SuperB Design and Update

M. Sullivan
for
the SuperB team

Thomas Jefferson National Accelerator Facility
Newport News, Virgina
January 26, 2010

Outline

- Some of the physics
- Accelerator Design
  - Basic concepts
  - Ring
  - Injector
  - Lattice – IR optics
  - Collision and crab waist
  - DAΦNE results
- IR Design
  - Parameters
  - Layout
  - QD0
  - Backgrounds
- Summary

Physics

- The success of the recent B-factories (KEKB and PEP-II) has led to interest in a super B-factory: one with 50 times more luminosity ($1x10^{36}$ $cm^{-2}s^{-1}$)
- A super B-factory would be able to integrate 15 ab^{-1} per year and collect 75 ab^{-1} in 5 years

Physics Program in two sentences

$$\frac{|\delta_{bq}|}{\Lambda_{eff}}$$

SuperB Physics Program is such that :

* if NP particles are discovered at LHC then SuperB can study the flavour structure of the NP

* SuperB can explore a NP scale beyond the LHC reach

$L \sim 10^{34}\ cm^{-2}\ s^{-1} \leftrightarrow$ EW scale ~100GeV

$L \sim 10^{36}\ cm^{-2}\ s^{-1} \leftrightarrow$ TeV scale

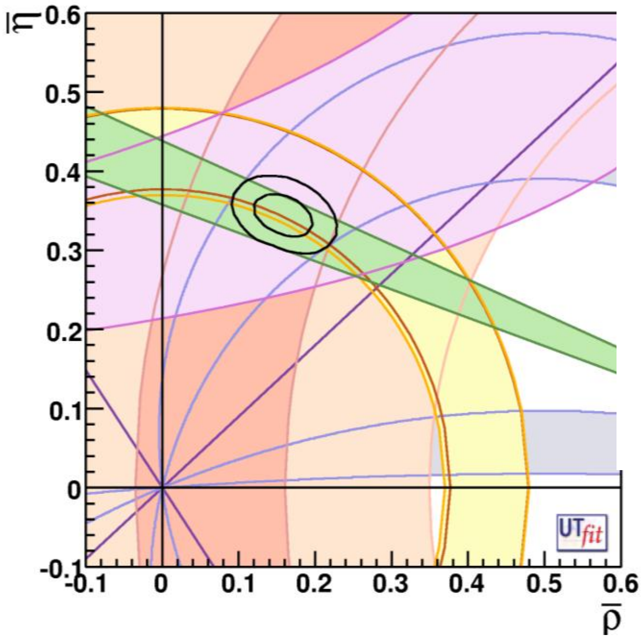
KEKB delivered 1 ab^{-1} in 10 yrs, PEP-II ~0.5 ab^{-1} in 8 yrs

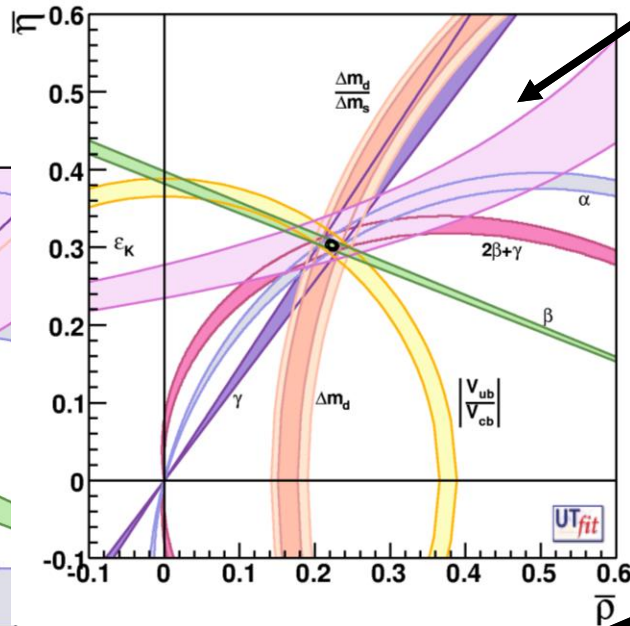
CP violation in the Standard Model

CKM matrix parameters

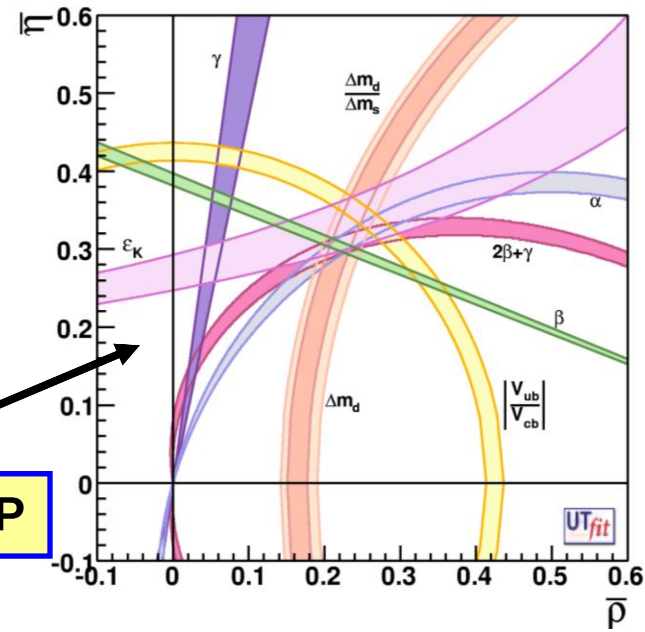
SM remains intact

Today





SuperB+Lattice improvements



SM inconsistent -> NP

ρ = 0.163   0.028
η = 0.344   0.016

Error reduction

ρ =   0.0028
η =   0.0024

Improving CKM is crucial to look for NP

Taken from the Physics Introduction at the SLAC workshop

New physics reach

- Dark Sector
  - New theory about dark forces at the 1 GeV scale
    - http://www-conf.slac.stanford.edu/darkforces2009/
  - High luminosity e+e- colliders will have a chance to look in this region for new physics
  - All low energy high luminosity machines??
  - Triggers have to be redesigned
  - Example:
    - Sit on the Upsilon 3S and look for events with only 2 pions in the final state that reconstruct to the mass difference between the 3S and the 1S. Then you have made a 1S that disappeared. You can now count the number of 1S events that decay invisibly. The SM has a prediction for this number. You look to see if the value you get is different. Some new physics models have a prediction for this number.

SuperB Accelerator

- Luminosity of $1x10^{36}$ $cm^{-2}s^{-1}$ on the Upsilon 4S
- How?
  - Same beam currents as now (~2 A)
  - About the same number of bunches (1000-1200)
    - PEP-II had 1750
  - Bunch length a little shorter but very similar (~5mm)
  - ---
  - Low emittance beams (2-3 nm in X, ~4 pm in Y)
    - PEP-II emittances (20-50 nm in X, ~2000 pm in Y)
    - Modern light sources are in this range
  - Very low beta*s (2-3.5 cm in X, 0.2-0.35 mm in Y)
    - PEP-II beta*s (25-40 cm in X, ~10 mm in Y)
  - Give up luminosity because beta* Y is much shorter than the bunch length (lose factor of ~20)
  - Improve the collision with a Crab Waist (gain a factor of ~3)
- Polarized electrons (>80%)
- Able to go to the other Upsilon resonances
- Able to go down to the Tau-Charm region
- Use a large fraction of the PEP-II accelerator and detector hardware

Indico links to the last four workshop presentations

- February 2009 (Orsay, France)
  - http://agenda.infn.it/conferenceDisplay.py?confId=959
- June 2009 (Perugia, Italy)
  - http://agenda.infn.it/conferenceDisplay.py?confId=1161
- October 2009 (SLAC)
  - http://agenda.infn.it/conferenceDisplay.py?confId=1742
- December 2009 (Frascati, Italy)
  - http://agenda.infn.it/conferenceDisplay.py?confId=1165

Super-B Accelerator Interested Contributors (Fall 2009)

- D. Alesini, M. E. Biagini, R. Boni, M. Boscolo, T. Demma, A. Drago, M. Esposito, S. Guiducci, G. Mazzitelli, L. Pellegrino, M. Preger, P. Raimondi, R. Ricci, C. Sanelli, G. Sensolini, M. Serio, F. Sgamma, A. Stecchi, A. Stella, S. Tomassini, M. Zobov (INFN/LNF, Italy)
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- F. Meot, N. Monseu (Grenoble, France)
- F. Bosi, E. Paoloni (Pisa University, Italy)

Machine Parameters

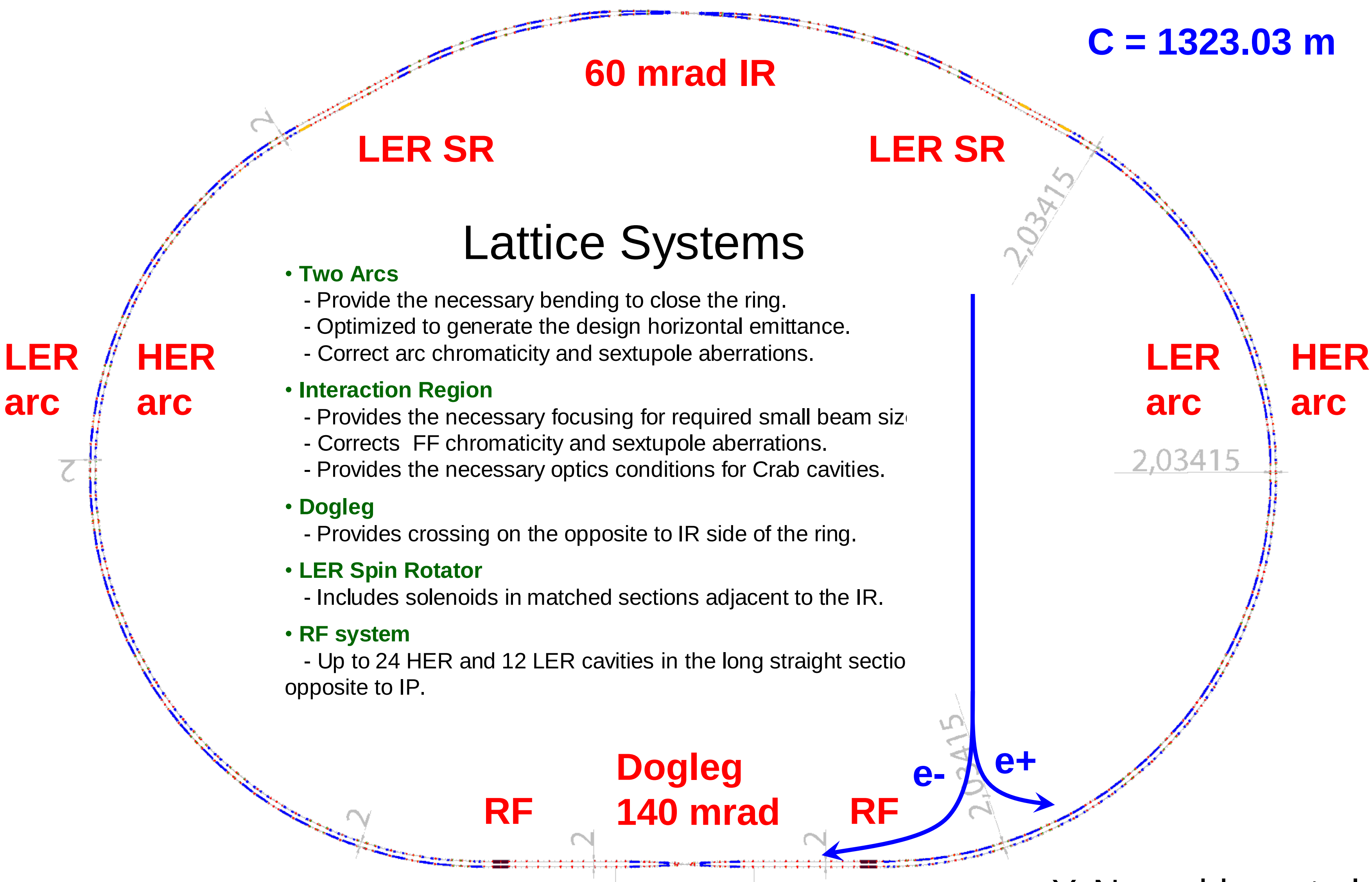
SuperB Parameters July 22 2009

SuperB Parameters		(in bold: computed values)			
Parameter	Units		Super-B		Super-B
			TorVergata		LNF
			1-Mar-09		22-Jul-09
			with SR		with SR LER
E HER (positrons)	GeV		6.9		6.7
E LER (electrons)	GeV		4.06		4.18
Energy ratio			1.70		1.60
r0	cm		2.83E-13		2.83E-13
X-Angle (full)	mrad		60		60
Beta x HER	cm		2		2
Beta y HER	cm		0.037		0.032
Coupling (high current)			0.0025		0.0025
Emit x HER	nm		1.6		1.6
Emit y HER	nm		0.004		0.004
Bunch length HER	cm		0.5		0.5
Beta x LER	cm		3.5		3.2
Beta y LER	cm		0.021		0.02
Coupling (high current)	%		0.0025		0.0025
Emit x LER	nm		2.8		2.56
Emit y LER	nm		0.007		0.0064
Bunch length LER	cm		0.5		0.5
I HER	mA		2200		2120
I LER	mA		2200		2120
Circumference	m		2105		1315
N. Buckets distance			2		2
Gap			0.97		0.97
Frf	Hz		4.76E+08		4.76E+08
Fturn	Hz		**1.43E+05**		**2.28E+05**
Fcoll	Hz		**2.31E+08**		**2.31E+08**
Num Bunch			**1619**		**1011**
N HER			**5.96E+10**		**5.74E+10**
N LER			**5.96E+10**		**5.74E+10**
Sig x HER	microns		**5.657**		**5.657**
Sig y HER	microns		**0.038**		**0.036**

SuperB Parameters July 22 2009

Sig x LER	microns		**9.899**		**9.051**
Sig y LER	microns		**0.038**		**0.036**
Piwinski angle HER	rad		**26.52**		**26.52**
Piwinski angle LER	rad		**15.15**		**16.57**
Sig x HER effective	microns		**150.15**		**150.15**
Sig x LER effective	microns		**150.37**		**150.32**
X-angle factor HER			**0.038**		**0.038**
X-angle factor LER			**0.066**		**0.060**
Cap Sig X	microns		**11.402**		**10.673**
Cap Sig Y	microns		**0.054**		**0.051**
R (hourglass factor)			0.900		0.900
Cap Sig X eff	microns		212.13		212.13
Lumi calc	/cm2/s		**1.02E+36**		**1.02E+36**
Tune shift x HER			**0.0018**		**0.0017**
Tune shift y HER			**0.1271**		**0.1170**
Tune shift x LER			**0.0052**		**0.0045**
Tune shift y LER			**0.1220**		**0.1170**
Damping_long HER	msec		21		14.5
Damping_long LER	msec		20.0		22.0
Uo HER	MeV		2.3		2.03
Uo LER	MeV		1.40		0.83
alfa_c HER			3.50E-04		4.04E-04
alfa_c LER			3.20E-04		4.24E-04
sigma-EHER			5.80E-04		6.15E-04
sigma-E LER			8.20E-04		6.57E-04
CM sigma_E			**1.00E-03**		**9.00E-04**
SR power loss HER	**MW**		**5.06**		**4.30**
SR power loss LER	**MW**		**3.08**		**1.76**
Touschek lifetime HER	min		33		35
Touschek lifetime LER	min		17		16
Luminosity lifetime HER	min		5.20		4.95
Luminosity lifetime LER	min		5.20		4.95
Total lifetime HER	**min**		**4.49**		**4.34**
Total lifetime LER	**min**		**3.98**		**3.78**
RF plug power	MW		**16.28**		**12.13**

