5$	$T_\mu > 0.1$	0.22×10^{-5}	0.27×10^{-6}	21.5 ± 0.04	21.69 ± 0.04	46.98 ± 0.3	46.72 ± 0.3
	$T_\mu > 1$	0.11×10^{-5}	0.19×10^{-6}	18.56 ± 0.03	18.71 ± 0.03	77.64 ± 0.1	77.56 ± 0.1

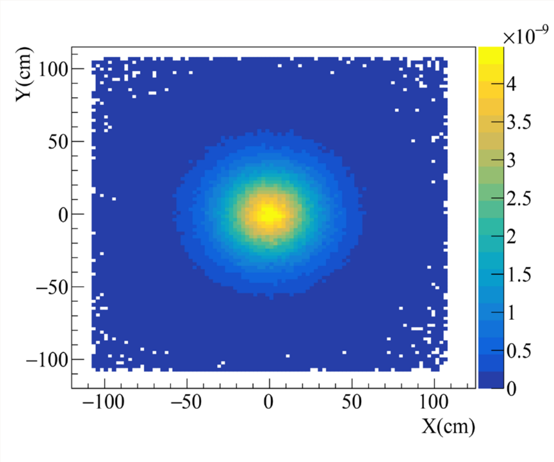


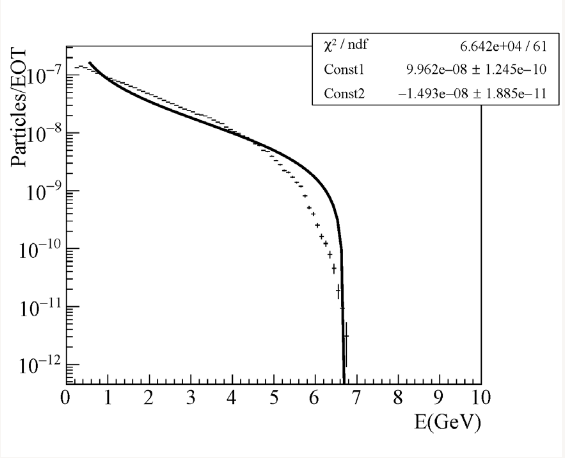
Results for a 6 GeV electron beam

Simulation of 10^7 electron on target (EOT) with a momentum $p_{e^-} = 6\ GeV$.

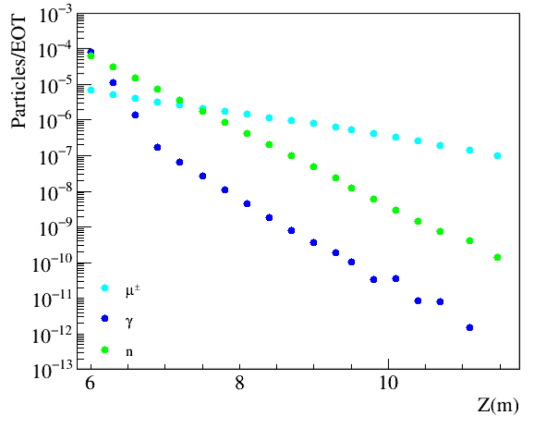
11 GeV electron beam

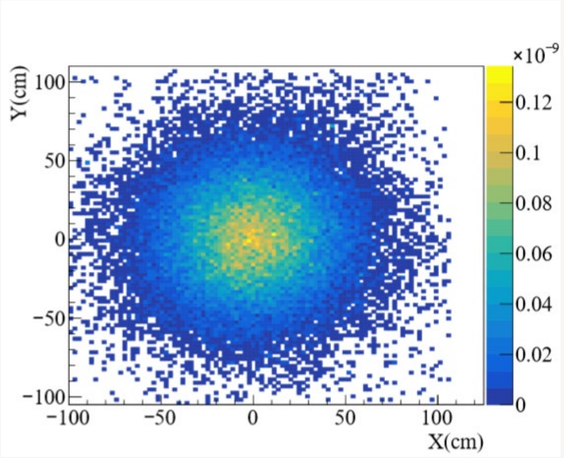


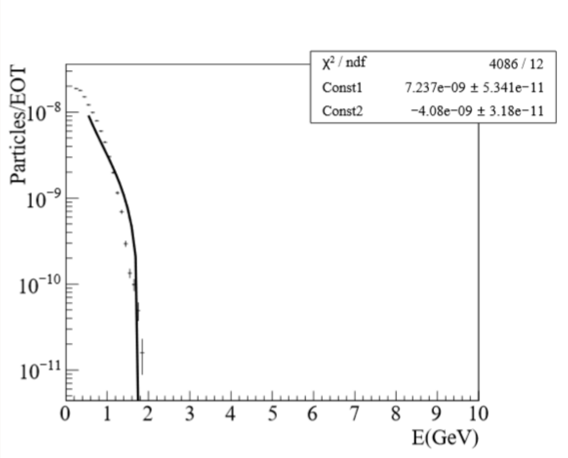




6 GeV electron beam







$T_\mu > 0.1$	9.96×10^{-8}	7.78×10^{-9}	28.89 ± 0.1	29.22 ± 0.1	43.3 ± 0.2	43.6 ± 0.2	

