New Perspectives 2014

The mu2e Experiment

J. Orduna

June 9, 2014

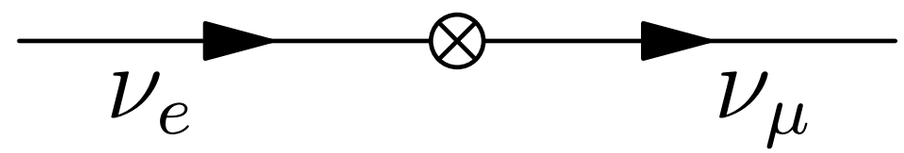
mu2e

The mu2e experiment is a search for Charged Lepton Flavor Violation.

Such a signature would unambiguously indicate BSM.

Charged Lepton Flavor Violation

Neutral lepton flavor violation has been observed (neutrino mixing)



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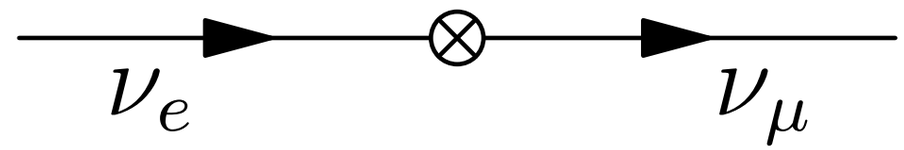
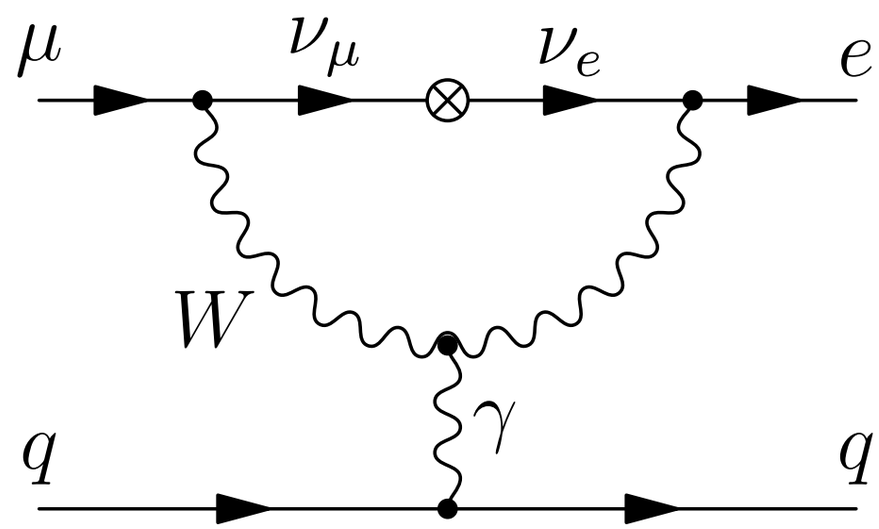


If you add a few SM vertices it's possible to get muon to electron conversion interacting with a quark.



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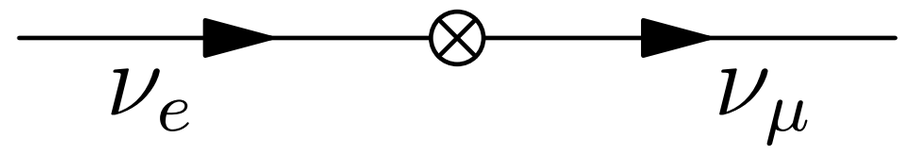

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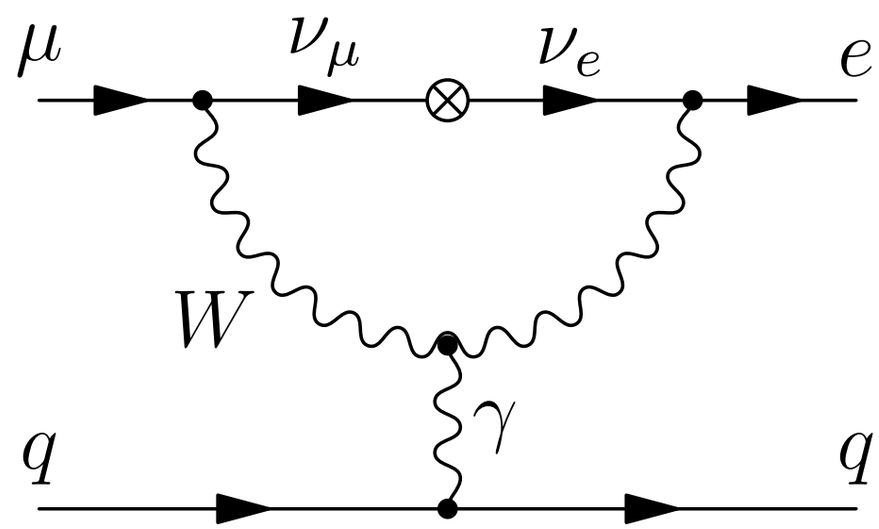


Not forbidden in the SM but its branching ratio is ~10^{-54} which is some 40 orders of magnitude below the experimental reach :(

Charged Lepton Flavor Violation

Allowed by various New Physics scenarios.

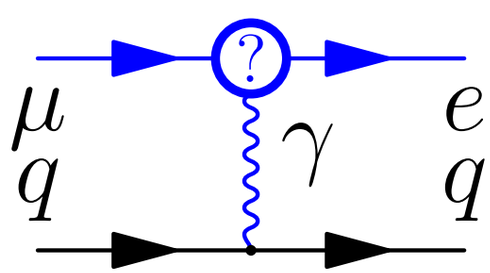
CLFV parameterized by model-independent Lagrangian.
A. de Gouvea and P. Vogl, Prog. In Particle and Nuclear Physics 71 (2013) 75

$$\mathcal{L}_{CLFV} = \frac{m_\mu}{(1+\kappa)\,\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\,\Lambda^2}\bar{\mu}_L\gamma_\mu e_L\left(\sum_{q=u,\,d}\bar{q}_L\gamma^\mu q_L\right)$$

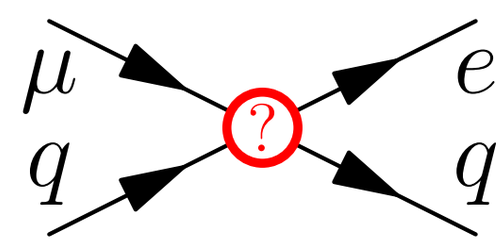
Λ: mass scale,

κ: importance of contact term.

Electromagnetic vertex

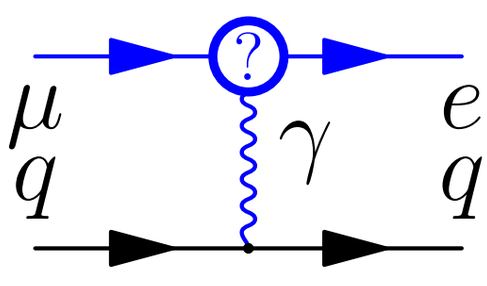


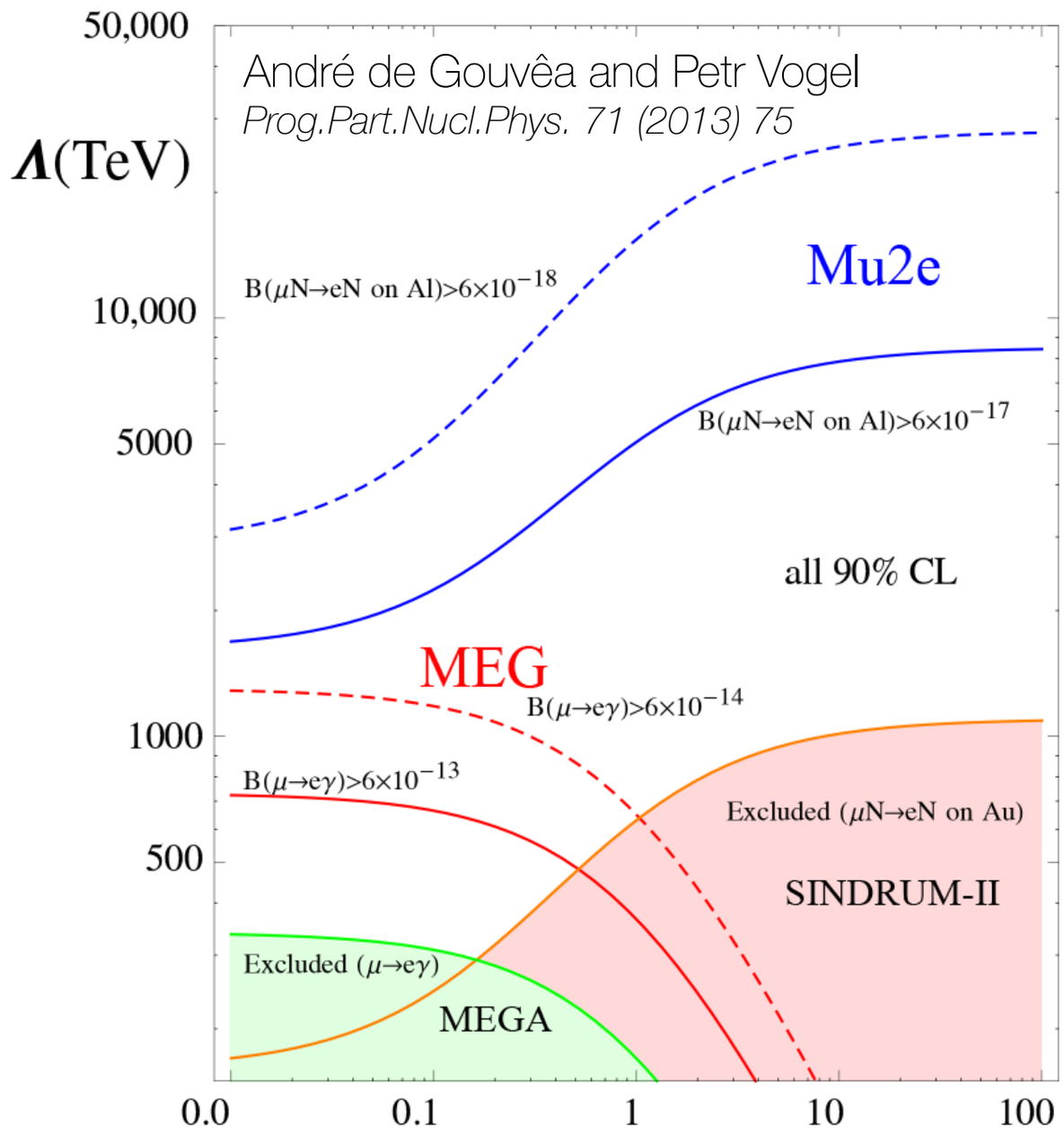
Contact interaction



Relative rates of conversion and muon to electron+gamma are model dependent.
Handle to discriminate New Physics models.

Muon LFV Physics Reach





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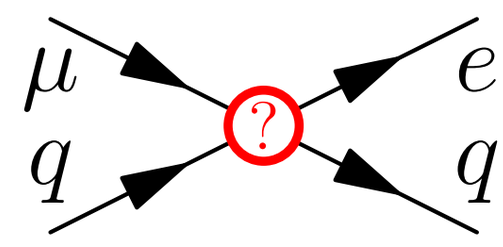
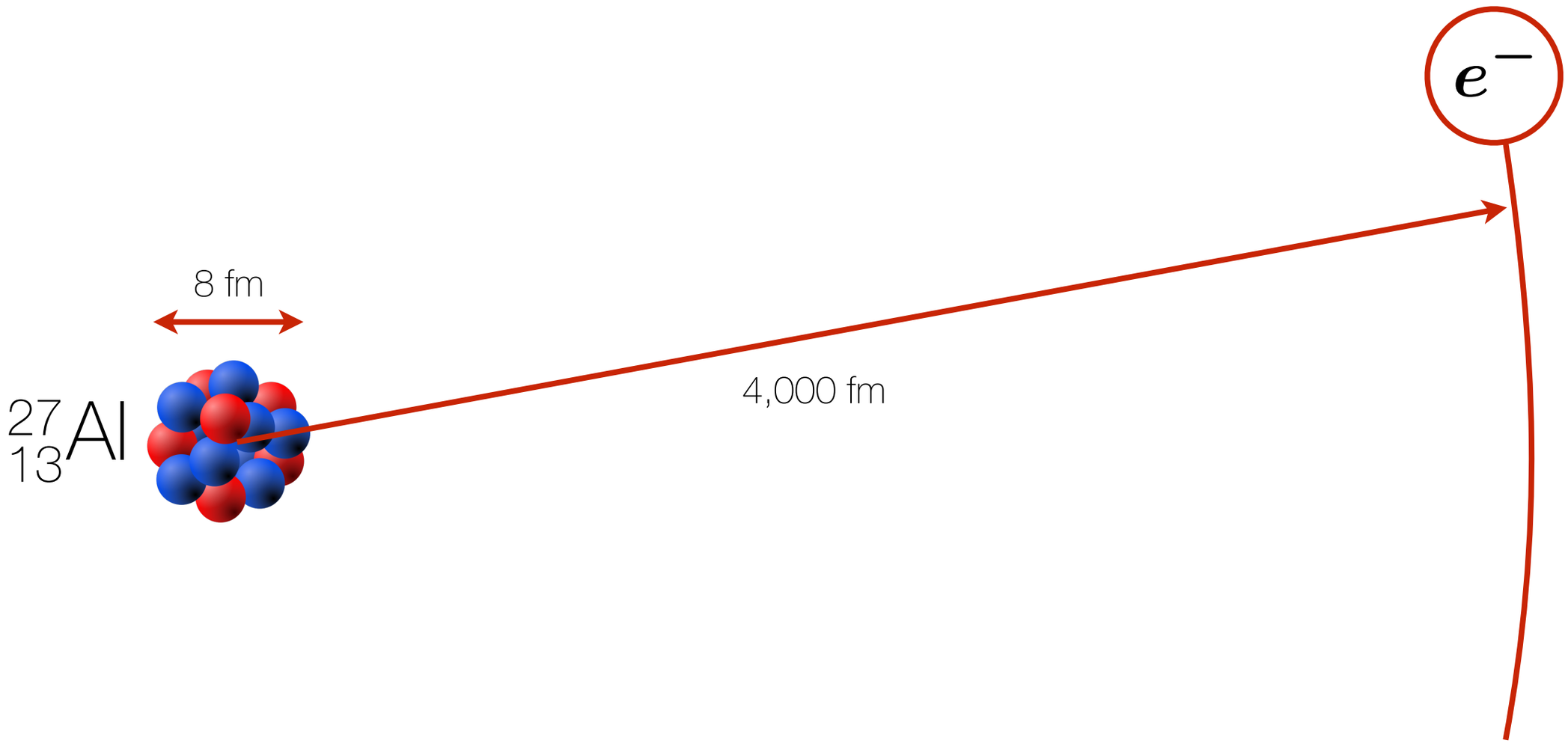
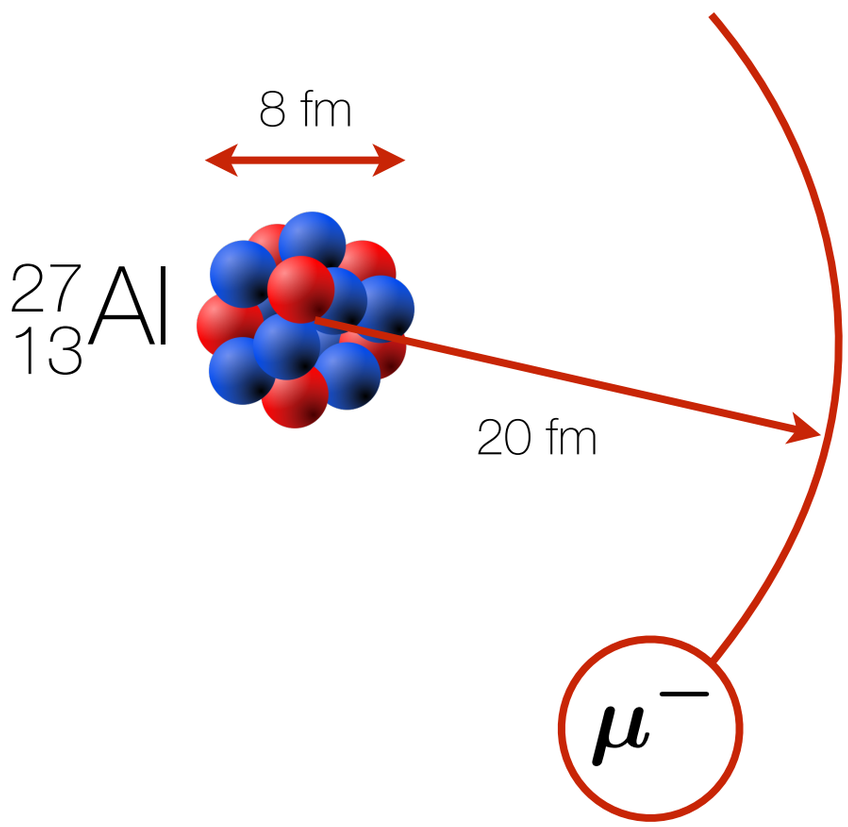


