Neutrino Factory Front End (IDS) and Variations

NuFACT99 -Lyon

David Neuffer

G. Prior, C. Rogers, P. Snopok, C. Yoshikawa, …

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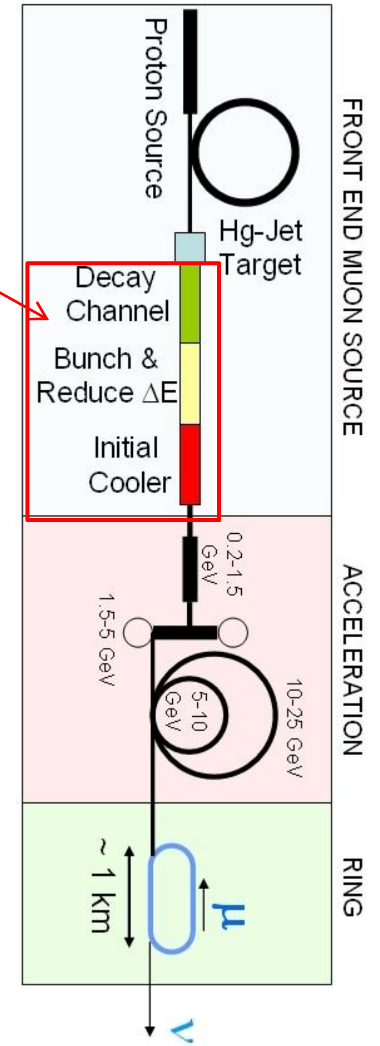
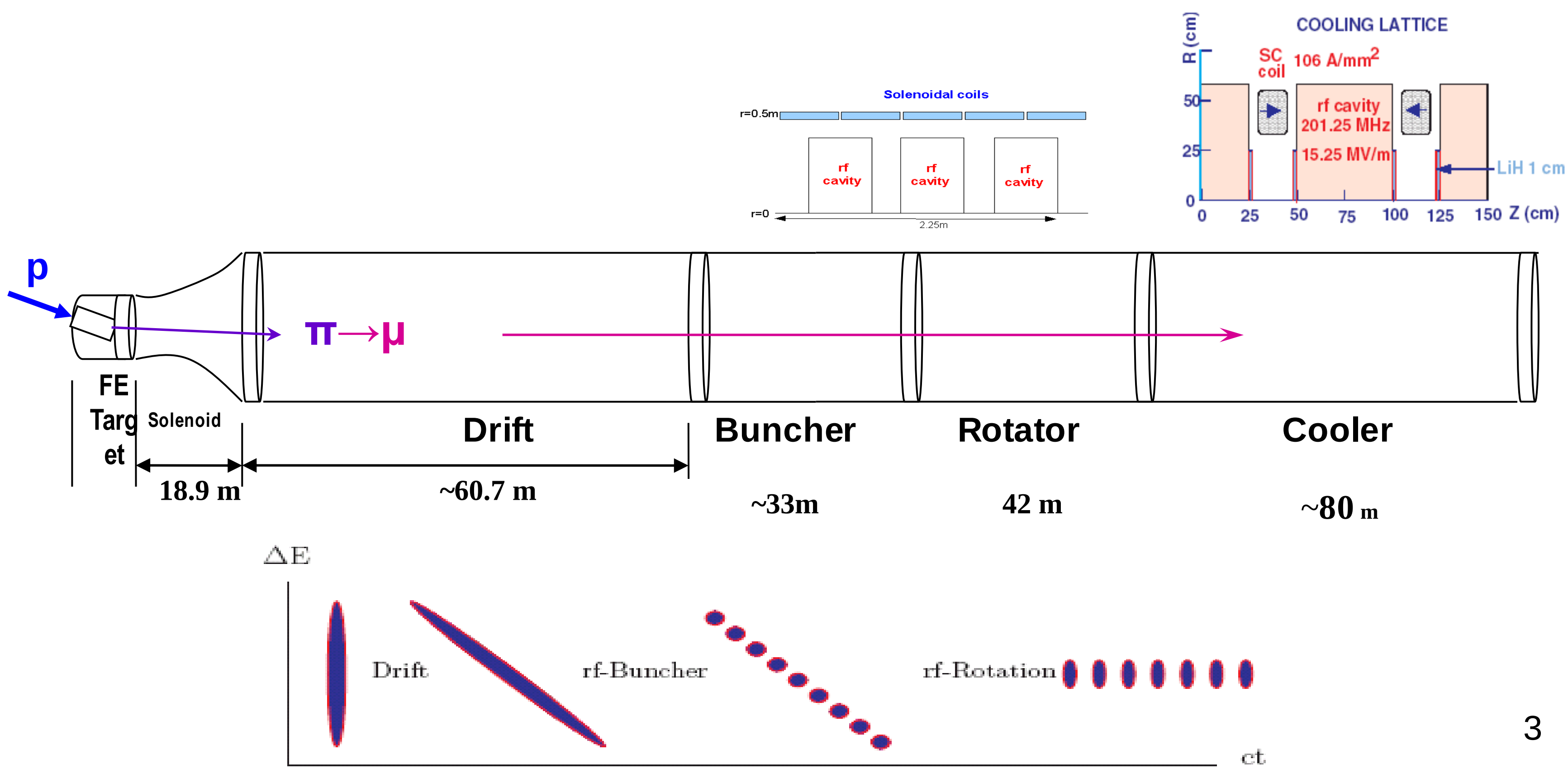
Outline

- **Front End for the IDS Neutrino Factory**
  - baseline design for IDS
    - Developed from study 2A, ISS
  - Basis for engineering/costs
    - Rf requirements
- **Variations**
  - rf gradient/ B concerns
    - alternatives
      - gas-filled rf/insulated rf/low-B/
  - Losses – control
    - Chicane, proton absorber
- **μ^+-μ^- Collider Front End**
  - Shorter bunch train
    - Larger V′, rebunching
  - Rebuncher
    - Time reverse front-end



IDS Baseline Buncher and φ-E Rotator

- Drift (π→μ)
- "Adiabatically" bunch beam first (weak 320 to 232 MHz rf)
- Φ-E rotate bunches – align bunches to ~equal energies
  - 232 to 202 MHz, 12MV/m
- Cool beam 201.25MHz



Neutrino Factory Front End

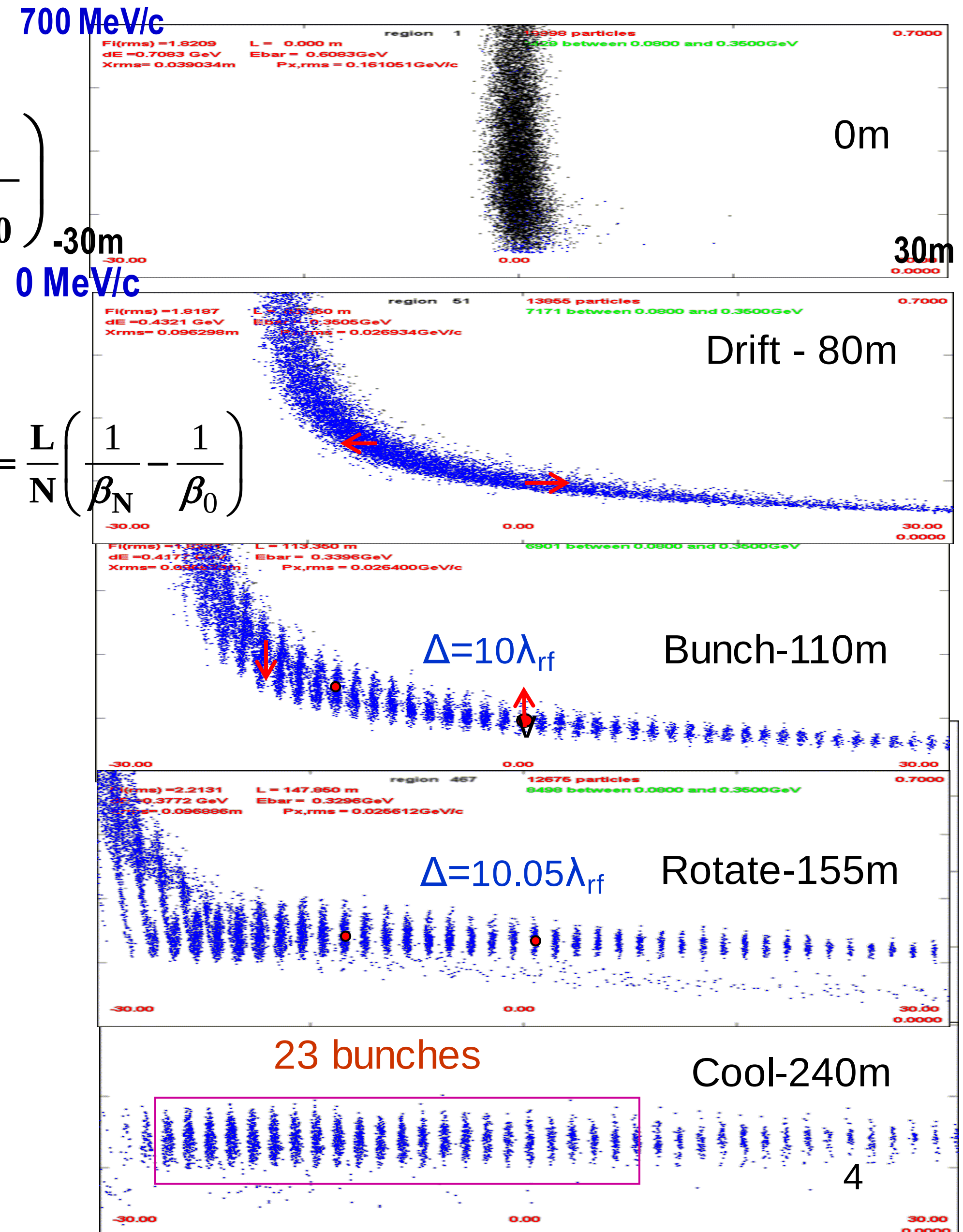
- Drift from target ~80m
  - Beam lengthens