Latest Ring Layout

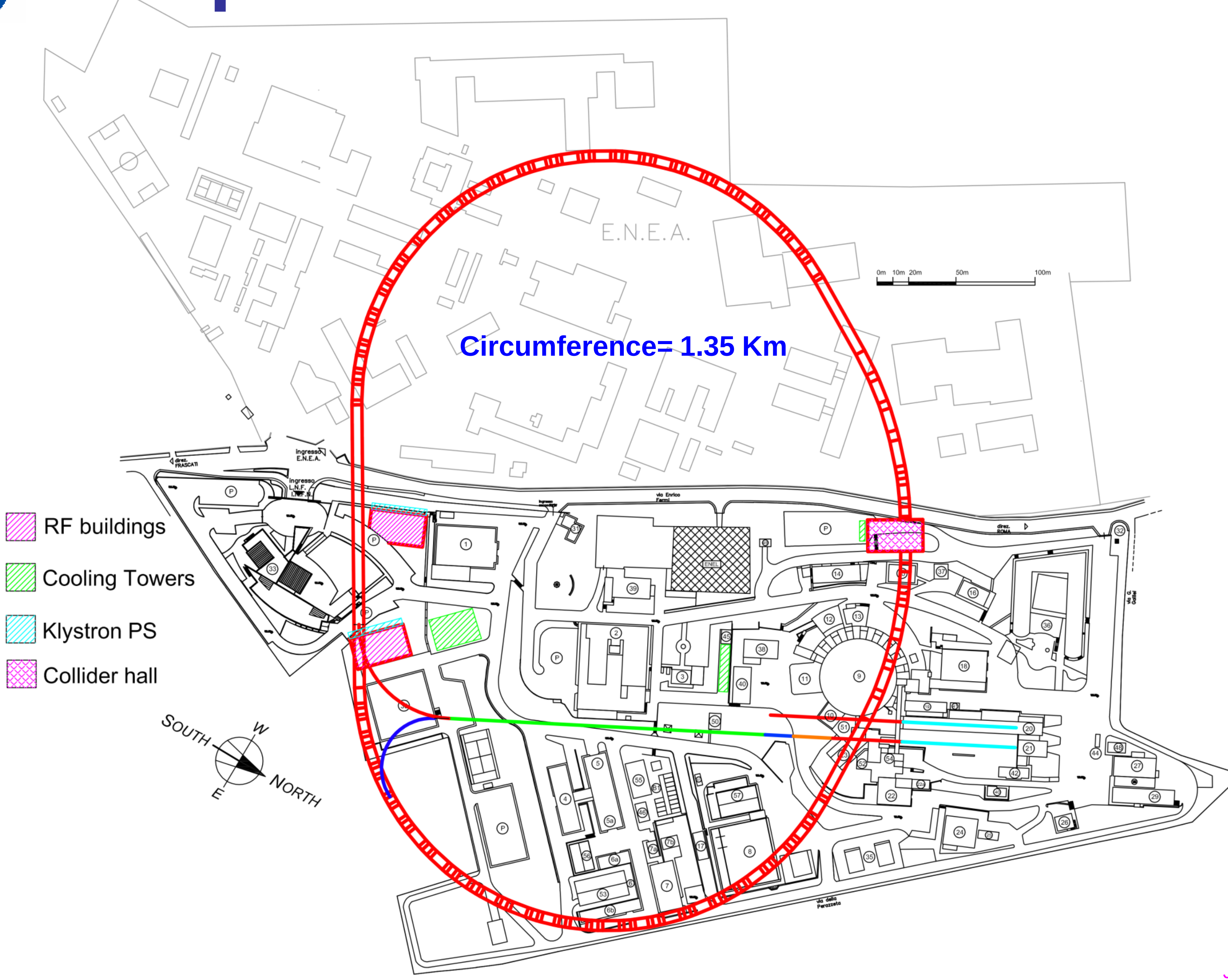


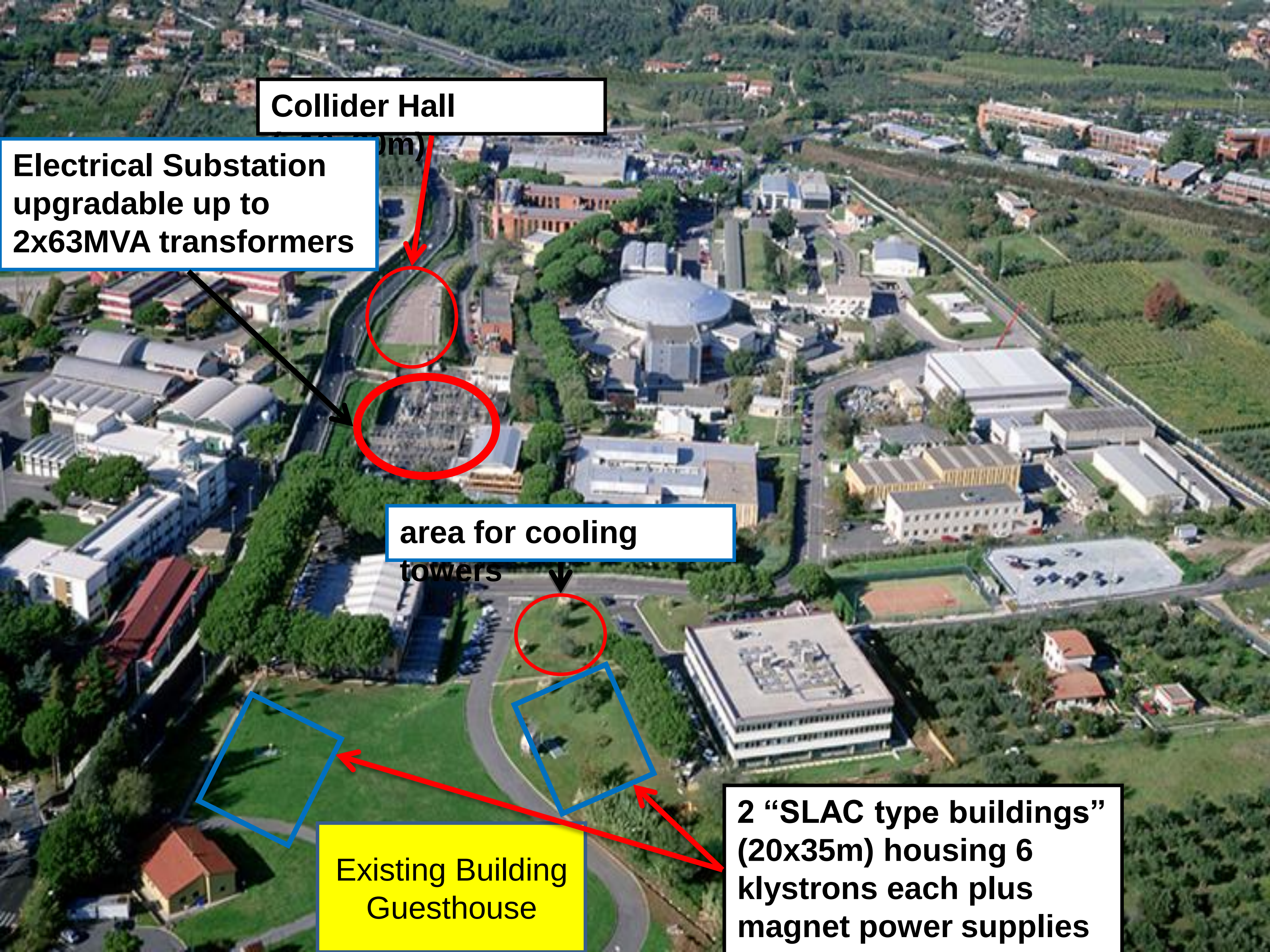
Lattice Systems

- **Two Arcs**
  - Provide the necessary bending to close the ring.
  - Optimized to generate the design horizontal emittance.
  - Correct arc chromaticity and sextupole aberrations.
- **Interaction Region**
  - Provides the necessary focusing for required small beam siz
  - Corrects FF chromaticity and sextupole aberrations.
  - Provides the necessary optics conditions for Crab cavities.
- **Dogleg**
  - Provides crossing on the opposite to IR side of the ring.
- **LER Spin Rotator**
  - Includes solenoids in matched sections adjacent to the IR.
- **RF system**
  - Up to 24 HER and 12 LER cavities in the long straight sectio opposite to IP.

Y. Nosochkov et al.

SuperB at the Frascati Labs



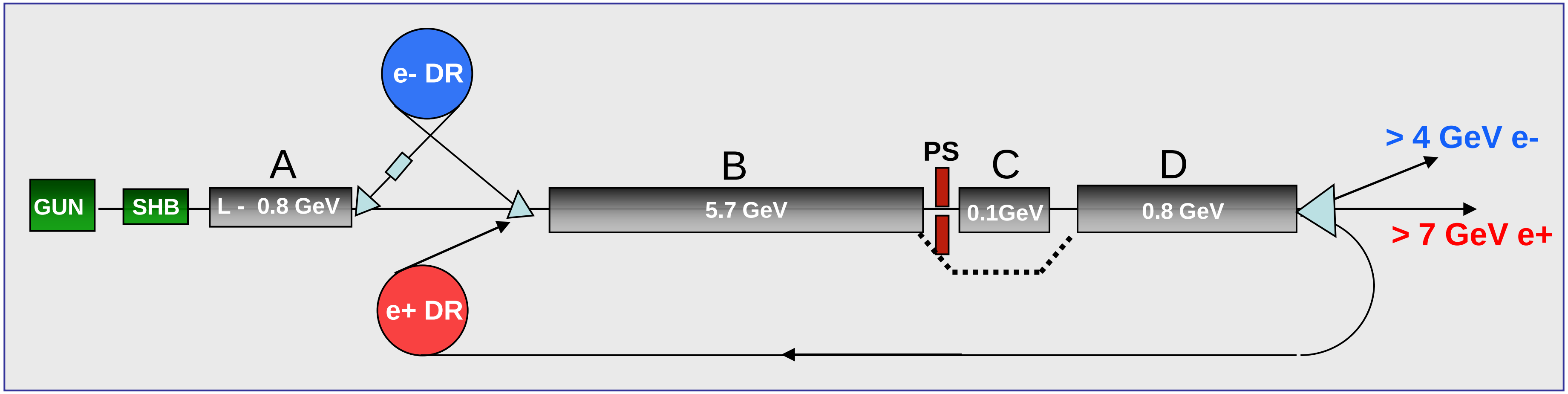

Collider Hall
Electrical Substation upgradable up to 2x63MVA transformers
area for cooling towers
Existing Building Guesthouse
2 “SLAC type buildings” (20x35m) housing 6 klystrons each plus magnet power supplies

STATUS OF THE INJECTION SYSTEM
(*oct. 2009*)

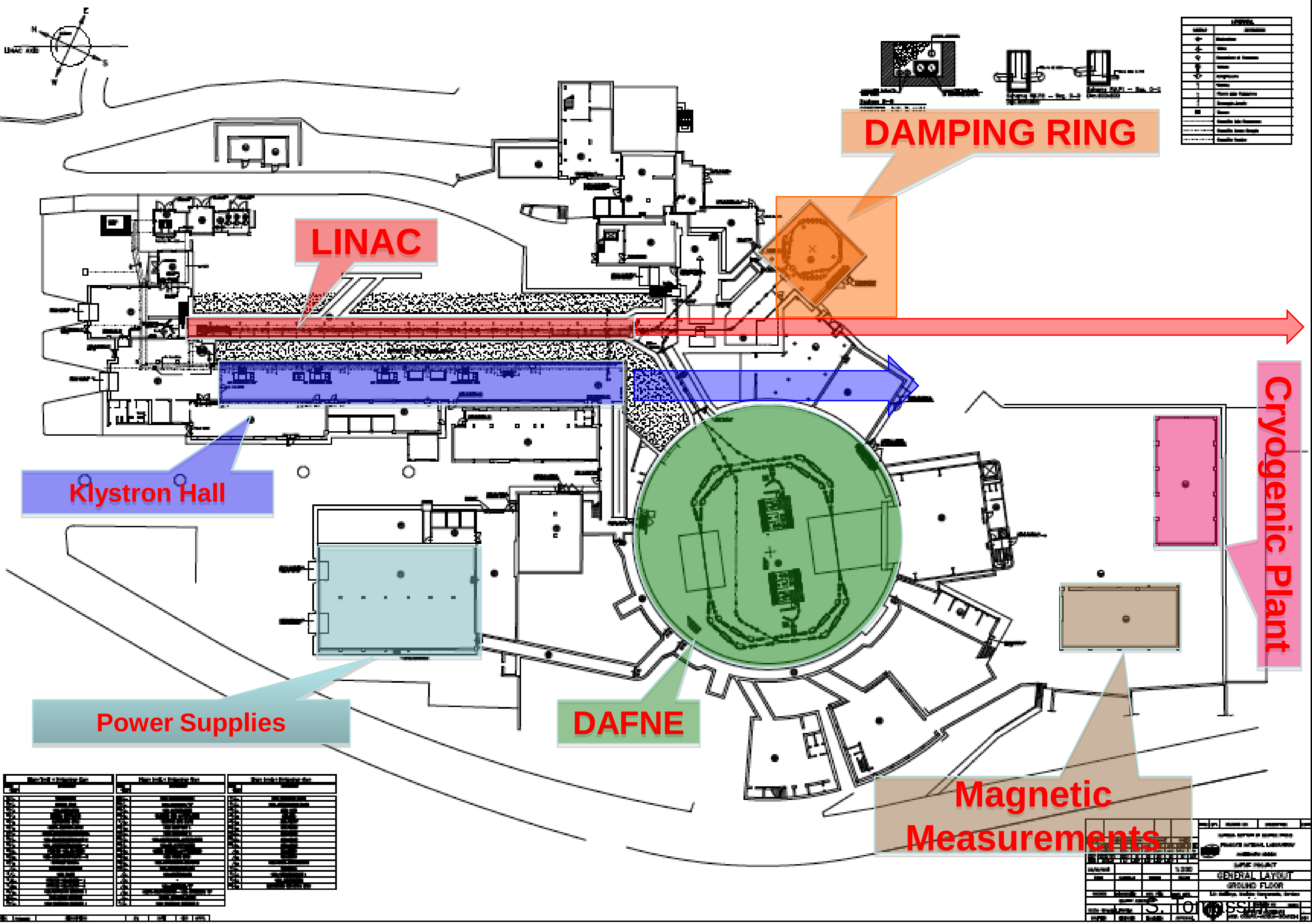
Injection process in 3 phases, to avoid simultaneous acceleration of *high-charge e- bunches* and *damped e+ bunches* in the linac B.

No fast kickers required

Rings filled every 60 msec (16.66 Hz)

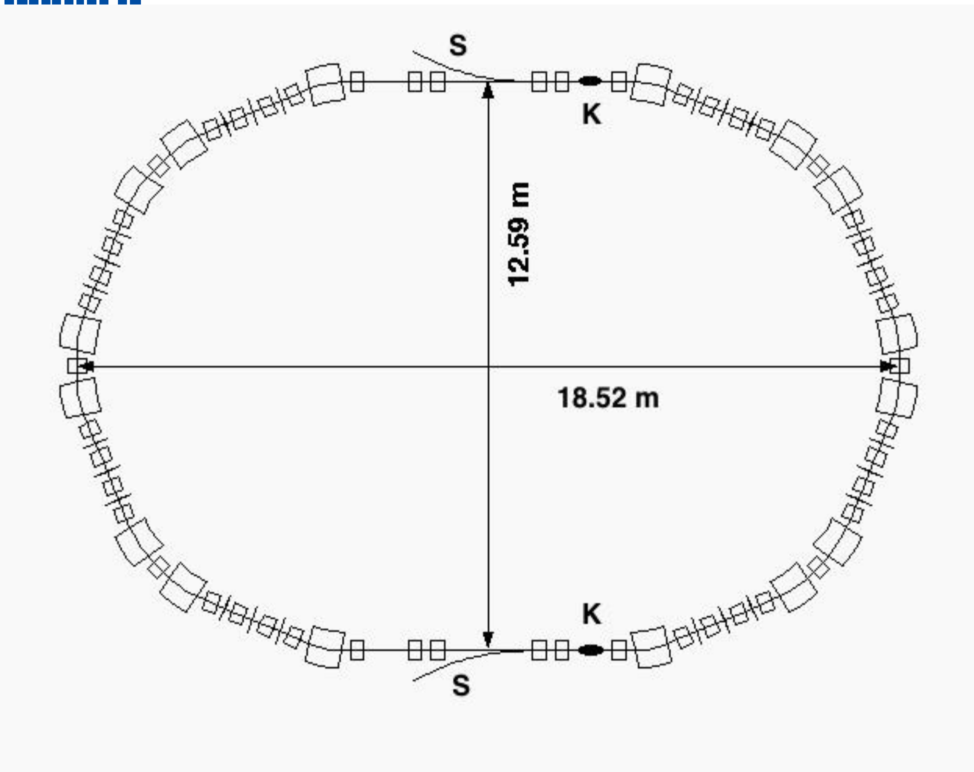


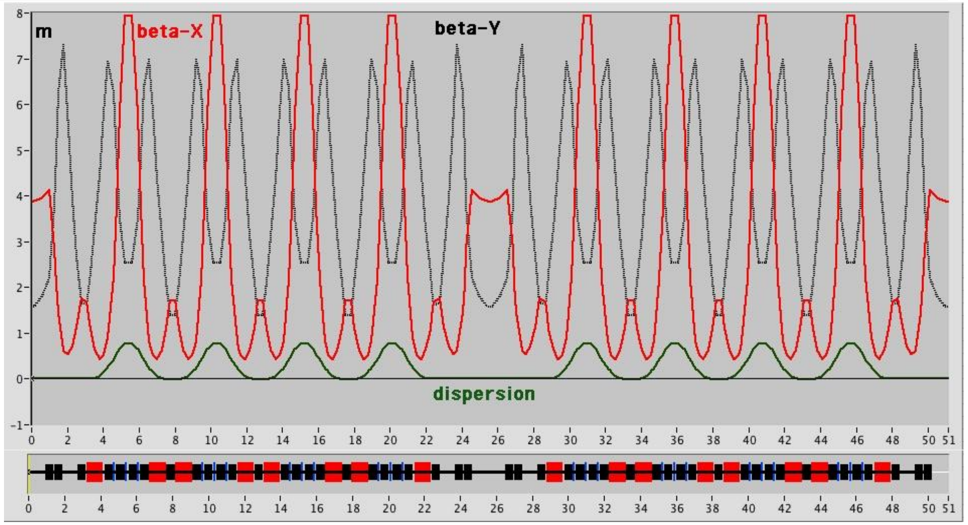
R.Boni, S.Guiducci, M.Preger, J.Seeman,



DAΦNE: LINAC, Storage Rings and damping Ring

Super-B damping ring





compact structure (51 m) for storing alternatively electrons and positrons

small equilibrium emittance:
23 nm @ 1 GeV

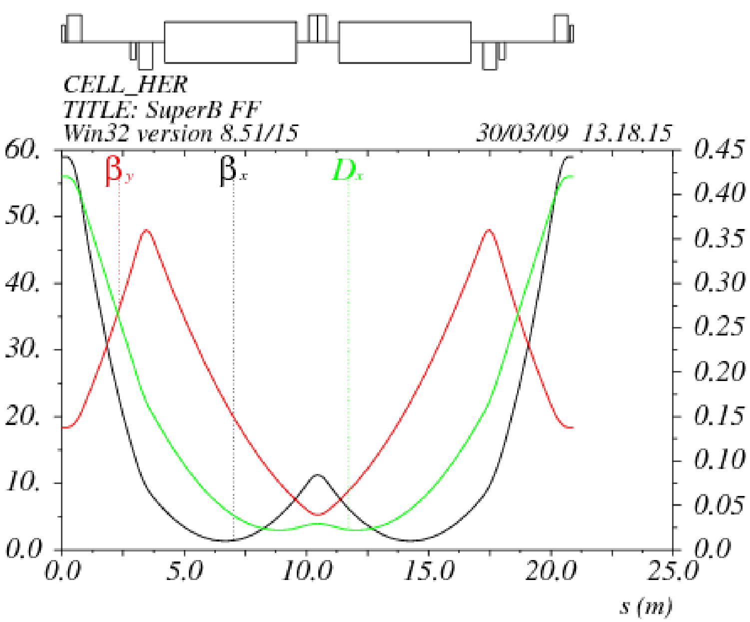
short betatron damping time:
7.3 ms

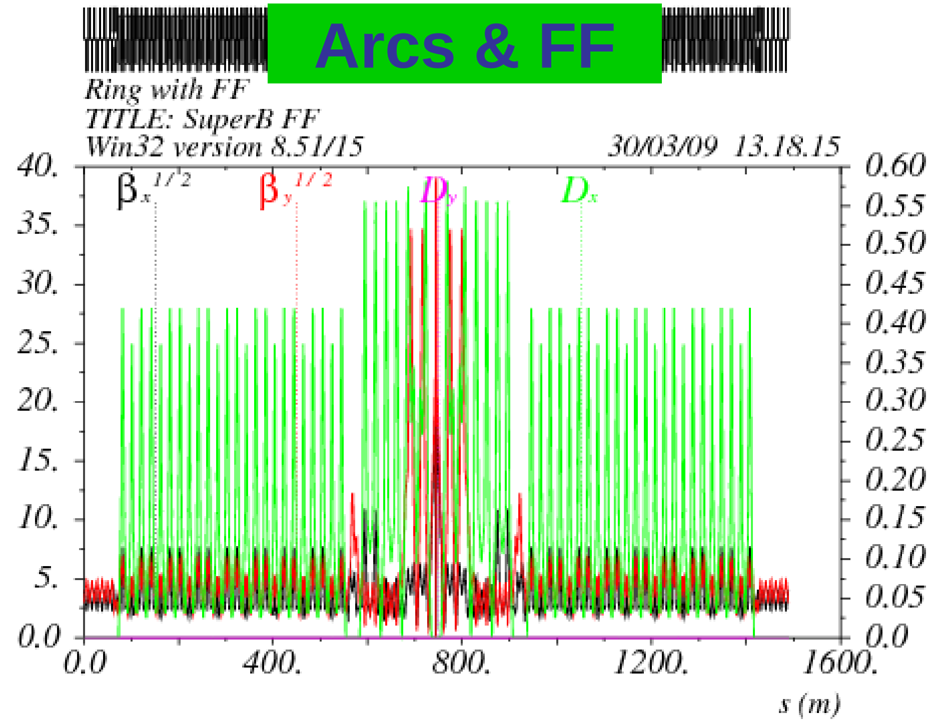
small momentum compaction:
5.7×10^{-3} => short bunch length

large dynamic aperture: ± 20 mm horizontal, ± 15 mm vertical for -2% < Δp/p < +2%

