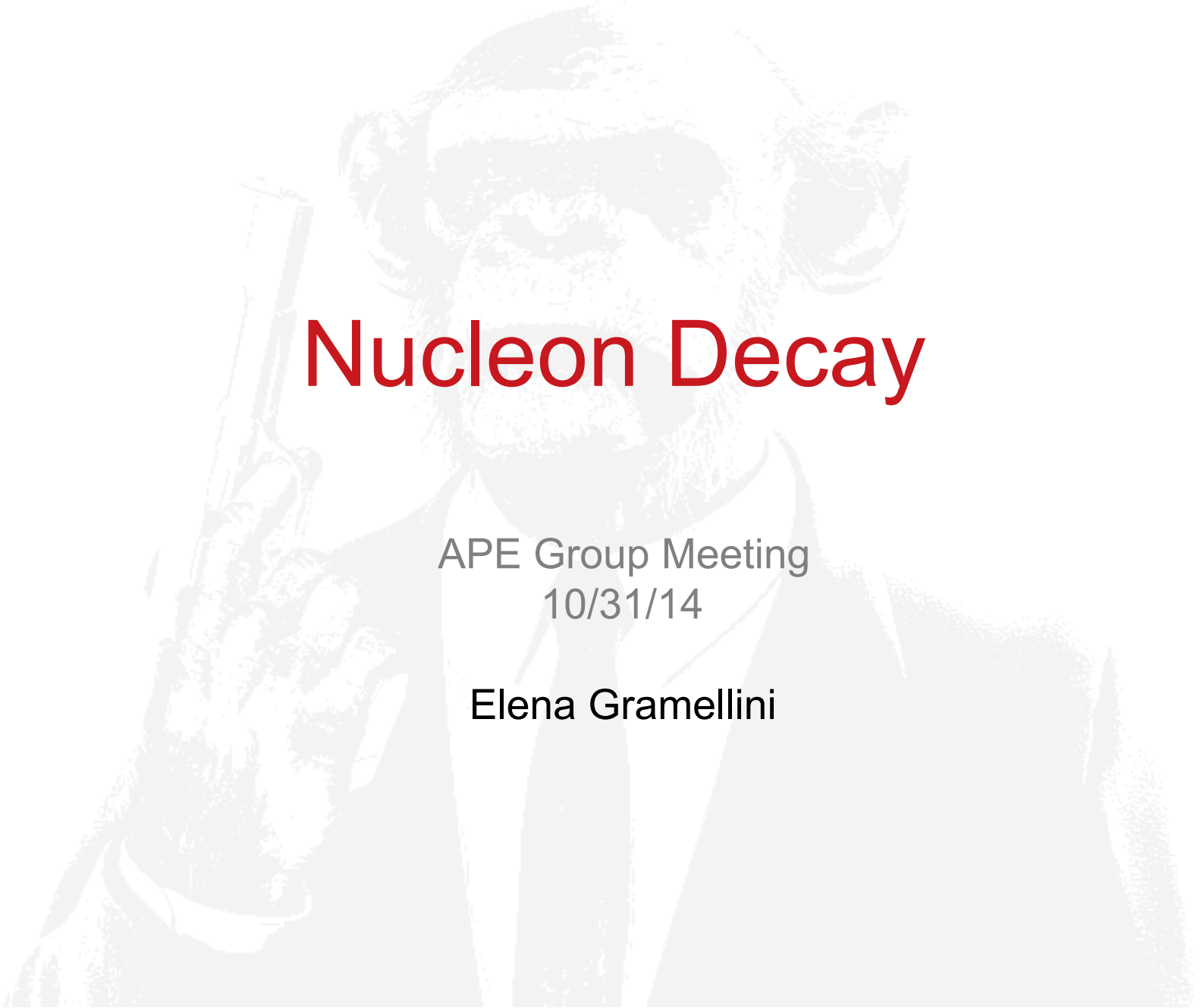


Nucleon Decay

APE Group Meeting
10/31/14

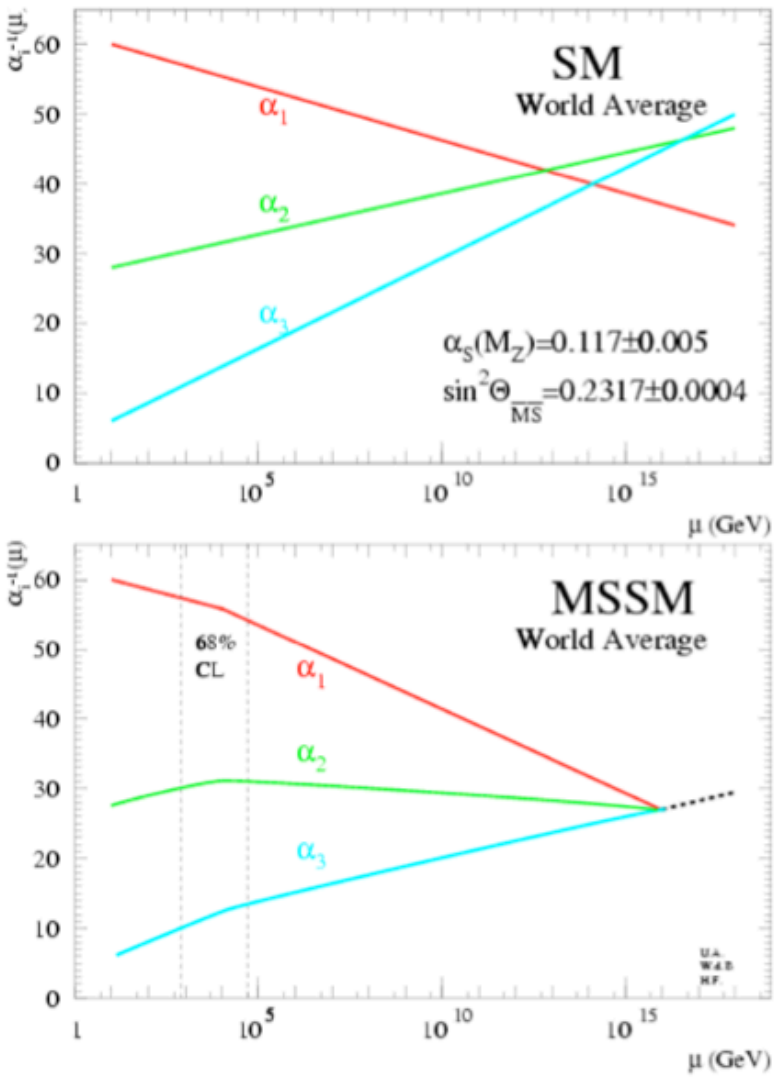
Elena Gramellini

Outline

- Motivations for nucleon decay studies
- Background studies in MicroBooNE
- A “recipe” for an analysis
- Future prospectives

