Cost Savings and High-Frequency "Adiabatic" μ-Buncher for a Neutrino Factory

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Outline

- Study I – II ν-Factory
  - Cost is still large
  - Large cost items: induction linacs, cooling, acceleration
- **Remove Induction Linac**,
  replace with **High-Frequency Buncher**
  - Capture beam in high-frequency buckets
  - Reduce energy spread with high-frequency ϕ–δE rotation
  - Inject into fixed-frequency cooling system
  - ICOOL, Simucool simulations and optimizations –
  - Comparisons with baseline scenario
- Discussion – future development and improvement

Study 2 Costs ….

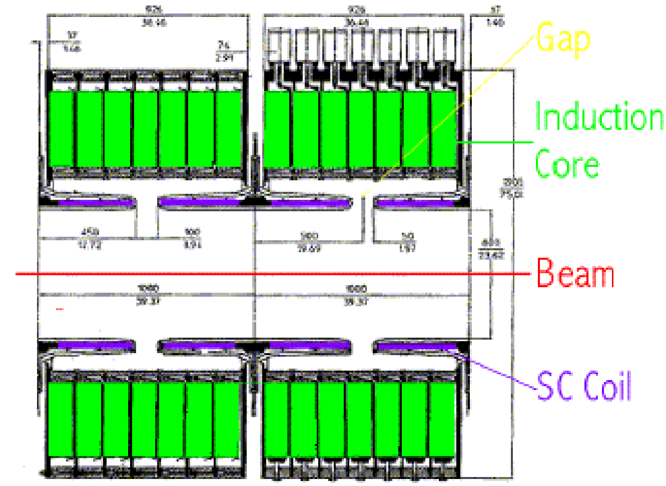
- "Cost" reduced by ~25% from Study I

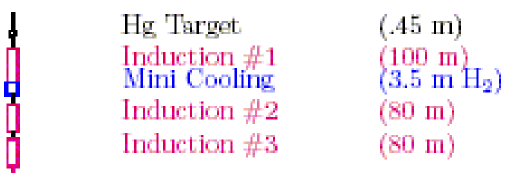
Table A.1: Construction Cost Rollup per Components for Study-II Neutrino Factory. All costs are in FY01 dollars.

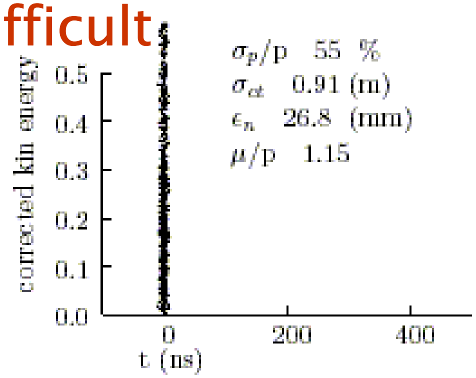
System	Magnets ($M)	RF power ($M)	RF cav. ($M)	Vac. ($M)	PS ($M)	Diagn. ($M)	Cryo ($M)	Util. ($M)	Conv. Facil. ($M)	Sum ($M)
Proton Driver	5.5	7.0	66.1	9.8	26.6	2.2	28.5		21.9	167.6
Target Systems	30.3			0.8	3.5	8.0	18.8		30.2	91.6
Decay Channel	3.1			0.2	0.1	1.0	0.2			4.6
Induction Linacs	35.0		90.3	4.4	163.3	3.0	3.6		19.5	319.1
Bunching	48.8	6.5	3.2	2.7	2.1	5.0	0.3			68.6
Cooling Channel	127.6	105.6	17.7	4.3	4.8	28.0	9.5		19.5	317.0
Pre-accel. linac	46.3	68.4	44.1	7.5	3.0	6.0	13.6			188.9
RLA	129.0	89.2	63.4	16.4	5.6	4.0	28.9		19.0	355.5
Storage Ring	38.5			4.8	2.2	29.0	4.8		28.1	107.4
Site Utilities								126.9		126.9
Totals	464.1	276.7	284.8	50.9	211.2	86.2	108.2	126.9	138.2	1,747.2

