High Luminosity LHC

Roll angle specifications for IR1/IR5

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Outline

previous specification:

FP7 Milestone Report: Initial Models of Correction Systems

1. Simulation setup
2. Simulation results with MADX
   a) IT
   b) Q4/Q5
   c) IT+Q4+Q5
2. Proposal for roll angle specification

Simulation setup for MADX

beam: 7 TeV (collision), no beam-beam

optics: HLLHCV1.0, round (0.15/0.15 m) and flat (0.075/0.30 m)

crossing scheme: separation: ±0.75 mm (IR1/5), x-angle: ±295 µm (round), ±275 µm (flat), (IR1/5)

error tables: IT_errortable_v66_5 (no b2 errors), D1_errortable_v1_spec, D2_errortable_v5_spec, Q4_errortable_v2_spec, Q5_errortable_v0_spec + measured errors for non HiLumi part

seeds: 60

Simulation Roll + Coupling correction

- roll of quadrupoles can be simulated as a_2 error (assuming b_2 component can be compensated by rematching):

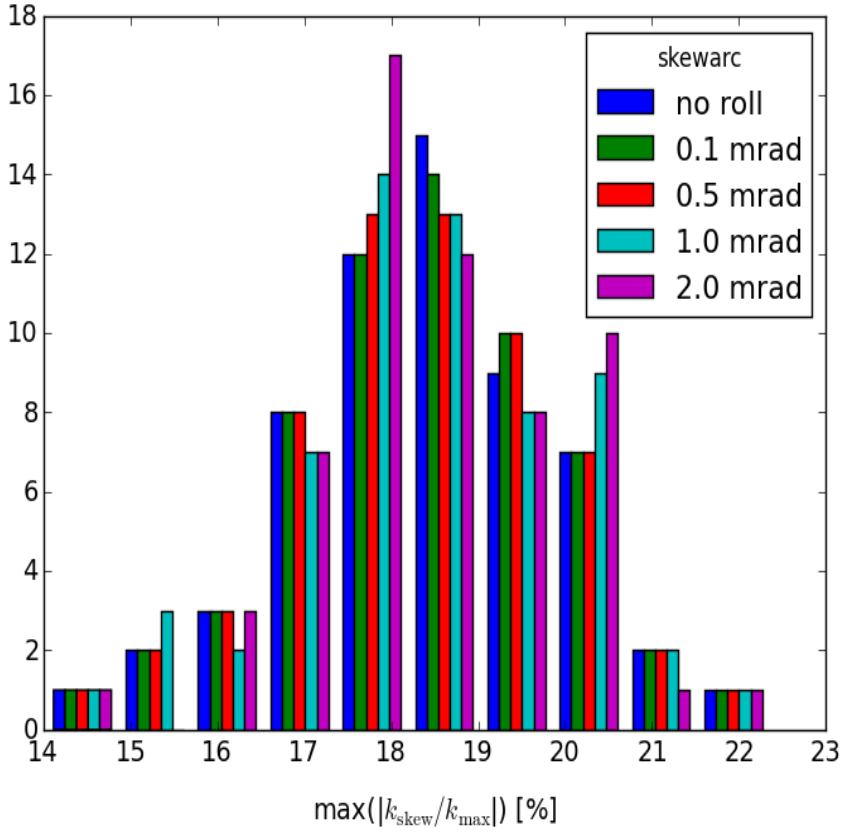
$$a_{2r}=\sin(2\,\delta\phi)\approx 2\,\delta\phi, \quad \text{with } \delta\phi = \text{roll angle}$$

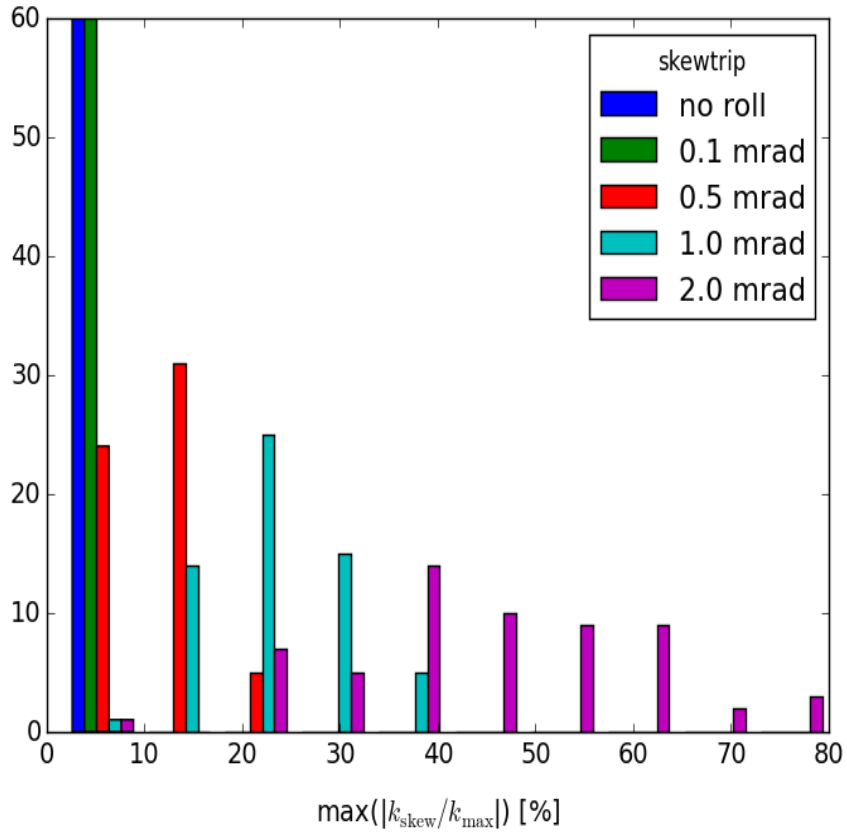
all roll values are given as 1σ values of a Gaussian distribution truncated at 3σ

- correction of a_2 errors (c_- resonance):
  - local correction with MCQSX3 (corrector package at IT in IR1/5) for IT roll
  - global correction with arc skew quadrupoles for Q4 and Q5 (only "fine tuning" for IT):
    - quantified with $dQ=Q_x-Q_y$:
      - closest0: initial Q_x-Q_y
      - closest1: Q_x-Q_y after minimization based on linear machine
      - closest2: Q_x-Q_y after empirical minimisation (matching)
    - skew quadrupoles in strong arc are not used for ATS optics as phase advance ($\mu_x+\mu_y\neq\pi$ -> source for c_+) changes between pairs of skew quadrupoles
- corrector strength limit:
  - IT: maximum corrector strength of MCQSX3 ($k_{max,MCQSX3}$= 27.9 T/m)
  - Q4/Q5: contribution should stay in the shadow of arc skew quadrupoles ($k_{max,MQS}$= 120 T/m)

Roll angle for IT – round optics

- roll angle is almost completely corrected by MCQSX3 (skewtrip)
- negligible contribution to skew quadrupoles strength in the arc (skewarc)
- similar results for flat optics (see backup slide)