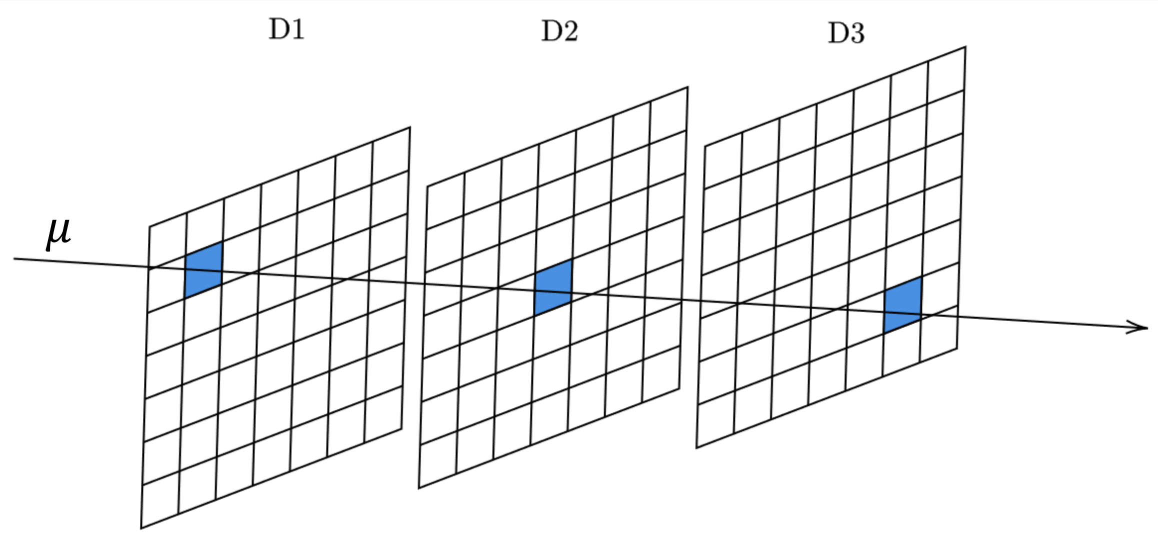
Muon tagging system

A muon "tagging" system was devised based on the data obtained through FLUKA in order to identify and characterize each muon.

The chosen method is **time-of-flight** (TOF).

The proposed system is made up of 3 detectors $40 \times 40\ cm^2$ each $5\ m$ away from each other.

Every detector consists of 1600 pixels of $1\ cm^2$.



A muon is identified when it is detected coherently between all three detectors, however not all muons can be tagged correctly.

The amount of untagged muons decreases with the electron current and with the dead time of the detectors, up to almost ~1% with 25μA electron current and 1μs of dead time.

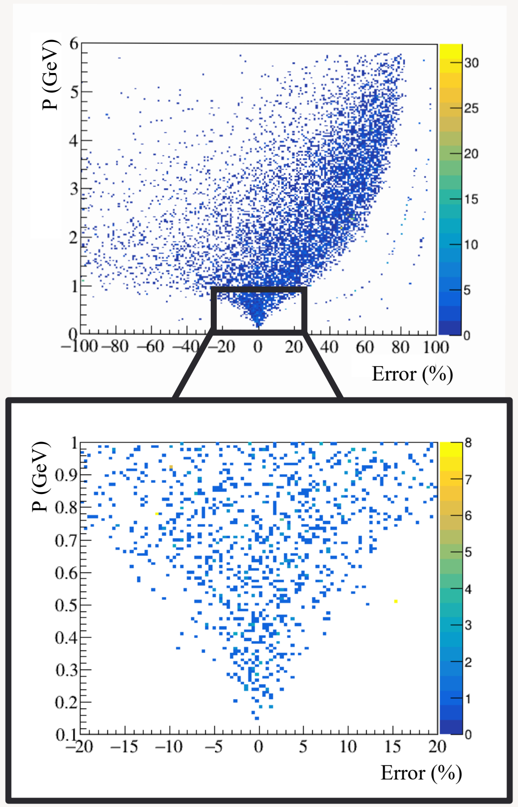
The **maximum muon current** that can be handled is:

$$I_\mu \approx 20\ MHz$$

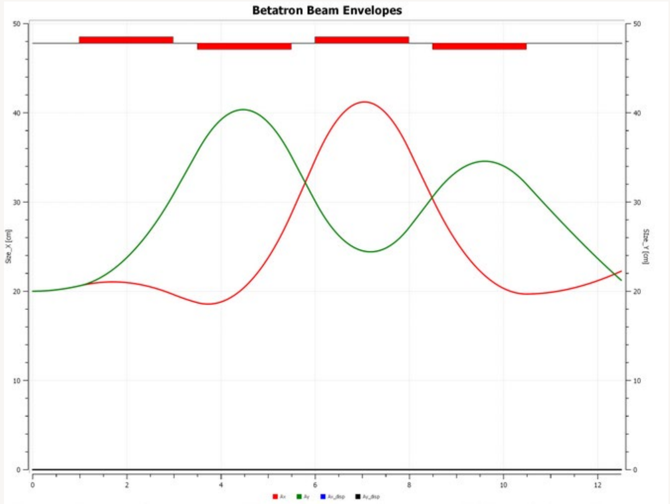
Muon beam momentum measurement

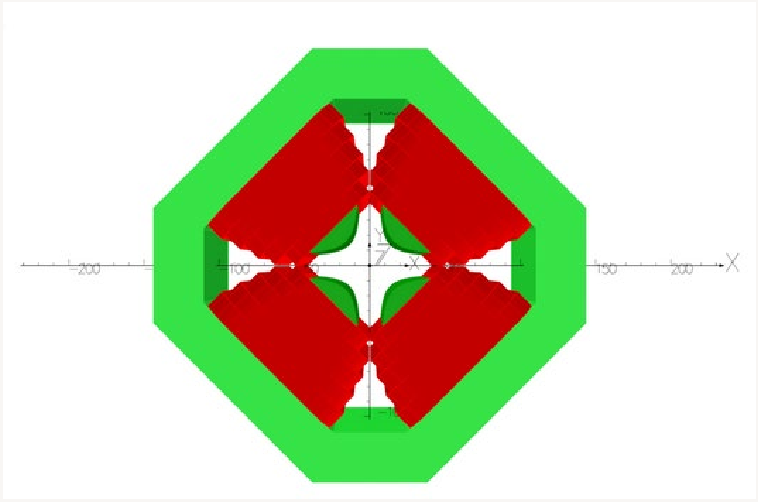
For very low energy muons the momentum can be measured with the TOF system

P (GeV) Vs Error (%)



For higer energy muons a focalization system is needed and is being studied and implemented in the simulations



