Beam Delivery Systems (BDS) and Machine Detector Interface (MDI)

Chapter 8 in Vol.3 of ILC TDR

田内利明, KEK

加速器・物理合同 ILC 夏の合宿、2013年7月20〜23日、
呉羽ハイツ、富山県

What is MDI ?

MDI is Machine Detector Interface

Machine : Beam Delivery System (BDS)

from LINAC-end to beam dump

collimation, energy/polarization, final focus,

extraction (energy/polarization) and beam dump

Detector : Interaction Region

experiment (physics; Higgs, Top, W/Z, SUSY, extra-D ...)

luminosity, background and minimum veto-angle

ILC : International Linear Collider

2005 - 2013 -

MDI

Detector /Physics

Research Director

Common task groups :MDI

↔

Machine

GDE director

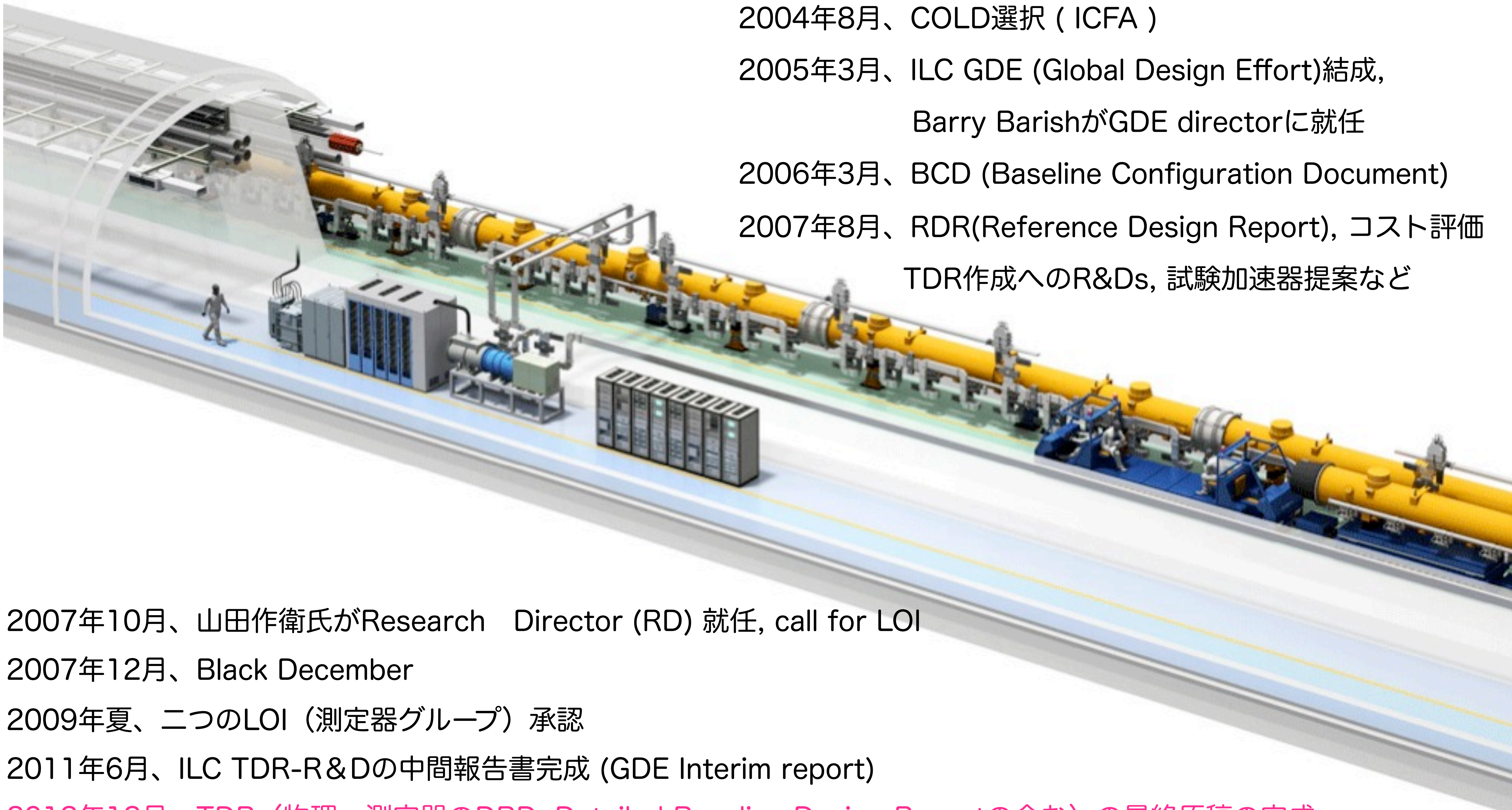
Accelerator Systems :BDS

(WG4@RDR)

collective view of requirements from detector /physics

国際リニアコライダー (ILC)

超伝導加速空洞による全長約31kmの線形加速器



2004年8月、COLD選択 (ICFA)

2005年3月、ILC GDE (Global Design Effort)結成,
Barry BarishがGDE directorに就任

2006年3月、BCD (Baseline Configuration Document)

2007年8月、RDR(Reference Design Report), コスト評価
TDR作成へのR&Ds, 試験加速器提案など

2007年10月、山田作衛氏がResearch　Director (RD) 就任, call for LOI

2007年12月、Black December

2009年夏、二つのLOI（測定器グループ）承認

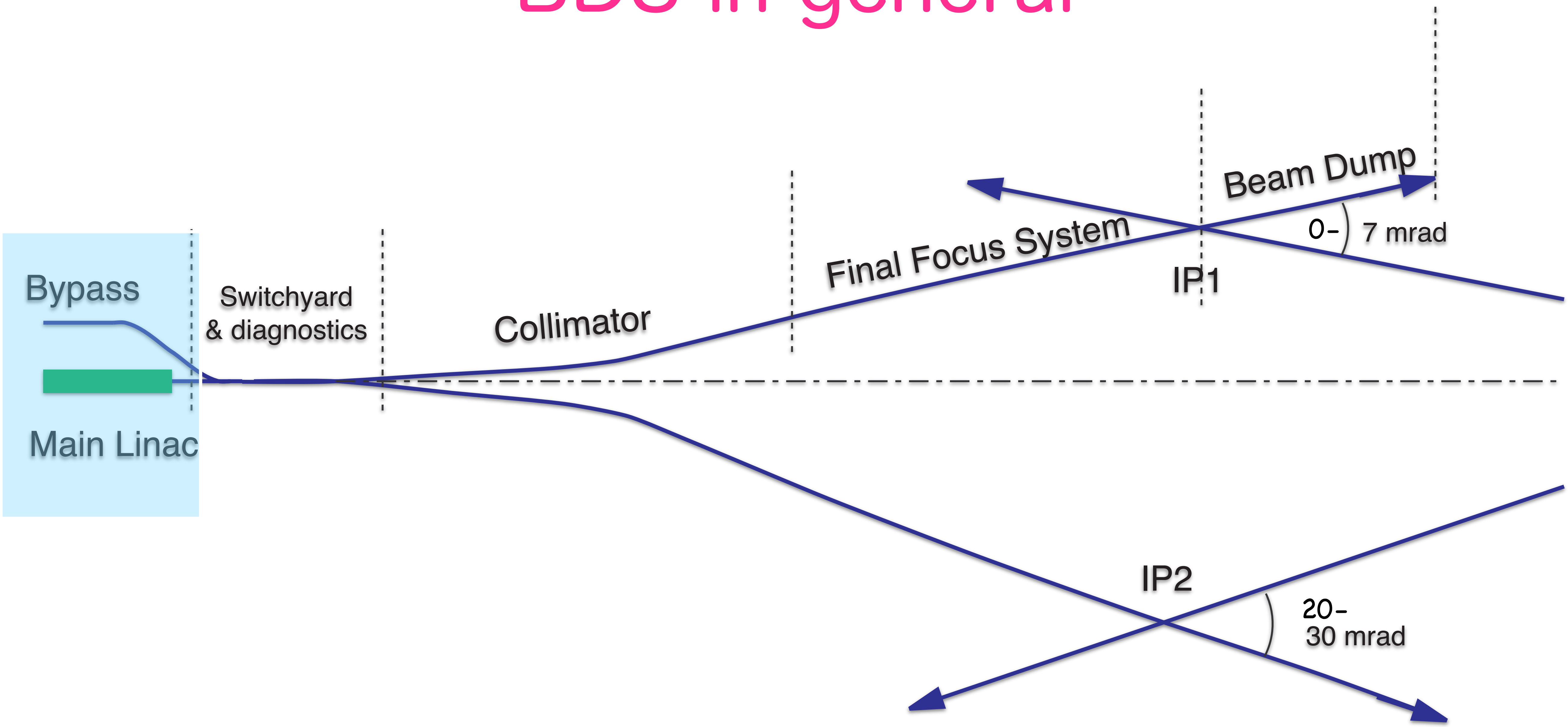
2011年6月、ILC TDR-R＆Dの中間報告書完成 (GDE Interim report)

2012年12月、TDR（物理・測定器のDBD, Detailed Baseline Design Reportの含む）の最終原稿の完成

2013年2月、新しいLinear Collider Collaboration結成，Lyn Evansが そのdirectorに就任

2013年6月、TDR完成

BDS in general



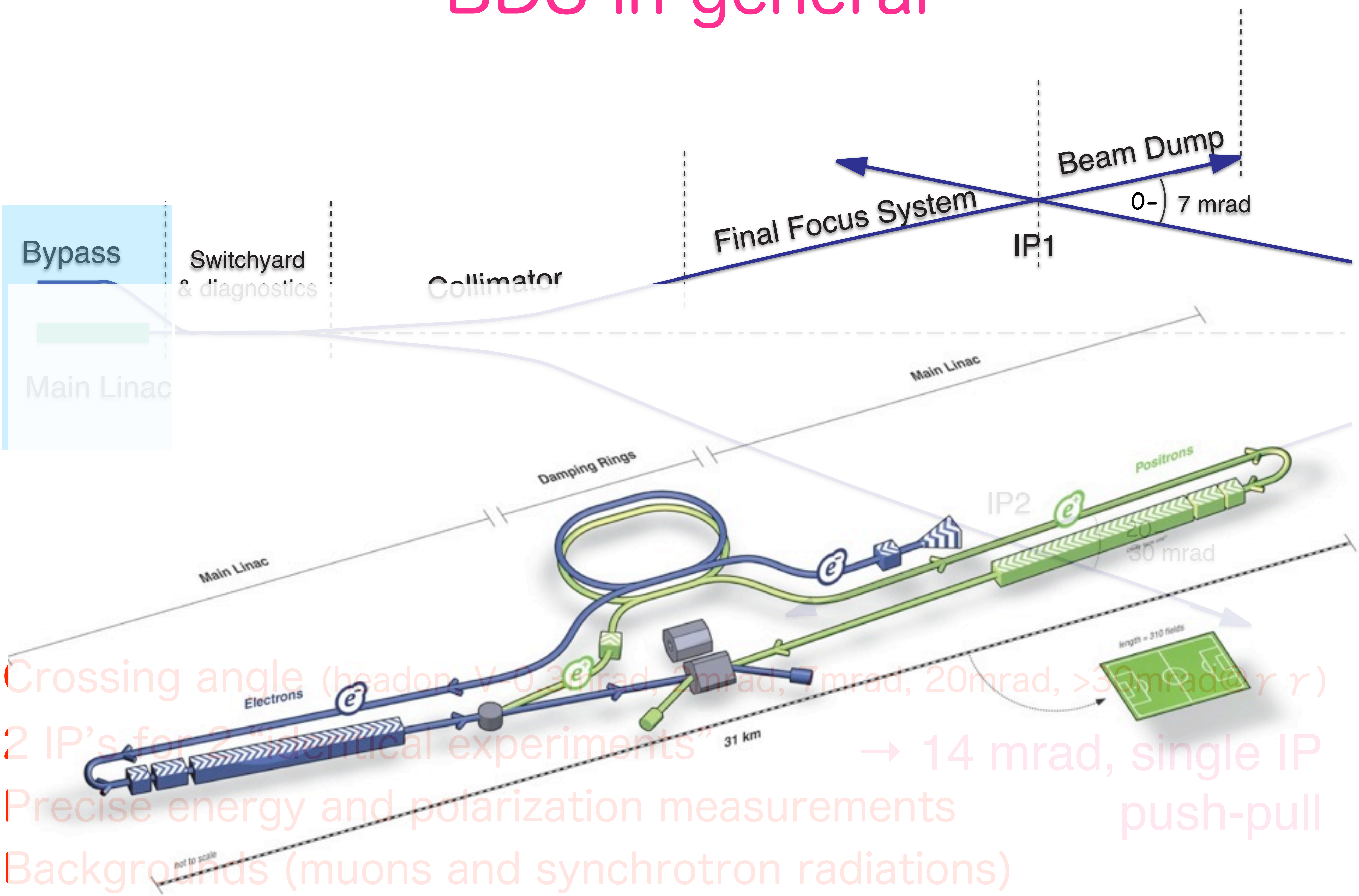
Crossing angle (headon, V-0.3mrad, 2mrad, 7mrad, 20mrad, >30mrad@$\gamma\gamma$)

2 IP's for 2 "identical experiments" → 14 mrad, single IP push-pull

Precise energy and polarization measurements

Backgrounds (muons and synchrotron radiations)

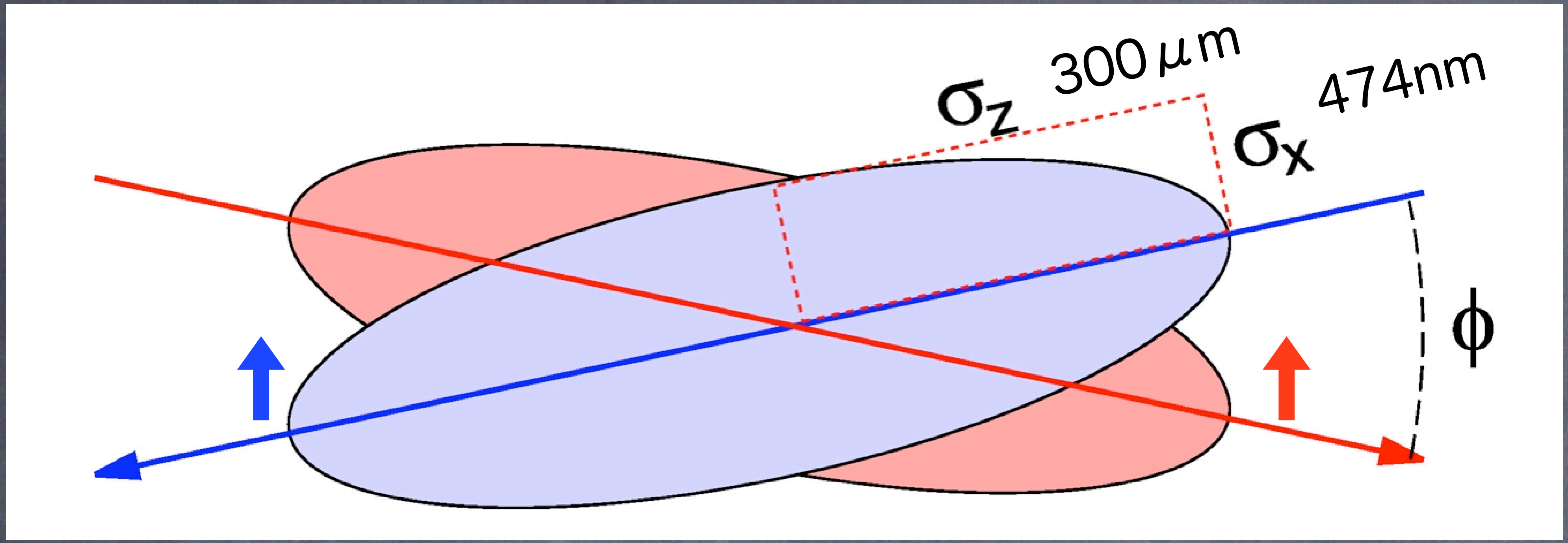
BDS in general



- Crossing angle (headon, V-0 3mrad, 2mrad, 7mrad, 20mrad, >30mrad@$\gamma\gamma$)
- 2 IP's for 2 "identical experiments" → 14 mrad, single IP push-pull
- Precise energy and polarization measurements
- Backgrounds (muons and synchrotron radiations)

Two main Linac's alignment issue is beyond MDI.

Horizontal Crossing Angle



Crab Crossing
by Bob Palmer,
1988

Small angle : $\Phi < 2\sigma_x/\sigma_z > \Phi$: Large angle

~ 3 mrad

timing of two crab cavities

16(50) fsec at Φ=20(7) mrad

easy extraction line

smaller dead cone (θ)

smaller back scattering ?

radiation/bend in solenoid

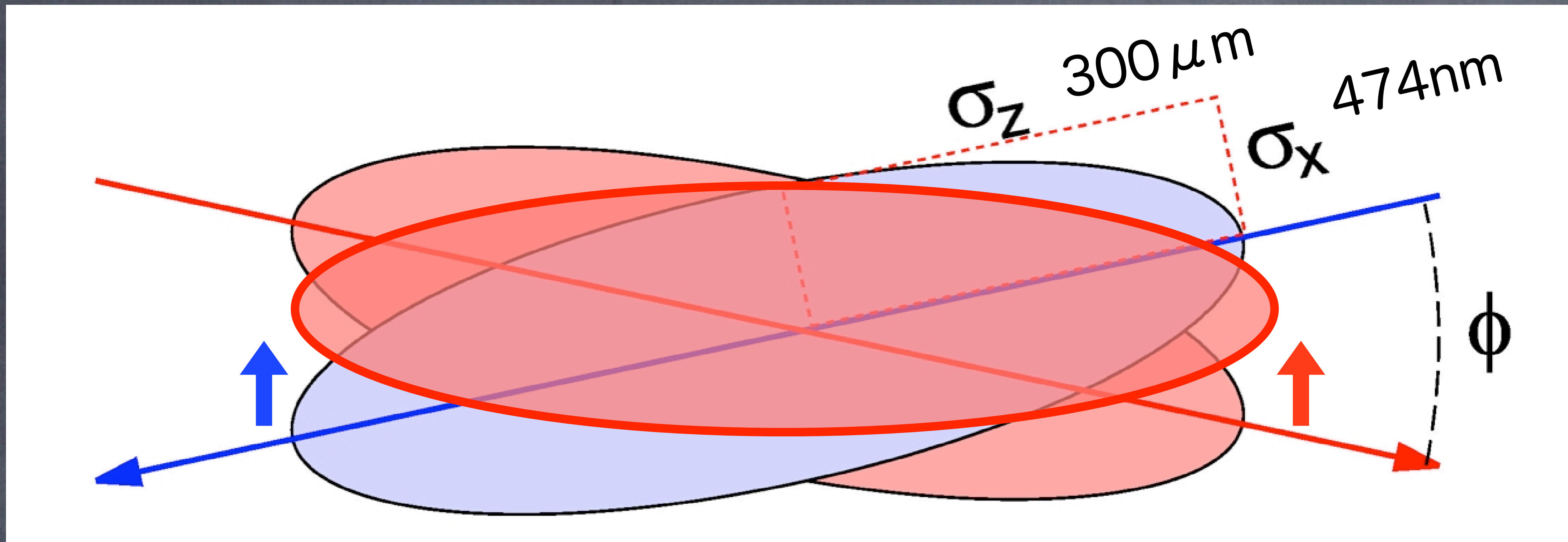
$\Delta\sigma_y^2 \propto (B\Phi L^*)^5$, $\Delta y' = B\Phi/(2B\rho)$

Δ(spin)=3.25°/100μrad (E/250GeV)

multi-bunch instability

irrelevant in “cold”

Horizontal Crossing Angle



Crab Crossing
by Bob Palmer,
1988

Small angle : $\Phi < 2\sigma_x/\sigma_z > \Phi$: Large angle

~ 3 mrad

timing of two crab cavities

16(50) fsec at Φ=20(7) mrad

easy extraction line

smaller dead cone (θ)

smaller back scattering ?

radiation/bend in solenoid

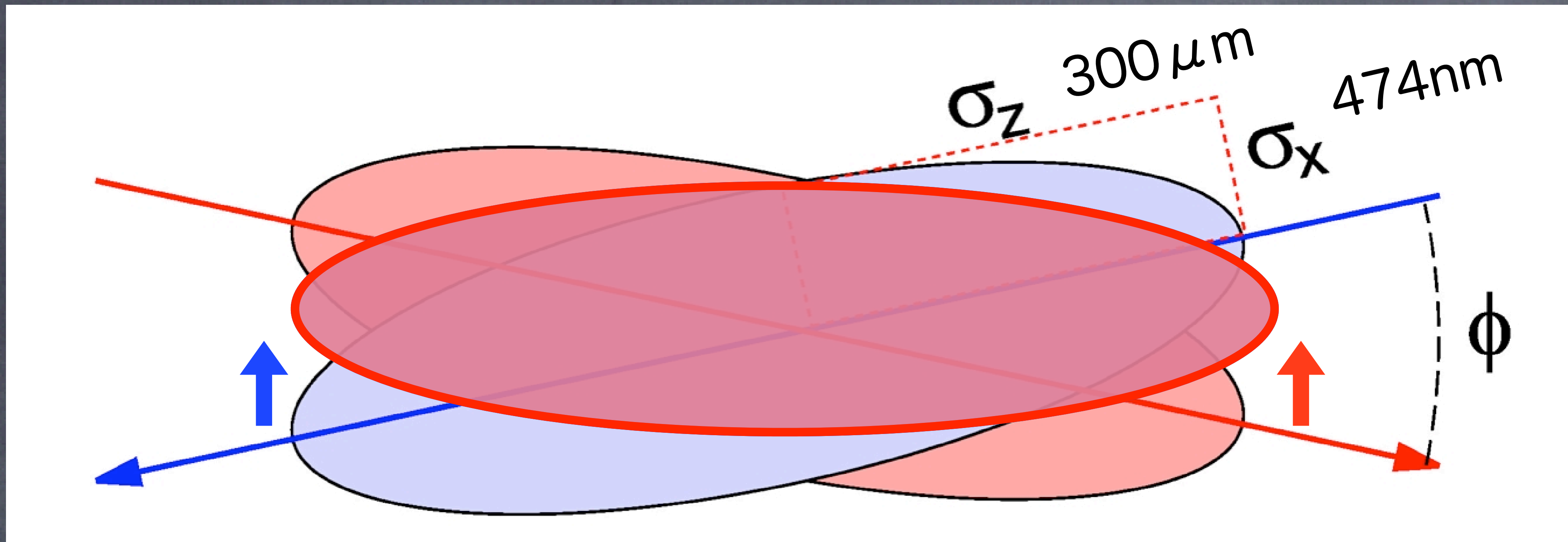
$\Delta\sigma_y^2 \propto (B\Phi L^*)^5$, $\Delta y' = B\Phi/(2B\rho)$

Δ(spin)=3.25°/100μrad (E/250GeV)

multi-bunch instability

irrelevant in “cold”

Horizontal Crossing Angle



Crab Crossing
by Bob Palmer,
1988

Small angle : $\Phi < 2\sigma_x/\sigma_z > \Phi$: Large angle

~ 3 mrad

timing of two crab cavities

16(50) fsec at Φ=20(7) mrad

easy extraction line

smaller dead cone (θ)

smaller back scattering ?

