Pixel detectors for laser-accelerated proton beams

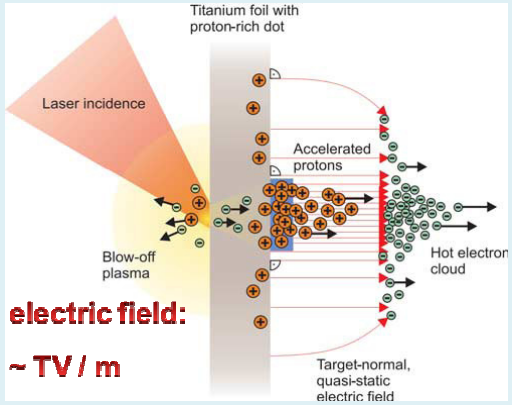
Sabine Reinhardt[a], Carlos Granja[b], Frantisek Krejci[b], Walter Assmann[a]

a) Fakultät für Physik, Ludwig-Maximilians-Universität München, Germany
b) Institute of Experimental and Applied Physics, Czech Technical University in Prague, Czech Republic

Outline

- *Motivation*
- *Detector systems*
  - *Timepix (scientific system)*
    - ➢ *collaboration with IAEA CTU Prague*
  - *RadEye (commercial system)*
- *Conclusion*
- *Outreach*

Principle of laser-driven acceleration (LDA) :



Schwoerer et al, Nature 439 (2006)

fs - laser pulse →

intense ns - ion pulses (> 10^7 p/cm²)

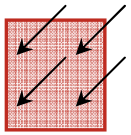
State of the art detectors:

non-electronic (film, CR39, image plate) → poster

Urgent need for real-time detectors!

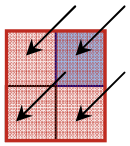
What about pixel detectors as beam monitors?

- real time measurement
- excellent spatial resolution
- good energy resolution



A, N

$$\Phi = \frac{N}{A} = \text{const}$$



$^1/_4$ A → $^1/_4$ N

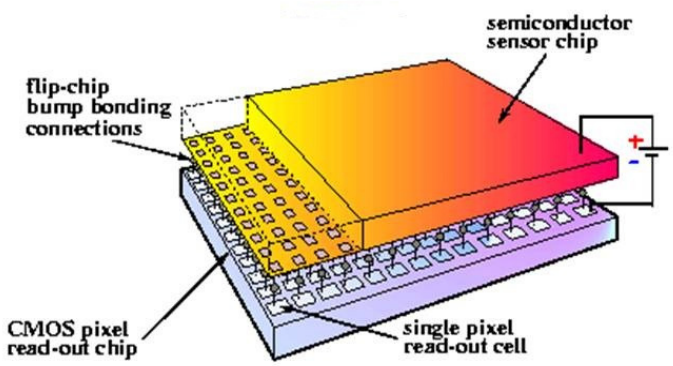
10^8 particles / cm²

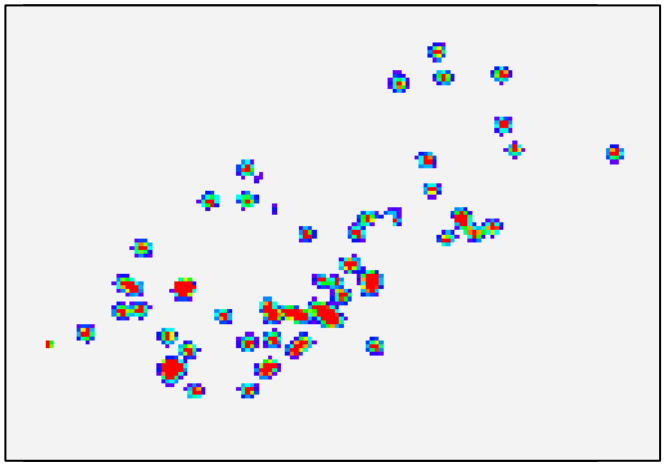
=

1 particle / µm²

Timepix (in collaboration with IAEP CTU Prague)

