Slow Extraction Design of J-PARC Main Ring

J-PARC: Japan Proton Accelerator Research Complex

KEK Acc. Lab. Masahito Tomizawa

- J-PARC facility
- Slow Extraction Scheme of 50GeV MR
- Simulation of Extracted Beam
- Loss study of particles scattered by ESS wires
- New idea to reduce loss by scattered particles

J-PARC in Tokai

中央制御棟（30日、竣功）

3GeVシンクロトロン建設地の掘削工事

50GeVシンクロトロン建設地の杭工事

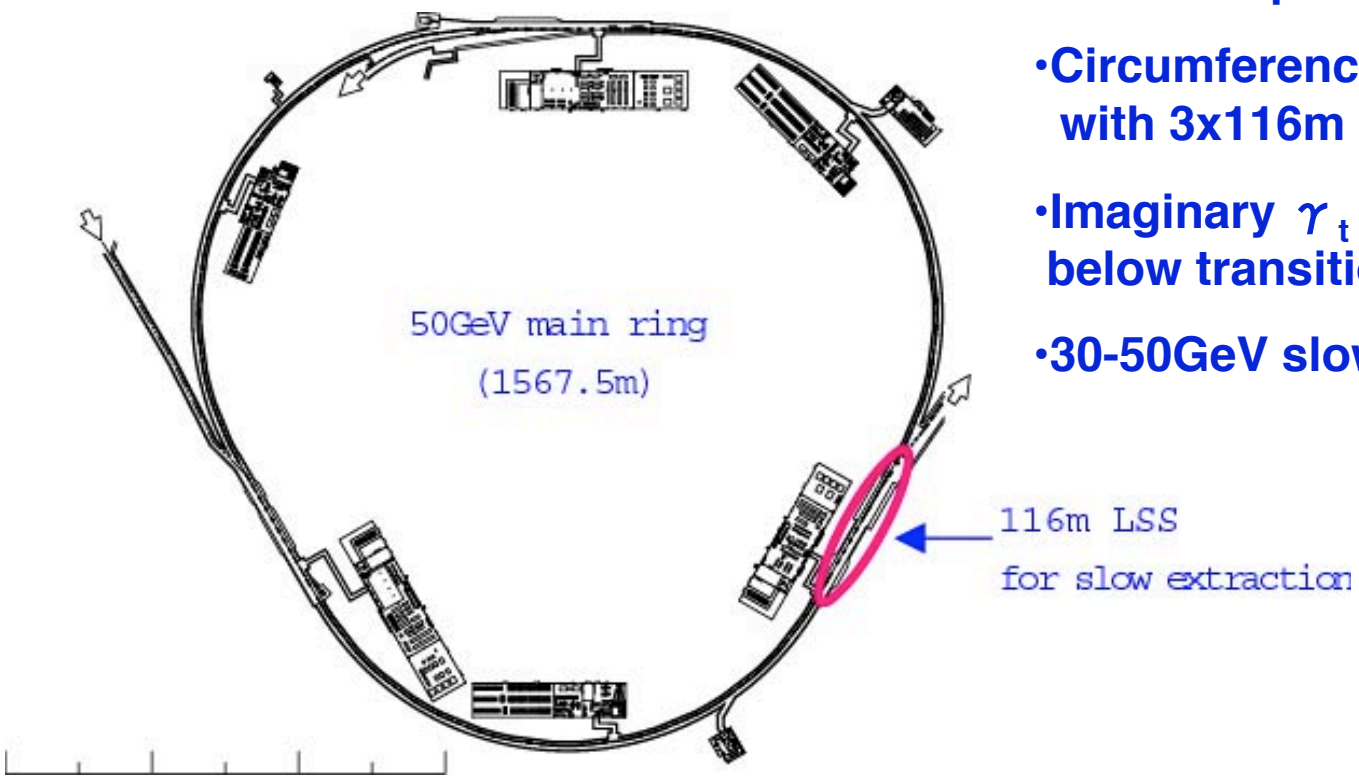
リニアックトンネル部の建設工事

コンクリート打設工事

50GeV-MR Schedule

- spring in 2006
  tunnel and buildings construction
- Middle in 2007
  beam commissioning
- March 2008
  slow extraction commissioning

50GeV-MR



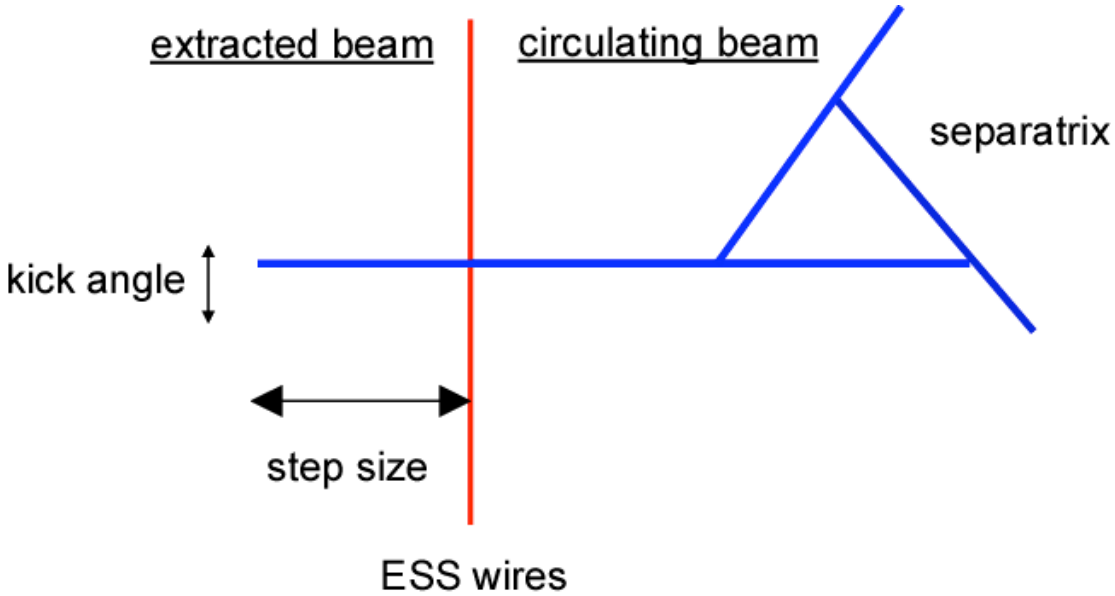
- 3.3×10^{14} protons per pulse(15μA)
  full beam power : 750kW @50GeV
- Circumference 1567.5m
  with 3x116m long straight sections
- Imaginary γ_t lattice
  below transition also for top energy
- 30-50GeV slow-extraction energy

50GeV-MR Slow Extraction

- full beam power : 750kW @50GeV
  → beam loss: as possible as small
  <1% (7.5kW) level
  radiation safety problem
- 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)

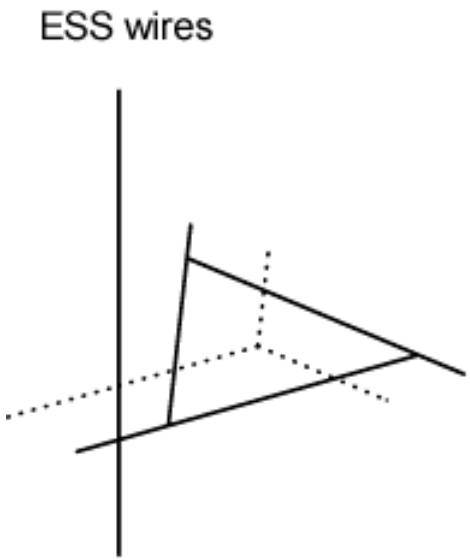
- ESS is placed between two focusing Q-magnets
  → large βx(=37m), small αx(=0.02)
  → 20mm step size @ ESS
  70π mm•mrad (acceptance of 81π mm•mrad)



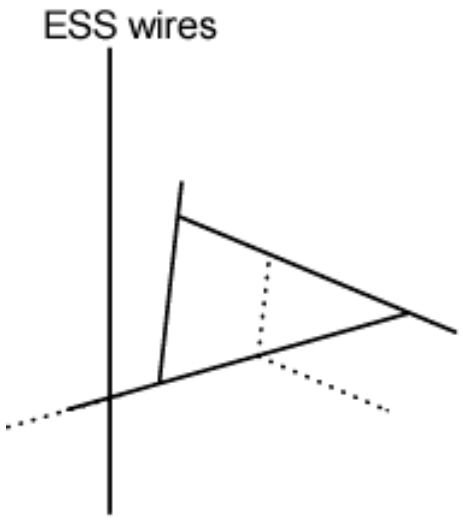
Slow Extraction Scheme of 50GeV MR (2)