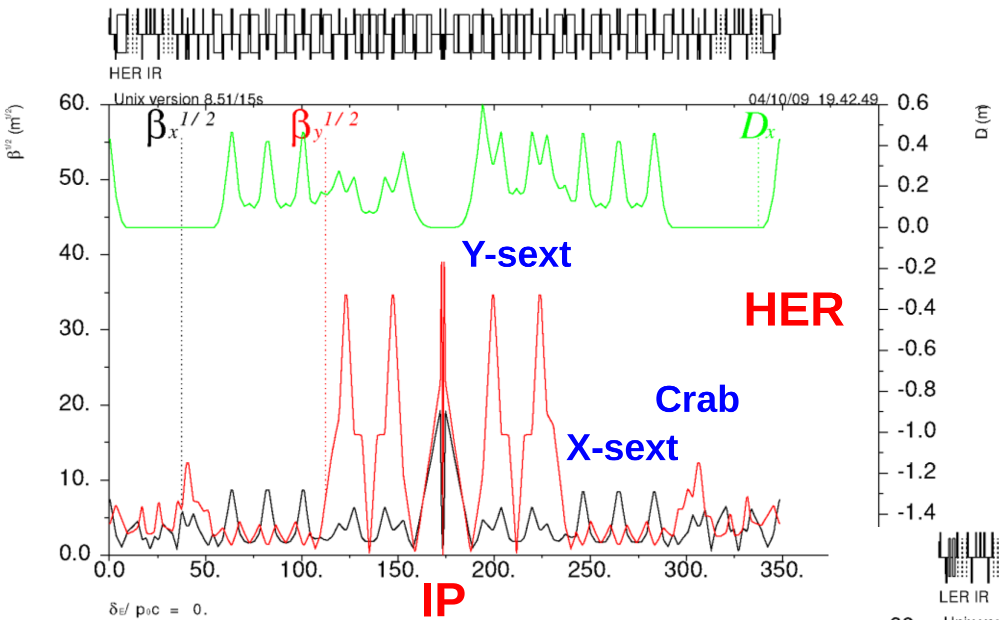
Arc Lattice

- Arc cell: flexible solution is based on decreasing the natural emittance by increasing μ_x/cell, and simultaneously adding weak dipoles in the cell drift spaces to decrease synchrotron radiation
- All cells have: μ_x=0.75, μ_y=0.25 → about 30% fewer sextupoles
- Better DA since all sextupoles are at –I in both planes (although x and y sextupoles are nested)
- Distances between magnets compatible with PEP-II hardware
- All quads-bends-sextupoles in PEP-II range



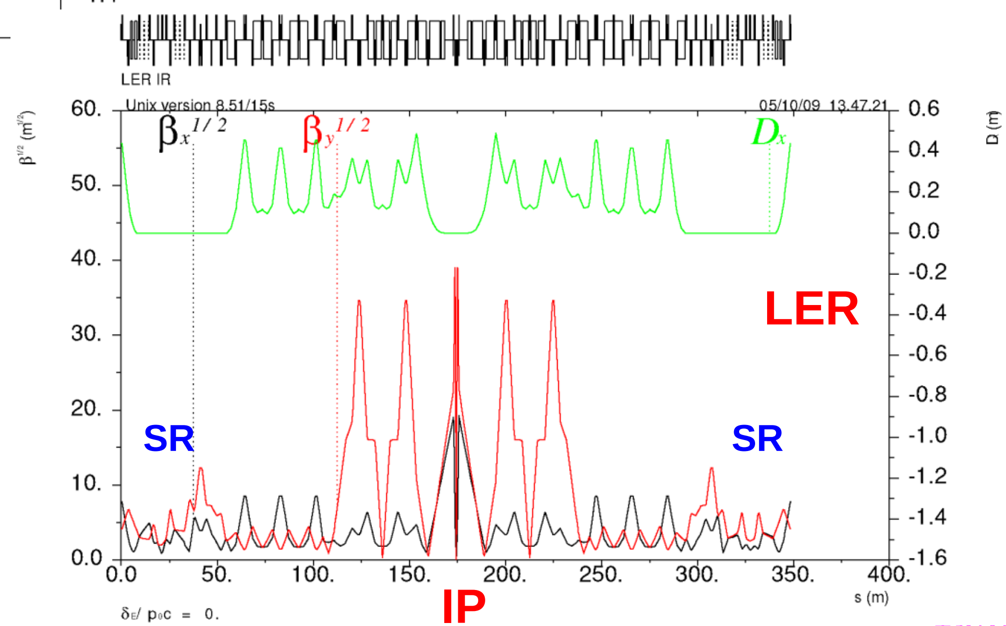


IR Optics



IR quadrupoles are rematched, but more optimization of chromatic correction is needed.

LER Spin Rotators need to be updated.

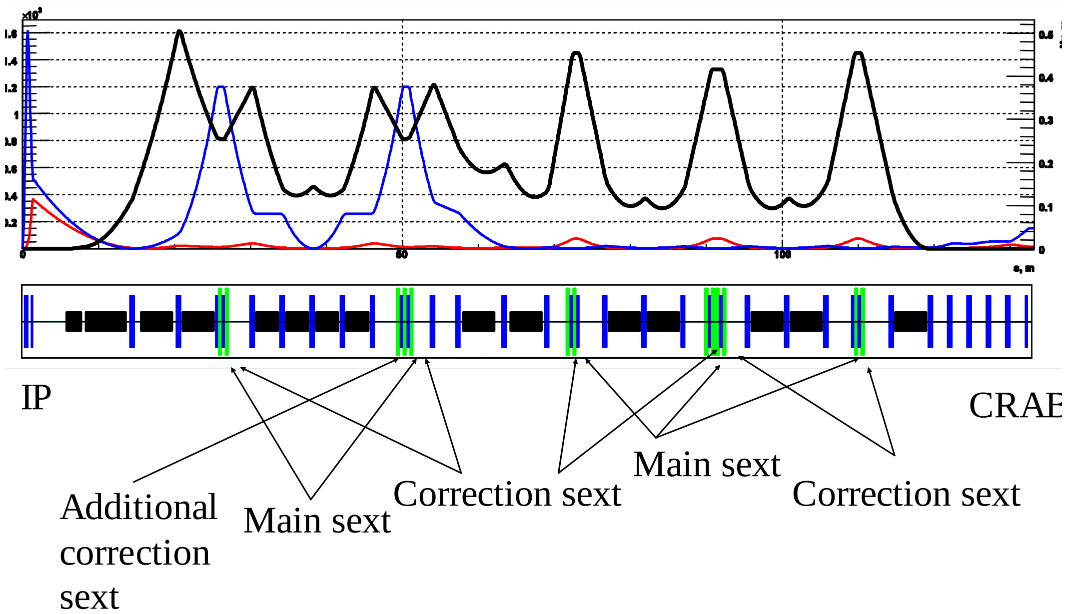


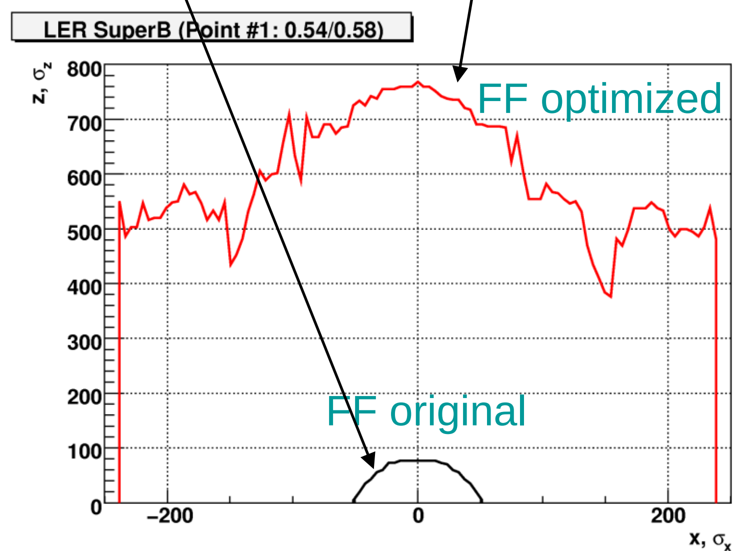
Additional IR correcting sextupoles are proposed for better dynamic aperture, but not yet included.

Final Focus 4D dynamic aperture

All sextupoles in the arcs are switched off
The black curve shows original DA (50 sigma_x X 80 sigma_y)
The red curve shows DA optimized by correction sextupoles (250 sigma_x X 750 sigma_y)

DA calculations (preliminary)





E. Levichev, P. Piminov et al. Presentation from last June (below) and see presentation at SLAC workshop
http://agenda.infn.it/materialDisplay.py?contribId=31&sessionId=10&materialId=slides&confId=1161

Crab Waist Advantages

Half crossing angle

1. **Large Piwinski angle**

$$\Phi = (tg)\theta^* \sigma_z / \sigma_x \cong \theta^* \sigma_z / \sigma_x$$

- a) Luminosity gain with N
- b) Very low horizontal tune shift

2. **Vertical beta comparable with overlap area**

$$\beta_y \approx \sigma_x / \theta$$

- a) Geometric luminosity gain
- b) Lower vertical tune shift
- c) Vertical tune shift decreases with oscillation amplitude
- d) Suppression of vertical synchro-betatron resonances

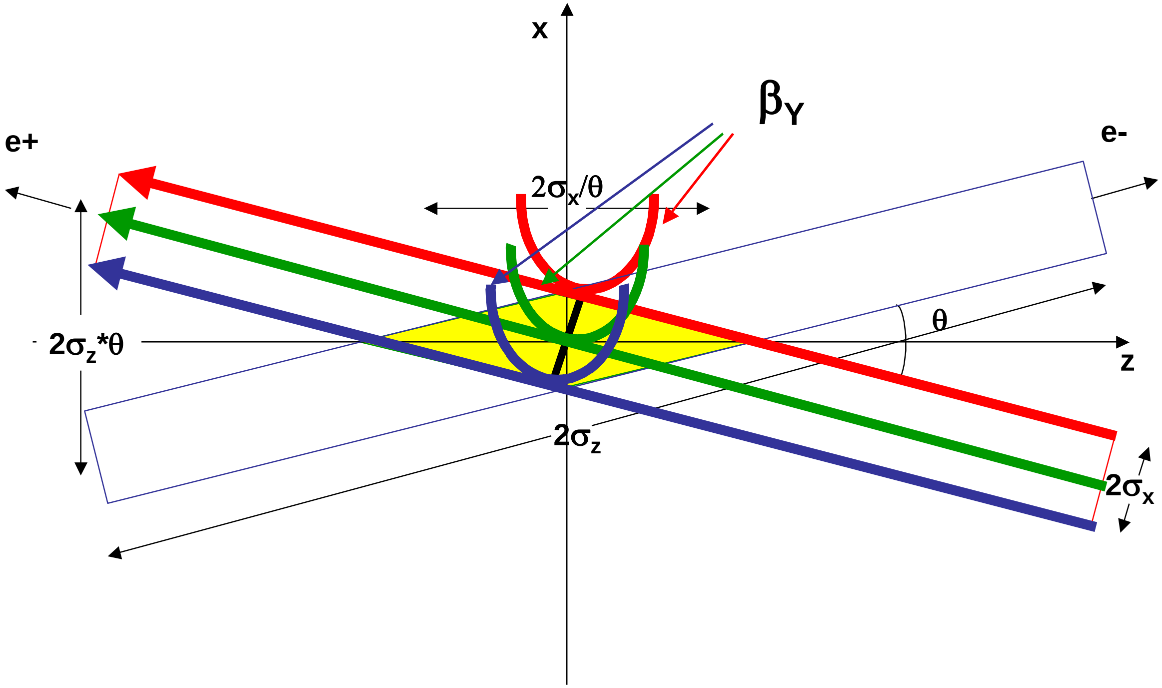
3. **Crabbed waist transformation**

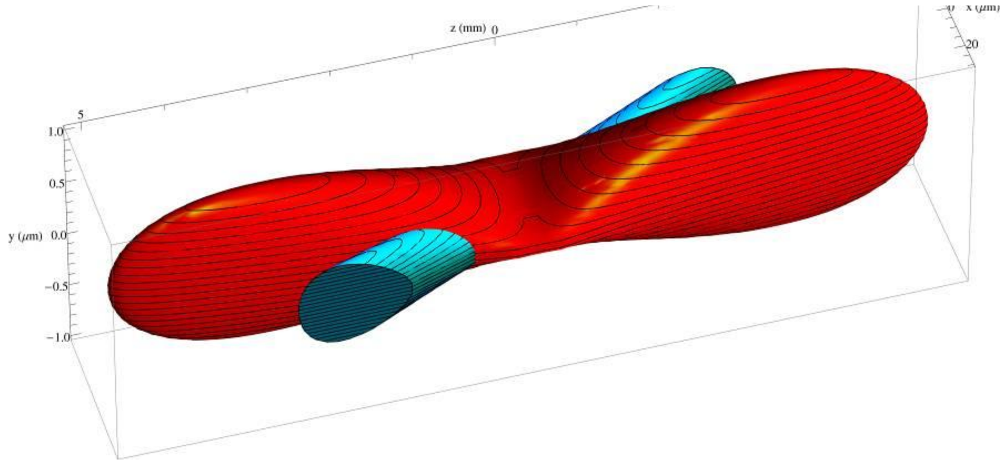
$$y = xy'/(2\theta)$$

- a) Suppression of X-Y betatron and synchro-betatron resonances
- b) Geometric luminosity gain

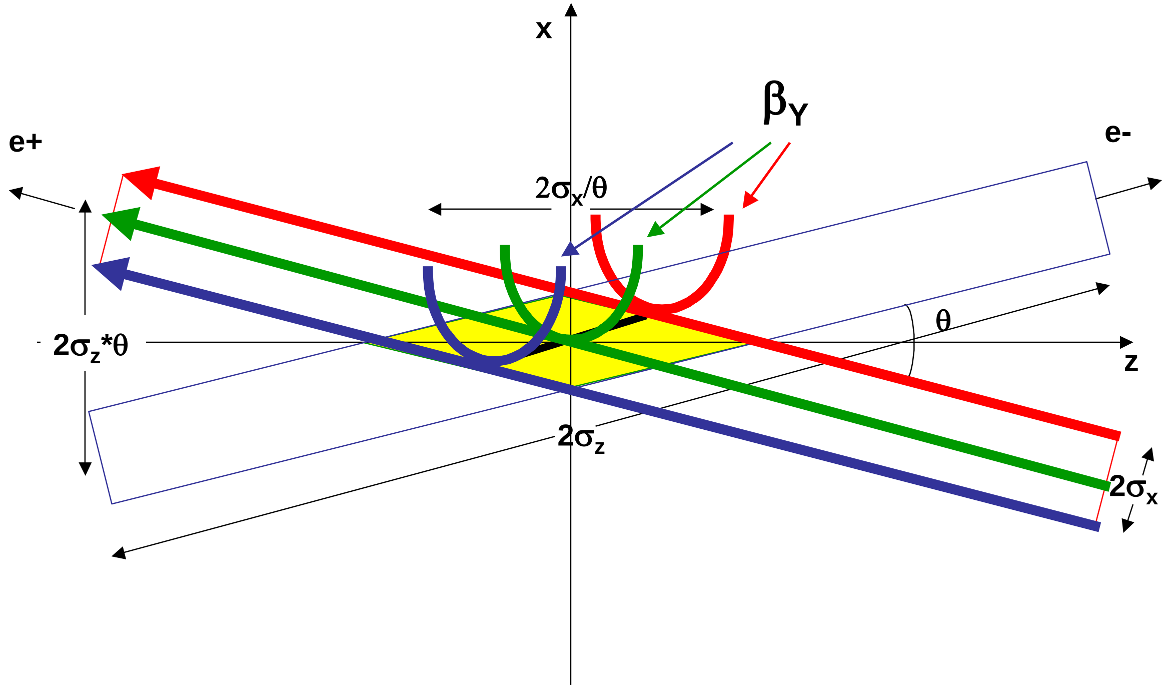
Paper by Raimondi, Shatilov, and Zorbov
http://arxiv.org/abs/physics/0702033

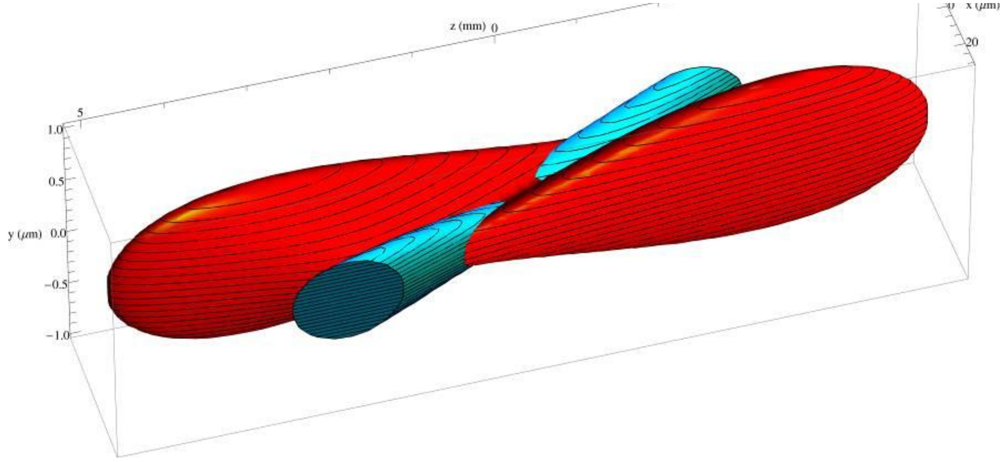
Crab Waist Scheme





Crab Waist Scheme

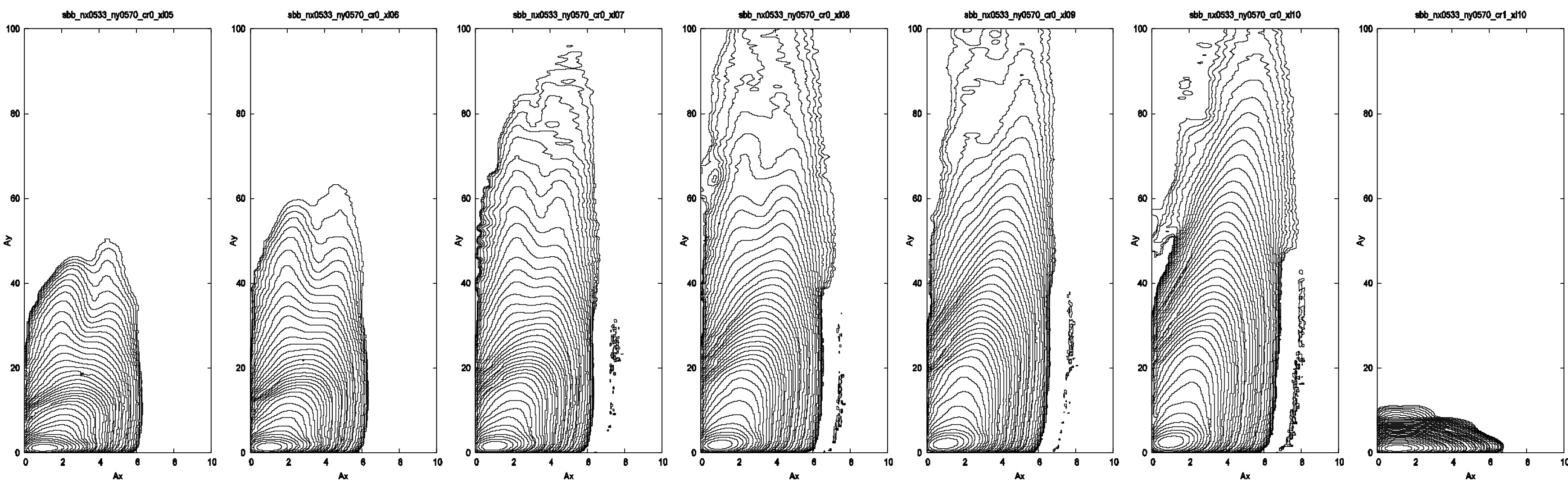




Beam Blowup and Tails in SuperB

Bunch Current

0.5 0.6 0.7 0.8 0.9 1.0 1.0 + crab



1.5 2.1 2.9 3.9 5.0 6.6 1.1

Crab Sextupoles Off

Crab Sextupoles On

The crab waist in DAΦNE

- In 2007-2008 DAΦNE was upgraded to include a crabbed waist
- There were some additional (conventional) improvements as well
  - Improved injection
  - Improved impedence reduction
  - Improved feedback systems
- The predicted luminosity increase was about a factor of 3 (from 1.6×10^{32} to 5×10^{32})