radiation/bend in solenoid

$\Delta\sigma_y^2 \propto (B\Phi L^*)^5$, $\Delta y' = B\Phi/(2B\rho)$

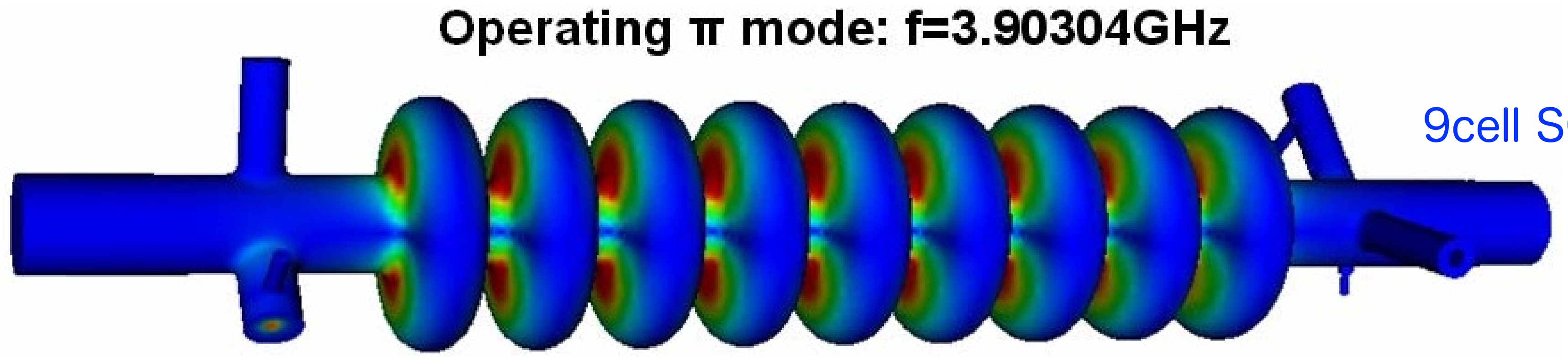
Δ(spin)=3.25°/100μrad (E/250GeV)

multi-bunch instability

irrelevant in “cold”

Crab Cavities

ILC : 2 cavities at 13.4m from IP, 2~3m long, the phase jitter < 61fsec

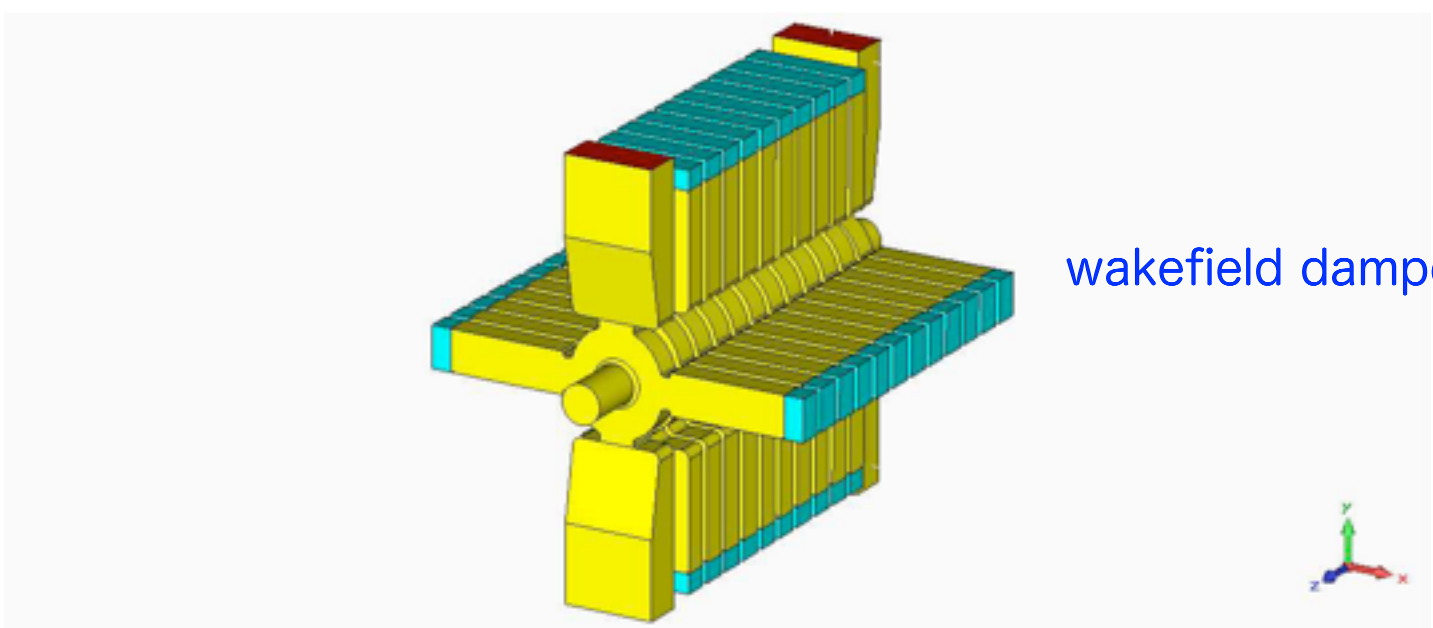


9cell SC cavities

Figure 10.18. Field distribution for the operating mode of the 3.9 GHz crab cavity

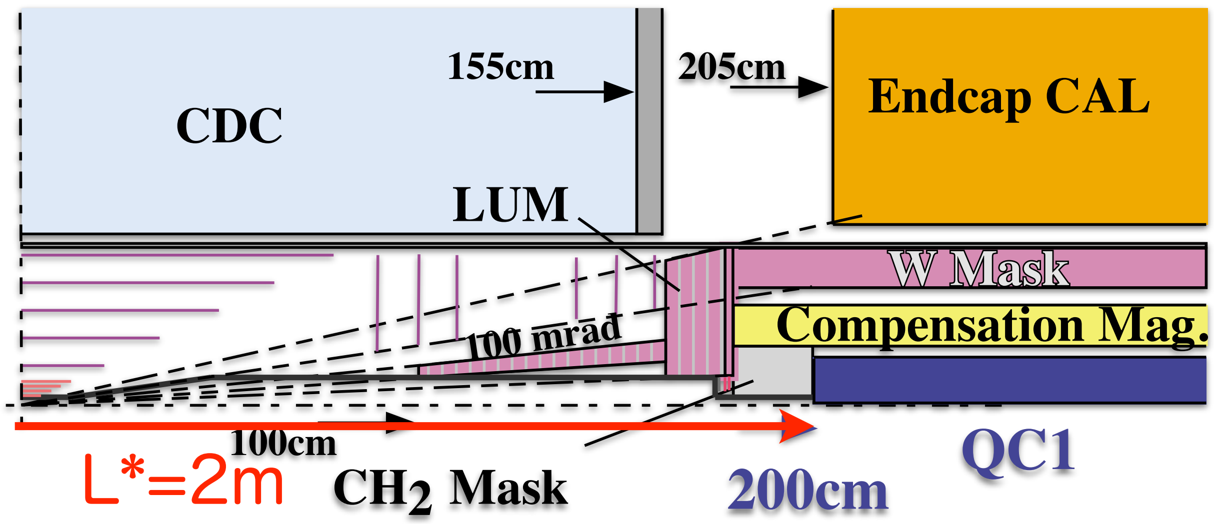
CLIC : ~3m long, the phase jitter < 0.02°(4.6fsec) and amplitude<2% at 12GHz

2% luminosity loss

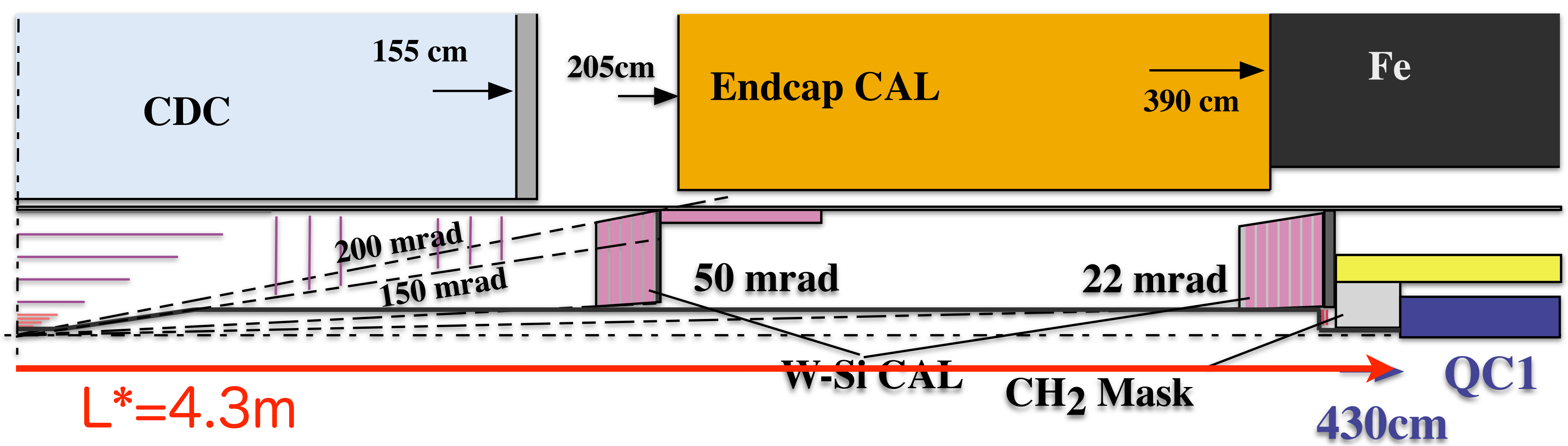


wakefield dampers

Interaction Region (IR)



L* = 2 → 4.3m
by the local chromaticity correction
(P.Raimondi, A.Seryi, 2001)



L* : Distance of QD0(QC1) from IP

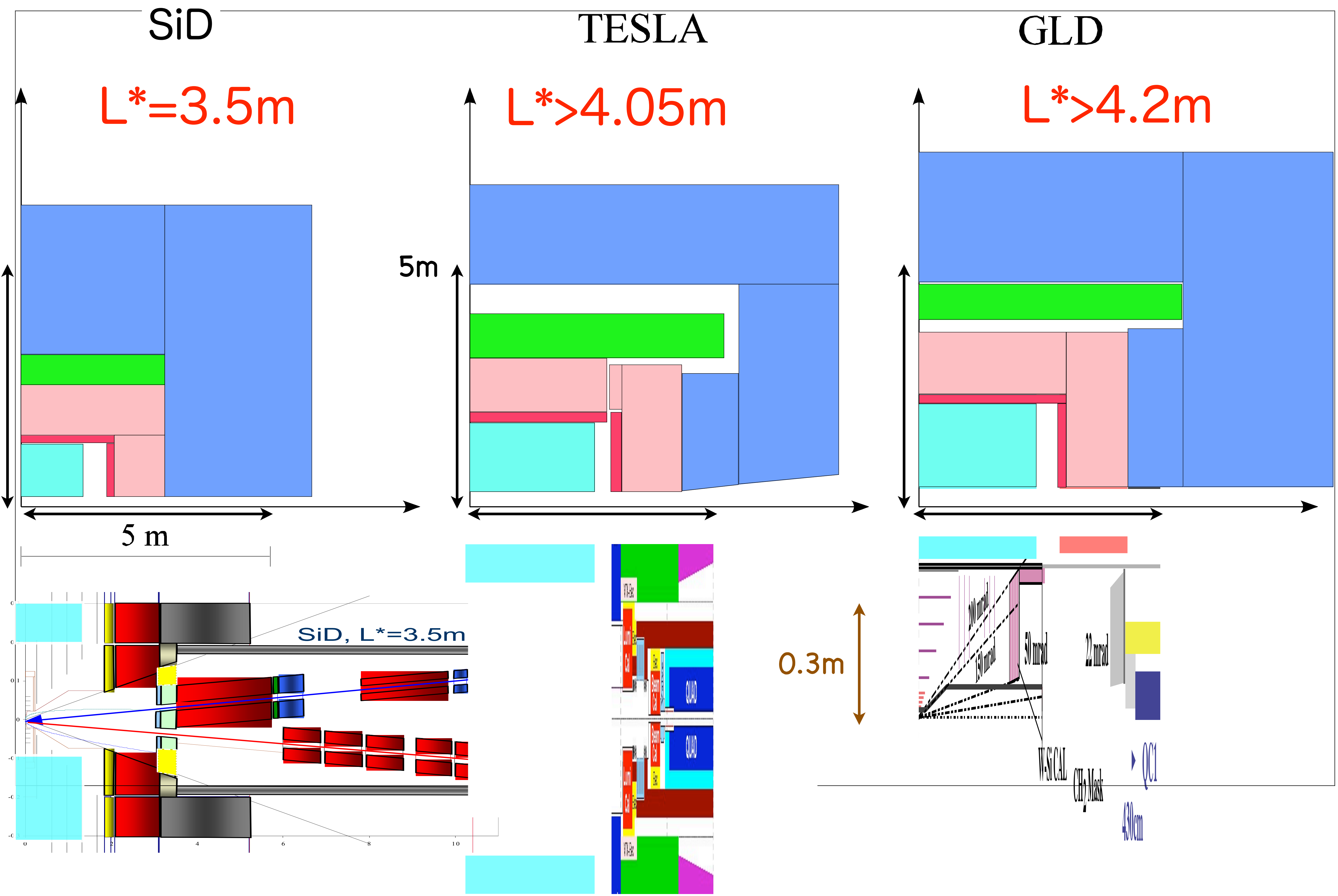
Vertex R (the innermost radius)

Minimum veto-angle (very forward calorimeter)

Backgrounds (pairs, mini-jets, backscattered γ and n)

Instrumentations (pair monitor, feedback, Shintake monitor ...)

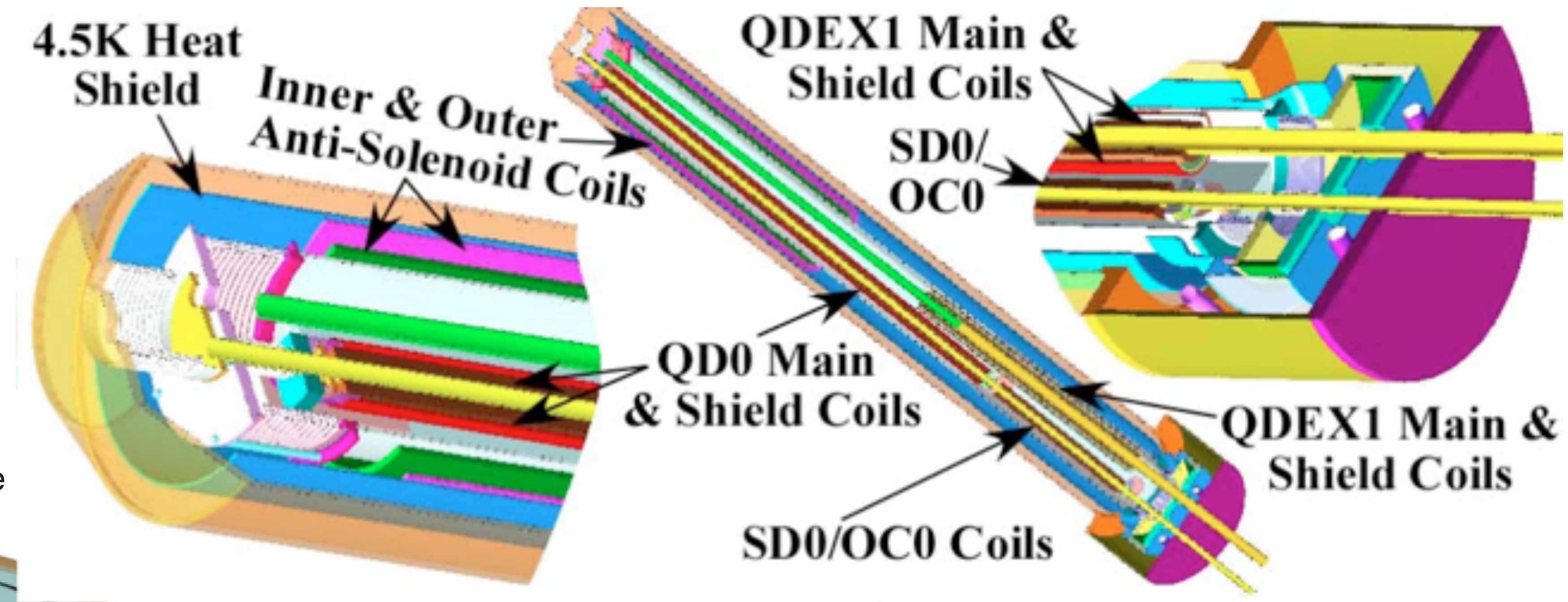
Choice of L*

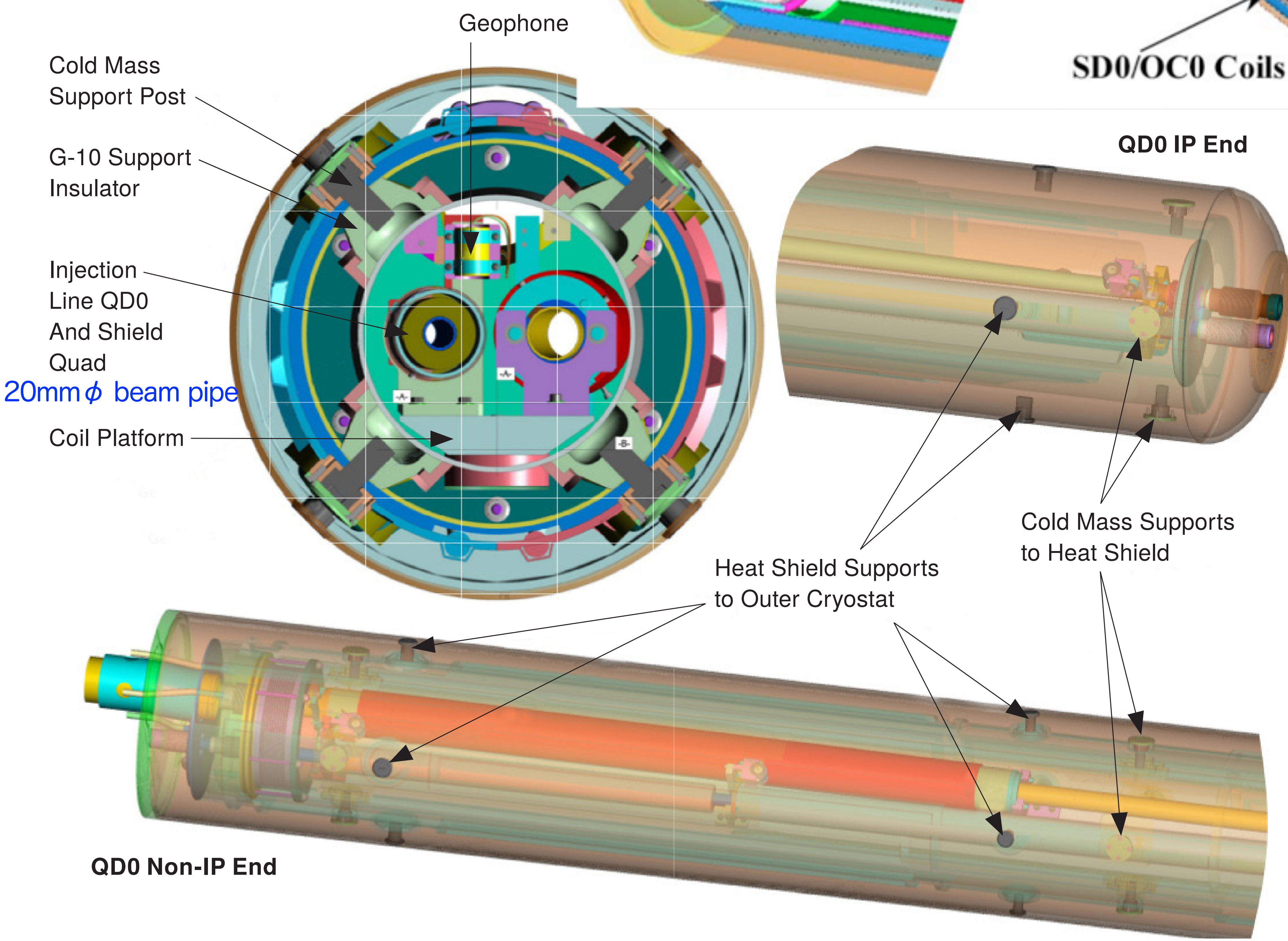

SiD
TESLA
GLD
L*=3.5m
L*>4.05m
L*>4.2m
5m
5 m
SiD, L*=3.5m
QUAD
0.3m
50 mrad
22 mrad
W-Si CAL
QC1

LC Parameters

parameter	symbol	unit	ILC (TDR)	"ILC-$\gamma\gamma$" V.Telnov's idea	CLIC (CDR)
energy	E	GeV	250	250	1,500(250)
emittance	$\gamma\varepsilon_x/\gamma\varepsilon_y$	μm	10/0.035	2.5/0.03	0.66/0.02
IP beta function	β^*_x/β^*_y	mm	11/0.48	1.5/0.3	6.9/0.068 (8/0.1)
IP beam size	σ^*_x/σ^*_y	nm	474/5.9	88/4.3	45/0.9 (202/2.3)
<Upsilon> $\gamma B_{beam}/B_{critical}$	Υ_{ave}		0.063	0.33	5 (0.2)
max. deflection angle	θ_d (θ_0, θ_0/x)	mrad	0.5	10 (e^-)	10 (coh.pair) $E_{coh.pair}/E > 0.05/\Upsilon$
crossing angle FD distance, aperture	Φ $>\theta_d+R_Q/L^*$ L^*, R_Q	mrad m, cm	14 L^*=3.5- 4.5 R_Q=2.8	25 L^*=4, R_Q=6	20 (18.6) L^*=3.5-4.3, R_Q=3.7
other				γ dump	

FD
ILC QD0 : SCQ





CLIC QD0 : Hybrid magnet

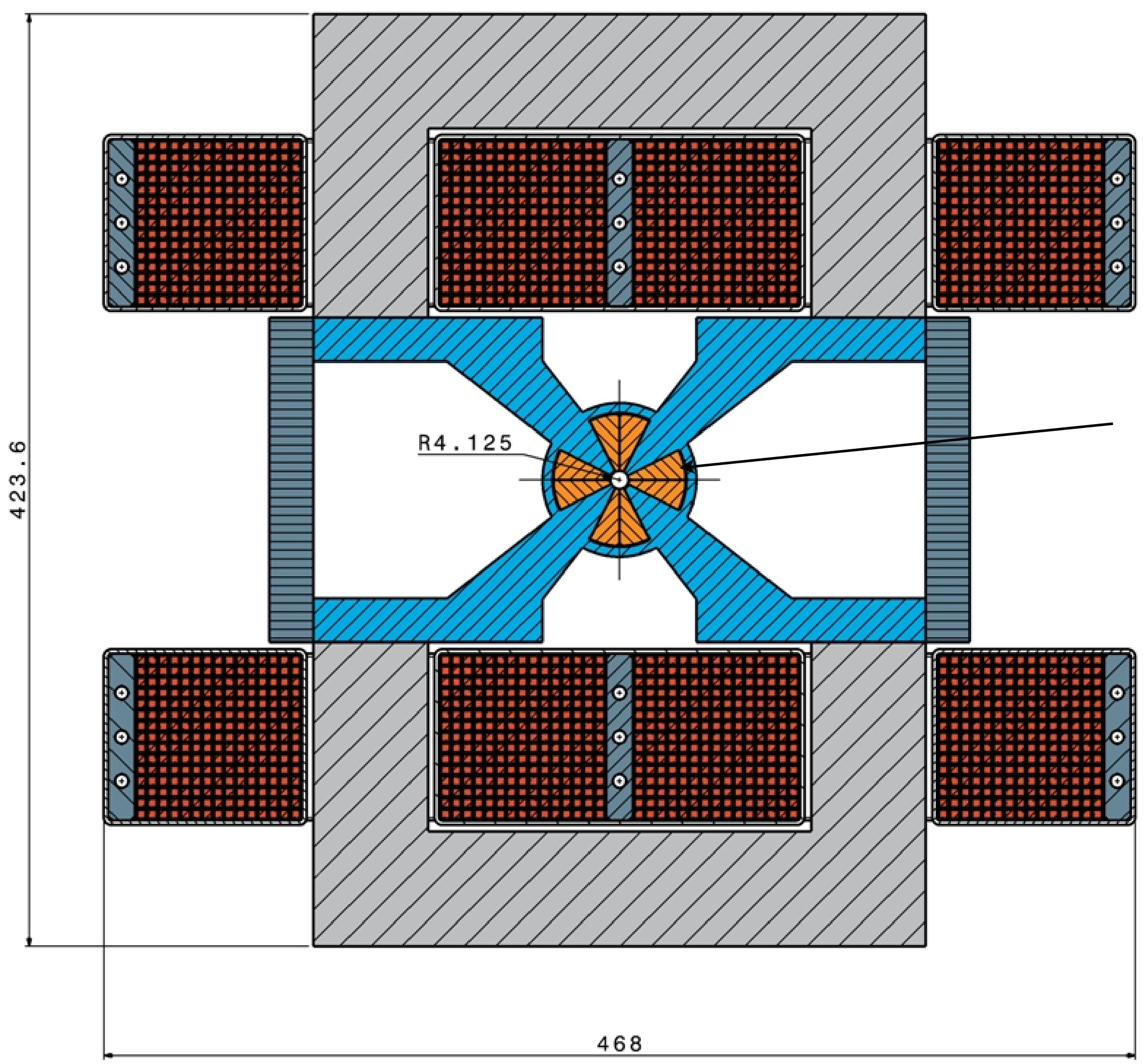


Table 4: Specifications of the FD QD0 quadrupole for the different L* cases.

