ILC luminosity optimization in the presence of the detector solenoid and anti-DID

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Outline

I. The effects of the detector solenoid and anti-DID

II. Compensation to restore nominal luminosity

III. Results – beam orbit and geometric luminosity calculation

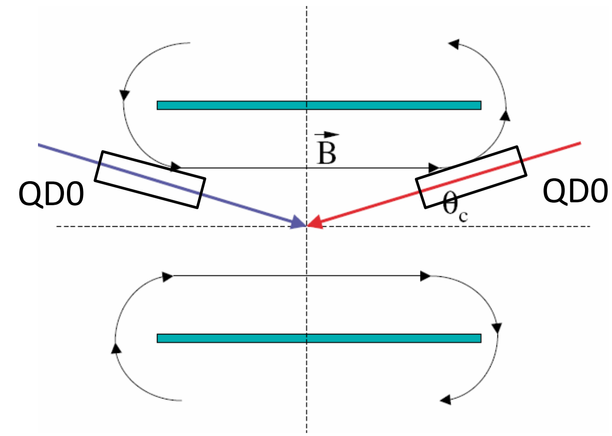
IV. Tolerances on correctors

V. Influence on crab crossing

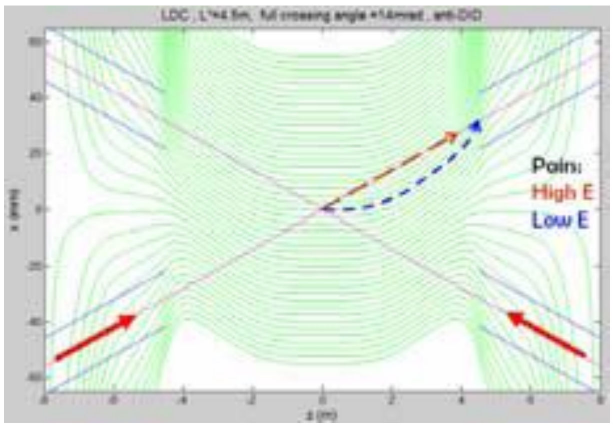
I. Solenoid and anti-DID effects

• Longitudinal field of the solenoid + Fringe field extending over QD0 -> **coupling** (x, y) (E,y)
=> beam size growth

• Radial field due to crossing angle -> **orbit deviation**, implying **synchrotron radiation**,
• Fringe field extending over QD0 -> no **compensation** of radial and longitudinal components,
=> non zero orbit at the IP



• **Anti-DID** field -> **additional radial field** deviating incoming particles.



	SiD, L*=3.5 m		ILD, L*=4.5 m	
	y_{IP}	σ_y / σ_{y0}	y_{IP}	σ_y / σ_{y0}
Solenoid	-12.6 µm	23	-25 µm	49
Solenoid +anti-DID	-150 µm	27	-323.9 µm	57.4

Orbit and beam size growth at the IP for 14mrad crossing angle and 0.1% momentum spread.

Effects of ILD solenoid and anti-DID on the beam are more important than those of SiD solenoid.

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II. Compensation of beam size growth and vertical orbit at the IP

1- Length, position and strength of the **anti-solenoid*** are optimized using **DIMAD**.

The solenoid field map is represented with short slices, final focus elements are inserted using thin lenses and horizontal displacements, to take the crossing angle into account.

2- BDS is described using **TraceWin** tracking code, allowing field map superimposition. The **anti-DID** is added.

Vertical deviation and dispersion arising due to anti-DID field are taken into account.

3- Total correction of the beam orbit, size and divergence.

Obtained using :

*- **dipoles** in the final focus : two are superimposed with QF1 and QD0, one additional (DIP) is necessary,*

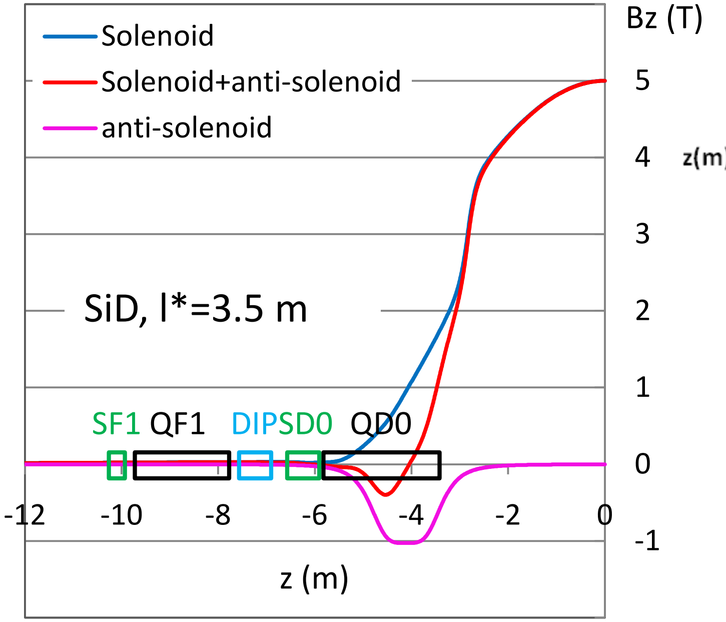
*- **skew correction** section and **sextupoles displacements** ('tuning knobs').*

