Beam Delivery System
Baseline Description and R&D in the Technical Design Phase

Karsten Buesser

13.12.2012

PAC Review

Beam Delivery System

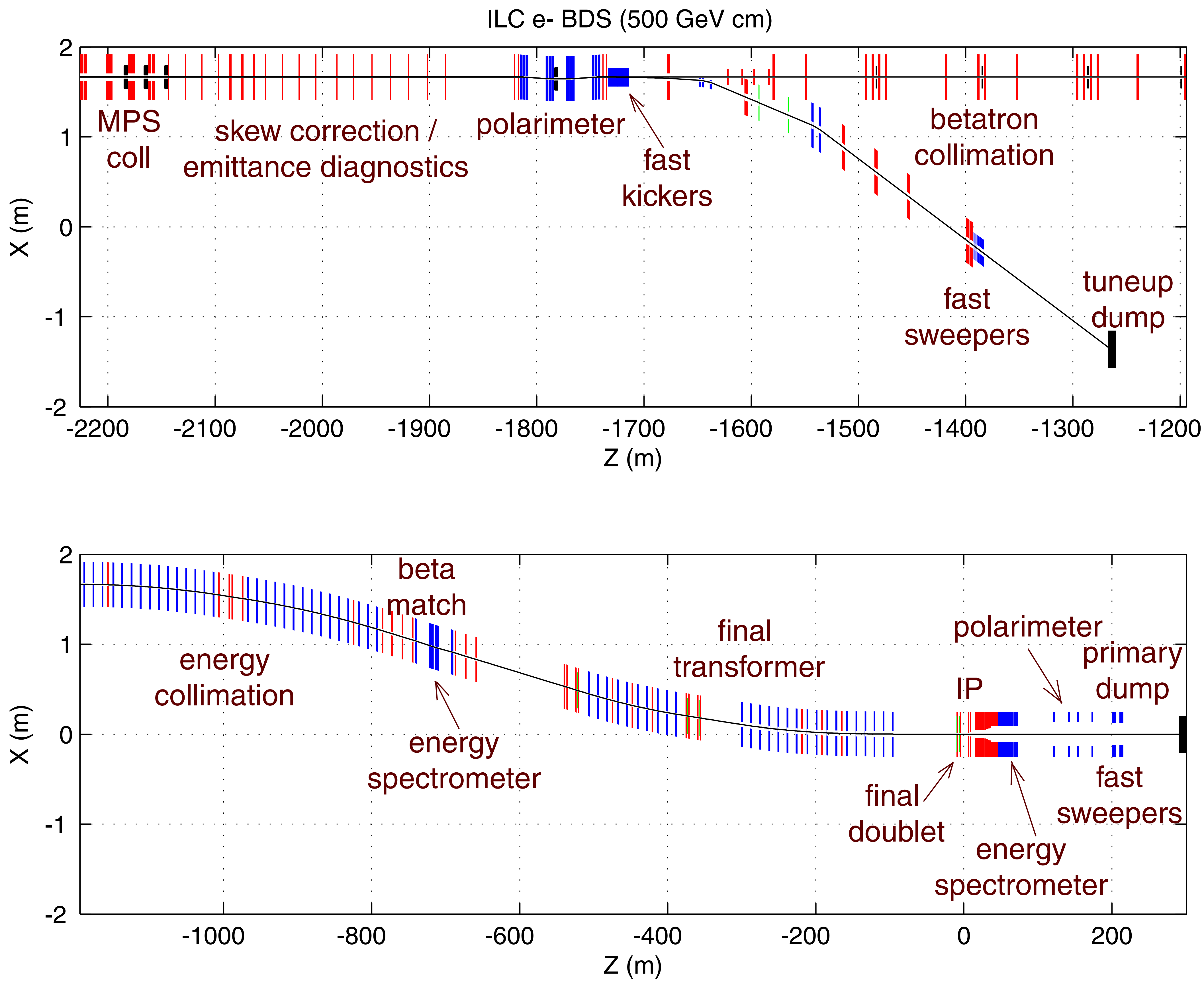
- Main tasks:
  - measure linac beam and match it to the final focus
  - protect beamline and detector against mis-steered beams from the main linacs
  - remove beam halo to minimise detector backgrounds
  - measure and monitor key beam parameters (energy, polarisation) before and after the collisions
  - extract and dump the spent beams
- $E_{cm,max}$= 500 GeV, upgradable to 1 TeV (with more magnets)

Parameter	Value	Unit
Length (start to IP distance) per side	2254	m
Length of main (tune-up) extraction line	300 (467)	m
Max. Energy/beam (with more magnets)	250 (500)	GeV
Distance from IP to first quad, L^*, for SiD / ILD	3.51 / 4.5	m
Crossing angle at the IP	14	mrad
Normalized emittance $\gamma\epsilon_x$ / $\gamma\epsilon_y$	10 000 / 35	nm
Nominal bunch length, σ_z	300	µm
Preferred entrance train to train jitter	<0.2–0.5	σ_y
Preferred entrance bunch to bunch jitter	< 0.1	σ_y
Typical nominal collimation aperture, x/y	6-10 / 30-60	beam sigma
Vacuum pressure level, near/far from IP	0.1 / 5	µPa

Beam Parameters

Parameter		Center-of-mass energy, E_{cm} (GeV) Baseline 200	250	350	500	Upgrades 500	1000 (A1)	1000 (B1b)	Unit
Nominal bunch population	N	2.0	2.0	2.0	2.0	2.0	1.74	1.74	$\times 10^{10}$
Pulse frequency	f_{rep}	5	5	5	5	5	4	4	Hz
Bunches per pulse	N_{bunch}	1312	1312	1312	1312	2625	2450	2450	
Nominal horizontal beam size at IP	σ^*_x	904	729	684	474	474	481	335	nm
Nominal vertical beam size at IP	σ^*_y	7.8	7.7	5.9	5.9	5.9	2.8	2.7	nm
Nominal bunch length at IP	σ^*_z	0.3	0.3	0.3	0.3	0.3	0.250	0.225	mm
Energy spread at IP, e^-	$\delta E/E$	0.206	0.190	0.158	0.124	0.124	0.083	0.085	%
Energy spread at IP, e^-	$\delta E/E$	0.190	0.152	0.100	0.070	0.070	0.043	0.047	%
Horizontal beam divergence at IP	θ^*_x	57	56	43	43	43	21	30	µrad
Vertical beam divergence at IP	θ^*_y	23	19	17	12	12	11	12	µrad
Horizontal beta-function at IP	β^*_x	16	13	16	11	11	22.6	11	mm
Vertical beta-function at IP	β^*_y	0.34	0.41	0.34	0.48	0.48	0.25	0.23	mm
Horizontal disruption parameter	D_x	0.2	0.3	0.2	0.3	0.3	0.1	0.2	
Vertical disruption parameter	D_y	24.3	24.5	24.3	24.6	24.6	18.7	25.1	
Energy of single pulse	E_{pulse}	420	526	736	1051	2103	3409	3409	kJ
Average beam power per beam	P_{ave}	2.1	2.6	3.7	5.3	10.5	13.6	13.6	MW
Geometric luminosity	L_{geom}	0.30	0.37	0.52	0.75	1.50	1.77	2.64	$\times 10^{34} cm^{-2} s^{-1}$
– with enhancement factor		0.50	0.68	0.88	1.47	2.94	2.71	4.32	$\times 10^{34} cm^{-2} s^{-1}$
Beamstrahlung parameter (av.)	Υ_{ave}	0.013	0.020	0.030	0.062	0.062	0.127	0.203	
Beamstrahlung parameter (max.)	Υ_{max}	0.031	0.048	0.072	0.146	0.146	0.305	0.483	
Simulated luminosity (incl. waist shift)	L	0.56	0.75	1.0	1.8	3.6	3.6	4.9	$\times 10^{34} cm^{-2} s^{-1}$
Luminosity fraction within 1 %	$L_{1\%}/L$	91	87	77	58	58	59	45	%
Energy loss from BS	δE_{BS}	0.65	0.97	1.9	4.5	4.5	5.6	10.5	%
e^+e^- pairs per bunch crossing	n_{pairs}	45	62	94	139	139	201	383	$\times 10^3$
Pair energy per B.C.	E_{pairs}	25	47	115	344	344	1338	3441	TeV

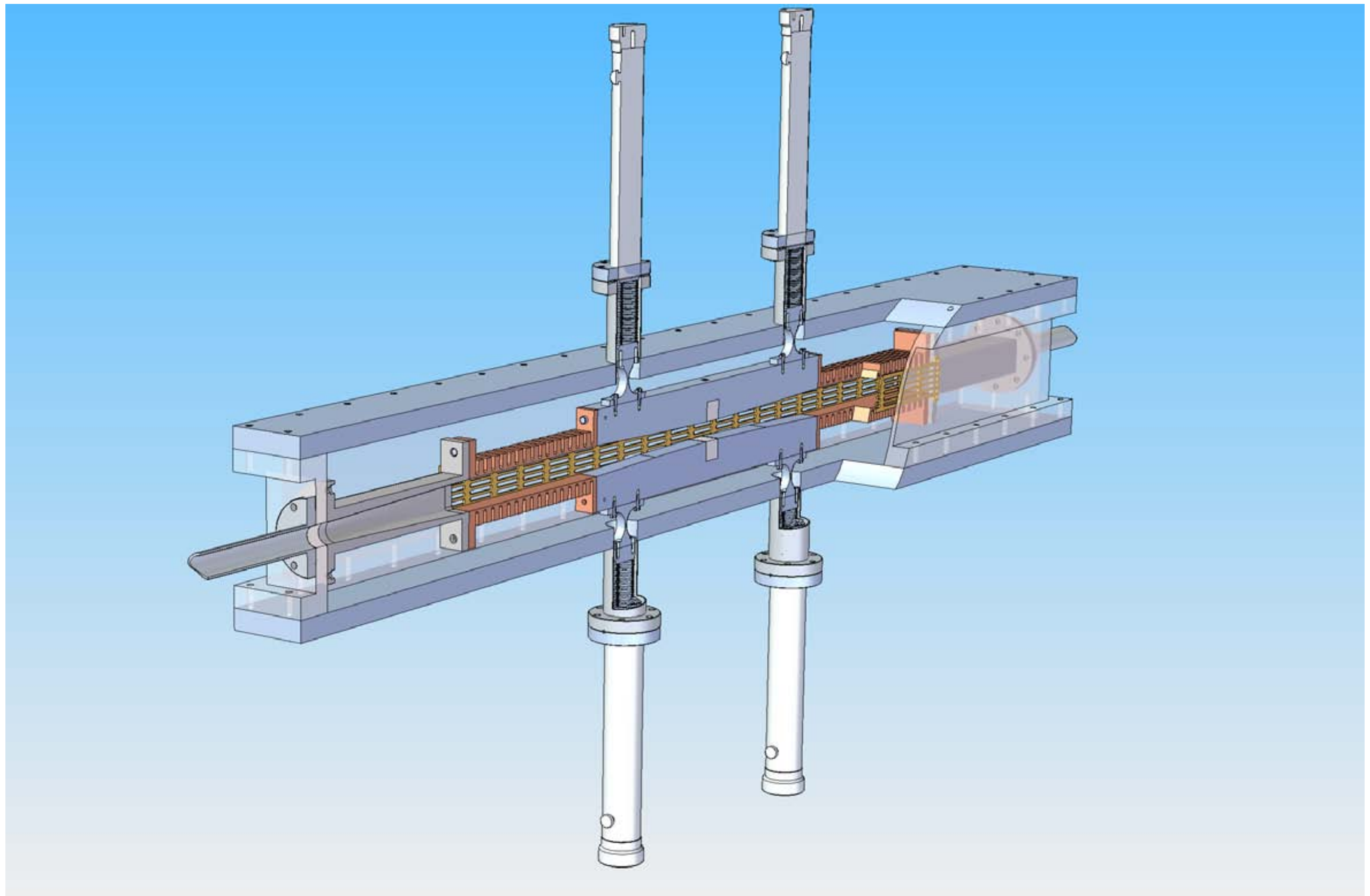
BDS Layout



ILC e- BDS (500 GeV cm)
MPS
coll
skew correction /
emittance diagnostics
polarimeter
fast
kickers
betatron
collimation
fast
sweepers
tuneup
dump
X (m)
Z (m)
2
1
0
-1
-2
-2200
-2100
-2000
-1900
-1800
-1700
-1600
-1500
-1400
-1300
-1200
beta
match
energy
collimation
energy
spectrometer
final
transformer
polarimeter
primary
dump
IP
final
doublet
energy
spectrometer
fast
sweepers
X (m)
Z (m)
-1000
-800
-600
-400
-200
0
200

Collimation System

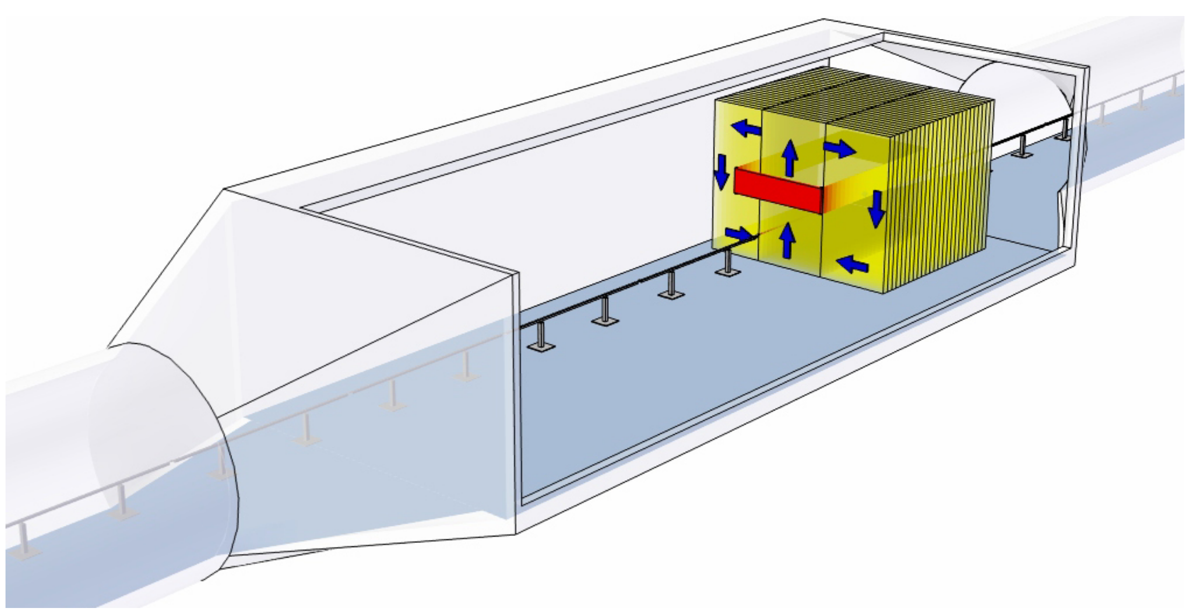
- Collimation system removes beam-halo particles to reduce detector backgrounds
  - halo electrons/positrons
  - synchrotron radiation in final doublet
- BDS contains
  - 32 variable aperture collimators
  - 32 fixed aperture collimators
- Smallest apertures are 12 adjustable spoilers in collimation system
  - 0.6-1.0 X_0 Ti spoilers with longitudinal Be tapers
  - absorbers: 45-60 X_0