L*	m	3.5	4.3	6.0	8.0
Gradient	T/m	575	382	200	211
Length	m	2.7	3.3	4.7	4.2
Beam aperture	mm	3.8	6.7	8	8.5
Jitter tolerance	nm	0.15	0.15	0.2	0.18
Gradient tol	10^{-6}	5	5	-	3
Octupolar error	10^{-4}@1mm	7	7	-	3
Prealignment	μm	10	10	8	2

permanent magnets

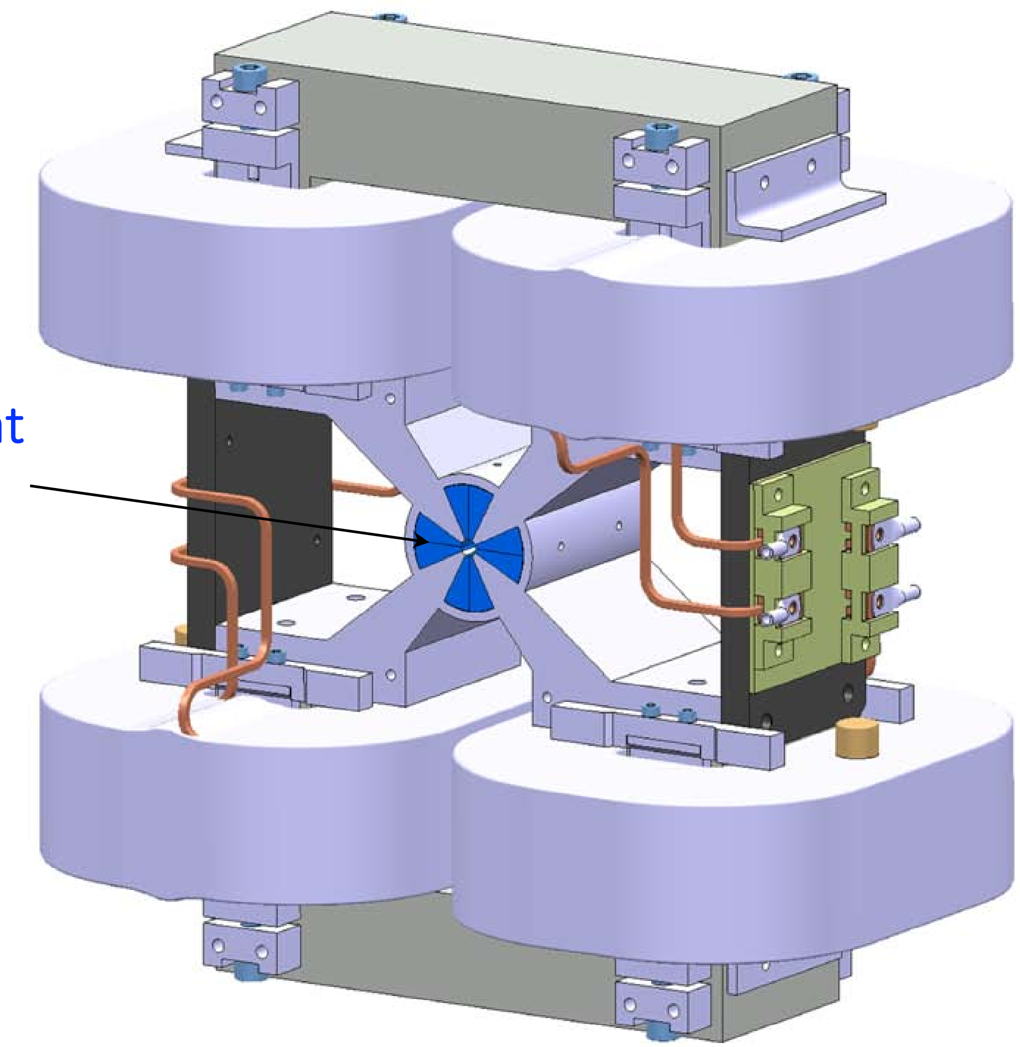


Fig. 5.289: Hybrid QD0 short prototype

with the same cross section but shorter length, which performs close to the specifications

Anti-DID

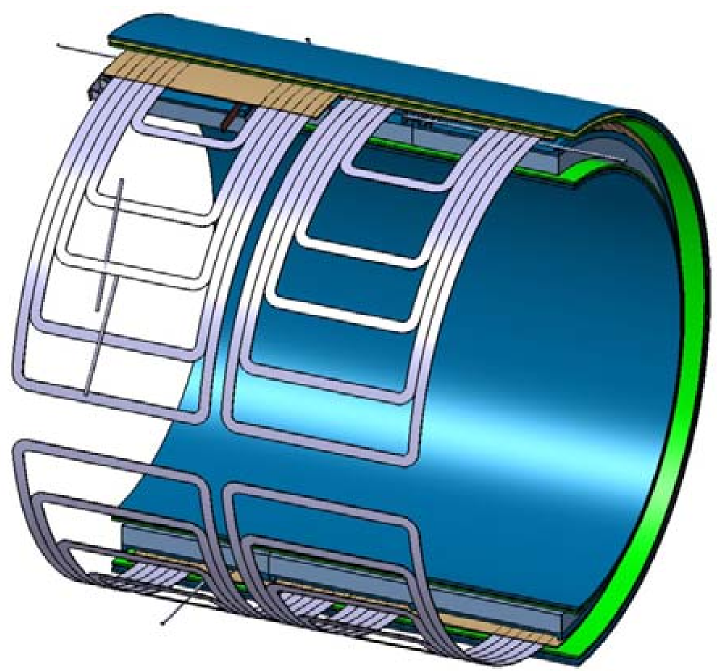
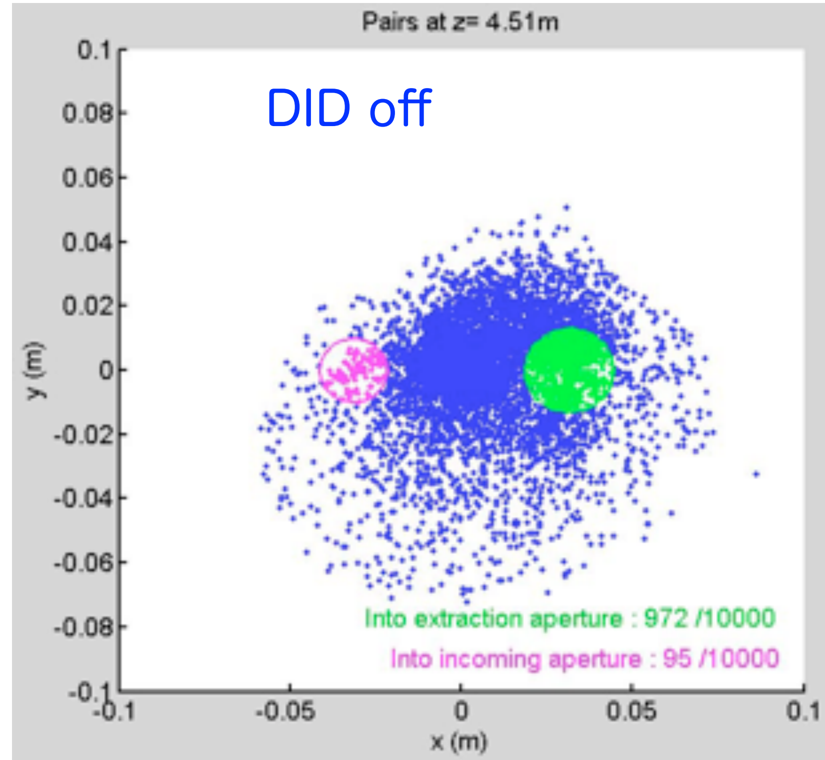
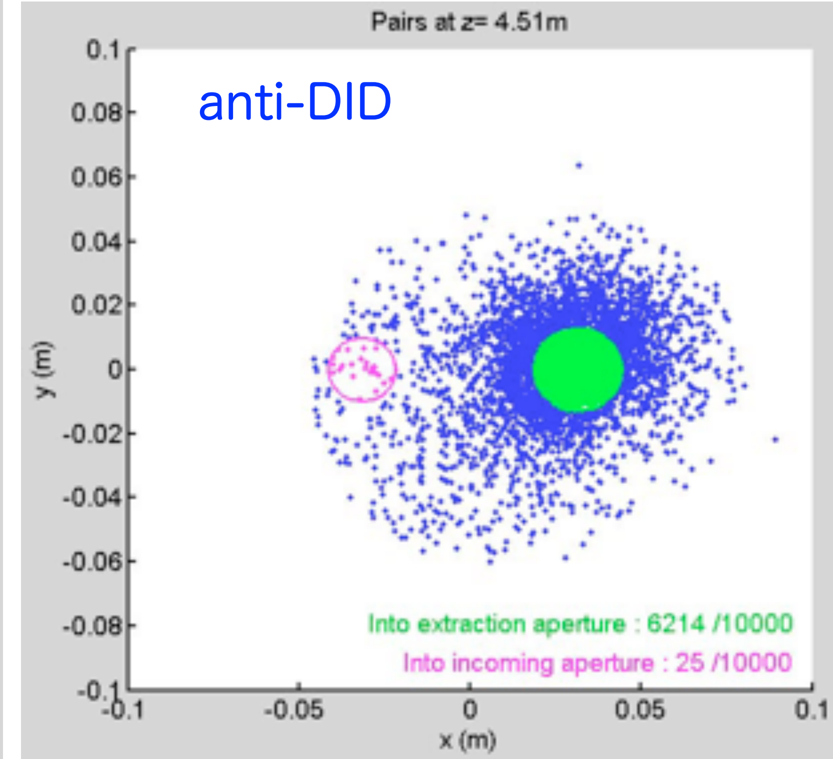
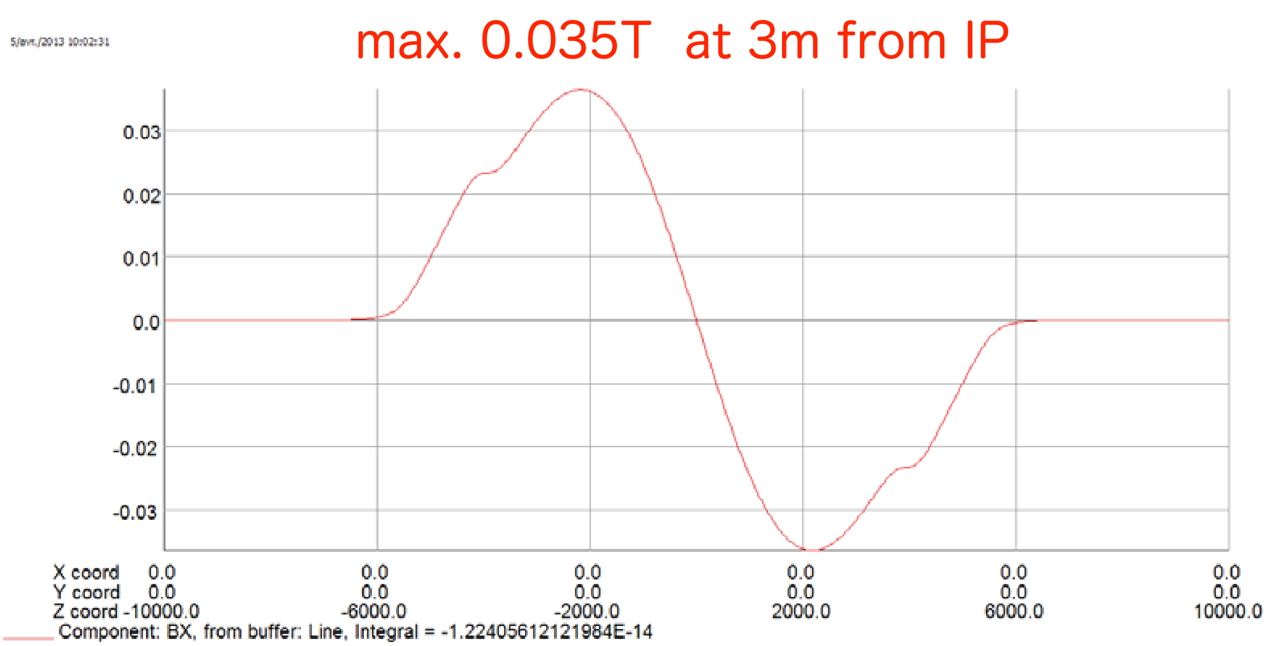


Figure 13: 3D view of the anti-DID (version 1).







Opera

Figure 14: Dipolar field $B_x = f(z)$ generated by the anti-DID (version 1). (Numbers on the vertical axis for B_x given are in T, labels on the horizontal axis for z are in mm).

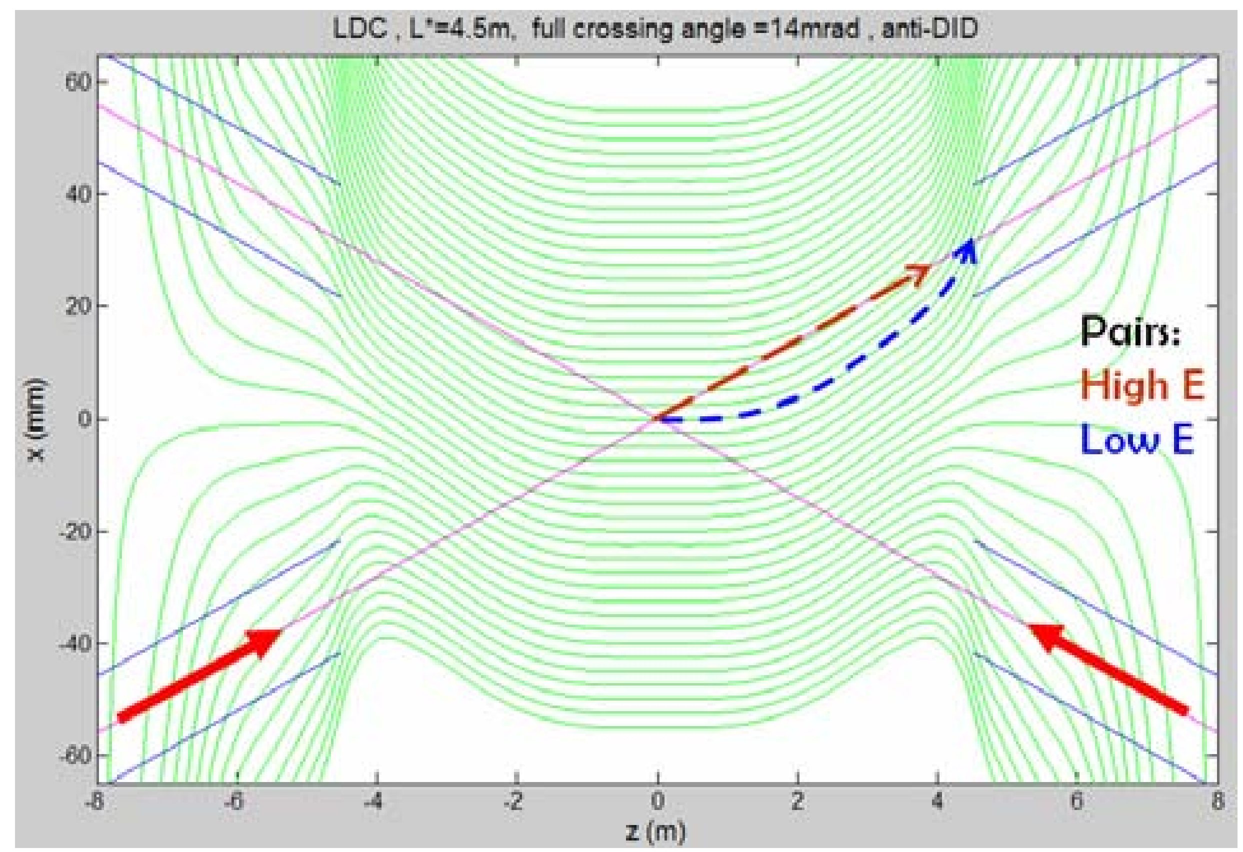
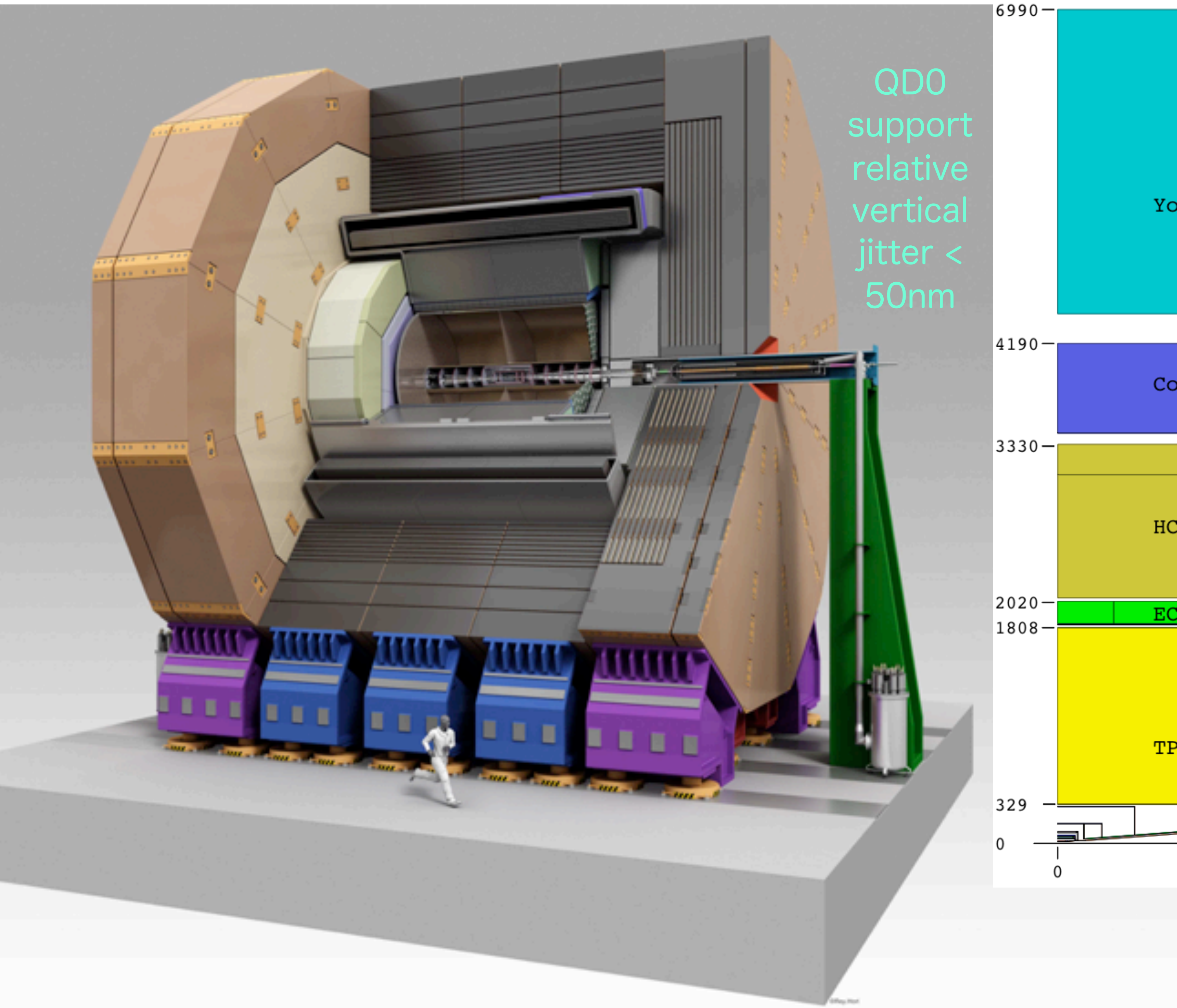


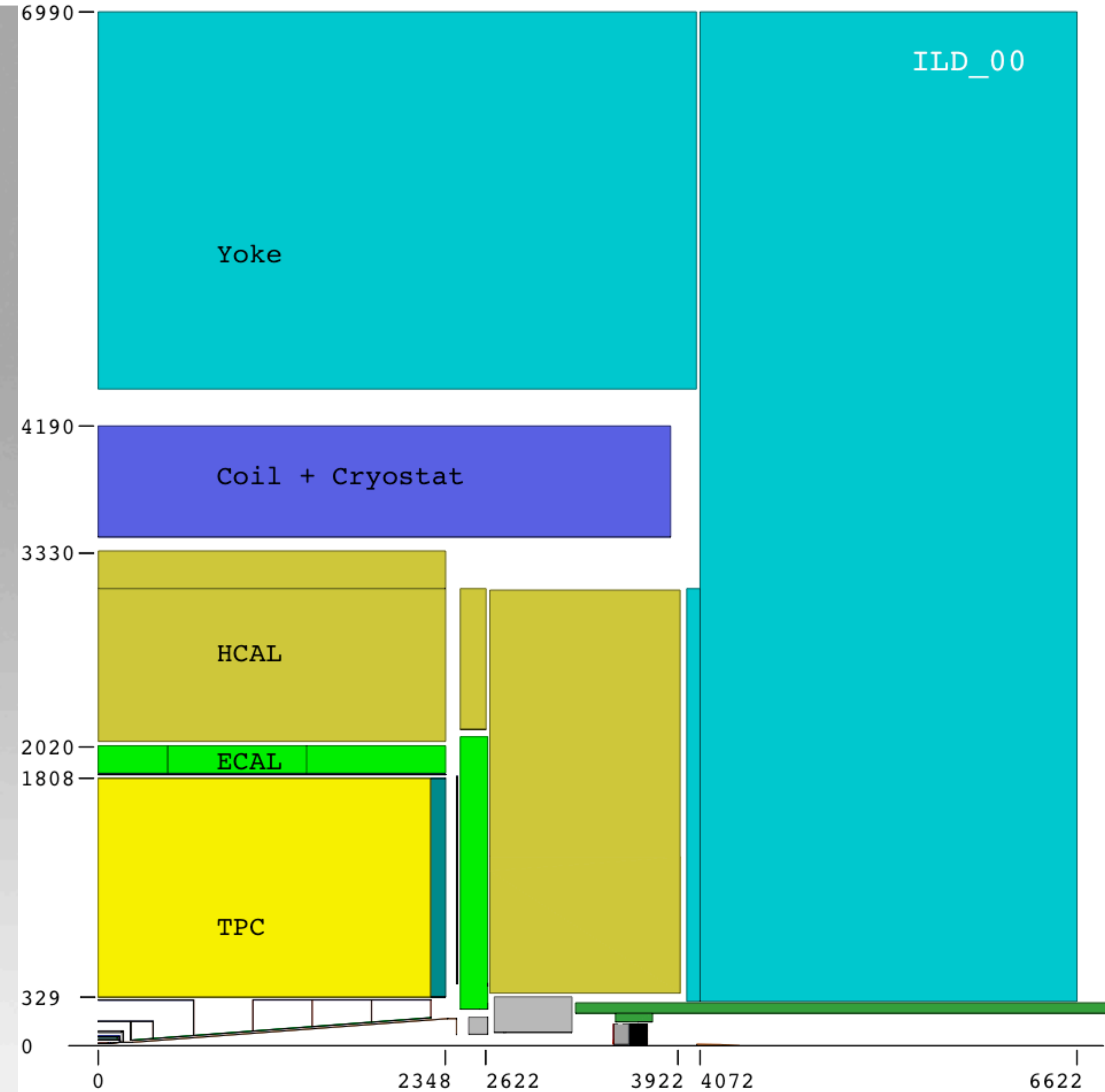
Figure 4: Field lines in LDC detector with anti-DID. The anti-DID field shape has flattened central region, to ease TPC calibration. The total crossing angle is 14mrad.

