HL-LHC Nominal/Ultimate Scenarios: Aperture and Beam-beam separation

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Nominal/Ultimate Scenario

Injection

	IP1	IP5	IP2	IP8
β*[m]	6	6	10	10
Half crossing angle (B1/B2) [θ, μrad]	±295(H)	±295(V)	±170(V)	±170(H)
Parallel separation (B1/B2) [d, mm]	±2	±2	±3.5	(-) ±3.5
Angular offset (B1/B2) [d, μrad]	0	0	-40	-40

Beginning stable beam (assuming LS2 Upgrade see table X. Buffat)

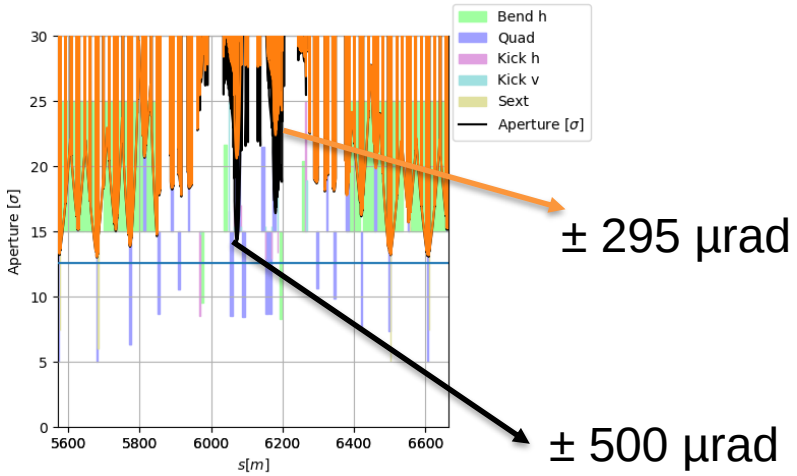
	IP1	IP5	IP2	IP8
β*[m] - ATS (Nominal)	0.61 (1x)	0.61 (1x)	10	1.5
β*[m] - ATS (Ultimate)	0.41 (2x)	0.41 (2x)	10	1.5
Half crossing angle (B1/B2) [μrad]	±250(H)	±250(V)	±170(V)	±250(H)
Parallel separation (B1/B2) [mm]	±0.55	±0.55	±1.4	±1

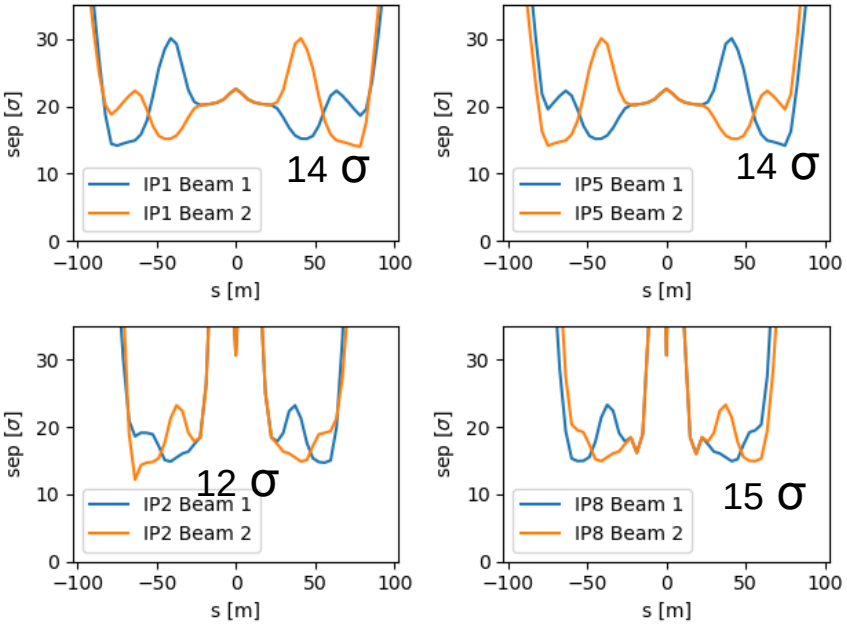
Update of the HL-LHC operational scenarios for proton operation, CERN-ACC-NOTE-2018-0002

Injection: apertures and separation

Parameters	Values
Radial CO [mm]	2
Energy error	$2\ 10^{-4}$
Spurious dispersion	0.14
Beam size	1.05
Target [σ]	12.6

