Proton Drivers & Muon Sources at Fermilab

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Fermilab

Introduction–Fermilab Future Plans (~Oddone)

- (Tevatron shuts down ~2009)
- First Priority – ILC
  - Global Study ~1 year –present to DOE (end of 2006)
  - IF favorable, push for near-term construction at Fermilab
- Second Priority – protons
  - Priorities are NUMI, NoVA, …
  - Some excess proton capacity for other experiments
  - If ILC near-term, continue facility incremental upgrades
  - Becomes high priority if ILC not encouraged

  PROTON DRIVER: 8 GeV, MW superconducting linac
- Accelerator Physics Center (from FRA bid)
  - Muon Collider Task Force

Fermilab proton sources

- **Adapt existing facility for "Super" NUMI and μ-e conversion experiment**
  - Future "upgrades"- configurations- up to~1MW at 125 GeV
  - Protons for muon source – A-D configuration
    - extract beam for mu-e conversion $\mu^- A \to e^- A$

- **Proton Driver – 8 GeV future source ?**
  - 1 to 4 MW at 8 GeV SRF Linac
  - for collider, ν-Factory, etc.
  - Need buncher ring to accumulate p's

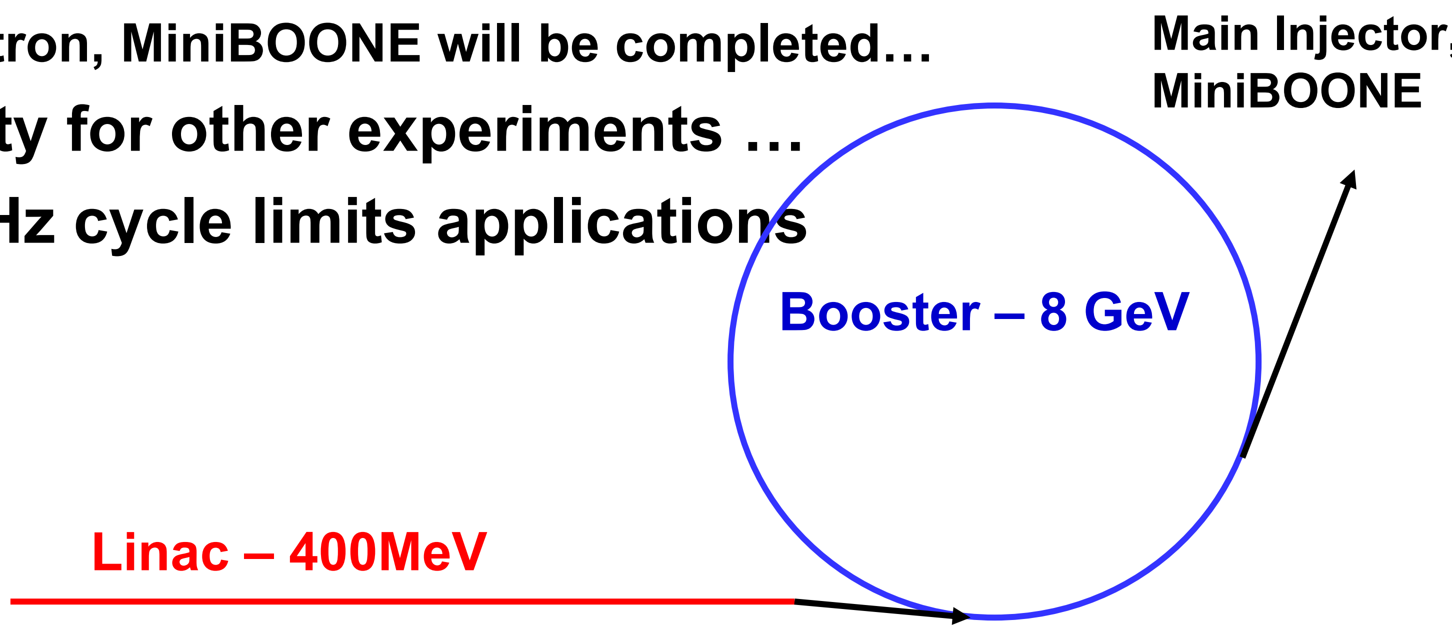
Present Proton Source: 8 GeV Booster

NOW: 400 MeV Linac→8 GeV Booster **(C=454m)**

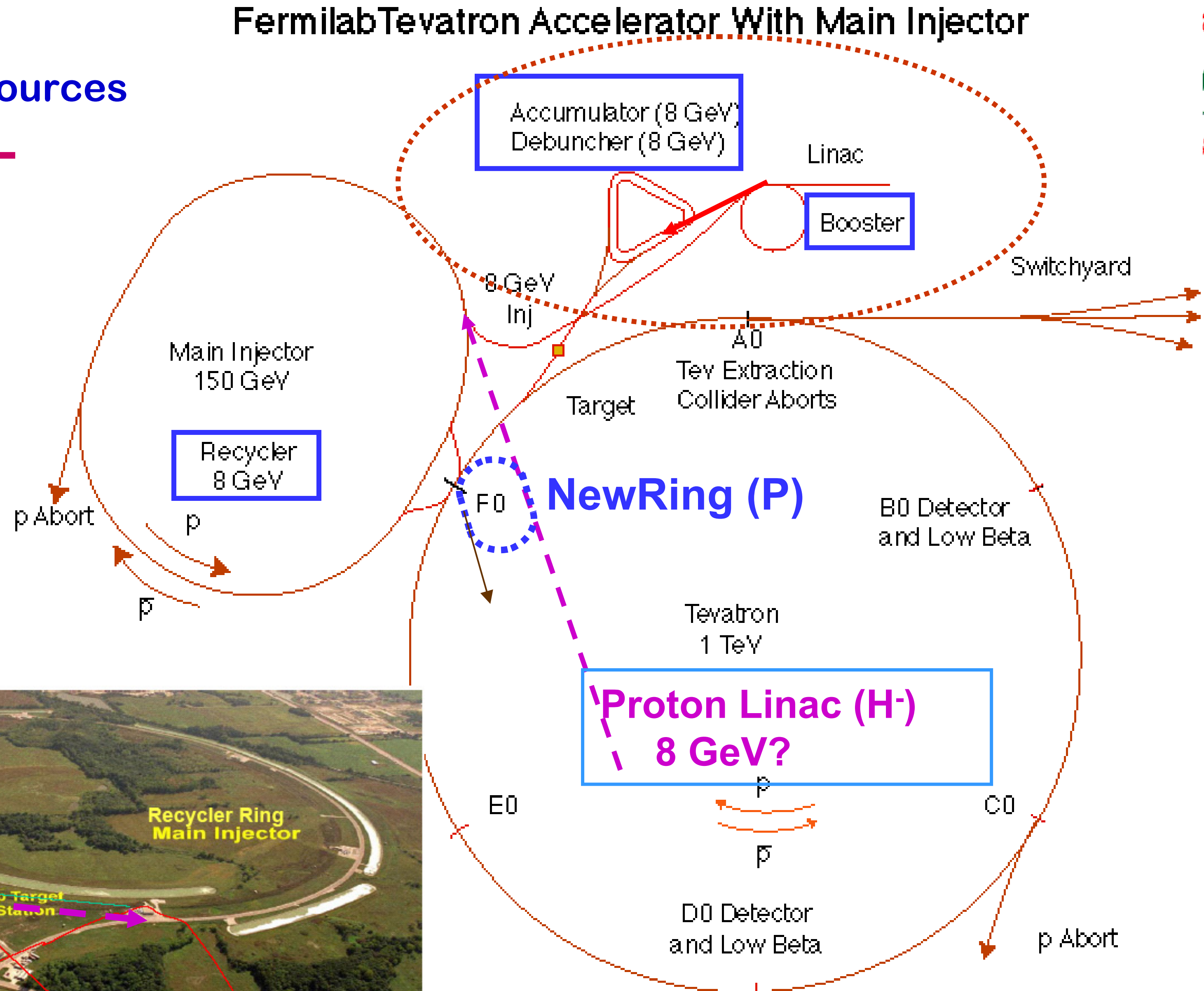
produces 80 bunches (53 MHz)

