Simulation of the time structure of hadronic showers in calorimeters with gas and with scintillator readout

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Outline

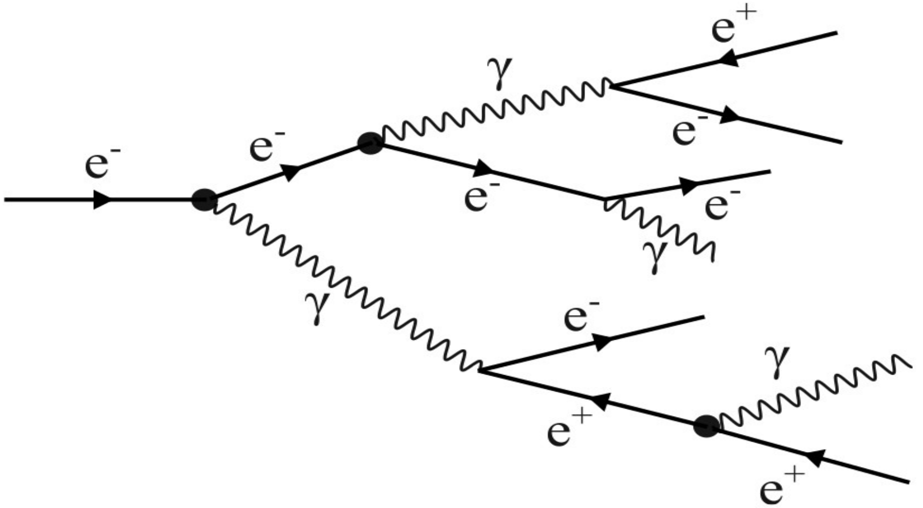
- Motivation
- Particle Showers
- Calorimeter
- Shower time development
- Hadronic calorimeter at linear colliders
- Simulation results / comparisons

Motivation

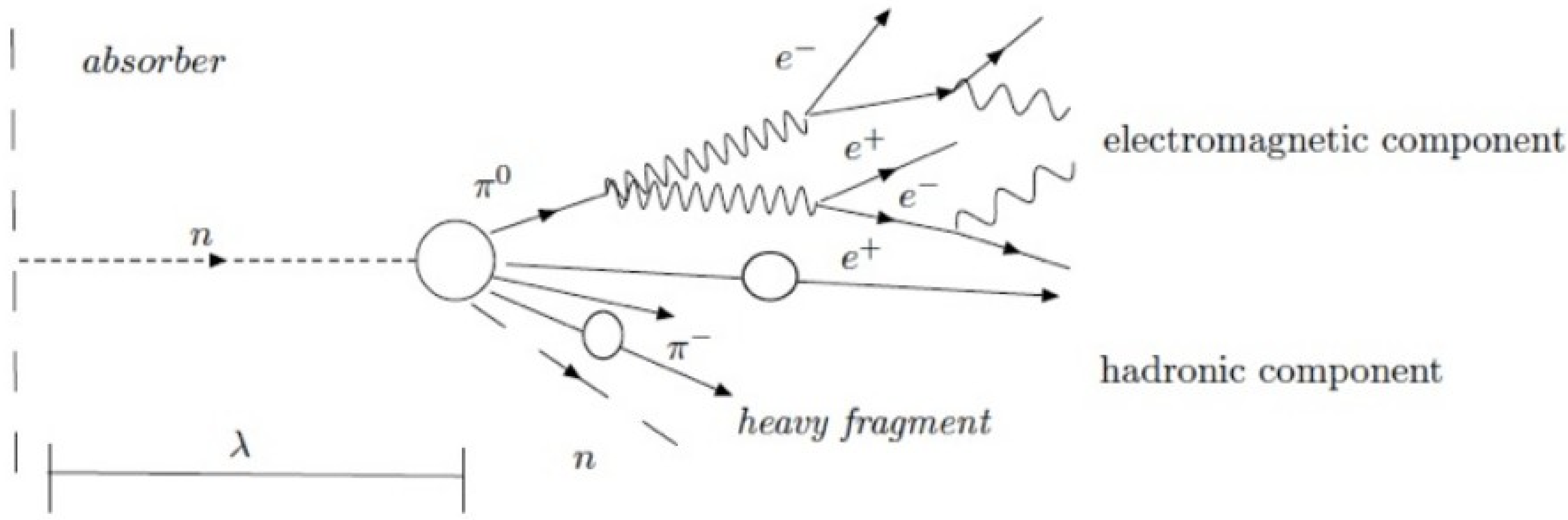
- Calorimeters determine particle energy in destructive measurements
- The time structure is interesting because it enables us to weight differently which allows higher resolution of subshower
- Tungsten Timing Test Beam (T3B) experiment is designed to provide validation of hadronic shower models
  - Measurement of the time structure of the interaction of hadrons in Calorimeter with nanosecond precision and high spatial resolution

EM Showers

- High energy electrons loose energy mostly through Bremsstrahlung
- Which leads to high energetic photons
- Photon with >1MeV → e+e- pair production
- Electromagnetic cascades, formation of a shower



Hadronic showers



- Hadronic showers produced by high energy hadrons interacting with matter
- Nuclear and strong interactions
- Produce secondary lower energy particles
  - Relativistic hadrons: result mostly in Pions ; 30% of which are P0 → 2 photons → EM
  - Excitation
  - Nuclear spallation
  - Fission

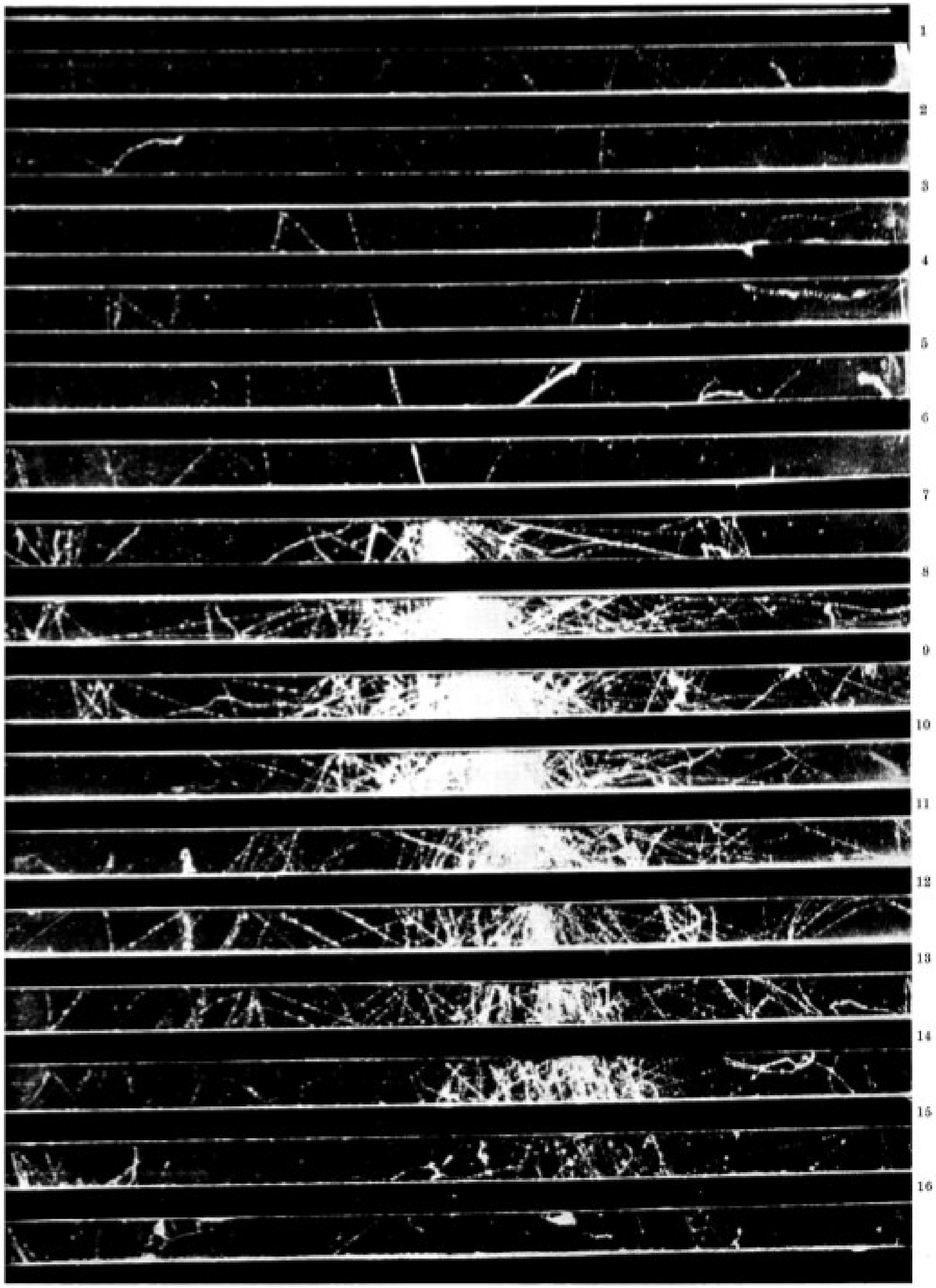
} Result in production of neutrons which lead to extended time structure

