Single Crystalline CVD diamonds for high intensity CBM/HADES experiments at FAIR

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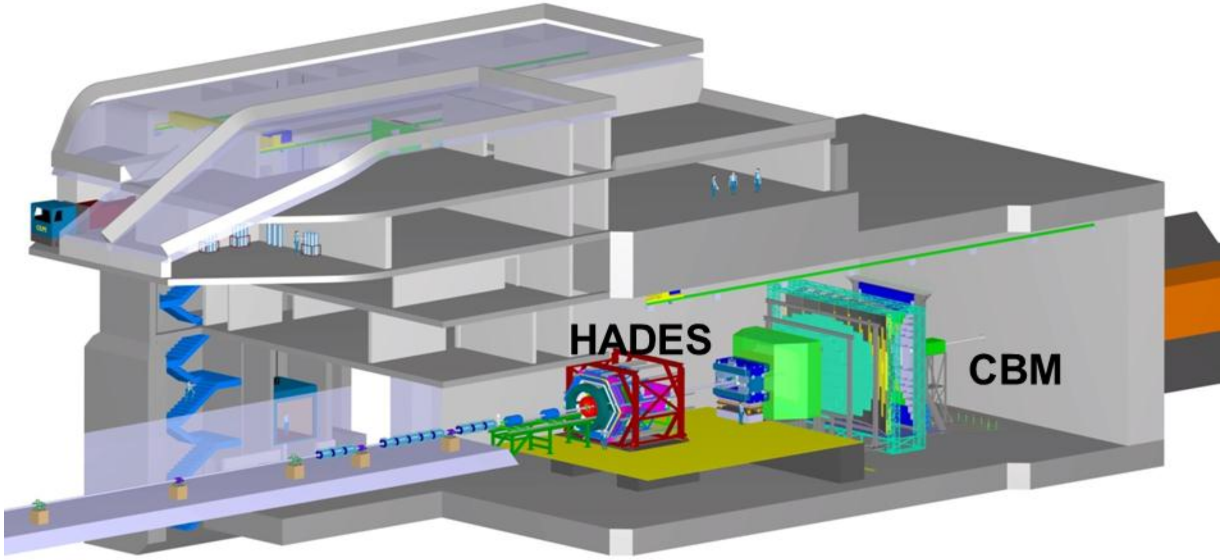
For HADES and CBM collaboration

Motivation and Proposed Setup

HADES placed in front of CBM in the proposed setup for FAIR.



Beam and T_0 detector requirements:

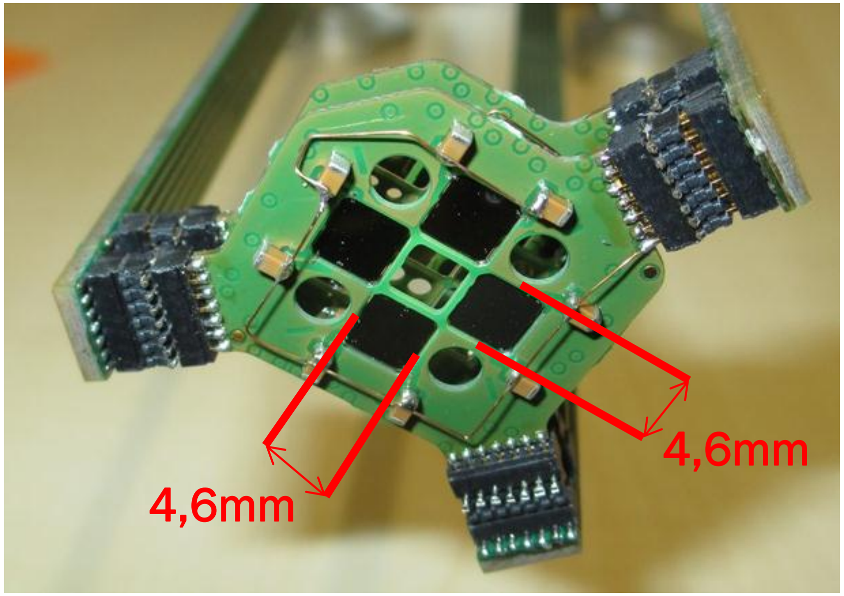
- Large dynamic range – beams from protons (MIPs) to HI (Au)
- Radiation hard
- High rate capability: 10^9 ions/second
- Good time resolution: ~50 ps
- Low budget material → low interaction probability
- Operational in vacuum conditions

Dynamic Range of Detecting Particles

- Signals proportional to energy losses ~ Z_{eff}^2/β^2
- Pions @ 690 MeV/c = MIPs (Z=1, β=1) → Energy losses in diamond ~ 0.6 keV/μm (amplification needed)
- Carbon ions @ 400 AMeV (Z=6, β=0.4) → dE/dx in diamond ~ 100 keV/μm
- Gold ions @ 1,23 AGeV (Z_{eff}=69, β=0.8) → dE/dx in diamond ~ 5 MeV/μm (approximately 9000 times more that for MIPs, no amplification needed)

HADES Pion Beam START Detector (MIPs)

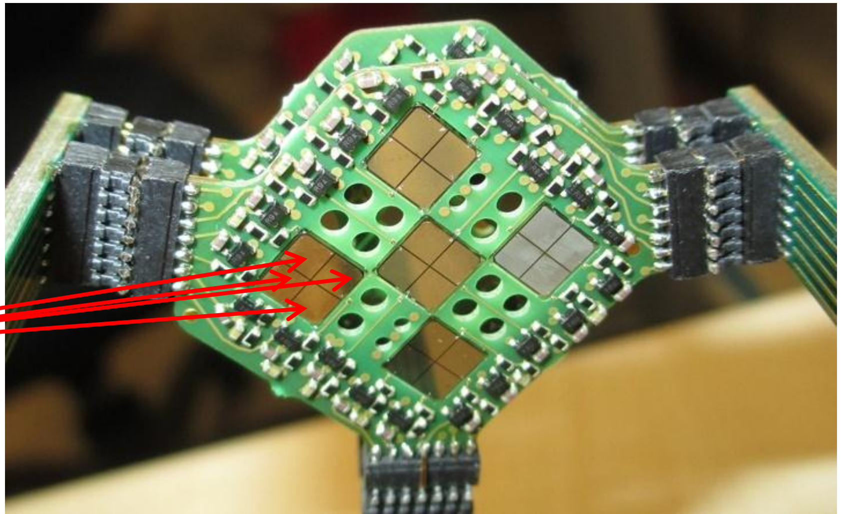
- Requirements
  - Minimum Ionizing Particle detection
  - Time resolution < 100 ps
  - Position resolution ≈ 2 mm
  - High Charge Collection Efficiency and Rate Capability



Mosaic scCVD diamonds needed

(For details: J. Pietraszko et al., Nucl. Instr. and Meth. A 618 (2010) 121-123)

