Slow Extraction Design for JHF Main Ring

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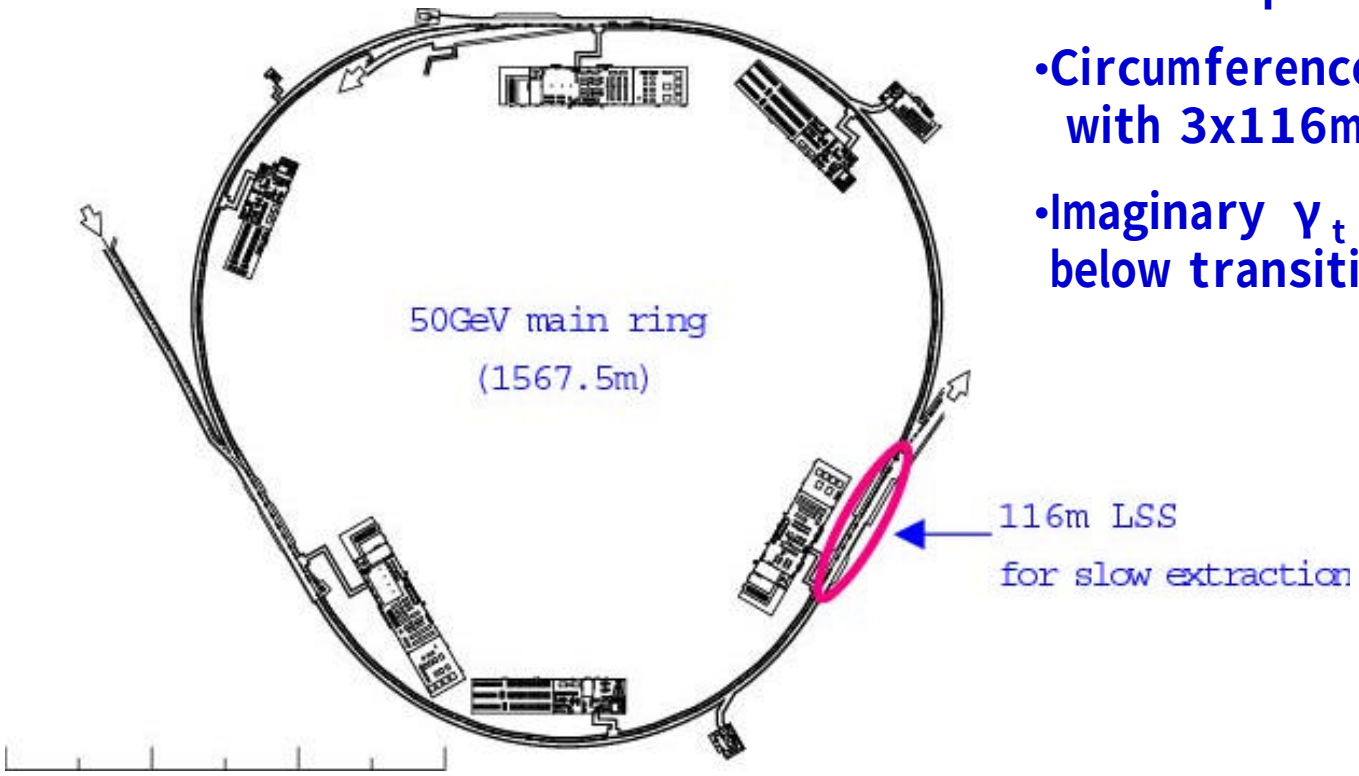
- Slow Extraction Scheme of 50GeV MR
- Simulation of Extracted Beam
- Beam Spill
- ESS
- High Intensity Issues (radiation, ,,,,)
- 1st phase operation

- 400MeV linacs
- 3GeV,25Hz(h=2) synchrotron (RCS)
- 50GeV synchrotron (MR)

50GeV-MR Schedule

- End of 2002-middle of 2005
  tunnel construction
- March 2007
  beam commissioning
- April 2007
  slow extraction commissioning

50GeV-MR



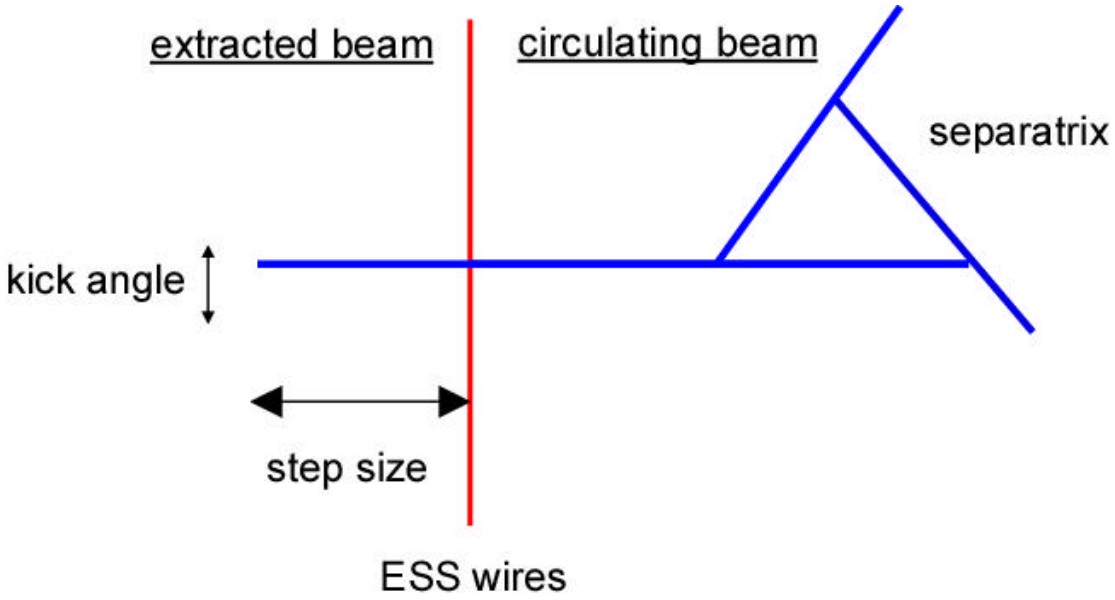
- 3.3×10^{14} protons per pulse(15μA)
  full beam power : 750kW @50GeV
- Circumference 1567.5m
  with 3x116m long straight sections
- Imaginary γ_t lattice
  below transition also for top energy

50GeV-MR Slow Extraction

- full beam power : 750kW @50GeV
  → beam loss: 1% (7.5kW) level
- coasting beam extraction
- third integer resonance
  separatrix : linear
  easy to tune separatrix angle and step size
  by adjusting resonant sextupoles