Motivations (1/2)

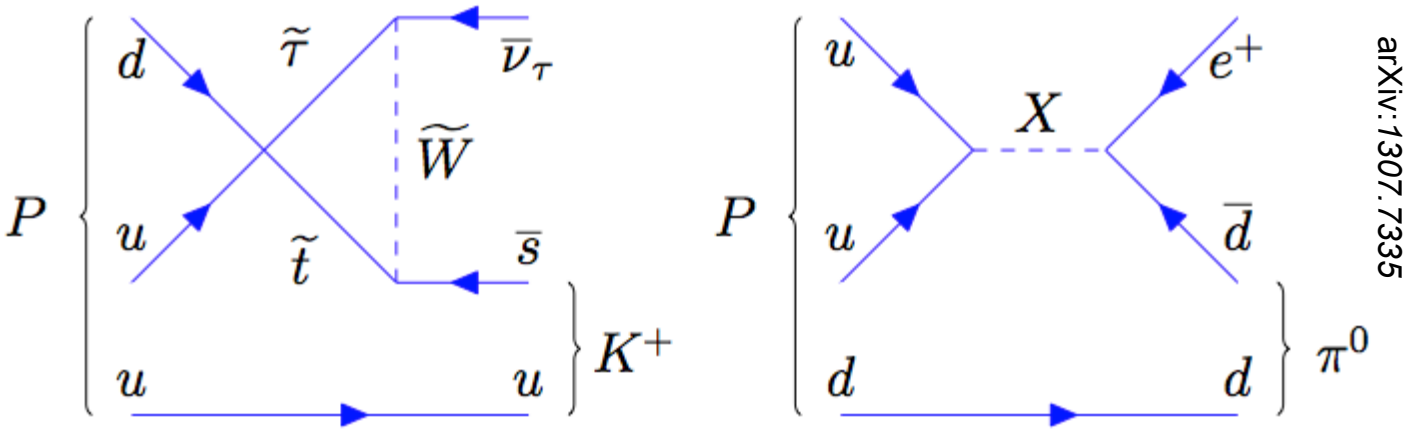
- Conservation of baryon number is “accidental”, i.e does not correspond to any known symmetry: its violation is predicted by almost all GUTs
- Proton (or bounded neutron) decay can occur only as a violation of baryon number, pointing to an indirect evidence for GUTs



Motivations (2/2)

- Golden channels…

p -> nubar K^+ p -> e^+ π^0



arXiv:1307.7335

Best limits on τ_P/B set by Super-Kamiokande

- … but not only! Every GUT prefer a specific decay mode. What decay modes can we see in LAr? With which sensitivity?

Generic signal signature in LAr

- Presence of a lepton (either e, μ,ν) and few other particles (2 bodies decays are favorite)
- Total energy ~ mass of nucleon
- Total momentum ~ 0 (smearing introduced by Fermi momentum and other nuclear effects)
- No energetic nucleon in final state
- Gamma from nuclear deexcitation of ^{39}Cl

LBNF & the Bueno Paper

- Proton decay searches are one of LBNF top physics goals (and a strong motivation to its underground positioning)

- The sensitivity for proton decay searches in LAr has been mainly studied in “the Bueno paper” (in 2008)
  Bueno et al., arXiv:hep-ph/0701101

- MicroBooNE is not massive enough to explore proton decay lifetimes not already excluded: $\tau_P > 2.3\ 10^{33}$yr, see BackUp for world’s experimental limits.
  But, the literature on nucleon decay backgrounds is pretty scarce => Space for MicroBooNE!!!

Decay modes in the Bueno Paper

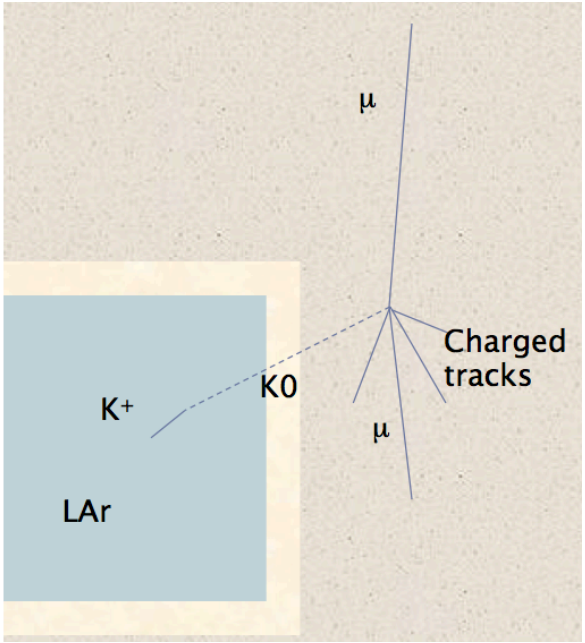
Decay mode	This paper (LAr TPC) Efficiency (%)	Atmospheric ν background 100 kton×year	Super-Kamiokande results [5, 10] Efficiency (%)	Atmospheric ν background 92 kton×year	Published limit 90% C.L.
(p1) $p \to e^+ \pi^0$	45.3	0.1	40	0.2	1.6×10^{33}
(p2) $p \to \pi^+ \bar{\nu}$	41.9	78.2			
(p3) $p \to K^+ \bar{\nu}$	96.8	0.1	8.6 (prompt-γ)	0.7	2.3×10^{33}
			6.0 ($K^+ \to \pi^+\pi^0$)	0.6	
(p4) $p \to \mu^+ \pi^0$	44.8	0.8	32	0.2	
(p5) $p \to \mu^+ K^0$	46.7	< 0.2	5.4 ($K^0_S \to \pi^0\pi^0$)	0.4	
			7.0 ($K^0_S \to \pi^+\pi^-$ method 1)	3.2	1.3×10^{33}
			2.8 ($K^0_S \to \pi^+\pi^-$ method 2)	0.3	
(p6) $p \to e^+ K^0$	47.0	< 0.2	9.2 ($K^0_S \to \pi^0\pi^0$)	1.1	1.0×10^{33}
			7.9 ($K^0_S \to \pi^+\pi^-$ method 1)	3.6	
			1.3 ($K^0_S \to \pi^+\pi^-$ method 2)	0.04	
(p7) $p \to e^+ \gamma$	98.0	< 0.2	73	0.1	
(p8) $p \to \mu^+ \gamma$	98.0	< 0.2	51	0.2	
(p9) $p \to \mu^- \pi^+ K^+$	97.6	0.1			
(p10) $p \to e^+ \pi^+ \pi^-$	18.6	2.5			
(n1) $n \to \pi^0 \bar{\nu}$	45.1	47.4			
(n2) $n \to e^- K^+$	96.0	< 0.2			
(n3) $n \to e^+ \pi^-$	44.4	0.8			
(n4) $n \to \mu^- \pi^+$	44.8	2.6			

