TCDQ positioning and collimator tolerances

Brennan & Thomas

Tracking results

- 7 TeV tracking made with ‘realistic’ setup, collimator positions, TCDQ settings, orbit, beta-beating…
- For some seeds IR7 collimators do not intercept beam.
  - Expected, as beta-beating changes phase advances
- But also…losses seen occasionally on some TCTs during asynchronous dump
  - Was puzzling as retraction is 0.8 σ…
  - Investigated further and is now understood…

Settings hierarchy (7 TeV)

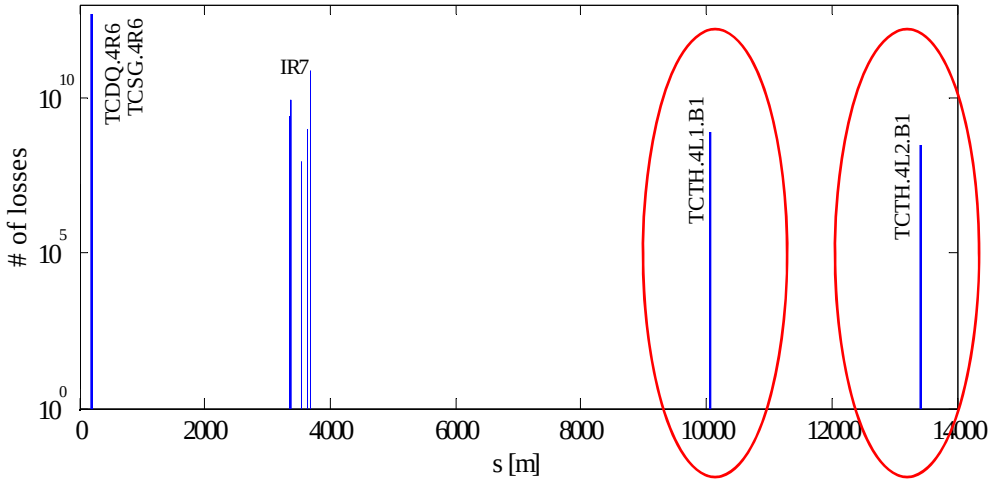
Values from Chiara's thesis

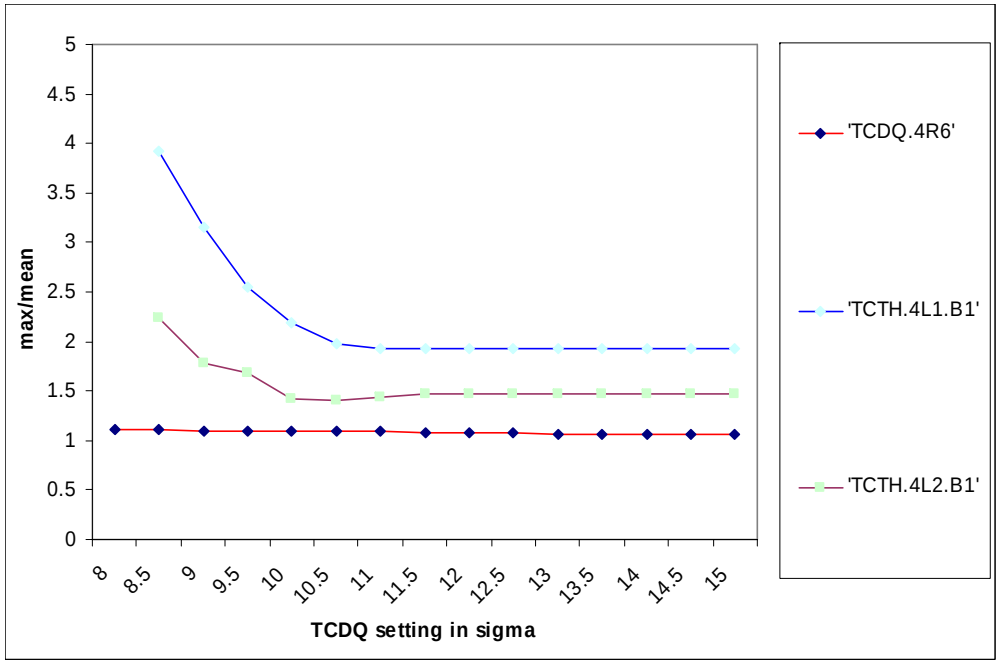
IR	Type	450 GeV [σ]	7 TeV [σ]
IR 1/IR 5	TCT TCL	9.5 out	8.3 10.0
IR 2/IR 8	TCLI TDI TCT	6.8 6.8 9.2	out out 30-40
IR 3	TCP TCSG TCLA	8.0 9.3 10.0	15.0 18.0 20.0
IR 6	TCSG TCDQ	7.0 8.0	7.5 8.0
IR 7	TCP TCSG TCLA	5.7 6.7 10.0	6.0 7.0 10.0

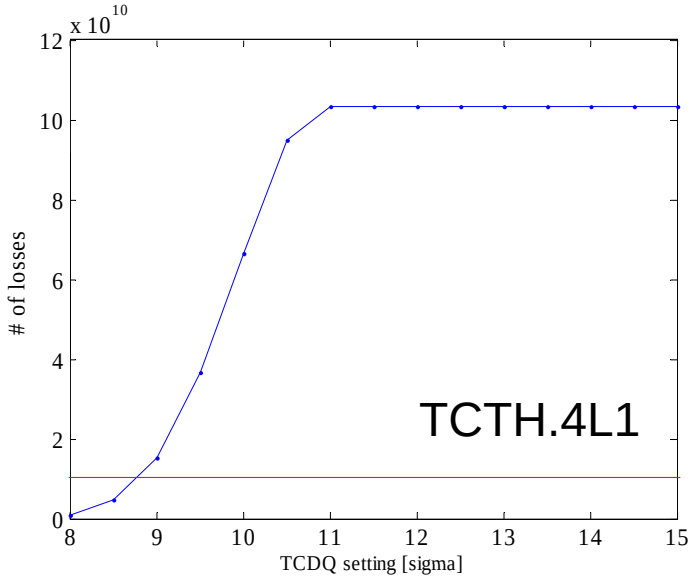
Values assumed in tracking

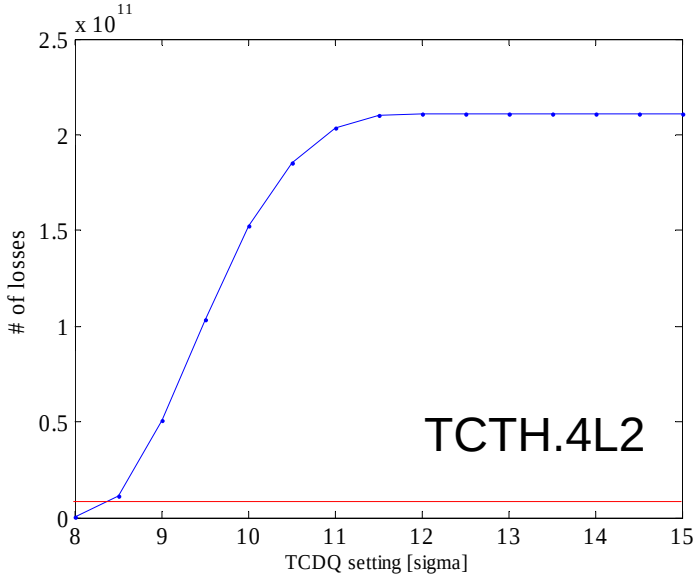
IR	Type	450 GeV [σ]	7 TeV [σ]
IR 1/IR 5	TCT TCL	17.0 10.0	8.3 10.0
IR 2/IR 8	TCLI TDI TCT	6.8 6.8 17.0	15.0 17.0 8.3
IR 3	TCP TCSG TCLA	8.0 9.3 10.0	15.0 18.0 20.0
IR 6	TCSG TCDQ	7.0 8.0	7.5 8.0
IR 7	TCP TCSG TCLA	5.7 6.7 10.0	6.0 7.0 10.0

7 TeV prefire case









Average losses – some seeds worse!

