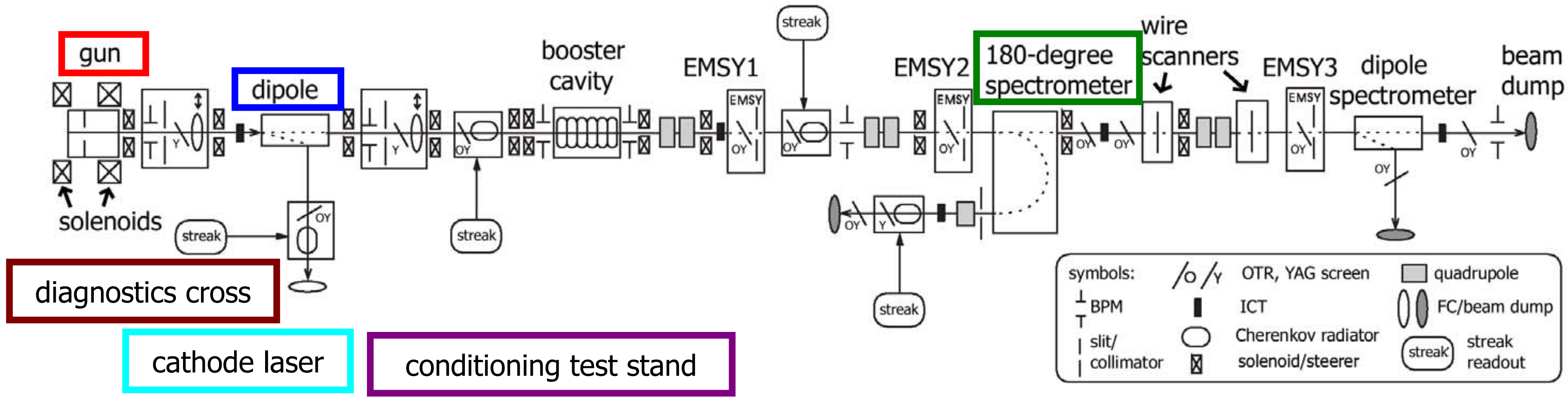
Status of the upgraded PITZ facility



Chase Boulware, DESY, Zeuthen, Germany,
for the PITZ collaboration

Prologue: Emittance and emittance compensation

Why is transverse emittance important for the operation of a free-electron laser like FLASH?

How does focusing with a solenoid reduce the emittance?

What is the role of the booster cavity in preserving this emittance?

For an FEL to operate, the electron beam must be focused into the optical mode that grows along the undulator.

Undulator, from the FLASH website

The undulator is **long**, and the gap is **thin**.

In fact, the optical mode is **thinner**, set by the output FEL wavelength.

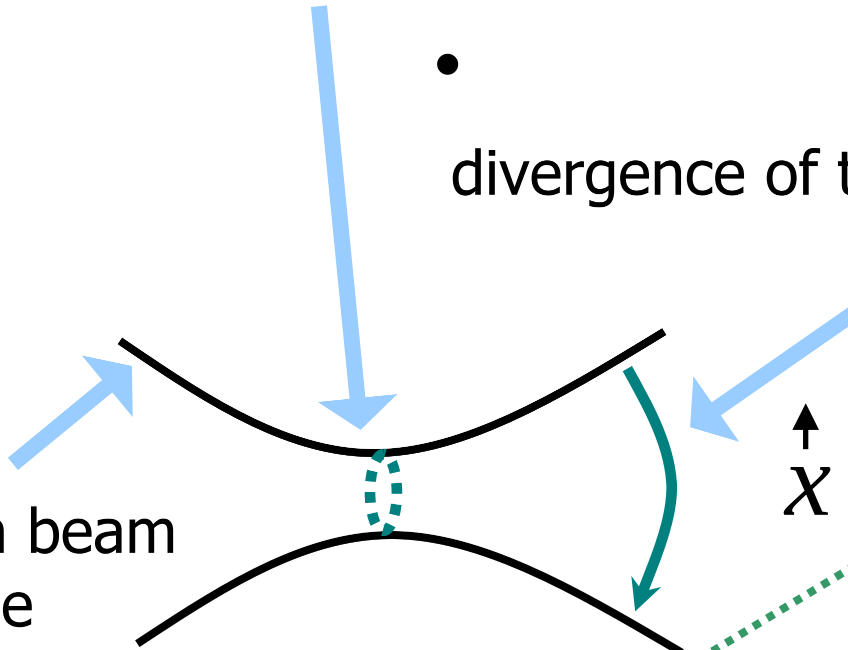
The electron beam needs to stay within the optical one over the undulator length.

The emittance is the product of the electron beam focus at its beam waist and its divergence.

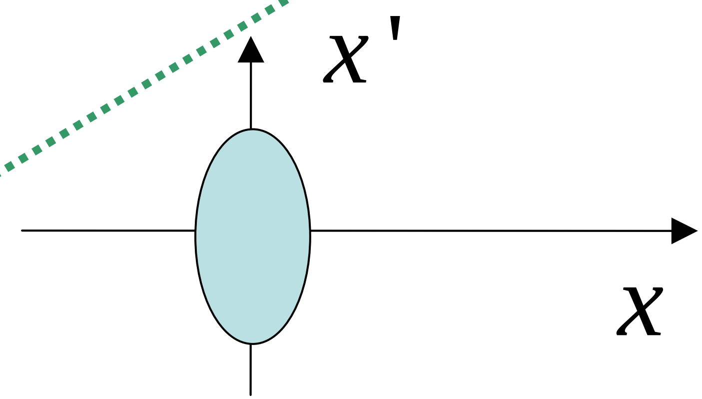
emittance = beam width at focus

- divergence of the beam

x is perpendicular to the beam axis.

