Overview of Extraction Line Designs and Issues

Y. Nosochkov (SLAC)

On behalf of the 14 mrad, 2 mrad and head-on teams

ILC Interaction Region Engineering Design Workshop
SLAC, 17 – 21 September, 2007

• Goal: To review the main features and issues of the three extraction options designed for: 14 mrad crossing angle (baseline), 2 mrad, and head-on collision.

• Largely based on the status presented at LCWS'07. Also, see a separate report by R. Appleby for details and updates in the 2 mrad design.

• Work of many people.

ilc

Proposal to modify the polarimeter chicane in the ILC 14 mrad extraction line

Ken Moffeit, Takashi Maruyama, Yuri Nosochkov, Andrei Seryi, Mark Woodley and Mike Woods*
SLAC
William P. Oliver
Tufts University

*presenting talk

M. Woods, SLAC   LCWS 2007 DESY, May 30 – June 3, 2007   1

Improved 2 mrad IR layout

Current status and plans

Philip Bambade
LAL-Orsay

On behalf of:
D.Angal-Kalinin, R.Appleby, F.Jackson, D.Toprek (Cockcroft)
P.B., S.Cavalier, O.Dadoun, M.Lacroix (LAL-Orsay)

Technical help & consulting:
O. Delferrière (CEA, Saclay), G.-L. Sabbi (LBL)

LCWS-DESY, MDI/BDS joint session, May 31 2007

dapnia
cea
saclay

ILC Head-On Interaction Region: Progress Report

Olivier NAPOLY
For the Head-on Task Group

ILC Workshop
31 May 2007

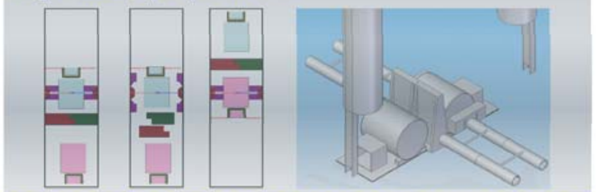
ilc *Special ILC Meeting "Lohmann's BNL Visit," held 22-23 January 2007 at BNL*

BROOKHAVEN NATIONAL LABORATORY
Superconducting Magnet Division

14 mr IR Magnet Status & Future Work

Brett Parker, BNL

"We have made a lot of progress but are still not quite caught up on the changes needed for push-pull" B. Parker



January 22, 2007   *ILC Global Design Effort*   1

GamCal Detector

- W. Morse (BNL): Coordinator
- M. Ohlerich et al. (Zeuthen): beam-strahlung simulations
- B. Parker (BNL): Machine interface issues
- M. Zeller, G. Atoian, V. Issakov, A. Poblaguev (Yale): GamCal detector design
- Y. Nosochkov (SLAC): Extraction line issues

W. Morse GamCal   2

Head-on Task Group

- GOAL : *Work on the ILC Head-on Scheme to make it more attractive from the* ***Collider Performance*** *and* ***BDS Cost*** *viewpoints.*
- Head-on Task Group ≈ Attendance of the *Small IR Mini-Workshop* at Orsay-Saclay on 19-20 October 2006
  http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=1150 1st day
  http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=1149 2nd day

1	ALABAU PONS Maria del Carmen	IN2P3/LAL	13	KIRCHER François	CEA/DAPNIA
2	ANGAL-KALININ Deepa	CCLRC	14	IWASHITA Yoshihisa	Kyoto University
3	APPLEBY Robert	Univ. Manchester	15	JACKSON Frank	CCLRC
			16	KELLER Lewis	SLAC
4	BAMBADE Philip	IN2P3/LAL	17	KURODA Shigeru	KEK
5	BORBURGH Johannes	CERN	18	NAPOLY Olivier	CEA/DAPNIA
6	BROSSARD Julien	CNRS	19	PAYET Jacques	CEA/DAPNIA
7	DADOUN Olivier	IN2P3/LAL	20	RIMBAULT Cécile	IN2P3/LAL
8	DELFERRIERE Olivier	CEA/DAPNIA	21	RIPPON Cyril	CEA/DAPNIA
9	DE MENEZES Denis	CEA/DAPNIA	22	SABBI Gian Luca	LBL
10	DEVRED Arnaud	CEA/DAPNIA	23	TOPREK Dragan	Univ. Manchester
11	DURANTE Maria	CEA/DAPNIA			
12	FELICE Helène	CEA/DAPNIA	24	URIOT Didier	CEA/DAPNIA

+ Bruno Balhan and Brennan Goddard (CERN)

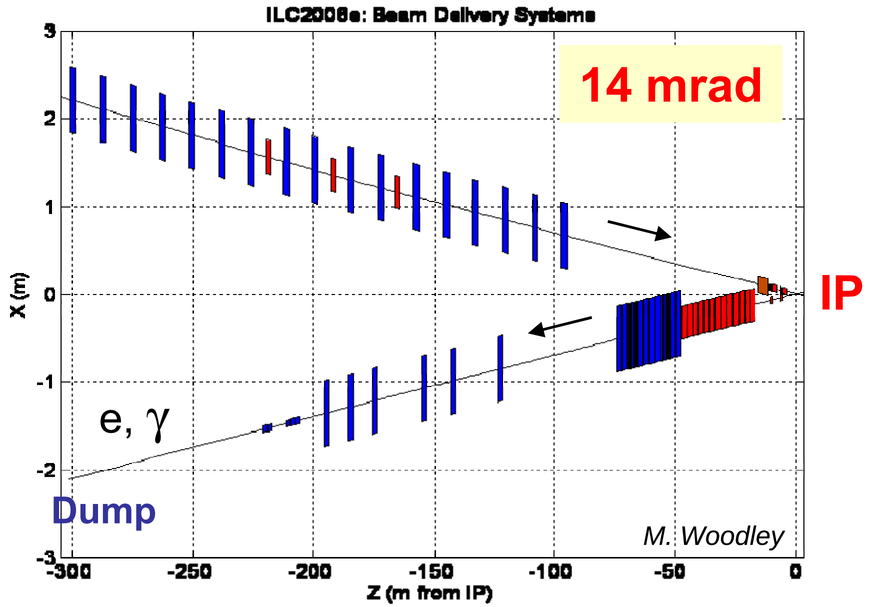
31 May 2007   ILC Workshop, DESY   2

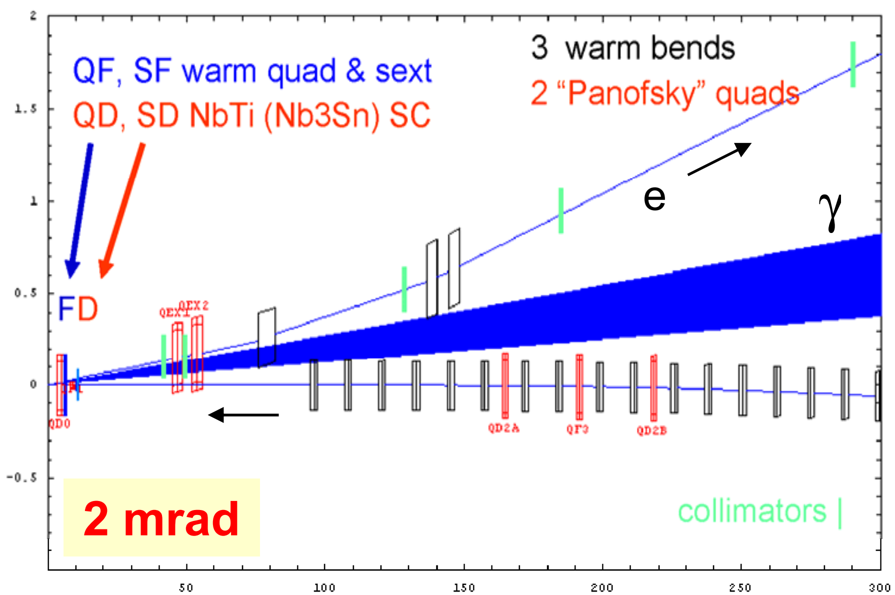
Extraction designs for three crossing angle options:

