Beam test of 3D pixel detectors up to fluences of $9x10^{15}$ n_{eq}/cm^2

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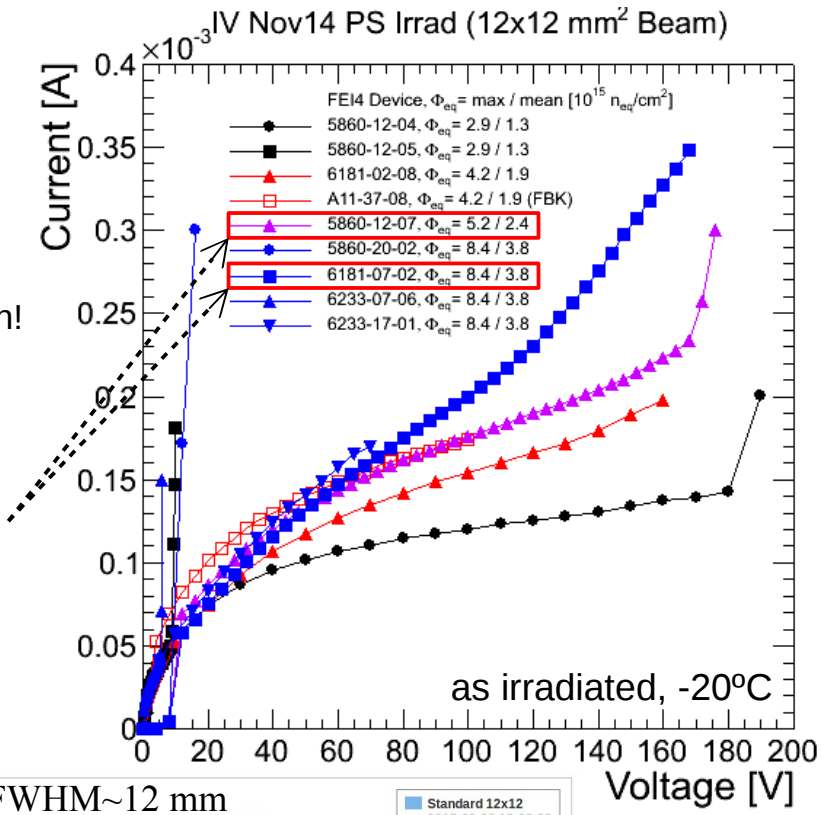
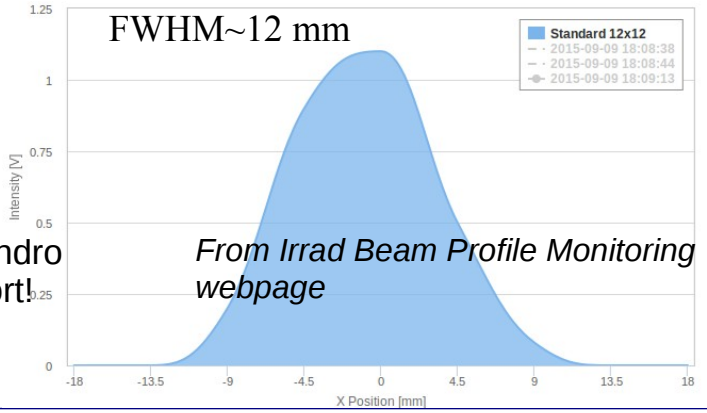
3D irradiation campaign

- IRRAD (CERN) 23 GeV protons (Nov 2014)
  - 9x 3D FEI4 bare assemblies (8 CNM/1 FBK)
  - No scanning available:
    - Non-uniform (12 mm FWHM)
  - Selected two devices for assembly and tests
    - Nominal fluences: 5.2x10^{15} n$_{eq}$/cm² and 8.4x10^{15} n$_{eq}$/cm² (as measured in 5x5 mm² Al)
  - Other devices were further irradiated up to 2x10^{16} n$_{eq}$/cm²
- JSI Lubljana neutrons (May 2015)
  - FEI3 irradiated up to 2x10^{16} n$_{eq}$/cm²
  - See J. Lange's presentation

Thanks to Federico Ravotti for irradiation!



