Magnet Analysis and Engineering Support

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SNS/BNL

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Ring AP Activities

- **Identifying and Solving problems:**
  - -Multipoles in 30Q44/30Q58 Quad
  - -30Q44 and injection and extraction line interference
- **Improvements:**
  - -Sorting schemes to minimize effect of nonlinear resonances
  - - Chicane #2 and #3 measurements, field angle measurement
  - -Sorting dipoles and quadrupoles
  - -Understanding solenoid configuration for e-p
- **Quality Assurance:**
  - -Checking magnet and power supply parameter list
  - -Accepting magnets and ½ cells
  - -Injection straight full trial assembly
  - -Update impedance table, apertures,acceptance
  - -RTBT-target, injection dump interface requirements
- **Installation and Commissioning Support:**
  - -Magnet assignment to lattice
  - -Global coordinates (Mad 1.2 including extraction kicker released)
  - -Checking installation drawings

Acknowledgements

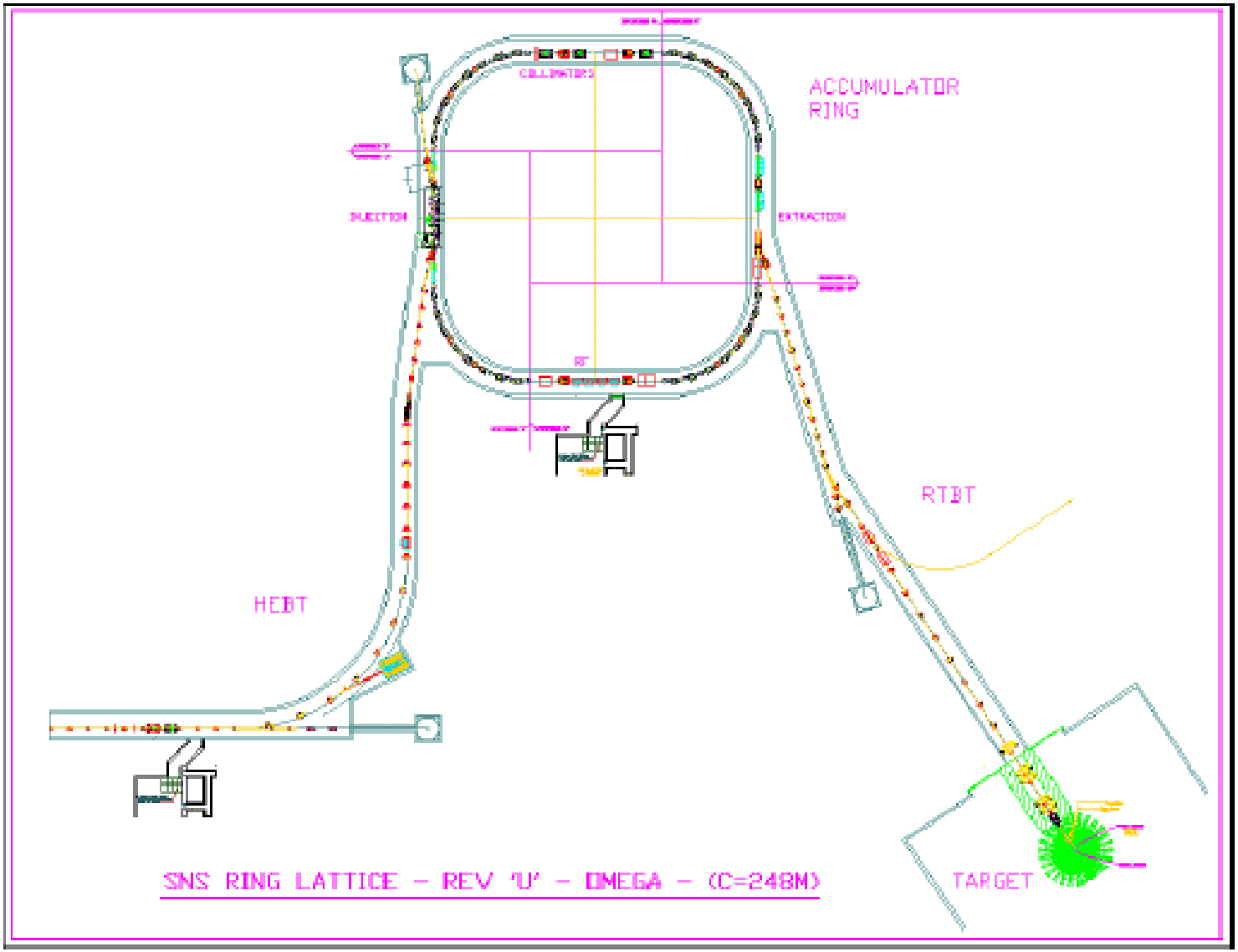
Contributors :

M. Blaskiewicz, A. Fedotov, C. Gardner, H. Hahn, J. Jackson, A. Jain, Y. Y. Lee, N. Malitsky, W. Meng, G. Parzen, T. Russo, S Tepikian, N. Tsoupas ,L. Wang, J. Wei, S.Y. Zhang

S. Cousineau,V. Danilov, S. Henderson, J. Holmes, J. Galambos,

M. Plum

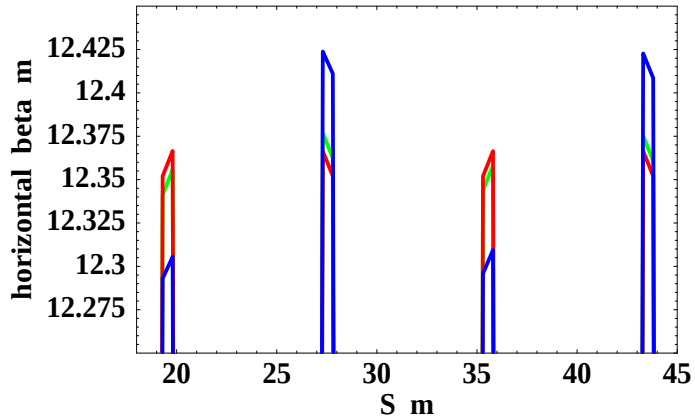
Transfer Lines & Ring



RING Quad Sorting

(D. Raparia, Y.Y. Lee, A. Fedotov et al.)

X beta-wave (21Q40 ITF sorting; 26Q40 & 30Q44, 30Q58 sorting of multipoles without ITF



red- ideal

green – sorted 21Q40

blue – beta-wave (mainly due to 30Q58)

•All measured quads=> 0.5% beta wave for and 10^{-3} tune shift.

•Two string of 8 ,21Q40

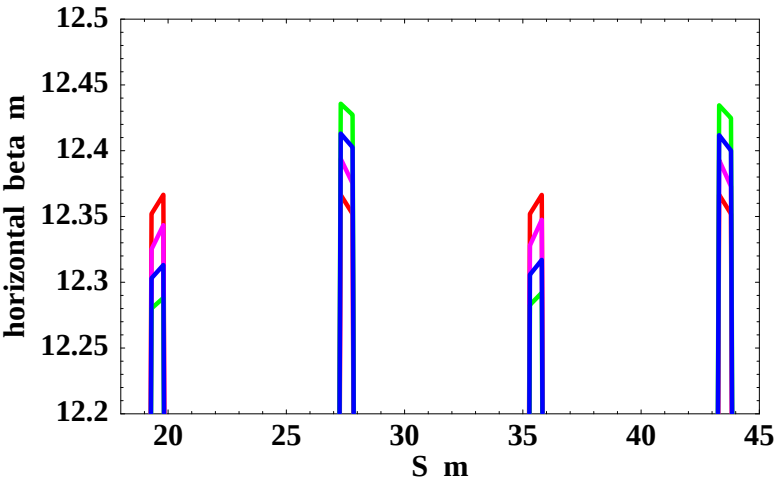
• One string of 12, 21Q40

•One string of 8, 26Q40

•One string of 8, 30Q58

•One sting of 8, 30Q44

X-beta wave at 1.3GeV with cut 30Q44



red – ideal

green – 2 magnets cut

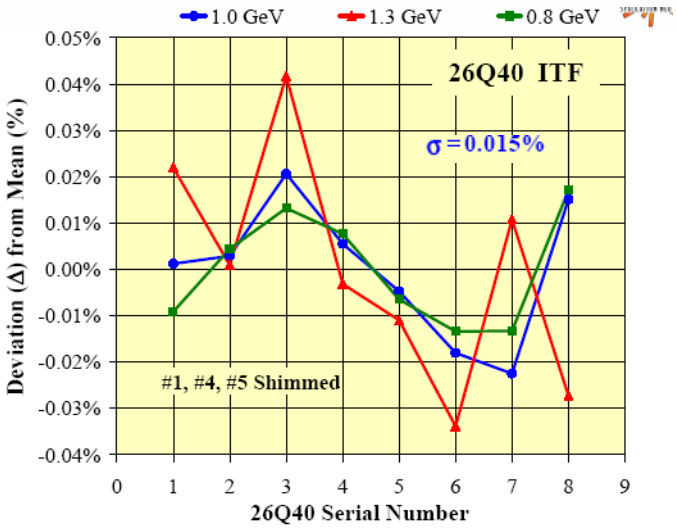
blue – 1 magnet compensated

pink – both magnets compensated

All 21Q40 were sorted and 7 were shimmed. Three 26Q40 were shimmed and one re-aligned. All 30Q58 coils were shimmed, three 30Q58 iron was rotated

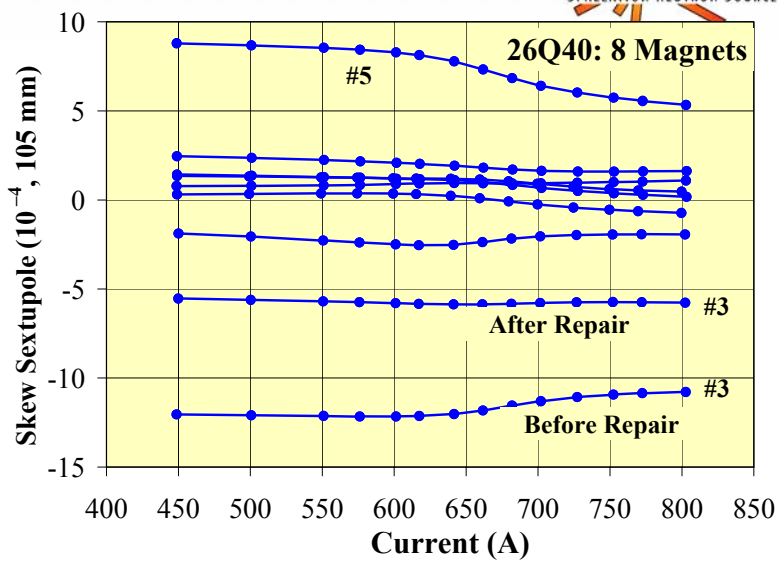
26Q40 Quadrupoles: Multipoles

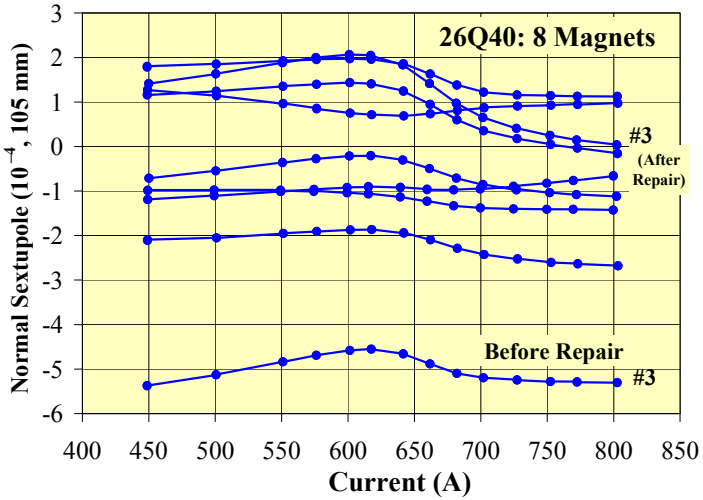
(P. Wanderer, A. Jain, J. Jackson, et al)

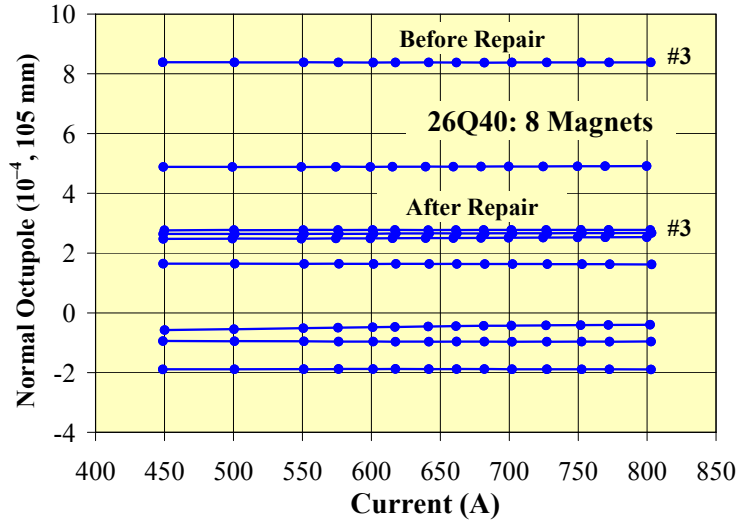


Harmonics at reference radius (480 π mm mrad)