	Trip. 1/5	Trip. 2/8	ARCS
Min Ap. [σ]	20.5	12.8	13.1-13.3

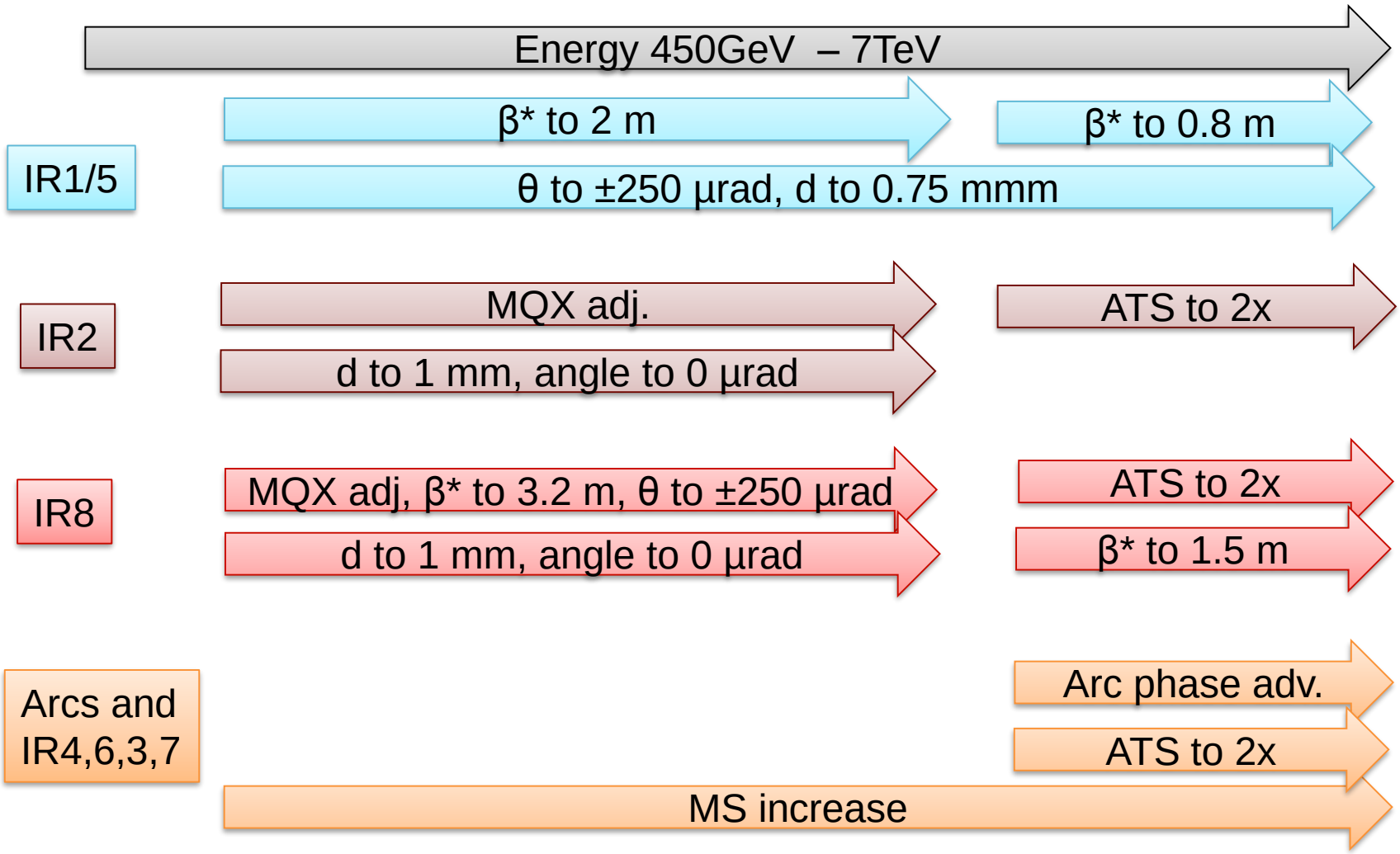




Crossing angle in IP1/5 could be increased up to ±500 μrad (22 σ), to be (mostly*) compatible with the apertures and reduced during the ramp.

(*) IR6, IR7 optics needs small retouch to gain 0.1-0.3 σ lost with extra dispersion with crossing angle.

