Muon Front End
for the Neutrino Factory

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NuFact05
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NF front end design

- requirements
  - accept π produced from proton driver + target
  - prepare a μ beam for acceleration
- major components of a front end
  - π/μ collection
  - π decay
  - development of E – t correlation
  - phase rotation (reduce Δp)
  - bunching
  - ionization cooling
- standard neutrino factory references
  - CERN-2004-002 (2004)
  - NuFactJ FS v1.0 (2001)
  - US-FS1 (2000)
  - US-FS2 (2001)
  - US-ST2a (2004)

Driver + target properties

• a wide variety of incident beam configurations have been considered

	P	E	f	σ_t	bunches	target
	MW	GeV	Hz	ns		
CERN-SPL	4	2.2	50	1	140	Hg
CERN-RCS	4	30	8	1	8	
RAL-RCS1	4	5	50	1	4	
RAL-RCS2	4	15	25	1	6	
JNF	1 - 4	50	0.3	6	1	W
US-FS1	1.2	12	15	3	4	C
US-FS2	1	24	2.5	3	6	Hg

Accelerator acceptance

- typically matches to linac + RLA/FFAG
- JNF feeds 0.3 to 1 GeV/c FFAG

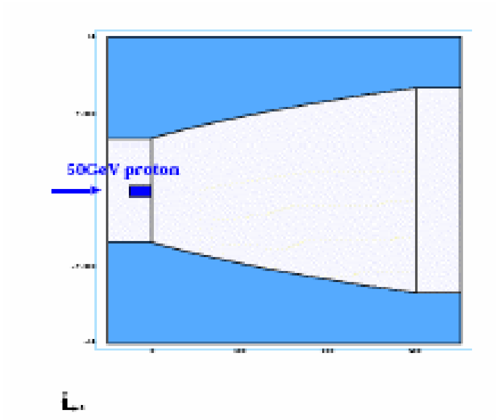
	A_{TN} [mm]	A_{LN} [mm]	f [MHz]	train	E [MeV]
CERN	15	280	88	Y	260
JNF	10 – 30	13000	5	N	300
US-FS1	9.4	150	201	Y	190
US-FS2	15	150	201	Y	210
US-ST2a	30	150	201	Y	270

Collection & decay

- use high field solenoid or horn for capture
- use solenoid channel for decay

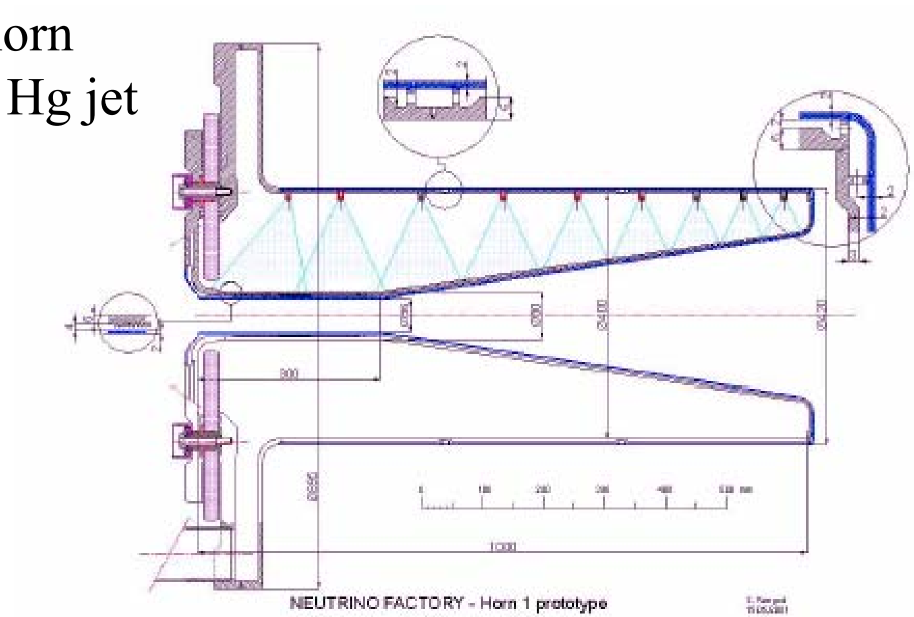
	type	B_C [T]	L_{TAP} [m]	B_D [T]	L_D [m]	r_D [cm]
CERN	H	1.5	1	1.8	30	30
CERN-2				4	15	20
JNF	S	20	3	5	?	16
US-FS1	S	20	2	1.25	50	30
US-FS2	S	20	19	1.25	18	30
US-ST2a	S	20	12	1.75	100	25

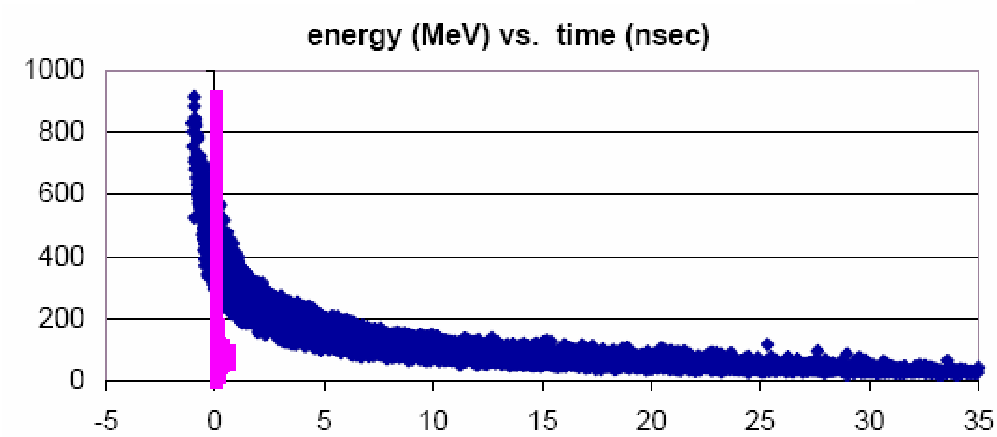
Collection & decay (2)