$$\delta(ct_i) = L\left(\frac{1}{\beta_i} - \frac{1}{\beta_0}\right)$$

- Buncher (~33m)
  - N=10
  - P_0=233MeV/c, P_N=154MeV/c
  - 330 → 235 MHz
  - V'= 0→9 MV/m

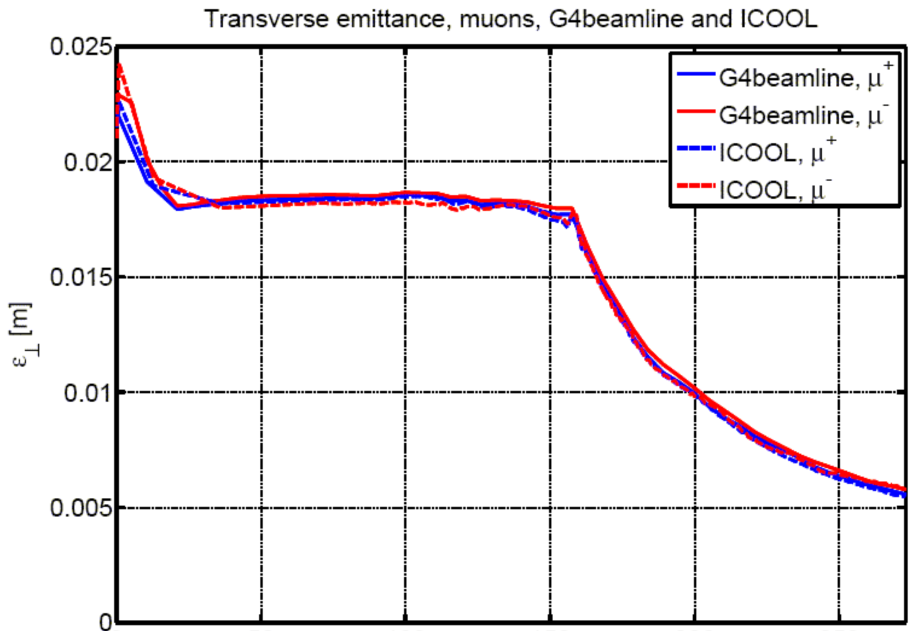
$$\lambda_{rf}(L) = \frac{\delta ct_{0N}}{N} = \frac{L}{N}\left(\frac{1}{\beta_N} - \frac{1}{\beta_0}\right)$$

- Rotator (~42m)
  - N=10.05 –
    - accelerate/decelerate bunches
  - 235 → 202 MHz,V'= 12 MV/m
- Cooler (~80m)
  - 201.25 MHz, ASOL lattice
  - 15MV/m in rf cavities
  - LiH or H_2 cooling
- Captures both μ^+ and μ^-

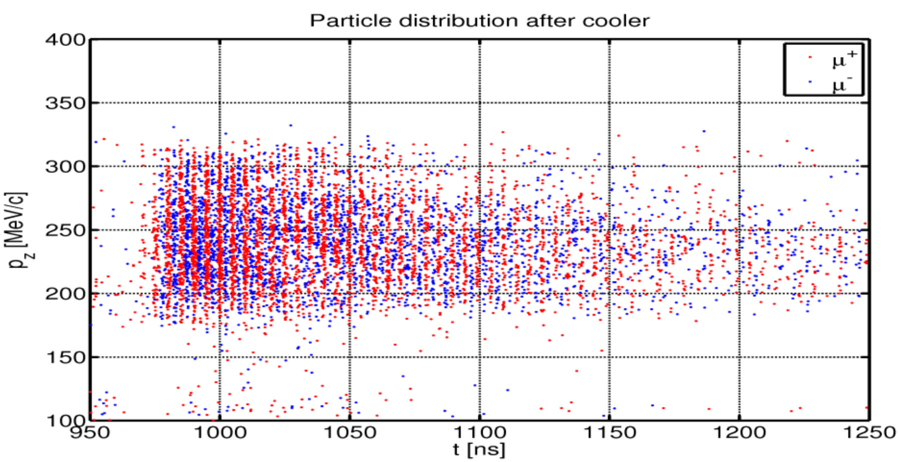


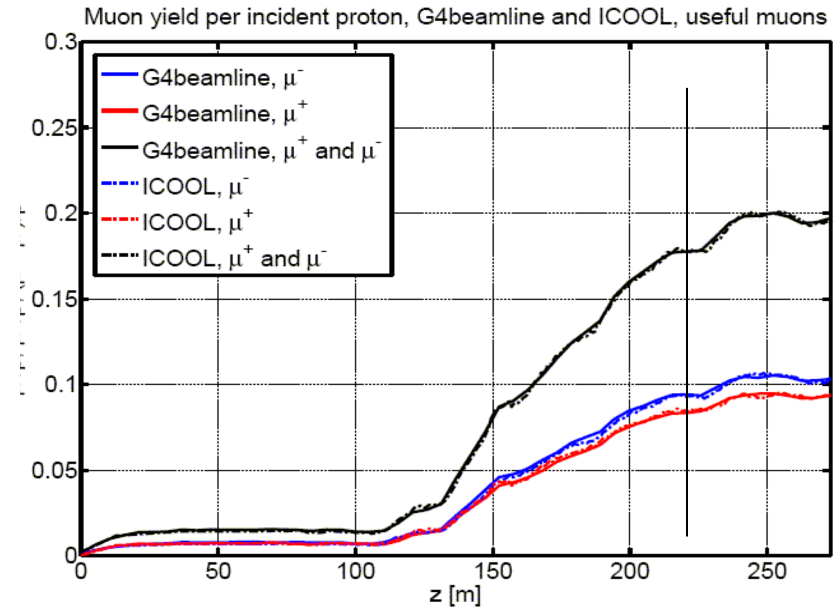
ICOOL - G4beamline

- **P. Snopok has run the IDS front end with both ICOOL & G4 beamline**
  - High statistics (>10^5 tracks)
  - Obtains ~0.1 μ^+ and μ^- /8 GeV p within acceptances
    - $\varepsilon_T < 0.03$, $\varepsilon_L < 0.15$



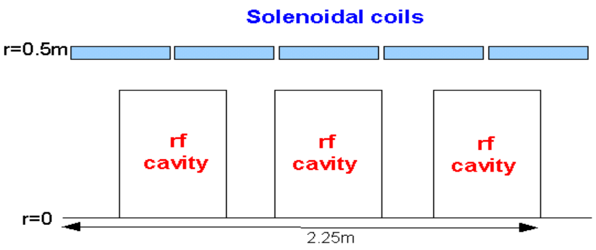
- **Validation of simulation codes**
  - Simultaneous simulation of both signs



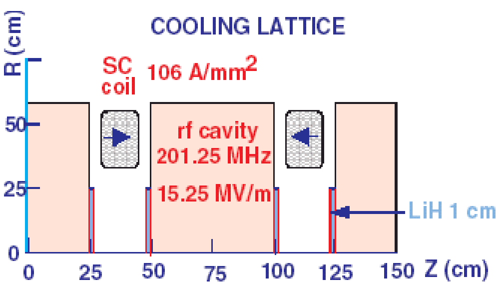


Parameters of IDR baseline

- Initial drift from target to buncher is 79.6m
  - 18.9m (adiabatic ~20T to ~1.5T solenoid)
  - 60.7m (1.5T solenoid)
- Buncher rf - 33m
  - 320 → 232 MHz
  - 0 → 9 MV/m (2/3 occupancy)
  - B=1.5T



- Rotator rf -42m
  - 232 → 202 MHz
  - 12 MV/m (2/3 occupancy)
  - B=1.5T



- Cooler (50 to 90m)
  - ASOL lattice, P_0 = 232MeV/c,
  - Baseline has 15MV/m, 2 1.1 cm LiH absorbers /cell

