ν-Factory Front End Phase Rotation Simulations

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ISS Workshop

KEK

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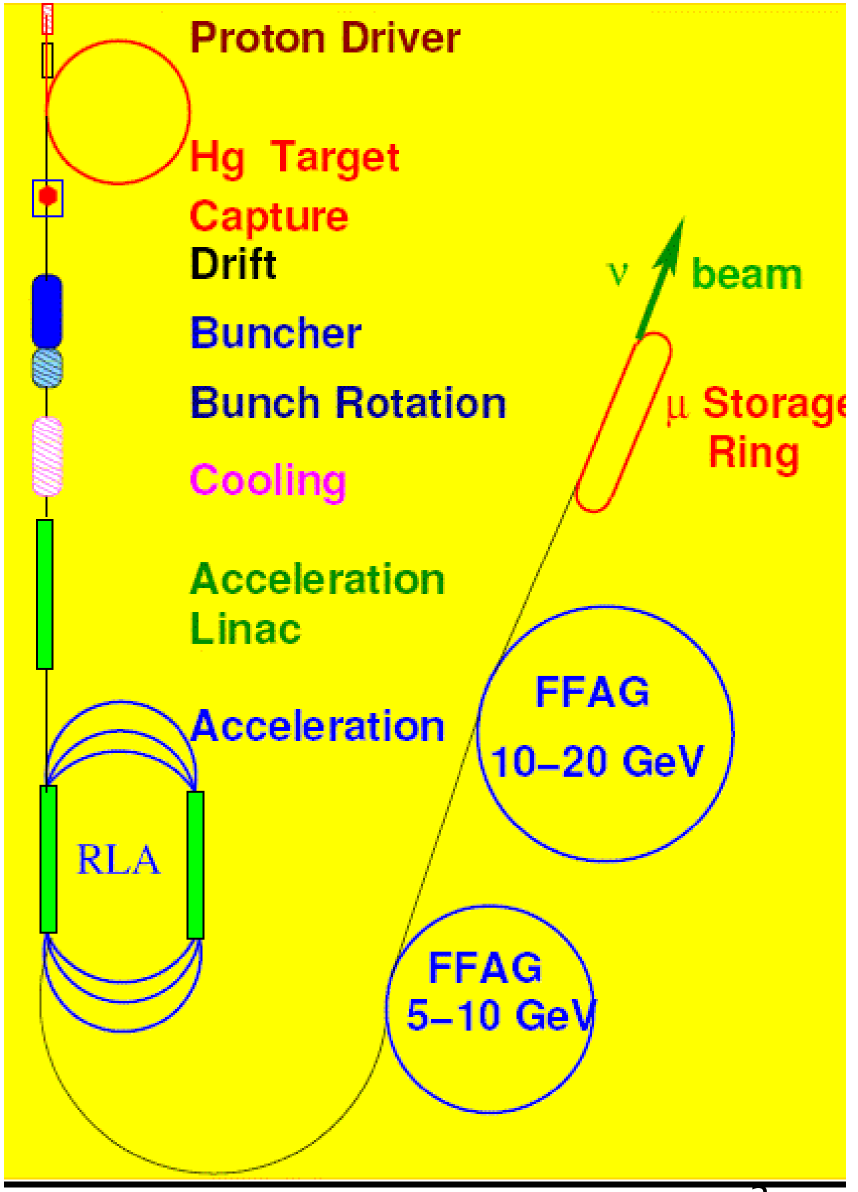
Outline

- Neutrino Factory Front End Optimization
  - Improve neutrino factory scenario
  - For International Scoping study
- "High-frequency" Buncher and ϕ–δE Rotation
  - Study 2A scenario, Obtains ~0.2 μ/p
  - Gas filled cavities
    - Higher gradients? In magnetic fields?
    - Cooling in buncher and rotator/shorter cheaper ? System

