High Rate MIPs Diamond Detectors with a Time Resolution σ < 50 ps ?

W.Koenig for the GSI Diamond Crew

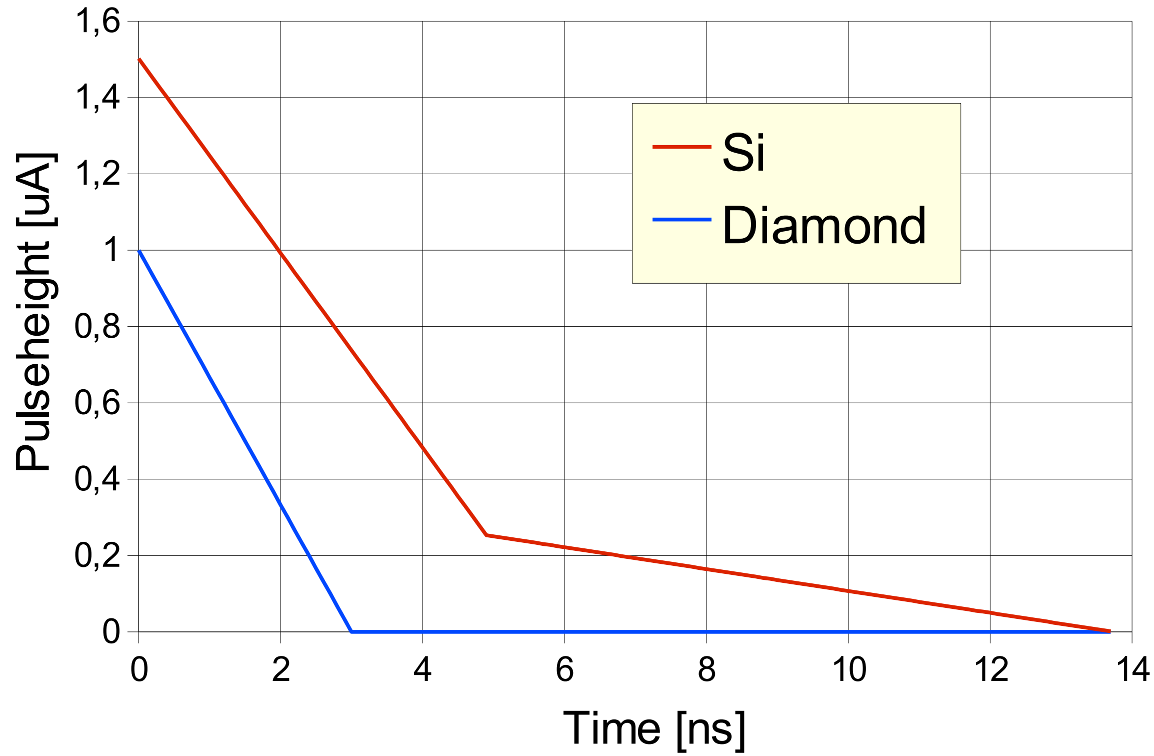
Menu:

- Some basics
- Some disapointing results
- Some improvements
- Some new and nice results
- Some conclusions (my point of view)

Basic diamond properties compared to Si detectors

Diamond is radiation hard

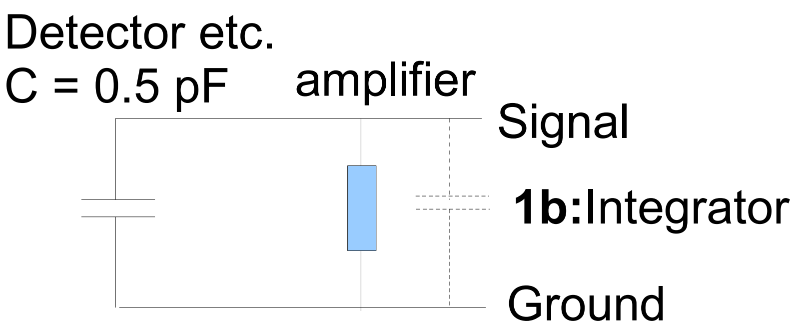
	Diamond	Si detector
L_{rad}	12 cm	9.4 cm
ε	5.7	11.9
E_{eh}	13 eV	3.6 eV



Primary current signal from a 300 μm detector
Field: **1 kV / mm** , **2kV / mm**

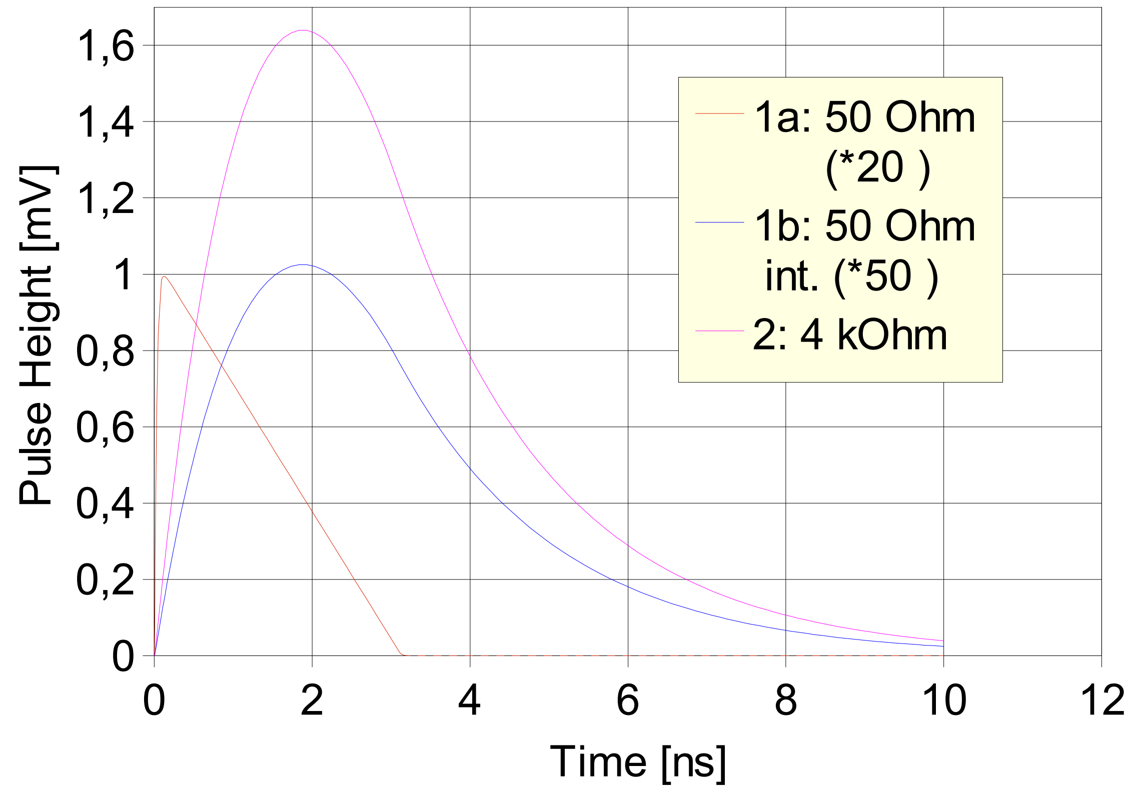
short timing signals:
Si advantage of a factor 3.6 more e-h pairs is nearly compensated by higher charge mobility, smaller capacitance (**ε**) and longer radiation length L_{rad}

Problem: 8000 e-h pairs for a 300 μm diamond is small



1a,b: R = 50 Ω

2: R = 4 kΩ



Impedance	Int. noise [μV]	Signal [μV]	S/N
50Ohm 0.5pF	56,6	49,7	0,9
50Ohm 40pF	10,1	20,5	2,0
4kOhm 0.5pF	90,2	1639	18,2

Improvement of 4k Ohm to 50 Ohm input impedance (same frequency response):

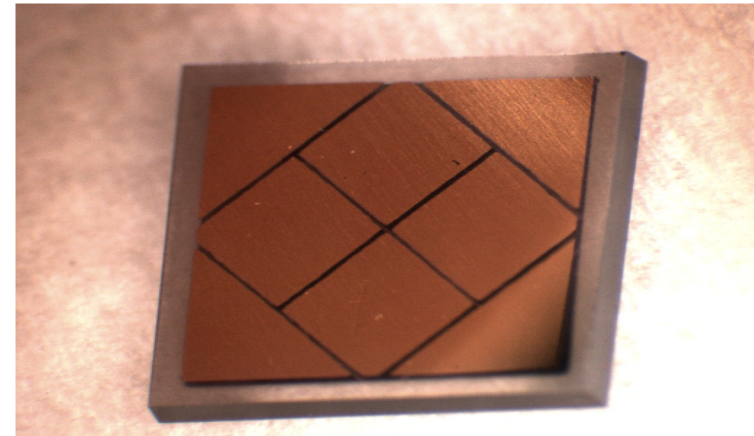
Input Signal height increases by factor 80