International Large Detector (ILD)

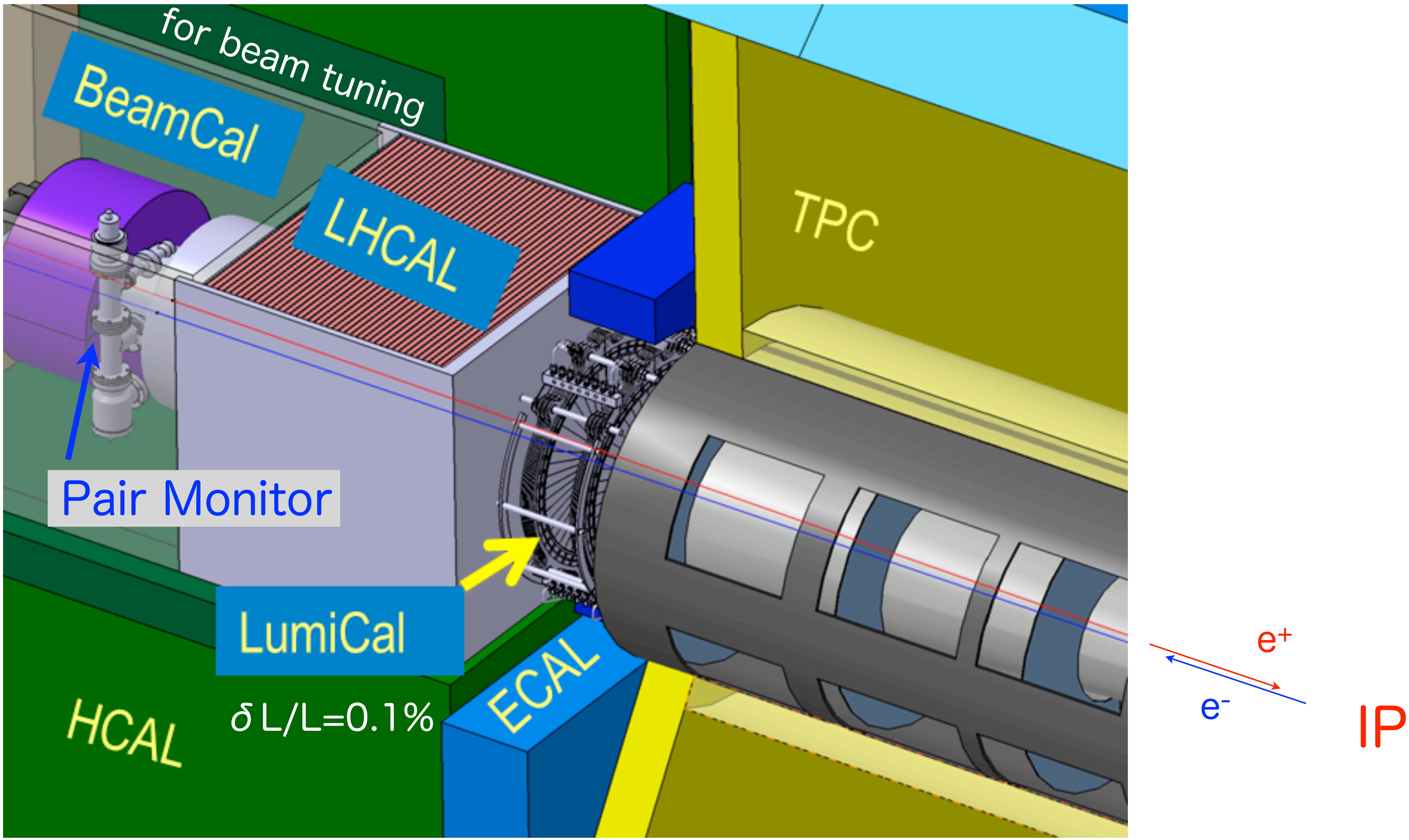
Detector solenoid : 3.5T

ILD is on purpose a large detector. At large radii particles within a jet are more separated, thus making it easier to measure them precisely. Having a large inner radius of the calorimeter does open the possibility to use a technology like the TPC as a central tracker. Last but not the least a large detector adapts more easily to higher energies of the collider than originally designed for.





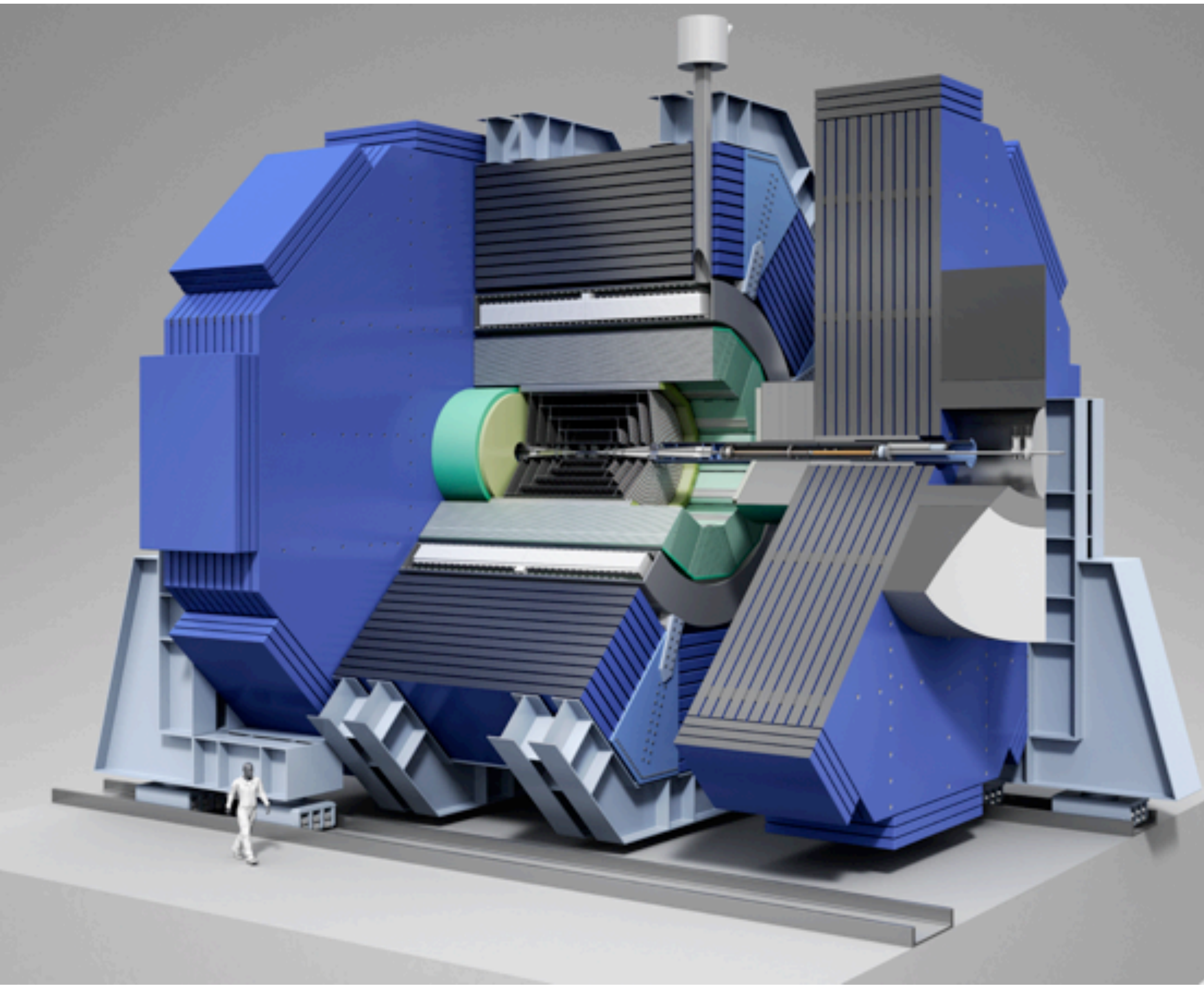
Forward Calorimeter System for MDI

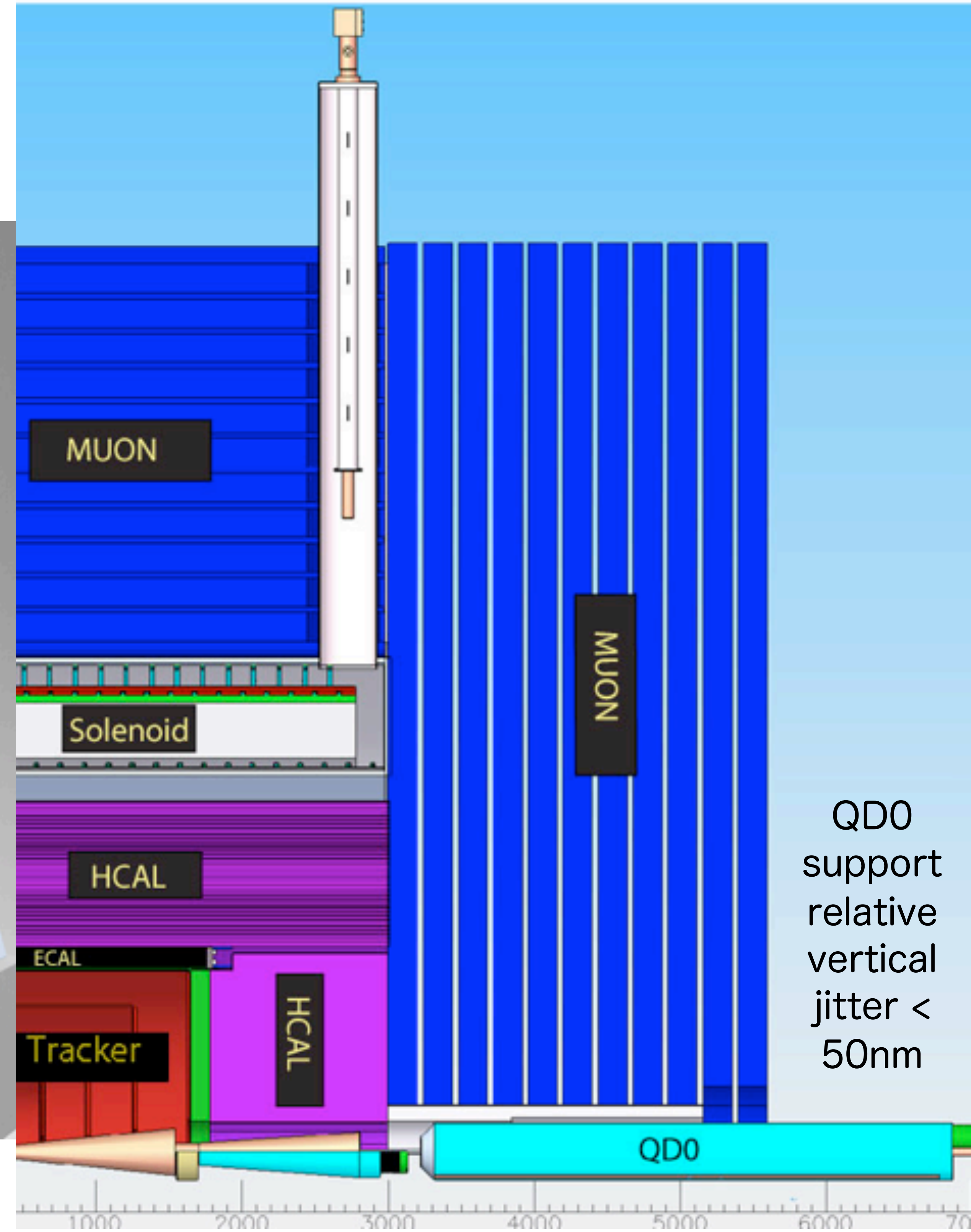


Silicon Detector (SID)

Detector solenoid : 5T

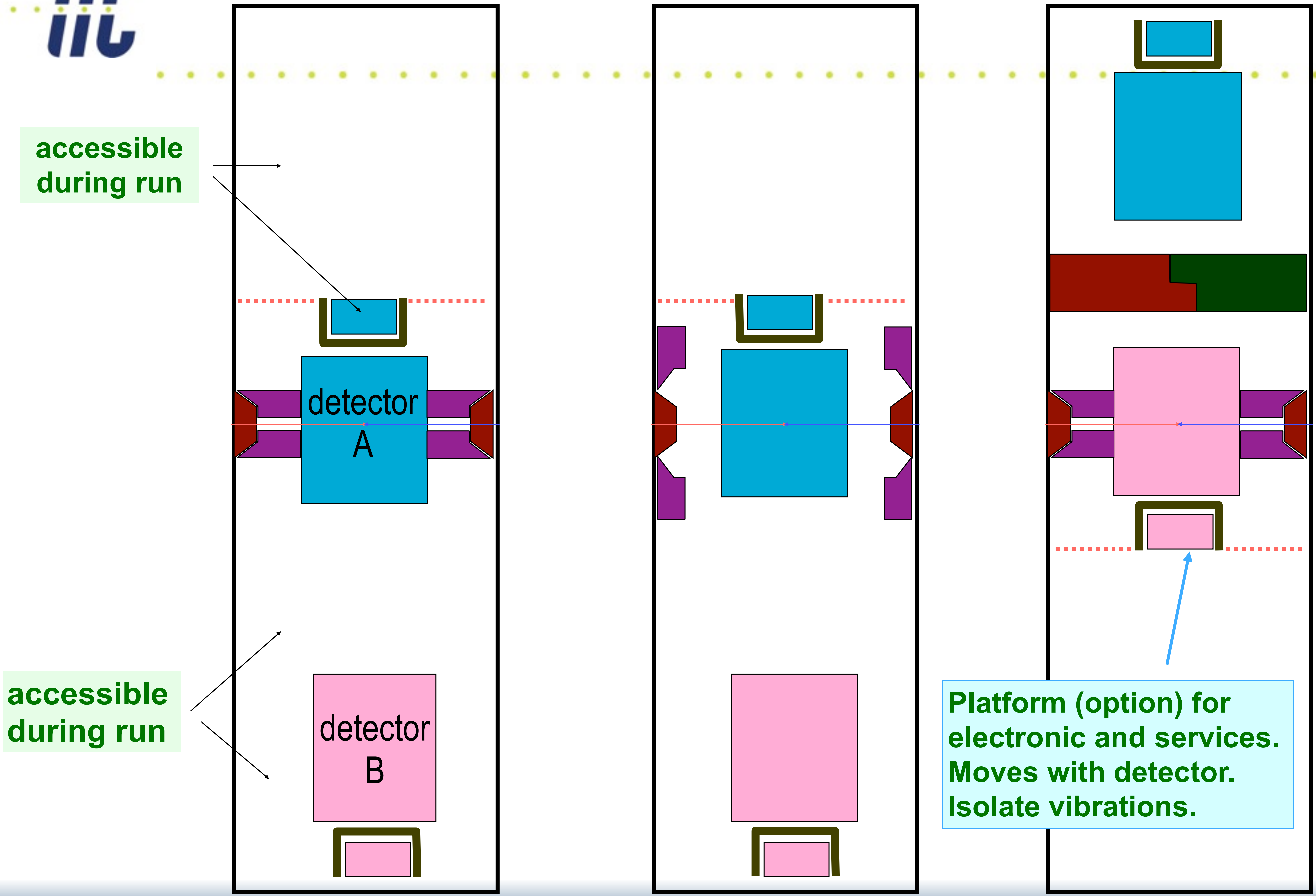
a powerful silicon pixel vertex detector, silicon tracking, silicon-tungsten electromagnetic calorimetry and highly segmented hadronic calorimetry.





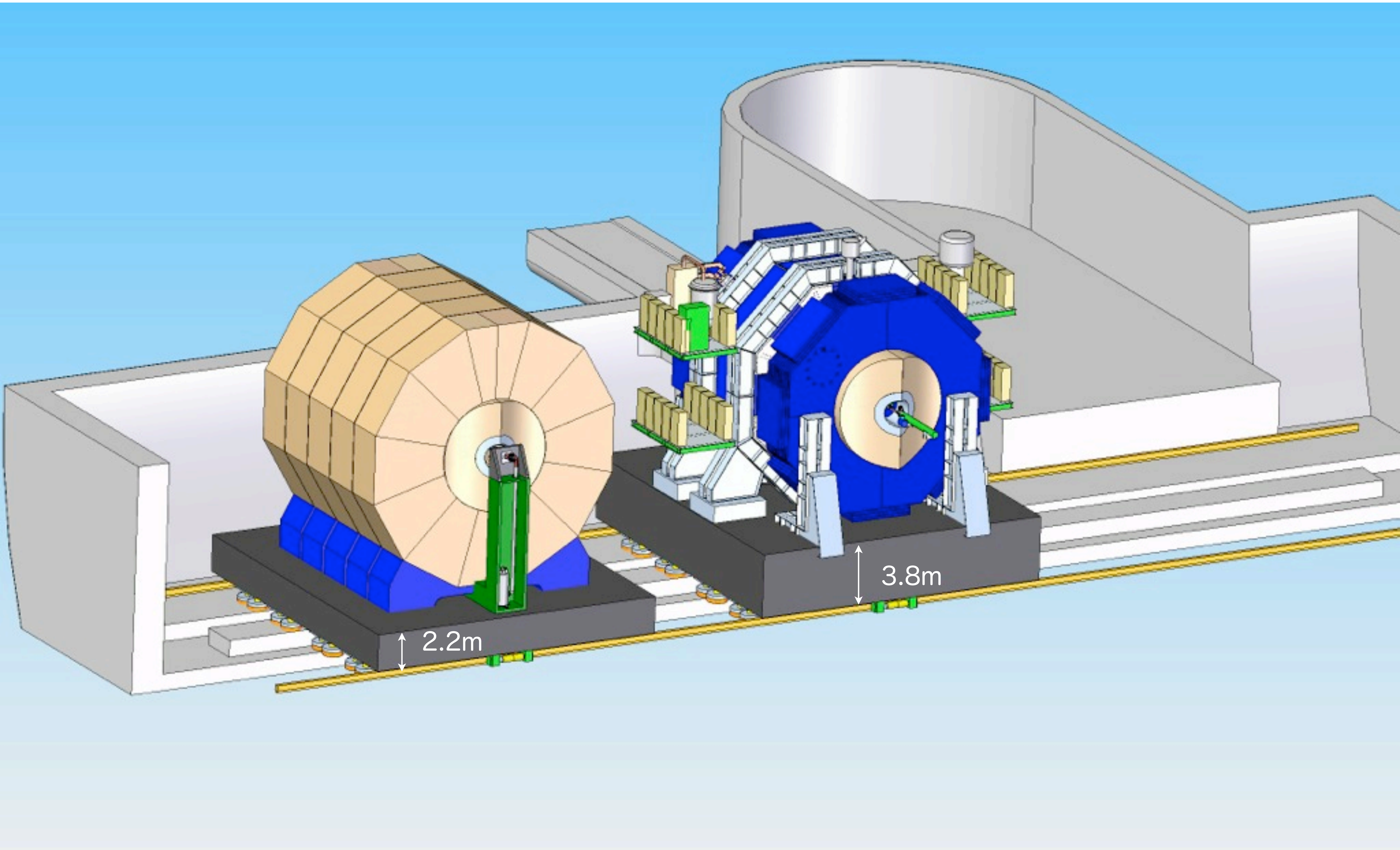
QD0 support relative vertical jitter < 50nm

Concept of single IR with two detectors



ILD and SID moving on platforms

Agreed at ALCPG11, March 19-23,2011, Eugene, OR, USA,

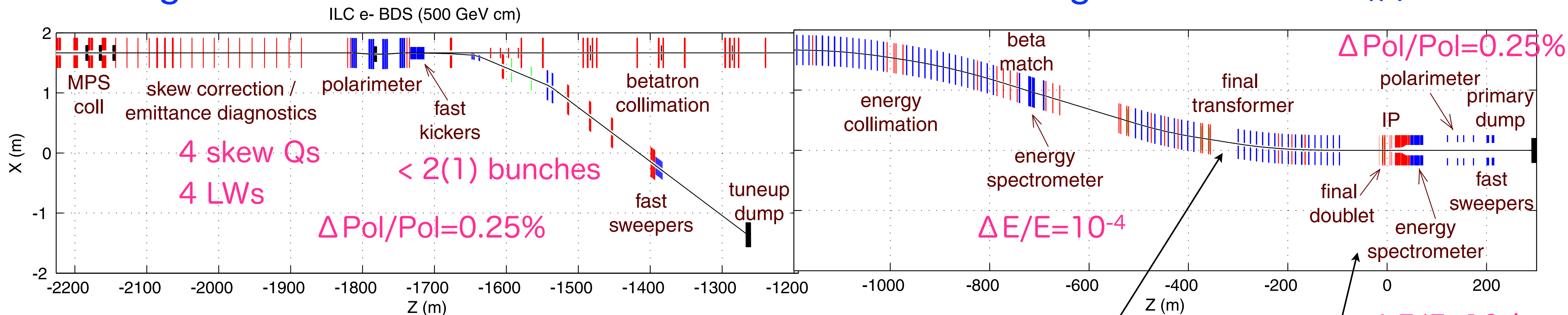


ILC BDS, E_{cm} =500GeV

to accommodate the upgrade to 1TeV center-of-mass energy

electron beam

Diagnostics　Collimation　Matching　Final Focus　IR　EXT& Dump



ΔE/E=10^{-4}

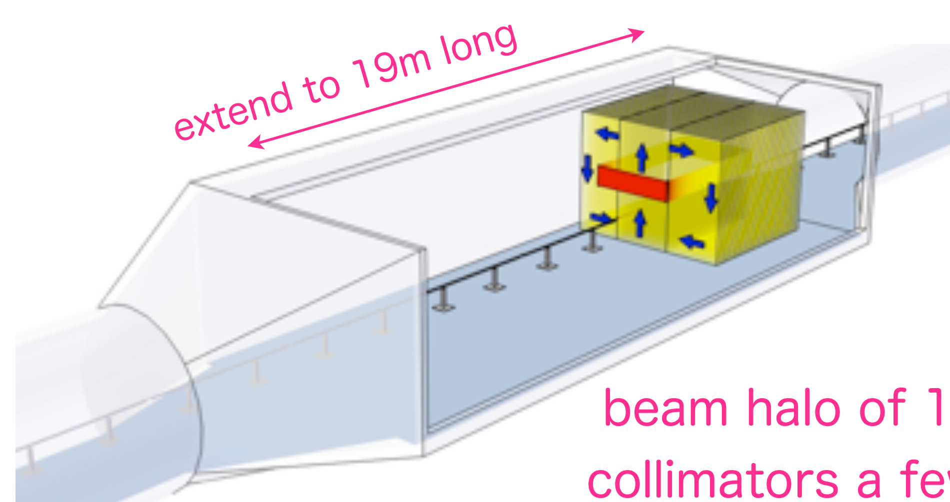
collimation depth = $9\sigma_x$ x $65\sigma_y$,
$\Delta\varepsilon_{x/y}/\varepsilon_{x/y}$=0.08%/4.4%