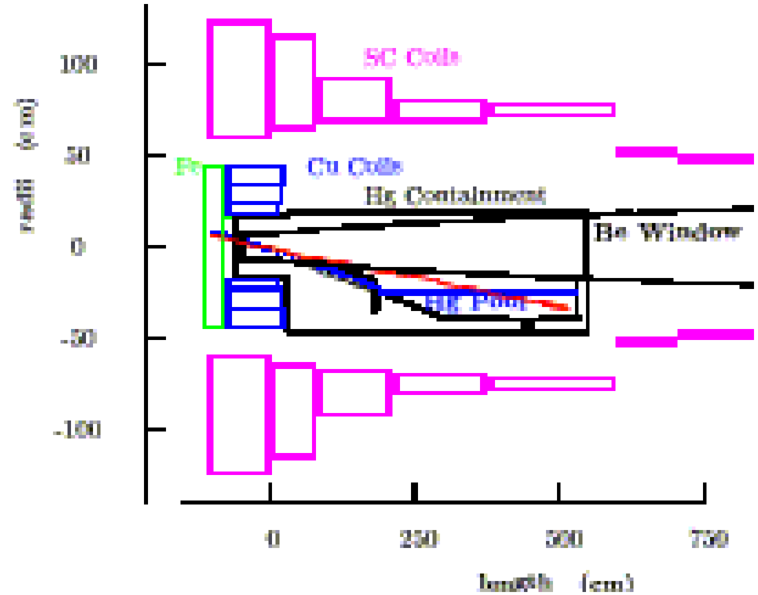
Neutrino Factory – Study 2A

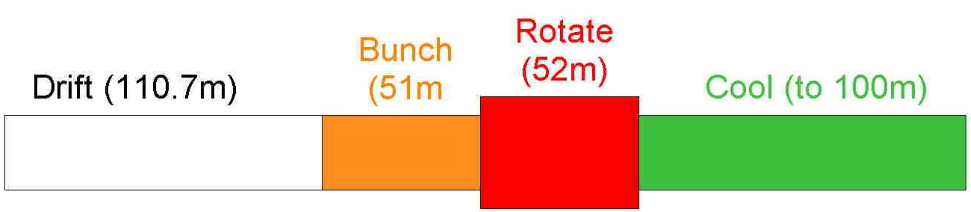
- Proton driver
  - Produces proton bunches
  - 8 GeV 10^{15} p/s
- Target and drift
  - $\pi \rightarrow \mu$ ($>$ 0.2 μ/p)
- **Buncher, bunch rotation, cool**
- Accelerate μ to 20 GeV
  - Linac, RLA and FFAGs
- Store at 20 GeV (0.4ms)
- $\mu \rightarrow e + \nu_\mu + \nu_e^*$
- Long baseline ν Detector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

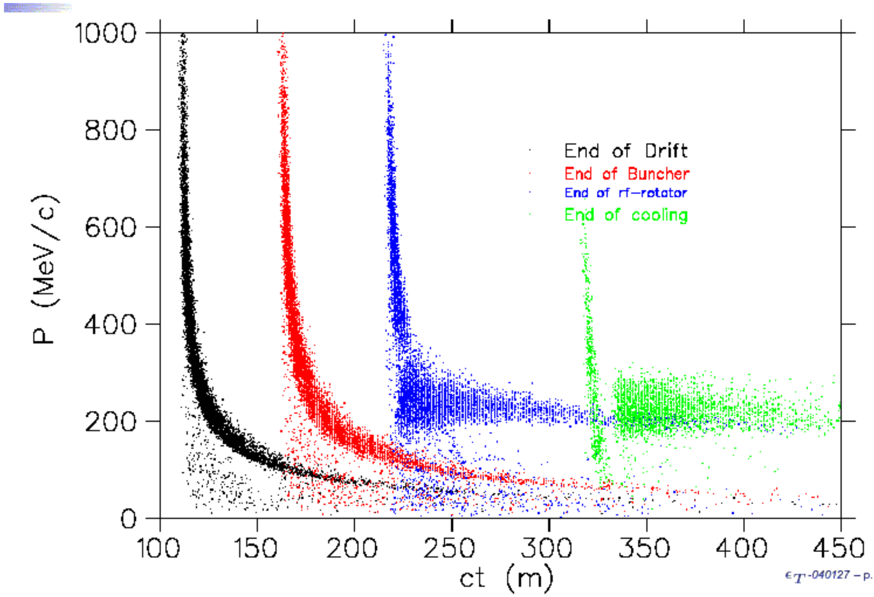


Study2AP June 2004 scenario

- Target– Hg-jet within 20T solenoid
- Drift –110.7m – within 1.75T solenoid
- Bunch –51m
  - $V\delta(1/\beta) = 0.0079$
  - 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
- “Realistic” fields, components

