NEWS

European Commission
H2020-MSCA-RISE-2016 – Grant Agreement N° 734303

WP 6, FNAL μ-campus

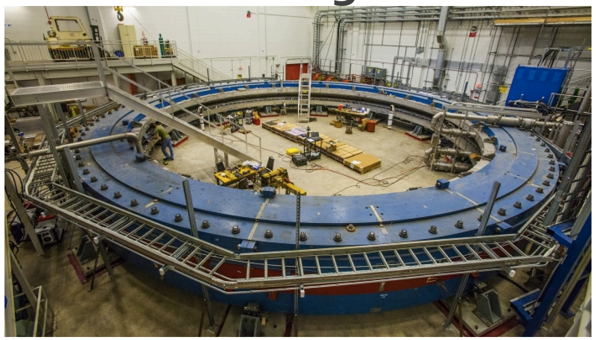
I. Sarra, G. Pezzullo, V. Giusti

WP 6 Co-leaders

Intensity frontier experiments @ Fermilab

Precision science refers to experiments that attempt to break the established laws of physics by testing predictions to the highest accuracy and searching for phenomena that are either extremely rare or forbidden. Deviations from expectations are an indication of new particles and new interactions.

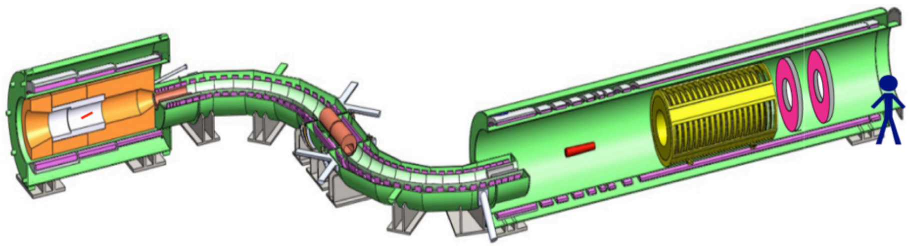
Muon g-2



Measure muon's magnetic moment to 140 parts per billion accuracy

- a factor of 4 improvement wrt previous measurement @ BNL

Mu2e

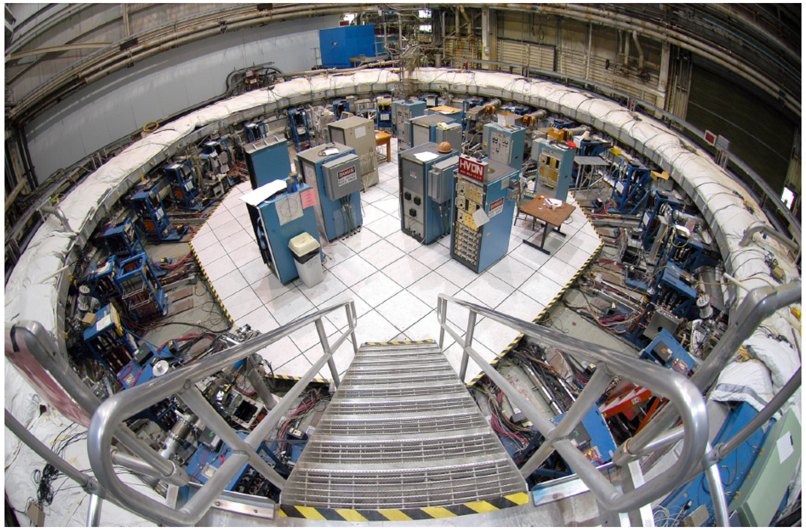


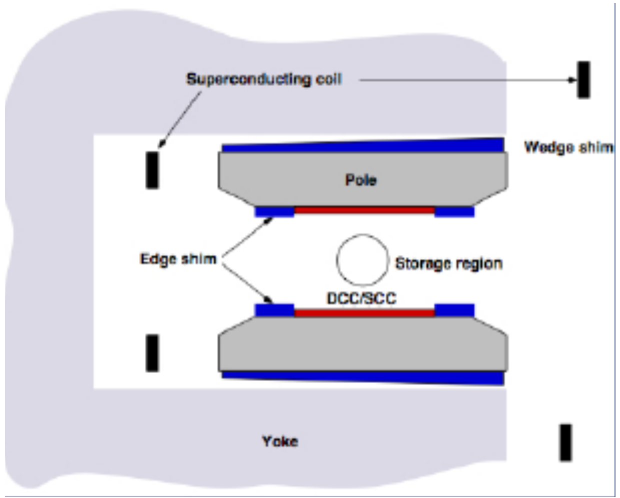
Search for spontaneous conversion of a muon to an electron (CLFV)

