How low can we go?

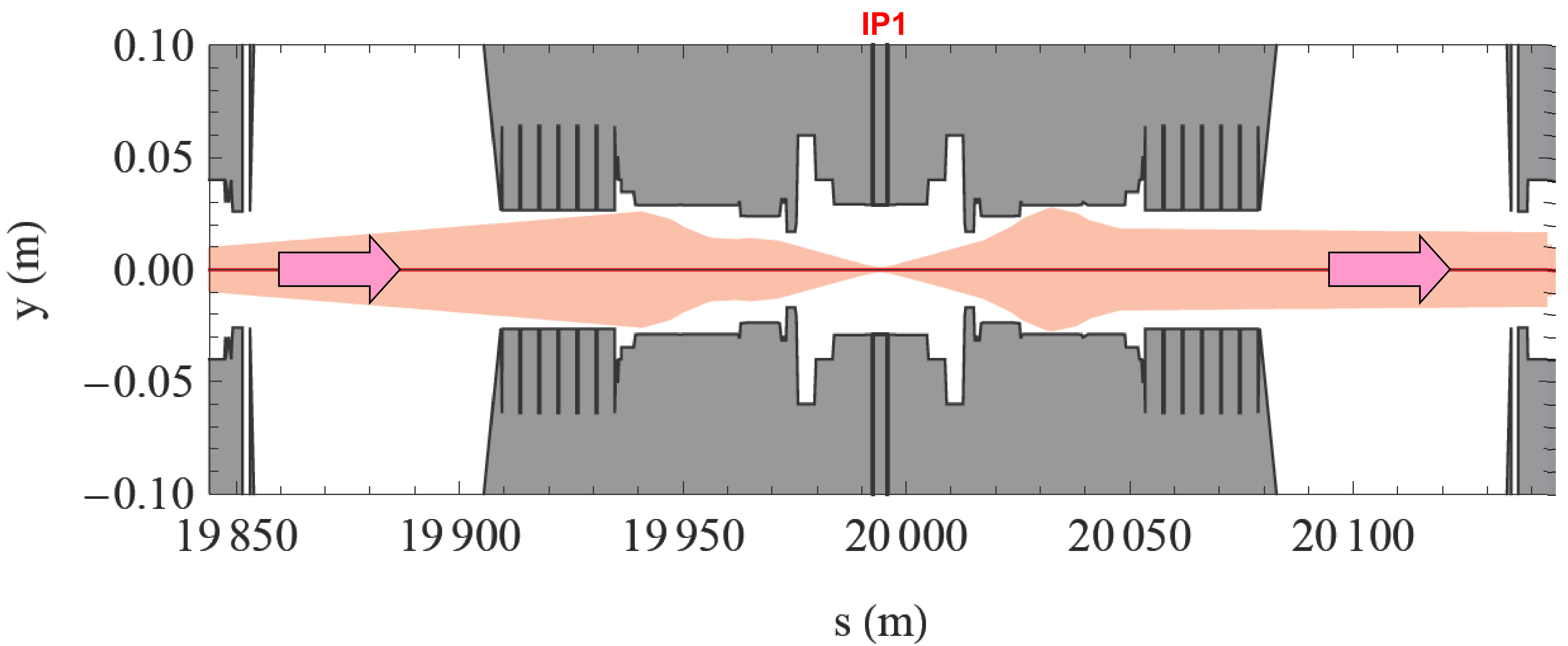
Getting below β^*=3.5m

R. Bruce, R.W. Assmann

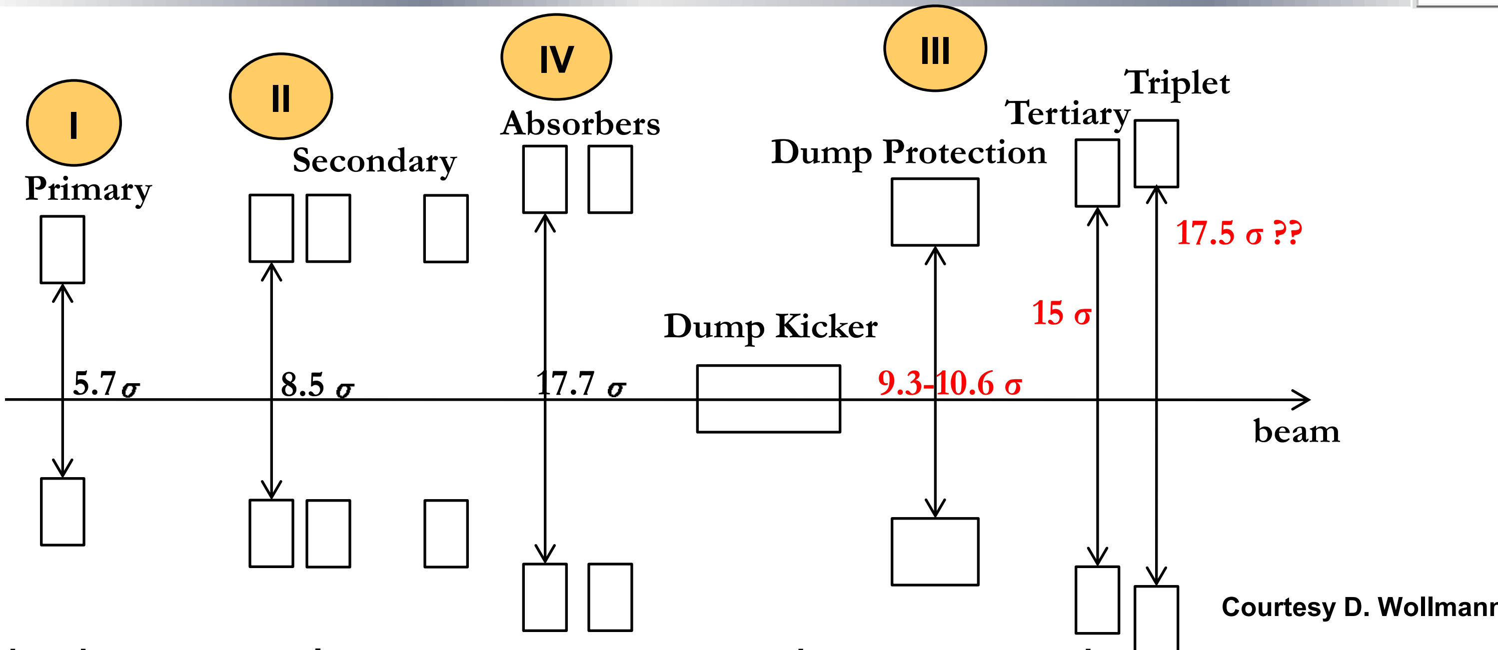
Acknowledgment:
T. Baer, W. Bartmann, C. Bracco, S. Fartoukh, M. Giovannozzi,
B. Goddard,W. Herr, S. Redaelli, R. Tomas, G. Vanbavinckhove,
J. Wenninger, S. White, D. Wollmann

Introduction

- Main limitations when going to smaller β*
  - Magnetic limits: max gradient in quadrupoles and chromaticity
  - Beam-beam limit …
  - Aperture limit: decreasing margins in triplet when decreasing β. Present limit!



Protection hierarchy



- Hierarchy between cleaning stages must be preserved to guarantee protection – limits β-beat and orbit variation
- To optimize β*, we have to review
  - Triplet aperture
  - Margin TCT/triplet
  - Margin Dump protection/TCT
  - Settings and margins for other collimators and dump protection

Triplet aperture

- Aperture traditionally calculated with MAD-X using n1
  - Takes into account mechanical tolerances and most pessimistic case of beta beating and orbit shifts
  - safe but possibly pessimistic approach
- Global aperture measured at injection energy: **aperture larger than expected**
  (from M. Giovannozzi, R. Assmann, R. Giachino, D. Jacquet, L. Ponce, S. Redaelli, and J. Wenninger, presentation LHCCWG 2010.09.14)

