International Design Study Front End & Variations

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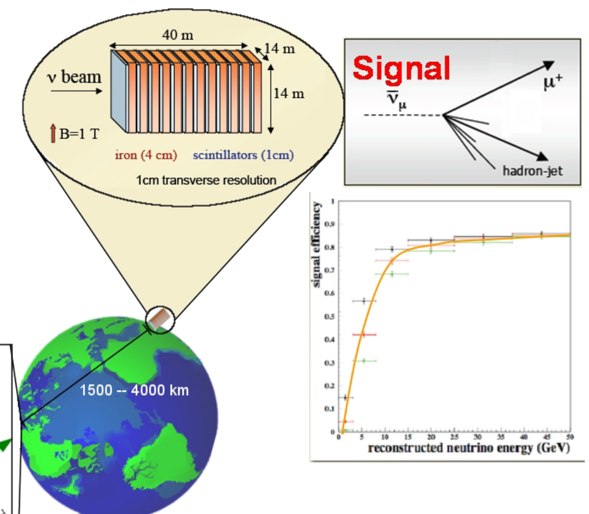
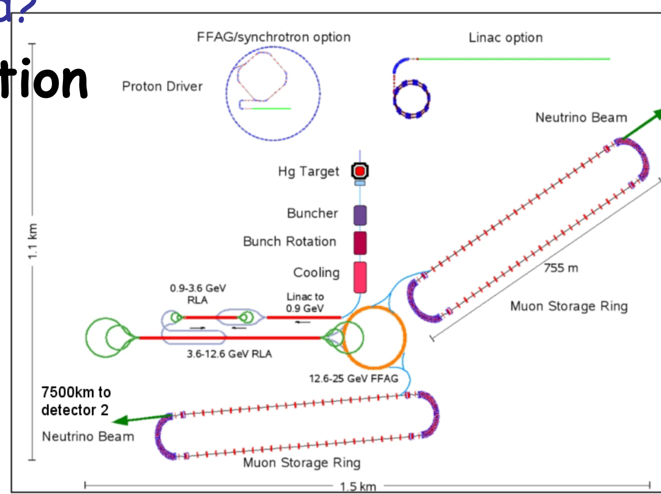
Outline

- IDS front end
  - Introduction
  - Baseline-
    - International Scoping Study (ISS)
    - **20⁺ GeV NuFactory**
  - Variations
    - Shorter cases
    - Collider capability
  - Difficulties
- rf Compatibility
  - Large gradient with large B
  - Open-cell? Insulated?
- 4 GeV NuFactory option
  - Overview
  - Variations





IDS Overview

- International Scoping Study ν-Factory parameters
  - ~4MW proton souce producing muons, accelerate to 20+ GeV, long baseline mu decay lines (2500/7500km)
- International Design study- develop that into an engineering design
  - cost specification
- Front end (Target to Linac) is based on ISS study
  - capture/decay drift
  - μ buncher/rotator
  - ionization cooling

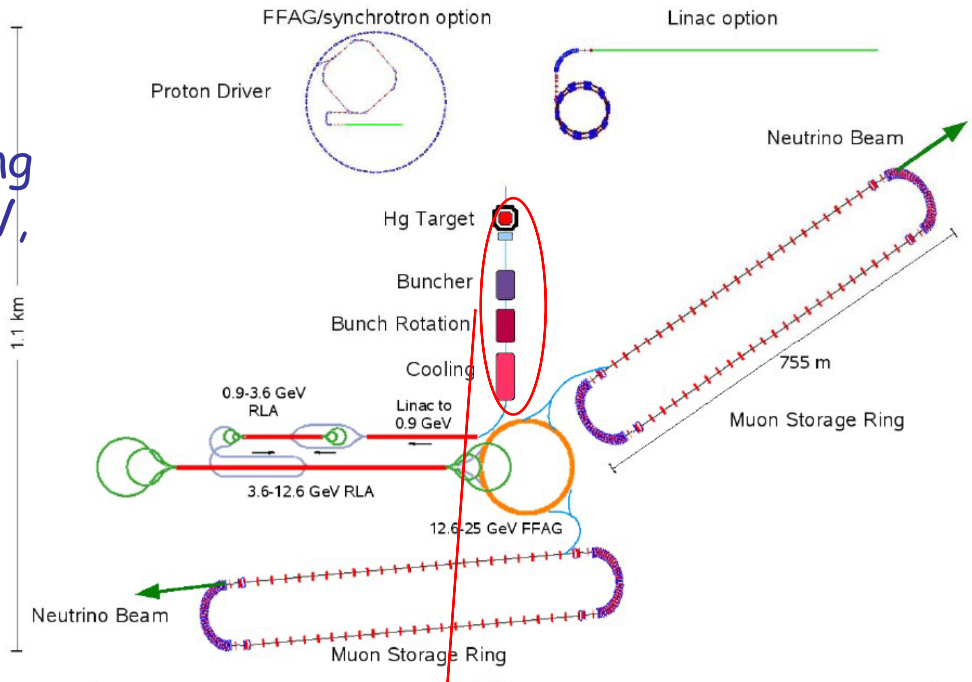
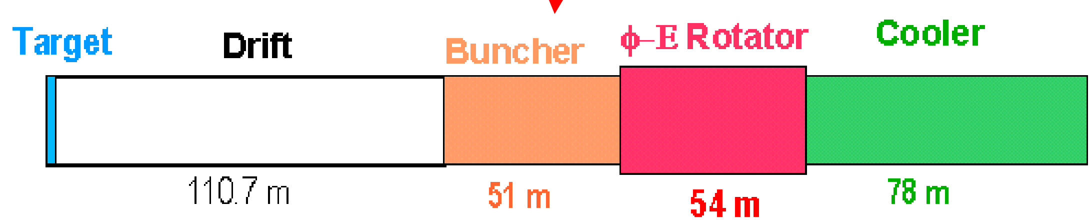
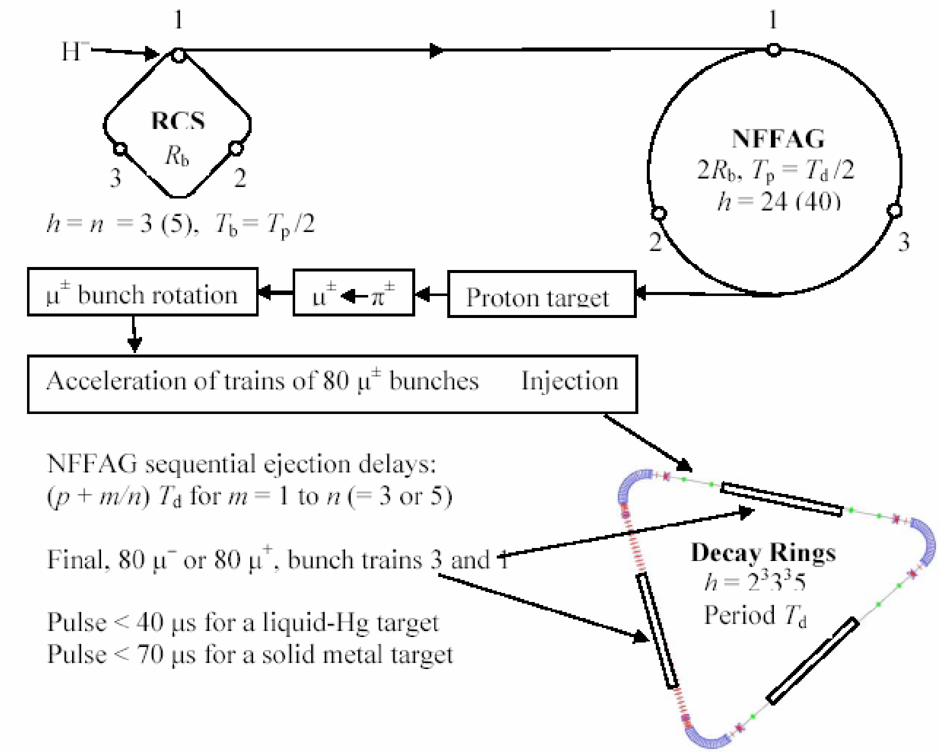


Figure 1: Schematic drawing of the ISS baseline for the Neutrino Factory accelerator complex. The various systems have been drawn to scale.