N	RMS (10^{-4})
b_2	1.35
a_2	3.27
a_3	2.53
b_6	0.95
b_{10}	0.36

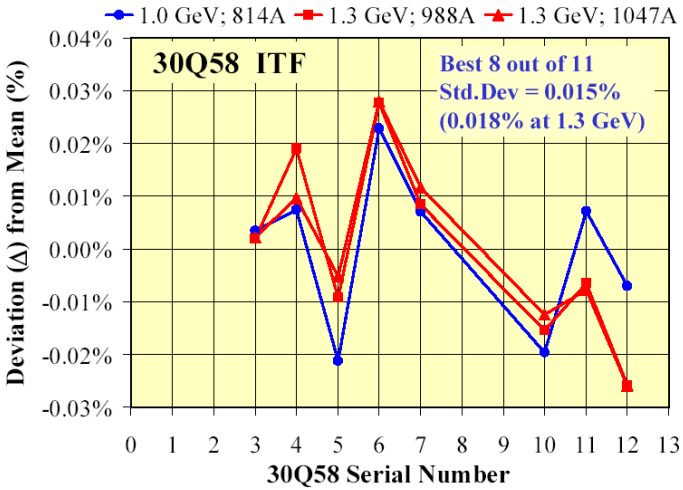






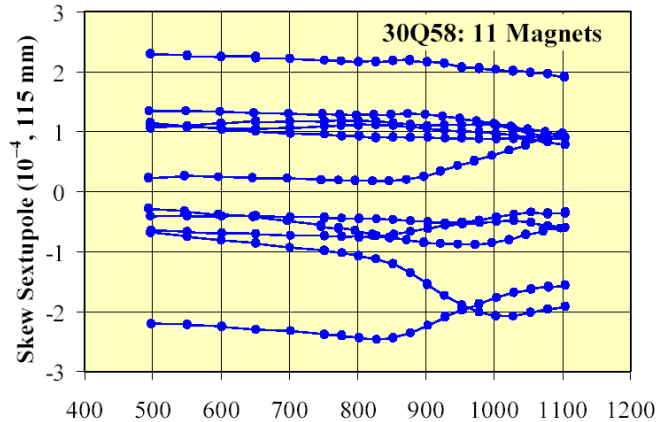
30Q58 Measurements

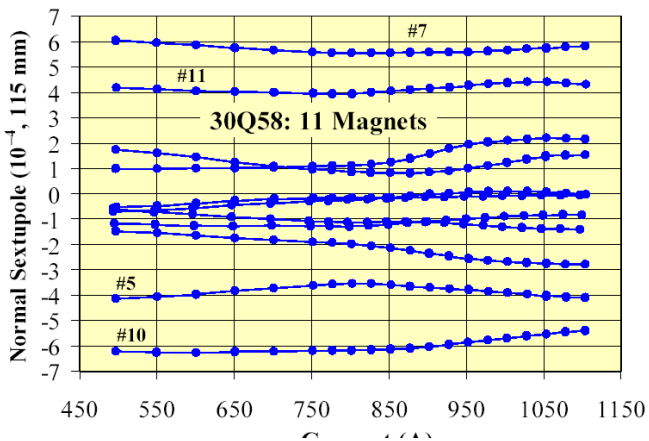
(P. Wanderer, A. Jain, J. Jackson, et al)

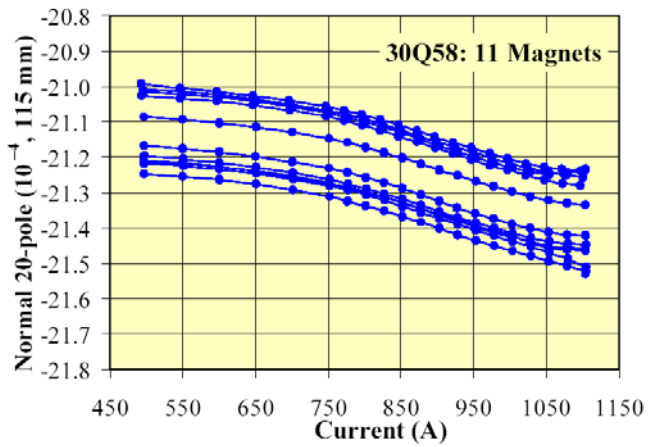


Harmonics at reference radius (480 π mm mrad)

N	RMS (10^{-4})
b_2	3.25
a_2	1.35
b_3	0.87
a_3	0.32
b_9	0.10

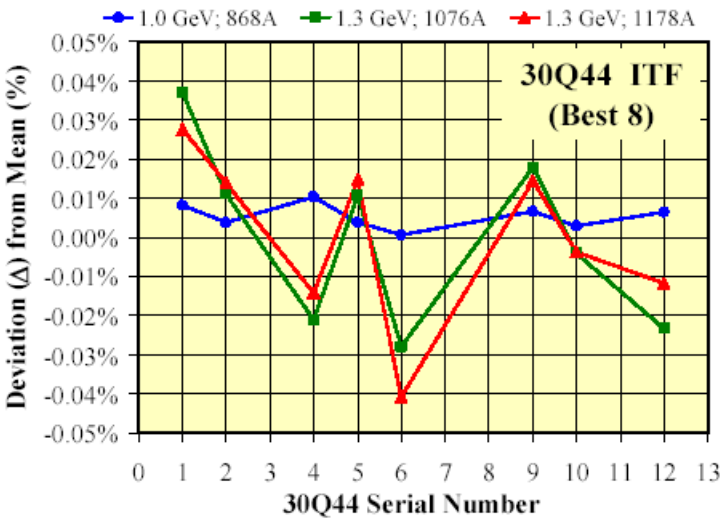






30Q44 Measurements

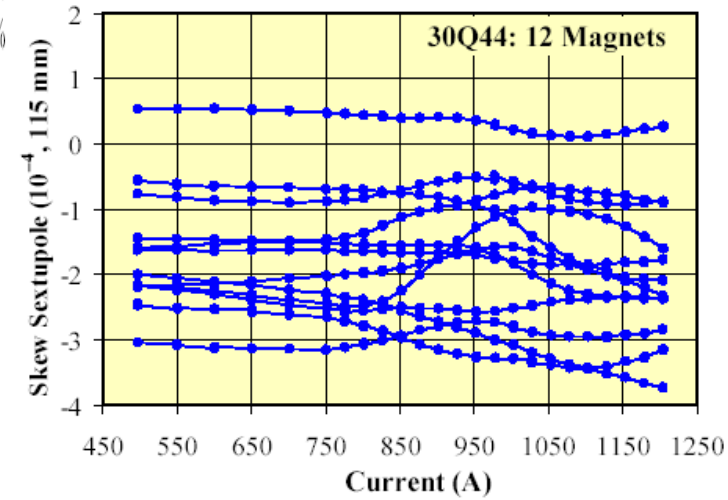
(P. Wanderer, A. Jain, J. Jackson, et al)

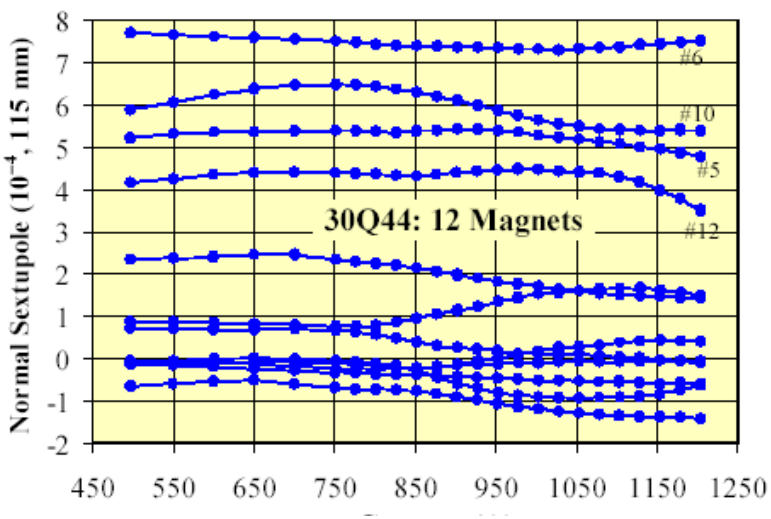


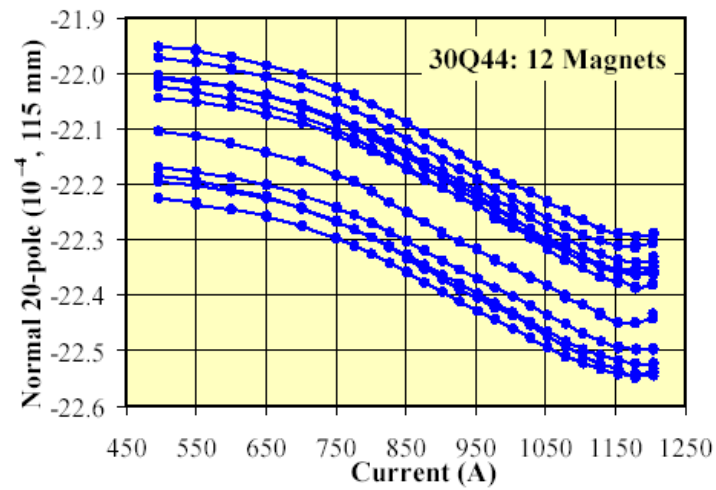
Best ITF matched 8 magnets: σ (1.0 GeV) = 0.01%
σ (1.3 GeV) = 0.02%

Harmonics at reference radius (480 π mm mrad)

N	RMS (10^{-4})
b_2	3.0
a_2	1.0
b_3	0.8
a_3	0.4
b_9	0.1





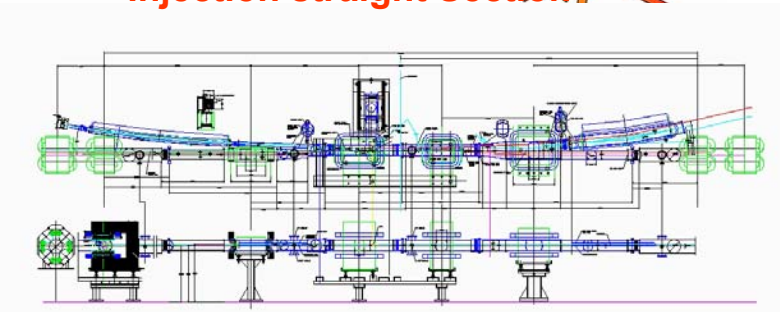


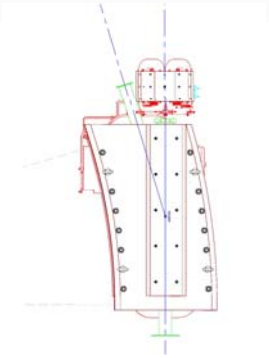
30Q44 Interference with Injection and Extraction lines

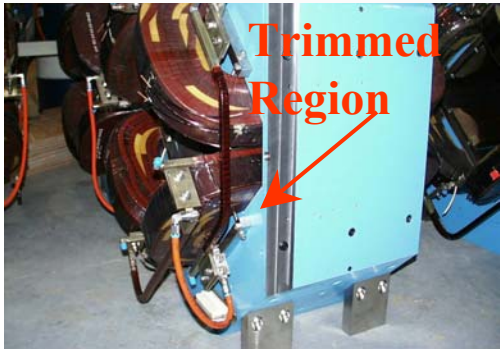
(P. Wanderer, A. Jain, J. Jackson, N. Tsoupas,)

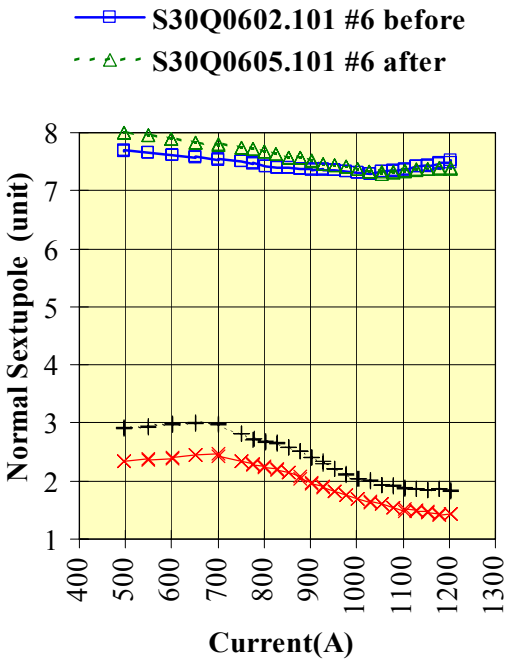
- Two of 30Q44 have interference with injection and extraction line
- A11 and C12 were cut at the both side symmetrically
- Negligible change in the Harmonics
- Negligible change in the ITF at 1.0 GeV, small change in ITF at 1.3 GeV and causes only 0.3% beta wave

