Beam Delivery System in the ILC

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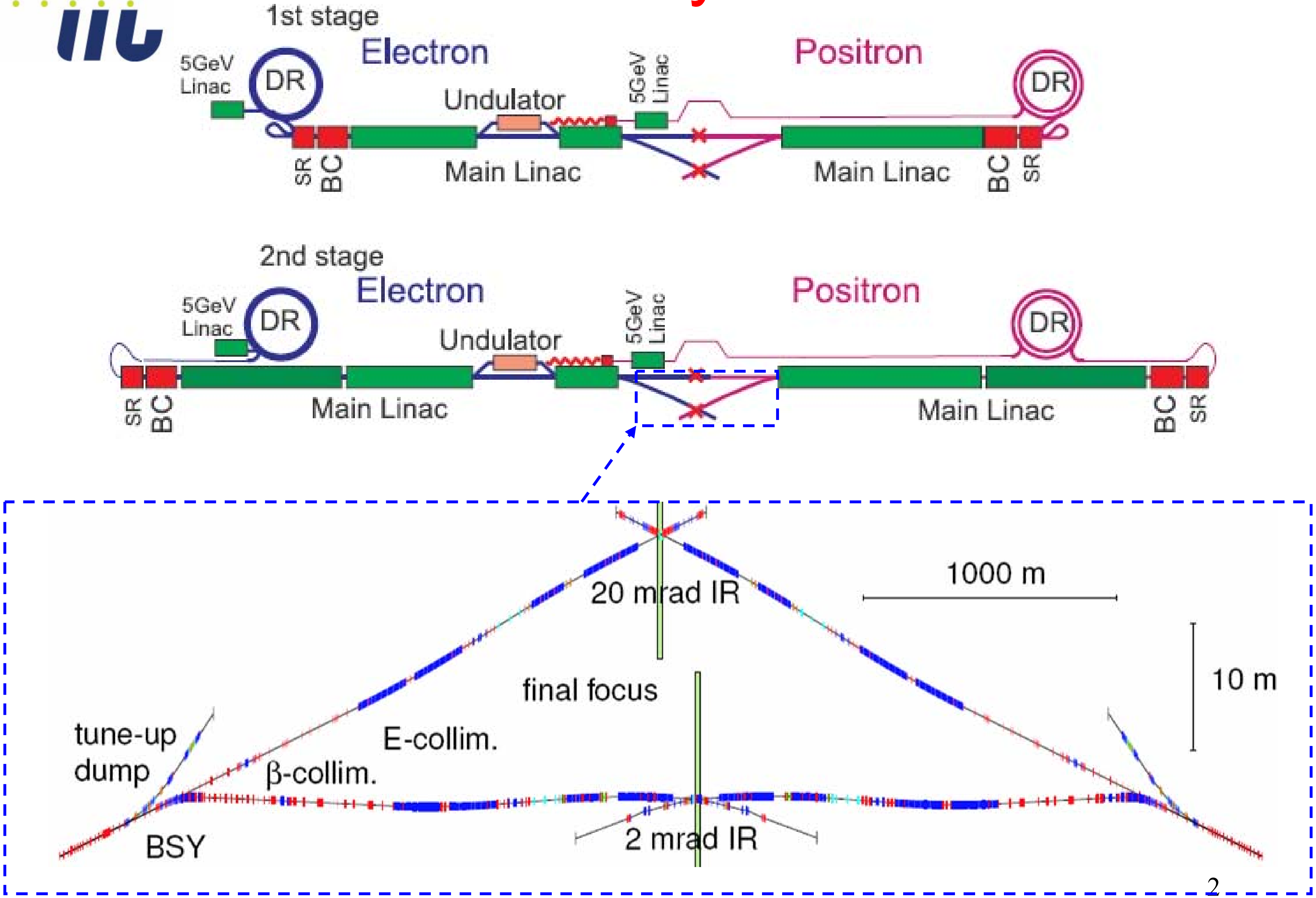
EPAC06

Edinburgh

28th June 2006

- Introduction
- SLC
- GDE Baseline concept
- Some key sub-systems
- ESA/FFTB/ATF2
- Outlook + Summary

ILC Layout



1st stage
Electron
Positron
5GeV Linac
DR
Undulator
5GeV Linac
DR
SR
BC
Main Linac
Main Linac
BC
SR
2nd stage
Electron
Positron
5GeV Linac
DR
Undulator
5GeV Linac
DR
SR
BC
Main Linac
Main Linac
BC
SR
20 mrad IR
1000 m
10 m
final focus
tune-up dump
E-collim.
β-collim.
BSY
2 mrad IR

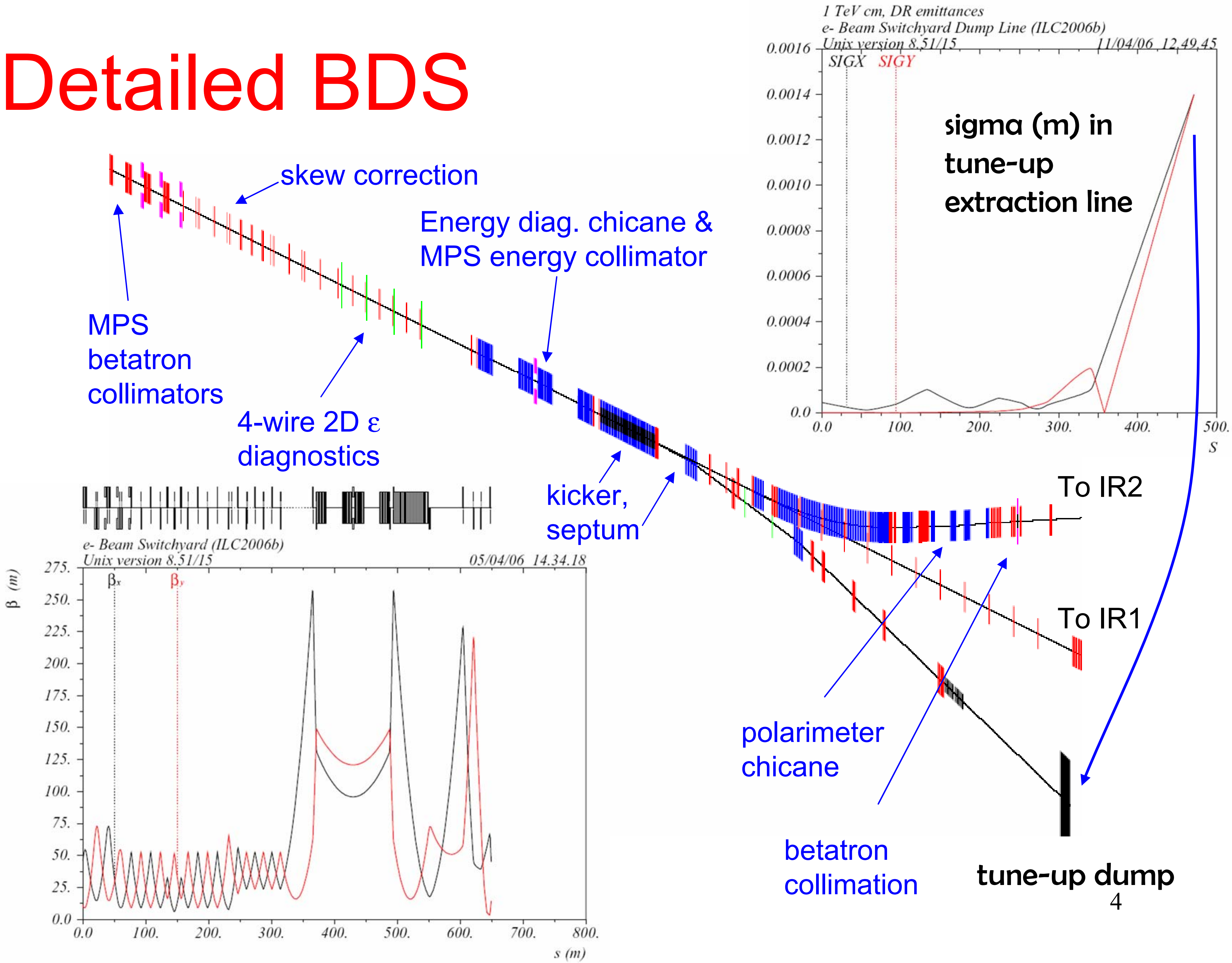
ILC parameters

		min		nominal		max	
Bunch charge	N	1	-	2	-	2	$\times 10^{10}$
Number of bunches	n_b	1330	-	2820	-	**5640**	
Linac bunch interval	t_b	**154**	-	308	-	461	ns
Bunch length	σ_z	**150**	-	300	-	500	μm
Vert.emit.	$\gamma\epsilon_y^*$	**0.03**	-	0.04	-	0.08	mm·mrad
IP beta (500GeV)	β_x^*	**10**	-	21	-	21	mm
	β_y^*	**0.2**	-	0.4	-	0.4	mm
IP beta (1TeV)	β_x^*	**10**	-	30	-	30	mm
	β_y^*	**0.2**	-	0.3	-	0.6	mm

BDS must:

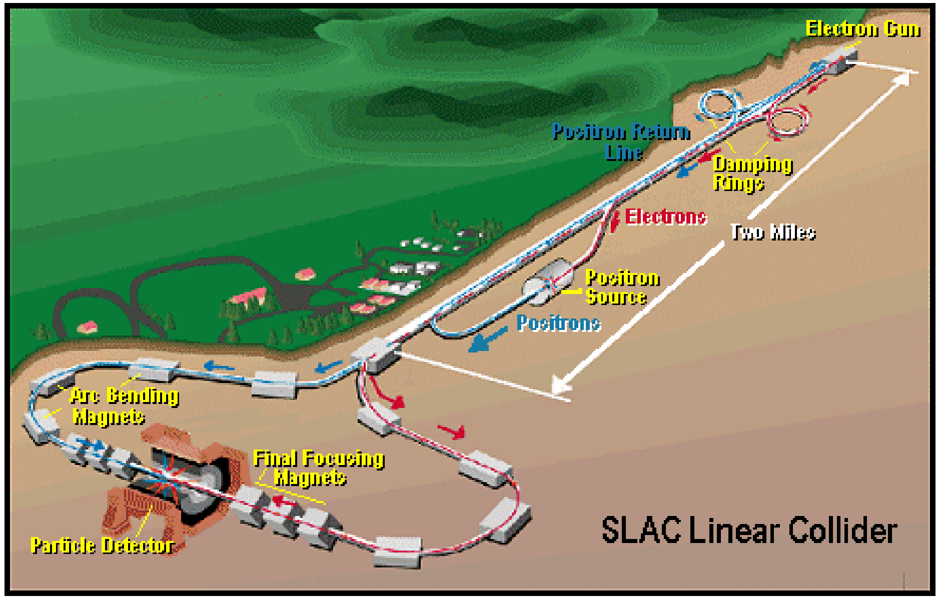
- Focus the beam to size of about 500 (x) × 5 (y) nm at IP
- Collimate beam halo
- Monitor the luminosity spectrum and polarization
- Measure incoming beam properties to allow tuning of the machine
- Protect detector and beamline components against errant beams
- Extract disrupted beams and safely transport to beam dumps

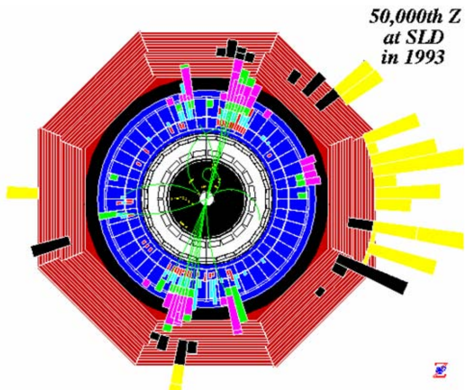
Detailed BDS



Stanford Linear Collider (SLC)

	Design	Achieved	Units
Beam charge	7.2×10^{10}	4.2×10^{10}	$e^{\pm}$/bunch
Rep Rate	180	120	Hz
FF ε_x	4.2×10^{-5}	5.2×10^{-5}	m rad
FF ε_y	4.2×10^{-5}	1.0×10^{-5}	m rad
IP σ_x	1.65	1.4	µm
IP σ_y	1.65	0.7	µm
Pinch Factor	220%	220%	Hd
Luminosity	6×10^{30}	3×10^{30}	$cm^{-2}s^{-1}$





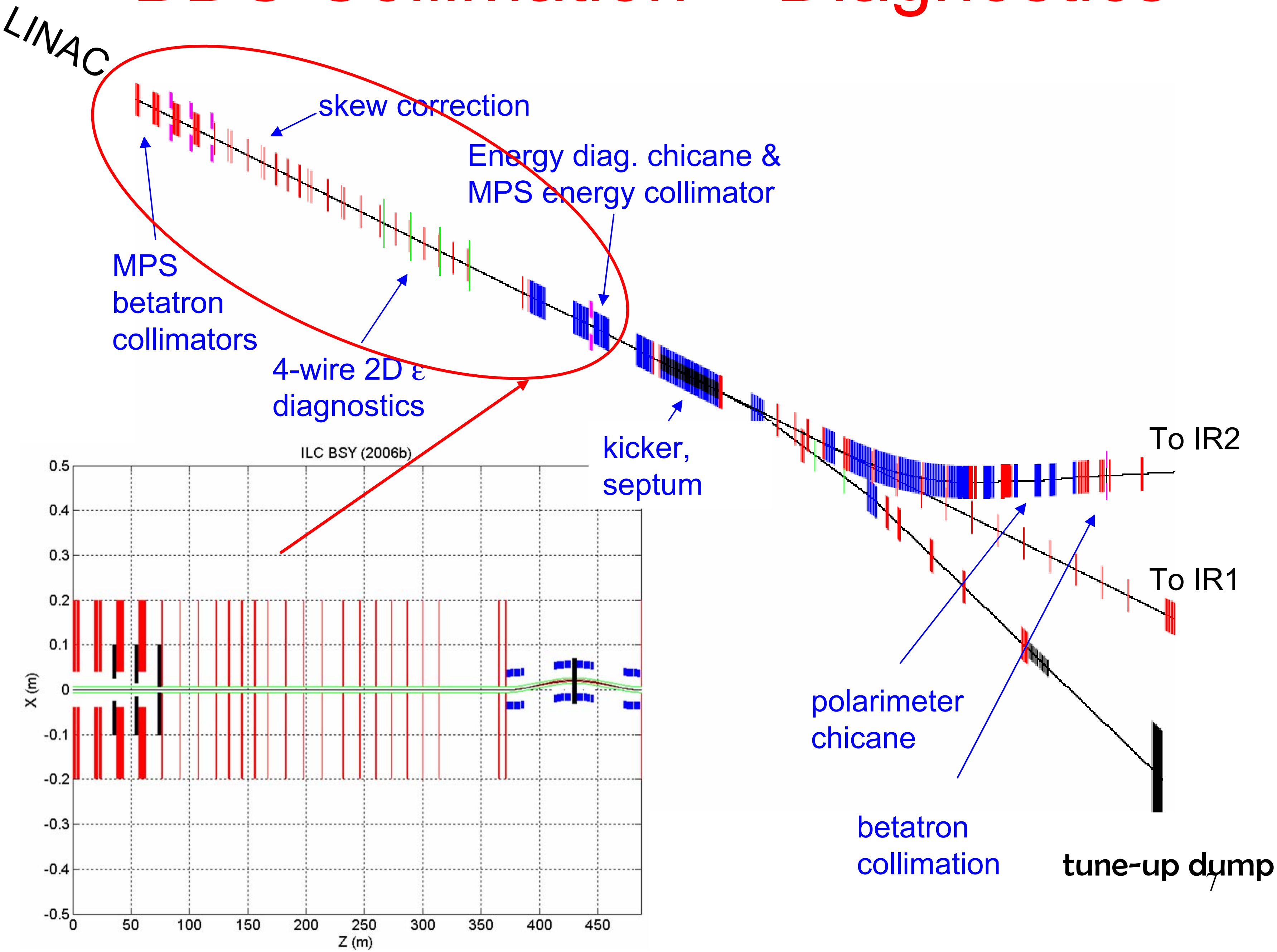
- 1992-1998
- first LC
- 45 GeV beams
- 300 Z^0's per hour
- e^- polarisation of 80%

- Many of today's ILC experts were involved in getting SLC to work
- Many important LC lessons learnt:

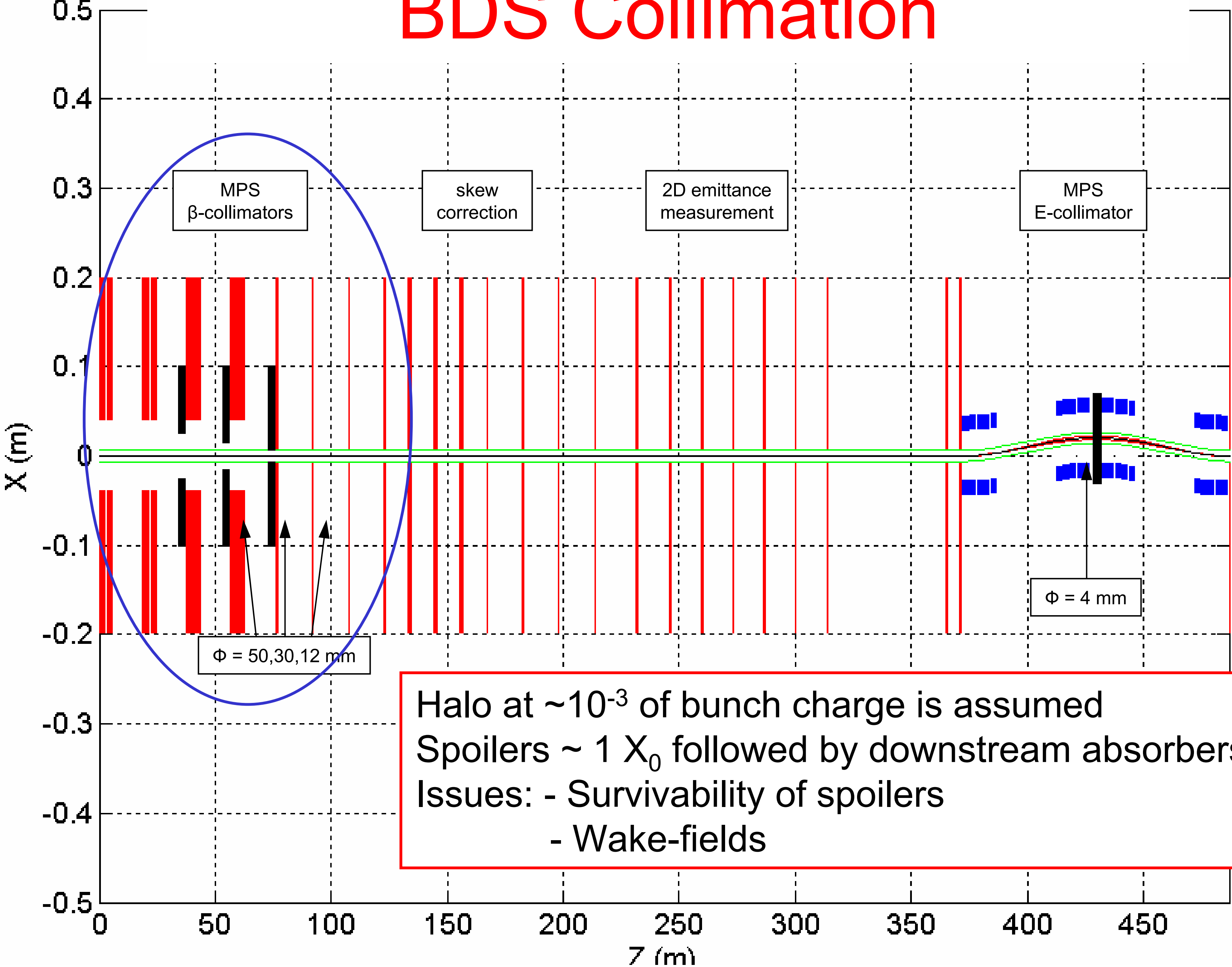
BDS: Lessons from the SLC

BDS	SLC
Precision diagnostics essential	> 60 wire scanners were needed
Automated diagnostics	long term history + correlations
Feedback system essential	> 50 needed for > 250 beam parameters.
Innovative tuning procedures	beam-based alignment, β-match…
SR must be minimised; implications for high E.	~30% luminosity dilution in the FF was due to SR in the CCS bends.
New FF design	FF optimised to reduce higher order aberrations
The most difficult problems will almost always be unexpected	They were…

BDS Collimation + Diagnostics



BDS Collimation



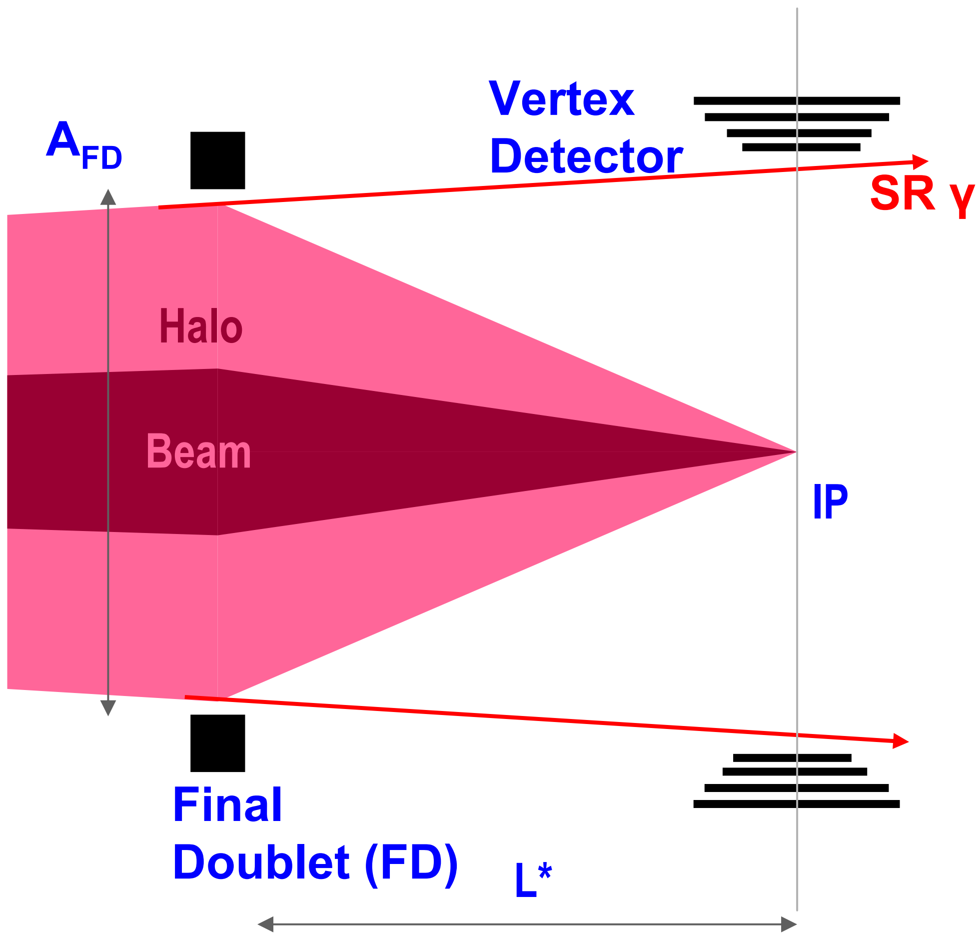
Halo at ~10^{-3} of bunch charge is assumed

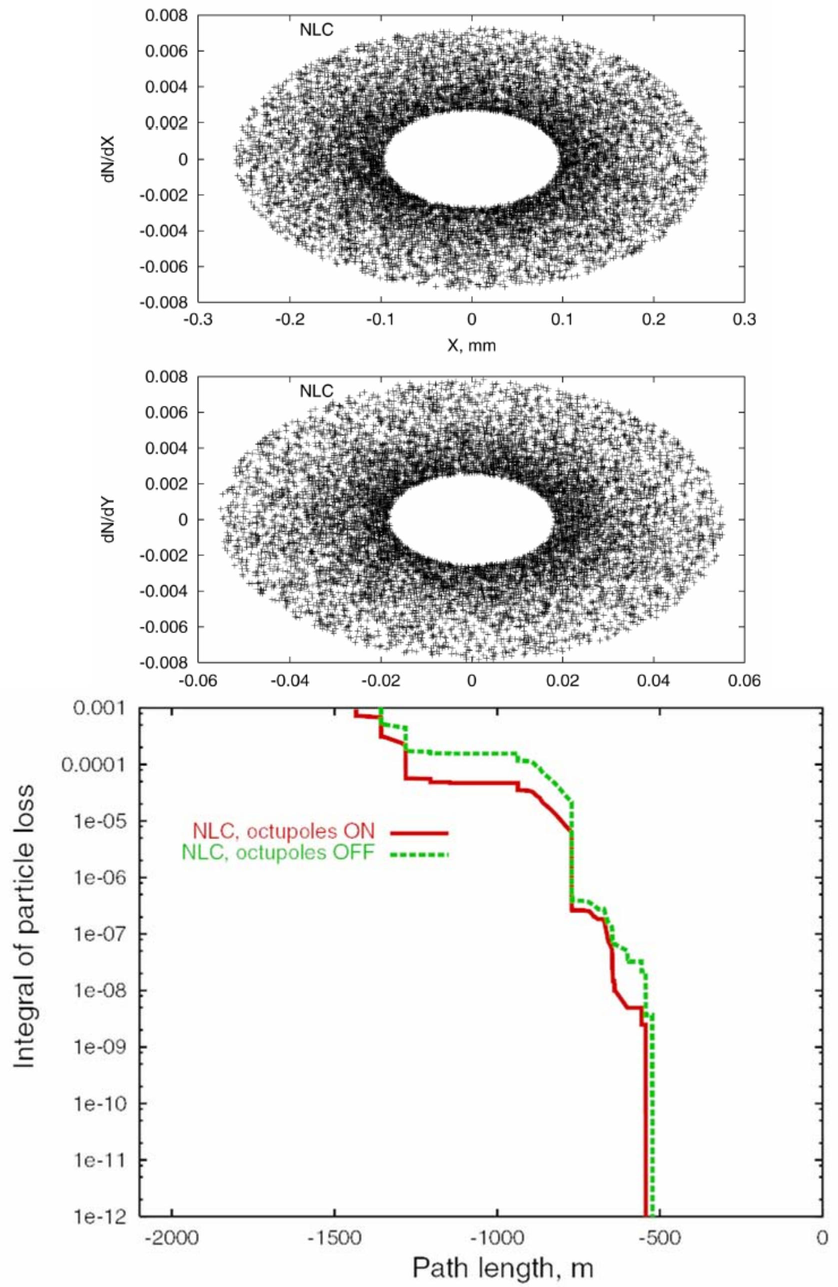
Spoilers ~ 1 X_0 followed by downstream absorbers

Issues: - Survivability of spoilers

- Wake-fields

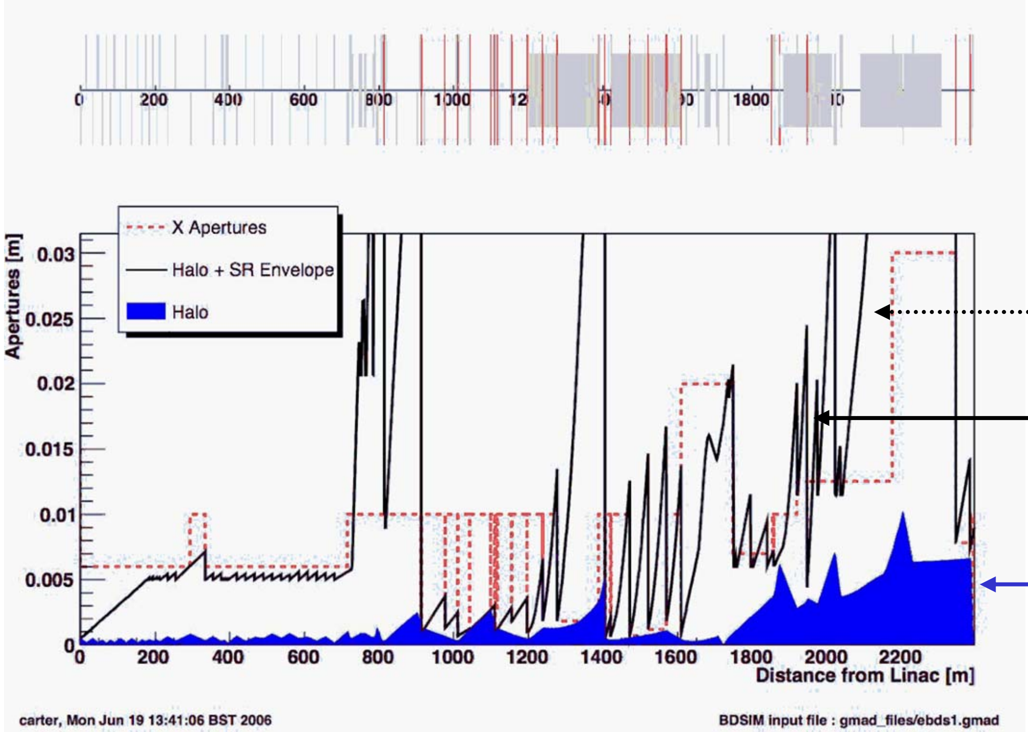
Beam halo & collimation





Smallest collimator gaps are ±0.6mm with tail folding octupoles and ±0.2mm without them.

BDS Full Simulations



Beam aperture

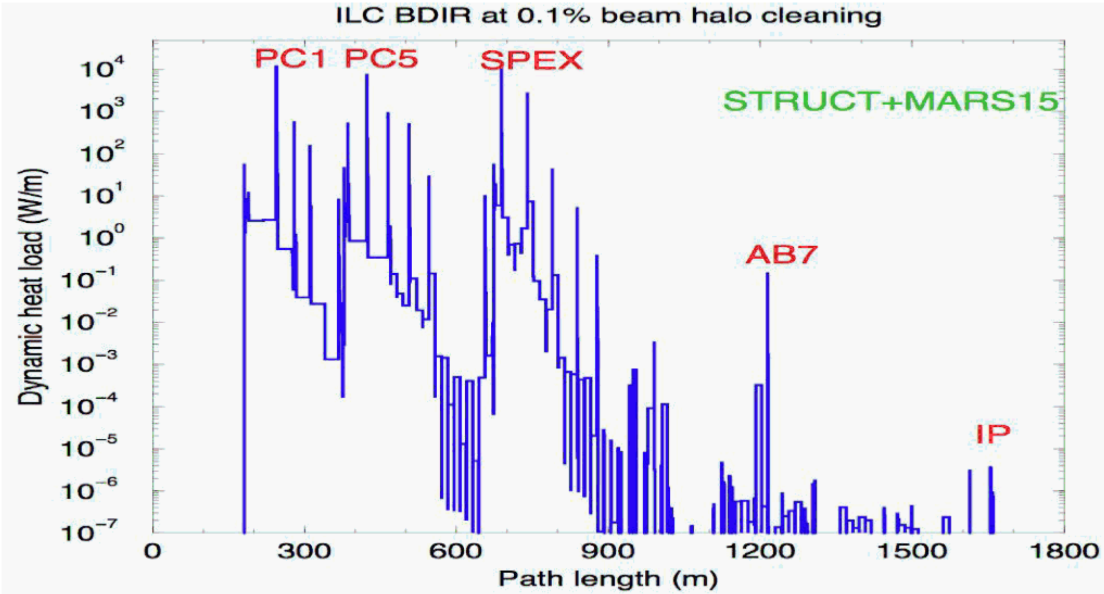
SR

halo

BDSIM

WEPCH124

Agapov et al.



MOPL082

Dynamic heat load

MARS+STRUCT

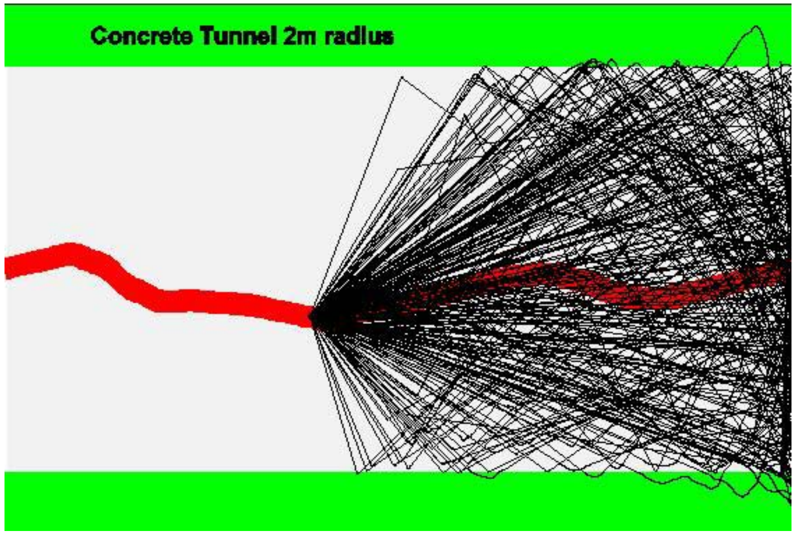
Mokhov et al.

Jackson et al. MOPLS074

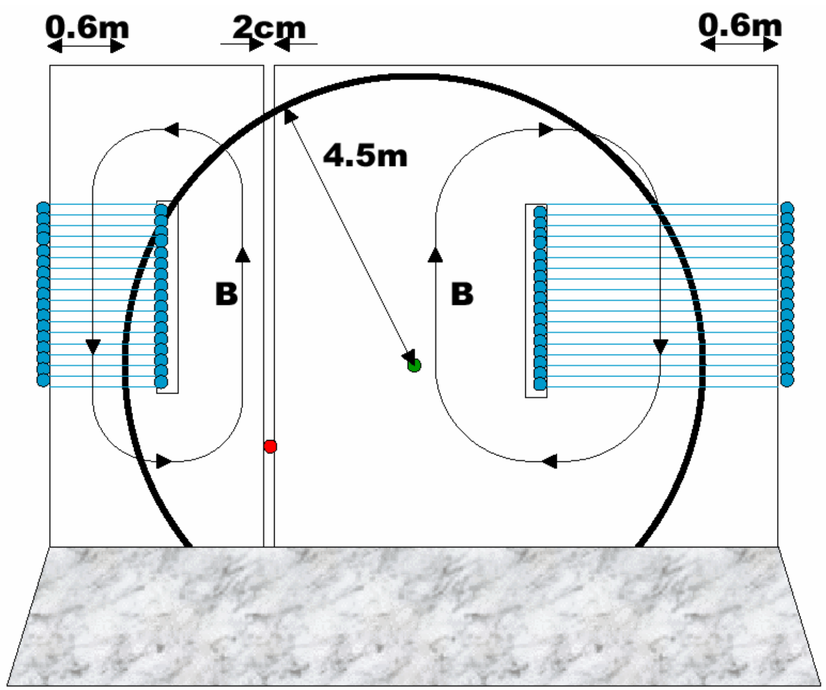
Amirikas et al. MOPLS062

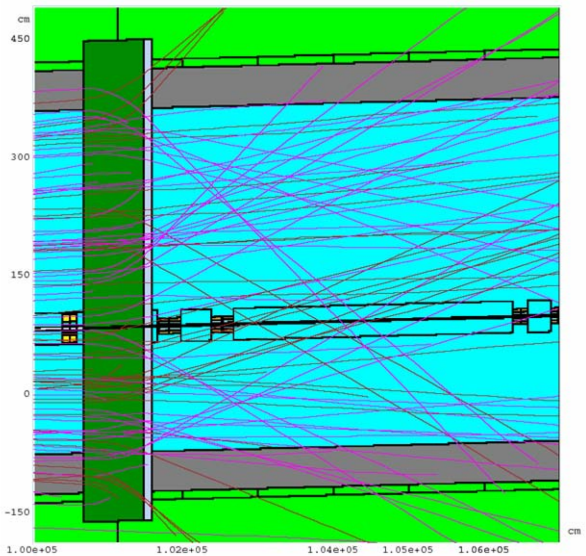
Dealing with muons in BDS

Assuming 0.001 of the beam is collimated, two tunnel-filling spoilers are needed to keep the number of muon/pulse train hitting detector below 10.



