Technology Specific

- Wire Detectors & Drift Chambers
- Time Projection Chambers
- Resistive Plate Chambers
- Micro-Pattern Gaseous Detectors

Wire detectors

Wire technologies with accent on simulation studies

Technologies of interest: **Wire chambers (incl. Straws, TGC, CSC, MWPCs, DT)**
-> 13 out of 69 relevant answers for the chosen technology
-> 5 out of 13 develop Straw tubes, 1 - CSC, 1 - MDT, others - did not specify

- **MWPC**: A mature technology for around ~50 years. Mass-produced in various sizes and shapes and integral components in many experimental setups, including those currently running at the LHC, like ATLAS, CMS, and LHCb Muon Spectrometers. Sub-millimeter localization accuracies in detecting ionizing radiation are routinely achieved in these apparatuses. In future experiments -> Na60+
- **CSC:** all endcap muon precision chambers at CMS and in low-angle region at ATLAS
- **Straws**: wide range of planned experiments: from Dark sector experiment with $50m^2$ straw area detector to 30μm thin film walls and in vacuum
- **TGC:** Small-strip Thin Gap Chambers (sTGC) upgrade the ATLAS muon endcap
- **DT:** Monitored Drift Tube (MDT) and small-diameter Muon Drift Tube (sMDT) for ATLAS muon spectrometer -> also considered for future colliders

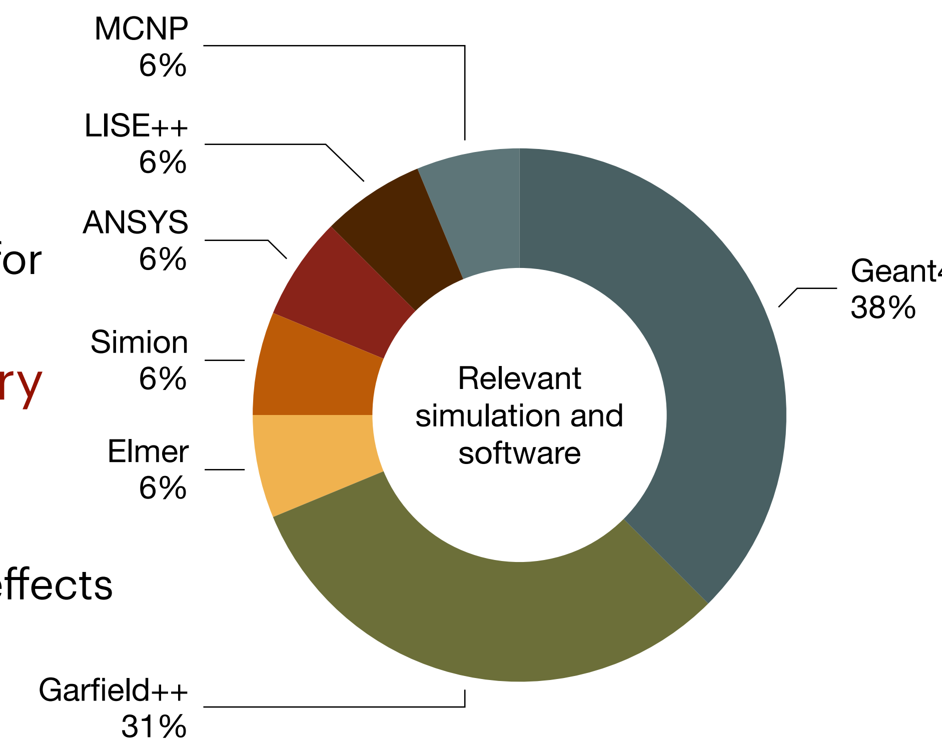
High usage of Geant4 simulation

- used for the simulation of the experiment as a whole
- modeling detectors to investigate how effective they will be in aiding in differentiating between muons and other particles in the actual experiment
- different detector geometries can also be simulated to find the optimal layout for particle identification.

Garfield++ for microscopic modeling of detector response (primary ionization, Townsend avalanche, etc.)

Possible future studies

- of aging effects observed in tests of the straw detectors. Understanding these effects should help to mitigate them; wire corrosion
- Eco-friendly gases.