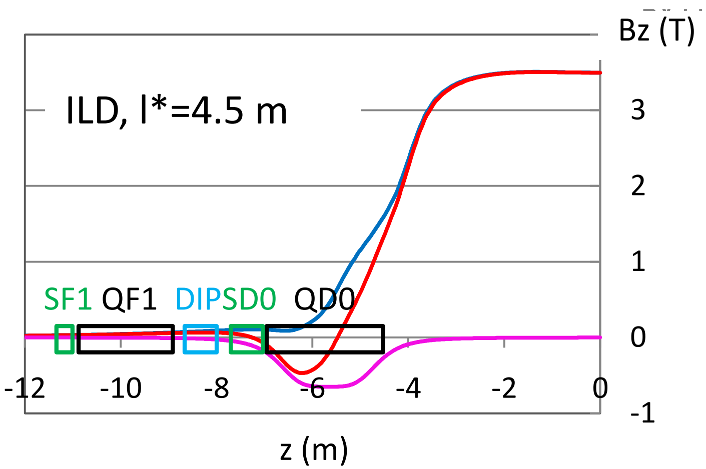
Remarks :

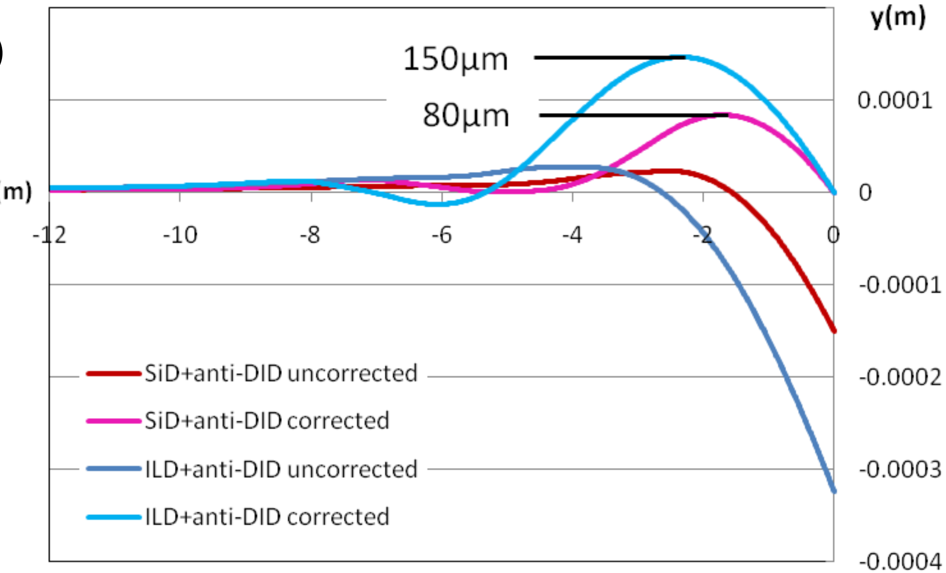
- Only one anti-solenoid was used in step 1
- Size and orbit compensation could be done independently in the case of SiD solenoid+anti-DID
- Correction in the case of ILD solenoid+anti-DID is more complicated, and more knobs (displacements of the sextupoles) are necessary.

