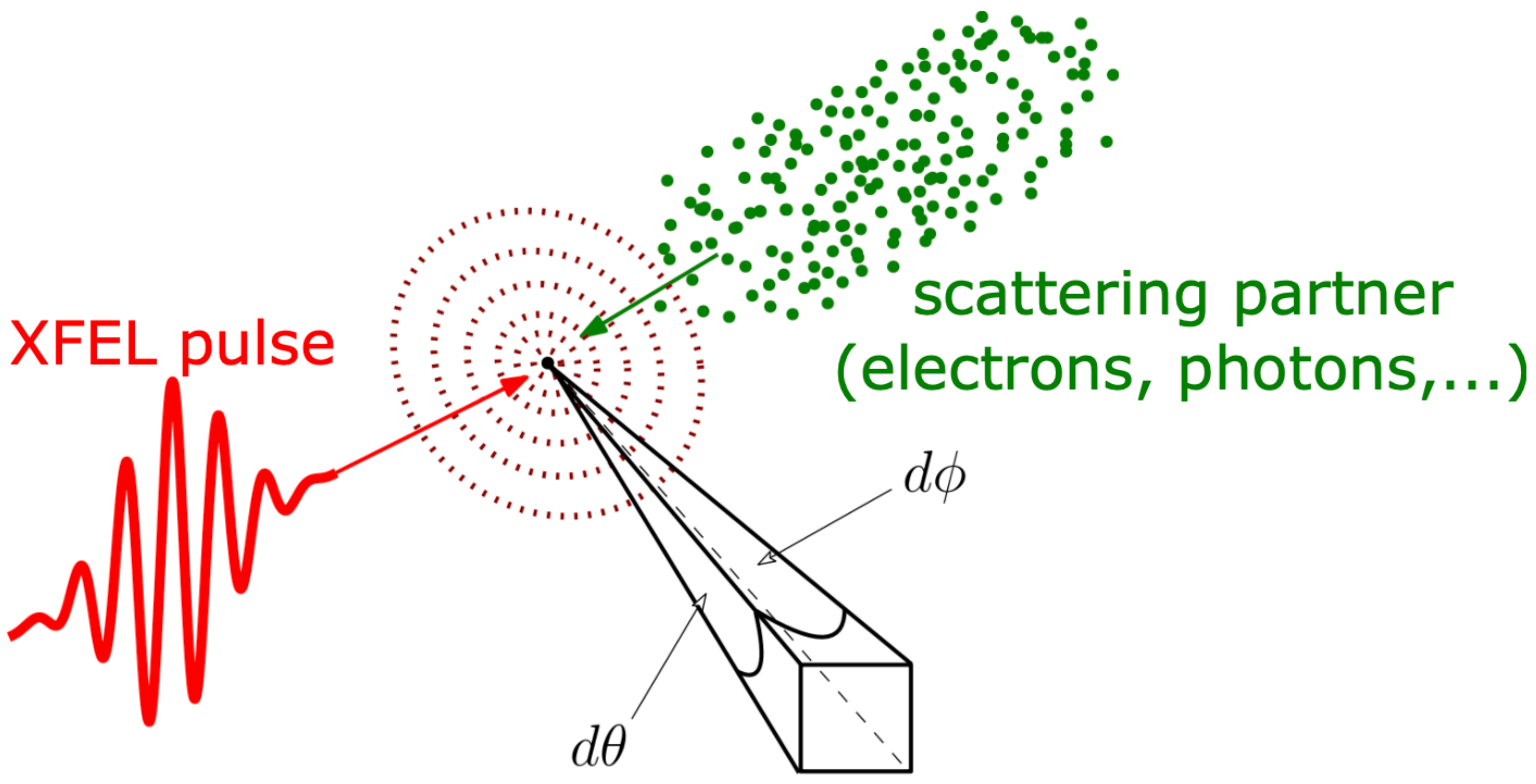
Laser-Matter Interaction

From strong-field QED to warm-dense matter

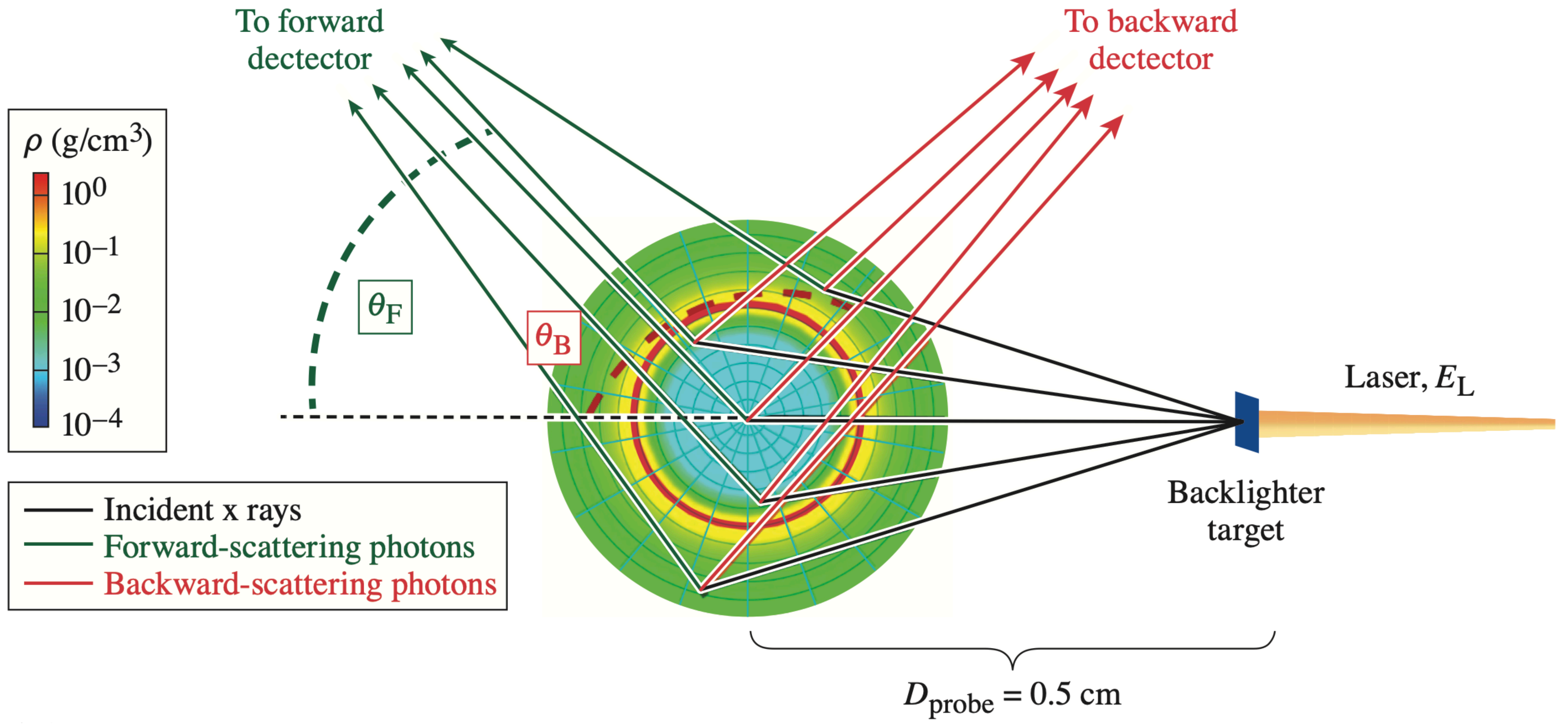
Uwe Hernandez Acosta — Democratizing models workshop — Bochum, November 26th, 2024

Overview: laser-matter interaction

Scattering process investigation



X-ray probing warm-dense matter



Taken from [Poole, Hannah, et al. "A case study of using x-ray Thomson scattering to diagnose the in-flight plasma conditions of DT cryogenic implosions." *Physics of Plasmas* 29.7 (2022).]

Our golden rule

Dynamical structure factor

Full differential cross section

$$\mathrm{d}\sigma = n(p_{\mathrm{in}}) \times S(Q) \times \mathrm{d}\sigma_{\mathrm{hard}}(p_{\mathrm{in}}, p_{\mathrm{out}})$$

Differential cross section of the hard scattering process

Incident particle distribution

Our golden rule

Dynamical structure factor

Full differential cross section

$$\mathrm{d}\sigma = n(p_{\mathrm{in}}) \times S(Q) \times \boxed{\mathrm{d}\sigma_{\mathrm{hard}}(p_{\mathrm{in}}, p_{\mathrm{out}})}$$