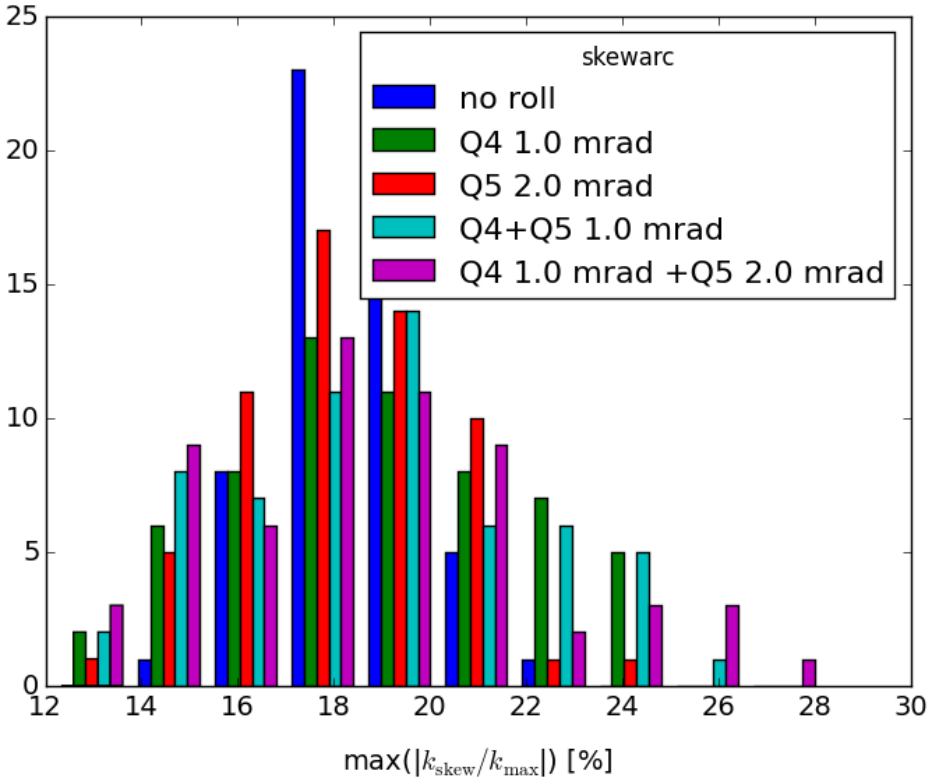
Roll angle for IT – some numbers

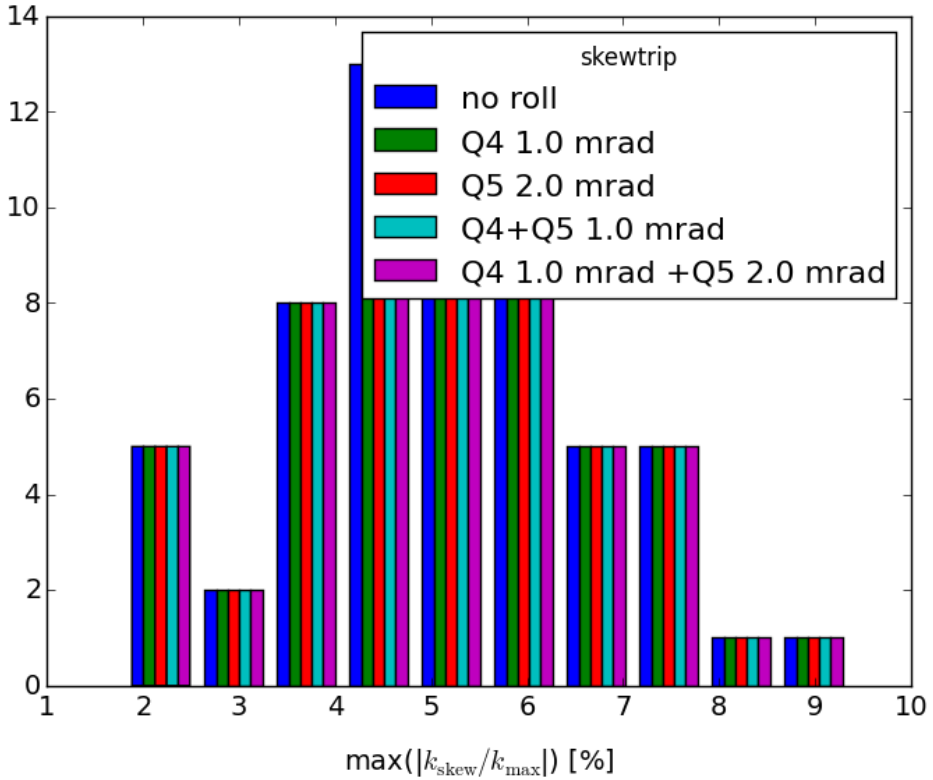
- strength limit from MCQSX3 ($k_{max,MCQSX3}$= 27.9 T/m): **1 mrad**
  (1 mrad roll correspond to mean + 3 std = 45% of the corrector strength)
  (2 mrad roll correspond to mean + 3 std = 91% of the corrector strength)
- correction limit smaller – to be checked: **0.5 mrad**
  (correction starts to degrade (>10^{-4}) for roll angles larger than 0.5 mrad)

Beam 1		**k/k_{max} [%] skewarc**		**k/k_{max} [%] skewtrip**			**#seeds with dQ**	
optics	**1std roll [mrad]**	**mean**	**1 std**	**mean**	**1std**	**max(dQ)**	**> 10^{-4}**	**> 10^{-3}**
round (0.15/0.15)	**no roll**	**18.44**	**1.48**	**5.06**	**1.64**	**1.03E-04**	**1**	**0**
	0.5	**18.44**	**1.47**	**11.22**	**3.74**	**1.22E-04**	**4**	**0**
	1.0	18.4	1.50	22.37	7.69	5.40E-03	11	2
	2.0	18.43	1.43	44.76	15.44	2.19E-02	24	9
flat (0.075/0.30)	**no roll**	**17.57**	**1.36**	**5.07**	**1.64**	**1.75E-04**	**3**	**0**
	0.5	**17.57**	**1.36**	**11.22**	**3.74**	**1.84E-03**	**6**	**1**
	1.0	17.55	1.42	22.37	7.69	1.56E-02	12	2

Roll angle Q4/Q5 – round optics

- only correction with skew quadrupoles in arc (skewarc), not with IT correctors (skewtrip)
- similar results for flat optics (see backup slide)





