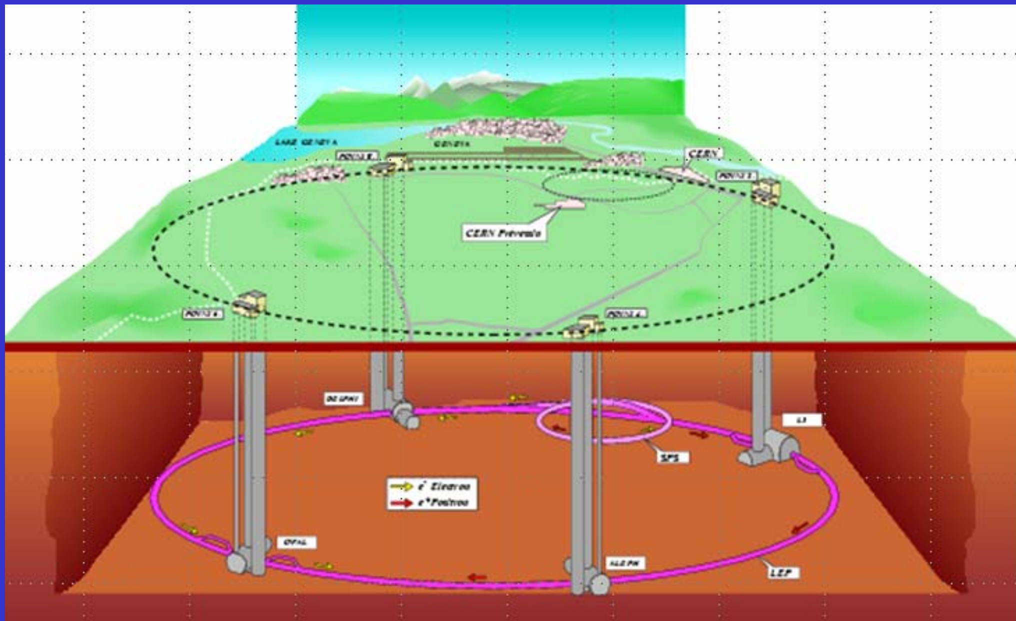
Radiation Hardness of Diamond Detectors

Outline: Beam Loss Monitor for LHC

Radiation hardness

Collaboration: GSI: E. Berdermann, M. Pomorski
Univ. Karlsruhe: WdB, A. Furgeri, S. Mueller

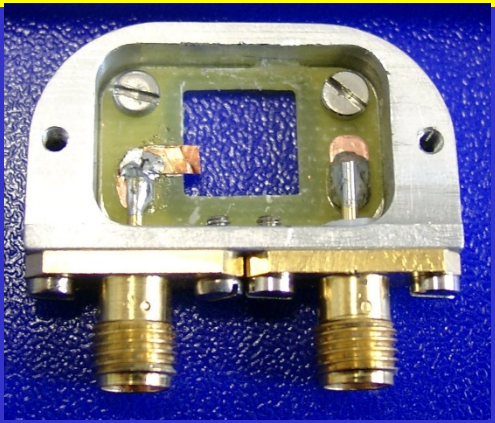
Beam loss monitoring at the LHC 14 TeV pp collider



Expected flux on LHC beampipe: 10^{15} p/cm^2 per yr

Expected radiation damage (RD42 Coll.):

$\Phi_{1/2}$ = 2. 10^{15} (24 GeV p)/cm^2

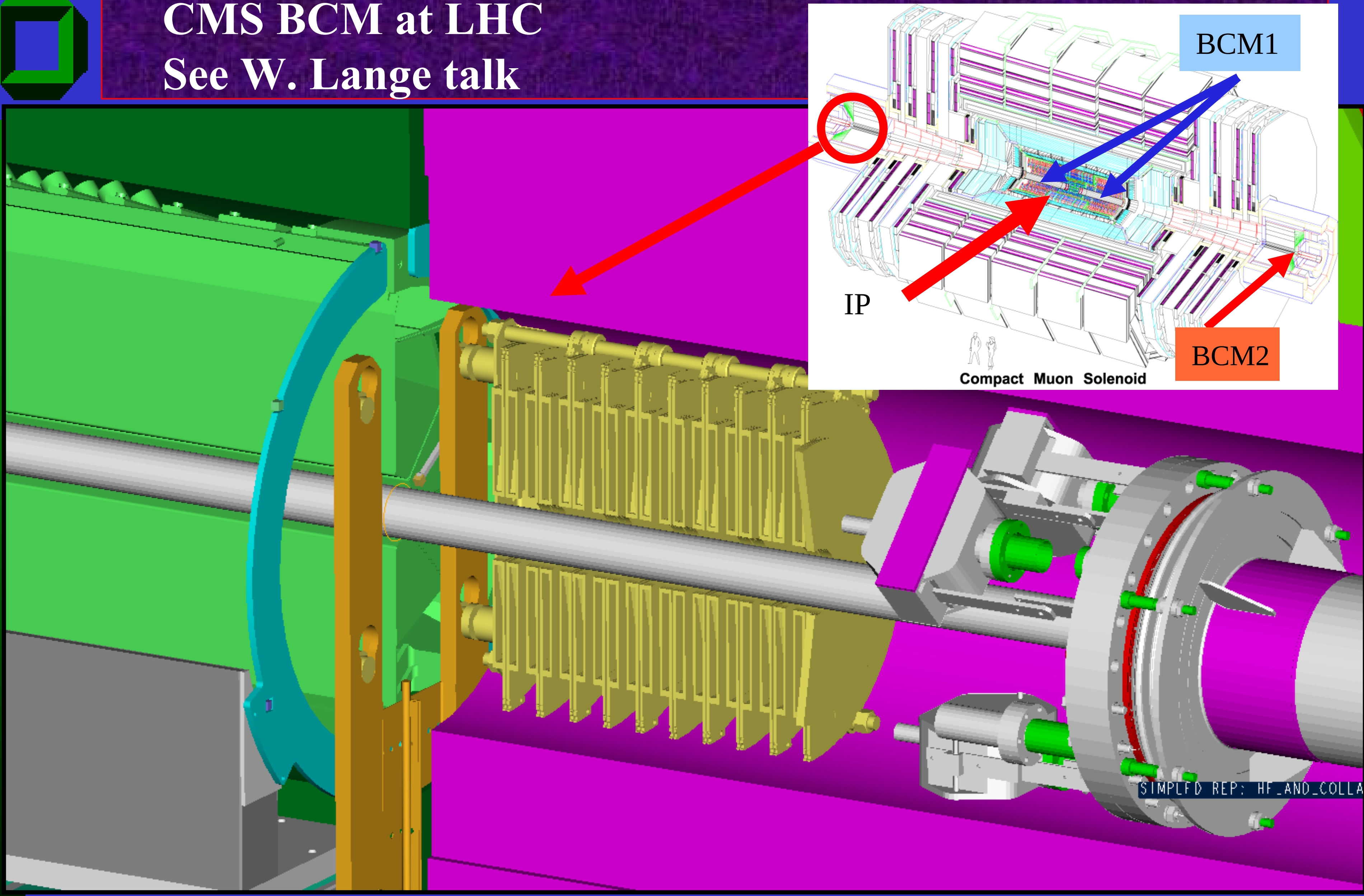


27 km long LHC tunnel filled with SC magnets. Beam loss monitoring by 3700 ionization chambers, which are replaced in experimental area with diamond sensors.

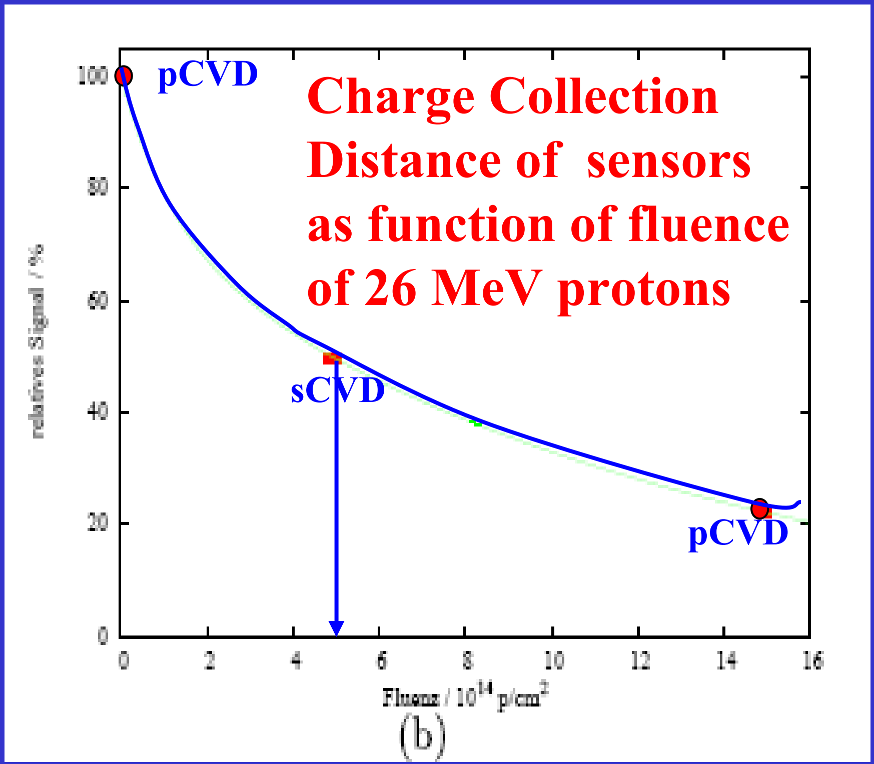
Problem: measured

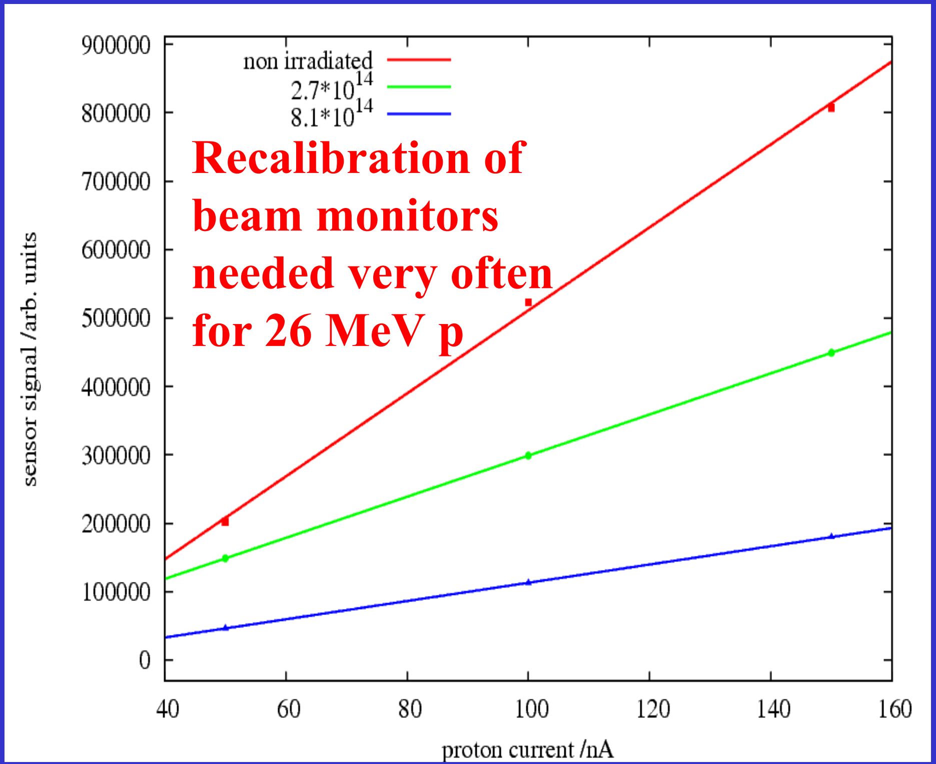
$\Phi_{1/2}$ = (3-5). 10^{14} (26 MeV p)/cm^2

CMS BCM at LHC
See W. Lange talk



Basic observations:





Fluence after which signal decreases by factor two:

$\Phi_{1/2}$ = 5. 10^{14} 26 MeV p/cm^2

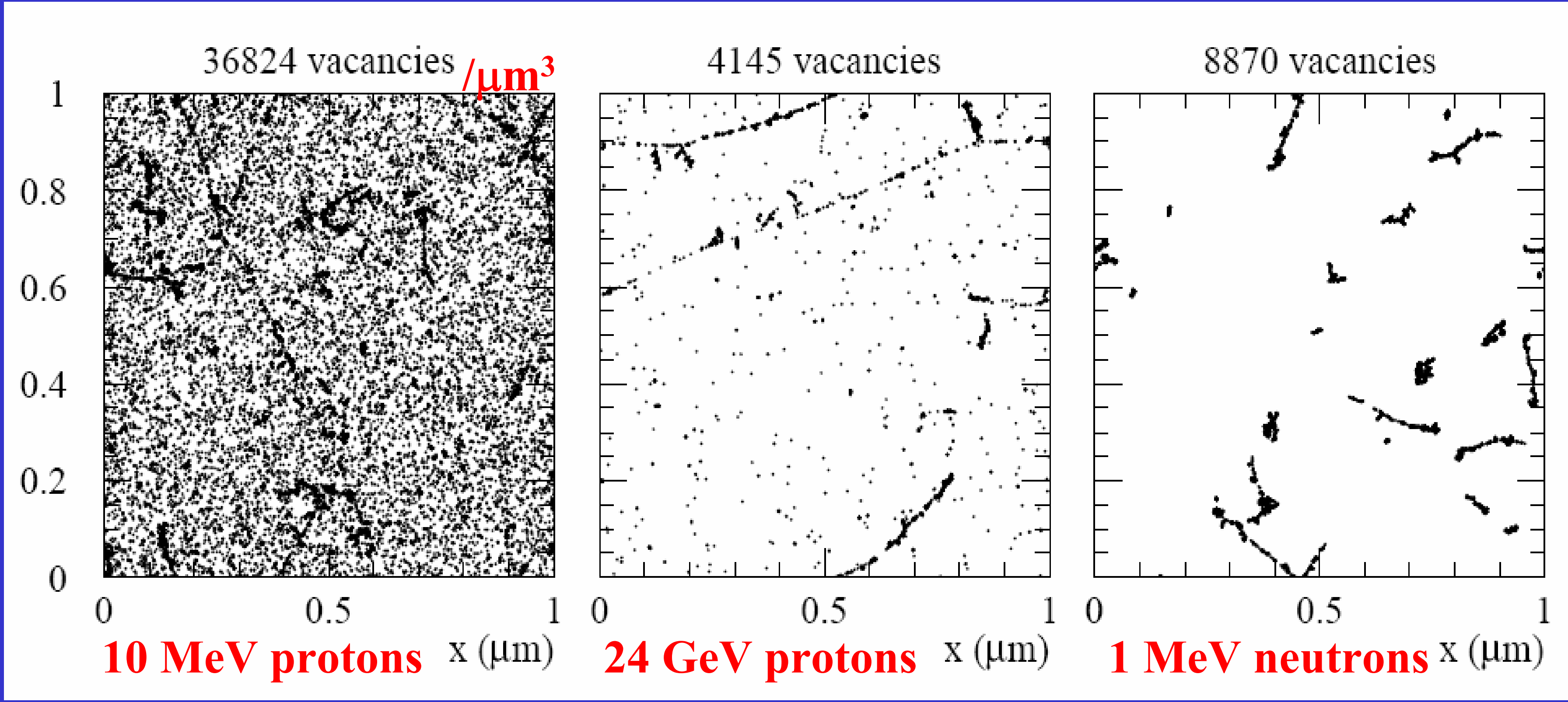
$\Phi_{1/2}$ = 2. 10^{15} 20 MeV n/cm2

After 8.10^{14} 26MeV p/cm^2 sensor practically dead

Radiation damage depends strongly on particle and its energy

Simulation of non-ionising energy loss and defect formation in silicon, M. Huhtinen, CERN, NIMA, 2001

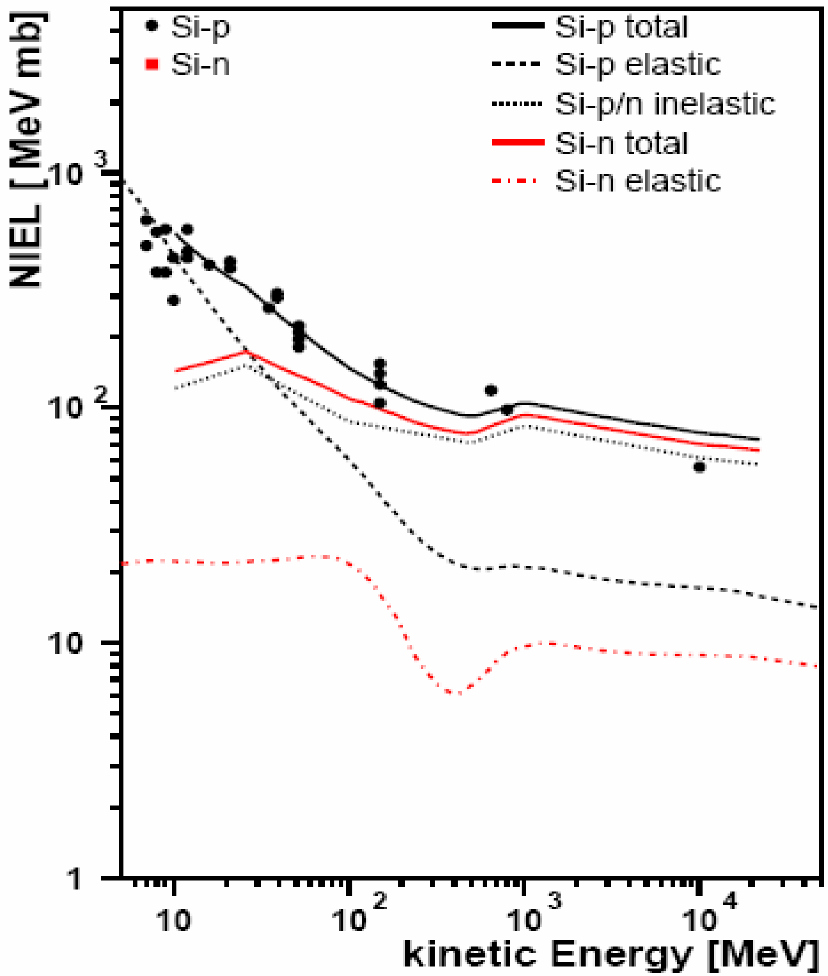
Initial distribution of vacancies for a fluence of $10^{14}/cm^2$



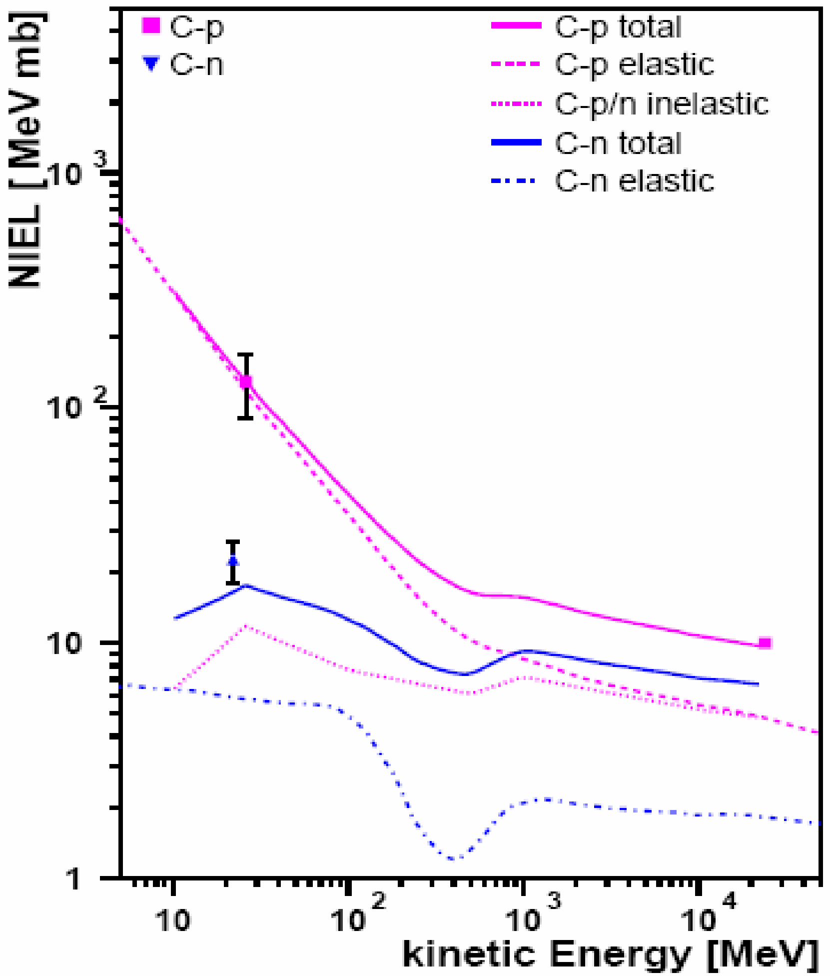
Conclusion: most dangerous beams are low energy charged particles (due to Rutherford scattering)
If a nucleus is hit -> cluster is formed by slow nuclear fragments

Comparison with NIEL cross sections

NIEL in Silicon



NIEL in Diamond

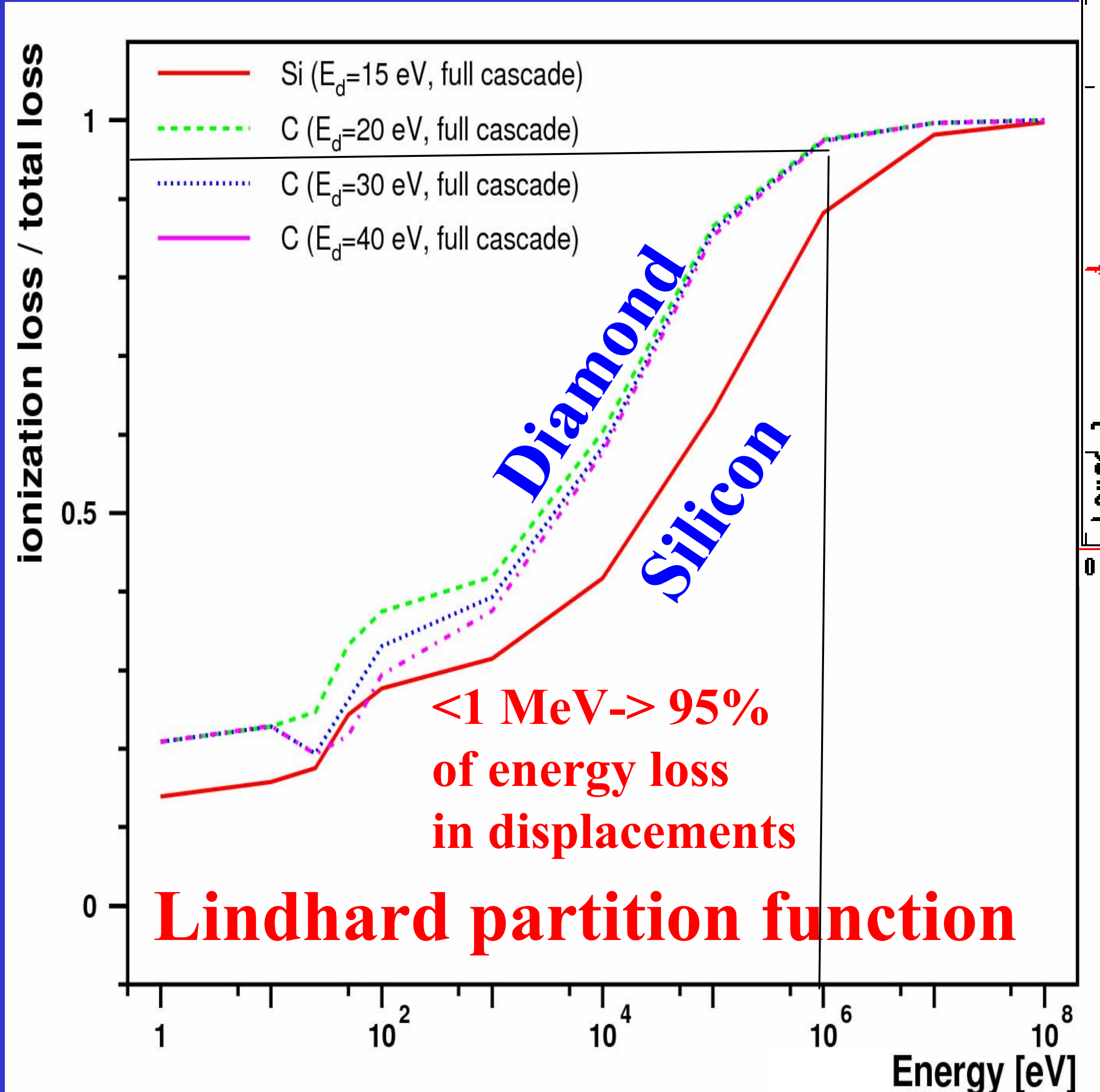


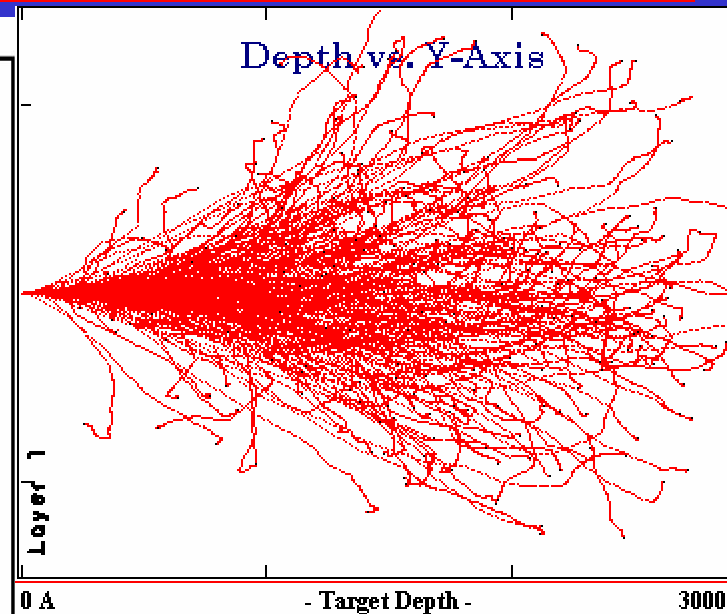
Details in: Wim de Boer, Johannes Bol, Alexander Furgeri, Steffen Muller, Christian Sander (Karlsruhe U.), Eleni Berdermann, Michal Pomorski (Darmstadt, GSI), Mika Huhtinen (CERN) .e-Print: arXiv:0705.0171

Definition of NIEL hypothesis (used sofar for Si)

NIEL= Non-Ionizing-Energy Loss
(given by Lindhard partition function)
Hypothesis: Sensor signal loss ∝ nr. of defects ∝
NIEL damage cross section in [MeVmb]

NIEL mainly by low energy impinging particles





Scattering of 0.1 MeV Al (Z=13) nuclear fragments in Si (Z=14) (simulation by SRIM www.srim.com)

Why Diamond so good at high energies?

Produced nuclear fragments by 10 GeV protons

Si

Z		Ions	NIEL
14	Si	417	4.2
13	Al	910	9.06
12	Mg	1384	12.47
11		1021	8.86
10		1225	8.45
9		265	1.41
8		493	2.09
7		398	1.31
6		909	2.36
5		270	0.55
4		383	0.66
3		662	0.67
2	He	11152	4.4
1	H	46107	0.9
Total		6559	57.38

C

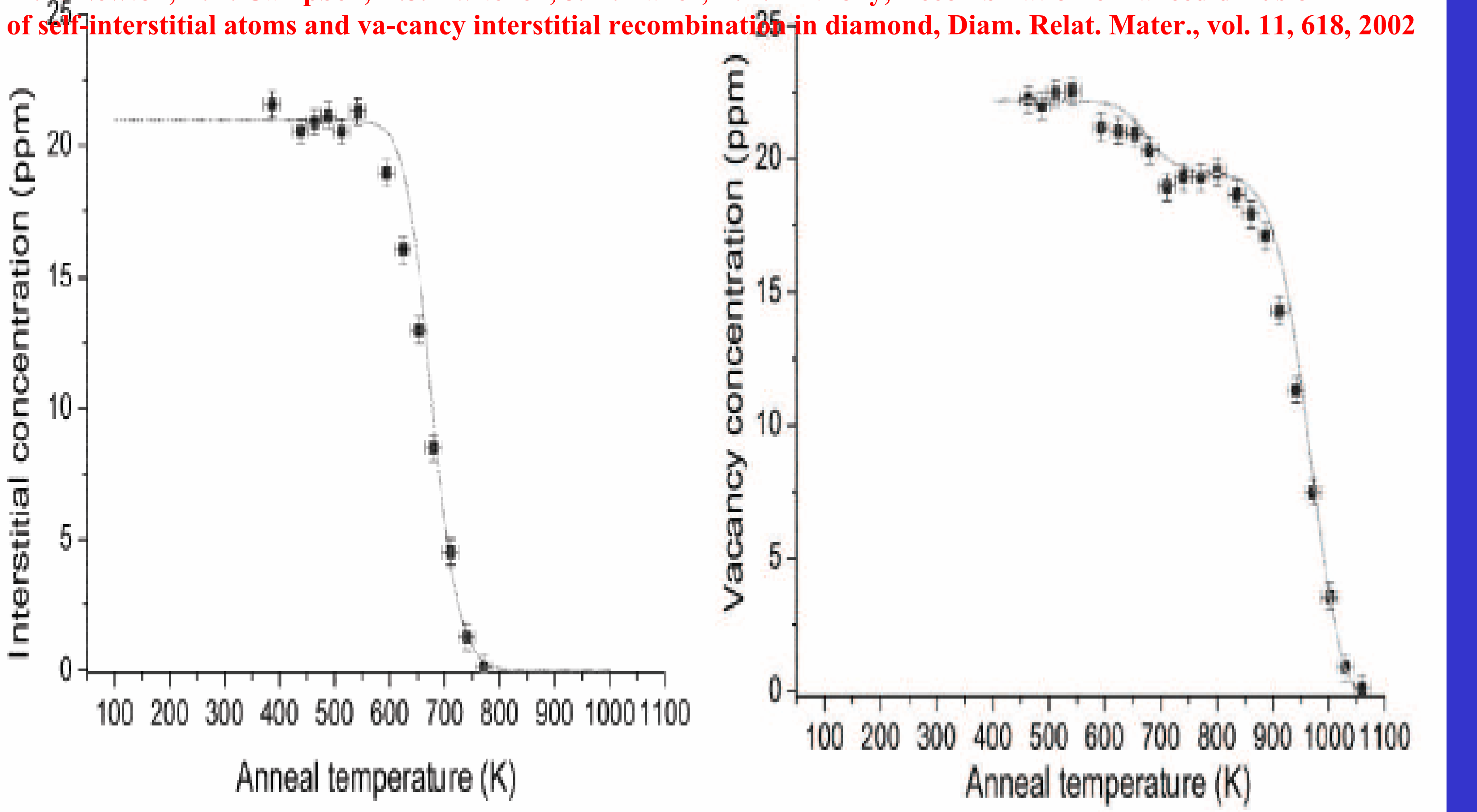
Z		Ion	NIEL
6		698	0.8
5		869	0.77
4		584	0.44
3		1133	0.55
2	He	10625	2.01
1	H	30465	0.24
Total		44374	4.81

Diamond has very stable nucleus->
small inelastic x-section.
Elastic x-section $\propto Z^2\rho$ =3.6 for Si / C

Diamond so good for heavy ions,
because nucleus so stable?

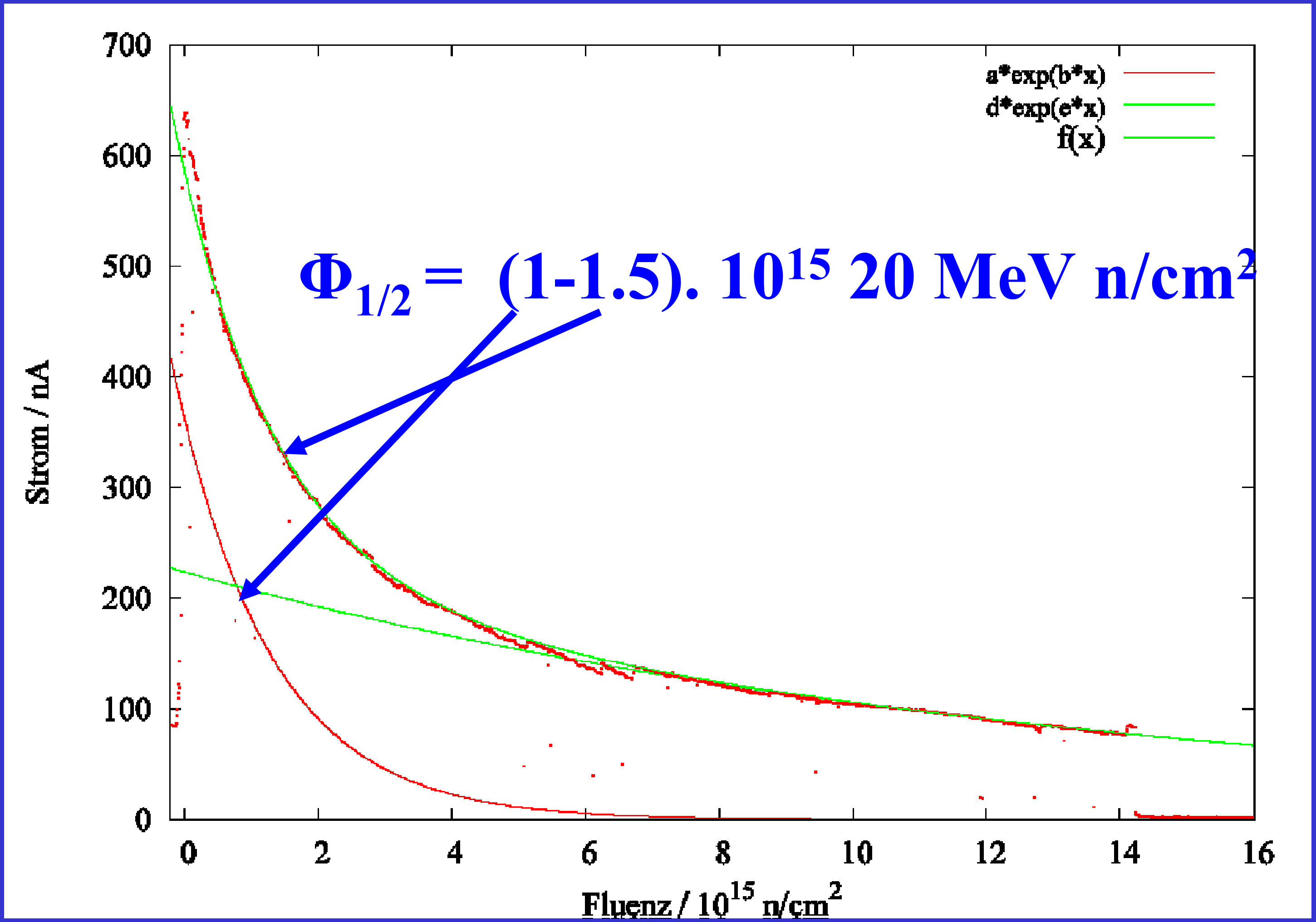
Annealing of Defects in Diamond 100% possible

M.E. Newton, B.A. Campbell, D.J. Twitchen, J.M. Baker, T.R. Anthony, Recombination-enhanced diffusion of self-interstitial atoms and va-cancy interstitial recombination in diamond, Diam. Relat. Mater., vol. 11, 618, 2002



CCE recovered after annealing at 1000 C (M. Pomorski, thesis)
Most defects simple vacancies and interstitials?

Decay of CVD signal during neutron irradiation



Expected signal decrease during irradiation

$$\frac{d}{dt}[A] = -k_a[A]$$

A=[C], k_a= defect creation rate

$$\frac{d}{dt}[B] = -\frac{d}{dt}[A] - k_b[B]$$

B=[defects],
k_b= recombination rate

$$\frac{d}{dt}[C] = -k_c[B]$$

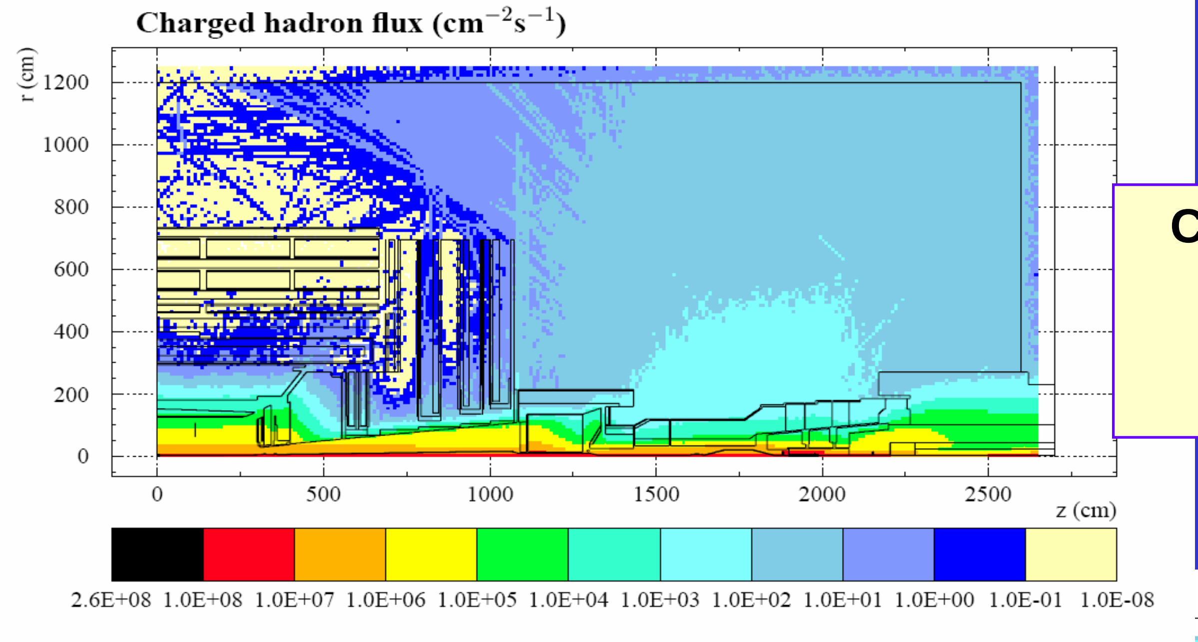
C=[defect with trapped charge],
k_c= trapping rate

Solution of coupled diff. equations:

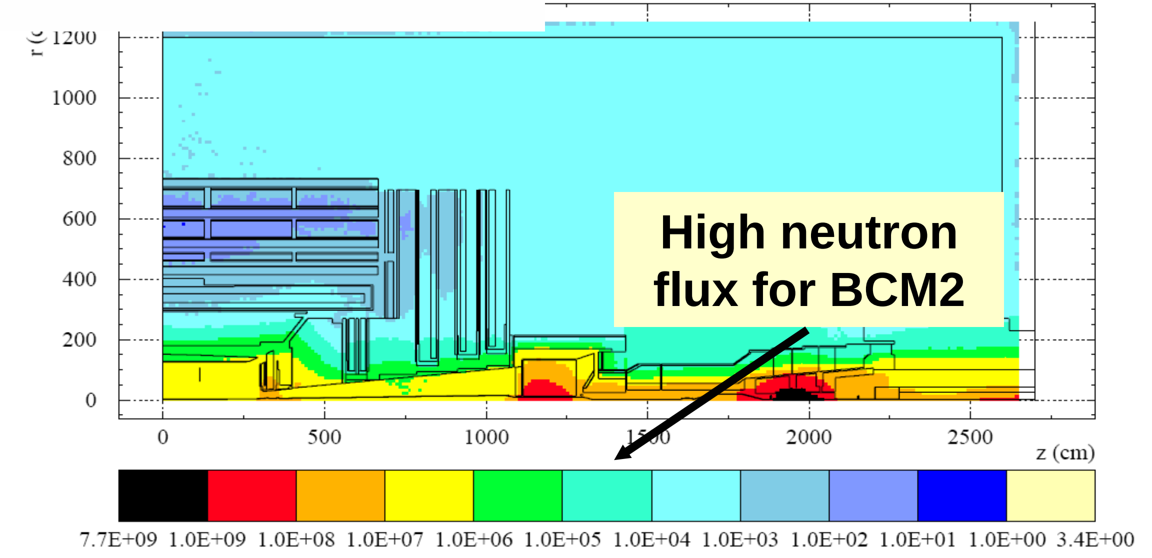
$$f(x) = a \cdot e^{b \cdot x} + c \cdot e^{d \cdot x}$$

Cannot use simple CCE efficiencies AFTER irradiation to compare with NIEL x-section dependence

CMS Flux Maps



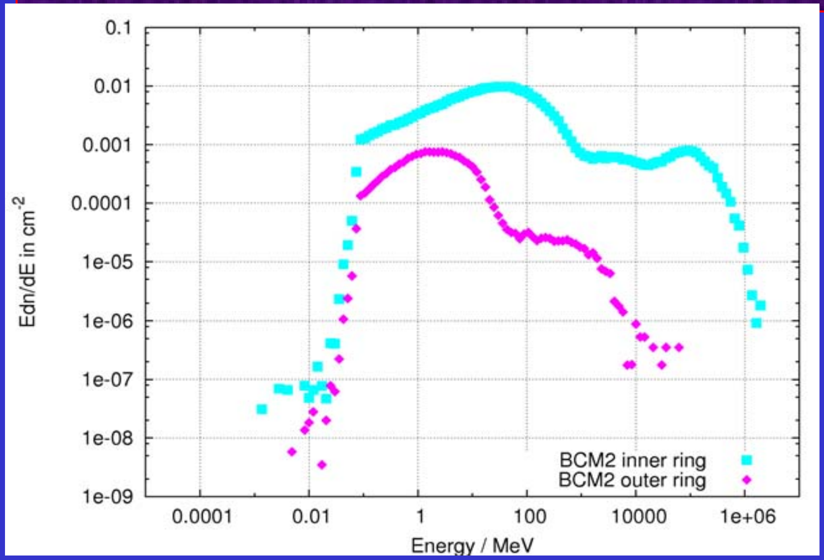
Charged particle flux at 10^{34}
BCM1 ~ $1x10^7 cm^{-2}s^{-1}$
0.25 cm^{-2} per BX

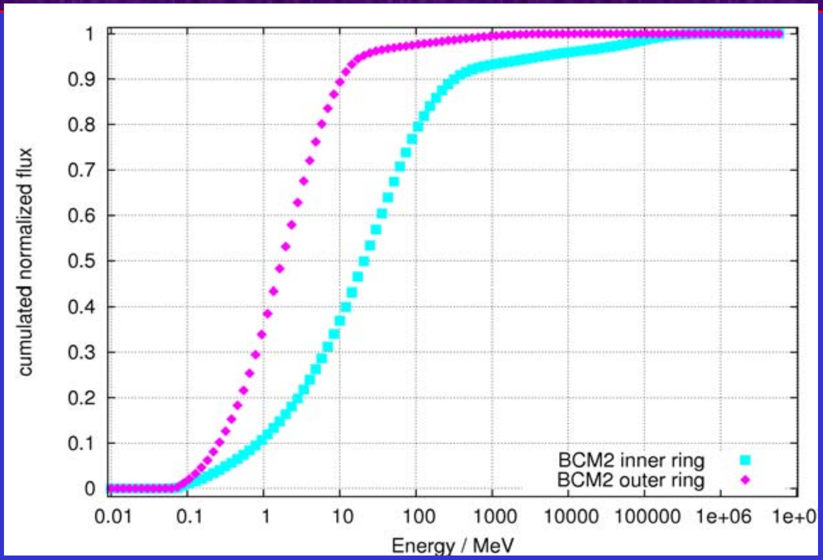


High neutron flux for BCM2

Neutron flux at 10^{34}
BCM1 ~ $1x10^7 cm^{-2}s^{-1}$
$0.25 cm^{-2}$ per BX

Most particles at LHC BELOW 100 MeV



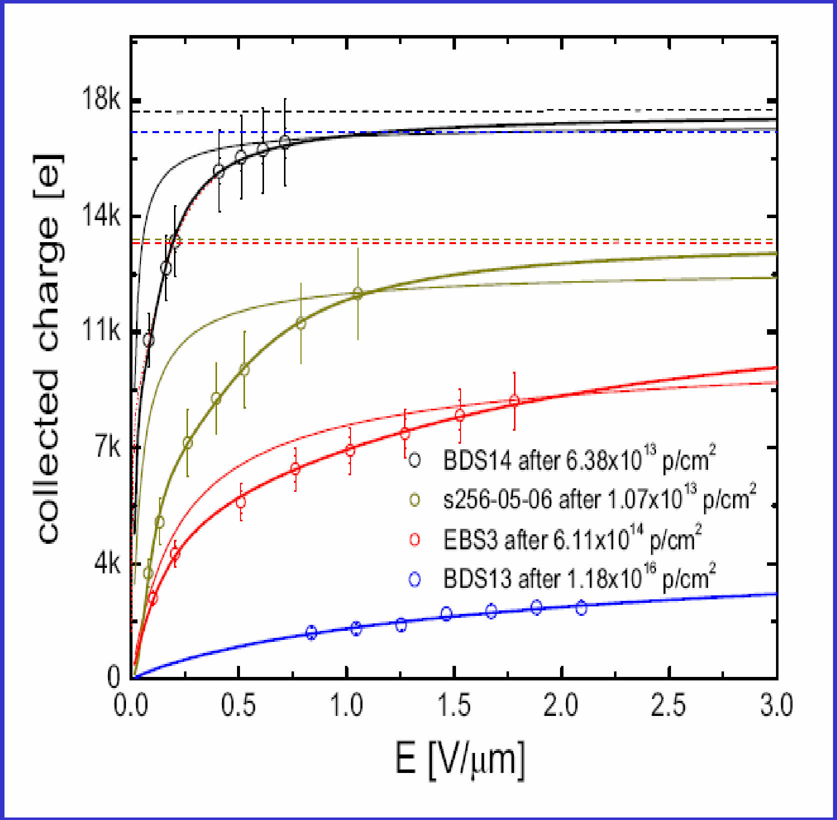


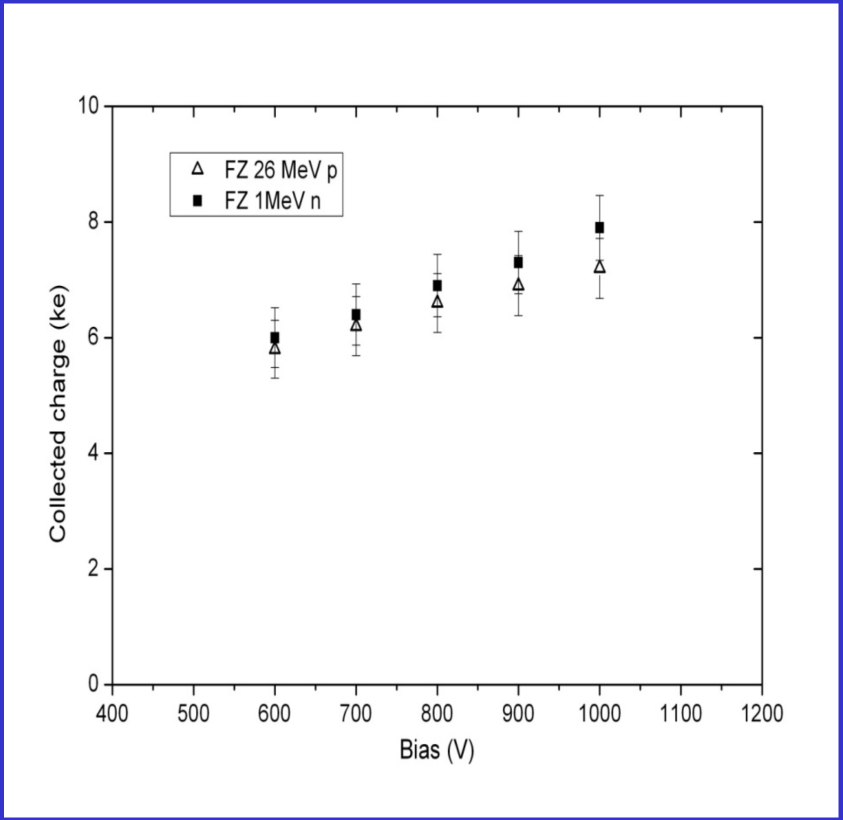
- Diamond has been foreseen for pixel/tracker detector material in future particle detectors as well as beam monitoring devices for accelerators with a nominal energy of > TeV, BUT: secondary and tertiary particles << GeV
- At this energy range the radiation hardness is far less than one would expect after measurements with high energetic particles. Instead of factor of ten diamond is only a factor of few better than silicon.

Signals in Si and C after 10^{16} 26MeV p/cm²

C: 3000 e after 10^{16} 26MeV p/cm²

Si: 7000 e after 10^{16} 26MeV p/cm²





M. Pomorski, Thesis, 2008, GSI

C: + no cooling, +no leakage current,
+ good mechanical and thermal properties, +fast, +good energy res.
+ ok for ions, - expensive, - small samples

G. Casse - 12th RD50 Workshop, 2-4 June 2008, Ljubljana, Slovenia

Si: - cooling to -30C,
+ large wafers

Conclusion

Radiation damage
at HIGH energy
dominated by inelastic cross sections.
C-nuclei smaller and more stable than Si.
Diamond order of magnitude better than Silicon.

Radiation damage
for LOW energy protons (O(MeV)) dominated by
elastic scattering C-nuclei have factor two smaller Z
than Si and higher displacement energy (≈40 eV vs 20 eV).

LHC: beam monitors still see mostly low energy particles!
Radiation damage will be an issue.

Future

Measure with more types of diamonds
with more particle beams
at different energies.

Wait what LHC will tell us