Front End Capture/Phase Rotation & Cooling Studies

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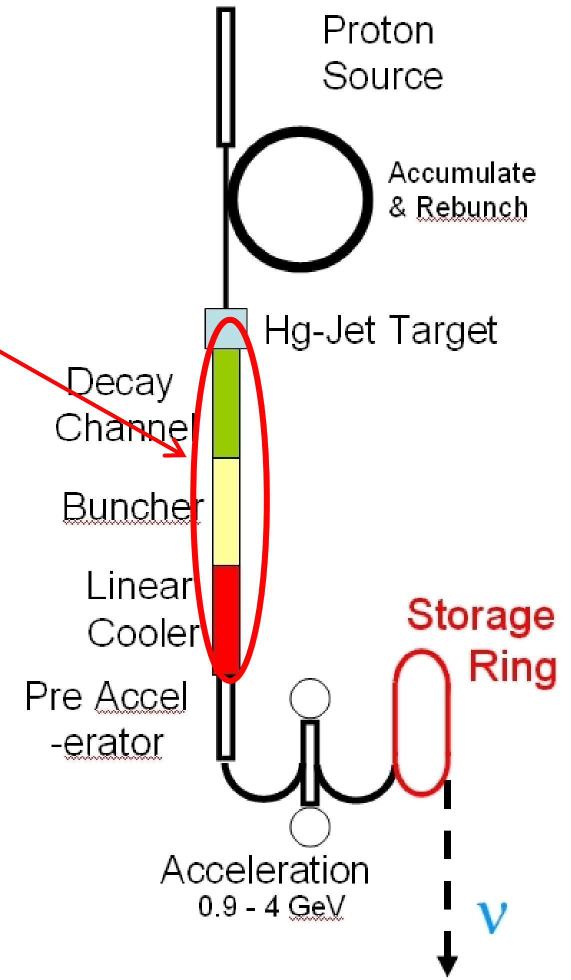
March 2008

Outline

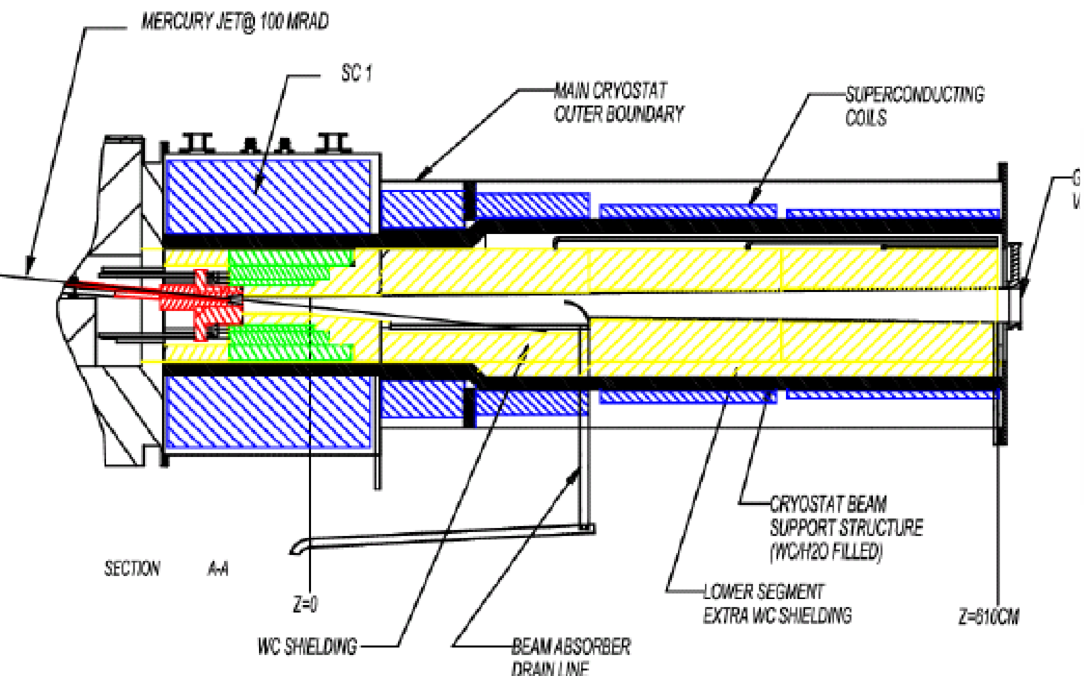
- Introduction
  - ν-Factory Front end and cooling
    - ν-Factory→μ^+-μ^- Collider
- Capture and Φ-E rotation
  - High Frequency buncher/rotation
    - Shorter versions
- Recent variation studies
  - Target studies 8 GeV, 56 GeV
  - Better cooling
  - Quad cooling
  - Rotate/cool combination
- Future studies
  - Discretization
  - Snake FOFO

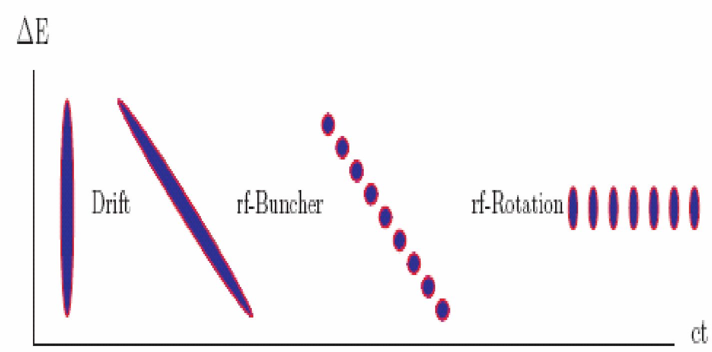


Neutrino factory

Solenoid lens capture

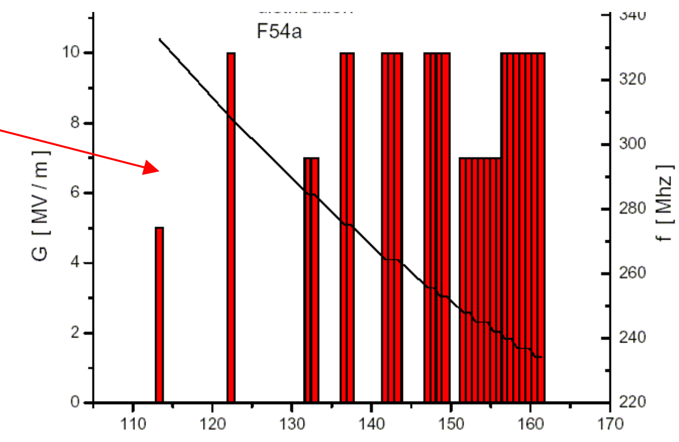
- Target is immersed in high field solenoid
- Particles are trapped in Larmor orbits
  - B= 20T -> ~2T
  - Particles with $p_\perp < 0.3\, B_{sol} R_{sol}/2 = 0.225$ GeV/c are trapped
  - Focuses both + and – particles
  - Drift, Bunch and phase-energy rotation