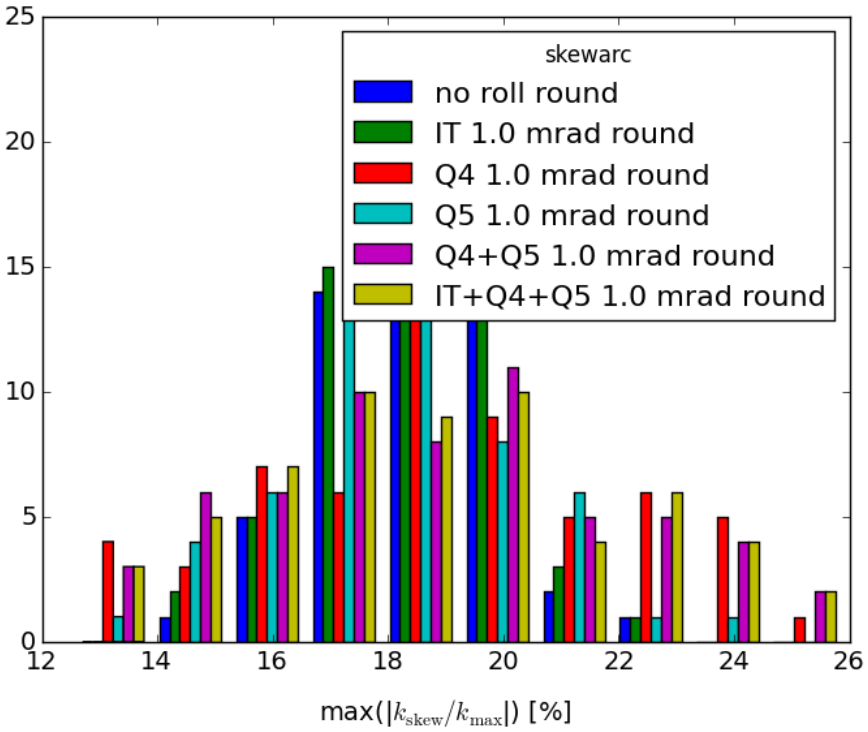
Roll angle for Q4/Q5 – round optics

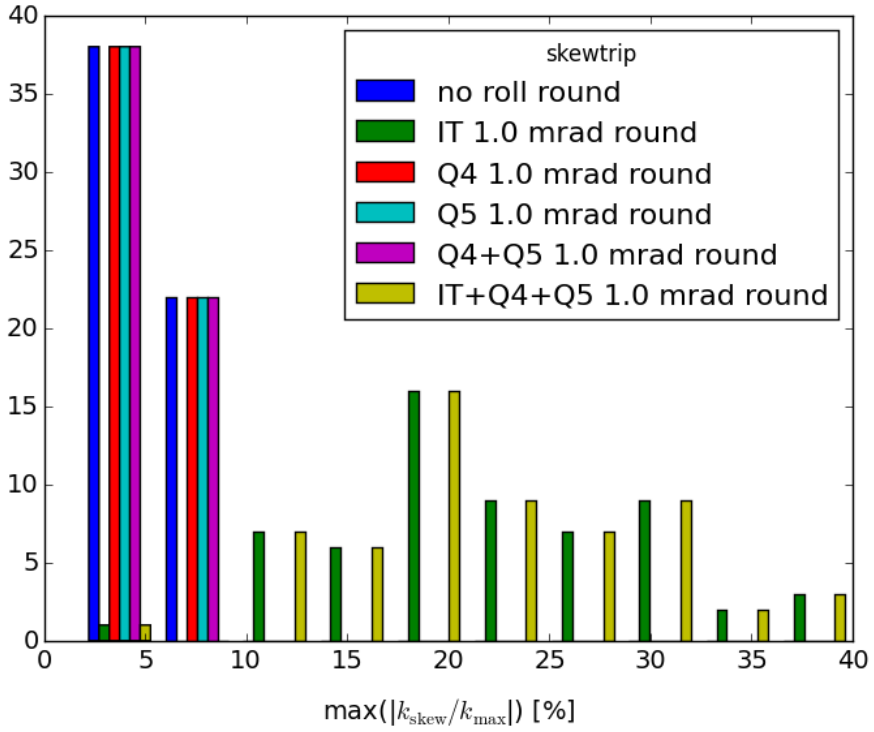
- Q4 approximately factor 2 more sensitive than Q5 (1 mrad for Q4 corresponds to 2 mrad for Q5)
- strength limit for Q4/Q5: **1 mrad (better 0.5 mrad)**
  (1 mrad already increases the strength slightly -> better reduce to 0.5 mrad)

Beam 1		**k/k_{max} [%] skewarc**		**k/k_{max} [%] skewtrip**			**#seeds with dQ**	
optics	**1std roll [mrad]**	**mean**	**1 std**	**mean**	**1std**	**max(dq)**	**> 10^{-5}**	**> 10^{-4}**
round (0.15/0.15)	**no roll**	**18.44**	**1.48**	**5.06**	**1.64**	**1.03E-04**	**59**	**1**
	Q4 1.0	18.93	2.92	5.06	1.64	2.09E-04	58	1
	Q5 1.0	18.26	2.09	5.06	1.64	1.86E-04	57	3
	Q4 2.0	20.28	4.55	5.06	1.64	3.17E-04	57	4
	Q5 2.0	18.16	3.04	5.06	1.64	1.33E-04	59	1
	Q4+Q5 1.0	**18.82**	**3.06**	**5.06**	**1.64**	**1.59E-04**	**58**	**1**
	Q4 1.0 + Q5 2.0	**18.80**	**3.51**	**5.06**	**1.64**	**1.13E-03**	**58**	**6**

Roll angle for IT+Q4+Q5 – round optics

- no significant increase of skew quadrupole strength in the arc, when all sources are combined



