SAND TPC simulations update

Pierre Granger - *Accelerator neutrino group CEA*

01/12/2021

Irfu - CEA Saclay

The analysis introduction

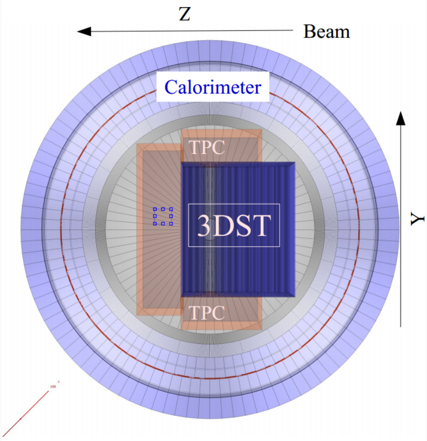
Goals of the analysis

- Estimating the resolution requirements with DUNE beam
- Evaluate the impact of different parameters such as the pad size, charge spreading (RC) and electronics shaping time.

Data used

- Only FHC for now
- Interactions simulated in the whole detector (Guang's simulations)

The TPCs in SAND



- 3 TPCs :
  - DOWNSTREAM : (x,y,z) $3.3\,\text{m} \times 3\,\text{m} \times 0.77\,\text{m}$
  - BOTTOM and TOP : (x,y,z) $3.3\,\text{m} \times 0.57\,\text{m} \times 1.41\,\text{m}$
- Cathode in the middle of the TPCs (x direction)
- 2 readout planes for each tpc

Simulation

Events generation

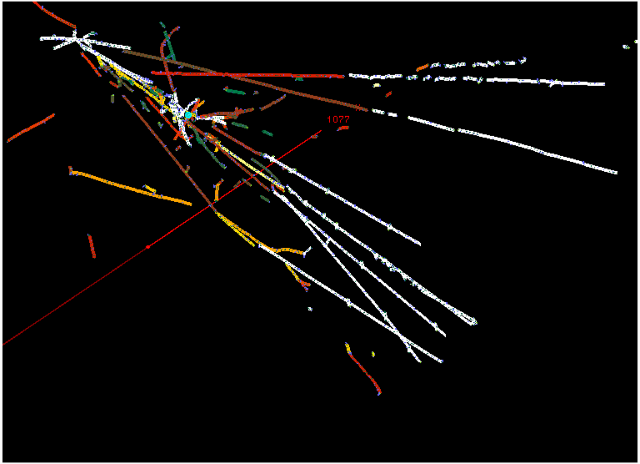
- Events are generated with GENIE.
- Energy deposits in all the active areas of the detector are computed by GEANT.

TPC simulation

1. Events are given a vertex time according to the beam time profile.
2. Energy deposition segments of charged particles are projected onto ERAMs
3. Drift effects taken into account : drift time, longitudinal spread, transversal spread
4. Fixed charge spreading applied on pads -> fixed multiplicity per hit
5. Each pad hit is stored
6. Computing overlaps for each pad in a given time window (proxy for spreading time + shaping time).

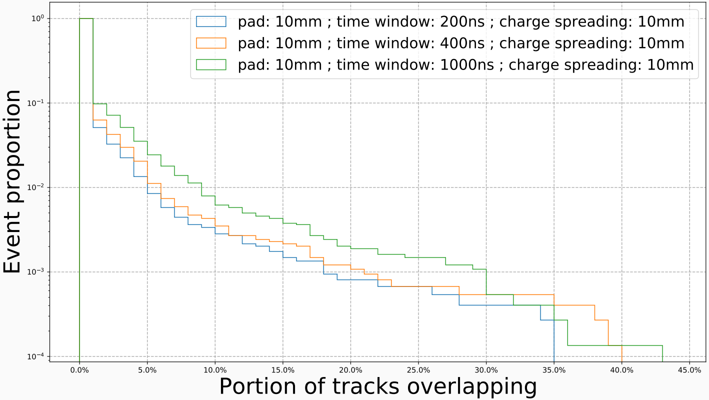
First implementation in erep-sim with the help of Clark that is now working on reconstruction.