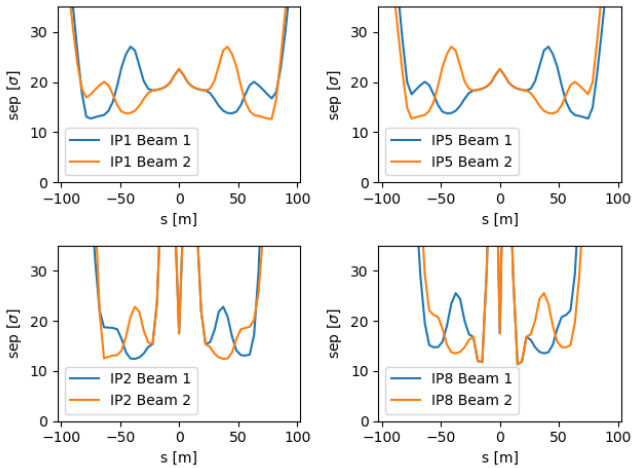
Ramp and squeeze (ultimate)



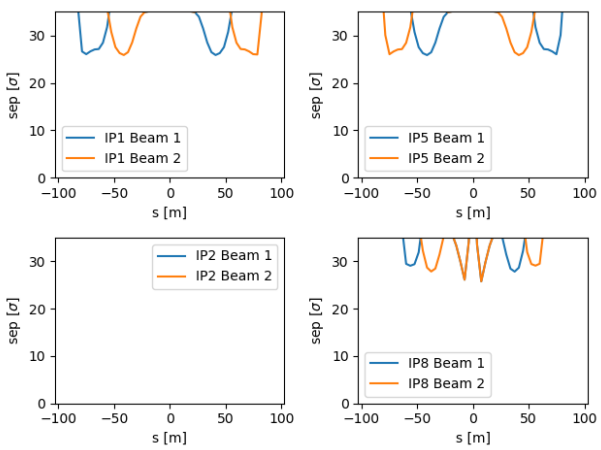
Ramp and squeeze: Settings (ultimate)

Energy [GeV]	450	2000	5000	7000
β*[m]	6,11,6,11	6,11,6,11	2,11,2,3.2	0.4,11,0.4,1.5
Θ [µrad]	295,170,295,-170	265,170,265,-190	260,170,260,-220	250,170,250,-250
d [mm]	2,3.5,2,-3.5	1,2,1,-2	1,1.4,1,-1.0	0.55,1.4,0.55,-1.0
a [µrad]	-,-40,-,-40	-,-0,-,-0	-,-0,-,-0	-,-0,-,-0