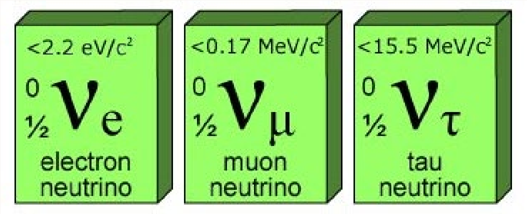


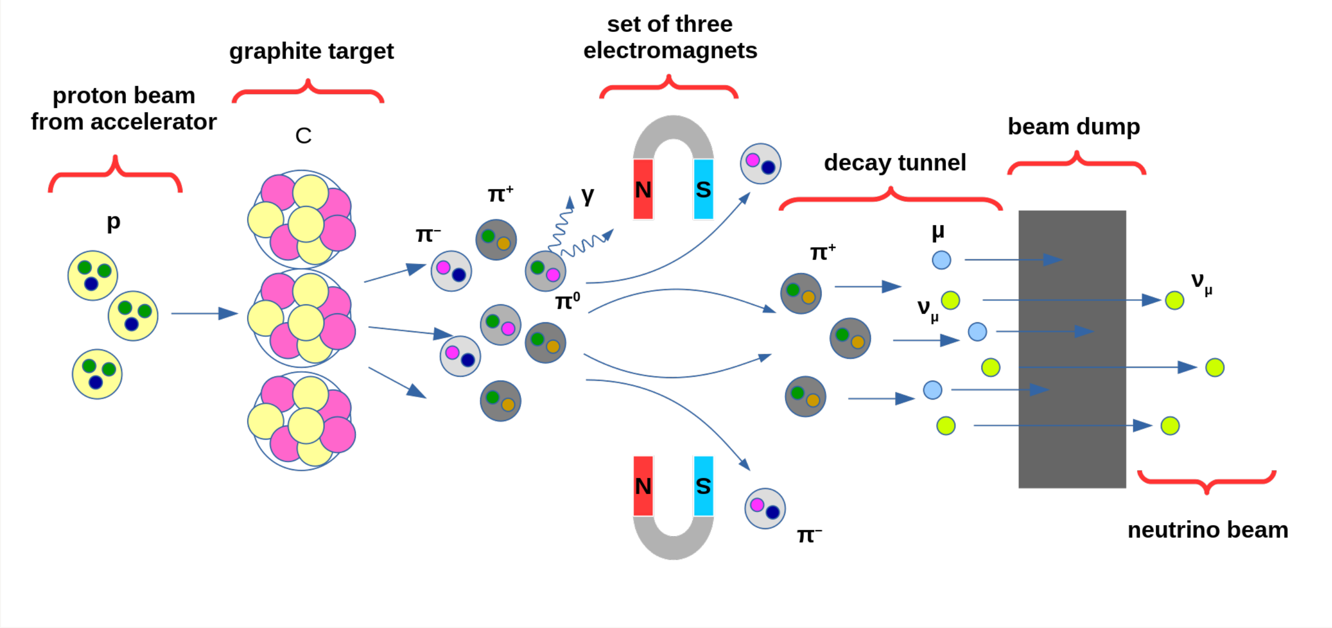
Images courtesy of Jay Benesch

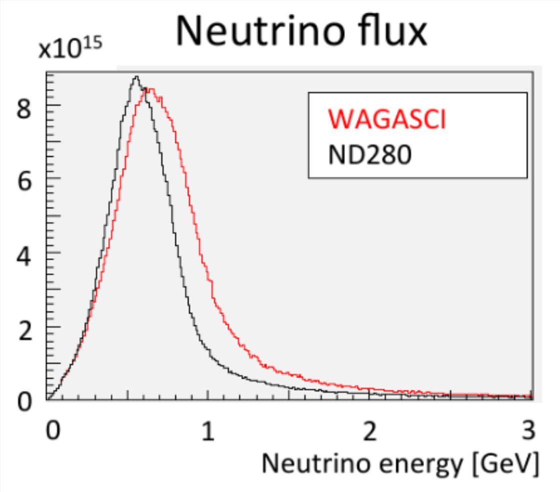
Jay Benesch studied and established the possibility of using a resistive quadrupole for focusing muons up to 6 GeV

Neutrino beam

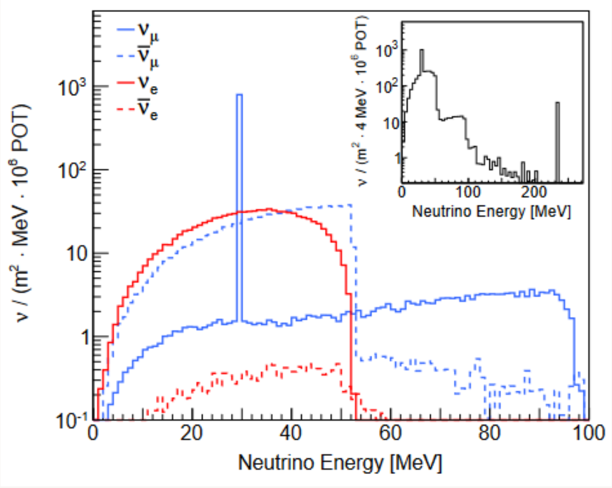
Neutrino beam are usually produced thorugh the **decay in flight** of pions and kaons.







T. Ovsiannikova et Al. (2016)



C. Grant, B. R. Littlejohn (2015)

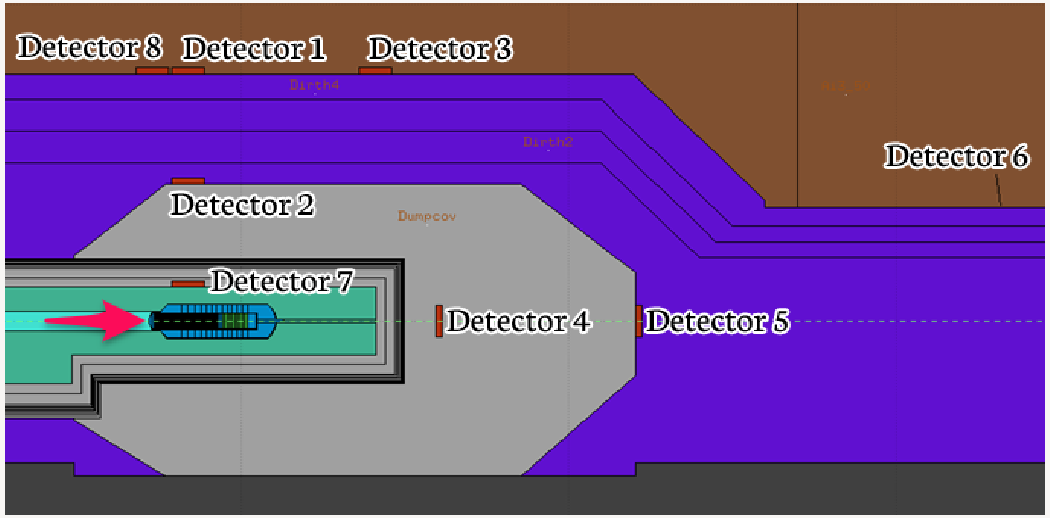
However a far-more-copious flux of lower-energy neutrinos are produced from the **decay at rest (DAR)** of pions, kaons, and muons.

Results for an 11 GeV electron beam

The simulations were made using FLUKA.

