DESY FEL Seminar 2016-04-19

FLASH-MD's : Recent Progress in Optics Setup

Mathias Vogt (MFL) & Johann Zemella (MPY)

- Introduction / Motivation
- Matching/Re–Matching : Methods
- Matching/Re–Matching : FLASH–Sections
- Consistency Checks : Orbit Response Matrix Measurements
- Summary
- Outlook: Orbit & Dispersion w/ `lmad`

FLASH
Free–Electron Laser
in Hamburg

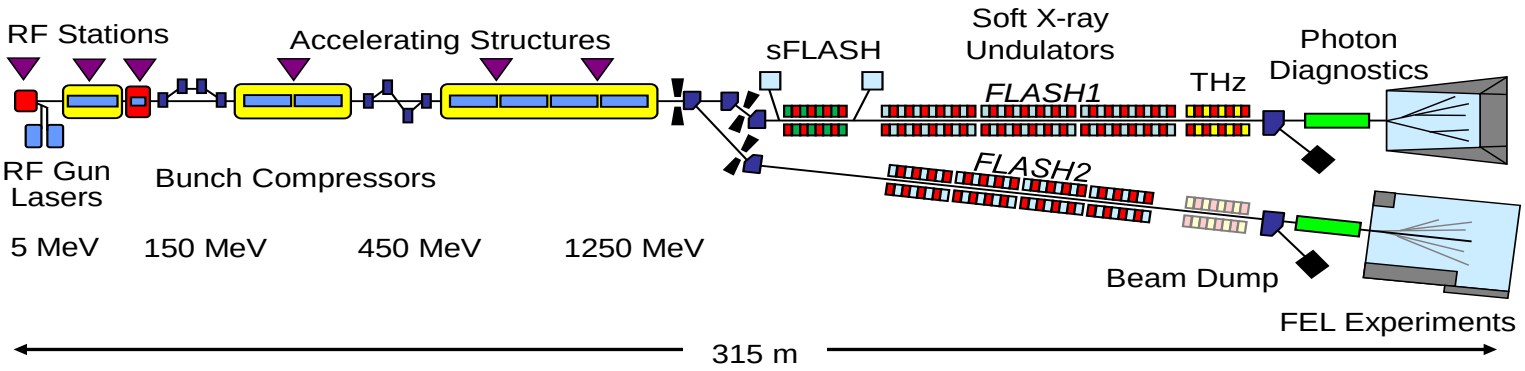
I report her on behalf of Johann & myself, but there's many people involved in this (in alphabetical order):

V.Balandin,
Chr.Behrens,
B.Beutner,
F.Christie (a.k.a. F.Mueller),
N.Golubeva,
Th.Hellert,
R.Kammering,
S.Meykopff,
E.Prat,
M.Scholz
J.Wilgen,
and many more.

Conference contributions directly related to this talk:

- IPAC14 : TUPRO050 :
  J.Zemella, T.Hellert, M.Scholz, M.Vogt :
  Measurements of the Optical Functions at FLASH
- IPAC15 : TUPWA035 :
  J.Zemella, T.Hellert, M.Scholz, M.Vogt :
  Progress in Optics Studies at FLASH

Introduction / Motivation



- **RF–GUN**: **space charge** dominated regime (lowest E)
- **Design Optics :**
  - → starts *exit* of solenoid **1GUN**
  - → zero current limit **(no SC)**
  - → valid only **un–compressed**

⇒ **DBC2**: **match** beam from RF–GUN into design optics in linac

- Dominant sources of optics perturbation (un–compressed):
  - → the "**ACC2**–Badlands" **:-(**
  - → energy profile (!!!) :

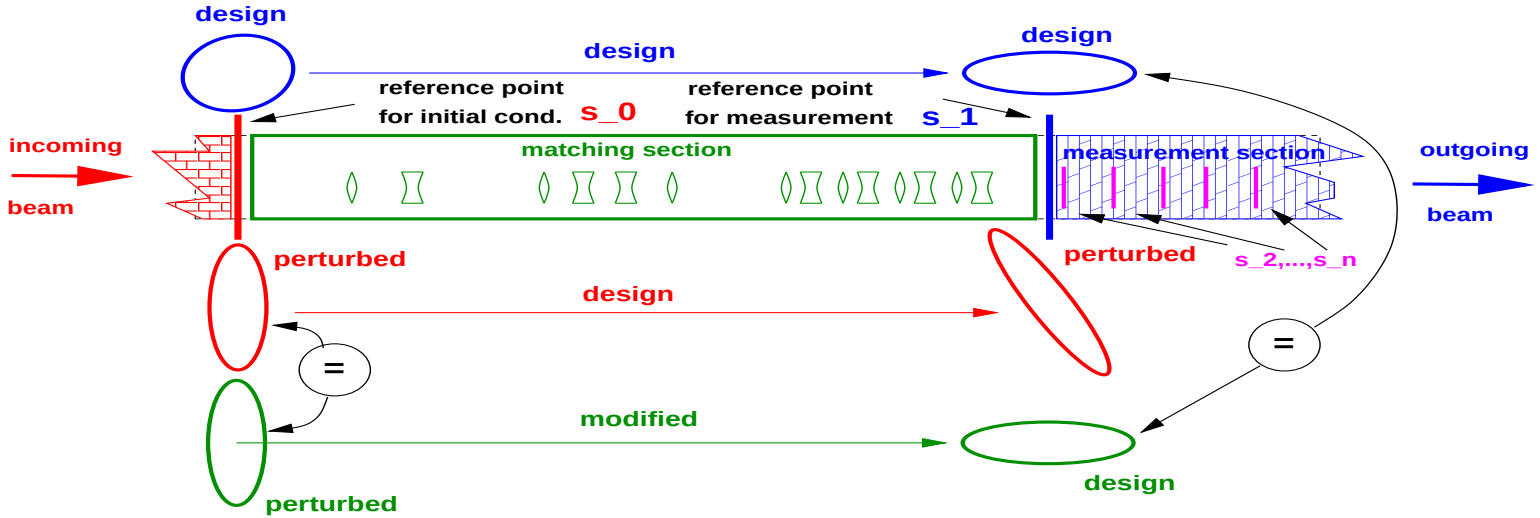
    $k_1 := (\partial B_y/\partial x) \times (p\ e)^{-1}$

⇒ Necessity of **re–match** → constraints

- (Finally:

  correct for SC in compressed beam!)

Matching / Re–matching **of Beamlines**: Basic Concepts (1)



- **linear optics !**
- beam ellipse: $\vec{z}^{\,\mathrm{T}}\,\underline{B}(s)^{-1}\,\vec{z} = \epsilon$
- $\underline{B}(s) = \begin{pmatrix} \beta(s) & -\alpha(s) \\ -\alpha(s) & \gamma(s) \end{pmatrix}$
- map $\underline{M}_{b\leftarrow a}(k_i,\ldots,k_j)$ from s_a to s_b through quads Q_i to Q_j w/ strengths k_i to k_j.

$$\rightarrow\ \vec{z}(s_b) = \underline{M}_{b\leftarrow a}(k_i,\ldots,k_j)\ \vec{z}(s_a)$$

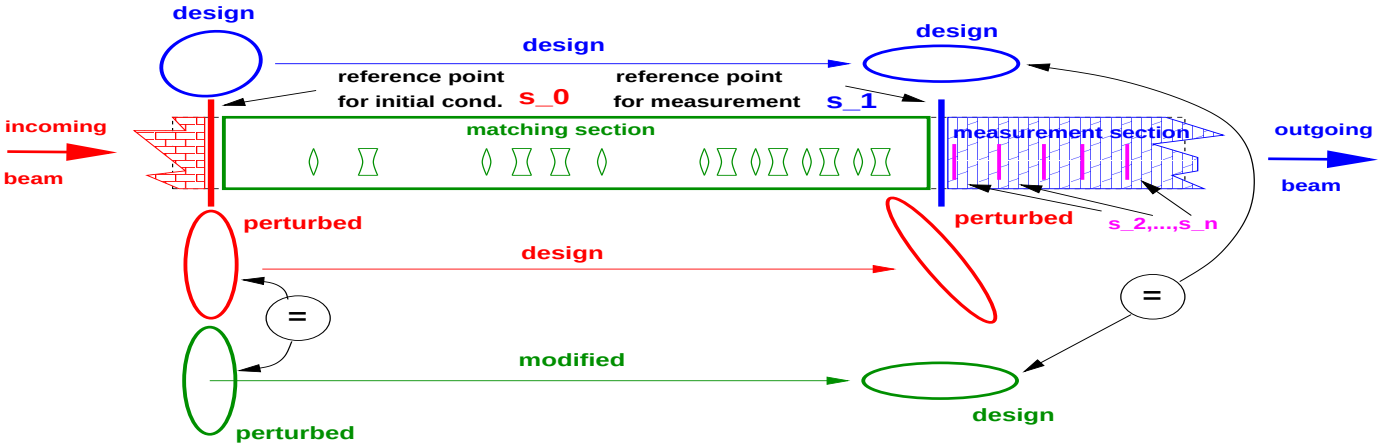
$$\Rightarrow\ \underline{B}(s_b) = \underline{M}_{b\leftarrow a}\,\underline{B}(s_a)\,\underline{M}_{b\leftarrow a}{}^{\mathrm{T}}.$$

$\leftarrow$ linear in $\underline{B}$, quadratic in $\underline{M}\rightarrow$

$$\begin{pmatrix} \beta_b \\ \alpha_b \\ \gamma_b \end{pmatrix} = \underline{\mathcal{T}}_{b\leftarrow a} \begin{pmatrix} \beta_a \\ \alpha_a \\ \gamma_a \end{pmatrix}.$$

- $\underline{\mathcal{T}}_{b\leftarrow a} = \underline{\mathcal{T}}_{b\leftarrow a}(k_i,\ldots,k_j)$

Matching / Re–matching **of Beamlines**: Basic Concepts (2)



- for each transv. plane (X & Y) :

1: **measure beamsizes** σ_i

$\sigma(s_i) = \sqrt{\beta_i \epsilon}$, $i = 2, \ldots, n \geq 4$

Twiss parameters at reference point s_1 as least square solution of:

$$\begin{pmatrix} \sigma_2^2 \\ \cdots \\ \sigma_n^2 \end{pmatrix} = \begin{pmatrix} (\underline{\mathcal{T}}_{2\leftarrow 1})_{1,*} \\ \cdots \\ (\underline{\mathcal{T}}_{n\leftarrow 1})_{1,*} \end{pmatrix} \begin{pmatrix} \beta_1 \epsilon \\ \alpha_1 \epsilon \\ \gamma_1 \epsilon \end{pmatrix}$$

2: **transport** β_1, α_1, γ_1 **backwards**

$$\rightarrow \begin{pmatrix} \beta_0 \\ \alpha_0 \\ \gamma_0 \end{pmatrix} = \underline{\mathcal{T}}_{0\leftarrow 1} \begin{pmatrix} \beta_1 \\ \alpha_1 \\ \gamma_1 \end{pmatrix}$$

$\rightarrow$ gives "measured" initial cond. β_0, α_0, γ_0

- Remark: $\underline{\mathcal{T}}_{i\leftarrow 1}$ $(i = 2, \ldots, n)$, and $\underline{\mathcal{T}}_{0\leftarrow 1}$ are assumed **close to design!**

3: **match** measured β_0, α_0, γ_0

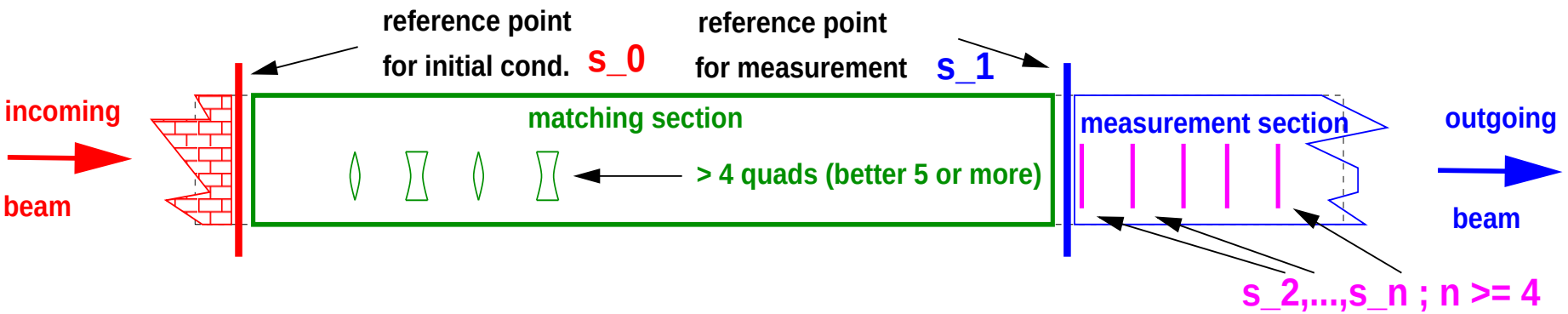
into **design** β_1, α_1, γ_1

$$\begin{pmatrix} \beta_1 \\ \alpha_1 \\ \gamma_1 \end{pmatrix} = \underline{\mathcal{T}}_{1\leftarrow 0}(k_i, \ldots, k_j) \begin{pmatrix} \beta_0 \\ \alpha_0 \\ \gamma_0 \end{pmatrix}$$

using quads Q_i to Q_j

- Remark: $\beta\gamma + \alpha^2 \equiv 1 \Rightarrow$ needs **at least 4 quads** for both planes (X & Y)

The $(n \geq 3)$–Screen/Wire Method



- typically $s_1 \equiv s_2$
- best: $n \geq 4$;($n = 3$: no errorbars)
- *screen:* measure X & Y simultaneously
- optimum phase advance per screen/wire : 45°
  (0°, 45°, 90°, 135° w/ 4 stat.)
- fit (1:) might yield negative $\beta_1 \epsilon$

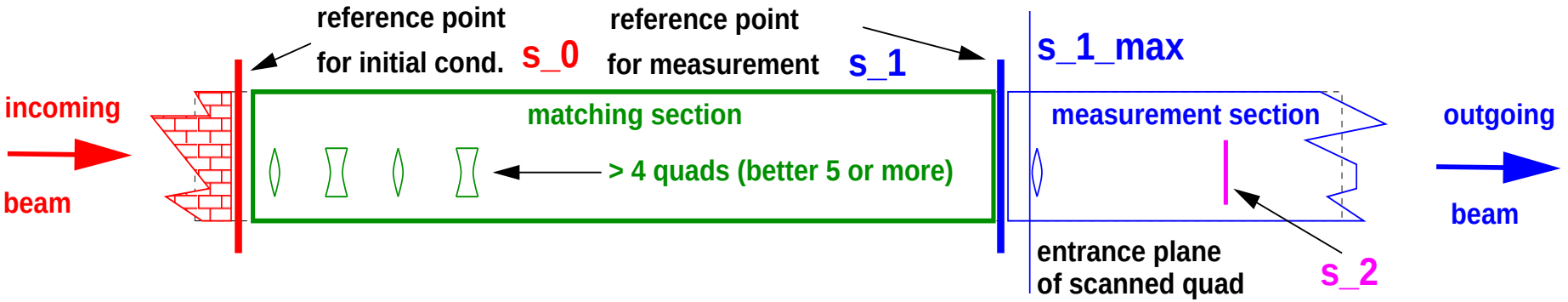
What can go wrong ? :
(apart from broken equipment. . .)

- large E–spread & spurious dispersion
- beam distorted / broken into beamlets
  ←how do σ's compare for totally different beam shapes?
- screen : coherent OTR

⇒ go to minimum E–spread
(m.o.l. on–crest)
& "beautify" beam (steering,. . .)!

- small charge → small signal

The Single–Quad–On–Single–Screen/Wire Method



- most downstream s_1 is entrance of scanned quad
- concept: changed focusing shifts beam waist through s_2
- (simplified evaluation for 1-quad-on-1-screen
  $\longrightarrow$ e.g. Minty & Zimmermann)
- for thin-lens quad: ${\sigma_2}^2(k_1)$ should be a parabola $(*)$
- *screen:* measure X & Y simultaneously — *iff* optics suited for (halfway) symmetric scan: ($k_1 \approx 0 \Rightarrow$ X & Y beam waists symmetric around s_2

- scan in cycle direction !

What can go wrong ? :

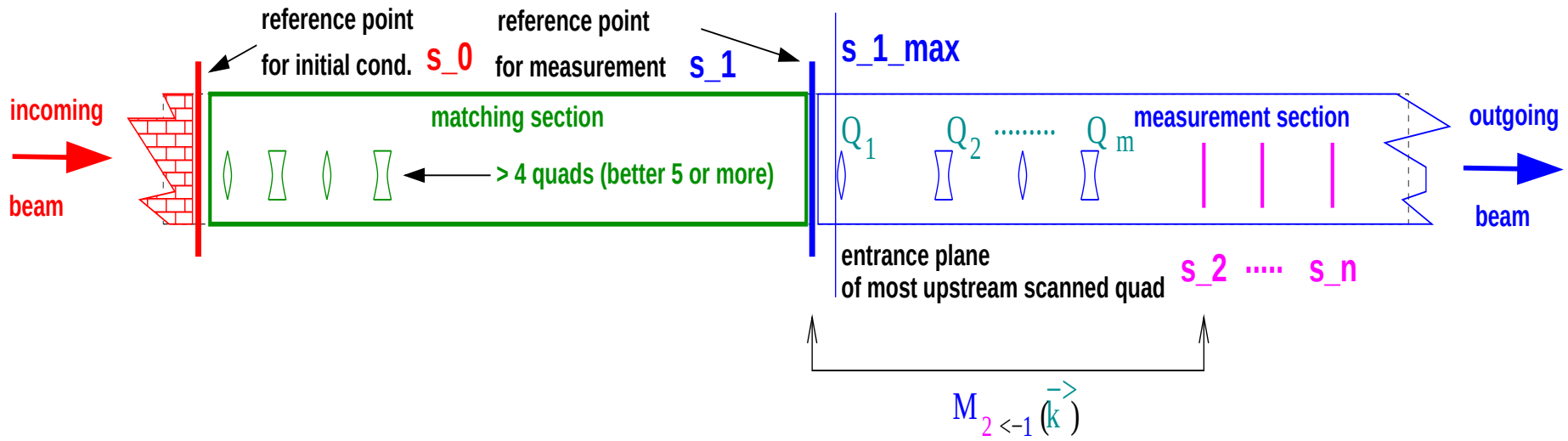
(apart from broken equipment. . .)

- Same as w/ $(n \geq 3)$–screen/wire method
- parabola $(*)$ not sufficient
  $\longrightarrow$ can still yield imaginary β_1

$\longrightarrow$ hard to judge quality of scan until finally evaluated

- FLASH:
  watch "injector cycle" vs. "linac cycle"

The Multi–Quad–Multi–Screen/Wire Method



- looks more complicated but might yield better scans w/ less mod's (more quads for matching) then the single quad scan w/ modified optics (next slide)
- match for uniform sampling of the X-, Y–waists $(0^\circ < \mu_{x/y} < 180^\circ)$ using quads between s_1 and $s_2 \longrightarrow \vec{k}$

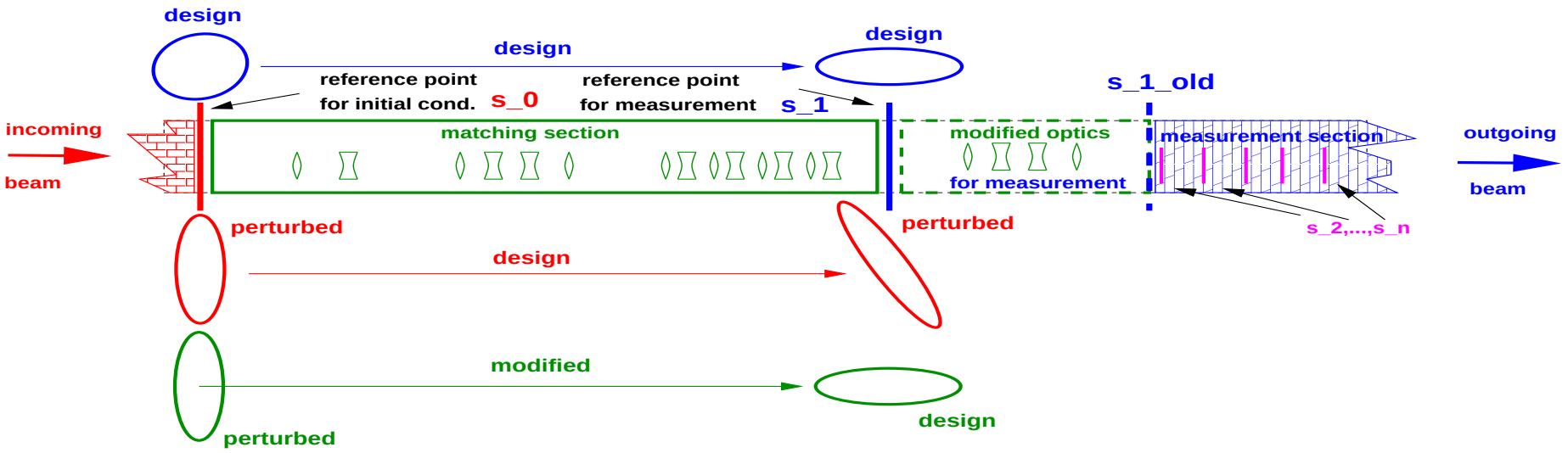
1^*: $$\begin{pmatrix} \sigma^2_{2,1} \\ \cdots \\ \sigma^2_{n,m} \end{pmatrix} = \begin{pmatrix} \left(\underline{\mathcal{T}}_{2\leftarrow 1}(\vec{k}_1)\right)_{1,*} \\ \cdots \\ \left(\underline{\mathcal{T}}_{n\leftarrow 1}(\vec{k}_m)\right)_{1,*} \end{pmatrix} \begin{pmatrix} \beta_1 \epsilon \\ \alpha_1 \epsilon \\ \gamma_1 \epsilon \end{pmatrix}$$

- use fit from (1^*:) instead of Minty/Zimmermann
- find sequence of matching k–tuples for minimum number of cycles needed.

What can go wrong ? :
(apart from broken equipment. . .)

- Same as w/ single–quad–scan
- might still require lots of cycling

Modified Optics Upstream Screens During Measurement



- while reducing number of quads for actual matching,
- modify optics between s_1 (from design) and s_2

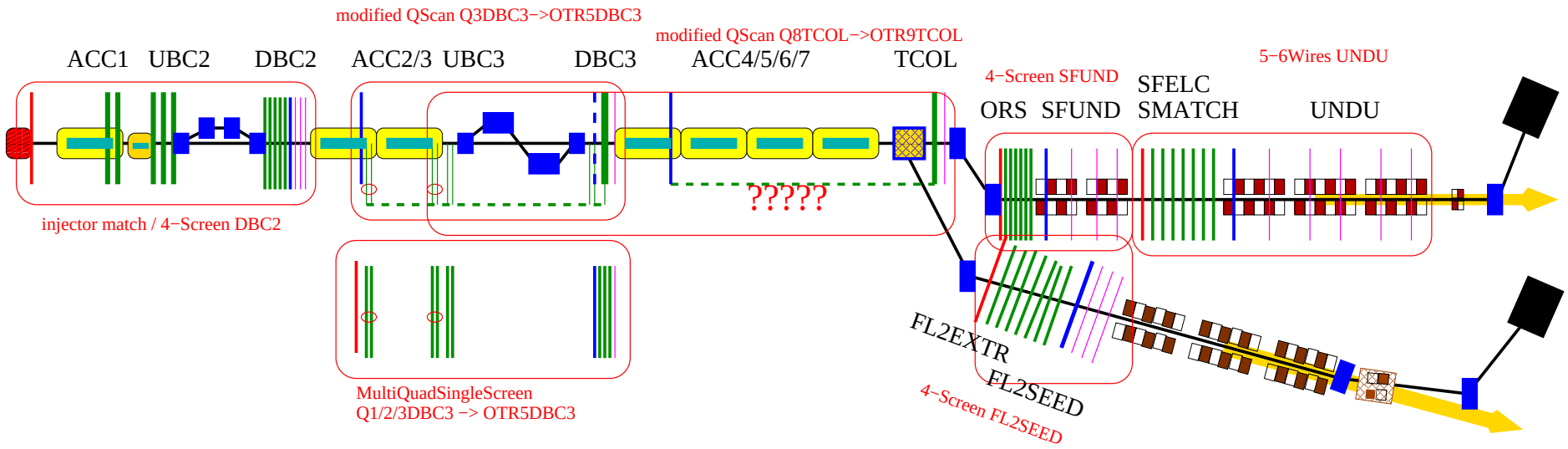
\+ to optimize measurements

- i.e. for **symmetric beam waist** for single–quad–scan.
- can be applied to all before mentioned techniques
- since optics between s_1 and $s_1^{(\mathrm{old})}$ modified from design

→ matching section prolonged further upstream

→ optimally suited for extremely long beam lines like FLASH :-)

Matching/Re–Matching in FLASH/1/2 (1)



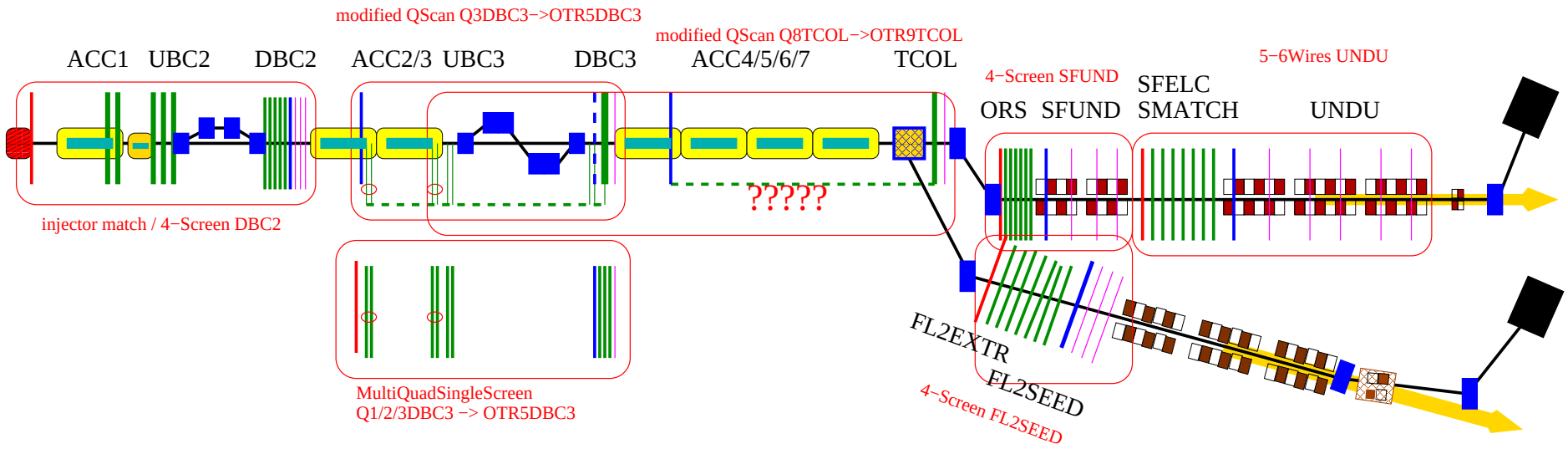
- **Injector Match:**
- 4 OTRs in DBC2
- 5 quads upstream BC2 (try preserving waist in last dipole)
  & 5 quads DBC2
- converges typically after 3 iterations
- nice beam required — or no convergence
- **modified quad scan**
  Q3DBC3 → OTR5DBC3:
- mod's use Q9ACC2 to Q2DBC3

→ no more matching quads downstream "ACC2–Badlands"

- **multi quad scan**
  Q1/2/3DBC3 → OTR5DBC3:
- no mod's upstream Q1DBC3

→ hardwired doublet Q9/10ACC2, semi–hardwired Q9/10ACC3 and singly powered quads Q1/2UBC3 available for matching (barely 4 d.o.f)

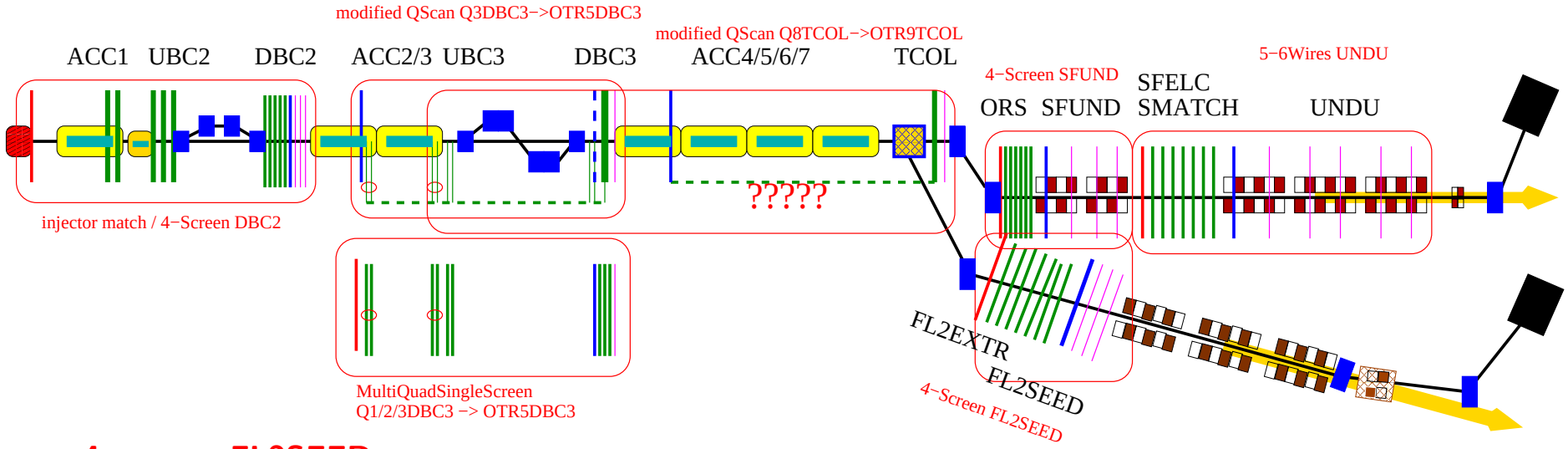
Matching/Re–Matching in FLASH/1/2 (2)



- **modified quad scan Q8TCOL → OTR9TCOL:**
- mod's use main–linac quads (ACC4/5/6/7)
- might work for restoring design waist at D1FL2EXTR (septum)
- **not yet tried!**
- **NO 4 screen at ORS:**
  - SyLi on OTR2ORS & 4ORS
  - matching only in collimator section

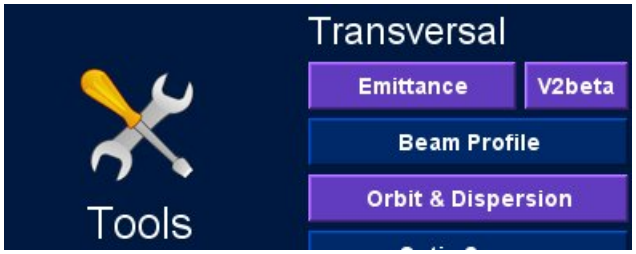
- **4 Screen at SFUND:**
- finally all 4 screen usable
- 6 matching quads in ORS
- often used by/for sFLASH
- **5–6 wires in UNDU:**
- hardware requires T.L.C.!
- 6 matching quads in SFELC/SMATCH
  - undulator match might violate LOLA, etc. constraints
- so far once converged . . .

Matching/Re–Matching in FLASH/1/2 (3)

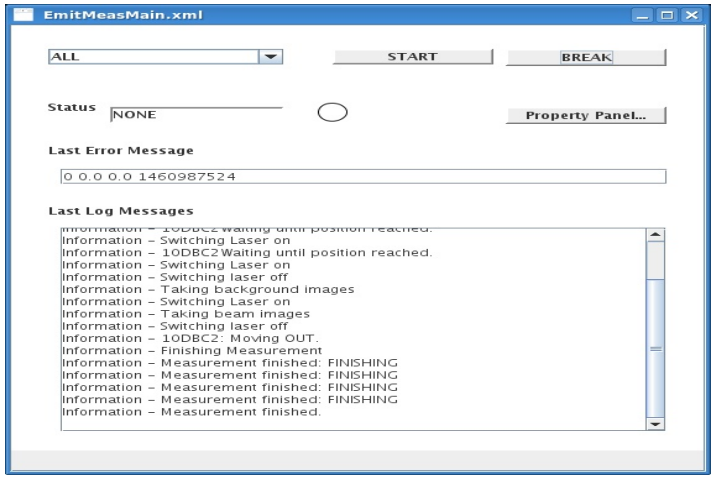


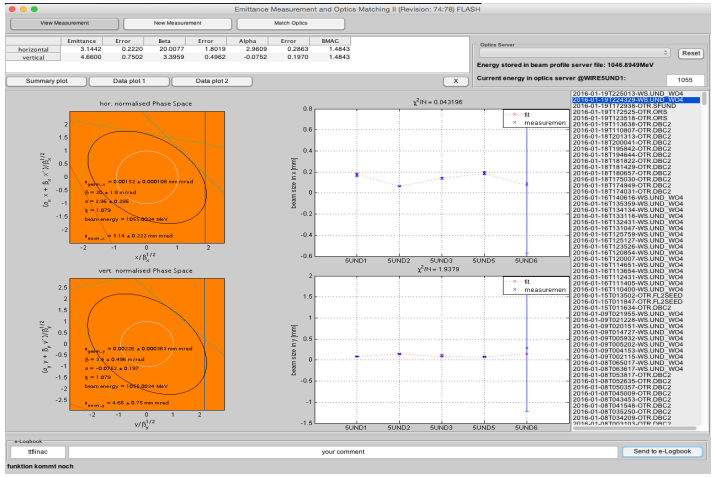
- **4 screens FL2SEED:**
- 6 matching quads in FL2EXTR and FL2SEED
- suffers extremely from spurious dispersion

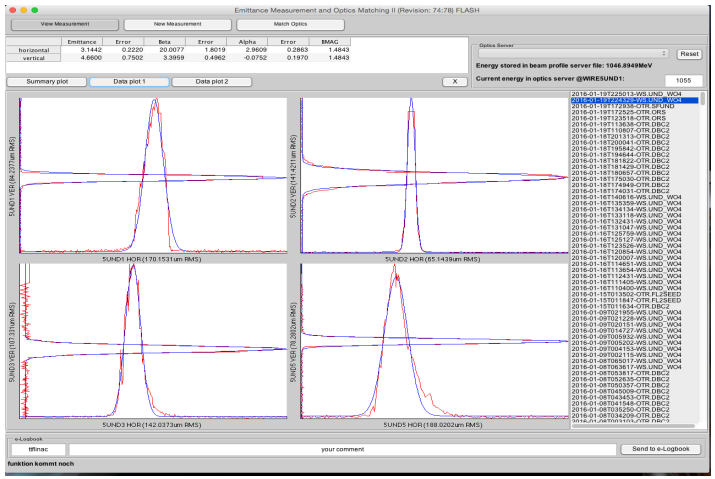
→ work in progress

- **IMPLEMENTATION :**
- `BeamProfileServer` **(J.Wilgen)**
  → manages data taking and σ comp.
  → for 4Screen/Wire sections:
  DBC2, (ORS), SFUND, UNDU, FL2SEED
  → extensible to SingleScreen ???
- `EmittanceTool`
  (S.Meykopff & B.Beutner)
  → uses `BeamProfileServer`
  & `OpticsServer`
  → can measure mismatch
  & perform rematch
  → matlab GUI : 2 versions
- 

ProfileServer & NewEmittanceTool

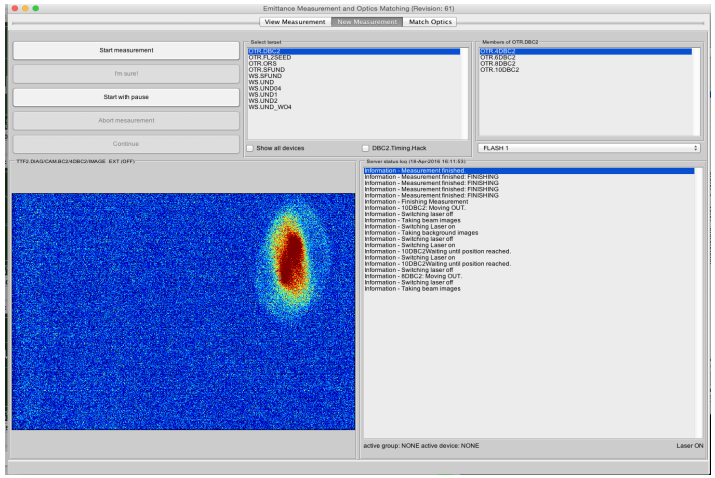


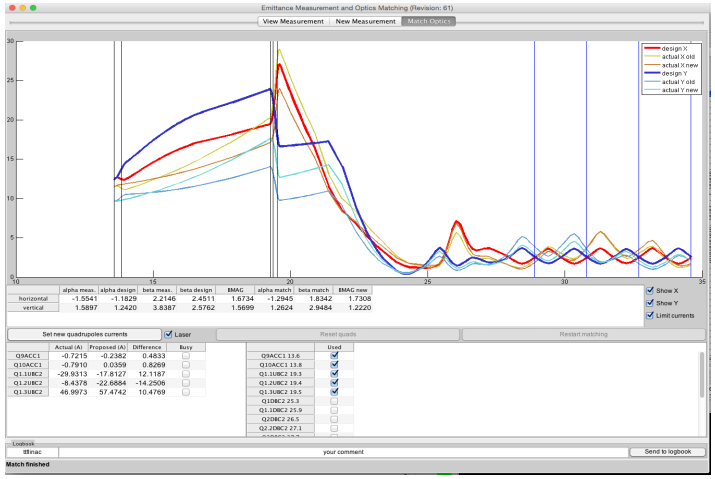


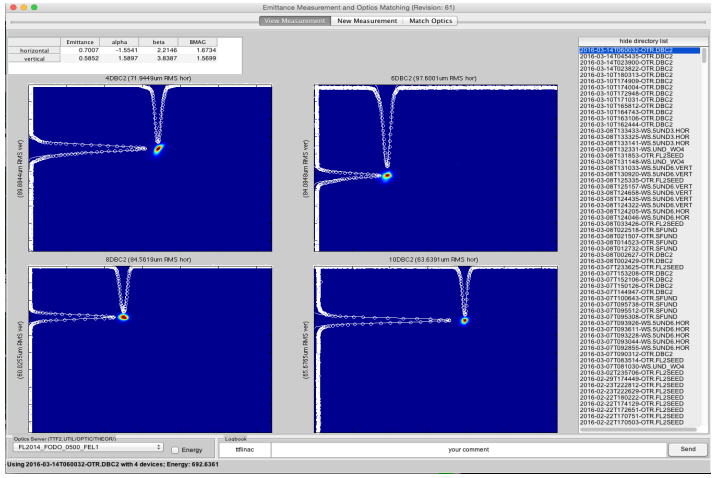


- top/left: `ProfileServer` panel (`jddd`)
- bot/left: `EmittanceTool` "V2beta": beam profiles panel
- top/right: `EmittanceTool` "V2beta": missmatch 'n' stuff

OldEmittanceTool

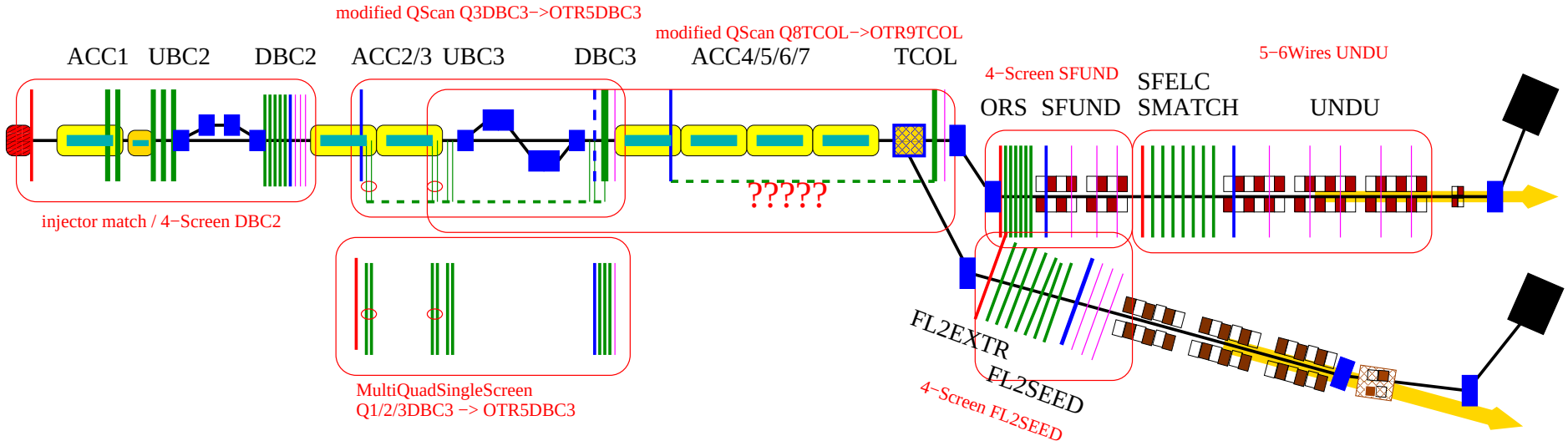






- top/left: `EmittanceTool`: new measurement
- bot/left: `EmittanceTool`: beam profiles
- top/right: `EmittanceTool`: matching

Matching/Re–Matching in FLASH/1/2 (4)



