Ask a Meddling Theorist: New Ideas for Liquid-Argon Detectors

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CCAPP

NSF

The Problem

CP Violation

Proton Decay

Supernova Nu

???

Prospecting in New Directions

1. Neutrino Detection
2. Weak Interactions
3. Cosmic-Ray Backgrounds
4. Detector Properties
5. Particle Properties

Neutrino Detection

(better particle ID)

Atmospheric Neutrinos

Present status:

Atmospheric-neutrinos signals in DUNE under-explored

Why it matters:

New way to test neutrino mixing with matter effects

Physics opportunities:

Exploit huge exposure of DUNE

Improve neutrino sign ID through identifying final states

Neutrino Sign ID in LAr

Possible methods:

Use known idea of sign ID from mu- capture

Add tests of e+ vs. e- by inflight annihilation

Fraction ~ 10%, favors ~ 1--10 MeV (Beacom and Yuksel)

astro-ph/0512411

How to test it:

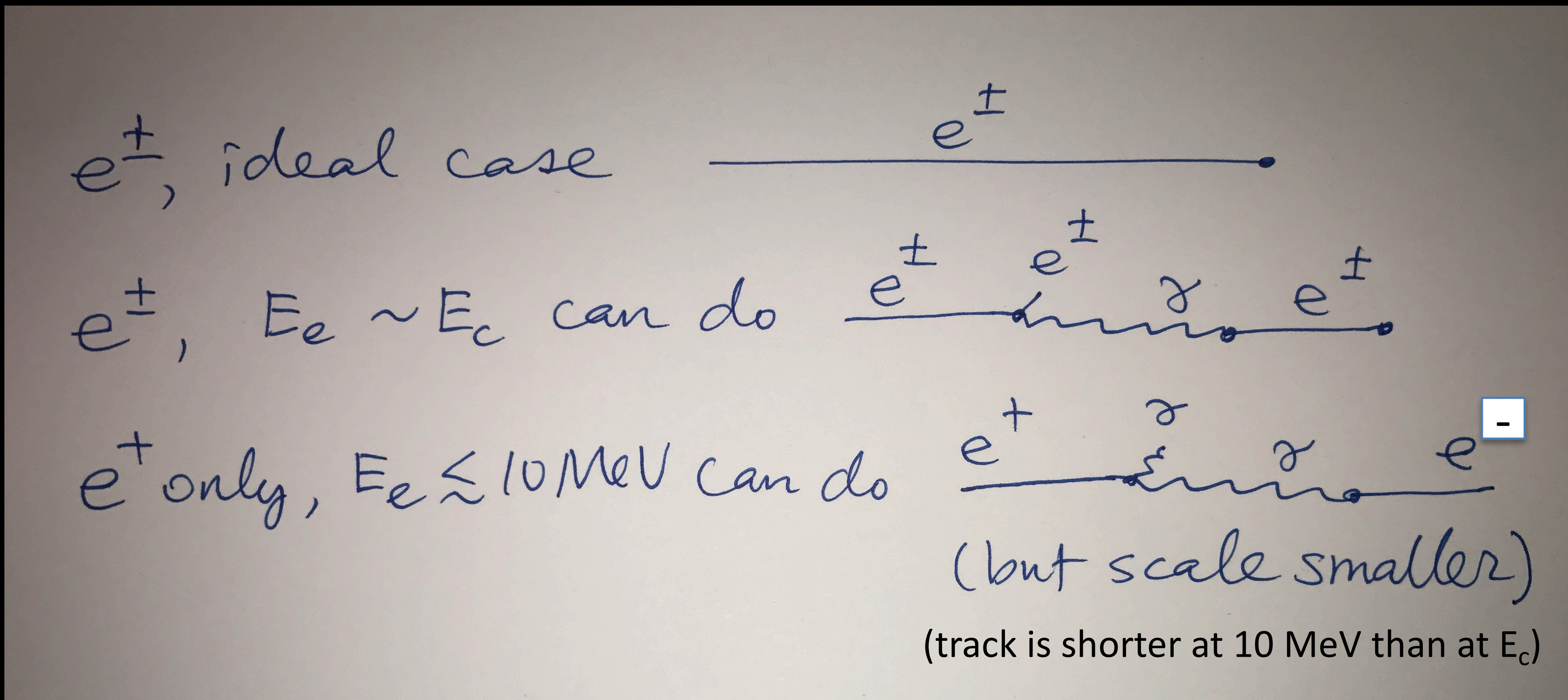
More pure sample of e+ from muon decay (mostly mu+)

Look for gaps in beta track at low energy

Possible plan:

Your name here

Positron Annihilation in Flight



(track is shorter at 10 MeV than at E_c)

Appendix: Neutrino Detection

More ideas:

- Reconstruction of pi, p, n to help PID, energy, direction
- Barkas effect for particle sign ID
- Measure sigma(MeV) with mu DAR at Oak Ridge*

  arXiv:1808.08232
- Measure sigma(MeV) at FNAL with ultra-off-axis beam

*Note added: For mu DAR at Fermilab, see also arXiv:1311.5958 and arXiv:1510.08431

$\boxed{\text{Weak Interactions}}$

(better nu cross sections)

Stopped Mu- Nuclear Capture

What it is:

Nearly all mu- atomic capture; most nuclear capture

Underlying process is mu- + p ---> nu + n, which is weak

In nuclei, often go to bound and unbound excited states

Energy release is ~ 100 MeV

Why it matters:

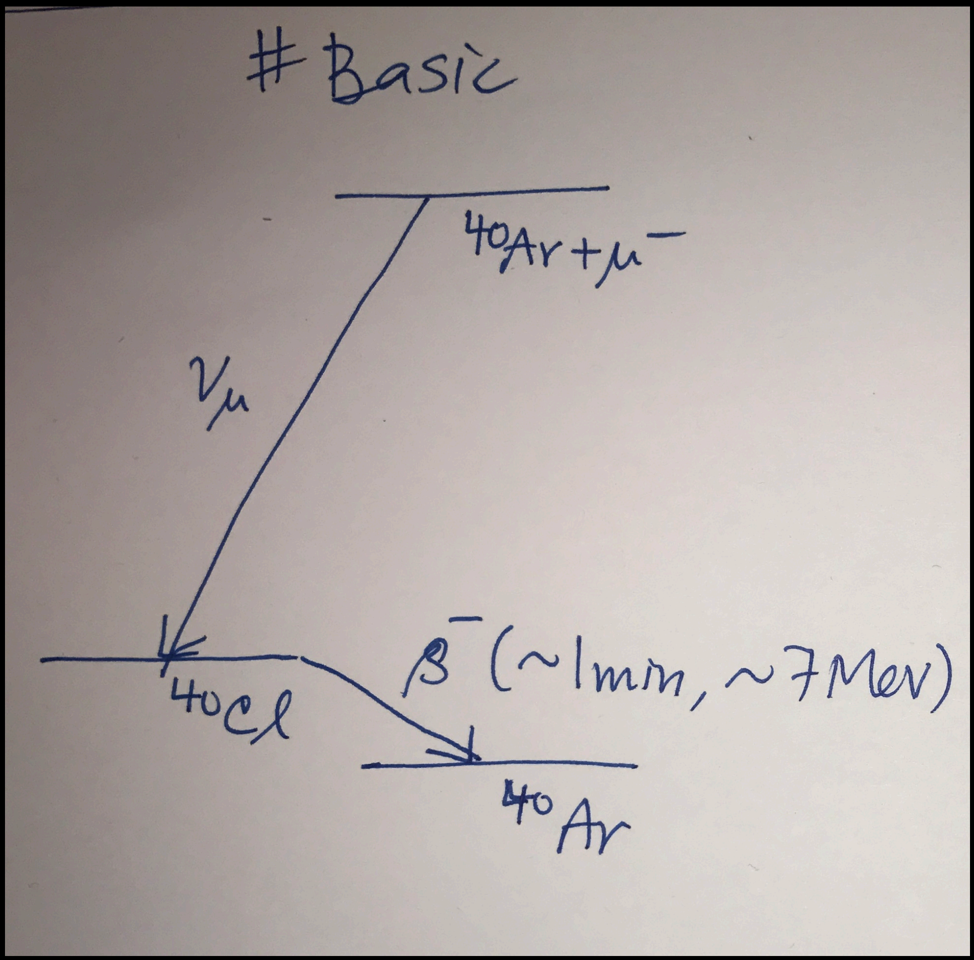
Help test matrix elements for neutrino cross sections

