Study of hadronic showers with the fastRPC analog readout

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TECHNISCHE UNIVERSITÄT MÜNCHEN

Calorimeter for ILC

$\Delta p \cdot \Delta q \geq \frac{1}{2} \hbar$

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

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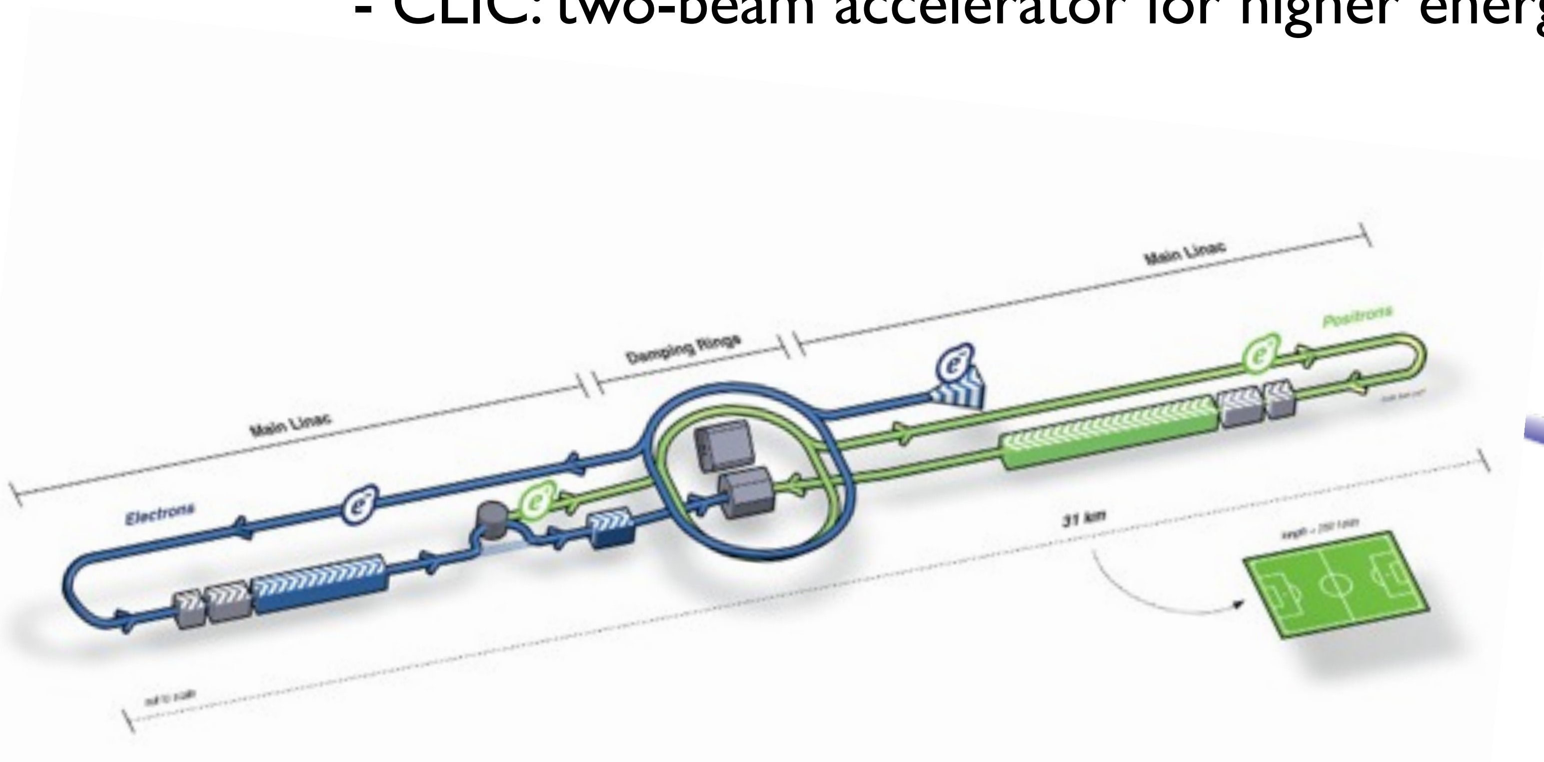
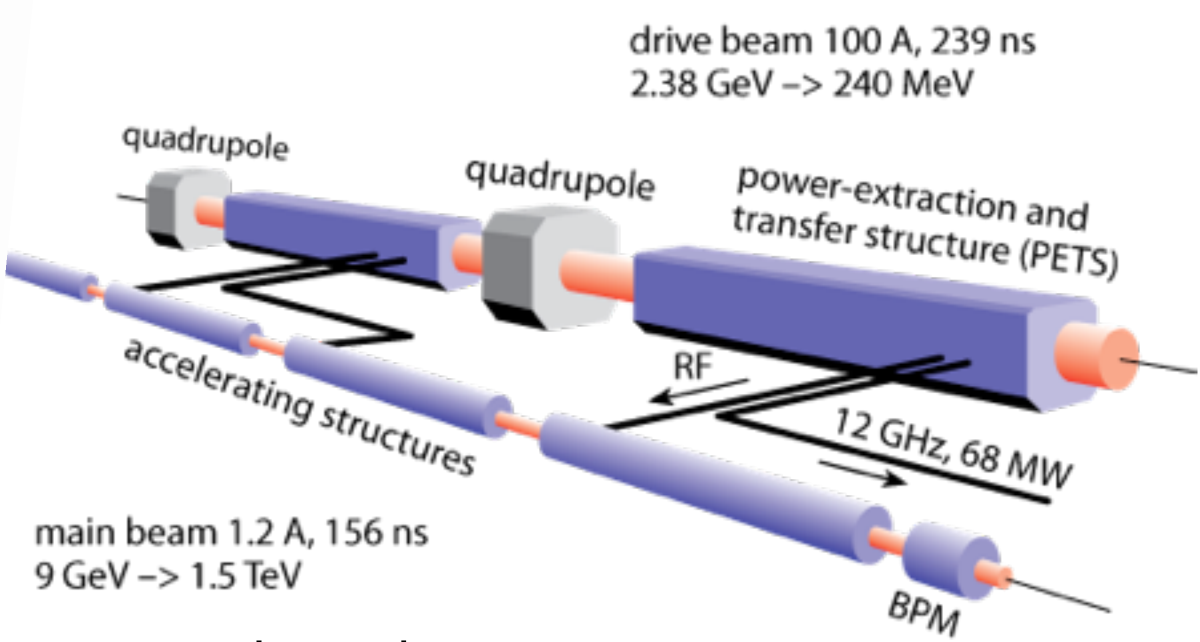
Linear Collider design concepts

- A lepton collider allows for precision measurements (clean events, well defined initial state)
  - in the TeV range to complement LHC
  - linear to prevent synchrotron radiation energy losses

- Two machine concepts:
  - ILC: superconductive accelerator technology - ready to build
  - CLIC: two-beam accelerator for higher energies - still in development



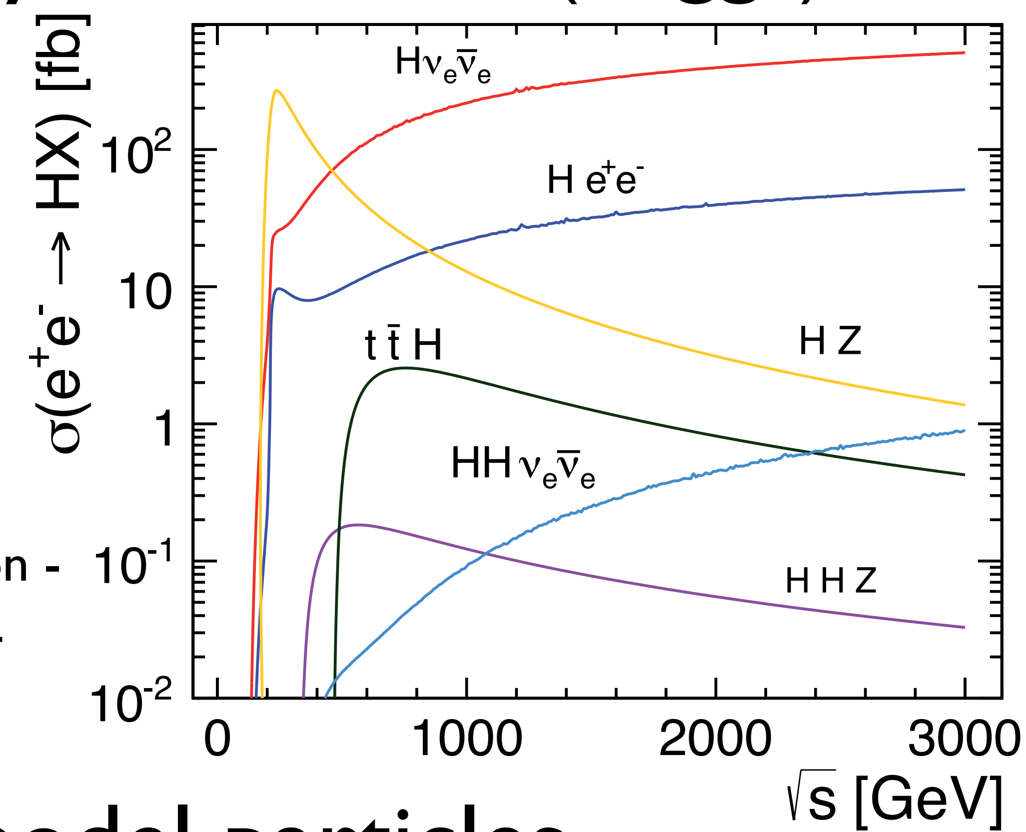
source: linearcollider.org



source: clic-study.org

Introduction:
Physics at e+/e- LC

- Precision measurement of the recently discovered (Higgs) boson
  - Model-independent measurements of coupling to fermions and bosons
  - Complete study of the Higgs sector



source: Frank Simon - arXiv:1211.7242

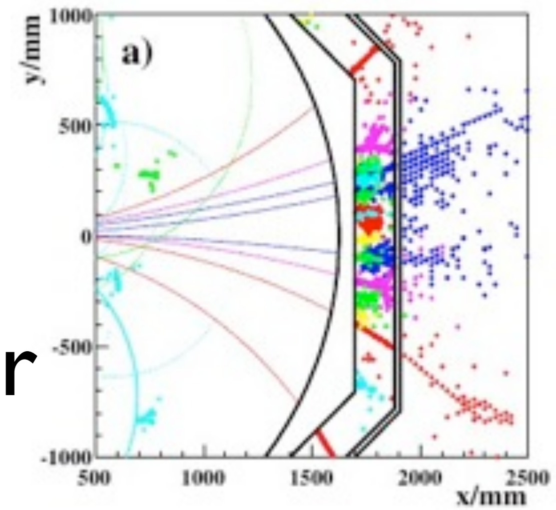
- Precision measurement of standard model particles
  - Top quark properties (mass, width, asymmetries)
  - Gauge bosons, coupling constants

- Direct and indirect search for possible BSM physics at TeV scale
  - particular strength in the weak sector, complementary to LHC

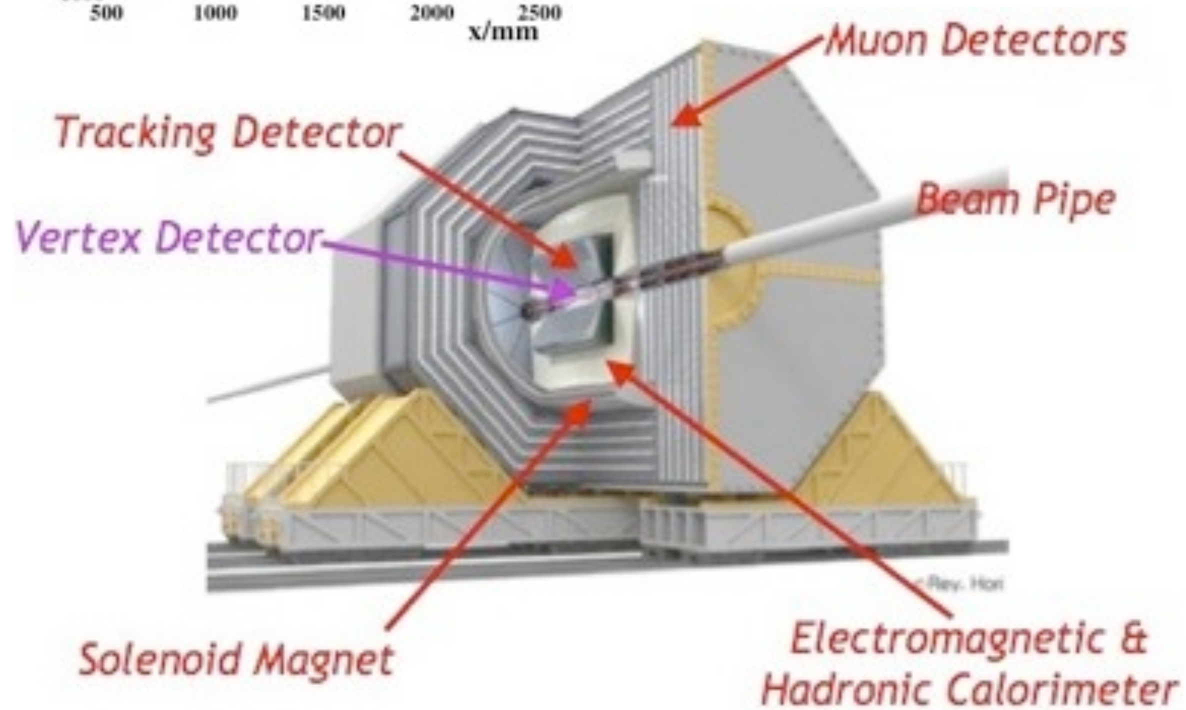
Detectors

- We need beyond state-of-the-art detector systems, including more sensitive calorimeters

- Event reconstruction based on Particle Flow algorithms
  ➔ High granularity in the calorimeter



