The Mu2e Experiment

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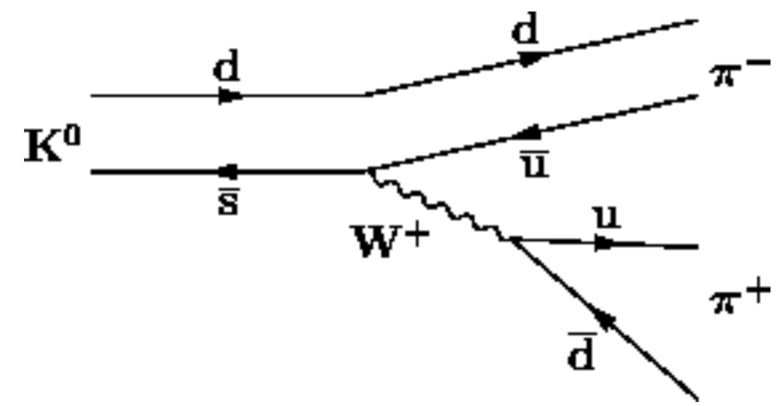
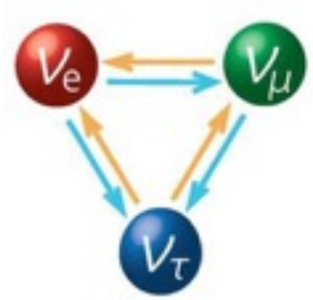
Fermilab
Marj Corcoran Symposium, Rice University
26 April 2017

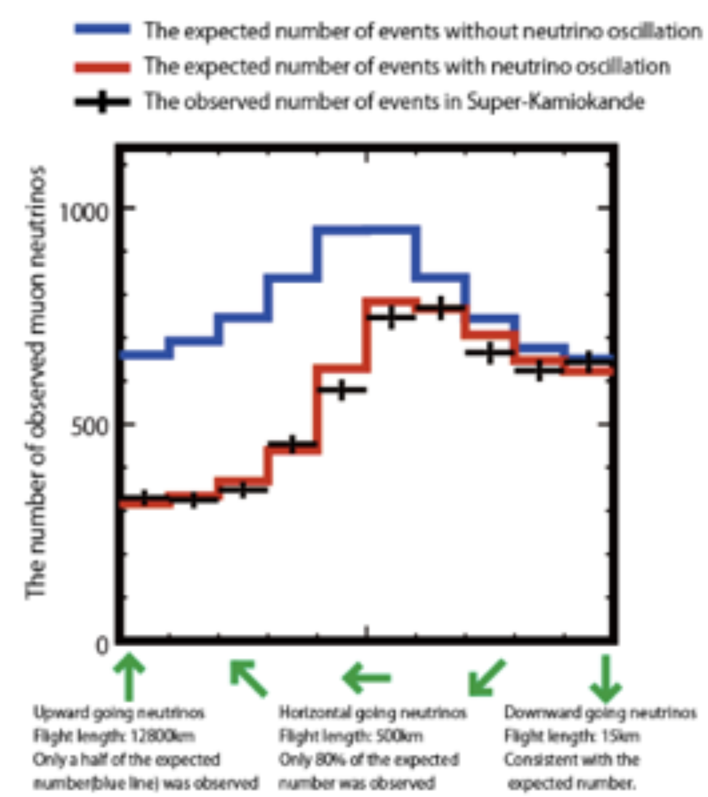
Flavor Violation

- Happens all the time in weak interactions in the quark sector
  - Ex: neutral kaon decay



- In 1998, discovered it in the neutral lepton (neutrino) sector
  - Neutrino oscillation



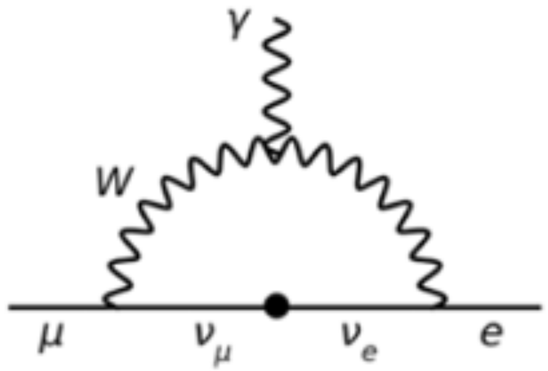


http://www-sk.icrr.u-tokyo.ac.jp/sk/sk/neutrino-e.html

- So, why shouldn't charged leptons do it too?
  - In particular, muons and electrons (taus are hard)

Charged Lepton Flavor Violation

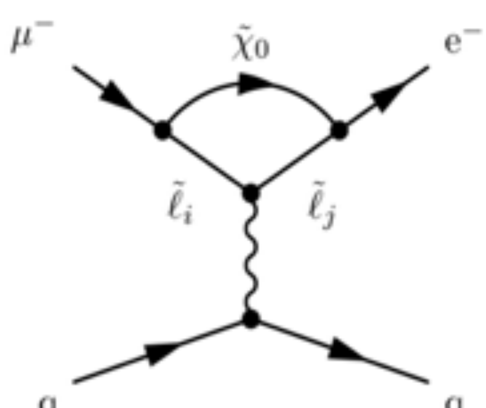
- In the Standard Model:



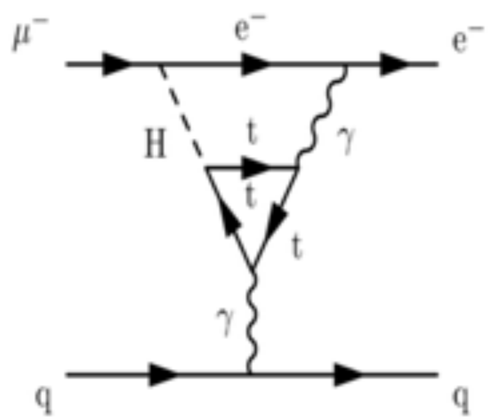
suppressed by $\Delta m_\nu^4/m_W^4$

— over 50 orders of magnitude…. good luck

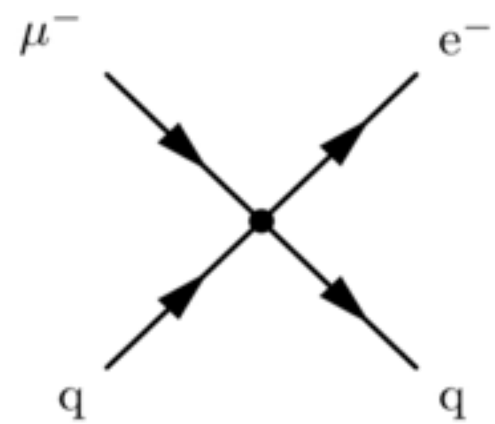
- Beyond the Standard Model:



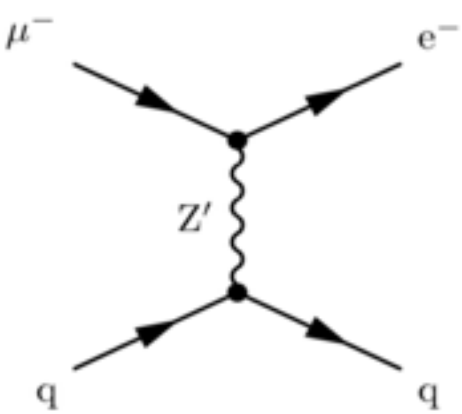
SUPERSYMMETRY



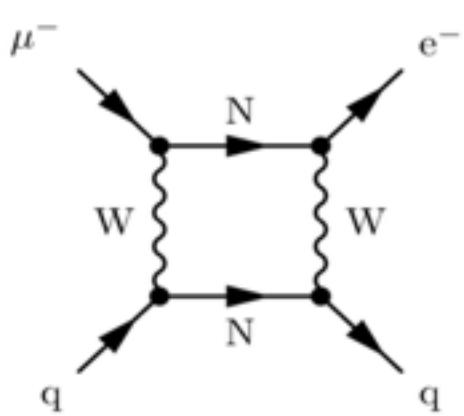
ADDITIONAL HIGGS



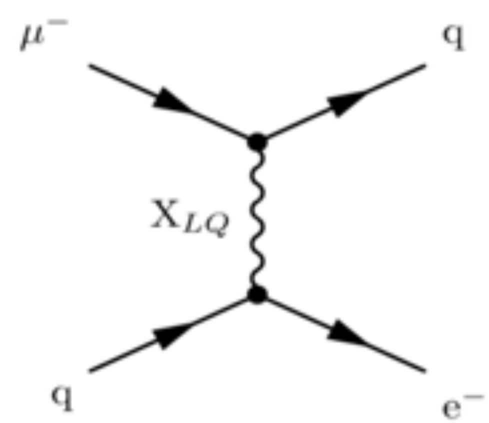
COMPOSITENESS



EXTRA DIMENSIONS



HEAVY NEUTRINOS



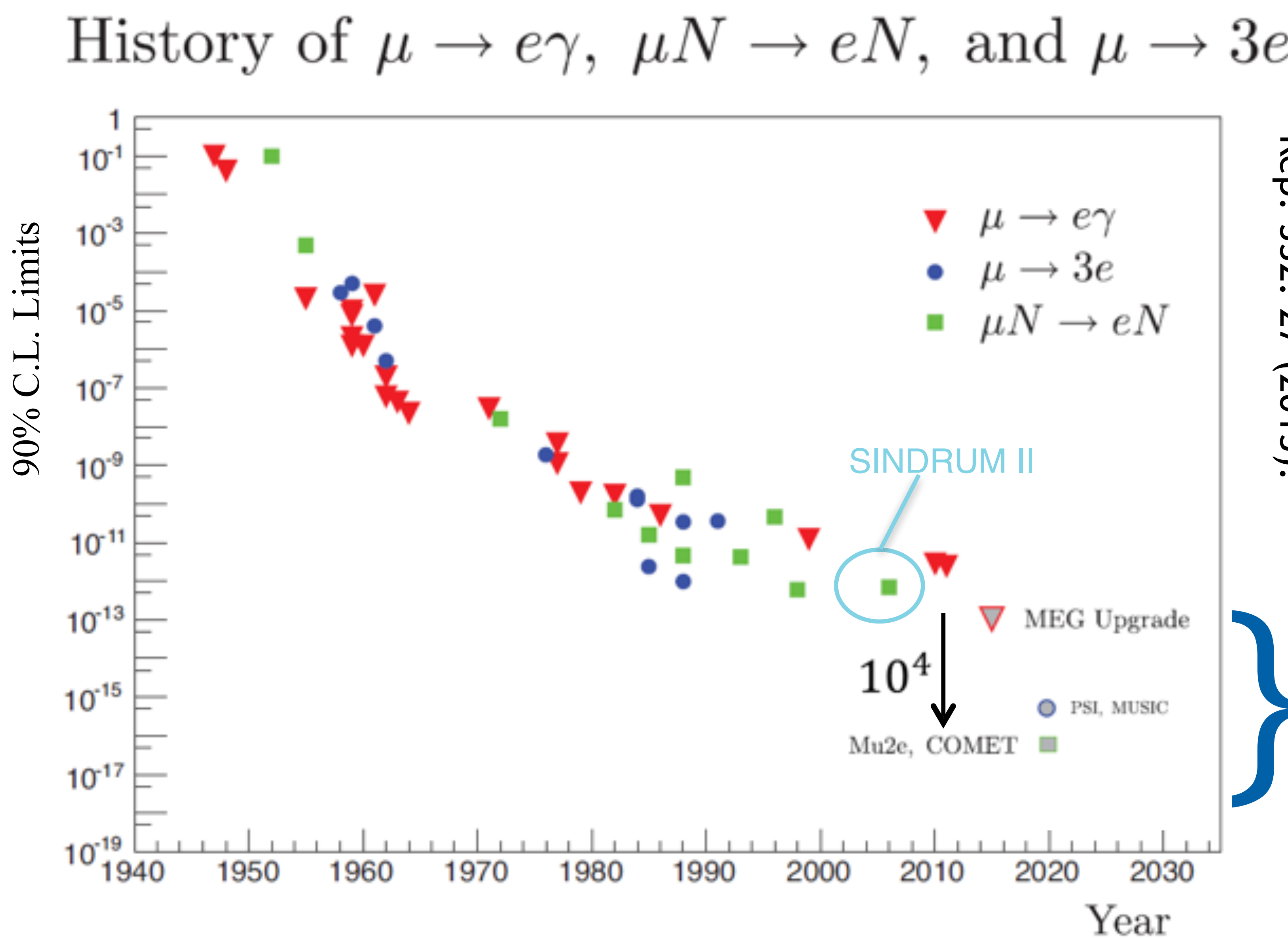
LEPTOQUARKS

Many SM extensions predict mu -> e with rates just beyond reach of current sensitivities

A mu -> e observation is unambiguous evidence of new physics

Fermilab

Muon CLFV history



Bernstein and Cooper, Phys. Rep. 532: 27 (2013).

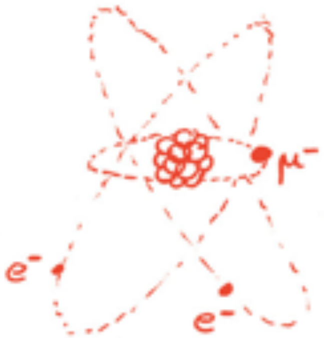
New physics?

- Mu2e represents an increase in sensitivity of four orders of magnitude over the current state of the art
  - How will we do that?

Muon to electron conversion

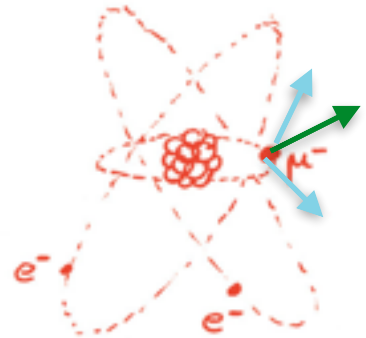
- Stop muons in an aluminum target

Muonic atom



Decay-in-orbit

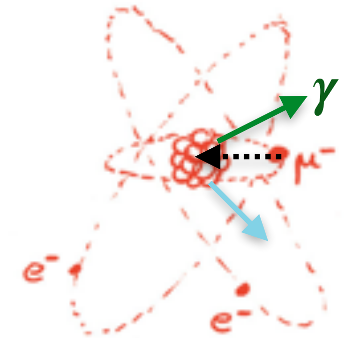
$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$