- 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



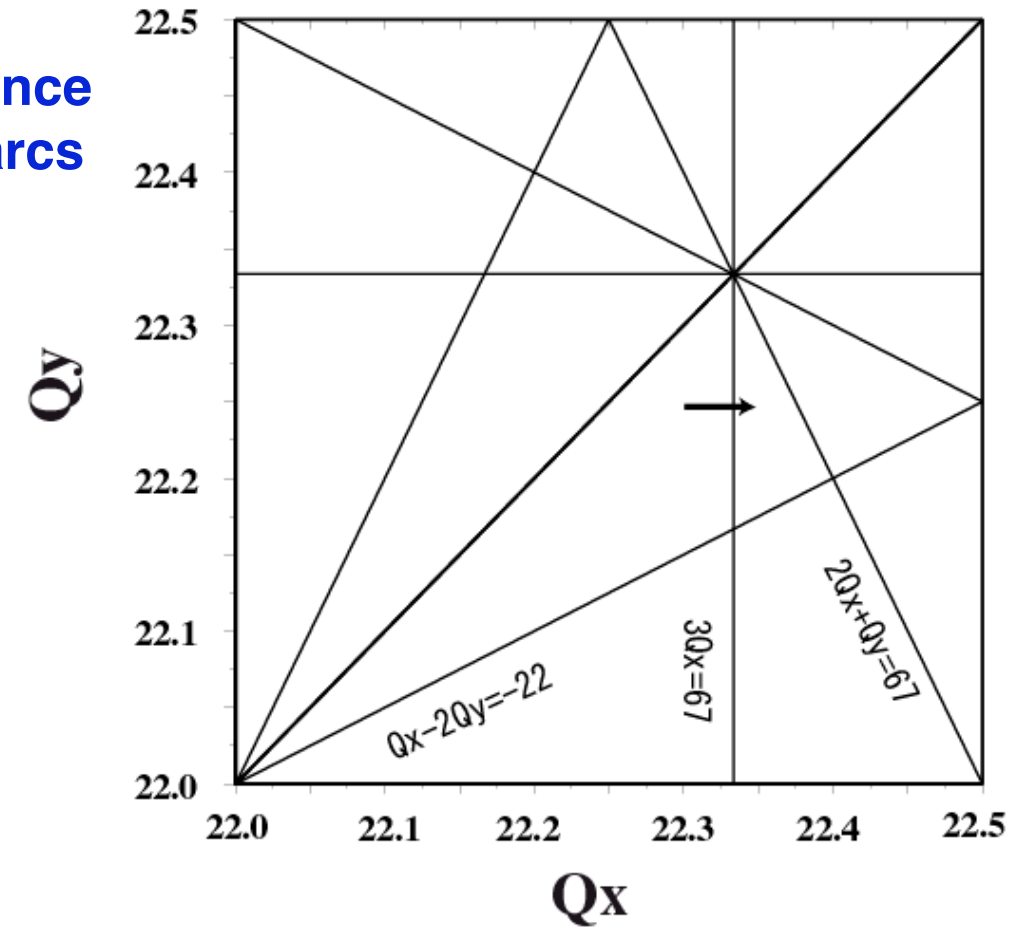
dynamic bump

Method to push the beam to the resonance

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

- Qx=67/3

- Qy=22.25
  Qy=20.78



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

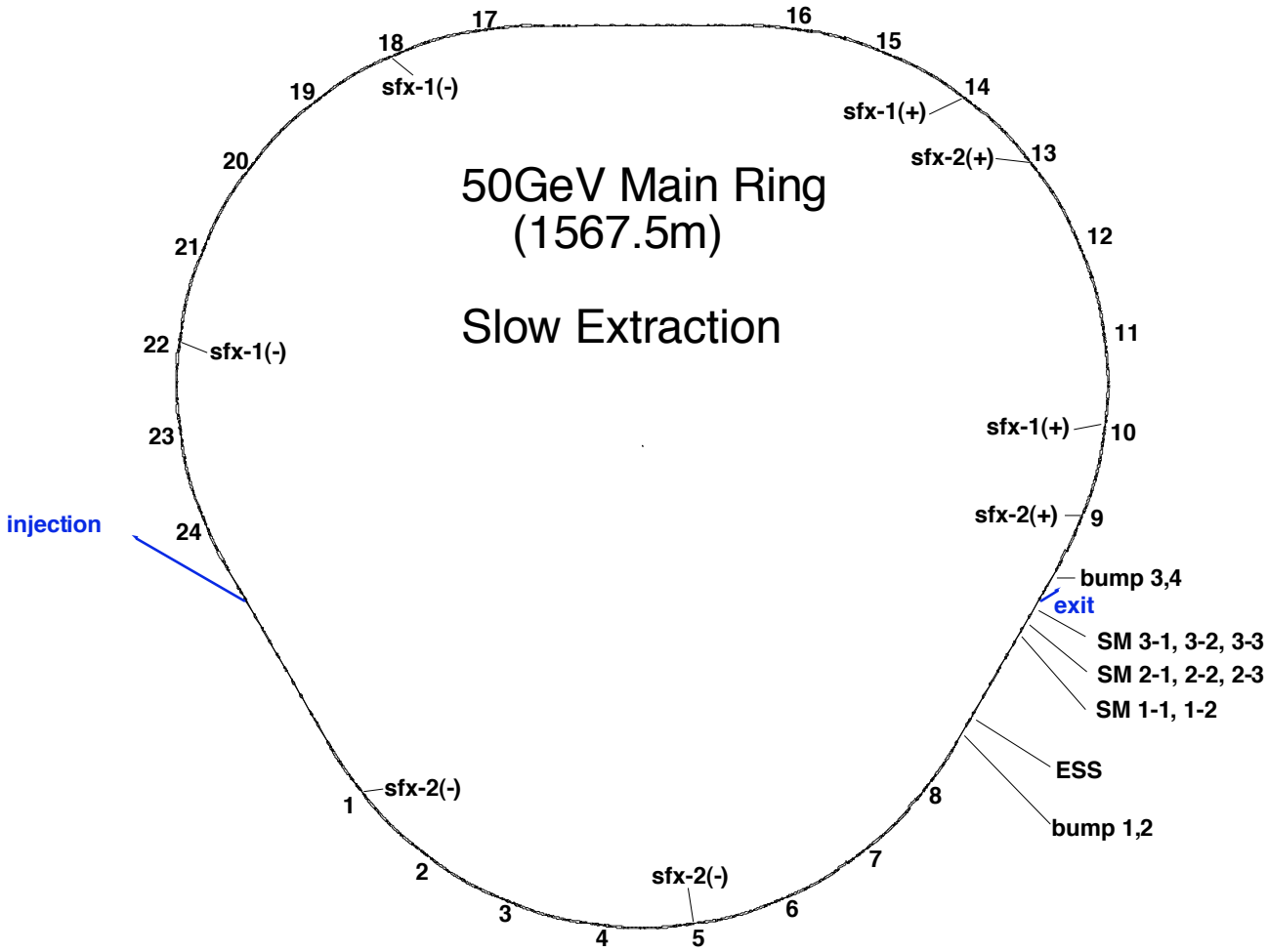
	field (T)	length (m)	V-gap (mm)	thickness (mm)
SM1(2 units)	0.114	1.5	45	1
SM2(2 units)	0.374	1.5	60	5
SM3-1	1.35	2.3	60	30
SM3-2	1.64	2.3	50	>30
SM3-3	1.64	2.3	50	>30

