Longitudinal Beam Profile Measurements of Pulsed Heavy-Ion Beams

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- Physics Motivation
- Detector Design
- Experiments with a ^{54}Cr Beam @ 4.75 AMeV
- Results
- Summary

Stopping of Heavy Ions in Solids: Bethe-Bloch formula.

Stopping in Plasmas: 'Modified' Bethe-Bloch formula.

$$\frac{d(E_{pr})}{dx} = -\frac{16\pi a_0^2 I_H^2 \overline{Q}_{pr}^2}{m_e v_{pr}^2} \left(\underbrace{n_Q \sum_{Q=0}^{Z_{tg}} (Z_{tg} - Q) \ln\left(\frac{2 m_e v_{pr}^2}{\bar{I}_Q}\right)}_{\text{bound electrons}} + \underbrace{n_e \ln\left(\frac{2 m_e v_{pr}^2}{\hbar \omega_{plas}}\right)}_{\text{free electrons}} \right)$$

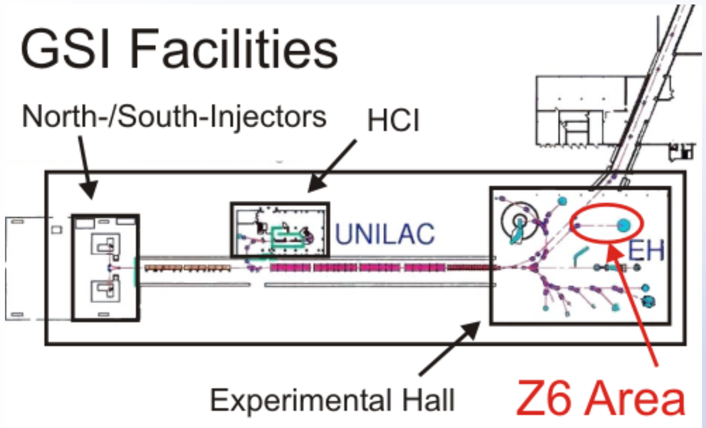
Higher Stopping Power of fully ionised plasma compared to solids or gas

- Higher projectile charge state
- More efficient energy transfer to free plasma electrons.

Stopping in Partially Ionised Plasmas:

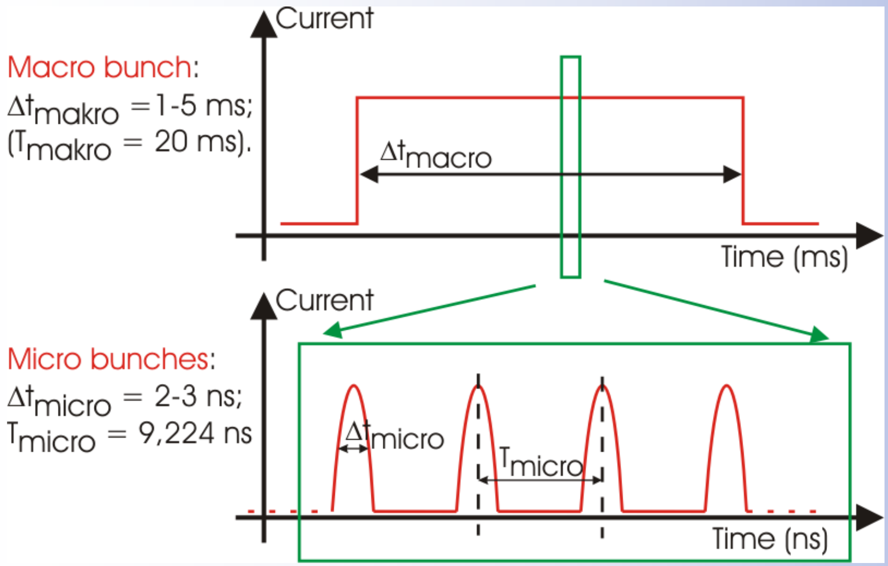
- Hot dense, laser-produced plasmas; e.g. carbon, 1^+ to 2^+, ~100 eV.
- Still discrepancies between theory and (rare) experimental data...