IDS : hardware specification

- Specify front end in specific rf cavities, frequencies
- Buncher – 13 rf frequencies
  - 319.63, 305.56, 293.93, 285.46, 278.59, 272.05, 265.80, 259.83, 254.13, 248.67, 243.44, 238.42, 233.61 (13 f)
  - ~100MV total
    - Keep V' < ~7.5MV/m
- Rotator – 15 rf frequencies
  - 230.19, 226.13, 222.59, 219.48, 216.76, 214.37,212.28, 210.46,208.64, 206.90, 205.49,204.25, 203.26, 202.63,202.33 (15 f)
  - 336MV total, 56 rf cavities
    - 12MV/m at 2/3 occupancy
- Cooler
  - 201.25MHz –up to 75m ~750MV
    - ~15 MV/m, 100 rf cavities

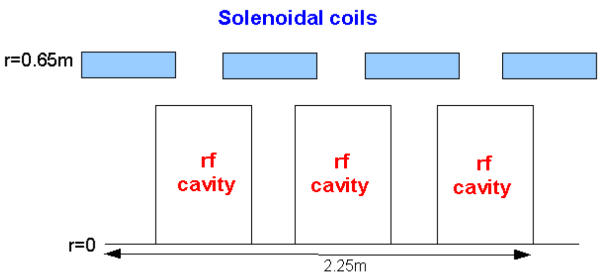
Magnet Requirements:

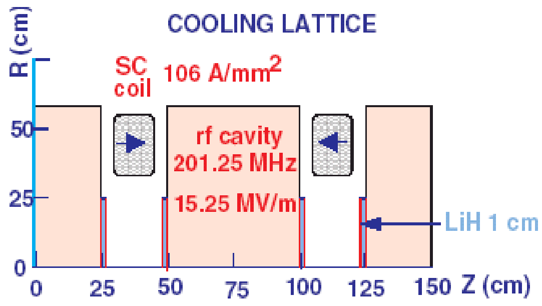
Table XIV. Summary of front-end magnet requirements.

	Length [m]	Inner radius [m]	Radial thickness [m]	Current density [A/mm^2]	Number
Initial transport	0.5	0.68	0.04	47.5	180
Cooling channel	0.15	0.35	0.15	±107	100

Rf Buncher/Rotator/Cooler requirements

- **Buncher**
  - 37 cavities (13 frequencies)
  - 13 power supplies **(~1—3MW)**
- **RF Rotator**
  - 56 cavities (15 frequencies)
  - 12 MV/m, 0.5m
  - **~2.5MW** (peak power) per cavity
- **Cooling System – 201.25 MHz**
  - 100 0.5m cavities (75m cooler), **15MV/m**
  - **~4MW** /cavity

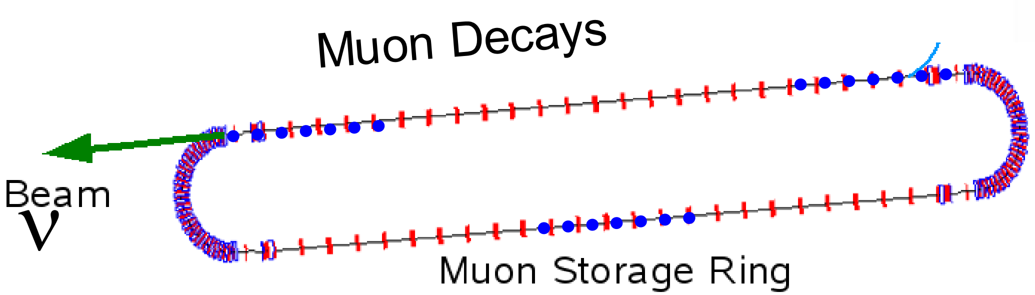


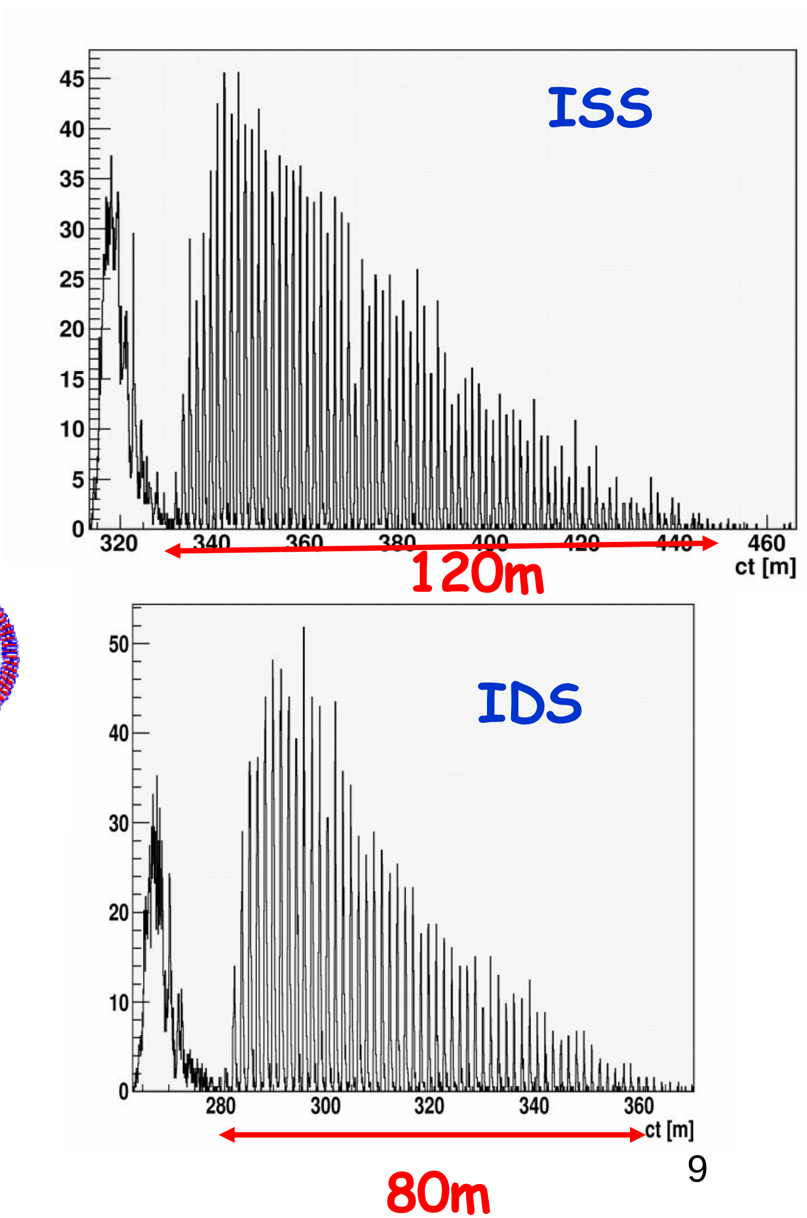


Front End section	Length	#rf cavities	frequencies	# of freq.	rf gradient	rf peak power requirements
Buncher	33m	37	319.6 to 233.6	13	4 to 7.5	~1 to 3.5 MW/freq.
Rotator	42m	56	230.2 to 202.3	15	12	~2.5MW/cavity
Cooler	75m	100	201.25MHz	1	15 MV/m	~4MW/cavity
Total drift)	~240m	193		29	~1000MV	~550MW

How Long a Bunch Train for IDS?

- ISS study alotted space for 80 bunches (120m long train)
- For IDS 80m (54 bunches) is probably plenty





IDS: ~3 bunch trains simultaneously

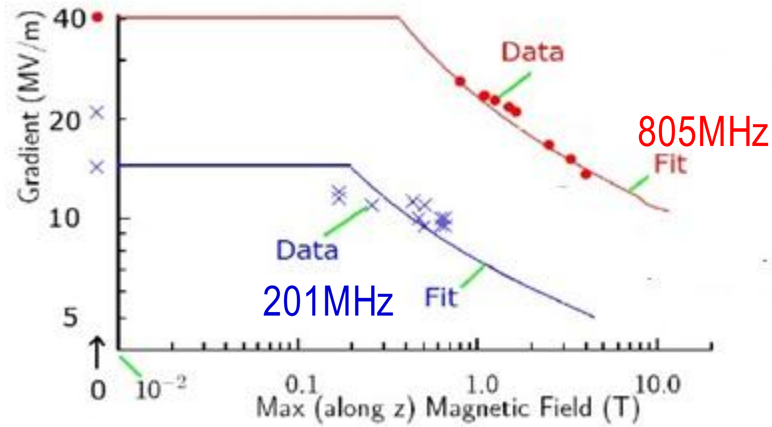
-both μ+ and μ⁻

Possible rf cavity limitations

V'_{rf} may be limited in B-fields

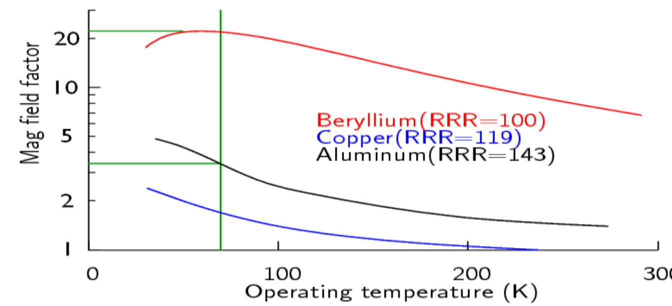
- 800 MHz pillbox cavity
- 200 MHz pillbox test (different B)

➢ NF needs up to ~1.5T, 12 MV/m
  - More for cooling



Potential strategies:

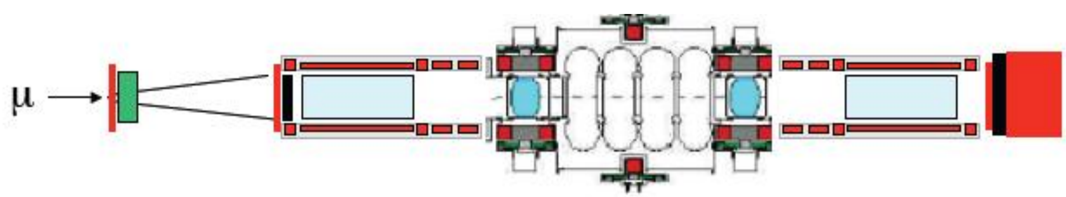
➢ Use Be Cavities (Palmer)



➢ Use lower fields (V', B)
- <10MV/m at 1.5T?
- Need variant for cooling ?