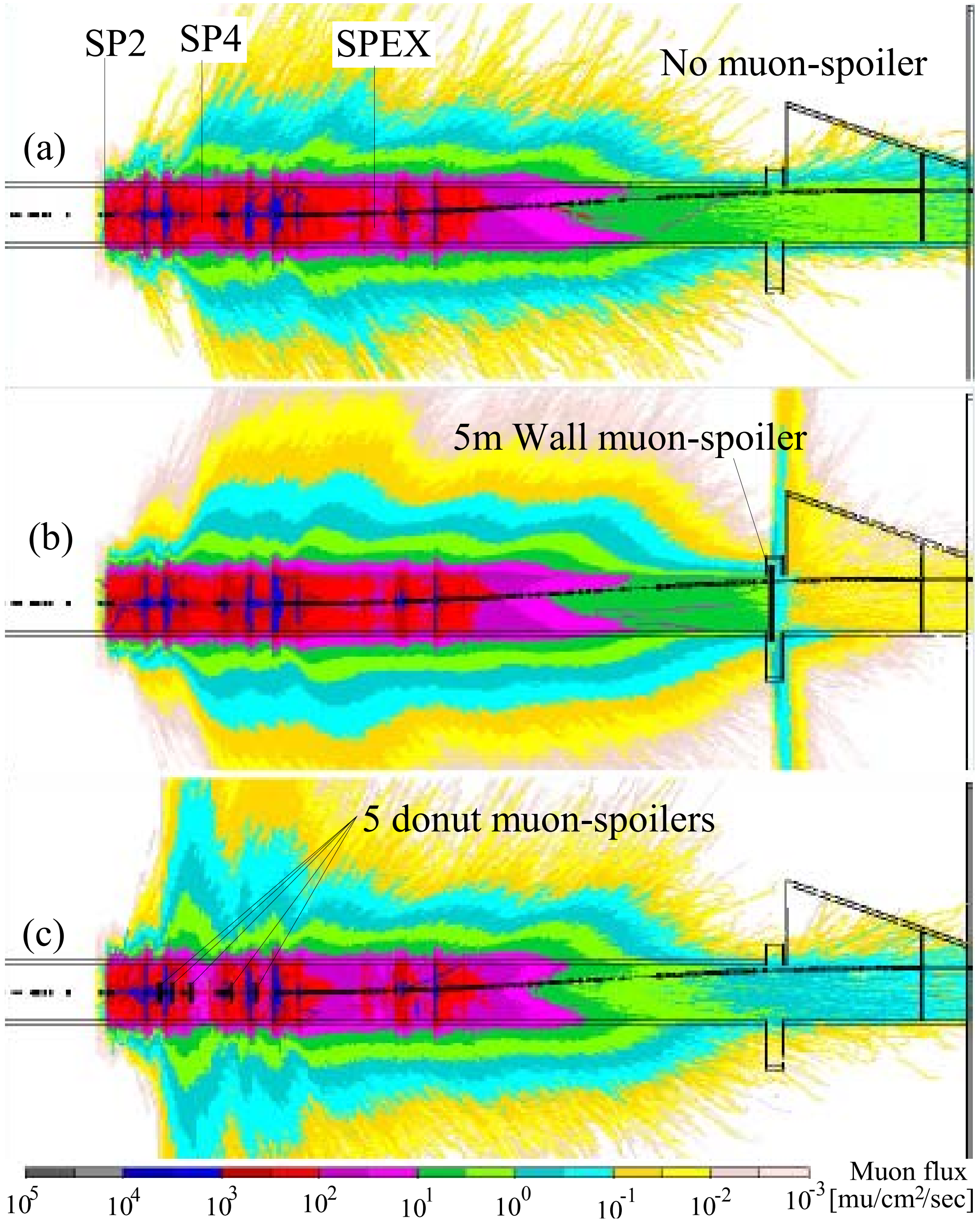


- Collimators are survivable
  - two/one full errant bunches (250/500 GeV/beam)
- Collimation depths:
  - ~6-9 σ_x, 40-60 σ_y

Muon Background Suppression

- Muons from collimation system can reach the experimental hall:
  - background source for the detector
  - radiation protection issue
- Magnetised iron walls („tunnel fillers“) deflect muons deflect muons away from experimental hall
  - At collimated halo fraction of 1-2 x 10^{-5}, only few muons per 150 bunches reach detector hall
- Muon shield upgradable to 19 m length, plus 9 m shield downstream
  - muon suppression capacity: 1 x 10^{-3} collimated beam fraction

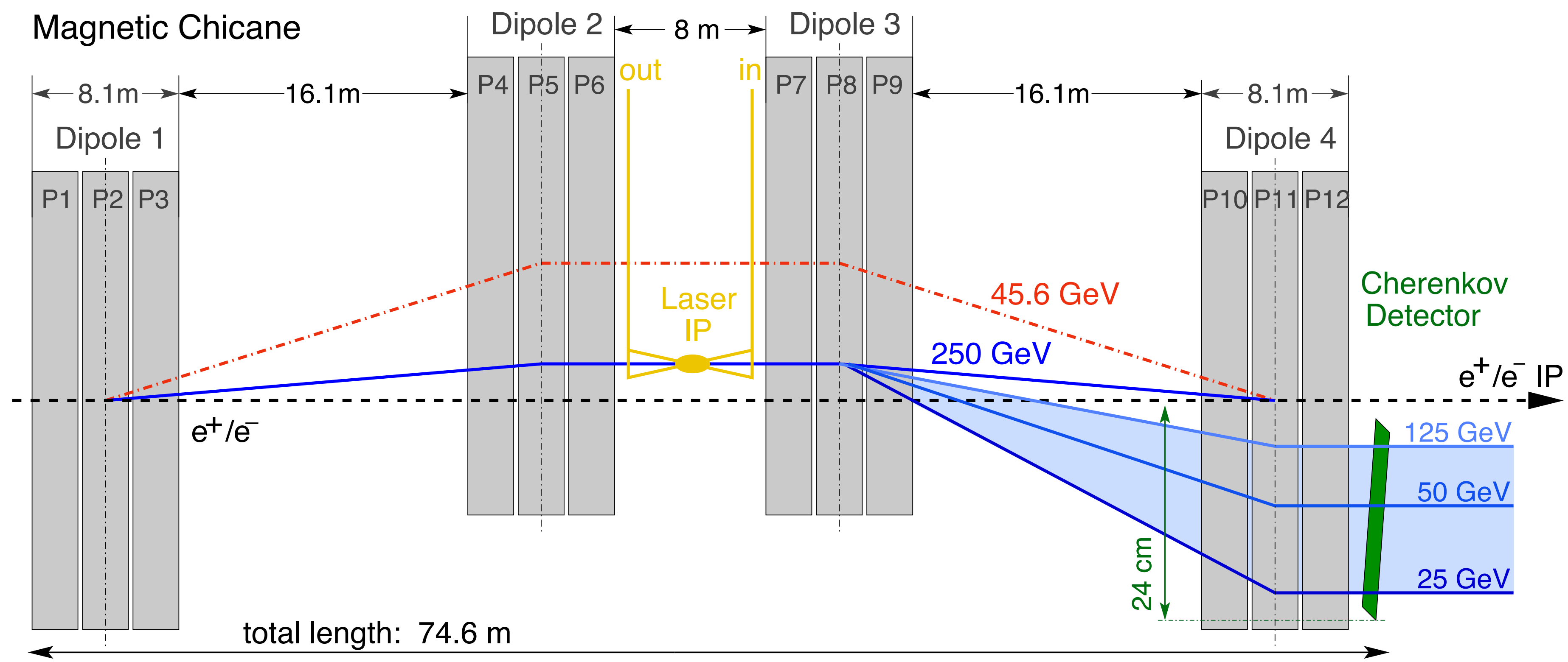


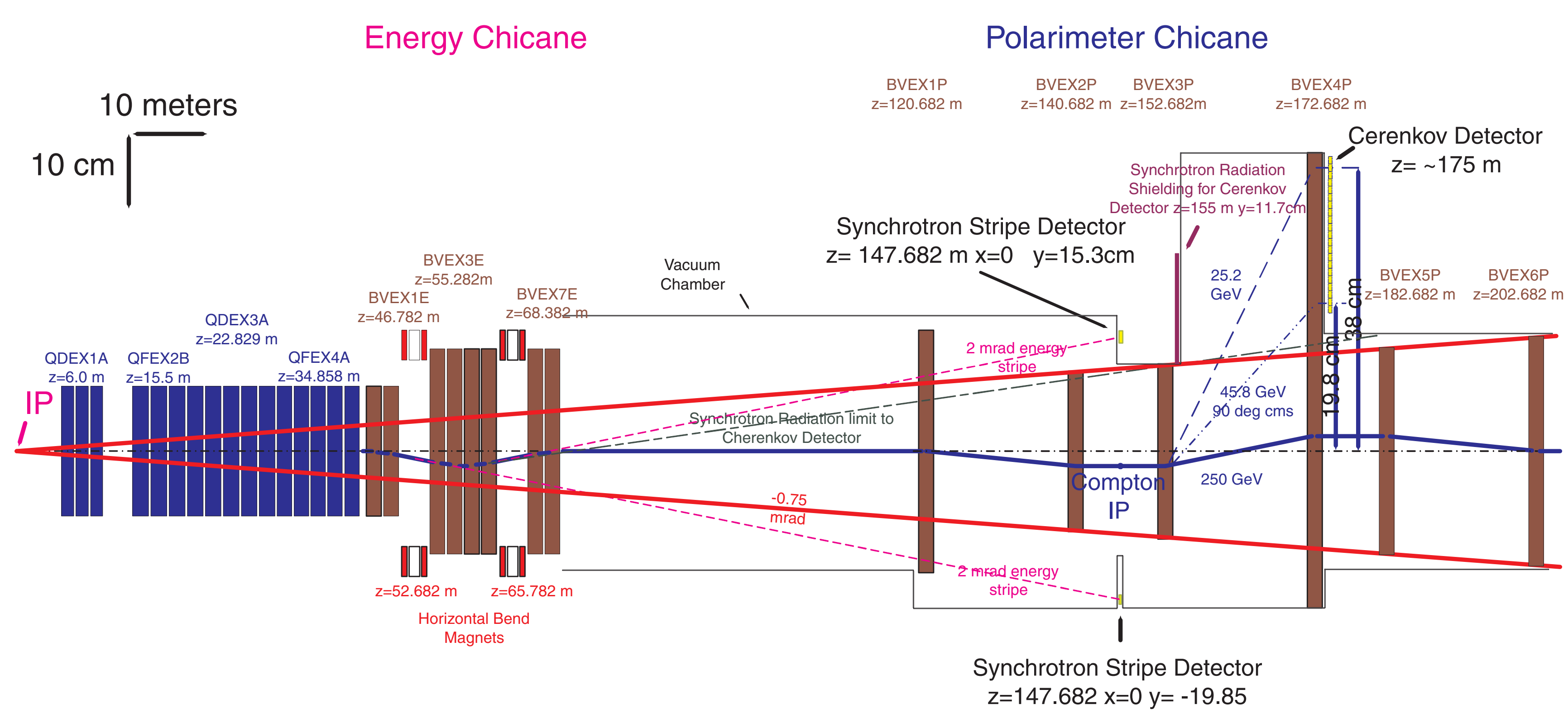


Drozhdin et al., SLAC-PUB-12741

Energy and Polarisation Measurement

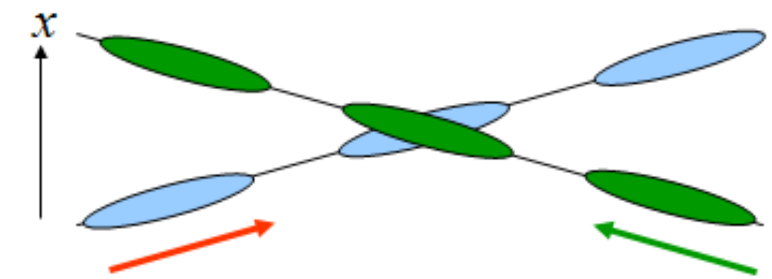
- Polarimeters:
  - Compton scattering
  - Δp/p < 0.25%
- Spectrometers:
  - magnetic chicanes
  - ΔE/E < 100 ppm
- Dedicated chicanes upstream and downstream of the IP

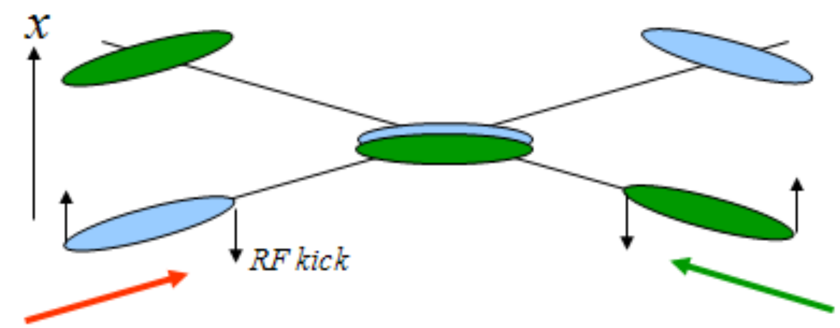


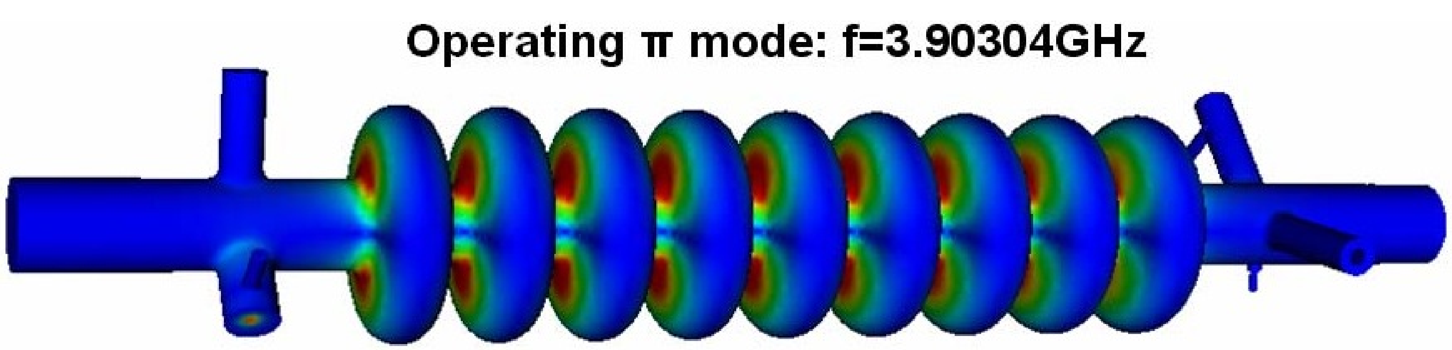


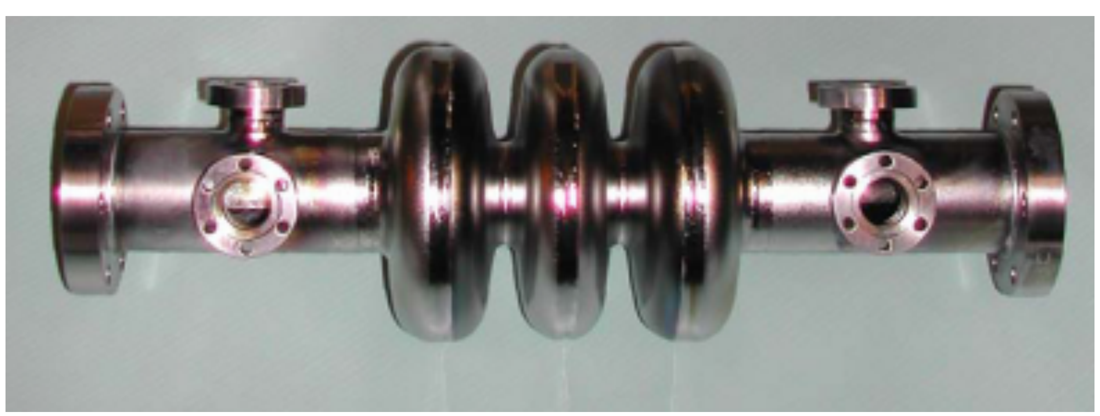
Crab Crossing

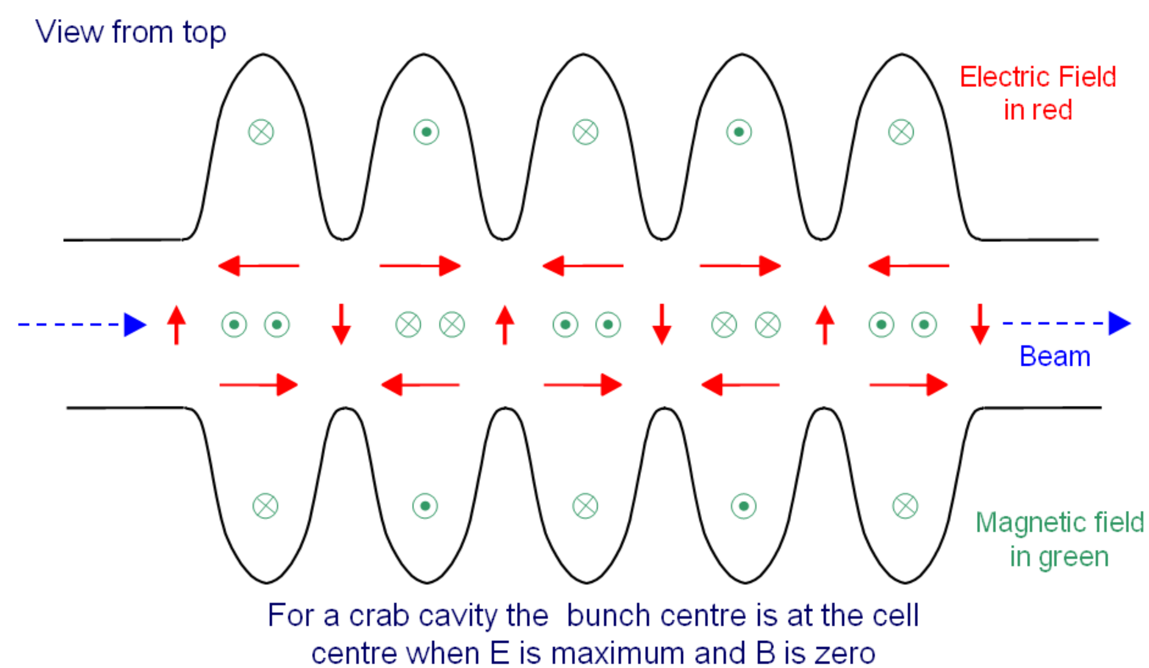
- Beams need to do crab crossing to preserve luminosity when colliding with 14 mrad crossing angle
- Crab cavities developed and tested that apply kicks to the beams