- Fermilab experiment will improve sensitivity by a factor of 10,000

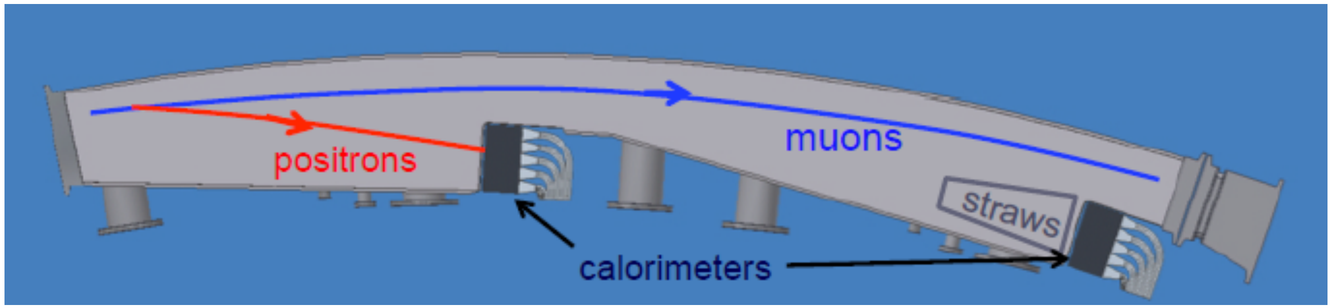
Muon g-2 experiment

- Reusing storage ring from BNL g-2 experiment





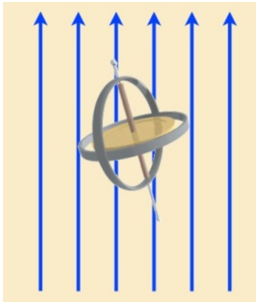
- New calorimeters and straw-tube tracking



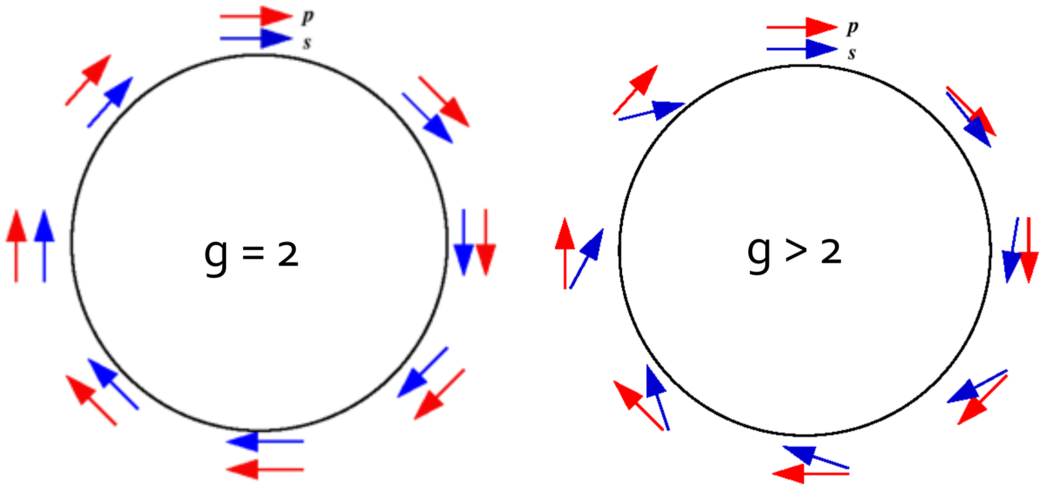
Measuring g-2

- Polarized muons in magnetic field precess with Larmor spin precession frequency

$$\vec{\omega}_s = -\frac{e\vec{B}}{\gamma mc} - \frac{e}{mc} a\vec{B} \qquad a = \frac{g-2}{2}$$