	Horizontal	Vertical
Beam 1	12.5	13.5
Beam 2	14.0	13.0

Global aperture in nominal beam σ. Expected: 8.4 σ

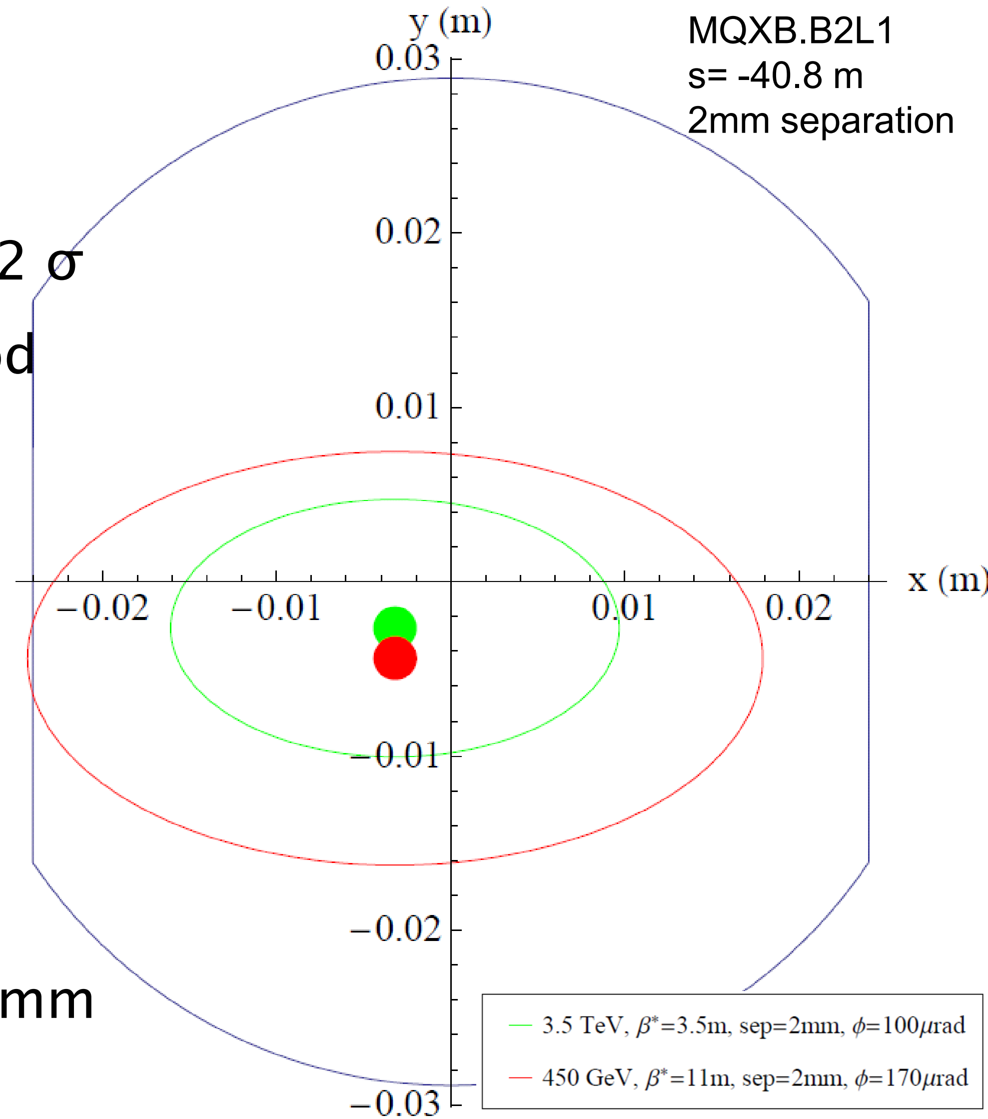
- Can we use this information to better estimate the triplet aperture?

