Cosmic-ray background in LBNE

Working Group on Cosmic Rays and Cosmogenics:

Martin Richardson

University of Sheffield / BNL

Karl Warburton, Vitaly A. Kudryavtsev

University of Sheffield

Chao Zhang, Dongming Mei

University of South Dakota

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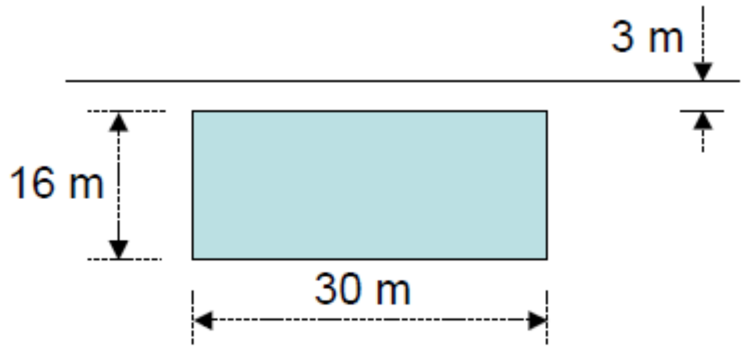
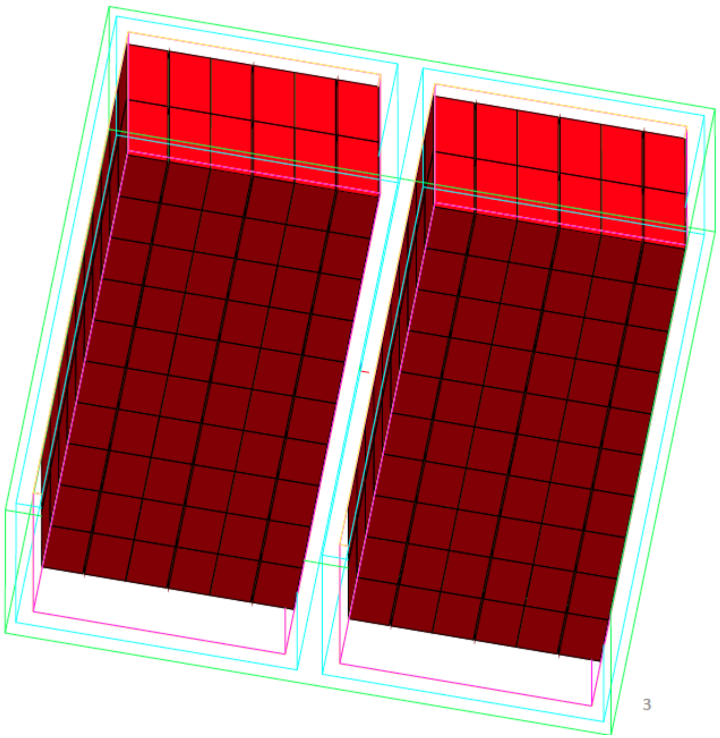
Work in progress

- Cosmogenics background for a detector at the surface (~10 ktons) – not a full MC, too many events to simulate, parameterisations for detector response, ramping down.
- Cosmogenics background for an underground detector (~10 ktons) – will start full MC.
- 35 ton prototype – not started yet (within our group); will start soon. Original idea: to simulate background in a similar way to the 10 kton detector at the surface and check/tune cuts with data. May not be needed on this scale now but cosmogenics simulations are still important.
- More details on the parallel session on Tuesday at 15:45 – cosmogenics / simulation and reconstruction.

10 kton at the surface: Summary of updates



- 8.1 m w. e. depth, flat surface. In fact the overburden will be bigger but this does not affect much muon background
- $30 \times 15 \times 16$ m^3 detector, total mass – about 10 kt.



- Two cryostats, each split into 120 cells, each with an active volume of $224.5 \times 226.8 \times 630$ cm^3.
- Total active mass of 10.7 ktons.
- 0.5 m concrete enclosing cryostats.
- 0.8 m fibre glass surrounding cryostats.
- 3 m concrete between cryostats.
- 0.5 inch stainless steel vessel.
- Already used in some previous simulations.