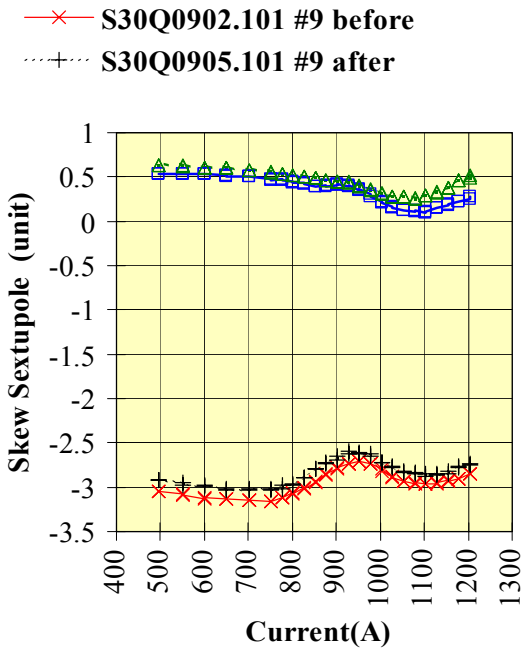
Injection straight Section

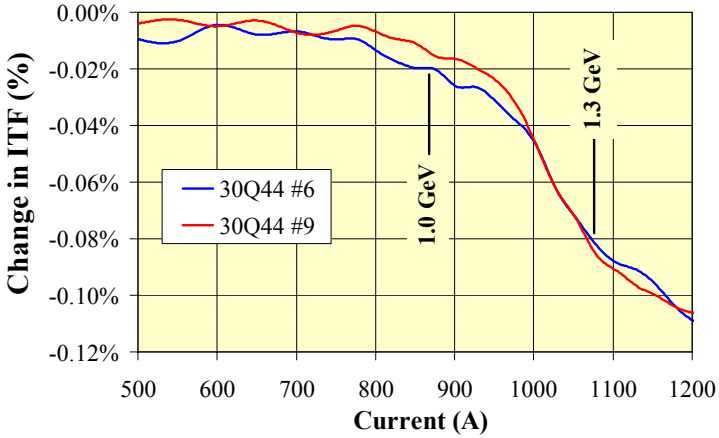








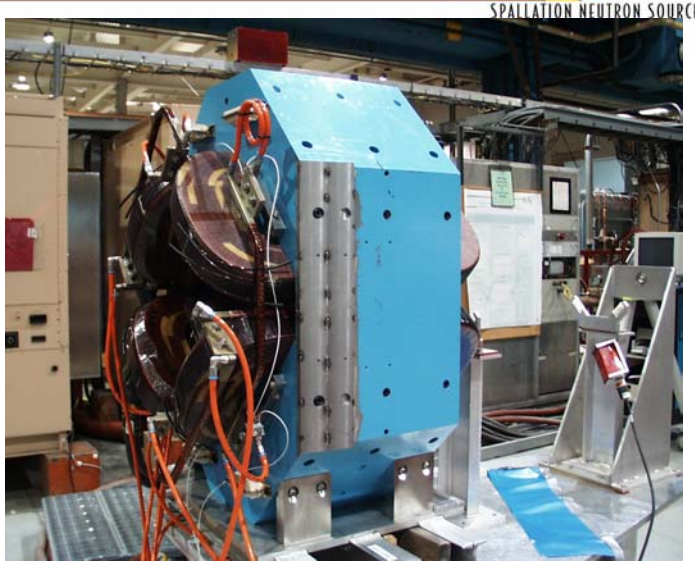


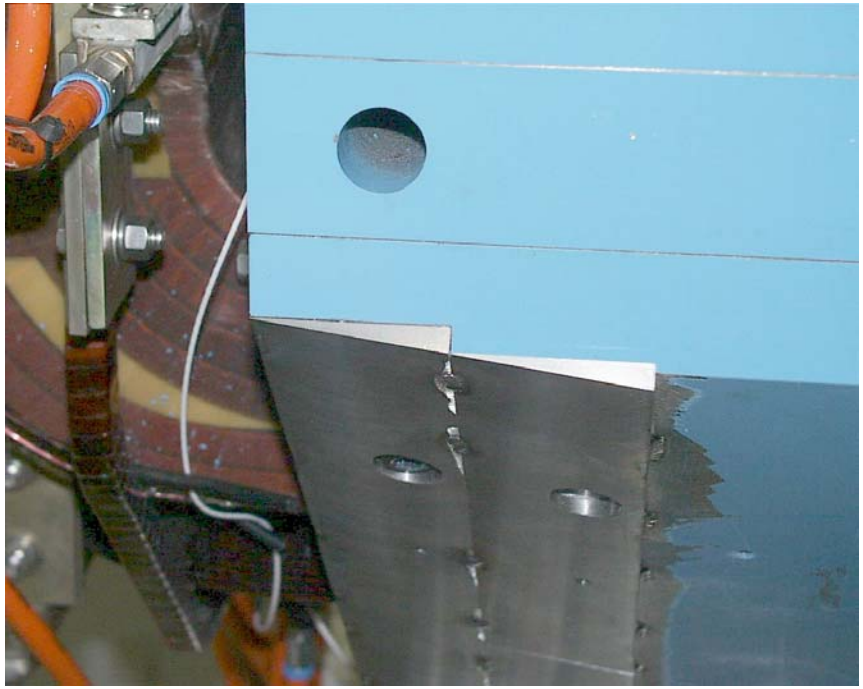


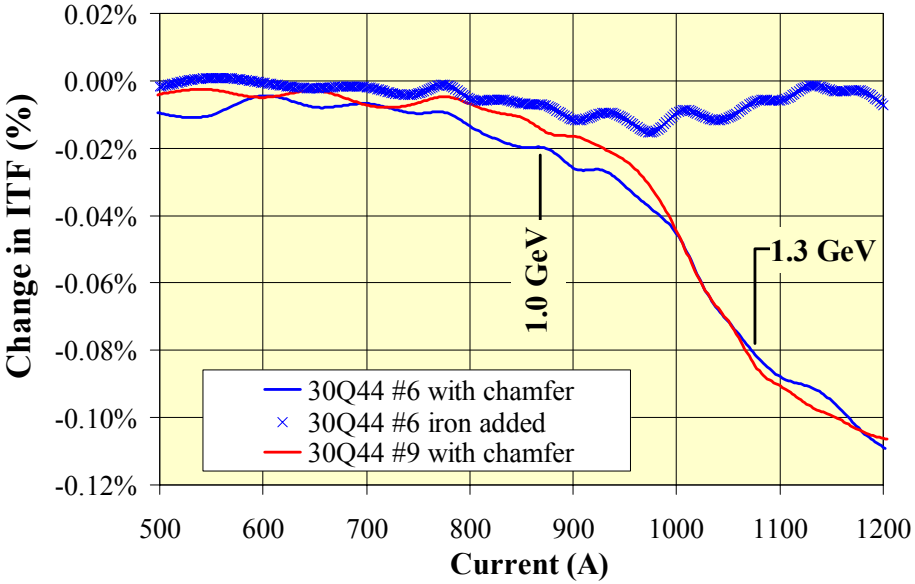
30Q44 Interference with Injection and Extraction Line Cont… (P. Wanderer, A. Jain, J. Jackson, N. Tsoupas,)

"The only way to escape a problem is to solve it"

- Approx. same amount of iron was added
- The ITF has now returned to the original value at all fields.
- Negligible change in the Harmonics







Design Requirement of #2 and #3 Chicane Magnets

(W. Meng, YY Lee, J. Jackson et al)

#2 --- Bo=3.0 kG

B (foil) = 2.5 kG > B(bottom);

$\tan^{-1}(Bz/By)$ >>65 mrd

Gap = 23.5 cm (8.750 inch)

#3 --- Bo = 2.4 kG (must smaller than 2.5 kG)

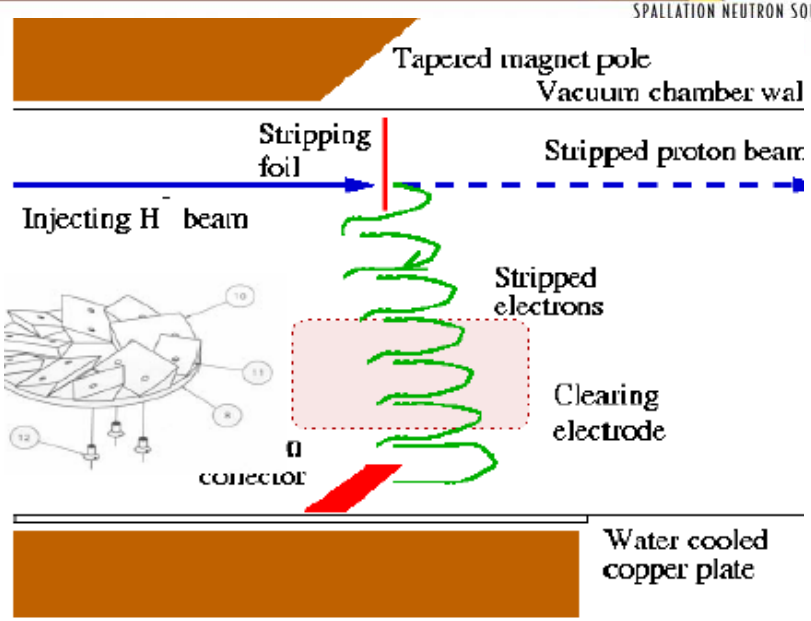
Distance (center to center) = 181.4 cm

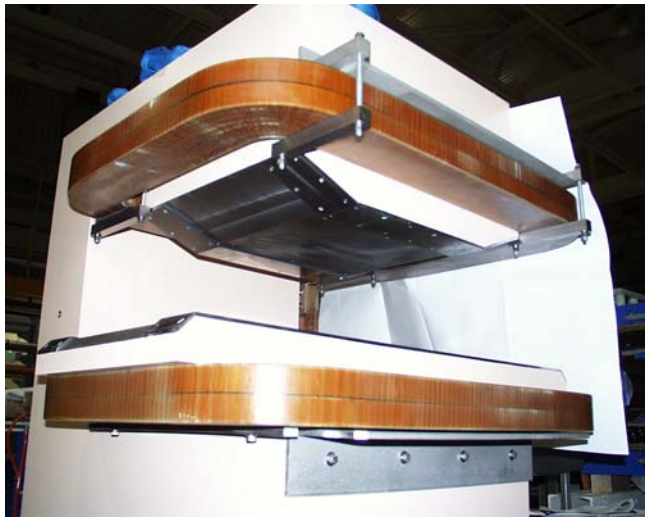
Field Integrals

$\int_{-\infty}^{Foil} By$= 237.6 kG-cm $\int_{Foil}^{\infty} By$ = 261.4 kG-cm

Two C magnets = 499 ± 5×10^{-4} kG-cm,

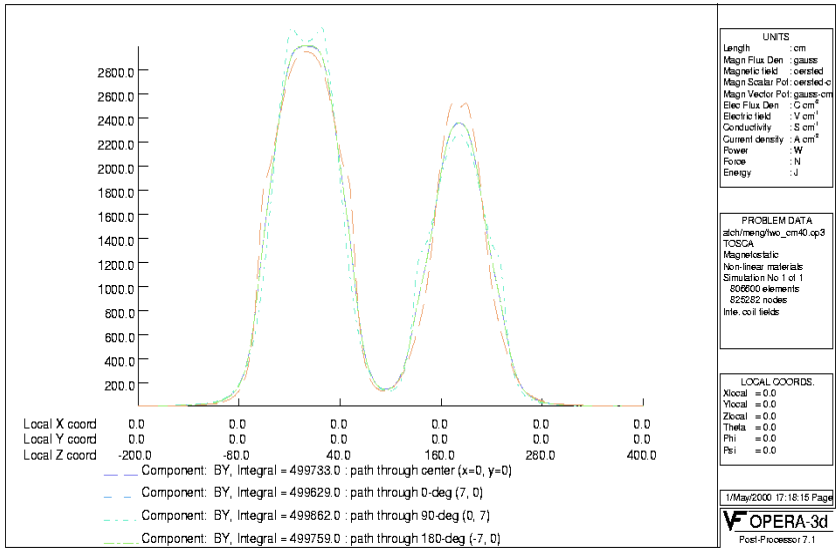
Goal <5×10^{-3} error

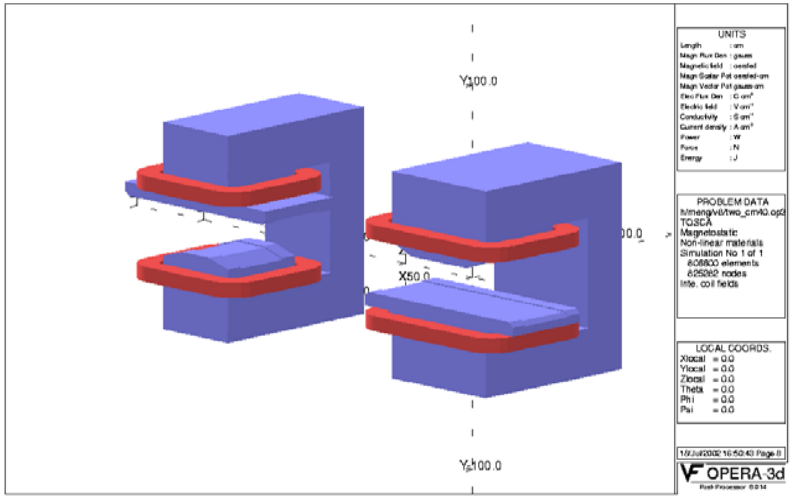




Total Integral for Chicane #2 & #3

(W. Meng, Y.Y. Lee, J. Jackson, et al)





- Total Integral along 0, 90, 180, 270 degree lines

Foil Location (0, 2, 30.7 cm)

By = 2.50 kG; Bz = -0.532 kG;

|B|=2.556 kG; $\tan^{-1}(Bz/By) = 0.2$ rad

Bottom pole B = 2.475 kG near the foil

$\int_{-\infty}^{foil} By = 237997$ g-cm,

$\int_{foil}^{\infty} By = 261751$ g-cm

Total Integral 2&3 499712.5 g-cm $\pm 3.2\times10^{-4}$ (R=7cm)

Operation current:

#2 I = 2168 A, N = 14 turn (per pole)

#3 I = 1716 A, N = 14 turn (per pole)

Integrated Multipoles (R=8 cm; z from –200 to 400 cm)

n	$\int (b_n)/(b_1)$	$\int (a_n)/(b_1)$
1	1.00000e+00	0.00000
2	-2.70378e-04	1.28250e-05
3	-1.81282e-04	-1.05606e-05
4	1.42300e-04	-4.70315e-06
5	1.77773e-04	-4.11747e-07
6	1.72624e-05	9.51574e-06

Chicane #2 & #3 Measurement

(A. Jain, W. Meng, Y.Y. Lee, J. Jackson, et al)

At mid plane

$\int_{-\infty}^{foil} By = 23795$ g-cm,

$\int_{foil}^{\infty} By = 26174$ g-cm

At foil

$\int_{-\infty}^{foil} By = 23861$ g-cm,

$\int_{foil}^{\infty} By = 26106$ g-cm

Integral Field Quality Measurements in Chicane #2 & #3

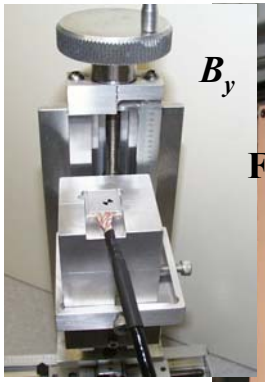
Measurements with a 40.8 mm radius, 4.75 m long coil

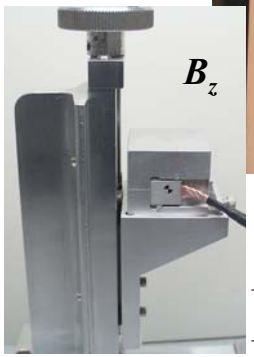
Harmonics expressed in 10^{-4} "units" at 80 mm radius

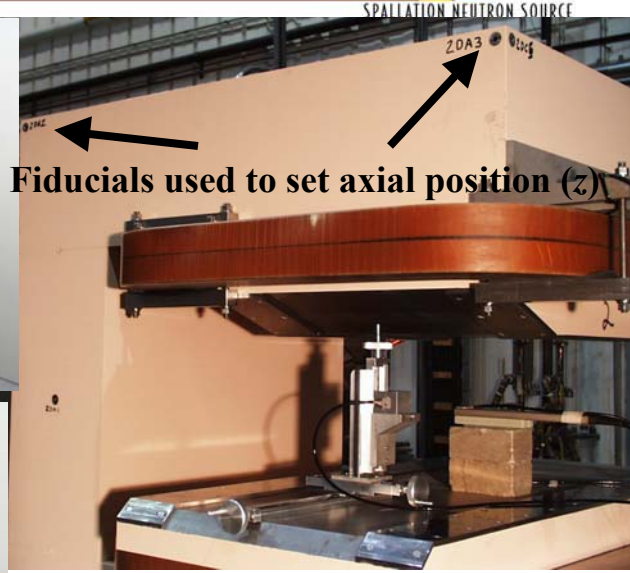
Harmonic	Chicane #2 (2154.8 A)	Chicane #3 (1732.0 A)	Chicane #2 (2154.7 A) + Chicane #3 (1733.2 A)	Chicane #2 + #3 (2154.7 A/1733.2 A) Normalized to 17D120 field
$\int B.d\ell$ (T.m)	**0.3006**	**0.2016**	**0.5012**	**1.106**
b_1	-1.8	-4.1	-1.9	**-0.9**
b_2	-8.2	-9.4	-9.2	**-4.2**
b_3	1.2	0.9	1.3	**0.6**
b_4	0.0	-0.4	-0.1	**-0.1**
b_5	0.5	-0.7	0.0	**0.0**
b_6	-0.9	0.0	-0.6	**-0.3**
a_1	116.0	-158.2	6.2	**2.8**
a_2	-8.0	9.6	-0.9	**-0.4**
a_3	8.0	-11.3	0.3	**0.1**
a_4	-0.5	0.4	-0.1	**-0.1**
a_5	1.5	-1.3	0.0	**0.0**
a_6	0.1	-0.3	0.0	**0.0**