** Y. Nosochkov and A. Seryi, Phys. Rev. ST Accel. Beams 8, 021001 (2005)*

III. Results - orbit deviation



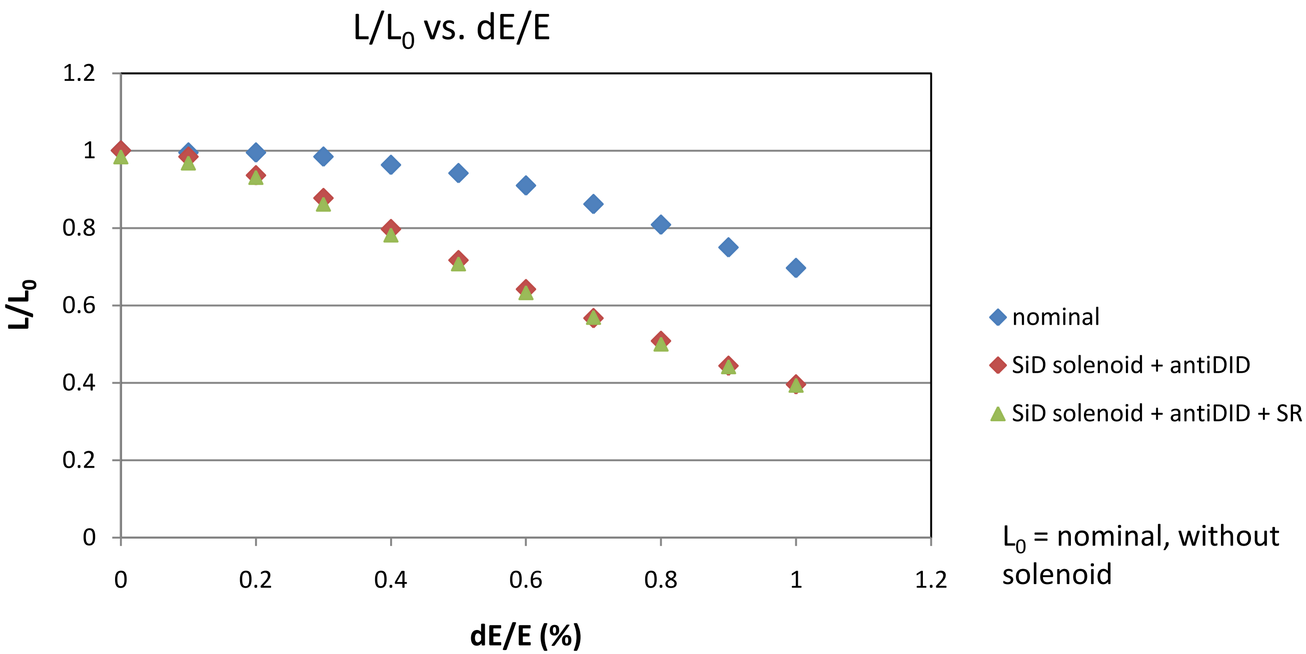




- The anti-solenoid is longer and weaker in case of ILD solenoid compare to SiD solenoid,
- An additional dipole corrector is inserted between QF1 and SD0,
- The beam orbit is totally corrected
- Sextupole displacements (horizontal and vertical) can be of a few microns for the smaller and almost 1mm for the bigger.

III. Results - geometric luminosity calculation

- Uses particle cloud after tracking in the whole BDS (TraceWin),
- Takes hourglass effect into account.



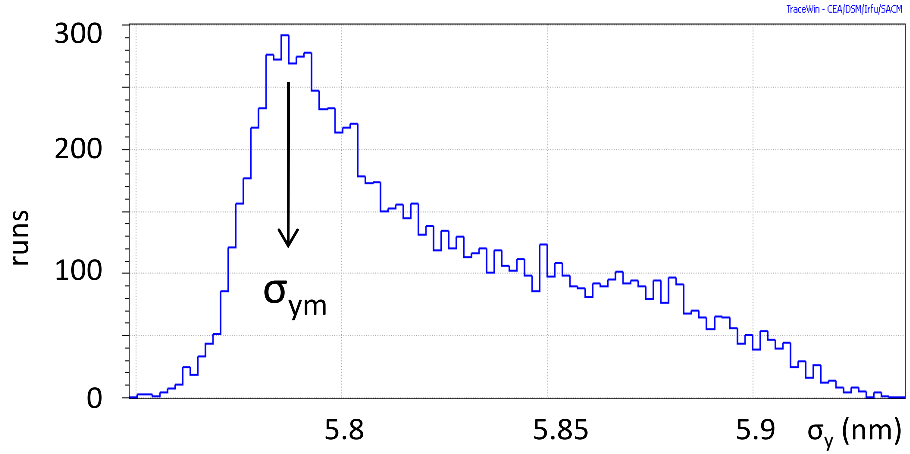
- Initial dE/E is modified, letting solenoid compensation same,
- Incoherent synchrotron radiation is calculated in the interaction region only.