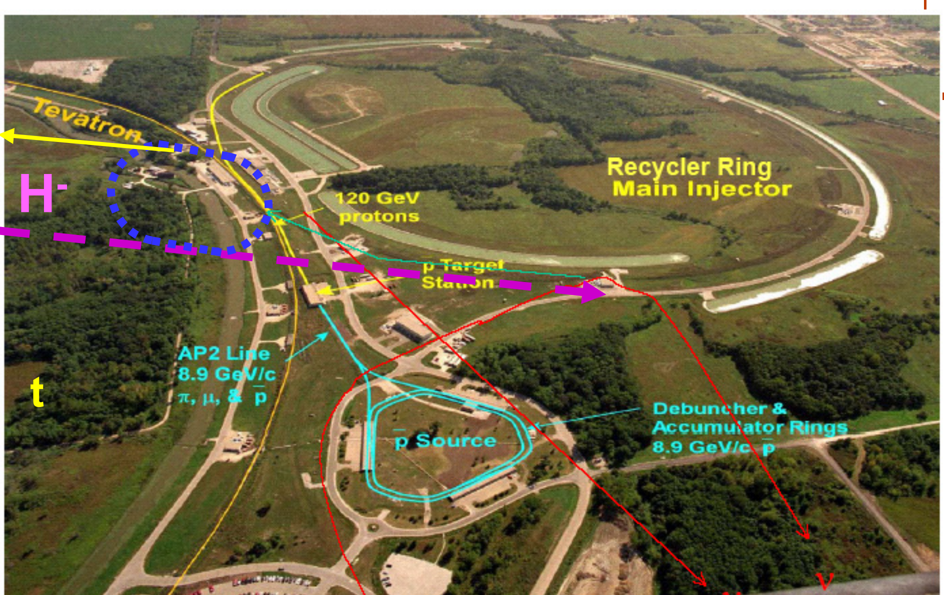
- Currently Limited by losses **in Booster**
- ~8Hz, ~ 4 × 10^{12}/ pulse: ~3×10^{20} p/year (0.04MW)
- **15Hz, 5 × 10^{12}/pulse possible (0.1MW) (6×10^{13} protons/s)**

- NUMI, **MiniBOONE, Tevatron p-source**
  - **Tevatron, MiniBOONE will be completed…**
- **Capacity for other experiments …**
- **But 15Hz cycle limits applications**



8 GeV f Proton sources





SNuMI stage 1: 700 kW
Recycler as an 8 GeV proton pre-injector

- **After the Collider: Use the Recycler as a p pre-injector**
  - **Booster batches are injected at 15 Hz rep rate to fill Recycler, transferred to MI and accelerated**
  - **if we use the Recycler to accumulate protons from the Booster while MI is running, we can save 0.4 s for each 6 Booster batches injected**
  - **6 batches (5×10^{12} p/bx) at 120 GeV every 1.467s $\Rightarrow$ 390 kW**

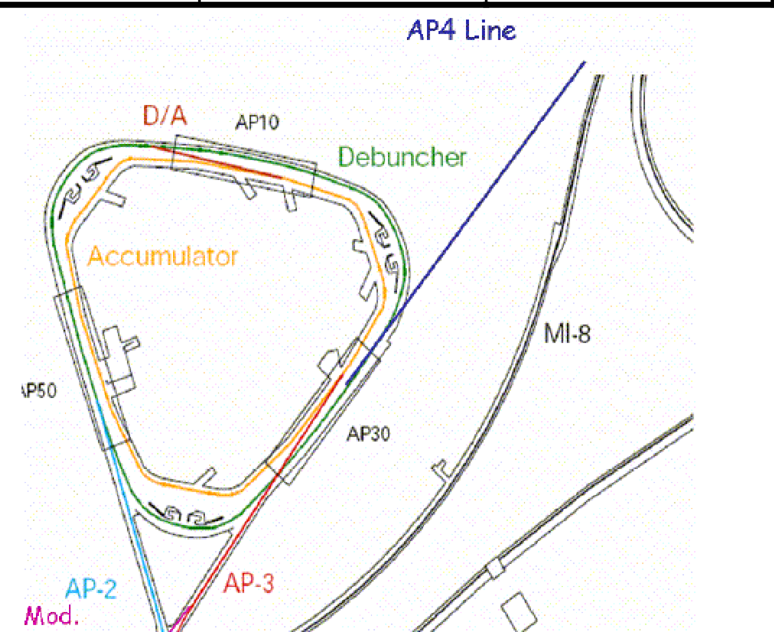
- **Recycler momentum aperture is large enough to allow "slip-stacking" in Recycler: up to 12 Booster batches injected**
  - **6 batches are slipped with respect to the other 6 and extracted to MI in a single turn**
  - **~4.7×10^{12} p/batch, 95% slip-stacking efficiency**
  - **↪ 5.4×10^{13} ppp at 120 GeV every 1.467 s $\Rightarrow$ 700 kW**

S. Nagaitsev, E. Prebys, M. Syphers 'First Report of the Proton Study Group', Beams-doc-2178

SNUMI stage 2: Use Accumulator

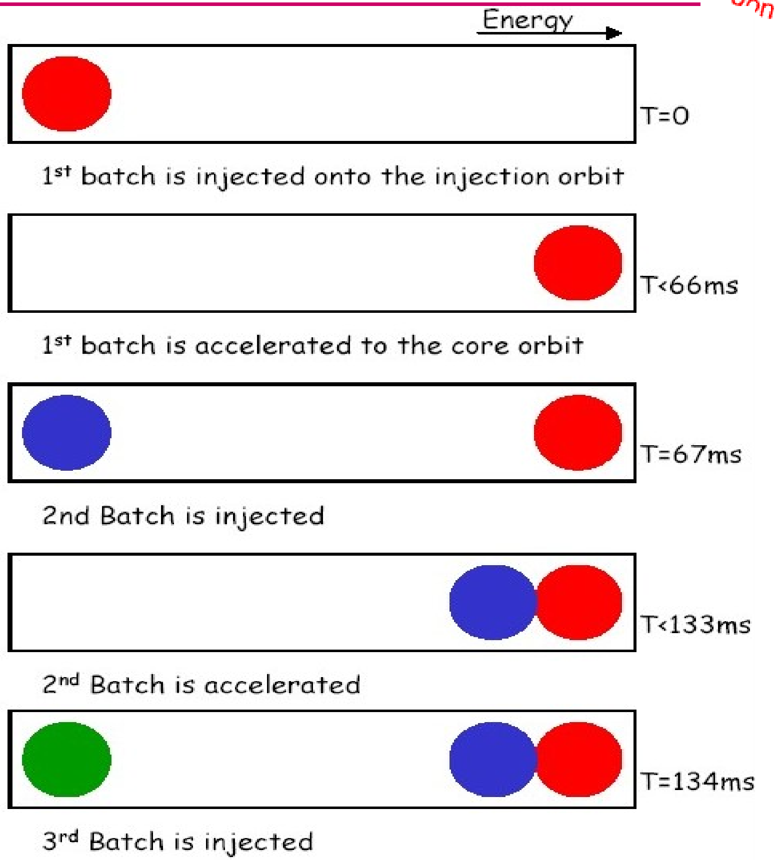
- After ~2009, accumulator and Debuncher, Recycler are not needed for Fermilab Collider
- Can be used for proton programs
- Accumulator could be used for momentum stacking from booster for ~NUMI
- Stacked beam could also be used for μ-e