Calorimeter

- A calorimeter is used to measure energy of a particle
- Particles get absorbed
- The denser the absorber is → the more energy the particles lose passing through
- Two types of Calorimeter
  - Electromagnetic calorimeter measure EM interactions
  - Hadronic calorimeter measure particles that interact via the strong nuclear force

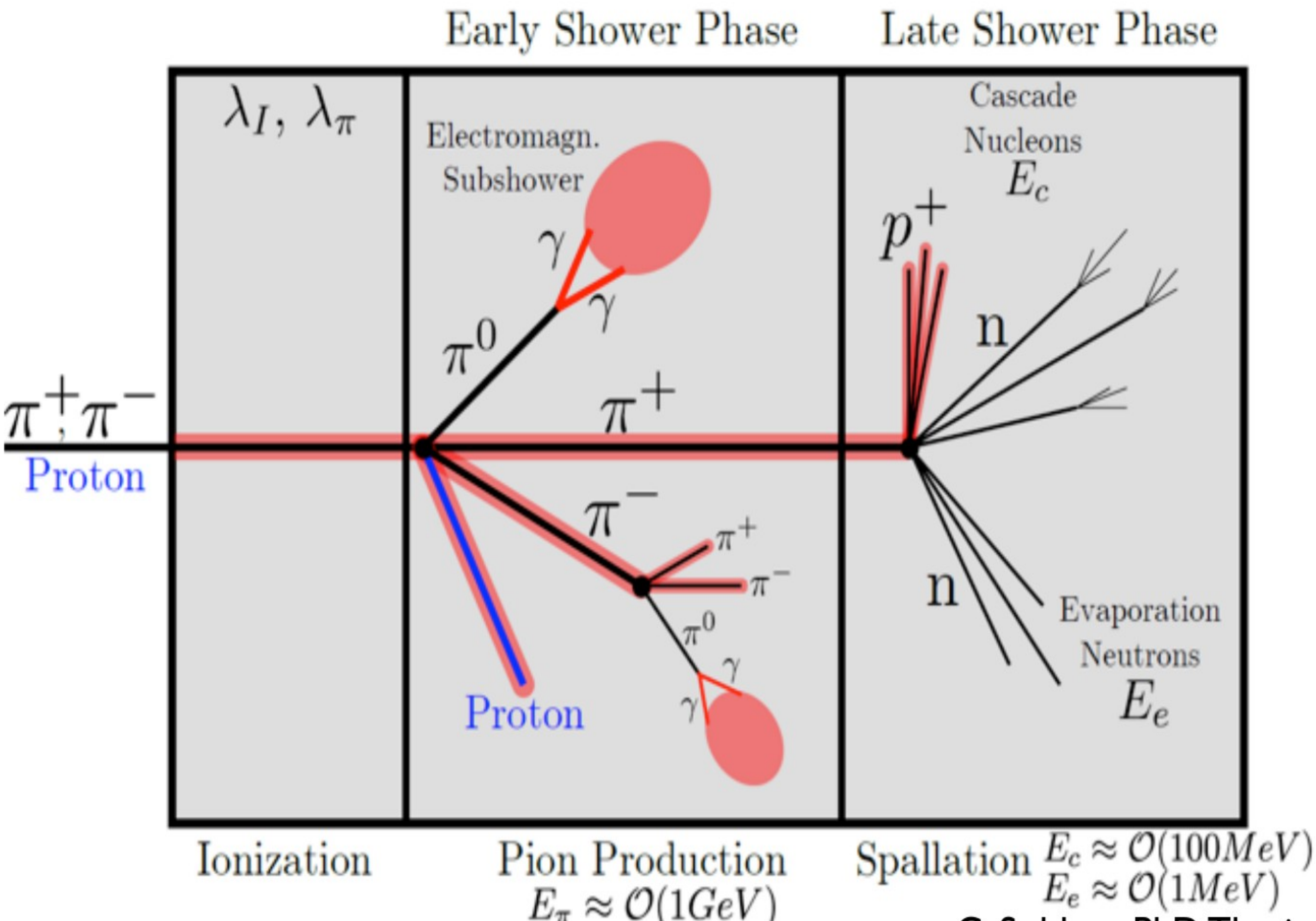
- We use a sampling calorimeter

Sampling Calorimeter



- Material that produces the particle shower is distinct from the material that measures the deposited energy
- Dense material is used to produce a shower that evolves quickly in a limited space
- Disadvantage: most of the energy is deposited in the wrong material and is not measured
- Thus the total shower energy must be estimated

Time development

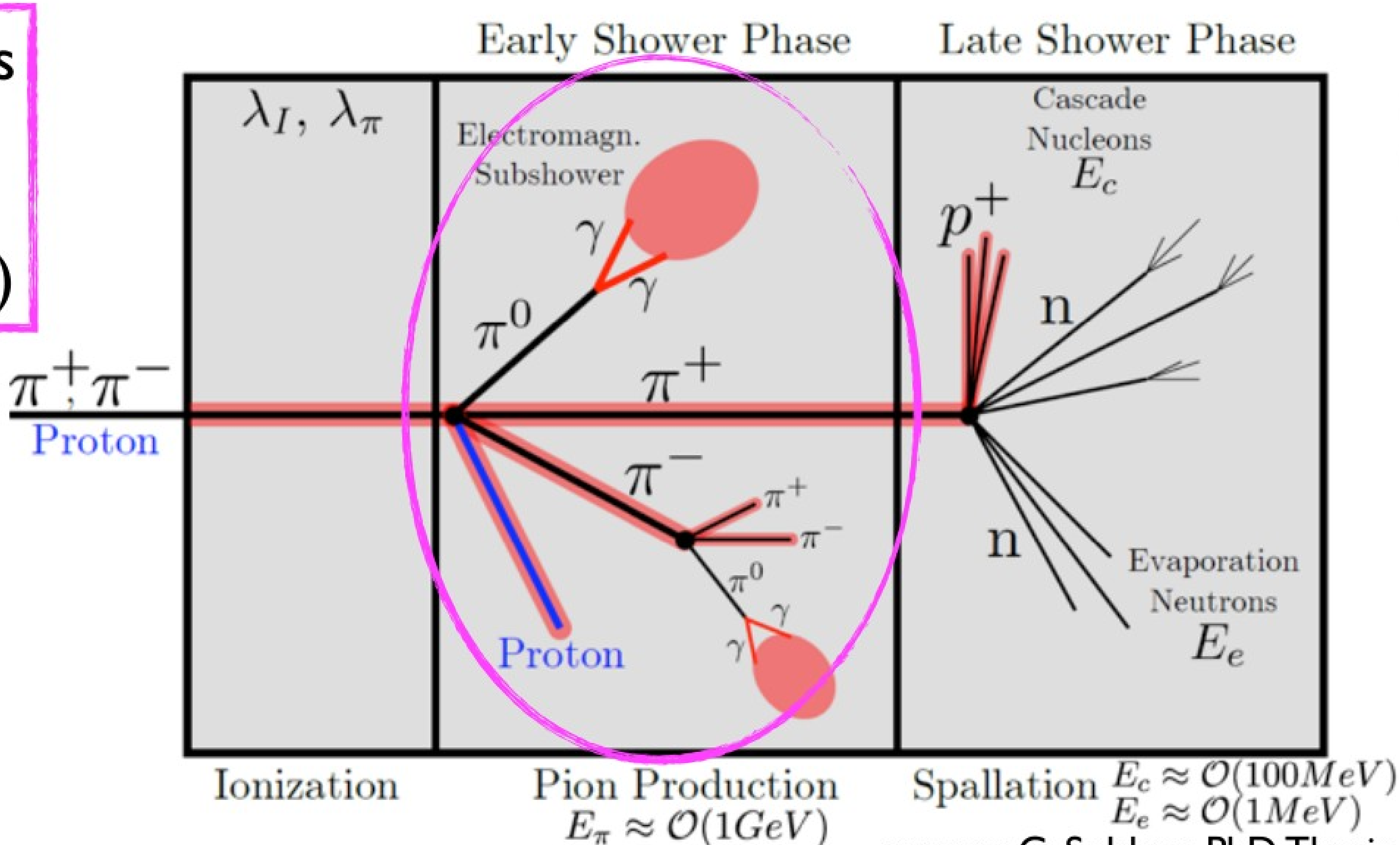


source: C. Soldner PhD Thesis

- Different phases of the shower

Time development

Early phase: instantaneous components (mainly relativistic hadrons and electromagnetic showers)