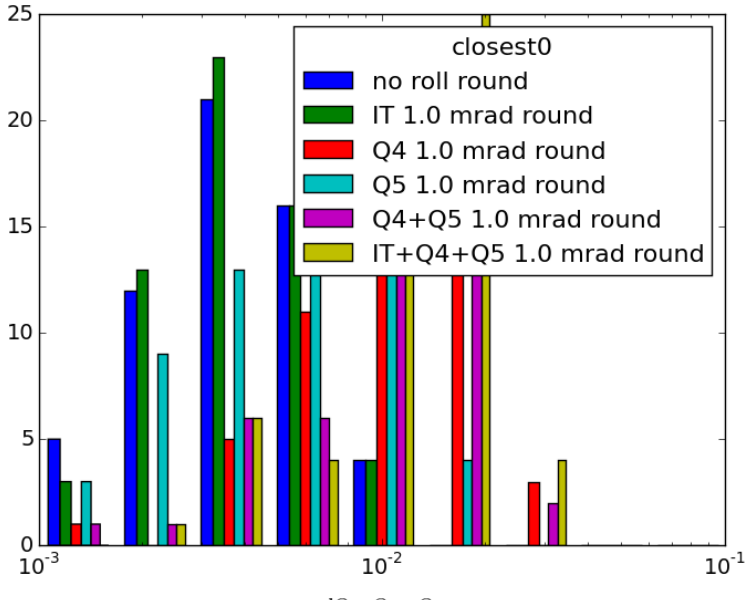


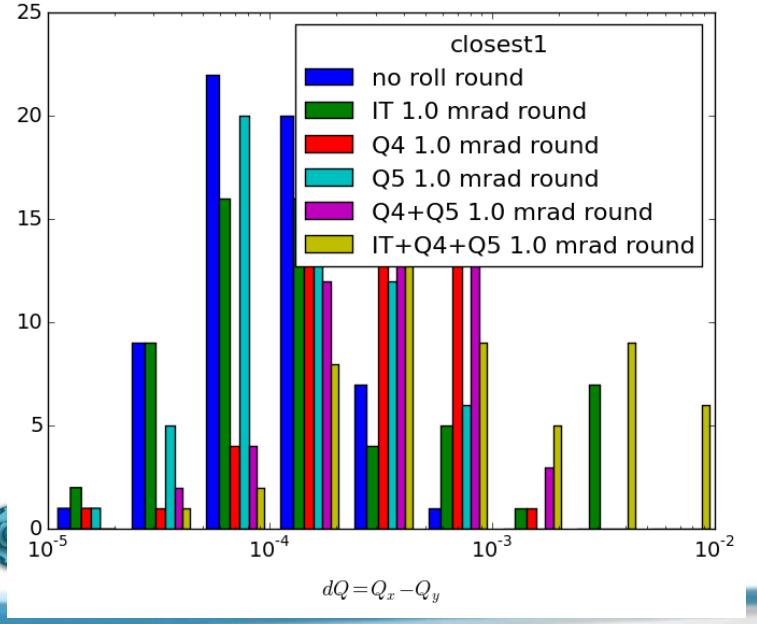
Roll angle for IT+Q4+Q5 – round optics

- corrector strength limit for IT, Q4 and Q5: **1mrad**
  - local correction (MCQSX3) - IT: mean + 3σ = 22.37 % + 3*7.69 % = 45.44 %
    (note: 2 mrad corresponds to 91 %)
  - global correction with arc skew quadrupoles: slight increase of mean and std – ok!
- correction limit for IT is 0.5 mrad and 1 mrad for Q4/Q5
- similar results for flat optics and beam 2 (see backup slides)

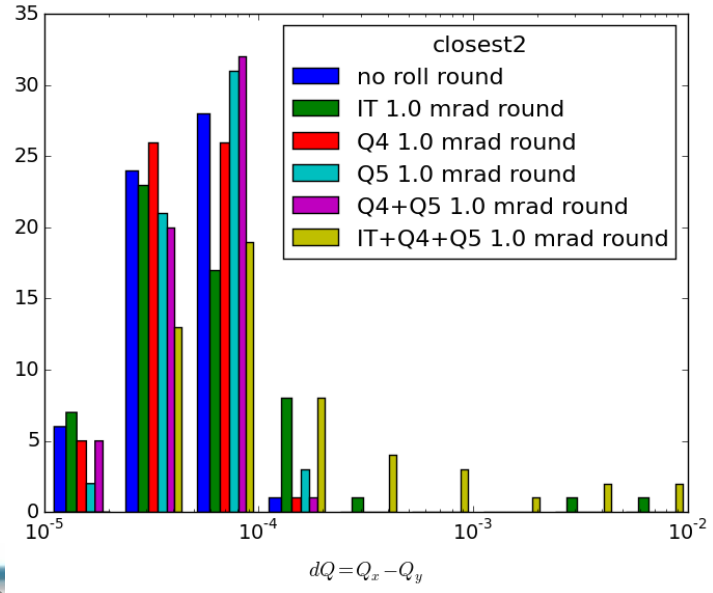
round optics Beam 1	k/k_{max} [%] skewarc		k/k_{max} [%] skewtrip			#seeds with dQ	
1std roll [mrad]	**mean**	**1 std**	**mean**	**1std**	**max(dQ)**	**> 10^{-4}**	**> 10^{-3}**
no roll	**18.44**	**1.48**	**5.06**	**1.64**	**1.03E-04**	**1**	**0**
IT 1.0	18.4	1.5	22.37	7.69	5.40E-03	11	2
Q4 1.0	18.93	2.92	5.06	1.64	2.09E-04	1	0
Q5 1.0	18.26	2.09	5.06	1.64	1.86E-04	3	0
Q4+Q5 1.0	18.82	3.06	5.06	1.64	1.59E-04	1	0
IT+Q4+Q5 1.0	**18.81**	**3.05**	**22.37**	**7.69**	**1.47E-02**	**23**	**8**

Coupling correction – convergence?



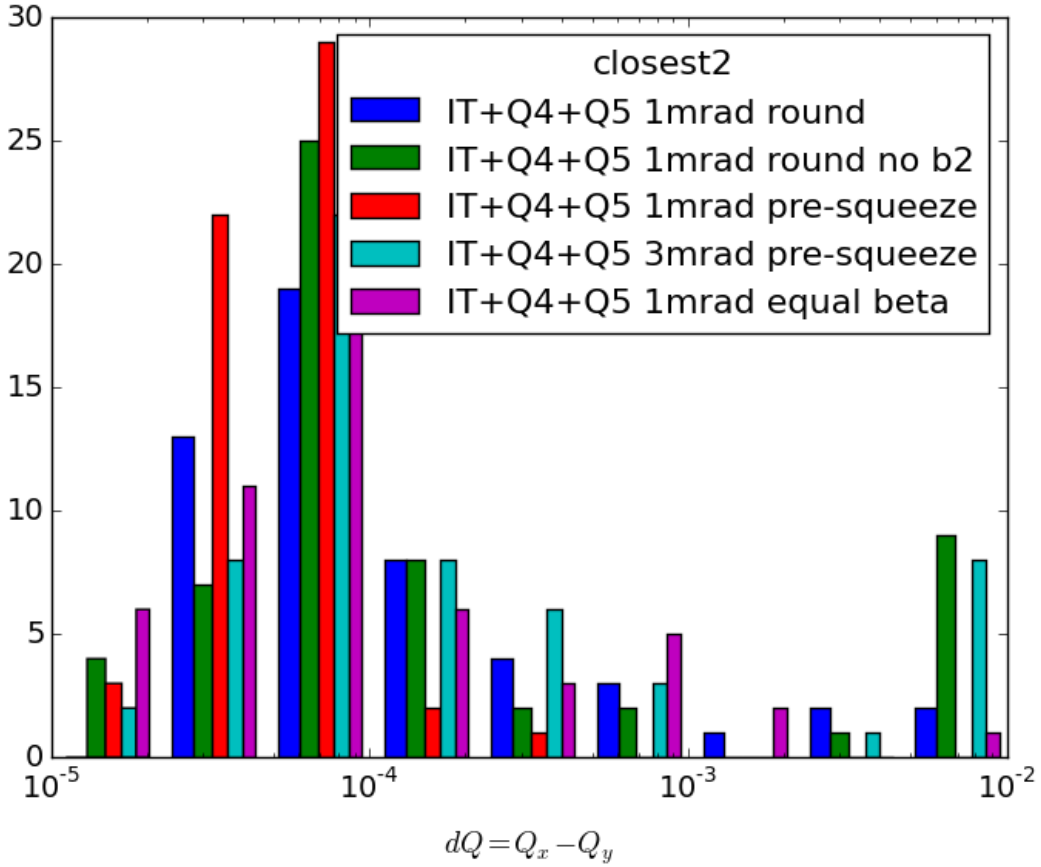


- majority of cases converges with $dQ<10^{-4}$
- possible sources for inefficiency of correction (Stephane):
  - **not optimal** (phase errors, no correctors in strong arcs) **coupling knobs for ATS** (-> try with pre-squeeze optics and larger source)
  - **beta-beating** (-> try without b2 error)
  - **imbalance between beta functions** of Beam 1 and Beam 2 resulting in an inadequate local correction of the IT a_2 error (->move MCQSX3 corrector to location with equal beta)



