Kickoff for the 2nd phase of Muons @ Project-X Physics Study

The Project-X Research Program

- ***Neutrino long-baseline and short-baseline experiments***
- A high-power proton source with proton energies between 8 and 120 GeV would produce intense neutrino beams directed toward near detectors on the Fermilab site and massive detectors at distant underground laboratories.

- ***Kaon, muon, nuclei & neutron precision experiments***
- These could include world leading experiments searching for muon-to-electron conversion and other rare muon processes, nuclear and neutron electron dipole moments (edms) & fundamental physics, and world-leading precision measurements of ultra-rare kaon decays.

- ***Platform for evolution to a Neutrino Factory and Muon Collider***
- Neutrino Factory and Muon-Collider concepts depend critically on developing high intensity proton source technologies.

- ***Nuclear Energy Applications***
- Accelerator, spallation, target and transmutation technology demonstration which could investigate and develop accelerator technologies important to the design of future nuclear waste transmutation systems and future thorium fuel-cycle power systems.

Detailed Discussion: Project-X website

Summary of the Charged Lepton Group of the Intensity Frontier Workshop

1.5 Summary

The enormous physics potential of the charged lepton experimental program was very much in evidence at this Workshop. There are discovery opportunities both in experiments that will be conducted over the coming decade using existing facilities and in more sensitive experiments possible with future facilities such as Project X. Sensitive searches for rare decays of muons and tau leptons, together with precision measurements of their properties will either elucidate the scale and dynamics of flavor generation, or limit the scale of flavor generation to well above 10^4 TeV. This information will be vital to understanding the underlying physics responsible for new particles discovered at the LHC.

The crown jewel of the program is the discovery potential of muon and tau decay experiments searching for charged lepton flavor violation with several orders-of-magnitude improvement in sensitivity in multiple processes. This is an international program, with experiments recently completed, currently running, and soon to be constructed in the United States, Japan, and Europe. The program is very interesting over the near term, with the completion of the now-running MEG experiment at PSI, and with the construction and completion of the Mu2e and COMET experiments at Fermilab and J-PARC, respectively. It will also be substantially improved by new facilities such as the super flavor factories for taus and Project X for muons.

An Incomplete Menu of World Class Research Targets Enabled by Project-X. continued…

Muon Physics:

Possible Day-1 Experiment

- **Next generation muon-to-electron conversion experiment, new techniques for higher sensitivity and/or other nuclei.**
- Next generation $(g\text{-}2)_\mu$ if motivated by next round, theory, LHC. New techniques proposed to JPARC that are beam-power hungry…
- μ edm
- $\mu \rightarrow 3e$
- $\mu^+ e^- \rightarrow \mu^- e^+$
- $\mu^- A \rightarrow \mu^+ A'$; $\mu^- A \rightarrow e^+ A'$; $\mu^- e^- (A) \rightarrow e^- e^- (A)$
- Systematic study of radiative muon capture on nuclei.

