ν–Factory Front End
Phase Rotation Gas–filled rf

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Outline

- Neutrino Factory Front End Optimization
  - Performance, cost,
- Study 2A Front End

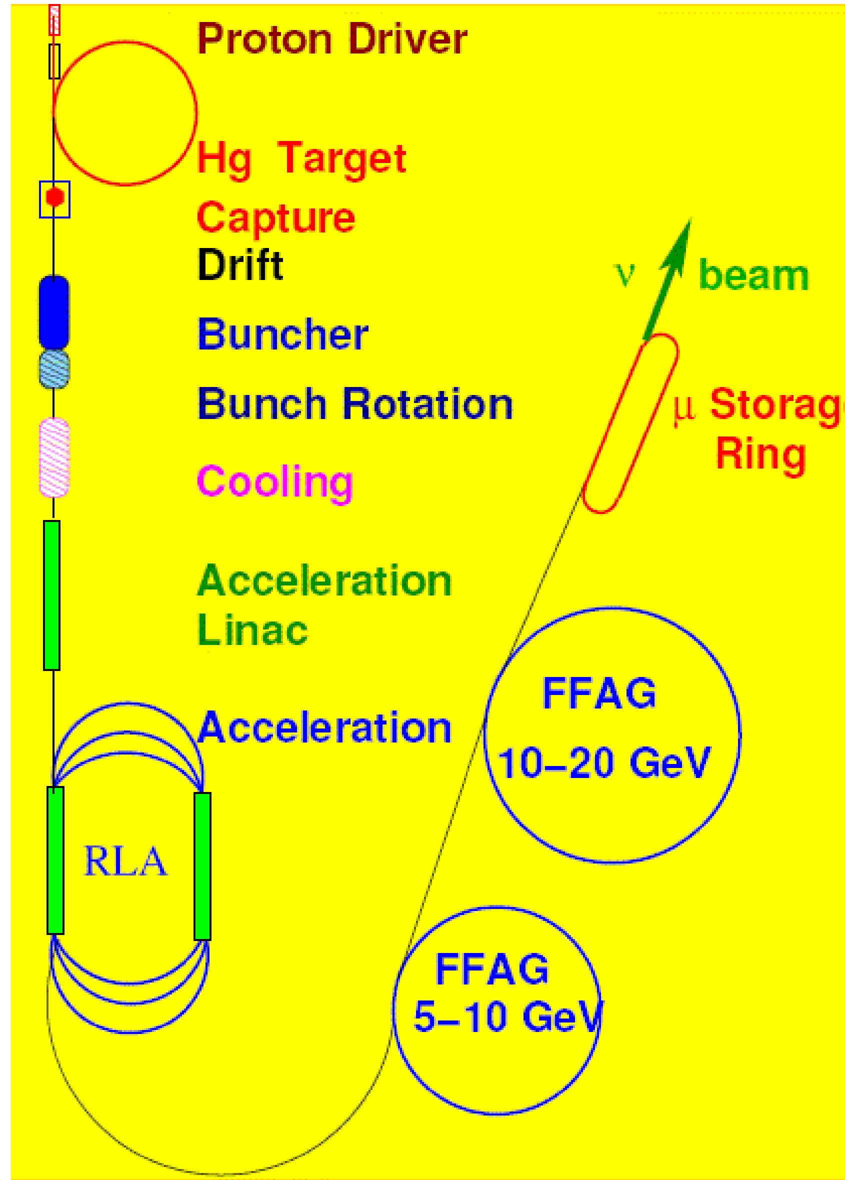
- Variations on Study 2A
  - Shorter rotator – less adiabatic

  - Gas-filled rf cavities
  - Global optimizations

- Different Approaches
  - Shorter bunch trains
  - Rotate, then bunch ?

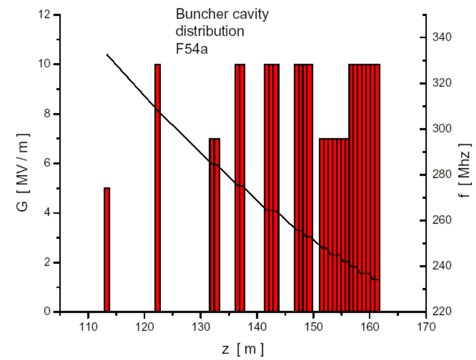
Neutrino Factory – Study 2A

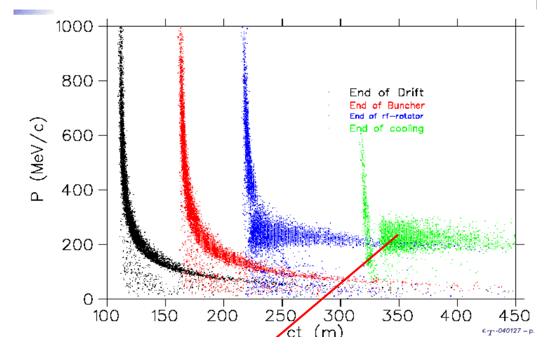
- Proton driver
  - Produces proton bunches
  - 8 or 24 GeV, ~10^{15}p/s, ~20Hz bunches
- Target and drift
  - $\pi \rightarrow \mu$ (> 0.2 μ/p)
- **Buncher, bunch rotation, cool**
- Accelerate μ to 20 GeV
  - Linac, RLA and FFAGs
- Store at 20 GeV (0.4ms)
- $\mu \rightarrow e + \nu_\mu + \nu_e^*$
- Long baseline ν Detector
- $>10^{20}$ ν/year

