Fermilab and Muons
Proton Driver
(for ν-Factory, μ^+-μ^- Collider, …)

David Neuffer
Fermilab

Outline

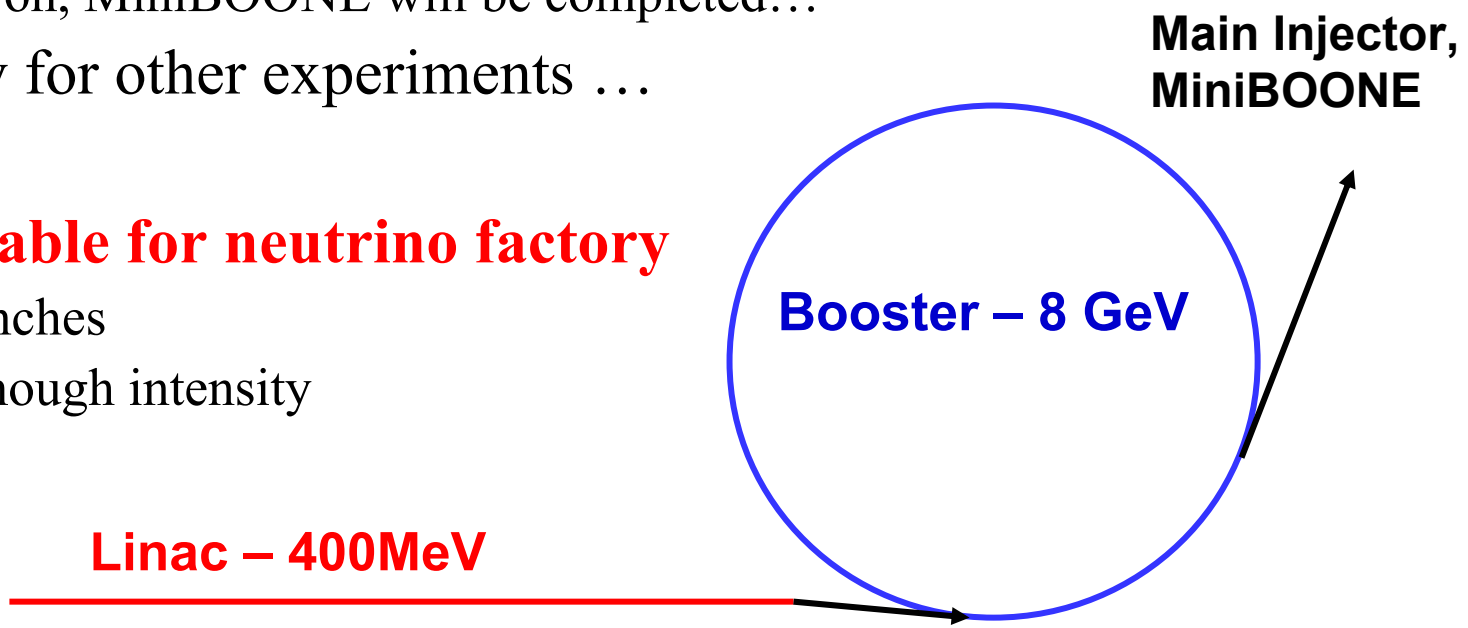
- Fermilab: Protons and Muons
- Present Proton source: Booster
- Future Source : Proton Driver
- Possible configurations, intensities

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
- **5Hz, ~ 3 × 10^{12}/ pulse: ~1.5×10^{20} p/year (0.02MW)**
- 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 …
- **Not suitable for neutrino factory**
  - 80 bunches
  - Not enough intensity