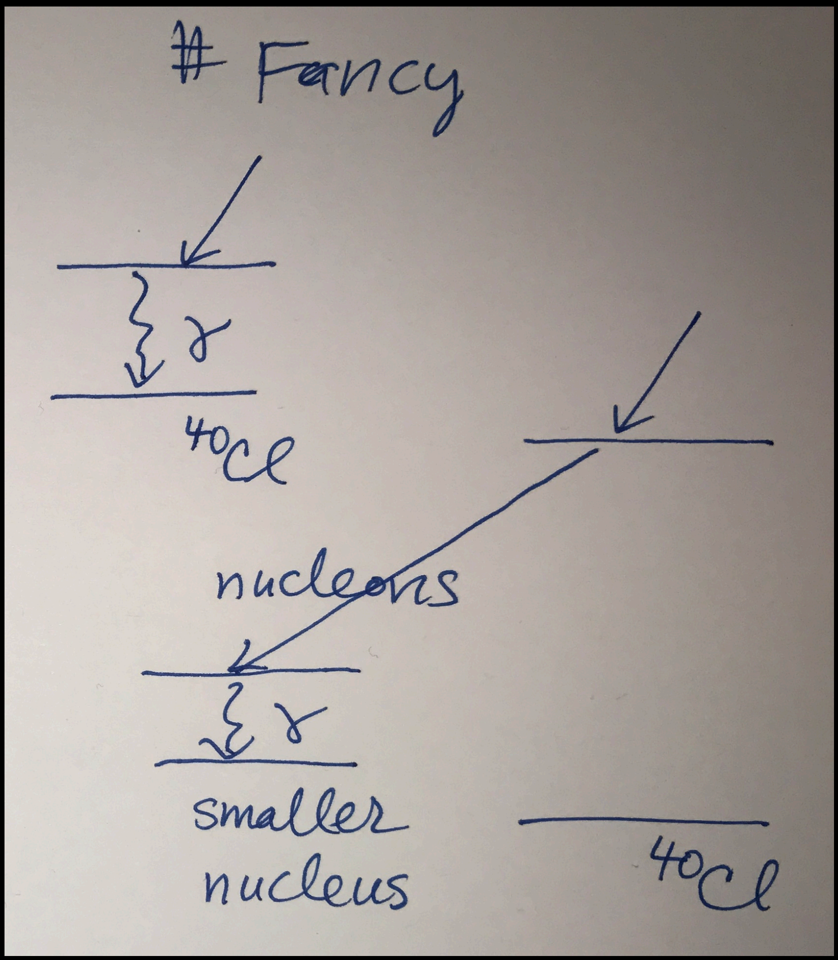
Physics opportunities:

Use LAr power to identify final-state particles

Measure transition rates for several nuclei

Mu- Nuclear Capture in LAr





Mu- Nuclear Capture in LAr

Estimated rate:

Expect large branching ratios to many final states

Large uncertainties

How to find them:

Identify stopping, non-decaying muons

Identify ejected products, possibly daughter nucleus

Possible plan:

Your name here

Appendix: Weak Interactions

More ideas:

- Identification of nuclear de-excitation gamma rays
- Reconstruction of nucleus by hadronic output
- Spallation tagging through beta-gamma decays

Cosmic-Ray Backgrounds

(better background control)

Spallation Backgrounds

What they are:

Beta decays of isotopes made by muons and secondaries

Energies of ~ 5--15 MeV, delays of ~ 1--10 s

Why they matter:

Leading background for solar, DSNB, and $\beta\beta0\nu$ studies

Physics opportunities:

Serious modeling by Zhu, Li, Beacom

Our cuts used on real data are working

arXiv:1402.4687
arXiv:1503.04823
arXiv:1508.05389
arXiv:1811.07912

Example: Spallation in MicroBooNE

Estimated rate:

Yield ~ 0.01 events per frame above 10 MeV
Yield ~ 1 event per frame above 5 MeV
These are highly uncertain due to our ignorance of some detector features, impact of non-muon cosmic rays

