IR and Beam-beam

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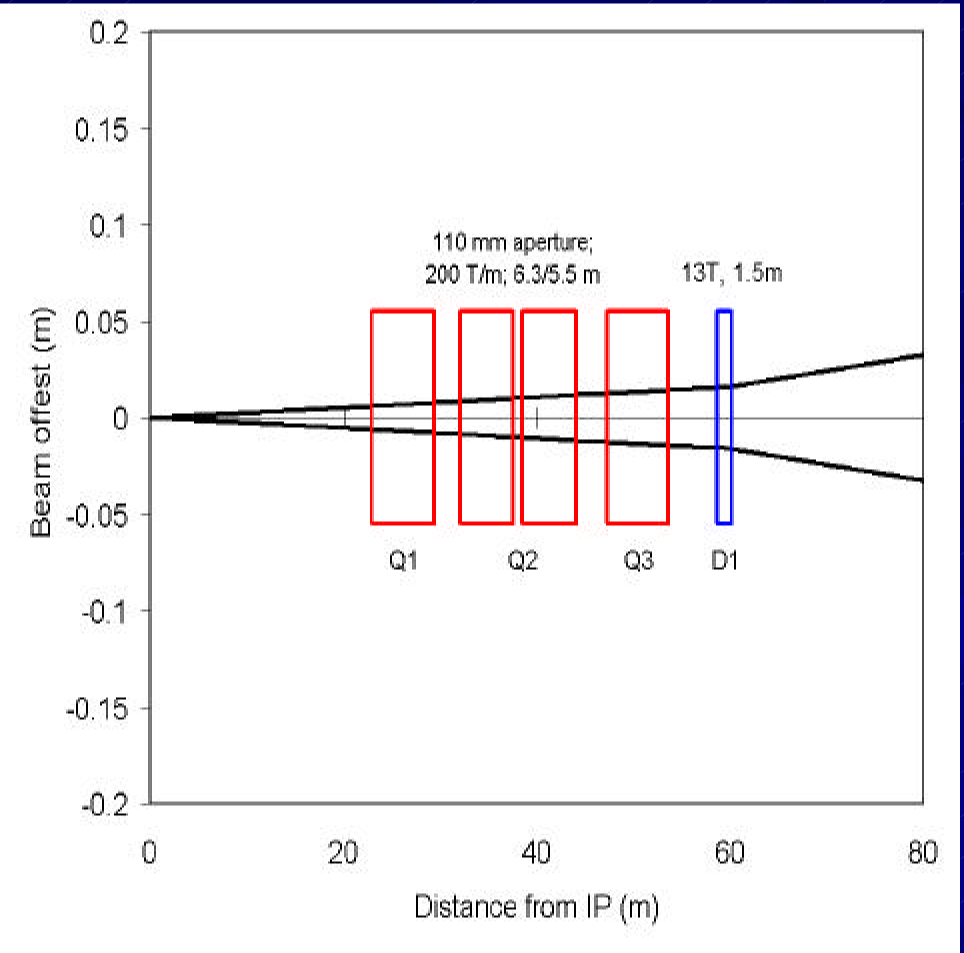
FNAL

Topics

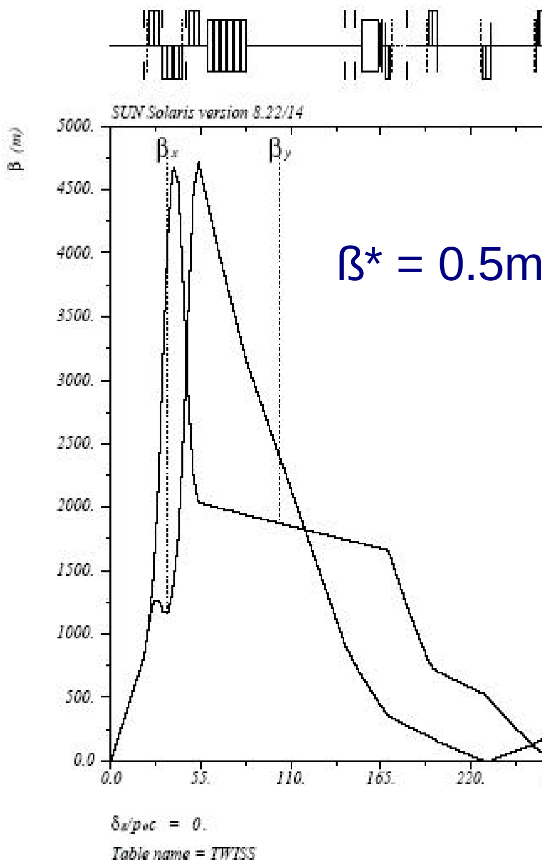
- Triplet first optics with ß* = 0.25m
- Dipole first optics with ß* = 0.28cm
  - Triplet focusing
  - Doublet focusing
- Wire compensation
  - Impact on IR design
  - Studies at RHIC
- Crab cavities and large crossing angles

Baseline Layout

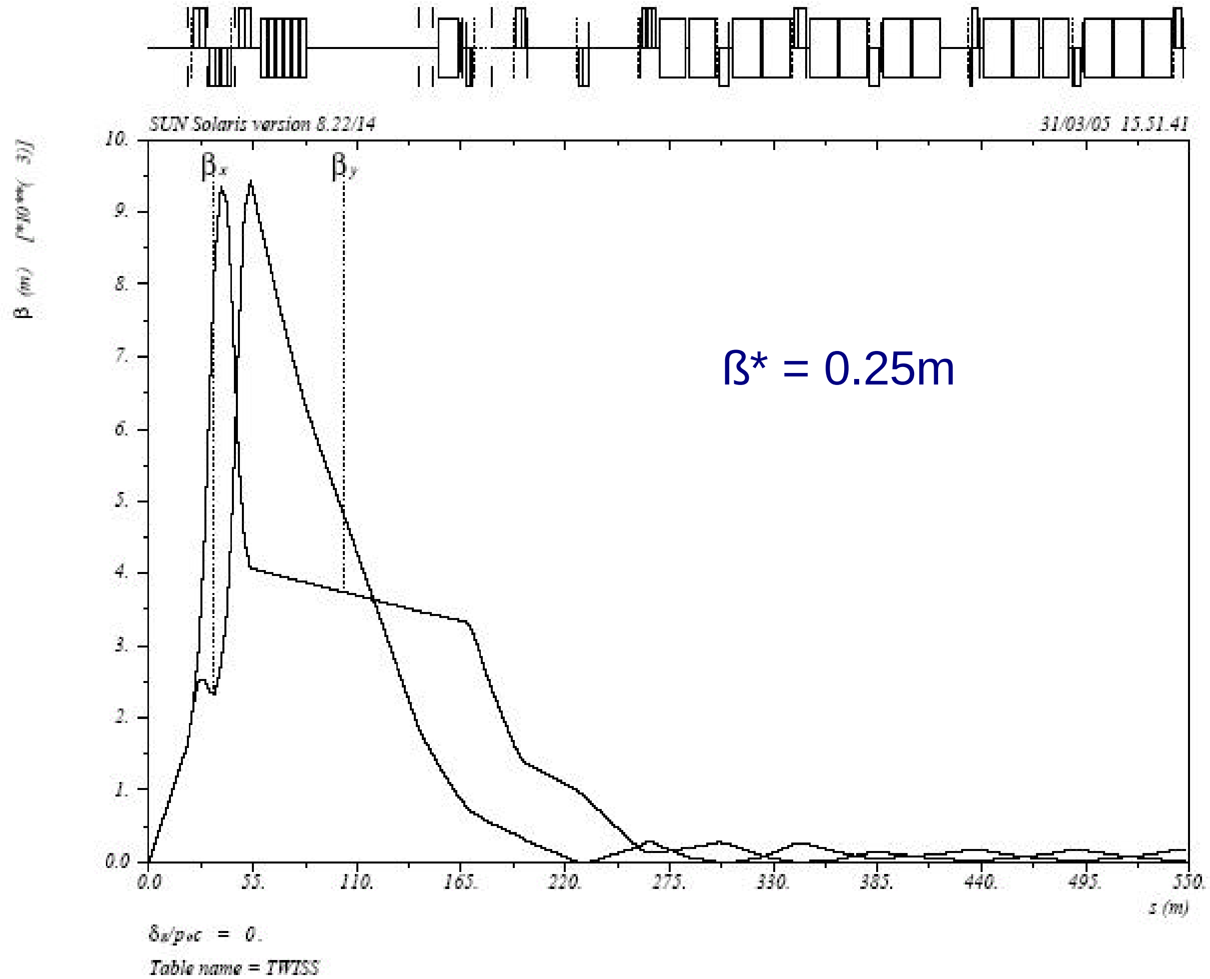


- Quadrupoles first followed by separation dipoles
- Beams go off-axis in the quadrupoles
- Correction algorithm acts on both beams
- 16 long-range interactions on either side of IP