Parameter	Symbol	Accumulator	Debuncher
Circumference	$C=2\pi R_{ave}$	~474m	504m
Momentum	P	8.89 GeV/c	8.89 GeV/c
Transition γ_T	γ_T	5.4	7.52
betatron fns	β_x, β_y, η max	47, 40, 9.6	19.8, 17, 2.2
Tunes	ν_x, ν_y	6.9, 8.9	9.65, 9.76
aperture	a, b		



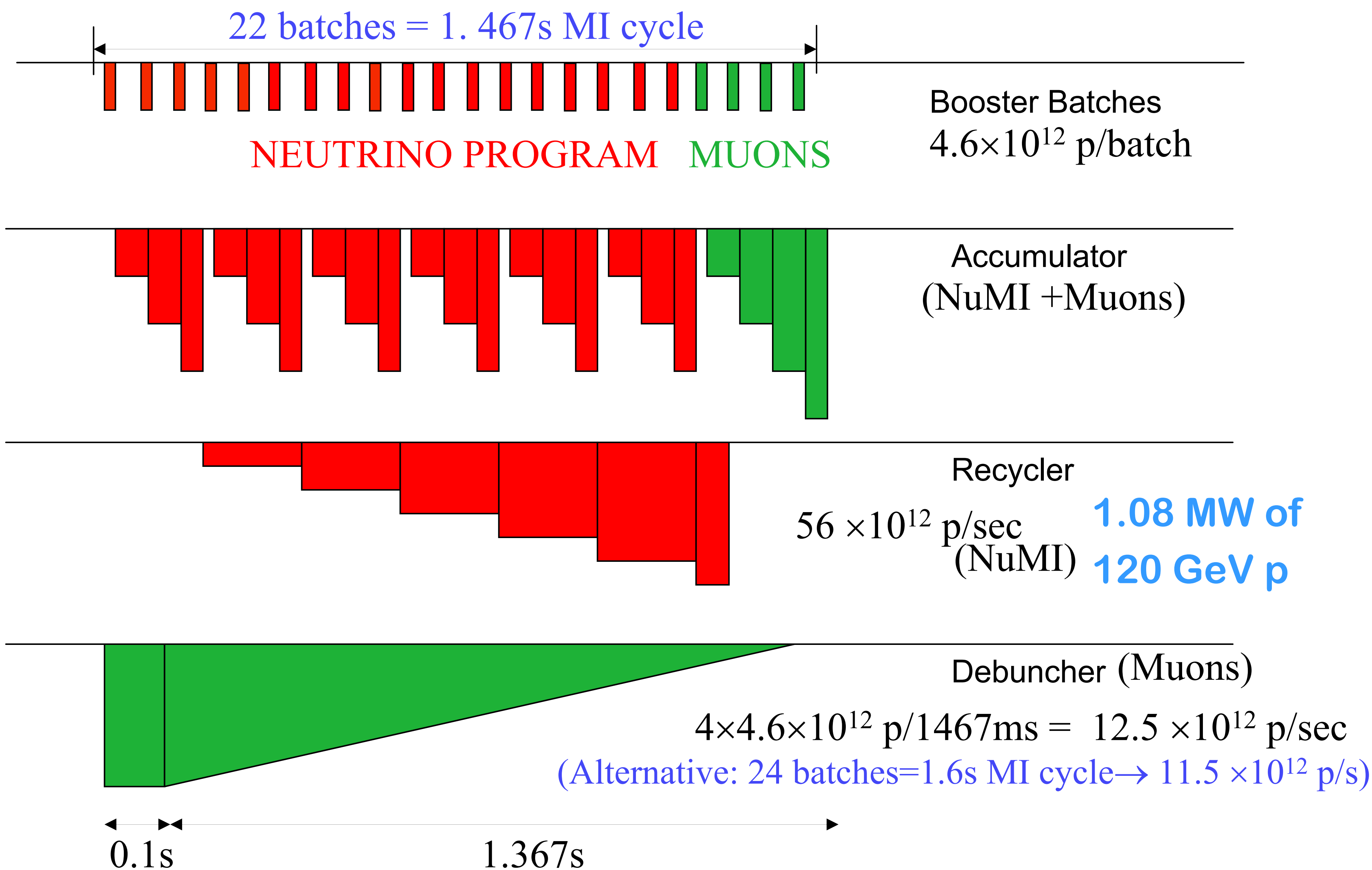
Momentum stacking in Accumulator

- Inject in a newly accelerated Booster batch every 67 mS onto the low momentum orbit of the Accumulator
- The freshly injected batch is accelerated towards the core orbit where it is merged and debunched into the core orbit
- Momentum stack 3-4 Booster batches



Accumulator stacks are boxcar stacked in Recycler;
6 accumulator stacks (18 booster fills) fills Recycler
Transfer to Main Injector for acceleration to 120 GeV