Summary of updates

- **Gradually moving to GEANT4.9.6 (v.10?). GEANT4 evolves quickly and we cannot follow this evolution with this speed.**
- **From flat surface to accurate surface profile – no big changes as expected.**
- **Splitting simulations into 2 steps (reducing CPU time):**
  - **Transport muons through rock to the detector (if they are passing through rock) and storing their parameters around the detector, a few metres in rock or on the surface;**
  - **Simulating muon events in the detector.**
- **Energy and angular smearing. Energy smearing, applied before, did not affect the results. Angular smearing slightly changes the results.**
- **PoCA with respect to all charged particles. Efficient but let's be cautious: it may overlap with e/γ separation cut.**
- **New, more pessimistic e/γ separation cut: 10% contamination (vs 3.2% energy dependent cut in 2013 and 2% energy independent cut in 2012). These are the results from NEST; no modelling of this in our simulations, only a background suppression factor is used.**

Background sources

- So far: background for electron neutrino events.
- Counting gammas or electrons as background events.
- Type of events:
  - Muons in the detector.
  - Muons missing the detector – small compared to muons in the detector.
  - Atmospheric neutrons.
  - Atmospheric protons.
  - Atmospheric photons – negligible compared to others.
- 2-3 independent simulations for each background source.

Simulations, normalisations and cuts

- **GEANT4.9.4/5/6 (Physics list - Shielding).**
- **2×10^7 s in a year of running, 1.3 s repetition time, 10 μs beam spill, 1.4 ms max drift time -> 21053 s of data acquisition (beam neutrino data) in a calendar year (for 1.4 ms data acquisition).**
- **Correction for the altitude (40% for muons, bigger for neutrons & protons).**
- **Cuts:**
  - **PoCA with respect to a muon (not always works): 10-30 cm. Background increases by ~2 if a 10 cm cut is used instead of 30 cm cut.**
  - **Distance from the walls (events without muons in the detector).**
  - **Angle with respect to the beam (energy dependent cut).**
  - **e/γ separation: currently a factor of 10 suppression, energy independent.**
  - **100% efficient photon detector: 1.4 ms -> 10 μs, 1/140 reduction.**
  - **PoCA with respect to other charged particles, very efficient but may overlap with e/γ separation (difficult to separate the two), also signal efficiency is difficult to predict.**

Muons in the detector: comparison for different detector geometries

More accurate geometry

	E > 0.25 GeV	PoCA > 30 cm	Θ_{beam}(E)	e/γ(E)	1/140
$\pi^0 \rightarrow \gamma$	2.32 E+06	5.98 E+04	2.61 E+04	2.61 E+03	18.6
Ext γ	4.67 E+06	4.98 E+03	2.37 E+03	237	1.69
Other→ γ	6.61 E+06	3.89 E+01	0	0	0
TOTAL	1.36 E+07	6.48 E+04	2.85 E+04	2.85 E+03	20.3

Simple geometry

	E > 0.25 GeV	PoCA > 30 cm	Θ_{beam}(E)	e/γ(E)	1/140
$\pi^0 \rightarrow \gamma$	2.11 E+06	9.70 E+04	4.78 E+04	4.78 E+03	34.1
Ext γ	1.93 E+06	6.62 E+03	343	34.3	0.245
Other→ γ	5.88 E+06	0	0	0	0
TOTAL	9.92 E+07	1.04 E+05	4.78 E+04	4.78 E+03	34.3

- **Flat surface profile for consistency.**
- **No PoCA wrt to all charged particles, only wrt muons.**
- **Only channels giving high contribution to the total background after all cuts are shown.**
- **e/γ(E) contamination assumed to be 10%.**

- **Annual rates of muon-induced gammas corrected for 1500 m altitude.**
- **Statistics is high enough to ignore statistical errors (<10%).**
- **Ext *γ* is higher now due to a much larger surface area of detector.**