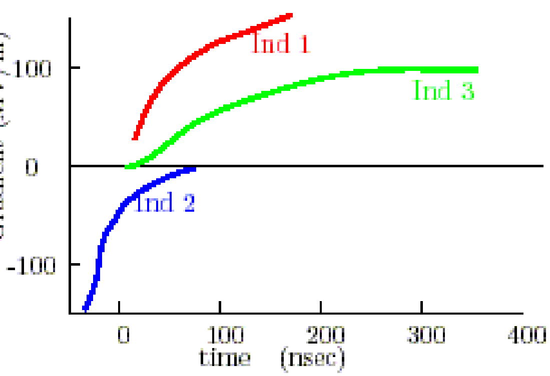
Induction Linac Technology

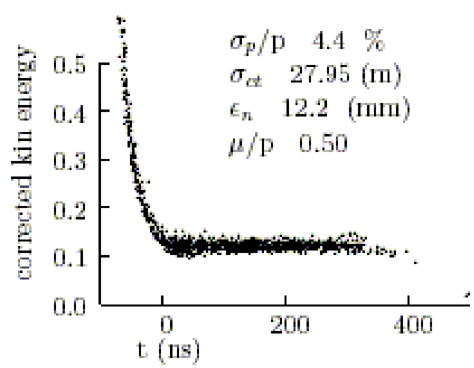
- Study II scenario uses ~ 250m long induction linac to capture muons.
- Cost is prohibitive
- Technology is difficult

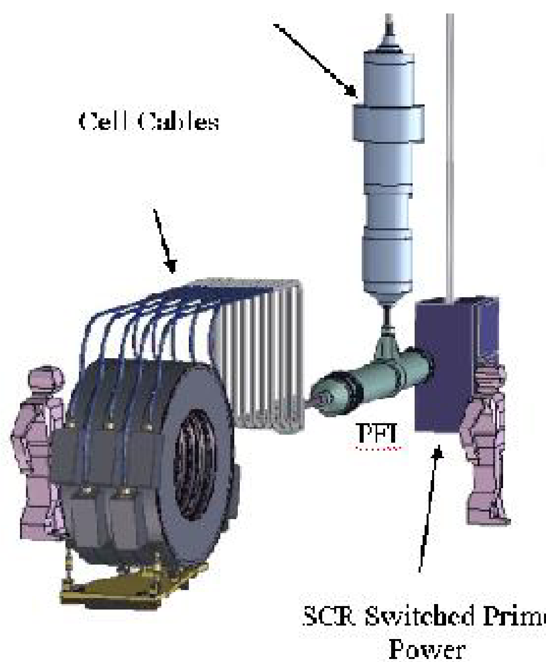












High Frequency $\phi-\delta E$ Rotation

Muon Collaboration

- **Induction Linac ϕ-δE Rotation is long and expensive; requires new technology**
- **Would like to use shorter system, which uses existing rf technology (~200 MHz…)**

⇒ Alternative Scenario:

- allow beam to decay + drift

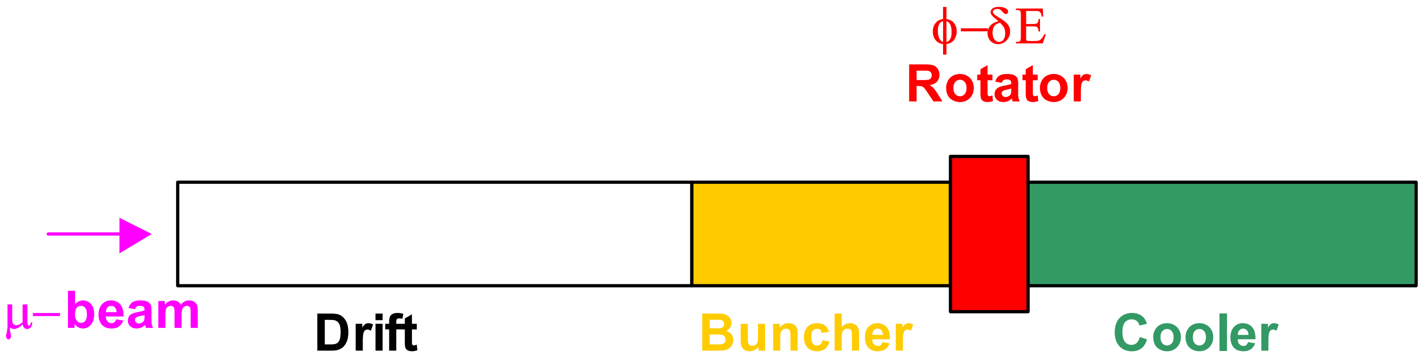
- impose varying-frequency rf to trap beam into string of ~200 MHz bunches