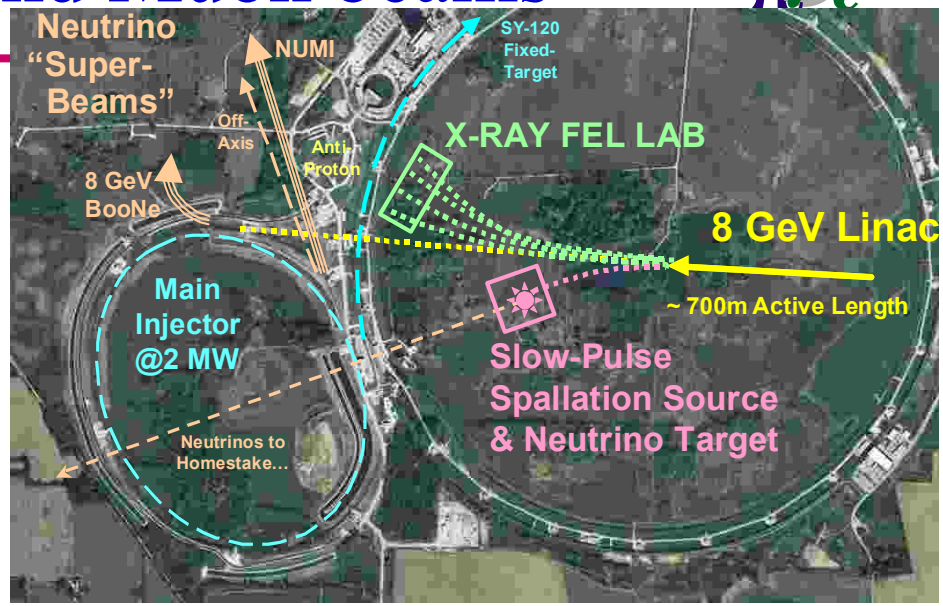


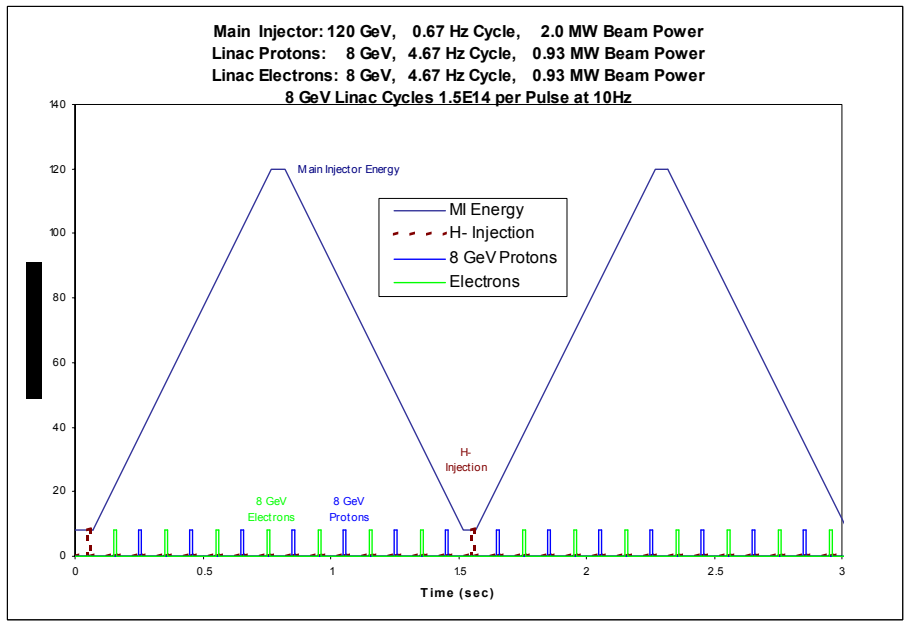
Proton Driver and Muon beams

- **8GeV Linac** can produce streams of 1.5×10^{14} 8GeV protons at up to 10Hz
  - **$> 10^{22}$ protons/year**
- **Neutrino Physics: main goal**
- But: Only 1/15 of these needed for Main Injector/NUMI

- **Are there muon beam experiments** that could use this intensity ??
- Tertiary muon beams:
  - $P + X \rightarrow \pi$
  - $\pi \rightarrow \mu + \nu$
- 10^{-1} $\mu/p \rightarrow$ **10^{21} μ/year or more**