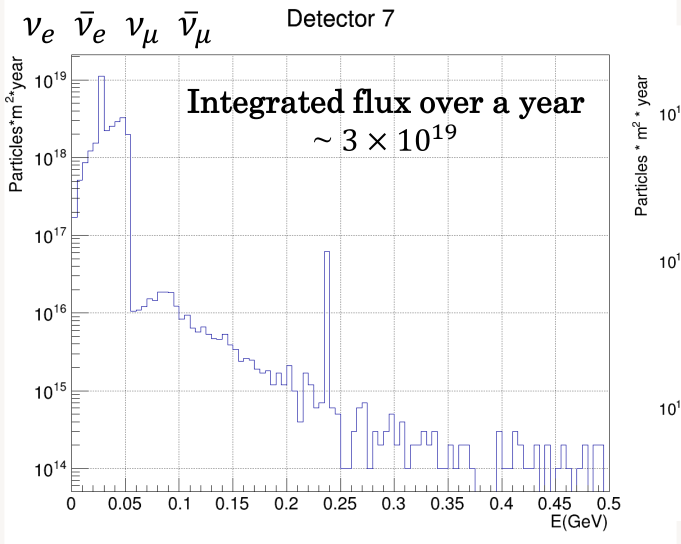
The e^- beam has a flat dispersion in x and y of 0.5 cm and 0.136 mrad of divergence

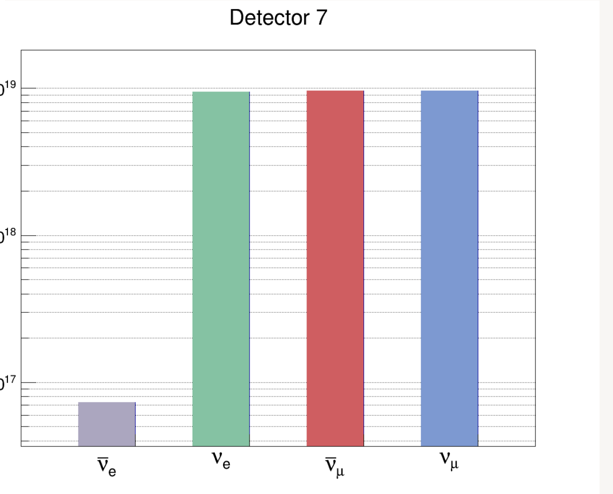
Collecting data over a year correspond to $\approx 10^{22}\ EOT$

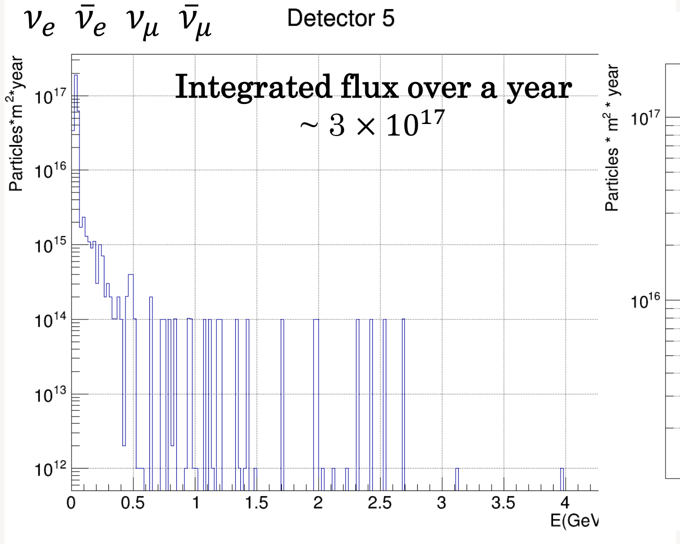


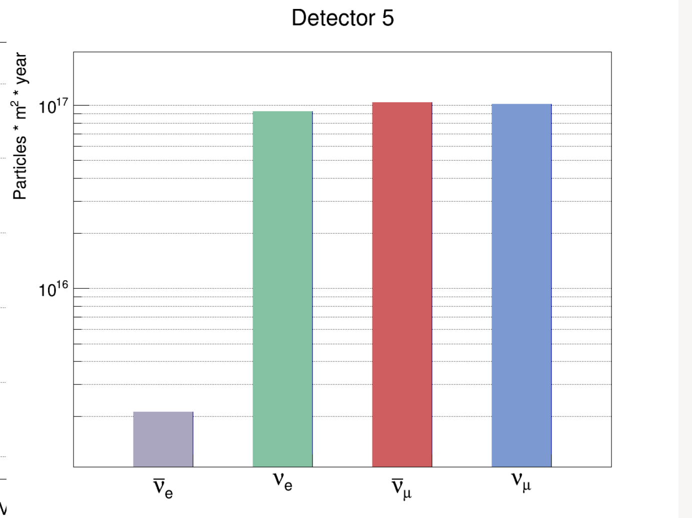
FLUKA geometry courtesy of L. Zana
@RadCon JLab

DAR neutrino flux is isotropic (scale as $\approx {}^{1}/_{r^2}$)