TPC + 3DST reconstruction example (Preliminary)



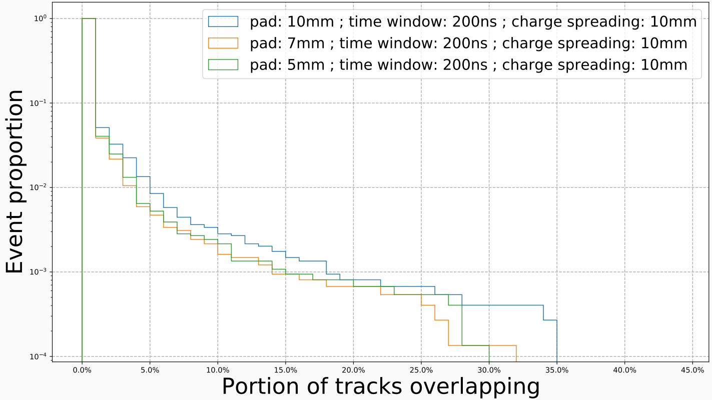
DIS event reconstruction. White tracks on the right side are in the TPC.

Inverse cumulative distribution of overlaps - Impact of time window



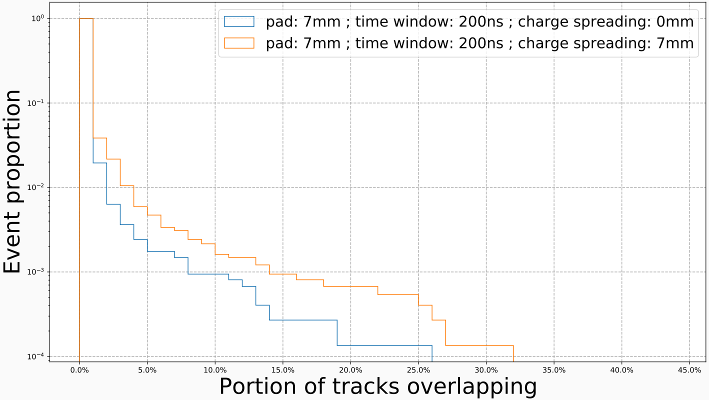
A narrower time window leads to less overlaps by mostly reducing inter-event overlaps.

Inverse cumulative distribution of overlaps - Impact of pad size



Smaller pads leads to slightly less overlaps.

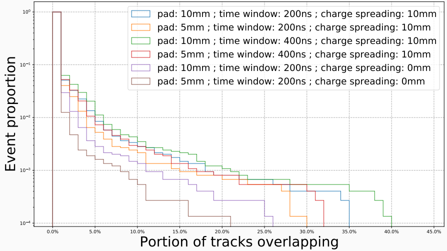
Inverse cumulative distribution of overlaps - Impact of charge spreading

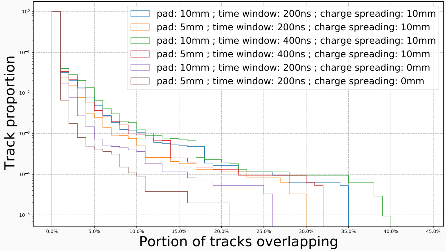


Charge spreading increases overlaps. Here a multiplicity of 3 pads per hit is considered.

Inverse cumulative distribution of overlaps - DOWNSTREAM

Inverse cumulative distributions





In all the tested configurations, less than 1 % of the events contain tracks with more than 10 % of overlapping pads (0.1 % of events for 20 % of overlapping pads).

Conclusions on overlaps

- Choosing a low enough shaping time is necessary to ensure event separation in a given spill.
- Charge spreading increases the amount of overlaps, mostly inside given events.
- Pad size seems to have only little effect on the overlaps (at least in the considered range).

Charge spreading

Currently charge spreading is only taken into account as a fixed pad multiplicity. Necessity to implement the physics behind it.

