Possible Common SW Developments

- **Several Common Topics:**
  - Maintenance, Development & Support of Existing Software
    - *Here should think also about documentation, training & dissemination*
    - *All technologies are interested: Wires, TPC, RPC, MPGD*
  - Simulation of Resistive Elements, Simulation of Large Gain
    - *Mostly MPGD, RPC*
  - Measurement of (Eco-)Gas cross-sections, Database
    - *All technologies are interested: Wires, TPC, RPC, MPGD*
  - Simulation of Discharges, Understand Ion & Photon Physics
    - *Technologies are interested in this for different reasons:*
    - *E.g. Wires (for Ageing), MPGD (maximum gain, discharges, correct signal shape), TPC (optical readout: scintillation), RPC (Dark Rate)*

Maintenance & Development of Software Tools

- **We should make a distinction between:**
  1. SW tools used to simulate response of a (Physics) Experiment
  2. SW tools used to simulate the physics processes in detectors
  3. SW tools usef for the design of detectors and electronics (CAD)
- For the (1) & (3):
  - Core SW is typically not written / maintained by our community
  - E.g. GEANT4, ILCSoft/Marlin, Key4HEP
  - we could think of grouping best practices, example procedures, increase exchange between different experiments/communities
  - Common acquisition of licenses? Few CERN based licenses available (e.g. ANSYS,COMSOL)
- For the (2):
  - Core SW is written / maintained by our community
  - Examples: Heed, Magboltz, Garfield++, NeBEM
  - Development & Maintenance are often multi-decade one-man projects – sensible to single point of failure
    - Many persons already pensionned or about to pension … *actions to be taken!*
  - Action should be taken to ensure:
    - SW can be continued to be developed (modern programming languages)
    - SW can be maintained / supported by larger group of people
    - SW should be modernized to take profit of contemporary computing (GPU, Multi-Thread)
  - Training, Training, Training! … *in common with WG8 – specific simulation training/schools*

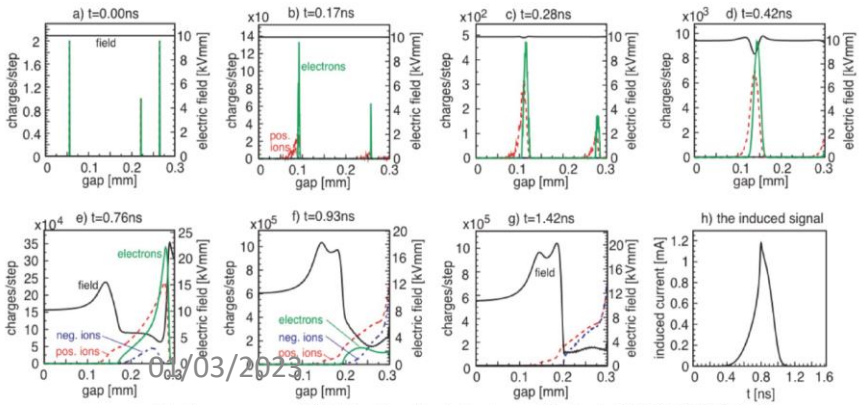
Behaviour & Simulation of Large Avalanches - Discharges

- **Garfield++ simulates well small-medium size Avalanches**
  - Microscopic tracking technique + penning effect for ionization through collision between exited states
- **Large size avalanches are not yet fully understood**
  - Space-charge effects, timing, emission & absorption of photons, non-equilibrium effects
  - Avalanche-to-streamer transition; streamer propagation & quenching
- **Detailed understanding of these processes can come through simulation and verification of simulation to data –** *critical review & physics modelling necessary*
- **Simulation of large gains beneficial for several detectors**
  - MPGDs with high gain (10^5 - 10^6), RPC, SiPMs, Silicon detectors (LGADs), …
  - Understand fundamental limits of our detectors
    - RPC: avalanche-to-streamer transition
    - MPGD: discharge simulation; understand Max Gain << Raether Limit
    - Resistive MPGD: spark quenching
- **We have ideas how to do it…**
  - Extend Microscopic tracking with clustering/super-particles to reduce computational needs (time, memory) – include space-charges (e.g. with NeBEM, use GPUs)
  - First attempts to photon tracking are being studied *(γ-feedback 2B proven or excluded)*
  - Will require extensive validation w.r.t. experimental results & inventary of relevant knowledge in other fields (e.g. Plasma Physics) to understand road(s) to follow ….

Simulation of Resistive Elements

- **Resistive elements to improve detector performance & stability (spark quenching)**
- **Resistive materials need time to evacuate and spread the charge**
  - *Local collapse of (strong) Efield – limiting avalanche growth*
- **Currently cannot calculate signal induction if signal propagation time is non-negligible**
  Possible Approaches:
  - *Analytic dynamic potential of the charge $\phi(\vec{x}, t)$ in simple geometries*
  - *Simulate time-dependent weighting field with FEM solvers (e.g. COMSOL,ELMER)*
  - *1.5D approach in early 2000 – need to extend now to 3D & implement size (or distance to GND)*
- **Other / Related studies in simulation with resistive elements:**
  - *Simulation of Dynamic Behaviour – Rate capability (use of equivalent circuits)*
  - *Simulation of Thermal Noise, Simulation of the size of the resistive layer (or distance to GND)*
  - *Non-uniformities and fluctuations in charge transport in resistive layers*

Simulation work:

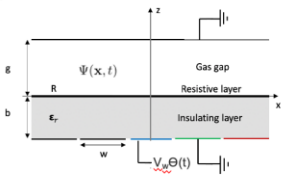


C. Lippmann and W. Riegler, Nucl. Instrum. Meth. A 517 (2004) 54–76

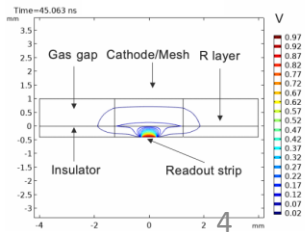
Ramo-Shockley theorem extension for conducting media

For detectors with resistive elements, the time dependence of the signals is not solely given by the movement of the charges in the drift medium but also by the time-dependent reaction of the resistive materials.

This dynamic $\psi(\mathbf{x}, t)$ can be calculated for a grounded electrode by:
- Remove the drifting charges
- Put the electrode at potential V_w at time t = 0
- Grounding all other electrodes



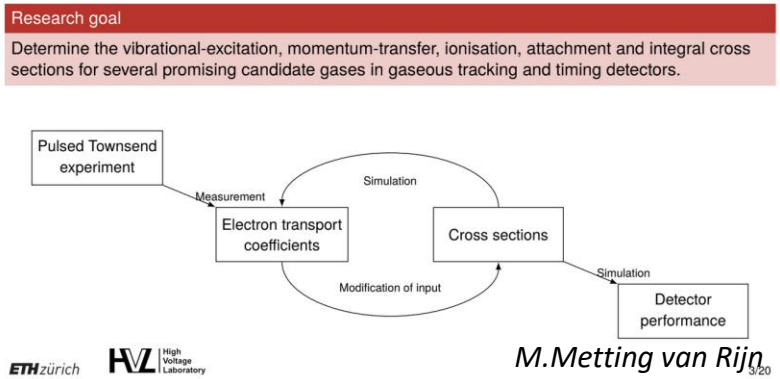
Weighting potential for a resistive layer separating the gas gap and insulating layer.



W. Riegler, Nucl. Instrum. Meth. A 535 (2004), 287-293.
W. Riegler, Signals in Particle Detectors, CERN's Academic Training Lecture Regular Programme (2019): https://indico.cern.ch/event/843083/

Study & Extraction of Gas Properties & Database

- **Activity in common with WG3 on Gas & New Materials**
- **Activity already started**
  - Database exists already – *started in Plasma Physics community:* **LXCAT**
    - https://nl.lxcat.net/home/
  - Collaboration ETH Zurich – CERN *(with CERN gas group & RD51 WG4 conveners)*
    - *SNF grant finally approved – 2 PhD students – timeline 2023-2026*
    - *Measurement of transport coefficients (α, β, excitations, …)*
    - *Extraction of electron cross-sections in HFO1234z and other Eco-gases*
      - *S. Biagi to held a "Cross-section extraction course at CERN" - summer 2023*
      - *Good first step to think about future of Magboltz*
    - *Implementation of electron cross-sections in LXCAT, Magboltz, *boltz, ...*
  - Discuss how other interests/activities can be complementary to ongoing
    - *Search for new gases*
      - ab-initio simulations of molecules to assess whether promising or not?
    - *still many Magboltz cross-sections not uploaded in LXCAT*
    - *LXCAT / other Boltzman solvers*
    - *Verify in other measurements: v_{drift}*
    - *Interest to MPGD for "fast" or "scintillating" gases*
    - *Gas chemistry under irradiation (ions,radicals)*



Modelling & Simulation of Ageing, Dark Rate, Tired-detector syndrom

- Some work on these topics started already using COMSOL
  - but simplified hydrodynamic approach cannot take into account stochastic fluctuations or photon ionization only diffusion assisted streamers
  - Particle Tracing is an upcoming toolset in COMSOL – but we have our own ;-)
  - *Nevertheless items are of interest to our community and some work can start already now*
- These topics would benefit tremendously if necessary simulation tools will be developed [critical & instrumental to further progress in the field]
  1. Maintenance & Development of CORE simulation tool with Microscopic Tracking
  2. Implementation of simulation of Large Avalanches => simulate discharges
- Interesting / Common topics are:
  - Simulation of Discharges … *initial work started with GEANT (~2010 - understand HIPs & Q-density)*
    - Understand discharge probability, avalanche-to-streamer formation, propagating discharges (T/Q-GEM)
    - Knowledge can lead to improved amplification structures
    - Challenging to bring the simulation times from ns to μs or ms – need new approaches in existing tools
  - Understanding of Dark Rate in RPCs & increase with absorbed radiation dose
  - Tired detector syndrom (MPGD): after a spark the HV cannot be restored to the nominal values for a few hours – detector need to rest
  - Understand ions/radicals created by avalanches in gas, simulate ageing
  - Heating of the gas and electrodes, thermionic emission?

Technology Specific Developments

- Some aspects of Simulation are currently not developed, but can be developed in the near future if there is need
- Should be pushed forward by the Technology that requires it
- Can find support / knowledge exchange with more ”core” SW-tools development team(s)
- Can group expertise in WG4 by meetings & coordination
- Should ensure DRD1 management to *”encourage”* inclusion of Simulation / SW Development Tasks in Application WP
- Examples can be:
  - Implementation of *negative ions* (TPCs for rare-event searches)
  - Implementation of *scintillation* & *recombination* (optical readout)
  - Simulation of *non-uniformities* of resistive materials
  - Further development of *fast-simulation techniques* (for experiments)
  - … [please add your favorite topic]

Discussion

- **Can we group people interested in the following topics?**
  1. **Simulation of Large Avalanches with Garfield++**
     - CORE: Implementation of smart techniques to scale MT to larger gains
     - CORE: Explore / Adapt code to run on modern structures (Parallel/GPU)
     - CORE: Implementation / exploration of Photon Tracking
     - APPL: Simulation of Discharges MPGD – Detector physics RPC
  2. **Simulation of Resistive Elements / Signals in Resistive Detectors**
  3. **Study & Extraction of Gas Properties**
  4. **Workgroup on Simulation of Ageing, Dark Rate, Discharges tired detector syndrome …**
     - Will depend on progress made in (1) and on availability of people *(consider fundamental to fill first 1-3)*
     - work can start with hydrodynamic simulations (COMSOL / ELMER)
- **Requests to the involved institutes :**
  - *We need Experts to coordinate the activity and to supervise tasks*
  - *Can we have support from CERN IT for modern programming & tools (part time ok)?*
  - *Need significant injection PhD students to dedicate substantial time to SW development & Simulation*
    - *How can we connect/reach out to ambitious/strong young people to work on these topics?*
    - *CERN summer student program: 1) introduction to topic 2) selection good students*
    - *Can DRD have funds to support young people for couple of months for project?*
- **How do we go forward?**
  - Have 1 dedicated WP for CORE Software Tools development?
  - Have several topical WPs (e.g. Resistive Detectors, Negative Ion TPC, Optical Readout, Discharges) with a substantial simulation Task?