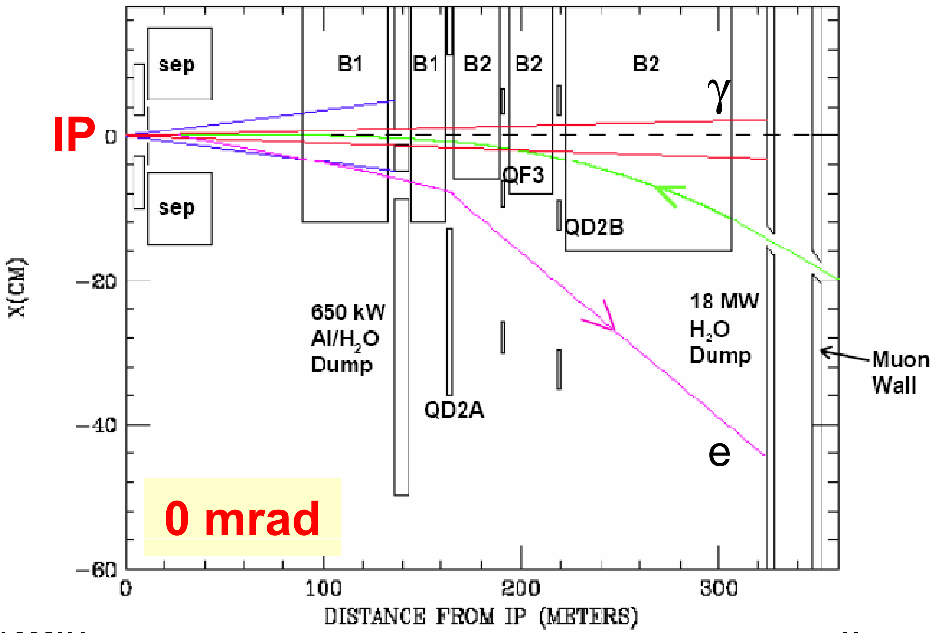
- 14 mrad (baseline), 2 mrad, and 0 mrad.

Beam line:

- 14 mrad: Independent straight line optics. One channel for e & γ.
- 0 and 2 mrad: Initial magnets shared with incoming beam, separate e and γ channels.







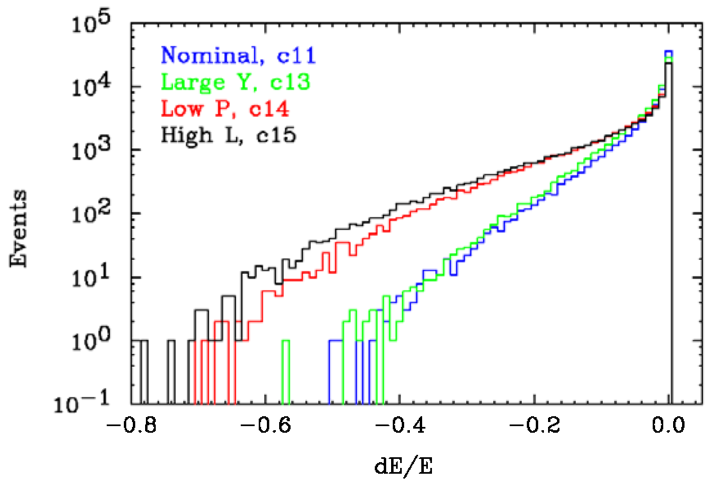
ILC e^+e^- collision creates disrupted beam:

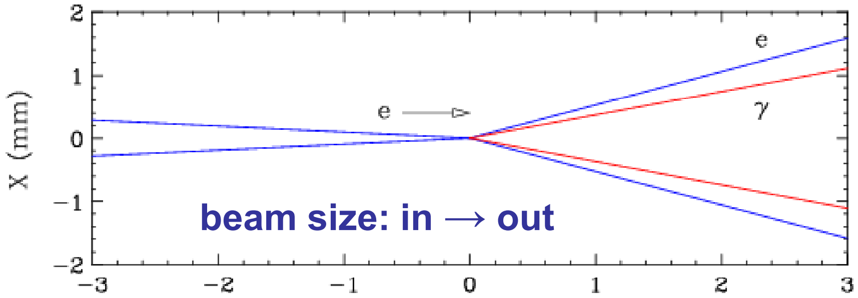
- Huge energy spread and large x,y divergence (emittance) in the outgoing electron beam.
- High power divergent beamstrahlung photon beam going in the same direction with electrons.

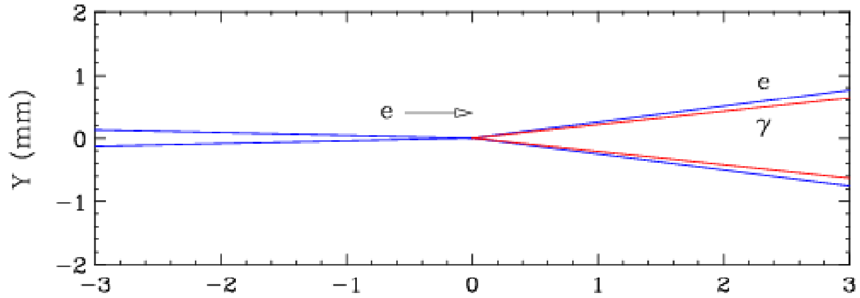
Issue:

- Potential high beam loss in the extraction line due to overfocusing of low energy electrons and divergence of the photon beam.

Disrupted energy spread







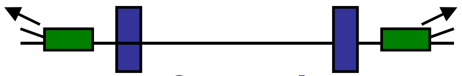
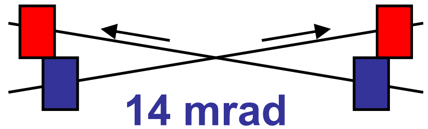
Maximum IP angles for disrupted electrons and beamstrahlung photons

Option	No beam offset at IP				Large vertical offset at IP			
	electrons		photons		electrons		photons	
	X' (μrad)	Y' (μrad)	X' (μrad)	Y' (μrad)	X' (μrad)	Y' (μrad)	X' (μrad)	Y' (μrad)
Nominal, c11	529	253	369	212	474	685	366	537
Large Y, c13	956	492	768	396	716	668	573	586
Low P, c14	1104	580	668	344	1120	1190	684	918
High L, c15	1271	431	723	320	1280	1415	783	1232

Design considerations for the extraction line

- **Beam channels**: to safely transport the outgoing electron and photon beams from IP to main dump(s).
- **Large optical acceptance**: to minimize beam loss from strong overfocusing and dispersion of low energy electrons. Requires careful optimization of energy dependent focusing and sufficient aperture.
- **Large geometric acceptance**: to minimize beam loss from the divergent beamstrahlung photons. Requires large aperture increasing with distance.
- **Beam diagnostic system**: to monitor luminosity, measure beam energy and polarization. Requires special downstream optics.
- **Collimation system**: to protect magnets and post-IP diagnostic devices from unavoidable beam loss and undesirable background.
- **Main dump protection system**: to avoid damage to dump window and prevent water boiling in the dump vessel from small undisrupted beam or under abnormal optical conditions (large errors, magnet failures). Requires enlargement of beam size at the dump window by optical means.