DAΦNE Upgrade Team

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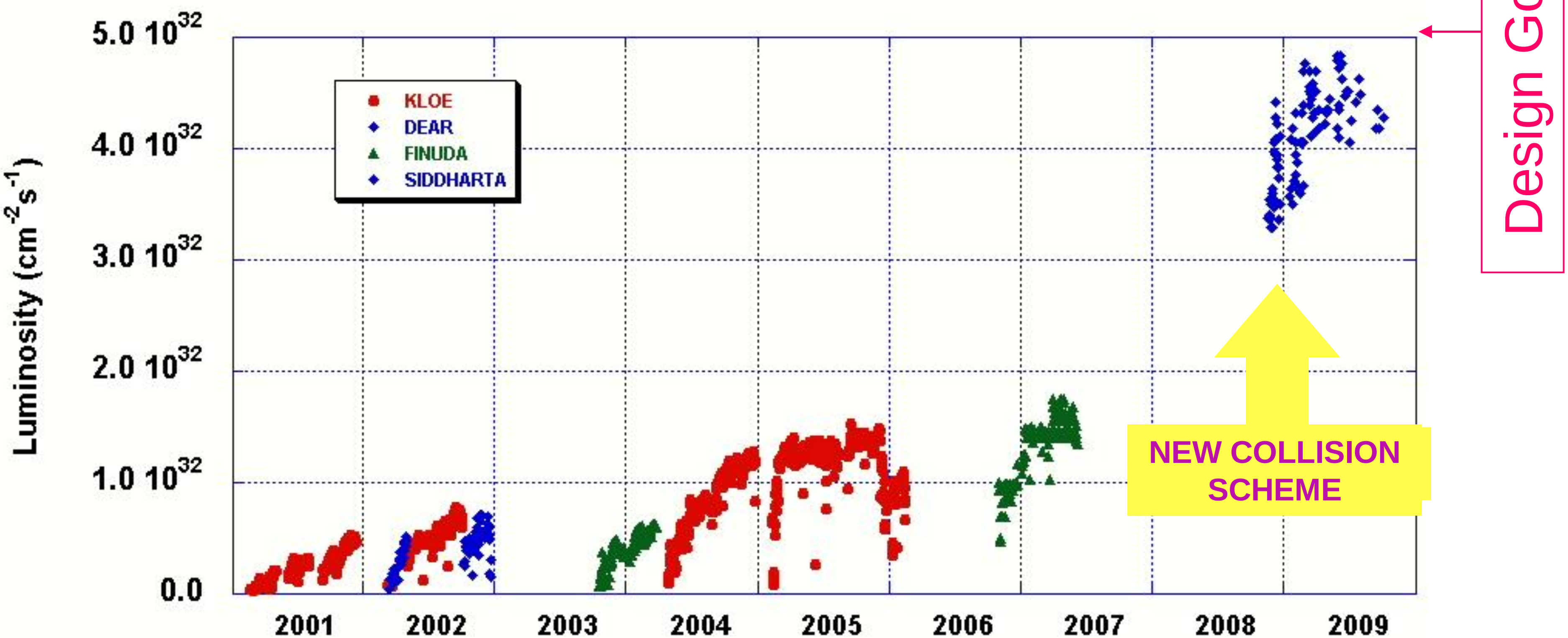
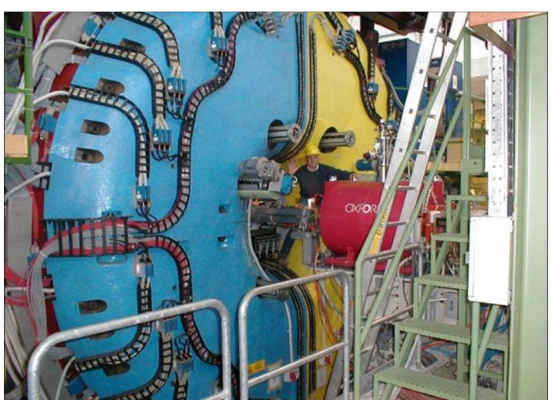
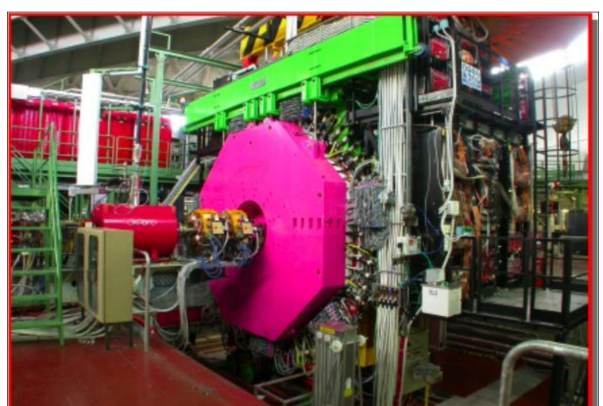
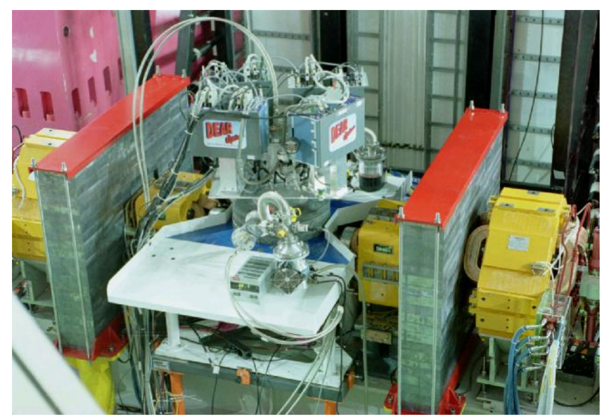
M.Esposito **(Rome University “La Sapienza”, Rome)**

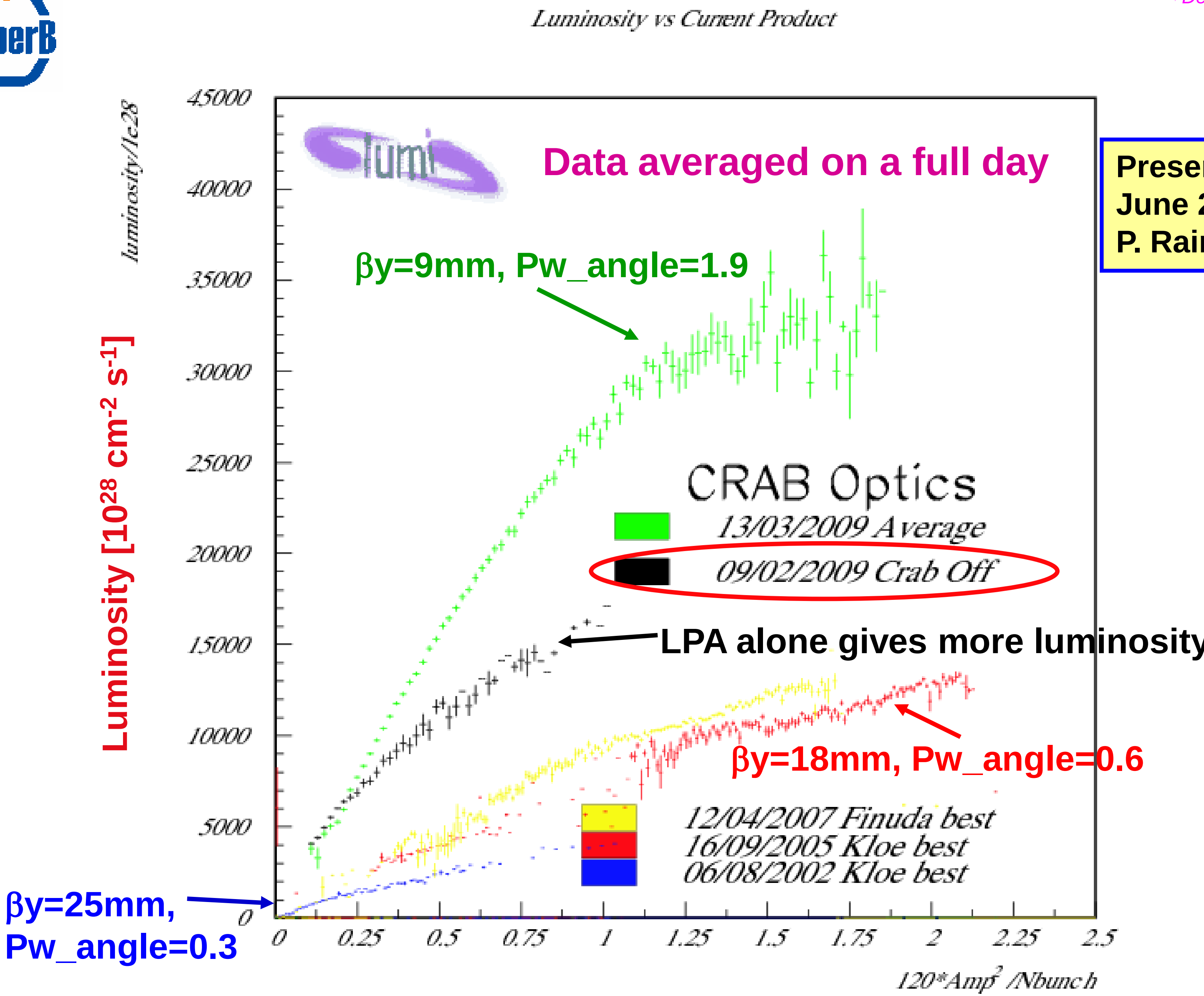
DAΦNE Peak Luminosity



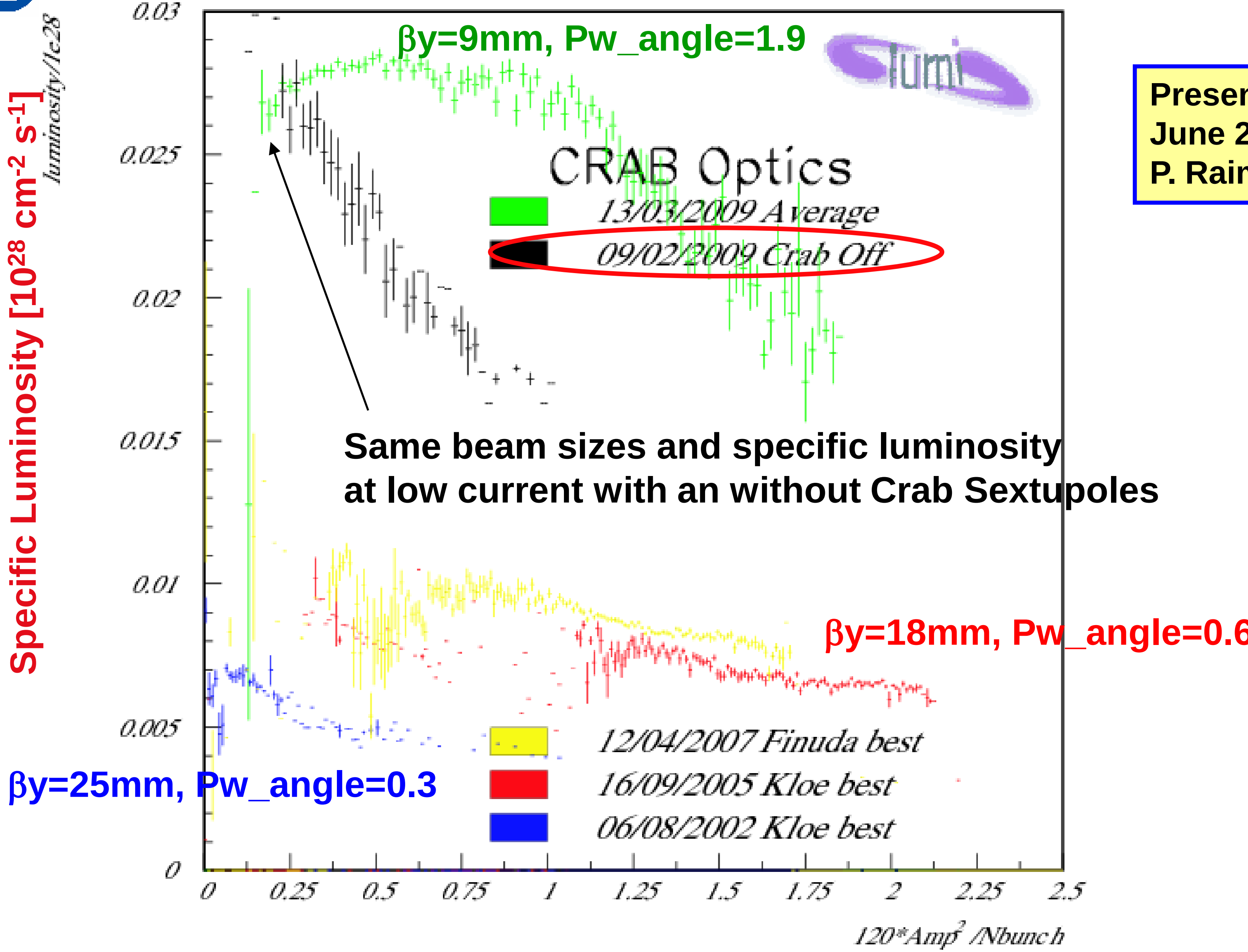






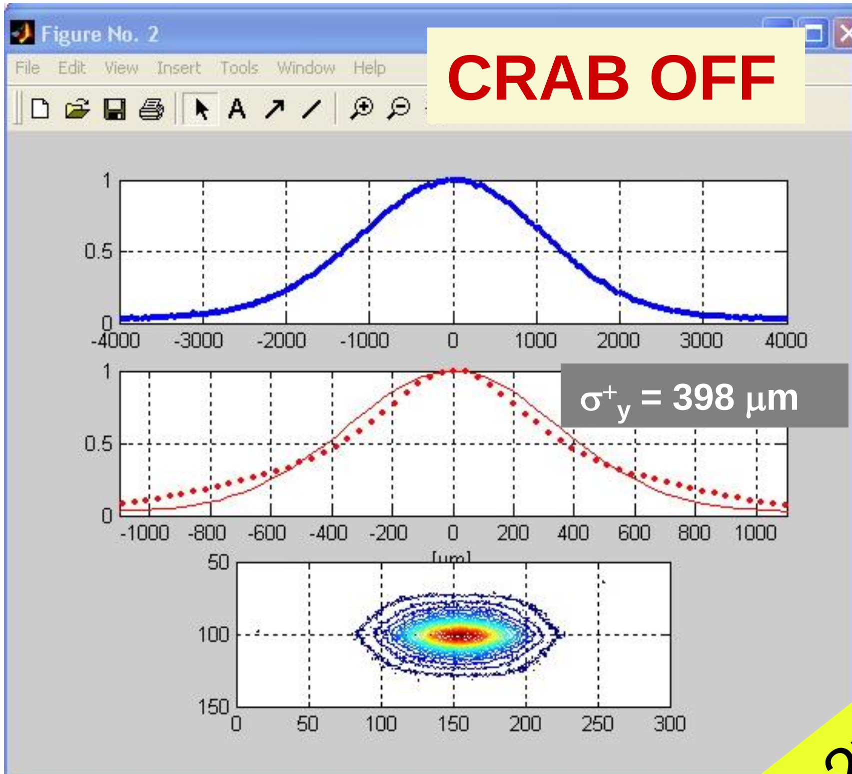


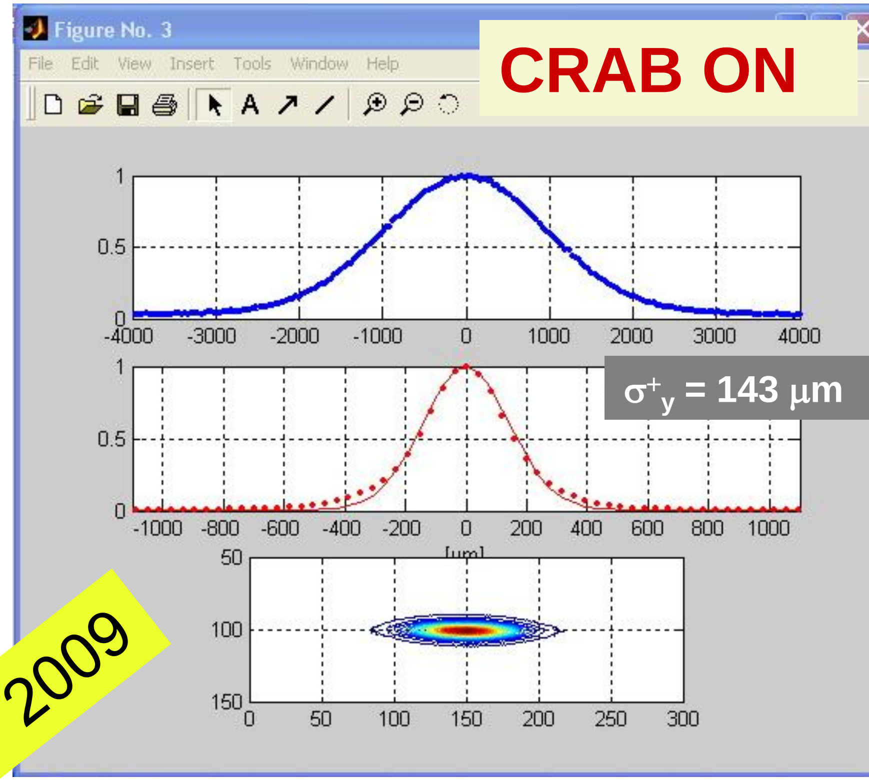
Presented June 2009 by P. Raimondi



Presented June 2009 by P. Raimondi

Transverse Beam Profile Measurements





Nov. 2nd 2009

103 colliding bunches

SuperB IR Design

- This is one of the more difficult parts of the SuperB design
- The very low β_y* means we must get as close as we can to the IP with our final focus magnets
- The very low emittance beams means that we cannot bend the beams very much
- Initially we tried a shared magnet ala PEP-II and KEKB but the crossing angle forces too much of a bend in either one or both of the beams and we were forced to abandon the idea (even if we lowered the crossing angle)
- We have since been concentrating on a dual quad design using SC magnets that are wound so that the fringe field of the nearby quad is cancelled
- In order to get these magnets in as close as possible we have opened the crossing angle to 60 mrad
- In order for this design to work the quad strengths are locked together (the ratio must be constant)