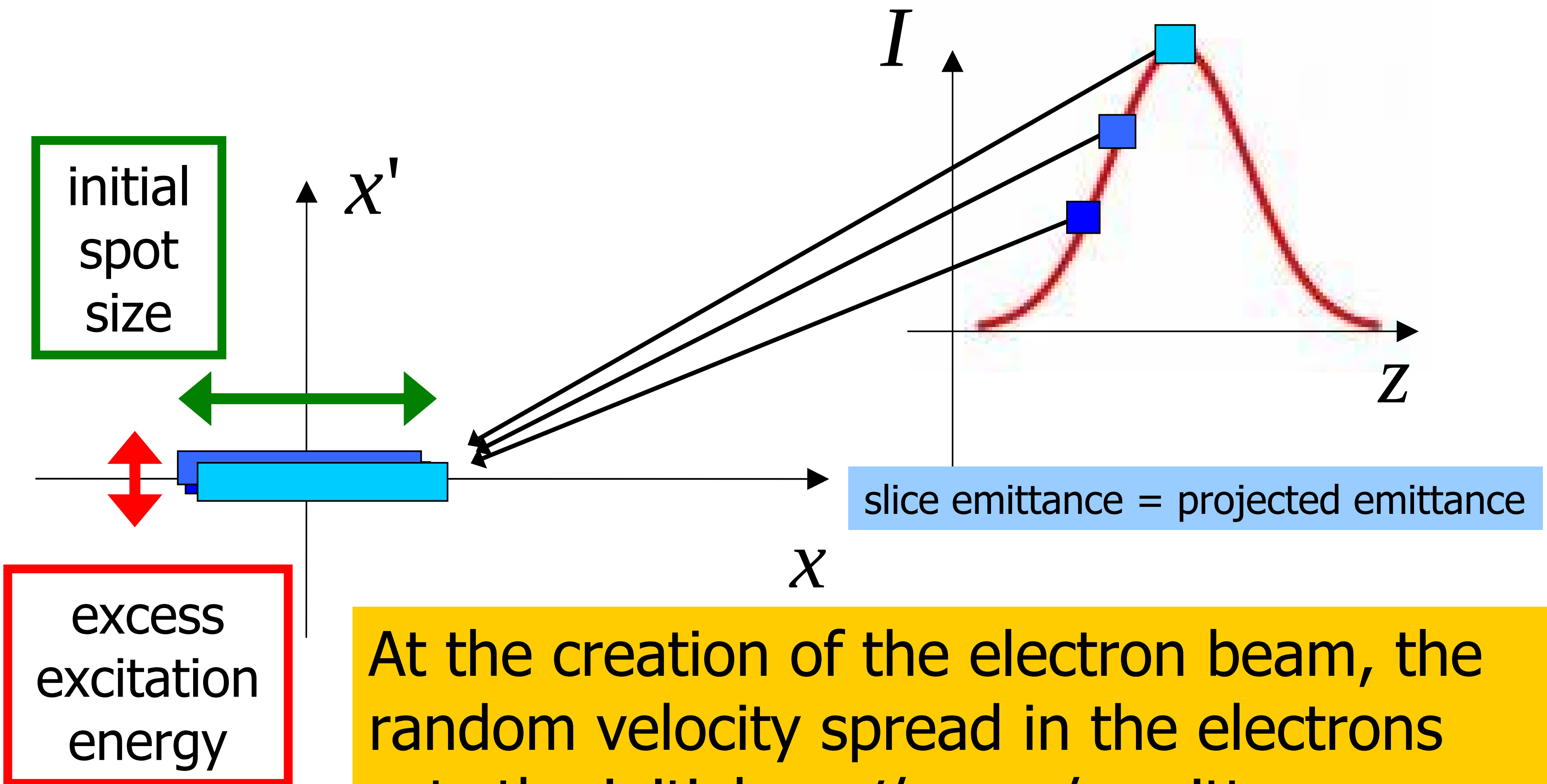


electron beam envelope



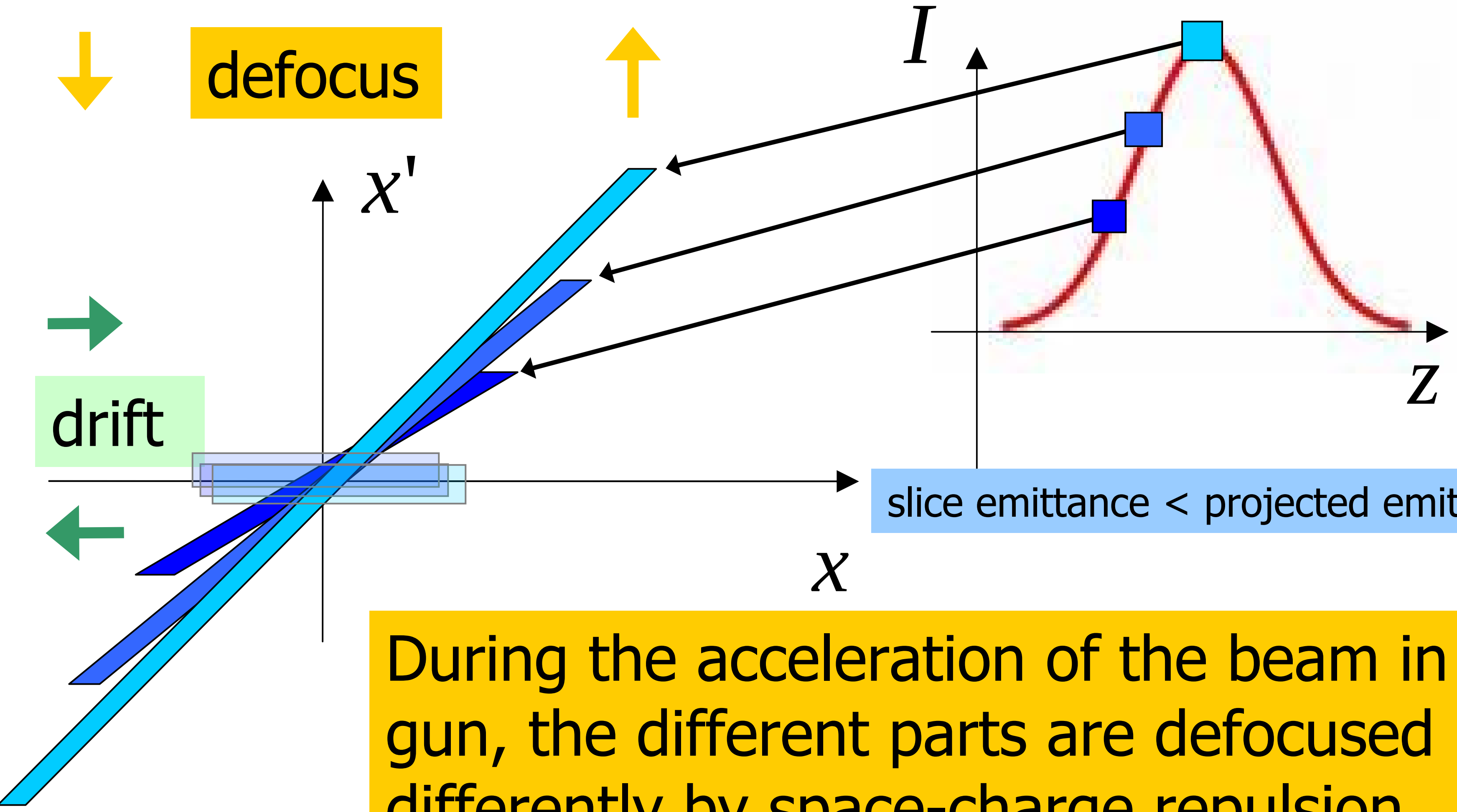
The emittance is also the area of the beam in trace space.

How does focusing with a solenoid reduce the emittance?



At the creation of the electron beam, the random velocity spread in the electrons sets the initial, or *thermal*, emittance.

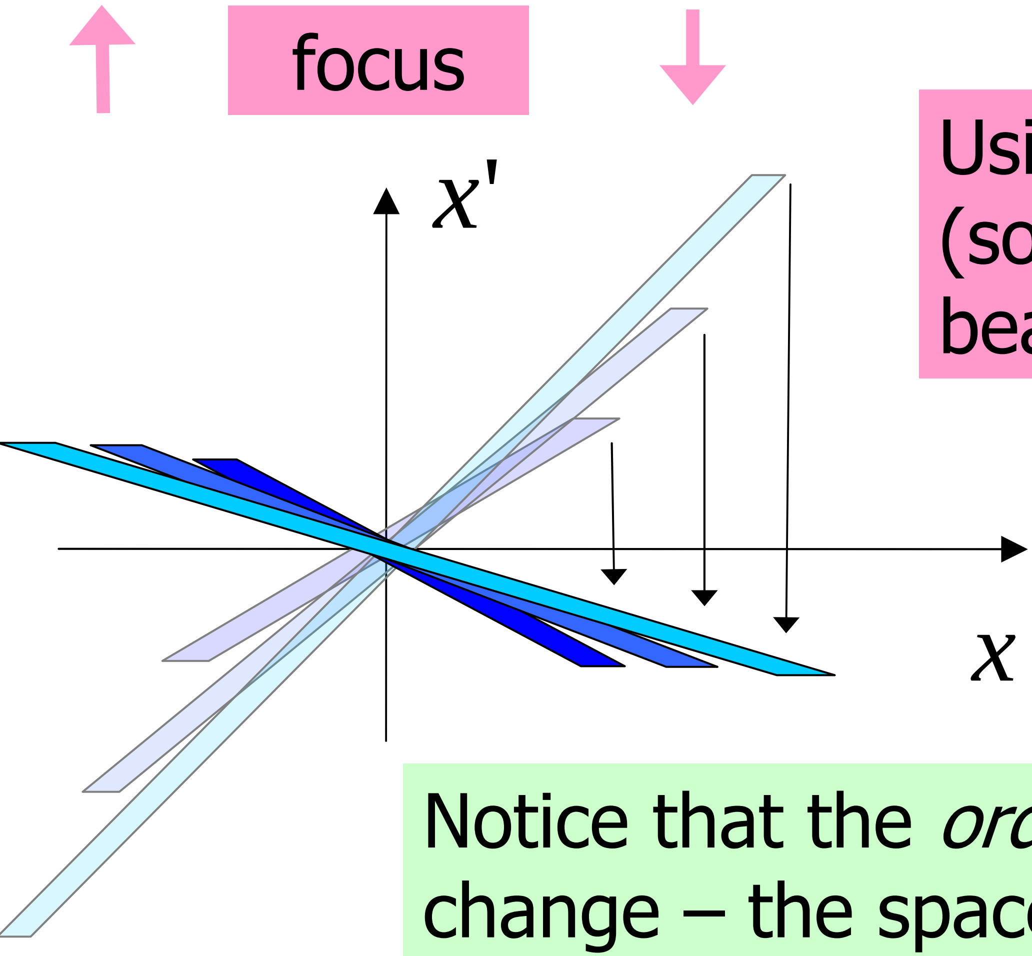
How does focusing with a solenoid reduce the emittance?



slice emittance < projected emittance

During the acceleration of the beam in the gun, the different parts are defocused differently by space-charge repulsion.