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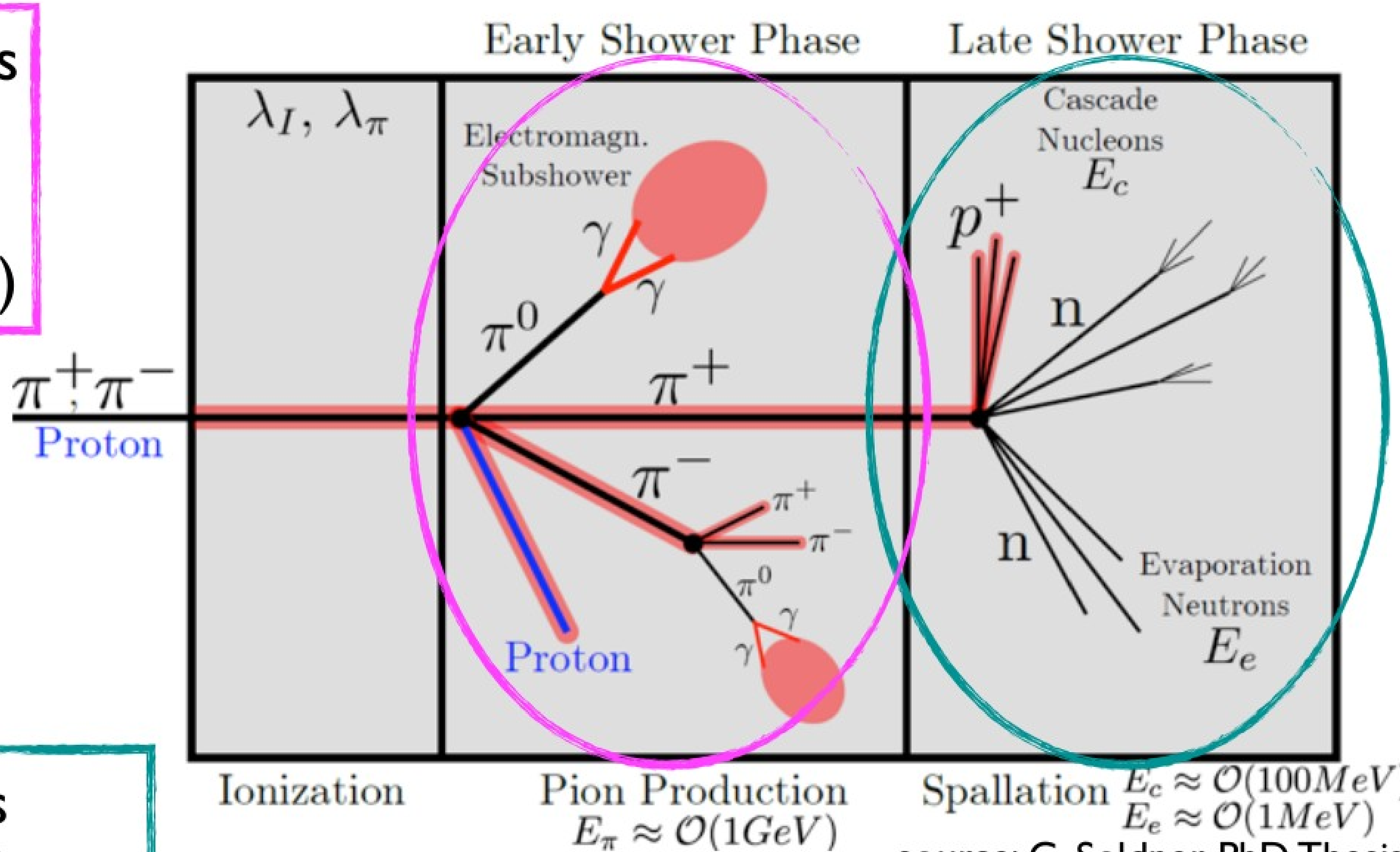
Time development

Early phase: instantaneous components (mainly relativistic hadrons and electromagnetic showers)

Late phase: slow neutrons capture, evaporation, spallation



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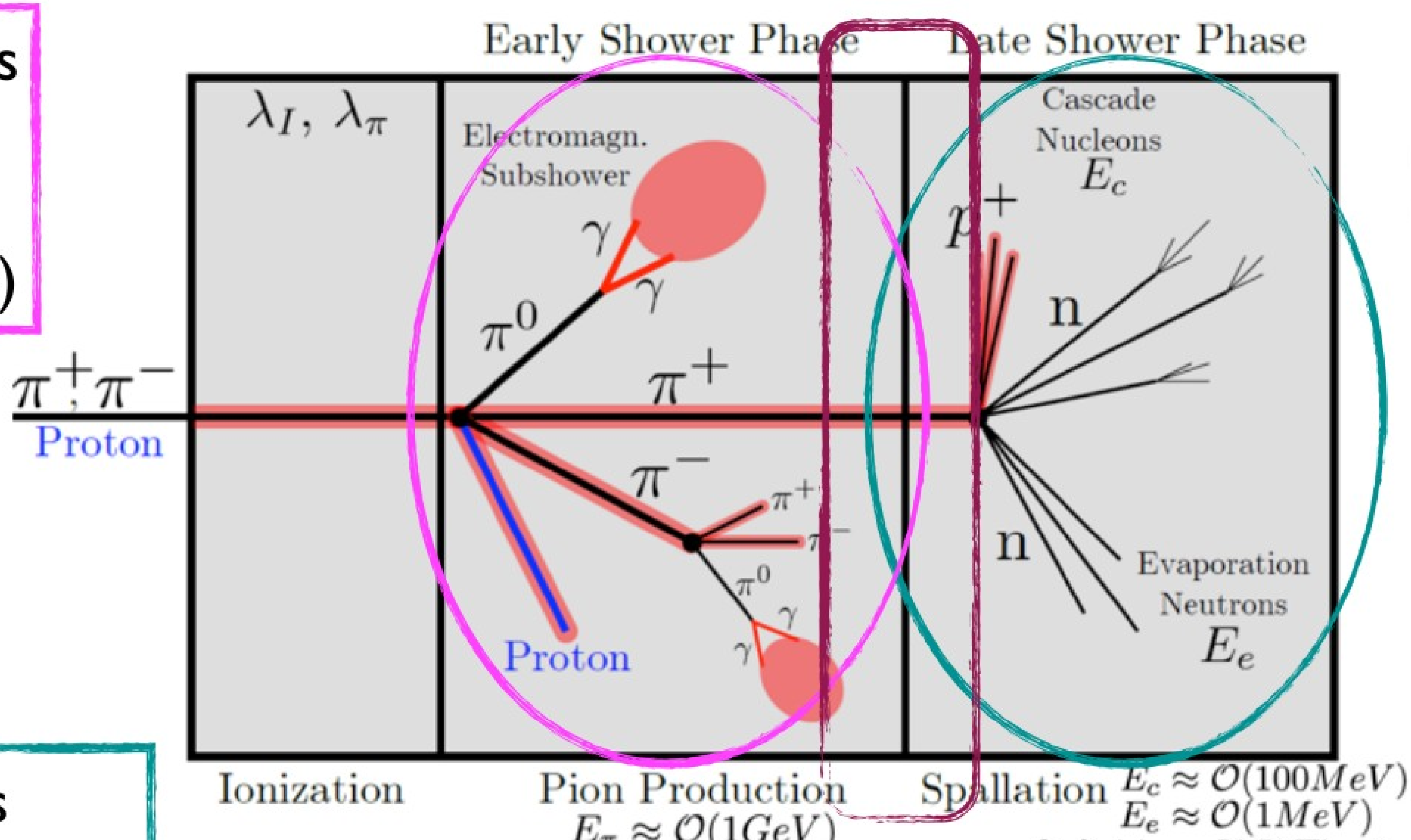
Time development

Early phase: instantaneous components (mainly relativistic hadrons and electromagnetic showers)

Intermediate phase: neutron scattering

Late phase: slow neutrons capture, evaporation, spallation



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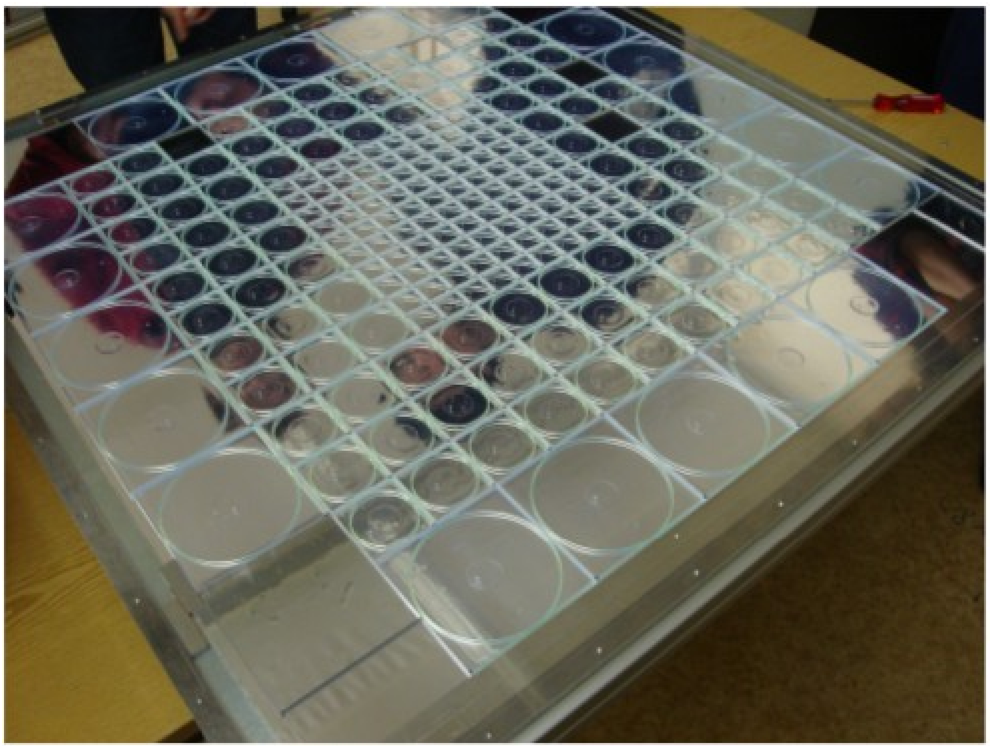
Intermediate phase: neutron scattering