JNF 20 T capture solenoid

CERN capture horn
short, surrounds Hg jet

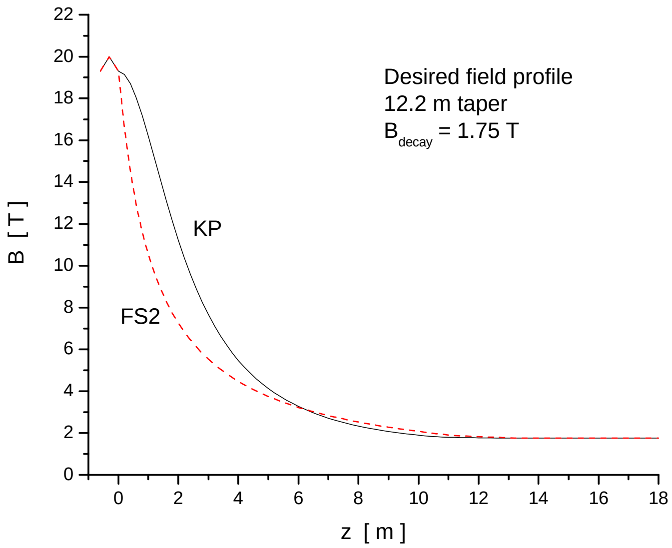


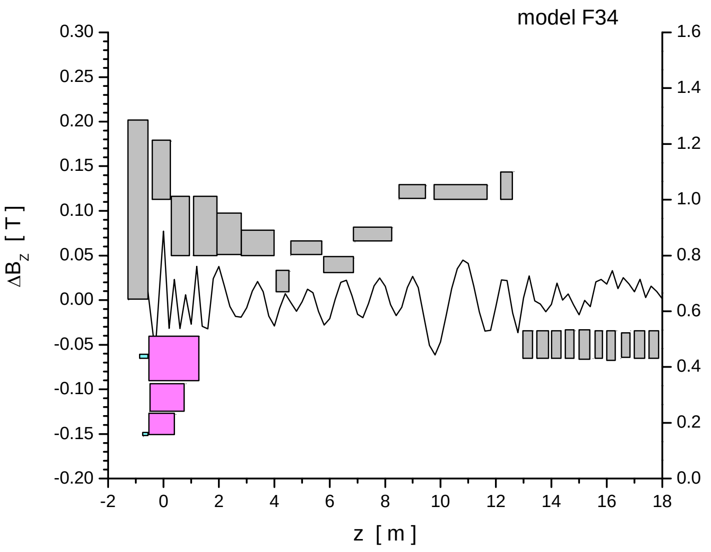


CERN decay region
E-t correlation for phase rotation
44/88 MHz channel

ST2a pion/muon collection

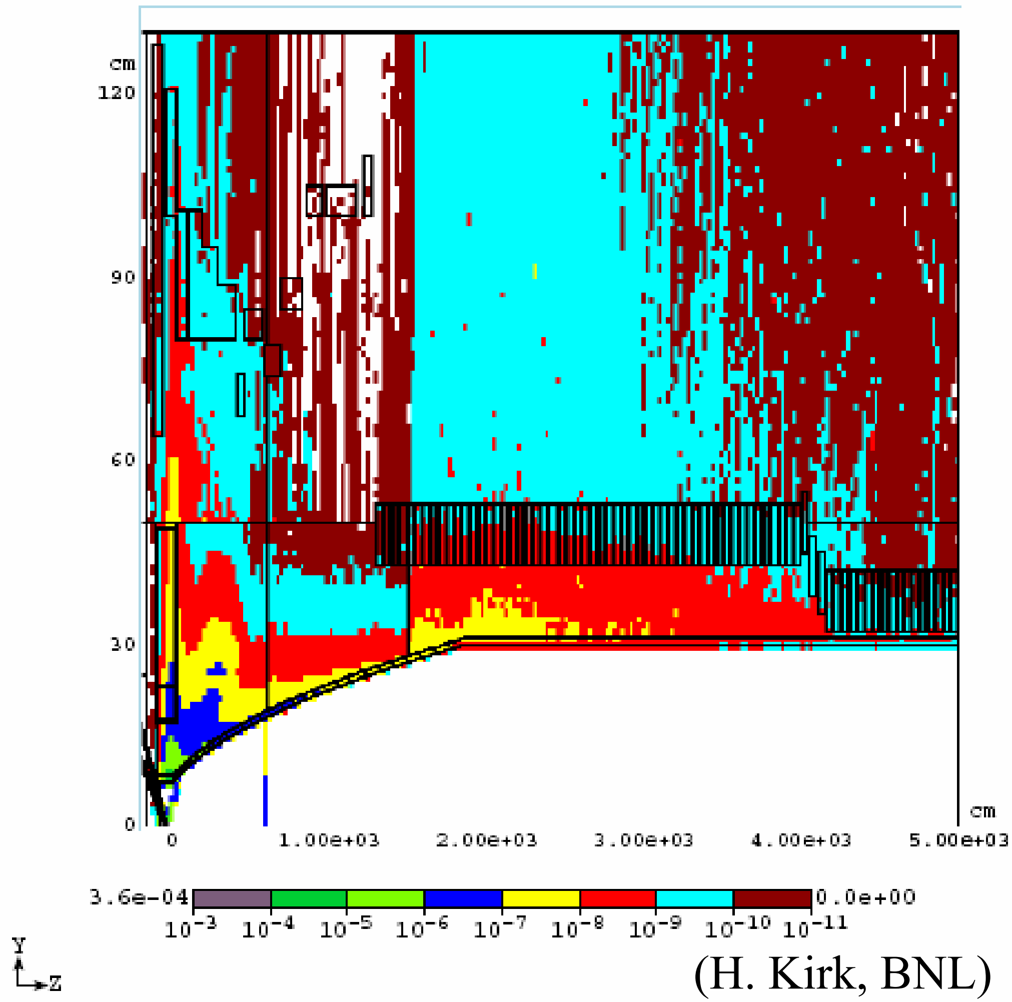
- 12.2 m taper from 20 T to 1.75 T





ST2a radiation levels

- MARS calculations
  of absorbed dose (H. Kirk)
- peak deposition in SC coils
  is ~ 1MGy/yr
- no problem with SC lifetime

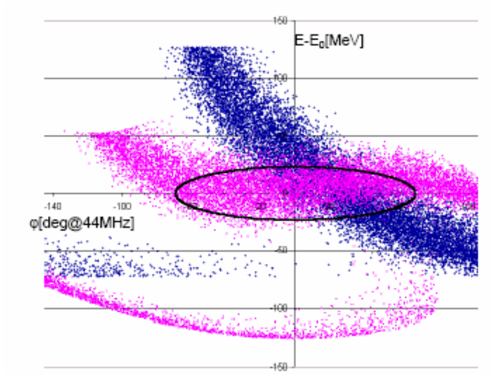


(H. Kirk, BNL)