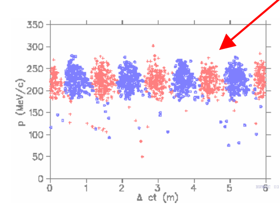


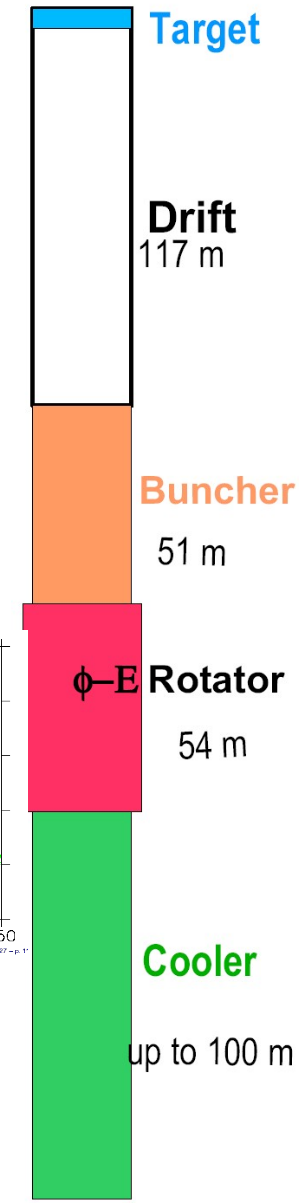
Study2A scenario details

- Target– Hg-jet within 20T solenoid
- Drift –110.7m – within 1.75T solenoid
  - Seems long …
- Bunch –51m (110MV total)
  - 12 rf freq., 330 MHz → 230MHz
  - Quasi-adiabatic
- ϕ–E Rotate – 54m – (416MV total)
  - 15 rf freq. 230→ 202 MHz
  - Longer than needed – adiabatic
  - Must work at B= ~1.75T or more
- Match and cool (80m)
  - 0.75 m cells, 0.02m LiH
  - H_2 would be better
  - Do we need cooling??
- Captures both μ^+ and μ^-







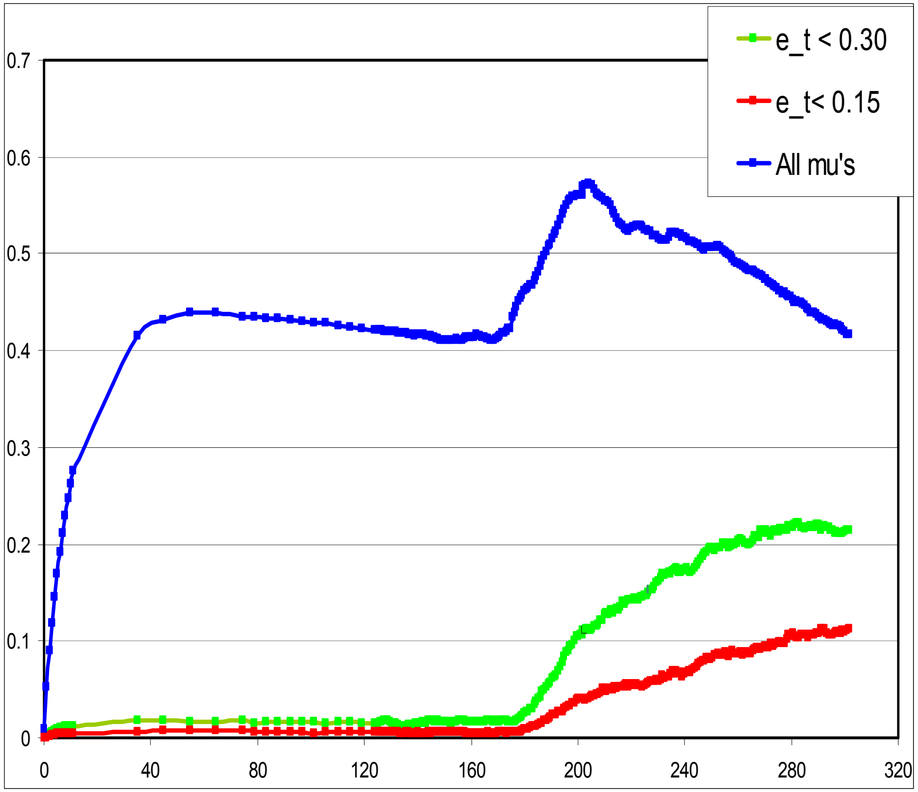


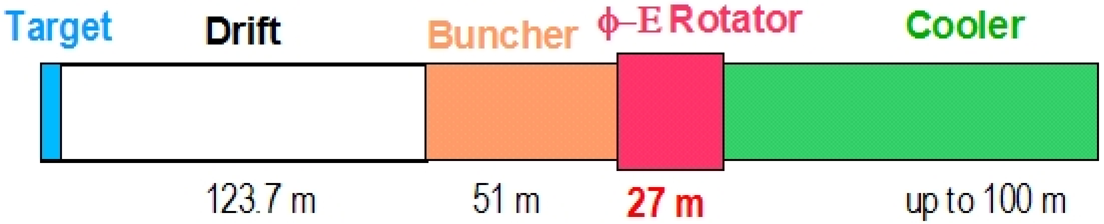
Features/Flaws of Study 2A Front End

- Fairly **long** section – ~350m long
  - Study 2 was induction linac 1MV/m
- Produces long bunch trains of ~200 MHz bunches
  - ~80m long (~50 bunches)
  - Matches to downstream acceleration rf ??
- Transverse cooling is only factor of ~2½ in x and y
  - No cooling or more cooling may be "better"
- Method works better than it should …
- Vary Study 2A baseline or try very different scenario

Reduce Rotator length

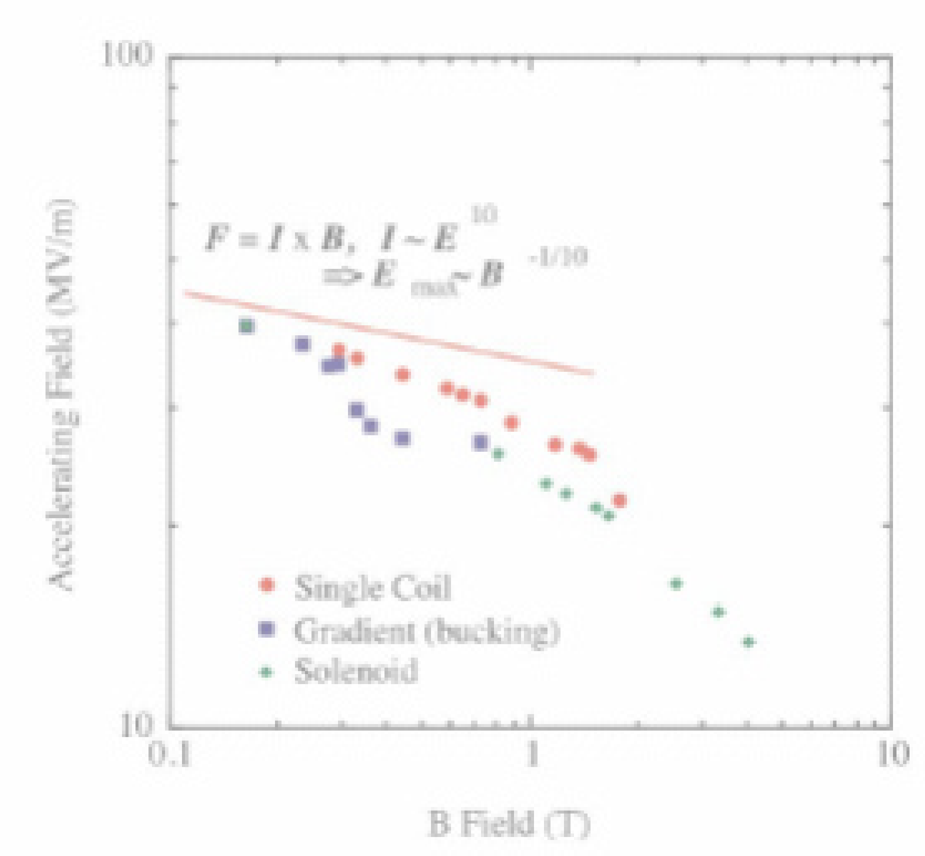
- Rotator reduced by factor of 2
  - 54m →27m
- Acceptance only slightly degraded
  - ~0.204 μ/p at ref. emittance
  - ~0.094 μ/p at 1/2 emittance
  - (in simplified ICOOL model)
- Would reduce cost by 42M$
  - Palmer-Zisman estimate…