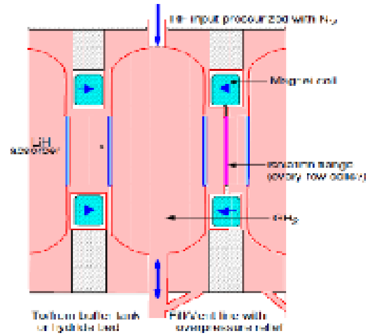
Need More Experiments !

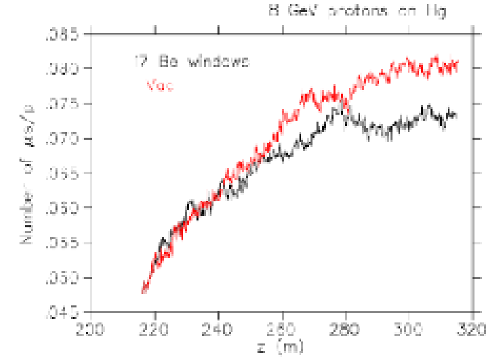
➢ Cooling channel variants
- Use gas-filled rf cavities
- Insulated rf cavities
- Bucked coils (Alekou)
- Magnetic shielding



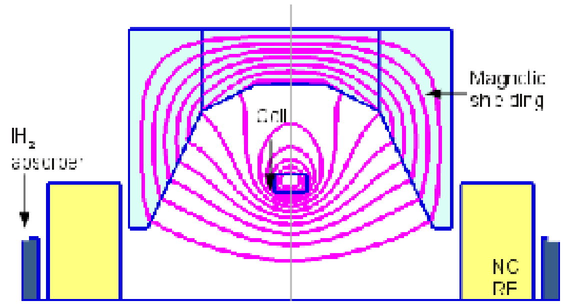
Cooling Lattice variations

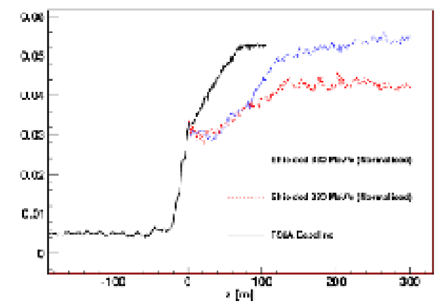
- Gas-filled rf
  - With LiH absorbers



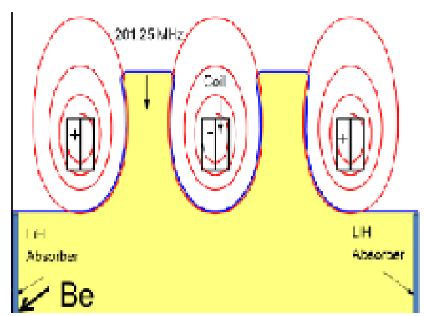


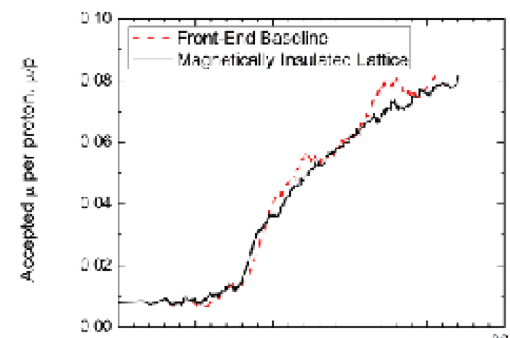
- Magnetically shielded
  - Small B at rf



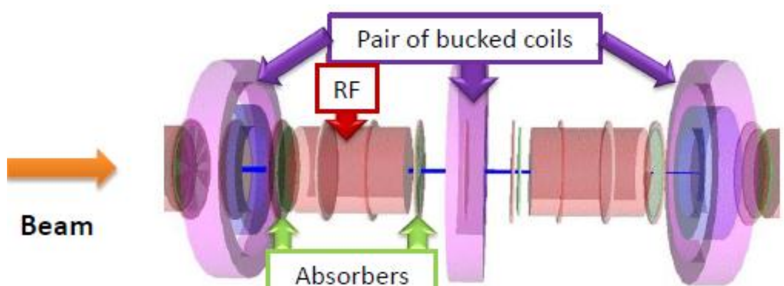


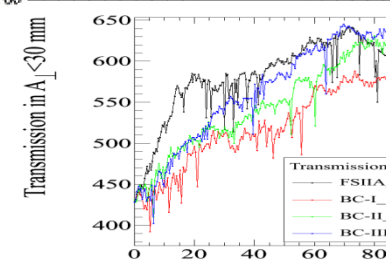
- Magnetically Insulated
  - B ⌨ rf surface





- Bucked Coil
  - Reduced B in rf
  - Alekou

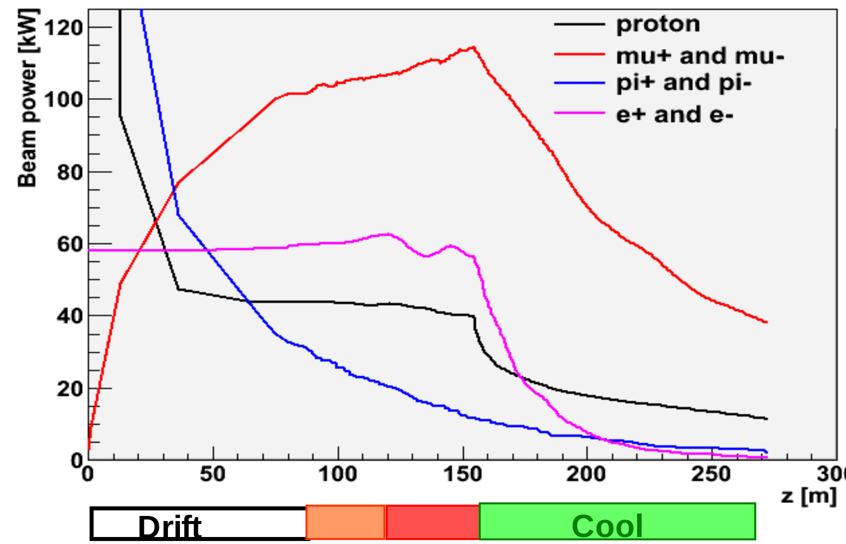


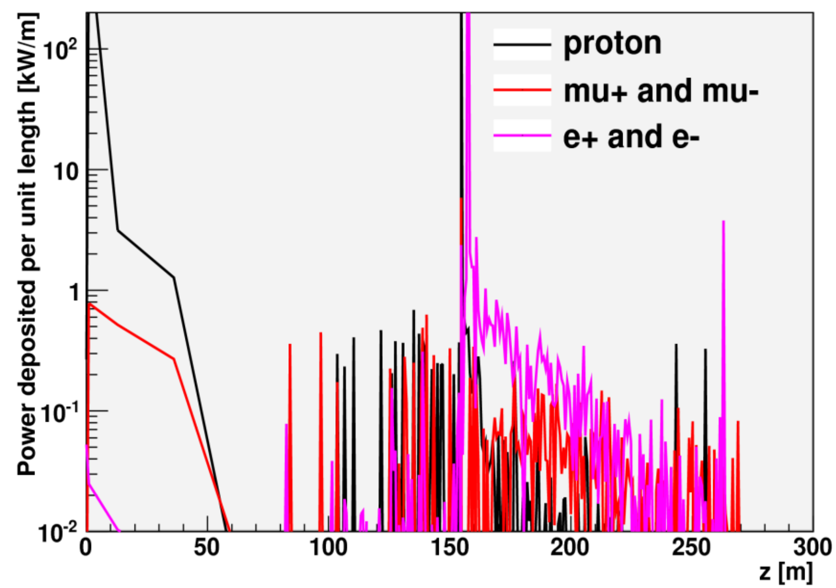


Problem: Beam losses along Front End

- **Start with 4MW protons**
  - End with ~50kW $\mu^+ + \mu^-$
    - plus p, e, π, …
    - ~20W/m μ-decay
  - ~0.5MW losses along transport
    - >0.1MW at z>50m
- **Want "Hands-on" maintenance**
  - hadronic losses < 1W/m
  - Booster, PSR criteria
  - Simulation has >~100W/m
    - With no collimation, shielding, absorber strategy