μ± tracks that reach IR





9 and 18m Toroid spoilers

Long magnetized steel walls

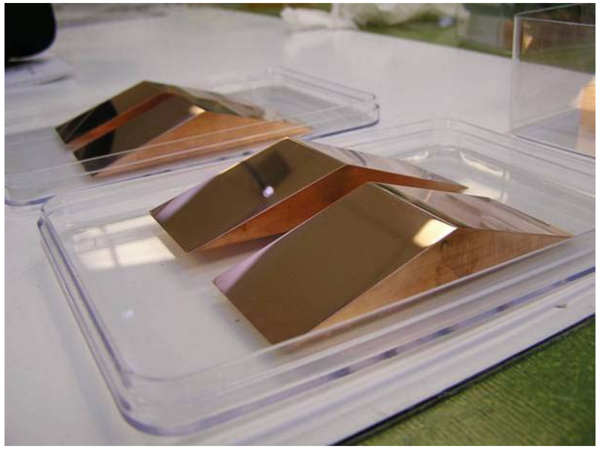
Keller et al.

Spoiler R&D

Spoiler should either:

- be able to survive at least 2 direct-hits from ILC bunch
- or be "consumable"

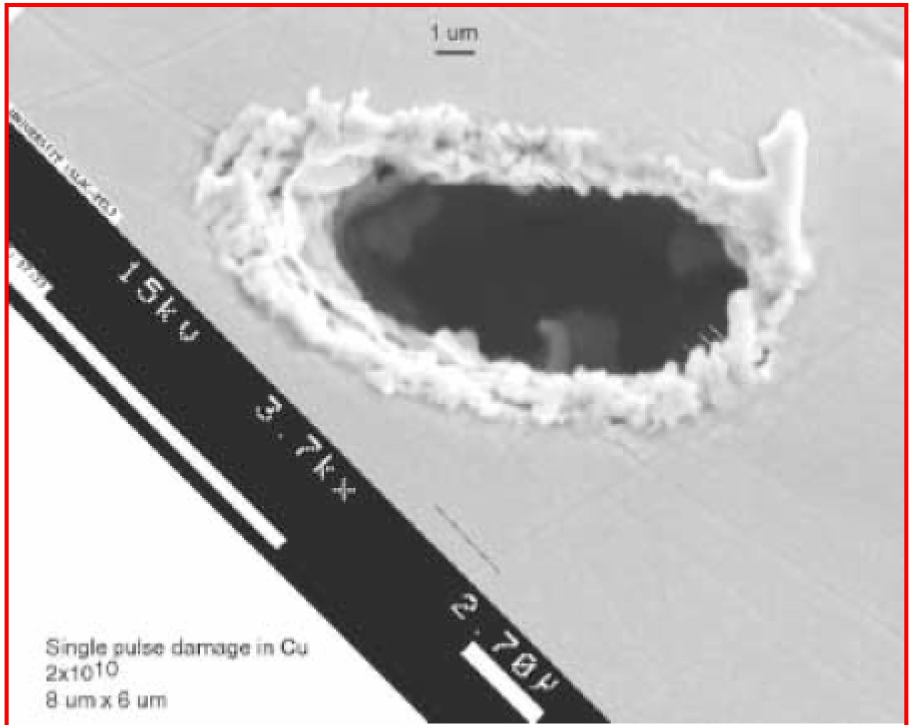
Both ideas have been considered:



MOPLS068

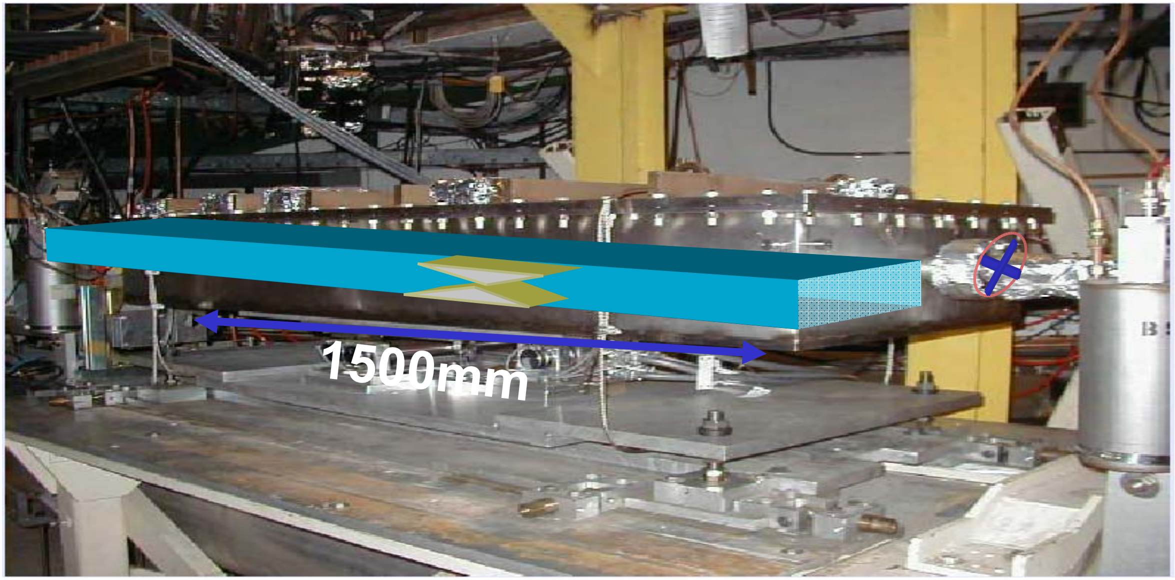
"permanent"

"consumable"
Frisch et al.

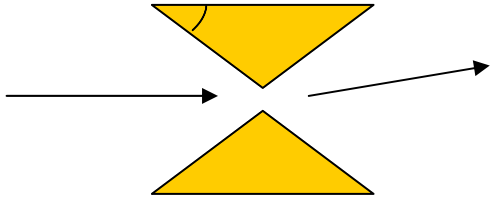


Picture from beam damage experiment at FFTB. The beam was 30GeV, 3-20x10^9 e-, 1mm bunch length, s~45-200um^2. Test sample is Cu, 1.4mm thick. Damage was observed for densities > 7x$10^{14}$$e^-$/$cm^2$. Picture is for 6x$10^{15}$$e^-$/$cm^2$

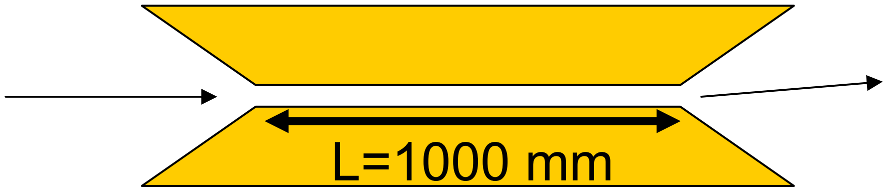
Spoiler Wakefield Studies



currently ongoing at
SLAC- ESA

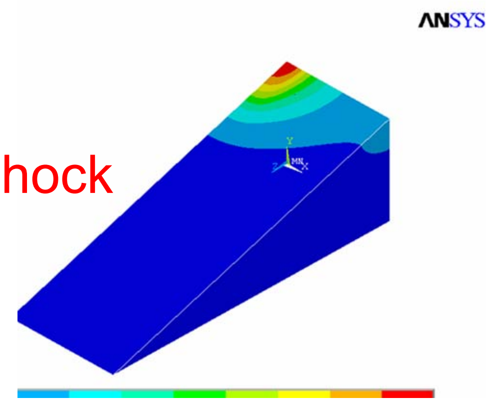


- Geometric wake-fields
- Resistive-wall wake-fields
- Benchmarking against simulation codes



Deflection angle
Measured downstream with
BPMs to give measure of
Wake-field kick

Studies of thermal shock
Survivability



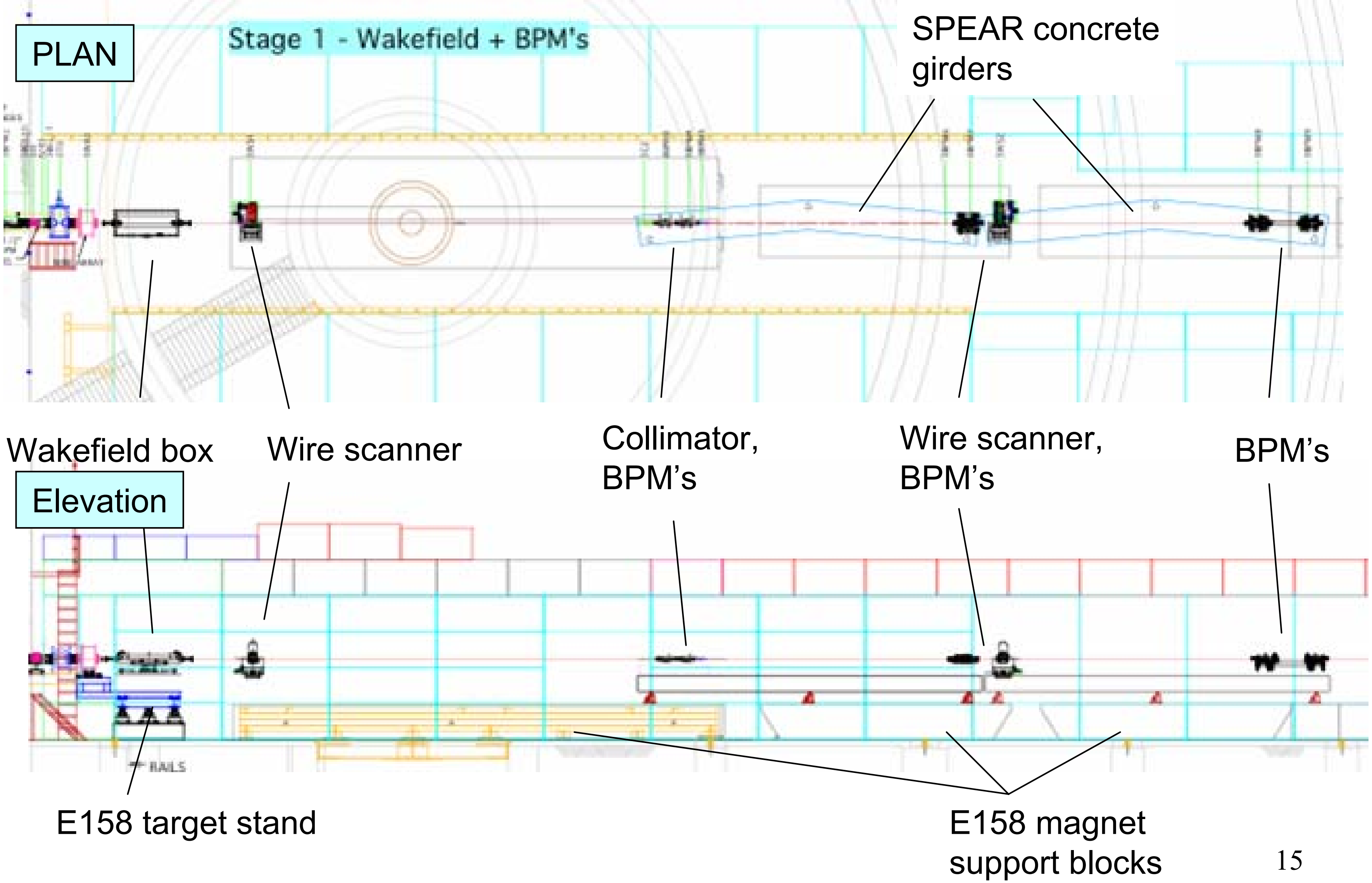
MOPLS070,071

Watson et al.

End Station A

Parameter	SLAC ESA	ILC-500
Repetition Rate	10 (up to 30) Hz	5 Hz
Energy	28.5 GeV	250 GeV
e^- Polarization	(85%)	>80%
Train Length	Single bunch; (up to 400 ns possible)	1 ms
Microbunch spacing	20-400 ns	337 ns
Bunches per train	1 (or 2)	2820
Bunch Charge	2.0×10^{10}	2.0×10^{10}
Energy Spread	0.15%	0.1%

End Station A



Other Beam Tests in ESA

MOPLS067

Woods et al.

1. BPM test stations
   - Linac BPMs, nano-BPMs
2. IP BPMs/kickers (necessary for fast inter-train and intra-train feedbacks)
   - Sensitivity to backgrounds, rf pickup
3. EMI impact on beam instrumentation or Detector electronics ?
   - Plans to characterize EMI along ESA beamline in progress using antennas and fast scopes
4. Bunch length and longitudinal profile measurements
   - electro-optic, Smith-Purcell, coherent transition radiation
5. Spray beam or fixed target to mimic pairs, beamsstrahlung, disrupted beam
   - for testing synchrotron stripe energy spectrometer, IP BPMs, BEAMCAL

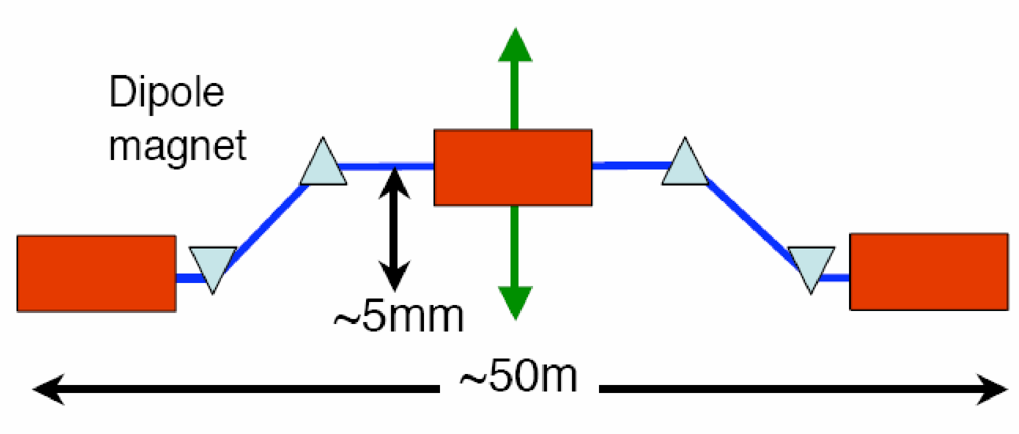
White et al. THPCH089

Beam Physics Measurements

Precision beam measurements are needed for ILC physics.

- Very accurate energy spectrometry is required (~10^{-4})
- cavity BPM system at the SLAC End Station A

Watson et al.
TUPCH105

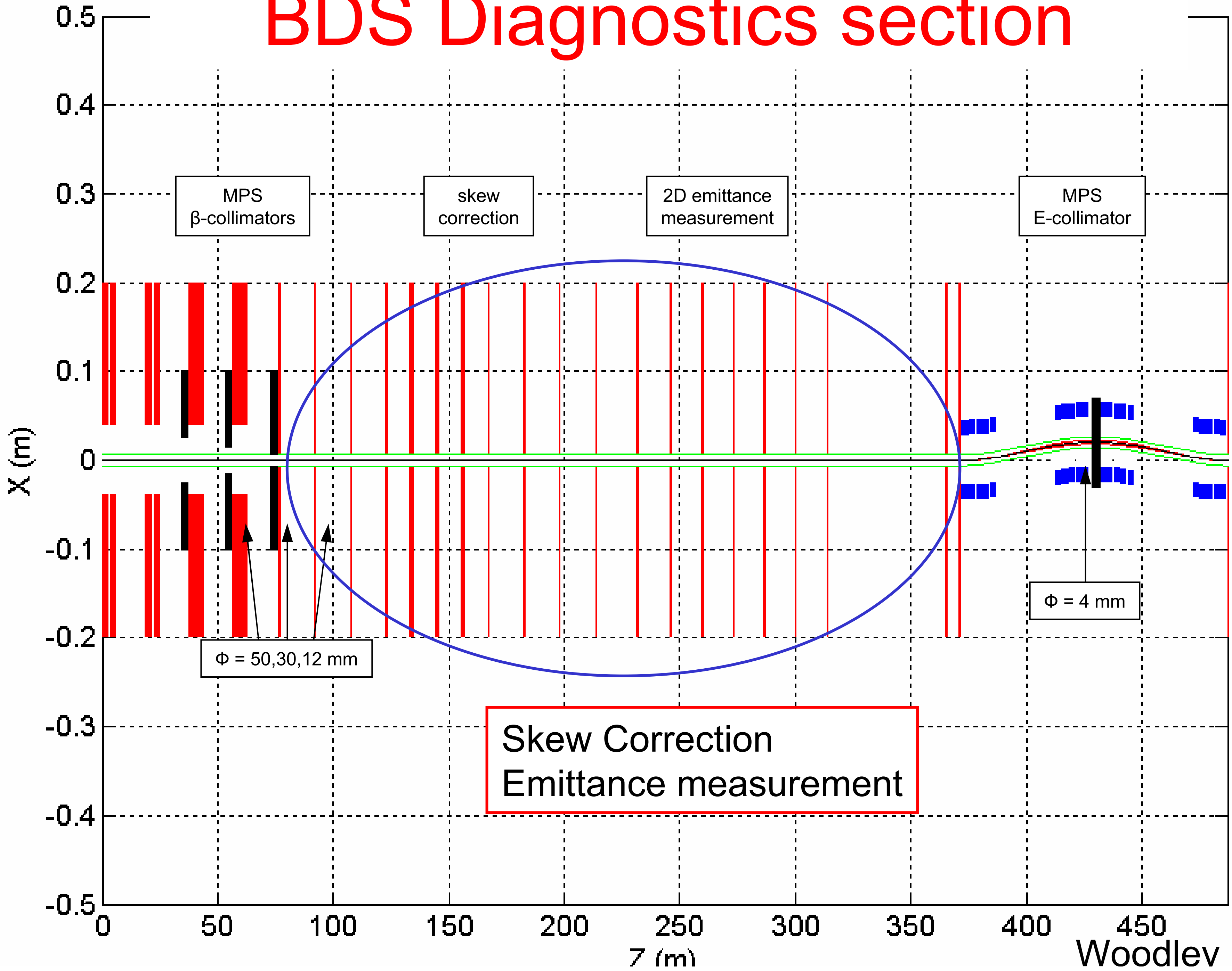


- Polarized beams important for ILC physics
- P(e^-)~ 90% and P(e^+) up to ~60%.
- strong programme of R&D is underway on the spin tracking issues.
- Measurement of the polarisation will be made both upstream and downstream of IP using Compton polarimeters