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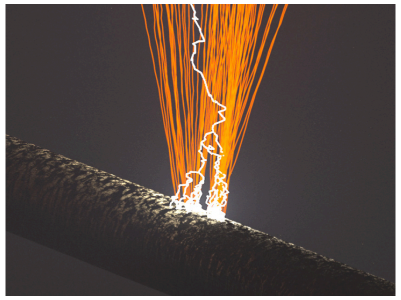
Drift chambers with accent on simulation studies

Technologies of interest: **Drift Chambers**
-> 9 relevant answers for chosen technology

Completed detector project: design and construction of drift chambers, including front-end electronics for the Big Karl spectrometer and COSY-11 experiment at the COSY-Juelich accelerator
New developments: new drift chambers for hadronic physics/nuclear physics. High-resolution, low-mass, multi-wire drift chambers



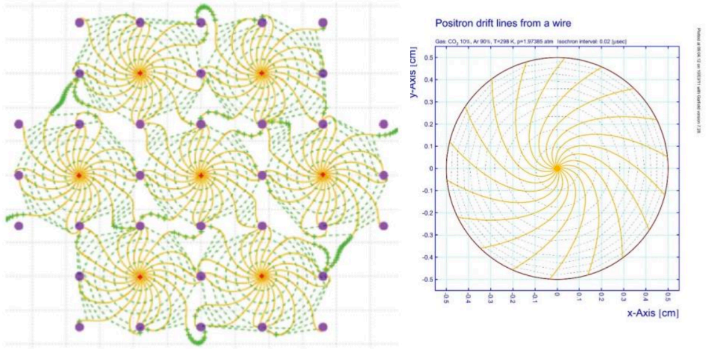
Garfield++, Geant4, Root, ANSYS

- Version compatibility issues with Comsol and Garfield++ . Expensive license. Integrating the comprehensive design based on Geant4, SolidWorks, and CAD design that models the detectors and materials directly into the simulation tools.

- Possible future studies
  - Eco-friendly gases, “aging-free“ gas mixtures
  - materials and components: new wire materials, new alloys, thinner field wires.
  - Studies on light composite materials, carbon monofilaments as cathode wires.

Beyond survey
Ongoing & Future:

- Drift chamber at “extreme“ luminosity for Belle II CDC at SuperKEKB, a large volume gas drift chamber with small drift cells
  - The highest transversal momentum resolution tracking in solenoid B-field
- MEG-II a single-volume cylindrical drift chamber (CDCH) able to sustain the required high rate
- IDEA at FCC-ee: full stereo, high resolution, an ultra-light drift chamber



Electron drift lines for drift cells (left) and straw tube (right) in solenoid B-field (Garfield simulation).

