Mu2e Accelerator and Cryo Needs

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Muon Campus Review

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Outline

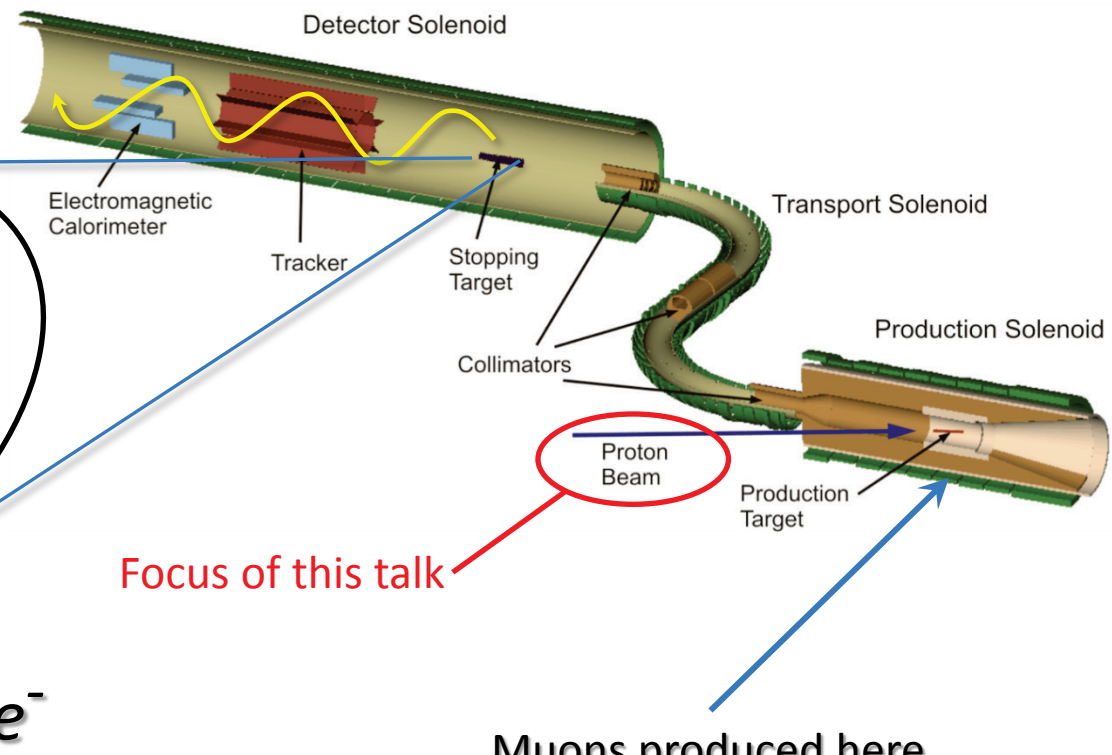
- Overview of the Mu2e Experiment
- Accelerator Configuration for Mu2e
- Beam longitudinal structure
- Transport & Delivery Ring Requirements
- Mu2e Cryo Requirements
- Mu2e Schedule – Installation and Commissioning
- Conclusions

MU2E OVERVIEW

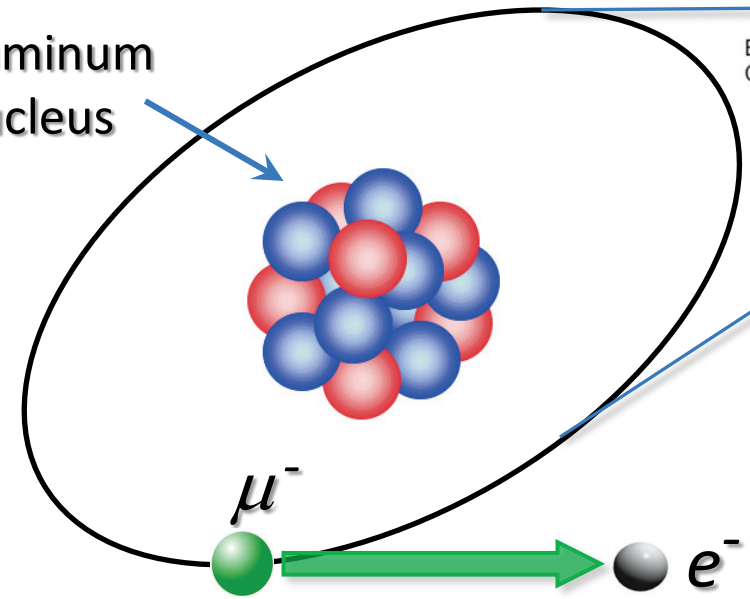
One-Slide Synopsis of Mu2e

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

Stop muons in an aluminum target



Aluminum Nucleus



Focus of this talk

Muons produced here

Captured μ^-

M_μ = 105 MeV/c^2

Monoenergetic electron

$E_e \approx$ 105 MeV

ACCELERATOR CONFIGURATION FOR MU2E

Use of Accelerator Facilities for Mu2e

Recycler Ring:

- 2.5 MHz re-bunching
- Single bunch extraction

Delivery Ring:

- Synchronous capture from Recycler RF
- Resonant extraction
- Beam abort

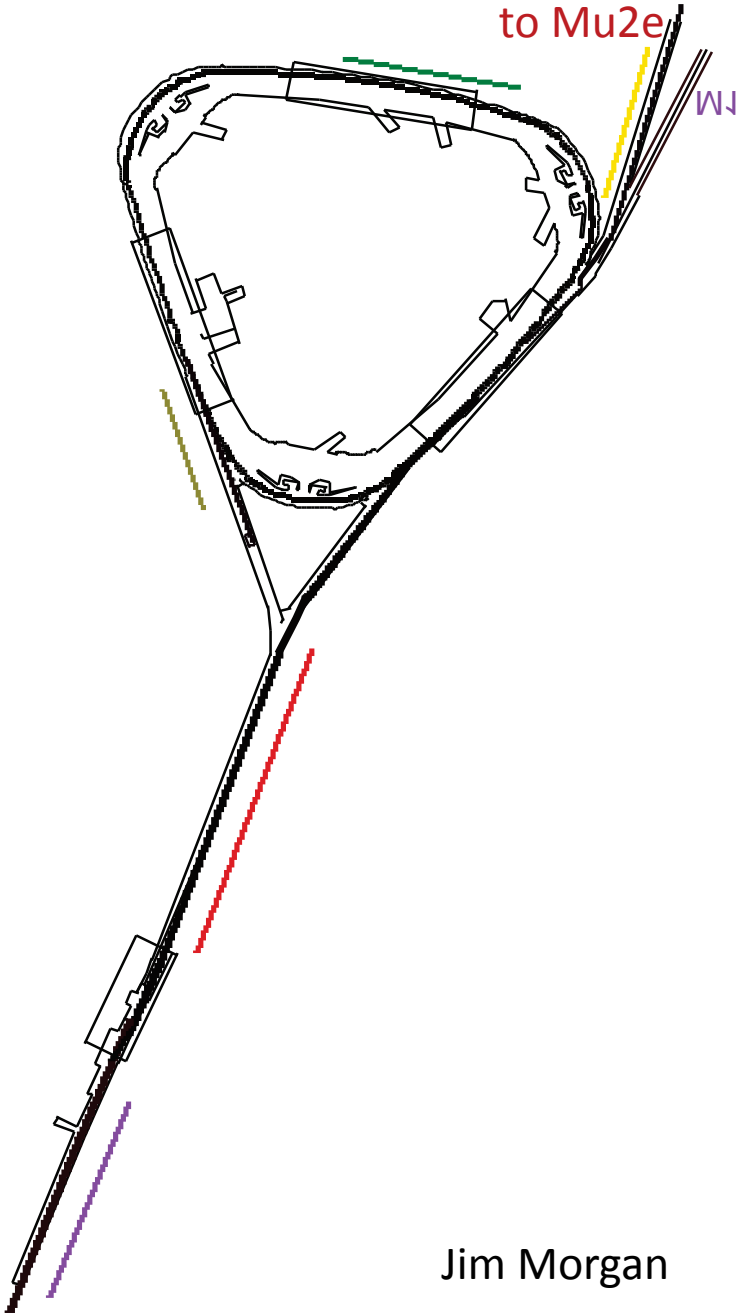
External (M4) Beamline:

- Extinction
- Final focus onto proton target

Muon Campus Beamlines

Former Antiproton Source beamlines have been renamed:

- M1 = former AP1 line
- M2 ≈ former AP2 line (not used by Mu2e)
- M3 ≈ former AP3 line
- Delivery Ring = former Debuncher Ring
- M4 = new beamline from D30 to Mu2e (g-2)

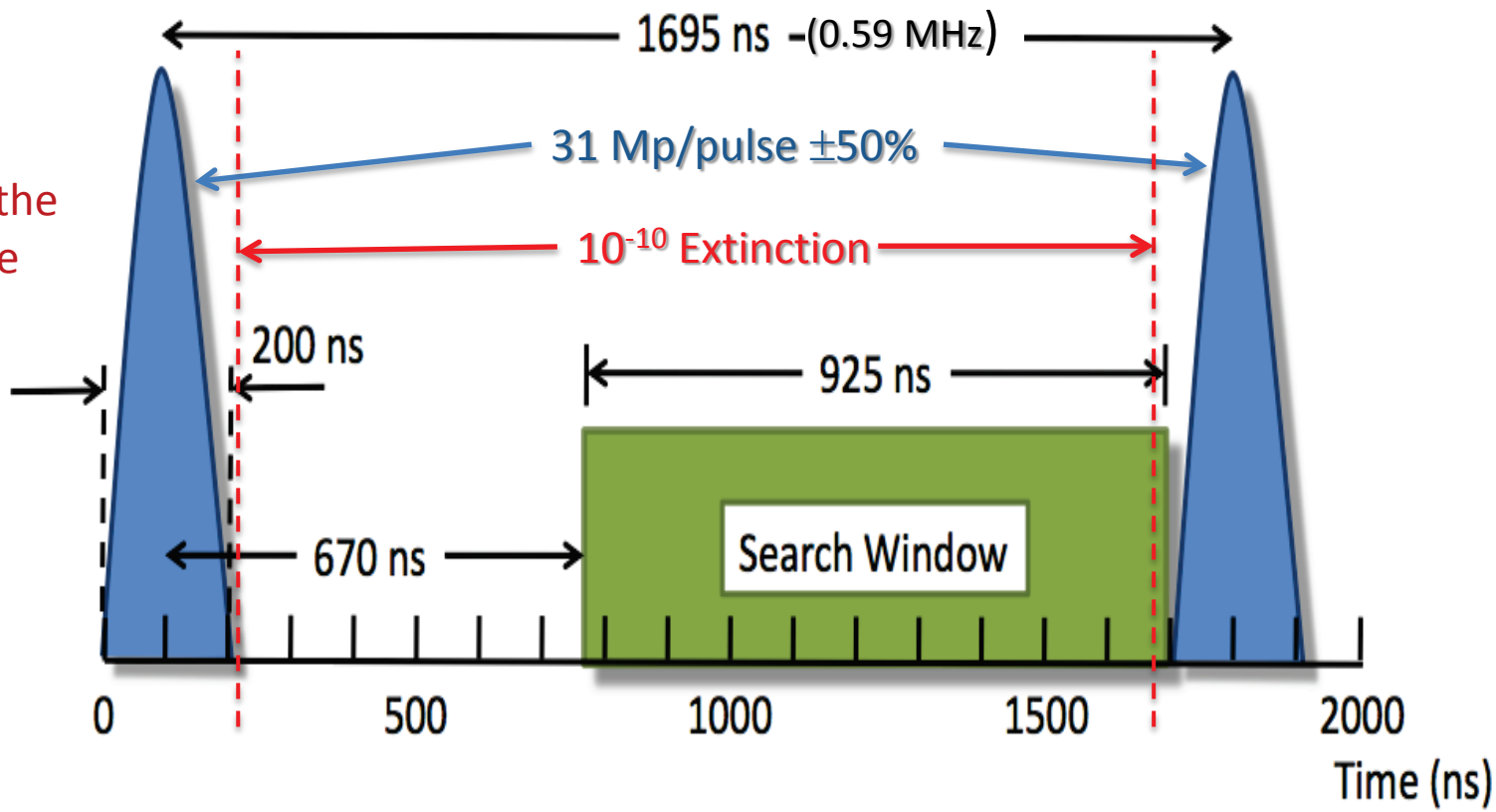


Jim Morgan

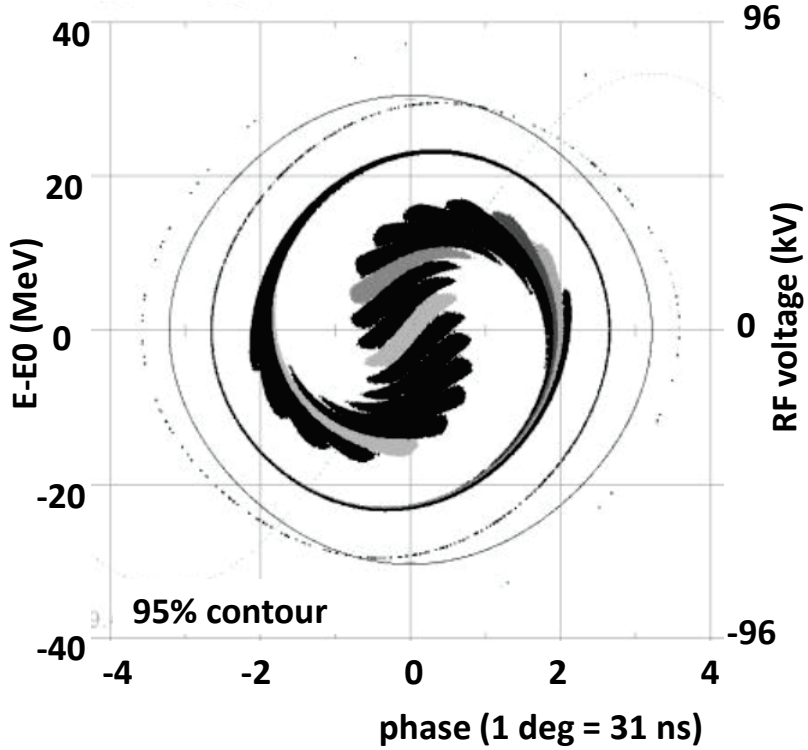
REQUIRED BEAM LONGITUDINAL STRUCTURE

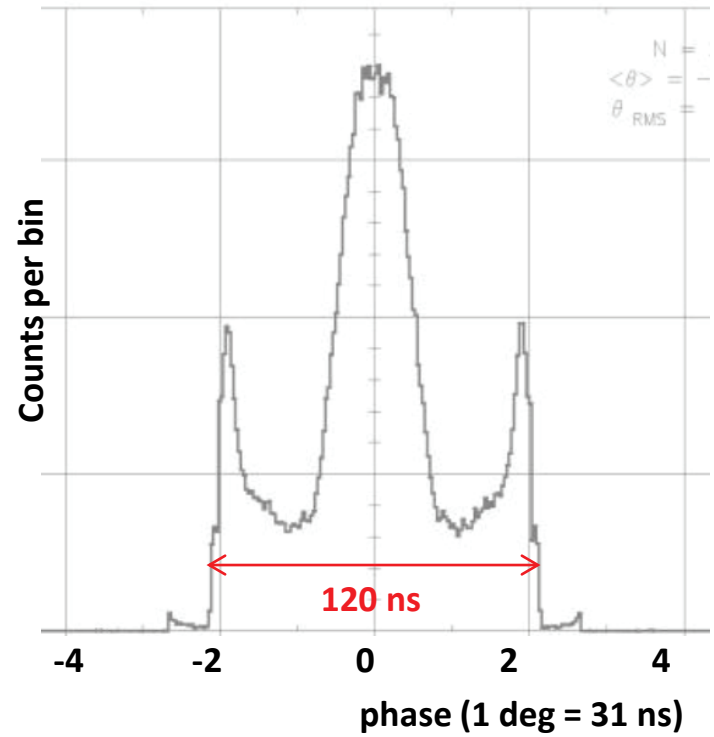
