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# ILC
# Head-On Interaction Region: Status Report

*Olivier NAPOLY*
*For the Head-on Task Group*

## *ILC BDS KOM*
***12 October 2007***

# Head-on Task Group

**TECHNICAL CHALLENGES FOR HEAD-ON COLLISIONS AND EXTRACTION AT THE ILC**
**(PAC'07, Albuquerque)**

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# Outline

- General Layout for Head-on Collision BDS
- General questions :
  1. Are the beam line elements feasible ?
  2. Is the beam line cost effective ?
  3. Is the beam line easily tunable w.r.t. Luminosity and Extraction ?
  4. Does it supply a Post IP beam diagnostics ?
- Conclusions

# Motivation for Head-on Collisions

For the collider operation, w.r.t. 14 mrad crossing angle,

**Head-on** makes focusing and colliding easier:

three machine devices are not needed **upstream** of the IP

1. Crab RF-cavities
2. Anti-DID (Detector Integrated Dipole)
3. Orbit correctors on top of each QD0

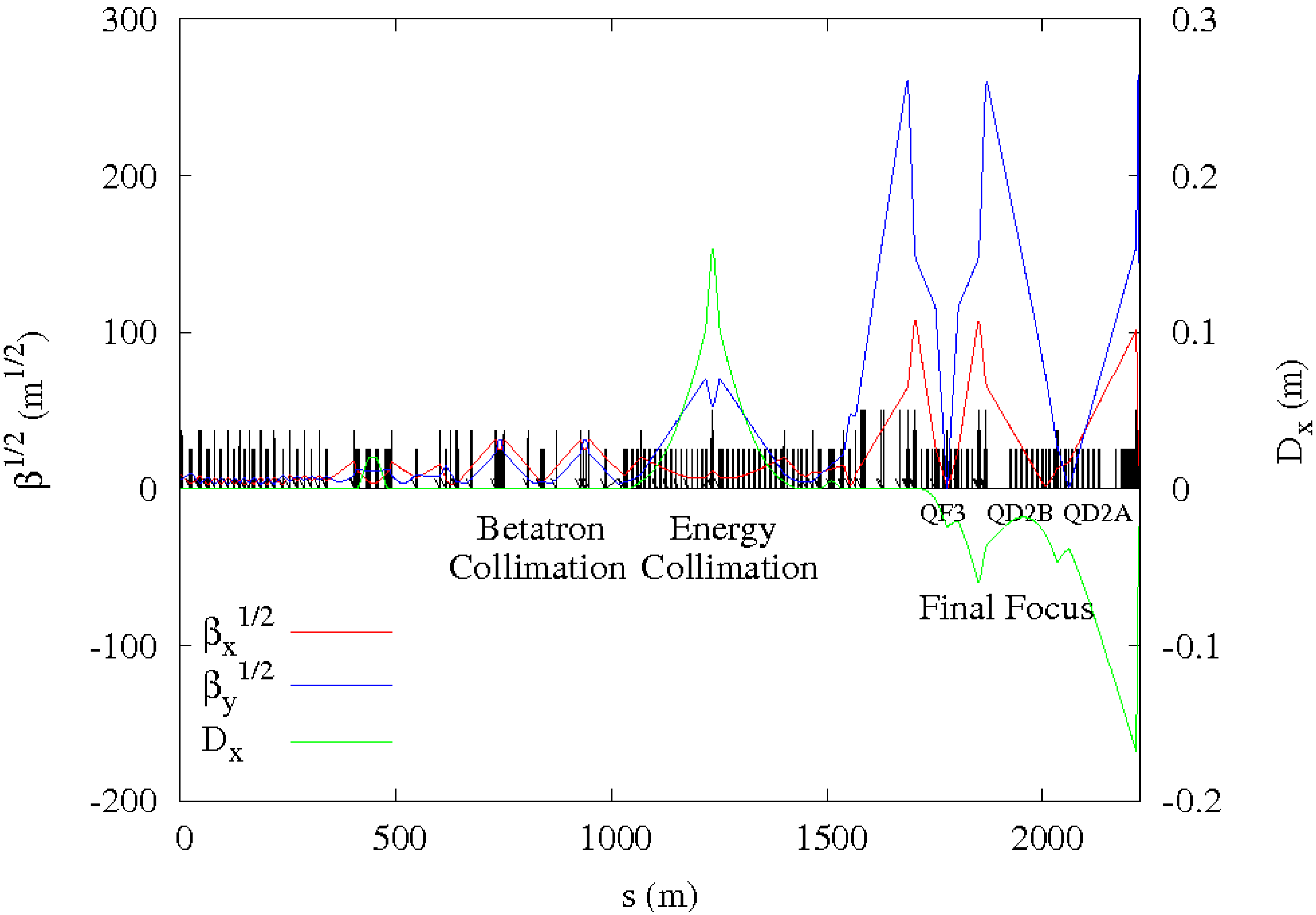
**Head-on** makes extraction more difficult:

beam extraction requires **overfocusing** in the outgoing doublet and **Electrostatic Separators to bend** the spent beams after the IP and before the first parasitic crossing ~ ($c\tau_b/2$)

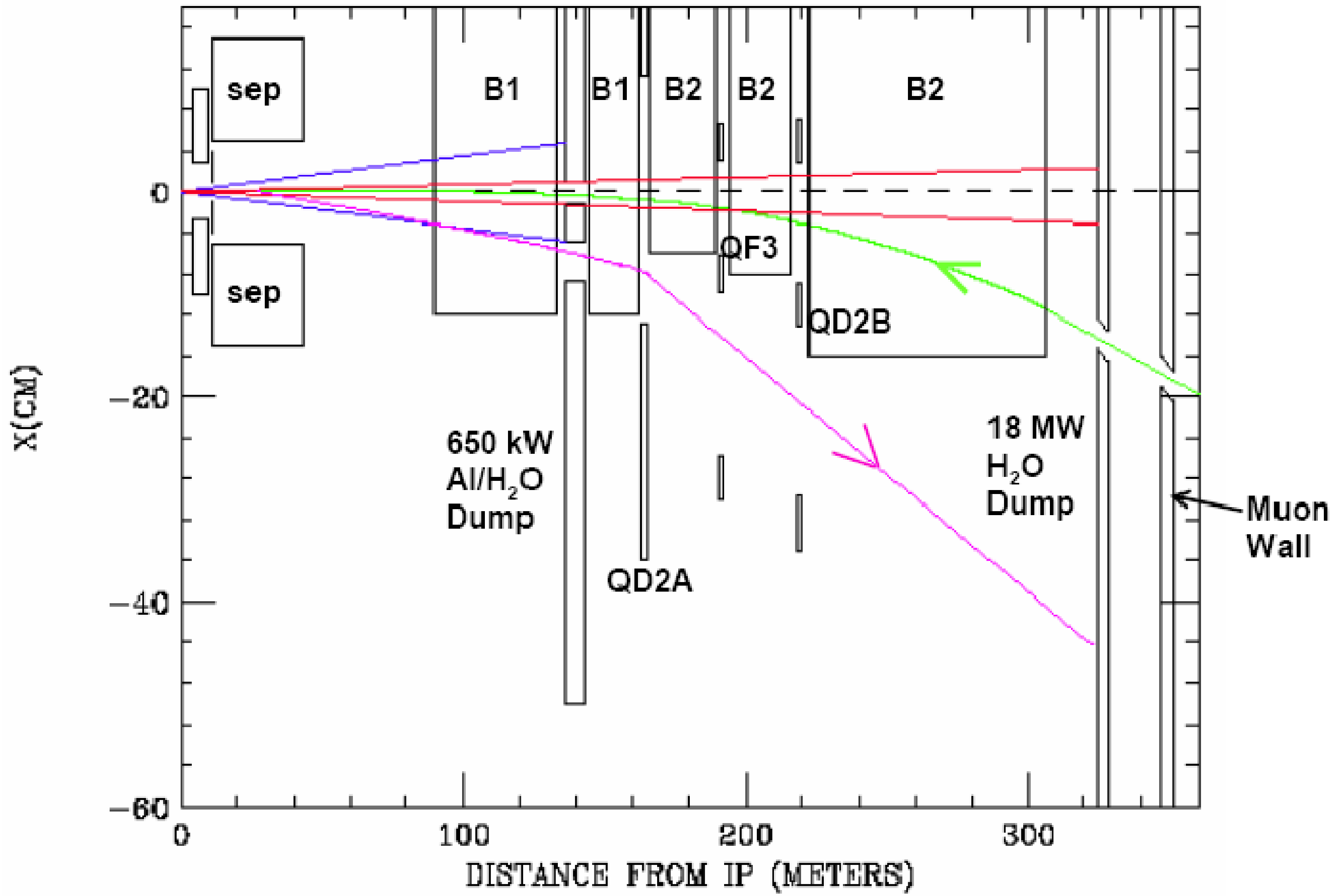
1. dispersion of the low energy tails
2. challenging beam usage and transport to the dump.

# Final Focus System

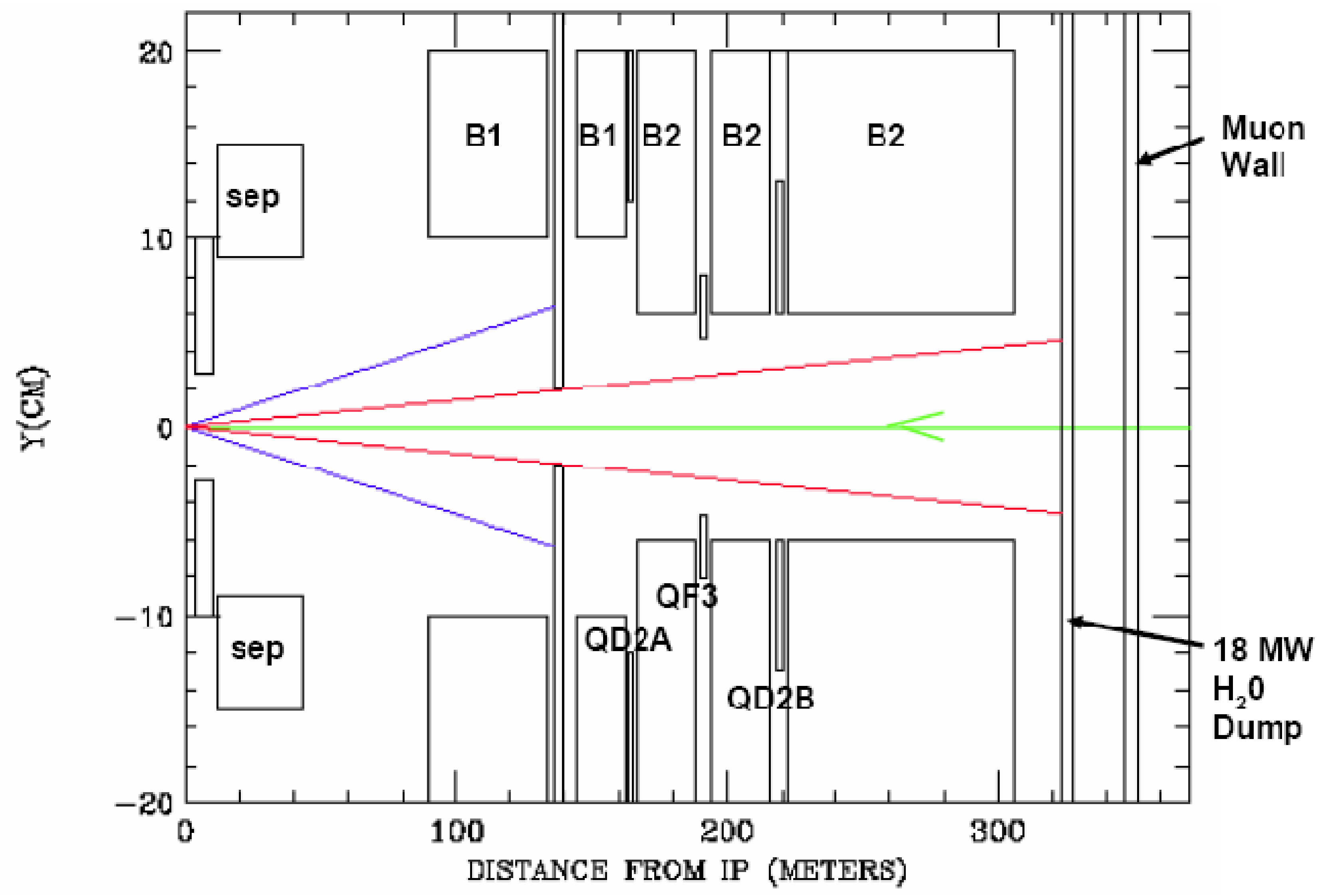
Final Focus and Chromatic Correction functions are combined