Triplet first optics



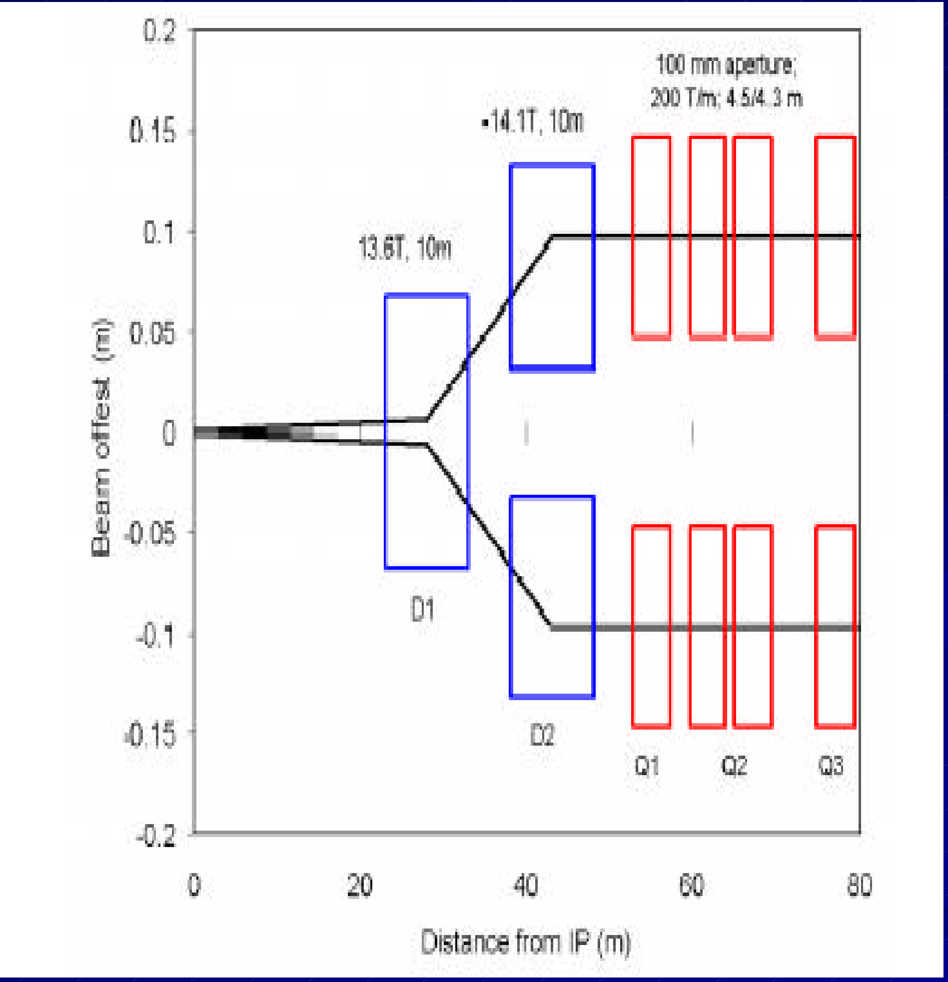
Baseline Optics



J. Johnstone

Gradients < 200 T/m

Separation Dipoles First



Pros

- Reduces long-range interactions 3 fold
- Independent nonlinear correction for each beam

Cons

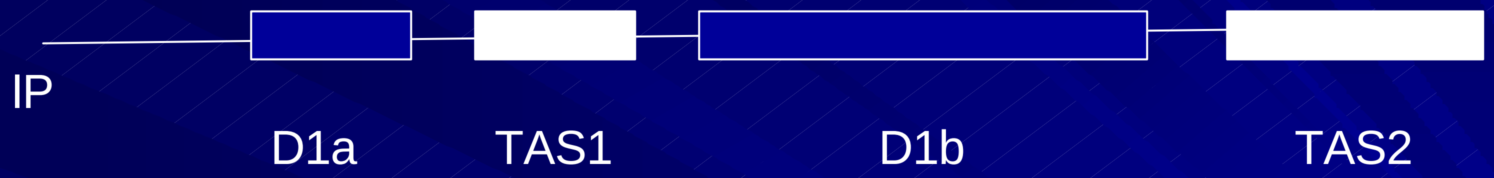
- Larger $ß^*$ for the same $ß_{max}$
- Higher energy deposition in D1 from charged particles

Dipoles First - Matching

- Beams in separate focusing channels
- Triplet quads Q1 – Q3 at fixed gradient = 200 T/m, exactly anti-symmetric
- Positions of all magnets kept the same – polarities change w.r.t quadrupoles first optics
- Strengths of quads Q4 to Q10 < 200 T/m
- Trim quad strengths QT10 to QT13 < 150T/m
- Phase advances across IR are different – could be tweaked
- Solution only at collision optics – sufficient for magnet designers