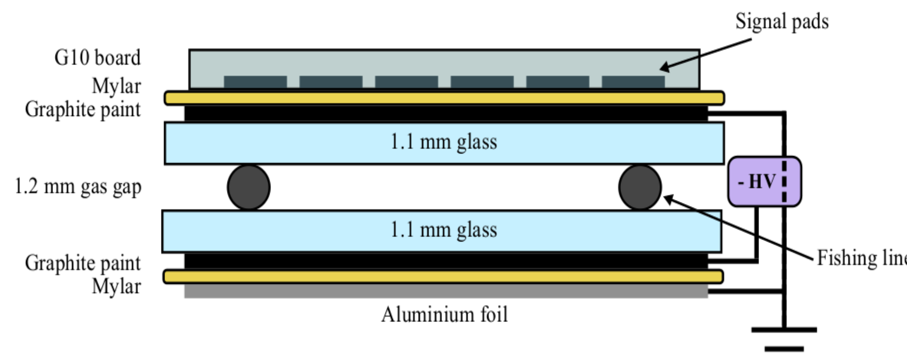
- Less Hydrogen in gaseous detector (density, material)

  → Less sensitive to neutron elastic scattering
- Assumption (backed by data):
  - Contribution from neutron elastic scattering should go down with less Hydrogen
- Monte Carlo Simulations can verify our assumption

Several concepts for the hadronic calorimeter at linear colliders

- Plastic scintillators tiles (left) with Silicon Photomultiplier (SiPMs) readout
- Resistive Plate Chambers (RPCs) with digital readout (DHCAL)





polystyrene

- High granularity → particle flow event reconstruction

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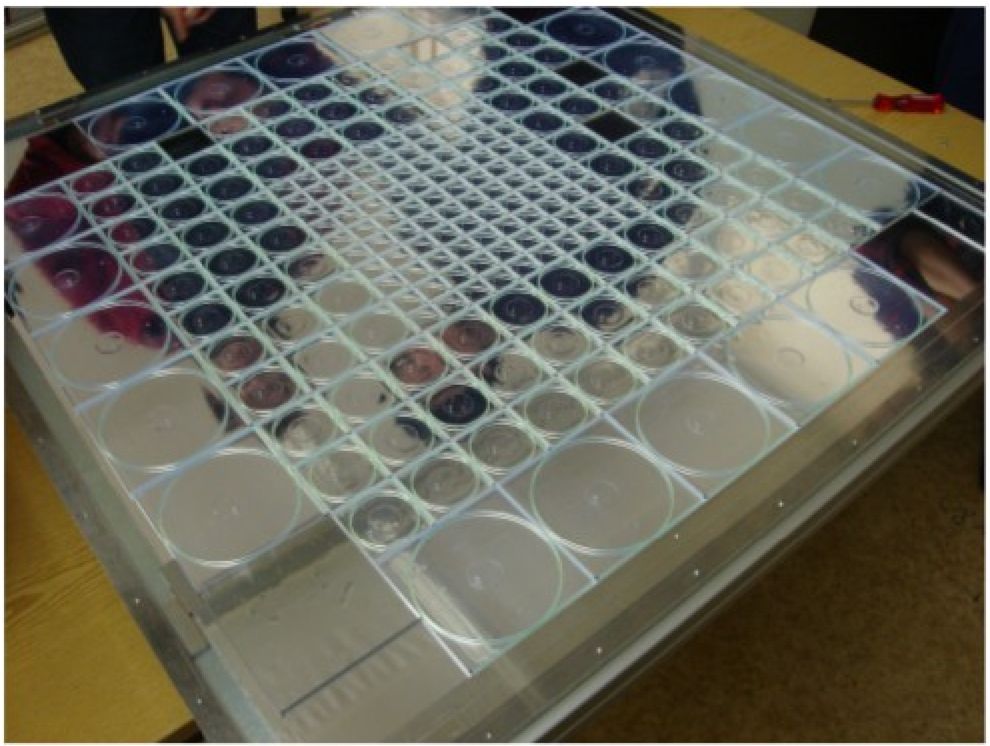
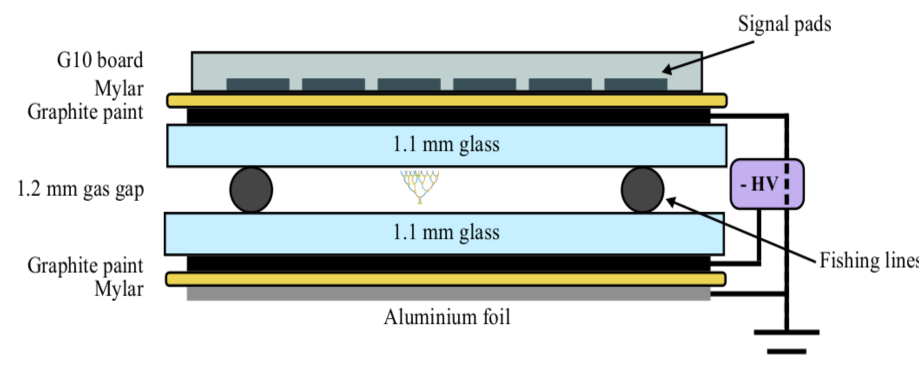




