Physic Opportunities at the Fermilab Booster Replacement

PAC Update

Roni Harnik

Fermilab Theory Dept.

HEP Working group: Greg Bock, Angela Fava, Laura Fields, Alex Friedland, Andrei Gaponenko, Stefania Gori, RH (chair), Gordan Krnjaic, Maxim Pospelov, Luciano Ristori, Nhan Tran, Matthew Toups, Richard Van de Water

Accelerator Working group: Mike Syphers (chair), Jonathan Jarvis, Alexander Valishev, Eduard Pozdeyev, Sam Posen, Jeff Eldred, Ioanis Kourbanis, Valeri A Lebedev, Bob Zwaska.

Charge and Overview

Charge: We ask the committee to review the scope and impact of the physics program being developed for the Booster Replacement.

Overview: a snapshot of Booster replacement activities.

- Premise for Booster Replacement
- Recent activity
  - Workshop (May 19)
  - Community input (ongoing)
  - Snapshot of output document
- Additional scope: “HE booster” and implications for DUNE physics and beyond.

Booster Replacement

Preamble

- P5 recommendation is for 2.4MW to DUNE
- 2.4 MW requires 1.5×10^{14} particles from MI @ 120 GeV
- Booster is not capable of accelerating 2.5×10^{13} no matter what the injection energy, or how it is upgraded: many issues
- *Achieving 2+ MW will require replacement of the Booster and possible upgrades of the MI.*

Booster Replacement Mission:

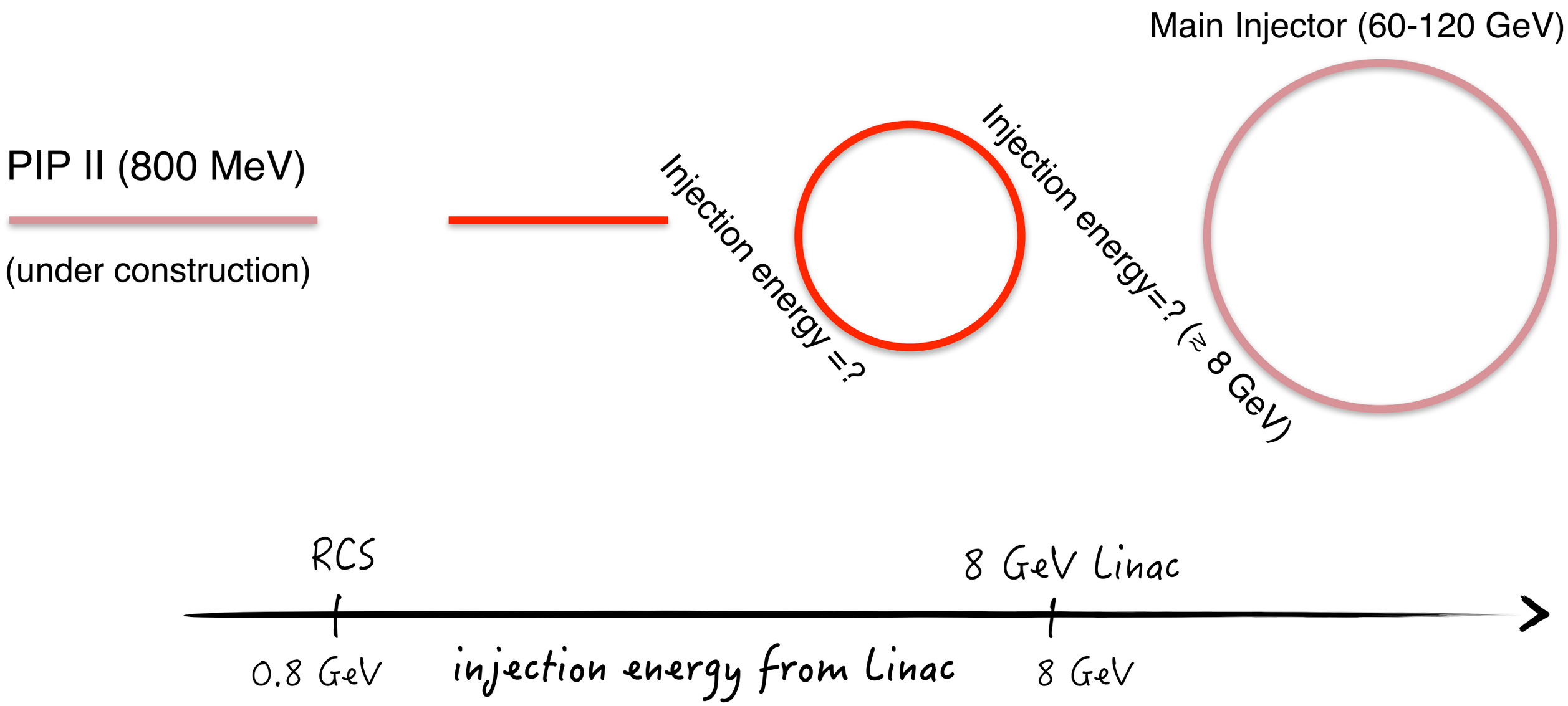
- Deliver 2.4 MW @ 60-120 GeV from the Main Injector to the LBNF beam line in support of the DUNE experiment
- Deliver up to 80 kW @ 8 GeV to support g-2, Mu2e, and short-baseline neutrinos
- Deliver ~100 kW CW @ 800 MeV (or more) to support a second generation Mu2e
- Exploit the capabilities of CW SRF PIP-II linac **to enable other physics opportunities**

