Proton Buncher Options for Muon Colliders

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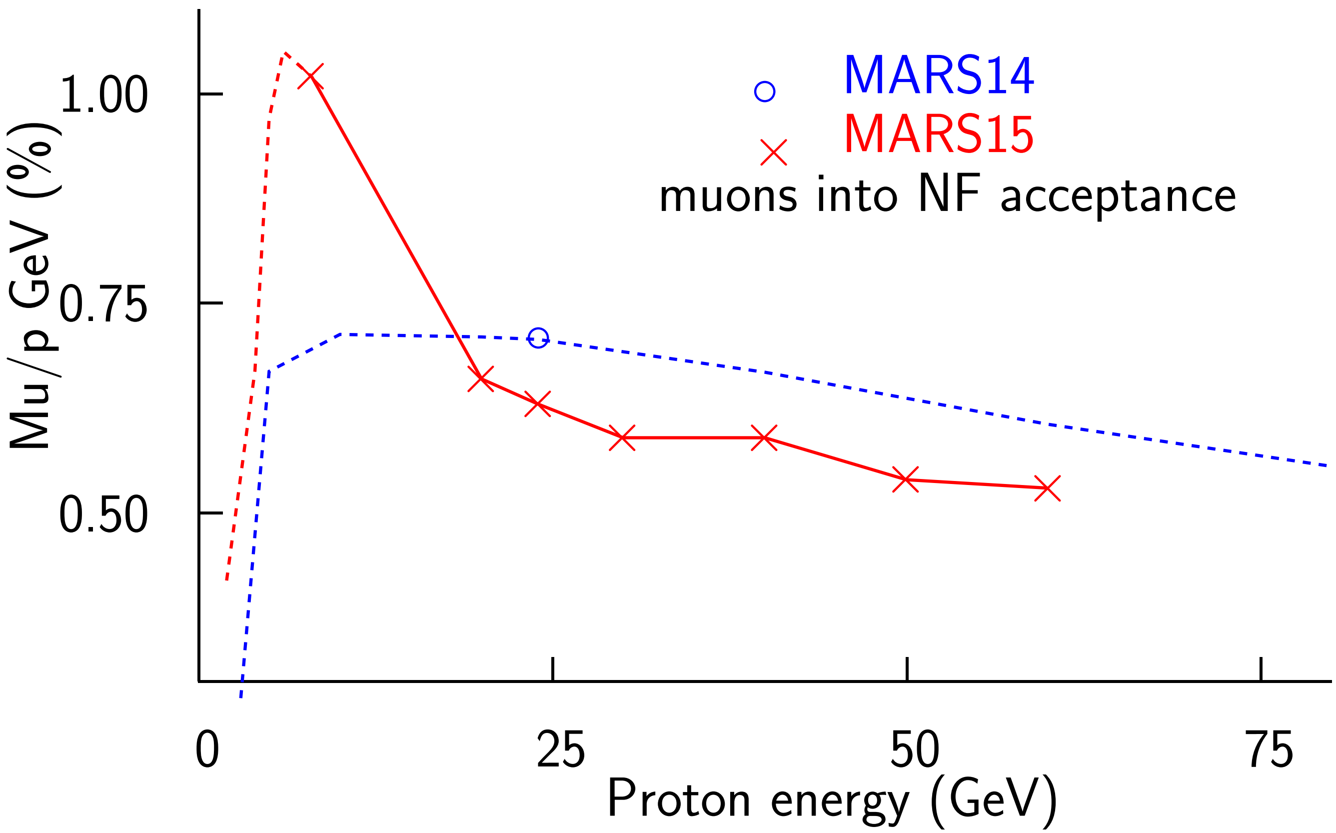
1. parameters of Colliders
2. Pion Production vs proton energy
3. Space Charge Tune Shift Calculation
4. Buncher Options
5. Conclusion

Pion production



- Production predicted by MARS15 with optimized target rad and length
- Peak is at 8 GeV
- Production, inc. cooling at 8 GeV=1.44 $\times$ MARS14 ISS & FS2a at 24 GeV
- Production down to 51% at 60 GeV