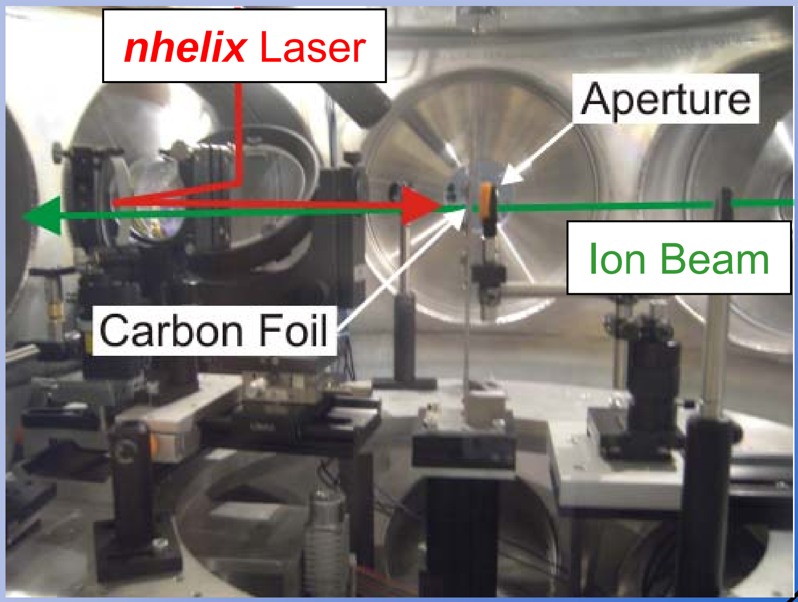
Physics Motivation:
Experimental Setup



- ^{12}C to ^{86}Kr beams: 4 to 6 AMeV

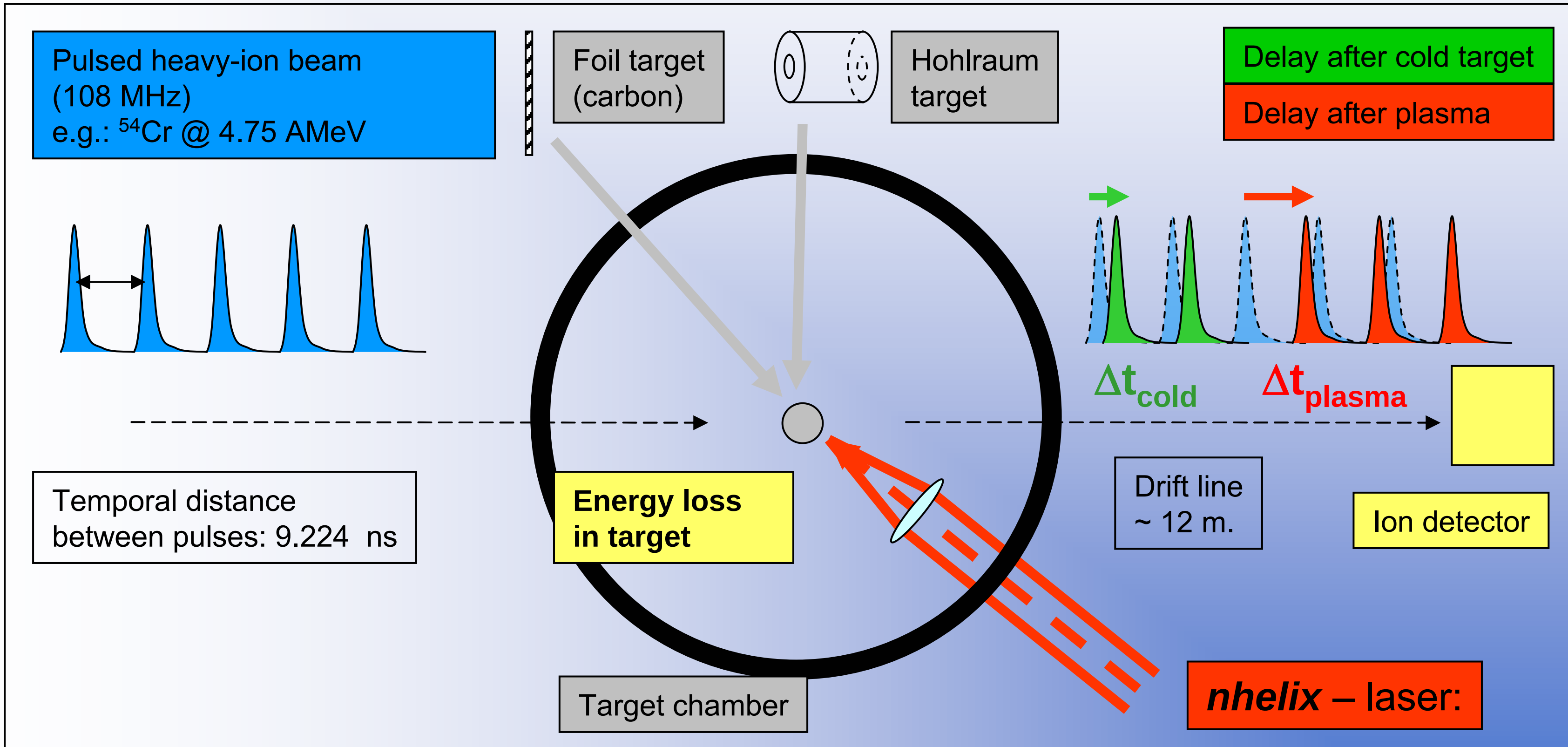
Nd:YAG/Nd:Glass Laser (1064 nm)
- Pulse Length: 10-14 ns
- Max. Energy: 120 J





Physics Motivation:
Energy Loss of HI Pulses via TOF

Experimental Setup @ Z6:



$\Delta t_{plasma} - \Delta t_{cold} \Rightarrow$ enhanced energy loss in plasma, $\Delta E_{plasma} - \Delta E_{cold}$.

Motivation:
Detector Requirements

Temporal Resolution:

- For 50% increased energy loss @ 5 AMeV, after 12 m drift:
- Expect TOF shift of $\Delta t_{plasma} - \Delta t_{cold} \leq 2.5$ ns between arriving micro pulses.

$\Rightarrow$ Need **temporal resolution $\leq$ 250 ps** !

Sensitivity for Heavy Ions:

- Beam current @ ion detector:
reduced by aperture to **$10^2 - 10^3$ ions / micro pulse.**

General:

- Heavy ions (^{20}Ne to ^{86}Kr) 5AMeV $\Rightarrow$ **radiation hardness** desirable.
- Intense x-radiation from plasma $\Rightarrow$ **low photosensitivity** desirable.

Solution: PC CVD Diamond. (SC not available yet at ~1 cm²)

