Time-based MRPC detector response simulations for the CBM time-of-flight system

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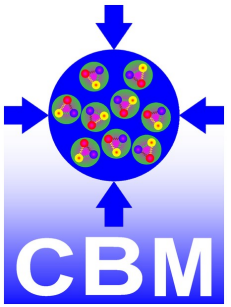
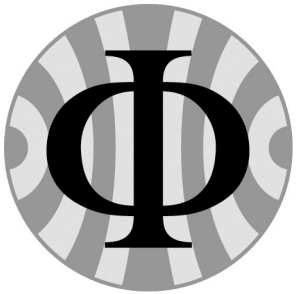




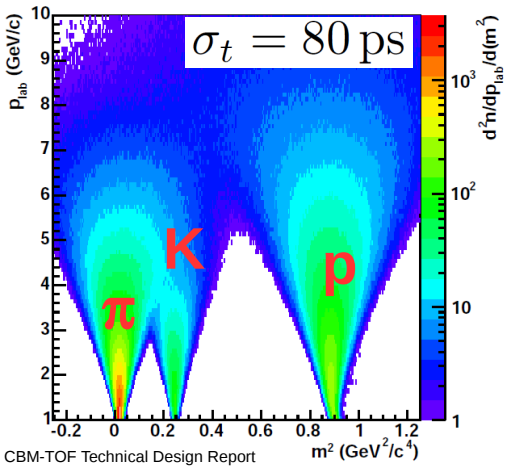
The CBM time-of-flight wall

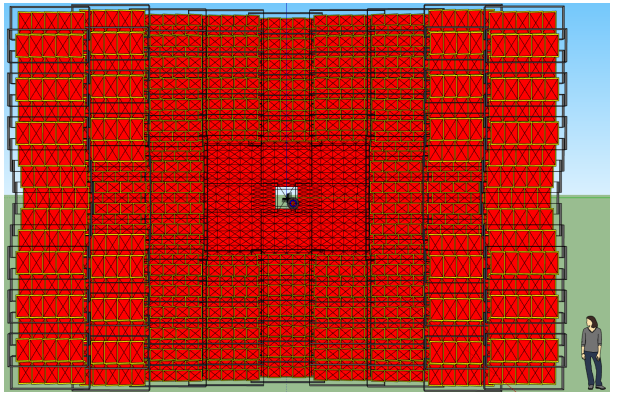
cf. D. Emschermann, “The Compressed Baryonic Matter experiment at FAIR”, **HK 66.1**
cf. I. Deppner, “The CBM Time-of-Flight wall”, **HK 38.1**

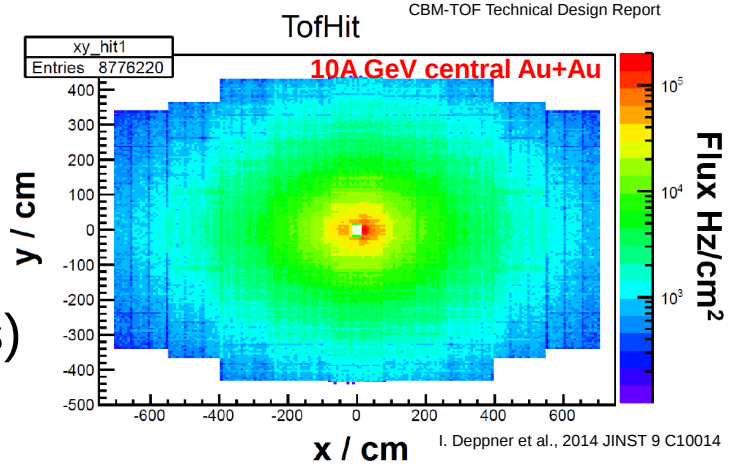
- main hadron identification tool up to momenta of 5 GeV/c in the angular range 2.5° - 25° covered by the S(ilicon) T(racking) S(tation) detector
- dimensions: 9 m high, 13.5 m wide, active area of about 120 m²
- time resolution 80 ps, efficiency > 95%

$$m^2 = p^2\left(\frac{1}{\beta^2} - 1\right)$$

$$\sigma_{m^2} = \frac{2p^2}{\beta^2}\frac{\sigma_t}{t}$$



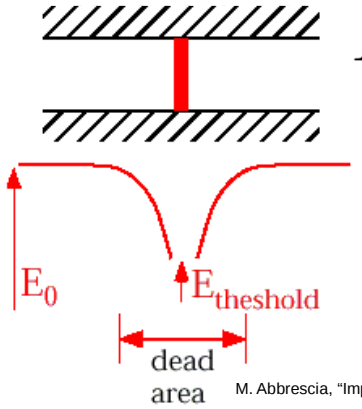




- strongly varying rates (up to 25 kHz/cm²)
- Multi-Gap Resistive-Plate Chambers (MRPCs)

