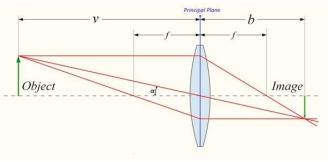


Outlook



- HEST overview.
- Outcome of Engineering Run 2018.
- HEST section in paramodi.
- What is beam optics?
- Optics tools. Where is MIRKO expert?
- Model quality.
- Trajctory response matrix.
- Optics measurements.
- Summary.









HEST overview (I)

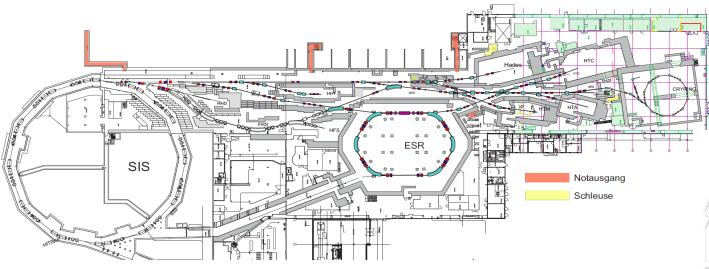


MK: M. Sapinski

STV: P. Schuett

(previous: C. Kleffner -

special thanks for help)



About 500 meters of beam transfer lines.

- Role: bring beams from SIS18 to Caves A, C, M, ESR, HADES, CryRing, HFS, HTD, HHT and beam dump (HHD).
- Also from ESR to Cave C, Cryring.
- Areas: NE3, NE5, NE8.
- Close collaboration with experiments.
- Documentation: http://sapinski.web.cern.ch/sapinski/physics/HEST/index.html

deputy for both: S. Reimann SIS Strahlführung ESR Cave A

HEST overview (II)



lots of particle types, ~20 different beam paths made of segments

→ protons ... uranium, RIPs, pions

HHD ions from SIS - beam dump

HFS RIPs from **FRS**

HHT ions from **SIS**

HTM ions from **SIS**

ESR ions/RIPs from SIS, FRS

HTA ions from SIS or ESR

HTA ions from SIS or ESR

HTB ions/RIPs from SIS, FRS or ESR

HTB $\pi^-\pi^+$ from π -target

HTC,D ions/RIPs from SIS, FRS or ESR

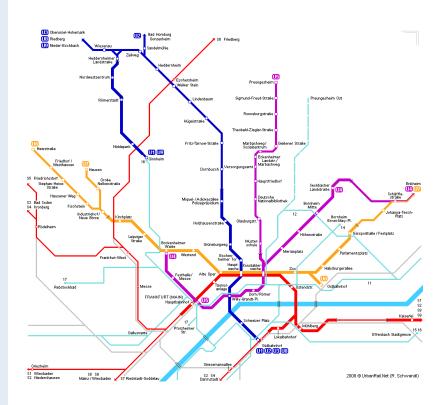
HTC,D $\pi^-\pi^+$ from π -target

HTP ions from SIS, ESR

HADES ions from SIS

HADES $\pi^-\pi^+$ from π -target

U-bahn plan by B. Schlei



HEST overview (II)



