LIGHT

...from laser ion acceleration to future applications

- project overview and lates experimental results -

1st European Advanced Accelerator Concepts Workshop
La Biodola, Isola d'Elba
2nd – 7th June 2013

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TU Darmstadt
Institut für Kernphysik
AG Prof. M. Roth

Laser Ion Generation, Handling and Transport

supported by
HGS-HIRe for FAIR Helmholtz Graduate School for Hadron and Ion Research
HIC for FAIR Helmholtz International Center

introduction: laser ion accleration

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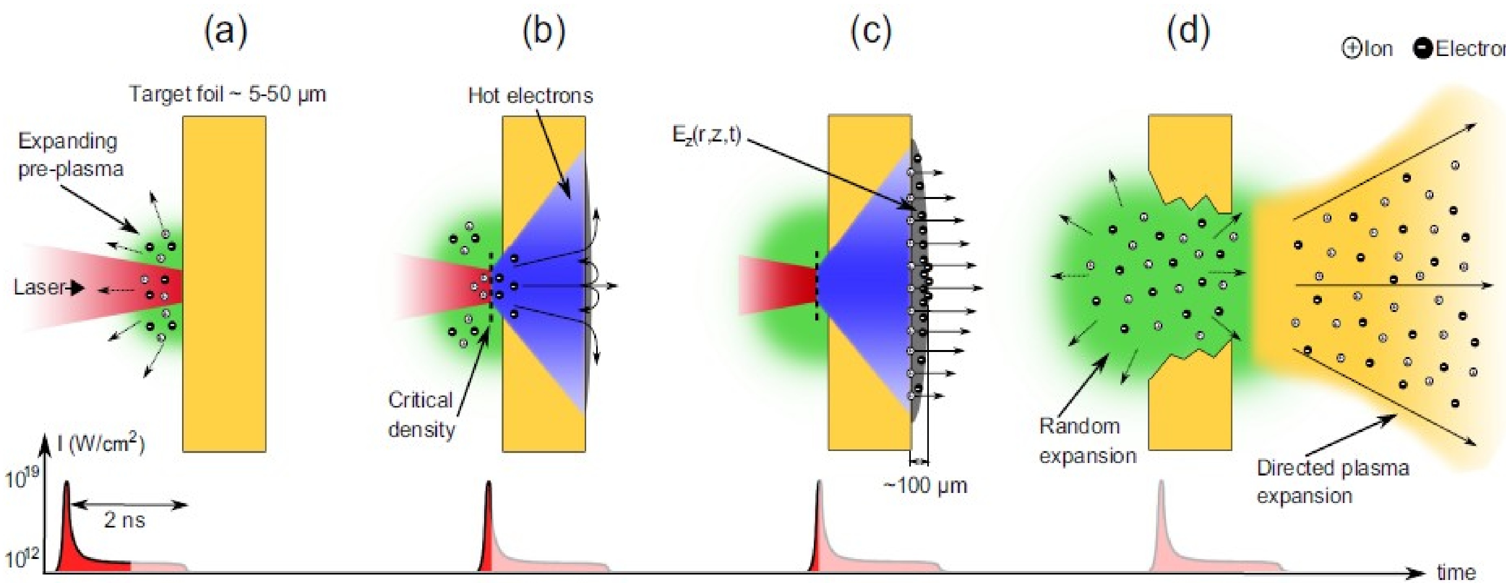

F. Nürnberg, PhD thesis TU Darmstadt (2010)

introduction: laser ion accleration

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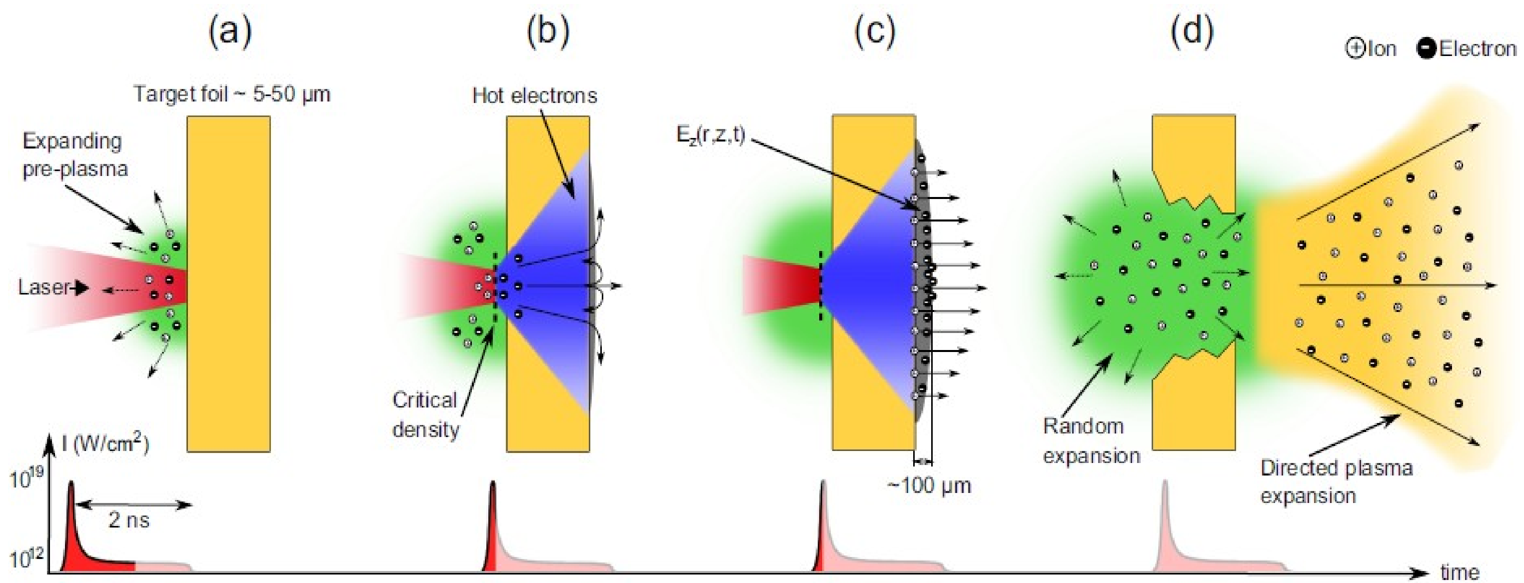
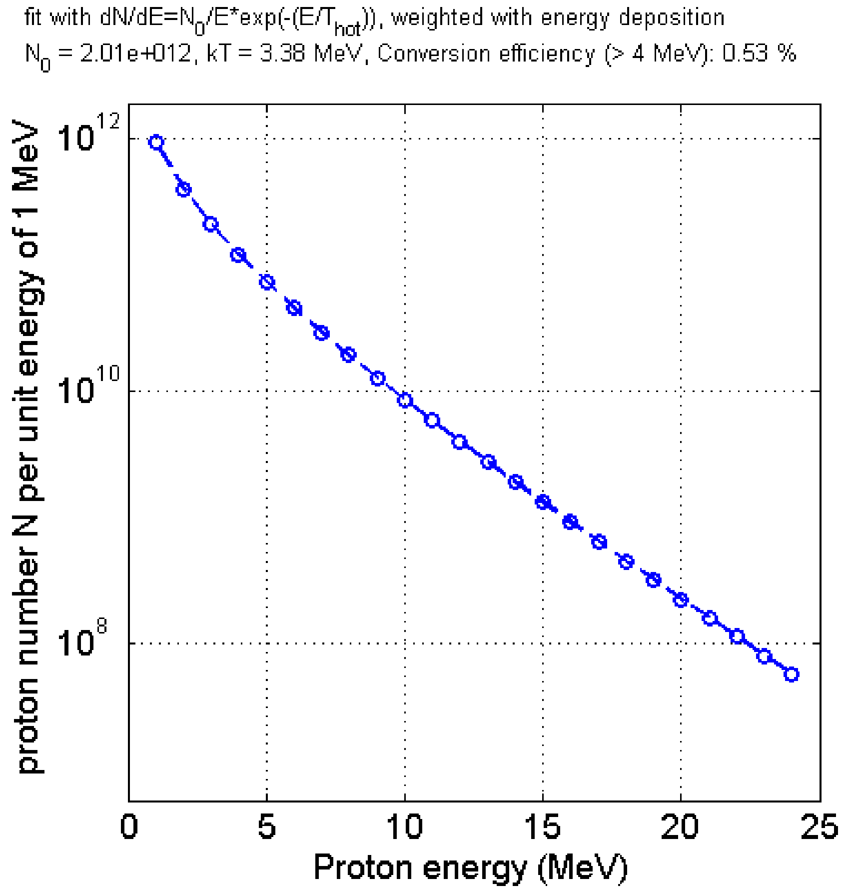
- very intense source: 10^{11}–10^{13} protons (total) in ≤1ps
- nearly ideal point source: 50-500µm source size
- ultra-low transverse emittance (<0.01 mm mrad)
- huge accelerating field gradients: TV/m
- intense laser matter interaction: x-rays, electrons, protons, debris...

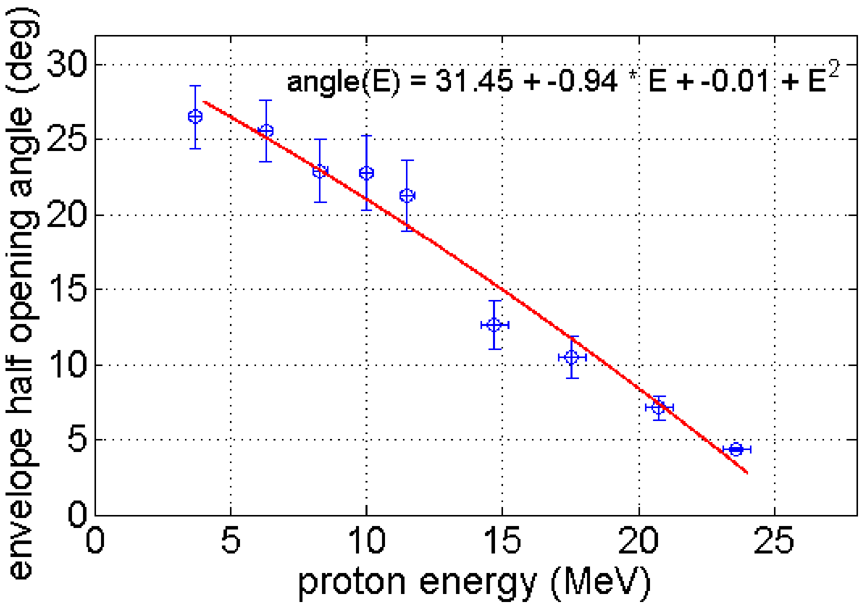


F. Nürnberg, PhD thesis TU Darmstadt (2010)

introduction: TNSA spectrum



- TNSA well understood and robust
- achievable cut-off energy today ~70MeV
- also heavier ions possible, e.g. carbon



LIGHT – the project

Laser Ion Generation, Handling and Transport

LIGHT – the project

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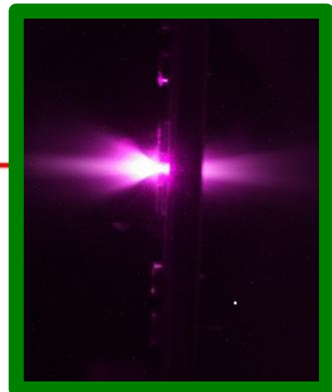
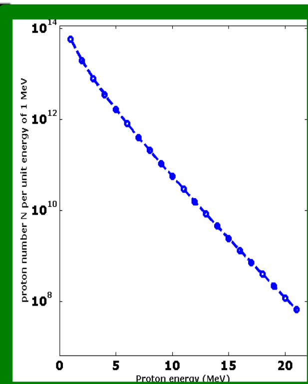


Laser Ion Generation, Handling and Transport

PHELIX 100 TW
- 15 J @ 1053 nm
- 650 fs
- $\geq 10^{19}$ W/cm²

LIGHT – the project



Laser Ion Generation, Handling and Transport

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TNSA mechanism
- high intensity ion beam
- exponential spectrum
- 100% energy spread
- large divergence