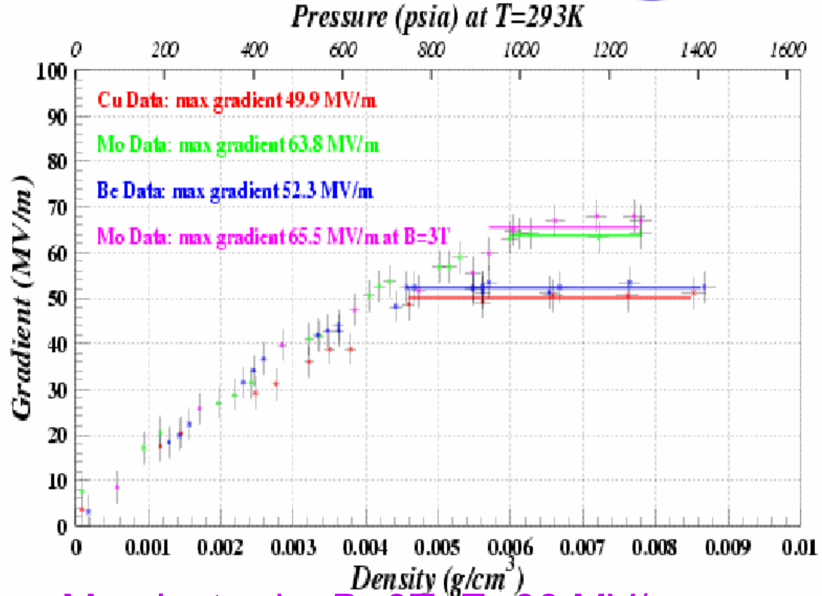
rf in Rotation/Cooling Channels:

- Can cavities hold rf gradient in magnetic fields??
- MUCOOL result :
  - V' goes from 45MV/m to 12MV/m (as B -> 4T)
  - 800MHz rf
- Vacuum rf cavity
- Worse at 200MHz ??



Use gas-filled rf cavities?

- Muons, Inc. tests:
  - Higher gas density permits higher gradient
  - Magnetic field does not decrease maximum allowable gradient
- Gas filled cavities may be needed for cooling with focusing magnetic fields
- Density > ~60 atm H_2 (7.5% liq.)
- Energy loss for μ's is >~ 2MV/m
- Can use energy loss for cooling

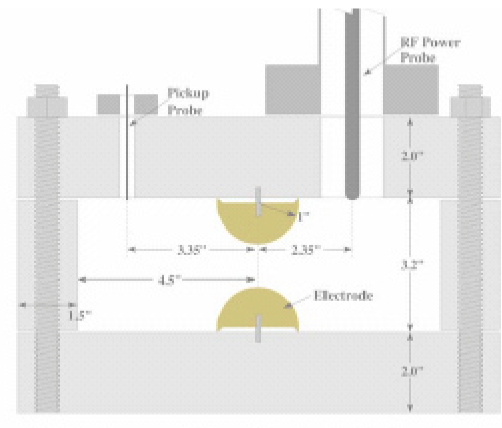


Mo electrode, B=3T, E=66 MV/m

Mo B=0 E=64MV/m

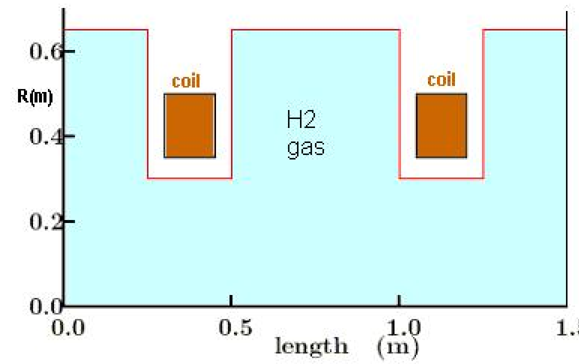
Cu E=52MV/m

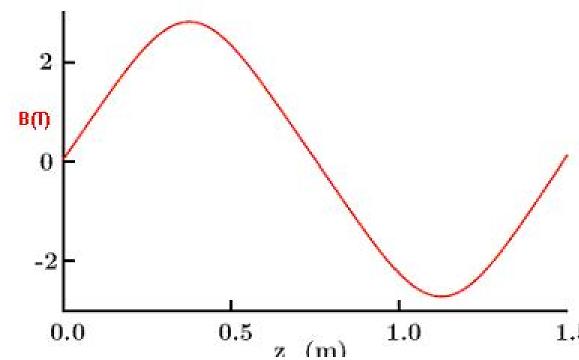
Be E= 50MV/m 800 MHz rf tests

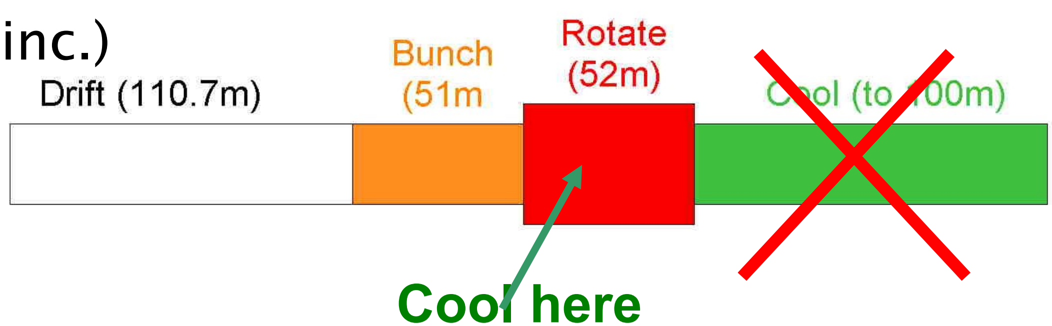


Gas-filled rf cavites (Muons, Inc.)