arXiv:hep-ph/0701101

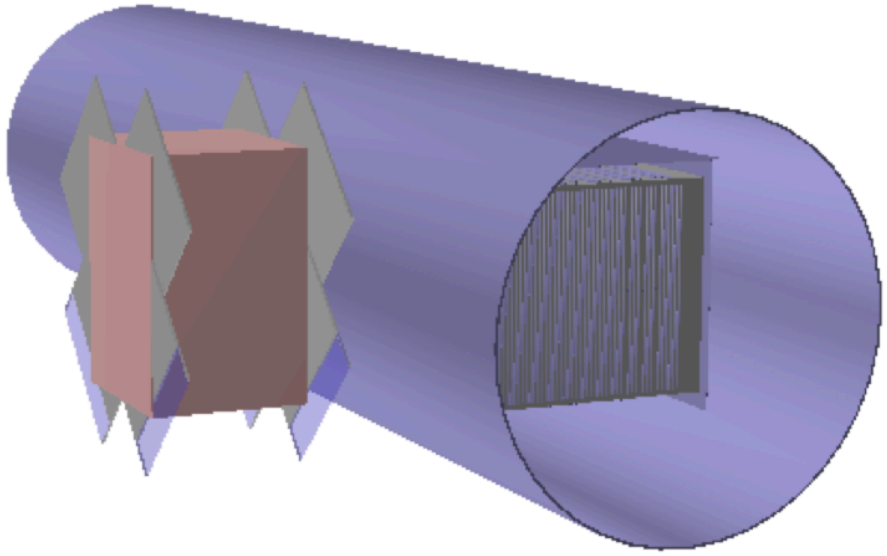
μB background studies
… what has been done

Background for p->$K^+\nu$

- A lot of work by the Nevis group, see docdb (e.g. 2073, 2307)
- Cosmogenics bkg: muons interacting in the rock producing K^0-> K^+ inside the detector.



Background induced
by cosmic muons in the rock



Stolen from docdb 2307

μB background studies
… what am I doing?!?

Cosmogenic background sensitivity

1) Pick 1 topology
2) Scan the MCC5 cosmics generation to extract events that mimic that decay topology
3) Count them! => MCTruth info
4) Reconstruct the cosmics events
5) Extract the reconstructed topology
6) Count the reconstructed events with our topology
7) Point 6)/ Point 3) is our background sensitivity

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Possible topologies

List of decay modes simulated in GENIE's standalone application for nucleon decay gevgen_ndcy

Native

ID	Decay channel
0	$p \to \pi^0 e^+$
1	$p \to \pi^0 \mu^+$
2	$p \to \eta^0 e^+$
3	$p \to \eta^0 \mu^+$
4	$p \to \rho^0 e^+$
5	$p \to \rho^0 \mu^+$
6	$p \to \omega^0 e^+$
7	$p \to \omega^0 \mu^+$
8	$n \to \pi^- e^+$
9	$n \to \pi^- \mu^+$
10	$p \to \bar{\nu} K^+$

Implemented this summer

ID	Decay channel
11	$p \to \bar{\nu} \pi^+$
12	$p \to \gamma e^+$
13	$p \to \gamma \mu^+$
14	$p \to K^0_L e^+$
15	$p \to K^0_S e^+$
16	$p \to K^0_L \mu^+$
17	$p \to K^0{}_S \mu^+$
18	$n \to \bar{\nu} \pi^0$
19	$n \to e^- K^+$