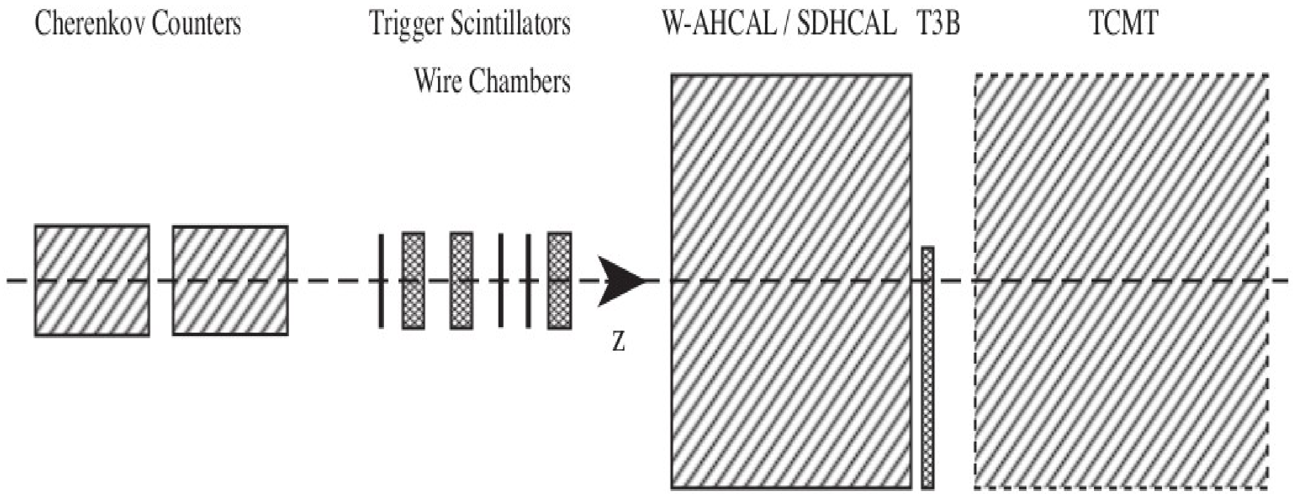
particles passing through

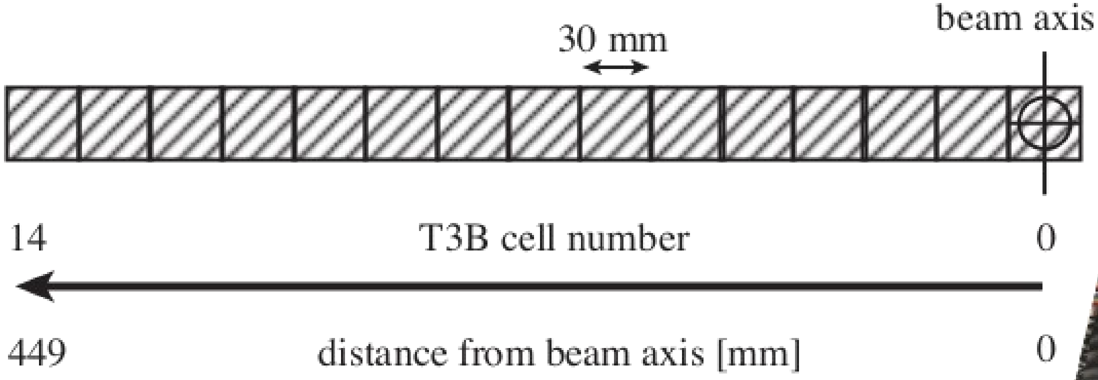
Ionizing Gas

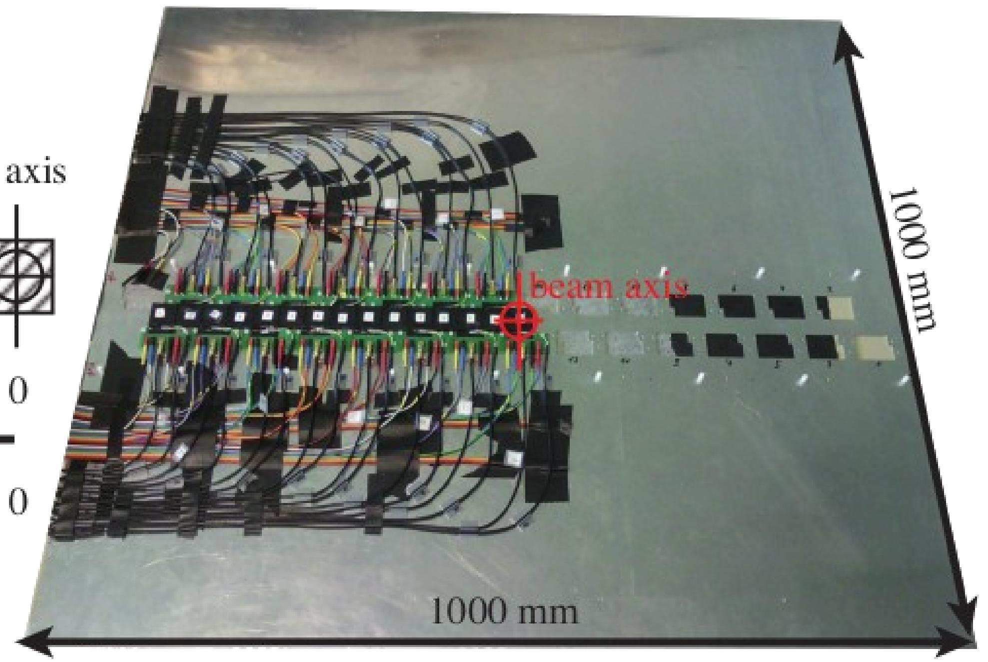
Electric field → knock further electrons free → avalanche

Setup

- Test beam at CERN SPS H8 beam line
- T3B behind HCal
- 1x Scintillator (T3B)
- 1x Gas (FastRPC)







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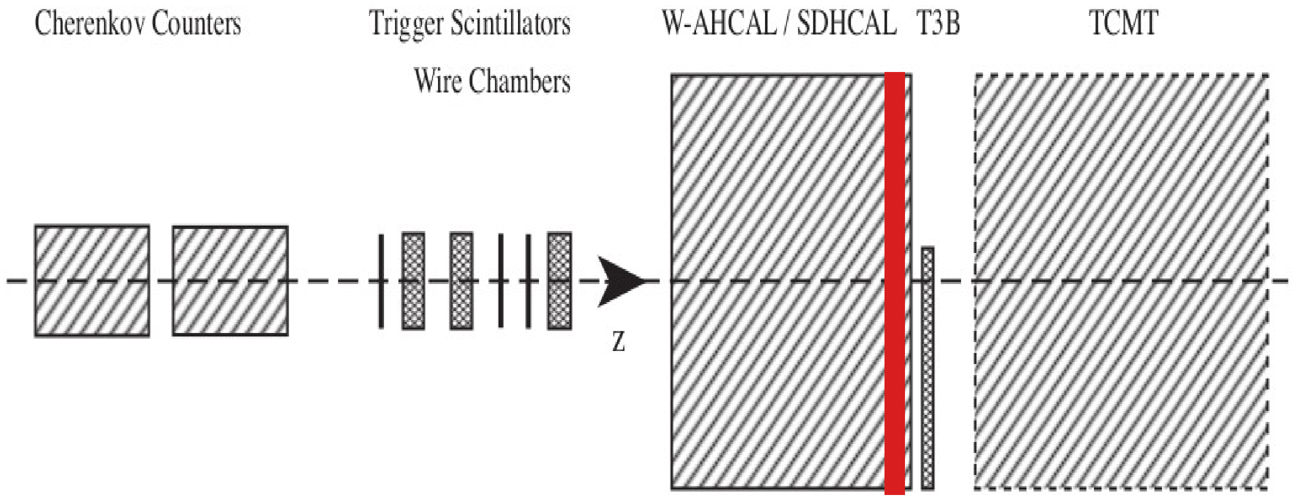
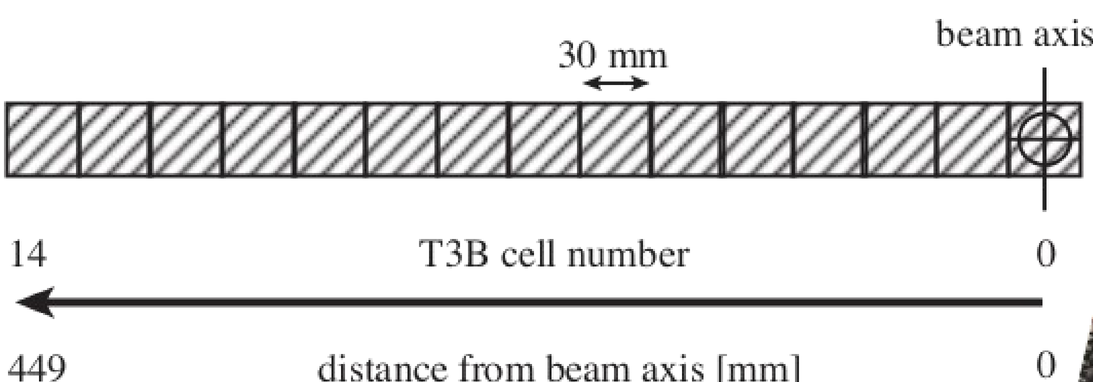
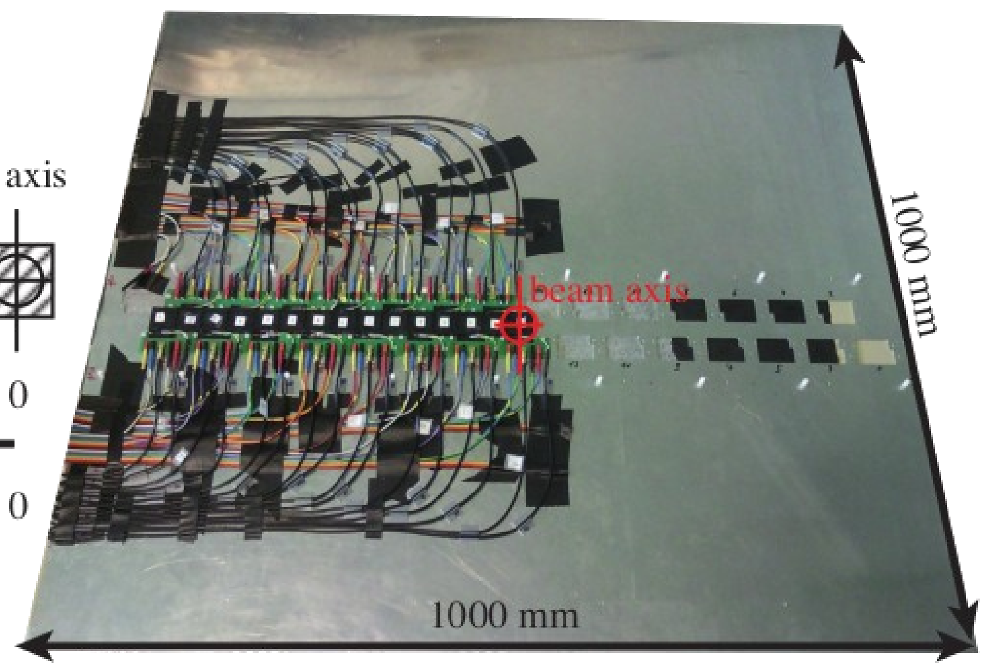