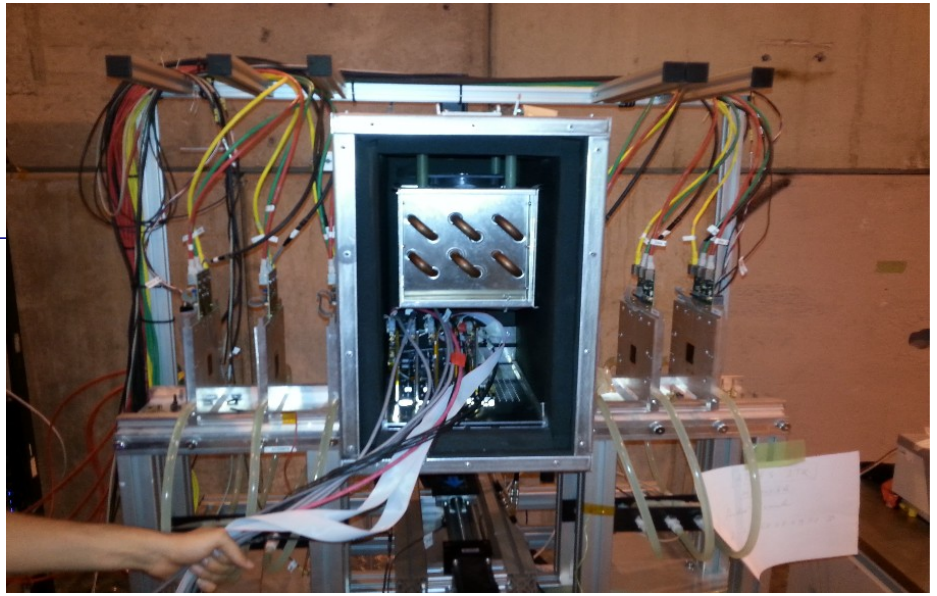


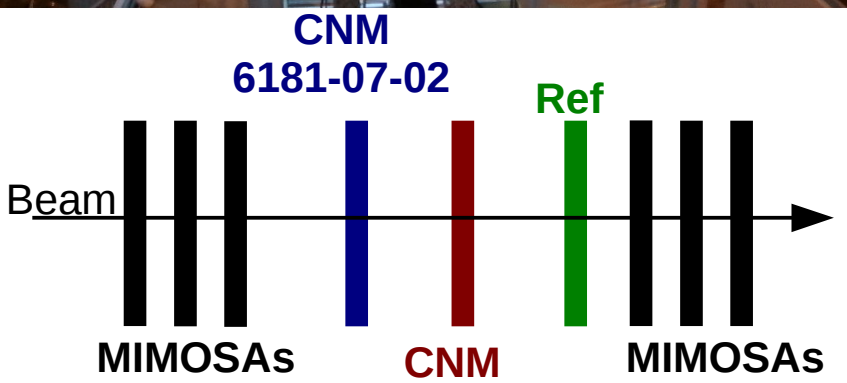
From Irrad Beam Profile Monitoring webpage

Thanks to Igor Mandic, Vladimir Cindro for irradiation and AIDA2020 support!