Crossing angle considerations

	 0 mrad	 2 mrad	 14 mrad
Beam separation	E-separators & bending Shared Final Doublet (FD)	Crossing angle & bending, shared FD	Crossing angle No shared magnets
Detector	One detector beam hole: more favorable hermeticity, background, calibration		2 holes: less favorable hermeticity, background, calibration
Luminosity	No luminosity loss Crab cavity (CC) not needed	~10% loss w/o CC CC ~0.5 km from IP	~70% loss w/o CC CC ~13 m from IP
Solenoid & DID field	No orbit from solenoid DID & correctors not needed	Small orbit DID is not needed	Larger orbit Anti-DID required
Push-pull	Beam trajectory not affected	Trajectory may change Correctors needed	Trajectory not affected
Optics for diagnostics	Difficult, baseline diagnostics is not included Alternate options are studied, but not yet a solution		Included: beam energy, polarization, GamCal
Transport (e,γ)	Separate e,γ channels	Separate e,γ channels	Shared e,γ channel
Dumps (e,γ)	Intermediate and main dumps with holes	One shared or two separate dumps with a hole	One shared dump without holes

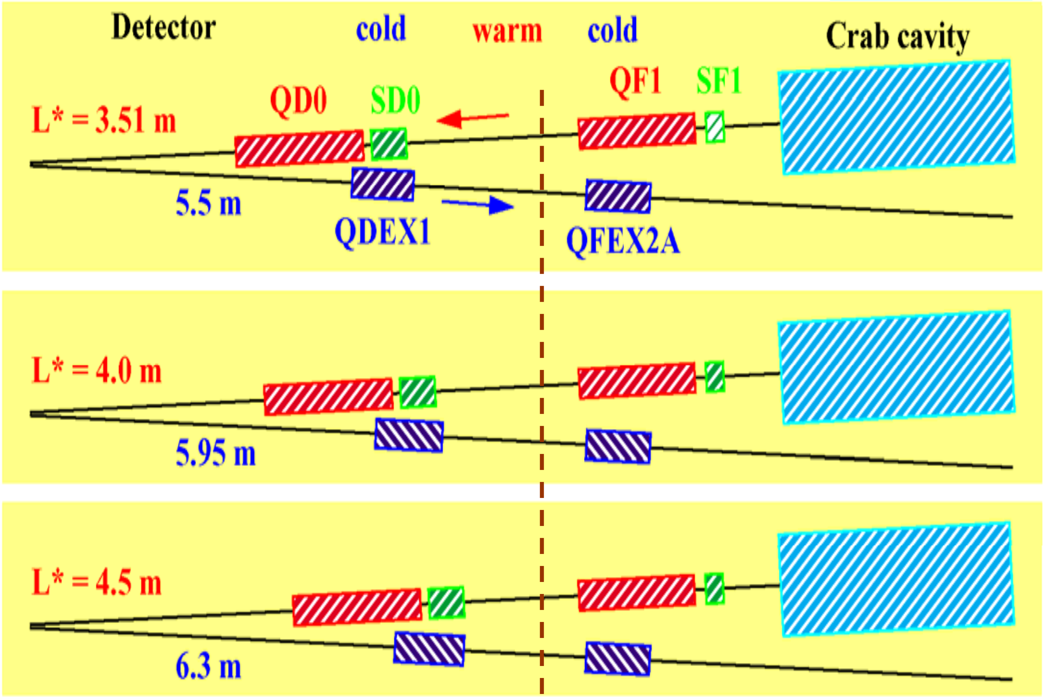
Push-pull options

14 mrad: Push-pull optics for L*= 3.51, 4.0, 4.5 m is designed. SC magnets QD0/SD0/QDEX1 exchange with the detector. Long warm drift is reserved for break-in point. SC QF1/SF1/QFEX2A in a separate cryostat and other magnets outside of detector do not change, except fine strength tuning.

0 mrad: Optics studied for L*=4-6 m. Push-pull possible, does not change trajectories.

2 mrad: Push-pull not yet studied (but see R. Appleby's update). It may affect extraction trajectory. Correctors needed.

14 mrad



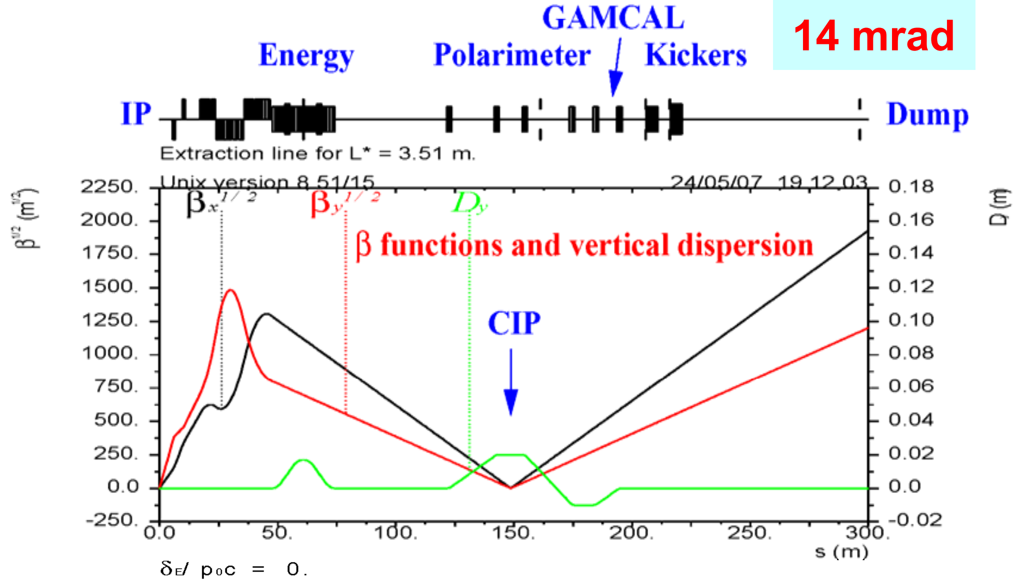
Extraction beam optics

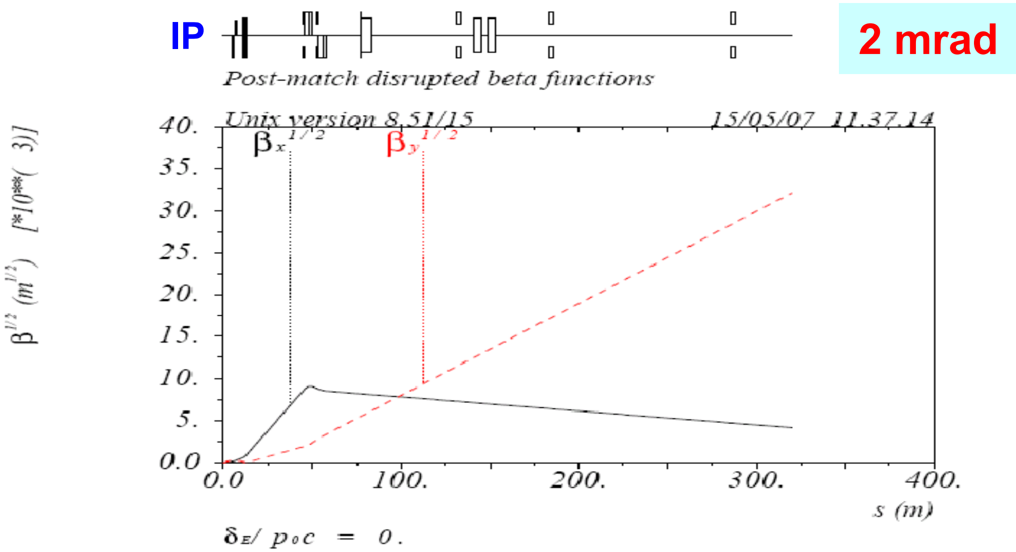
14 mrad:

- **No shared FD:** easier optics.
- **Quadrupoles:** to focus at Compton IP, optimized for minimal loss.
- **Dipole chicanes:** for diagnostics - beam energy, polarization and GamCal.
- **Fast sweeping kickers:** for dump protection.
- **Collimators:** for magnet and diagnostic protection.

0 and 2 mrad:

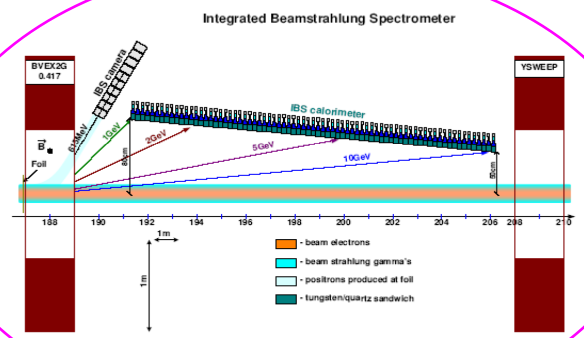
- **Shared FD & bending:** optics is more difficult.
- **Minimal optics, few magnets, collimators:** for bare beam transport to dump, optimized for minimal loss.
- **No diagnostic optics.**
- **Sweeping kickers** need to be included for dump protection.