Required Longitudinal Structure of Mu2e Proton Beam

- Bunch width established with Recycler RF
- Bunch spacing is Delivery Ring T_{rev}
- Extinction is accomplished in the external beamline



Recycler 2.5 MHz Re-bunched Beam

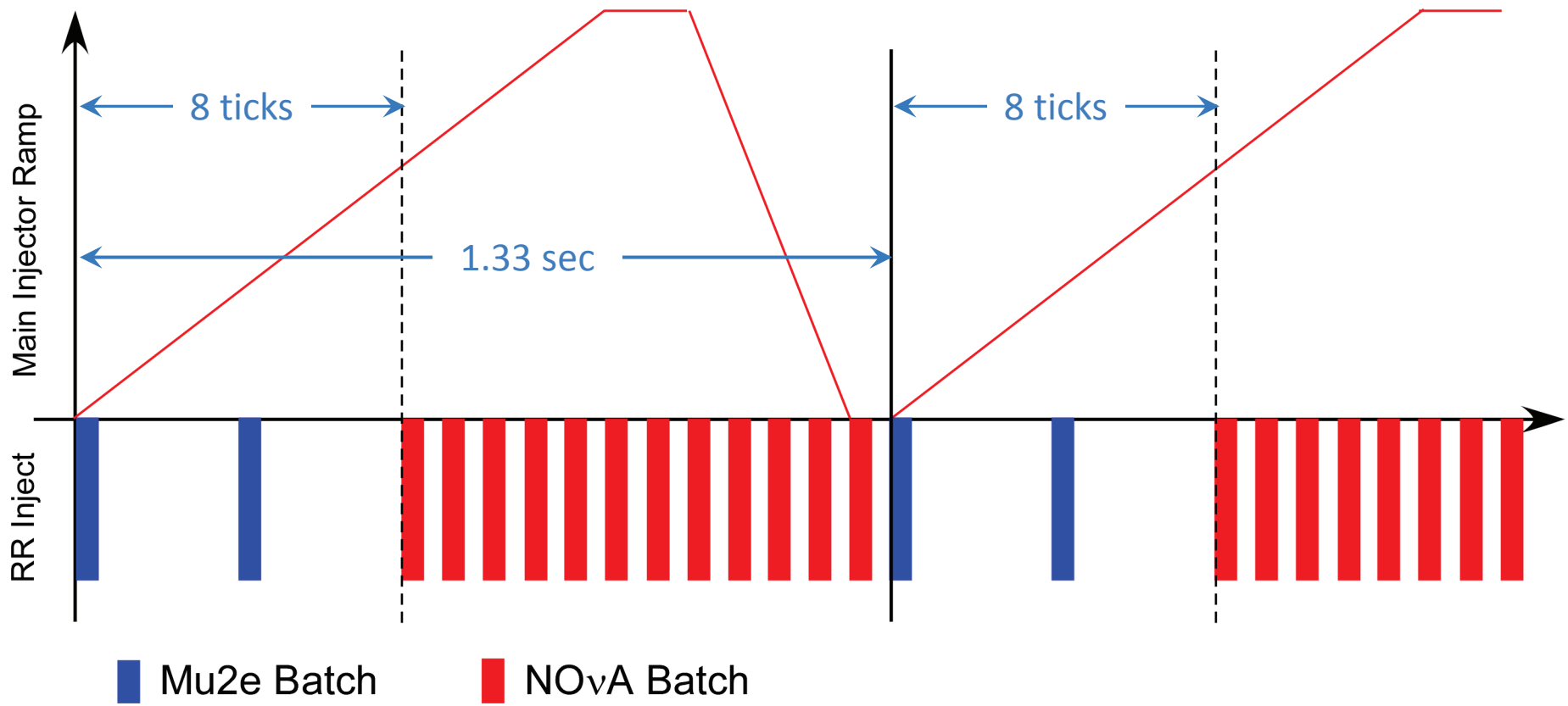




- 95% capture efficiency, 95% of captured beam w/in 120ns
- Mu2e requires full width < 200ns

Ioanis Kourbanis
ESME Simulation

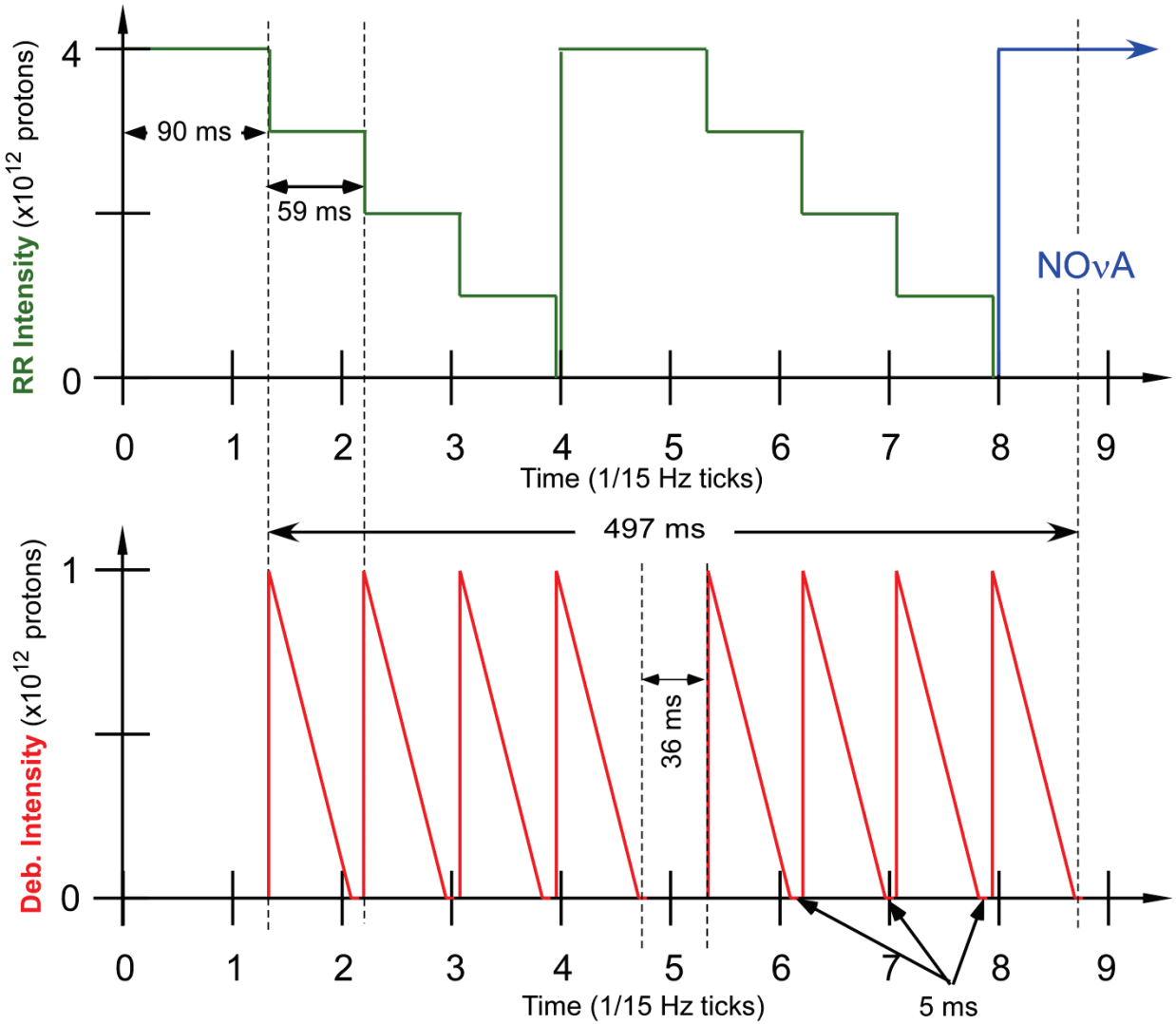
Time-Sequence of Mu2e and NOνA Batches in the Recycler Ring