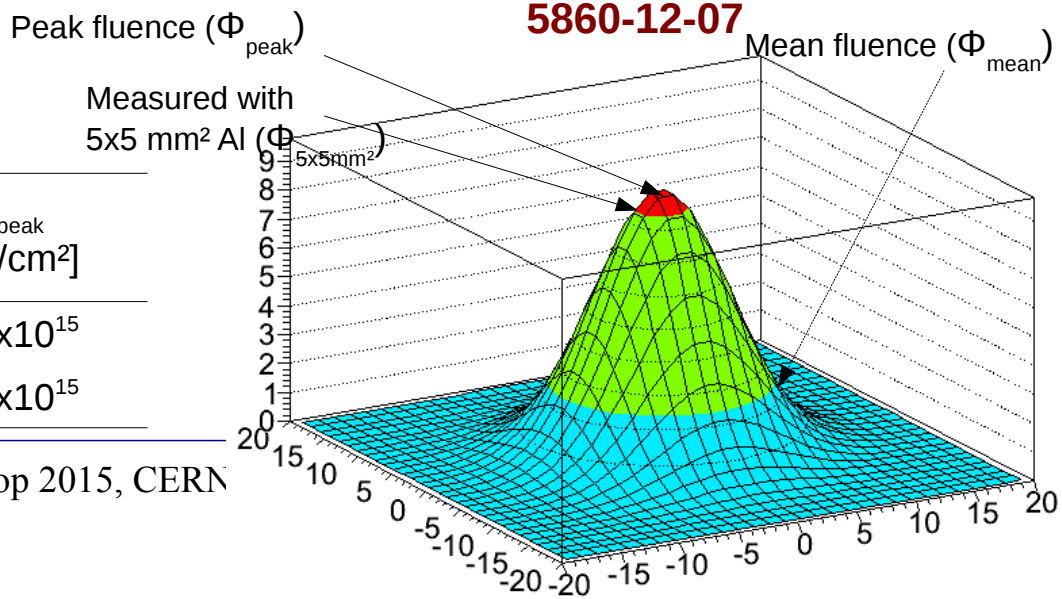
Testbeam

- Irradiated FE-I4 CNM 3D sensors:
  - 6181-07-02: 5.2x10^{15} n_{eq}/cm² (peak 5.6x10^{15})
  - 5860-12-07: 8.4x10^{15} n_{eq}/cm² (peak 9.1x10^{15})
- July 2015 ITk testbeam at CERN:
  - Temperature: -40 and -30 ºC
    - Temperature in cooling box, sensor is ~5 ºC warmer
  - Tuning:
    - Threshold: 1500 e
    - ToT: 10ToT at 10ke





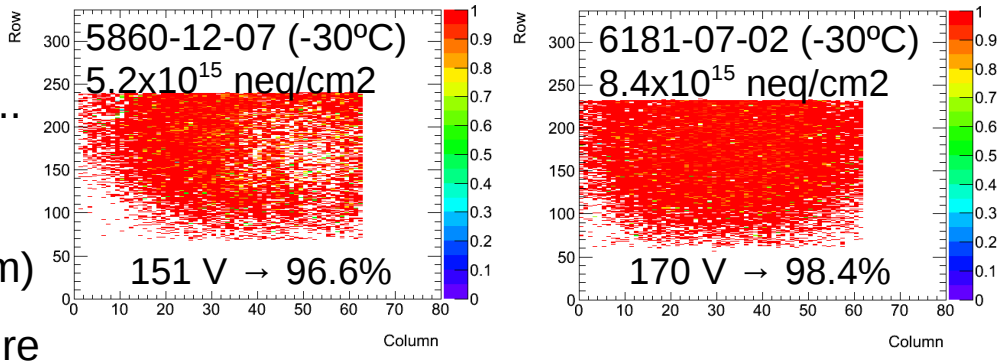
	$\Phi_{5x5\ mm^2\ Al}$ [n_{eq}/cm²]	Φ_{mean} [n_{eq}/cm²]	Φ_{peak} [n_{eq}/cm²]
6181-07-02	5.2x10^{15}	2.4x10^{15}	5.6x10^{15}
5860-12-07	8.4x10^{15}	3.8x10^{15}	9.1x10^{15}