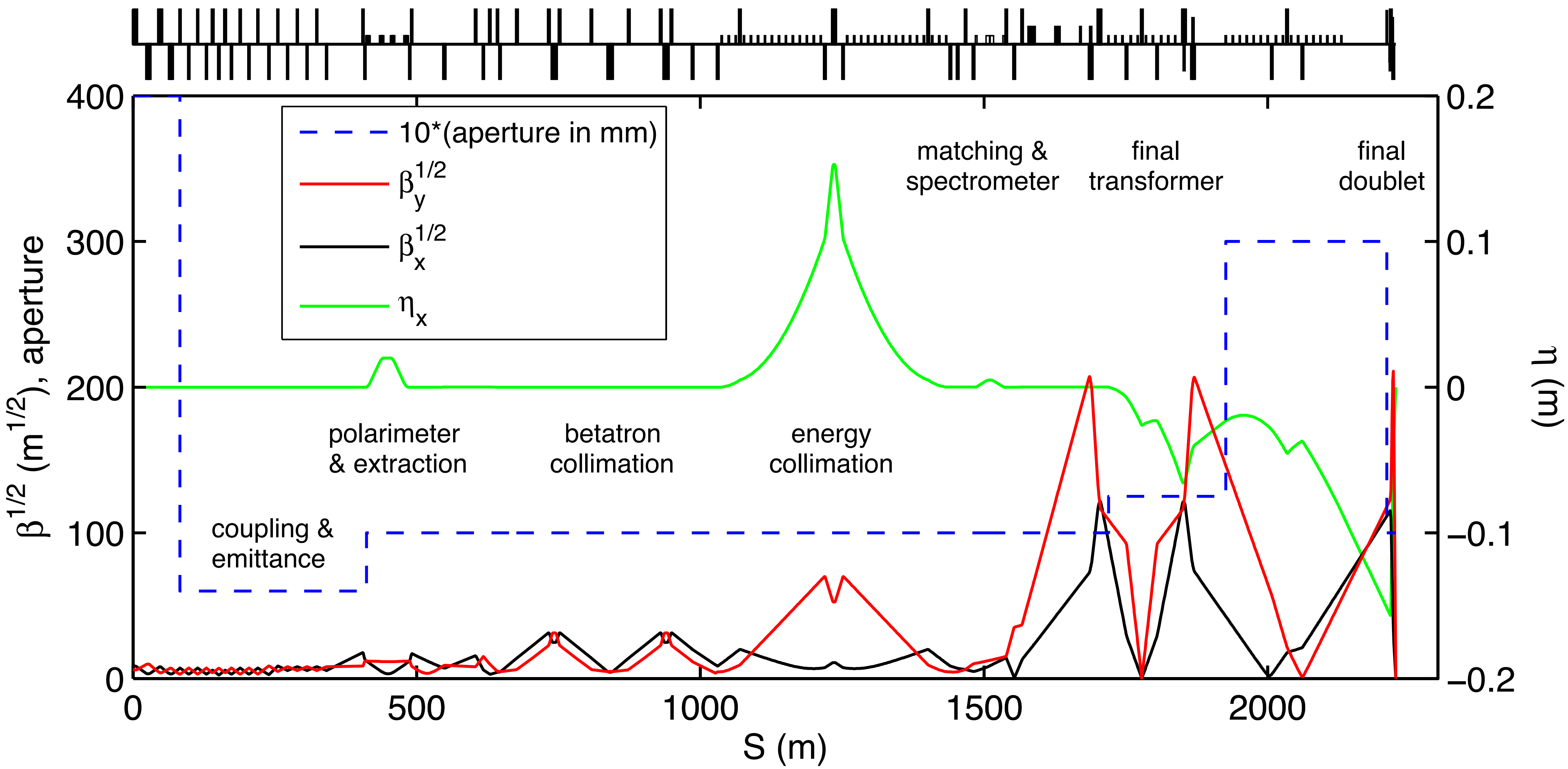






TM110 Dipole Mode

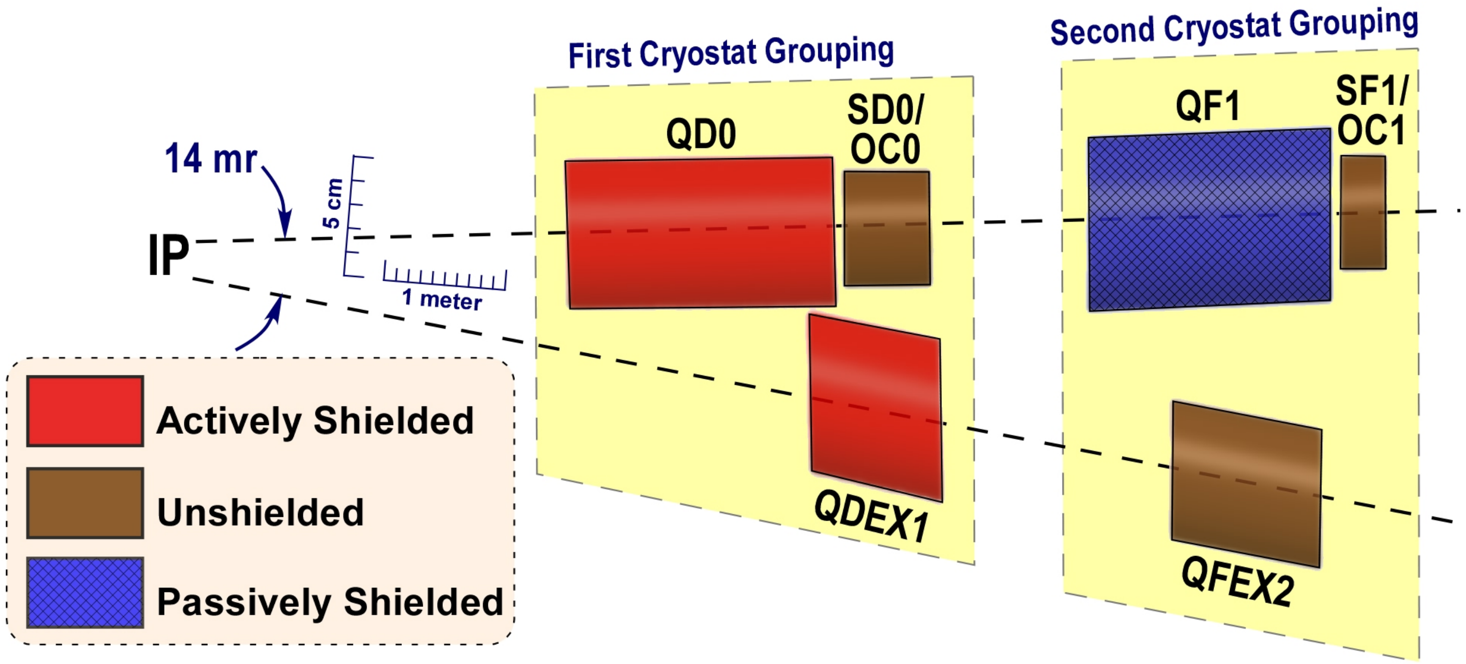
Final Focus

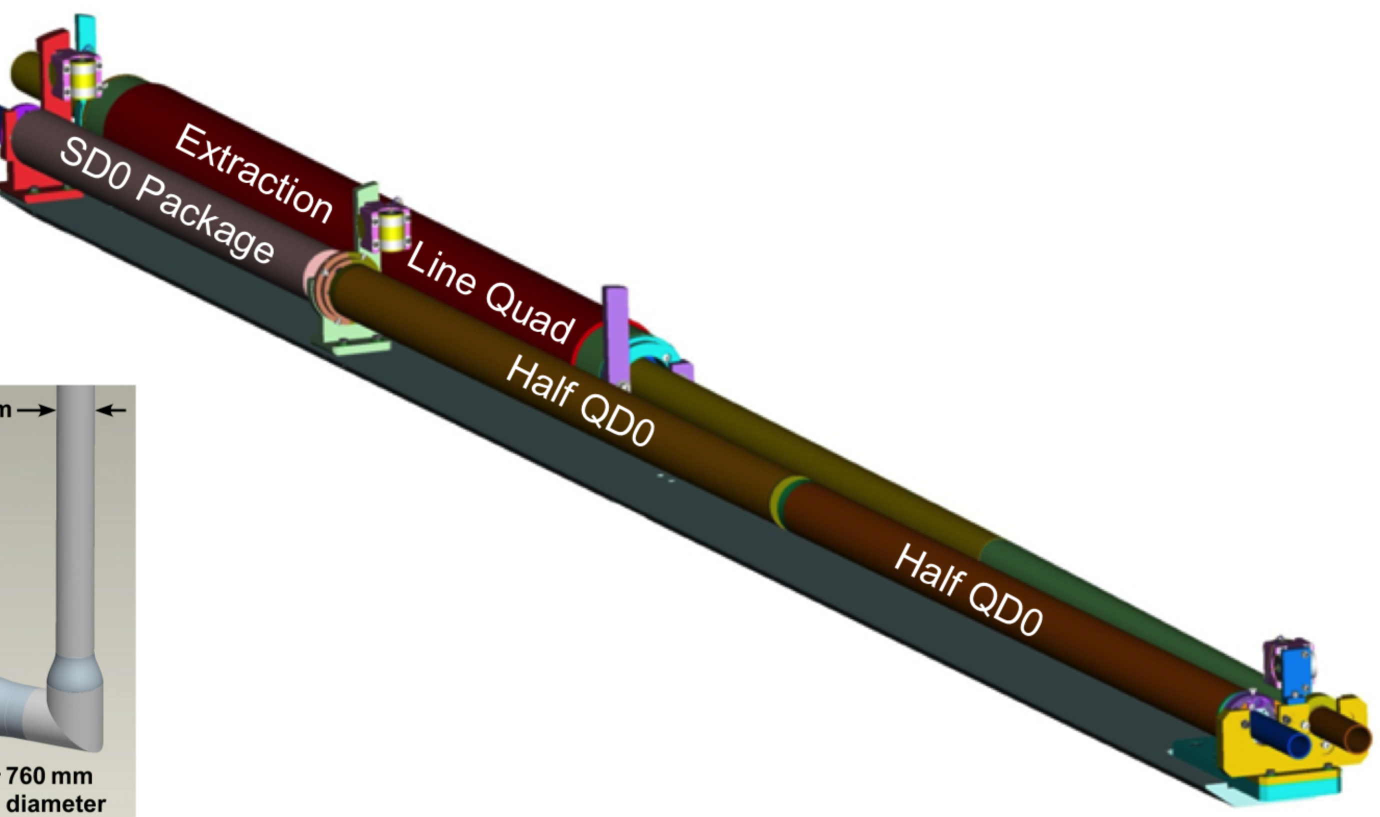


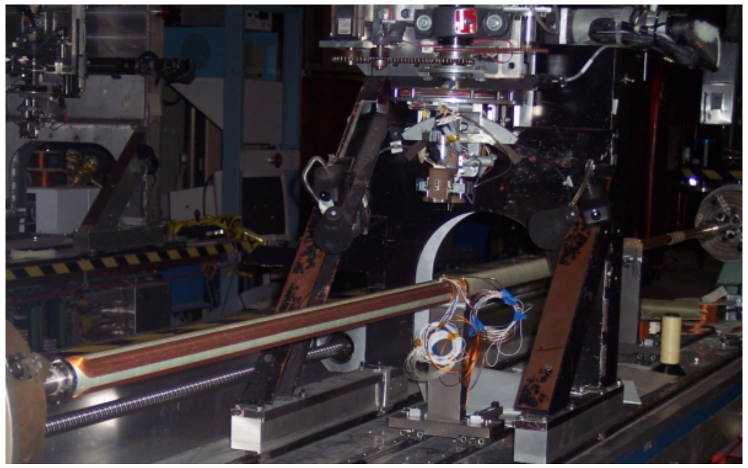
- De-focus beams to IR size (474 nm x 5.9 nm)
- Local chomaticity correction using sextupoles next to final doublets

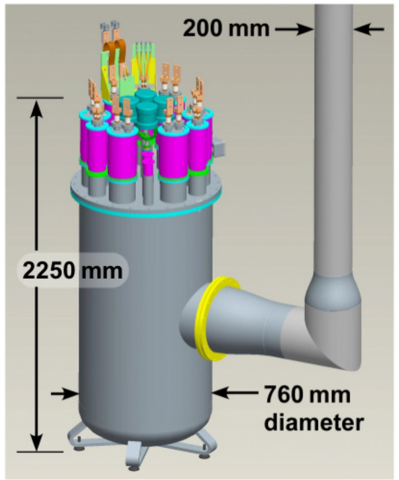
S/C Final Doublet Design

- Final doublet will be separated for push-pull operations
  - QF1 stays in tunnel
  - QD0 moves with detector
- Split QD0 model optimised for running at lower energies
- Allows for tighter collimation depths at $E_{cm} < 300$ GeV
  - ~10% vertical increase
  - ~30% horizontal increase