- **Add gas** + higher gradient to obtain cooling within rotator
- ~300MeV energy loss in cooling region
- Rotator is 54m;
  - Need ~4.5MeV/m H_2 Energy
  - 133atm equivalent 295°K gas
  - ~250 MeV energy loss
- Alternating Solenoid lattice in rotator
- 20MV/m rf cavities
- Gas-filled cavities may enable higher gradient (Muons, inc.)

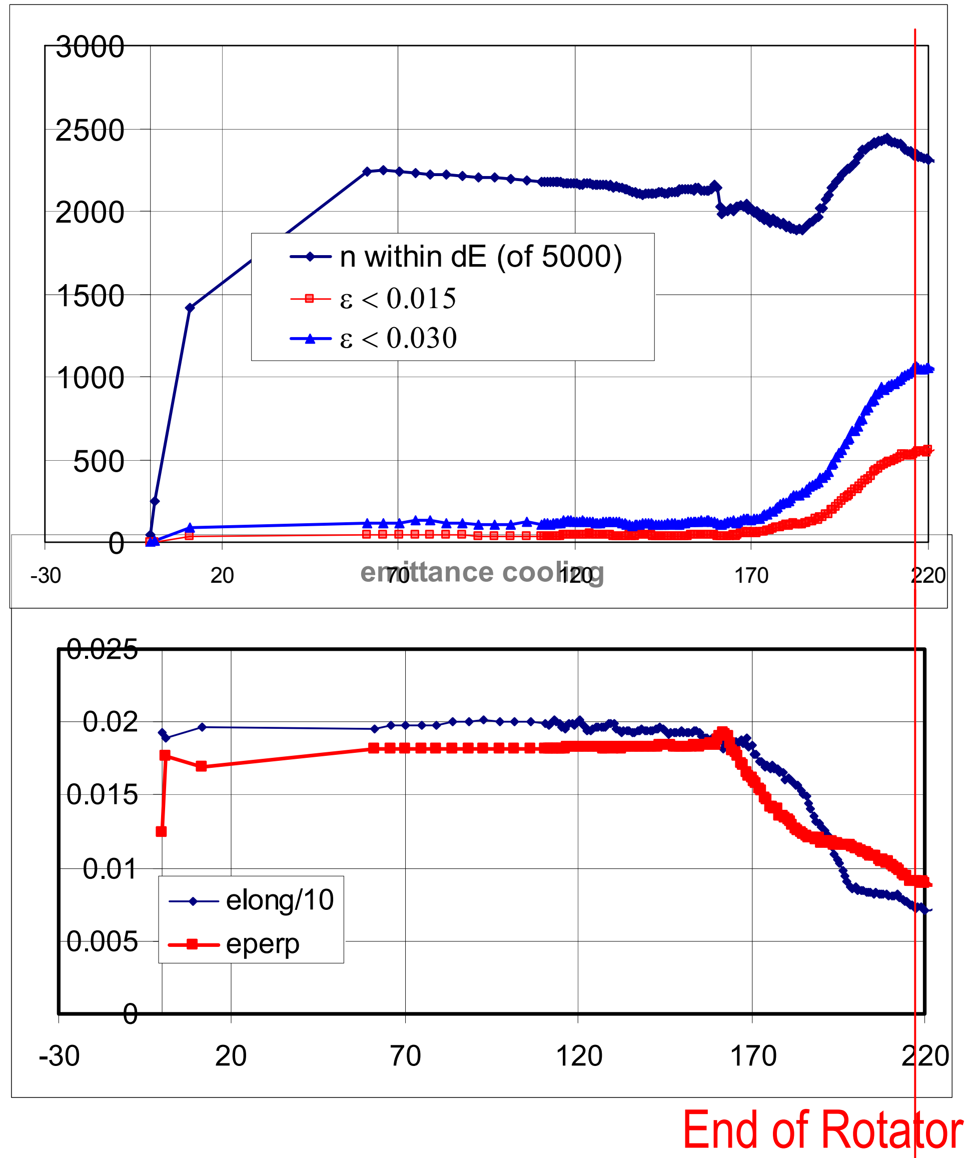






ICOOL results– gas cavities

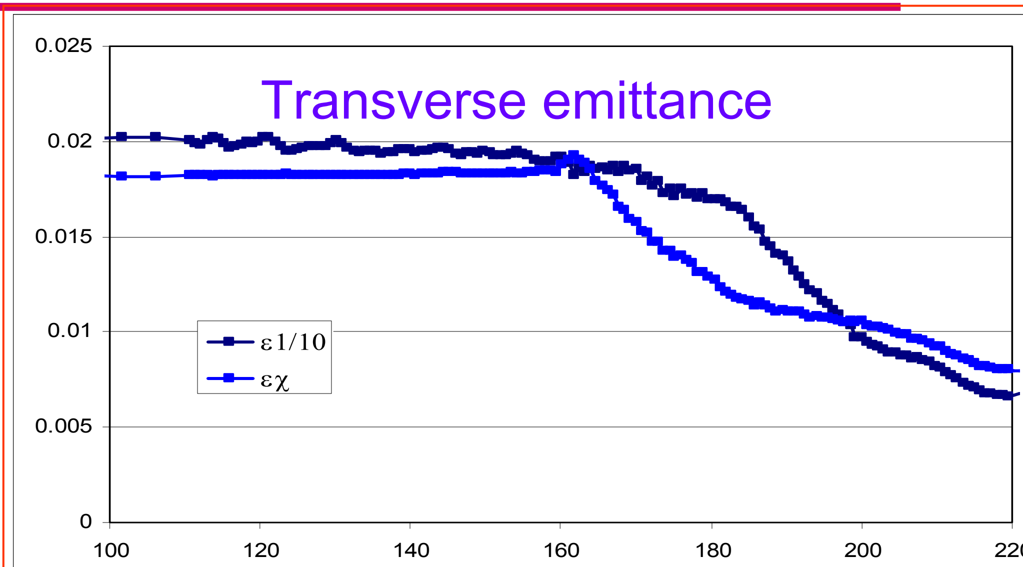
- ~0.20 μ/p within reference acceptance at end of φ–E Rotator
- ~0.10 μ/p within restricted acceptance ($\epsilon_\perp$<0.015m)
- Rms emittance cooled from $\epsilon_\perp$ = 0.019 to $\epsilon_\perp$ = ~0.009
- Longitudinal rms emittance ≅0.075
- Continuing ~ Study 2A cooling can improve to
  - ~0.22 μ/p, $\epsilon_\perp$ = ~0.008
  - ~30m, V' = 18MV/m