- Measure g-2 using cyclotron



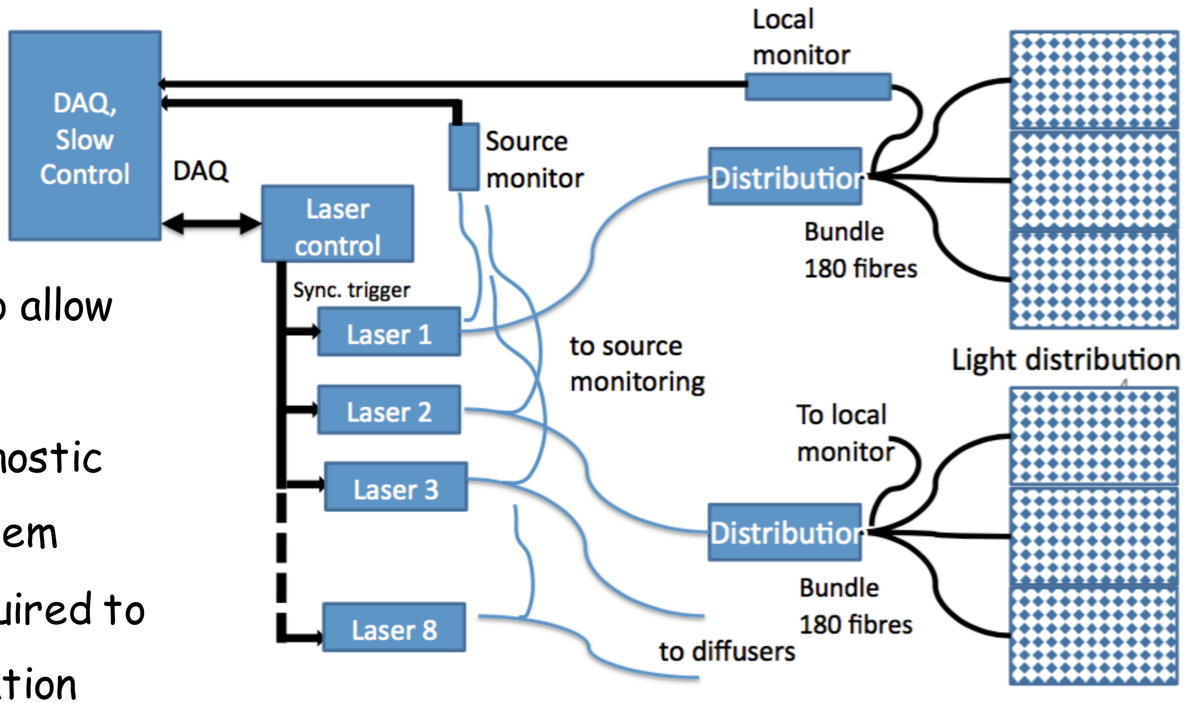
$$\vec{\omega}_c = -\frac{e\vec{B}}{\gamma mc}$$

$$\vec{\omega}_a = \vec{\omega}_s - \vec{\omega}_c = -\frac{e\vec{B}}{2mc}(g-2)$$