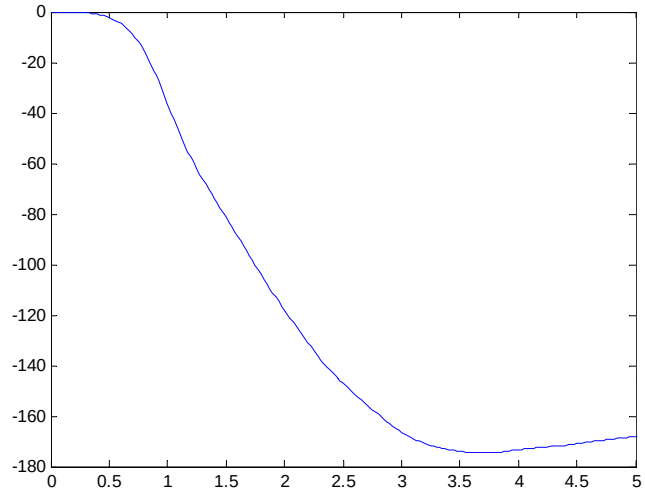
7 TeV tracking results

	With all errors						Clean machine					
	Prefire case			Normal case			Prefire case			Normal case		
'sigma'	8	10	15	8	10	15	8	10	15	8	10	15
'TCDQ.4R6'	4,66E+12	4,07E+12	3,11E+12	3,08E+12	2,85E+12	2,42E+12	4,81E+12	4,15E+12	3,11E+12	3,12E+12	2,88E+12	2,42E+12
'TCDQM.4R6'	0	0	0	0	0	0	0	0	0	0	0	0
'TCLA.A7R7.B1'	0	2,76E+08	8,18E+10	0	0	3,87E+10	0	0	7,08E+10	0	0	3,40E+10
'TCLA.C6R7.B1'	0	0	1,32E+10	0	0	5,84E+09	0	0	1,01E+10	0	0	5,06E+09
'TCP.C6L7.B1'	2,39E+09	8,83E+09	4,60E+10	1,66E+09	4,19E+09	7,54E+10	0	0	1,01E+10	0	0	5,98E+09
'TCSG.4R6'	2,32E+11	1,84E+11	1,24E+11	9,99E+10	8,11E+10	6,46E+10	1,79E+11	1,35E+11	8,56E+10	6,95E+10	4,83E+10	3,50E+10
'TCSG.6R7.B1'	7,62E+10	2,38E+11	4,53E+11	2,87E+10	8,44E+10	1,64E+11	5,80E+10	2,82E+11	5,79E+11	2,21E+10	8,51E+10	2,01E+11
'TCSG.A4L7.B1'	9,20E+07	1,84E+08	1,84E+08	0	0	4,60E+07	x	x	x	x	x	x
'TCSG.A4R7.B1'	x	x	x	4,60E+07	4,60E+07	4,60E+07	x	x	x	x	x	x
'TCSG.A5L7.B1'	x	x	x	0	0	4,60E+07	x	x	x	x	x	x
'TCSG.A6L7.B1'	8,19E+09	1,56E+10	5,90E+10	3,17E+09	5,43E+09	6,56E+10	5,52E+09	1,75E+10	7,27E+10	3,68E+09	5,06E+09	2,48E+10
'TCSG.B5L7.B1'	x	x	x	0	0	6,90E+08	x	x	x	x	x	x
'TCSG.B5R7.B1'	9,20E+08	1,29E+09	1,66E+09	5,06E+08	5,06E+08	5,52E+08	1,84E+09	1,84E+09	1,84E+09	9,20E+08	9,20E+08	9,20E+08
'TCSG.D4L7.B1'	0	2,76E+08	5,36E+11	0	0	2,85E+11	0	0	5,58E+11	0	0	2,57E+11
'TCTH.4L1.B1'	7,36E+08	6,64E+10	1,04E+11	1,84E+08	2,54E+10	4,21E+10	0	6,53E+10	1,05E+11	0	3,40E+10	5,15E+10
'TCTH.4L2.B1'	2,76E+08	1,53E+11	2,11E+11	1,38E+08	5,77E+10	8,24E+10	0	1,64E+11	2,11E+11	0	6,16E+10	8,37E+10
'TCDSA.4L6.B1'	4,89E+12	5,14E+12	5,14E+12	2,00E+12	2,10E+12	2,10E+12	4,84E+12	5,08E+12	5,08E+12	1,98E+12	2,08E+12	2,08E+12

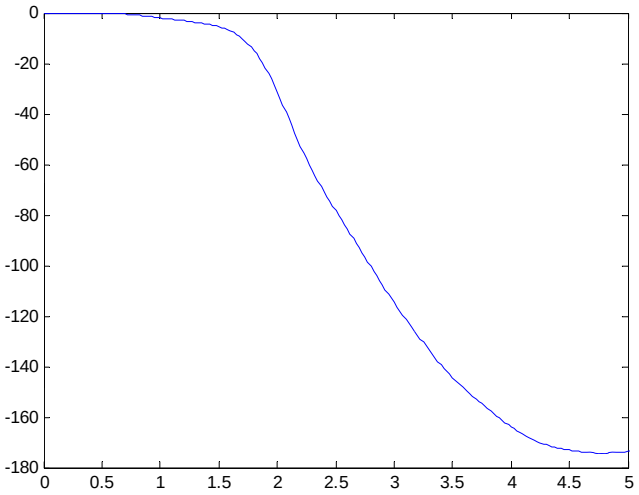
TCT's were hit in every case (10 seeds only)!

MKD system kick – pre-trigger case calculated from measured waveforms with 1000ns retriggering delay plus 15 ns / generator