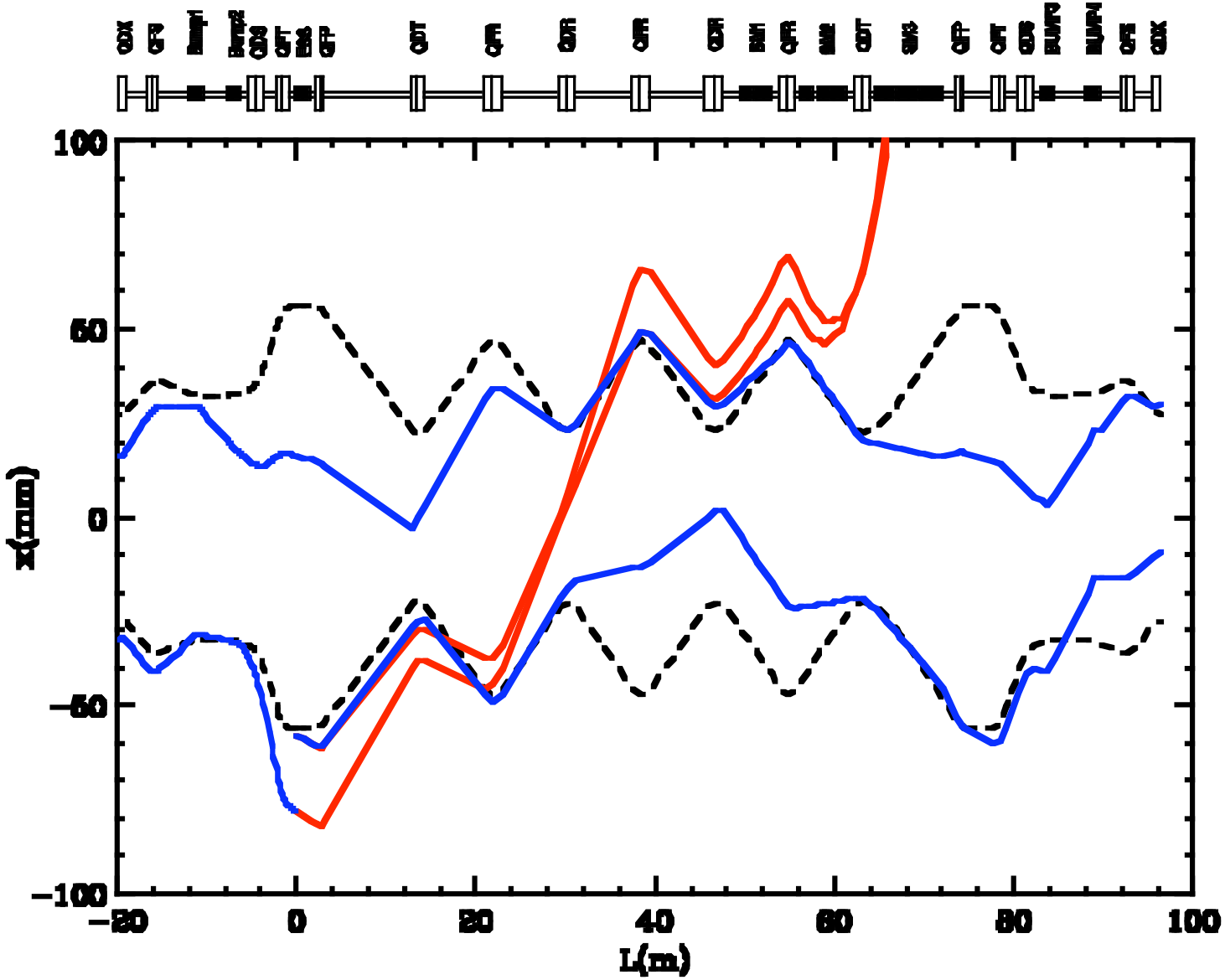
bump magnets

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

sextupole magnets

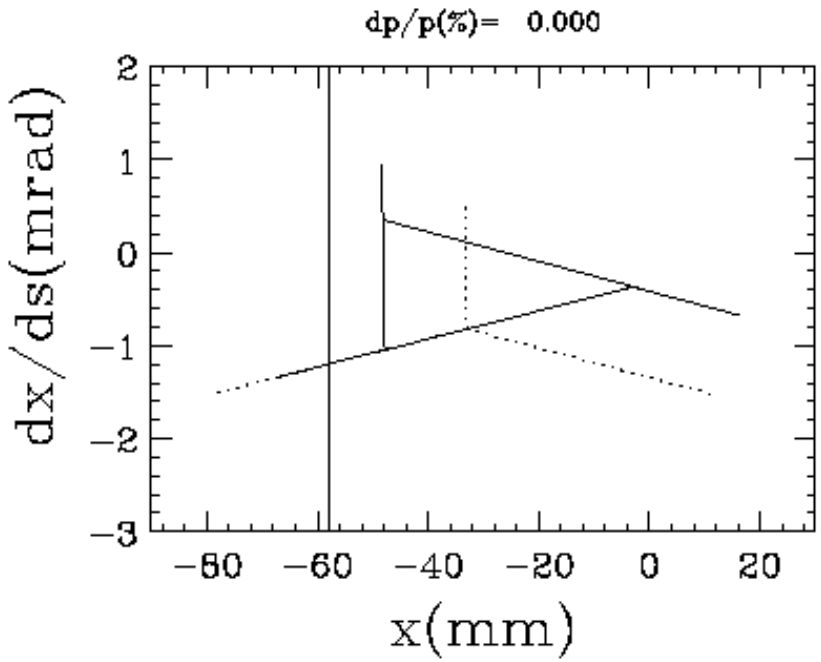
family1: 4, family 2: 4


50GeV Main Ring
(1567.5m)
Slow Extraction
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
sfx-1(-)
sfx-1(+)
sfx-2(+)
sfx-1(-)
sfx-1(+)
sfx-2(+)
bump 3,4
exit
SM 3-1, 3-2, 3-3
SM 2-1, 2-2, 2-3
SM 1-1, 1-2
ESS
bump 1,2
sfx-2(-)
sfx-2(-)
injection

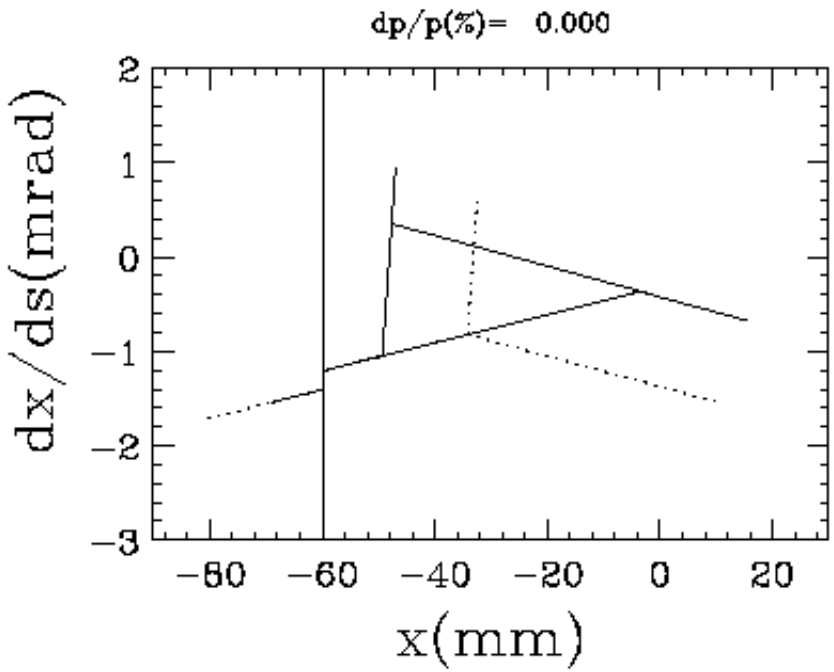

100
50
0
−50
−100
x(mm)
−20
0
20
40
60
80
100
L(m)

ESS

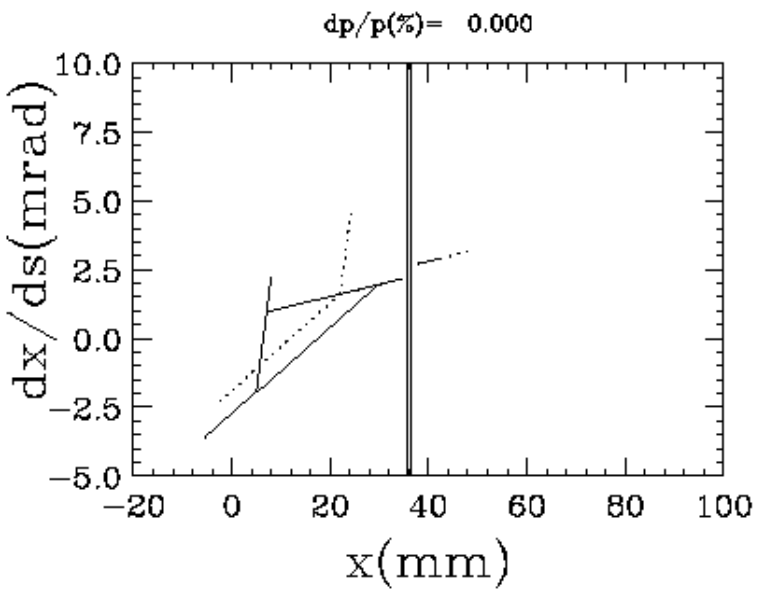
entrance



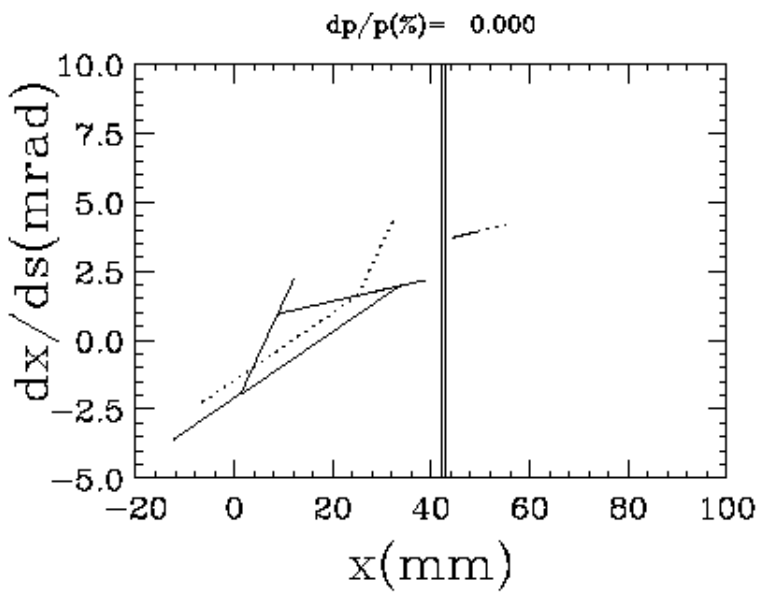
exit



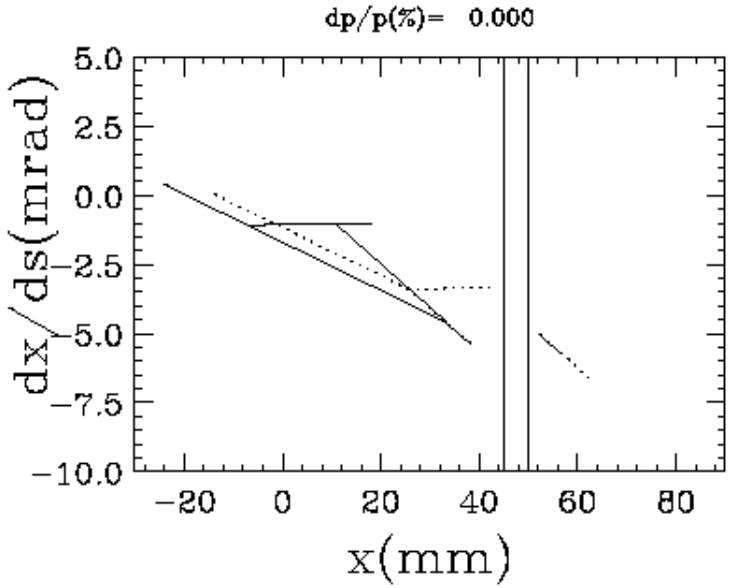
SM-11


dp/p(%)= 0.000
dx/ds(mrad)
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−20
0
20
40
60
80
100
x(mm)