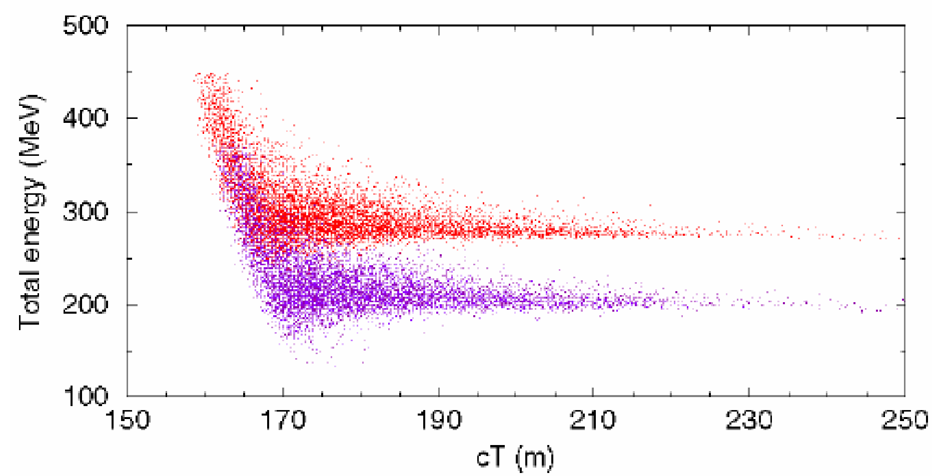
Phase rotation & bunching

	L [m]	B [T]	type	f [MHz]	G [MV/m]
CERN-R	30	1.8	RF	44	2
CERN-R-2	8	4	RF	88	4
US-FS1-R	100	3	IL	---	1.5
US-FS1-B	17	5	RF	201	6 - 8
US-FS2-R	100, 80, 80	1.25	IL	---	1.5
US-FS2-B	55	2	RF	201, 402	6 – 8
US-ST2a-B	50	1.75	RF	333 - 234	5 – 10
US-ST2a-R	55	1.75	RF	234 - 201	12

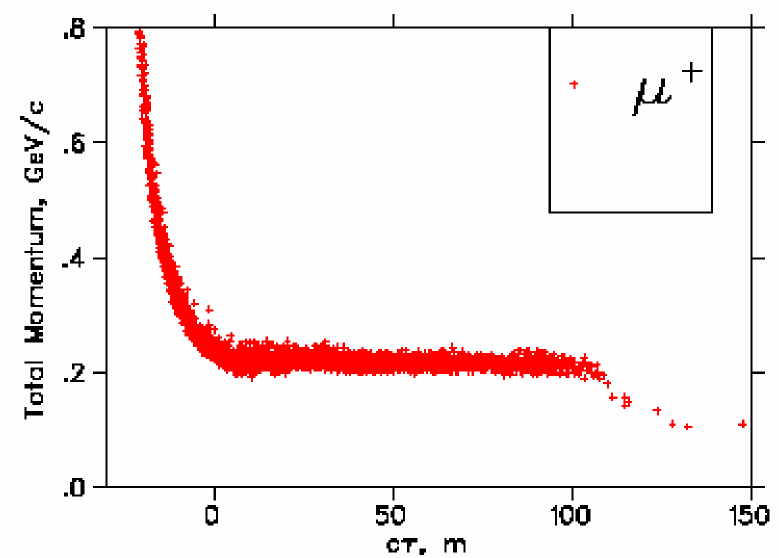
Phase rotation



CERN 44 MHz

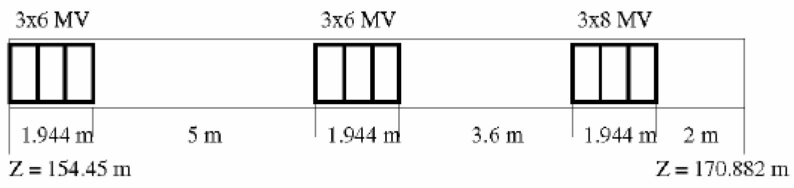


FS1 induction linac
before/after LH_2 minicooling

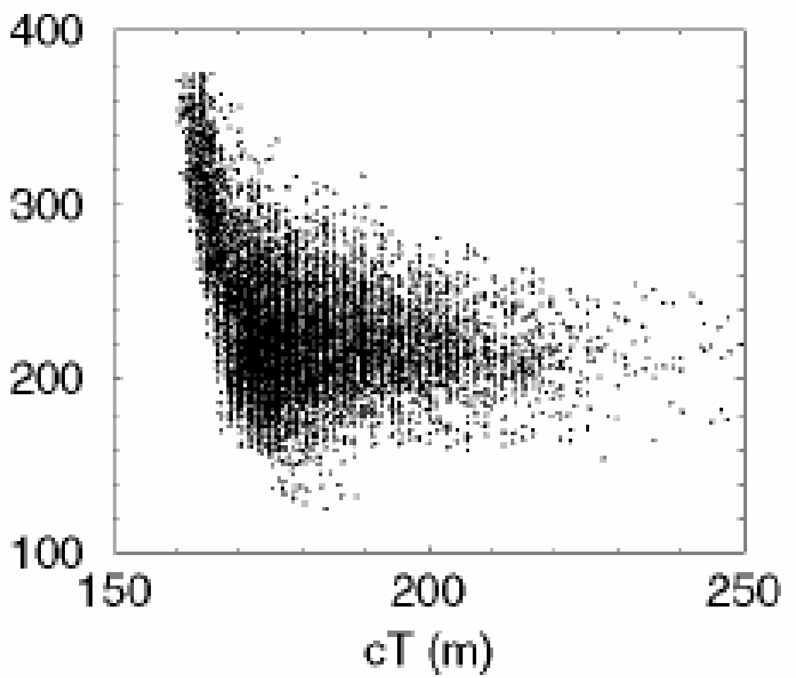


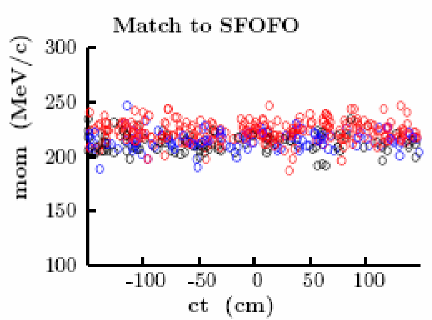
FS2 induction linacs
"non-distorting"