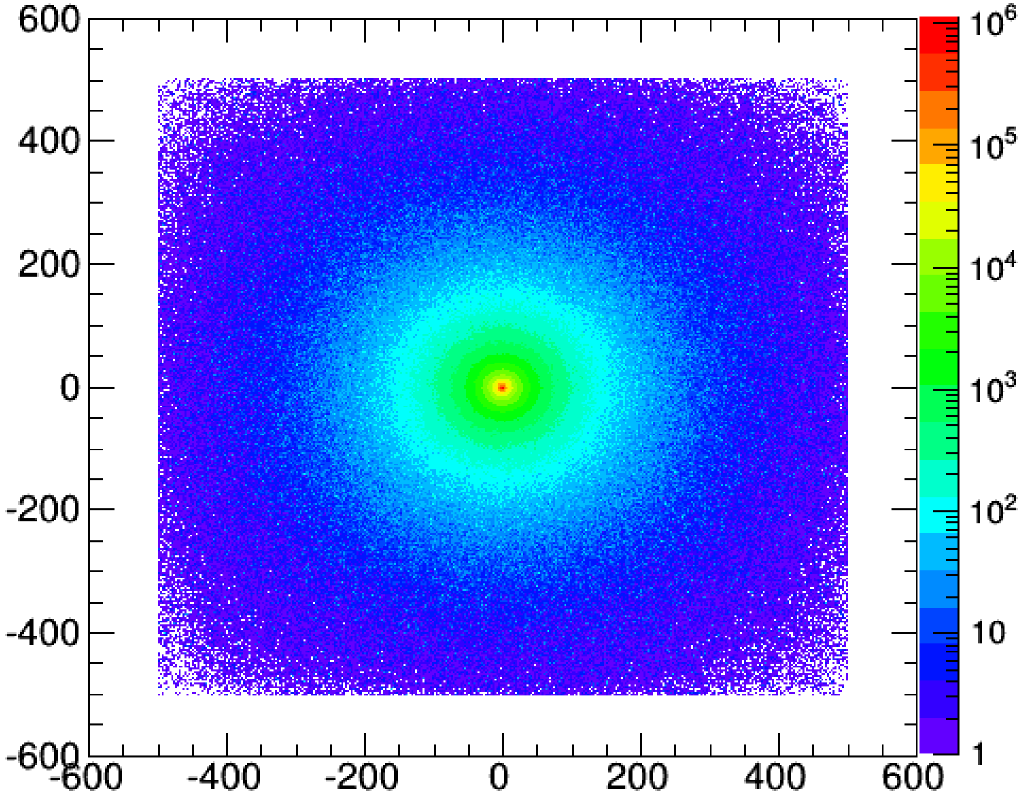
Simulation of the last Layer

same # of 60 GeV Pions → Steps in Geant4

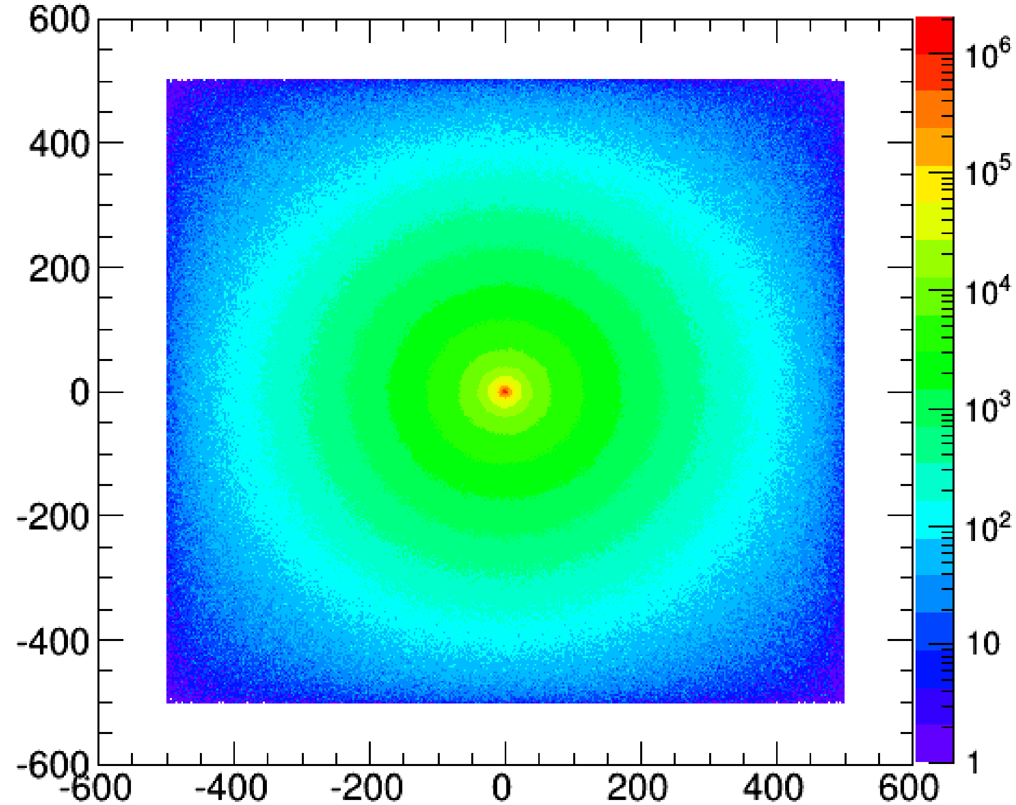
more in Scintillator due to density

neutrons lead to energy deposits at large distances from beam axis

Gas



Scintillator

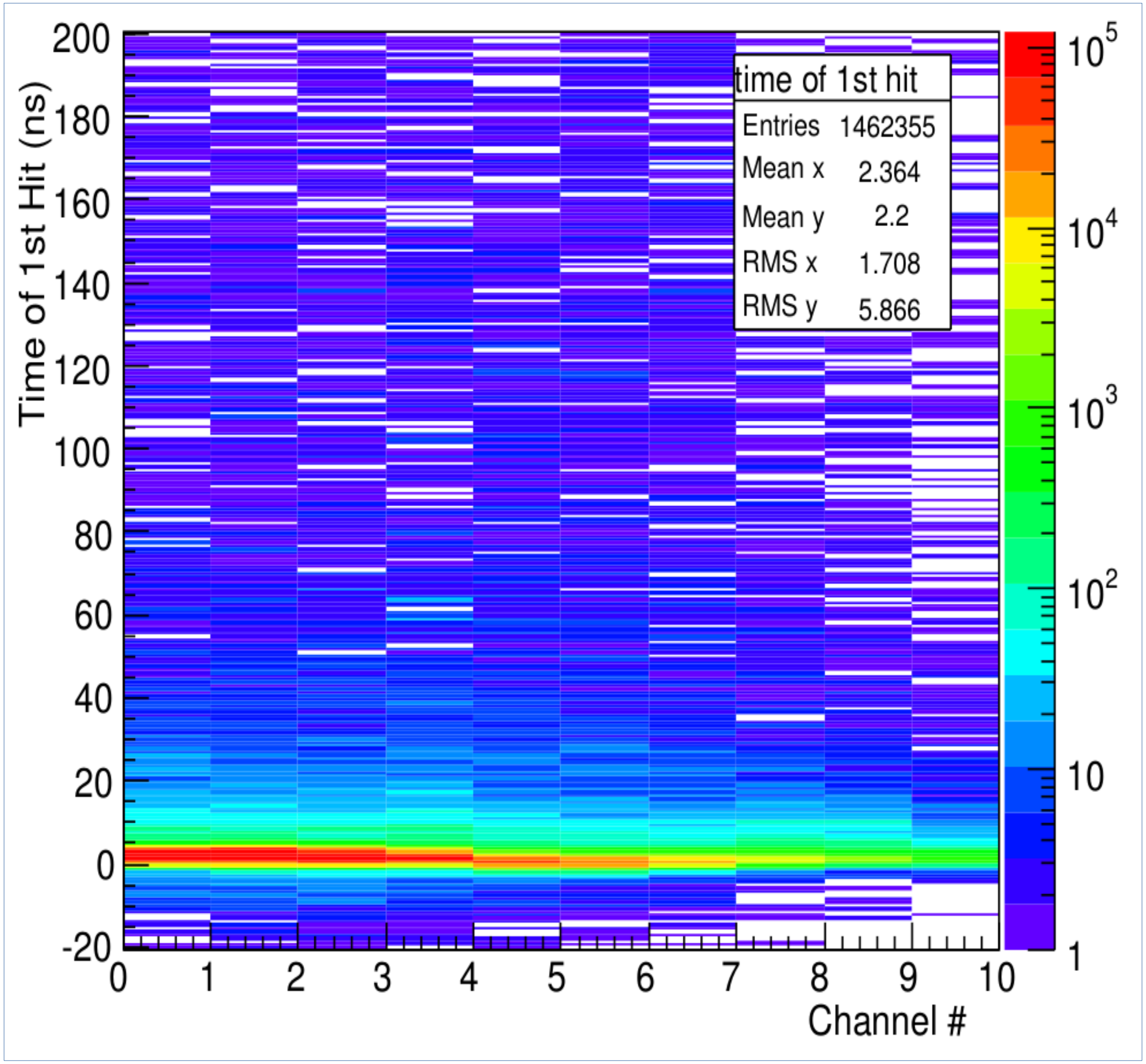


Time of first hit

- When a particle looses more energy than the energy of a Minimum Ionizing Particle, this interaction is counted as first hit
  - Minimum Ionizing Particles (MIPs) are charged particles, which embody the minimum ionizing energy loss in substances
  - A hit is a physical interaction in the sensitive region of a detector

