S. Yaramyshev, W. Barth, I. Hofmann, A. Orzhekhovskaya, B. Zielbauer

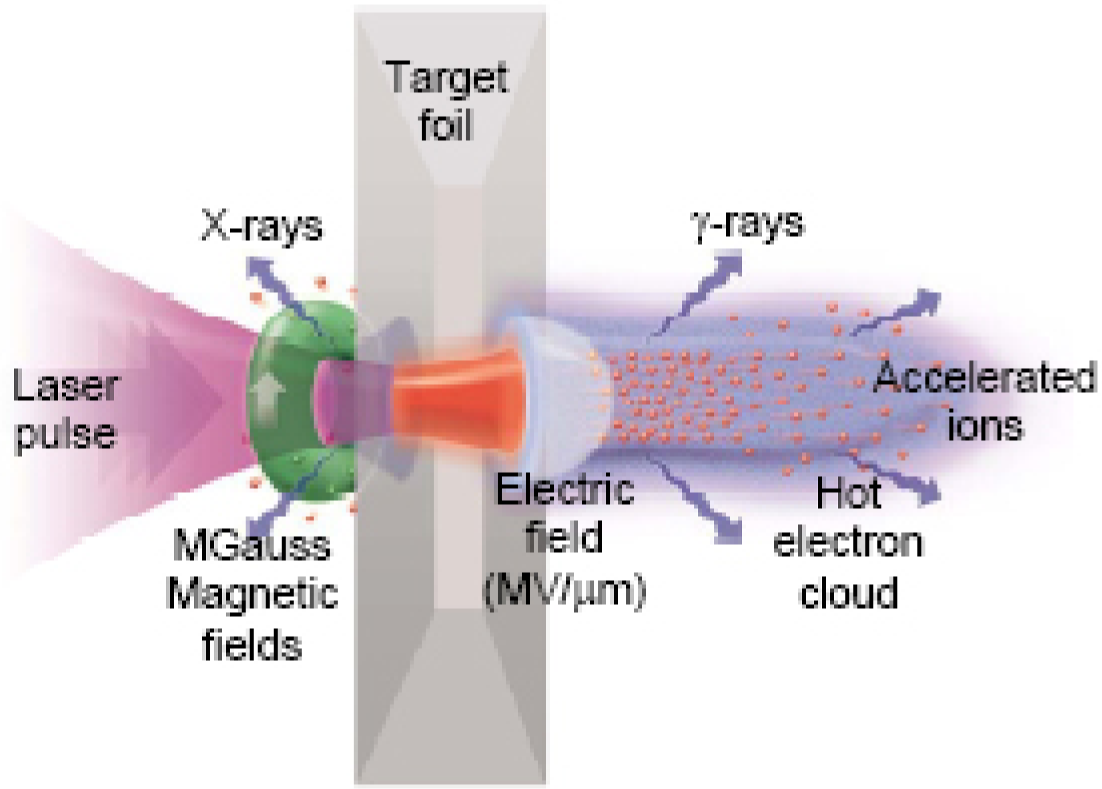
Helmholtzzentrum GSI, Darmstadt

Capture and transport of the laser accelerated ion beams for the LIGHT project

LIGHT project: **L**aser **I**on **G**eneration, **H**andling and **T**ransport

Work supported by EURATOM (IFK KiT) and HIC for FAIR

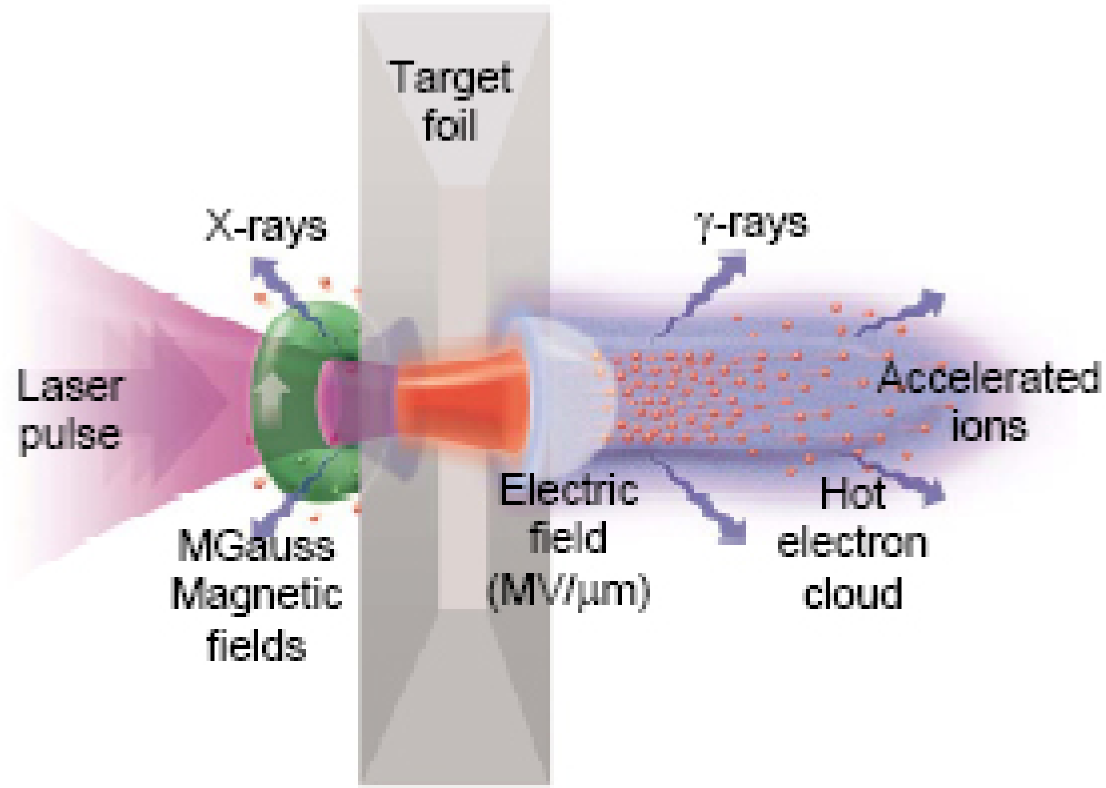
Laser Ion Source (LIS)



Advantage:

- high current
- low emittance

Laser Ion Source (LIS)



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Advantage:

- high current

- low emittance

Disadvantage:

- high current

- low emittance

- **energy spread**

- **transverse divergence**

LIGHT collaboration partners

Technical University Darmstadt [1]
Helmholtzzentrum GSI Darmstadt [2]
Institute for Applied Physics at Frankfurt University [3]
Helmholtz-Institute Jena [4]
Helmholtzzentrum Dresden-Rossendorf [5]

A. Almomani [3], V. Bagnoud [2,4], W. Barth [2], A. Blazevic [2], O. Boine-Frankenheim [2], C. Brabetz [3], T. Burris-Mog [5], S. Busold [1], T. Cowan [5], M. Droba [3], H. Eickhoff [2], P. Forck [2], A. Gopal [4], K. Harres [1], S. Herzer [4], G. Hoffmeister [1], I. Hofmann [2], O. Jäckel [4], M. Kaluza [4], O. Kester [2,3], F. Nürnberg [1], A. Orzhekhovskaya [2], G. Paulus [4], J. Polz [4], U. Ratzinger [3], C. Rödel [4], M. Roth (project leader) [1], T. Stöhlker [2,4], A. Tauschwitz [2], W. Vinzenz [2], S. Yaramyshev [2], B. Zielbauer (project coordinator, editor) [4]

MOPS028, WEPS031, WEPS033, WEPZ002, THPS012

The LIGHT Project

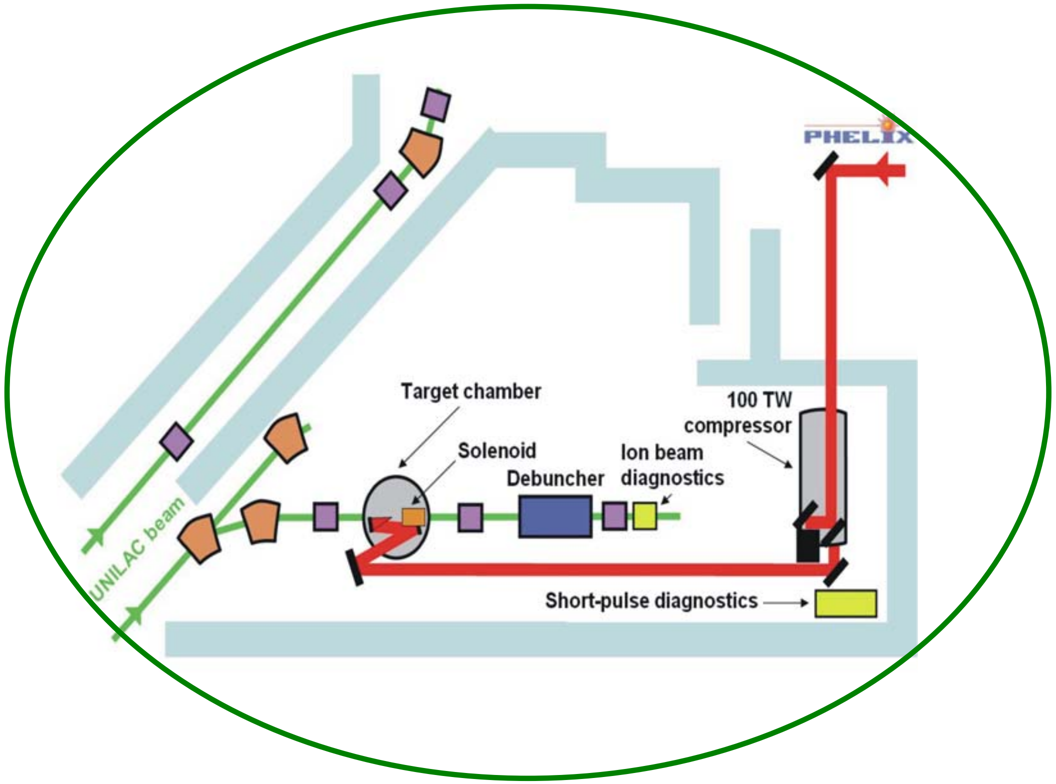
The LIGHT Project combines three different tasks:

- a development of the powerful laser and a delivery of the laser beam to the target;
- the simulations of the very early expansion of the laser generated electron-ion cloud and an optimization of a target;
- capture, collimation, focusing and rotation of the ion beam including its matching to the conventional accelerating-focusing structures.