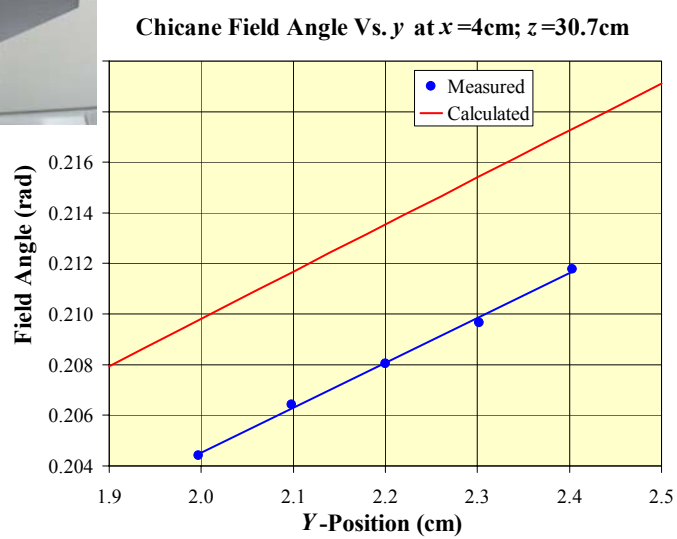
Measurement of Field Direction in the Chicane Dipole No. 2 at the Foil Location (Ed Hoey A. Jain, W. Meng, Y.Y. Lee, J. Jackson, et al)

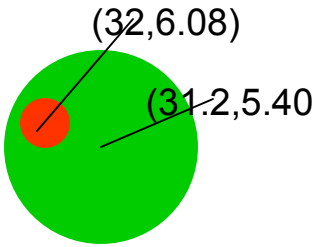
- Foil location is at (40, 22, 307) mm with the center of Chicane #2 as the origin
- A single LPT-141 Hall probe was used to measure all the field components
- Measurements were repeated after flipping the probe 180 deg. to minimize errors due to Hall element position and orientation uncertainties
- Measured field angle at the foil location is ~ 5.5 mrad off from the calculated value.
- Measurement uncertainties:
  - Probe calibration 0.1% ⇒ Error < 0.4 mrad
  - Probe position < 0.1 mm ⇒ Error < 0.2 mrad (Y-position is the most critical)
  - Probe orientation < 2 mrad ⇒ Error < 2 mrad
  - Other errors averaged out by 180 deg. flipping
  - Overall error estimated to be < 3 mrad









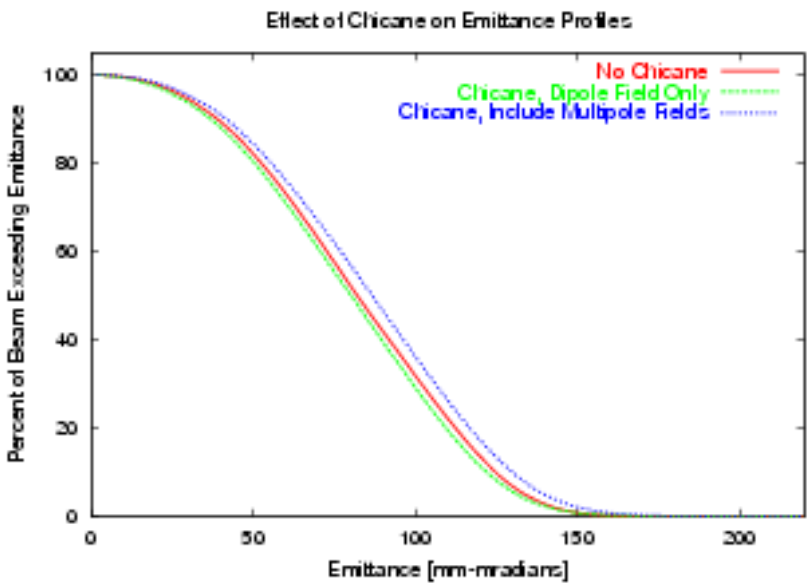


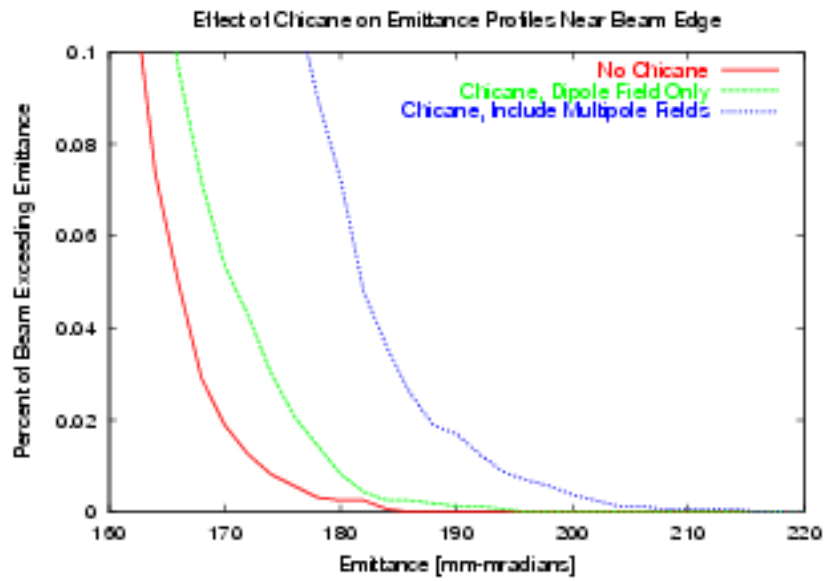
- Electrons have been re-traced and they will be capture by electron catcher

Injection Chicane Field Study

(Holmes, Cousineau, et al)

- New ORBIT simulations performed with measured integrated multipole field data.
- Simplectic tracking used, time-dependent injection kickers model.
- Results show slight beam core and halo emittance growth (~15 πmm·mrad), compared to case without multipoles.

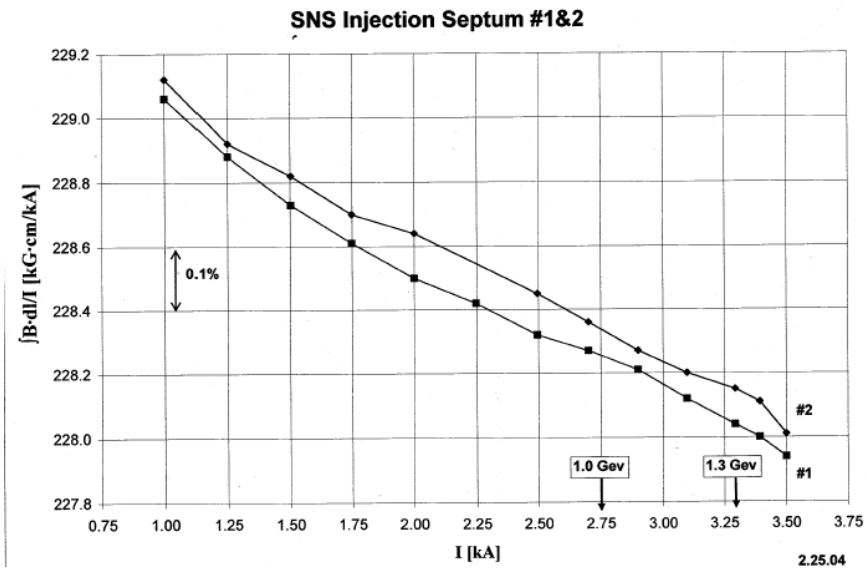




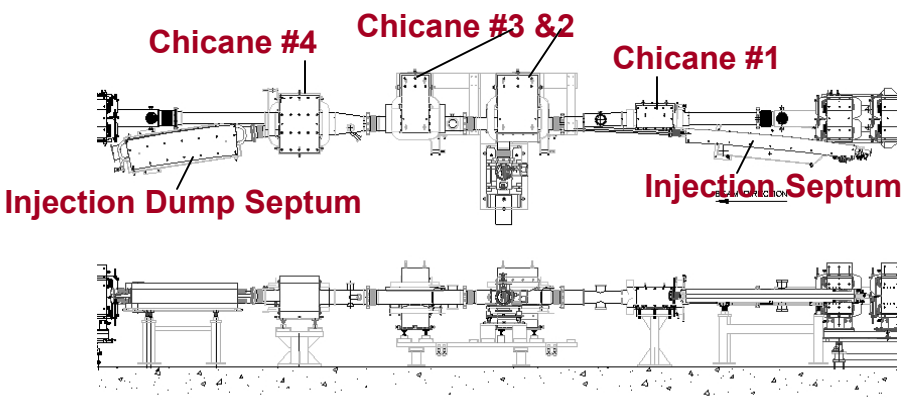
- Next step is to model transport through full 3D fields inside chicane using OPERA/TOSCA simulation.

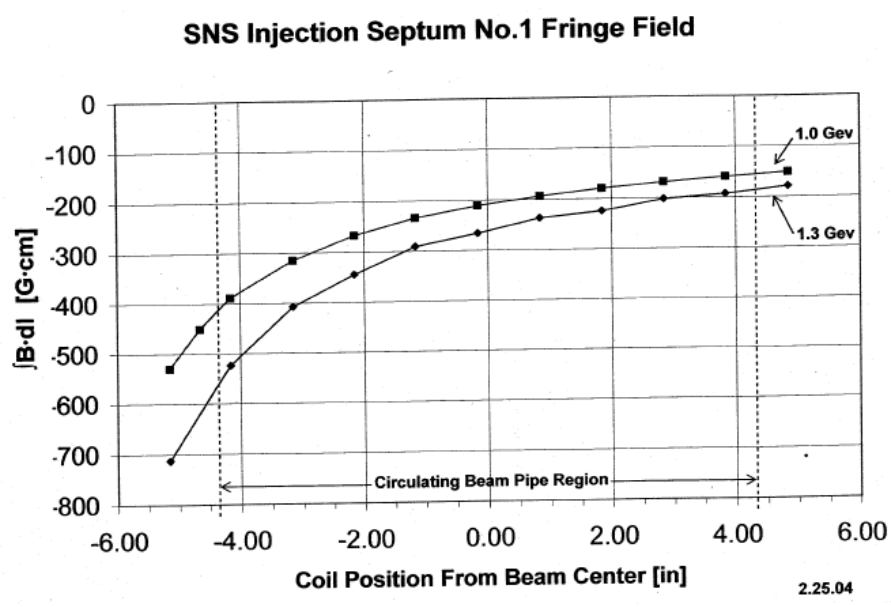
Injection Septum Magnet # 1 & #2

(J.. Jackson, W. Meng, Y.Y. Lee al)

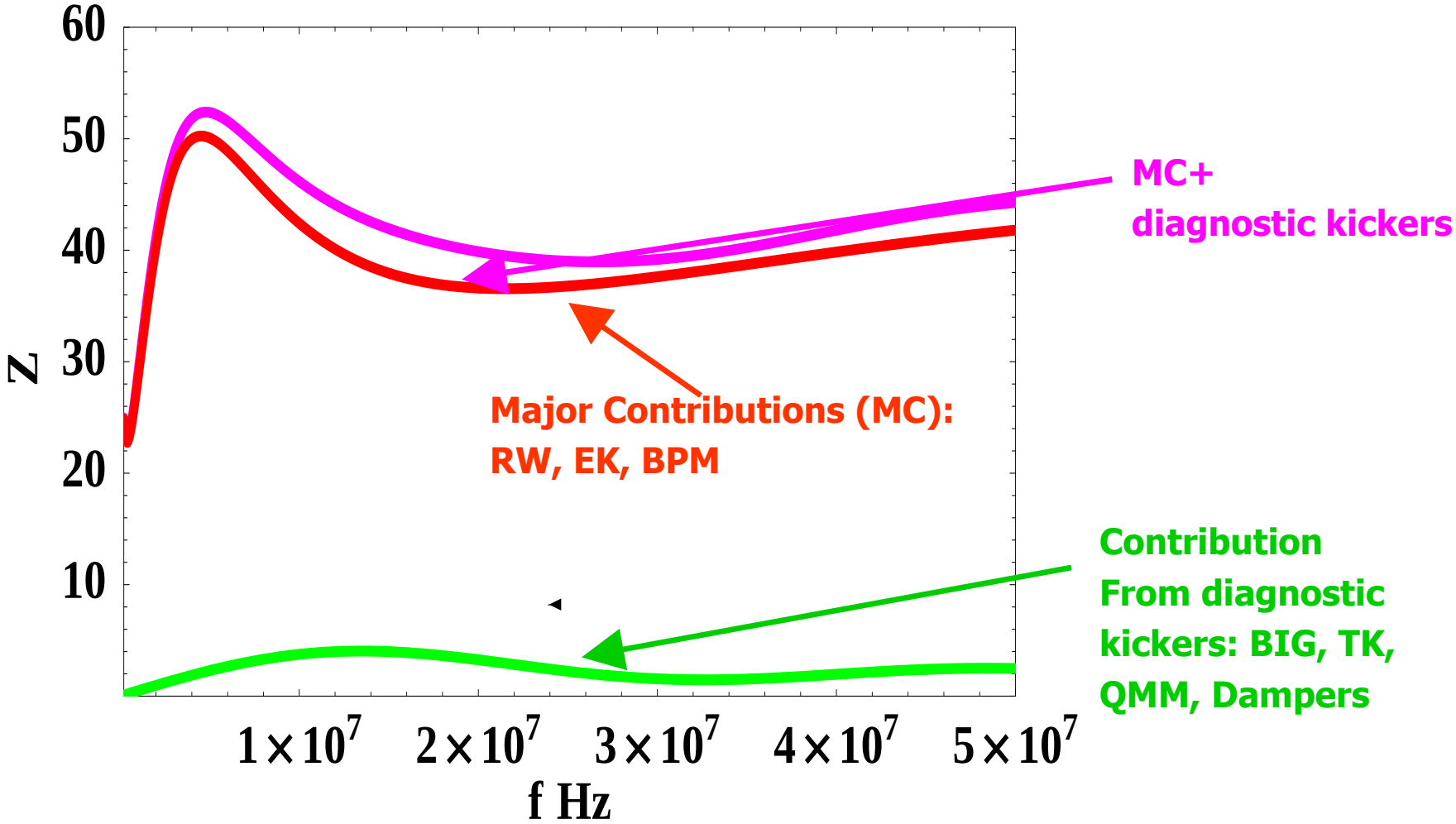


- Integral magnetic field measured at central trajectory with curved long flip coil
- Integral magnetic field measured with long flip coil at several positions within the circulating beam vacuum chamber
- Fringe field effect on the circulating beam is within corrector strength





Correction to total Re(Z) transverse impedance due to diagnostic kickers (A. Fedotov, Y.Y. Lee, J. Wei, et al.)



