MonteCarlo for DELight: an update

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DELight Meeting, 26.03.2024

MC framework checklist @ latest CM

- Implemented first geometry ✓
- Implemented energy deposit physics lists (SaG4n, EM standard4, …) ✓
- Implement propagation of quanta
- Post-processing ✓
- ER/NR partitioning ✓
- Waveform simulation ✗

MC framework checklist today

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Quasiparticle propagation

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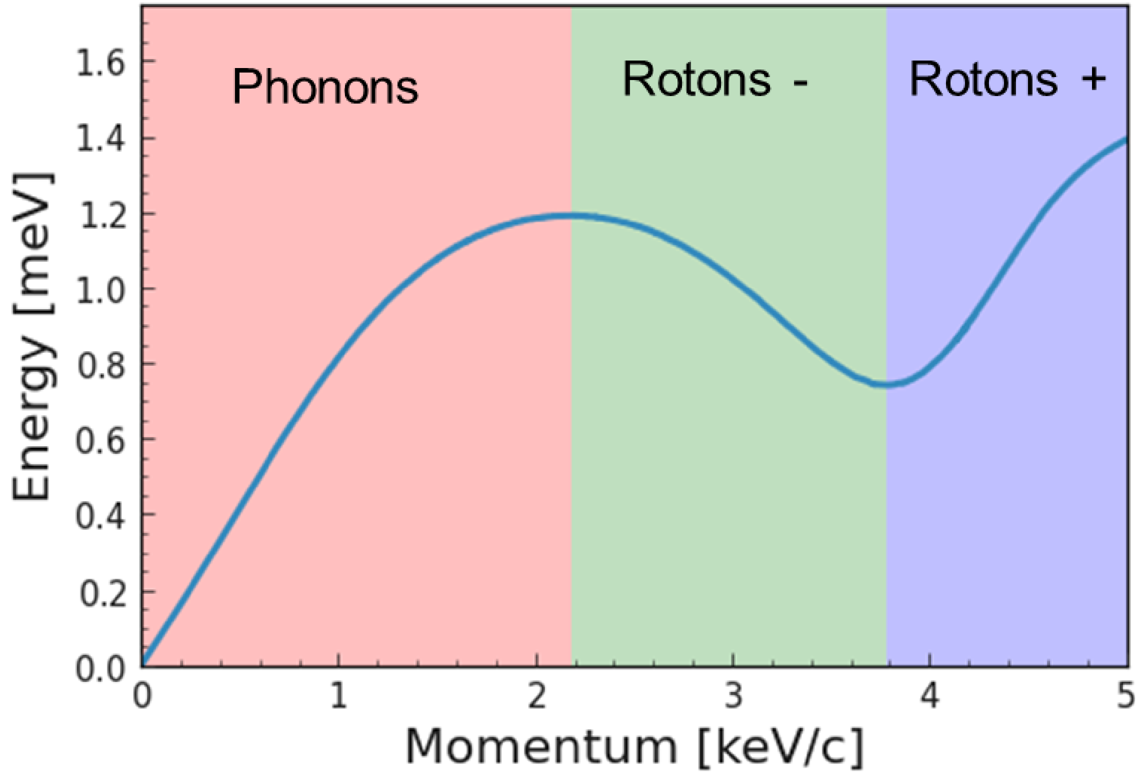
- Non-monotonic dispersion relation makes quasiparticles with p $\gtrsim$ 0.83 keV/c ballistic;
- anharmonic decay also for rotons + (see HeRALD paper), but nothing found in literature;
- when scattering off a surface, only energy and parallel component of momentum need to be conserved $\Rightarrow$ nature of quasiparticle can change!



Quasiparticle implementation in GEANT4

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- Implemented new particle *„phonon“*: stable, massless and chargeless;

- implemented *DELightPhononUtils* singleton class including dispersion relation curve (as polynomial fit) and other useful quasiparticle-related functions;

- DELightPhononUtils gives access to extra track information (*DELightPhononTrackInfo,* daughter class of G4VUserTrackInformation) such as the momentum of the particle.

Quasiparticle physics implementation

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- Bulk behaviour of quasiparticles is implemented in *DELightPhononPhysics* following the exotic physics example of *G4Monopole.*
  - *DELightPhononDrift* does nothing;
  - *DELightAnharmonicDecay* calculates the phonon decay mean free path based on Rev. Mod. Phys. 49, 341 (1977) and destroys the primary phonons creating two daughters. The momentum is shared followinng a uniform probability distribution function;
  - *DELightBelowThreshold* destroys all quasiparticles with energy below the quantum evaporation threshold (following propagation is computational expensive and pointless).