Detector Design:
PC CVD Diamond 1

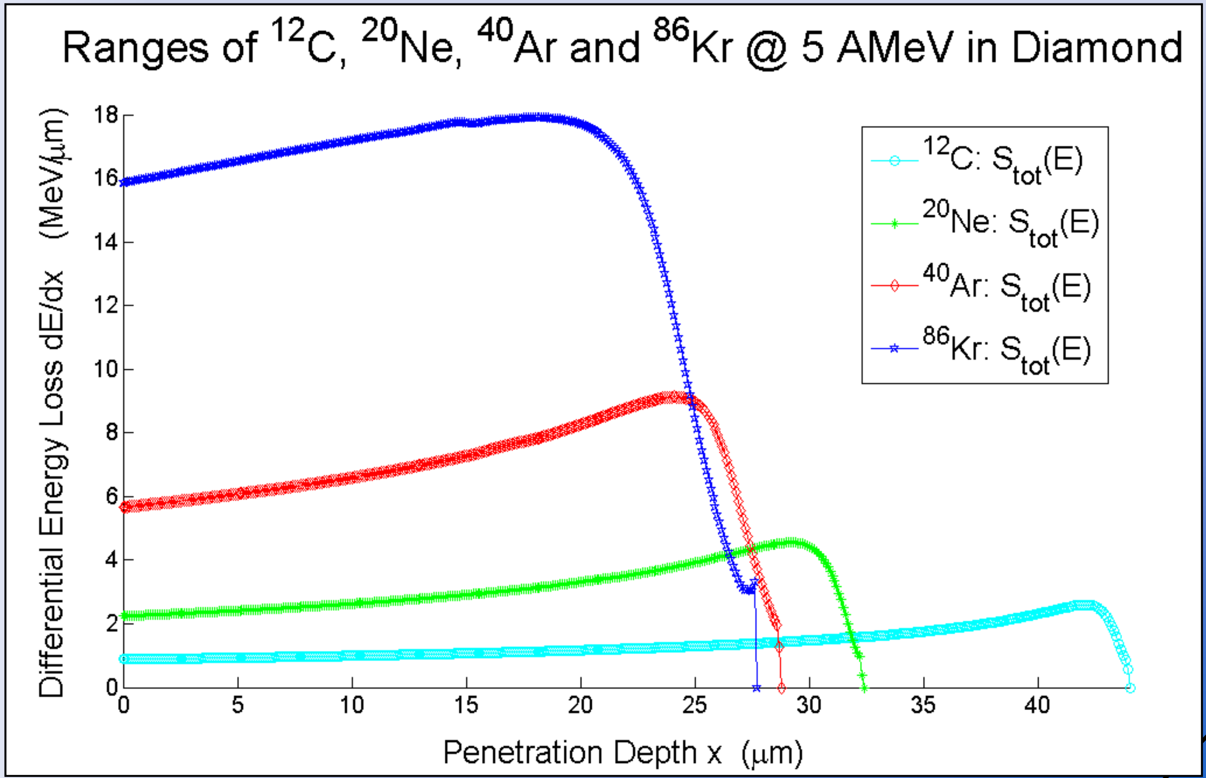
'Problem' with pc CVD Diamond:
Pulse height defect during irradiation due to internal polarisation, especially when projectiles are stopped.

Goal: Homogeneous ionisation density for heavy ions in diamond, i.e. **traversing particles**.

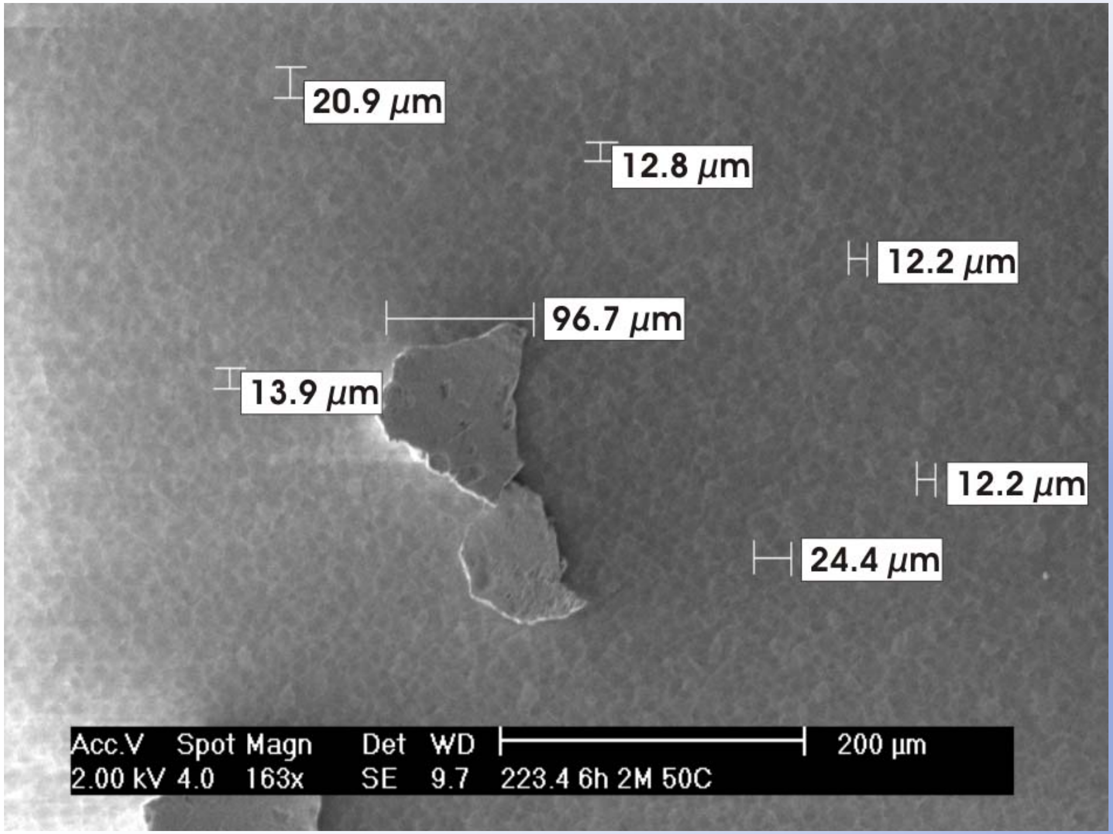
Ranges:

^{12}C to **^{86}Kr** @ 5 AMeV:

44 µm to **28 µm**.



4 'thin' Samples from FIAF: ☆



- Size: 1x1 cm²
- ~3 µm of substrate side removed
- Oxygen etching
- Mechanical polishing
- Thickness: **13**, **19**, **20.5** and **60** µm

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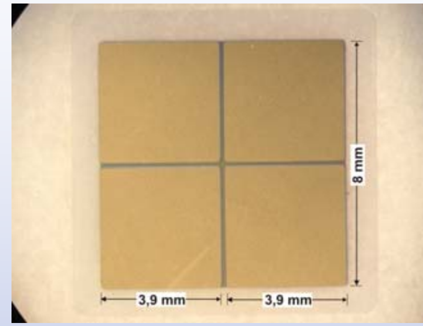
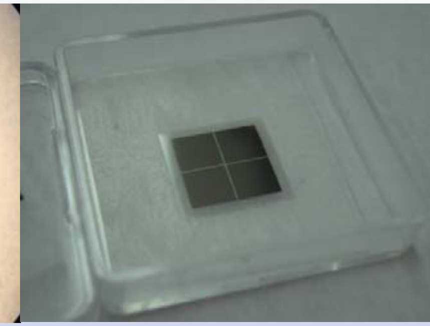
Detector Design:
Construction & Assembly