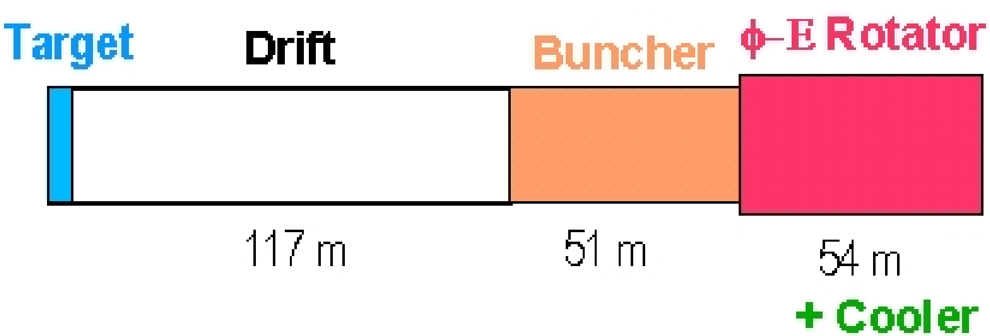


Modify initial solution

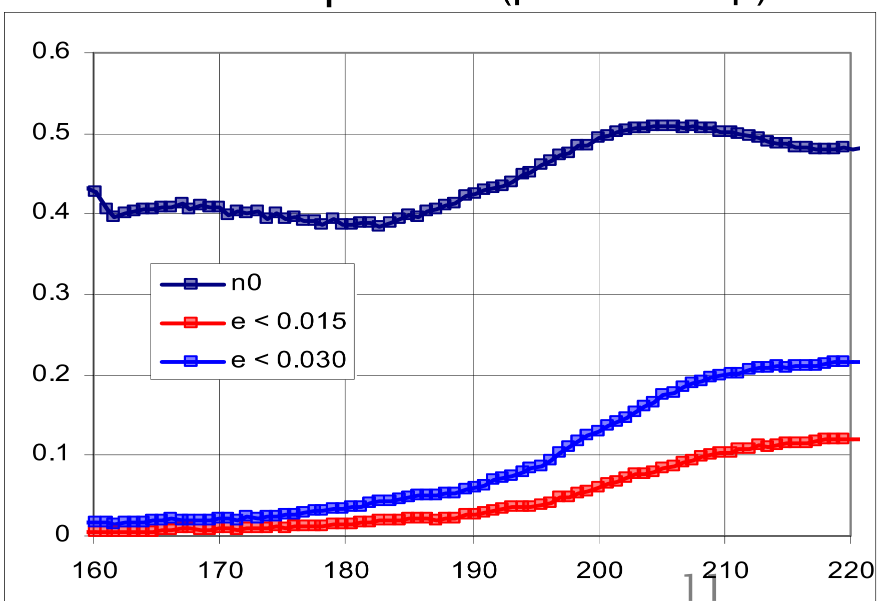
- Change pressure to 150Atm
- Rf voltage to 24 MV/m
- Transverse rms emittance cools 0.019 to ~0.008m

- Acceptance ~0.22μ/p at $\epsilon_T < 0.03$m
- ~0.12μ/p at $\epsilon_T < 0.015$m
- **About equal to Study 2B**