- **Requires precise measurements of ω_a and of the magnetic field**

Muon g-2 experiment: laser system

- Laser system operated successfully during the commissioning run



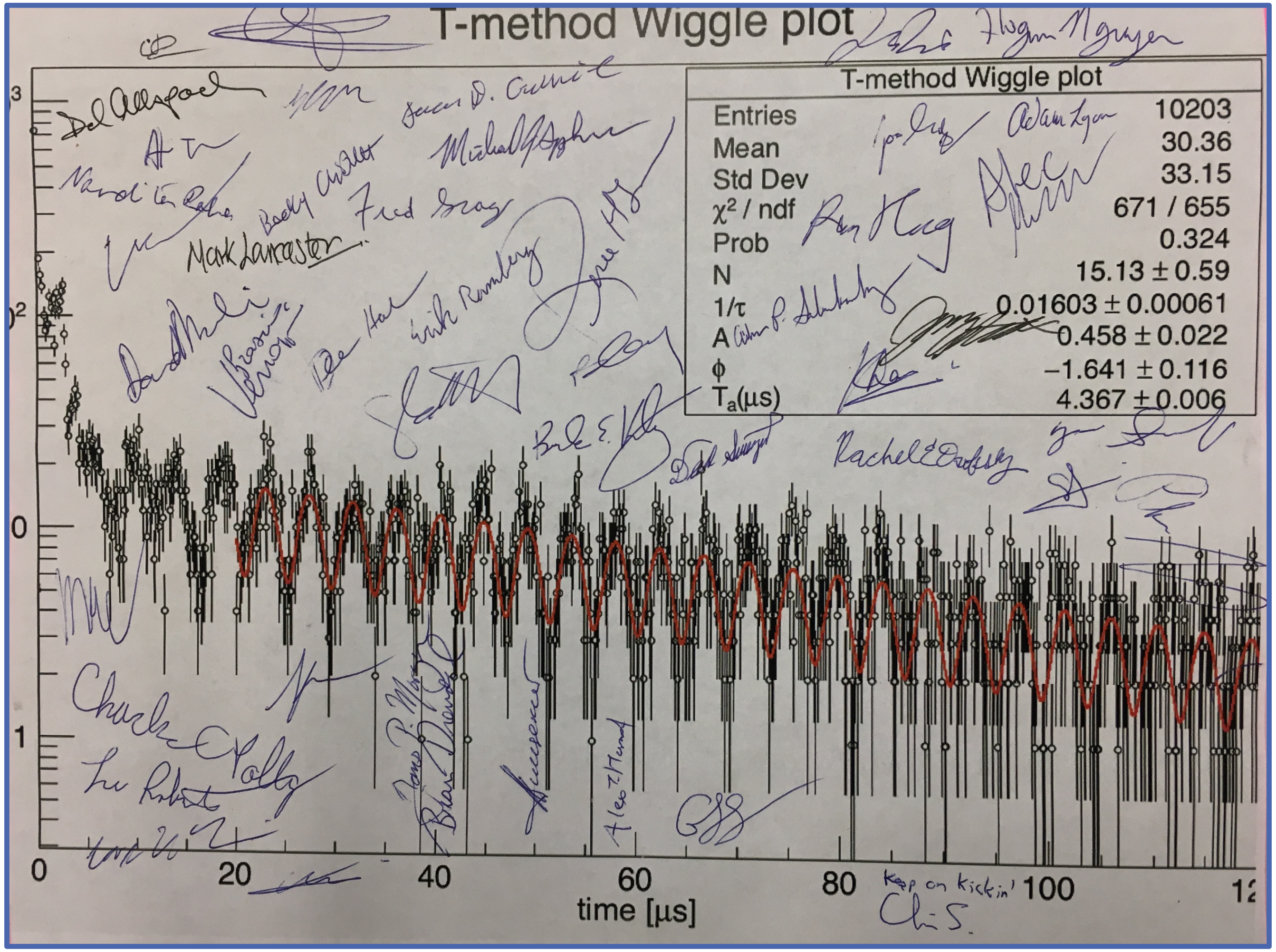
8 single "laser+diffuser+monitoring" units

NEWS contribute:

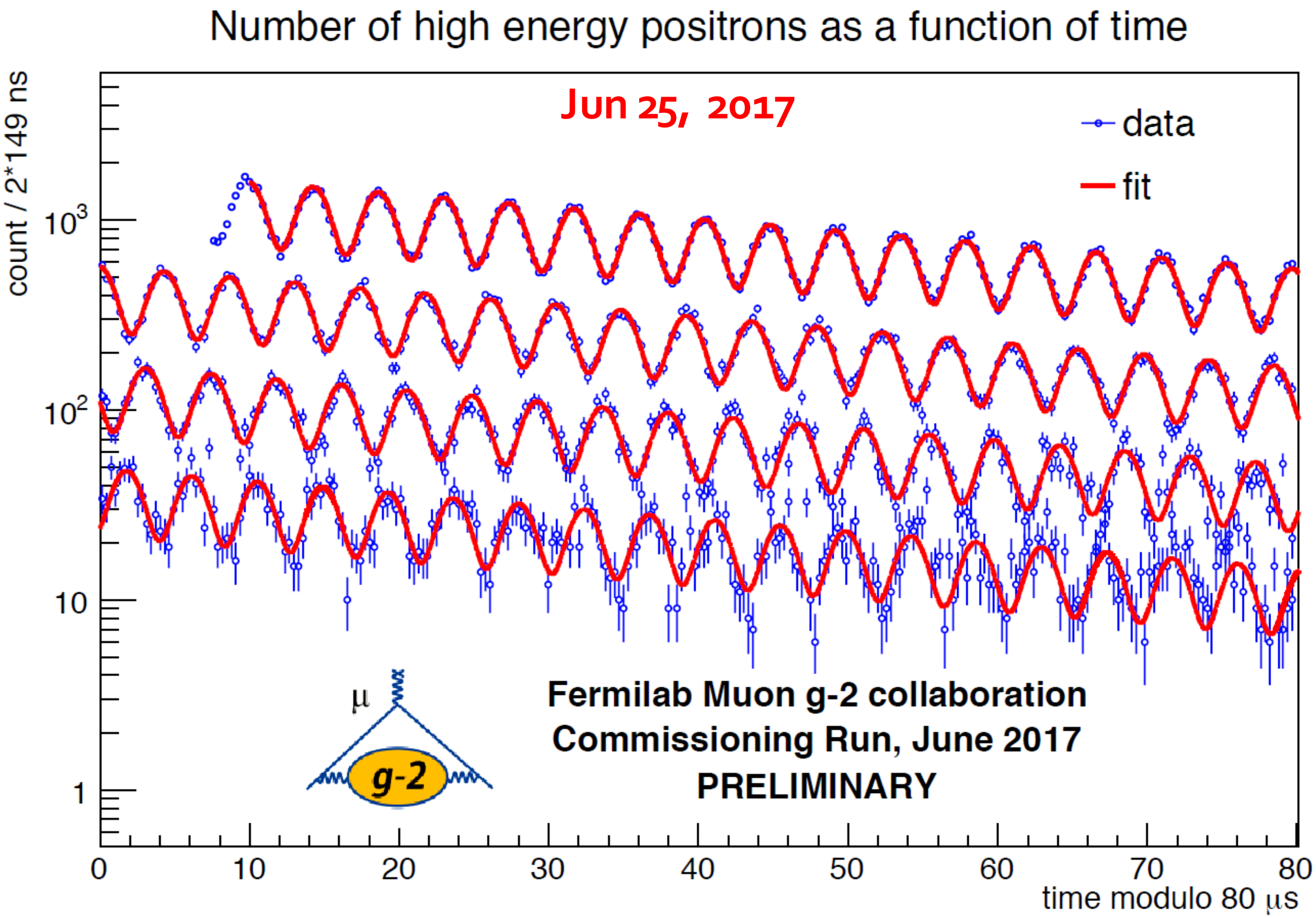
- Upgrade the hardware to allow double pulse generation
- Implement/improve diagnostic tools to monitor the system
- Implement software required to provide long-term calibration