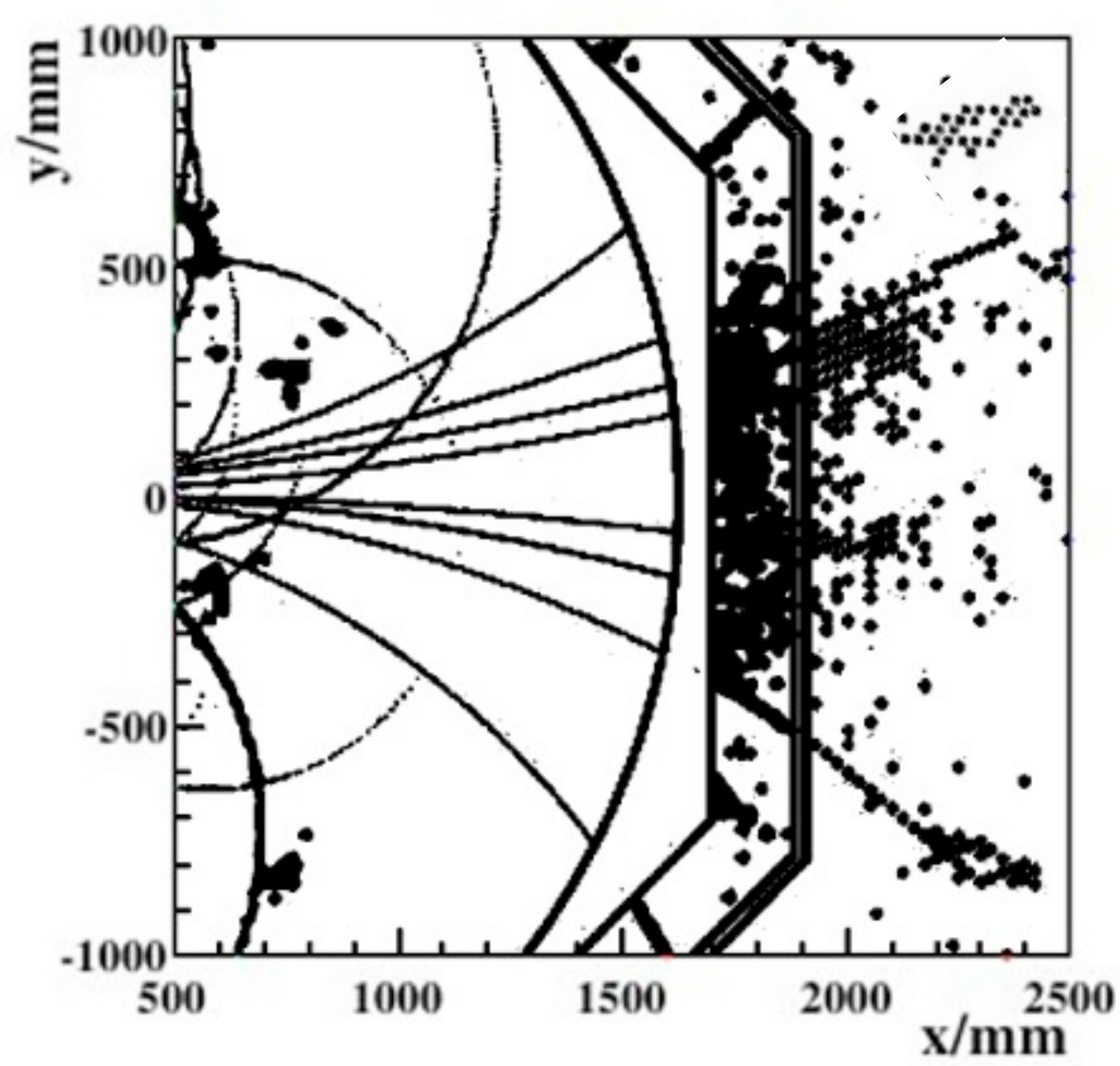
source: ilcild.org



- Precise timestamping of all the subdetectors

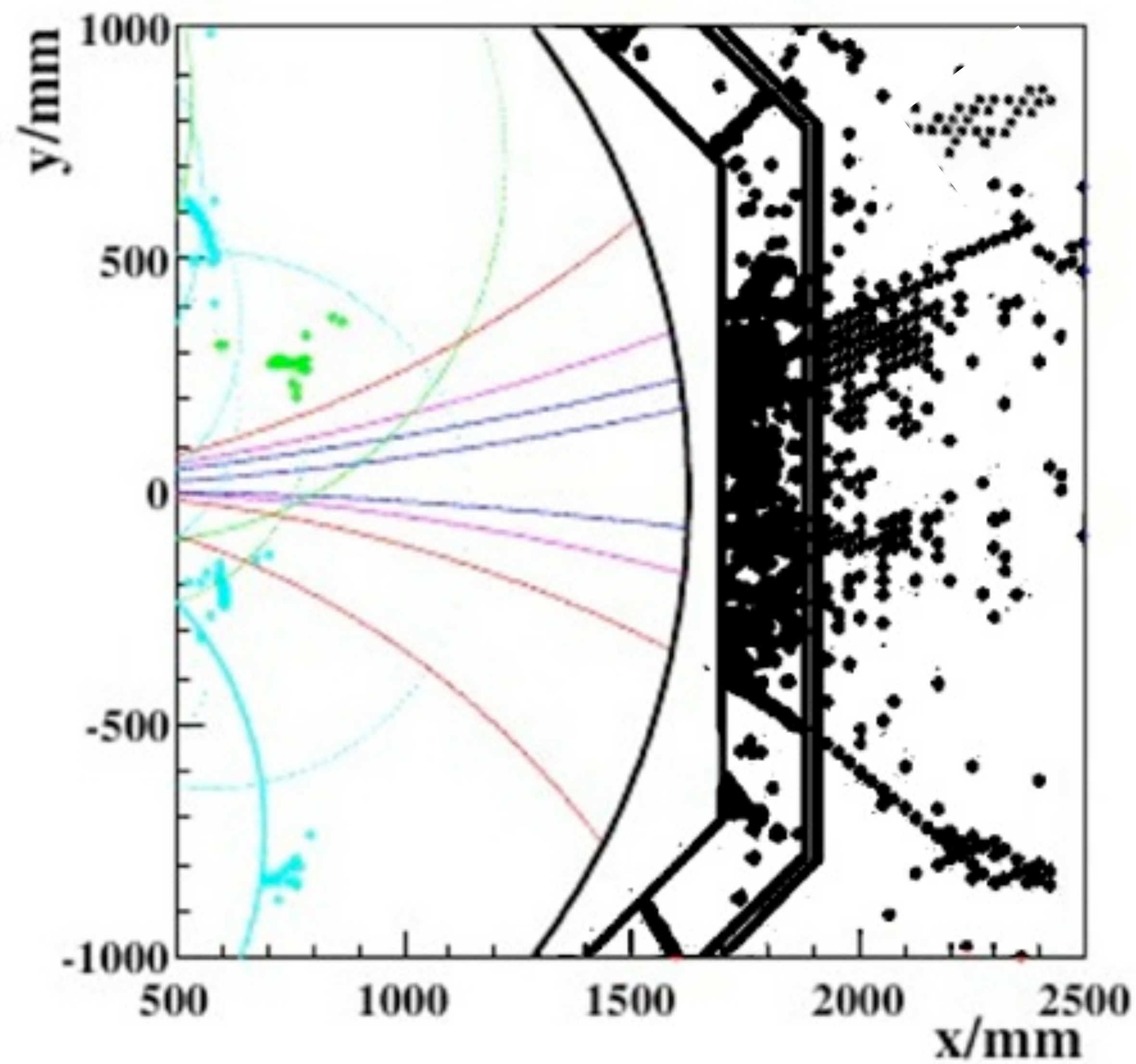
- Use of tungsten as absorber for the hadron calorimeter of a multi-TeV collider to fit in the magnet barrel

Detectors - Particle Flow Algorithms



Raw data from the detector

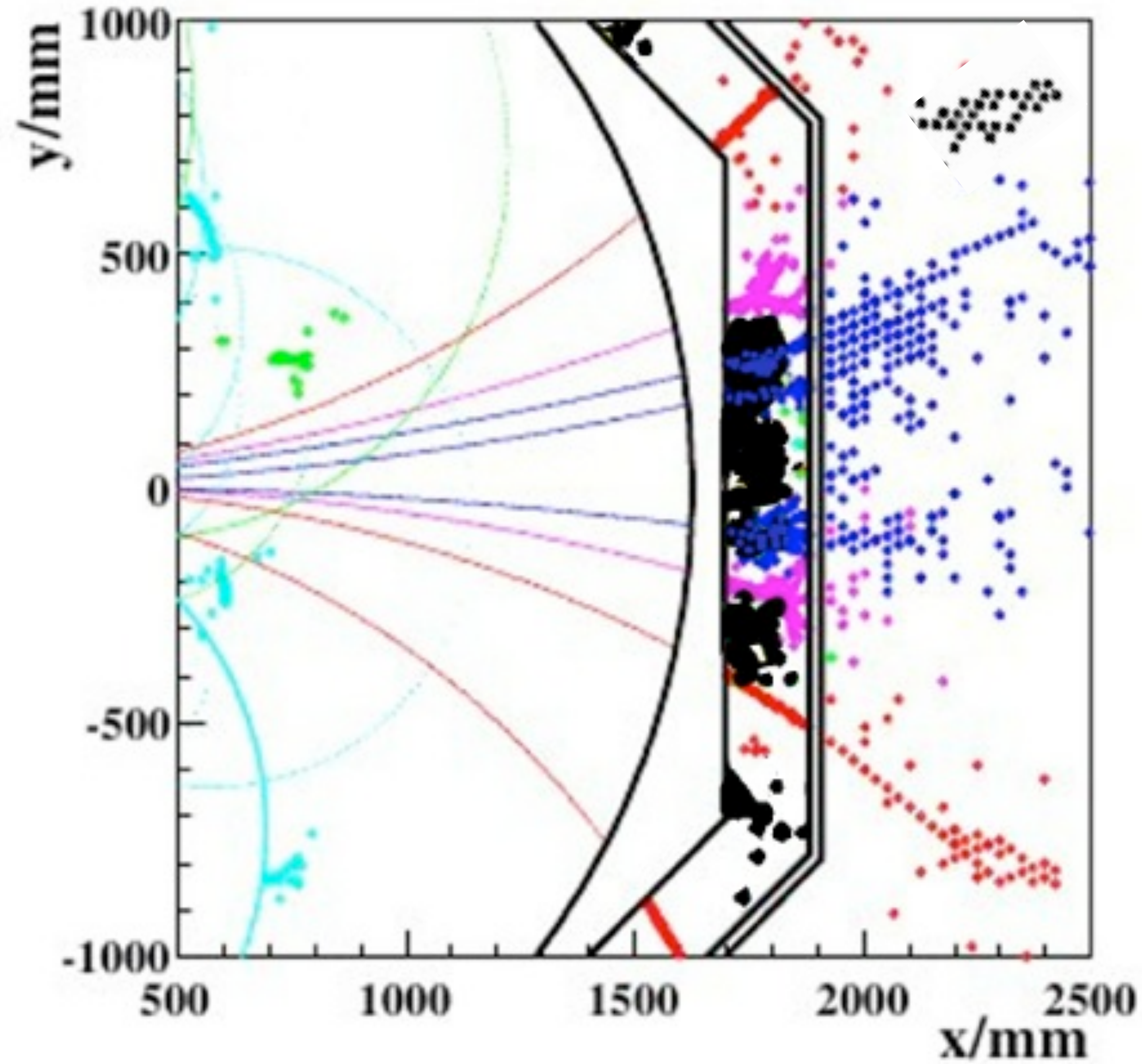
Detectors - Particle Flow Algorithms



Track finder algorithm reconstruct charged particles tracks

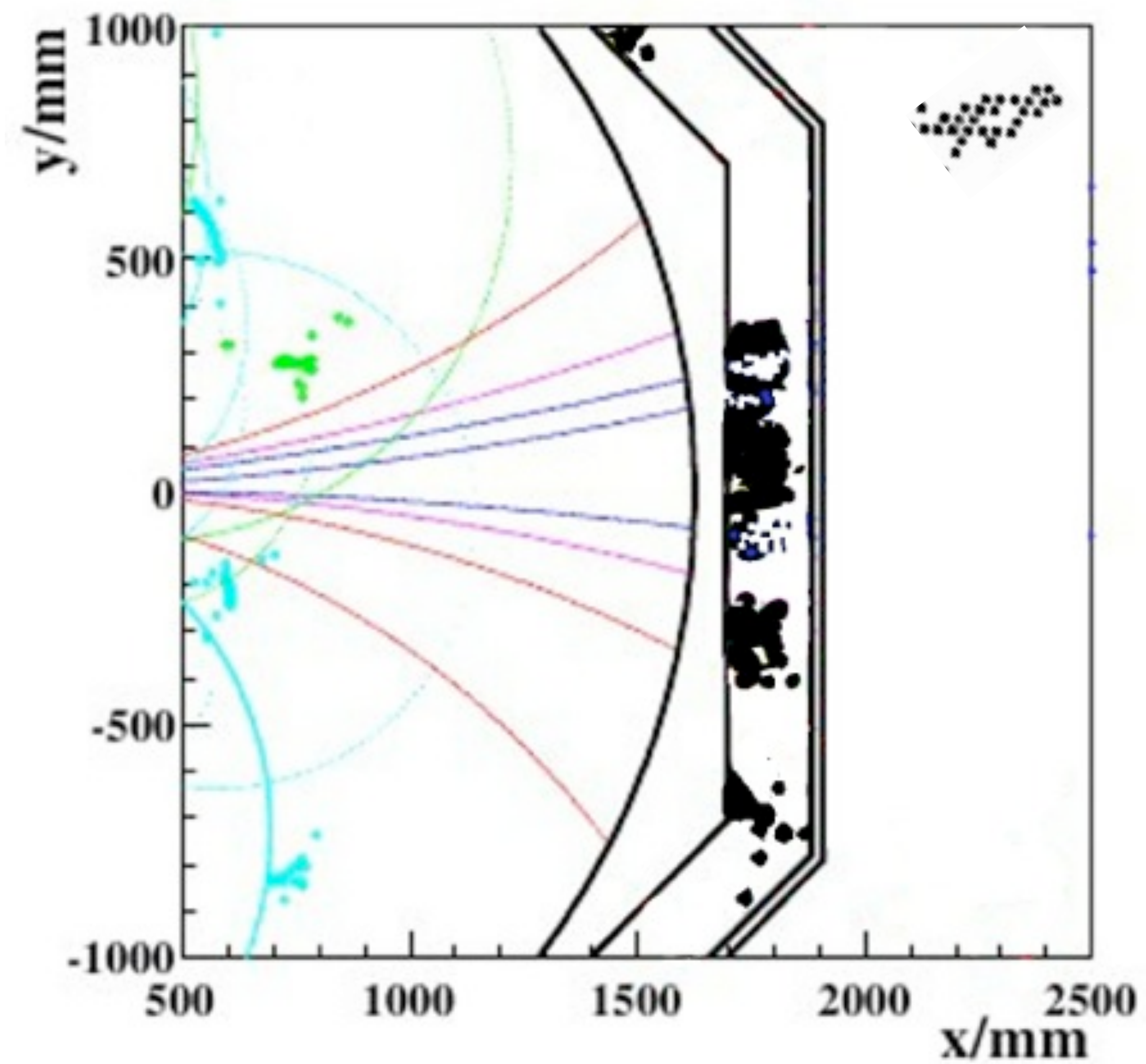
Introduction:

Detectors - Particle Flow Algorithms



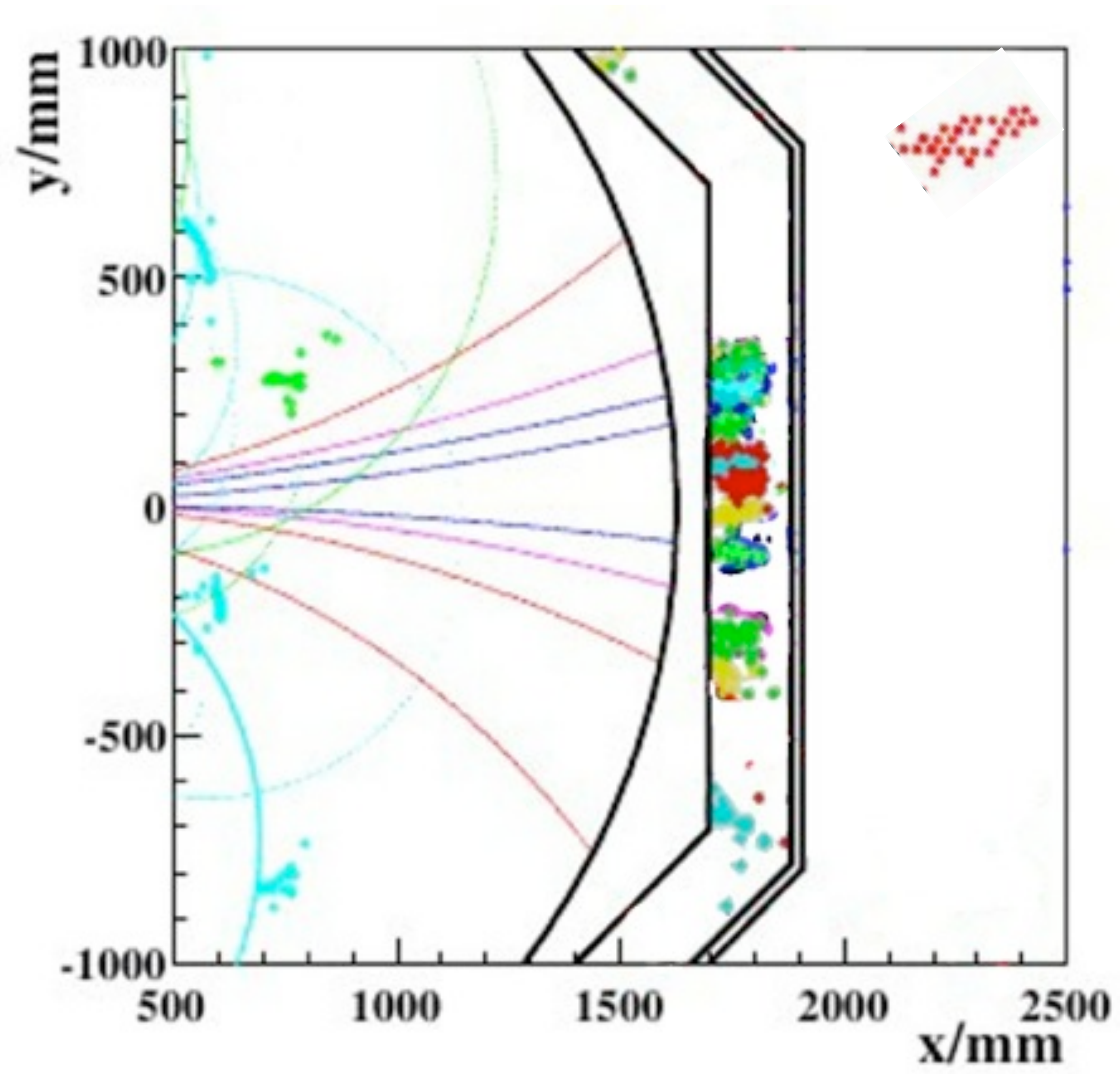
PFA assign ECAL and HCAL hits to tracks

Detectors - Particle Flow Algorithms



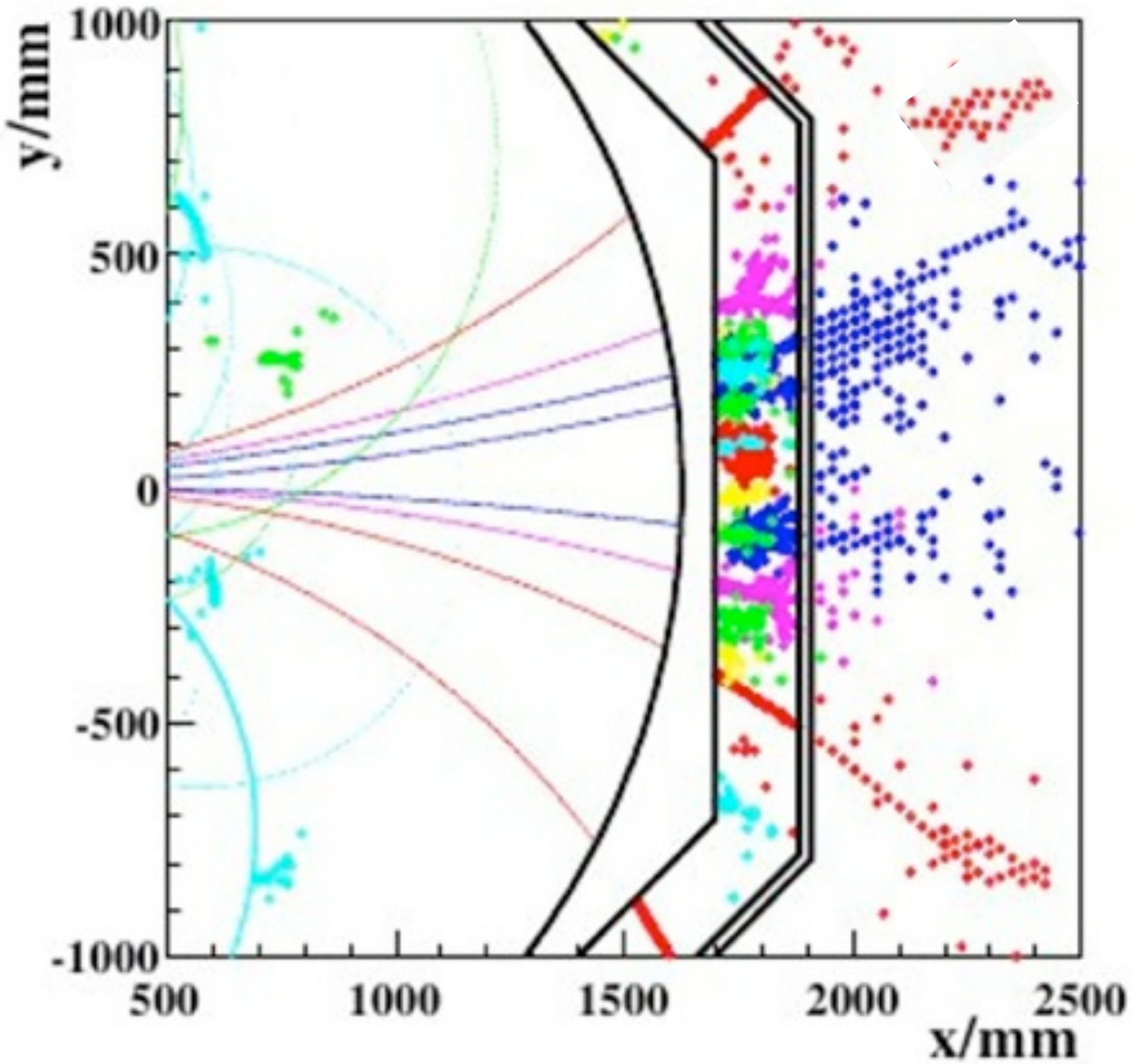
PFA removes assigned hits from the list

Detectors - Particle Flow Algorithms



Remaining tracks are identified as photons or neutral hadrons

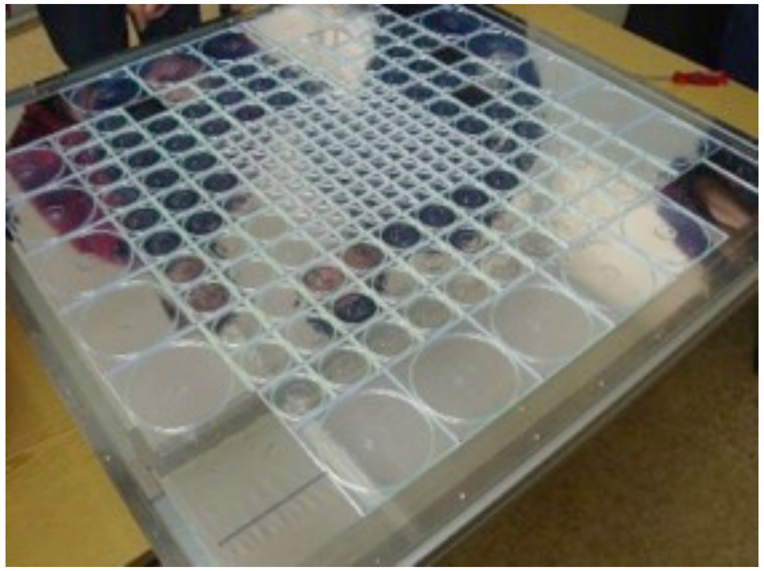
Detectors - Particle Flow Algorithms



Overall result

Detectors - Hadronic Calorimetry

- Several concepts for the hadronic calorimeter:
  - Plastic scintillators with SiPMs and analog readout (AHCAL)



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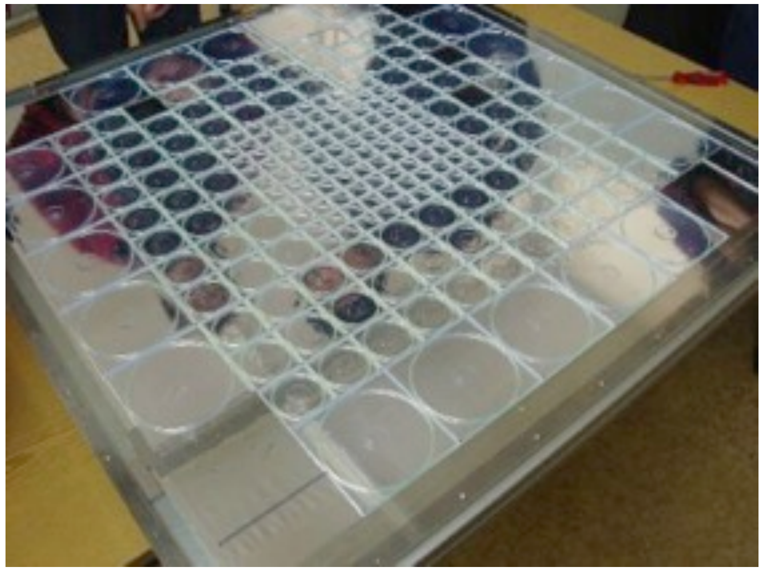
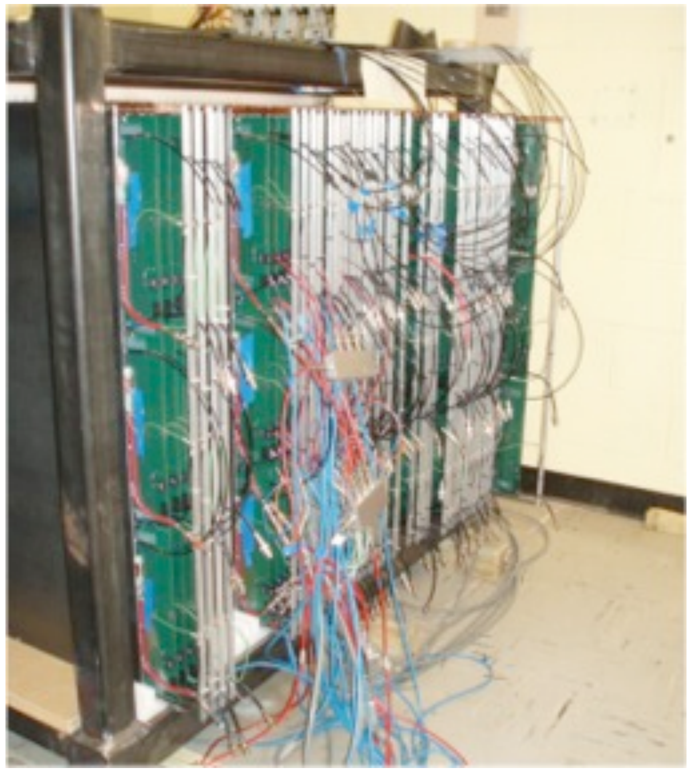


  - RPCs with digital readout (DHCAL)



Almost 500000 channels in total:
a record for a calorimeter system!

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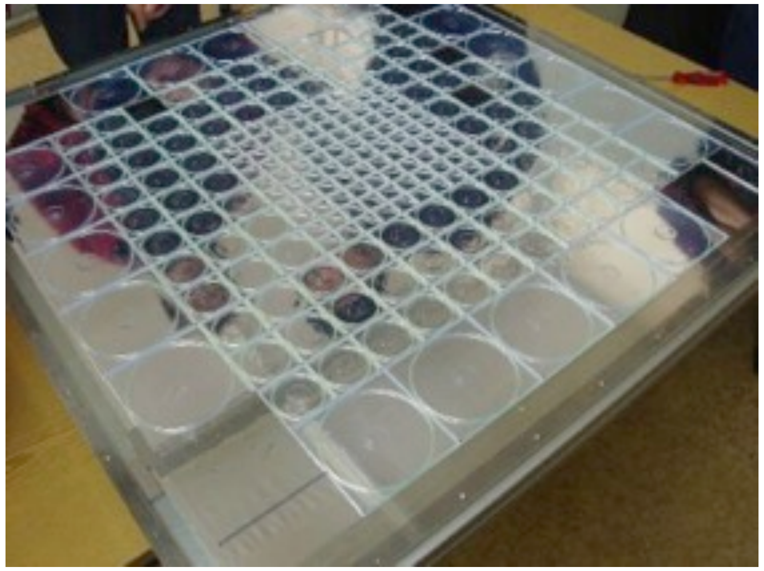
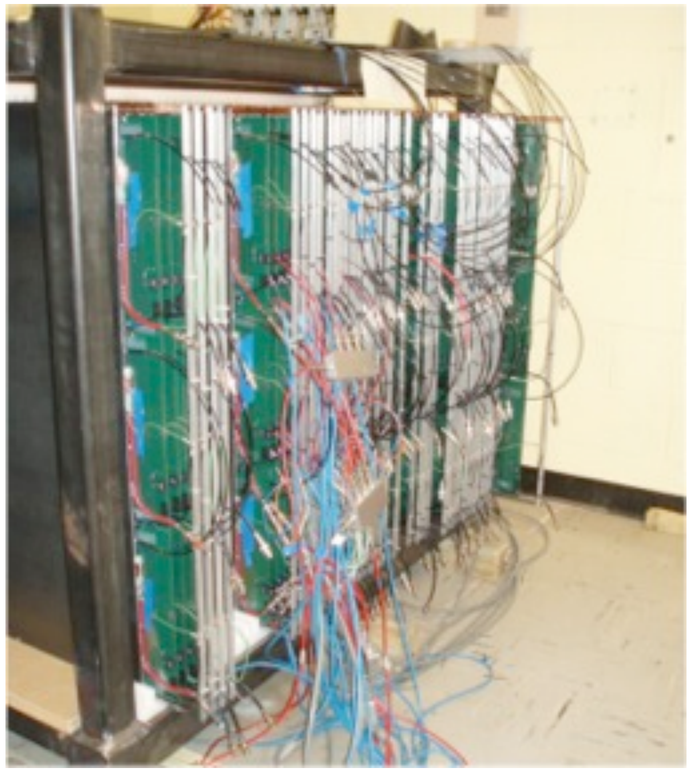


38-layer prototype with steel or tungsten absorber



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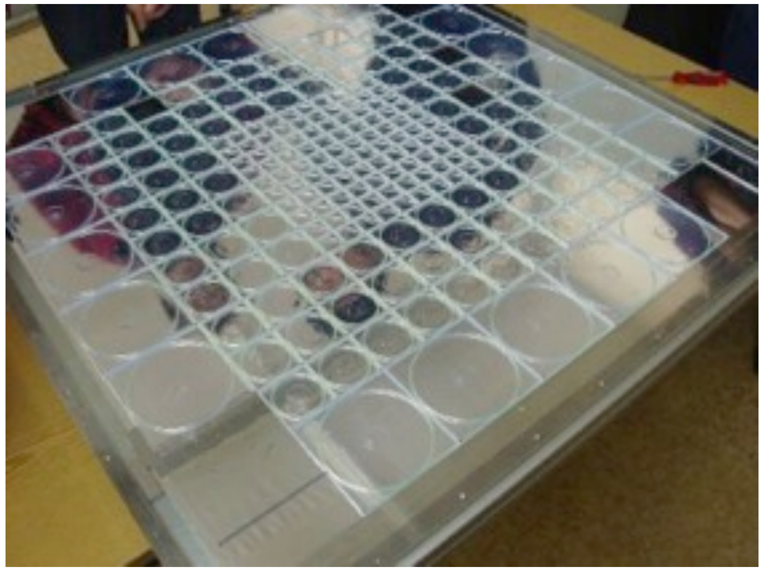

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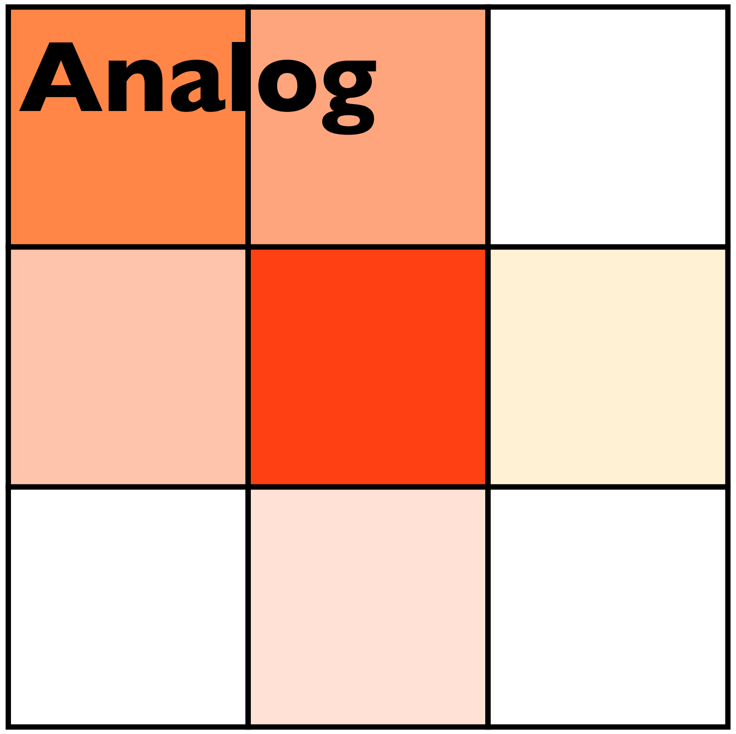