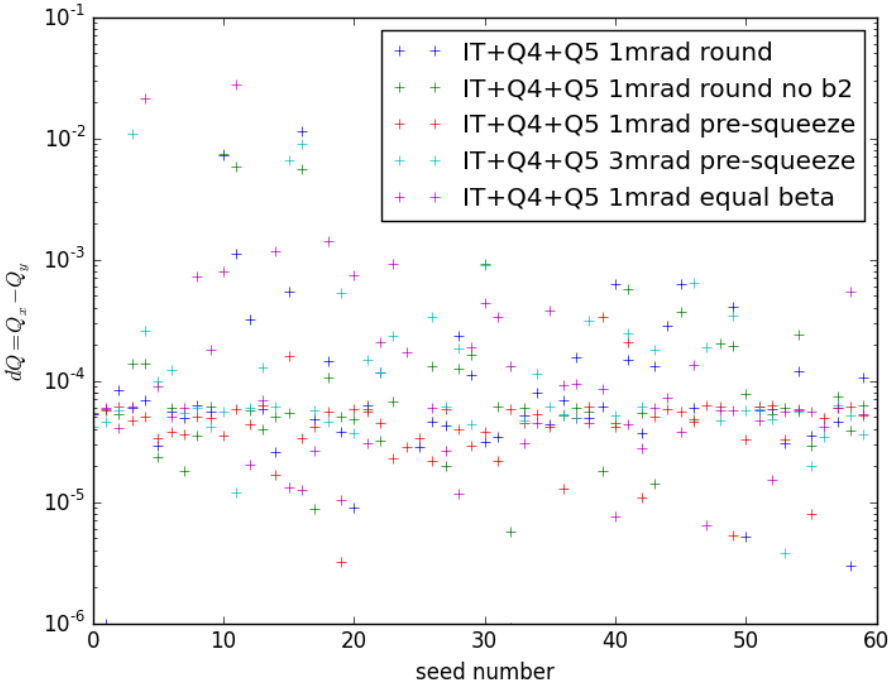
Coupling correction – convergence?

- worse correction without b2 errors (IT+Q4+Q5 1mrad round no b2) –> beta-beat due to b2 error is not the source, but why does it even get worse?
- rescaling the a_2 error (1 mrad -> 3 mrad corresponds approximately to factor 0.44/0.15) for the presqueezed optics the correction gets worse (IT+Q4+Q5 3mrad pre-squeeze) -> phase error is not the source of the insufficient convergence



- inserting the skew correctors at a location of equal beta (53.37 m from IP, IT+Q4+Q5 1mrad equal beta) helps, but still some cases with an insufficient convergence -> equal beta functions for Beam 1 and Beam 2 improves the correction, but there are still cases with an insufficient convergence

Coupling correction – convergence?



case	seeds with dQ>1.e-3
IT+Q4+Q5 1mrad round	10, 11, 16, 23, 24, 47, 48, 56
IT+Q4+Q5 1mrad round no b2	10, 11, 16, 24, 25, 34, 35, 44, 47, 56
IT+Q4+Q5 1mrad pre-squeeze	-
IT+Q4+Q5 3mrad pre-squeeze	3, 15, 16, 24, 25, 31, 32, 39, 44, 45
IT+Q4+Q5 1mrad equal beta	4, 11, 14, 18, 25, 50

- some seed dependence, but no real strong correlation

Recommendation for roll angle specification

Corrector strength limit:

IT: 1 mrad leading to 45% of maximum corrector strength

Q4/Q5: 1 mrad in order to stay in the shadow of the overall contribution (on the limit, better 0.5 mrad)

Correction limit:

IT: 0.5 mrad to achieve $dQ<10^{-4}$

Open Questions:

- review the coupling correction:
  - insufficient convergence for some seeds
  - limit of correction in terms of which dQ is still measureable
- overlap/tilt of beam ellipses at IP