5m-long magnetized muon shield(1.5T)

σ_x=474nm
σ_y=5.9nm
Horizontal crossing angle =14mr

$\Delta\varepsilon_x$<1% at chicanes of polarimeter and energy spectrometer

$\Delta\varepsilon_x$<0.5(1)% in bends at E_{cm}=0.5 (1) TeV

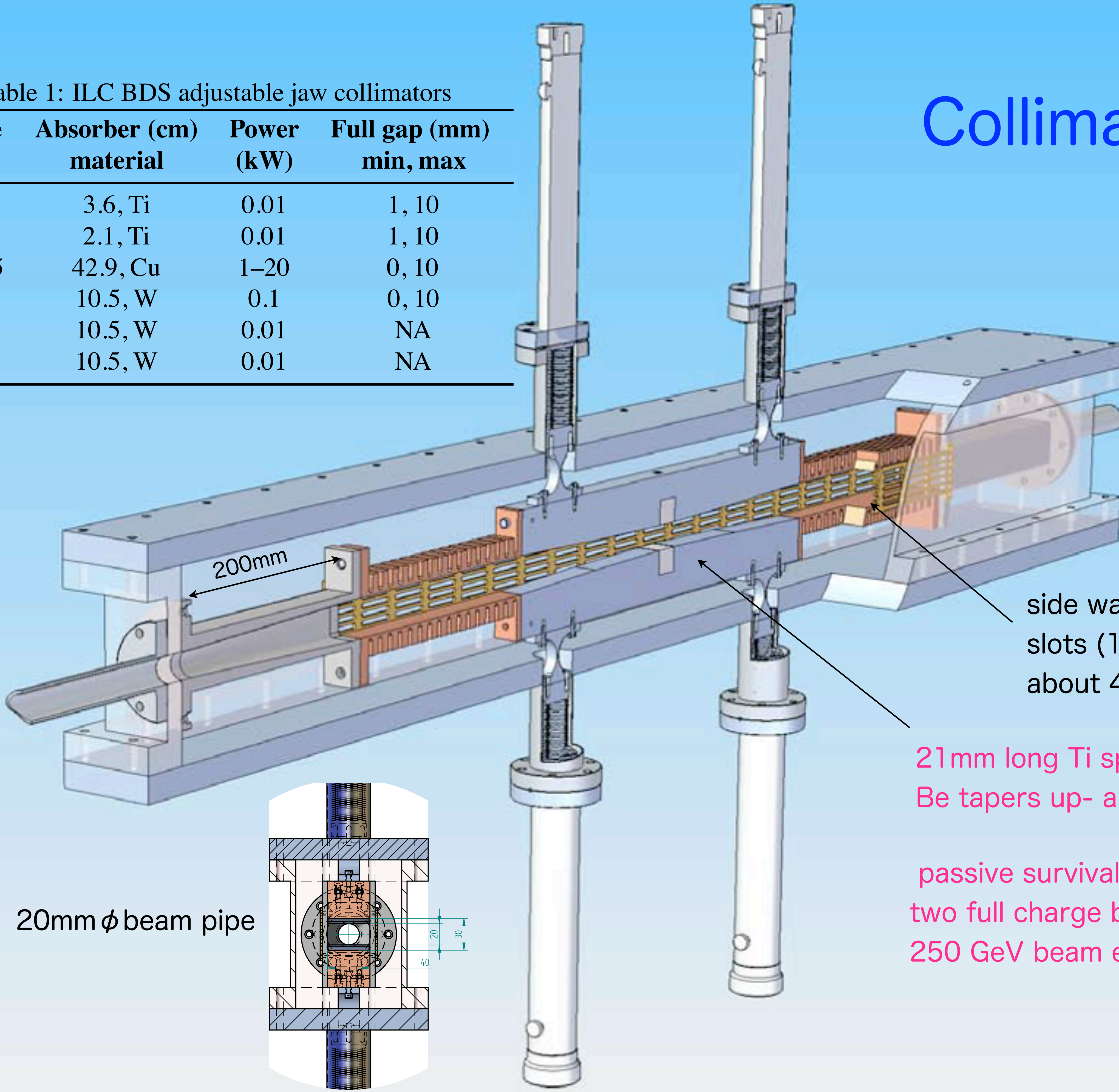


beam halo of 1-2 x 10^{-5} hit the collimators a few μ / 150 bunches

Collimator

Table 1: ILC BDS adjustable jaw collimators

Device	Absorber (cm) material	Power (kW)	Full gap (mm) min, max
SPEX	3.6, Ti	0.01	1, 10
SP1–5	2.1, Ti	0.01	1, 10
AB2–5	42.9, Cu	1–20	0, 10
ABE	10.5, W	0.1	0, 10
MSK1	10.5, W	0.01	NA
MSK2	10.5, W	0.01	NA



20mm ϕ beam pipe

side walls with pumping slots (1:1 aspect ratio, about 40% transparency)

21mm long Ti spoiler block with Be tapers up- and downstream

passive survival of spoilers up to two full charge bunch impacts at 250 GeV beam energy

Upstream Polarimeter

$\delta P/P \sim 0.25\%$ averaging over 2 entire trains with opposite helicity

1800m upstream from IP

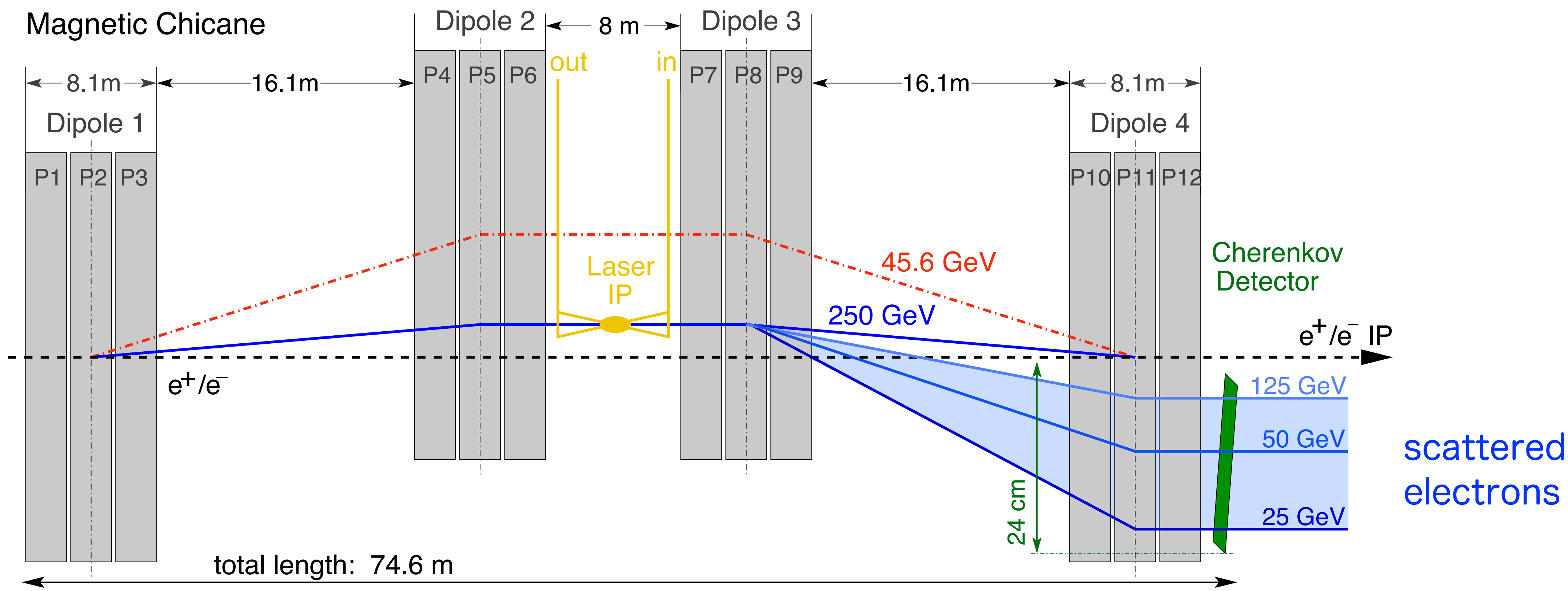


Figure 2.4.3: *Schematic of the upstream polarimeter chicane.*

Upstream Energy Spectrometer

E = 45.6GeV to 500GeV

700m upstream from IP

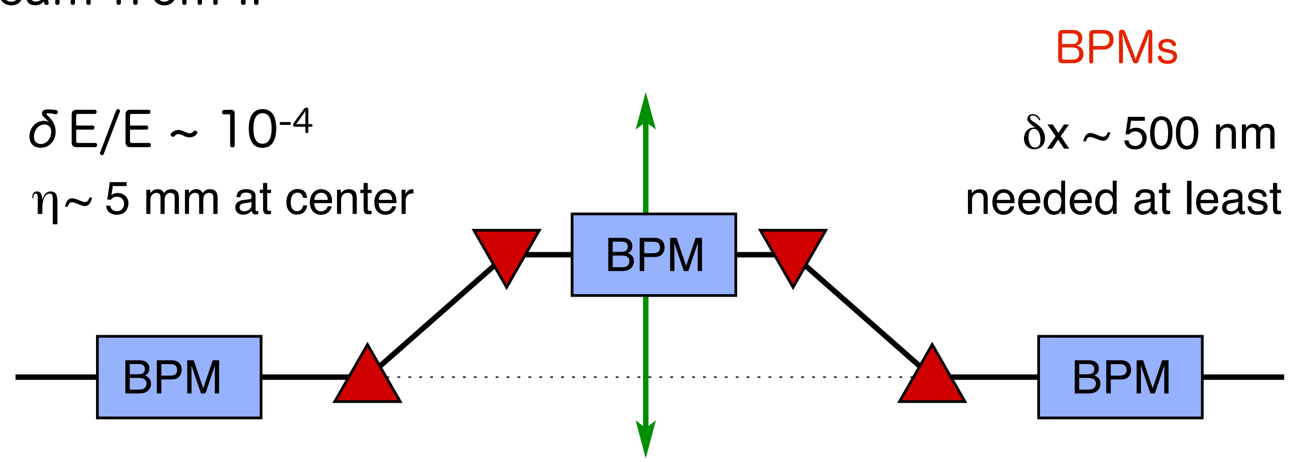


Figure 2.4.1: *Schematic for the upstream energy spectrometer using BPMs.*

Polarimeter principle

The opposite sign helicity configuration ($P\lambda$=-1), which has parallel spins (m_j=3/2) , dominates at **the Compton edge** over the other helicity and spin orientation ($P\lambda$=+1 and m_j=1/2).

E_0 (GeV	λ (nm)	ω_0 (eV)	x	ω_{max} (GeV)	E_{min} (GeV)
45.6	1064	1.165	0.813	20.4	25.2
	532	2.33	1.63	28.3	17.3
	266	4.66	3.25	34.9	10.7
250	1064	1.165	4.46	204	46
	532	2.33	8.92	225	25
	266	4.66	17.8	237	13

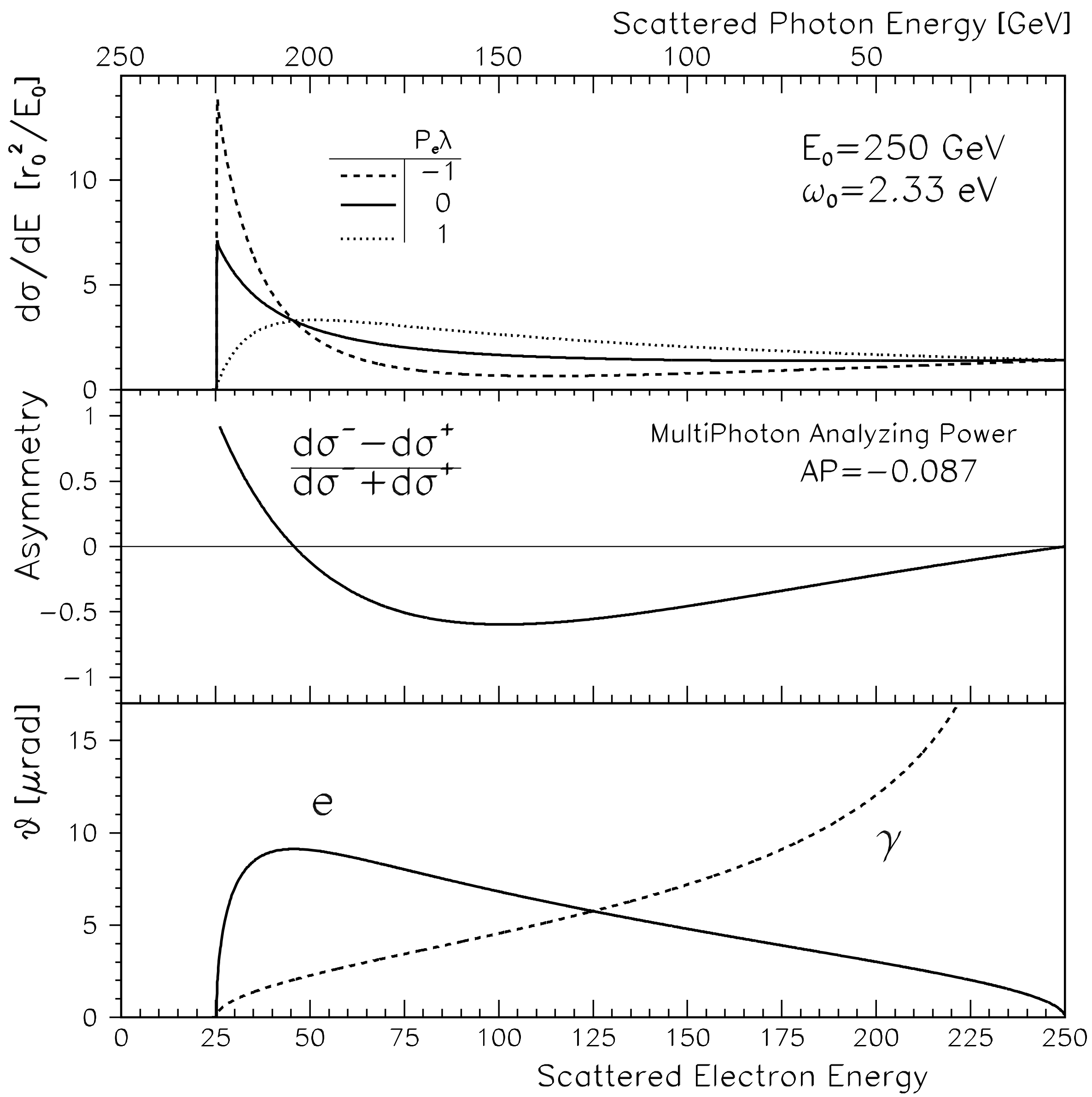


Figure 4. Energy spectra (top), spin asymmetry (middle) and scattering angles (bottom) of Compton scattered electrons and photons, for a beam energy of 250 GeV and a green laser.

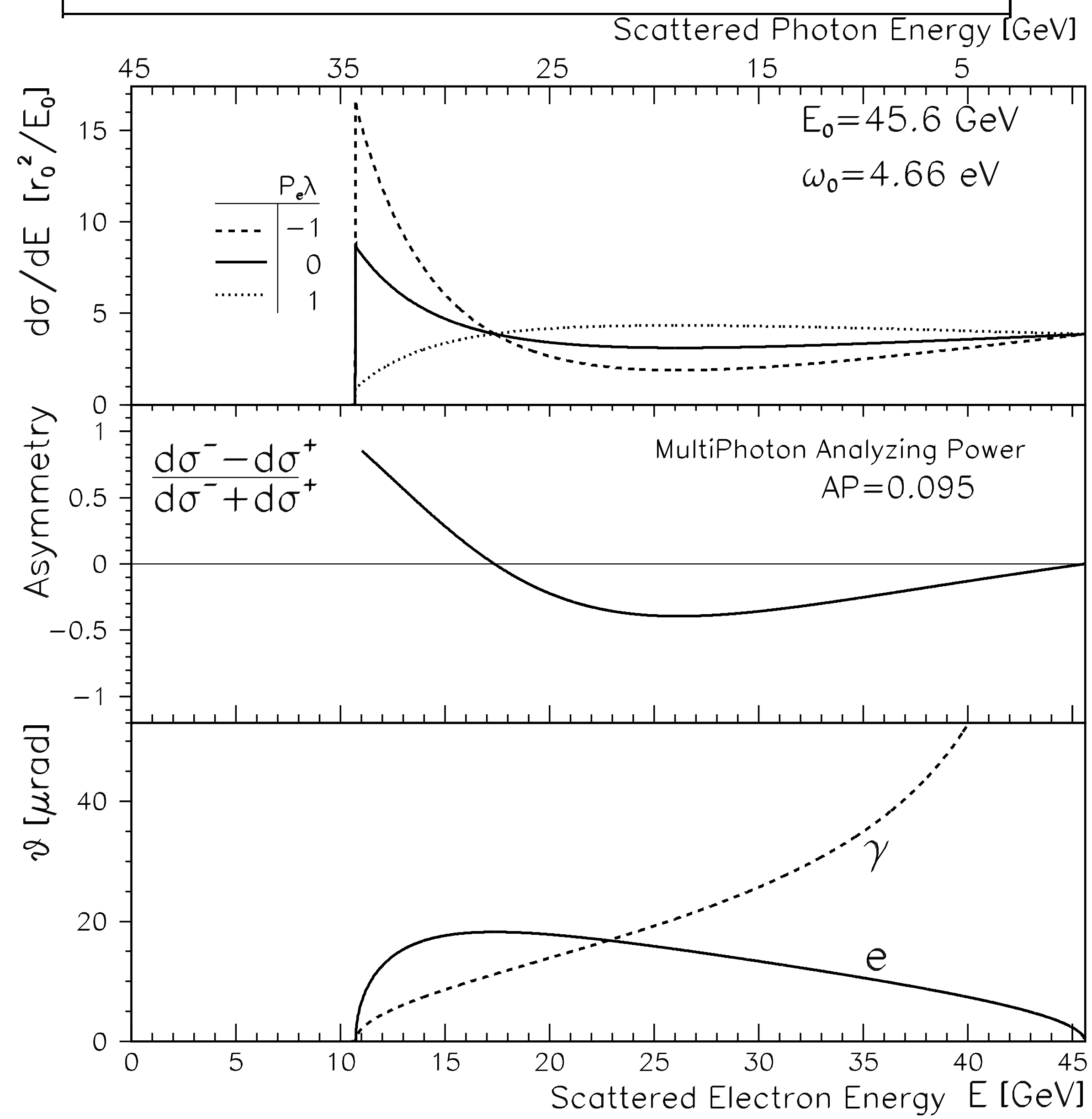


Figure 6. Energy spectra (top), spin asymmetry (middle) and scattering angles (bottom) of Compton scattered electrons and photons, for a beam energy of 45.6 GeV and an ultraviolet laser.