Slow Extraction Scheme of 50GeV MR (1)

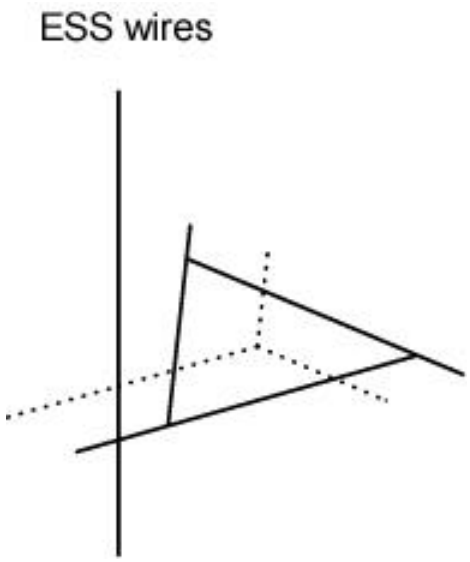
- ESS is placed between two focusing Q-magnets
  → large βx(=39m), small αx(=-0.001)
  → 20mm step size @ ESS
  70π mm•mrad (acceptance of 81π mm•mrad)



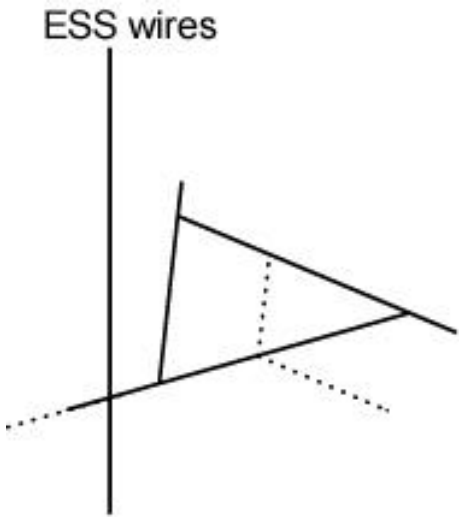
Slow Extraction Scheme of 50GeV MR (2)

- Dispersion free @LSS
  horizontal chromaticity Qx'=0
  →separatrix is independent of momentum

- Bump orbit is moved during extraction (dynamic bump)
  →small angular spread @ ESS



fixed bump

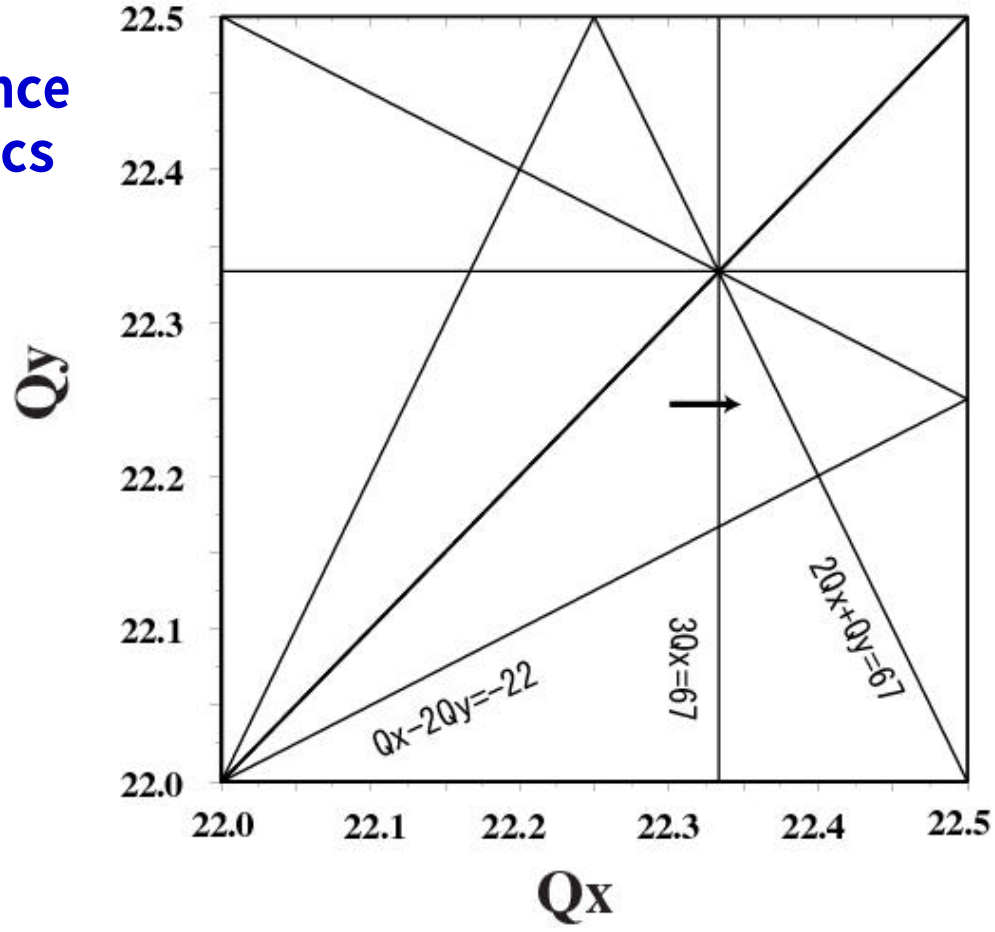


dynamic bump

Method to push the beam to the resonance

- Approach tune to resonance by ramping QF (QFN) in arcs

- Qx=67/3 (Qy=22.25)



electrostatic septum

kick	field	voltage	lengh	thickness	H-gap
-0.2 mrad	6.79 MV/m	0.17 MV	1.5 m	0.1 mm	25 mm