Flat surface vs accurate surface profile

Flat surface

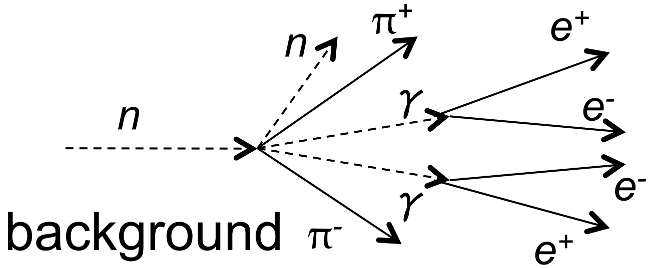
	E > 0.25 GeV	PoCA > 30 cm	Θ_{beam}(E)	All PoCA > 10 cm	e/γ(E)	1/140
$\pi^0 \rightarrow \gamma$	2.52 E+06	6.53 E+04	3.02 E+04	1.03 E+03	103	0.736
Ext γ	5.04E+06	5.99 E+03	2.82 E+03	669	66.9	0.478
Other→ γ	7.14 E+06	62.2	31.1	15.6	1.56	0.011
TOTAL	1.47 E+07	7.13 E+04	3.30 E+04	1.70E+03	171	1.21

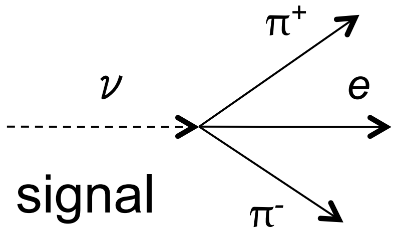
Accurate surface profile

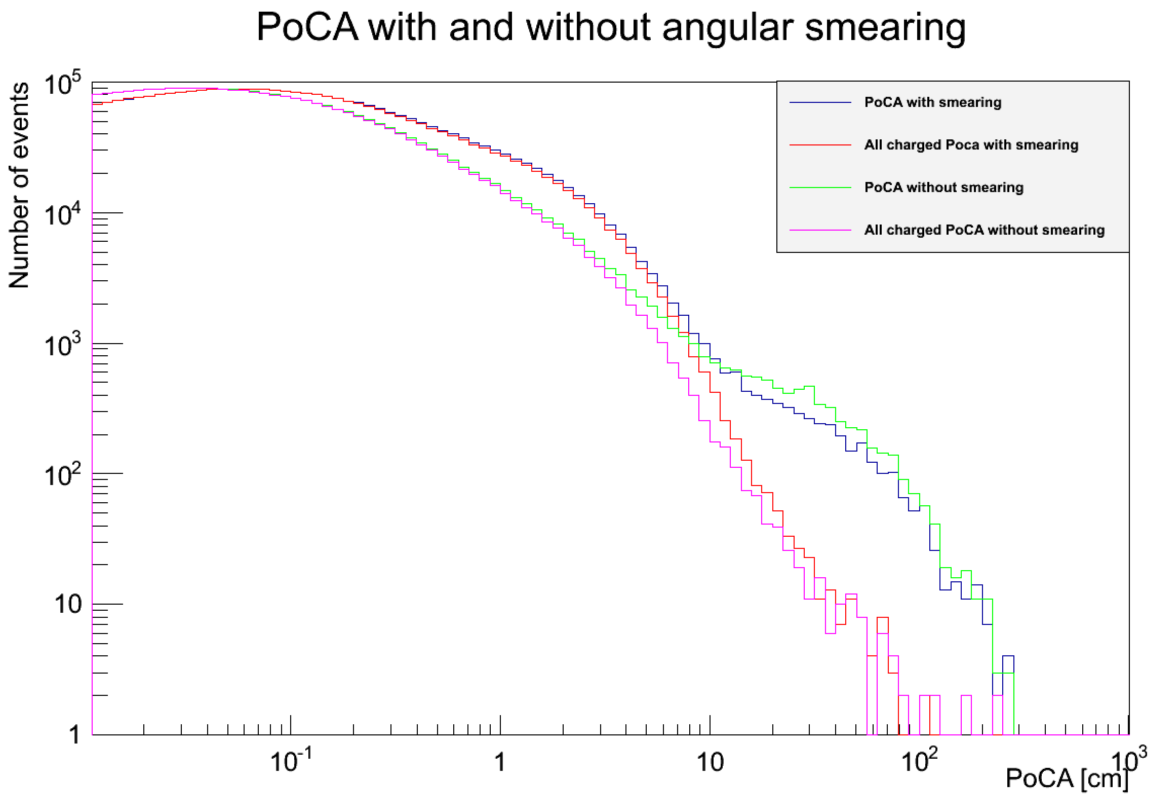
	E > 0.25 GeV	PoCA > 30 cm	Θ_{beam}(E)	All PoCA > 10 cm	E-γ(E)	1/140
$\pi^0 \rightarrow \gamma$	2.32 E+06	5.98 E+04	2.61 E+04	817	81.7	0.583
Ext γ	4.67 E+06	4.98 E+03	2.37 E+03	622	62.2	0.444
Other→ γ	6.61 E+06	38.9	0	0	0	0
TOTAL	1.36 E+07	6.48 E+04	2.85 E+04	1.44 E+03	144	1.03