Simplistic calculation procedure

- Find s-value of limiting triplet aperture with MAD-X (h and v)
- Assume *pessimistically* injection aperture=global limit+2 σ
- Only one plane matters with good approximation – reduce to 1D
- Scale beam size to pre-collision (larger β_x and γ), add orbit offsets in relevant plane

$$|u_i| + n_i\sigma_i = |u_p| + n_p\sigma_p$$

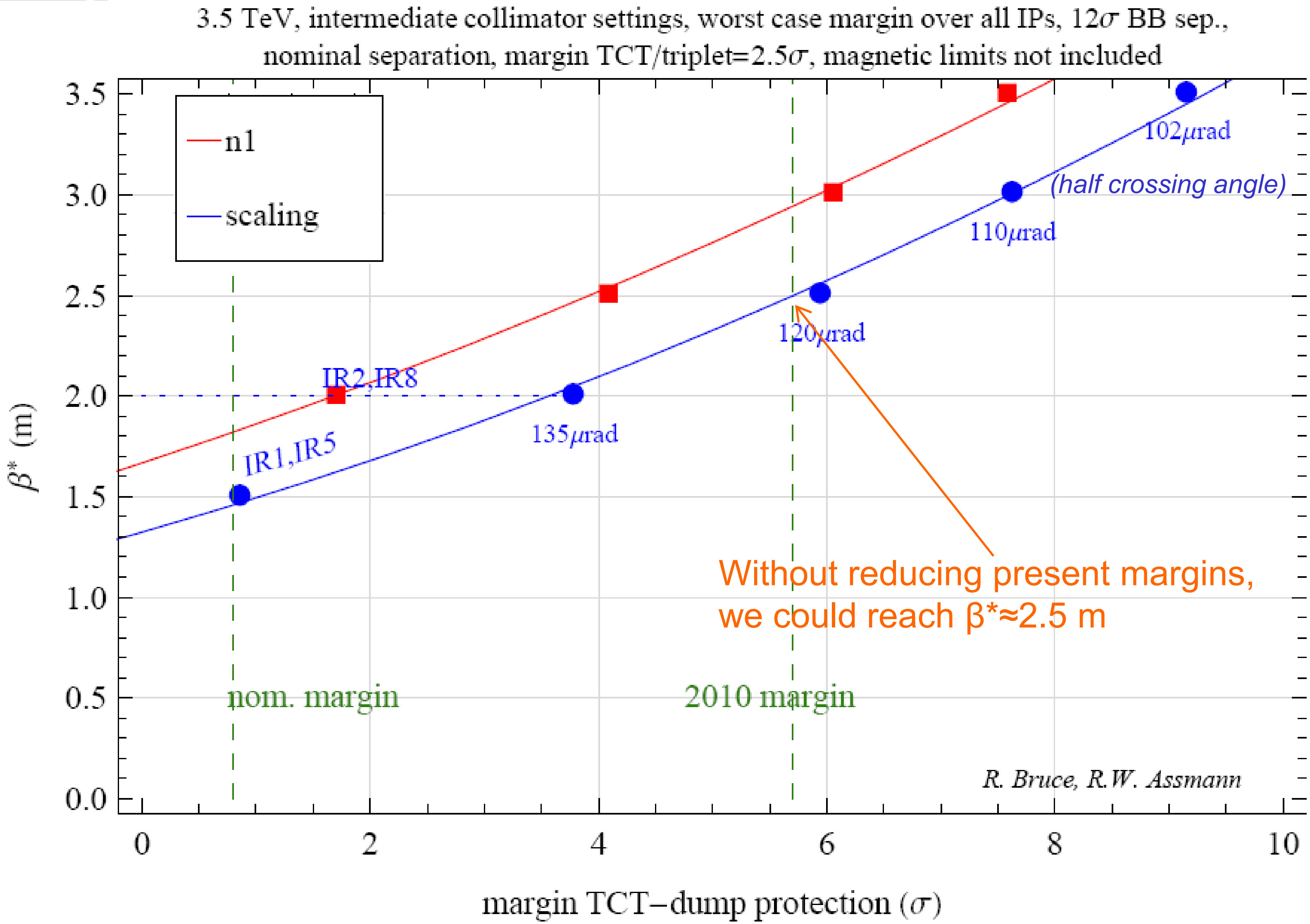
- Solve for top energy aperture
- Additional assumption: reduce separation to nominal value 0.7 mm