“Superbeam” NEUTRINO PROGRAM + μ-source



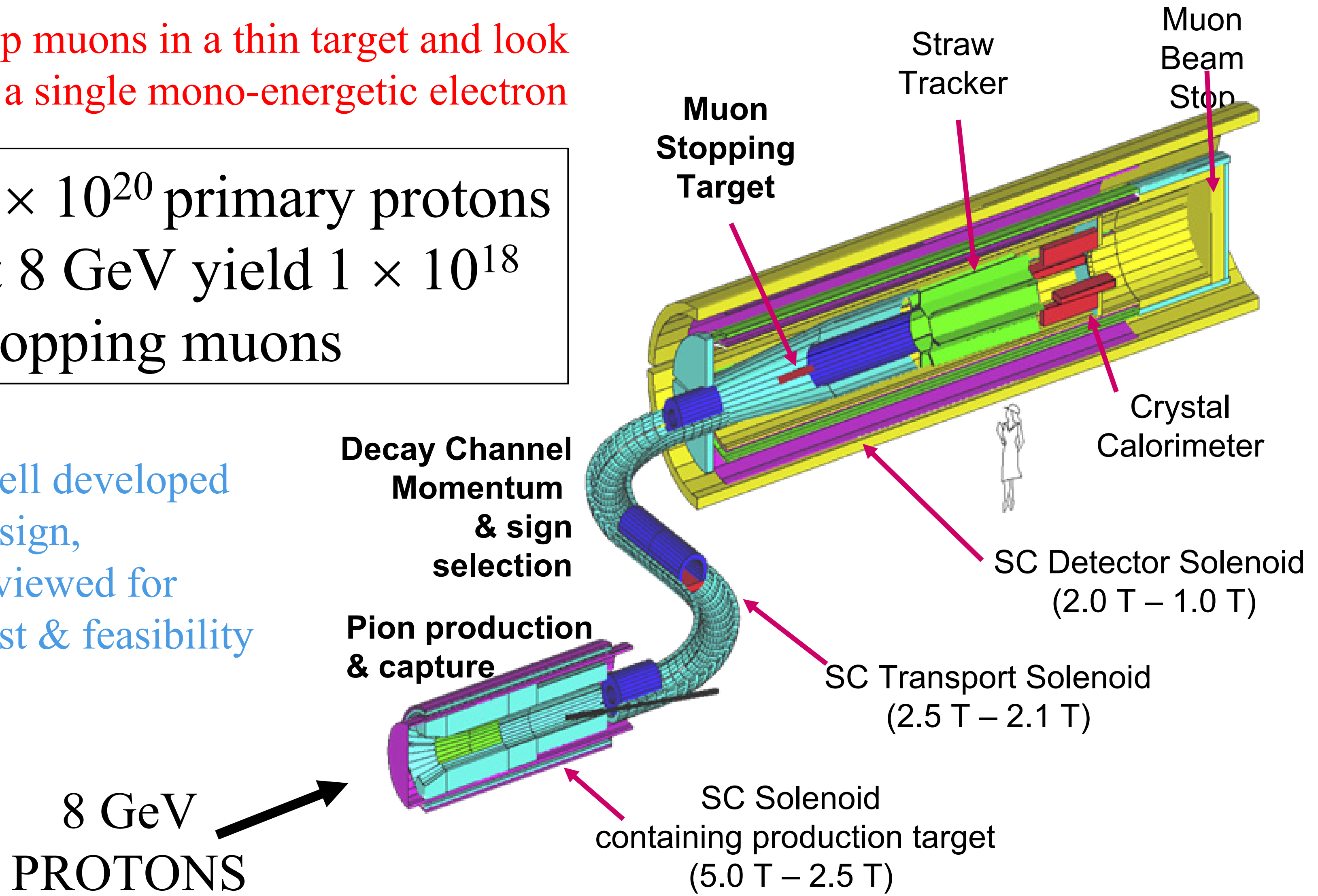
~ MECO PROPOSAL – adapted to Fermilab …

http://www.bnl.gov/henp/mu-e_docs/Draft_MECO_Tech_Prop.pdf

Stop muons in a thin target and look for a single mono-energetic electron

4×10^{20} primary protons at 8 GeV yield 1×10^{18} stopping muons

Well developed design, reviewed for cost & feasibility



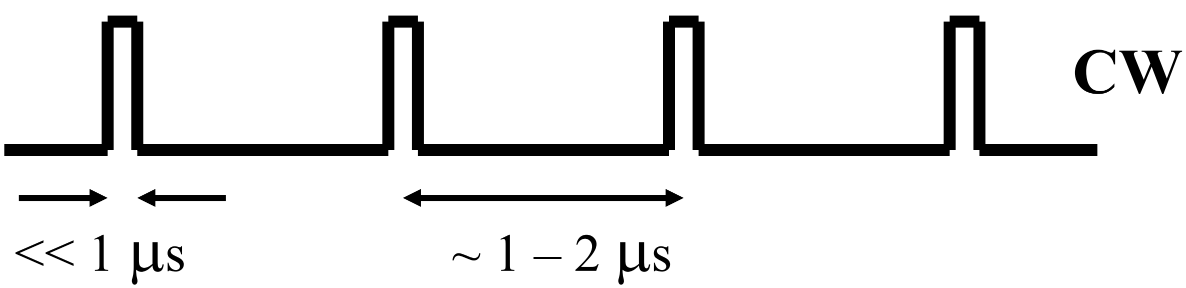
BEAM REQUIREMENTS

To reach MECO goal: Low energy bunched muon beam providing $\sim 10^{18}$ muons per yr: Requires $\sim 10^{20}$ primary 8 GeV protons per yr.

Bunch lengths short compared to the lifetime of muons in a nucleus (1.1 ms for Al), with a bunch spacing longer than this.

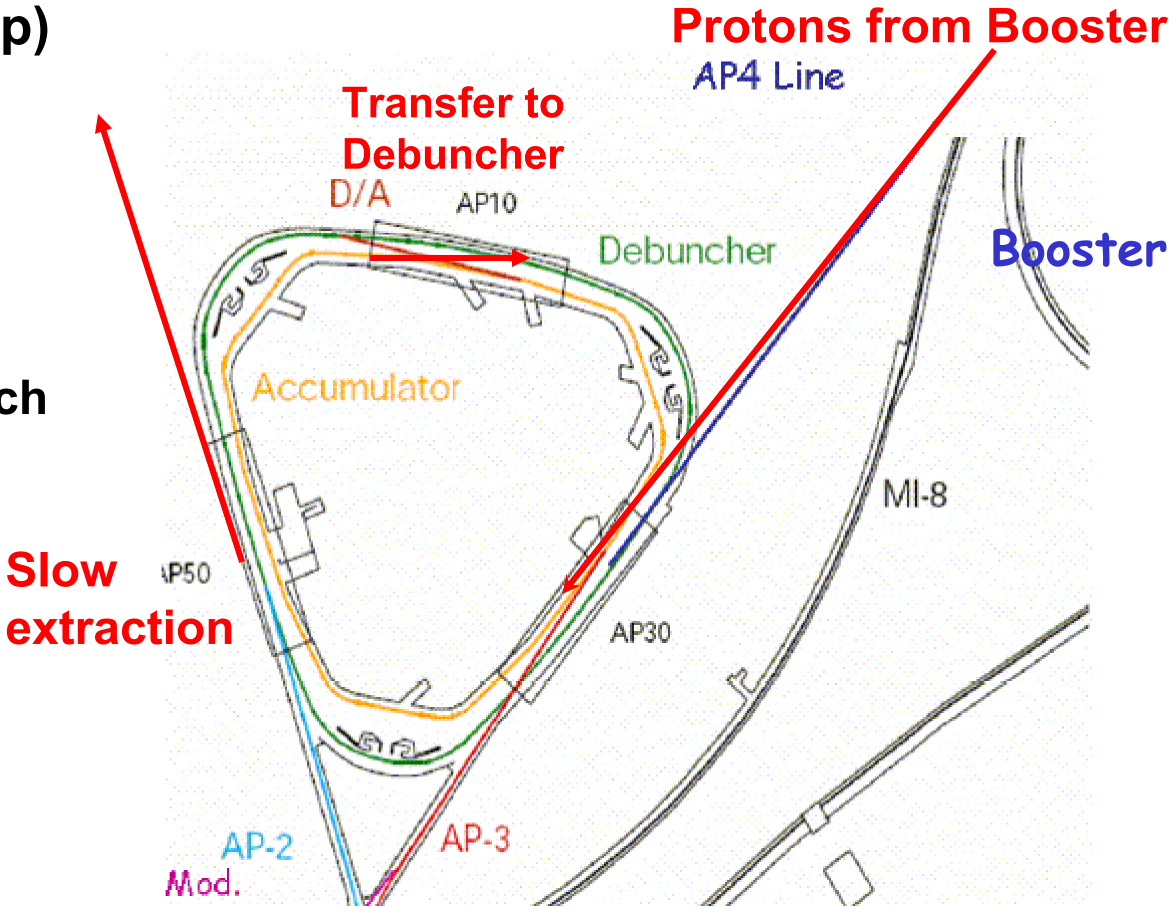
Experimental signature: mono-energetic electron & nothing else. To minimize backgrounds, when there is no incoming primary beam there must be no beam at the level of 1 part in 10^9.