Project-X High-Intensity Campus

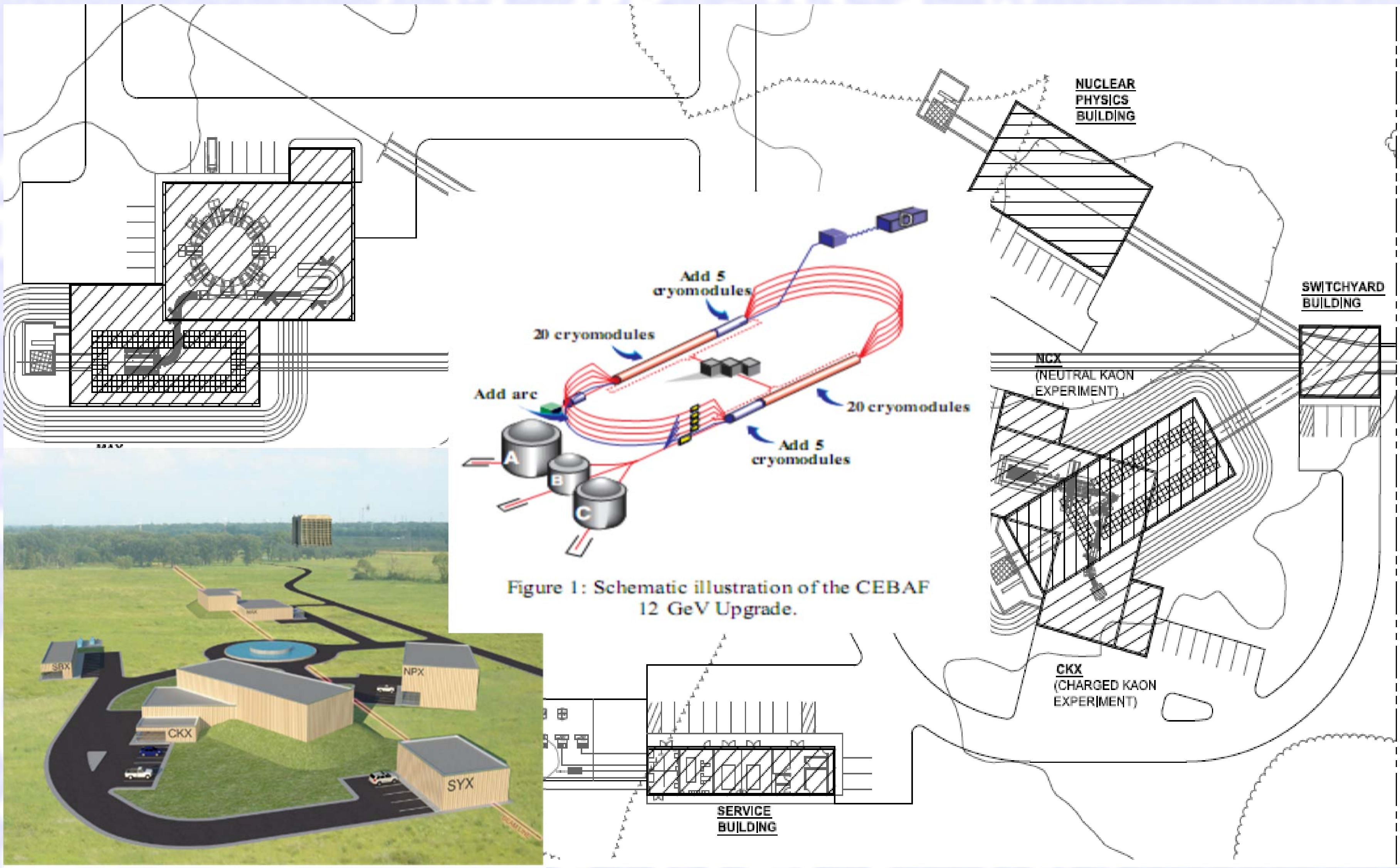


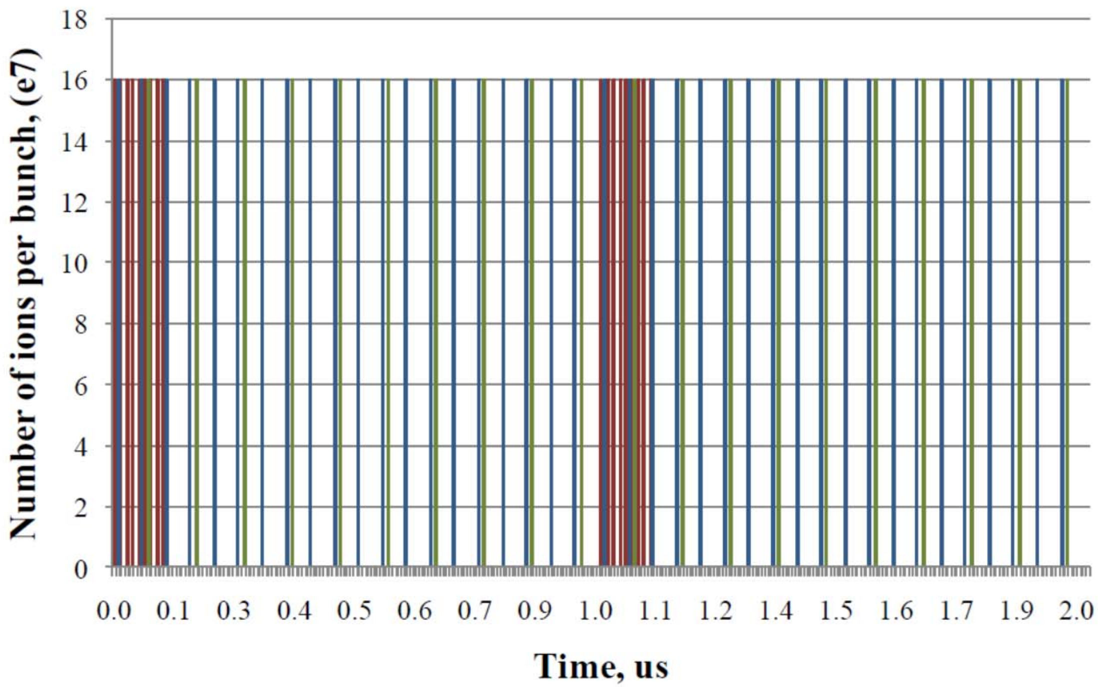
Figure 1: Schematic illustration of the CEBAF 12 GeV Upgrade.