lots of particle types, ~20 different beam paths made of segments

→ protons ... uranium, RIPs, pions

HHD ions from SIS - beam dump

HFS RIPs from **FRS**

HHT ions from **SIS**

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HTA ions from SIS or ESR

HTA ions from SIS or ESR

HTB ions/RIPs from SIS, FRS or ESR

HTB $\pi^-\pi^+$ from π -target

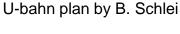
HTC,D ions/RIPs from SIS, FRS or ESR

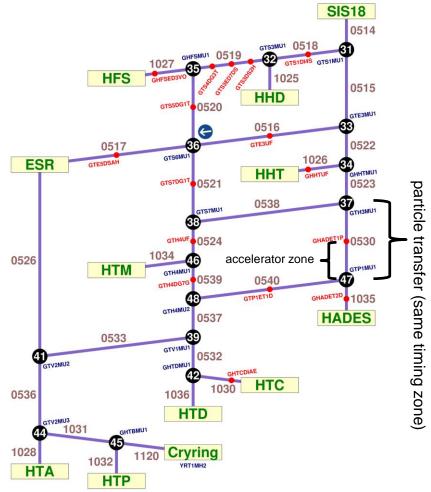
HTC,D $\pi^-\pi^+$ from π -target

HTP ions from SIS, ESR

HADES ions from SIS

HADES $\pi^-\pi^+$ from π -target



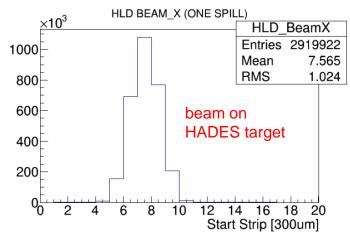


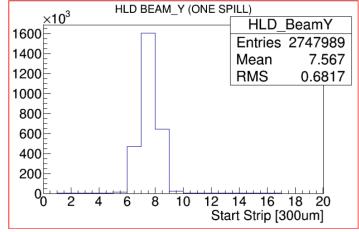
courtesy J. Pietraszko

Outcome of Engineering Run 2018



- Test of control system, operational tools, settings, etc.
- Beam lines tested: HADES, Cave C and D, Cave A and M.
- Injection to ESR.
- Lot of time spend on HADES, very nice example of collaboration when HKR was using experiment's detector to optimize the beam quality.
- Spill structure optimization study.
- The features most missing for efficient operation:
 - potiboard
 (November 21st shift: Christoph, Marcus, Henning, GHADMU1 sign)
 - online model (MIRKO expert)
- Control system hugely improved with respect to June 2018.

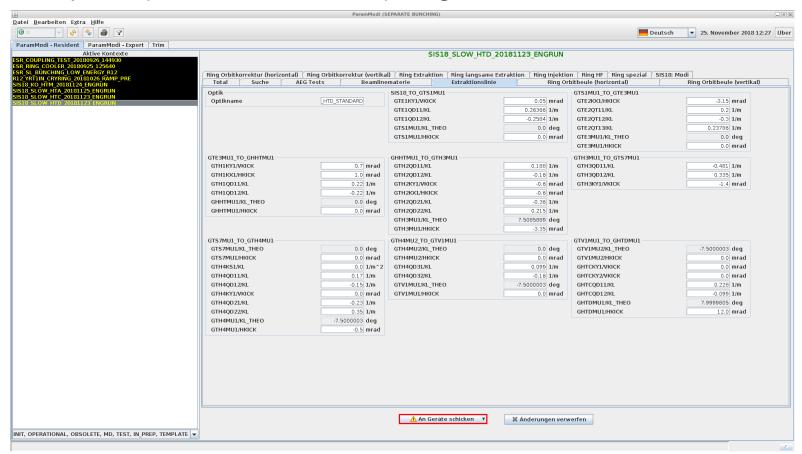




Beam line in paramodi



- Assumption: UNILAC and SIS-18 are setup correctly.
- Extraction line settings: kL-values for quadrupoles, deflection angle for dipoles (correction to default), angle for steerers.



Setting the beam line optics



- k-value and magnet focal length: $f = \frac{1}{kL}$ [m] (independent on beam energy).
- k-value and field gradient: $k = \frac{g}{n/a}$, where
 - g quadrupole gradient (T/m),
 - p/q beam rigidity (Tm); unit of k is $1/m^2$.
- initial k-values are determined using optics programs (MADX or MIRKO):
 - input: sequence of magnets (positions), beam parameters at extraction from SIS18
 - constraints:
 - maximum strength of the magnets,
 - beam parameters at synchrotron extraction,
 - beam parameters on target (eg. spot size, ...),
 - beam size along the beam line (minimization of beam losses),
 - other constrains, eg. phase advance, dispersionless regions, etc, etc...
 - method: various optimization algorithms are available; optimization is multi-objective
 - output: a set of k-values (called optics); usually there are many solutions for optics, the final choice is a compromise between various objectives.
 - the *optics* is sensitive to small drifts in magnet positions, k-values errors (due to magnetic hysteresis), etc, etc. It is also sensitive to beam changes at SIS18 extraction. 'Nachoptimirung' is almost always needed!

Distribution of β (optical function) along the beam line is most often used to illustrate optics.

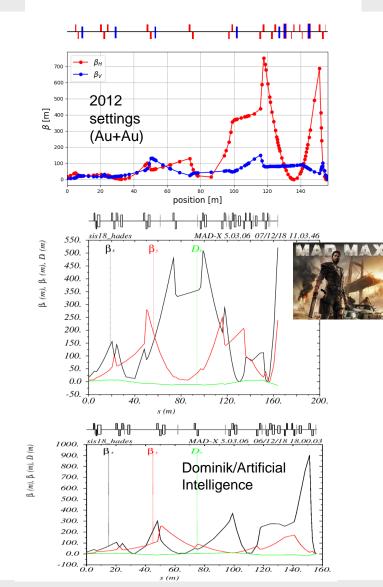
Example: HADES

FAIR ESSI

- <u>June</u>: MIRKO optics from svn archive found not good, suggested to use settings from 2012.
 - rather large horizontal beam size
 - step focusing good but beam is divergent after target
- October: new solution proposed, with more 'telescopic' focus on target.
- Other solutions proposed by
 S. Ratschow, S. Appel, D. Vilsmeier, some tested ok.