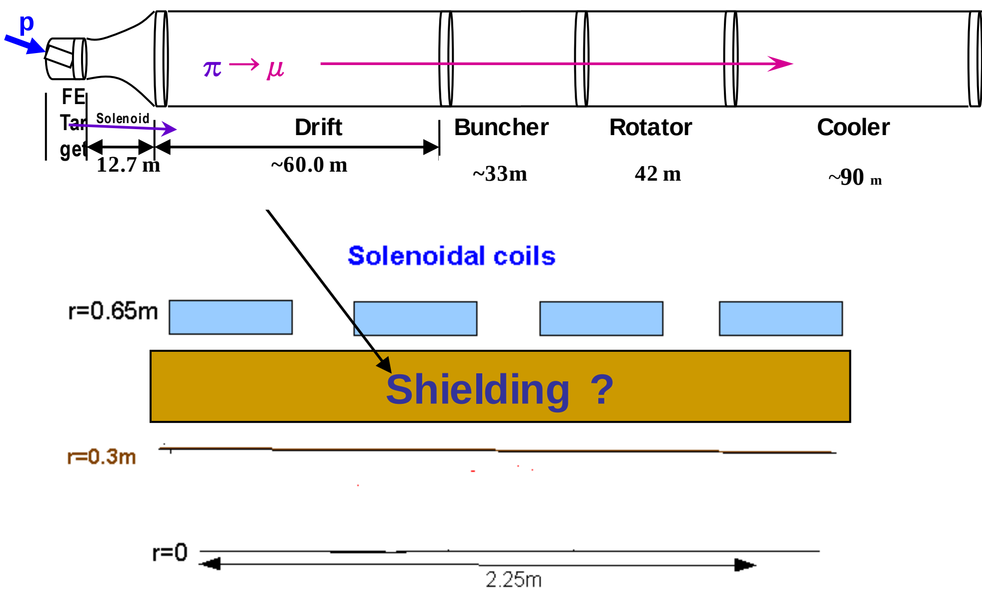
"Particles, particles, particles."



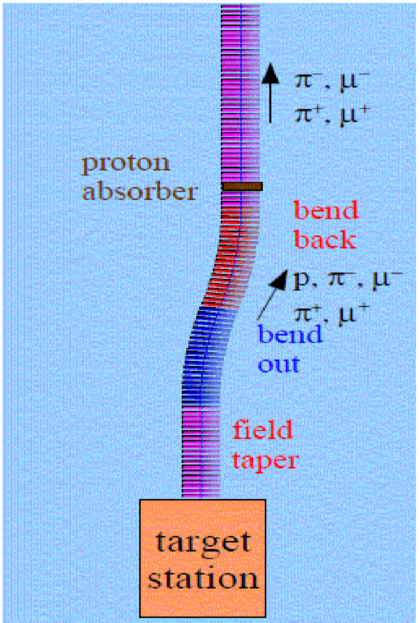


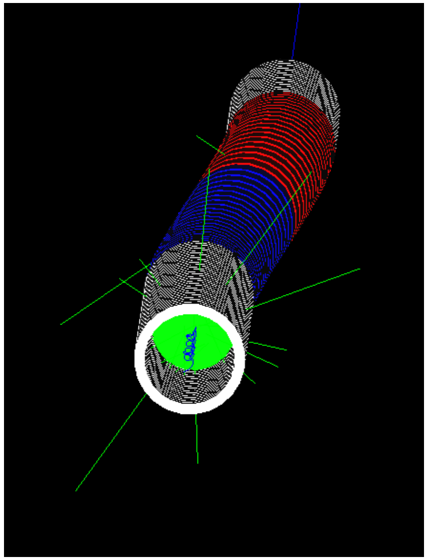
Control of Front End Losses

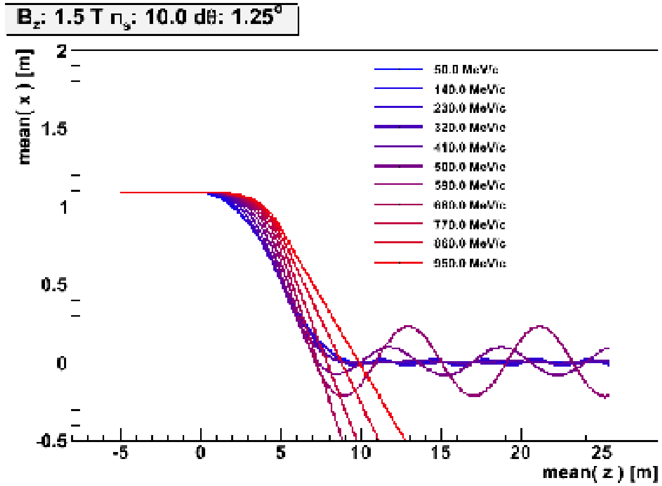
- Add shielding
  - Resulting losses ?



- Chicane and proton absorber to localize losses (C. Rogers)
  - Removes most protons
  - Most desired μ's survive
  - Greatly reduces downstream activation problem

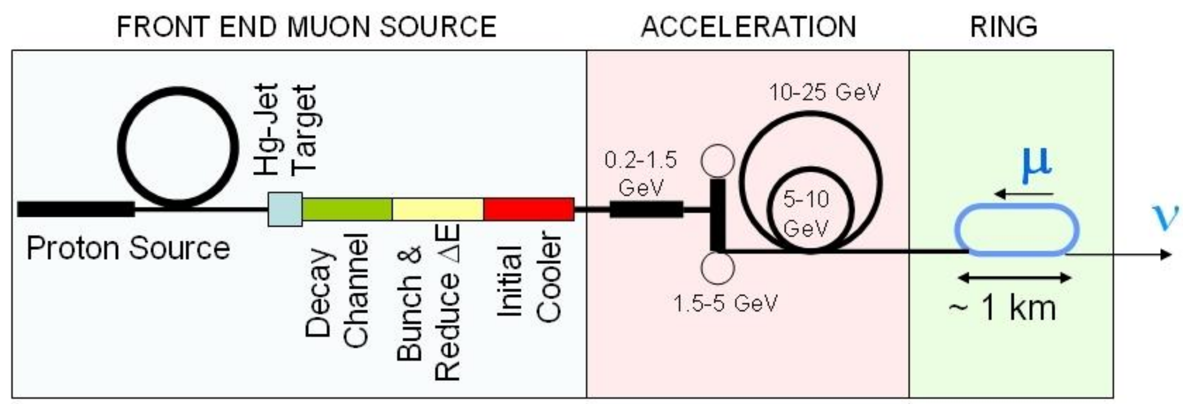




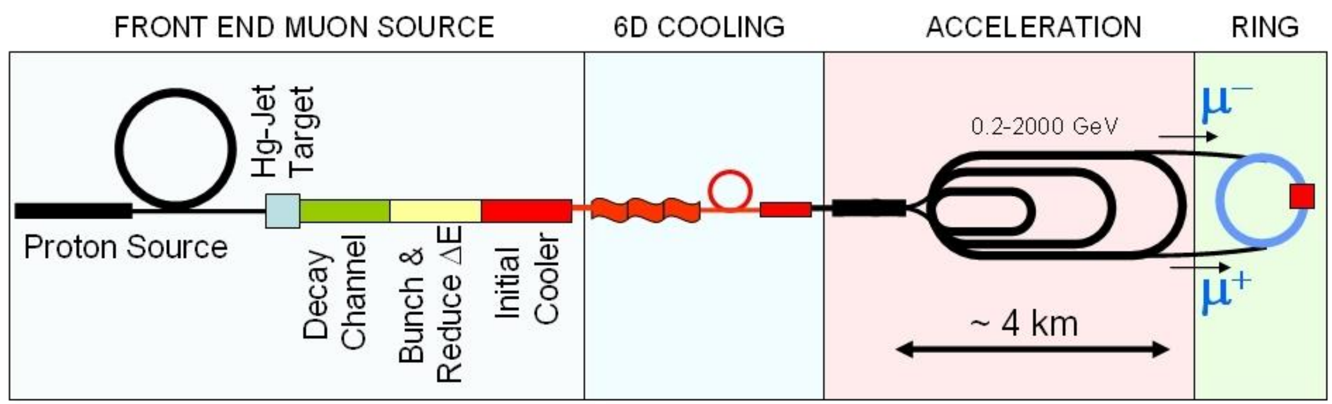


Muon Collider/NF Beam Preparation

- **Baseline Muon Collider beam preparation system identical to that for Neutrino Factory**
  - downstream portions (6D cooling, acceleration, collider) are distinct
    - much more cooling and acceleration needed for collider