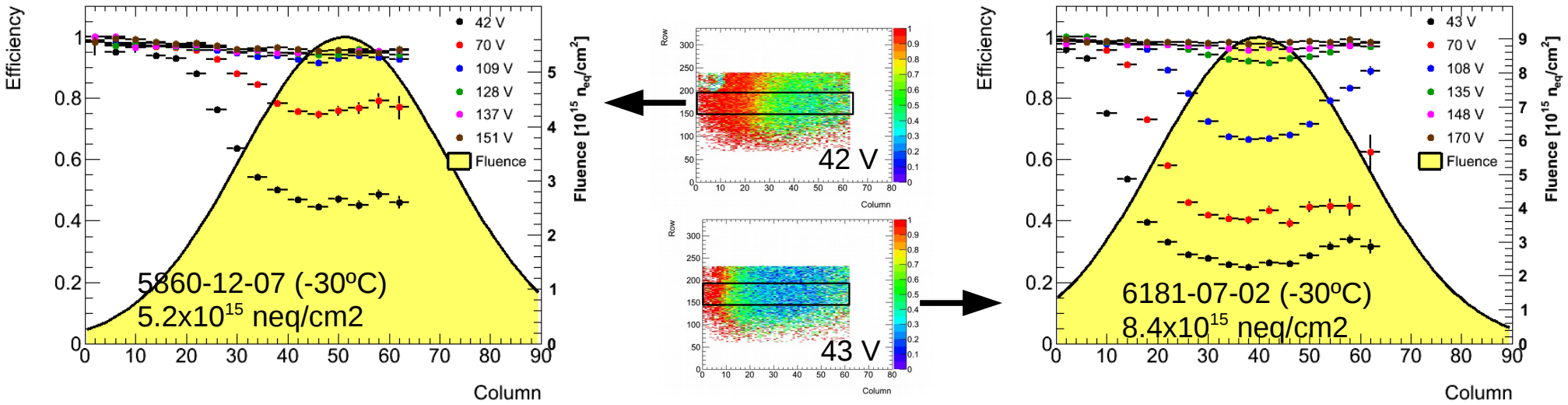


Overall efficiencies

- Good overall efficiencies
  - But low efficiencies might be averaged out...
- Non-uniform fluence
  - Assume Gauss distribution (FWHM ~12 mm)
    - More sophisticated analysis in the future
  - Peak of Gauss by fitting a parabola around minimum of TOT vs column/row
  - Probe vast range of fluences for the same device

Overall efficiencies





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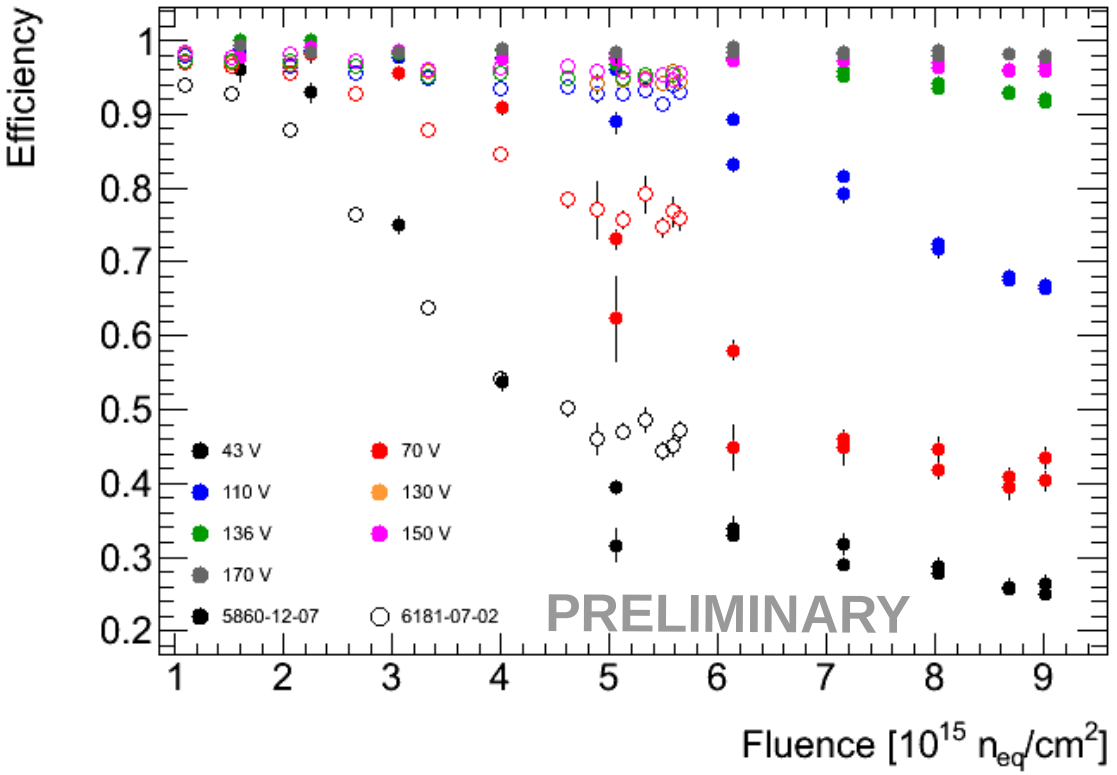
Efficiencies vs fluence