Aluminum Atom



Muonic Atom



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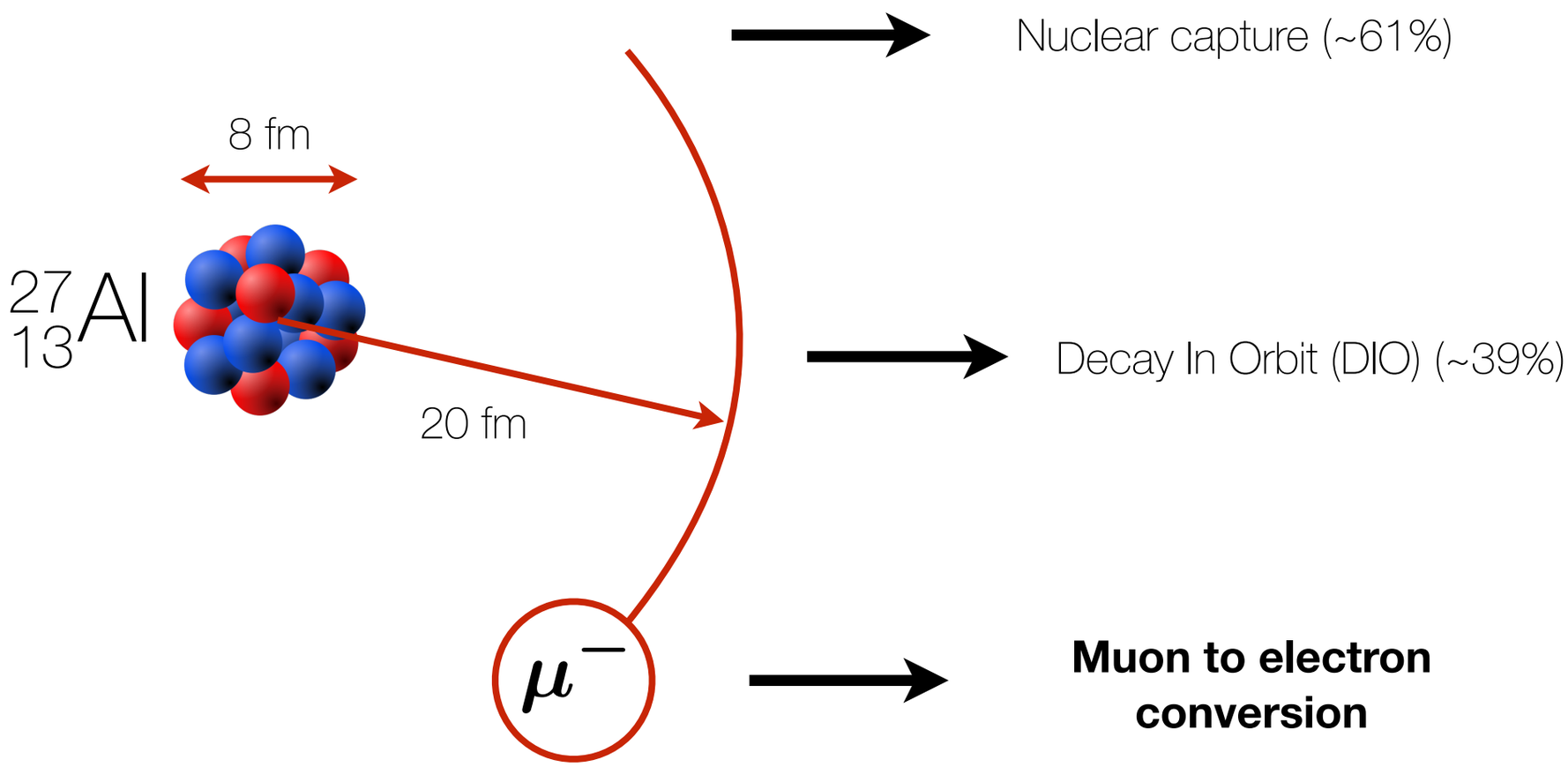
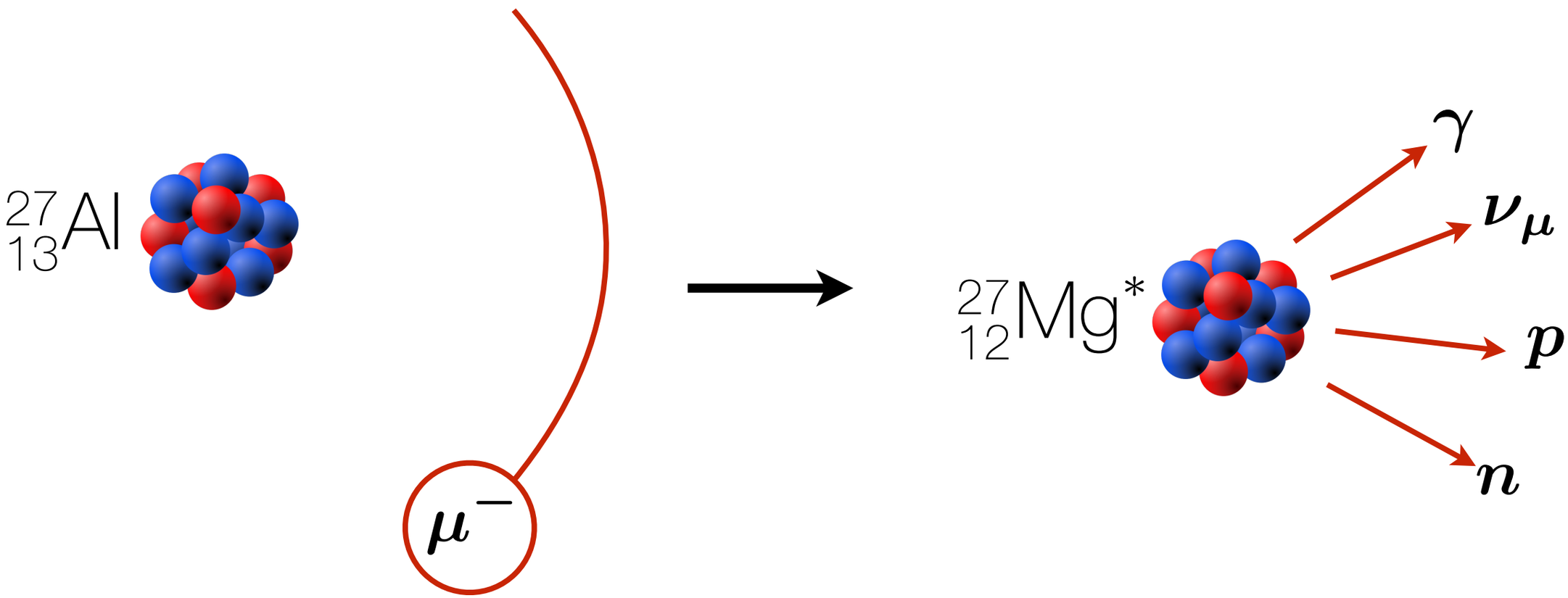

Nuclear capture (~61%)
8 fm
$^{27}_{13}$Al
20 fm
Decay In Orbit (DIO) (~39%)
μ^-
Muon to electron conversion

Muonic Atom

Nuclear capture

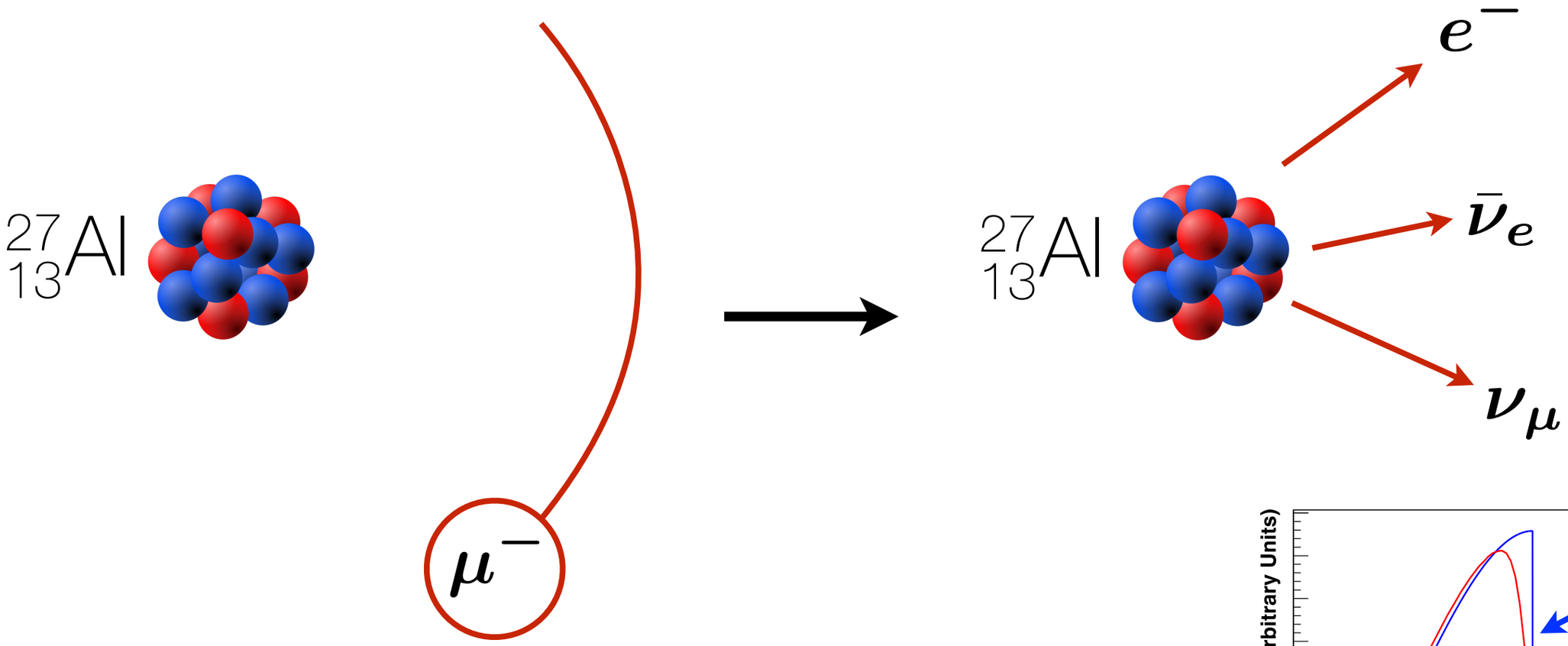
$$\mu^- + N \rightarrow \nu_\mu + N'$$



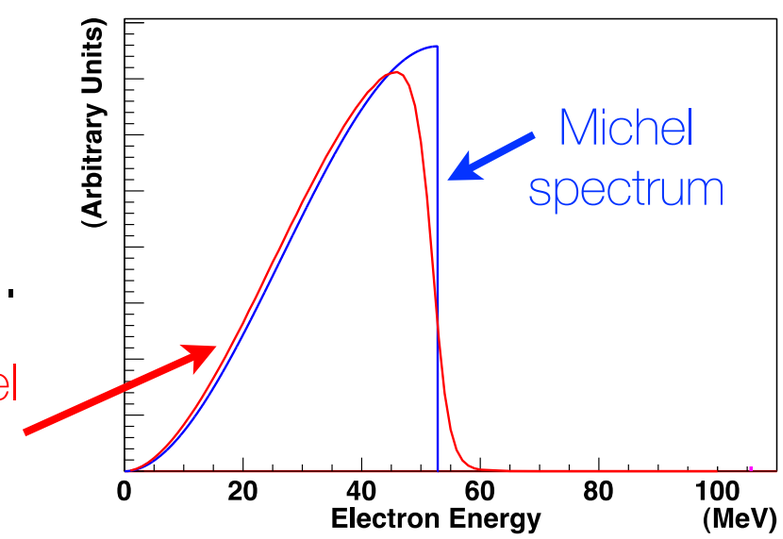
Muonic Atom

Decay In Orbit (DIO)

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



E_e = 0-53 MeV for Al.



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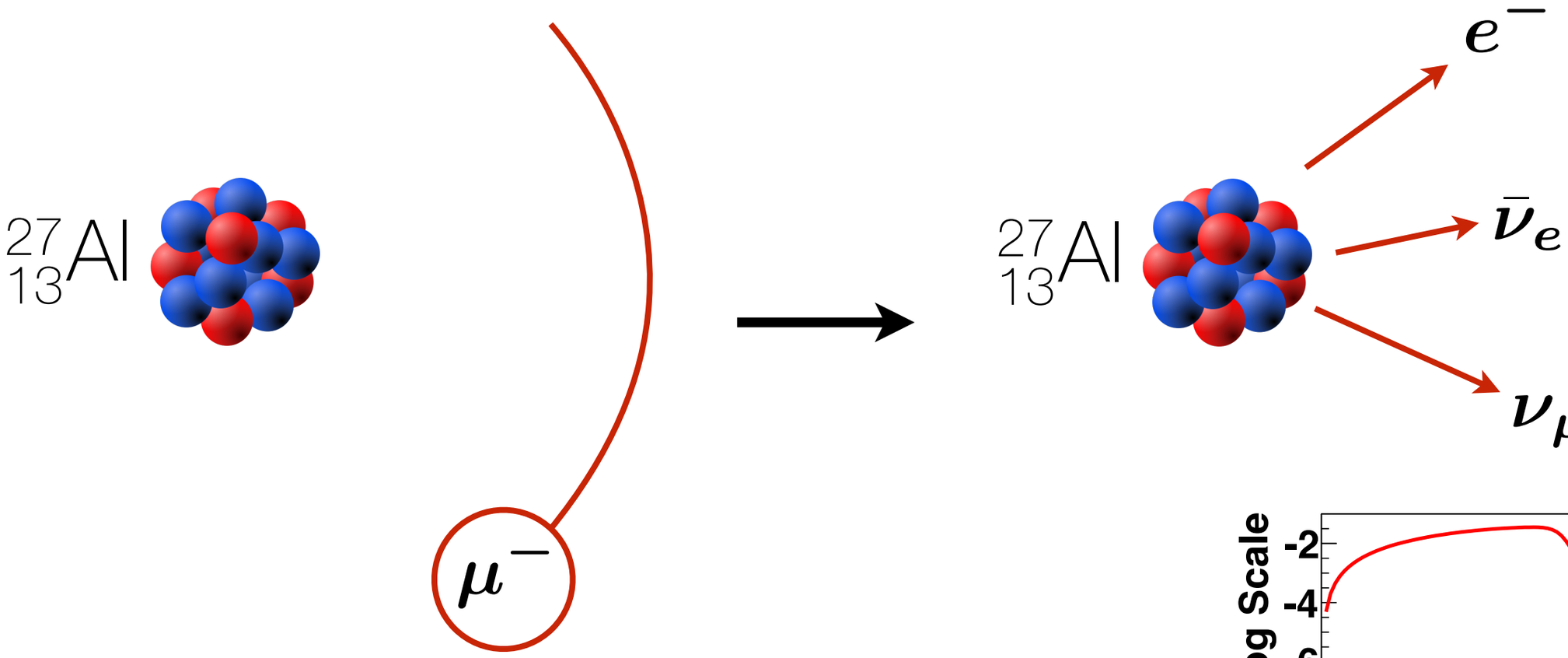

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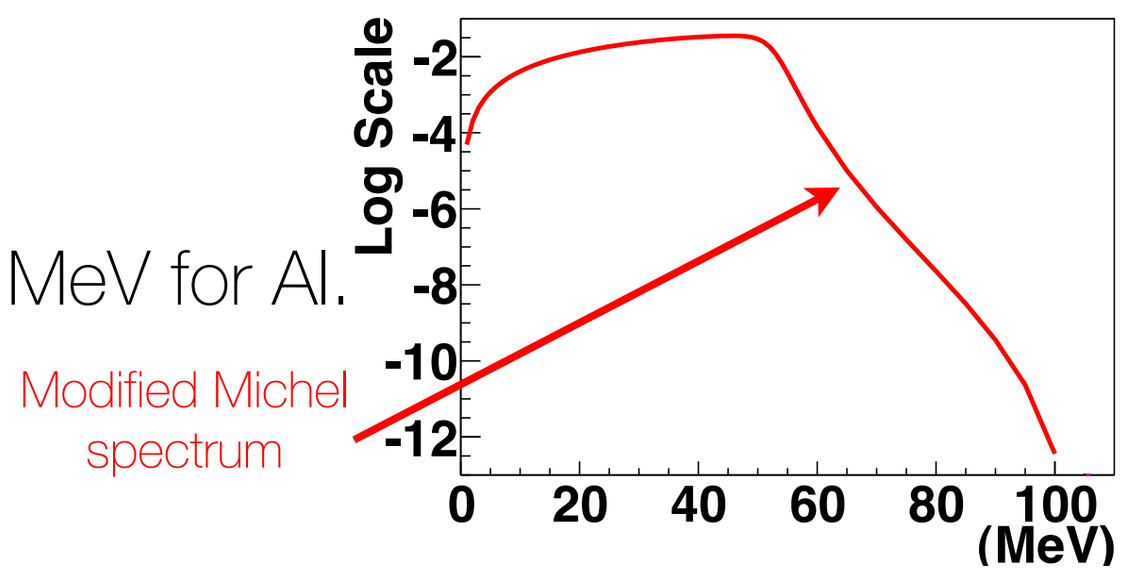
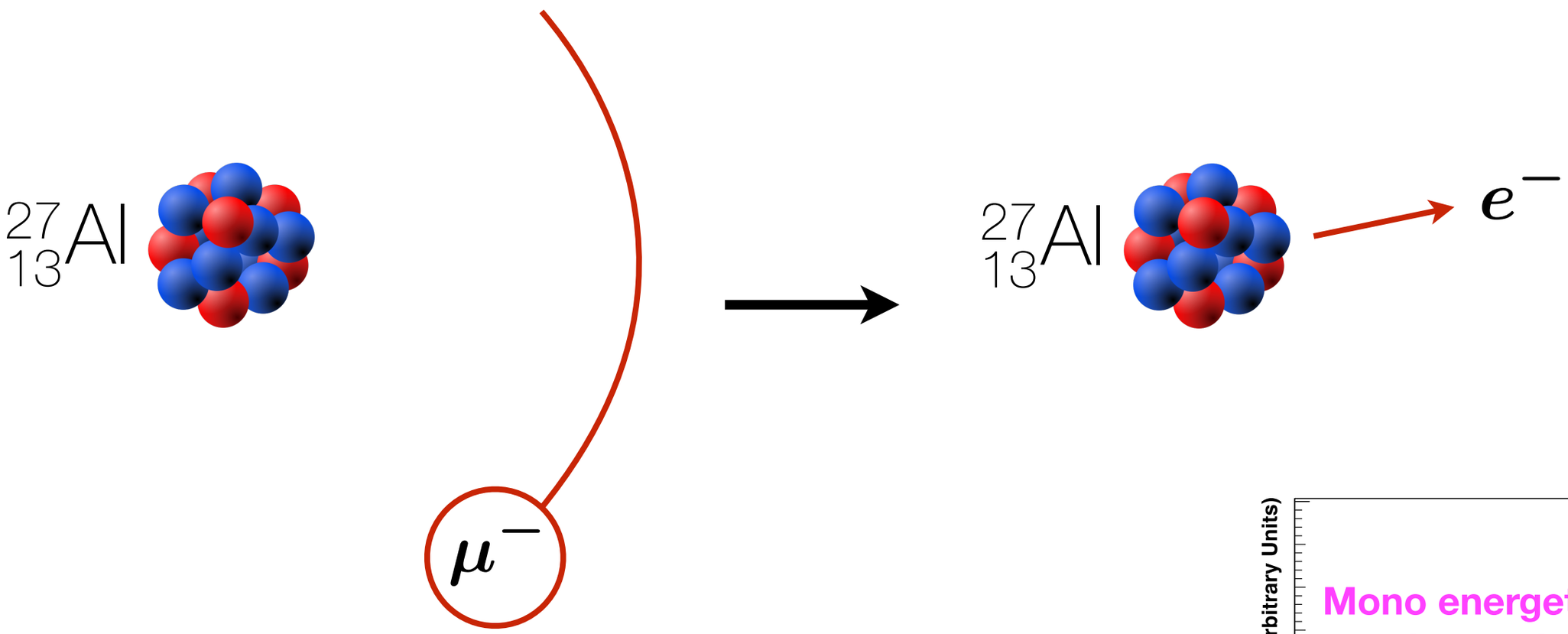


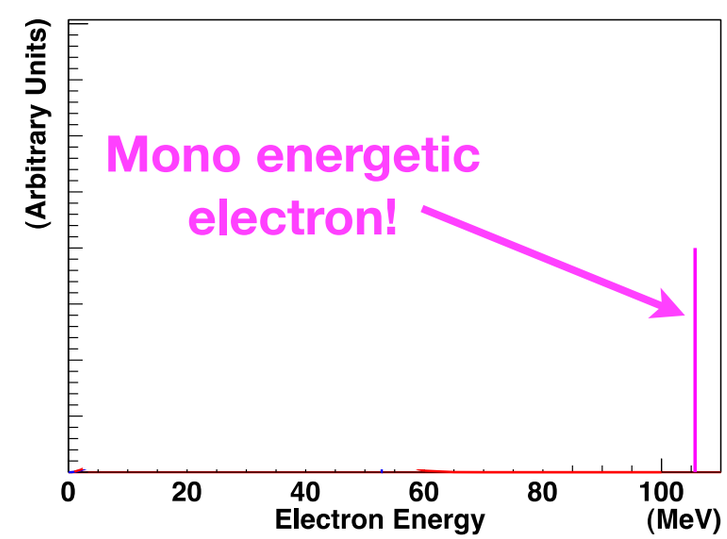
Muonic Atom

Muon to electron conversion

$$\mu^- + N \rightarrow e^- + N$$



$$E_e = m_\mu c^2 - E_b - E_{recoil} = 104.973 \text{ MeV for Al.}$$



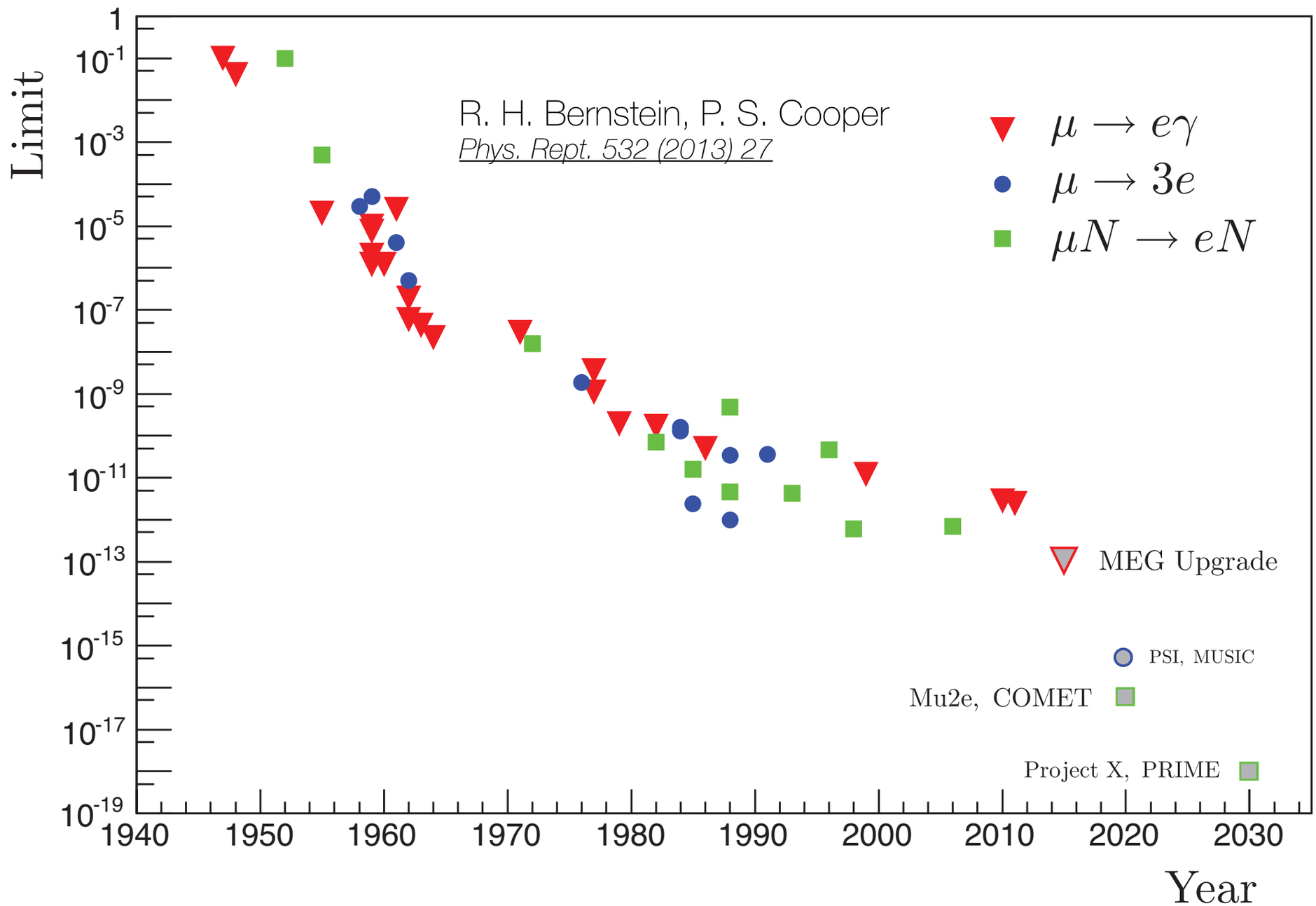
What We Want To Measure

Signal: coherent muon to electron conversion on nucleus
Normalization: all nuclear captures
reduces theory uncertainty (nuclear wavefunction cancels).