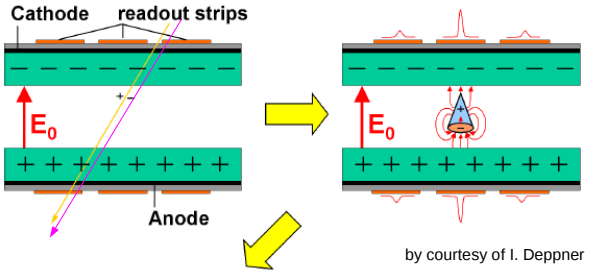
(M)RPC Working Principle

- gas detectors for timing measurements and trigger applications
- charged particles traversing the chamber form electron-ion pairs in the gas by ionization
- due to the applied high-voltage field the electrons are accelerated and ionize further gas molecules ("avalanche")
- external read-out electrodes are low-ohmic in contrast to HV electrodes and resistive plates
  → electrons induce mirror charges
- charges compensate on the resistive plates

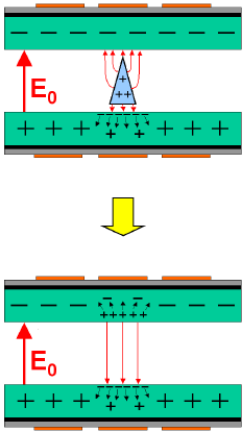


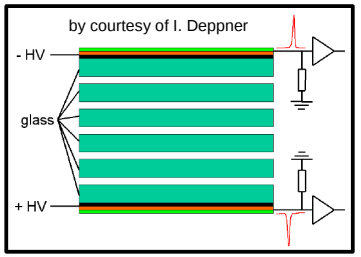
$$E(t) = E_0\left(1 - \exp\left(-t/\tau\right)\right)$$