<u>Ideal Bunch Structure for a MECO-like Experiment</u>:



Scenario overview

- Protons from Booster injected into accumulator
- Stack 1 to 4 booster turns, debunch (w/extraction gap)
  - ~$4 \cdot 10^{12}\, n_{turns}$ protons
- Extract into Debuncher
- Rebunch in Debuncher
  - to ~40ns rms single bunch
- Slow extract to muon conversion experiment
  - over ~1.5s



Barrier bucket in Debuncher

- γ_T=7.6- more isochronous
- Needs less rf but more time
- Compression within ~0.2s

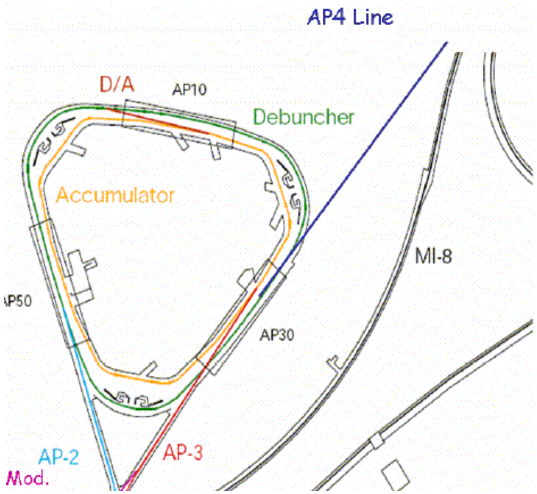
- A:Rf-14kV barrier bucket
  - Square wave rf
- B: h=4 rf 14 to 30 kV
  - Sinusoidal rf

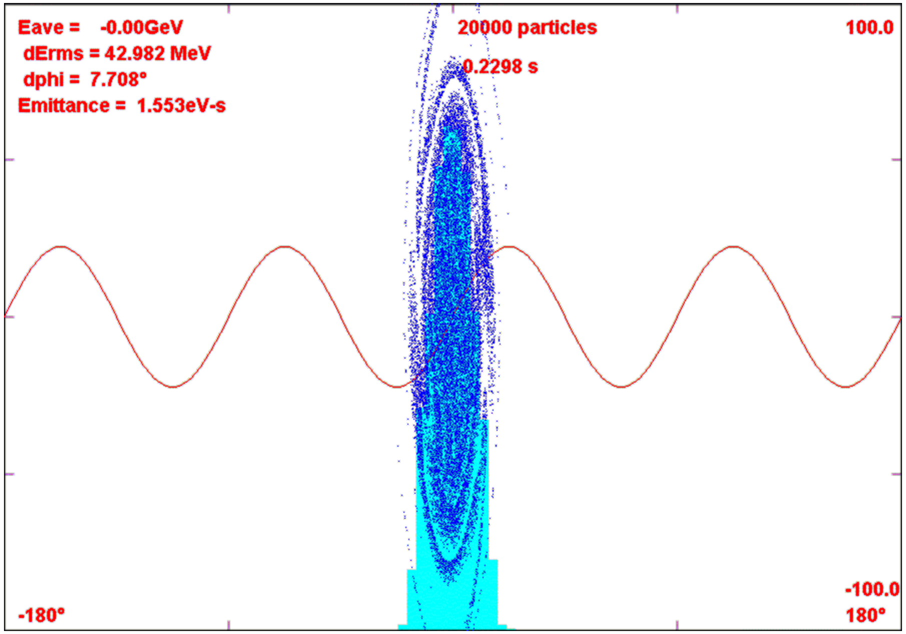
  ~2.5 MHz

- Start:±150°, σ_E = 3.3MeV
  - ~4 batches

- $\varepsilon_L = 6\pi\sigma_t\sigma_E$= ~24 eV-s

- Finish: σ < 30ns, σ_E = 42MeV
  - Small dilution





μtoe EXPERIMENT LOCATION:

Experimental Area could also be used for other π,μ, etc. experiments

Detector

Target

Extracted Beam Line From Debuncher

Future Option: f Proton Driver

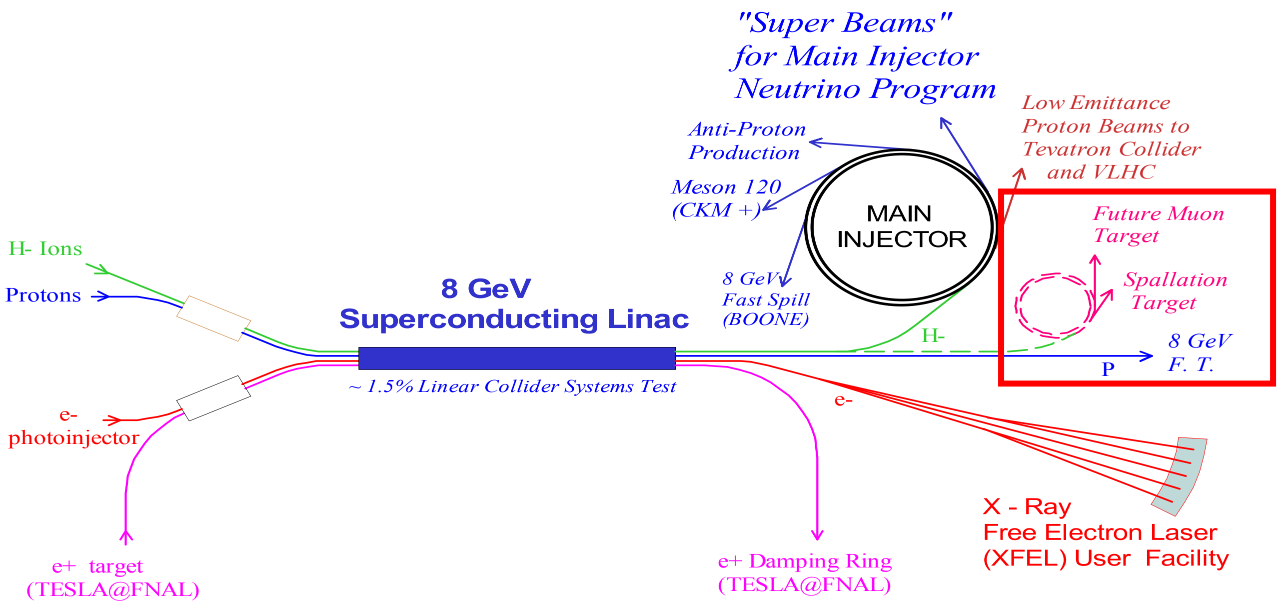
- **Fermilab may develop new proton source to replace "8-GeV" Booster at a multi-MW level**
  - Studied at Fermilab but deferred to focus on ILC
  - R&D continues on technology
    - HINS – "High Intensity Neutrino Source" research
  - deferral will be reevaluated as ILC develops …

- Upgrade options
  - **8-GeV SRF proton linac**
    - **leading high-intensity possibility (HINS research)**
    - **Needs Collector ring for many applications**
  - Booster-like rapid-cycling synchrotron but higher intensity
    - Larger apertures, injection linac upgrade, deeper tunnel

2 MW Proton Driver Parameters (short list)

8 GeV Superconducting LINAC (1300 MHz rf)

Energy	**GeV**	**8**
Particle Type	H- Ions, Protons, or Electrons	
Rep. Rate	**Hz**	2.5 to **10**
Active Length	m	614
Beam Current	mA	25
Pulse Length	msec	3 to **1**
Beam Intensity	**P / pulse**	**1.5E+14** (can also be H-, P, or e-)
	P/s	1.5E+15
Linac Beam Power	MW avg.	**0.5 to 2**
	MW peak	200