Signal / RMS-Noise Ratio impoved by 8.94 = √ 4kΩ / 50Ω

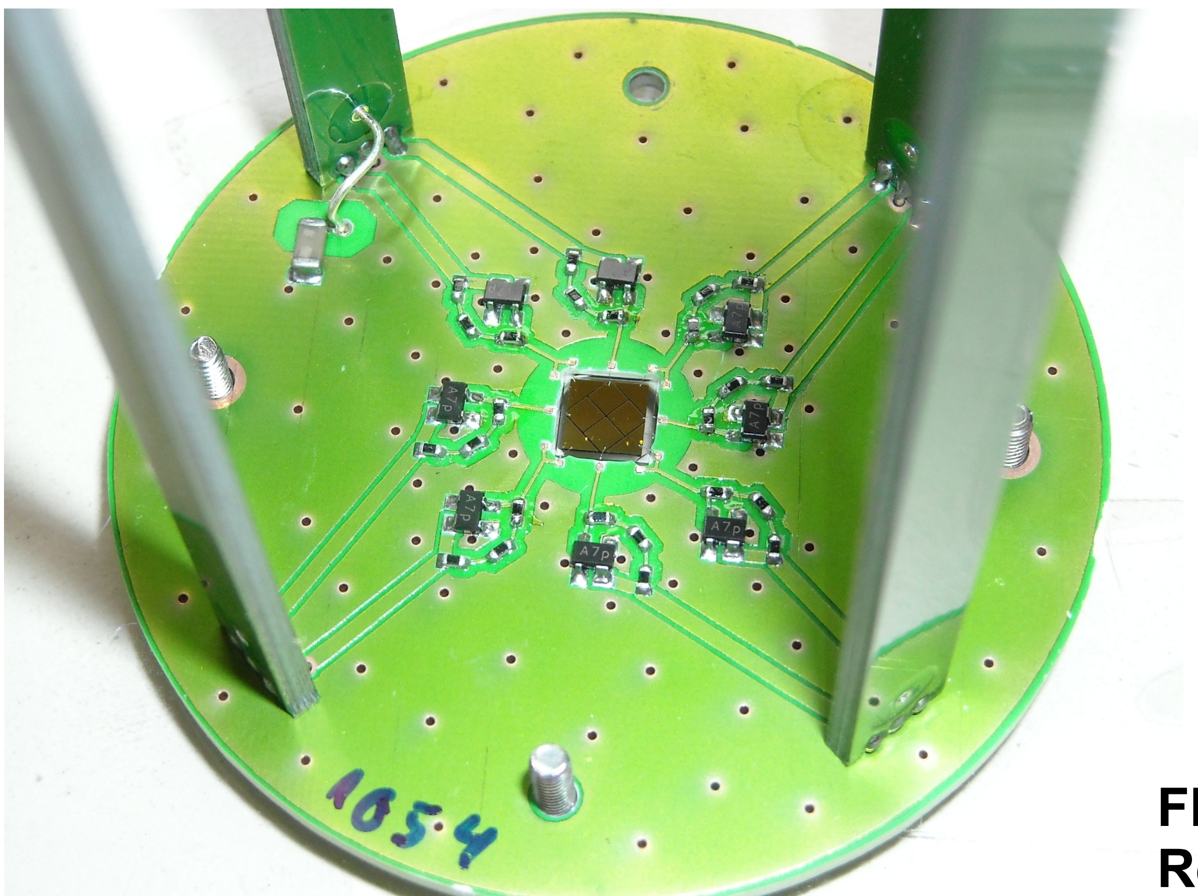
Dedicated shaping improves S / N by ≈ 2

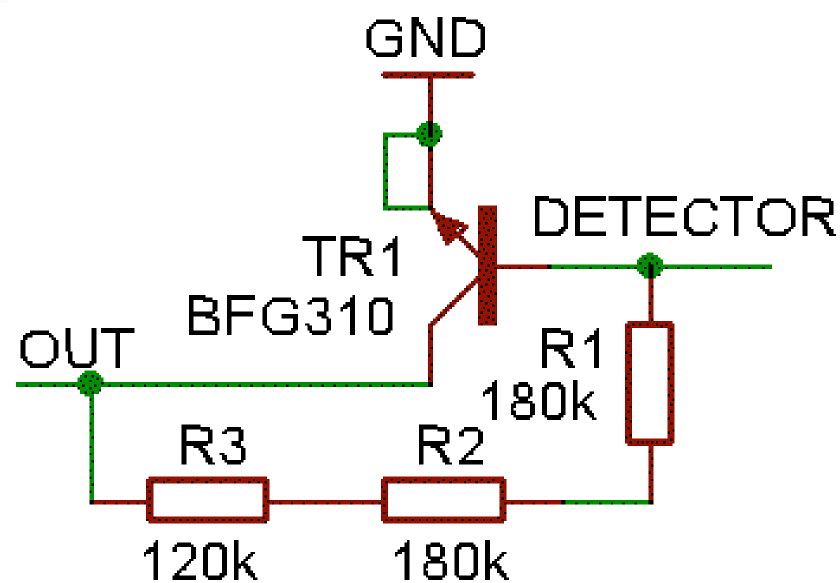
HADES start detectors for protons:

300µm: 4 segments 3.5*3.5 mm², 500 µm: 8 segments 4.7*4.7 mm²



Diamond (center) surrounded by 8 amplifiers





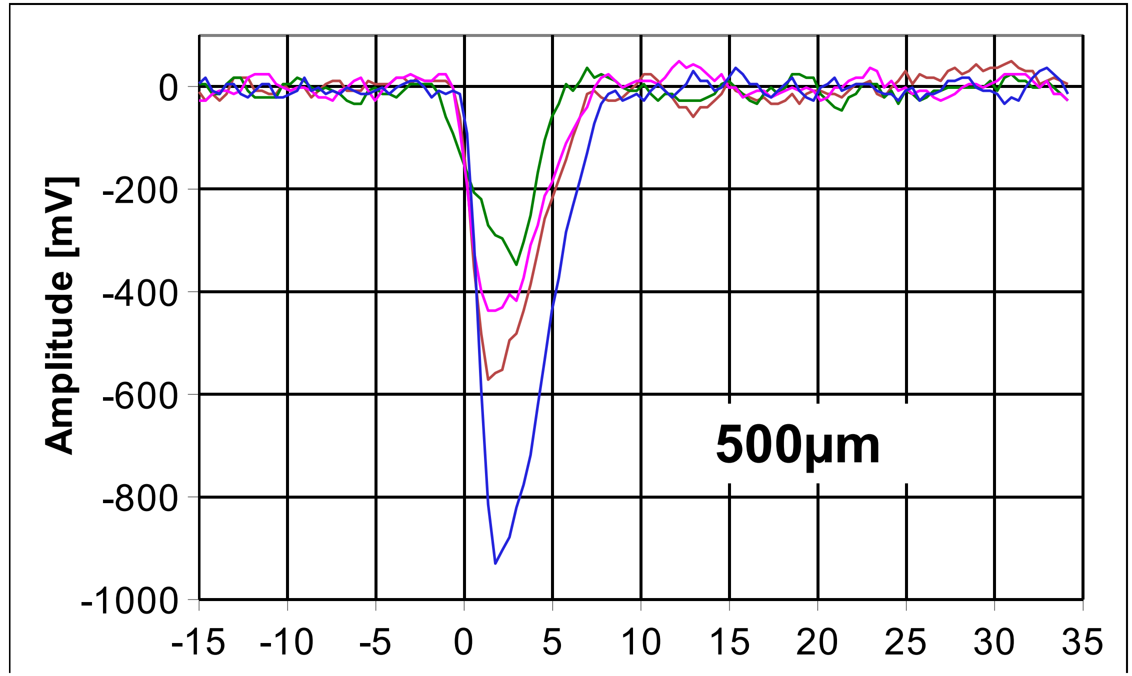
FEE: 5mW/ch, no explicit power suply

Ref.: Horrowitz, section bad designs

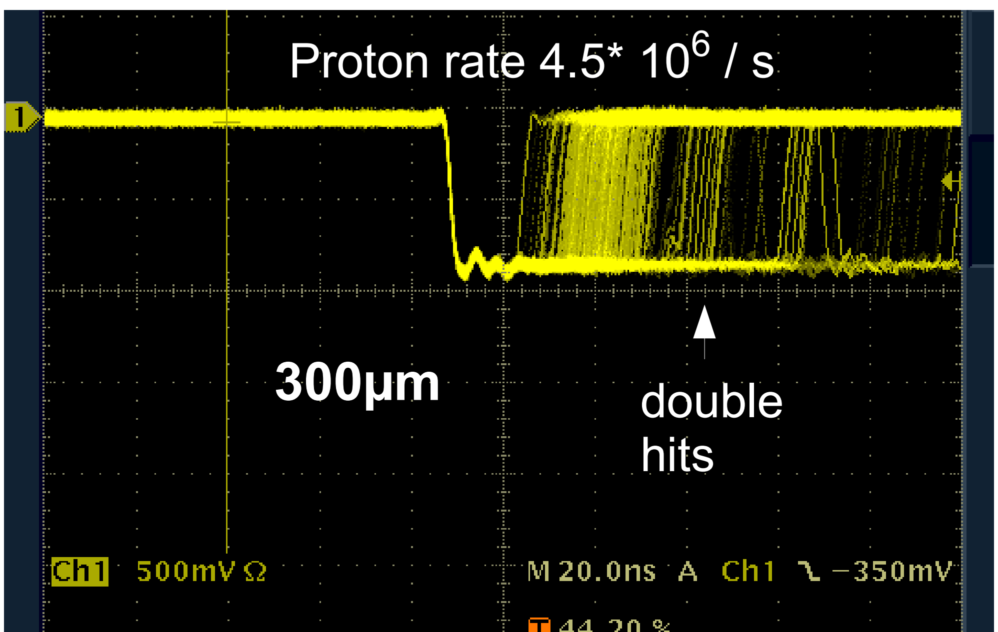
Measured pulse shapes for monocrystalline diamonds (Sr90)

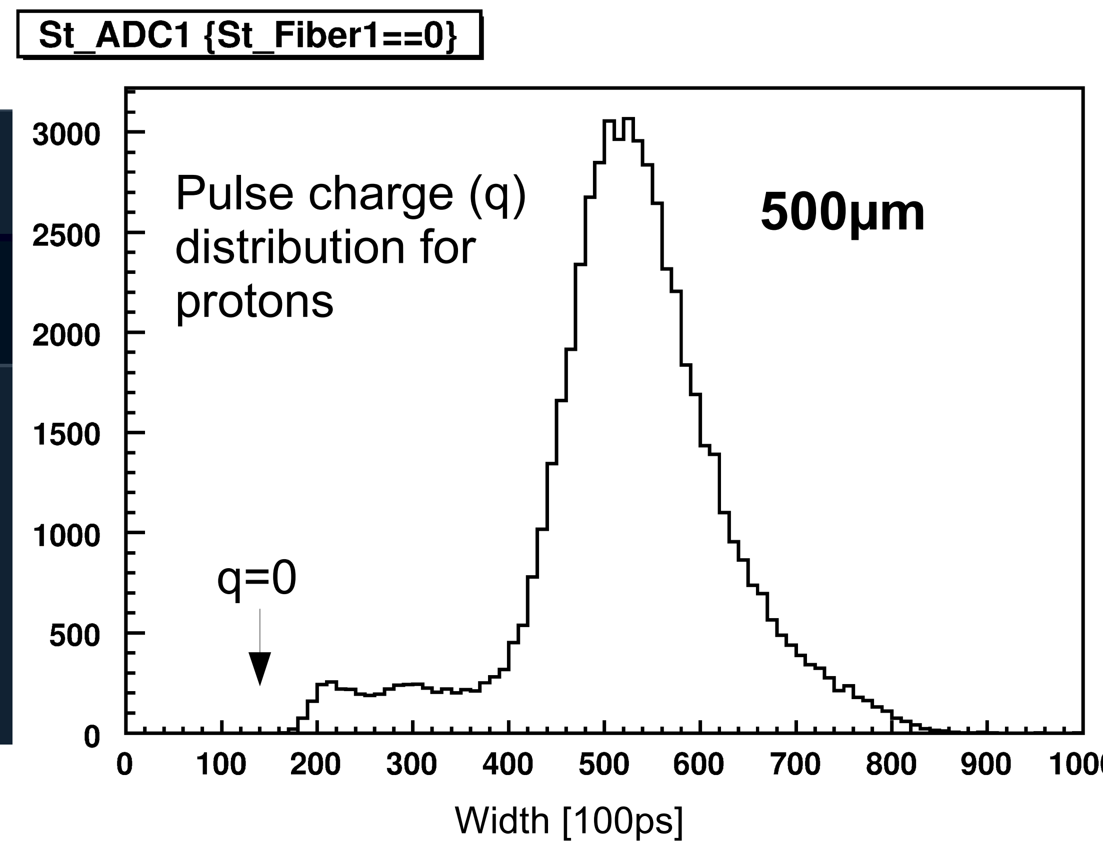
Dedicated shaping by booster amp.

