Hybrid Garfield++ simulations of GEM detectors for tokamak plasma radiation monitoring

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RD51 Collaboration Meeting

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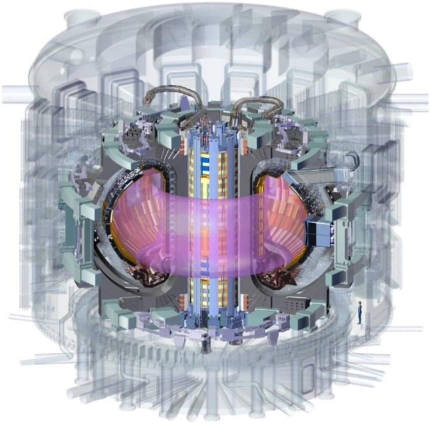
Magnetic confinement fusion challenges



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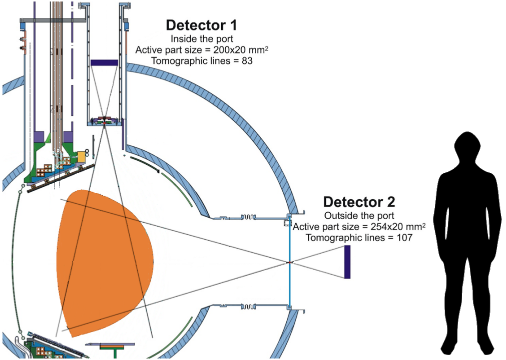
- 150 million K D-T plasma
- high ~ 14 MeV neutron damage:
  - ITER divertor ~ 1 dpa
  - DEMO divertor ~ 6 dpa
  - DEMO blanket 20 – 50 dpa
  - DEMO vacuum vessel ~ 0.1 dpa
- intense X-ray spectrum

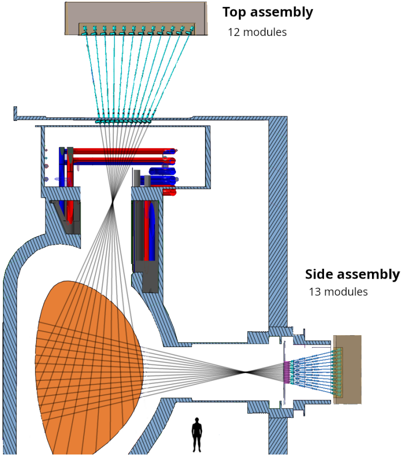
X-ray tomography

WEST



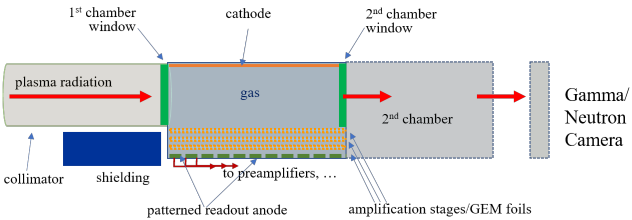
Chernyshova et al. JINST 10 (2015)

DEMO

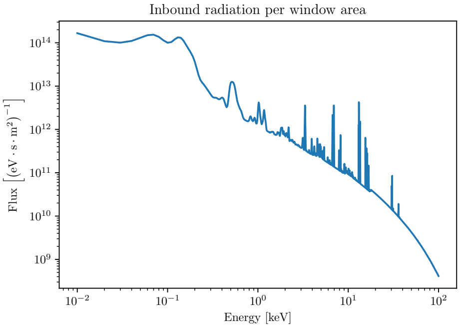


`https://idm.euro-fusion.org/?uid=2MYU3T` (EUROfusion internal)
more information in Luís et al. Sensors 23 (2023)