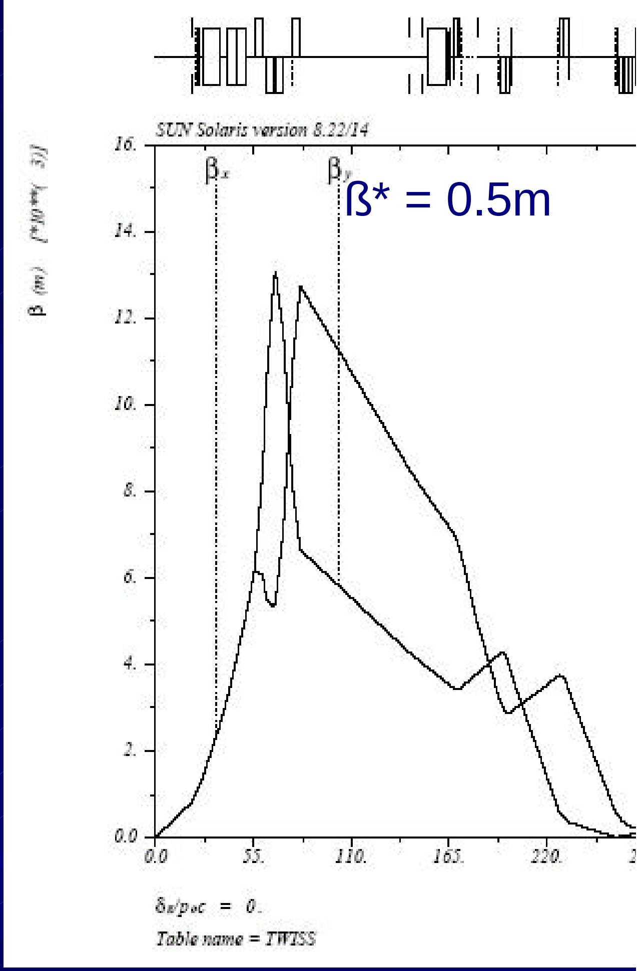
Dipole first optics - 1

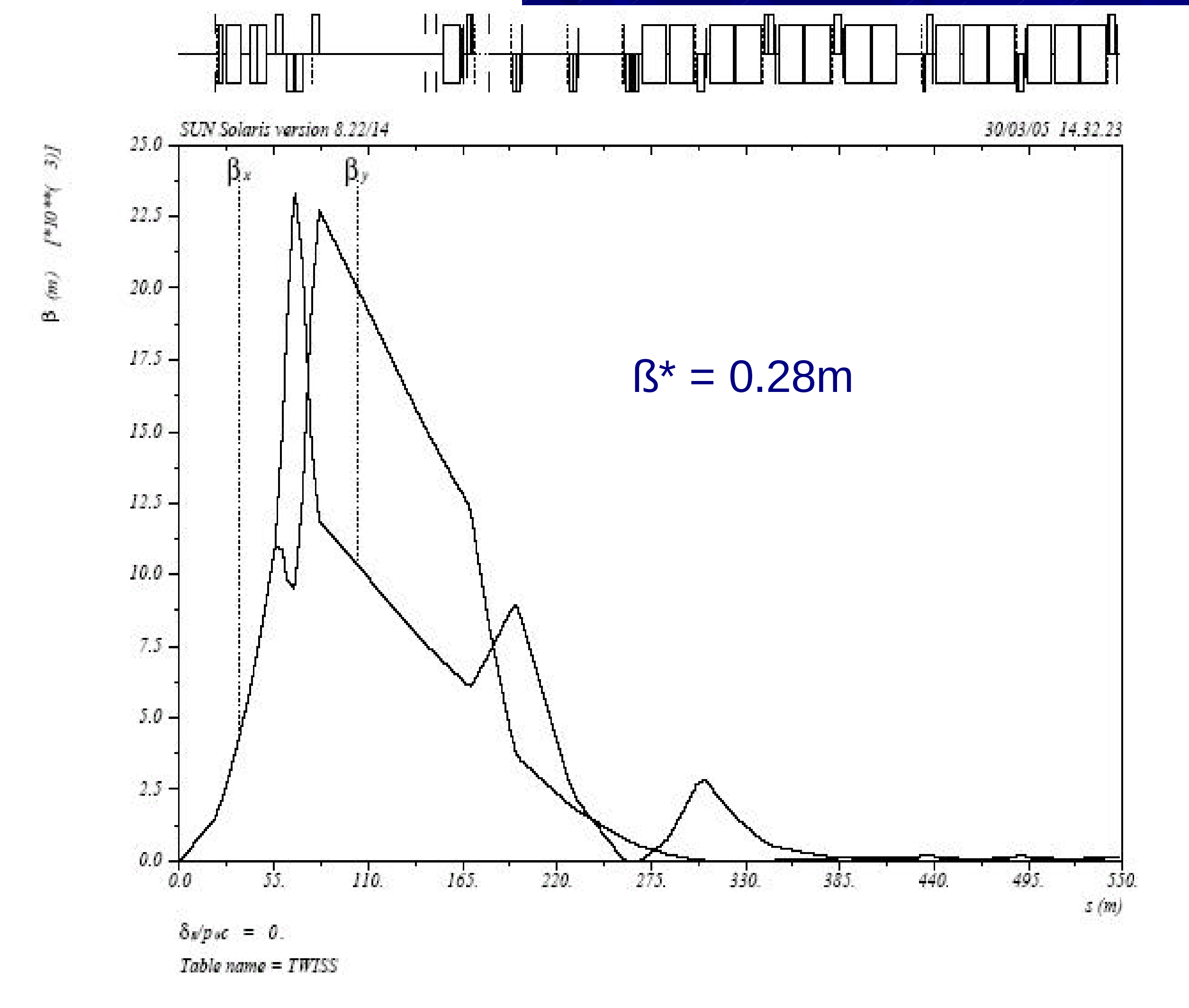
Additional TAS absorber in the present layout – per N. Mokhov



	Earlier layout (PAC 03)	Present layout
D1 dipole	10m long	D1a 1.5m long, D1b 8.5m long
TAS absorber	After D1	TAS1, after D1a TAS2 after D1b
β^*	0.26 m	0.28 m
β^{max}	23 km	23 km

Dipole first optics - 2



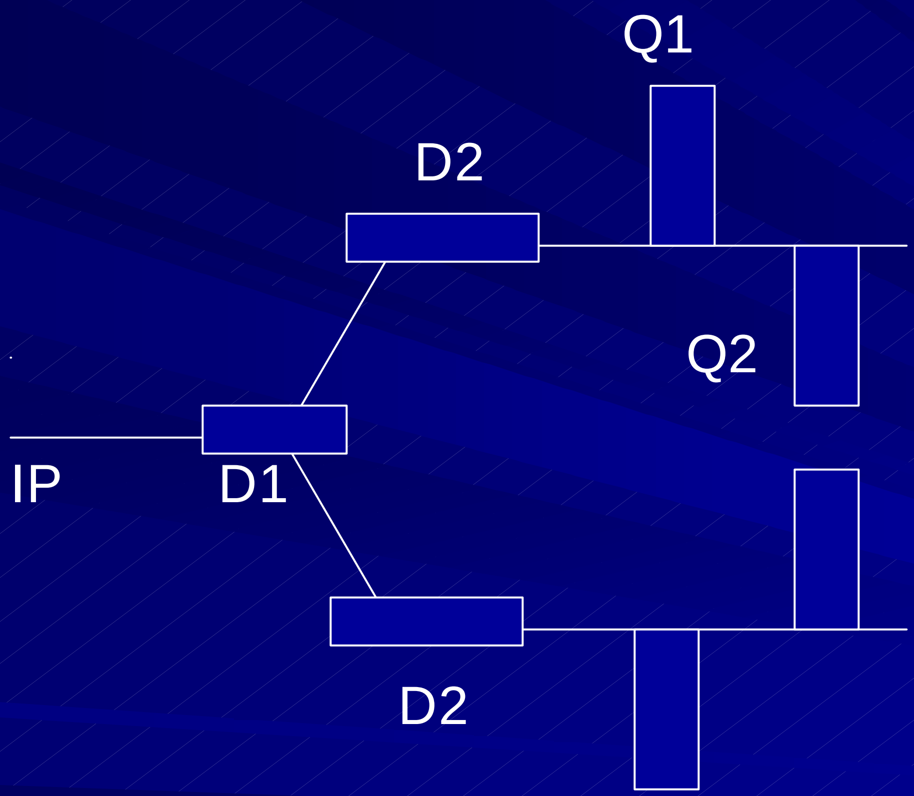


Gradients < 200 T/m

ß Maximum in Quads

	Quads first β^{max} [m]	Dipoles first β^{max} [m]
Q1	4538	15100
Q2	9193	23036
Q3	9427	22720
Q4	3323	12517
Q5	1559	8859
Q6	984	2791
Q7	285	748
Q8	261	2857
Q9	270	693
Q10	153	162
QT11	181	185
QT12	183	183
QT13	173	172

Dipoles first and doublet focusing



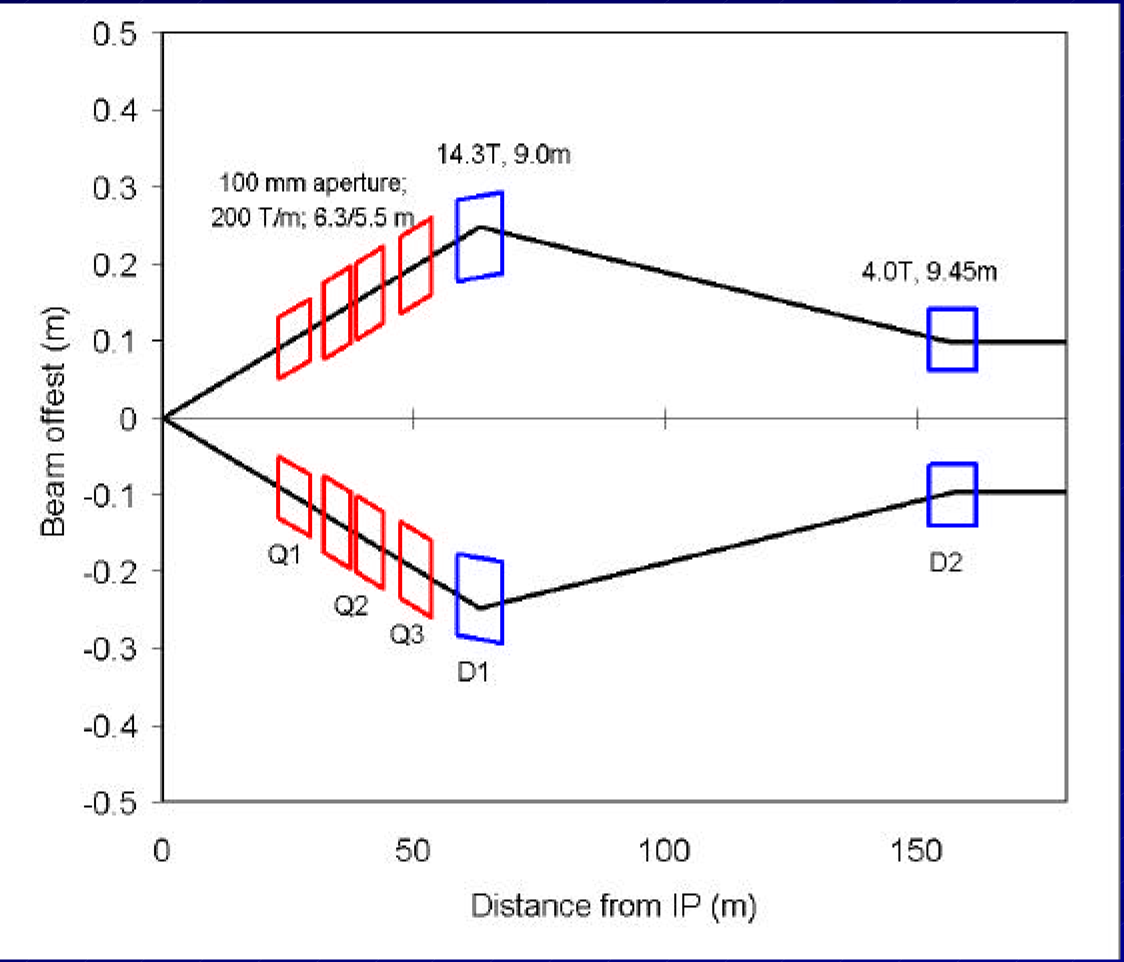
Focusing symmetric about IP

Features

- Requires beams to be in separate focusing channels
- Fewer magnets
- Reduces $ß^{max}$
- Beams are not round at the IP
- Polarity of Q1 determined by crossing plane – larger beam size in the crossing plane to increase overlap
- Significant changes to magnets in matching section.