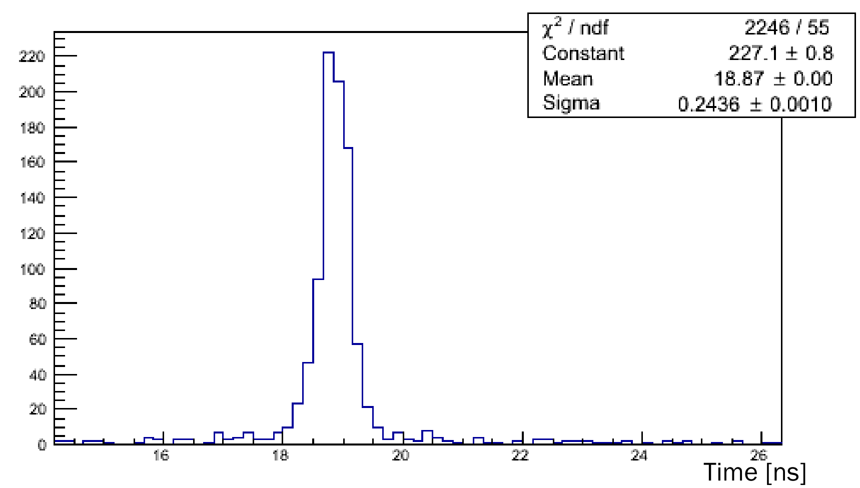
- Technical Solution
  - 9 diamonds in two planes
  - Diamond dimensions 4,6 x 4,6 mm^2 and 300 µm
  - Readout segmentation to get position information
  - Two stage amplification



HADES Pion Beam START Detector (MIPs)

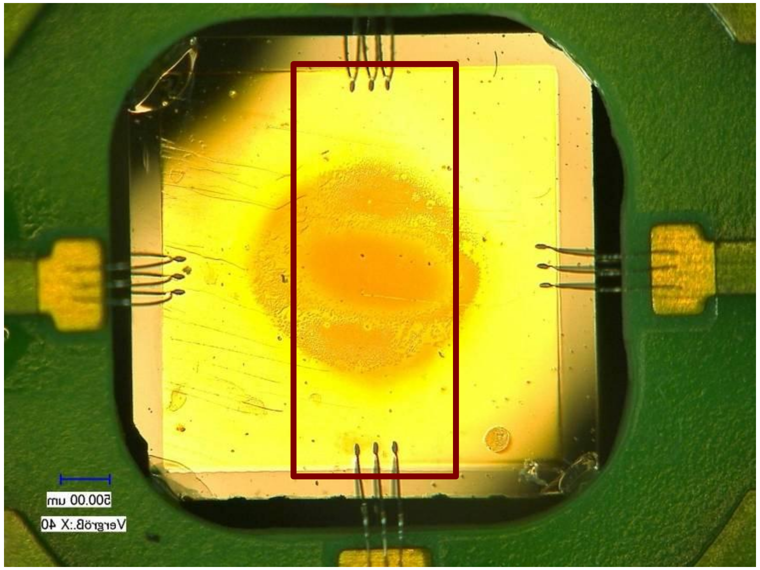
- Tested with pions @ 690 MeV/c with rate of $3x10^5$ parts/s on whole detector for several weeks

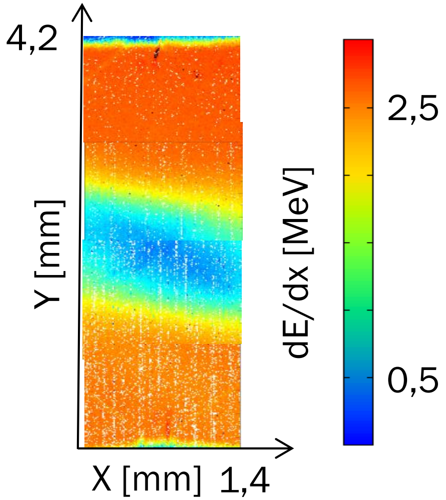
- Results
  - Signals amplitude 20mV
  - Charge collection efficiency ~ 100%
  - Confirmed high rate capability
  - Time resolution ~ 170 ps (worse than expected, probably due to S/N ratio)



Radiation Hardness

- Tested with Au @ 1,23 AGeV on 4,2 mm x 4,2 mm x70 µm scCVD diamond
- Proven rate capability 10^7 parts/s/mm^2
- Achieved time resolution < 50 ps
- Total dose of 87 MGy was estimated
- Decrease of signal amplitude by factor of 5
- No change in time resolution due to irradiation was observed

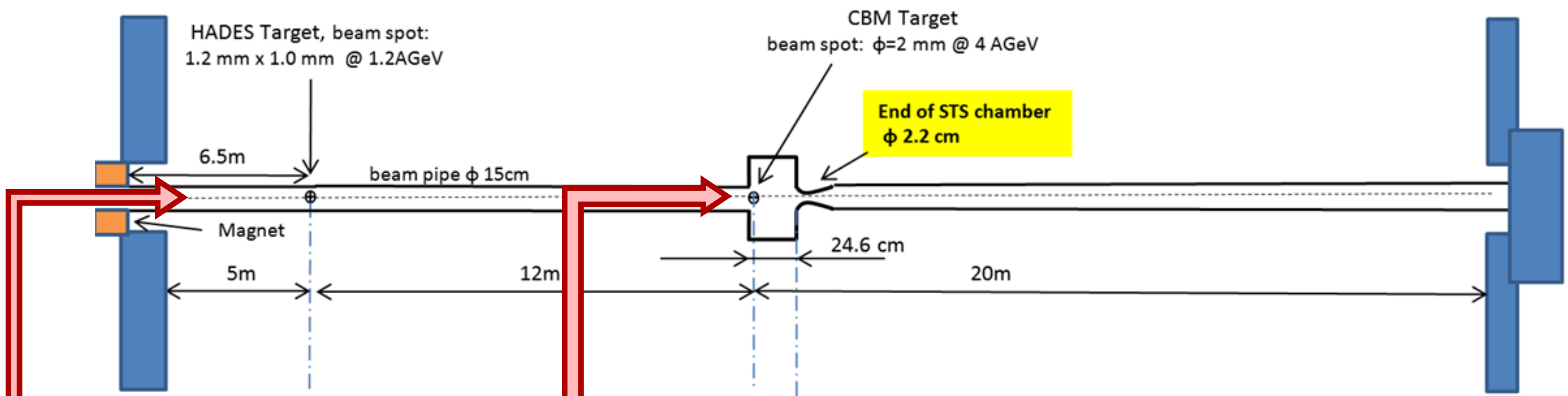




For details: J. Pietraszko et al., Nucl. Instr. and Meth. A 763 (2014) 1-5
Institute Ruder Boskovic, Zagreb, Croatia

High Rate Requirement

- CBM beamline aperture



<u>Just behind the magnets:</u>

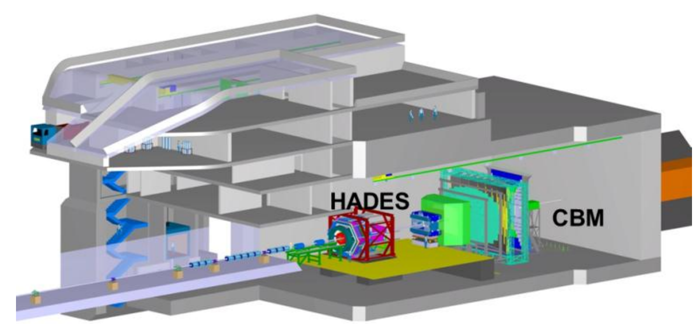
1.2 x 10^5 parts/s/mm^2
Beam diameter: 100 mm
Area: 7850 mm^2