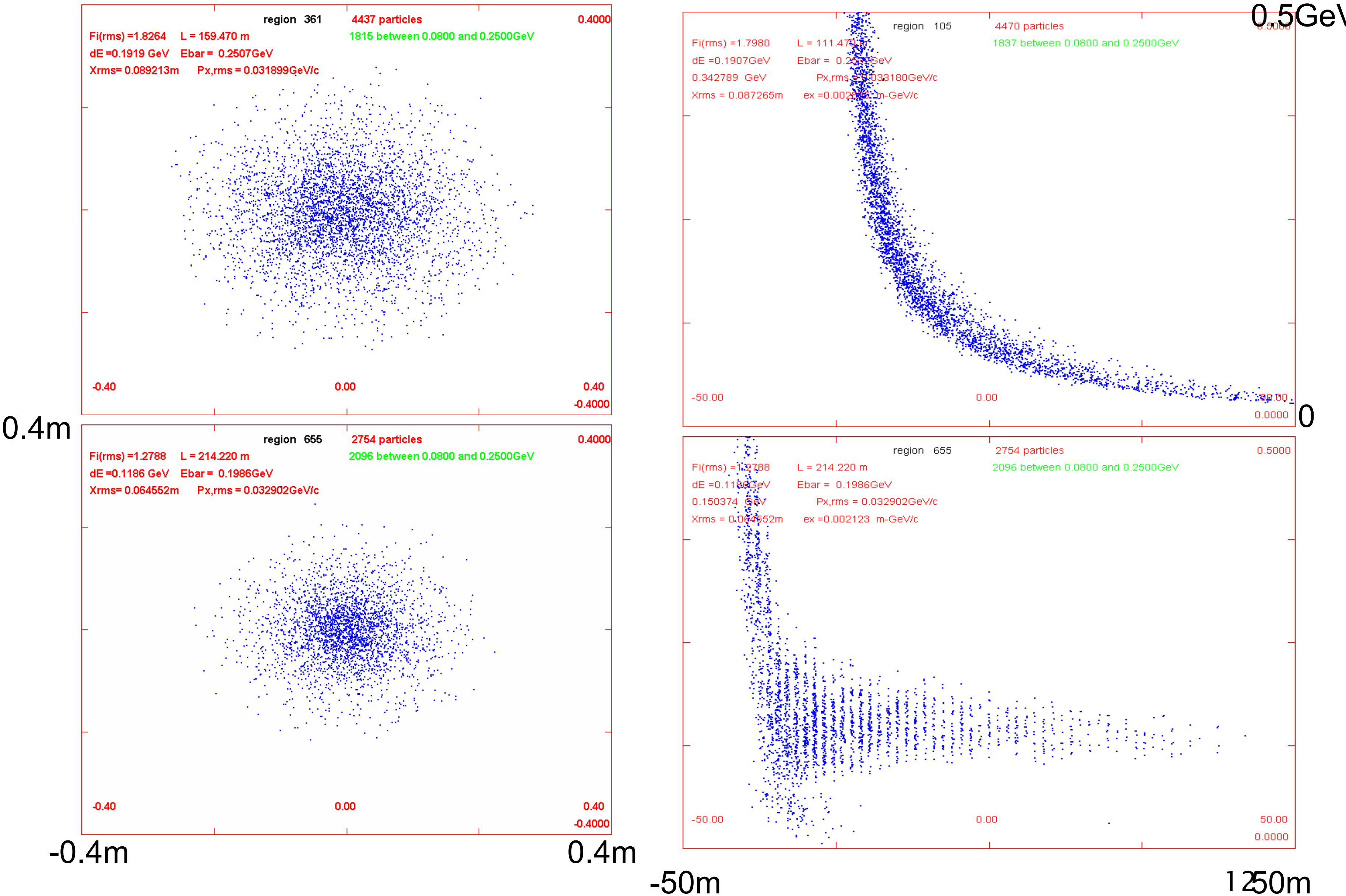




Acceptance (per 24GeV p)



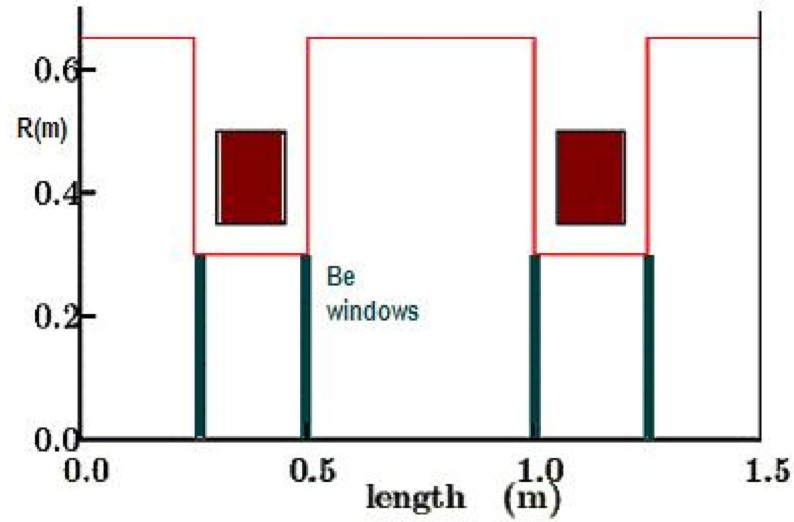
Cooling simulation results



Same geometry – Be or LiH Windows

Muon Collaboration

- Replace 150A H_2 with 0.65cm thick Be windows or 1.2 cm LiH windows
- Similar dynamics as H_2 but
- Much worse than Study 2B performance (?)
- Transverse emittance cooling : 0.019→ 0.0115 (Be)
    - → 0.0102m LiH
- Muons within Study 2B acceptance:
    - 0.134 μ/p ($\epsilon_t < 0.03$) Be
    - 0.056 μ/p ($\epsilon_t < 0.015$)
    - 0.160 μ/p ($\epsilon_t < 0.03$) LiH
    - 0.075μ/p ($\epsilon_t < 0.015$)



Worse than expected;
Needs reoptimization?

Cost impact of Gas cavities

- Removes 80m cooling section (–185 M$)
- Increase V_{rf}' from 12.5 to 20 or 24 MV/m
  - Power supply cost $\propto V'^2$ (?)
  - 44 M$ → 107M$ or 155M$
- Magnets: 2T → 2.5T Alternating Solenoids
  - 23 M$ → 26.2 M$
- Costs due to vacuum → gas–filled cavities (??)
- Total change:
  - Cost decreases by 110 M$ to 62 M$ (???)

Summary

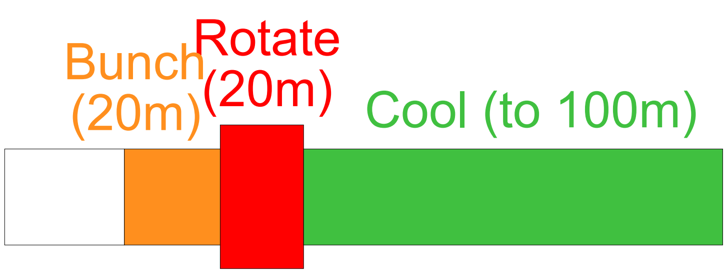
- Buncher and $\phi-\delta E$ Rotator (ν-Factory) Variations
- **Gas-filled rf cavities can be used in Buncher-Rotator**
  - Gas cavities can have high gradient in large B (3T or more?)
- Variations that meet Study 2A performance can be found
  - **Shorter systems – possibly much cheaper??**
- **Gas-filled rf cavities**