Moortgat-Pick et al.
WEPLS032

K. Moffeit *et al.*SLAC-PUB-11322, N. Meyners presentation at LCWS05;

BDS Diagnostics section

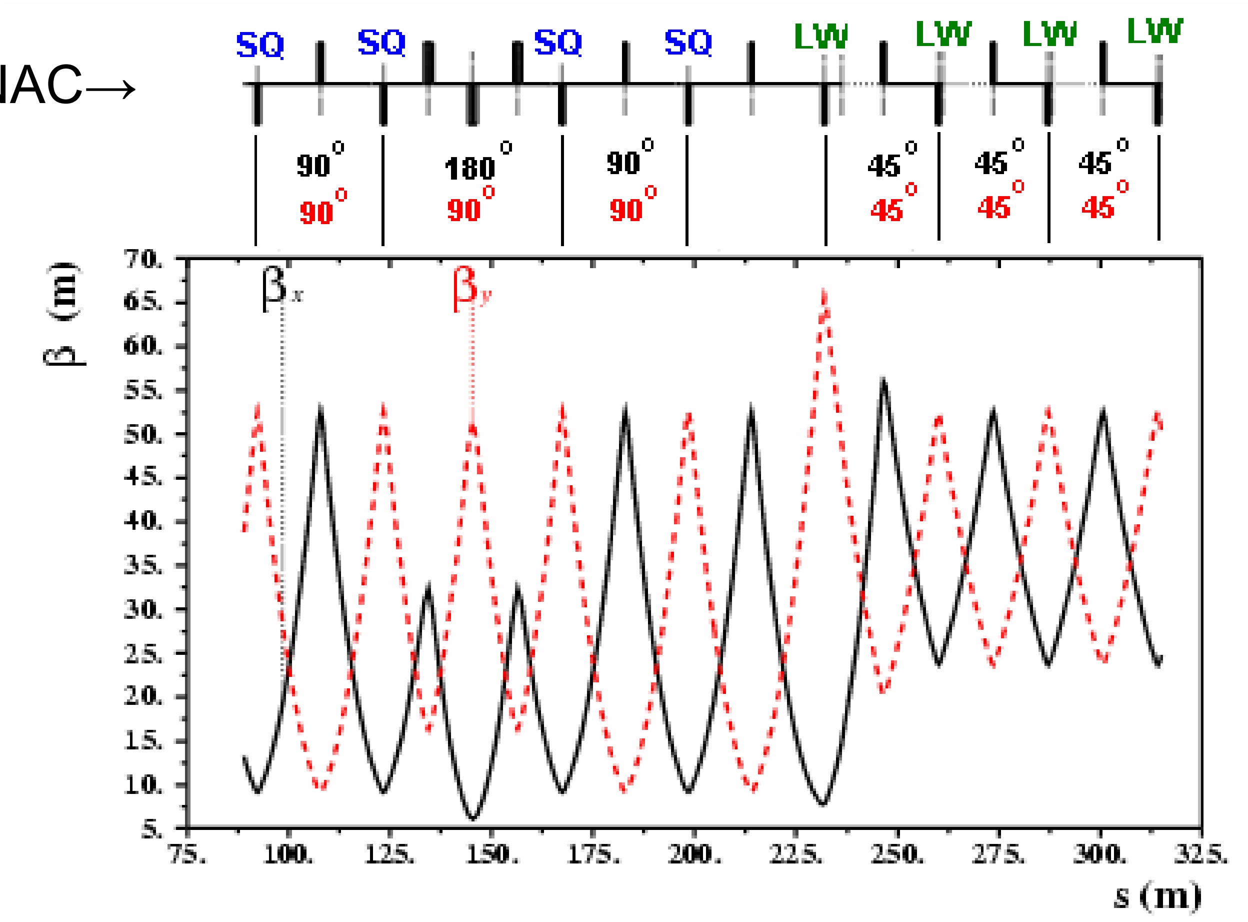


Skew Correction

4-skew quads to minimise
Horizontal-vertical coupling

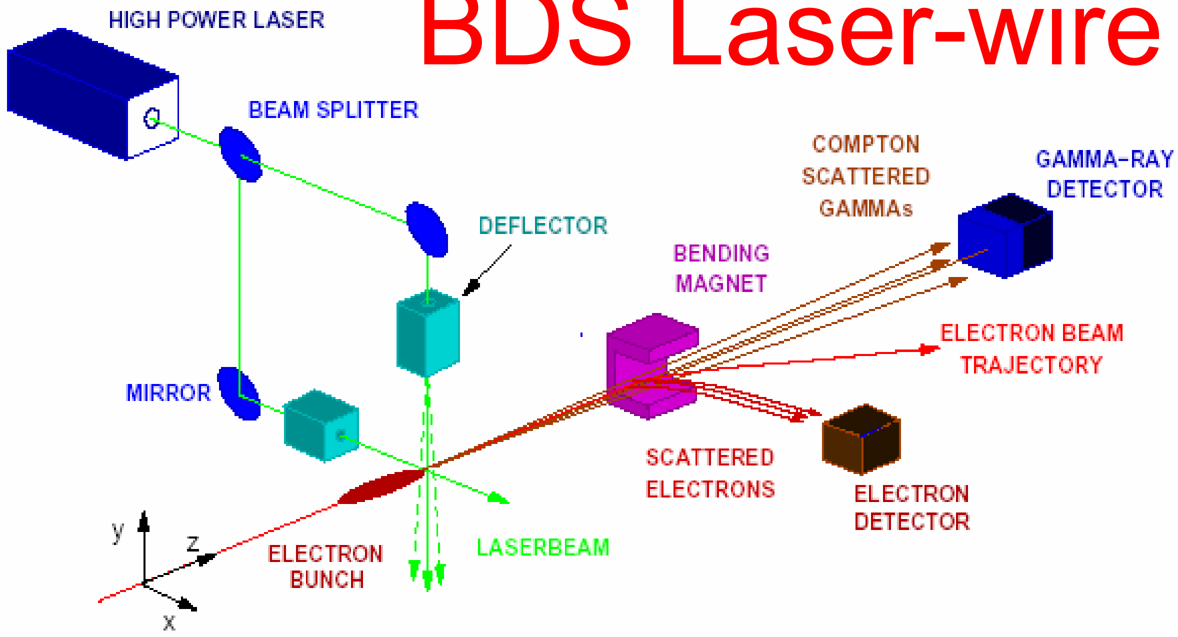
4-laser-wire IPs, each measuring
Vertical and horizontal spot-size
 quads to minimise
Minimum vertical spot-size ~ 1 μm

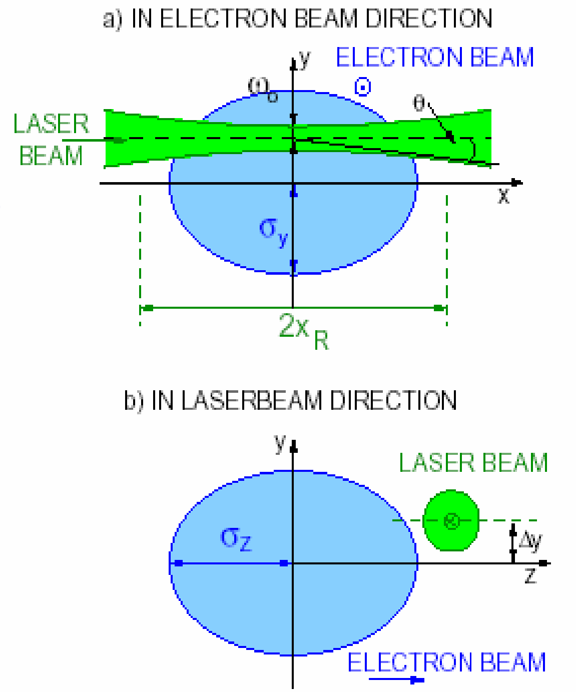
LINAC→



Jenner et al.
TUPCH048

BDS Laser-wire

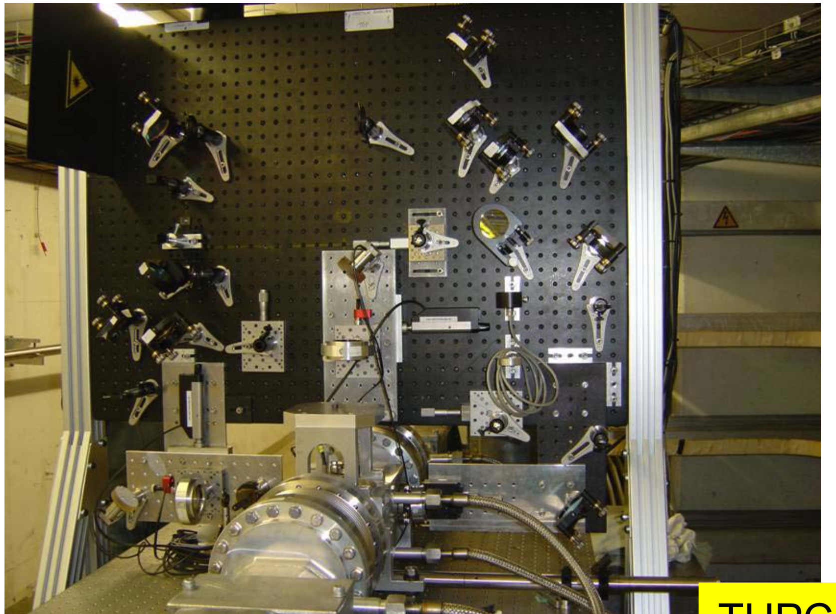




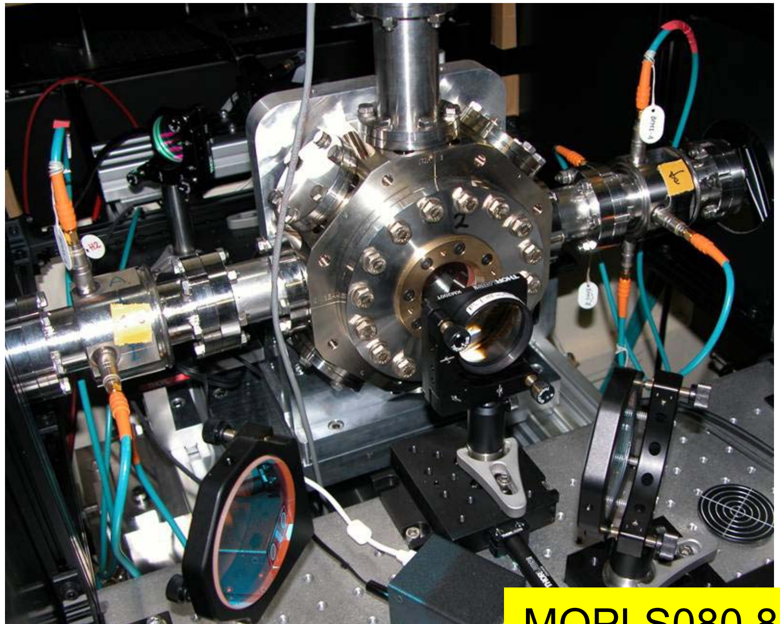
2-d scans at PETRA

BDS-LW
R&D

μm scale R&D at ATF Ext



TUPCH049,050



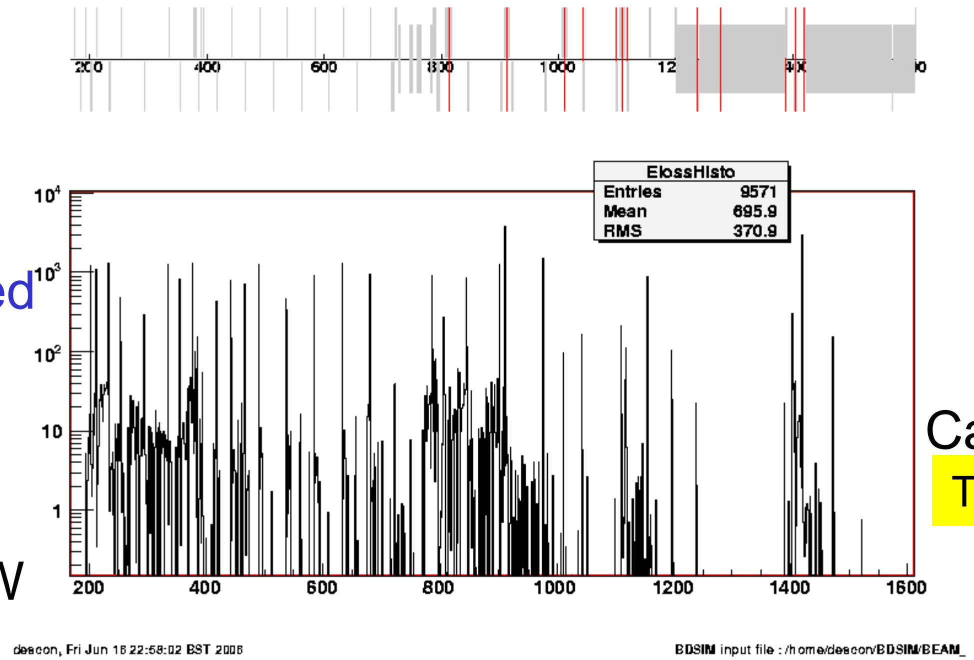
MOPLS080,81

BDS Laser-wire Issues

- Electron spot-sizes can (eventually) approach ~1μm in 1 TeV machine
  - laser waist should be smaller than this for emittance measurement
  - R&D programme on-going at ATF to address this
- 4 Vertical and Horizontal (ie 2-d) LW stations required
  - R&D programme at PETRA to address this
- Other machine errors may dominate emittance measurement
  - beam jitter, residual dispersion, beta-function error, ….
- Intra-train scanning will require ultra-fast laser scanning techniques
- Extraction of signal – best to use photons:

Energy depsoit (GeV/m) from LW Compton-scattered electrons

LW

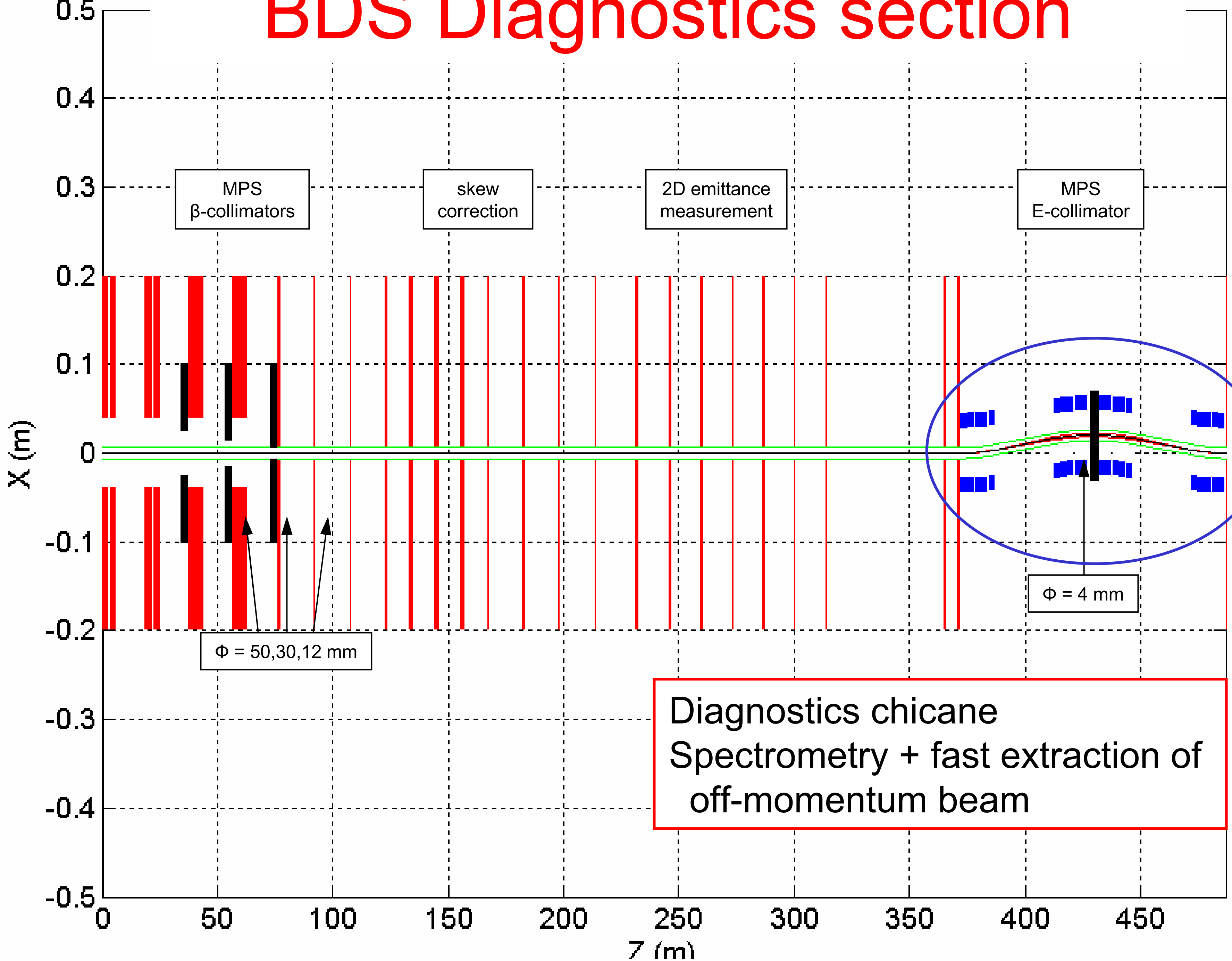


IP

Carter et al

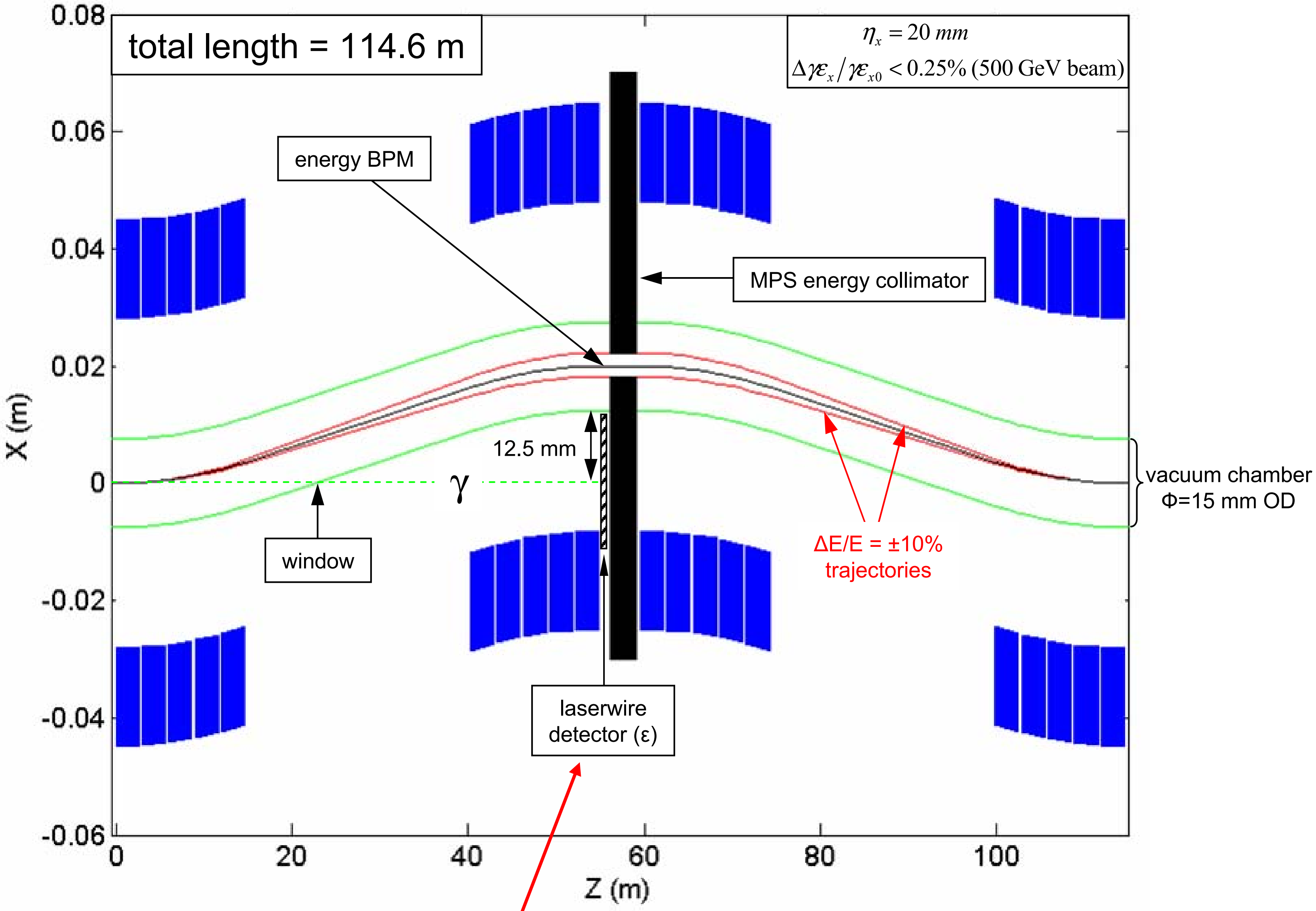
TUPCH048

BDS Diagnostics section



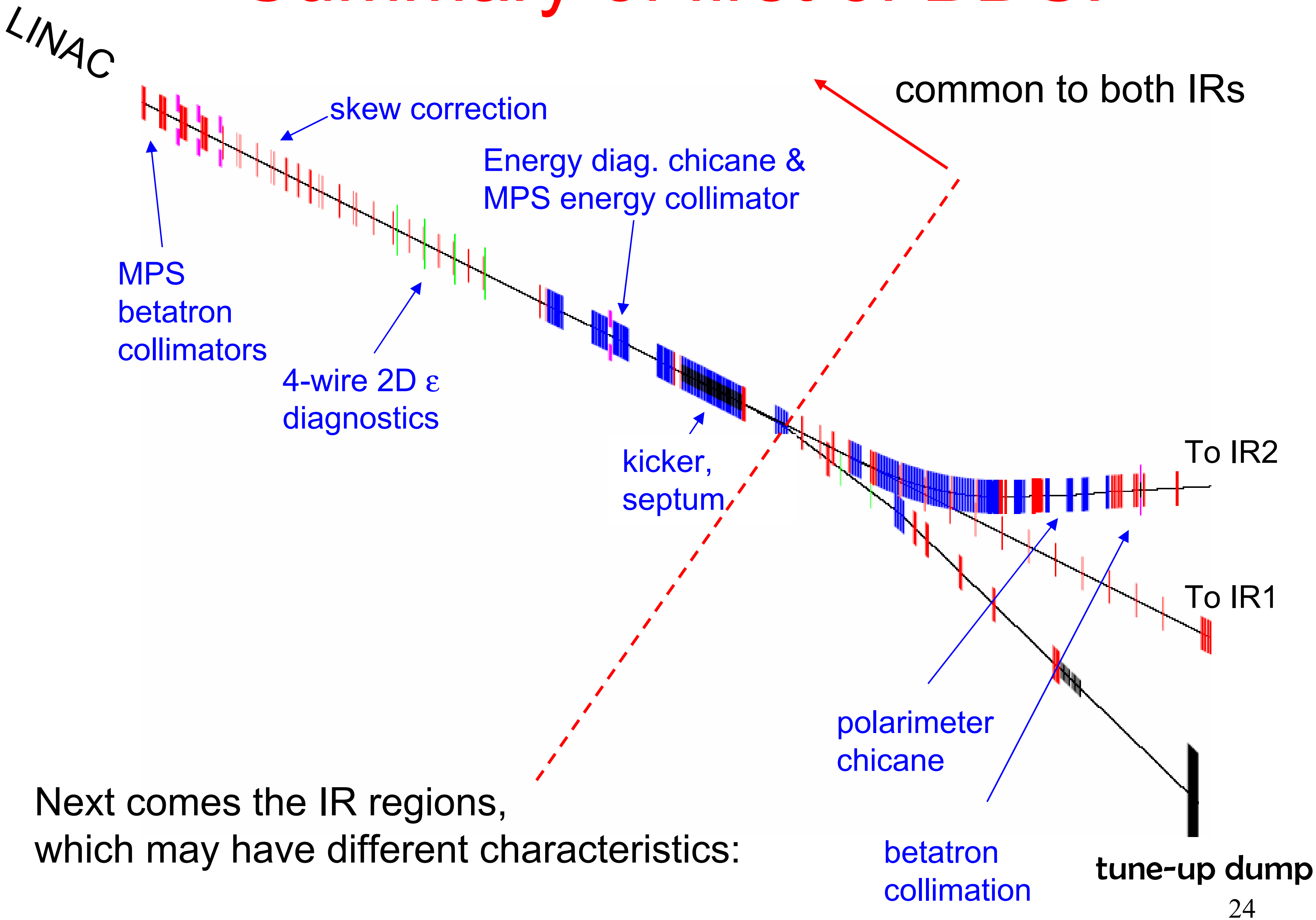
Diagnostics chicane
Spectrometry + fast extraction of off-momentum beam

Diagnostic Chicane



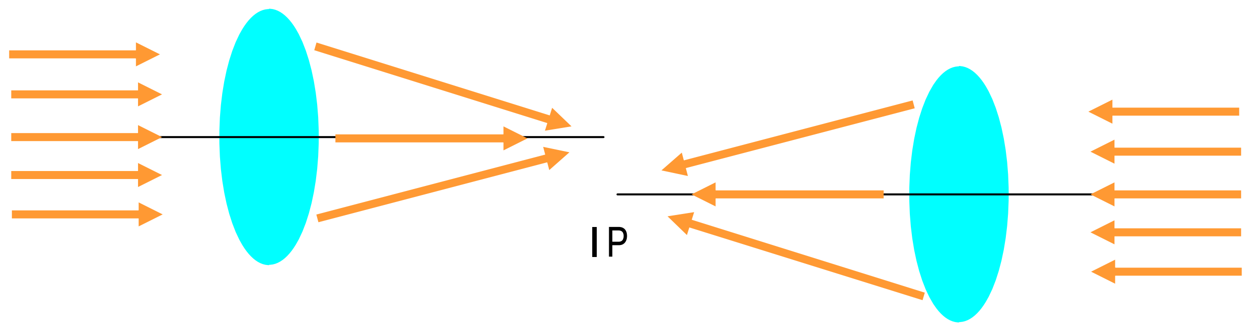
up to ~ 113 TeV of energy per bunch in LW photon detector

Summary of first of BDS:

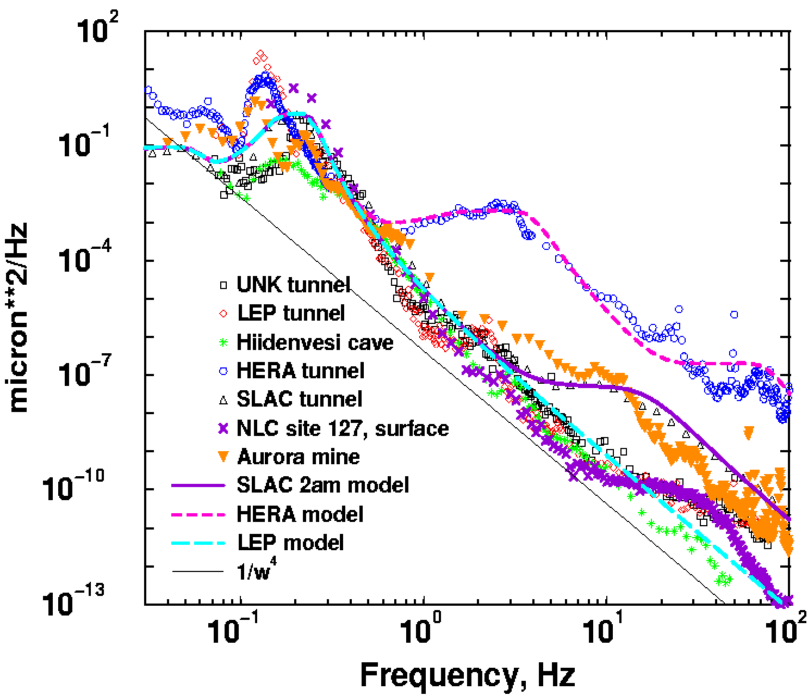


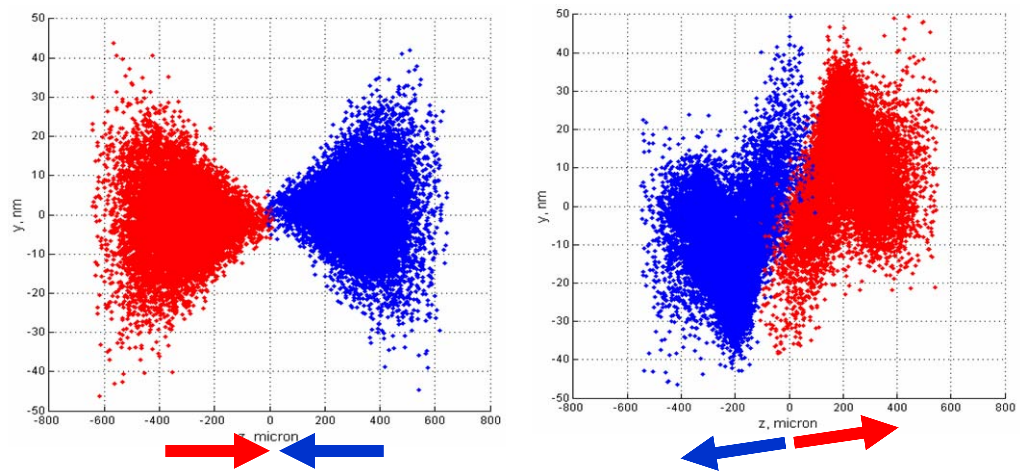
Next comes the IR regions,
which may have different characteristics:

Stability – Tolerance to FD motion



Ground motion

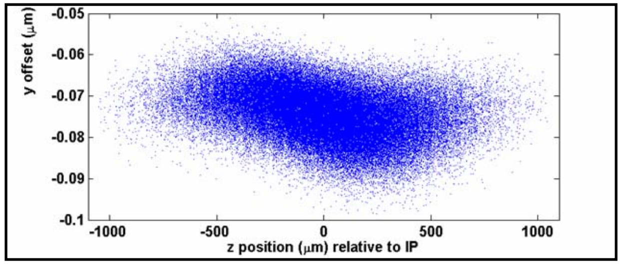


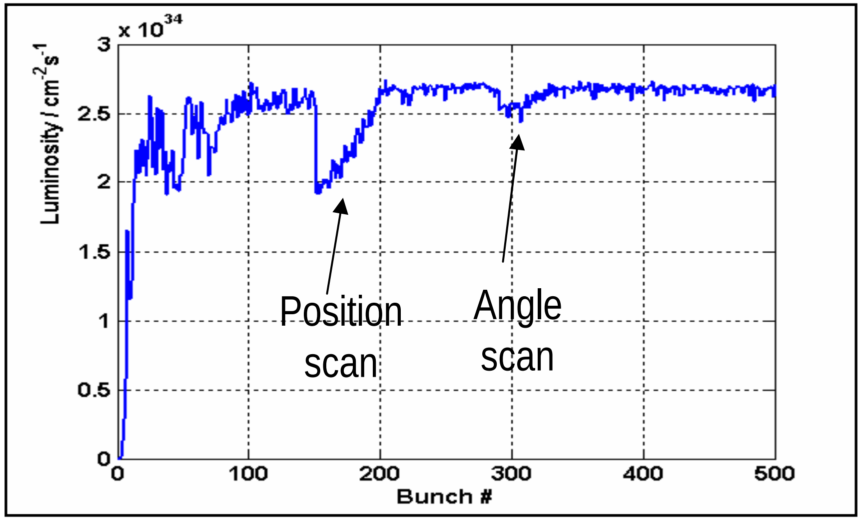


IP offset leads to angular deflection after interaction

ILC intratrain simulation

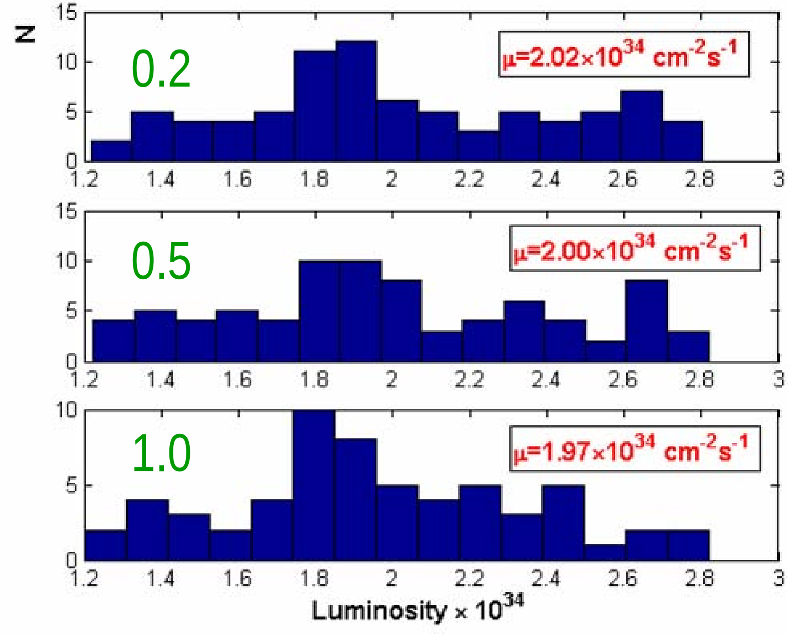
ILC intratrain feedback (IP position and angle optimization), simulated with realistic errors in the linac and "banana" bunches, show Lumi ~2×10^{34} (2/3 of design). Studies continue.





Luminosity through bunch train showing effects of position/angle scans (small). Noisy for first ~100 bunches (HOM's).

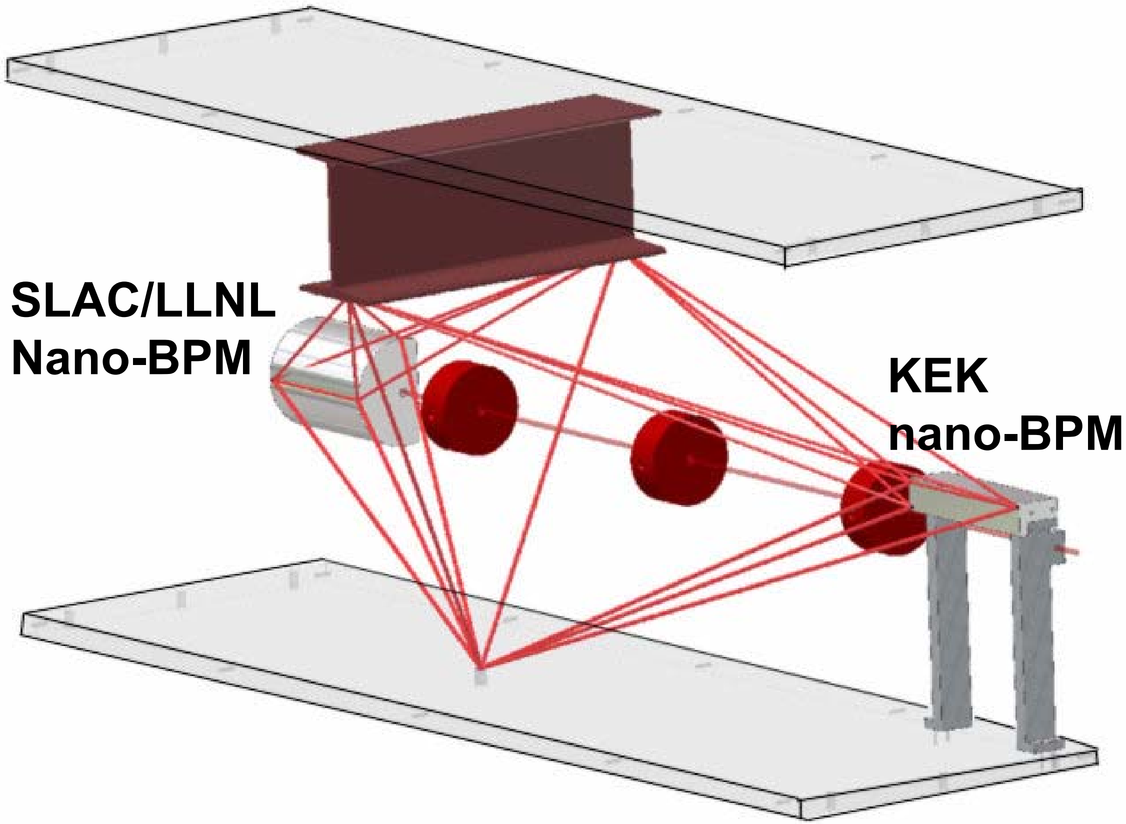
Luminosity for ~100 seeds / run

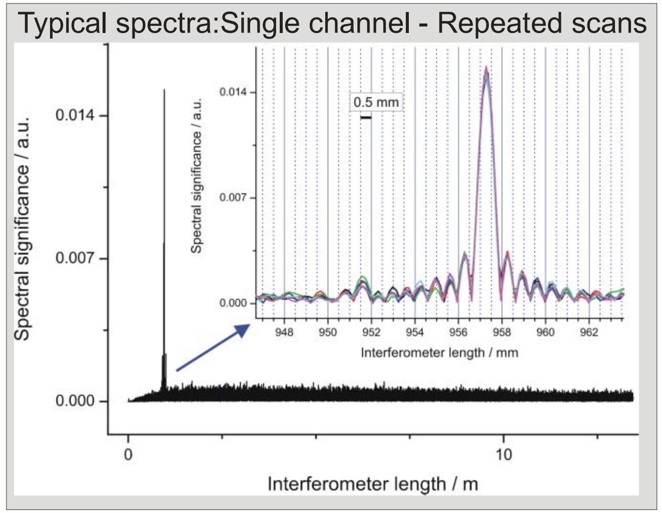


Injection Error (RMS/s_y): 0.2, 0.5, 1.0

MOPLS122,3 Burrows et al.