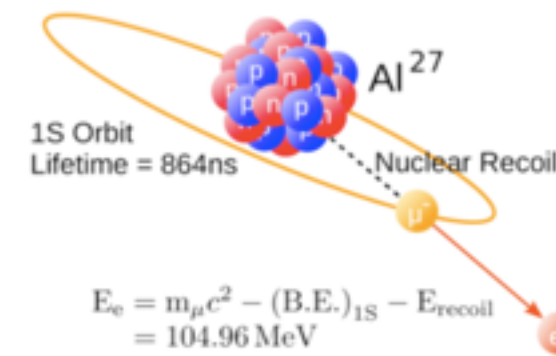
or

Muon capture

$\mu^- N \rightarrow \nu_\mu N^{'} (+\gamma?)$



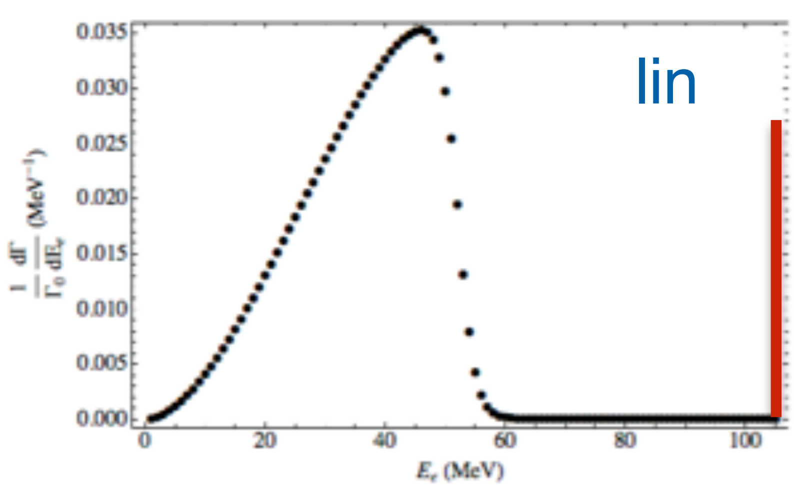
Muon-to-electron conversion

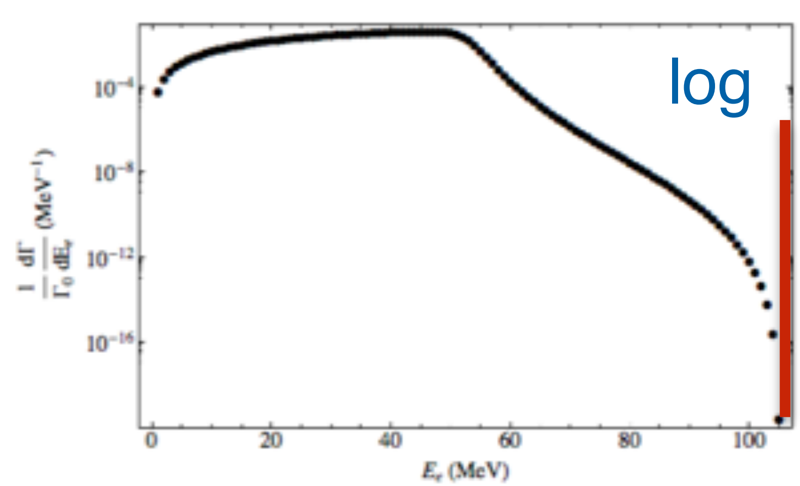


What "normally" happens

What we hope happens

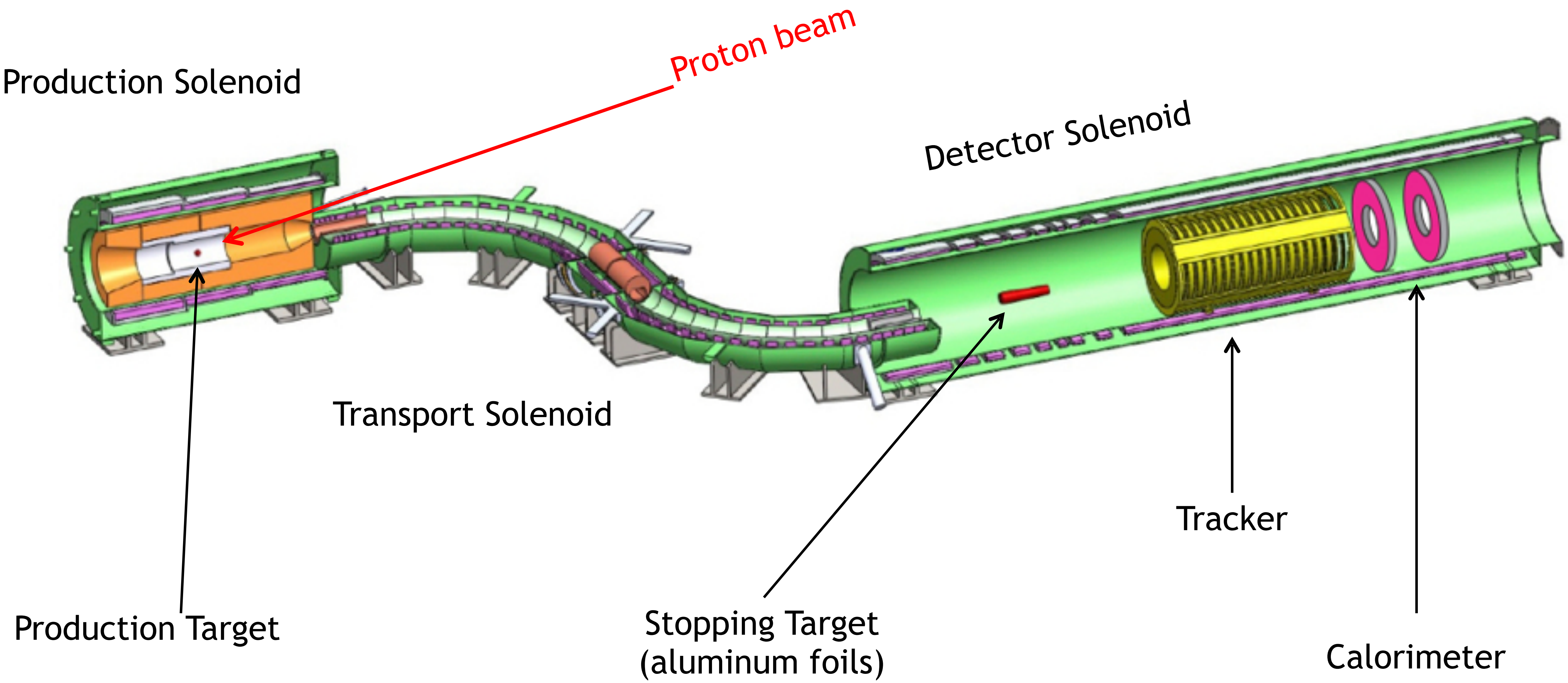
- Clean signature: an electron with kinetic energy (almost) equal to the muon rest mass
  - Compare with DIO spectrum including recoil from heavy nucleus



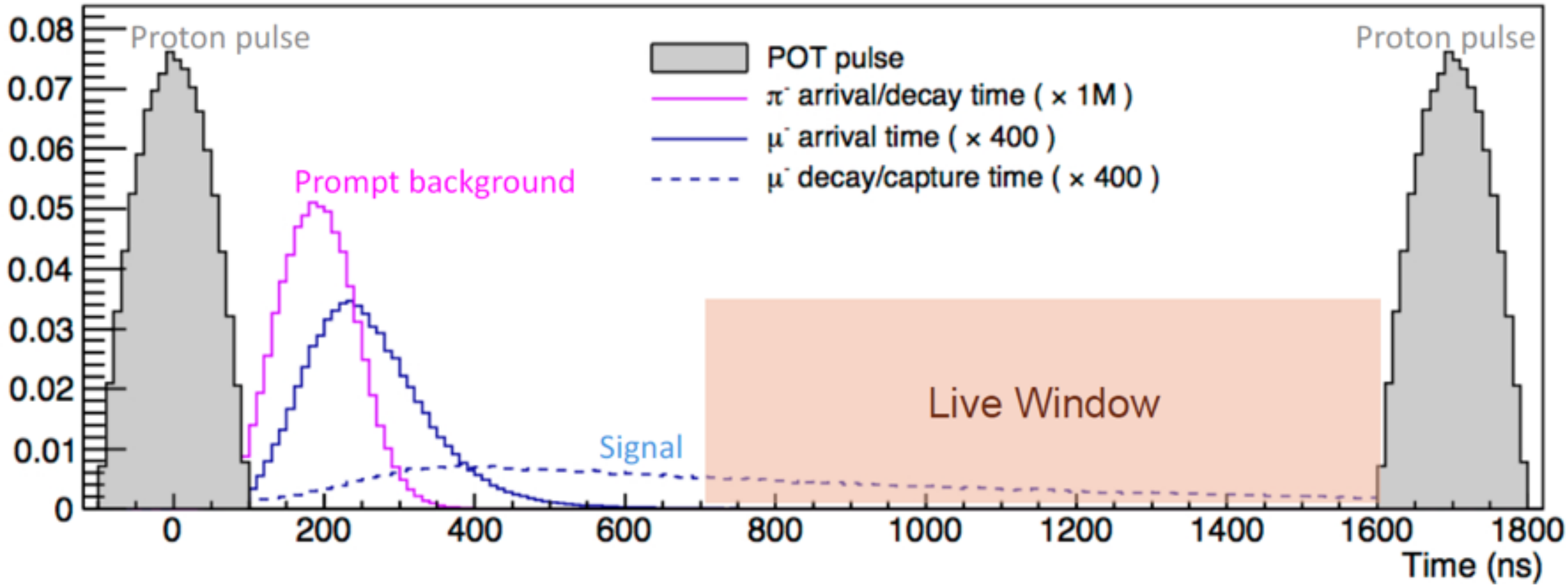


Czarnecki, Tormo, and Marciano, *Phys. Rev. D* **84**, 013006 (2011)