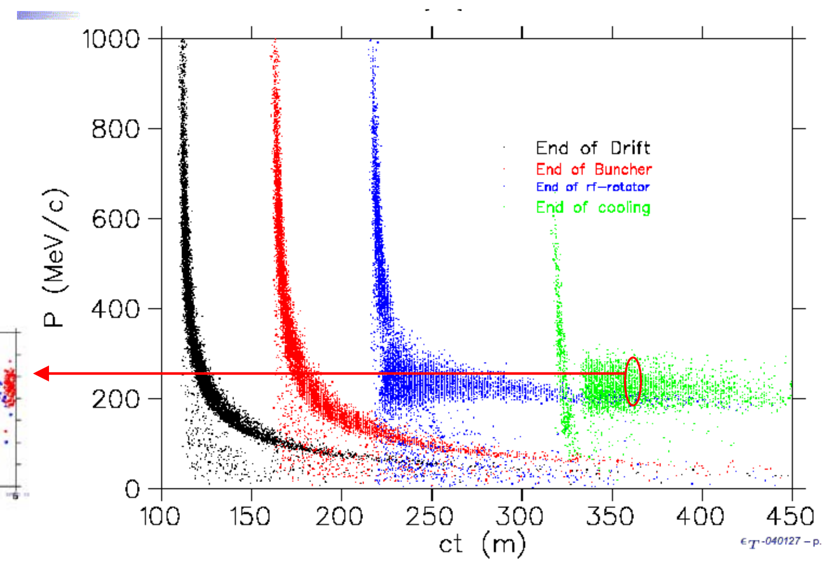


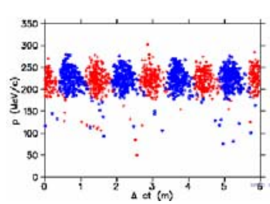


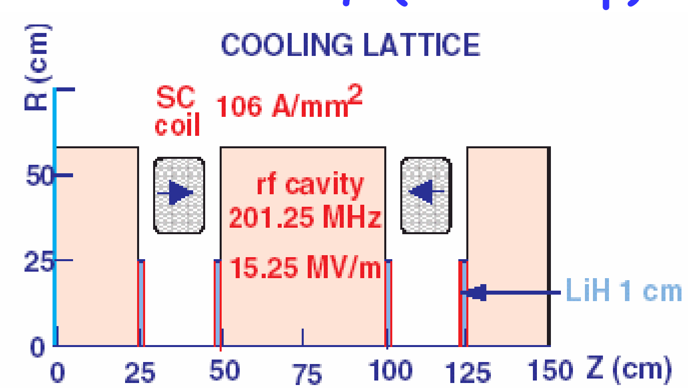
Study2B June 2004 scenario (ISS)

- **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)**



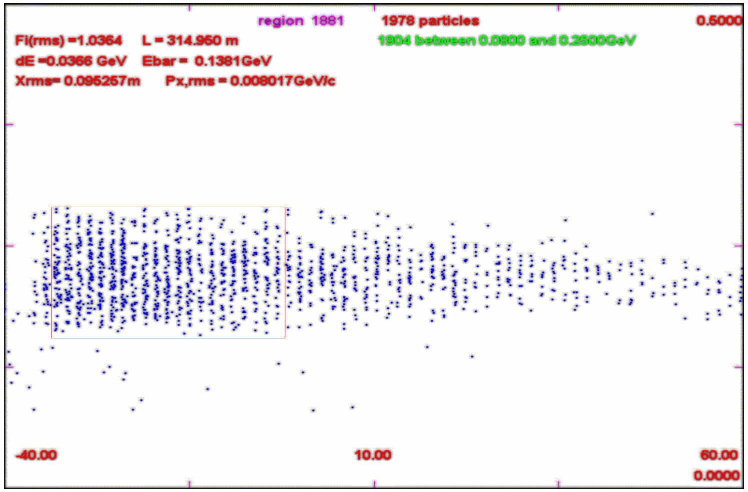






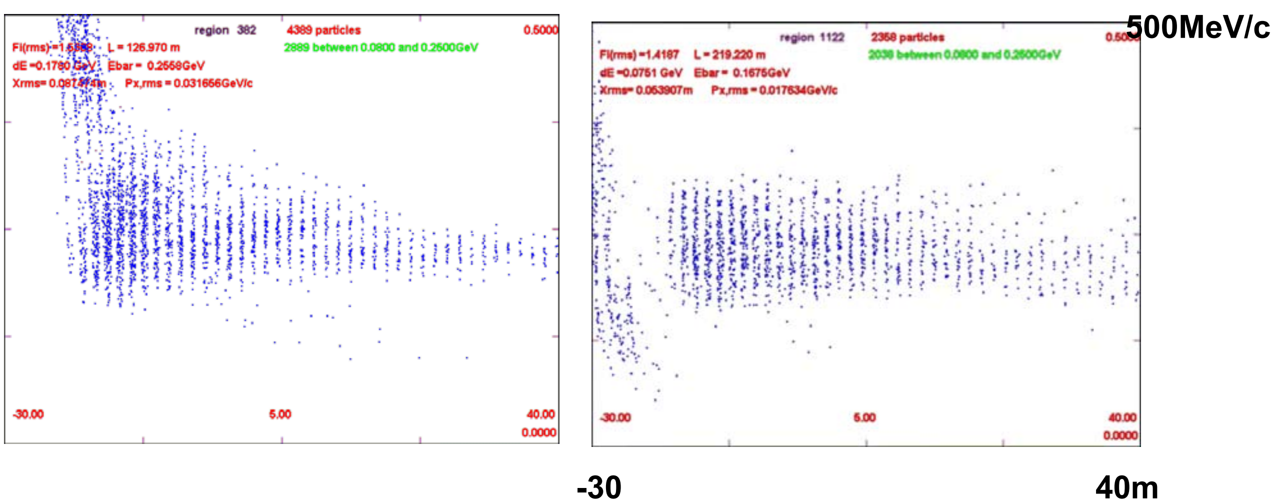
Features/Flaws of Study 2B Front End

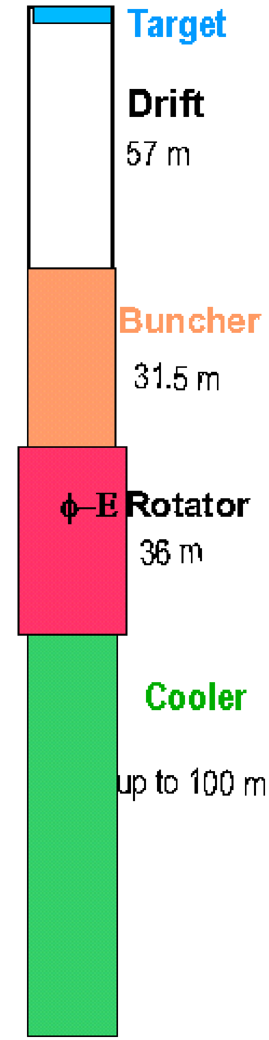
- Fairly long system ~300m long (217 in B/R)
- Produces long trains of ~200 MHz bunches
  - ~80m long (~50 bunches)
  - Transverse cooling is ~2½ in x and y, no longitudinal cooling
  - Initial **Cooling is relatively weak** ? -
- Requires rf within magnetic fields
  - in current lattice, rf design; 15 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