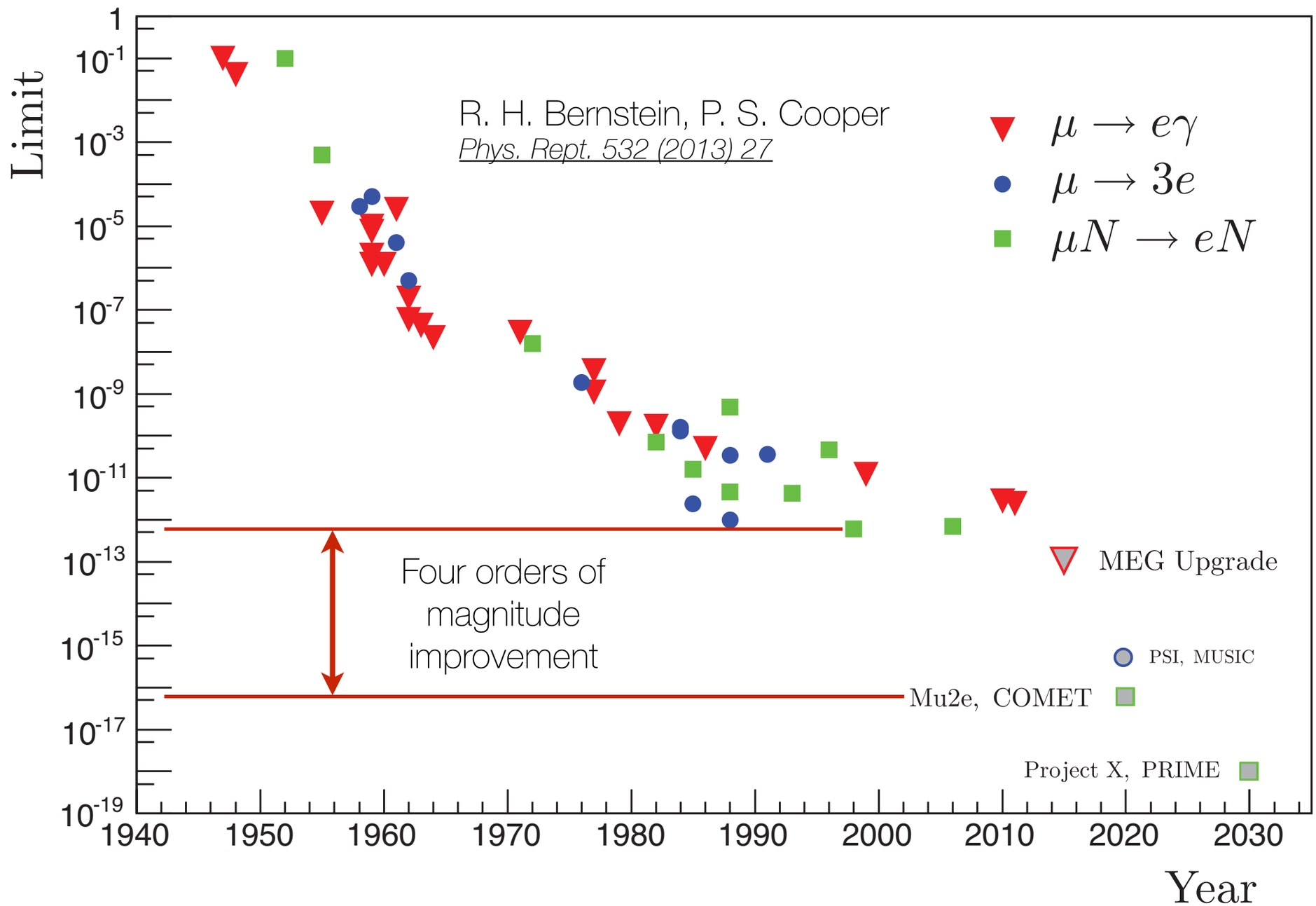
$$R_{\mu e} = \frac{\Gamma\left[\mu^- + (A,\ Z) \rightarrow e^- + (A,\ Z)\right]}{\Gamma\left[\mu^- + (A,\ Z) \rightarrow \nu_\mu + (A,\ Z-1)^*\right]}$$

The goal for mu2e is a single event sensitivity of 10^{-17}.

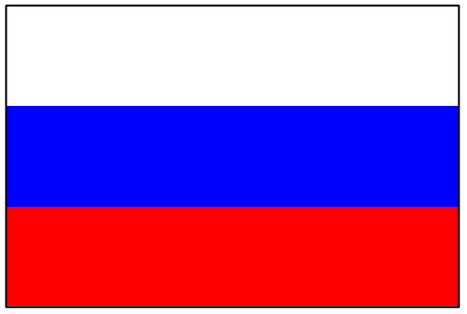
CLFV history



CLFV history



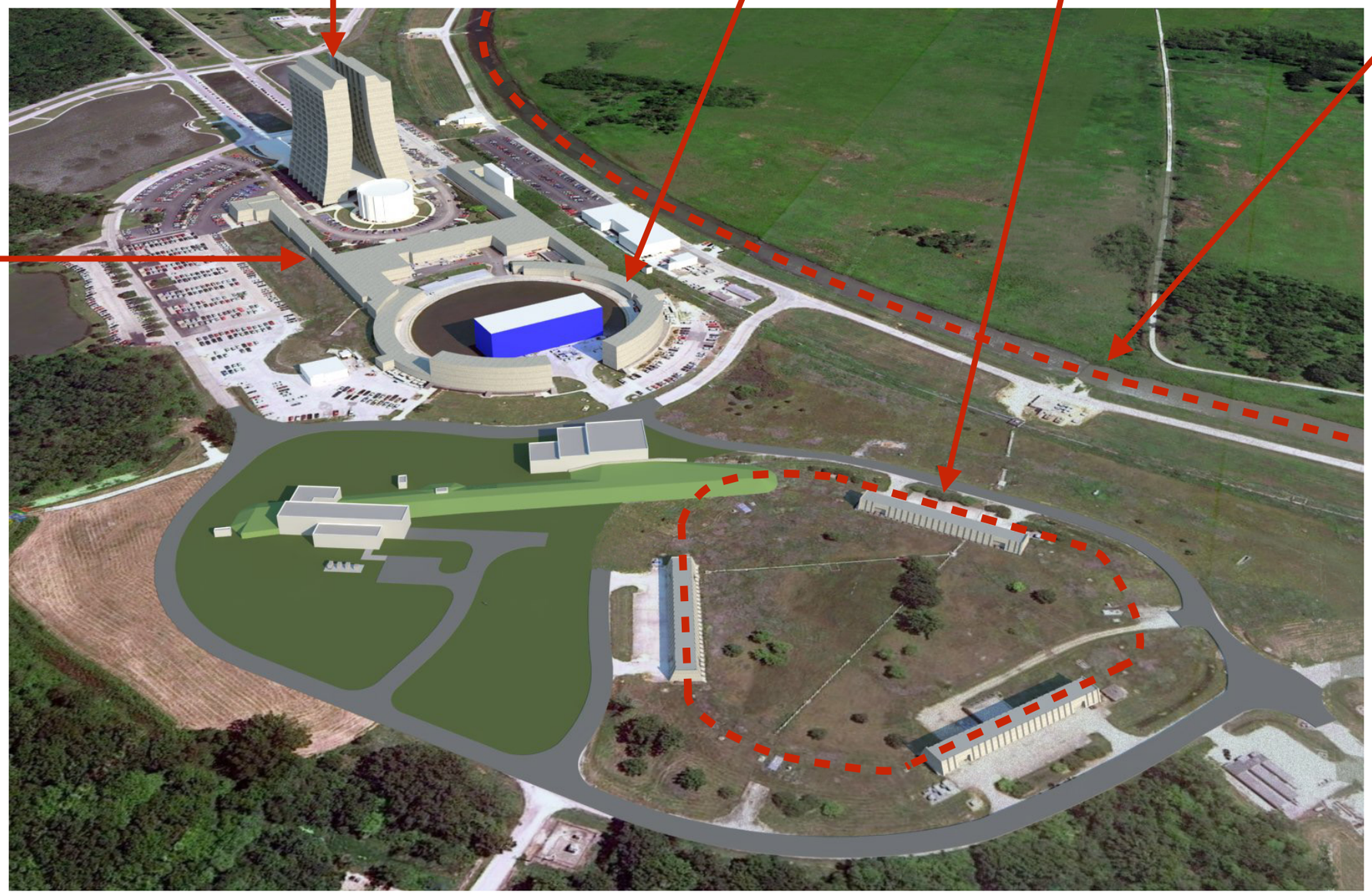
The Collaboration



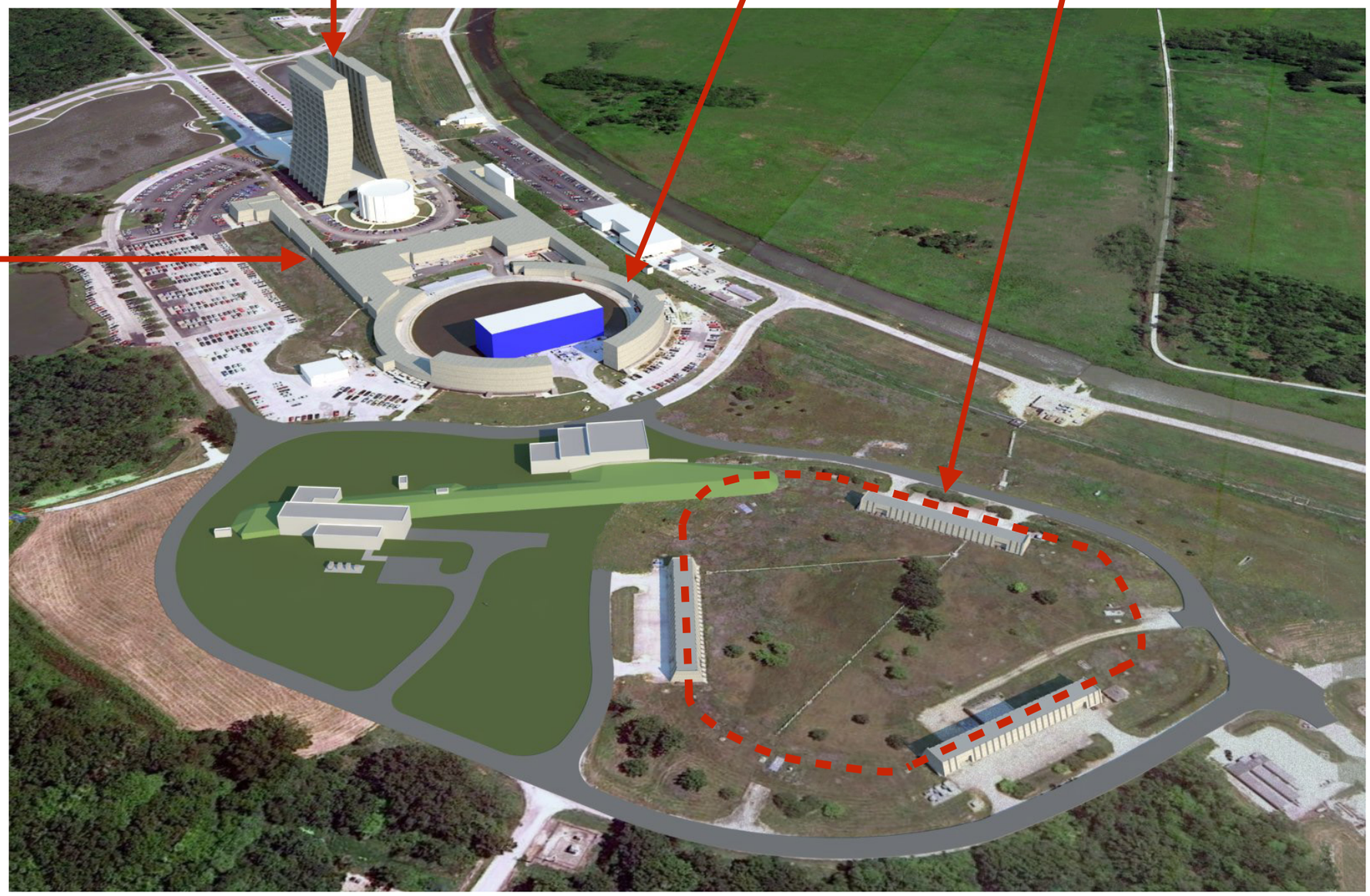
Approx. 140-150 collaborators from 28 institutions in three countries.