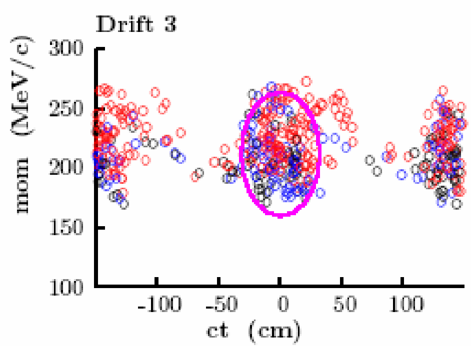
Bunching



FS1 201 MHz RF buncher



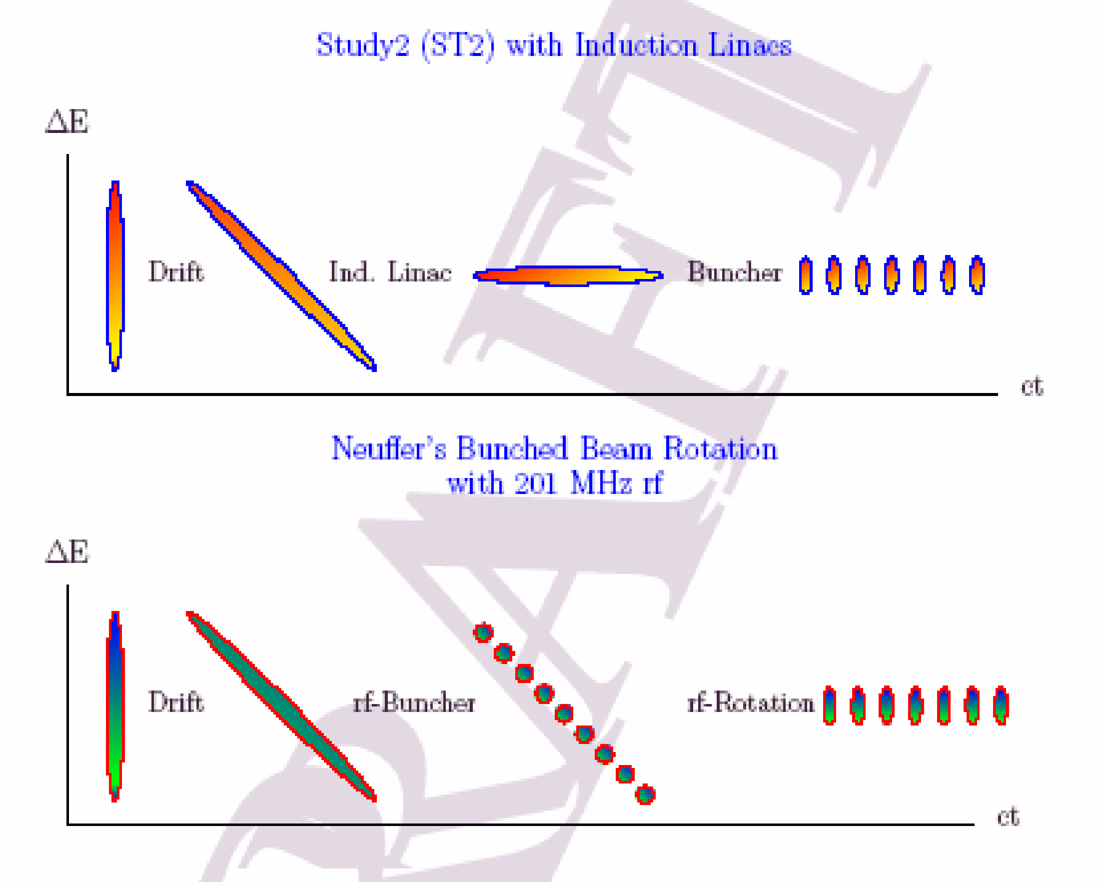




FS2 bunch train

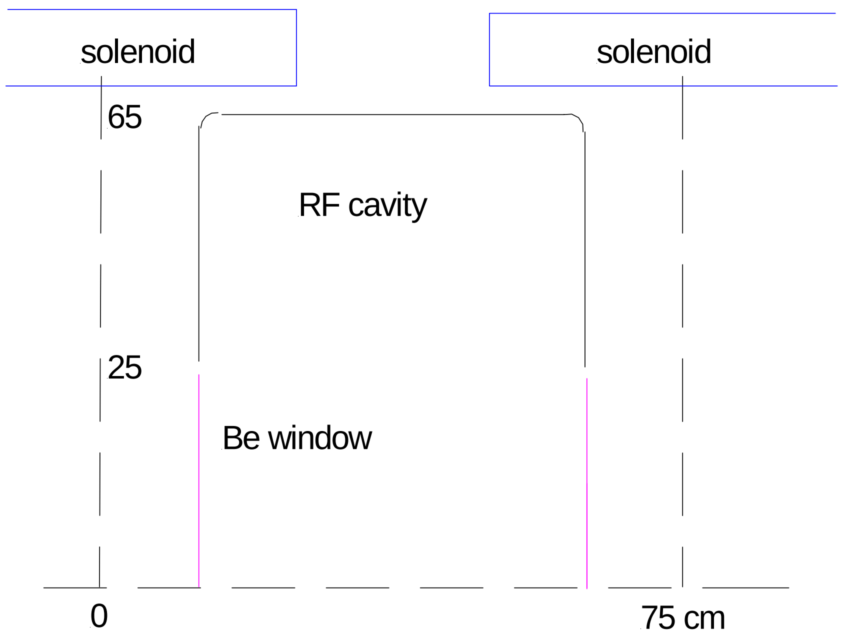
Adiabatic buncher and phase rotation

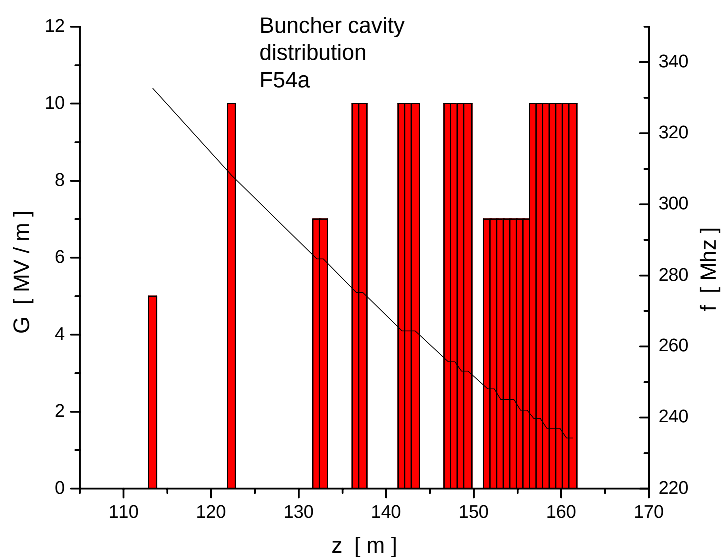
- this new concept had major influence on front end design