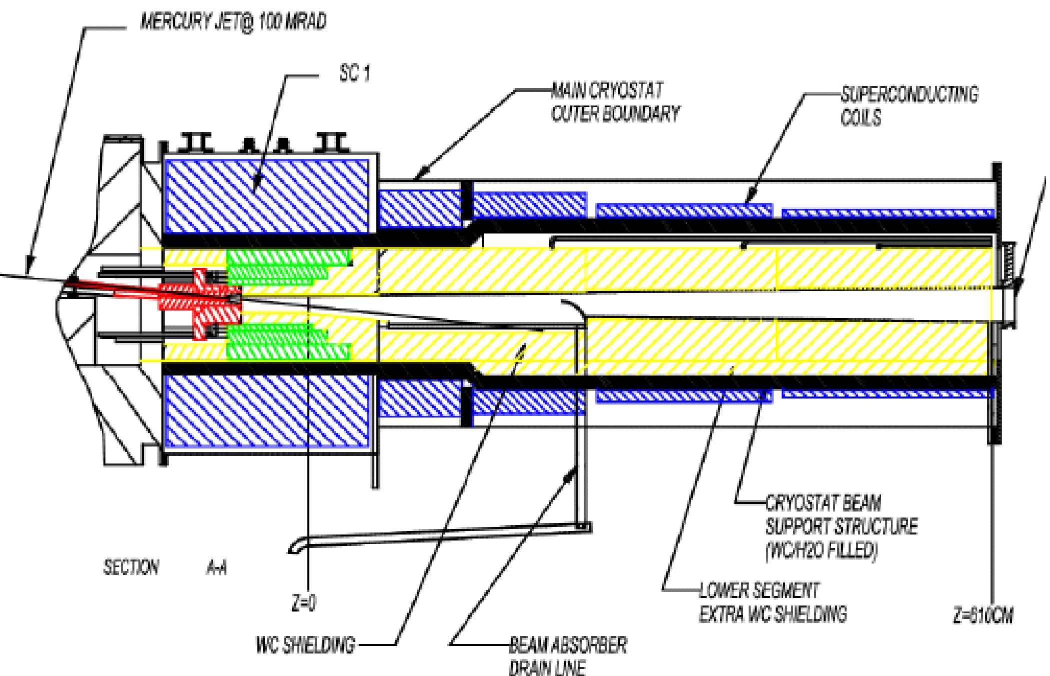
ISS baseline Proton source

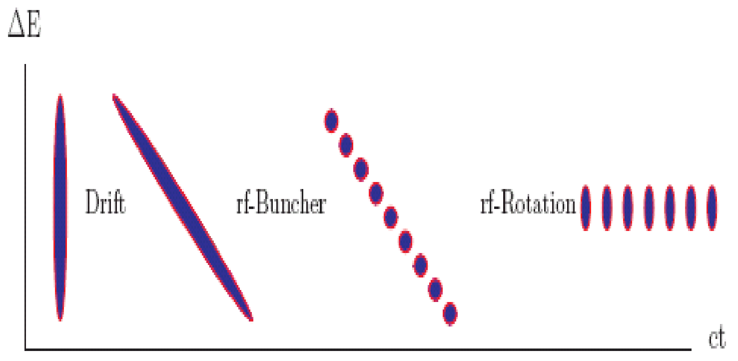
- Proton source is somewhat site-dependent …
- 4MW
  - 50Hz, 5×10^{13}, 10 GeV
- Three proton bunches per cycle
  - Separated by ?? 40 to 70μs
  - Rf needs to recover (?) between passages
- Hg-jet target scatters in 40μs



Solenoid lens capture

- Target is immersed in high field solenoid
- Particles are trapped in Larmor orbits
  - B= 20T -> ~2T
  - Particles with $p_\perp$ < 0.3 $B_{sol}R_{sol}/2$=0.225GeV/c are trapped
  - Focuses both + and – particles
  - **Drift, Bunch and phase-energy rotation**

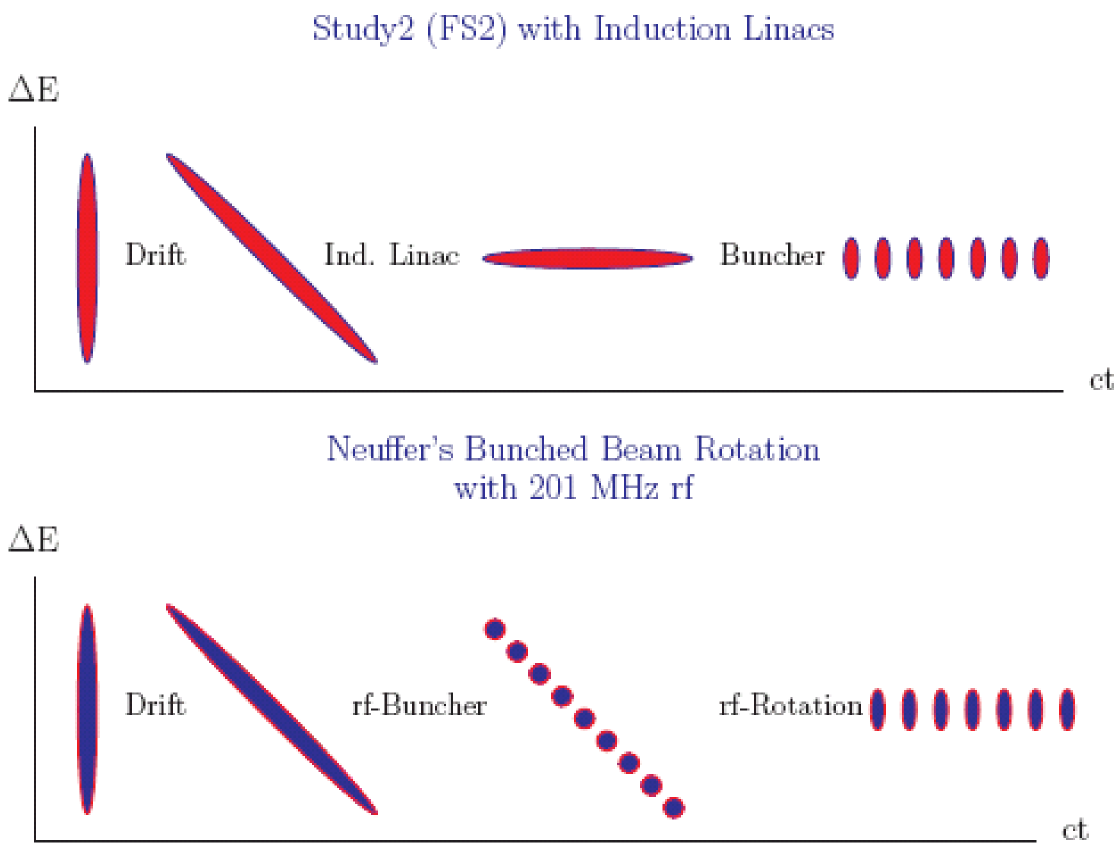




High-frequency Buncher and φ-E Rotator

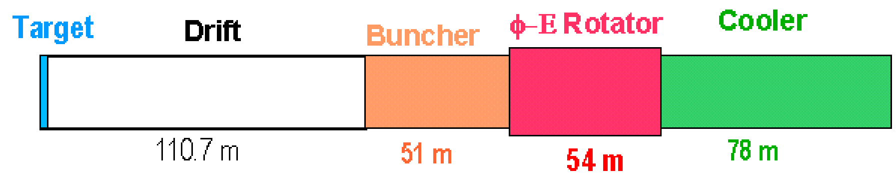
- Form bunches first

- Φ-E rotate bunches

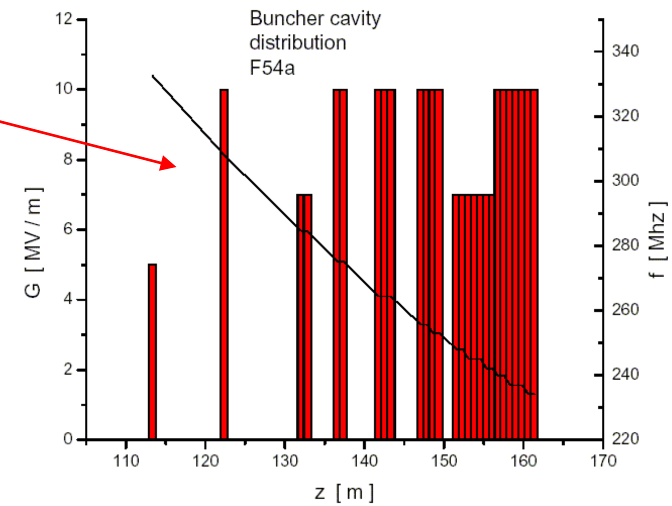


Study2B (and ISS)

- **Drift –110.7m**

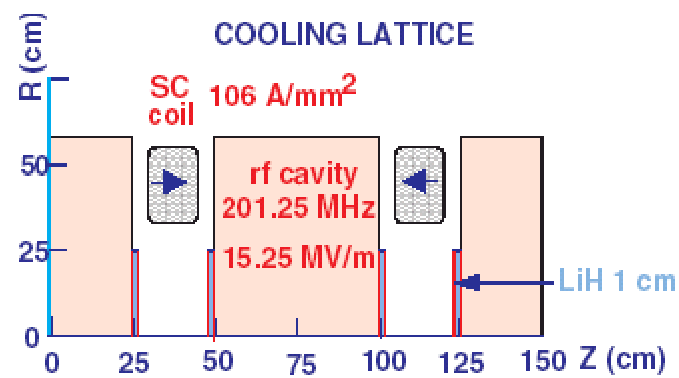


- **Bunch -51m**
  - $\delta(1/\beta) = 0.008$
  - **12 rf freq., 110MV**
  - 330 MHz → 230MHz



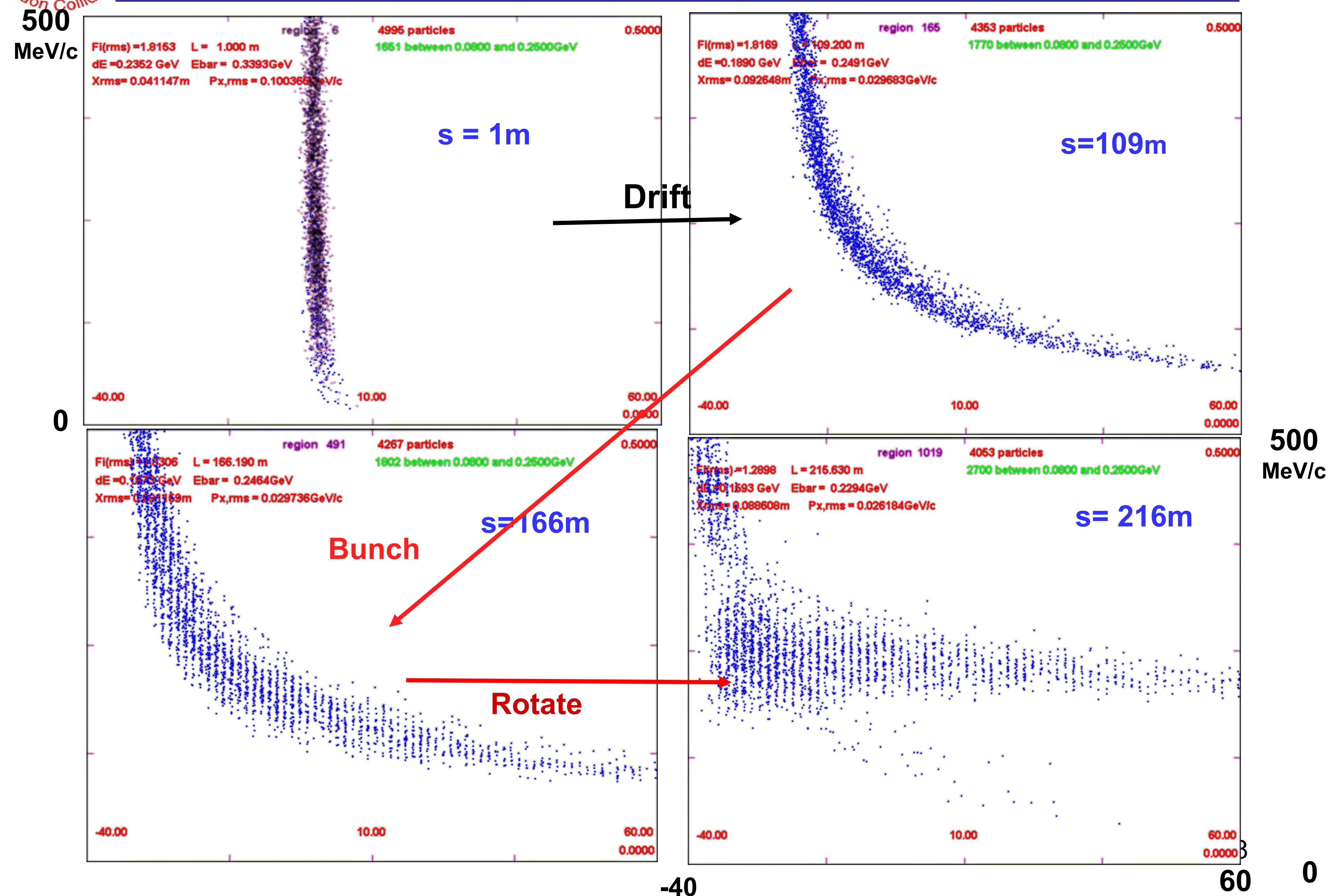
- **ϕ-E Rotate – 54m – (416MV total)**
  - **15 rf freq. 230→ 202 MHz**
  - P_1=280 , P_2=154 **δN_v = 18.032**