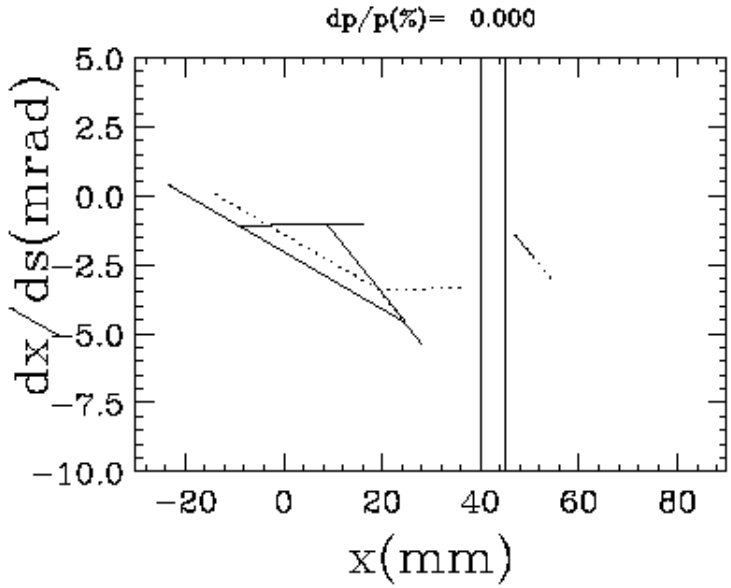
SM-12


dp/p(%)= 0.000
dx/ds(mrad)
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−20
0
20
40
60
80
100
x(mm)