(other experiments will also be possible)





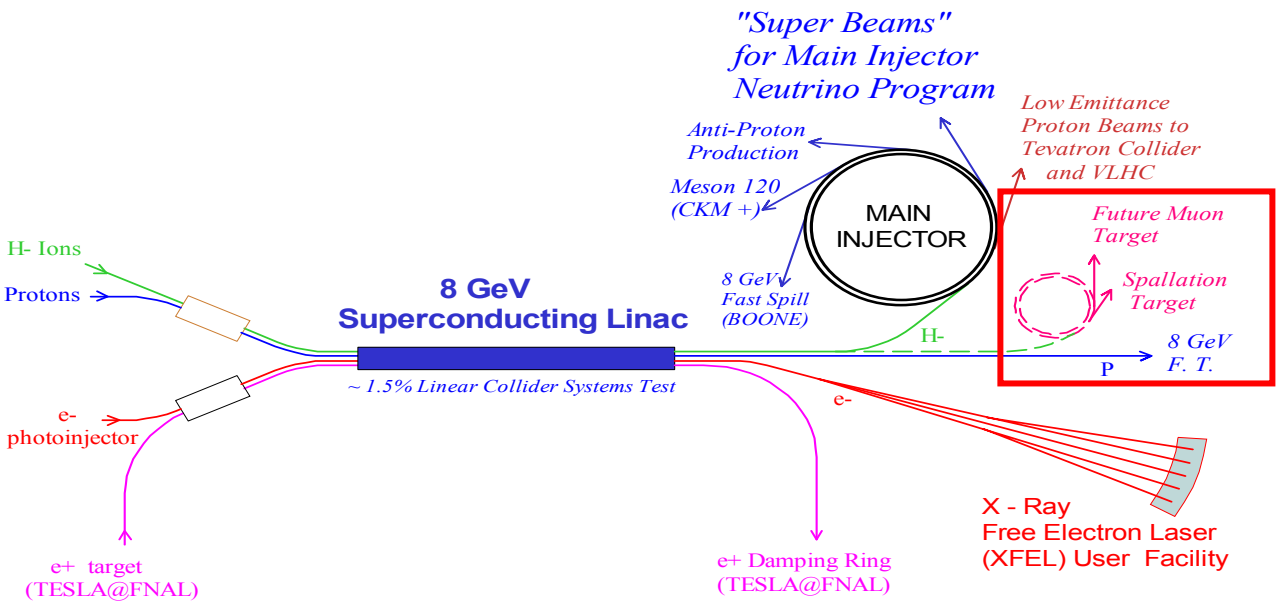
Primary Parameter List (Foster, March 2005 reference)

PRIMARY PARAMETERS	8 GeV Initial 0.5 MW {Ultimate 2MW in Brackets}		
Linac beam kinetic energy	8	GeV	
Linac Particle Types	H - ions		Baseline Mission
	Protons		via foil stripping in transfer line
	Electrons		Possible w/upgrade of Phase Shifters & Injector
Linac Stand-Alone Beam power	0.5 {2.0}	MW	8 GeV beam power available directly from linac
Linac Pulse repetition rate	2.5 {10}	Hz	
Linac macropulse width	3.0 {1.0}	ms	
Linac current (avg. in macropulse)	8.7 {26}	mA	
Linac current (peak in macropulse)	9.3 {28}	mA	
Linac Beam Chopping factor in macropulse	94	%	For adiabatic capture with 700ns abort gap.
Linac Particles per macropulse	1.56E+14		
Linac Charge per macropulse	26	uC	
Linac Energy per macropulse	208	kJ	
Linac average beam current	0.07 {0.26}	mA	
Linac beam macropulse duty factor	0.75 {1.0}	%	
Linac RF duty factor	1.00 {1.3}	%	
Linac Active Length including Front End	614	m	Excludes possible expansion length
Linac Beam-floor distance	0.69	m =27 in.	same as Fermilab Main Injector
Linac Depth Below Grade	9	m	same as Fermilab Main Injector
Transfer Line Length to Ring	972	m	for MI-10 Injection point
Transfer Line Total Bend	40	deg	two 20-degree collimation arcs
Ring circumference	3319.4	m	Fermilab Main Injector
Ring Beam Energy	8-120	GeV	MI cycle time varies with energy
Ring Beam Power on Target	2	MW	~ independent of MI Beam Energy
Ring Circulating Current	2.3	A	
Ring cycle time	0.2-1.5	sec	depends on MI beam energy & flat-top
Ring Protons per Pulse on Target	1.50E+14	protons	
Ring Charge per pulse on target	25	uC	
Ring Energy per pulse on target	200-3000	kJ	at 8-120 GeV
Ring Proton pulse length on target	10	us	1 turn, or longer with resonant extraction
Linac Wall Power	5.5 {12.5}	MW	approx 3 MW Standby + 1MW / Hz