→ Bigger detector required

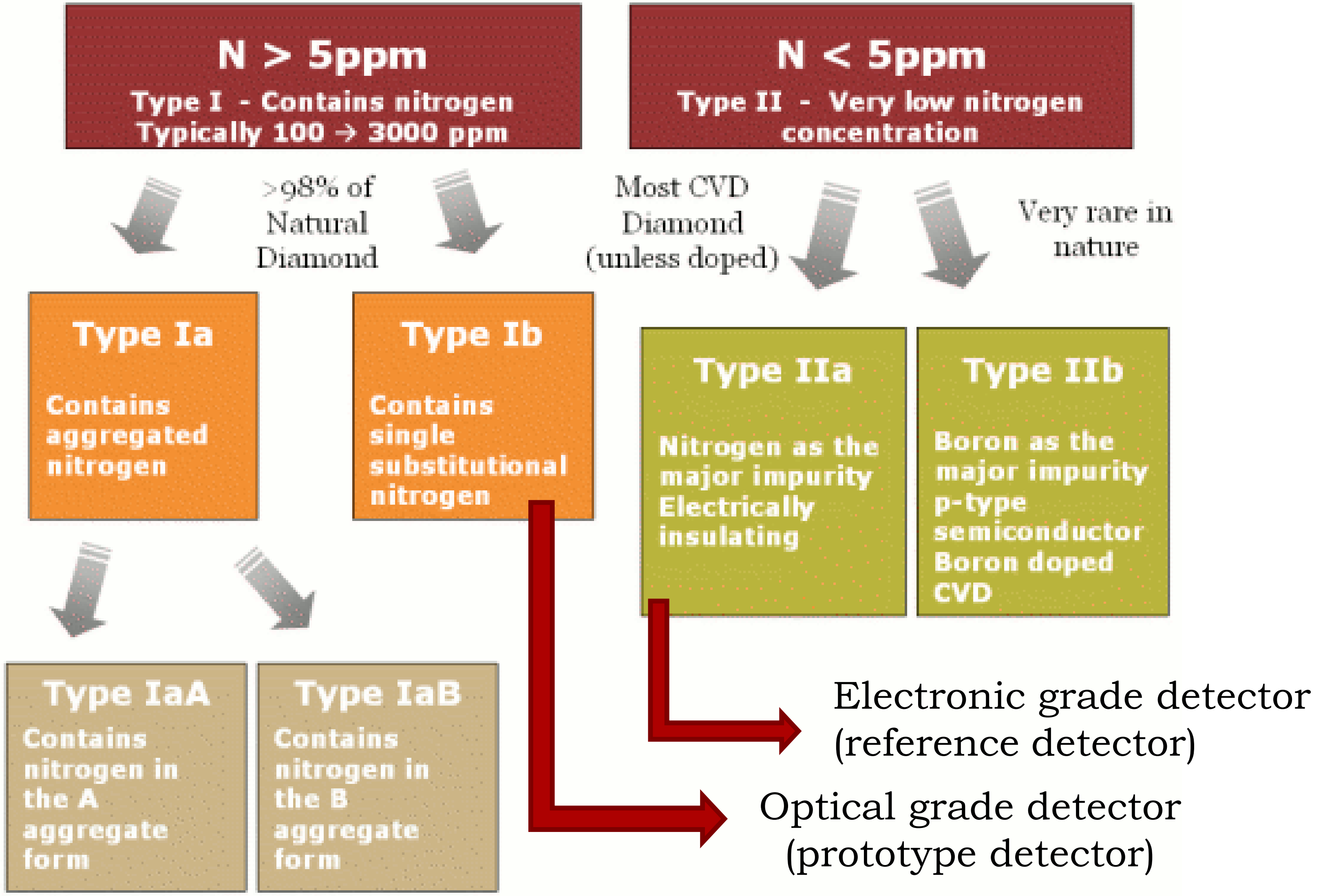
<u>At the target point:</u>

10^9 parts/s/mm^2
Beam diameter: 1 mm
Area: 0.8 mm^2

→ Electronic limitation



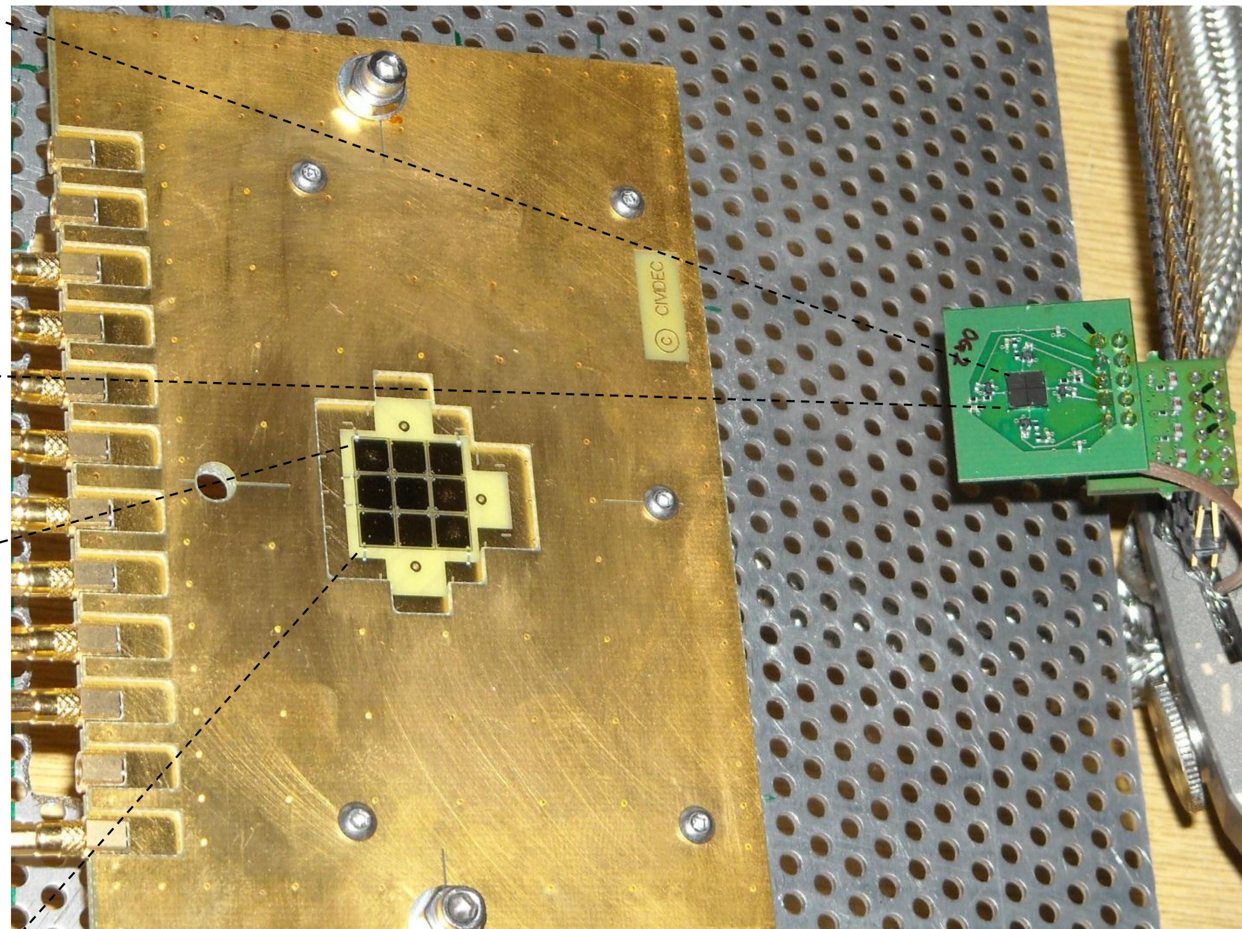
Classification of CVD Diamonds



Diamond Test Setup

<u>Optical grade diamond:</u>

- Type Ib
- Prototype test detector
- Nitrogen impurities
- Cost: £210.00
- 4.5mm x 4.5mm x 0.5mm
- Cr/Au – 500 °C