→ electric field breaks down locally and recovers with a time constant of ~ 1s



by courtesy of I. Deppner



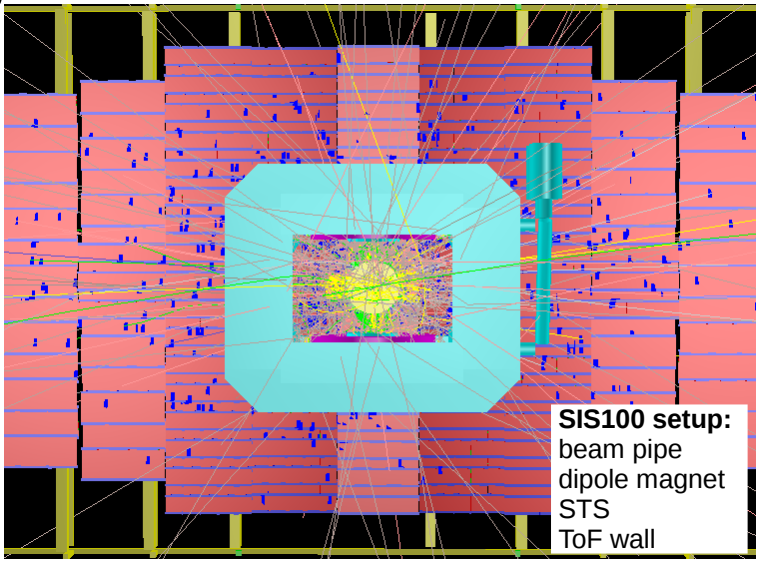


multiple gaps

M. Abbrescia, "Improving rate capability of Resistive Plate Chambers", RPC2016

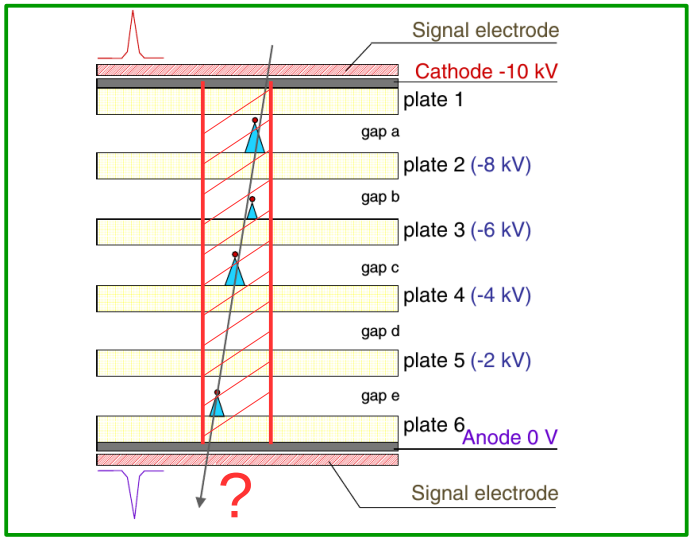
Monte Carlo simulation in CbmRoot

- A nuclear collision seed obtained from a transport code (UrQMD, HSD, PHSD, Pluto, SHIELD) is propagated through the CBM setup by a Monte Carlo (MC) engine (GEANT 3.21, Geant4 and FLUKA) handling
  - decays into secondary particles
  - material effects (energy loss, Coulomb multiple scattering)
- When a MC track enters a detector volume marked “active” material a Monte Carlo point object is created storing information such as
  - detector element address
  - interaction point coordinates
  - time passed since event start
- ToF points contain no information about
  - analog/digital sensor response
  - hit density effects
  - rate effects (motivation for time-based simulations)

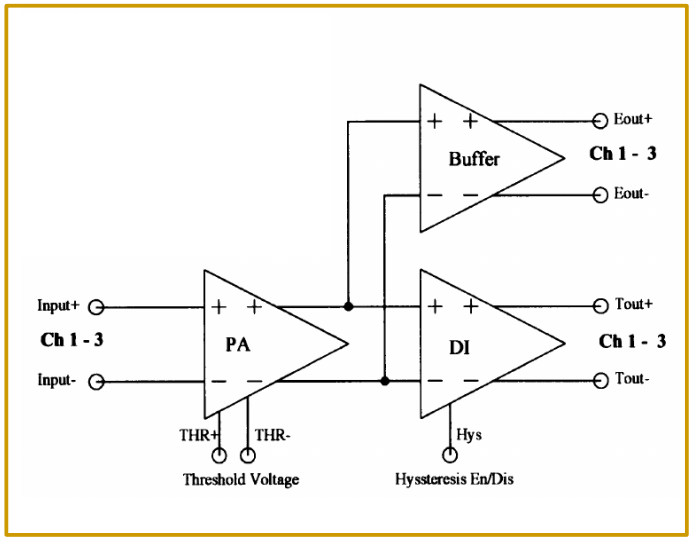


The digitization task

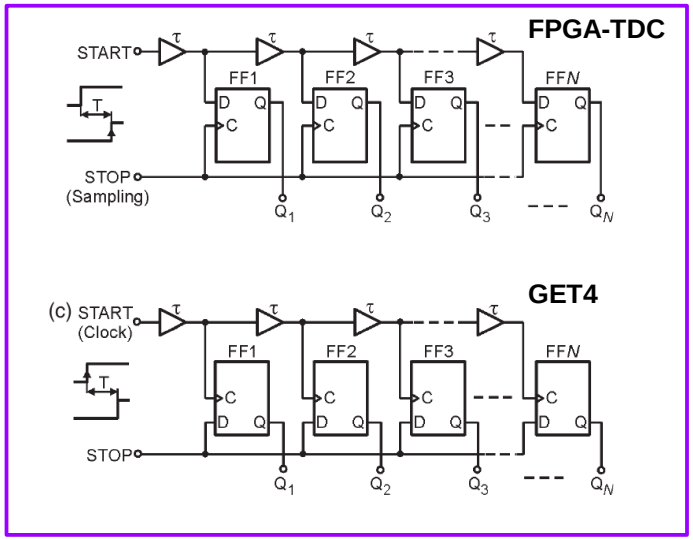
- For each MC point in the ToF wall, simulate the analog response of the MRPC and the subsequent signal processing by the preamplifier/discriminator and the time-to-digital converter stage



