μ- Running in Muon g-2

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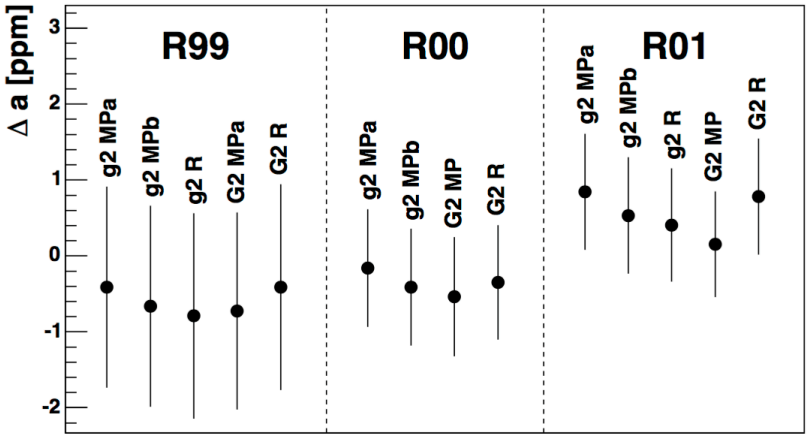
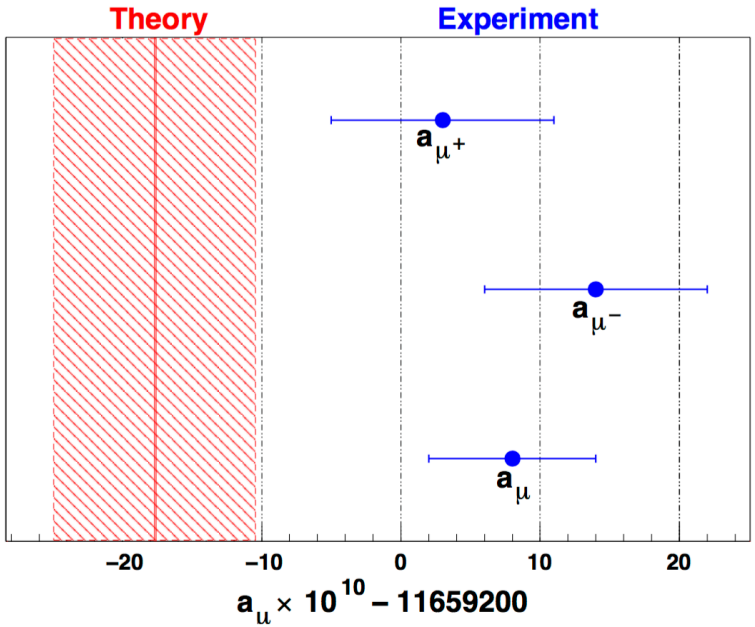
4 April 2017

Muon g-2

Running μ-

- BNL experiment was able to run μ- with a matched sensitivity to μ+
- FNAL experiment only approved to run μ+
  - Complicated by x2.5 reduction in π- relative to π+
- Good reasons to propose a μ- era of running
  - Still have no idea of the origin of the matter/anti-matter asymmetry → generally good to have precision experiments of both charge species whenever possible
  - Capitalizes on $100M invested in ability to measure g-2 at FNAL
  - Muon g-2 in Japan cannot run μ-
- An equivalent statistics μ- run would reduce overall error on a_μ by 15-40% depending on how well systematics are controlled





*Outdated (thy error reduced by 20-30%)

CPT analyses enable by running μ-

- Having μ- enables 3 types of CPT analyses to be completed
  - Comparison of $a_{\mu-}$ to $a_{\mu+}$
    - In Kostelecky's formalism, constrains b_Z term for muons
    - Would expect this to improve by a factor of 4 compared to BNL (equally matched μ- error)

$$b_Z^{\mu} = -(1.0 \pm 1.1) \times 10^{-23}\ \text{GeV}$$

*X. Huang thesis

  - Sidereal analysis
    - Sidereal day 4 minutes shorter
    - Will improve by better than sqrt(n) due to running 10 months out of year compared to 3 months at BNL