- Scientific system
- Medipix collaboration (CERN)
- hybrid detector system
- 300 µm Si-sensor
- 256 x 256 pixel (55 x 55 µm^2)
- USB-based read-out interface
- 3 different read-out modes:
  - *Medipix mode (counting)*
  - *Timepix mode (time)*
  - ***TOT mode (energy)***





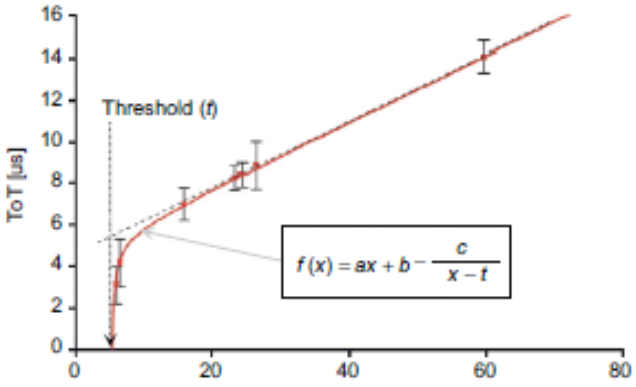
http://medipix.web.cern.ch/medipix/pages/medipix2.php

TOT mode → energy calibration

- Charachteristic X-rays in 5-60 keV range
- Homogenous irradiation of all pixels
- Only single events per pixel allowed
- Gaussian fit of pixel response
- Fit ***calibration function for each pixel***

$$f(x) = ax + b - \frac{c}{x - t}$$

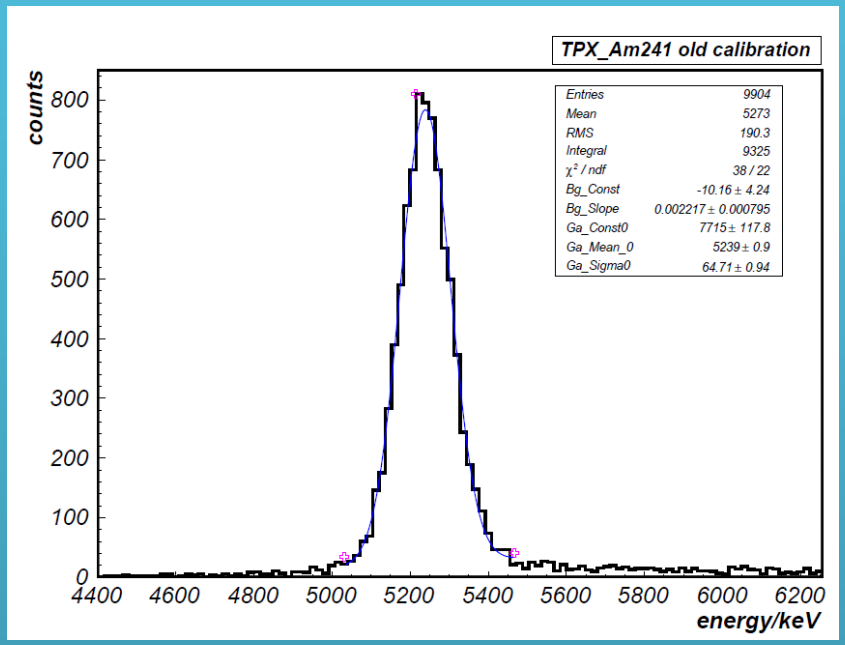
x = energy, f(x) = TOT-signal
a,b,c,t calibration parameters



Jakubek et al, Nucl. Instr. Meth. A 591 (2008) 155-158

Calibration check with ^{241}Am source:

5486 keV (84,4%)