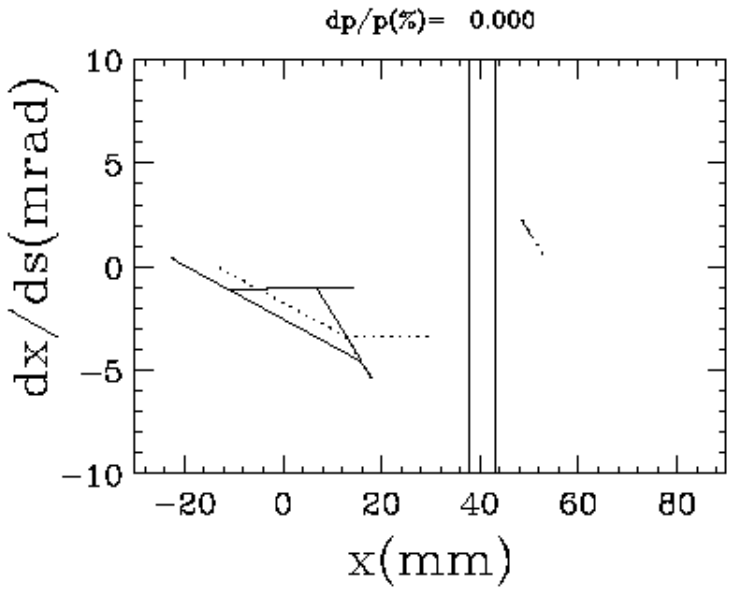
SM-21



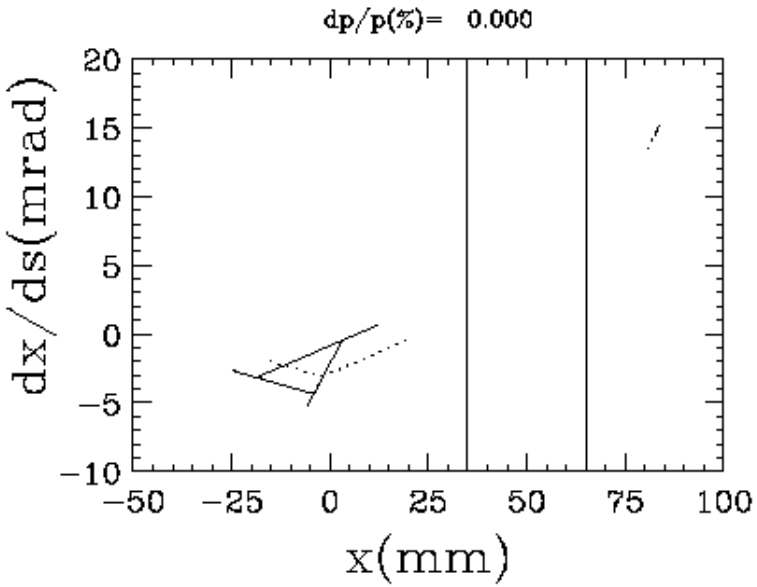
SM-22



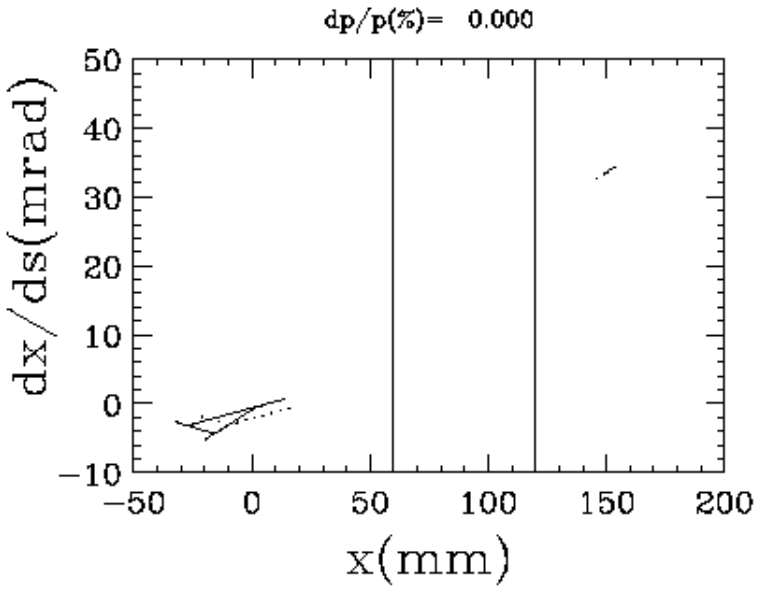
SM-23



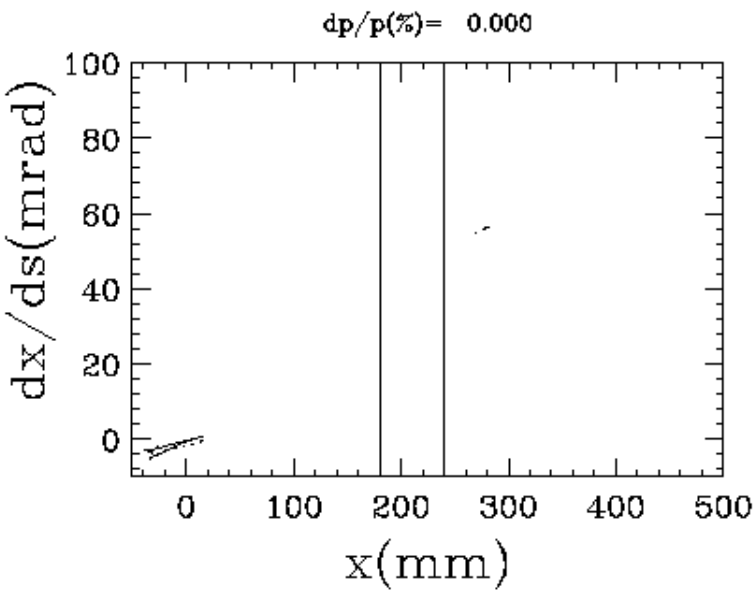
SM-31



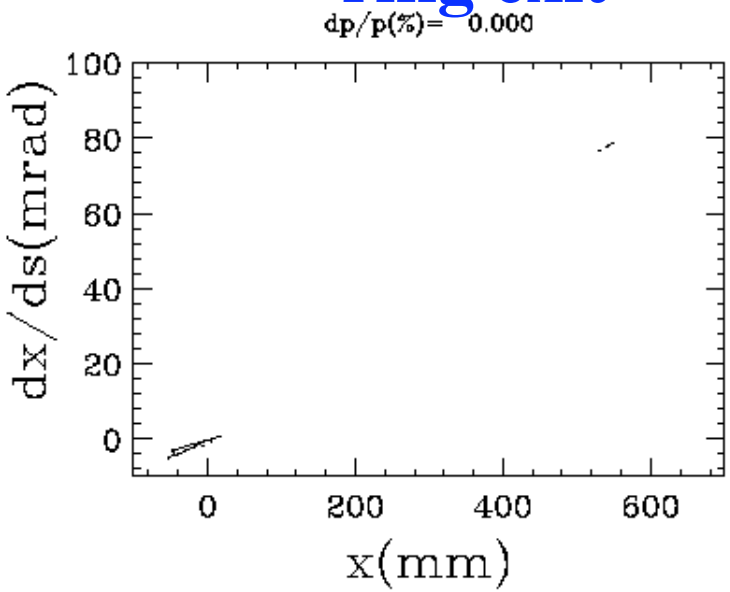
SM-32



SM-33

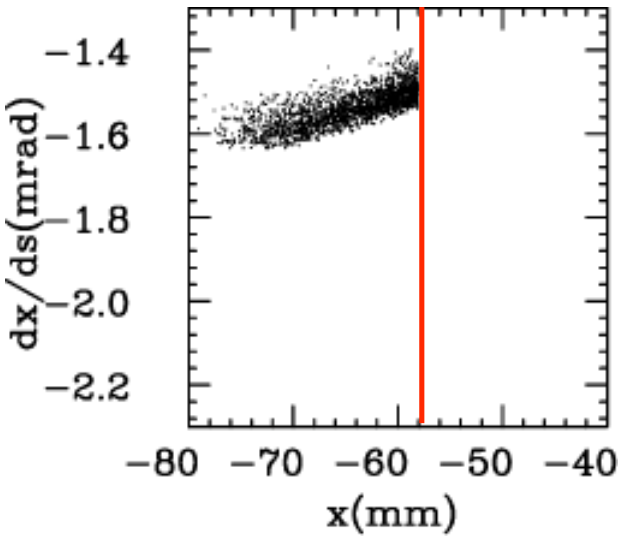


ring exit



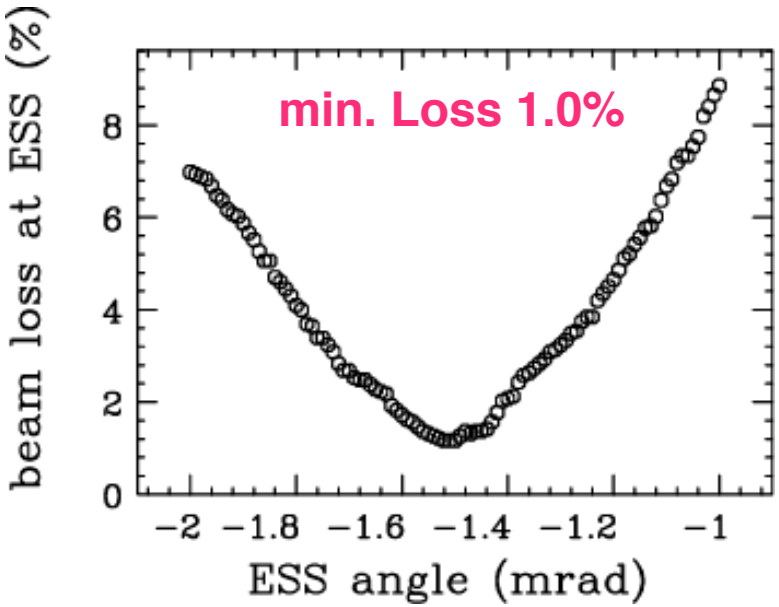
50GeV-extracted beam at ESS

dynamic bump



Qv=22.25 tri0061_090

beam hit rate on ESS wires



Circulating Beam Parameters

ε_x=6.1 π mm•mrad
ε_y=6.1 π mm•mrad
$\Delta p/p$=±0.31%

particles hitted at ESS wires

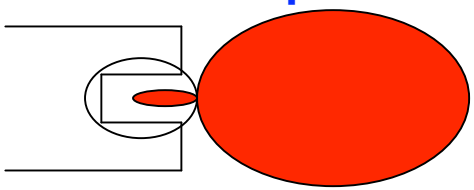
1% (7.5kW) beam hits the wires

Tracking code:

- initial beam condition by MARS
- calculates losses at ESS, SM and vacuum chambers with real shape
- tracked up to ring exit
- two x-y collimators (downstream from ESS)

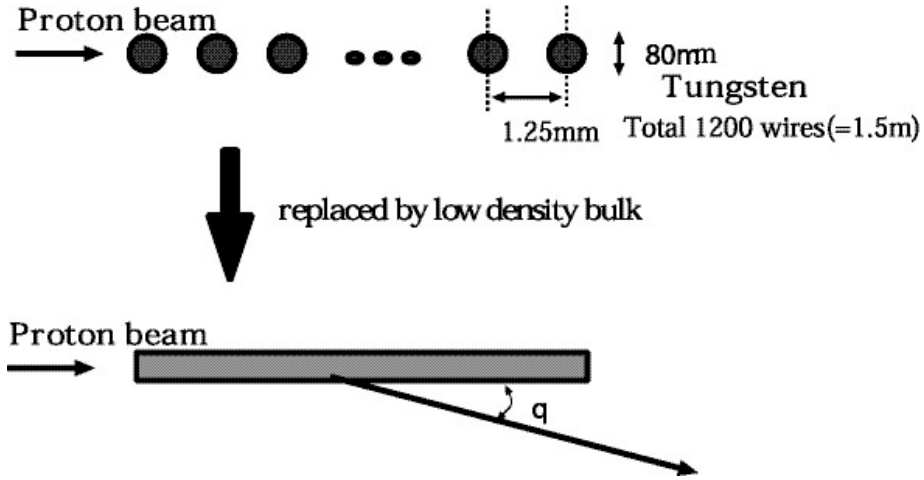
  collimate halo of scattered particles

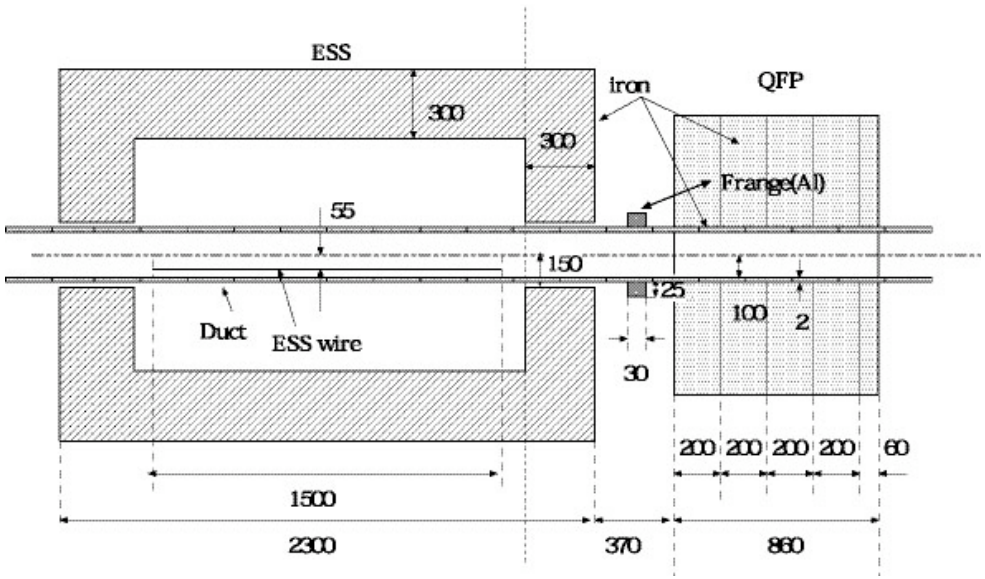
  do not collimate main extracted beam



MARS Simulation Model of the ESS

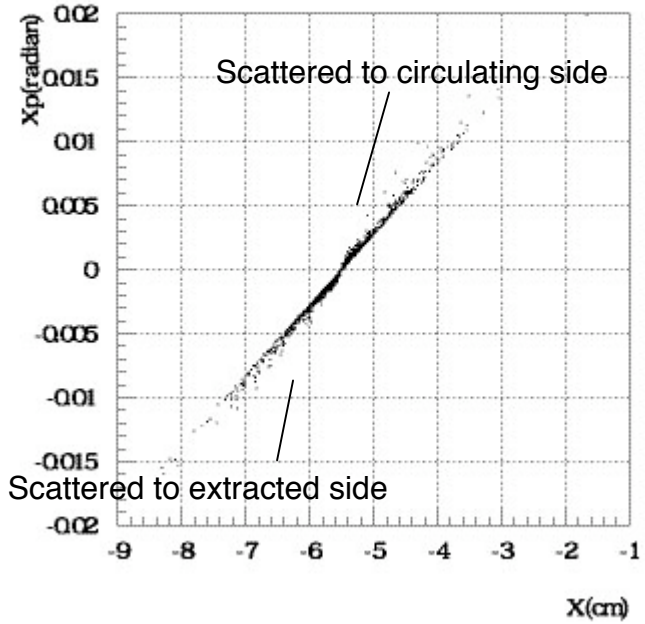
Uniformly distributed beam
(H:80□m, V:20mm)
hits the ESS wires normally