A Straightness Monitor Made from Distance Meters



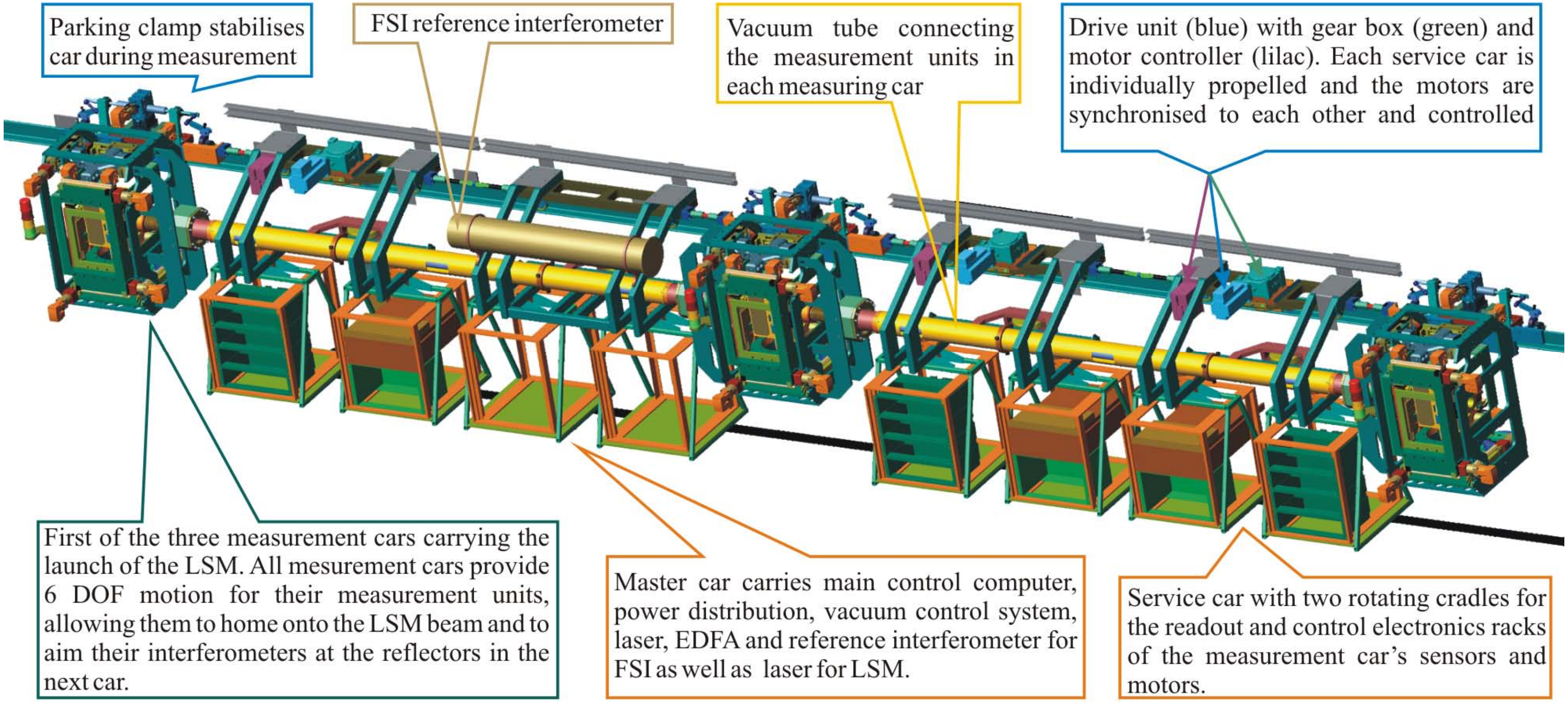


Single line distance meter results from Oxford; few microns precision

- Setup planned at KEK
- Red lines: Distance meter.
- Multilateration measure 6D coord. of A with respect to B.

THPCH090 Urner et al.

IP Stabilisation + BDS alignment

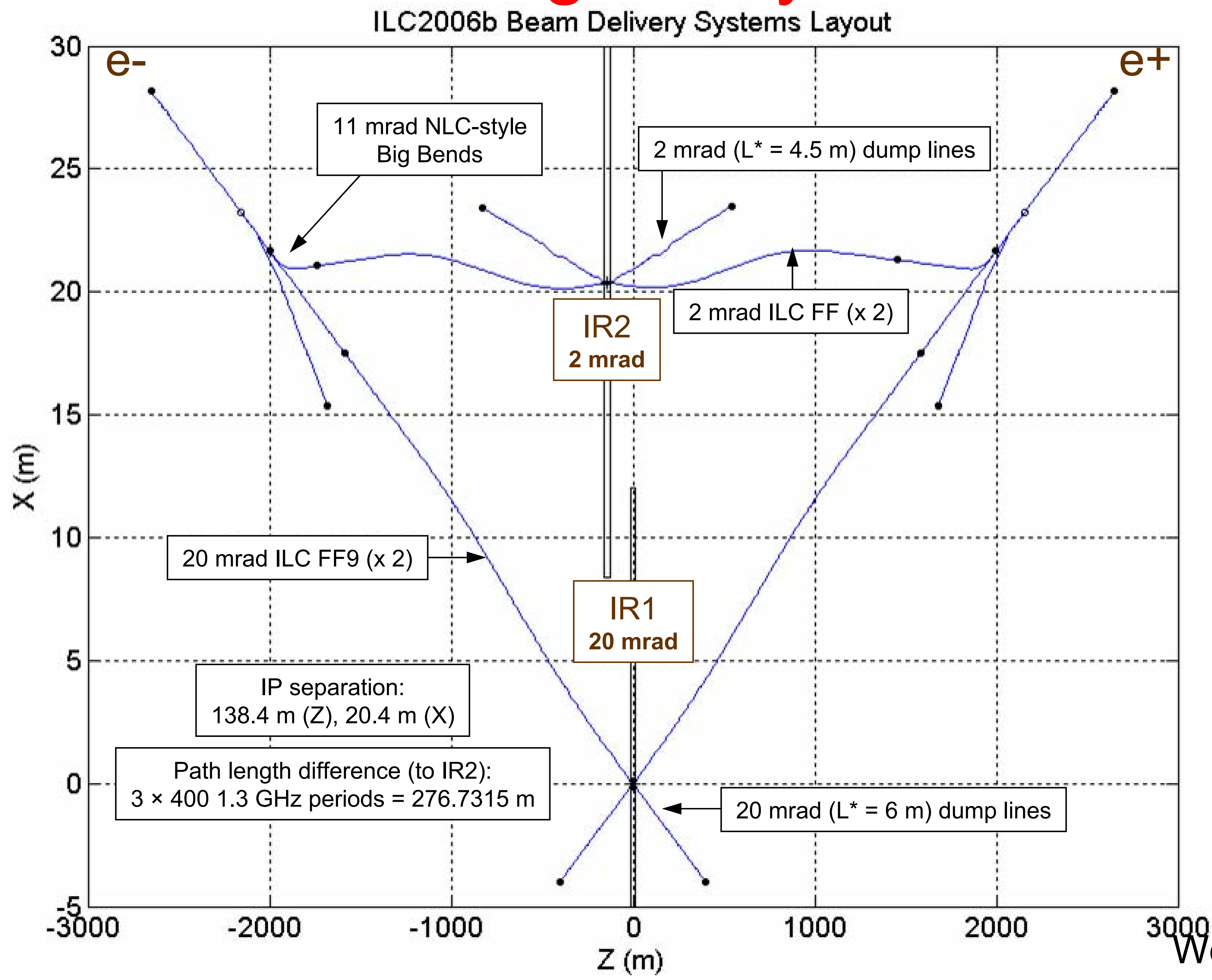


MOPCH195 Reichold et al.

BDS alignment

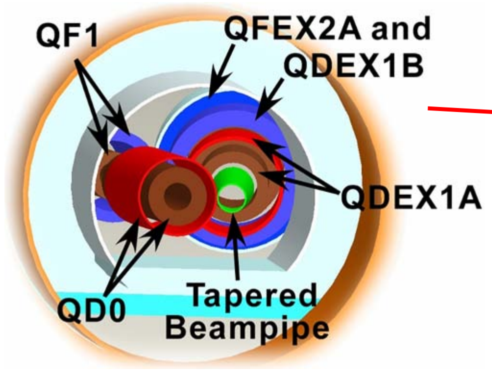
MOPCH195 Reichold et al.

IR Region layout

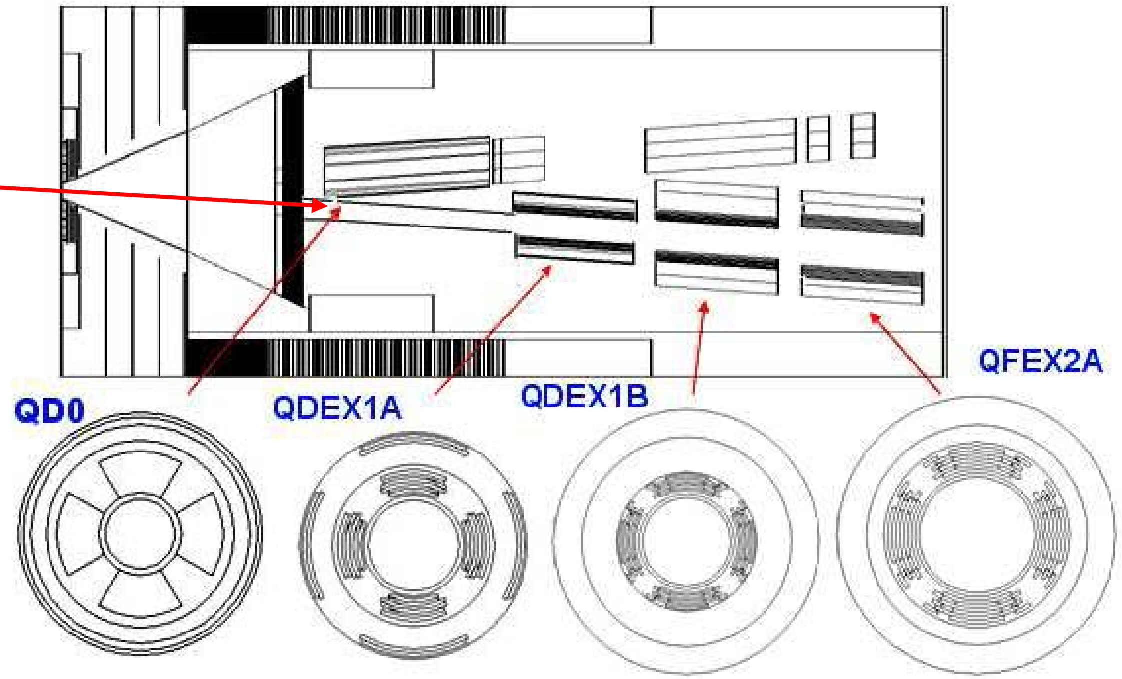


Woodley

‘Large’ crossing angle (14 mrad)

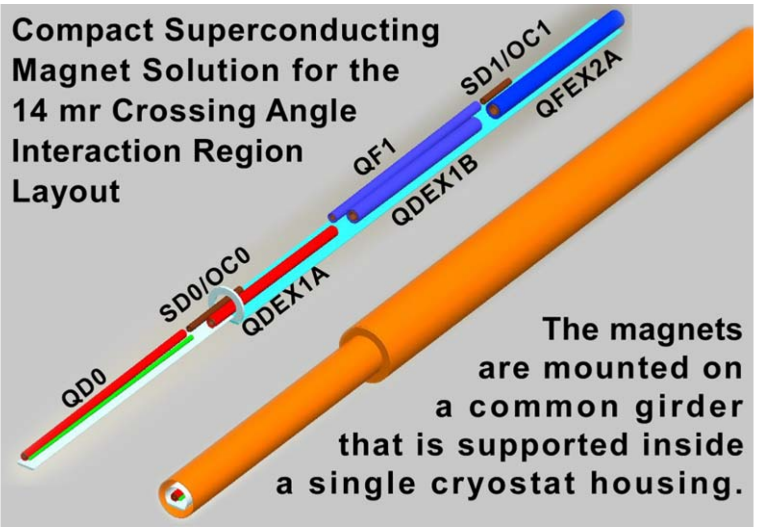


B. Parker et al.

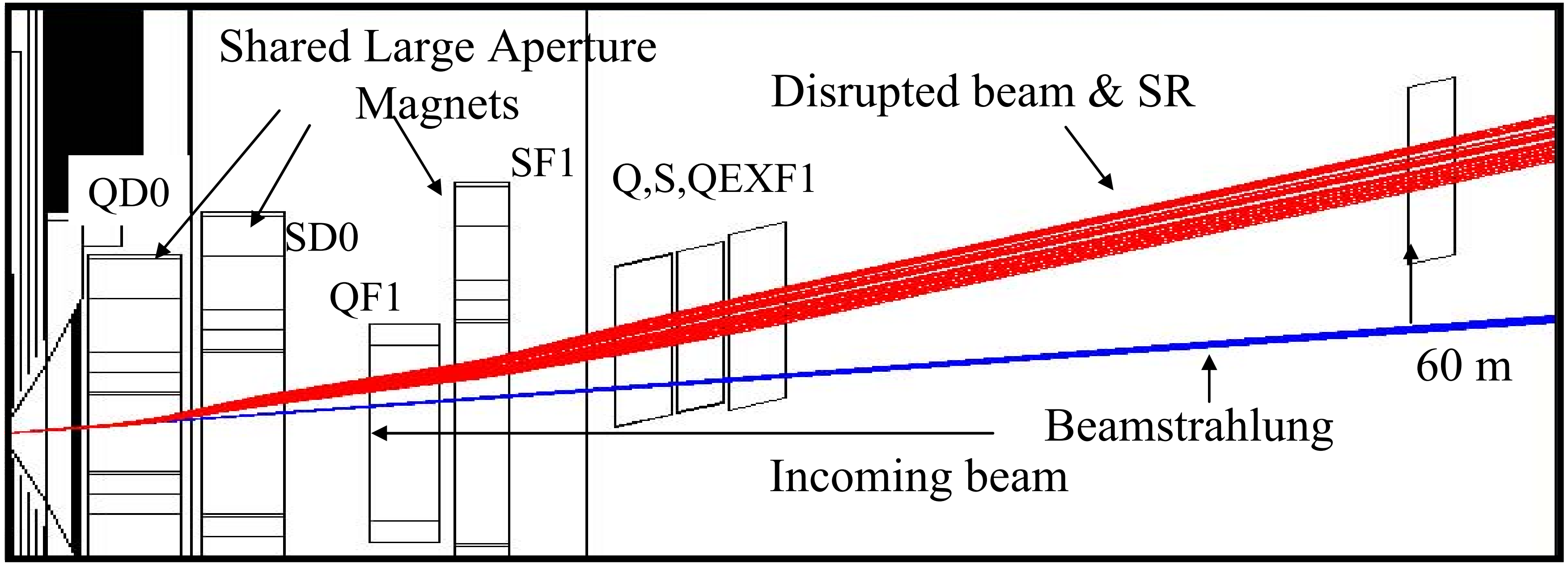


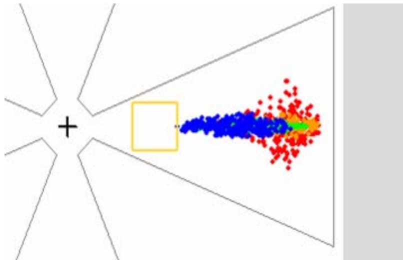
Issues:

- Incoming and outgoing beams separate
- Strong dependence on crab-cavity
- Detector hermeticity at forward angles



'Small' crossing angle (~2 mrad)





Appleby et al.
MOPLS077

Issues:

- Incoming and outoing beams share magnets close to the IP;