Rise time [ns]:	500µm:1.35
	300µm:1.24
Signal / RMS noise:	500µm: 34 (p: 27)
	300µm: 29 (p: 23)



Discriminator converts signal charge to output width.





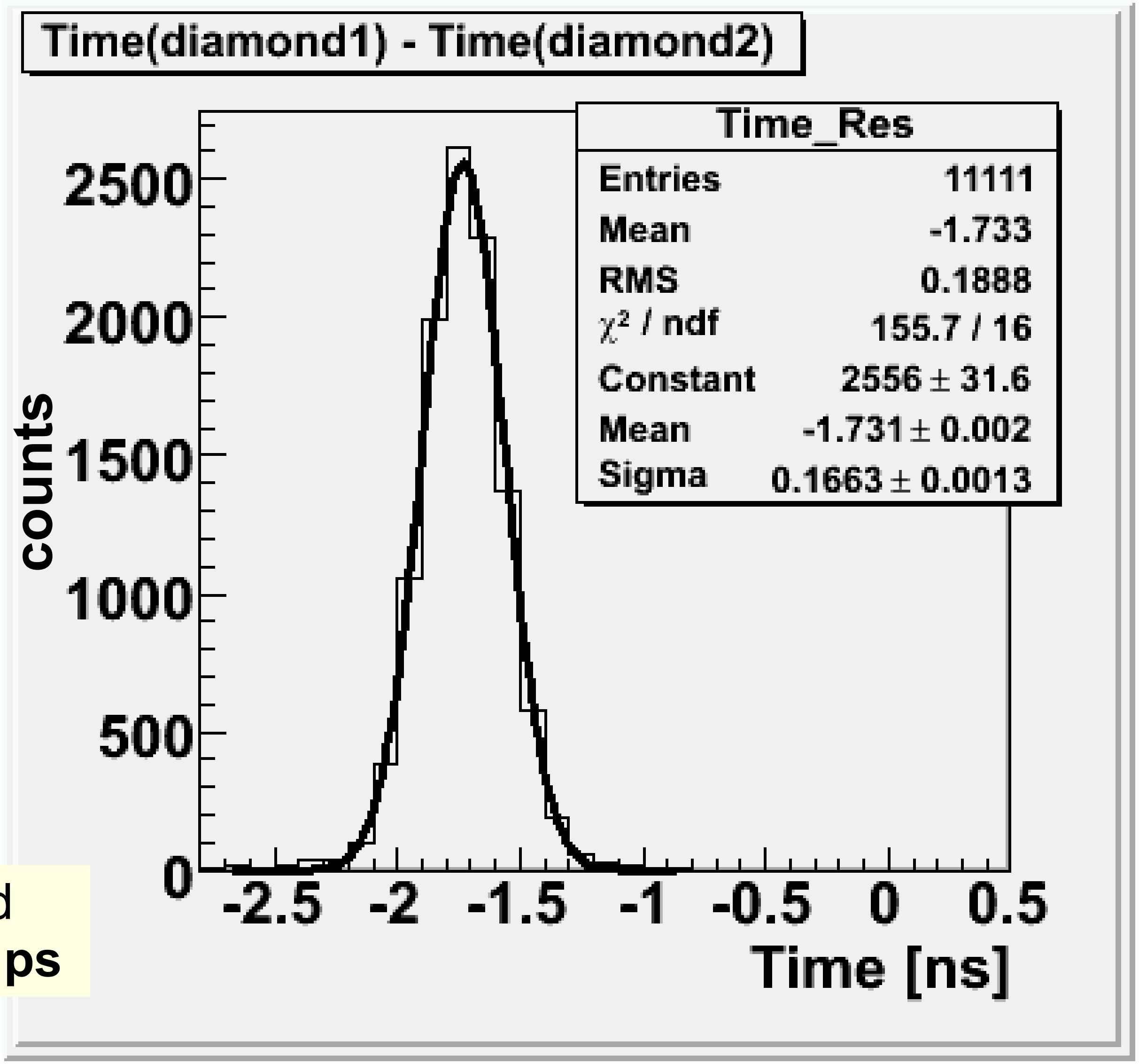
Measured time resolution for 1.75 GeV protons (MIPS)

Time difference between 2 diamonds without any correction

MIPS (1.2 - 3.5 GeV p):