Margins in aperture calculation

- All mechanical and alignment errors already included in measurement – nothing changes between injection and top energy
- Orbit variations must be accounted for
  - Up to 2mm difference in orbit shift from injection to top energy between measurement and MAD-X at BPMs close to triplets
  - 1 mm fill-to-fill variations at top energy at BPMs close to triplets
  - Using total orbit uncertainty of 3mm going in pessimistic direction
- β-beat must be accounted for
  - High reproducibility from fill to fill
  - Using the measured beam size at injection and top energy
- Calculating aperture both with traditional n1 (3mm orbit as worst case observed in triplet and 10% method and β-beat) aperture scaling

Result 3.5 TeV, 2010 margins



Margin TCT/triplet

- Presently 2.5 σ margin used. Can this be reduced?
- Orbit at TCTs seen to deviate up to 2 σ (seen in IR2) during stable beams (*see talk S. White*)
  - Large deviations partly due to luminosity leveling in ALICE – different strategy possible?
  - Other IPs stable within around 1 σ
- Except during scans and levelling, orbits at TCT and triplet are closely correlated. Movements follow within 0.3 σ
  - During small scans, orbit moves by less than 0.2 σ at the TCT. This is within tolerances. During van der Meer scans, TCTs must follow orbit. Implementation?
- Beta beat mainly *increases* margins TCT/triplet in present machine (ratio $\beta_{meas}/\beta_{model}$ larger at TCT)
  - Some exceptions, IR8 vertical plane worst. Use margin optimization as constraint for beta beat correction: input to β-beat team (R. Tomas et al.)
  - Taking into account a possible 5% drift of the β-beat
- Proposal: Margins can be decreased to 1.5 σ (0.7-1.3mm at $\beta^*=1.5$m)

Achieved stability 2010

- Investigating 2010 performance to conclude on collimators margins
- Feasible global β-beat: 10%
- Reproducibility of β-beat: better than 5%
- Worst orbit in fills that reached stable beams since September 18 shows up to 2σ deviations from reference orbit at TCTs (but mean < 1σ deviation for all IRs except IR2)

Input: R.Tomas, G. Vanbavinckhove, S. White

Observed uncertainty 2010 (σ at 3.5 TeV, β*=3.5m)

Device	orbit	beta beat (5%)	positioning (40 um)	setup (10 um)	lumi scans	uncertainty (sum)	uncertainty (quadratic sum)
TCT	2	0.4	0.1	0.02	0.2	2.7	2.0
TCSG IR6	0.4	0.2	0.1	0.01		0.7*	0.5
TCSG IR7	1.2	0.2	0.2	0.04		1.6	1.2
TCP IR7	1.2	0.1	0.1	0.03		1.5	1.2

Are we overly cautious if we add all uncertainties ?

interlocked at end 2010 to 1.2 sigma…

Margin TCT–dump protection

- Asynchronous dump test with TCTs moved in from 15 σ to 13 σ carried out (*C. Bracco, B. Goddard , R. Assmann, et al.*).
  - No direct proton leakage from IR6 to TCTs even with reduced setting
- Adding uncertainties linearly gives 3.4 σ margin between dump protection (TCSG at 9.3 σ) and TCT. This would imply TCT at 12.7 σ (2.1 σ margin to TCDQ) in present optics
- Proposal: Reduce margin TCT–dump protection from 5.7 to 3.4 σ (a little less than qualified in 2010).
- Margins reduced correspondingly if orbit variations at the TCTs are reduced
- All dump protection settings to finalised with beam dump team
- Validation (systematic study of leakage from TCDQ to TCT during asynchronous dumps as function of retraction would be useful)

