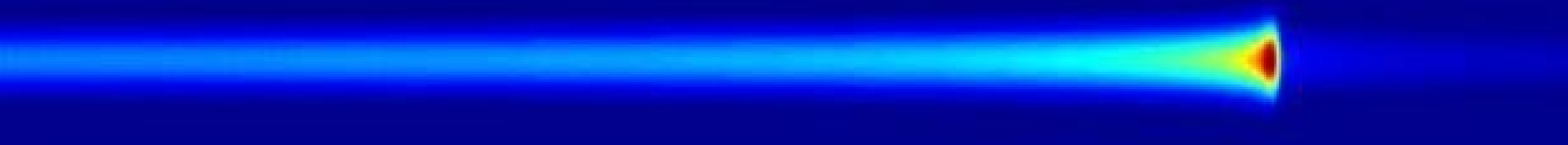

Diamond detectors for charged-particle beams

(Online dosimetry)

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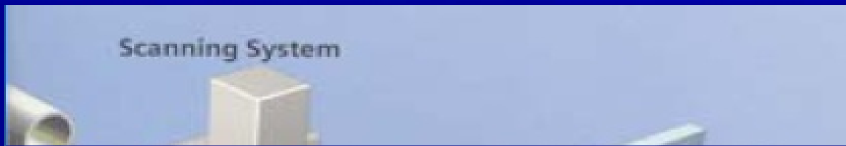
GSI detector laboratory

Outline

- Fields of work
- Aims & Requirements
- Experiments & Set-ups
- Results
- Summary & Outlook

Particle cancer therapy



3) <u>Beam profile-</u> & <u>Dose-verification</u>
& <u>Biological studies:</u>

→ Stopped Beam
→ Bragg-Peak region

→ mixed field irradiation
(projectile fragments, 10..20% dose)
⇨UNILAC (biology, clean conditions)

medium volume
unless not a phantom required

2

<u>Offline</u>: radiographic films, CR39,
TLD (pCVD), PET

<u>Online</u>: CG+IC
pin-point ionization chambers
scintillation screens

1) Online <u>Beam preparation</u>

2) Online <u>Treatment steering</u>

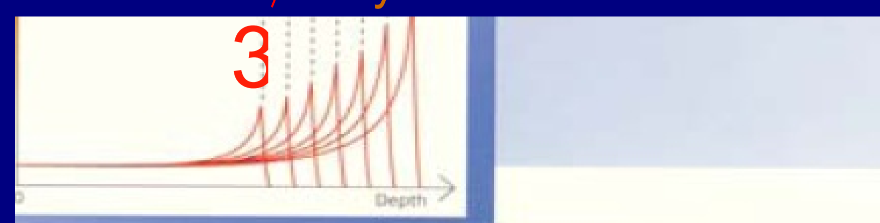
→ Passing Beam
→ Bragg plateau
→ 'always in',
no change in beam quality !

large area 250 x 250 mm²

Intensity(t) sampling every 10μs
Parallel-plate ionization chambers

Position(x,y) sampling every 100μs
Multi-Wire proportional chamber

→ time-consuming daily calibration
and constancy checks



Aim & Requirements

<u>'In the end it's all particle numbers at a certain position'</u>

→ Measure intensity & structure (x,y,t) of the extracted beam
by **counting individual particles**
close to the **GHz/channel**-range
with **100 % detection efficiency**

<u>Requirements for the detection system:</u>

- high-speed (ns)
- high accuracy of counting (1%)
- high detection efficiency (100%, also with moderate collection efficiency)
- good S/N ratio (threshold)