Shorter Bunch train example

- Reduce drift, buncher, rotator to get shorter bunch train:
  - 217m ⇒ **125m**
  - **57m drift, 31.5m buncher, 36m rotator**
  - Rf voltages up to 15MV/m (×2/3)
- Obtains ~0.26 μ/p_{24} in ref. acceptance
  - Slightly better ?
    - ~0.24 μ/p for Study 2B baseline
- 80+ m bunchtrain reduced to < 50m
  - Δn: 18 -> 10



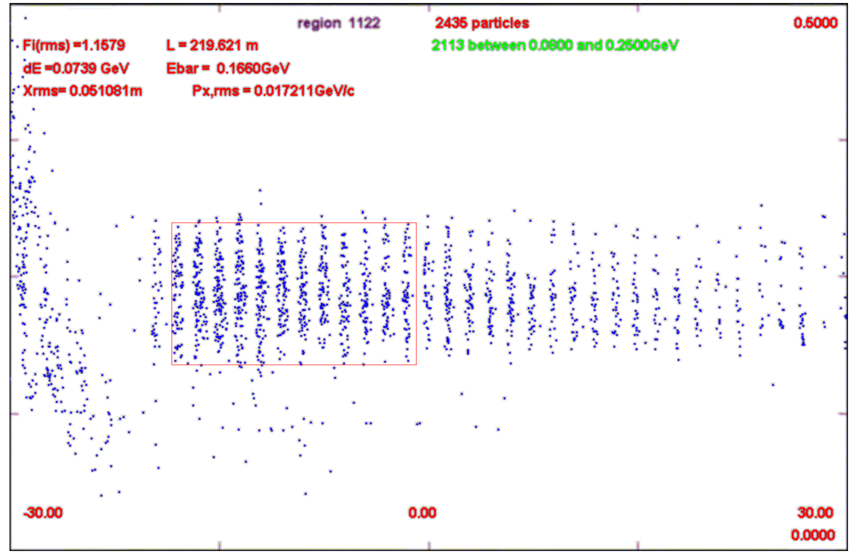


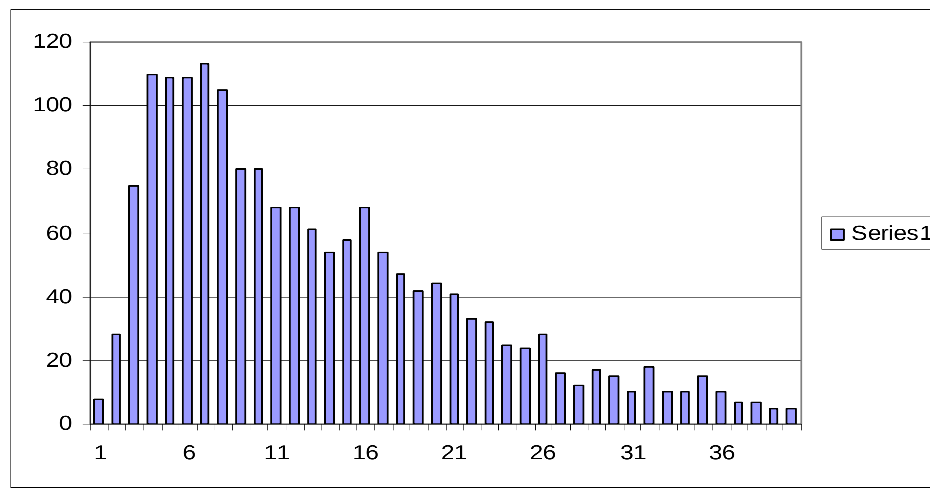
Further iteration/optimization

- Match to 201.25 MHz cooling channel
- Reoptimize phase, frequency
  - f = 201.25 MHz, φ = 30°,
- Obtain shorter bunch train

- Choose ~best 12 bunches
  - ~ 21 bunch train for Collider at N_B= 18 case

~12 bunches (~18m)
  - ~0.2 μ/p_{ref} in best 12 bunches
    - ~70%
  - Densest bunches are ~twice as dense as N_B = 18 case