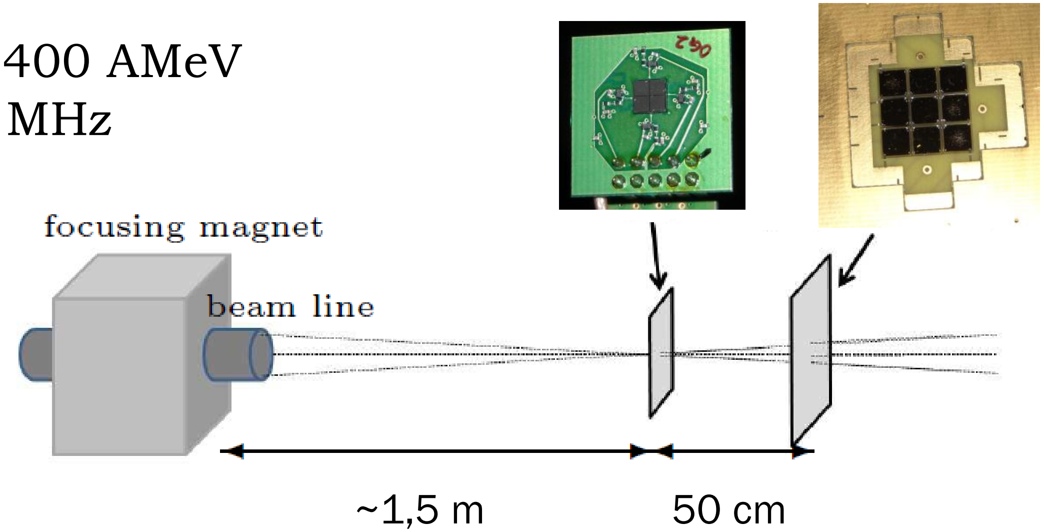


<u>Electronic grade diamond:</u>

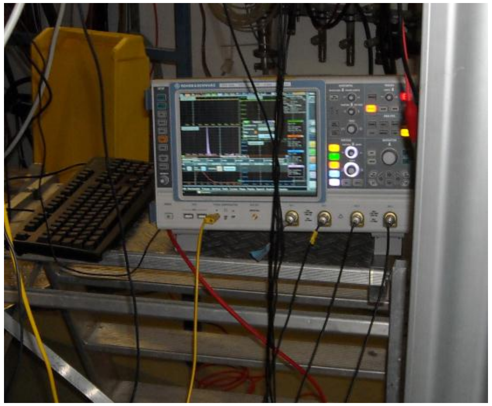
- Type IIa
- 9 x 4.5 mm x 4.5mm x 0.5mm
- Single substitutional nitrogen
- Single plate cost: £1475.00
- Pt/Ti/Au – 400 °C

Experimental Setup (DAQ – scope waveforms)