V. Gharibyan, N. Meyners and P. Schuler, “The TESLA Compton polarimeter,” LC-DET-2001-047

Downstream Polarimeter and Energy Spectrometer

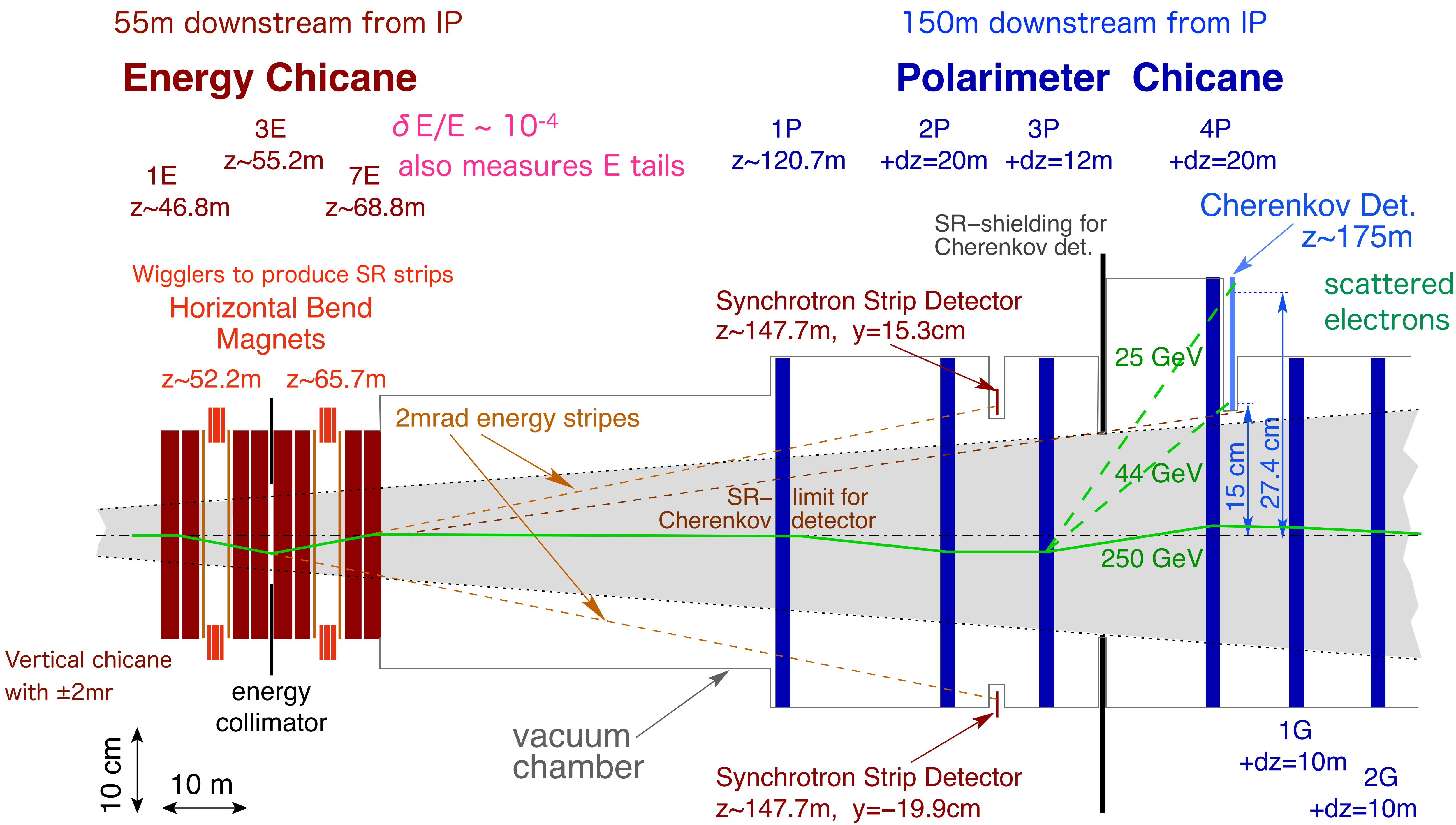
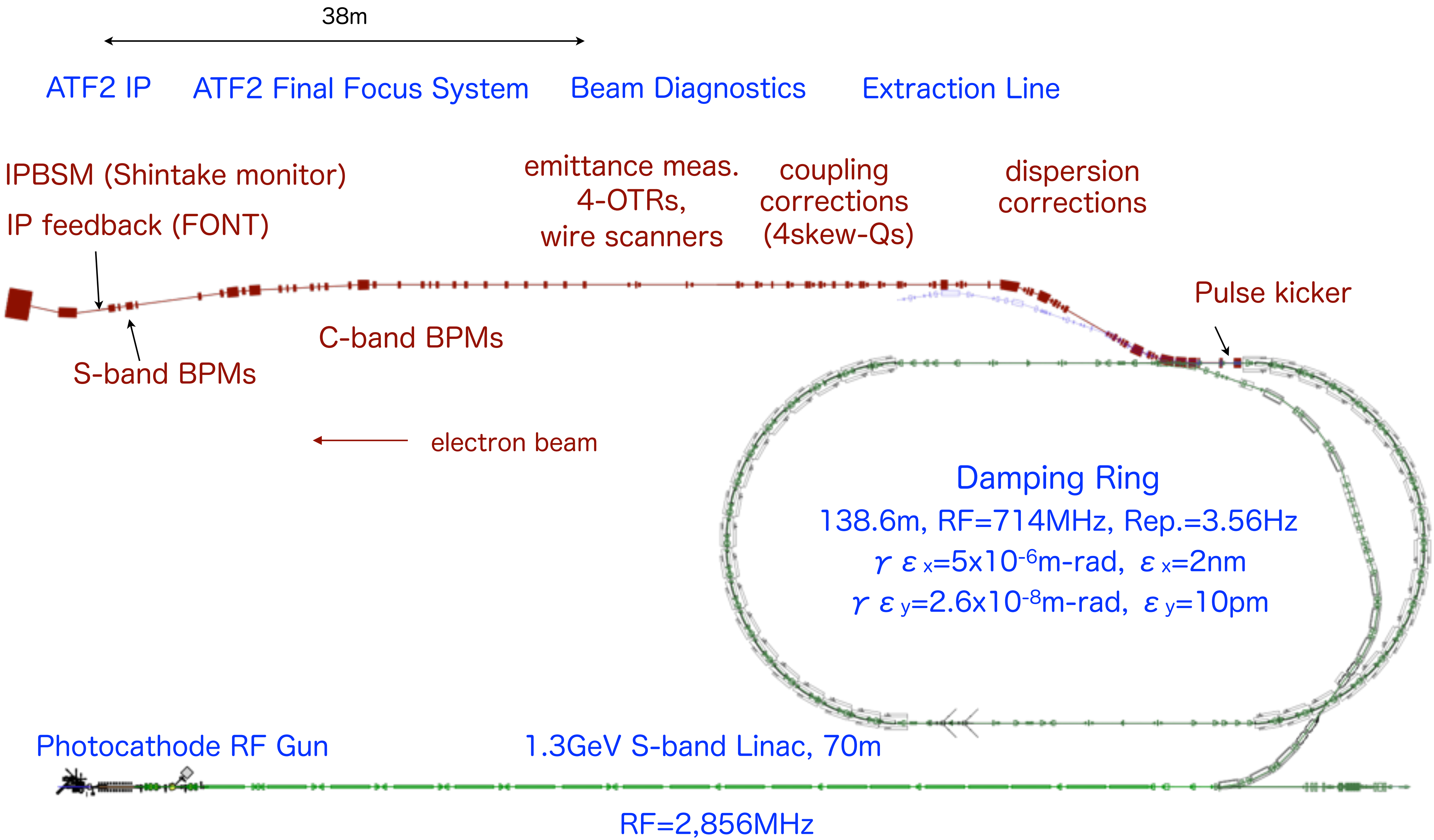
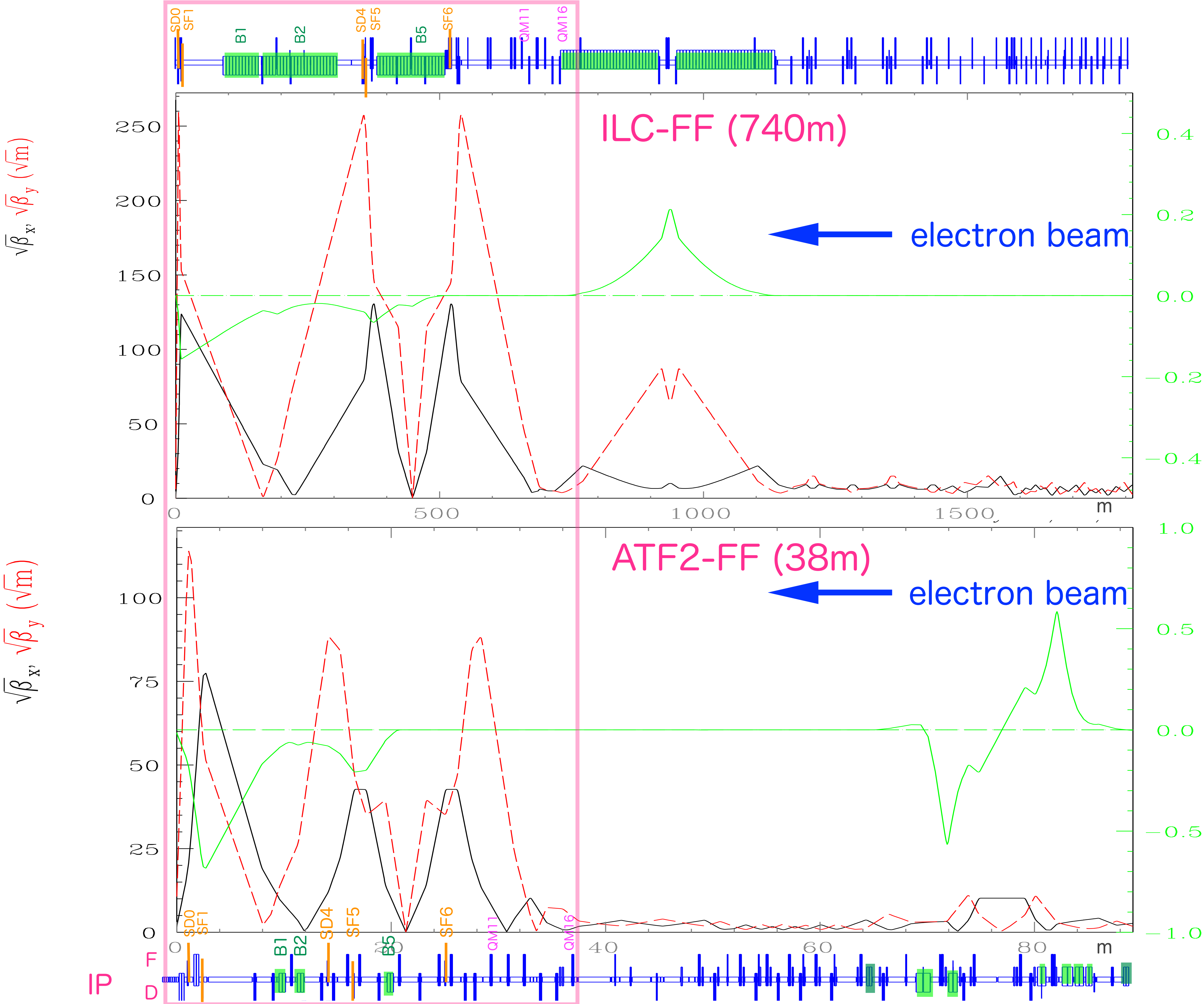


Figure 2.4.2: *Schematic of the ILC extraction line diagnostics for the energy spectrometer and the Compton polarimeter.*

WISRD:Wire Imaging Synchrotron Radiation Detector
consisting of radiation-hard 100um quartz fibers

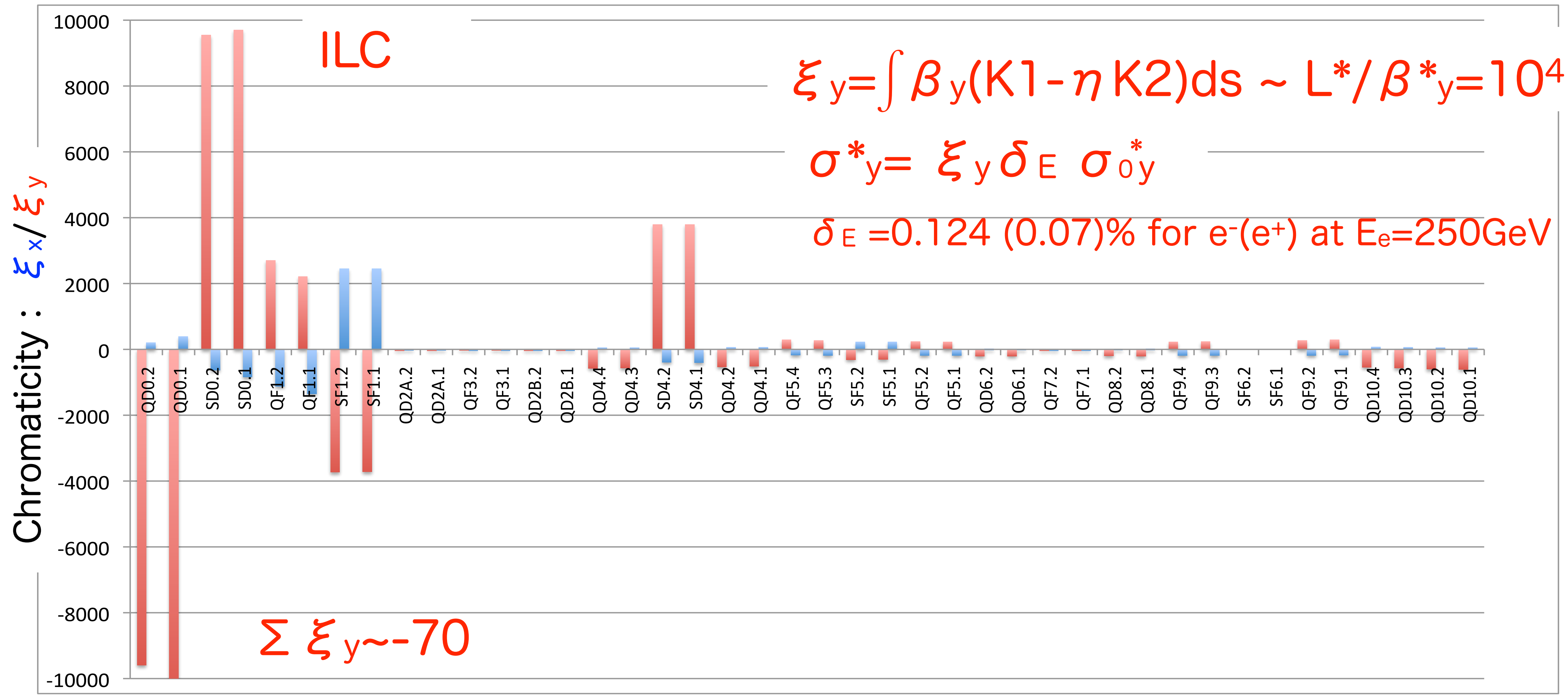
Test Facility : ATF and ATF2

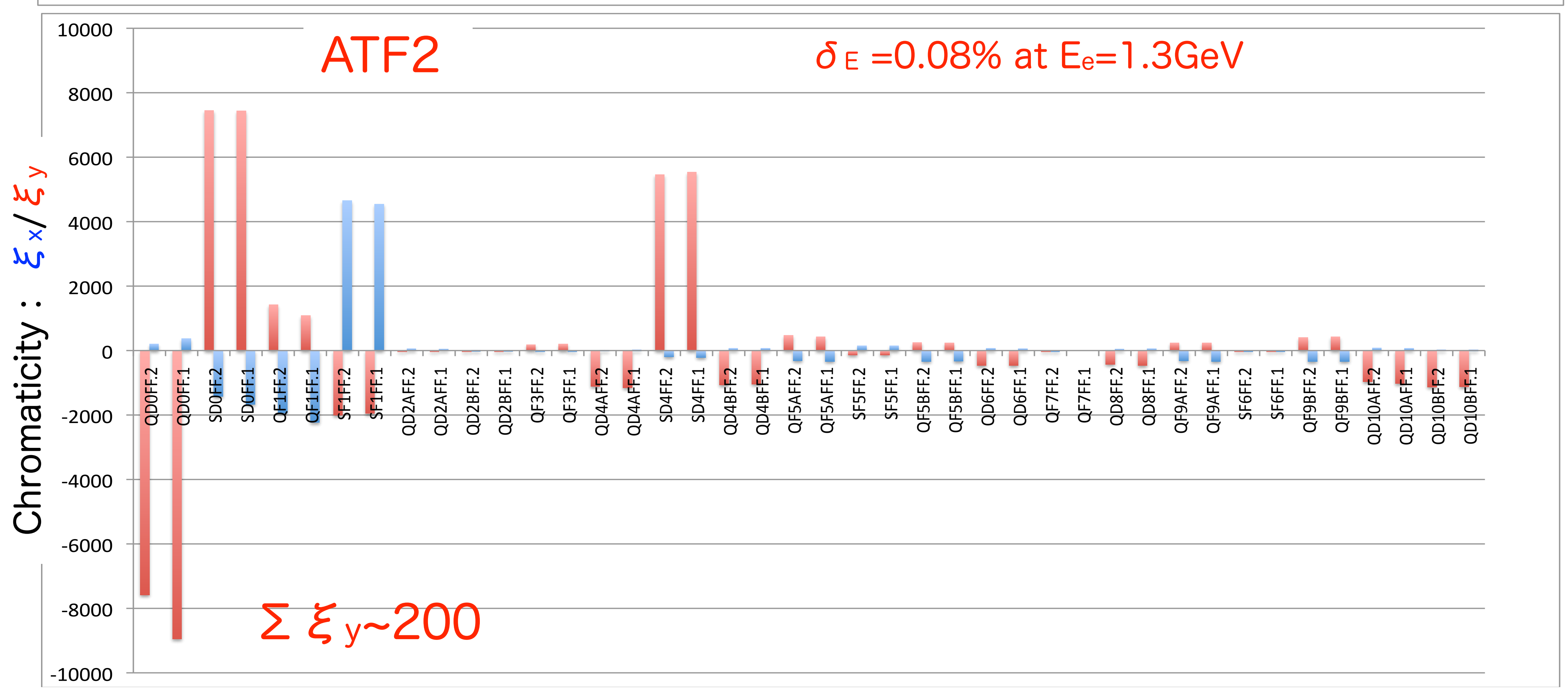


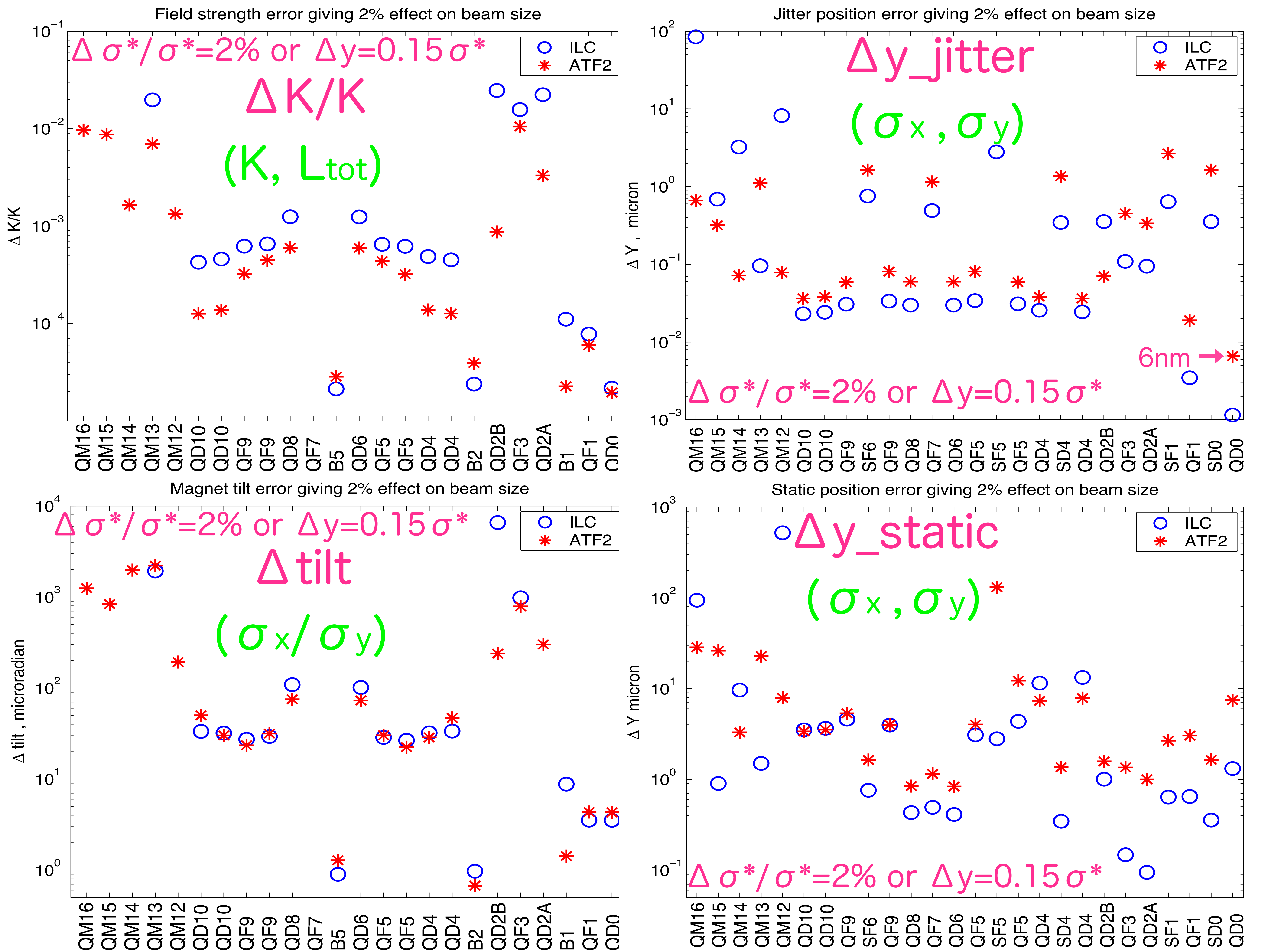


2013年 7月 22日 月曜日

Chromaticity at quadrupole and sextuple magnets

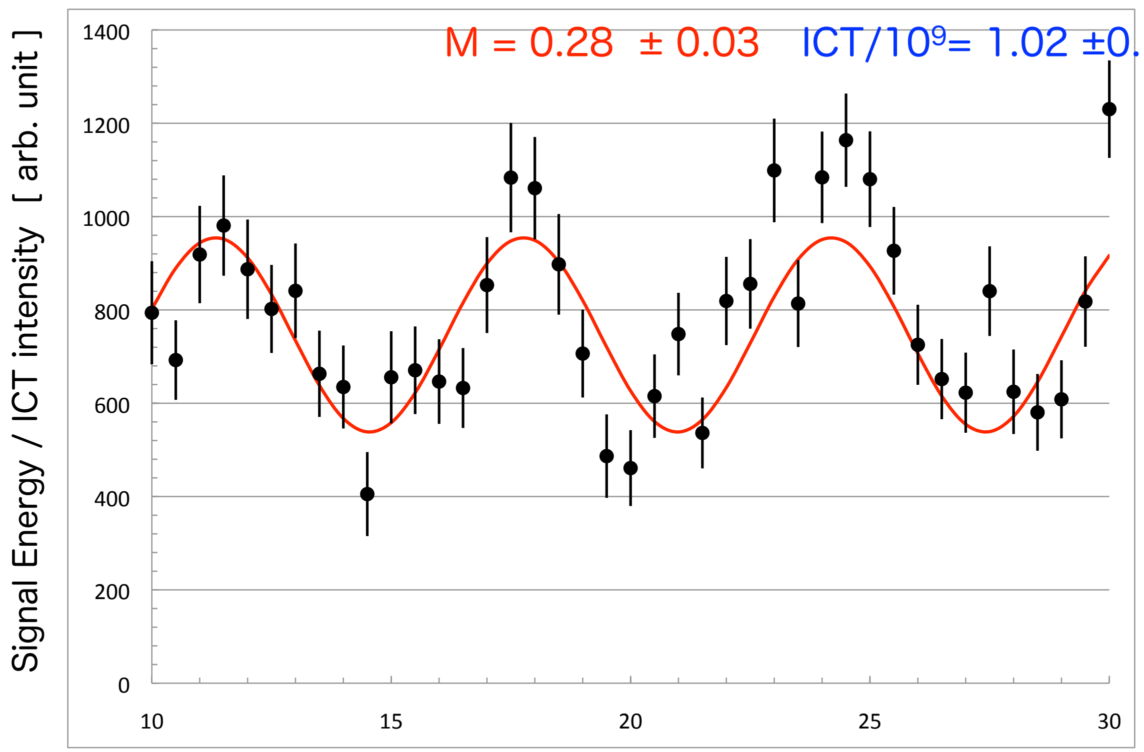






2013年 7月 22日 月曜日

Preliminary **ATF2@KEK** meas121221_183019



at 174 degree mode
266nm/pitch

FFTB@SLAC

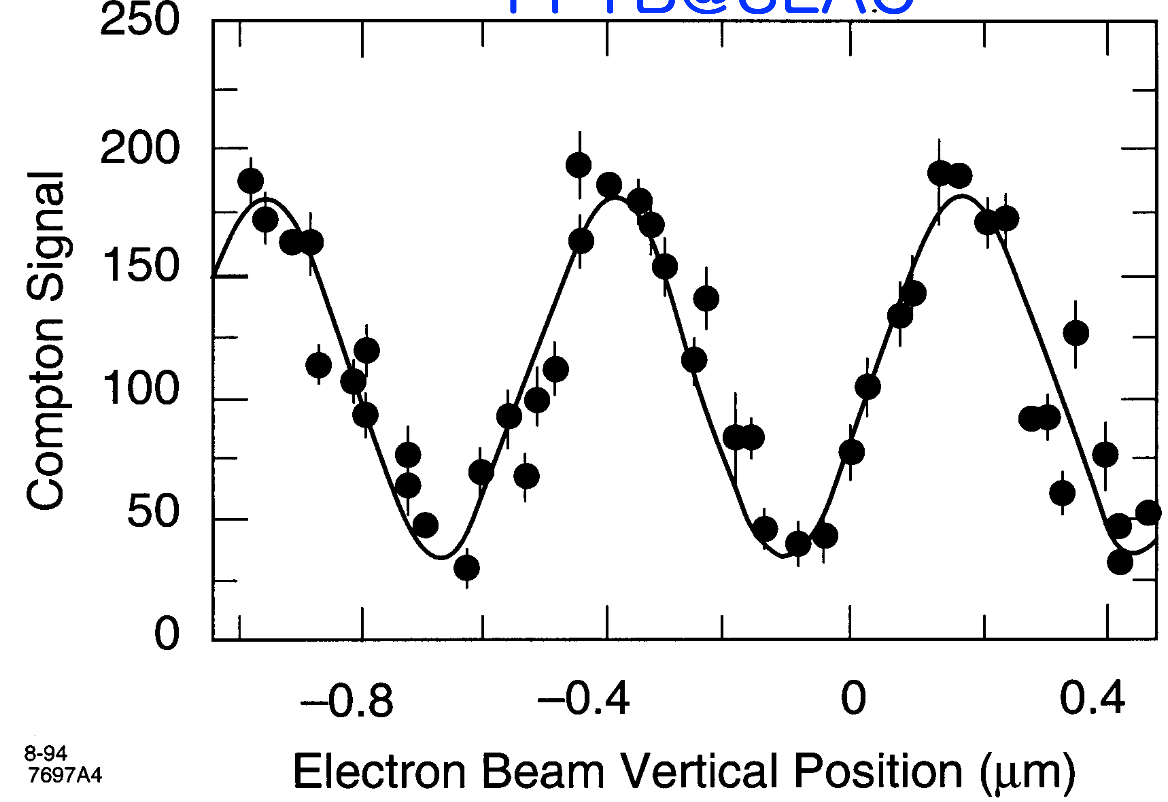
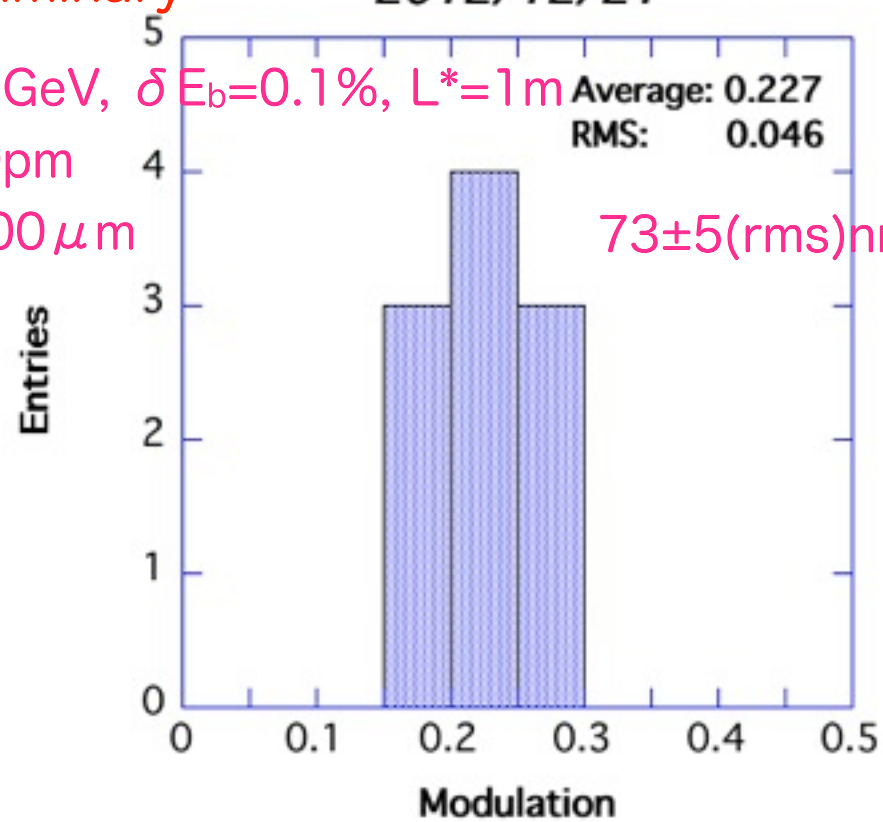


Figure 5.6: Laser-Compton beam size measurement performed in May of 1994. The measured size is 77±7 nanometers.