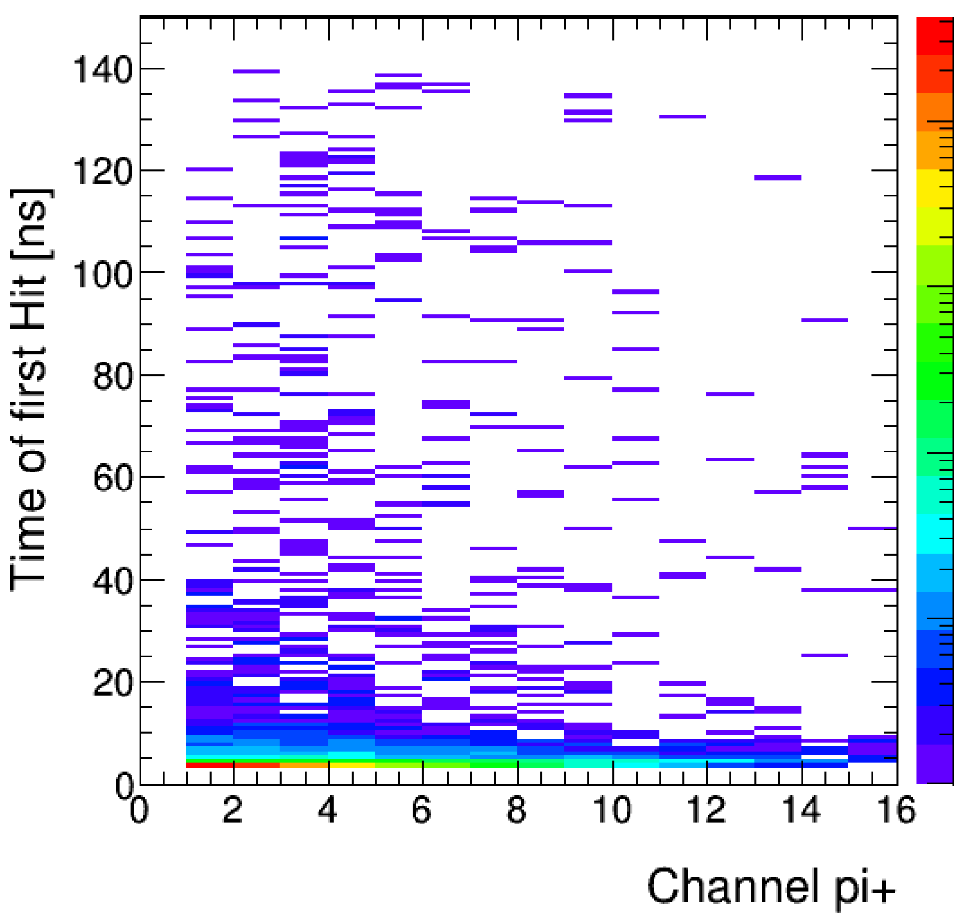
Data taken in test beam

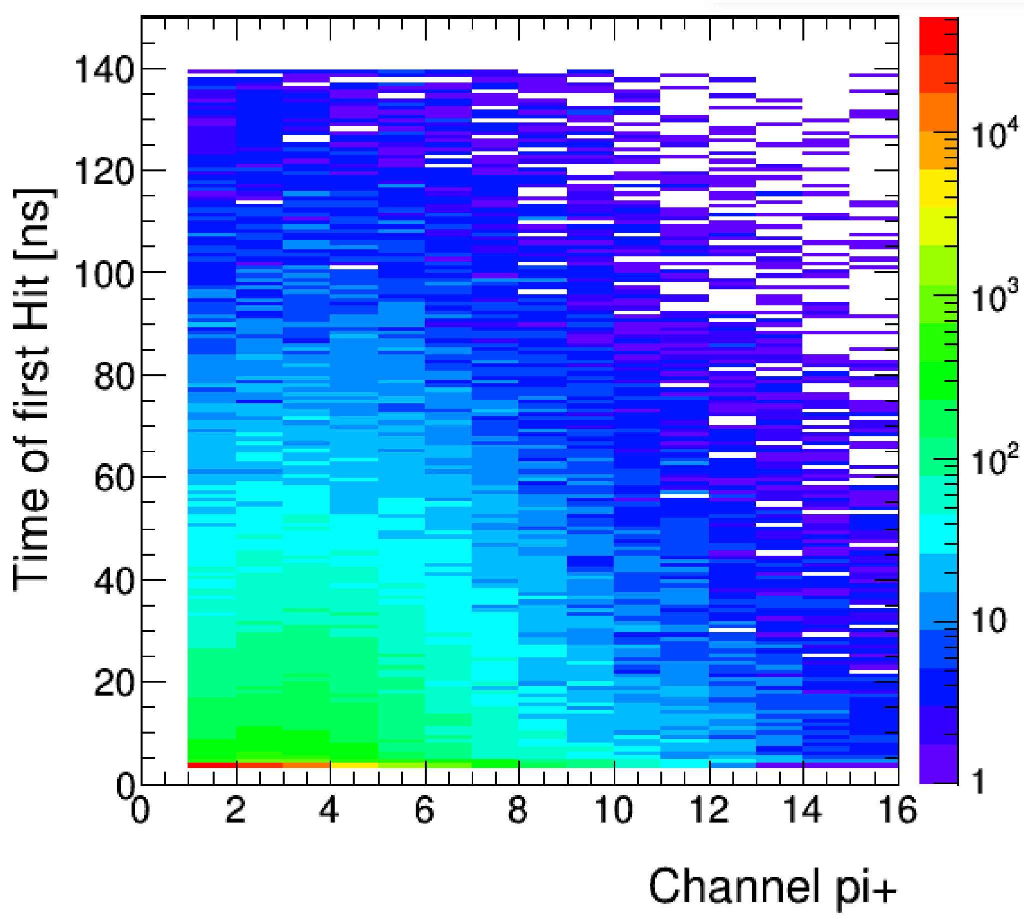
- Inside the special Layer
- Channel vs. Time of 1st Hit vs. number of entries per bin
- 80 GeV Pions
- Data taken from FastRPC Gas detector
- After few tens of ns the only energy contributions remaining come from neutrons



Not normalised

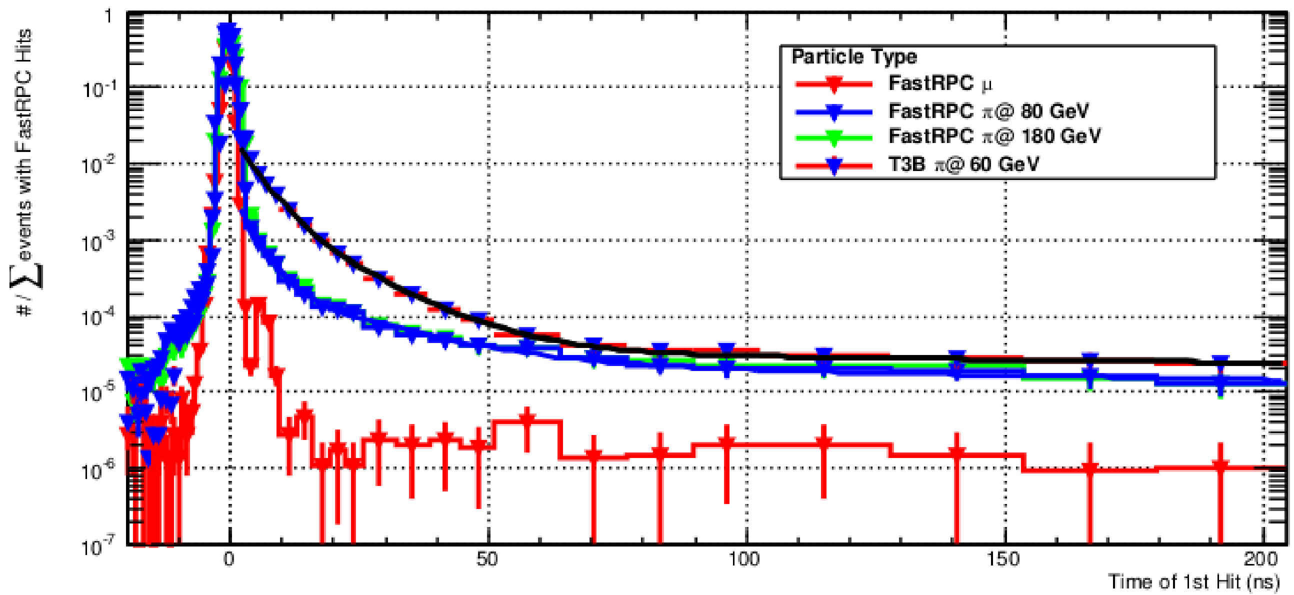
Time of first Hit simulated



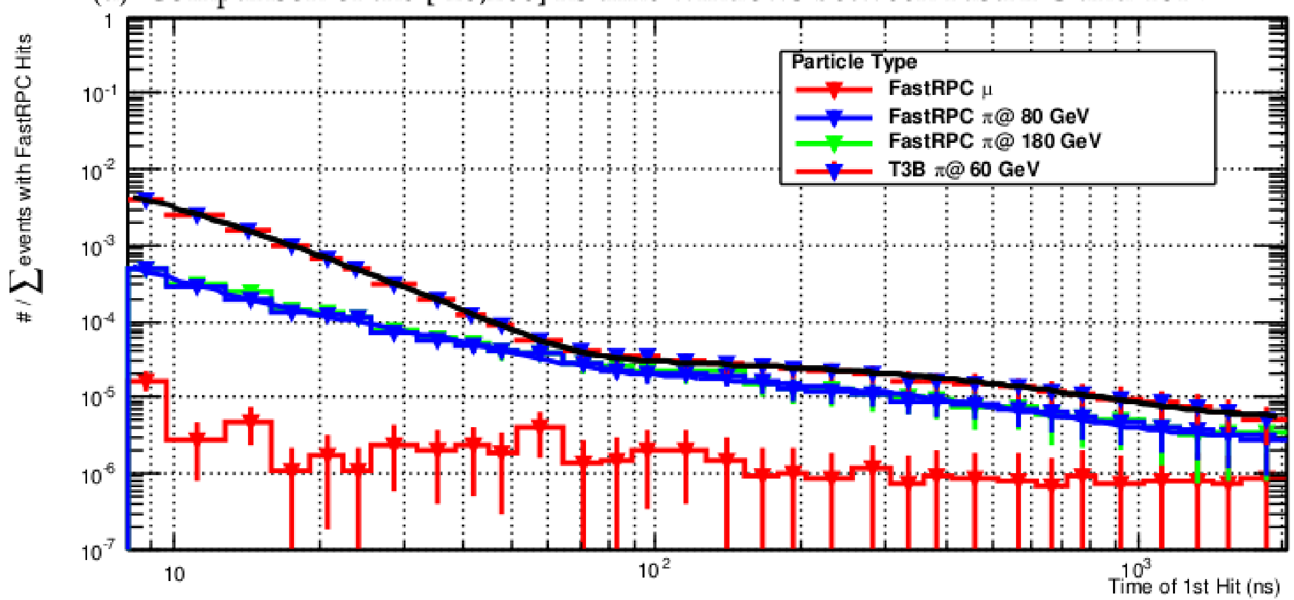


- Channel vs Time of first hit vs number of entries per bin
- Much more signal in scintillator in late times