95% CL upper limit

$$\check{b}_{\perp}^{\mu^-} = 2.6 \times 10^{-24}\ \text{GeV}.$$
$$\check{b}_{\perp}^{\mu^+} = 1.4 \times 10^{-24}\ \text{GeV}.$$

*X. Huang thesis

  - Annual variation (TMK never done before due to BNL runs always being at same time of year)

- Trackers also open door for similar EDM analyses

Proton planning

μ- opportunity

		FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	
LBNF/PIP II	LBNF/PIP II							LBNF	LBNF	LBNF / PIP II			
	SANFORD						DUNE	DUNE	DUNE	DUNE	DUNE	DUNE	
NuMI	MI	MINOS+	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN			ν
		MINERvA	MINERvA	MINERvA	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN			
		NOvA	NOvA	NOvA	NOvA	NOvA	NOvA						
BNB	B	μBooNE	μBooNE	μBooNE	μBooNE	μBooNE	μBooNE					OPEN	
			ICARUS	ICARUS	ICAR US	ICARUS	ICARUS	ICARUS				OPEN	
			SBND	SBND	SBND	SBND	SBND	SBND				OPEN	
Muon Campus		g-2	g-2	g-2	g-2								μ
		Mu2e	Mu2e	Mu2e	Mu2e	Mu2e	Mu2e	Mu 2e	Mu2e	Mu2e		Mu2e	
SY 120	MT	FTBF	FTBF	FTBF	FTBF	FTBF	FTBF	FTBF	FTBF	FTBF		FTBF	p
	MC	FTBF	FTBF	FTBF	FTBF	FTBF	FTBF	FTBF	FTBF	FTBF		FTBF	
	NM4	SeaQuest	SeaQuest	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN		OPEN	
		FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	

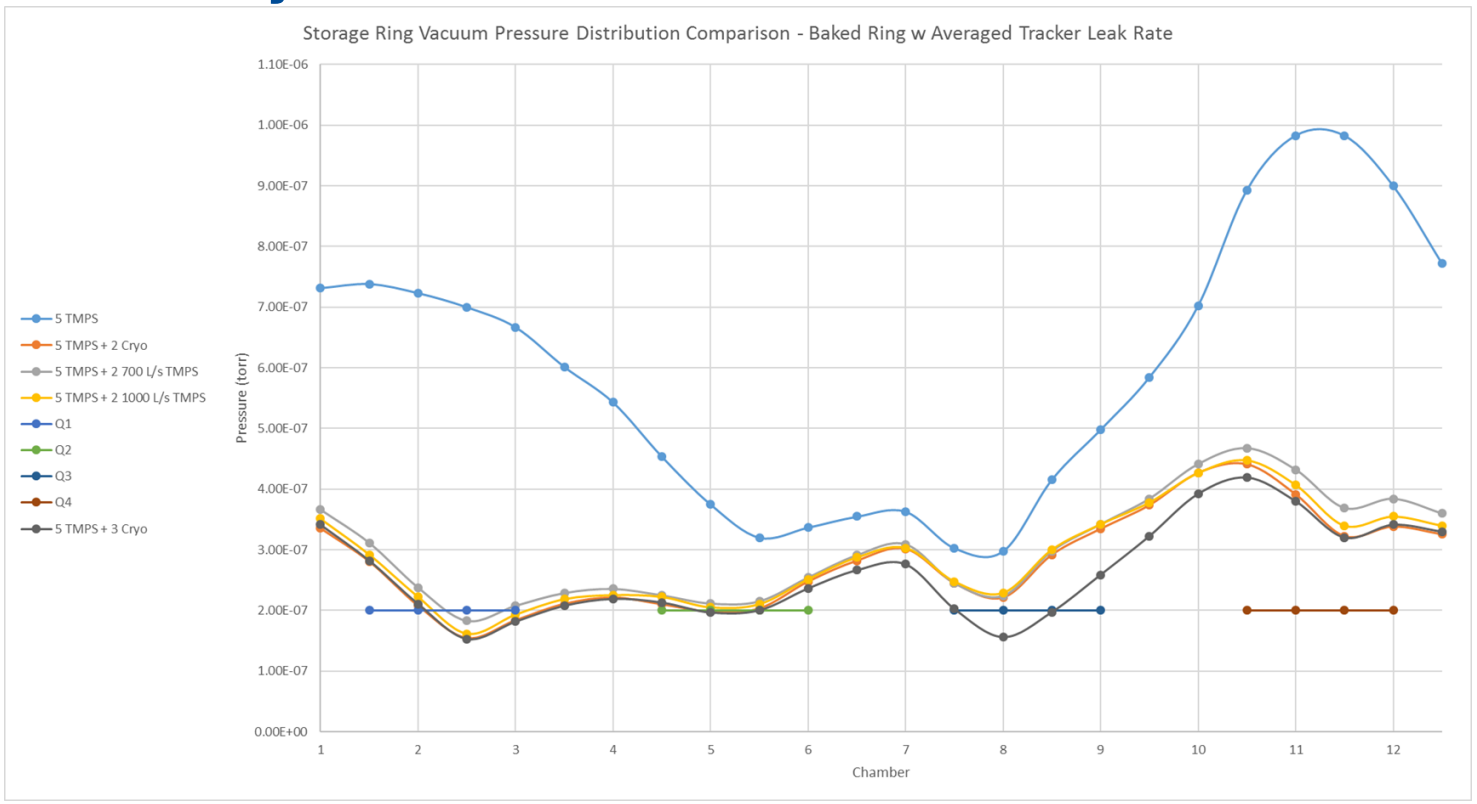
Summer shutdown | Construction / commissioning | Run | Extended running possible