Note: g-2 uses 4 batches per MI cycle

Beam Intensity vs. Time in RR and DR

- Eight 54 msec spills per MI cycle (17 Hz inst., 6 Hz ave.)
- Instantaneous Rate = 18.5×10^{6} protons/sec to Mu2e target
- Duty Factor = 32%
- Mu2e beam off for 836 msec every MI cycle



TRANSPORT & DELIVERY RING REQUIREMENTS FOR MU2E

Delivery Ring and Transport to Delivery Ring – Summary of Requirements

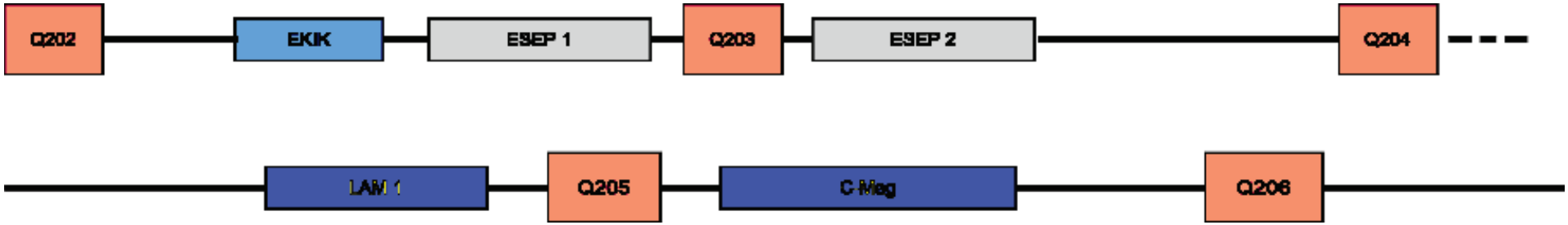
- The Mu2e requirements for beam transport upstream of the AP0 target are the same as those for g-2 (longitudinal and transverse beam sizes are identical).
- The large M3 beamline aperture required for g-2 is more than adequate for Mu2e transport and injection to the Delivery Ring
- The Delivery Ring circulating beam emittance during resonant extraction is 34 π mm-mrad (un-normalized). This is within the 40 π mm-mrad admittance of the Delivery Ring
- The emittance of Mu2e extracted beam is 1 π mm-mrad (un-normalized), which is much smaller than g-2 extracted beam.
- Mu2e also requires the ability to single-turn extract proton beam for external beamline commissioning and studies. The g-2 extraction kickers are used for this purpose and are expected to be effective for 8.9 GeV/c proton beam.
- The details of the Delivery Ring and injection and extraction will be given in Jim Morgan's Beamlines talk

Beam Parameters and Requirements: (evaluated at Delivery Ring Injection)

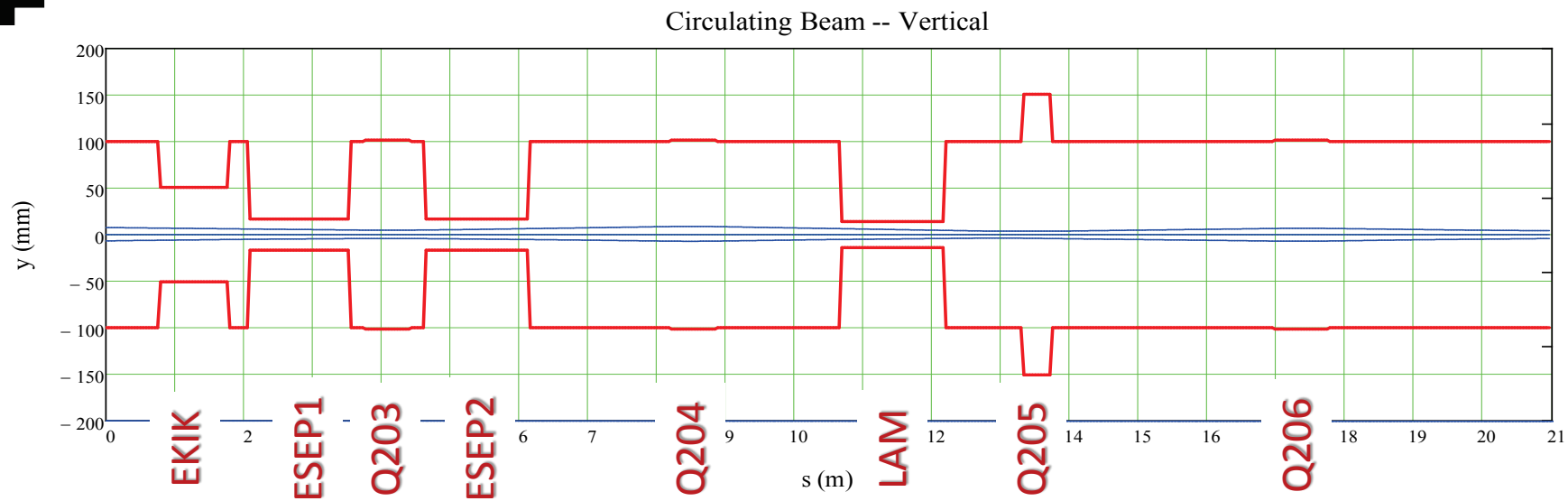
Parameter	Value	Requirement	Source of Requirement
Beam Momentum	8.889 GeV/c	8.889 GeV/c	
Bunch Length (Full Width)	120 nsec	< 200 nsec	Required to reduce Mu2e backgrounds
$\Delta p/p$ (Base Width)	$\pm$0.28%	$\pm$2%	Delivery Ring Momentum Aperture
Horizontal Emittance	15 π mm-mrad	< 379 π mm-mrad	Delivery Ring Admittance
Vertical Emittance	15 π mm-mrad	< 379 π mm-mrad	Delivery Ring Admittance
Intensity	1×10^{12} protons/bunch	--	
Beam Power	8 kW	8 kW	