Preliminary

Both assumes no modulation reduction



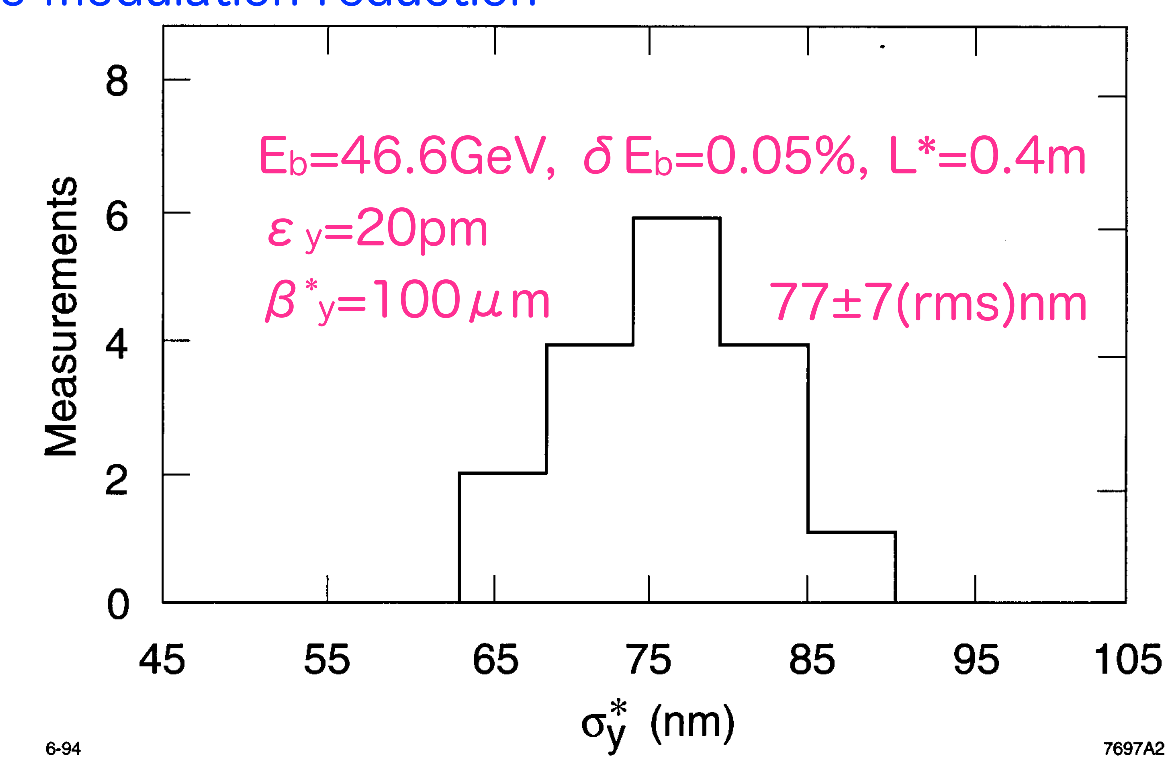
E_b=1.3GeV, δE_b=0.1%, L*=1m

ε_y=20pm

β^*_y=100μm

73±5(rms)nm

rms of laser size = 17/12um



E_b=46.6GeV, δE_b=0.05%, L*=0.4m

ε_y=20pm

β^*_y=100μm

77±7(rms)nm

Figure 5.7: Histogram of measurements made during the last 3 hours of the May, 1994 FFTB run. Average size measured was 77 nm, with an RMS of 7 nm.

rms of laser size = 50um -> M reduction of 10%

Learns from SLC experiences

SLC has never achieved the design luminosity, e.g. finally half of design luminosity after 10 years operations

with smaller beam sizes,

i.e. 1.5(x), 0.65(y) μm v.s. 1.65(x), 1.65(y) μm of the design

by careful emittance preservation and improvements in the final focus optics

with less beam intensities,

i.e. 4 - 4.5 $\times 10^{10}$/bunch v.s. 7.2 $\times 10^{10}$/bunch of the design

and the repetition rate of 120Hz instead of 180Hz.

ILC and CLIC have been designed with these SLC experiences.

1. Less beam intensity and smaller beam sizes, control of emittance growth
2. Final focus systems are based on the local chromaticity correction scheme which has better performance than the separated function chromaticity correction scheme at SLC.
3. ATF2 is very important to verify the expected performances as a ILC/CLIC FF test facility
4. Additional skew sextupoles, octupoles and decapoles should be included in the baseline designs to minimize the residual higher-order aberrations.

IR arrangements

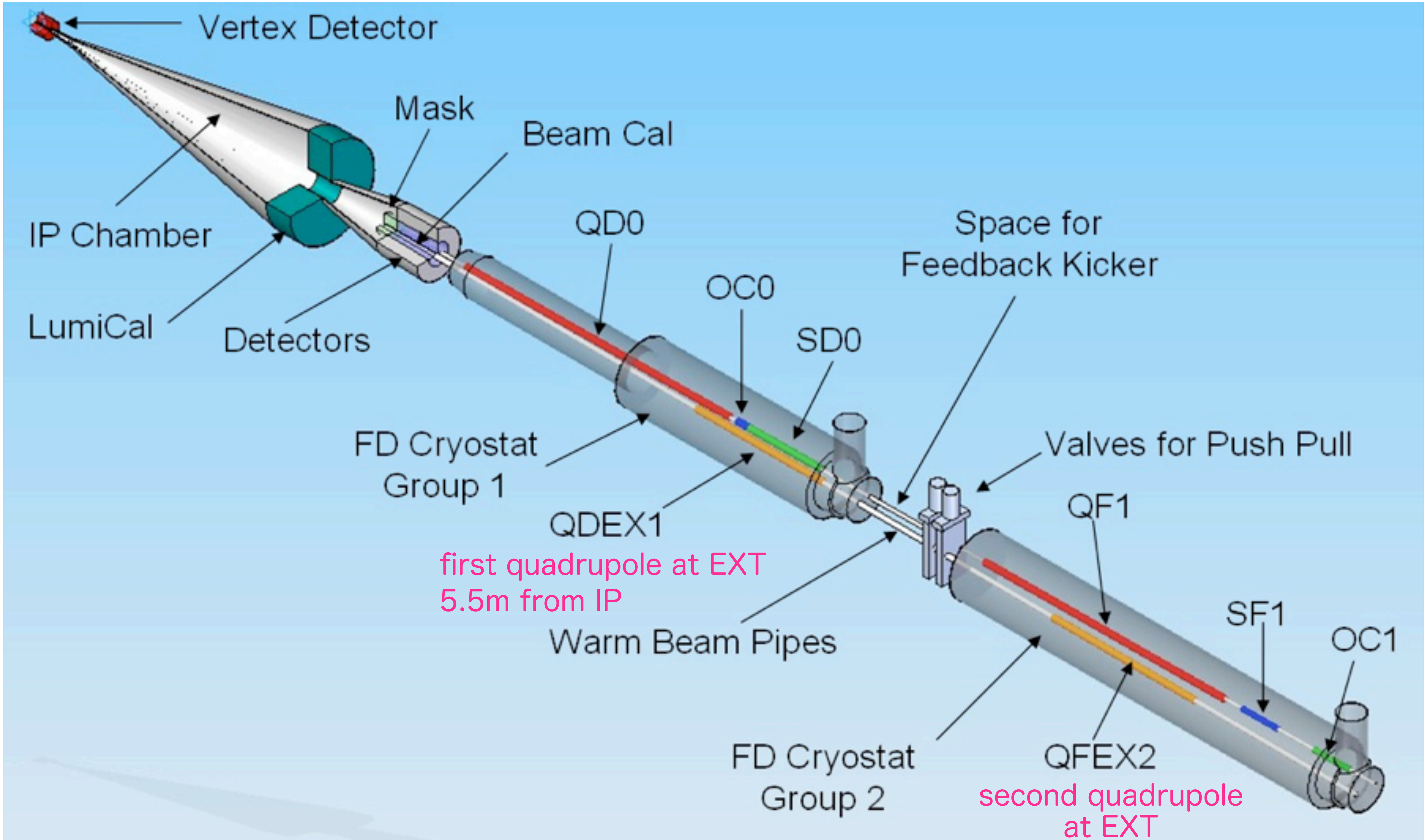
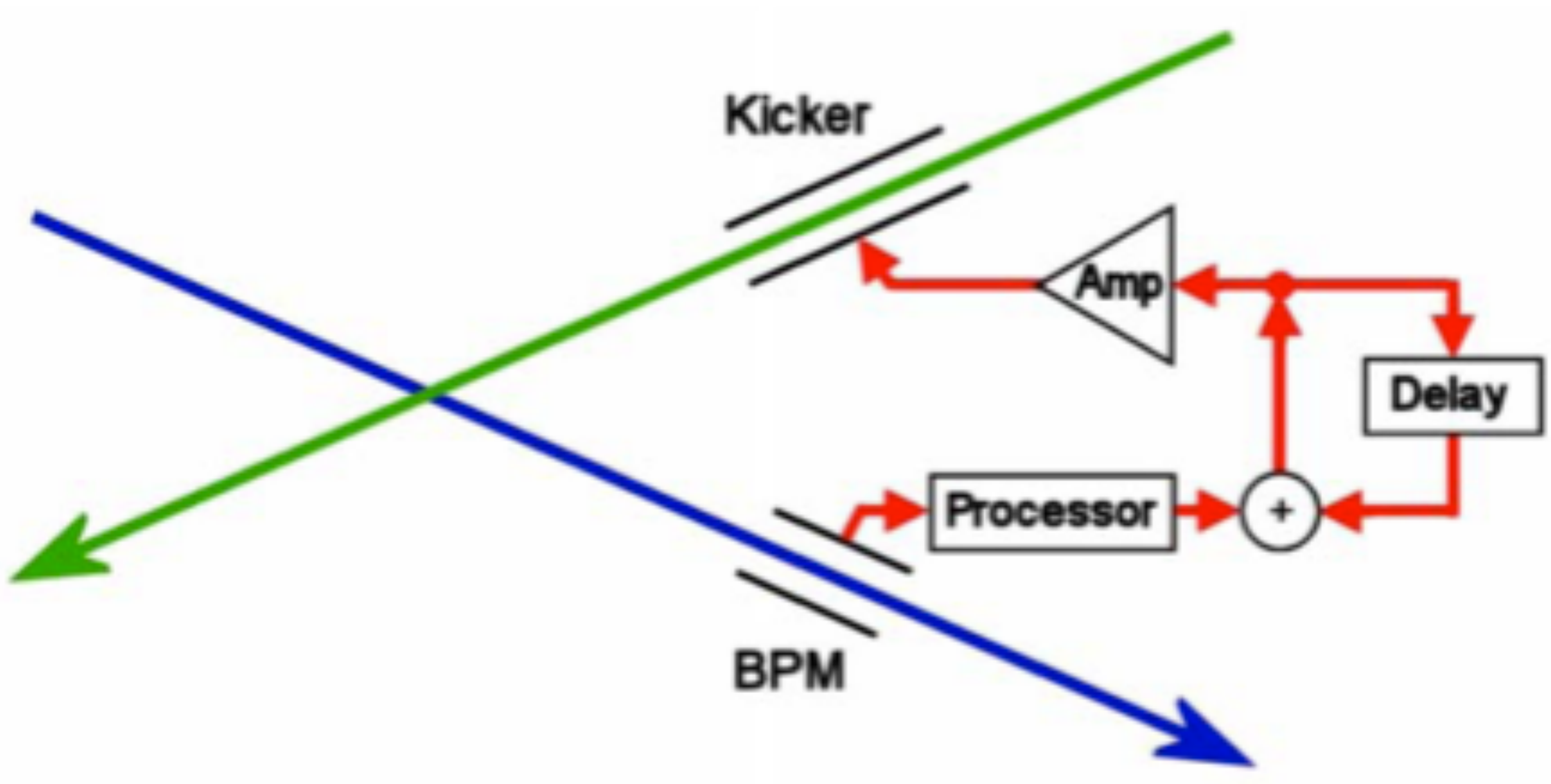


Figure 2.7-11 in RDR

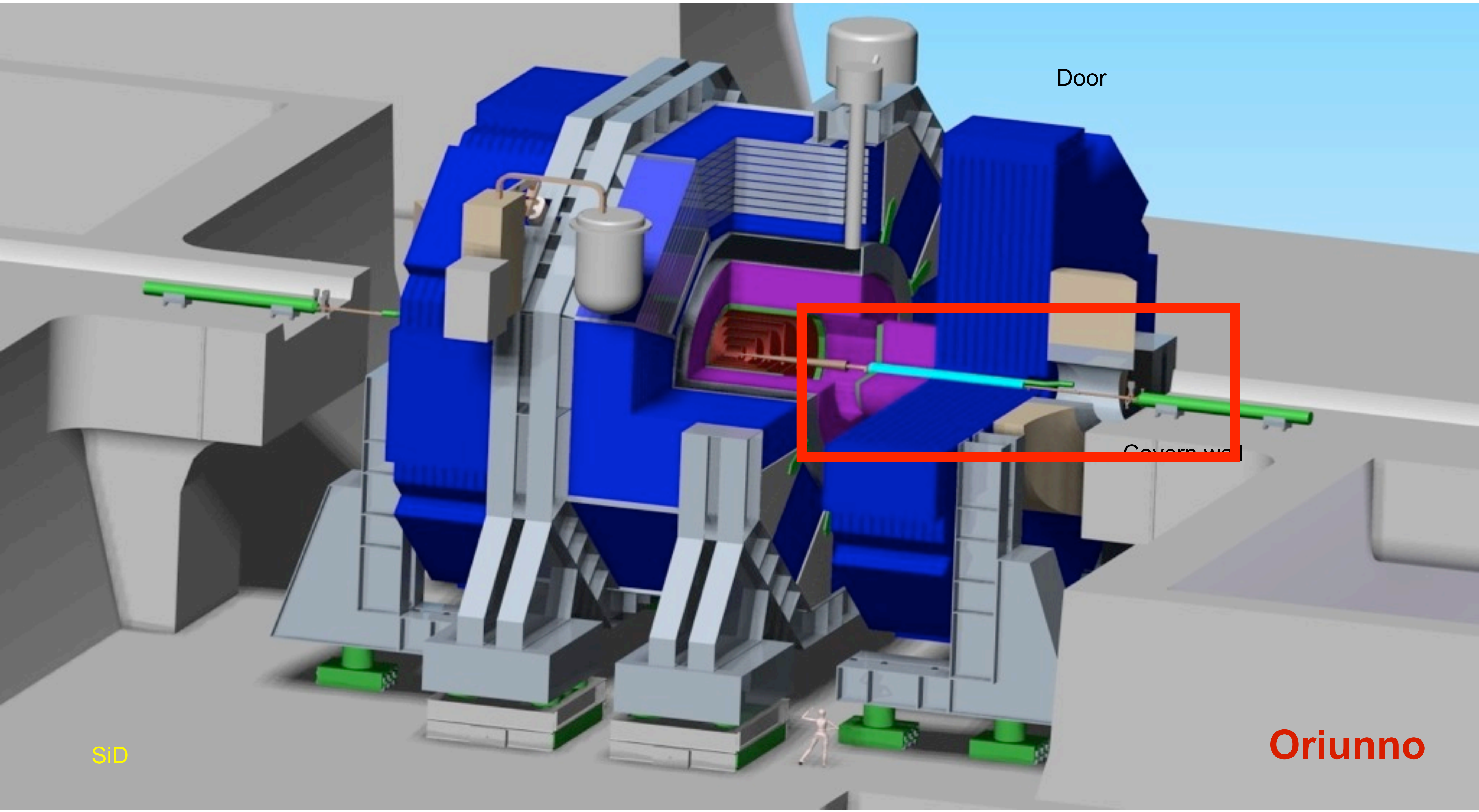
IP beam feedback concept

- Last line of defence against relative beam misalignment
- Measure vertical position of outgoing beam and hence beam-beam kick angle
- Use fast amplifier and kicker to correct vertical position of beam incoming to IR



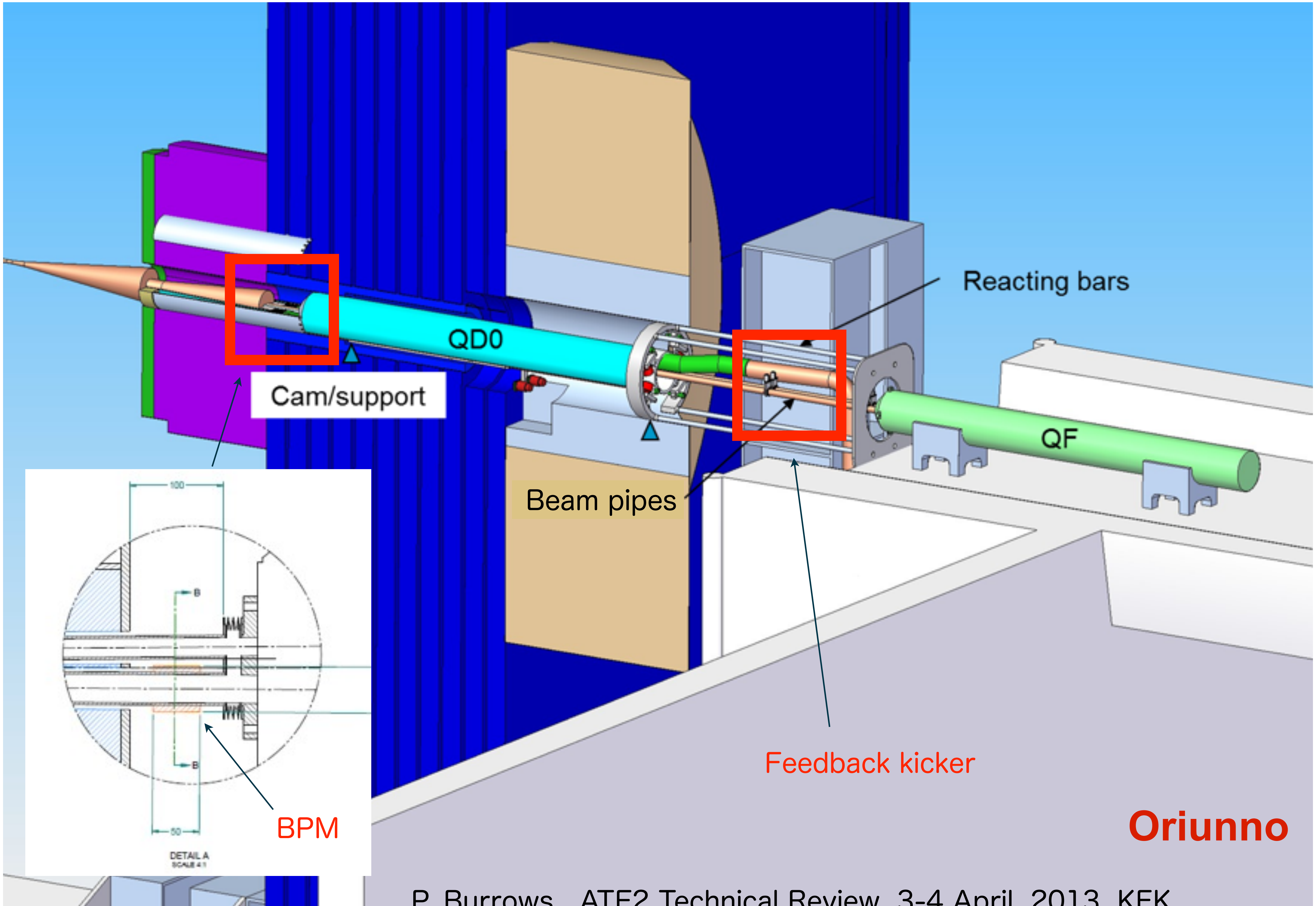
FONT – Feedback On Nanosecond Timescales

ILC IR: SiD for illustration



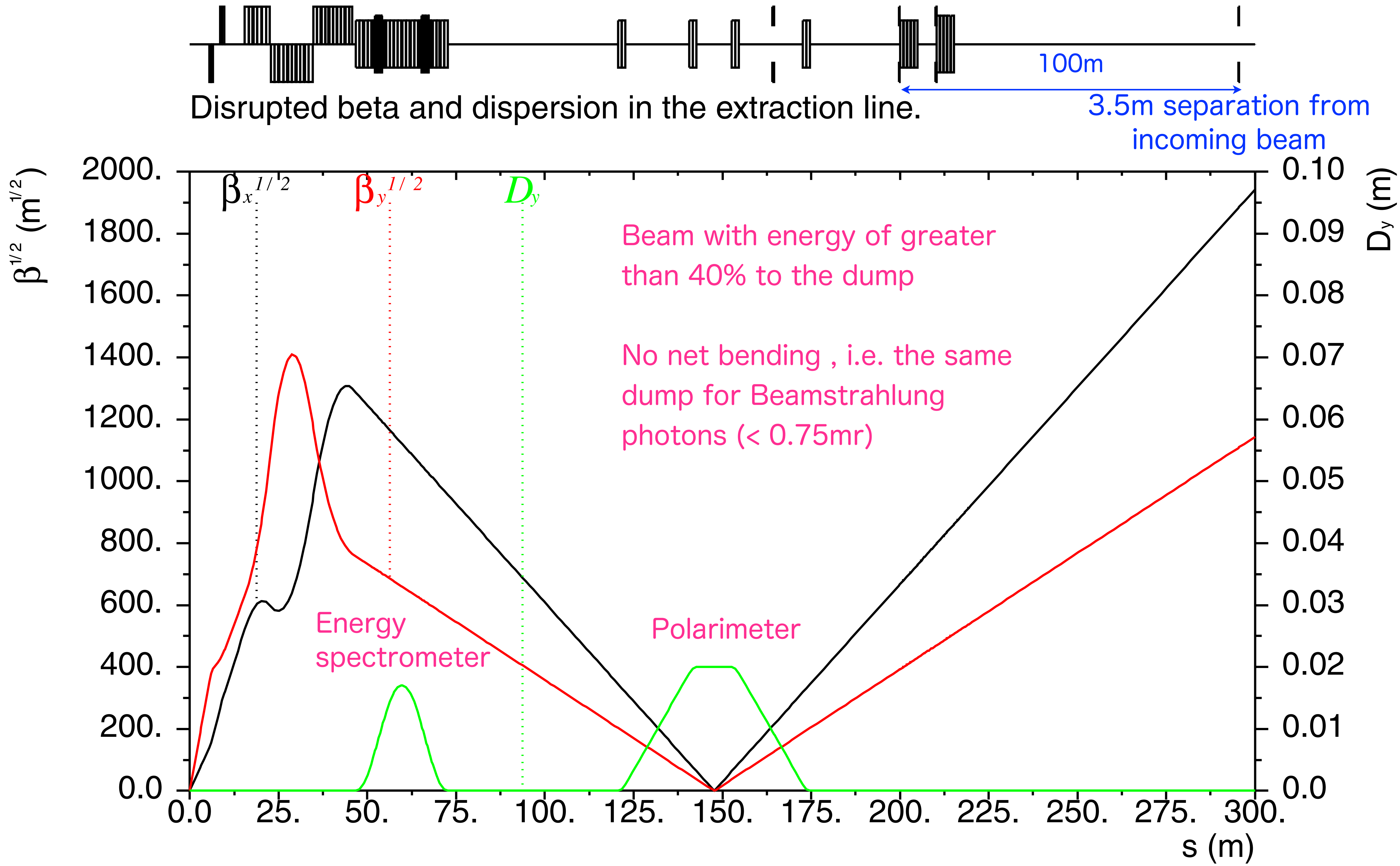
P. Burrows, ATF2 Technical Review, 3-4 April, 2013, KEK