- Opportunity to propose μ- in FY20-22, has to be coordinated with Mu2e start-up
  - Good for the lab to have a strong g-2 collaboration supporting the lab as users
  - Good for the field to have measurement of g-2 for μ-
  - Good for the agency to capitalize on the $100M investment in the Muon Campus and Muon g-2
- Simulation projects 5 weeks of μ- running to surpass BNL, 24 months to match μ+
  - New inflector reduces runtime by 33%

Switching to μ-

- Have to switch polarity of AP0 Target, Muon Campus Beamlines, and Delivery Ring
  - ~2 weeks to complete
  - Have had past experience with proton tune-up during pbar days
- Switch polarity of main ring
  - Have to run magnet through a few cycles to remove hysteresis
  - Done before at BNL with field uniformity unaffected
- Switch polarity of electrostatic quadrupoles
  - Easy to implement, but requires vacuum to improve from low 10e-6 to low 10e-7 Torr due to increased electron trapping
- Switch polarity of electromagnetic kickers
  - Can do it by brute force, but Cornell looking into more elegant switching mechanism

Vacuum analysis



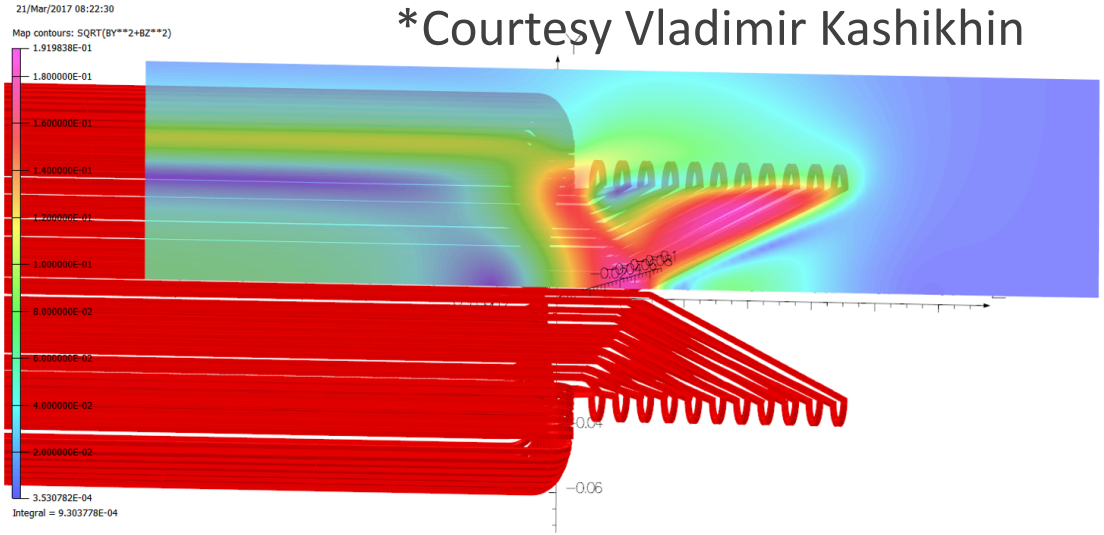
- Adding 2 more TMPs gets us to the spec
- Depends critically on actual measured outgassing rate of trackers
  - Project ordering 2 more TMPs to mitigate risk
- Can also choose to run a lower quad voltage as fallback solution

