DRD1 WG4

Reflections towards a general framework for the realistic simulation of gaseous detectors

A blue-sky contemplation

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(Blue-sky) aims

To be able to deliver **realistic** “observable” quantities such as individual signals and distributions, stability.

User-friendly operation: no detailed knowledge of all the underlying physics required. GEANT or FLUKA-like. (Can’t compare with GARFIELD, sorry.)

Reasonable execution time, in order to be useful for parameter-scanning studies.

Most major detector types covered.

Benchmarked against well-controlled reference detectors

Know the zillions of physical parameters need.

Relatively easy cases

Small avalanches at low rates in metallic detectors ⇒ space and time locality.

Difficult cases

Resistive detectors in general because the resistive elements break locality, producing fluctuations in the actual operating field
⇒ large **area** simulation needed over several relaxation **time**s in order to reach steady-state.

Detectors with dielectrics (e.g. GEM) because of local charge-up that affects the actual operating field. Probably can be treated as a resistive detector with long relaxation **time**.

High-rates: avalanche overlap, ionic pile-up (e.g. wire chambers, TPC). Again, requires some simulation **time** to reach steady-state.

Geometrical non-uniformity (e.g. RPC inner pressure, wire sagging) -> large **area**.

Non-proportional avalanches: RPC (space-charge and streamer onset), limited proportionality and SQS modes in wires.

Edges.

Very difficult cases

Evolution and effects of streamers, discharges and sparks. E.g.: RPC normal operation (!), discharge propagation in multi-GEMs, “tired detector” effect.

Phenomena to be covered (a lot already exists)

Primary charge generation and its statistics

Calculation of the applied (static) electric field.

Transport (drift, diffusion, attachment, detachment, charge transfer, multiplication, etc.) of electrons and ions including its stochastic aspects.

Photon emission/absorption, both short (intra-avalanche) and long range, including its stochastic aspects.

Generation of secondary charges (photonic, ionic, Malter), including its stochastic aspects.