Formula for charge dispersion of 2D continuous RC network :

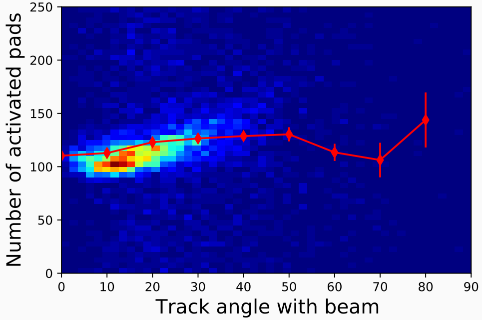
$$\frac{\partial \rho}{\partial t} = \frac{1}{RC}\left(\frac{\partial^2 \rho}{\partial x^2} + \frac{\partial^2 \rho}{\partial y^2}\right)$$

Solution for infinite size and initial gaussian distribution :

$$\rho(x, y, t) = \frac{Nq_e}{2\pi(2ht + w^2)} \exp\left[-(x^2 + y^2)/(2(2ht + w^2))\right]$$

$h = \frac{1}{RC}$, w is the initial gaussian width and Nq_e the initial quantity of charged deposited. Ongoing implementation in erep-sim.

δP_t resolution - inputs



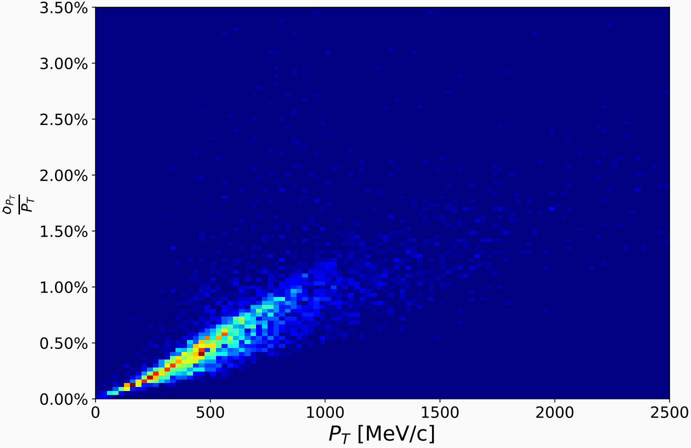
Number of tracks as function of the angle in simulation.

DESY resolution data ($\sigma_{r,\phi}$) as function of angle are used.

Resolution is computed with :

$$\frac{\sigma_{p_T}}{p_T} = \frac{p_T}{0.3BL^2}\sqrt{\frac{720}{N+4}}.\sigma_{r\phi}$$

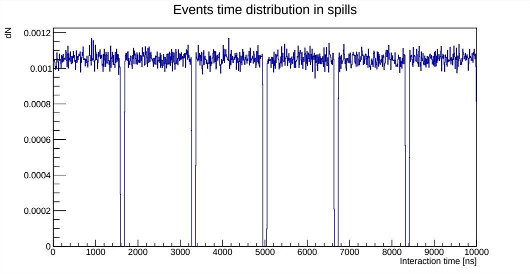
δP_t resolution

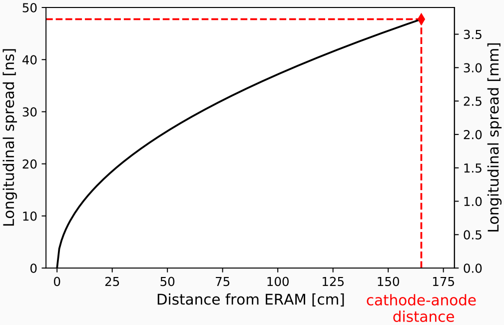


Estimated resolution from simulation (10mm pads).