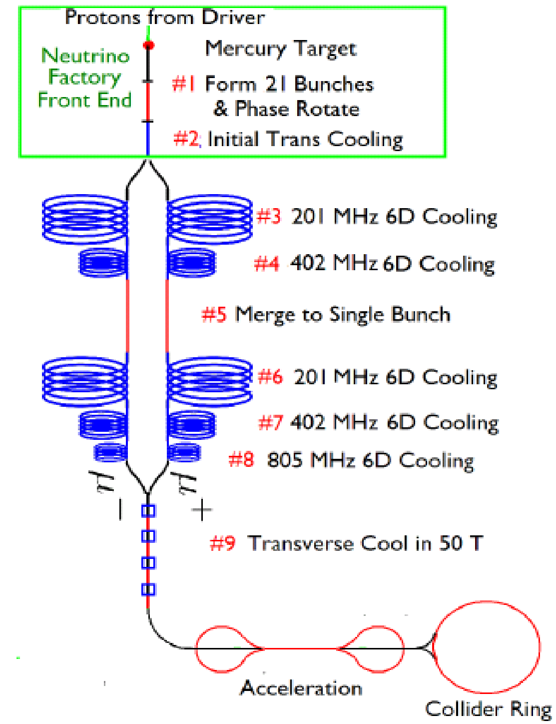
Neutrino Factory



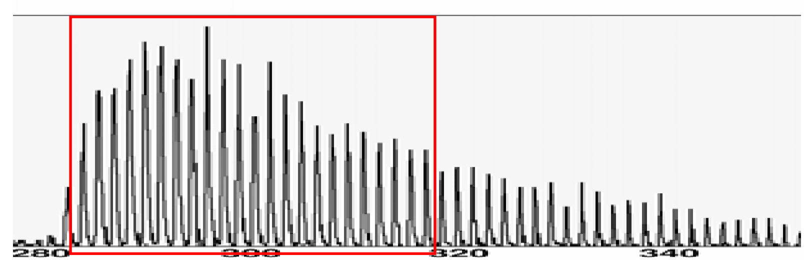
Muon Collider

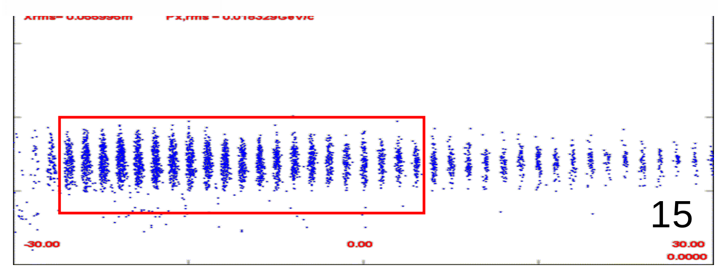
Front End for Muon Collider

- **Muon Collider front end is different**
  - **must** capture μ^+ and μ^-
  - want single bunches (not trains)
    - Bunches are recombined …
  - Maximum μ/bunch wanted
  - Longitudinal cooling needed;
  - Larger rf gradient can be used (?)
    - NF will debug gradient limits
    - Cost is less constrained



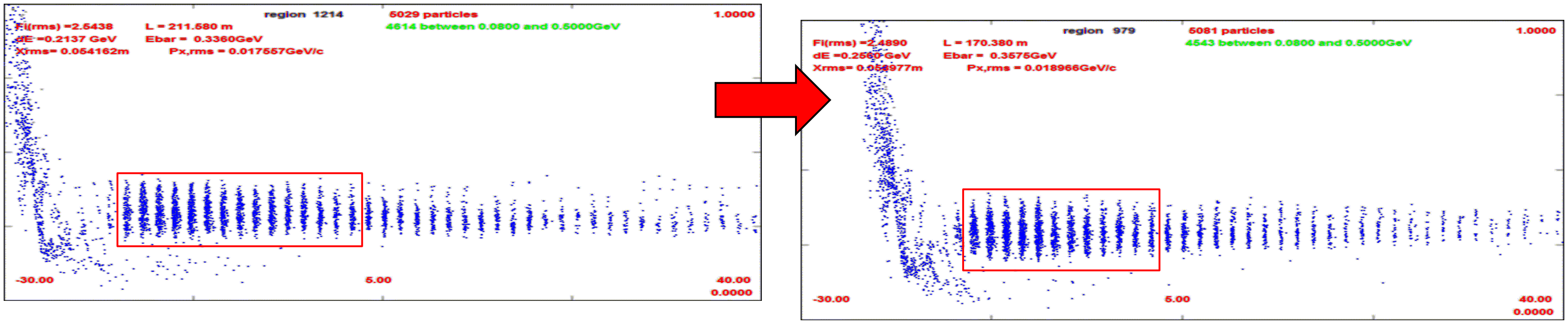
- **Use shorter BR system, more gradient, and capture at higher momentum**
  - 230 → 270 MeV/c
  - 150m → 120m
  - 9/12/15 MV/m → 15/16/18 or 15/18/20 MV/m
  - 1.5T→2T

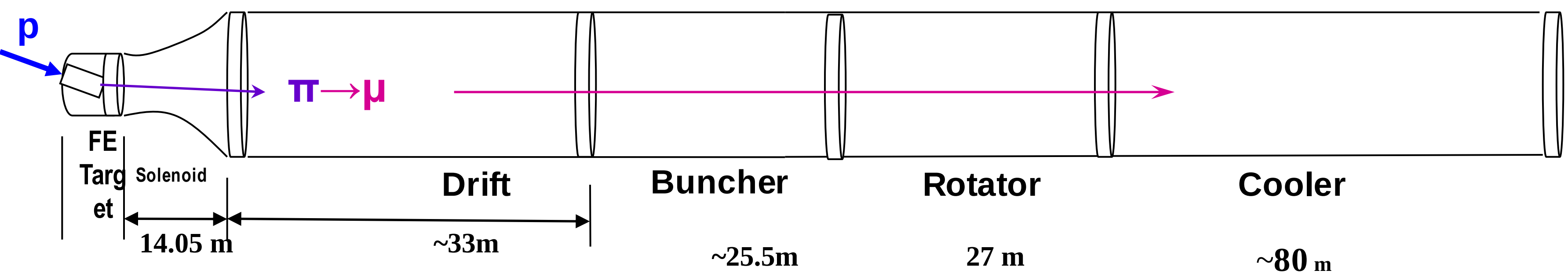




Muon Collider variants

- ΔN: 10→8
- Rf gradients: 12.5 → 15 → 18 MV/m
  - Or 15 → 18 → 20 MV/m
- Shorter system ~102m