ST2a buncher configuration

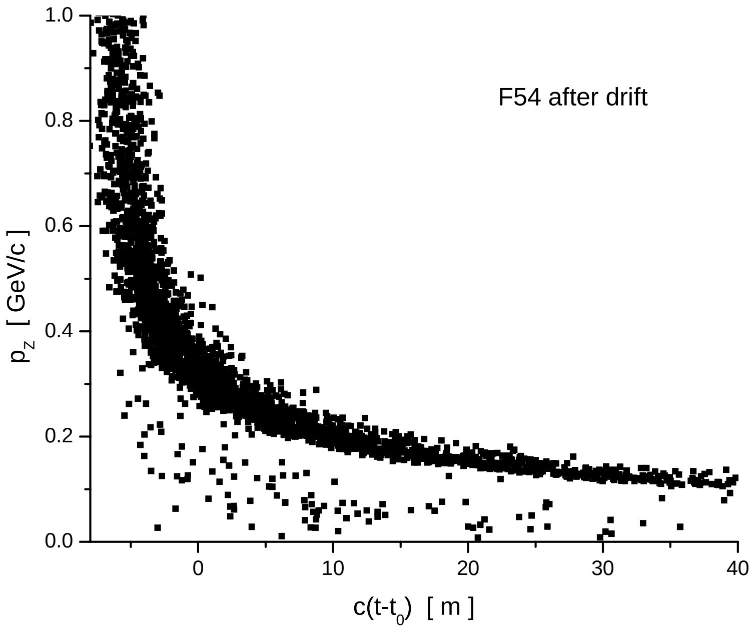
- 51 m long
- 27 cavities with 13 different frequencies (333→234 MHz)
- gradients (5 → 10 MV/m)
- window thickness (200 – 395 μm)

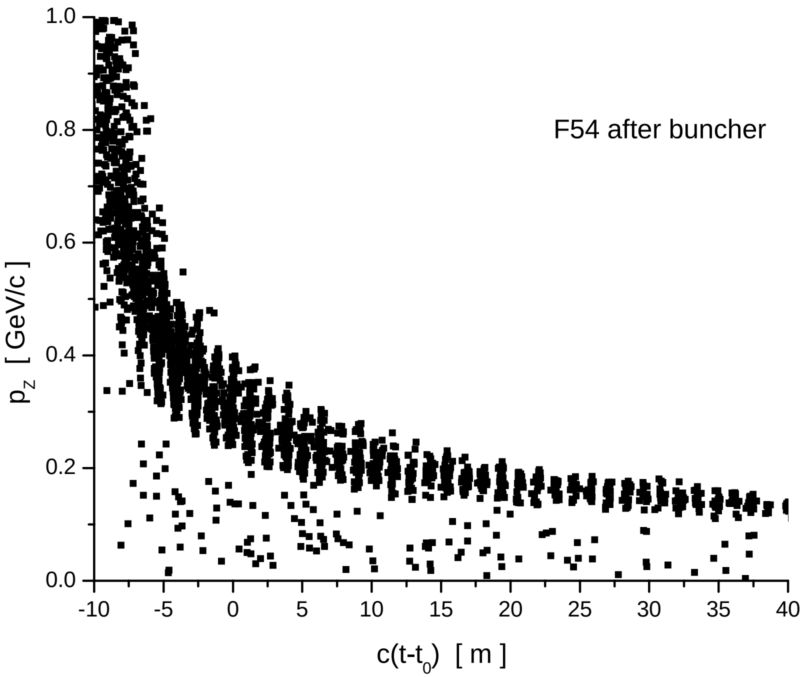




ST2a buncher performance

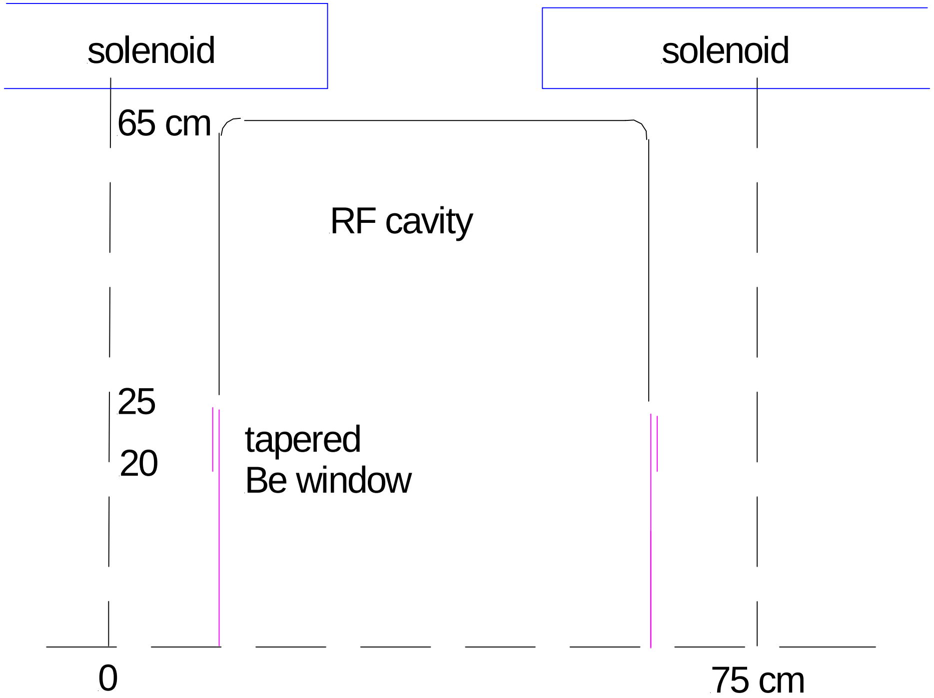
- 92 bunches in train at 295 m

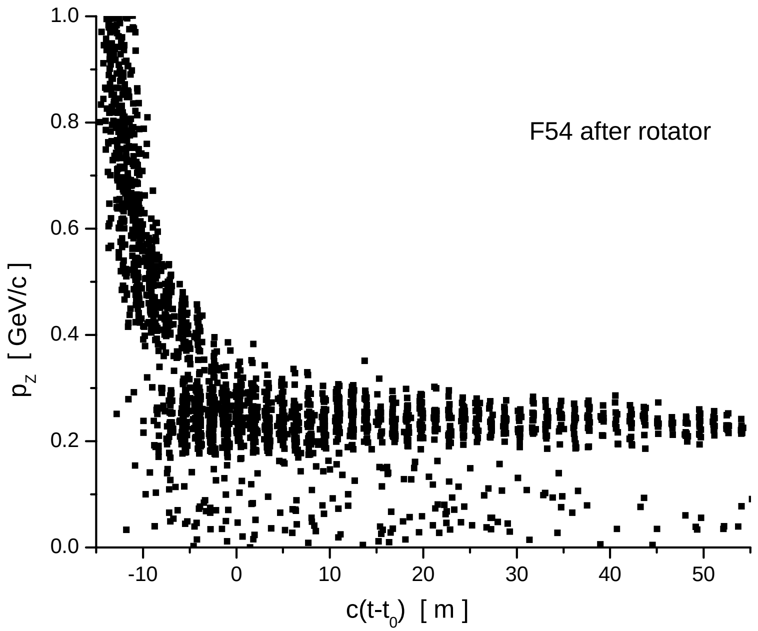




ST2a rotator

- 54 m long
- 72 cavities with 15 different frequencies (232→201 MHz)
- gradient 12.5 MV/m
- window thickness (750 + 750 μm)