Backup slides

Timing



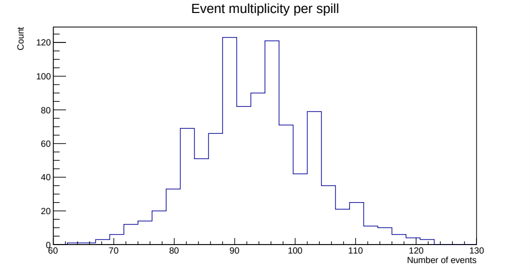


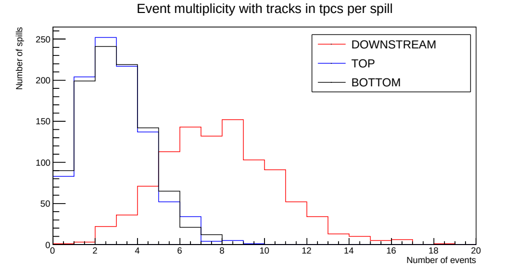
- 10 µs spills of 6 100 ns separated bunches
- Maximum longitudinal spread is $\sim 50\,\mathrm{ns}$

T2K gas parameters :

- $v_{\mathrm{drift}} = 7.8\,\mathrm{cm}\,\mu\mathrm{s}^{-1}$
- $\sigma_L = 290\,\mu\mathrm{m}/\sqrt{\mathrm{cm}}$

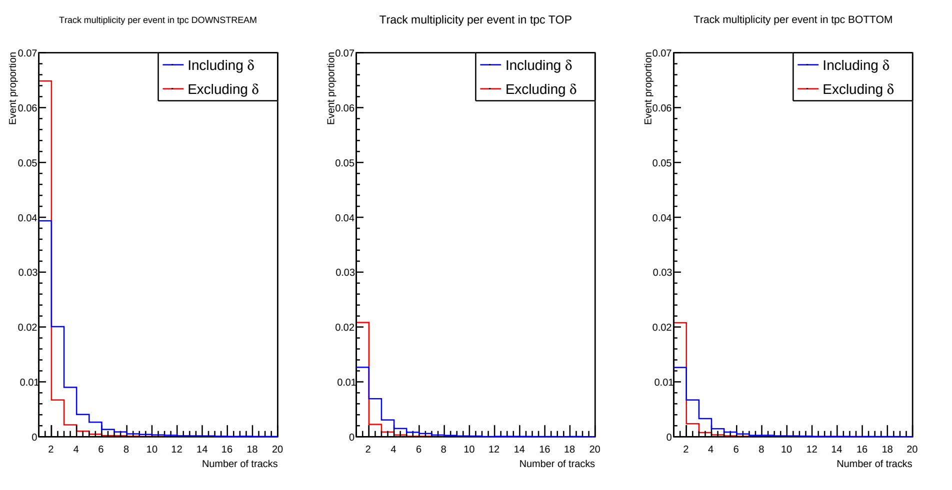
Statistics about events





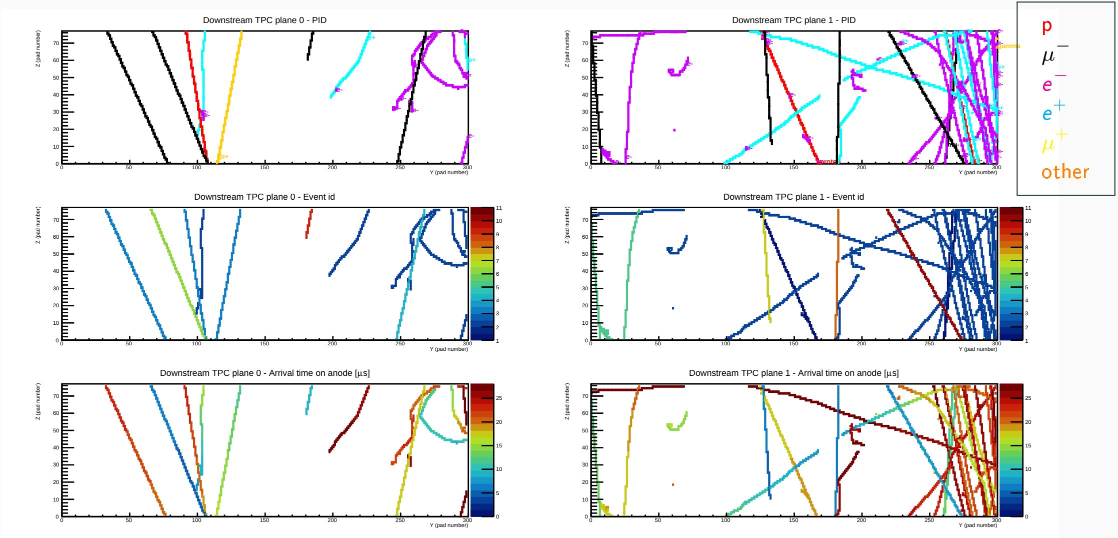
- 93,017 simulated events in 1,000 spills
- Only 1,714 interactions inside 3DST
- 1,363 3DST interactions lead to at least 1 track in a TPC
- 8,104 ECAL+Yoke interactions lead to at least 1 track in a TPC