- Agreement in efficiency for areas irradiated at the same fluence in both devices
  - Some disagreement due to uncertainties in fluence distribution
    - Distribution not exactly a gaussian
    - Nominal fluence uncertainty ~10%
- Good efficiency (> 97 %) reached at ~170 V for all fluences
- Probed an almost continuous range of fluences with only two devices



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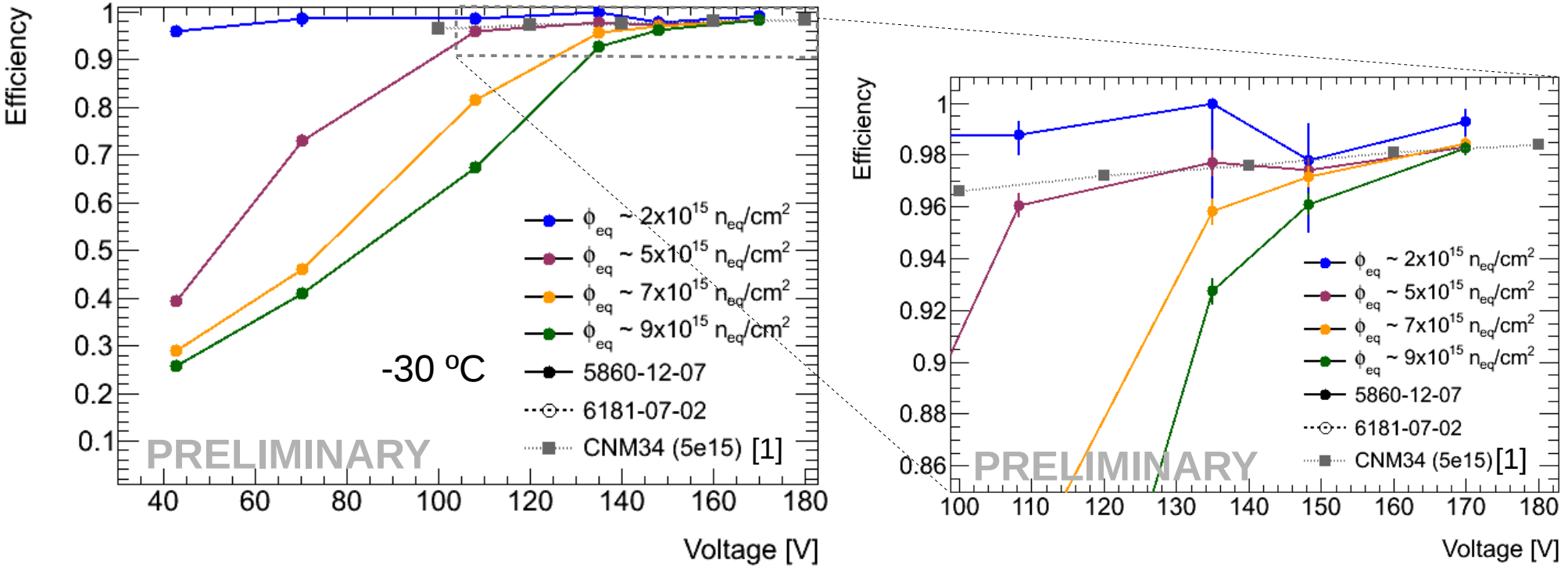
Efficiency vs voltage