Proton Driver Parameters (short list)

8 GeV Superconducting LINAC

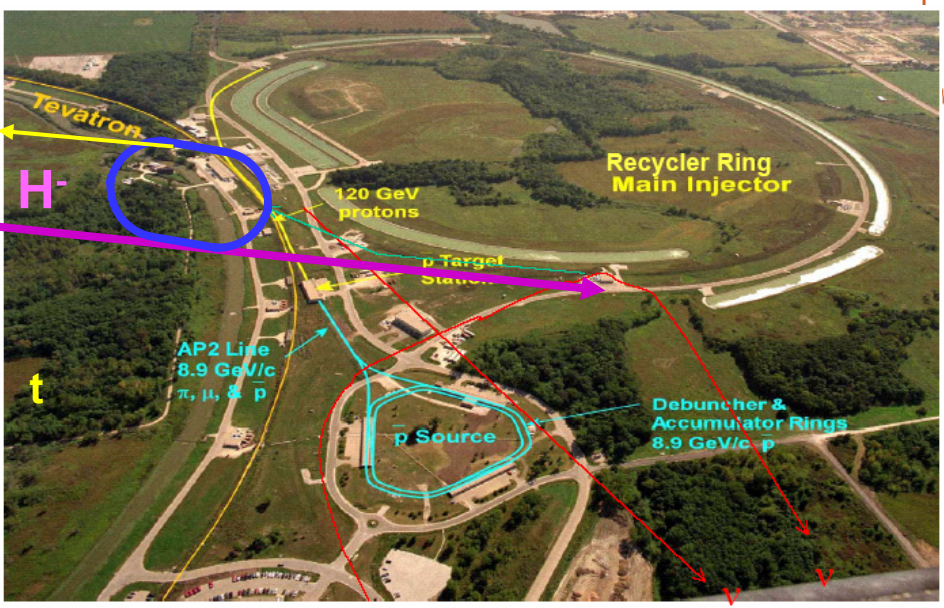
Energy	**GeV**	**8**	
Particle Type	H- Ions, Protons, or Electrons		
Rep. Rate	**Hz**	2.5 to **10**	
Active Length	m	614	
Beam Current	mA	25	
Pulse Length	msec	3 to **1**	
Beam Intensity	**P / pulse**	**1.5E+14**	(can also be H-, P, or e-)
	P/s	1.5E+15	
Linac Beam Power	MW avg.	**0.5 to 2**	
	MW peak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