Delivery Ring Extraction for Mu2e

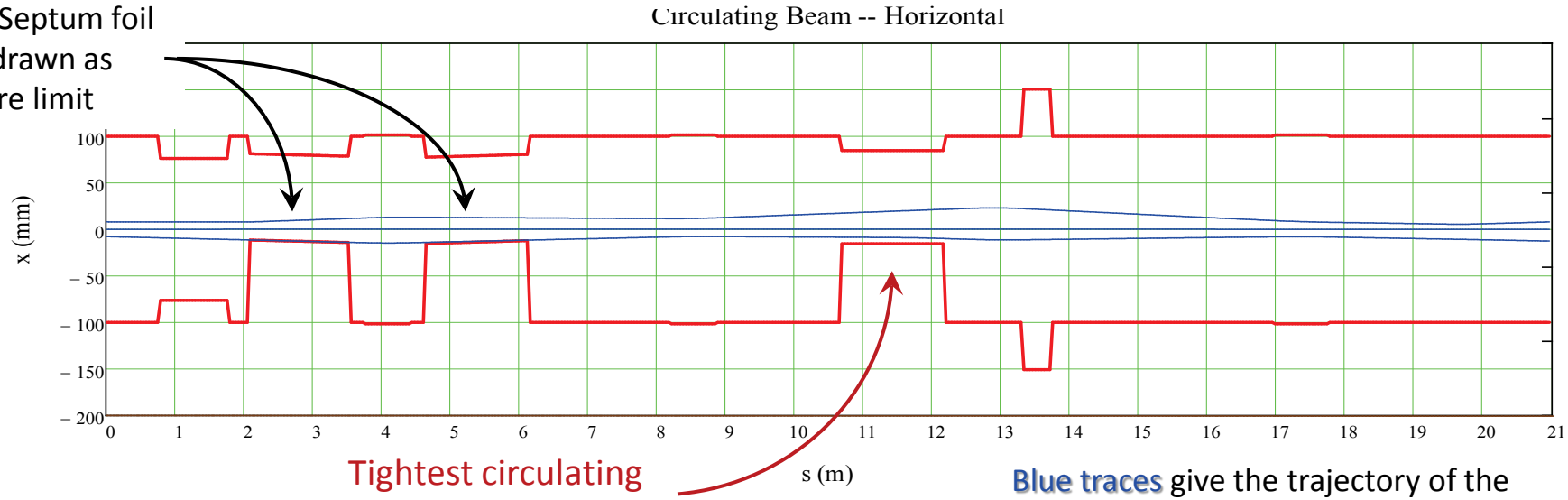
- The next three slides show results of tracking circulating and extraction channel beam during resonant extraction.
- Beam is tracked through the D30 beamline elements shown below.
- The Delivery Ring extraction scheme presently under development appears to be adequate for Mu2e resonantly extracted beam.
- The details of the Delivery Ring extraction will be given in Jim Morgan's Beamlines talk.



Circulating Beam Extraction Aperture



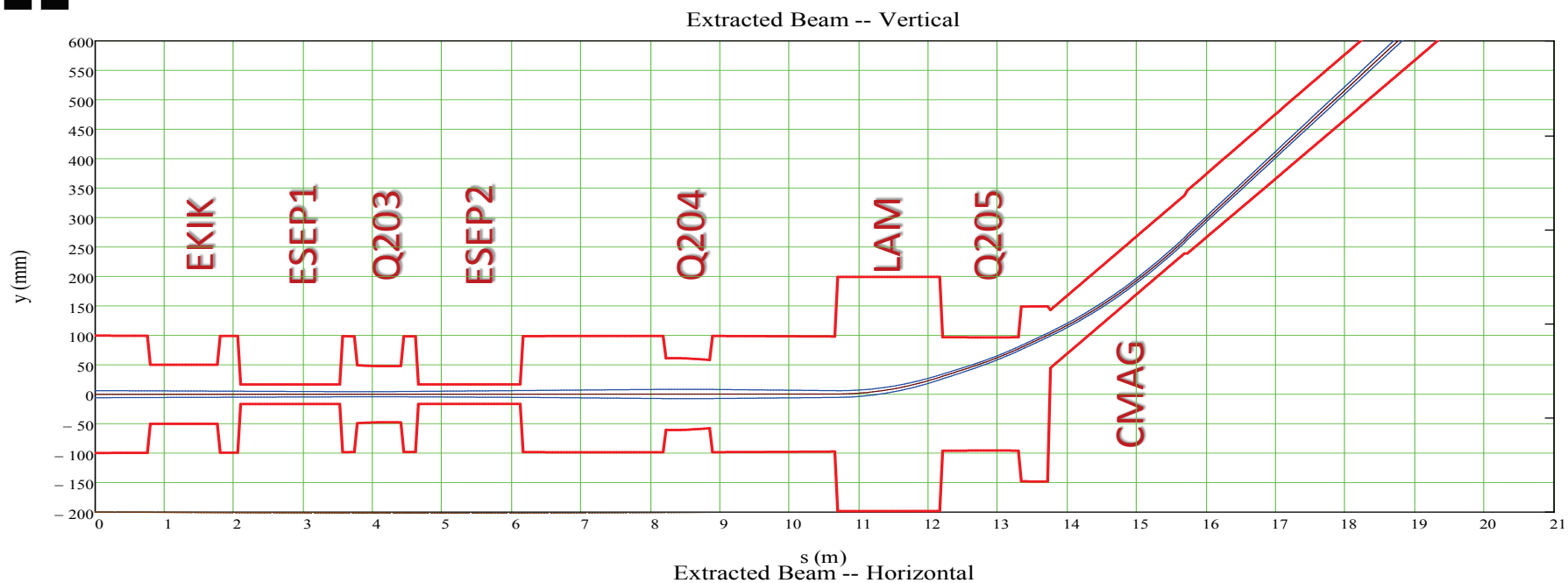
NOTE: Septum foil plane drawn as aperture limit