- **Annual rates of muon-induced gammas.**
- **PoCA wrt all charged particles reduces the background rate by a factor of 15-20.**

PoCA wrt all charged particles







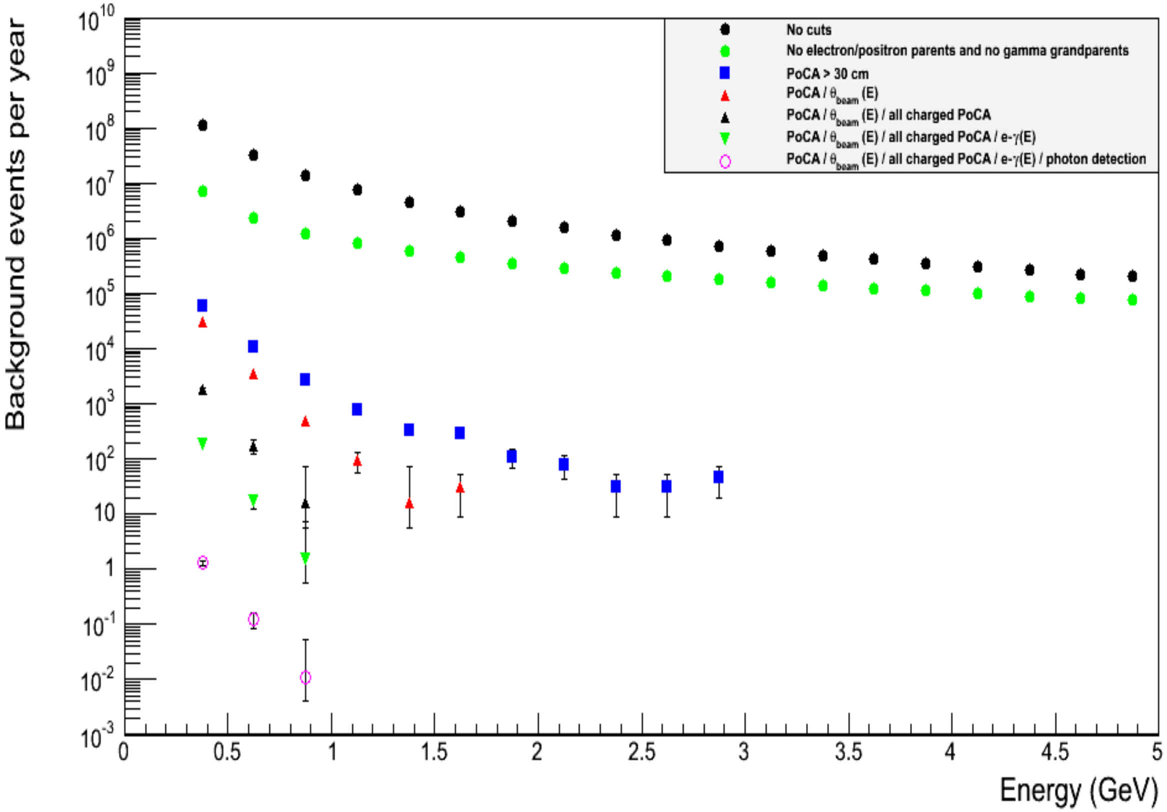
Summary table (February 2014)