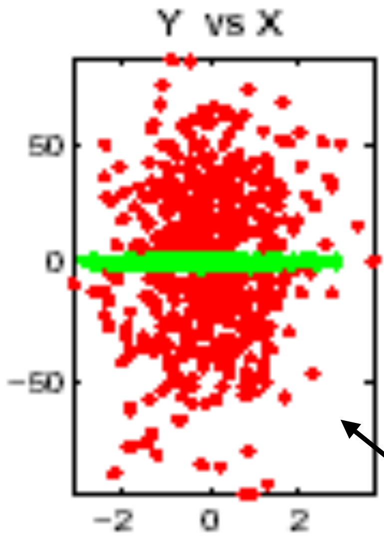






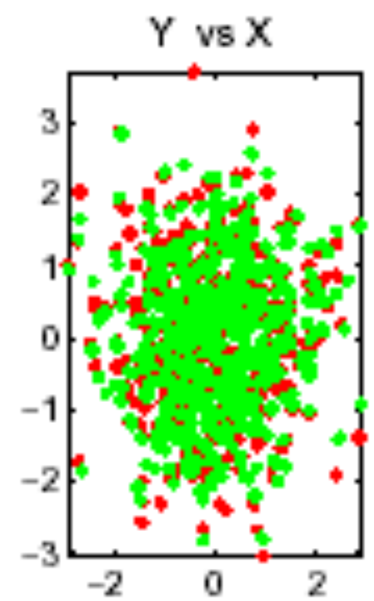
Anti-Solenoids

IR coupling compensation



without compensation

$\sigma_y / \sigma_y(0)=32$

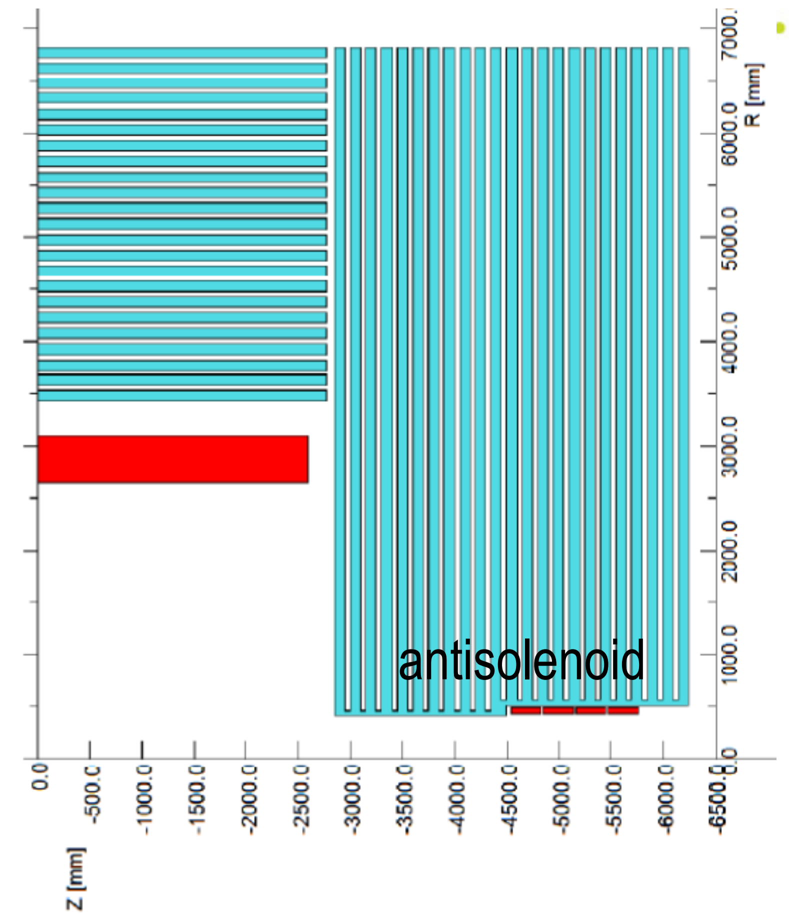


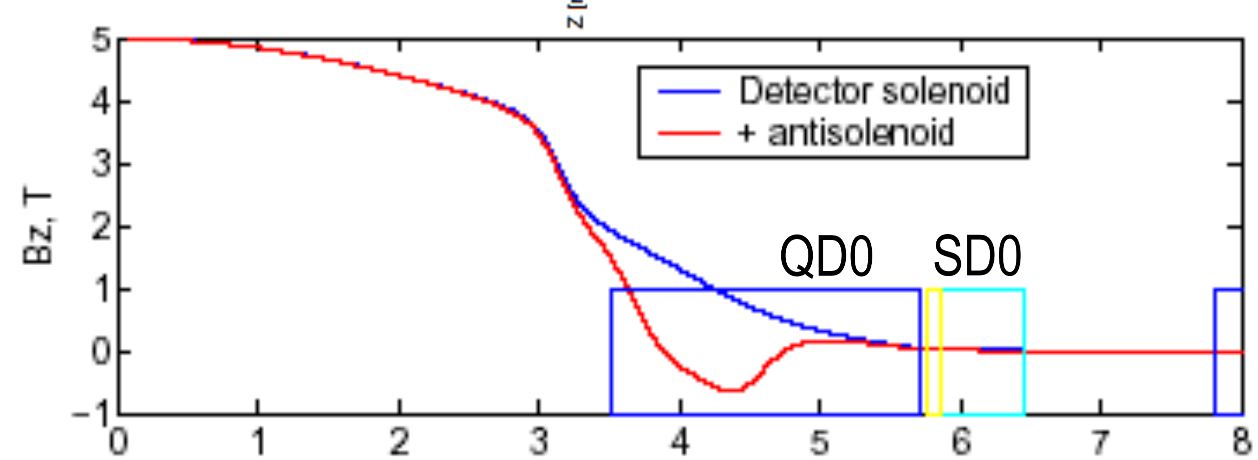
with compensation by antisolenoid

$\sigma_y / \sigma_y(0)<1.01$

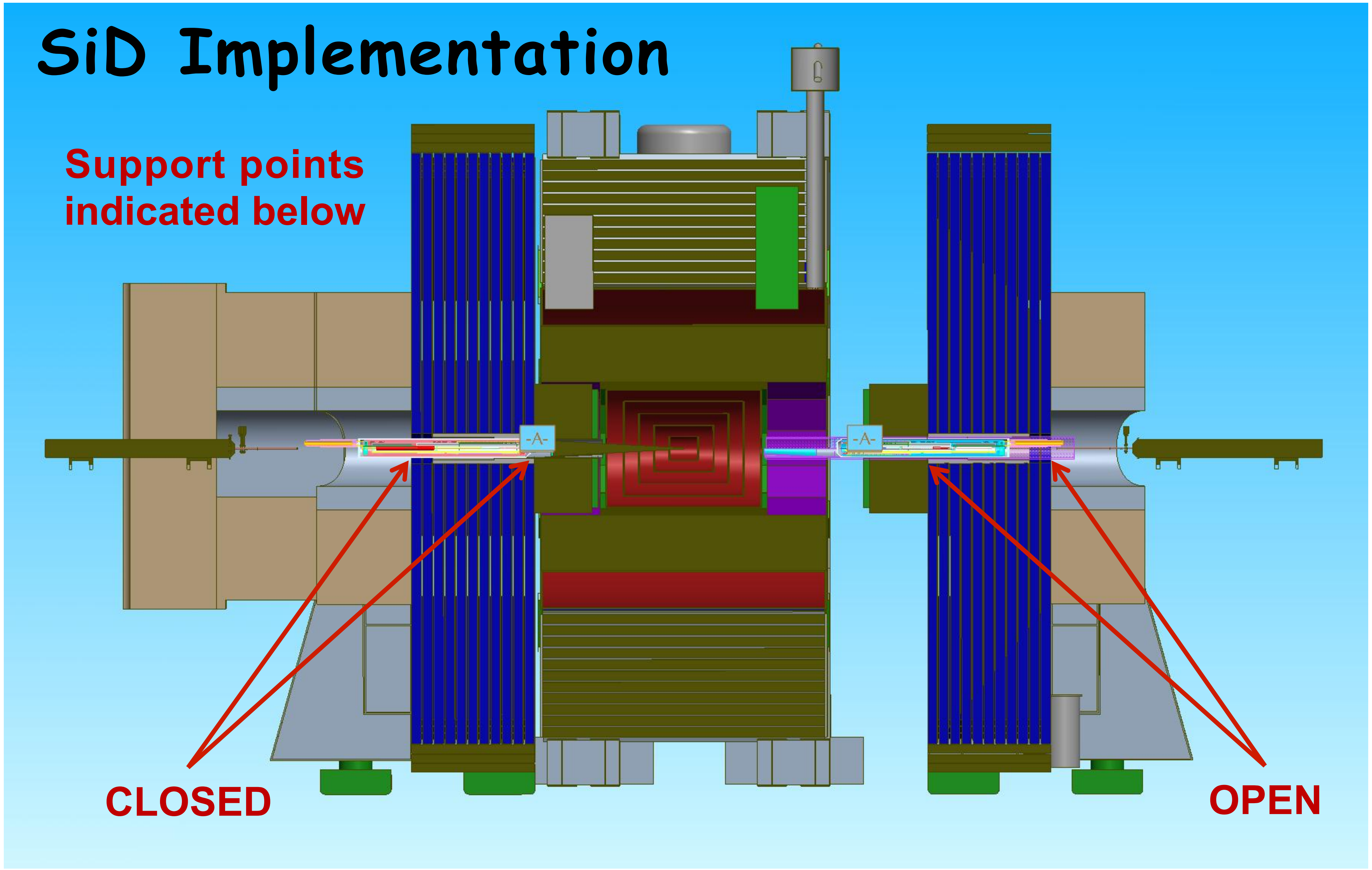
When detector solenoid overlaps QD0, coupling between y & x' and y & E causes large (30 – 190 times) increase of IP size (green=detector solenoid OFF, red=ON)

Even though traditional use of skew quads could reduce the effect, the local compensation of the fringe field (with a little skew tuning) is the most efficient way to ensure correction over wide range of beam energies





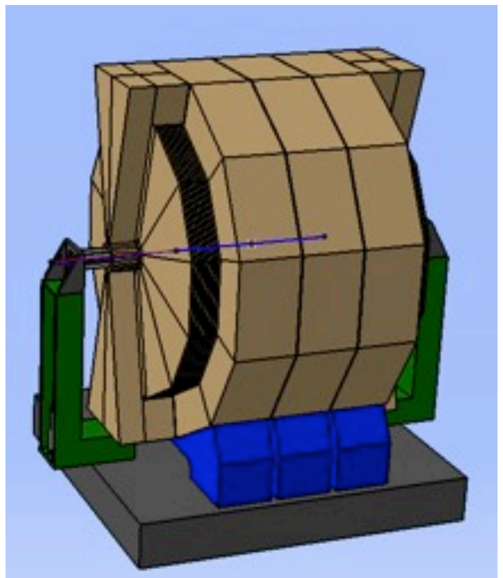
QD0 Support in Detectors



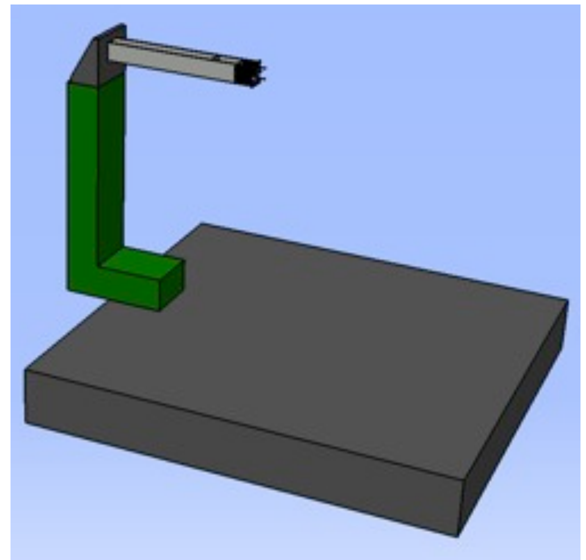
*Extracted from "QD0 Support Tube B.pptx," Bill Sporre email dated 27 September 2011.