Parameters

C of m Energy	1.5	3	TeV
Luminosity	0.77	3.4	10^{34} cm^{2}sec^{-1}
Muons per bunch	2	2	10^{12}
Muon per 8 GeV p	0.008	0.007	
Protons per bunch at 8 GeV	170-250*	190-280*	10^{12}
Repetition Rate	15	12	Hz
Proton Driver power	3.5-4.8 *	3.0-4.3 *	MW

* Protons & power requirements include/exclude MARS15 8 GeV gain

- In what follows I will assume the higher proton intensities and power

Space Charge Tune Shift (S Y Lee p110)

$$\Delta\nu \;=\; F_{dist} \left(\frac{2\pi R}{\sqrt{2\pi}\;\sigma_z}\right) \frac{N_p\; r_o}{2\pi\;\epsilon_N\;\beta_v\gamma^2}$$

- For Gaussian beams $F_{dist} = 3.8$
- ϵ_N is normalized (95%) emittance as used for protons at FNAL
- $\epsilon_\perp\; (= \epsilon_N/6)$ used in Muon Collider studies is normalized and rms
- Remember that normalized emittances, for the same beam dimensions and momentum, depend on mass
- The ring circumference is $C \;=\; 2\pi R$

$$\Delta\nu \;=\; 0.63 \left(\frac{C}{\sqrt{2\pi}\;\sigma_z}\right) \frac{N_p\; r_o}{2\pi\;\epsilon_\perp\;\beta_v\gamma^2}$$

FNAL Booster to check calculation

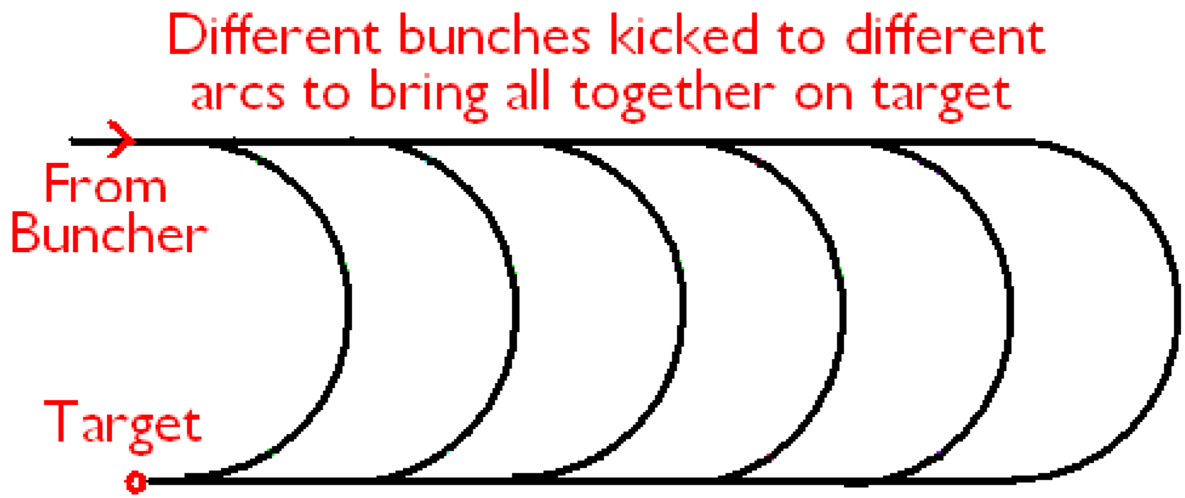
1. FNAL Booster at 400 MeV injection.
   $N_p = 6\;10^{10}$ circ=474 (m) $\sigma_z \approx$ 1.5 (m) $\Delta\nu =$ 0.4 (as published)