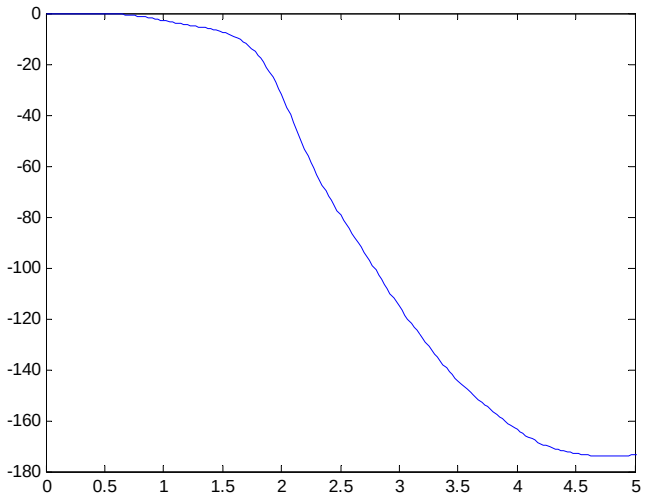
Nominal



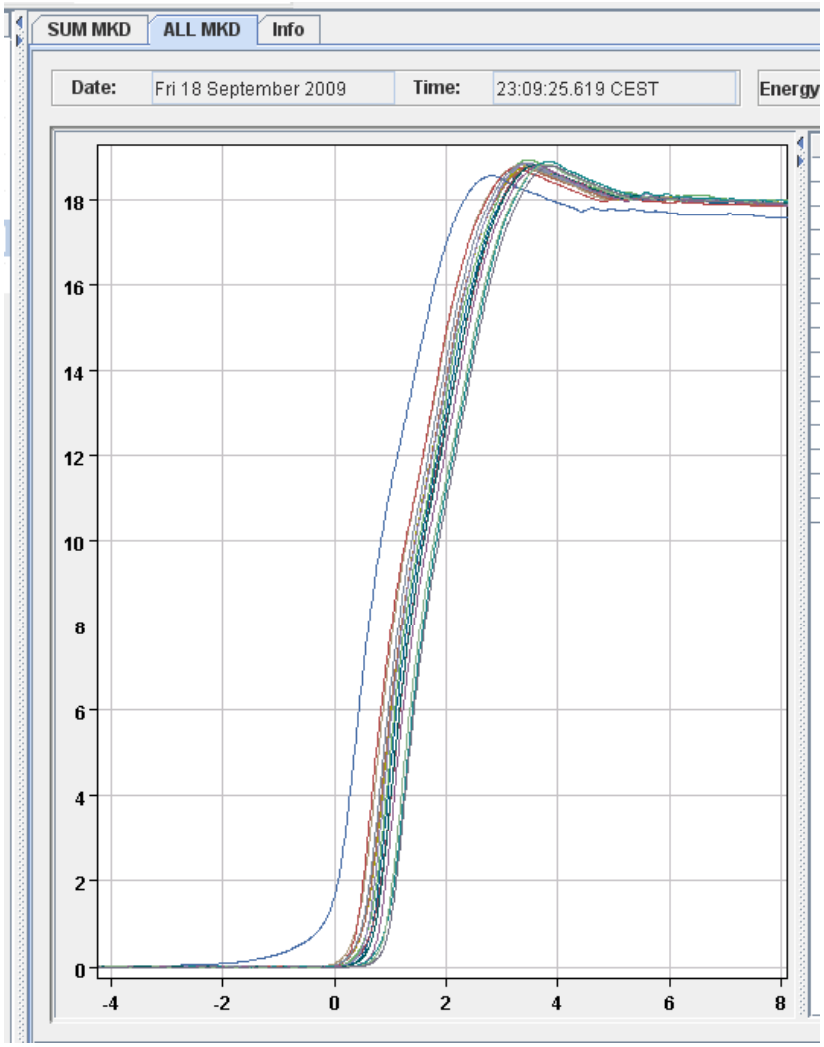
MKD.A pre-trigger

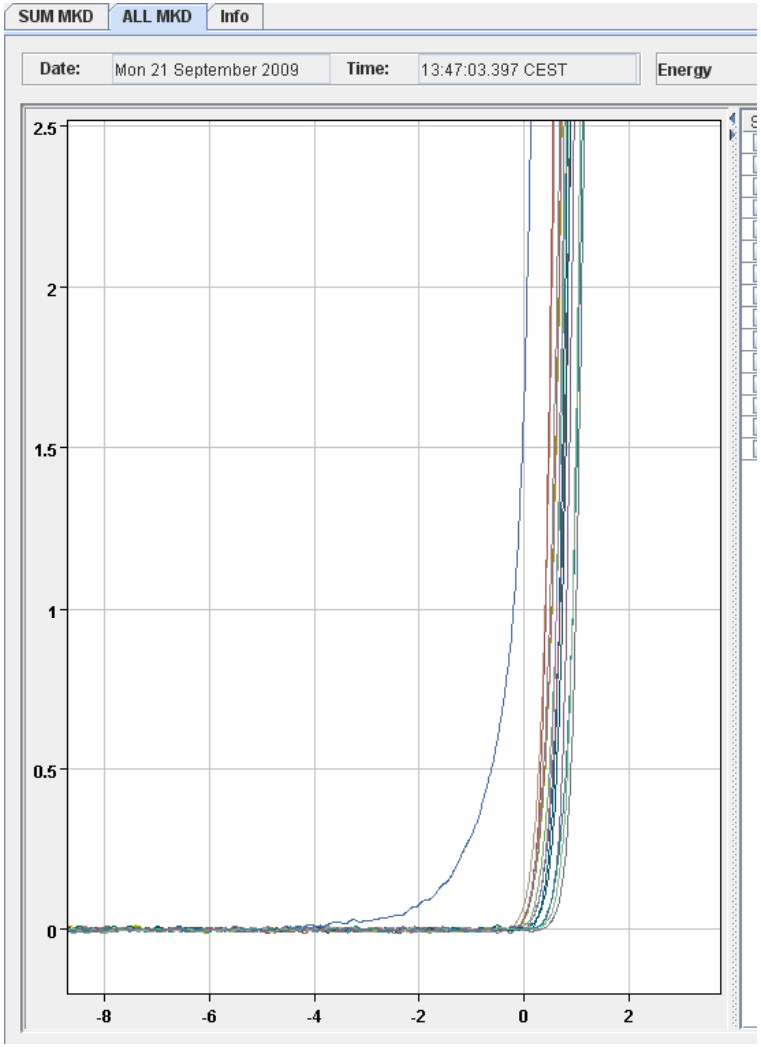


MKD.O pre-trigger



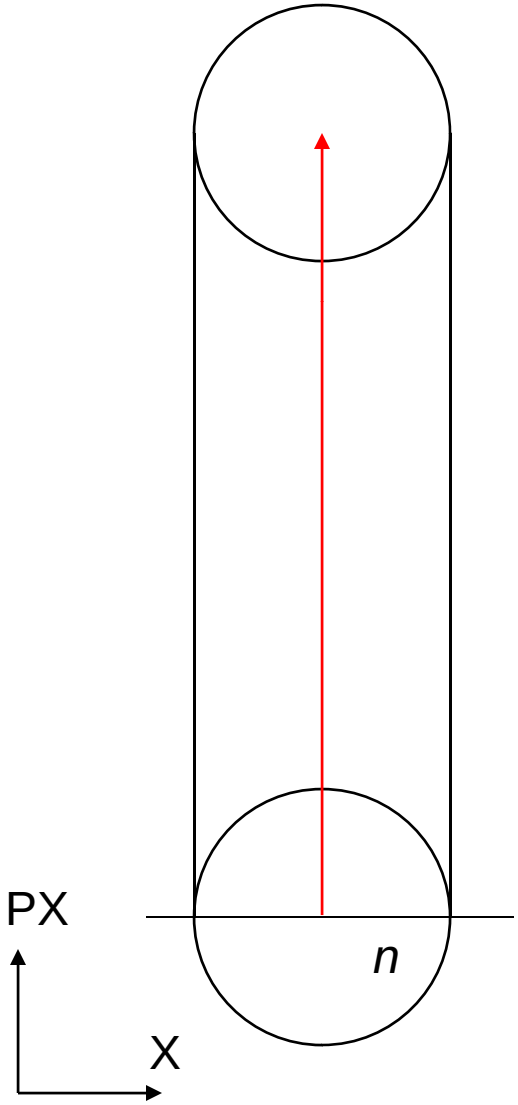
Measured prefire pulse form – (from pre-trigger in LHCs in last few days!)

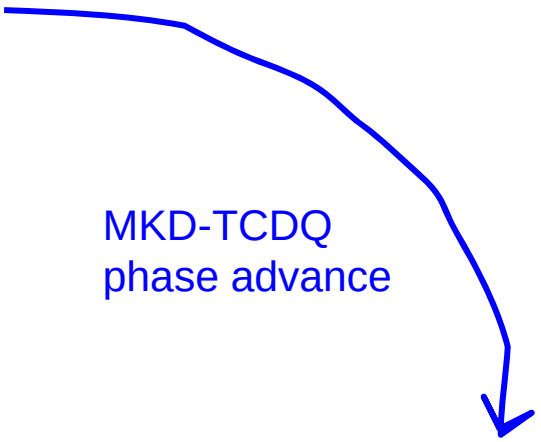




Rise time in the very beginning slower than assumed in MAD-X model – data extracted for dedicated simulations…. (Thanks to Jan and Etienne)

MKD kick (pretrigger or asynch.)