LIGHT – the project

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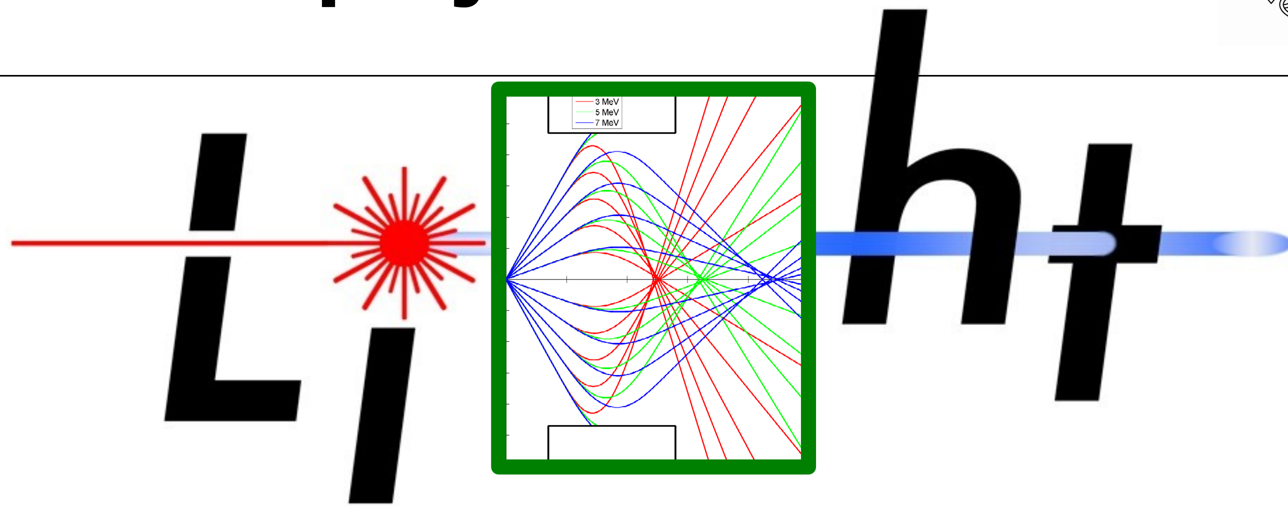

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PHELIX 100 TW
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TNSA mechanism
· high intensity ion beam
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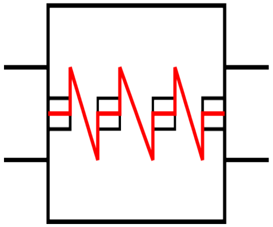
pulsed high field solenoid
· capture and transport
· energy selection

LIGHT – the project

1 MV total



Laser Ion Generation, Handling and Transport

PHELIX 100 TW
- 15 J @ 1053 nm
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TNSA mechanism
- high intensity ion beam
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pulsed high field solenoid
- capture and transport
- energy selection

rf cavity
- phase-space-rotation

LIGHT – the project

re-focussing

post-acceleration

injection

Laser Ion Generation, Handling and Transport

unique beam and hybrid technology testbed

$N = 10^{10}$ protons

$E = 10$ MeV

$\tau \approx$ ns / sub-ns

$\Delta E < 4\%$

LIGHT – location

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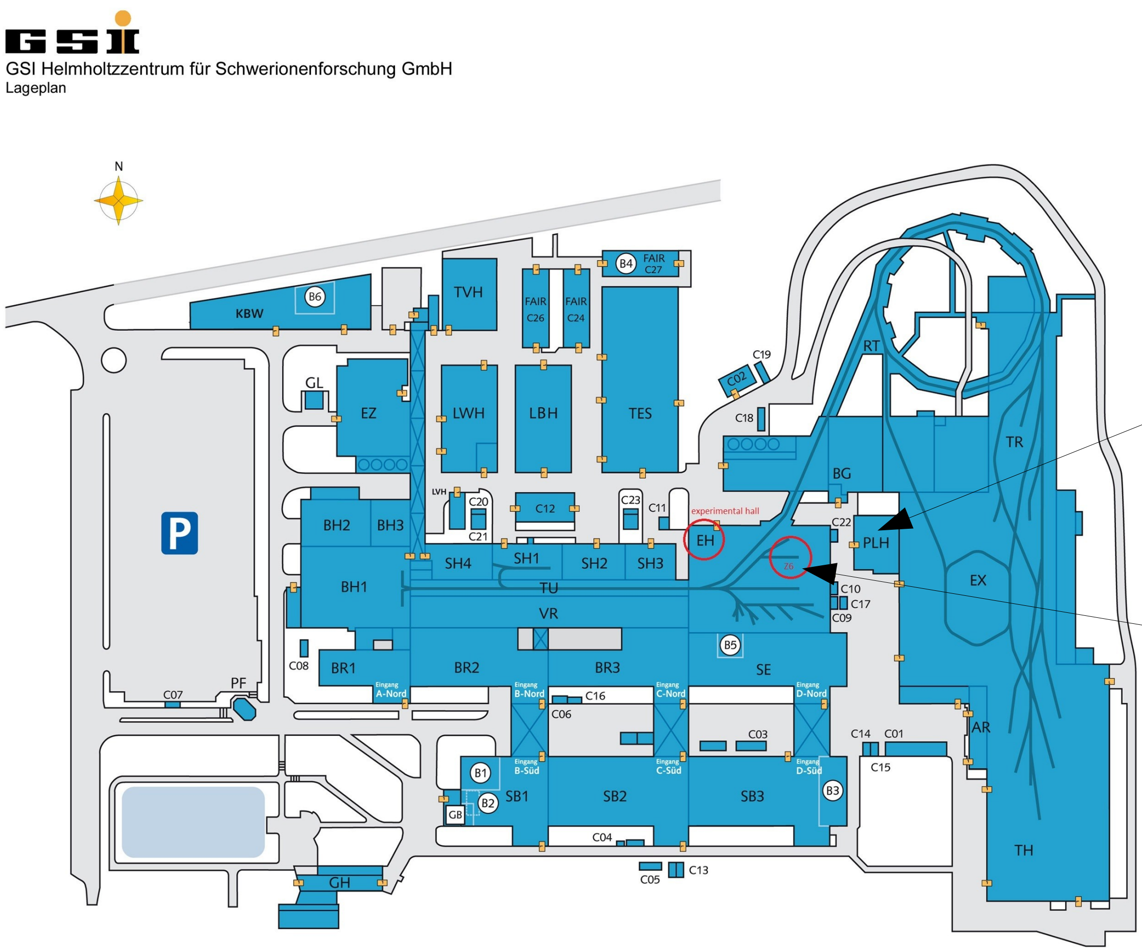

PHELIX laser bay

Z6 experimental area

LIGHT – location

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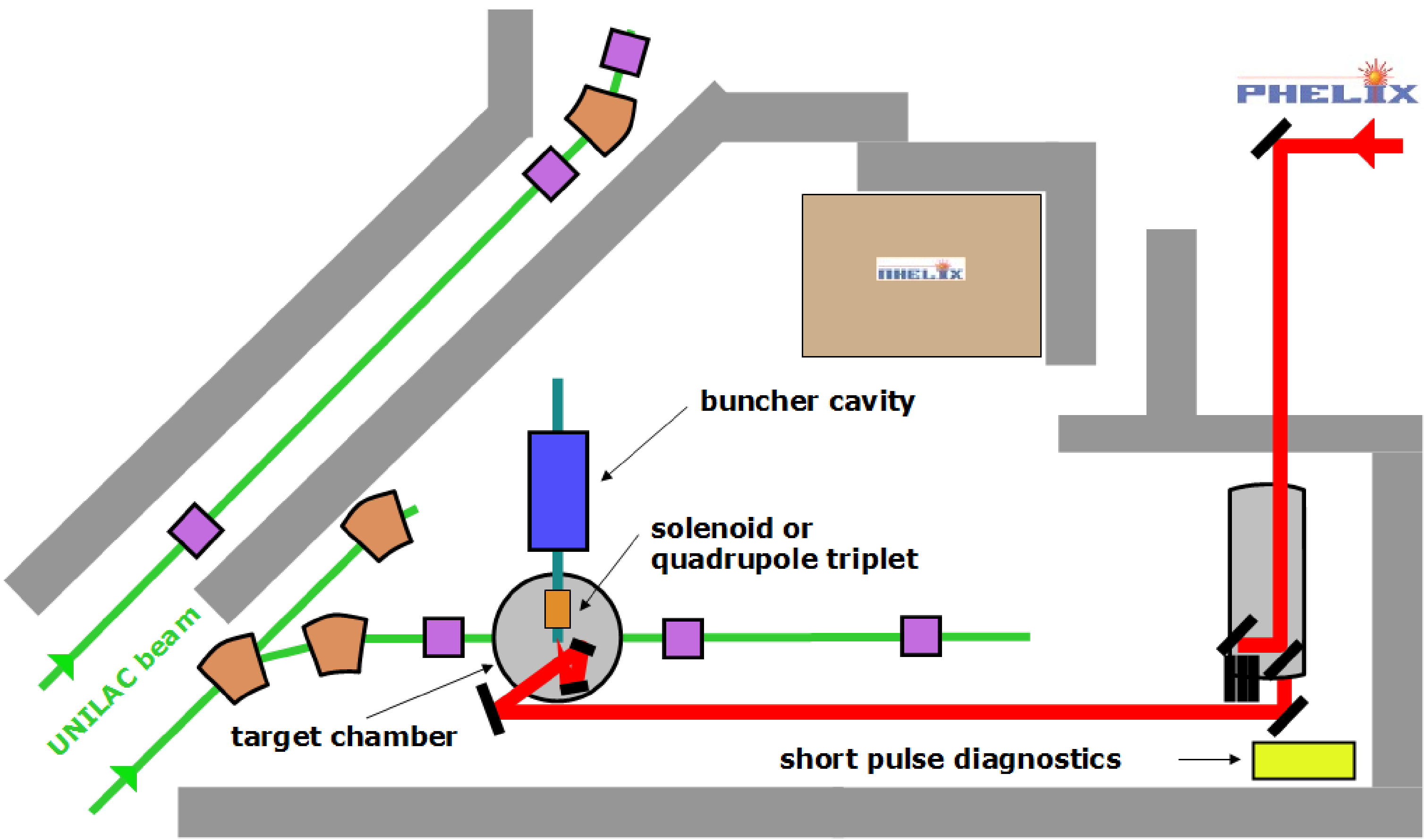

LIGHT – overview

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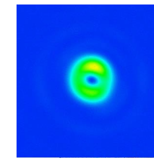
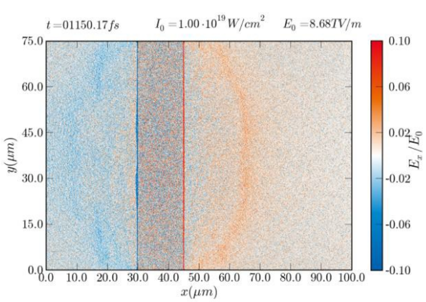
detailed simulation studies

- ab initio PIC (EPOCH, VORPAL, LASIN)
- beam transport (TraceWin, DYNAMION)
- post-acceleration studies

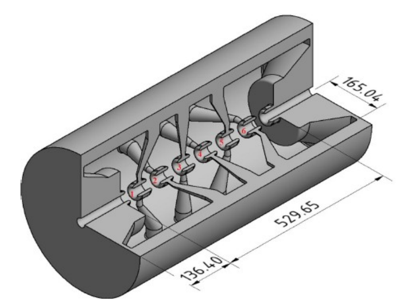
experimental work



- divergence reduction via laser focus shaping
- beam optimization via target design
- new acceleration mechanisms (BOA, RPA)



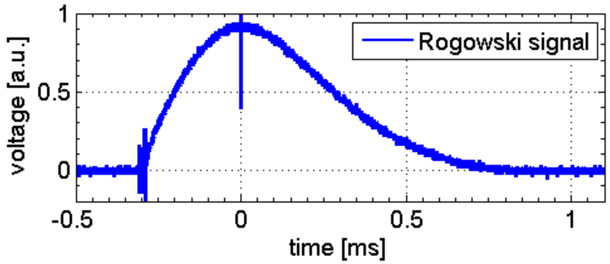
- I. Hofmann et al., PR-STAB 14, 031304 (2011)
- T. Burris-Mog et al., PR-STAB 14, 121301 (2011)
- A. Almomani et al., PR-STAB 15, 051302 (2012)
- I. Hofmann et al., NIM-A 681, 44 (2012)
- I. Hofmann, PR-STAB 16, 041302 (2013)
- G. Hofmeister et al., PR-STAB 16, 041304 (2013)
- S. Busold et al., paper in preparation
- Z. Lecz et al., paper in preparation



solenoid

solenoid & pulsed power

stand alone pulsed power system



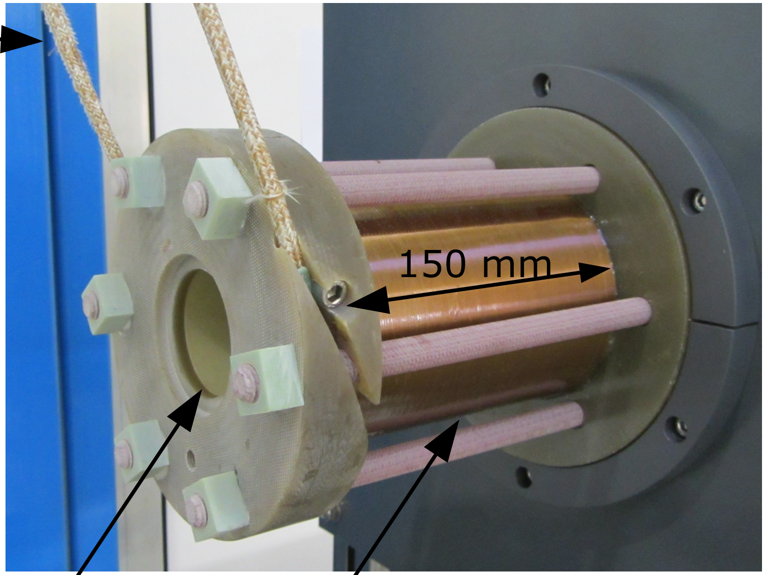
· possible charging up to 16 kV, driving...