Possible topologies

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5	$p \to \rho^0 \mu^+$
6	$p \to \omega^0 e^+$
7	$p \to \omega^0 \mu^+$
8	$n \to \pi^- e^+$
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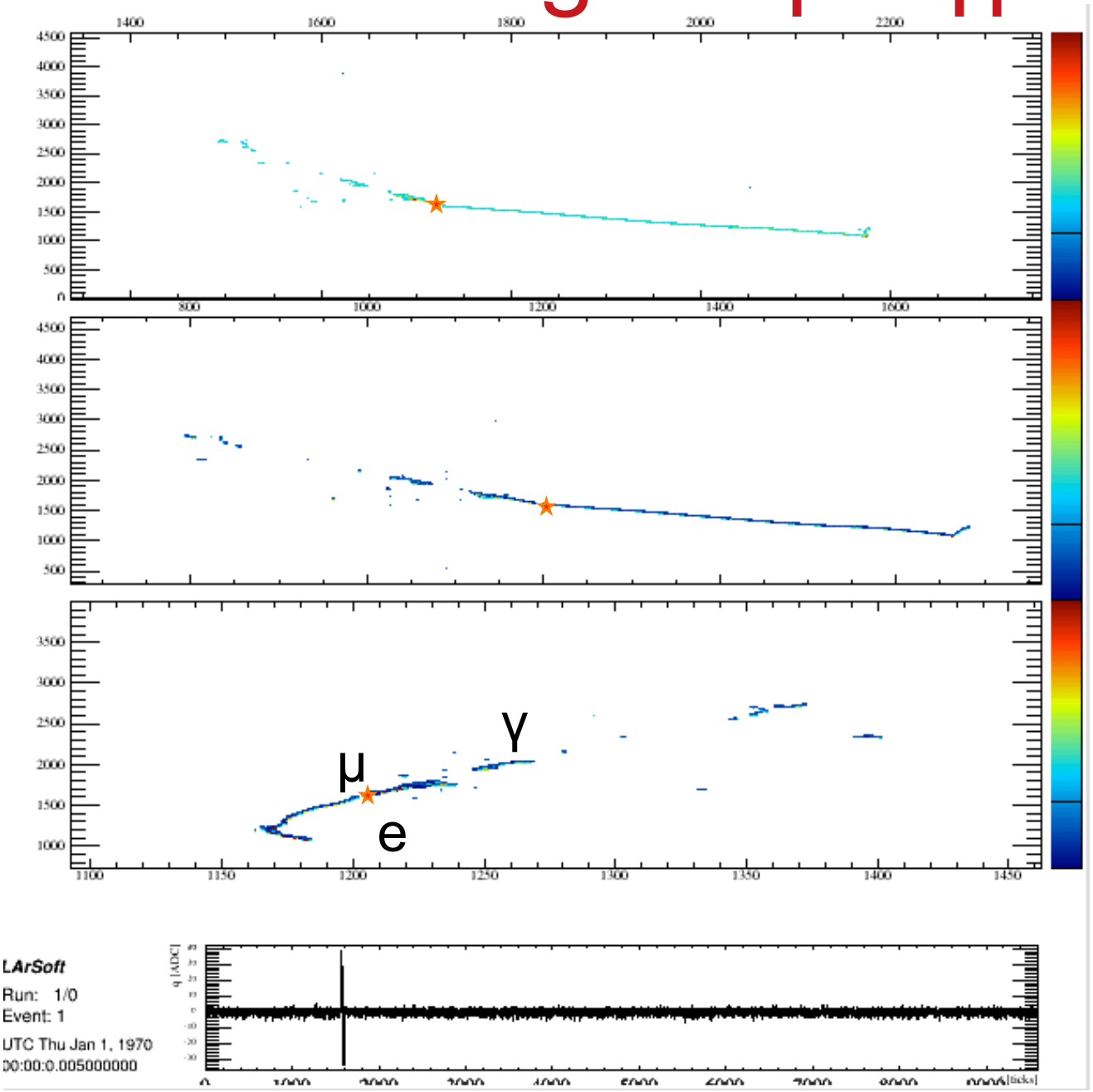
16	$p \to K^0_L \mu^+$
17	$p \to K^0{}_S \mu^+$
18	$n \to \bar{\nu} \pi^0$
19	$n \to e^- K^+$