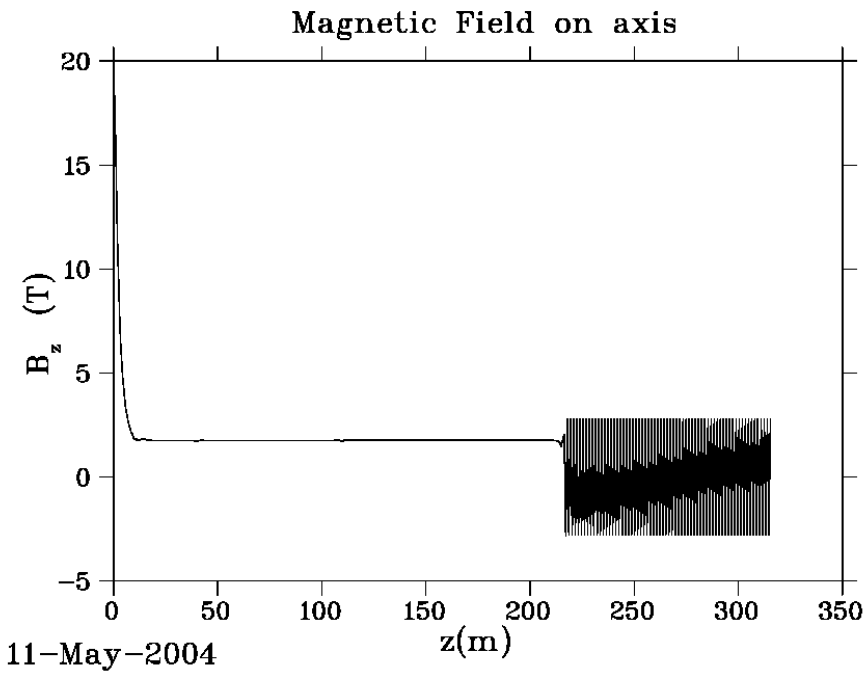


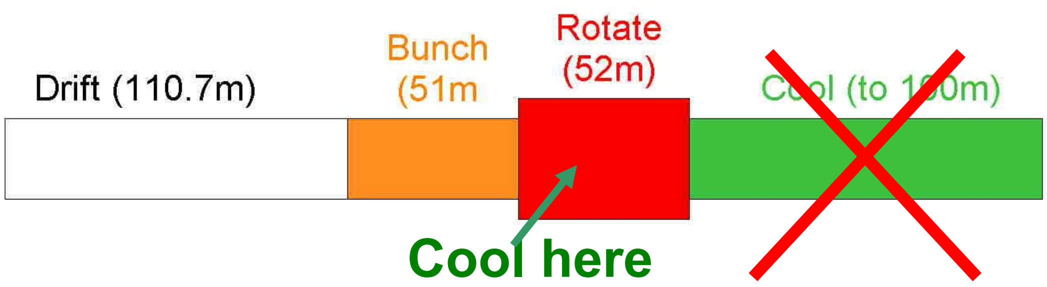




Simplest Modification from Study 2A

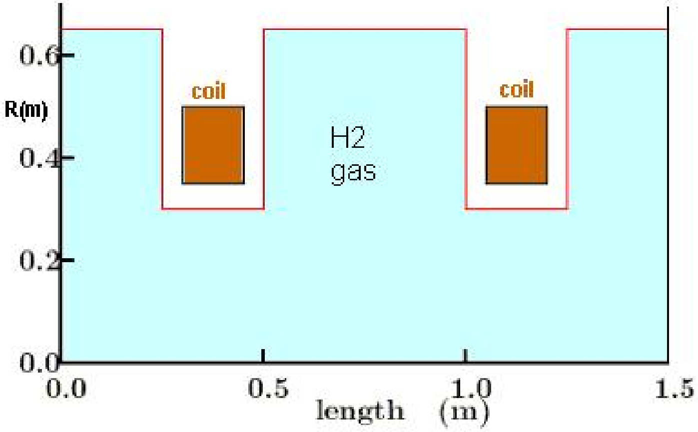
- **Add gas** + higher gradient to obtain cooling within rotator
- ~300MeV energy loss in cooling region
- Rotator is 54m;
  - Need ~4.5MeV/m H_2 Energy
  - 133atm, 295°K gas
  - ~250 MeV energy loss
- Alternating Solenoid lattice in rotator
- 20MV/m rf
- Lattice changes