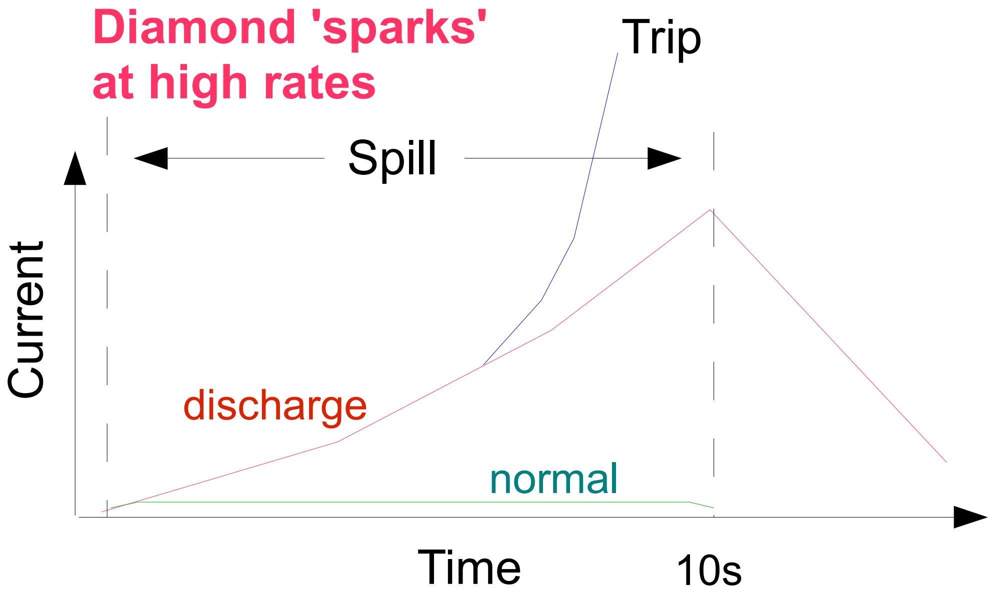
Rate <= $5*10^6$ / s / $10mm^2$

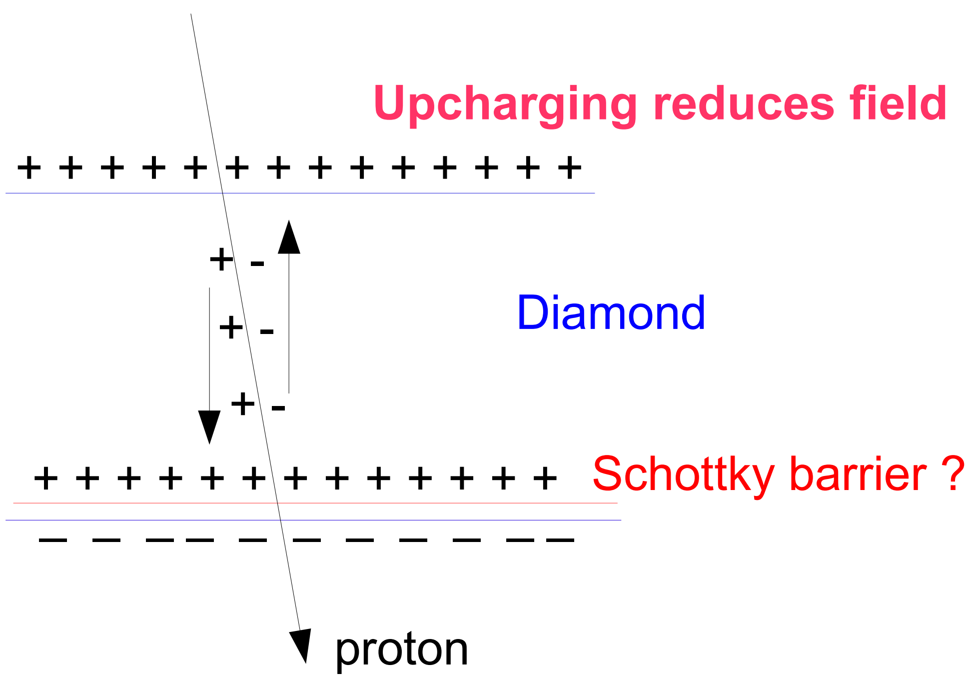
Efficiency >= 95%

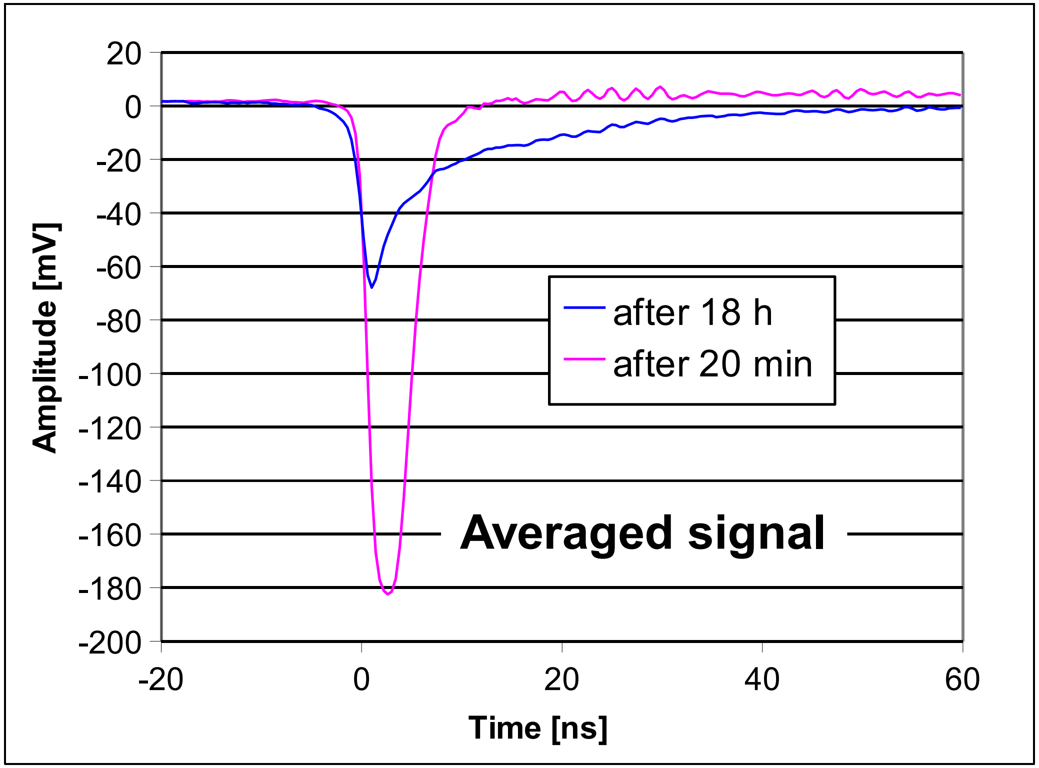


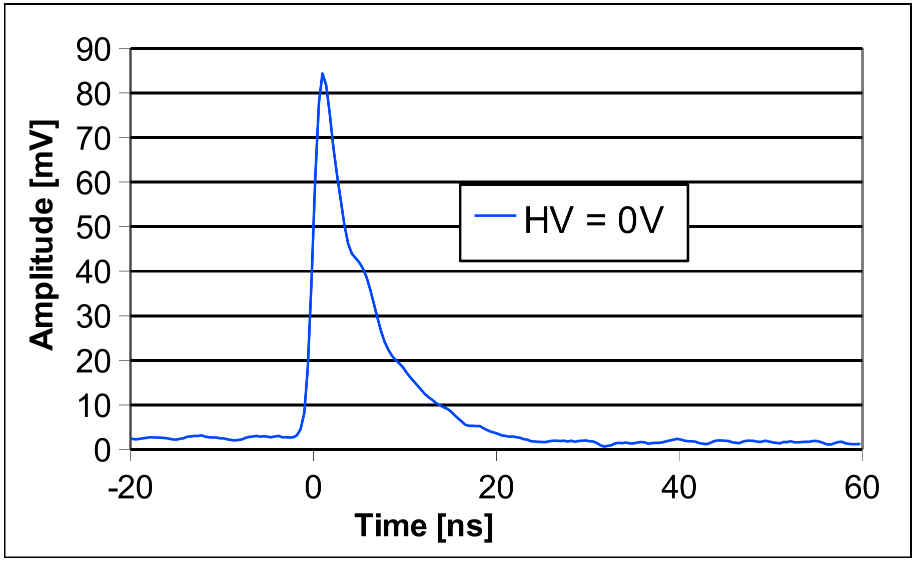
Time resolution for a single diamond corrected for TDC contribution: **100 ps**

Problem: Diamond metallization and surface properties









Inverted signal without high voltage

Dedicated metallization procedure improves

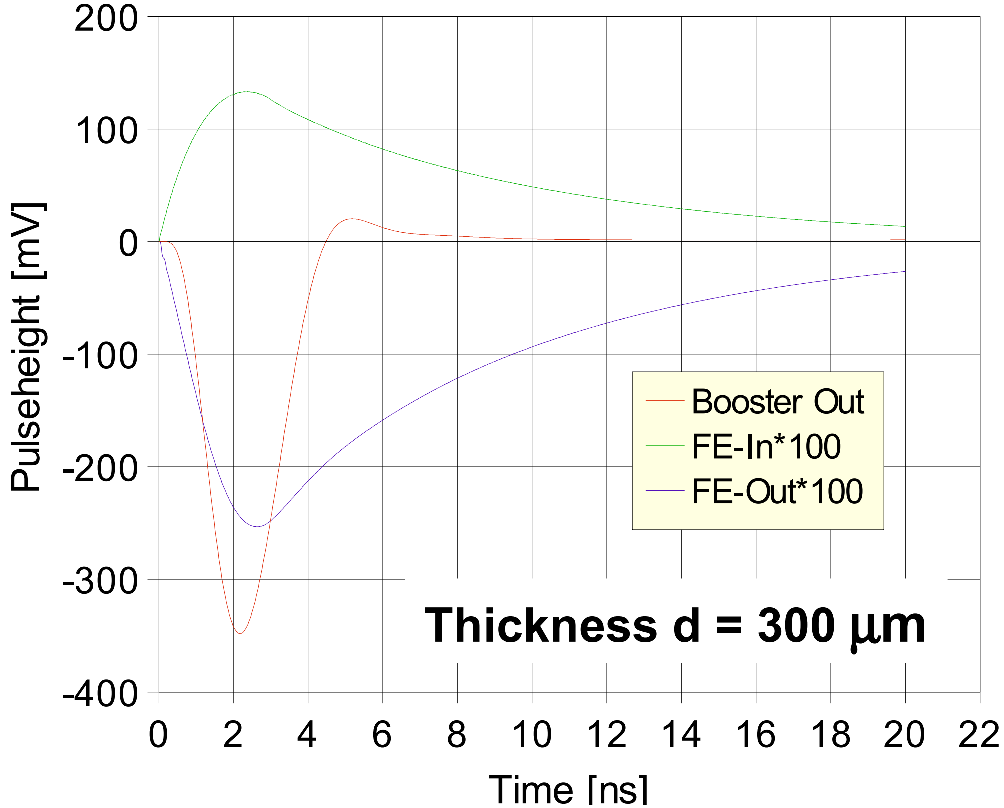
Latest electronics development

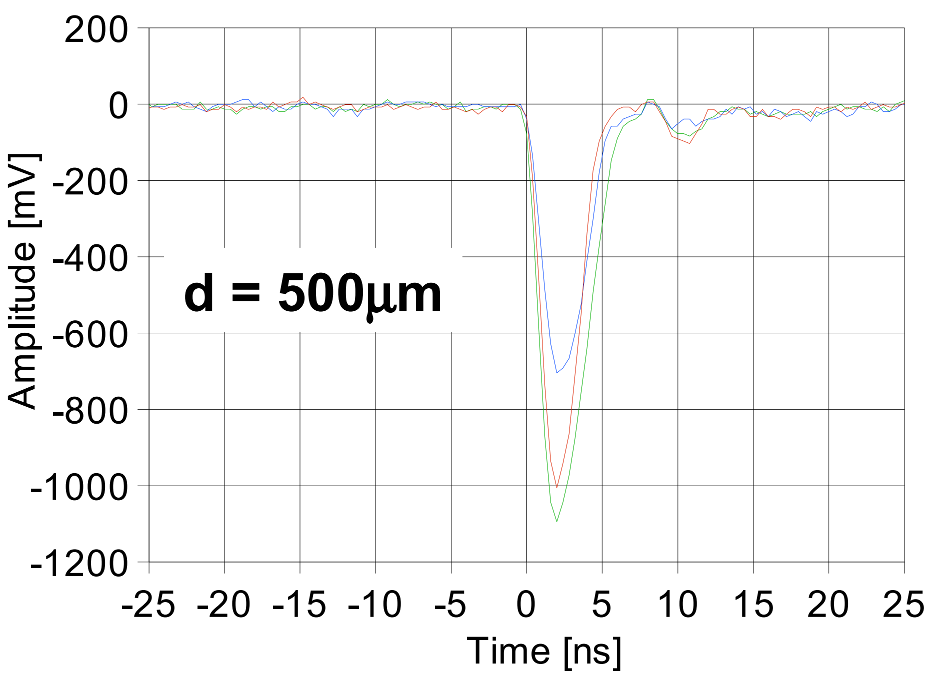
State of the art SiGe:C transistor BFR705L3RH
- S/N improved by nearly 50%
- Risetime decreased by 10%

d[μm]	S/N	t_r [ns]	σ [ps]
500	38	1.2	39
300	34	1.1	40
200	28	0.94	42
100	17.3	0.73	53