M.C.S. Williams, J. Phys. G: Nucl. Part. Phys. 39 (2012) 123001



M. Ciobanu et al., IEEE Nucl. Sci. Symp. Conf. Rec. 2008 (2008) 2018



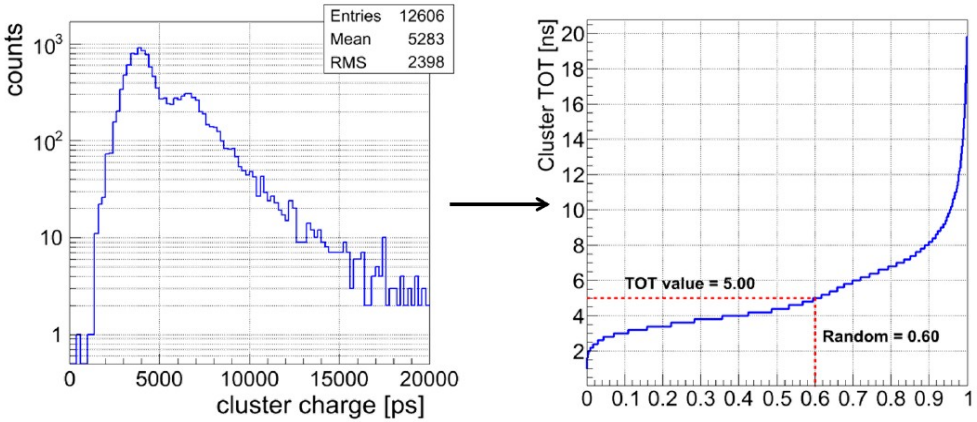
J. Kalisz, Metrologia 41 (2004) 17

- An analytic or MC treatment of the MRPC response in particular is not straightforward and very time consuming

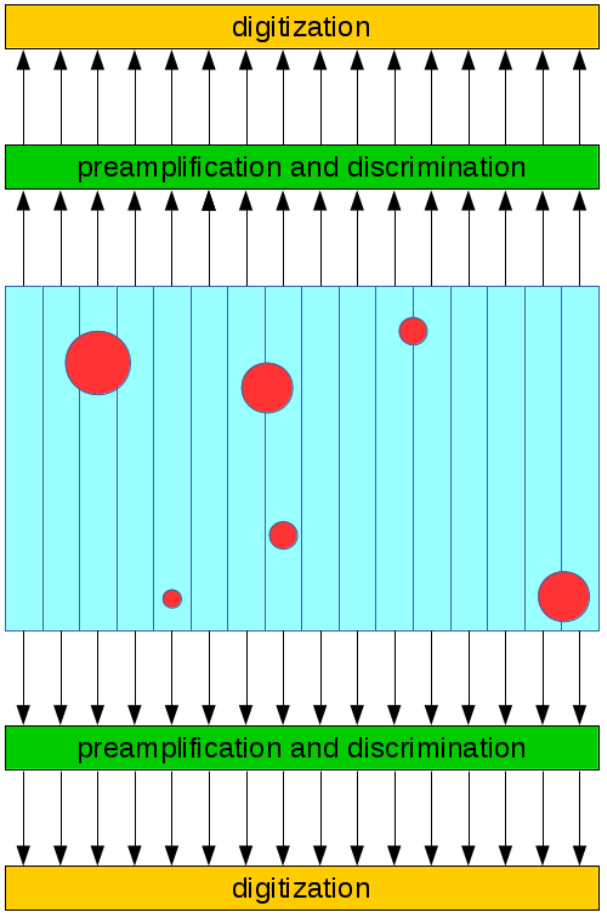
  → determine a simple self-consistent parametrization of the response

Event-based solution

- input parameters from cosmic or in-beam irradiation of the MRPC
- throwing dice on MRPC characteristics for a certain ToF point
  - efficiency [0,1]
  - time resolution [histogram]
  - cluster size [histogram]
  - cluster charge [histogram]