- rotate string of bunches to obtain same mean energy of bunch using (?) fixed-frequency rf

-capture beam into cooling rf

System Components

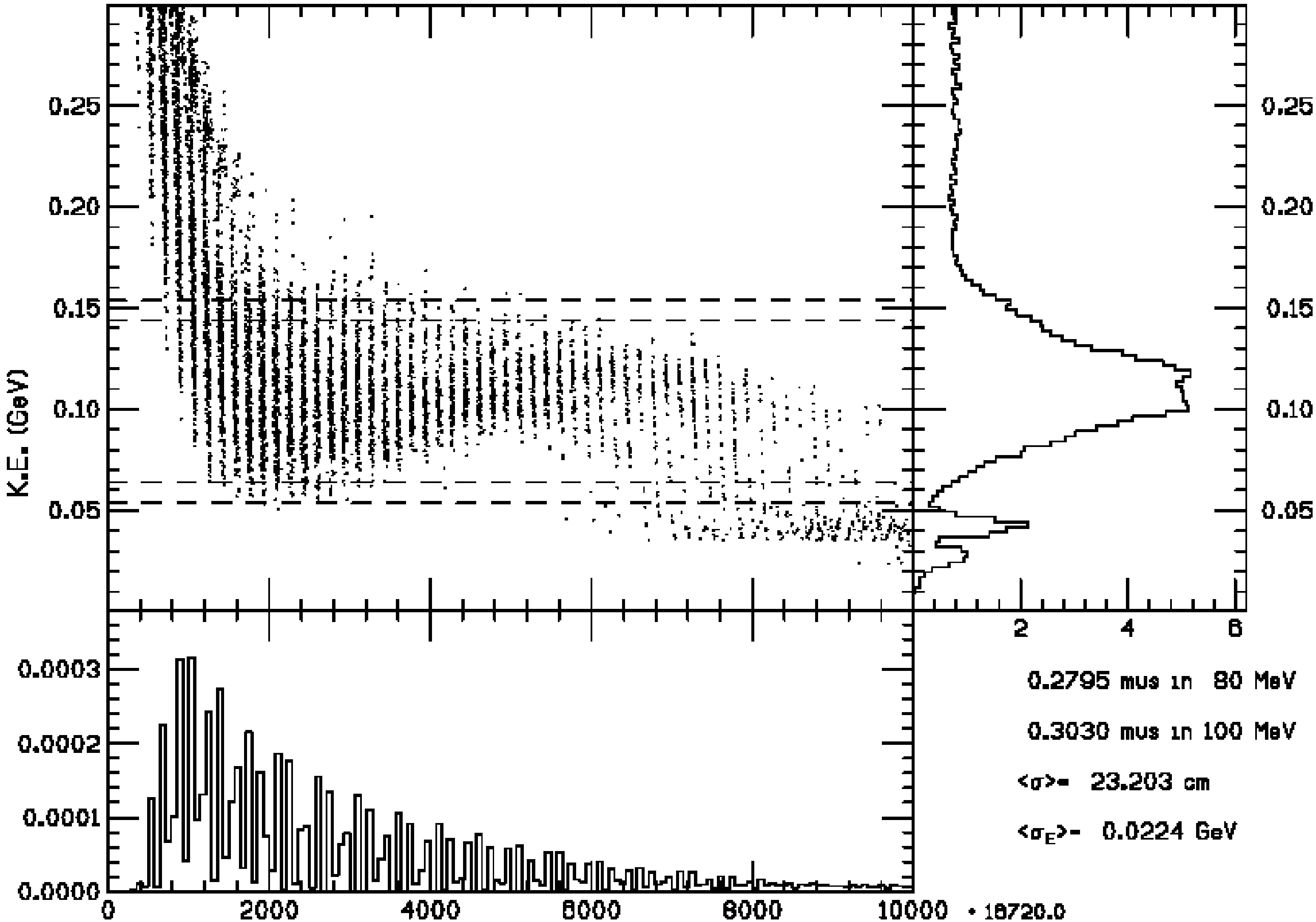
Overview of transport



- **Drift (100m)**
- **Buncher (60m) 300→187MHz, V′ → 4.8 $(z/L)^2$ MV/m**
- **φ–δE Rotator(8.4m) 187MHz, V′ = 10 MV/m**
- **Cooler (100m) 183MHz**