· ...up to **10.4 kA current** through critically damped LC circuit within about 1 ms...

· ...resulting in $B_{z,max}$ = 8.7 T in solenoid

· large open aperture for high capture efficiency

current supply cables

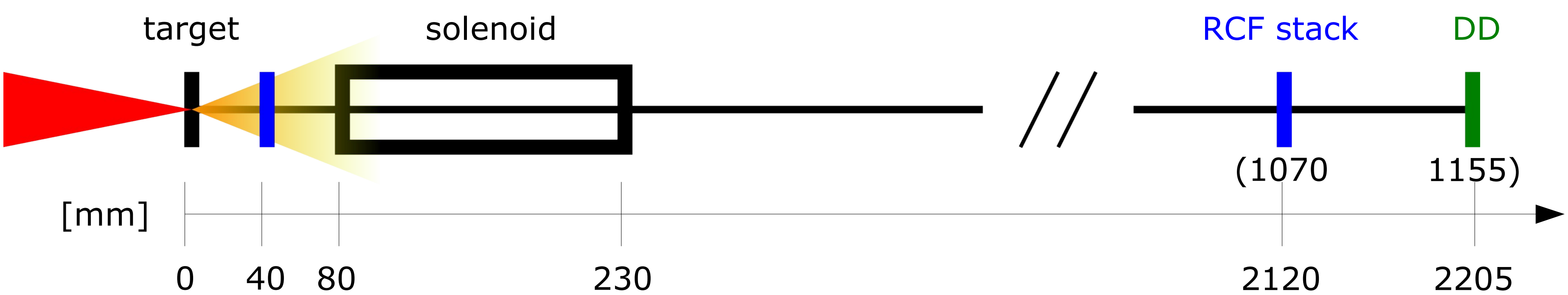


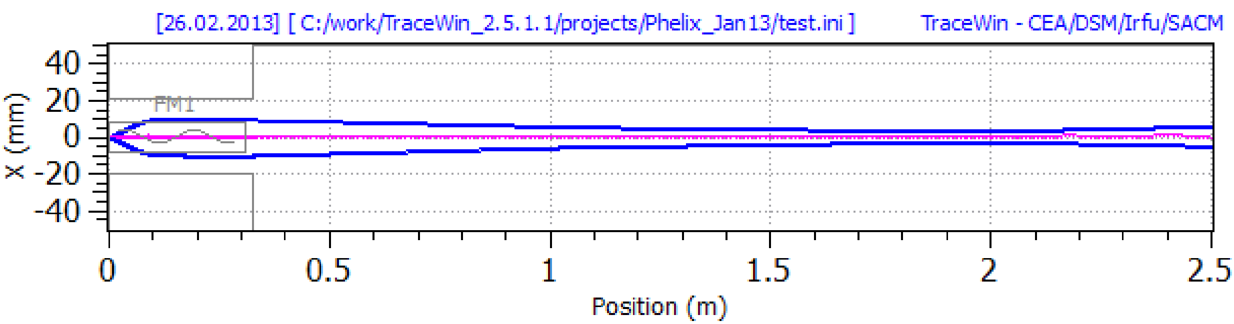
40.5 mm open aperture

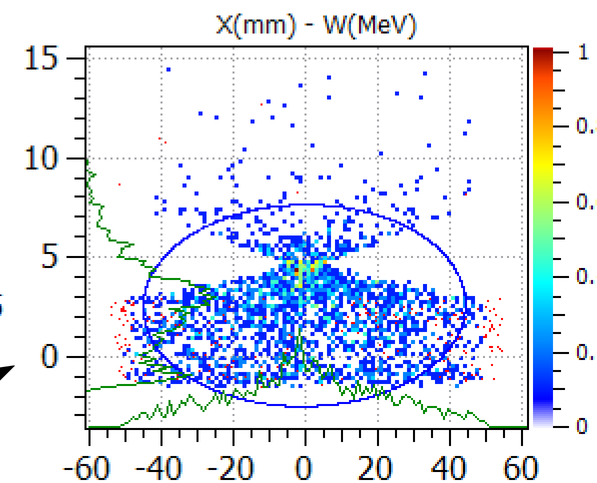
4 layers copper windings

experimental setup

laser (RCF stack)



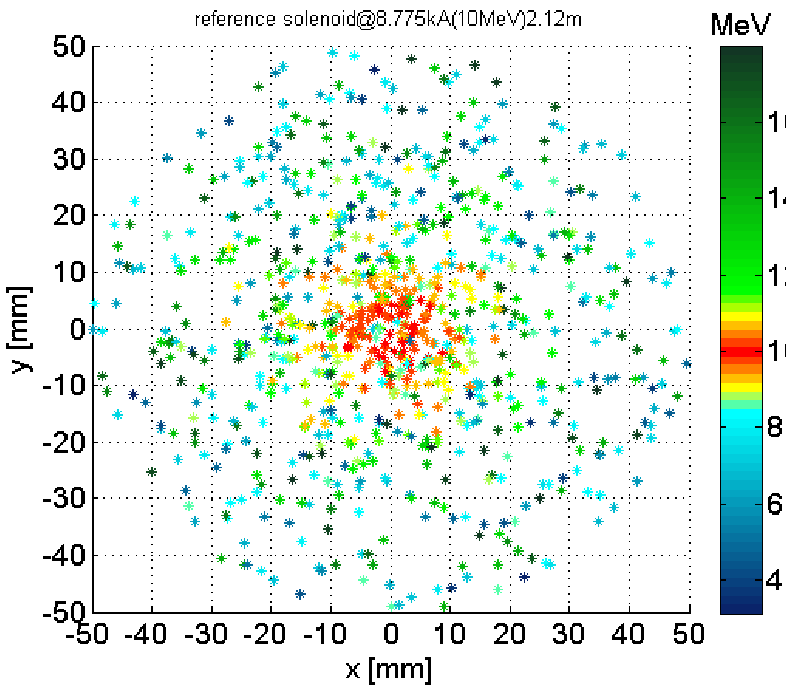


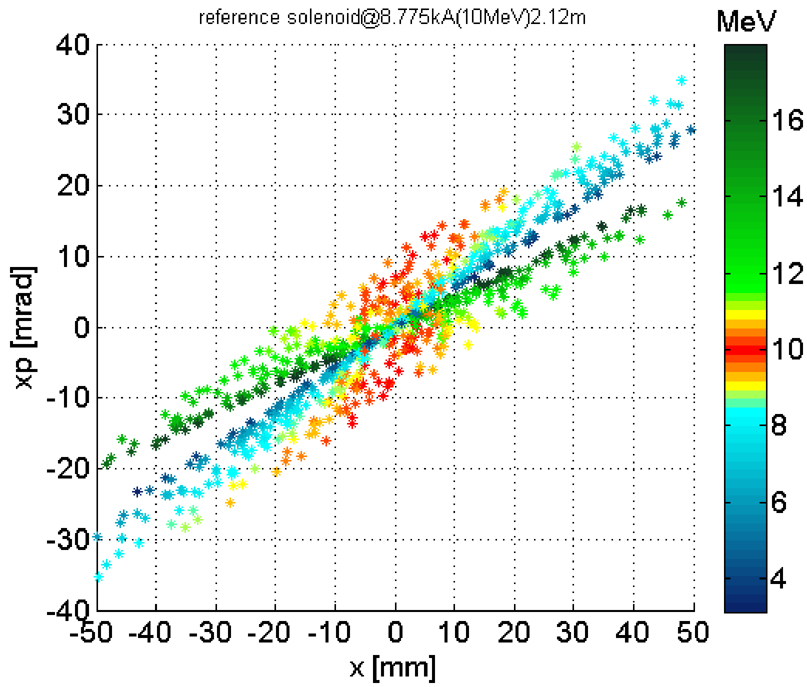


0=5.5

simulation – solenoid

focussing @2.12m distance to source





experimental setup – detectors

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RCF

RadioChromic Film in stacked configuration

- film with proton-sensitive layer
    - blue coloring
- **very high spacial resolution**
- used in stack configuration
    - Bragg peak of different energies in different layers
- full characterisation of laser-accelerated proton beam possible

DD

Diamond Detector

- 20µm thin diamond
- 4 4x4mm² segments
- time of flight measurement
- protons pass through and excite electron-hole pairs
- **high time resolution**

- F. Nürnberg et al., RSI 80, 033301 (2009)

experimental results – solenoid

transport through solenoid

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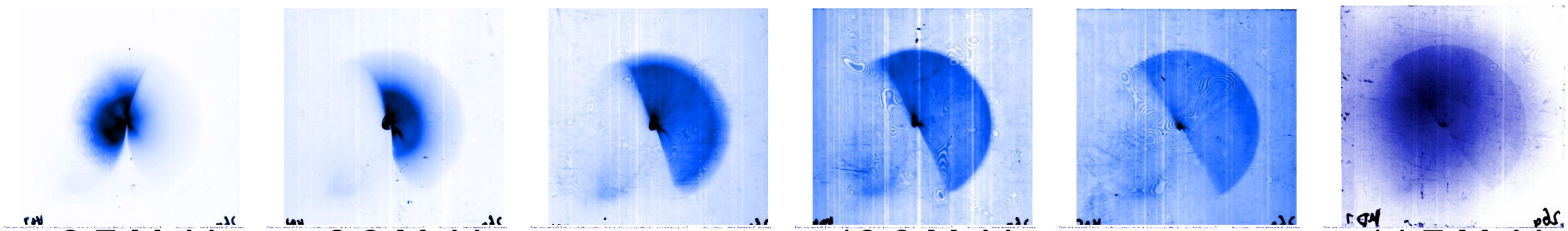
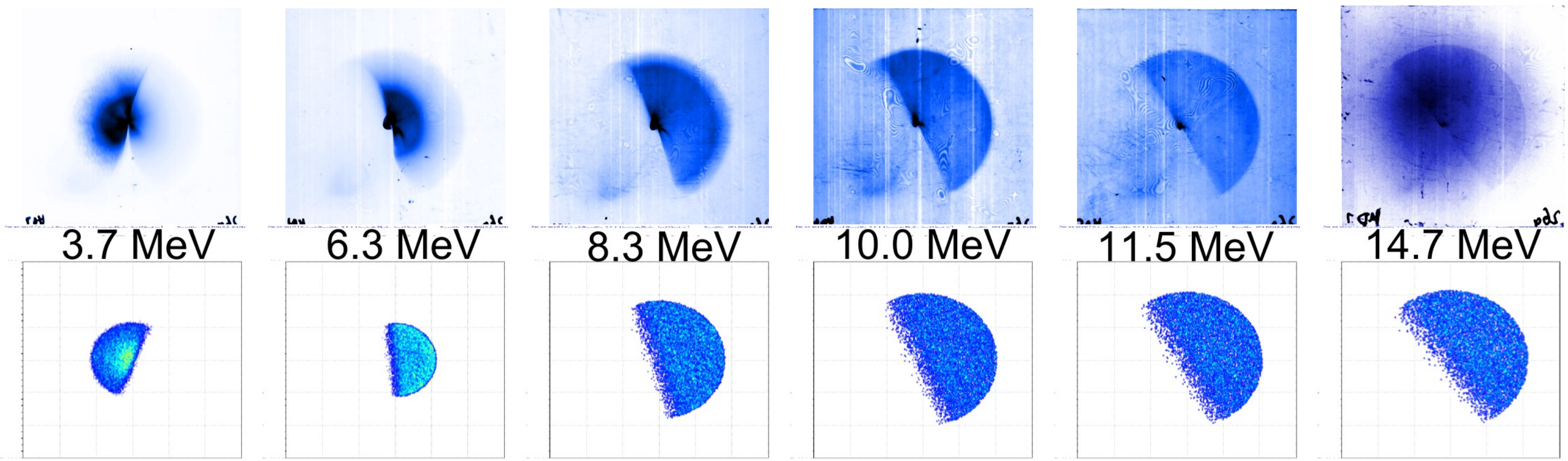