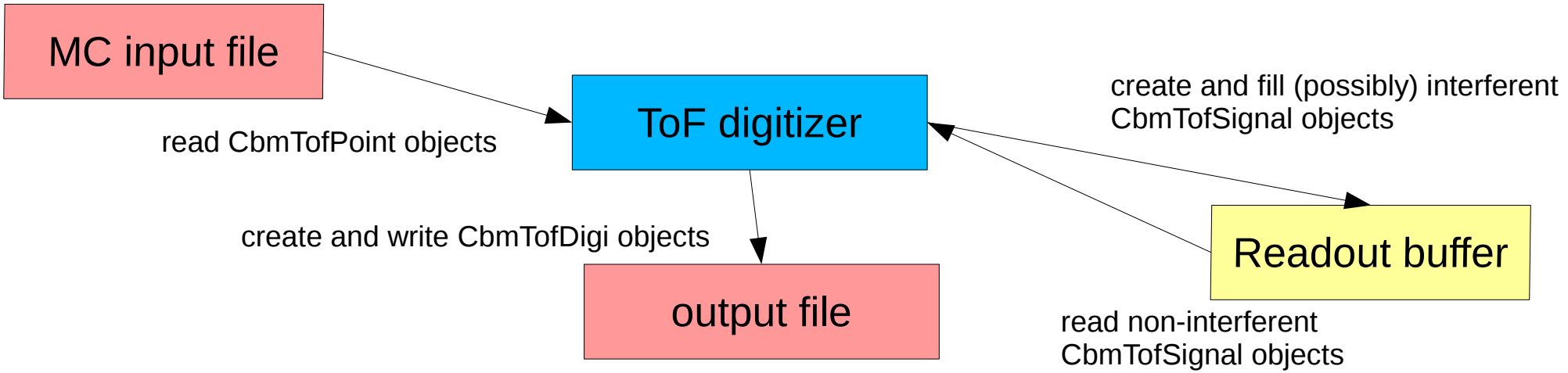
P.-A. Loizeau, Ph.D. Thesis, Heidelberg University, Heidelberg, Germany, 2014



- hit density and rate effects not yet included

Time-based framework in CbmRoot

- Dedicated class CbmReadoutBuffer for analog interference handling in the digitizer classes



- a transient CbmTofSignal object can interfere with other CbmTofSignal objects within a given time interval
- if all possible interferences have been resolved, create a CbmTofDigi object (readout channel address, ToF point time folded with detector and electronics response functions)

Event-based vs. time-based mode

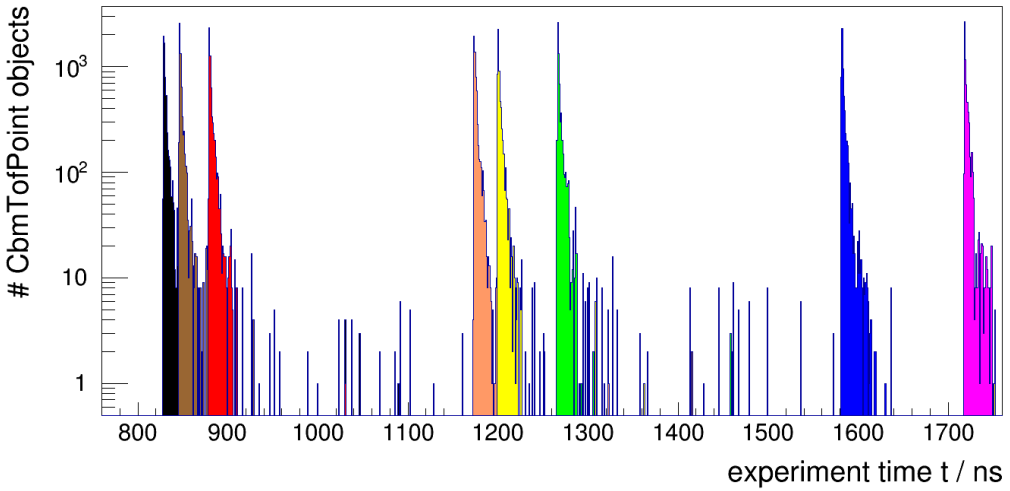
cf. G.Kozlov, “Time-based cluster and hit finding for the STS detector in the CBM experiment at FAIR”, **HK 8.3**

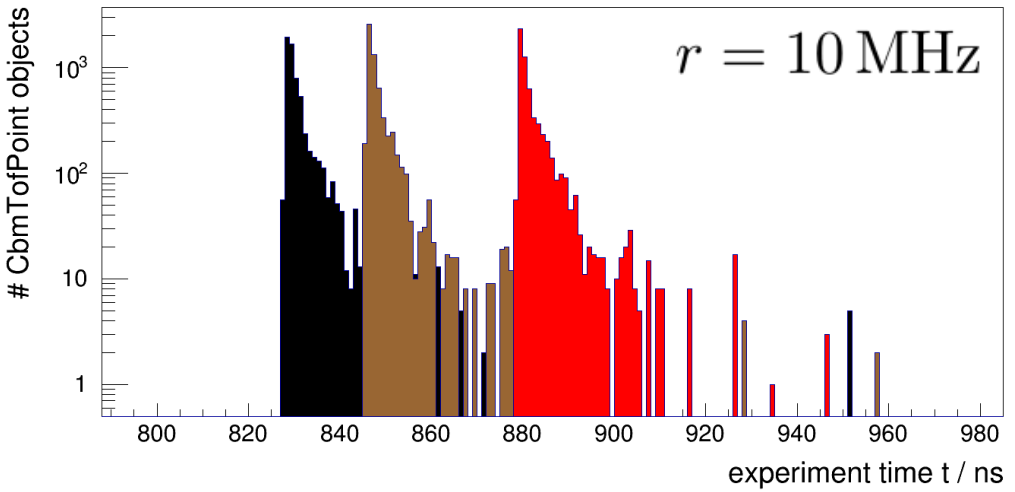
- event-based mode: interference only between particles in a single event
  - MRPC rate effects and electronics dead time are reset after 1 event
- time-based mode: interference across events
  - assumption: Poisson distribution of # events within a given time interval (e.g. 1 event per 100 ns for 10 MHz interaction rate)