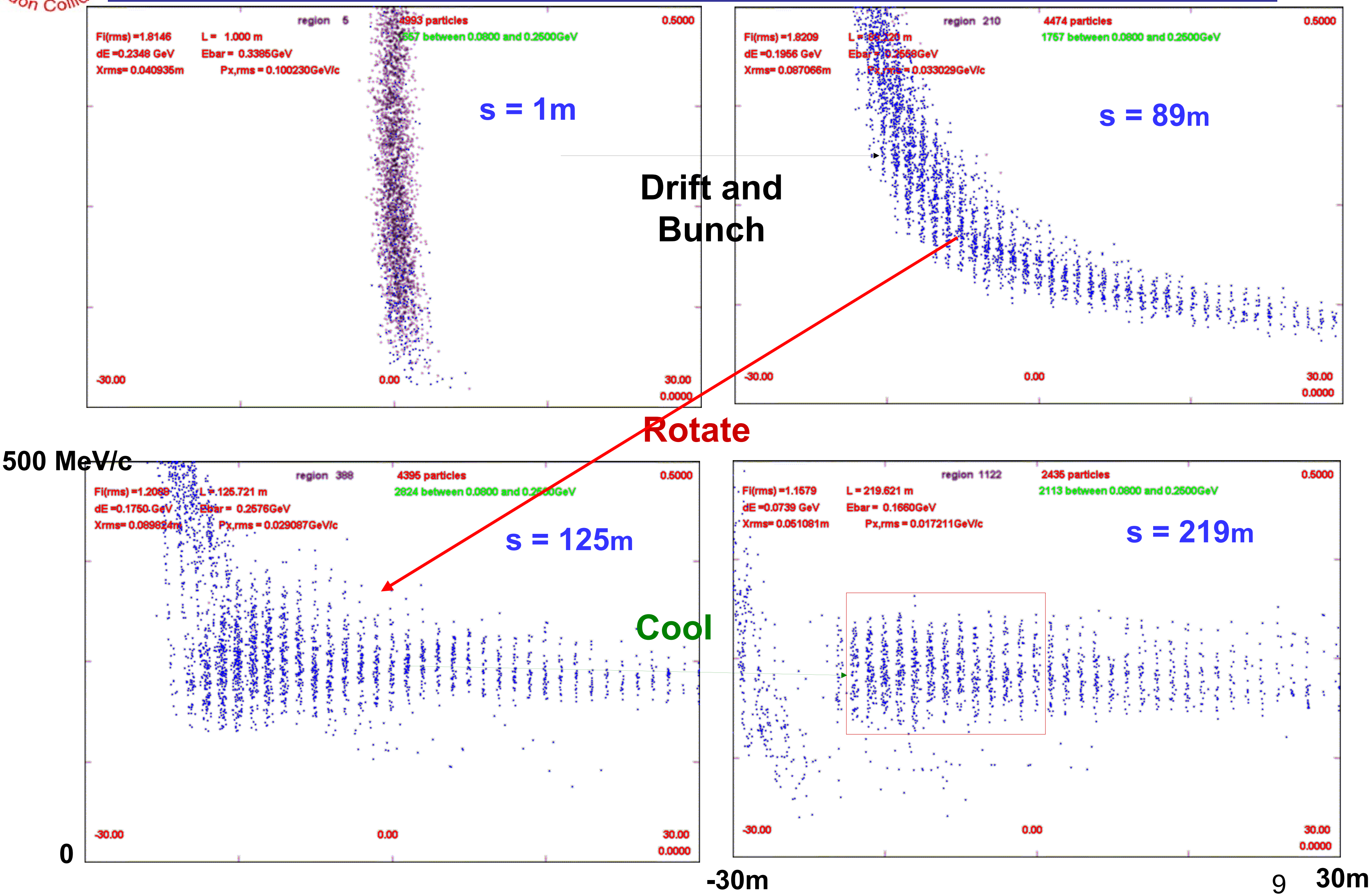




Details of ICOOL model (N_B=10)

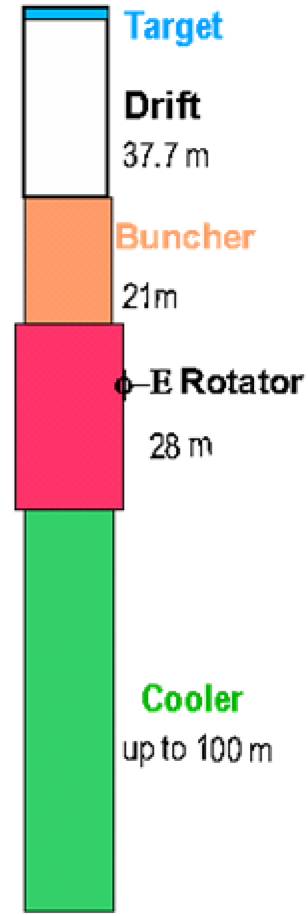
- **Drift- 56.4m**
  - B=2T
- **Bunch- 31.5m**
  - $P_{ref,1}$=280MeV/c, $P_{ref,2}$ =154 MeV/c, δn_{rf} = 10
  - V_{rf} 0 to 15MV/m (0.5m rf, 0.25m drift) cells
  - 360 MHz $\rightarrow$ 240MHz
- **ϕ-E Rotate – 36m –**
  - V_{rf} = 15MV/m (0.5m rf, 0.25m drift) cells
  - δN_V = 10.08 (240 -> 202 MHz)
- **Match and cool (80m)**
  - Old ICOOL transverse match to ASOL (should redo)
  - P_{ref}= 220MeV/c, f_{rf} = 201.25 MHz
    - 0.75 m cells, 0.02m **LiH**, 0.5m rf, 16.00MV/m, φ_{rf} =30°
  - Better cooling possible (H_2, stronger focussing)

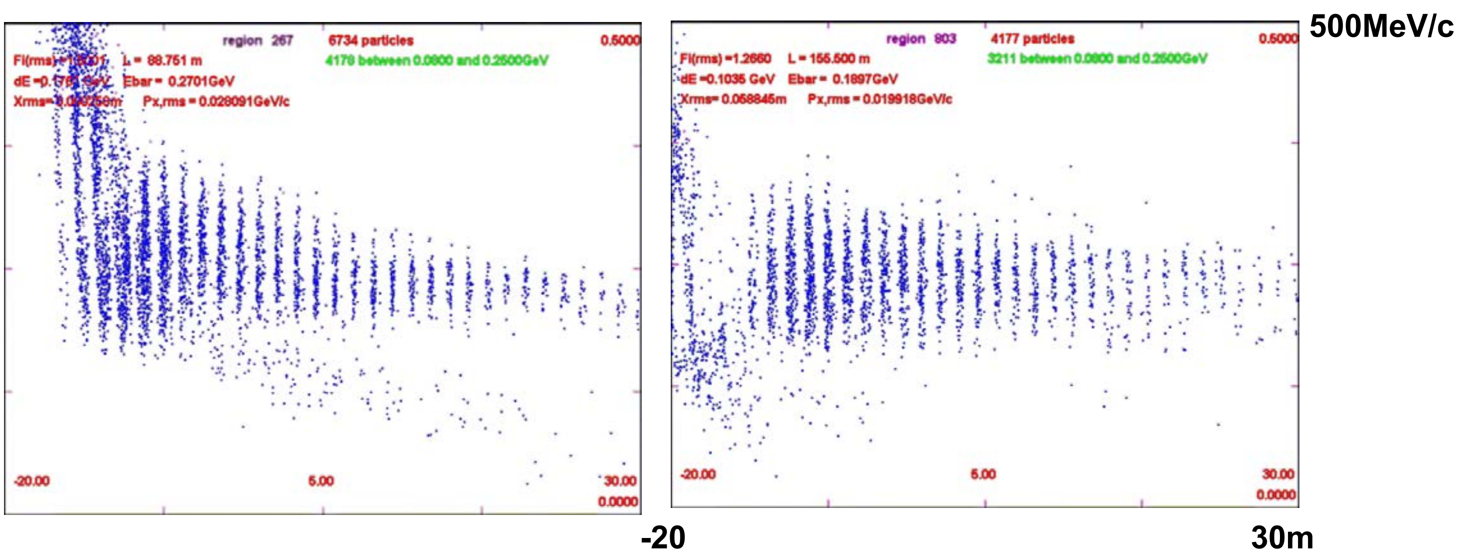
Simulations (N_B=10)



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

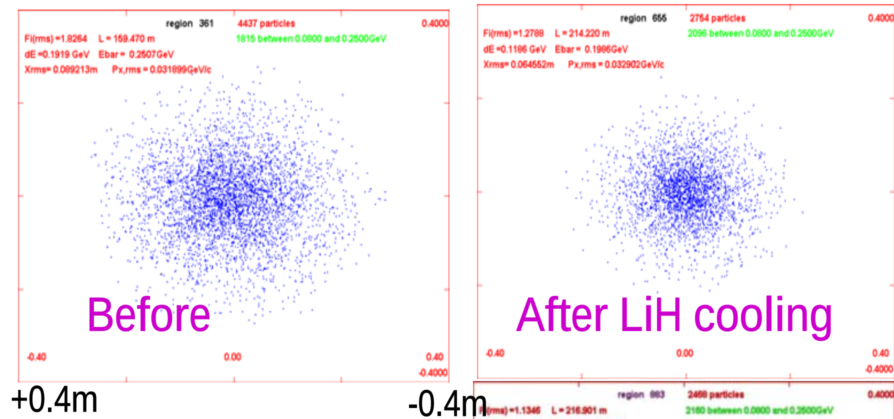
- Reduce drift, buncher, rotator to get even shorter bunch train:
  - 217m ⇒ 86m
  - 38m drift, 21m buncher, 27m rotator
  - Rf voltages 0-15MV/m, 15MV/m (×2/3)
- Obtains ~0.23 μ/p in ref. acceptance
  - Slightly worse than previous ?
- 80+ m bunchtrain reduced to < 30m
  - 18 bunch spacing dropped to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