3.7 MeV | 6.3 MeV | 8.3 MeV | 10.0 MeV | 11.5 MeV | 14.7 MeV

- RCF stack at 36.8 cm behind target
- 20% transmission at targeted energy (10 MeV)
- 25% transmission for ideal Gauß

experimental results – solenoid

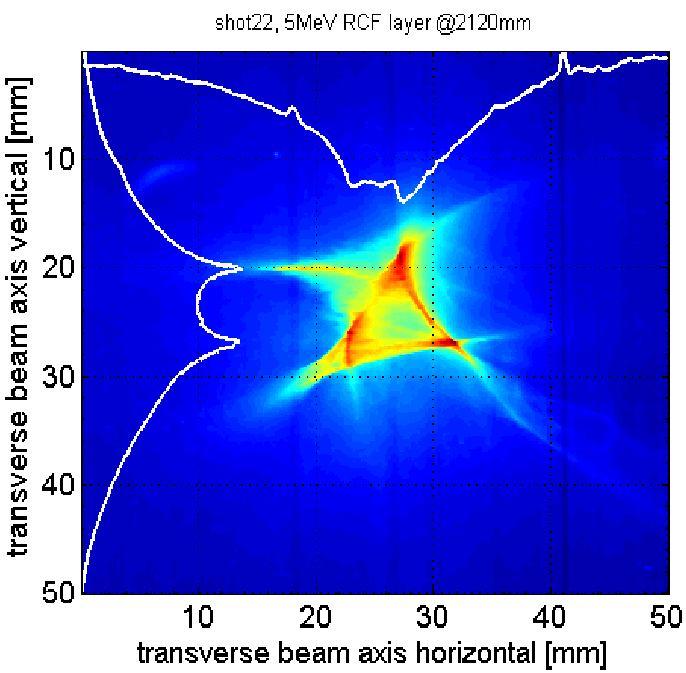
transport through solenoid

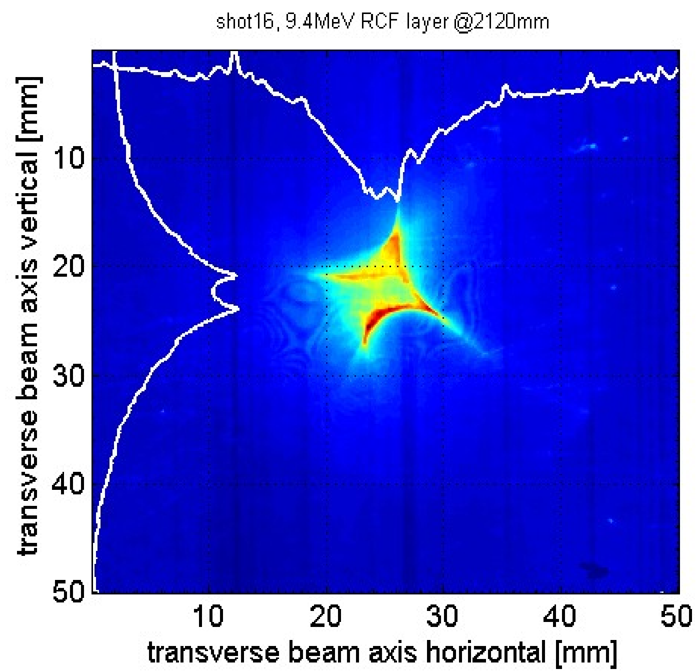


- RCF stack at 36.8 cm behind target
- 20% transmission at targeted energy (10 MeV)
- 25% transmission for ideal Gauß
- beam size and rotation angle fit very good to simulations

experimental results – solenoid

focussing @2.12m distance to source





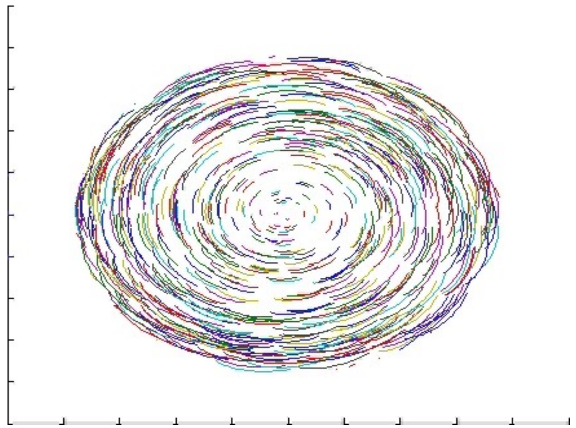
focusing of 5MeV protons
· about 2.2e9 particles

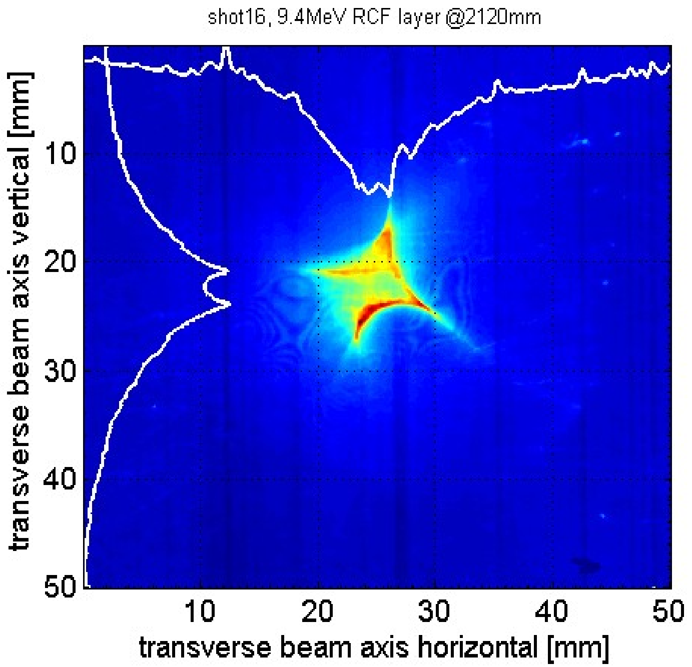
focusing of 10MeV protons
· about 5e8 particles

· focal shape due to imperfect solenoid field
· higer energies contribute to background

experimental results – solenoid

focussing @2.12m distance to source





simulation based on realistic solenoid wire-arrangement...

focusing of 10MeV protons
· about 5e8 particles

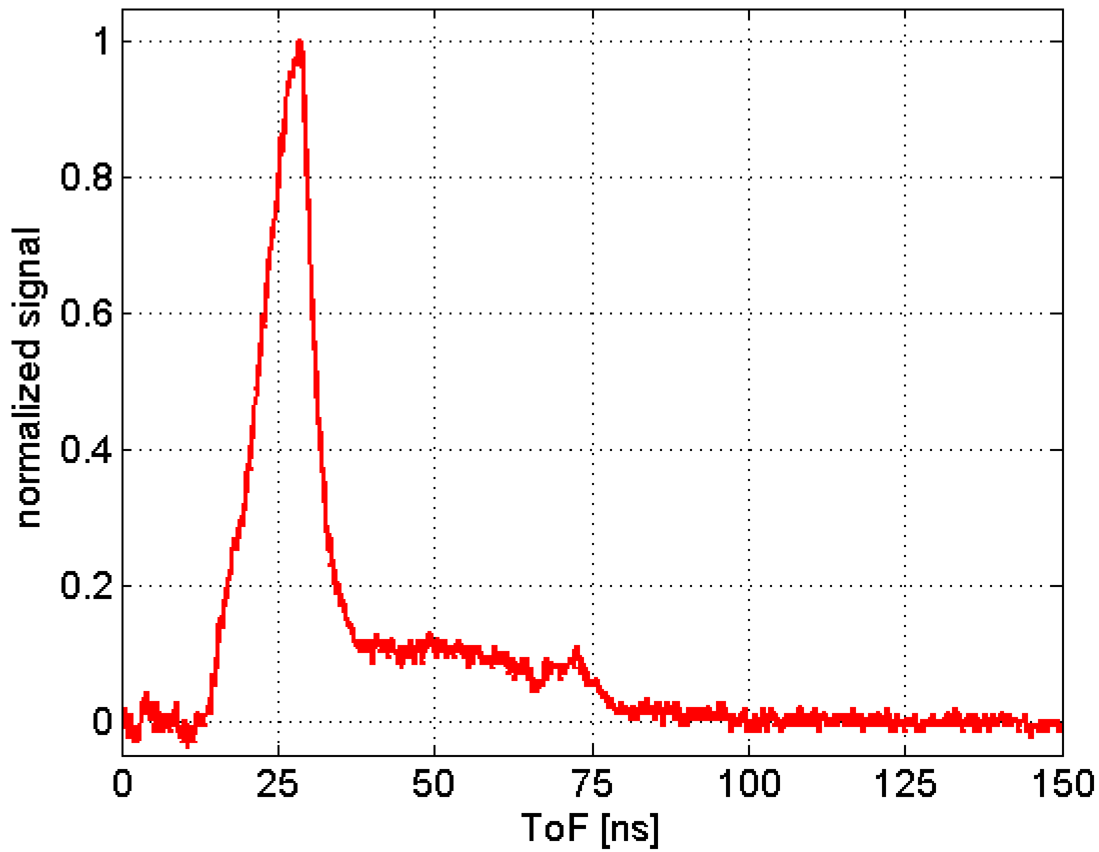
· focal shape due to imperfect solenoid field
· higer energies contribute to background