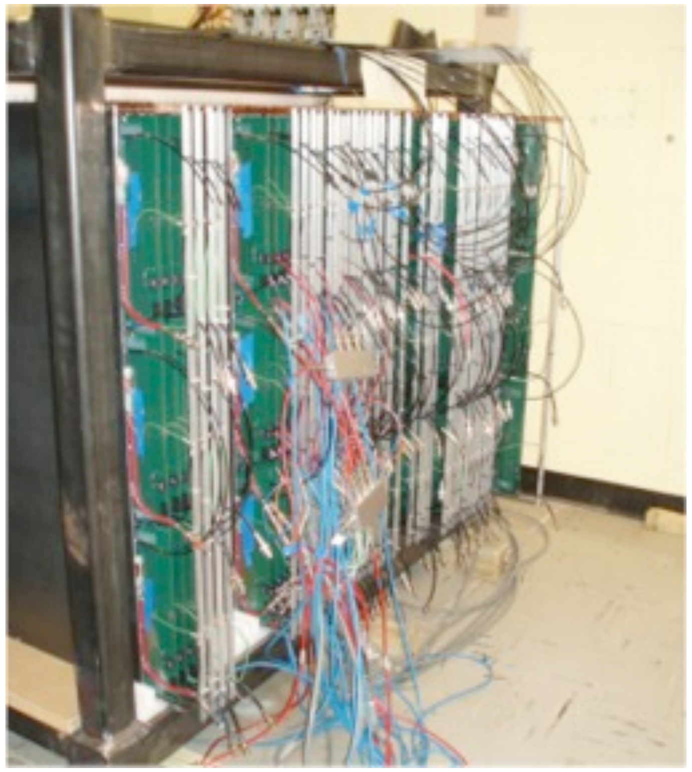

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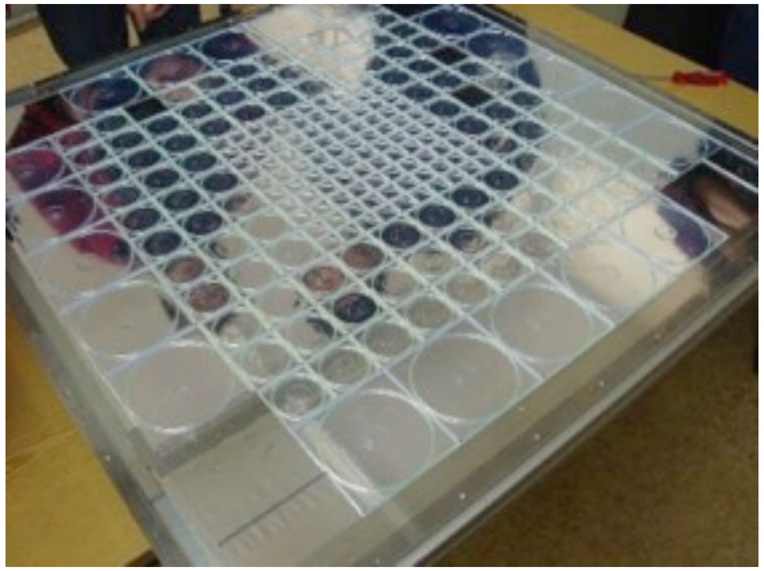

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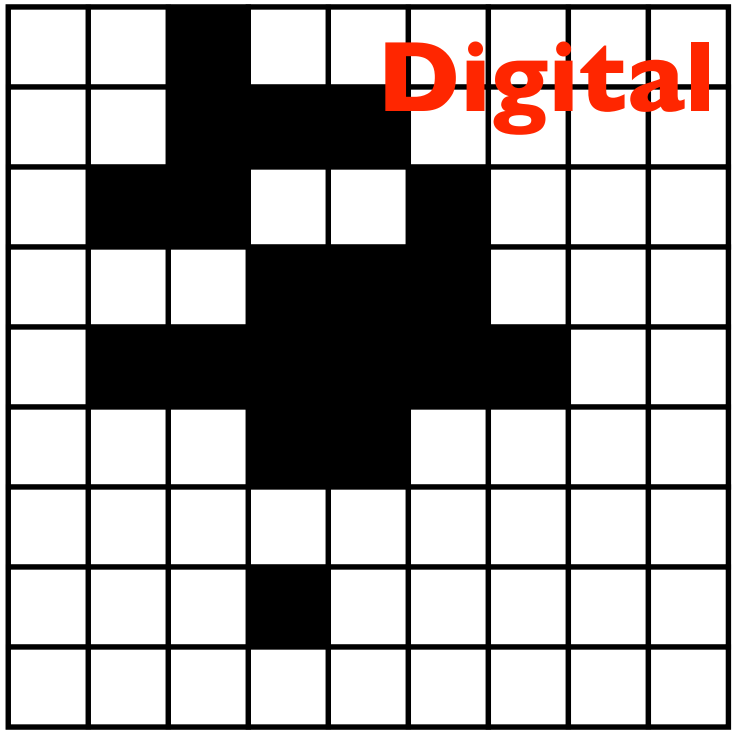

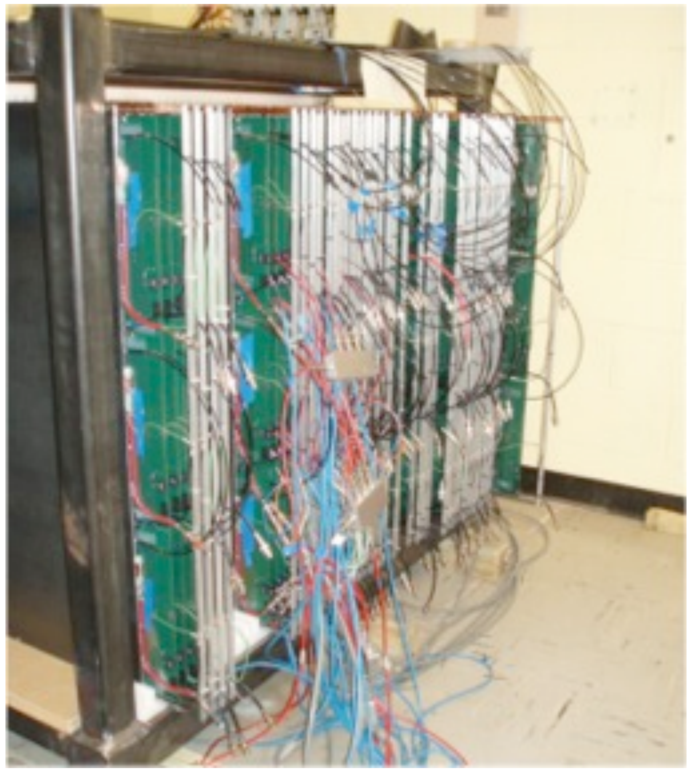

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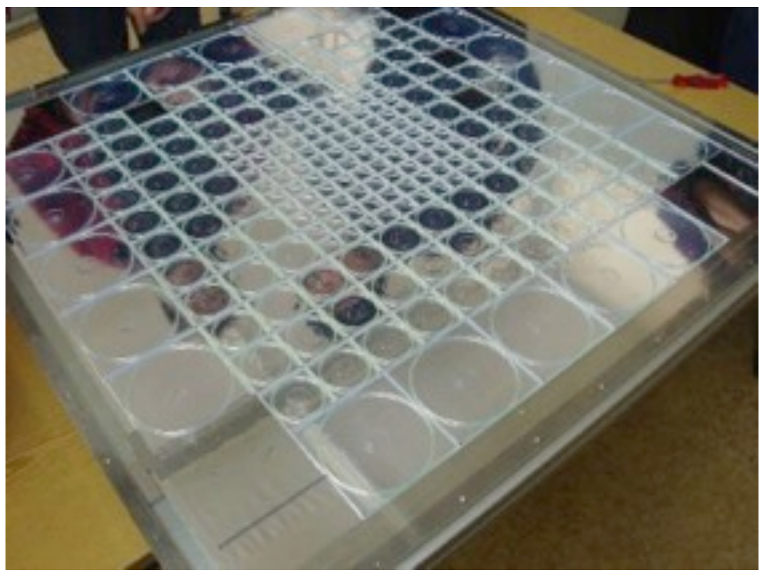

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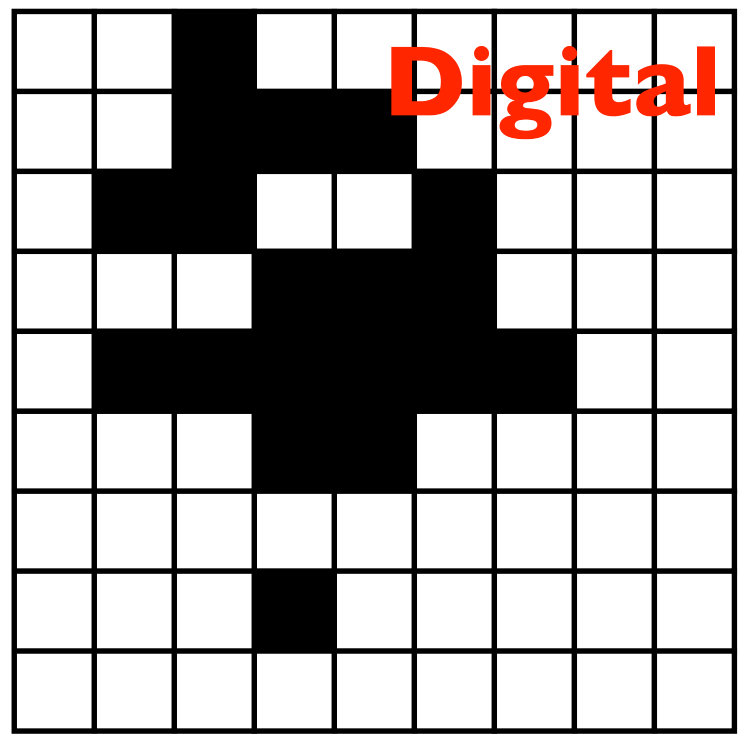
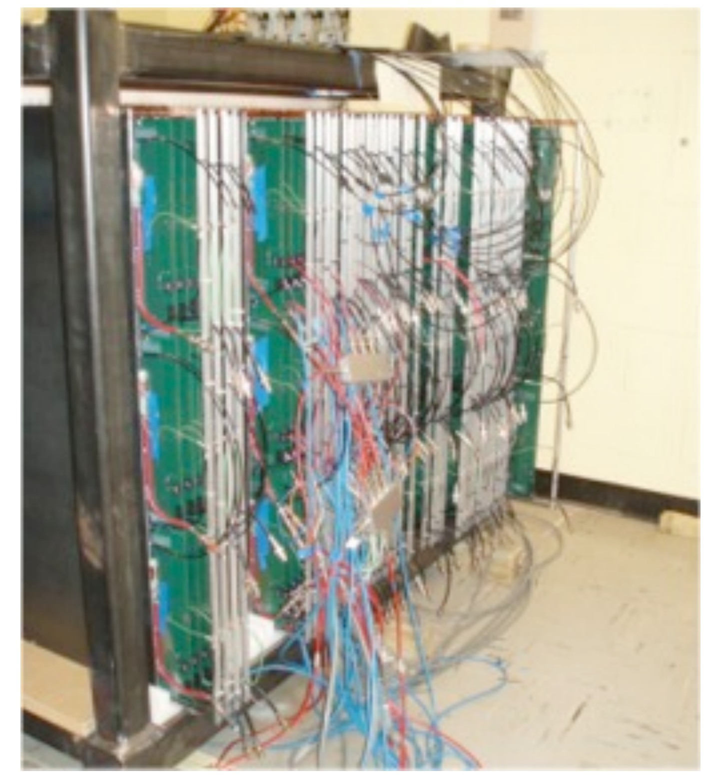




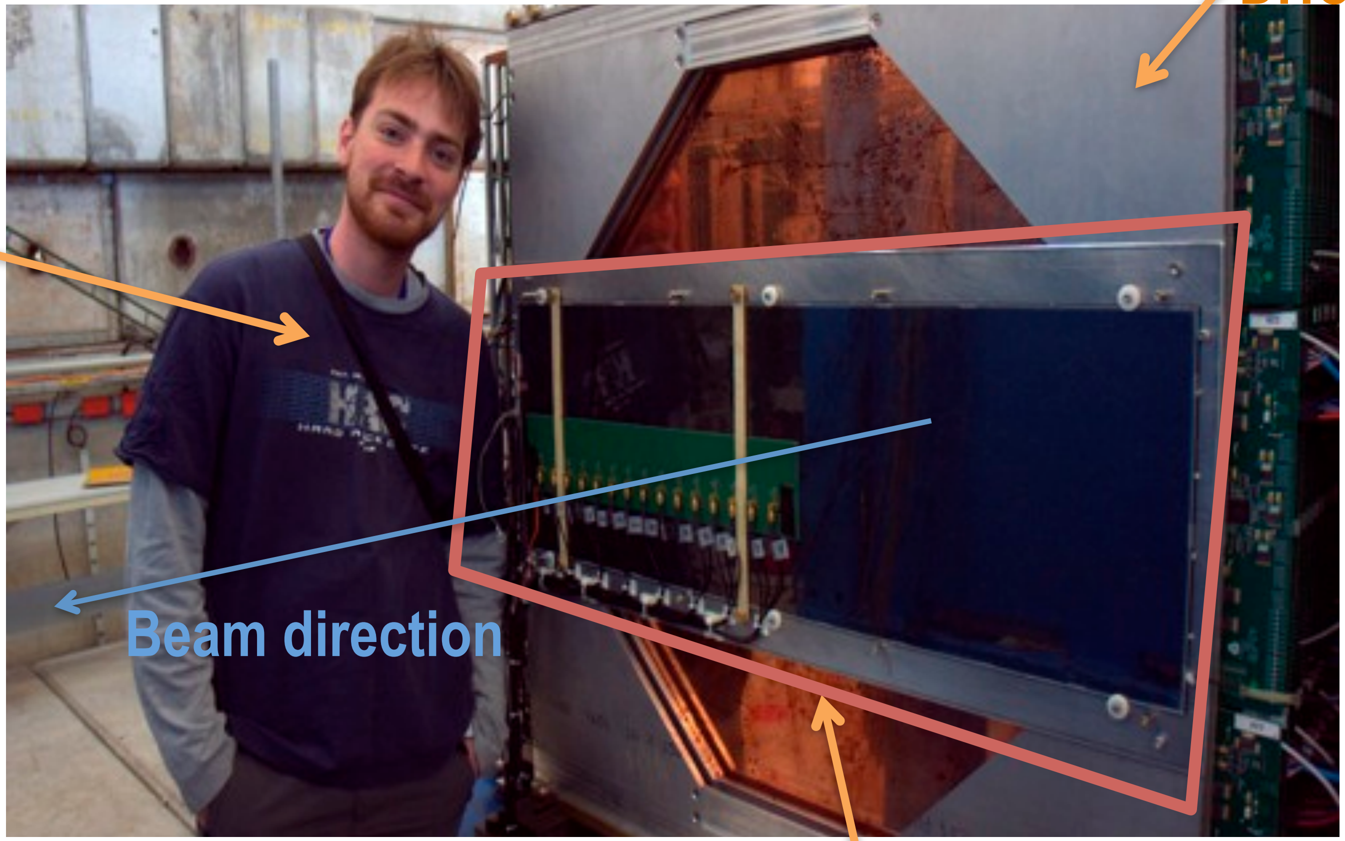
38-layer prototype with steel or tungsten absorber

Almost 500000 channels in total: a record for a calorimeter system!

  - RPCs with semidigital readout (SDHCAL)

Overview

Goal of the experiment: measure the time structure of an hadronic shower using a high time-resolution analog readout

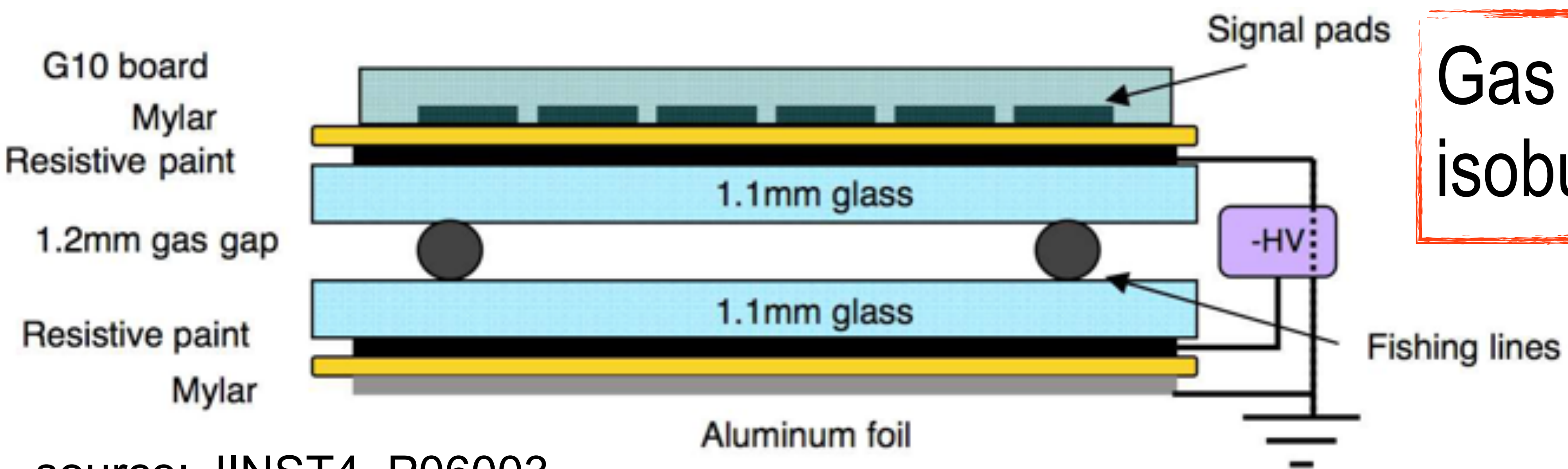


Understand the relevance of the time structure for Particle Flow Algorithms and background rejection

Input for detector simulations

Implementation - Active layer

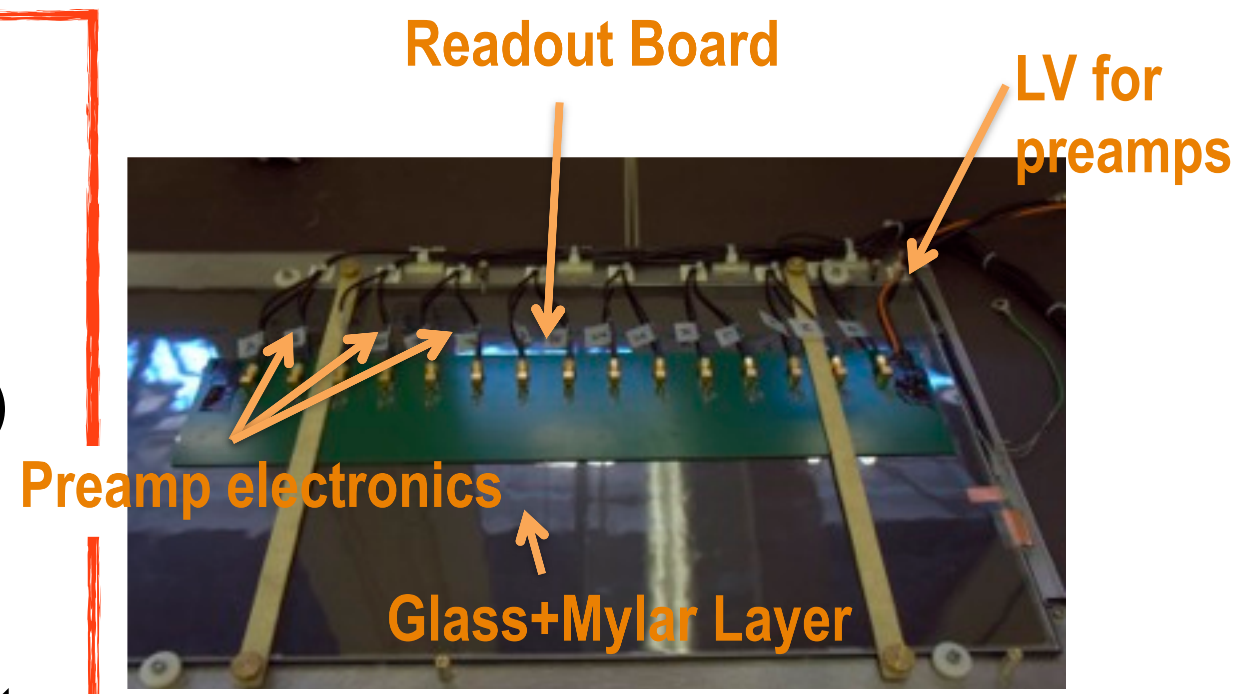
Resistive Plate Chamber



source: JINST4_P06003

Gas mixture: R134A 94.5%, isobutane 5.0%, SF_6 0.5%

- High resistance of the electrodes (~10^{12} Ωcm)
- High Voltage (6-7 kV ➔ E~55-65 kV/cm)
- Gas Amplification (Gain ~ 10^5)
- Highly quenching gas mixture to prevent streamers



Implementation - Active layer

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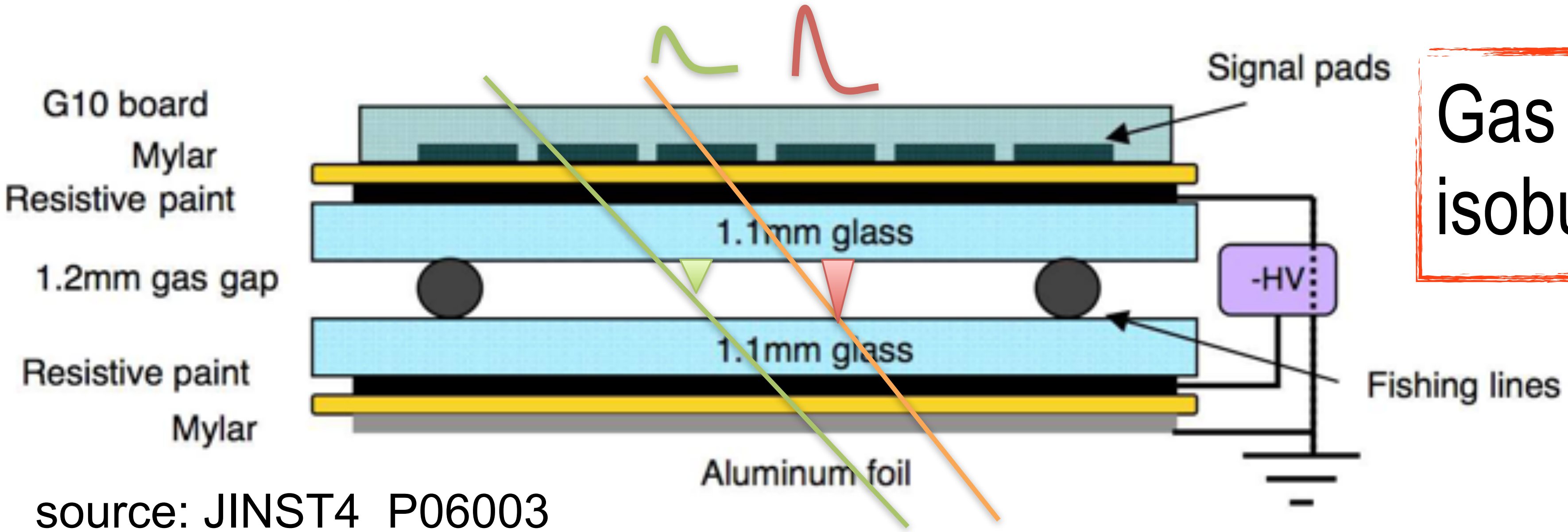

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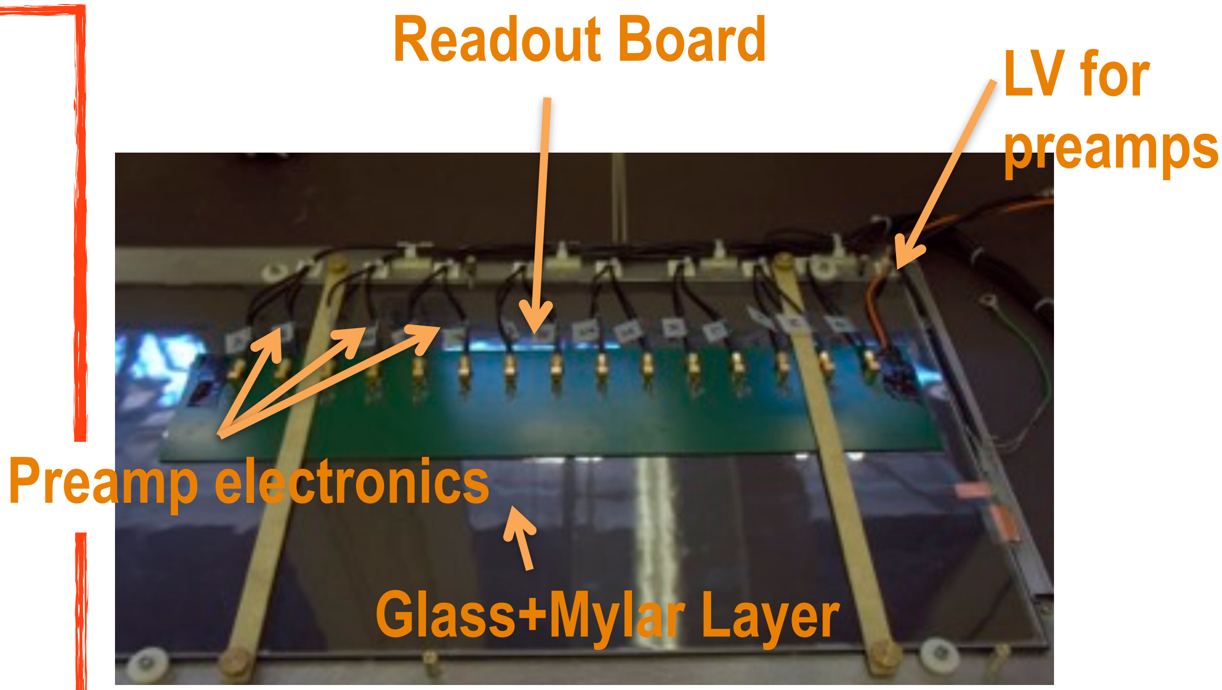
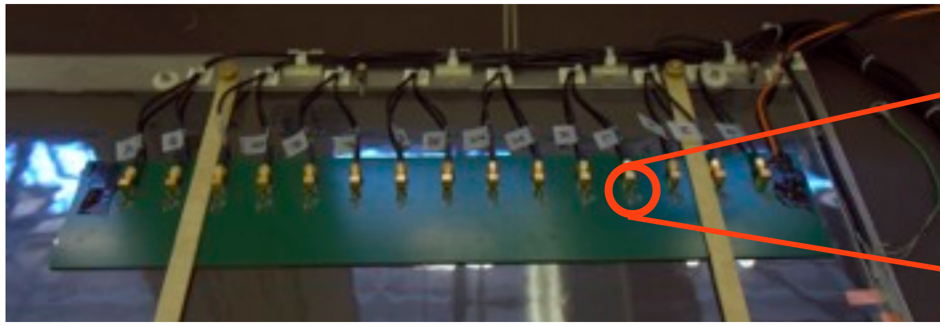
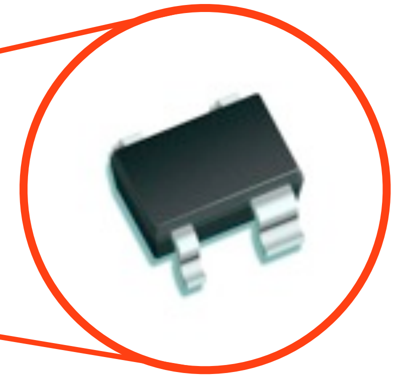


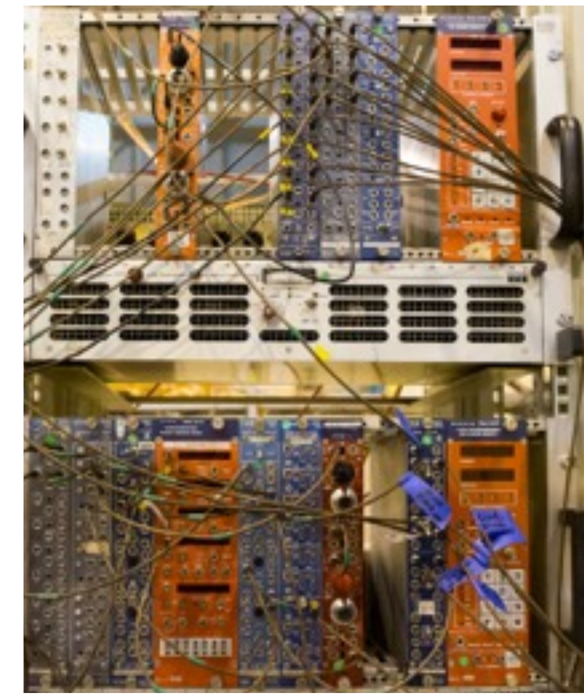
The FastRPC setup:
Implementation - readout

15 x 3x3 cm^2 pads



Infineon BGA614 preamp





spill info
scintillator triggers
DHCAL synchronization

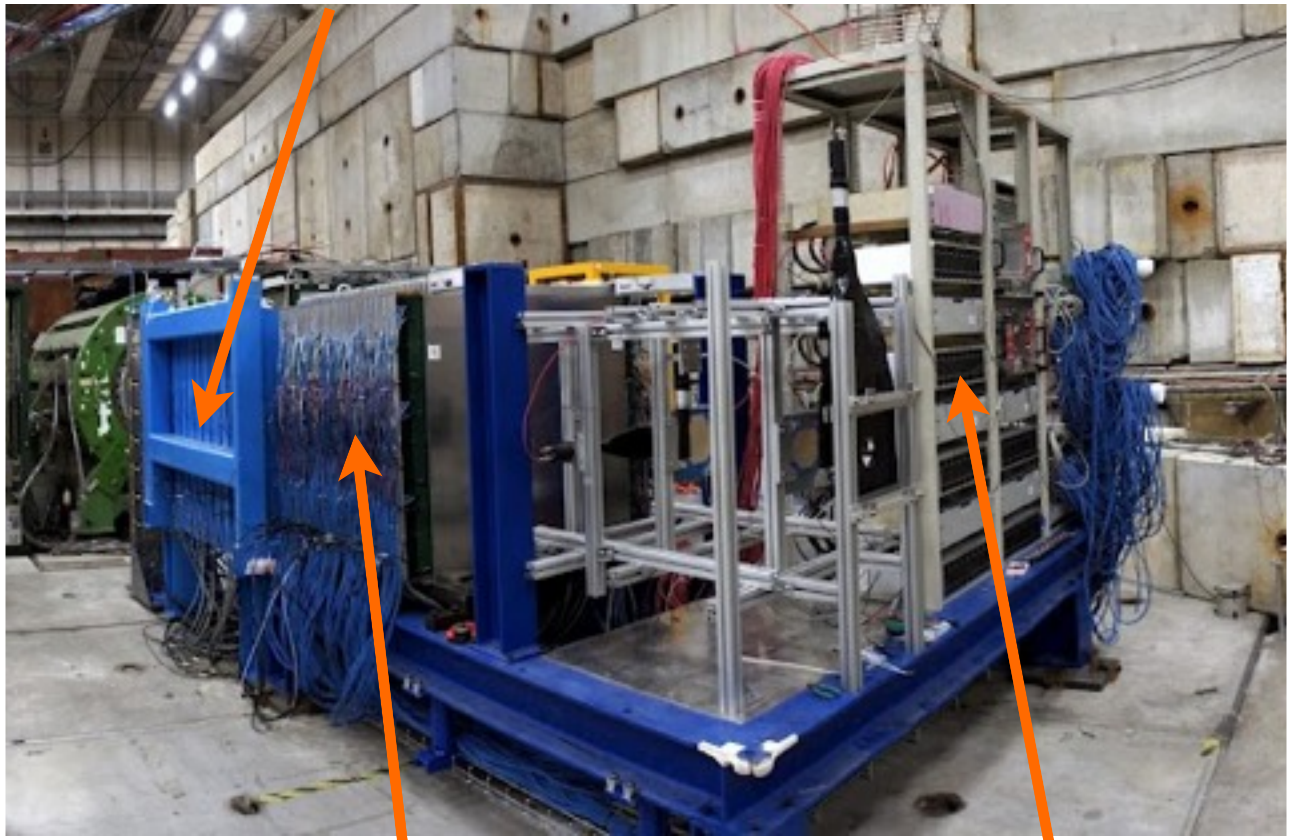
USB

4xPicoscope 6000 (16 channels in total)
8bit - 1.25GHz - 2.4μs sampling window

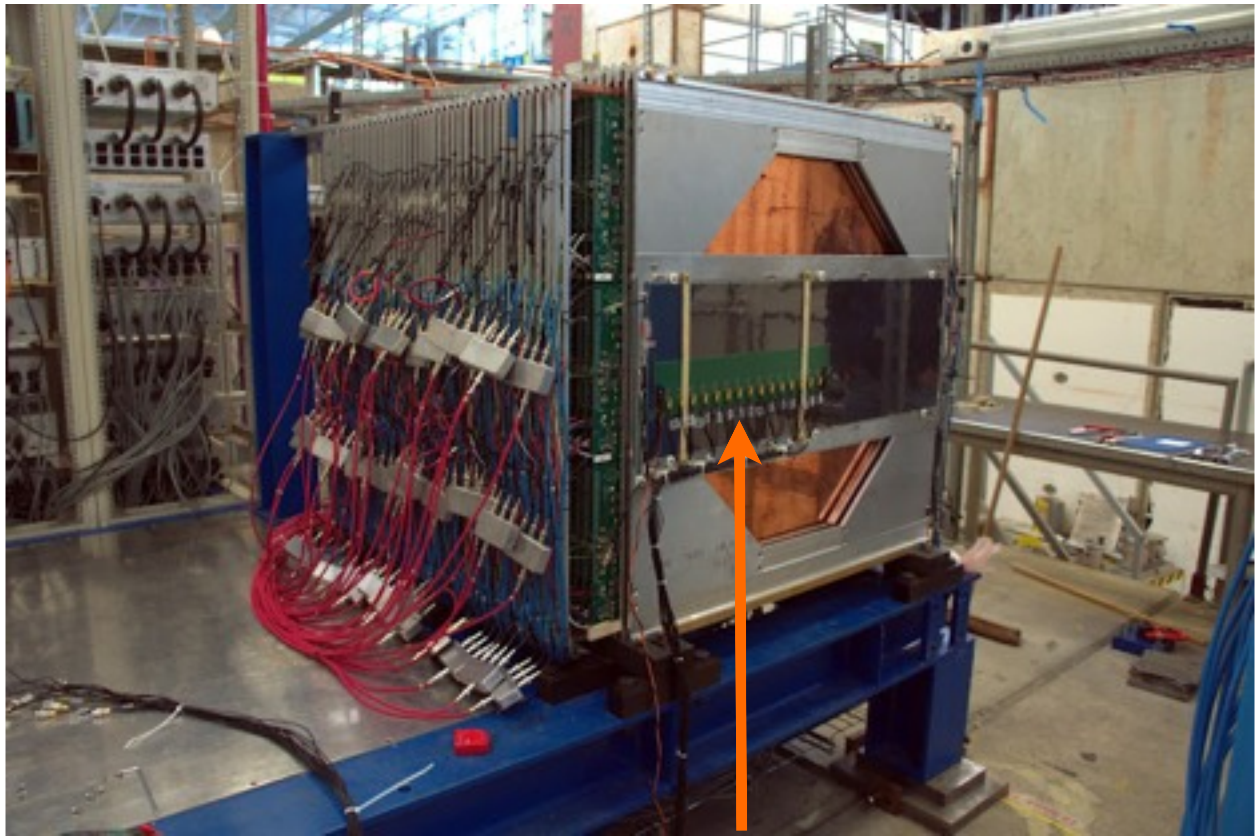
Overview

Experimental setup in place at CERN PS facility

Tail catcher with RPC readout



WDHCAL electronics



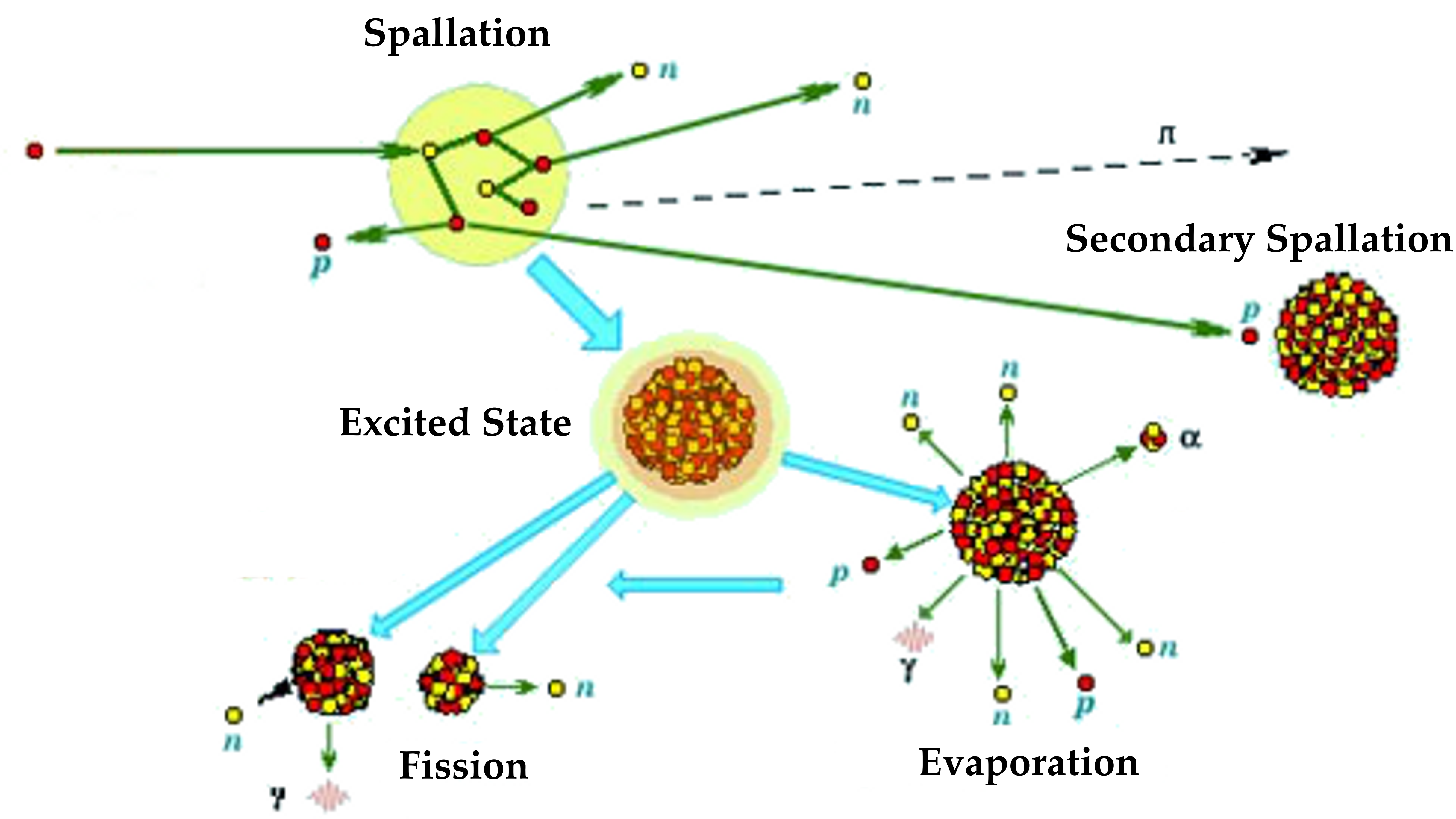
FastRPC

Almost 500000 channels in total:
a record for a calorimeter system!

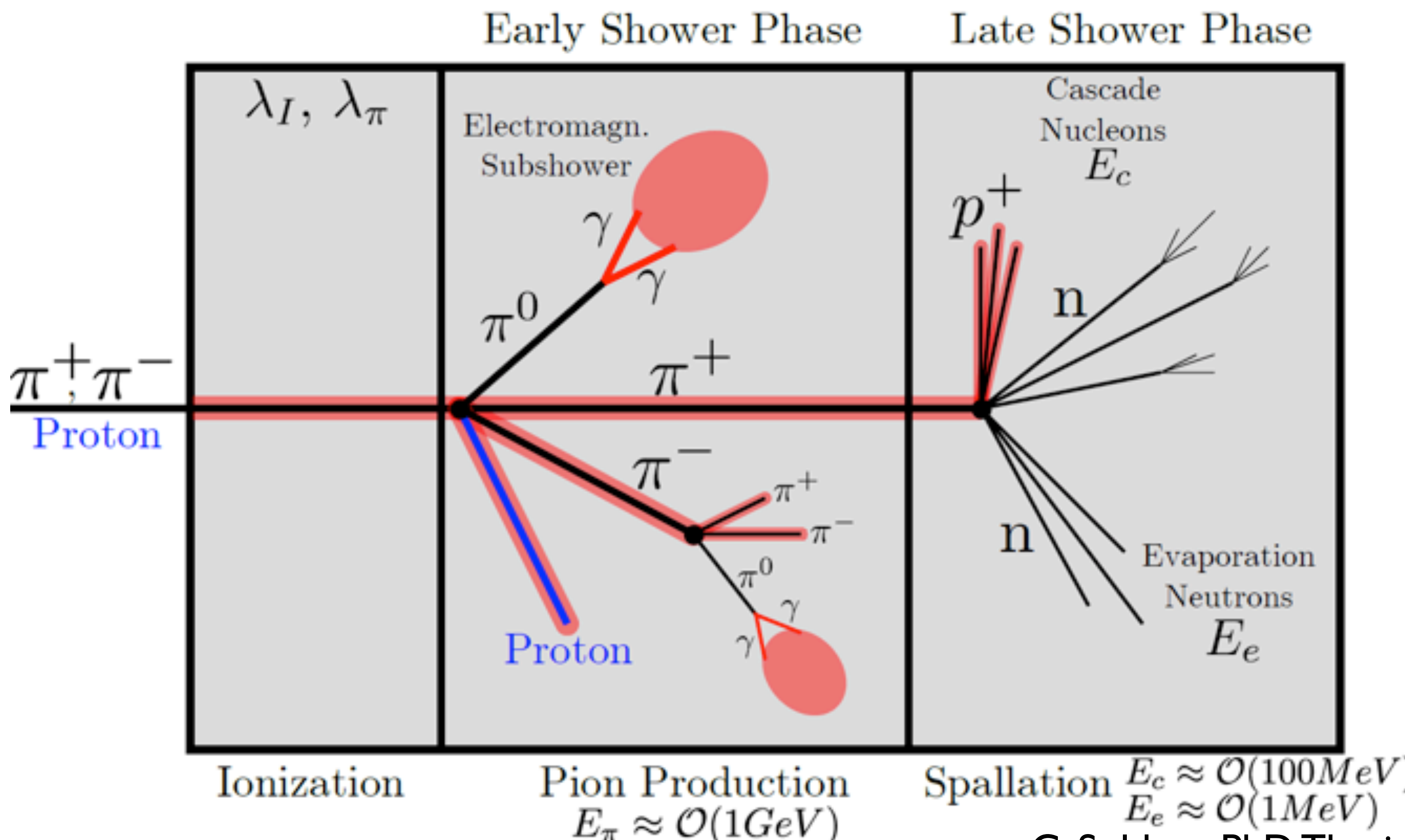
Testbeam at CERN

- Commissioning at PS
  hadrons & muons runs up to 10GeV
- Very good run with ~1.5Mio muon and ~16Mio hadron triggers
- Physics run at SPS
  hadrons & muons runs up to 180GeV
- ~3Mio muon and ~7Mio hadron triggers (luminosity limited by DHCAL trigger rate)

Hadronic Showers:
Development



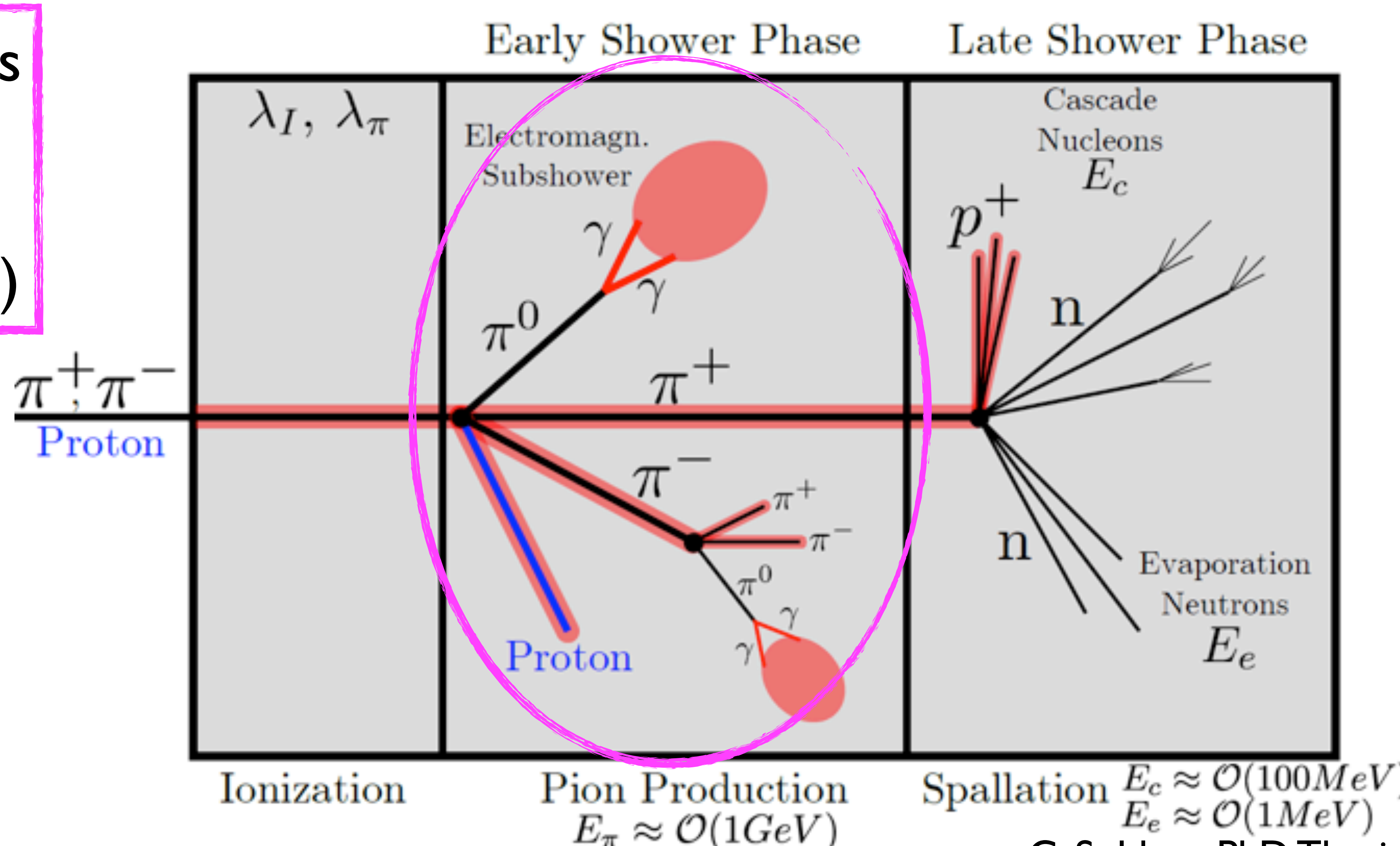
Time development



source: C. Soldner PhD Thesis

Time development

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



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Hadronic Showers:

Time development

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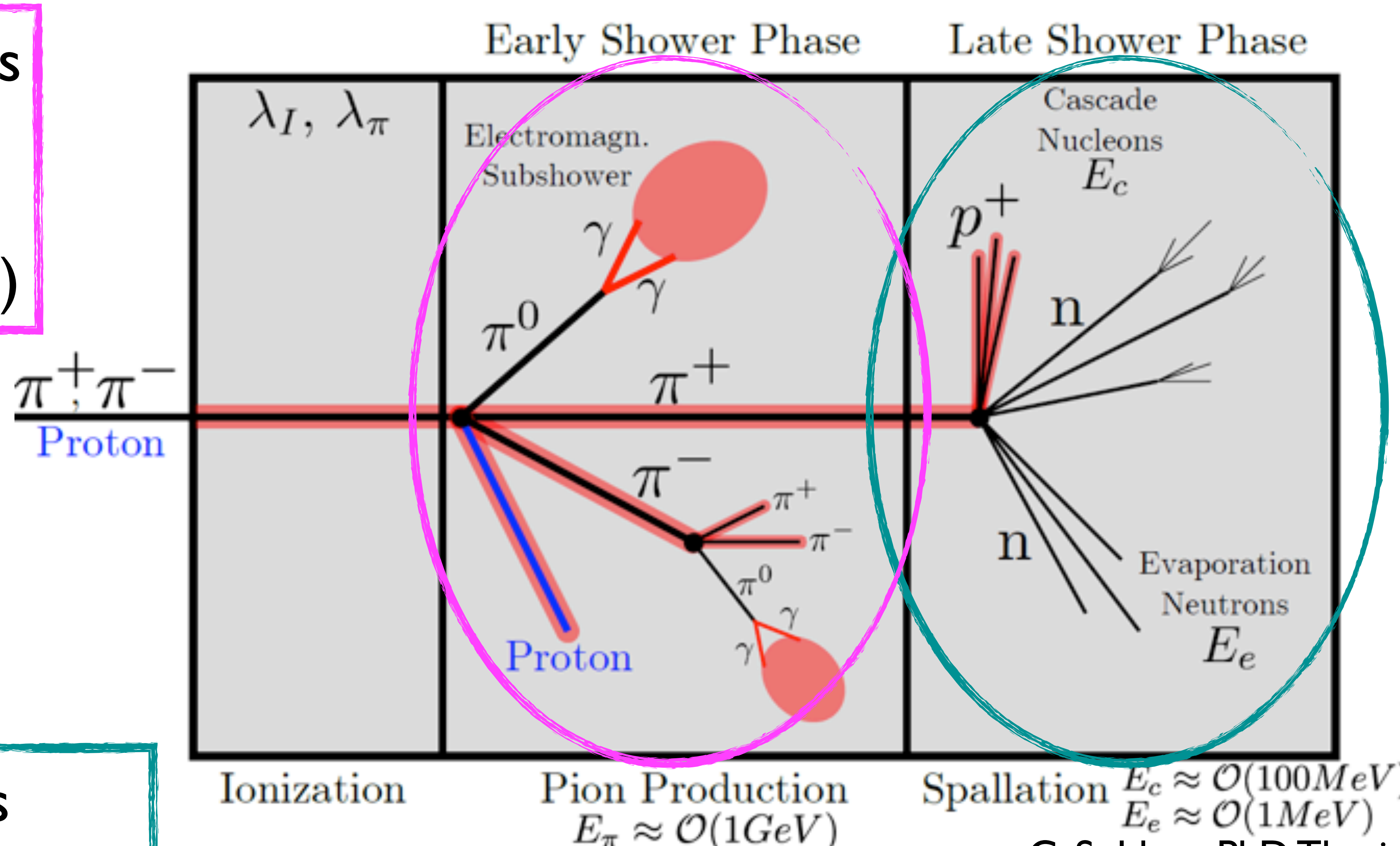


source: C. Soldner PhD Thesis

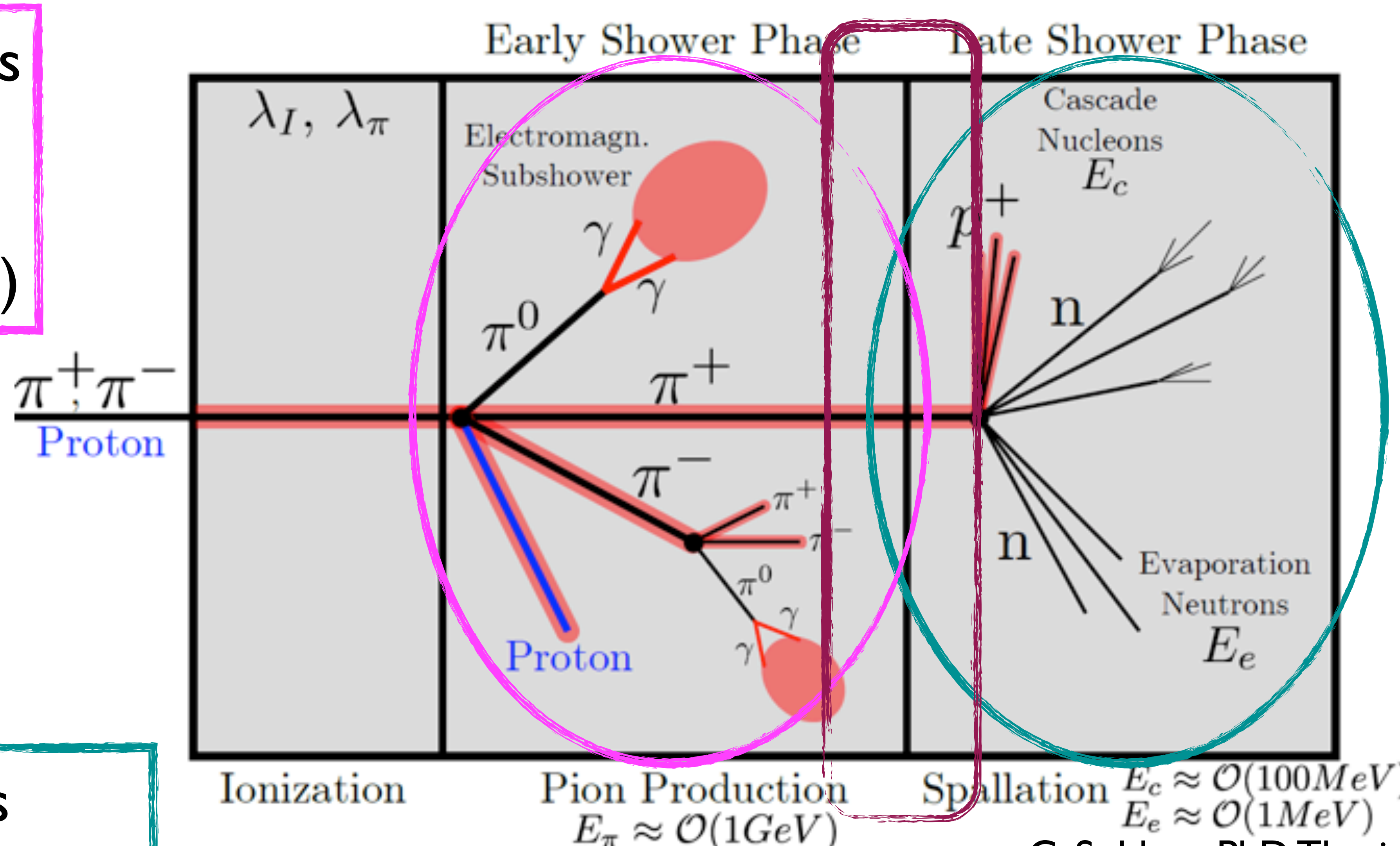
Late phase: slow neutrons capture, evaporation, spallation

Hadronic Showers:
Time development

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

Intermediate phase: neutron scattering

Late phase: slow neutrons capture, evaporation, spallation

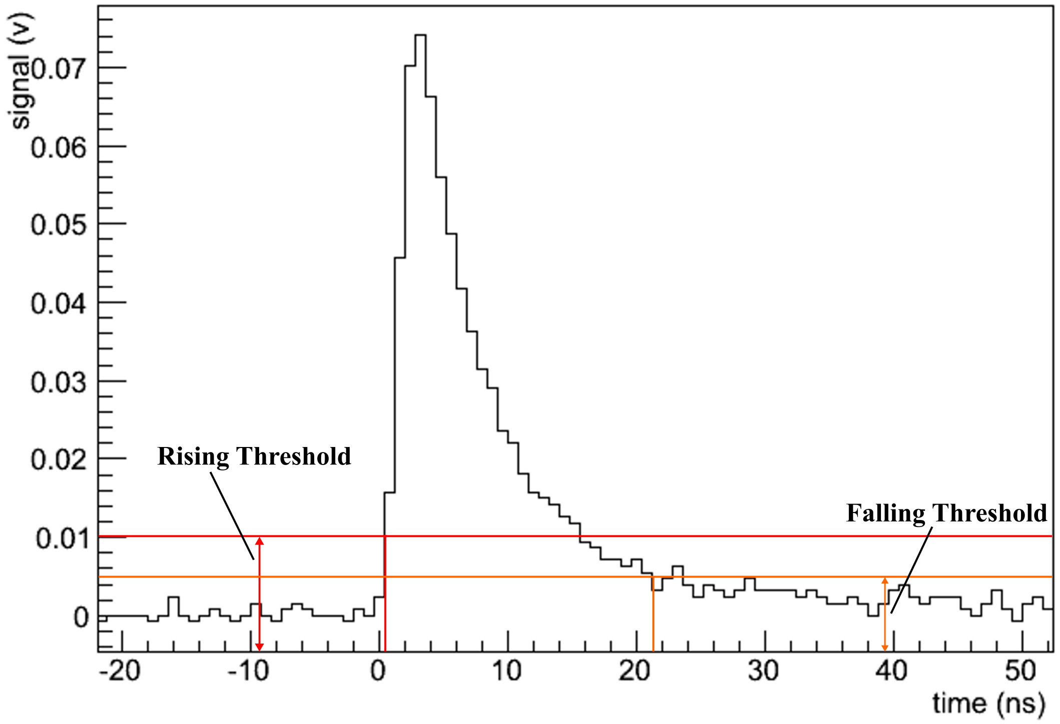


source: C. Soldner PhD Thesis

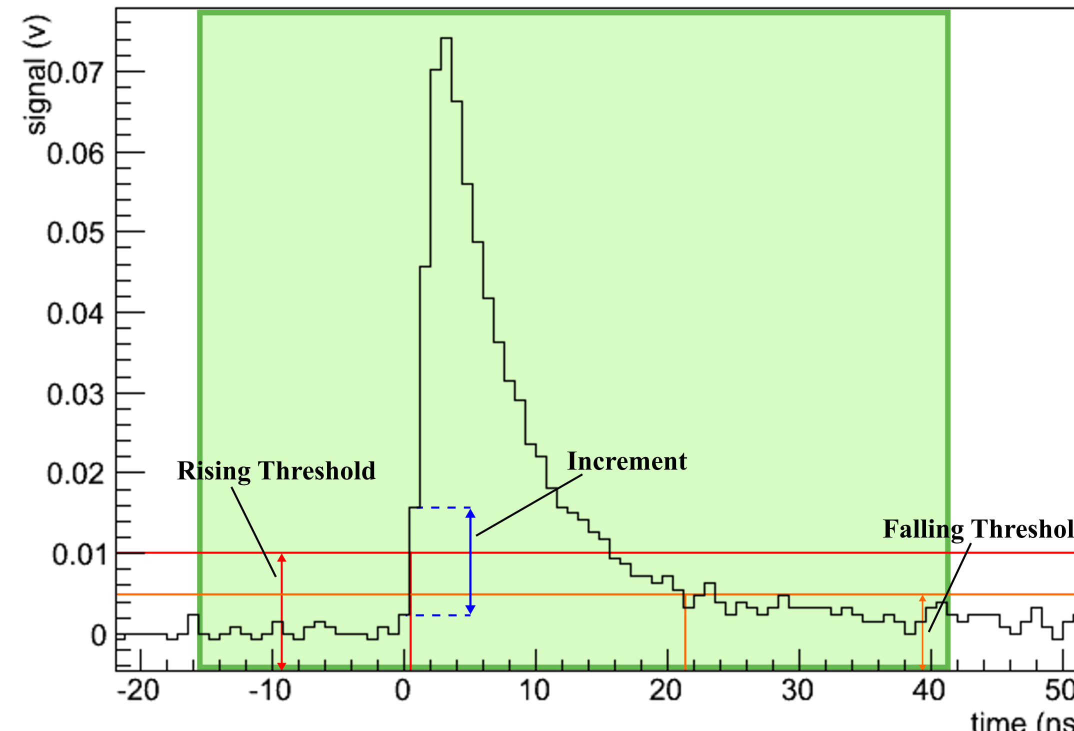
Hydrogen content in a gaseous detector is much lower than in plastic scintillators ➔ less sensitive to neutron elastic scattering