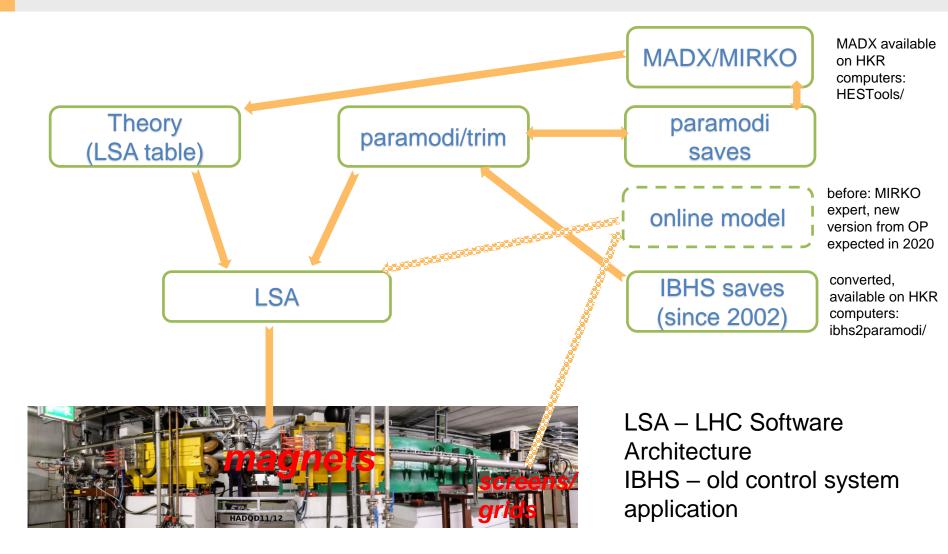
Remark: theory optics always needs tuning, but mainly with correctors (orbit to magnetic centers of quadrupoles), not too much with quadrupoles.

For example, in case of Max's optics, a few minutes of tuning gave good focus.



Where does the optics come from?





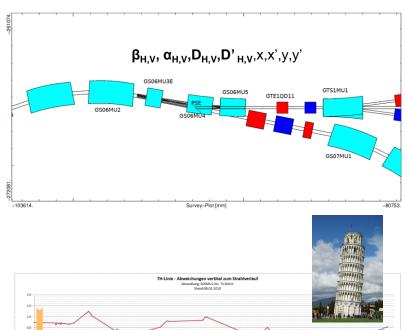
FAIR GmbH | GSI GmbH M.Sapinski@gsi.de

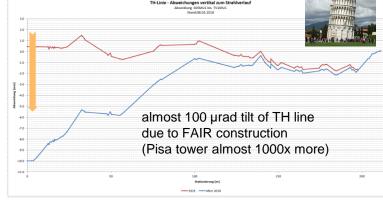
Quality of the optics models



Two groups of uncertainties:

- SIS18 extraction parameters
 - a set of parameters, established by Benno, not changed since years, the same for fast and slow extraction, probably measured, but this measurement is not documented.
- Positions of magnets, alignment, field gradient errors, fringe fields.
 - Benno:MIRKO settings very good, verified and tuned over years.
 - Translation to MADX is quite tricky, probably some errors introduced during this translation.





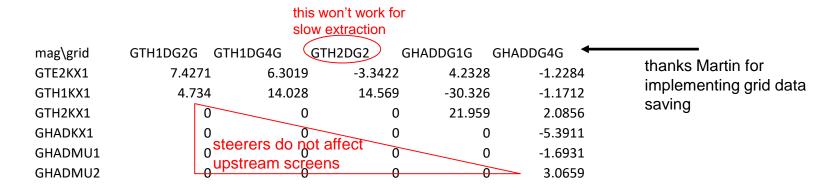
Model verification – response matrix



Trajectory response matrix (TRM)



MADX simulation, horizontal plane only: (horizontal and vertical planes can be coupled!)