# Beam Extraction Scheme



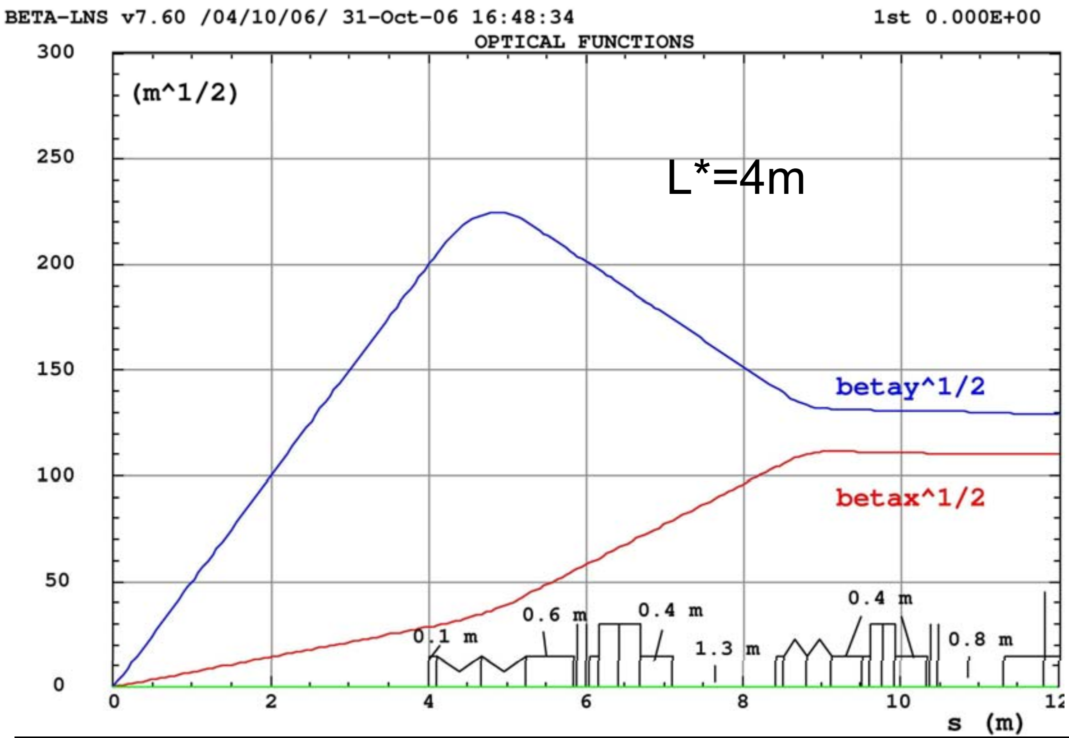
# Beam Extraction Scheme



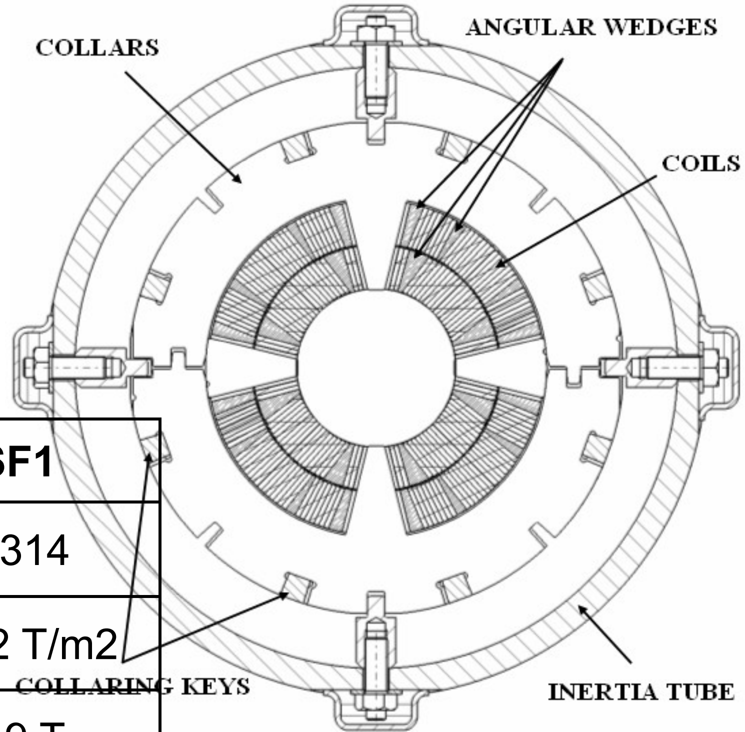
# Q1 : Are the beam line elements feasible ?

- Essential beam line elements:
  - Large aperture superconducting quadrupole and sextupole doublets
  - Electrostatic separators
  - High power collimators
  - Extraction quadrupoles

# Final Doublet for 500 GeV cm Energy

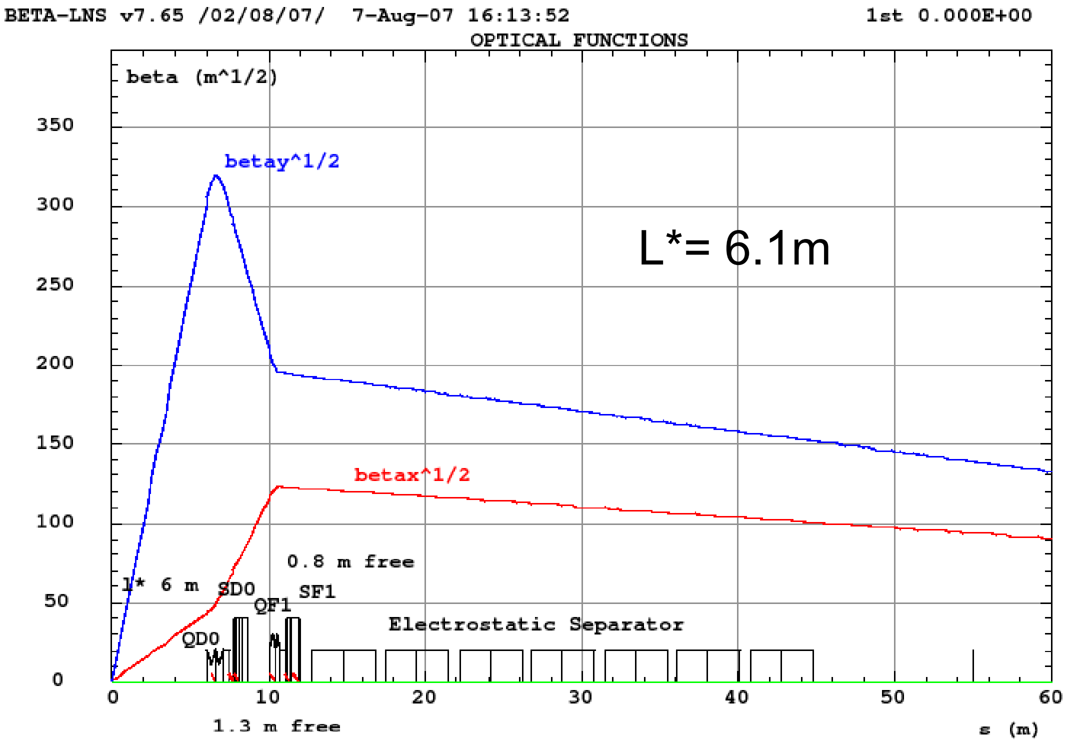



Final doublet design assumes engineered LHC arc superconducting Quadrupoles and Sextupoles with 56 mm bore diameter




| | QD0 | QF1 | SD0 | SF1 |
|---|---|---|---|---|
| Length [m] | 1.146 | 0.593 | 0.548 | 0.314 |
| Gradient | 250 T/m | 250 T/m | 3880 T/m2 | 3662 T/m2 |
| Field @ bore | 7 T | 7 T | 3 T | 2.9 T |

# Final Doublet for 500 GeV cm Energy

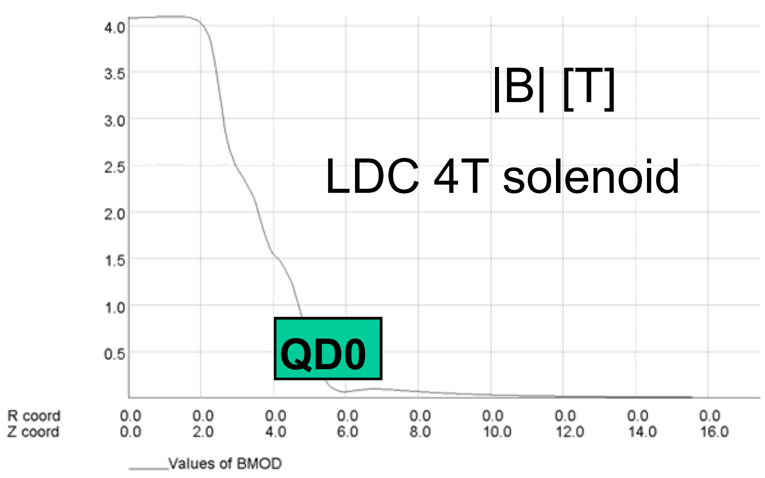


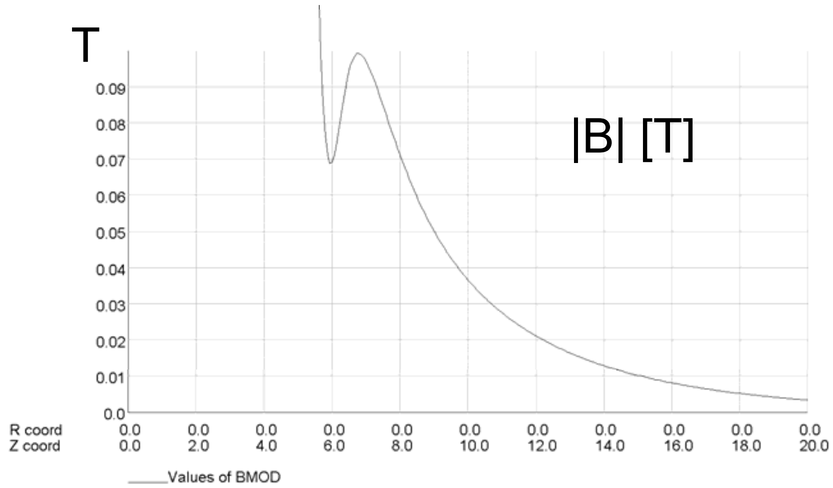

Final doublet design assumes Nb3Sn superconducting Quadrupoles and Sextupoles with 90 mm bore diameter and 225 T/m (G.L. Sabbi)

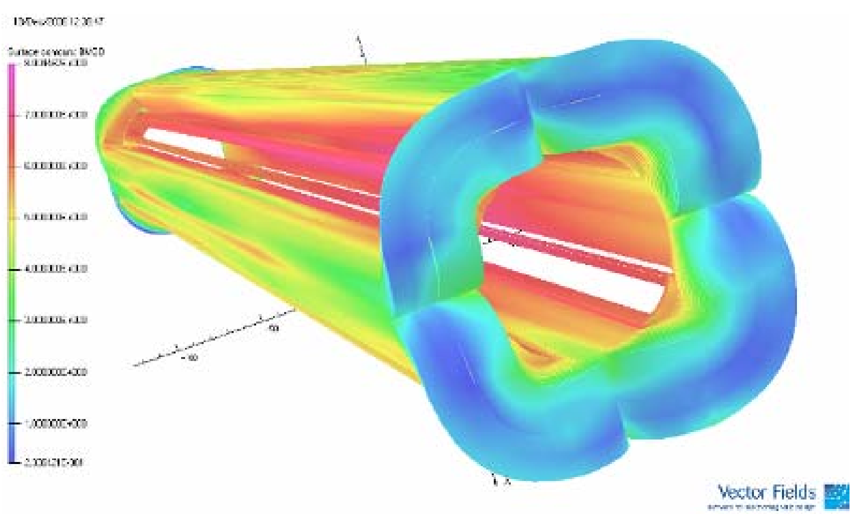
Is L*=6.1 m large enough for detector push-pull ?