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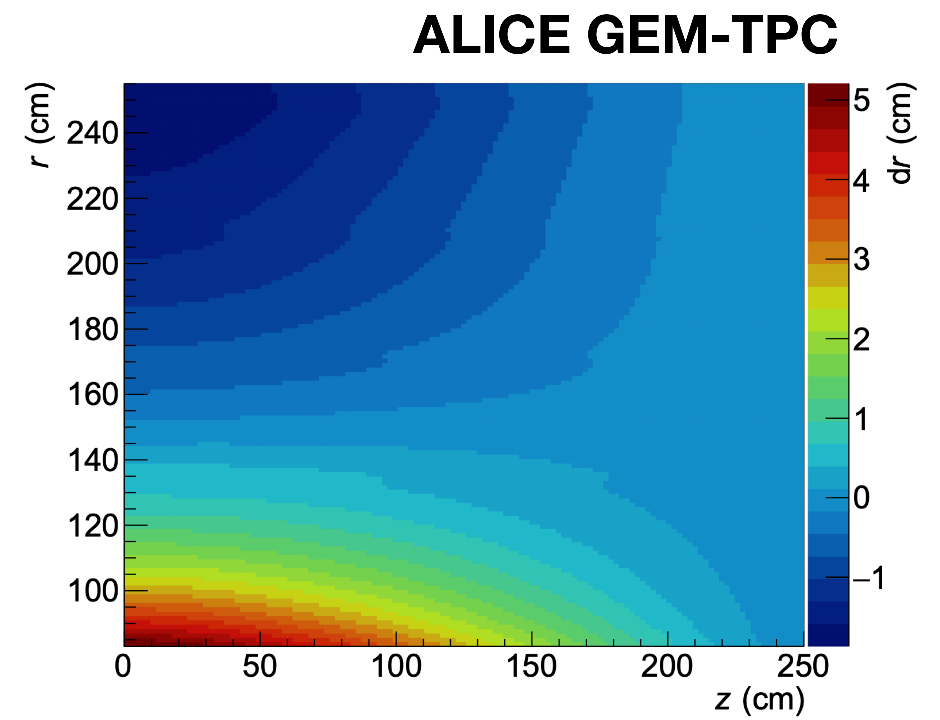
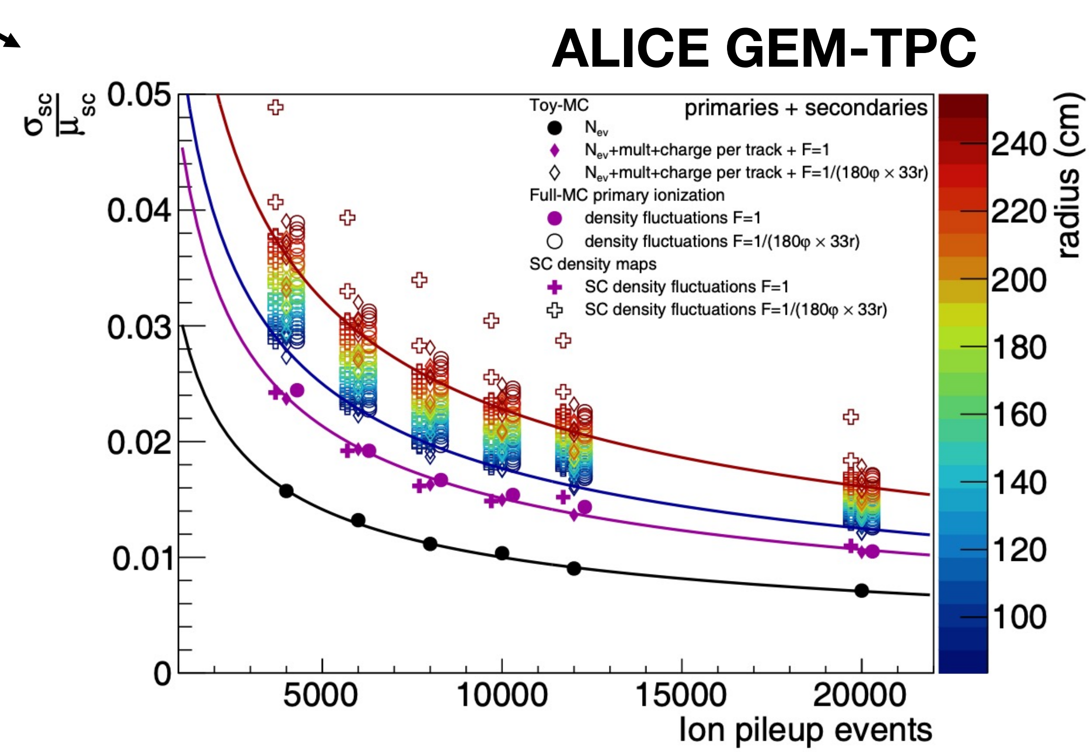
Time Projection Chambers

Correction of distortions

Space Charge

- Relevant in TPCs with no gating, despite the low ion backflow (1% or less) of modern MPGD readout
- Average distortions on O(minute) time scale are either **simulated**, extracted from track residuals exploiting external detectors **[EPJ Web Conf. 245 (2020) 01003]** or from **laser tracks**
- Fluctuations on O(ms) time scale need to be taken into account
  - input: **integrated currents** in the readout pads **[EPJ Web Conf. 251 (2021) 03020]** or **laser tracks**
  - methods: **numerical integrations** of Poisson equation (slow), **machine learning approaches** (fast)
- Both synchronous (i.e. online, for calibrations) and asynchronous (i.e. offline, for reconstruction) approaches