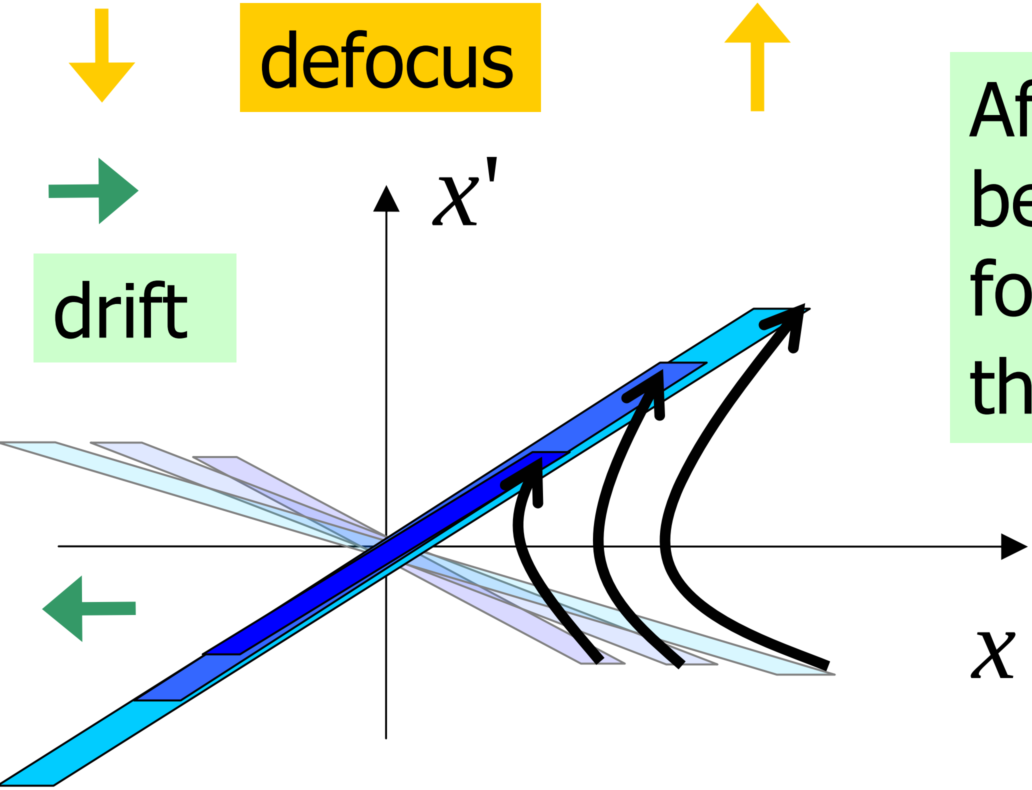
How does focusing with a solenoid reduce the emittance?



Using a linear lens (solenoid), the electron beam is focused.

Notice that the *order* of the slices, doesn't change – the space-charge effect can not be fixed with just a linear lens.

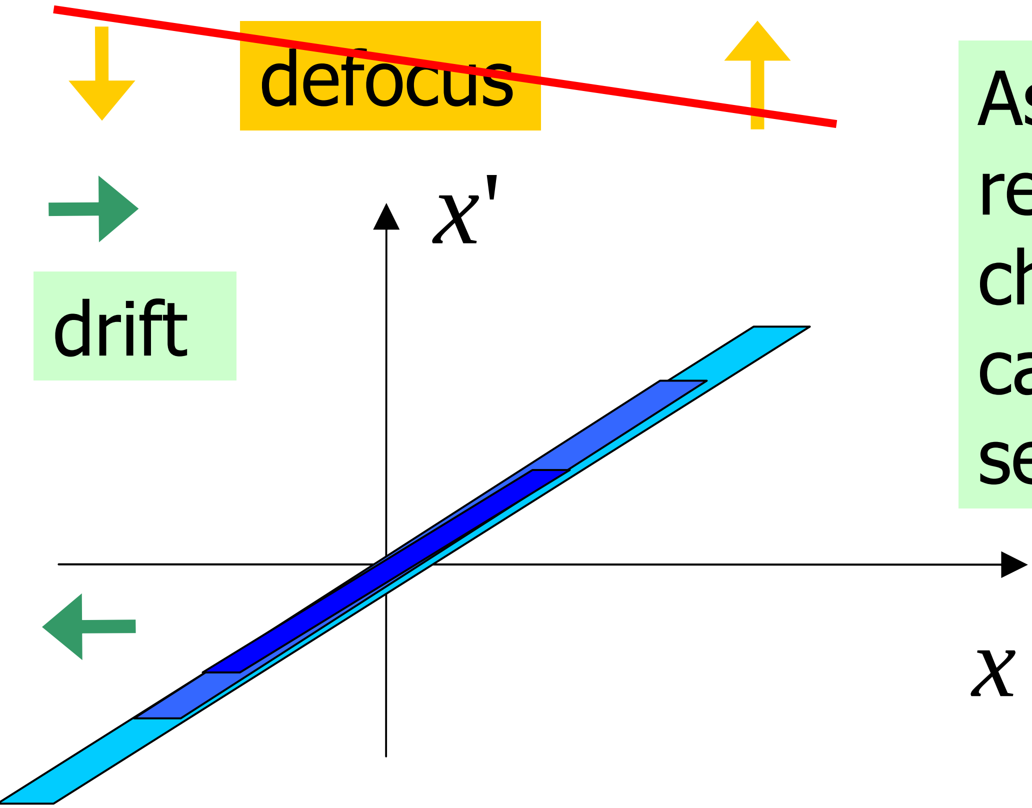
How does focusing with a solenoid reduce the emittance?



After the solenoid, the beam comes to a laminar focus (no particles cross the $x = 0$ axis).

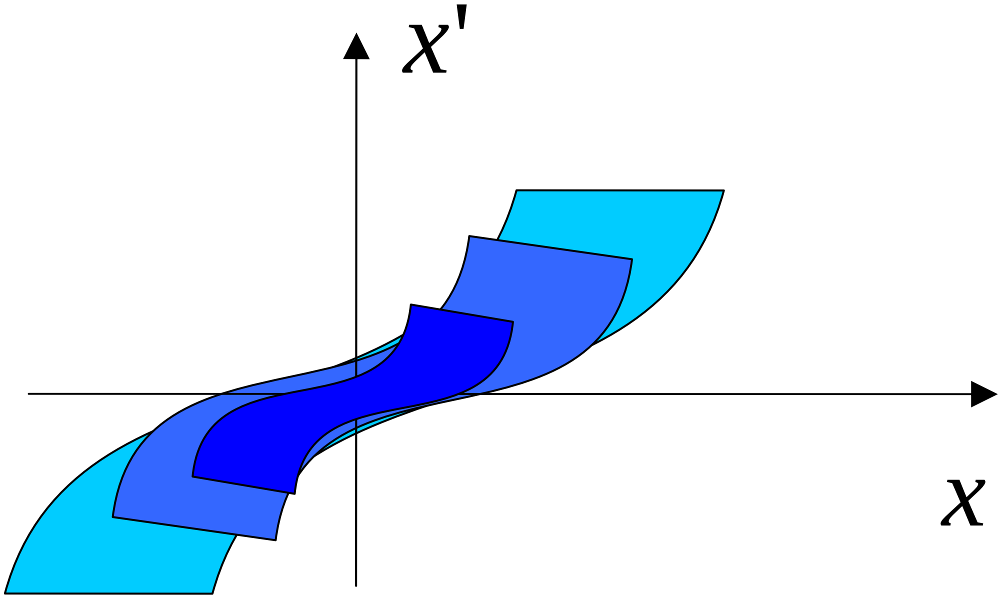
The key of the compensation is that the low-current slices come to a tighter waist, so space-charge defocus becomes **stronger**.

How does accelerating with the booster cavity preserve the emittance compensation?



As the beam becomes relativistic, the space-charge defocus is cancelled by the beam's self magnetic field.

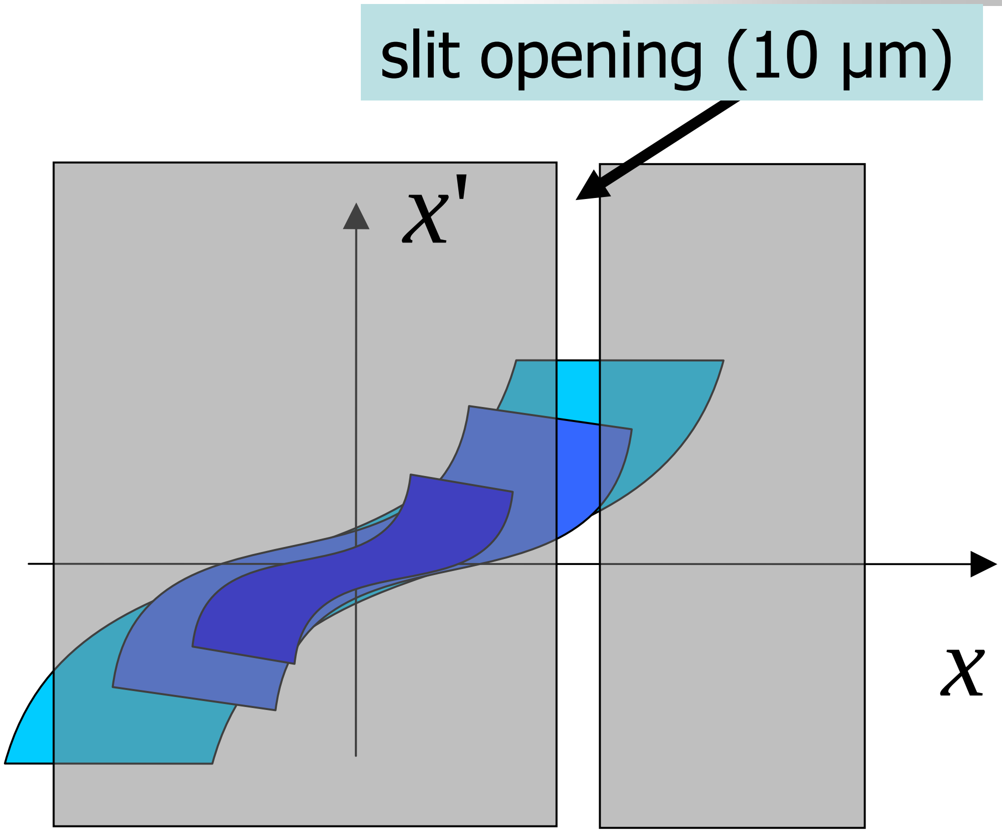
The further beam acceleration should be optimized to freeze in the compensated emittance.