Review of the PD/Linac Cost

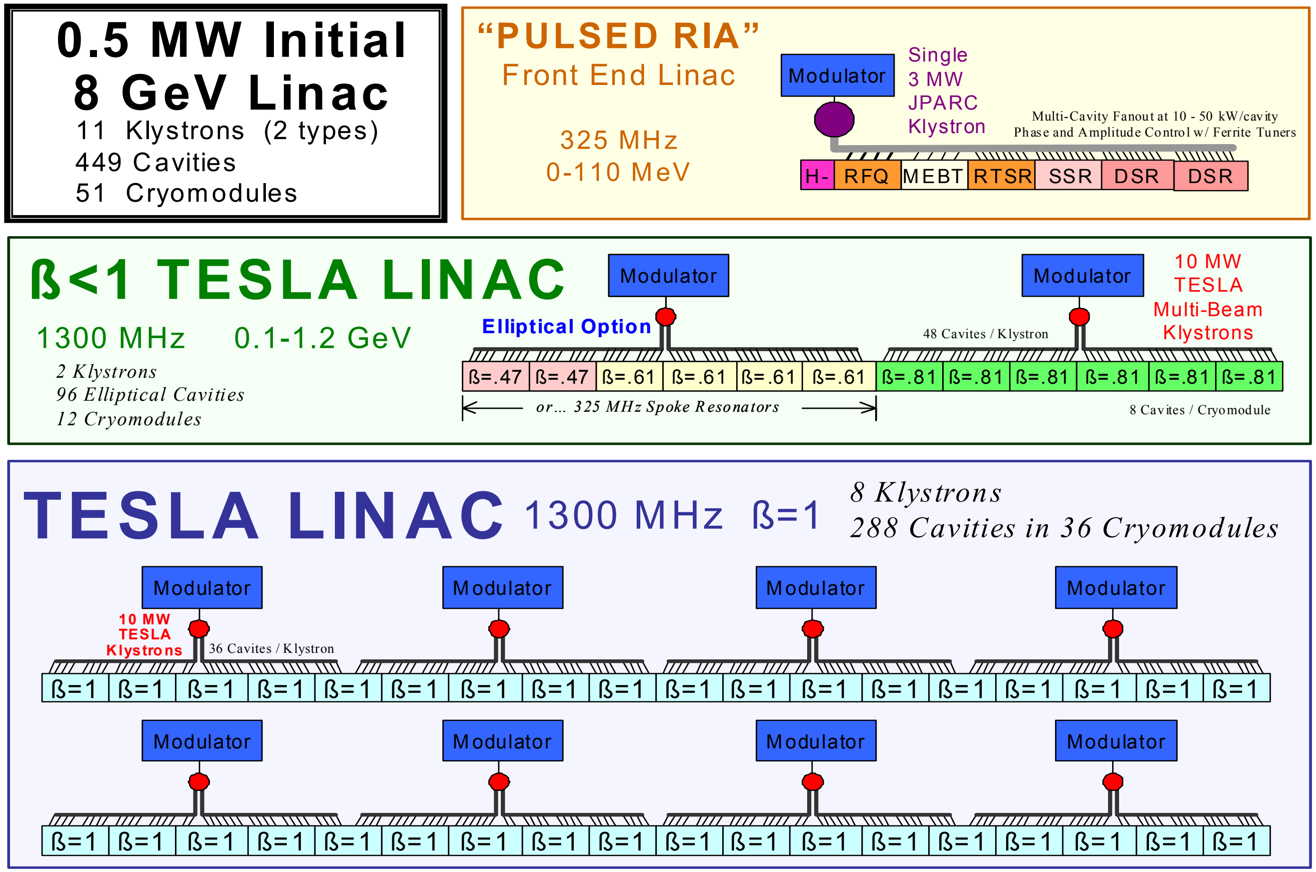
(All costs in 2004 K$)	Linac
Project M&S*	229,779
Project SWF	89,118
Project Subtotal	318,897
G&A# (16.05% M&S & 30.35% Labor)	63,927
Project (incl. G&A)	382,824
Contingency (30%)	114,847
Total Cost	497,670

* Davis Bacon labor shows up as M&S
# G&A rate will be lower on large POs

	Linac 0.5 MW
Total Cost Estimate	*497,670*
Contingency (30%)	*114,847*
Project (incl. G&A)	*382,824*
G&A (16.05 M&S & 30.35% SWF)	*63,927*
Project Subtotal	*318,897*
Project Management	*25,000*
Civil Construction	81,168
EDIA	21,044
In-House EDIA (20% of Total Civil M&S)	12,025
Contracted EDIA (15% of Total Civil M&S)	9,019
Subtotal Civil M&S	60,125
Site Work (incl. environmental controls)	3,107
Utilities	9,431
Enclosures (incl. total OH&P)	22,498
Main PD Enclosure	7,577
Transport Line	8,723
Access Stairs/Alcoves	2,448
Buildings	24,462
Klystron Gallery	7,661
Utility Support Buildings - Cryo	6,273
Service Buildings (4 Req'd)	10,528
Absorber Enclosure	626
Technical Systems	212,728
Front End	8,077
Ion Source	904
Front End and RFQ	2,143
MEBT	644
RT Triple Spoke Resonator	2,108
Beam Diagnostics & Controls	2,278
Cryomodules (incl. warm Debuncher)	101,608
Spokes	23,357
Ellipticals	76,693
Utilities	6,671
LCW	5,896
Vacuum	775
Cryogenic System	28,589
Modulators & Pulse Transformers	13,902
RF Klystrons & Distribution	26,089
Instrumentation & Controls	10,994
8 GeV Transport Line (incl. Injection)	8,773
Absorbers & Misc Elements	1,079
Infrastructure & Integration	6,948

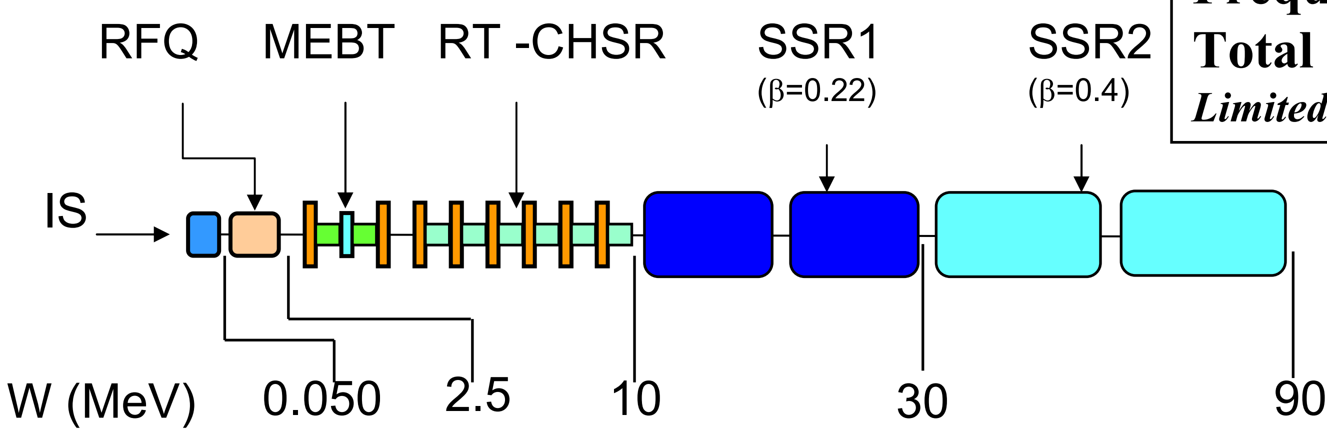
HINS R&D

- Technology development toward Proton Driver
- Build and test 325 MHz section of 8 GeV Linac
  - ion source, 2.5 MeV rfq, 10 MeV RT linac, 100 MeV SRF



HINS Front End - Beam Line Layout

Ion source H^-, LEBT			50 keV
Radio Frequency Quadrupole		4-5 m,	2.5 MeV
MEBT	(2 bunchers, 3 SC sol., chopper)	4 m	
RT TSR section	(16 resonators, 16 SC solenoid)	10 m	10 Mev
SSR1 section	(18 resonators, 18 SC solenoids)	14 m	30 MeV
SSR2 section	(22 resonators, 12 SC solenoids)	20 m	90 MeV