Impedance estimate due to aperture size

(S. Y. Zang, A. Fedotov, Y.Y. Lee, D. Hseuh, et al.)

Steps	Number	Z/n
7.5 to 6.3	8	34.4
8.0 to 7.5	4	3.4
10 to 8.5	2	10.2
11.5 to 10	2	9.2
9.25 to 8.5	2	3.2
16 to 8	1	65.2
7 to 8	1	3.0
7.9 to 9.1	4	14.8
8 to 12	1	24.6
8 to 24	1	283
24 to 12	1	97.7
24 to 11.5	2	269.2
7 to 24	1	57.0
12 to 14	1	6.6
7.9 to 10.5	2	68.5
7.9 to 11.8	1	31.5
11.8 to 16	2	54.2
inch		j mΩ

Total j 1.036 Ω

Impedance update: February 2004 (< 10 MHz) (A. Fedotov, Y.Y. Lee, J. Wei, et al.)

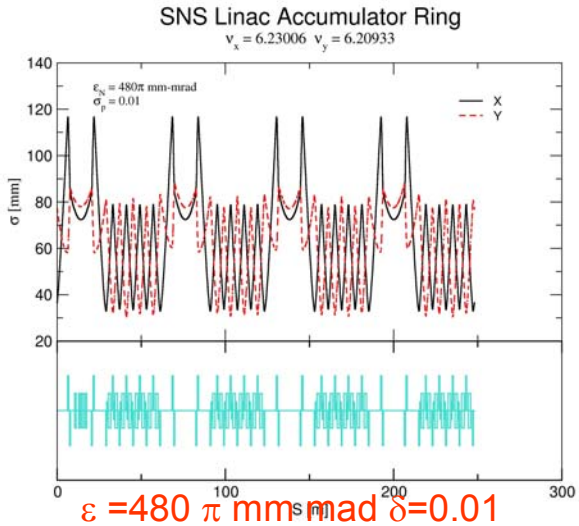
	Z_ℓ/n [Ω]	Z_T [kΩ/m]
Space charge	-j196	j(-5.8+0.45)[1] x10[3]
Extraction kicker[2]	0.6n+j50	33+j125[3]
Injection kicker[4]	≈0.5, at ω_0	17.5 (lowest tune 200 kHz)
RF cavity	Resonances: (f=7.5 MHz, Q≅88, 0.6 Ω); (11.37, 59, 0.2); (35, 1, 0.1); (87, 20, 0.9).[5]	18 (at resonance)[6]
Injection foil assembly	j0.05[7]	j4.5
Resistive wall	(j+1)0.71, at ω_0	(j+1)8.5, at ω_0
Broadband		
BPM	j4.0	j18
BIG,TK,QMM,Damp.	4+j7.0	3+j0.8
Bellows	j1.3	j11
Steps	j1.9	j16
Ports	j0.49	j4.4
Valves	j0.15	j1.4
Collimator	j0.22	j2.0
Total BB	4+j15	3+j54

Impedance update: February 2004 (at 50 MHz) (A. Fedotov, Y.Y. Lee, J. Wei, et al.)

	Z_ℓ/n [Ω]	Z_T [kΩ/m]
Space charge	-j196	j(-5.8+0.45)[8] x10[3]
Extraction kicker, 25 Ω termination	19.4[13]+j12	12.5 + j65[9]
RF cavity	See before	≅ 0 [10]
Injection foil assembly	j0.05	j4.5[11]
BPM	2 + j3.5	9+j16
BIG,TK,QMM,Damp	0.5+j1.2	0.5+j0.1
Broadband		
Bellows	j1.3	j11
Steps	j1.9	j16
Ports	j0.49	j4.4
Valves	j0.15	j1.4
Collimator	j0.22	j2.0
Total BB	j4.1	j35

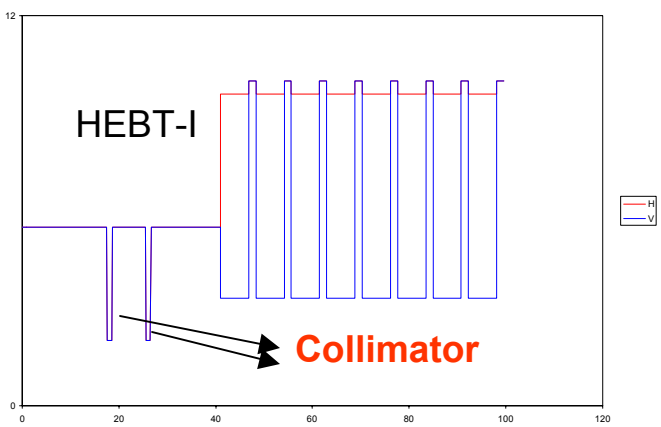
HEBT & Ring Apertures

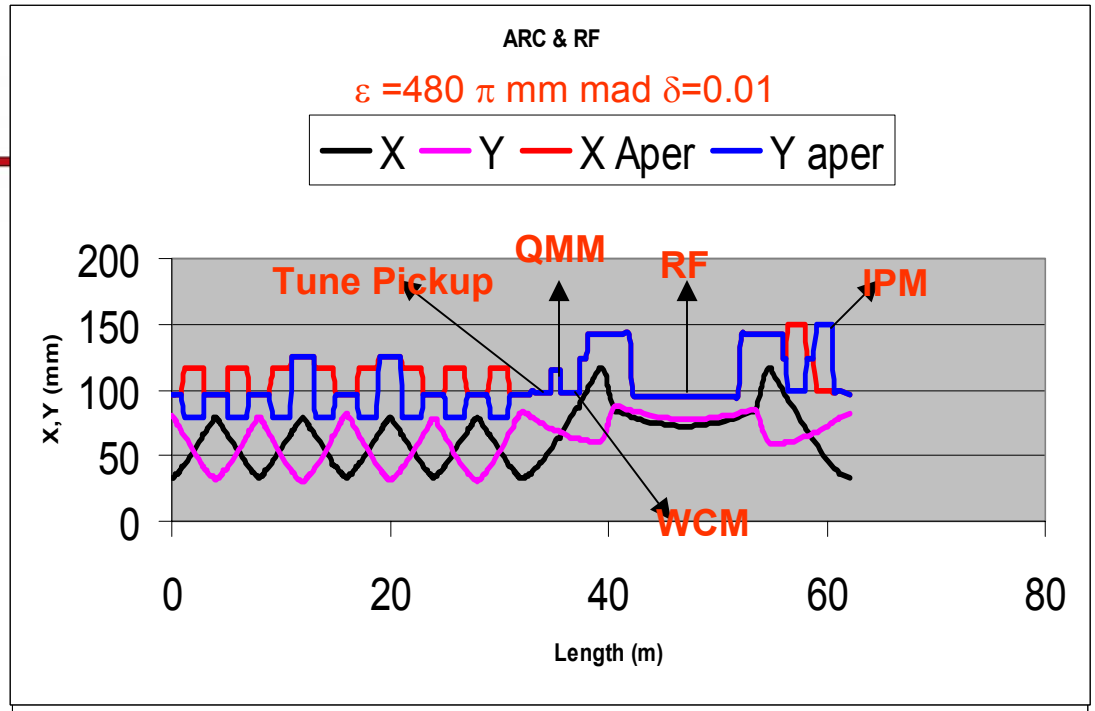
(D. Hseuh, Tepikian et al)

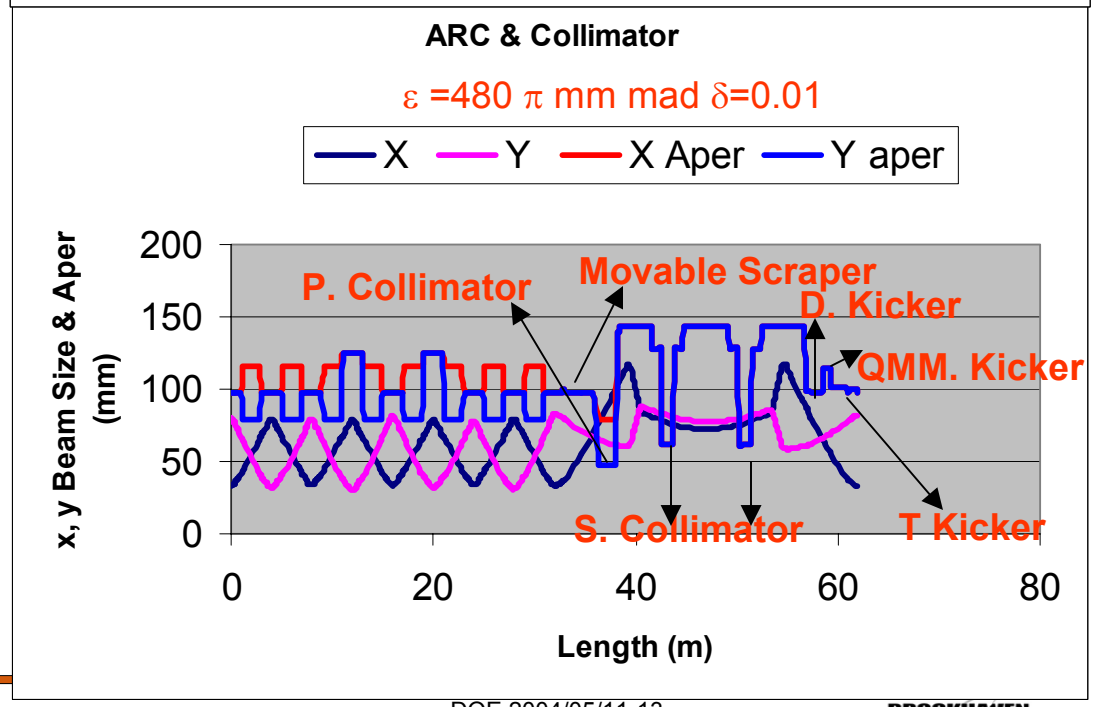


ε =480 π mm mad δ=0.01

- HEBT, Ring arc, Collimator , RF straight section finished
- Injection & extraction straight section and RTBT to be finish







Sorting of quadrupole to minimize effect of nonlinear resonances: compensation of emittance growth due to sextupole resonance

(D. Raparia, Y.Y. Lee, A. Fedotov et al.)

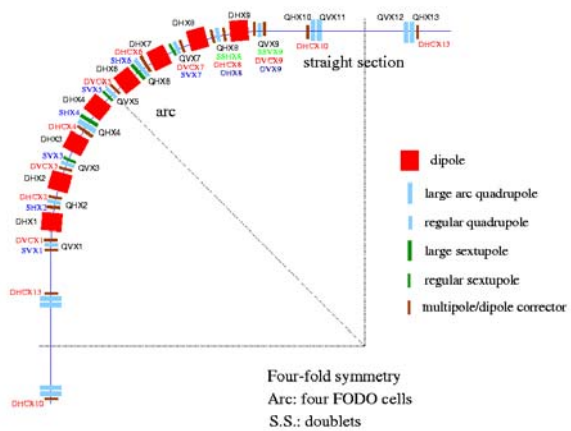
Primary goal – sort magnets to minimize effect of dangerous resonances.

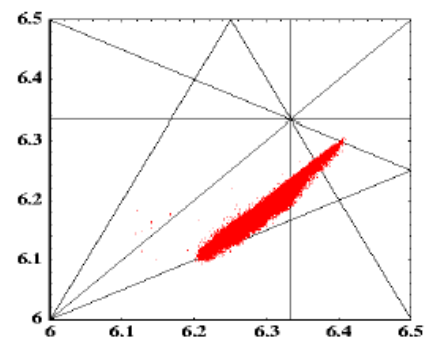
After sorting technique was demonstrated to work, real measured multipoles were used and best sorting schemes were developed

Measured 26Q40 multipoles:	beam halo
1. No correction:	0.3% at 240 pi
2. Sorting based on total field:	0.2% at 240 pi
3. Sorting based on phase advances:	0.3% at 240pi

To develop the most effective scheme measured errors were further scaled to a factor of 9 which results in beam halo of 6% at 240 pi

g or resonance

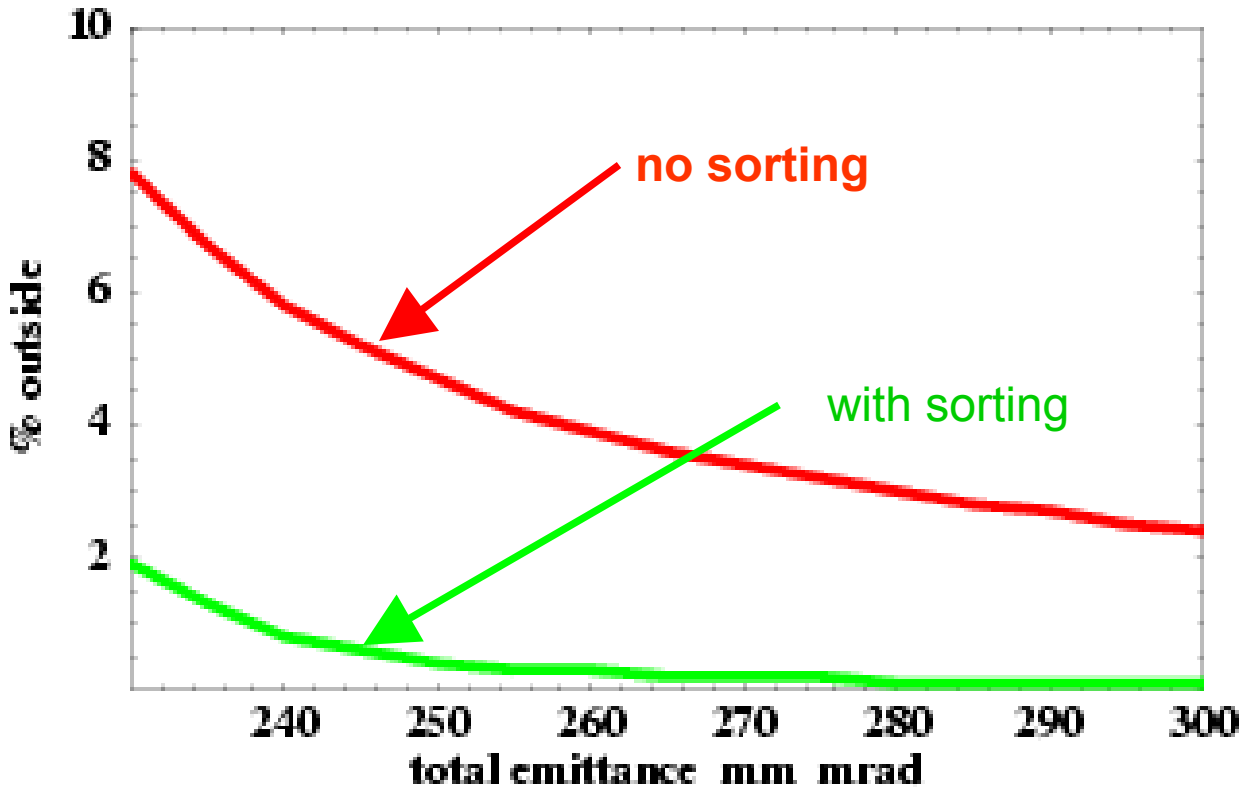




Tune spread for 2MW beam with dp/p=0.6 %

Demonstration of developed sorting scheme to minimizing effect of skew-sextupole resonance (26Q40)