Thermal emittance (the initial width of the slices in the x' plane) cannot be reduced by the solenoid compensation method.

Also not corrected is any slice distortion by nonlinear forces, including space-charge due to a nonuniform distribution of the beam.

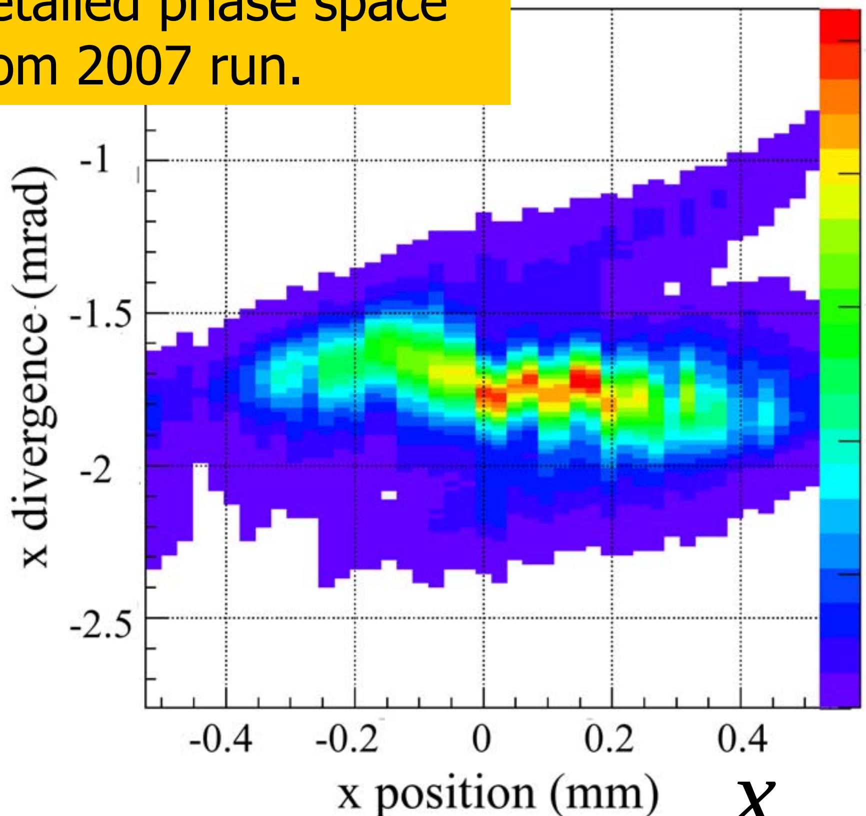
Emittance measurement with a single slit



The phase space can be measured by scanning a slit across the beam in the x direction and observing the spread of the "beamlet" on a downstream screen.

This is not the only way to measure the emittance, but it works in this energy range (~15 MeV) and directly maps the phase space.

Detailed phase space from 2007 run.



x'

x

We observe the S-shaped phase space predicted by simulations for the projected emittance from a photoinjector.

We don't yet have the advantage to observe the slices – to see the shape of the head and tail of the bunch vs. the central parts.

The results obtained at PITZ so far show promise for achieving the XFEL design parameters (a main goal of the facility).

	FLASH	XFEL
normalized rms transverse emittance	2 mm mrad	0.9 mm mrad (injector) 1.4 mm mrad (undulator)
bunch charge	1 nC	

Both creating and *measuring* emittance at this level is a real challenge.

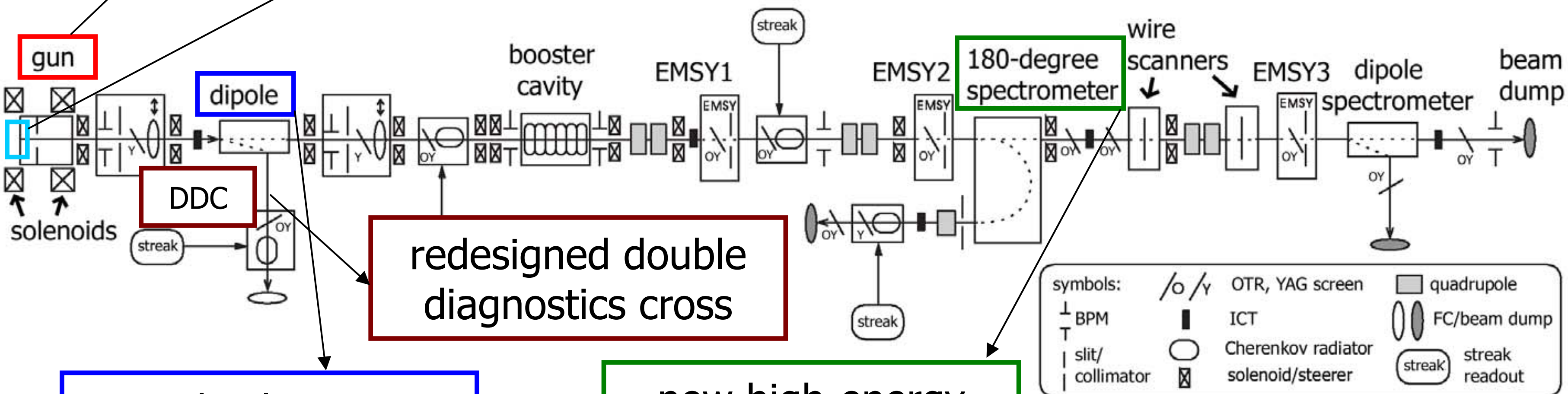
The best measured rms transverse emittance for 1 nC so far at PITZ: 1.26 ± 0.13 mm mrad (100% of detected charge, geometric average of the transverse planes ± measurement standard deviation).

Overview of upgrades to the PITZ facility

new 1-1/2 cell L-band gun

new photocathode drive laser

Virtually every component of the beamline has been relocated in the last 8 months.