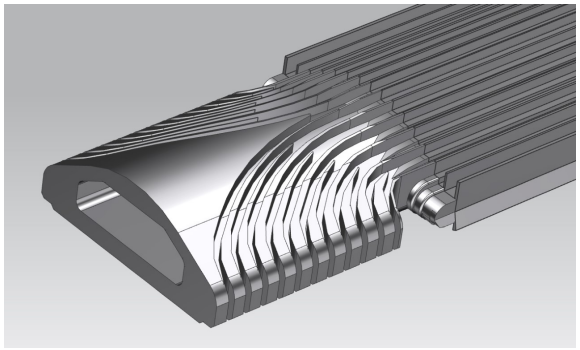
New inflector plan

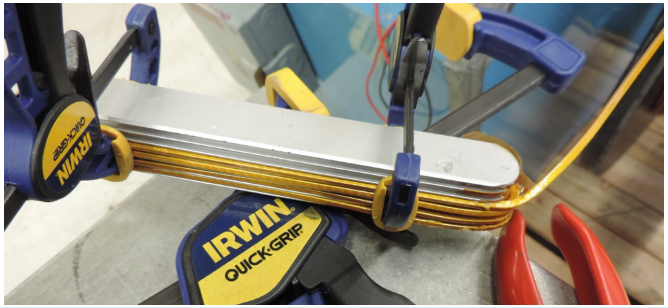
- We have already obligated nearly all $ for the parts
  - Mandrels, Al case recycled from original E821 inflector that failed
    - Also have its superconducting shield although it was thinner
  - Superconducting shield entering final fabrication steps in Japan
  - Last of the ASTROMAG conductor received (thanks Akira!)
  - New (open-wound) end pieces set to be ordered next week
  - Cable insulating machine and winding table nearly ready
- All told we have invested $620k to get to this point (+$80k from operations to buy/process the last of the NbTi/Cu shield material)
- Have spent the last month revisiting the cost estimate and schedule to produce a new cold mass
  - Several iterations with engineer, cost estimate reviewed and blessed by TD upper management
- $250k total
  - $225k in remaining labor
  - $25k in M&S
  - Engineering estimates have a 40% estimate uncertainty
- Approval received last week to proceed with first $95k of construction