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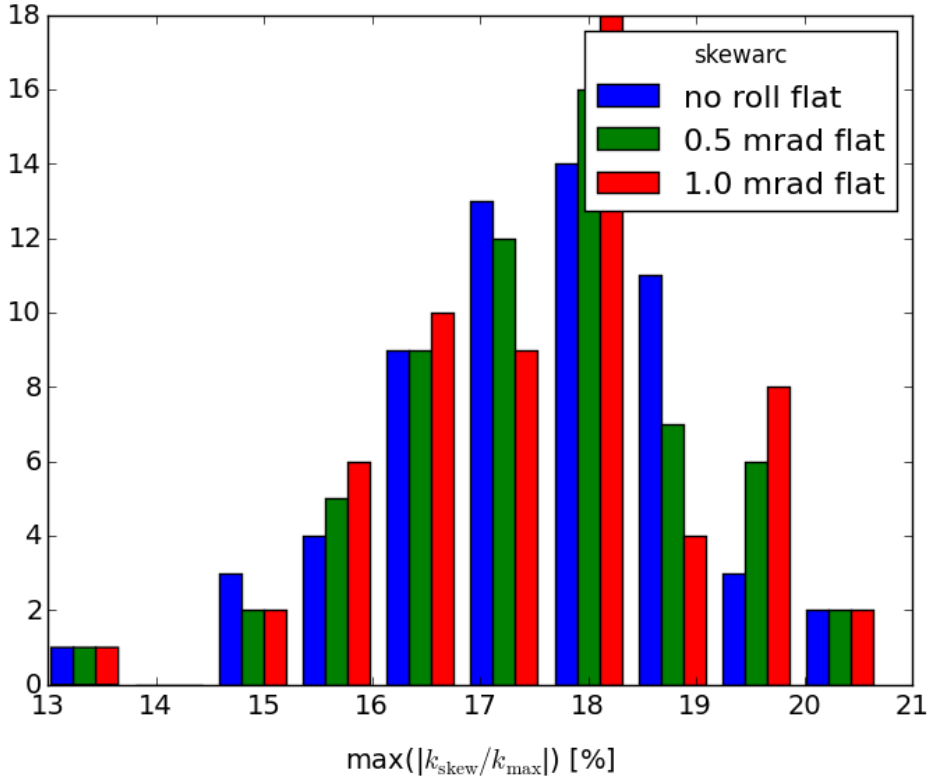
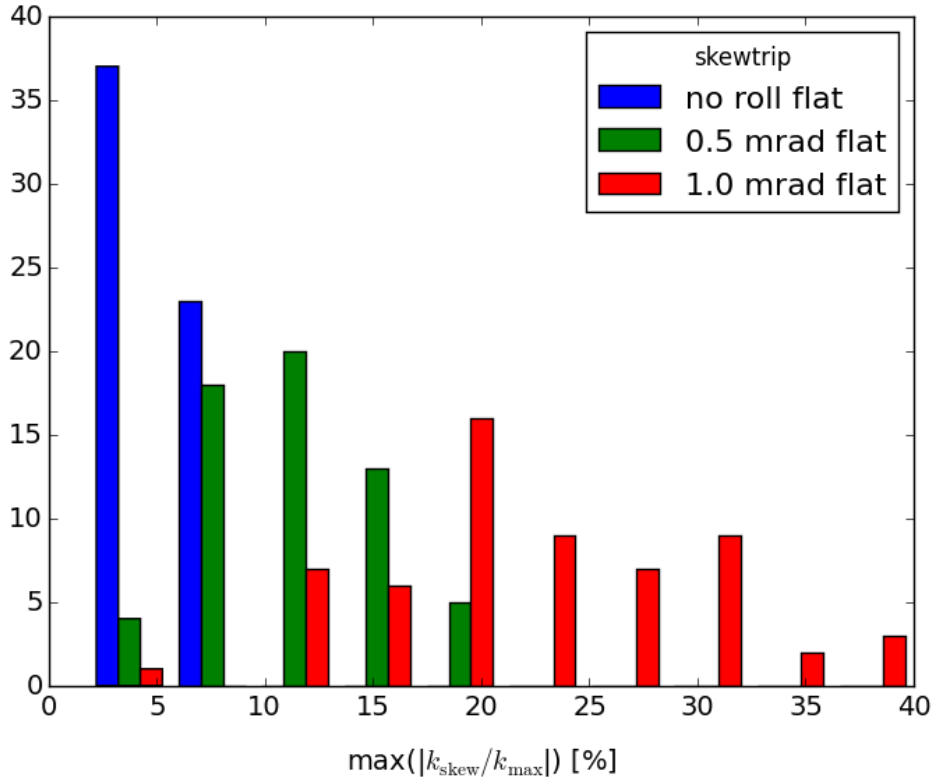
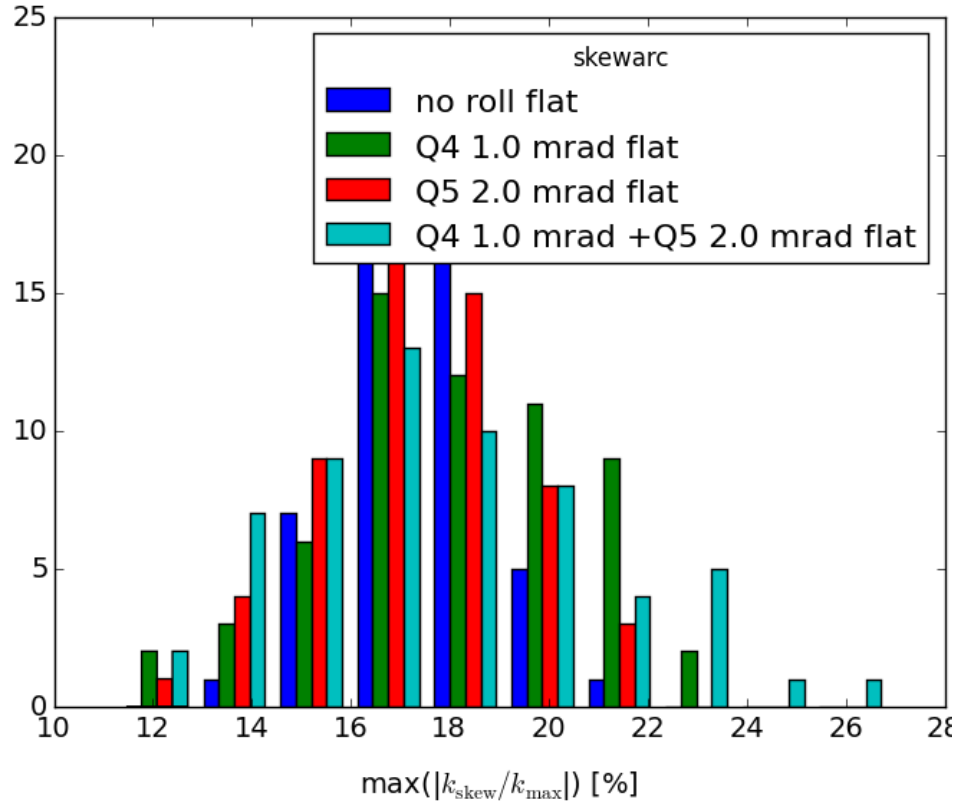
Roll angle for IT – flat optics