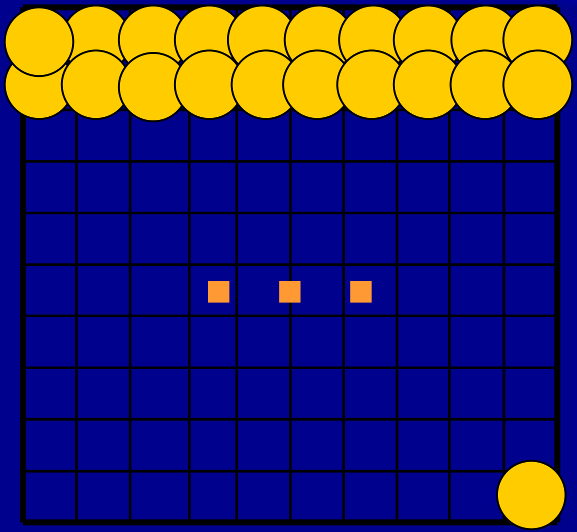
+ 'small' signals
+ reasonable sizes

→ scCVD

Parameters

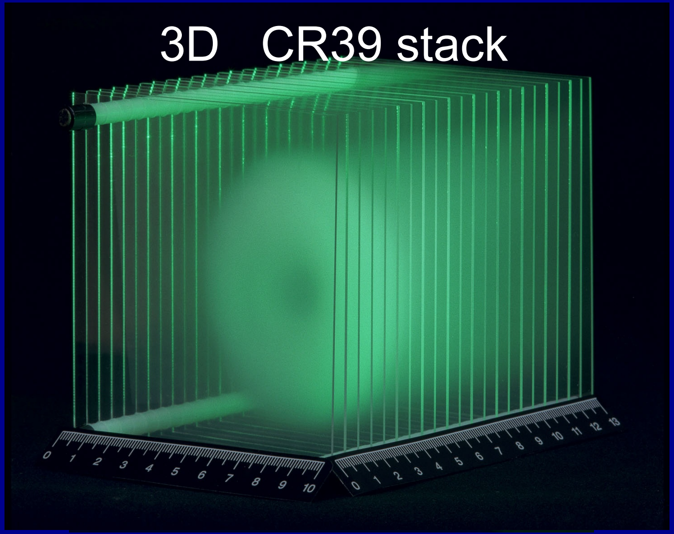
	SIS		UNILAC		
Energy	80 - 430 MeV/u **'High'**	^{12}C (p, He, C, O) Therapy conditions Scanning beam	11,4 MeV/u **'Low'**	^{12}C ^{40}Ar ^{48}Ca ^{54}Cr ^{152}Sm ^{208}P ^{238}U …	10.2 MeV/u 7.1 MeV/u 8.3 MeV/u 7.6 MeV/u 5.8 MeV/u 3.65 MeV/u 4,2 MeV/u
Beam size	Pencil beam 4 -10 mm (fwhm) 200 x 200 mm^2		Fixed field 45 mm Ø		
Operation	Transmission mode (Plateau)		Stopping mode (Bragg-Peak)		
Intensity	10^6 - 10^8 (10^{10}) ions/second 10^4 - 10^8 ions/cm^2		10^4-10^5 ions/second/mm^2 (in average)		
Time Structure	'slow extraction', duty cycle 0.5, bunch length 2s, dynamic range 10 (no zeroes)		Micro- (μs) & Macro-(ms) Pulses High dynamic ranges 10^4		
Charge gen.	n x 10 fC		n x 100 fC		
DBA (discrete)	unipolar	unipolar	unipolar	unipolar	unipolar
NINO (ASIC)	bipolar	bipolar	bipolar	bipolar	bipolar

High-energy set-up



Field of 9 cm^2

256 irradiation points

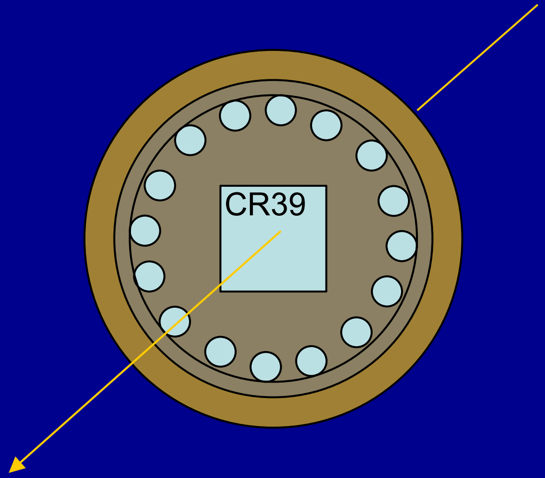


Focus ↓
(7)

Ø 2,2 – 8,8 mm

← Energy (253)

Low-energy set-up



Field size 16 cm^2

<u>Requirement</u>

Homogeneous
beam intensity (x,y) = const

<u>'Online' Beam delivery control</u>

Parallel-plate ionization chamber
→ Saturation / Recombination

<u>'Offline' Calibration</u>

Nuclear track detector (CR39)

→ 'dirty', time consuming,
precision & reproducibility (5..20%)

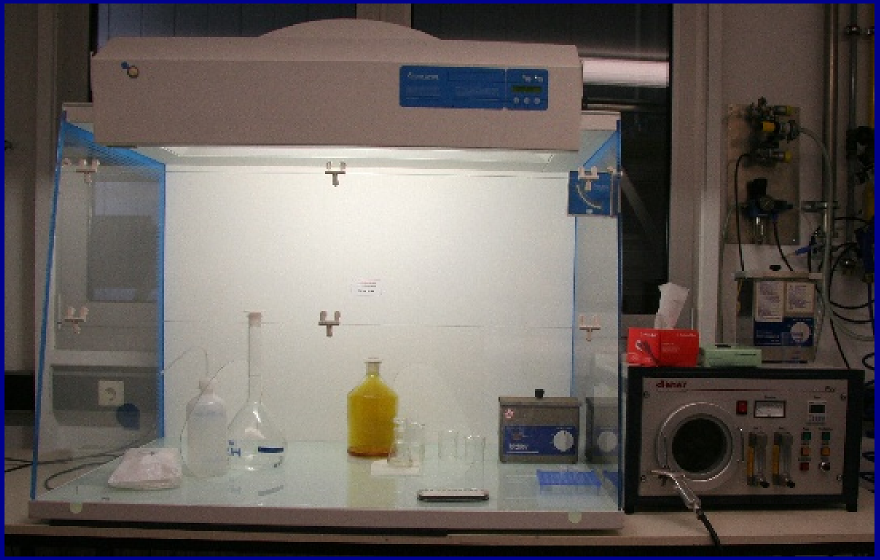
→ probing the fluence with an active detector
at several points or with high pixeling