8 GeV Buncher Examples

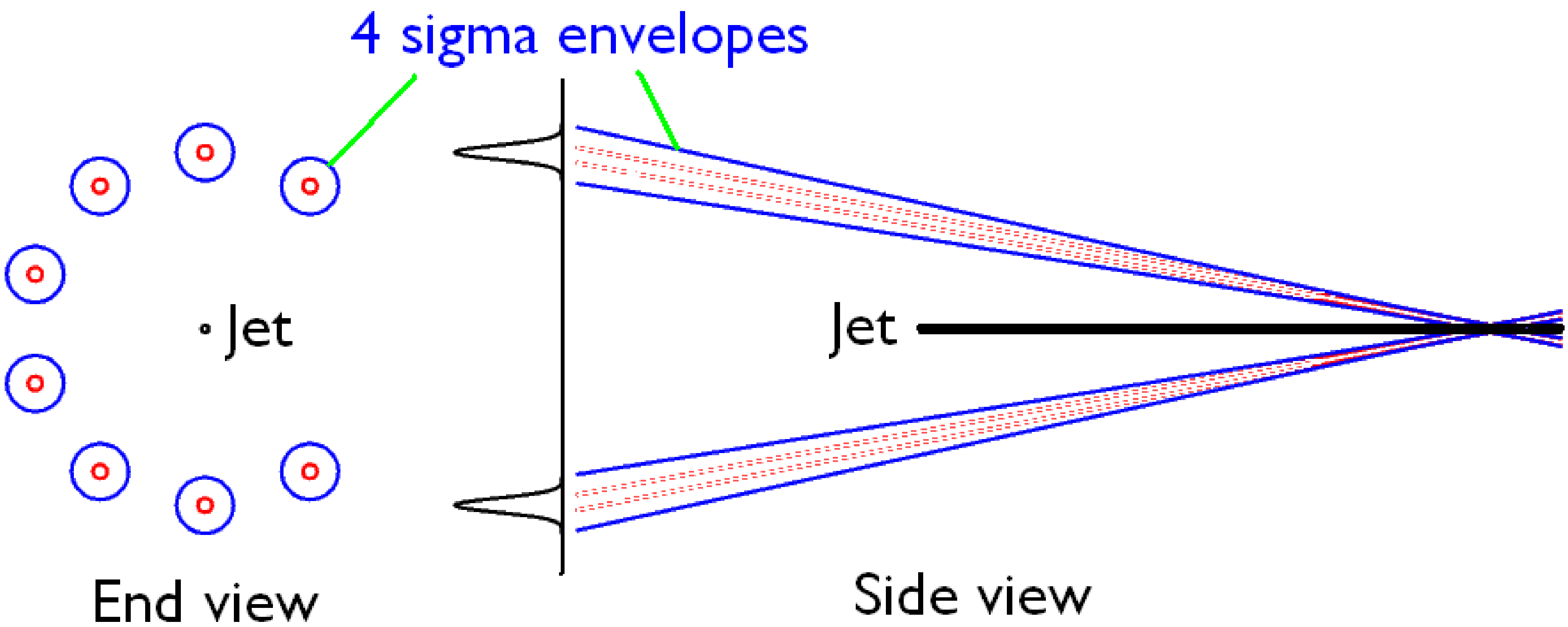
2. Use booster-like ring for bunching 250 Tp to 1 m at 8 GeV
   Assume emittance giving same beam size as at booster injection ($\epsilon \propto \beta_v \gamma$)
   With single bunch, $\Delta\nu = 4.2$ Very bad

3. Assume, with superconducting magnets (5T vs. 1T), we should get same acceptance with a smaller circumference
   with the needed straight sections, 200 (vs 474) m should be possible
   With single bunch, $\Delta\nu = 1.8$ Still not ok

4. Same as above but with 8 bunches separately extracted and merged after trombones (Ankenbrand)
   $\Delta\nu = 0.22$ which is ok