The LIGHT test stand

GSI-PHELIX

The **P**etawatt **H**igh-**E**nergy **L**aser for Heavy **I**on E**X**periments

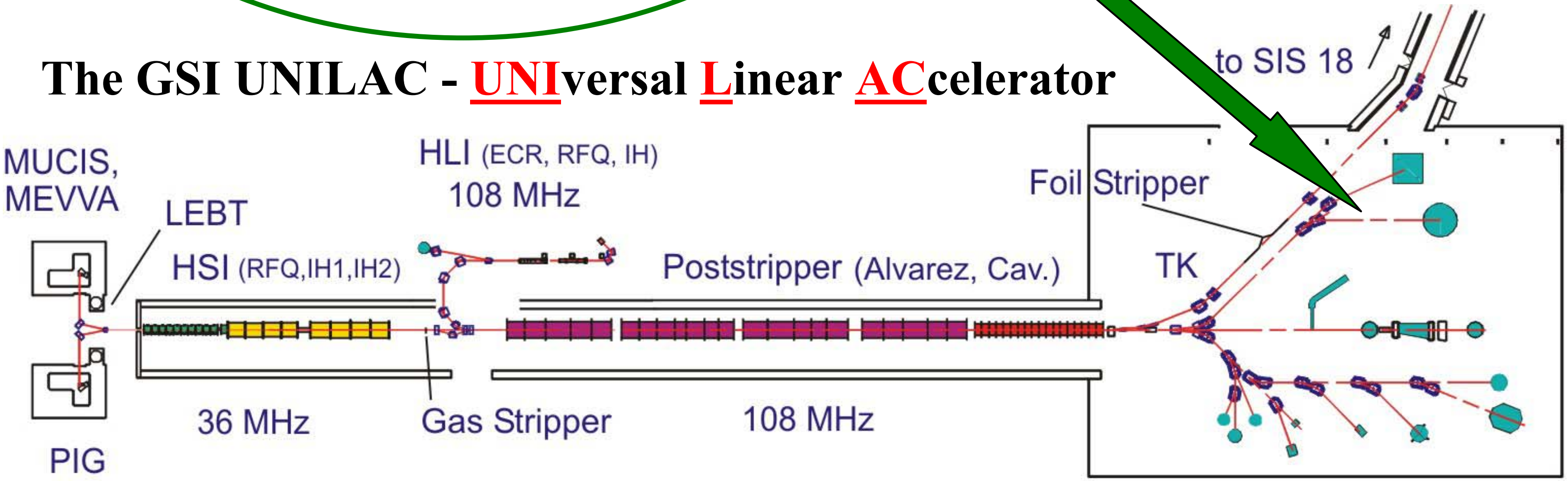


The LIGHT test stand integrated to the UNILAC experimental beam line.

An ion beam with variable energy from routine UNILAC operation can be used for a tuning of the beam line settings and for a calibration of the diagnostics

W. Barth et al. WEPS031

The GSI UNILAC - UNIversal Linear ACcelerator



Estimated beam parameters for beam dynamics simulations

Proton energy	10 MeV
Energy spread	± 50%
Bunch length	< 1ps
Beam radius	30 mkm
Divergence	± 172 mrad

10^{12}-10^{13} particles per shot

are equivalent to
≈500 mA beam current

Transverse focusing: solenoid
Longitudinal bunch rotation: buncher

Standard beam dynamics codes use paraxial approximation:

- transverse particle velocity is much less than longitudinal one (divergence is about few tens of mrad);
- 3D equation of particle motion is divided into longitudinal and transverse parts which are solved separately.

For this case paraxial approximation doesn't work !!!

A universal and powerful code with detailed decryption of electromagnetic field
is required for reliable beam dynamics simulations

Advanced multiparticle code for beam dynamics simulations **DYNAMION**

S. Yaramyshev, W. Barth, A. Orzhekhovskaya (GSI, Darmstadt)

A. Kolomiets, T. Tretyakova (ITEP, Moscow)

The DYNAMION code is dedicated for linac design and optimization of the operating facilities

High level of DYNAMION reliability was demonstrated by numerous comparisons of measured data and simulated results for the operating linacs in ITEP, GSI, CERN, INFN, ANL and other leading centers

S. Yaramyshev et al, "Development of the versatile multi-particle code DYNAMION", Nuclear Inst. and Methods in Physics Research A, Vol 558/1 pp 90-94, (2006)

DYNAMION main features

- 3D equation of particle motion in the most common form is integrated on time;

- end-to-end simulations of beam dynamics in a linac, consisting of the arbitrary sequence of the RFQs, DTLs and transport lines can be done **in one run;**

- external field in an RFQ and DTL is calculated solving the Laplace equation for the **real topology** of the elements;

- **transport lines** may include magnetic and electrical lenses (quadrupole, octupole, etc.), bending magnets, solenoids, slits, steerers, apertures, stripper sections, etc;

- **space charge** effects are included.

Can be used in the code:

- external electromagnetic fields, **measured** or **simulated** by special codes;

- multi-charged beam;

- input particle distribution from **measured emittance** or other calculations;

- misalignments of the elements.

Typical particle trajectories along test transport line

2008 - 2011

I. Hofmann et al.
HIAT 2009

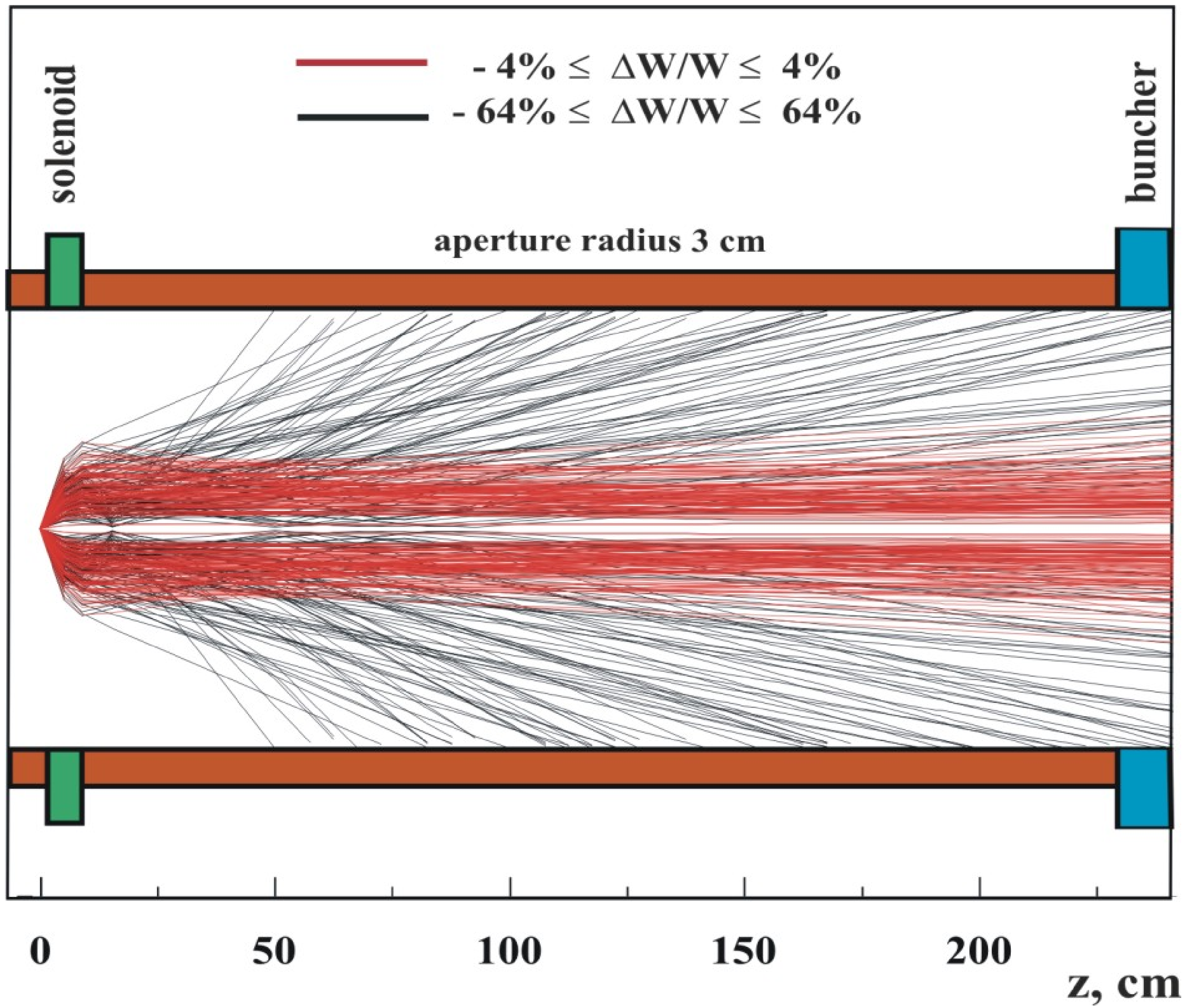
S. Yaramyshev,
A. Orzhekhovskaya
Seminar of Milan Univ. & INFN (June 2010)

A. Orzhekhovskaya et al.
HB 2010

A. Orzhekhovskaya et al.
GSI Annual Report 2010

I. Hofmann et al.
Phys.Rev. Vol. 14 (2011)

S. Yaramyshev et al.
LIGHT Meeting (June 2011)

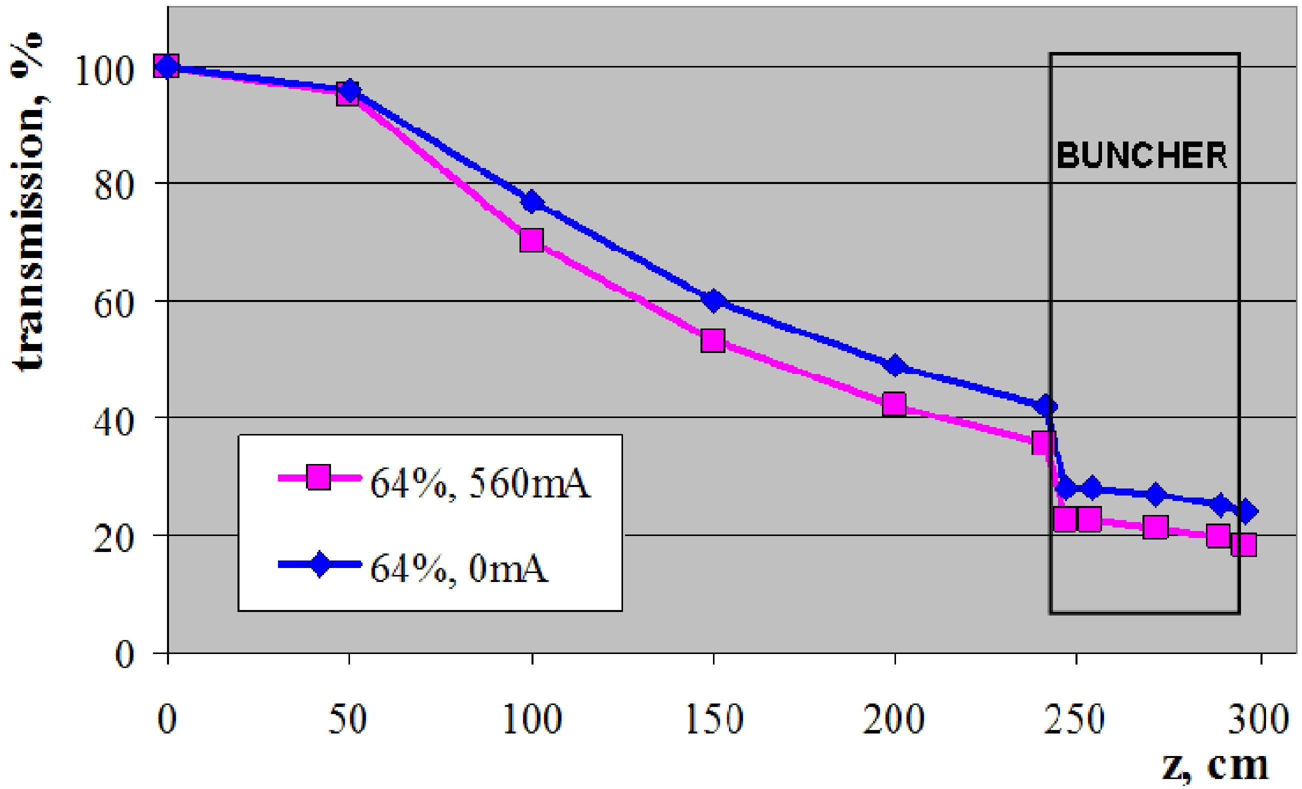


Space charge effects

Test channel:

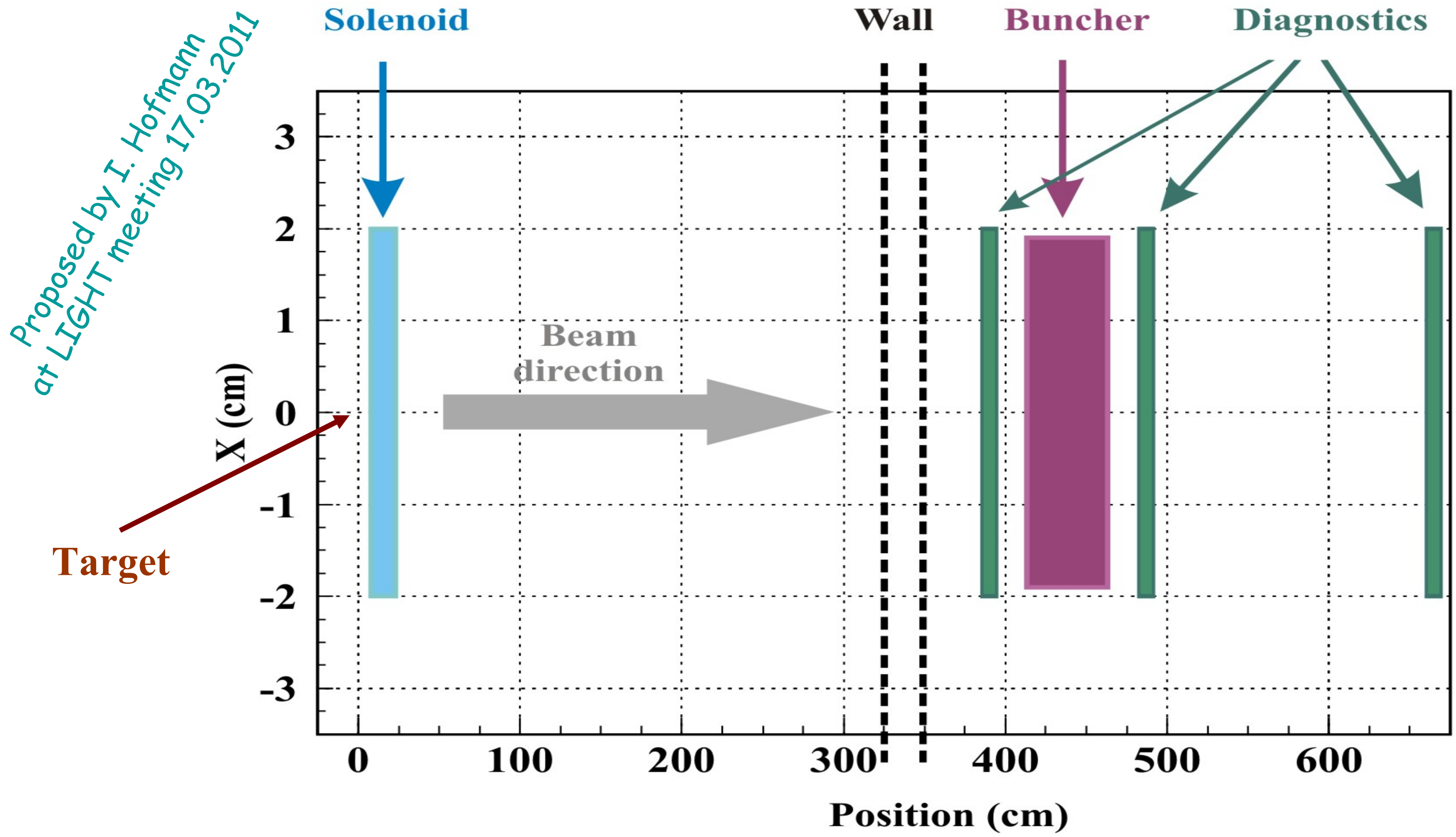
beam current	560 mA
energy spread	± 64 %
divergence	± 172 mrad

Behind a small area of a few mm from the target, an influence of the space charge is relatively low.