beam: C 400 AMeV
up to 10 MHz



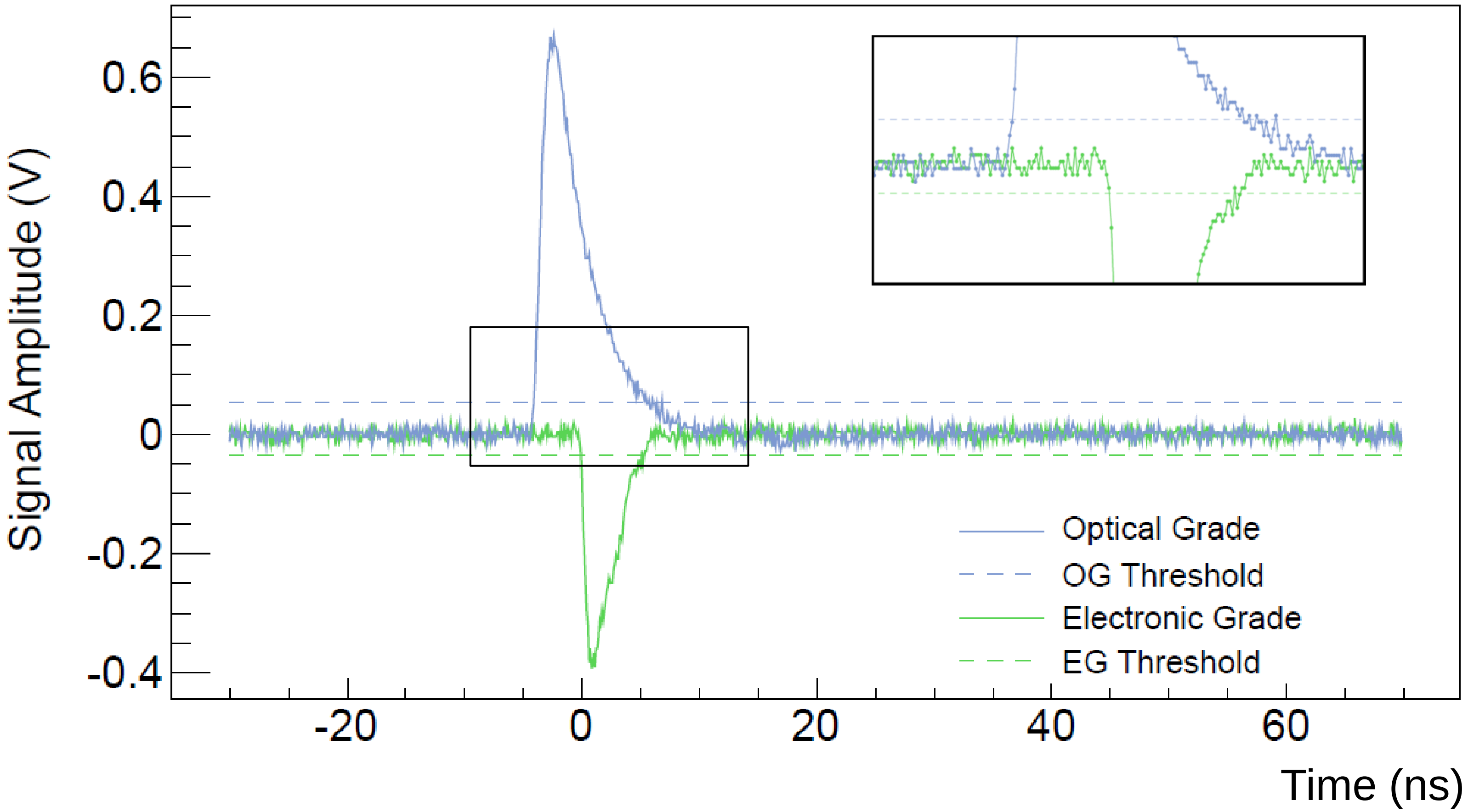
Detectors on PCBs → Amplifiers →



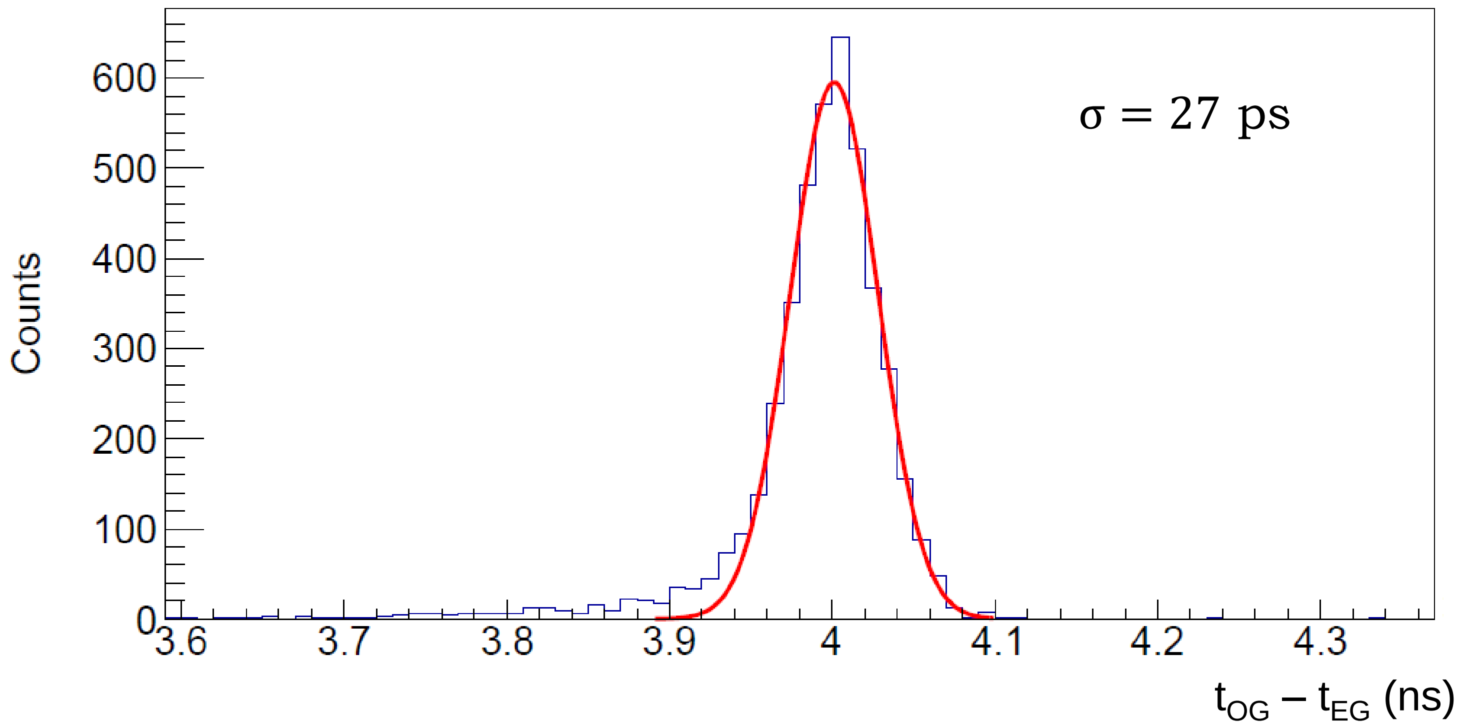
ROHDE&SCHWARZ RTO 1044 oscilloscope

Results: Time Resolution

- Scope waveform offline analysis
- Obtained from the time difference between the two detectors



Results: Time Resolution



$$t = t_{OG} - t_{EG} \Rightarrow \sigma^2 = \sigma_{OG}^2 + \sigma_{EG}^2$$

$$\sigma_{OG} \approx \sigma_{EG}$$

$$\Rightarrow \sigma_{OG} = \frac{\sigma}{\sqrt{2}} = \frac{27}{\sqrt{2}} = \mathbf{19\ ps}$$