Large crossing angles - quads first

Twin Quads 1st



Pros

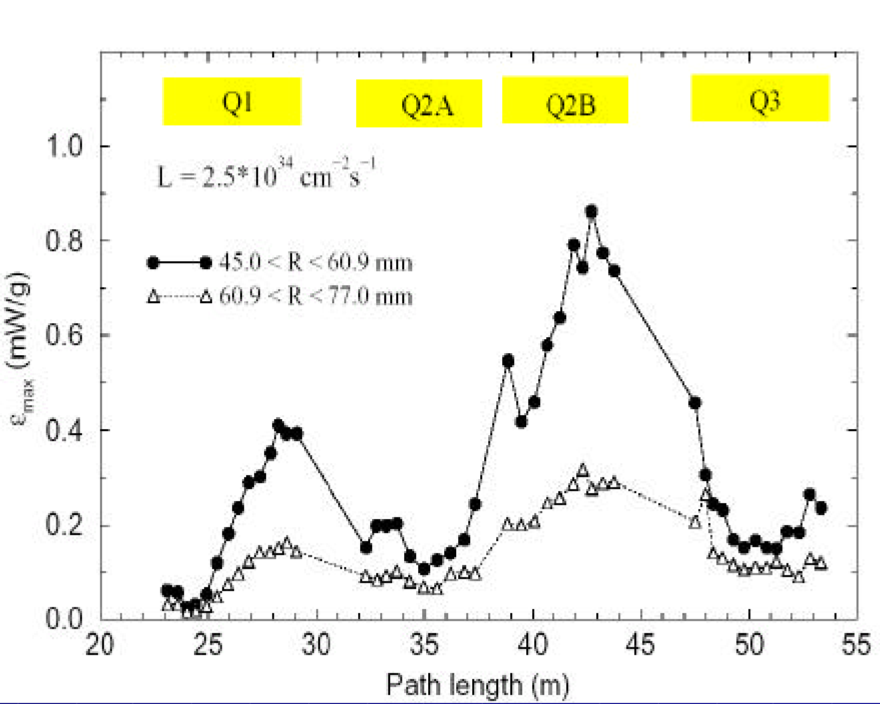
- ➢ Large early separation,
- ➢ Quads closest to the IP, reduces β^{max}

Cons

- ➢ Dual aperture quads with non-parallel axes. AP and magnet issues
- ➢ Large energy deposition in D1
- ➢ Requires crab cavities to restore luminosity if not at beam-beam limit.

Energy Deposition in Quads

- Energy deposition and radiation are *major* issues for new IRs.
- In quad-first IR, Edep increases with L and decreases with quad aperture.
  - E_{max} > 4 mW/g, $(P/L)max$ > 120 W/m, $P_{triplet}$ >1.6 kW at $L = 10^{35}$ cm^{-2} s^{-1}.
  - Radiation lifetime for G11CR < 6 months at hottest spots.



N, Mokhov

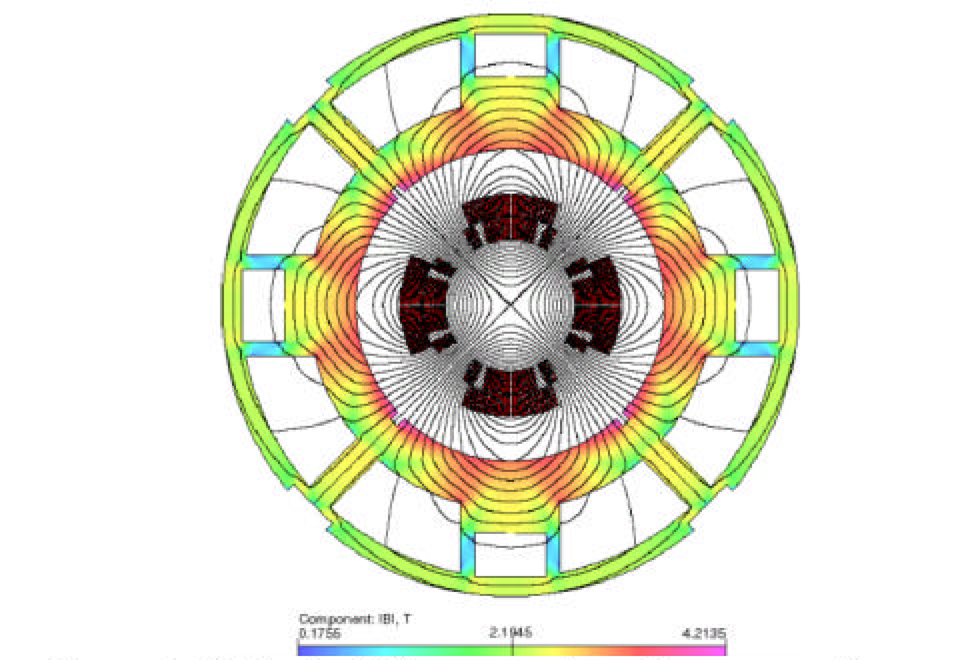


Figure 1: Optimized 90-mm quadrupole cross-section.

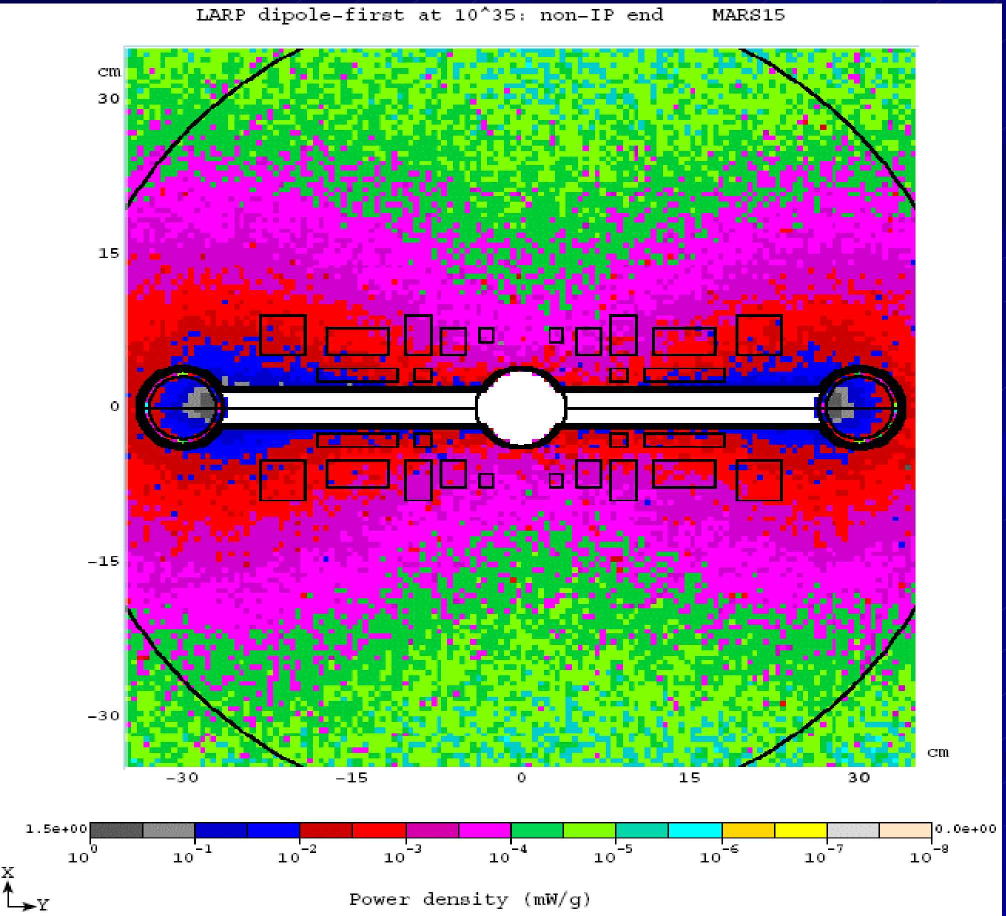
A. Zlobin et al, EPAC 2002

Energy deposition in dipoles

Problem is even more severe for dipole-first IR.