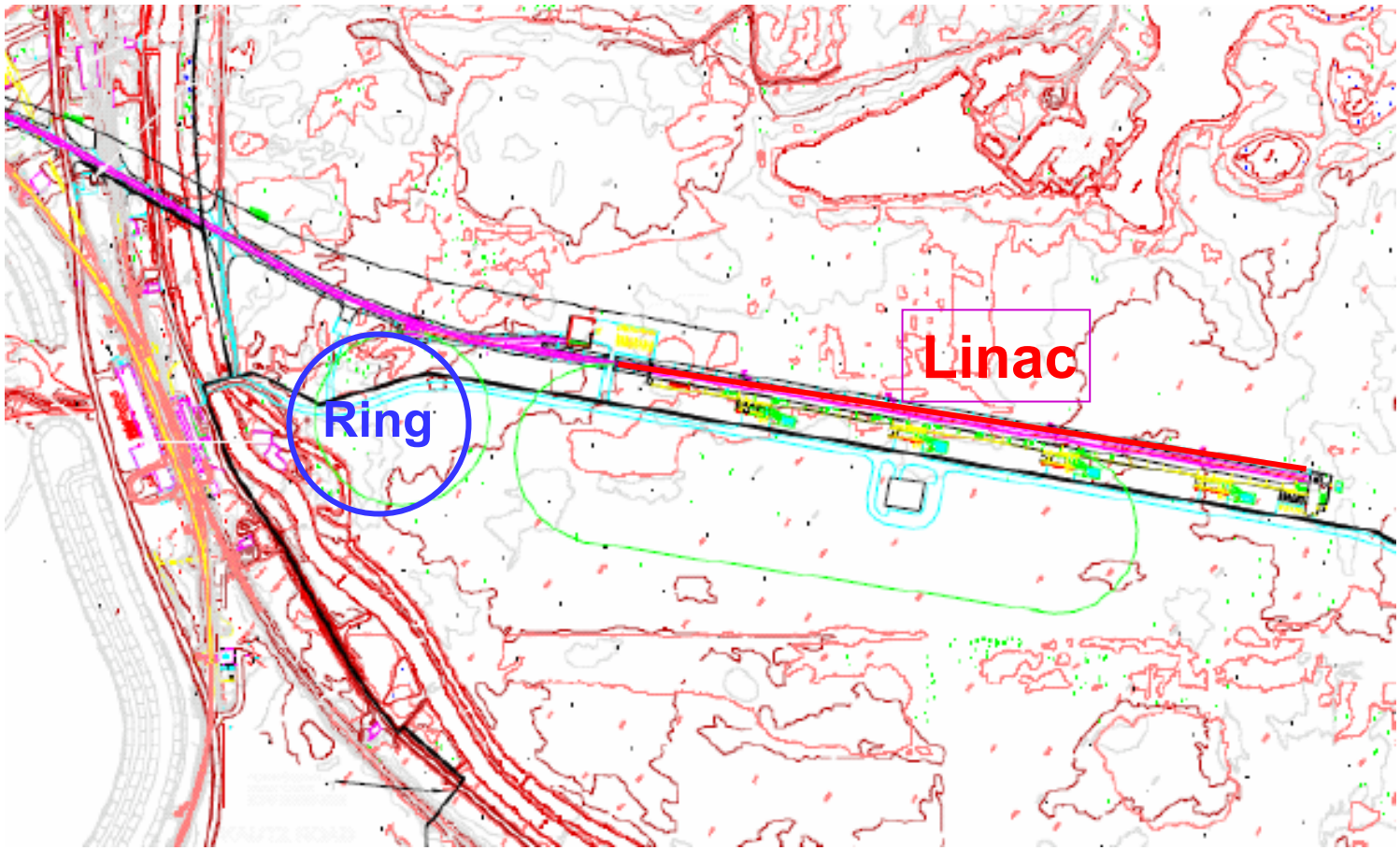
Proton Driver bunch structure

- Proton Linac produces 1ms string of bunches (1300Mz SRF, 325MHz spacing (350000 bunches ….)
- ν-Factory wants single bunches,(~15Hz)
- **Add Buncher ring to accumulate protons**
  - H^- injection, stripped to protons
  - Transverse emittance increases
  - 1ms inject, ~50 ms to bunch into small number of short bunches
- Strawman scenario
  - 454m storage ring (booster size), bunch into 4 bunches
  - Extract bunch by bunch onto target (up to 20 Hz cycle)