experimental results – solenoid

focussing @2.12m distance to source

Diamond Detector (DD)
for ToF measurement

→ very high temporal resolution



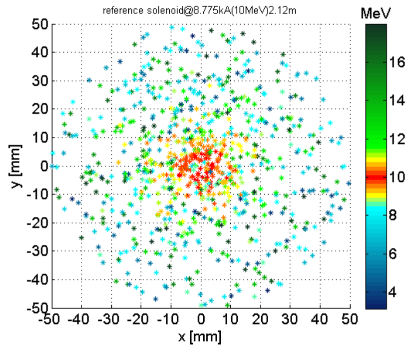
experimental results – solenoid

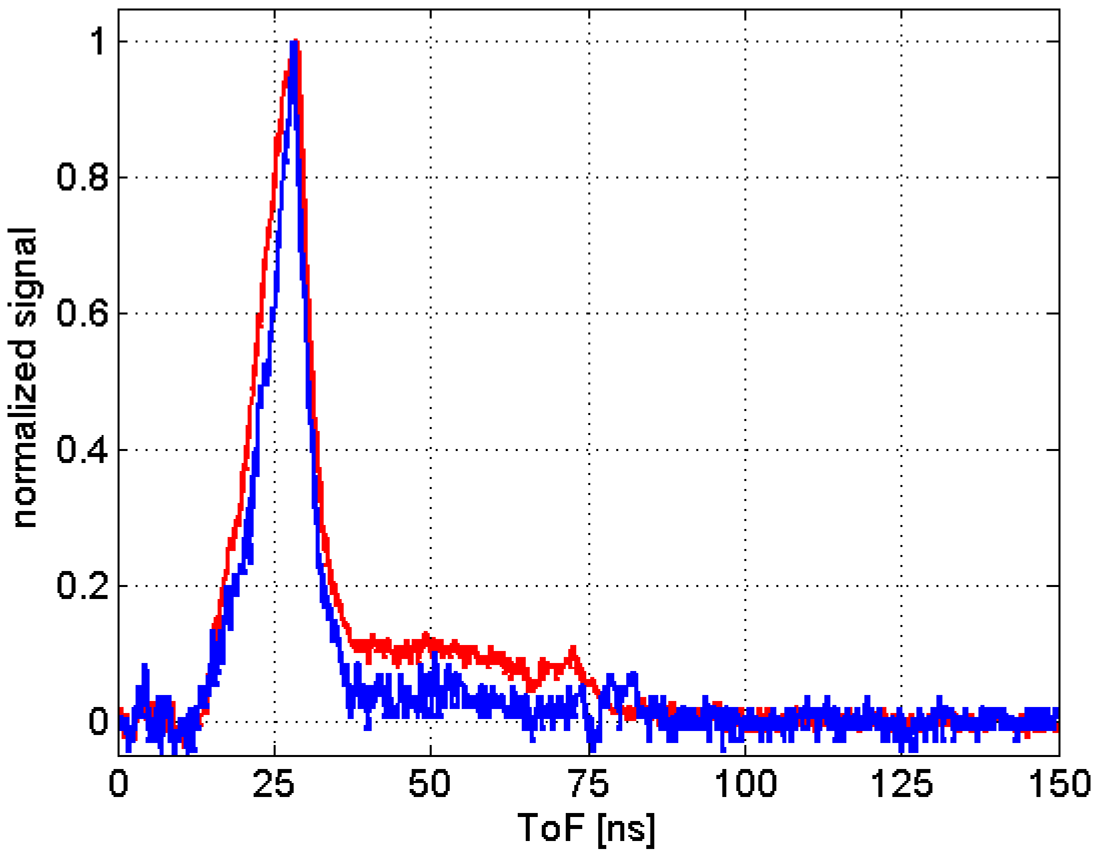
focussing @2.12m distance to source

Diamond Detector (DD) for ToF measurement

→ very high temporal resolution

→ visible effect of applying an aperture (5mm diameter) at the focal position





experimental results – solenoid

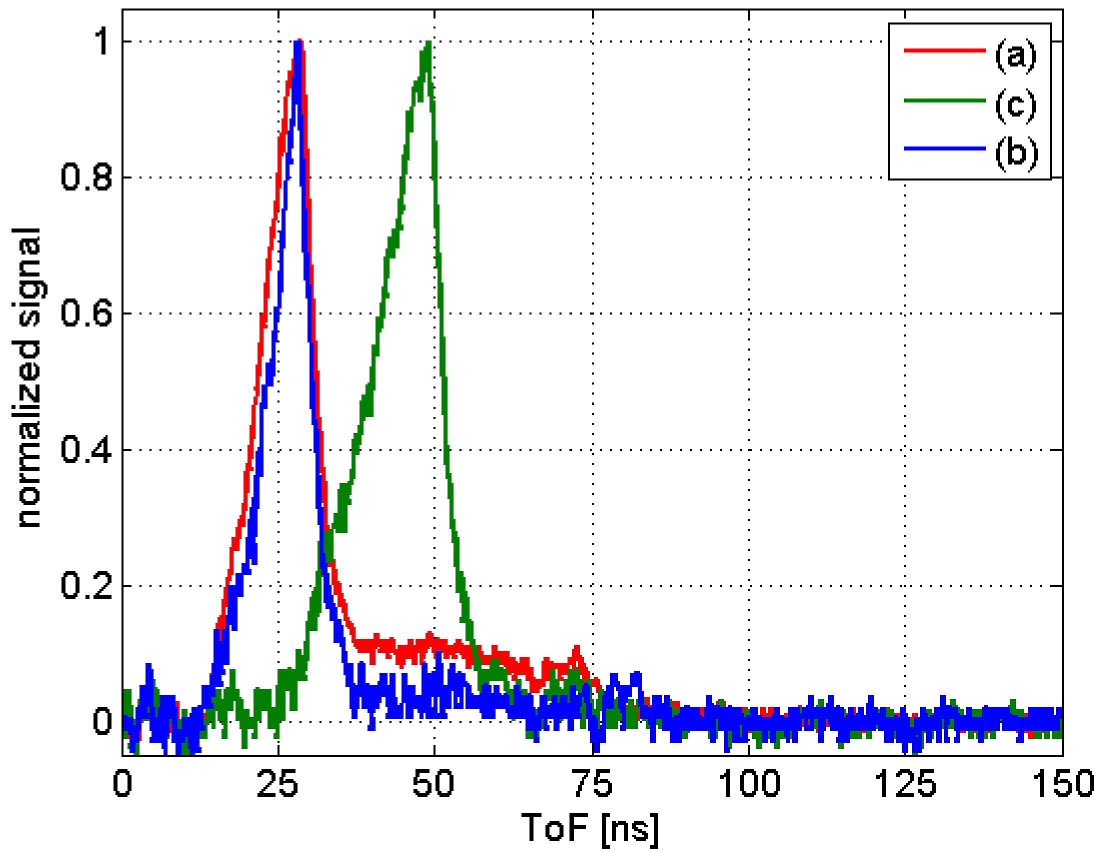
focussing @2.12m distance to source

Diamond Detector (DD)
for ToF measurement

→ very high temporal resolution

→ visible effect of applying an aperture (5mm diameter) at the focal position

→ clear peak at the focused proton energy



experimental results – solenoid

focussing @2.12m distance to source

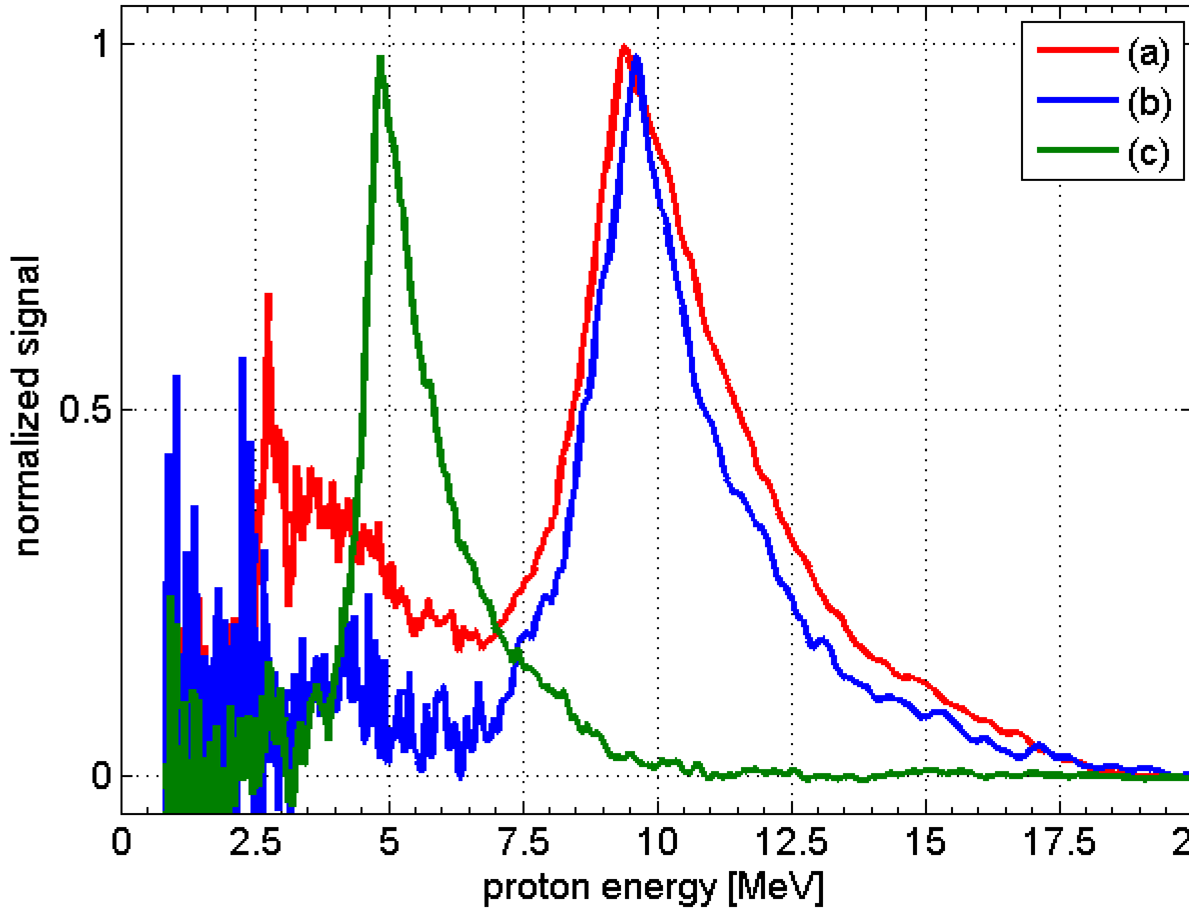
Diamond Detector (DD)
for ToF measurement