E_{max} on mid-plane ~ 50 mW/g; P_{dipole} ~3.5 kW for L = 10^{35} cm^{-2} s^{-1}.

“Exotic” magnet designs required, whose feasibility is not known.



Open mid-plane
=> showers originate outside the coils; peak power density in coils is reasonable.

Tungsten rods at LN temperature absorb significant radiation.

Considerable R&D required

R. Gupta and N. Mokhov, 2004

Upgrade with NbTi

Table 2: 'Large bore' baseline option: triplet quadrupole lengths and apertures for $\beta^* = 0.25$ m compatible with the NbTi gradient limit (lower curve in Fig. 1).

quad	length m	gradient at 7 TeV T/m	coil aperture mm
Q1	6.0	275	53
Q2	7.4	197	85
Q3	7.8	196	82

"… the choice of coil aperture is driven more by the power density than by the beam acceptance"

"… limitations due to heat deposition not taken into account"

F. Ruggiero et al, EPAC2004

Quad-first IR with $\beta^* = 16$ cm

Nb_3Sn: length = 6m, aperture = 110 mm

NbTi: estimate length ~ 8-9m, aperture ~120-130 mm

=>~30% increase in β_{max}; 15~20% more parasitic collisions.

But

Current NbTi technology is not sufficiently radiation hard.

Smaller temperature margin => more sensitive to beam heating.

And dipole-first IR requires highest possible field: => requires Nb_3Sn

Magnet R&D challenges

All designs put a premium on achieving very high field:

Maximizes quadrupole aperture for a given gradient.

Separates the beams quickly in the dipole first IR

=> bring quads as close as possible to the IP.

Push B_{op} from 8 T -> 13~15 T in dipoles or at pole of quad

=> Nb_3Sn.

All designs put a premium on large apertures:

Decreasing b^* increases b^{max} => quad aperture up to 110 mm?

Large beam offset at non-IP end of first dipole.

=> Dipole horizontal aperture >130 mm.

Energy deposition:

quench stability, cooling, radiation hard materials.

Nb_3Sn is favored for maximum field and temperature margin, but considerable R&D is required to master this technology.

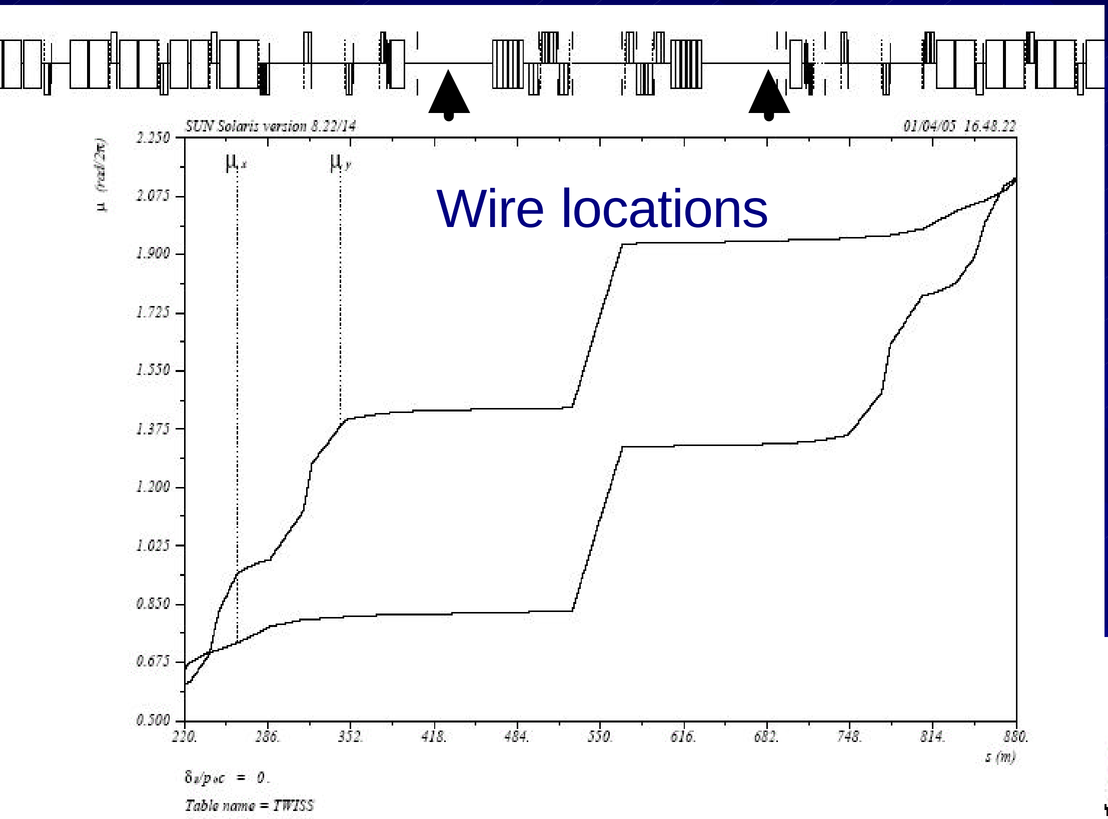
Wire compensation & IR design

If the compensation of long-range interactions is successful, then

- Suggests that quadrupoles first may be the preferred design option for the upgrade

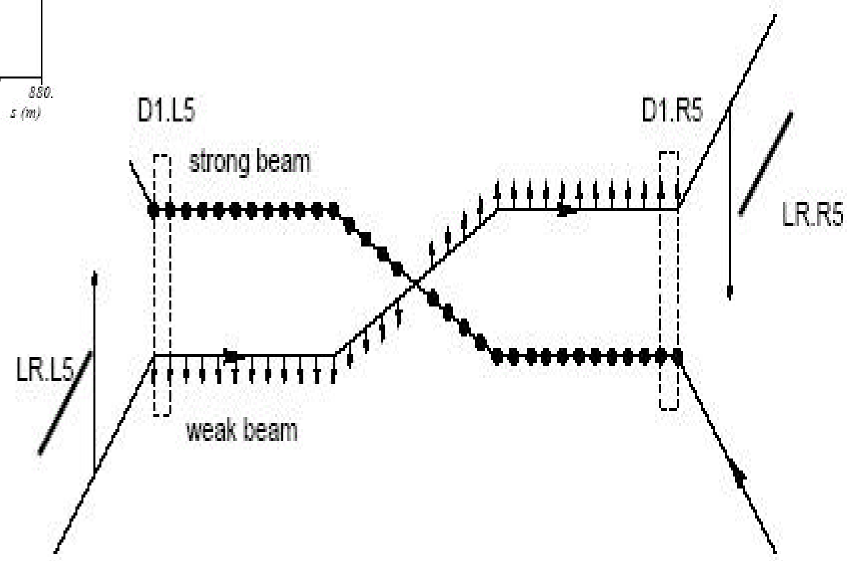
- May allow a smaller beam separation or a smaller crossing angle.
  - Direct increase in luminosity
  - More physical aperture in magnets

LHC – Wire Compensators



Average phase advance from wire to parasitics = 2.6º

Phase advances across IR



J.P. Koutchouk
LHC Project Note 223

SPS Wire compensation studies in 2004

One beam, two wire compensators BBLR1 and BBLR2

July: compensation of BBLR1 by BBLR2,
mismatched emittance ,
scan compensator current and position,
tune scans around SPS & LHC tunes

August test of crossing schemes XX, YY planes
tune scan around LHC tunes

September compensation of BBLR1 by BBLR2,
smaller emittance beam at smaller distance