TCDQ

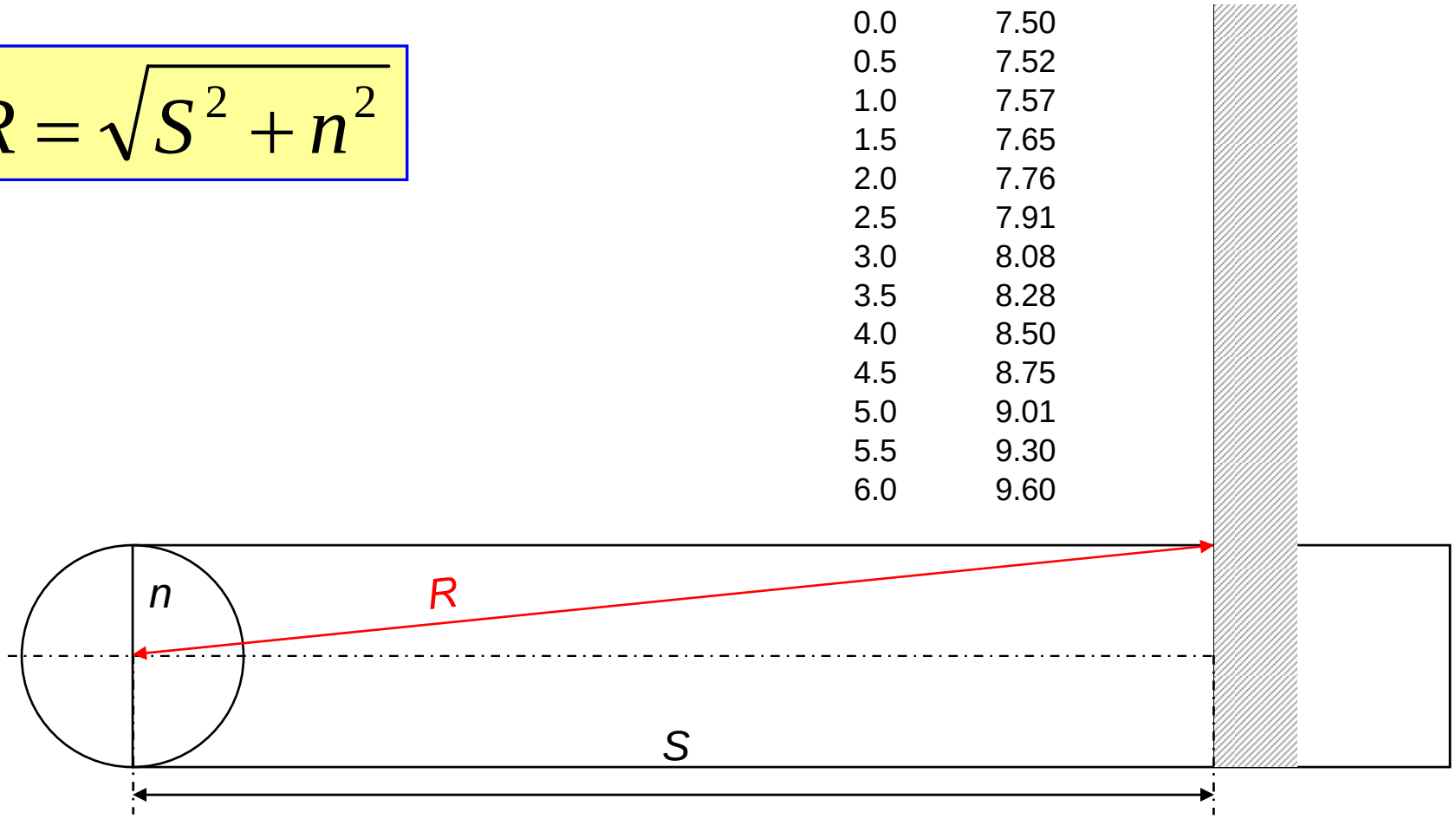
TCSG

Single pass ≠ multiple pass!

For $\Delta\psi = 90°$; $\theta = 0$, R > S

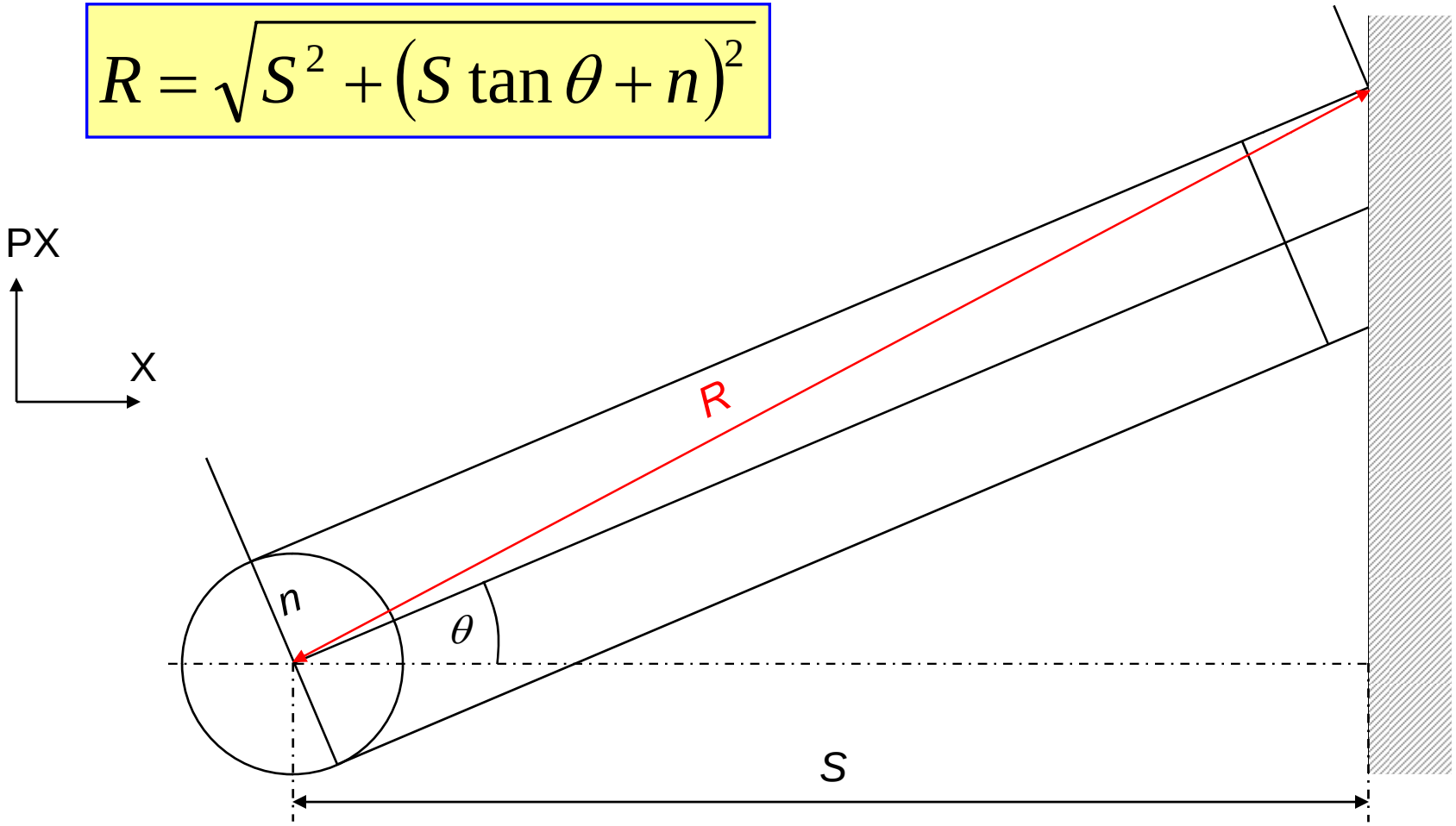
$$R = \sqrt{S^2 + n^2}$$

n	R
0.0	7.50
0.5	7.52
1.0	7.57
1.5	7.65
2.0	7.76
2.5	7.91
3.0	8.08
3.5	8.28
4.0	8.50
4.5	8.75
5.0	9.01
5.5	9.30
6.0	9.60



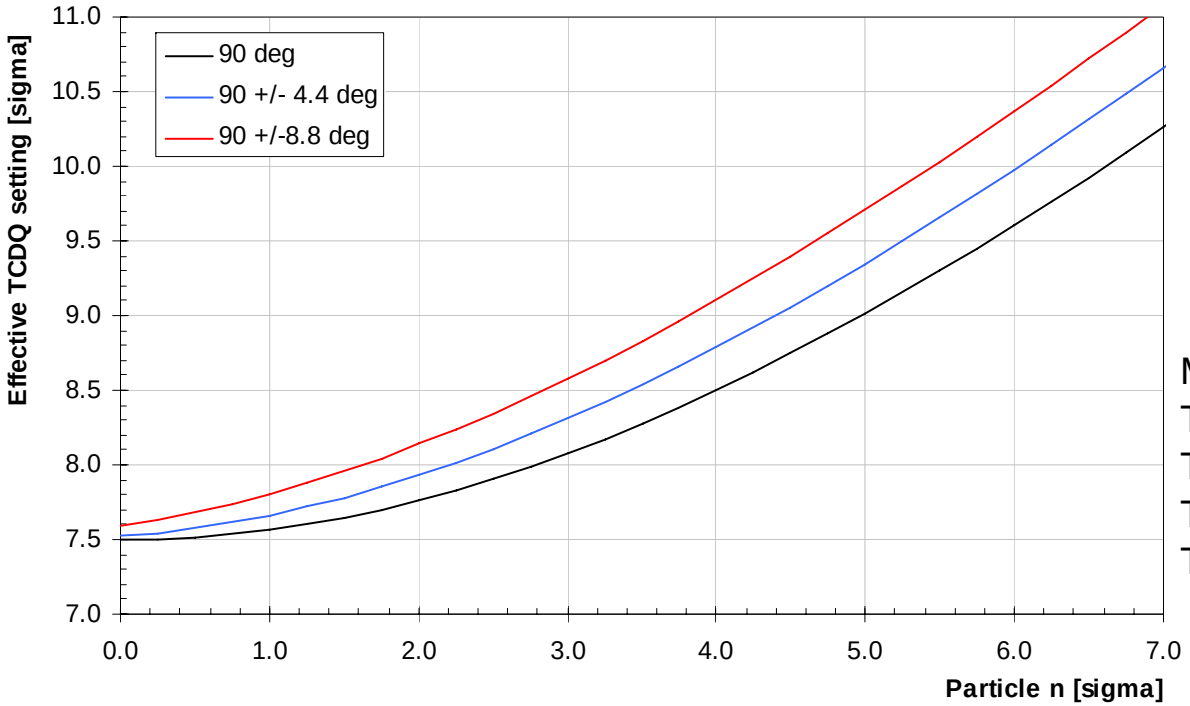
Phase advances/errors and finite beam sizes make it worse….

