Improvements in optics measurement resolution and error reconstruction.

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Outline.

- Optics measurement improvements
- Segment-by-Segment technique
- Summary / Outlook

Optics measurement.

Optics measurement.

- Oscillation will be excited on the beam (Kicker, AC Dipole)
- Turn-by-turn data from the BPMs is recorded

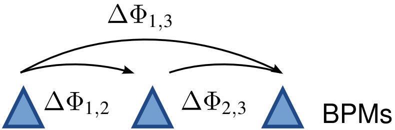
$\rightarrow$ Harmonic analysis $\rightarrow$ phase advance of betatron oscillation

- Phase advance of 3 BPMs can be used to derive optical parameters

$$\beta_{\text{BPM }1} \propto \cot(\Phi_{1,2}) - \cot(\Phi_{1,3})$$

$$\beta_{\text{BPM }2} \propto \cot(\Phi_{1,2}) + \cot(\Phi_{2,3})$$

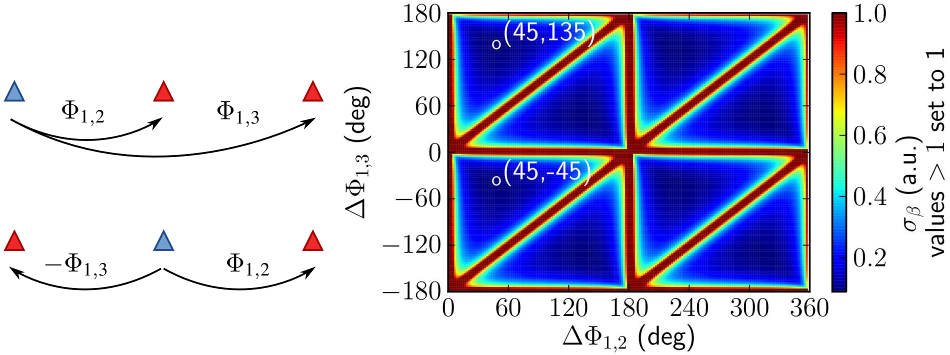
$$\beta_{\text{BPM }3} \propto \cot(\Phi_{2,3}) - \cot(\Phi_{1,3})$$



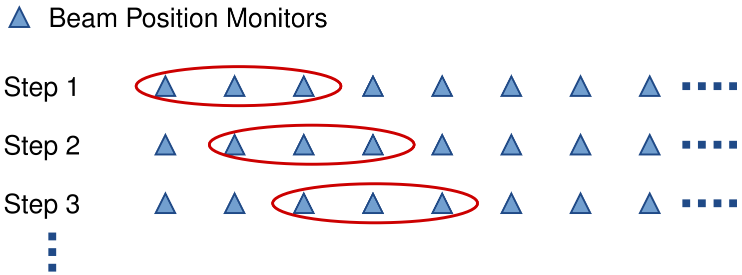
- Resolution depends on phase advances

Resolution dependency of the phase advances.

- Conditions on the phase advance for optimal resolution:
  - Phase advance from probed BPM to the two other BPMs should be close to $(45^\circ + n \cdot 90^\circ, n \in \mathbb{N})$
  - Avoid phase advances of $(n \cdot 180^\circ, n \in \mathbb{N})$ in between BPM pairs



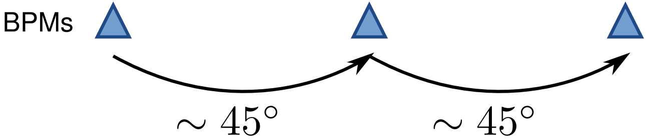
Implementation of the current algorithm.



- Algorithm goes step by step through all available BPMs
- Every set of three neighboring BPMs is used to calculate the optical functions at the three BPM positions

→ For every BPM position the optical functions are calculated 3 times and averaged

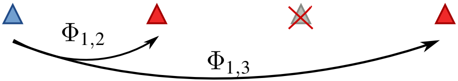
Situation in the arcs.

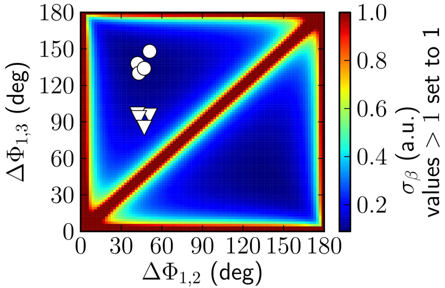


- In general the phase advance between BPM pairs is at about 45°
- This is the optimum for the case that the probed BPM is in between the other two
- For the case that the probed BPM is left or right to the other two BPMs the phase advances are at about 45° and 90°

$\rightarrow$ In the later case a phase advance of 45° and 135° with respect to the probed BPM would be better

Improvements for the arc.





▽ current algorithm
○ different BPM choice

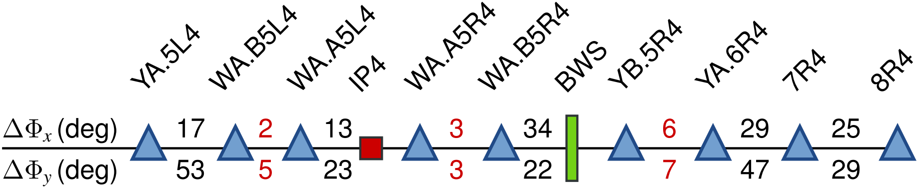
BPM 15R4	Current Algorithm	Skip BPM for 135° in edge
β_x (m)	31.1	30.7
Error propagation from $\Delta\Phi$		
$\sigma_{\beta_x,1}$ (m)	0.21	0.17
Standard deviation (3 BPM sets)		
$\sigma_{\beta_x,2}$ (m)	0.22	0.43
β_y (m)	168.85	168.86
Error propagation from $\Delta\Phi$		
$\sigma_{\beta_y,1}$ (m)	1.69	1.03
Standard deviation (3 BPM sets)		
$\sigma_{\beta_y,2}$ (m)	1.93	2.04

- Propagated error from phase decreases, but standard deviation increases

- Model uncertainties contribute more if further away BPM are used

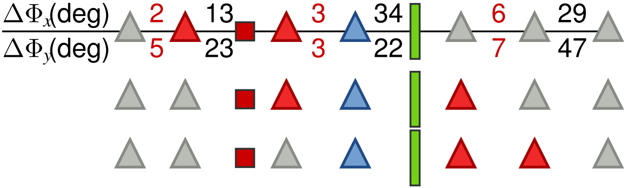
Situation in the IRs.

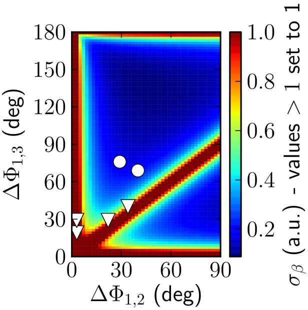
- In the interaction regions (IRs) the phase advances between BPM pairs differ from 45°
- In many cases smaller phase advances, in some cases even just a few degree
- Sketch shows phase advances for BPMs close to IP4



Improvements for IR4.

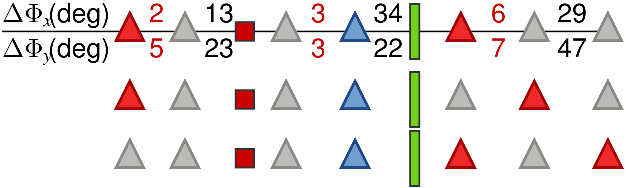
- Choice of BPMs in old algorithm (▽ in right plot)

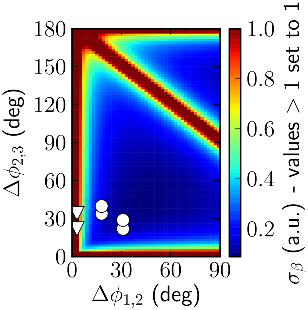




▲: probed BPMs ▲: used BPMs ▲: unused BPMs

- Better choice of BPMs (○ in right plot)





Improvements for IR4.

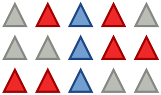
BPMWA B5R4	Current Algorithm	Optimized BPM sets
β_x (m)	183.1	190.2
Error propagation from $\Delta\Phi$		
$\sigma_1\beta_x$ (m)	23.7	2.1
Standard deviation (3 BPM sets)		
$\sigma_2\beta_x$ (m)	2.4	0.2
β_y (m)	174.0	167.1
Error propagation from $\Delta\Phi$		
$\sigma_1\beta_y$ (m)	21.5	1.9
Standard deviation (3 BPM sets)		
$\sigma_2\beta_y$ (m)	4.6	0.2

BPMYB B5R4	Current Algorithm	Optimized BPM sets
β_x (m)	197.6	191.8
Error propagation from $\Delta\Phi$		
$\sigma_1\beta_x$ (m)	15.6	3.0
Standard deviation (3 BPM sets)		
$\sigma_2\beta_x$ (m)	1.7	0.7
β_y (m)	405.1	407.7
Error propagation from $\Delta\Phi$		
$\sigma_1\beta_y$ (m)	32.9	4.6
Standard deviation (3 BPM sets)		
$\sigma_2\beta_y$ (m)	9.1	3.3

Improvement of one order of magnitude on the error bar!

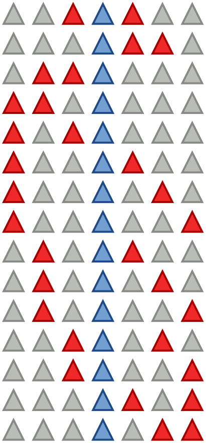
Implementation of a new algorithm.

Old algorithm



: probed BPMs
: used BPMs
: unused BPMs

New algorithm

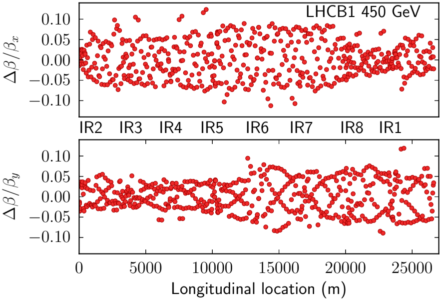


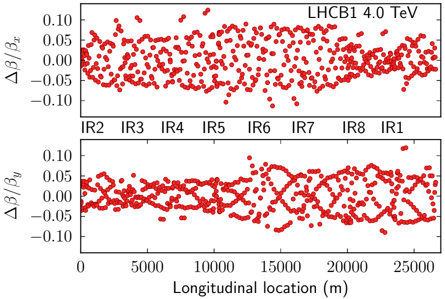
- Old algorithm
  - 3 BPM sets of the nearest neighbors per BPM position
  - Final optical functions are the average from the 3 BPM sets
- New algorithm
  - One additional BPM right and left of the probed BPM are used

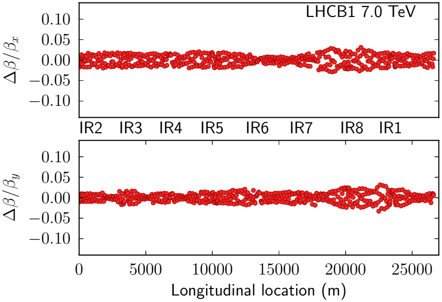
→ 15 combinations of BPM sets

→ The 3 BPM sets which feature the lowest errors are chosen and averaged

Including dipole b2 errors in the model.



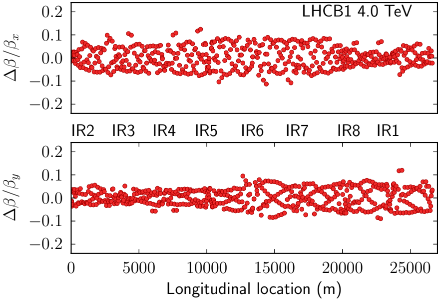




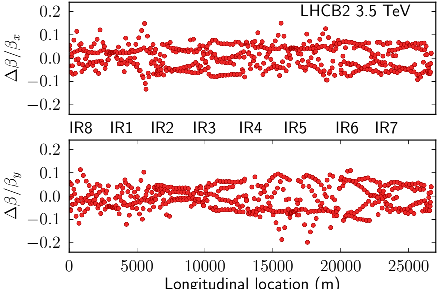
- More precise model
- Better accuracy for the beta calculation expected
- Higher effect at lower energy

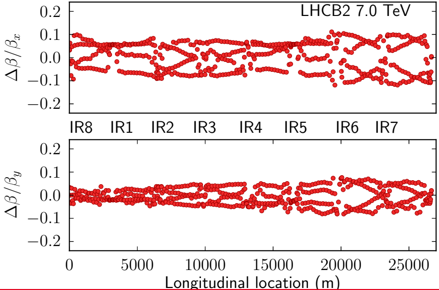
Including dipole b2 errors in the model.

Nominal



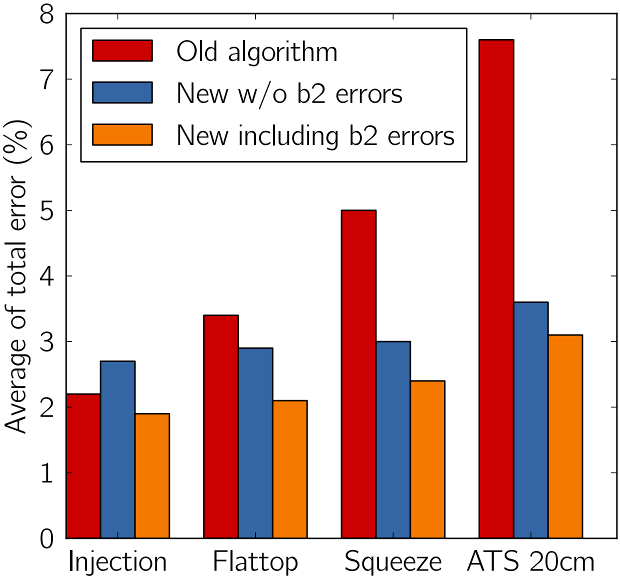
ATS 20cm





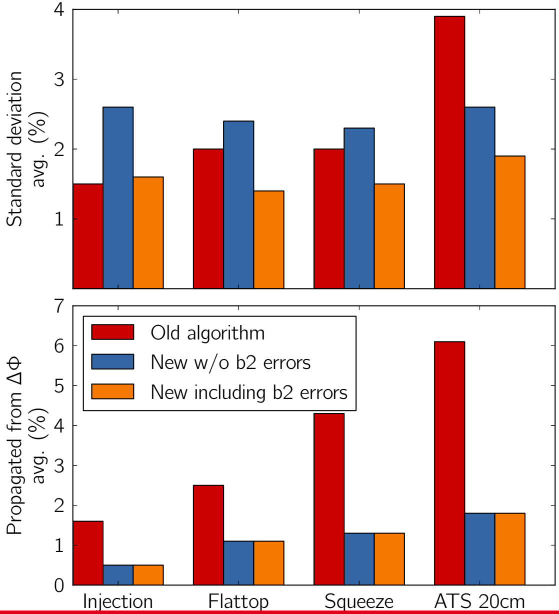
- Similar effect for nominal and ATS optics at 3.5 and 4 TeV
- In ATS optics the effect is not significantly reduced for 7 TeV

Errors bars of measured betas.



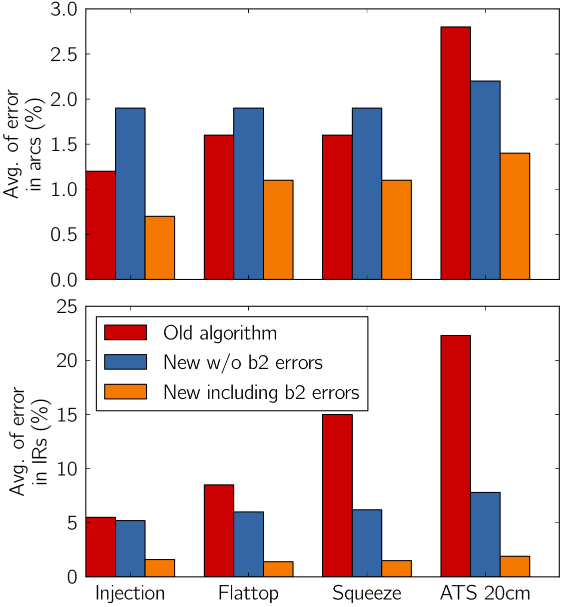
- Averaged $\Delta\beta$
- Errors larger than 200% were removed
- b2 dipole errors increase precision of the measurement

Two contributions to the error bar.



- New algorithm improves significantly errors propagated from $\Delta\Phi$
- Standard deviation is more sensitive to the model
  $\rightarrow$ improves when using b2 errors

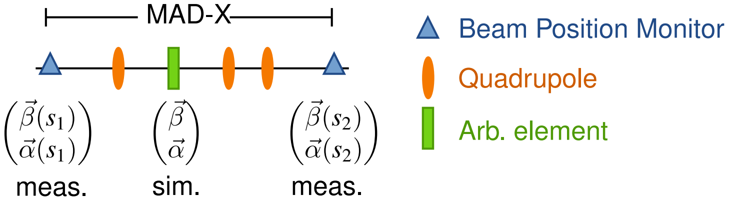
Error bars in arcs and IRs.



- Largest errors are in general in the IRs
- Here the algorithm shows the strongest improvements
- Errors in the arcs already on a low level
- Can be slightly improved with the new algorithm in combination with b2 errors

Segment-by-Segment technique.

Segment-by-Segment



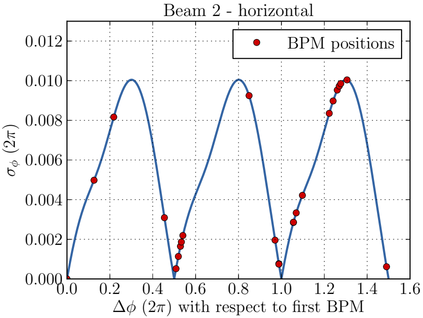
- Transport of optical functions from a BPM position
- Technique for investigating local corrections
- Calculation of optical functions at specific elements
- Uses measured optical function at starting point of simulation

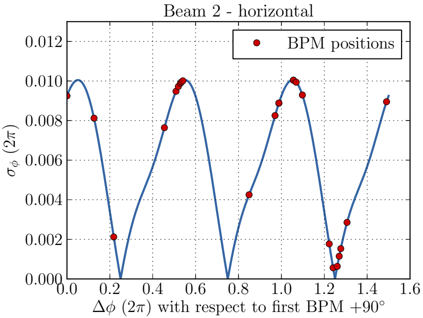
Systematic errors.

- Errors on the measured β- and α-functions propagate to an error of the phase advance $\rightarrow$ so far not taken into account
- Error on phase advance has minima
- Usually different start positions are favorable for horizontal and vertical plane

$\rightarrow$ Separate both planes

$\rightarrow$ Local corrections might be better constrained by using 2 segments with starting location separated by $\approx 90°$





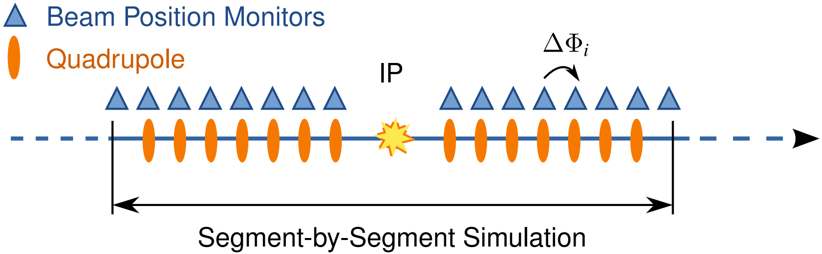
Systematic errors.

- The propagation of $\Delta\beta$ and $\Delta\alpha$ is estimated by simulating several cases with $\beta_0 \pm \Delta\beta$ and $\alpha_0 \pm \Delta\alpha$ at the start position
- Both errors can be analytically estimated
- Together with the errors on the simulated phase, a more sophisticated error treatment is possible

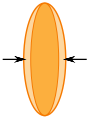
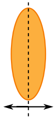
$\rightarrow$ Useful for local correction techniques

$\rightarrow$ Important for calculating optical functions at specific elements

Local corrections.



- Monte-Carlo Approach to fit optics to measured constraints

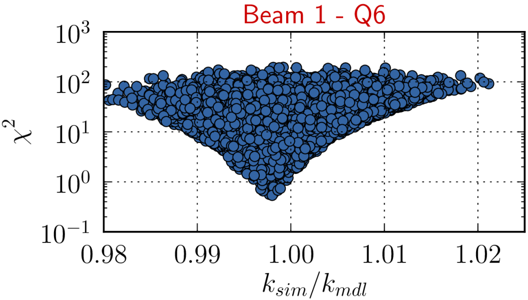
- Vary quadrupole strengths Δk  and long. positions Δs 

$\rightarrow$ Variation of simulated phase advances $\Delta\Phi_{i,Sim}$

- Minimize $\chi^2 = \sum_i \left(\frac{\Delta\Phi_{i,Meas} - \Delta\Phi_{i,Sim}}{\sigma(\Delta\Phi_i)} \right)^2$

Local corrections.

- This method is currently investigated in IR1 in combination with constraints from ALFA detector measurements
- In general this method can be applied on other IRs as well



$\rightarrow$ β-function propagation benefits from a better knowledge of the optics

$\rightarrow$ Precise calculation of optical functions (new algorithm) will help further
$\rightarrow$ Lower uncertainty of start values of the Segment-by-Segment simulation

Summary.

- Improved algorithm for β-function calculation studied
  - Significant improvements on the error bars
  - Precise knowledge of the model (b2 errors) crucial
- Foressen improvements for Segment-by-Segment
  - More sophisticated error treatment
  - Monte-Carlo approach for local corrections
- Propagation of β-function to specific elements will benefit from these improvements

Thank you for your attention.