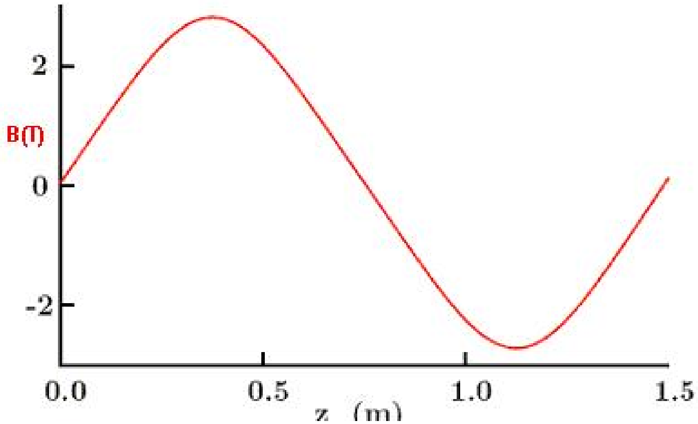




"Final" configuration

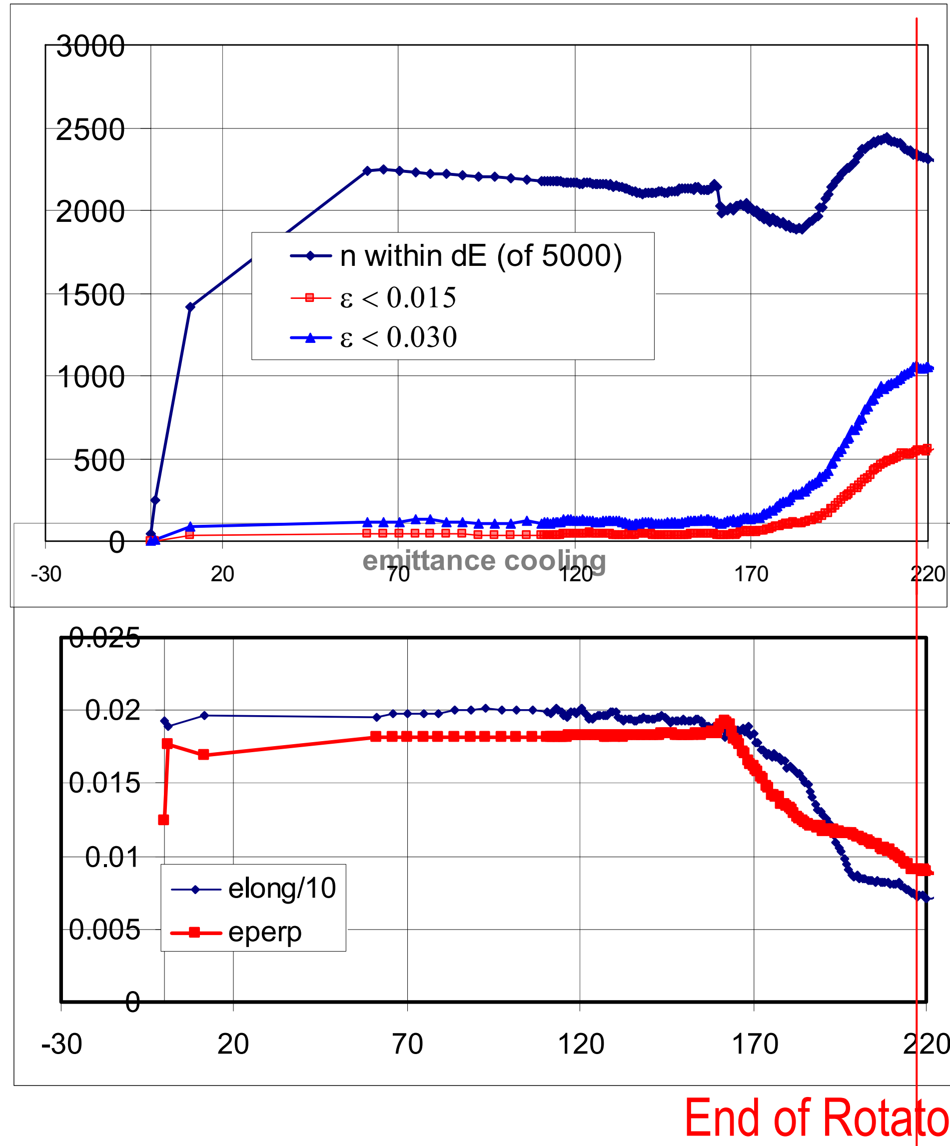
- Drift, buncher as before:
  - 300 →230MHz rf
  - 51m, $V = 3\, z/z_0 + 9(z/z_0)^2$
- "match" fron 2 T to 2.75T alternating solenoid at end of buncher
- Rotator lattice
  - 0.75m cells, 0.5m rf/cell
  - 133A H_2, 3.4 MeV/cell
  - V=20MV/m, ϕ=20°
  - 54m
- Post Rotator Cooling lattice
  - V=16MV/m
  - 133A H_2