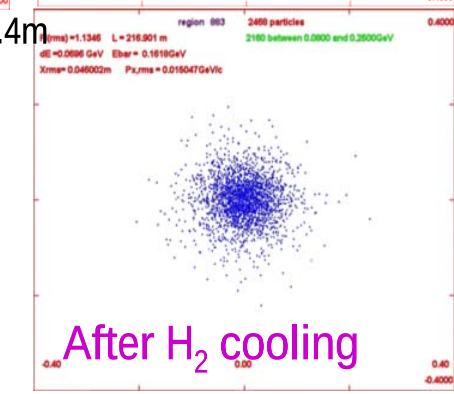


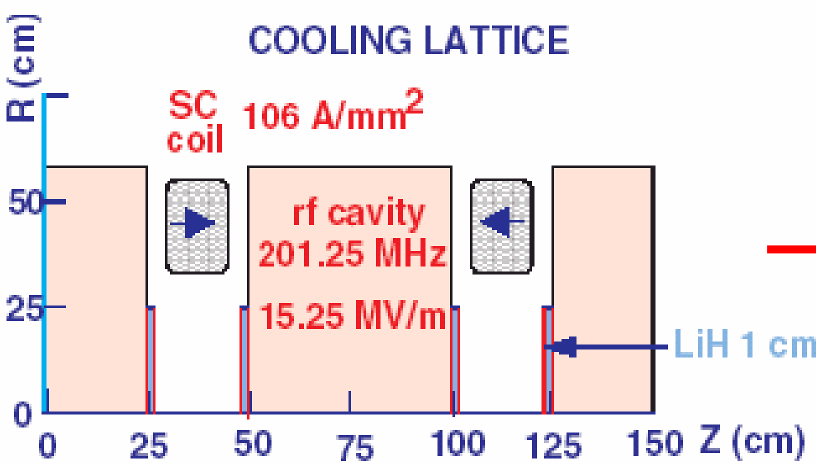
Variation: ν-Factory Cooling Channel

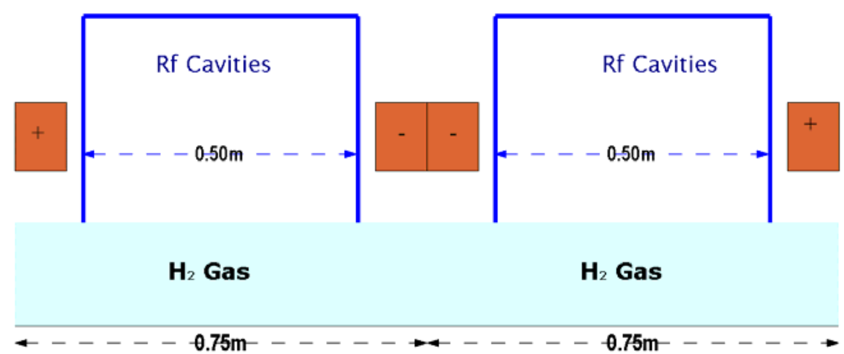
- **Cooling is limited:**
  - LiH absorber, $\beta_\perp \cong 0.8$m
  - $\varepsilon_\perp$ from ~0.018 to ~0.0076m in ~80m
  - $\varepsilon_{eq} \cong 0.006$m
- **Could be improved**
  - H_2 Absorber (120A) or smaller $\beta_\perp$
  - $\varepsilon_\perp \rightarrow$ ~0.0055
  - $\varepsilon_{eq} \cong 0.003$m
  - ~20% more in acceptance
  - Less beam in halo



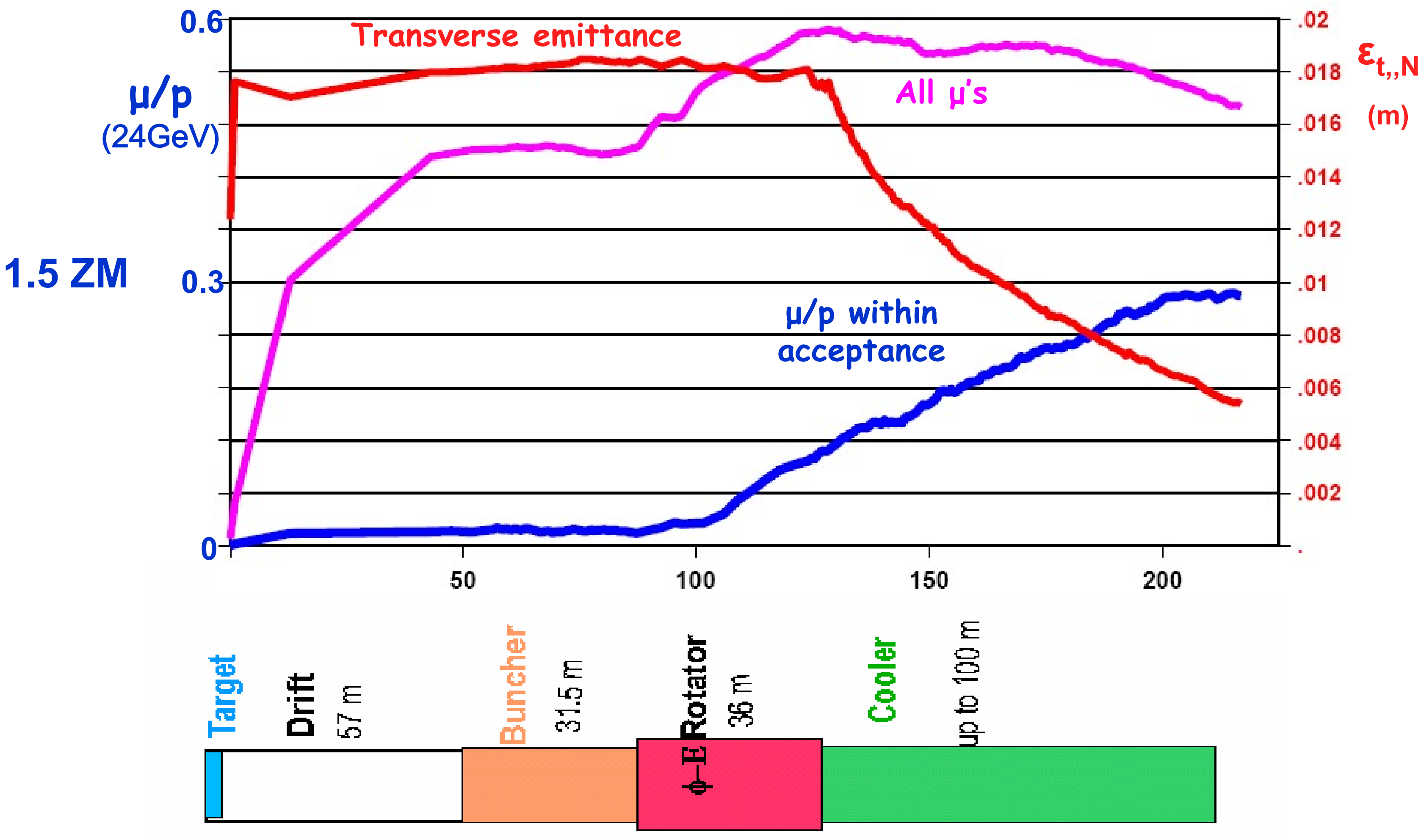
$$\frac{d\varepsilon_N}{ds} = -\frac{1}{\beta c p_\mu}\frac{dE}{ds}\varepsilon_N + \frac{\beta\gamma\ \beta_\perp}{2}\frac{E_s^2}{\beta^2 c^2 p_\mu^2 L_R}$$