magnetic septa

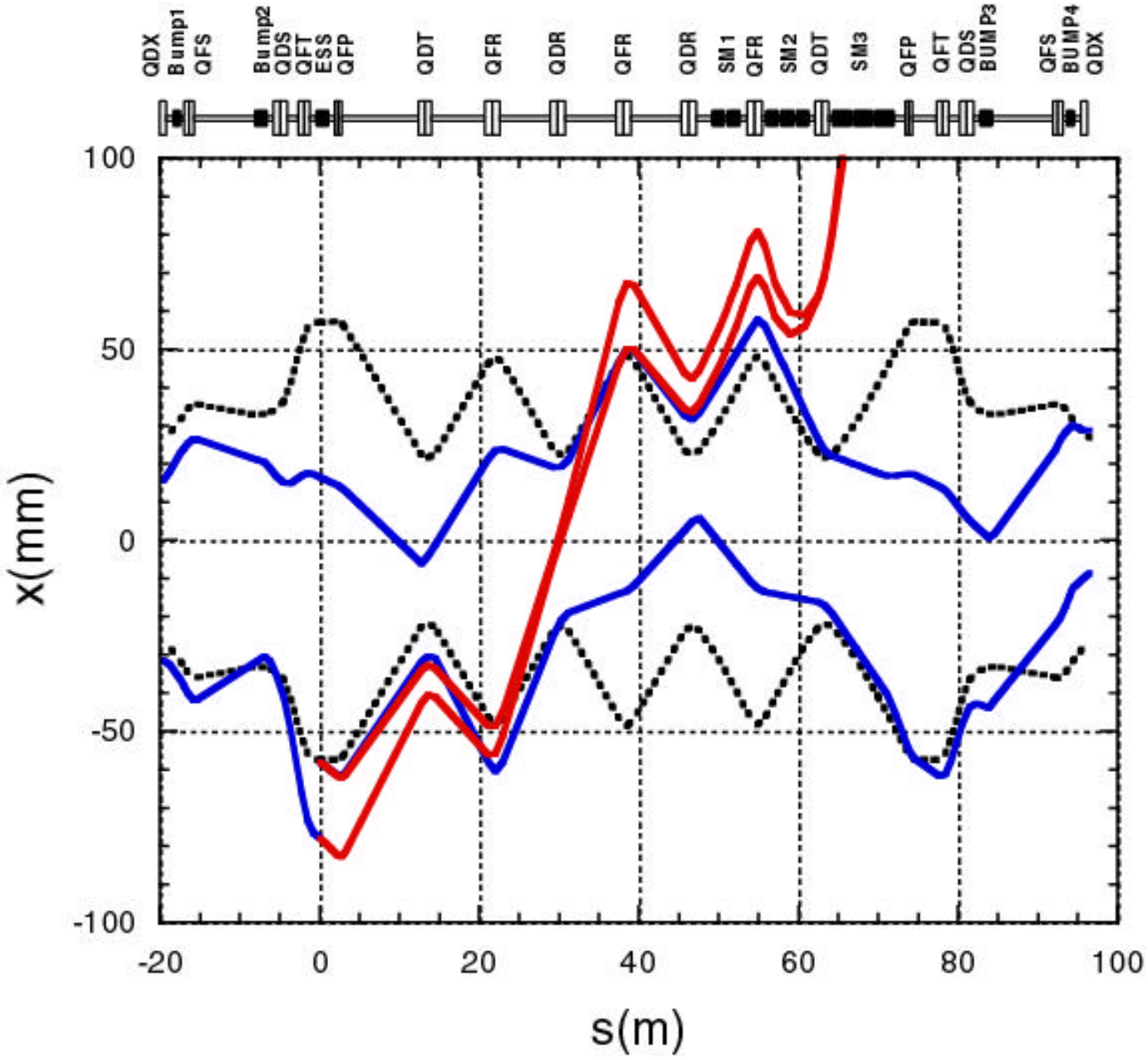
	field (T)	length (m)	V-gap (mm)	thickness (mm)
SM1(2 units)	0.114	1.5	45	1
SM2(2 units)	0.374	1.5	60	5
SM3-1	1.35	2.3	60	30
SM3-2	1.64	2.3	50	>30
SM3-3	1.64	2.3	50	>30

bump magnets

	field	length	V-gap
BMP-1,4	0.65 T	1.0 m	130 mm
BMP-2,3	0.65 T	1.5 m	130 mm

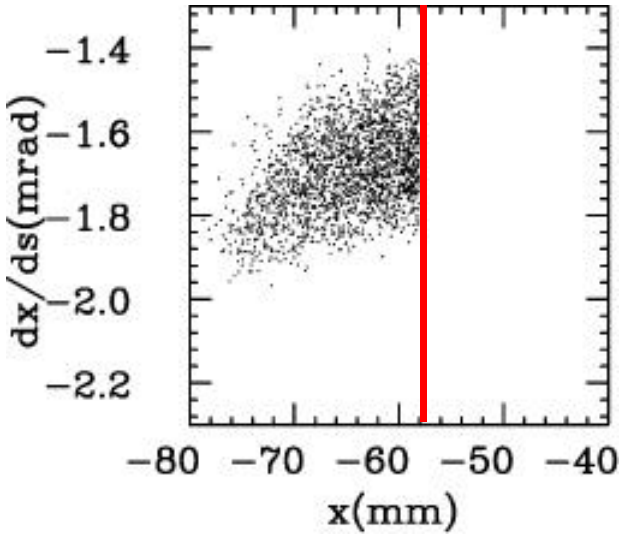
sextupole magnets

family1: 4, family 2: 4


QDX
Bump1
QFS
Bump2
QDS
QFT
ESS
QFP
QDT
QFR
QDR
QFR
QDR
SM1
QFR
SM2
QDT
SM3
QFP
QFT
QDS
BUMP3
QFS
BUMP4
QDX
100
50
0
-50
-100
x(mm)
-20
0
20
40
60
80
100
s(m)