- **Match and cool (80m)**
  - 0.75 m cells, 0.02m LiH



- **Captures both μ^+ and μ^-**
  - **~0.2 μ/(24 GeV p)**

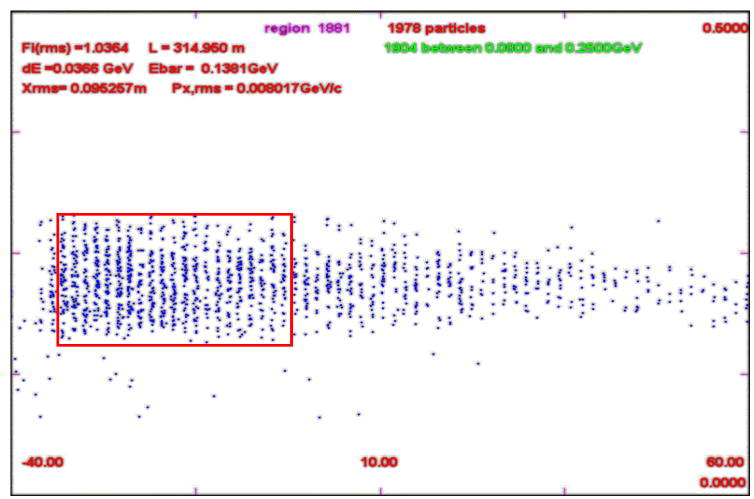
Study 2B ICOOL simulation (N_B=18)



Features/Flaws of Study 2B Front End

- Fairly long system ~300m long (217 in B/R)
- Produces long trains of ~200 MHz bunches
  - ~80m long (~50 bunches)
  - Transverse cooling is ~2½ in x and y, no longitudinal cooling
  - Initial **Cooling is relatively weak** ? -
- Requires rf within magnetic fields
  - in current lattice, rf design; 12 MV/m at B = ~2T, 200MHz
  - MTA/MICE experiments to determine if practical
- For Collider (Palmer)
  - Select peak 21 bunches
  - Recombine after cooling
  - ~1/2 lost

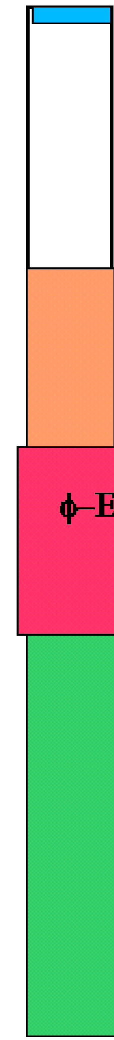
500 MeV/c

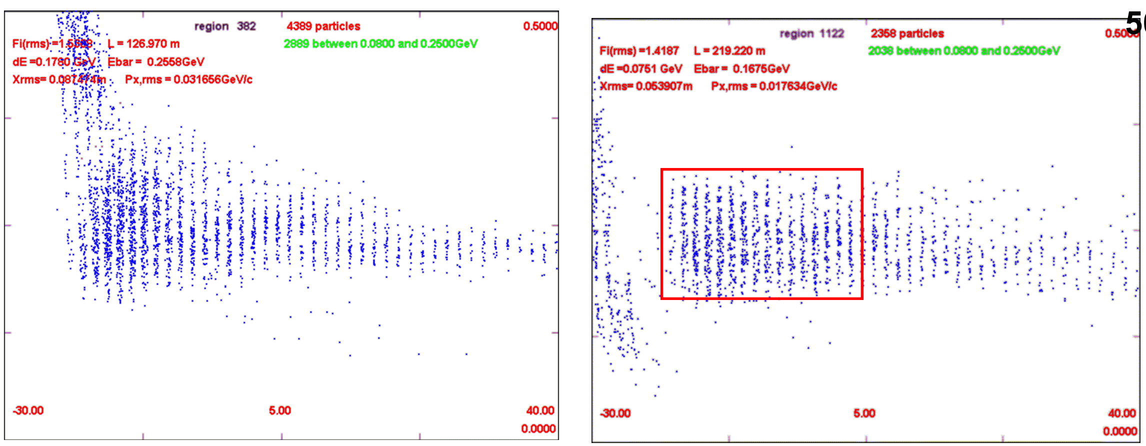


-40 60m

Try Shorter Buncher

- Reduce drift, buncher, rotator to get shorter bunch train:
  - 217m ⇒ 125m
  - 57m drift, 31m buncher, 36m rotator
  - Rf voltages up to 15MV/m (×2/3)
- Obtains ~0.25 μ/p_{24} in ref. acceptance
- 80+ m bunchtrain reduced to < 50m
  - ΔN_B: 18 -> 10
- More suitable for collider