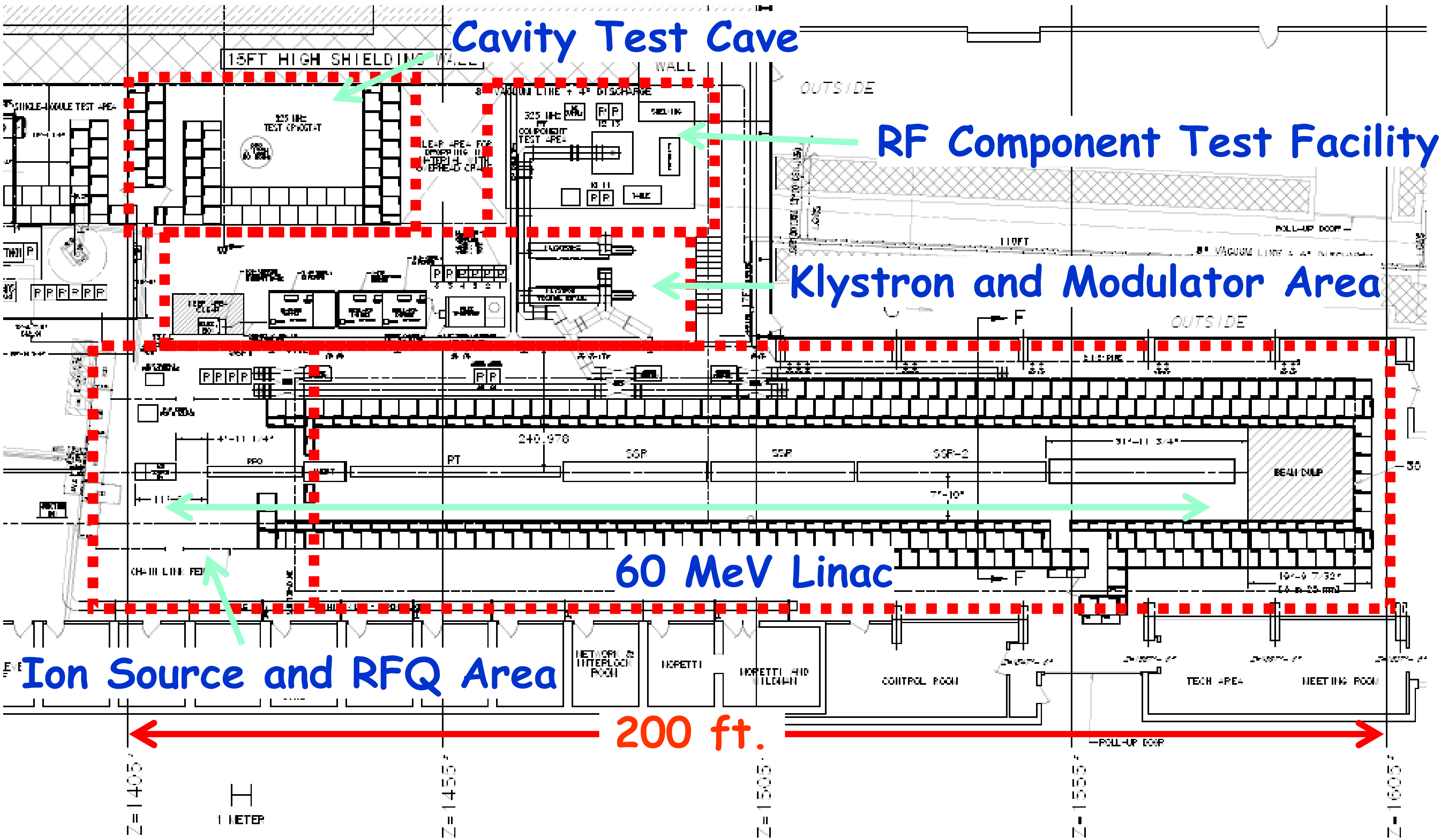


Frequency 325 MHz
Total length ~ 55 m
Limited by Meson Building

HINS Schedule 2006-2008

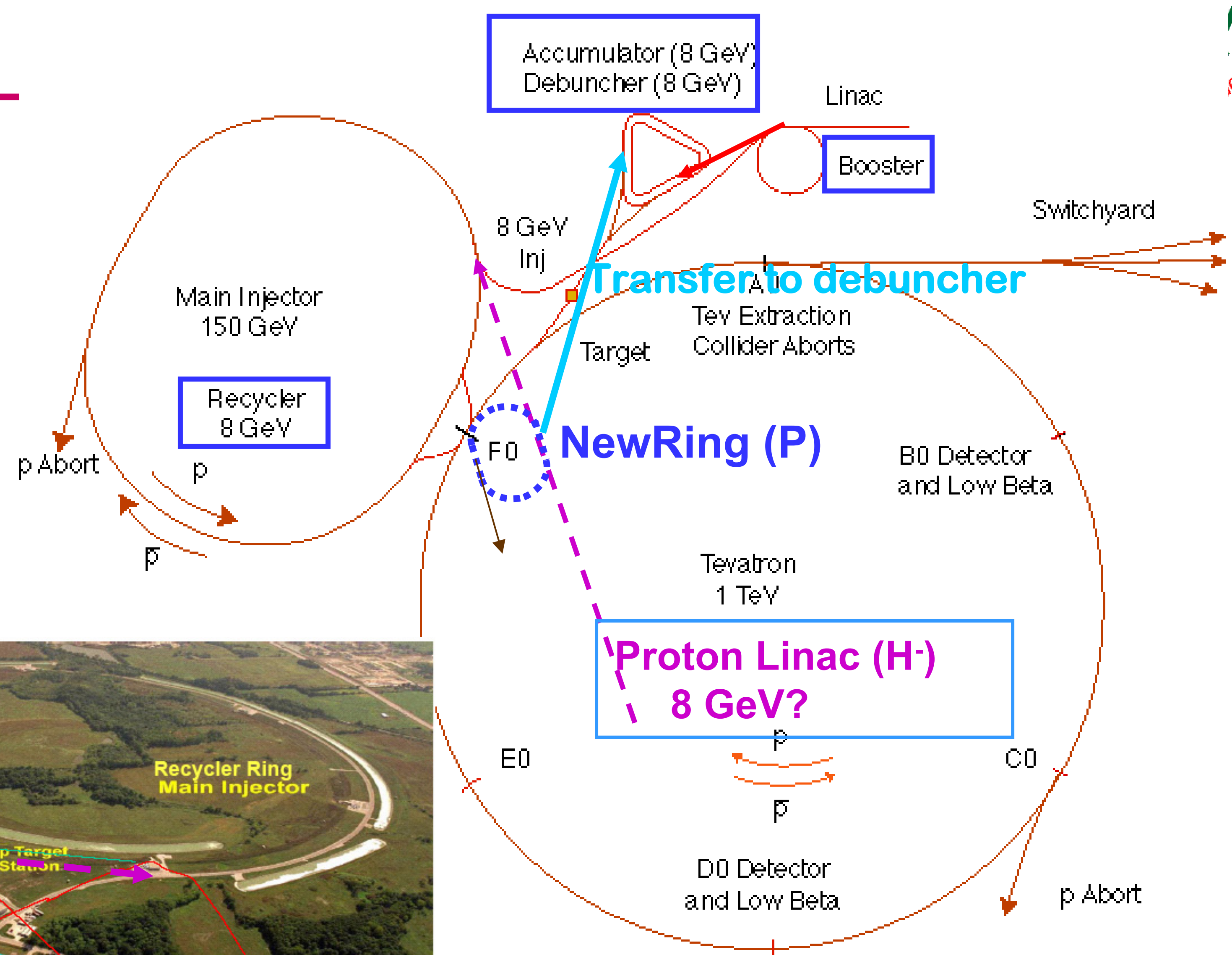
- 325 MHz RF power system, rf component tests
  - July 2006
- Superconducting cavity test cryostat installation
  - October 2006
- Ion Source installation in Meson Lab
  - November 2006
- RFQ delivery and power testing
  - January 2007
- 2.5 MeV beam tests
  - Beginning February 2007
- First SC spoke resonator power tests in test cryostat
  - April 2007
- Full 10 MeV RT linac installed; Beam operation
  - April 2008
- First SC spoke resonator cryomodule installation
  - October 2008
- Tests of RT + SC cavity RF distribution and control, 20 MeV Beam
  - December 2008