Processes	$E > 0.25$ GeV	PoCA/D>30 cm	Beam angle	PoCA(c.p.)>10 cm	e/γ	10 µs
$\pi^0 \rightarrow \gamma \rightarrow e^{\pm}$	2.3×10^6	6.0×10^4	2.6×10^4	820	82	0.58
$\mu \rightarrow \gamma \rightarrow e^{\pm}$	5.9×10^6	41	0	0	0	0
Ext $\gamma \rightarrow e^{\pm}$	4.7×10^6	5.0×10^3	2.4×10^3	622	62.2	0.44
$\pi^0, K^0 \rightarrow e^{\pm}$	8.1×10^3	~520	~180	~10	~10	~0.1
Missing μ	7.1×10^3	1.7×10^3	580	Not applied	58	0.41
Total μ	1.3×10^7	6.8×10^4	2.9×10^4	$\sim1.5\times10^3$	*200*	*1.5*
Atm n	7.7×10^4	5.3×10^4	1.8×10^4	2.9×10^3	290	2.1
Atm p	1.1×10^5	7.3×10^4	2.8×10^4	3.1×10^3	310	2.2
Atm γ	10	5	2		0.05	0.0004
Total	$\mathbf{1.3\times10^7}$	$\mathbf{1.8\times10^5}$	$\mathbf{7.5\times10^4}$	$\mathbf{7.5\times10^3}$	**800**	**5.7**

Background event rates in a calendar year of running, corrected for an altitude of 1500 m above sea level. Neutrons and protons – simple detector geometry.

The rates in all columns but last are given for a time window of 1.4 ms corresponding to the maximum electron drift time. The last column shows the rate with an efficient photon detection system which will reduce the time window to 10 µs. The first four rows show events with a muon in the detector: '$\pi^0 \rightarrow \gamma \rightarrow e^{\pm}$' – events originated from neutral pions, '$\mu \rightarrow \gamma \rightarrow e^{\pm}$' – events from muon bremsstrahlung, 'Ext $\gamma \rightarrow e^{\pm}$' – events where a photon was produced by a muon or another particle outside the detector. The row '$\pi^0, K^0 \rightarrow e^{\pm}$' shows events originated in direct decays of neutral hadrons to electrons. The row 'Missing µ' shows events without a muon in the detector where PoCA cannot be applied but events within 30 cm from the walls (D < 30 cm) are rejected. The rows 'Atm n', 'Atm p' and 'Atm γ' show background events caused by atmospheric neutrons, protons and photons, respectively. Different columns correspond to different cuts: energy greater than 0.25 GeV, PoCA and distance from the walls greater than 30 cm, angle with respect to the beam is selected to keep almost 99% of signal events, e/γ separation cut retains 90% of signal events, time window for signal events is reduced from 1.4 ms down to 10 µs.