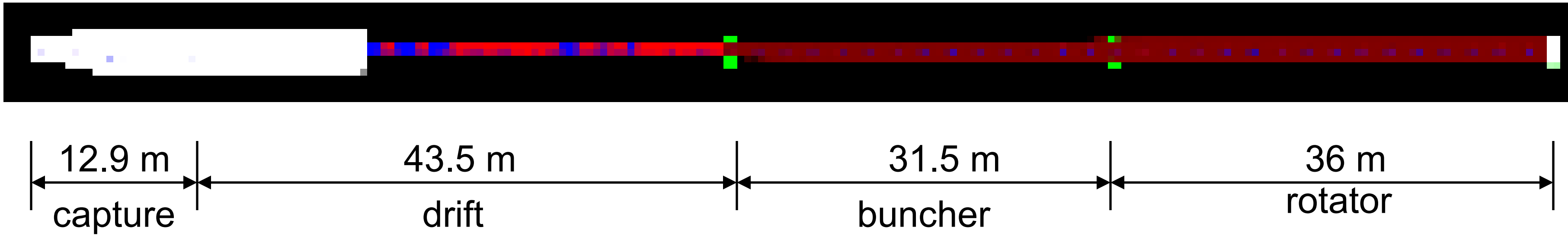


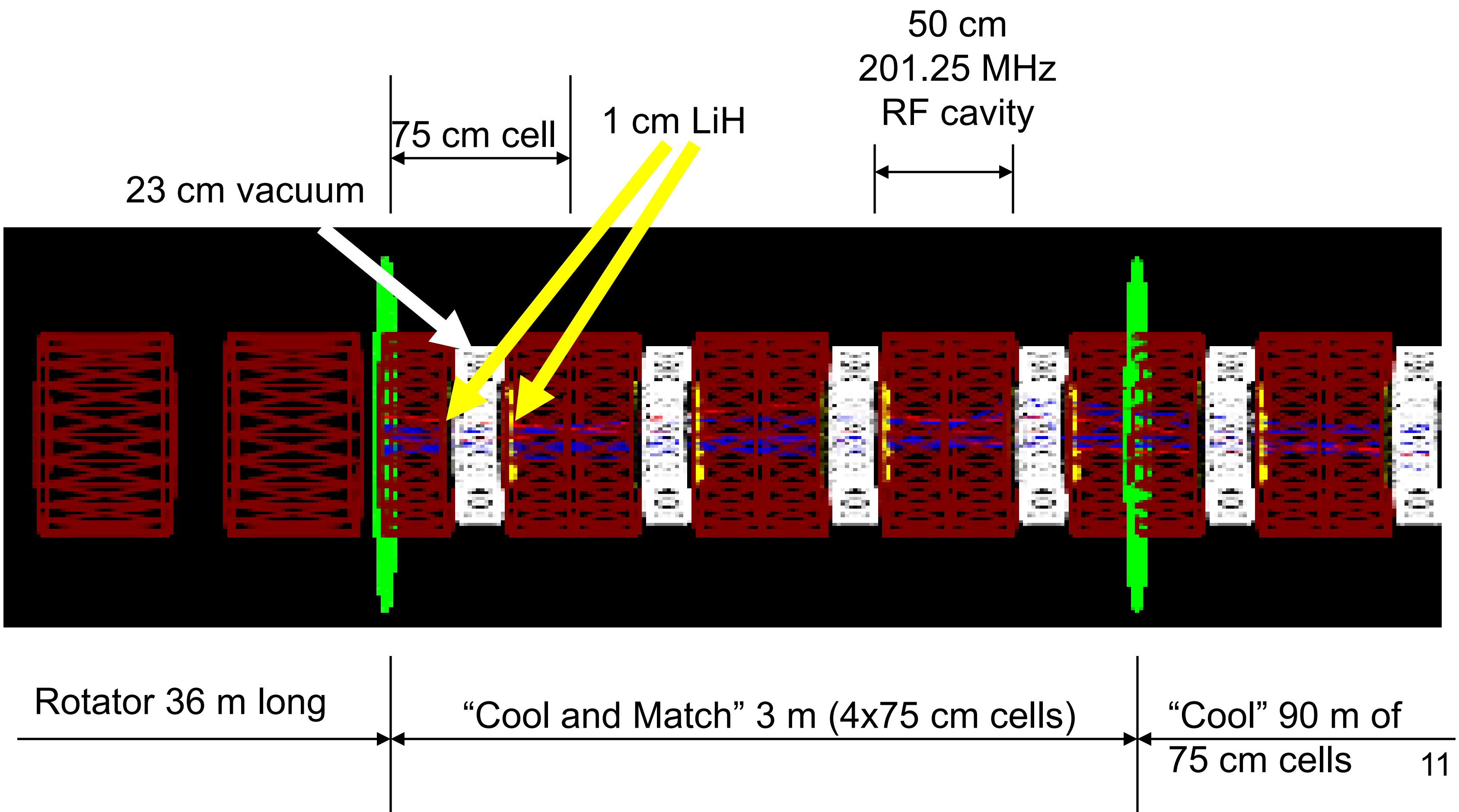


500MeV/c

-30 40m

Front End in G4beamline: w. C. Yoshikawa



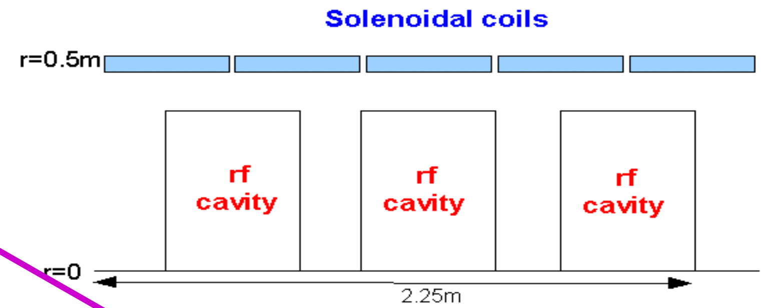


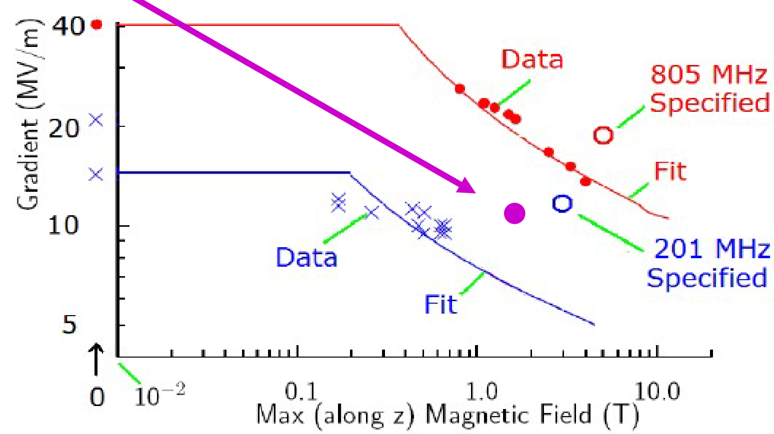
Comparisons of ICOOL and G4BL

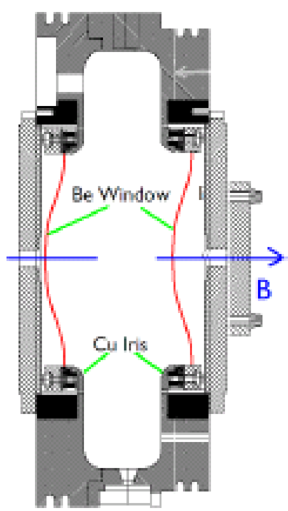
- **Simulations of front end and cooling agree**
  - ICOOL and G4Beamline results can be matched
  - dE/dx is larger in ICOOL, Phasing of rf cavities uses different model
- **Buncher – rotator – cooler sequence can be developed in both codes**
- **Optimization: Reduce number of independent freq.**
  - Buncher- 42 cavities, Rotator- 48 cavities
    - 360 to 202 MHz
  - Reduce # by 1/3 (14 in buncher; 16 in rotator)
  - Nearly as good capture (<5% less)
  - But: Reduce by 1/6 is ~20% worse
    - (7 buncher, 8 rotator frequencies)

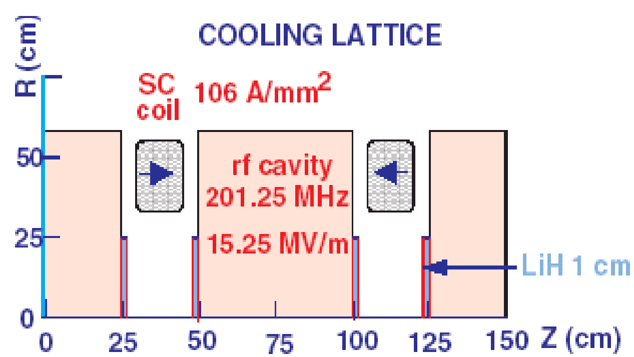
Rf in magnetic fields?

- Baseline has up to 12 MV/m in B=1.75to 2T solenoid
- Appears to be outside what is permissible?
  - $V'_{max} \propto (f_{rf})^{1/2}$???
- Buncher may only need ~5MV/m
  - Rotator needs more …



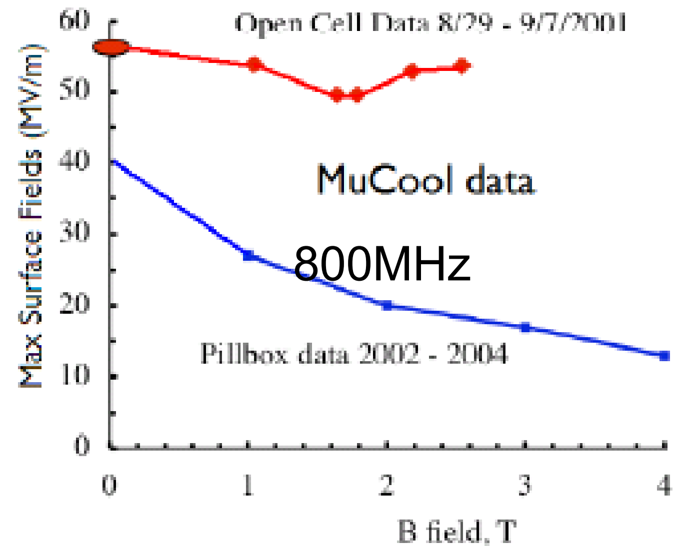


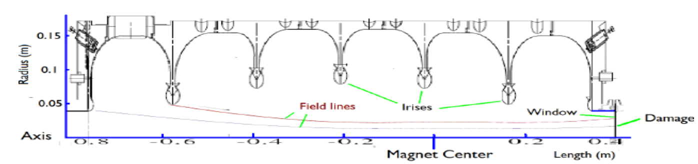


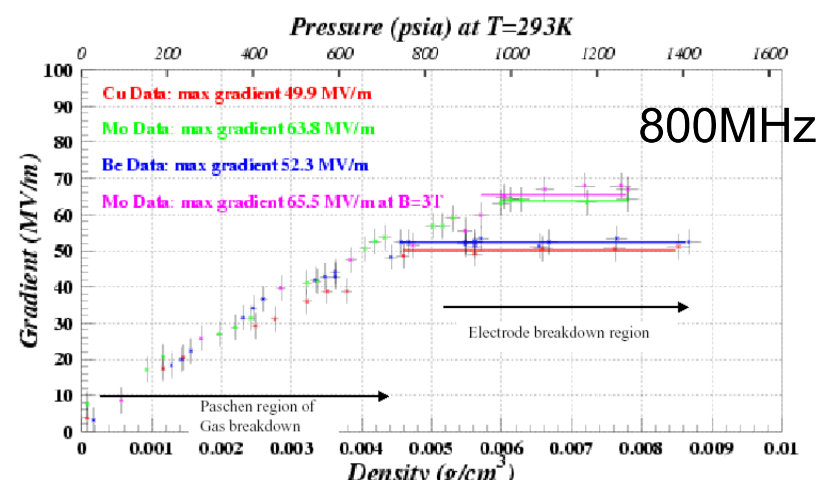


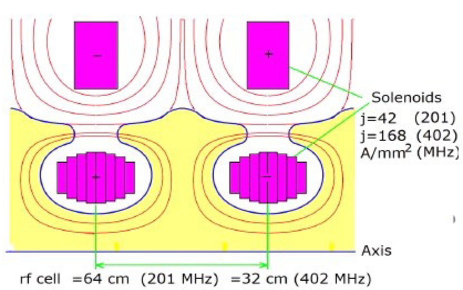
Need rf option

- Pillbox cavities
  - Cannot hold high enough gradient at high B (?)
- Open cell cavities
  - can hold high gradient with B-Field (?)
  - 200 Mhz experiment needed
- Gas-filled cavities ?
  - Suppresses breakdown
  - Would beam-induced electrons/ions prevent use?
- “magnetically insulated” cavity
  - also open-cell (?)
  - fields similar to alternating solenoid