Differential cross section of the hard scattering process

Incident particle distribution

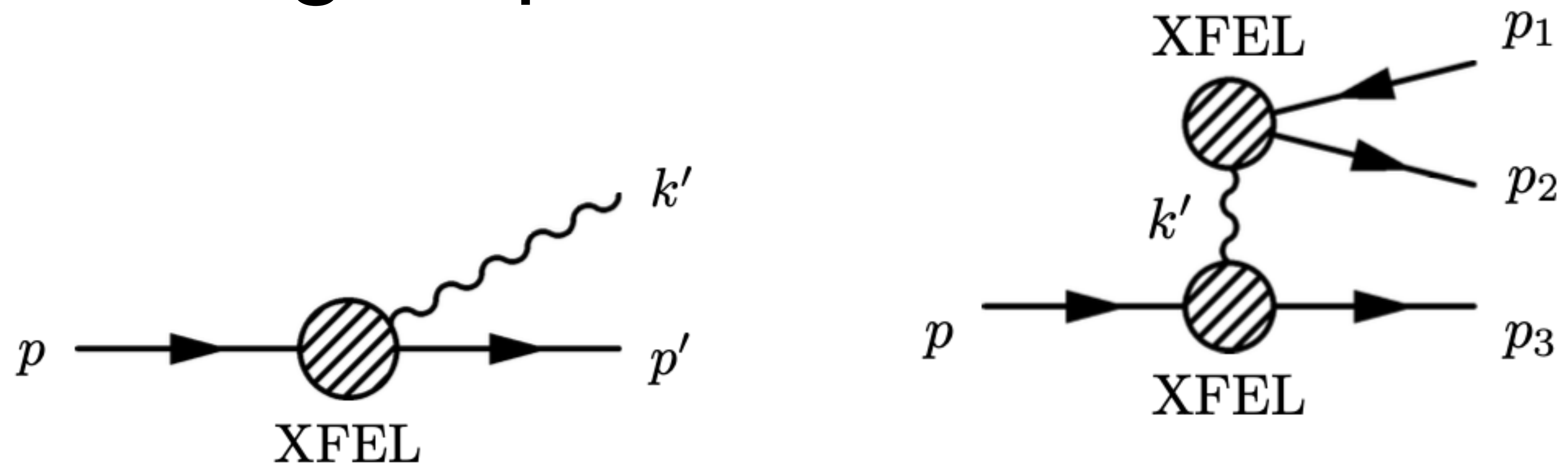
Hard scattering part

Phase space measure

$$\mathrm{d}\sigma_{\mathrm{hard}}(p_{\mathrm{in}}, p_{\mathrm{out}}) = N \times \sum |\mathscr{M}|^2 \times \mathrm{d}\Phi_n$$

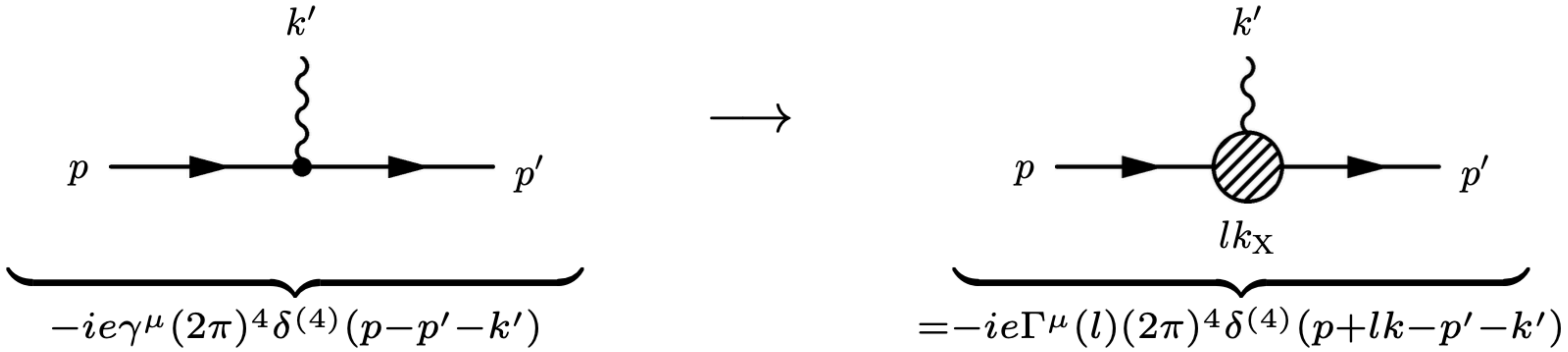
Incident flux factor

Scattering amplitude



Scattering amplitudes

Strong-field QED



Dressed vertex: $$\Gamma^\mu(l,p,p') = \gamma^\mu B_0(l) + \Gamma_1^{\mu\nu} B_{1\nu}(l) + \Gamma_2^\mu B_2(l)$$