Making and stopping muons



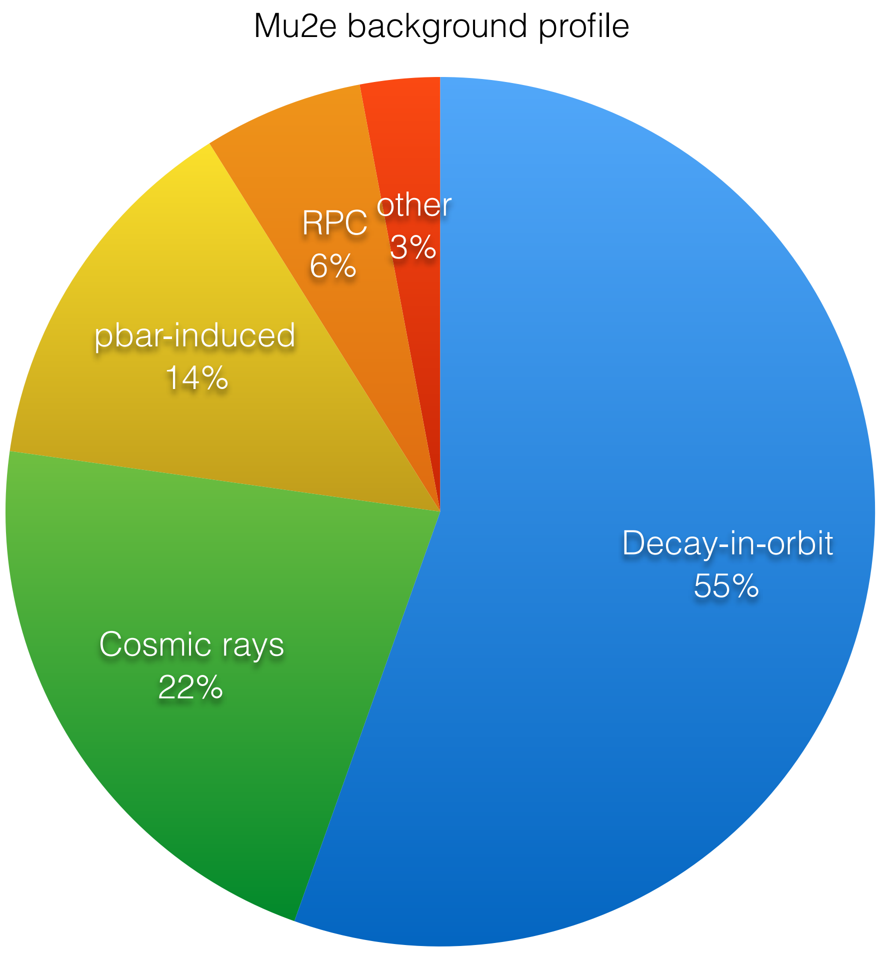
Pulsed beam strategy



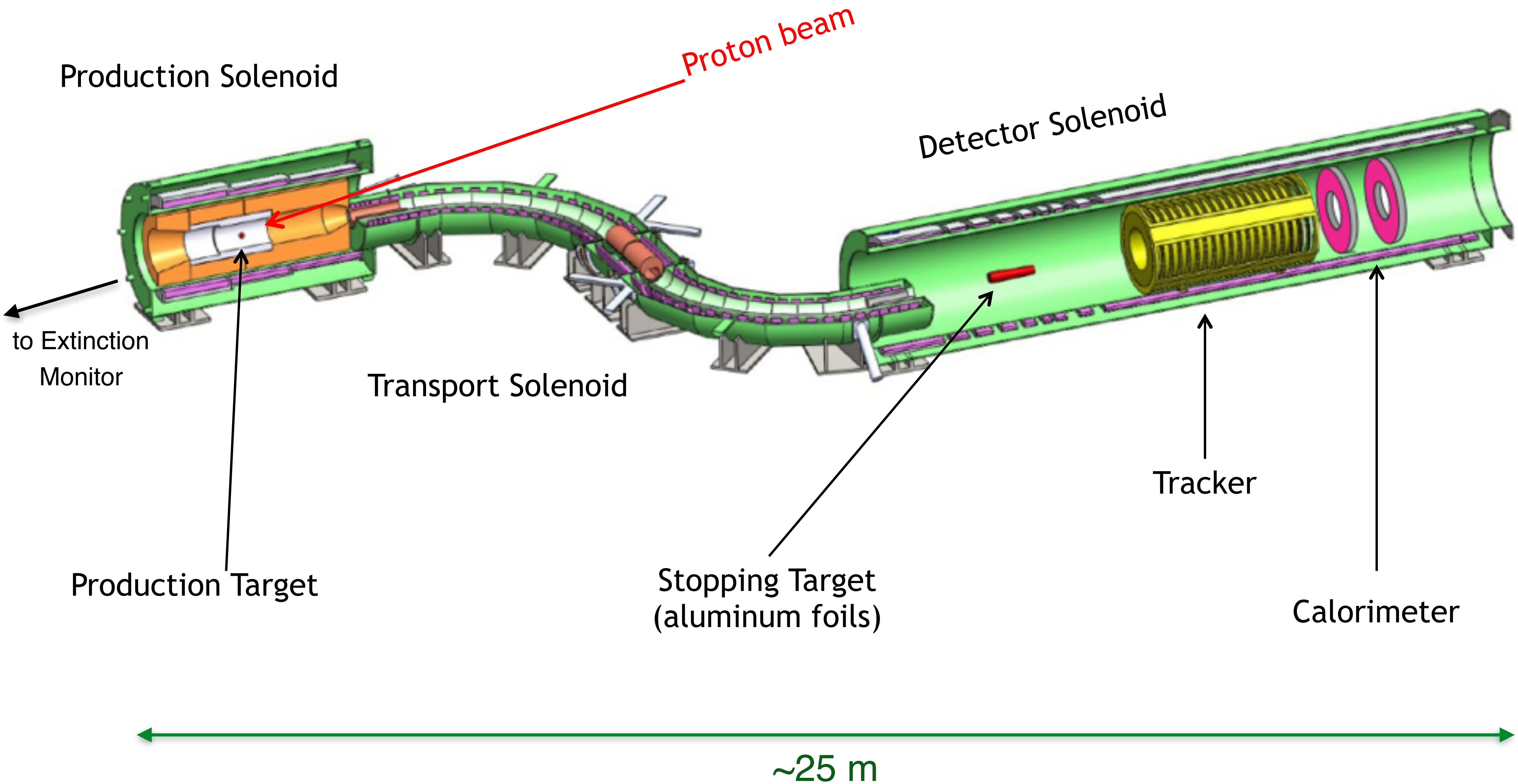
- Take advantage of 864 ns lifetime of μ-Al 1S state
  - Let beam-related backgrounds blow past before looking for signal
- Ways for backgrounds to sneak into live window
  - Residual protons in between main pulses
    - Require beam “extinction” 10^{-10} or better
  - Particles trapped in solenoid fields
    - Require monotonically decreasing field along the muon beamline