General IR Design Features

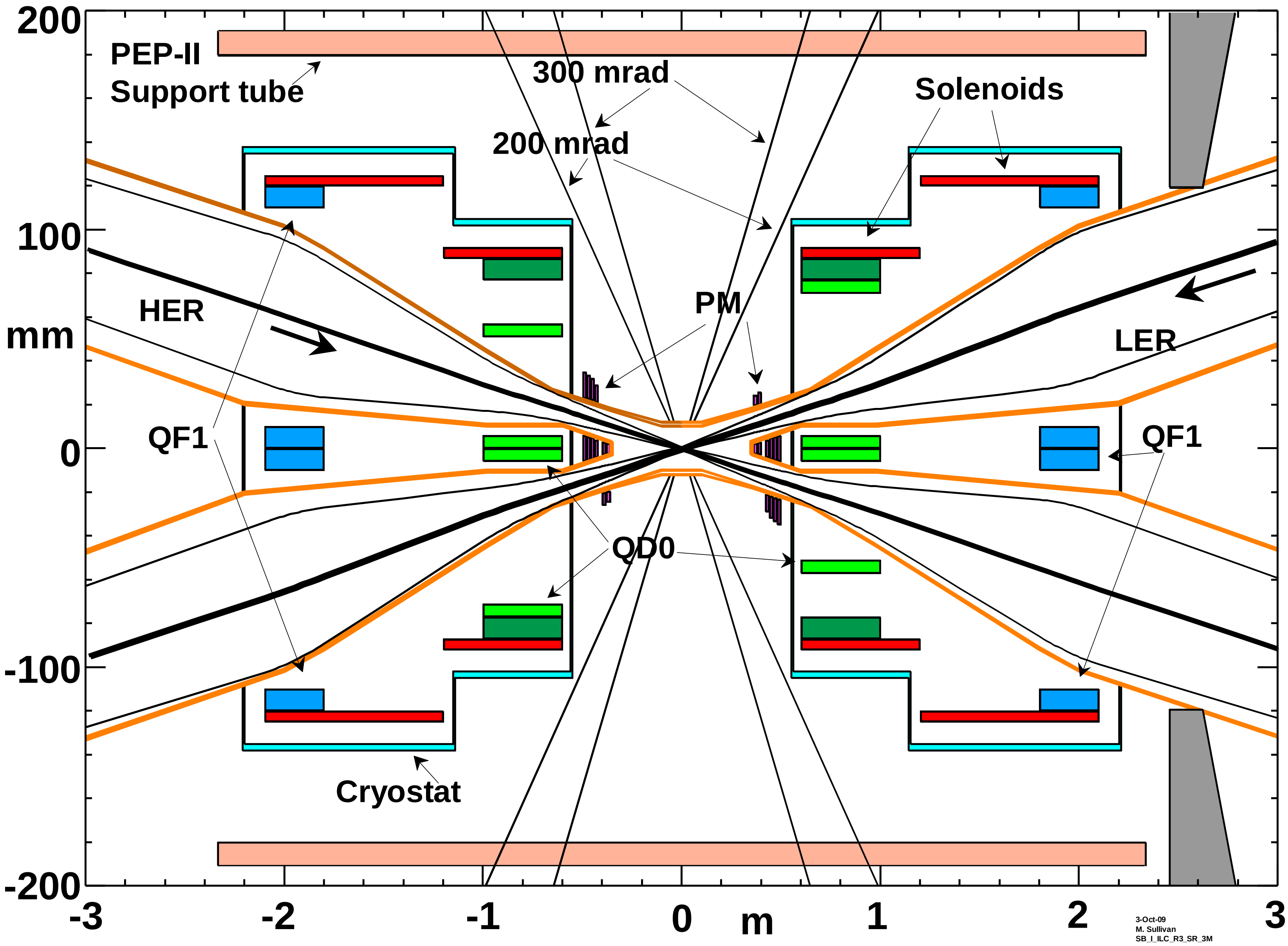
- Crossing angle is +/- 30 mrads
- Cryostat has a complete warm bore
  - For synchrotron radiation reasons
  - Both QD0 and QF1 are super-conducting
- PM in front of QD0
- Soft upstream bend magnets
  - Further reduces SR power in IP area
- BSC to 30 sigmas in X and 140 sigmas in Y (10 sigma fully coupled)
- Detector beam pipe radius 1 cm

Do NOT want to design out upgrades

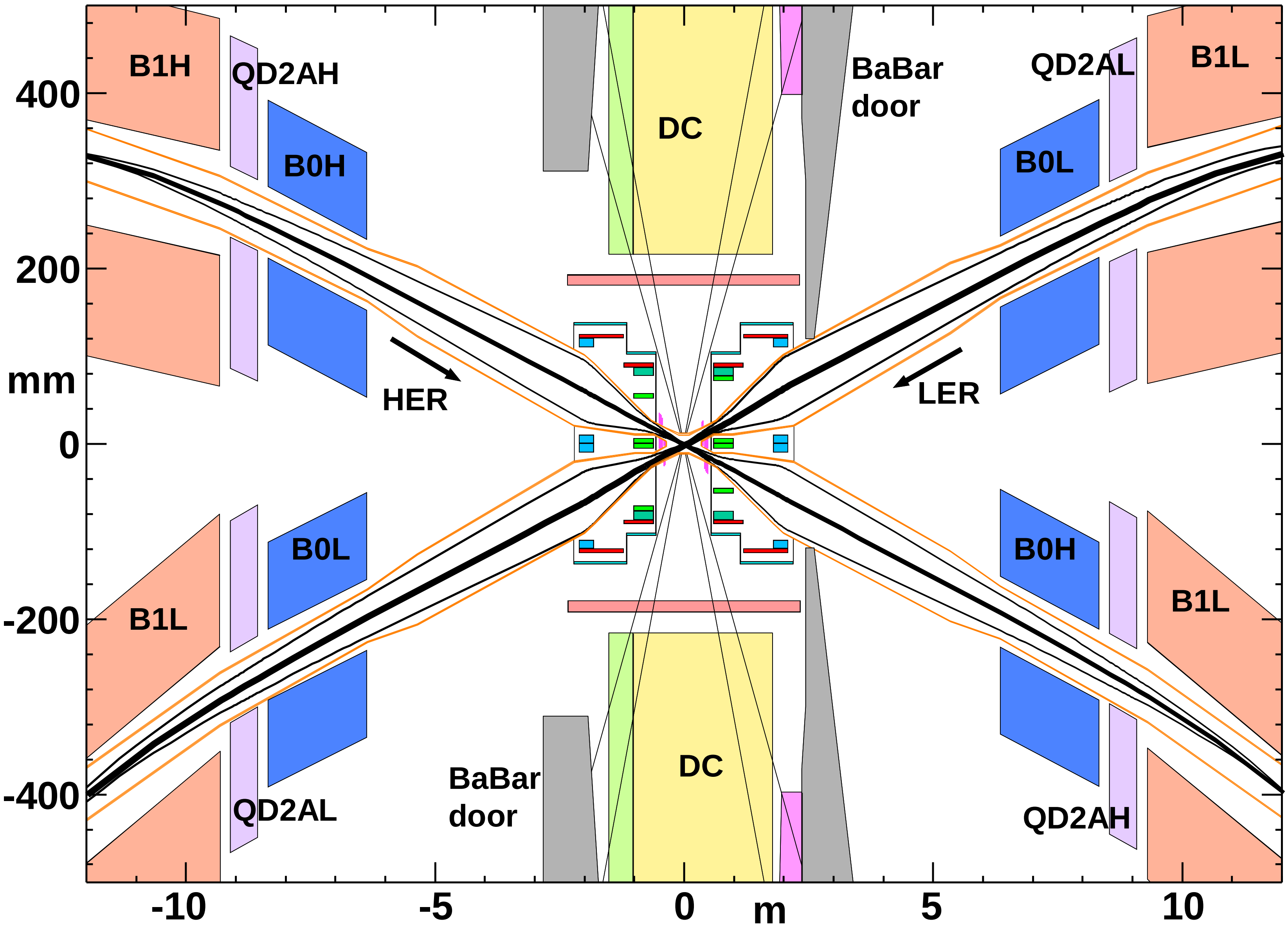
Parameters used in the IR

Parameter	HER	LER
Energy (GeV)	7	4
Current (A)	2.12	2.12
Beta X (mm)	20	32
Beta Y (mm)	0.32	0.20
Emittance X (nm-rad)	1.60	2.56
Emittance Y (pm-rad)	4.0	6.4
Sigma X (μm)	5.66	5.66
Sigma Y (nm)	36	36
Crossing angle (mrad)	+/- 30	

The Present Design



Larger view

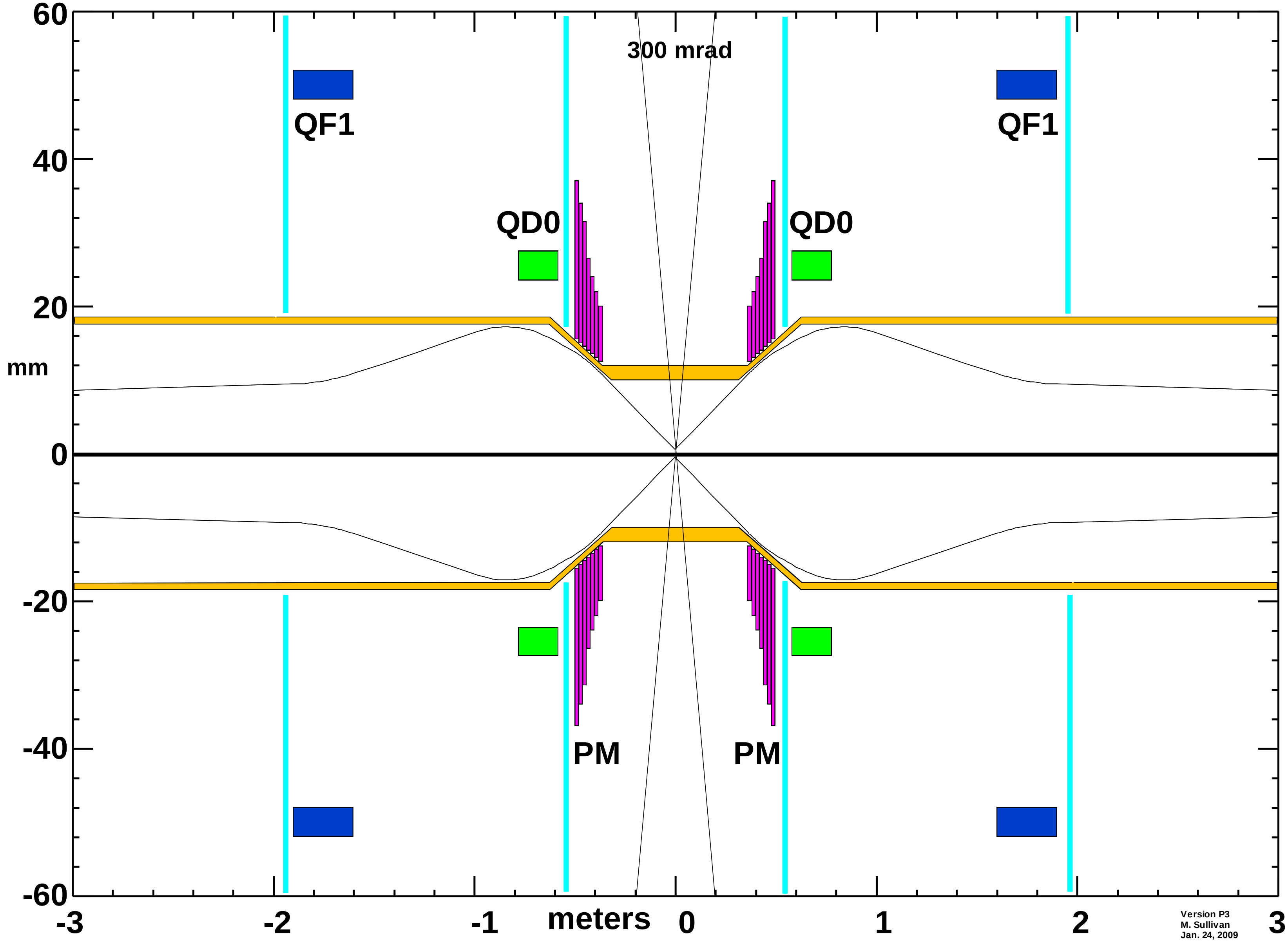


B1H
QD2AH
B0H
DC
BaBar
door
QD2AL
B1L
B0L
HER
LER
B0L
B1L
B0H
B1L
DC
BaBar
door
QD2AL
QD2AH
400
200
mm
0
-200
-400
-10
-5
0
m
5
10

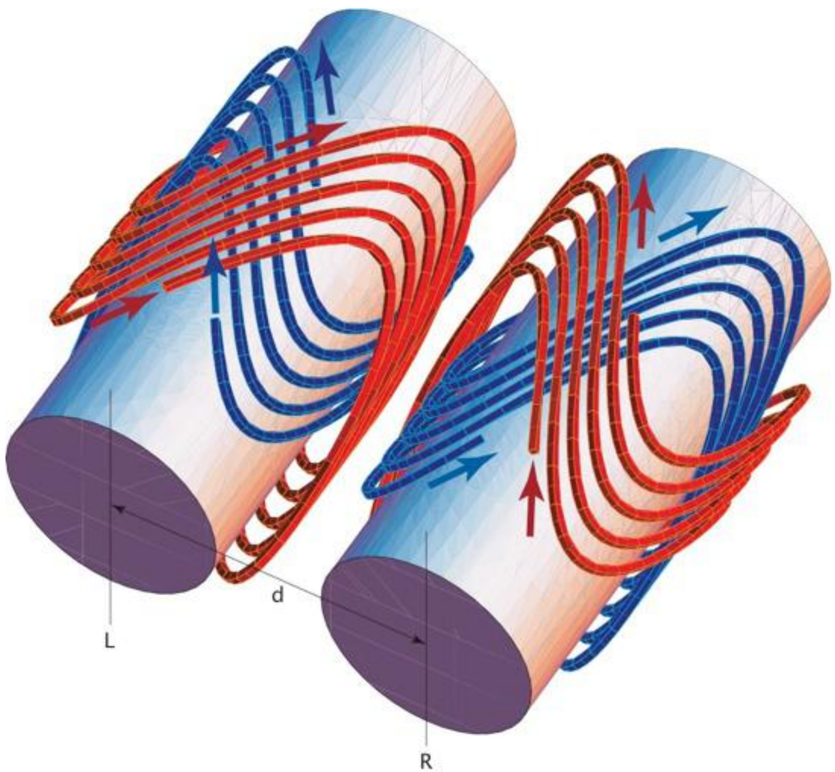
Improvement details

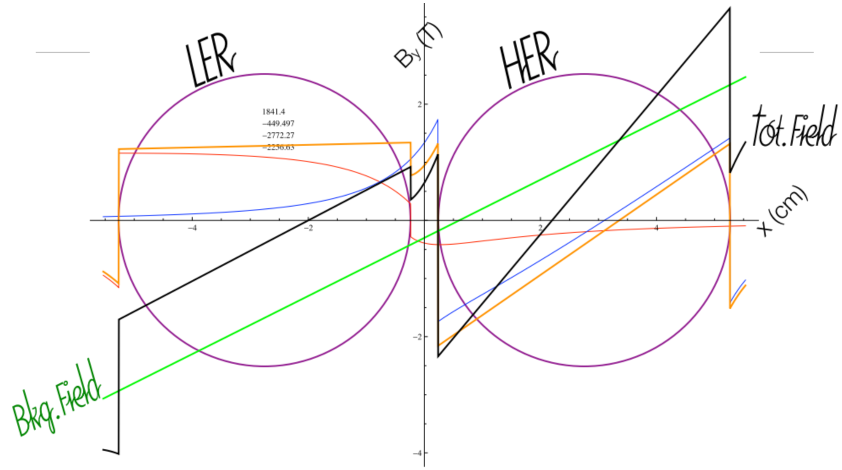
	Old	New
QD0	HER/LER	HER/LER
– R inside (mm)	24.0/31.5	22.5/32.5
– R outside (mm)	28.0/35.5	28.5/38.5
– Length (m)	0.40	0.40
– Dist to IP (m)	0.58	0.60
– Gradient (T/cm)	-1.192/-0.522	-1.025/-0.611
– Field at inside radius (T)	2.80/1.61	2.31/1.99
– Maximum β_y (m) (sqrt)	1970(44)/2193(47)	1550(39)/2566(51)
QF1		
– R inside (mm)	50.0	50.0
– R outside (mm)	56.0	60.0
– Length (m)	0.30	0.30
– Dist to IP (m)	1.60	1.80
– Gradient (T/cm)	0.726/0.399	0.640/0.358
– Field at inside radius (T)	3.48/1.92	3.20/1.79
– Maximum β_x (m) (sqrt)	580(24)/200(14)	799(28)/486(22)