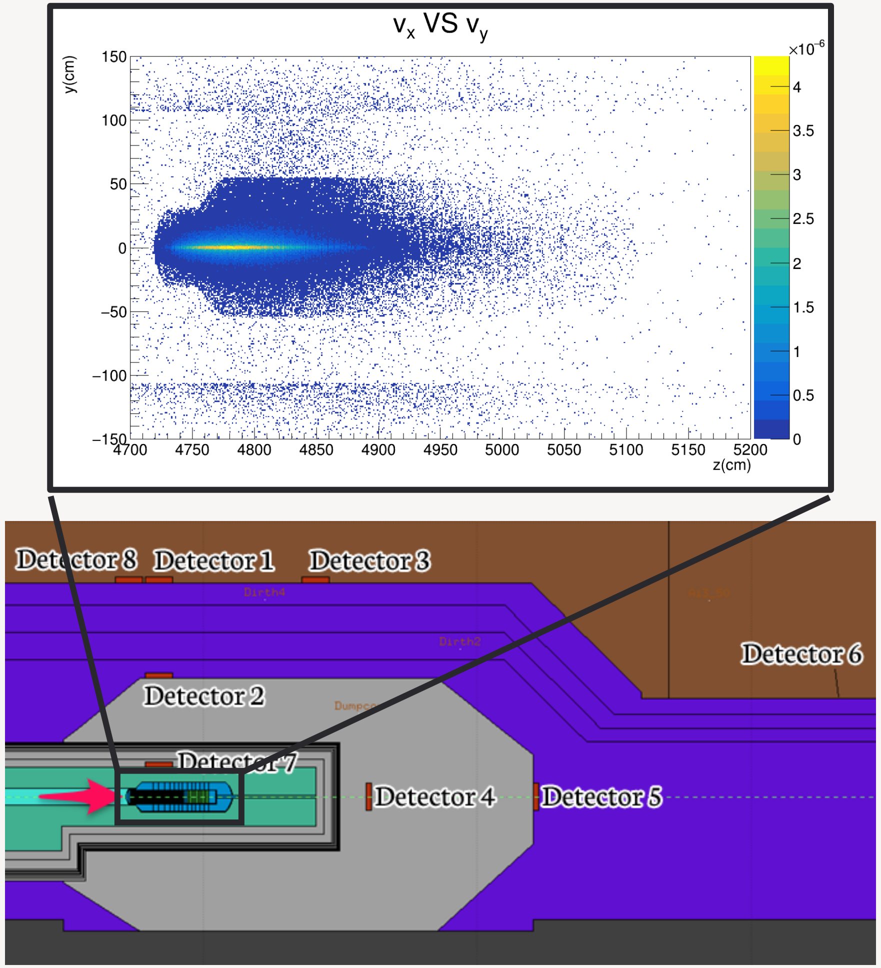




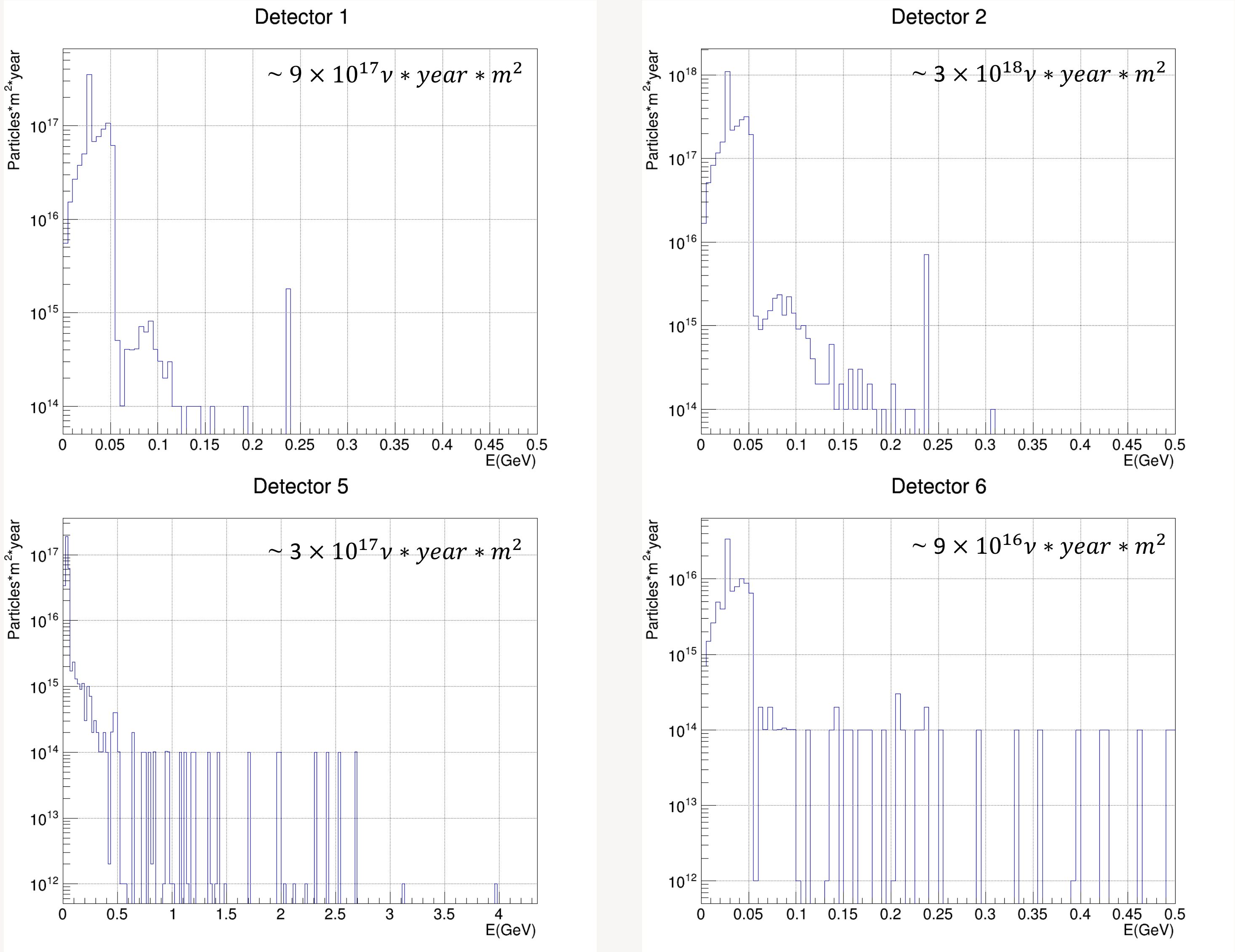


Results for an 11 GeV electron beam

Neutrino are mainly produced in the first layers of the dump

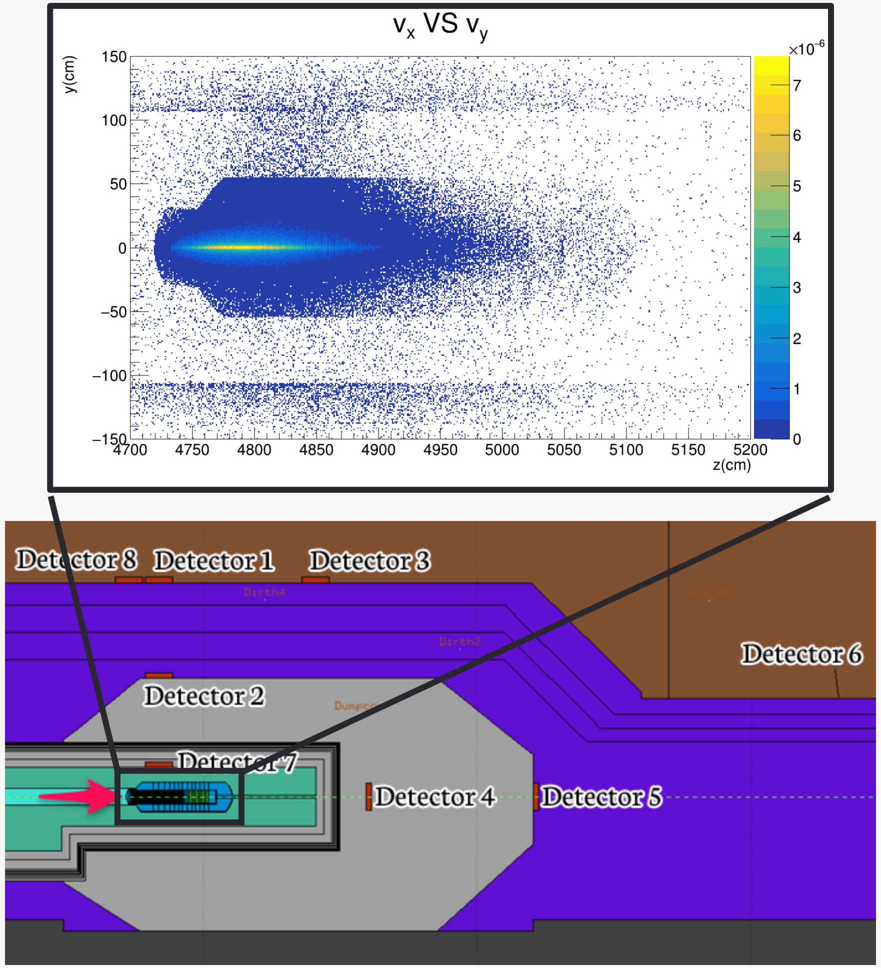


FLUKA geometry courtesy of L. Zana @RadCon JLab

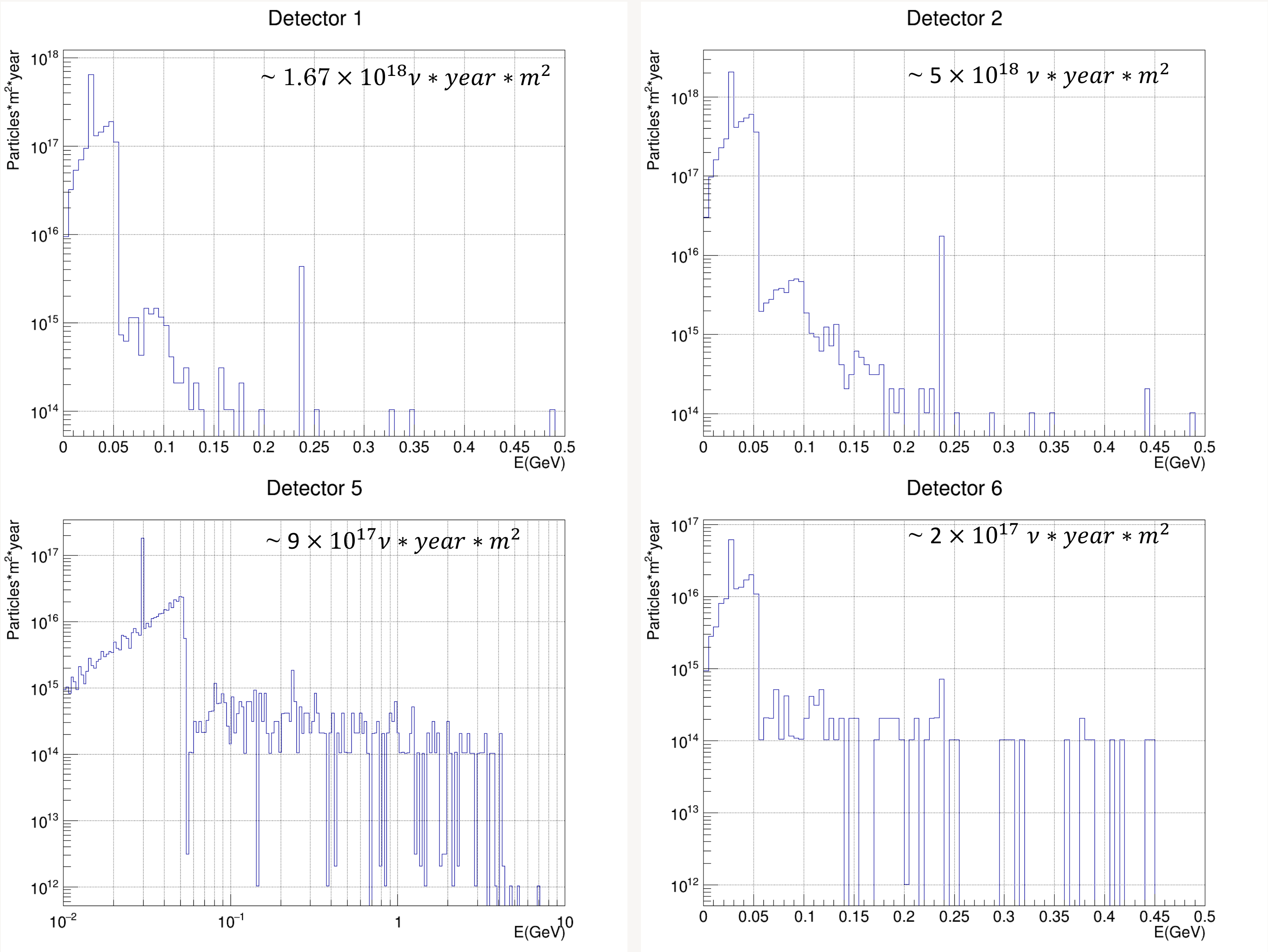


Results for a 20 GeV electron beam

Neutrino are mainly produced in the first layers of the dump



FLUKA geometry courtesy of L. Zana @RadCon JLab



Conclusion

- Assuming 50uA, 11 GeV electron beam on Hall-A beam dump (10^{22} EOT in 1 year)

- **Muon beam:**
  - expected flux $\approx 10^9\ \mu/s$ in the z-direction
  - energy up 6 GeV with a bremsstrahlung-like energy spectrum
  - requires dedicated infrastructures (magnets, drift, …) to tag and measure muon momentum upstream of the BDX shielding

- **Neutrino beam**
  - Expected flux of $\approx 10^{17} \div 10^{18}\ \nu * y * m^2$ (depending on the location)
  - DAR energy spectrum (0 - 50 MeV, 30% monochromatic @~30MeV)
  - High-energy nu flux ($E > 100$ MeV) is reduced by a factor ~100
  - The detector can be located perpendicularly to the dump above-the-ground or on the concreate vault surface

- **Work in progress: neutron background**
  - A combination of passive shielding and active/veto should reduce the neutron background to negligible values
  - FLUKA simulations are running for a first assessment
  - Shielding optimization in progress