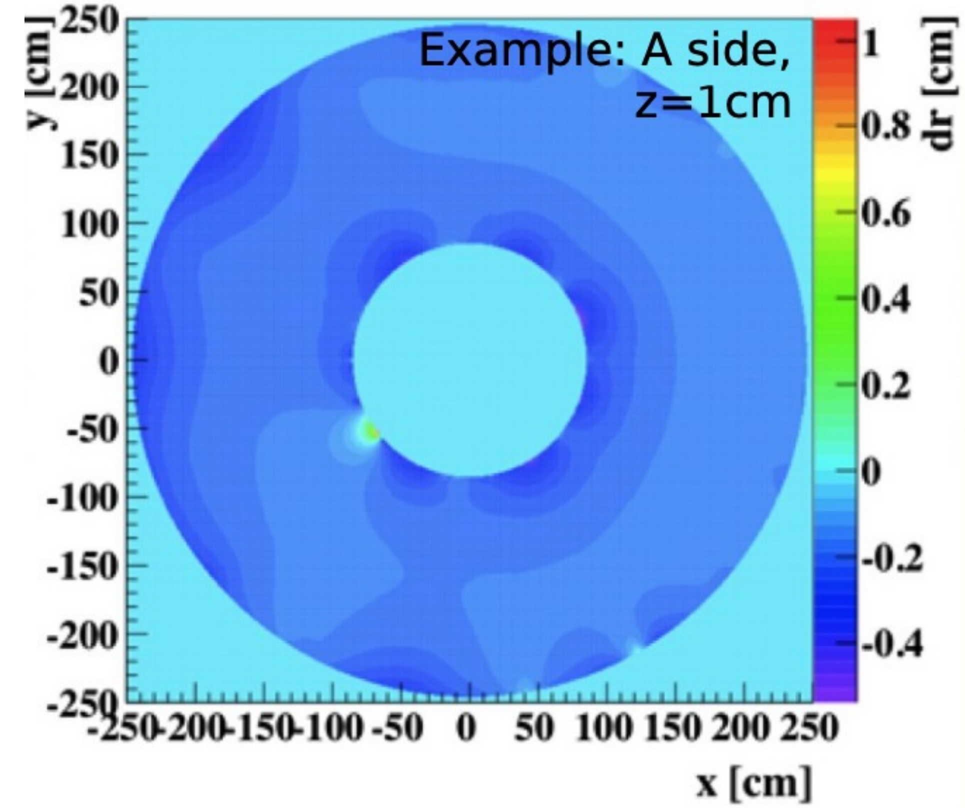


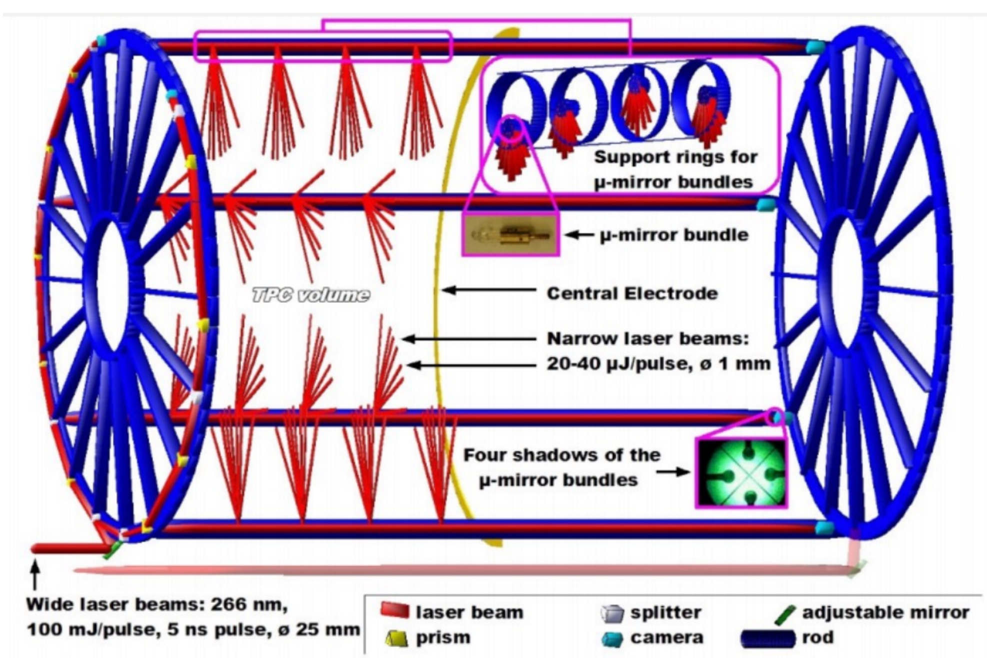
Correction of distortions

Gas and fields

- Gas properties (e.g. temperature) can be disuniform and inconstant on large volumes
- Imperfections in the field cage determine the real E field (disuniformities, ExB effects)
- **Laser tracks** combined with **numerical and machine learning approaches** are widely used

ALICE GEM-TPC





Interplay with other technologies

- Simulation of gas properties
- Simulation of MPGD and wire response
- Numerical calculation of fields
- Pattern recognition and track fit in crowded environments

Outlook

- Application of Machine Learning approaches to correct field disuniformities is wide but relatively recent — room for improvement
- Development of software frameworks to apply corrections based on IDCs and laser tracks would be beneficial, to not reinvent the wheel every time (see the example of millepede for alignment)
- Application of these methods to different geometries (e.g. radial drift)

Resistive Plate Chambers

Notes for the DRD1 meeting on RPC/MRPC physics and simulation

Some info from the Survey

of groups interested in RPC/MRPC: 26

# of groups interested in physics/simulation of RPC/MRPC: 22 (basically the whole community)

# of groups interested in:

- detector physics: 17
- detector performance studies: 17
- software development: 8
- gas properties: 8:
- detector design: 17

Actually some of them are interconnected

Some info from the Survey

Relevant simulation software:

GARFIELD: 10

GEANT: 7

ANYS: 4

COMSOL: 3

ROOT, SOLIDWORKS, Custom software: 2

ILCSOFT, MARLIN, KEY4HEP, MADGRAPH, WIZARD, PYTHIA, NEBEM, AD, KATIA, FLUKA, SPICE: 1

Some info from the Survey

ıs your team involved in software development:

- 9 yes (one of which NOT interested in physics/simulation)
- 17 no

Would you be willing to contribute to common software?

- 14 yes (one of which NOT interested in physics/simulation)
- 12 no