Muon g-2 analyses

Jun 11: First evidence of stored muon precession



Muon g-2 analyses: getting better…



Mu2e experiment

(1) Production Solenoid:

➡ Proton beam strikes target, producing mostly pions

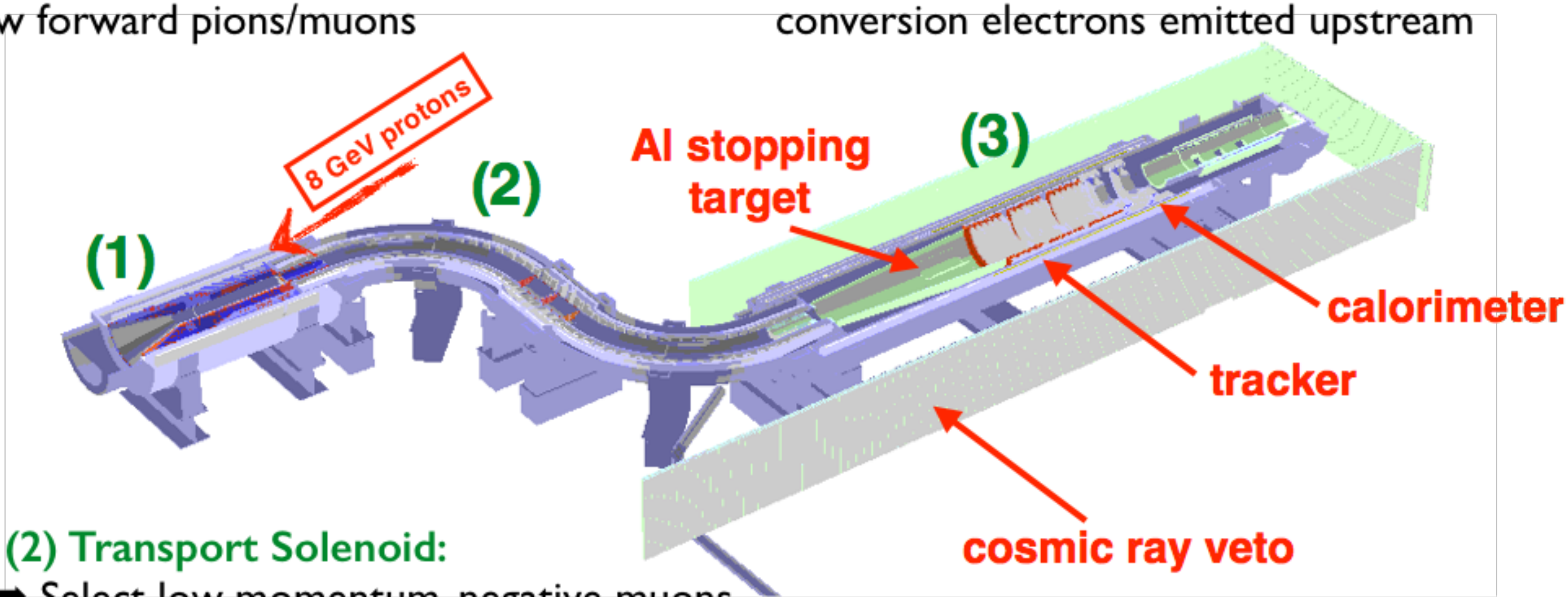
➡ Graded magnetic field contains backwards pions/muons and reflects slow forward pions/muons