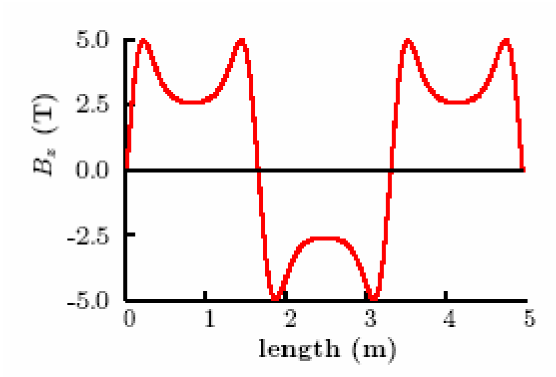


Ionization Cooling

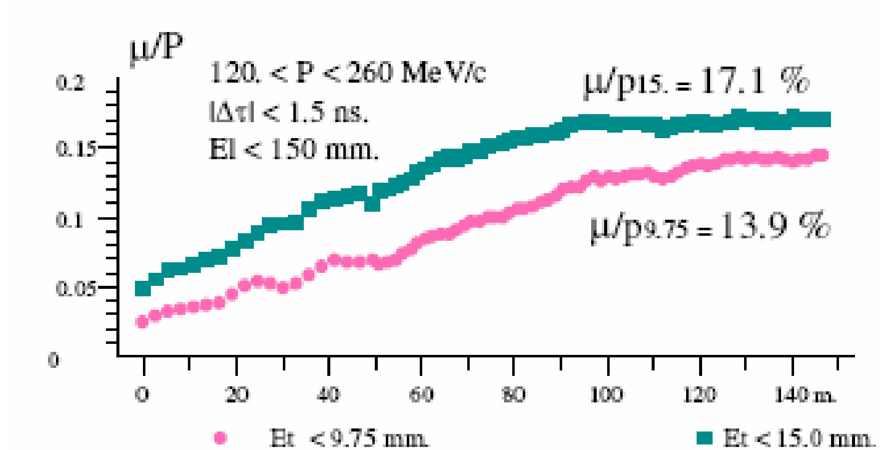
- present designs only use transverse cooling

	L	p	B	L_{cell}	f	G	abs
	m	GeV/c	T	m	MHz	MV/m	
CERN	46	287	2	4.2	44	2	H
CERN-2	90	371	4	6.4	88	4	H
US-FS1	140	200	3.4	1.1	201	15	H
US-FS2	108	238	3.5, 5	2.75, 1.65	201	16	H
US-ST2a	80	220	2.8	0.75	201	15	LiH

Ionization Cooling (2)

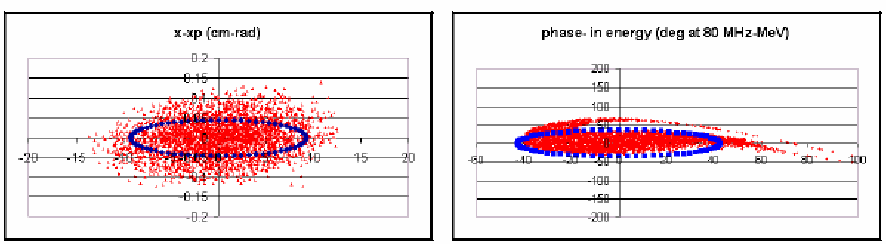


FS2 B field on-axis
SFOFO lattice



FOM is increase in μ / p in accelerator acceptance
D = 2.7 for FS2

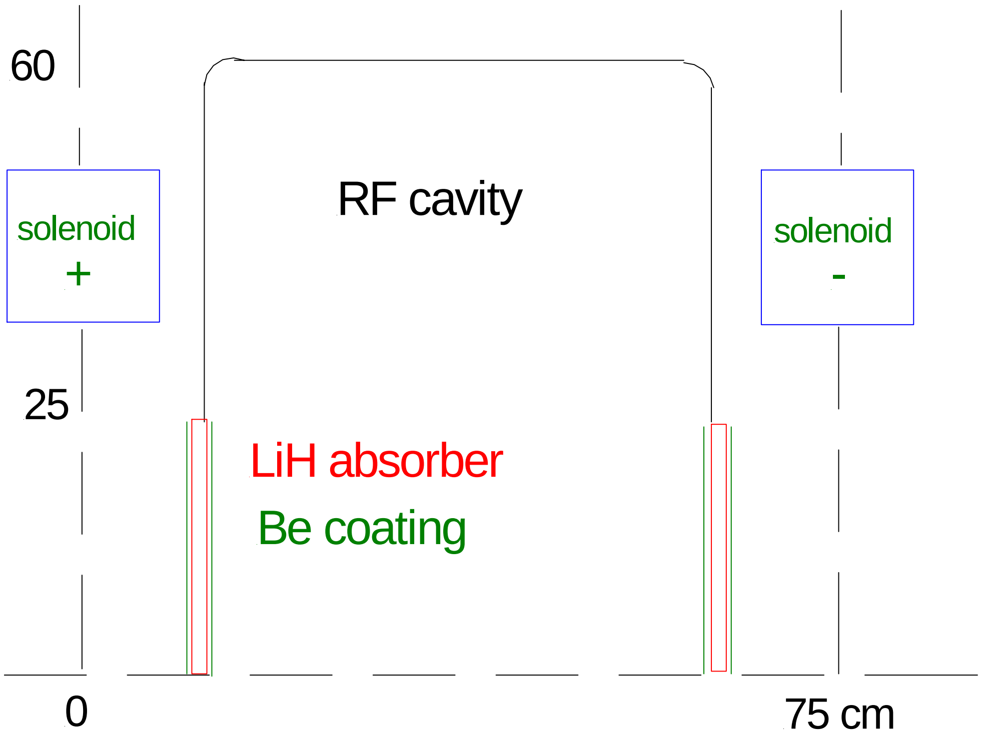
RF 0.5 m	RF 0.5 m	RF 0.5 m	RF 0.5 m	RF 0.5 m	RF 0.5 m	RF 0.5 m	RF 0.5 m	H_2 0.4m