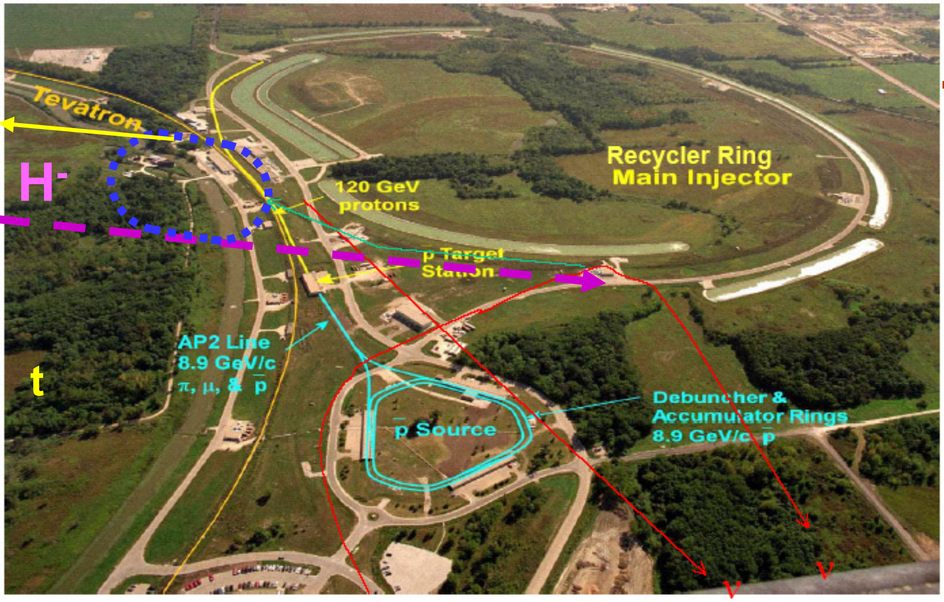
Meson Building Floor Plan



8 GeV f

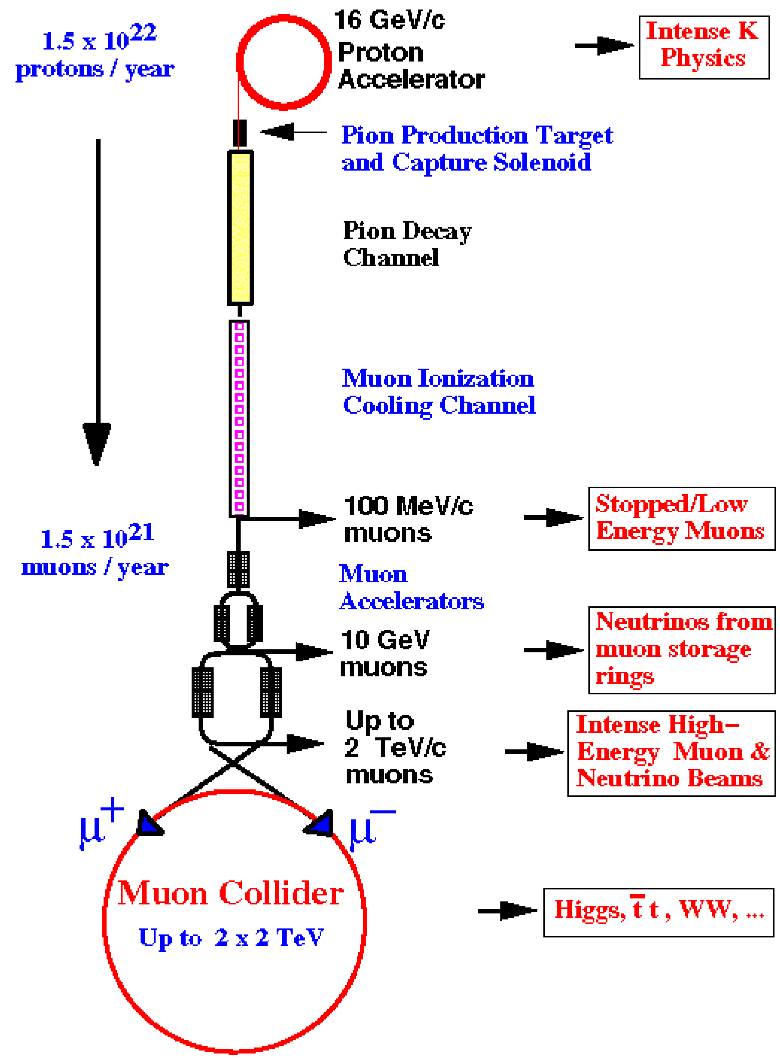
Proton sources





f APC program: μ^+–μ^- Collider

- Recent advances
  - Improved cooling scenarios
  - Muons, Inc. innovations
    - gas-filled rf cavities
  - "Complete" cooling scenario
- Potential high-energy machine if ILC not enough energy …
- Cooling innovations may enable "low-emittance" collider
  - helical cooling channel
  - Parametric resonance cooling
  - Reverse emittance exchange
  - low-energy cooling
- LEMC workshop Fermilab
  - Feb 12-16



μ^+–μ^- Collider Parameters

Parameter	4TeV(2000) NFMCC baseline	4TeV low emittance Muons, Inc. inspired
Collision Energy($2E_\mu$)	4000	4000 GeV
Energy per beam(E_μ)	2000	2000 GeV
Luminosity($L=f_0 n_s n_b N_\mu^2/4\pi\sigma^2$)	10^{35}	10^{35} $cm^{-2}s^{-1}$
Source Parameters	4 MW	0.9 MW p-beam
Proton energy(E_p)	16	8 GeV
Protons/pulse(N_p)	$4\times3\times10^{13}$	$2\times1\times10^{13}$
Pulse rate(f_0)	15	20 Hz
μ acceptance(μ/p)	0.2	0.05
μ-survival (N_μ/N_{source})	0.4	0.2
Collider Parameters		
Mean radius(R)	1200	1000 m
μ /bunch($N_{\mu\pm}$)	2.5×10^{12}	2×10^{11}
Number of bunches(n_B)	2	2
Storage turns($2n_s$)	1500	2000
Norm. emittance(ε_N)	0.6×10^{-2}	2.5×10^{-4} cm-rad
Geom.. emittance($\varepsilon_t=\varepsilon_N/\gamma\beta$)	3×10^{-6}	1.3×10^{-7} cm-rad
Interaction focus β_0	0.3	0.1 cm
IR Beam size $\sigma=(\varepsilon\beta_0)^{1/2}$	3.1	0.36 μm
$\delta E/E$ at collisions	0.12	0.2%

Summary/Comments

- **A proton source is important for Fermilab future**
- **Proton source could be:**
  - **extension of existing facilities**
  - **New facility based on 8 GeV SRF Linac**

- **Accelerator Physics Center:**

New 8 GeV **Accumulator/buncher/stretcher**

- Type: FODO racetrack,
  - Superferric arcs
  - nonscaling
- H^- injection into NewRing (10Hz)
  - 700 turns
  - Transverse emittance can be enlarged (ε_N =120π mm-mrad or more 20mm-mrad rms)
- Harmonic 4 buncher for ν-Factory, single bunch extraction (400ns spacing)
- single bunch extraction mode
- Also useful for PRISM/PRIME, muon collider, …

Circumference	$C=2\pi R_{ave}$	~454m
Momentum	P	8.89 GeV/c
rf frequency, Voltage	h=4 V_0	2.6 MHz <1MV
Slip factor	$\eta=1/\gamma^2-1/\gamma_t^2$	-0.022
Tunes	ν_x, ν_y	6.9, 8.9
aperture	a, b	~8, 5 cm