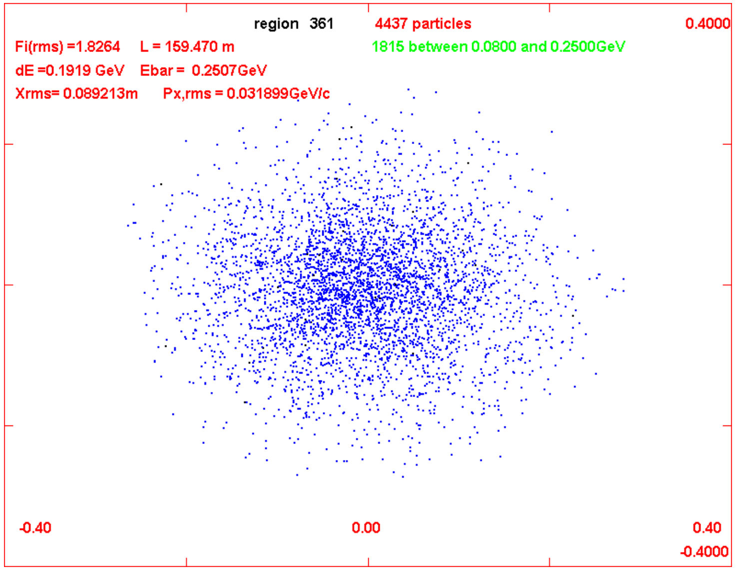


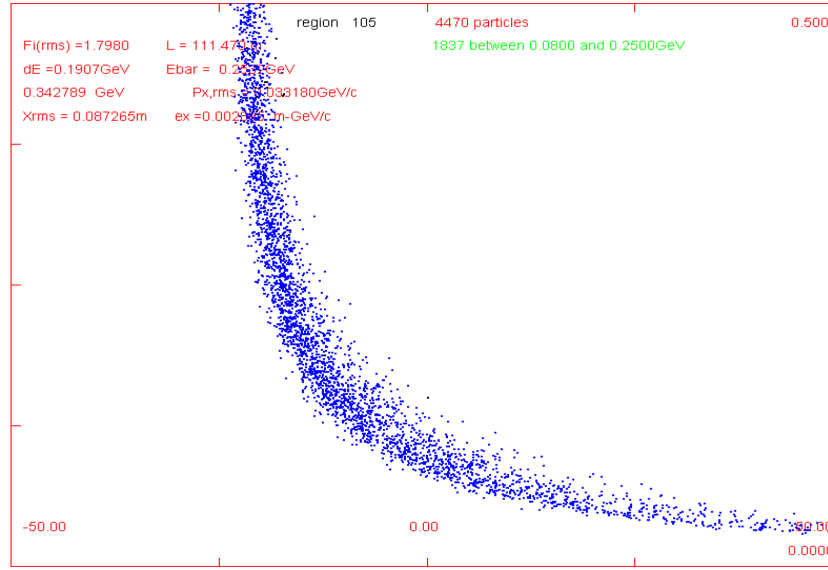
ICOOL results- gas cavities

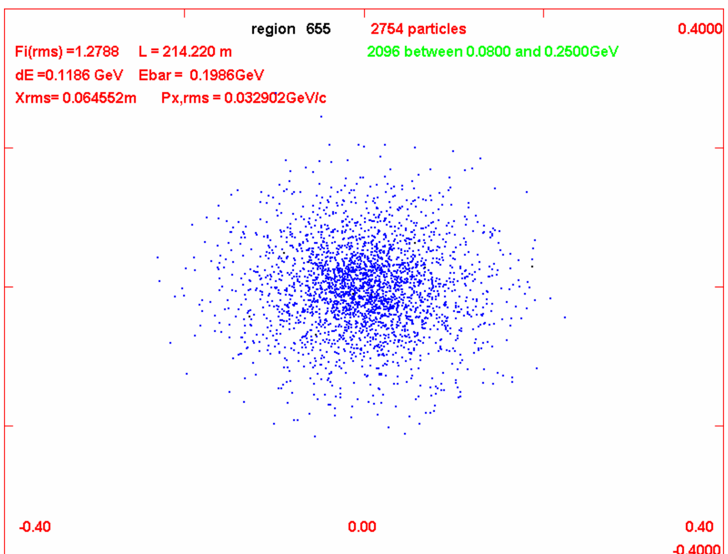
- ~0.20 μ/p within reference acceptance at end of φ–E Rotator
- ~0.10 μ/p within restricted acceptance ($\epsilon_{\perp}$<0.015m)
- Rms emittance cooled from $\epsilon_{\perp}$ = 0.019 to $\epsilon_{\perp}$ = ~0.009
- Longitudinal rms emittance ≅0.075
- Continuing Study 2A cooling does not greatly improve acceptance