(3) Detector Solenoid:

➡ Capture muons on Al target

➡ Measure momentum in tracker and energy in calorimeter

➡ Graded field "reflects" downstream conversion electrons emitted upstream



(2) Transport Solenoid:

➡ Select low momentum, negative muons

➡ Antiproton absorber in the mid-section

Mu2e shielding

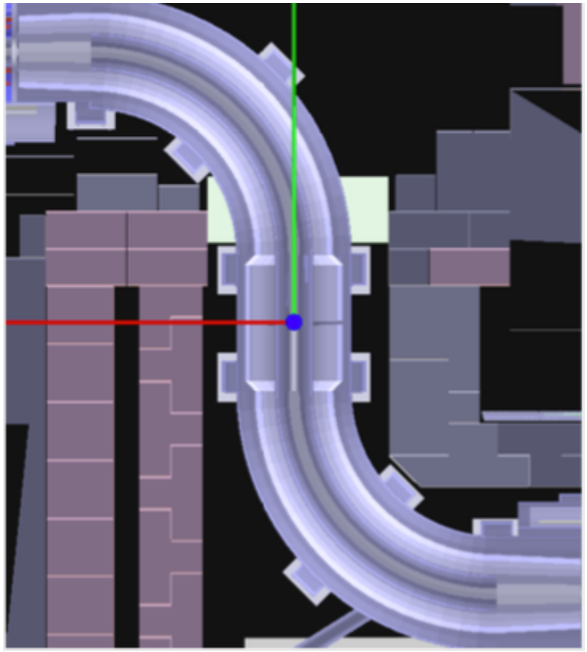
- Shielding surrounding the Cosmic-ray veto (CRV) is necessary to:
  1. Reduce the flux of neutral particles coming from the PS
  2. Keep the neutron flux in the CRV SiPMs below 10^{10} $n/cm^2_{1MeV\ eq}$

Why?

R-1. High rate in the CRV induces large dead time

R-2. Above 10^{10} $n/cm^2_{1MeV\ eq}$ SiPMs cannot provide single PE

- Current design is based on GEANT4 sim

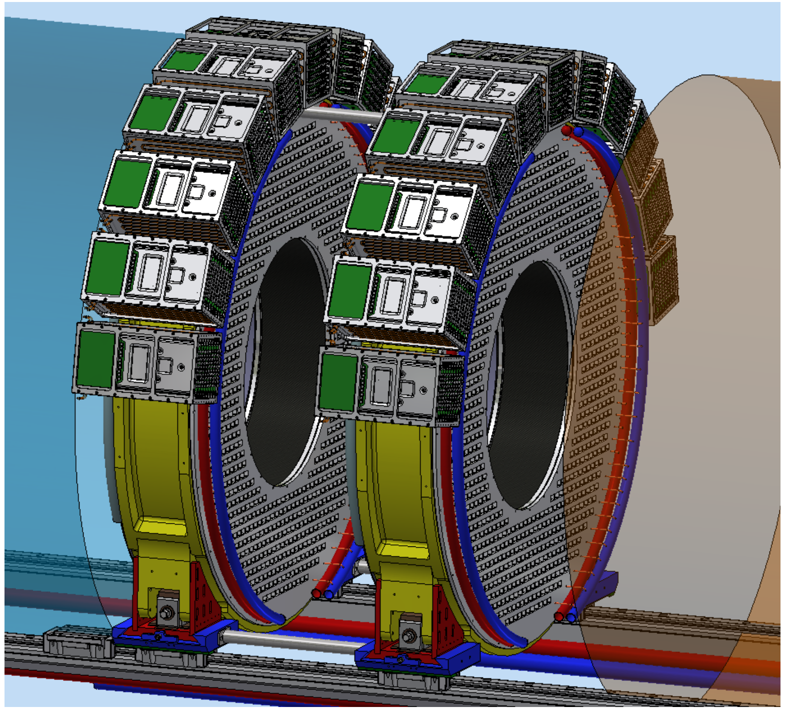


NEWS contribute:

- Development of FLUKA and MCNP6 model of the Mu2e apparatus will allow to improve the design
  - Completely independent from GEANT4
  - MCNP6 is "data" based

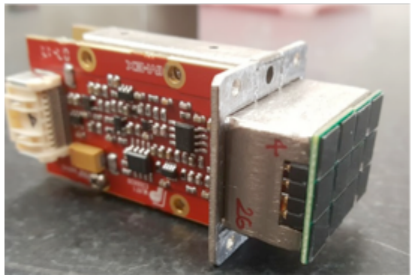
Mu2e crystal calorimeter

- 2 disks; each disk contains 678 undoped CsI crystals 20 x 3.4 x 3.4 cm^3
- Disk separation ~ 75 cm
- Inner/outer radii: 37.4/66 cm
- **Crystal choice:** undoped CsI provides
  - light yield (LY) > 100 pe/MeV
  - longitudinal response uniformity < 10%
  - emission decay time τ ~ 16 ns
- **Photosensor choice:** custom array 2x3 of 6x6 mm^2 UV-extended SiPM



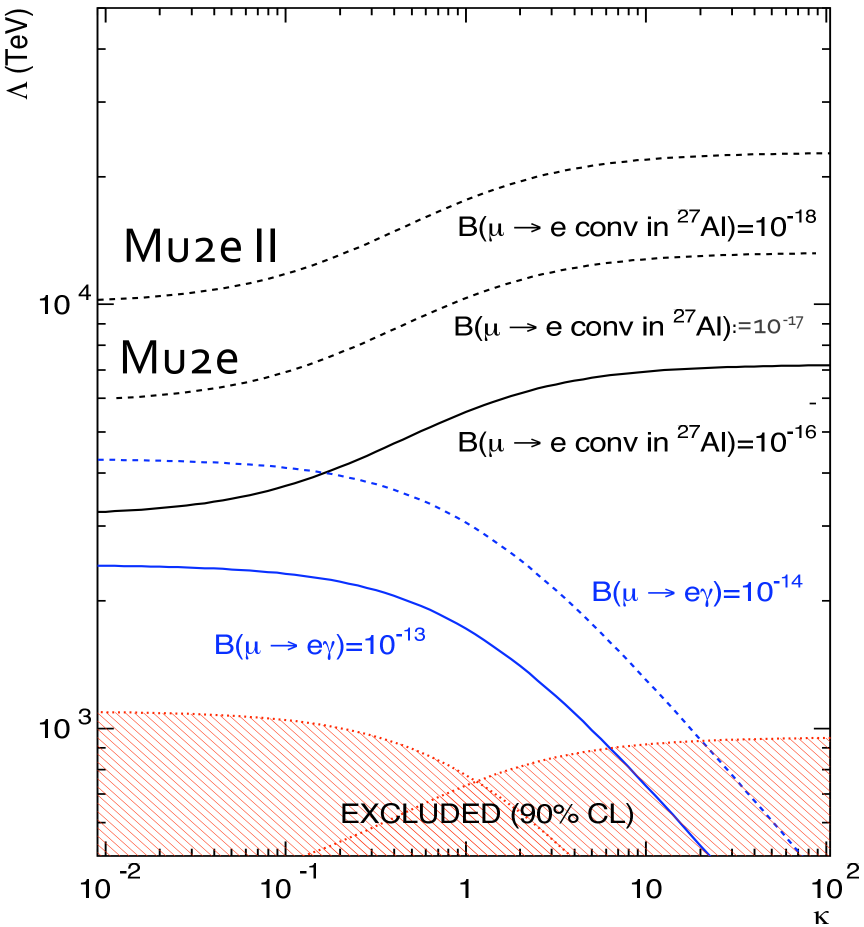
undoped CsI

SiPM array + FEE



Mu2e experiment: the future

- Plan the next generation of precision experiments at Fermilab
  - Develop requirements for a Mu2e-II experiment that further explores charged lepton flavor violation by utilizing planned upgrades to the Fermilab accelerator complex as input to the PIP-II program
  - PIP-II will provide ~ x10 intensity in the beam