QD0 Supports in Detectors

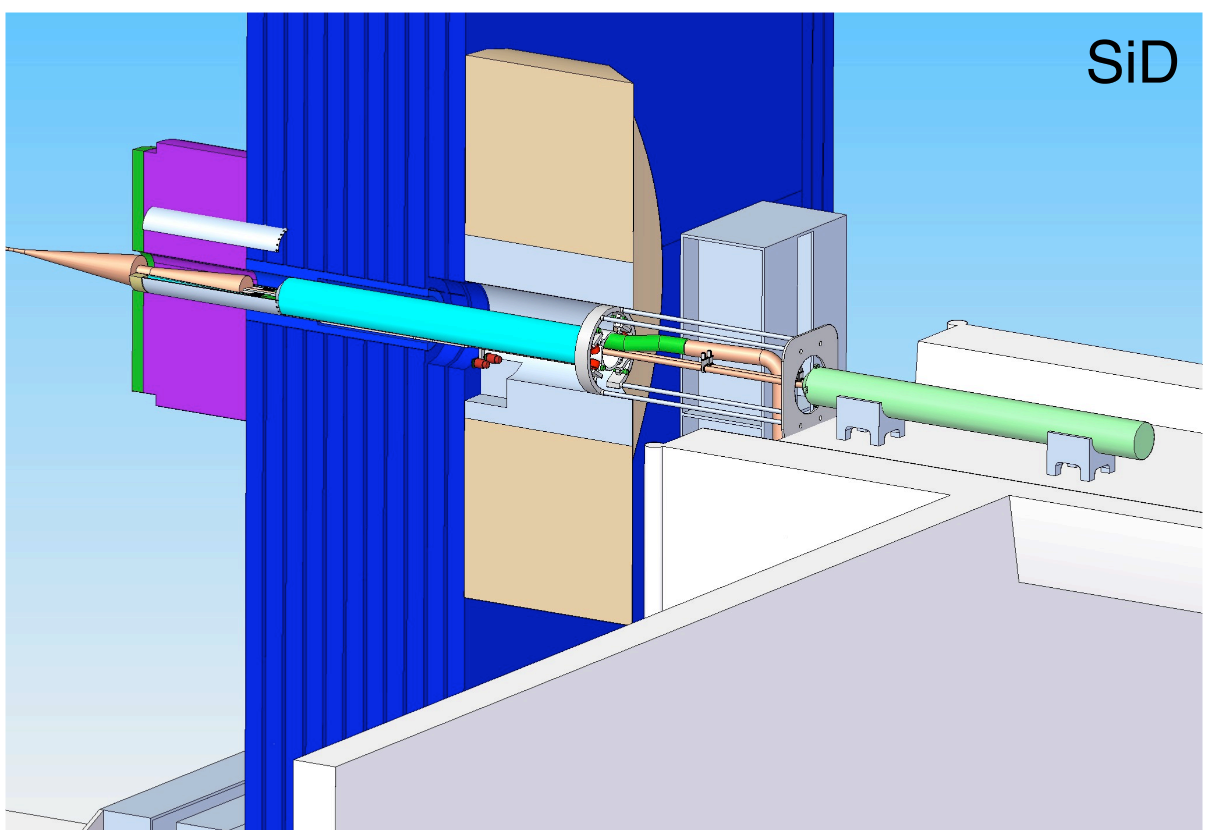
ILD00 model



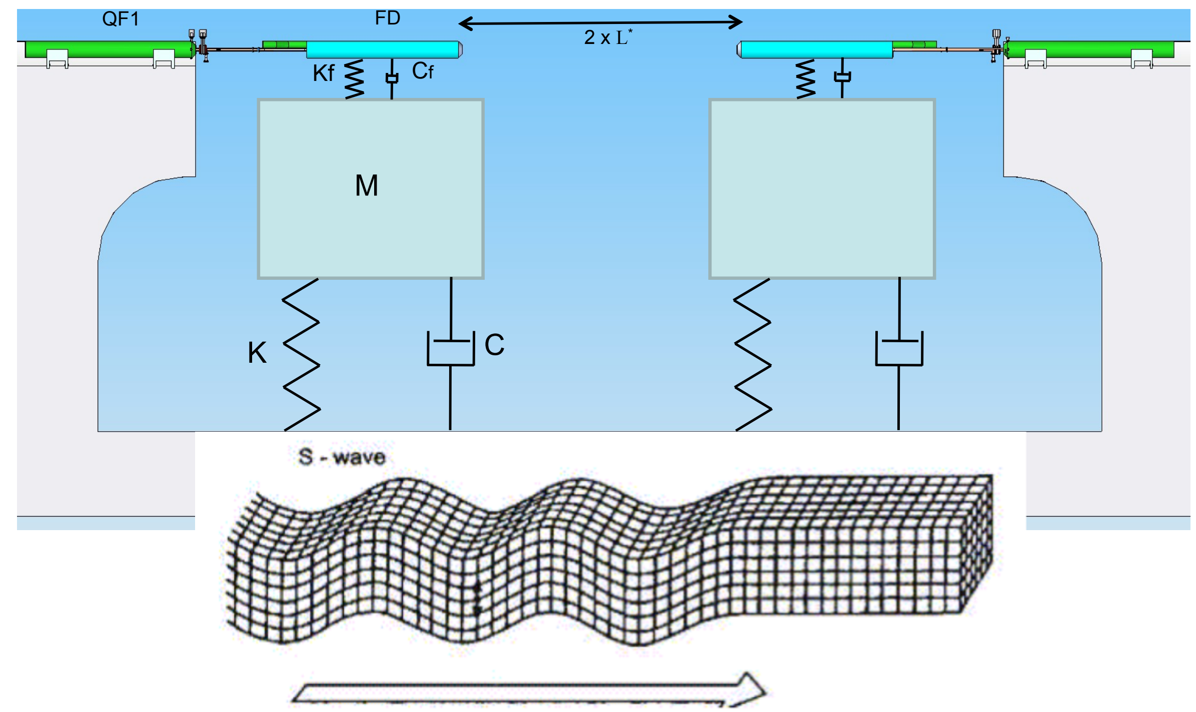
ILD QD0 support system



M . Joré

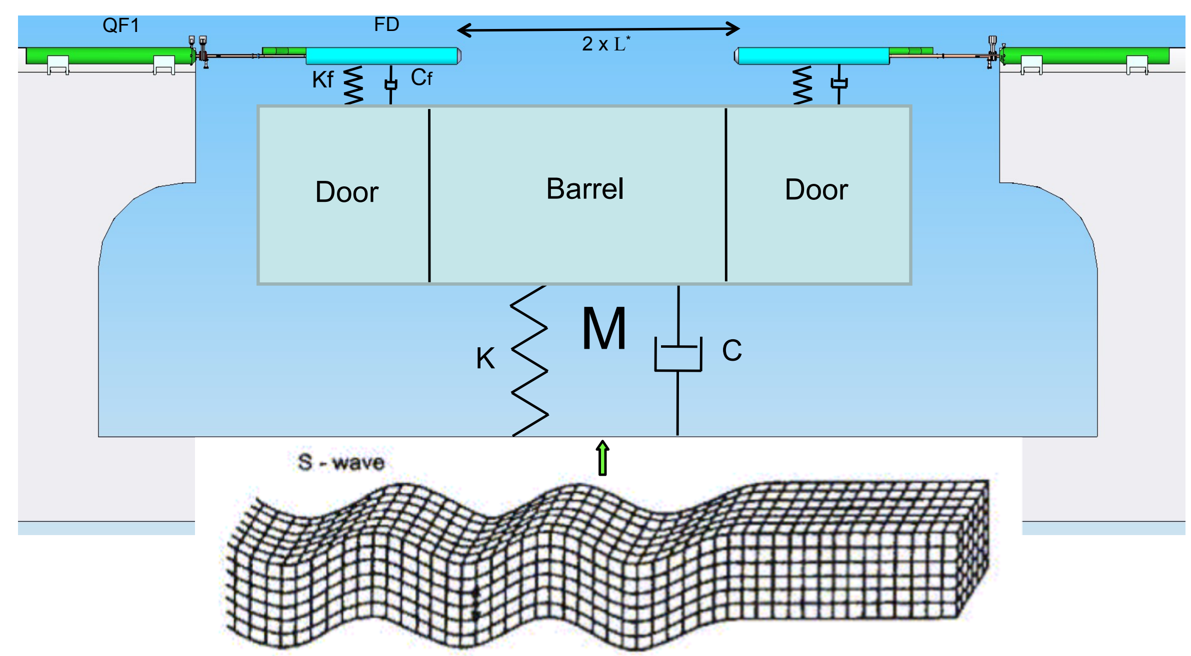


Independent Supports (Cavern,Pillars Platform)



Low Coherence

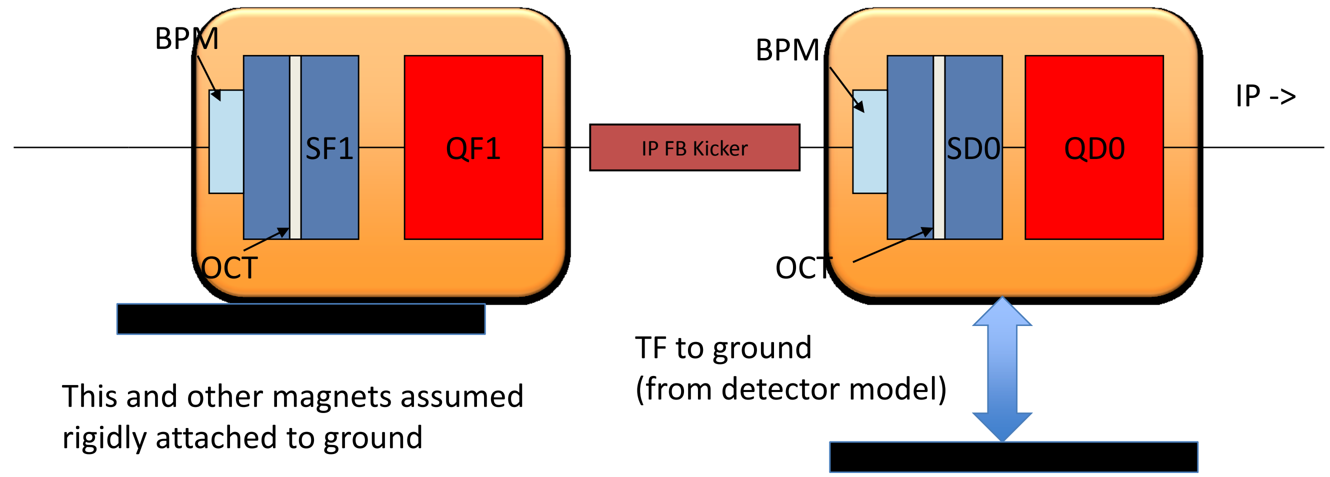
Common Supports (Detector under mag.field)

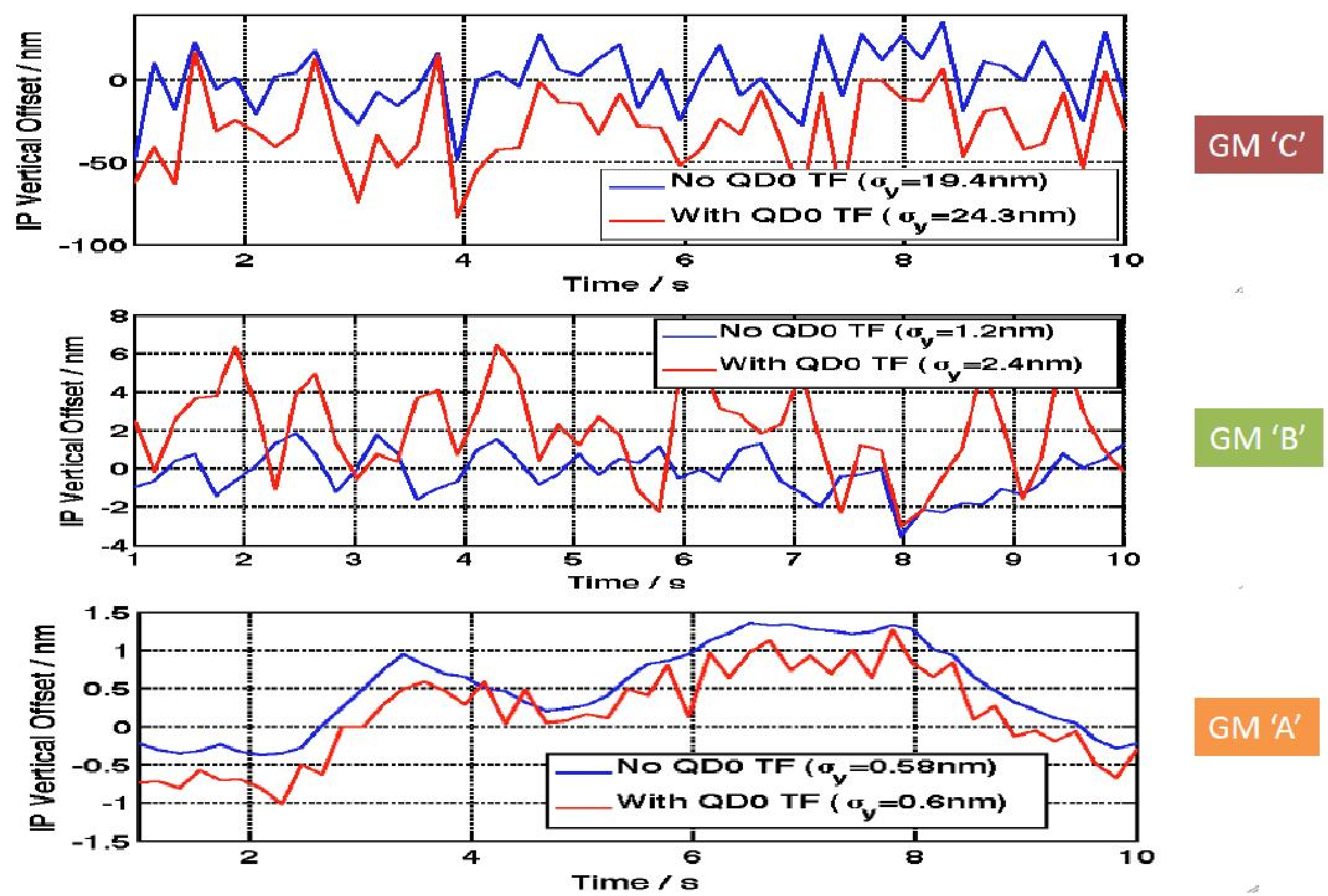


High Coherence

Vibration Analysis

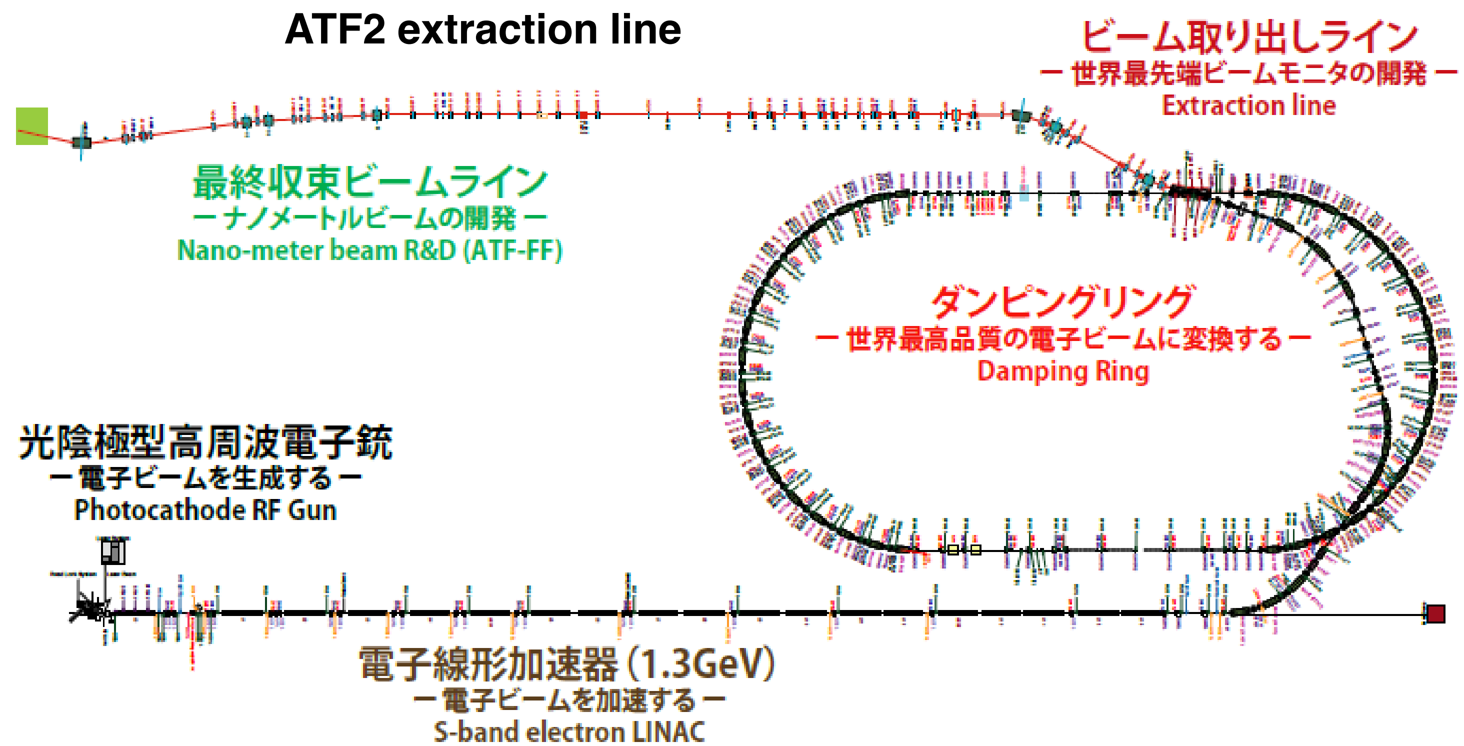
- Vibration limits for QD0 magnets:
  - Δ(QD0(e+)-QD0(e-) < 50 nm during 1 ms pulse
- Beam transport simulations with different ground motion models take into account transfer functions of detector platform and QD0 support
- 50 nm goal can be achieved

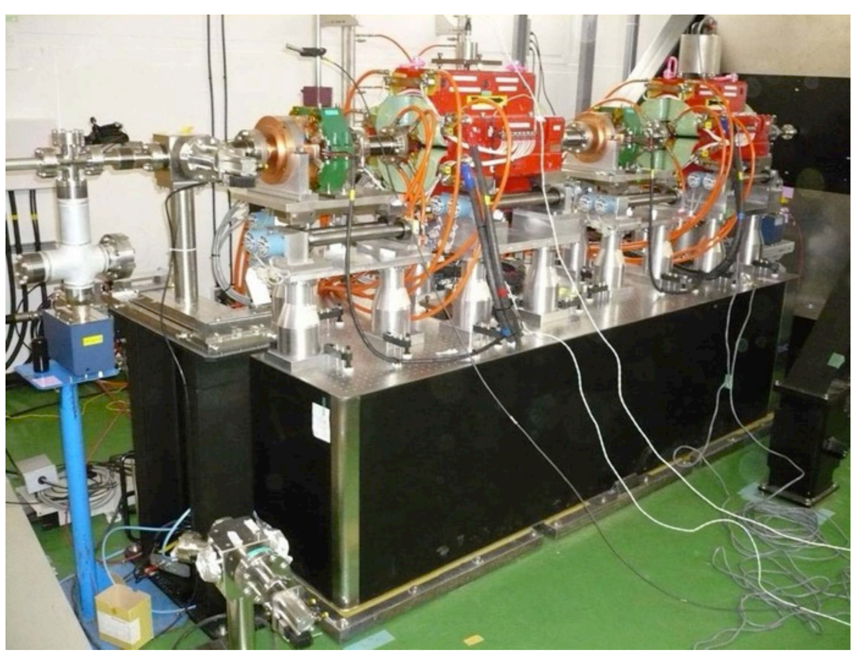




ATF2 Final Focus Experiment

- ILC like final focus beamline with local chromaticity correction
- Primary goals:
  - achieve 37 nm vertical beam size at the IP
  - stabilise beam at that point at nanometre level