	Φ_{eq} [n$_{eq}$/cm^2]	V [V]	Eff [%]
CNM34 IBL [1]	5x10^{15}	140	97.6
6181-12-07	5x10^{15}	150	97.5
6181-12-07	9x10^{15}	170	97.8

[1] JINST 7 P11010 (2012)

- **Able to reach over 97% efficiency for all fluences at maximally 170 V**
- **Agrees with IBL 5e15 results**

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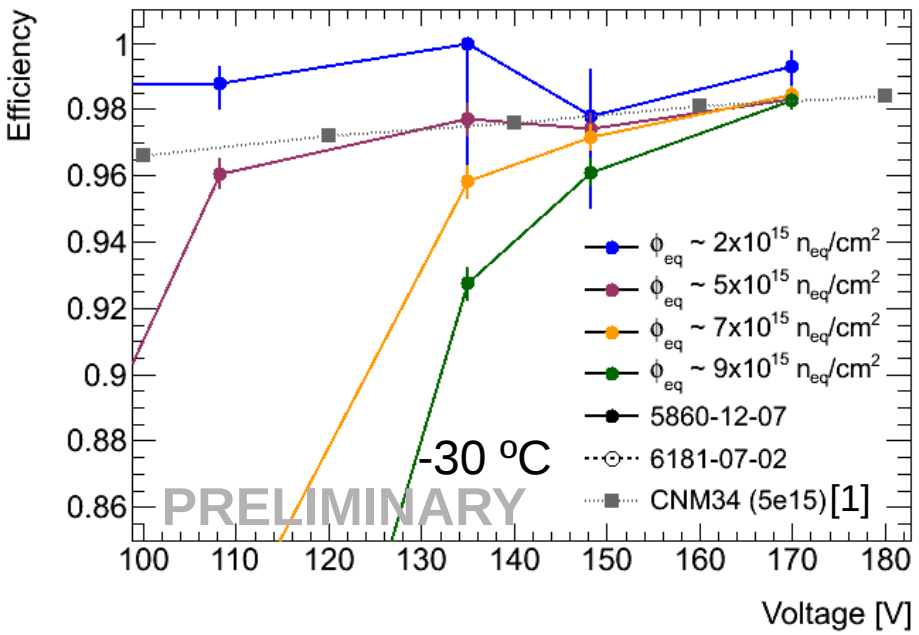
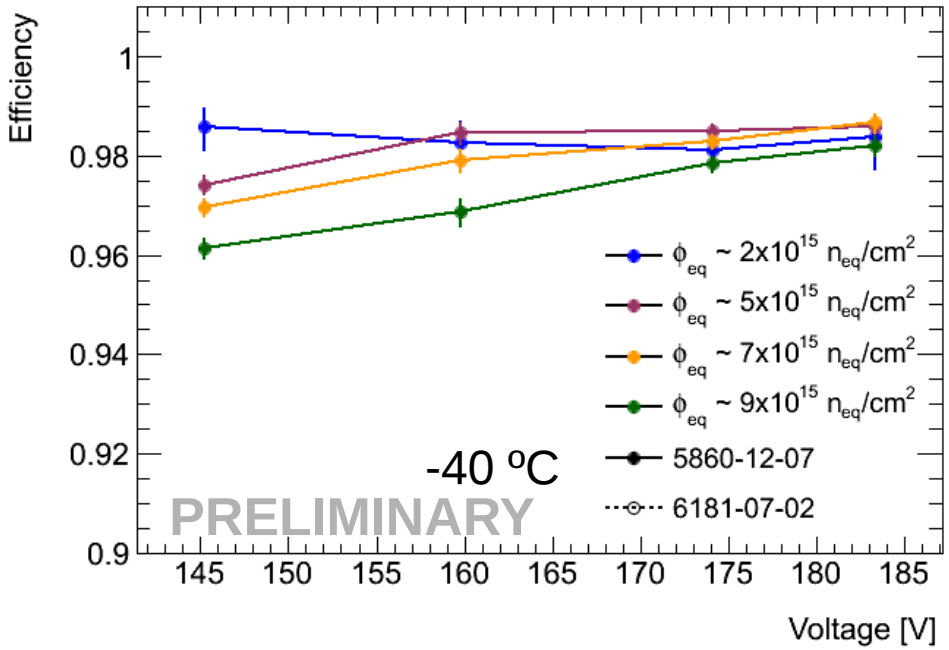
Efficiency vs temperature