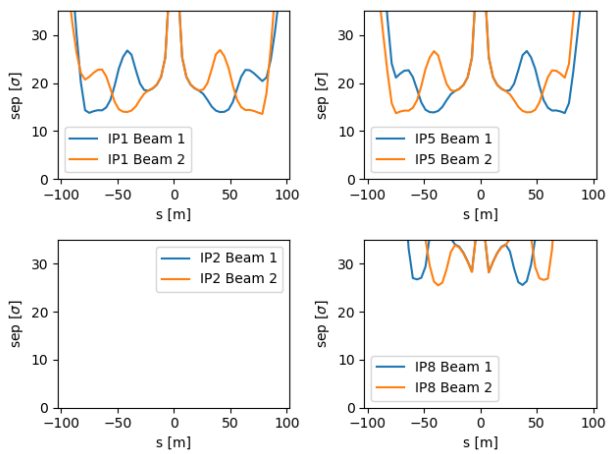
2000 GeV



5000 GeV



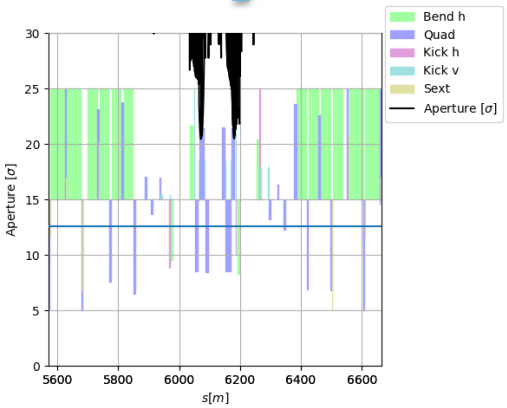
7000 GeV



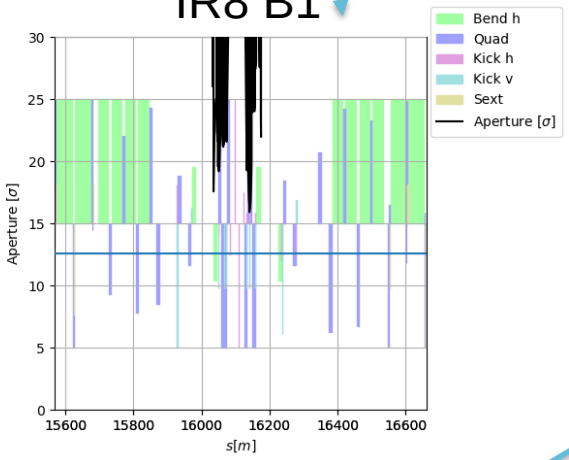
Ramp and squeeze: Apertures

Energy	Trip. 1/5 [σ]	Trip. 8 [σ]	ARCS [σ]
2000 GeV	28	25	28
5000 GeV	41	18	43
7000 GeV	20	12.4	35(ats)-49

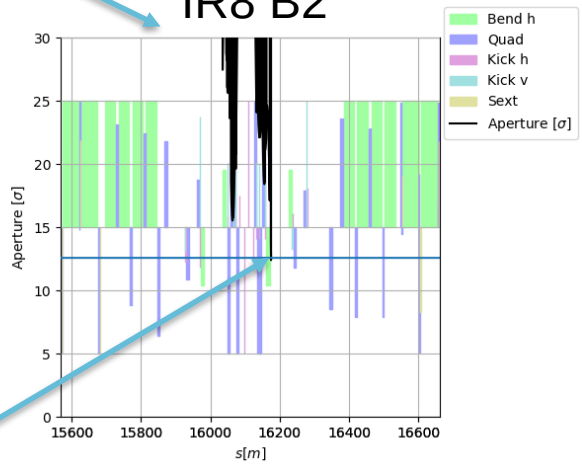
IR5 B1



IR8 B1



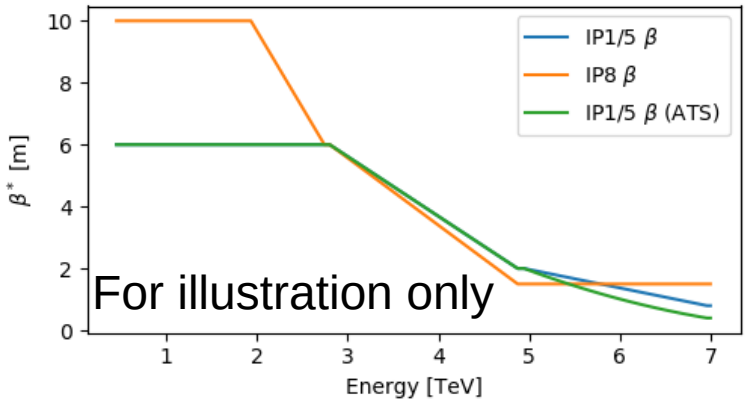
IR8 B2



TCDDM bottleneck: either replaced or reduction crossing angle (e.g. 220 µrad)