Metallisation:

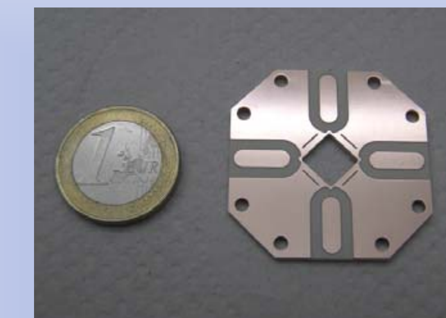
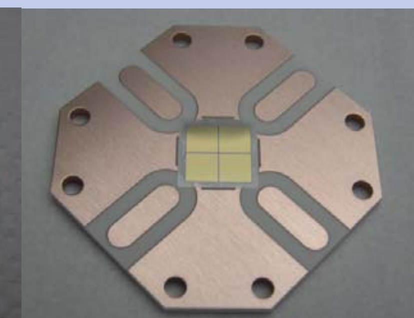
- 4-pixels beam-side, 3.9*3.9 mm²
- ⇒ reduce capacitance / time constant
- 1-pixel backside, 8*8 mm²
- Ti/Pt/Au: 20/30/100 nm, Al: 100nm
- Annealed in N_2 @ 500°C





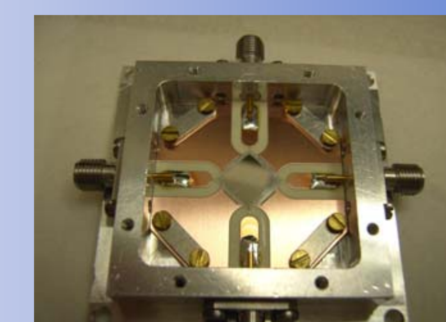
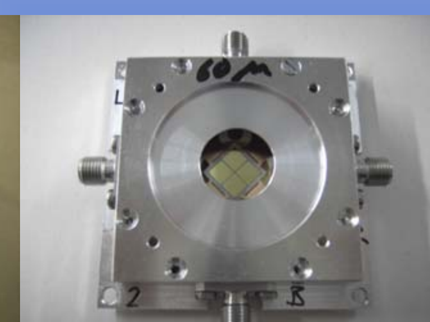
Contacting:

- RO 4350B™ HF-Circuit Board
- 50 Ohm impedance geometry
- Silver conductive glue
- Aluminium bonding wires

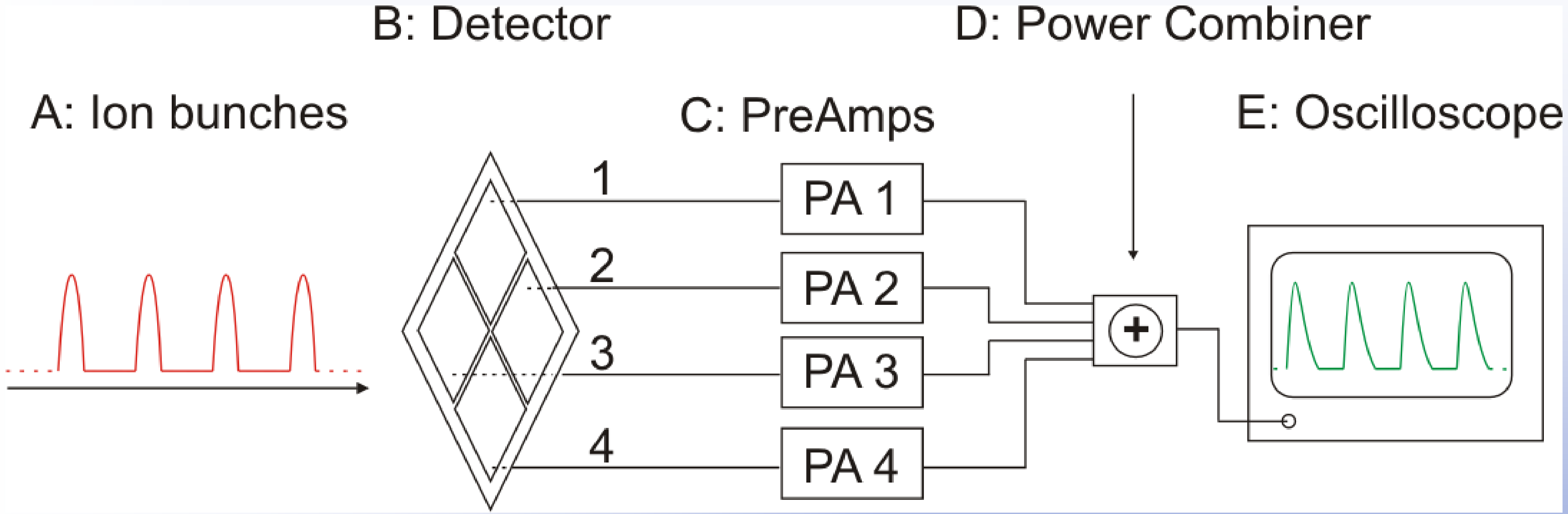



Aluminium Housing:

- CF100 beam pipe suitable
- SMA connectors
- Caps and beam apertures

Data Acquisition



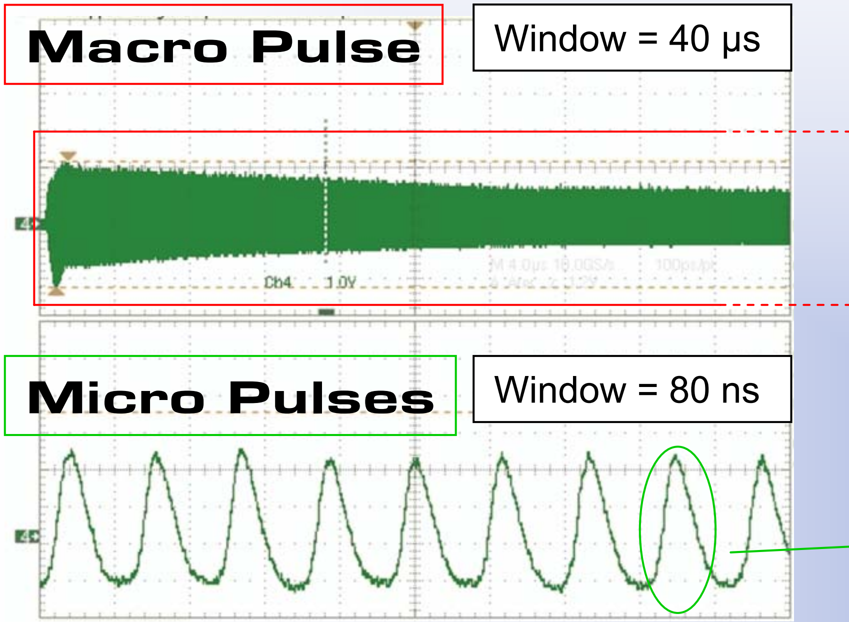
- **DBA4 broadband amplifiers** (by GSI).
- 10 GS/s Oscilloscope.

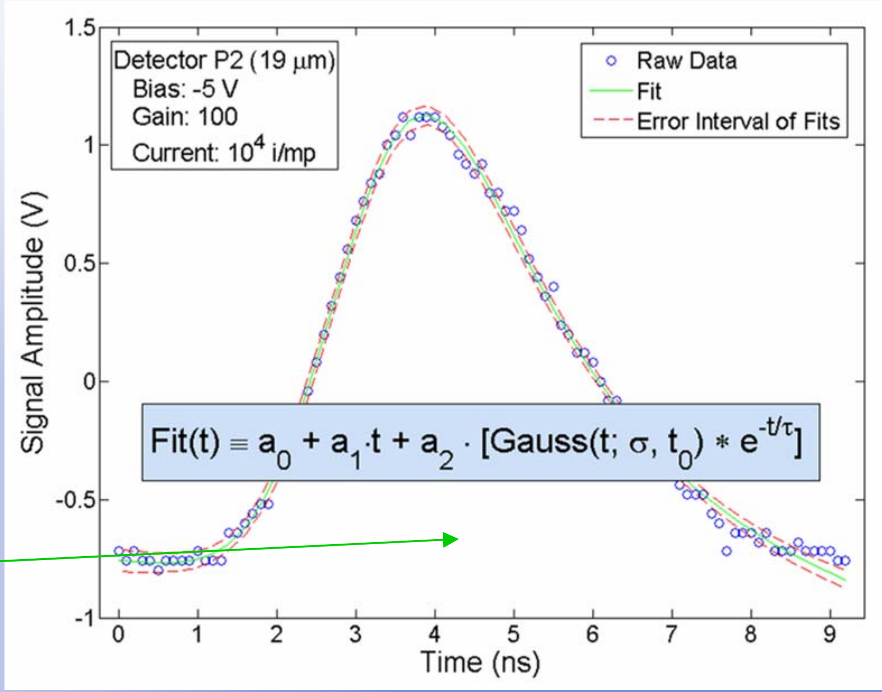
Experimental Parameters:

- Beam current: 3.6 µA to 280 nA ↔ ~ 10^4 to 10^3 ions / micro pulse (**i/mp**).
- Detector thickness (4 different detectors: 13, 19, 20.5 and 60 µm).
- Detector bias voltage (-2 V/µm to + 2 V/µm).
- (PreAmp gain: 100 or 10 absolute)

Experiments with a ^{54}Cr Beam:
Data Analysis

Example: 19 µm Detector @ -5 V and ≈ 10^4 i/mp.





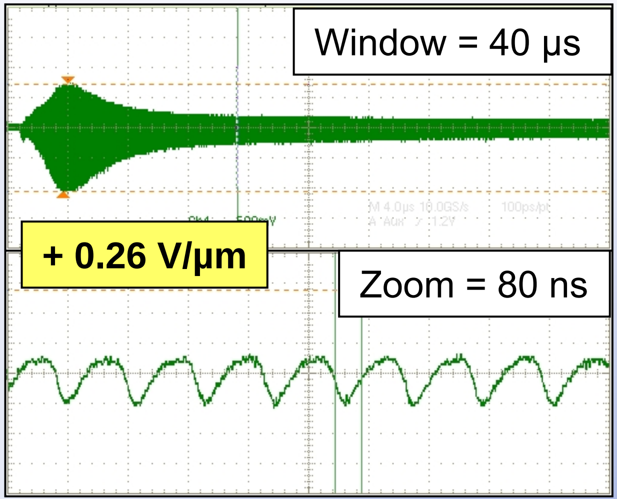
- **Fit function**: Convolution of gaussian with detector response (exp. decay).
- **Fit parameters:** Gaussian: centre $\mathbf{t_0}$, width σ, amplitude $\mathbf{a_2}$
  Baseline: slope $\mathbf{a_1}$, offset $\mathbf{a_0}$.

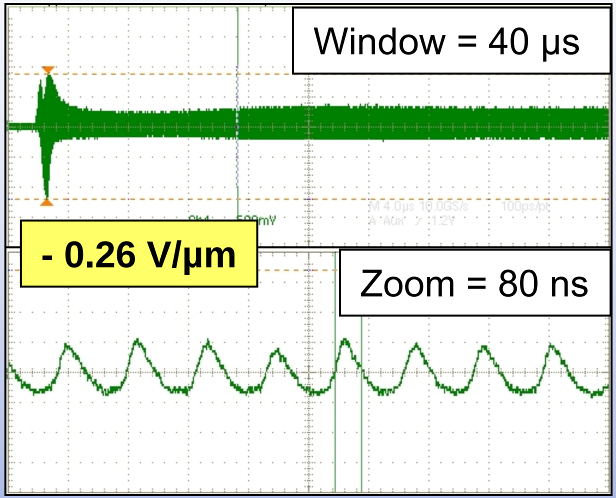
Relevant for determining energy loss via TOF variation: position of centre, $\mathbf{t_0}$