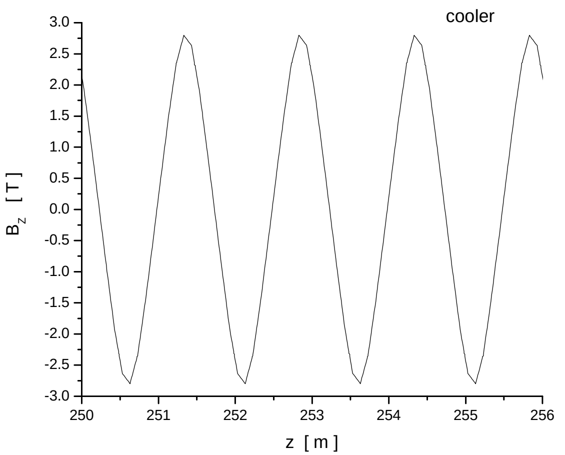


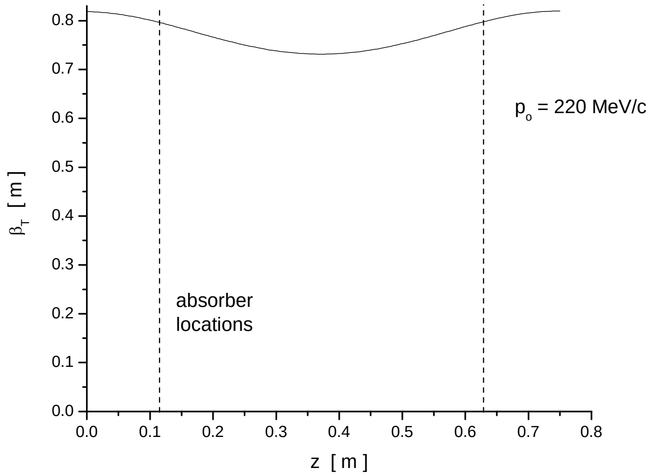
CERN 88 MHz cooling cell
final phase space

ST2a cooler design

- 80 m long alternating solenoid channel, $B_S = 2.8$ T
- large, relatively flat $\beta_\perp \sim 80$ cm
- use LiH absorbers as RF windows

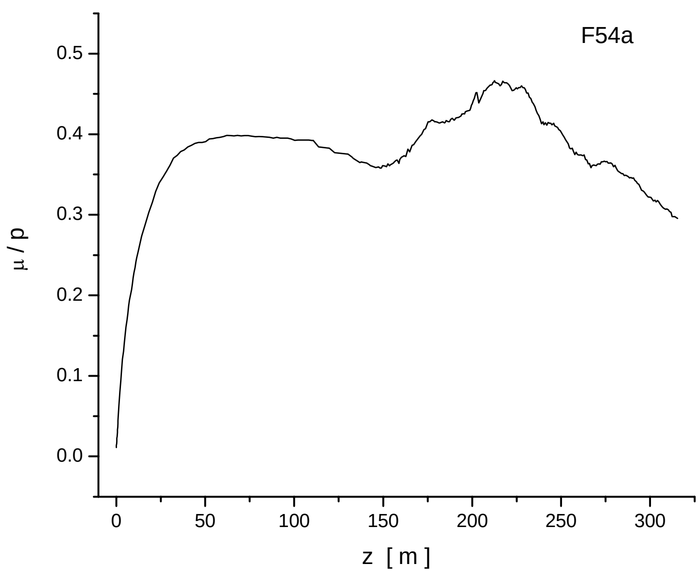


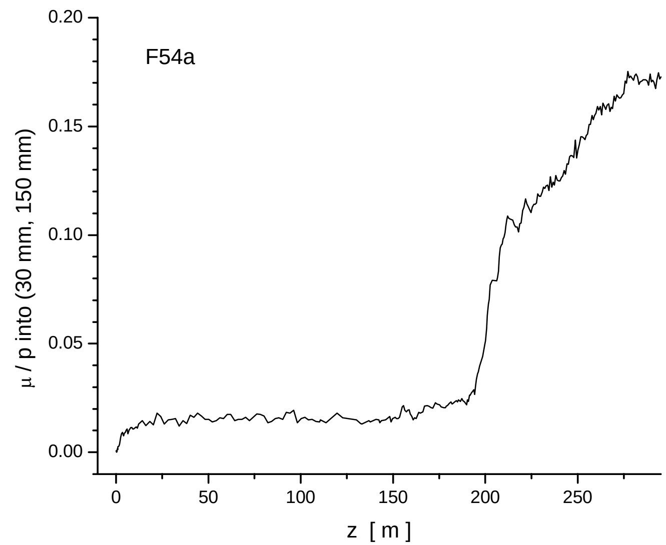




ST2a performance

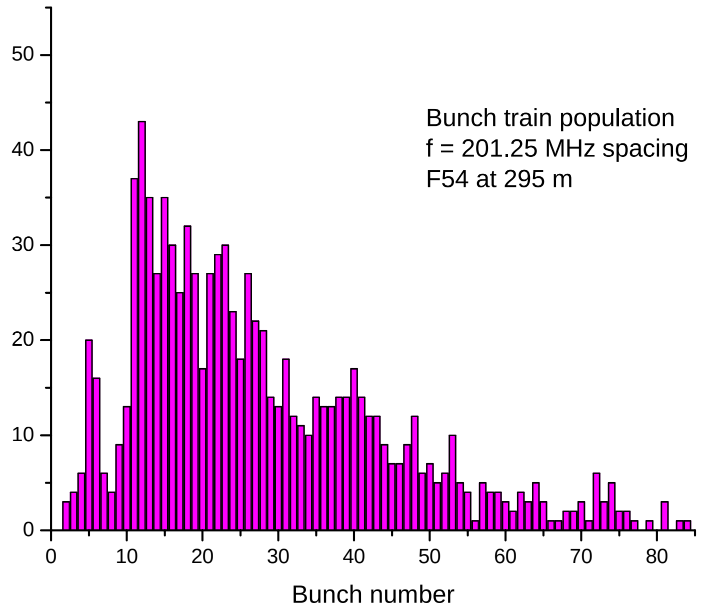
- cooling decreases total μ in Δp band by ~30%
  mostly due to particles falling out of bucket (decay loss is 6%)
- cooling increases μ density into accelerator acceptance by factor of 1.7