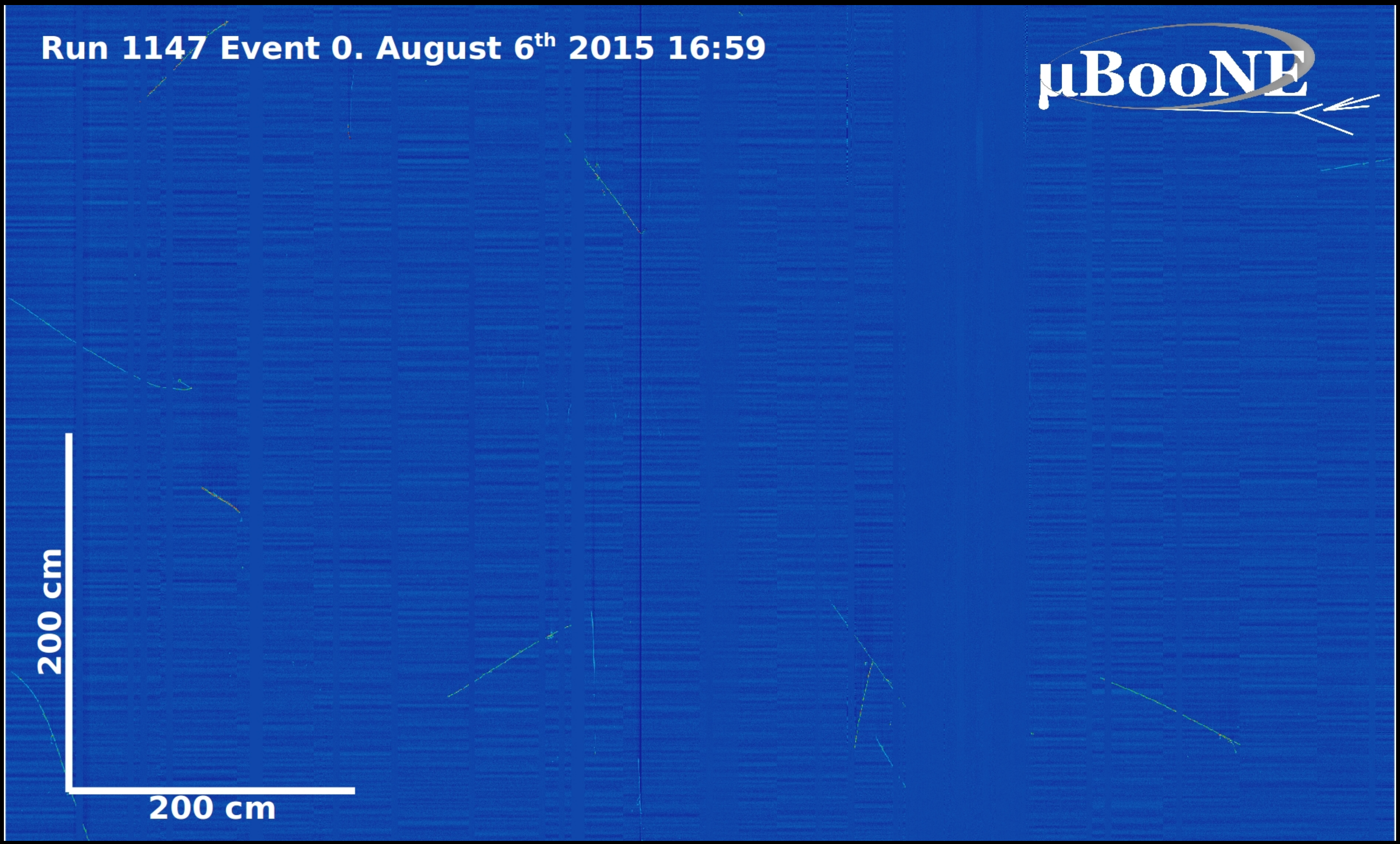
How to find them:

Measure steady state rate, giving up on muon correlation
Low-energy betas, isolated from muons and walls

Possible plan:

Your name here

Sample Frame from MicroBooNE



Appendix: Cosmic-Ray Physics

More ideas:

- Measure mu+/mu- charge ratio at low energies
- Measure mu polarization through beta direction
- Muon bundles
- Other cosmic-ray details at low energies

Detector Properties

(better understanding of detectors)

Impurities that Affect Electron Loss

Present status:

Loss fraction of electrons during drift is uncertain

Electron attachment to impurities can be a problem

Why it matters:

When t0 is unknown, it affects electron energy estimate

Physics opportunities:

New calibration tools are needed

Near-surface LAr detectors have abundant cosmic rays

Charge Drift in LAr

What happens first:

Charged particles in LAr produce electrons and +ions

Ideal response:

Electrons drift one way over a few ms

+ions drift the other way over minutes

Non-ideal response:

Electrons drift one way over a few ms

-ions drift one way over minutes

+ions drift the other way over minutes

Electron Loss Measurement in Surface LAr

Underlying idea:

Can’t measure the nuclear drift time in equilibrium

How to test it:

Use rare big cosmic-ray showers as a burst of charge
Measure how the system responds out of equilibrium
Determine role of impurities in electron loss

Possible plan:

Your name here

Appendix: Detector Properties

More ideas:

- MeV calibrations with specific spallation decays

  arXiv:1811.07912

- MeV calibration with neutron capture gamma line

  arXiv:1808.08232

- KE calibrations with pi ---> mu, pi --- > e channels

Particle Properties

(other physics goals)

Rare Muon Decays

What they are:

Anything but mu --- > e + nu + nubar

Why they matter:

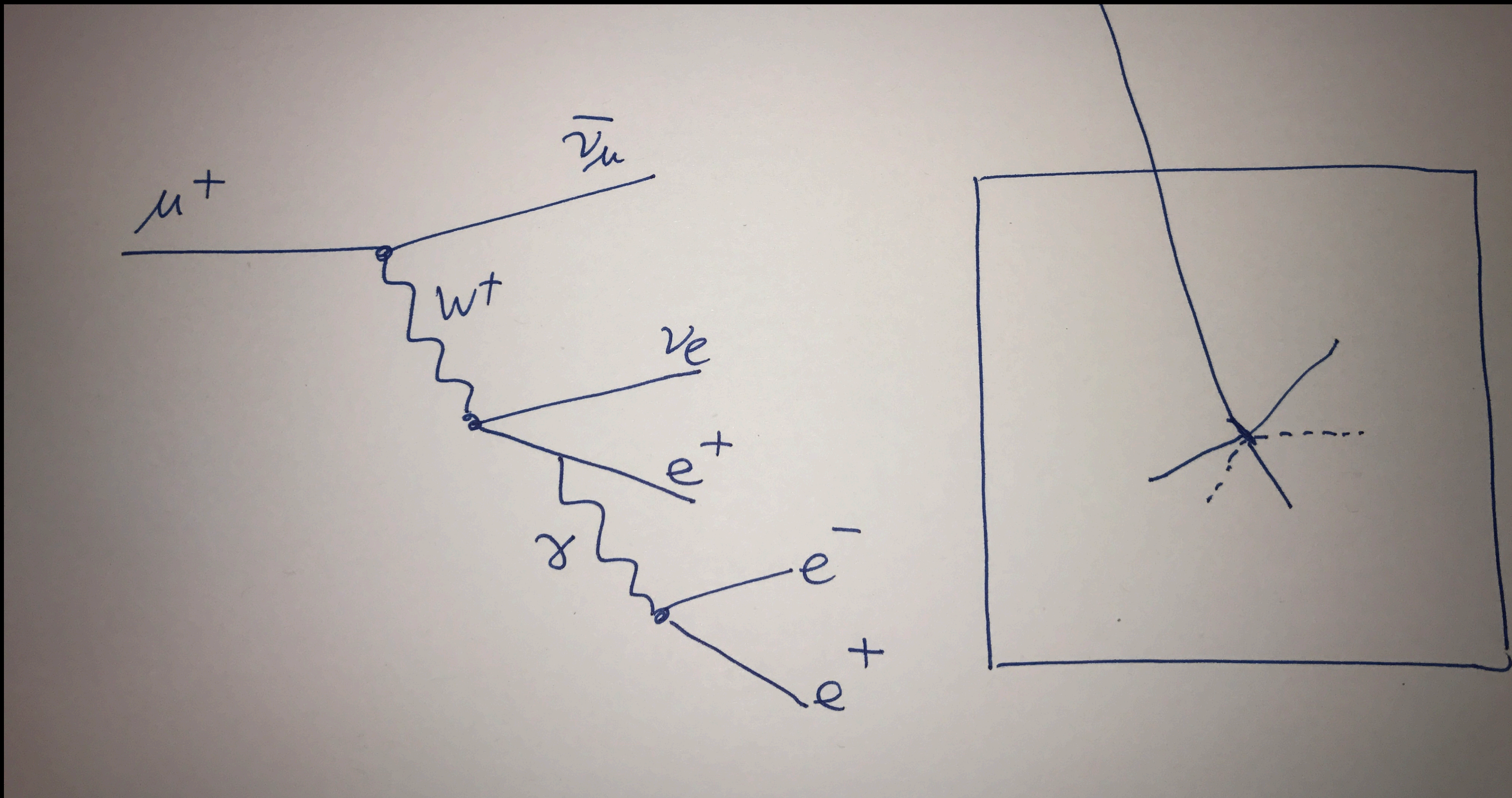
Test new physics, get new entries in PDG tables

Physics opportunities:

Huge number of stopped cosmic-ray muons

Use LAr power to identify final-state particles

Muon Decay with Three Betas



Rare Muon Decays in LAr

Estimated rate:

Decay mu ---> e + nu + nubar + e + e not well measured

BR ~ (3.4 +/- 0.4) x 10^{-5}

How to find them:

Identify stopping, decaying muons

Identify three beta tracks with no gaps from muon end

Separate from radiative losses of electrons by energy

Need > 10^7 stopping muons to improve precision

Possible plan:

Your name here

Appendix: Particle Properties

More ideas:

- Lots of other possible rare muon decays
- Muon decay in orbit with high-energy betas
- Pion, etc. rare decays
- Maybe probe hadronic interactions at low energies

Conclusions

To be continued!