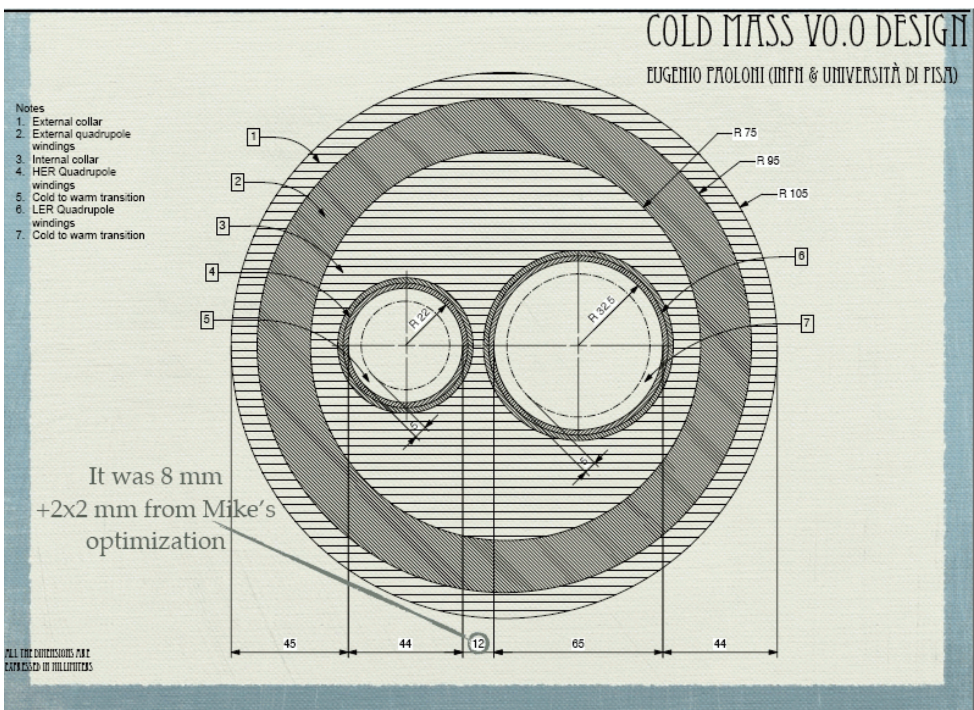
Vertical View – same as before



QD0 design

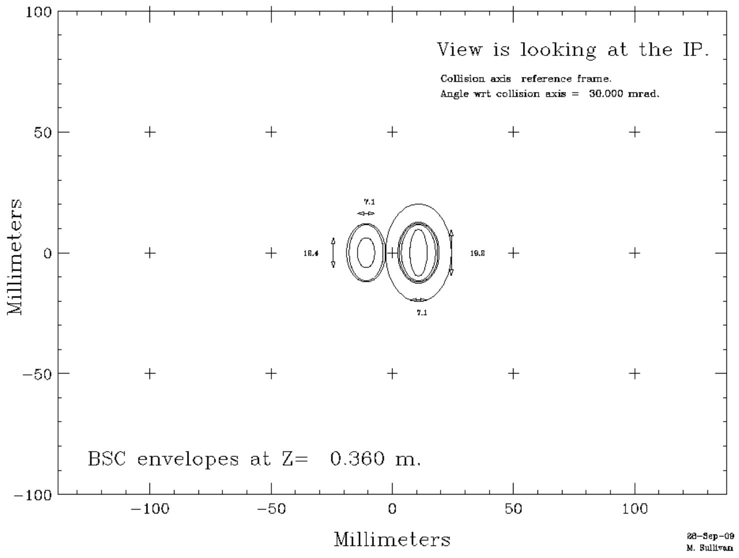




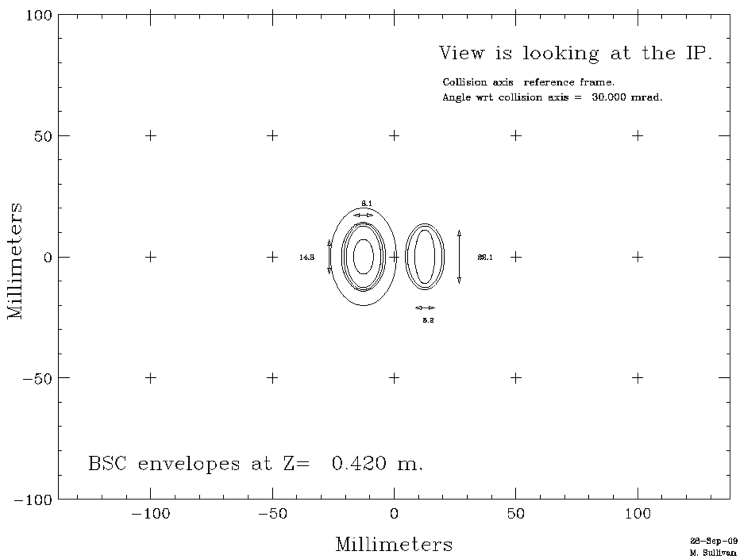


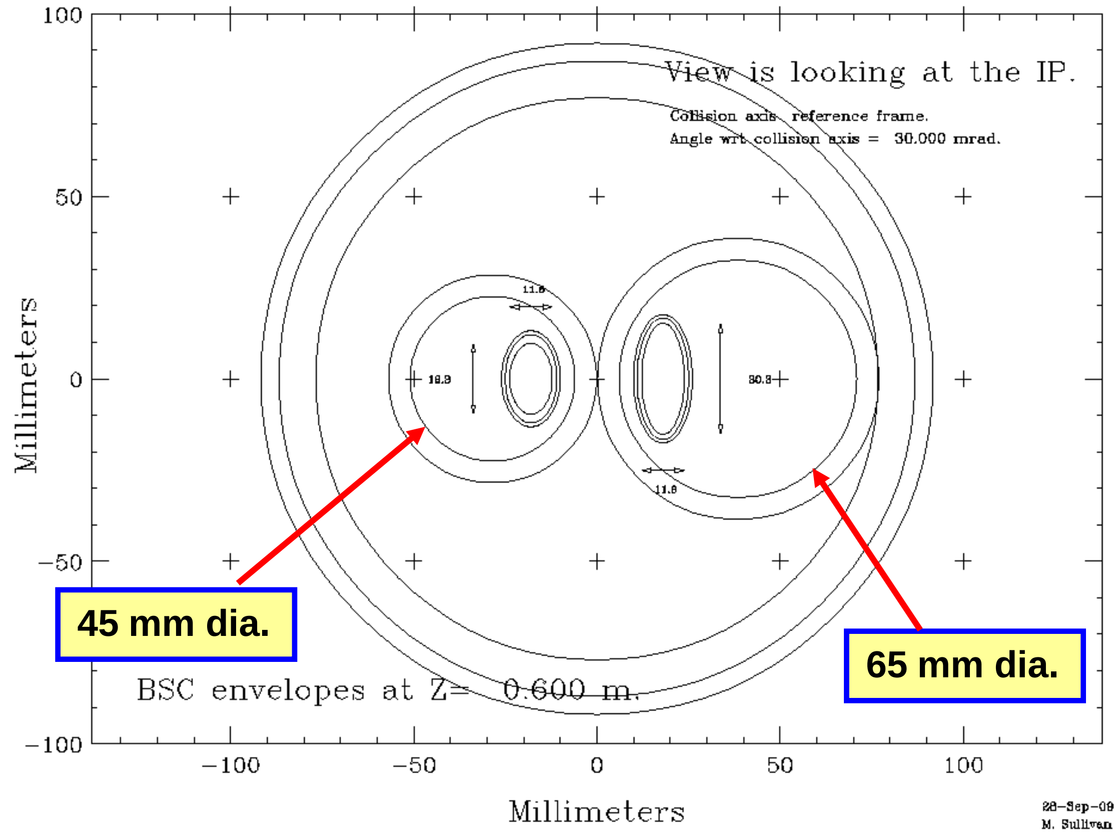
Self-compensating windings
Magnetic field ratios are fixed

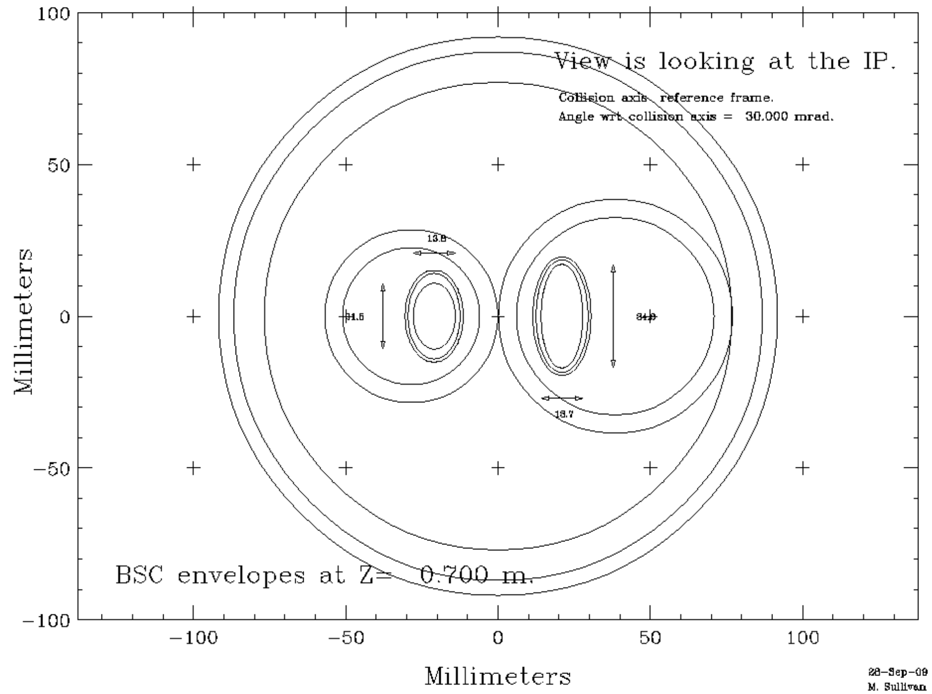
Beam sizes in QD0

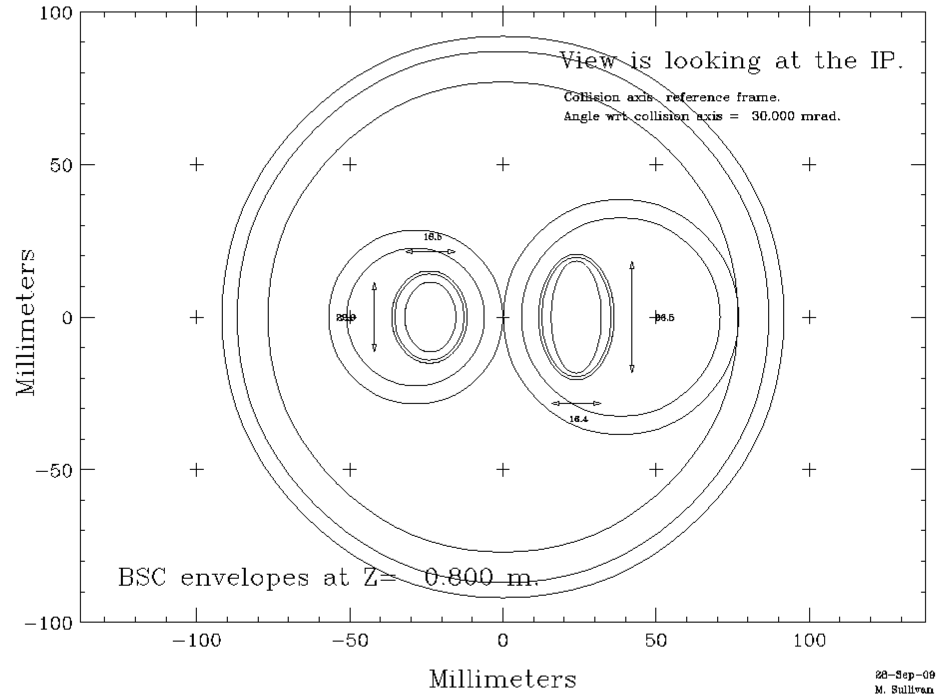


Beams in the PM slices






View is looking at the IP.
Collision axis reference frame.
Angle wrt collision axis = 30.000 mrad.
BSC envelopes at Z= 0.700 m.
Millimeters
Millimeters
28-Sep-09
M. Sullivan


View is looking at the IP.
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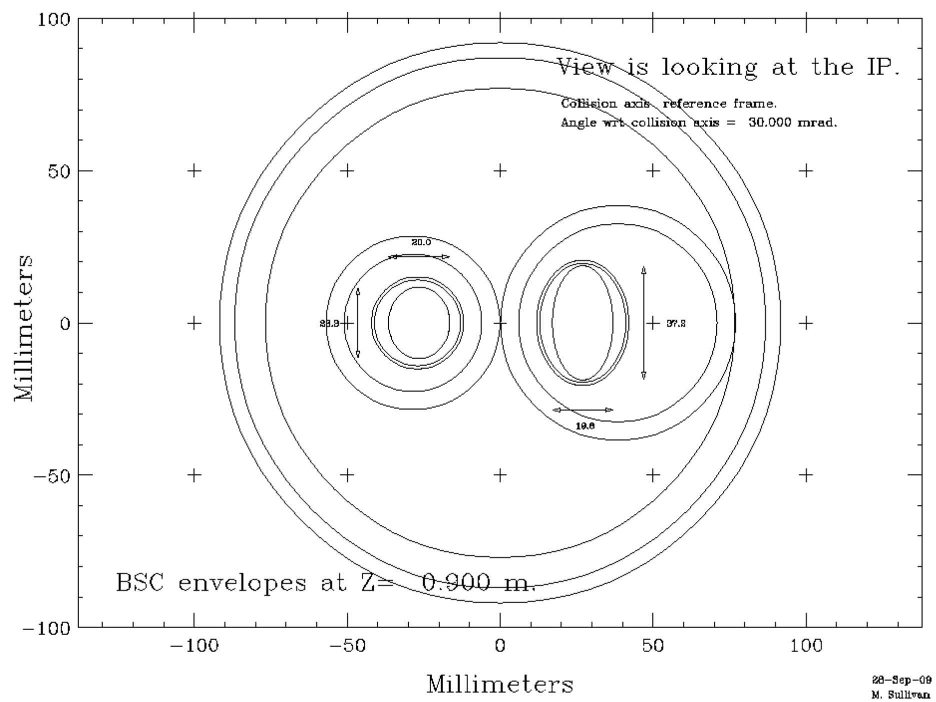
Angle wrt collision axis = 30.000 mrad.
BSC envelopes at Z= 0.800 m.
Millimeters
Millimeters
28-Sep-09
M. Sullivan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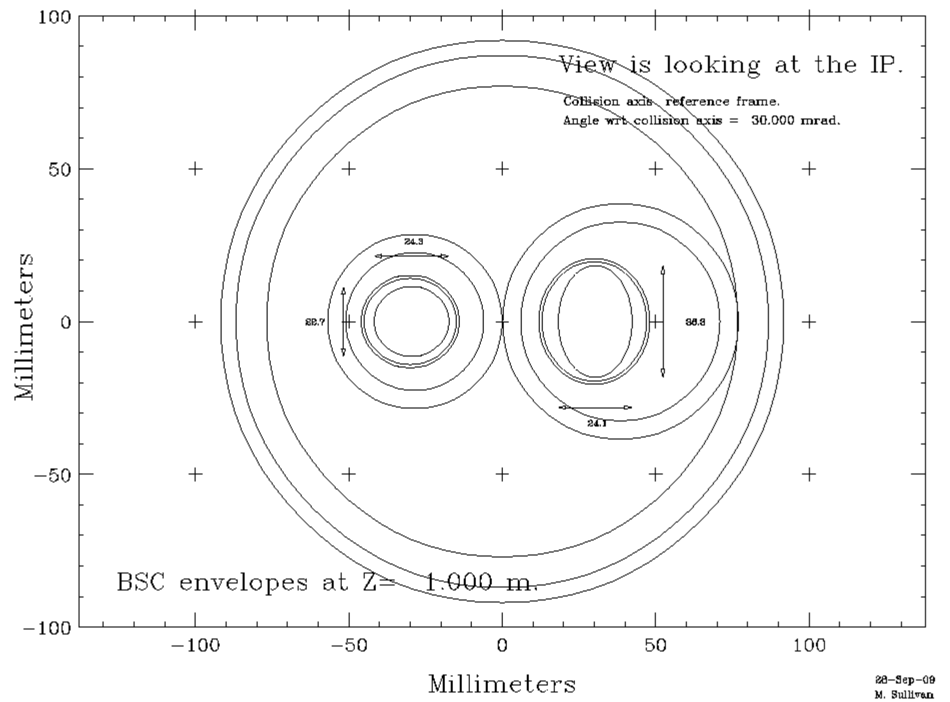
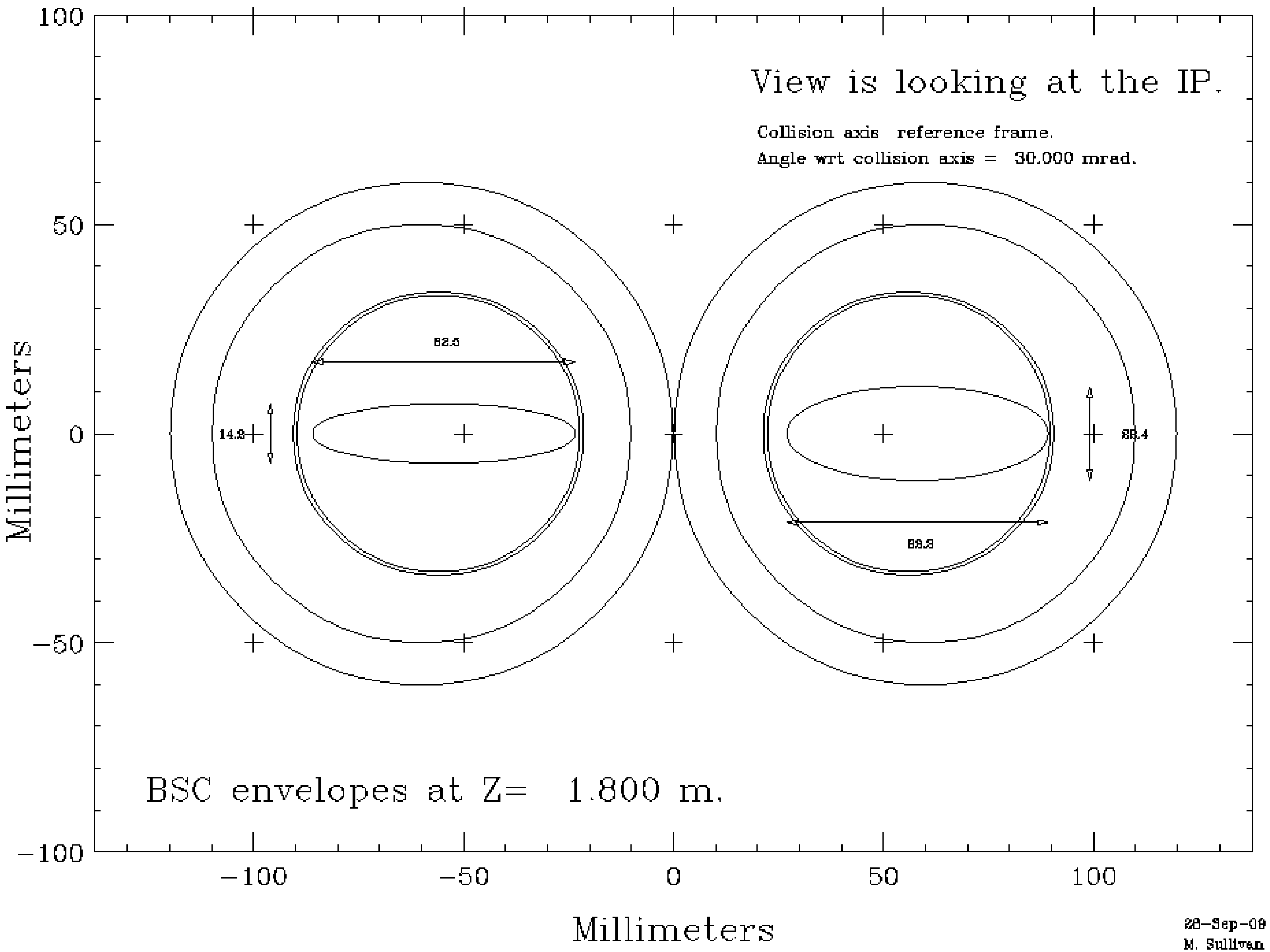
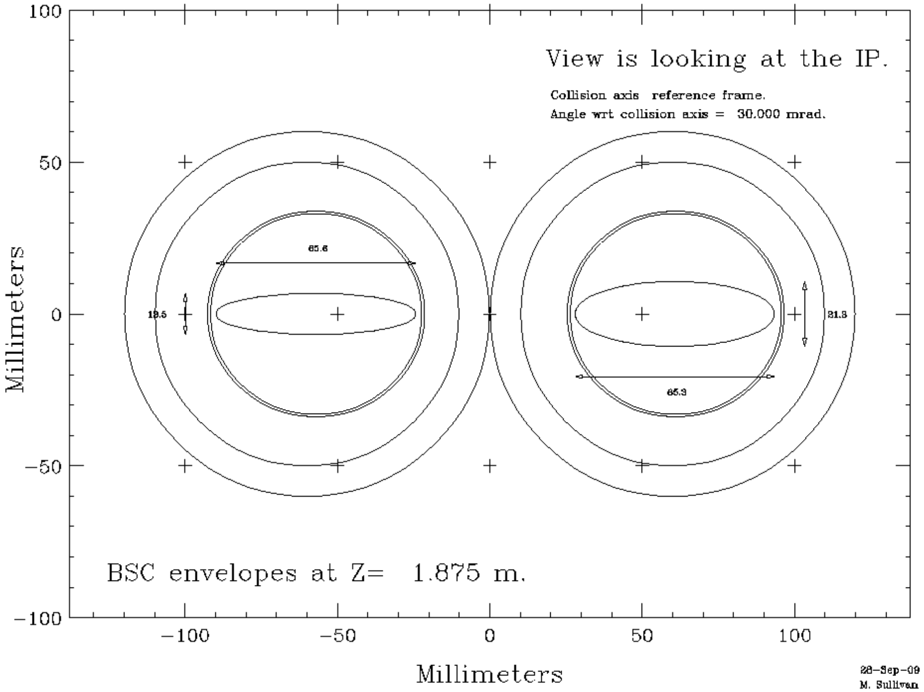
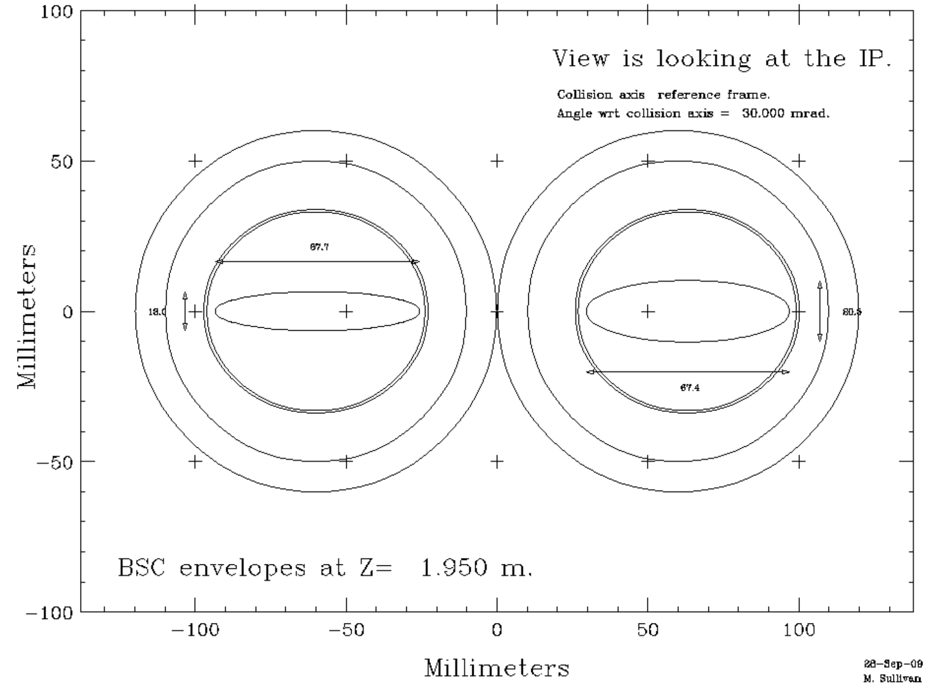
BSC envelopes at Z= 0.900 m.
Millimeters
Millimeters
28-Sep-09
M. Sullivan