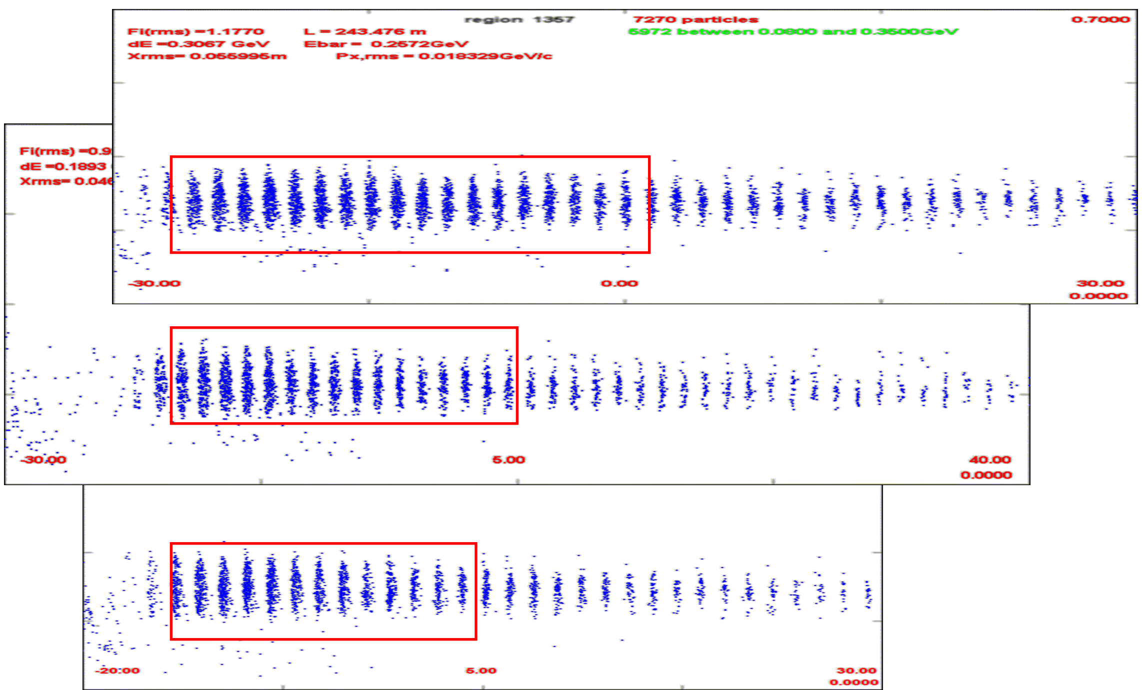




Variant front ends for muon collider

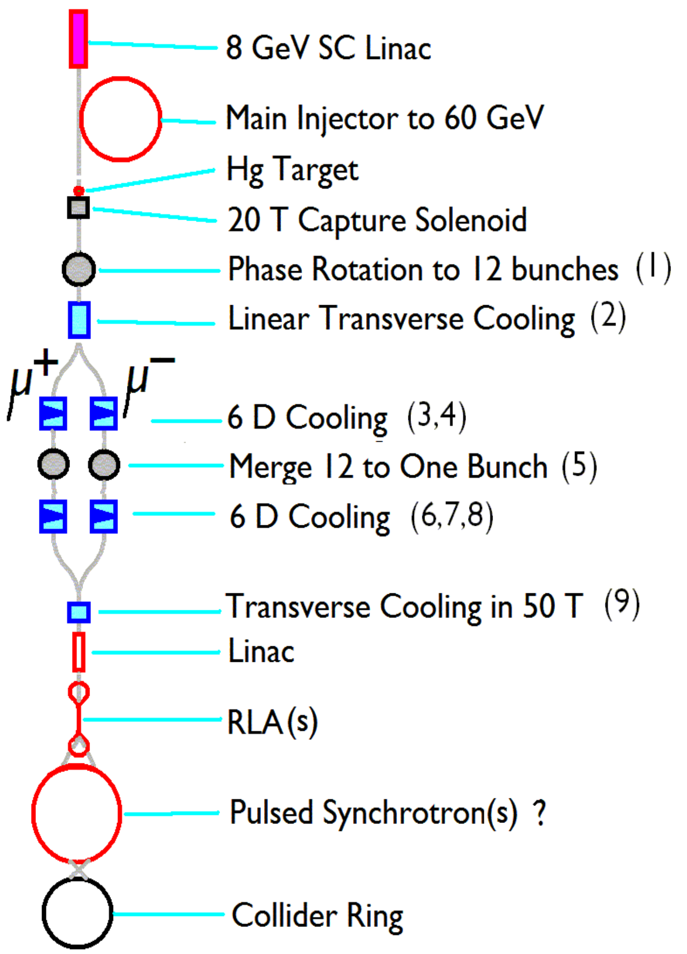
Table 1: Comparison of muon source front end systems.

Front end Scenario	Drift, Buncher, Rotator Length	Rf Voltages	Full length (w 75m cooling)	μ^+/p (ε_t<0.03, ε_L<0.3m)	μ^-/p (ε_t<0.03, ε_L<0.3m)	Core bunches, N_B, all μ^-/p
IDS/NF	80.6, 33, 42m	0→9, 12, 15	230m	0.086	0.116	20/0.107
N=10	55.3, 31.5, 33	0→12, 15, 18	205	0.106	0.143	16/0.141
N=8	47.8, 35.5, 27 m	0→15, 18, 20	180	0.102	0.136	13/0.123



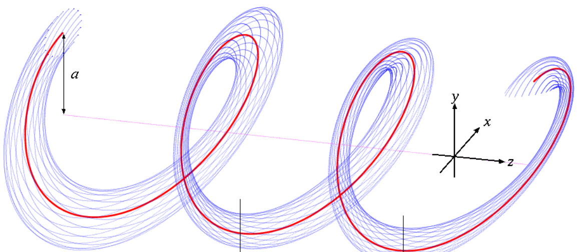
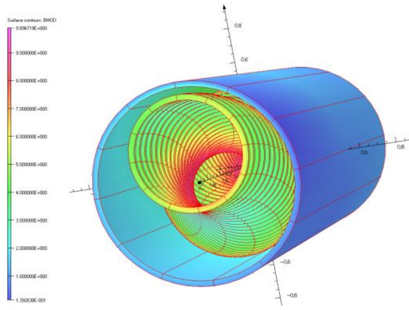
Integrate into 6-D cooling system

- **Initial Cooling transition**
  - NF transverse cooling only
  - Transition to 6-D cooling needed
    - Snake ? HCC? "Guggenheim"?
    - Split μ^+- μ^-
    - Cool 6-D by large factors
- **Recombine Bunches**
    - After cooling to small bunches
  - Front end splits 1 huge emittance bunch into string of smaller ε – bunches
    - Can we time reverse to combine cooled bunched to single bunches ?



Bunch Recombination: Helical Channel

- **Would like a large dependence of path length on energy**

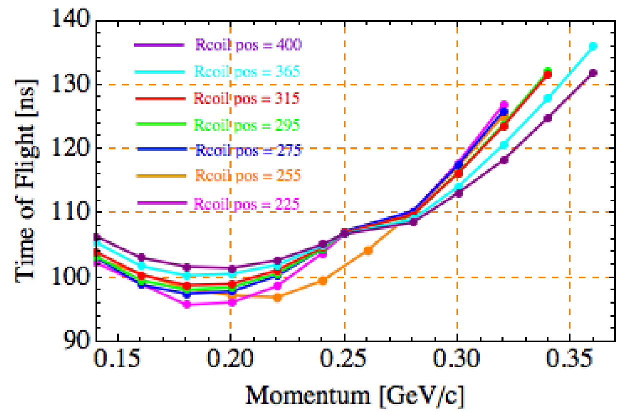



$$\kappa = \frac{2\pi a}{\lambda} = \frac{p_\phi}{p_z}$$

$$\delta t = \eta \frac{\Delta E}{mc^2}$$

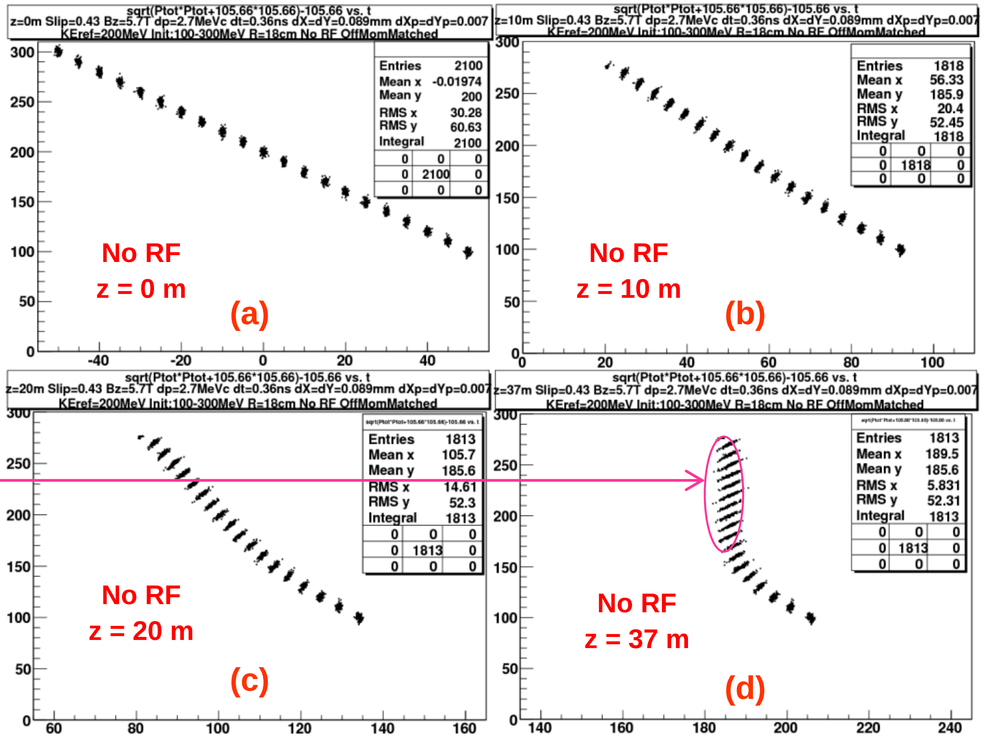
$$\eta = \frac{\sqrt{1+\kappa^2}}{\gamma\beta^3}\left[\frac{\hat{D}\kappa^2}{1+\kappa^2} - \frac{1}{\gamma^2}\right]$$

- **Helical channel naturally has that**
  - Linear dependence is nicest …
- **η=0.43 looks possible**
  - HC – B= 4.2T b_d=0.75, b_q=0.4
  - κ=1, λ=1.6m, P_0=290MeV/c
  - D^=1.7, D=0.44m
    - "γ_t"=1.085