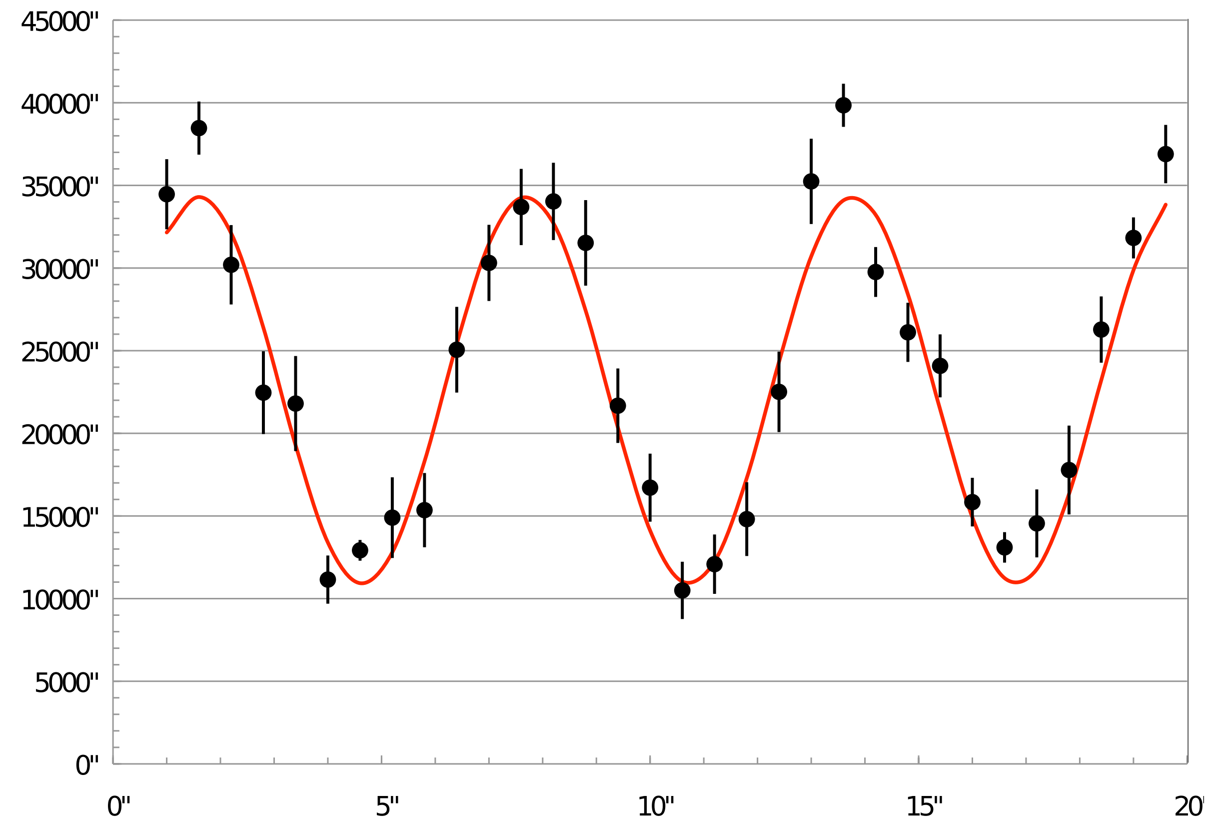




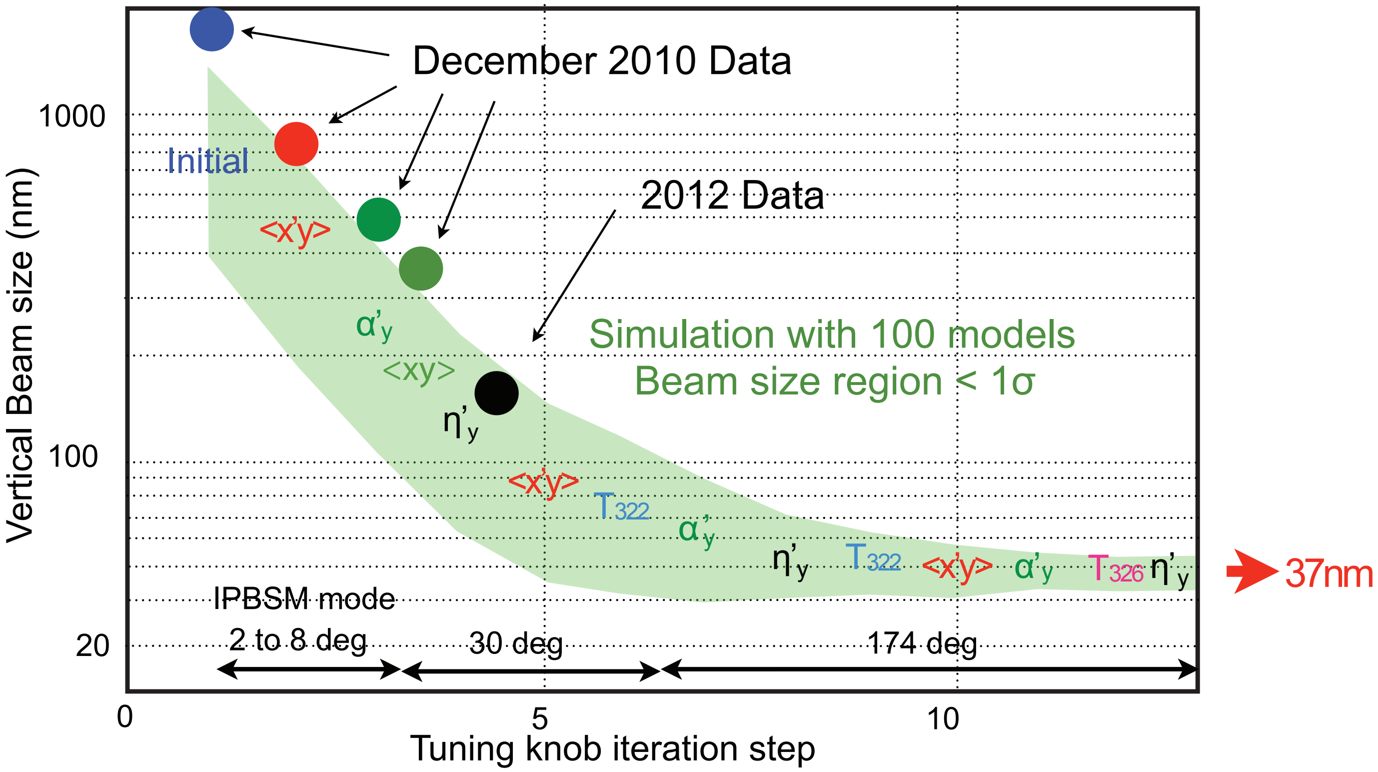
Parameter		Unit	ATF2	ILC
Beam energy	E	GeV	1.3	250
Effective focal length	L^*	m	1	3.5 - 4.5
Horizontal emittance	ϵ_x	nm	2	1.0 (damping ring)
Vertical emittance	ϵ_y	pm	12	2 (damping ring)
Horizontal IP β function	β_x^*	mm	4	21
Vertical IP β function	β_y^*	mm	0.1	0.4
Horizontal IP dispersion divergence	η_x'		0.14	0.0094
Relative energy spread	σ_E	%	~ 0.1	~ 0.1
Vertical chromaticity	ξ_y		$\sim 10^4$	$\sim 10^4$
RMS horizontal beam size	σ_x^*	µm	2.8	0.655
RMS vertical beam size	σ_y^*	nm	37	5.7

ATF2 Final Focus Experiment

- IP Beam Size Monitor (aka Shintake Monitor) measurement (February 2012): 166.2 ± 6.7 nm:

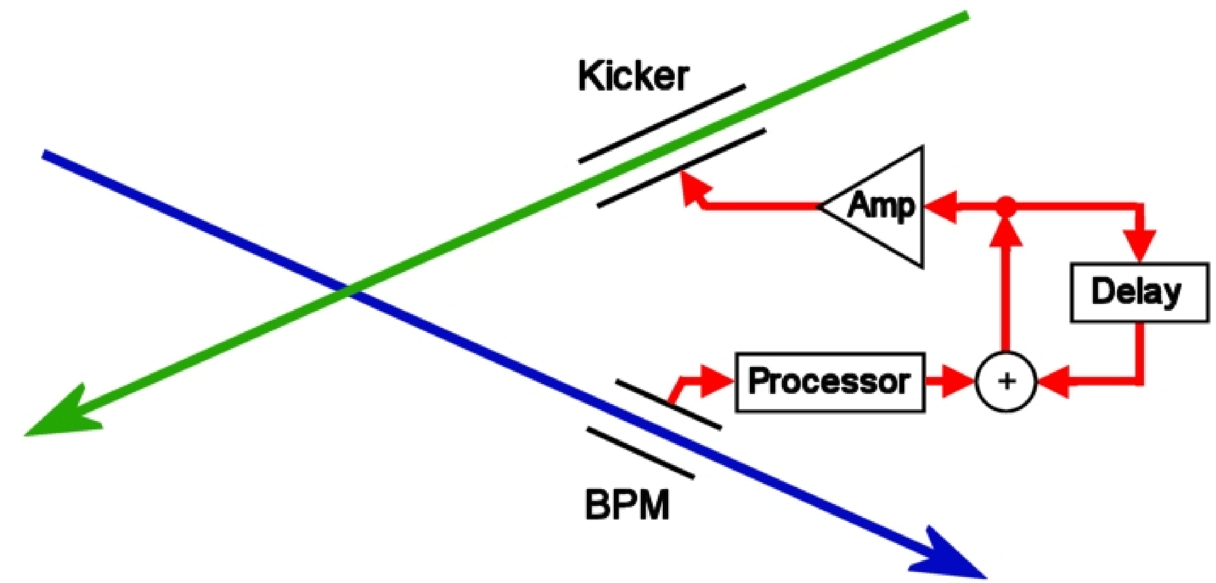


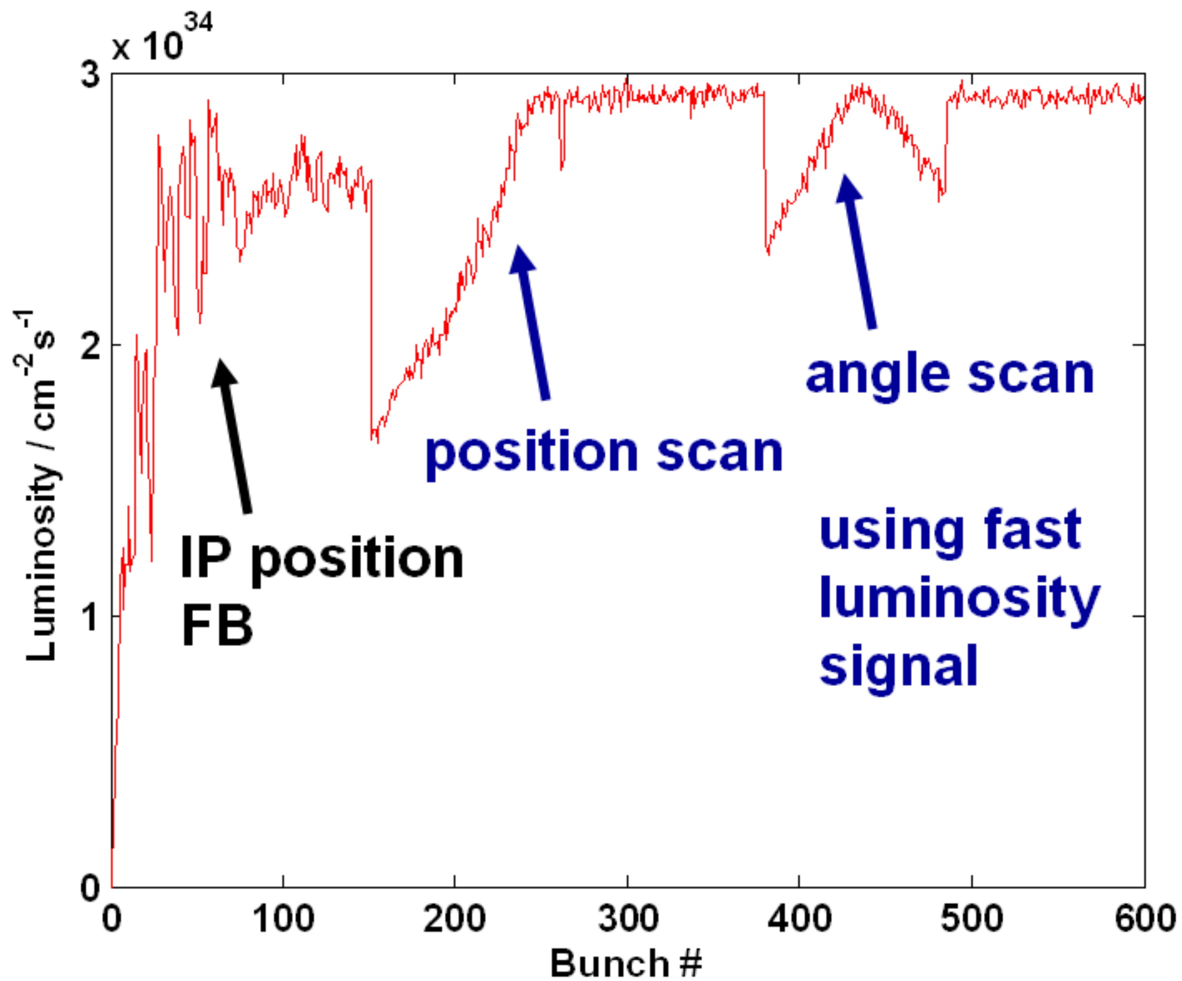
- MC simulation of beam tuning procedure:



Final Focus Feedback FONT

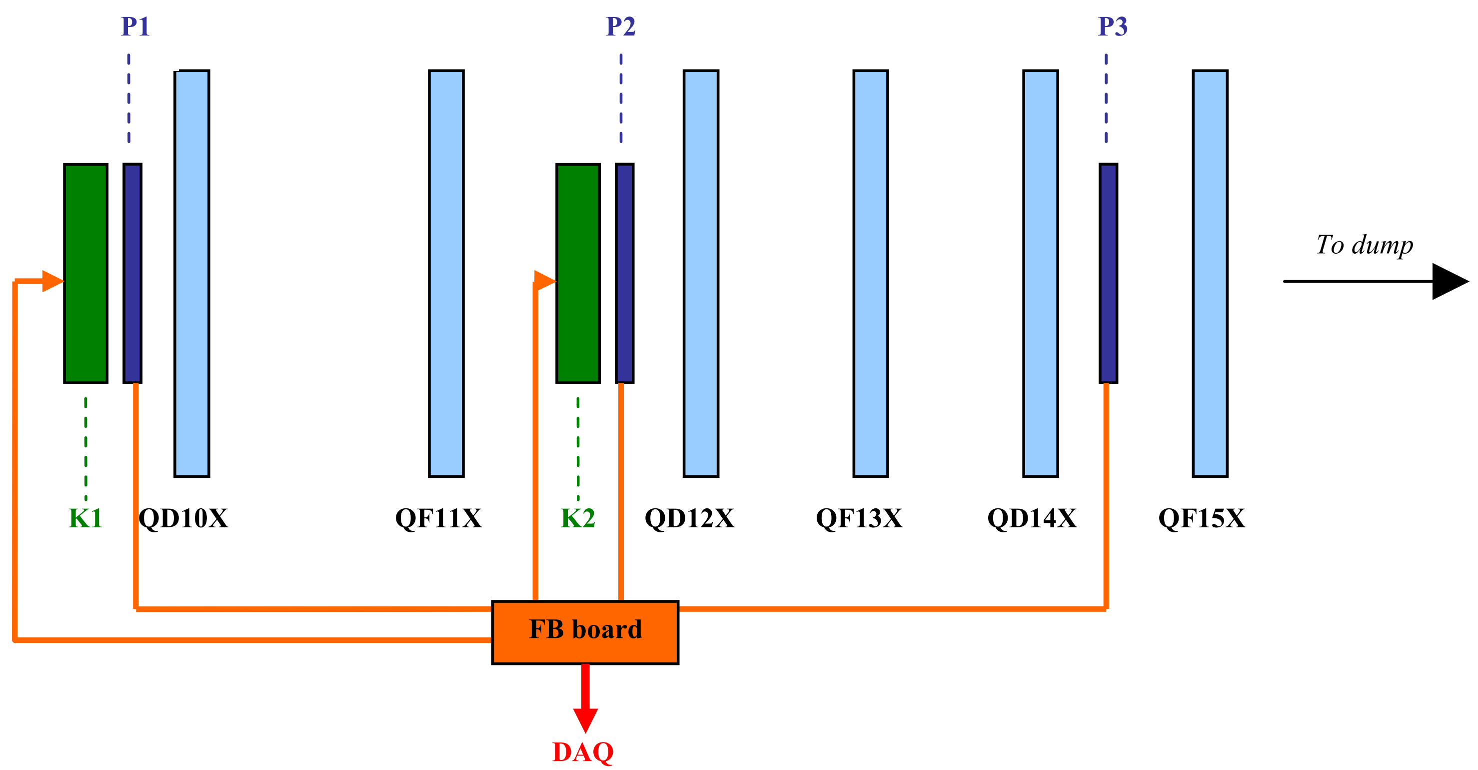
- Intra-train IP feedback system
- Measures offsets and angles of outgoing beam
- Corrects incoming beam
- Beam-beam interction enhances nm level offsets to tens of mrad deflections
- Micron-resolution BPMs can detect offsets on sub-nm level
- Stripline kickers to correct the incoming beam
- Latency is crucial: ~4 bunch spacings possible
- BPMs and kickers need to be integrated in interaction region