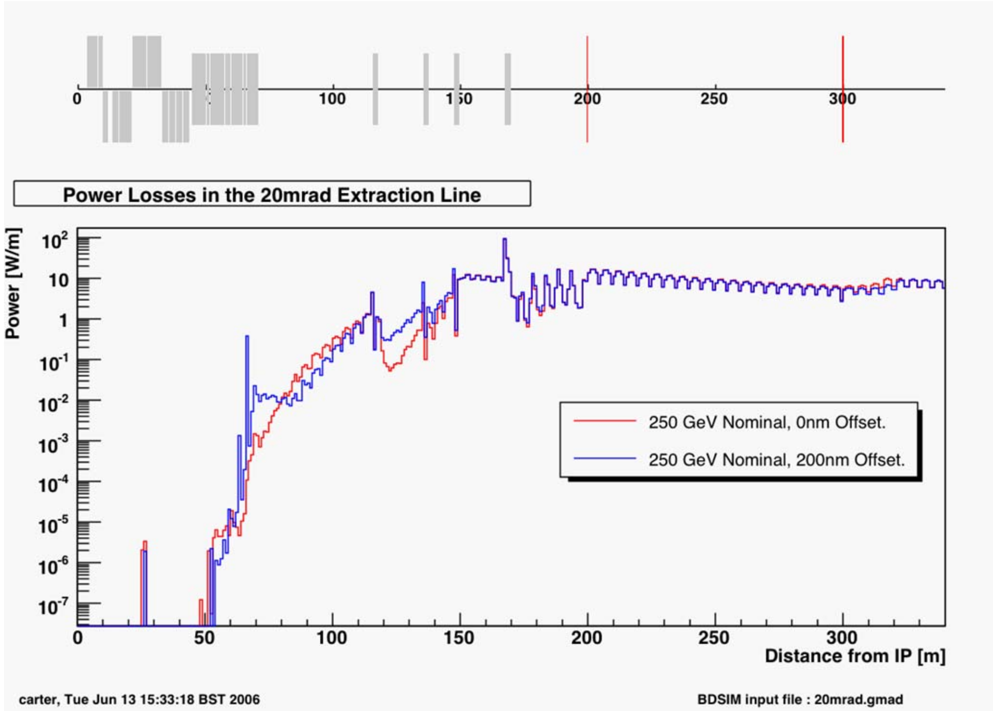
→ less flexibility in design and minimisation of backgrounds

- Less dependence on crab-cavity
- Improved detector hermeticity at forward angles

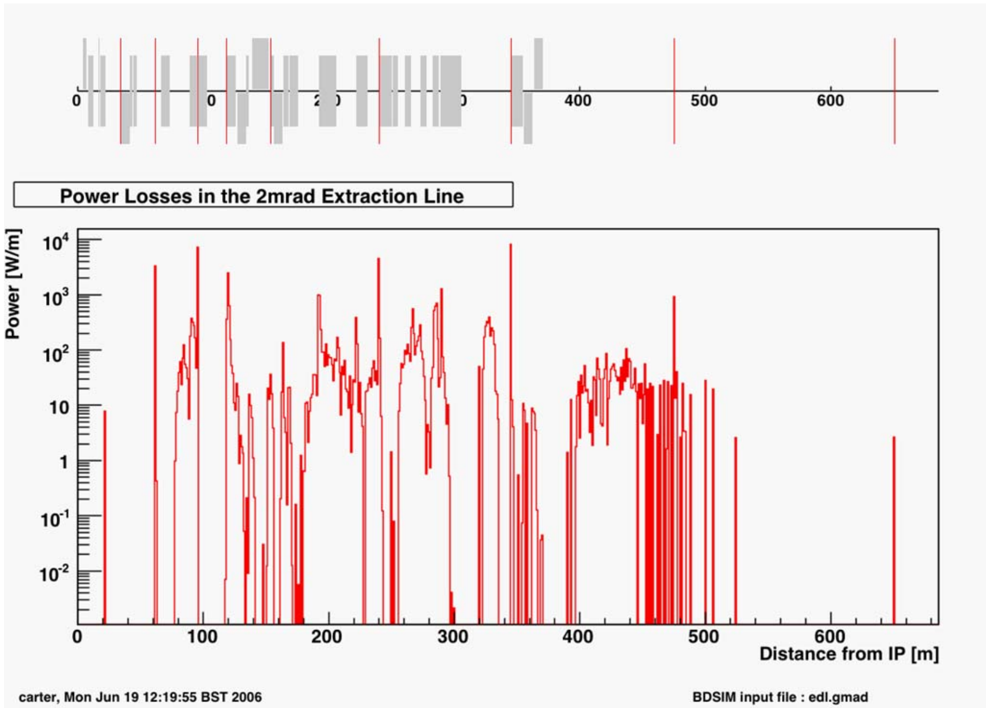
Payet et al.
MOPLS060

A head-on scheme (zero crossing angle) is also currently being studied.

Extraction line Full Simulations



20 mrad

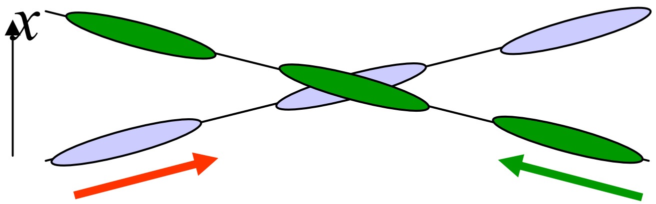


2mrad

Optimisation ongoing

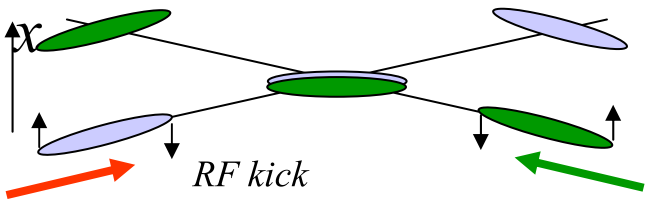
MOPL082 Carter et al.

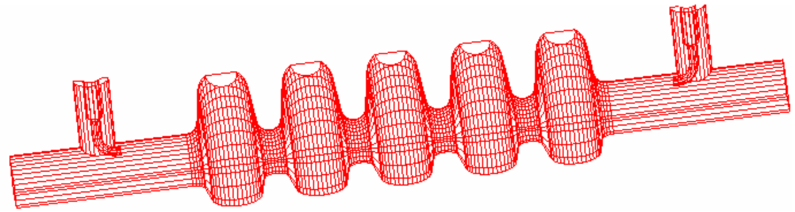
Crab crossing



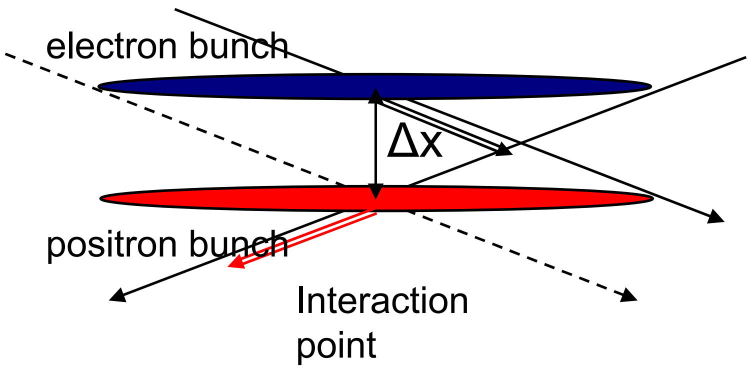
$$\sigma_{x,projected} \approx \sqrt{\sigma_x^2 + \phi_c^2 \sigma_z^2}$$
$$\approx \phi_c \sigma_z$$
$$= 20\mathrm{mr} \times 100\mu\mathrm{m} \approx 2\mu\mathrm{m}$$

→ factor 10 reduction in Lumi





need one or two multi-cell cavities
~15m from IP

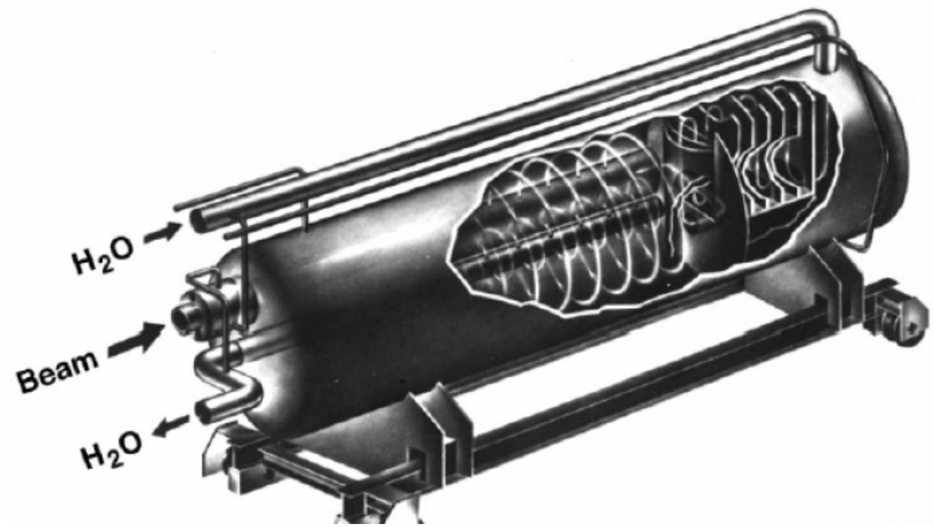


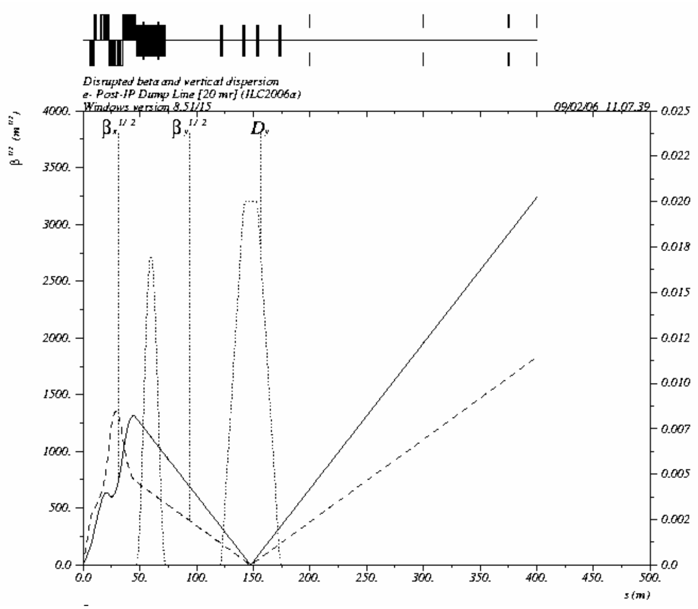
	Phase error (degrees)	
Crossing angle	*1.3GHz*	*3.9GHz*
2mrad	0.222	0.665
10mrad	0.044	0.133
20mrad	0.022	0.066

Burt et al. MOPCH163 MOPLS075

Beam dump for 18MW beam

- Water vortex
- Window, 1mm thin, ~30cm diameter hemisphere
- Raster beam with dipole coils to avoid water boiling
- Deal with H, O, catalytic recombination
- Gas dump also being studied
- 3MW beamstrahlung dumps near IR

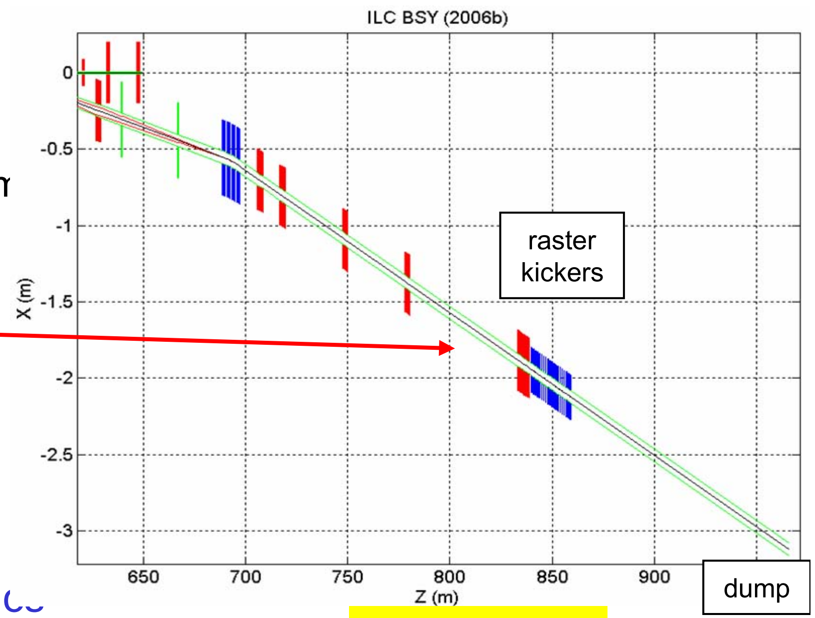




undisrupted or disrupted beam size does not destroy bean dump window without rastering.

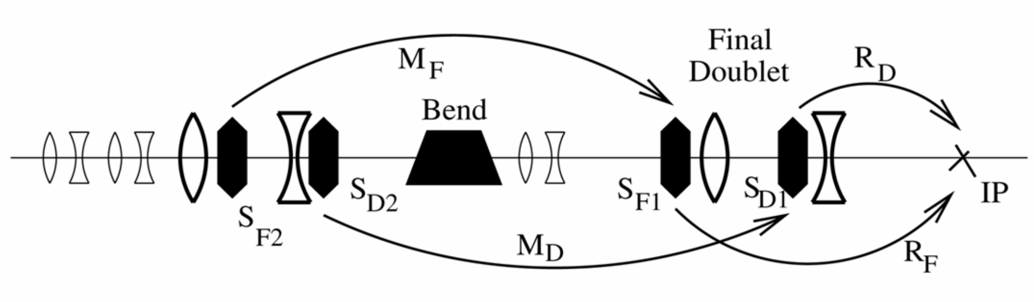
Rastering to avoid boiling of water

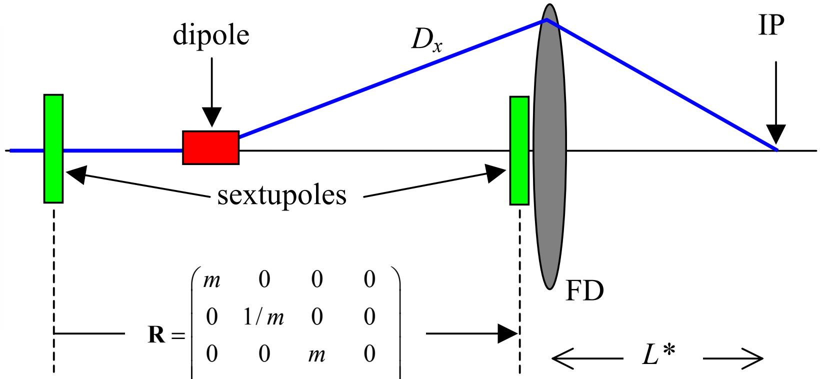
20mr extraction optic



MOPLS079

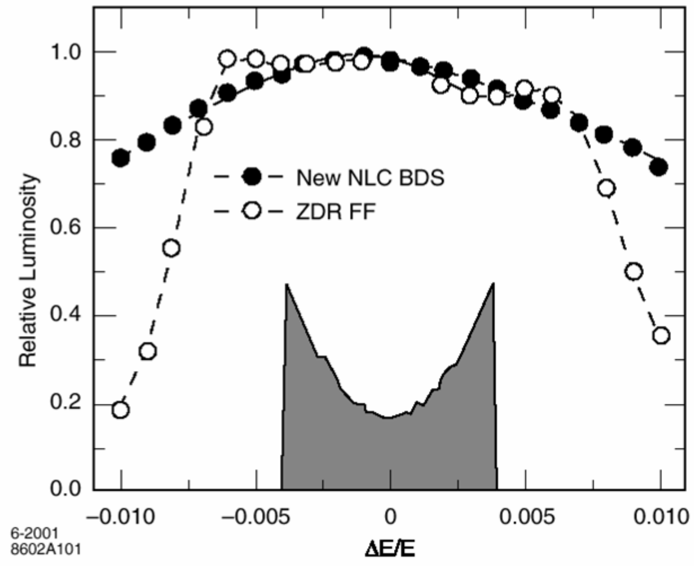
FF with local chromatic correction





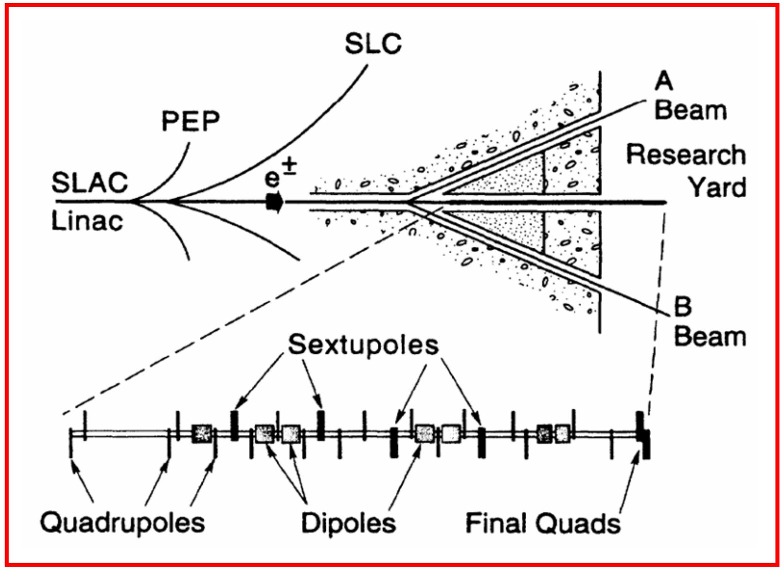
$$\mathbf{R} = \begin{pmatrix} m & 0 & 0 & 0 \\ 0 & 1/m & 0 & 0 \\ 0 & 0 & m & 0 \\ 0 & 0 & 0 & 1/m \end{pmatrix}$$

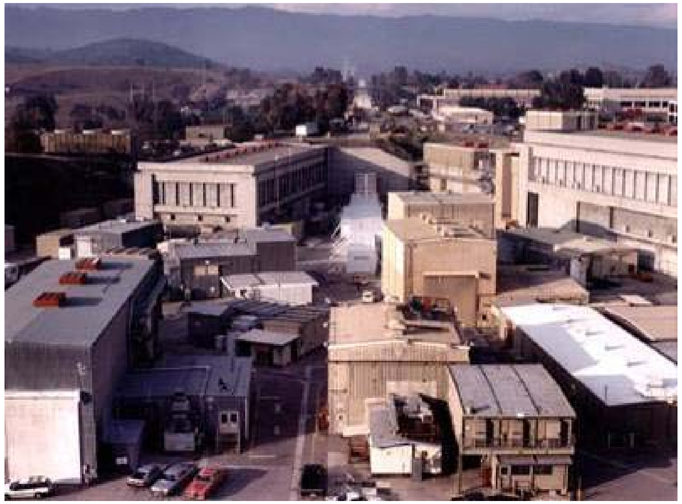
- Chromaticity is cancelled locally by two sextupoles interleaved with FD, a bend upstream generates dispersion across FD
- Geometric aberrations of the FD sextupoles are cancelled by two more sextupoles placed in phase with them and upstream of the bend
- One third the length - many fewer components.
- Can operate with 2.5 TeV beams (for 3 ~ 5 TeV cms)
- 4.3 meter L* (twice 1999 design)
- Improved bandwidth



Raimondi+Seryi Phys.Rev.Lett.86:3779-3782,2001

Final Focus Test Beam





- Started operation at SLAC in 1993
- Aimed at 60 nm spot-sizes
- Eventually achieved:

  1.7µm (σ_x) × 75nm (σ_y),

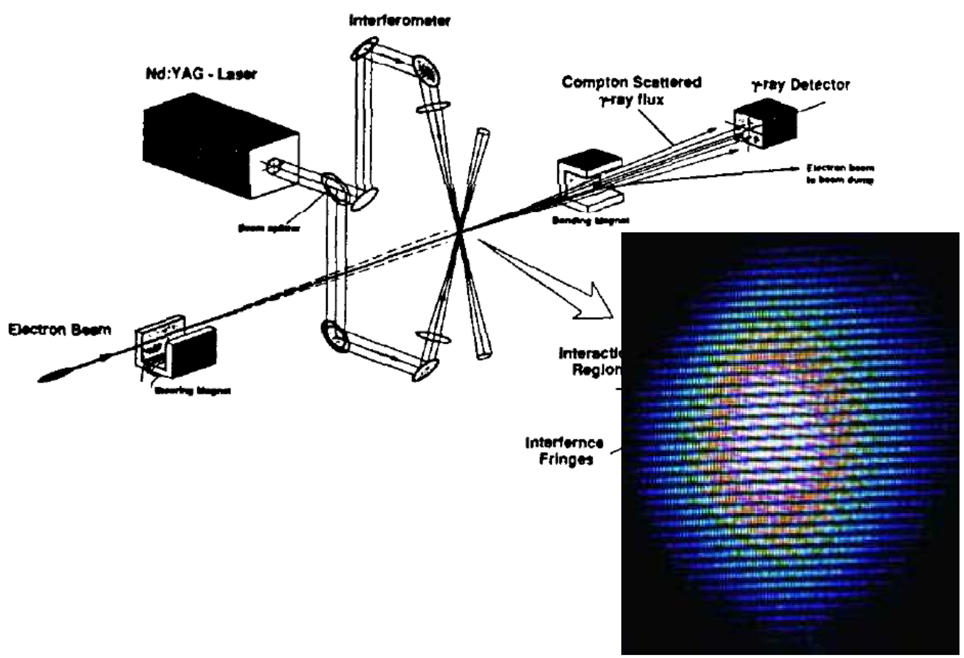
  Ground motion?