Technical details

*Courtesy Vladimir Kashikhin

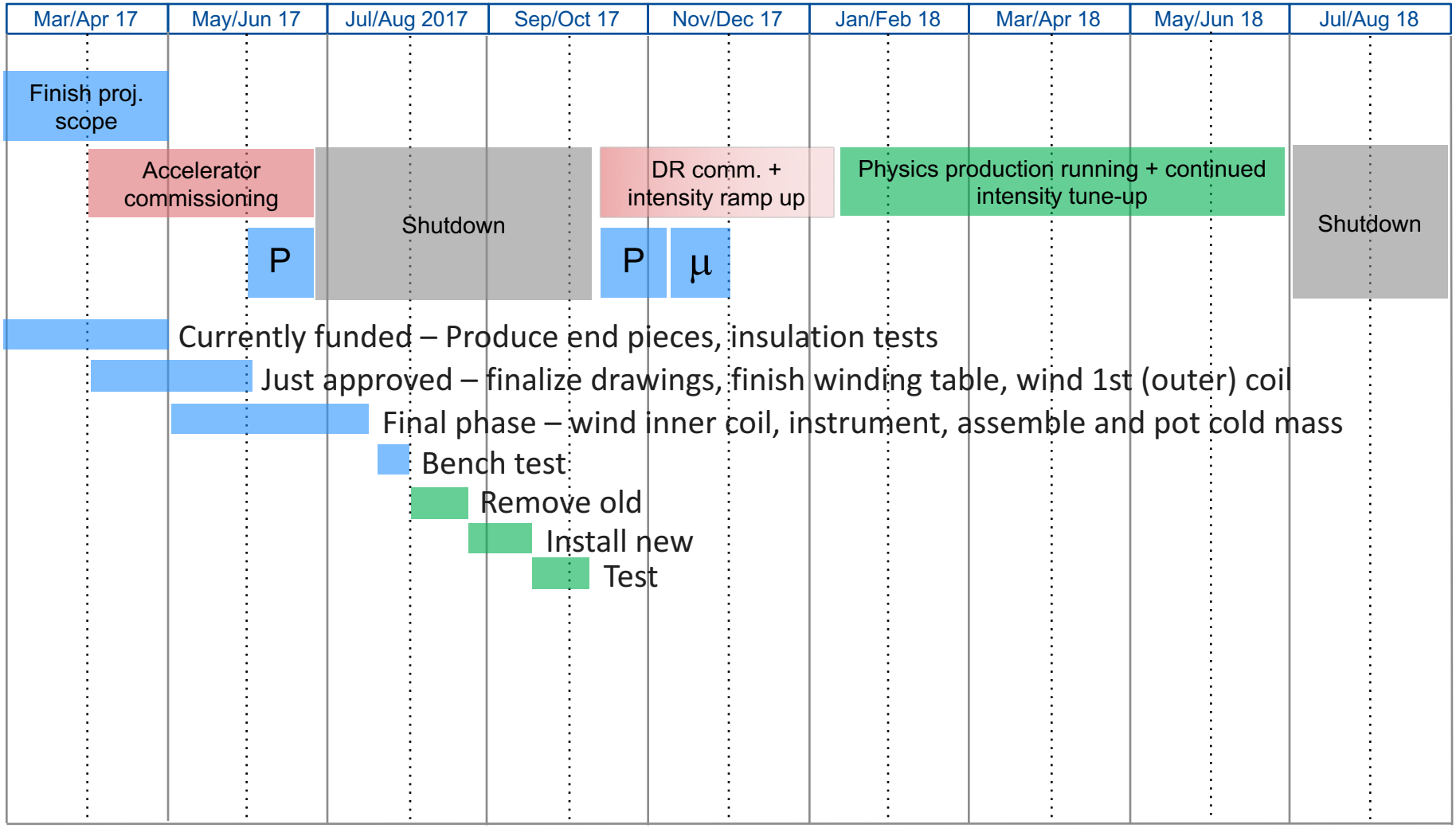






- New model addresses technical committee concerns
  - Single wrap mitigates risk of insufficient cooling
  - Reusing ASTROMAG superconductor w/ Kapton wrap addresses insulation concerns
- Performance is outstanding with 0.196T peak stray field on NbTi/Cu shield
  - Better than last design and currently installed inflector that leak 0.25T
  - Predict 340 A/mm2 peak currents, vendor specs critical current at 1200 A/mm2 (1.5T,4.2K)
  - Retains open channel for 50% increase in storage efficiency

Schedule overlay



Conclusion

- Adding a μ- run for Muon g-2 is a compelling addition to the science program
  - Capitalize on large investment in Muon Campus and Muon g-2
  - Unique capability at Fermilab
  - Supports a strong user base from the collaboration who would continue to collect μ- data and publish many more CPT-related results
- Will likely make a proposal to PAC later in FY18 once the μ+ rates have been confirmed
  - Anything we can do to improve muons to the storage ring throughout the μ+ running helps μ- proposal to overcome x2.5 reduction in pions from target
  - Still surpass BNL μ- result in 5 weeks of running
- Project is doing our best to set the stage to enable this opportunity
  - New inflector is biggest gain in muons stored
  - Adding additional pumping capacity
  - Looking into polarity switch for kickers