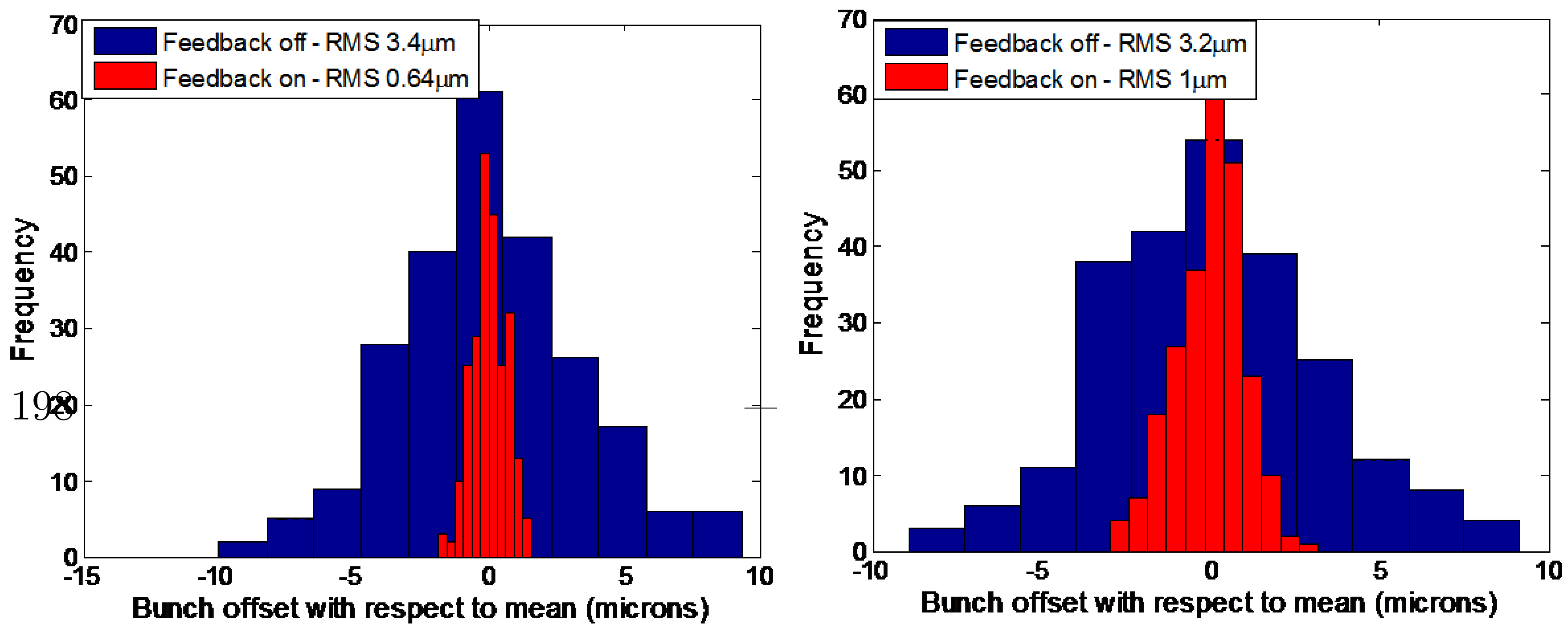


FONT at ATF2

- 3 vertical BPMs
- 2 vertical stripline kickers
- Latency: 140 ns
- 3 bunches extracted from ATF2, 140-300 ns distance

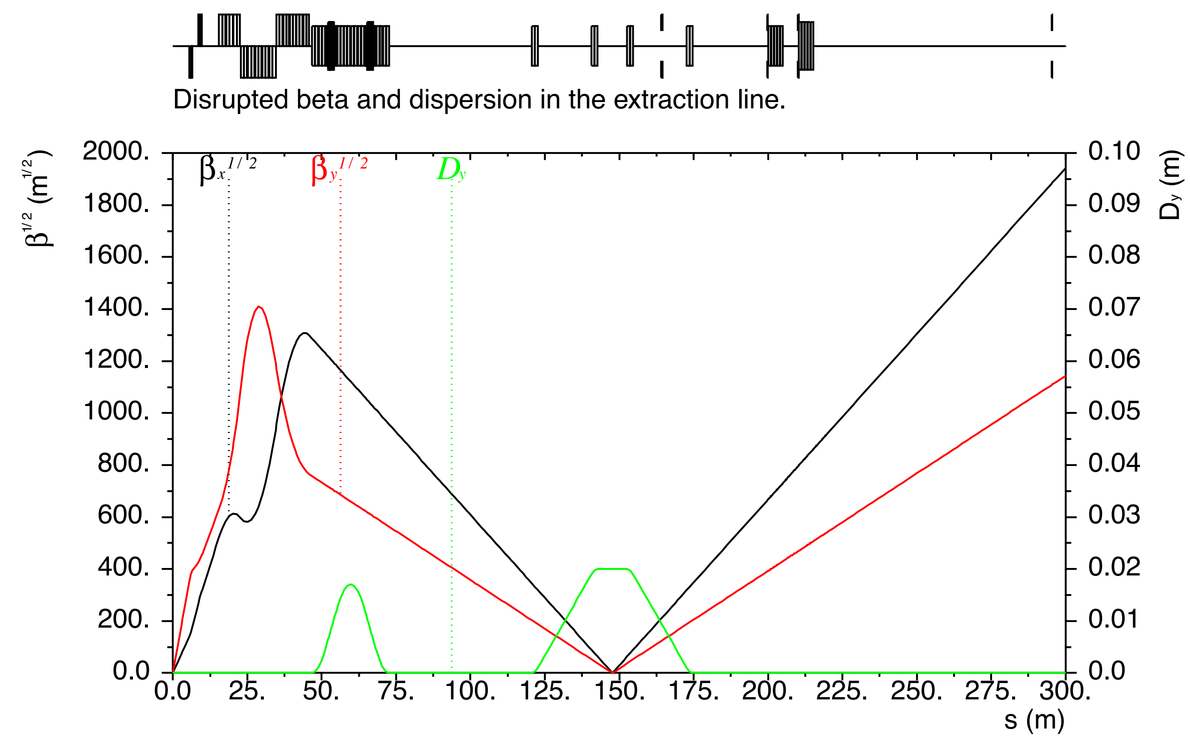


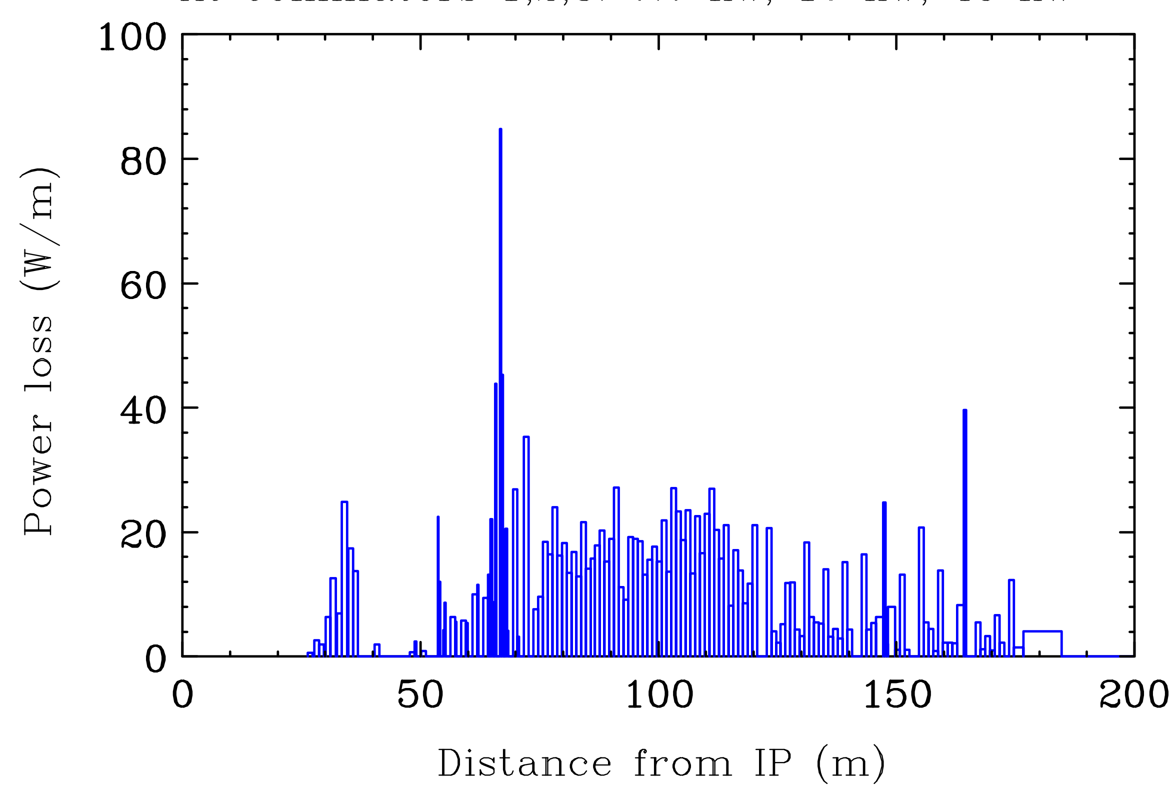
- Jitters of second bunch:



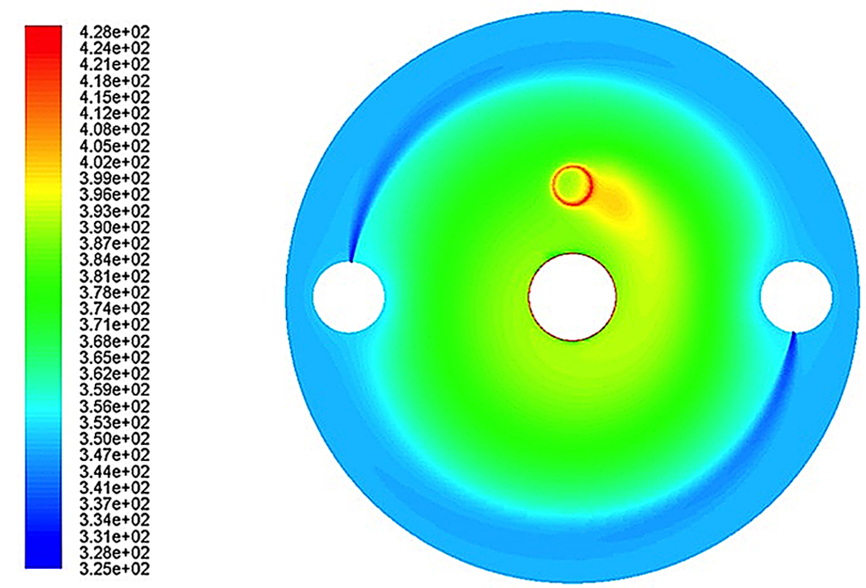
Extraction Line

- Transports spent beams from IP to main beam dump
- Main issues:
    - minimise beam losses
    - keep space for beamstrahlung photon beam
    - provide space and optics for diagnostics (polarisation, energy)
- Beam loss simulation (250 GeV beam):





Main Beam Dumps

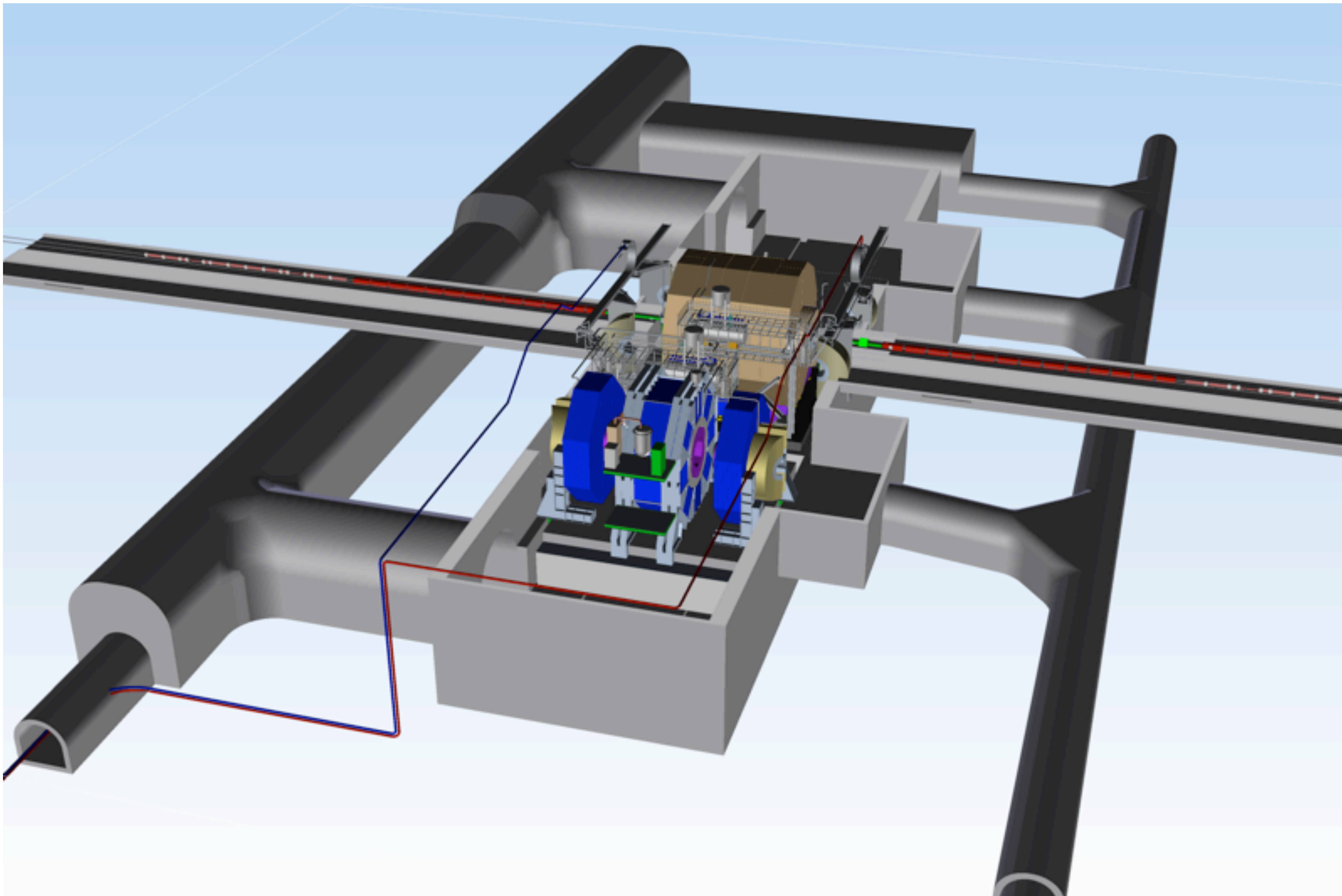


- Two tune-up and two main beam dumps in BDS
- Designed for 18MW 500 GeV beams (TeV upgrade already foreseen)
- 30 X_0 10 bar water tank
- Beams are sweeped circularly over the 1mm thick Ti window
- Integrity of water system, dump and dump window are crucial
- Water activation products need to be filtered out
- H_2O radiolysis products are treated in catalyst filters