Phase integrals:

$$B_0 = \int \mathrm{d}\phi \exp(il\phi + iG(\phi)) \qquad B_2 = \int \mathrm{d}\phi A^2(\phi) \exp(il\phi + iG(\phi))$$

$$B_1^\mu = \int \mathrm{d}\phi A^\mu(\phi) \exp(il\phi + iG(\phi))$$

Our golden rule

Dynamical structure factor

Full differential cross section

$$\mathrm{d}\sigma = n(p_{\mathrm{in}}) \times \boxed{S(Q)} \times \mathrm{d}\sigma_{\mathrm{hard}}(p_{\mathrm{in}}, p_{\mathrm{out}})$$

Differential cross section of the hard scattering process

Incident particle distribution

The matter part

Dynamical structure factor

$$S(Q) = S(\vec{q}, \omega) = \frac{1}{2\pi N} \int \mathrm{d}t \, \langle \varrho_q(t) \varrho_{-q}(0) \rangle \, \mathrm{e}^{i\omega t}$$

- Models response of many particles with one perturbation
- Returns a weight for a given momentum transfer $Q = k' - k$
- “Exactly” computable with costly PIMC simulations

Dynamical Structure factor (DSF)

Example: the Chihara model

$$S(\vec{q}, \omega) = |f_i(\vec{q}) + q(\vec{q})|^2 S_{ii}(\vec{q}, 0) + Z_f S_{ff}(\vec{q}, \omega) + Z_c S_{bf}(\vec{q}, \omega)$$

Ion form factor

Screening cloud

Ion-Ion DSF
(elastic)