> $\Rightarrow$ **L(dE/E) is deteriorated, almost 10% luminosity loss for dE/E=0.2%**
> $\Rightarrow$ **Loss due to synchrotron radiation is about 1% at nominal dE/E.**

IV. Tolerances on correctors - anti-solenoid

Histograms :

- 10 000 particles
- 10 000 runs, with compensated solenoid and anti-DID
- error on anti-solenoid strength random between 0 and 1%
- same condition for both SiD and ILD cases.

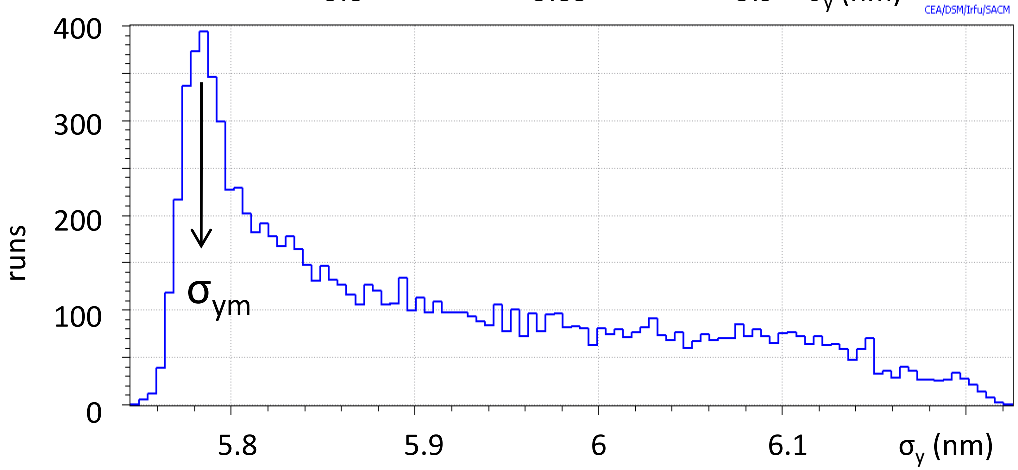


SiD detector :

$<\sigma_y/\sigma_{y0}> = 1.012$

$(\sigma_y/\sigma_{y0})_{max} = 1.033$

$\sigma_{ym}/\sigma_{y0} = 1.006$



ILD detector :