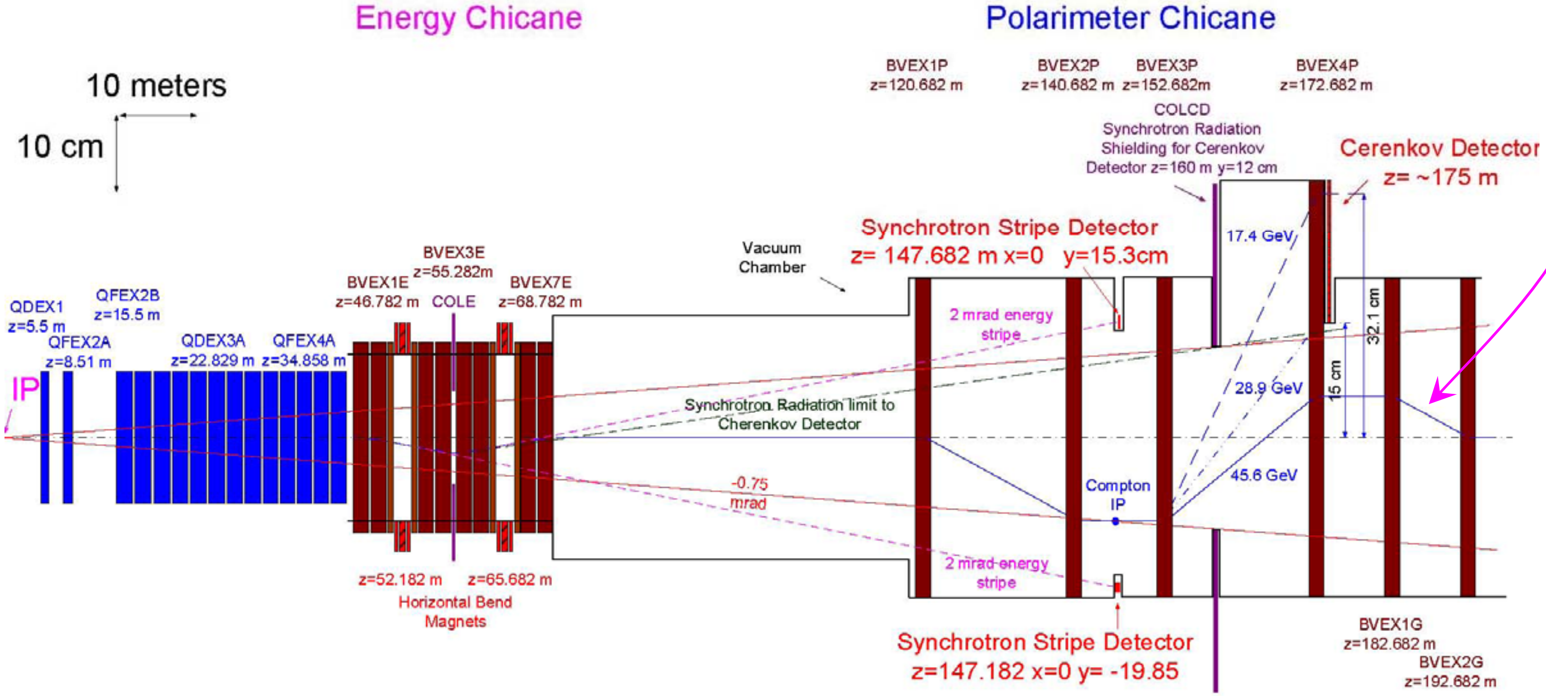


Extraction diagnostics: 14 mrad

• **Energy measurement** using synchrotron radiation created in 8-bend vertical chicane with horizontal bump magnets.
• **Polarization measurement** using laser to produce Compton-scattered electrons at extraction focal point in the 4-bend chicane.
• **Luminosity diagnostic** using GamCal between 2 vertical bends.
0 and 2 mrad: Baseline diagnostics not included.



Gamma Calorimeter



Detector solenoid & anti-DID

Effects:

• X-Y coupling due to B_z field causing IP beam size growth. It is corrected independent of crossing angle (anti-solenoid and/or skew quads).

• Orbit due to B_x field induced by crossing angle. It causes the out of IP e^+e^- pairs to miss the beam exit hole thus increasing detector background. Can be corrected by Detector Integrated Dipole (DID).

0 mrad: No orbit. DID is not needed.

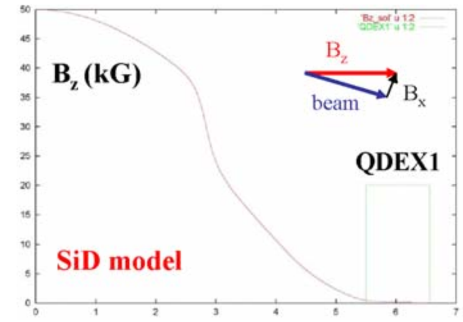
2 mrad: Orbit effect is small - DID is not needed. Correctors outside of the detector can compensate residual extraction orbit.

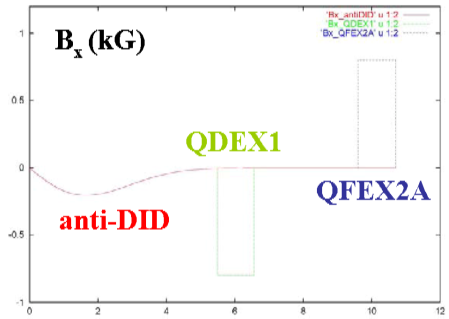
14 mrad:

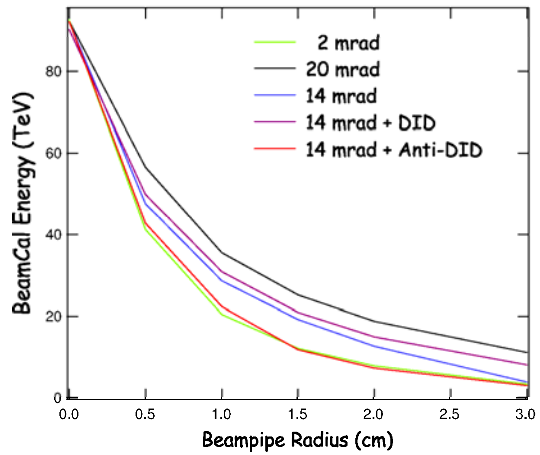
• Anti-DID (~0.2 kG) is required to reduce detector background.

• After correction, the 14 mrad background is of the same level with 2 mrad.

• Corrector coils built on QDEX1, QFEX2A quads compensate the residual extraction orbit.