Keys to Mu2e success

- LOTS of stopped muons
  - ~10^{18} over 6 x 10^{7} s of beam time (~ 3 years)
- Almost no background (estimate 0.36 events over same 3 years)
  - Requires
    - Excellent momentum resolution to isolate 104.96 MeV electrons
    - High-efficiency (99.99%) cosmic ray veto
    - Anti-proton absorbers
    - Excellent beam extinction
- …resulting in an expected 90% CL upper limit on $\mu \rightarrow e$ conversion rate of 6×10^{-17}

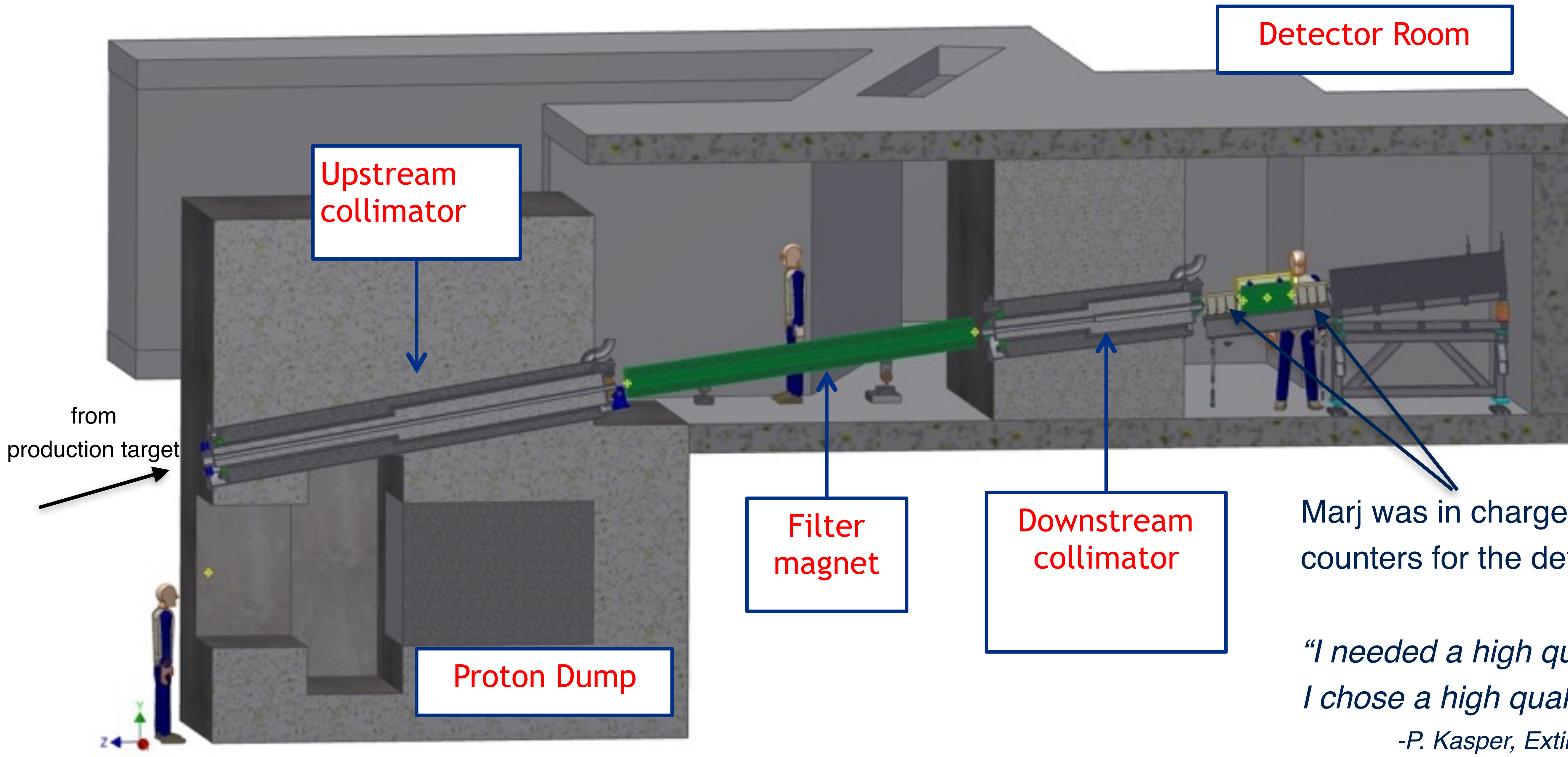


Highlights of the Mu2e apparatus



Extinction Monitor

- Verify 10^{-10} extinction by sampling particles from production target both in-time and out-of-time



Marj was in charge of the trigger counters for the detector.

"I needed a high quality product so I chose a high quality provider."

-P. Kasper, Extinction Monitor Leader

The Mu2e superconducting solenoids

Production Solenoid

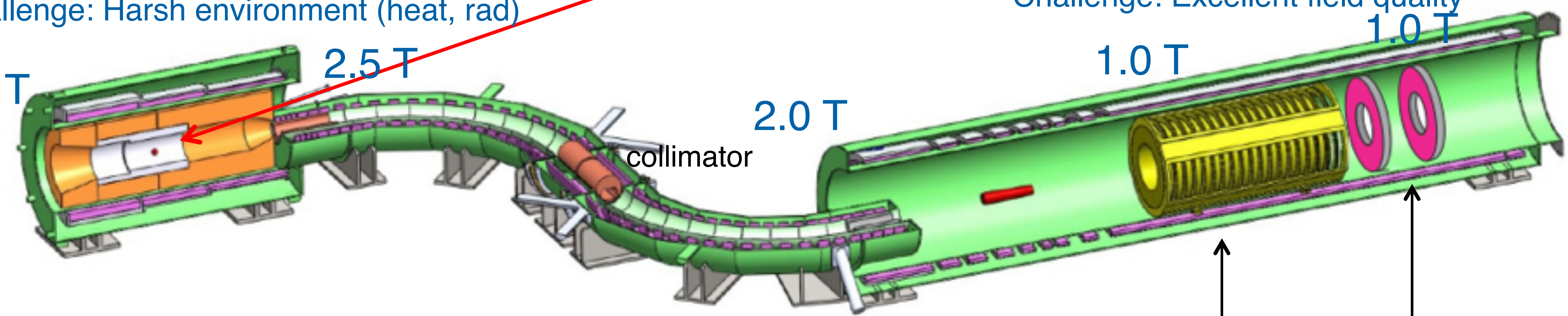
Function: Reflect pions and muons back toward Transport Solenoid

Challenge: Harsh environment (heat, rad)

Detector Solenoid

Function: Guide electrons from stopping target to spectrometer, provide spectrometer field