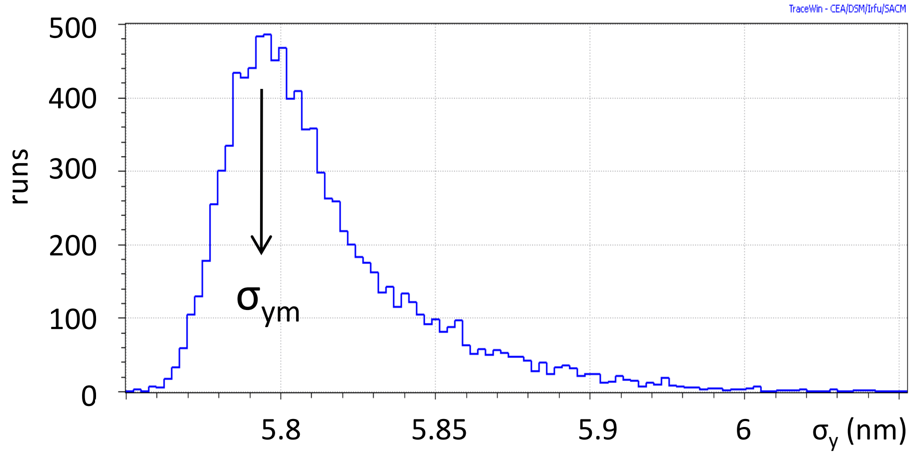
$<\sigma_y/\sigma_{y0}> = 1.028$

$(\sigma_y/\sigma_{y0})_{max} = 1.043$

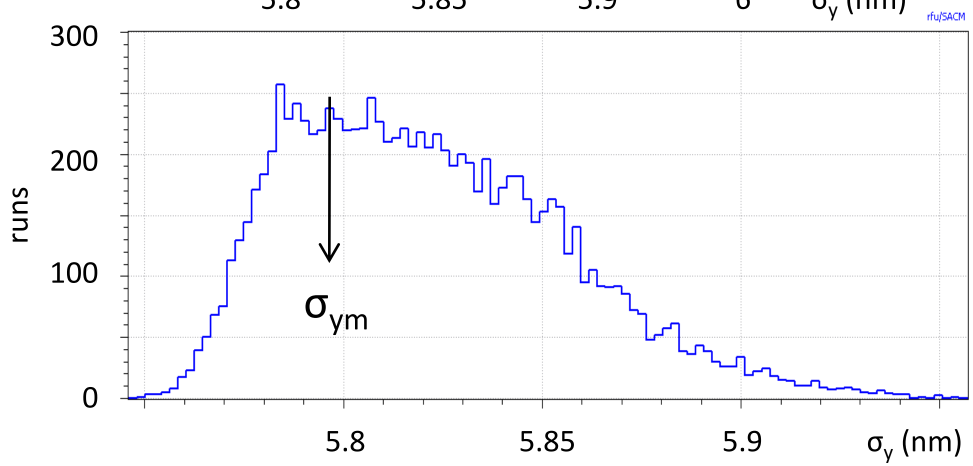
$\sigma_{ym}/\sigma_{y0} = 1.005$

IV. Tolerances on correctors - tuning knobs

Tuning knobs = skew quadrupoles strengths and sextupoles displacements



SiD detector :
random errors
between 0 and 10%,
$<\sigma_y/\sigma_{y0}> = 1.010$
$(\sigma_y/\sigma_{y0})_{max} = 1.043$
$\sigma_{ym}/\sigma_{y0} = 1.008$



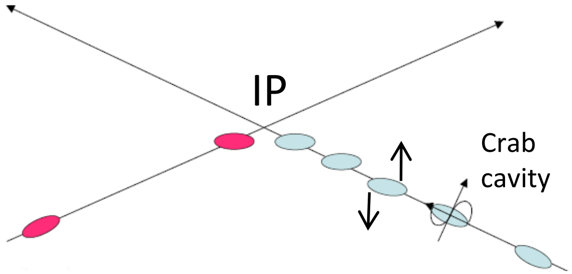
ILD detector :
random errors
between 0 and 20% ,
$<\sigma_y/\sigma_{y0}> = 1.012$
$(\sigma_y/\sigma_{y0})_{max} = 1.037$
$\sigma_{ym}/\sigma_{y0} = 1.01$

⇒ *Anti-solenoid* : as it corrects ~95% of beam size growth, **less than 1% error** on the strength can lead up to **4% loss of luminosity**,
⇒ *Tuning knobs* : errors compensate each other, **10% max. error** on all knobs keeps $\boldsymbol{\sigma_y/\sigma_{y0} \leq 2\%}$**.**

V. Solenoid effect on crab crossing

Transverse potential in the crab cavity :

$$V = \sqrt{V_{x0}^2 + V_{y0}^2}\,\sin\left[\frac{2\pi f}{c} z\right]$$
$$\approx \sqrt{V_{x0}^2 + V_{y0}^2}\,\frac{2\pi f}{c} z$$



V_{x0} is calculated to give the right kick to compensate the **horizontal crossing angle θ_c.**

Crab cavity representation : thin matrix at 13.4m from the IP

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & M_{25} & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & M_{45} & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ M_{61} & M_{62} & 0 & 0 & 0 & 1 \end{pmatrix}$$

with

$$\begin{cases} M_{25} = -\dfrac{\theta_c}{2}\dfrac{R_{34}}{R_{12}R_{34} - R_{14}R_{32}} \propto V_{x0} \\ M_{45} = +\dfrac{\theta_c}{2}\dfrac{R_{32}}{R_{12}R_{34} - R_{14}R_{32}} \propto V_{y0} \\ M_{61} = M_{25} \\ M_{62} = M_{45} \end{cases}$$

R_{ij} being the matrix terms of the transport from the crab cavity to the IP.