- **IMPLEMENTATION (2):**
- **Suite of scripts**: (**J.Zemella**)
- based upon: `bash`, `python`, `lmad` (= `mad8` + acceleration), `doocsget/put`, `c++`
- on linux (e.g. **flashlxuser1**)
- (certain features not yet on MAC)
- `/home/ttflinac/MAD/MADmatching/`
- `MultQuadMultScrnScan.sh`: data taking
- `CalcMultQuadMultScrn.sh`: evaluation
- single quad scan `QuadScan.sh`
- `getProfMonData.sh`: extract data from `ProfileServer`
- `MultScrnMethod.sh`: n screen/wire evaluation
- `runMatch.sh`: rematch using `lmad`

Johann's Scripts (examples)

MultQuadMultScrnScan.sh :

- `$ ./MultQuadMultScrnScan.sh Q2DBC3 OTR5DBC3`
- `$ ./MultQuadMultScrnScan.sh OTR4DBC2 OTR6DBC2 OTR8DBC2...`
- interactive data taking (I_{quad}, screenshots $\rightarrow \sigma$'s)
- user makes sure that currents properly set & beam on screen!

runMatch.sh :

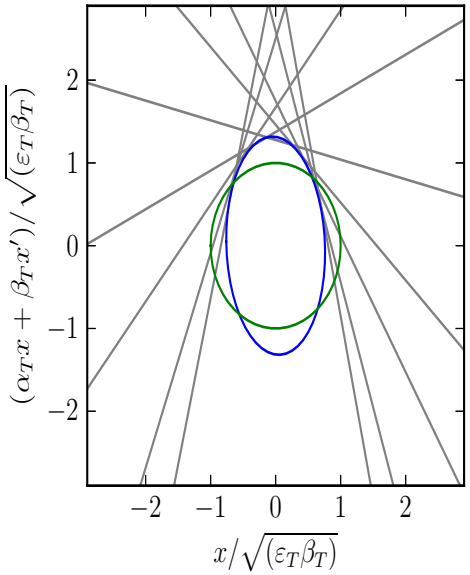
- `./runMatch.sh` $< \mathrm{START}_{\mathrm{Beamline}} >< \mathrm{END}_{\mathrm{Beamline}} >< \mathrm{Matchpoint} >$ $< \beta_x >< \alpha_x >< \beta_y >< \alpha_y >< \mathrm{Quad}_1 >, \ldots, < \mathrm{Quad}_k >$
- computes optics from currents (real machine)
- matches ($\rightarrow$ "Basic Concepts" slides)
- diagnostic output & plots & loadable sr-file :

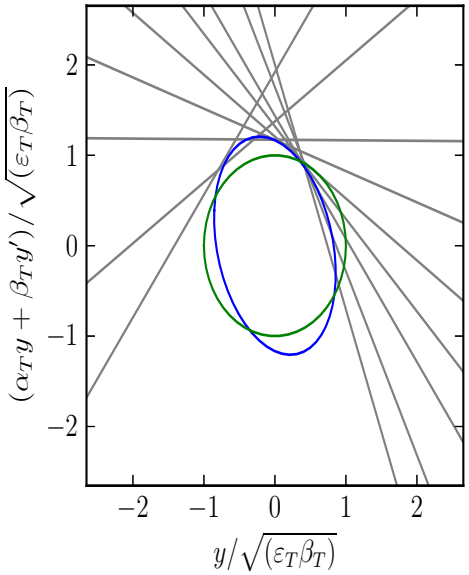
$\rightarrow$ `/home/ttflinac/save_restore/Magnets/MADmatching/match.sr`

Quadscan Evaluation

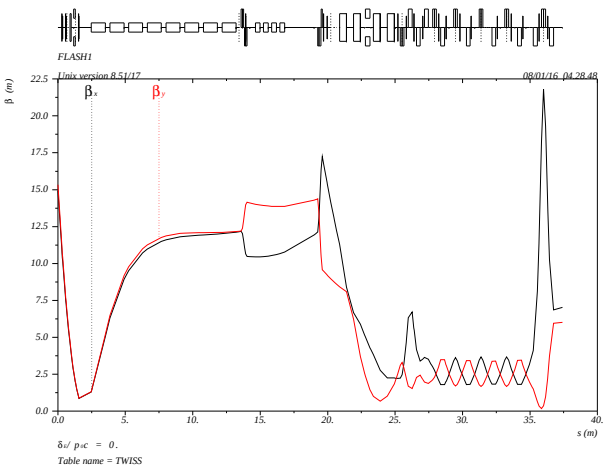
- single quad scan
- Q3FL2SED1 → OTR1FL2SEED4
- after matching FL2EXTR-FL2SEED w/ 4 screens in FL2SEED

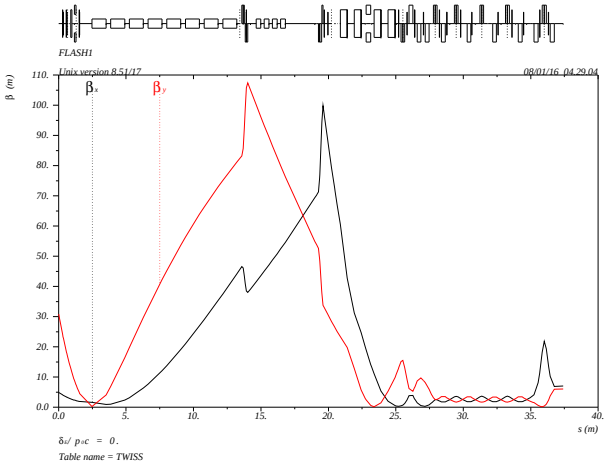
β_T = 13.87 m	β_M = 8.02 m	β_T = 6.93 m	β_M = 5.09 m
α_T = -3.09	α_M = -1.72	α_T = 2.57	α_M = 2.15
ε_T = 7.03 um	ε_M = 7.03 um	ε_T = 6.70 um	ε_M = 6.70 um
m_P = 1.16	λ_P = 1.74	m_P = 1.09	λ_P = 1.54

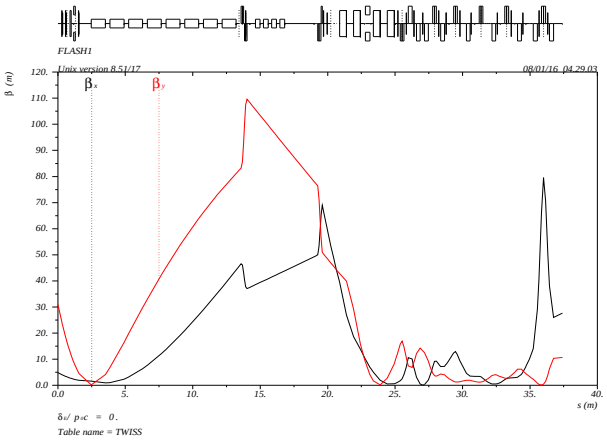




InjectorMatch (1 intermediate iteration)







- top/left: design
- bot/left: reconstructed
- top/right: re–matched
- final iteration
  → (typically after 3—6):
- reconst == rematched

ORMs

- Response of BPM i to Steerer j
  $\rightarrow dx_i/dk_j = \left(\underline{M}_{i\leftarrow j}\right)_{1,2}$
  $\rightarrow \left(\underline{O}\right)_{i,j} := dx_i/dk_j$
  $\rightarrow M$ BPMs & N steerers $\Rightarrow$
  $\underline{O} \in \mathbb{R}^{M\times N}$
- measured vs. design :