Signal: p->γμ

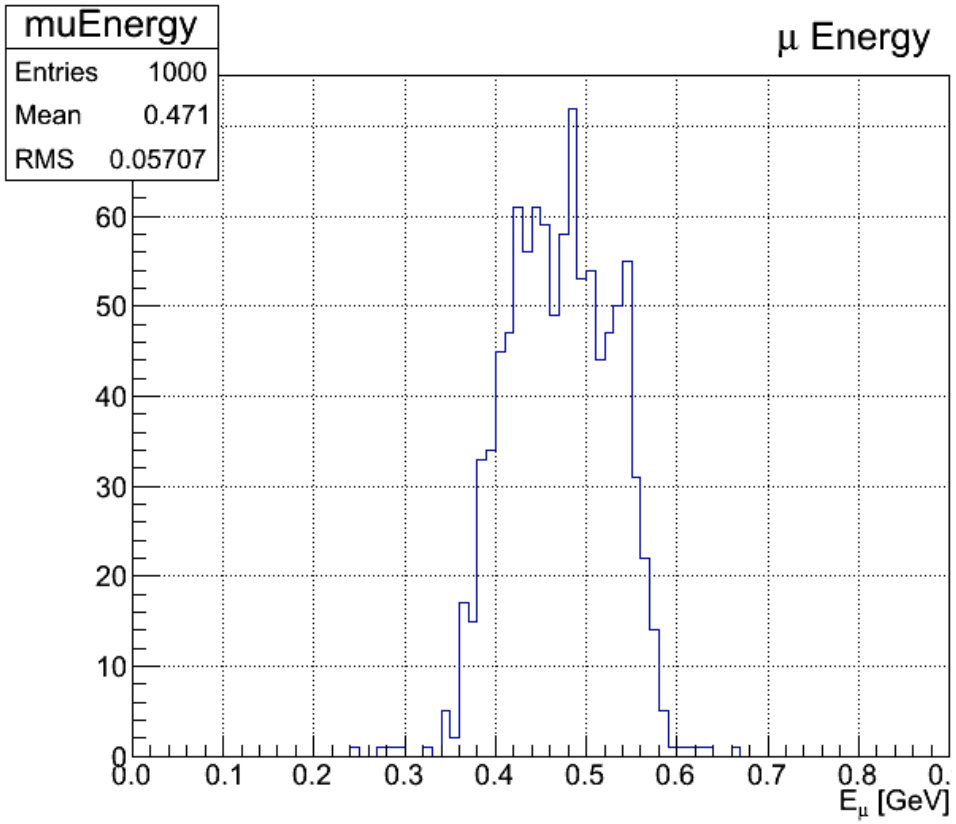


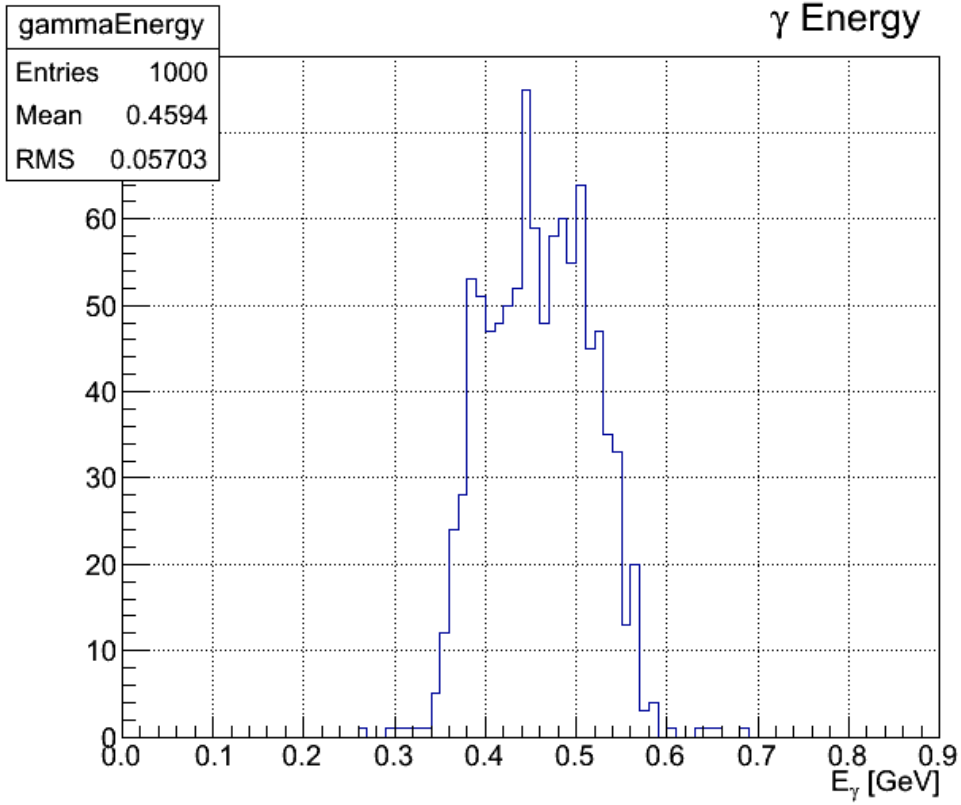
Raw data

p -> γ μ^+

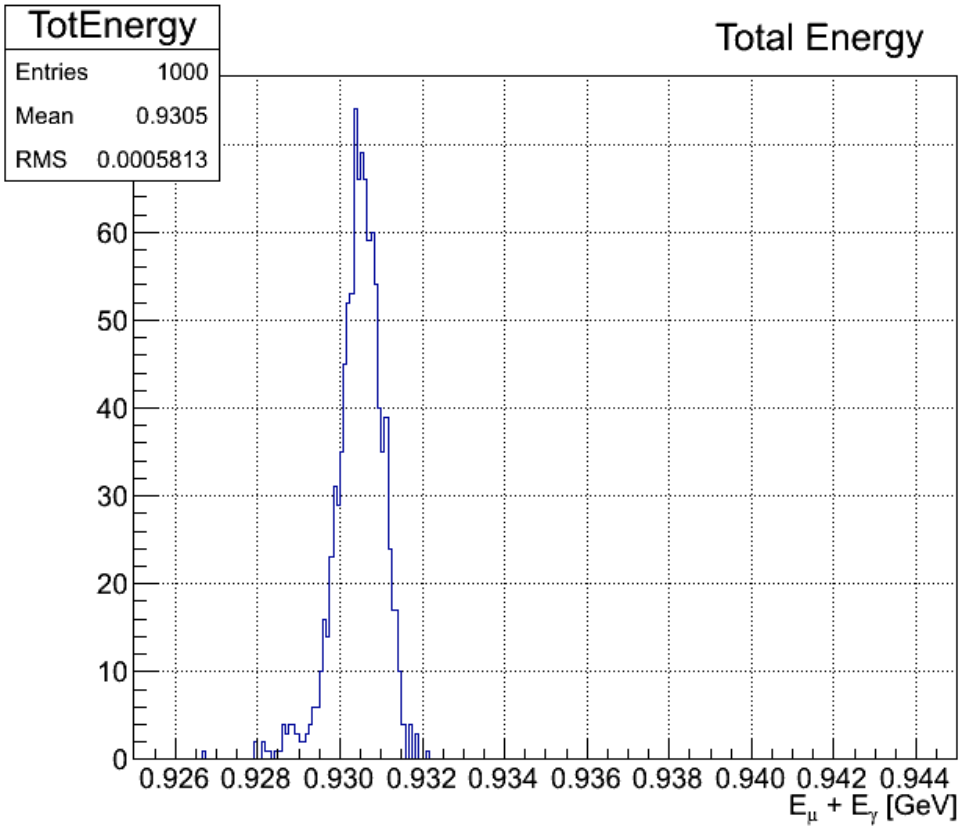
Signal characteristics (1)