| | QD0 | QF1 | SD0 | SF1 |
|---|---|---|---|---|
| Length [m] | 1.008 | 0.644 | 0.366 | 0.212 |
| Gradient | 225 T/m | 225 T/m | 3880 T/m2 | 3662 T/m2 |
| Field @ bore | 10.1 T | 10.1 T | 8.8 T | 8.8 T |

# Final Doublet : (Solenoid + Quad) 3D Map




**Preliminary analysis**:

- Solenoid Br component is negligible

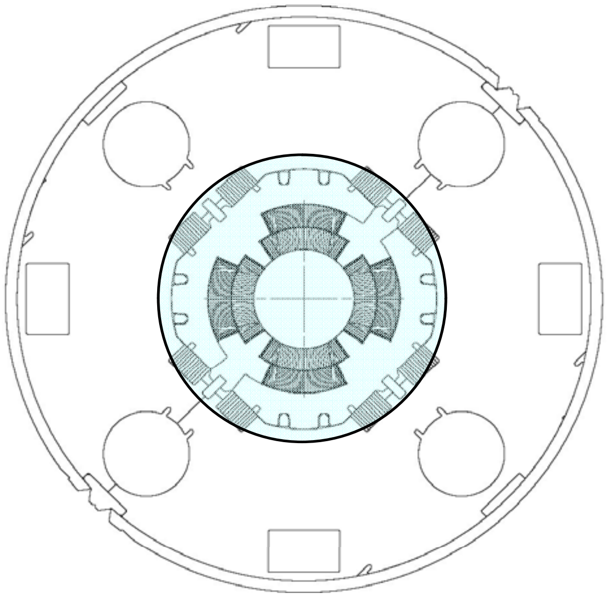
- Solenoid Bz < 2 T @ QD0

⇒ Bmax = 7.65 T ⊕ 2 T in quadrature

⇒ Bmax ≈ 8 T on QD0

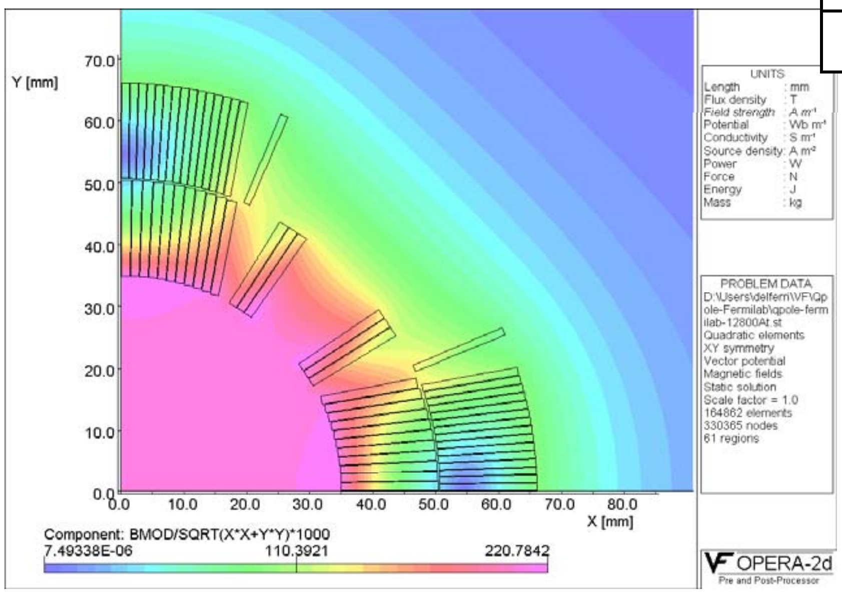
⇒ Standard NbTi doublet is feasible for 500 GeV cm energy

# Final Doublet : 1 TeV upgrade

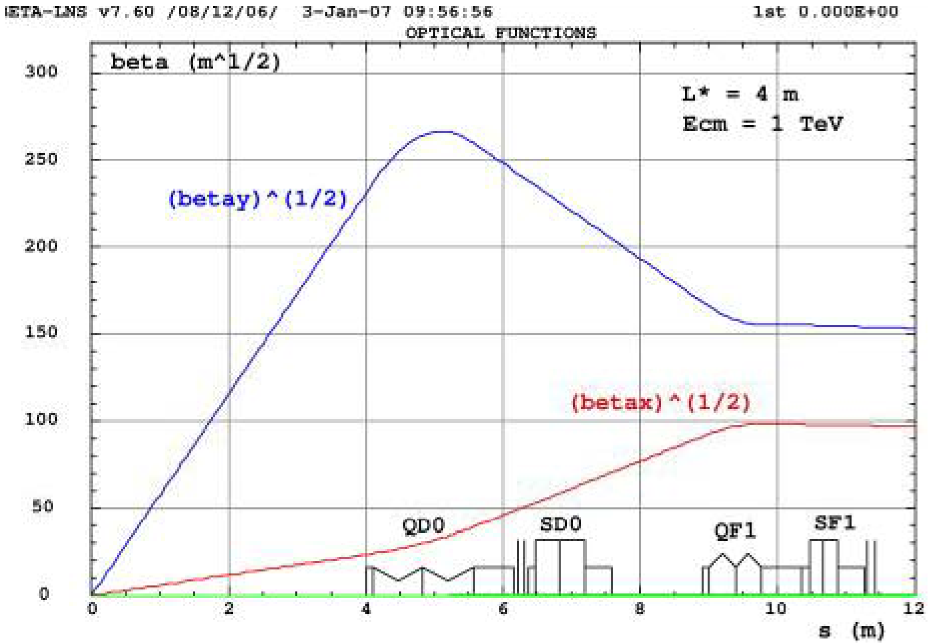


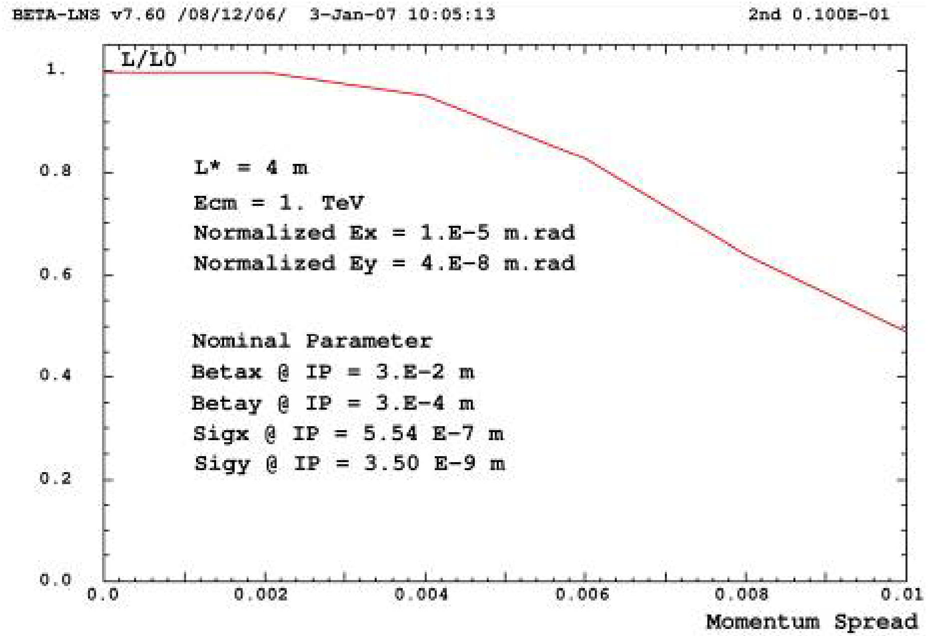
## MQXB cross section quadrupole

| | | |
|---|---|---|
| Coil radius | 35 mm | |
| Gradient | 210 $Tm^{-1}$ (adapt. to 250 $Tm^{-1}$) | |
| Nominal current | 12800 A (adapt. to 15 000 A) | |
| Conductor characteristics (adapt. to $Nb_3Sn$) | | |
| Conductor | internal | external |
| Radial length | 15.4 mm | 15.4 mm |
| Little side | 1.326 mm | 1.054 mm |
| Big side | 1.587 mm | 1.238 mm |
| Turns/pole | 14 | 16 |