Material

Samples: Free standing films of

NCD, pCVD, scCVD <100> oriented

Size: 10x10, 20x20, 4x4 x 0.1–0.5 mm^3

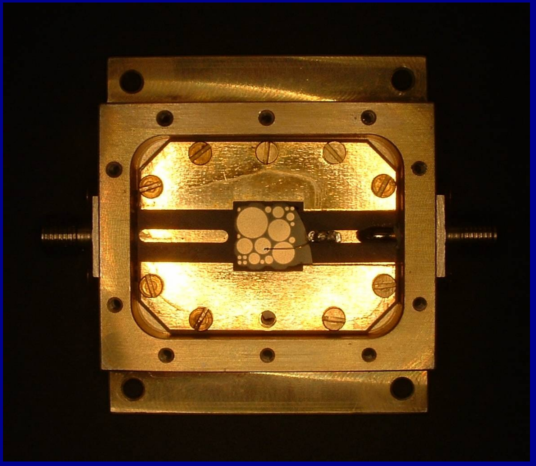


DETECTOR FABRICATION:

surface cleaning and oxidation

H_2SO_4 + KNO_3 (boiling), DI water

VARIOUS CONTACTS:

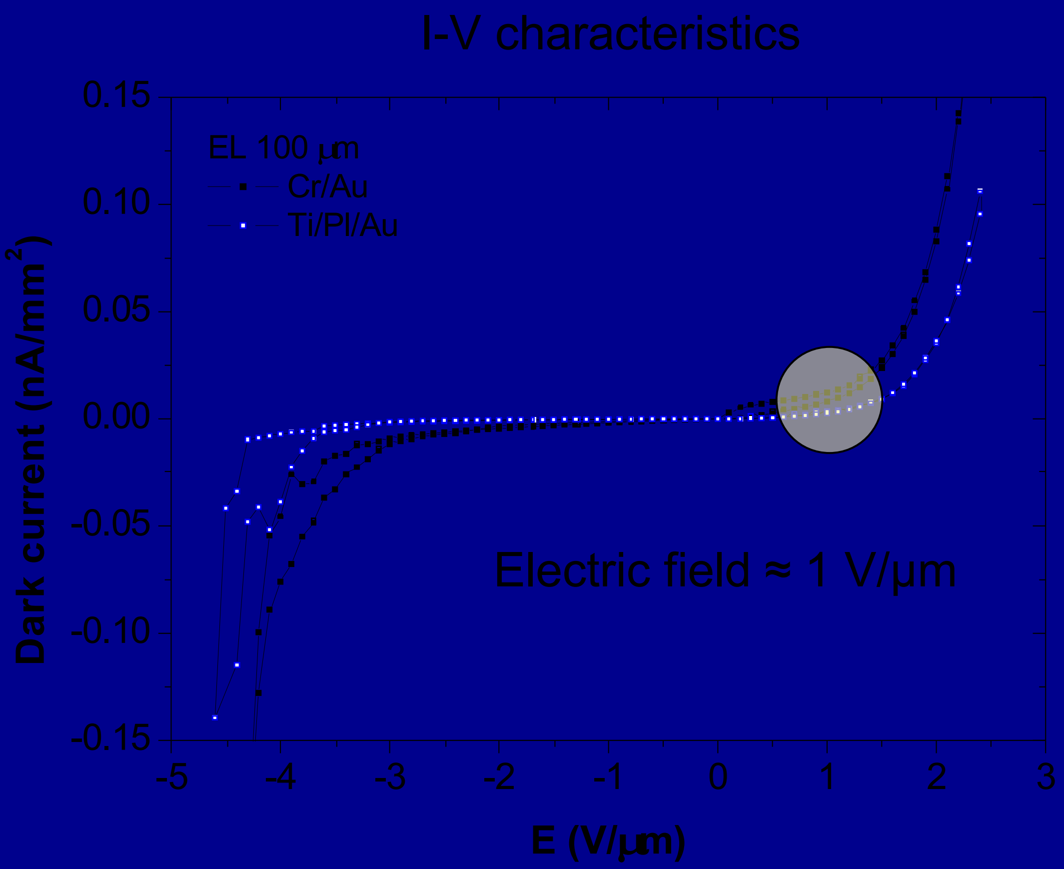


sputtered circular / strip / pixel electrodes
(parallel plate geometry)
contact area: 0,2 – 16 mm^2
annealing at 600°C

carbide former: Cr (50nm) + Au (100nm)
Ti (20nm) + Pt (30nm) + Au (100nm)

non carbide former: Pd (100nm), Al (100nm)