Accelerator Complex

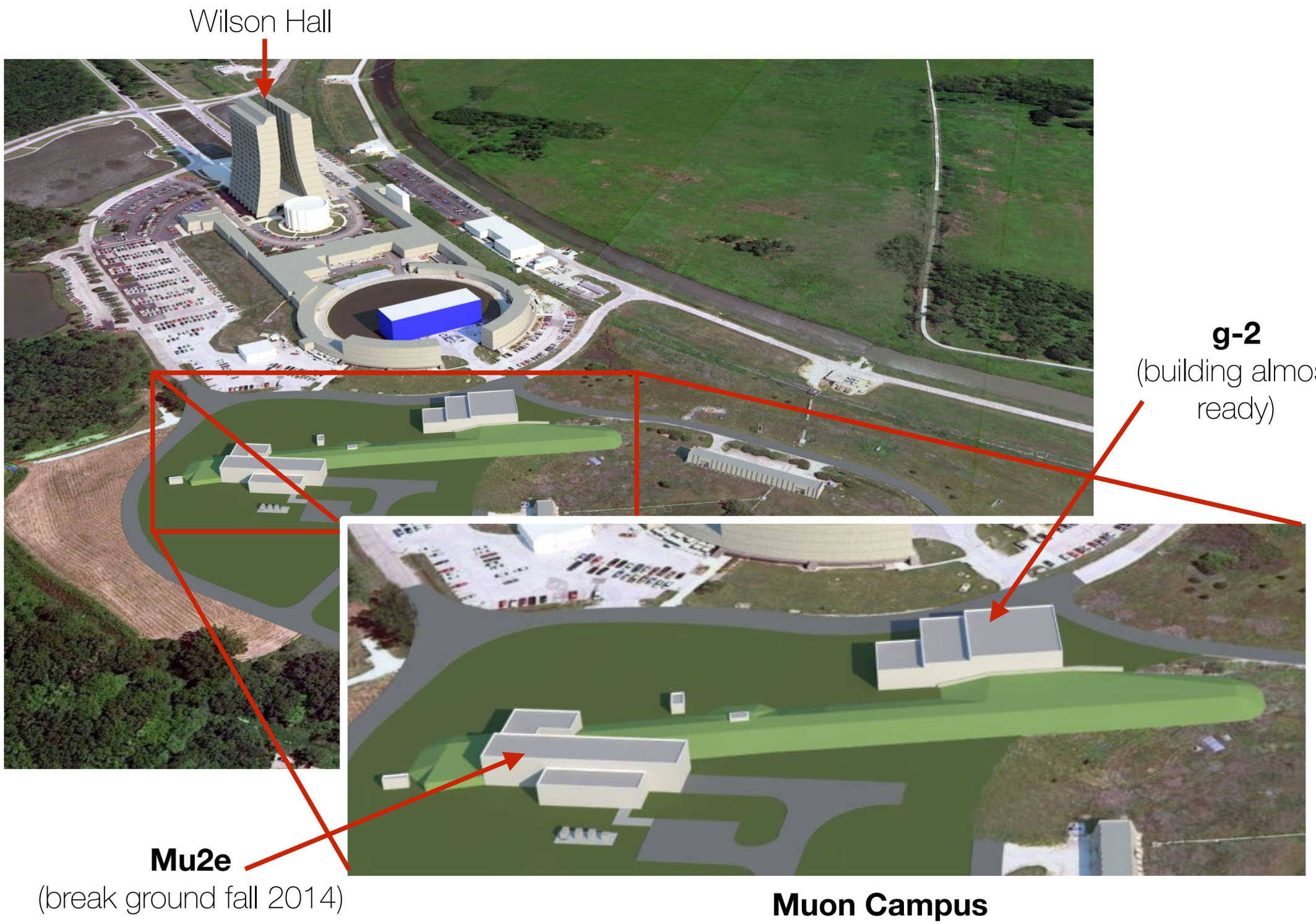
Tevatron Era



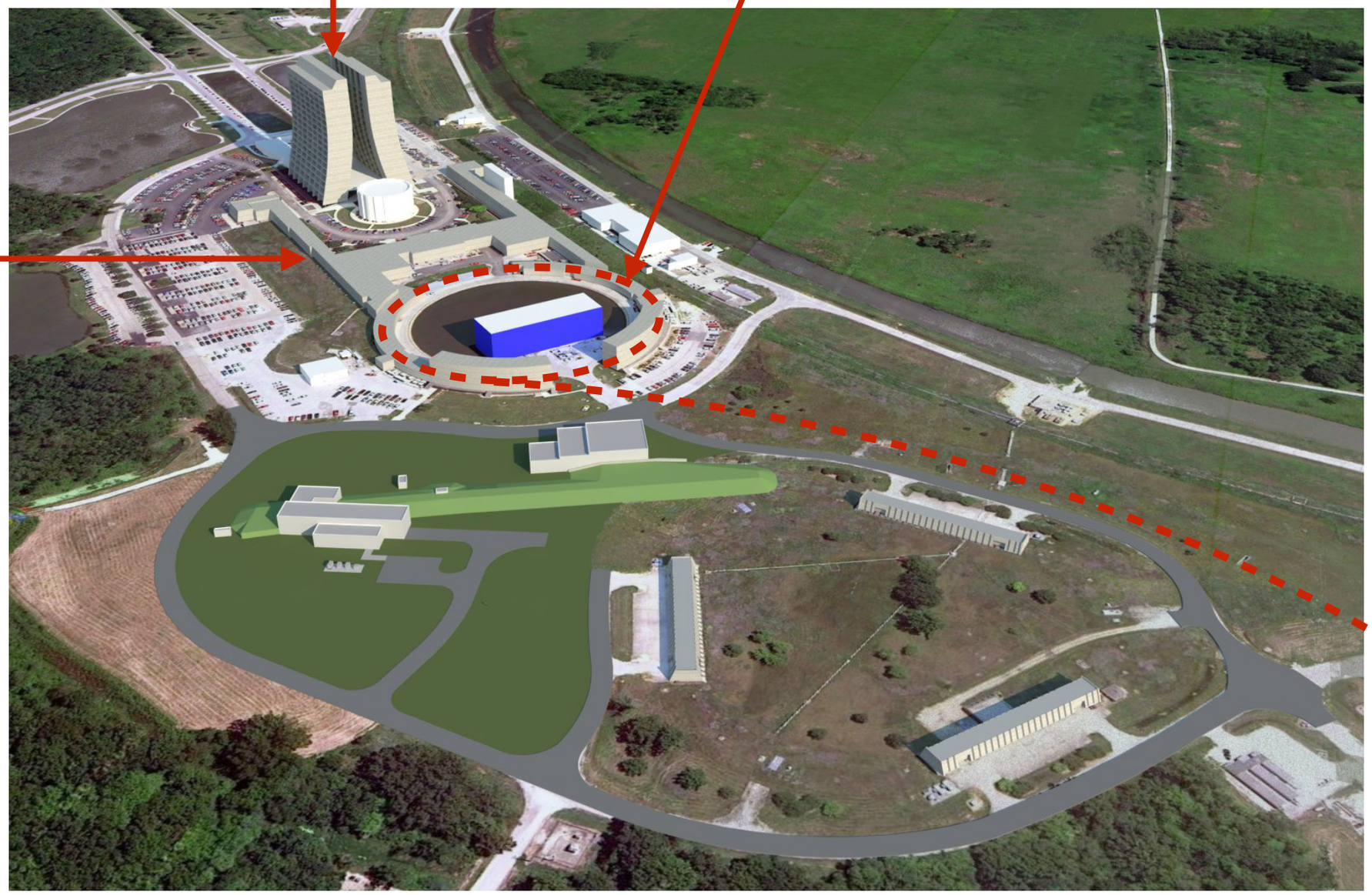
Post Tevatron



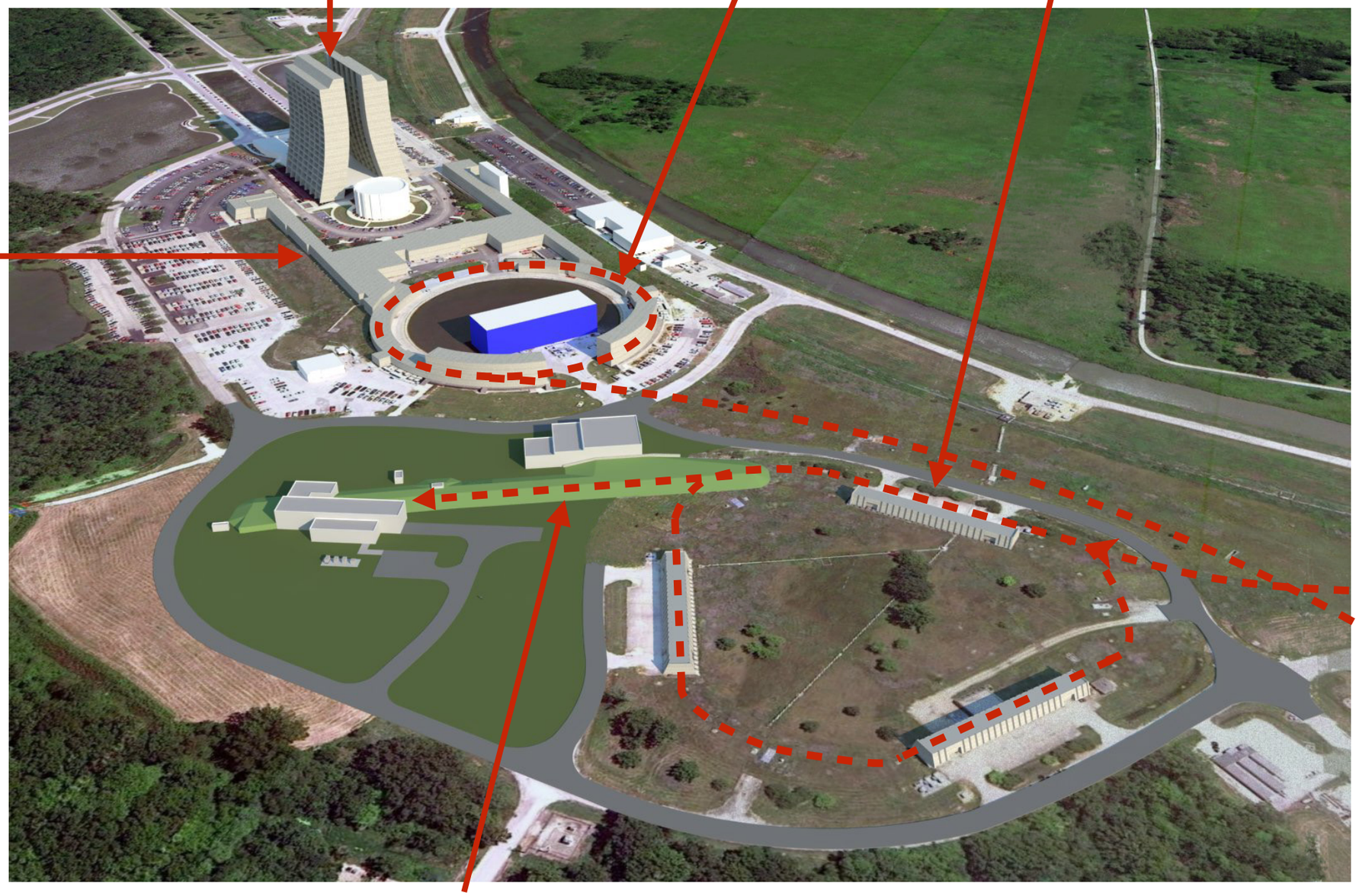
Muon Campus


Wilson Hall
g-2
(building almost ready)
Mu2e
(break ground fall 2014)
Muon Campus

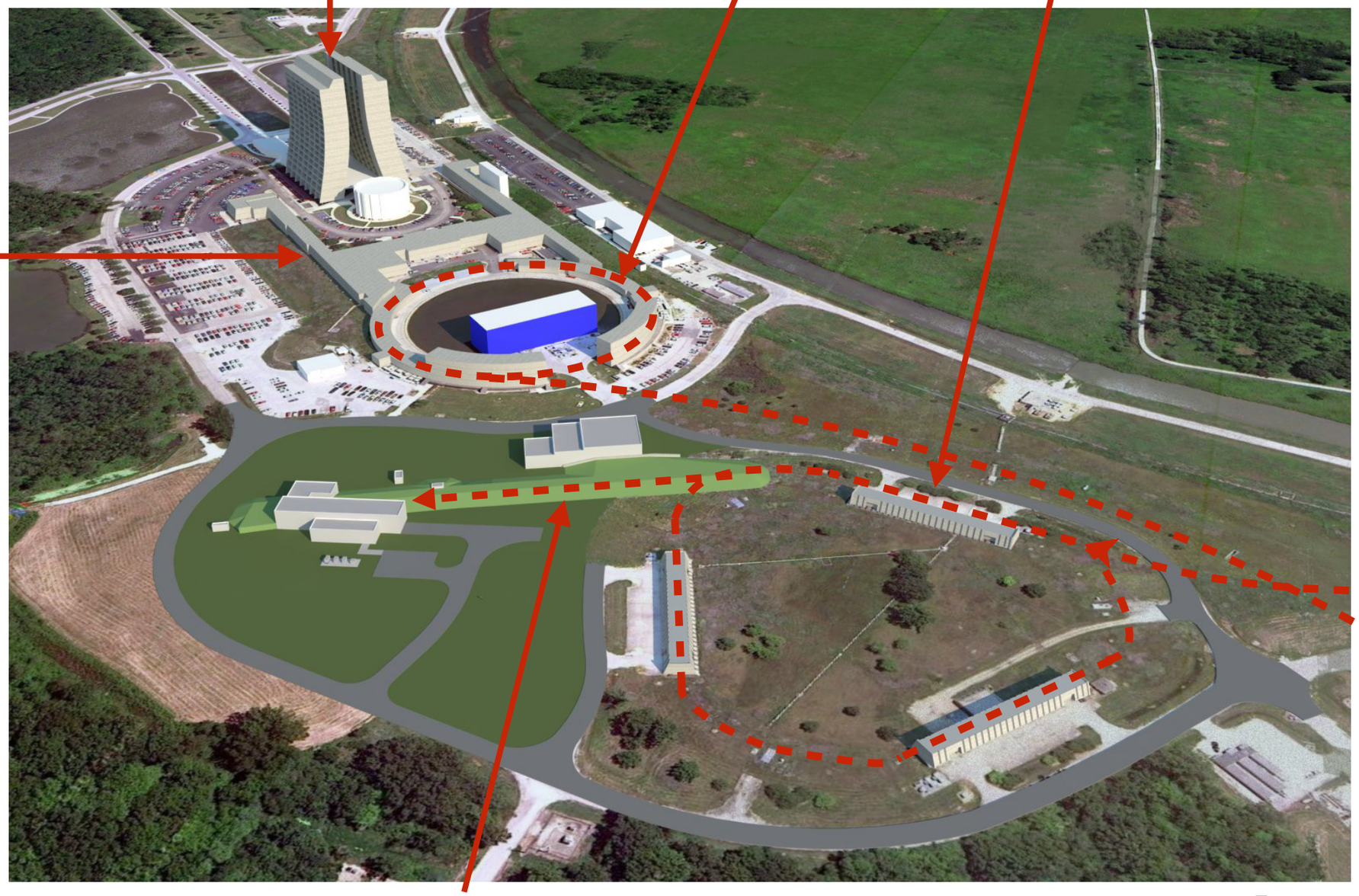
Proton Path


Wilson Hall
Booster: **8 GeV** protons
Linac
Protons
to Recycler

Proton Path


Wilson Hall
Booster: **8 GeV** protons
Delivery Ring: proton pulses
Linac
Protons from Recycler
Protons to Recycler
Protons to mu2e every 1694 ns (~600 kHz)

Proton Path



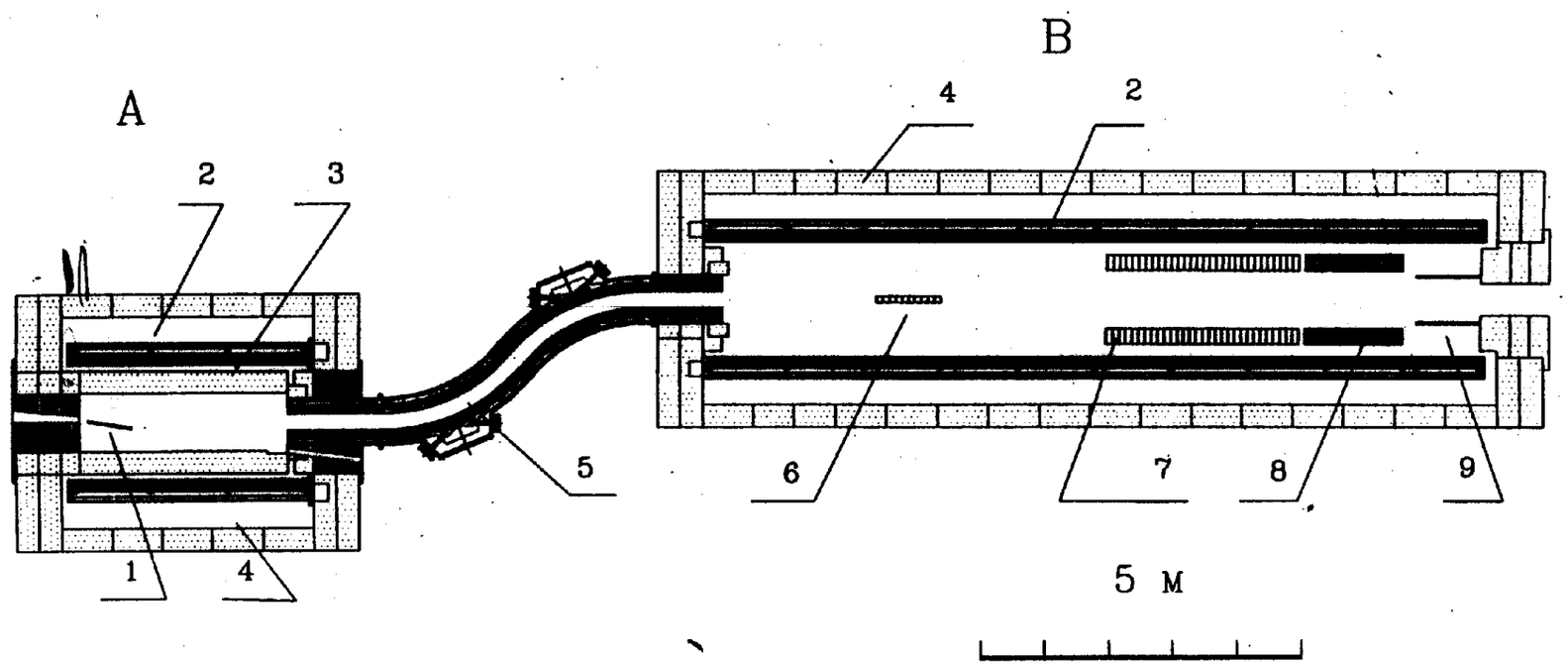
Protons to mu2e every 1694 ns (~600 kHz)

Delivered protons per pulse: ~10^7
Delivered protons per second: ~10^{12}
Delivered protons per year: ~10^{20}
Total delivered protons (3 yr run): 3.6 x 10^{20}

Apparatus

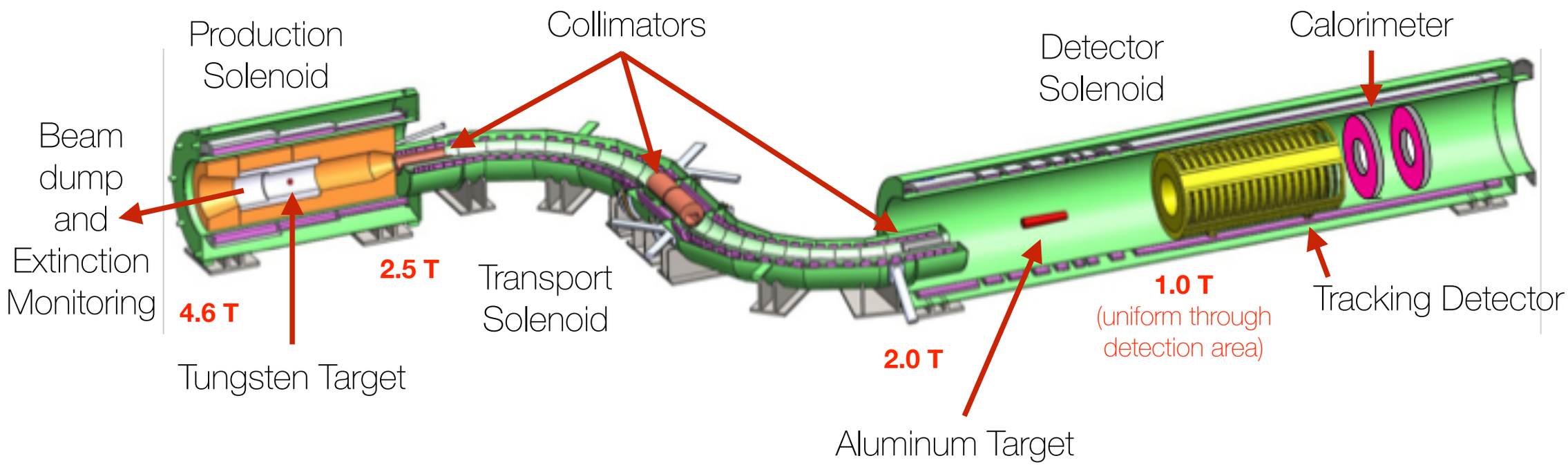
In the past

R. M. Dzhilkibaev and V. M. Lobashev,
"On the search for mu to e conversion on nuclei"
Sov. J. Nucl. Phys. 49, 384 (1989)



1992 MELC experiment proposal

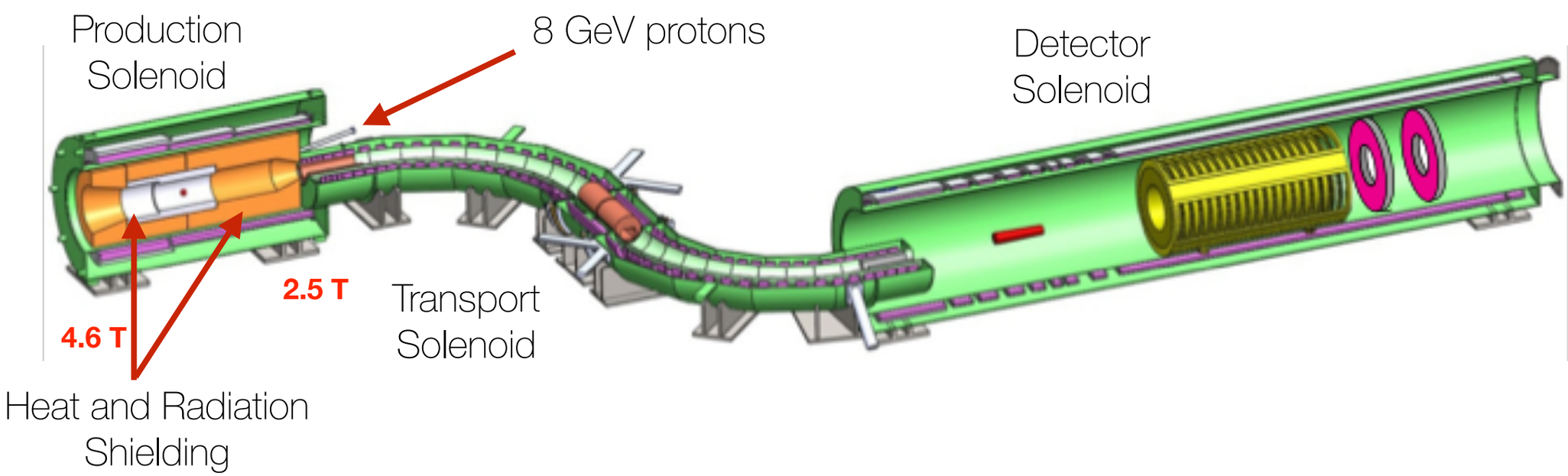
mu2e @ Fermilab



Approx. 25 m long.
Surrounded by lots of shielding.

Production Solenoid

Protons are set to hit a cylindrical tungsten target the size of a pencil located in the Production Solenoid.