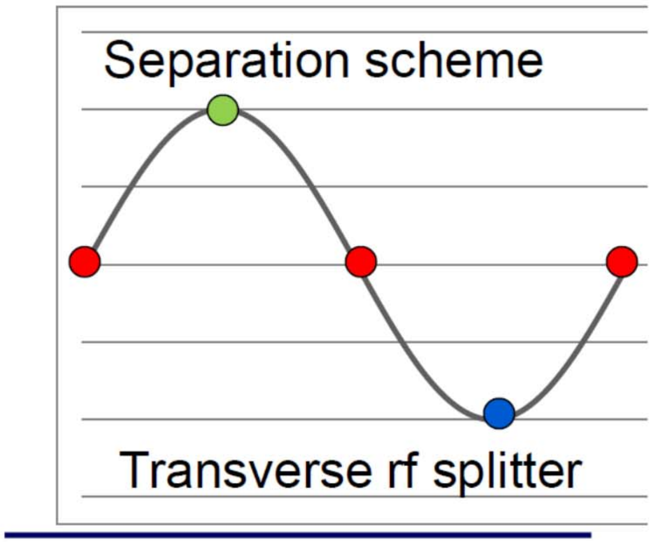
Chopping and splitting for 3-GeV experiments

1 μsec period at 3 GeV

Muon pulses (16e7) 81.25 MHz, 100 nsec at 1 MHz	700 kW
Kaon pulses (16e7) 20.3 MHz	1540 kW
Nuclear pulses (16e7) 10.15 MHz	770 kW

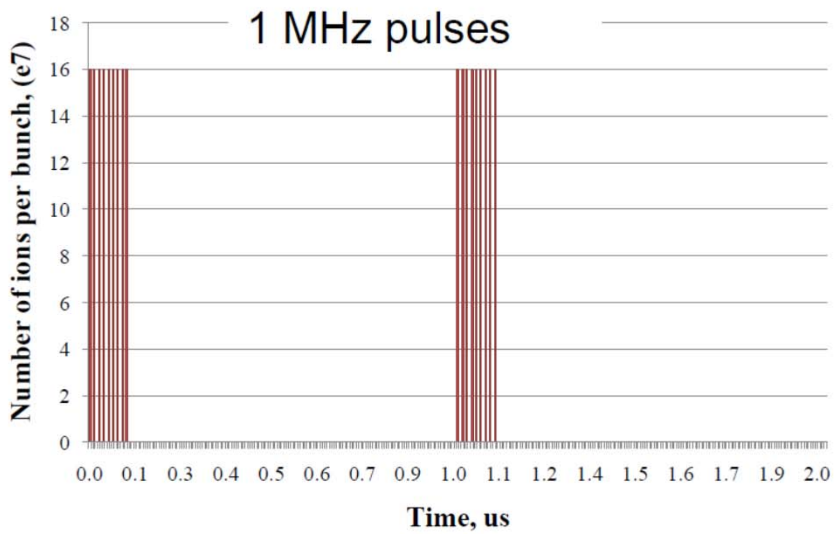
Ion source and RFQ operate at 4.2 mA
75% of bunches are chopped at 2.5 MeV after RFQ