Example: N_B = 10, H_2 cooling



Discussion

- **Guess: Optimum is $N_B \approx 10$**
  - (for both collider and ν-Factory)
  - As many μ/p as baseline in more compact bunch train
  - Bunch train is ~1/2 that of Study 2B
- **Develop as new baseline parameter**
  - Shorter buncher/rotator may be cheaper
    - 215m -> 125m, cost × ~0.8 ?? …. (150->120)
  - Better cooling is desirable
    - H_2 absorber and/or stronger focussing

- **Assumed for these scenarios:**
  - ~15 MV/m at B ≅ 2T and f ≅ 200MHz is practical
  - Capture at ~150 to 300 MeV/c is optimal

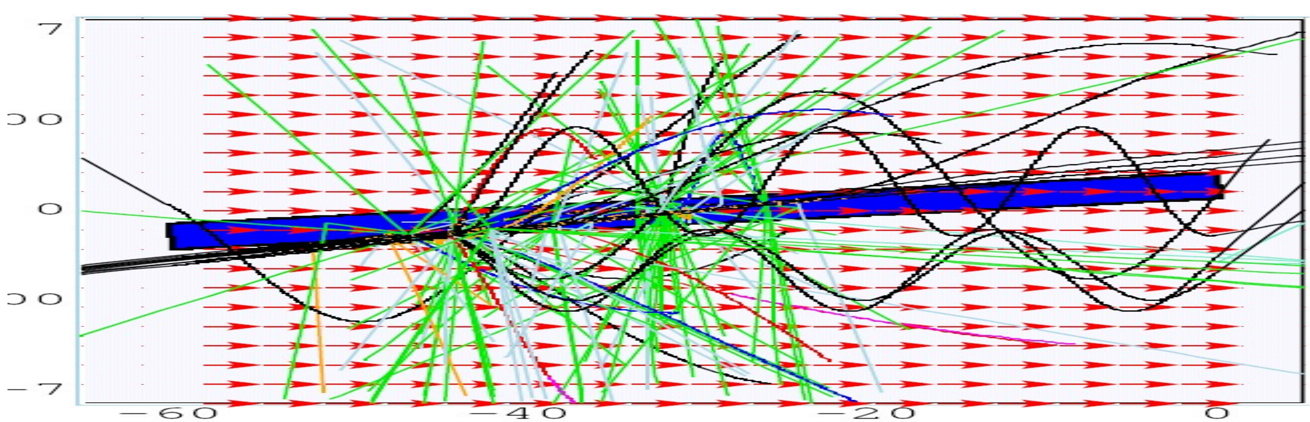
Variations

- Beam energy, bunch length, longitudinal acc.
  - Target variations
- Quad channel
- Rotator + cooler
- Tilted solenoid - Y. Alexhin
- Rf/experiment comments
- Discrete frequencies
  - More realistic geometries

8 GeV baseline

- **Consider 8 GeV initial beam**
  - New beam from Mars simulation – C. Yoshikawa
    - B=20T, Hg-jet target, 8-GeV p-beam~60cm long target region, ~MERITgeometry, 1 to 3 ns rms

- **Express yield in "E-independent" units**
  - **Z = Zetta = 10^{21}**
  - 0.2μ/(24GeV p)=1.042 Zμ/year-MW (ZyM)
    - (10^{21} μ/ MW-year) , where year is 2×10^{7} s
      - Study 2B is ~0.885 ZyM … (or ZM =ZisMans ?)



ZyM-ology – ICOOL results

- Place 8GeV in N_B=10 lattice
  - LiH lattice
  - Yield is 1.293 ZM (ε_t<0.03,ε_L<.2)(1ns)
    - (0.0814 μ/p)
  - 1.213 ZyM @(ε_t <0.03,ε_L<.0.2)(3ns)
- Compare w/ 24 GeV N_B=10
  - St2 ref. beam: 1.375 ZM (3ns)
  - St2A ref. beam: 1.156 ZM
- This initial beam is ~12% "worse" than ST2 reference beam
  - but ~5% "better" than study 2A reference beam

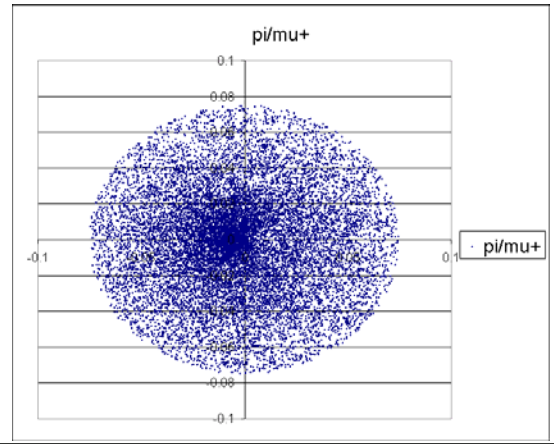
- Change to H_2 cooling (~20% more …)
  - ~1.59 ZM (ε_t<0.03,ε_L<.2,1ns) 8GeV (1.51@3ns beam)
- ~Sensitive to longitudinal acceptance:
  - ~1.42 ZM(ε_t<0.03,ε_L<.15,1ns)

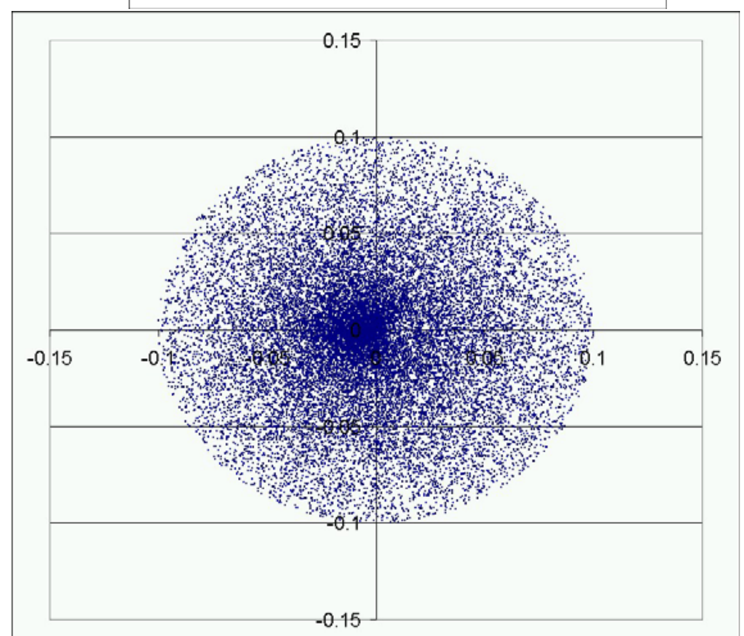
Is 7.5cm adequate?