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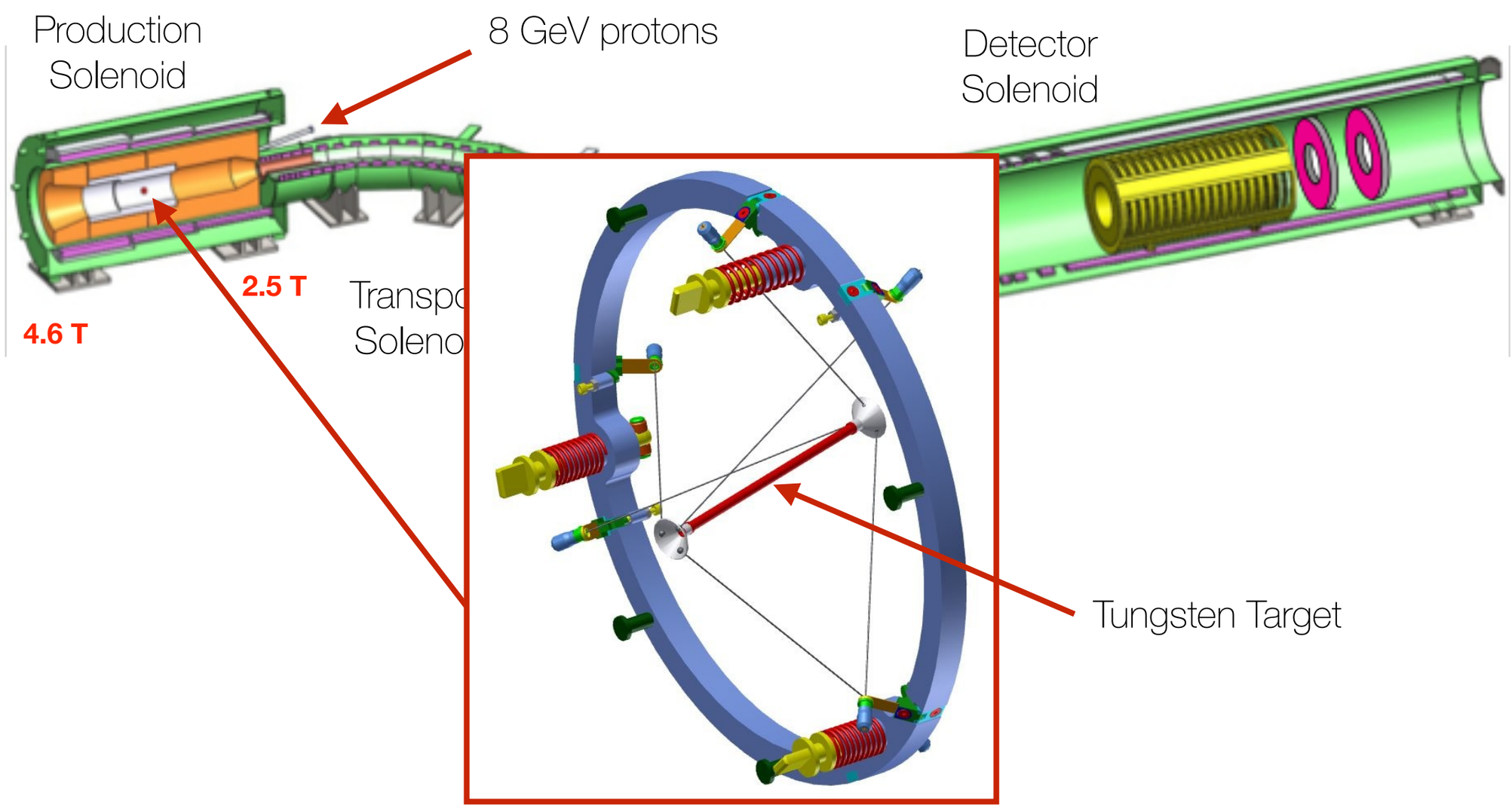
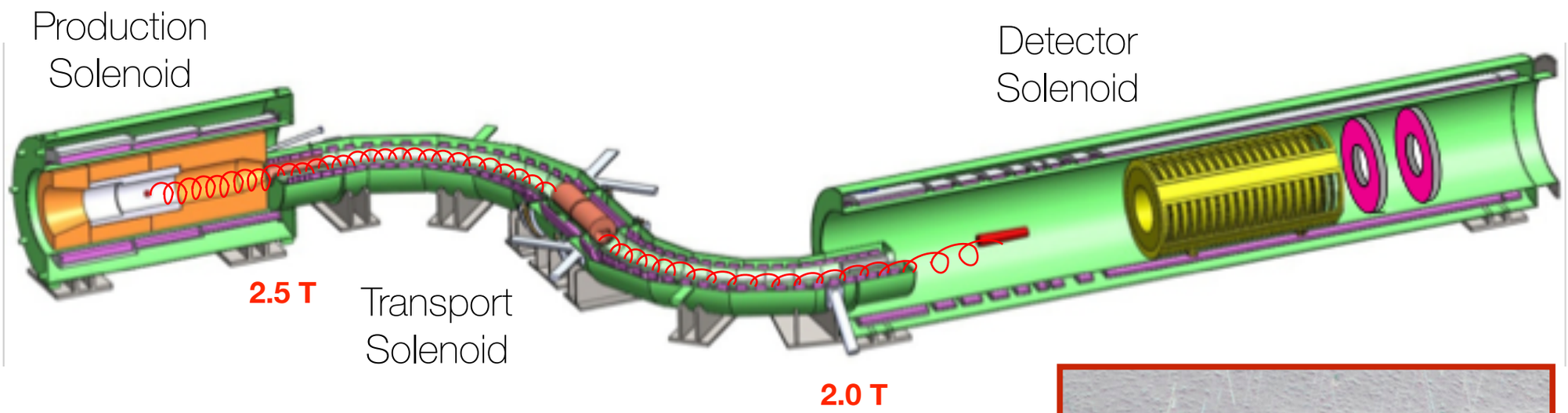


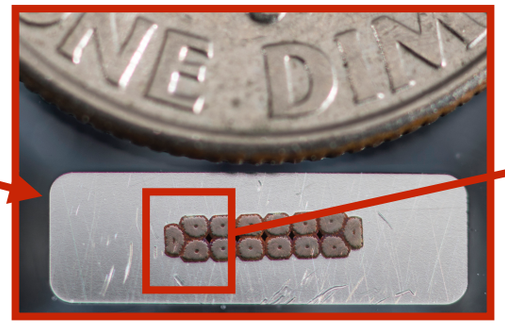
Transport Solenoid

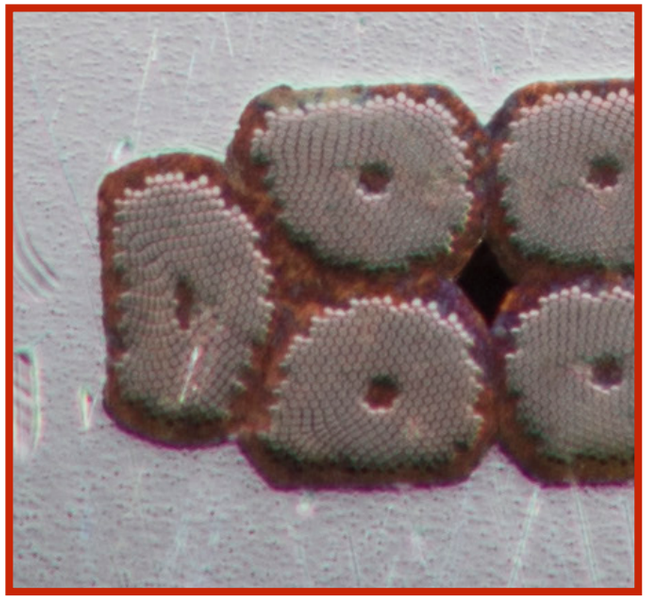
Pions and muons (from pion decays) travel through the Transport Solenoid to reach the detector area.



Transport Solenoid:

- Allows pions to decay.
- ~50 superconducting coils.
- Selects sign of particles.





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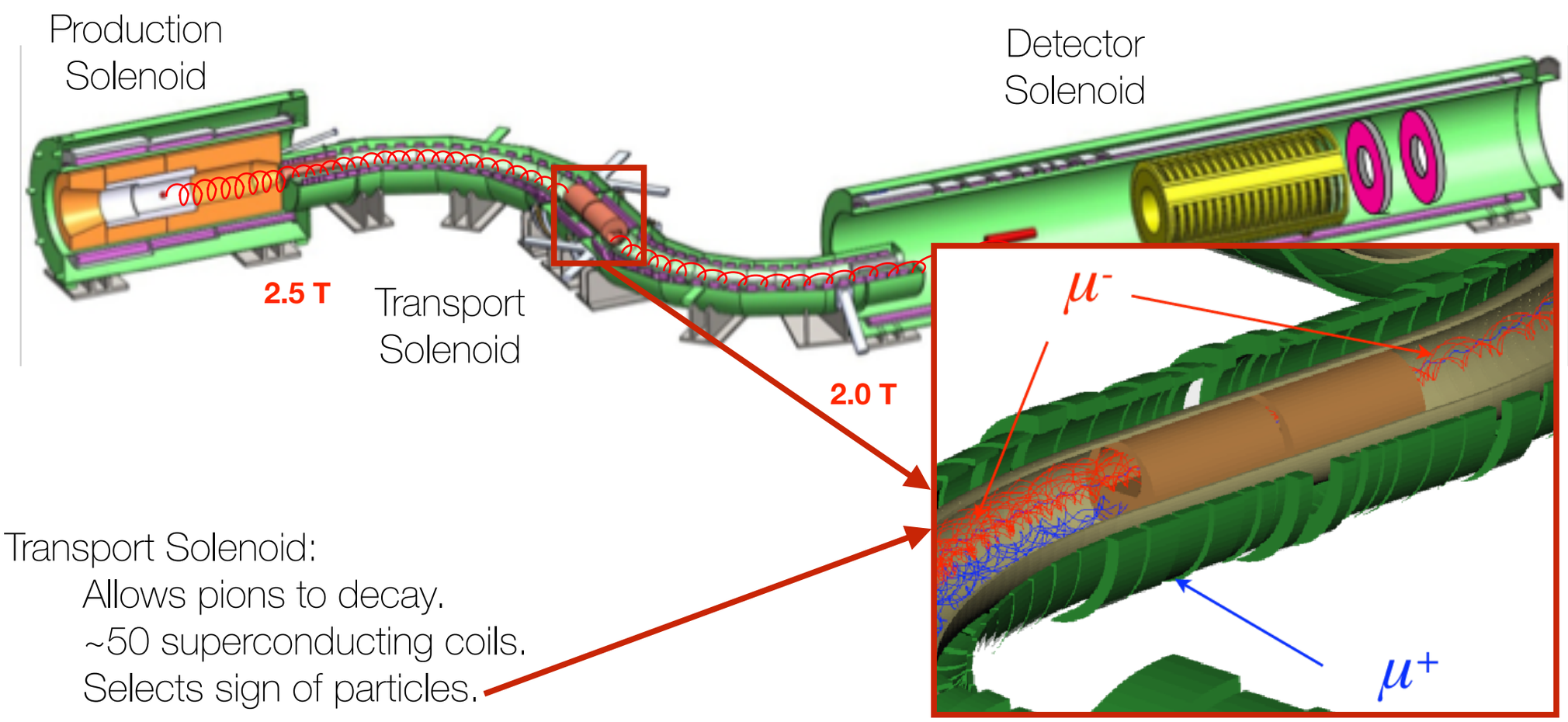


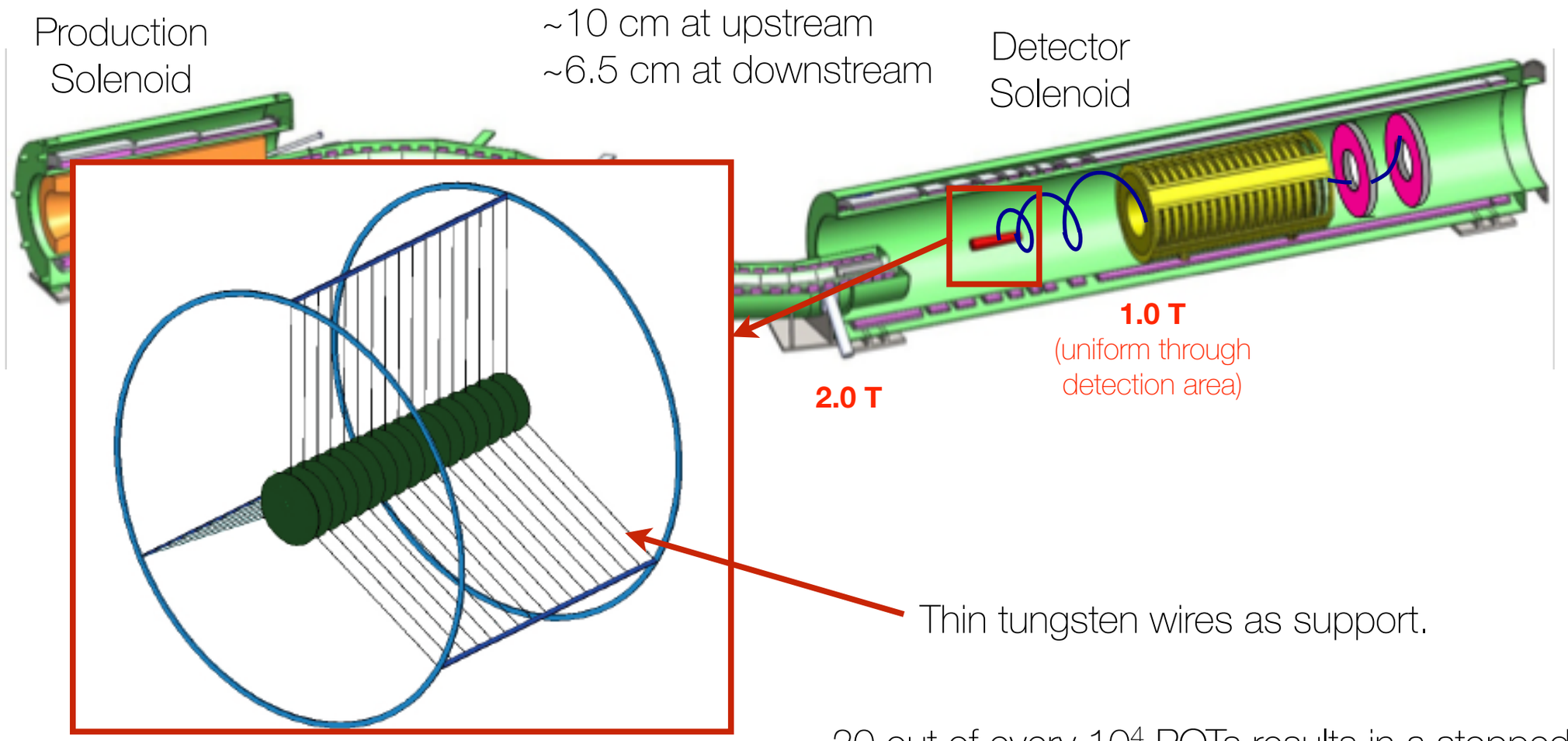
Transport Solenoid:
- Allows pions to decay.
- ~50 superconducting coils.
- Selects sign of particles.

John David Jackson.
Classical Electrodynamics, 3rd Edition.
Sec. 12.4: Particle Drifts in Nonuniform, Static Magnetic Fields

Detector Solenoid

Stopping Aluminum Target

17 target foils
0.2 mm thick
5 cm spacing
Radius:
~10 cm at upstream
~6.5 cm at downstream



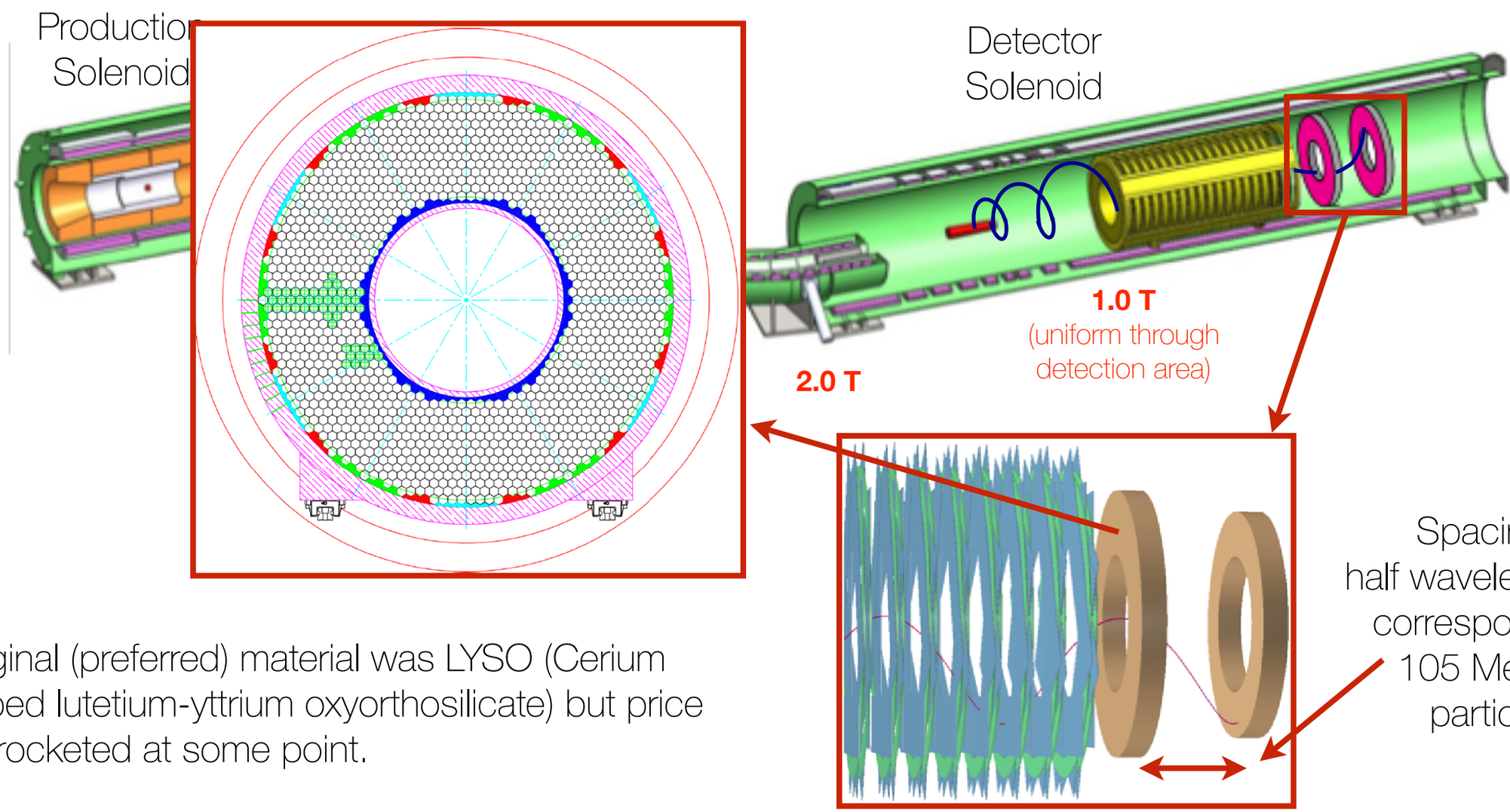
Thin tungsten wires as support.

~20 out of every 10^4 POTs results in a stopped muon.
(remember 10^{-17}?)

Detector Solenoid

Two-disk calorimeter

Hex BaF_2 crystals
Readout: APD or SiPM
Precise timing, PID, background rejection,
alternate track seed and possible calibration trigger.

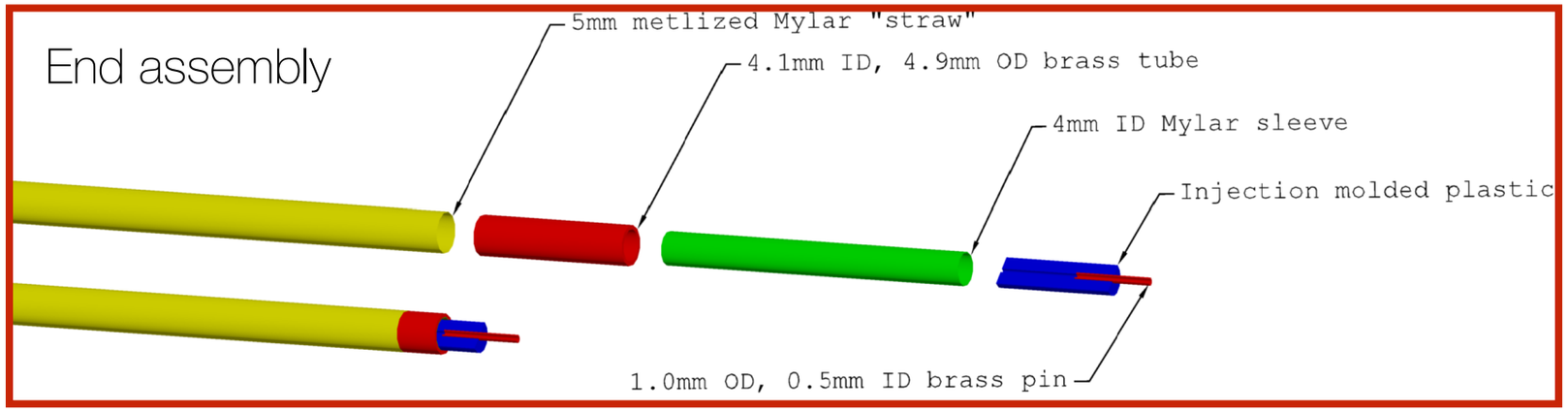


Original (preferred) material was LYSO (Cerium doped lutetium-yttrium oxyorthosilicate) but price skyrocketed at some point.