Simucool-optimized buncher and fixed frequency ϕ–δE rotation

- Obtains ~0.28 μ/p at end of buncher



Component Parameters

- **Drift (100m)**
  - **Allows $\pi \rightarrow \mu$ beam to decay; lengthens to develop $\phi - \delta E$ correlation**
- **Buncher (60m (?))**
  - **Bunching rf with E_0 = 125±50 MeV set at 15 λ separation**
    - **V_{rf} increases gradually from 0 to 4.8 MV/m**
- **$\phi - \delta E$ Rotation (~10m)**
  - **Fixed frequency; V_{rf} set at a maximum value (10MV/m)**
    - **Beam rotates by ~1/4 synchrotron oscillations to reduce δE**
- **Cooler**
  - **fixed frequency transverse cooling system (~100m long)**

Hardware For Adiabatic Buncher

- Transverse focussing (currently)
  - B=1.25T solenoidal focusing
  - R=0.30m transport for beam

Rf requirements:

- Buncher: ~300→~200 MHz; 0.1→4.8MV/m (60m)

  (initially 1 cavity every 1m; reduces frequency in 2–4MHZ steps; 1–D and other early simulations indicate ~10 frequencies are sufficient (~10MHz intervals)
- $\phi - \delta E$ Rotator: 230→220 MHz; 10MV/m (~10m)

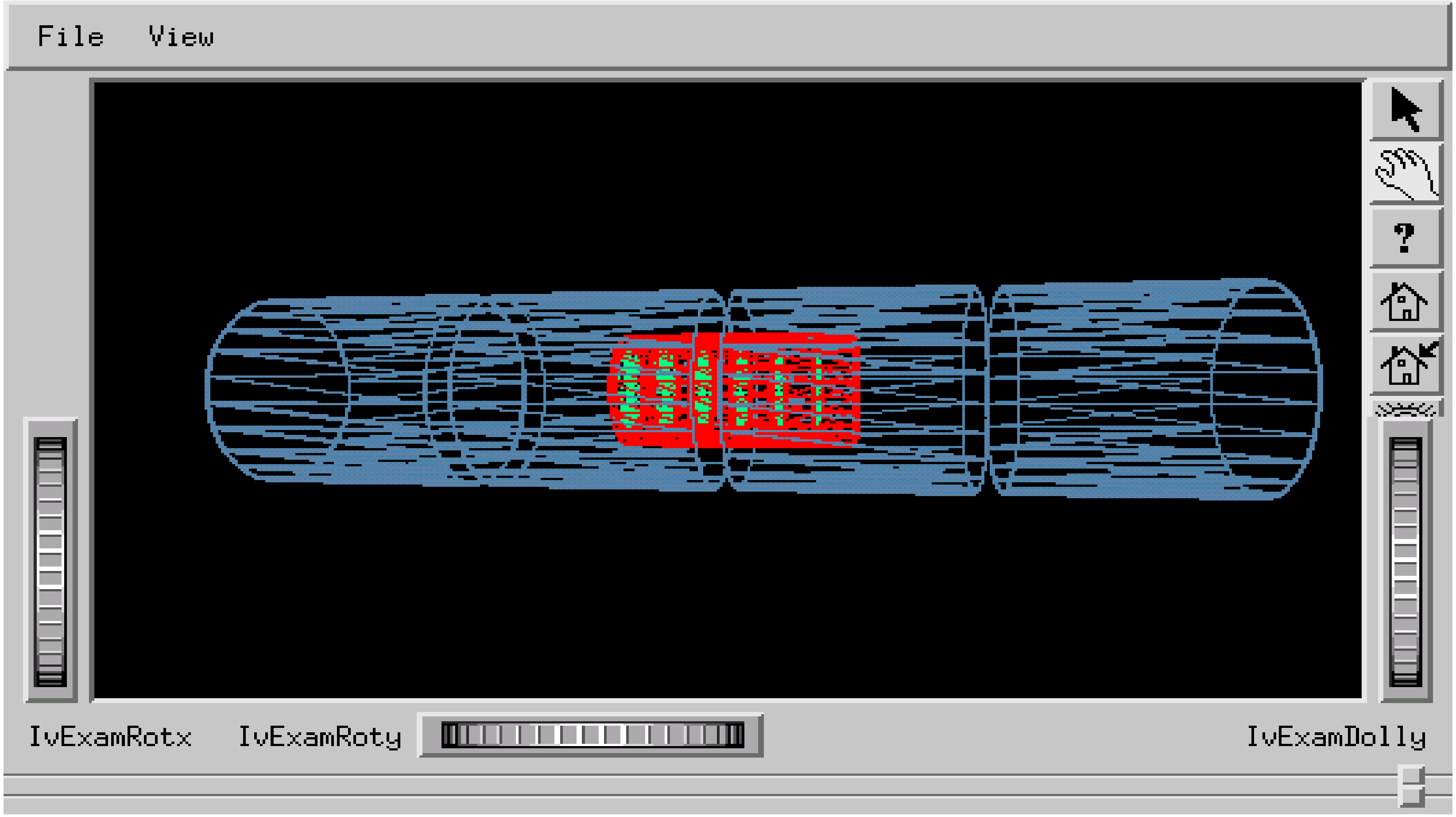
RF requirements for High-frequency buncher and phase rotation