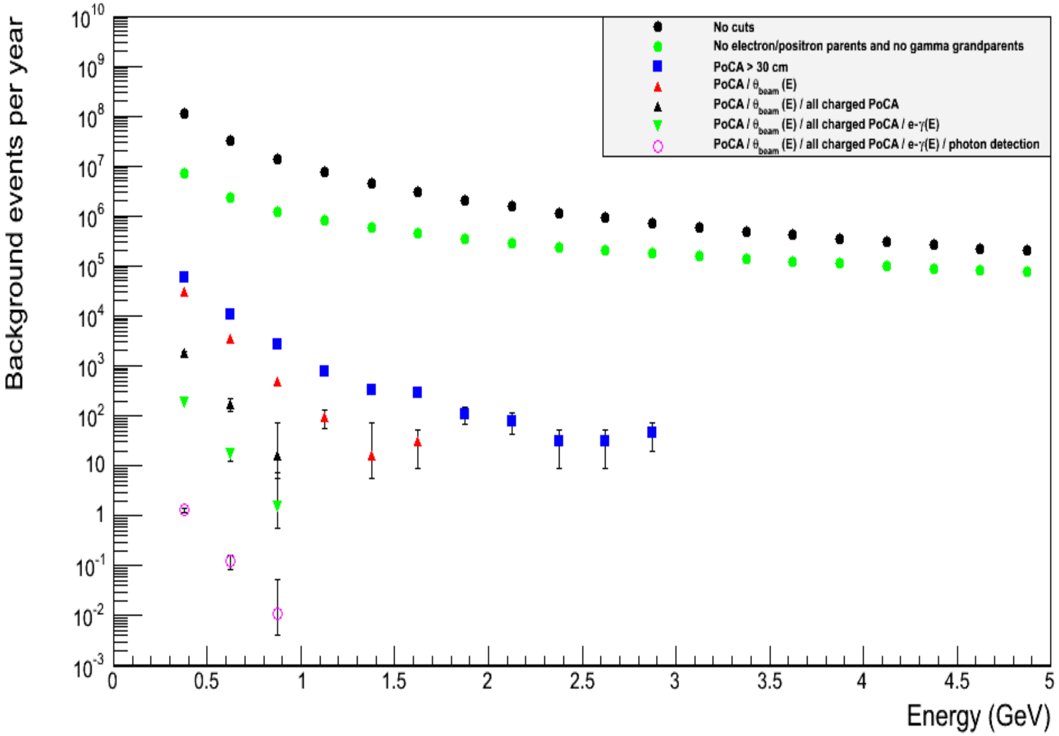
Energy spectra (muon-induced events)



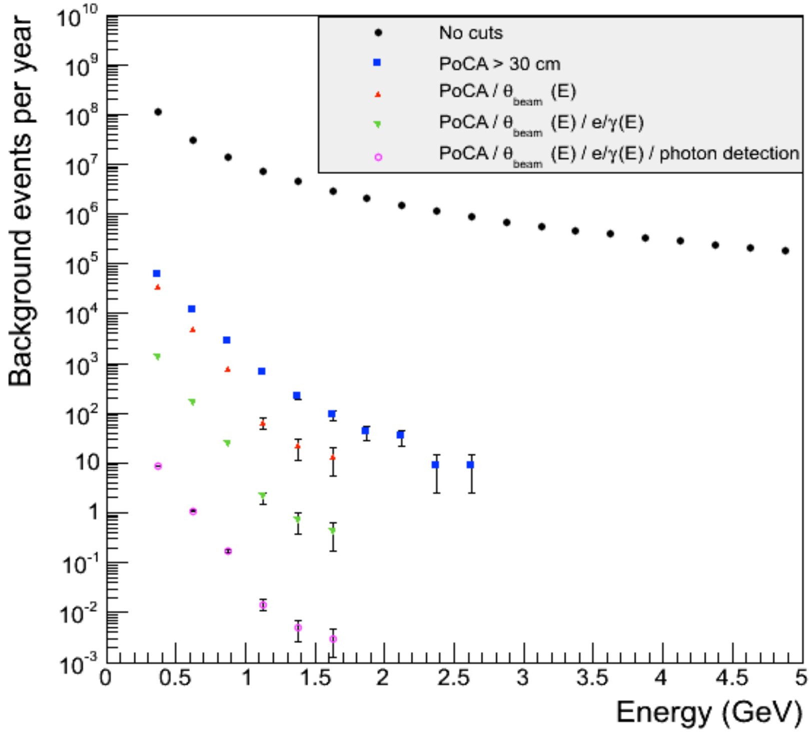
Energy spectra of muon-induced background events before and after background rejection cuts. Simulations have been done for a muon spectrum at sea level. Correction for an altitude of 1500 m above sea level has not been applied to the data on this graph.