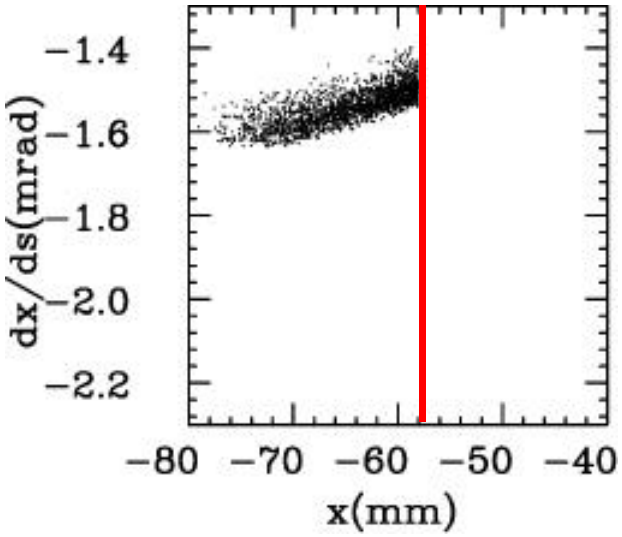
50GeV-extracted beam at ESS

fixed bump



tri0060_090

dynamic bump



tri0061_090

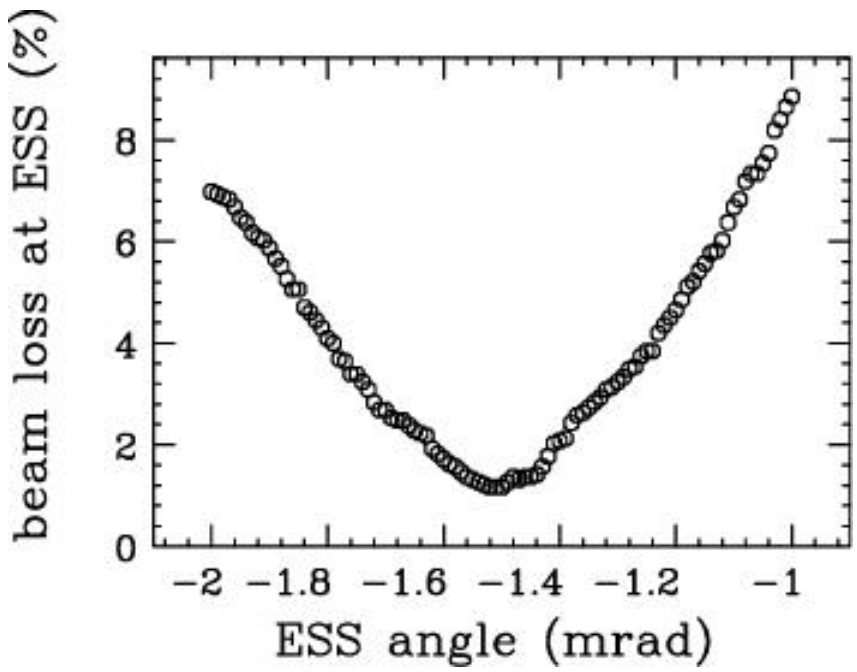
Circulating Beam Parameters

$\varepsilon_x = 6.1\pi$ mm•mrad
$\varepsilon_y = 6.1\pi$ mm•mrad
$\Delta p/p = \pm 0.31\%$

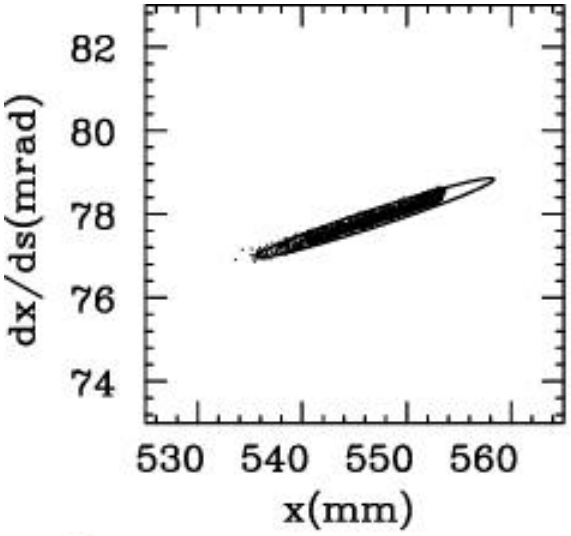
beam hit rate on ESS wires

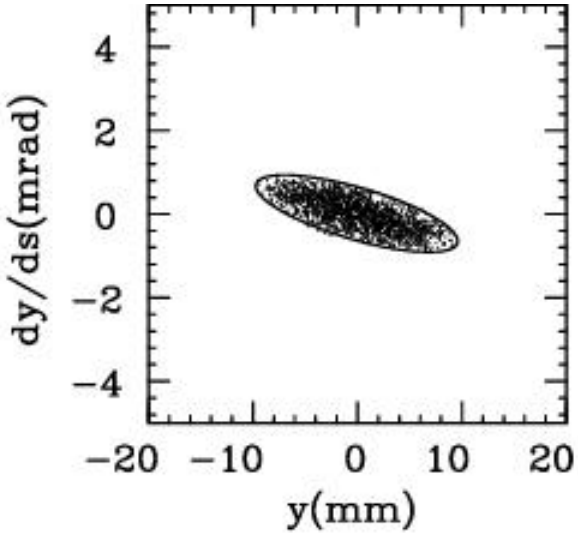
1.0% @50GeV

1.1% @30GeV



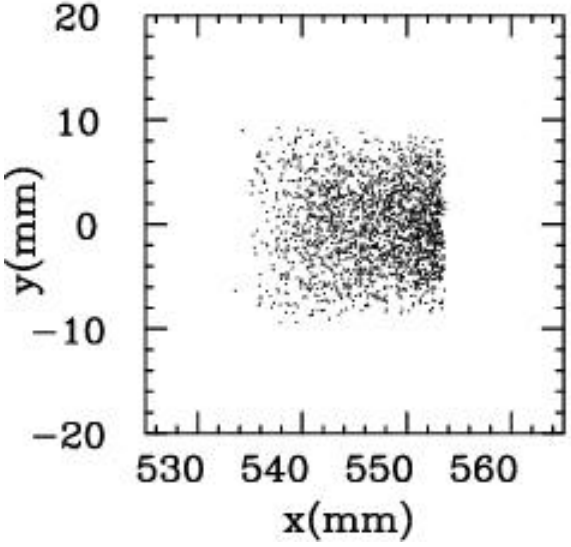
50GeV-extracted beam at ring exit (dynamic bump)





--emittance--
x,y-emit (pi mm mrad)
---
x-6rms-u-emit= 2.478
y-6rms-u-emit= 6.210

---center---
x_cent(mm)= 546.965
xp_cent(mrad)= 77.907
y_cent(mm)= −0.069
yp_cent(mrad)= 0.012



-twiss parameter-
betax(m)= 52.213
alphax= −4.253
betay(m)= 15.007
alphay= 1.025

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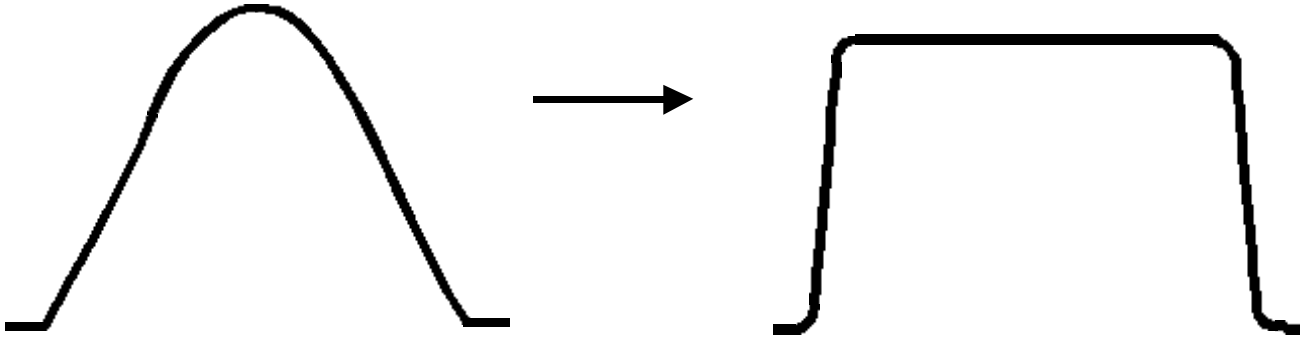
tri0061

Spill Shape

As flat as possible

- tune ramping speed is changed at nonlinear pattern
- feedback system: spill monitor+analyzer
  and extra-quadrupoles



constant tune ramping speed

Spill Structure

is modulated by ripples of

- lattice focusing quadrupole P.S.
- lattice dipole P.S.
- sextupoles P.S.

- Ripples of IGBT - P.S. for Q,D,SX magnets
  $<1x10^{-6}$,f=8 or 16KHz
- Feedback system: spill monitor+analyzer
  and air core - quadrupoles

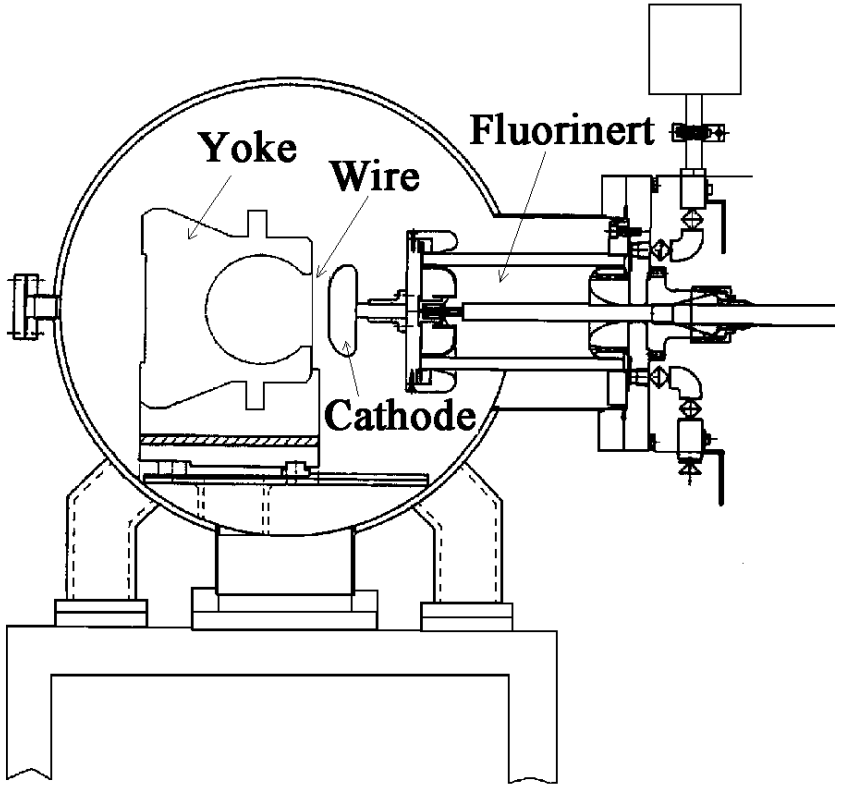
ESS

spec. 170kV/25mm (6.8MV/m), eff. thickness 100μm, L=1.5m

R&D ESS

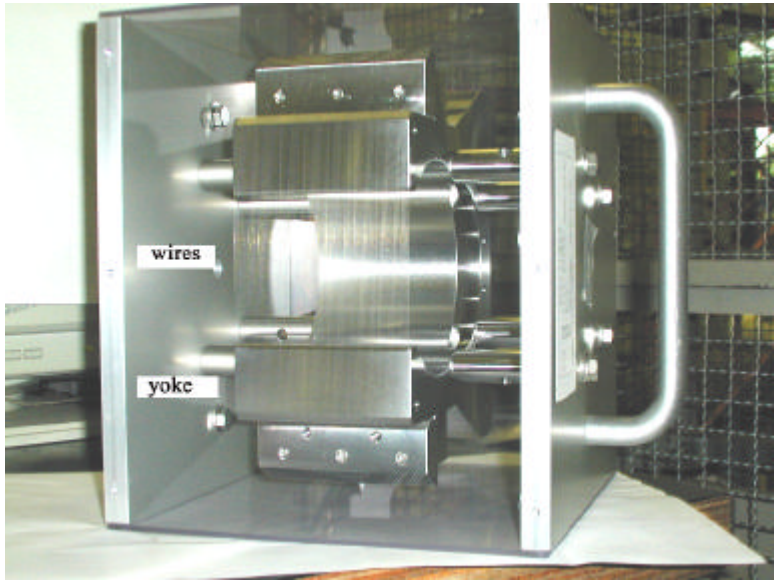
L=0.7m, wire thickness 80μm
237kV/25mm gap, A479(99%)
broken by discharge

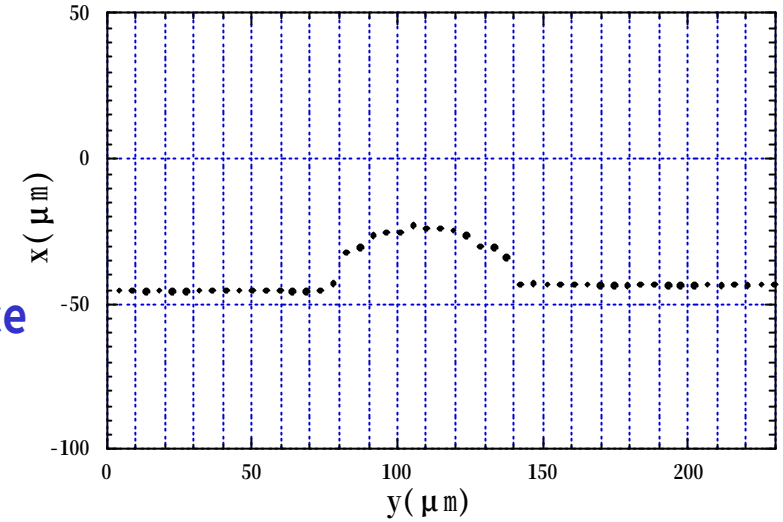
→KP-999(99.9%), 20mm longer
Now testing

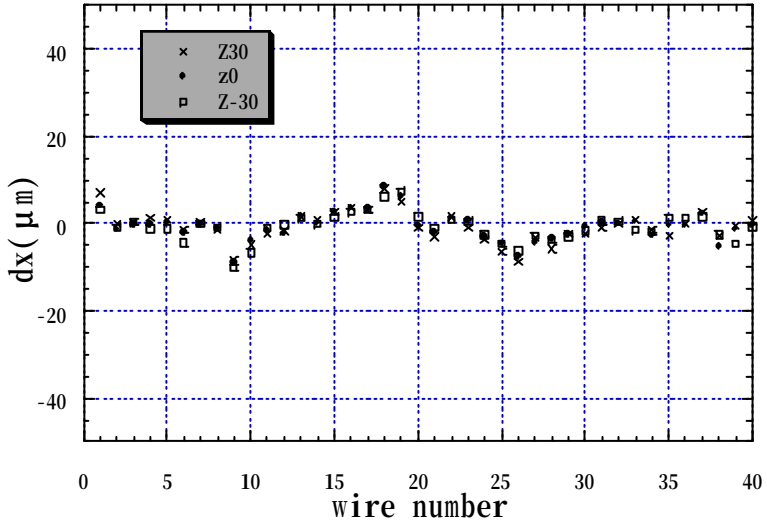


Measurement of Wires Alignment by laser focus displacement meter

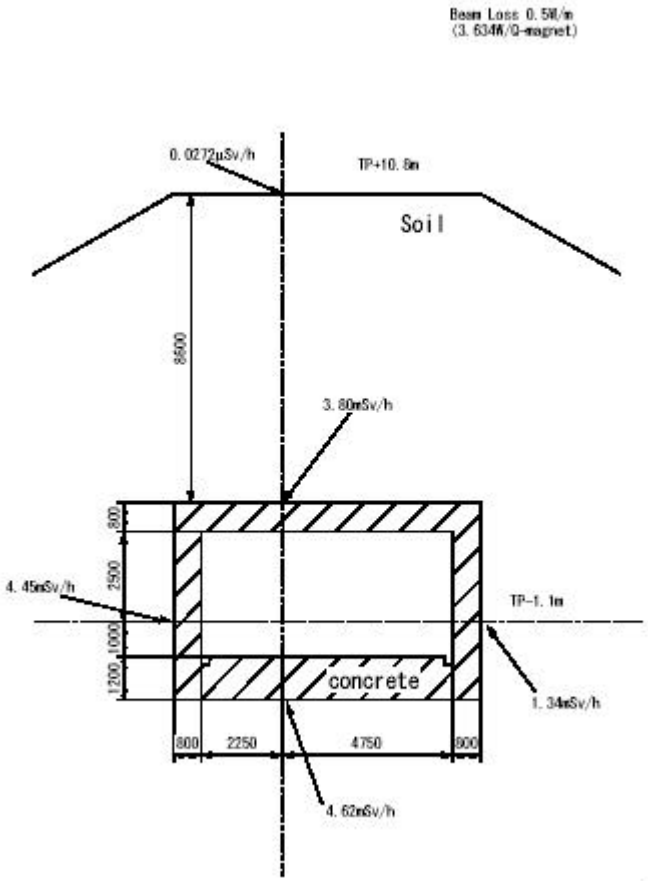
- Measured alignment error (a test machine) →±15μm
- Alignment error < ±10μm is possible by careful machining of surface to determine alignment



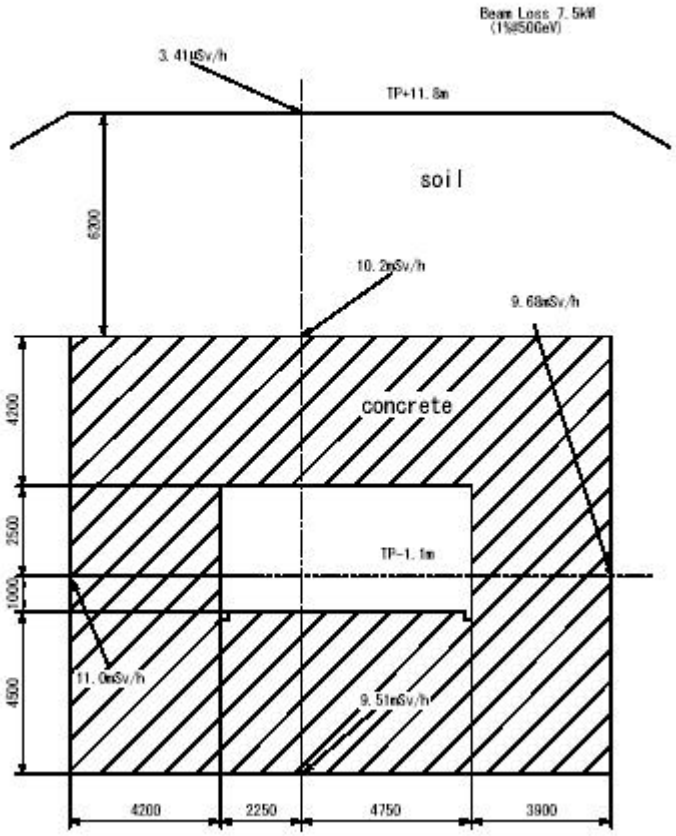




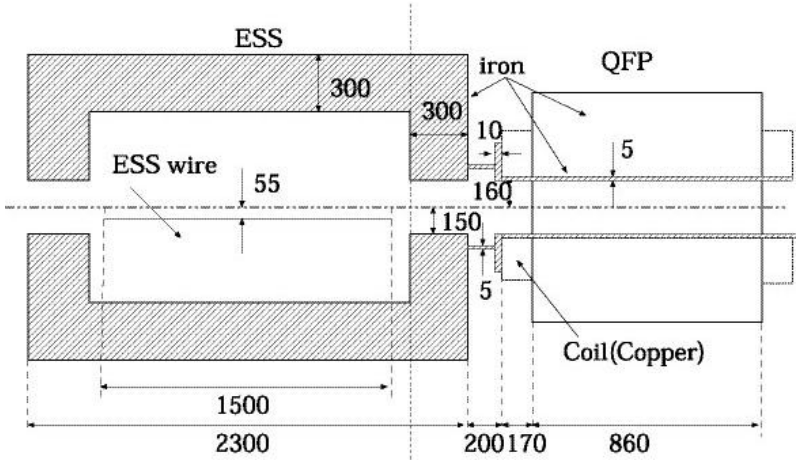
Straight Section

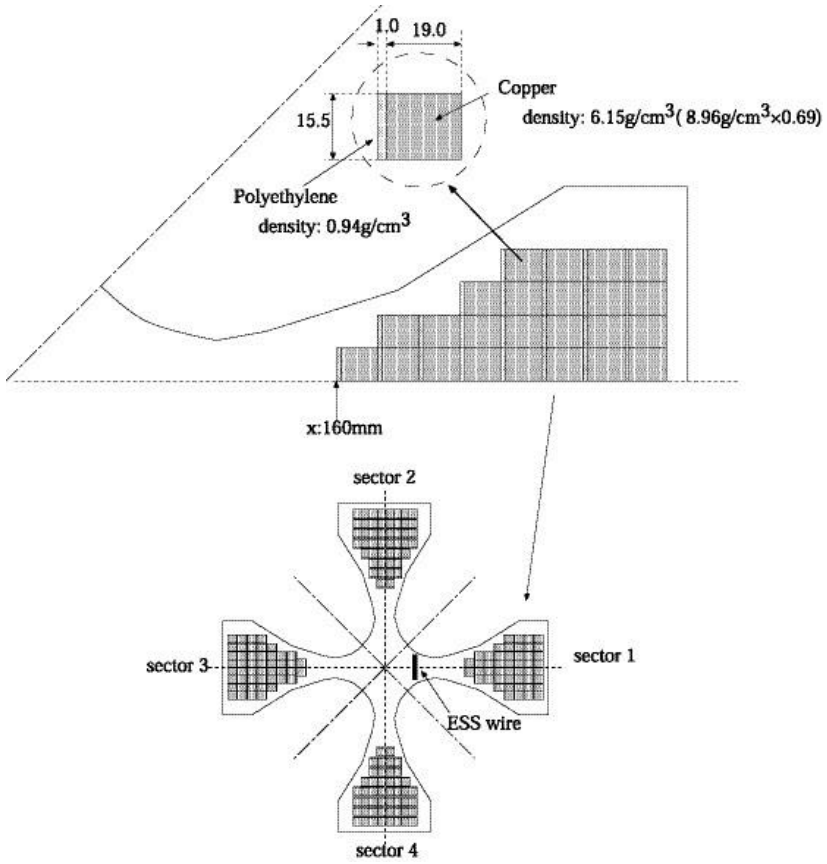


Slow Extraction



Absorption dose in the Q-magnet (QFP) just after the ESS by MARS





Coil insulation: polymid

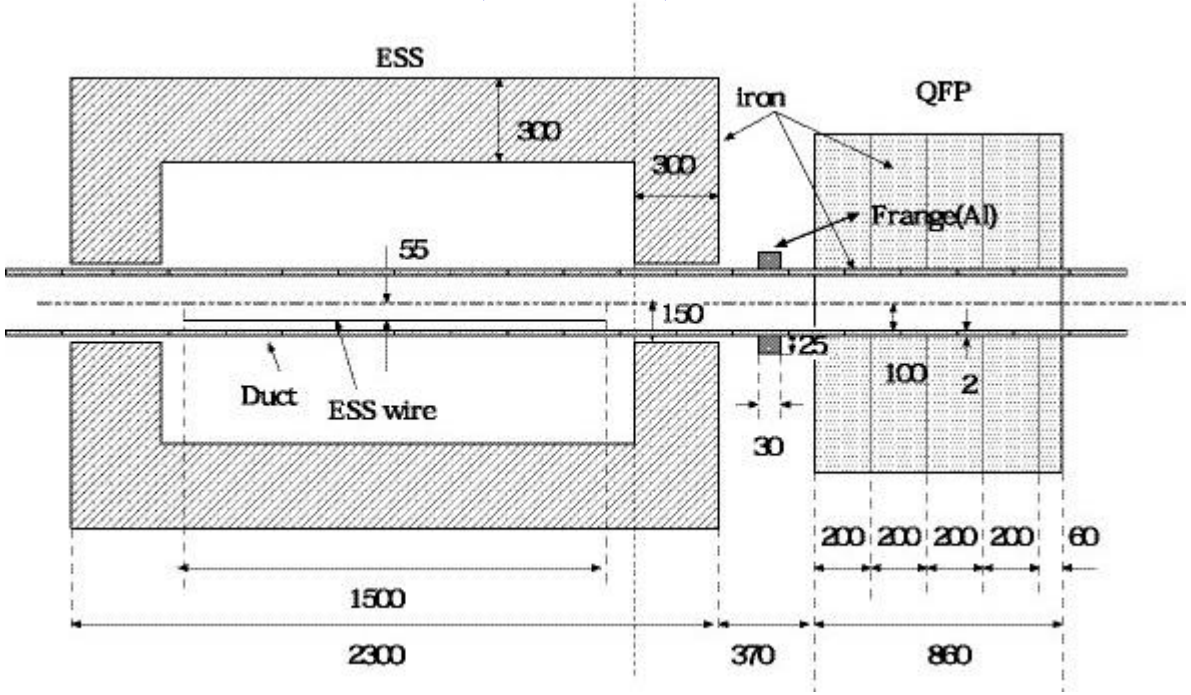
1% hit on the wires

5000h/y operation

~16MGy/year

life time ~25years

residual dose around the ESS (MARS)



30day operation
+1day cooling

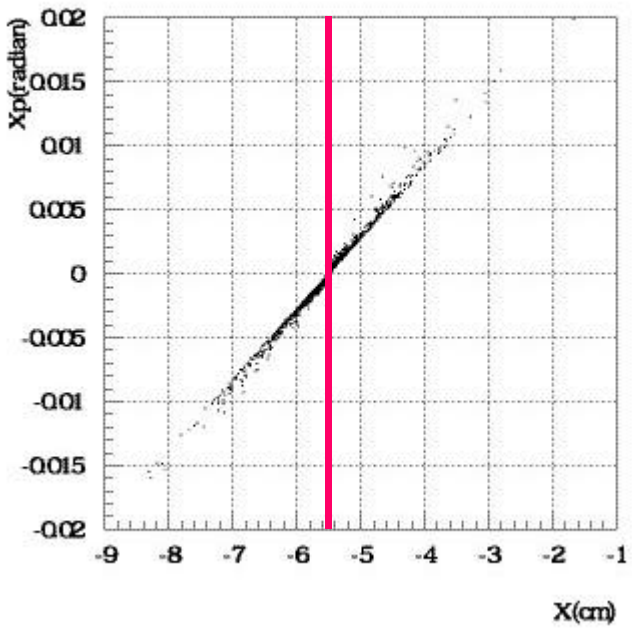
side of ESS:	max 6mSv/h
SUS-duct:	max 150mSv/h (Ti duct :1/3 of SUS)
side of QFP:	max 15mSv/h
inside of QFP:	max 250mSv/h

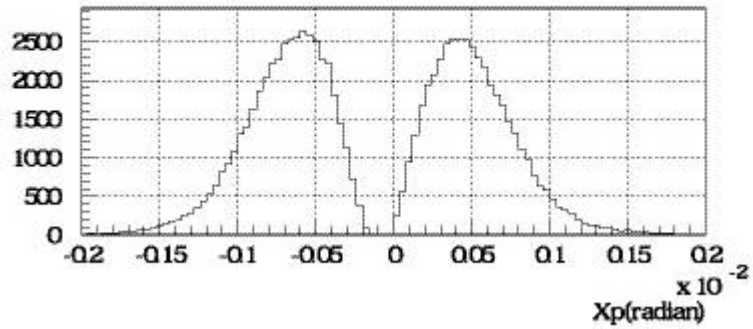
Concrete or marble shielding ??

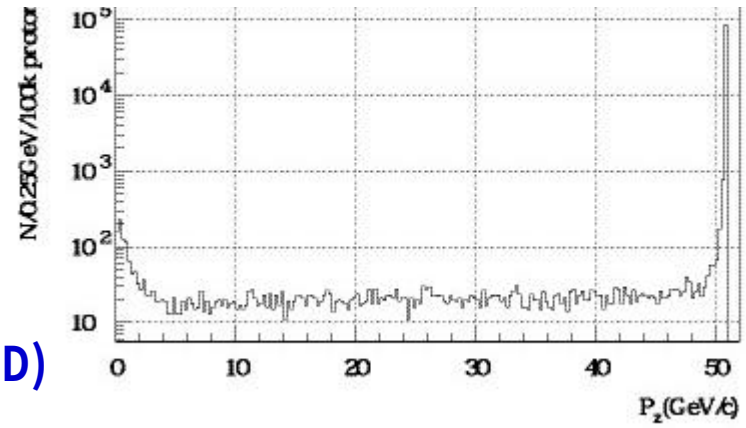
remote connection-disconnection system for vacuum flange

Protons scattered by the ESS wires

MARS







Scattered protons (MARS → SAD)

1. Loss map in the ring
2. circulating and extracted → hallo
3. Effective collimating (crystal collimator?)

EP instability

(Coasting Beam)

neutralization factor= $\lambda e / \lambda p$

KEK Ohmi

Wake field induced by electron-cloud
→Keil-Schnel criterion
→threshold neutralization factor
(λp, slippage, $\Delta p / p$)

AGS booster	0.15	observed
AGS	0.026	not observed
PSR	0.025	observed
50GeV-MR	0.0021	??
MI	0.00055	??

Spill Modulation

- Observed at AGS slow extraction
- Longitudinal phenomena?
- Does it occur also at 50GeV MR?

- 50GeV MR
  zero x-chromaticity
  (x-tune is independent of momentum)
  below transition

- If occurs, VHF cavity will be introduced
  (finite x-chromaticity)

First Phase of MR Operation

- 40GeV (fast extraction)
- 30GeV (slow extraction)

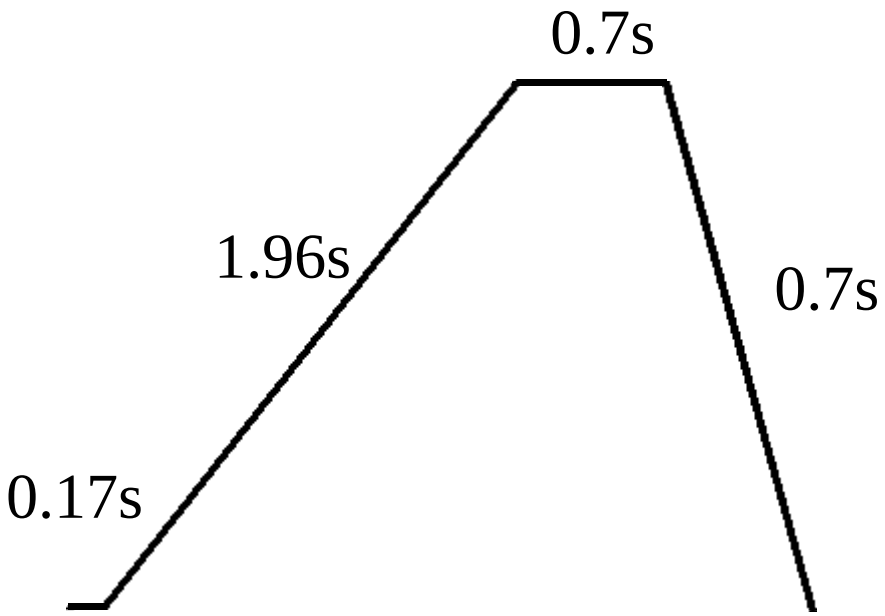
- 180MeV linac

Original: RCS (h=2, 2bunches) → MR (h=9, 2bunches x 4)

Proposed:RCS (h=2, 1bunch) → MR (h=18, 1bunch x 15)

Acceleration Patterns and Beam Power(1)

harmonic=9(8 bunches)

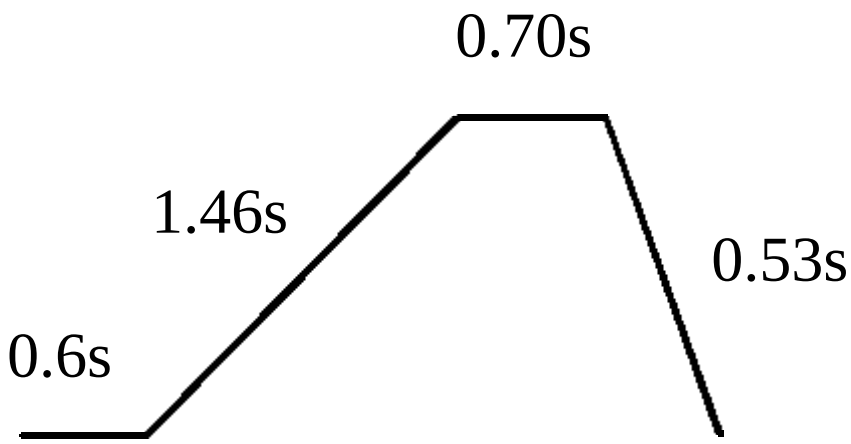


repetition period 3.53s
Duty=20%

- **50GeV original pattern**
  750 kW (400MeV Linac)

Acceleration Patterns and Beam Power(2)

harmonic=18 (15 bunches)



repetition period 3.29s
Duty=21.3%

- **30GeV(180MeV Linac)**
  905 kW x α

Much longer flat top is possible!!
Flat top 2s → duty=43.6%

α :relative beam power of RCS

Slow Extraction of High Intensity Proton Machine

	energy (GeV)	ppp/T (10^{13}/s)	current (μA)	power (kW)	loss (%)	loss power (KW)
KEK PS(1/2)	12	0.4/4	0.16	1.92	20	0.38
CERN PS(1/3)	23	2/2	1.6	37	5	1.84
AGS(1/3)	25	7/5.1	2.24	56	2-4	1.1-2.2
MI(1/2)	120	3/2.9	1.66	200	2.2	4.4
50GeV(1/3)	50	33/3.5	15	750	1	7.5