Results:
Detector Bias

Bias Polarity:

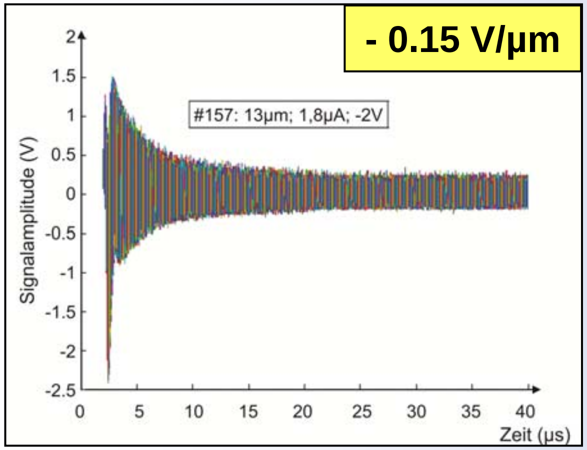
19 μm Detector
Gain: 10
Current: ~10^4 i/mp

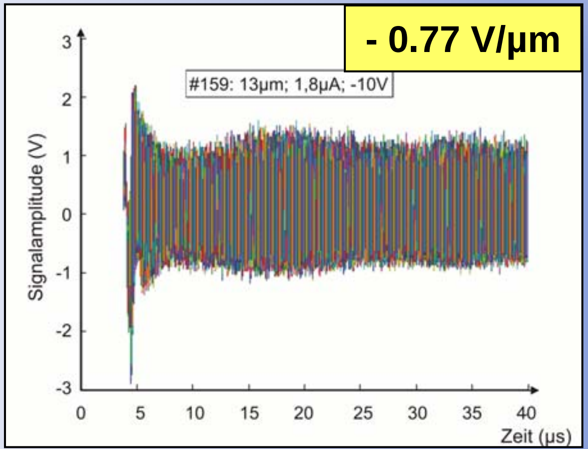


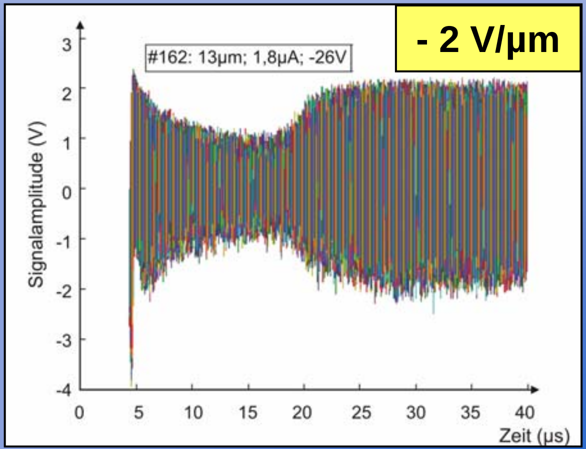


Bias Value:

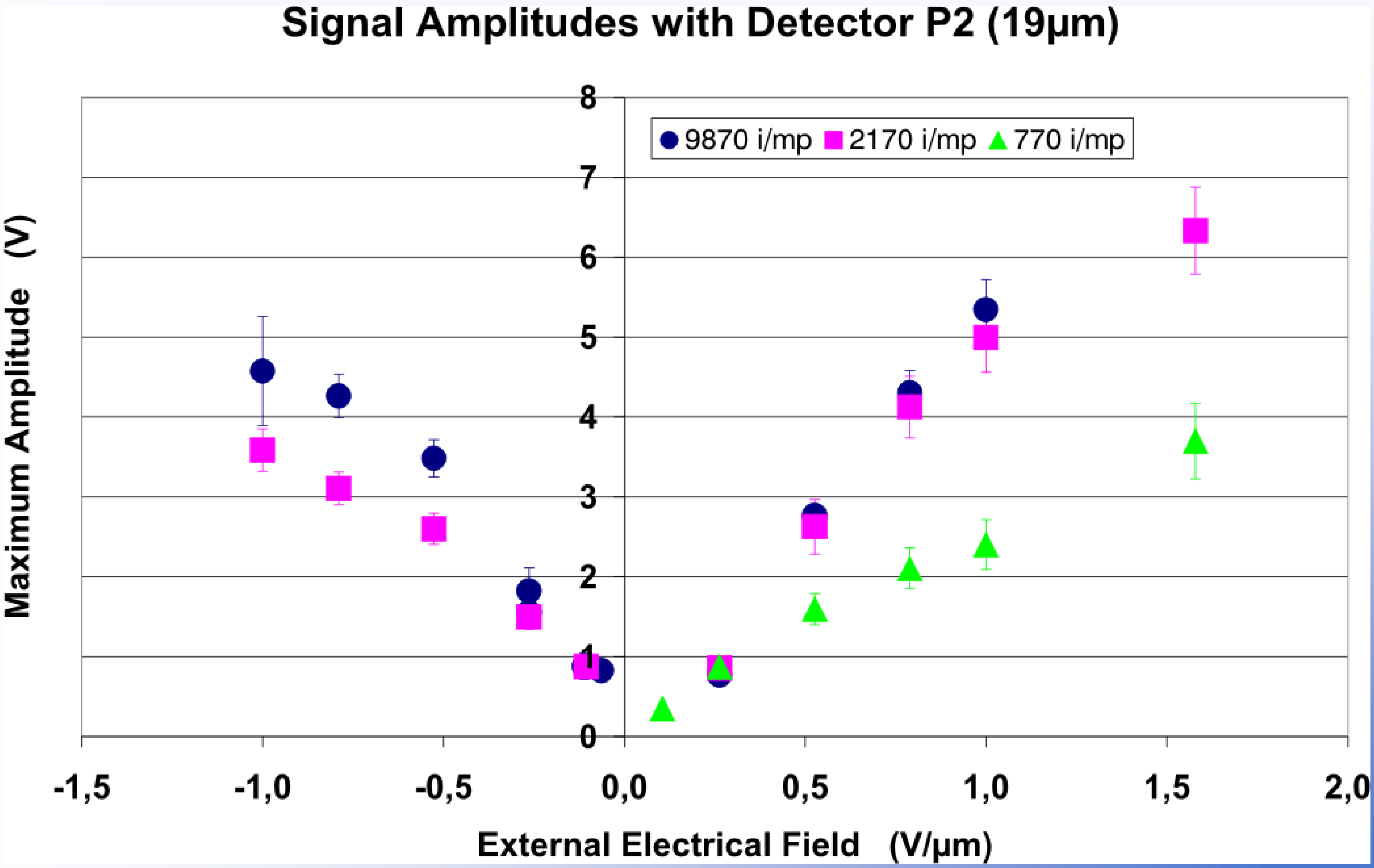
13 μm Detector
Gain: 10
Current: ~10^2 i/mp





