Heteroepitaxial Diamond Detectors for Heavy Ion Beam Tracking

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NSCL / Michigan State University

3rd NoRHDia Workshop

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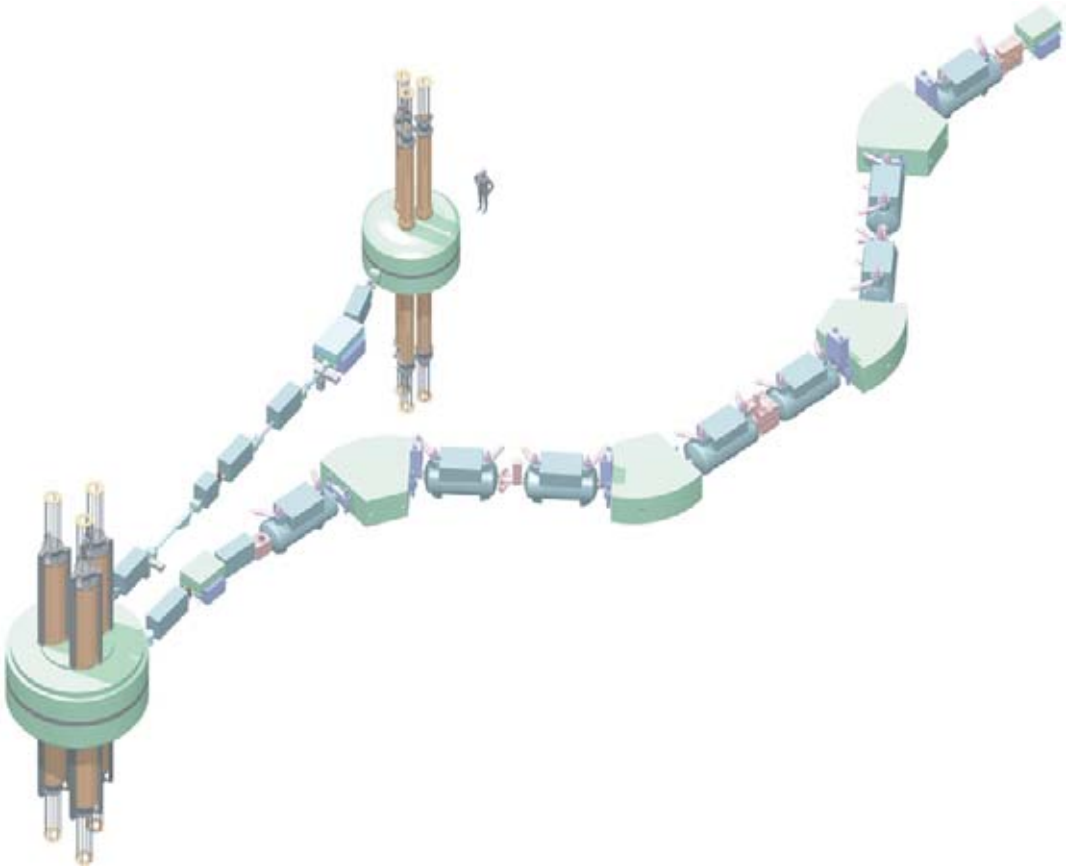

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Outline

Investigation of electronic properties
(high temperature DC transport measurements)

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Evaluation as detector material
(time and energy resolution)

.

First applications in nuclear physics experiments
at the NSCL

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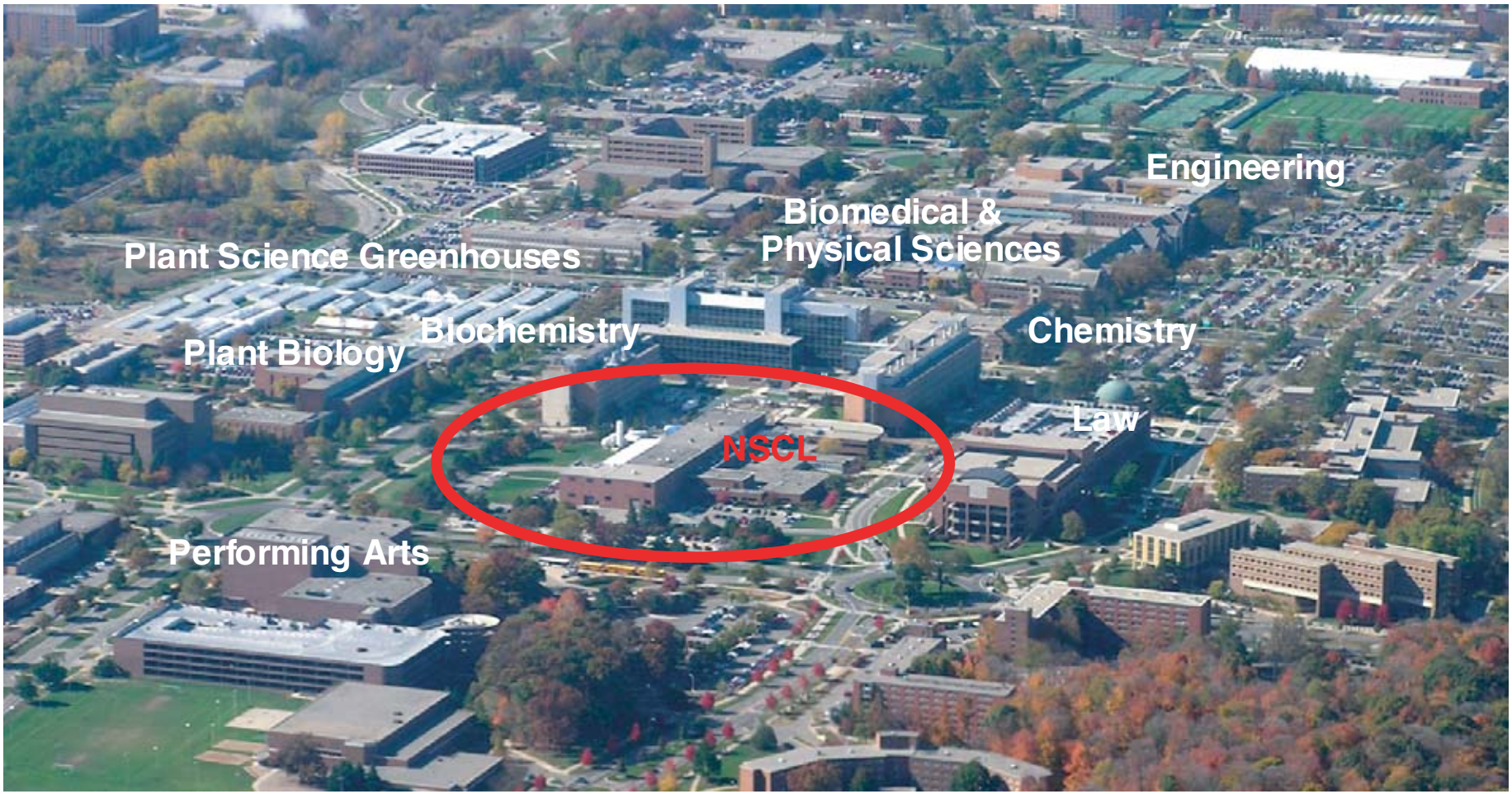
National Superconducting Cyclotron Laboratory



~280 employees, incl. ~50 undergraduate and ~50 graduate students

User group of over 600 CCF users

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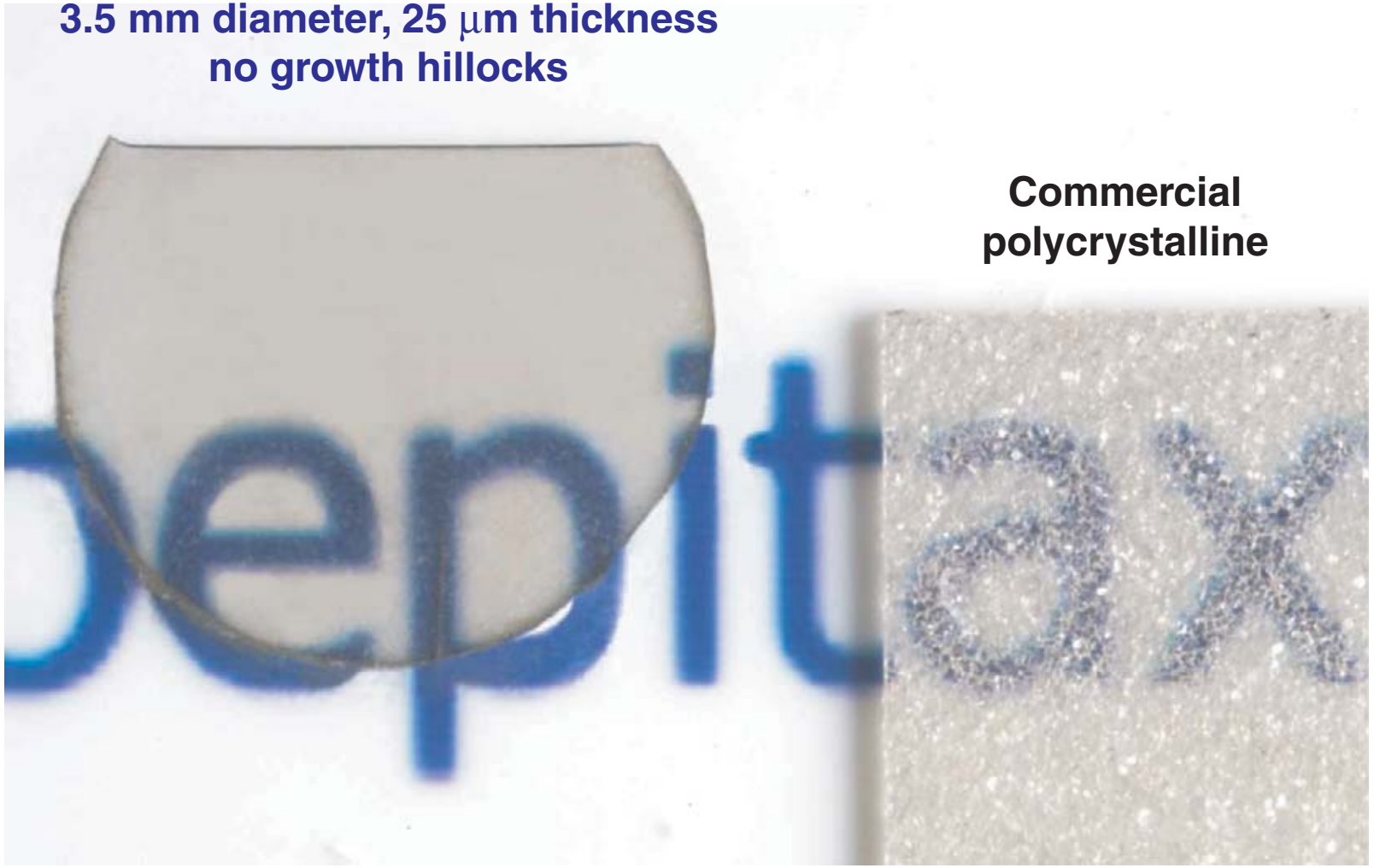
Heteroepitaxy single-crystal diamond



both samples as grown

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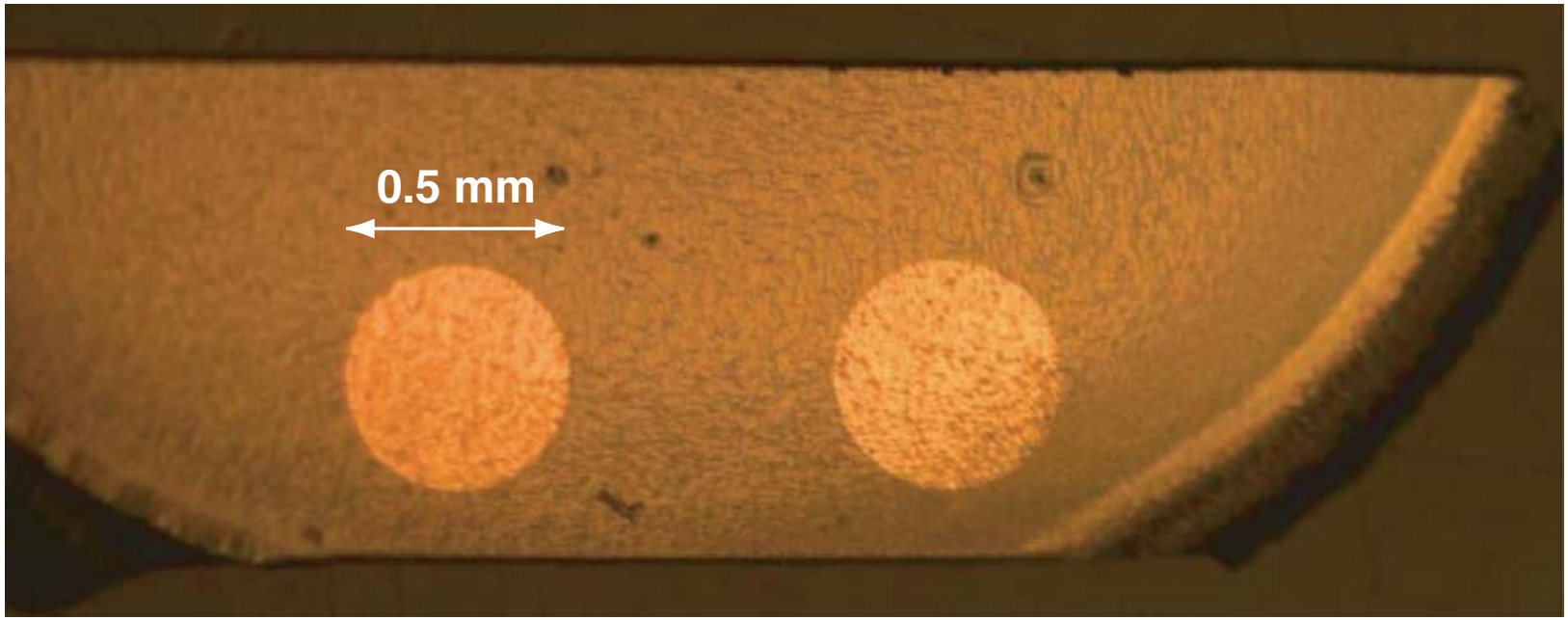
SC diamond sample with electrodes



top surface chemically cleaned

electrodes:
top side: 10 nm Ti, 100 nm Au, annealed at 600 ^{o}C
back side: Ir buffer layer

oxygen plasma treatment

→ **no in-plane current measureable**

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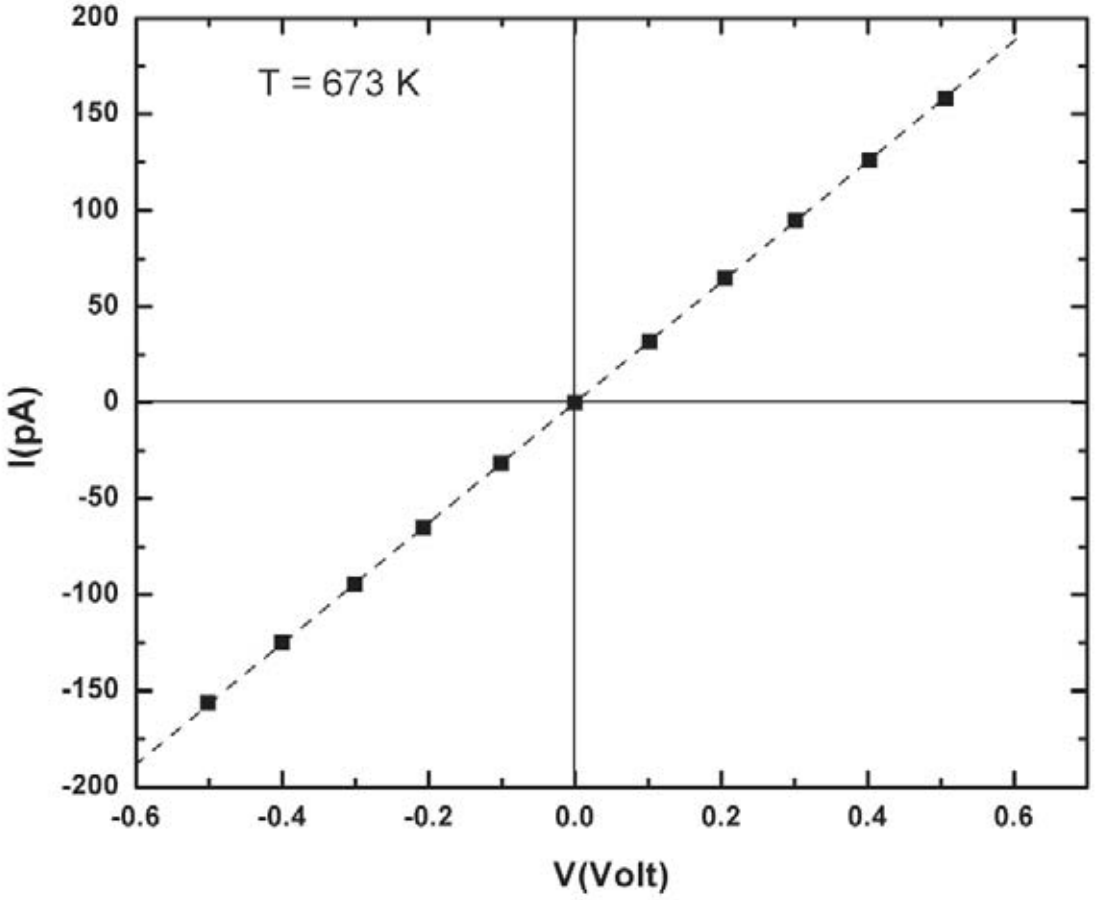
Current-Voltage Characteristics

CVD heteroepitaxial diamond crystal



sample as grown on Ir buffer layer, thickness 20 μm

→ **ohmic behavior of contacts and material**

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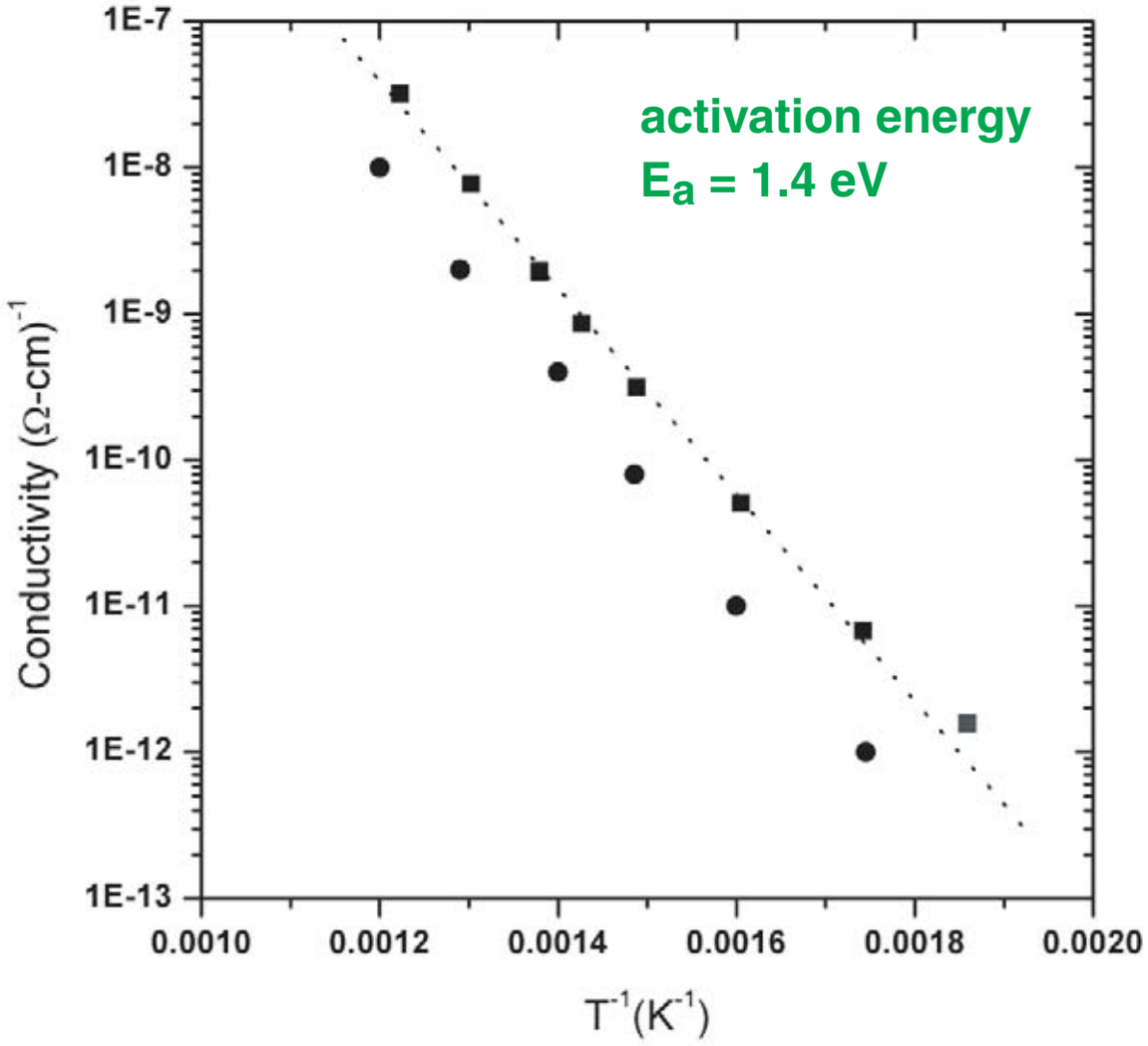
DC Conductivity



- **heteroepitaxial diamond crystal**
- **natural type IIa diamond**
  (Wandersande & Zoltan)

J. W. Vandersande, L. D. Zoltan,
Surface and Coatings Tech. 47, 392-400 (1991).

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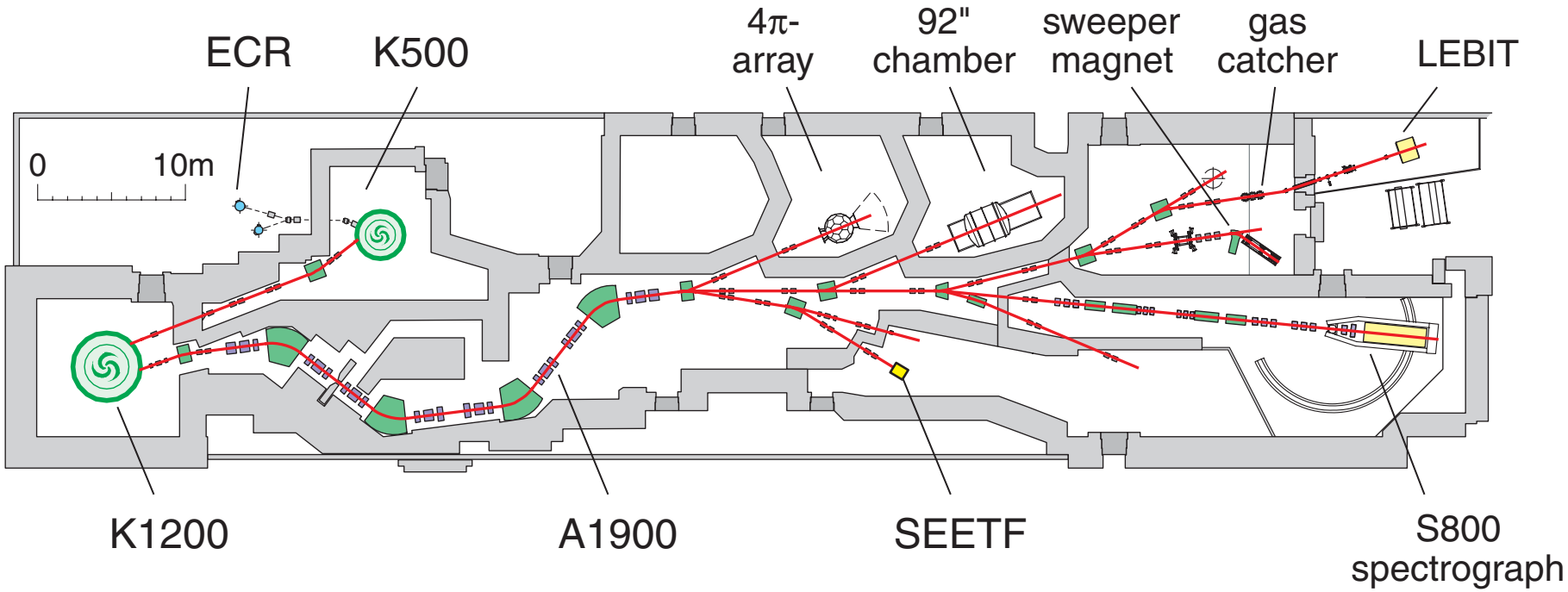
NSCL Experimental Facility



State-of-the-art apparatus:

A1900 fragment separator, 4pi-Array, 92-inch chamber,

S800 magnetic spectrograph, large aperture sweeper magnet spectrograph,

large area (2x2 m^2) position sensitive neutron detectors,

segmented Ge and Si-strip-CsI arrays,

beta-NMR and beta-counting station,

Gas cell (1 bar He) for stopping rare isotopes, 9.4 Tesla Penning Trap, …

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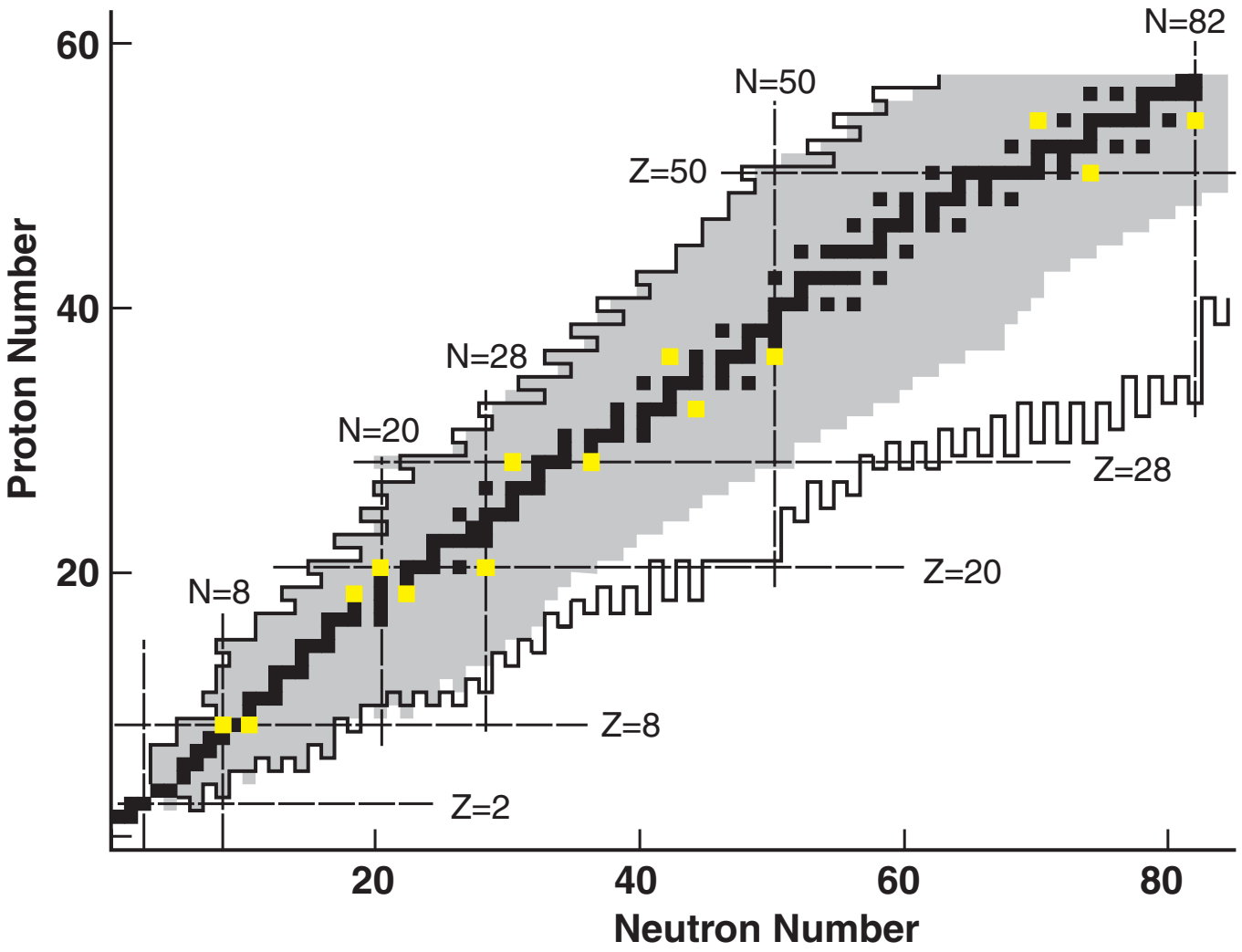
NSCL Primary Beam List



Particle	Energy [MeV/u]	Intensity [pnA]
^{16}O	150	125
^{18}O	120	125
^{36}Ar	150	50
^{40}Ar	140	50
^{40}Ca	140	22
^{48}Ca	90	15
	110	15
	140	40
^{58}Ni	140	5
	160	5
^{64}Ni	140	7
^{76}Ge	130	20
^{78}Kr	140	25
^{86}Kr	100	10
	140	20
^{96}Zr	120	3
^{124}Xe	140	2
^{124}Sn	120	1.5
^{136}Xe	120	2
^{209}Bi	80	1

Primary beam list as offered for PAC-30 experiments

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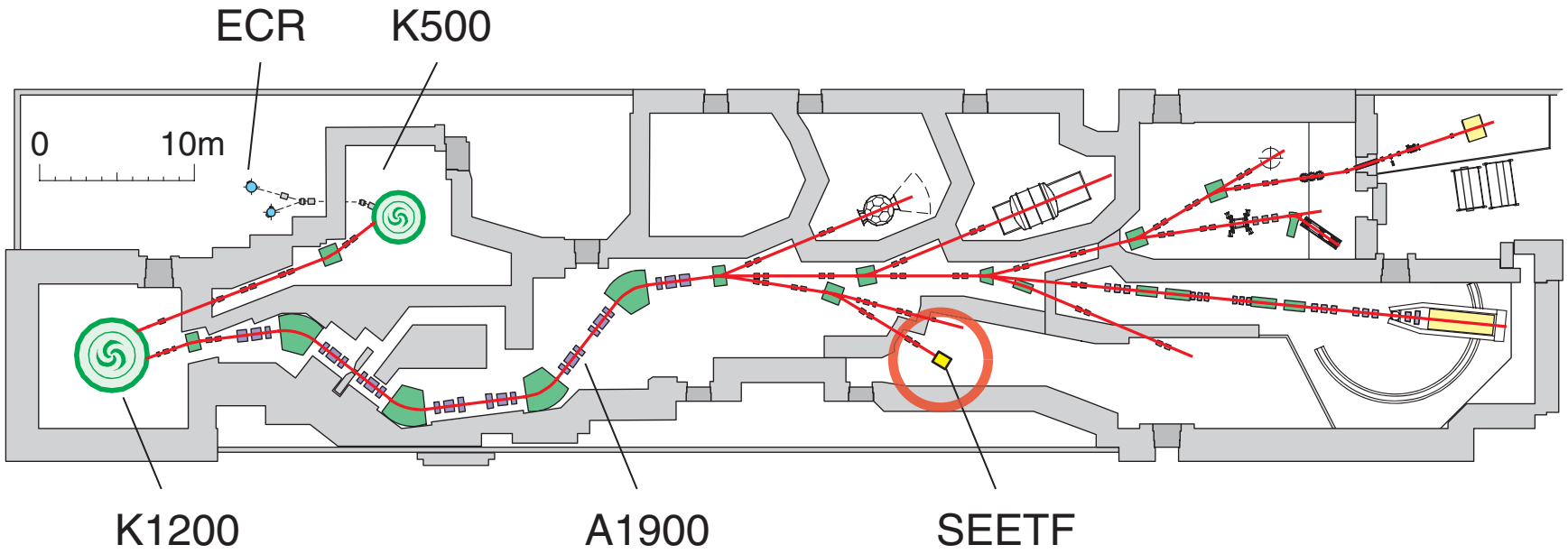
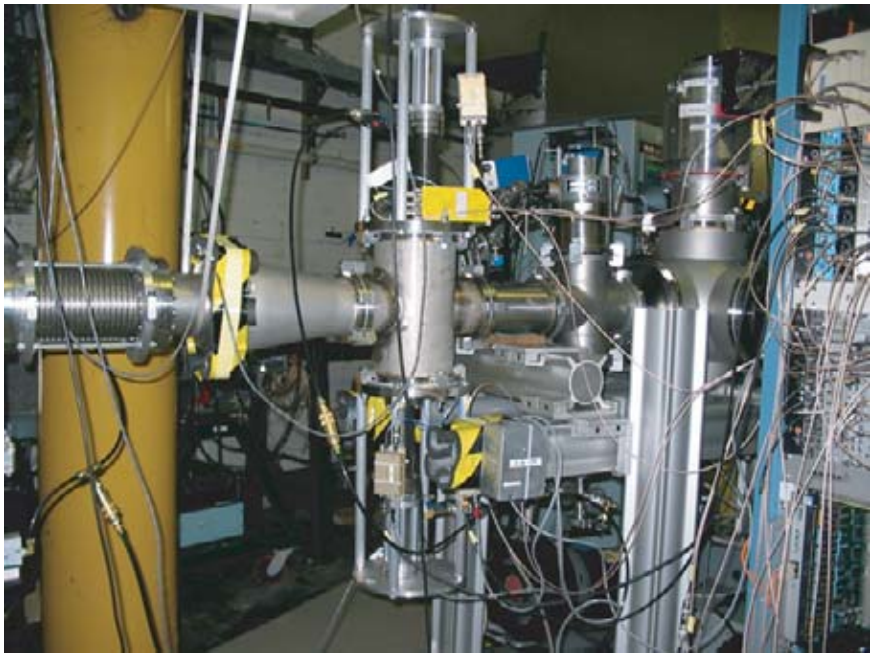
Test of diamond detectors at the NSCL



primary beams: ^{16}O - ^{124}Xe

energy: 50 - 150 MeV/u

intensity: 1 - 10^{12} particles/sec



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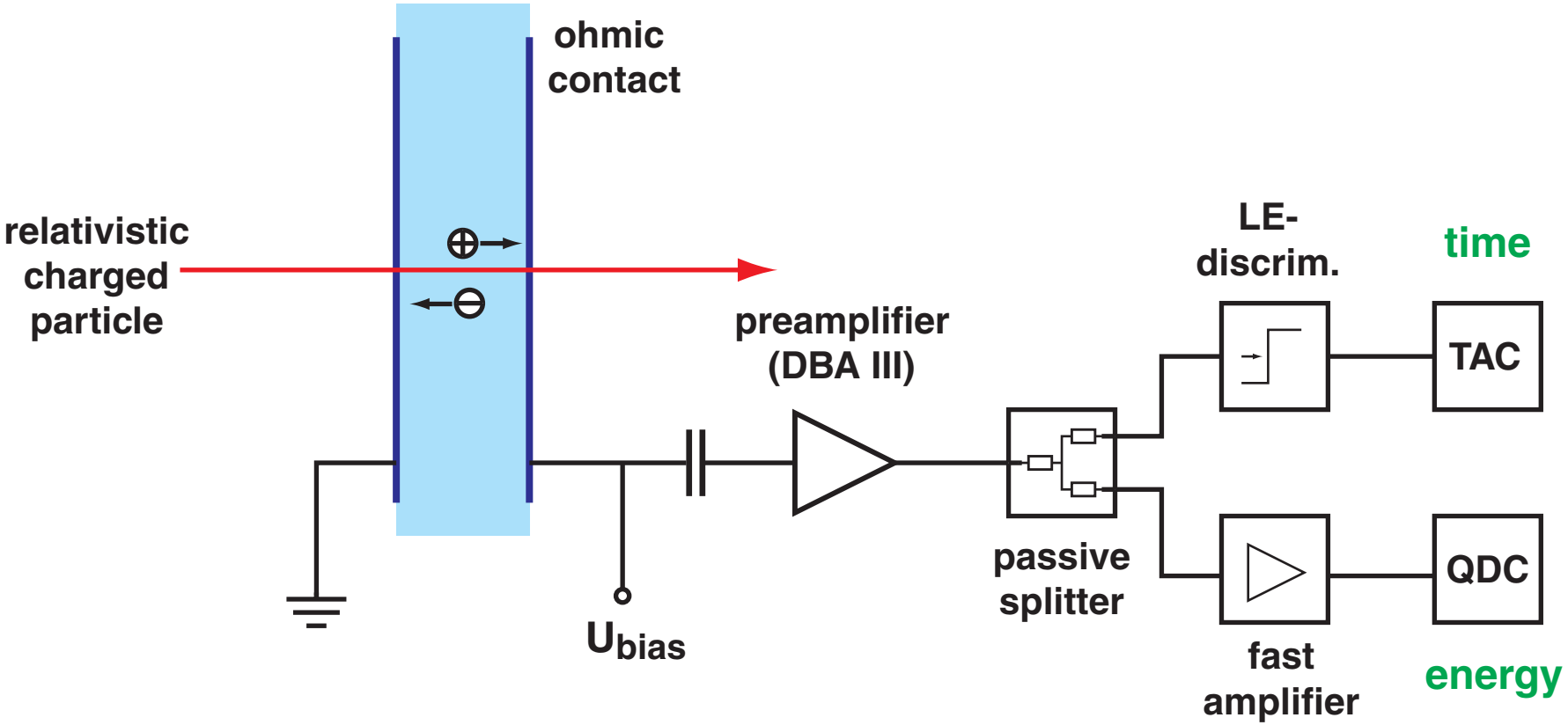
Diamond as a charged particle detector



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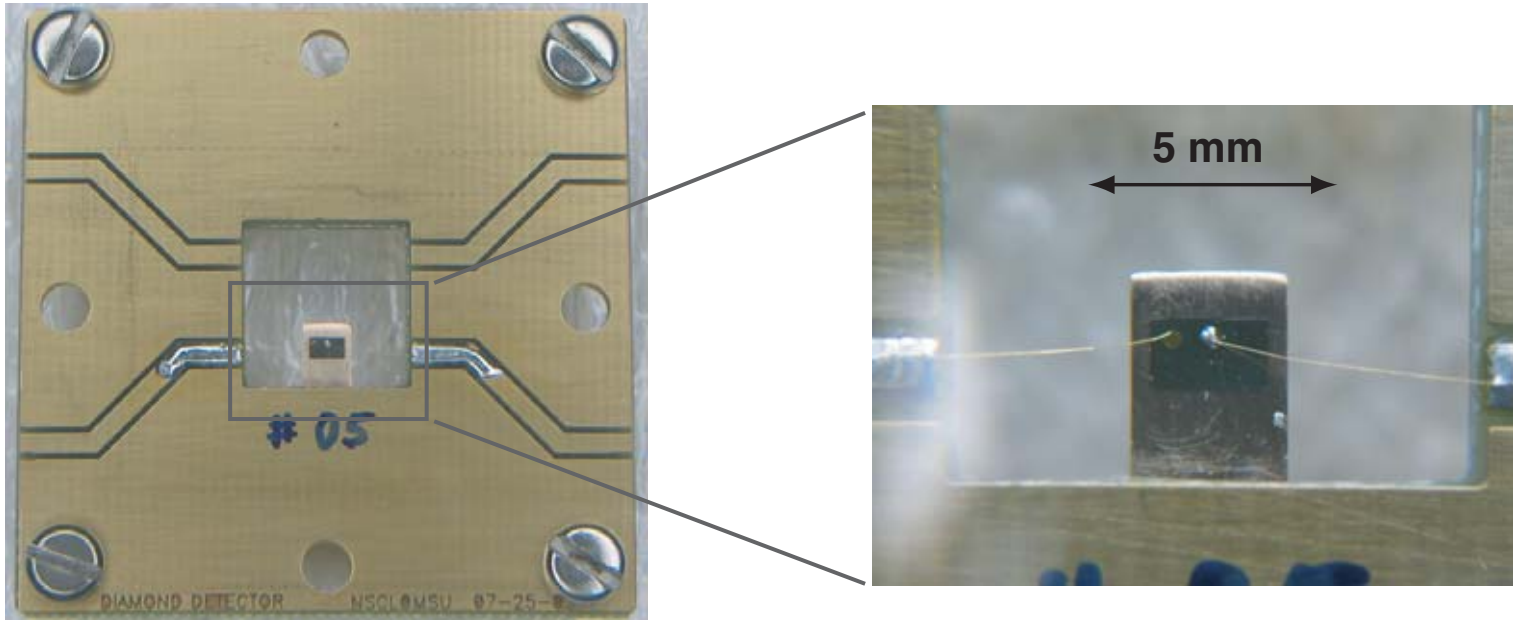
SC Diamond Test Detector



mounted on printed circuit board
connections 50 Ohm transmission line

contacted with W wire (25 micron, Au plated)

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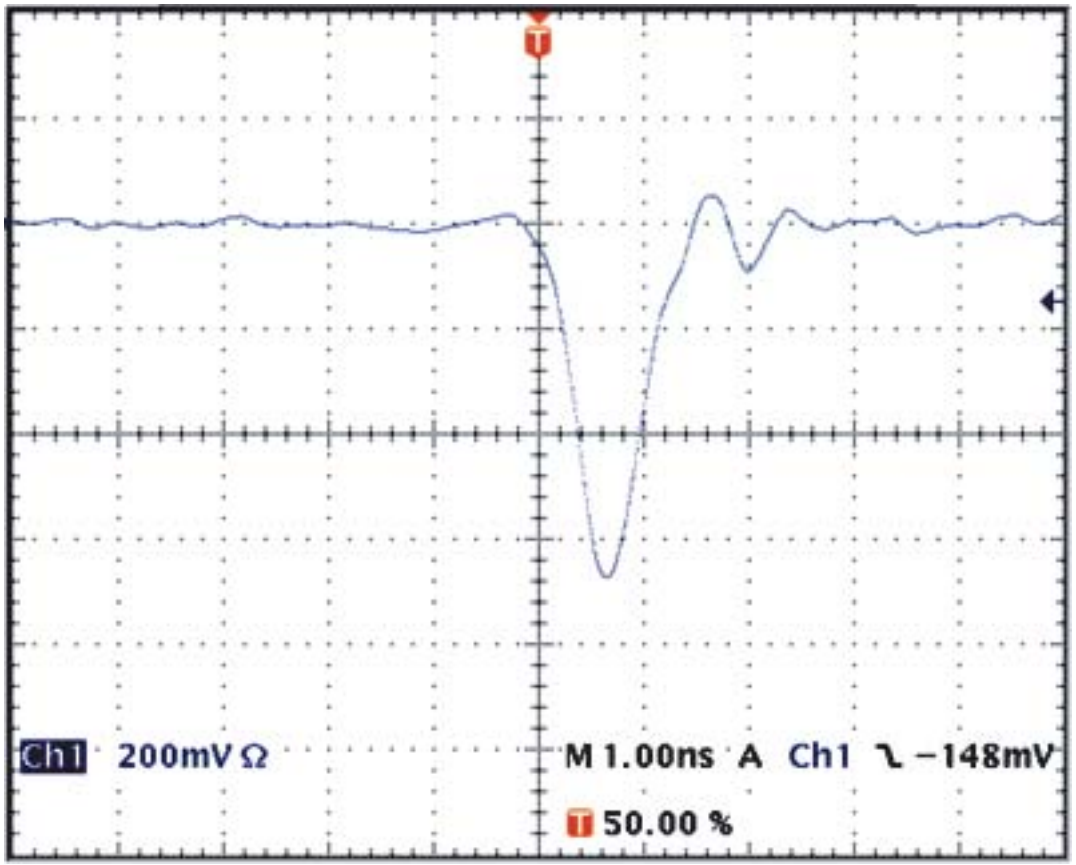
Preamplifier Signal

^{76}Ge, 100 MeV/u

20 micron het.ep. SC diamond, as grown on Ir buffer layer



low-noise, broadband preamp
bandwith 2.3 GHz
gain +38 dB

digital storage scope
bandwidth 500 MHz
sampling rate 5 GS/s

energy loss of beam particle
in detector <0.6%

preamp signal rise time ~ 0.5 nsec

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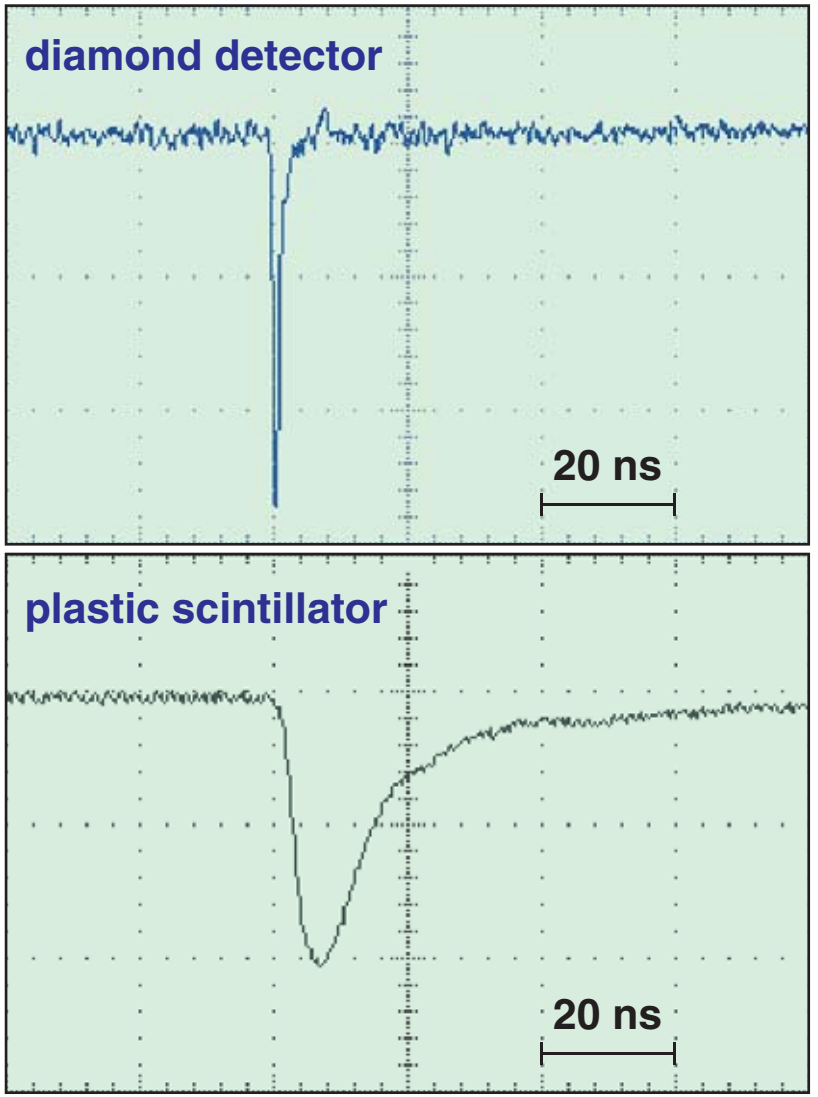
Comparison diamond vs. plastic scintillator

typical detector signals
for single particle event



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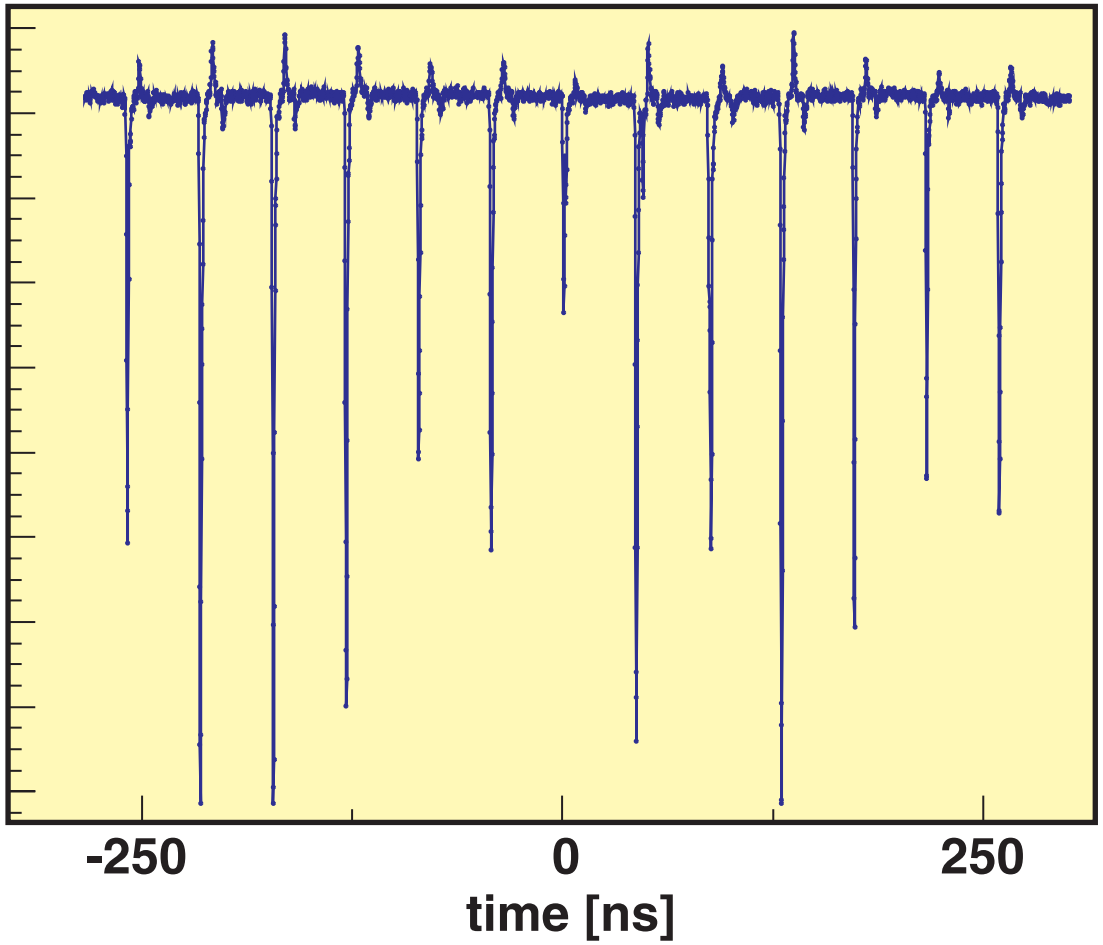
Time Structure of Cyclotron Beam

measured with diamond detector
(cyclotron RF frequency ~25 MHz)



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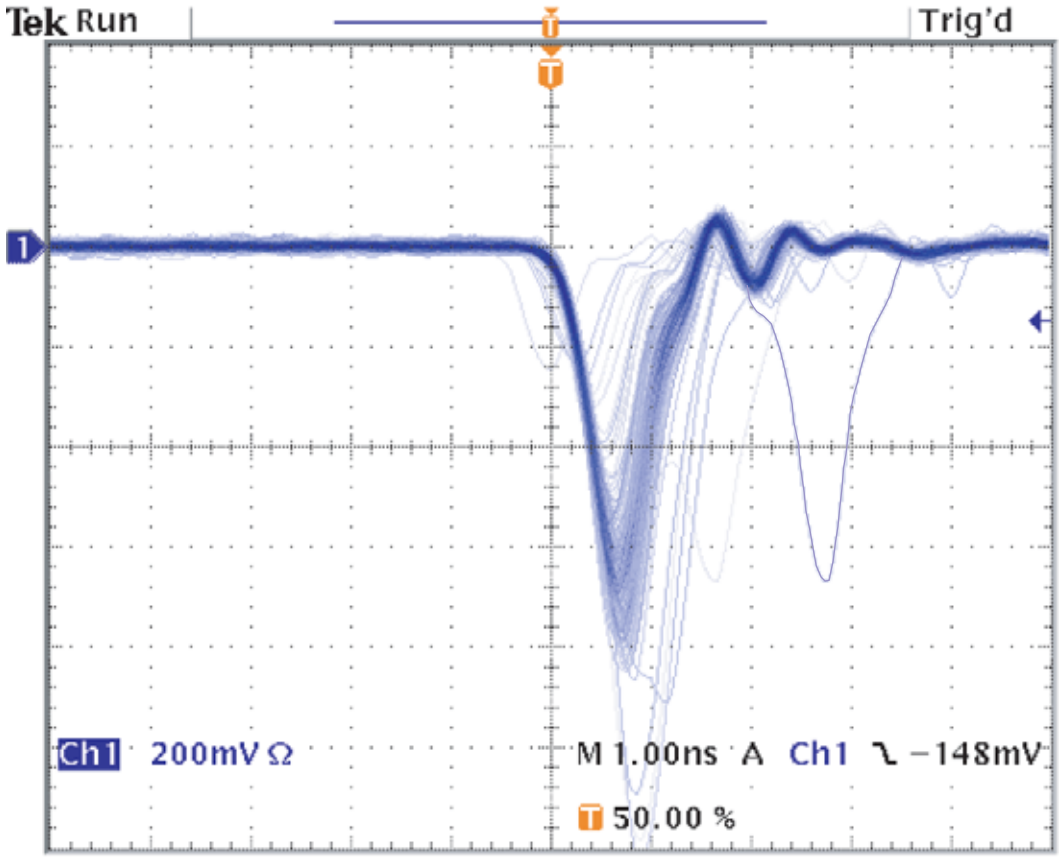
Preamplifier signal at high rate

^{76}Ge, 100 MeV/u, 10^6 particles/sec

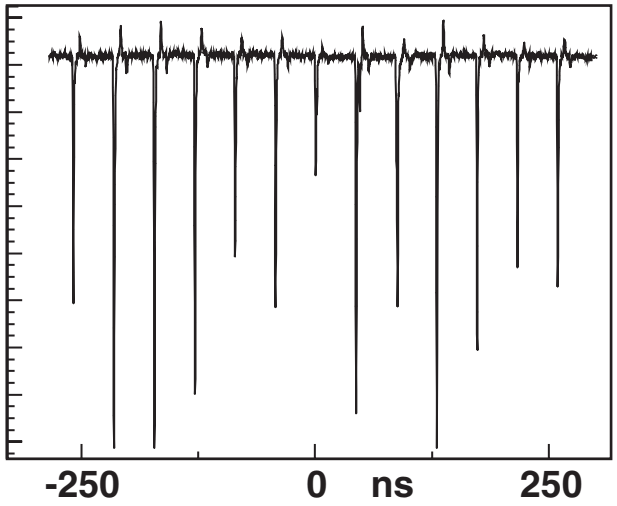
20 micron het.ep. SC diamond, as grown on Ir



Overlay of ~1000 single particle events

beam intensity: 10^6 particles/sec

beam structure from cyclotron (frequency 25 MHz)



preamp signal rise time ~ 0.5 nsec

low-noise, broadband (2 GHz) preamps

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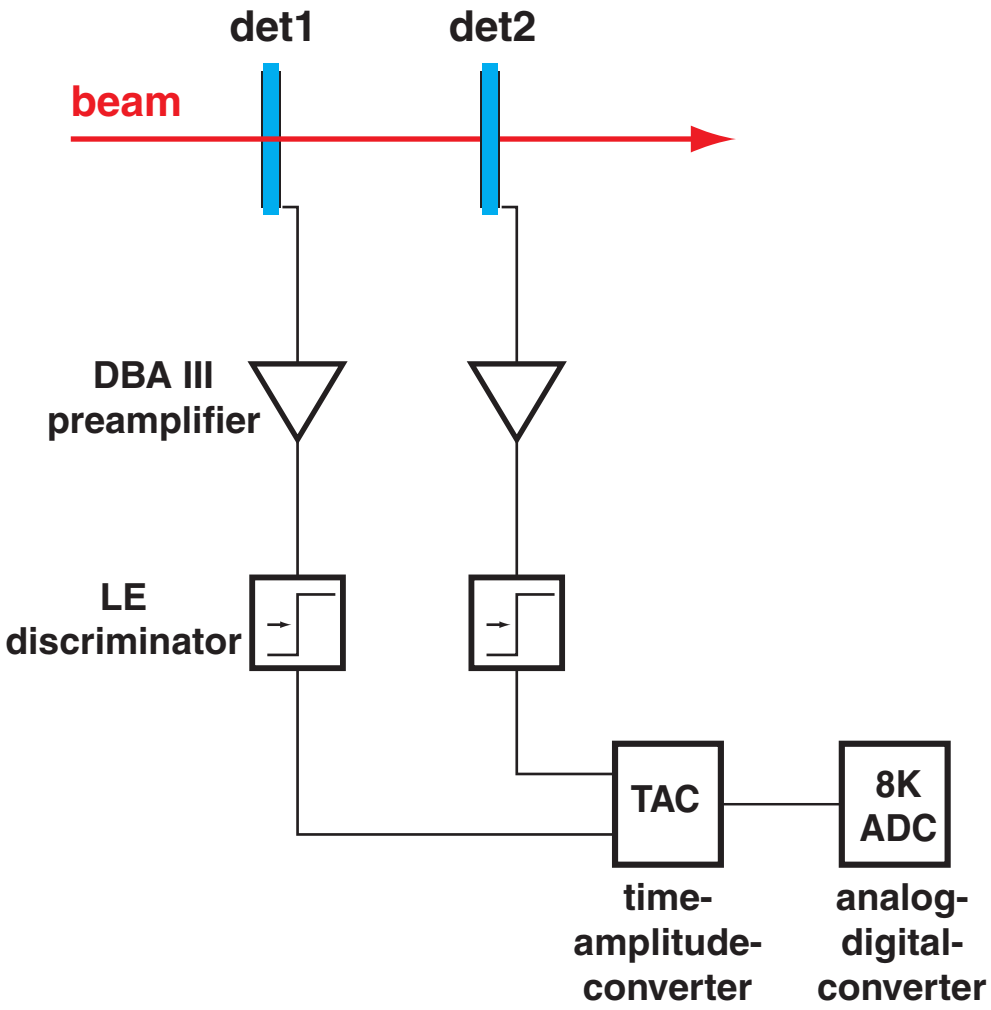
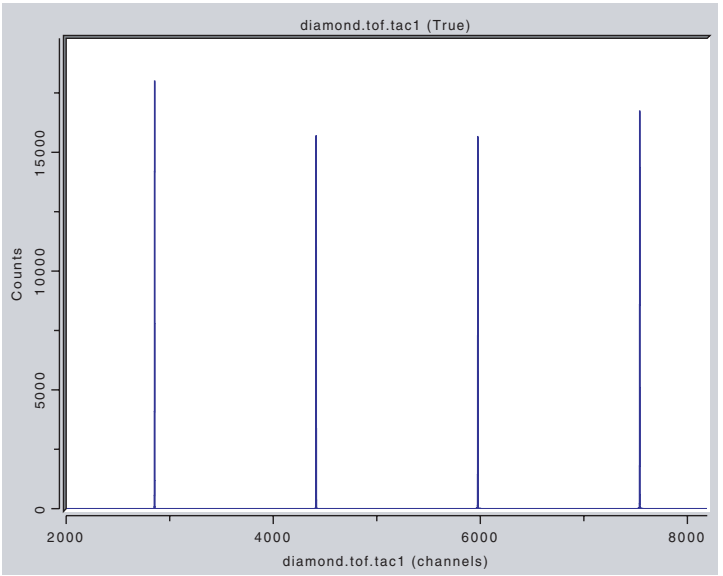
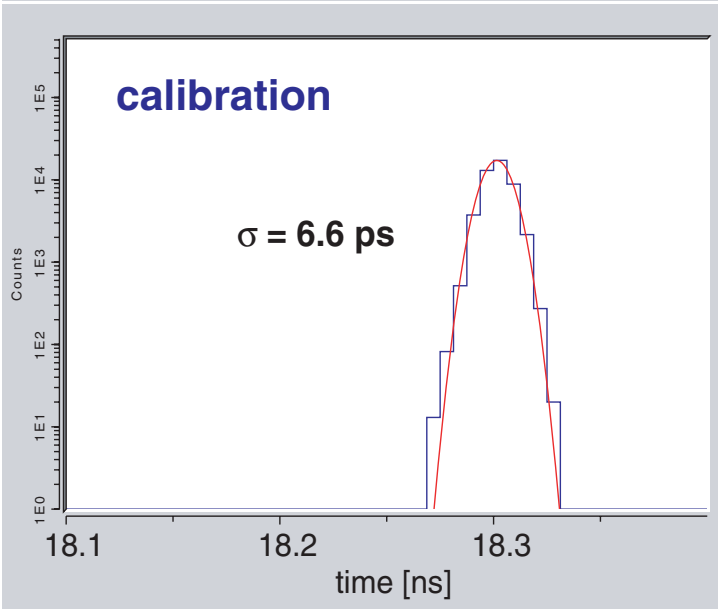
Time resolution - Measurement Setup



test with time calibrator





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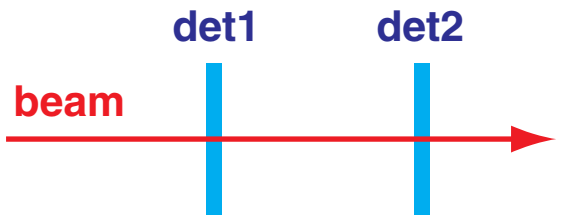
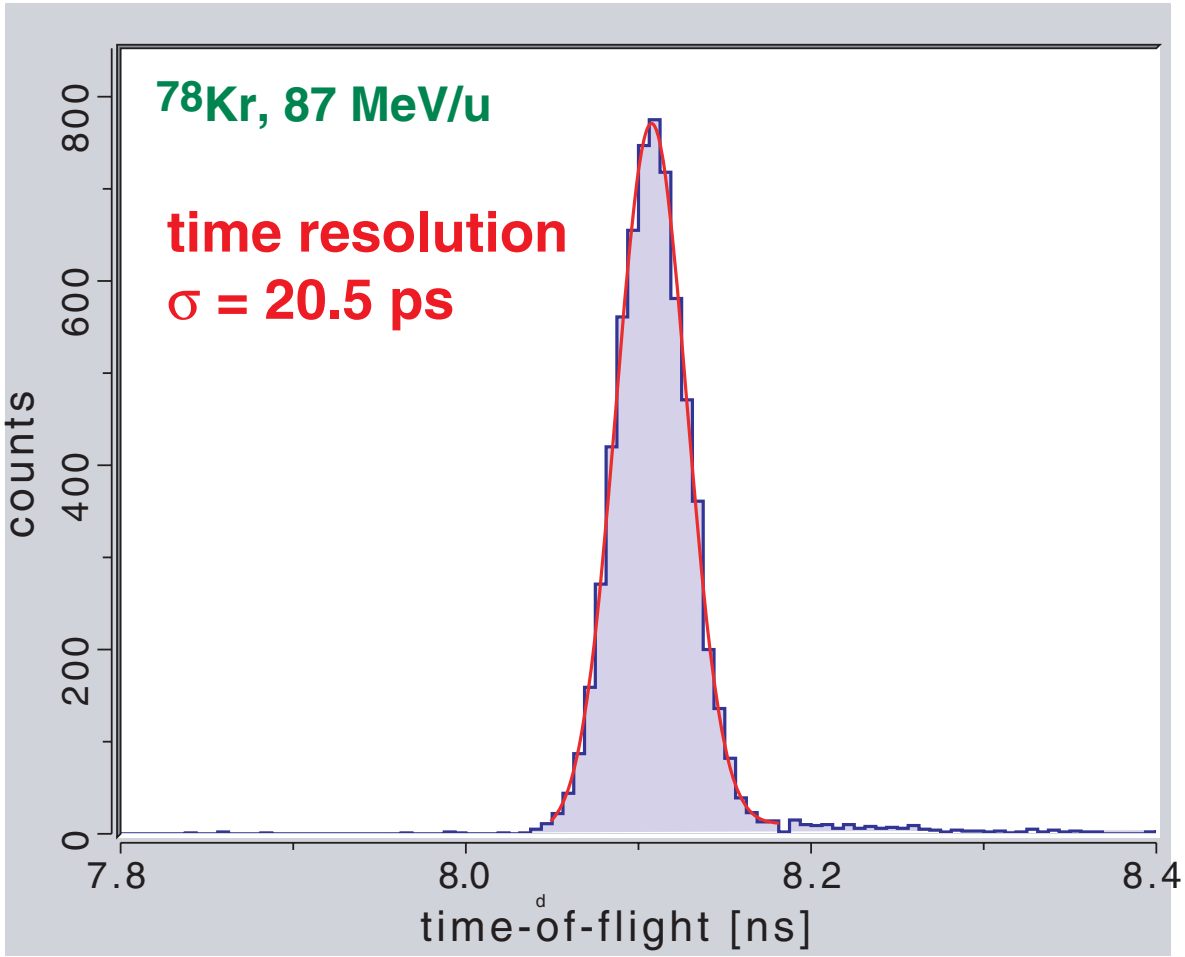
Time Resolution

2 single-crystal diamond detectors (20 μm + 35 μm) in transmission mount





no degradation of time resolution up to rates of $2 \cdot 10^6$ particles/sec = 10^7 particles/(sec mm^2)

intrinsic detector resolution
σ = 15 ps

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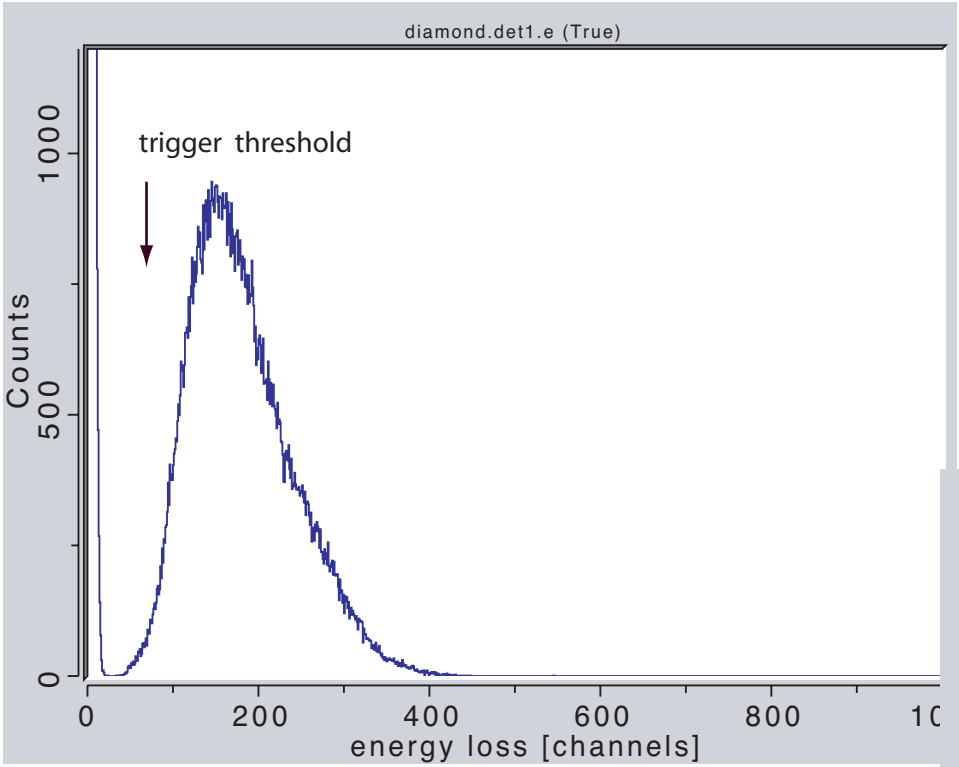
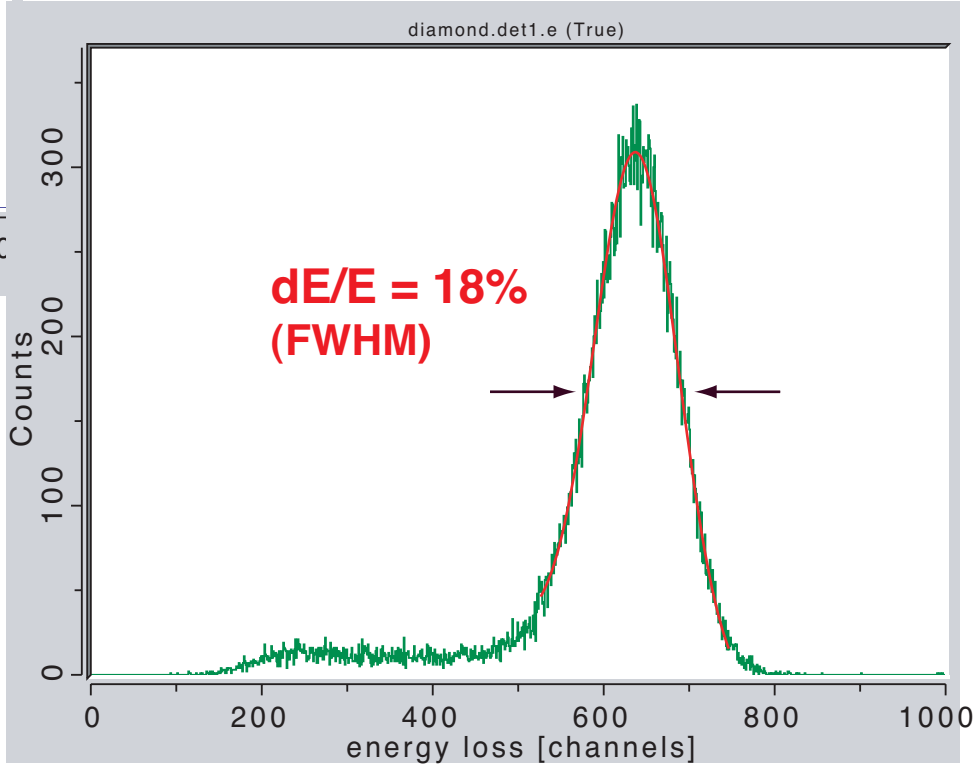
Energy Resolution



poly-crystalline CVD diamond (commercially available)

single-crystal CVD diamond (MSU)
thickness 20 μm
sample with as grown surfaces including Ir growth surface



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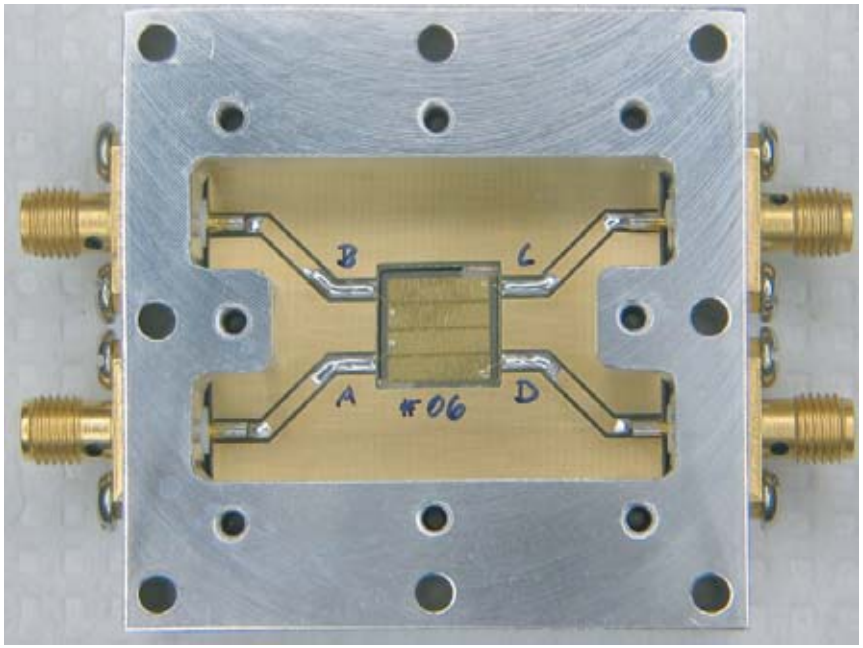
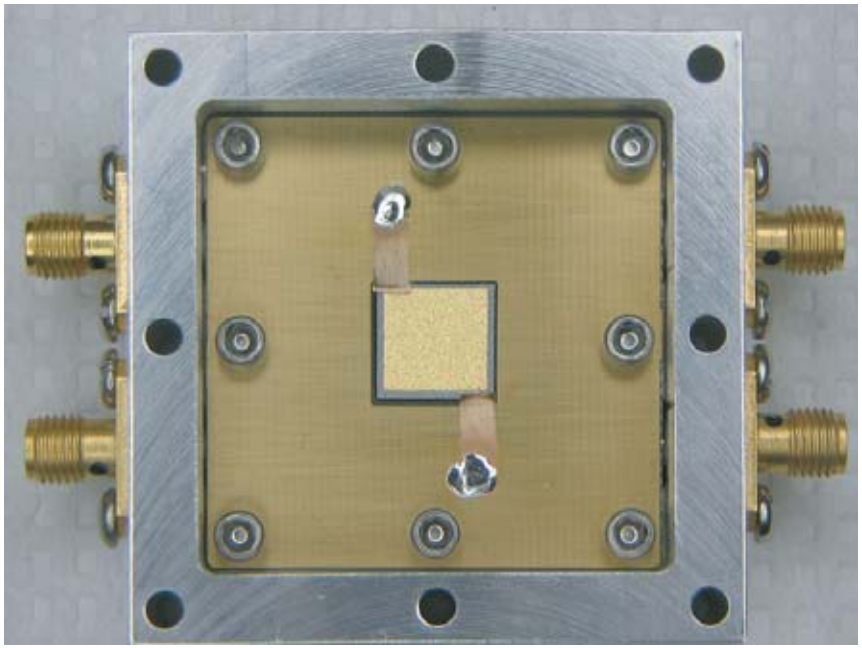
Diamond Strip Detector

Poly-crystalline CFD diamond
active area 9 x 9 mm^2
thickness 100 μm (35 mg/cm^2)
4-fold segmented cathode, common anode
single-strip readout





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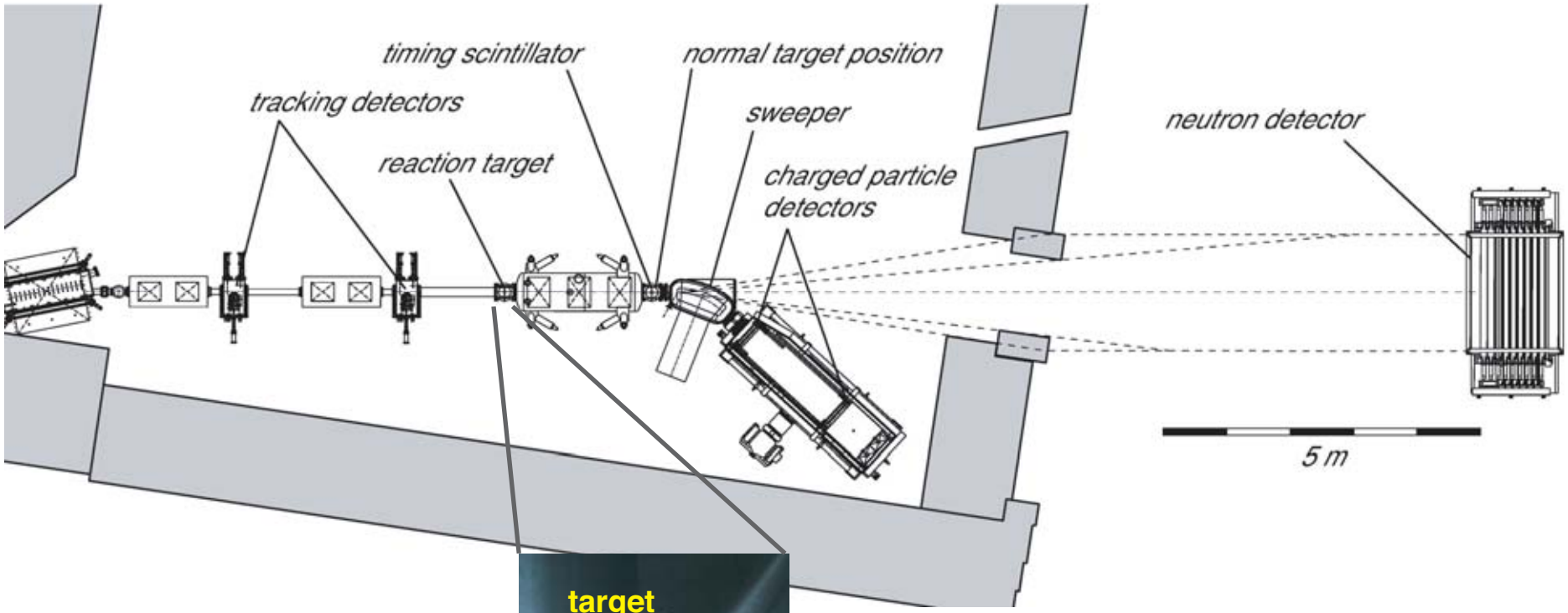
Diamond Detector Application



beam →

^{48}Ca, 60 MeV/u + 9Be

particle identification by energy loss and time-of-flight measurement

diamond strip detector for time-of-flight measurement

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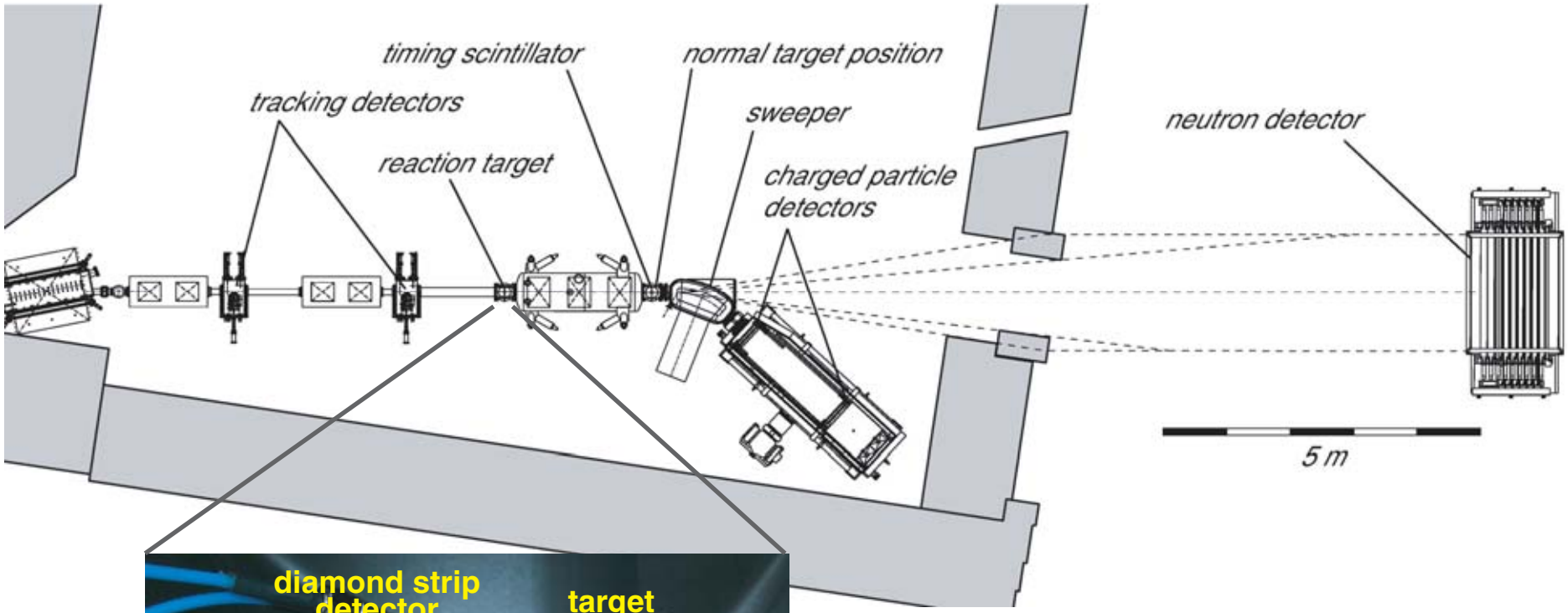
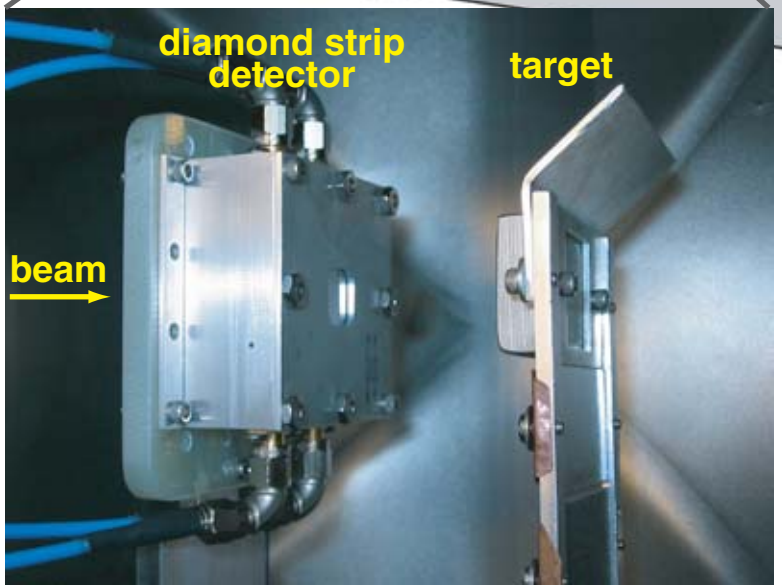
Diamond Detector Application





^{48}Ca, 60 MeV/u + 9Be

particle identification by energy loss and time-of-flight measurement

diamond strip detector for time-of-flight measurement

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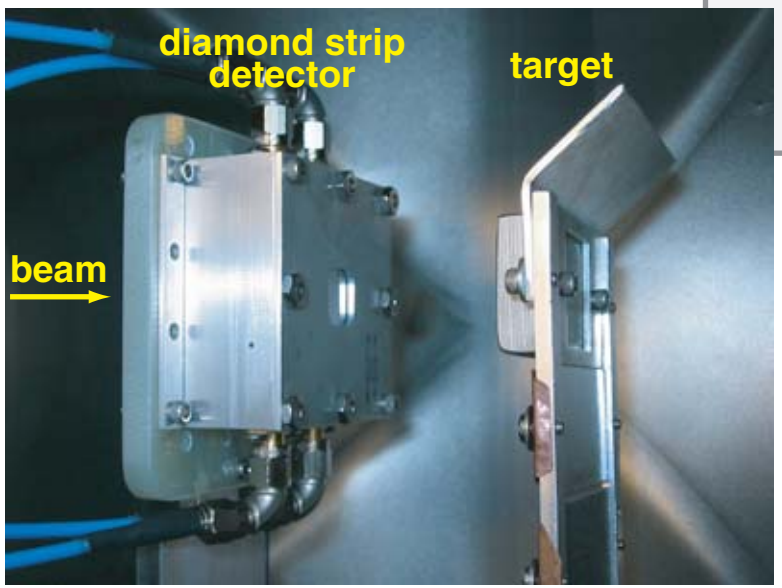
Diamond Detector Application

^{48}Ca, 60 MeV/u + 9Be

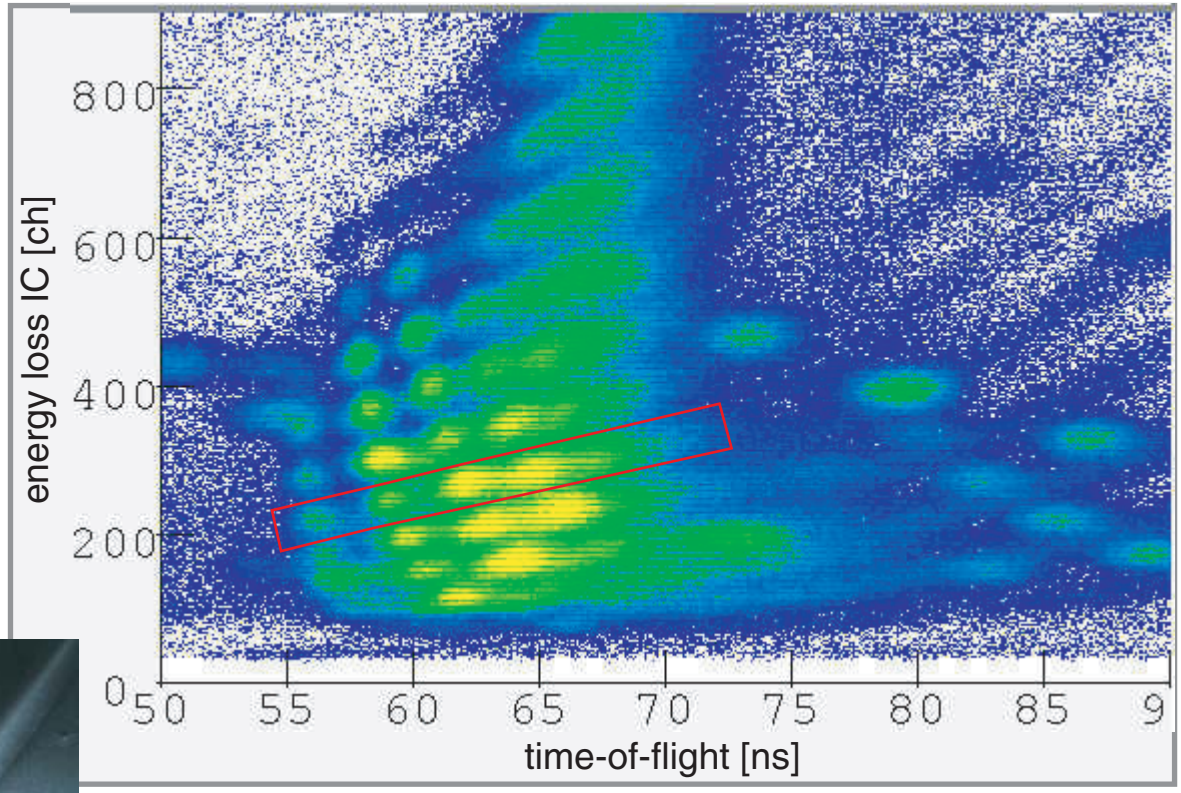
diamond strip detector for time-of-flight measurement

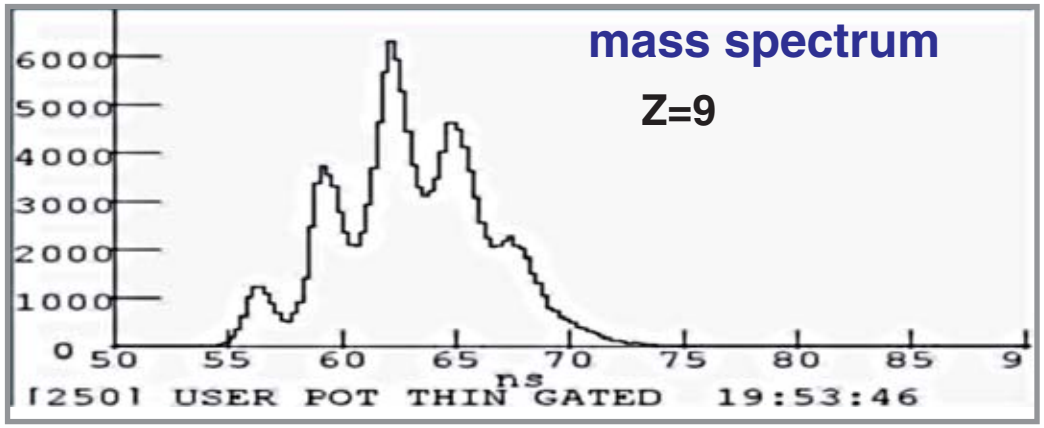
total rate on detector: 10 MHz

detector efficiency: 97%



particle identification plot





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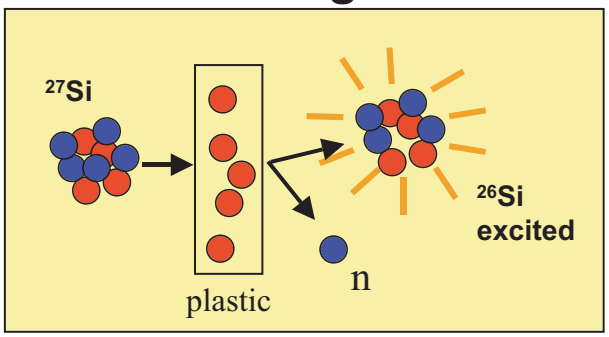
Diamond Detector Application - S800 Spectrograph

NSCL Exp. 05043:
Search for decay cascade in ^{26}Al



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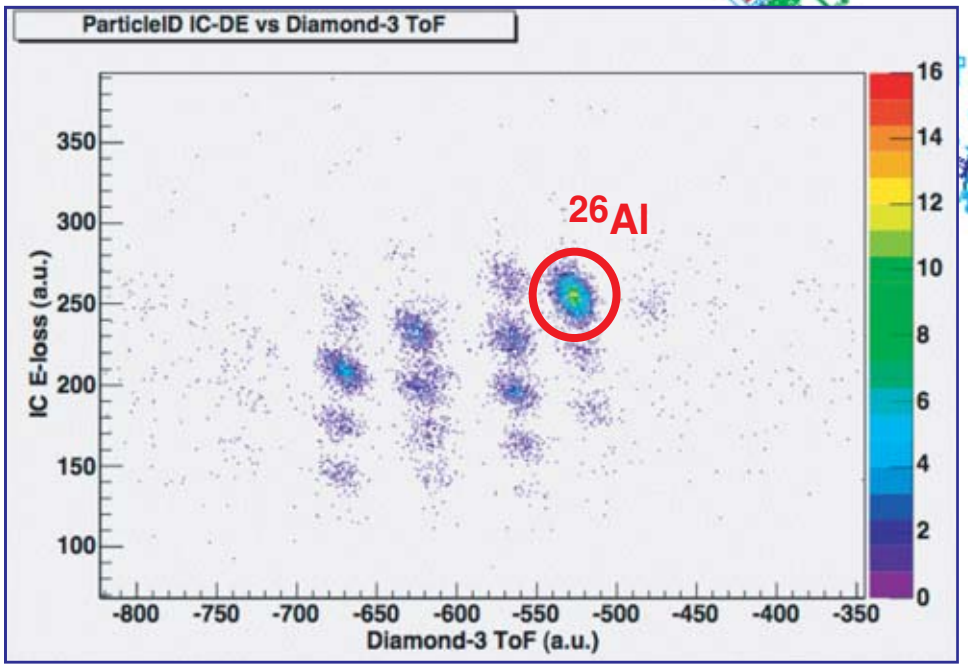
Diamond Detector Application - S800 Spectrograph

NSCL Exp. 05043:
Search for decay cascade in ^{26}Al

S800

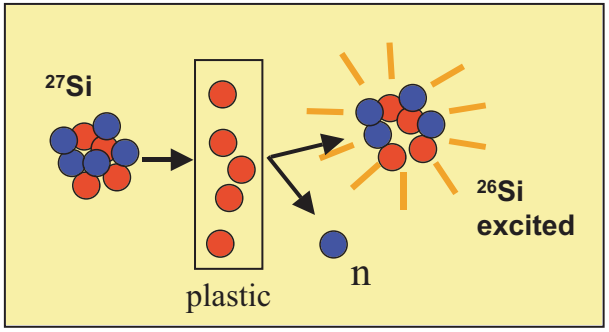
^{27}Al object box

diamond detector:
TOF start + position



^{27}Al

reaction target



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Conclusions

Electronic properties of heteroepitaxial diamond

Conductivity of heteroepitaxial diamond is thermally activated with a single activation energy (E_a=1.4 eV)

Activation energy and conductivity are remarkably similar to high purity Type IIa natural diamond

Heteroepitaxial diamond as particle detectors

time resolution of thin detectors (20 μm): σ_{TOF} = 21 psec

used with beam intensities > 10^7 particles/second

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