$$R = \sqrt{S^2 + \left(S \tan\theta + n\right)^2}$$



Consequences

- Even for 90° phase advance, for a single pass the TCDQ intercepts beam at desired setting ONLY for PX=0
- Transmitted particle amplitude (in sigma) depends on its PX and on phase advance MKD to TCDQ



Nominal $\Delta\psi$

MKD to…	Deg B1	Deg B2
TCDQ entr	93.55	93.75
TCDQ exit	94.47	94.65
TCSG entr	94.60	94.78
TCSG exit	94.71	94.89

Tracking with 3.5 TeV

- Started to implement with latest 3.5 TeV settings from Adriana

  – 7 TeV sequence and strength adapted to 3.5 TeV (same tune)
  – TCDQ (TCSG) 11.6 (10.2), TCTH/V.IR1 12.8, etc.
  – Beta* in: IP1=2m, IP2=10m, IP5=2m, IP8=3m
  – Crossing bumps off (2mm oscillation if on -> unmatched IP??) , separation on

  Optics seems to be ok, but still some issues with MAD-X concerning tracking (awkward behavior) to be solved.

  Work ongoing…

“Analytical” checks

- Used 3.5 TeV settings from Adriana 08/09/09
  - TCSG.IR6 at 10.2 sigma, *plus 1.0 σ* setting/orbit error (0.8 mm)

- Beam distributions generated in normalised phase space
  - Gaussian (nominal emittance, 2 × nominal emittance)
  - Parabolic (uniform phase space density)
  - Hybrid Gaussian with parabolic tails (90-10% and 99-1%)

- Worst-case asynchronous dump applied
  - MKD.O5L6, 1000 ns retrigger delay + 15 ns per generator (slightly pessimistic at 3.5 TeV).

- Damage level of TCTs assumed to be 3×10^{9} at 3.5 TeV
  - 1×10^{9} at 7 TeV, scaled by $E^{1.7}$

- No help from collimators in cleaning insertions

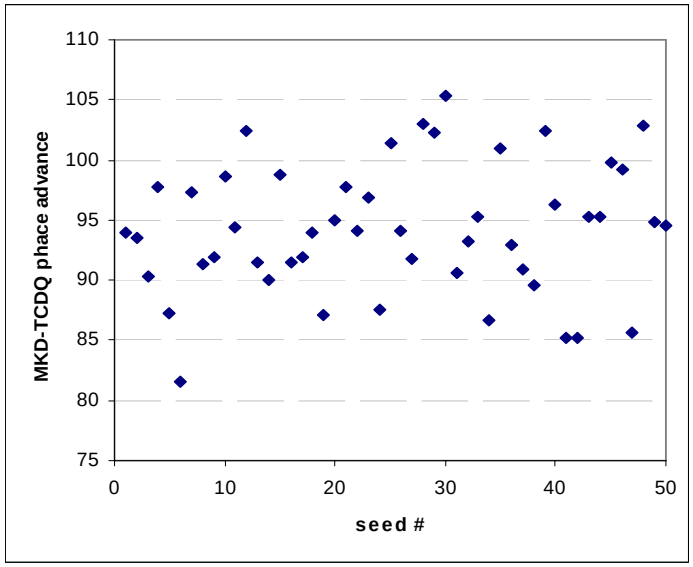
- Worst-case phase advance taken for losses on TCT

MKD-TCDQ phase advance errors

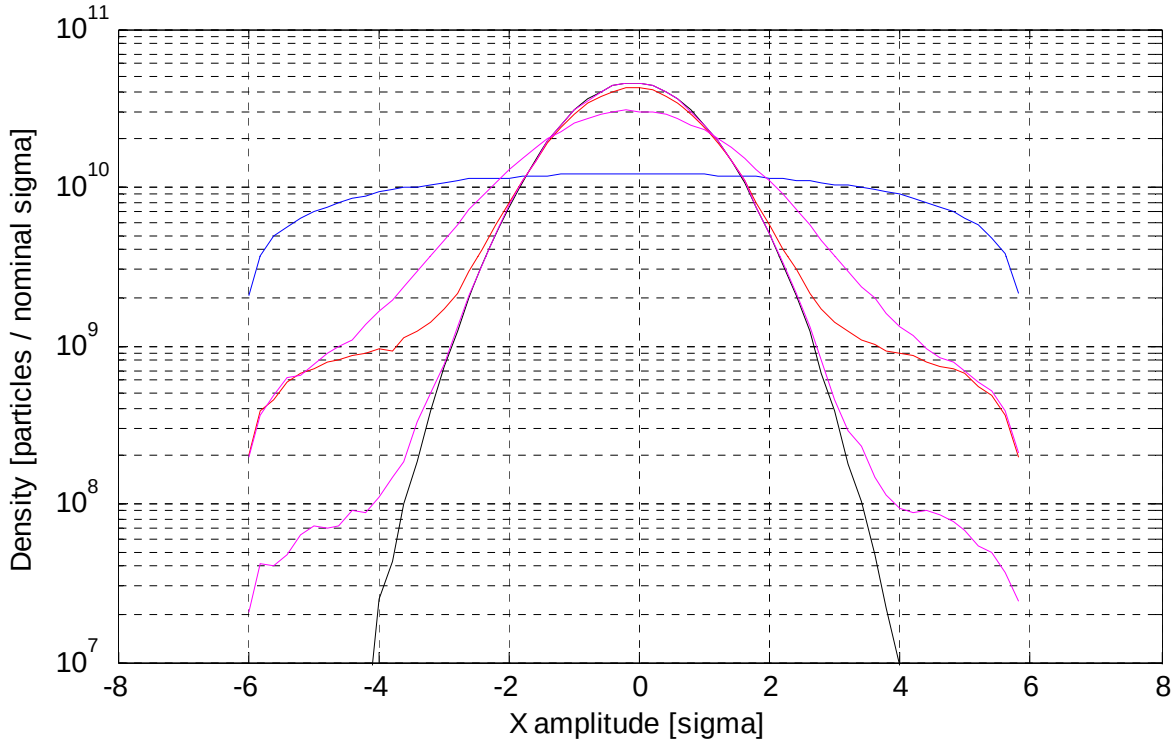
- Nominal $\Delta\psi$ ~94.6°
- Run Twiss on LHC machine with all errors
  - LHC error table 9901, misalignments etc.
  - Corrected tune and chromaticity back to nominal
- Max. MKD – TCDQ phase advance 106°
  - Max phase advance error is ±12°
  - RMS 5.4°

MAD-X Simulation output 50 seeds:

nominal	93.80
avg	94.22
max	105.40
min	81.61
stdv	5.42
max dev. (pos.)	11.60
max dev. (pos.)	12.19