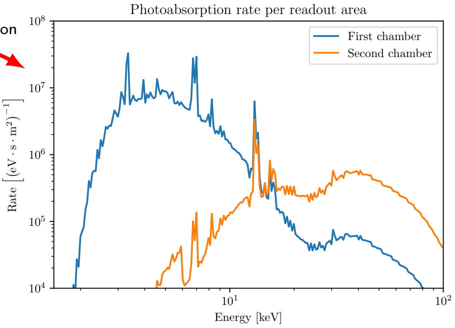
Detector modules



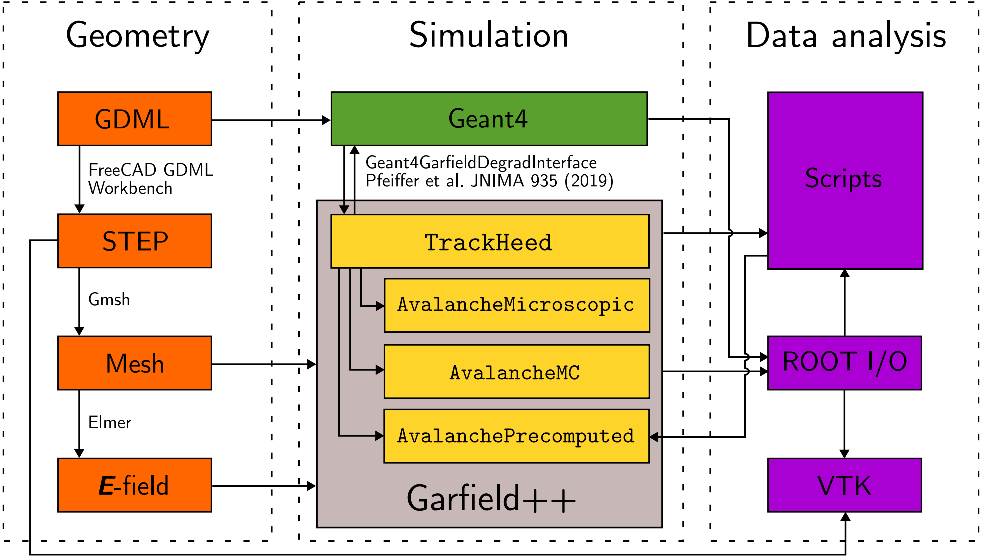
Chernyshova et al. JINST 17 (2022)