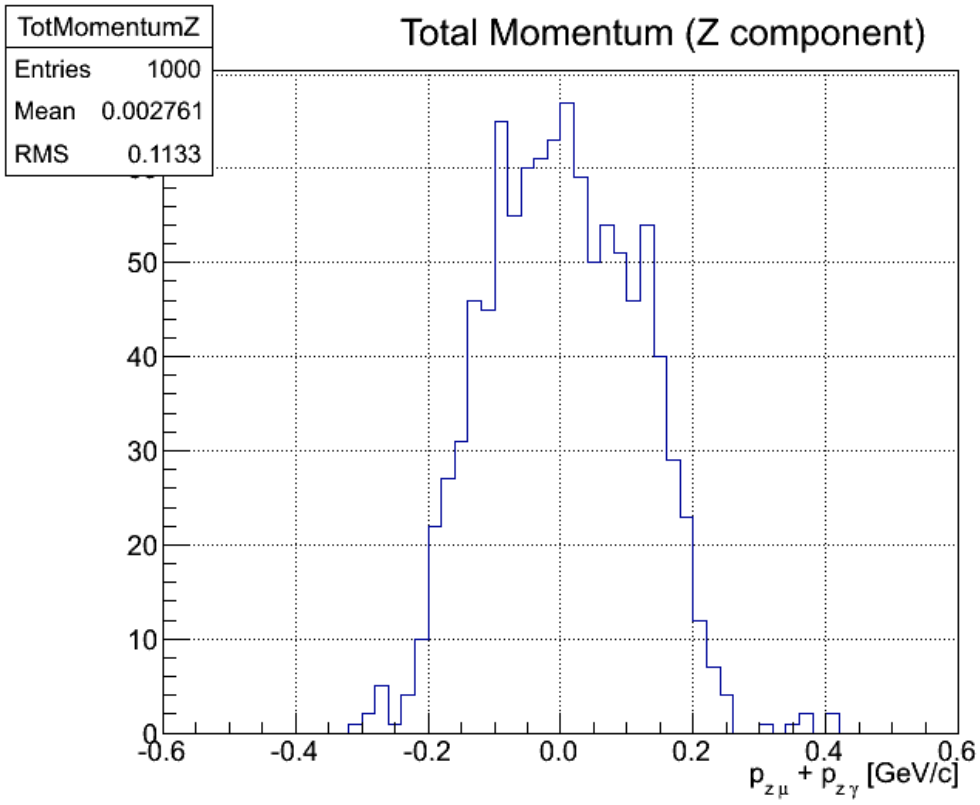
Signal generated by GENIE's gevgen_ndcy ,
parsed by LArSoft module NDKGen





Signal characteristics (2)





And, of course μγ are generated in the TPC
at the same point and time.

Cosmogenic background sensitivity

1) Pick 1 topology
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Cosmics Files & Preliminary Cuts

- ~ 192 cosmics files:
  /pnfs/uboone/scratch/uboonepro/mcc5.0_ext/v03_03_00/mcshower/prodcosmics_uboone/

  Thanks Kazu for introducing me to the wonders of MCShower!

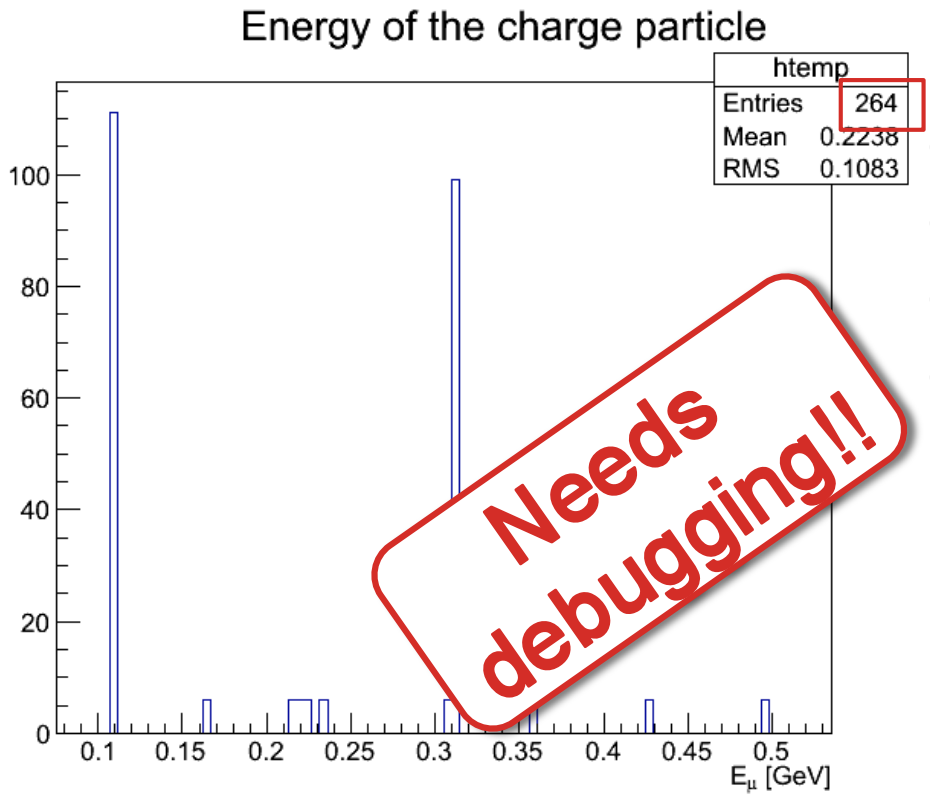
- Preliminary cuts:

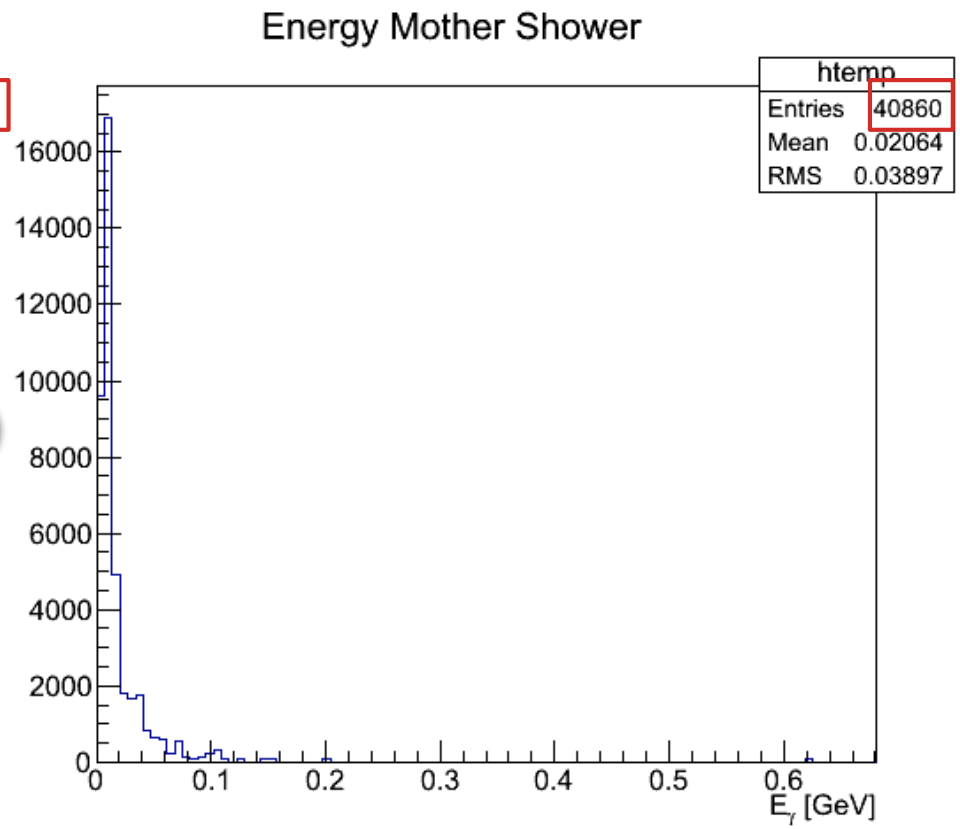
  - $\mu^{\pm}$, $\pi^{\pm}$: Energy < 2 GeV, origin inside TPC