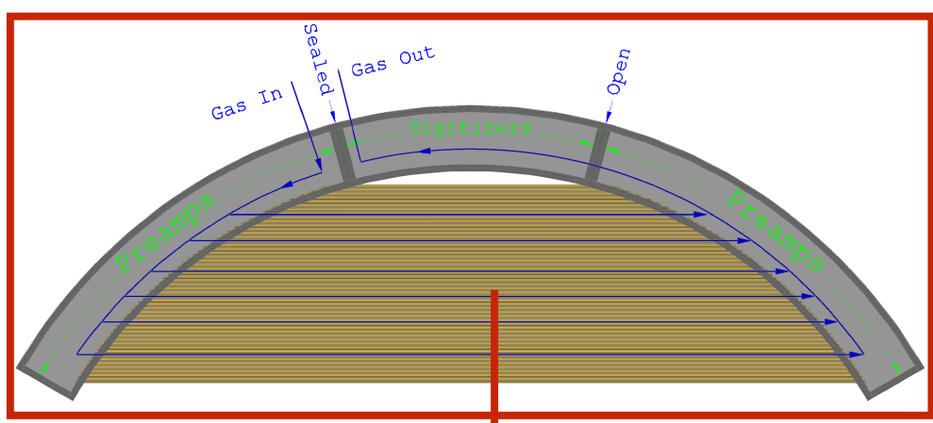
Tracking Detector

Tracking Detector

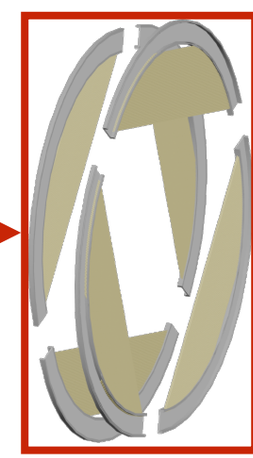
Straw filled with Ar-CO_2 (80:20) with a 25 micron tungsten-wire in the middle and connections in both ends.

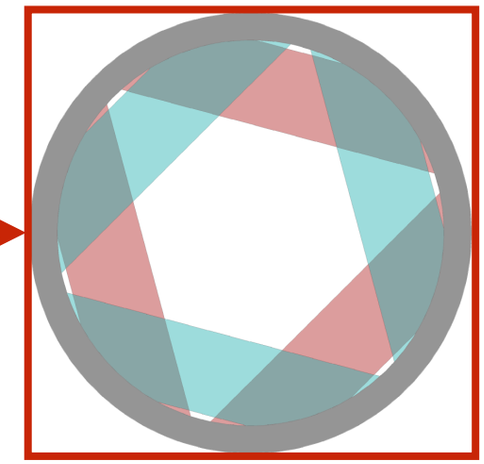


Panel: two layers of 48 straws each.



Plane: six panels

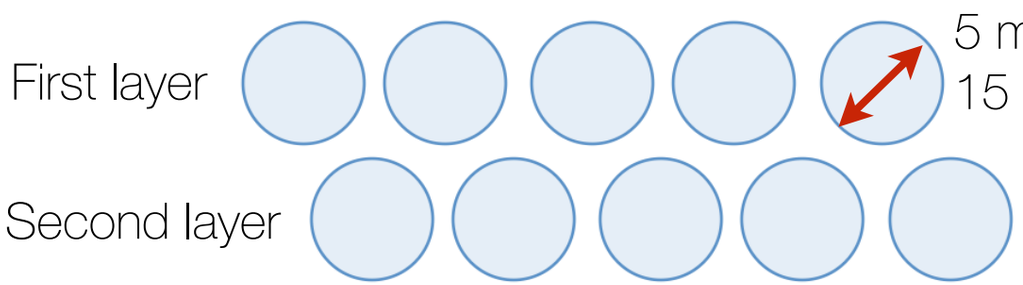




Straw:

5 mm OD.

15 micron metalized mylar wall.

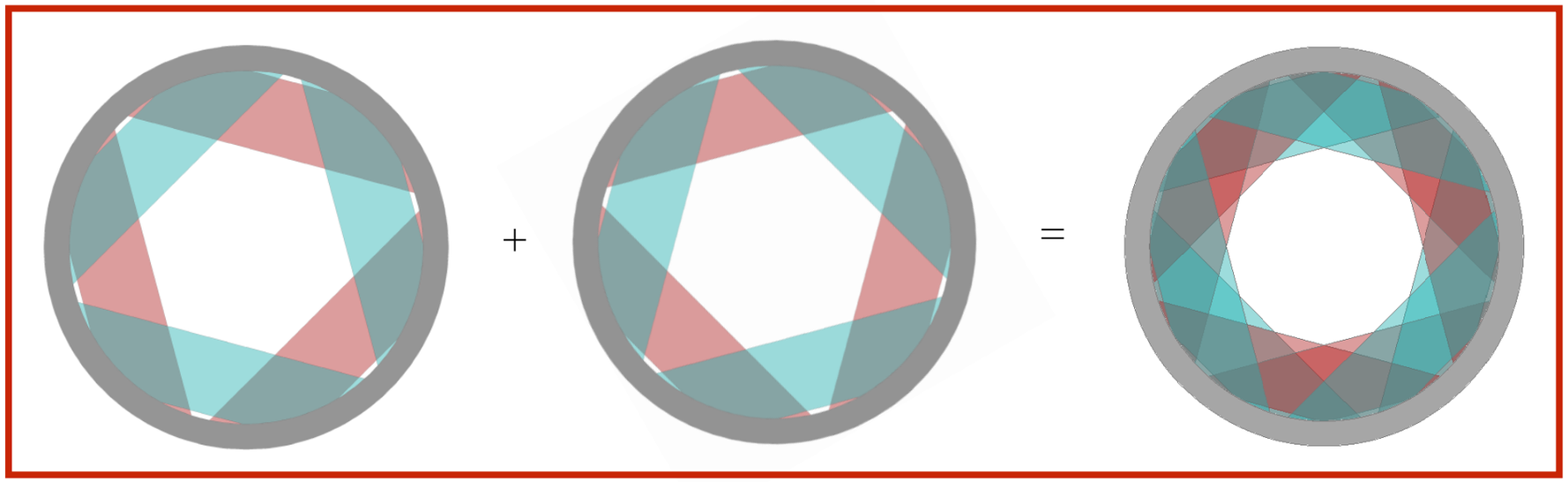


Tracking Detector

Station: two planes

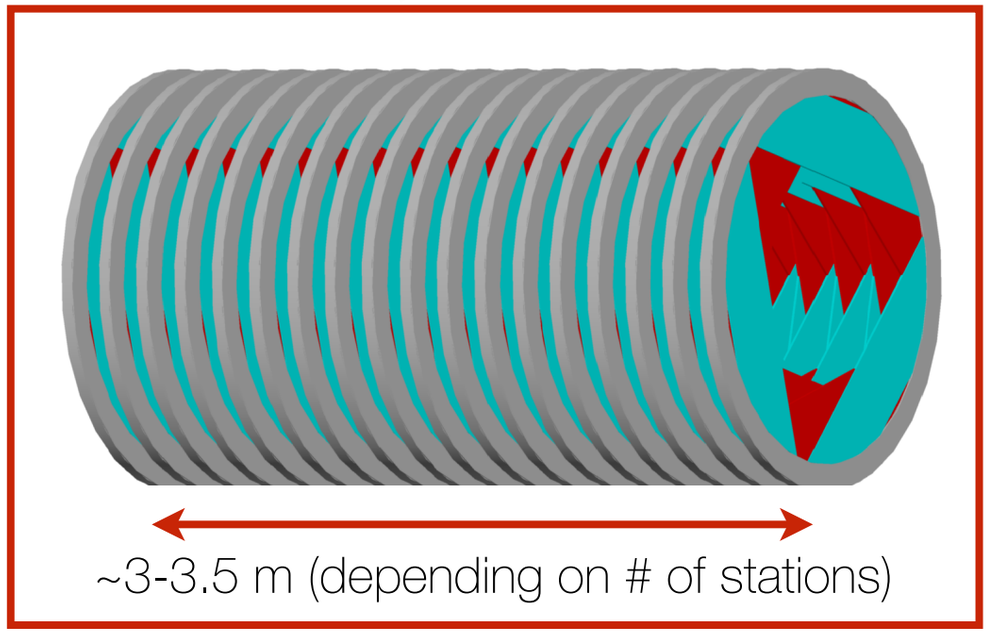
Mirror + rotation.

Relative rotation under study.



Tracking detector: 22 stations

Number of stations and their relative rotations still being optimized.

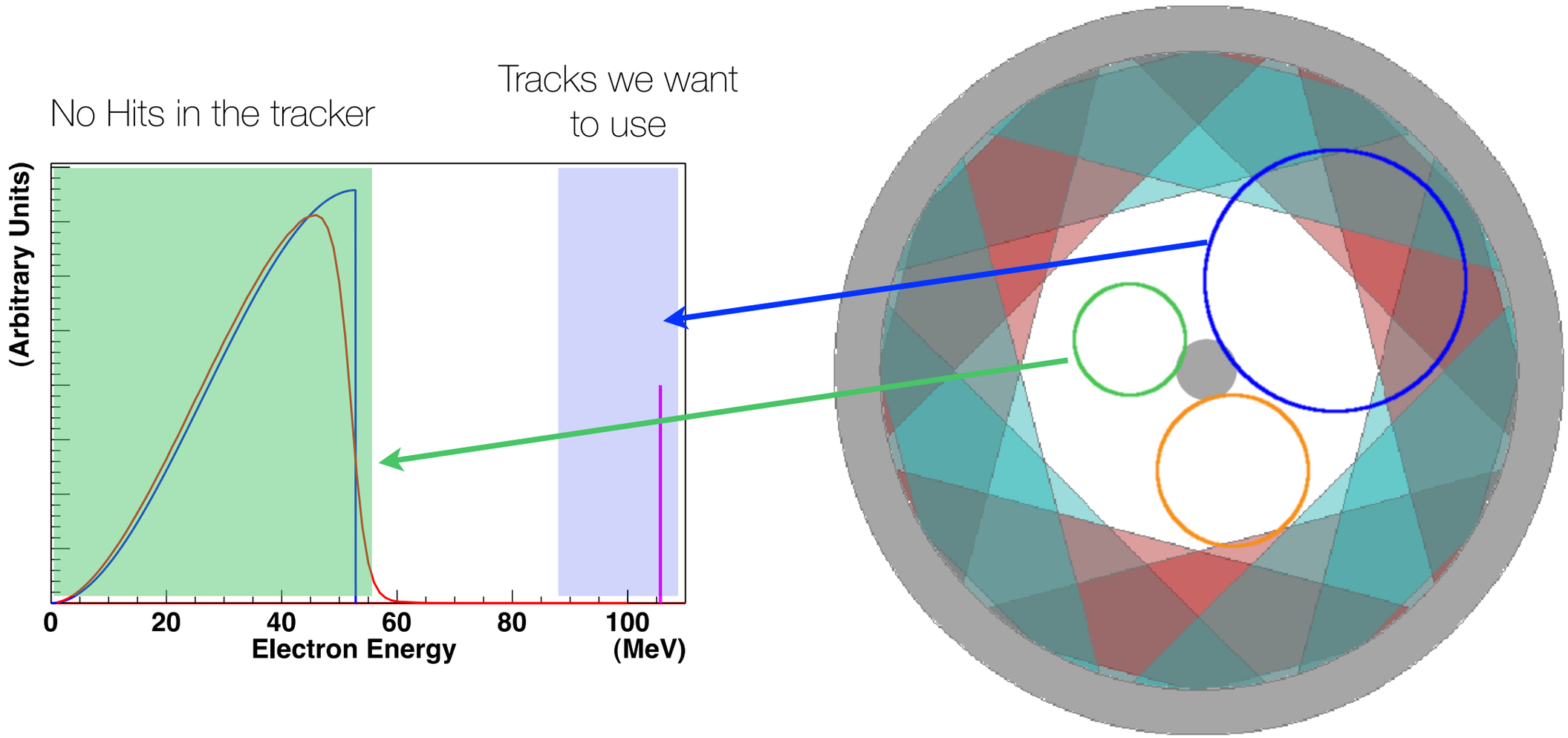


Detector under vacuum (~10^{-4} Torr).

Total number of straws

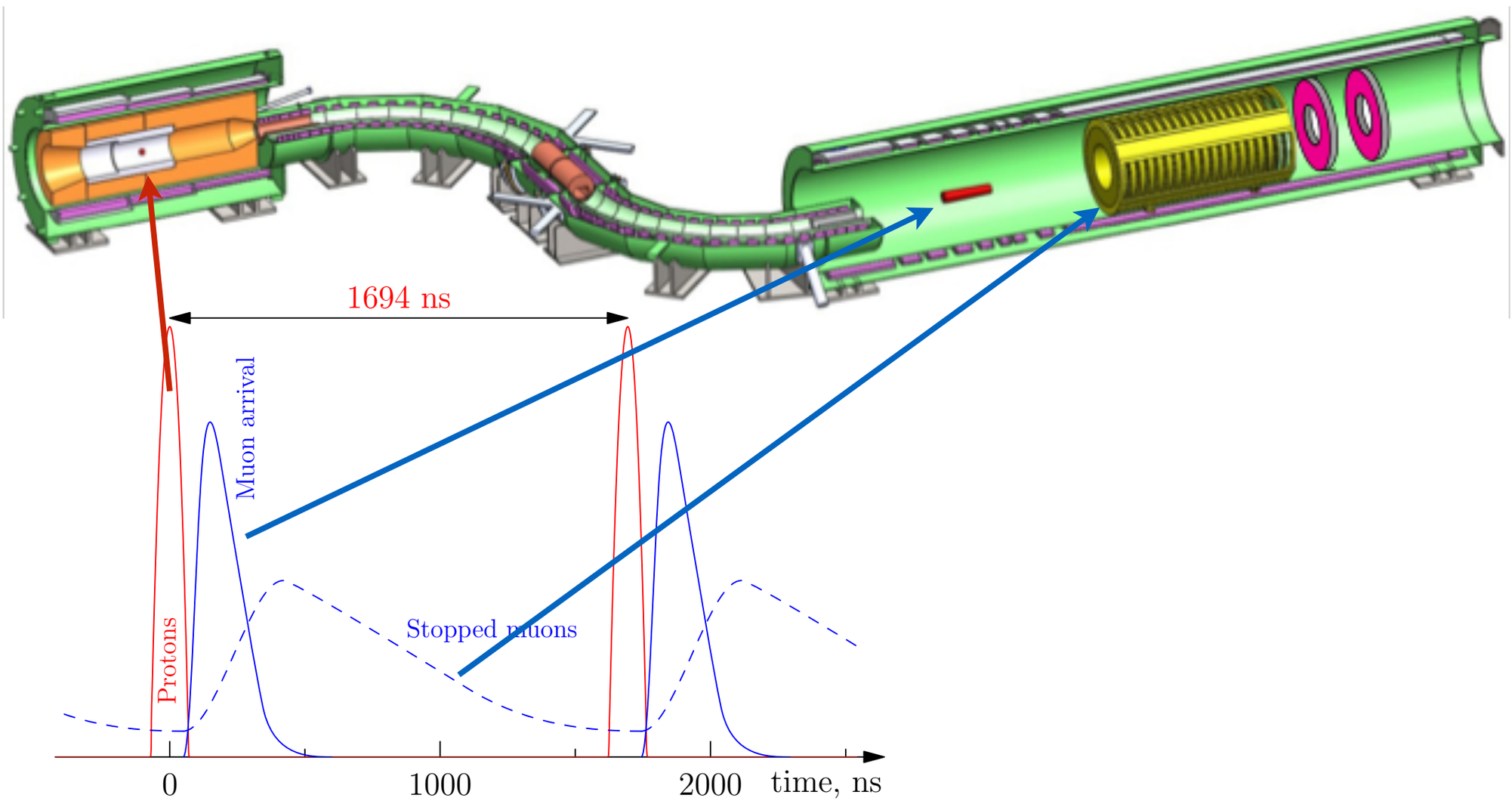
$48 \times 2 \times 6 \times 2 \times 22 =$ **25,344**

Tracking Detector



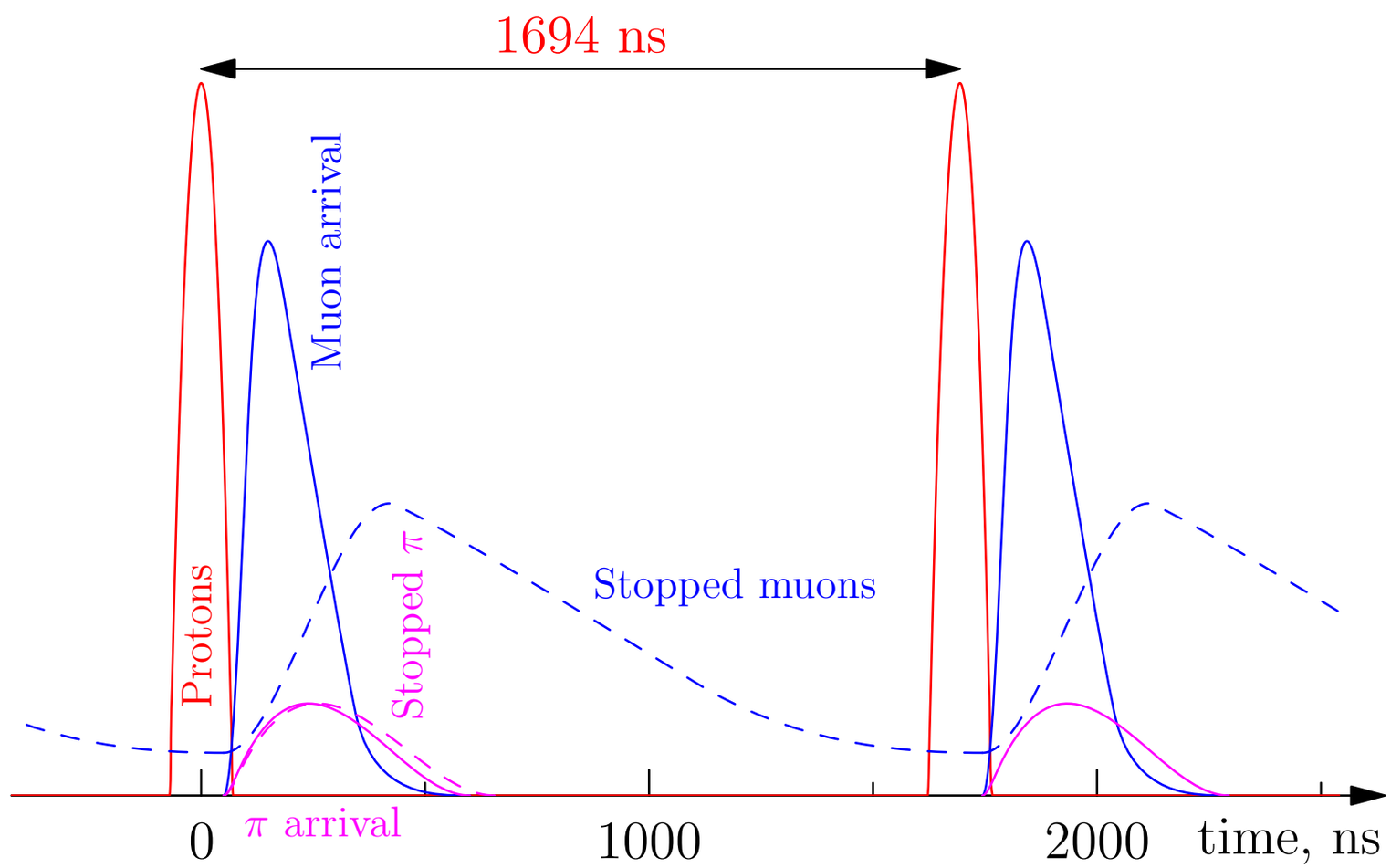
mu2e Time Structure

Due to the time structure we have to work with,
we need a careful selection of the observation window