Track multiplicity per event



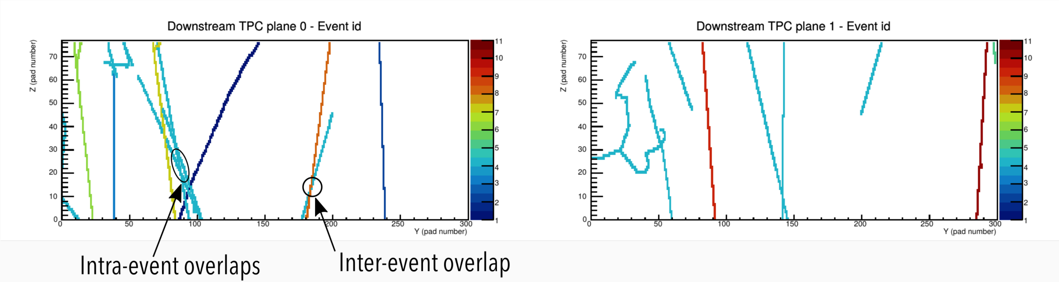
Events with 0 tracks are not shown but are taken into account in the event proportions.

Understanding events with a lot of overlapping pads



Electromagnetic shower from ECAL interaction

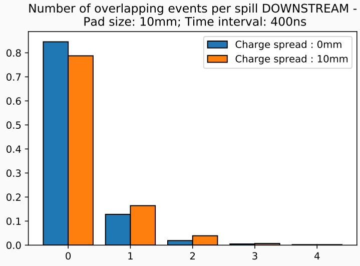
Overlaps

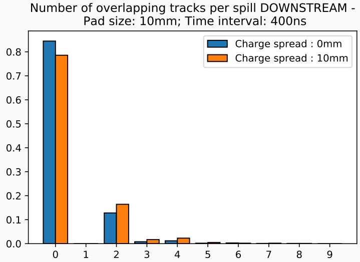


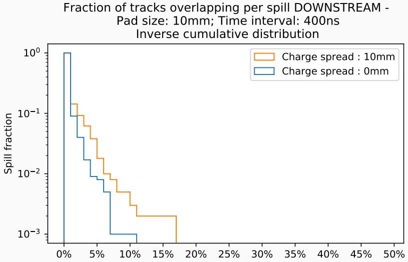
2 different kind of overlaps are considered

- inter-event overlaps : overlaps between tracks of two different events from the same spill
- intra-event overlaps : overlaps between tracks of the same event

Evolution of inter-events overlaps with charge spread - DOWNSTREAM



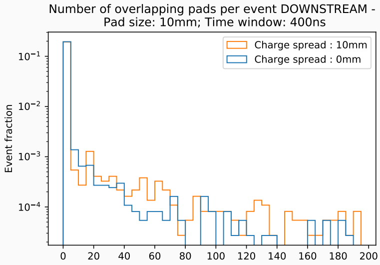


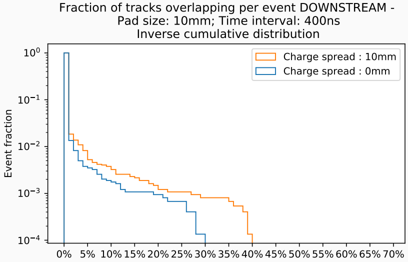


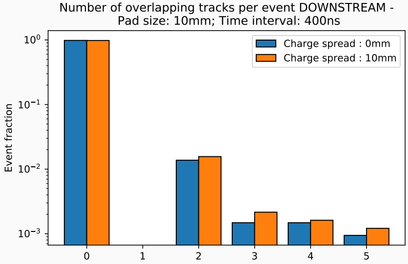
- 10 mm charge spread on each side $\implies$ 3 pads multiplicity.