[Excerpt from Nigel's charge]

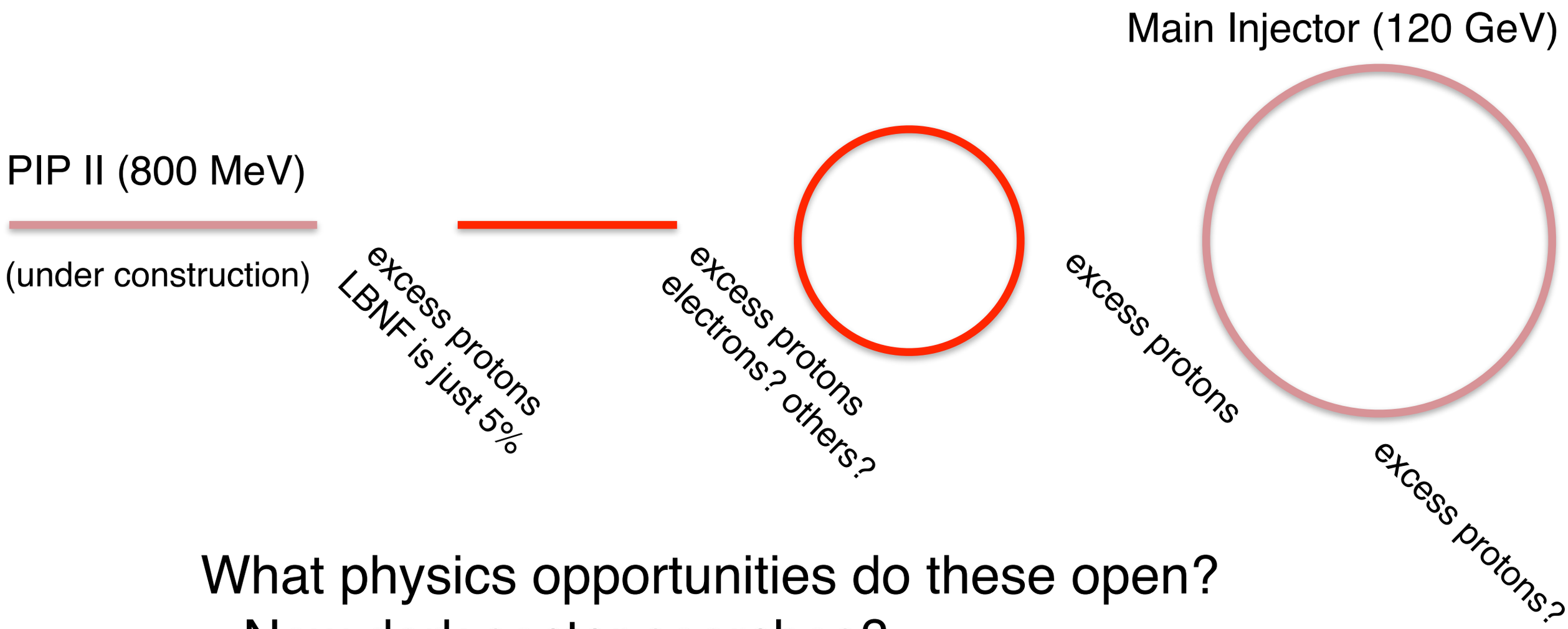
Booster Replacement Possibilities:

Two technologies: An extension of the Linac and/or a new Rapid Cycling Synchrotron (RCS).

The transition between these is a major design choice.