    → exponential distribution of time intervals between events

$$r = 10\,\mathrm{MHz} \quad : \quad P(t \leq 25\,\mathrm{ns}) \simeq 22\%$$
$$r = 100\,\mathrm{kHz} \quad : \quad P(t \leq 25\,\mathrm{ns}) \simeq 0.2\%$$

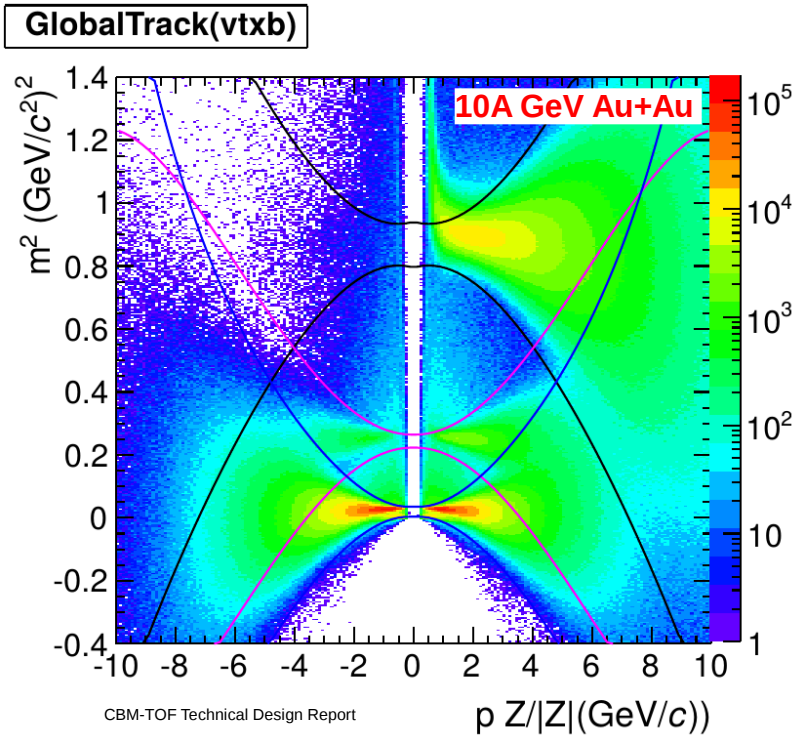
$$P(t)\,dt = e^{-rt}\,r\,dt$$





Further data processing

- Reconstruct CbmTofHit objects from CbmTofDigi objects ("clustering")
- Assign CbmTofHit objects to extrapolated "global" particle tracks
  - event hypothesis necessary (event start information)
- Identify particles based on track properties



Conclusions and Outlook

- An event-based digitizer class for CBM ToF that parametrizes the MRPC response function based on in-beam test results is available
- CbmRoot supports both event-based (removing all analog and digital traces in the ToF system after processing one event) and time-based data handling
- Limitations of the event-based digitizer (hit density) are known and parameters for a transition to a time-based digitizer (local electric field breakdown and recovery) have been identified
- The implementation of the time-based response calculation is work in progress

The CBM ToF group

Participating institutes

- THU DEP, Beijing, China
- IFIN-HH, Bucharest, Romania
- GSI, Darmstadt, Germany
- TUD IKP, Darmstadt, Germany
- HZDR ISP, Rossendorf, Germany
- GU IRI, Frankfurt, Germany
- USTC DMP, Hefei, China
- RKU PI, Heidelberg, Germany
- CCNU IOPP, Wuhan, China
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