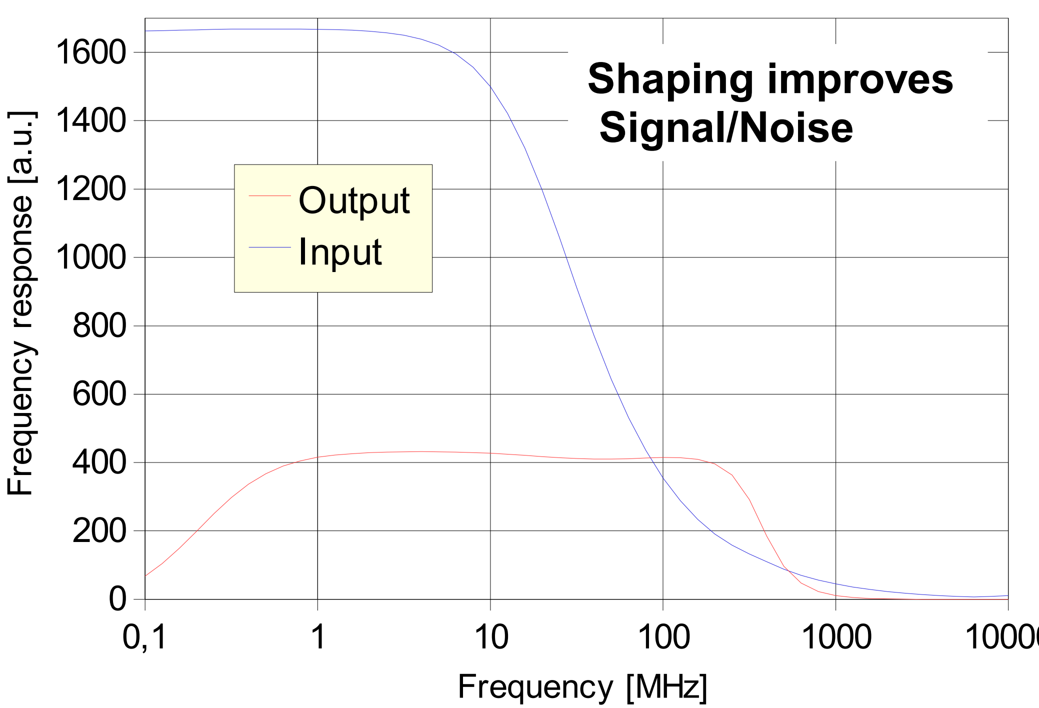
Simulation

Power consumtion: 2.5 mW/ch.
Total size of all components: 2 mm^2

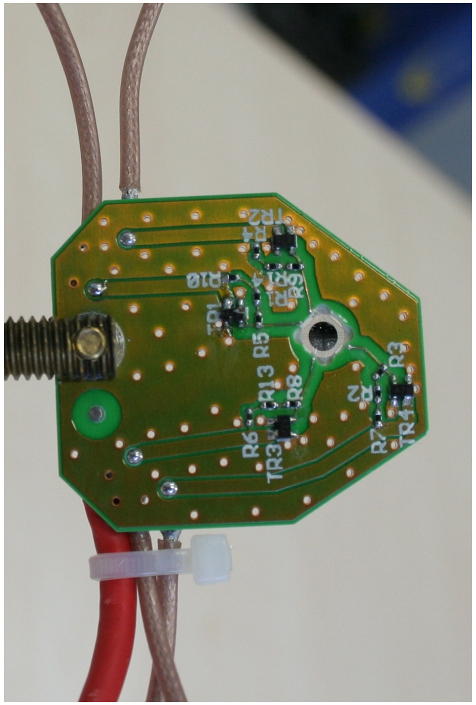




First result Sr90 source: S/N = 50
Basewidth: 6ns

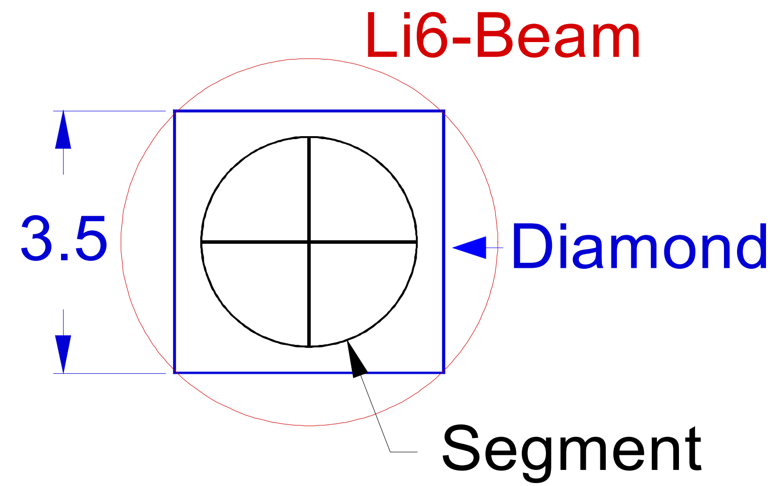


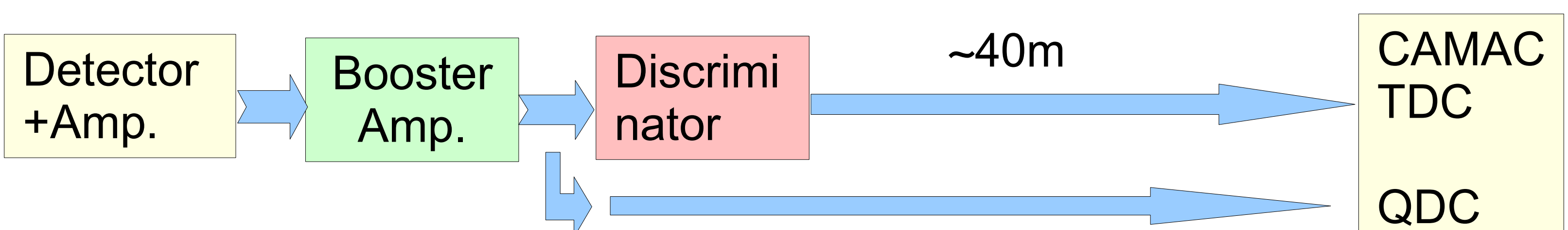
Test-Beamtime October 2009



Li6 (Z=3) compared to protons:

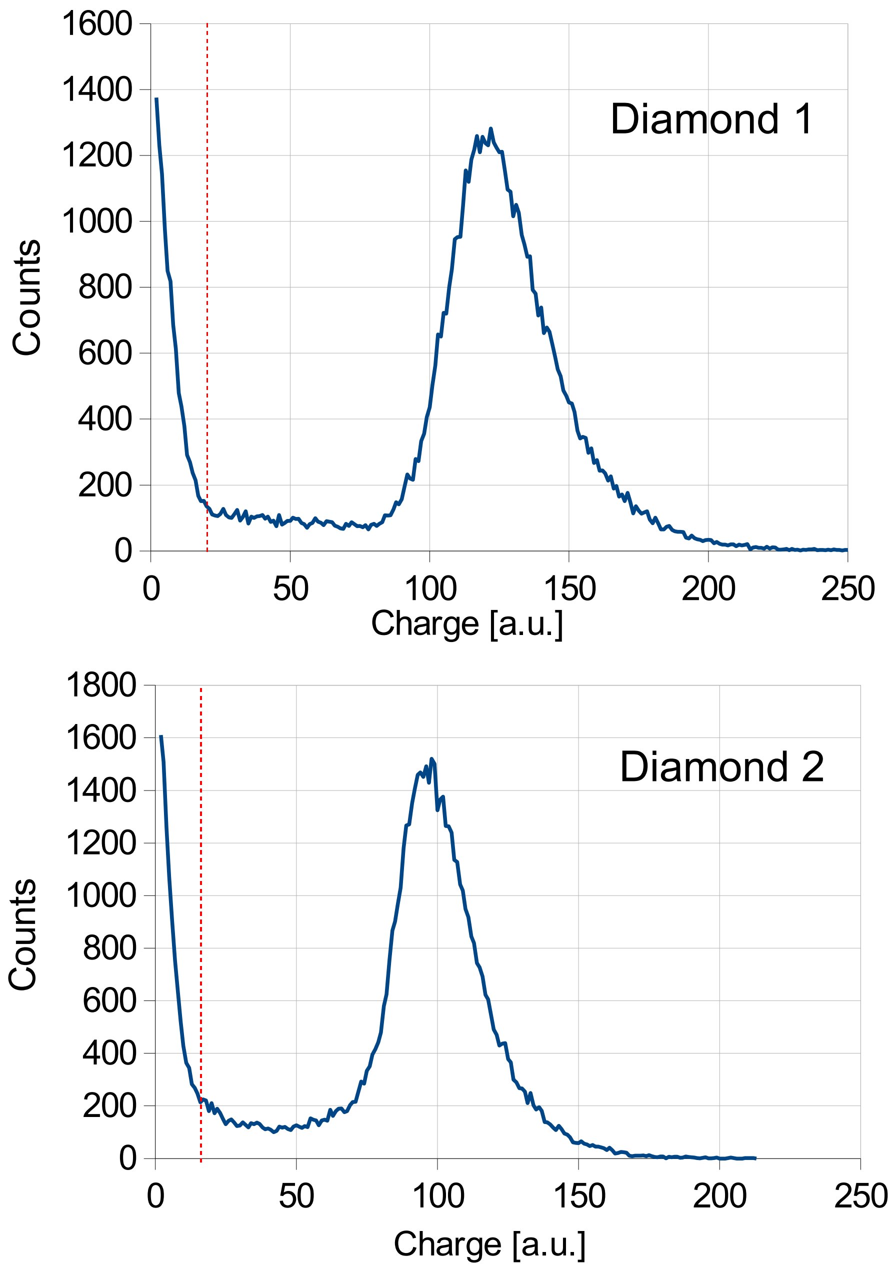
- Energy-loss 9* larger than for protons
- Diamond thickness 50µ instead 500µ
  - 10* less charge produced
  - shorter primary signal
  - Segment capacitance 10* larger