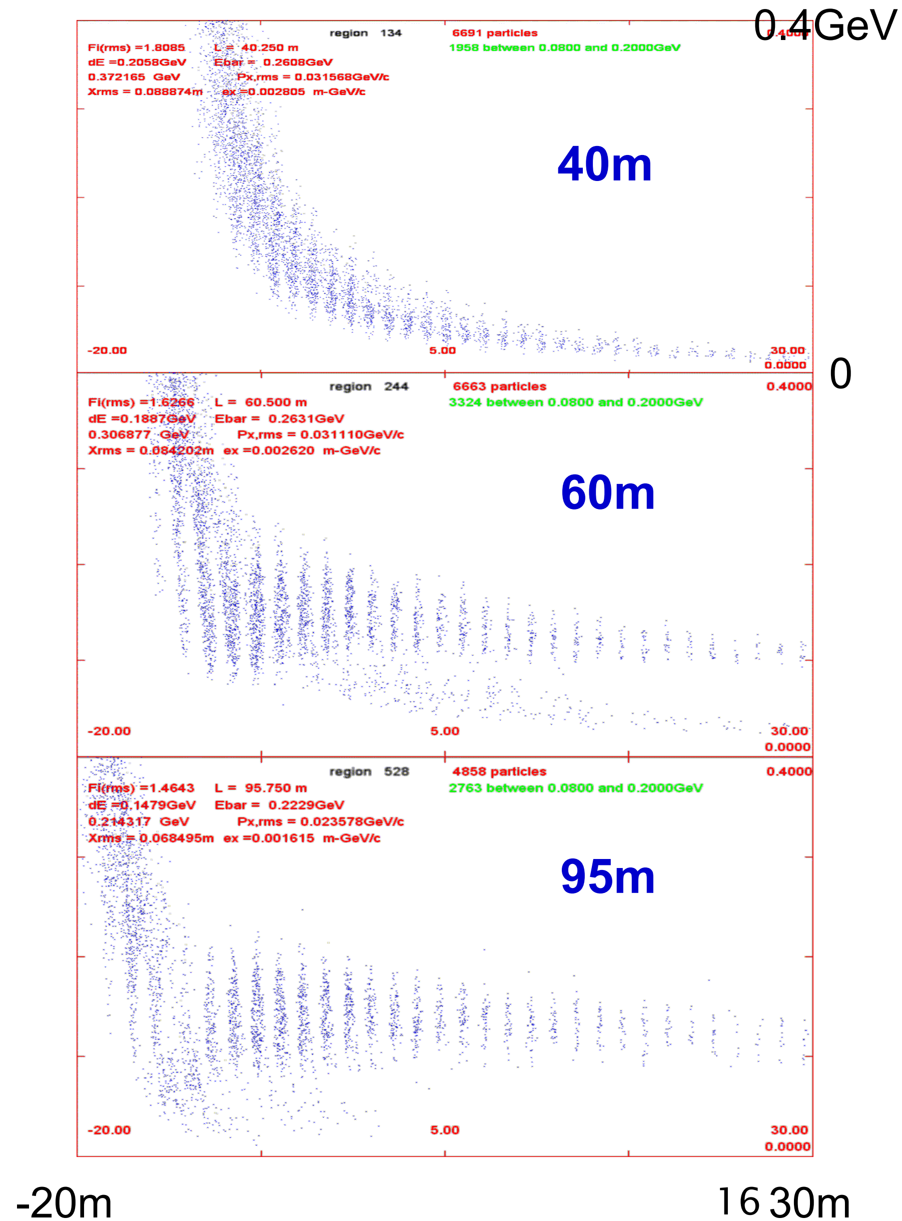
To do:

- Optimizations, Best Scenario, cost/performance …
- More realistic systems

Short Front-end option

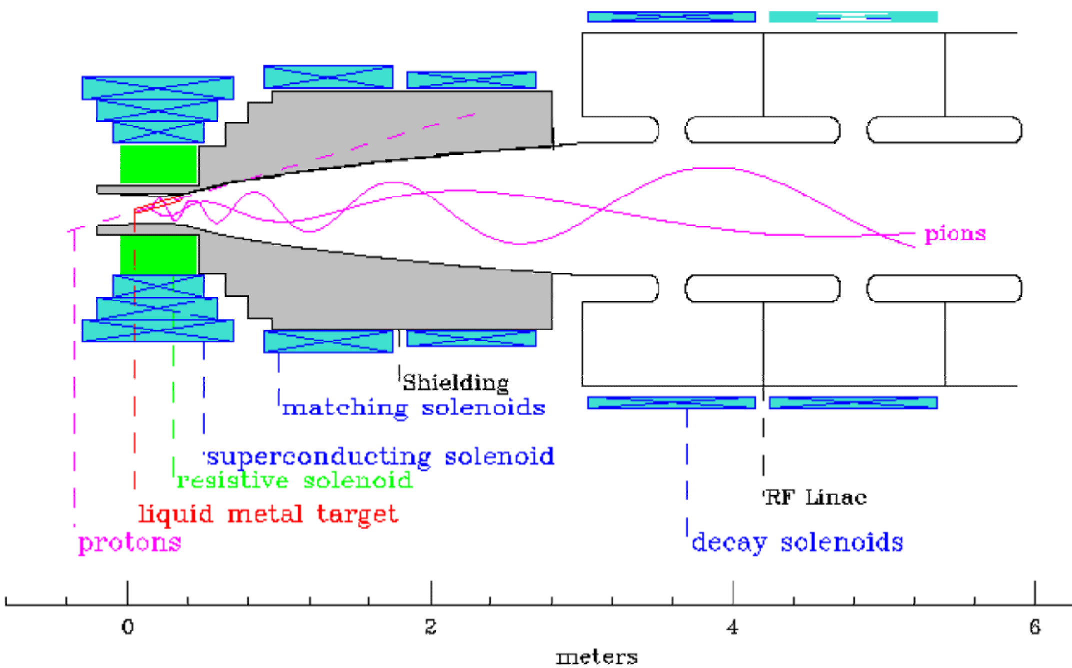
- Drift (20m), Bunch-20m (100 MV)
  - Vrf = 0 to 15 MV/m (× 2/3)
- Rotate – 20m (200MV)
  - Vrf = 15 MV/m (× 2/3)
- Cooler up to 100m
  - Study 2B Cooler
- ICOOL results
  - 0.12 μ/p within 0.3π cm
  - Only ~10 bunches (15m train)
- Reduces base cost by ~100 MP$





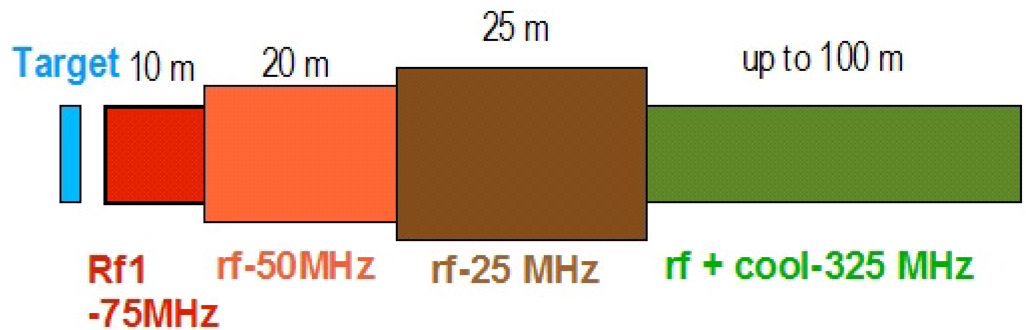
Front-end variant (K. Paul)