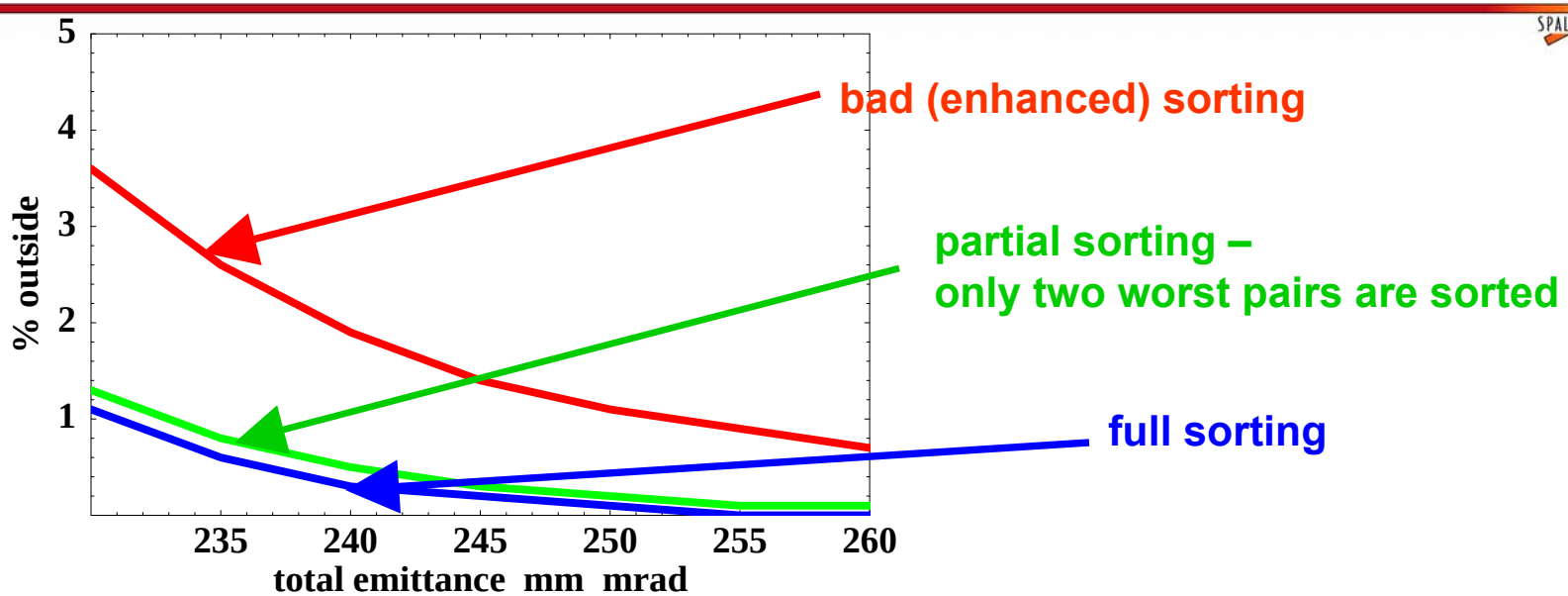
(D. Raparia, Y.Y. Lee, A. Fedotov et al.)



Demonstration of sorting scheme to minimize effect of skew-sextupole resonance: w.p. (6.4,6.3), N=1.5*10^14, measured skew-sextupole multipoles in 26Q40 magnets multiplied by a factor of 9 – no resonance correction.

Sorting of 30Q44 and 30Q58

(D. Raparia, Y.Y. Lee, A. Fedotov et al.)

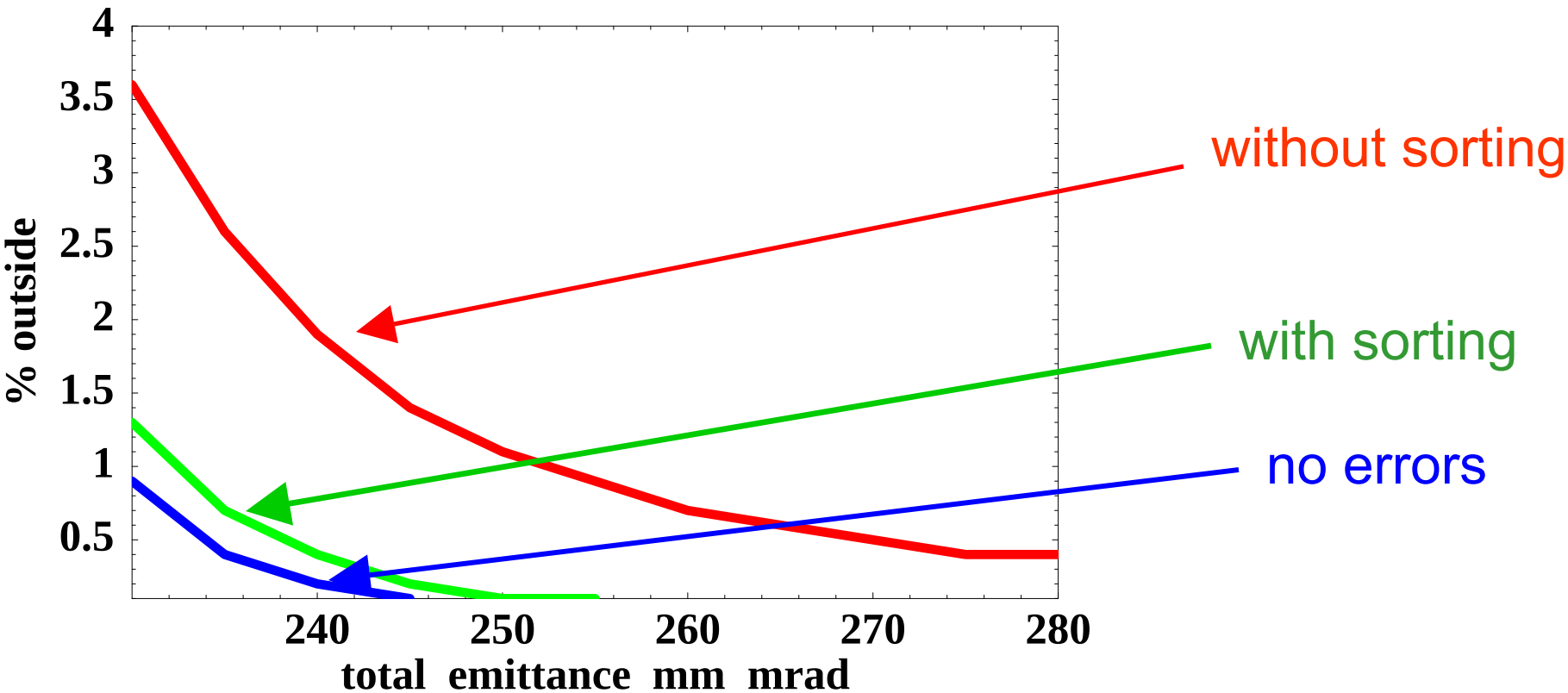


- 30Q58 and 30Q44 shows little higher Sextupole and skew Sextupole components
- 8 quads of each kinds were selected out of 12
- Three 30Q58 were rotated by 180 degrees to the sign of Sextupole Component
- Normal Sextupole components were compensated each doublet
- Sew Sextupole components were compensated by placing doublet at π phase advance
- Simulation shows negligible emittance growth.

Summary: effect of 21Q40,26Q40,30Q44 and 30Q58

(D. Raparia, Y.Y. Lee, A. Fedotov et al.)

All quadrupoles with measured sextupole and skew-sextupole multipoles



TiN coating of extraction kicker ferrite modules (Hseuh , Lanfa …)

Purpose: To reduce secondary electron emission from ferrite (and Cu) surface, suppress multipacting

Goal: 0.1 μm TiN on ≥ 90% inner surface, with good adhesion

AP Calculations: Eddy current & heating, E-M smoothing...
(Aleksandrov, 12/00', Blaskiewicz, 12/01')
i.e strips of 1 cm wide: $\Delta T \sim {}^{o}C$, $\Delta P \sim$ watts, $\Delta t \sim$ ns

Effectiveness of electron suppression with 90% coating

Coating: developed using kicker test chamber and prototype kicker

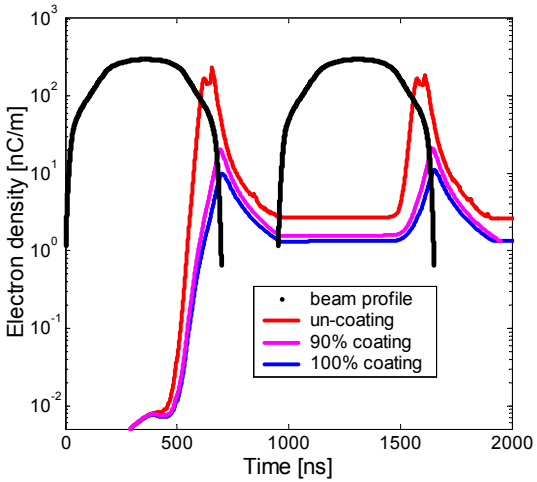
Coating strips of 1cm (Y) x 5cm (Z) with 1mm gaps using custom masks

Good adhesion;

Resistance across strips > 100 Ohm;

E-M smoothing time of < 1 ns (Blaskiewicz, 4/04'); may be reduced with improved masking or scraping after coating

un-coated, λ_{peak}=200nc/m
100% coated, λ_{peak}=10nc/m
90% coated, λ_{peak}=20nc/m



Two turns shown

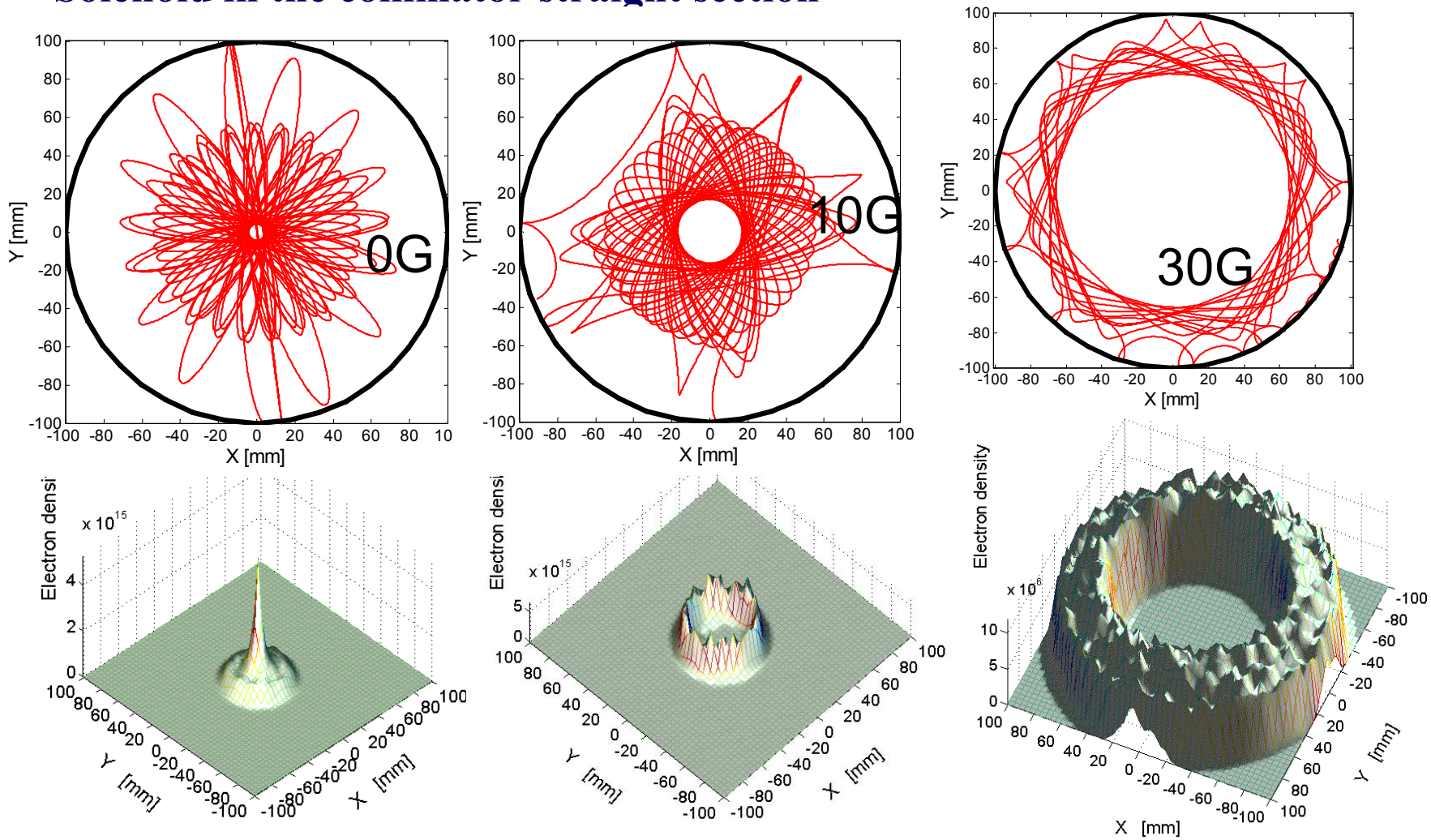
SEY in Un-coated ferrite area 2.5

SEY in ferrite area coated with TiN 1.9

Solenoid effects

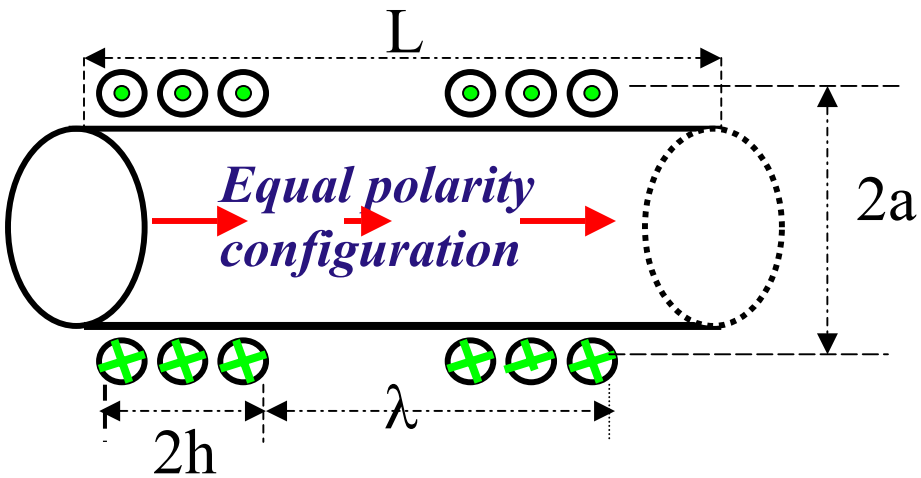
(L. Wang, J. Wei, M. Blaskiewicz, et al)