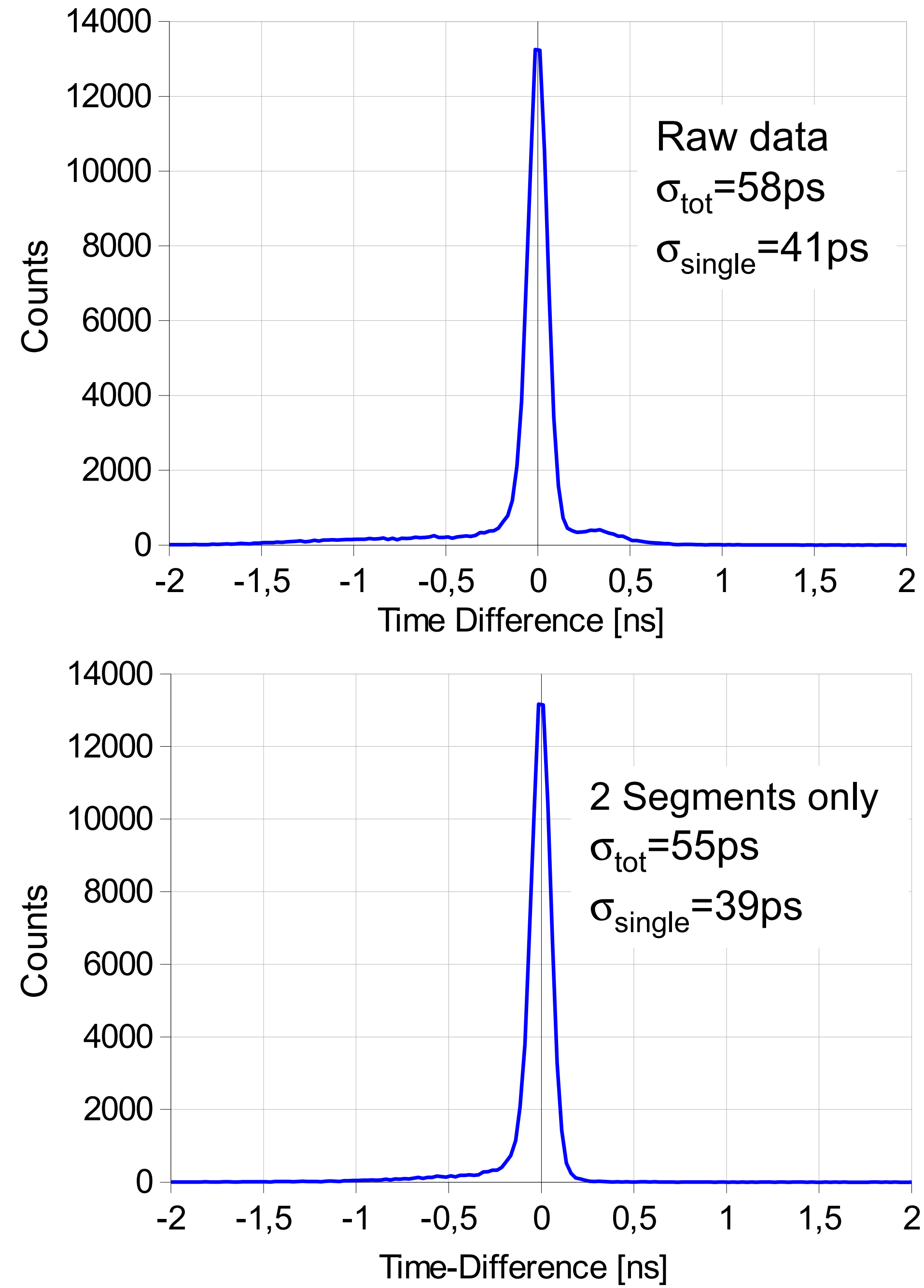


2^{nd} setup with FET as 1^{st} stage (higher impedance, larget capacitance)

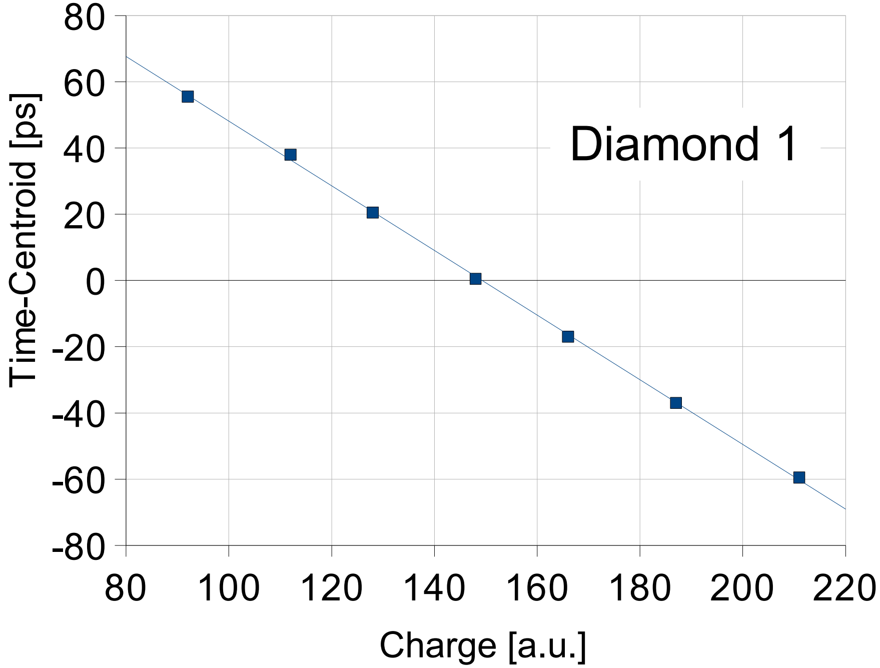
Charge distribution (after shaping), 100µ diamonds)

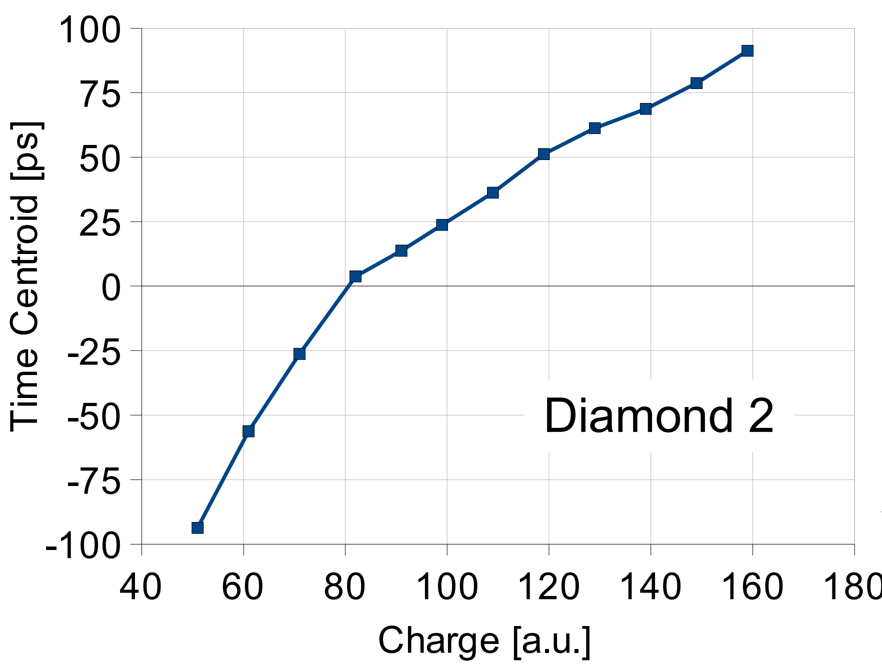


Time resolution (two 100µ diamonds

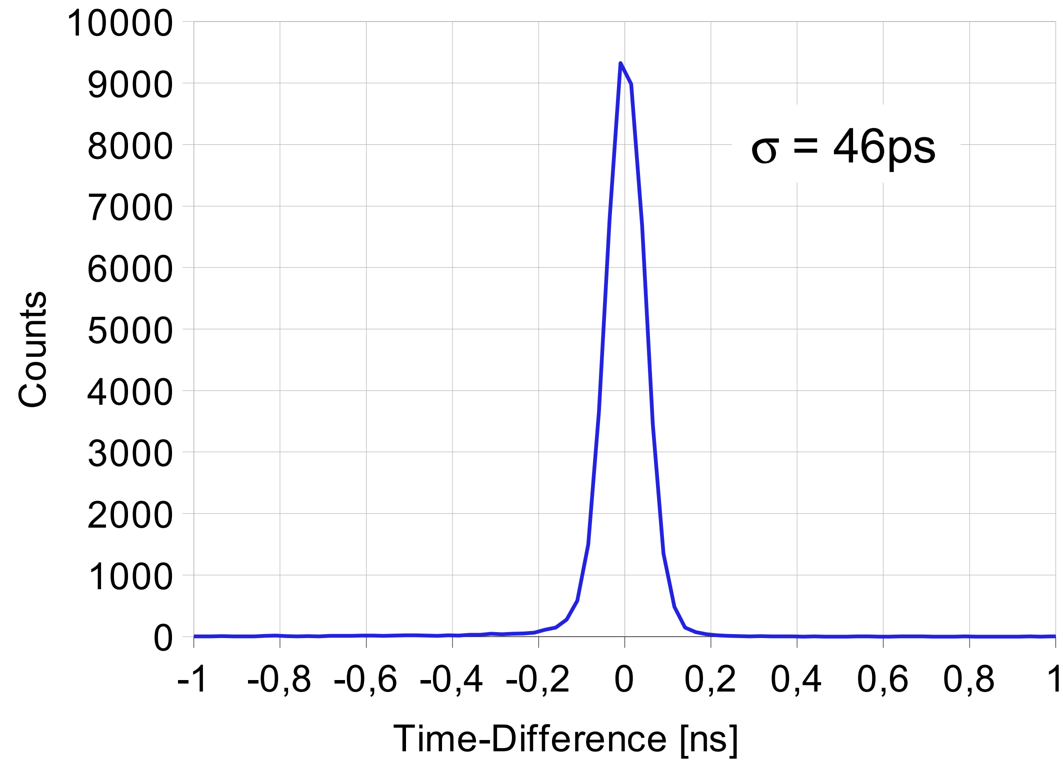


Walk Correction





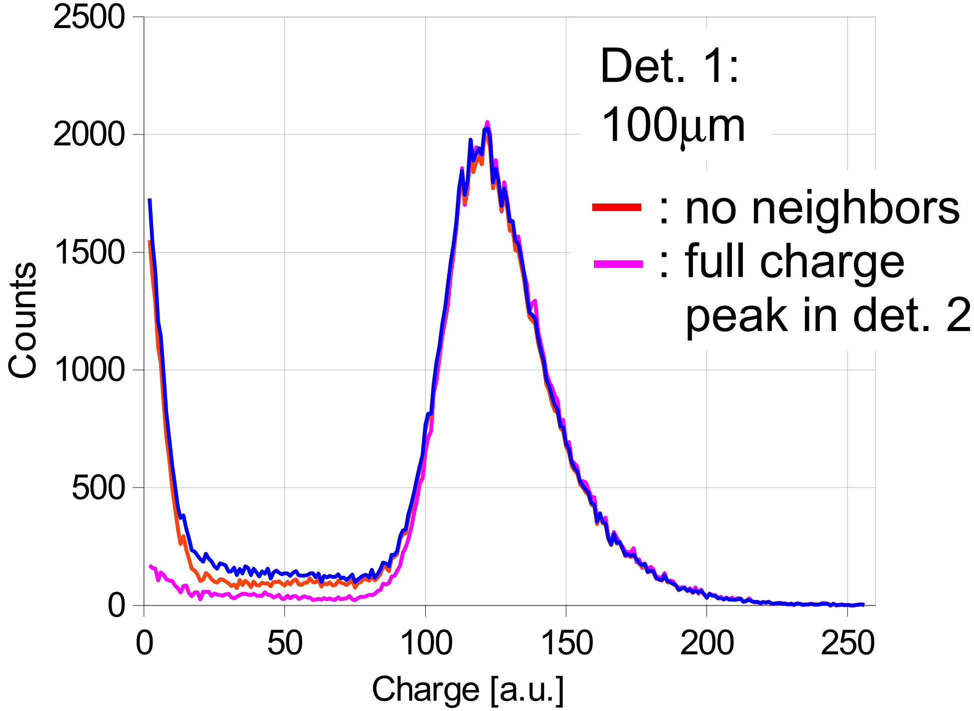
Final Result:
time difference for two 100µ diamonds