The introduction of charge spreading slightly increases the number of inter-events overlaps.

Evolution of intra-event overlaps with charge spread - DOWNSTREAM



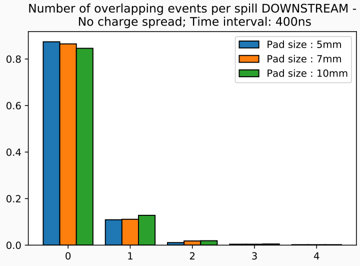


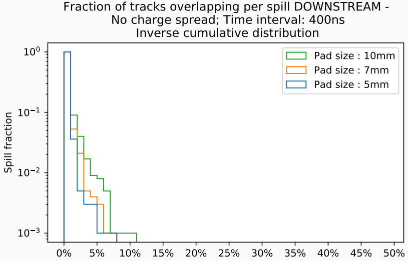


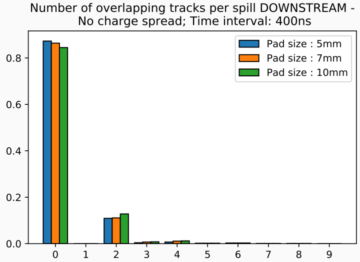
Only events with at least 1 track in the TPC are considered.

Charge spreading increases the amount of overlapping pads.

Evolution of inter-events overlaps with pad size - DOWNSTREAM

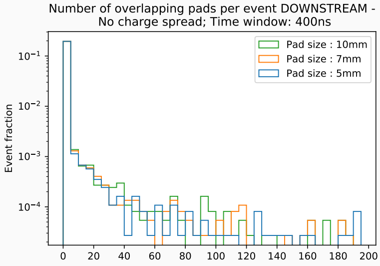


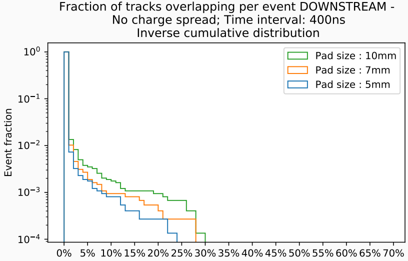


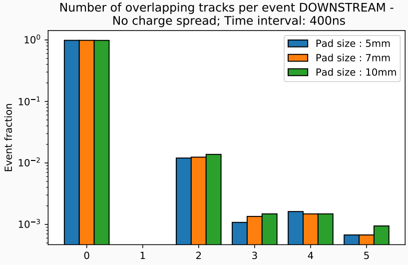


Using smaller pads only slightly reduces the number of inter-events overlaps.

Evolution of intra-event overlaps with pad size - DOWNSTREAM

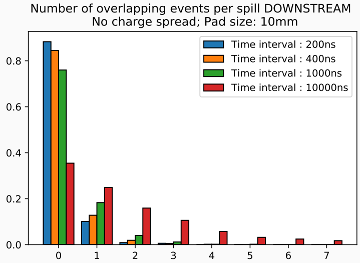


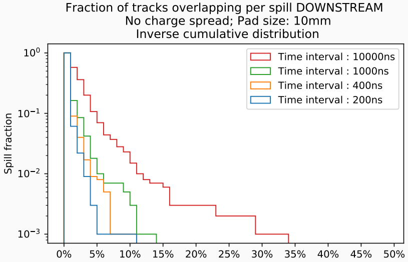


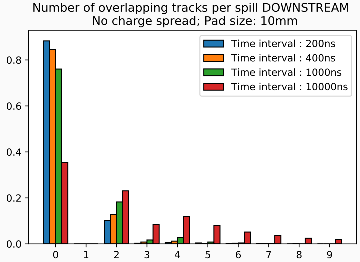


Pad size seems not to impact largely the number of overlaps.