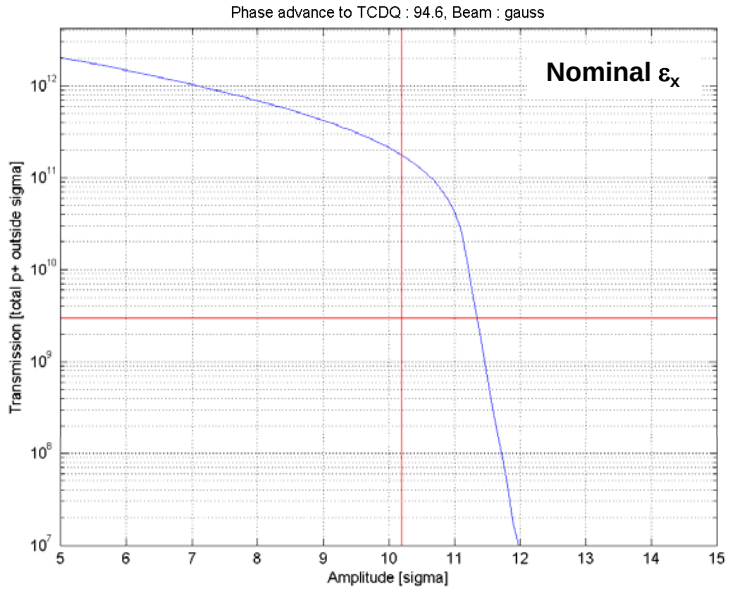
Beam distributions – tails included…

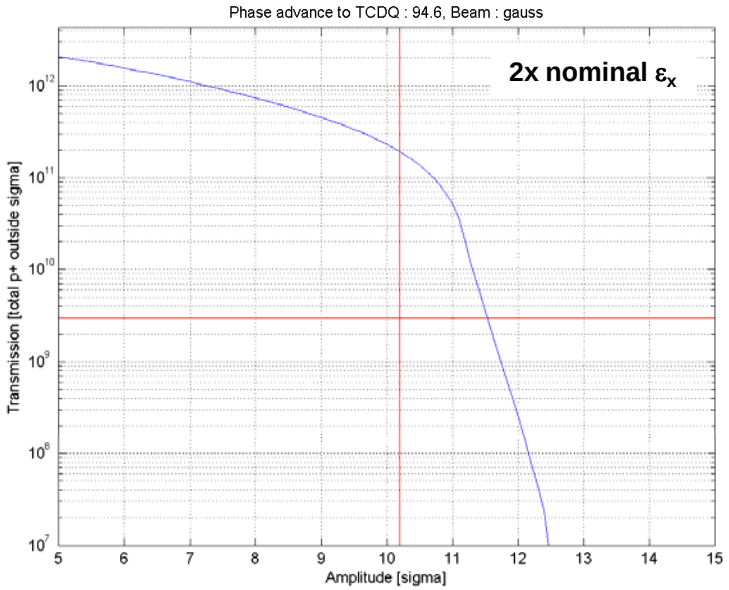


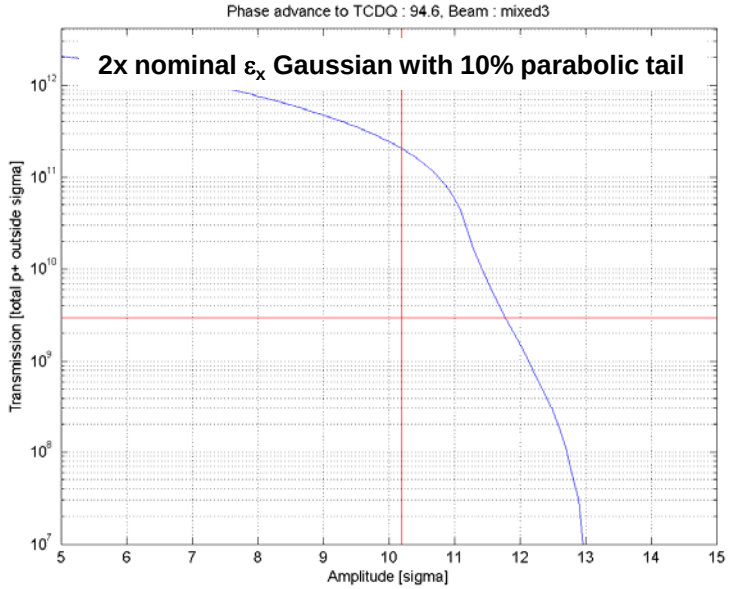
Results

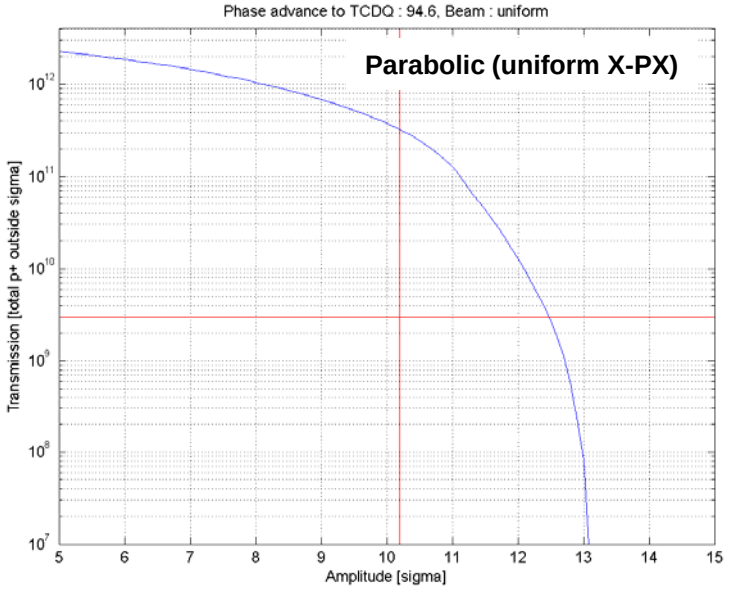
1. with 1.15×10^{11} p+/bunch at 25ns
   - Nominal intensity and spacing