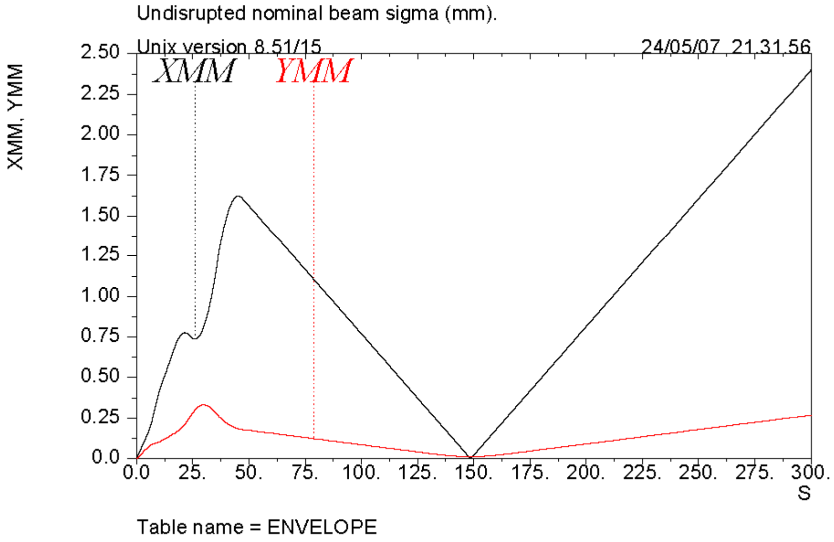


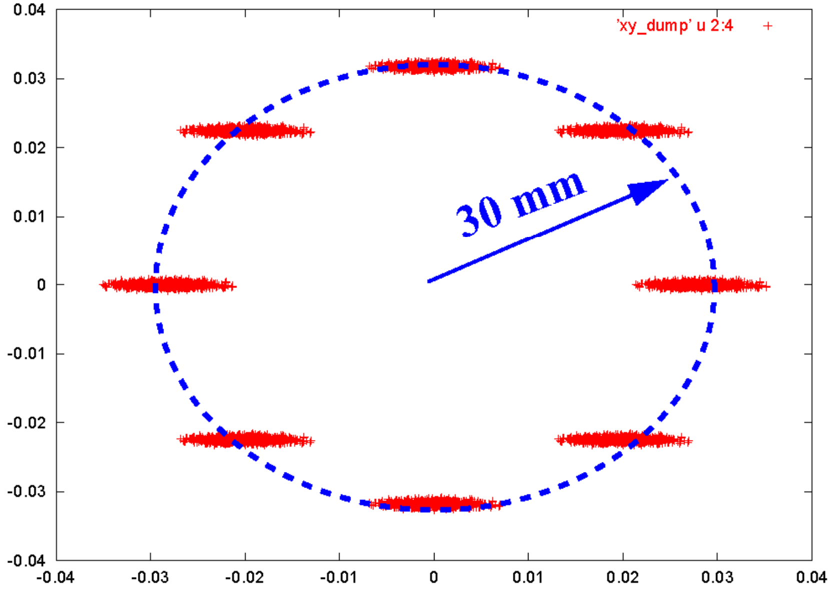


Fast sweeping system

14 mrad: System of fast (1 kHz) X-Y kickers is included to sweep bunches of each train in one turn on 3 cm circle at the dump window. It enlarges the beam area to protect from window damage and water boiling caused by very small beam size in cases of undisrupted beam or under certain abnormal optics conditions (large errors, magnet failures).
0 and 2 mrad: Not in the current design, but can be included.

Undisrupted σ (mm) **14 mrad** **Undisrupted bunches at dump**



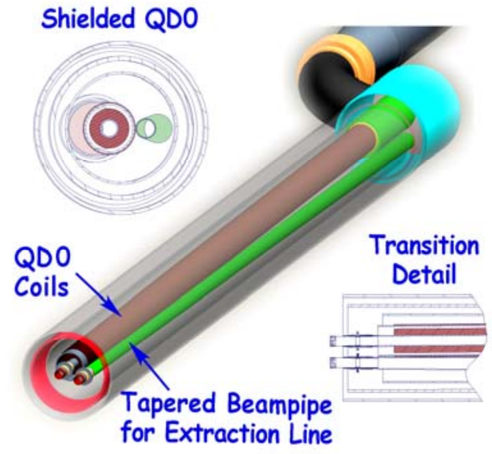


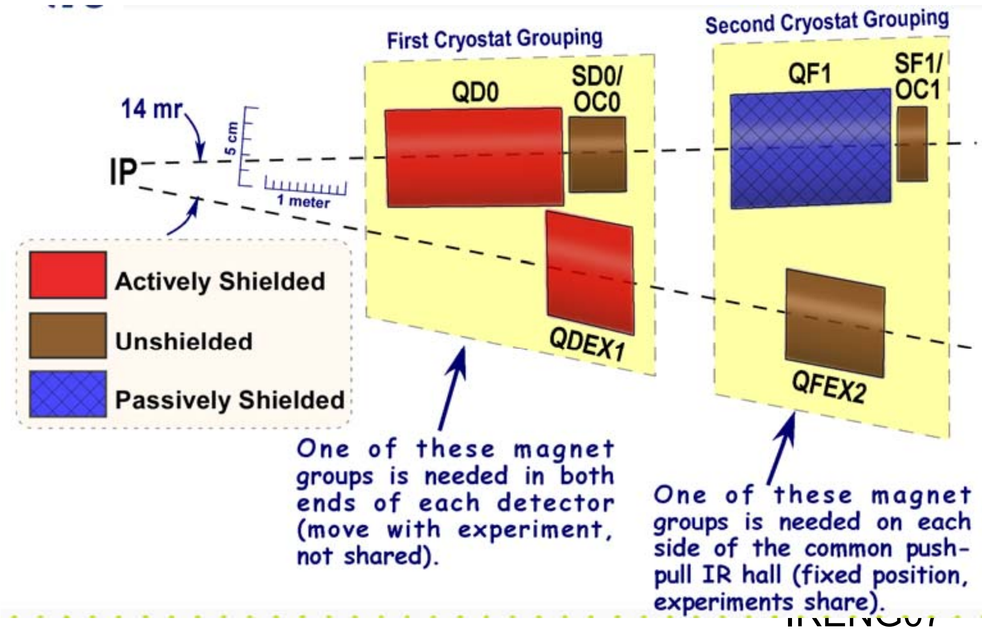
Superconducting magnets: 14 mrad

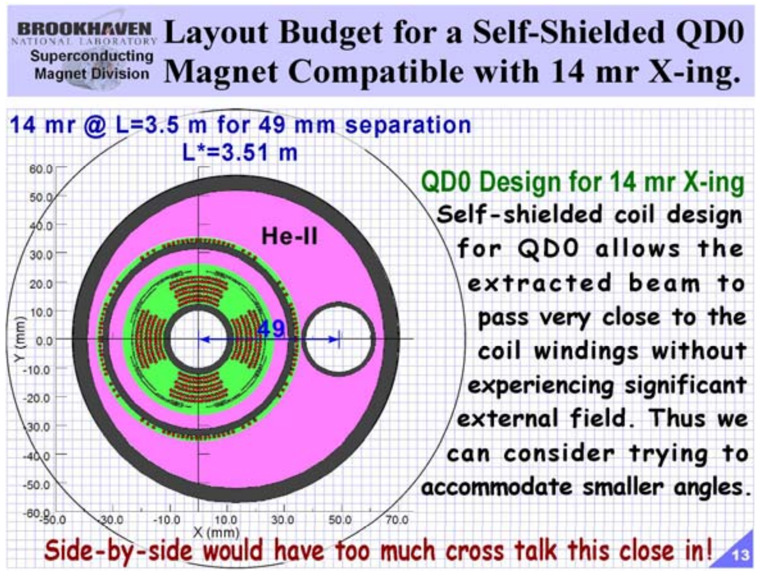
- Magnet design is well developed (BNL).
- Based on compact SC technology.
- Field shielding and correcting coils are built in.
- 38 cm QD0 prototype was tested in solenoid field and showed excellent field and quench performance.
- SC extraction quad parameters at 500 GeV CM:

- QDEX1: L=1.06-1.19 m, G=86-98 T/m, R=15-18 mm,
- QFEX2: L=1.1 m, G=31-36 T/m, R=30 mm.

- SC magnets require upgrade for 1 TeV CM.



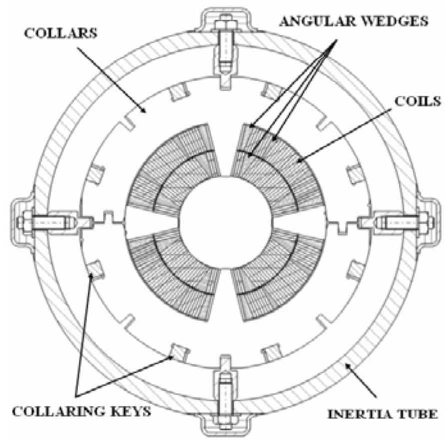




Superconducting magnets: 0 mrad

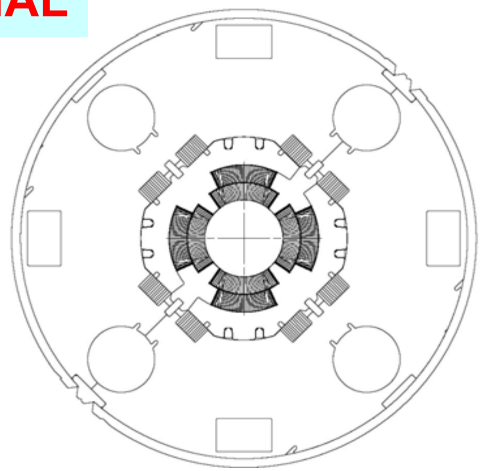
- Based on engineered LHC SC quadrupoles and sextupoles with R = 28 mm bore radius.
- Other option: FNAL design of SC quadrupole with 35 mm bore radius.
- NbTi coils to achieve 250 T/m (7 T) at 500 GeV CM.
- Nb_3Sn coils to achieve 370 T/m (10.5 T) for 1 TeV CM upgrade - preliminary – R&D needed.