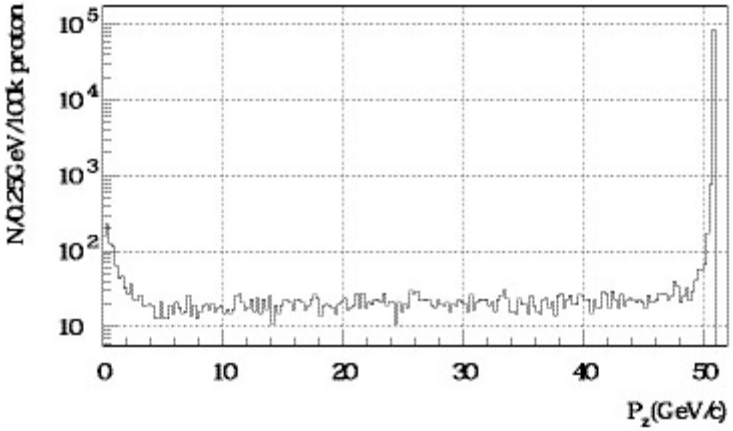


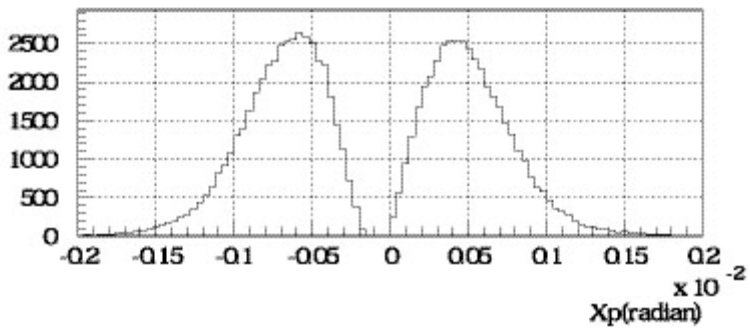


Protons scattered at the ESS wires (MARS)

40cm downstream from ESS exit





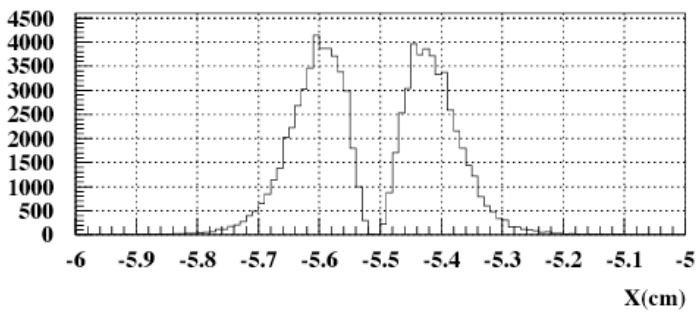


"real loss" = N(hitted p)-N(scattered p)/N

real loss 0.14%=1kW

remaining protons

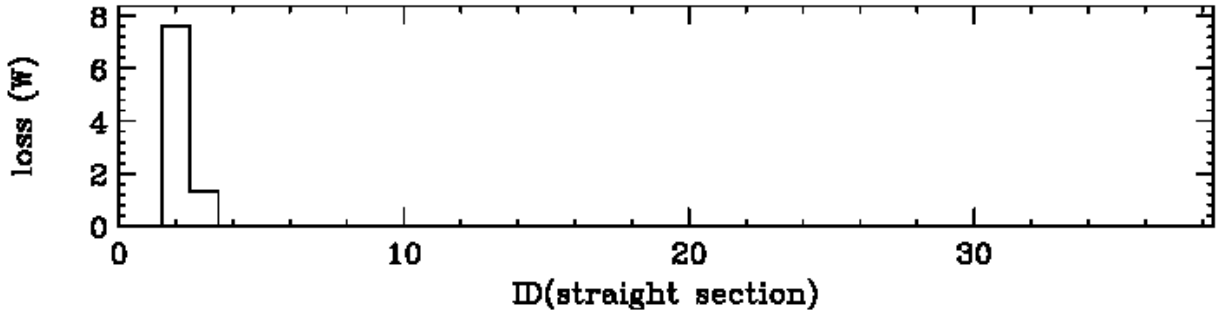
- **scattered to extracted side (one pass)**
- **scattered to circulated side (circulate in the ring)**

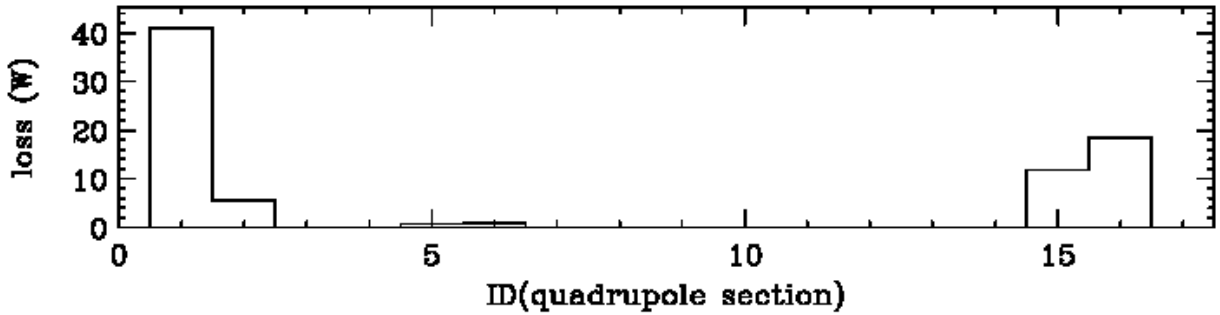


Loss of particles scattered to extracted side

sca0109_1_031

ID: counted from ESS





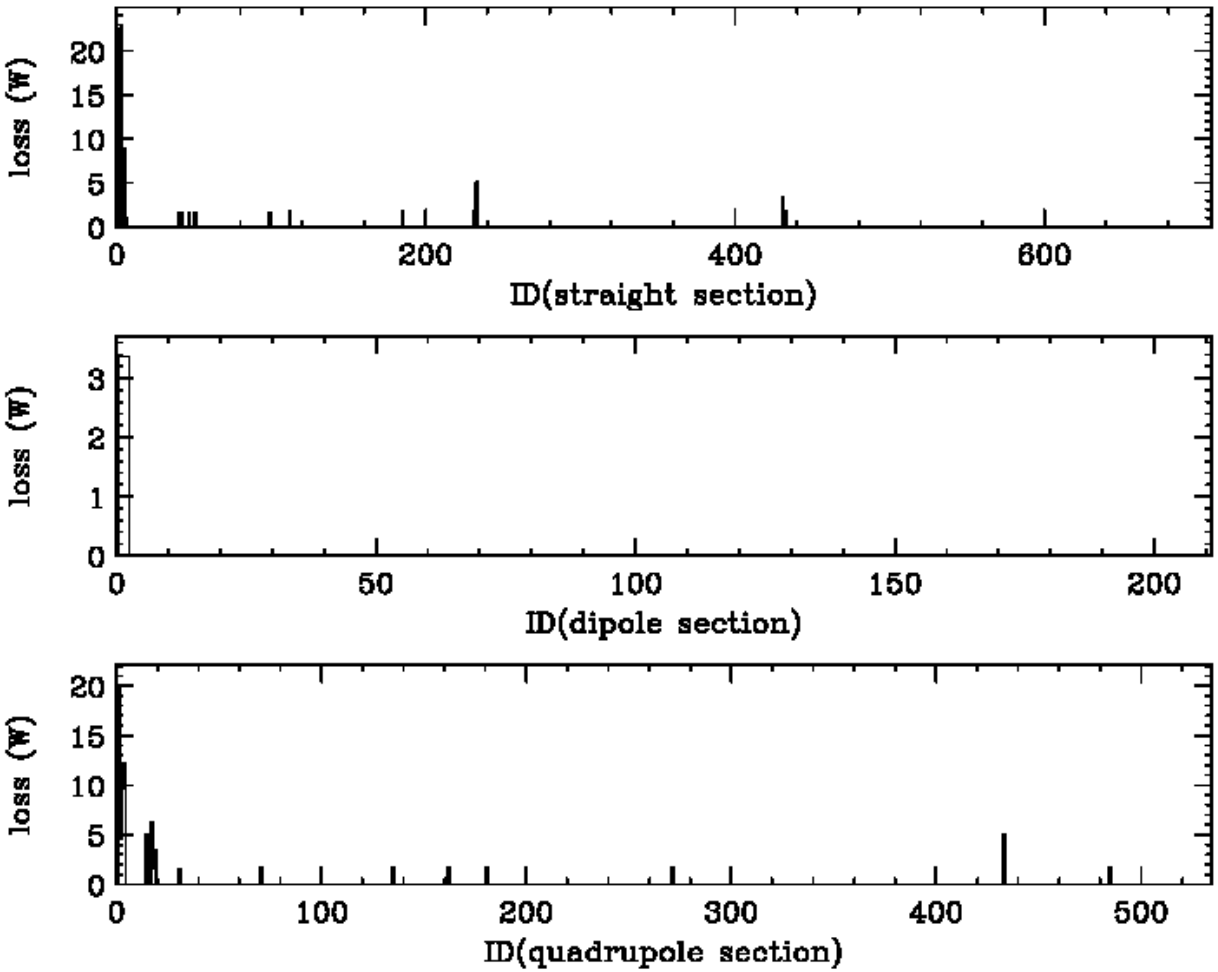
hit rate (1%=7.5kW)