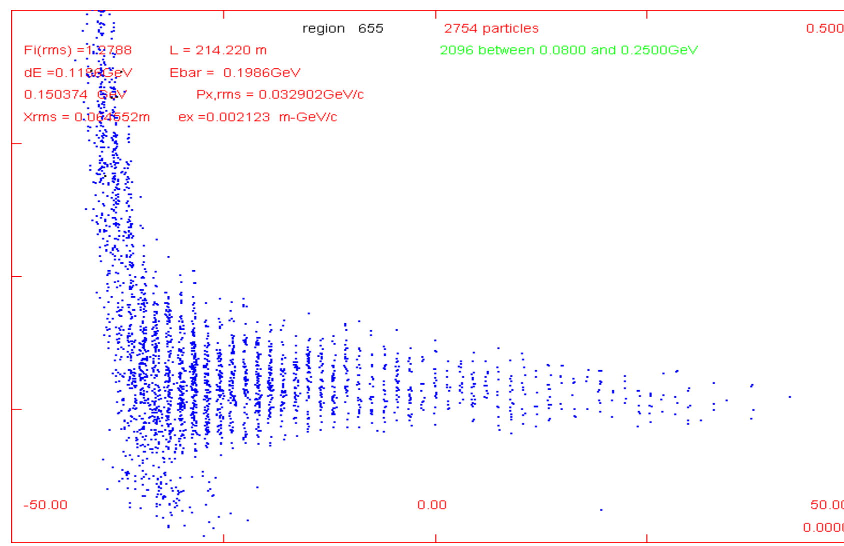


Cooling simulation results









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
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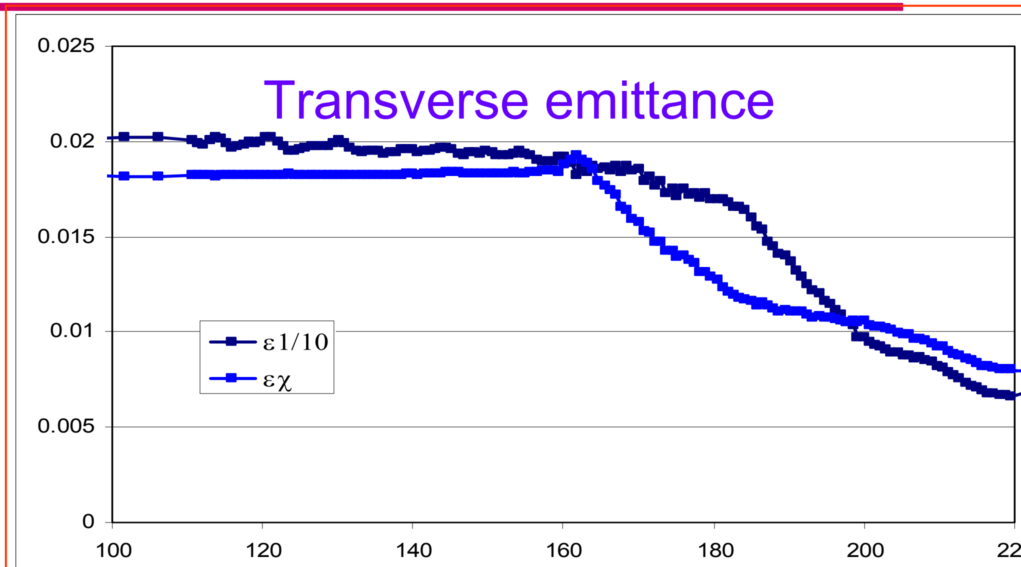
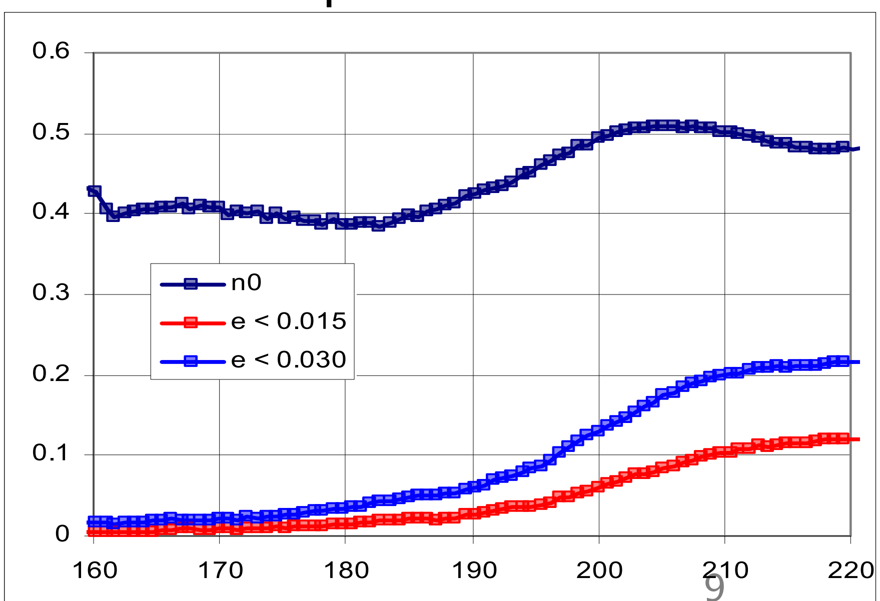
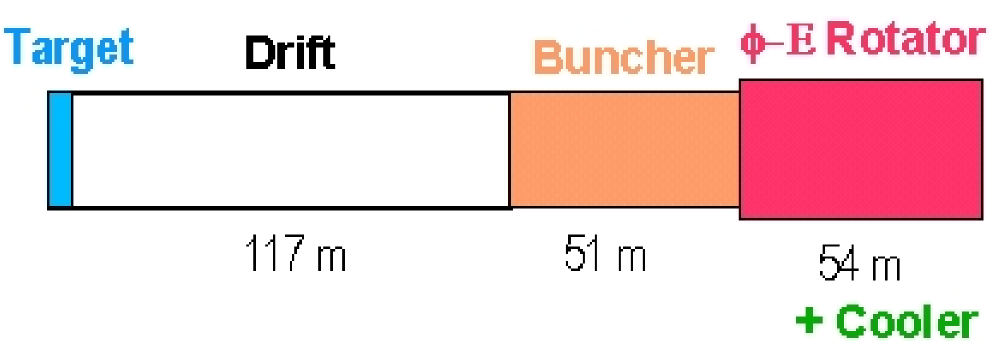