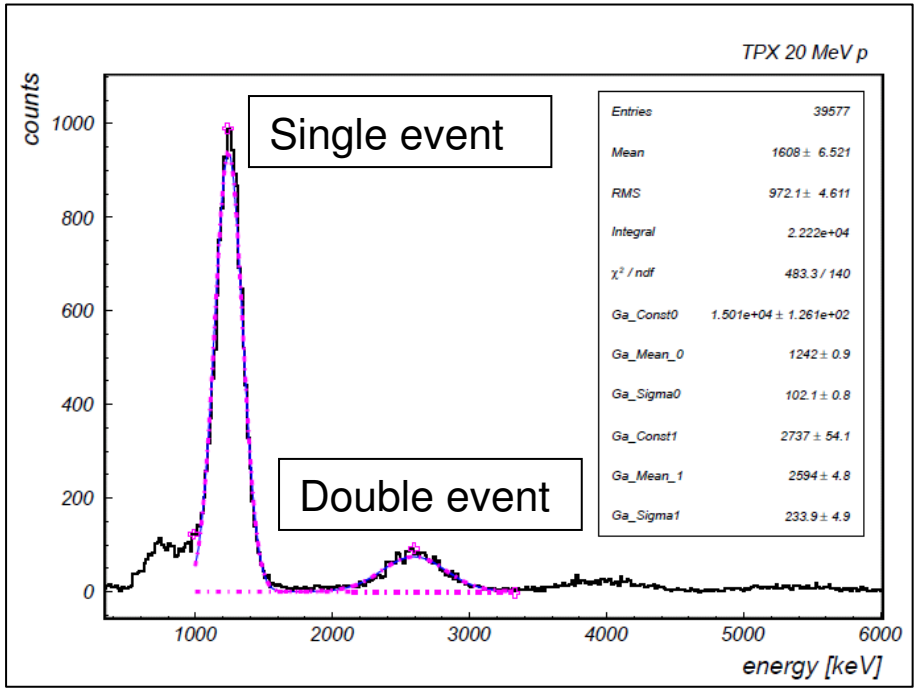


Timepix measurement:	
Energy [keV]	5239
energy resolution [keV]	65

Proton irradiation at the 14 MV- Tandem van de Graaff accelerator

Beam parameters:
- *20 MeV*
- *continuous beam*
- *low fluence*

TPX standard configuration
THL coarse = 7 *THL = 438*
Bias = 51 V



Energy loss [keV] in 300 μm Si:	
Simulation (SIMNRA 6.04)	1499
Measurement (single hit)	1242
Measurement (double event)	2594

Single and double p events discriminable.

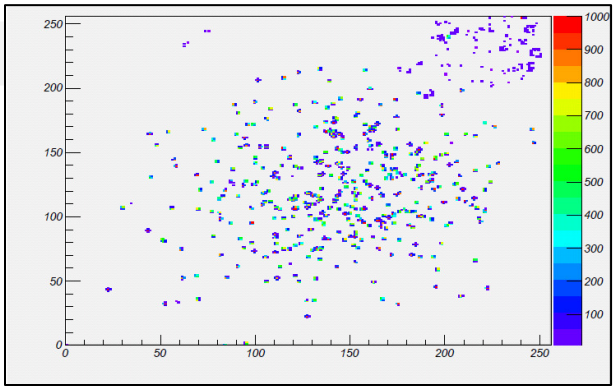
Good energy resolution, although small deviation ~ 200 keV in energy measurement.

Irradiation with pulsed (~ ns) proton beam

Beam-parameters:
20 MeV
Pulsed beam with FWHM
(31.25 +/- 17.68) ns

Timepix:
Standard TPX-configuration

few 100 protons/cm^2

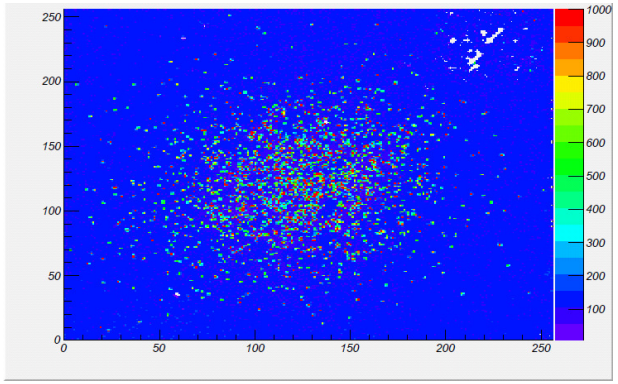


- Increasing pulse intensity:

→ Increasing charge sharing effect

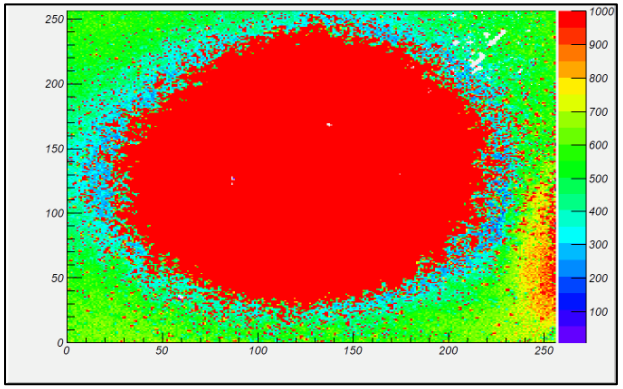
→ Non-linear effects

$3.3 \cdot 10^3$ protons/cm^2

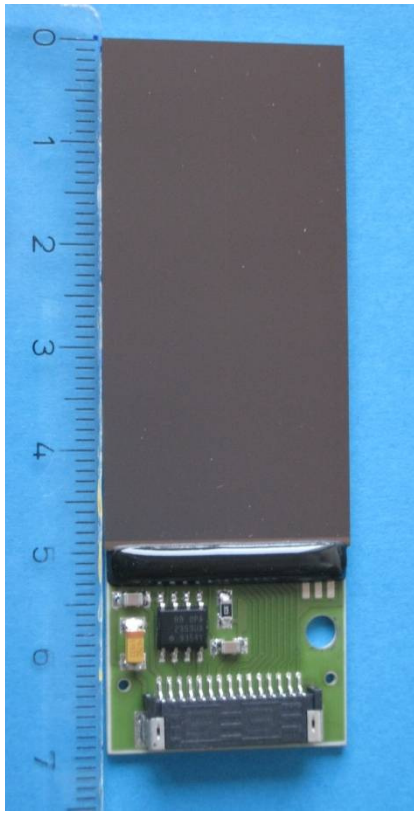


- ***Saturation limit not sufficient*** for expected laser-driven proton pulse!

$2.5 \cdot 10^5$ protons/cm^2

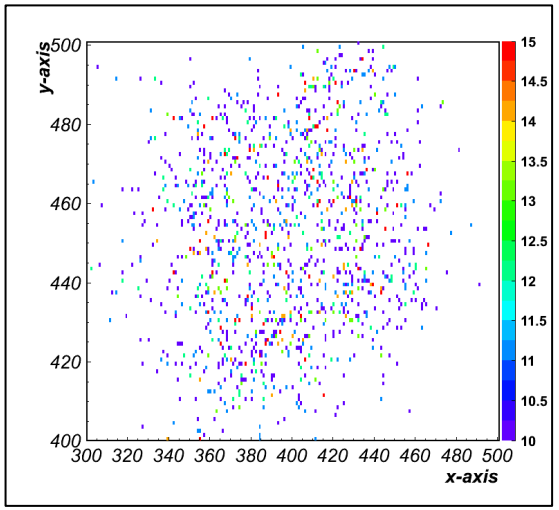


Rad Eye detector system



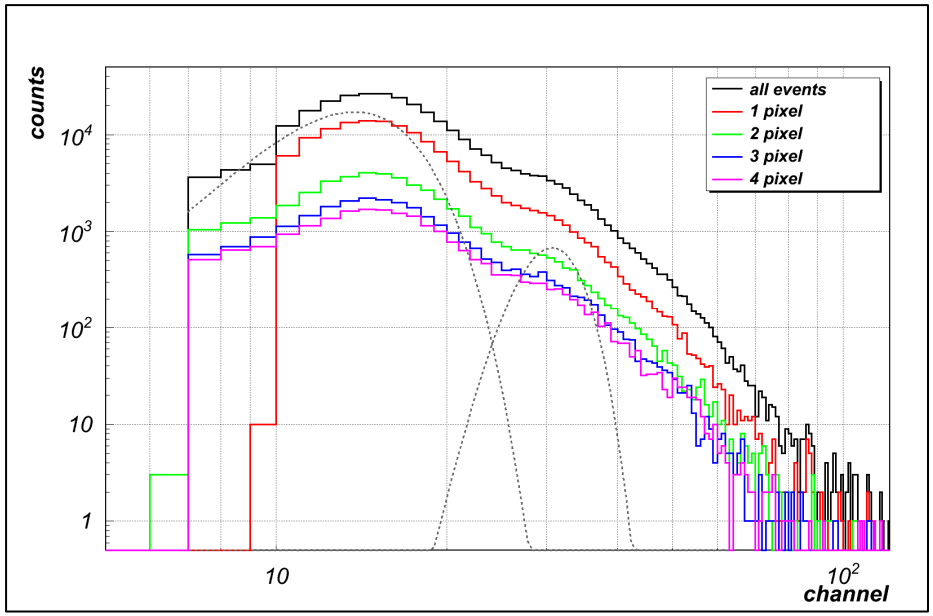
- ***commercial system***
  (Rad-Icon Imaging Corporation, Sunnyvale, USA)