Slow collimator-1	**220W**
Slow collimator-2	**170W**
SM	**0W**
Total hit rate	**0.49kW (3.375kW)**

Loss of particles scattered to circulated side

Sca0108_8_031

ID: counted from ESS



hit rate (1%=7.5kW)

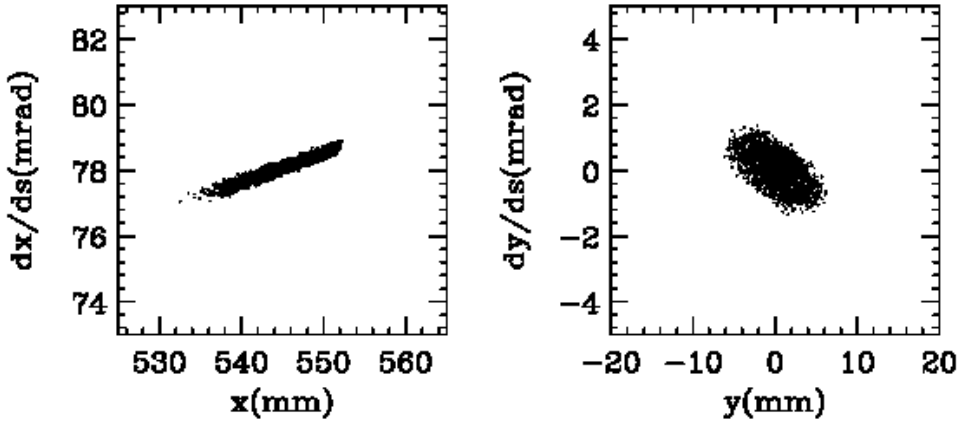
Injection collimator	**0W**
Injection collimator	**42W**
Slow collimator-1	**396W**
Slow collimator-2	**366W**
ESS	**378W**
SM1-1	**261W**
SM2-1	**172W**
Total rate	**1.9kW**
	(3.375kW)

ring exit

Main extracted beam

Sca0110_044

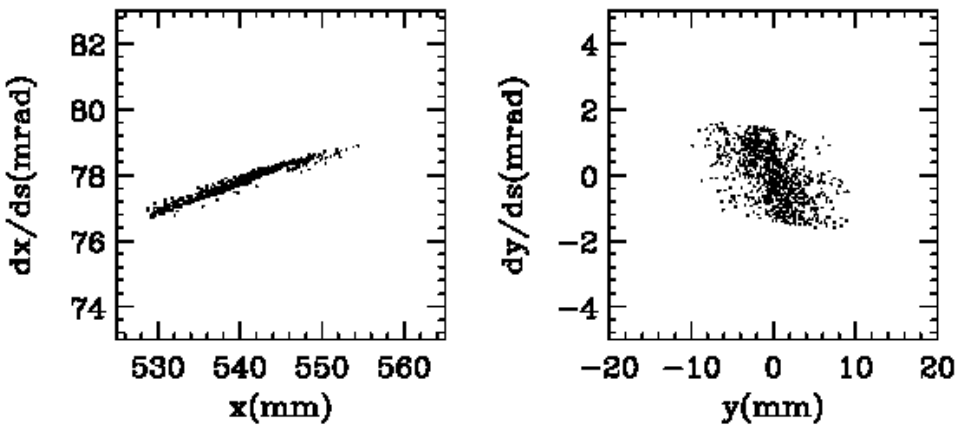
99%



Scattered to circulated side

sca0108 8

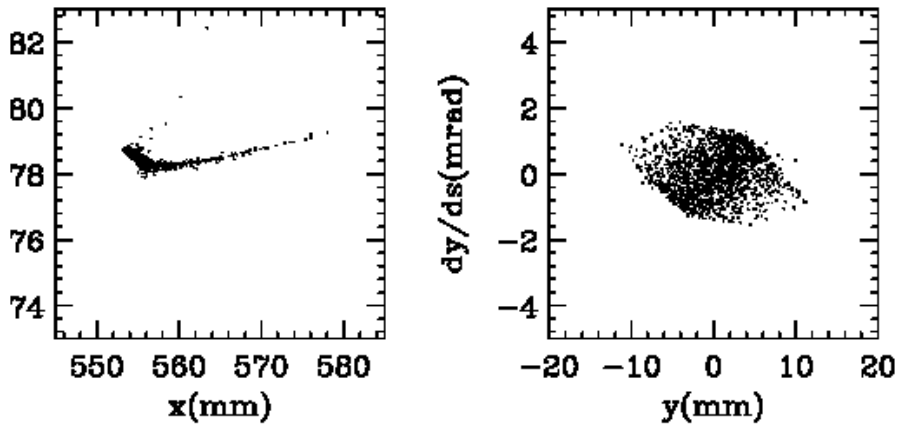
0.20%

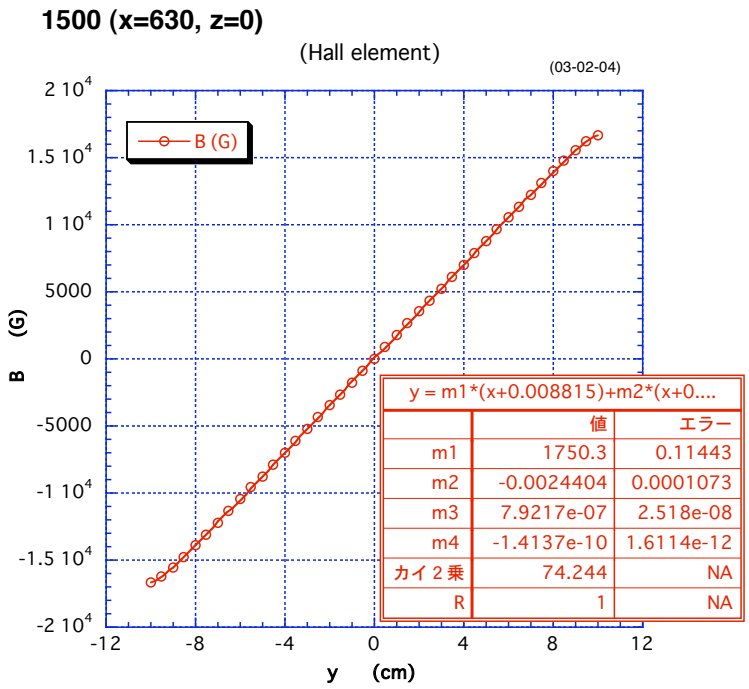


Scattered to extracted side

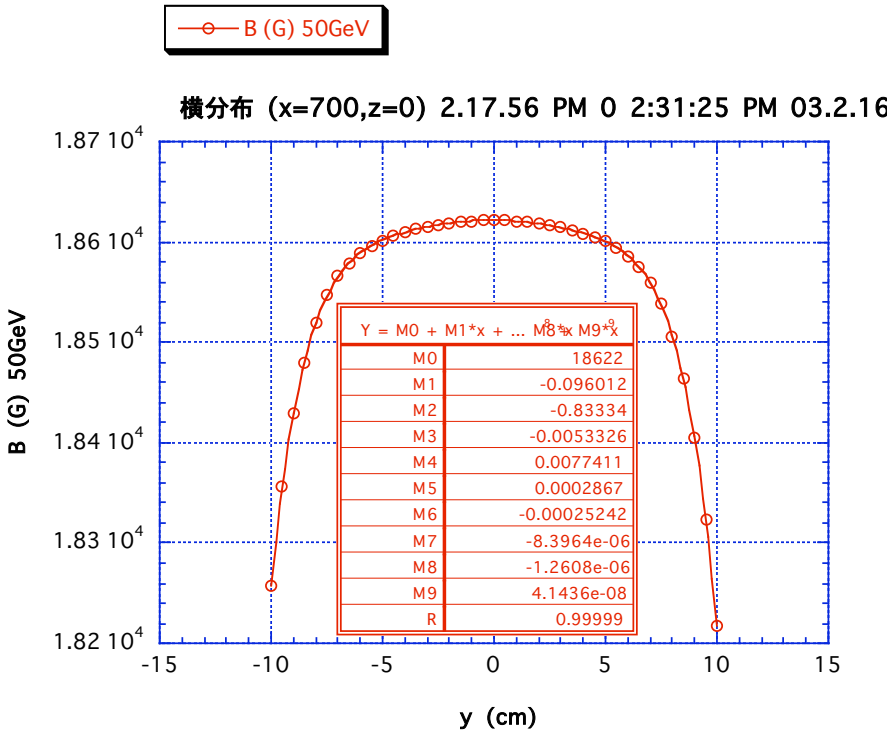
sca0109 1 044

0.38%





y = m1*(x+0.008815)+m2*(x+0....		
	値	エラー
m1	1750.3	0.11443
m2	-0.0024404	0.0001073
m3	7.9217e-07	2.518e-08
m4	-1.4137e-10	1.6114e-12
カイ２乗	74.244	NA
R	1	NA