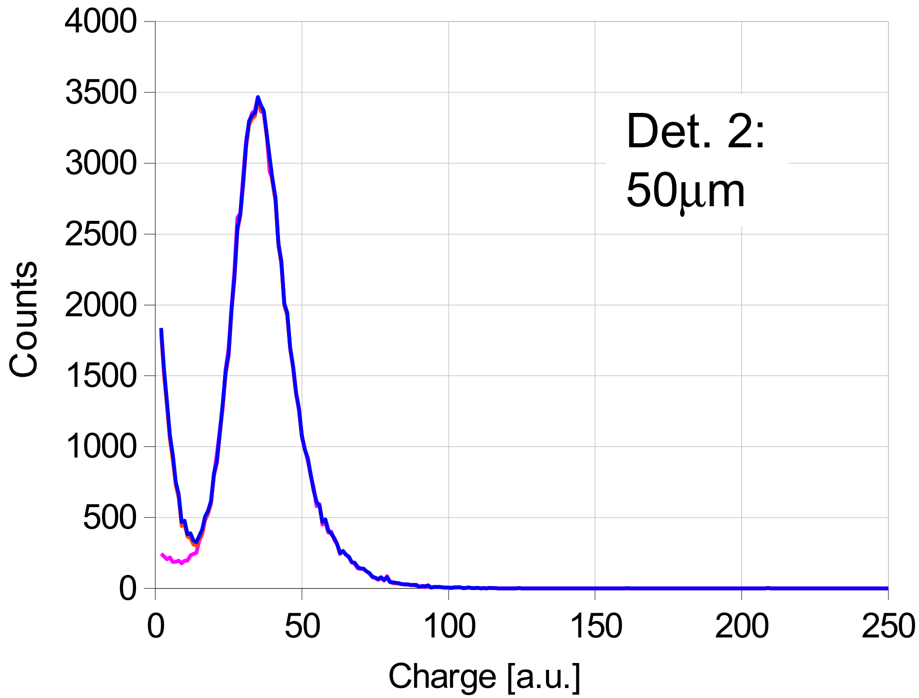


Time resolution:
One diamond: σ = 33ps
Corrected for digital resolution: σ = **21ps**
(Two pulser measurements
extrapolated to infinite pulseheight: 25 ps)

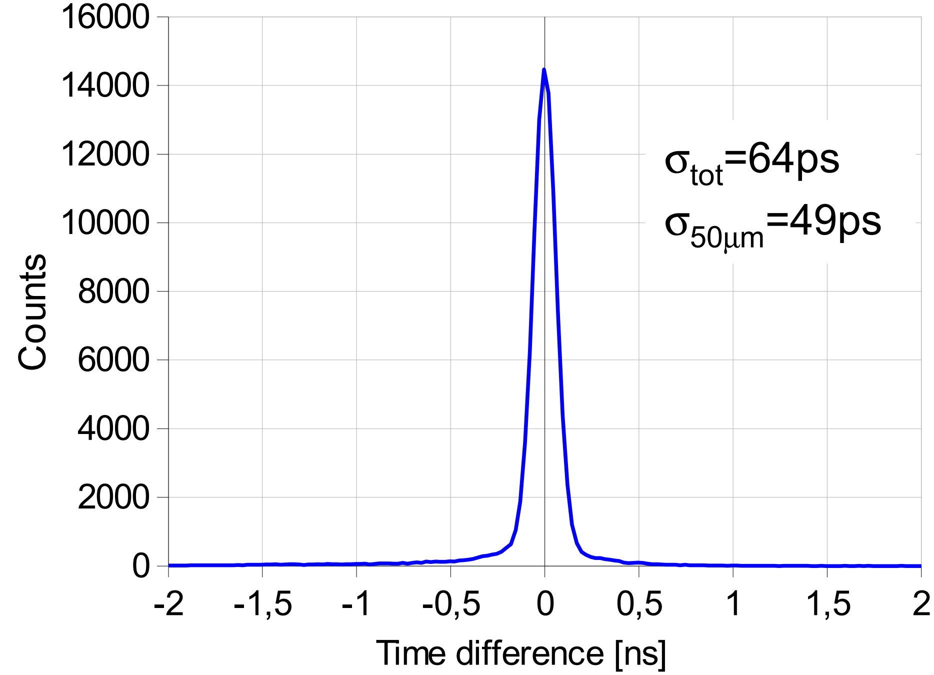
Different slope for low charge tail
(reduced field in non-metalized area ?)

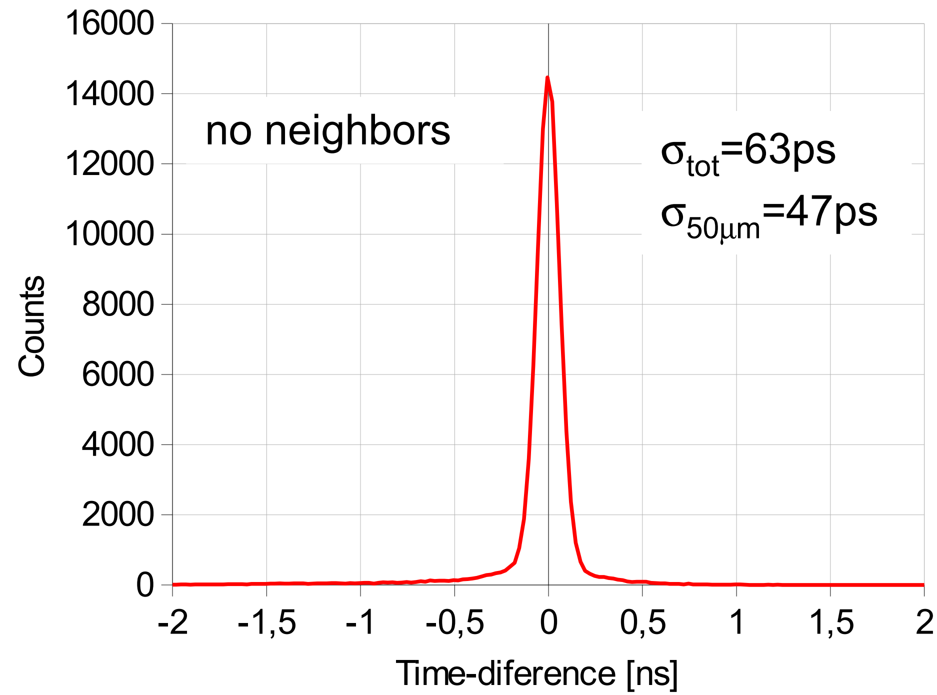
Charge distribution (after shaping), 100µ / 50µm diamonds)