In principle there could be the space for increasing activities related to physics/simulation in the RPC/MRPC community

RPC and MRPC physics: what's understood

Owing to the simple geometry of RPCs, analytical approaches have been attempted for parts of the problem. Of course, these must always be considered as enlightening approximations. Main topics were:

- Townsend (small) avalanches
- Small avalanche statistics (relevant for efficiency?)
- Charge induction.
- Timing properties in the small threshold regime (with some limits)
- Signal propagation in multiple strips (but only 1D).
- Charge transport in resistive materials (Ohm's law seems to hold).
- Shot-noise statistics arising from charge transport in the resistive elements.

RPC and MRPC physics: what’s to be understood

- Avalanche-streamer transition with realistic photonic parameters and other
- Avalanche statistics (charge, time distribution) of large avalanches.
- Streamer propagation and quenching.
- The detailed origin of dark counts (with experimental proof).
- Gas chemistry under irradiation (polymerization, deposits, inhibition of it).
- Detailed understanding of processes at high rate

RPC and MRPC simulation: what is to do

- Develop a practical model of avalanches yielding the required distributions (prev. slide). Clarify and validate the avalanche-streamer transition onset (THE fundamental limit).
- Integrate this with the simpler electromagnetic calculations in a comprehensive tool. Mind the wide range of time scales involved.
- Propagation of the streamer and the streamer-electrode interaction - “quenching” (determines the “streamer” charge).

RPC and MRPC simulation: what is there

MATURE

- Primary charge deposition (HEED)
- Analytic (hydrodynamic) description of uniform-field Townsend avalanches.
- Microscopic (Garfield) description of small Townsend avalanches.
- Signal induction, including resistive layers (both analytical and numerical).
- Specialized electromagnetic solvers for signal induction/propagation.