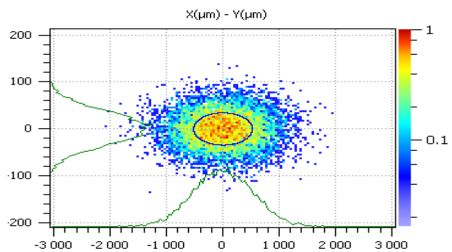
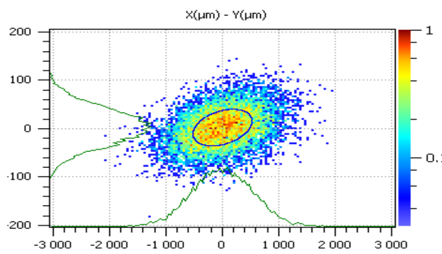
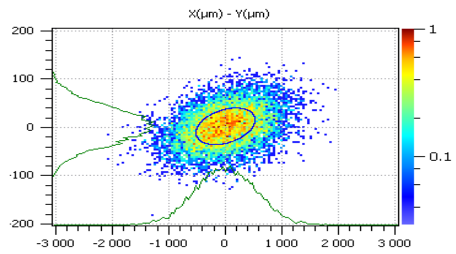
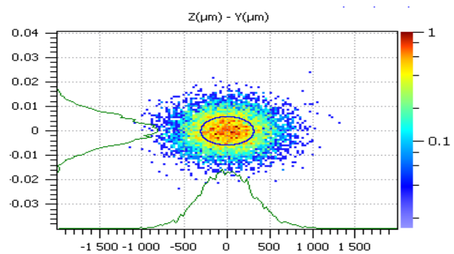
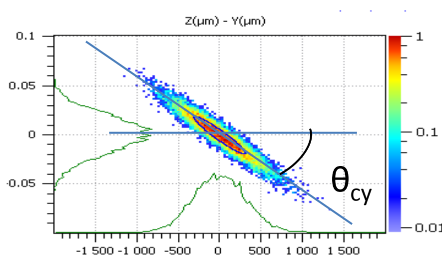
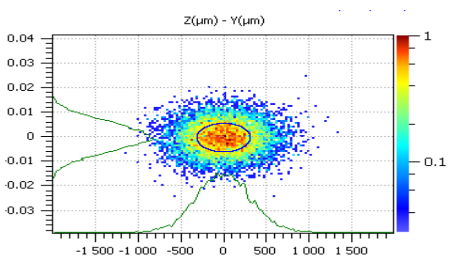
Nominal (no solenoid) : $R_{32} = 0$ → **V_{y0} is zero,**
Compensated solenoid : $R_{32} \neq 0$ → **V_{y0} should not be zero** to compensate for **coupling between the crab cavity and the IP**, otherwise a non zero **vertical crab crossing angle is present** at the IP.

V. Solenoid effect on crab crossing

In the presence of **compensated solenoid,**
$V_{y0} = 0$ implies $\boldsymbol{\theta_{cy} = 60\ \mu rad}$
which corresponds to **70% luminosity loss**, same loss as if there was no crab cavity.

For f = 3.9 GHz, $V_{x0} \approx$ 1.3MV and $\boldsymbol{V_{y0} \approx 75kV}$
$\boldsymbol{\approx 0.057\ V_{x0}}$.

Transverse and longitudinal beam profiles at the cavity location and at the IP, for $V_{y0} = 0$ and $V_{y0} \neq 0$:

	Solenoid OFF, $V_{y0} = 0$	Solenoid ON, $V_{y0} = 0$	Solenoid ON, $V_{y0} \neq 0$
y vs. x, at crab cavity location			
y vs. s at the IP			

Conclusion

- Solenoid and anti-DID effects are compensated for a nominal momentum spread,
- Luminosity versus momentum spread is degraded after compensation of solenoid and anti-DID effects,
- Less than 1% error on the anti-solenoid strength can lead up to 4% luminosity loss because of the statistical distribution; 10% error on tuning knobs (skew quadrupoles and sextupoles displacements) keep luminosity loss less than 2%,
- Luminosity loss due to synchrotron radiation in the interaction region is about 1% at nominal momentum spread,
- In the case of compensated solenoid, a vertical component of the potential in the crab cavity is necessary not to lose luminosity, as coupling remains in the transfer line from the crab cavity to the IP.

Thank you

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Anti-solenoid parameter	SiD, L*=3.5m	ILD, L*=4.5m
Length	0.75m	1.1m
Strength	-1.01T	-0.65T
Position from IP	3.74m	5.14m

Skew corrector	Gradient (T/m)	
	SiD, L*=3.5m	ILD, L*=4.5m
SQ1	3.77	-0.78
SQ2	7.93	-3.69
SQ3	6.83	-0.35
SQ4	-3.69	-3.92

Displaced sextupole	Displacement (µm)			
	SiD, L*=3.5m		ILD, L*=4.5m	
	horizontal	vertical	horizontal	vertical
SF6	0	15.81	3.54	-204.3
SF5	0	71.46	72.25	-992.9
SD4	0	2.16	7.07	0

Dipole corrector	Field (T)	
	SiD, L*=3.5m	ILD, L*=4.5m
Wound on QF1	-0.0021	-0.00066
Additional 'DIP'	0.020	0.022
Wound on QD0	0.016	-0.027