Upgraded calorimeter for Mu2e II

	LSO/LYSO	GSO	YSO	CsI	BaF_2	CeF_3	$CeBr_3$	$LaCl_3$	$LaBr_3$	Plastic scintillator (BC 404) [1]
Density (g/cm^3)	7.4	6.71	4.44	4.51	4.89	6.16	5.23	3.86	5.29	1.03
Melting point (°C)	2050	1950	1980	621	1280	1460	722	858	783	70[#]
Radiation Length (cm)	1.14	1.38	3.11	1.86	2.03	1.7	1.96	2.81	1.88	42.54
Molière Radius (cm)	2.07	2.23	2.93	3.57	3.1	2.41	2.97	3.71	2.85	9.59
Interaction Length (cm)	20.9	22.2	27.9	39.3	30.7	23.2	31.5	37.6	30.4	78.8
Z value	64.8	57.9	33.3	54	51.6	50.8	45.6	47.3	45.6	5.82
dE/dX (MeV/cm)	9.55	8.88	6.56	5.56	6.52	8.42	6.65	5.27	6.9	2.02
Emission Peak[a] (nm)	420	430	420	420 310	300 220	340 300	371	335	356	408
Refractive Index[b]	1.82	1.85	1.8	1.95	1.5	1.62	1.9	1.9	1.9	1.58
Relative Light Yield[a,c]	100	45	76	4.2 1.3	42 4.8	8.6	99	15 49	153	35
Decay Time[a] (ns)	40	73	60	30 6	650 0.9	30	17	570 24	20	1.8
d(LY)/dT [d] (%/°C)	-0.2	-0.4	-0.1	-1.4	-1.9 0.1	~0	-0.1	0.1	0.2	~0

a. Top line: slow component, bottom line: fast component.

b. At the wavelength of the emission maximum.

c. Relative light yield normalized to the light yield of LSO

d. At room temperature (20°C)

#. Softening point

1. http://www.detectors.saint-gobain.com/Plastic-Scintillator.aspx

http://pdg.lbl.gov/2008/AtomicNuclearProperties/HTML_PAGES/216.html

The sub-ns fast scintillation in BaF_2 promises a very fast crystal calorimeter to face the challenge of high event rate expected by future HEP experiments at the intensity frontier

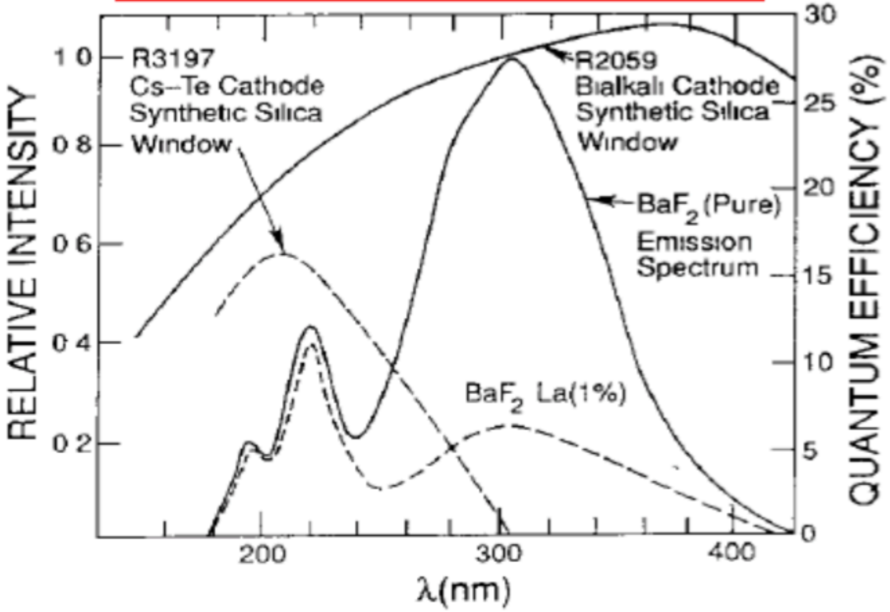
Solar-blind, rad hard SiPM

- The ideal photo-sensor should provide:
  - high quantum efficiency @ 220 nm and be blind for larger
  - Capability to sustain up to 50 krad and 10^{12} n/cm$^2_{1MeV}$

NEWS contribute:

- Develop a SiPM with:
  - enhanced QE in the deep-UV region
  - Thin anti-reflecting coating to provide solar blindness property
  - Rad hard

R. Y. Zhu, "On Quality Requirements to the Barium Fluoride-Crystals," *Nucl Instrum Meth A*, vol. 340, pp. 442-457, Mar 8 1994



Summary

- The FNAL Muon Campus will host two world leading experiments: Muon *g*-2 and Mu2e
- Both the experiments are very fascinating and will produce excellent physics results over the next few years
- NEWS WP-6 will provide a leading contribution on both experiments