Detector operation

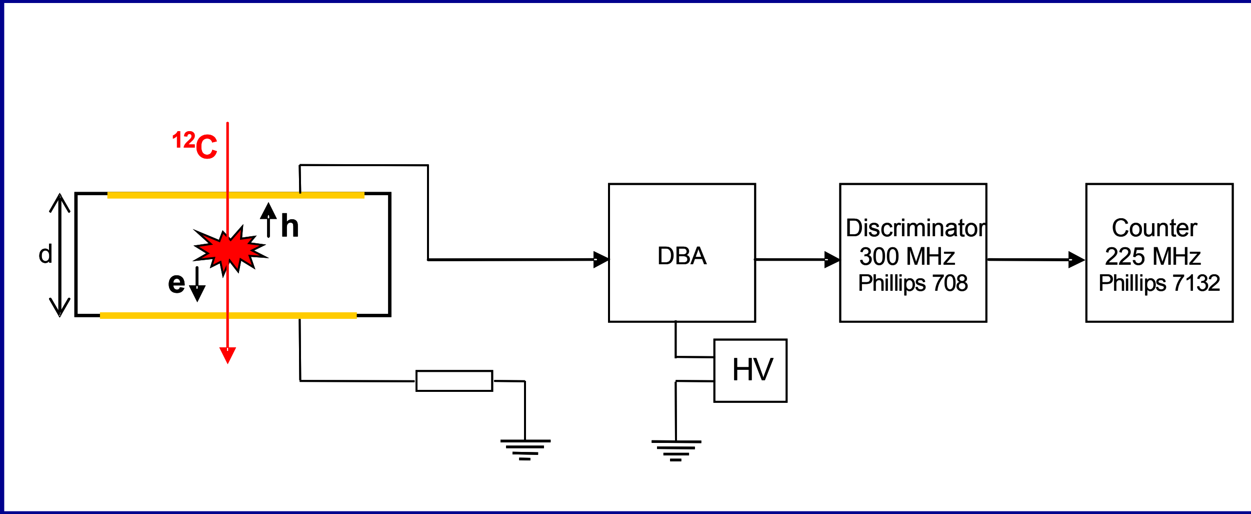


Electronics (1)

- **DBA** – **D**iamond **B**road-Band **A**mplifier
  designed specially for diamond at GSI, commercially available

- Various types: DBA-II -III -IV
- Band width 2.3 - 2.1 GHz
- Low noise, remote controlled gain (DBA-III, -IV)
- Analog output signal
- Pulse-area proportional to the charge

✂ ☺ Quite good for heavy ion (high signal) beam monitoring
✂ ☹ Only single channel read-out
✂ ☹ Unipolar, pick-up noise relatively high (in our applications)

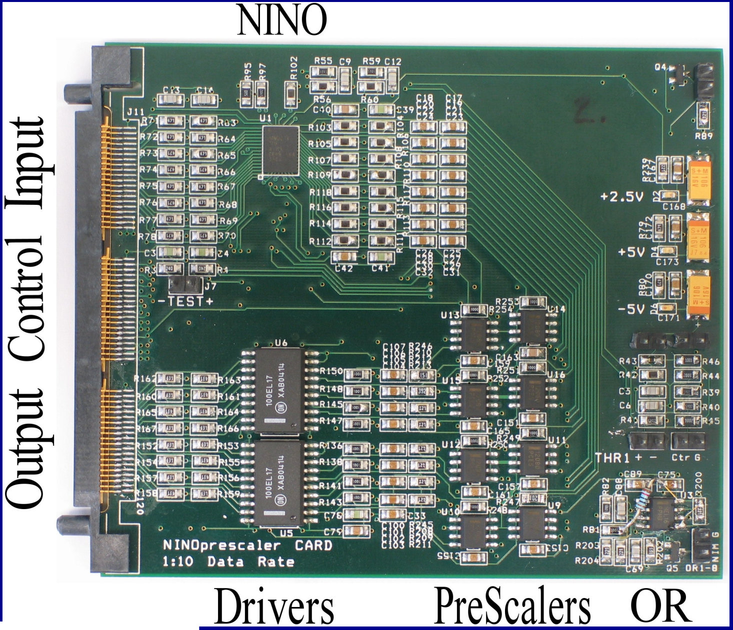


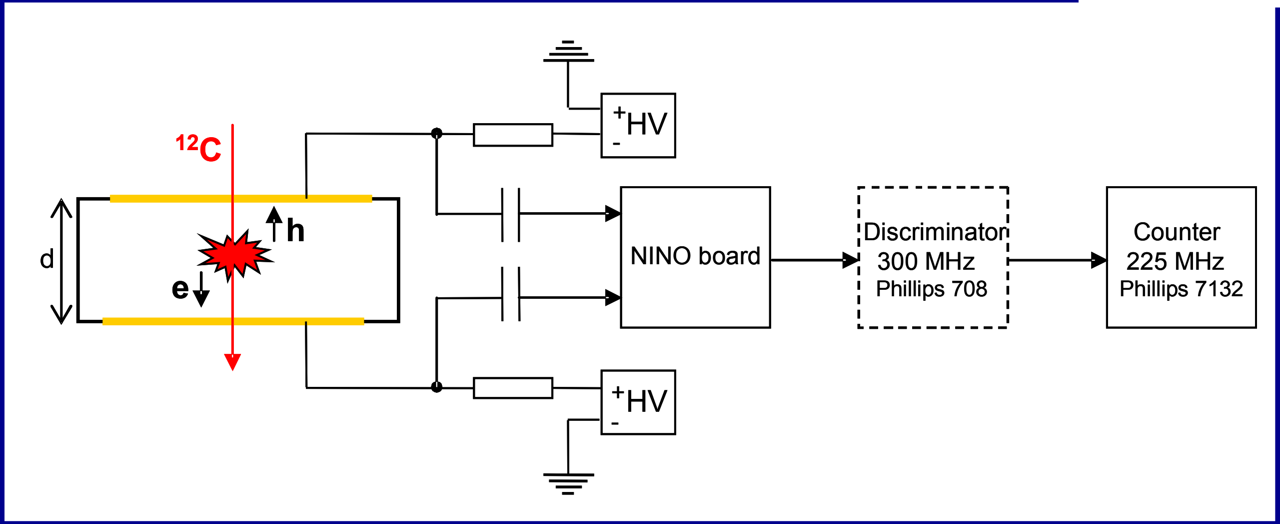
Electronics (2)