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To be removed if we detect phonons in helium: new criterion to stop propagation needed, then.

Quasiparticle boundary implementation

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- Scattering probabilities depend on surface type and chosen physical model: information stored in new class *DELightSurface* (daughter of G4OpticalSurface) as acoustic type and model;

- boundary processes are implemented in the new *DELightPhononBoundaryProcess* class following the G4OpBoundaryProcess:
  - energy, quasiparticle type and incidence angle of incident quasiparticle are retrieved;
  - information on acoustic type and model determine the scattering probability maps to be used (stored in *$DELIGHTMCDATASURF*);
  - as the momentum of the outgoing quasiparticle (or evaporated helium atom) is sampled, the primary quasiparticle is destroyed and a new one with the given momentum is created.

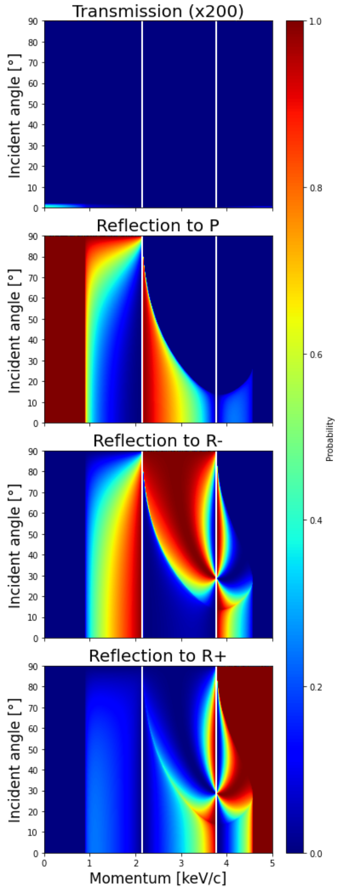
- 20% probability of phonon destruction (not absorption) at surface.

Possible models

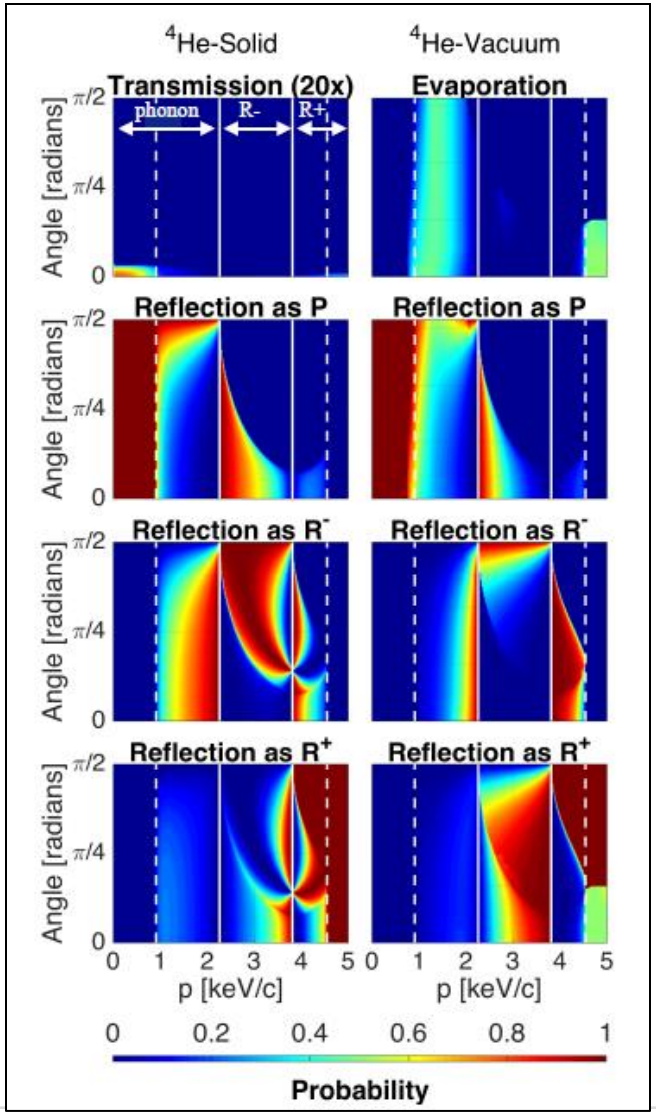
Sobnack model	Tanatarov model
• ONLY for He-vacuum interface	• Both for He-solid and vacuum interface
• microscopic theory of superfluid ^{4}He	• continuous medium approach (λ_{qp} larger than interatomic distance)
• exact solution of equation of motion technically possible (numerically challenging)	• pressure wave following ideal liquid
• interpolation of results from three different angles	• exact solutions based on polynomial interpolation of dispersion relation

Reflection maps

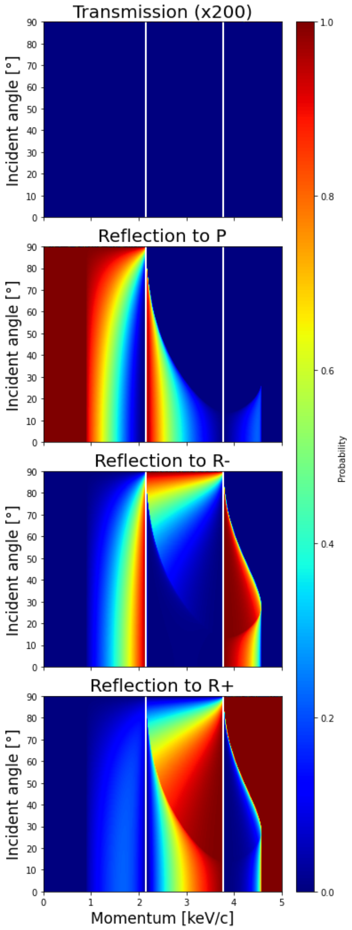
Tanatarov



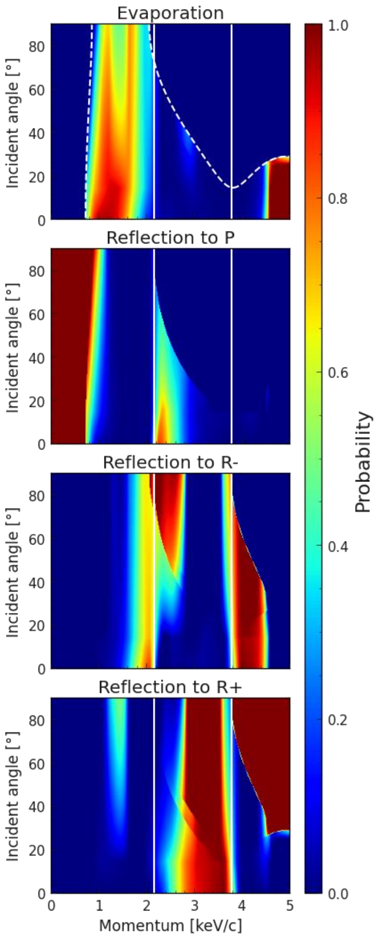
HeRALD



Tanatarov



Sobnack



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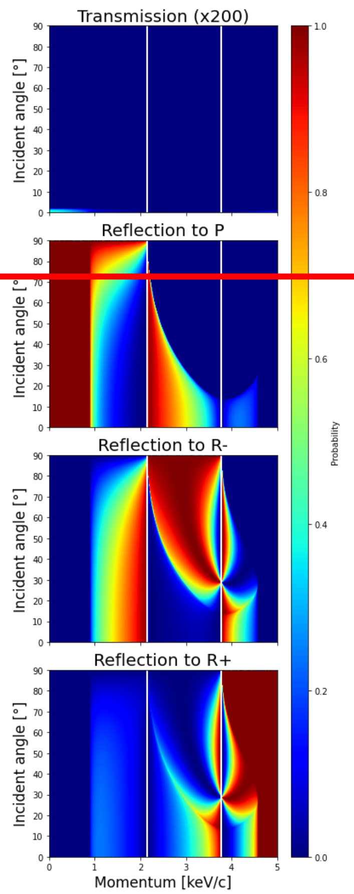
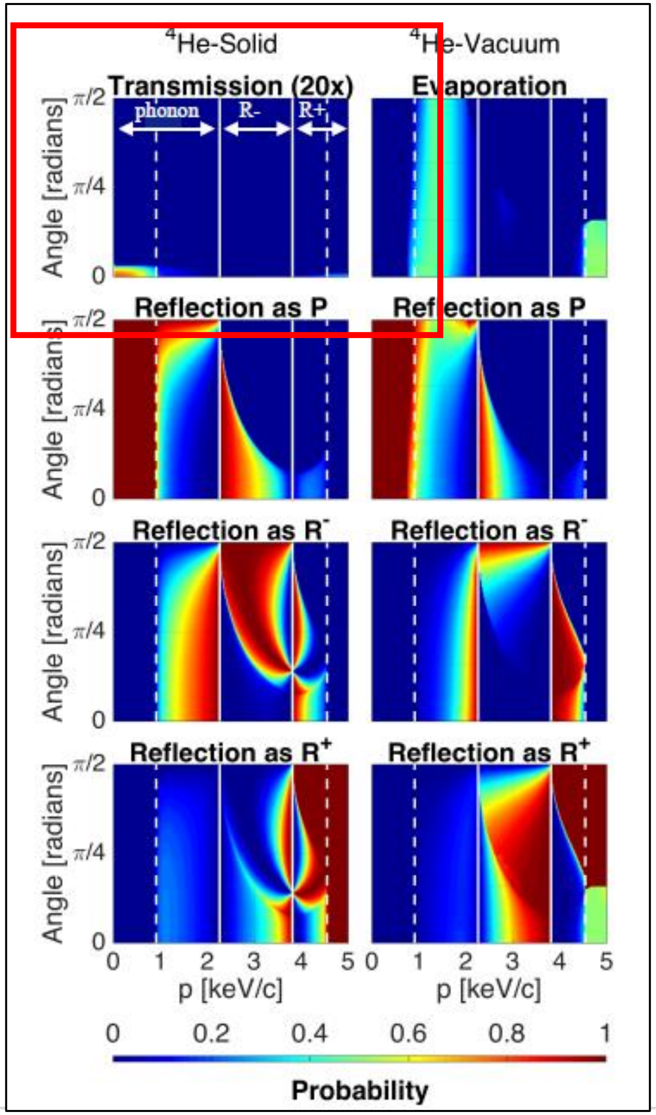


HeRALD

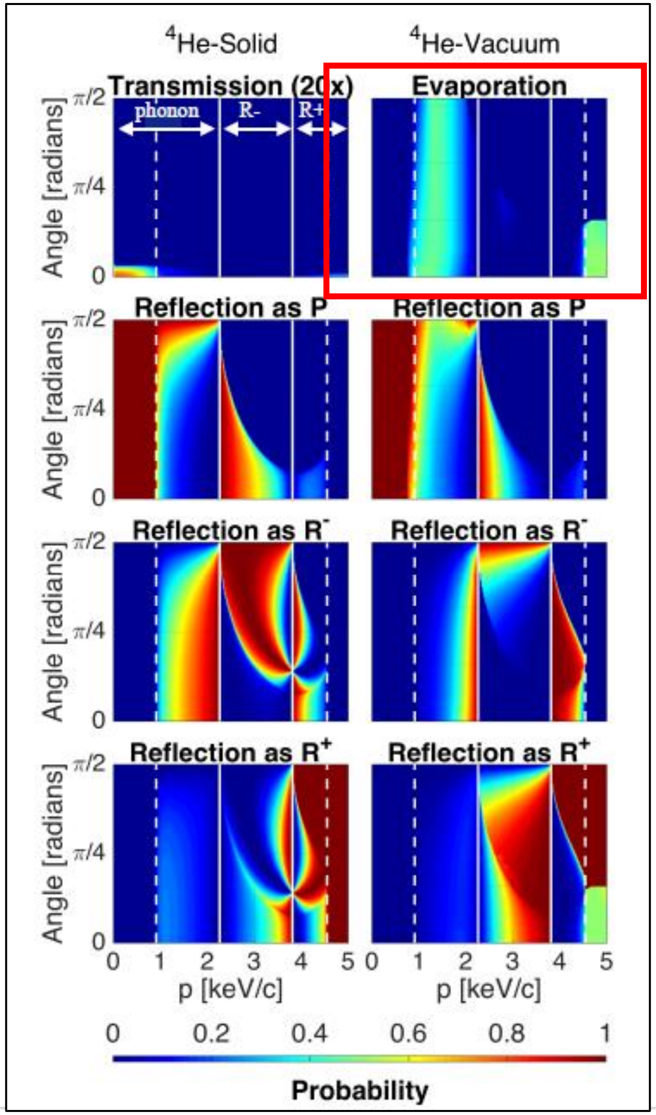


Much higher transmission probability for HeRALD: retrieved when using Tanatarov‘s assumption of densities ratio of 0.1 (we are using actual values).

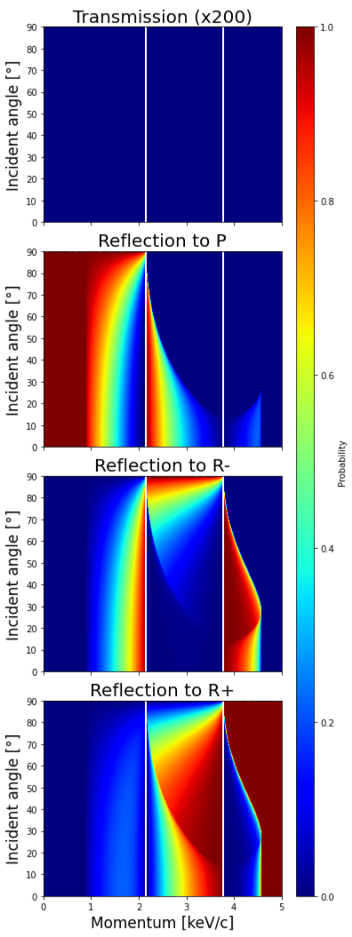
Reflection maps

From Adams‘ PhD scaling of 0.55 applied to match model and measurements, but he used a different model (Delfovo). Mesurements are also affected by many systematics.

HeRALD



Tanatarov



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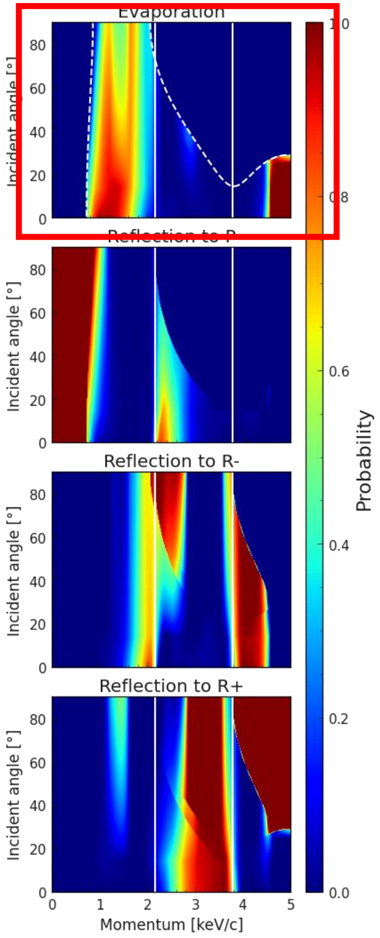
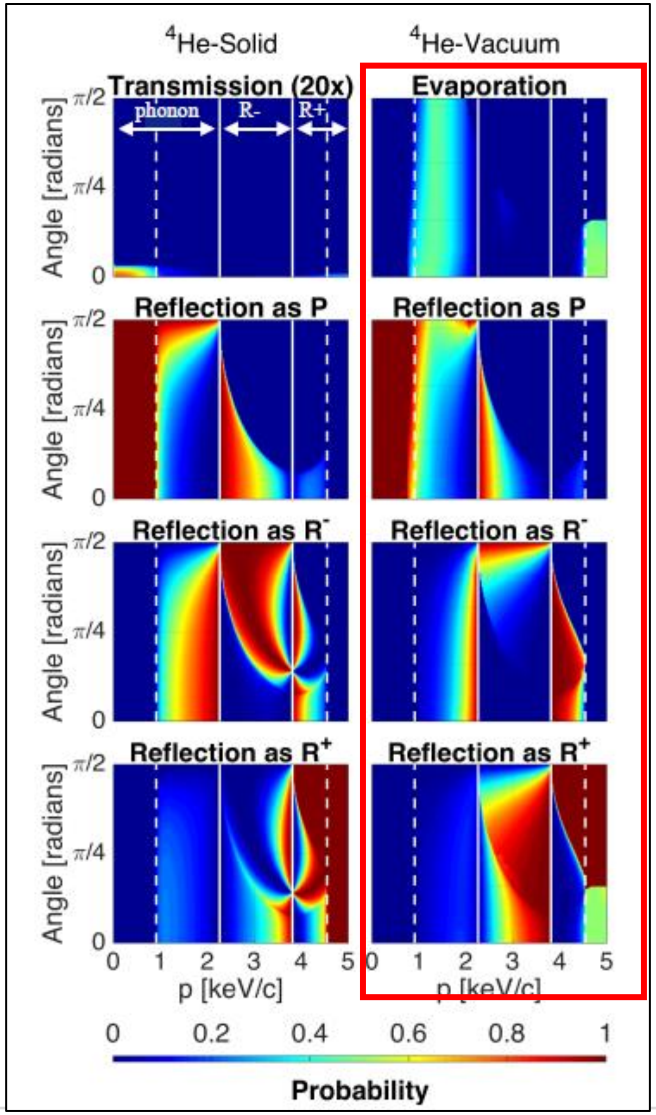


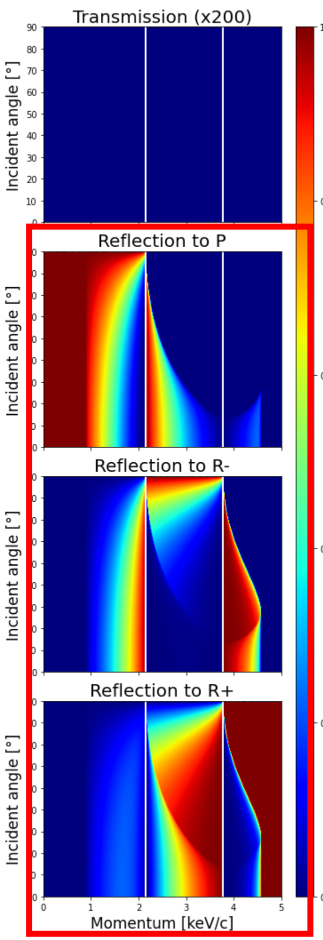
Reflection maps

HeRALD uses a mix of Sobnack and Tanatarov results.

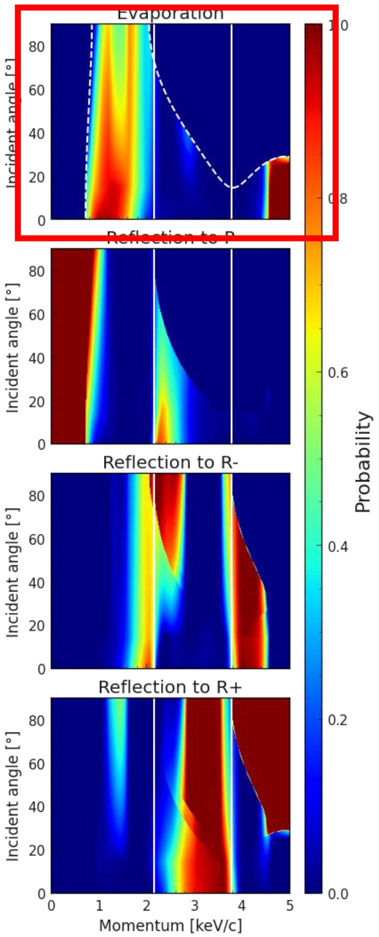
HeRALD



Tanatarov



Sobnack



Validation simulations

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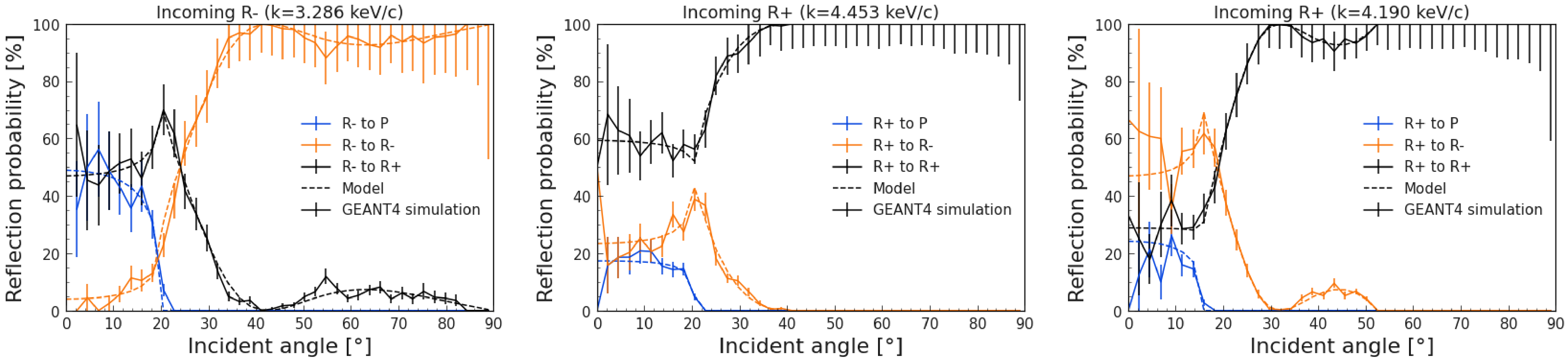
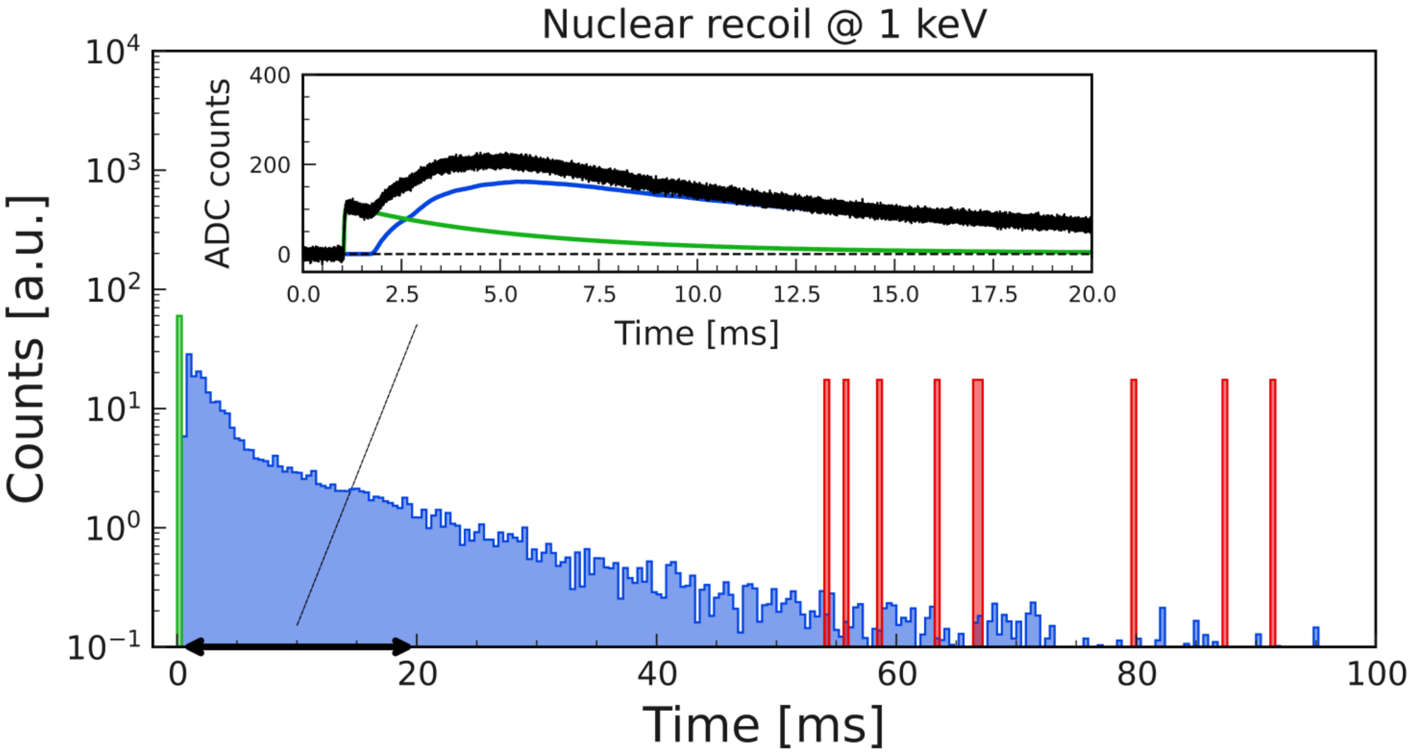
- Reflection probabilities validated considering reflection of phonons from bottom of cell;
- nature of quasiparticle estimated from inferred propagation speed (further validation).



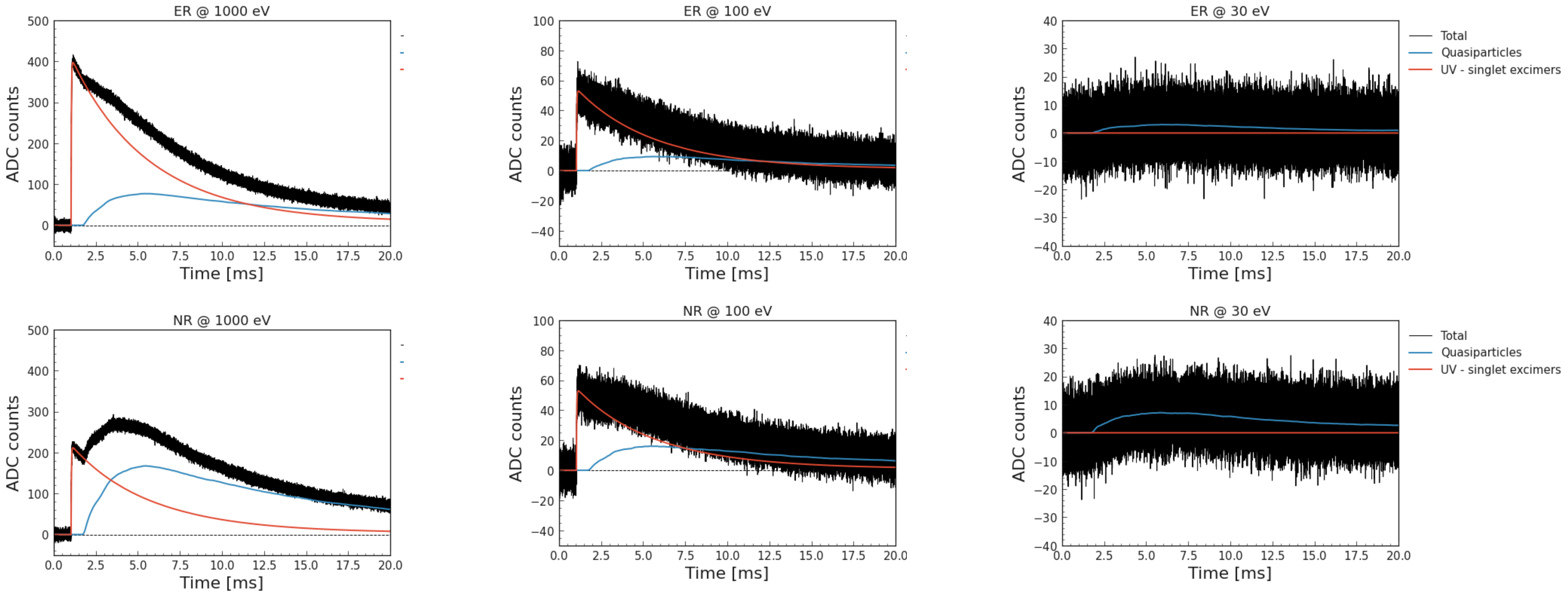
Time distribution

- Time distribution studies are now possible



Waveform simulations

- First waveform simulations using x-ray MMC template



Conclusions

- First version of quasiparticle propagation is implemented and already in the main branch of the DELight GEANT4 repository;

- simple use:

```
./DELight_G4 -n 2000 -m macros/geantino_sims/phonon_HeTarget.mac -o example2.root -P
```

```
/gps/particle phonon
# /gps/energy 1 keV
/DELgps/setPhononMomentum 1.4 keV/c
# /gps/polarization 1. 0. 0.
/gps/position 75. 0. -1850. mm
```

- we are ready to start looking into waveforms and discrimination potential.

To do

- Implement documentation and versioning (so far more focus on making a working version 0).

- triplet phyiscs needs to be changed based on some HeRALD findings:
  - interaction with surface prompts a singlet UV emission, not energy absorption in solid;
  - assisted-decay of triplet on surface (e.g., Penning, ^{3}He impurities, etc.);
  - timing marginally affected, MMC distribution more affected.

- as Kalinka is back, we can have first more massive simulations.