View is looking at the IP.
Collision axis reference frame.
Angle wrt collision axis = 30.000 mrad.
BSC envelopes at Z= 1.000 m.
Millimeters
Millimeters
28-Sep-09
M. Sullivan

QF1 cross-sections




View is looking at the IP.
Collision axis reference frame.
Angle wrt collision axis = 30.000 mrad.
BSC envelopes at Z= 1.875 m.
Millimeters
Millimeters
28-Sep-09
M. Sullivan


View is looking at the IP.
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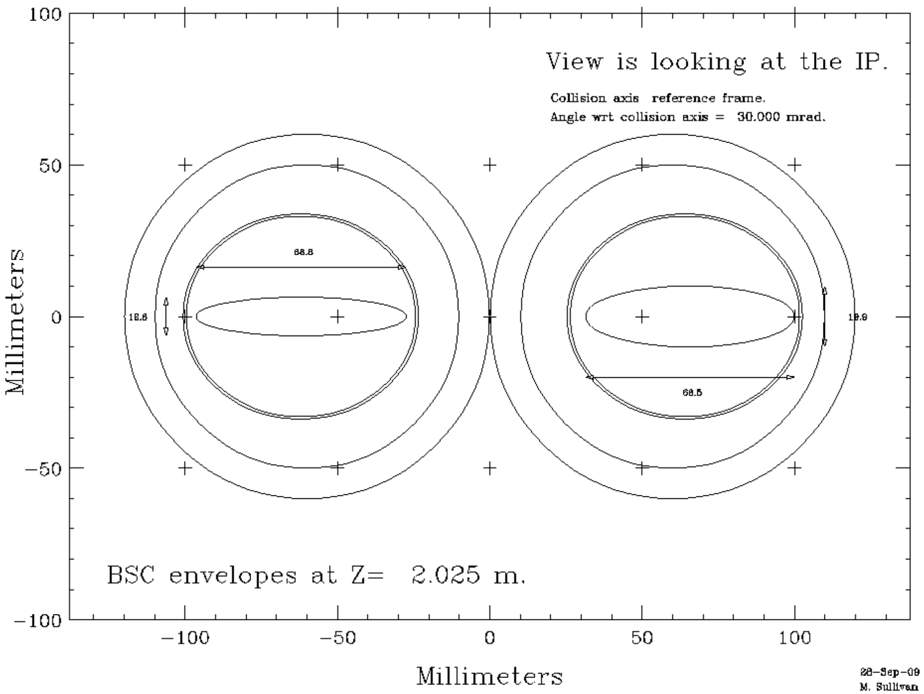
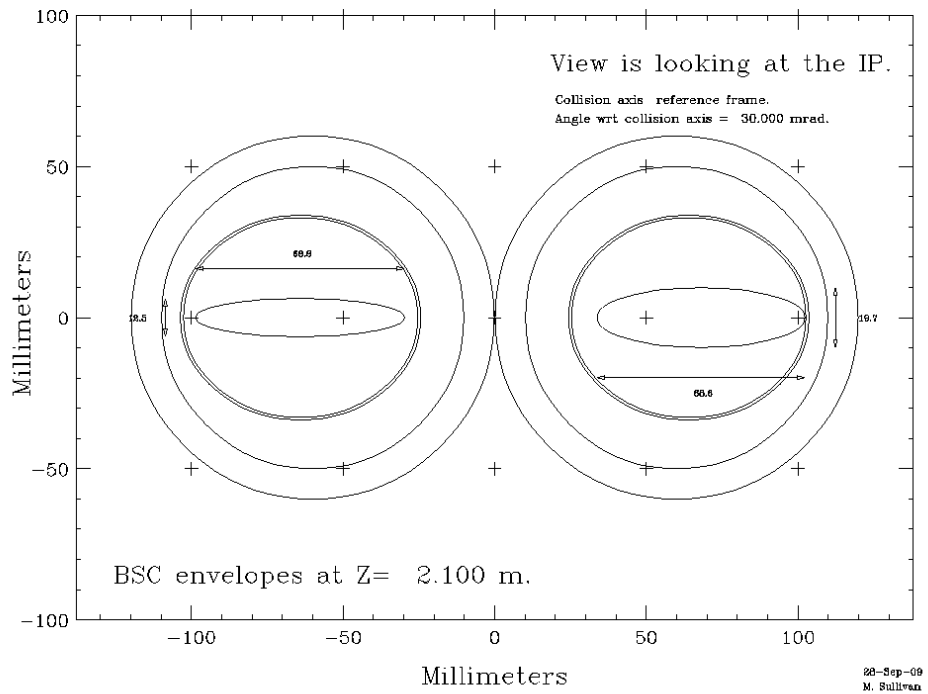
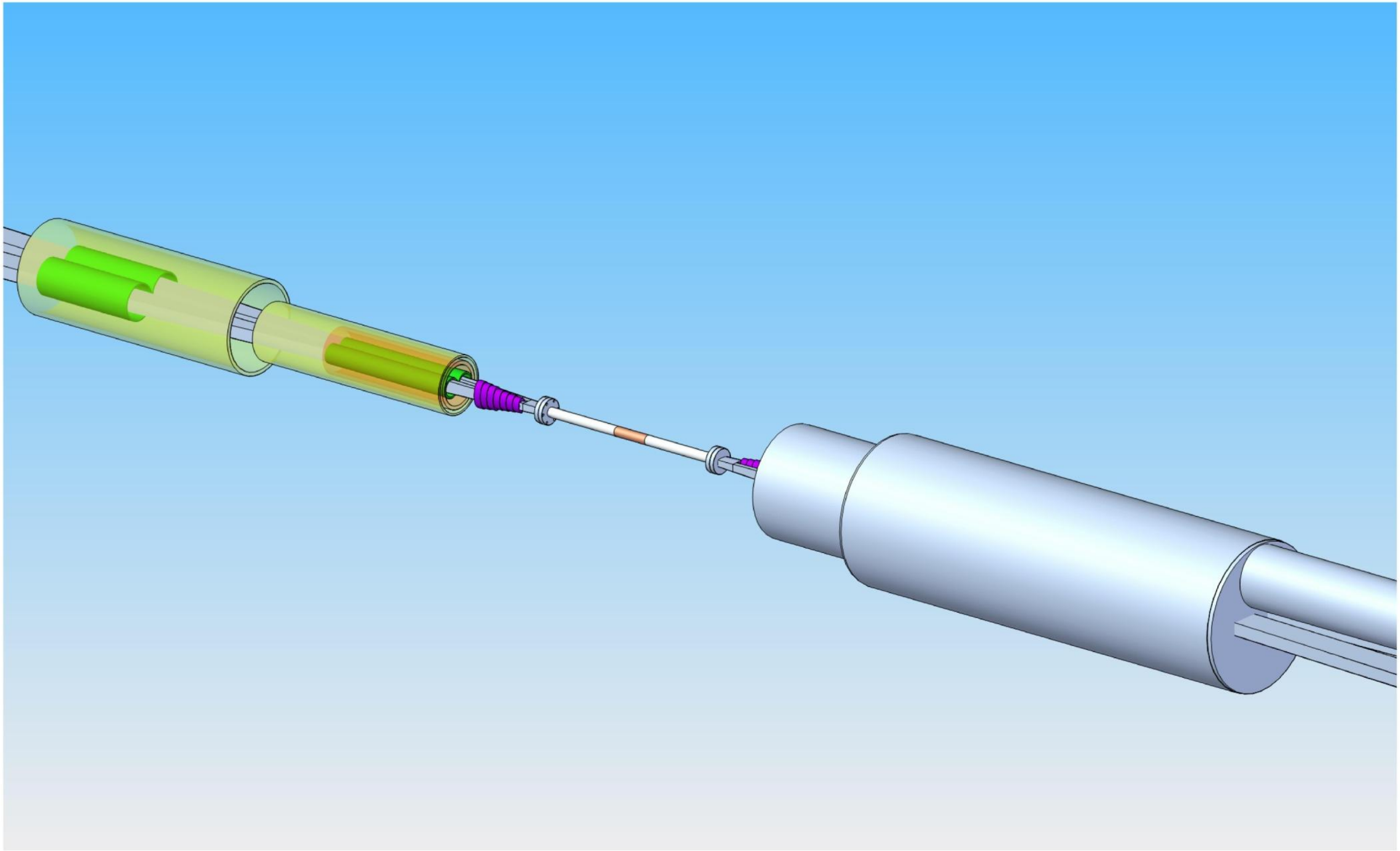
Angle wrt collision axis = 30.000 mrad.
BSC envelopes at Z= 1.950 m.
Millimeters
Millimeters
28-Sep-09
M. Sullivan


View is looking at the IP.
Collision axis reference frame.
Angle wrt collision axis = 30.000 mrad.
BSC envelopes at Z= 2.025 m.
Millimeters
Millimeters
28-Sep-09
M. Sullivan


View is looking at the IP.
Collision axis reference frame.
Angle wrt collision axis = 30.000 mrad.
BSC envelopes at Z= 2.100 m.
Millimeters
Millimeters
28-Sep-09
M. Sullivan

Initial Cryostat Design



SR backgrounds

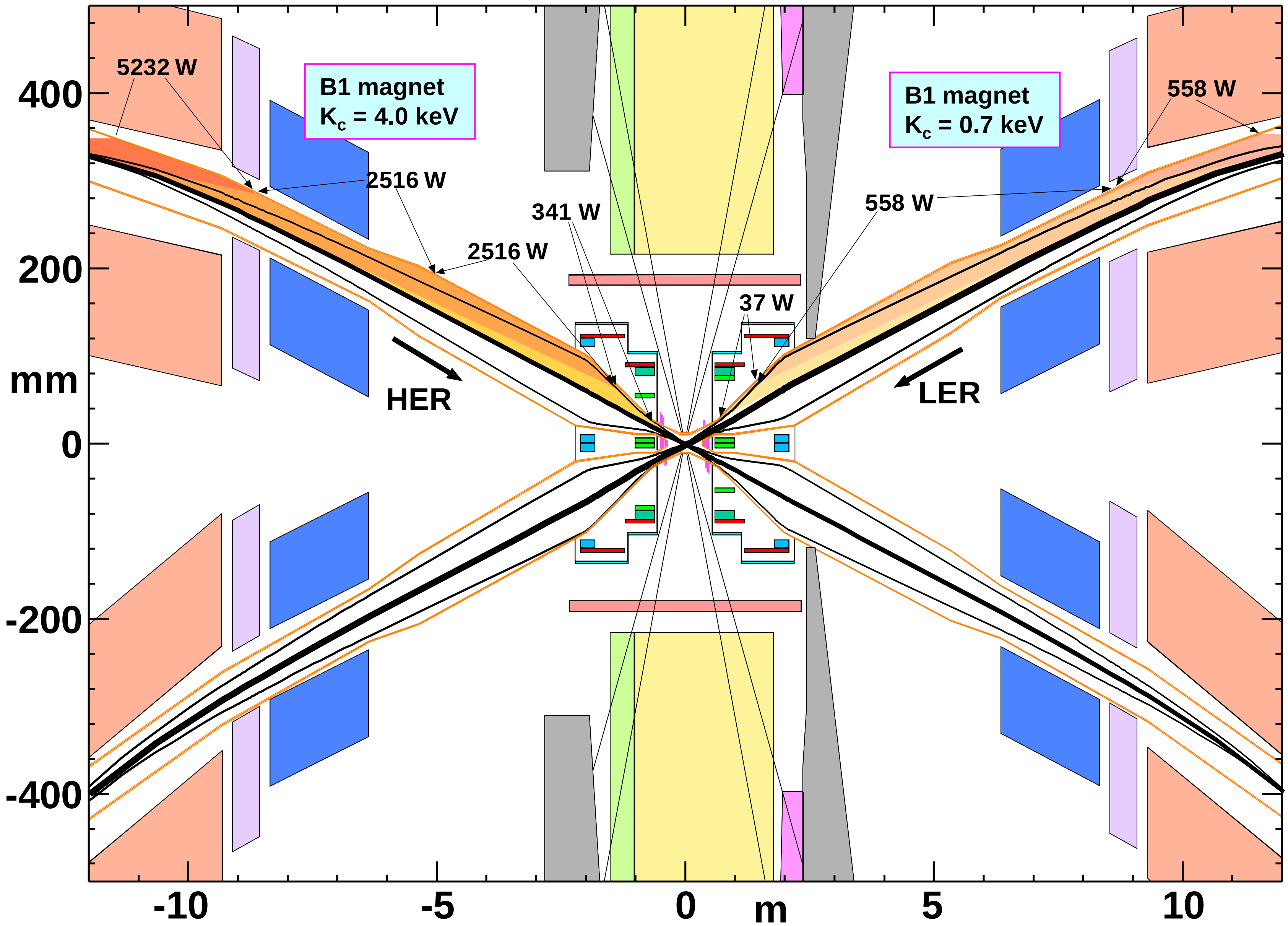
- **No photons strike the physics window**
  - **We trace the beam out to 20σ X and 45σ Y**
  - **The physics window is defined as +/-4 cm for a 1 cm radius beam pipe**

- **Photons from particles at high beam sigmas presently strike within 5-6 cm downstream of the IP**

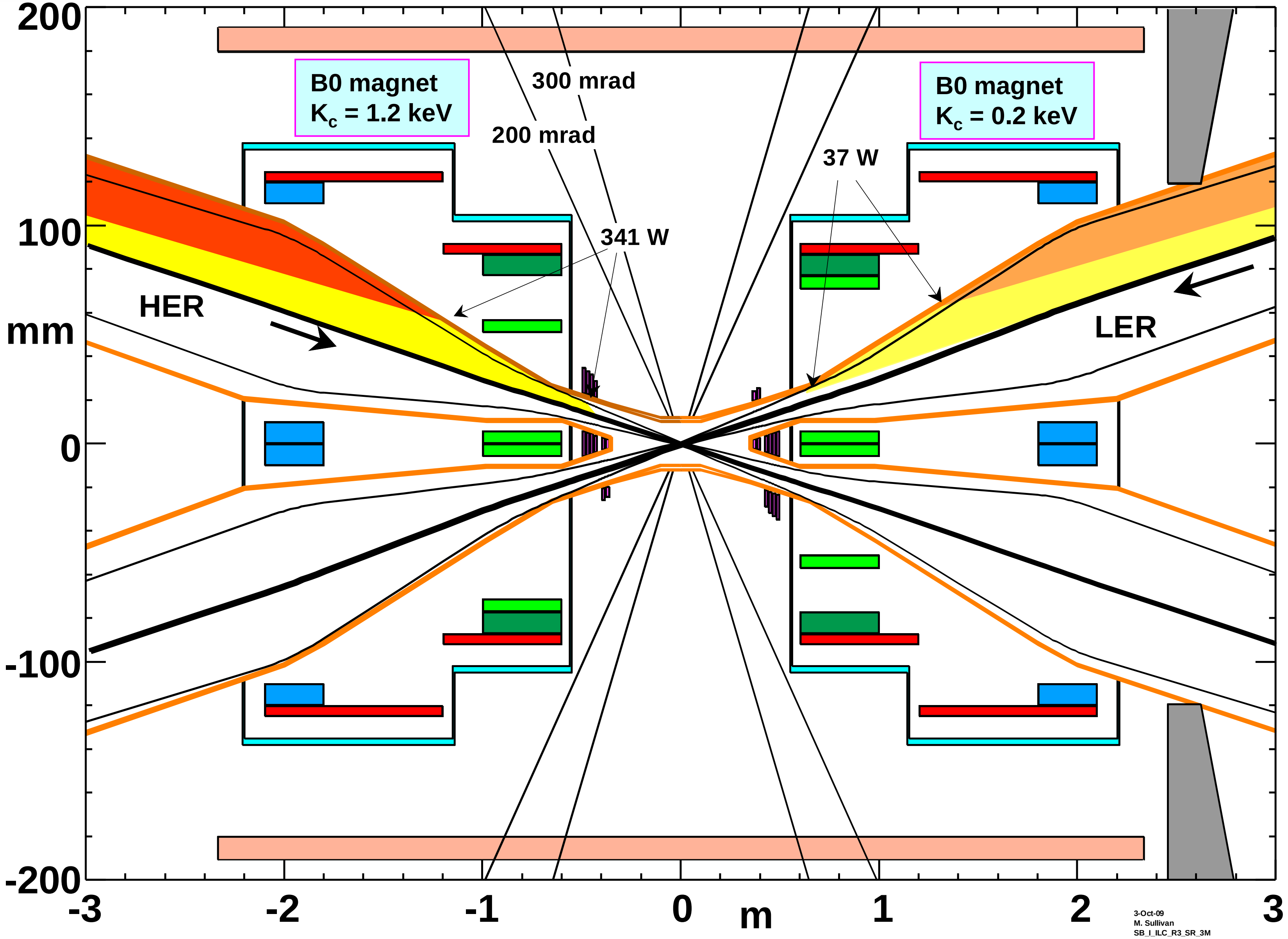
- **However, the highest rate on the detector beam pipe comes from a little farther away where the photon rate significantly increases on the local beam pipe**