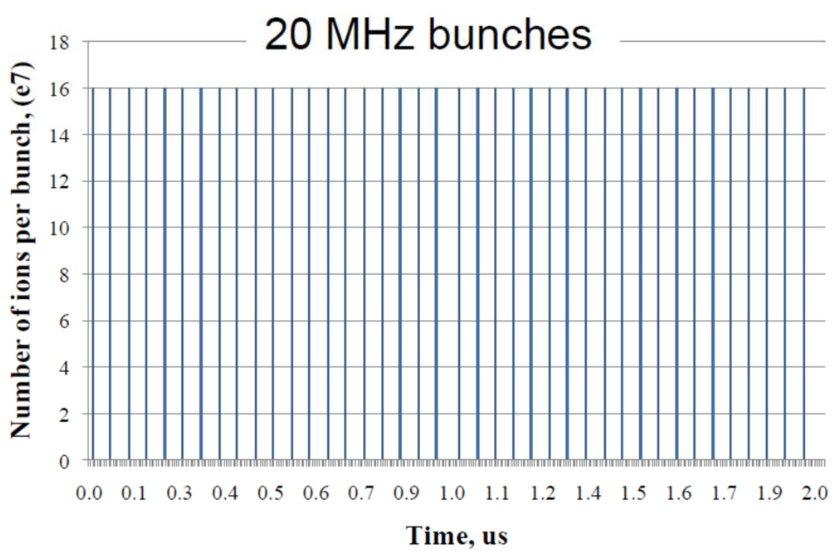


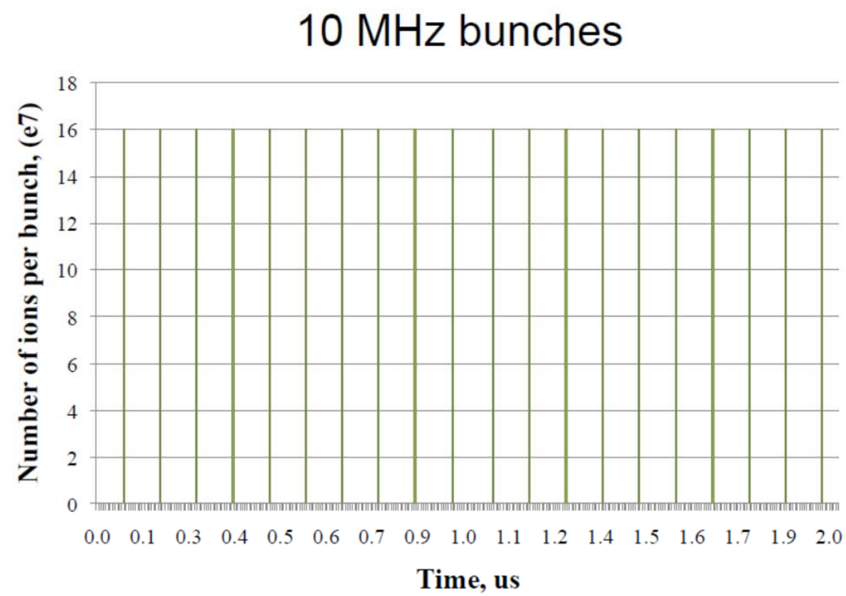


Courtesy of Nagaitsev

Beam after splitter







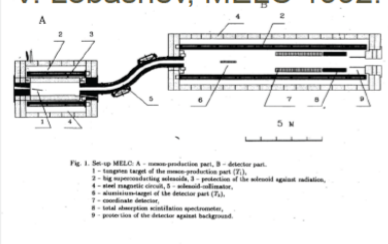
The "PXIE" R&D project develops the LEBT & MEBT technology to validate this opportunity.

Courtesy of Nagaitsev

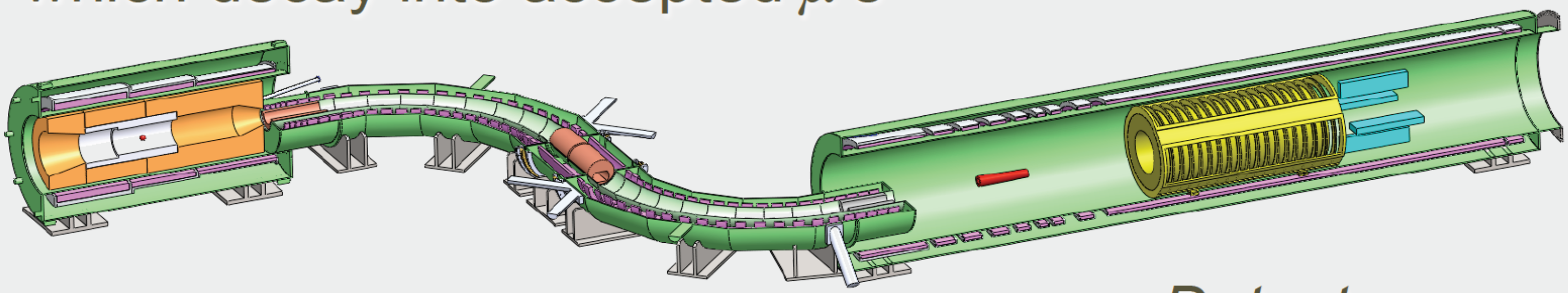
The Mu2e experiment at Fermilab

Mu2e Overview

V. Lobashev, MELC 1992:



- *Production*: Magnetic bottle traps π's, which decay into accepted μ's



- *Transport:* S-curve eliminates backgrounds and sign-selects
- *Detector:* Stopping Target, Tracking and Calorimeter