LHC



500 GeV	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

FNAL



1 TeV	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

Superconducting magnets: 2 mrad

• QD0 will be based on LHC SC quadrupoles with R = 28 mm bore radius.
• SD0 requires large R = 60 mm bore radius – needs to be designed.
• NbTi coils to achieve 225 T/m (6.3 T at bore) at 500 GeV CM.
• Nb3Sn coils for 350 T/m (8.8 T) for 1 TeV CM upgrade – preliminary – R&D needed.
• QF1, SF1 are normal conducting warm magnets.

Table 1: The 500 GeV final doublet parameters.

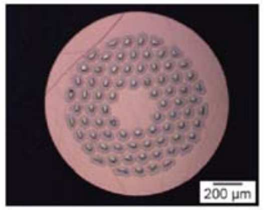
Parameter	QD0	SD0	QF1	SF1
Length [m]	1.059	1.469	1.596	0.75
Strength	-0.270 m^{-2}	2.969 m^{-3}	0.0786 m^{-2}	-2.044 m^{-3}
radial aperture [mm]	28	60	20	30
gradient [T/m]	225	-	65	-

Table 4: The 1 TeV final doublet parameters.

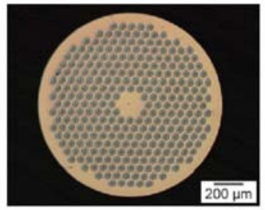
Parameter	QD0	SD0	QF1	SF1
Length [m]	1.352	2.5	3.192	1.5
Strength	-0.210 m^{-2}	1.502 m^{-3}	0.0394 m^{-2}	-0.943 m^{-3}
radial aperture [mm]	25	59	20	30
gradient [T/m]	350	-	66	-

Final Doublet : 1 TeV upgrade

NED Nb3Sn conductors achieve **Jc > 1500 A/mm²**



Alstom/NED
(workability program milestone)
1.25 mm ; 78x85 µm sub-element
740 A (~1500 A/mm²)
@4.2 K & 12T
(measured at CERN & INFN-Mi)



SMI/NED
(step II iteration)
1.26 mm ; 288 x 50 µm tube
1400 A (~2500 A/mm²)
@4.2 K & 12T
(measured at TEU & INFN-Mi)

Other magnets: 14 mrad

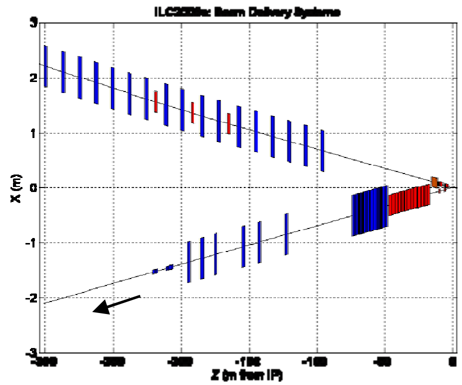
- Magnets share e & γ beams.
- Normal conducting bends and quadrupoles. Preliminary designs.
- Field can be doubled for 1 TeV upgrade. Polarimeter and GamCal bends do not change field for 1 TeV.
- Fast sweeping kickers assume TESLA design, but with larger aperture. Design feasible - to be done.

Bend field (T), length (m) and aperture (mm) at 250 GeV

Bends and kickers	Qty	L (m)	B (T)	Half-gap (mm)	Diagnostics
BVEX1E,2E,...,8E	8	2.0	0.4170	85	Energy
BVEX1P,2P	2	2.0	0.4170	117	Polarimeter
BVEX3P	1	2.0	0.6254	117	
BVEX4P	1	2.0	0.6254	132	
BVEX1G,2G	2	2.0	0.4170	147	GAMCAL
XSWEEP	5	0.8	0.071	120	Kickers
YSWEEP	5	0.8	0.071	120	

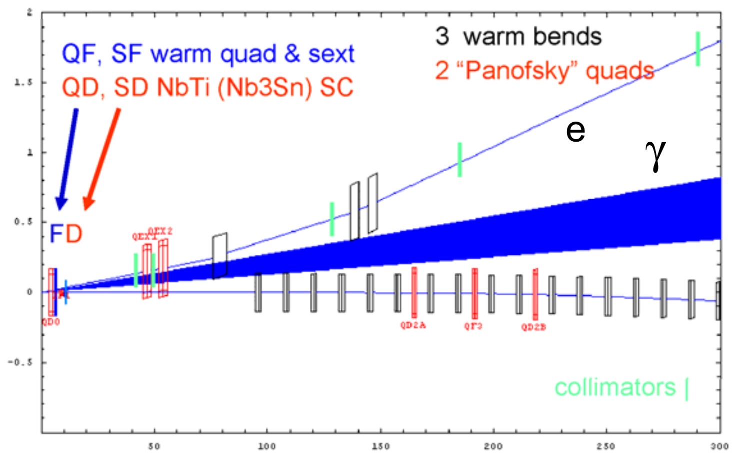
Quadrupole gradient (T/m), length (m) and aperture (mm) at 250 GeV

Quad	Qty	L* = 3.51 m			L* = 4.0 m			L* = 4.5 m		
		Grad	L	Aper	Grad	L	Aper	Grad	L	Aper
QDEX1 (SC)	1	98.00	1.060	15	89.41	1.150	17	86.39	1.190	18
QFEX2A (SC)	1	31.33	1.100	30	33.67	1.100	30	36.00	1.100	30
QFEX2B,2C,2D	3	11.12	1.904	44	11.27	1.904	44	11.36	1.904	44
QDEX3A,3B	2	11.39	2.083	44	11.37	2.083	44	11.36	2.083	44
QDEX3C	1	11.39	2.083	44	11.37	2.083	44	11.36	2.083	44
QDEX3D	1	9.82	2.083	51	9.81	2.083	51	9.80	2.083	51
QDEX3E	1	8.21	2.083	61	8.20	2.083	61	8.19	2.083	61
QFEX4A	1	7.05	1.955	71	7.04	1.955	71	7.04	1.955	71
QFEX4B,4C,4D,4E	4	5.89	1.955	85	5.88	1.955	85	5.88	1.955	85

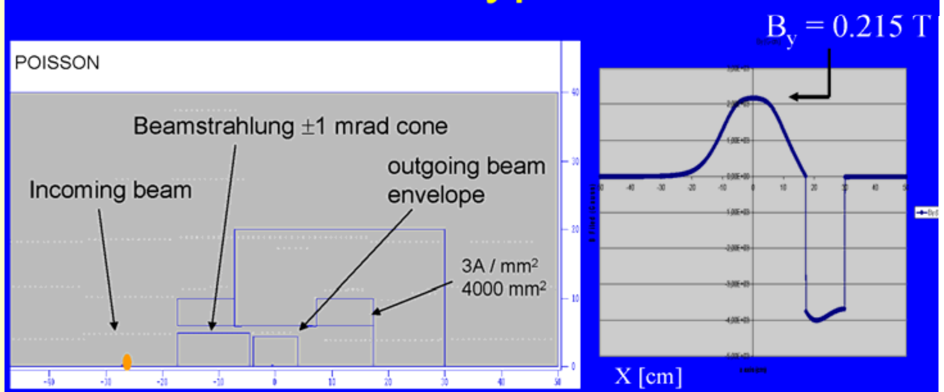


Other magnets: 2 mrad

- Initial magnets share the outgoing diverging e & γ beams.
- QF1, SF1: warm quadrupole and sextupole with 20 & 30 mm radius. Shared with incoming beam. Extracted beam goes off-axis through coil pockets → highly non-linear field. To be designed.
- Panofsky type QEX1,2 quadrupoles with large aperture (100-115 mm) for e & γ beams. Must provide field free region for incoming beam (150 mm away). To be designed.
- C-type warm BHEX1 bend for e & γ beams. Some residual field on incoming beam → requires correction. To be designed.
- Sweeping kickers need to be included.