- **NINO** ASIC
  designed for ToF ALICE
  modifications on implementation by GSI

- 16 channels per card
- Digital output signal
- Width of the pulse proportional to the charge

✂ ☺ fully differential design → elimination of pickup noise
✂ ☹ threshold too high ←→ sensitivity too low





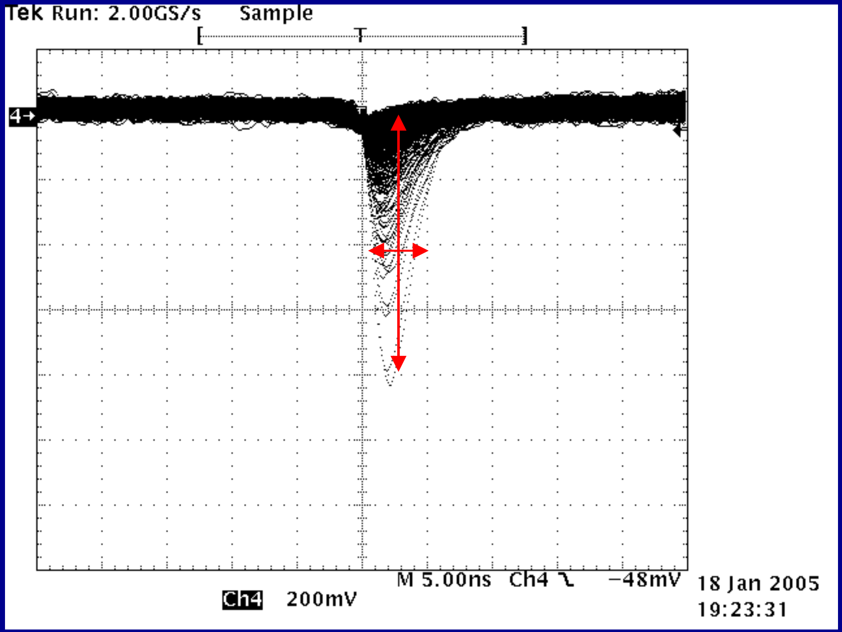
Electronic Pulse characteristics

UNILAC ^{48}Ca 8,3 MeV/u

16-pixel detector pCVD 150µm

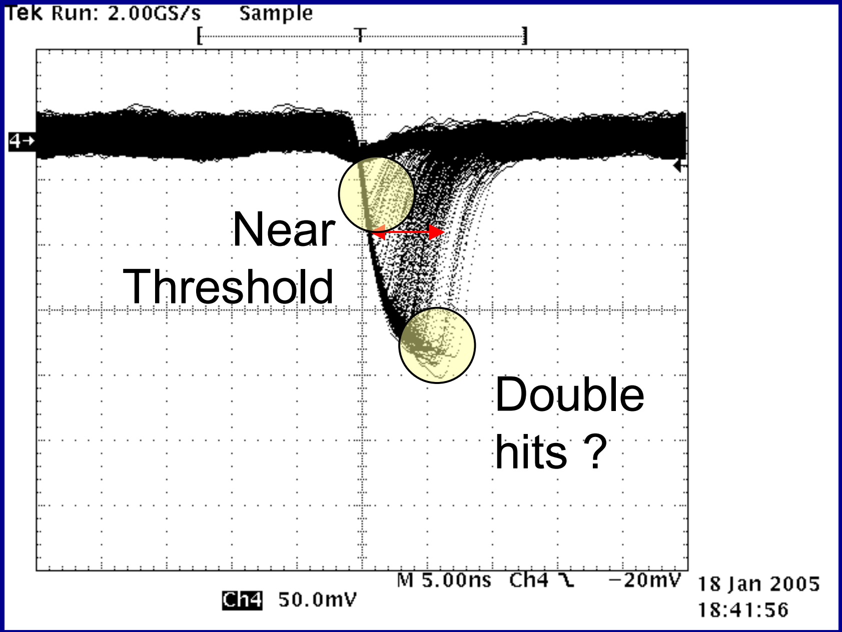
unipolar read-out, single shots

DBA-IV



Pulse area ~ Q_C

NINO



Pulse with ~ Q_C

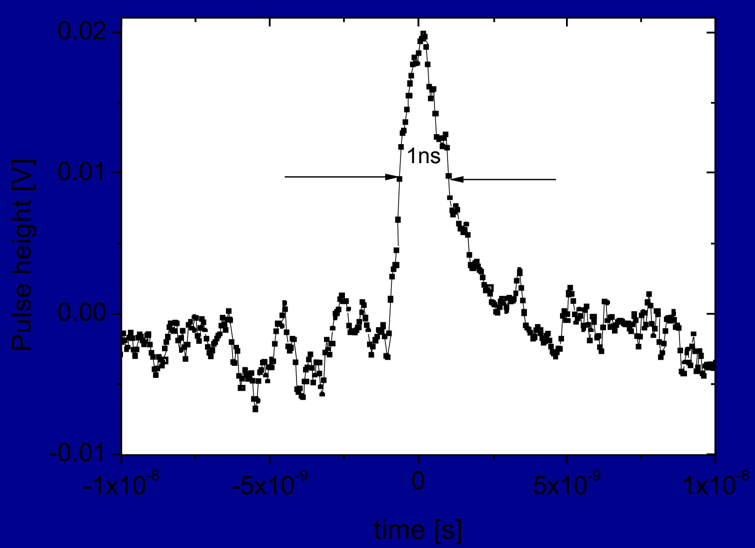
Electronic Pulse characteristics

SIS ^{12}C 253 MeV/u

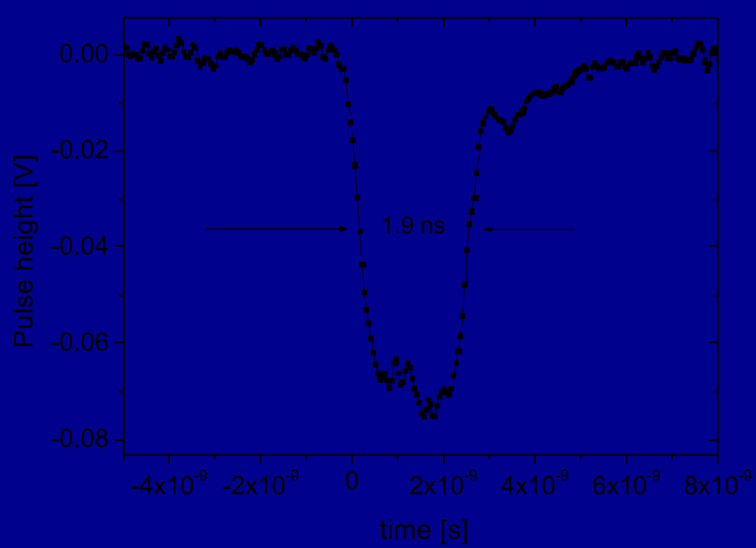
16-pixel detector pCVD 150µm

unipolar read-out, single shots

DBA-III



NINO



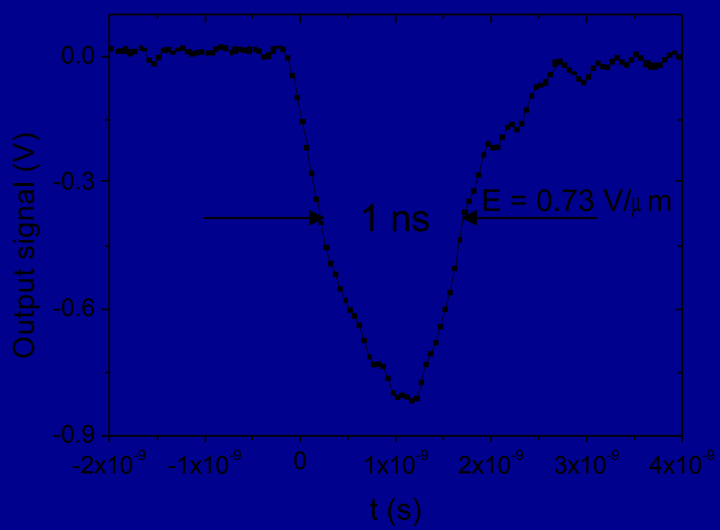
→ High pick-up noise with DBA
better for NINO (even with unipolar input)