Pulsed muon-to-electron conversion experiment

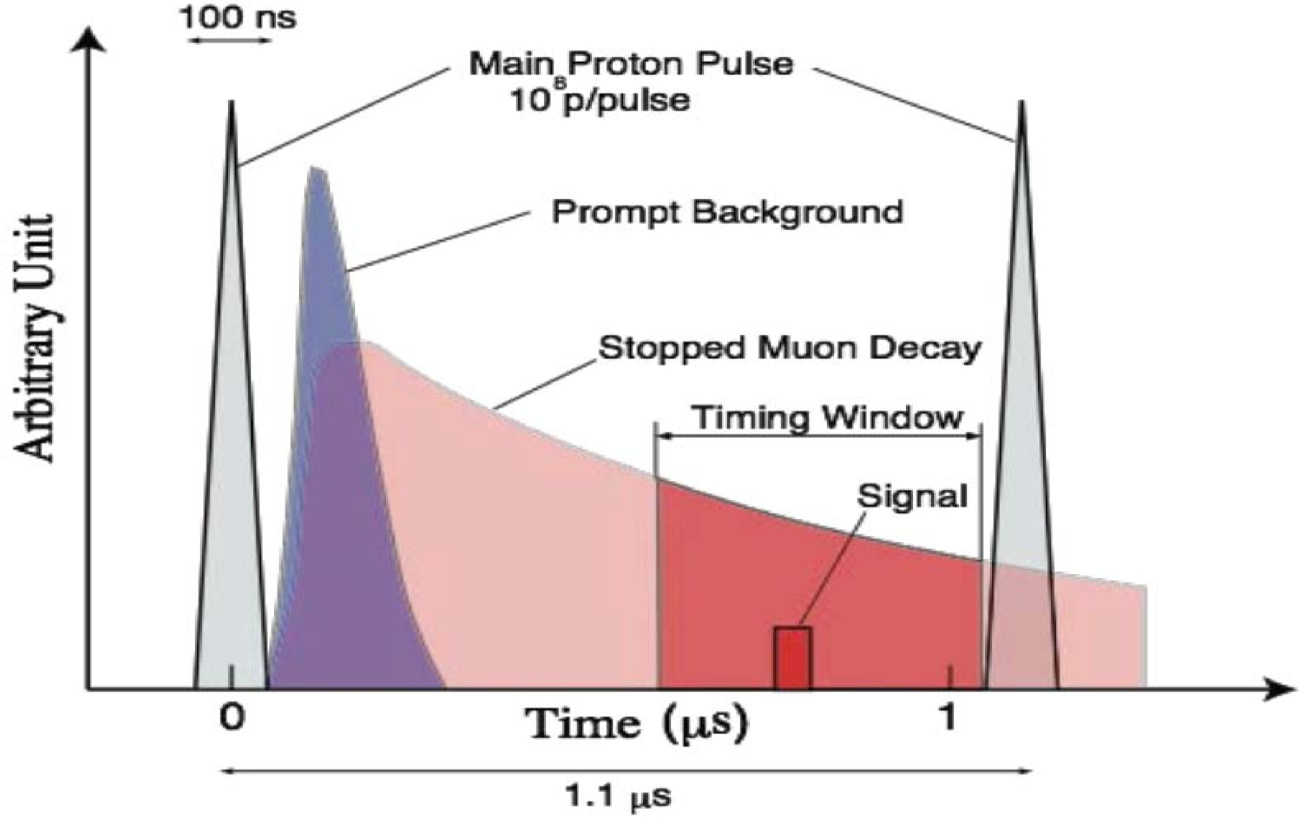
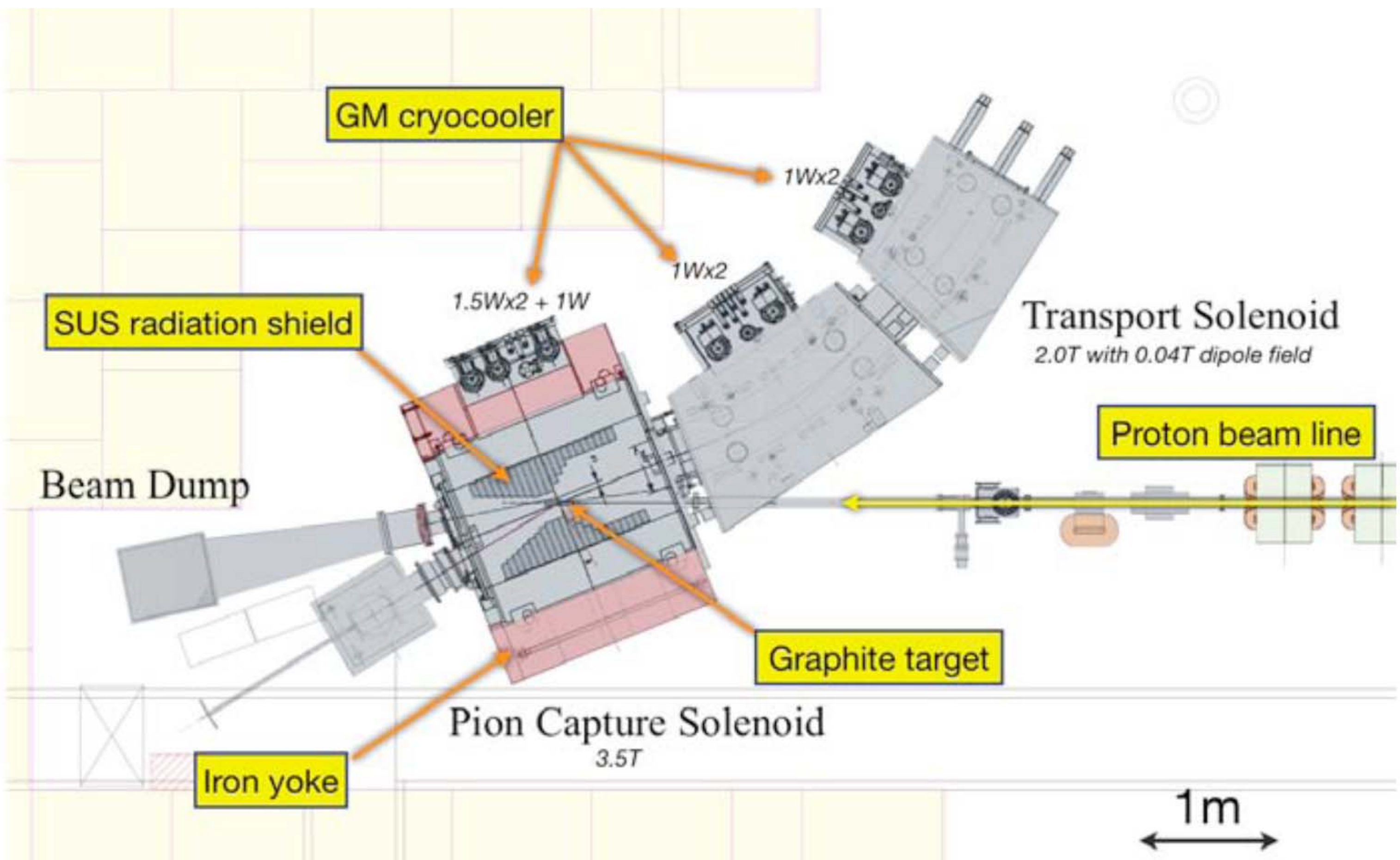