Final Doublet Region (SiD)



P. Burrows, ATF2 Technical Review, 3-4 April, 2013, KEK

ILC-BDS/EXT Optics



electron beam →

3cm radius circle by raster kickers in a 15cm radius dump window

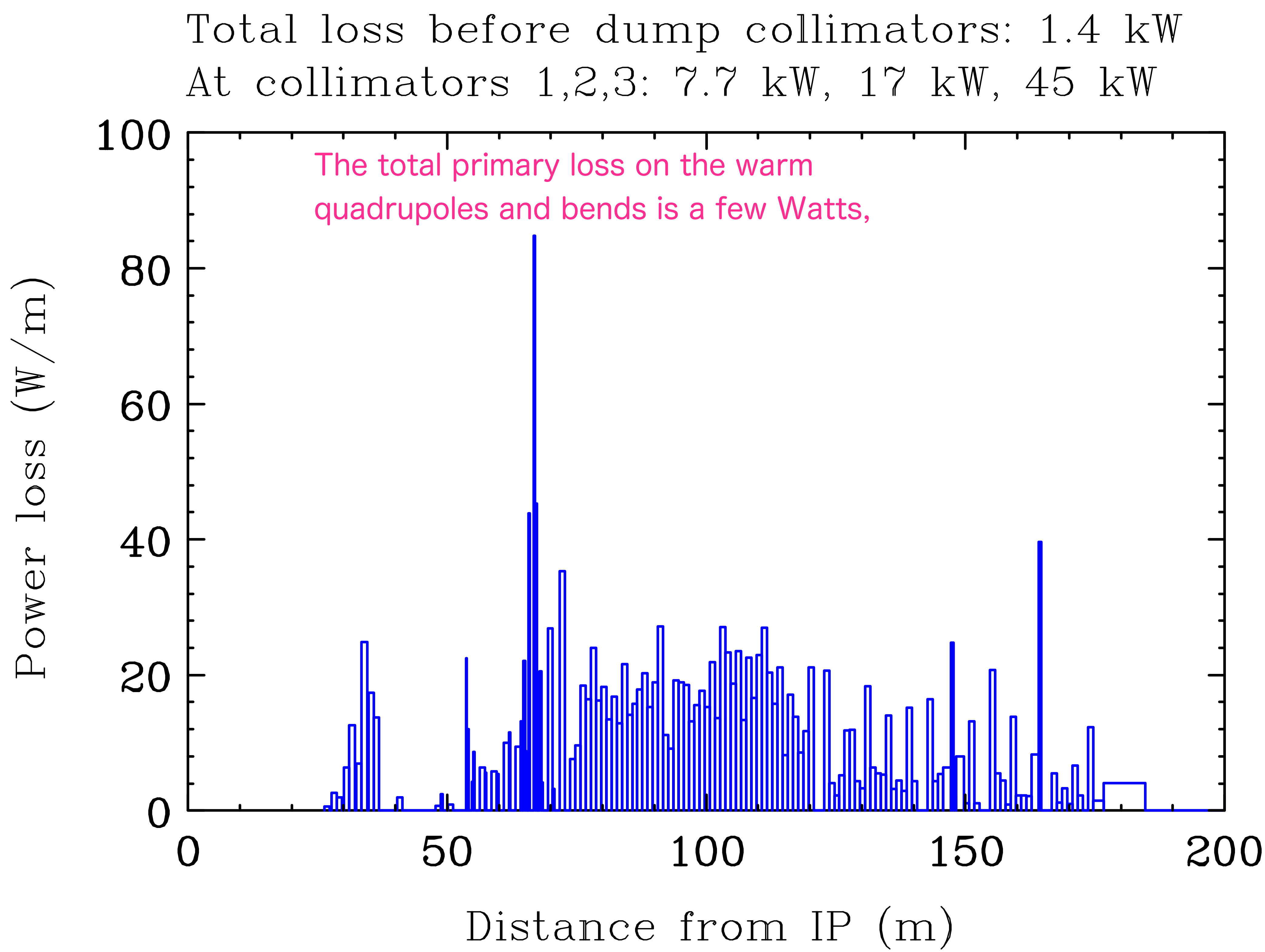


Figure 8.5. Power loss density in the magnet region for disrupted beam at 250 GeV, for high-luminosity operation.

Radiation Rules at KEK

- Normal operation
  - **0.2 μSv/h for Non-designated area (K1)**
  - **1.5 μSv/h for Supervised area (K2)** **experimental hall**
  - **20 μSv/h for Simple controlled area (K3)**
  - **100mSv/h for access restricted**
- Shielding 100 **μSv/event(K2)**
  1mSv/event (K3)
- Mis-steering beam loss
  - **1 hour integration of dose rate should not exceed 1.5 μSv/h using radiation monitor.**

    (Terminate injection and wait 1 hour)

In the KEK regulation, there is no explicit description of ambient dose limit for beam operation conditions and beam loss classification such as SLAC-RSS

SiD and ILD : Shielding capability of 250 mSv/h / 18 MW = 0.014 mSv/h/kW is required everywhere to meet SLAC requirement

T.Sanami, IRENG 09/14/2007

Area classification : SLAC rule

- Normal operation (S1) including screen, wire-scanners
  - **0.5 μSv/h for GERT (General Employ Radiation Training)**
  - **5 μSv/h for Radiation Worker (RW)**

- Mis-steering (S2) hardware failures, operator errors,..
  - **4 mSv/h**
- Annual dose should be less than 10mSv/year (S1,S2).
- System failure (S3) beam stopper failure and/or electric power failure of important bending magnet
  - **250 mSv/h and 30 mSv/event**

(from SLAC-I-720-0A05Z-002-R001 Radiation Safety Systems (Technical Basis Document, April 2006))

T.Sanami, IRENG 09/14/2007

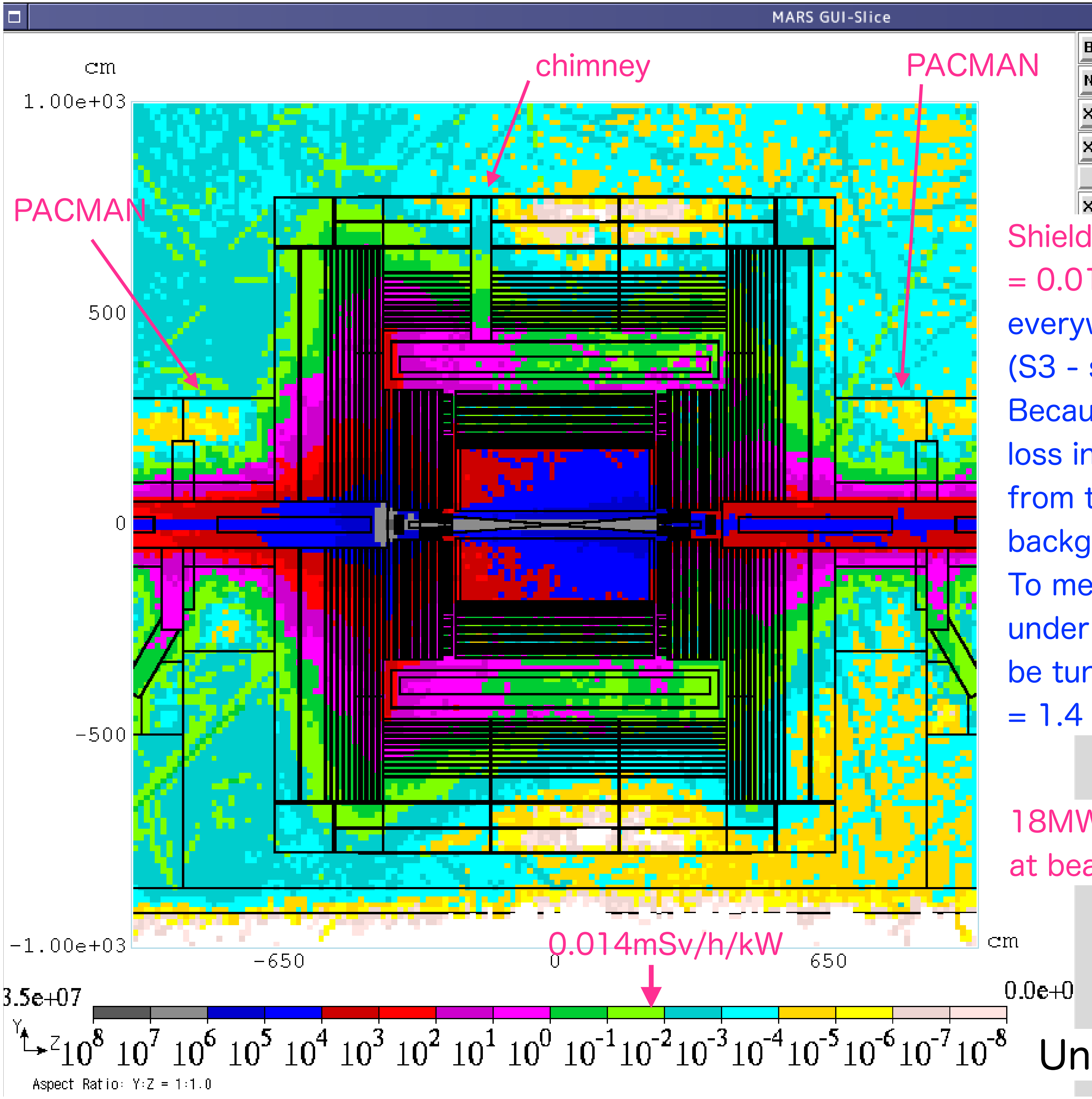
Area classification : LHC design

- Normal operation
  - **0.1 μSv/h for Non-designated area**
  - **1 μSv/h for Supervised area**
  - **3 μSv/h for Simple controlled area**

- Total beam loss
  - **0.3 mSv/h for Non-designated area**
  - **2.5 mSv/h for Supervised area**
  - **50 mSv/h for Simple controlled area**

(from **http://indico.cern.ch/conferenceDisplay.py?confId=1561 talk of D. Forkel-Wirth**)

Self-shielding of the detector (ILD0) at IR



Shielding capability of 250 mSv/h/18MW = 0.014mSv/h/kW is required everywhere to meet SLAC requirement (S3 - system failure).

Because of detector design, total beam loss in the IR hall must be below 1 W from the requirement to reduce detector background.

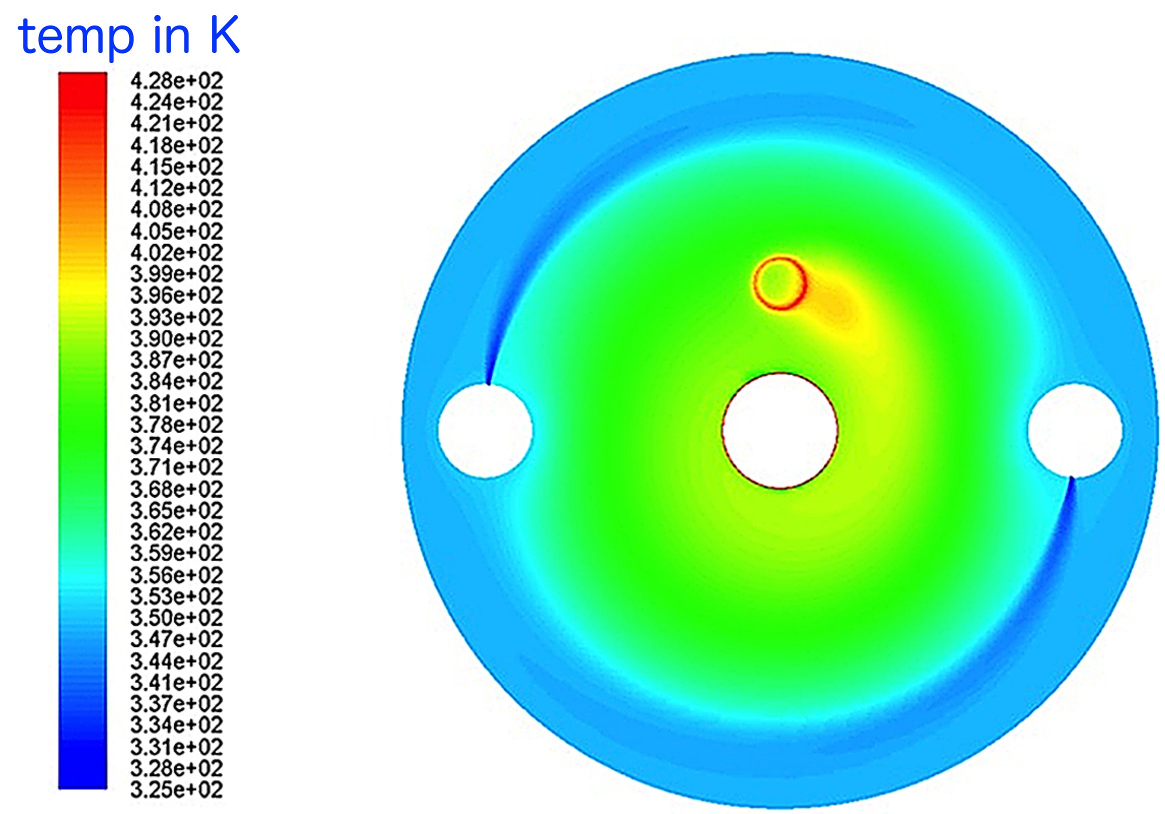
To meet KEK guideline for integral dose under accidental beam loss, beam should be tuned off within 0.1 mSv / 250mSv/h = 1.4 seconds.

18MW 500GeV beam loss at beam calorimeter

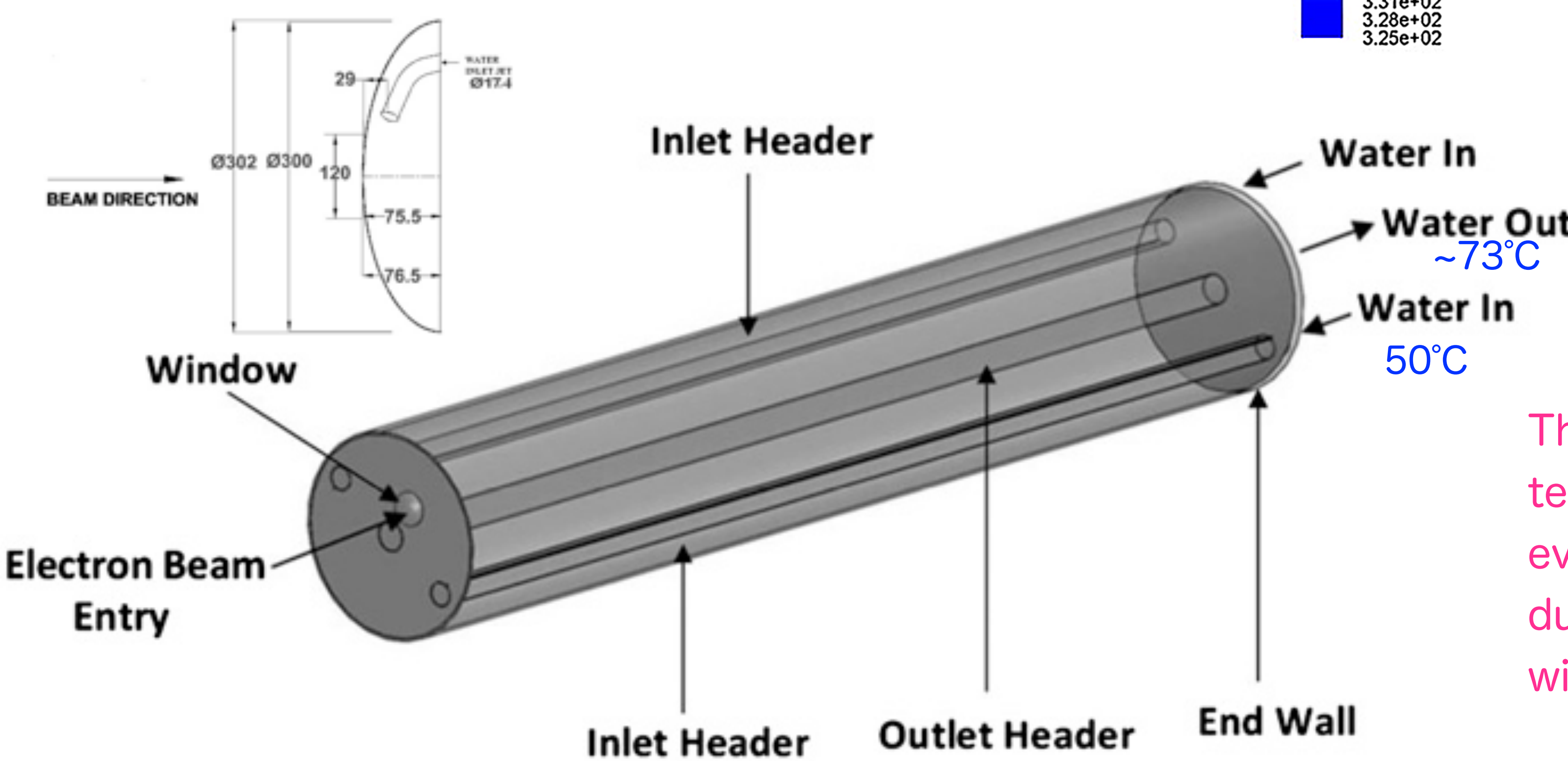
Unit: mSv/hr/kW

Beam dump

1.8 m-diameter cylindrical stainless-steel high-pressure (10 bar) water vessels with a 30 cm diameter, 11m(30X_0) length, 1 mm-thick Ti window.



18MW/500GeV per beam
z=2.8m (8.1X_0)
Maximum temperature = 155°C
with the beam train passage
and beam sweep radius 6cm



The pressurisation raises the boiling temperature of the dump water; in the event of a failure of the sweeper, the dump can absorb up to 250 bunches without boiling the dump water

Shielding and protection of site ground water

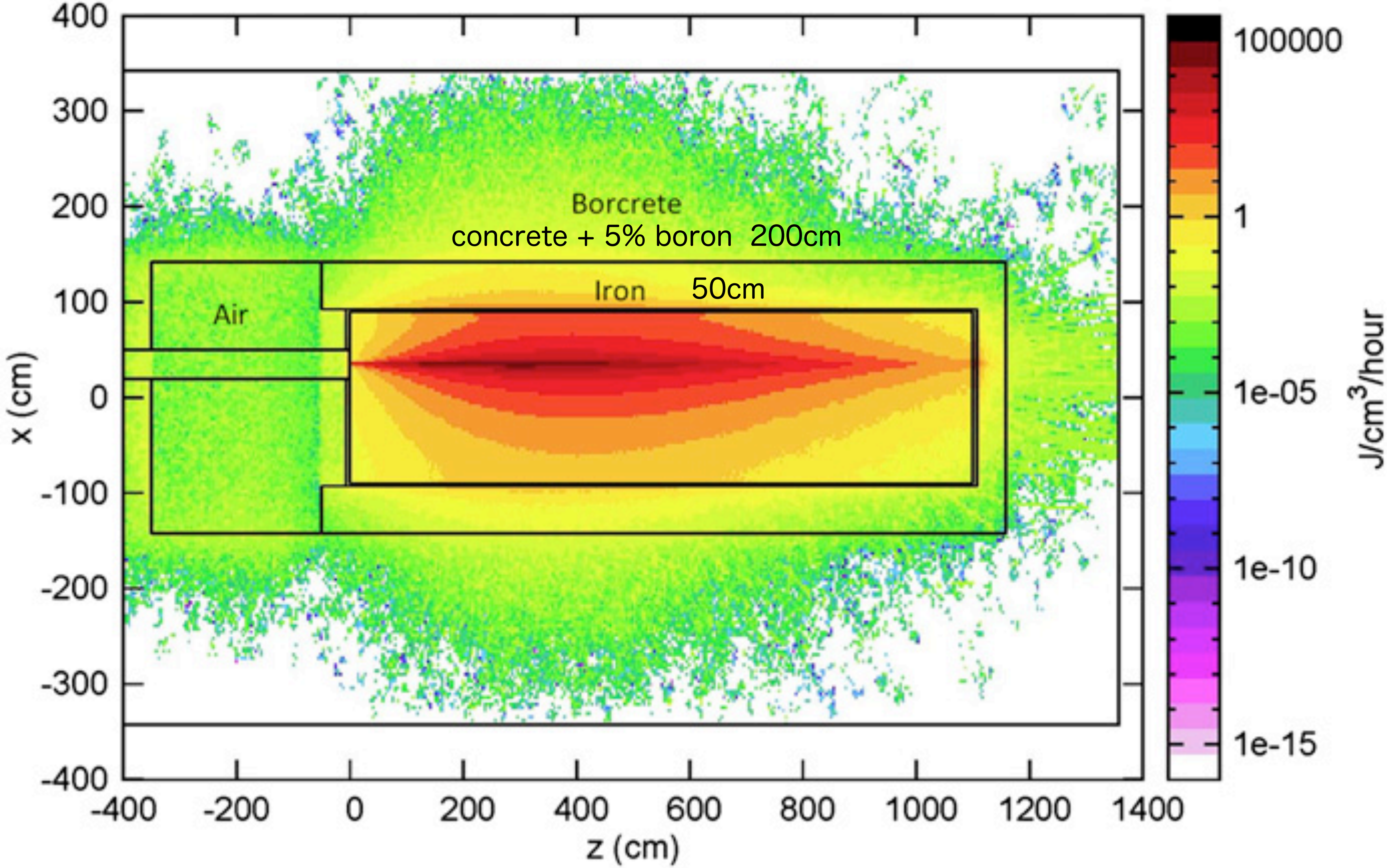


Fig. 29. Power depositions in the entire dump region (average of y=-342.5 cm and +342.5 cm).

LCC : Common paths for ILC and CLIC BDS

towards the same design lattice designs of some sub-system

Possible issues :

1. Lattice repository
2. Parameters; staging energies at 250GeV@ILC, 350GeV@CLIC,
   crossing angles of 14mrad@ILC and 20mrad@CLIC
3. Crab cavity tolerances; 61fs@ILC and 4.6fs@CLIC
4. Lattice design options; changes with accommodation of octupoles (tail folding)
   alternative lattices
5. QD0 technology; superconducting and hybrid
6. Polarimetry; post-IP polarimetry is needed ?
7. Collimation ; active protection@ILC and passive@CLIC
8. Final Focus System (FFS) tuning; lessons from ATF2
9. Beam dumps
10. Energy spectrometry
11. Instrumentation (LW, OTR, BPM) and feedback
12. MDI issues; push-pull, QD0/QF1 alignment ...
13. Commissioning strategy

to be discussed at LCWS 2013, Tokyo