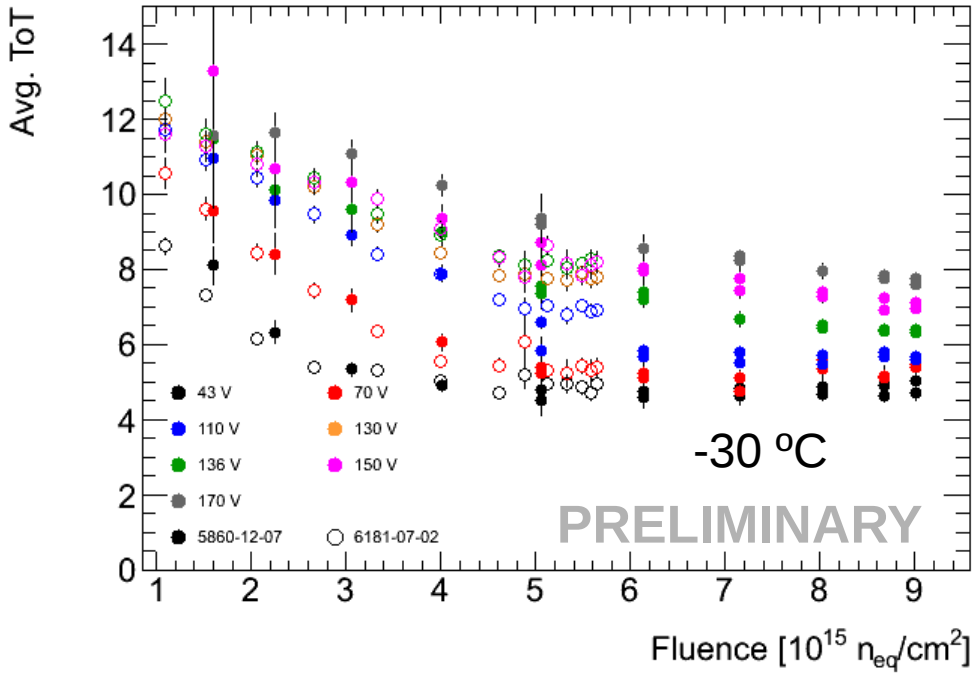
Note: different scale!