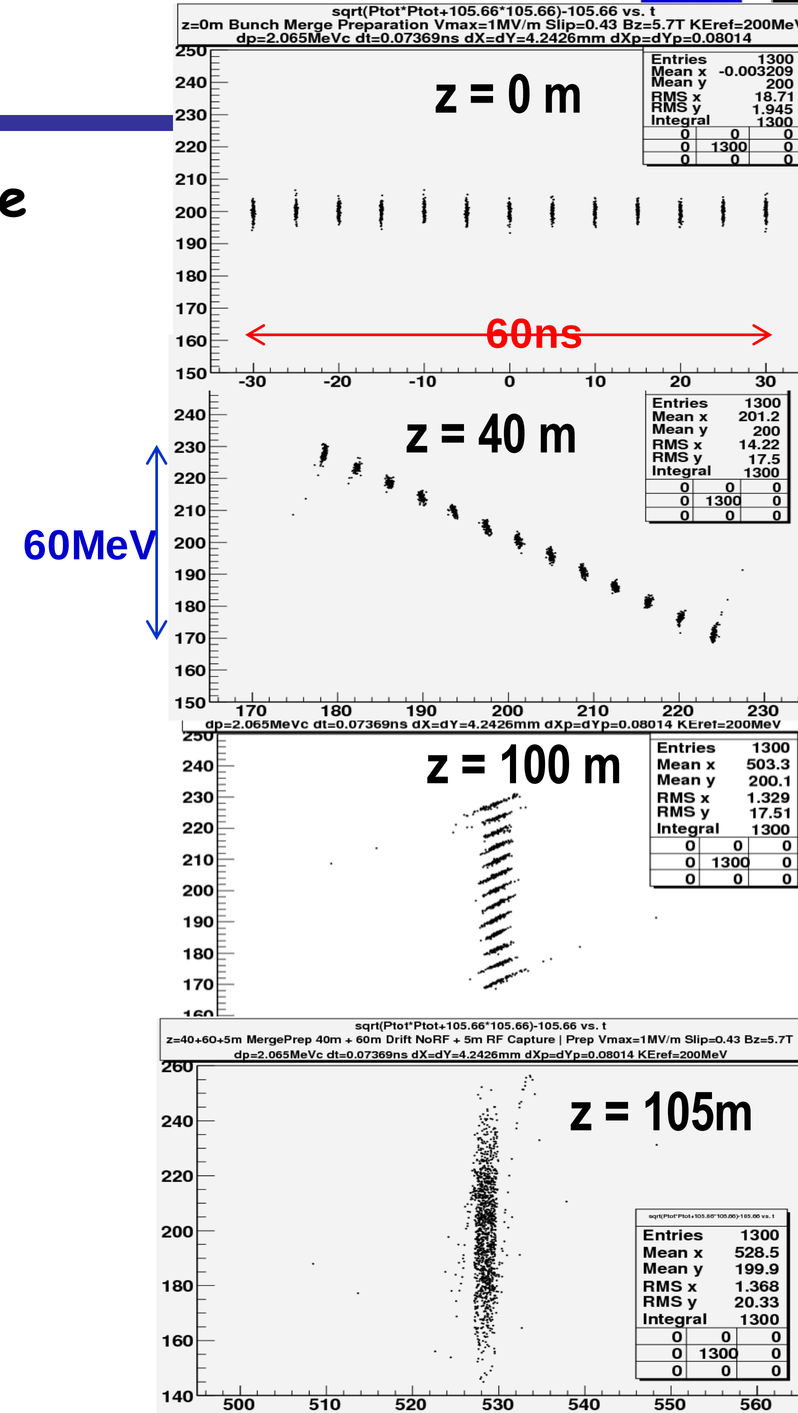
Longitudinal Dynamics in Helical Channel

- Set up an HCC & see if bunch recombination is possible
  - κ=1, η=0.43
    - λ=1m
- Very linear bunching over T=150—280 MeV
- See if one can set up HC line for rebunching with this case
  - Defer matching problem by using constant HCC



Simulate in 3-D- G4BL
HCC Yoshikawa

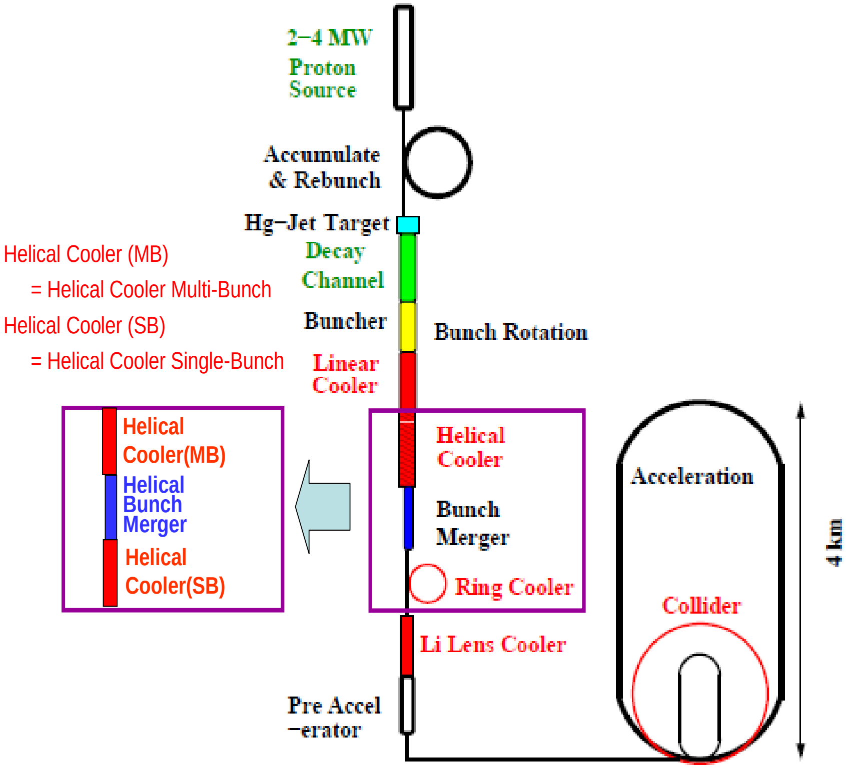
- Obtain beam from end of 3-stage HCC channel - K. Yonehara
  - 13 bunches, ε_L =0.0011m
  - η=0.43 transport
- 40m 1MV/m rf
  - 204 → 270 MHz
    - (+45° to -45°) (N=12.25)
    - η=0.43
- 60m drift
- 200MHz rf -10MV/m
  - >95% capture
  - ε_L = ~0.040



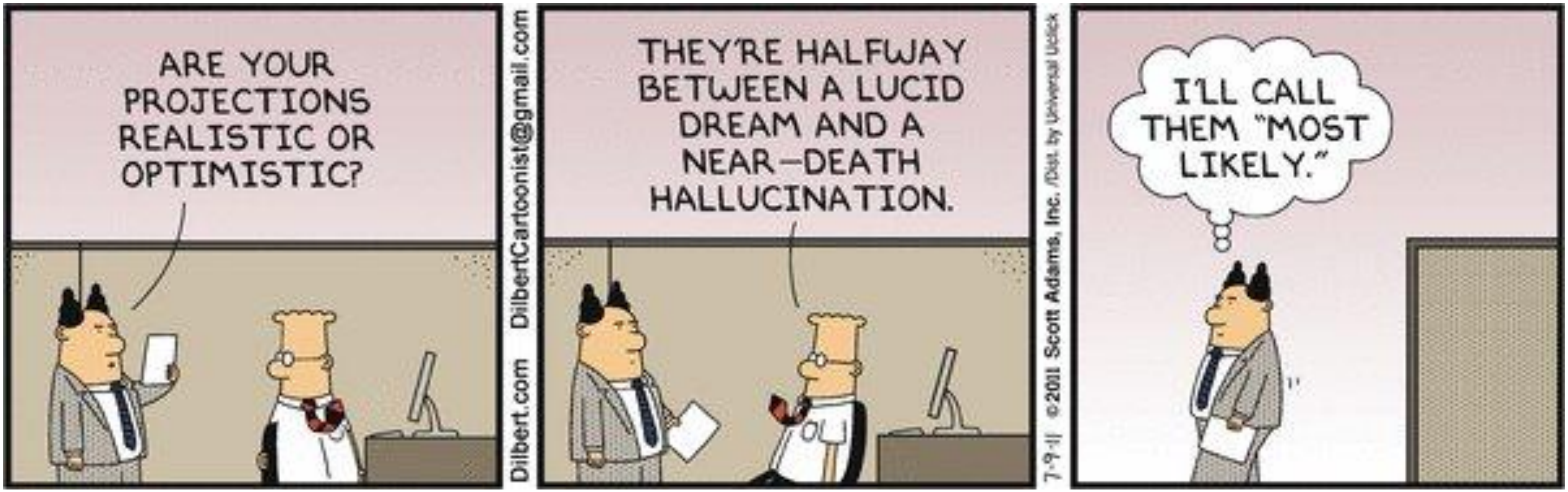
Summary

- **Muon Collider:**
  - Need to integrate bunch combiner into complete cooling scenario

- **ν-Factory front end**
  - costing exercise for IDR
    - "Most Likely" cost range?
  - rf in magnetic fields ?
    - adapt to rf measurements
  - manage losses
    - chicane/absorber/…
    - simulation studies



Questions?


ARE YOUR PROJECTIONS REALISTIC OR OPTIMISTIC?
Dilbert.com DilbertCartoonist@gmail.com
THEY'RE HALFWAY BETWEEN A LUCID DREAM AND A NEAR-DEATH HALLUCINATION.
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I'LL CALL THEM "MOST LIKELY."