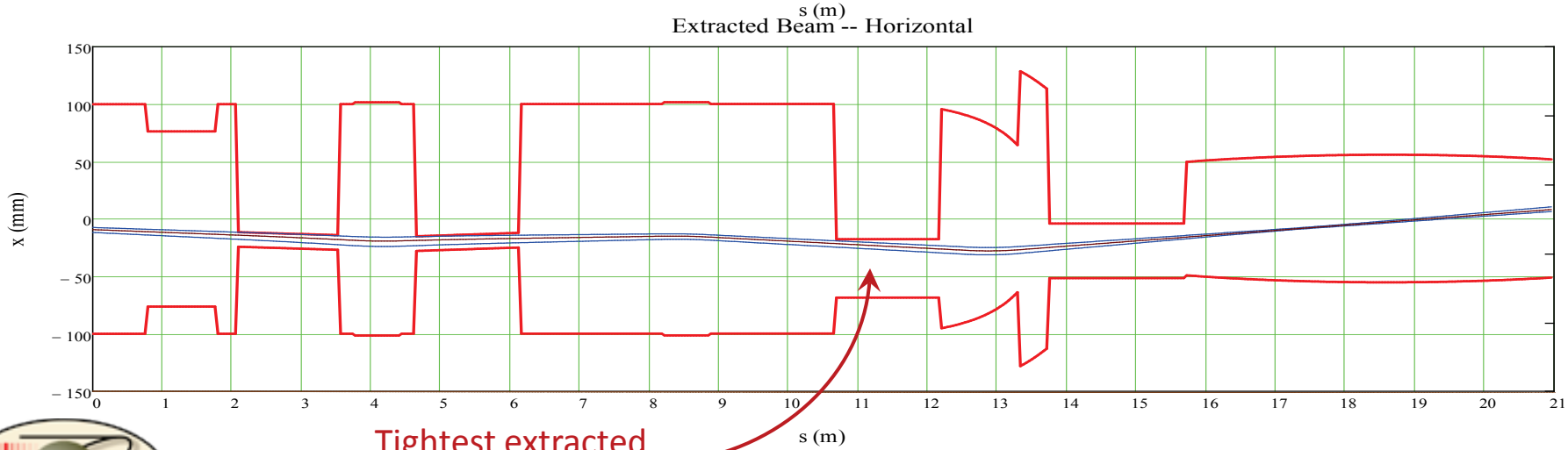


Tightest circulating beam aperture

Blue traces give the trajectory of the min and max amplitude particles

Extracted Beam Apertures

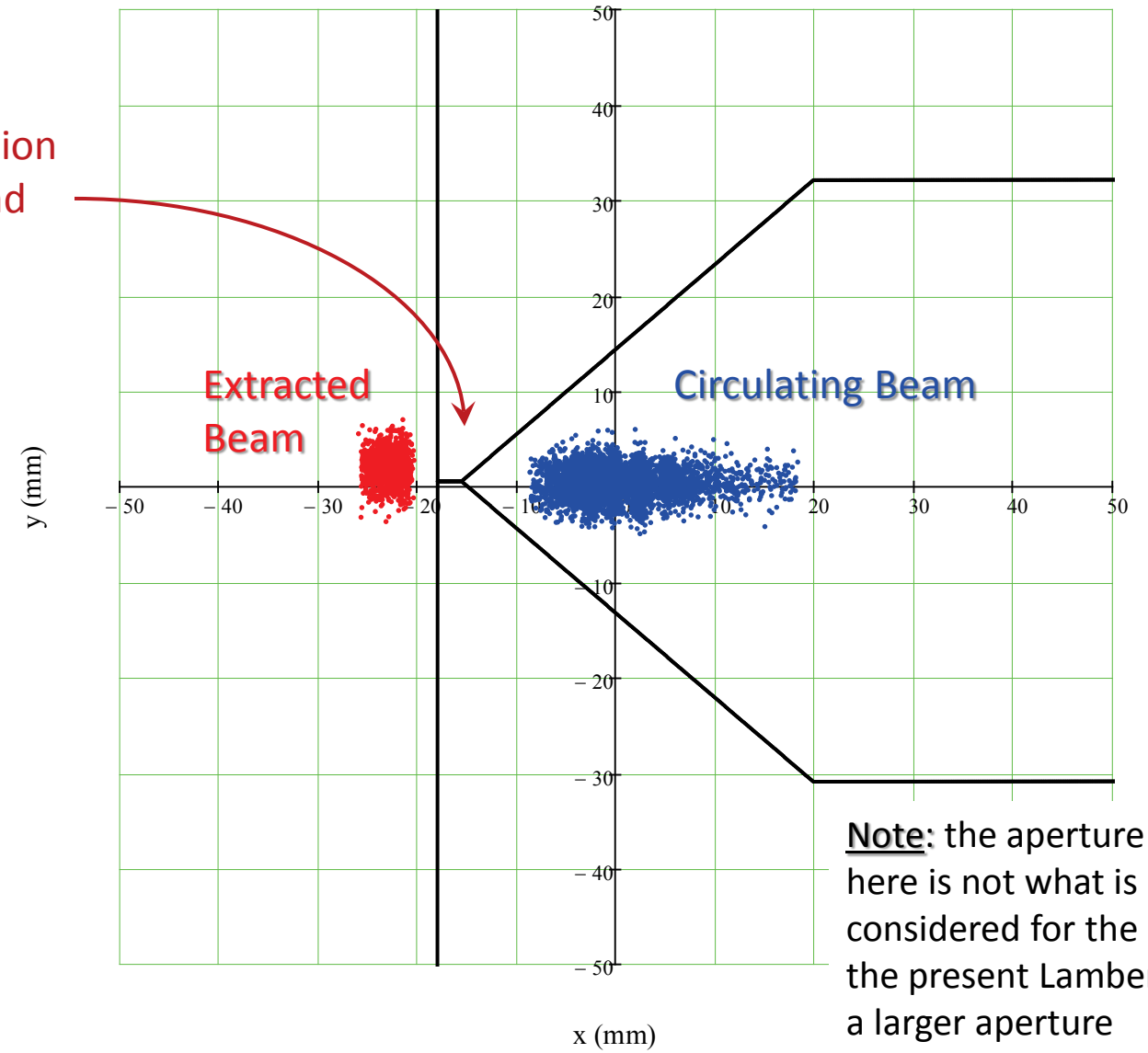




Tightest extracted beam aperture

Extraction Lambertson

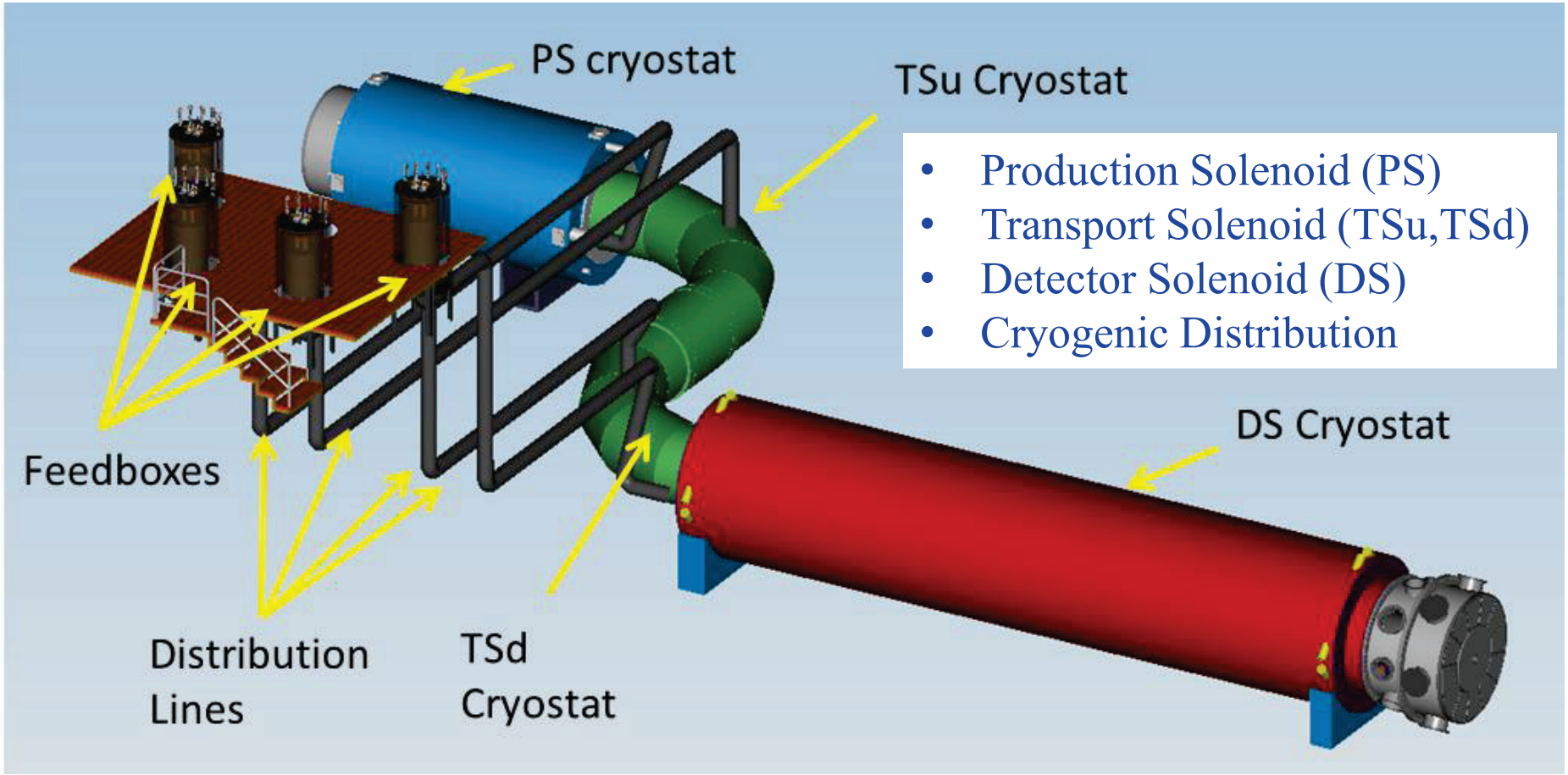
12 mm separation at upstream end of Lambertson