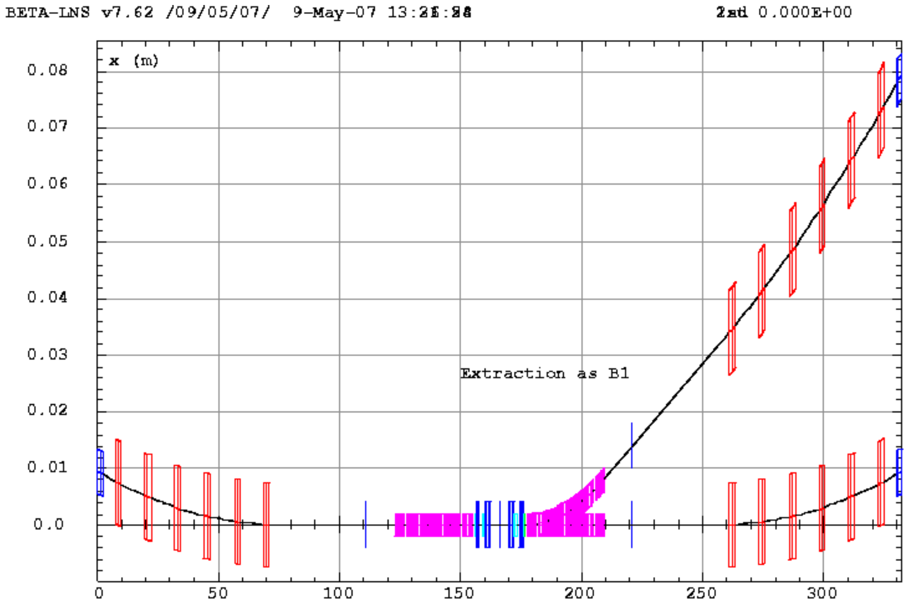
# Final Doublet : 1 TeV upgrade

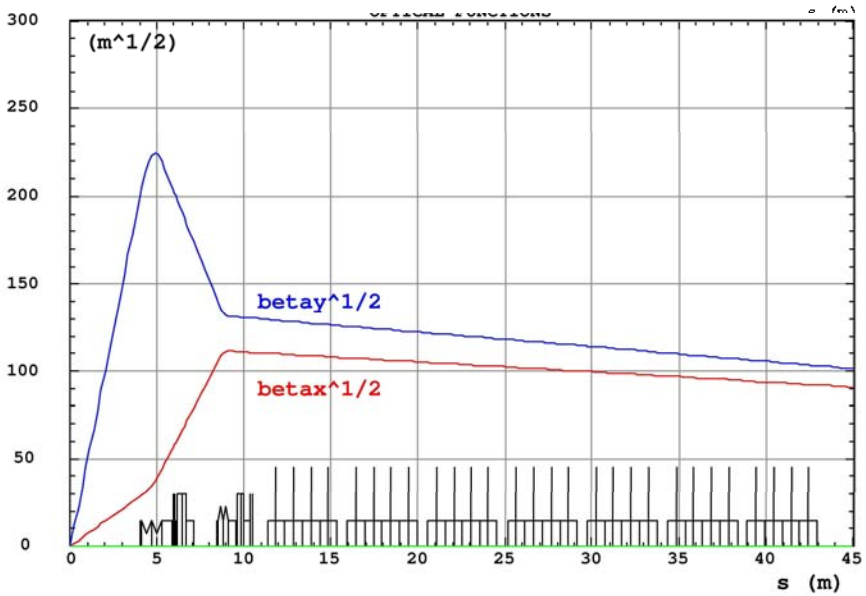


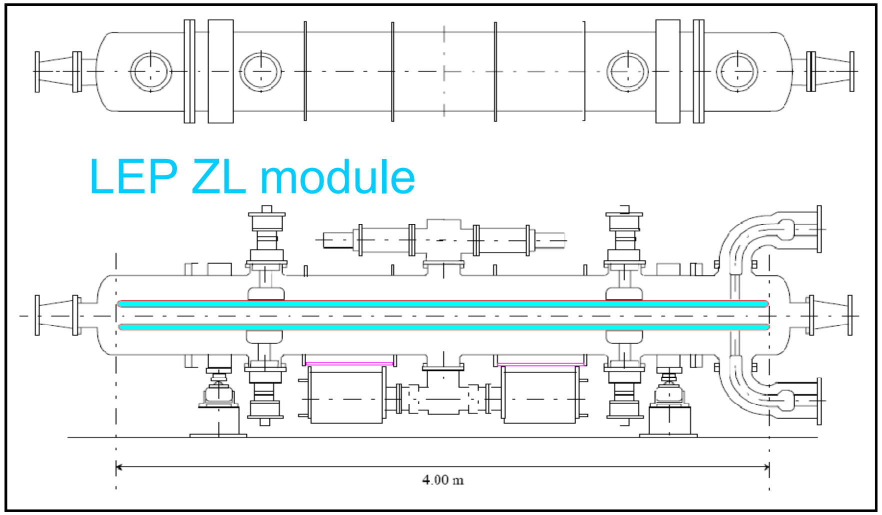

| | QD0 | QF1 | SD0 | SF1 |
|---|---|---|---|---|
| Length [m] | 1.374 | 0.746 | 0.7 | 0.4 |
| Gradient | 373 T/m | 370 T/m | 5243 T/m2 | 4873 T/m2 |
| Field @ bore | 10.5 T | 10.5 T | 4.11 T | 3.82 T |

# Extraction Scheme : Parasitic Crossing




First stage separation is provided by seven 4 m long Electrostatic Separator modules with Es = 26 kV/cm
\+ 8 mT compensating dipoles




Beam-beam instability from parasitic crossings is under control when :

- Horizontal transverse separation is larger than 11 mm, and
- $R_{34}$( IP $\rightarrow$ 1st PIP) < $\beta^{*1/2}$ x 100 $m^{1/2}$

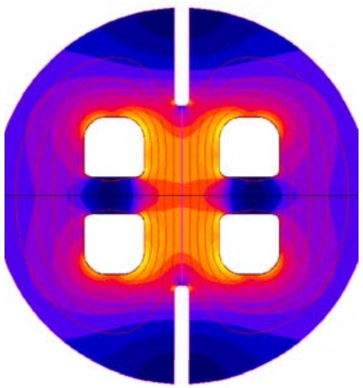
# Updated ILC separator specifications

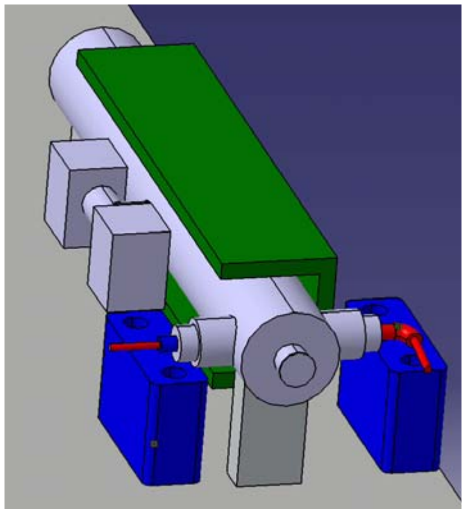
The total deflection provided by separator of 252 μrad is :

-12mm separation at 55 m from IP

- 70 mm at QD2A

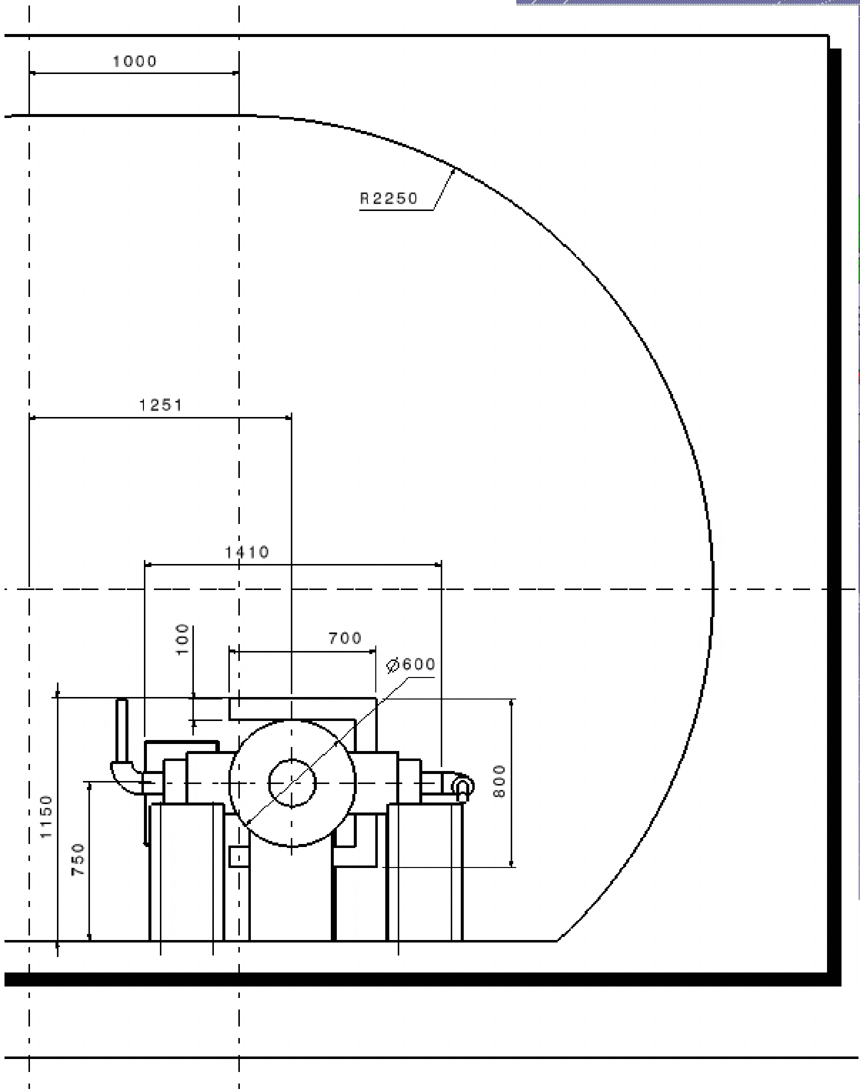
(1st separator electrode starts at 11.314 m from IP)

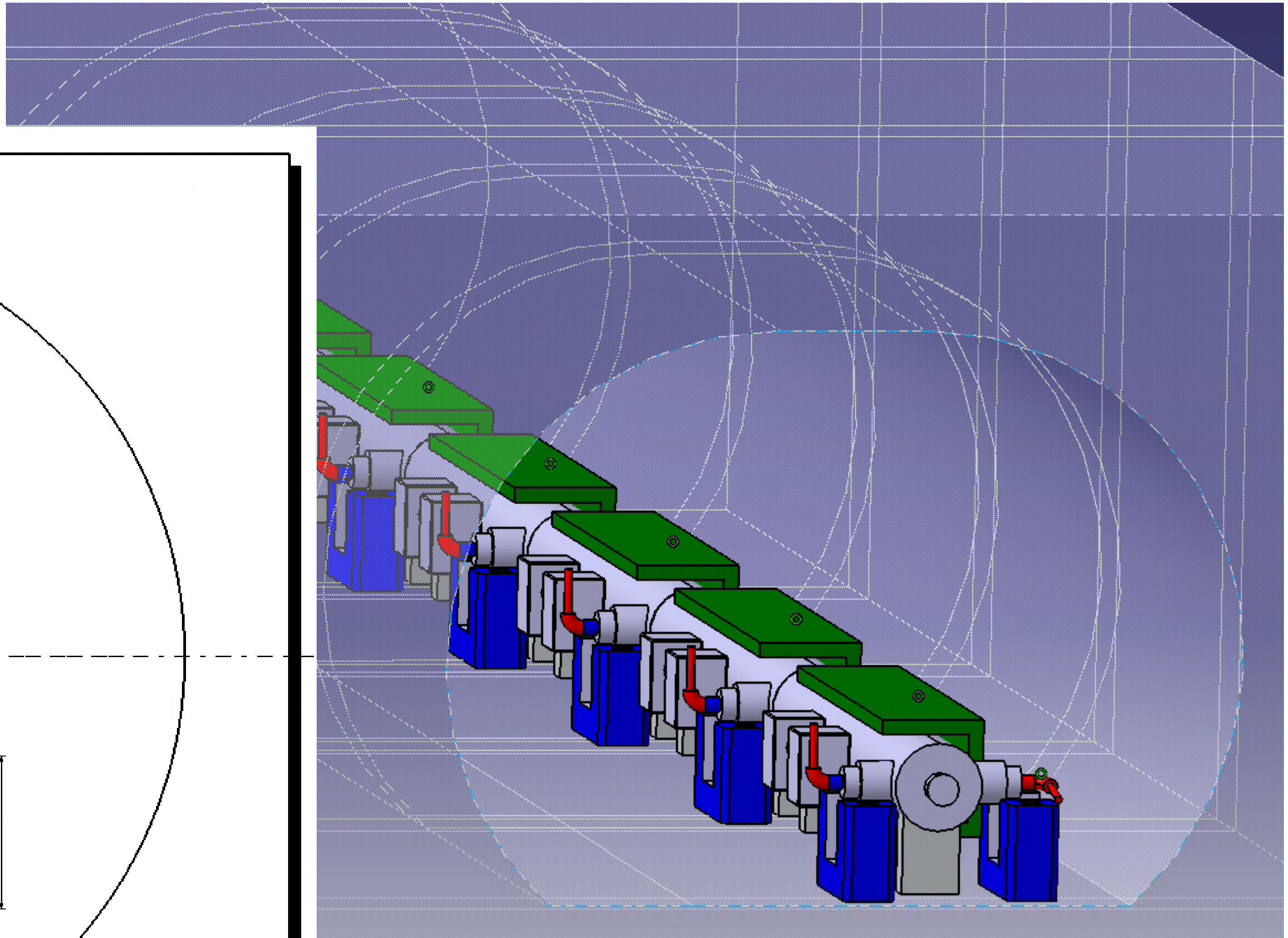




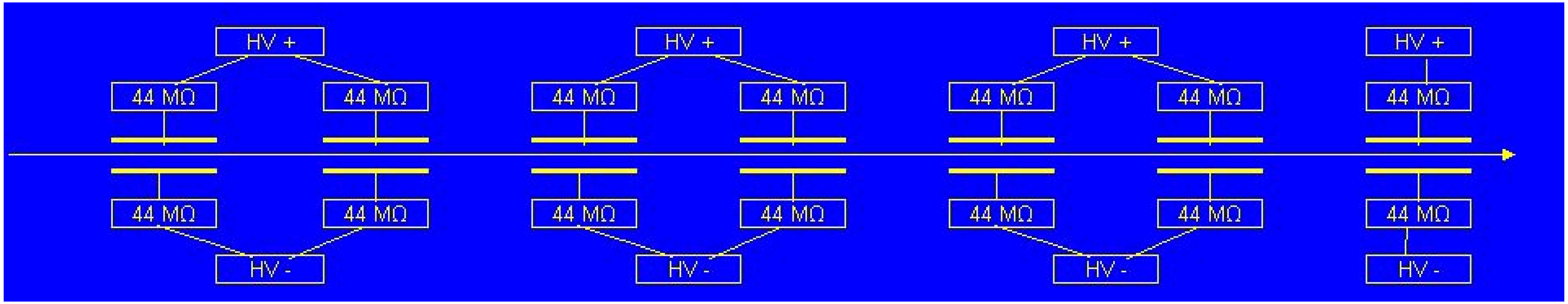
| Separator parameters for | 250 GeV | 500 GeV | |
|---|---|---|---|
| Active length | 28 | | m |
| Number of tanks | 7 | | |
| Electrode length per tank | 4 | | m |
| Electrode spacing | 0.65 | | m |
| total installation length | 32.55 | | m |
| Electrode material | **titanium** | | |
| Total deflection required | 252 | | μrad |
| $E_0$ (at separator center) | **2.25** | **4.50** | MV/m |
| Split size in electrodes | 50 | 50 | mm |
| Gap width | 100 (70-140) | | mm |
| Max. field between electrodes | **2.62** | **5.23** | MV/m |
| Applied Voltage | 131 | 262 | kV |
| Spark rate / tank | < 0.04 | | #/hr |
| Field homogeneity | 1.0E-02 | | |
| in area | 22 x 12 | | mm |
| Quadrupole component | 0.E+00 | | |
| Sextupole component | 1.60E-03 | | |
| Octupole component | 0.E+00 | | |
| Decapole component | 1.14E-04 | | |
| Required HV generator | 300 | | kV |
| # of tanks per HV generator | 2/2/2/1 | | |