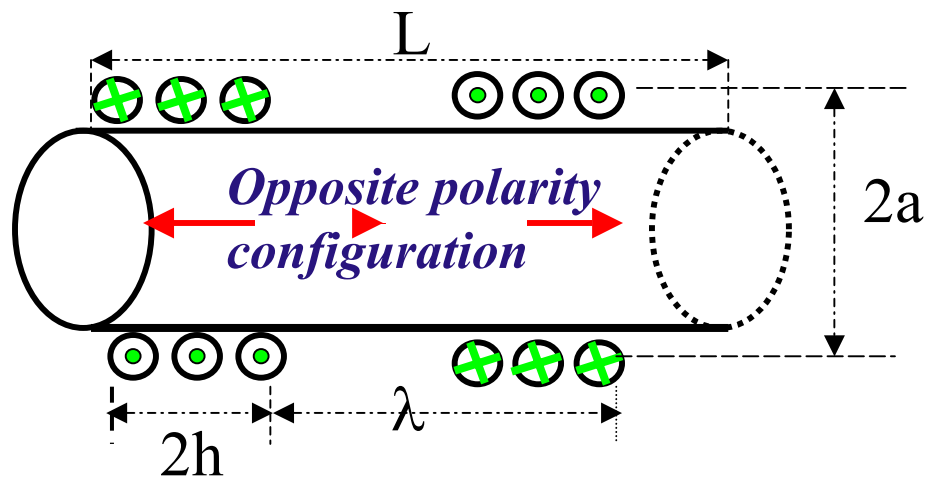
- 30G Solenoid field can reduce the e-cloud density with a factor 2000 !
- Solenoid in the collimator straight section



Solenoid---Configuration

(L. Wang, J. Wei, M. Blaskiewicz, et al)





$$B_r = B_0 \frac{2ka}{\pi} \sum_{n=1}^{\infty} \sin nhk K_1(nka) I_1(nkr) \sin nkz$$

$$B_z = B_0 \left(\frac{2h}{\lambda} + \frac{2ka}{\pi} \sum_{n=1}^{\infty} \sin nhk K_1(nka) I_0(nkr) \cos nkz \right)$$

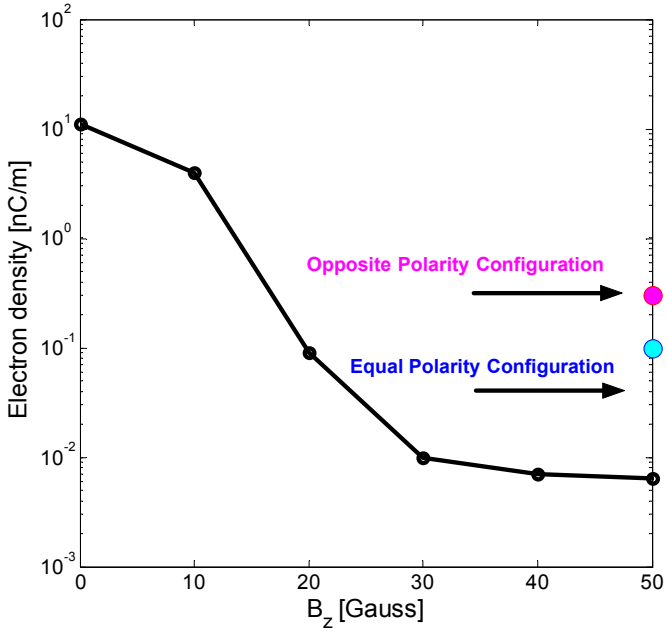
$$B_r = B_0 \frac{4ka}{\pi} \sum_{n=1,3,5}^{\infty} \sin nhk K_1(nka) I_1(nkr) \sin nkz$$

$$B_z = B_0 \frac{4ka}{\pi} \sum_{n=1,3,5}^{\infty} \sin nhk K_1(nka) I_0(nkr) \cos nkz$$

By E. Perevedentsev

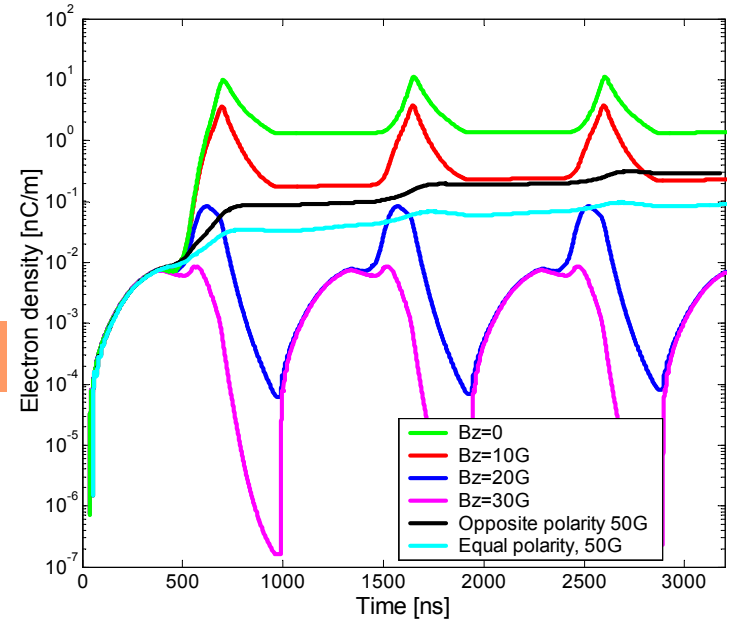
B_0=50 Gauss, h=0.4 m, a=120 mm, λ =1 m and 2 m

Solenoid configuration effects (L. Wang, J. Wei, M. Blaskiewicz, et al)

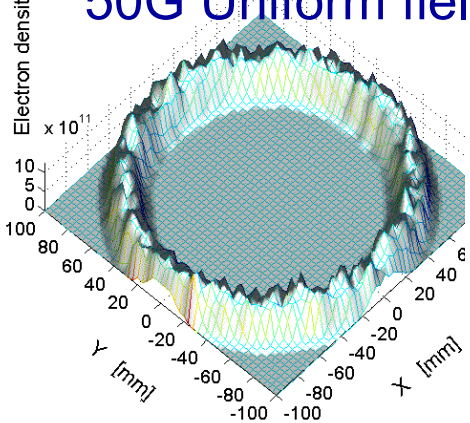


Factor 36

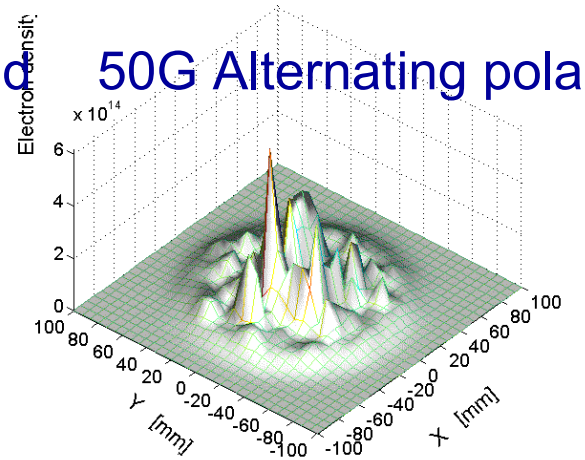
Factor 110



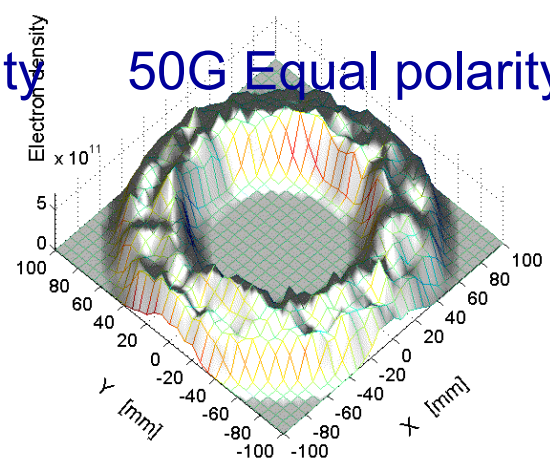
50G Uniform field



50G Alternating polarity



50G Equal polarity



Global Coordinates

(S. Tepikian,M. Hemmer, N. Tsoupas, D. Raparia et al)

-Ring lattice MAD 1.2 including extraction kicker released

-Global Coordinate of the momentum dump in the HEBT

-Global coordinates for diagnostics in the HEBT and RTBT completed

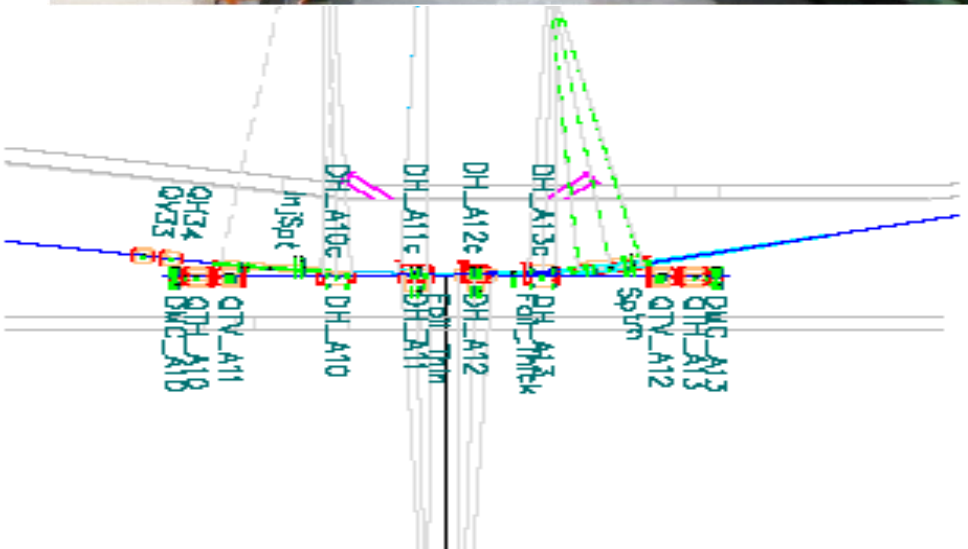
- Full section trial-assembly at BNL to assure compatibility

SNS RING

BROOKHAVEN NATIONAL LABORATORY

Lattice

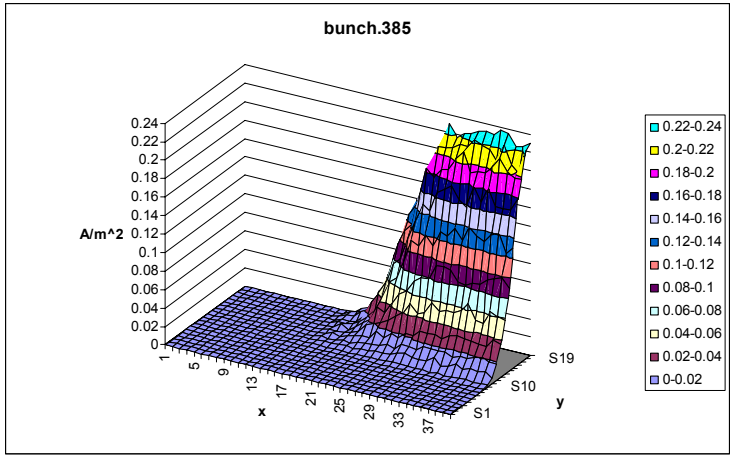
- Version 1.0 in MAD structure
- Version 1.1: SNSRing.v.1.1 623_620_00.mad
- Version 1.2 SNSRing.v.1.2 623_620_00.mad
- Matching example
- MAD optics outputs



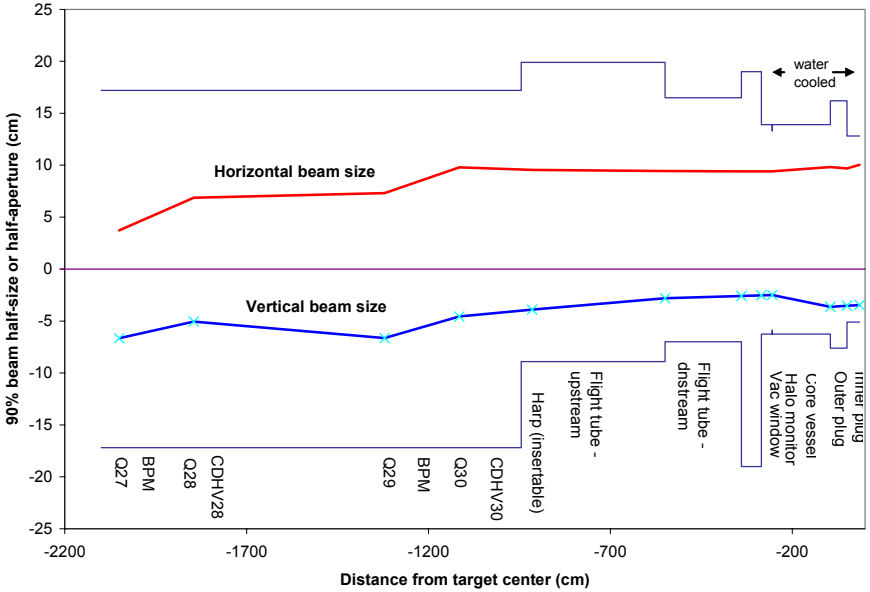
RTBT-Target Interface

(Raparia, Plum et al)

- RTBT-Target interface design is not yet finalized,
  - -Considering splitting doublets for maintenance ease
  - -Linear optics (TRANSPORT) shows present PS is adequate
- Radiation from backsplash shows fife time of these magnet > 30years
- Magnetic field from shielding should be limited to an average of 48 Gauss.
- Enough steering strength > 6cm (x,y) at target