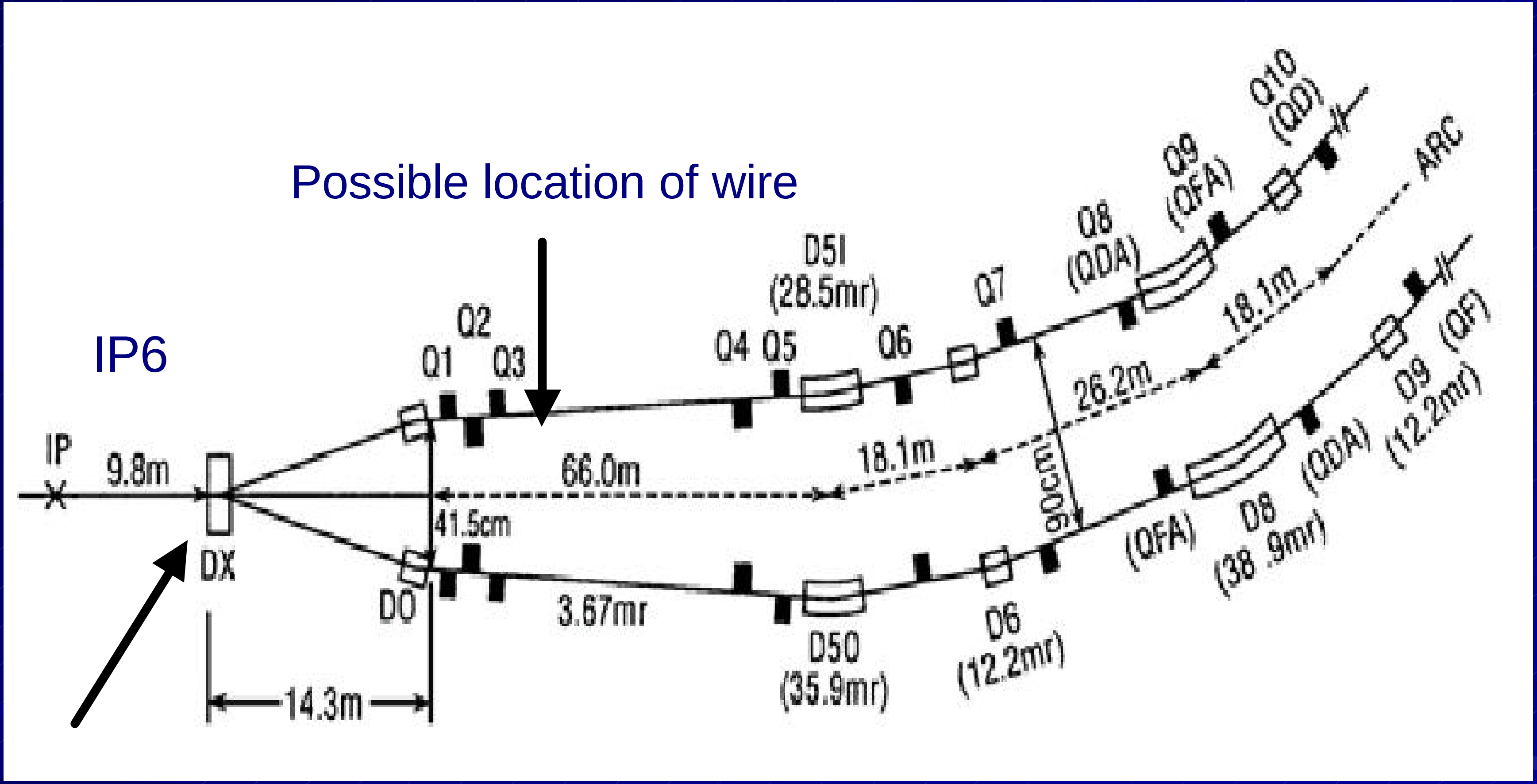
November: test of crossing XY plane, measurement of tails, tune scans

Main result: Compensation of one wire by another worked well at LHC tunes.
Analysis in progress

Complete test of principle: requires long-range interactions between 2 beams

RHIC – Wire compensator

W. Fischer



Parasitic interaction

Phase advance from parasitic to wire = 6^{o}

RHIC: beam-beam studies

- Phase 1: influence of parasitics on lifetime (Apr – May 05)
  Injection energy, 1 bunch/beam
  Parasitic interaction close to DX next to IP6
  Vary beam separation from 1 – 10 s
  Observe: lifetimes, losses, emittances, tunes, orbits
  If necessary, could inject more bunches with more parasitics

If parasitic(s) adversely impact lifetime, proceed to Phase 2

- Phase 2: impact of a wire compensator (Oct 05 or Summer 06)
  Install wire compensator close to Q3
  Study impact of wire compensation and tolerances on beam lifetime etc.
  Will require prior theoretical analysis and simulations

Construction of a compensator

- SPS wire compensator cannot be used in RHIC because of aperture restrictions
- If we proceed to Phase 2, need to build it in the US => requires new LARP funds
- BNL or FNAL could build it
- FNAL – K. Krempetz (PPD)

  If start in May, could be ready by September

  Need drawings for cost estimate

Monitoring the wire compensation

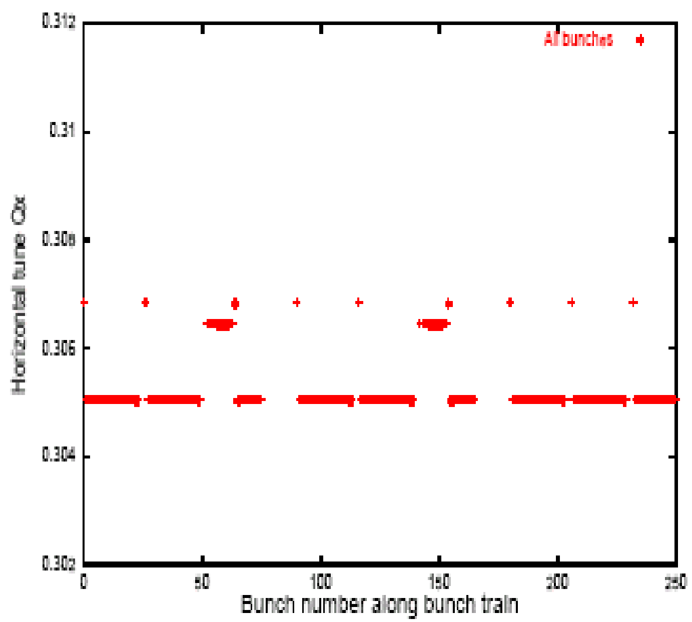


Figure 11: Tune variation along bunch train, new scheme with 75 ns spacing. Alternating crossings.

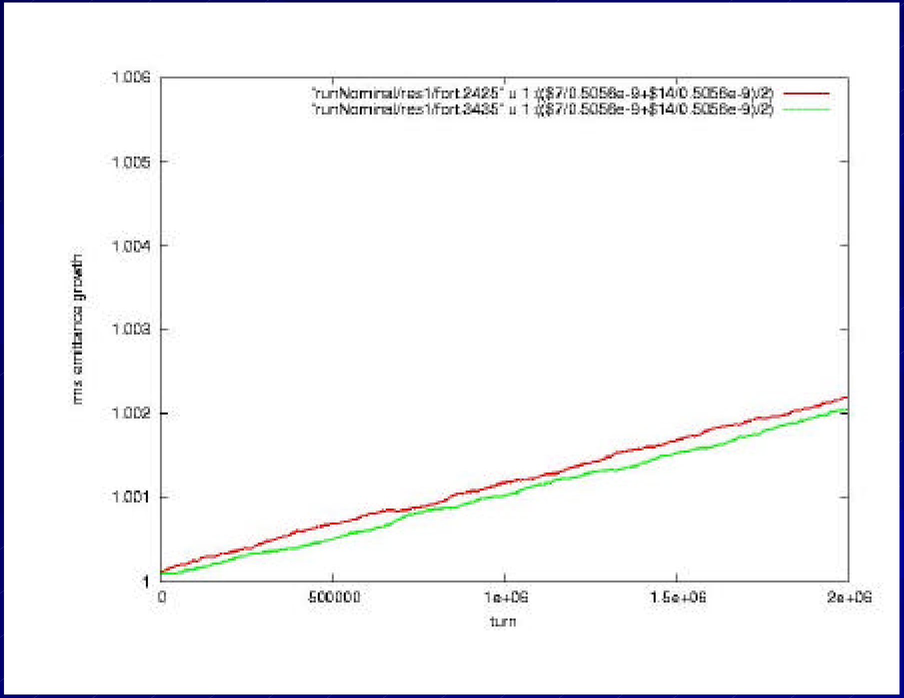
Observations and diagnostics
- Lifetimes and losses first
- Tunes and orbits also
- In the LHC, require tune resolution < 5x 10^{-4} to measure bunch to bunch differences
- Schottky monitor with bunch to bunch capability would be very useful
- May also allow to passively monitor emittance changes bunch to bunch