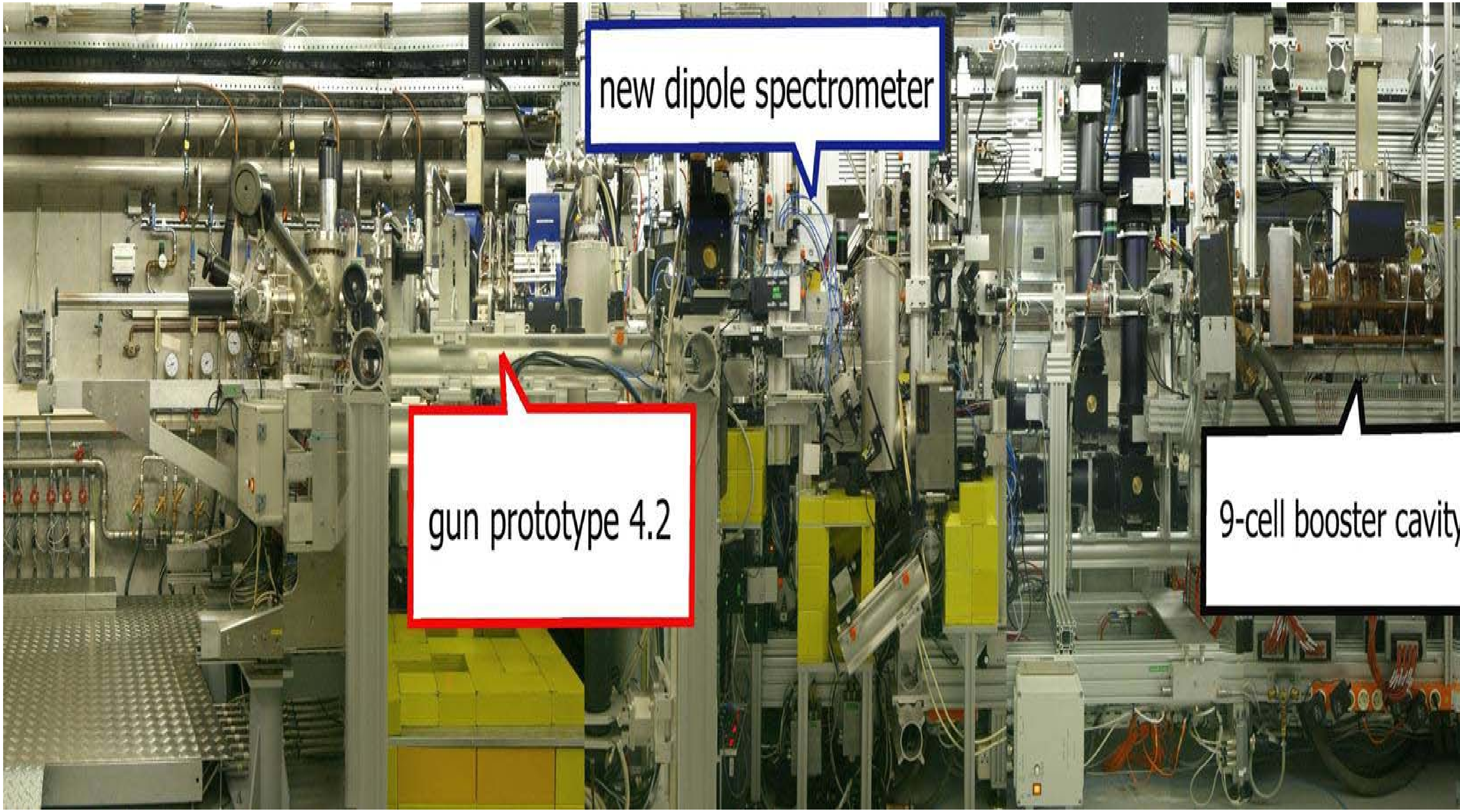
redesigned double diagnostics cross

new dipole magnet in low-energy dispersive section

new high-energy spectrometer based on 180-degree dipole magnet

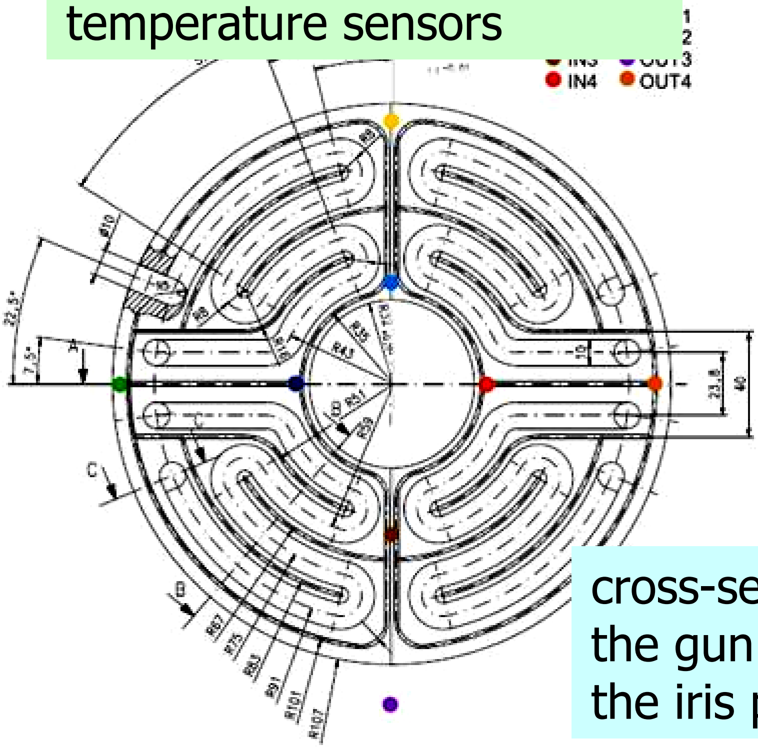
conditioning test stand (separate from main linac)

Panorama of the PITZ tunnel

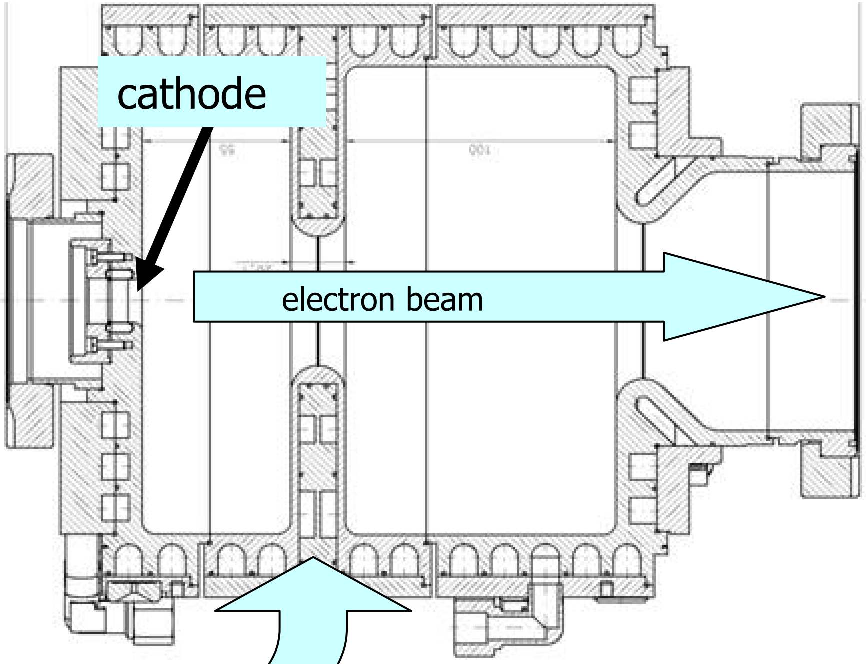


The new gun prototype has a more sophisticated water cooling design than previous guns.

greater surface area for water channels and more temperature sensors

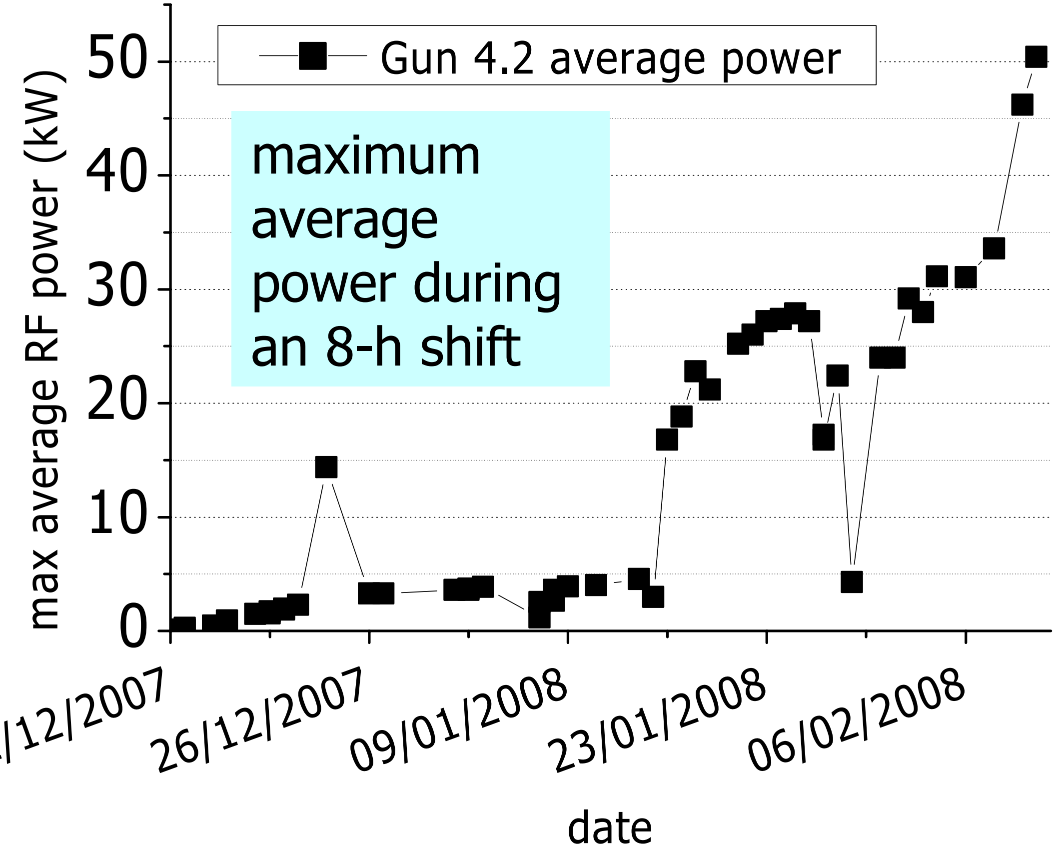


cross-section of the gun cavity at the iris plane



Water flow rates in the 14 input channels of the new gun are independently measured and adjusted.

The new gun cavity has been conditioned up to 50 kW average RF power.