ONGOING

- Numeric (hydrodynamic) calculation of large avalanches + photon feedback (if any…).
- Microscopic + mesoscopic (clustering) calculation of large avalanches.
- Empirical modifications of the analytical uniform-field Townsend avalanches, trying to introduce space-charge effects.
- Analytic description of signal propagation in multiconductor transmission lines (only 1D available).

Distant goal: GEANT-like simulation tool yielding realistic distributions. Required ingredients:

- Primary charge distribution & cluster statistics (SOLVED: HEED?).
- Large avalanche development (yielding charge densities and velocities), including avalanche statistics and the onset of streamers. (VERY DIFFICULT)
- Signal induction, propagation and collection (IN PRINCIPLE CALCULABLE).
- Non-uniformities and slow fluctuations arising from charge transport in the resistive elements. (IN PRINCIPLE CALCULABLE)
- Other effects, e.g. gap(s) uniformity, temperature (e.g. dissipation in gas at high rates?) (IN PRINCIPLE CALCULABLE)
- Final “streamer” charge and inclusion of the corresponding effects. (EXTREMELY DIFFICULT)
- High-rate “pileup” effects? (VERY DIFFICULT)

Also nice to have

- Good understanding of the gas chemistry under irradiation (dissociation products and probabilities, polymerization, deposits/erosion and their inhibition).
- Good understanding of the origin and properties of the dark count rate.

Micro-Pattern Gaseous Detectors

Current situation MPGD Simulation

- **Workgroup in RD51 collaboration dedicated to "Modelling of Physics Processes and Software Tools"**
  - *Conveners: Rob Veenhof, Ozkan Sahin, Piet Verwilligen*
  - *See: https://rd51-public.web.cern.ch/wgactivities-wg4*
  - *Lectures & Tutorials*
  - *Simulation session during Collaboration meeting:*
    - *students & researchers show results & further development of code*
- **Maintenance & development of *Garfield***
  - *originally in FORTRAN for simulation of drift chambers (R.Veenhof)*
  - *Simulation of Primary Ionization (interface to HEED)*
  - *Simulation of electron drift & multiplication (interface to MAGBOLTZ)*
  - *Re-written in C++ as Garfield++ https://garfieldpp.web.cern.ch/garfieldpp/* [well documented!]
  - *Developed Microscopic Tracking to get correct predictions for Micro-Pattern Gaseous Detectors*
  - *RD51 actively maintained, developed & supported this software*
- *=> Very important legacy of RD51 Collaboration*
- **Our community is exploring also other simulation programs**
  - *E.g. COMSOL for the simulation of space-charge effects and discharges*
  - *E.g. Fast simulations based on parametrizations obtained with Garfield++*
  - *E.g. interface GEANT4 – Garfield++, Electric field calculations in NeBEM, …*
- **Measurements to extract missing cross-sections, drift velocities, ion mobilities, …**

Future needs for MPGD Simulation

- **We would like to:**
  - **Continue the program that was succesful in RD51**
    - Trainings and schools to enlarge group of knowledgeable people
    - Continue maintenance, development and support of Garfield++
    - Continue exchange of users through presentations of their work – give visibility to contributers
  - **Make tools more easy to use …**
    - Better interfaces, more examples, better manuals
  - **Make people contribute to the same project / single tool**
    - Keep everything in a single framework
  - **Bring tools into the 21th century**
    - Parallelize Garfield++; Optimize code to use GPUs, …
    - Modern build system for Garfield++ (release planning, PR testing)
  - Extend applicability of the tools:
    - Simulate larger gains (e.g. dynamic switch Microscopic Tracking to hydrodynamic?)
    - Include space-charge effects (e.g. BEM method + microscopic tracking on GPU?)
    - Simulate detectors with resistive Elements
    - Implement negative ions for rare-event searches
  - Extend the user base of simulation tools & recognise SW development
    - Improve career opportunities of people dedicated to SW development
    - Promote a "healty" mix of hardware work and simulation / SW development work
    - Apply (& obtain) external funding for PhD & provide career paths for young scientists