Scintillator vs. RPC measured



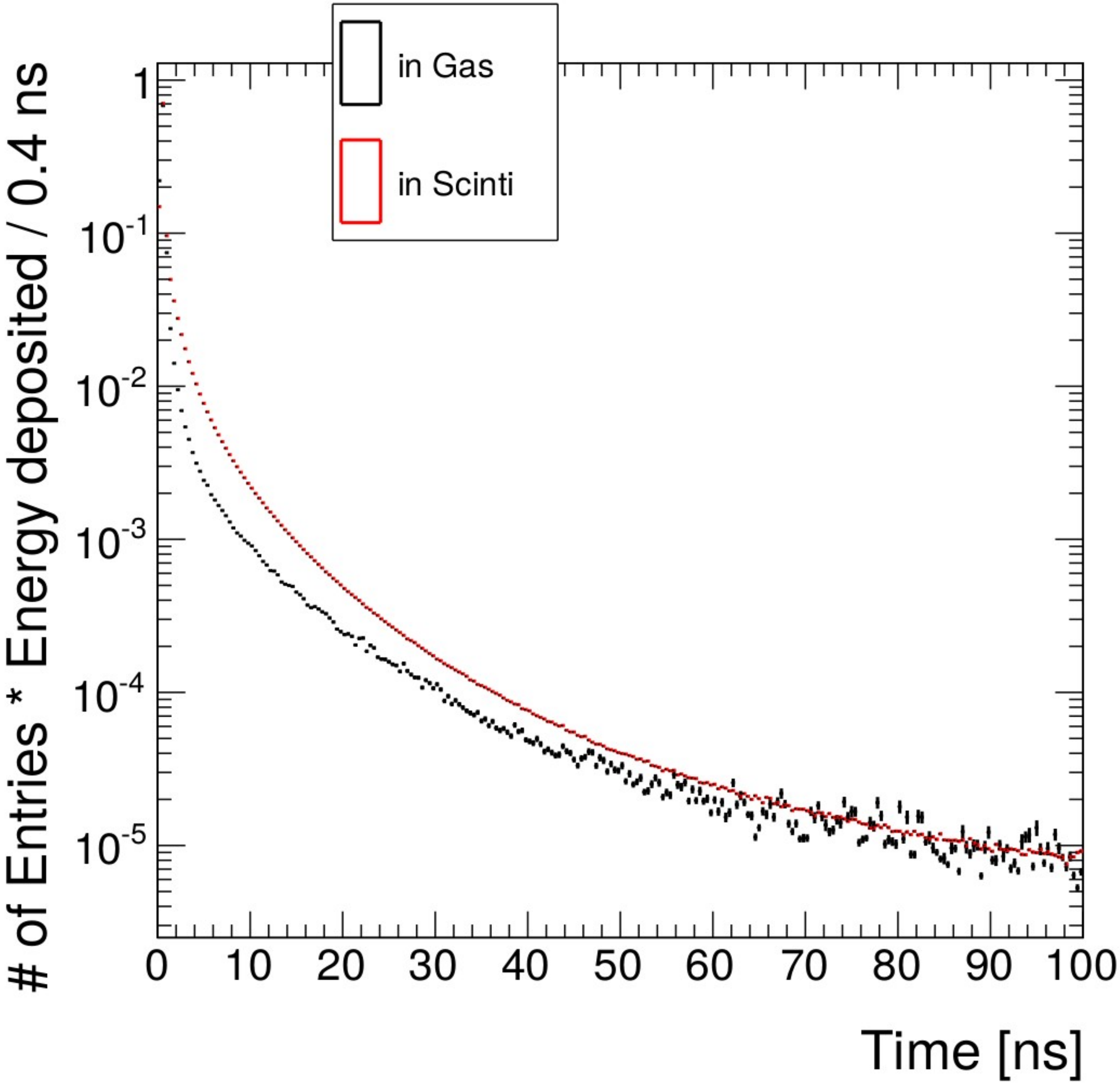
(a) Comparison of the [-20,200] ns time windows between FastRPC and T3B.



- RPC drops steeper
- Signals get back together
- Interpretation backed by data
- Late contribution mostly due to neutrons

- zoom

Scintillator vs. RPC simulated



- Normalied over the first 3,2 ns
- Gas drops steeper
- Signal gets back together
- No smearing

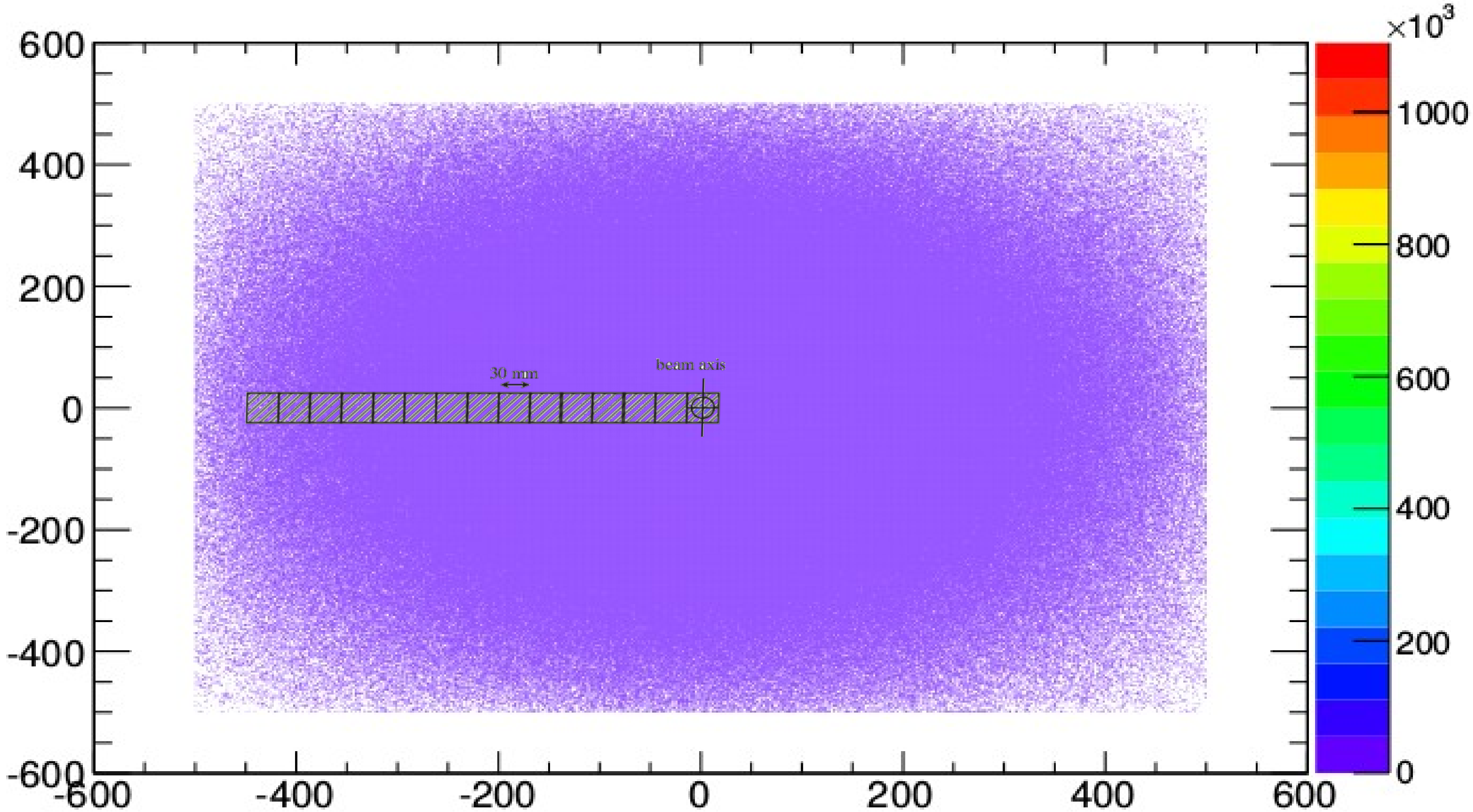
Summary and Outlook

- These new calorimeters and their understanding can help to improve simulations
- With the simulation we want to understand in detail what happens
- Made Monte Carlo simulation with GEANT4
- Full simulation of CALICE Detector Prototype
- Quantitative comparison of simulation with measured data
- All the presented is work in progress

The End

Thank you for your attention!

Backup



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beam axis