Y = M0 + M1*x + ... M8*x^8 M9*x^9	
M0	18622
M1	-0.096012
M2	-0.83334
M3	-0.0053326
M4	0.0077411
M5	0.0002867
M6	-0.00025242
M7	-8.3964e-06
M8	-1.2608e-06
M9	4.1436e-08
R	0.99999

Loss summary of scattered particles

○Slow extraction long straight section

		hit rate
ESS		7.5kW (real loss 1kW)
Slow collimator 1		0.6kW
Slow collimator 2		0.6kW
SM1-1		0.3kW
SM2-1		0.2kW
duct	<30W	(several sections)

○Other LSS、arc. section <0.5W/m

・Loss can be localized at slow extraction LSS
・radiation study and maintenance scenario

in order to decrease beam loss

BNL(AGS) W-foil strip

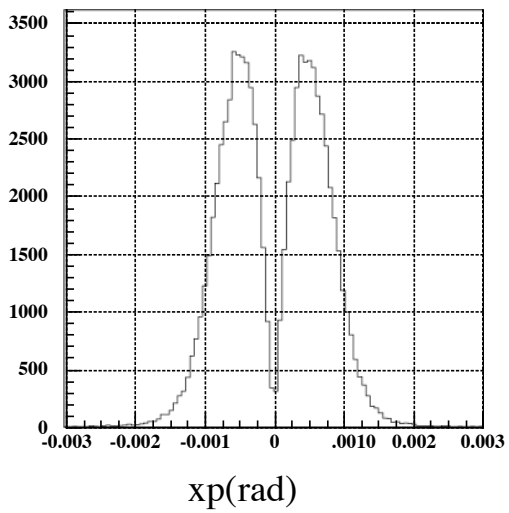
thickness:25μm, width 0.875mm, spacing 3mm?, length 2.3m

Comparison by MARS

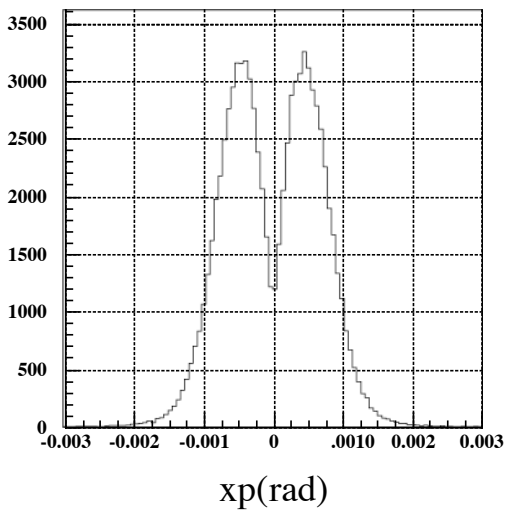
- wires: φ80μm, 1.25mm spacing, 1.5m long
  hit rate 1% "real loss":13611/100000
- strip: 30μm thick, 1mm wide, 3mm spacing, 1.5m long
  hit rate 0.4% "real loss":15217/100000x0.4/1

loss of strip is less angular spread is same

30μm foils



80μm wires



Idea of Scatter＋ESS

Rutherford Scatter with low average mass density

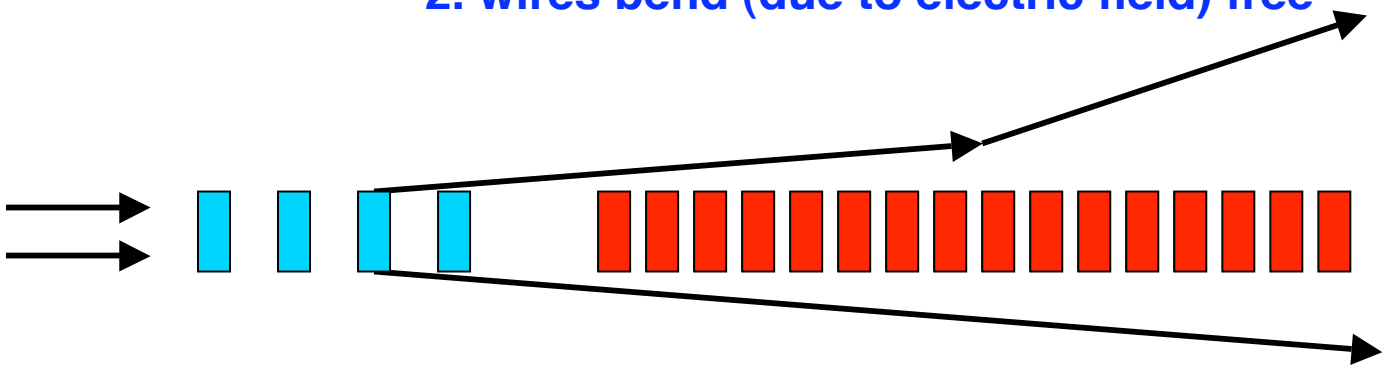
- hitted particles are mainly scattered out, nuclear reaction (radiation) rate is small
- makes low beam density area downstream

--> to get low average mass density

1. choose low density material
2. increase spacing of wires

Scatter without electric field is also effective.

1. stray electric field free
2. wires bend (due to electric field) free



Rutherford scatter

ESS

example

□30□m wires, 1.2mm spacing, 0.5m long tungsten scatter
(average density 1/40 of bulk tungsten)
＋ BNL tungsten strip foil

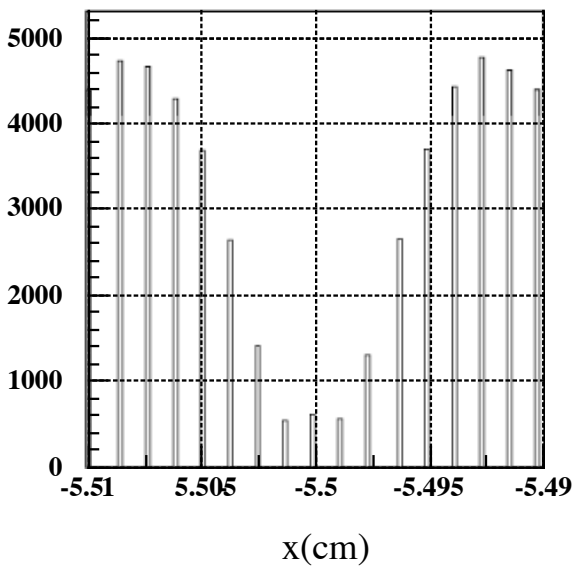
Scatterer ESS

MARS:

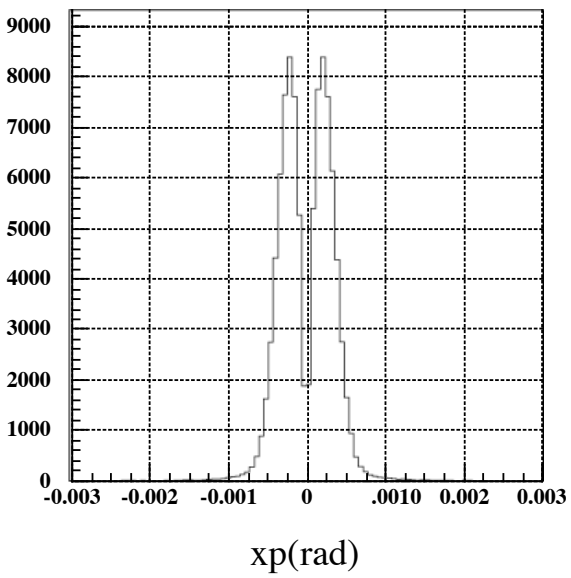
Real loss 3480/100000 ―＞1/4 of BNL strip foil

Angular spread due to scattering -> half of BNL strip foil

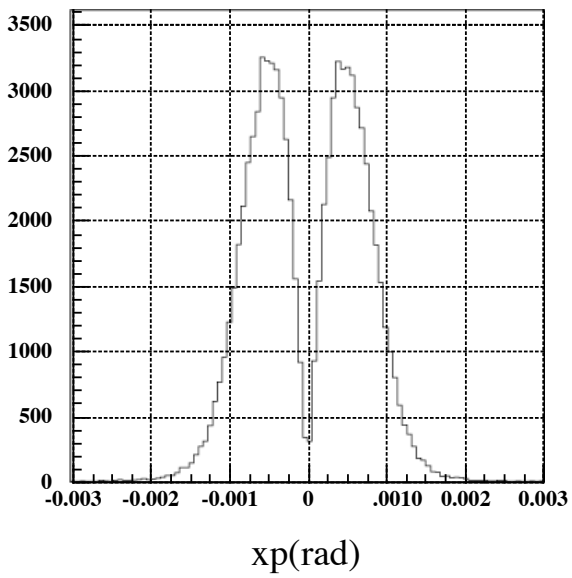
Present



Present



BNLタイプ



High Intensity Phenomena

Do they occur at 50GeV MR?

- **Spill modulation (AGS,CERN?)**

  ---> VHF cavity (finite x-chromaticity)

- **Beam loss increase (AGS)**

  ---> positive y-chromaticity

- **E-P instability (PSR,,,)**

  KEK Ohmi
  result strongly depends on the model