FermilabTevatron Accelerator With Main Injector



Layout on Fermilab site



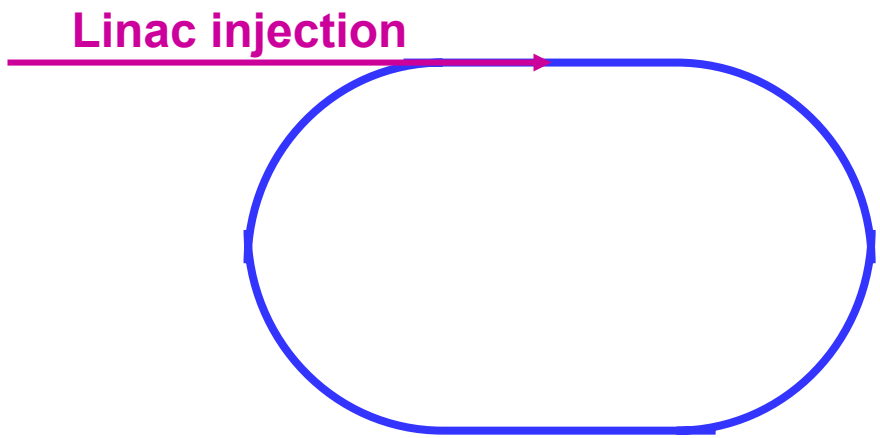
Proton Beam Scenario for ν-Factory

- **Proton Driver Linac**
  - 1 ms pulses of 8 GeV H^- ions, up to 10 Hz
  - Up to 1.5×10^{14} H^-/pulse (1.5×10^{15}/s) – **2MW**
  - **Go to 20 Hz for 4MW (22.5MW wall-plug power)**
- **Accumulator/Buncher Ring (454m)**
  - Charge-exchange multiturn injection $H^-\rightarrow p$ (1ms, 700 turns)
  - Bunch into $n_B = 4$ bunches over ~50ms
  - Extraction of short bunches (σ_z<5ns) over ~50ms
  - Up to 40 bunches/s onto π-production target (Hg-jet) (80/s at 4MW)
- **Neutrino Factory**
  - **1.5×10^{15} p/s,** 1.5×10^{22} p/year
  - 1.5×10^{21} μ/year at 0.1μ/p
- 2-bunch (or 4) half-size ring also possible (227m)
  - -better for ν-Factory
  - 20 bunches/s on target (40/s at 4MW)

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



Space Charge Difficulty

- Space Charge tune shift:

$$\delta\nu = \frac{3 r_p N_{tot}}{2\beta\gamma^2 B_F \varepsilon_N}$$

- Parameters: $N_{tot}=1.5\times10^{14}$, $\varepsilon_N = 120\pi$ mm-mrad
  - Emittance was increased to reduce δν