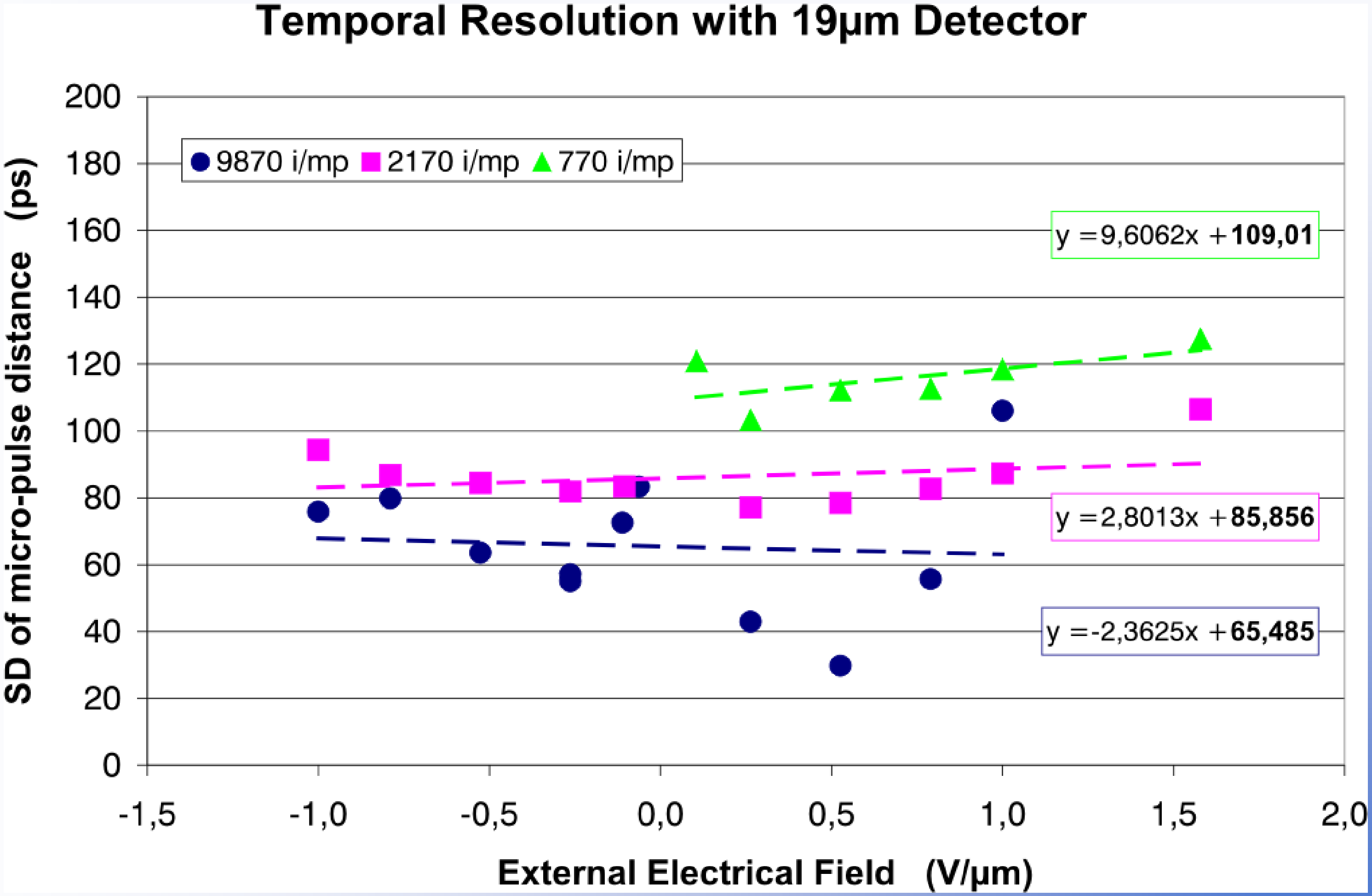


Results:
Signal Amplitudes



Higher amplitudes for **positive** bias voltage.

Results:
Temporal Resolution



- Analyse the temporal distance between micro pulses in one macro pulse.
- Take the **standard deviation** of the mean (9.224 ns) as temporal resolution

Summary:
Conclusions and Outlook

This Work:

- 4 pc CVD diamond detectors have been constructed, 13 µm to 60 µm thick
- Experiments with ^{54}Cr-beam @ 4.75 AMeV:
  - Macro Pulse structure: complex initial tuning phenomena
  - Micro Pulse height: ~ 1 – 6 V, depending on gain, ion current and bias
  - **Temporal resolution** with 19 µm detector: **~ 65 to 110 ps**
- **Thin (pc) CVD Diamond seems to be suitable as a detector for the longitudinal properties of pulsed heavy ion beams at energies ~ 5 AMeV.**

Future Tasks & Applications:

- Tests with different heavy-ion species.
- Understanding the intrinsic response of the detector system to UNILAC heavy ion beams ⇒ calibration for beam shape / current.
- Strip detectors for position sensitive devices.