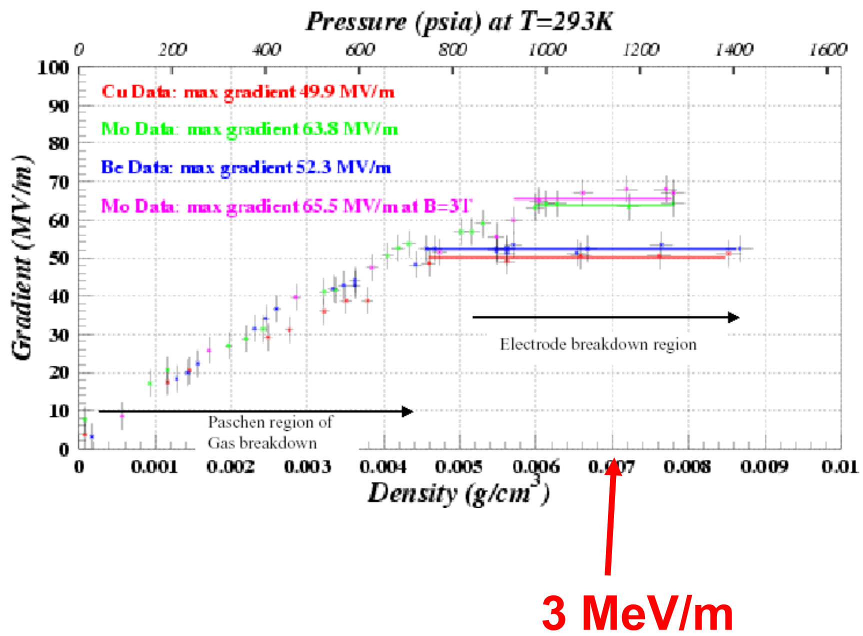




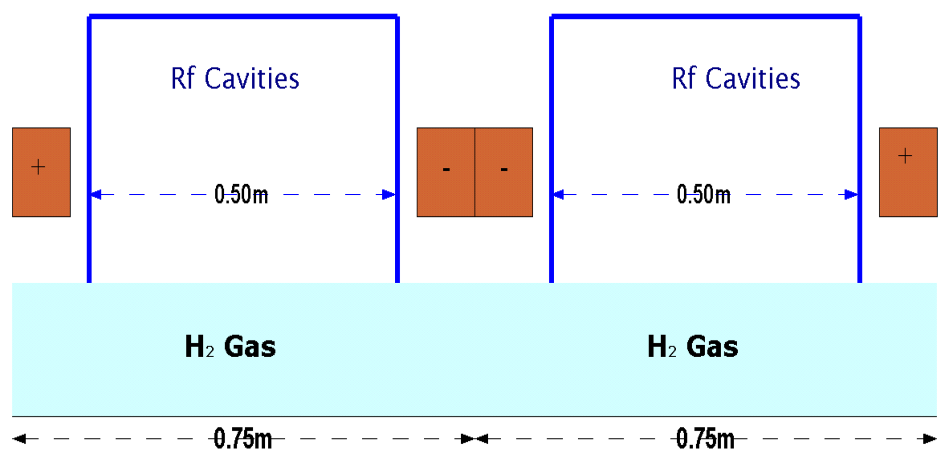


Gas-filled rf cavities ??

- Breakdown suppressed, even in magnetic fields
- electrons produced in gas may drain cavities?
  - at high intensities? $e^- + H_2 \rightarrow H + H^-$
  - without recombination?
    - Tollestrup



- Gas-filled rf cavities cool beam
  - H_2 is best possible cooling material
  - improves performance over LiH cooling …
- Need detailed design
  - Be windows /grid ?
  - ~200MHz

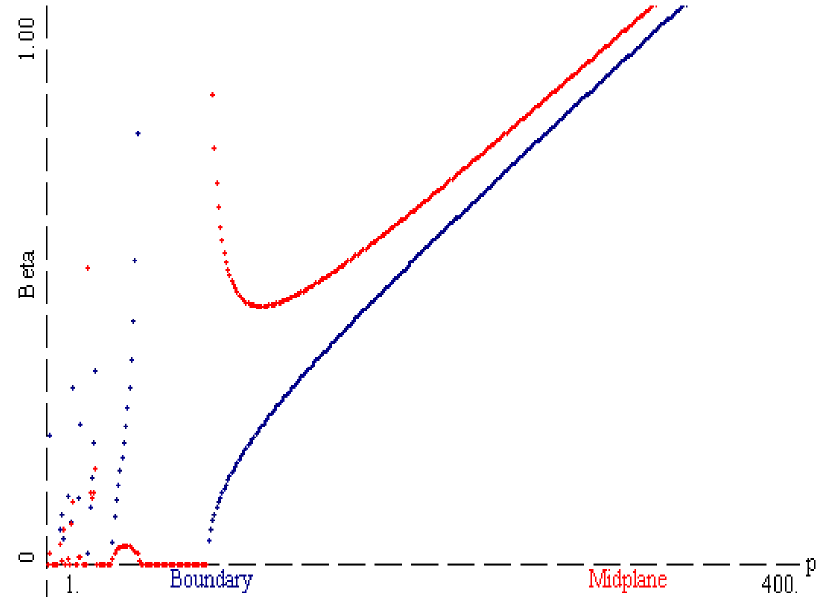


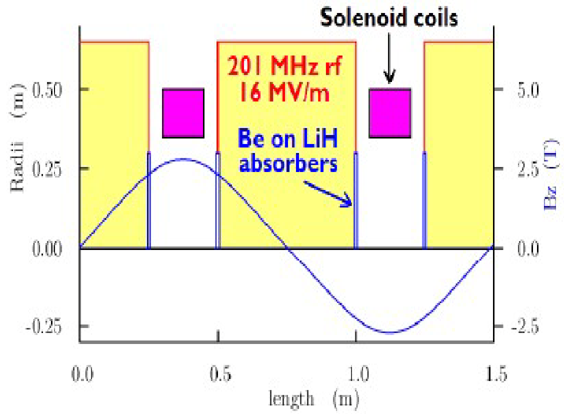
Use ASOL lattice rather than 2T

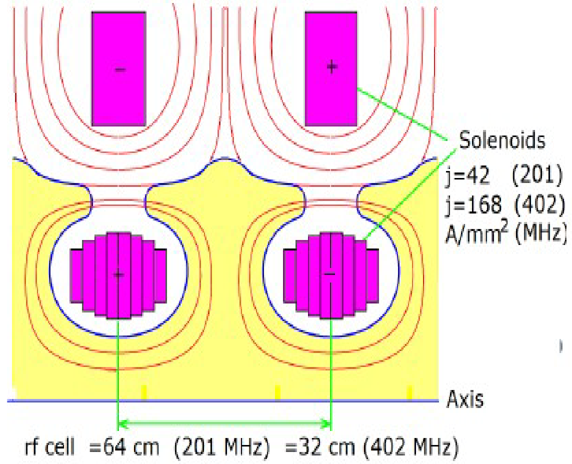
- "magnetically insulated" lattice similar to alternating solenoid

- Study 2A ASOL
  - B_{max}= 2.8T, β^*=0.7m,
  - P_{min}= 81MeV/c
  - 2T for initial drift
  - Low energy beam is lost
    - (P < 100MeV/c lost)
    - Bunch train is truncated
  - OK for collider

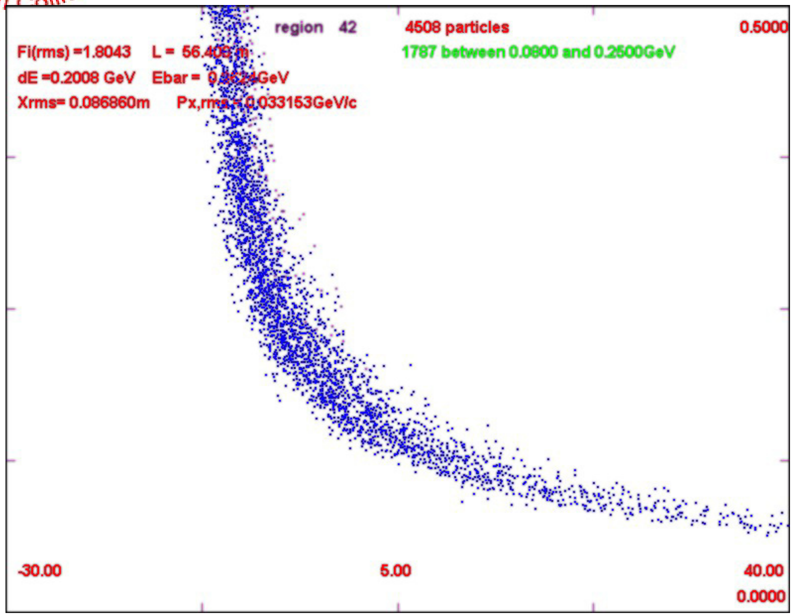
- Magnetic focusing similar to magnetically insulated