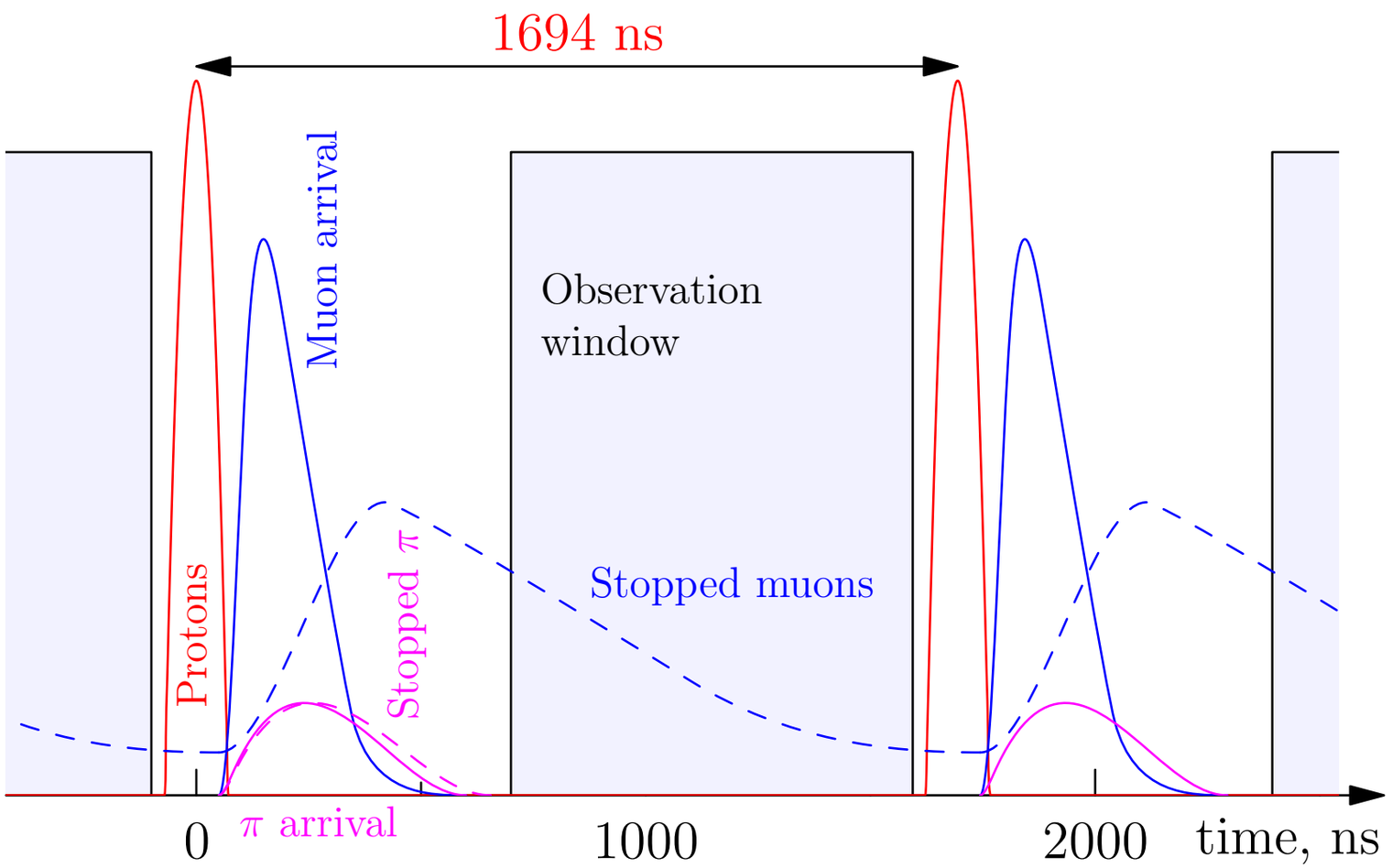
mu2e Time Structure

We need an observation window as clean as possible



mu2e Time Structure

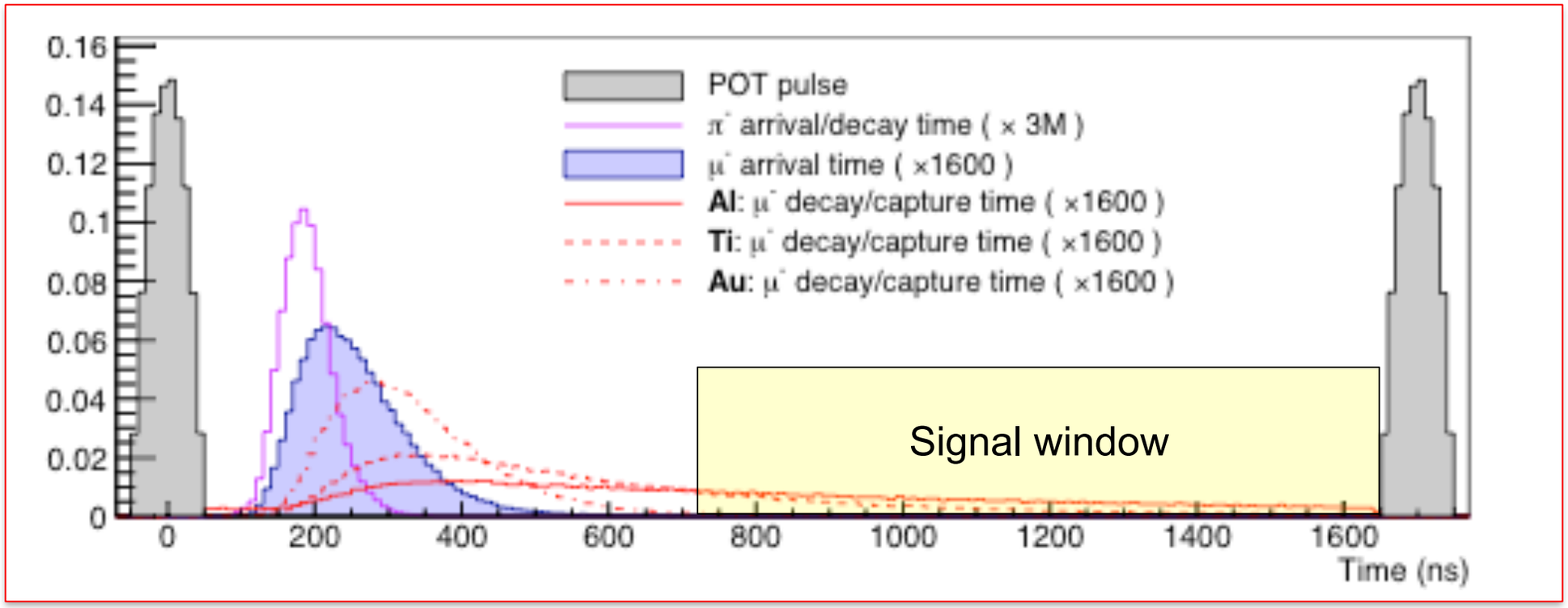
We start to observe things around 700 ns after the protons reached the production target and collect data almost until the end of the 1,694 ns cycle.



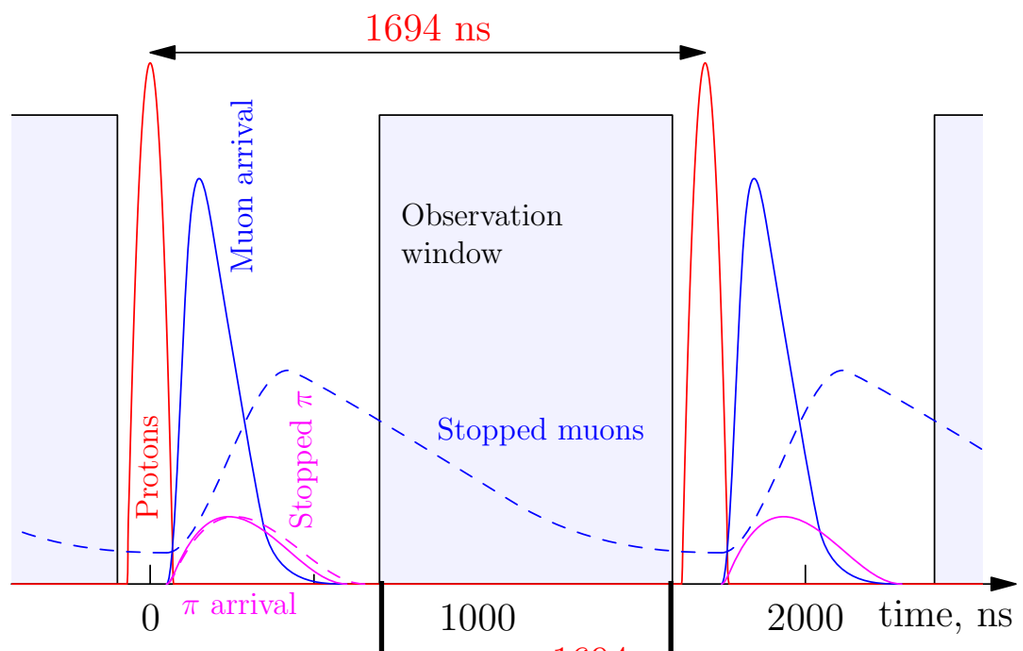
mu2e Time Structure

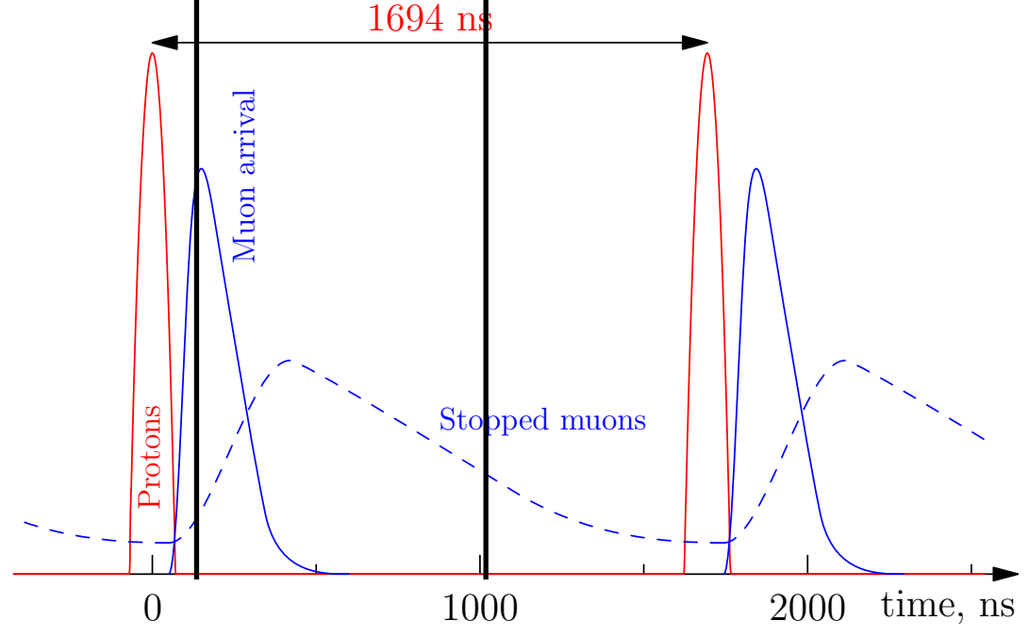
The election of aluminum as stopping target also has to do with the time structure.

Future upgrades will enable mu2e to use different stopping targets mainly due to a different time structure.



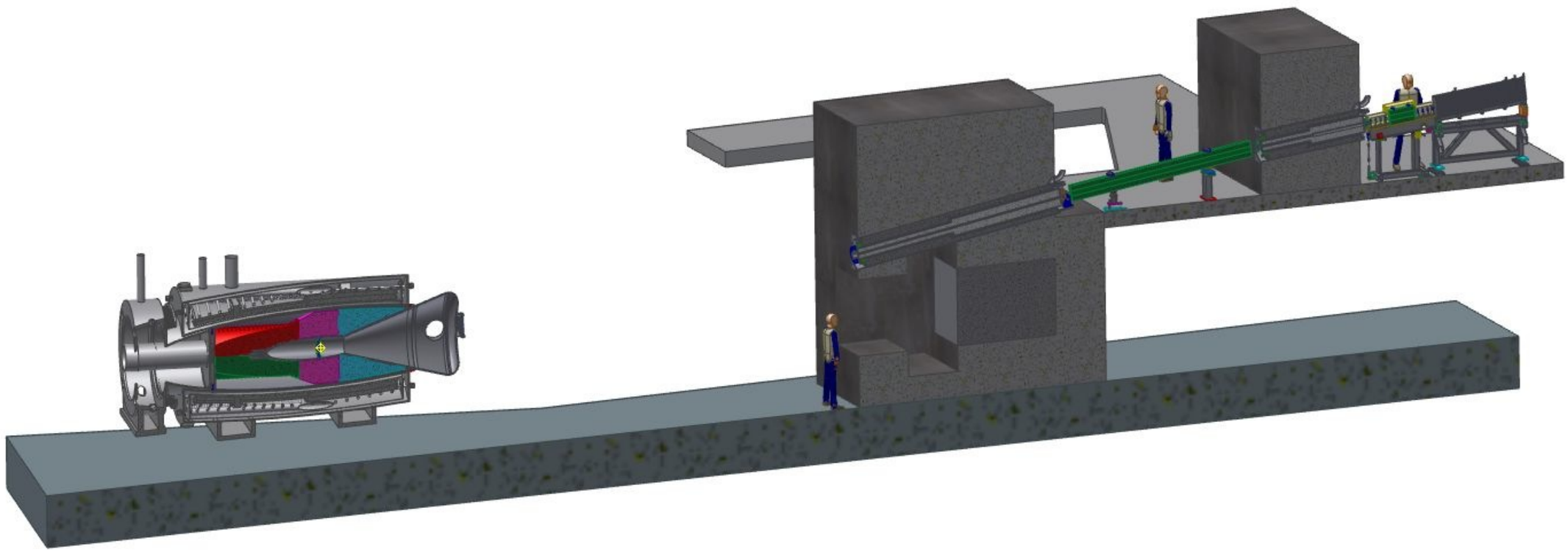
Extinction Monitor





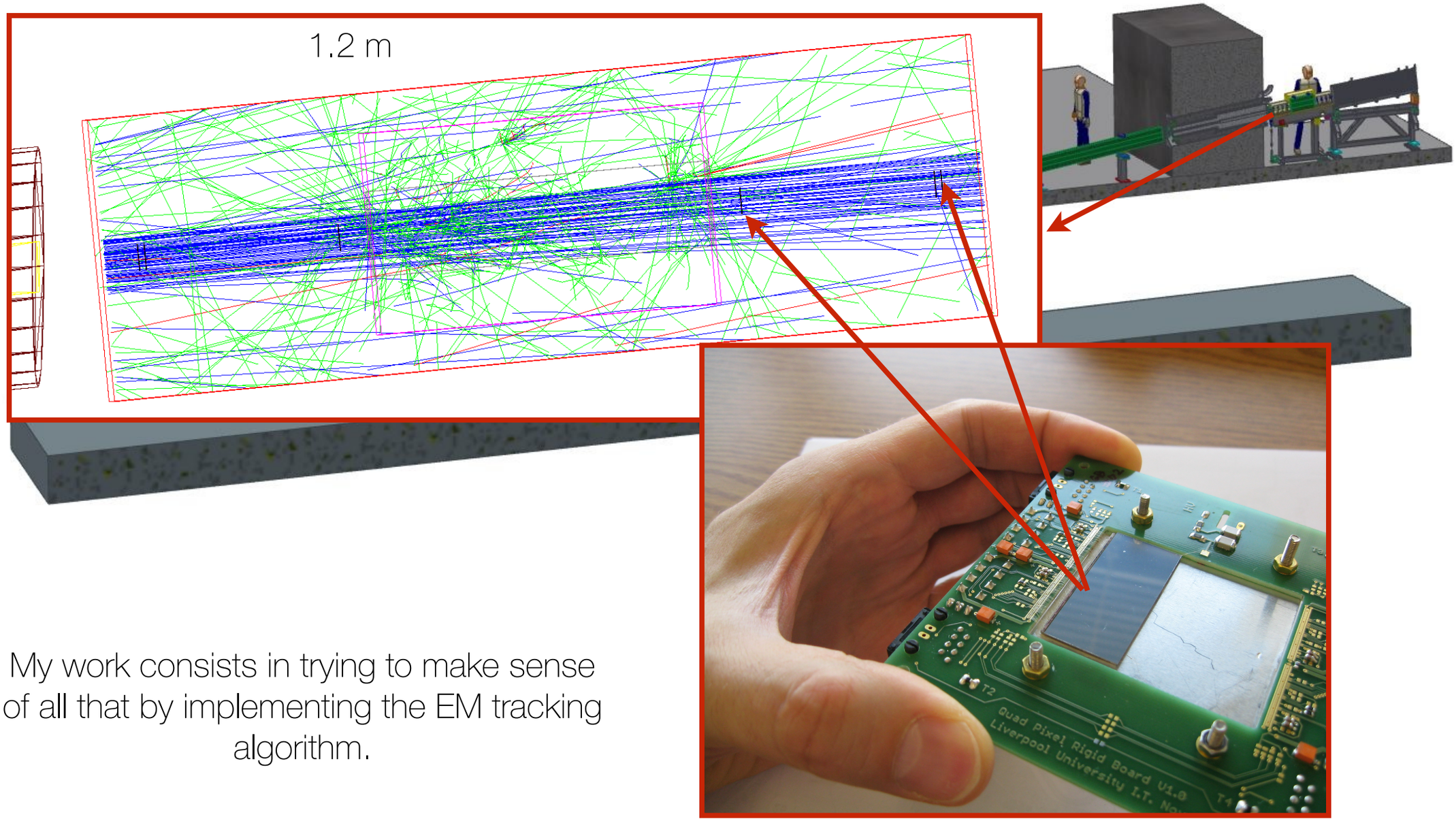
What could happen if we receive protons out of time?

Extinction Monitor



Extinction Monitor

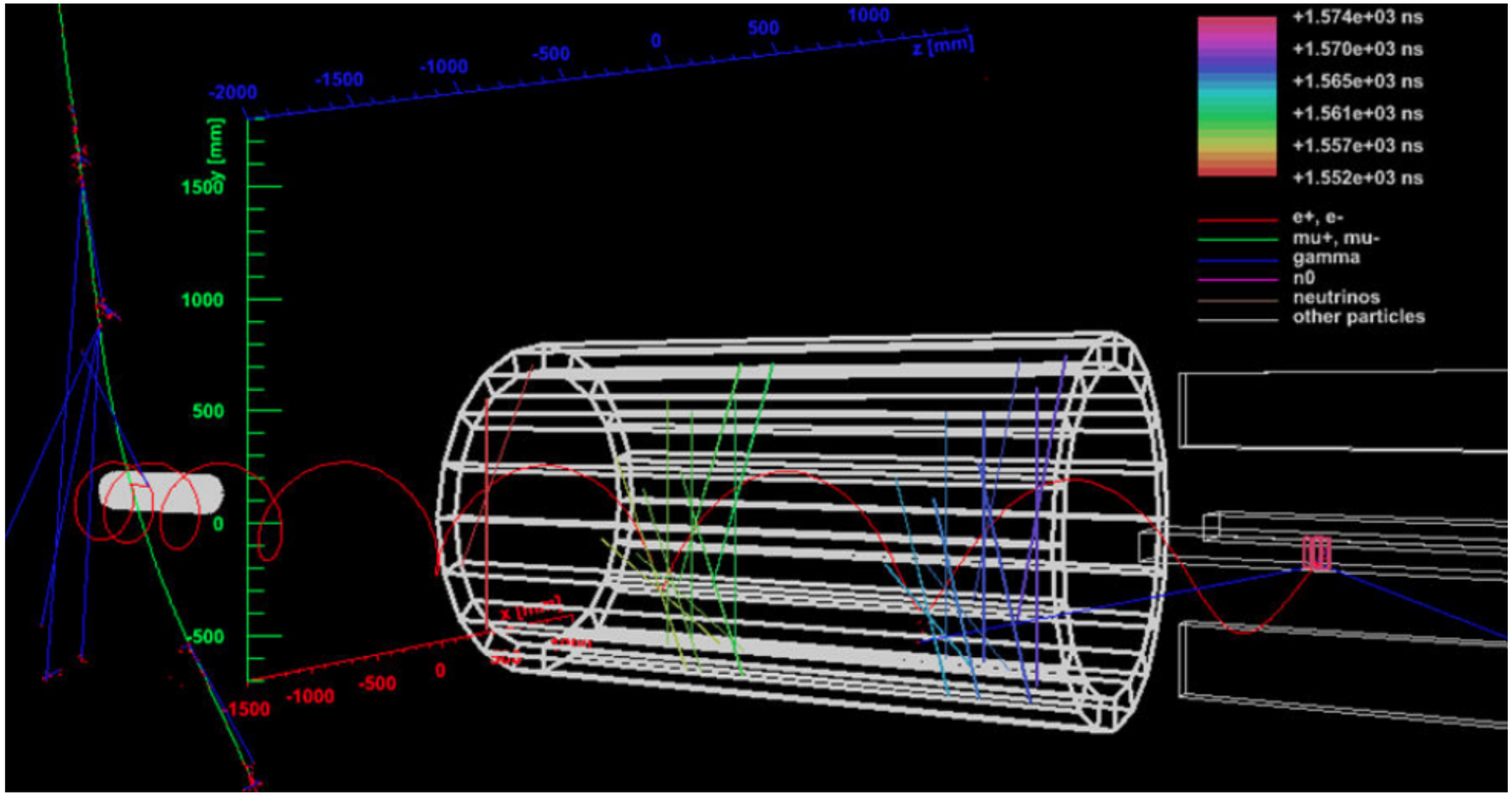
Previous version of the Extinction Monitor



My work consists in trying to make sense of all that by implementing the EM tracking algorithm.