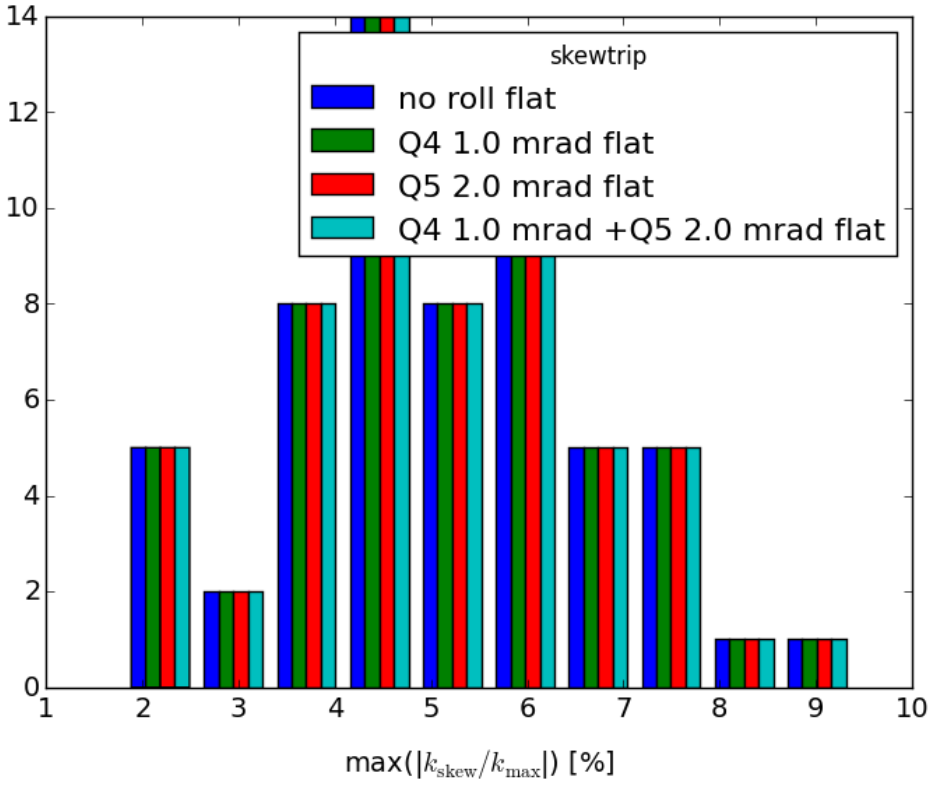




similar results as for round optics

Roll angle Q4/Q5 – flat optics





similar results as for round optics

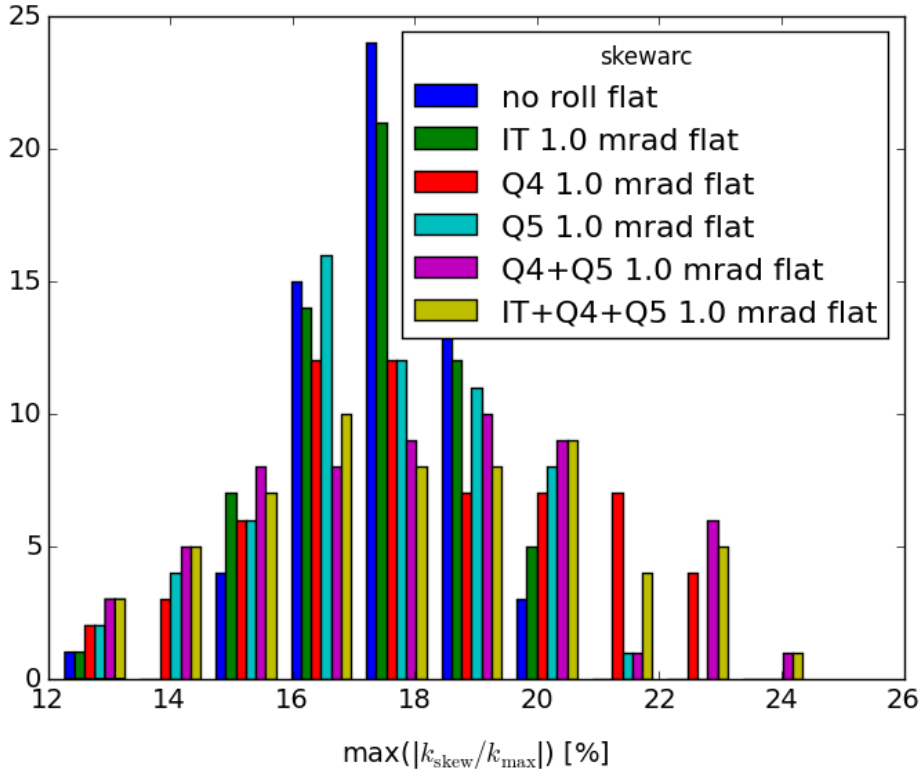
Roll angle for Q4/Q5 – flat optics

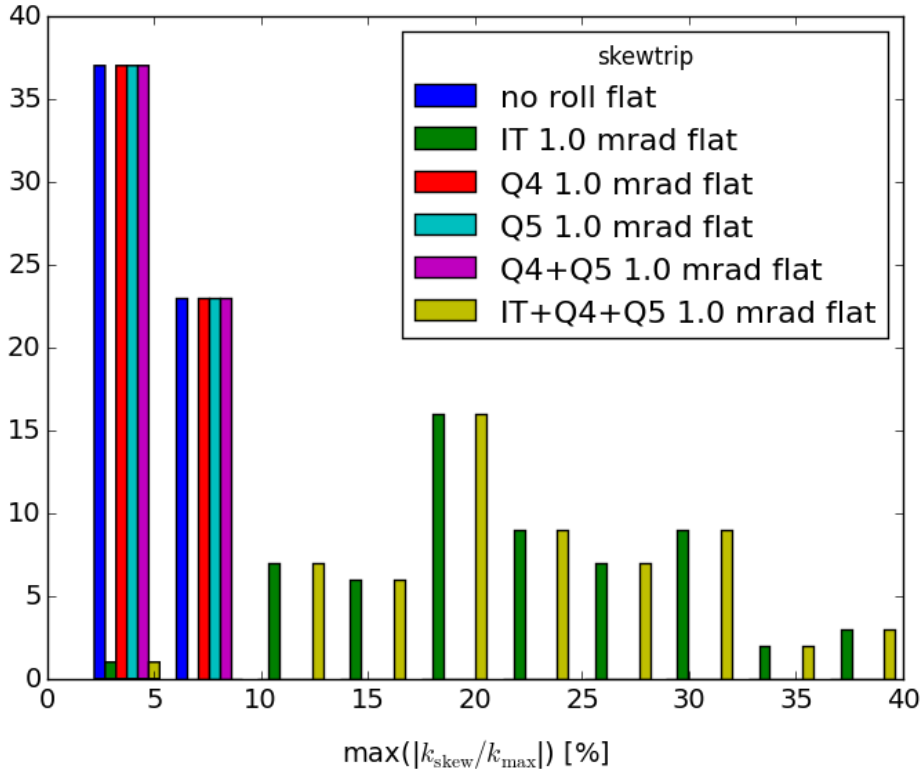
- Q4 approximately factor 2 more sensitive Q5 (1 mrad for Q4 corresponds to 2 mrad for Q5)
- limit for Q4/Q5: contribution of Q4/Q5 should stay in the shadow of the overall correction ($k_{max,MQS}$= 120 T/m):

1 mrad roll for **Q4** and **Q5**

Beam 1		**k/k_{max} [%] skewarc**		**k/k_{max} [%] skewtrip**			
optics	**1std roll [mrad]**	**mean**	**1 std**	**mean**	**1std**	**max(dq)**	**#seeds max dQ > 10^{-4}**
round (0.15/0.15)	17.57	1.36	5.07	1.64	17.57	1.03E-04	1
	18.06	2.54	5.07	1.64	18.06	2.09E-04	1
	17.37	1.99	5.07	1.64	17.37	1.86E-04	3
	17.35	2.85	5.07	1.64	17.35	1.33E-04	1
	17.86	3.23	5.07	1.64	17.86	1.59E-04	1
	17.57	1.36	5.07	1.64	17.57	1.13E-03	6