Rf frequency	Voltage (Quadratic to Linear ramp)
300 MHz	0.075 – 1 MV – 6m
290 MHz	0.675 – 4 MV – 6m
280 MHz	1.875 – 7 MV – 6m
270 MHz	3.675 – 10 MV – 6m
260 MHz	6.08 – 13 MV – 6m
250 MHz	9.08 – 16 MV – 6m
240 MHz	12.7 – 19 MV – 6m
230 MHz	16.9 – 22 MV – 6m
220 MHz	21.7 – 25 MV – 6m
210 MHz Buncher:	28 MV – 6m (Total rf voltage: 101 to 145 MV)
200 MHz	100 MV (10m) – Rotator

Rf Cost Estimate (Moretti)

Frequency	Cavity length	Cavity Cost	Rf Power	Total
300MHz	0.5 m	225 k$	225 k$	450k$
290	1	450	350	800
280	2	900	700	1600
270	2	900	1000	1900
260	2	900	1000	1900
250	2	900	1000	1900
240	2	900	1000	1900
230	3	1200	1500	2700
220	4	1400	1500	2900
210	5	1800	2000	3800
200	10	3800	4200	8000
	33.5m	13375	14475	27850k$

Geant View of Magnet+ Cavity



Buncher section:

6m – long 1.25 T solenoid + rf cavities

Transport requirements

- Baseline example has 1.25 T solenoid for entire transport (drift + buncher + rf rotation) (~170m)
- Uncooled μ−beam requires 30cm radius transport (100m drift with 30cm IR – 1.25T)
- In simulations, solenoid coils are wrapped outside rf cavities.
  ⇒(~70m 1.25T magnet with 65cm IR)
- FODO (quad) transport could also be used …

Cost of Solenoid (PDG handbook)

- Stored Energy:

$$E = \frac{\pi}{2\mu_0} B^2 R^2 L$$

- Cost:

$$\text{Cost} = 0.532\left[E(\text{MJ})\right]^{0.662}$$

- Combine 2 solenoids: 3.5 + 7.9 = 11.4 M$
- Mutiply by ~2 $\Rightarrow$ ~20 M$??? Magnet Cost
- (D. Summers can do Al solenoids for ~10 M$)

Other Cost Items

- Conventional facilities ~10 M$
- Cryogenics: 3 M$
- Diagnostics 4 M$
- Vacuum 3 M$
- Other ???

$$ Cost Savings ??

- High Frequency $\phi-\delta E$ Rotation replaces Study 2:
  - Decay length (50m, 5M$)
  - Induction Linacs + minicool (350m, 320M$)
  - Buncher (50m, 70M$)
- Replaces with:
  - Drift (100m)
  - Buncher (60m)
  - Rf Rotator (10m)
  - Rf cost =30M$; magnet cost =20M$?? Conv. Fac. 10M$ Misc. 10M$ ……
- Back of the envelope (my guess)

(400M$ $\rightarrow$?? 80M$)