Evolution of inter-events overlaps with time interval - DOWNSTREAM

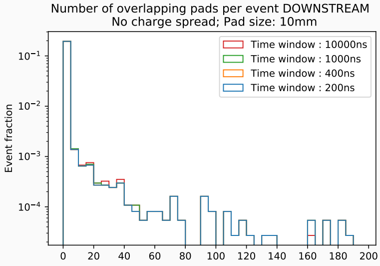


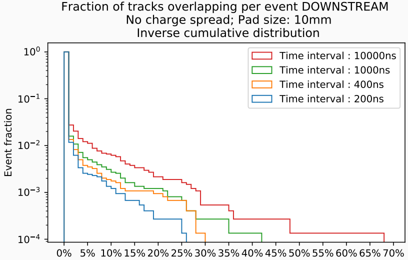


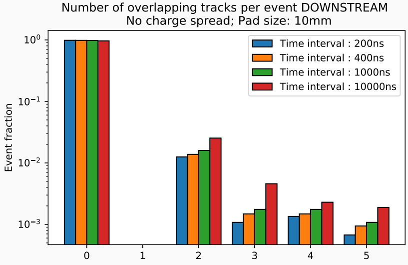


The shaping time is very important to discriminate the tracks in time and impacts a lot inter-events overlaps.

Evolution of intra-event overlaps with time interval - DOWNSTREAM

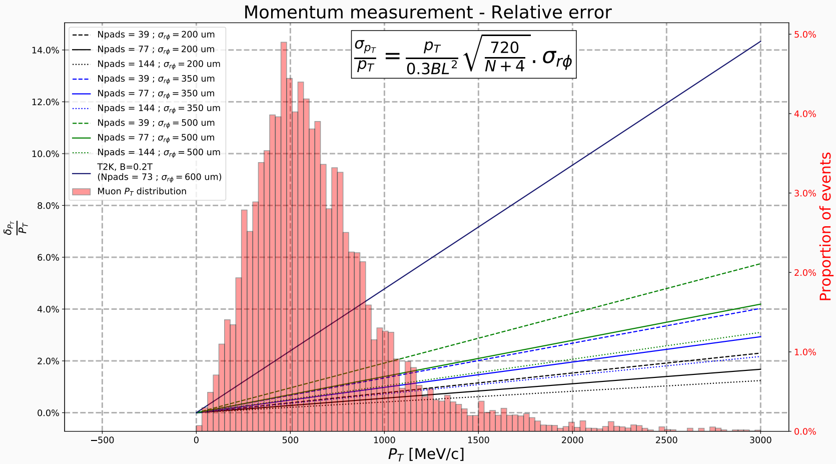






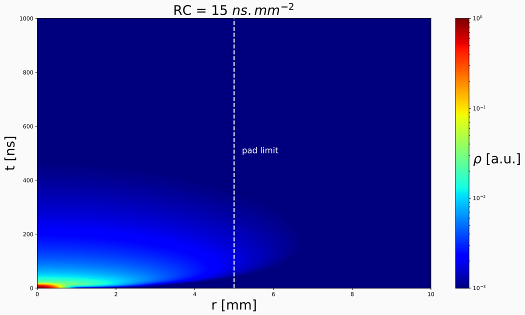
Time window has no effect on the number of overlapping pads for intra-event overlaps.

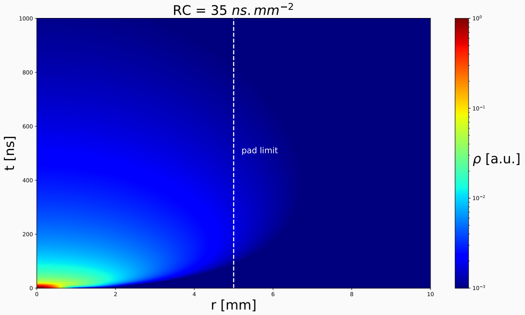
Estimation of P_T resolution



A resolution $< 2\,\%$ can be achieved if the occupancy is reasonable.

Charge spreading





The charge spreading radius does not depend on the RC value. RC only impacts the speed of the charge spreading.

Ongoing implementation in erep-sim.