  - γ-shower, $e^{\pm}$-shower : in case 1 μ/π in event, Energy < 2 GeV, shower start inside TPC

A glance at the statistics

- 100 events (1 MC File), after the preliminary cuts are applied.





Sanity checks required!!!!

Cosmogenic background sensitivity

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Count them: refined selection

- Ideally, a refined selection of events would be driven by the characteristics of the decay simulated by GENIE. So:
  - $E_{TOT\mu\text{-}\gamma\ pair}$ = 930 ± resolution in energy MeV
  - $P_{TOT\mu\text{-}\gamma\ pair}$ = 0 ± 300 MeV/c
  - μγ generated at the same time and within a radius of 5 cm
- In practice, we might want to loosen these constraints depending on how many events are left after the preliminary selection, in order to allow a meaningful reconstruction

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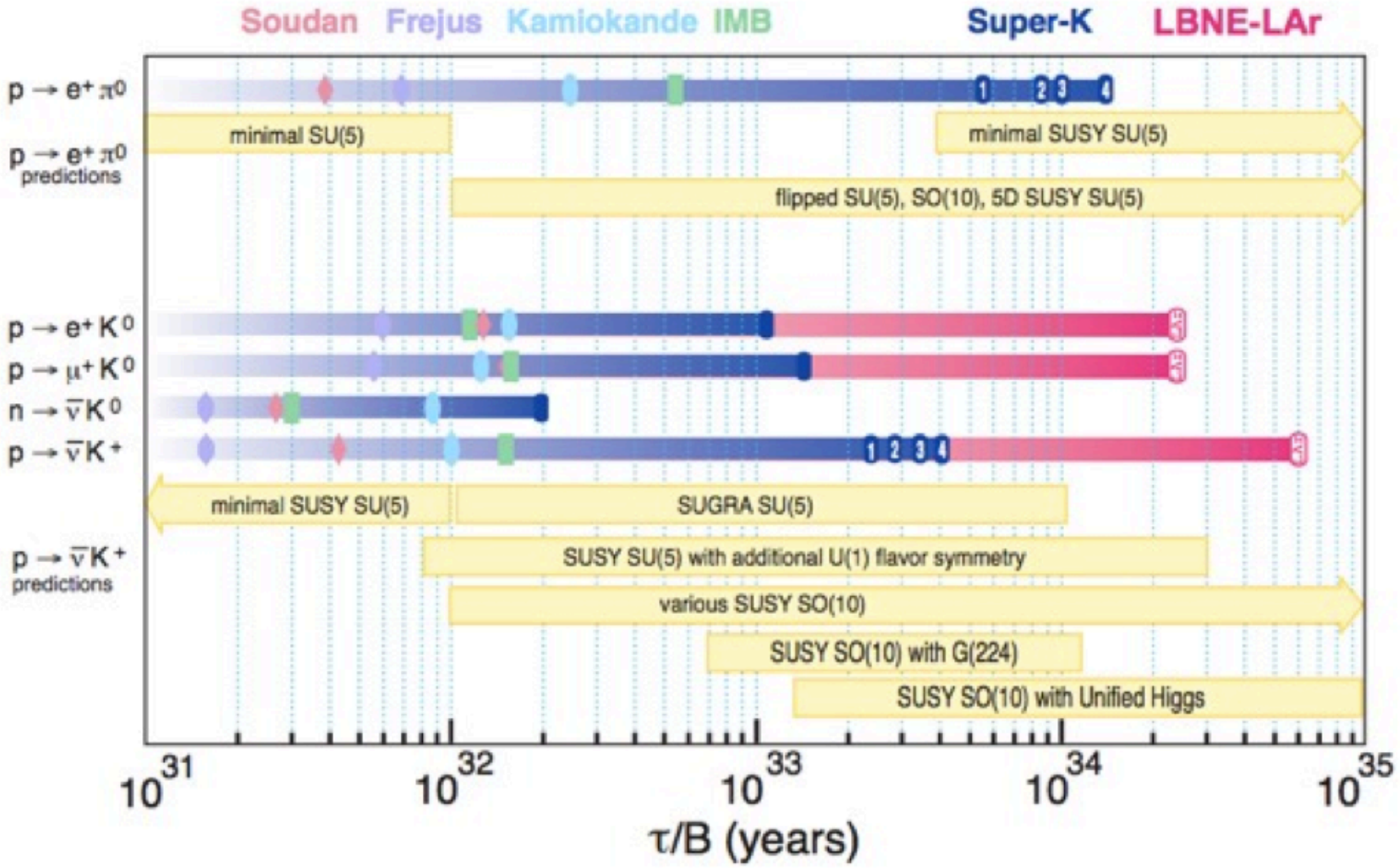
Future developments

- Repeat this “recipe” for the other 2-bodies modes
- Repeat all the studies on cosmics with overburden
- Implement the 3-bodies modes in GENIE and in the LArSoft parser

MICROBOONE

Thanks!