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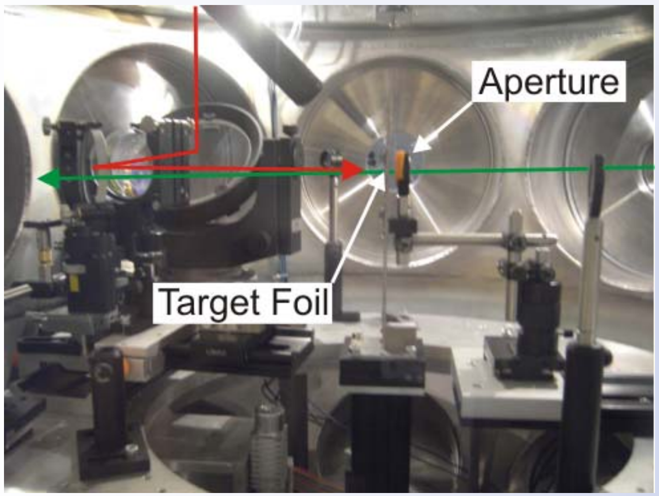
TUD Detector Laboratory:

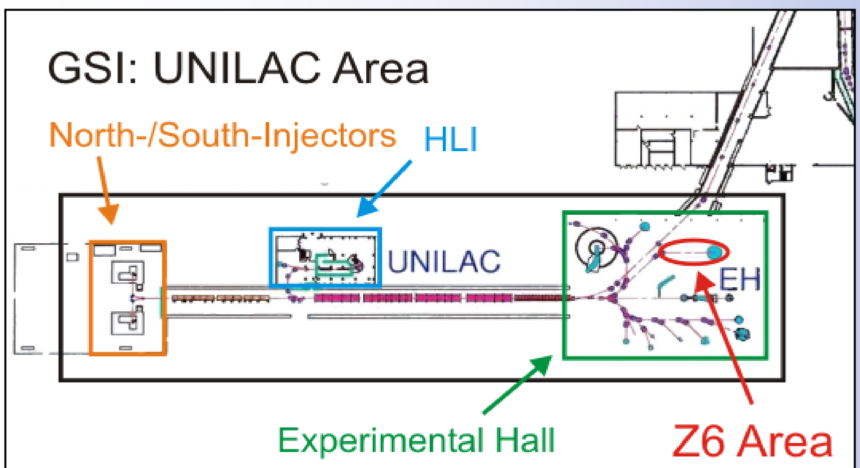
J. von Kalben

Extra:
All That's Left Behind

Laser-Plasma:
- $kT_e \leq 10^{21}$ cm^{-3}
- $n_e \leq 100$ eV

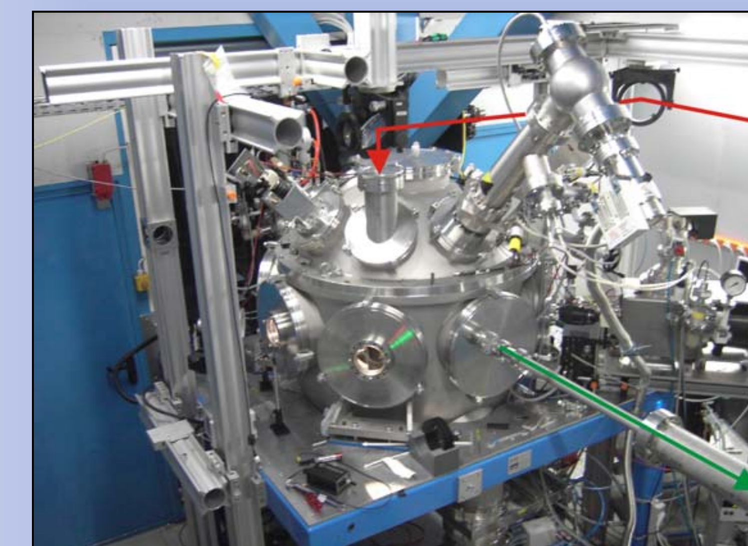
Spatial Beam Extent:





Overview / Summary:

- High Temporal Resolution
- 'High' (sufficient) Sensitivity
- Radiation Hardness
- Low Photosensitivity

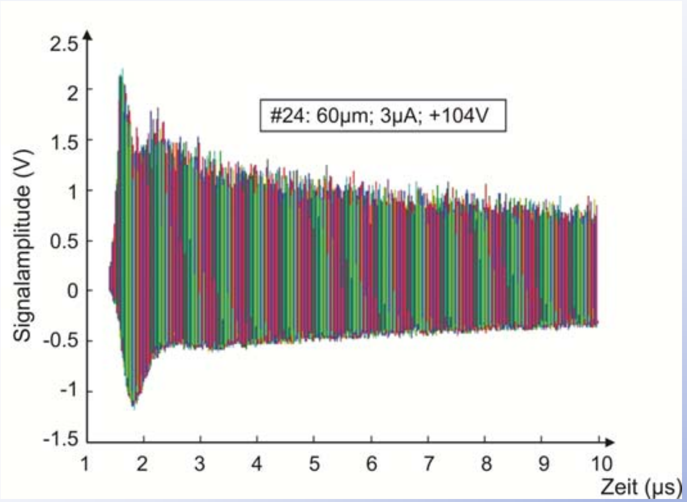


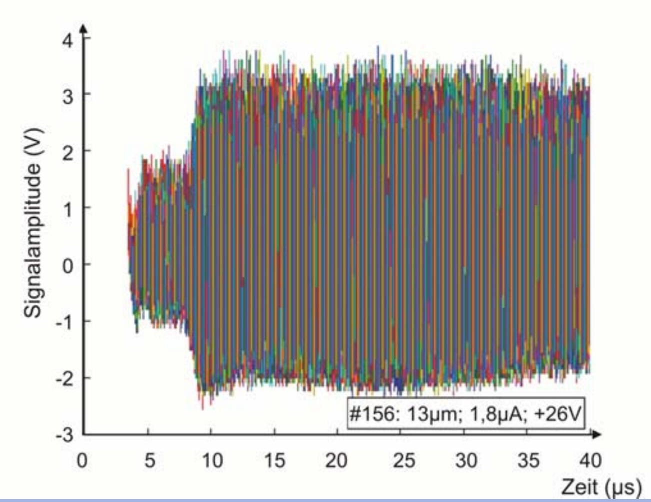
Thickness of Diamond Sample

60 µm

13 µm

Macro Shape





Micro Shape