W. Herr, LHC Project Note 321

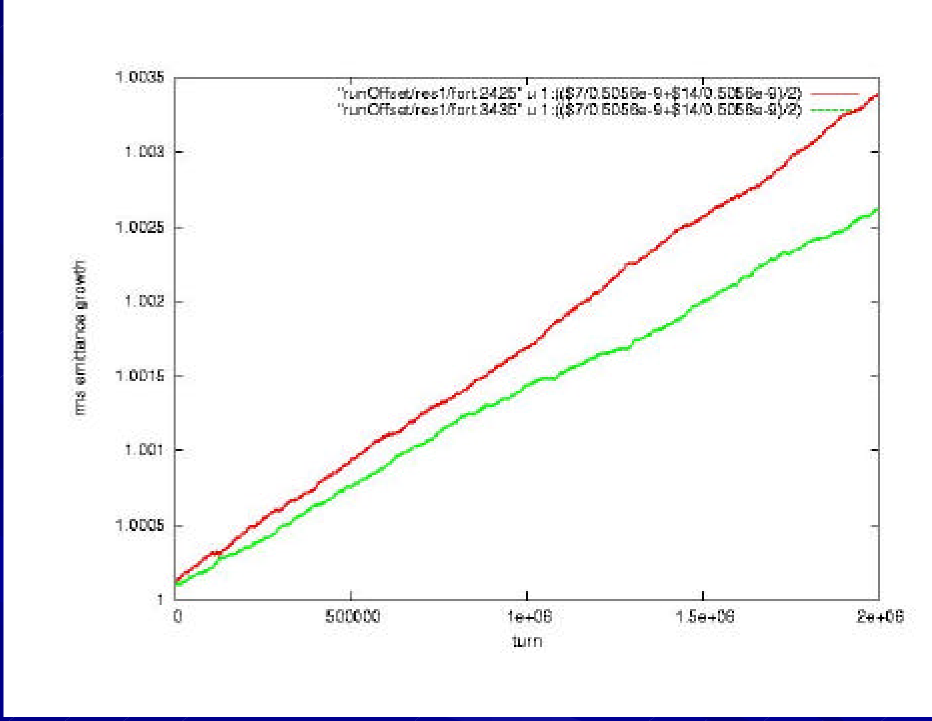
Strong-strong simulations -1

J. Qiang

RMS Emittance growth



Nominal case

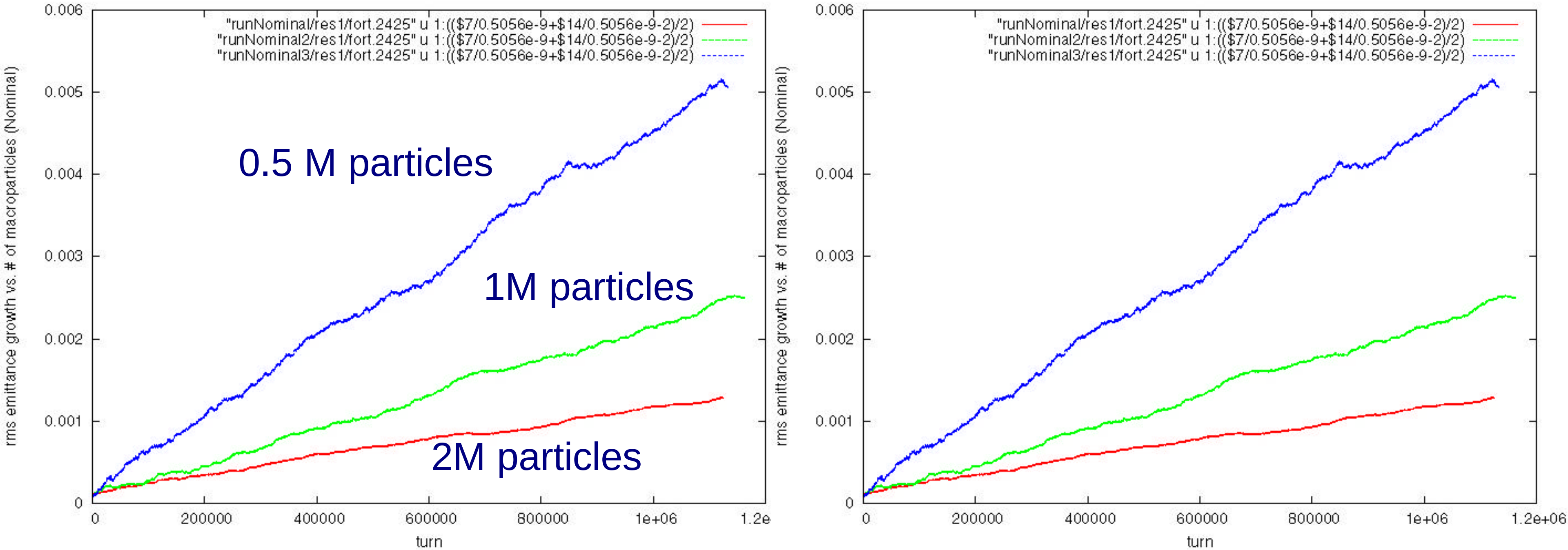


Beams offset by 0.15 sigma

Strong-strong simulations - 2

J. Qiang

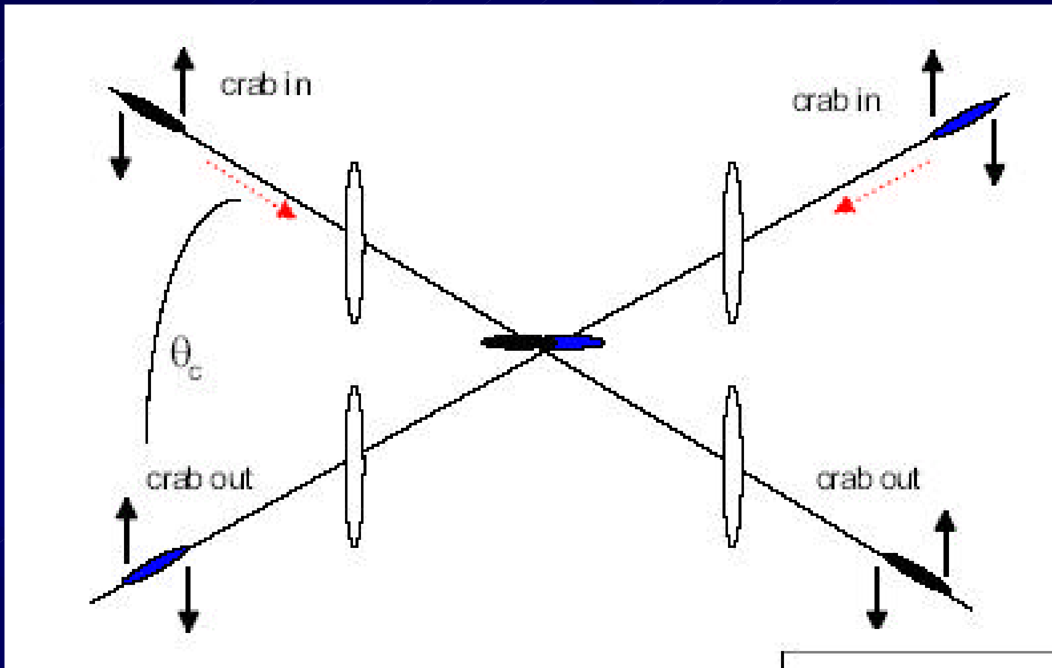
Dependence on number of macro-particles



Beam 1 Beam 2

$$\Delta\varepsilon / \varepsilon_0 = 0.0015 + 0.0003 \times T / M^{0.87}$$

Crab Cavities



At large crossing angles, required to restore luminosity

		KEK B	LHC
crossing angle	θ [mrad]	22	8
beam energy	E [TeV]	0.008	7
collision beta	β^* [m]	0.33	0.25
crab beta	β_{crab} [km]	0.1	2
RF frequency	f_{RF} [GHz]	0.51	1.3
RF voltage	V [MV]	1.4	46

Issues

- Large voltages required
- Sensitivity to cavity noise
- Test with accelerating cavities in a hadron collider

IR and Beam-beam tasks – FY06-07

- IR design

  Quad first – lowest feasible β* consistent with gradients and apertures, field quality

  Dipoles first – Triplet: β*, apertures, gradients, field quality

  Dipoles first – Doublet: explore feasibility
- **Beam-beam compensation**

  Phase 1: Machine studies in RHIC, simulations

  Phase 2: Build wire compensator, machine studies in RHIC and weak-strong simulations with BBSIM
- Strong-strong beam-beam simulations: emittance growth with swept beams (luminosity monitor), **wire compensation**, and halo formation (Beambeam3D)
- Energy Deposition

  IR designs (quadrupole and dipole first), tertiary collimators, and the forward detector regions (CMS, TOTEM, FP420 and ZDC).