Challenge: Excellent field quality



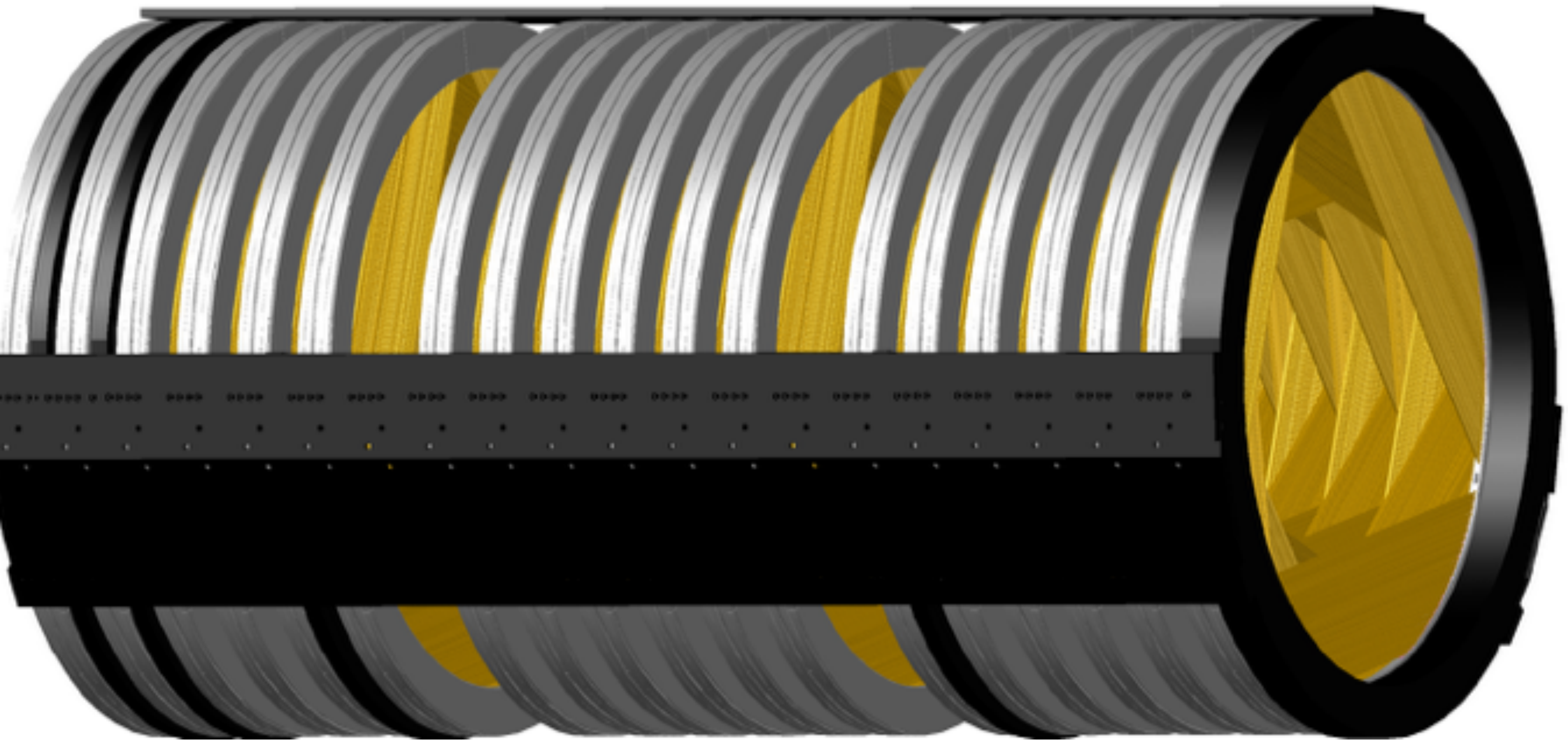
Transport Solenoid

Function: Disperse beam by charge and momentum (select with collimator)

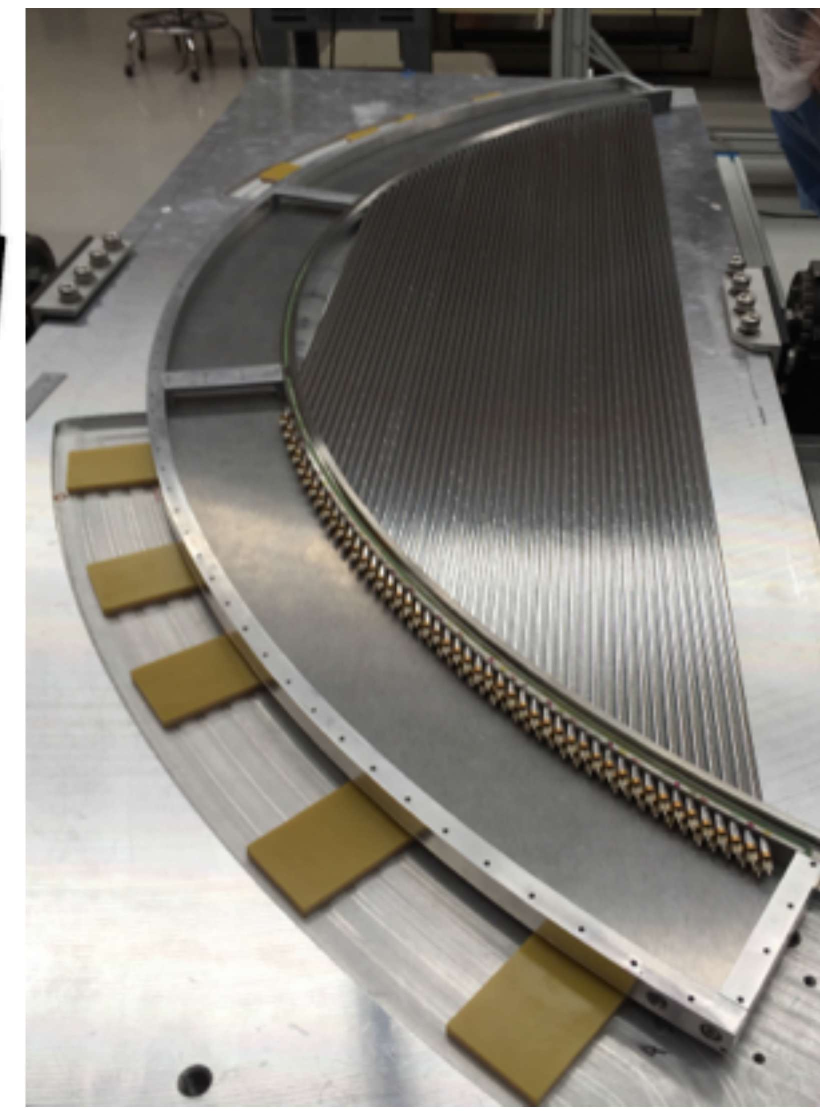
Challenge: Complex geometry

The overall grade of the field increases muons on target and electrons in spectrometer, as well as preventing particle traps

Mu2e straw tracker



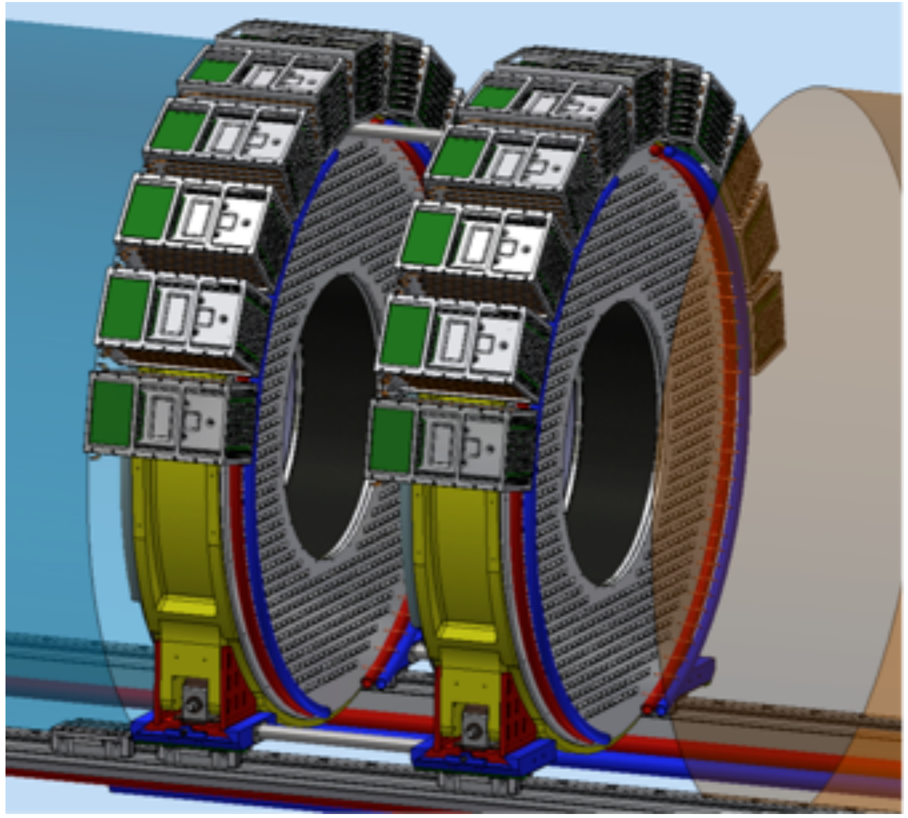
Responsible for measurement of the electron momentum: key discriminant for dominant DIO background