Figure 2.1: Timing of the COMET data acquisition.

RCNP MUSIC Facility



RCNP MUSIC Facility

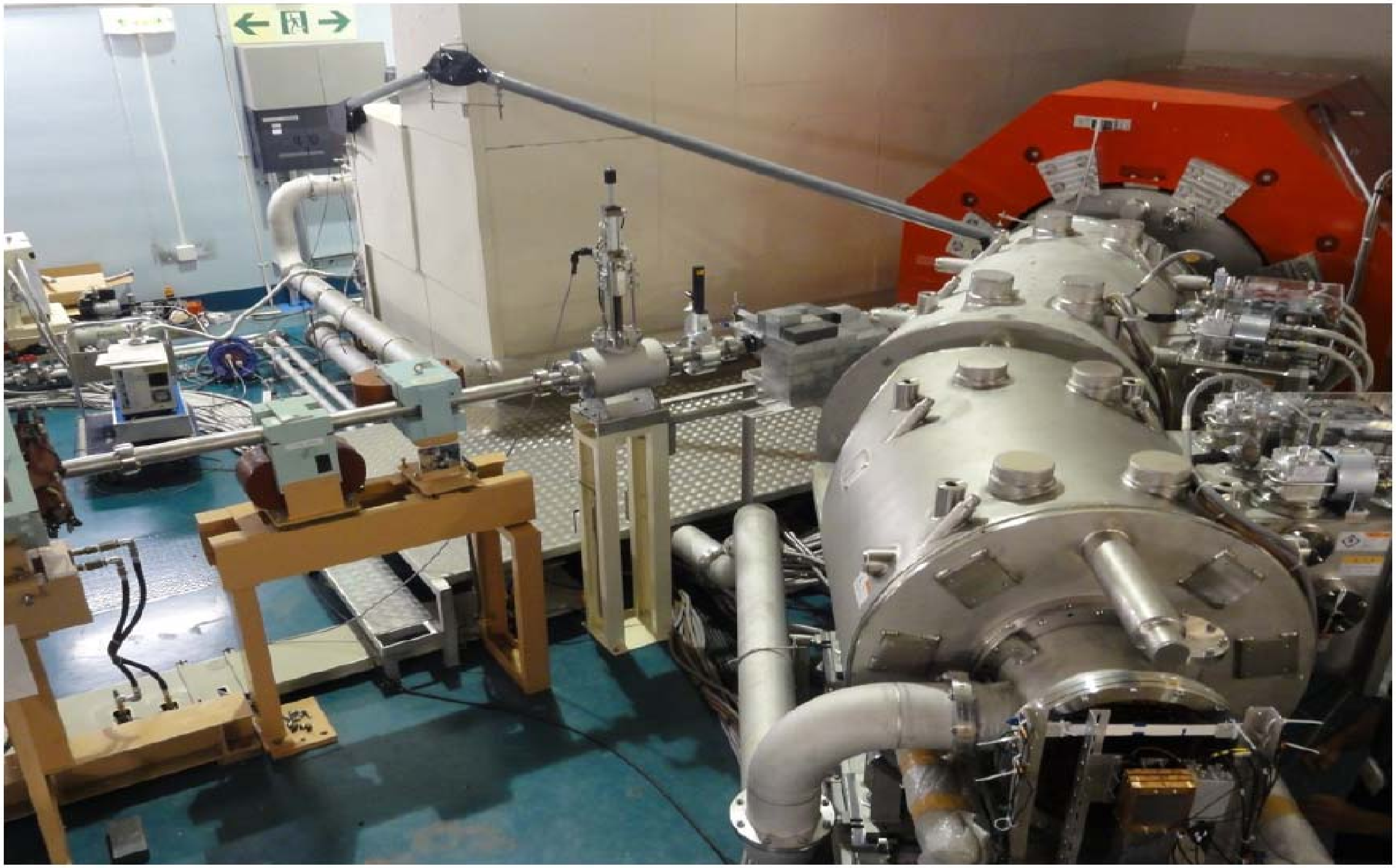


Figure 4.5: Photos of the pion capture system with muon transport at MuSIC.

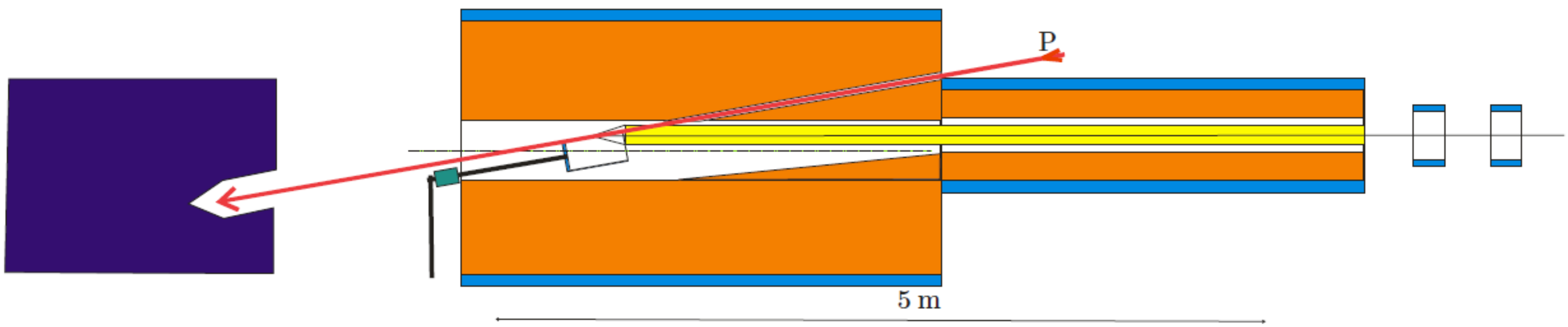
Phase-I of Muon Study: Lebedev, Pronskikh, Striganov

Objective

- Project X can deliver ~1 MW beam
  - Factor ~40 larger than the power expected in μ-to-e
  - Variable time structure of the beam
    - Almost arbitrary within few μs period
- How to use this power?
  - How should the target look like?
- What kind of experiments can be done?
- Which additional possibilities for experiments can the large power result in?
  - Achievable muon flux
  - What else can be done to improve experiments with stopped muons?