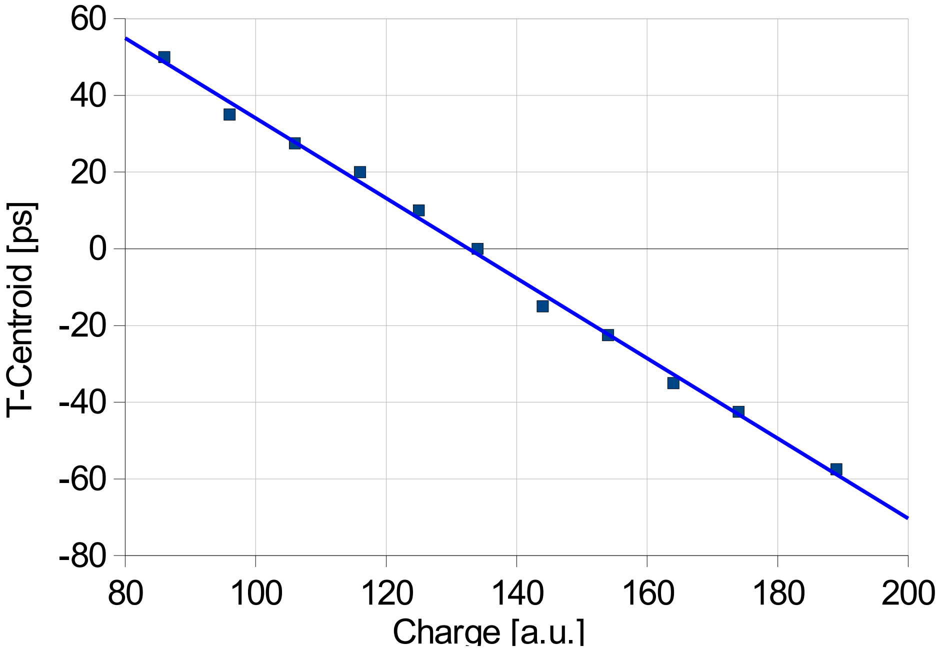


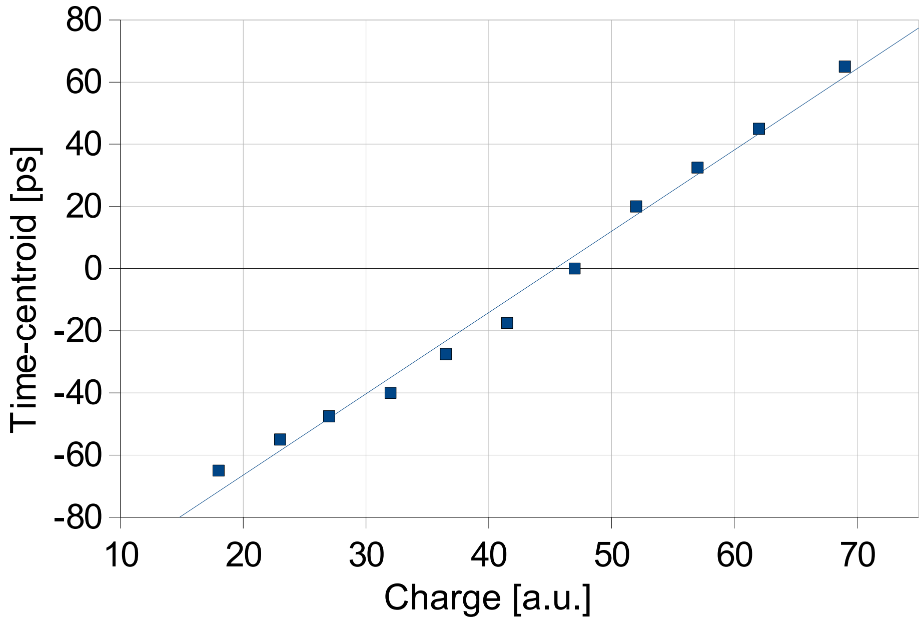
Time resolution (100µ / 50µm diamonds



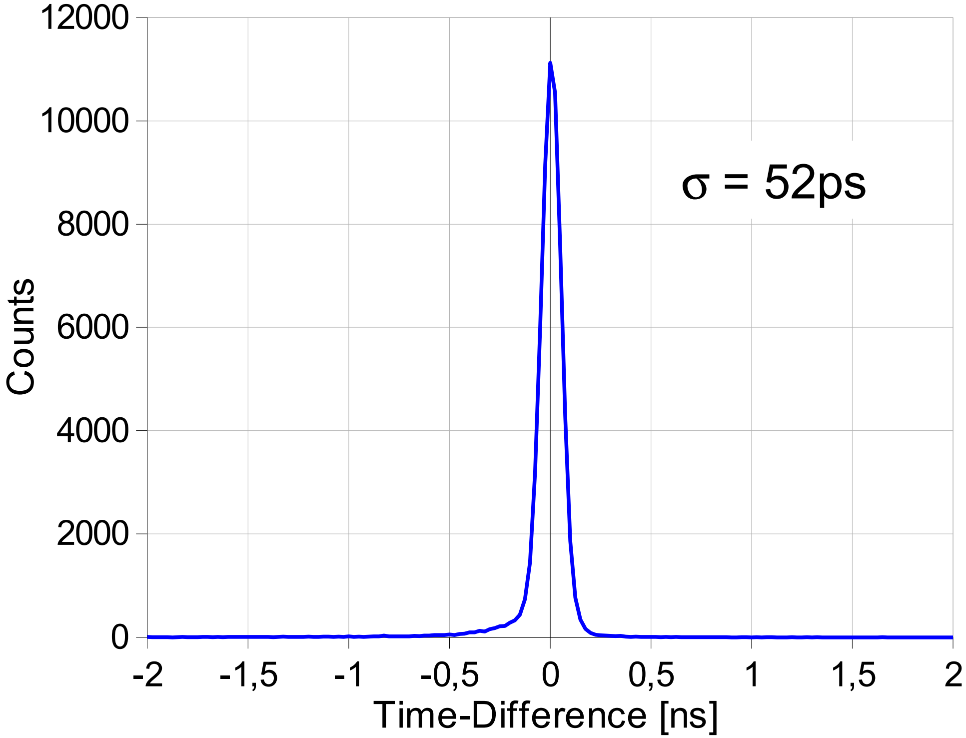


Walk Correction



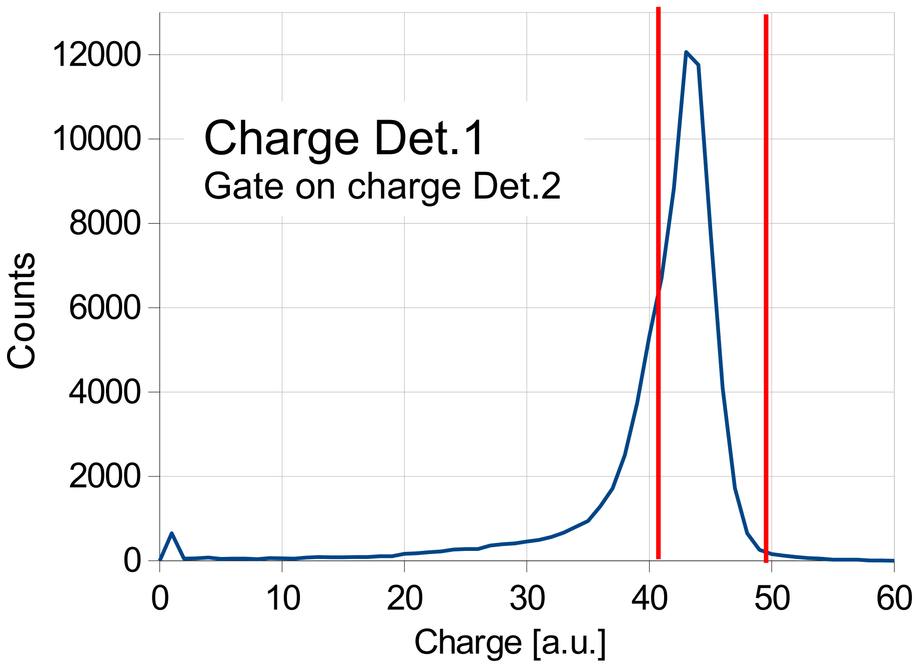


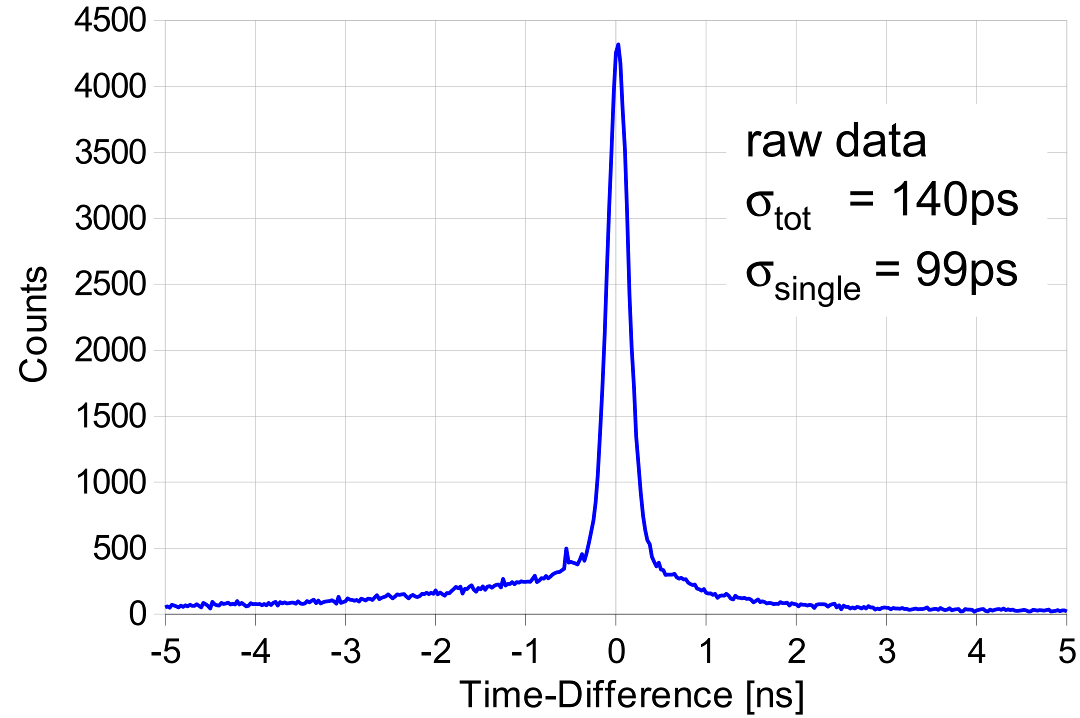
Final Result:
time difference for 100µ / 50µ diamonds



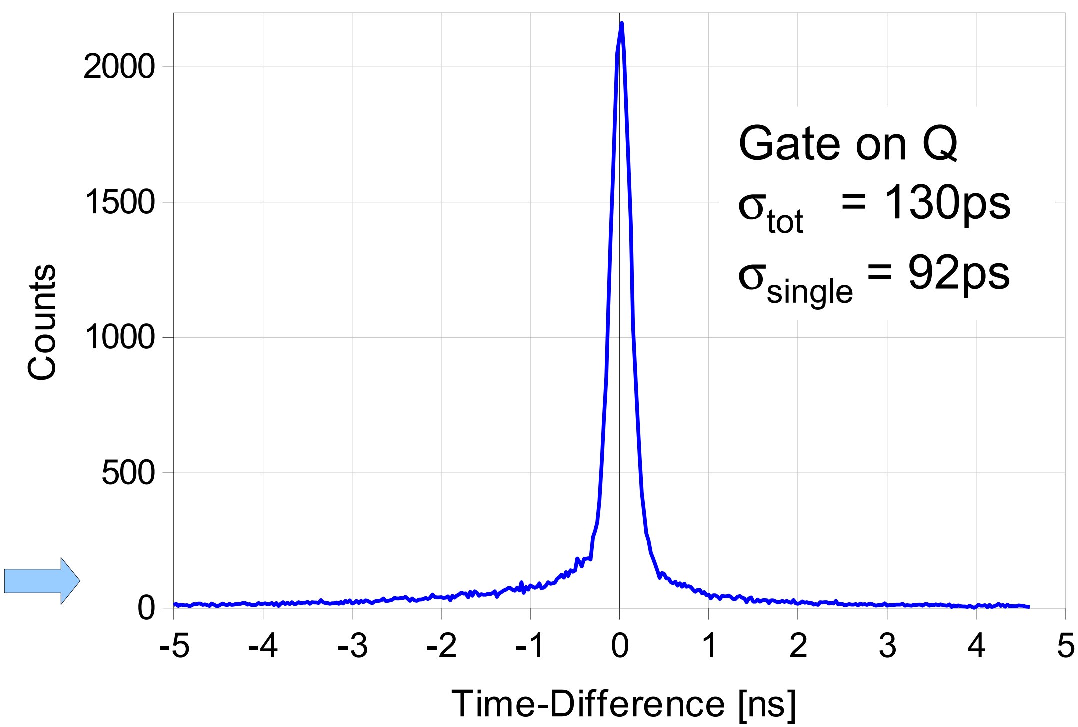
Time resolution:
50µ diamond: σ = 40ps
Corrected for digital resolution: σ = **31ps**

2nd setup (amplifier not integrated)
300μm diamonds (old surface treatment)
Unfair comparison (no walk correction)!





reduced tails



Conclusions (my point of view)

- State of the art electronics allows for Diamond readout of MIPs signals at 10^6 Hz / pixel with 50ps resolution (200-300 μm thickness, may be 100μm)
- Smaller thickness possible on the expense of reduced resolution
- Major progress of diamond surface treatment and metallization during past two years made this possible
- Best performance can be achieved by using ASICs (dedicated amplification stage, low power consumption, high segmentation)
- Large area diamonds (>100 mm^2) still require polycrystaline material. Optimized polycrystaline diamonds should be usable for MIPs

Thank you for your patient attention