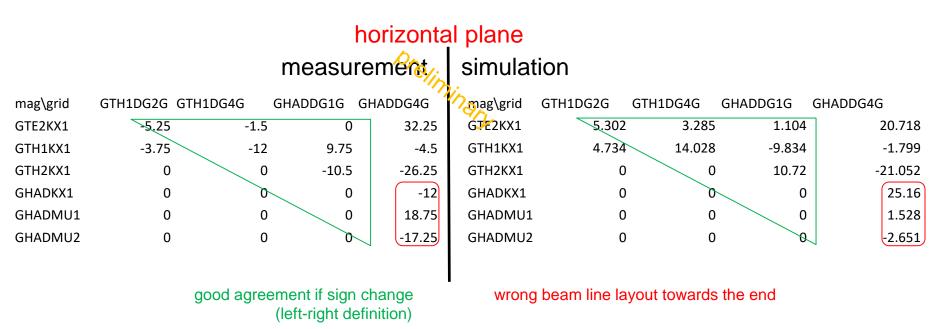


 Comparison of simulated and measured TRM allows to measure model errors of beam line elements, without extraction parameters!

Response matrix measurement (I)



 measurement on November 27, using Oksana's COCO* application (but paramodi can also do the job)



(*) COCO is an application to perform various orbit corrections (local, global) based on TRM measurement. For the moment it is an expert tool.

Response matrix measurement (II)



vertical plane

measurement.

simulation

mag\grid	id GTH1DG2G GTH1DG4G GHADDG1G GHADDG4G						
GTE1KY1	21.7	'5 36.7	75 -27.75	-1.5			
GTH1KY1	4.	.5 12.7	75 -4.5	-0.75			
GHADKY1		0	0 (0			
GHADKY2		0	0 (0			
GHADKY3		0	0 (0.75			
GHADKY4		0	0 (0.75			

mag\grid GTH1DG2G GTH1DG4G GHADDG1G GHADDG4G

iliag (gi lu	UII	ب تحصیر	HILLDO 4 0 Q	LINDOGIO GI	IADDU40
GTE1KY1		25.355	35.485	-73.513	-75.37
GTH1KY1		5.234	14.528	-10.562	-6.177
GHADKY1		0	0	0	-22.572
GHADKY2		0	0	0	42.89
GHADKY3		0	0	0	12.88
GHADKY4		0	0	0	1.38

good agreement

factor 2?

wrong beam line layout towards the end: recheck during shutdown!

Optics measurement



- other methods to measure the twiss parameters (what includes assumption about SIS-18 twiss parameters at extraction point):
 - dispersion measurement
 - multiple screen method
 - quadrupole scan
 - beam tomography
 - ...
- we have relatively good agreement between measured and simulated TRM at the beginning of the beam line, so we could in principle extrapolate twiss parameters to SIS-18 extraction point.

Dispersion measurement (I)

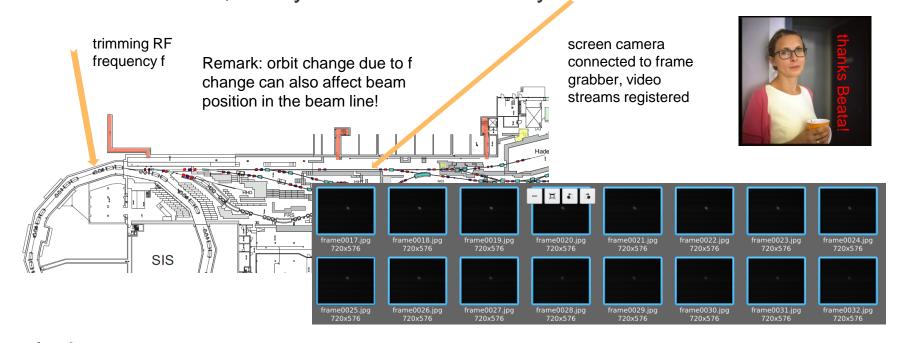


- Dispersion measures transverse change of beam position with relative momentum change: $D = \frac{\Delta x}{dp/p}$ [m].
- Dispersion is generated by dipoles, so it is small in vertical plane.
- Dispersion-free regions can be required by experiments (dispersion contributes to the beam size) or to simplify measurement of beam properties (see quadrupole scan).
- Measurement od December 14th

Dispersion measurement (II)



 Initially planned to measure dispersion at all screens and grids on HADES beam line, but measurement lead to high beam losses and radiation alarms, finally data was taken only for screen GTH2DFA.



Analysis: video file (mpeg) split into frames. For a subseries of frames (manually selected, spill length depends on frequency trim) with reasonable signal horizontal profiles created and added. Gaussian fit performed, mean value determined.