- Nominal phase advance MKD to TCDQ (**94.6**°), 1.15×10^{11}, 25ns

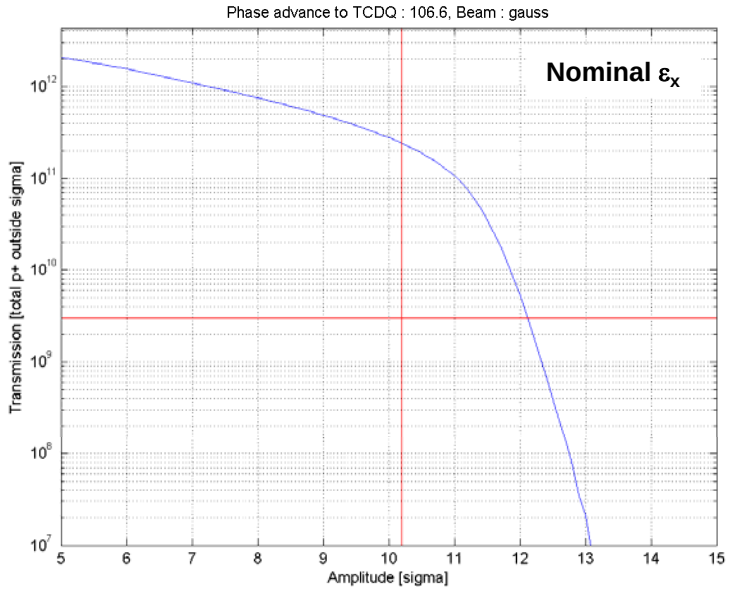


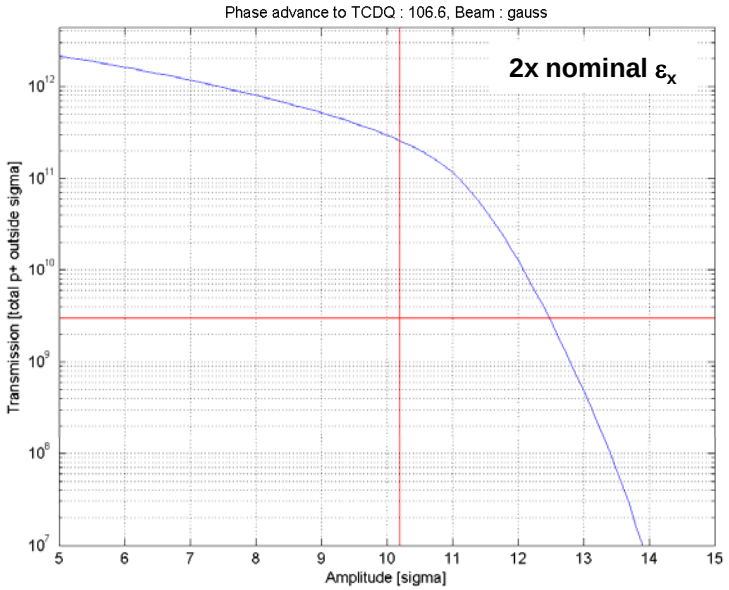


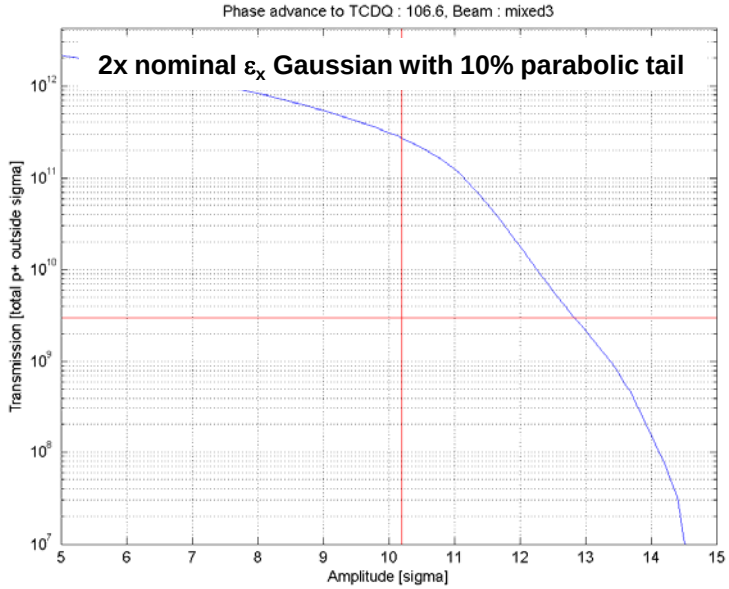


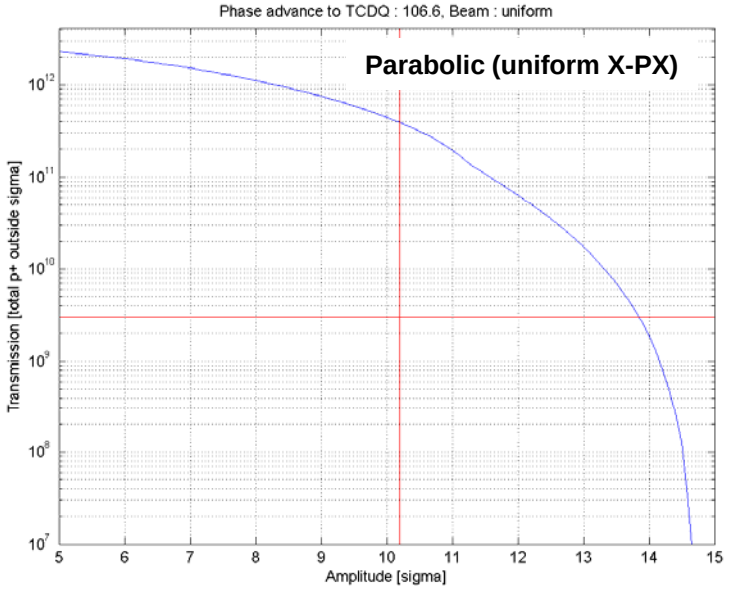


- 12° phase advance error MKD to TCDQ (**106.6**°), 1.15×10^{11}, 25ns





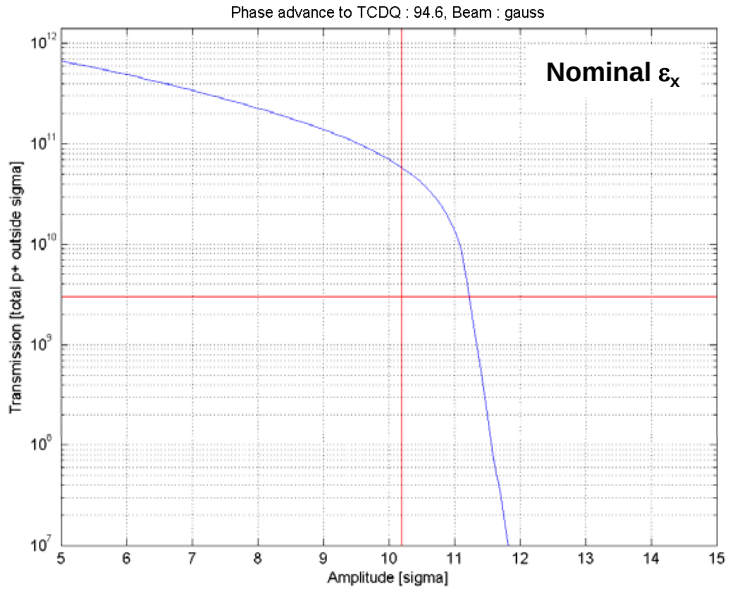


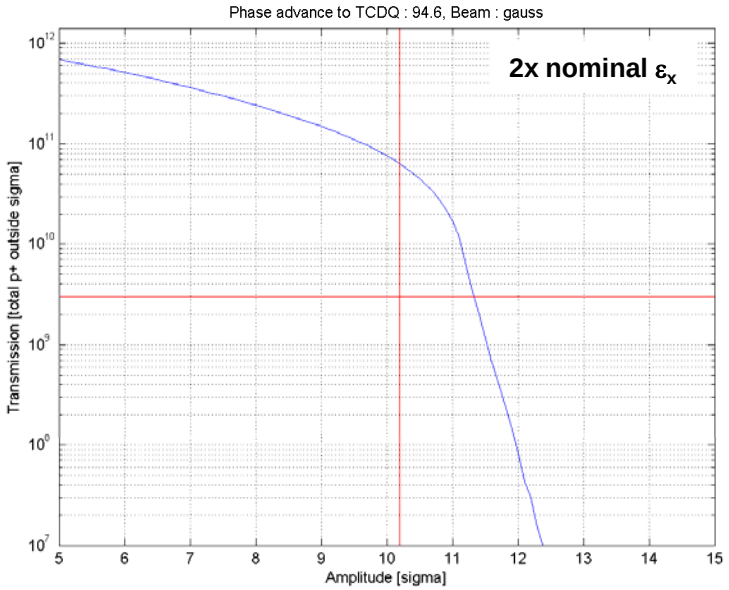


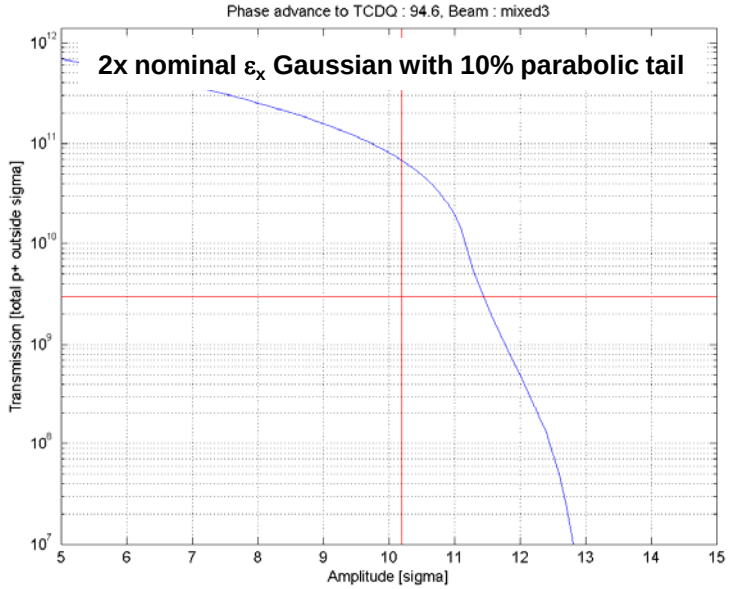
Results

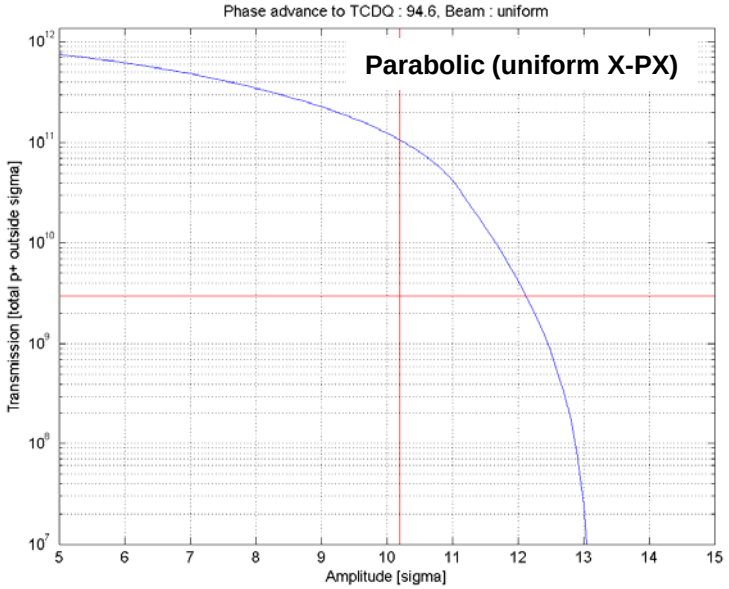
2. with 7.6×10^{10} p+/bunch at 50ns
   - (assumed worst case for 3.5 TeV)
   - Total I of 6×10^{13} in 792 bunches