Moving other collimators

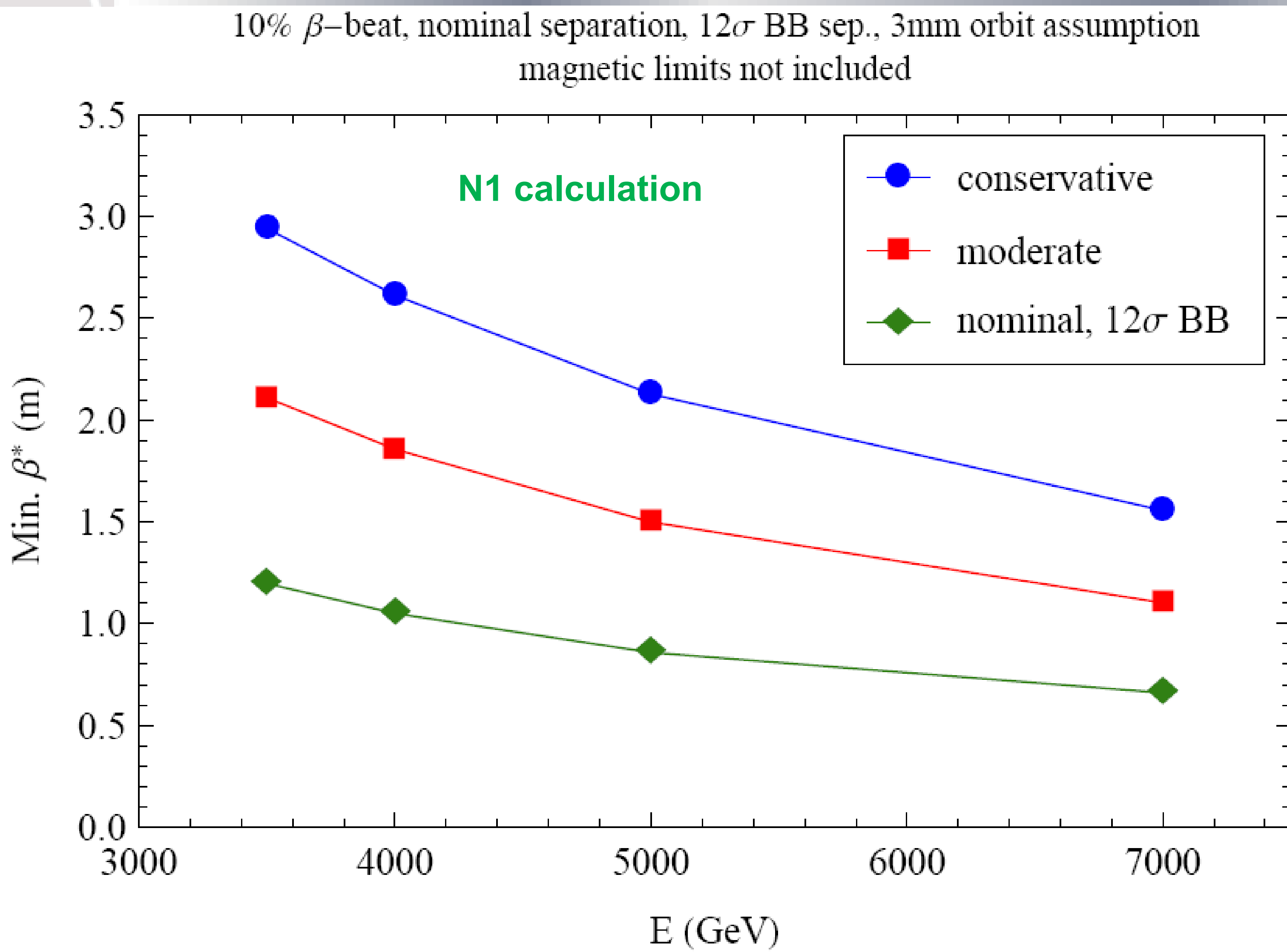
- Nominal collimator settings:
  - TCT at 8.3 σ
  - TCSG6/TCDQ at 7.5/8.0 σ
    - => Orbit stability of 0.2-0.3 σ required. We're not quite there yet…
- Adding uncertainties linearly, present margin between TCP and TCS in IR7 seems to be needed
- Emittance is smaller than nominal – could we collimate closer to the beam, keeping intermediate settings?
  - Impacts on impedance and efficiency
  - To be discussed later (Chamonix)

So how low can we go?