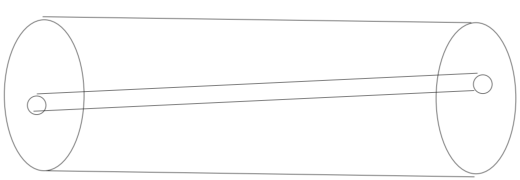
- **Mars simulation obtains:**
  - 0.38 π/8GeV proton forward
    - B=20T R=7.5cm
  - 0.53 π/8GeV hit sides

- **Increase radius to 10cm:**
  - ~0.54 π/8GeV proton forward
  - ~0.37 π/8GeV hit sides

- **But many larger radius π/μ are not accepted:**
  - 1.39 ZM→1.51 ZM (?)
    - 42%more initial; but only 9% more in acceptance cuts







Reduce number of rf frequencies

- Study 2B discretization exercise:
  - Buncher : 12 rf frequencies; Rotator 15 rf freq.
- Buncher 31.5m – 42 cavities (× 1/3 = 14)
  - 362.15, 348.52, 335.87, 324.12, 313.15, 302.91, 293.31,
  - 284.31, 275.84, 267.86, 260.33, 253.21, 246.47, 240.08
- Rotator 36m -48 cavities (× 1/3 = 16)
  - 235.95, 230.62, 225.97, 221.91, 218.36, 215.26, 212.57, 210.25, 208.26, 206.58, 205.19, 204.07, 203.20, 202.58, 202.2,202.0
- As for study 2B, simulate and compare
  - ~10% worse (not yet simulated, however)

Rf cavity comments

- Frequencies from 360 to 200 MHz
  - 5 to 15 MV/m to ? **In B = ~2T**
- Normal-conducting Short-pulse rf
  - 15 to 60 Hz
- Simulation cavity length – 0.5m-??
- Be windows? "gas-filled" ? options
- **NEED R&D to determine E_{cf} /B limits**
  - 200, 800 MHz,

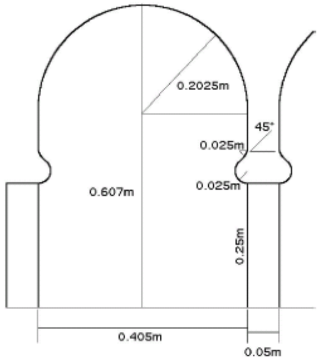
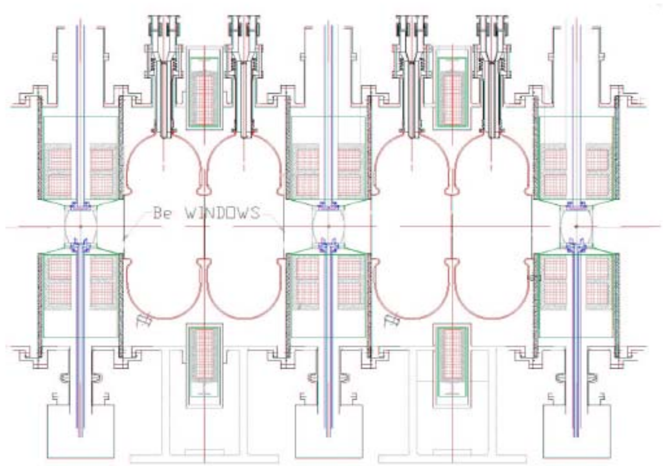
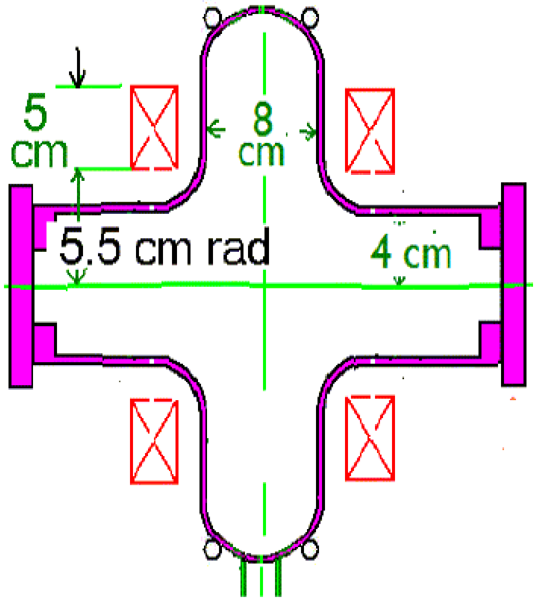


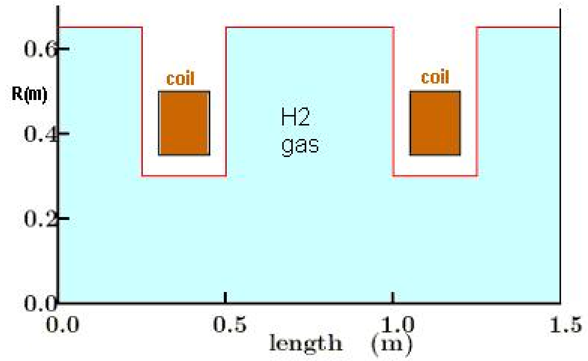
Figure 8.6: Section of one cavity.