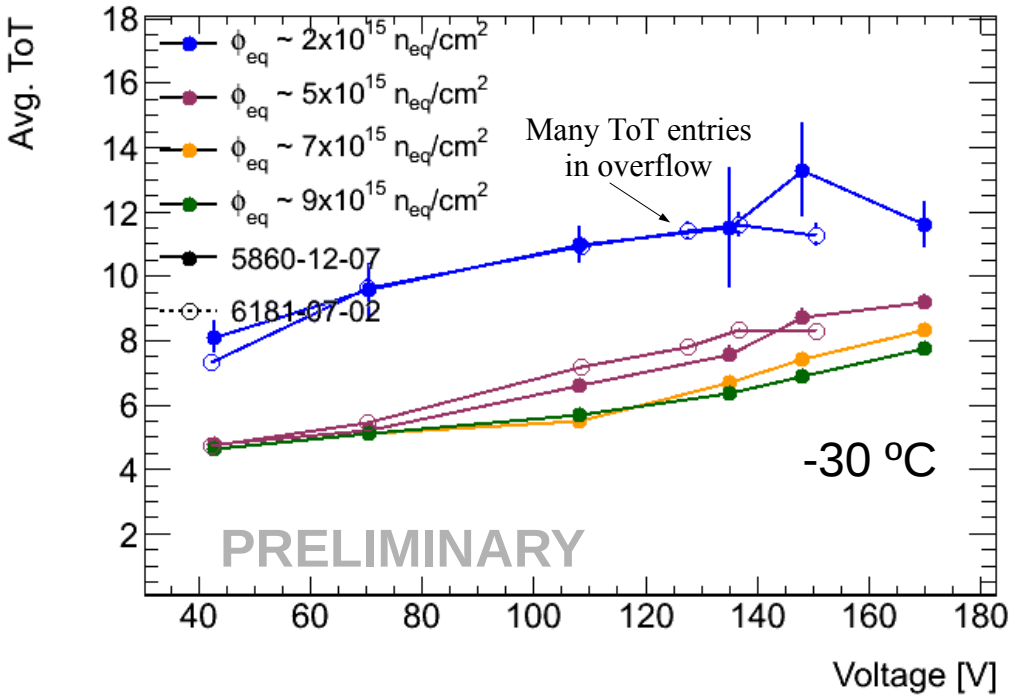


- Consistent efficiencies at different temperatures for similar voltages
  - Efficiency is not affected by temperature

Charge collection vs fluence

- Tuned at 10ToT @ 10ke, 1500e threshold
  - For low fluences (< ~3e15) and high voltages, most ToT entries are in the overflow bin
    → Re-measured at different ToT tunings for charge collection studies, analysis underway
- Good agreement between the two devices in the same fluence regions for the same voltages
- Average of 8ToT (~8000 e) at highest voltage and fluence
  → well above threshold for so high fluences





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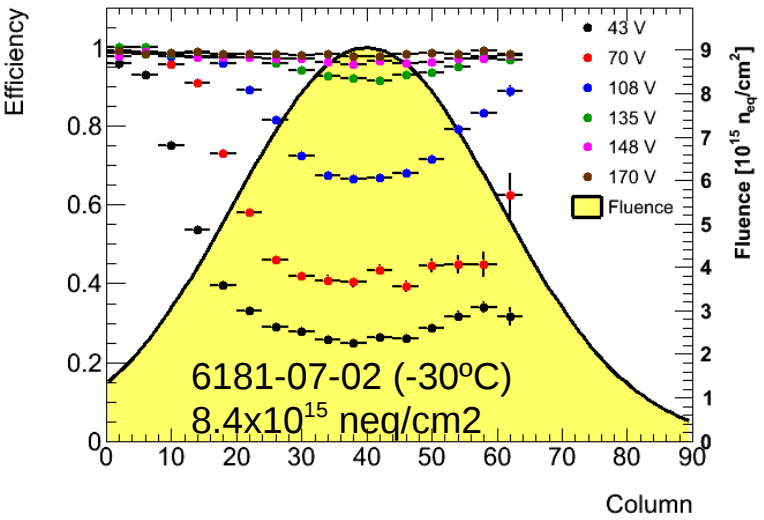
Conclusions

- Studied efficiency at intermediate ITk fluences (up to ~9e15 n_{eq}/cm^2) with CNM 3D FEI4 devices
  - Irradiated at CERN PS Nov 2014 → No scanning available:
    - Non-uniform (12 mm FWHM)
      → Assume gauss distr and probe large range of fluences
  - Two devices assembled and tested in testbeam:
    - Nominal fluences: $5.2x10^{15}$ n_{eq}/cm^2 and $8.4x10^{15}$ n_{eq}/cm^2
      (as measured in 5x5 mm^2 Al → larger peak fluences)
- IBL/AFP generation 3D detectors proven suitable for ITk
  - FEI3 n-irrad:
    - 15 (10) mW/cm^2 at $1x10^{16}$ n_{eq}/cm^2 for 230 (150) μm
    - CCE > 20% at $2x10^{16}$ n_{eq}/cm^2 for 2.5 ke threshold
  - FEI4 p-irrad:
    - Up to ~97.5% efficiency at ~$9x10^{15}$ n_{eq}/cm^2 (170V)
  - Expect improvement with lower thresholds and smaller electrode distance



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Back-up slides