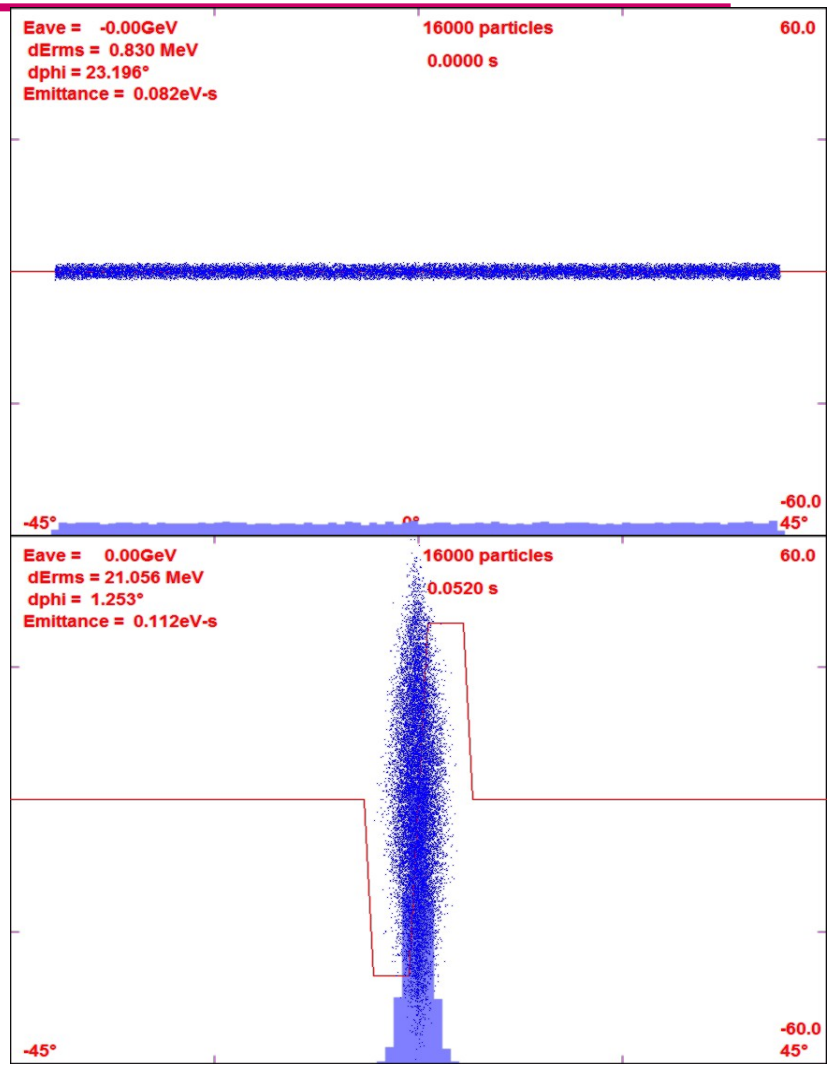
$$\delta\nu = \frac{0.01}{B_F}$$

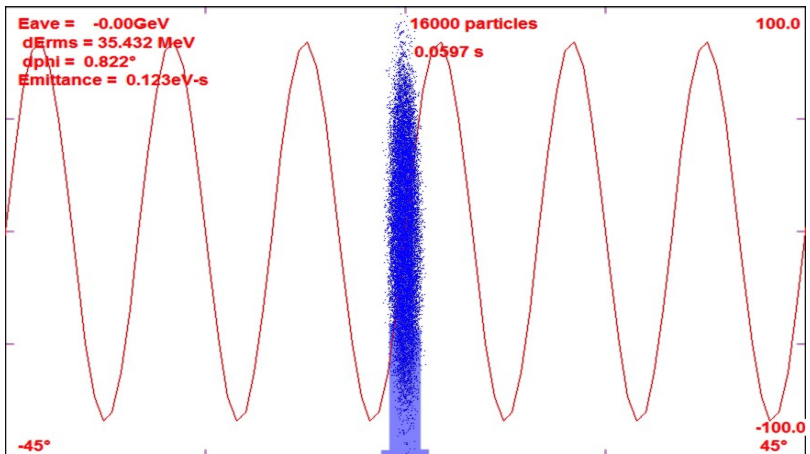
- **Booster-size Ring: 4 bunches, 4*10ns/1.5μs** : B_F= 0.027
  →δν = ~ 0.375 : not too large
  - σ_z = ~4ns, up to 40 Hz bunches on target
  - Shorter bunch possible with extraction compressor
    - (σ_z <4ns ?)

- **Smaller circumference proton ring could be better**
  - C= 227m, 2 bunches; would obtain 20Hz on target

Bunching example (454m ring)

- Bunch to short bunches with barrier-bucket rf within ~0.05s
- V_{rf} = 400kV, 5° pulse width
- Compresses to ~5ns rms
- Add h=24 rf to get <4ns
- Compression not optimized





Summary

- **Proton driver with new storage ring could provide intense 8GeV bunches for ν factory or μ^+–μ^- Collider**

- **PRISM/PRIME, other expts., etc. …** could be hosted

- More Detailed design needed
  - Proton Collection
    - **New Stretcher/Buncher ring**
  - Beam line(s)
  - ν–Factory layout
  - Experimental area(s)

Proton Driver Cost