So how low can we go?

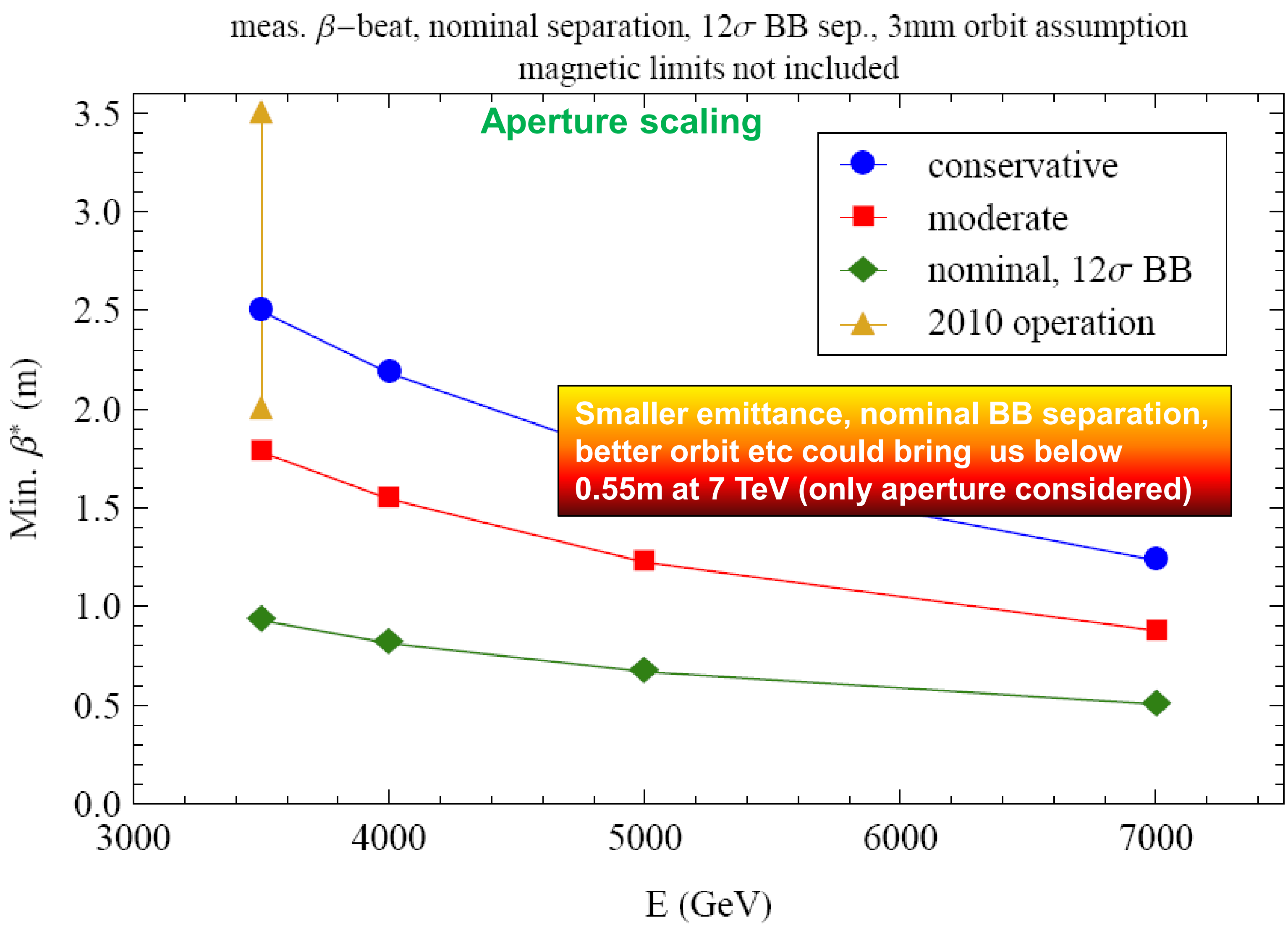
- Minimum β* calculated for three options, using n1 and scaling method:
  - Conservative: Keep 2010 margins
  - Moderate: Keep intermediate collimator settings. Reduce margins to aperture-TCT=1.5 σ and TCT-TCDQ=2 σ
  - Nominal collimator settings with increased beam-beam separation
- Assumptions in calculations:
  - Always taking min margin over all IPs, planes and beams
  - Minimum β* given by intersection between interpolation and desired margin (see slide 9)
  - Using nominal 0.7 mm separation
  - Using measured β-beat at injection and top energy with 5% reproducibility, 10% β-beat in n1 calcualtion
  - Assuming max 3 mm orbit shift in pessimistic direction between measurement at injection and top energy
  - Assuming 12 σ beam-beam separation (larger than nominal)
  - Triplet aperture at injection assumed 2 σ larger than global limit