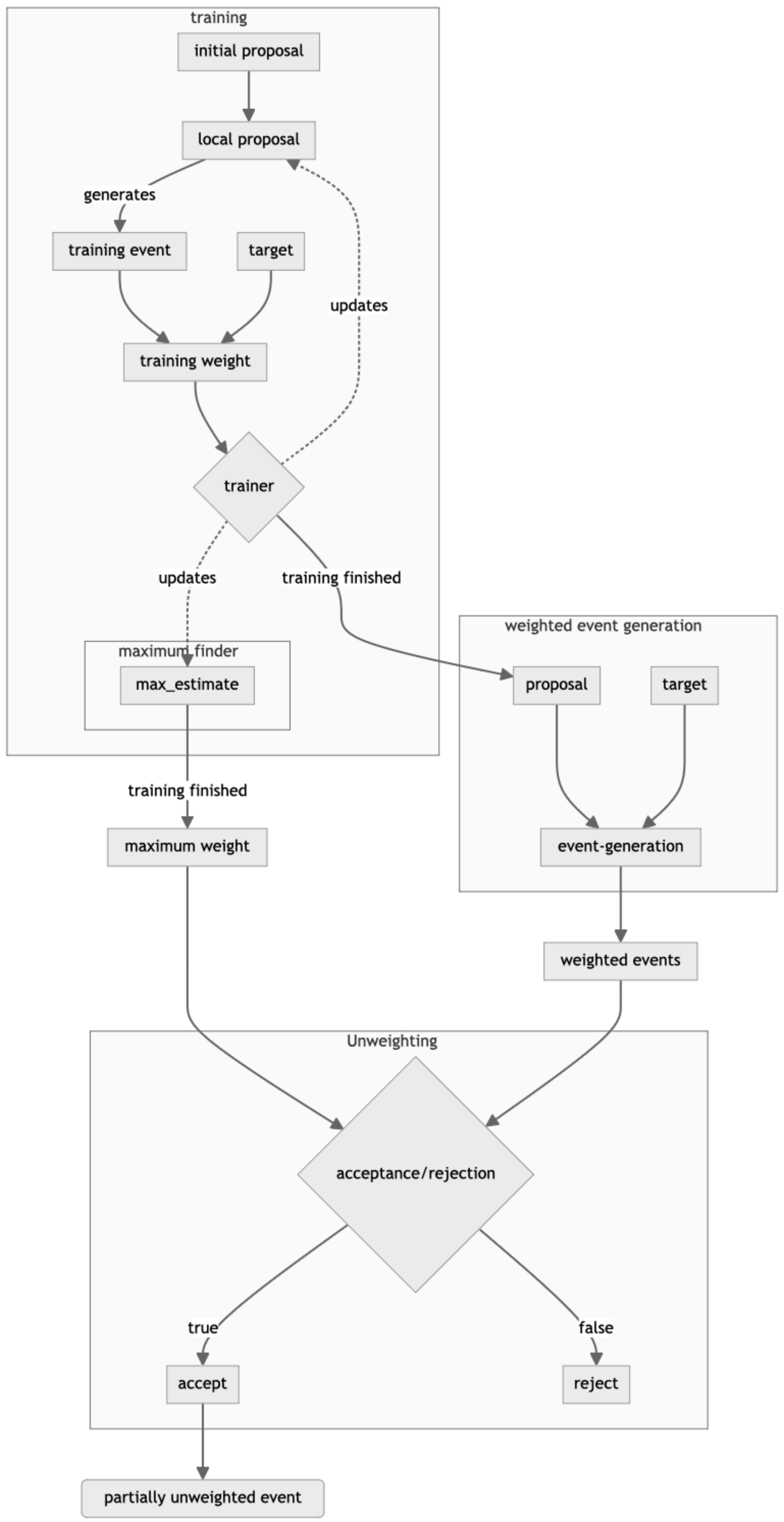
Free-free DSF

bound-free DSF

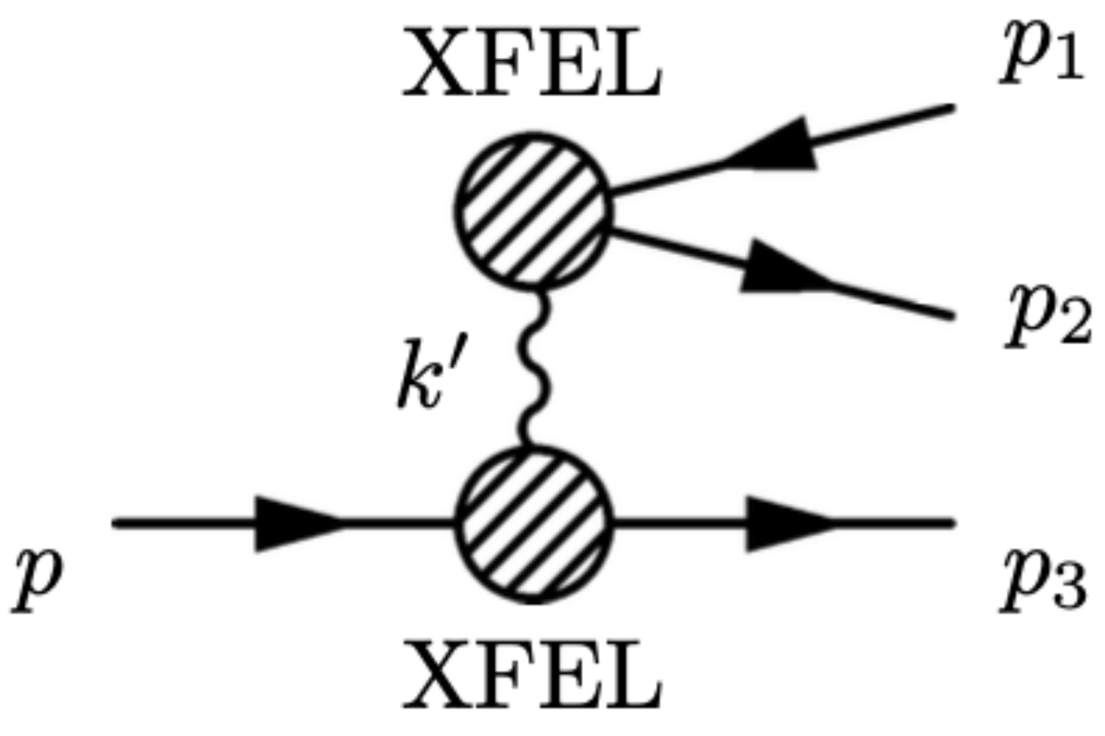
Event-generation pipeline

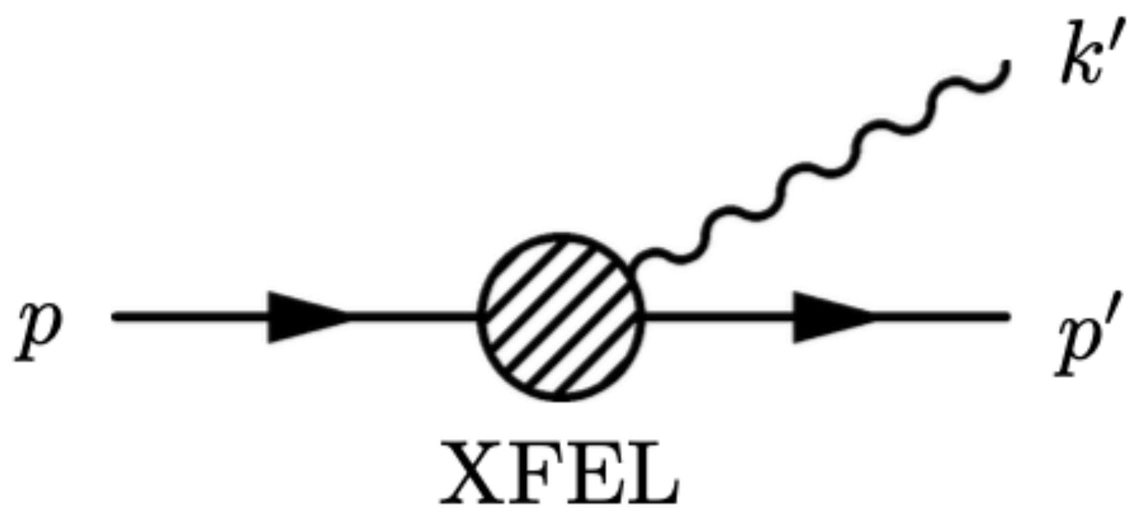
Sample $x = (p_{\text{in}}, p_{\text{out}})$ **from** $f(x) = \mathrm{d}\sigma(p_{\text{in}}, p_{\text{out}})$

1. Train a proposal distribution $g(x)$
2. Find maximum w_{max} of $f(x)/g(x)$
3. Perform acceptance-rejection loop
    1. Draw proposal x_{trail} from $g(x)$
    2. Draw $u \sim \mathcal{U}(0,1)$ independently
    3. If $f(x_{\text{trail}})/g(x_{\text{trail}}) > u \times w_{\text{max}}$ accept, reject otherwise
    4. Repeat