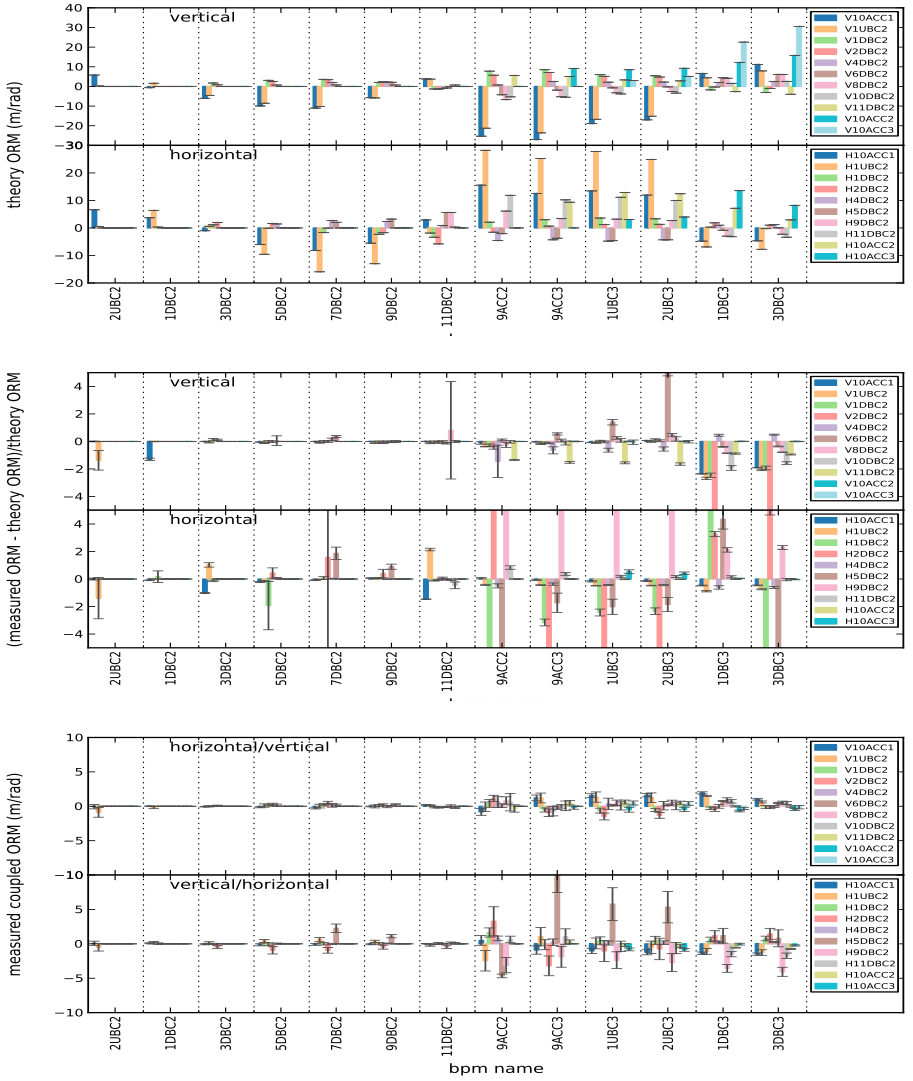
$\Rightarrow$ may identify s–**location** of optics perturbation...

... among others (BPM calib., steerer calib., etc.)

$\leftarrow$ tedious evaluation!

- Helped narrowing in on the "ACC2–Badlands"
- Nice consistency check!

ORM: ACC1...DBC3: theory/rel.diff/coupled:



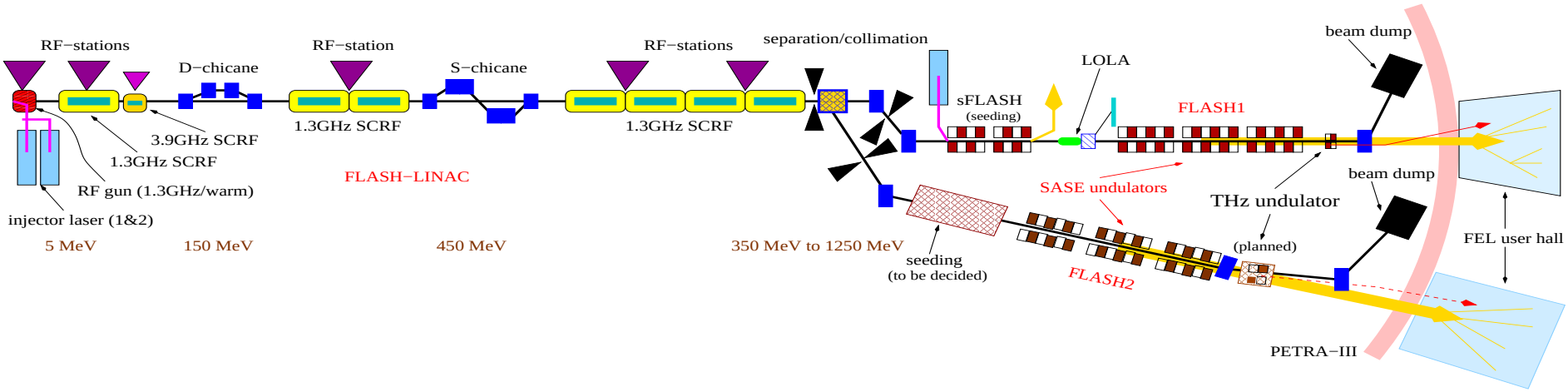
Summary (1)

- The linear optics zero–current optics in FLASH was a challenge since the beginning.
- Already one local source of opt.–perturbation identified ($\rightarrow$ "ACC2–badlands").
- More to come ??? Let's hope not !
- Additionally E–profile is common source of (hopefully moderate) perturbations.
- Besides unavoidable injector–match: rematch in later sections strongly desirable to recover optics features required for efficient FEL operation!
- Several std. techniques implemented.
- Operator friendly tools from BeamDynGroup/HiLevSooftwareGroup $\leftarrow$ are they already totally robust ?

Summary(2)

- For the unix connoisseur & BD–expert: Suite of scripts (J.Zemella)
  $\rightarrow$ in expert's hands : more robust & versatile
- Routinely achieved Injector–match
- Several control measurements in various section successfully implemented
- Rematch, e.g. UNDU & FL2SEED : some success but not yet routinely
- Difficult due to constraints and restrictions (sometimes lacking efficient d.o.f.'s)
- Work in progress!
- We're getting there...

Outlook: Orbit & (Spurious) Dispersion Correction in FLASH/1/2



- unwanted dispersion :
  2 reasons

a: dispersion not suff. contained in dispersive sections (BC's, ECOL, FL2EXTR)

b: spurious dispersion from orbit steerers

- measurement w/ either
  matlab–GUI (**M.Scholz**)

- or script:
  `/home/ttflinac/MAD/MADdispersioncorrection`
  `meas OrbDispCorr.sh` or
  `meas OrbDispCorFL2r.sh`

a: corr.: Q2ECOL, Q10FL2EXTR, Q15FL2EXTR

b: dispersion correction using the `lmad` engine under construction (**J.Zemella**)

Veelen Dank oog för't Tohörn!