Operation here only with careful tuning

- 7.2 MW peak RF power in the gun

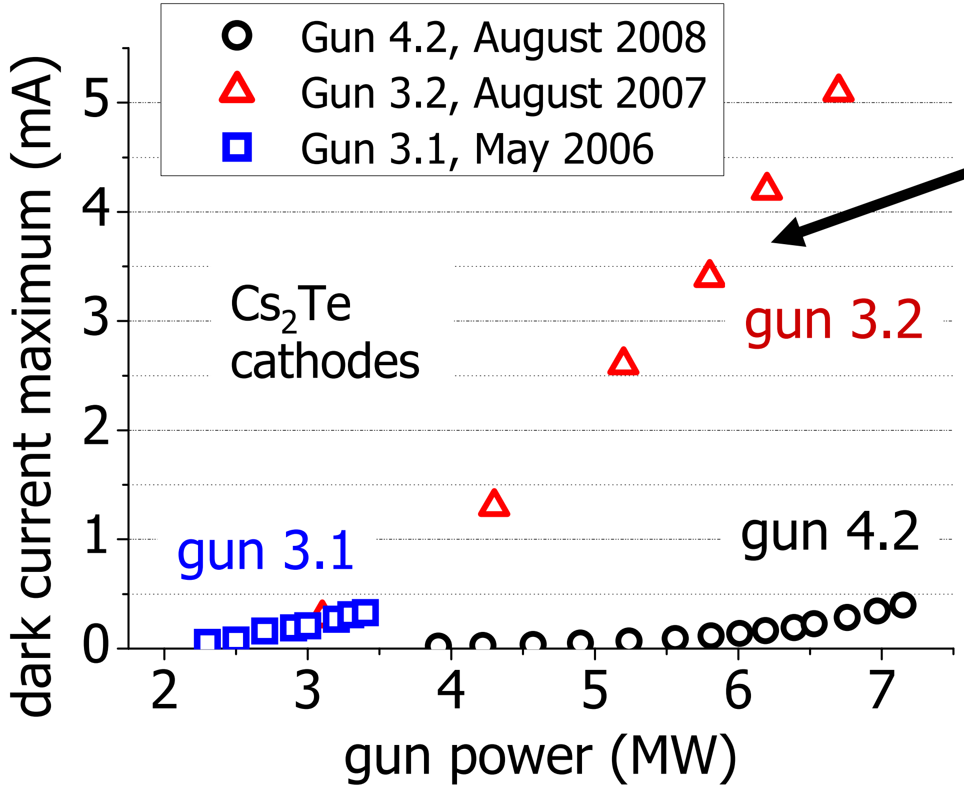
- 700 µs flat-top pulse length

- 10 Hz repetition rate

XFEL RF duty cycle

This conditioning was performed at a dedicated conditioning test stand.

The new cavity, prepared with a dry-ice cleaning procedure, shows markedly reduced dark current and reflected RF power.

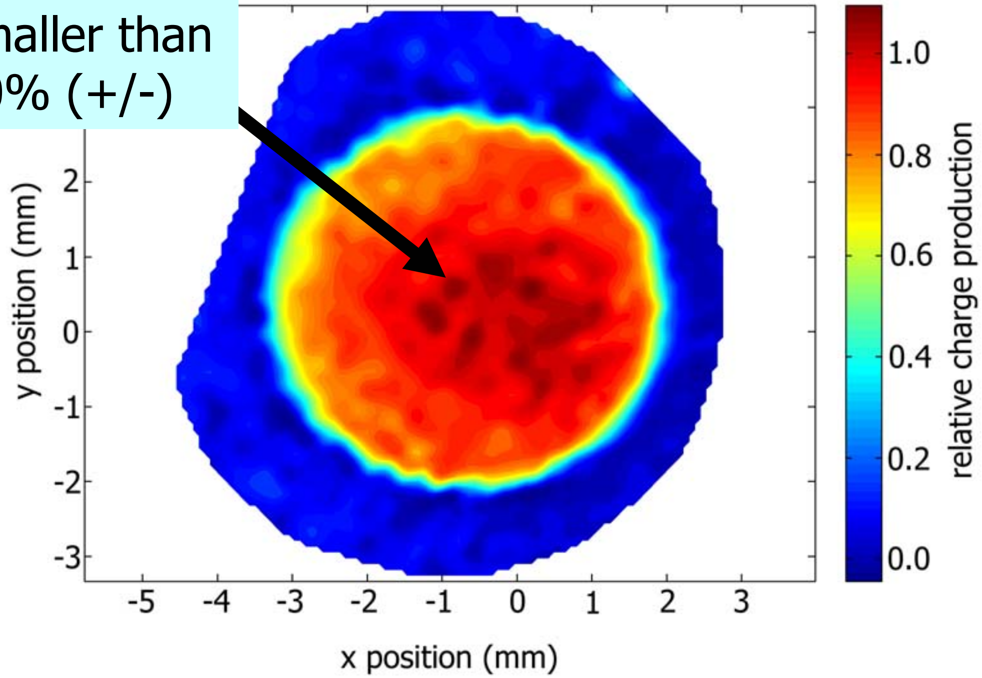


Dark current in the mA range has an adverse effect on cathode lifetime, and creates high radiation levels in the accelerator tunnel.

Reflected RF power from gun cavity 4.2 is also reduced by about an order of magnitude, down to ~0.3% of the input power.

Cathode uniformity is routinely monitored with quantum efficiency (QE) maps.

modulations smaller than 10% (+/-)



Raster scan with a small UV spot (diameter ~ 200 µm)

The largest spot size used for beam operation has a diameter of 3.0 mm.

Cs_2Te cathode lifetimes*

2007 run:

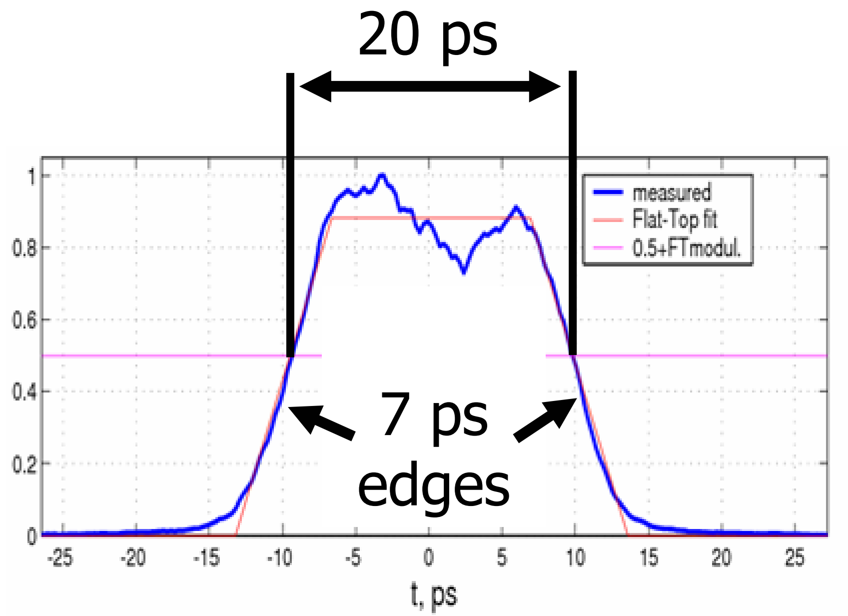
~100 hours at high peak field

Present run:

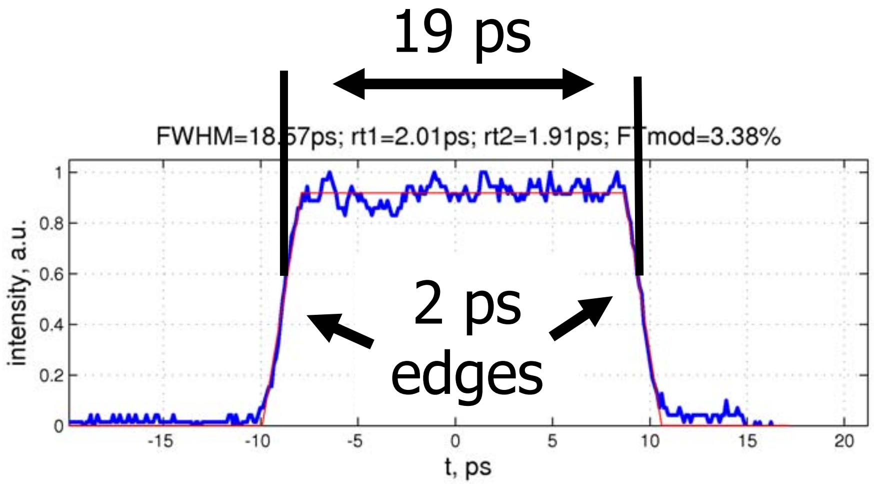
>**250 hours** and still running with QE = 5 – 10% at high field

*requirement to reach 1 nC is around 0.5% QE

The new photocathode laser produces flat-top pulses with much shorter rise and fall times.