Note: the aperture model used here is not what is presently being considered for the Delivery Ring – the present Lambertson design has a larger aperture

MU2E CRYO REQUIREMENTS

Overview Solenoids/Supporting Infrastructure



- Production Solenoid (PS)
- Transport Solenoid (TSu,TSd)
- Detector Solenoid (DS)
- Cryogenic Distribution

Mike Lamm

Mu2e Cryo Requirements

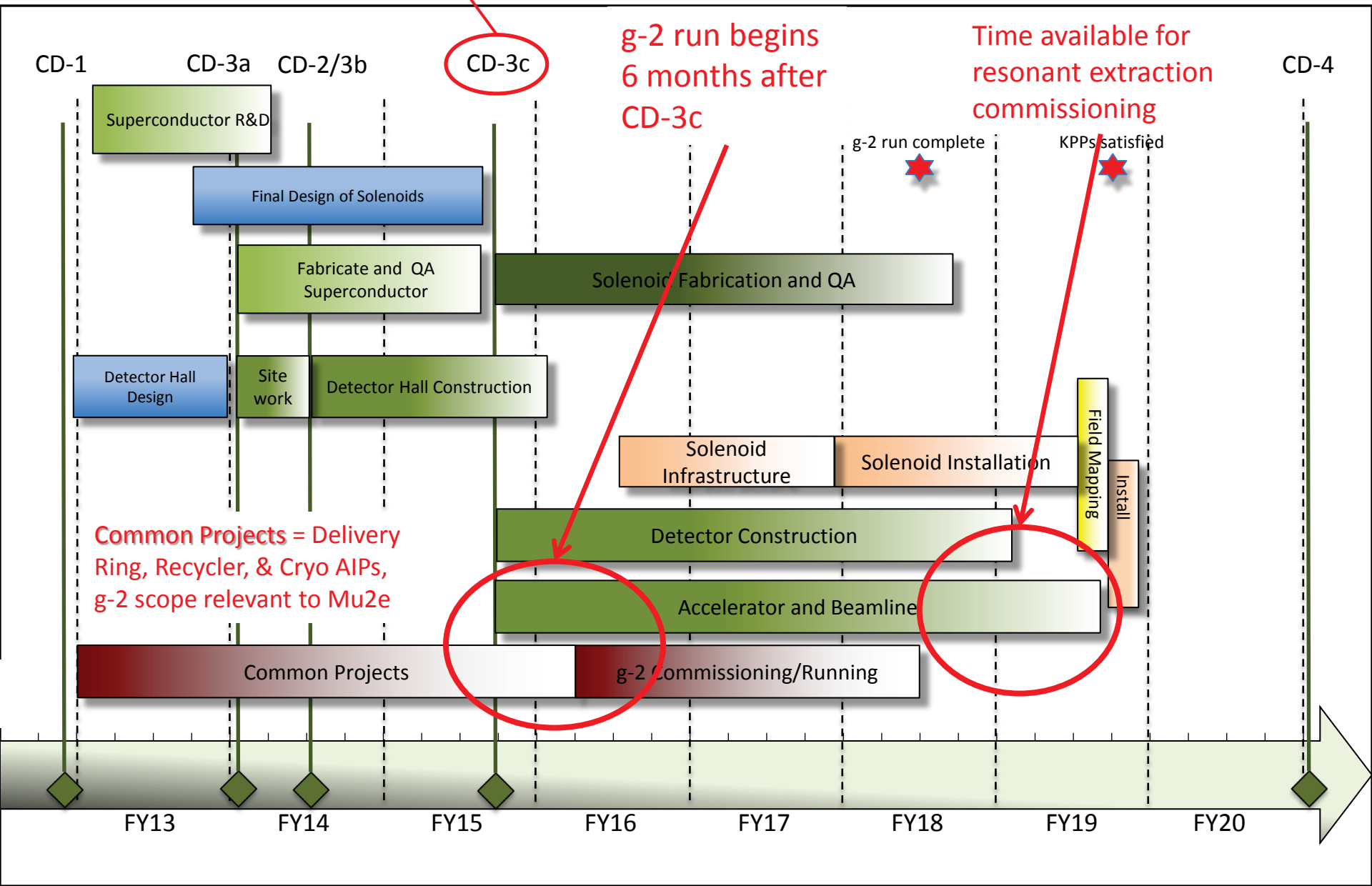
- Mu2e to the refrigerator building (MC1) transfer line with a bayonet can at the refrigerator end and a distribution box at the Mu2e end
- Mu2e Maximum cryogenic load:
  - Liquefaction load – 0.48 [g/sec]
  - Refrigeration load – 370 [W]
  - LN2 Shield flow rate – 20 [g/sec]
- Mu2e Operating Parameters (nominal and tolerances):
  - Operating pressures
    - Single phase pressure – $P \geq 13 \pm 1$ [psig]
    - Two phase pressure – $5 \leq P \leq 7$ [psig]
    - LN2 supply pressure – $5 \leq P \leq 10$ [psig]
  - Operating temperatures - at saturation [K]

Tom Page

MU2E SCHEDULE:

DESIGN, CONSTRUCTION, INSTALLATION AND COMMISSIONING

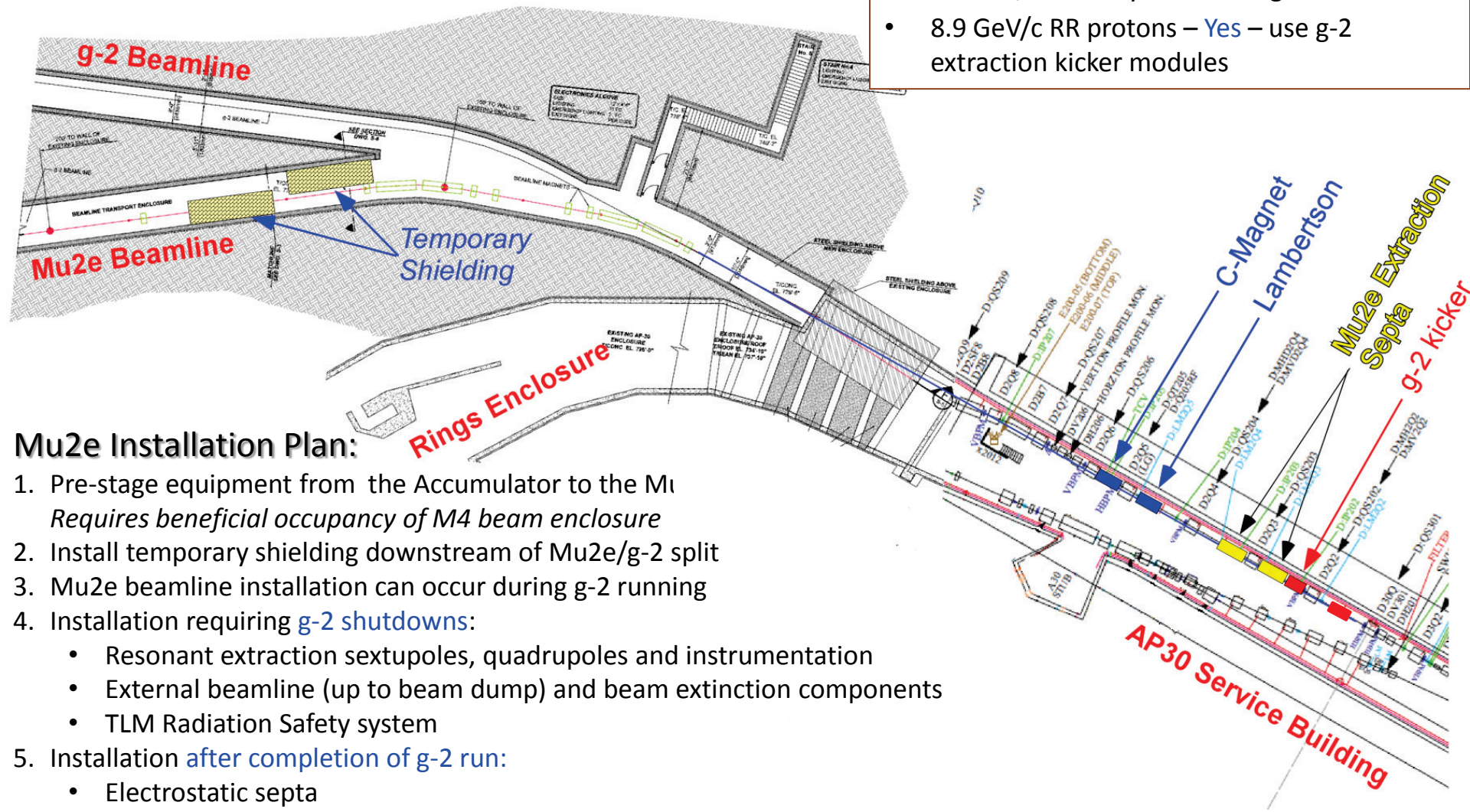
Draft Schedule



Mu2e Installation & Commissioning

What beam used to commission beamline?

- 3.1 GeV/c muons – No, intensity too low
- Resonantly extracted protons – No, intensity too low, not ready soon enough
- 8.9 GeV/c RR protons – Yes – use g-2 extraction kicker modules



Mu2e Installation Plan:

1. Pre-stage equipment from the Accumulator to the Mu
   Requires beneficial occupancy of M4 beam enclosure
2. Install temporary shielding downstream of Mu2e/g-2 split
3. Mu2e beamline installation can occur during g-2 running
4. Installation requiring g-2 shutdowns:
   - Resonant extraction sextupoles, quadrupoles and instrumentation
   - External beamline (up to beam dump) and beam extinction components
   - TLM Radiation Safety system
5. Installation after completion of g-2 run:
   - Electrostatic septa
   - RF cavity
6. Installation of most Target Station components occurs after PS installation

Mu2e Accelerator Commissioning

1. The primary goal of commissioning is to establish the ability to run design intensity beam everywhere with losses well below the Radiation Safety TLM trip limits ➔ This will require a lot of time

2. A second goal of commissioning is to be able to deliver physics quality beam to the Mu2e proton target when the Mu2e detector installation is complete.

Phases of Mu2e Commissioning:

1. Beam loss, TLM, and shielding studies
   - This work has already started using the existing accelerator configuration
   - Should be able to accomplish much of this during the g-2 run

2. Mu2e external (M4) beamline commissioning
   - Set D30 + M3 & M4 beamline elements to 8.9 GeV/c (g-2 runs at 3.1 GeV/c)
   - Delivery ring commissioning requires setting entire ring to 8.9 GeV/c
   - Extract RR protons using g-2 extraction kicker module
   - Requires installation/removal of temporary shielding in M4 line
   - Possible during g-2 run (requires an interruption of beam to g-2)

3. Resonant Extraction commissioning
   - Expect this to be difficult and lengthy (6 months – 1 year)
   - Cannot begin until completion of g-2 run (requires installation of electrostatic septum)

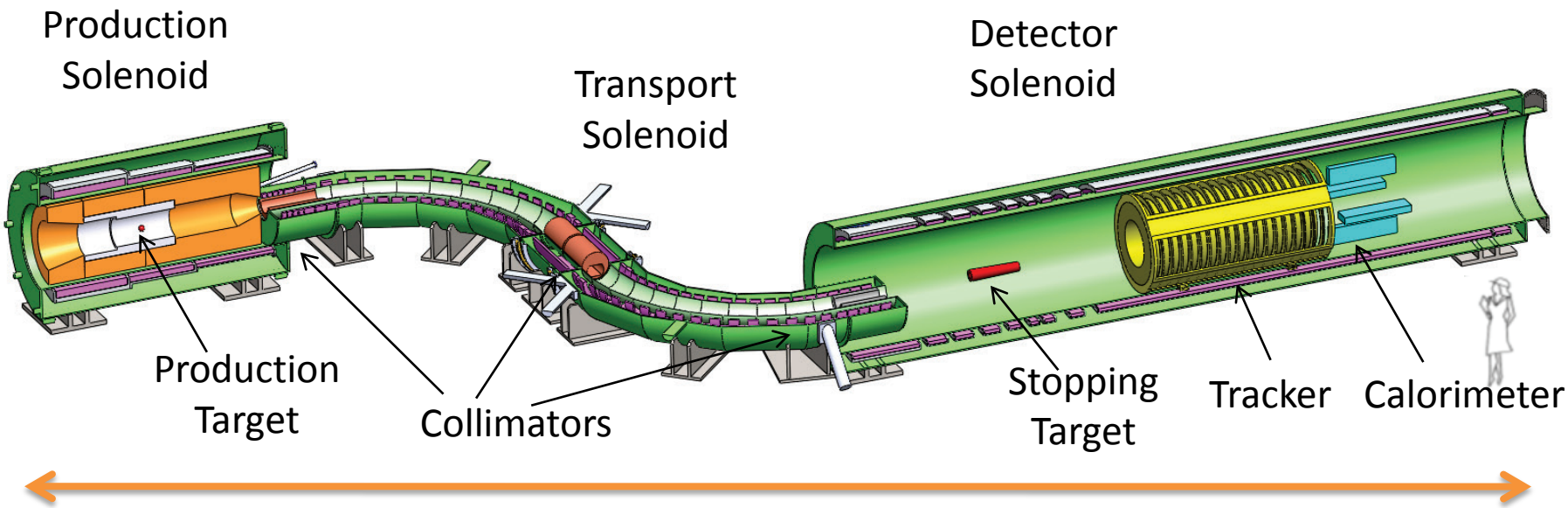
CONCLUSIONS

Conclusions

- Where facilities are shared, g-2 requirements are more stringent than those of Mu2e. Therefore, designing and building to g-2 standards will guarantee that Mu2e requirements are met.
- The present beamline, Delivery Ring, and cryo appear to meet the requirements of Mu2e
- The Mu2e installation and commissioning schedule depends critically on the g-2 running schedule
  - In particular: any delay in the g-2 run will reduce the time available to commission resonant extraction

BACKUP SLIDES

Mu2e Experimental Apparatus



about 75 feet end-to-end

Mike Lamm