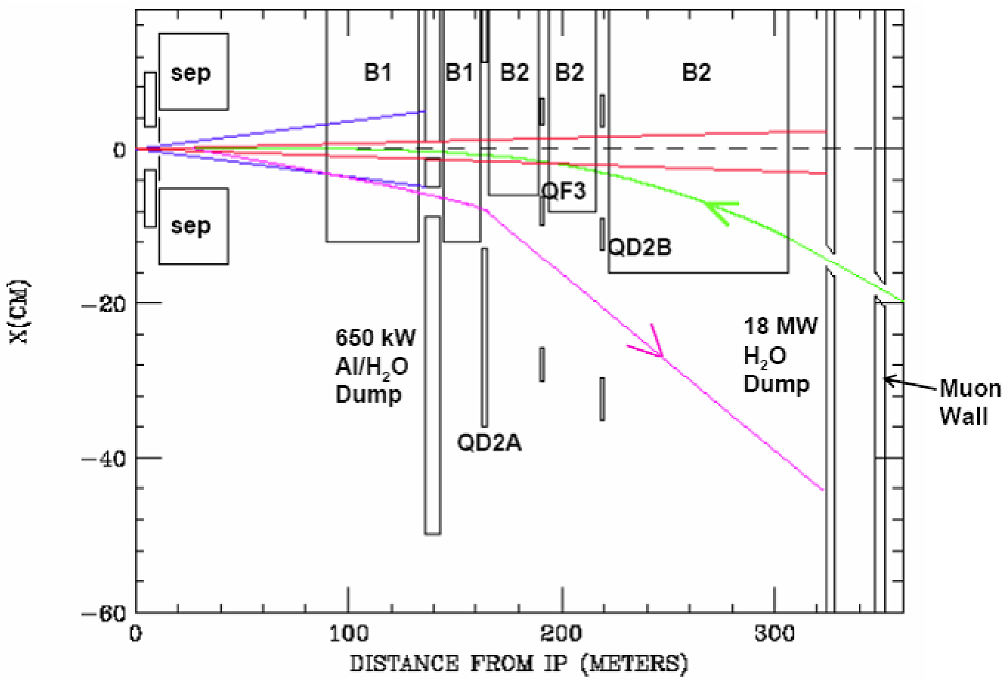
BHEX1 C-type bend



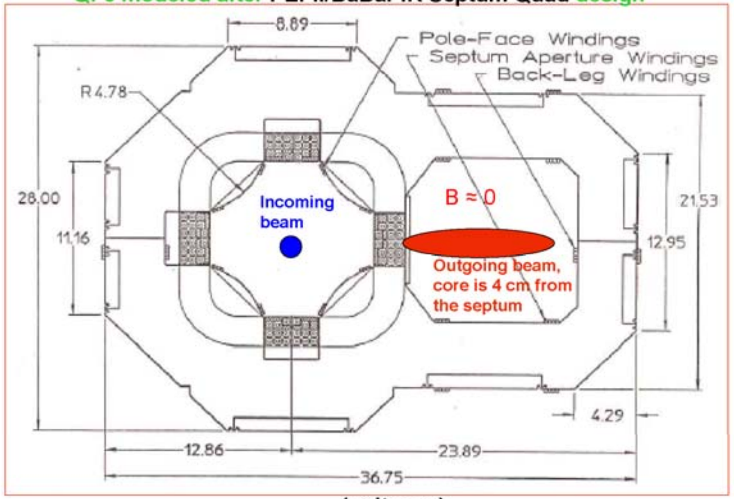
- $B_y(x)$ homogeneity < 3.2 % (with shims) within outgoing beam envelope → checked to be sufficient
- Residual B_y on incoming beam ~ 1% → 20 μrad (7.5 $\sigma_{x'}$)→use corrector
- Residual $B_x(y)$ dependence on incoming beam → only even powers can absorb sextupole refitting SD / SF, decapole → U_{3444} aberration ??

Other magnets: 0 mrad

- Extracted e & γ beams are transported through the incoming magnets which must have large aperture.
- Initial 0.5 mrad deflection by 28 m E-separator overlapped with B-field.
- C-type B1 & B2 bends with large aperture. To be designed.
- Large aperture QD2A quad for 7 cm offset extracted e beam. To be designed.
- QF3 septum quadrupole based on PEP2 IR magnet. To be designed.
- Sweeping kickers need to be included.



QF3 modeled after PEPII/BaBar IR Septum Quad design



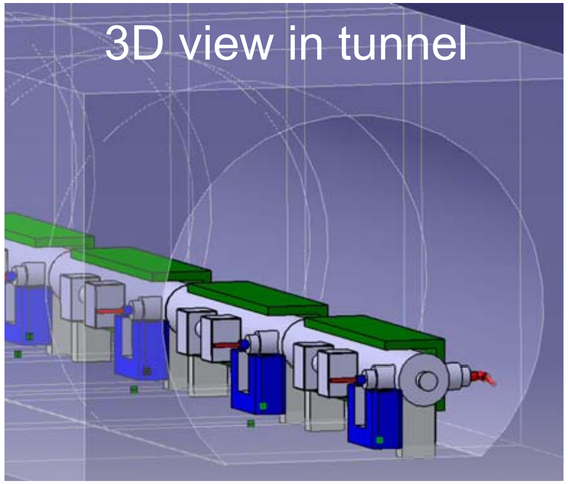
(units cm)

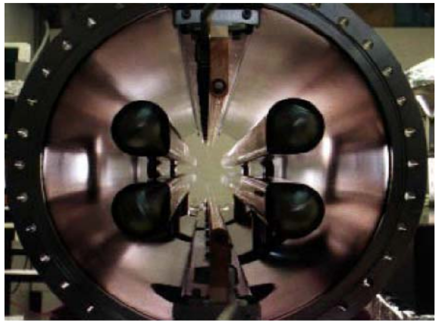
Electrostatic separators: 0 mrad

- Based on LEP experience and CESR separator design with split electrodes.
- Seven 4 m separators, enclosed in 8 mT dipole field for total 0.5 mrad kick.
- Sufficient 12 mm separation at beam parasitic crossing, 55 m from IP.
- 100 mm gap with 26.2 kV/cm field at 500 GeV CM.
- 50 mm split electrodes to avoid ~kW beam loss.
- 4 generators to avoid chain sparking.
- Assumed sparking rate <0.04 per hour.

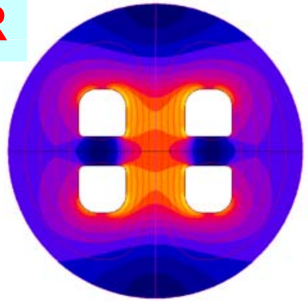
Lots of R&D needed:

- Sparking rate versus beam loss.
- Field quality and stability with split electrodes.
- 50-60 kV/cm for 1 TeV upgrade.
- Performance under radiation.
- Insulator support design in harsh environment.
- Optimal electrodes.
- Sparking effects: field coupling through beam & γ, circuit effects, recovery.





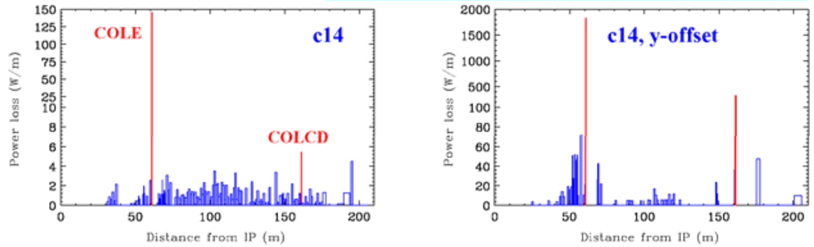
CESR



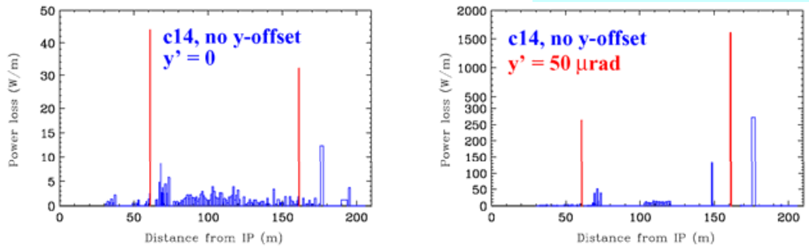
Beam power loss: 14 mrad

- Quad focusing optimized for minimal beam loss.
- 5 collimators to protect magnets, diagnostics and dump: COLE – for low energy collimation, COLCD – for Cherenkov detector protection, COLW1, COLW2, COLW3 – for fast kicker and dump protection.
- Power loss is small at 500 GeV CM nominal parameters (c11), and acceptable at high disruption parameters (c14).
- No primary and photon loss on SC quads.
- Large y-offset and y-angle at IP increase load on collimators. These non-ideal conditions need to be efficiently corrected.