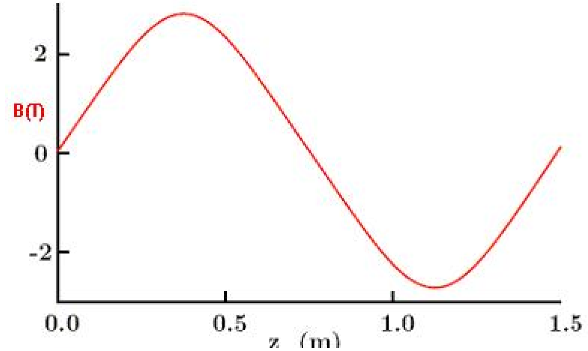


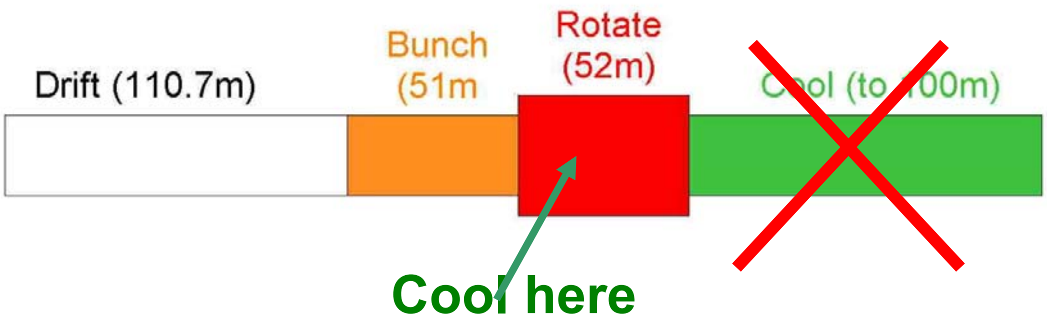


Gas-filled rf cavities (w/Muons, Inc.)

- Add gas + **higher gradient to obtain** cooling within rotator
- **Rotator is 54m;**
  - Need ~5MeV/m cooling
  - **150atm** equivalent 295°K gas
  - Alternating Solenoid lattice in buncher/rotator
- **24MV/m rf(0.5m cavities)**
- **Gas-filled cavities may enable higher gradient**
- ~0.22μ/p **at ε_T < 0.03m**
  - ~0.12μ/p at ε_T < 0.015m
  - $\varepsilon_\perp$ cools to ~0.008m
- About equal to Study 2A

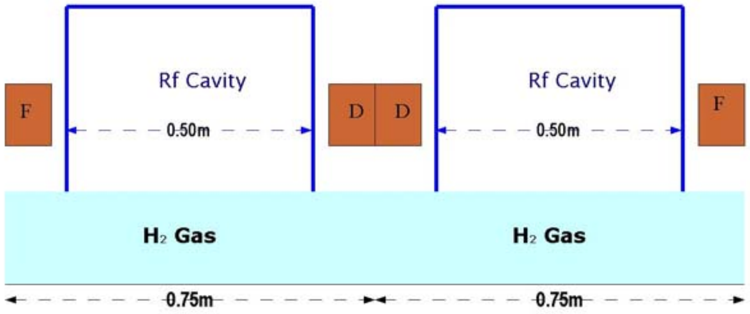


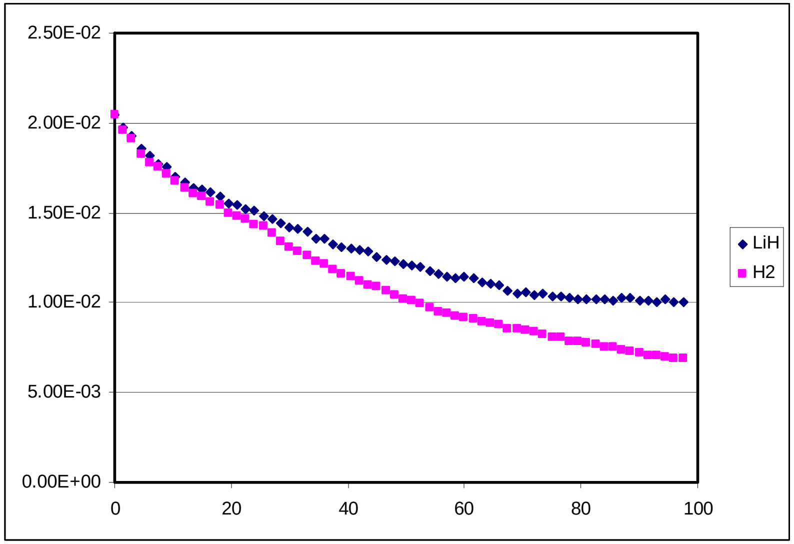




Quad cooling channel for front end

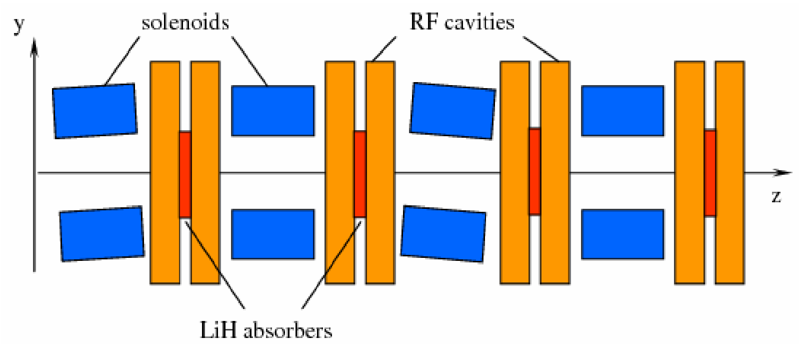
- w. A. Poklonsky
- **Use 1.5m long cell – FODO**
  - 60° to 90°/cell at P_{μ} 215MeV/c
  - β_{max} = 2.6m; β_{min}=0.9 to 0.6m
  - B′ = 4 to 6 T/m
- ***Advantages:***
  - ***No large magnetic fields along the axis***
  - ***Quads much cheaper ?***
  - ***No beam angular momentum effects***
- Disadvantages
  - ***No low β* region***
  - ***Relatively weak focusing***
- ***H_2-cooled example as good as Study2B LiH case***

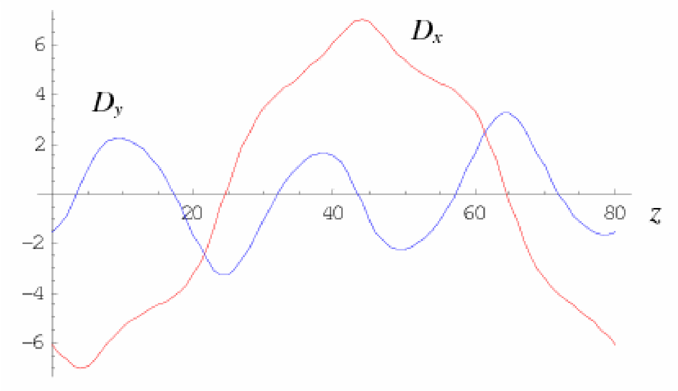




Tilted Solenoid? – Y. Alexhin

- Tilt solenoids to insert dispersion
  - ~6cm ?
- Allows wedge absorbers to cool longitudinally
- If wide aperture, oscillations of both μ^+ and μ^- particles can be within the channel
- Try to simulate in front end





Conclusions

- **Can use high-frequency capture to obtain bunch train for ν-Factory → μ^+-μ^- collider**
  - (~10 to 14 bunches long at 200MHz)
  - Recombine after cooling for collider mode

- **Questions**
  - Is ~200 MHz optimal?
  - ~15 MV/m at B ≅ 2T and f ≅ 200MHz is OK?
  - Is ~12 bunches OK for Collider scenario

- **To Do:**
  - **Turn into detailed design for IDS ??**