Results n1



10% β–beat, nominal separation, 12σ BB sep., 3mm orbit assumption
magnetic limits not included
N1 calculation
conservative
moderate
nominal, 12σ BB
Min. β* (m)
E (GeV)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
3000
4000
5000
6000
7000

Results with aperture scaling



Conclusions (1)

- Squeeze limited by available triplet aperture
- Measurements at injection show that real aperture is larger than predicted by n1, implying more margins. Used to calculate top energy aperture besides usual n1 method. Gain ≈ 0.5m in β^*
- Analysis shows that 2010 running was conservative: We could have run at β^*=3.0m (n1) or β^*=2.5m (scaling) instead of β^*=3.5 m
- Reducing separation to nominal increases aperture margin
- Margins between triplet, TCT and TCDQ can be reduced but not to nominal
- Three sets of margins evaluated. Possibilities at 4 TeV:
  - Keeping 2010 margins: β^*=2.5 m with scaling
  - Moderate, reducing margins to feasibility level observed in 2010 operation: β^*=1.5 m with scaling
  - Nominal: not possible with present orbit stability

Conclusions (2)

- Proposal for 2011 running: β^*=1.5 m, intermediate settings, margins: 1.5 σ aperture–TCT, 2.1 σ TCT–TCDQ. n1 gives slightly more pessimistic results but we have seen that aperture is larger than predicted
- **Any β^* and collimator settings will be qualified through provoked losses before being used during runs!**
- Propose to start like this but will try gain more in 2011 (IR aperture measurement, move towards nominal collimator settings etc.)
- Ongoing work on TCT damage limits (Chamonix): could lead to reduced further TCT–TCDQ margin

Wishlist

- Detailed measurements of the local triplet aperture in all IRs
  - Calculations presented here still rely on pessimistic assumptions
  - Global emittance blowup method can be used with addition of local bumps in the Irs
- Detailed study to fully understand discrepancy between n1 calculation and measurements
- Detailed analysis of all collimator margins based on stability
- Better orbit and β-beat
- β-beat corrected to increase margins TCT-triplet
- Study of leakage TCDQ-TCT during asynchronous dumps for different retractions (needs 1 ramped/collided beam per measurement point)

Min β* (m) from n1 method for different margins

2010 margins, 3.5 TeV

orbit beta beat	1mm	2mm	3mm
10.00%	2.5	2.7	2.9
5.00%	2.4	2.6	

2010 margins, 4 TeV

orbit beta beat	1mm	2mm	3mm
10.00%	2.2	2.4	2.6
5.00%	2.1	2.3	

Moderate, 3.5 TeV

orbit beta beat	1mm	2mm	3mm
10.00%	1.8	2	2.1
5.00%	1.7	1.9	

Moderate, 4 TeV

orbit beta beat	1mm	2mm	3mm
10.00%	1.6	1.7	1.9
5.00%	1.5	1.6	

Nominal margins, 3.5 TeV

orbit beta beat	1mm	2mm	3mm
10.00%	1	1.1	1.2
5.00%	1	1.1	

Nominal margins, 4 TeV

orbit beta beat	1mm	2mm	3mm
10.00%	0.9	1	1
5.00%	0.9	0.9	