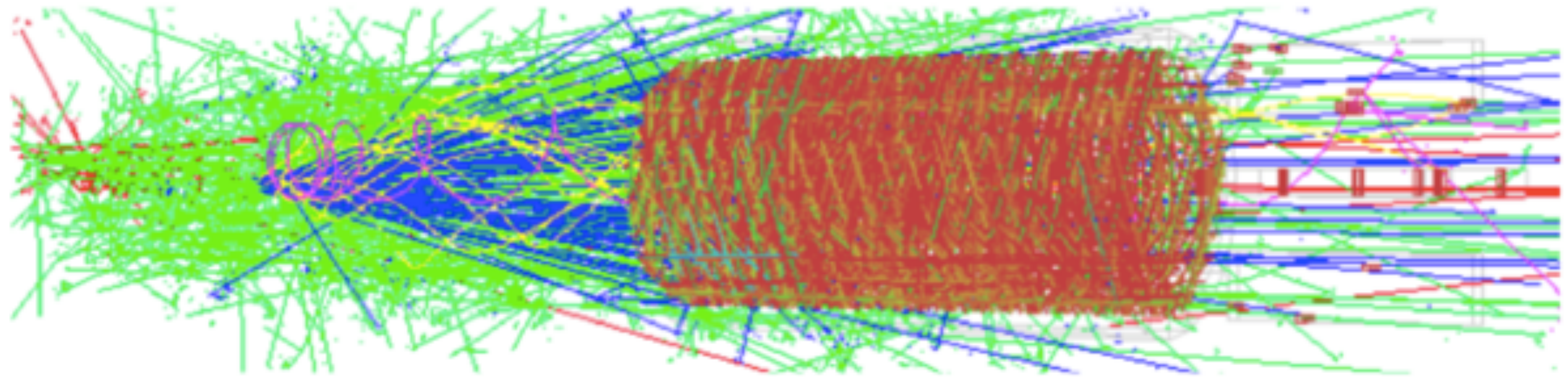


To be covered in detail in next talk from J. Bono!

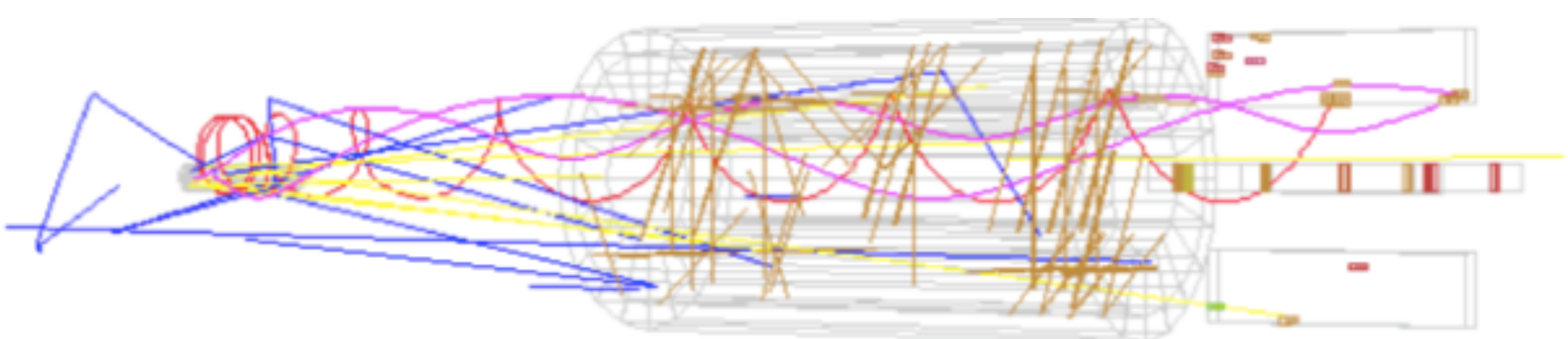
Mu2e CsI calorimeter

- Fast, compact, rad hard
- ~5% energy resolution, combine w/ tracker momentum measurement for particle ID
- High granularity for ~ 1cm position resolution
- 500 ps time resolution