Current during the squeeze

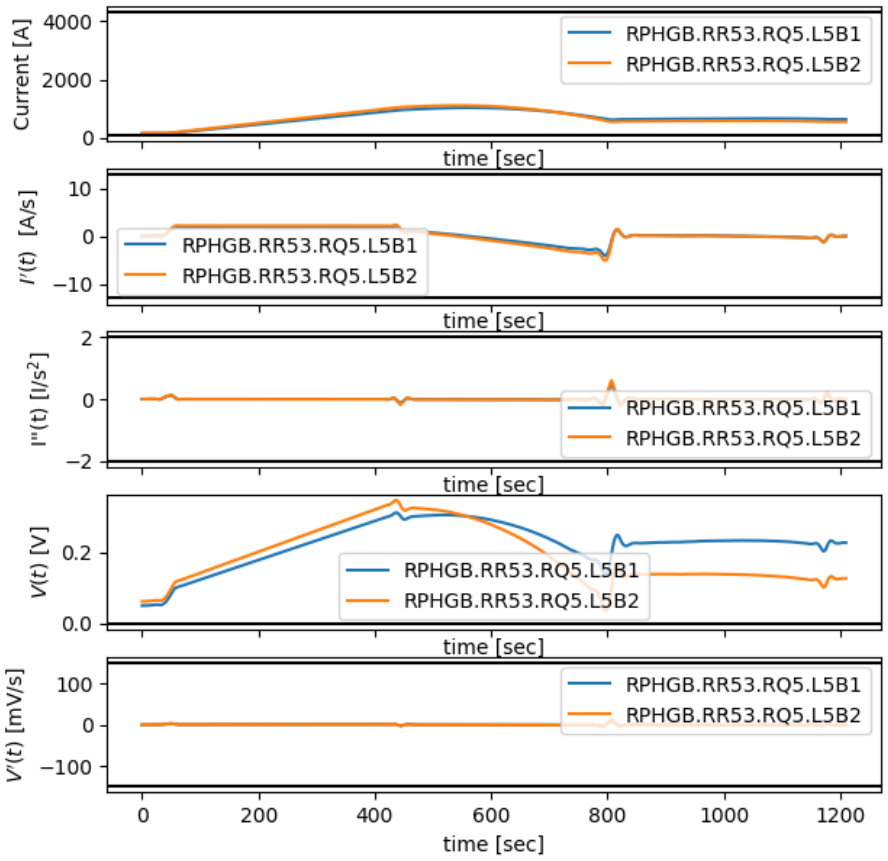
Work in progress to finalize the squeeze, implementing smooth transitions.



This ramp&squeeze fulfill the power converter constraints in all quadrupoles (but 3 trims). [artifacts in the transition to be removed]

Discussion on going for an implementation in LSA.

For illustration: Q5 L5



Conclusion

- Beam-beam separations and apertures are well within specifications also with the ultimate scenario with 2x ATS after the ramp, with an ATS squeeze from 5 to 7 TeV.
- The TCDDM is a bottleneck with ± 250 µrad in any scenarios. Migrations, besides hardware changes: reduction crossing angle: ± 250 H or ± ± 165 V.
- Squeeze sequence under optimization, relies on smooth transitions that are under development.

Backup

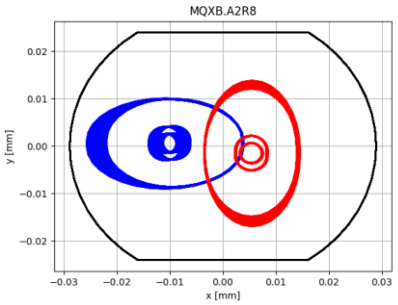
Aperture limitations in collision

Maximum half external crossing angle as function of β*

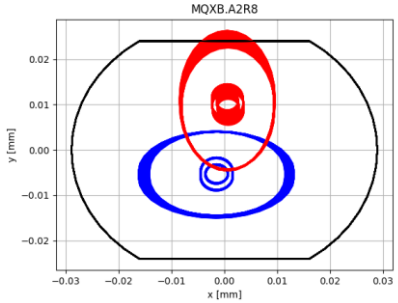
β* [m]	H[1] [μrad]	H[2] [μrad]	V[3] [μrad]	V[1,4] [μrad]
1	-165	-220	±115	±220
1.5	-225	-275	±165	±235
2	-265	-310	±205	±270
3	-310	-310	±250	±310

[1] with present TCDDM
[2] without present TCDDM
[3] crossing plane can be rotated during the ramp (difficult to setup)
[4] if beam screen is rotated, introducing strong limitations during the ramp

Aperture in the triplet is not symmetric (H=57.8 mm, V=48 mm) and cannot be rotated easily.

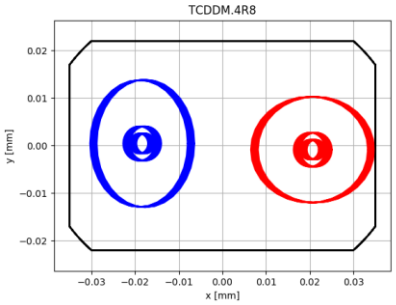


H crossing

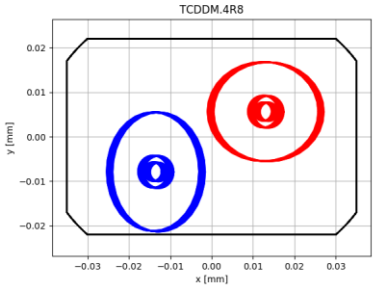


V crossing

TCDDM needed for D1 protection
Present aperture bottleneck for Beam 2 H and Beam 1 V.