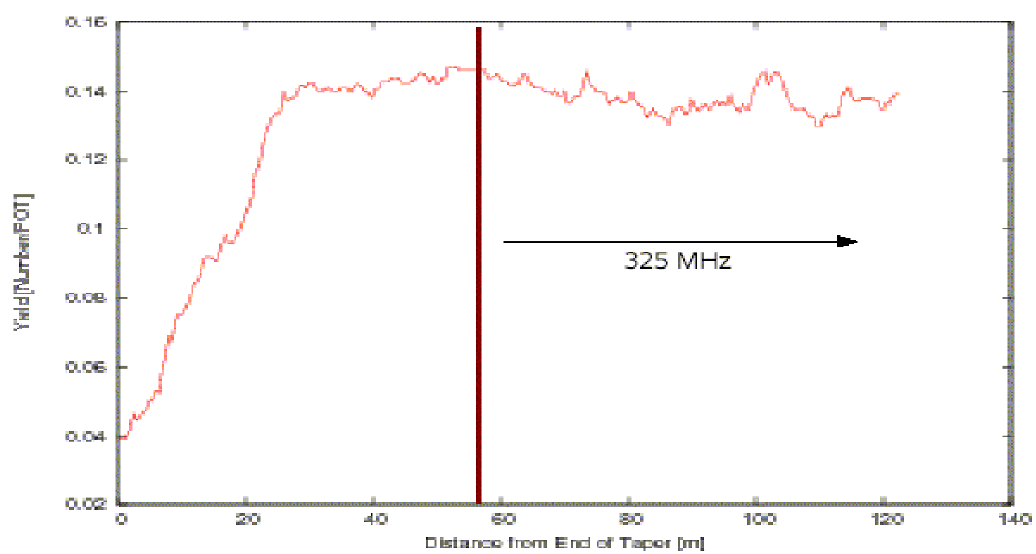
- Low frequency capture and phase rotation
  - SuperInvar target, 8GeV protons
  - Solenoid capture (20T→5T)
- Rf: Start at 75MHz
  - Reduce frequency as bunch lengthens
  - 75→50→25 MHz : phase-energy rotation
- Rebunch at 325MHz (~8 bunches)
  - ~0.14 μ/8 GeV proton
  - 5 to 10 bunches
- Cool with gas-filled rf cavities



Phase/energy rotation

- 75MHz – 4MV/m
- 50MHz – 2MV/m
- 25MHz – 1MV/m
- 325MHz – 5+ MV/m





Cost estimates:

- Costs of a neutrino factory (MuCOOL-322, Palmer and Zisman):

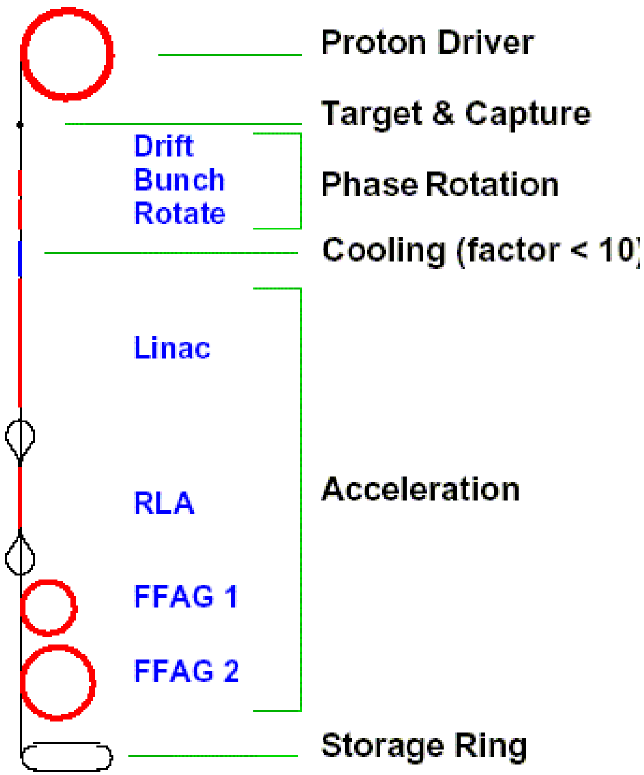


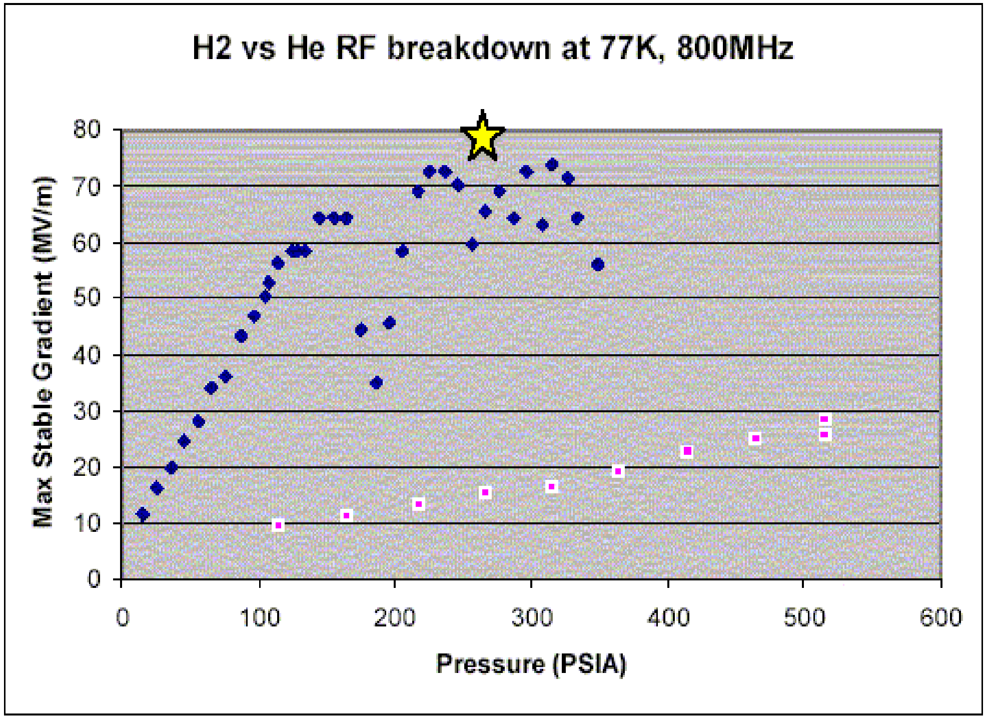
Table 12: Study IIb Costs

	Study 2		Study 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

"Study 2B front end reduces cost by ~ 350MP$

Advantages of high-pressure cavities

- **high gradient rf**
  - In magnetic fields B=3T, or more …
  - With beam
- Can Integrate cooling with capture
  - Capture and phase-energy rotation + cooling
- Can get high-gradient at low frequencies (30, 50, 100 MHz ???)
- Beam manipulations



Research can be funded…