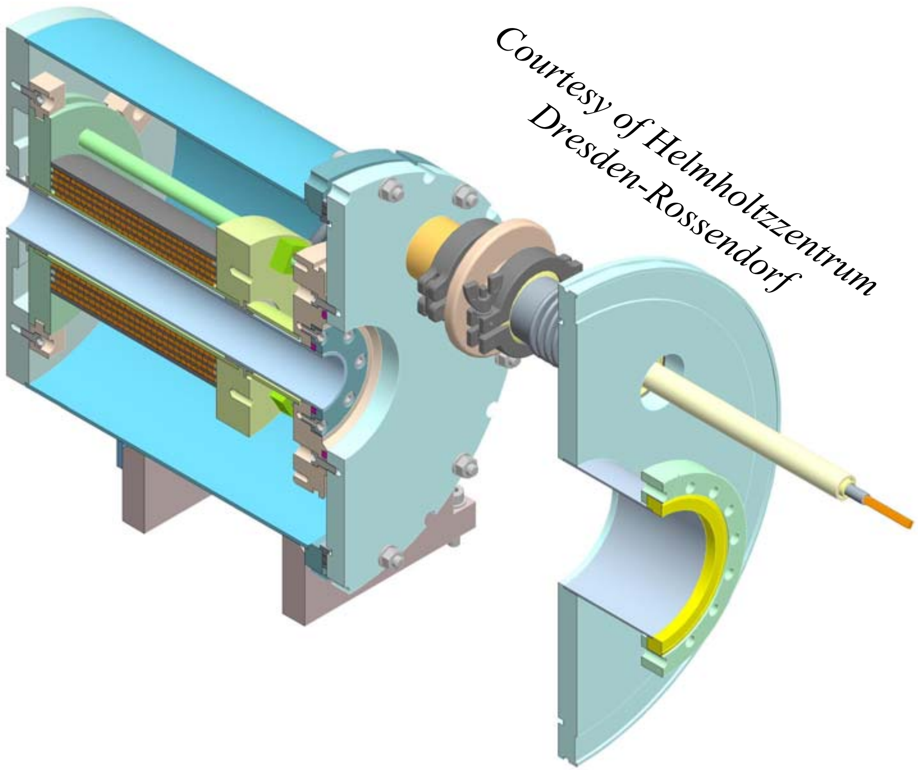
The results of the recent simulations were obtained neglecting the space charge effects and can be treated as an optimum level for the emittance growth and particle transmission.

Recent layout of the LIGHT transport line

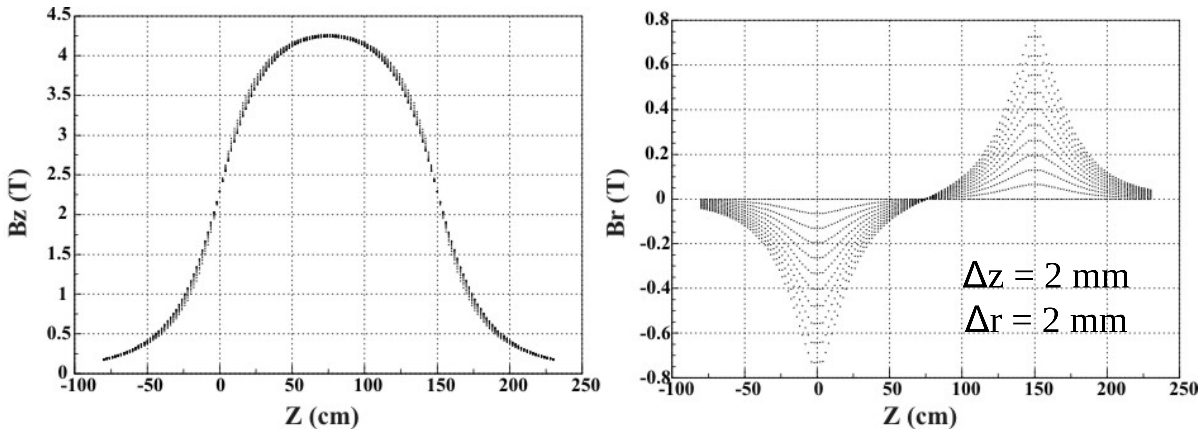


On the base of presented beam dynamics simulations the buncher will be shifted closer to the solenoid.

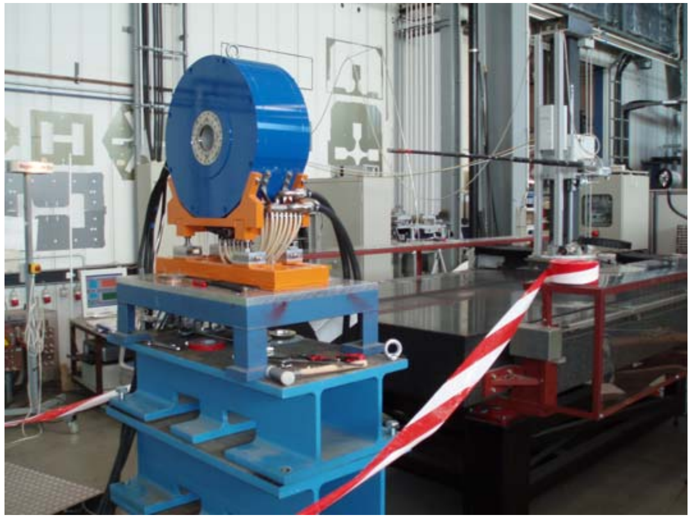
Solenoid 3D field mapping



Calculated magnetic field (S. Busold)

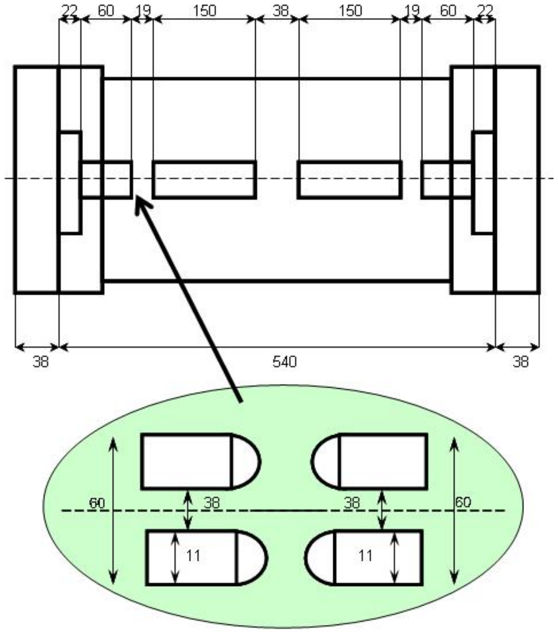


Use of the measured at GSI 3D magnetic field is foreseen for the further study

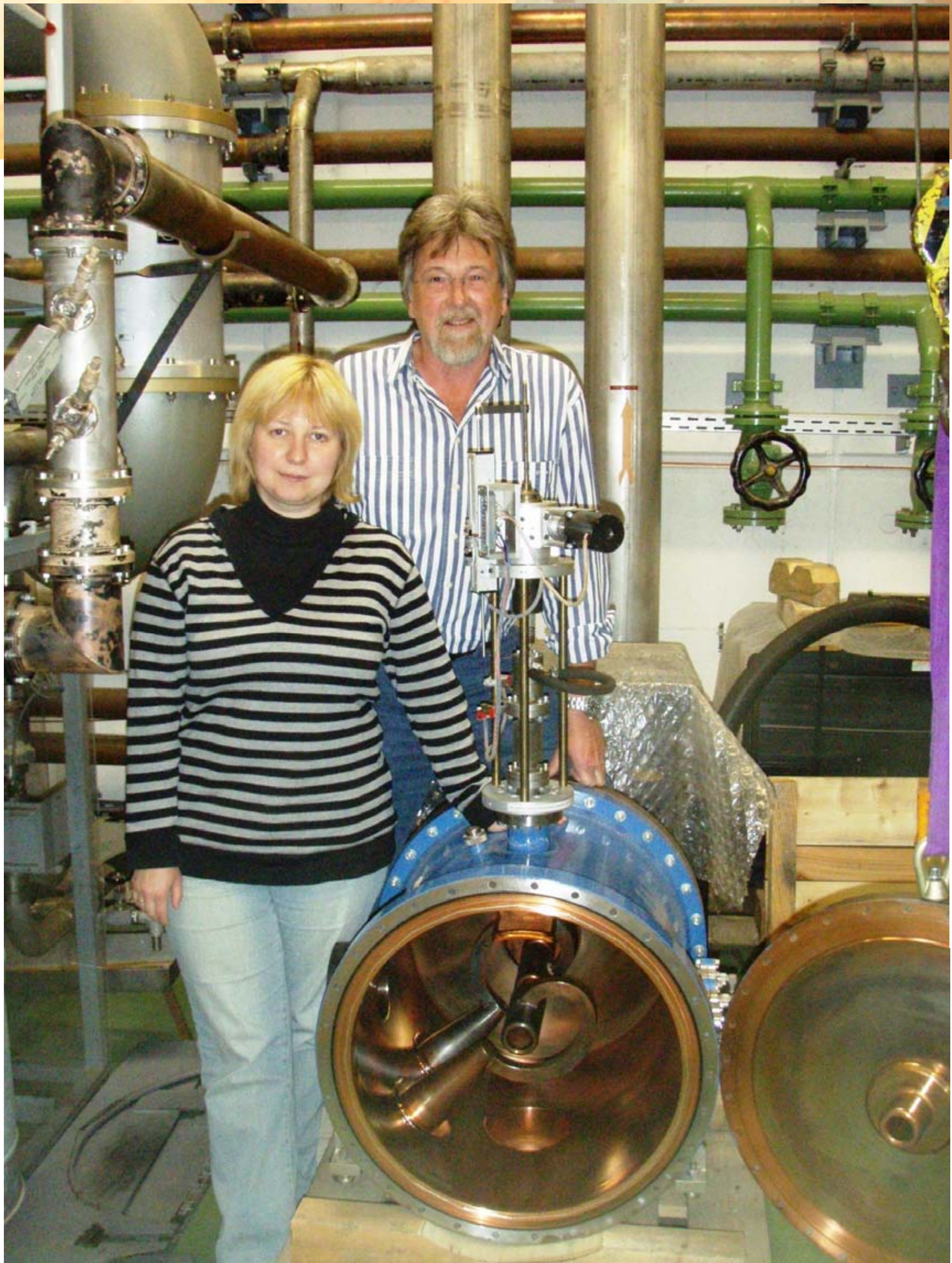


Discrete measured data can be extended to the whole aperture of the solenoid using relaxation scheme

3-Gap 108 MHz GSI buncher



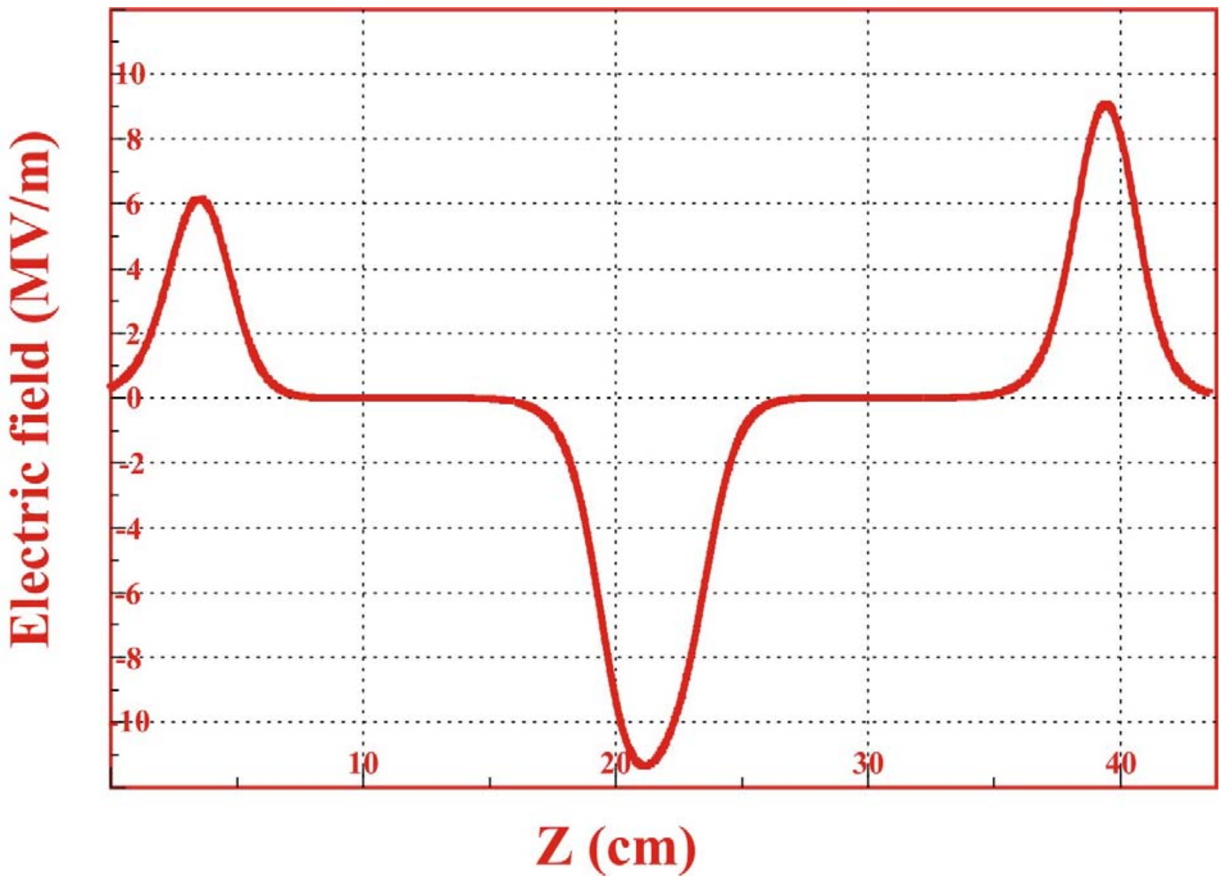
3D electric field calculated in the code DYNAMION solving Laplace equation for real topology of tubes and gaps (length, inner and outer diameters, rounding of tubes)



GSI-buncher: measurements & simulation

Electrical field along 3-gap buncher:

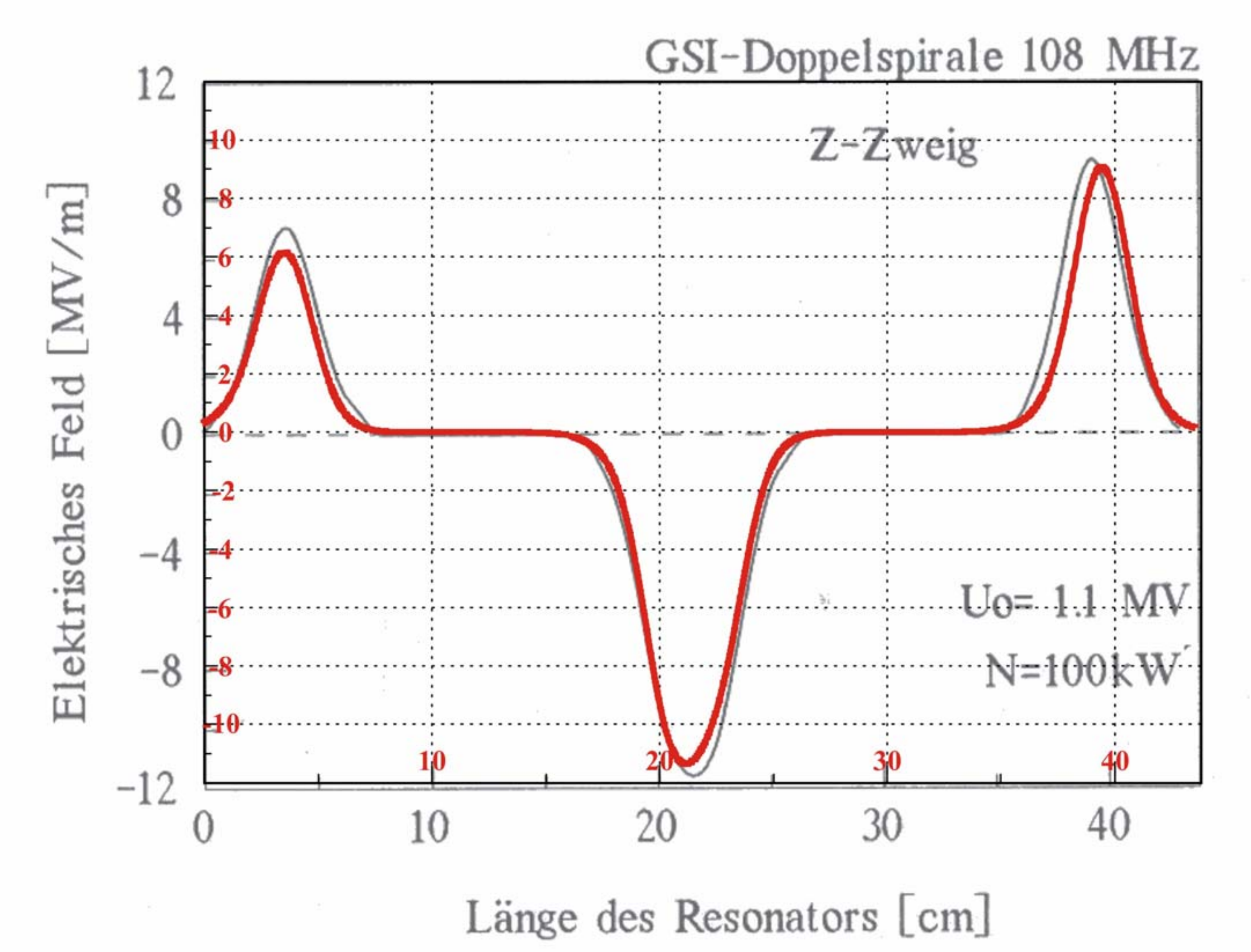
- calculated (DYNAMION, 2009)



GSI-buncher: measurements & simulation

Electric field along 3-gap buncher:

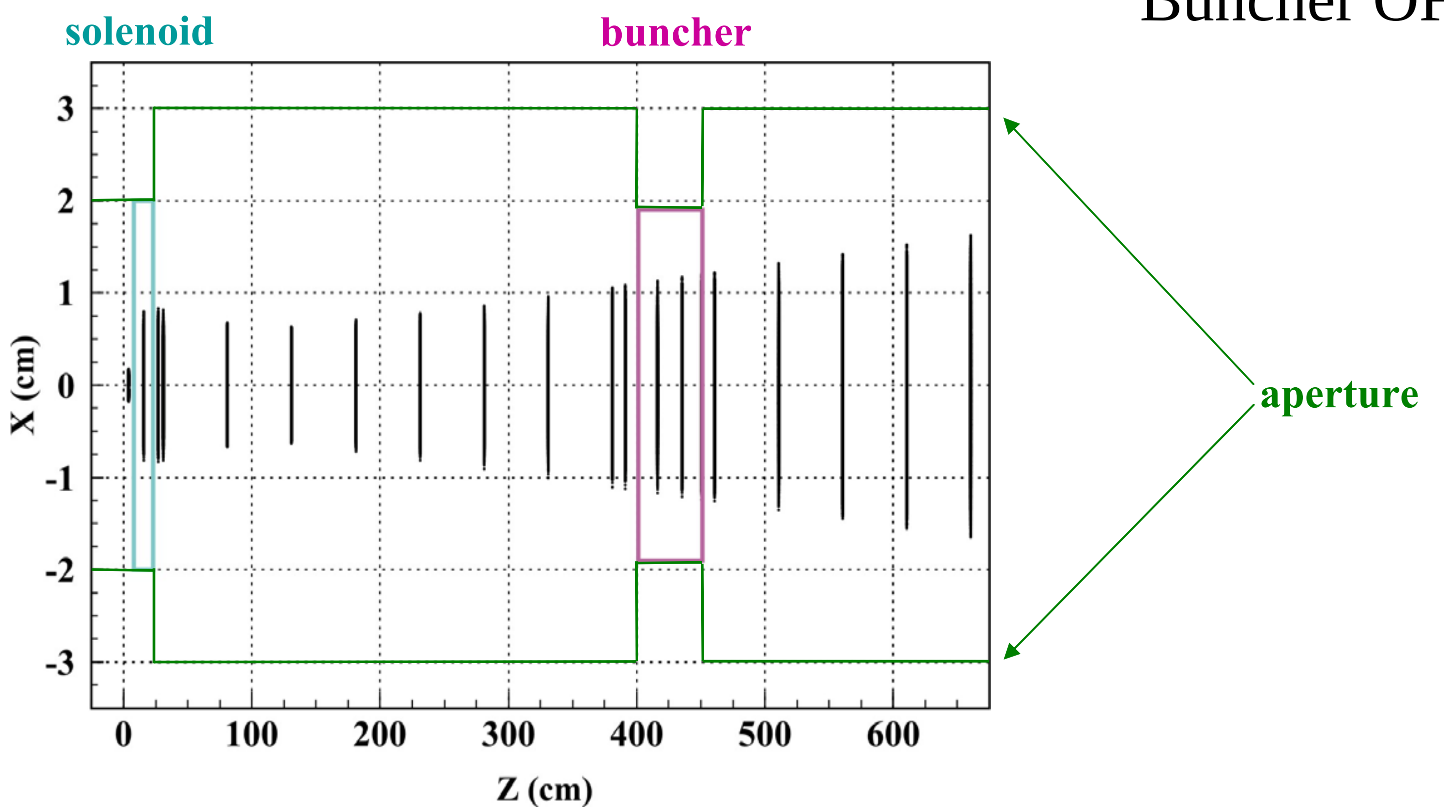
- measured (W. Vinzenz, J. Häuser, 1991)
- calculated (DYNAMION, 2009)



Beam focusing with the solenoid

Energy spread	± 0%	*estimated* ± 50%
Divergence	± 43 mrad	*estimated* ± 172 mrad
Magnetic field	7.5 T	*optimum focusing*
Proton energy	10 MeV	

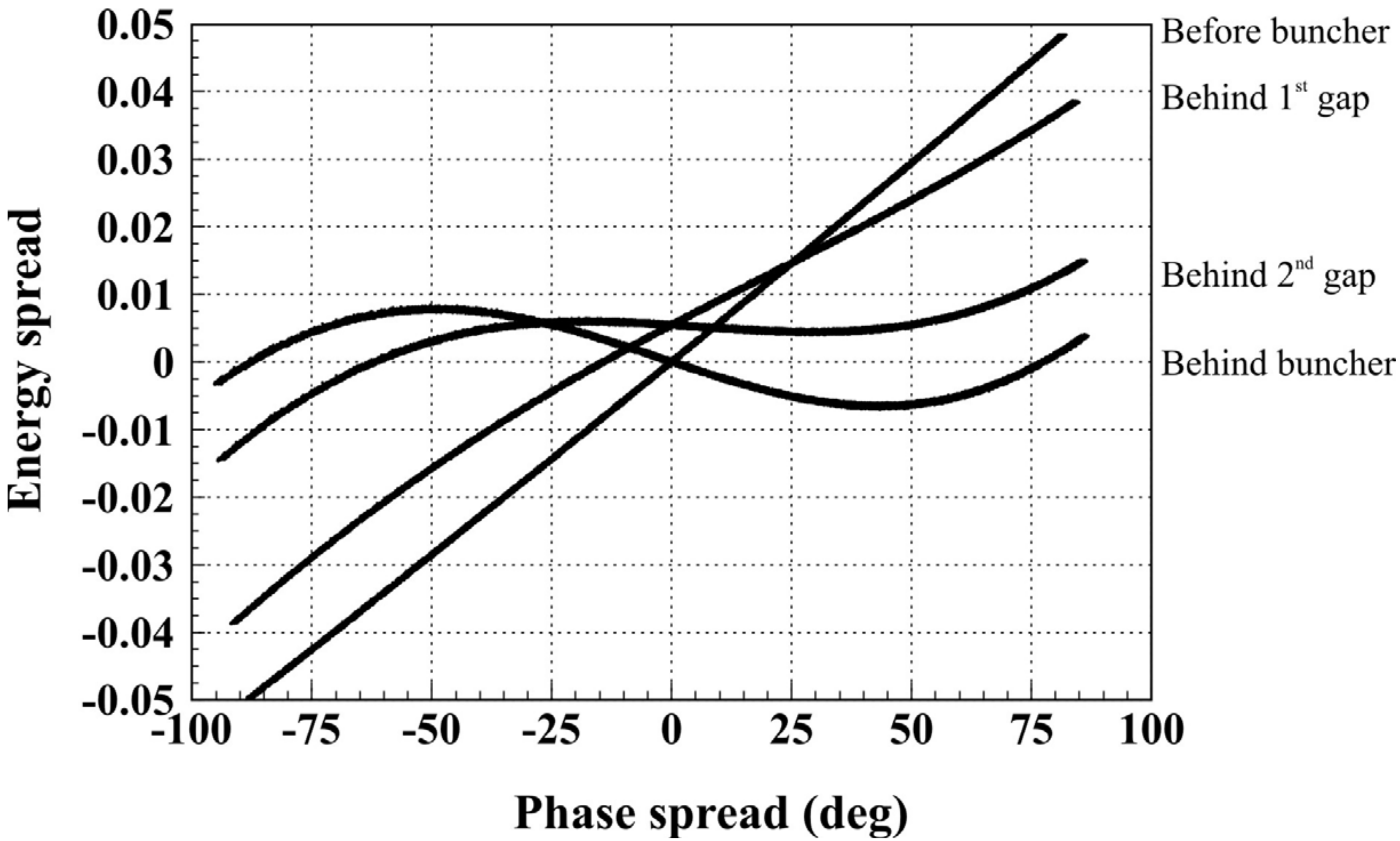
Buncher OFF



Bunch rotation

Energy spread	±5%	*estimated* ± 50%
Divergence	±43 mrad	*estimated* ± 172 mrad

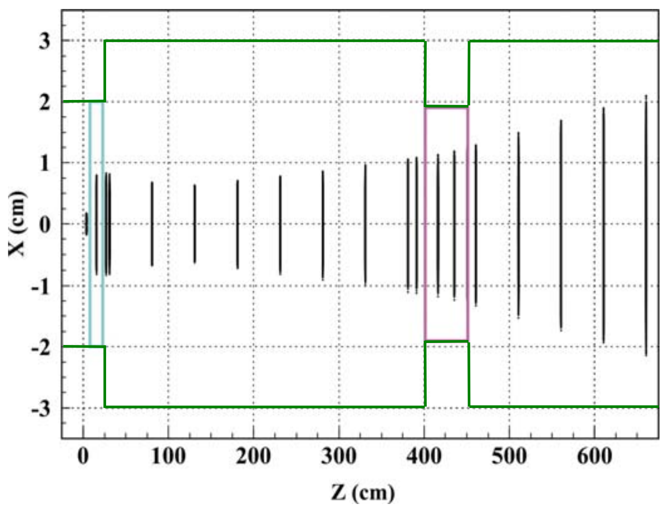
Buncher voltage 550 kV (nominal 1.0 MV)



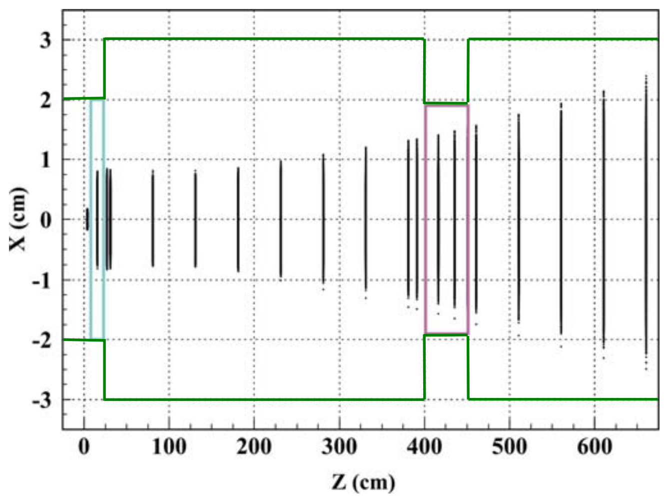
Influence of input energy spread

Divergence	±43 mrad	*estimated* ± 172 mrad
Magnetic field	7.5 T	

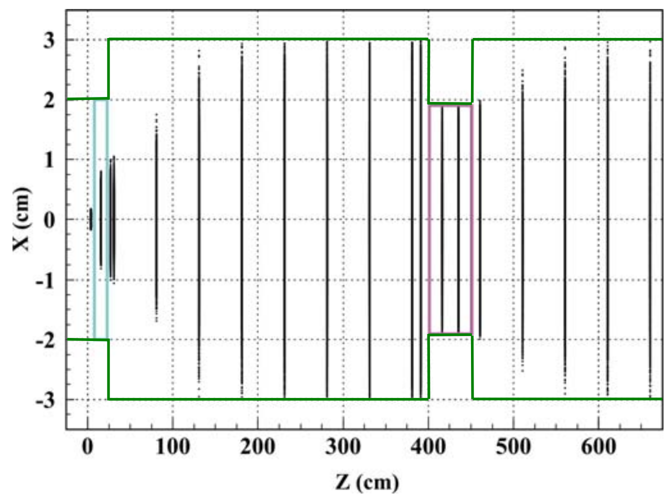
Energy spread ±0%



Energy spread ±5%



Energy spread ±50%

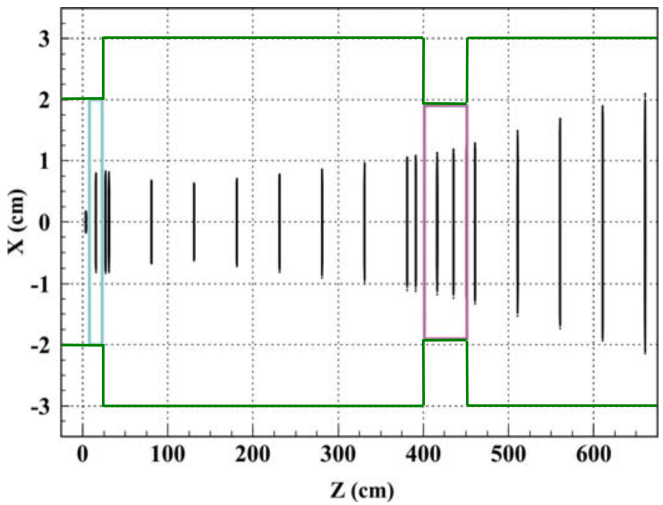


Influence of input transverse divergence

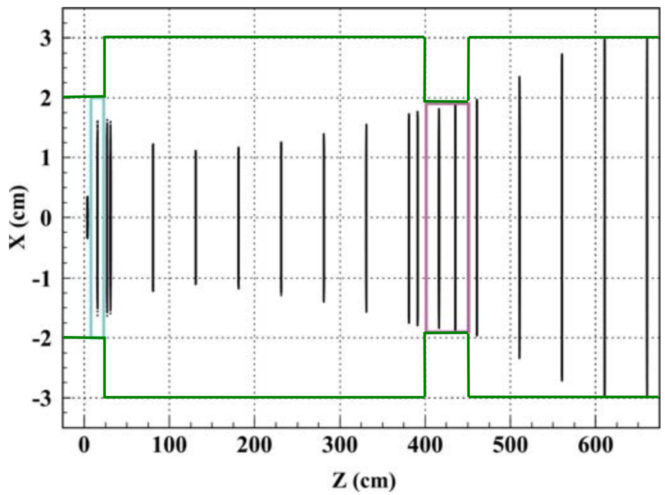
Energy spread ±0% *estimated* ± 50%

Magnetic field 7.5 T

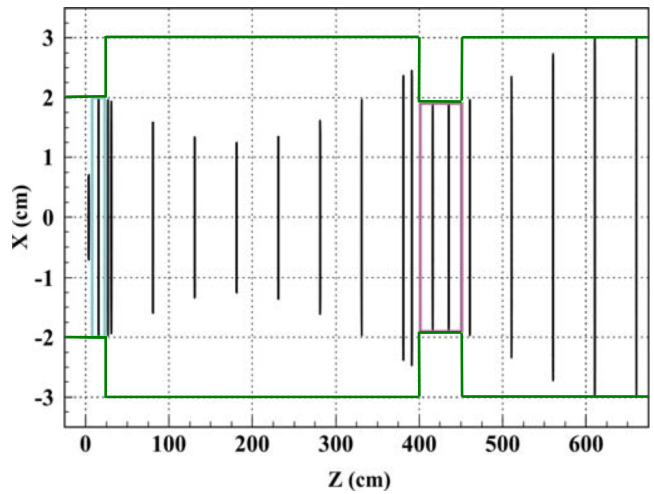
Divergence ±43 mrad



Divergence ±86 mrad



Divergence ±172 mrad

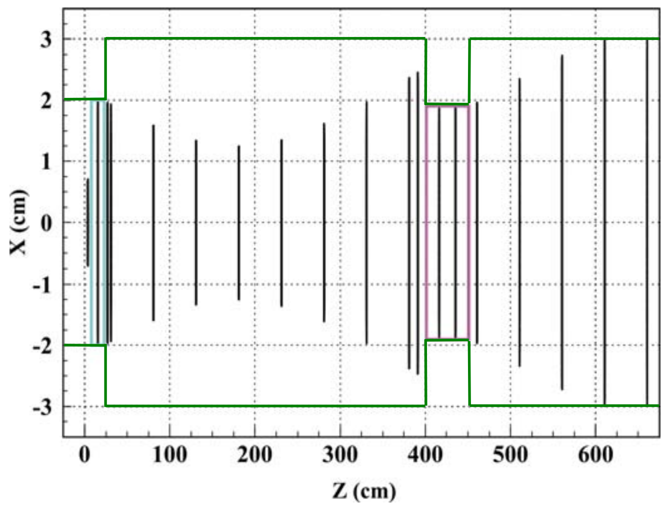


Input energy spread & transverse divergence

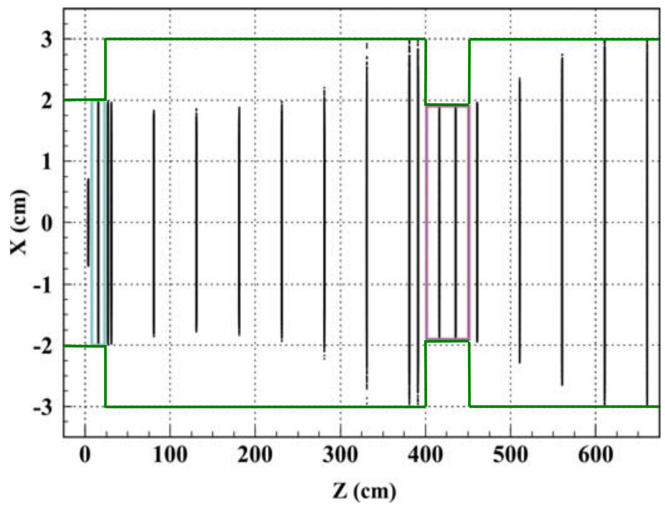
Divergence ±172 mrad

Magnetic field 7.5 T

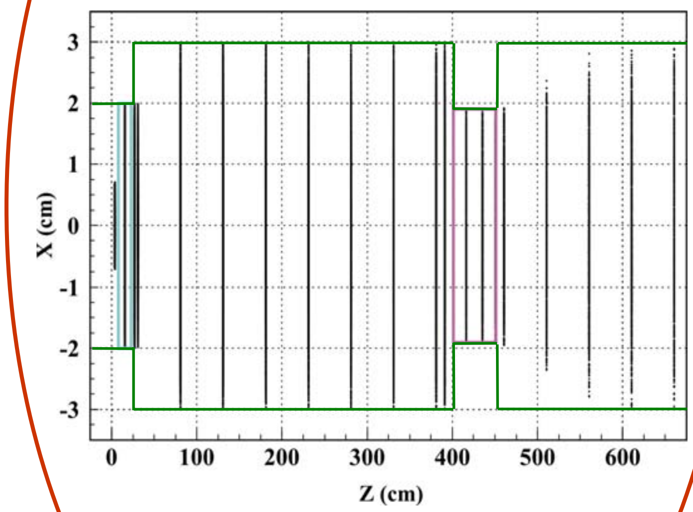
Energy spread ±0%



Energy spread ±5%



Energy spread ±50%



Particle transmission

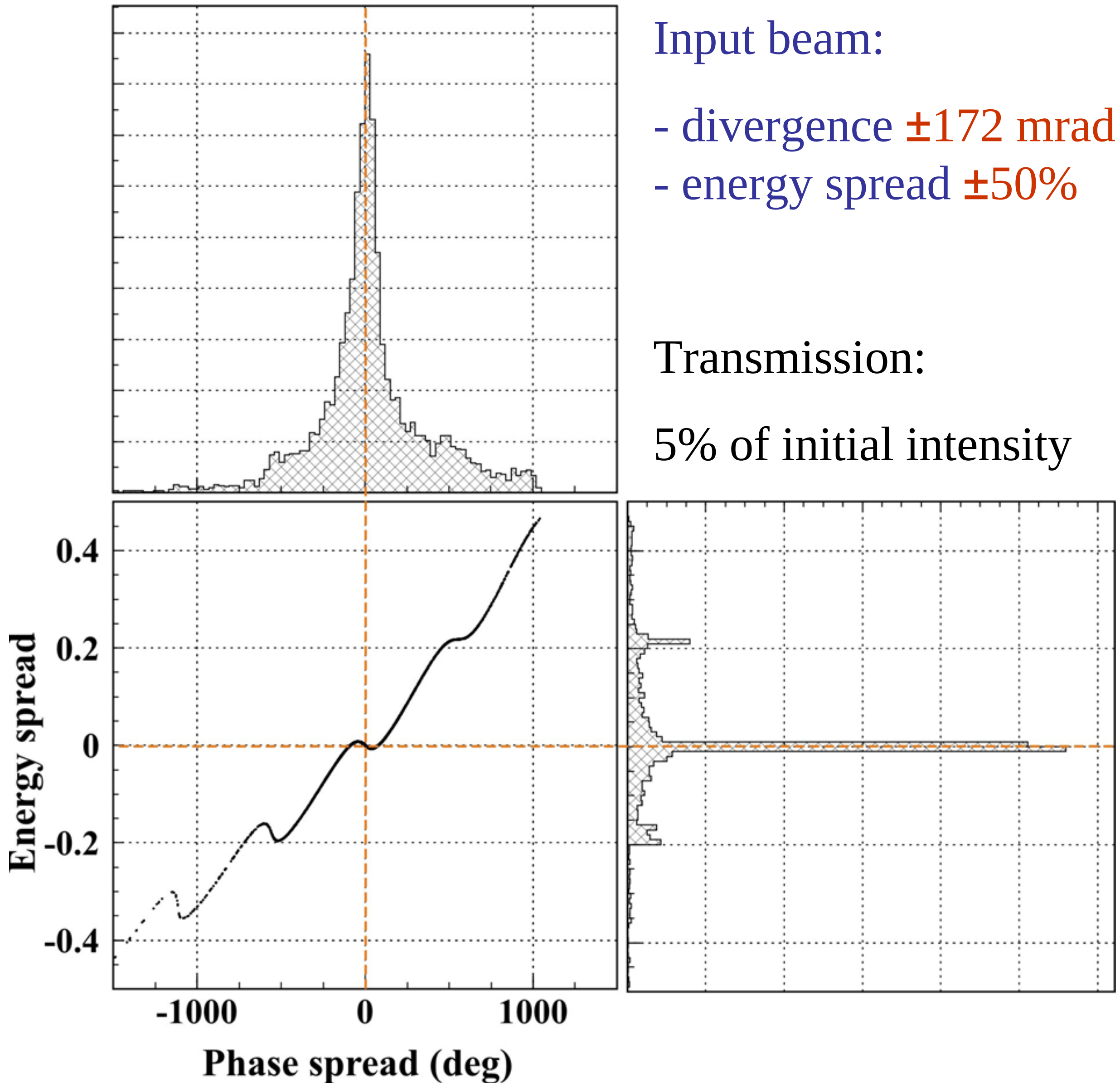
Magnetic field 7.5 T

Energy of protons 10 MeV

Particle transmission (%) through the beam line (7 m)

Energy spread / Divergence	0%	5 %	50 %
43 mrad	98	44	13
86 mrad	97	42	12
172 mrad	32	12	5

Longitudinal particle distribution at the end of the beam line



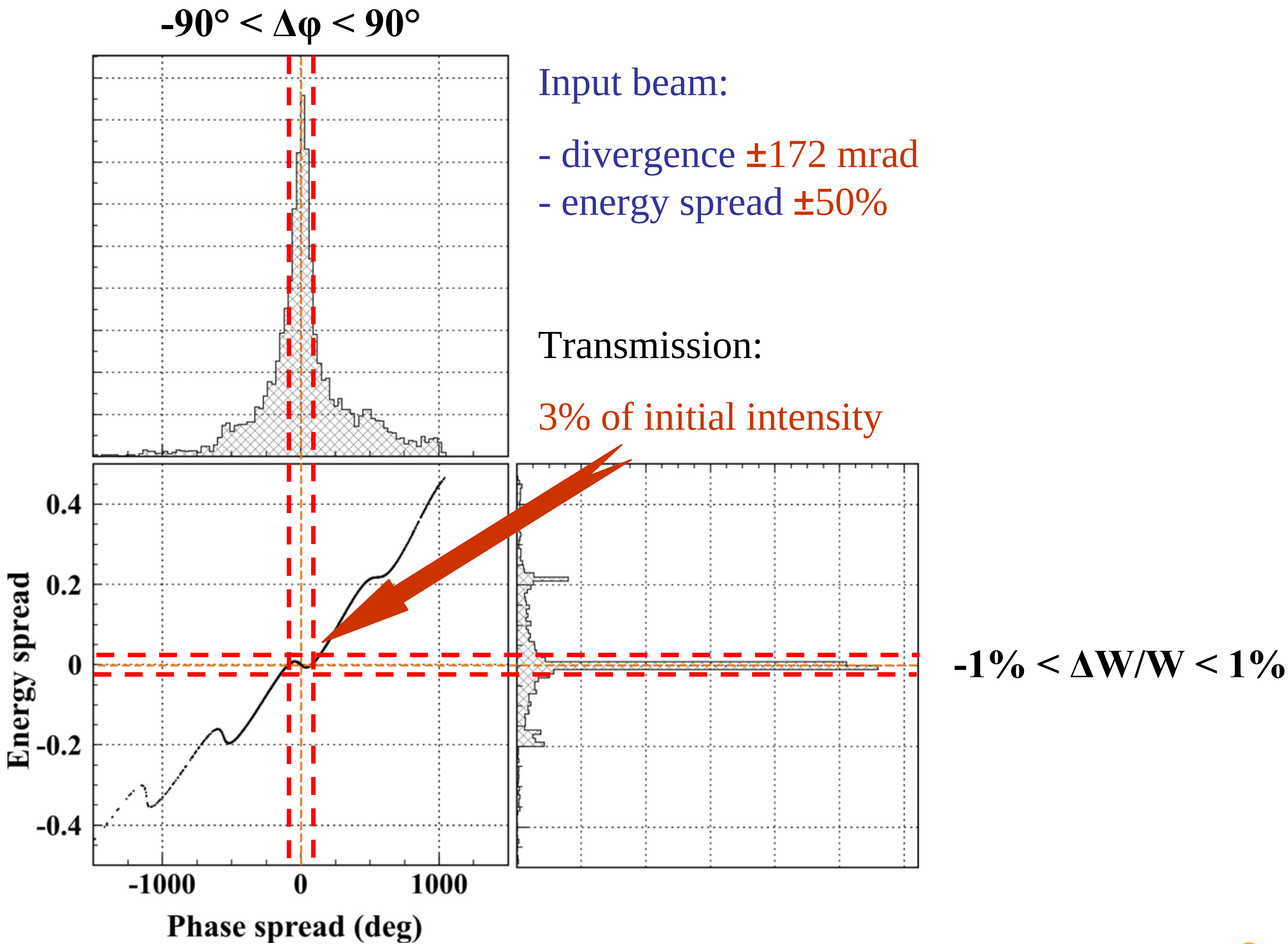
Input beam:

- divergence ±172 mrad
- energy spread ±50%

Transmission:

5% of initial intensity

Longitudinal particle distribution at the end of the beam line



Input beam:

- divergence ±172 mrad
- energy spread ±50%

Transmission:

3% of initial intensity

Conclusion and outlook (I)

LIGHT project: experimental investigation of the laser driven proton beam at GSI

- An unique installation for the transport, collimation and rotation of the proton beam, generated by powerful laser PHELIX, is already integrated into GSI UNILAC beam line.
- An ion beam with variable energy from routine UNILAC operation can be used for a tuning of the beam line settings and for a calibration of the diagnostics.
- Dedicated experiments were already performed in 2010 and 2011 including laser generation of the proton beam and its focusing with the solenoid.

Conclusion and outlook (II)

LIGHT project: experimental investigation of the laser driven proton beam at GSI

- Advanced beam dynamics simulations, done by means of multiparticle DYNAMION code, are used for the optimization of the beam line, as well as for the prediction of the experimental results.

- An energy resolution calculated behind the buncher is demonstrated. This result is promising for the planned experimental parameter study at the LIGHT test stand.

- The buncher position will be optimized to provide for the improved beam matching and higher particle transmission.

- Experiments with laser generated proton beam, focused by the solenoid and rotated with the buncher are planned for 2012.