Roll angle for IT+Q4+Q5 – flat optics





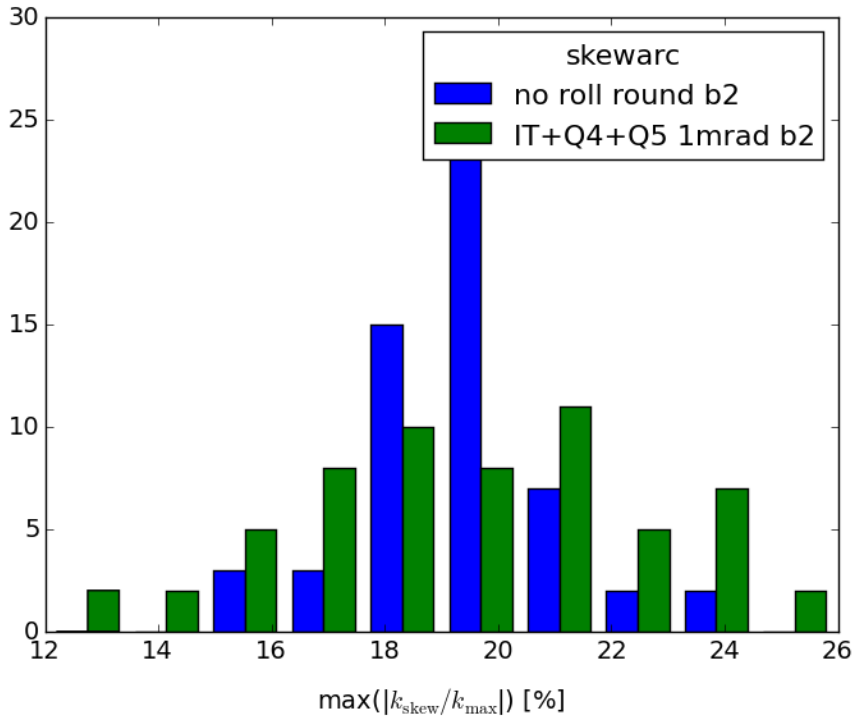
similar results as for round optics

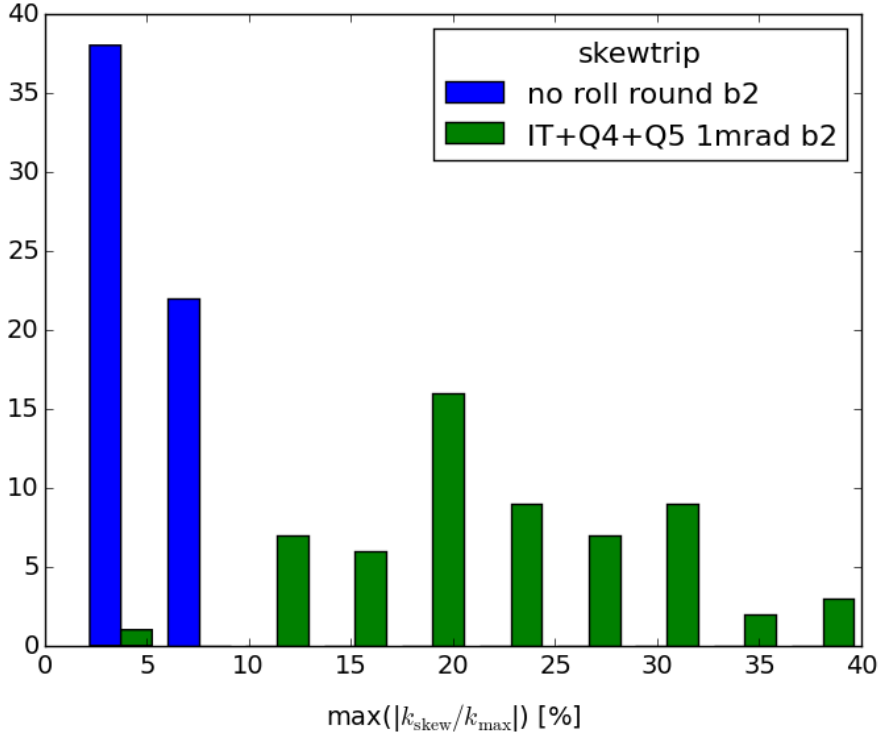
Roll angle for IT+Q4+Q5 – flat optics

similar results as for round optics

flat optics Beam 1	k/k_{max} [%] skewarc		k/k_{max} [%] skewtrip			
1std roll [mrad]	mean	1 std	mean	1std	max(dQ)	#seeds max dQ > 10^{-4}
no roll	17.57	1.36	5.07	1.64	1.75E-04	3
IT 1.0	17.55	1.42	22.37	7.69	1.56E-02	12
Q4 1.0	18.06	2.54	5.07	1.64	4.62E-04	4
Q5 1.0	17.37	1.99	5.07	1.64	1.14E-04	1
Q4+Q5 1.0	17.9	2.71	5.07	1.64	6.81E-04	4
IT+Q4+Q5 1.0	17.93	2.83	22.37	7.69	1.30E-02	22

Roll angle for IT+Q4+Q5 – round optics Beam 2

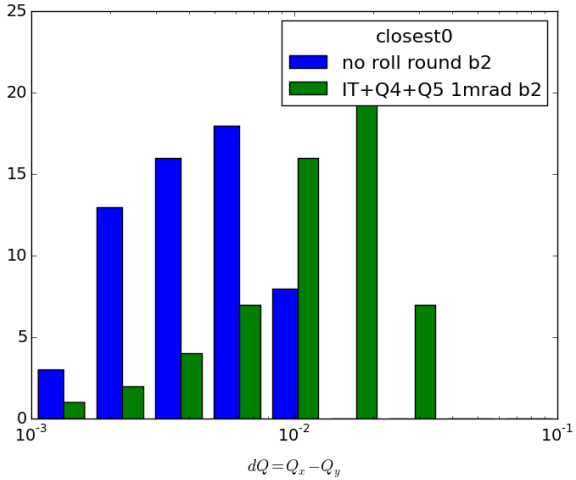


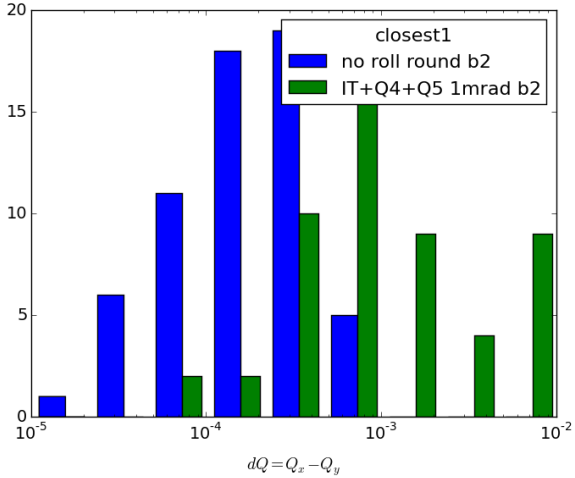


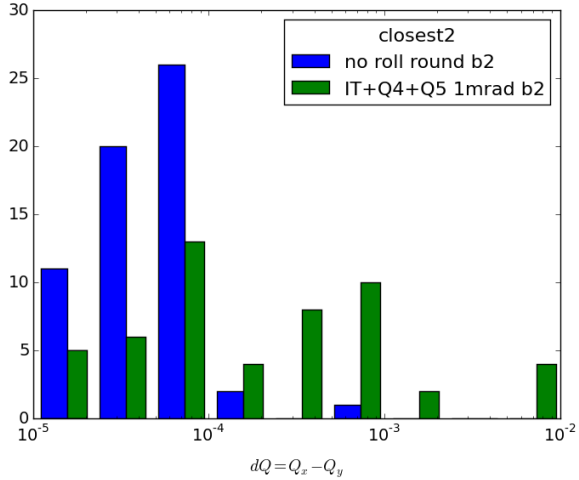
similar results as for beam 1

Roll angle for IT+Q4+Q5 – round optics Beam 2

round optics Beam 2	k/k_{max} [%] skewarc		k/k_{max} [%] skewtrip			
1std roll [mrad]	**mean**	**1 std**	**mean**	**1std**	**max(dQ)**	**#seeds max dQ > 10^{-4}**
no roll	19.35	1.65	5.06	1.64	4.78E-04	3
IT+Q4+Q5 1.0	19.5	3.1	22.37	7.69	2.63E-02	34







slightly worse than for Beam 1