- ***RadEye 1 sensor***
  - ***Si-photodiode array***
  - ***48 µm x 48 µm pixel size***
  - ***2 µm depletion depth***
  - large sensitive area: ***25 mm x 50 mm***
  - additional sensors tillable

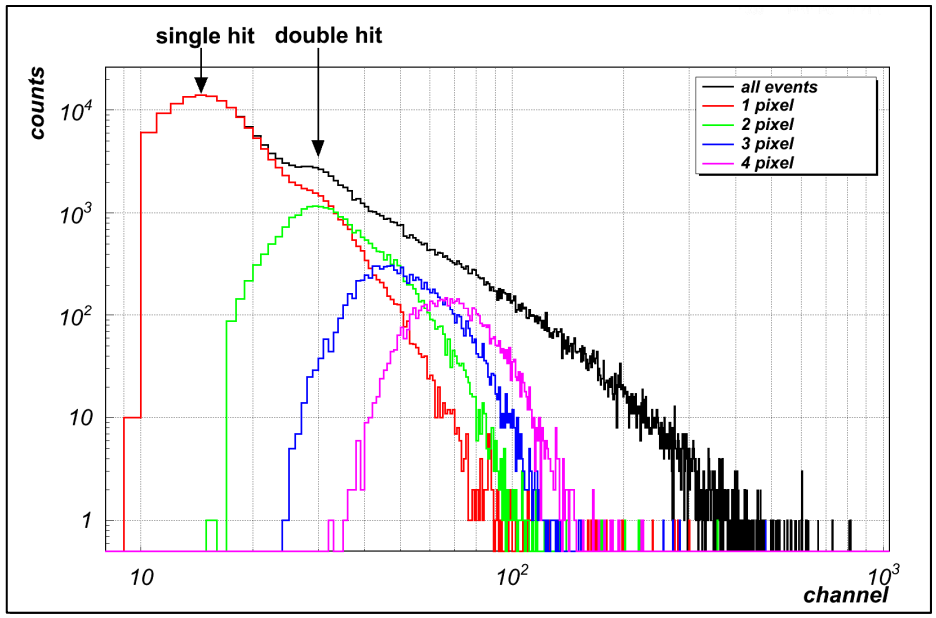


Munich 14 MV Tandem accelerator
- continuous beam
- 15 MeV protons
- ~ 10^4p/cm^2/s

Cluster pixel distribution:



Cluster distribution:

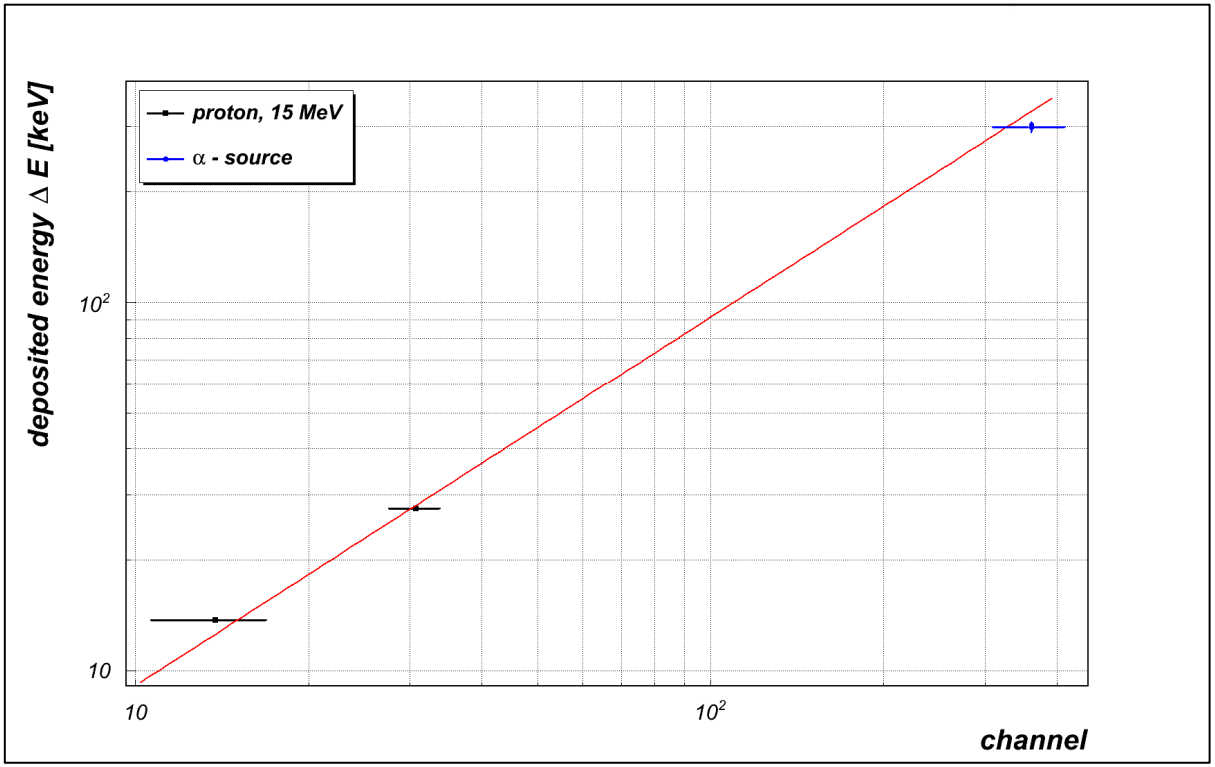


cluster = adjacent pixel above threshold

No charge sharing effects observed

Single and double hits can be distinguished

Energy calibration



SRIM 2008:
Simulation of energy loss

Linear fit for proton data:

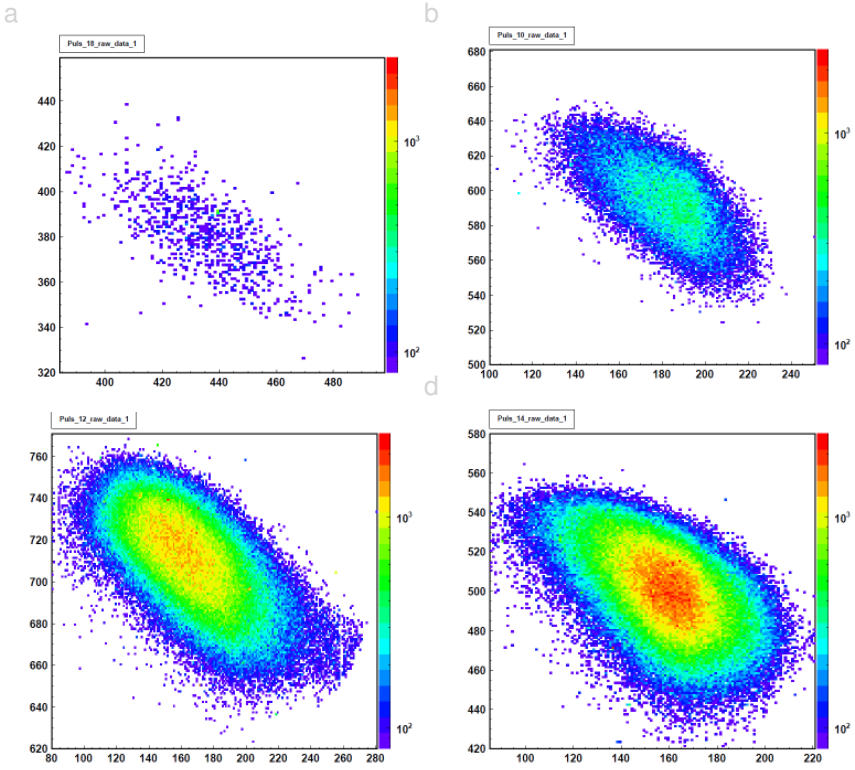
ΔE (channel) = 0.91 x channel

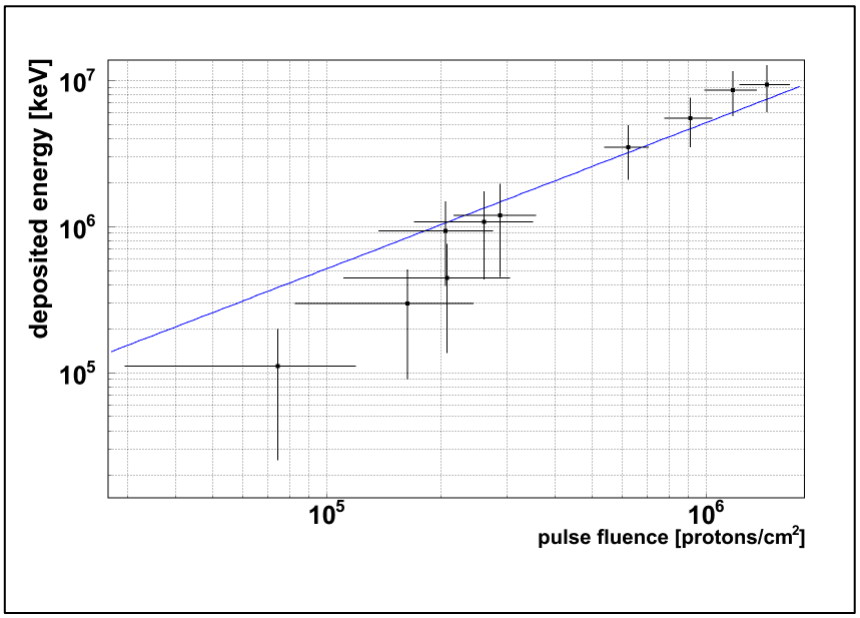
Good agreement with α-source

but:

Energy resolution only 50%

Munich 14 MV Tandem accelerator
- pulsed beam
- 20 MeV protons
- 10^4 - ***10^7 p/cm^2/ns***