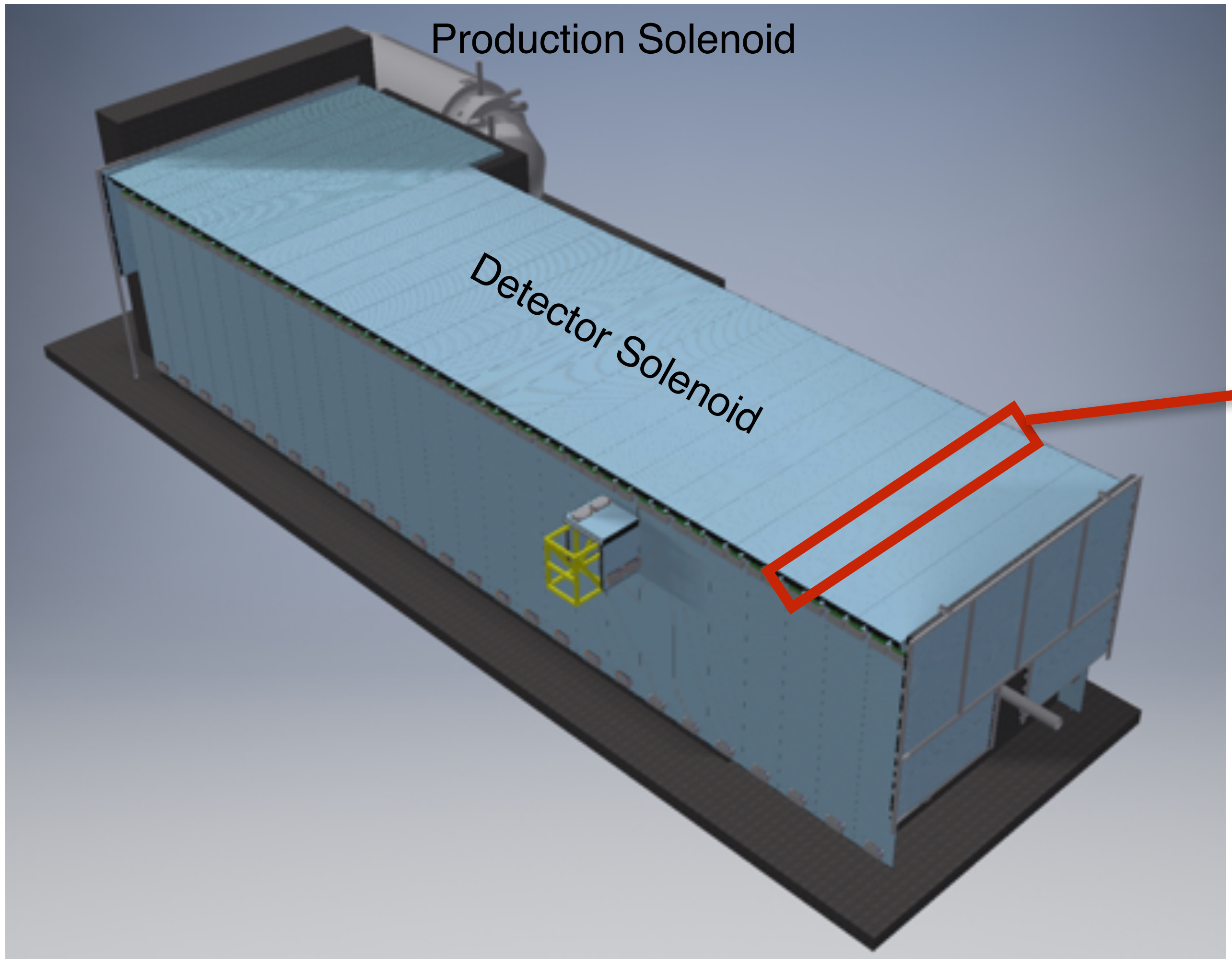


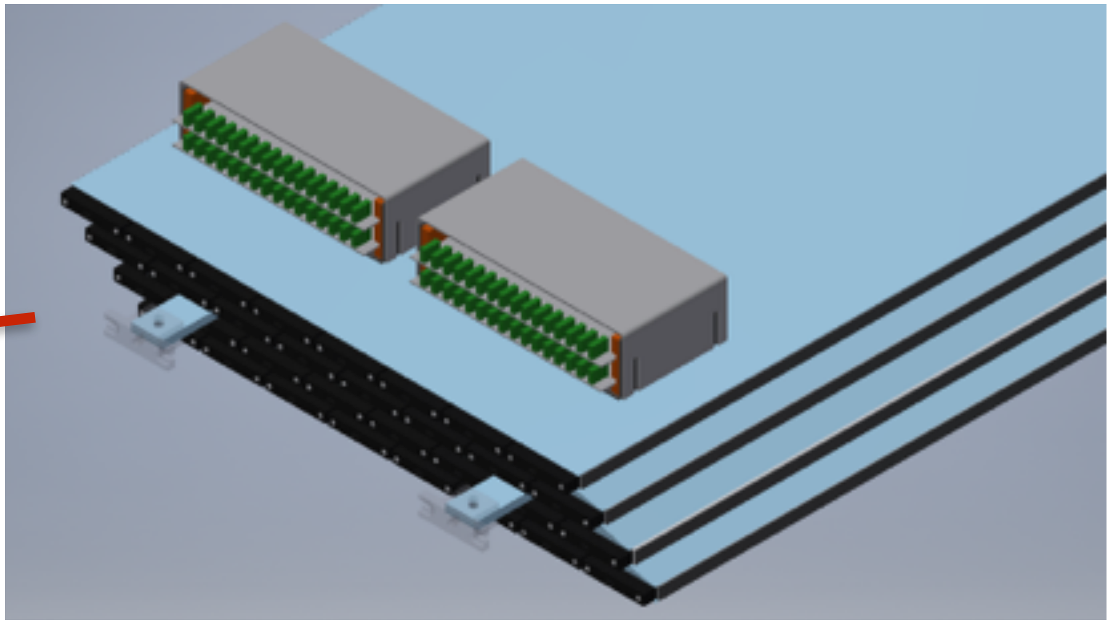
When tracker hits are matched in space and time to calorimeter hits, this…



…becomes this

Mu2e Cosmic Ray Veto





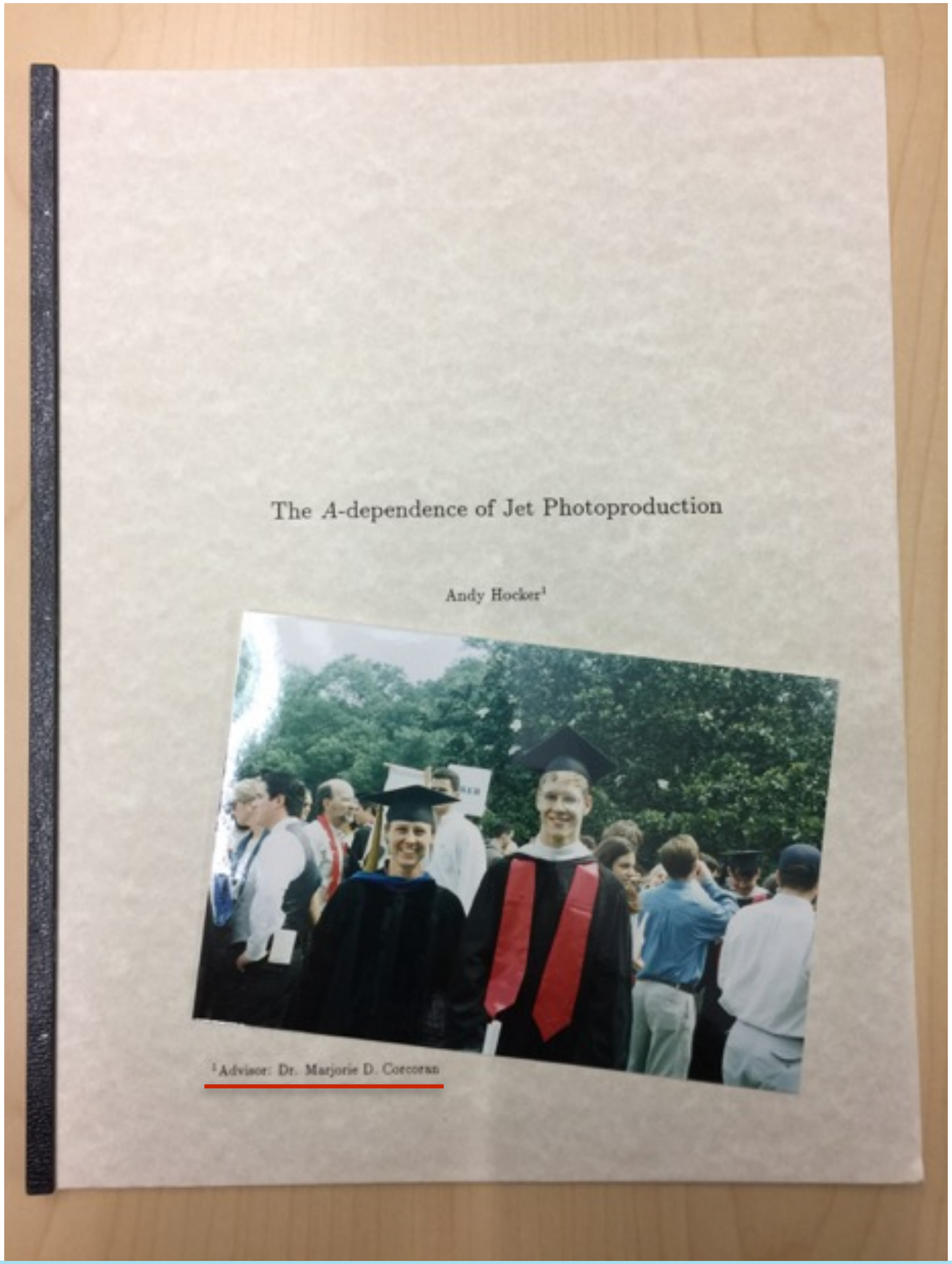
- Four layers of scintillator counters with embedded optical fiber

- Completely covers Detector Solenoid and half of Transport Solenoid
- Scintillator, fiber, and silicon photomultiplier readout verified in test beam to yield a single counter efficiency > 99.4%
  - Requiring signal in 3 out of 4 layers achieves needed 99.99% veto efficiency

Outlook

- Design phase is wrapping up and construction is getting started
- Commissioning and data taking to start in 2020
- The discovery potential for Mu2e is excellent
  - Charged lepton flavor violation is a hallmark of a broad swath of Standard Model extensions
  - An indirect probe of energy scales beyond the reach of the Large Hadron Collider
  - An unprecedented leap in sensitivity, not an incremental improvement
  - The signal is unambiguous: as physics stands today, there is just no way to get an electron from a muon without neutrinos coming along for the ride
- We can all look forward to exciting times in the ‘20s

Thanks (to you, and to Marj)



(senior thesis)