Results: High Voltage Scans

Optical grade diamond detector

- Charge collection begins to saturate for increasing high voltage

Electric field intensity

↓

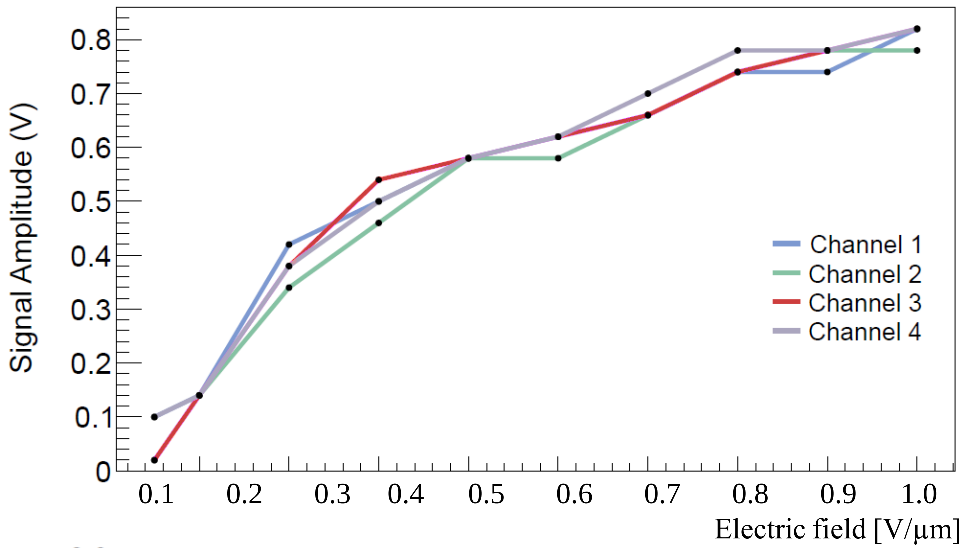
Drift velocity

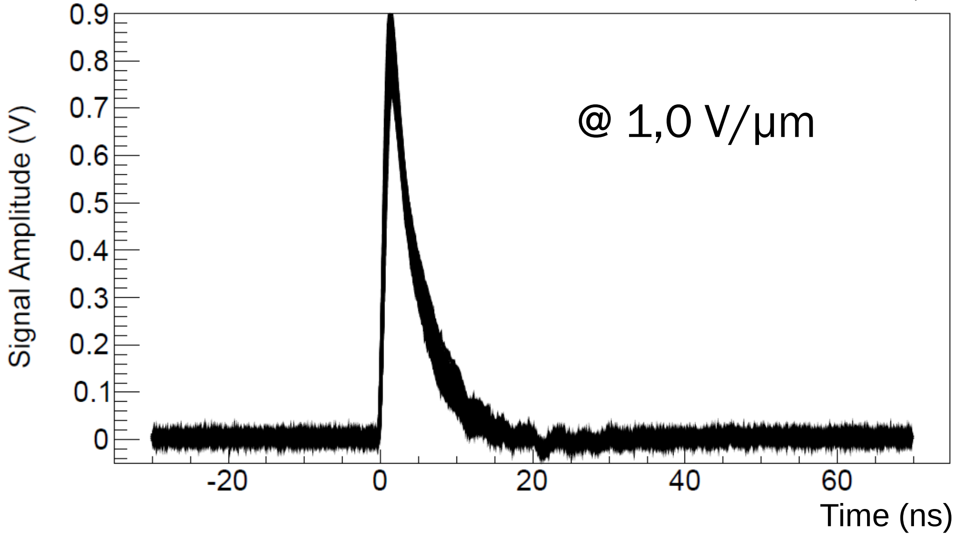
↓

Charge collection

↓

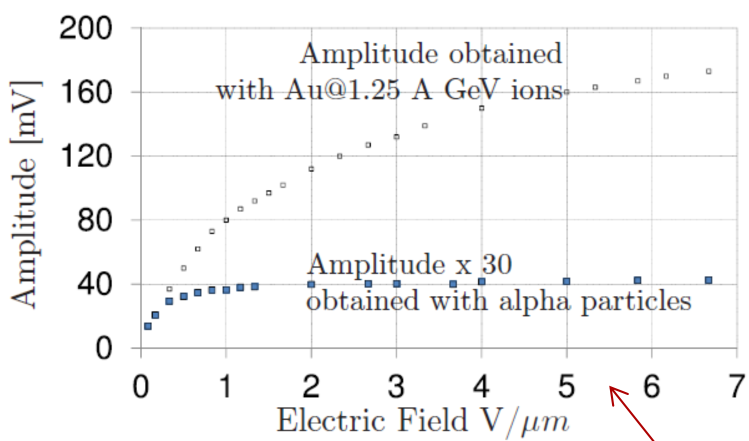
Signal amplitude



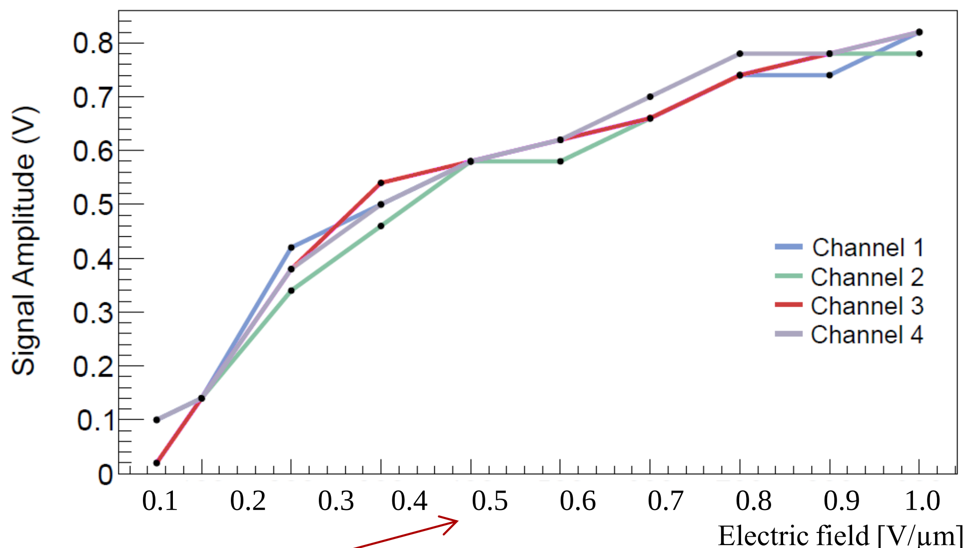


Results: High Voltage Scans

Electronic grade diamond detector



Optical grade diamond detector



beam: C 400 AMeV
up to 10 MHz

note different Electric Field scales !!!
different amplitudes

- Same trend seen

Results: Simulation

Simulation assumes:

- 400 AMeV carbon beam
- 500 μm thick detector
- 100% collection efficiency

↓

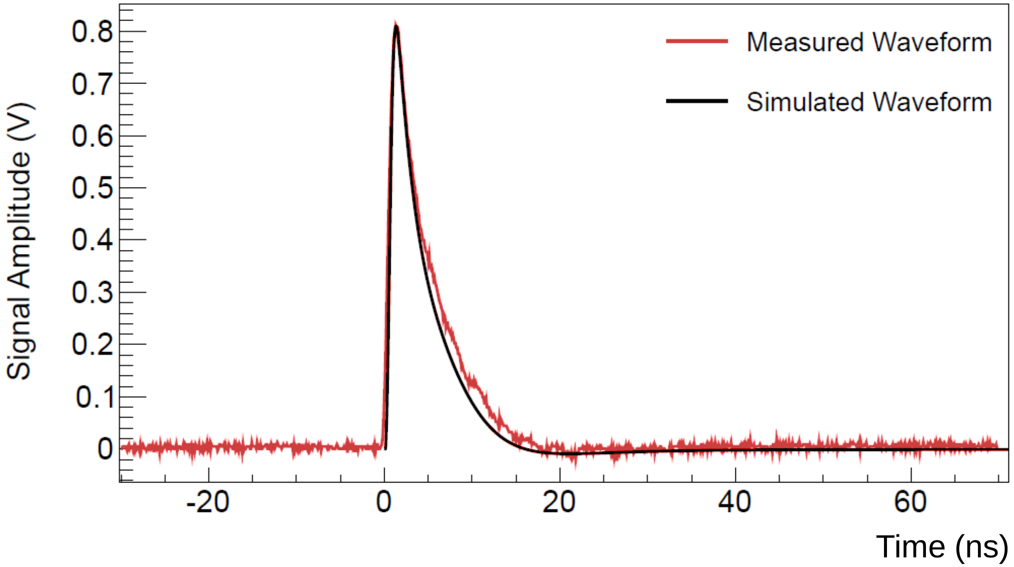
Obtain dE/dx and Q

↓

Simulated frontend electronics

↓

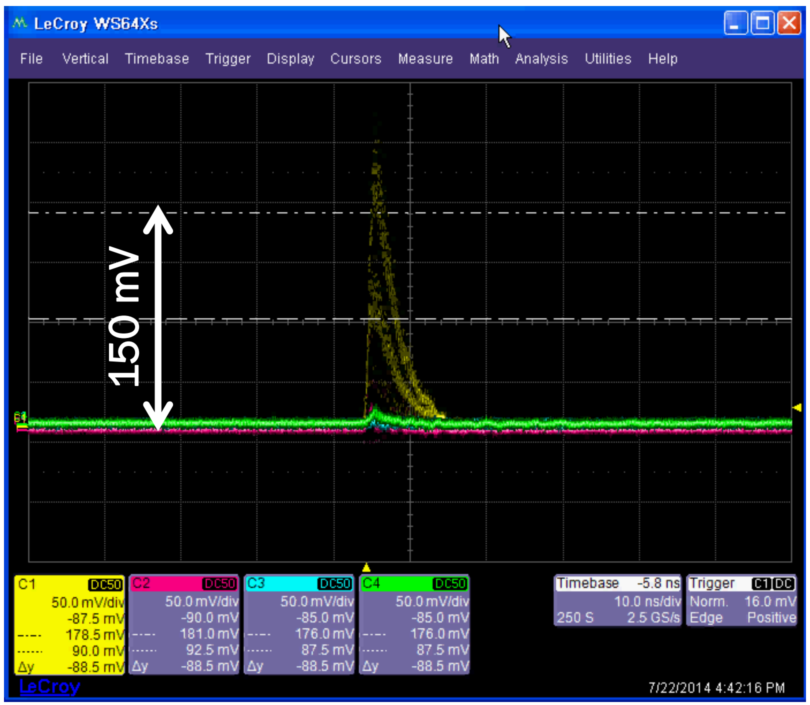
Simulated Waveform



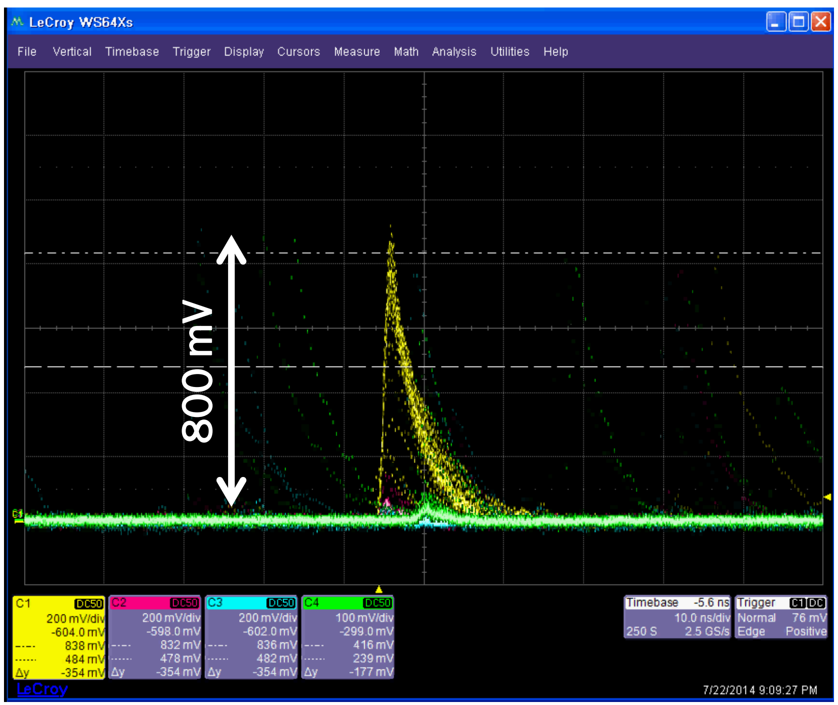
- Experimental charge collection efficiency close to 100%

Results: Rate Test on OG Diamond

- Hypothesis: High beam intensity results in OG diamond performing similarly to EG diamond



low beam intensity1 kHz (1 V/μm)



high beam intensity 1 MHz (1 V/μm)

Summary & Outlook

- Gold ions beam test – high rate capability and radiation resistance confirmed
- Pion beam test – MIPs detection working but needed improvement in time resolution
- Optical grade R&D ongoing:
  - Beam time in October 2014 with Sm @ 1,2 AGeV (ended last week)
    - Determine the critical value for energy losses in detector to fill the holes/traps
    - Determine lifetime of the traps remain filled

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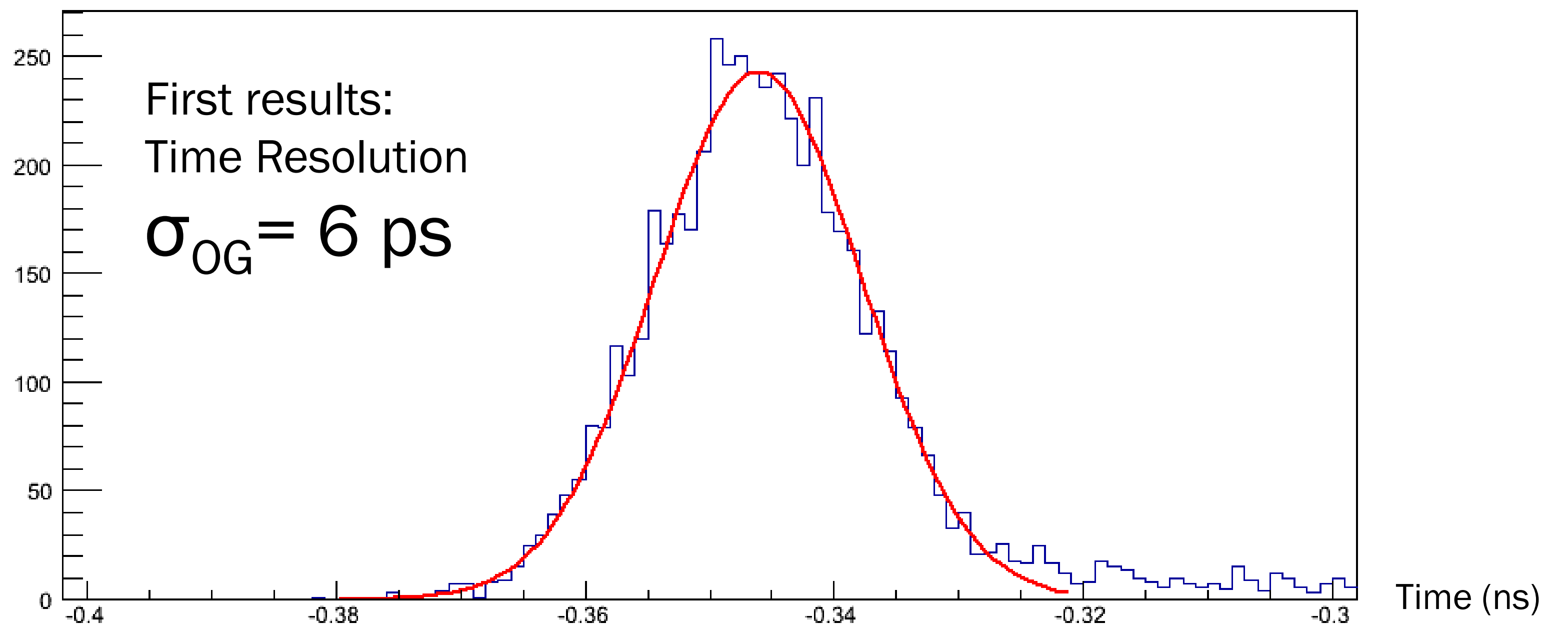

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    - Determine the critical value for energy losses in detector to fill the holes/traps
    - Determine lifetime of the traps remain filled
  - Repeat these measurements with MIPs particles

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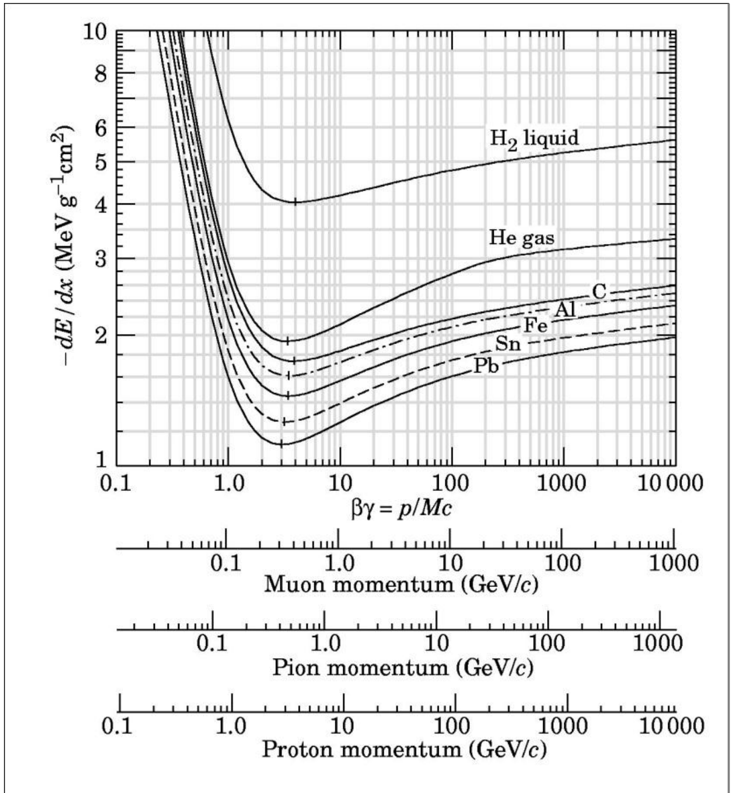
Thank you for your attention!