Level of effort FY06-FY07

	BNL	FNAL	LBL
IR design		1*	-
Beam-beam	0.2 + student	0.5	1*
Energy deposition	-	1*	-

Does not include wire construction cost (labor and materials)

* - requires new post-doc hire

IR Mini-Workshop at FNAL

- In October 2005 at FNAL, before the next collaboration meeting
- Topics

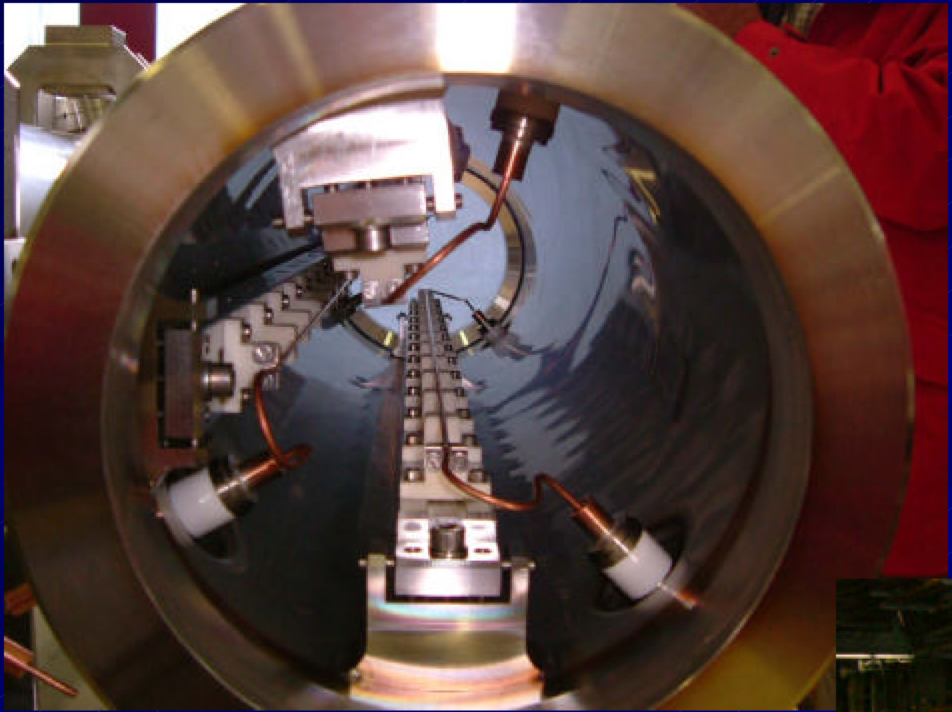
  - Beam-beam compensation: wires, e-lens

  - Energy deposition, quench levels, TAN/TAS integration

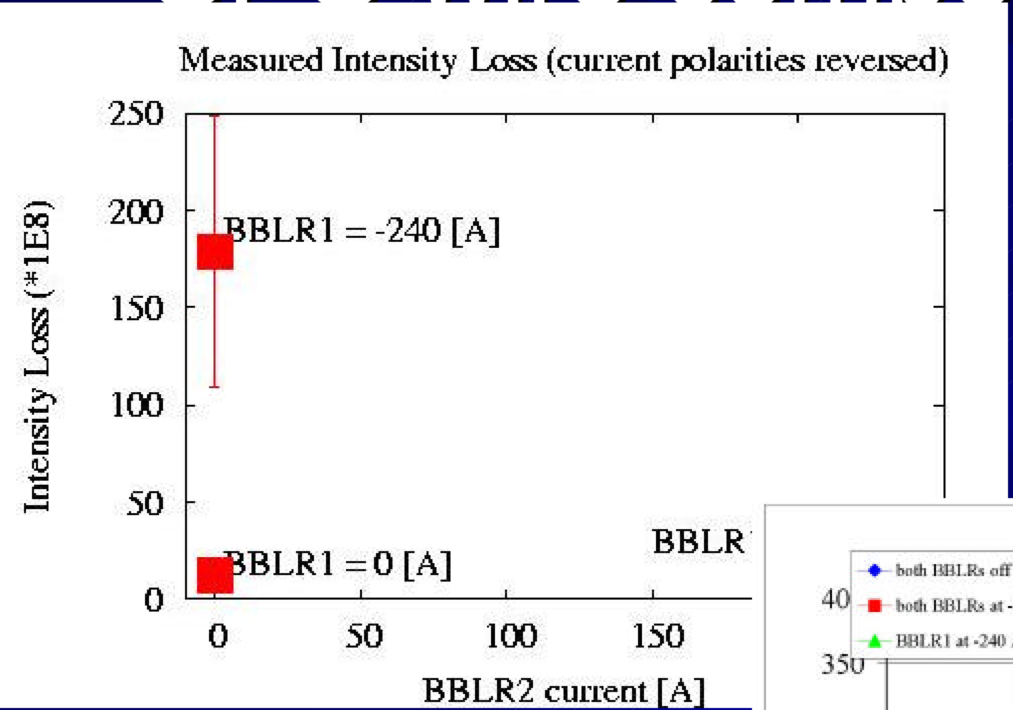
  - Feasibility of large x-angles and crab cavities in hadron colliders

Backups

SPS Wire experiment - 2004



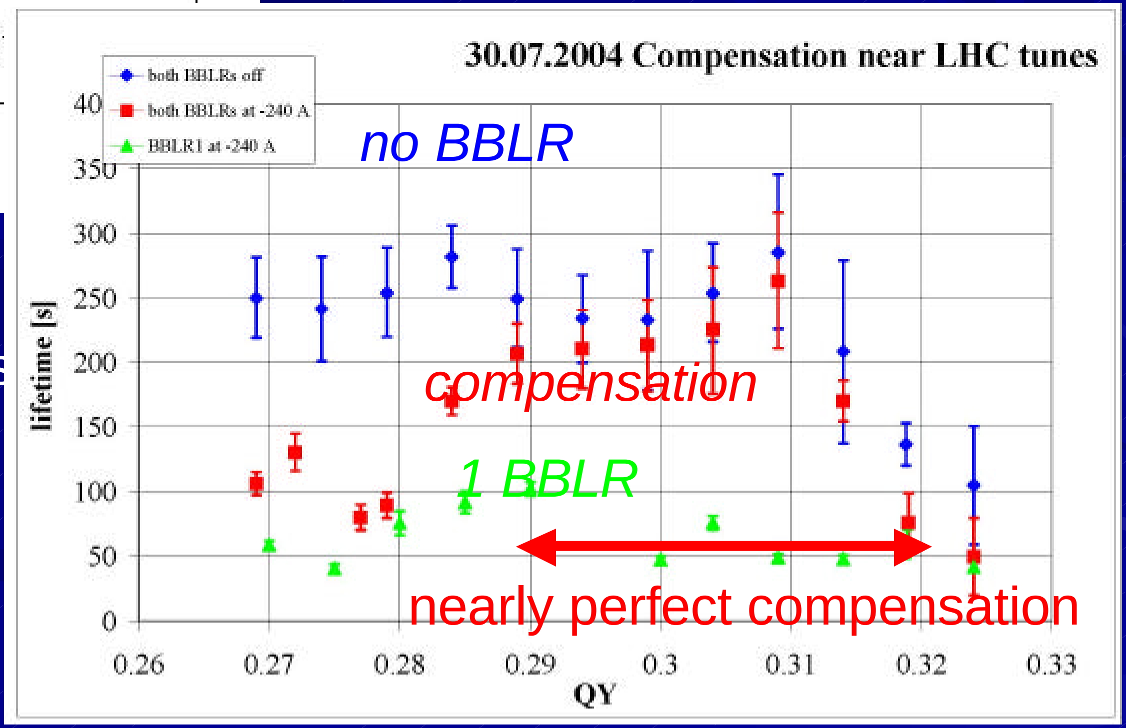
SPS wire compensation results



Intensity Loss compensated by 2nd wire

Tune scan around LHC tunes

tune scan with compensation of 2 BBLRs in the CERN SPS near the LHC working point



Crab Cavities – Emittance Growth