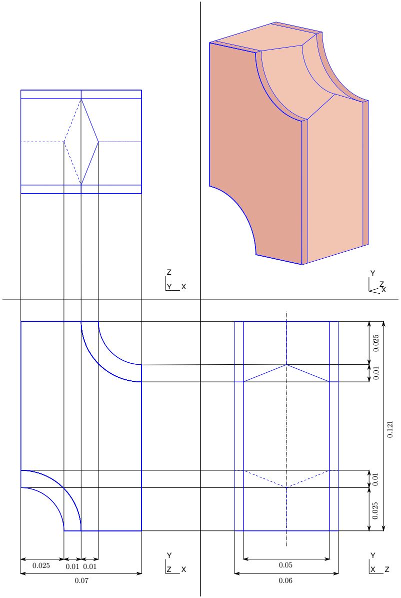
filters, absorption

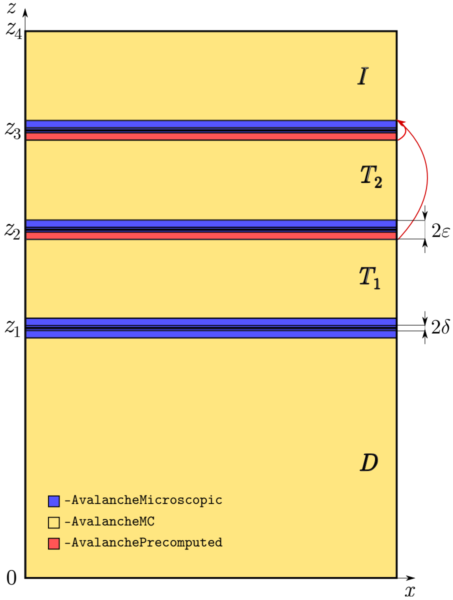


Software overview



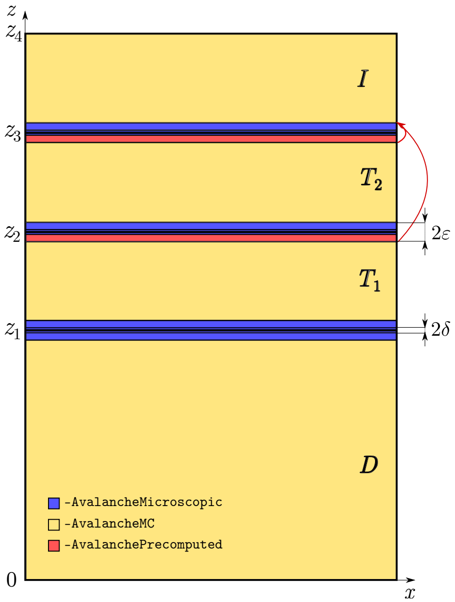
Detector structure



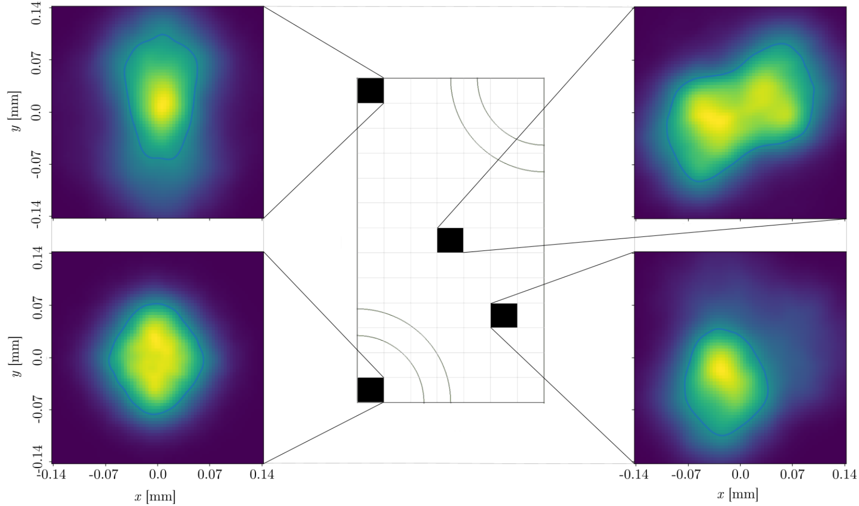


Performance

- Hybrid MC – $\sim 50\%$ gain over Microscopic, requires optimizing ε.
- Callgrind – `AvalancheMicroscopic` accounts for $\sim 50\%$ of calls but $\sim 90\%$ cost.
- Hybrid MC/Precomputed – requires precomputation for each new geometry/field configuration, runtime cost is negligible:
  - $\sim 3\times$ gain over hybrid MC with full induction - signal calculation,
  - $\sim 20\times$ gain over hybrid MC with shortened induction - no signal.
- Induction bottleneck – precomputed Shockley-Ramo components?



Statistical method

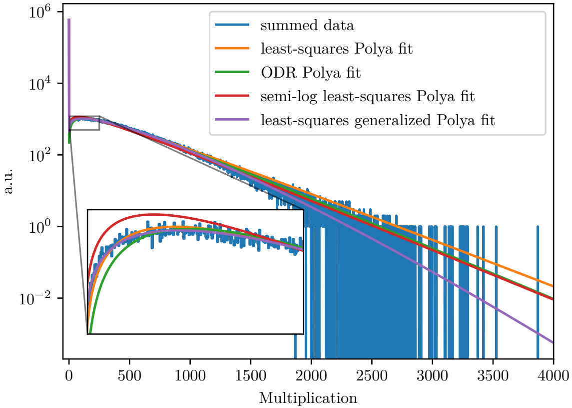


Statistical method

Polya distribution:

$$P(n) = C_0 \left(\frac{n}{\bar{n}}\right)^{\theta} \exp\left(-(1+\theta)\frac{n}{\bar{n}}\right),$$

$$P_\delta(n) = P_0 \delta_{n,0} + P(n).$$



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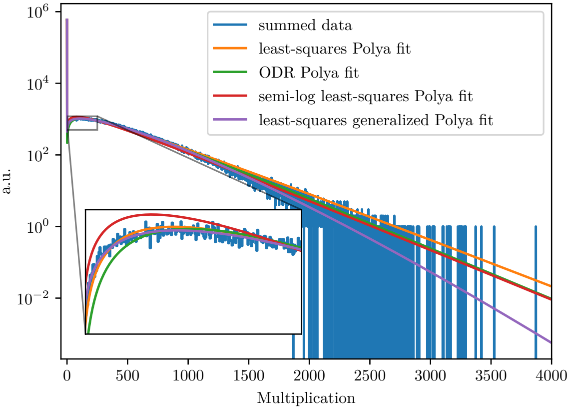
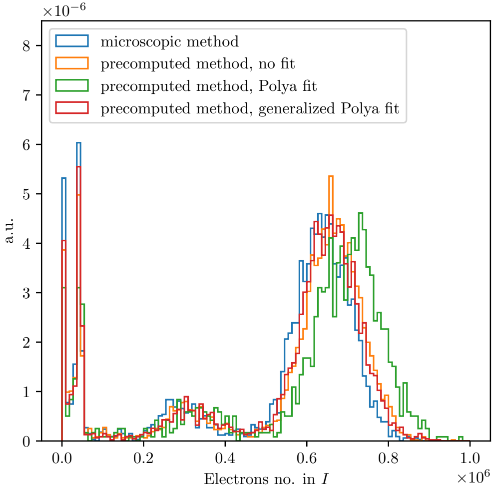
Generalized Polya (Gamma) distribution:

$$P_g = C_0 \left(\frac{n}{\bar{n}}\right)^{\theta} \exp\left(-\left((1+\theta)\frac{n}{\bar{n}}\right)^{p}\right),$$

$$P_{g,\delta}(n) = P_0 \delta_{n,0} + P_g(n).$$



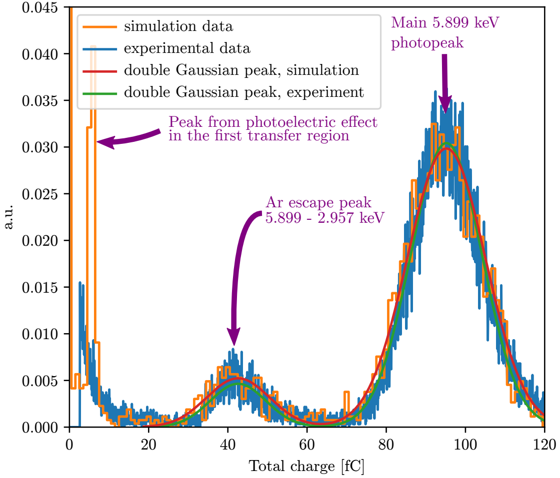
Validity of statistical method



p-values for two sample Kolmogorov–Smirnov test of microscopic simulation against different approaches:

- no fit statistical method - $p = 0.25$
- Polya fit statistical method - $p = 2.2 \cdot 10^{-16}$
- generalized Polya fit statistical method - $p = 0.61$

Comparing simulation with experimental data



Double gaussian fit, experiment rescaled and shifted to simulation based on two peak values:

- Main peak: 95.1 fC
- Escape peak: 42.6 fC

FWHM in simulation:

- Main peak: 23.0 fC (24.2%)
- Escape peak: 19.2 fC (45.1%)

FWHM in experiment:

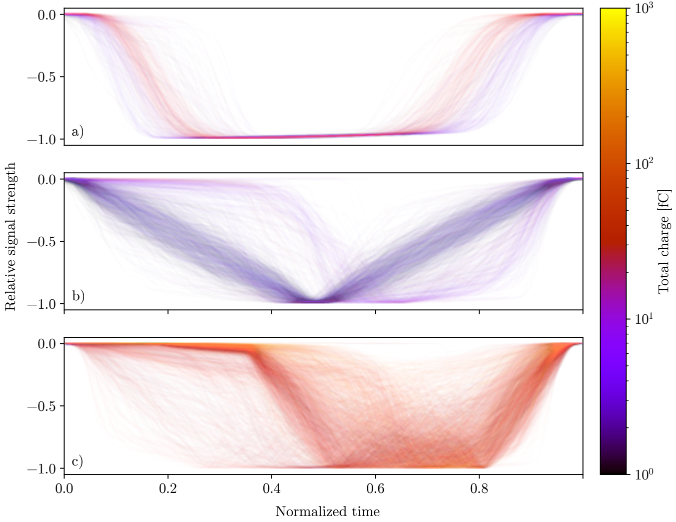
- Main peak: 20.5 fC (21.5%)
- Escape peak: 15.4 fC (36.1%)

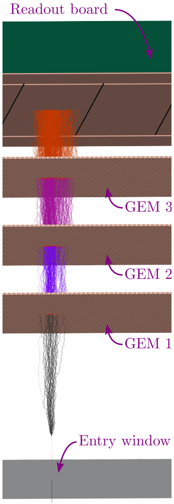
High energy photon signals

lowest value appears no later than 20 ns from the beginning – limited to one region

initialized by fast electrons on first foil or later – sharp slope

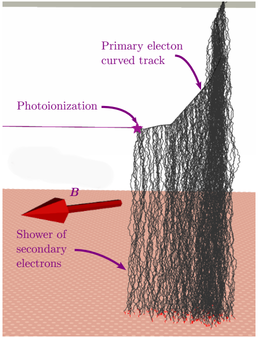
primary ionization in the drift region, but not limited to one region – stepwise growth





More applications

- magnetic field interactions (mostly done)
- filter interactions
- neutrons
- charging-up – neBEM? quasi-static models?
- response profile basis decomposition



Thank You