→ very high temporal resolution

→ visible effect of applying an aperture (5mm diameter) at the focal position

→ clear peak at the focused proton energy

→ translation into energy via ToF



experimental results – solenoid

focussing @2.12m distance to source

Diamond Detector (DD) for ToF measurement

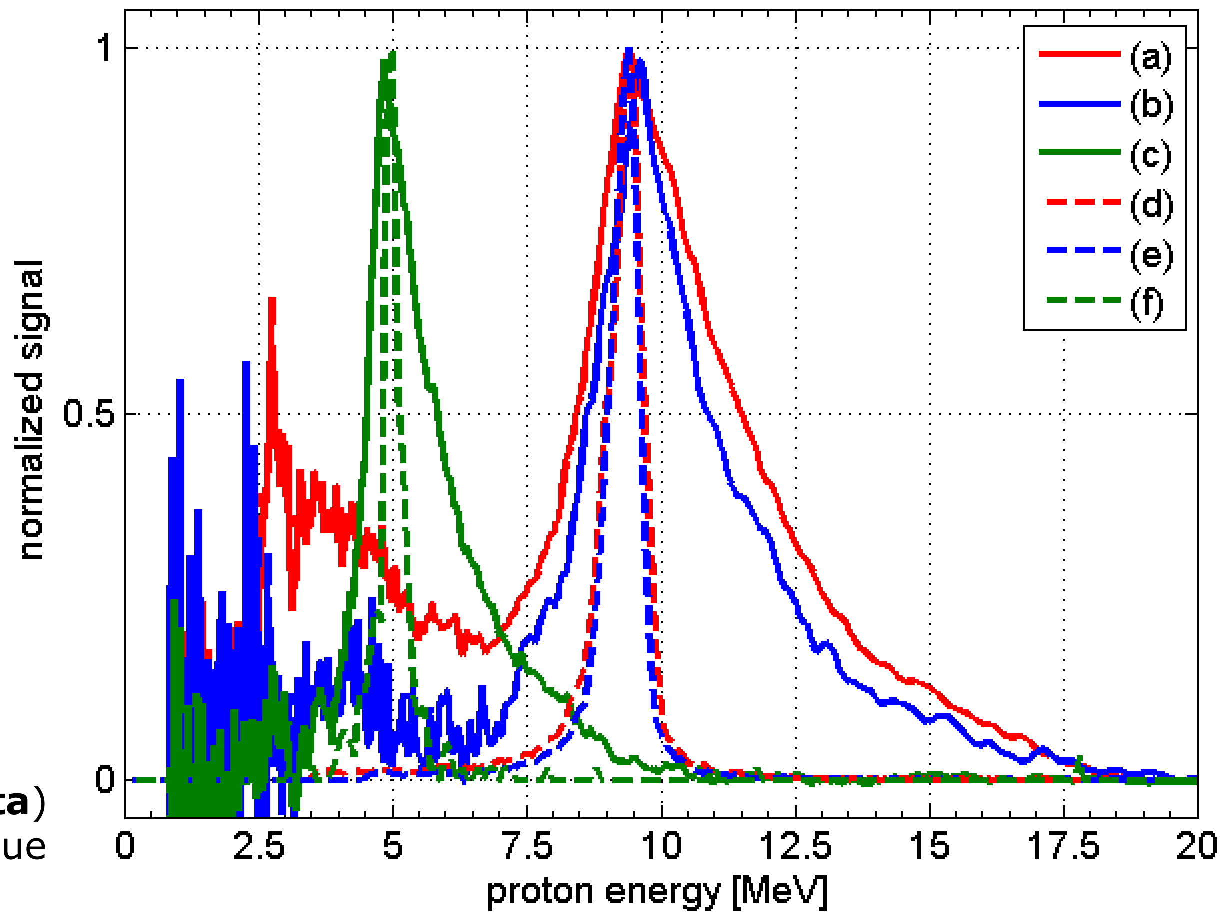
→ very high temporal resolution

→ visible effect of applying an aperture (5mm diameter) at the focal position

→ clear peak at the focused proton energy

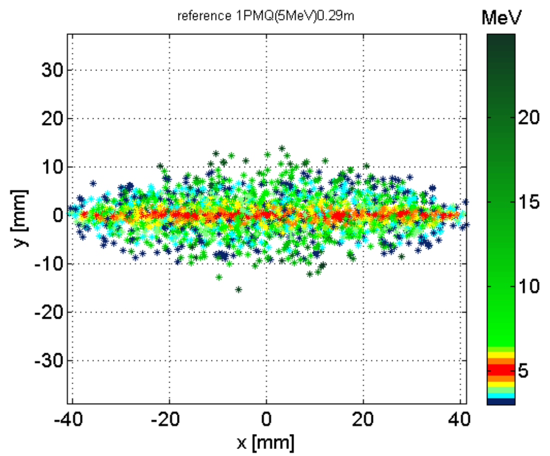
→ translation into energy via ToF

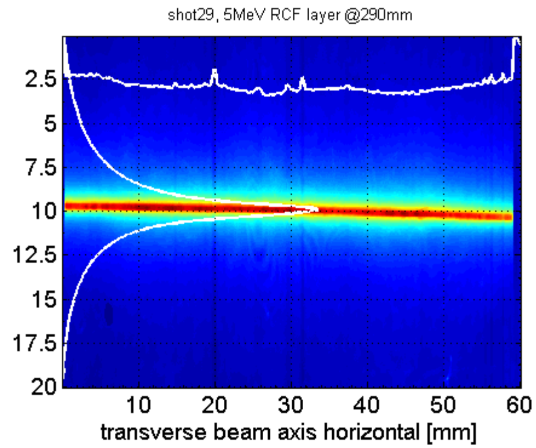
→ simulations (**and RCF data**) reveal non-linear response due to high intensity

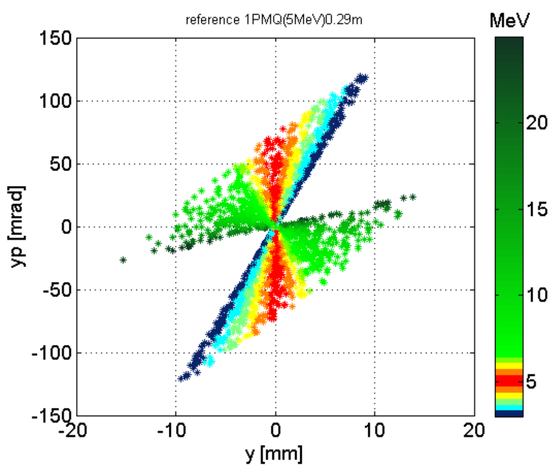


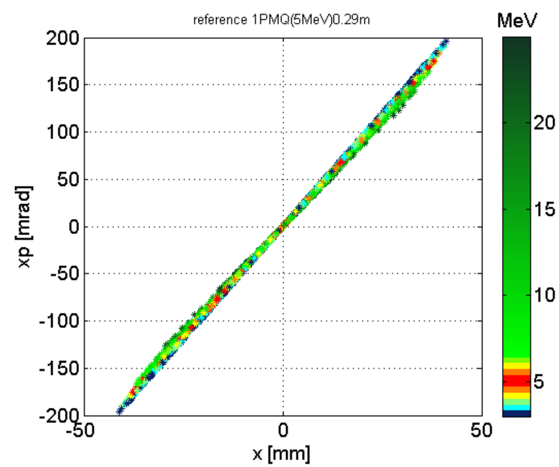
quadrupoles

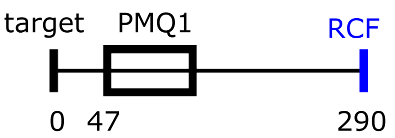
alternative: PMQs











permanent magnetic quadrupoles (PMQs)

- 80 mm length
- 85 T/m field gradient
- open aperture of 24 mm diameter

experimental setup – doublet

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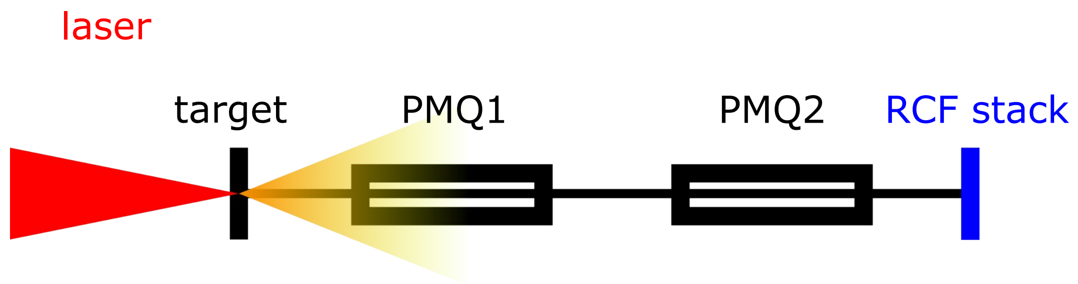
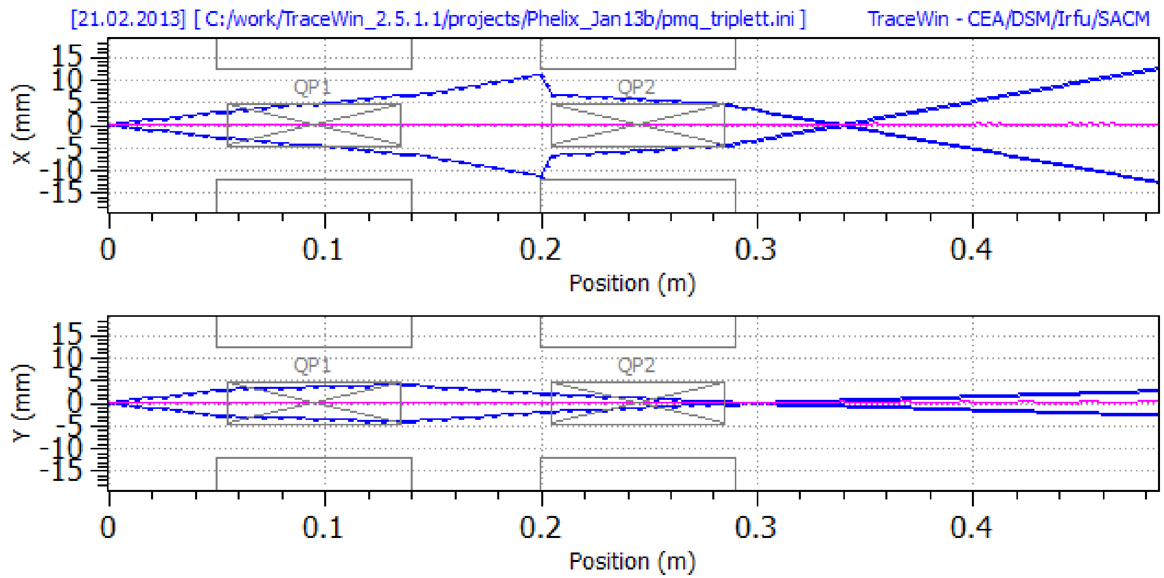
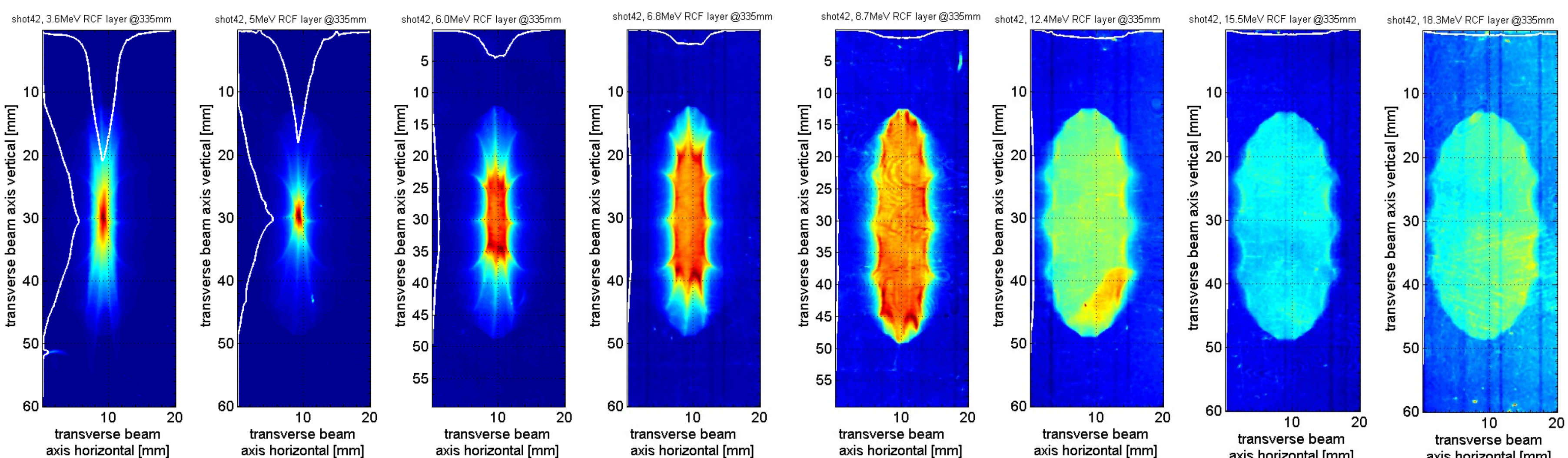