Acceptance



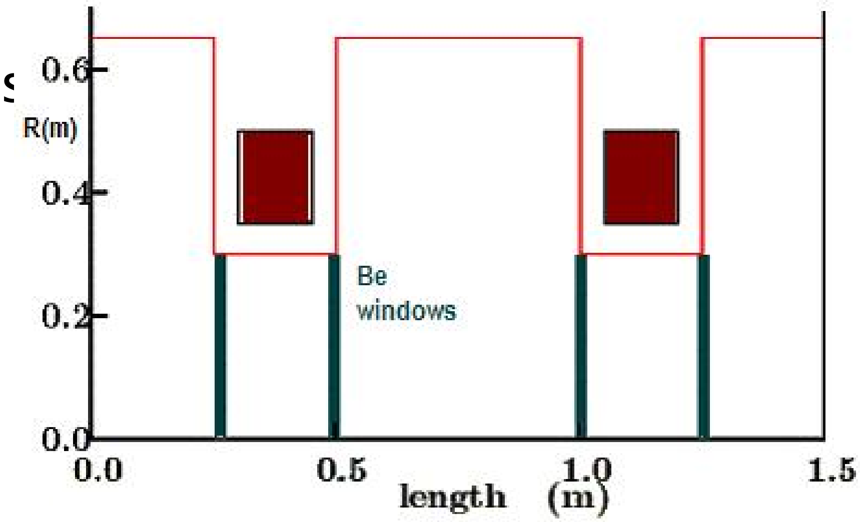


Same geometry – Be Windows

- Replace 150 A gas with 0.65cm thick Be windows on cavities
- Similar dynamics as H_2 but
- Much worse Study 2A performance (?)
- Transverse emittance cooling : 0.019→ 0.0115
- Muons within Study 2A acceptance:
  - 0.134 μ/p ($\epsilon_t < 0.03$)
  - 0.056 μ/p ($\epsilon_t < 0.015$)

  Needs reoptimization?