    - Can ionization cooling of muons help?

Target and Target Cooling

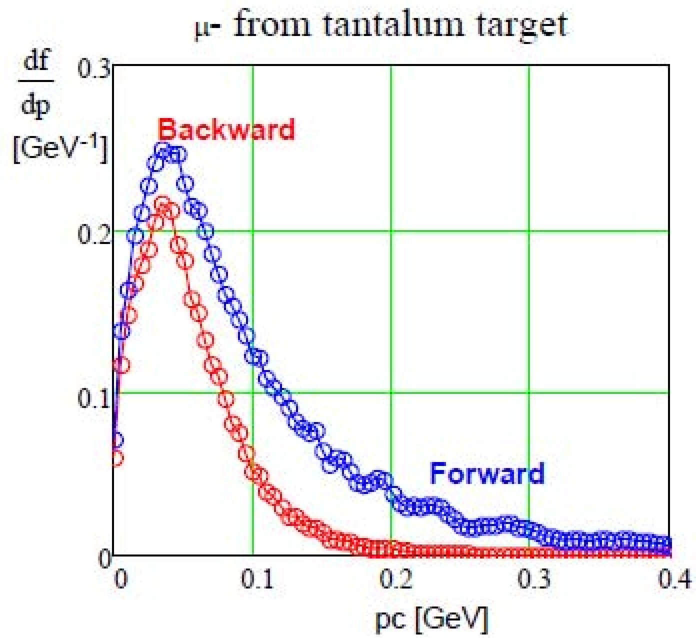
- Optimal target length should be ~1.5 of nuclear interaction length
  - ⇒ i.e.: carbon ~60 cm; tantalum ~15 cm
- The beam leaves ~10% of its energy in the target;
- For 1 MW beam power the power left in the target is ~ 100 kW
- Large beam power prohibits usage of pencil-like target
  - Heat cannot be removed from pencil target: $dP/dS \geq 2$ kW/cm^2 for R~0.5cm
  - Mercury stream is another possibility but it has significant problems with safety. Therefore it was not considered.
- Cylindrical rotating target looks as the most promising choice
  - Carbon (graphite) and tantalum targets were considered
  - Tantalum or any other high Z target has a problem with heating