experimental results - doublet

comparison experiment to TraceWin simulation



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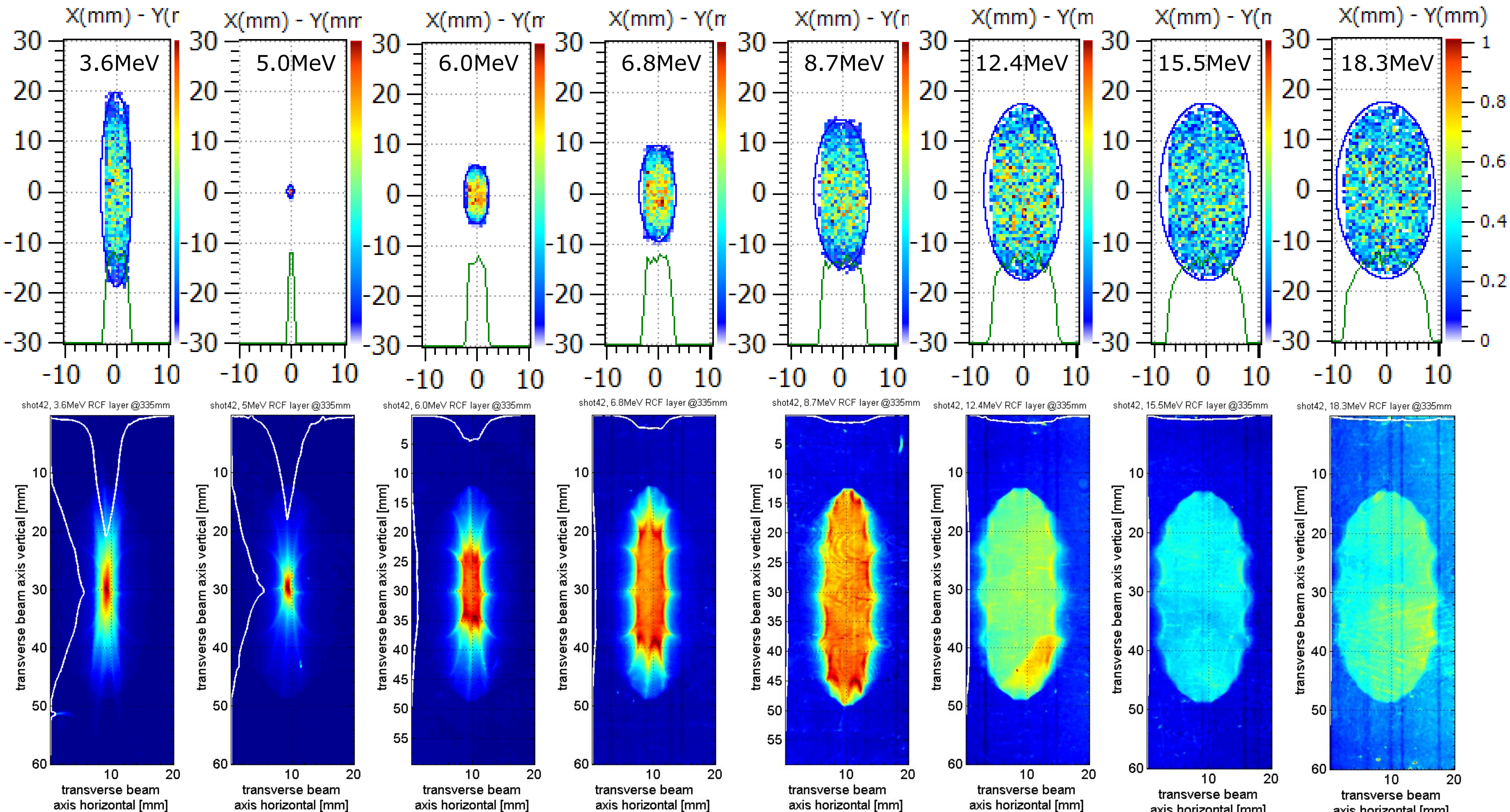
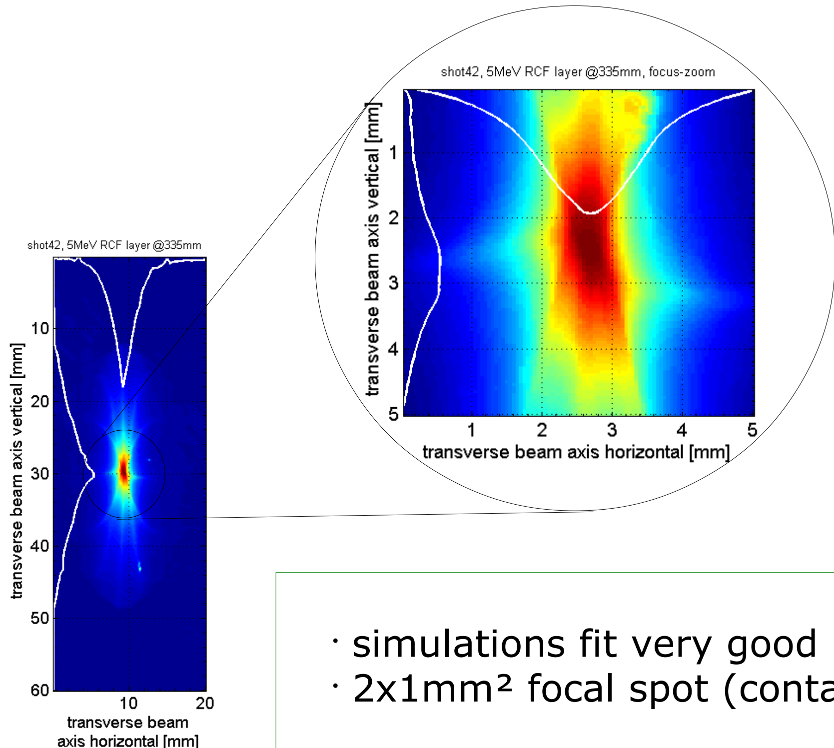
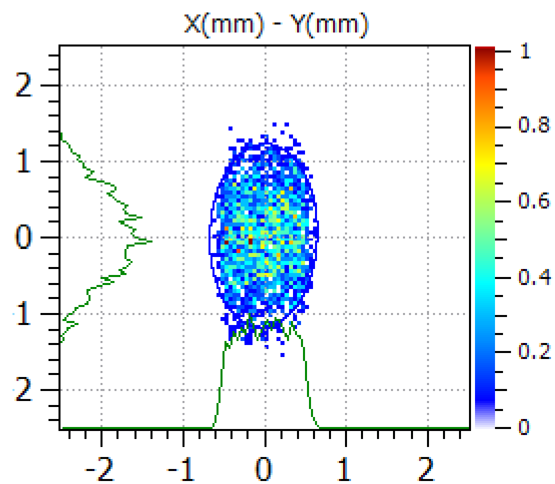


experimental results - doublet

focal spot analysis





- simulations fit very good
- 2x1mm² focal spot (containing about 1e9 protons)

Summary

- **PHELIX sub-aperture beam at Z6 provides for efficient proton acceleration**
  - max. proton energies of 28.4 MeV
- **focusing of 5MeV/10MeV protons at 1m/2m distance from source demonstrated**
  - 5mm focus at 1m
  - 10mm focus at 2m
  - temporal bunch structure
  - particle numbers >1e9 now. 1e10 possible
- **exploration of PMQs as possible alternative to pulsed solenoid**
  - compact, easy handling
  - better optical qualities

Outlook

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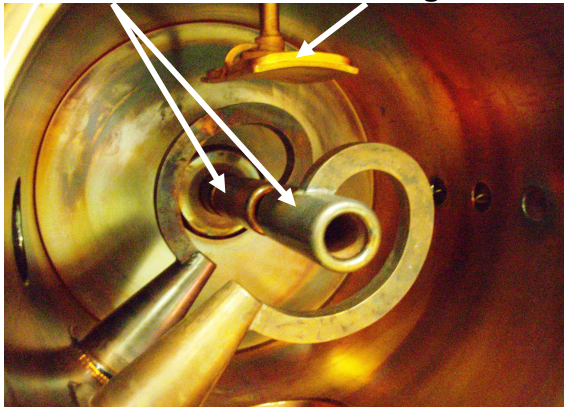
- parallel work by the GSI Linac group:
- ✓ rf cavity specified and tested
  3 gap spiral resonator,
  rebuncher at 108.4 MHz,
  35 mm aperture,
  1 MV



- **installation of cavity is currently in progress**

- next beamtime in July 2013
  → **demonstrate phase rotation**

- further exploration of the possibilities of PMQs

- future: **1. provide beam for secondary experiments and injection**
  2. higher proton energies, heavier ions

Thanks

Thank you for your attention!

Questions?

The LIGHT collaboration:

Ali Almomani[4], Husam Al-Omari[4], Vincent Bagnoud[2,6], Winfried Barth[2], Abel Blazevic[2], Oliver Boine-Frankenheim[2,3], Christian Brabetz[4], Trevor Burris-Mog[5], Simon Busold[1], Tom Cowan[5], Oliver Deppert[1], Martin Droba[4], Peter Forck[6], Amrutha Gopal[6], Thomas Herrmannsdörfer[5], Sven Herzer[6], Gabi Hoffmeister[1], Ingo Hoffmann[2,6], Oliver Jäckel[6], Malte Kaluza[6], Florian Kroll[5], Anna Orzhekovskaya[2], Ulrich Ratzinger[4], Markus Roth[1], Peter Schmidt[3], Ulrich Schramm[5], Dennis Schumacher[2], Thomas Stöhlker[2,6], Andreas Tauschwitz[2], Wolfgang Vinzenz[2], Stephan Yaramishev[2], Bernhard Zielbauer[2,6] und Lecz Zsolt[3] — [1]TU Darmstadt, IKP, Schlossgartenstr. 9, 64289 Darmstadt — [2]GSI Helmholtzzentrum für Schwerionenforschung, Planckstr. 1, 64291 Darmstadt — [3]TU Darmstadt, TEMF, Schlossgartenstr. 8, 64289 Darmstadt — [4]JWG Universität Frankfurt, IAP, Max von Laue Str. 1, 60438 Frankfurt — [5]Helmholtzzentrum Dresden-Rossendorf, Bautzner Landstr. 400, 01328 Dresden — [6]Helmholtzinstitut Jena, Helmholtzweg 4, 07743 Jena

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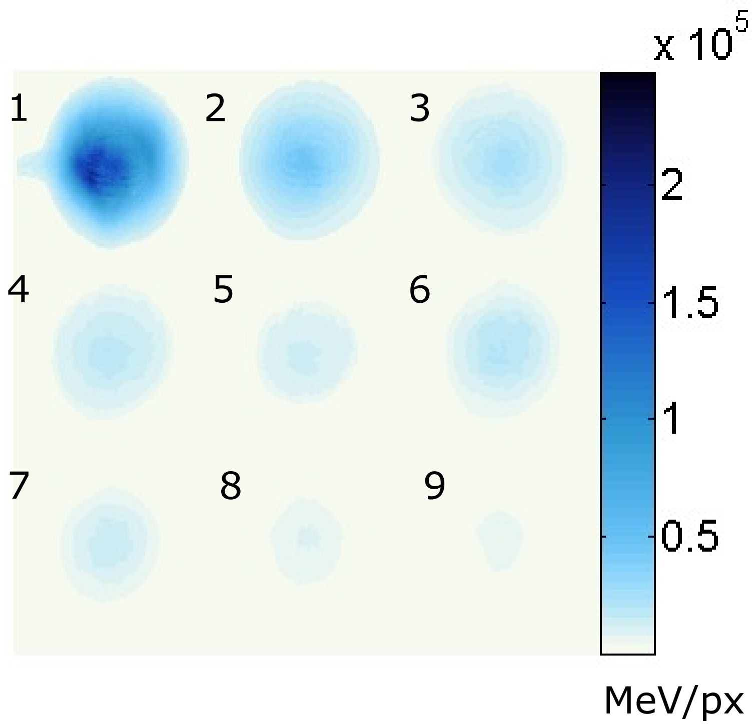
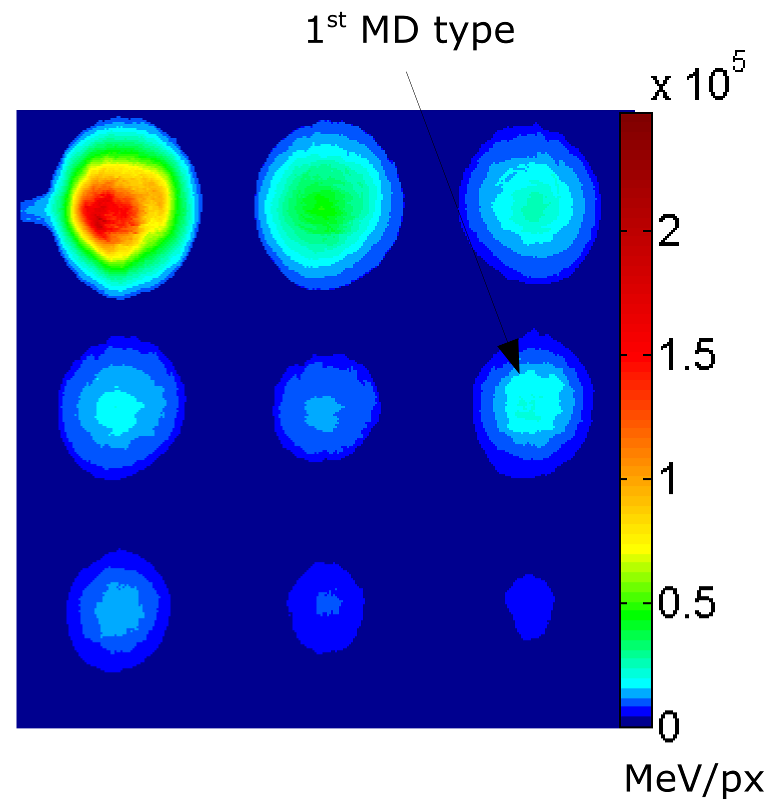
RCF – method

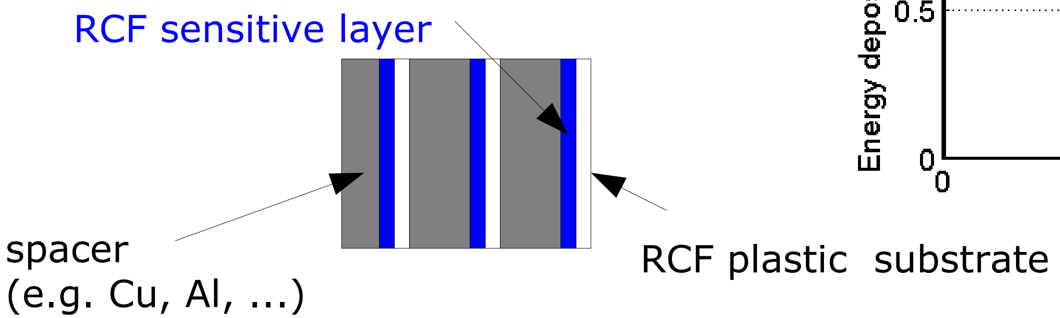


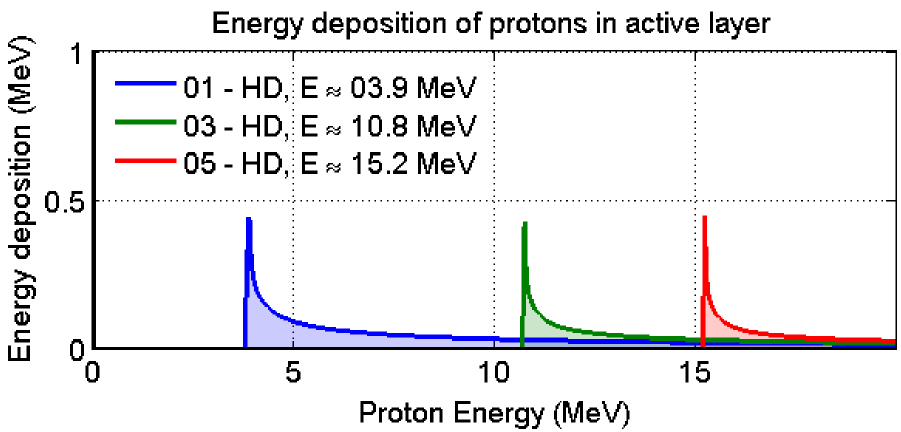


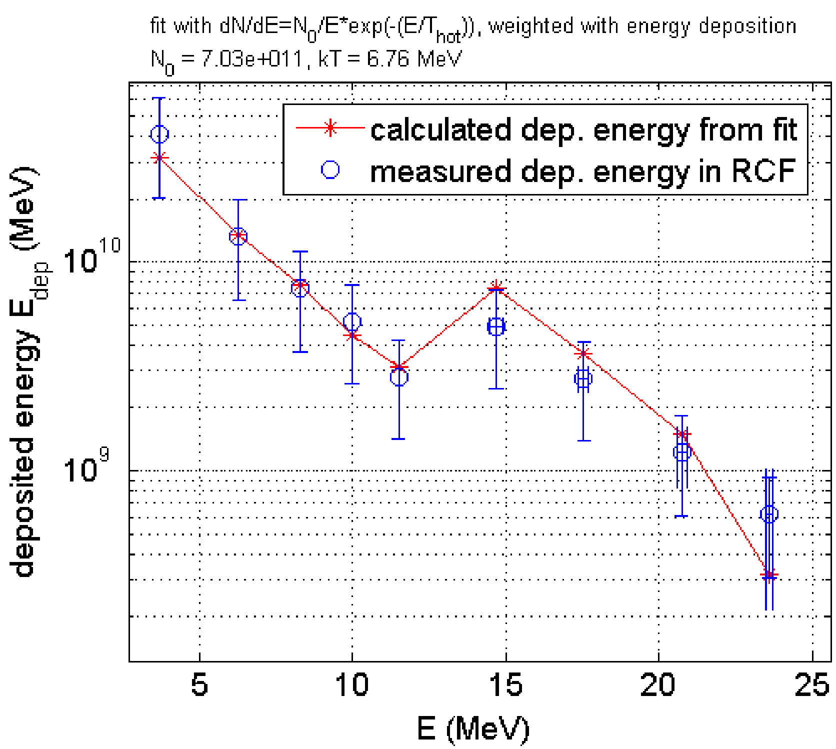
backup slides

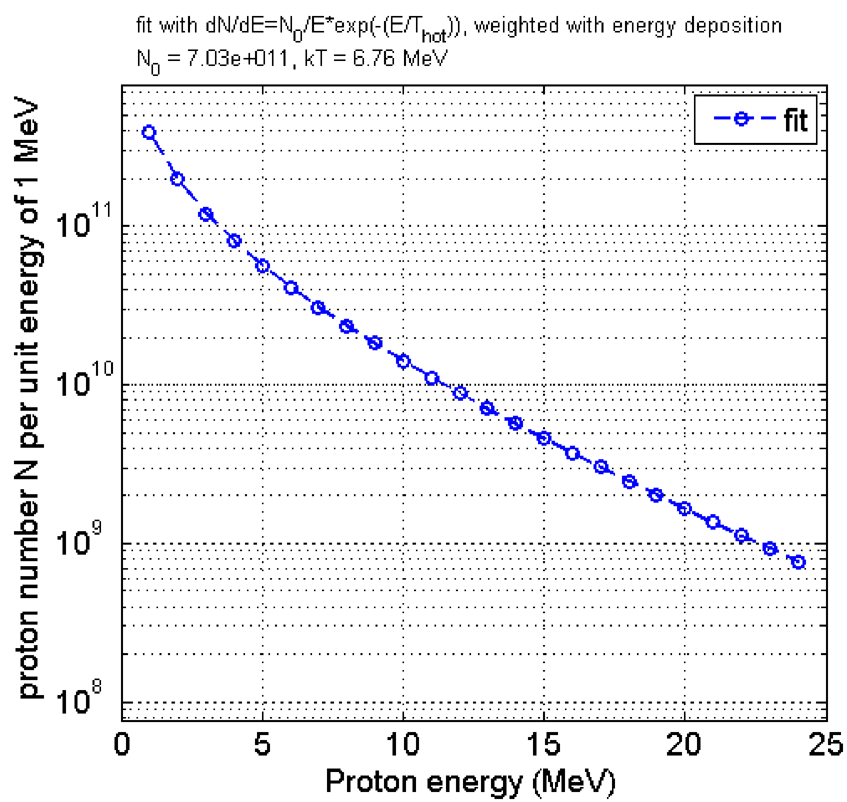
RCF – method

RIS, see F. Nürnberg et al.,
Rev. Sci. Instr. **80**, 033301 (2009)





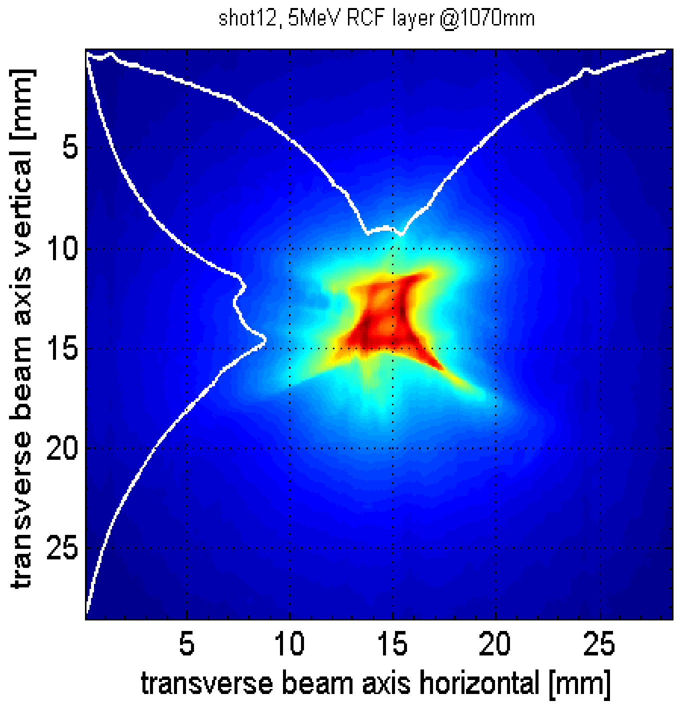


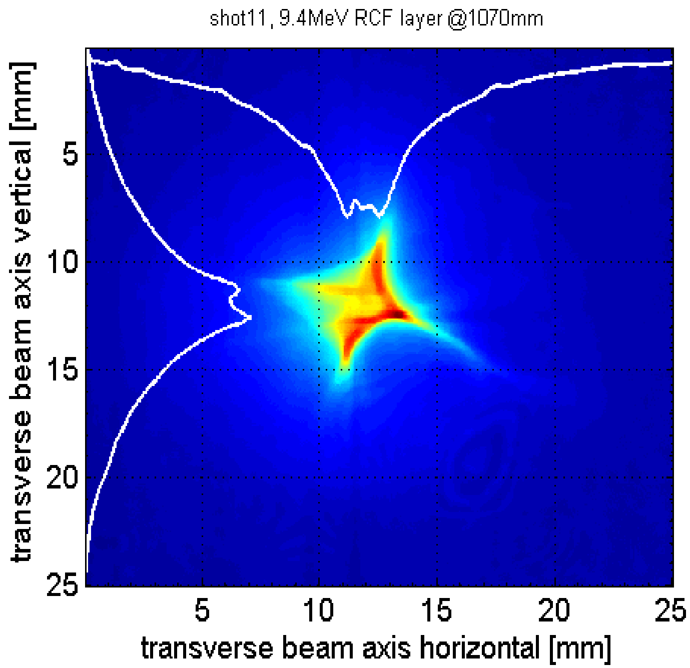


backup slides

experimental results – RCF

focussing @1.07m distance to source





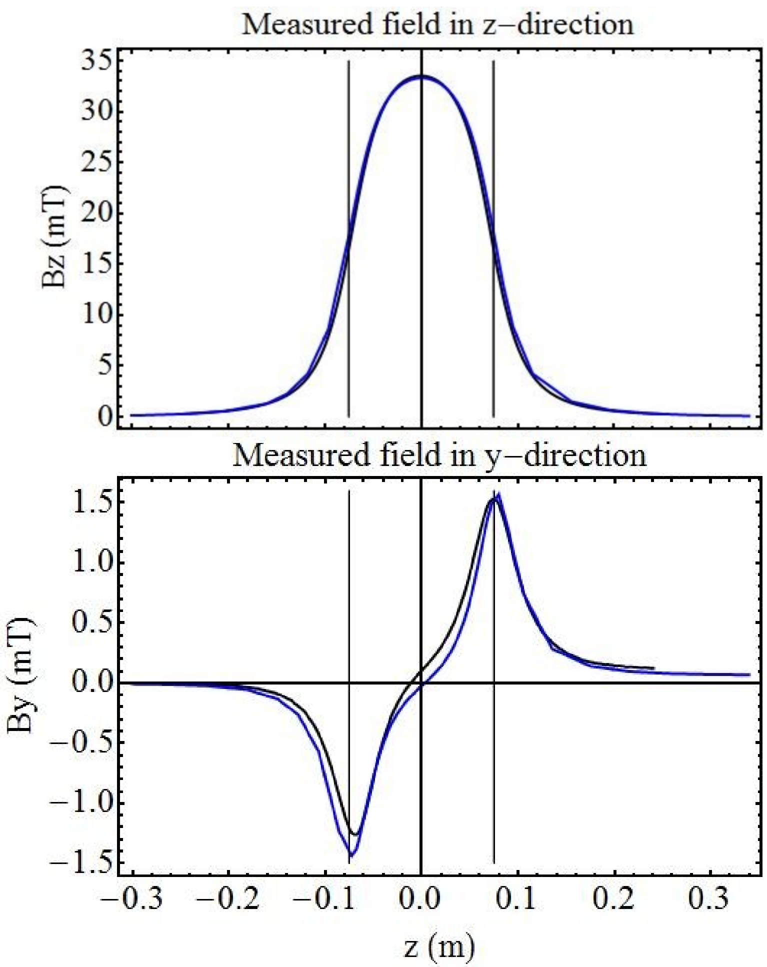
focusing of 5MeV protons
· about 2e9 particles

focusing of 10MeV protons
· about 1e9 particles

· focal shape due to imperfect solenoid field
· higer energies contribute to background

backup slides

Solenoid: B Field Simulation



measured
simulated

detailed **simulation study with CST**

→ dynamic effects

· very good agreement in z (and x) direction
· still good agreement in y direction, cable influence clear
· choosing the right timing makes eddy currents neglegible

courtesy of P. Schmidt

Laser Ion Generation, Handling and Transport

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pspec