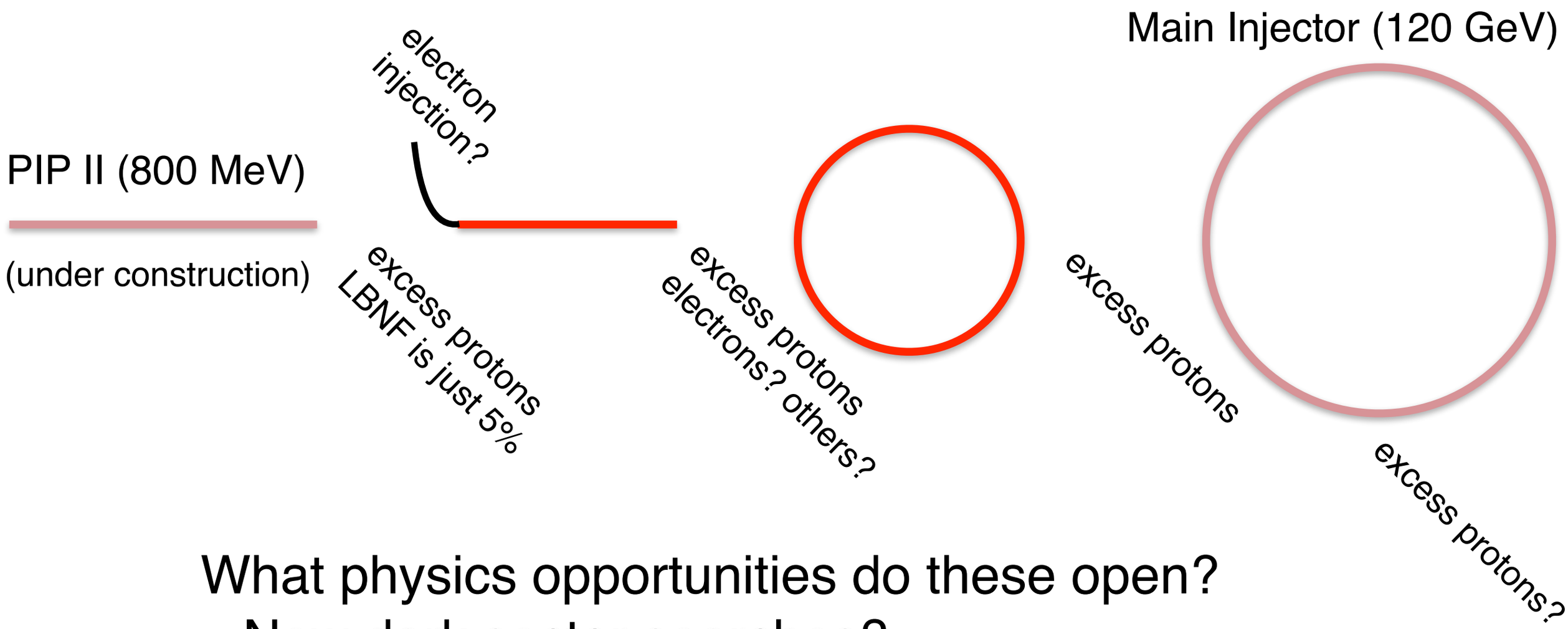
Physics Opportunities in the Gaps b/w Accelerators



What physics opportunities do these open?

- New dark sector searches?
- New precision tests?
- Acceleration of electron or other in the Linac?
- ...

Physics Opportunities in the Gaps b/w Accelerators



What physics opportunities do these open?

- New dark sector searches?
- New precision tests?
- Acceleration of electron or other in the Linac?
- ...

Physics Opportunities

- **The goal of the physics working group is to inform the accelerator design about potential physics opportunities. Solicit input from the community** (workshop).

- We are interested in concrete ideas and near term opportunities, but also a long-term and inclusive approach:
  - The Fermilab Booster was designed ~50 years ago. Its replacement will be with us for decades.
  - We cannot foresee what will be motivated decades ahead.
  - Best leave as many doors open to exciting physics. Plan the accelerators as well as the gaps between them.

Activity

- The Accelerator and Physics Was began work in February.
- Fermilab hosted workshop was planned for May 18-19 and announced in early March. That plan changed.

- Workshop was replaced by a process:
  - **May 19th:** All-day Zoom meeting with HEP and accelerator experts (over 100 participants throughout the day). https://indico.fnal.gov/event/23352/
  - Scope broadened a bit at workshop (more later).
  - **Now:** A period of input collection from the community. Leveraging LOI's that are being written for snowmass. Preliminary input passed on to Accelerator WG.
  - Future zoom meeting.
  - A more polished version of a menu of physics opportunities planned for August/September (snowmass LOI's are due in august).
  - Like submitted as snowmass white paper (to the TBD Frontier).