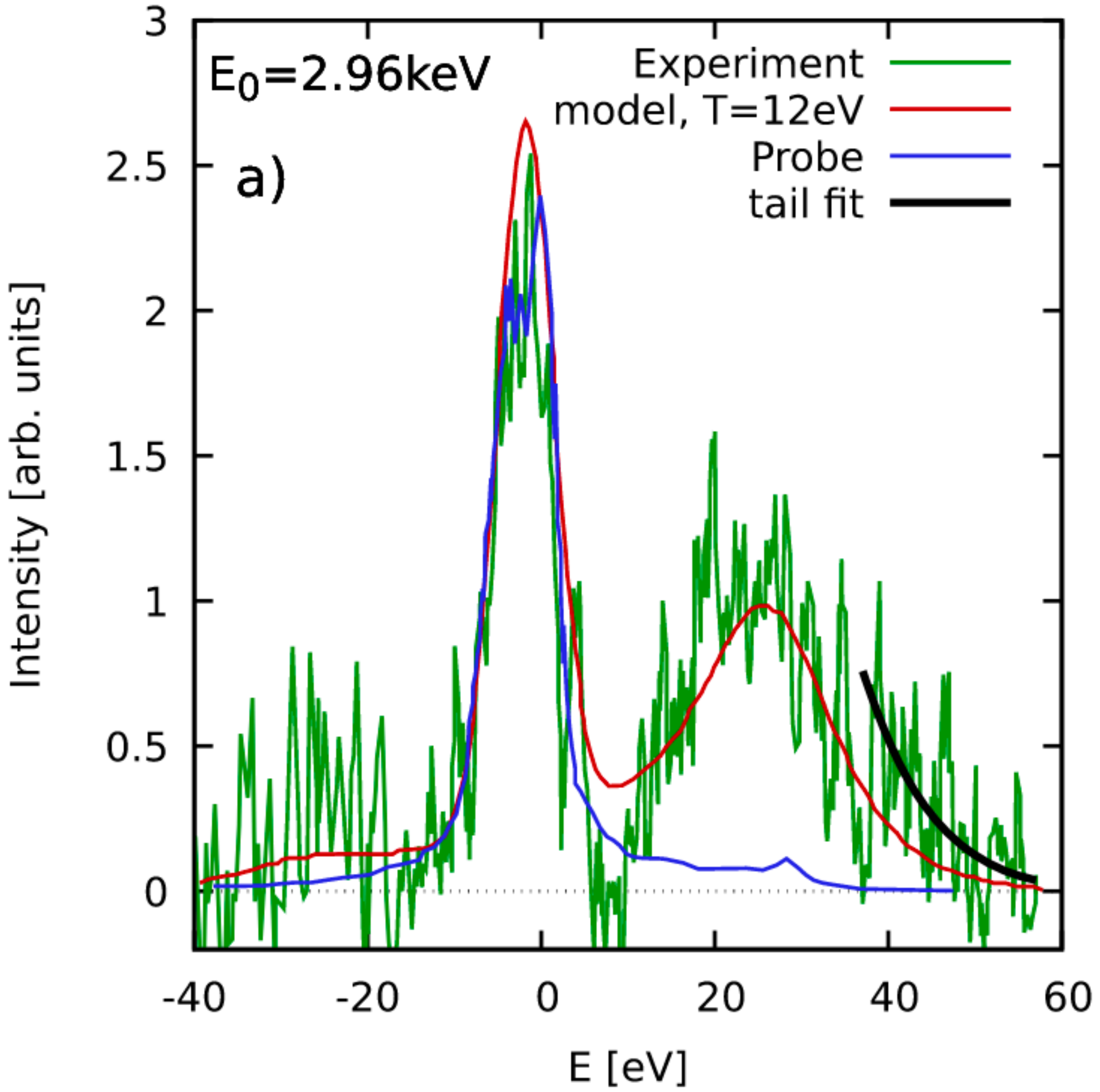


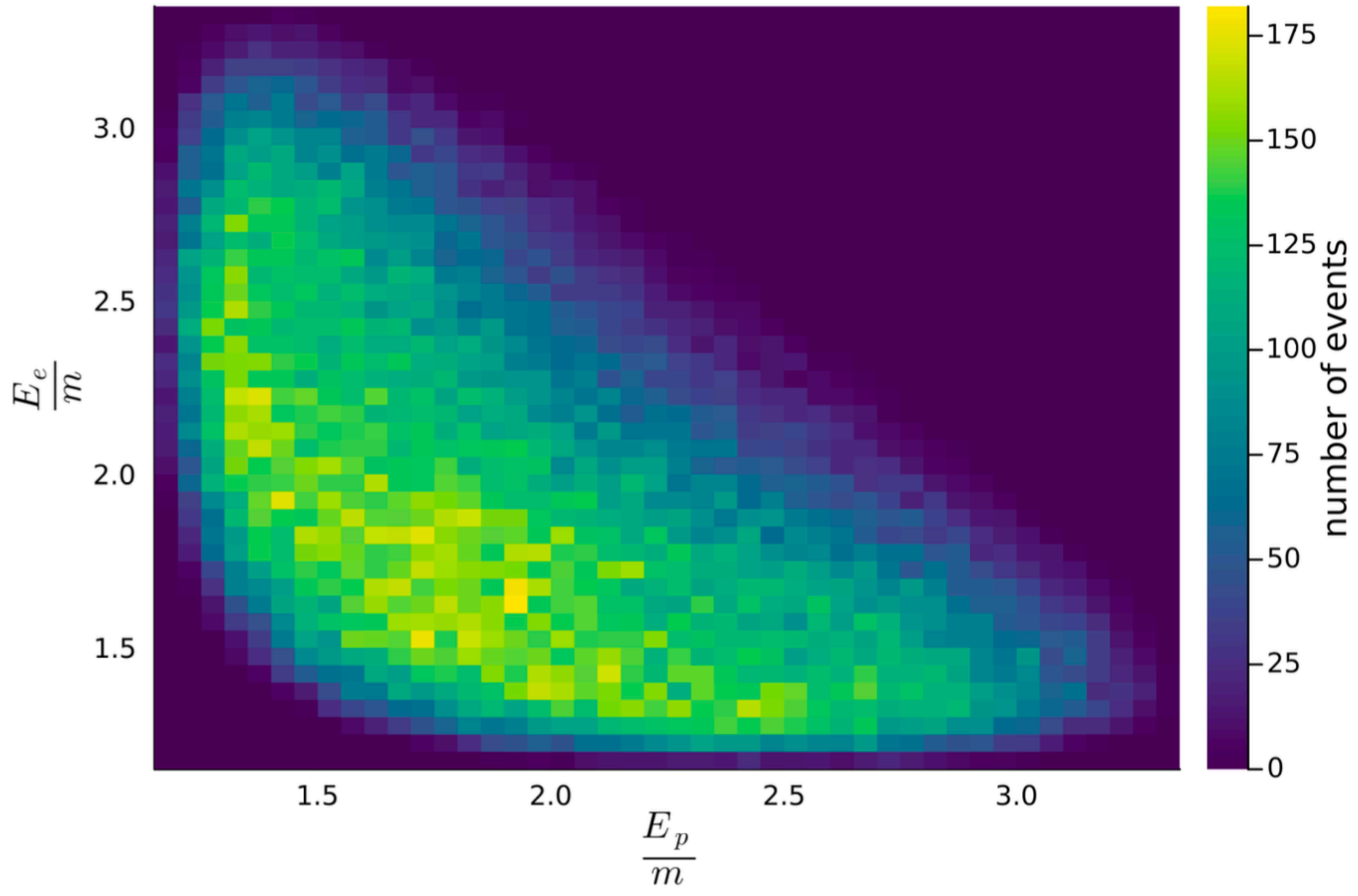
Some results

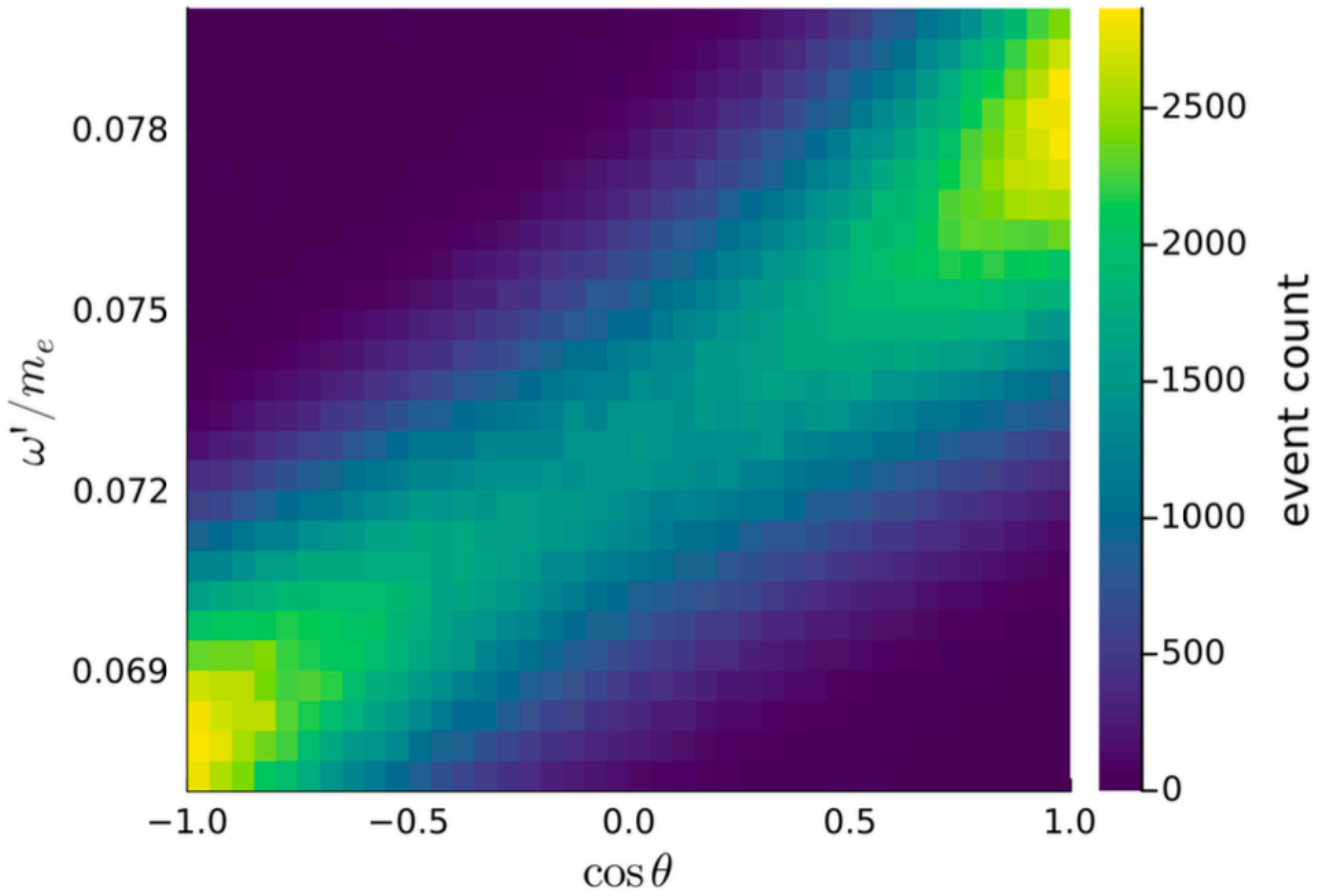




warm dense Beryllium







Taken from [Glenzer, S. H. et al. Observations of Plasmons in Warm Dense Matter. Phys.Rev.Lett.98,065002(2007)]