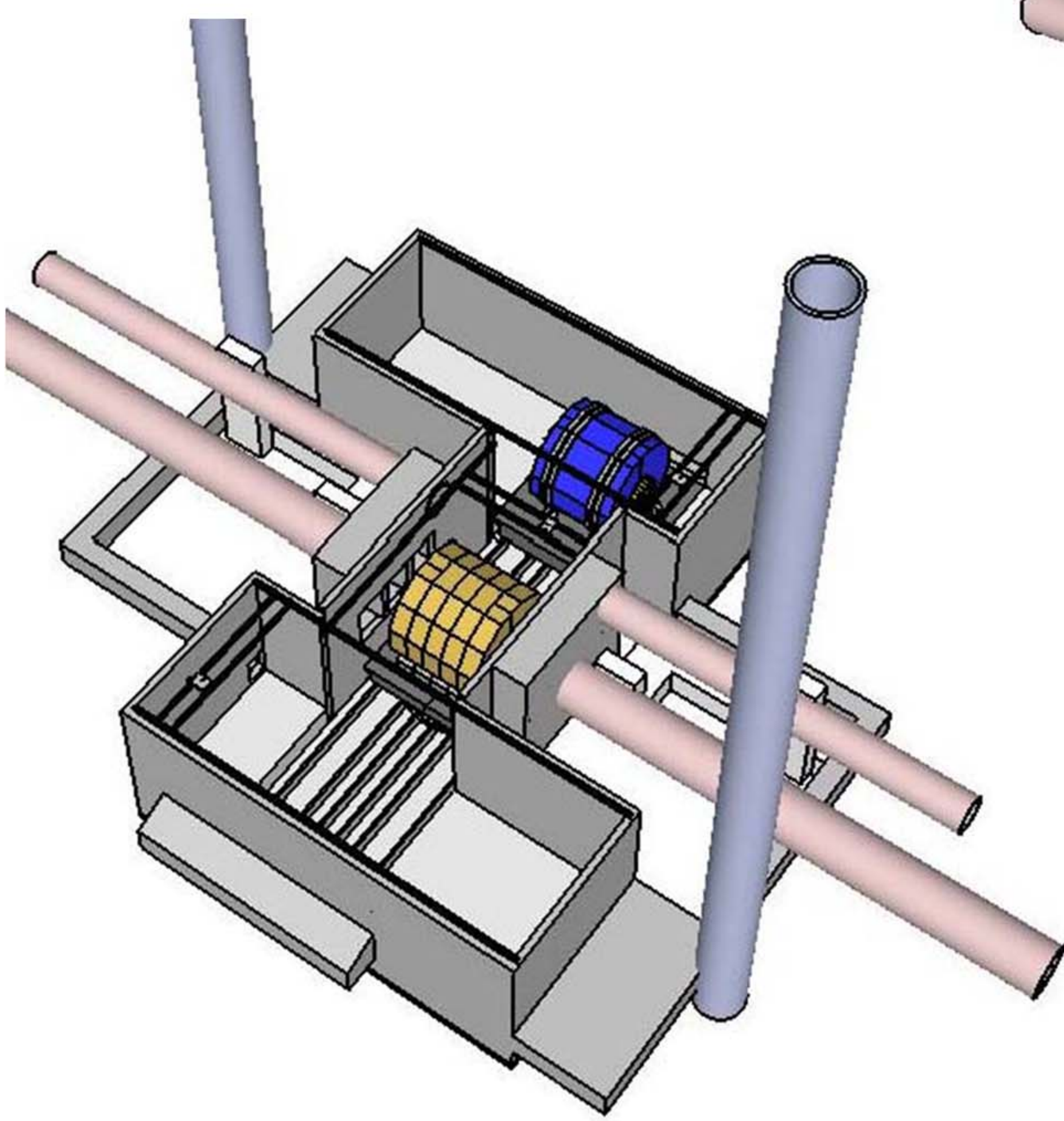
Interaction Region Site Differences for Detectors

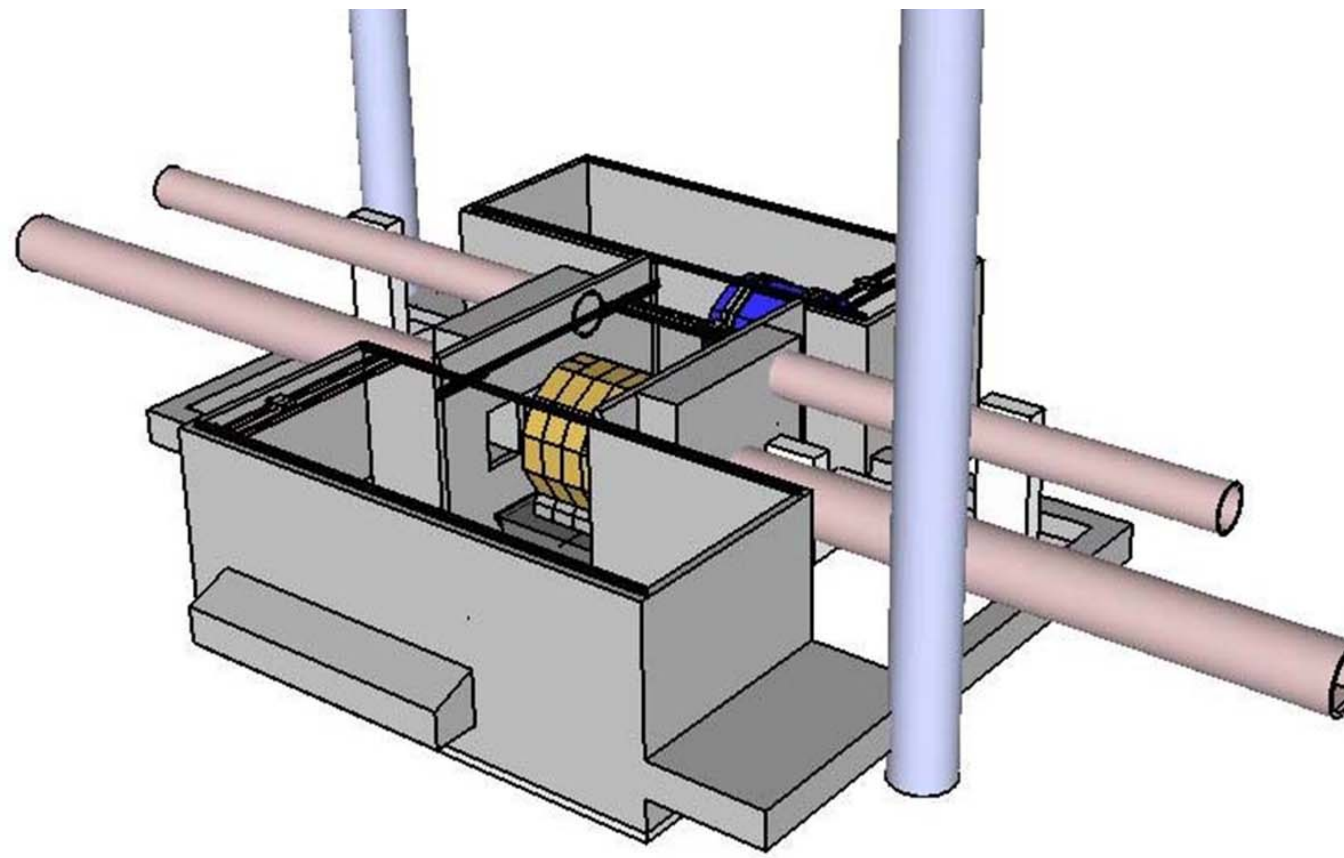
Flat Sites	**Mountain Sites**
Access via vertical shaft:	*Access via horizontal tunnel:*
~18 m diameter, ~100 m long	~11 m diameter, ~1 km long, ~10 % slope
Assembly in CMS style:	*Modified assembly scheme:*
pre-assemble and test large detector parts	assemble sub-detectors as far as possible
max. part dim.: < ~3.5 kt, < ~17.5 m	max. part dim.: < ~400 t, < ~9m
minimise underground work (~1a)	long underground work (~3a)
Installation schemes of detectors and machine de-coupled to large extent	*Installation schemes of detector and machine coupled at high level*

Mountain Underground Sites



Flat Sites: Experimental Cavern



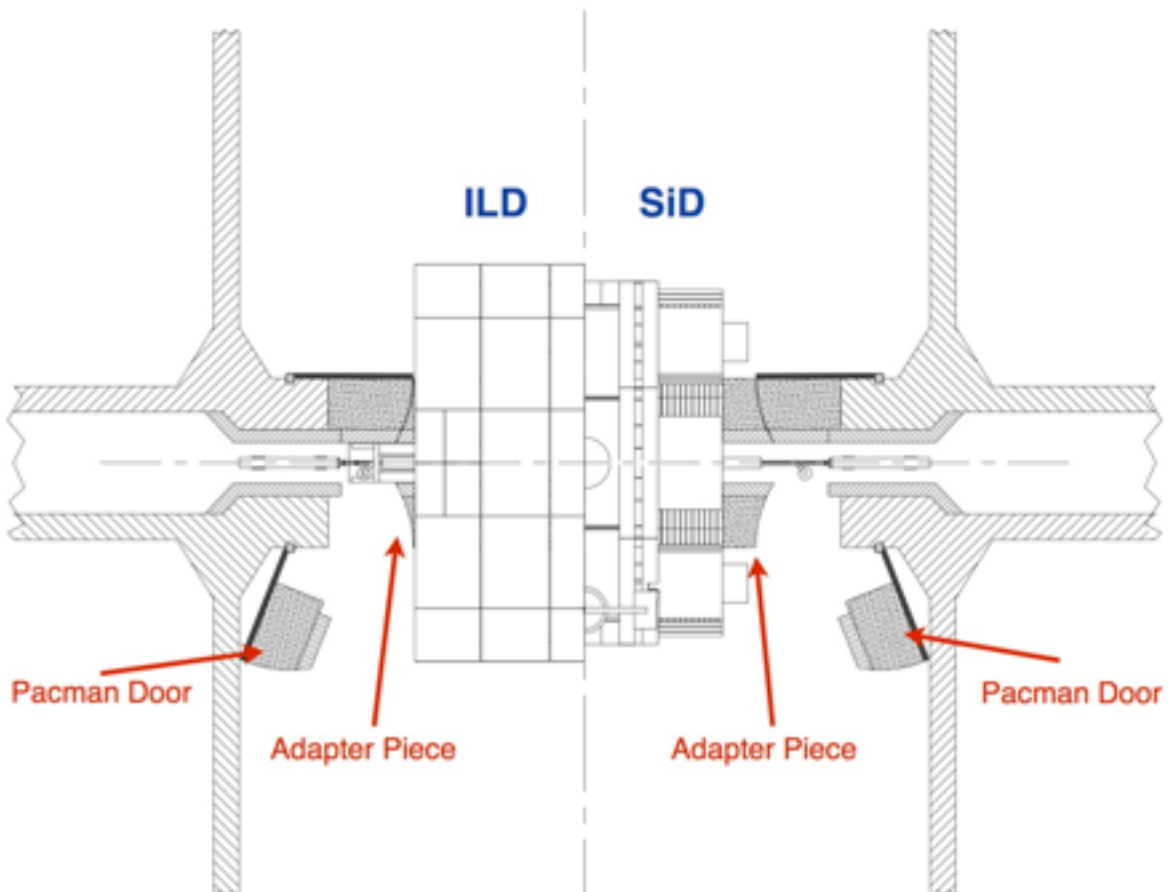


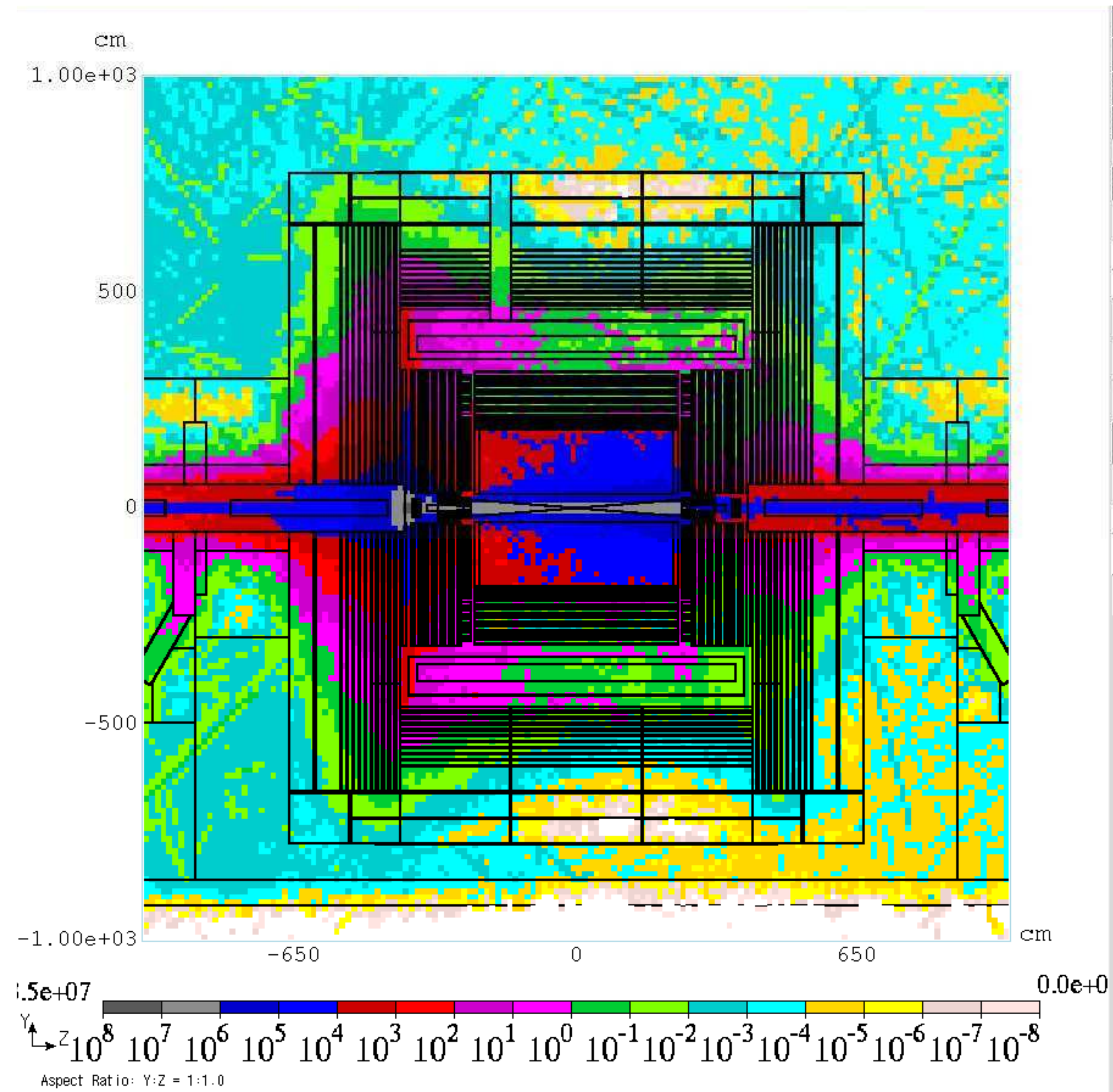
More will be discussed in MDI presentation tomorrow

T. Lackowski

Interaction Region Radiation Shielding

- Detectors are self-shielding w.r.t. maximum credible beam loss scenarios
- Adaptable shields between hall and detector („pacman“) required





Sanami et al., SLAC-RP-09-08

Summary

- A coherent design of the ILC Beam Delivery System has been developed for the TDR
  - centre-of mass energy reach 500 GeV, upgradable to 1 TeV with additional magnets
- Complete lattice description exists
- Properties have been studied in beam simulations
- Critical hardware systems have been studied on prototype level
  - QD0 design (warm and cold)
  - Crab cavity
  - Final focus studies at ATF2
  - Feedback studies at ATF2
  - (...)

- Interaction region design will be discussed in more detail in the Machine-Detector Interface presentation tomorrow.