# Electrostatic Separators in Enlarged Tunnel



# Electrostatic Separators: HV Circuit

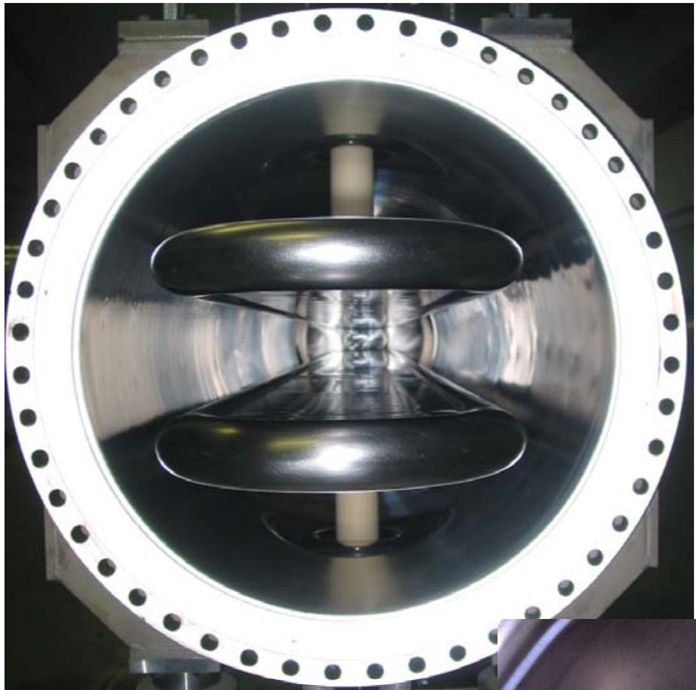



4 generators per polarity for the seven tanks

The corresponding dipoles should allow for the same degree of freedom (number of power supplies

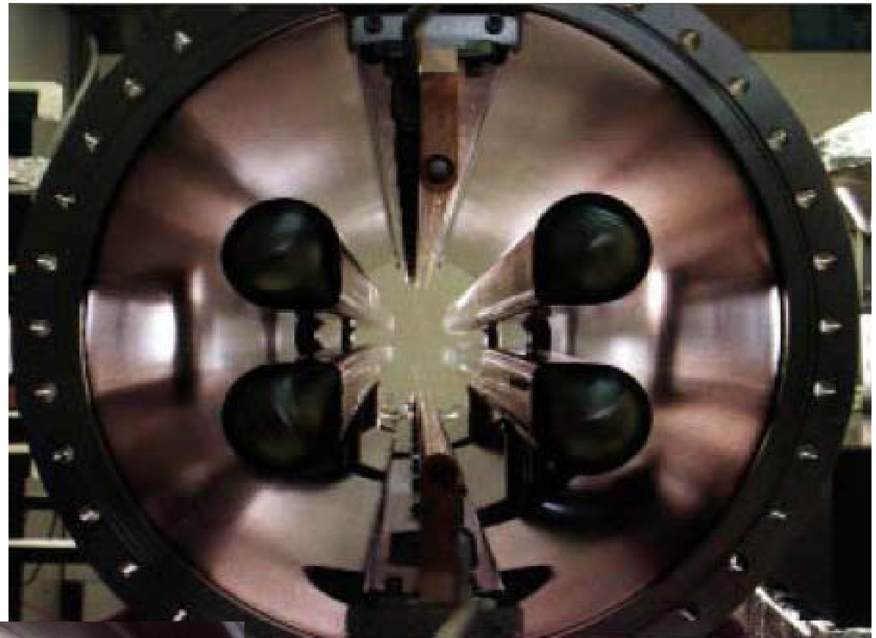
If needed to avoid particle showers on the last separator (in particular in the low energy parameter set of the ILC) it would be possible to increase the field strength seen by the beam by using flat electrodes for the 1$^{st}$ two separators (efficiency 100%, instead of 84%) and opening the gap on the 7$^{th}$ separator. To obtain the same total required deflection, the applied voltages would remain the same.

# Electrostatic Separators Experience

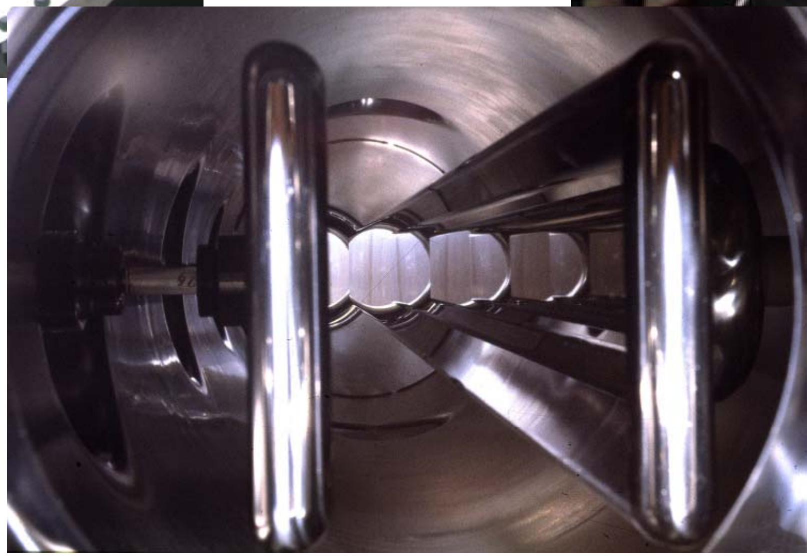


LEP ZL separator

Electrode layouts



CESR separator



SPS ZX separator

Titanium

# Electrostatic Separators Experience

| *From Jan Borburgh* | LESB II (1979) [1] | Tristan (1989) [2] | Tevatron (1992) [3] | SPS ZX (1982) [4] | LEP ZL (1996) | CESR (1999) [5] | BEPC II (2001) [6] |
|---|---|---|---|---|---|---|---|
| Nominal gap (mm) | 150 | 80 | 50 | 40 (20 – 160) | 100 (60 – 160) | 85 | 100 |
| Operational field strength (MV/m) | < 5.2 | 3.0 | 5.0 max. | 5.0 | 2.5 (tested to 5.0) | 2.0 | 2.2 |
| HV supply (kV) | +/-390 | +/- 120 | +/- 125 | 0/-200 | +/- 150 | +/- 85 | +/- 110 |
| Electrode dimension (mm x mm) | n.a. | 4600 x 150 | | 3000 x 160 | 4000 x 260 | 2700 | |
| Electrode material | Glass | Ti | | Ti | SS | | |
| Device length (mm) | n.a. | 5105 | 3000 | 3380 | 4500 | | |
| Working pressure (mbar) | $10^{-6}$ | | | $10^{-10}$ | $10^{-10}$ | | |
| Operational spark rate (#/h) | <1 | <0.02 | | < 0.03 | 0.2 | 0.04 | |
| Particle beam | p- | e- e+ 9mA 15GeV | p p- | p p- (270 GeV) | e- e+ (100 GeV) | e- e+ 150 mA | e- 576 mA |

# Electrostatic Separators: Required R&D

- **Performance under irradiation**
  - Evaluation of radiation in existing set-ups
  - Expected dose rates and profile
  - **Tests with beam**

- **Feedthrough & insulator support design to cope with harsh environment**
  - (some work by CERN on insulator treatments available)

- **System performance at 5.2 MV/m (1 TeV) and beyond**

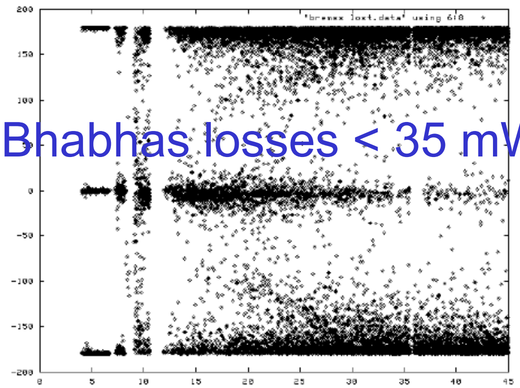
- **Optimal electrodes**
  - Cross section profile
  - Manufacturing techniques in case of hollow Ti

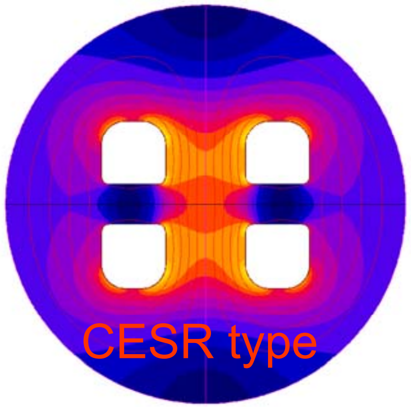
- **Coupling in the event of sparking**
  - Geometry effects (coupling of field, coupling via the beam / photons etc.)
  - Circuit effects (partly dealt with by increasing the number of HV generators, partly to be dealt with by a carefull study of the value of the decoupling resistors)
  - Recovery

# Electrostatic Separators

Remaining Questions :

- Sparking rate vs. Beam loss intensity
  → no record from LEP
  → beam test at ESA (or KEK, …)
- Field quality in case of slit electrodes
- 1 TeV upgrade requires 50 - 60 kV/cm
  → Titanium electrode

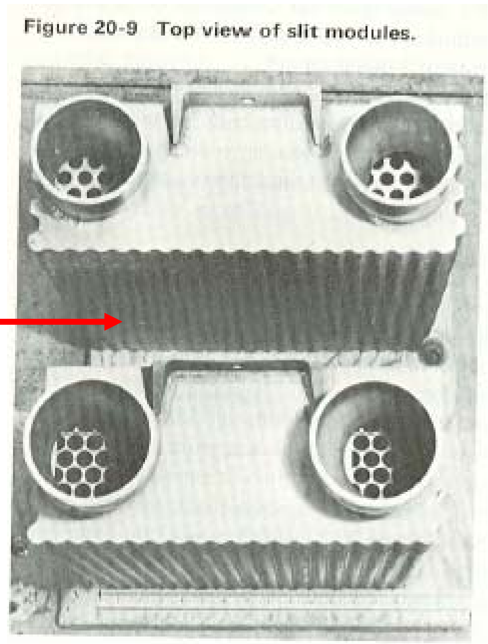


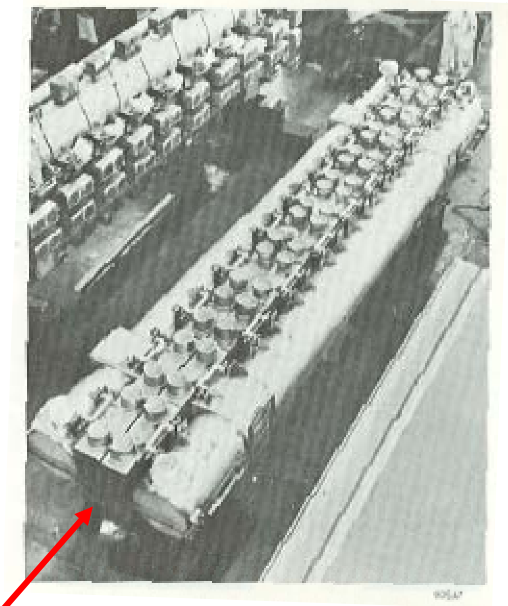
# Intermediate Beam Dump

## Concept based on SLAC 2 MW Aluminum/Water Collimator and Dump

Beam

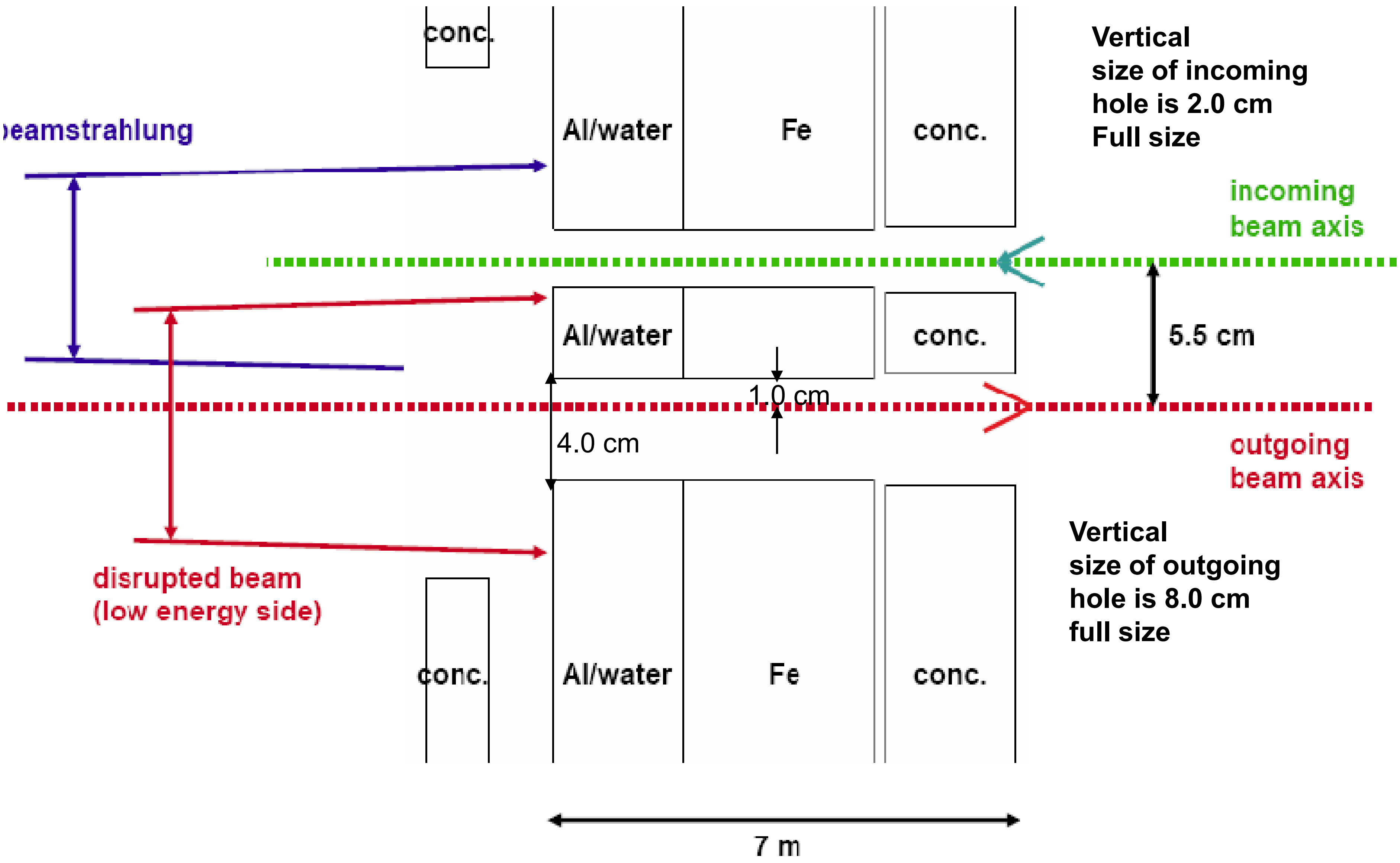



**Assembled 2 MW slits ≈ 5 m long**



Beam

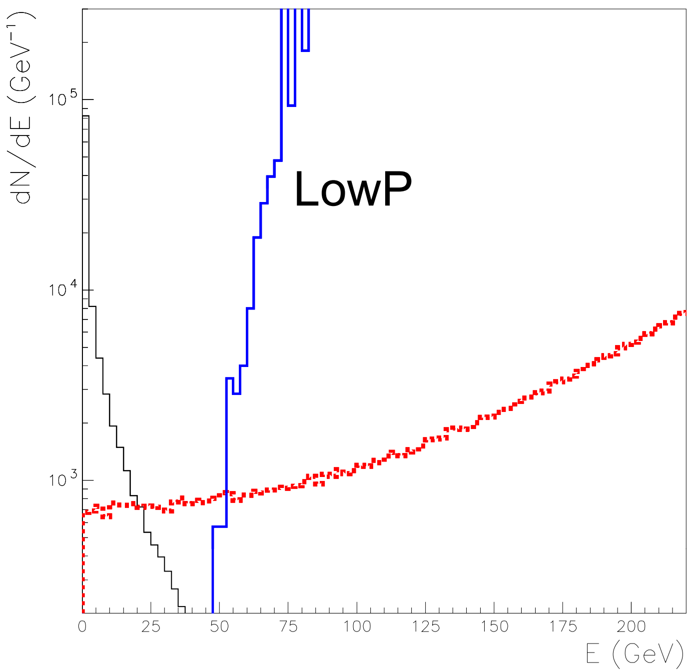
# Beam Holes Through Intermediate Dump

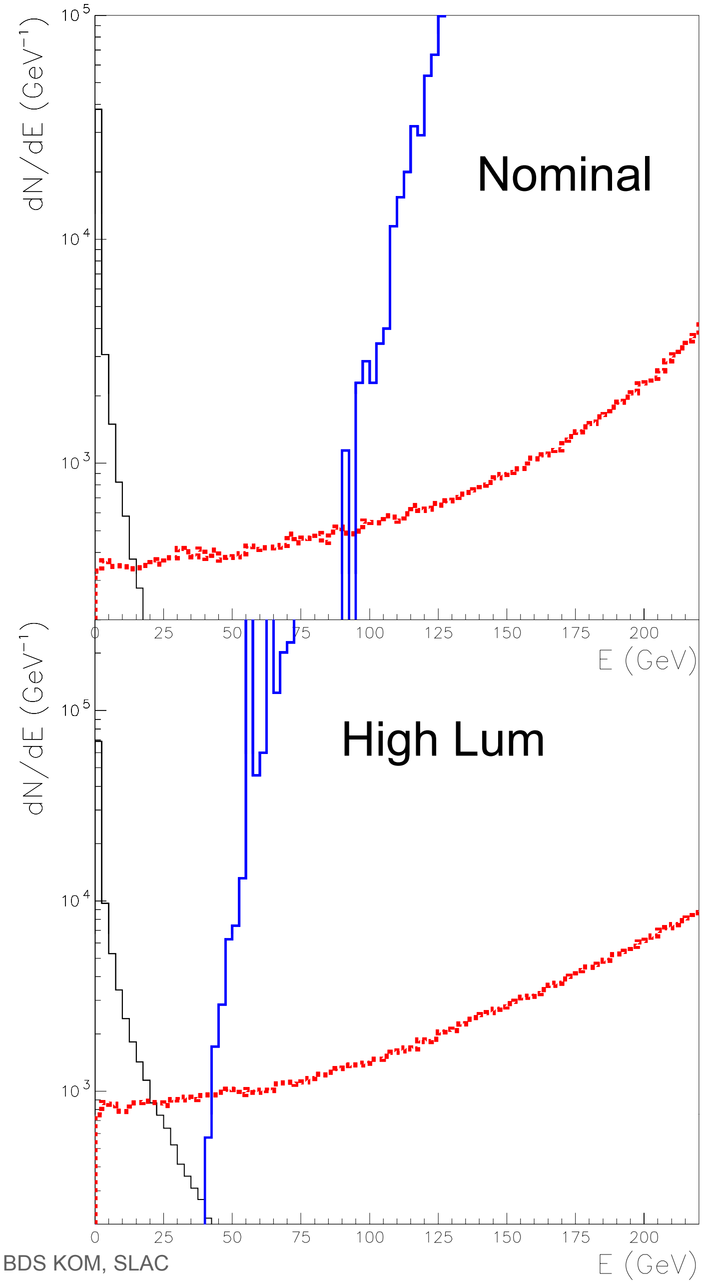


# Charged Beam Losses

$E_{cm}$=500 GeV

Pairs
Compton
Disrupted beam



# Estimate of Headon Beam Losses (kW), 500 GeV CM

May 2007

charged (red)
beamstrahlung (blue)

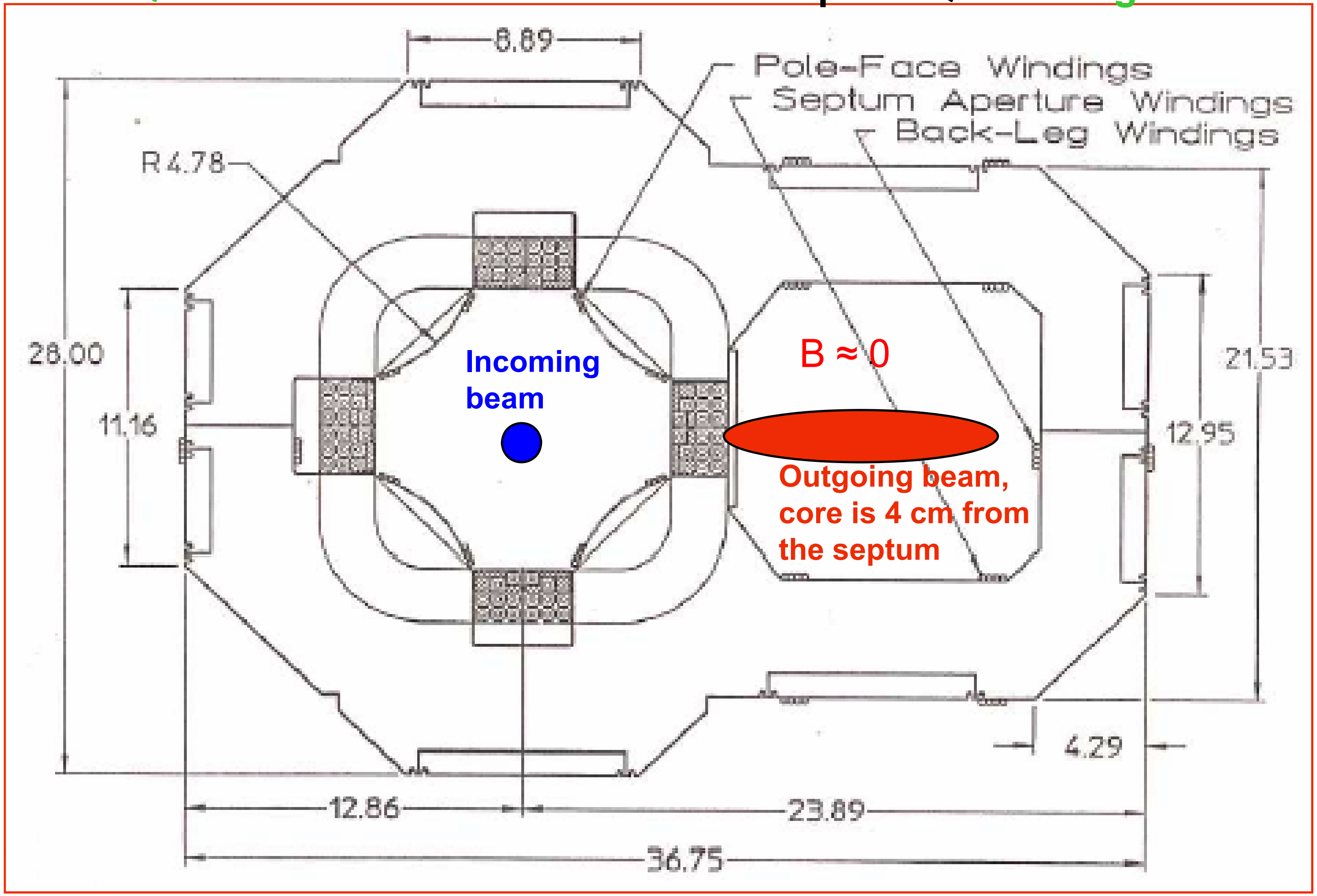
| Loss Location | Nominal Parameters | | Low Power Parameters | | |
|---|---|---|---|---|---|
| | Headon | Vertical offset | Headon | Vertical offset | Radiative Bhabha's |
| QD0/SD0 (1) | 0. | 0. | 0. | 0. | 1.5E-05 |
| QF1/SF1 (1) | 0. | 0. | 0.0010 | 2.0E-04 | 2.5E-05 |
| Synch. Mask (2) (Z = 12 m) | 0. | 0. | 0.0023 | 0.0011 | 5.5E-05 |
| Sep. plates (3) | 3.6E-04 | 2.4E-04 | 1.5 | 2.0 | 5.5E-04 |
| Inter. dump (Z = 136 m) | 75 (charged)<br>140 (beamstrahlung) | 90 (charged)<br>240 (beamstrahlung) | 415 (charged)<br>215 (beamstrahlung) | 539 (charged)<br>416 (beamstrahlung) (4) | - |
| Main dump | 10,160 (charged)<br>125 (beamstrahlung) | 10,030 (charged)<br>135 (beamstrahlung) | 4,500 (charged)<br>115 (beamstrahlung) | 4,200 (charged)<br>95 (beamstrahlung) | - |

Notes:

(1) 5.6 cm bore
(2) 2.0 cm full horizontal gap
(3) 10.0 cm full horizontal gap
(4) Exceeds the nominal 650 kW small beam limit for Al/water dumps – must check if OK for widely dispersed beam

# Beam Extraction Scheme

**QF3 modeled after PEPII/BaBar IR Septum Quad design**




**(units cm)**

# Q2 : Is the beam line cost effective ?

- Cost Drivers
  - Tunnel length and diameter
    - Is Head-on more economical ?
  - Number of beam dumps
    - Can the main dump be used for the LINAC commissioning from the other side (à la TESLA) ?
  - Electrostatic separator
    - total price estimate ~ 6 M$ for 14 tanks
  - Final quadripole and sextupole doublets
    - total price ???
  - Intermediate collimator
    - total price ???
  - Detector push-pull
    - $l^*$ = 6.3 m is feasible : moves the final doublet out of the detector area.

# Q3 : Is the beam line tunable w.r.t. Luminosity and Extraction ?

**Questions concerning the 14 mrad crossing angle:**

- with ±7 mrad angle, the vertical orbit displacement due to Bx along the solenoid at the IP is of the order of 100 μm, depending on the Solenoid fringe pattern, the Anti-DID configuration and the position of QD0:

$\Rightarrow$ all magnets creating and correcting this effect must be stable to better that $10^{-5}$

- the scanning of the centre of mass energy can be done by scaling all magnets with energy, except if the main Solenoid field is kept constant:

$\Rightarrow$ the orbit correction in the final doublet needs to be re-optimized for every energy step.

- what is the interplay between the $\langle x\delta \rangle$ (local chromaticity), $\langle xz \rangle$ (crab cavity), $\langle y \rangle$ (solenoid compensation) bumps ?

# Q3 : Is the beam line tunable w.r.t. Luminosity and Extraction ?

**Questions concerning the Head-on scheme :**

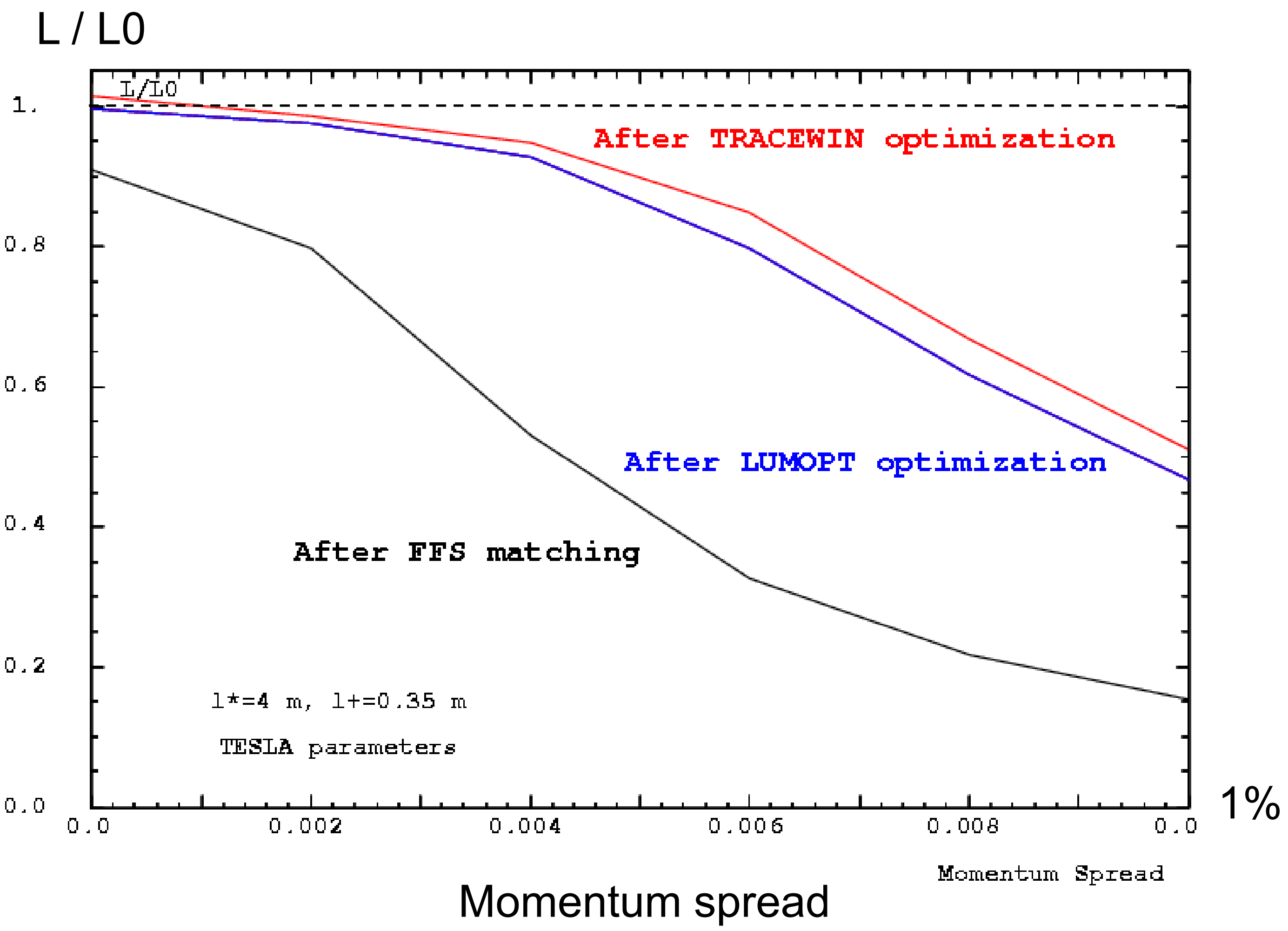
- Solenoid coupling correction : skew quad or anti-solenoid?
  $\rightarrow$ Final doublet magnet design

- Electrostatic separator failure handling in the IR ?

- Effect of the extraction collimators background on the detector operation

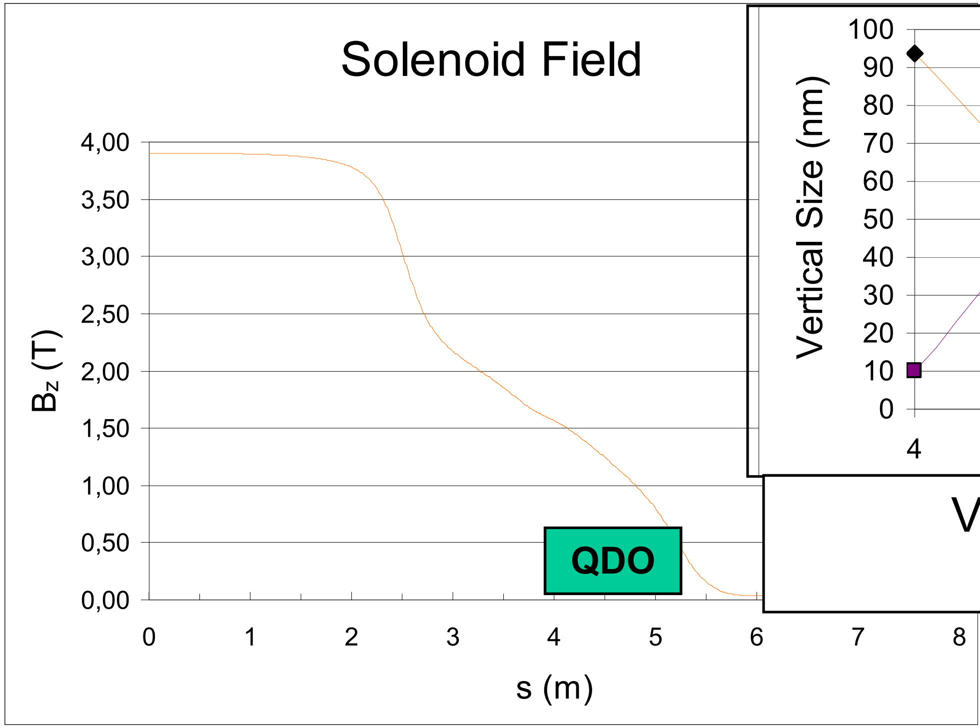
- …

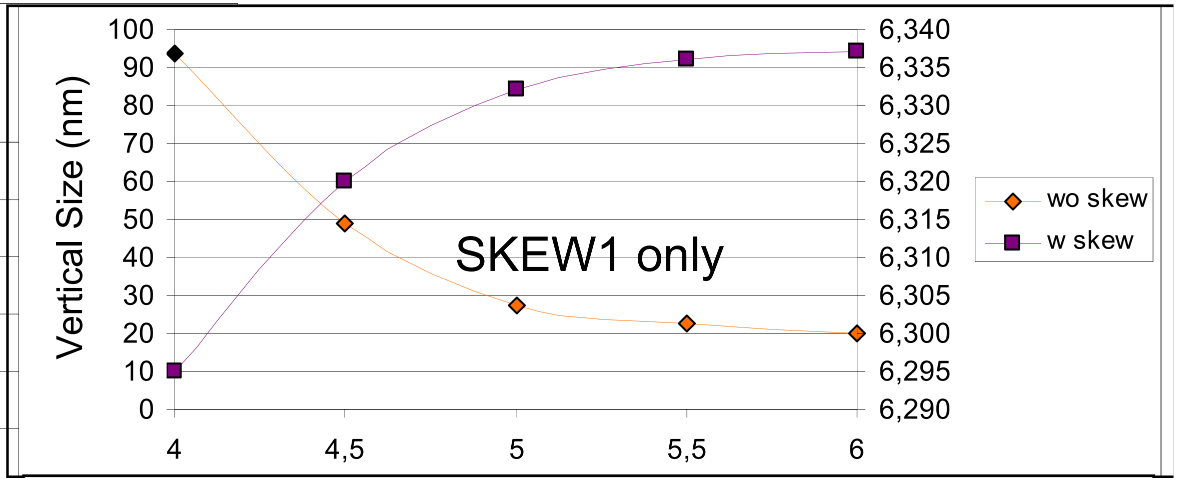
# Tuning of Head-on FFS at 2nd order



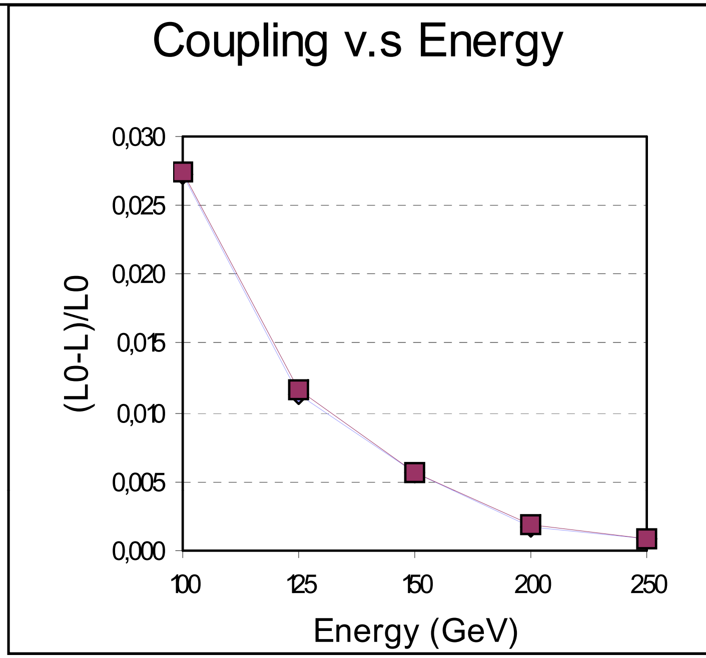

Automatic CCS matching based on Luminosity optimisation

# Solenoid Coupling Correction



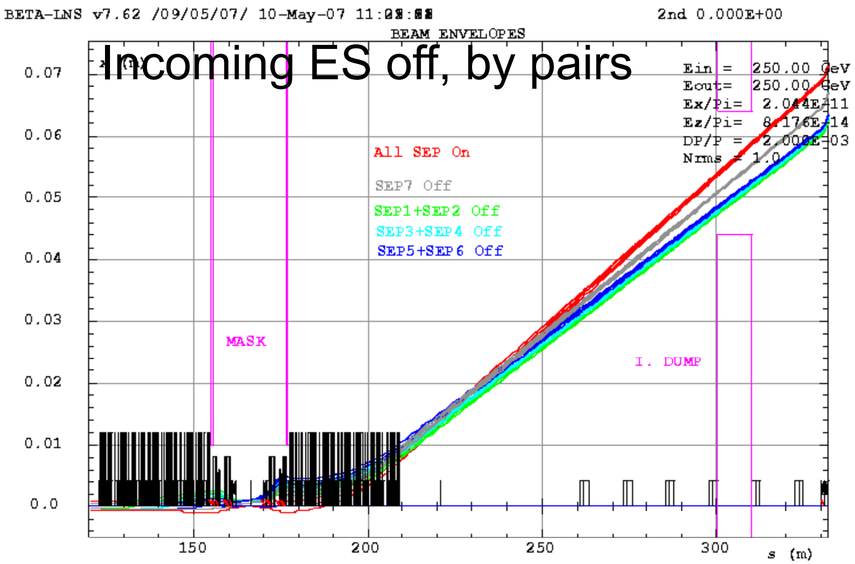

Vertical sizes @ IP as function of l*, with and without skew corrector

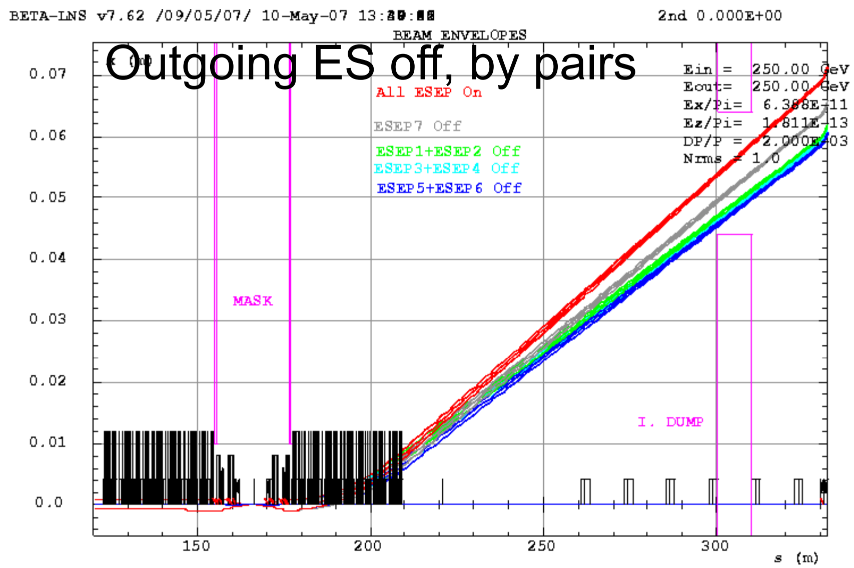


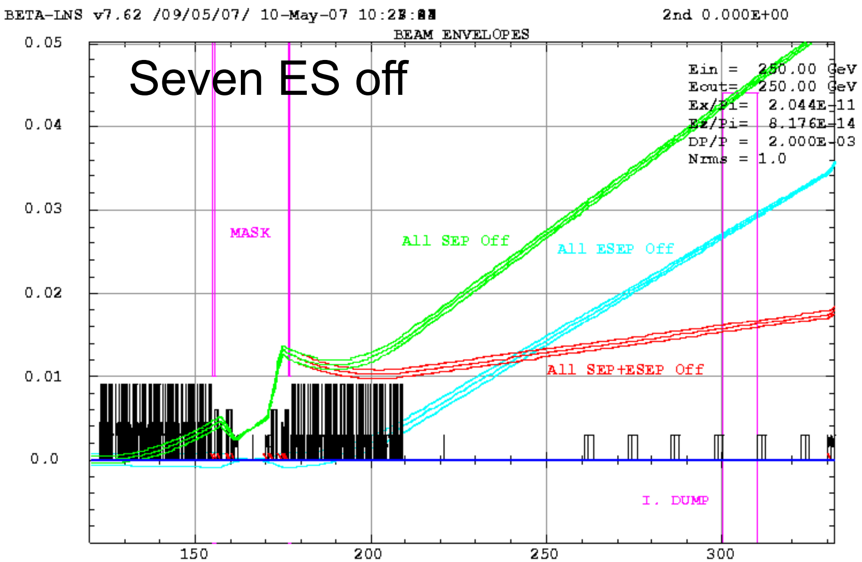

SKEW1 near SD0,
SKEW2 near QD4, and
SKEW3 in the energy collimation section.

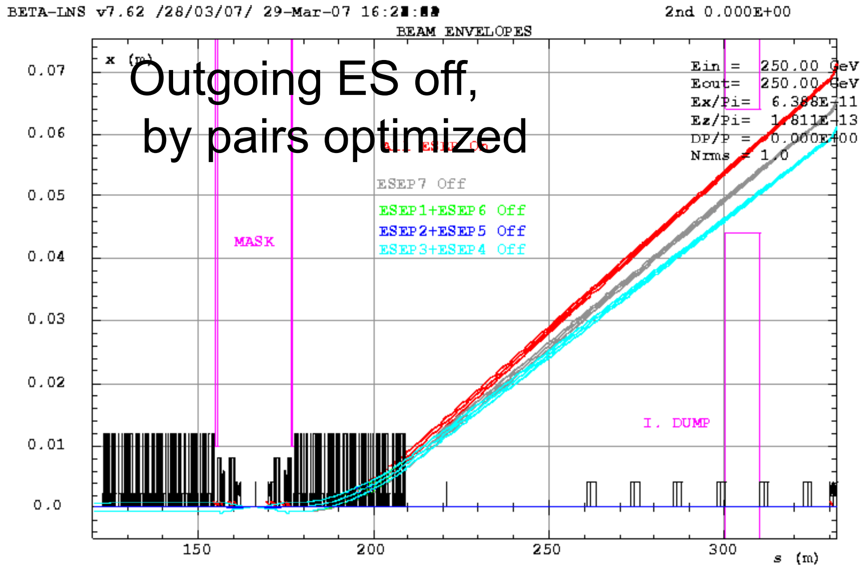
The position of the skew quadrupoles is not fully optimized.

# Electrostatic Separator Failures



# Q4 : Does the beam line allows for Post IP beam diagnostics ?

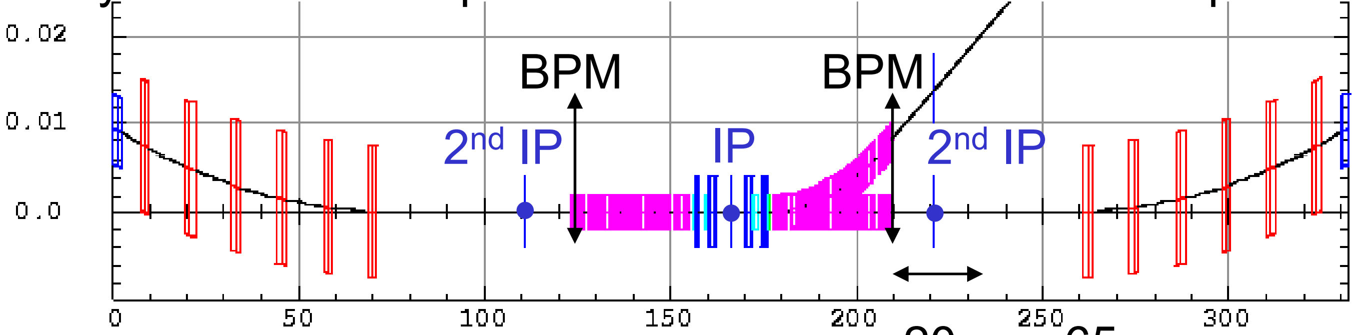
Tentative concepts

- **Polarimeter** using Compton collision at the IP
  $\Rightarrow$ bring a suitable LASER at (or close to) the IP

- **Spectrometer** using the Extraction Bends
  and 2 BPMs

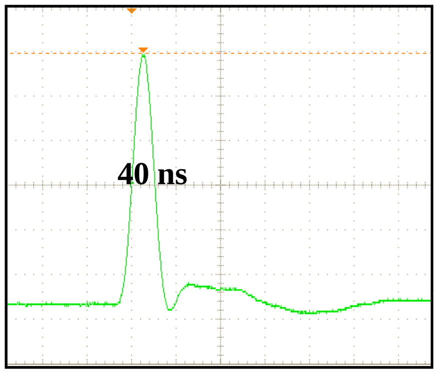
# Spectrometer with 2 BPMs

Symmetrical BPM pair to measure IN and OUT beam positions




~20 m = 65 ns
between bunch *n*-out and *(n+1)*-in

- FF optics has about 120 mm dispersion
  ~ 0.01% energy resolution
- Extraction optics has about 8 mm dispersion
  ~ 0.1% energy resolution




FLASH BPM with
78 mm inner diameter
demonstrated
4 μm resolution
over 10 mm range,
and 40 ns time resolution

# Prospects

- **Head-on IR** has the potential to be a **Luminosity** and **Cost** effective option for 500 GeV and 1 TeV ILC

- **Head-on IR** has the potential to make full profit from the high-field superconducting magnet technological developments driven by SLHC

- **Spent beam extraction system** has been found with manageable beam and beamstrahlung losses.

- **Post-IP instrumentation** would require new concepts :
    - Compton polarimetry at the IP with 25-50 GeV electrons
    - Energy measurement via ES-BPM

- Beam test of an existing LEP ZL **separator module** or better, a CESR split separator is necessary.