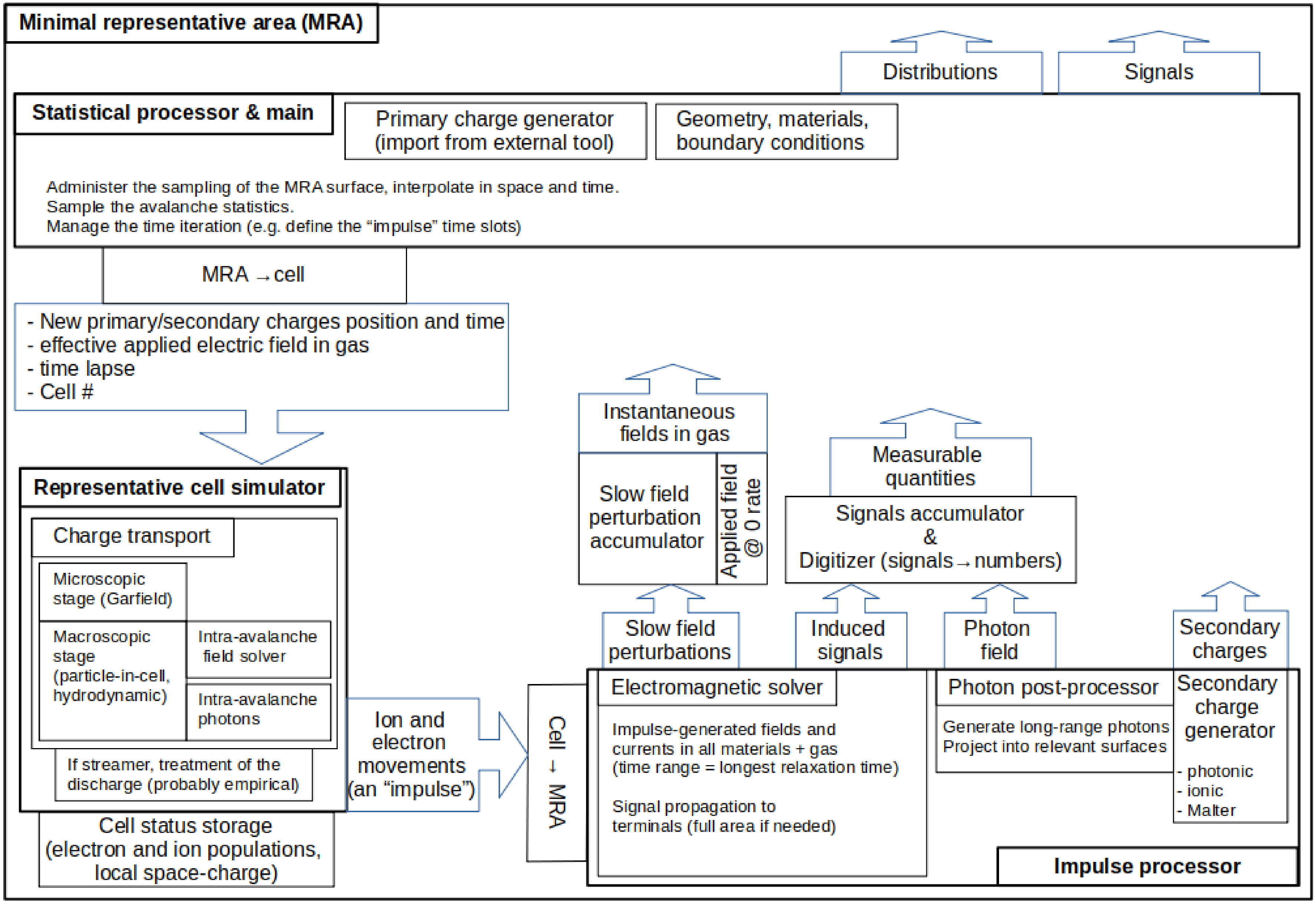
Space-charge effects in single avalanches (e.g. RPC), in avalanche pile-up (high-rate) and in drift spaces (e.g. TPC).

Avalanche-streamer transition (“detector stability”), including its stochastic aspects.

Treatment of discharges or sparks (possibly empirical),

Currents induced in electrodes (both metallic and resistive) and their propagation, generating field transients. Includes cancelation of charges deposited over surfaces.

Possible organization of the simulation



Minimal representative area (MRA)

Distributions

Signals

Statistical processor & main

Primary charge generator (import from external tool)

Geometry, materials, boundary conditions

Administer the sampling of the MRA surface, interpolate in space and time.
Sample the avalanche statistics.
Manage the time iteration (e.g. define the "impulse" time slots)

MRA → cell

- New primary/secondary charges position and time
- effective applied electric field in gas
- time lapse
- Cell #

Representative cell simulator

Charge transport

Microscopic stage (Garfield)

Macroscopic stage (particle-in-cell, hydrodynamic)

Intra-avalanche field solver

Intra-avalanche photons

If streamer, treatment of the discharge (probably empirical)

Cell status storage (electron and ion populations, local space-charge)

Ion and electron movements (an "impulse")

Cell → MRA

Instantaneous fields in gas

Slow field perturbation accumulator

Applied field @ 0 rate

Measurable quantities

Signals accumulator & Digitizer (signals → numbers)

Slow field perturbations

Induced signals

Photon field

Secondary charges

Electromagnetic solver

Impulse-generated fields and currents in all materials + gas (time range = longest relaxation time)

Signal propagation to terminals (full area if needed)

Photon post-processor

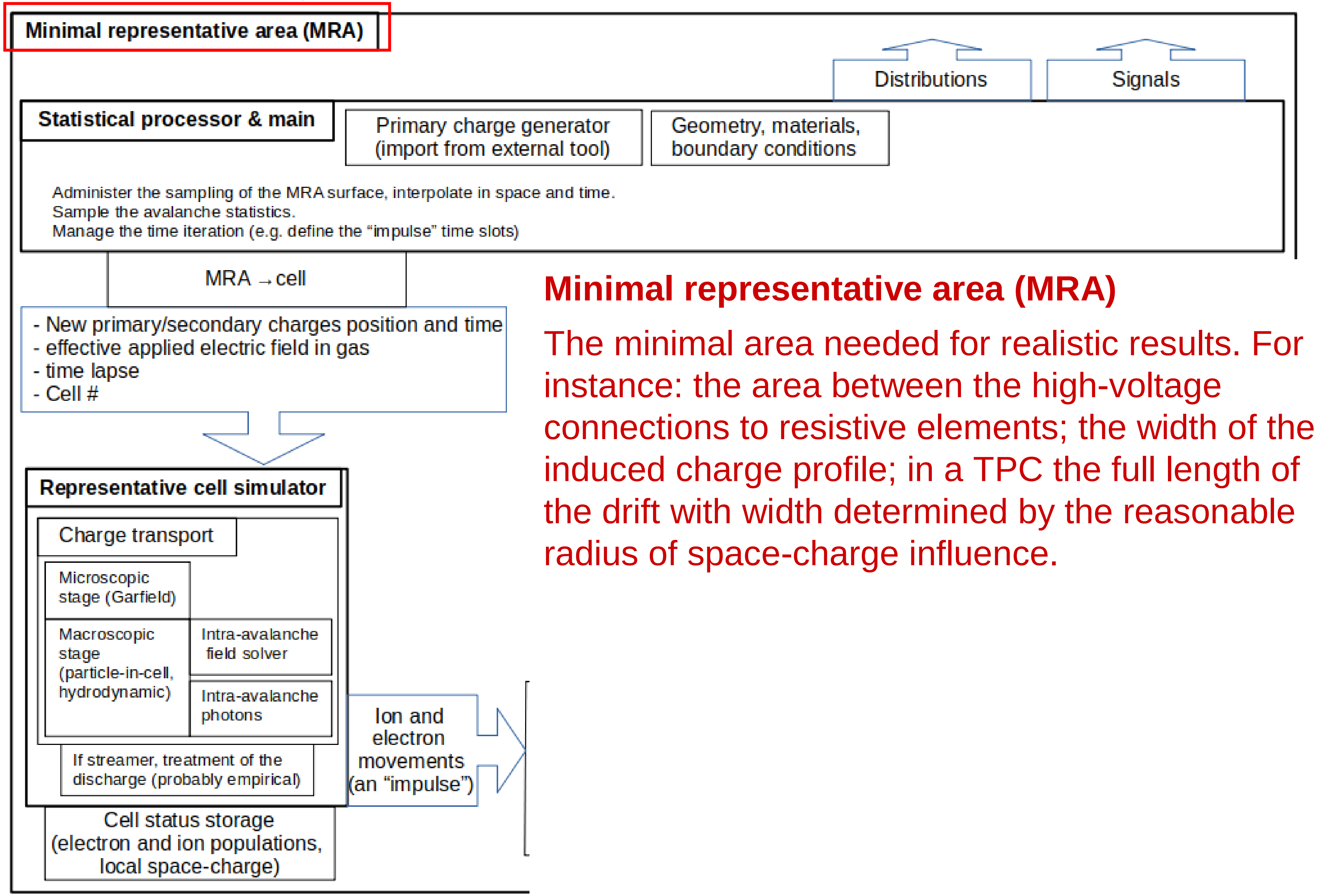
Generate long-range photons
Project into relevant surfaces

Secondary charge generator

- photonic
- ionic
- Malter

Impulse processor

Possible organization of the simulation



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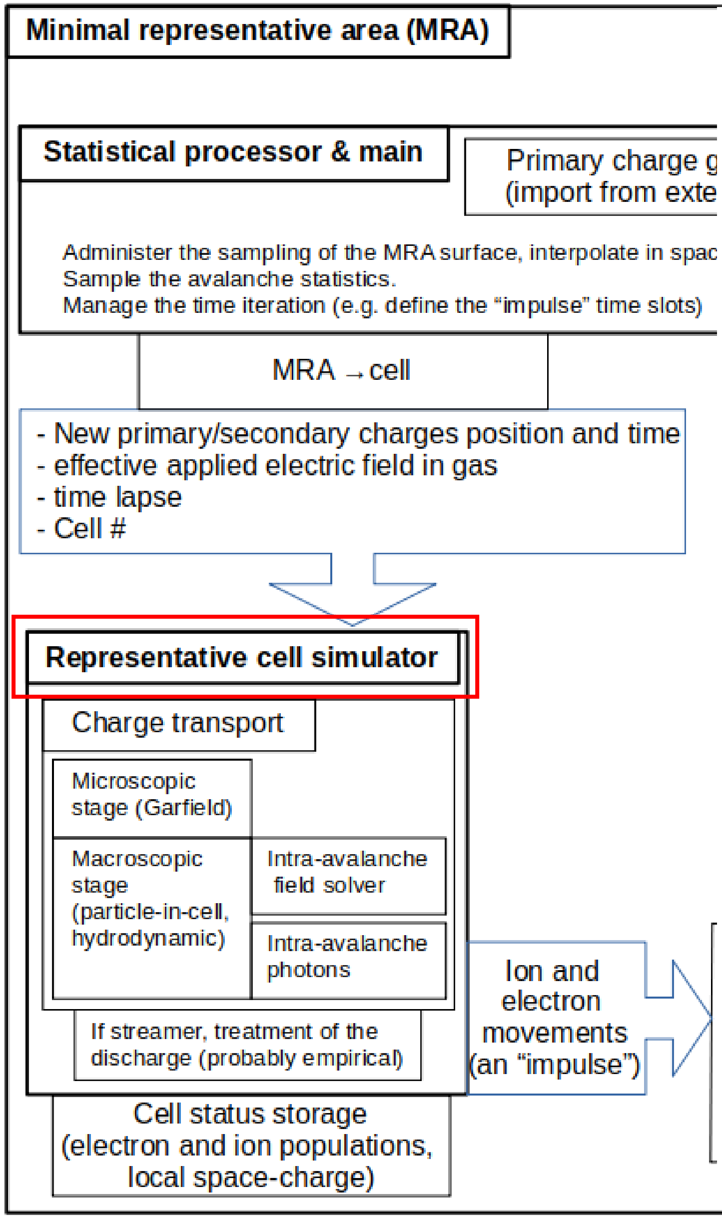
Minimal representative area (MRA)

The minimal area needed for realistic results. For instance: the area between the high-voltage connections to resistive elements; the width of the induced charge profile; in a TPC the full length of the drift with width determined by the reasonable radius of space-charge influence.

Possible organization of the simulation



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Representative cell simulator

Minimal element wide enough to contain the full movement of charges and the short-range interactions (space-charge, photonic) between them.

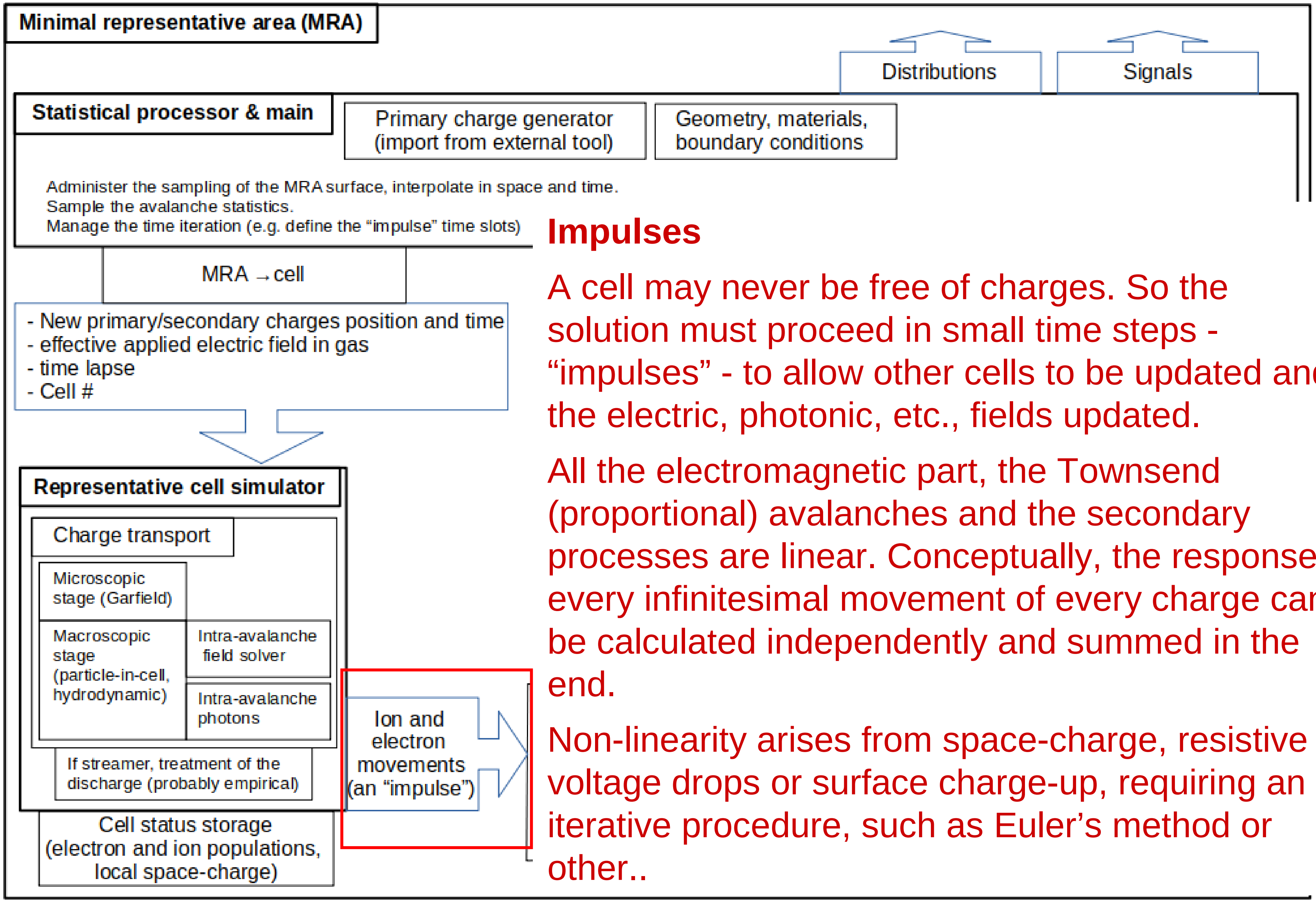
For instance: a GEM hole cell, a short length of a cell in a multiwire/multidrift chamber; in RPC/ MICROMEGAS the region where space-charge interaction can occur between multiple avalanches; in a TPC the full length of the drift with width determined by diffusion and field non-parallelism.

Charges are indefinitely kept because even immobile charges have electromagnetic effects.

For efficiency, at some point a transition from a microscopic to a continuous description may be needed.

Several algorithms may be selectable, depending on the accuracy required for the particular simulation. Of course, this is true in general.

Possible organization of the simulation



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Impulses

A cell may never be free of charges. So the solution must proceed in small time steps - “impulses” - to allow other cells to be updated and the electric, photonic, etc., fields updated.

All the electromagnetic part, the Townsend (proportional) avalanches and the secondary processes are linear. Conceptually, the response to every infinitesimal movement of every charge can be calculated independently and summed in the end.

Non-linearity arises from space-charge, resistive voltage drops or surface charge-up, requiring an iterative procedure, such as Euler’s method or other..

Possible organization of the simulation

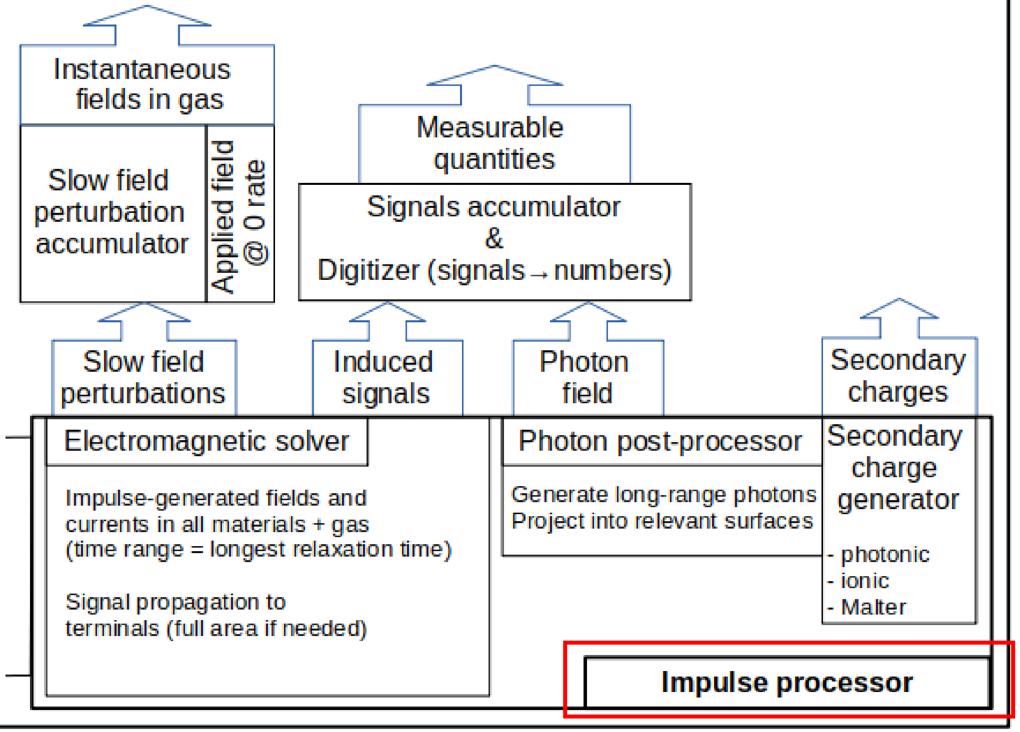
Impulse Processor

Handles the effects of the charge movements in an impulse.

The Electromagnetic Solver generates the response to each impulse of the set of materials that compose the detector, with a time range equal to several times the longest relaxation time, delivering such impulsive responses to accumulators that yield the actual readout signals and field perturbations.

The Photon Processor generates the long-range photons from the electron movements, propagates and projects them into surfaces (e.g.: optically readout detectors). It is implicit that short-range photons are handled only within the Cell Simulator

The Secondary Charge Generator takes input from the Photon Processor and from the ion movements to generate secondary charges from surfaces.



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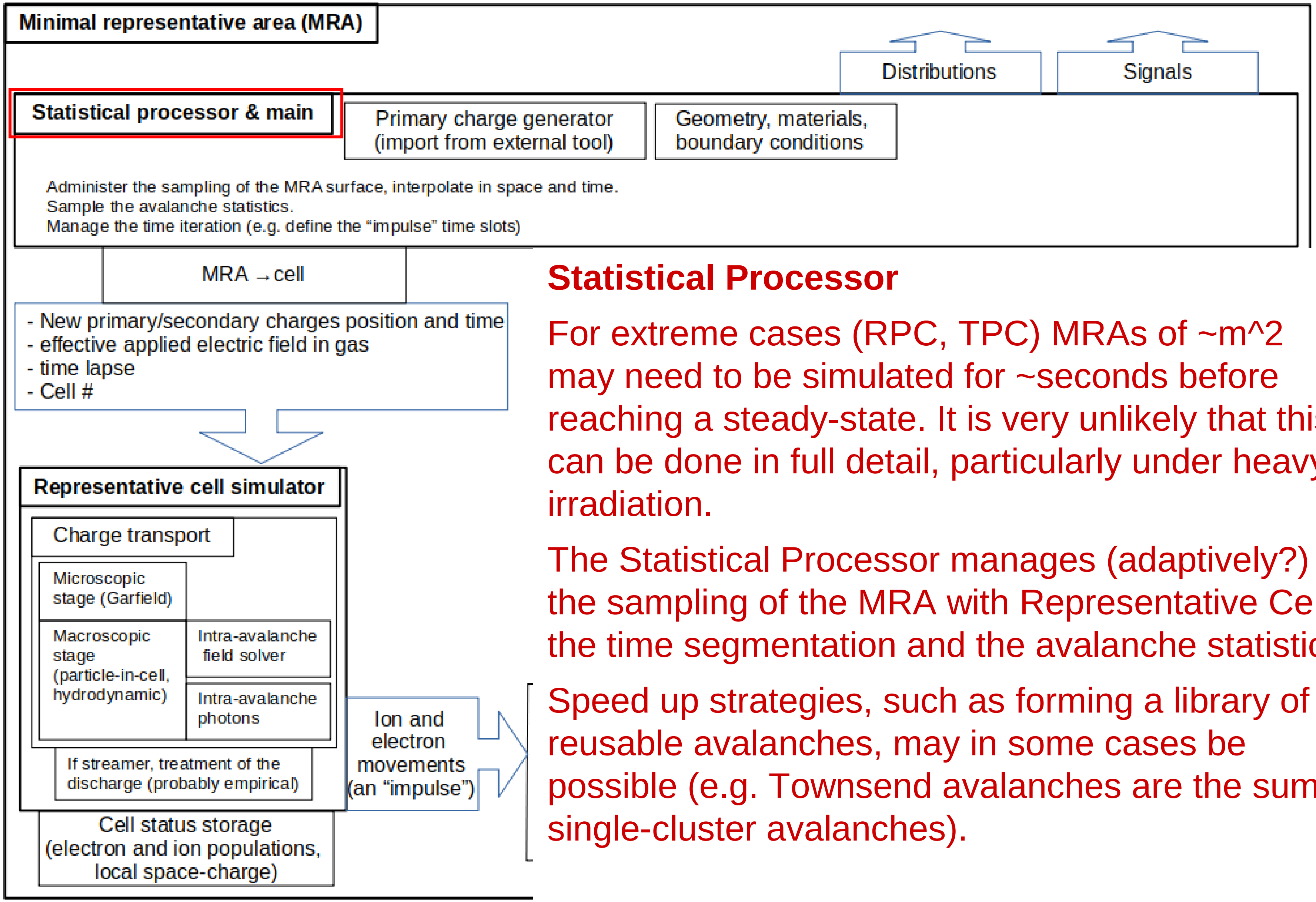

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Ion and electron movements (an “impulse”)

Cell status storage
(electron and ion populations,
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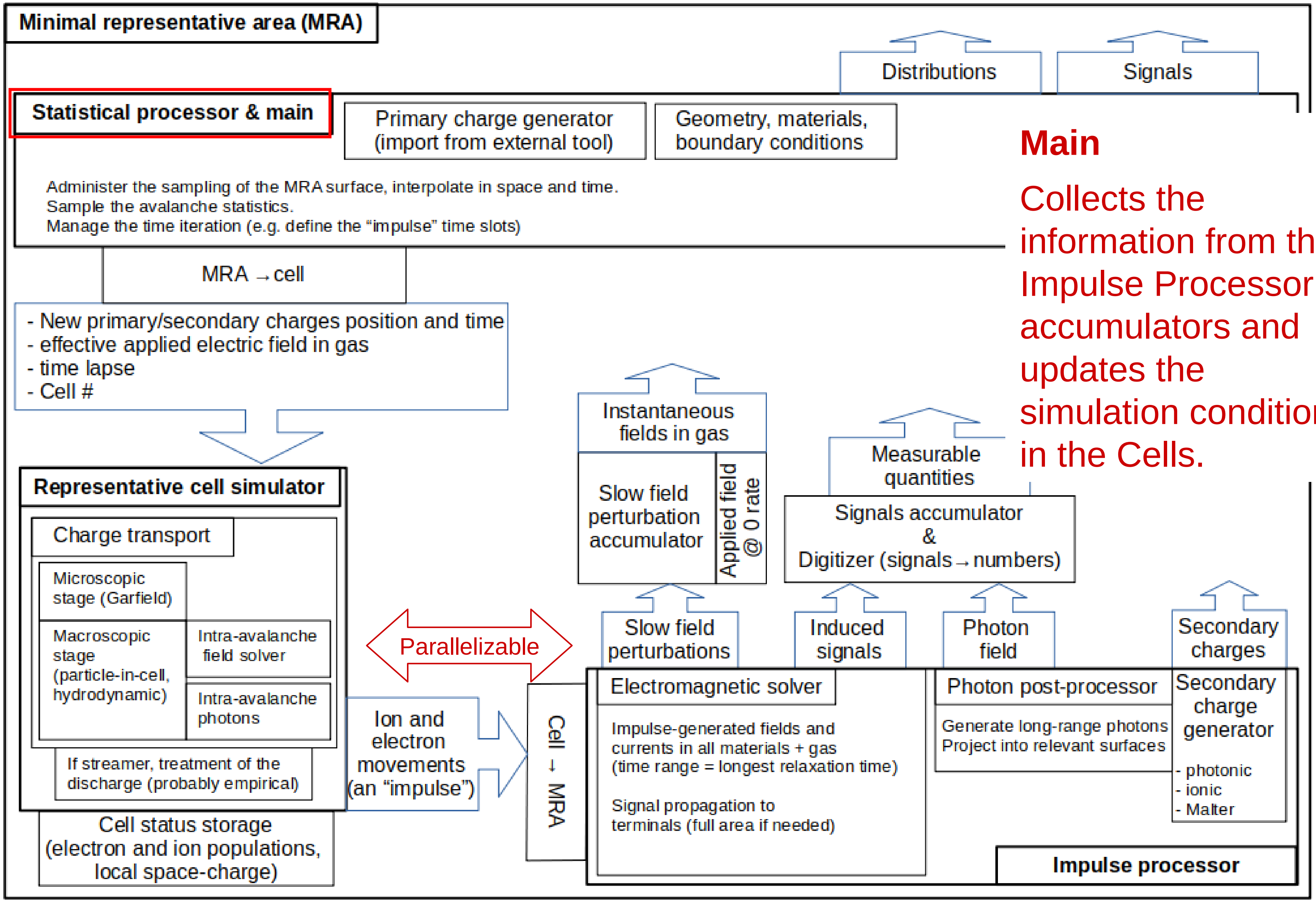
Statistical Processor

For extreme cases (RPC, TPC) MRAs of ~m^2 may need to be simulated for ~seconds before reaching a steady-state. It is very unlikely that this can be done in full detail, particularly under heavy irradiation.

The Statistical Processor manages (adaptively?) the sampling of the MRA with Representative Cells, the time segmentation and the avalanche statistics.

Speed up strategies, such as forming a library of reusable avalanches, may in some cases be possible (e.g. Townsend avalanches are the sum of single-cluster avalanches).

Possible organization of the simulation



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Parallelizable

Ion and electron movements (an “impulse”)

Cell → MRA

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Applied field @ 0 rate

Measurable quantities

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Impulse processor

Main

Collects the information from the Impulse Processor accumulators and updates the simulation conditions in the Cells.