- **Unlike PEP-II, the SuperB design is sensitive to the transverse beam tail distribution**

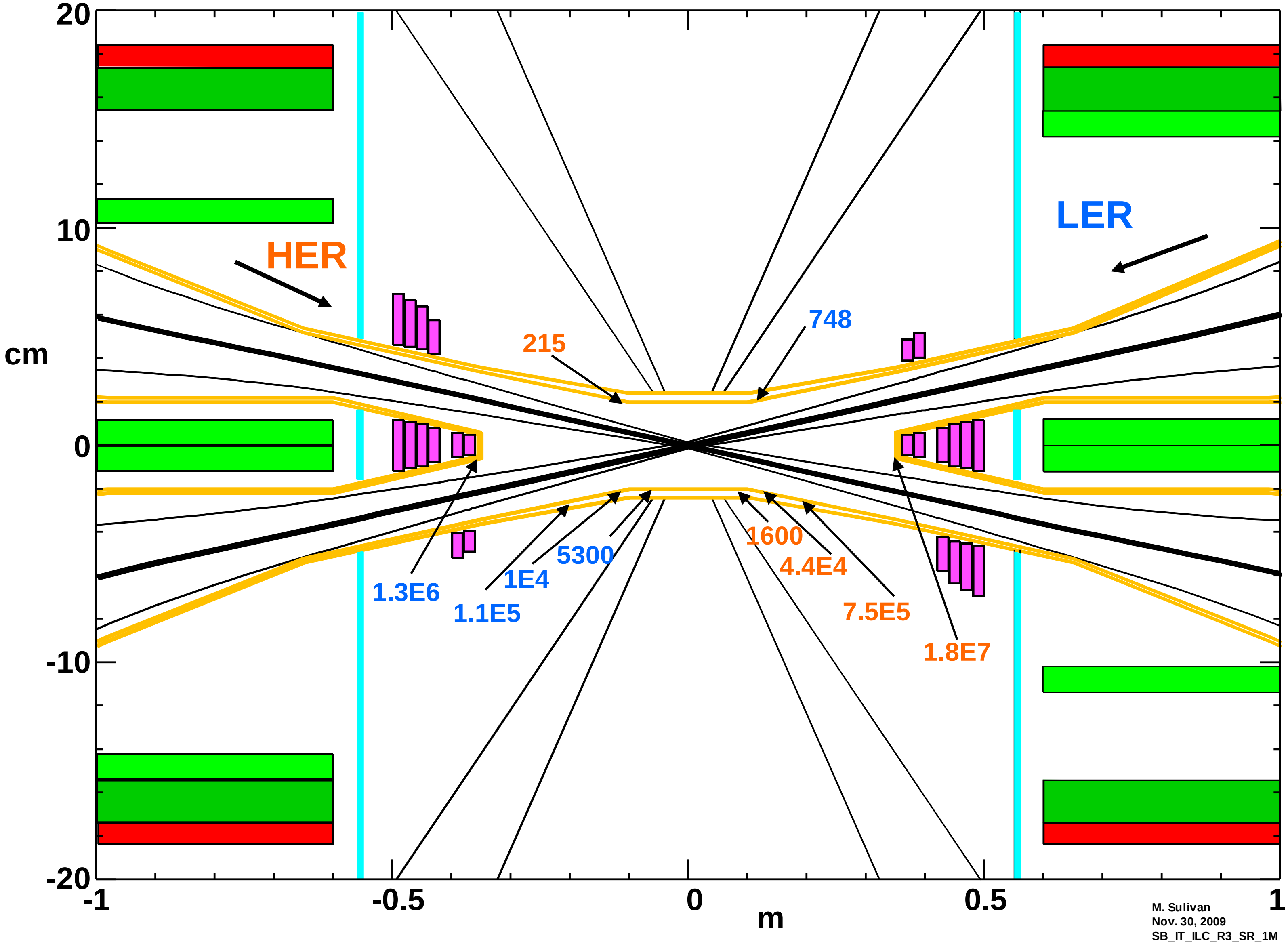
SR from the upstream bends



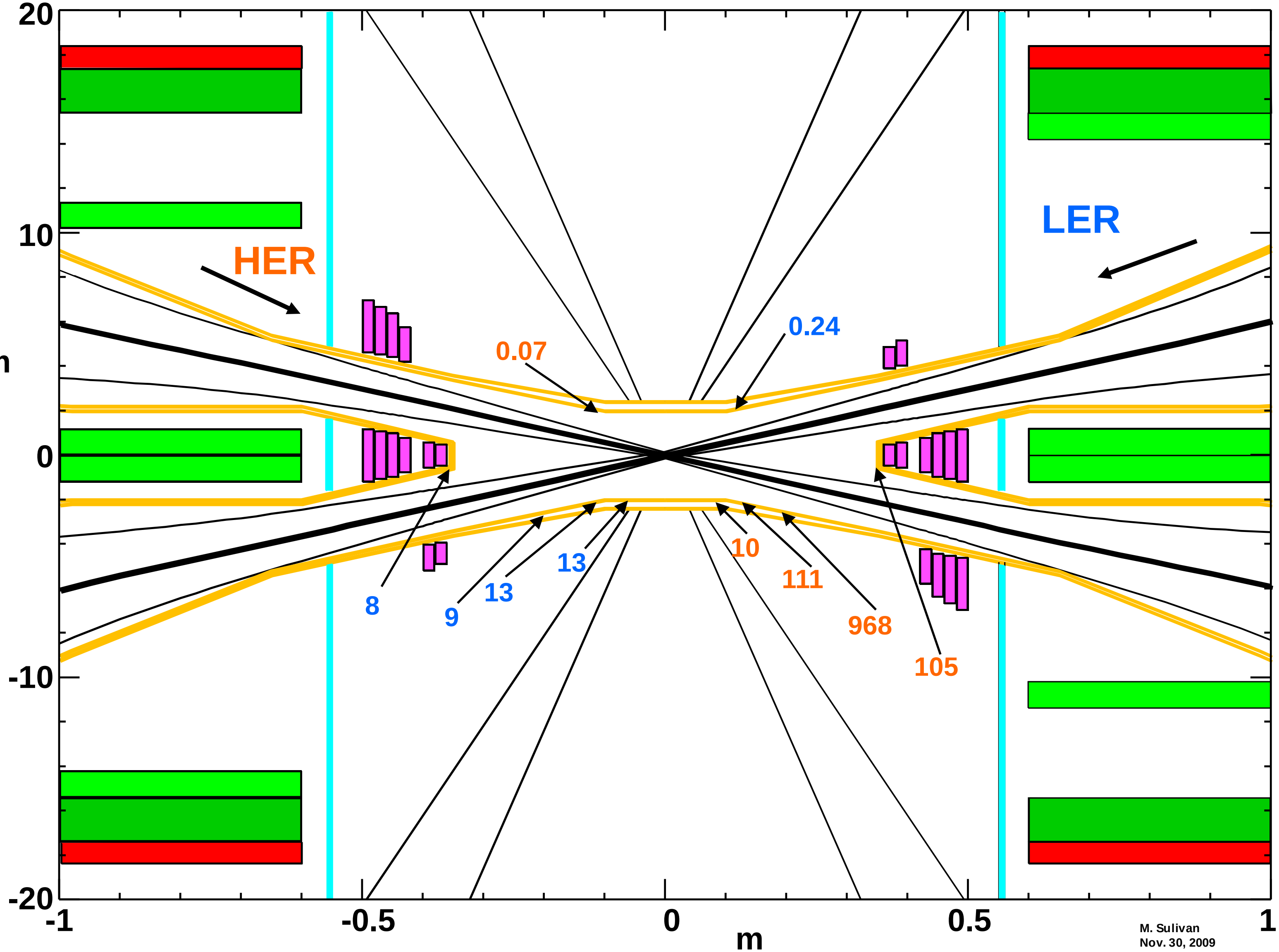
SR power from soft bends



SR photon hits/crossing



SR photon hits/crossing on the detector beam pipe from various surfaces

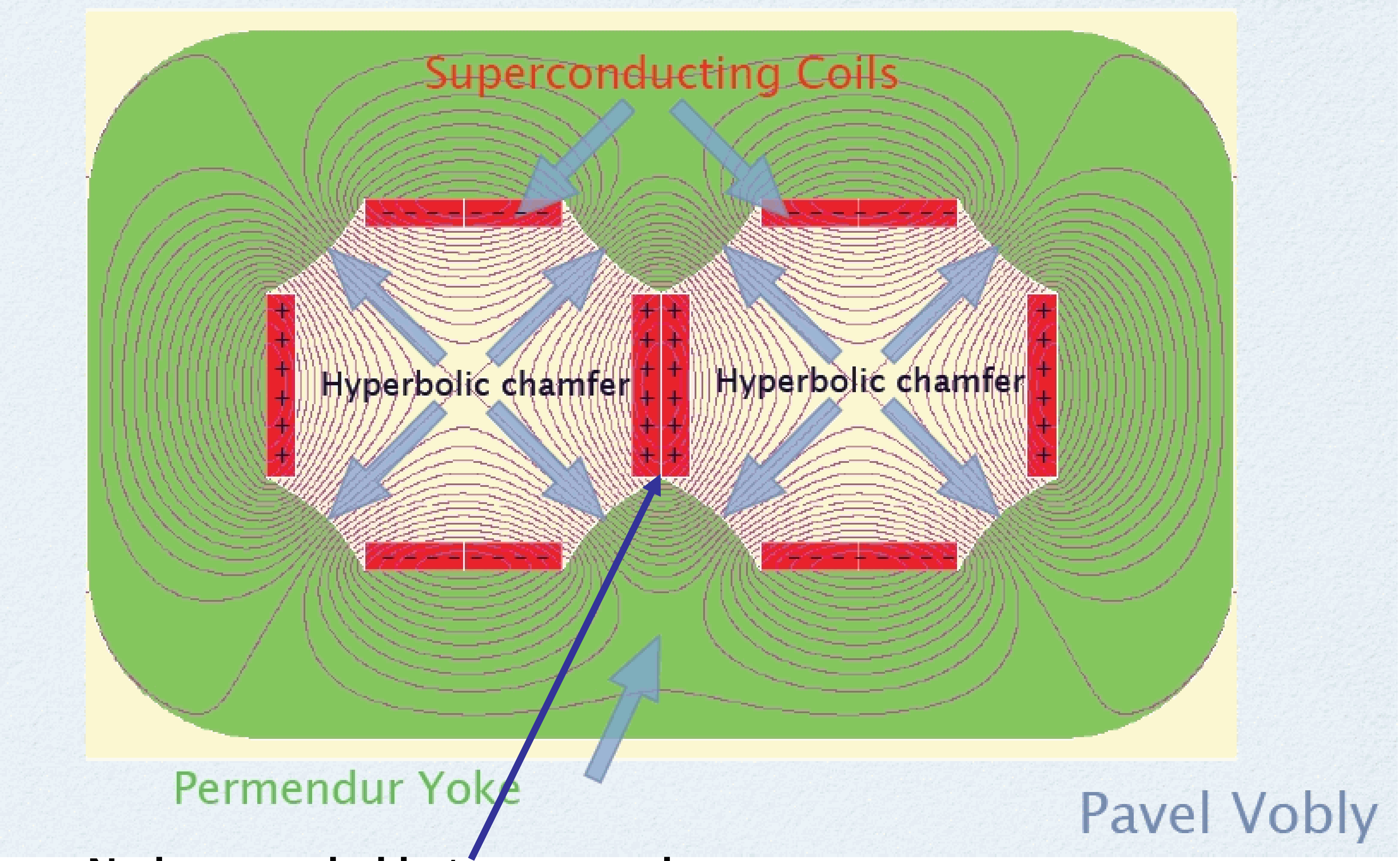


After including the backscattering SA and absorption rate (3% reflected)

New Idea – Super-ferric QD0

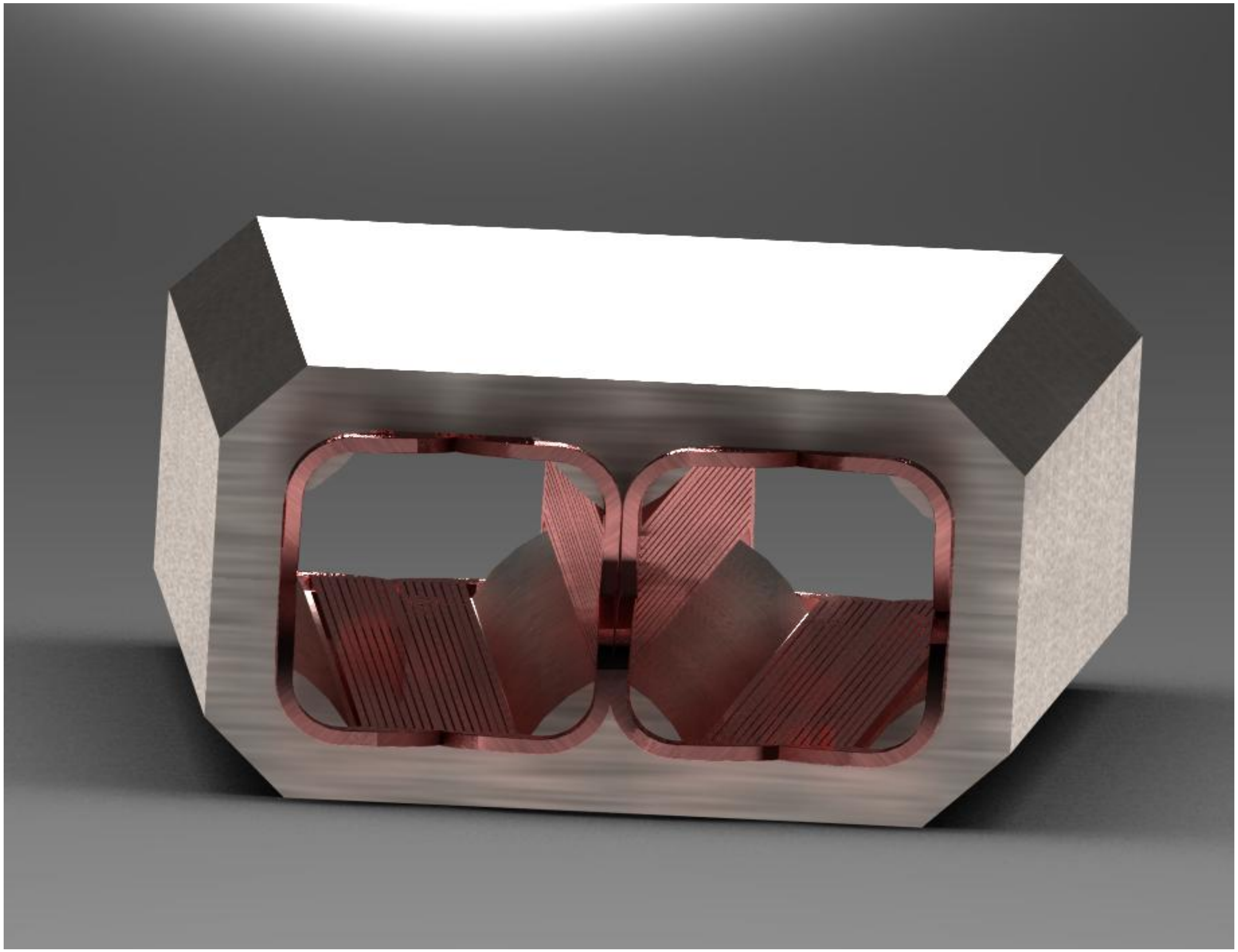
- Pavel Vobly from BINP has come up with a new idea for QD0 (mentioned at the end of the workshop at SLAC in October)
  - Use Panofsky style quadrupoles with Vanadium Permendur iron yokes
- This new idea has some added constraints but it is still attractive because it is easier to manufacture and the precision of the iron determines the quality of the magnet

Two Panofsky style quads



No iron needed between quads

The quads can be on axis with the beams



Super-ferric QD0

- **Extra constraints**
  - Maximum field of no more than 2T at the pole tips
  - Equal magnetic fields in each quad
  - Square apertures
- **Advantages**
  - Easier to build
  - Self-shielding
  - If we can get enough space we can separate the magnets in z
- **Both QD0 designs need a well cancelled detector field**
  - We will use solenoid windings around the cold mass

Design constraints

- The requirement of the maximum field strength to be less than 2 T has forced us to move the magnets back from the IR, but this also makes the beam size increase which is one of the reasons the QF1 aperture is so large.
- The requirement of a square aperture does not seem to cause any problems so far. We seem to be dominated in aperture in the X plane instead of in the Y plane.

SR backgrounds for the Super-ferric QD0

- We tested the case of putting all of the magnet centers on beam axis which we can do in the super-ferric design
- Unfortunately the straight on-axis solution generates SR photons from the high-sigma region of the beam profile that directly strike the detector beam pipe
- These photons come from the beam rays with the steepest slope out of QF1
- Both the current baseline design and the super-ferric design must have offset QD0 axes

QD0 Summary

- The baseline "Italian style" design is still being pursued
  - The manufacture of this design is one of the most difficult parts – wire placement and stability are crucial
- The new Panofsky style QD0 shows promise and is being investigated
  - A very recent discovery (for me) is the existence of the rare earth Holmium
  - It has the highest magnetic moment of any element
  - The metal becomes ferric at 20° K and has a saturation field of ~3.8T
  - Vanadium Permendur saturation field is ~2.4T
  - Holmium is not as mechanically strong as iron so we will have to see if we can use it
- We have recently started work on re-optimizing the permanent magnet part of the design for both the panofsky style QD0 and the "Italian style" QD0

Project Status

- The SuperB proposal is in the Agenda of CIPE (Inter-ministry Committee for Economic Planning)

- The proposal is supported by the Ministry of Education Science and Technology with a very high priority

- The President of INFN is closely in touch with the Ministry high level officers and with the Minister

From the presentation of Marcello Giorgi at the SuperB workshop Dec 1-5, 2009

Project Status (2)

- The status of SuperB was reported last November at the ECFA plenary meeting at CERN
- There were no objections or criticism of any kind from the audience
- The CERN planning committee has stated that this is a good regional project
- We are hoping to hear about funding next month

From the presentation of Marcello Giorgi at the SuperB workshop Dec 1-5, 2009

Summary

- In order to achieve a factor of 50 over present day B-factories we must:
  - Collide state-of-the-art low emittance beams and
  - Use very low β^* values
  - This combination has never been done
- However, the design uses proven technology wherever possible
  - Bunch current, number of bunches, total current, bunch length
- The SuperB design is converging
- Polarization of the electron beam looks feasible
- The accelerator design has flexibility

Summary (2)

- The Italian government favors the proposal
- We hope to hear from the government this coming month
- We are in the midst of writing a white paper describing the physics, the detector and the accelerator
- This is a preliminary step toward a TDR which we hope to have finished by the end of this year (2010)

Conclusion

- The physics argument for a Super B-factory is compelling
  - Complimentary to the LHC
  - A higher new physics mass reach than the LHC
- The accelerator design is converging
  - All aspects are starting to look feasible
- As always, more work needs to be done
- We hope to hear soon about project funding