H crossing



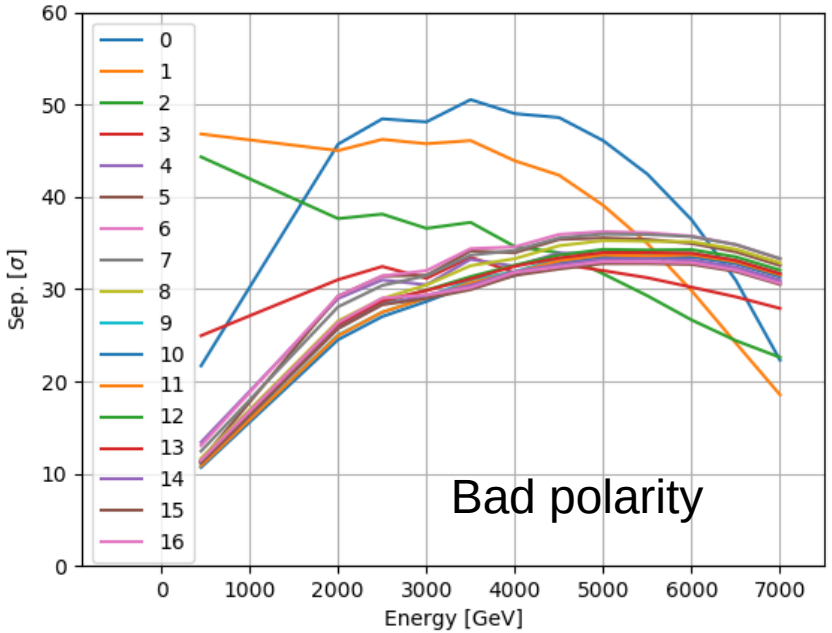
V crossing

Compatible with previous scenarios and still aperture margin for $\beta^*_{//}$.
Beam screen rotation not needed so far in V crossing, and, if it would, the issues are at injection…

Ramp and squeeze

Present ramp and squeeze from 2 TeV:

- H Crossing -170 µrad → -250 µrad [0.45 → 7TeV]
- V Separation -3.5 mm → -1 mm [2 → 7TeV]
- V Angle offset -40 µrad → 0 [2 → 7TeV]
- β* 10 m → 3 m [2 → 7TeV]

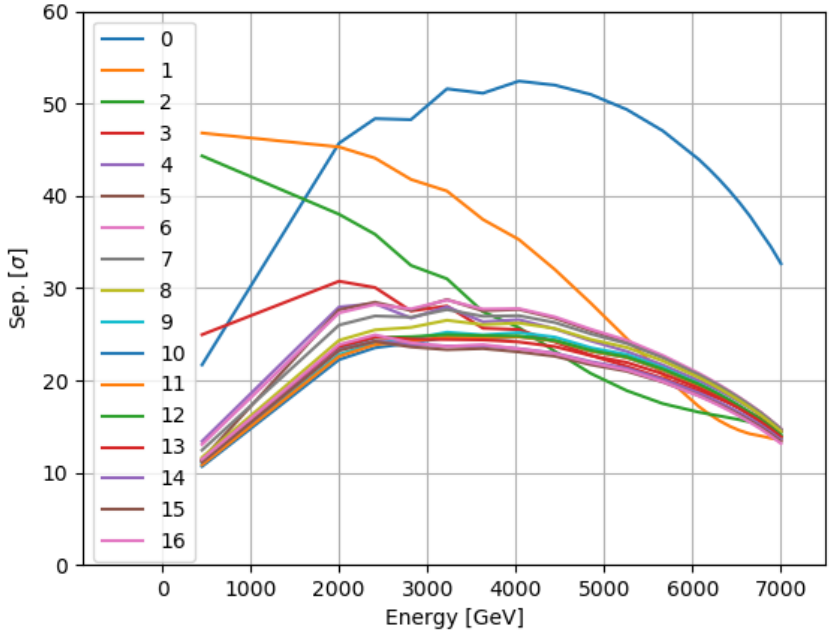


Most of the LR above 30σ,
Minimum is still about 20σ

Ramp and squeeze

Vertical crossing β*=1.4, ramp and squeeze from 2 TeV:

- Crossing -170 µrad → -160 µrad
- Separation -3.5 mm → -0.5 mm [2→7 TeV]
- Crossing plane 0 → 90° [from 2→7 TeV]
- V Angle offset -40 µrad → 0 [from 2→7 TeV]
- β* 10 m → 1.4 m [from 2→7 TeV]



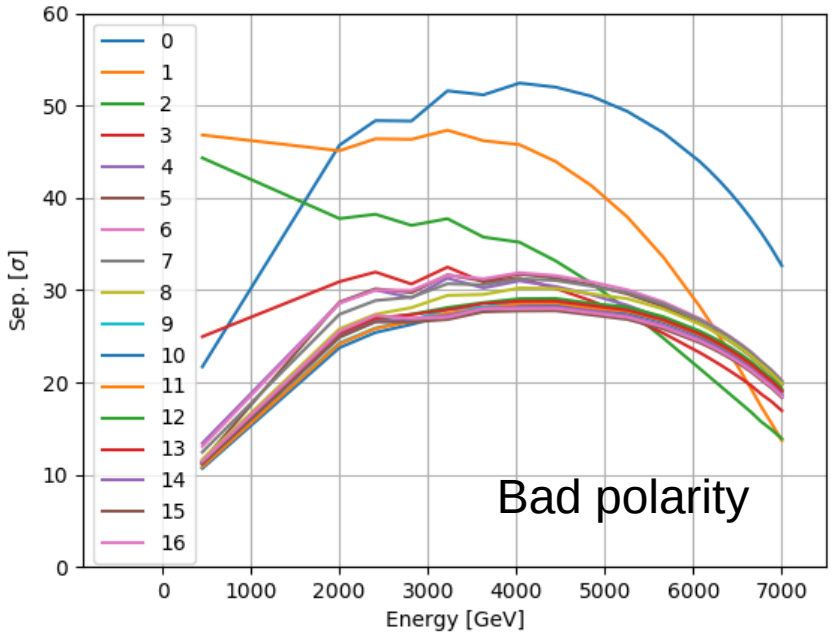
Increasing to β*=1.4, put LR to about 14 σ.

Overall vertical crossing does not seem too advantageous.

Ramp and squeeze

Pushed case β*=1.4, ramp and squeeze from 2 TeV:

- H Crossing -170 μrad → -220 μrad [0.45 → 7TeV]
- V Separation -3.5 mm → -1 mm [2 → 7TeV]
- V Angle offset -40 μrad → 0 [2 → 7TeV]
- β* 10 m → 1.4 m [2 → 7TeV]



Most LR above 19 σ.
With present TCDDM.

One could look at flat beams for higher luminosity

Protected Apertures

$\Delta\mu_x$ MKD-TCT [°]	Aperture [σ@2.5μm]
0-20	11.2
30	11.9
40	12.9
50	13.8
60	14.5
70-90	14.6
No TCT	19.4
Injection	12.6

Parameter	7 TeV	0.45 TeV
Radial CO [mm]	2	
Mom offset	$2\ 10^{-4}$	$8.6\ 10^{-4}$
Dispersion	0.1	0.14
Beam size	1.1	1.05

R. Bruce et al. CERN-ACC-2017-0051

Point 6: optics, aperture, crossing plane

	Round	FlatCC	Flat
β* Xing/Sep [cm]	15/15	18/7.5	30/7.5
Xing angle [μrad]	±250	±240	±245
MKD-TCT [°] IP5	30	22	25
Protected H Ap. [σ] IP1/5	11.2/11.9	11.2/11.4	11.2/11.7
Protected V[1)] Ap. [σ] IP1/5	11.2/11.2	11.2/11.2	11.2/11.2
Crossing plane IP5	V or H	H	H
Aperture Xing plane [σ]	13.1	14.2	15.6
Aperture Sep plane [σ]	16.5	12.7	12.7

1) assuming different settings for TCTH and TCTV, which is under study (R. Bruce)

Enough aperture with free choice of crossing plane for round optics.

- Present baseline is V-plane in IP5 based on maximizing the round optics margins.
- Need to get input for the forward physics program from the experiments.
- Potential of a flat optics with crab cavities requires more studies.
- What is the time scale for the finalization of the crab cavity layout?