Old laser profile (streak camera measurement)

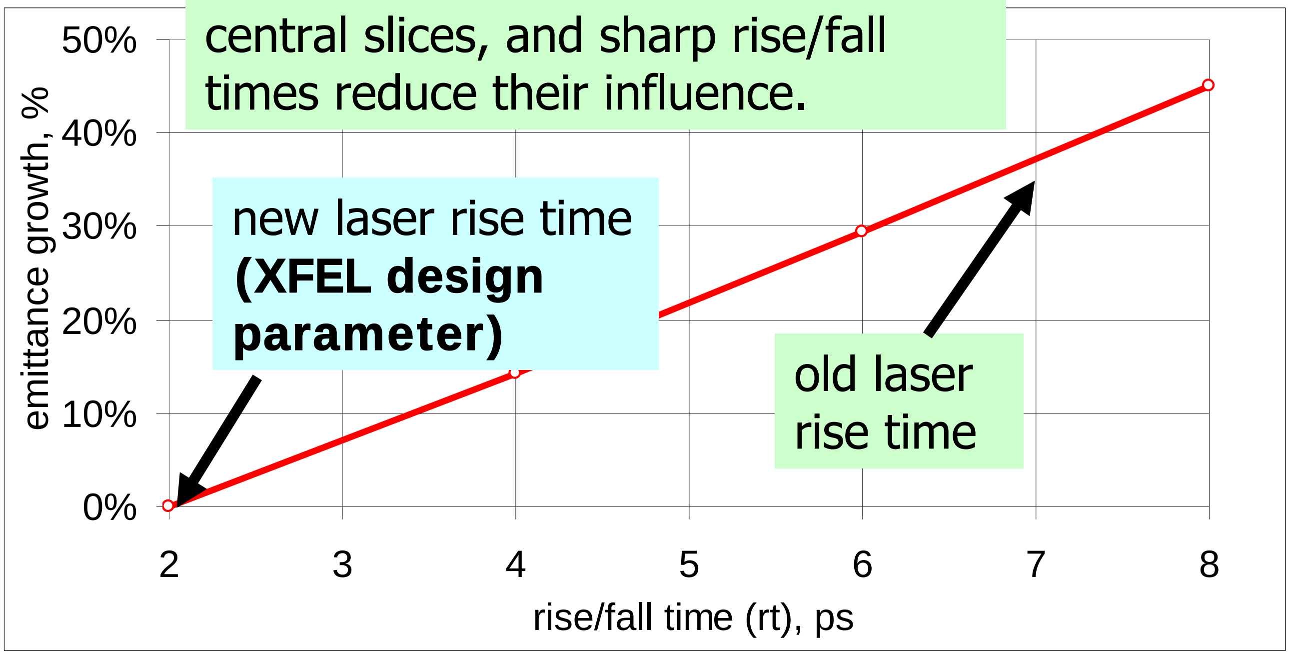


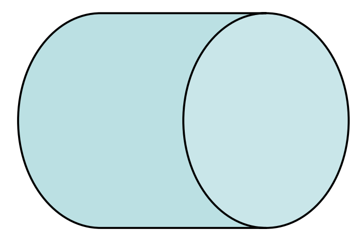
Temporal profile of the **new** laser system, measured by the optical sampling system developed at MBI

The resulting electron bunch will not exactly reproduce this shape.

Simulation results predict that the shorter rise and fall times of the laser bring a reduction of 20% in the rms projected emittance.

The head and tail of the bunch have around twice the emittance of the central slices, and sharp rise/fall times reduce their influence.



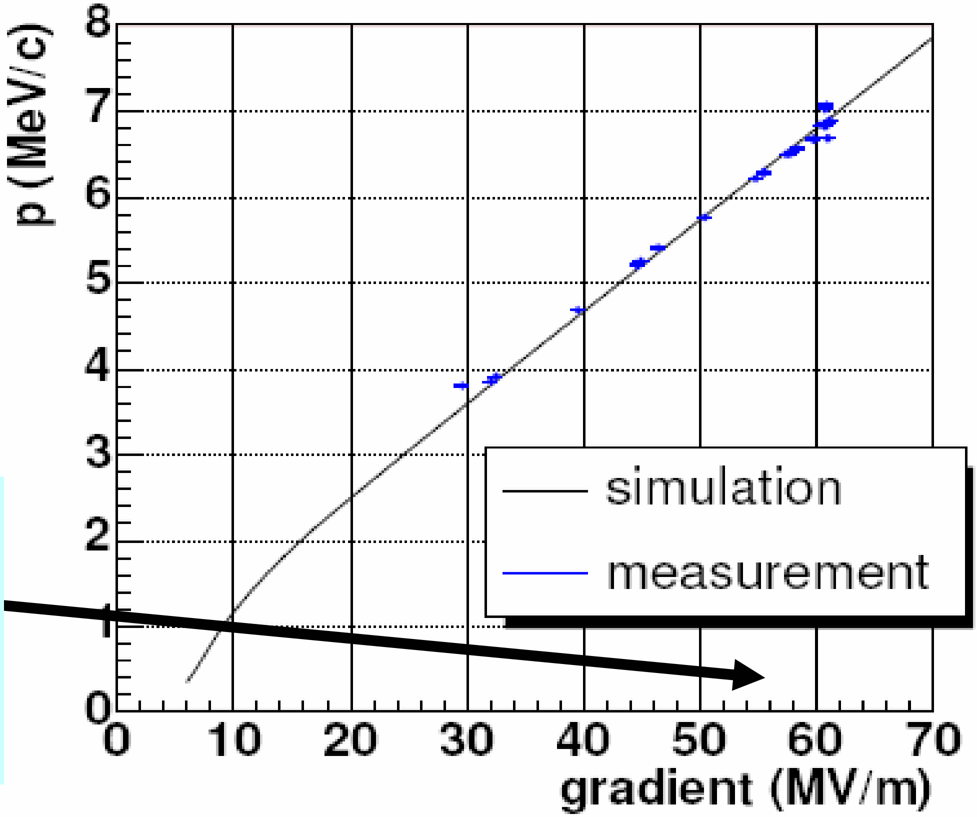


Pancake → beer can?

Measurements of beam momentum before the booster (1.1 m downstream the gun) have been performed with the redesigned dipole magnet.

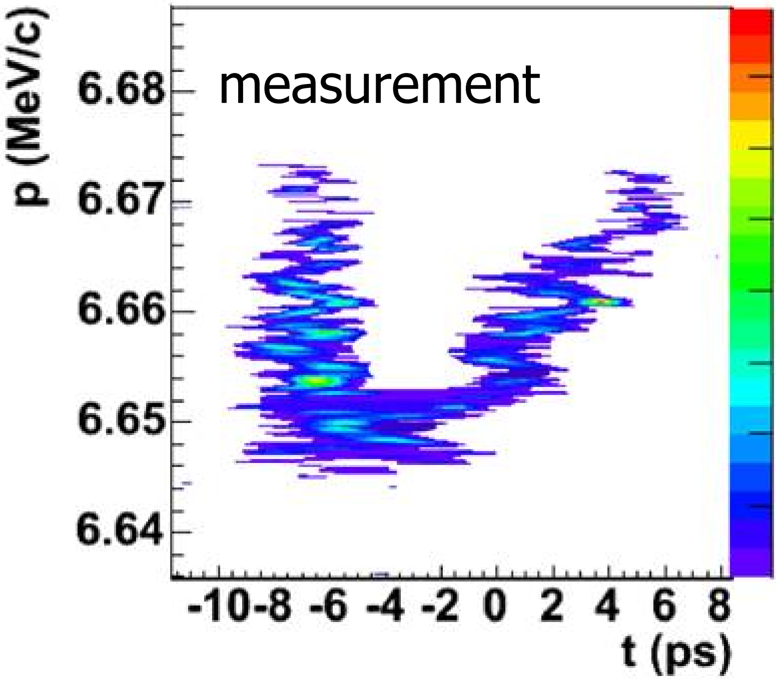
increased inner chamber width (27 mm) for transmission over a broader range of focusing conditions

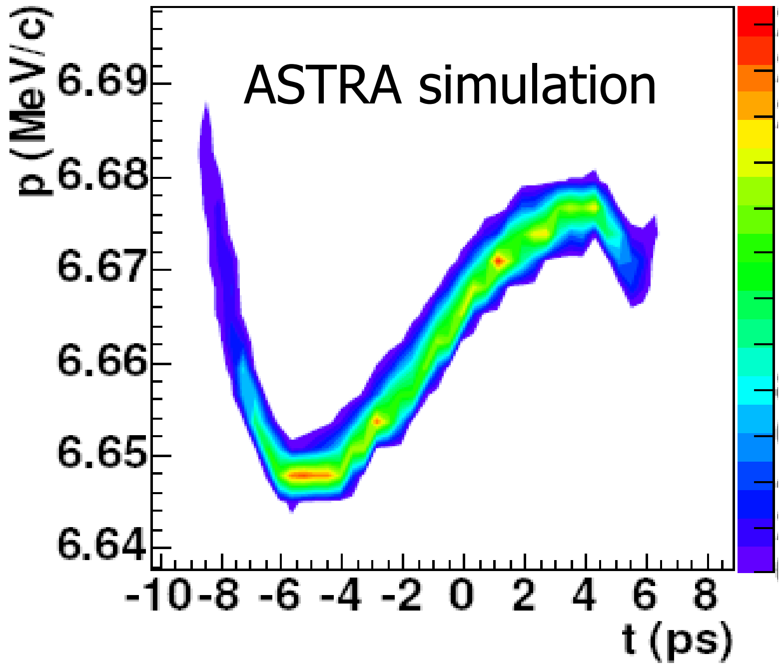
dispersion coefficient at the observation screen = 425 mm



Simulations of the momentum vs. RF power measurements confirm gun gradients ~ 60 MV/m **(XFEL design parameter)**.