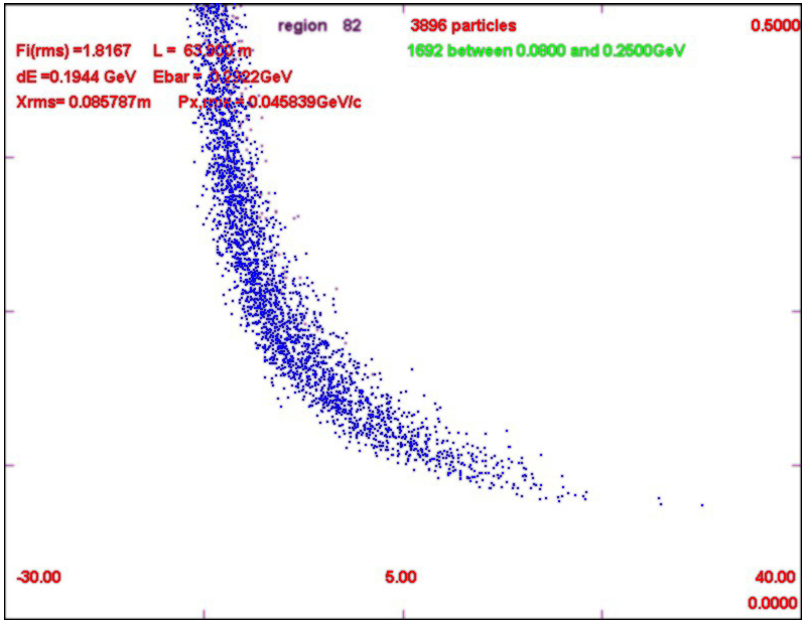


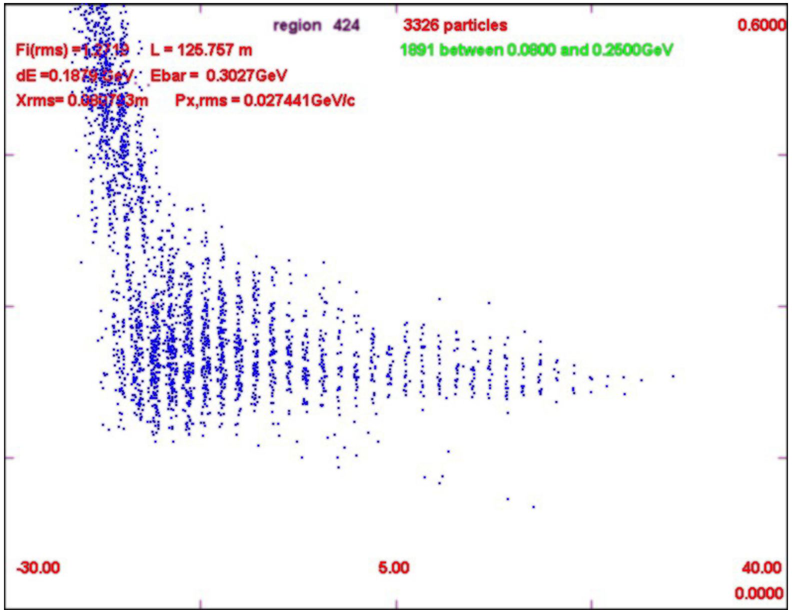


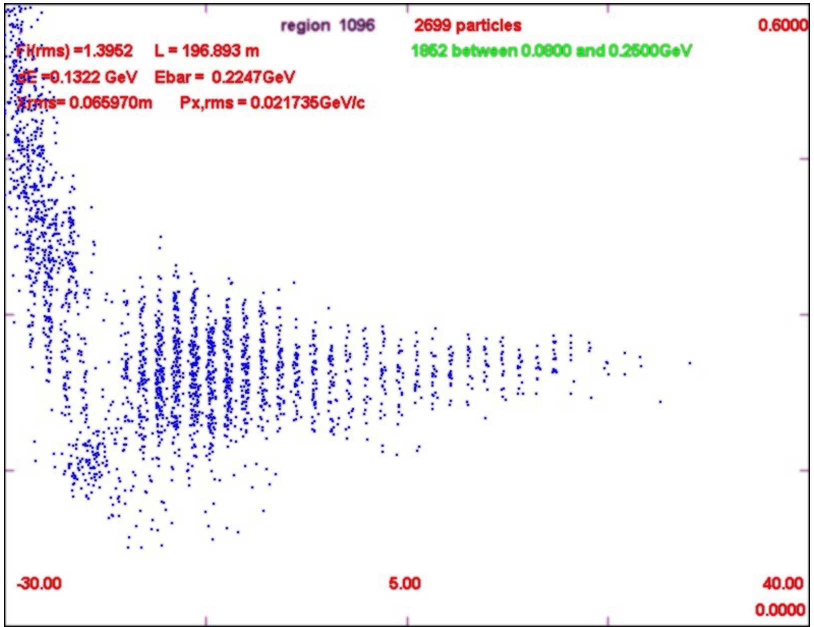


2T -> ASOL


region 42
4508 particles
0.5000
Fi(rms) =1.8043
dE =0.2008 GeV
Xrms= 0.086860m
1787 between 0.0800 and 0.2500GeV
-30.00
5.00
40.00
0.0000


region 82
3896 particles
0.5000
Fi(rms) =1.8167
dE =0.1944 GeV
Xrms= 0.085787m
1692 between 0.0800 and 0.2500GeV
-30.00
5.00
40.00
0.0000

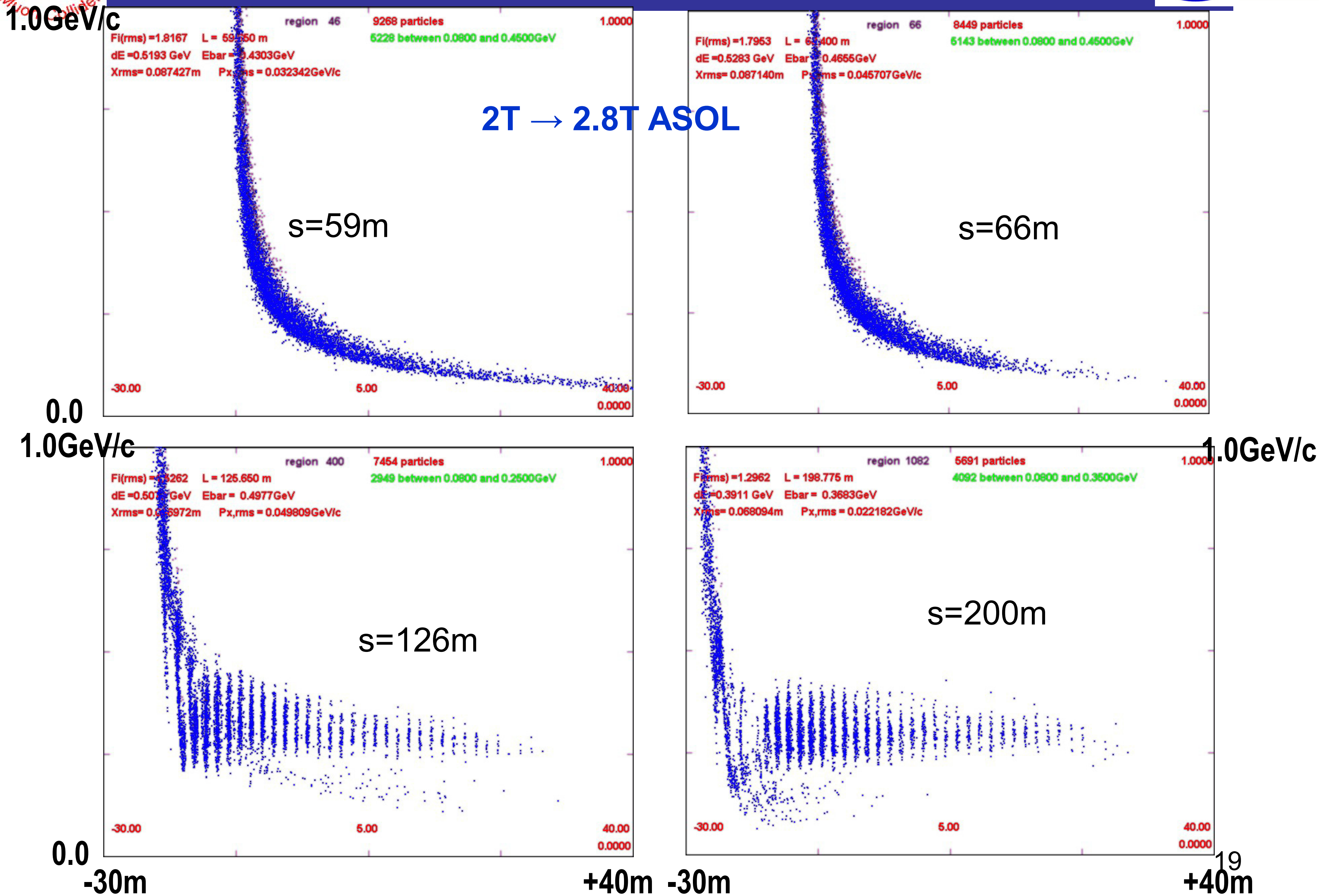

region 424
3326 particles
0.6000
L = 125.757 m
Ebar = 0.3027GeV
Px,rms = 0.027441GeV/c
1891 between 0.0800 and 0.2500GeV
-30.00
5.00
40.00
0.0000


region 1096
2699 particles
0.6000
L = 196.893 m
Ebar = 0.2247GeV
Px,rms = 0.021735GeV/c
1852 between 0.0800 and 0.2500GeV
-30.00
5.00
40.00
0.0000

ASOL results

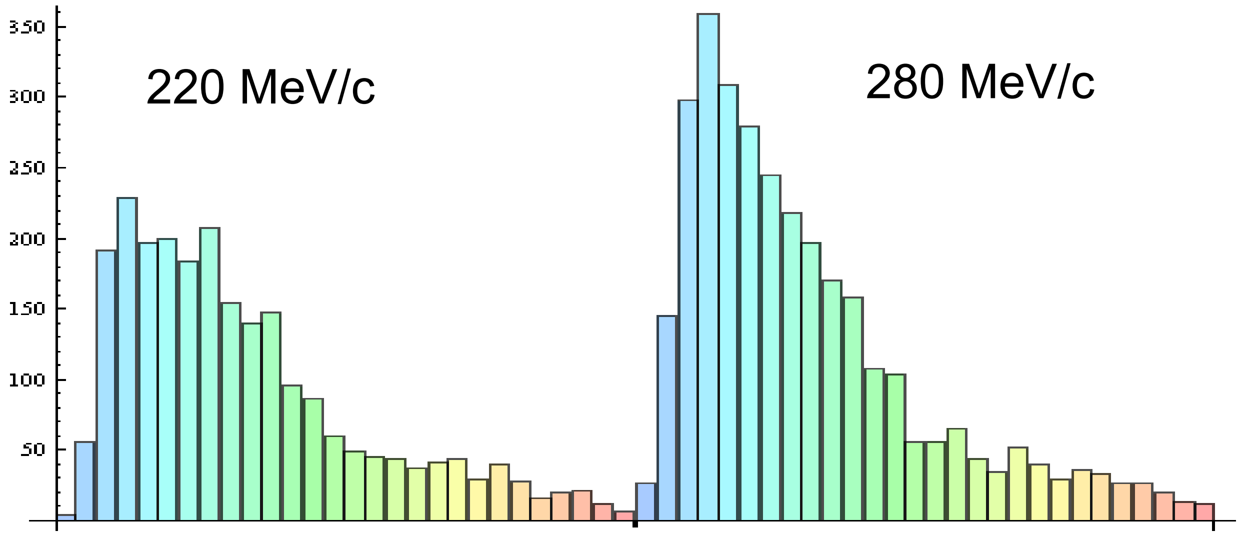
- **Simulation results**
  - *2T -> 2.8T ASOL*
  - 0.18 μ/24 GeV p, 0.06 μ/8 GeV p
  - Cools to 0.0075m
  - shorter bunch train
- **Baseline (2T -> ASOL) had**
  - ~0.25 μ/24 GeV p
  - ~0.08 μ/8 GeV p
- **Try weaker focusing**
  - 1.3T->1.8T ASOL
  - 0.2μ/24 GeV p, 0.064 μ/8 GeV p
  - **~10% more μ/p**
  - bunch train not shortened
  - Cools to 0.0085m; **less cooling**
- **Variation**
  - Use 2T -> 2.8T ASOL
  - capture at higher energy