- Nominal phase advance MKD to TCDQ (**94.6**°), 7.6×10^{10}, 50ns

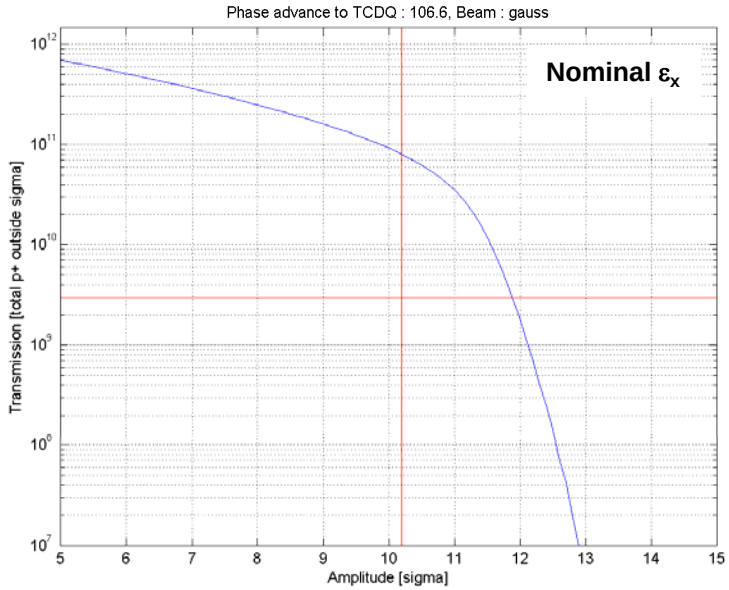


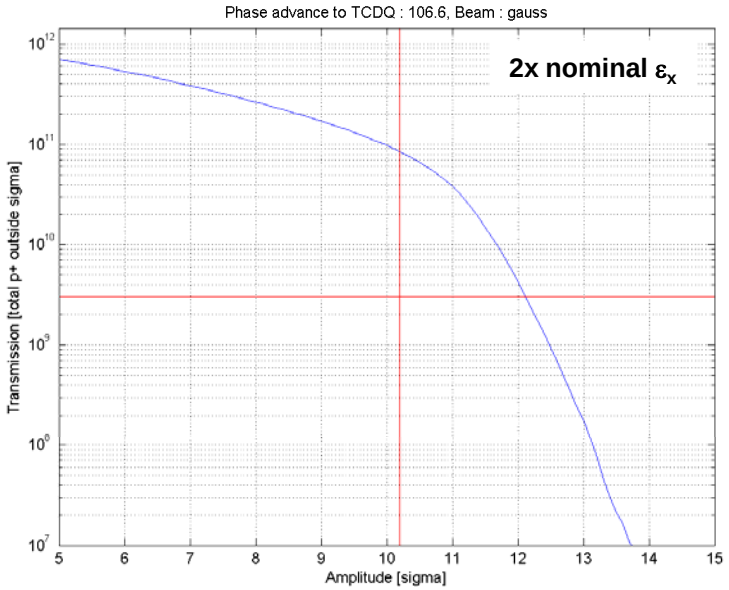


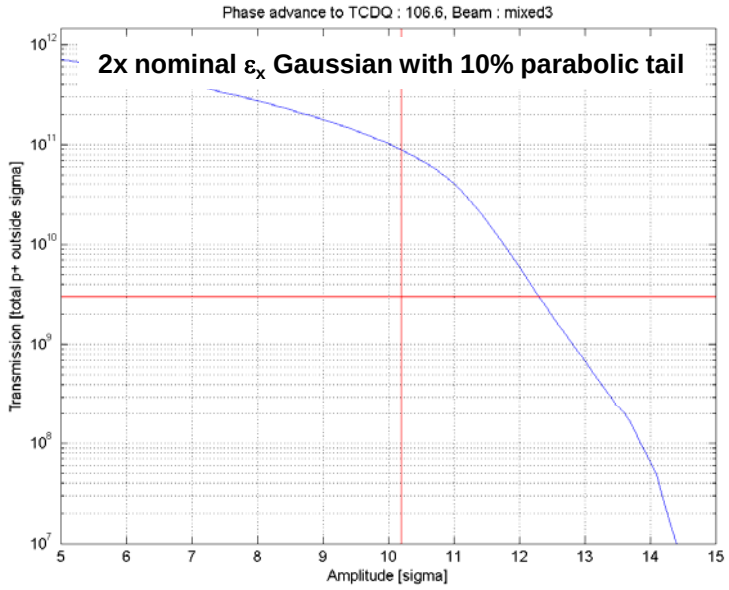


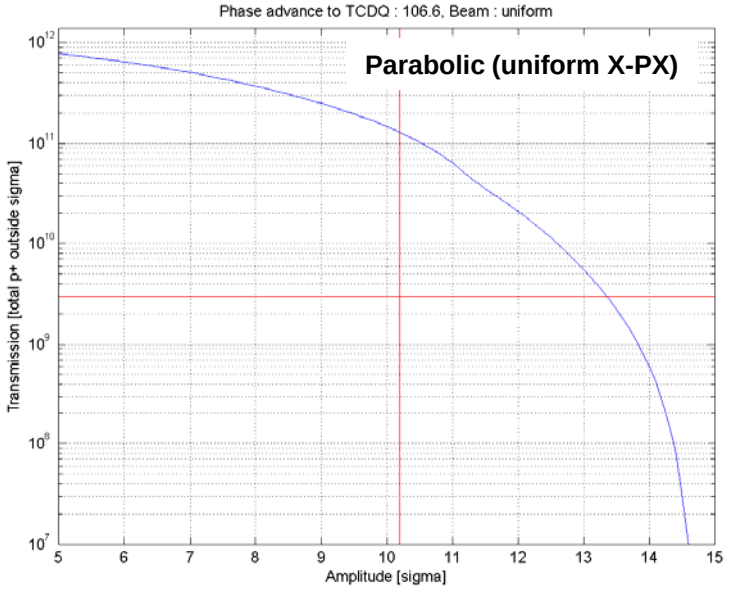


- 12° phase advance error MKD to TCDQ (**106.6**°), 7.6×10^{10}, 50ns









Summary of minimum TCT positions [σ]

Bunch pattern	1.15×10^{11} p+/bunch at 25ns			7.6×10^{10} p+/bunch at 50ns		
MKD-TCDQ phase	94.6°	100.6°	106.6°	94.6°	100.6°	106.6°
Gaussian nominal ε_x	11.3	11.7	12.2	12.2	11.5	11.9
Gaussian 2× nominal ε_x	11.6	11.9	12.5	11.3	11.7	12.2
Gaussian 2× nominal ε_x with 10% parabolic tail	11.8	12.2	12.8	11.5	11.8	**12.3**
Parabolic (uniform X-PX)	12.5	13.1	13.8	12.2	12.8	13.3

- 12.3 σ for minimum TCT *position* would seem just OK.
  - What margin to add (setting-up accuracy, dynamic beta-beat, …)? 0.5 σ?
- **12.3 + (0.5) σ as the minimum setting**
  - Assuming 2× nominal ε_x, 10% parabolic tails, 12° MKD-TCDQ phase error, 7.6×10^{10} p+/bunch at 50 ns, 1.0 σ TCDQ setting up error.

Discussion…

- Losses on TCTs seen in MAD-X tracking studies for asynchronous dumps are 'real'
- Particles can be transmitted with (much) larger amplitudes than TCDQ/TCSG setting
  - Single-pass cut transmits particles with higher PX at larger sigma
- The problem is that TCTs are not robust
  - TCT damage limit? 1% of a nominal bunch at 7 TeV???

- **Short-term – keep TCTHs sufficiently retracted wrt TCDQ/TCSG**
  - Suggest keep at 12.3 σ PLUS margin of 0.5 – 1.0 σ
  - Ingredients used to decide retraction…
    - TCDQ/TCSG position wrt beam : tolerance 1.0 σ (SW interlock only…final value 0.5 σ)
    - Worst-case MKD-TCDQ $\Delta\psi$: assume 106.6°
    - TCT damage limit : assume 3e9 at 3.5 TeV
    - Wosrt case X-PX beam distribution : assume 2x nominal ε_x with 10% in parabolic tail cut at 6 σ
- **Longer term**
  - Extend to 5 TeV….
  - Study auxiliary collimators ~$\pm$8° from TCDQ, upstream of TCTs…?
  - (More) robust TCTs…?