Black filled circles: events before any cuts are applied. Green circles: remove events like μ→e→γ. Blue squares: only events with PoCA wrt the muon track greater than 30 cm are selected. Red triangles: in addition, angle with respect to the beam is chosen to retain 99% of signal events. Black triangles: only events with PoCA > 10 cm wrt to all charged particles are selected. Green triangles: e/γ separation cut of 10% is applied. Magenta open circles: photon detection is assumed to allow the reduction of the time window from 1.4 ms to 10 microseconds.

Energy spectra (muon-induced events)



New results (Feb2014) to the left: new detector, surface profile, additional PoCA cut wrt charged particles, smearing in energy and angle



Old result from July 2013 to the right: simple geometry, flat surface, no smearing, limited cuts.

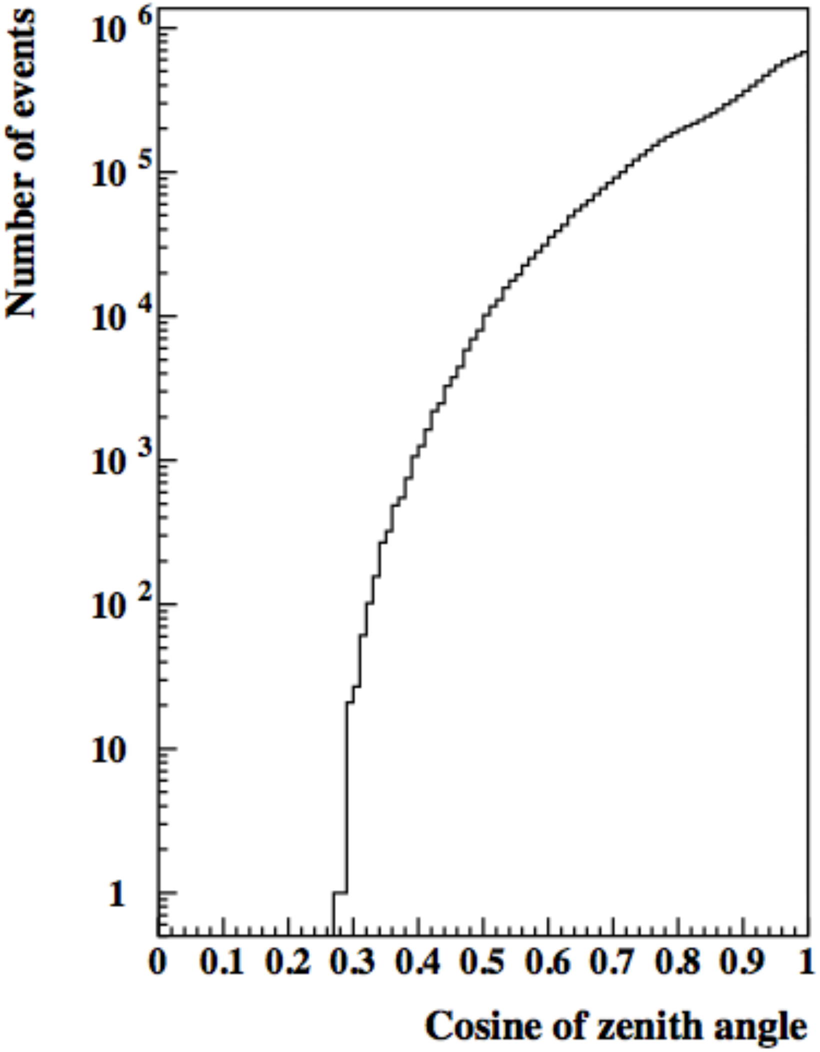
Background for proton decay

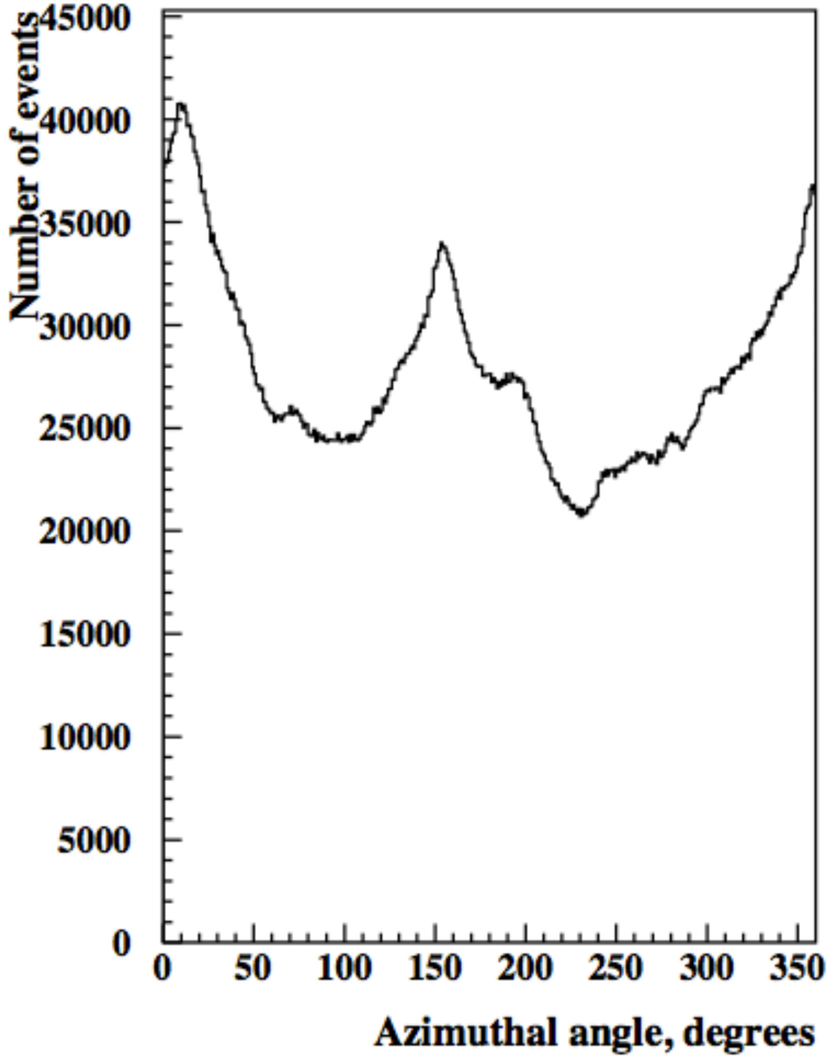
- **Proton decay search is possible (manageable background from muons) if the detector is underground (>500 m w. e.).**
- **Simulations so far were for 800 ft level and 4 km w. e. (LAGUNA-LBNO). Both show optimistic results.**
- **Expected muon rate at 4850 ft level for a 34 kton detector is ~0.1 s^{-1}. Dead time can be about 2 ms for each muon, i.e. less than 0.02%. Anticoincidence with a muon removes most of background events.**
- **If a muon misses the detector, a set of cuts on the energy deposition, distance from walls (10 cm) etc, removes remaining background. Currently estimated upper limit is <0.07 background events (caused by muons) per year in 34 ktons.**

Cosmic-ray muons at 4850 ft level

- **Full Monte Carlo is in progress.**
- **Muon generator for a new site is almost ready but requires some checks: exact detector position, rock density etc.**
- **Muon flux: 6.65×10^{-9} cm^{-2} s^{-1} (through a sphere).**
- **Mean muon energy: 281 GeV.**
- **Mean rock overburden: 4429 m w. e. (density may be higher than currently assumed).**
- **Mean zenith angle 26.2^{o}.**

Cosmic-ray muons at 4850 ft level





Summary

- **A good progress in identifying background for the detector near surface and developing cuts to remove them.**
- **Overall rate is not a limiting factor at the moment for a detector operation at the surface.**
- **Underground detector: muon rate is much smaller and large statistics is not required. Can be a full MC within LArSoft.**
- **Moving (coming back) to a simulation for an underground detector: proton decay background. We are happy to help with backgrounds for other tasks.**
- **35 ton prototype…**