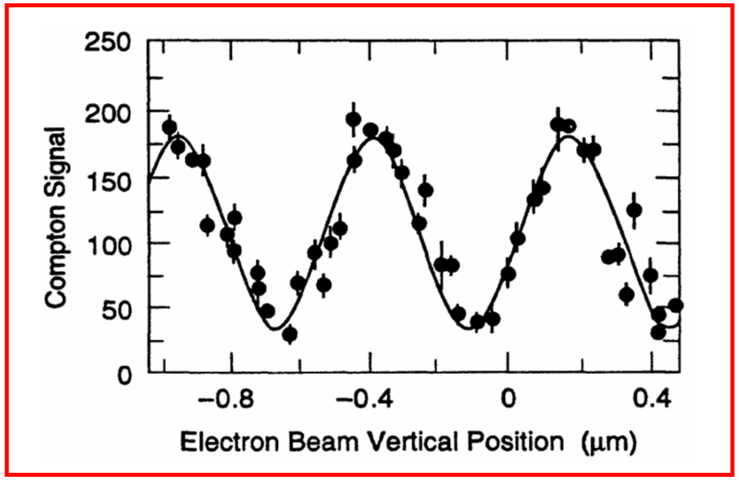
	SLC	FFTB	ILC
E_{beam} (GeV)	45.6	46.6	250
σ_E/E (%)	0.25	0.25	0.1
N_{e-} ($\times 10^{10}$)	4.2	1	2
σ_y (nm)	800	60	5.7
$\gamma\varepsilon_y$ (m-rad)	1×10^{-5}	3×10^{-6}	4×10^{-8}
Asp. ratio x/y	2.5	16	115
σ_z (mm)	~1	~1	0.3

Final Focus Test Beam

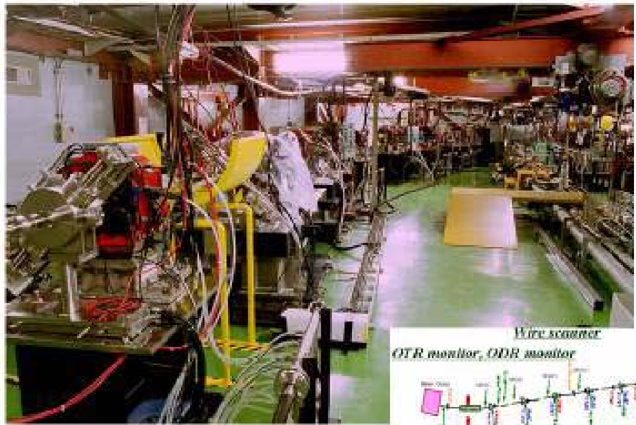
A Prototype ILC Final Focus system:

- Used “conventional” FF chromatic correction.
- Pole-faces of the final quads were fabricated to ±2 μm and the magnet strength stability for critical elements was 10^{-5}.
- A cavity BPM with nm pulse-to-pulse resolution at the IP.
- “Shintake-monitor” (now being upgraded for ATF2)



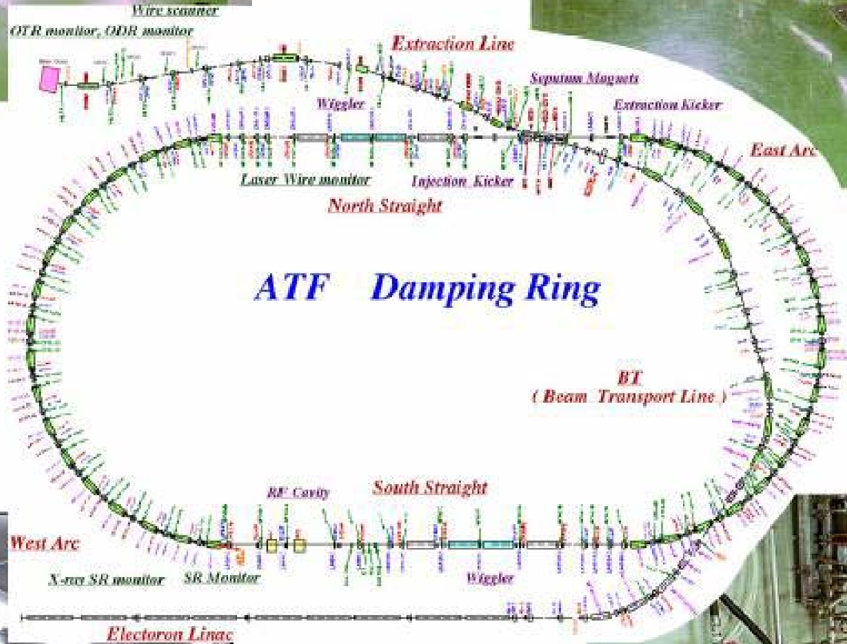


ATF/ATF2

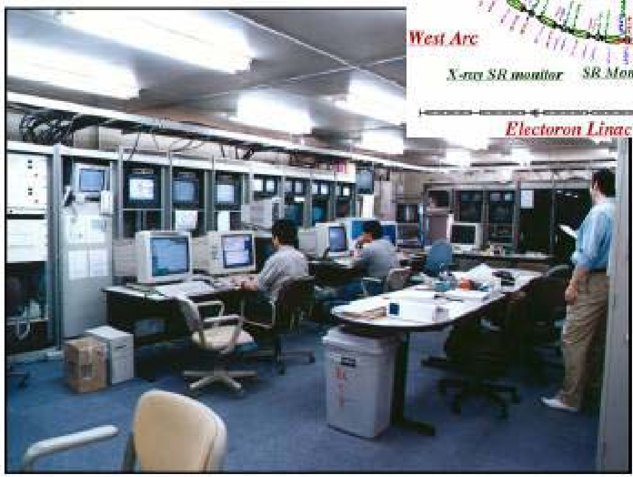


Extraction Line

Damping Ring



Control Room



Linac

Present Research Programmes at ATF

1. Pol. Positron generation R&D at EXT (ended June 2005)
2. Laser wire R&D in Damping Ring (Kyoto University)
3. High quality electron beam generation by photo-cathode RF Gun (Waseda University)
4. X-SR Monitor R&D (University of Tokyo)
5. ODR R&D (Tomusk University)
6. Beam Based Alignment R&D
7. Nano-BPM project of SLAC, LLNL and LBNL
8. Nano-BPM project of KEK
9. FONT project (UK Institutes)
10. Laser Wire project at EXT (UK Institutes)
11. Fast Kicker Development project (DESY, SLAC, LLNL)
12. Fast Ion Instability Research
13. Multi-bunch Instability Study

ATF2: The next step on the nm trail:

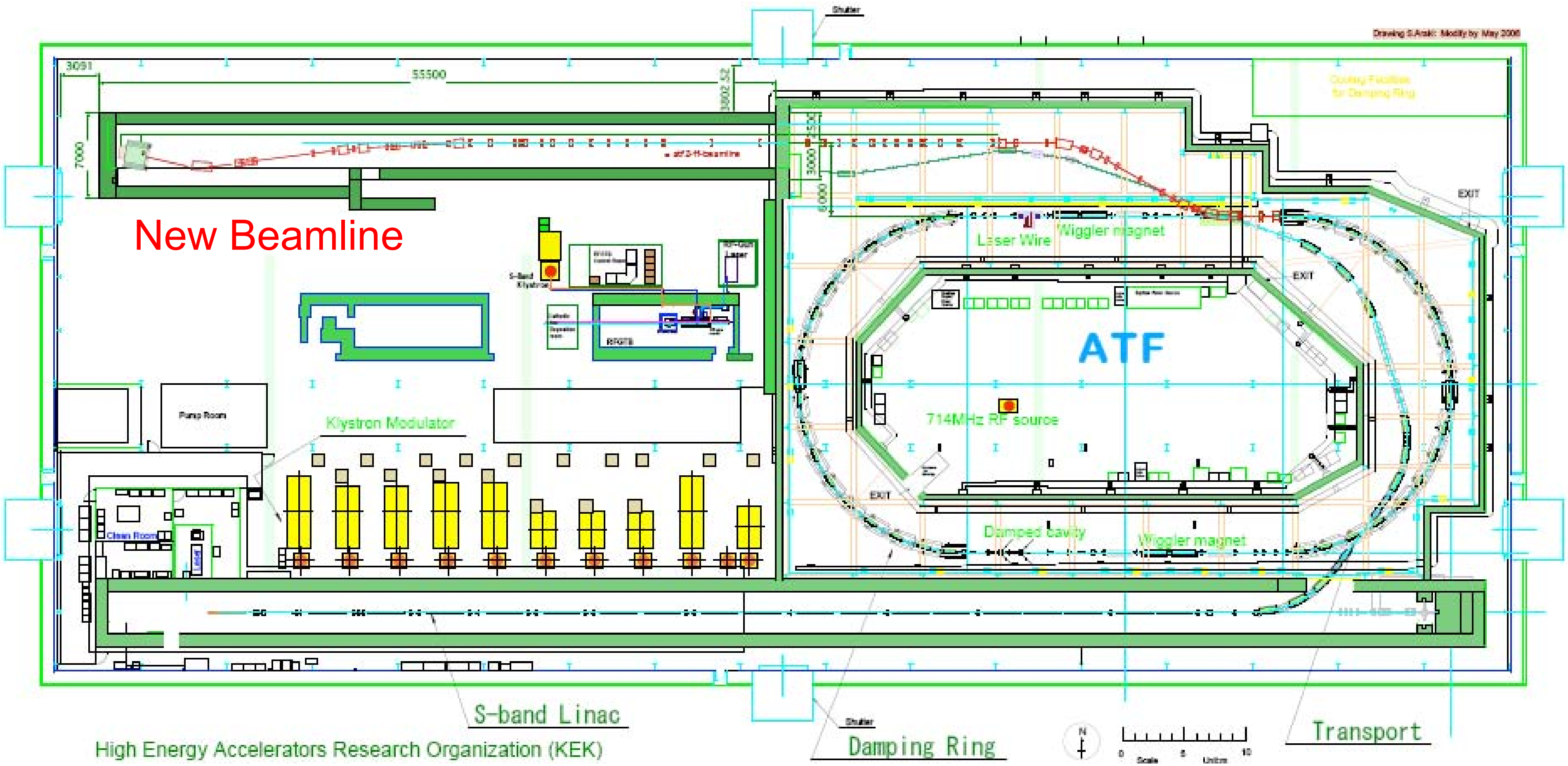
	SLC	FFTB	ATF2	ILC
E_{beam} (GeV)	45.6	46.6	1.3	250
σ_E/E (%)	0.25	0.25	0.1	0.1
N_{e-} ($\times 10^{10}$)	4.2	1	1-2	2
σ_y (nm)	800	60	37	5.7
$\gamma\varepsilon_y$ (m-rad)	1×10^{-5}	3×10^{-6}	3×10^{-8}	4×10^{-8}
Asp. ratio x/y	2.5	16	13	115
σ_z (mm)	~1	~1	~5	0.3

- Use new FF optics – verification of system
- Extract ILC-like train from DR using fast kickers
- Commission ILC-like diagnostics + feedback
- Train next generation of accelerator physicists + engineers

ATF2

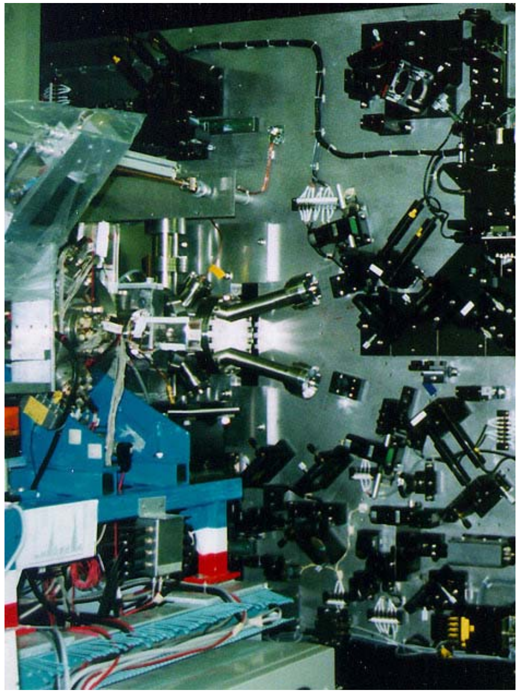
(A) Small beam size
- Obtain $\sigma_y \sim 35$nm
- Maintain for long time

(B) Stabilization of beam center
- Down to < 2nm by nano-BPM
- Bunch-to-bunch feedback of ILC-like train

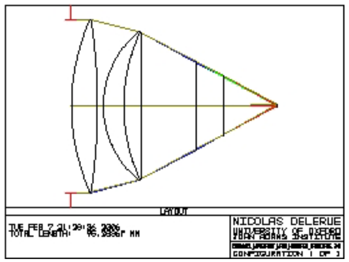


Advanced beam instrumentation at ATF2

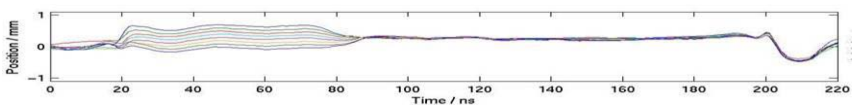
- BSM to confirm 35nm beam size
- nano-BPM at IP to see the nm stability
- Laser-wire to tune the beam
- Cavity BPMs to measure the orbit
- Movers, active stabilization, alignment system
- Intratrain feedback, kickers to produce ILC-like train



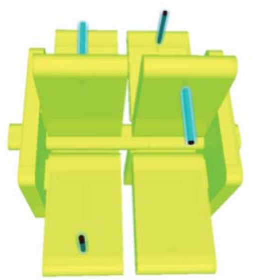
IP Beam-size monitor (BSM) (Tokyo U./KEK, SLAC, UK)



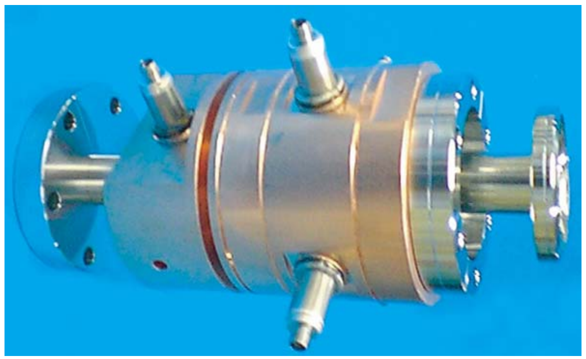
Laser-wire beam-size Monitor (UK group), low-f optics



FONT – UK group



Cavity BPMs with 2nm resolution, for use at the IP (KEK)



Cavity BPMs, for use with Q magnets with 100nm resolution (PAL, SLAC, KEK)

Higher Energy Issues

ILC BDS has been optimised for 0.5 -1 TeV CMS.

If need to extend to multi-TeV :

- a crossing angle of about 20 mrad is required
- any horizontal bend between the high energy end of the linac and the BDS should be less than 2 mrad.
- There should be zero vertical bend.
- The final stages of the linac should be laser-straight; this will enable extension of the BDS into the linac tunnel, in case it proves necessary.

Many thanks to:

- The ILC BDS team; especially
  A. Seryi, D. Angal-Kalinin, M. Woodley for input.
- PPARC/CCLRC LC-ABD collaboration.
- All collaborators at the ATF, ESA, …
- Everyone whose results I have used

Further background:

- ILC Baseline Conceptual Design:
  http://www.linearcollider.org/wiki/
- A. Seryi lecture at ILC summer school 2006.

SUMMARY

- ILC BDS is in good shape, with feasible designs for several crossing angles.
- Strong international R&D in many of the key issues for beam diagnostics, feedback, and control.
- We look forward to a vigorous collaboration at ATF2 to achieve 37nm spot-sizes for extended periods.
- Full simulations are now maturing and will give major input to the ILC TDR phase.
- Still lots to do…