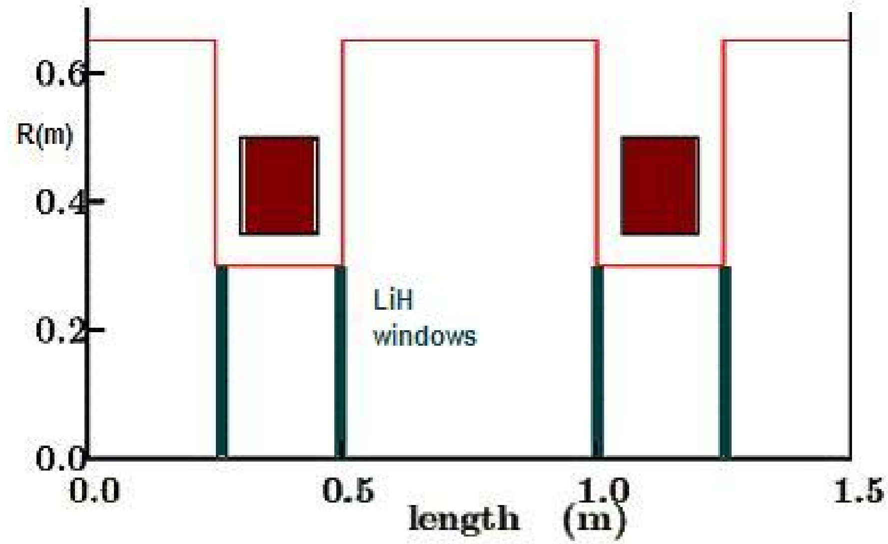
  -



Try LiH Windows

- Replace 150 A gas with 1.2cm thick LiH windows on cavities
- Similar dynamics as Be but
- Slightly better than Be performance (?)
- Transverse emittance cooling : 0.019→ 0.0102
- Muons within Study 2A acceptance:
  - 0.160 μ/p ($\epsilon_t < 0.03$)
  - 0.075μ/p ($\epsilon_t < 0.015$)

  Needs reoptimization?



Cost estimates:

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

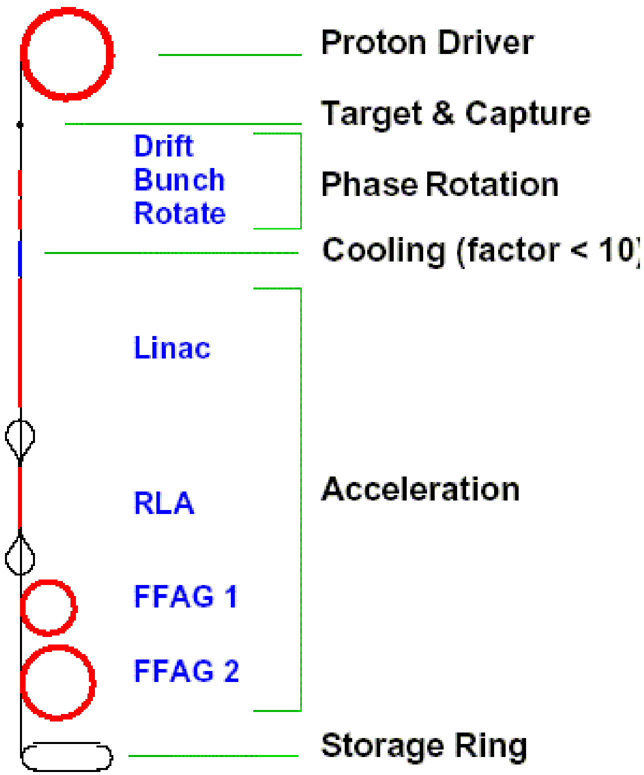


Table 12: Study IIb Costs

System	Study 2	M$	Study 2B	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

Combining cooling and phase rotation may reduce cost by ~ 100M$

Component cost basis

M$/GeV?

Table 5: Study IIb Buncher and Phase Rotation Costs

	M$	Length	k$/m	GeV	k$/GeV	Scaling
Buncher	44.84	49.25		.12		
Conventional	5.71		116			length
Magnets +PS	20.16		115x3.59=409			length x $(BR^2)^{.577}$
Cryo	0.37		2.1x3.59=7.54			length x $(BR^2)^{.577}$
Vacuum	2.17		44			length
200 MHz RF 9 MV/m	4.29			.12	20x(16.1/9)=36	$V/\mathcal{E}$
200 MHz PS	8.05			.12	120x(9/16.1)=67	$V\mathcal{E}$
Diagnostics	4.09		83			length
Phase Rotation	84.52	56.25		0.469		
Conventional	3.69		65.6			length
Magnets + PS	23.00		115x3.59=409			length x $(BR^2)^{.577}$
Cryo	0.42		2.1x3.59=7.54			length x $(BR^2)^{.577}$
Vac	0.96		17			length
200 MHz RF 12.5 MV/m	12.1			.469	20x(16.1/12.5)=25.8	$V/\mathcal{E}$
200 MHz PS	43.70			.469	120x(12.5/16.1)=93.2	$V\mathcal{E}$
Diagnostics	0.65		11.5			length

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

- High-frequency Buncher and $\phi-\delta E$ Rotator (ν-Factory)
  - Variations (Poklonskiy may help),
  - Shorter systems ??
  - Other frequencies ?

- Gas-filled rf cavities
  - Higher gradient??
  - Optimize V'
  - Cool in buncher rotator

To do:

- Optimizations, Best Scenario, cost/performance …

Motivation …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