Dispersion measurement (III)



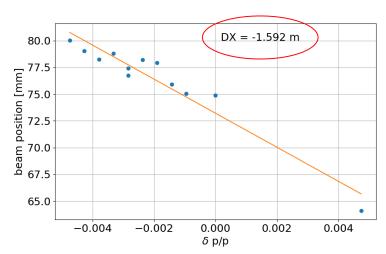
- The beam moves horizontally during the spill, we find the average position for various Δf/f
- $\frac{\Delta p}{p} = -\frac{1}{\eta} \frac{\Delta f}{f}$ where η is slip factor:

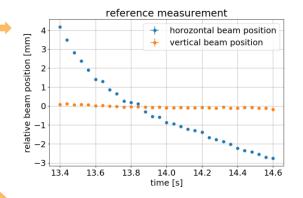
$$\eta = \frac{1}{\gamma_{tr}^2} - \frac{1}{\gamma^2}, \qquad \gamma_{tr}^1 = 5.58$$

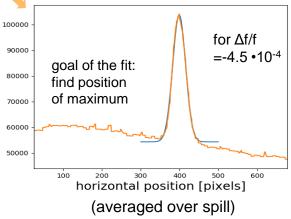
 result: 1.6 m, but MADX model gives 10 m and MIRKO 4 m (Petra).



"to be investigated"







Quadrupole scan - theory



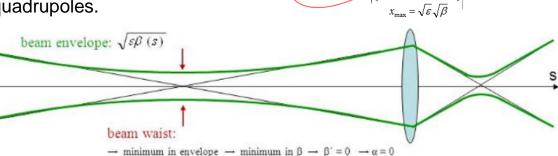
the same

Giuliano's lecture

ellipse as in

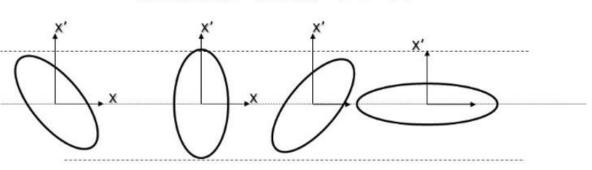
 Beam ellipse = region in phase space containing the beam particles (not always ellipse).

- Ellipse parameters are related to twiss parameters.
- It is easy to measure beam size, but rather difficult to measure distribution of angle of beam particles.
- Ellipse rotates in phase space as beam propagates.
- Rotation is affected by upstream quadrupoles.
- Changing the quad strength and measuring the beam size we obtain various projection of the beam phase space ellipse.
- From those projection we can reconstruct emittance and twiss parameters in the location of quadrupole.



Area = πε

 $x'_{\text{max}} = \sqrt{\varepsilon} \sqrt{\gamma}$



Example of quadrupole scan



- Preliminary results for HADES beam line optics used for physics test.
- Location of the measurement is not dispersion free.
- However dp/p for quadrupolar slow extraction is very small, so dispersion effect should be small.
- Beam size varies during spill by ~10%
- MADX model gives:

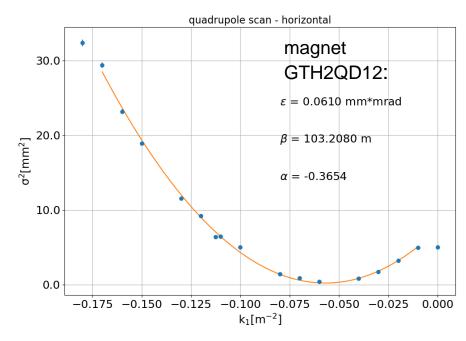
•
$$\beta_x = 136.5 \text{ m}$$

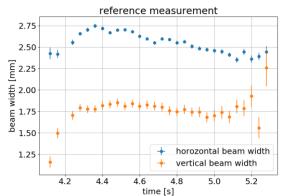
• $\alpha_x = 14.15$



 Emittance, typical value rumor. 0.25 mm*mrad (factor 4 larger)







Summary



- Goals of the Engineering Run achieved, HEST is under control.
- Lot of interesting measurements done (many not discussed here, z.B.: beam loss monitors, particle counters, knob tests, etc, etc.)
- Still a lot of work for modelling! Models contain errors.
- We need online model application and it will be written.
- Acknowledgements: C. Kleffner (previous MK), B. Schlei (LSA hierarchy for HEST), O. Geithner (TRM), S. Ratschow (support in optics), B. Walasek-Hoechne, Ch. Schmidt (Leuchtargets), P. Boutchakov (BLMs, PDCs), M. Stein (grids software), J. Pietraszko (HADES), Ch. Hessler and others.
- And last but not least thank YOU: THE OPERATRION CREW