Muon Task Force, Valeri Lebedev

https://indico.fnal.gov/getFile.py/access?sessionId=37&resId=0&materialId=0&confId=4953

Muon Yield from Cylindrical Target



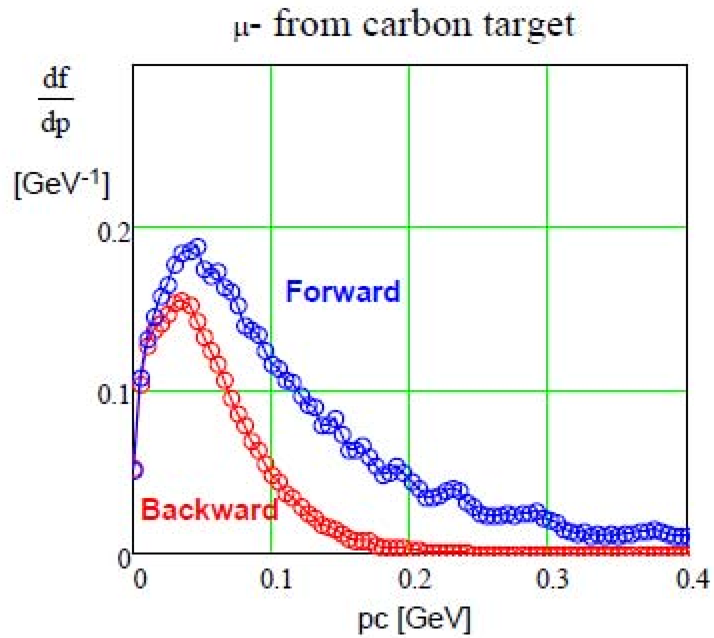
Tantalum hollow cylinder

R_{out}=20 cm, ΔR=5 mm, L=16 cm, θ=300 mrad

Total muon yield at ±10 m

Forward – 1.4% per proton GeV

Backward – 0.73% per proton GeV



Carbon hollow cylinder

R_{out}=20 cm, ΔR=5 mm, L=40 cm, θ=200 mrad

Total muon yield at ±10 m

Forward – 1.3% per proton GeV

Backward – 0.59% per proton GeV

Yield per 1 GeV of proton energy: pc=3 GeV/ (E_{kin}=2.2 GeV),

$\sigma_x = \sigma_y$ = 1 mm – parallel beam, proton multiple scattering unaccounted

- Small difference between forward and backward muons for Pc<50 MeV
- For pc<120 MeV a weak dependence on E_{kin_prot} for $E_{kin\_prot} \in [1, 8]$ GeV/c

https://indico.fnal.gov/getFile.py/access?sessionId=37&resId=0&materialId=0&confId=4953

Conclusions

- 1 MW target in a few Tesla solenoidal field is feasible
  - Graphite rotating cylinder cooled by the black-body radiation
  - Loss of efficiency ~20% relative to a pencil like target (@ pc~100 MeV)
  - Radiation shielding: R ≈ 80 cm (for μ-to-e) → R ≈ 110 cm
    - ⇒ Smaller B if the same energy is stored in the field;
      - Magnetic field change: $B \propto R^{-3/2} \approx (80/110)^{3/2} \approx 0.6$
      - overall loss of muon yield is smaller than factor of 2
      - ~ 20 times more muons than present Mu2e (1 MW, 1 - 3 GeV)
- Muon yield per unit power weakly depends on proton energy [1-8 GeV]
  - Only ~15% reduction if the energy is reduced from 2.2 to 1 GeV
- Beam line option
  - Creates wide possibilities for the phase space manipulations
    - Isochronicity of beam transport
  - Muon flux reduction by more than an order of magnitude
  - Decelerating or degrading of muons does not look promising
  - Ionization cooling of muon is presently hardly feasible
  - Requirement to have only low energy muons for stopping in a thin target (pc<<100 MeV) results in drastic reduction of muon flux

Phase-II Goals of the Muons @ Project-X Study

- Document Phase-I results.
- Develop a companion analysis of detector optimization exploiting:
  - Lower proton beam energy -> lower anti-proton backgronds.
  - More prompt proton pulse, 200 nsec - > 20 nsec.
  - Flexible pulse train frequencies.
- The μ->3e case.
- Pre-conceptual design of ionization cooling toward a higher stopping fraction
- Integrated documentation by the close of calendar 2012.