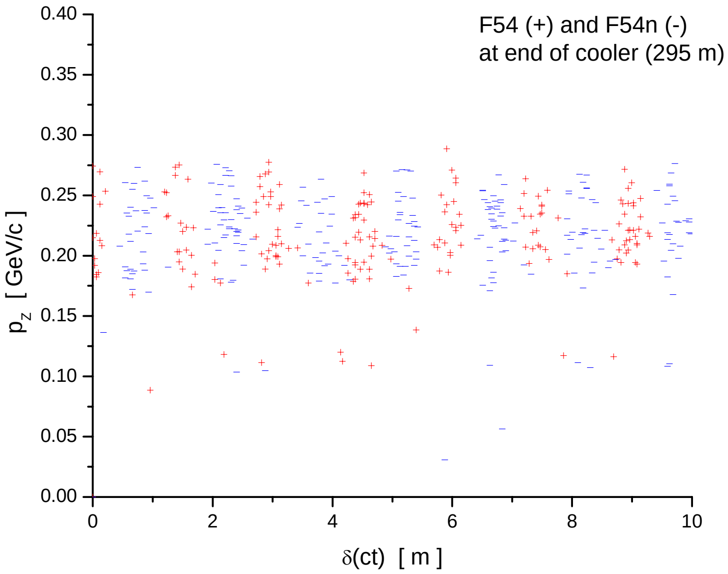




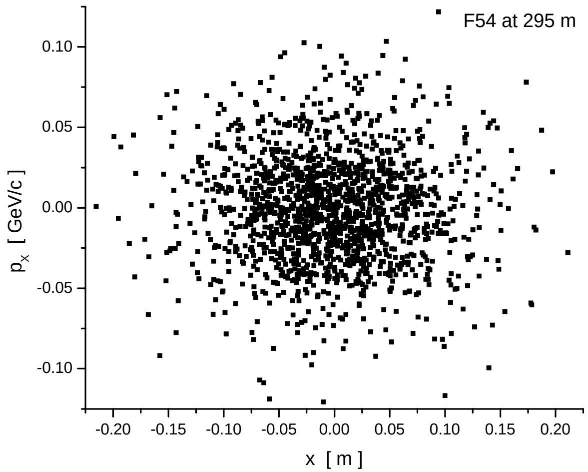
ST2a - both signs

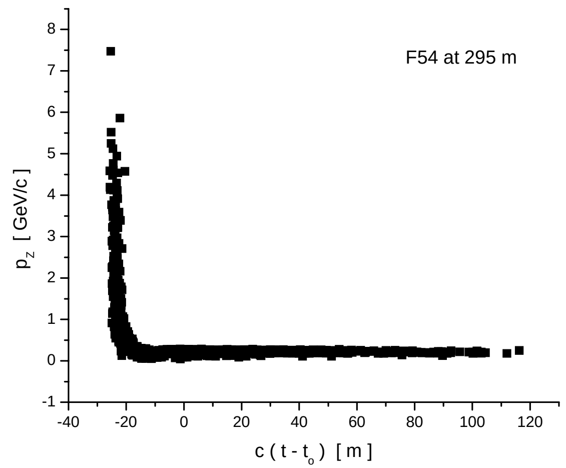
- adiabatic buncher captures both μ^+ and μ^- bunches
- distinguish μ source by timing at detector

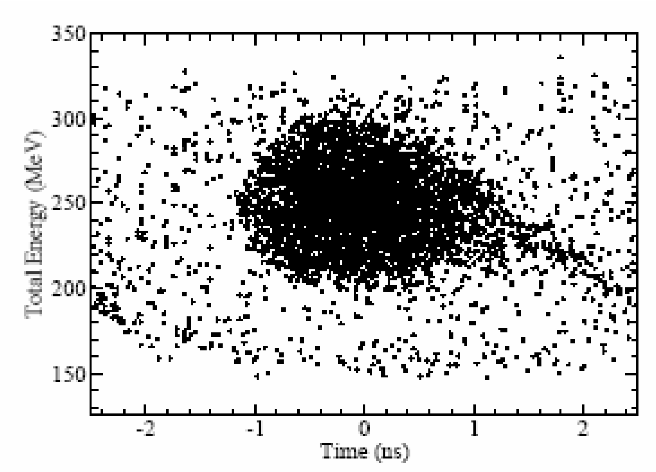




ST2a phase space at end







(Scott Berg, BNL)

Front-end comparison

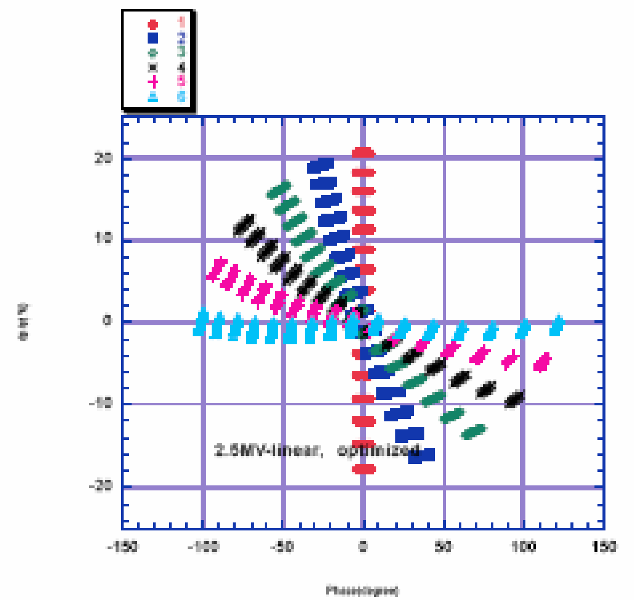
	L [m]	bunches	μ / p	signs
CERN	250	140	0.02	1*
JNF	~20?	1	0.3 – 0.5	2$
US-FS1	350	50	0.02	1
US-FS2	562	67	0.17	1
US-ST2a	295	89	0.17	2

*with horn

$with charge separation in injection

Some other front-end ideas

- multiple targets with funnel optics
  - avoid target and horn problems
- phase rotation in FFAG ring, e.g. PRISM
- RF phase rotation with magnetic compression
  - improves RF bucket density
- reverse phase-slip bending chicane
  - reduce non-linearities in acceleration
- velocity-compliant bunching
  - variation on adiabatic bunching
- quad precooling channel
- gas-filled cooling channel
- helical cooling channel
- cooling rings



PRISM
phase rotation in 5 turns

Summary

- there has been excellent progress in NF front end designs
- we now have 5 detailed design reports
- additional good ideas are available for study
- performance has been increasing over time
- costs have been coming down
- confident we can design a satisfactory FE for the WDS