Backup Slides

- Bethe-Bloch formula:

$$-\frac{dE}{dx} = \frac{4\pi n}{m_e c^2}\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \frac{Z^2}{\beta^2}\left[\ln\left(\frac{2m_e c^2\beta^2}{I(1-\beta^2)}\right) - \beta^2\right]$$



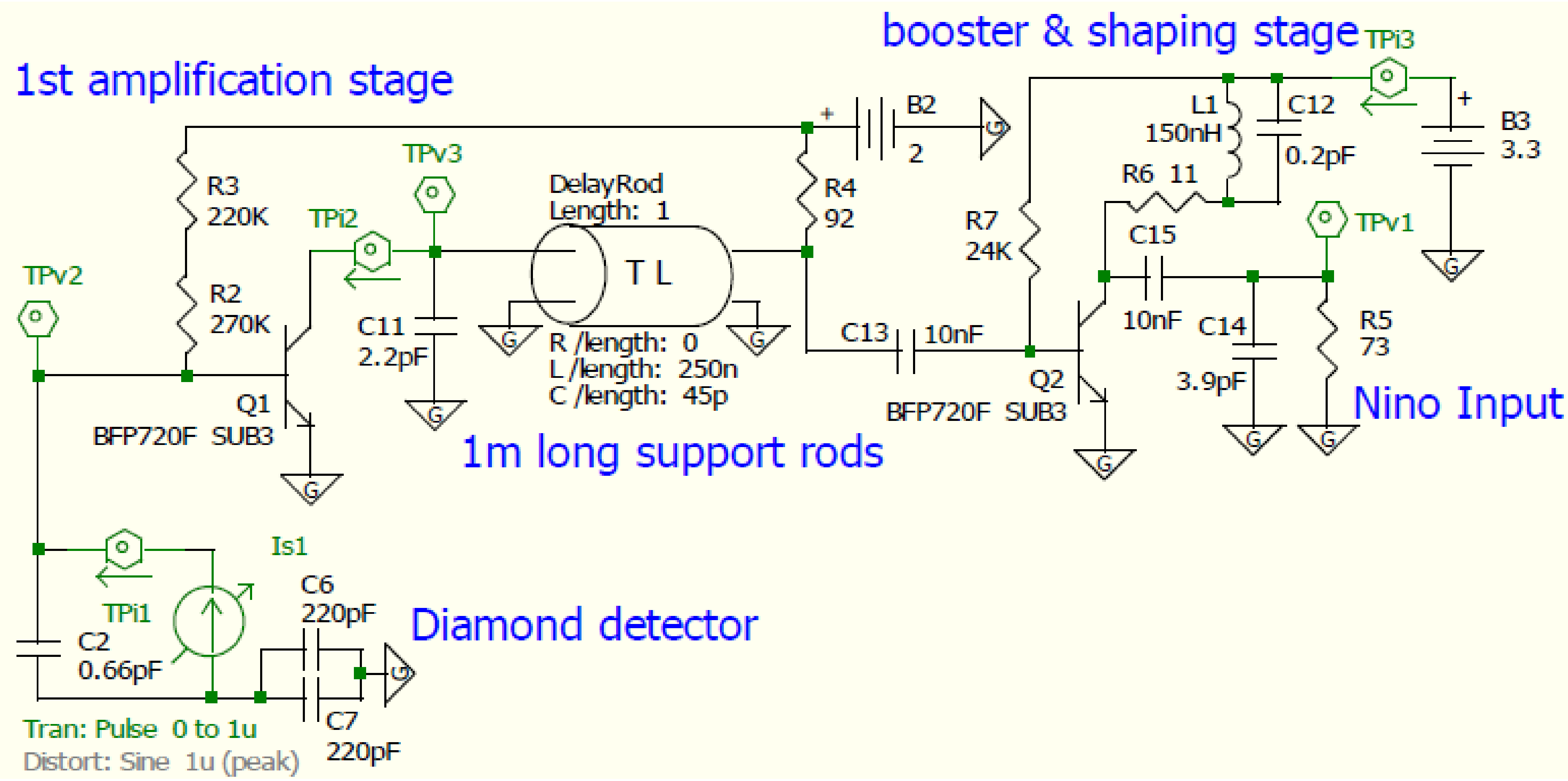
Backup Slides

- Diamond properties:

Physical Properties at 300 K	Diamond
atomic charge	6
mass density [g·cm^{-3}]	3.5
lattice constant [Å]	3.57
band gap [eV]	5.45
intrinsic carrier density [cm^{-3}]	< 10^3
energy to create e-h pair [eV]	13
energy to remove an atom from the lattice [eV]	80
thermal conductivity [W cm^{-1} K^{-1}]	20
thermal expansion coefficient [K^{-1}]	0.8×10^{-6}
resistivity [Ω cm]	> 10^{11}
breakdown field [V/cm]	10^7
electron mobility [cm^2/Vs]	2200
hole mobility [cm^2/Vs]	1600
saturation velocity [km/s]	220
dielecric constant	5.7

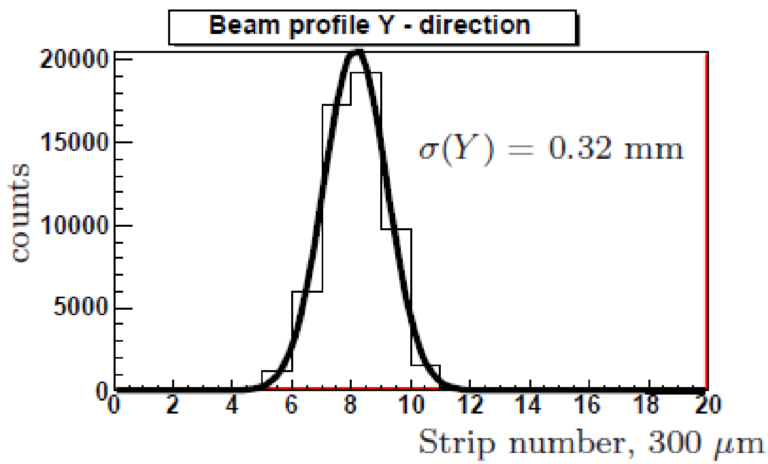
Backup Slides

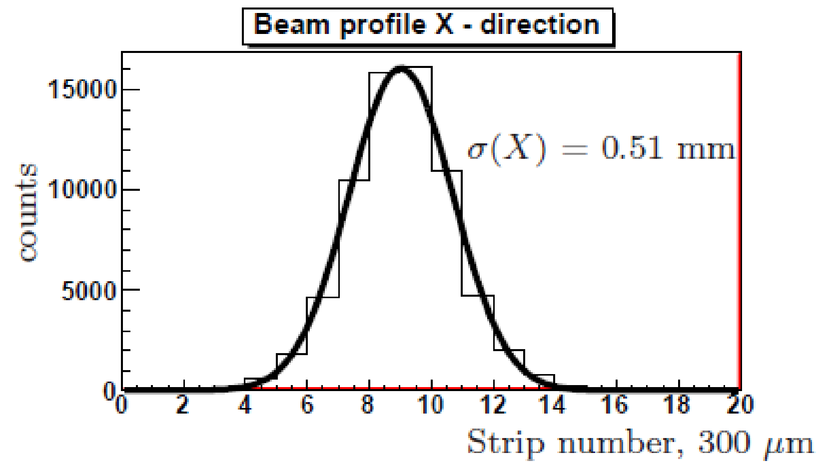
- Two stage amplification for MIPs:



Backup Slides

- Beam profile for Au ions beam test:





- Time resolution: