Diamond versus Silicon: Signal-to-Noise Ratio at HL-LHC Fluences

J.-W. Tsung[a], M. Havranek[a], F. Hügging[a], H. Kagan[b], H. Krüger[a], N. Wermes[a]

[a] University of Bonn, [b] Ohio State University

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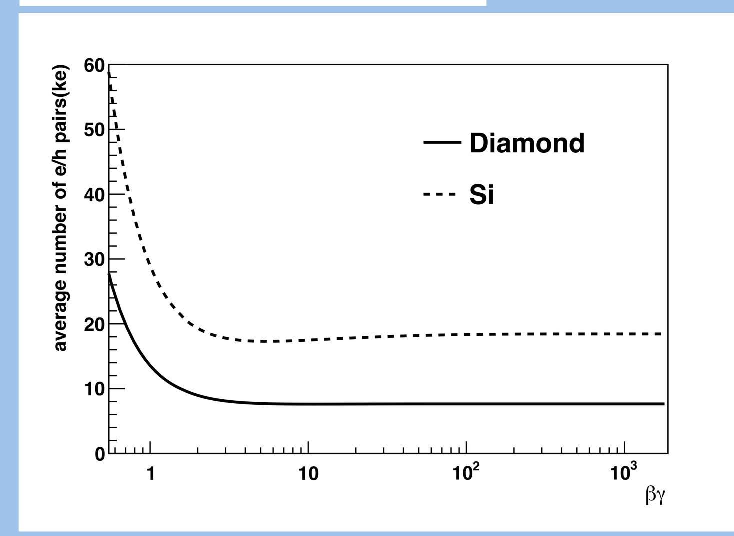
SI LAB Silizium Labor Bonn

MOTIVATION

- **Silicon** is
  - well understood, also in terms of charge collection and radiation damage
  - still works at LHC radiation fluences (Φ ~ 10^{15} cm^{-2})
  - radiation damage predictable → NIEL curve
    - at high fluences trapping dominates
- **Diamond** is
  - "newer" … pCVD … scCVD not in large quantities …
  - has no leakage current, smaller C_{det}
    … has nice thermal features
  - to be traded off against a ~2.5x smaller signal
- **Question**
  - **Predict radiation damage** → damage curve for diamond
  - **How much** better/worse is diamond versus Si at HL-LHC fluences > 10^{15} cm^{-2} → **in terms of S/N**

THE SIGNAL

Signal before irradiation

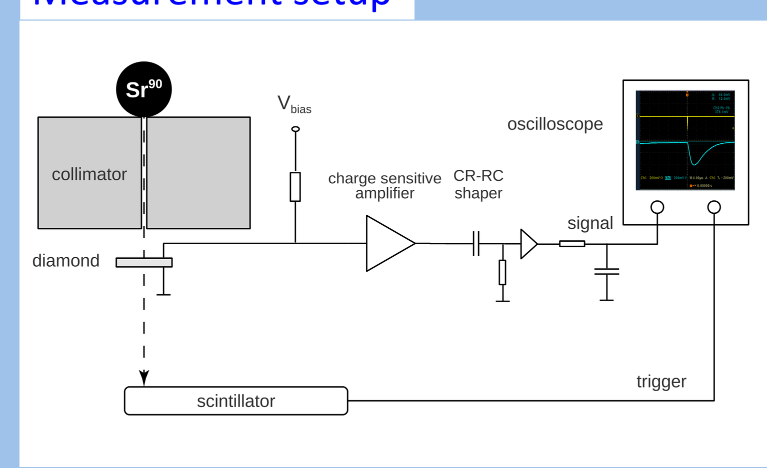


$$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \rho \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{cut}}{I^2} - \frac{\beta^2}{2}\left(1 + \frac{T_{cut}}{T_{max}}\right) - \frac{\delta}{2} \right]$$

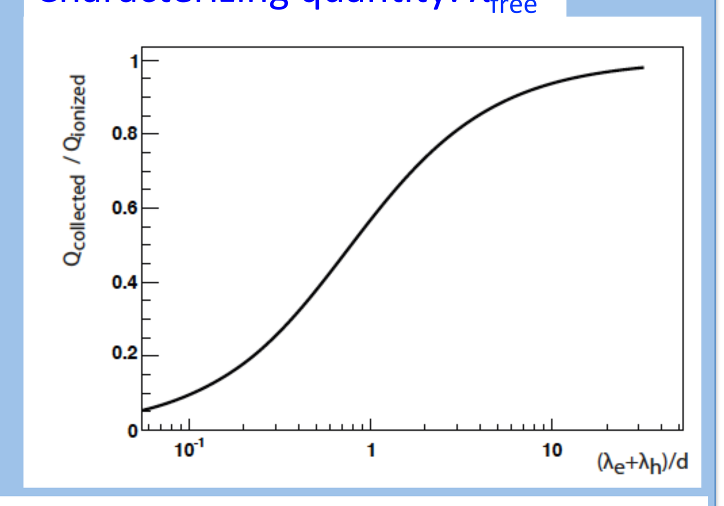
$$\frac{\left\langle \frac{dE}{dx} \right\rangle_{diamond}}{\left\langle \frac{dE}{dx} \right\rangle_{Si}} \approx 1.58$$

in 200 µm
Si: 17350 e
CVD: 7600 e

Measurement setup

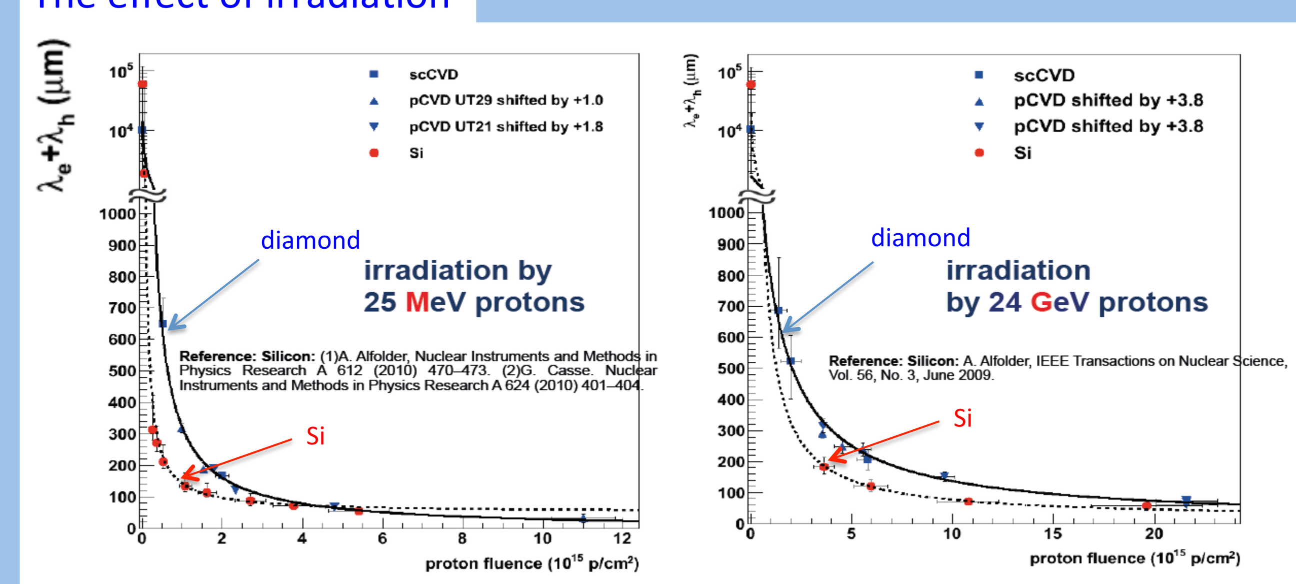


Characterizing quantity: λ_{free}



$$\frac{CCD}{d} = \frac{Q_{collected}}{Q_{ionized}} = \frac{\lambda_{e/h}}{d} \cdot \left[1 - \frac{\lambda_{e/h}}{d}\left(1 - e^{-\frac{d}{\lambda_{e/h}}}\right)\right] + (e \leftrightarrow h)$$

The effect of irradiation



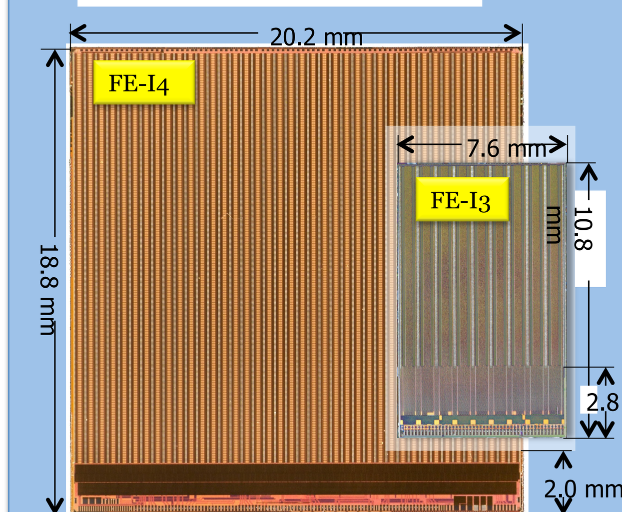
$$\lambda_{e/h} = \frac{\lambda_0}{1 + \lambda_0 k \Phi} + \alpha \Phi^{\beta}$$

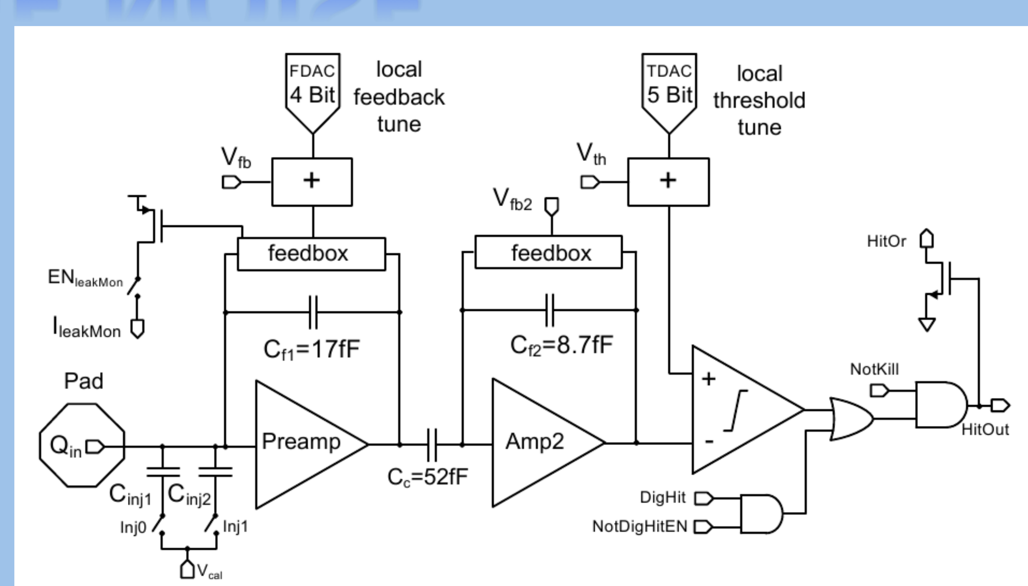
	25 MeV protons	24 GeV protons
$k_{diamond}$	$3.02^{+0.42}_{-0.36}$	$0.69^{+0.14}_{-0.17}$
k_{Si}	$10.89^{+1.79}_{-1.79}$	$1.60^{+0.38}_{-0.38}$

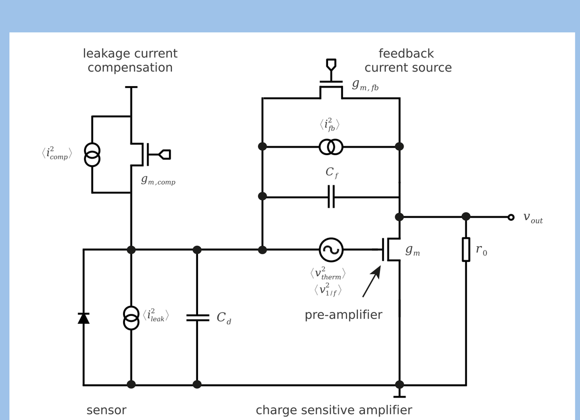
k-factors ~ 2-3 smaller for diamond

THE NOISE

ATLAS FE-I4 chip







$$\langle ENC^2 \rangle = A_{parallel} \cdot \frac{\tau_b^2}{\tau_b + \tau_c} + A_{serial}^{thermal} \cdot \left[\frac{1}{\tau_c} + \frac{\tau_a^2}{2\tau_c^3}\right] + A_{serial}^{1/f} \cdot \left[\frac{\tau_a^2}{2\tau_c^2} + \ln\left(\frac{\tau_b}{\tau_c}\right)\right]$$

$$A_{parallel} = \frac{2 i_{leak} + i_{fb}}{2q}$$

$$A_{serial}^{thermal} = \frac{C_D^2}{q^2} \frac{kT}{2 g_m}$$

$$A_{serial}^{1/f} = \frac{C_D^2}{q^2} \frac{K_F}{C_{ox} W L}$$

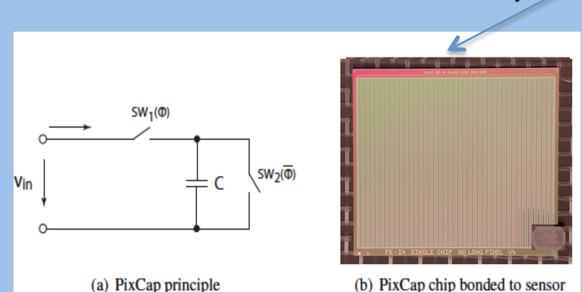
dominant noise terms

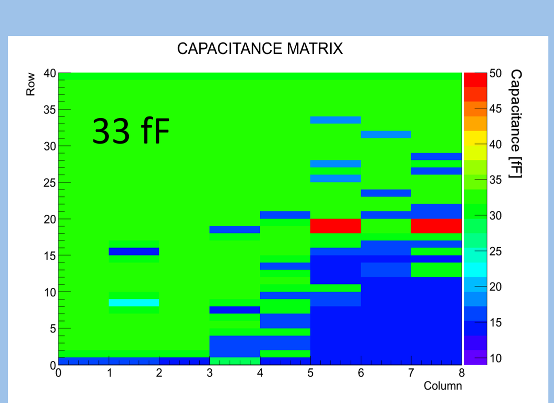
→ need to know: C_D and i_{leak}

measure it

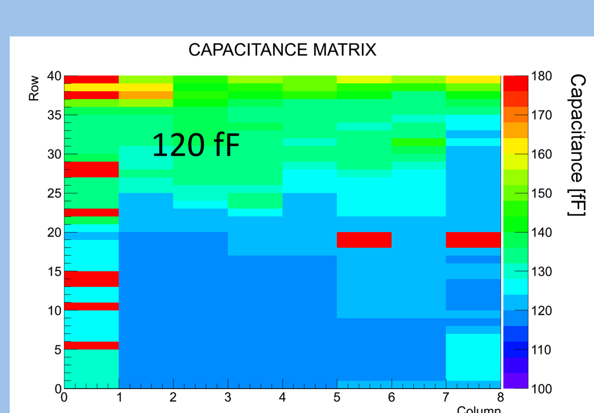
$$i_{leak} = i_{leak,0} + \alpha_i \Phi \cdot V$$

The PixCap chip





diamond pixels



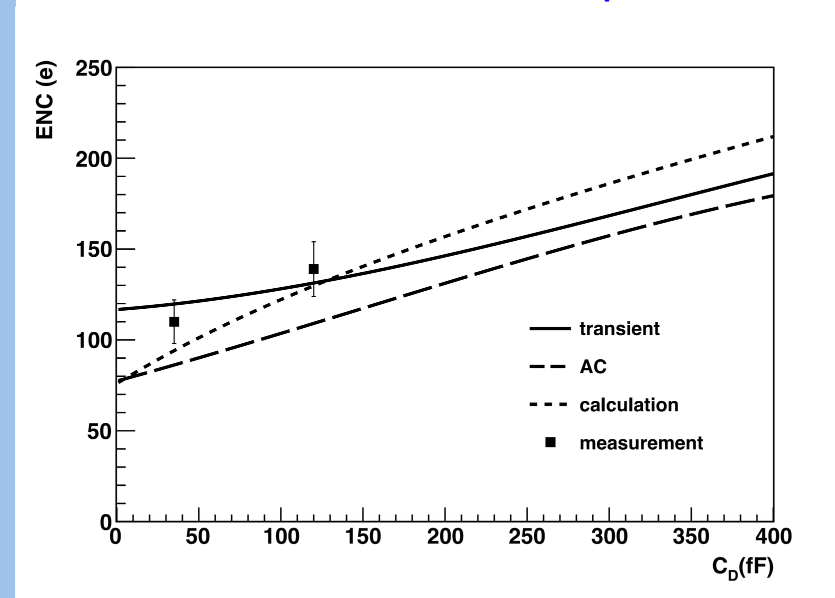
planar silicon pixels

measured pixel capacitances

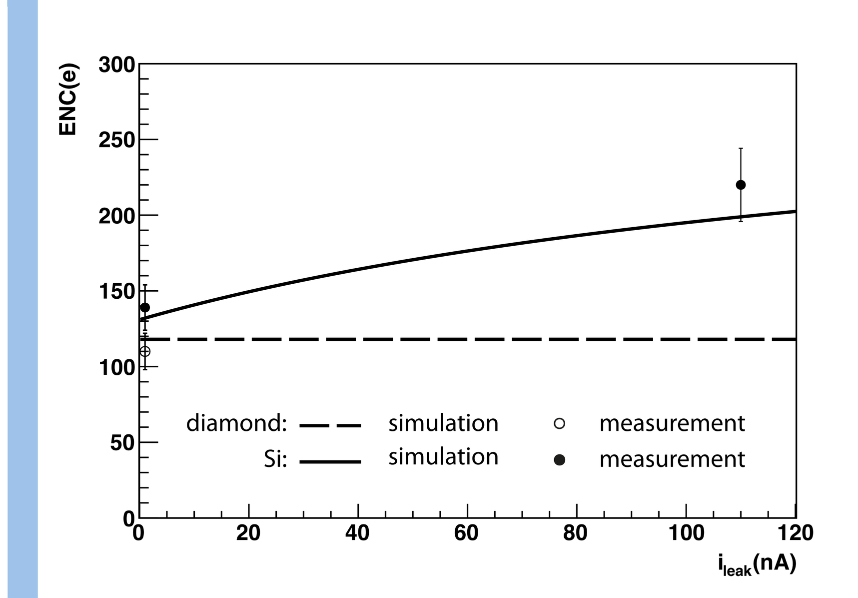
$\langle C_D^{CVD} \rangle = (33 \pm 1) fF$	diamond, metallized
$\langle C_D^{Si} \rangle = (117 \pm 2) fF$	planar electrodes, sample A
$\langle C_D^{Si} \rangle = (123 \pm 4) fF$	planar electrodes, sample B
$\langle C_D^{Si} \rangle = (181 \pm 2) fF$	3D electrodes

THE SIGNAL TO NOISE RATIO

noise versus detector capacitance

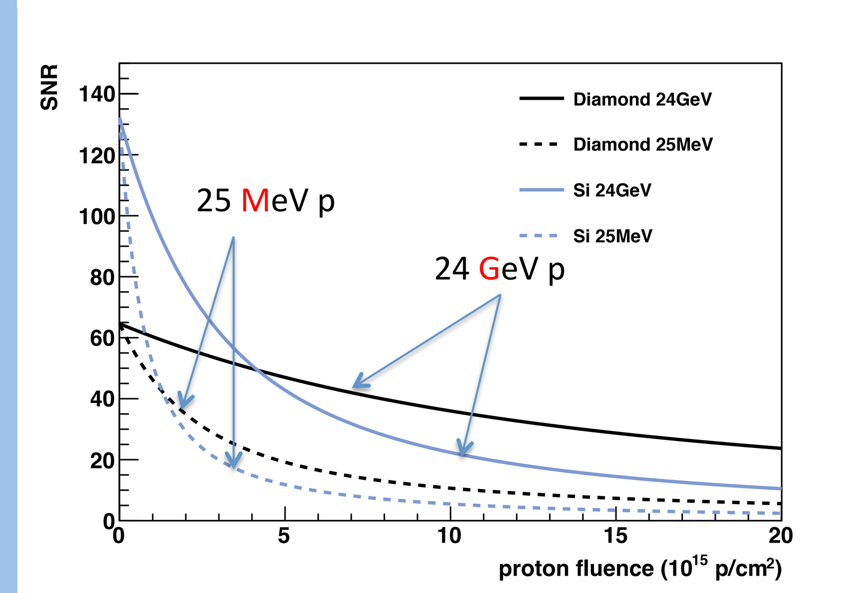


noise versus leakage current



Result:
SNR of Diamond is larger than that of planar Siliconpixels at fluences above a few × 10^{15} p/cm²

SNR versus fluence (d=200 µm)



SNR versus fluence (0.1 x/X_0)