Variant-capture at 0.28 GeV/c



Capture at 280 MeV/c

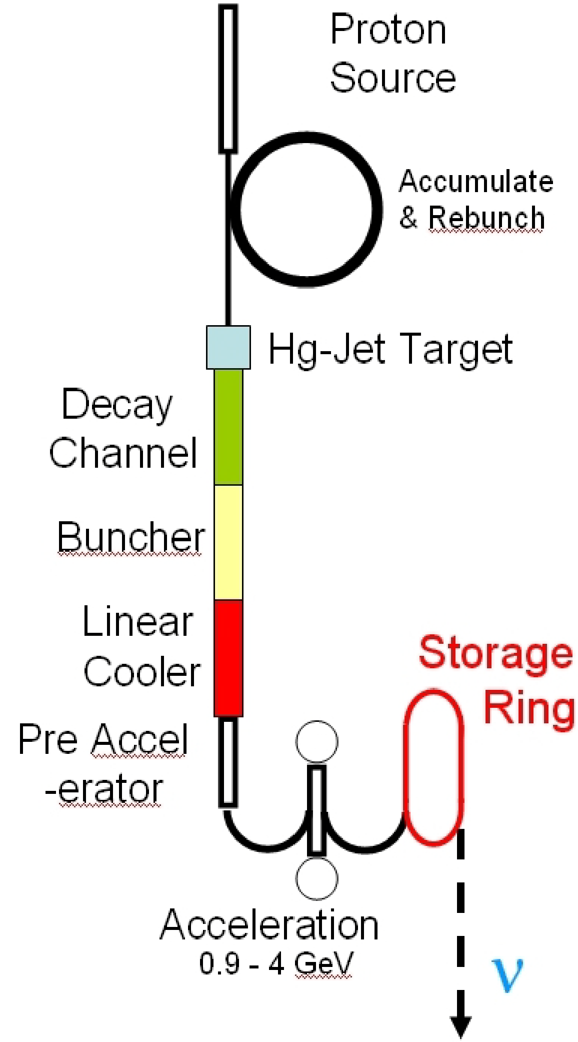
- **Captures more muons than 220 MeV/c**
  - For 2.T -> 2.8T lattice
  - But in larger phase space area
  - Less cooling for given dE/ds Δs
- **Better for collider**
  - Shorter, more dense bunch train
  - **If** followed by longitudinal cooling



Variation: 4 GeV ν-Factory

- Use magnetized totally active scintillator detector
- 4 GeV muons provide adequate neutrino beam for detector
- Fermilab to DUSEL (South Dakota) baseline -1290km

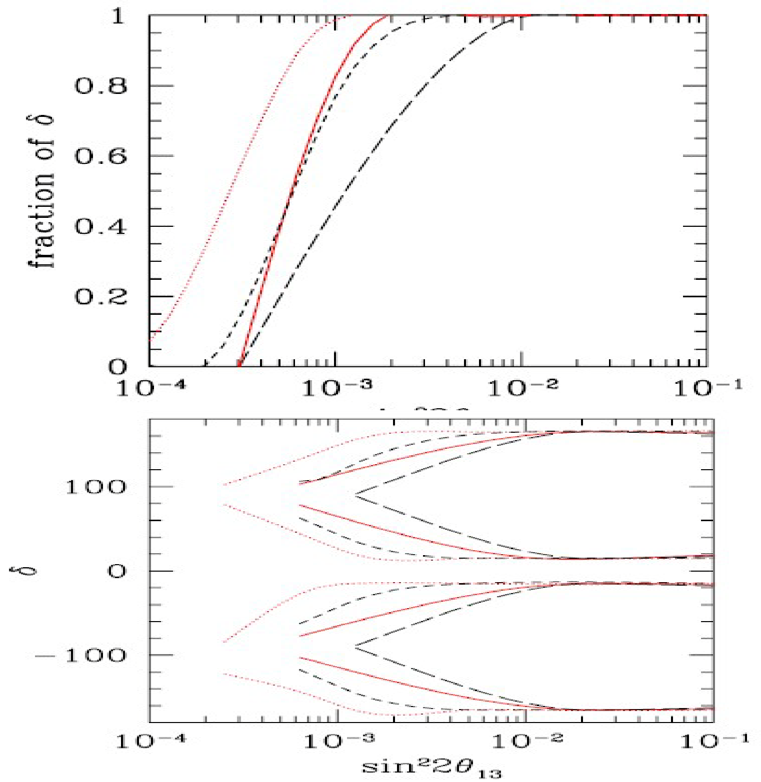
A. Bross et al.
Phys. ReV D 77, 093012 (2008)

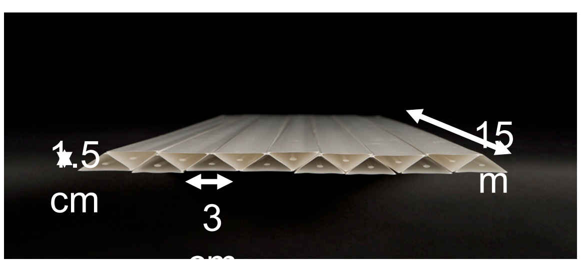


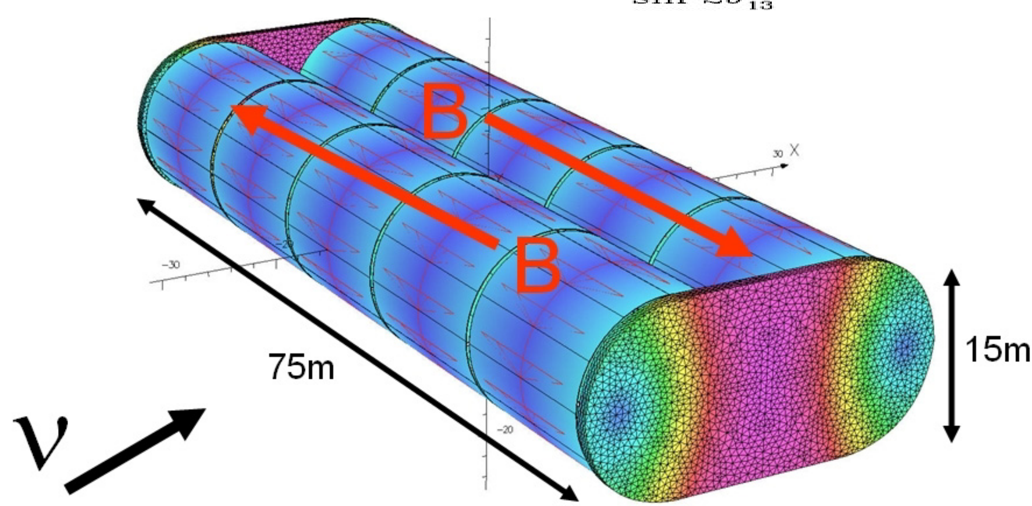
C. Ankenbrandt et al.
Fermilab-Pub-09-001-APC

Detector, Sensitivity

- Factory at Fermilab, Detector at Homestake, SD
  - ~1290km baseline
- Totally Active Scintillator Detector
  - ~20000 m^3
- B=0.5T magnetic field
  - easily identify charge and identify particles
- ν's from 4 GeV μ's
  - ~0.5GeV ν's
  - no charged τ

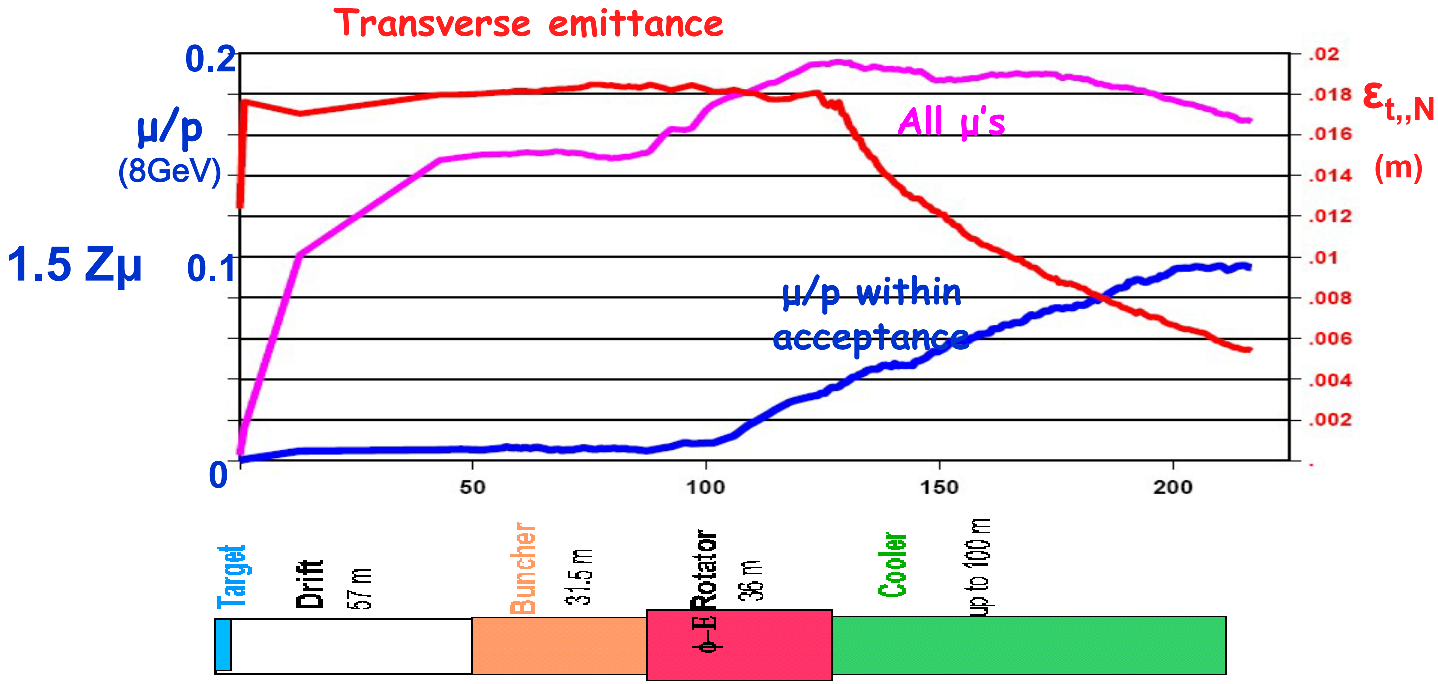






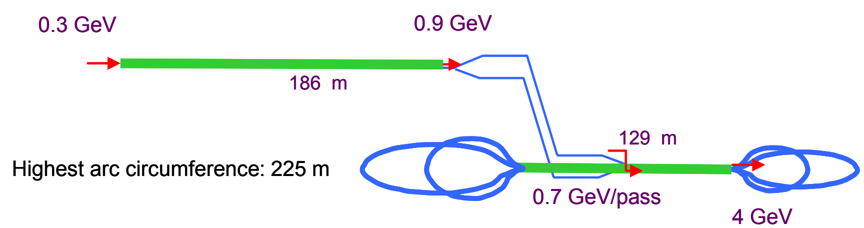
4 GeV ν-factory Front End

- Proton driver ≈ IDS
  - 4MW
    - 8GeV p, 5×10^{13}, 60Hz
- Front End
  - ~same as IDS
  - Used shorter baseline example for paper

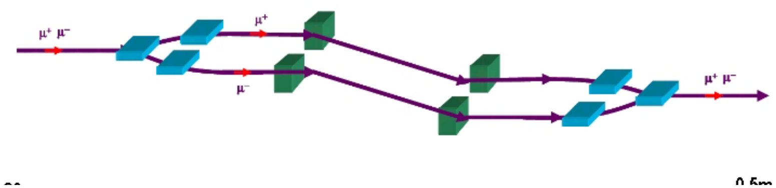


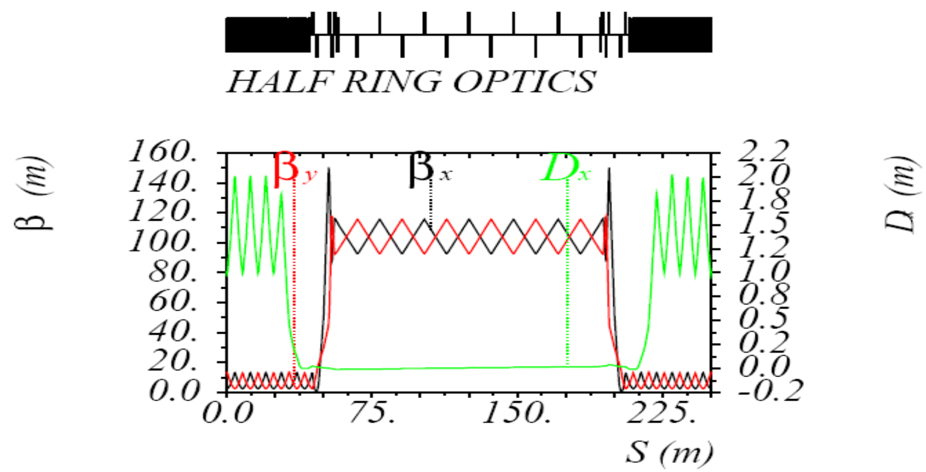
4 GeV Neutrino Factory

- **Acceleration** (A. Bogacz)
  - Linac + RLA ~0.3 GeV to 4 GeV
  - accelerates both μ^+ and μ^-
  - no FFAGs



- **Storage Ring** (C. Johnstone)
  - C = 900m, r = 15cm
    - half the circumference
  - B < ~1T
    - conventional or permane magnet





Cost savings for 4 GeV ν-Factory
(Palmer-Zisman, Mucool 322)

- **Front End is ~30% of total costs**
- **Dominated by transport (∝L) and power supply costs (∝V^2L)**

- **Shorter B/R ~ 30 MP$ less**
  - cooling not changed yet

- **$ 4 GeV Accelerator (~½)**
  - saves ~220 MP$
  - storage ring ~40MP$ less
- **934 -> 630 MP$**

- **Upgradeable by adding more acceleration**

Table 12: Study IIb Costs

ST 2 ST 2B

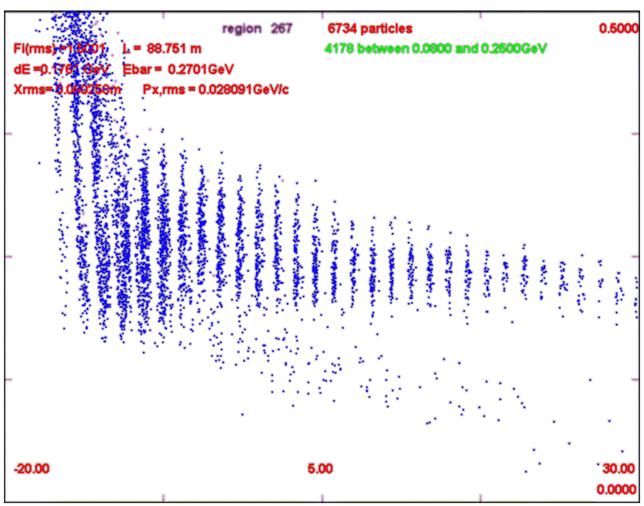
System		M$		M$	%
Target, capture, 18 m drift		97.3		96.1	99
	Target	91.5	Target	89.7	
	18 m Drift	5.8	18 m Drift	6.4	
Bunch and Phase Rotate		393.6		148.6	38
	Rotator	306.7	82 m Drift	19.3	
	Mini-Cool	11.3	Buncher	44.8	
	Buncher	75.6	Rotator	84.5	
cool		310.2		185.1	60
Acceleration		544.2		421.4	77
	Match	56.7	Match	23.1	
	Pre-Acc	136.8	Pre-Acc	98.5	
	RLA	350.9	RLA	99.6	
			FFAG 1	91.1	
			FFAG 2	109.1	
Ring		82.5		82.5	100
Total		1427		934	65

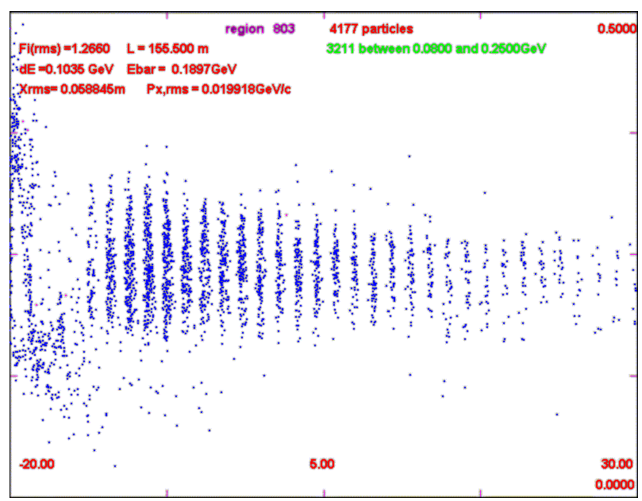
Discussion

- High frequency phase-energy rotation + cooling can be used for the IDS
  - Baseline system is ~300m long
- Shorter system better for Collider
  - Shorter bunch train; denser bunches
- Rf in magnetic field problem must be addressed
  - Is open-cell cavity possible?
  - "magnetic insulated" lattice could be used rather than B = 2 or 1.75 T lattice
    - Slightly worse performance (?)

Even Shorter Bunch train ~(2/3)^2

- Reduce drift, buncher, rotator to get even shorter bunch train:
  - 217m ⇒ 86m
  - 38m drift, 21m buncher, 27m rotator
  - Rf voltages 0-15MV/m, 15MV/m (×2/3)
- Obtains ~0.23 μ/p in ref. acceptance
  - Slightly worse than previous ?
- 80+ m bunchtrain reduced to < 30m
  - 18 bunch spacing dropped to 7

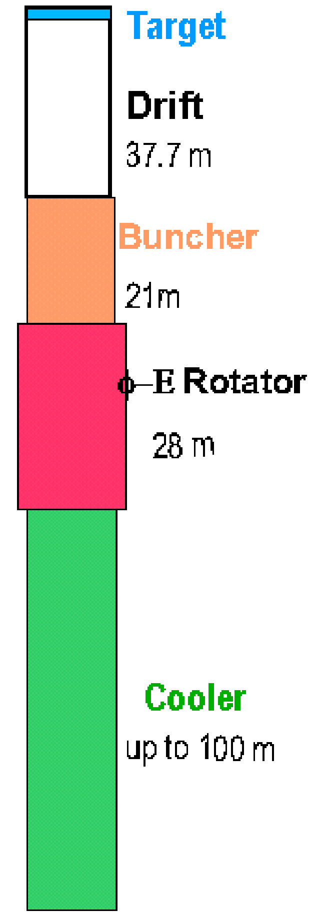




500MeV/c

-20

30m



Features of Study 2B baseline

- **Has pillbox cavities with Be foils throughout**
  - Cools beam from 0.017 to 0.014 in rotator
  - Cools further to 0.006 in cooling channel
- **Are Pillbox cavities a good idea?**
  - Rf breakdown across the cavity may be a problem
  - ? Particularly