World experimental limits



Stolen from Eric's presentation docdb 2076

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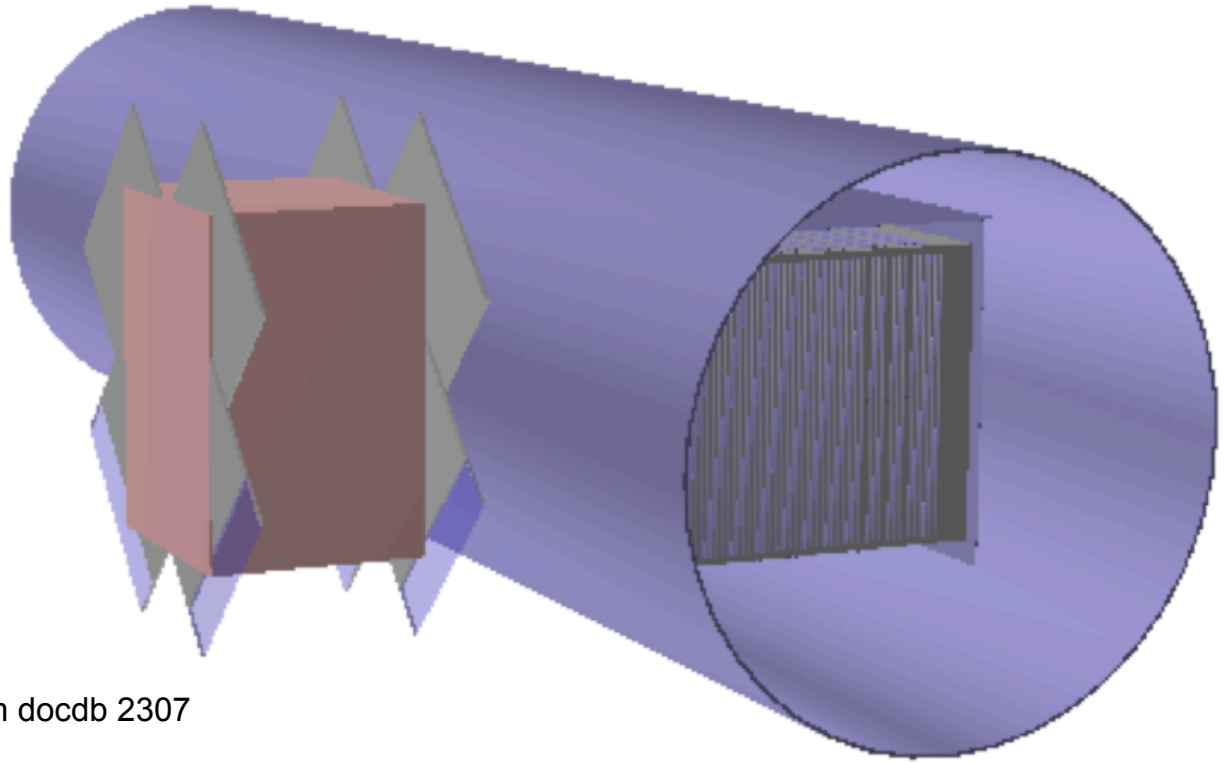
(n4) $n \to \mu^- \pi^+$	44.8	2.6			

arXiv:hep-ph/0701101

The granite block

- Idea: simulate rock surrounding the detector
- Nevis group, see docdb (e.g. 2073, 2307)



Stolen from docdb 2307

Simulation with GENIE (1)

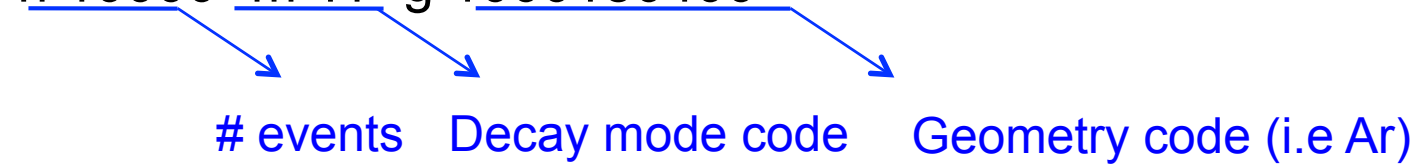
- GENIE R-2_8_0: section “Non-Neutrino Event Generation Modes”
- gevgen_ndcy is GENIE’s standalone application for nucleon decay: it is disabled in the default configuration

“*The primary decay is simulated using a phase-space-decay generator. For bound nucleons, the nuclear environment is simulated as in neutrino scattering. The nucleon is assigned a Fermi momentum and removal energy and it is off the mass shell. The propagation of decay products is simulated using an intranuclear cascade MonteCarlo*.” The GENIE Neutrino Monte Carlo Generator PHYSICS & USER MANUAL

Simulation with GENIE (2)

- A possible way to launch the application:

$ gevgen_ndcy -n 10000 -m 11 -g 1000180400



- Output: 1 rootfile and a txt file. The rootfile is translated into a GHEP-likefile thru:

$ gevdump -f ndk.1000.ghep.root > ndk.out

- For the newly implemented modes a sample of 10000 events per each decay mode was generated:
  - Nice and easy: ~ 1 min to generate 10000 events
  - seconds to convert the root file to the GHEP-like file

Validation into LarSoft

- From the GHEP record one can load MCParticles and run events with the LArSoft module NDKGen_module.cc
- I'm using v02_02_00 larsoft and uboonecode and I'm runing: argoneut_nuance+microboone_largeant +microboone_simwire (no reco)
  - Placing the proton at the center of the detector (x,y,z) = (geo->DetHalfWidth(), 0 , 0.5*geo->DetLength()) for some random events the geant4 simulation "gets stuck"
  - Displacing the proton a little bit (by ~0.314159 cm in each direction) no event "gets stuck"
- Events parsed by LarSoft: 1000

Outline

- Motivations for nucleon decay studies
- MicroBooNE, LBNF and “the Bueno paper”
- Future prospectives