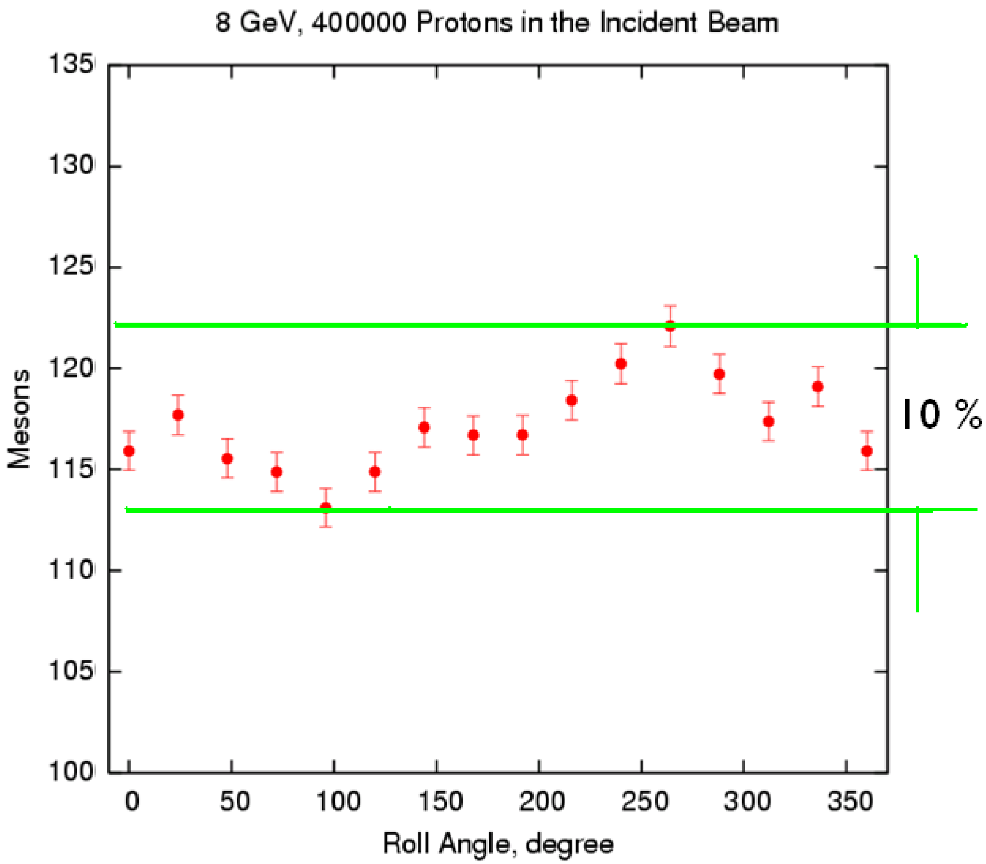


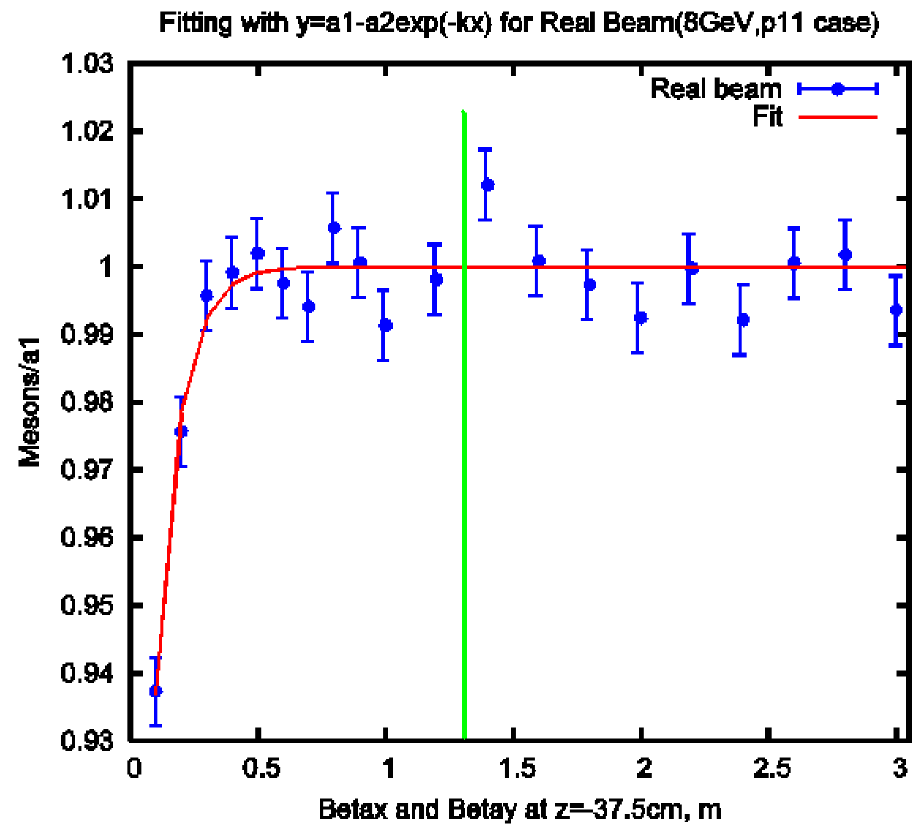
Multiple beams on target



- $\beta^* = \sigma_\perp/\sigma_\theta = 1.66\ mm/1.3\ mrad = 1.3\ m$ No prod loss in simulation
- Real situation is complicated by proton bending in 20 T magnet
- But appears practical

Loss of efficiency vs. azimuth and β^* (H Kirk X Ding)





- For 8 bunches worst loss $\approx$ 5% Ave loss $\approx$ 2.5%
- No loss with β^*=1.3 m

5. Use of very large acceptance FFAG-like rings

e.g. 5-10 GeV FFAG designed for muon acceleration in ISS & Study 2a

- 339 m circumference ring has momentum acceptance of order $\pm$ 30% which we would not use
- It's muon acceptance $=$ 30,000 $(\pi\ mm\ mrad)$
- Take rms emit as $1/10$ of acceptance $\epsilon_\perp(\mu)\ =\ $ 3000 $(\pi\ mm\ mrad)$
- Correct for masses $\epsilon_\perp(p)\ =\ 3000 \times 106/970\ =\ 330\ (\pi\ mm\ mrad)$
  With single bunch, $\Delta\nu =$ 0.2 ok

- But for focus to σ_r=1.66 mm (1/3 jet radius): $\sigma_\theta =$ 23 mrad
- 4$\times\sigma_\theta$= 93 mrad $\approx\ 3\ \times$ crossing angle
- So this is not an option

Higher energy Buncher Options

6. - 9. Same buncher ring acceptance and average bending field as #s 4 & 5

Get required proton intensity using optimized production vs. energy

then $\Delta\nu$s = 0.22, 0.11, and 0.03, for 20, 30, and 60 GeV   all ok

but heavy price in proton power if the MARS15 predictions are correct

10. **But 12 GeV instead of 8 GeV**

For circ=12/8*200=300   nb=4 $\Delta\nu$=0.22   ok

Loss of production 13%, but this is within the errors

Summary

		E	circ	N	P	sigz	σ_θ		ϵ_N 95%	$\epsilon_\perp$ rms	nb	$\Delta\nu$	
		GeV	m	Tp	MW	m	mrad		$\pi\mu m$	$\pi\mu m$			
	FNAL Booster												
1	booster at injection	0.4	474	0.06		1.5	1.3	ok	12	2	84	0.4	ok
	8 GeV Driver												
2	booster at 8 GeV	8.0	474	250	4.8	1.0	1.3	ok	112	19	1	4.2	X
3	SC ring	8	200	250	4.8	1.0	1.3	ok	112	19	1	1.8	X
4	SC ring & trombones	8	200	250	4.8	1	1.3	ok	112	19	8	0.22	ok
5	FFAG	8	393	250	4.8	1	23	X	2000	330	1	0.2	ok
	Higher Energy Driver												
6	SC ring	20	235	144	6.9	1	0.5	ok	112	19	1	0.22	ok
7	SC ring	30	348	102	7.3	1	0.4	ok	112	19	1	0.11	ok
8	SC ring	60	686	66	9.5	1	0.2	ok	112	19	1	0.03	ok

Conclusion

- Pion, and thus muon, production predicted to be maximum for 8 GeV protons
- Parameters require very intense ($\leq$250 Tp) proton bunches with $\sigma_z \approx 1$ (m)
- Space charge tune shifts in a Booster like ring is excessive ($\Delta\nu \approx 4$)
- Space charge is reduced if higher bending fields allow small circumference (474$\rightarrow$200), but tune shift still unacceptable ($\Delta\nu \approx 2$)

- But ok if multiple (8) bunches with trombone (Ankenbrand) used
- And bringing such multiple beams onto the target appears ok

- The alternative of an FFAG ring with its huge accetance is ok for tune shift, but makes too large a beam on target
- Tune shift & beam size are ok for single bunches in super-conducting rings at higher proton energies (E$\geq$20 GeV), but MARS15 predicts need for higher proton power