1/4 Beam foot print on the target



Beam size and aperture for beam spreader in the RTBT

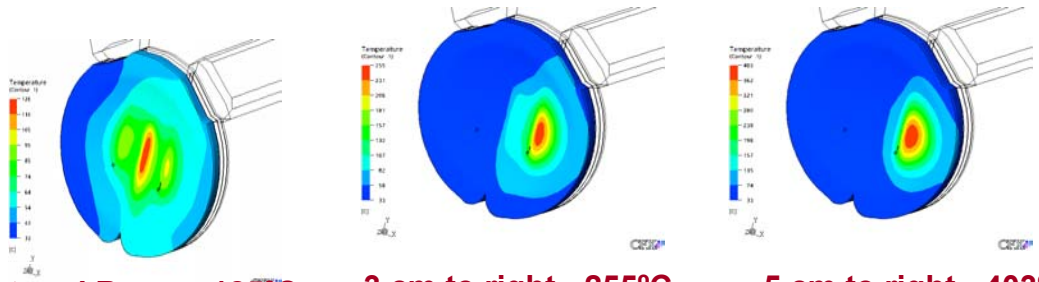
Injection Dump Interface

(Raparia, Plum, M. Wendel et al)

Parameter list state the requirements for the injection dump

Power	150	kW
Particle density	$5x10^{15}$	PPP/m^2
Displacement	± 50	mm
Beam diameter (99%)	20	cm

Simulations for Injection dump show higher temperature for particle density of $5x10^{15}$ PPP/m^2 at ± 50 mm

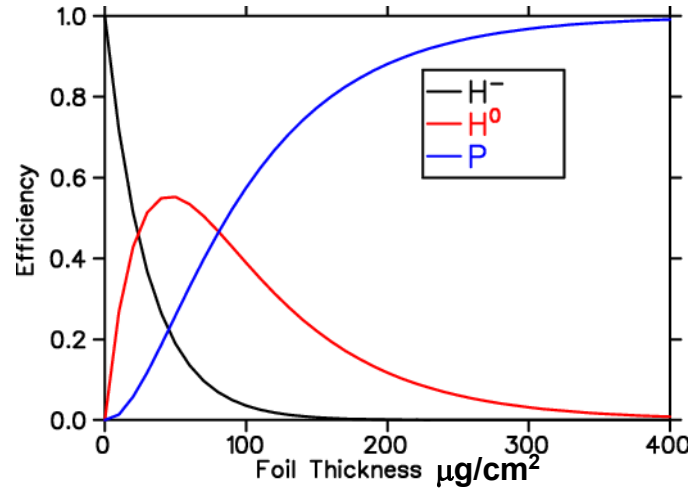


Centered Beam - 125ºC 3 cm to right - 255ºC 5 cm to right - 403ºC

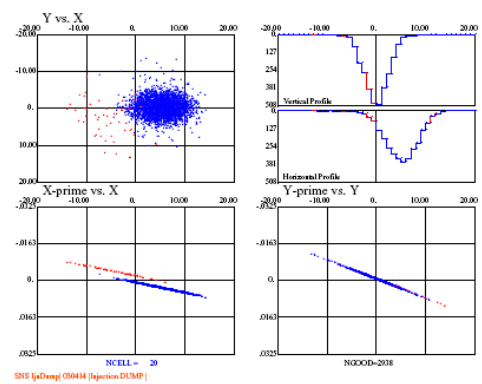
Simulations show for base line design can have ± 50 mm displacement
If all the error ($5x10^{-3}$) in the chicane and injection dump magnets are included

Charge exchange foil can generate up 10% of H^0 depending on the foil thickness
About 2% H^- will miss the foil
Fix: Foil thickness >300 μ g/cm^2

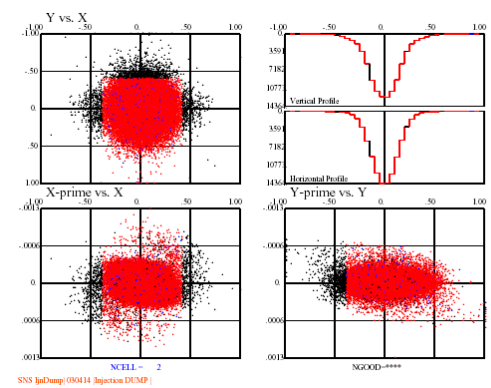
Fractions of H^0, H^- and P at 1Gev



Particle Distribution at Dump



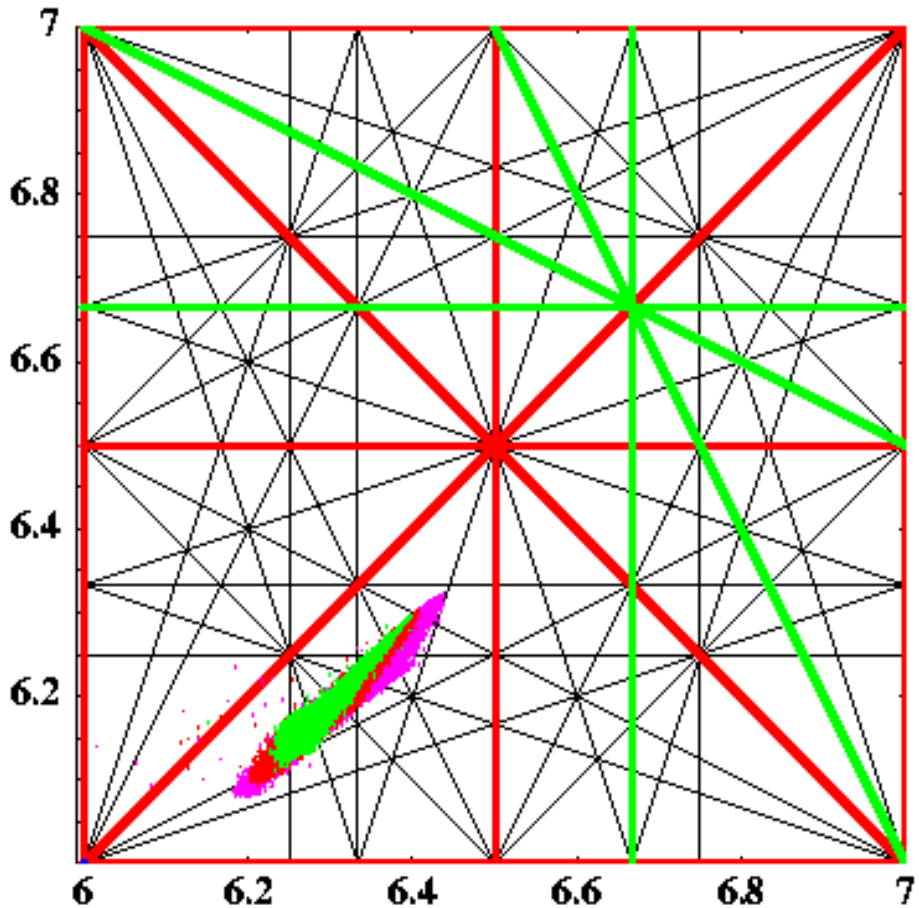
Particle Distribution at Foil



Summary

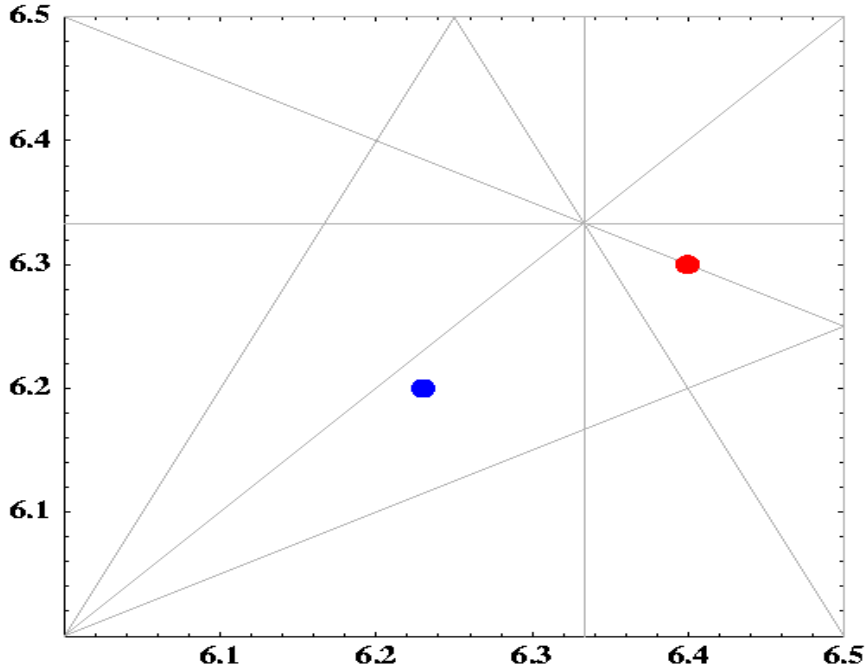
- **Continue to improve and and maintain beam performance:**
  - -Successfully corrected ITF at 1.3GEV in 30Q44 magnets
  - -Successfully achieved tight field variations in all magnets (10E-4,rms)
  - -Sorting schemes were developed to reduce the effect of ITF variation
  - -Sorting schemes were developed to minimize effect of nonlinear resonances
  - -Chicane #2 and #3 multipoles have shown small emittance growth
  - -Tracking with measured field in Chicane #2 shows electron will collected by electron catcher
  - -Better understanding of solenoid configuration
  - -Mad 1.2 including extraction kicker released
  - -Target and injection dump interface
- **Quality Assurance:**
  - -Accept magnets and ½ cells
- **Support installation and commissioning :**
  - -Generate global coordinates complete
  - -Checked installation drawings
- **Continue to explore ring capabilities beyond base line (1.4 MW)**

Ring tuning spread

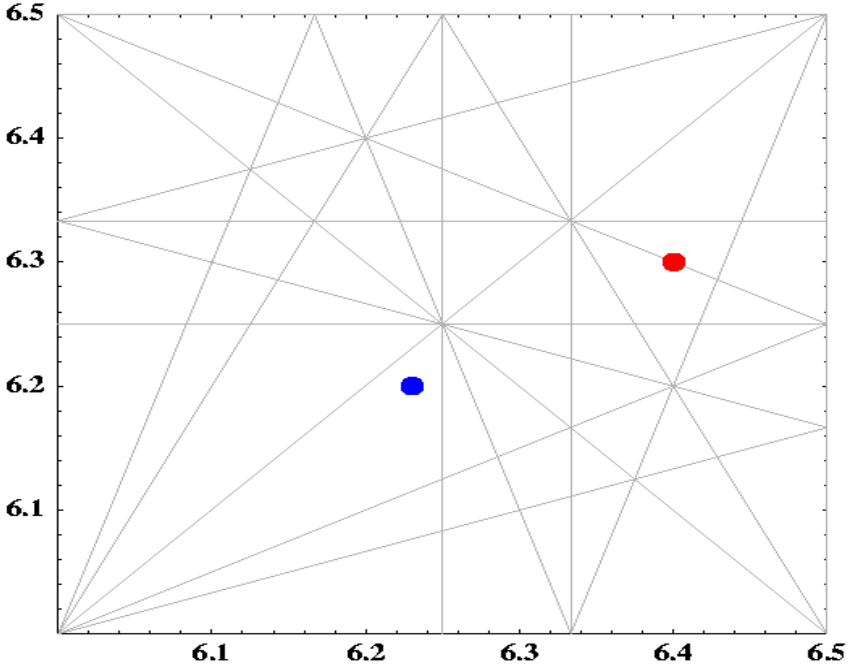


- 2 MW beam at 1 GeV
  - Space charge tune spread about 0.2 (green)
  - Chromatic tune spread must be controlled by Sextupole (red: beam core Dp/p=+/-0.6%; pink: partial halo Dp/p=+/-1.0%)
- Imperfection non-structure resonances are shown in black

Two regions of working points

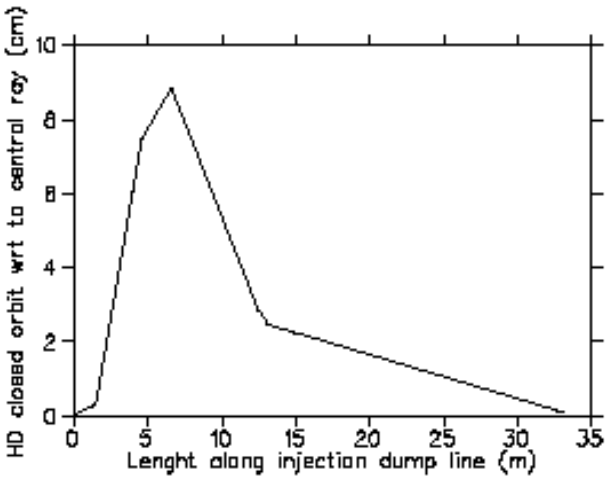


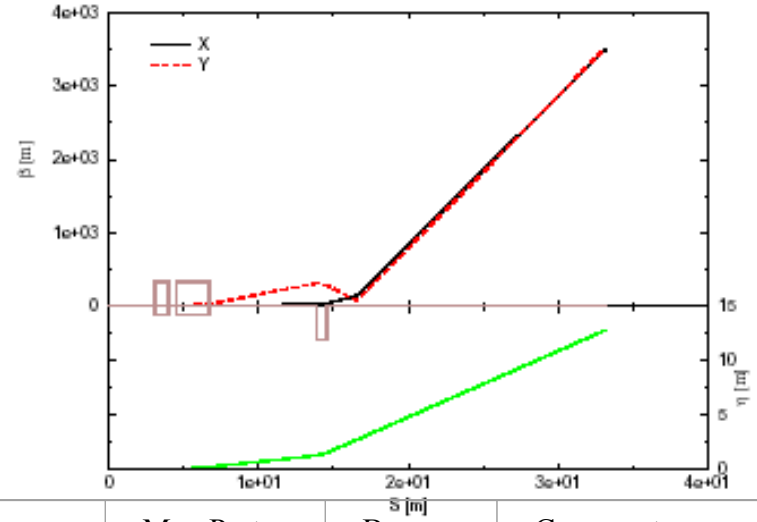
Imperfection resonances up to 3rd order



Imperfection resonances up to 4th order

Injection Dump Optics





Run#	Beam Loss					Max Part. PPP/m^2	Beam inside 20 cm Dia. %	Comments
	Chicane # 2 %	Chicane #3 %	Chicane #4 %	Dump Sept +Quad %	Flight Tube %			
Ref	10^{-3}	-	-	4×10^{-2}	0.07	2.4×10^{15}	99.8	Reference Part. Dis.
1A	10^{-3}	-	-	4×10^{-2}	0.40	2.49×10^{15}	91.9	Match Inj. 1x emit
10	10^{-3}	-	-	4×10^{-2}	0.01	5×10^{15}	99.5	Match Inj. 1x emit
11	10^{-3}	-	-	0.007	0.07	5.3×10^{15}	96.3	Match Inj. 1x emit, error,c4.5cm
7B	10^{-3}	-	-	4×10^{-2}	0.26	3.32×10^{15}	92.9	Mismatch Inj, 2x emit
9C	10^{-3}	-	-	0.15	0.54	2.45×10^{15}	91.5[map1]	Mismatch Inj. 3x emit