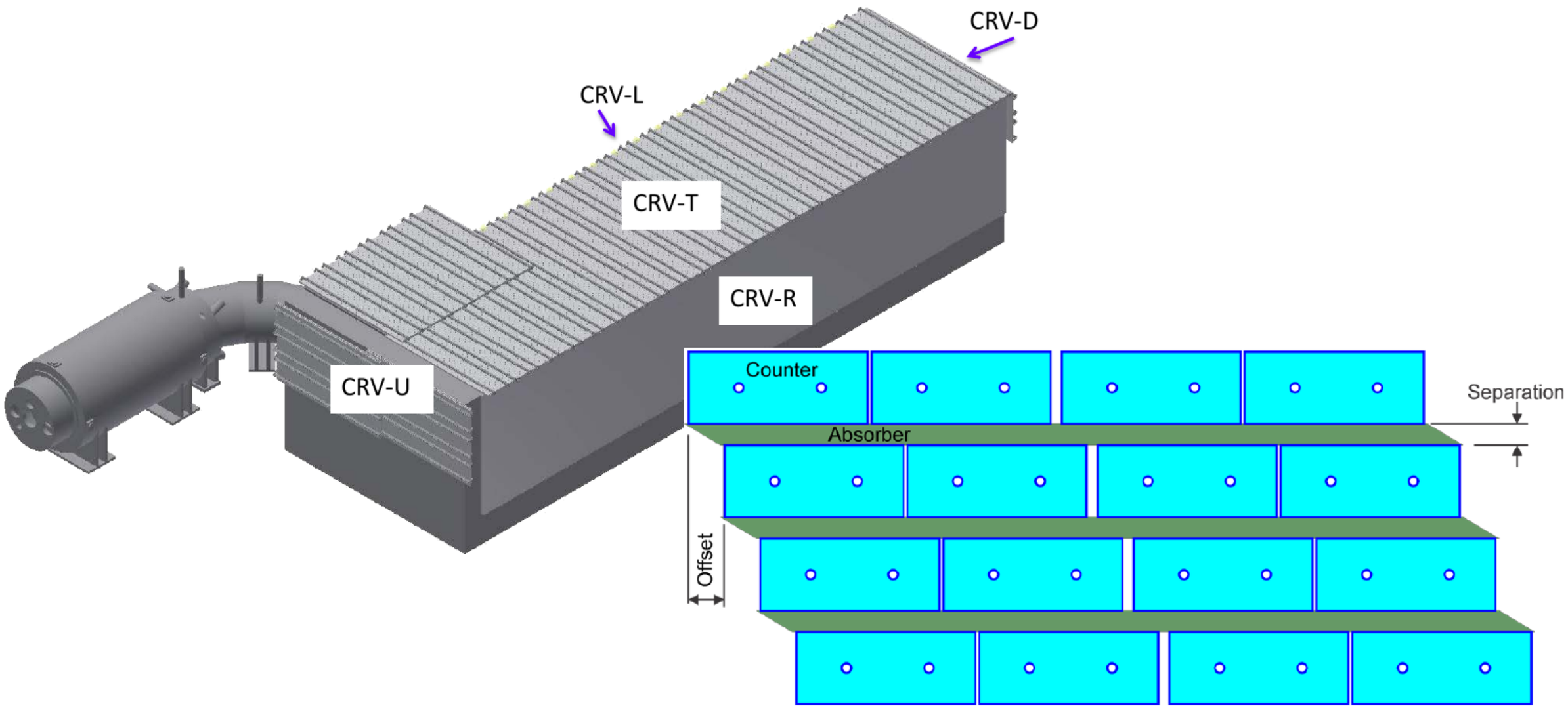
Cosmic Ray Veto

Even at the high rate environment we expect, cosmic rays can produce a signal-like event, as often as once per day!



Cosmic Ray Veto

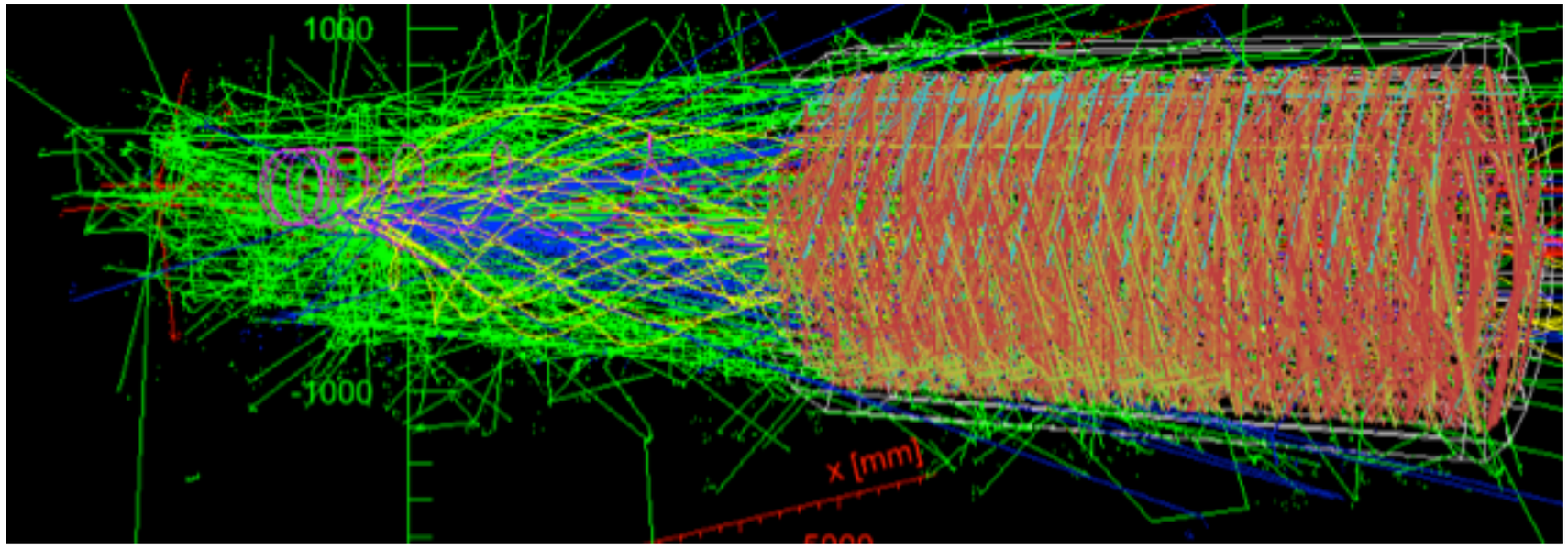
Lots of shielding and scintillating modules grouped into four layers, separated by aluminum absorbers.
Cosmic ray backgrounds vetoed by rejecting 2- and 3-layer coincident signals.



Cosmic Ray Veto

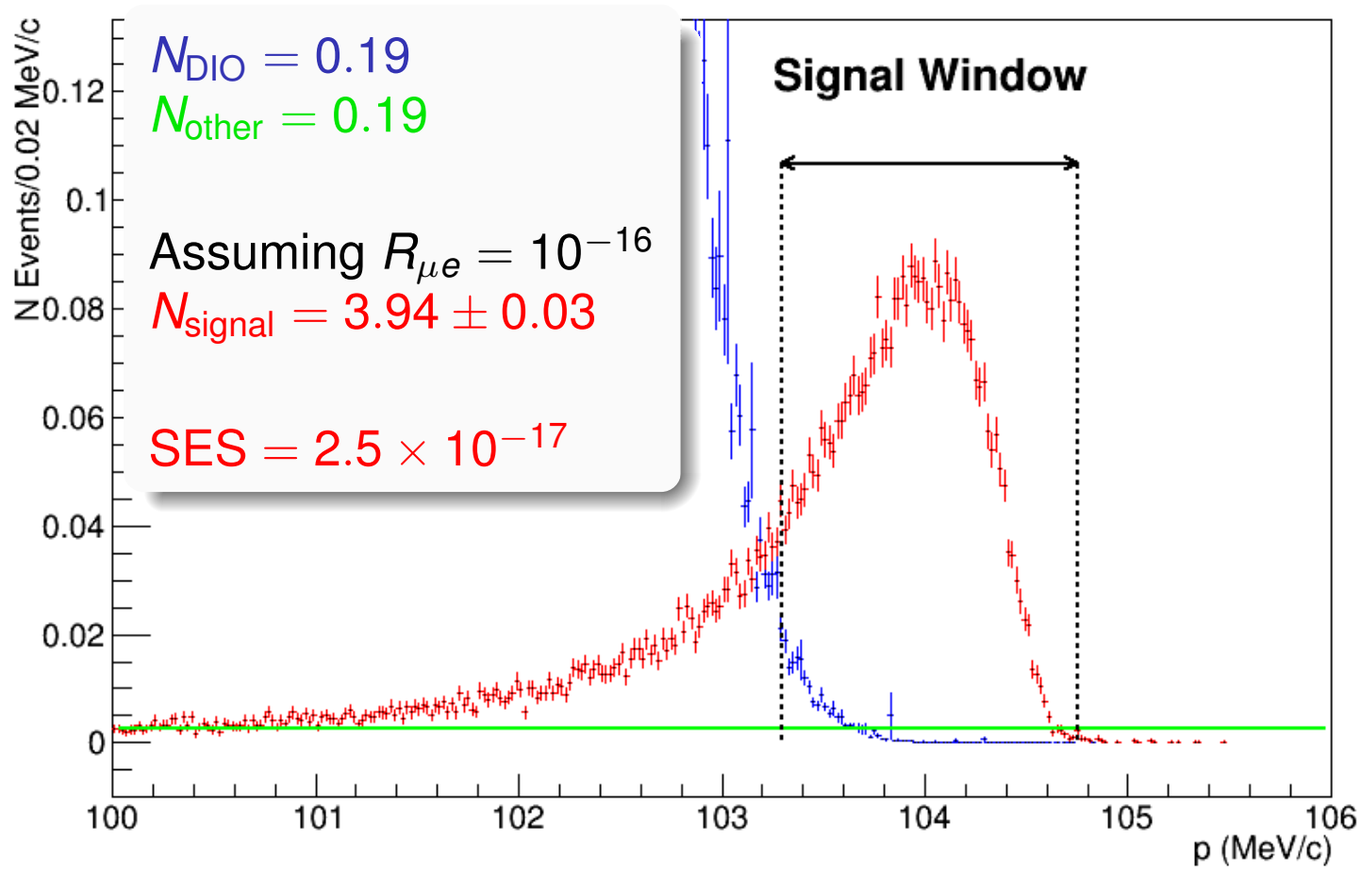
CRV counters overwhelmed by neutron/photon backgrounds from production target, and stopping target (2-3 neutrons per captured muon).

Need significant amounts of neutron shielding around transport and detector areas.



What we expect

3 year run: 5.8×10^{17} stopped μ^-



Full G4 & reconstruction without truth inputs

$R_{\mu e} = 10^{-16}$: 4 signal events over 0.4 background

Andrei Gaponenko 79 IF Seminar 2013-12-12

Cosmic Ray Veto

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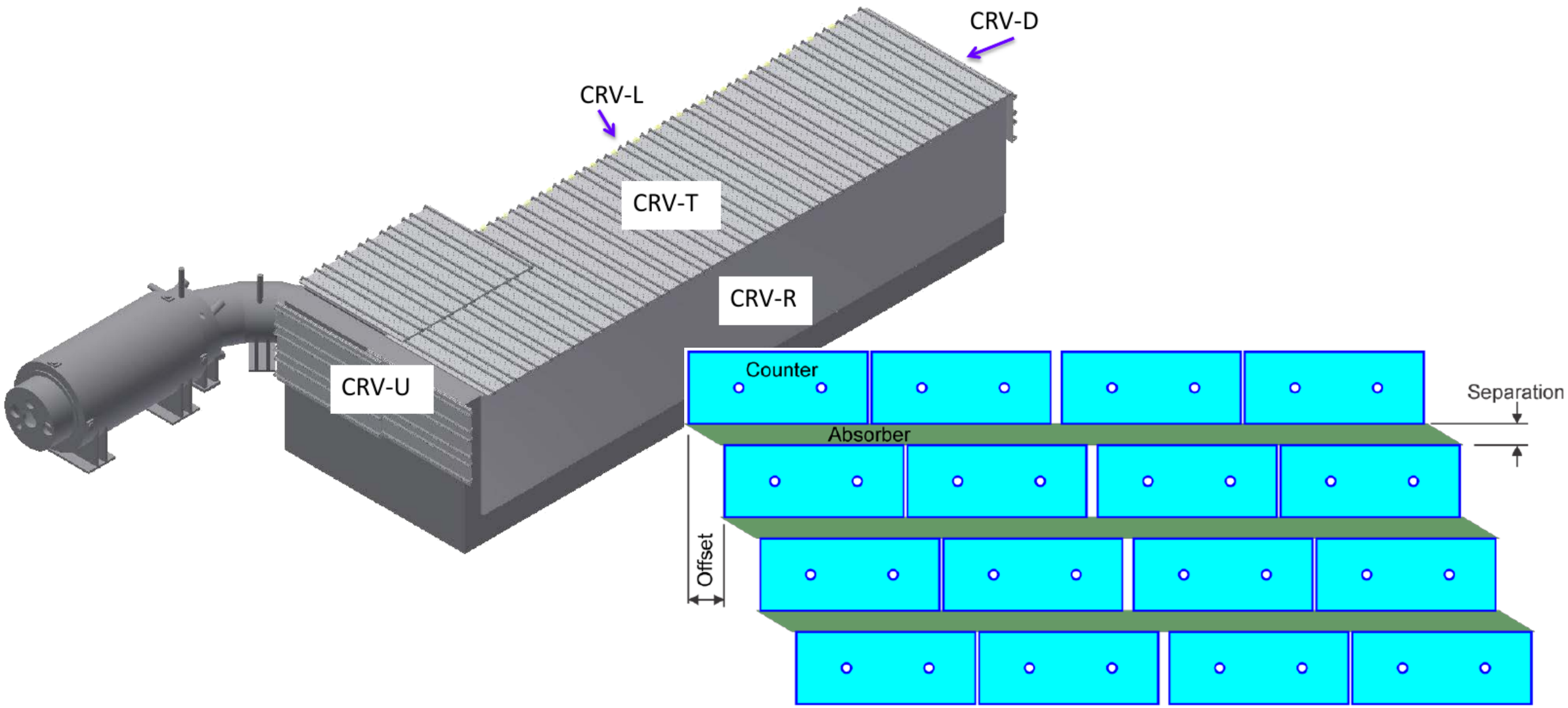
Cosmic ray backgrounds vetoed by rejecting 2- and 3-layer coincident signals.



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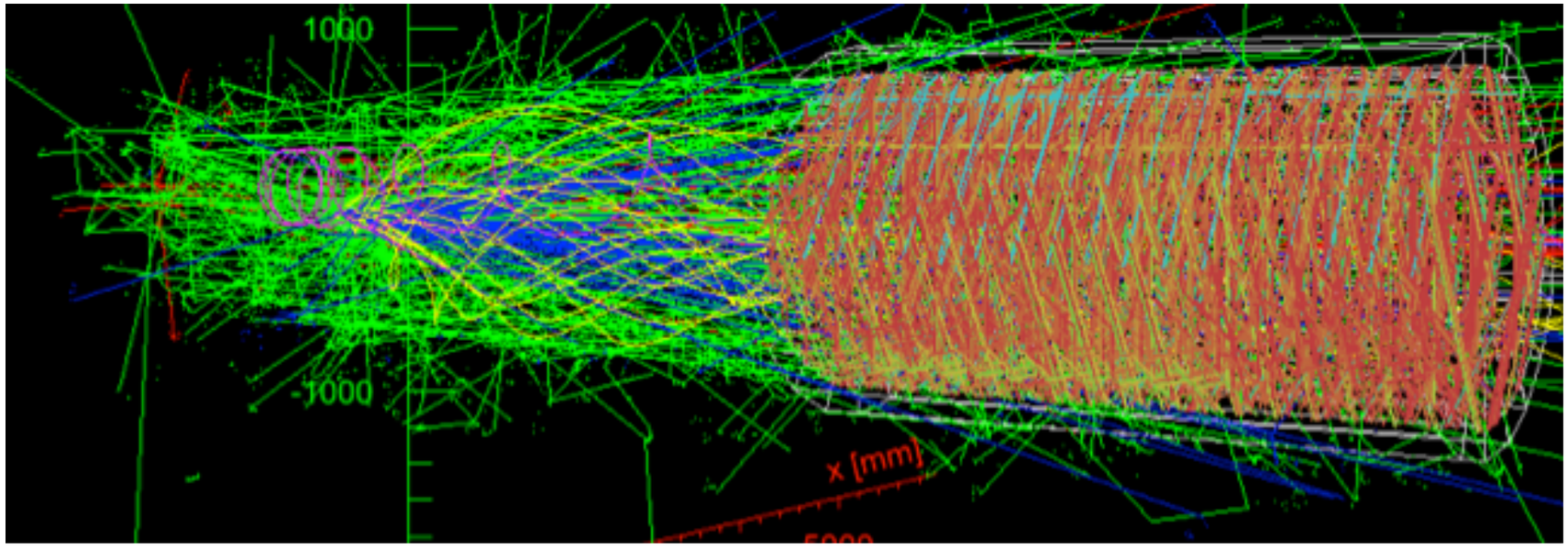
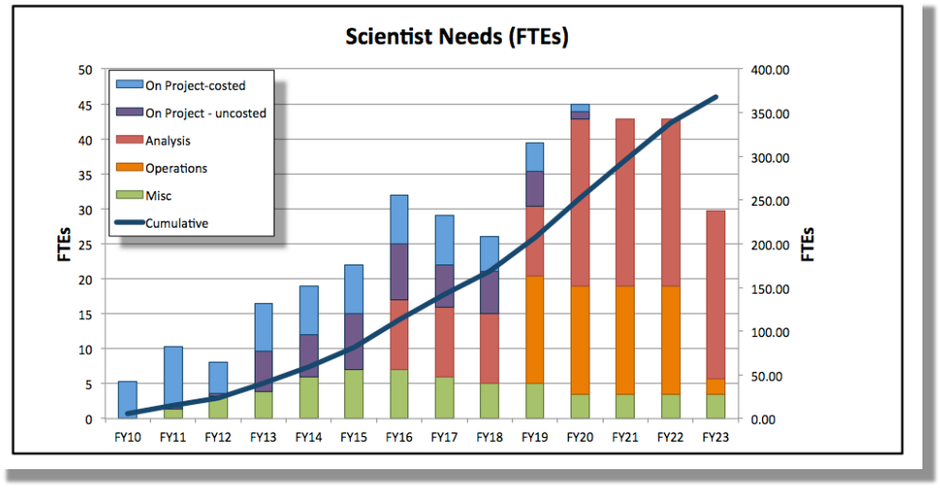


People needed

Estimation of the number of physicists needed by project phase, including operations and data analysis.

Scientific FTEs

1 FTE =1768 hours



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Included in Scientific FTEs

- Online Operations
  - People who carry pagers
  - Detector calibration
  - Data quality monitoring
  - Shifts
- Offline Operations
  - Calibration coordinator
  - Production farms
  - Simulations
  - Ntuples
  - Framework
- Analysis Preparation
  - Alignment
  - Momentum and energy calibration
  - Trigger studies
  - Analysis Coordination
- Analysis Groups
  - Individual backgrounds
  - Physics groups
- Misc
  - Spokespersons
  - Editorial Boards
  - Talks Committee
  - Analysis Reviews

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Summary

Mu2e search for coherent conversion of a muon to an electron (CLFV) will improve by 10^4 the expected conversion rate with respect to the previous experiment.

Experimental design is well along and continues to improve.

We have P5's blessing.

Next stage in decision making for mu2e is expected for this summer with ground breaking to follow in fall.

New people is always welcome!