The longitudinal phase space is measured by combining the dipole dispersion with streak camera measurements.

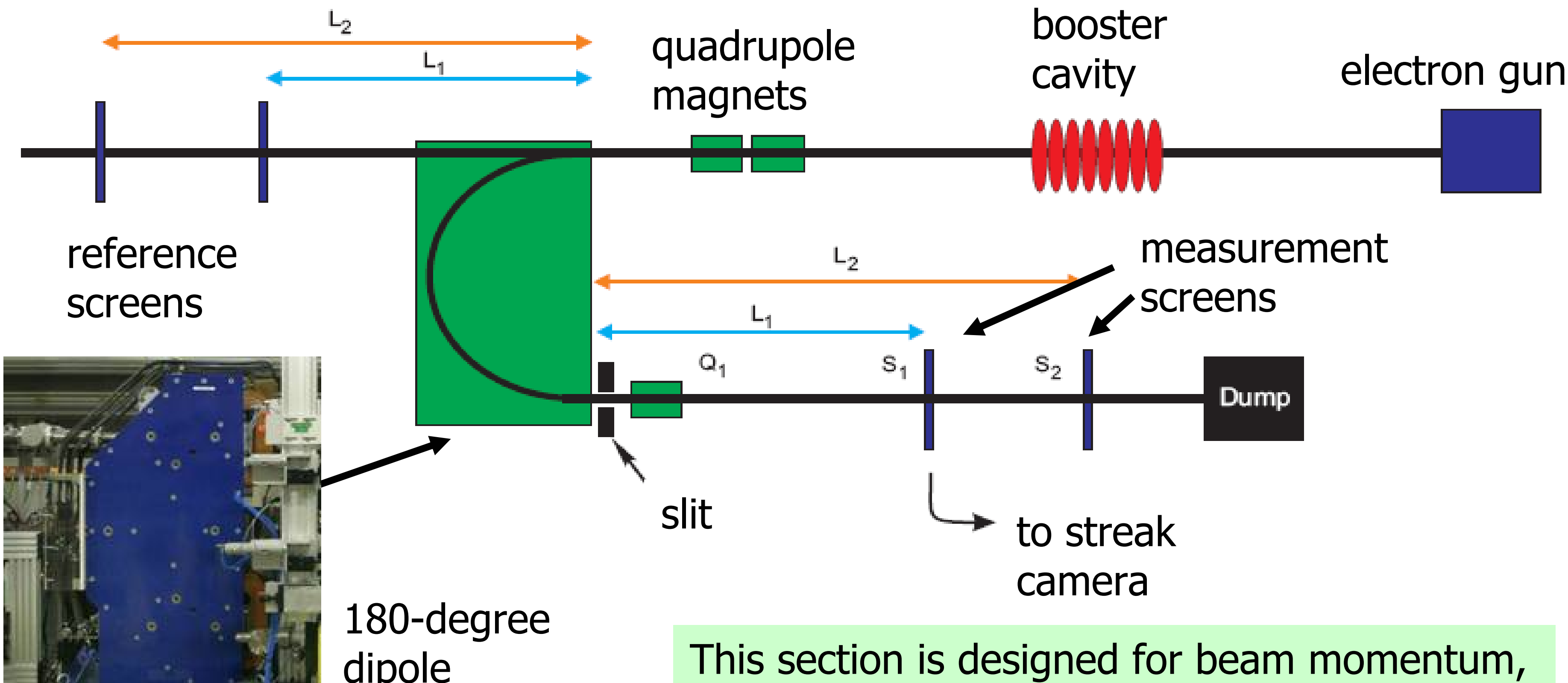




	pulse length (FWHM)
photocathode laser	2.1 ps, Gaussian
electron bunch	13 ps

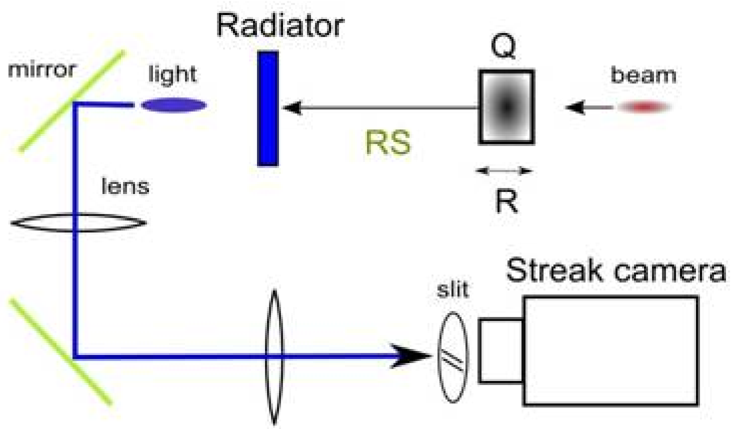
1-nC bunches

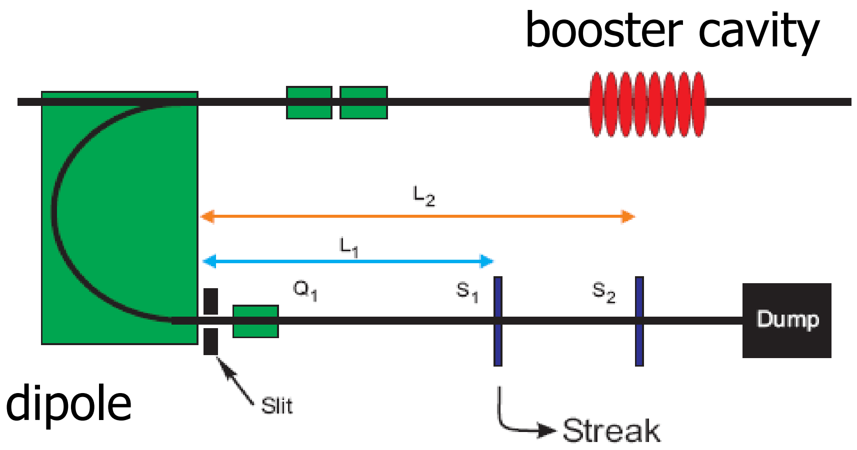
A multipurpose dispersive section has been installed after the booster cavity.



This section is designed for beam momentum, longitudinal phase space, and slice emittance measurements.

Two programs for slice emittance measurements are being pursued.





Quadrupole scan with streak camera:
Errors are very large for the single quadrupole scan (optical resolution, lost signal at streak camera slit, space-charge effects), so multiple-quadrupole techniques are being considered.

Off-crest acceleration in the booster cavity:
Difficulties include the proper solenoid optimization and errors caused by any steering after the booster, but estimations of error are reasonable (5-10%).

The PITZ facility has been substantially upgraded and the measurement program is underway.

new 1-1/2 cell L-band gun

conditioning test stand

improved cooling, dry-ice cleaned

60 MV/m peak field at cathode*, lower dark current and lower reflected RF power (factor of 10)

---

new photocathode drive laser

rise and fall times of laser pulse shortened from 7 to **2 ps*** → simulation predicts lower transverse emittance

---

new dipole magnet in low-energy section

momentum and longitudinal phase space measurements already performed

---

new high-energy spectrometer

designed for beam momentum, longitudinal phase space, and slice emittance measurements

*** European XFEL specifications**

The further beam characterization program is in progress, including thermal emittance and emittance at 1 nC.

Acknowledgments

G. Asova*, J. Bähr, C. Boulware#, K. Flöttmann, H. J. Grabosch, L. Hakobyan†, M. Hänel, Y. Ivanisenko, S. Khodyachykh, S. Korepanov, M. Krasilnikov, S. Lederer, B. Petrosyan, S. Rimjaem, D. Reschke, T. Scholz, A. Shapovalov§, R. Spesyvtsev, L. Staykov, F. Stephan,
DESY, Zeuthen/Hamburg, Germany
K. Rosbach, **Humboldt University, Berlin, Germany**
D. Richter, **BESSY, Berlin, Germany**
J. Rönsch, **University of Hamburg, Germany**
P. Michelato, L. Monaco, C. Pagani, D. Sertore, **INFN-LASA, Milan, Italy**
G. Klemz, I. Will, **Max Born Institute, Berlin, Germany**
T. Garvey‡, **LAL, Orsay, France**
W. Ackermann, E. Arevalo, **TEMF, Darmstadt, Germany**

chase.boulware@desy.de
§ on leave from MEPHI Moscow, Russia
‡ now at PSI, Villigen, Switzerland
* on leave from INRNE Sofia, Bulgaria,
† on leave from YERPHI Yerevan, Armenia

This work has partly been supported by the **European Community**, contracts RII3-CT-2004-506008 and 011935, and by the 'Impuls- und Vernetzungsfonds' of the **Helmholtz Association**, contract VH-FZ-005.

2 postdoc positions and 1 PhD student position are currently open! See **http://pitz.desy.de**