Electronic Pulse characteristics

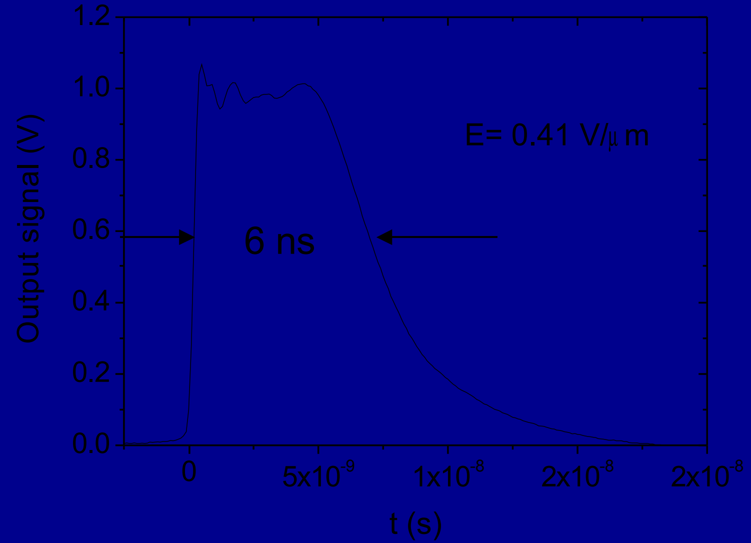
UNILAC	^{132}Xe	4,2 MeV/u	UNILAC	^{12}C	10 MeV/u
Augsburg	‘sc‘CVD	341µm	E6	scCVD	483µm

→ kind of ‘bad’ scCVD but better than pCVD

DBA-III



DBA-II



→ nice pulse shape for counting applications

→ inappropriate pulse shapes (too long)

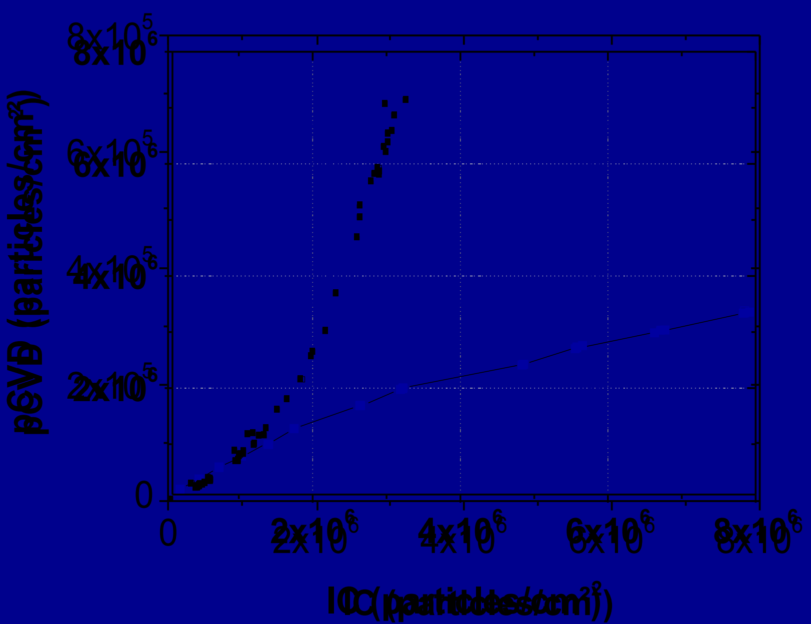
→ much thinner detectors needed

Results low Energies

UNILAC

1 pixel detector **pCVD** **500µm**

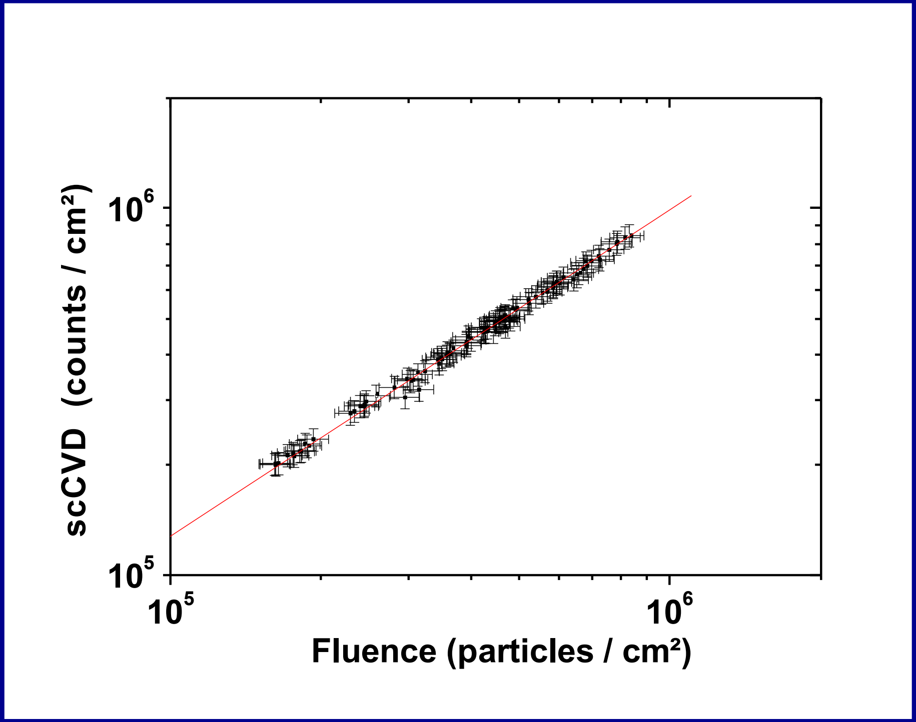
^{238}U 4,2 MeV/u



→ Problems: pickup noise
noise separation
time structure (micro/macro-pulse)