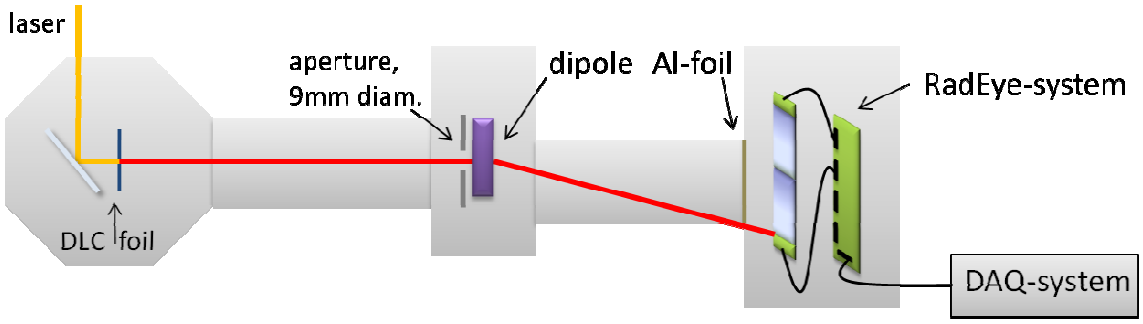


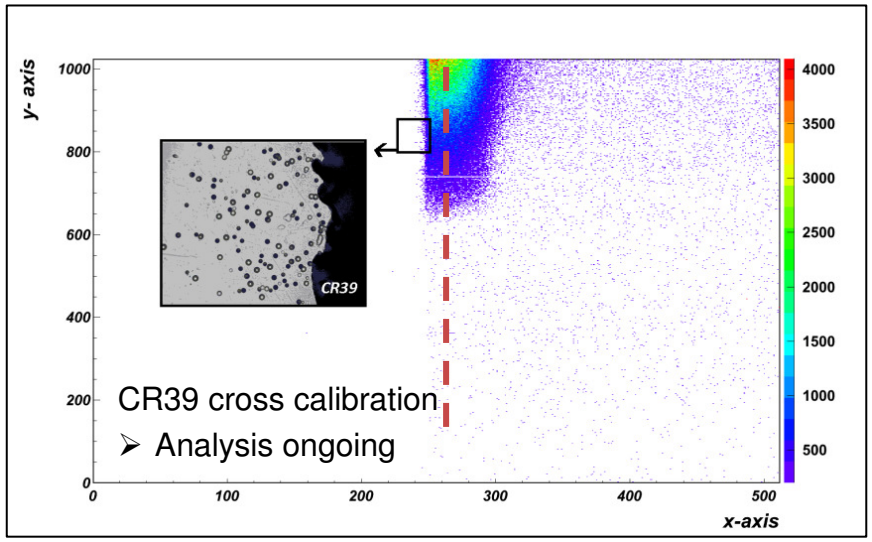
No detector saturation observed
Good agreement to continuous measurements

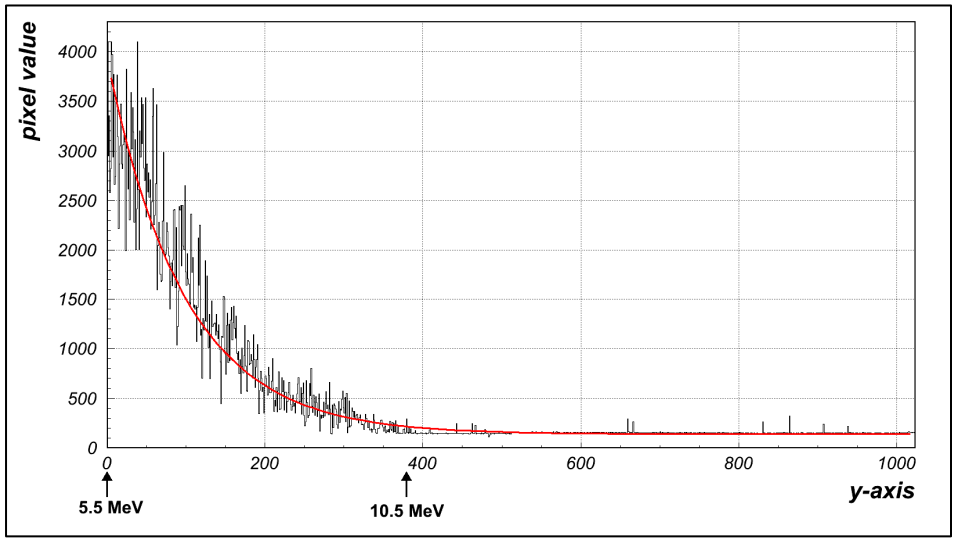
System ready for laser-acceleration experiment

Test at the MPQ Atlas laser

MPQ Atlas laser
- 400 mJ
- 30 fs
- single shots
- DLC foil 5-40 nm thickness







Conclusion

Medipix

- Good energy resolution
- Dynamic range not sufficient for direct detection of laser accelerated pulses

RadEye-Detector

- Limited energy resolution
- Sufficient radiation hardness
- Linear pulse dose response up to 10^7 p/cm^2
- No problems with EMP in Laser-environment

RadEye-Detector system of choice for laser accelerated proton detection

Outlook:

- *radiation hardness test (November 2011)*
- *routine use in laser acceleration experiment*

Compact integrated system “RE4PC”

- Stand alone system
- Compact size: 30 x 25 x 25 cm^3
- Parallel read-out of 4 RadEye detectors

Thanks for your attention!