Low-P (c14) w/o solenoid



with solenoid

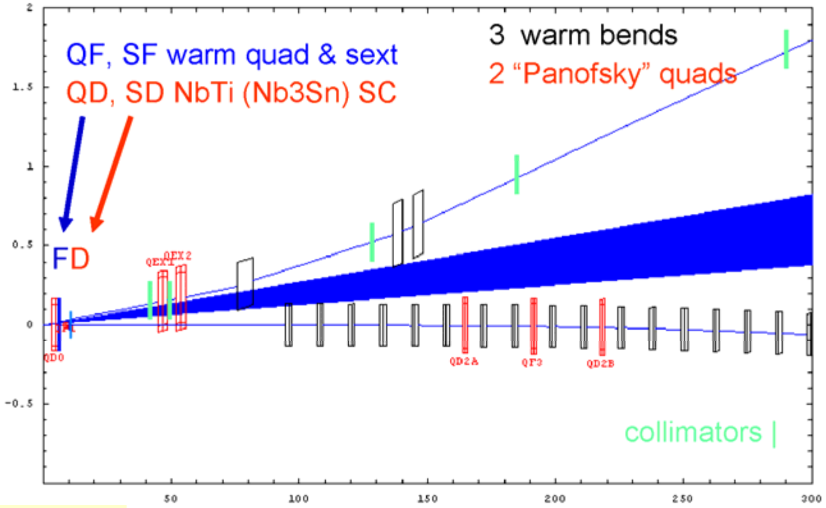


Beam power loss (kW) for optics with L* = 3.51 m without solenoid

Option	Primary electrons						BS photons		
	Total on magnets and pipe	Diagnostic collimators		Dump collimators			Dump collimators		
		COLE	COLCD	COLW1	COLW2	COLW3	COLW1	COLW2	COLW3
c11	0	0	0	0	0	0.272	0	0	0
c11, y-offset	0.001	0.001	0.0003	1.12	2.59	11.2	0.0001	0.025	0
c13	0.007	0.001	0.0001	1.02	1.57	6.54	0.570	0.820	0
c13, y-offset	0	0.0001	0	1.08	1.76	9.05	0.138	1.82	0
c14	0.126	0.044	0.003	2.62	6.18	26.3	0.035	0.171	0
c14, y-offset	0.581	0.549	0.161	85.9	43.7	82.1	10.9	20.1	0

Beam power loss: 2 mrad

- FD is optimized for minimal loss.
- Less than 1 W on SC QD0, SD0.
- Acceptable loss on NC magnets.
- Collimators to protect extraction magnets (load <5 kW).
- Collimators to limit beam size at dump. May have high load (200 kW) in high luminosity option. Use rotating Al balls in flowing water.



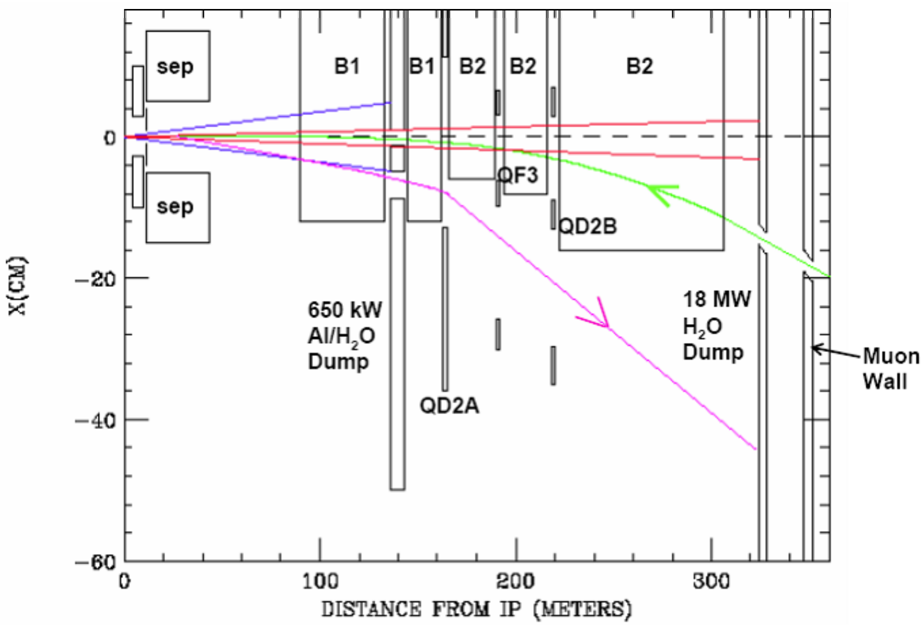
- Choice of separate or joint dumps for e & γ.
- γ dump must have a hole for incoming beam.

High luminosity parameters

Collimator 0.5 / 1 TeV	S [m]	Length [m]	Power load [kW]
QEX1COLL	44.7 / 46.4	1	0.2 / 7.9
QEX2COLL	52.7 / 56.4	1	0.0
BHEX1COLL	76.7 / 82.4	1	0.1 + 0.8 / 0.0
COLL1	131	2.5	52.3 / 111.3
COLL2	183	2.5	207.5 / 206.1
COLL3	285	2.5	0.0

Beam power loss: 0 mrad

- No loss on SC QD0, SD0. Up to 1 W loss on SC QF1, SF1 in low-P option.
- 1-2 kW loss on separators w/o splitting, acceptable loss with split electrodes.
- High power (650 kW) intermediate dump ~140 m from IP with two holes. Protects magnets from large angle photon and low energy electron loss. The dump model assumes Al & water 2.2 MW device at SLAC. Requires shielding protection. Backscattering to IP and E-separators needs to be checked.
- Set of collimators to remove photon tails and limit incoming magnet aperture.
- Main dump with a hole for incoming beam.



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

May 2007

charged (red)
beamstrahlung (blue)

Loss Location	Nominal Parameters		Low Power Parameters		Radiative Bhabha's
	Headon	Vertical offset	Headon	Vertical offset	
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)	75 140	90 240	415 215	539 416 (4)	-
Main dump	10,160 125	10,030 135	4,500 115	4,200 95	-

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

Summary of pros & cons

(including input from Snowmass'05 BCD)

Advantages

14 mrad: Independent flexible optics; larger magnet separation; downstream diagnostics; small to moderate beam loss; one beamline; one dump w/o holes; better compatible with $\gamma\gamma$ and e^-e^- options.

2 mrad: DID not needed; less dependent on crab-cavity; favorable detector hermeticity, background and calibration; small to moderate beam loss.

0 mrad: Crab-cavity and DID not needed; favorable detector hermeticity, background and calibration.

Disadvantages and R&D issues

14 mrad: Crab-cavity, anti-DID & orbit correction required; less favorable detector background, hermeticity and calibration; SR in solenoid.

2 mrad: No downstream diagnostics; shared FD; beam in non-linear field of QF1/SF1 coil pocket; large aperture SC sextupole; large aperture NC magnets close to incoming beam; SR in FD → photon backscattering; dump(s) with a hole; feedback BPM & kicker shared with disrupted beam.

0 mrad: No downstream diagnostics; shared FD; least flexible optics; parasitic crossing; challenging E-separators; special large aperture incoming magnets; high power collimation ~140 m from IP → backscattering; intermediate and main dumps with holes; feedback BPM & kicker shared with disrupted beam.