1 pixel detector scCVD 483µm

^{238}U 4,2 MeV/u

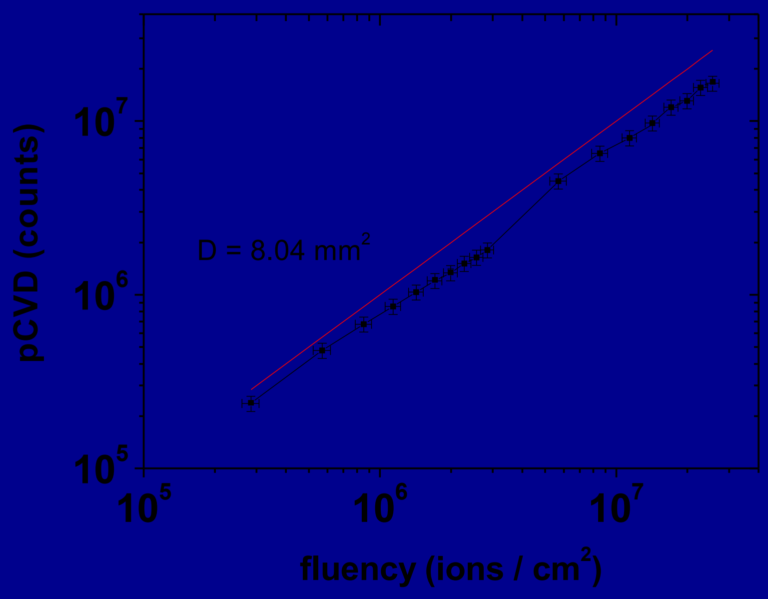


→ Counting efficiency 100 ± 7 %
no polarization observed
(but present with other detectors & ions)

Results high Energies

SIS ^{12}C 89 MeV/u

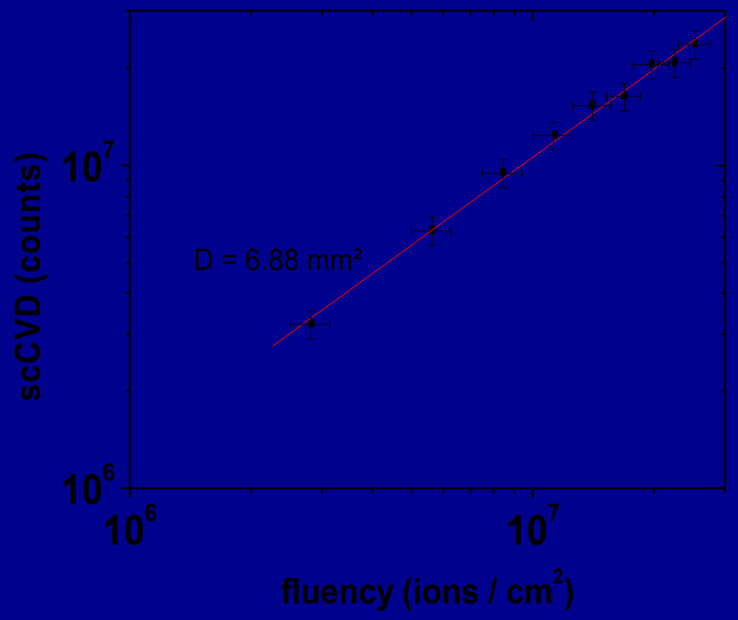
4-pixel detector pCVD 100µm



→ Missing counting efficiency due to detector & electronics

SIS ^{12}C 399 MeV/u

4-pixel detector scCVD 483µm



→ Improvement of counting efficiency **100 ± 7 %**

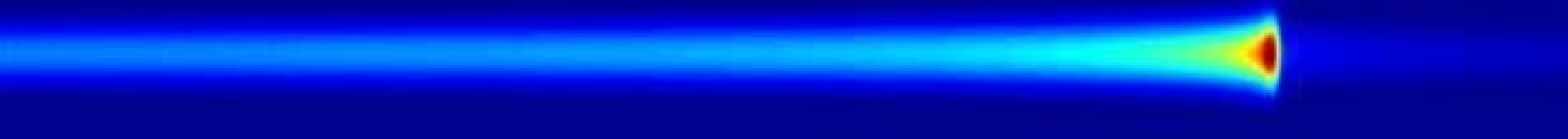
Summary & Outlook

- Various CVD diamond detectors tested
- Various ion species & energies used
- Fast single- & multi-channel electronics tested

(100 ± 7)% counting efficiency achieved

- Best choice: scCVD, ≤ 100 μm thick, large area

Problems:	Solution / Task:
Double hits & time structure (UNILAC)	→ smaller pixels, analog signal
Mixed field irradiations	→ faster FEE (QDC, scalers)
Active area (200 x 200 mm^2)	→ bigger detector size (patchwork, n x 10^2)
	→ large amount of pixels (n x 10^4)
	→ dense electronic 'on-board'
Detector quality	→ diamond (pulse shape)
	→ contacts (stability, polarization → doping?)
Electronics noise limits accuracy	→ work on DBA
	→ multi channel ASIC with analog output



Thank You!