Kick-off Meeting: (May 19th)

https://indico.fnal.gov/event/23352/

10:00	**Introduction**	*Roni Harnik*	
	Zoom		10:00 - 10:15
	Overview of Booster Replacement Options	*Alexander Valishev*	
	Zoom		10:15 - 10:45
	PIP-II and Possible Linac Extensions	*Eduard Pozdeyev*	
11:00	*Zoom*		10:45 - 11:15
	Future accelerator complex capabilities with SRF linacs	*Sam Posen*	
	Zoom		11:15 - 11:30
	Beam Physics and Technology Implications of a Booster Upgrade	*Jeffrey Eldred*	
	Zoom		11:30 - 12:00
12:00	**Main Injector Impacts**	*Ioanis Kourbanis*	
	Zoom		12:00 - 12:30
	Path Forward	*Roni Harnik*	
	Zoom		13:30 - 13:50
	Example: Low Energy Protons	*Matthew Toups*	
14:00	*Zoom*		13:50 - 14:05
	Example: High Energy Protons	*Stefania Gori*	
	Zoom		14:05 - 14:20
	Example: Lepton Beams	*Gordan Krnjaic et al.*	
	Zoom		14:20 - 14:35
	Example: Lepton Flavor Violation	*Andrei Gaponenko*	
	Zoom		14:35 - 14:50
	Discussion		
15:00	*Zoom*		14:50 - 15:35

Community input

- We are collecting (and providing) input into a document. Written collectively on overleaf.
- For a snapshot see: https://www.overleaf.com/read/scgtzvbngfxr
- Some inputs are written by the working group while others are by community members.

- Document structure:
  - Subsection 1: A free-form description of the physics experiment and its motivation. A snowmass LOI can be used.
  - Subsection 2: A “form” on accelerator needs - particle, energy, intensity needs, time structure, target, etc.

Document Preview:

Physics Opportunities for the Fermilab Booster Replacement

Physics task force

June 29, 2020

Abstract

This is a menu of physics opportunities afforded by the Fermilab Booster Replacement and its various options . As in any self-respecting fancy restaurant, there are no prices in the menu.

Contents

1 Introduction to this Template 2

2 Charged lepton flavor violation: muon to electron conversion 3

3 Charged lepton flavor violation with muon decays 5

4 Stopped Pion Source 6

5 Kaons Decay at Rest 8

6 DM searches with Intermediate Energy Protons 10

7 High Energy Proton Fixed Target 12

8 Electron missing momentum 14

9 Nucleon Electromagnetic Form Factors from Lepton Scattering 16

10 Electron beam dumps 19

11 Muon Missing Momentum 21

12 N-Nbar oscillations 24

13 Muon Collider R&D and Neutrino Factories 26

14 Tau Neutrinos 28

15 Rare Decays of Light Mesons 30

16 Proton Irradiation Facility 33

17 Proton Storage Ring: EDM and Axion Searches 35

Preliminary

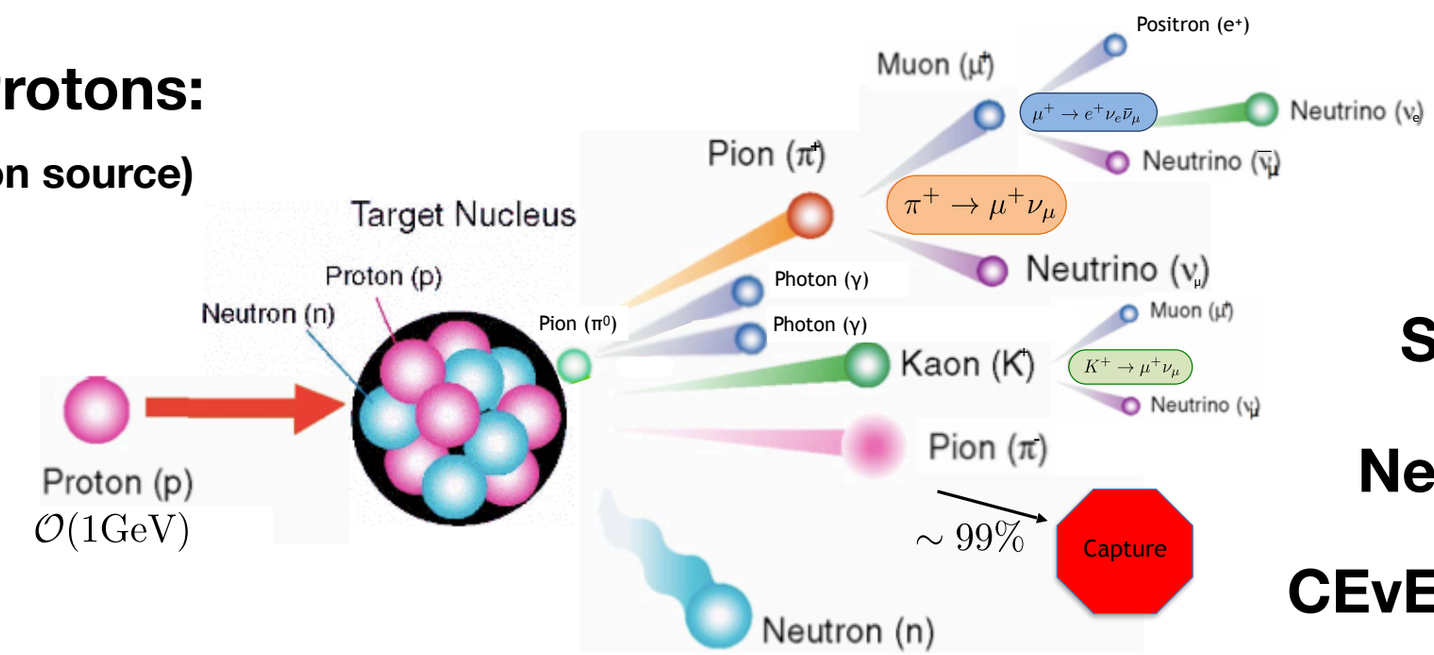
	dark sectors	ν physics	CLFV	Precision tests	R&D
Charged lepton flavor violation: muon to electron conversion			■		
Charged lepton flavor violation with muon decays	■		■		
Stopped Pion Source	■	■			
Kaons Decay at Rest	■	■			
DM searches with Intermediate Energy Protons	■	■			
High Energy Proton Fixed Target	■				
Electron missing momentum	■	■			
Nucleon Electromagnetic Form Factors from Lepton Scattering		■		■	
Electron beam dumps	■				
Muon Missing Momentum	■	■			
N-Nbar oscillations				■	
Muon Collider R&D and Neutrino Factories		■			■
Tau Neutrinos		■			
Rare Decays of Light Mesons	■			■	
Proton Irradiation Facility					■
Proton Storage Ring: EDM and Axion Searches	■			■	

Preliminary

Highlights - Dark sectors

~1 GeV Protons:

(stopped pion source)



π decay to light DM.

π, K decay to mediators
(e.g. axion-like particles, dark photons)

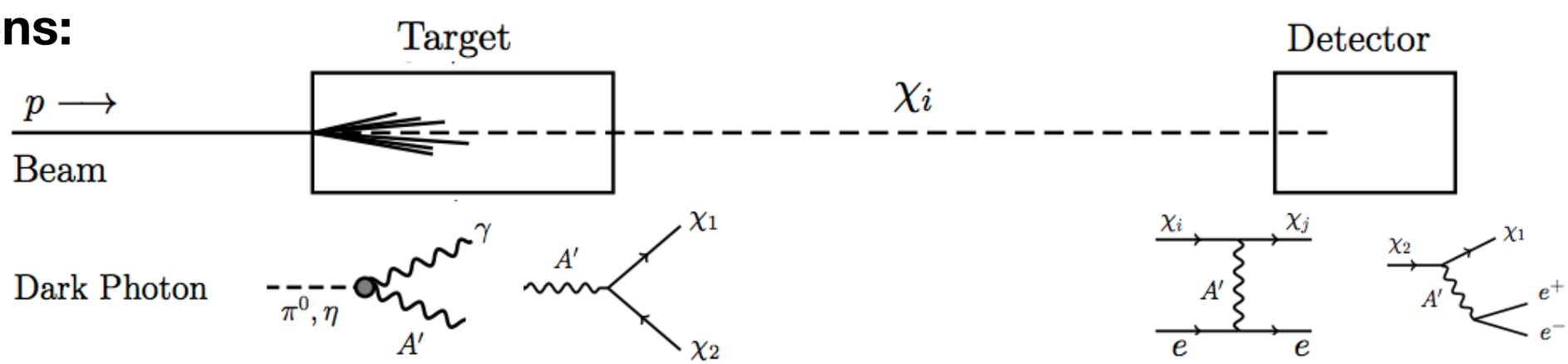
Sterile ν via oscillation.

Neutrino NSI.

CEvENS **(requires low duty factor)**

ν cross section and SN neutrinos

~10 GeV Protons:



Dark matter searches

see talk by M. Toups at workshop.

see talk by Gori

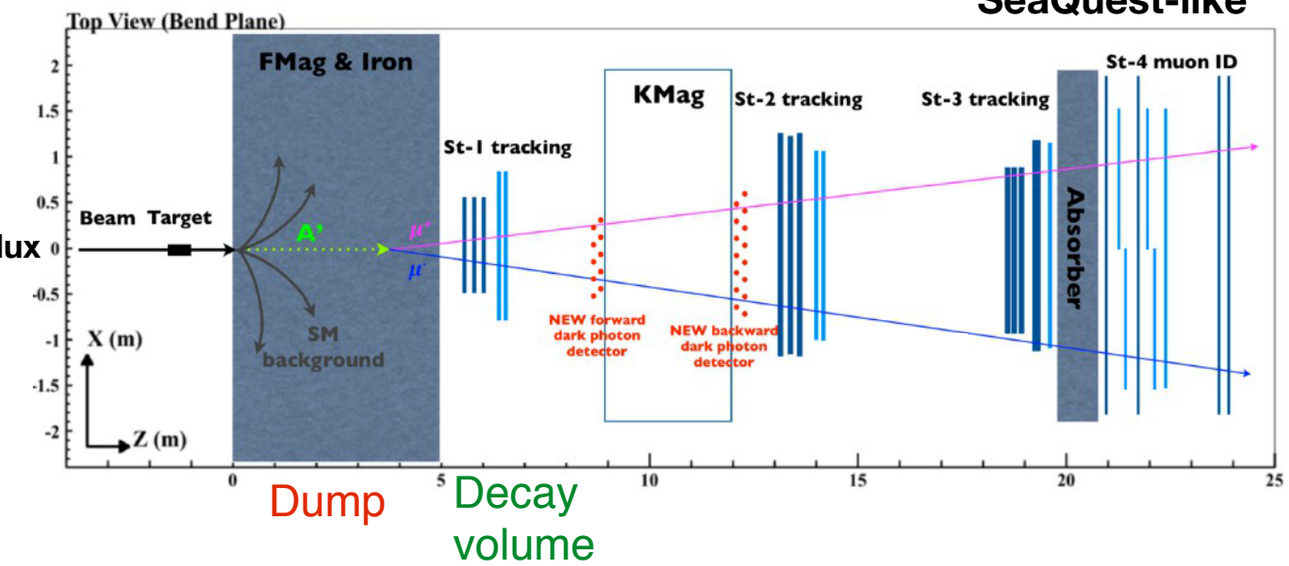
Highlights - Dark sectors

~100 GeV Protons:

("compact" beam dump)

say, 5% of LBNF flux

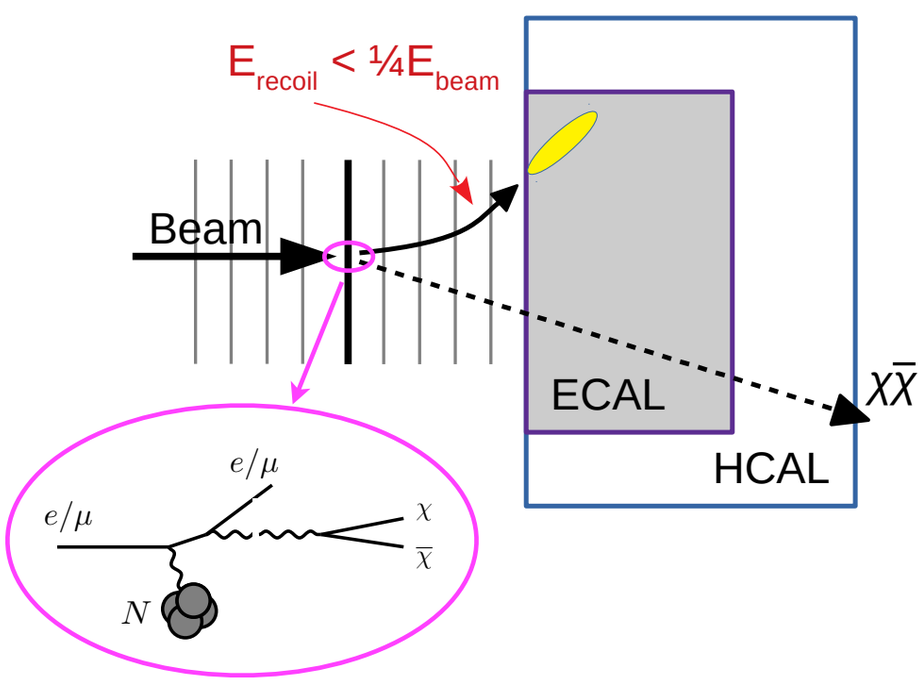
SeaQuest-like



Searches for displace decays. Mediators.

~Electrons (few GeV):

electron missing momentum

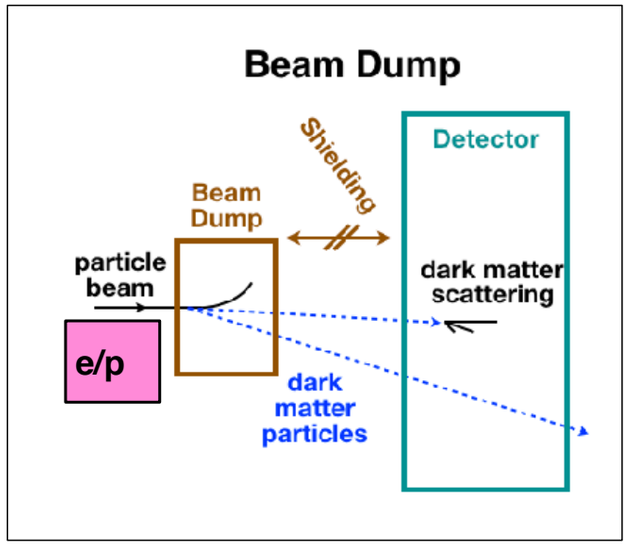


DM searches

Dark sectors

e-N scattering for ν cross sections

electron beam dump



DM + mediator searches

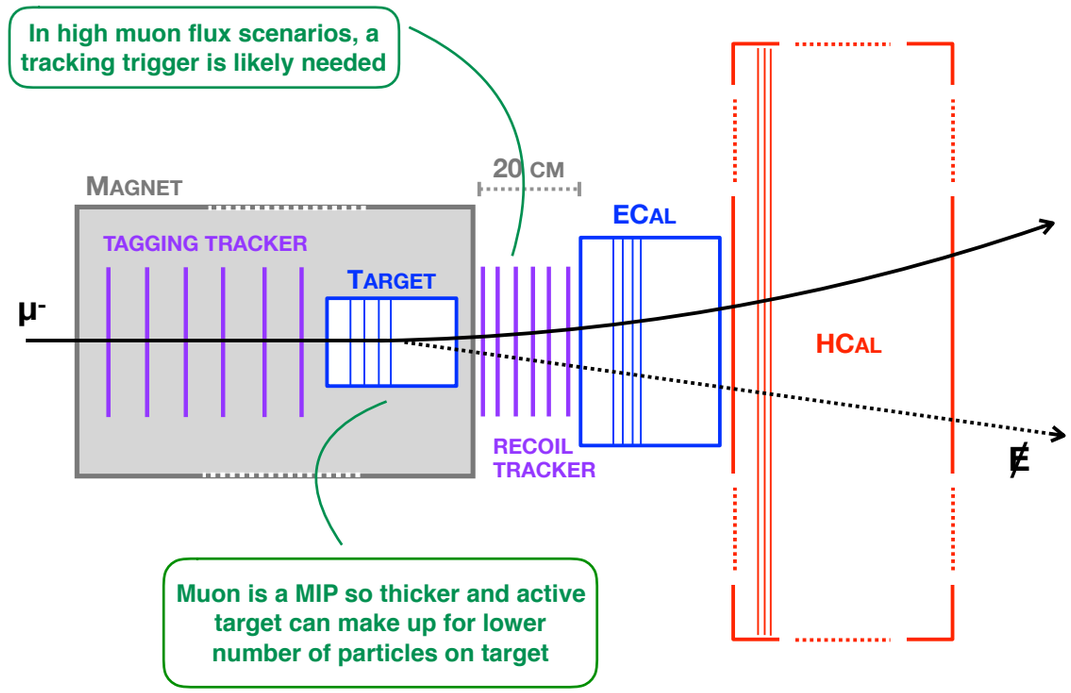
see talk by Krnjaic

Muons

see talk by Krnjaic

Muon missing momentum

μ's (10+ GeV)

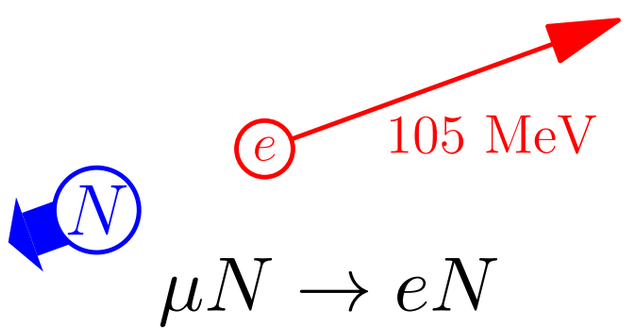


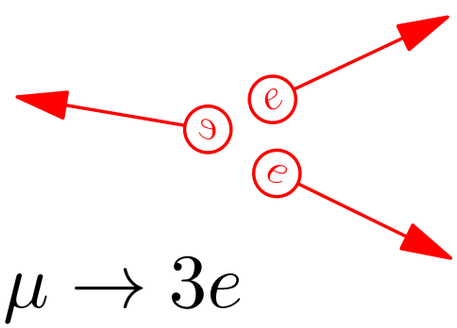
Mu-philic DM

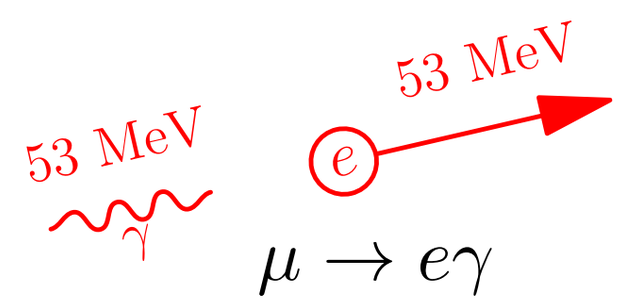
models for g-2

Flavor Violating Muon:

Exploring opportunities to bring all world leading μ CLFV channels to FNAL





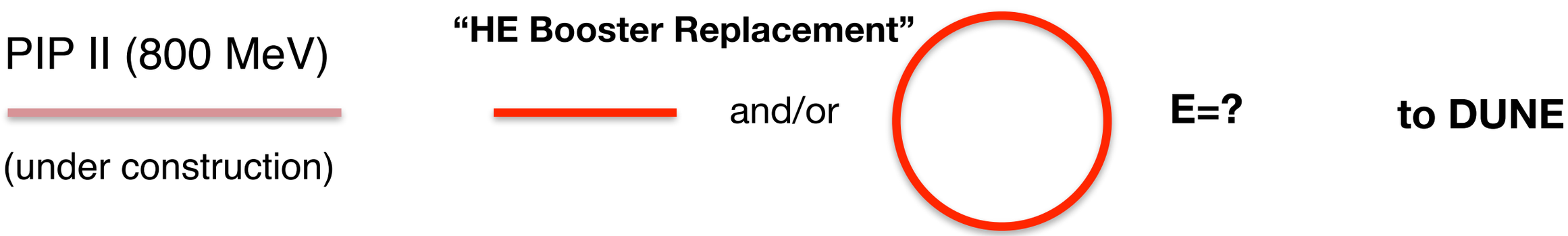


see talk by Gaponenko

Thinking ahead: Beyond the Main injector (MI)

- Going beyond 2.4 MW for DUNE is also desirable. MI may be next limitation.
- The beam energy at LBNF, 60-120 is optimized given MI capabilities.
- Booster replacement planning should also consider the long term plan.

- Questions for a beyond-MI era:
  - Can *DUNE achieve its long base line physics goals at < 60 GeV? With other beam timing structures?*



  - *Does this provide a simpler path to beyond 2.4 MW?*
  - *What are possible accelerator technologies and time structures?*
  - *What are target limitations?*
  - *How would these affect other DUNE physics?*

Thinking ahead: Beyond the Main injector (MI)

- Going beyond 2.4 MW for DUNE is also desirable. MI may be next limitation.
- The beam energy at LBNF, 60-120 is optimized given MI capabilities.
- Booster replacement planning should also consider the long term plan.

- Questions for a beyond-MI era:
  - Can *DUNE achieve its long base line physics goals at < 60 GeV? With other beam timing structures?*

This is an ongoing inquiry.

We are in discussion with accelerator experts and with DUNE physics coordinators to understand what DUNE's "green field" needs are, in order to inform accelerator planning.

  - *Does this provide a simpler path to beyond 2.4 MW?*
  - *What are possible accelerator technologies and time structures?*
  - *What are target limitations?*
  - *How would these affect other DUNE physics?*

Conclusion

- Two working groups have begun considering Fermilab's Booster Replacement.
  - Accelerator: a set of options for booster replacement and MI upgrades are considered.
  - Physics: A diverse menu of physics options is being drawn up to inform the accelerator design.
  - Physics': Set the boundary conditions for future planning. What are DUNE's needs in a post MI era? (inquiry in progress)

- The choices made now will affect generations of HEP. We would like to make informed choices and maintain plenty of options for exciting physics.