Data Analysis:
Calibration

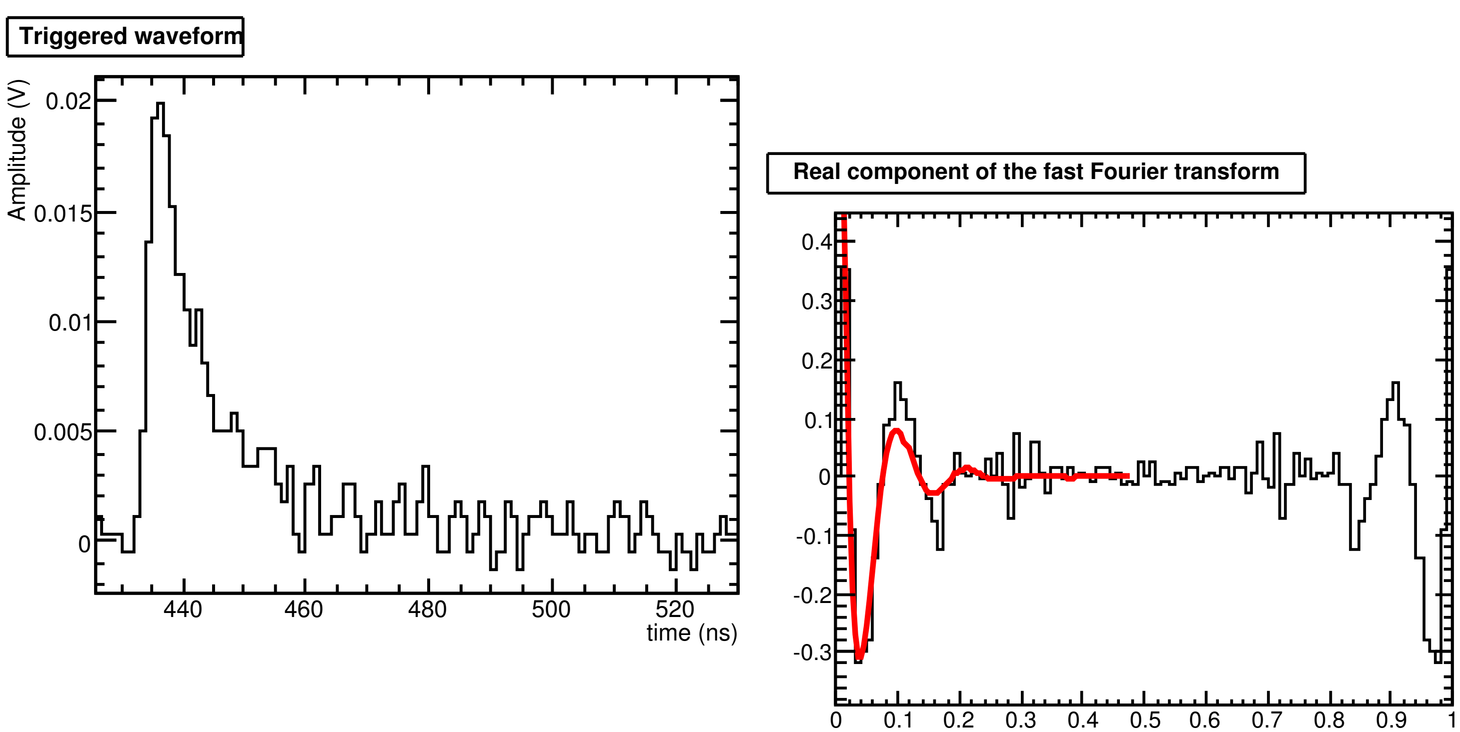
Threshold cut



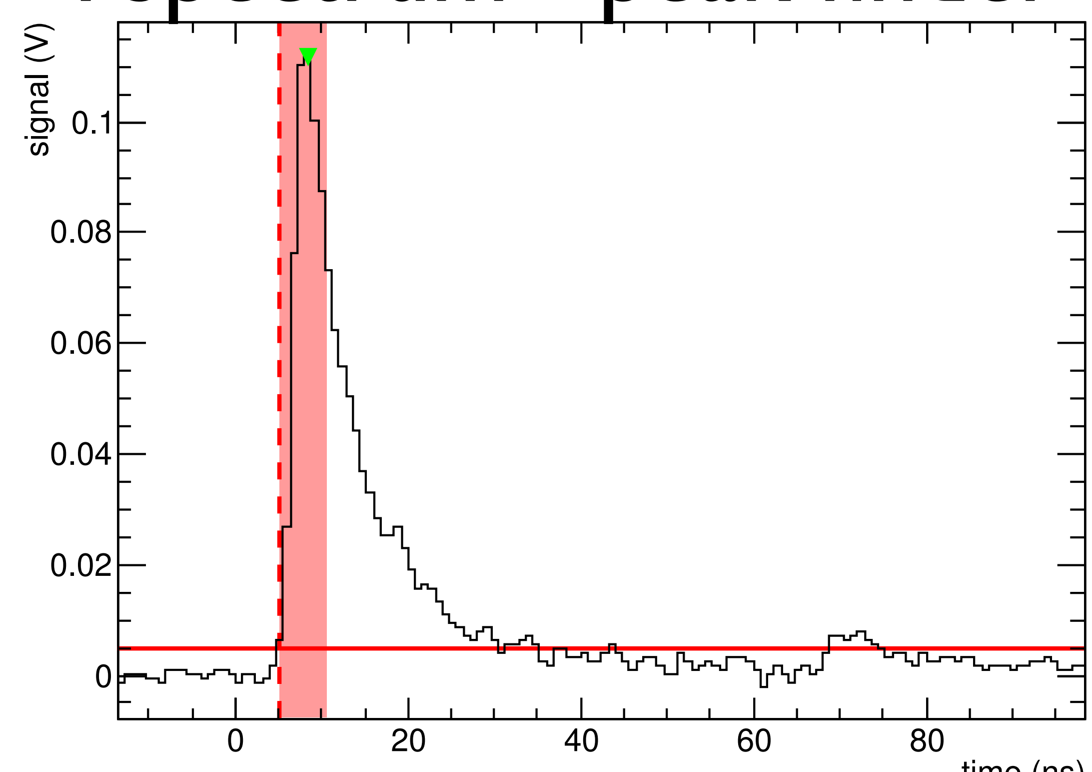
Threshold cut + derivative



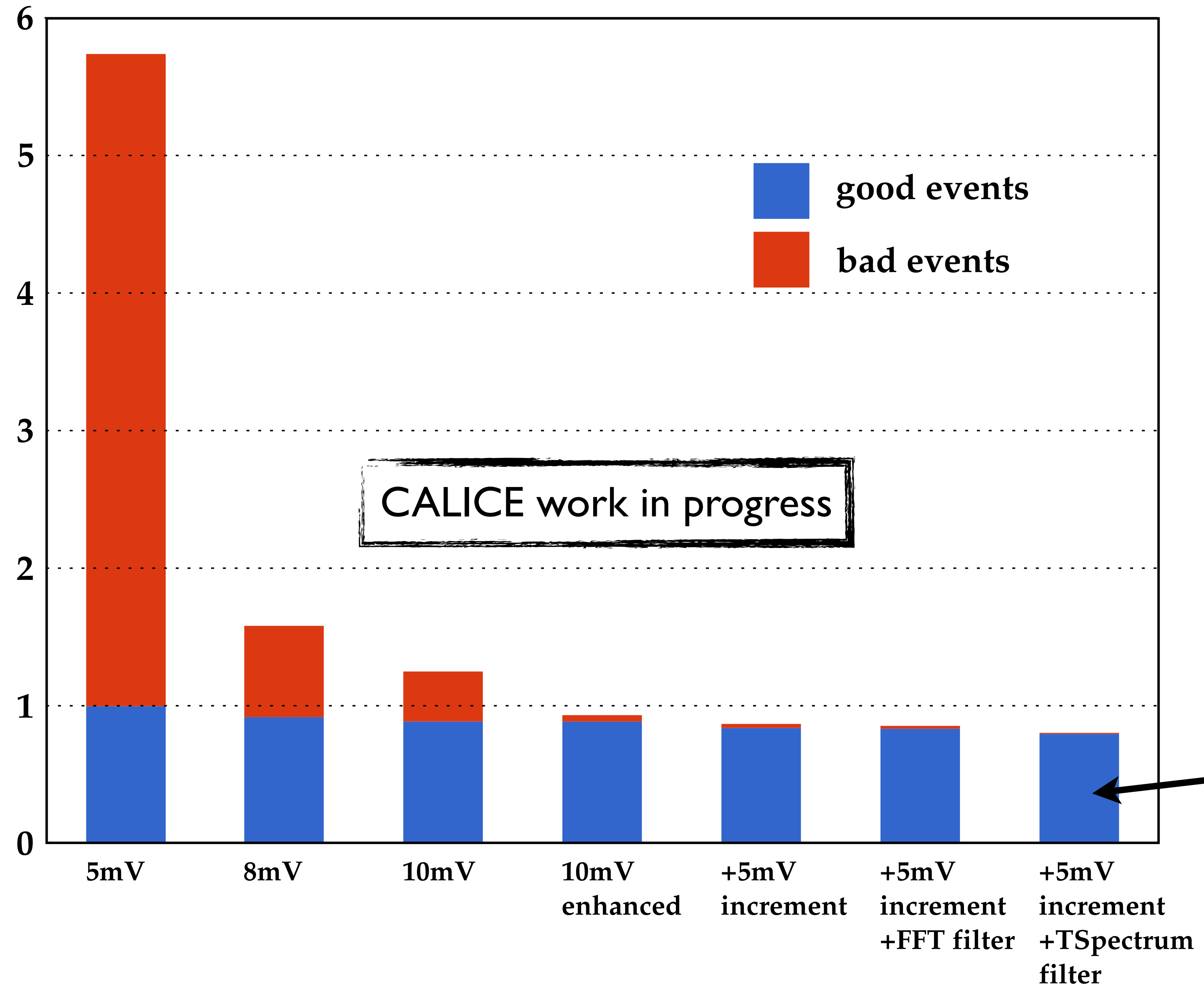
FFT + fit



TSpectrum - peak finder

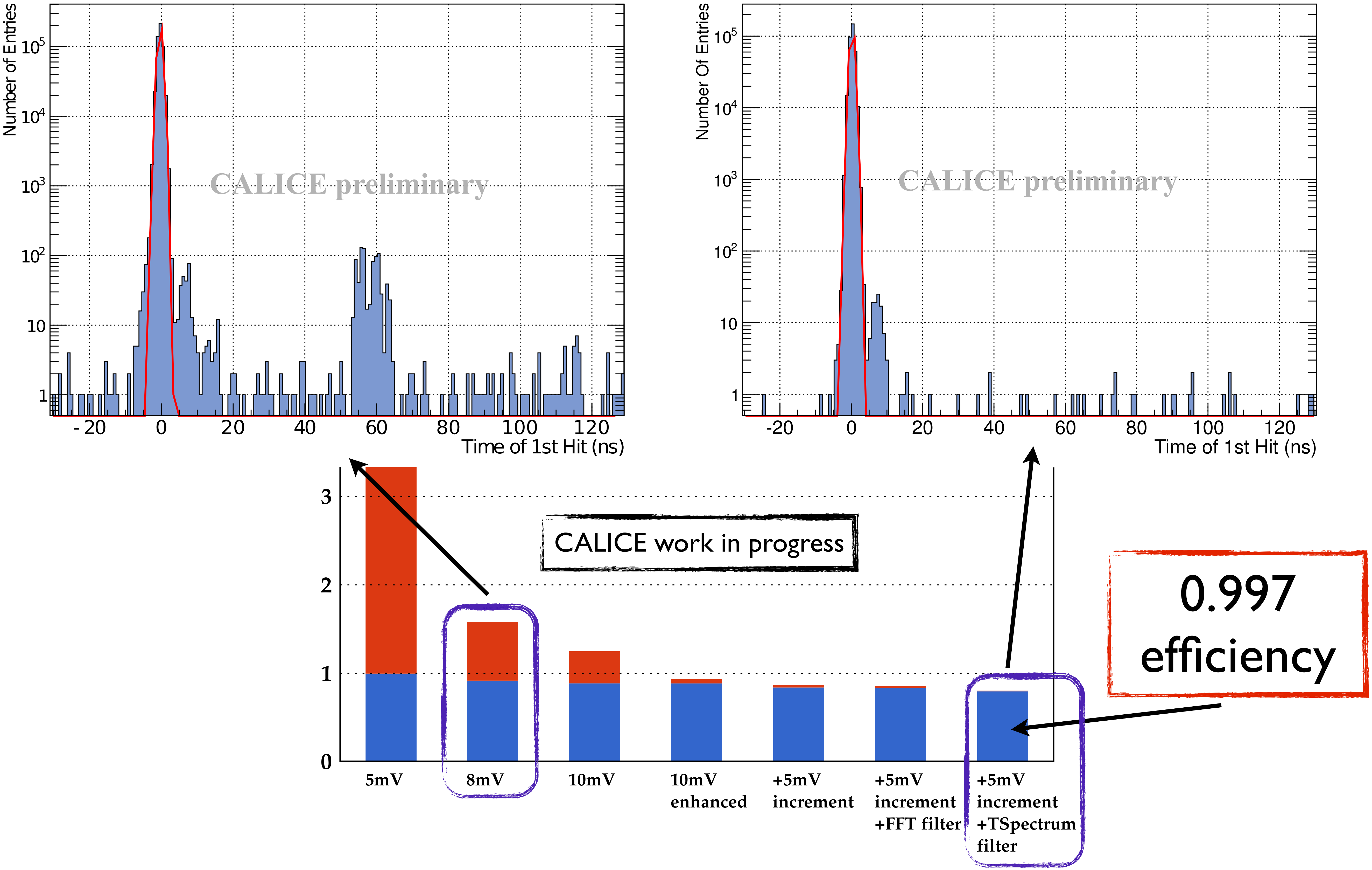


Data Analysis:
Calibration Benchmark

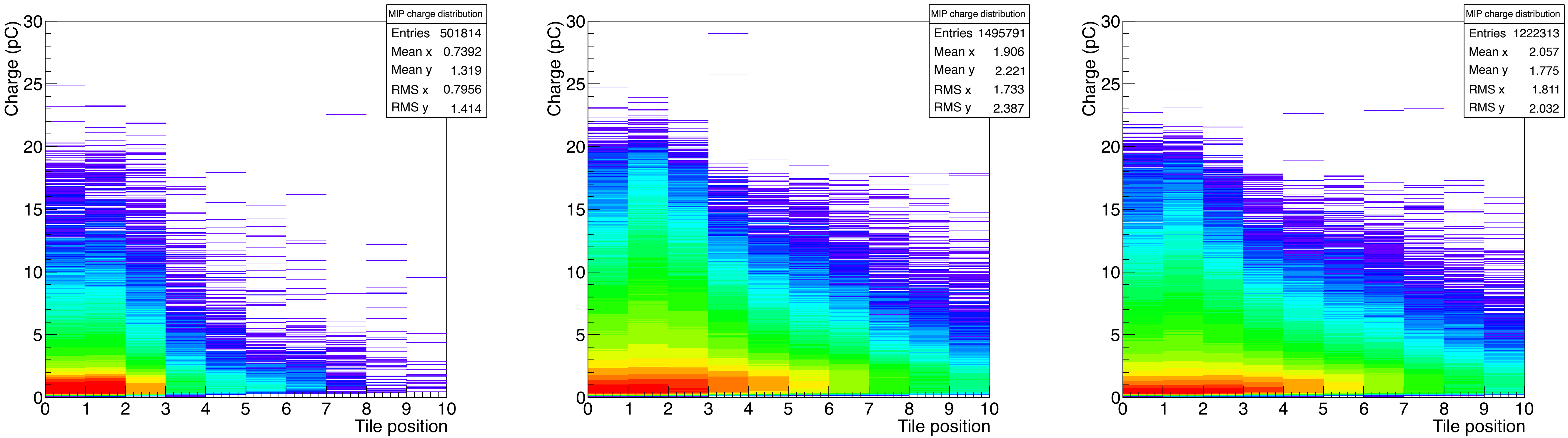


0.997 efficiency

Data Analysis:
Calibration Benchmark



Data Analysis:
Charge Distribution



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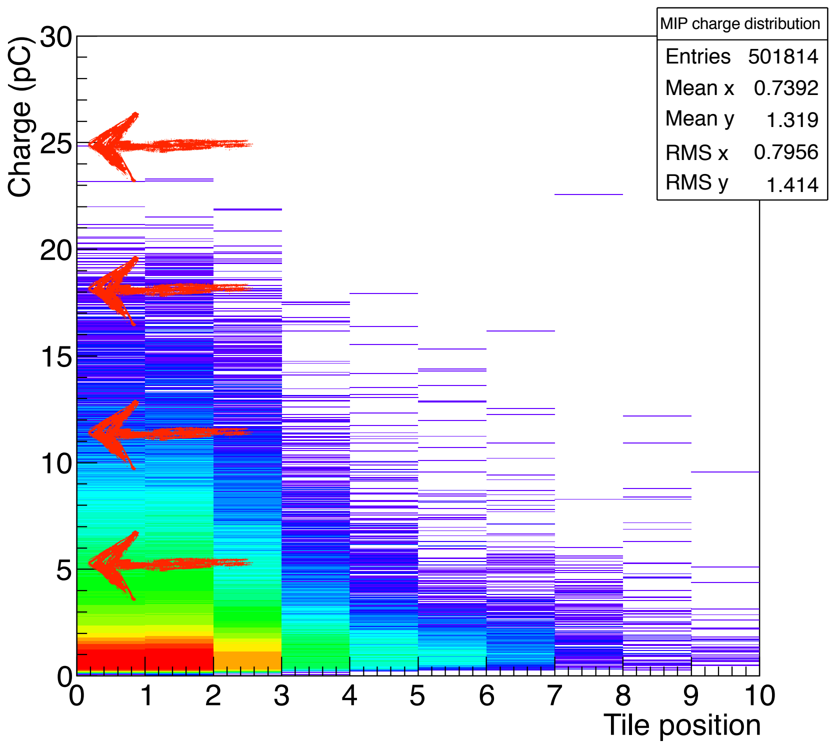

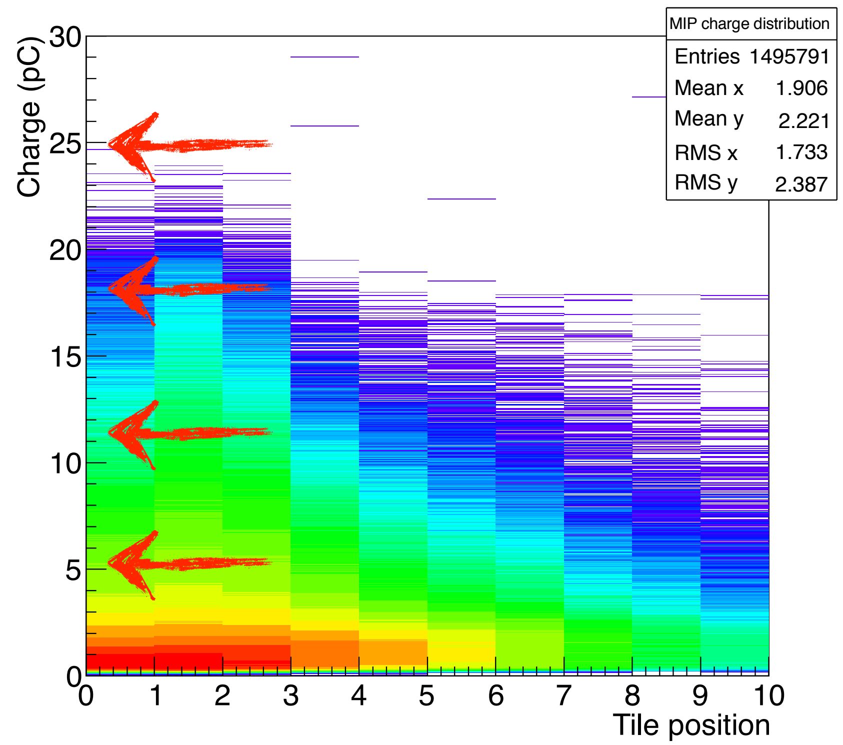

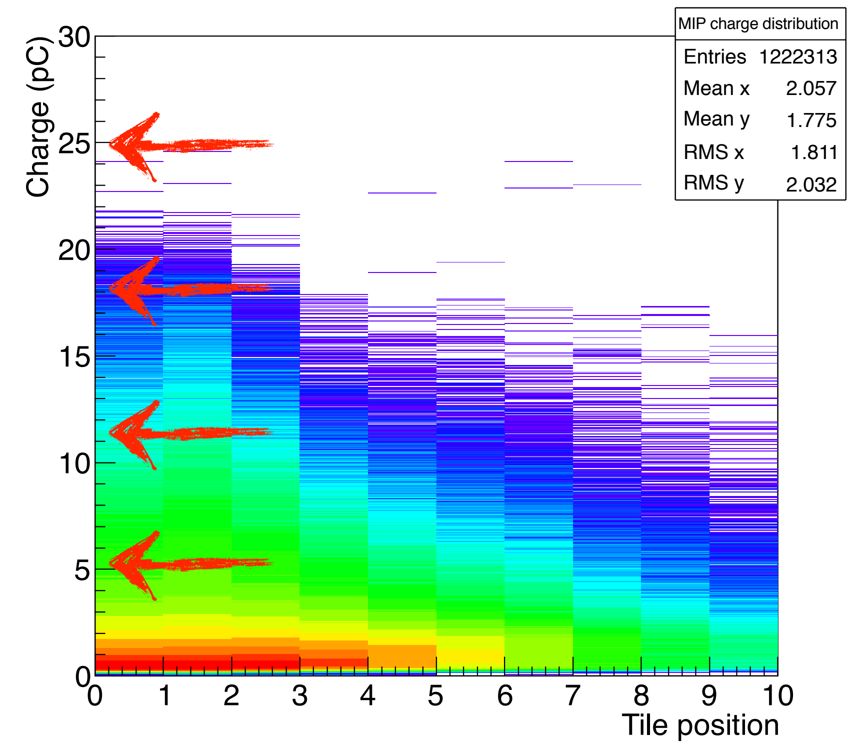

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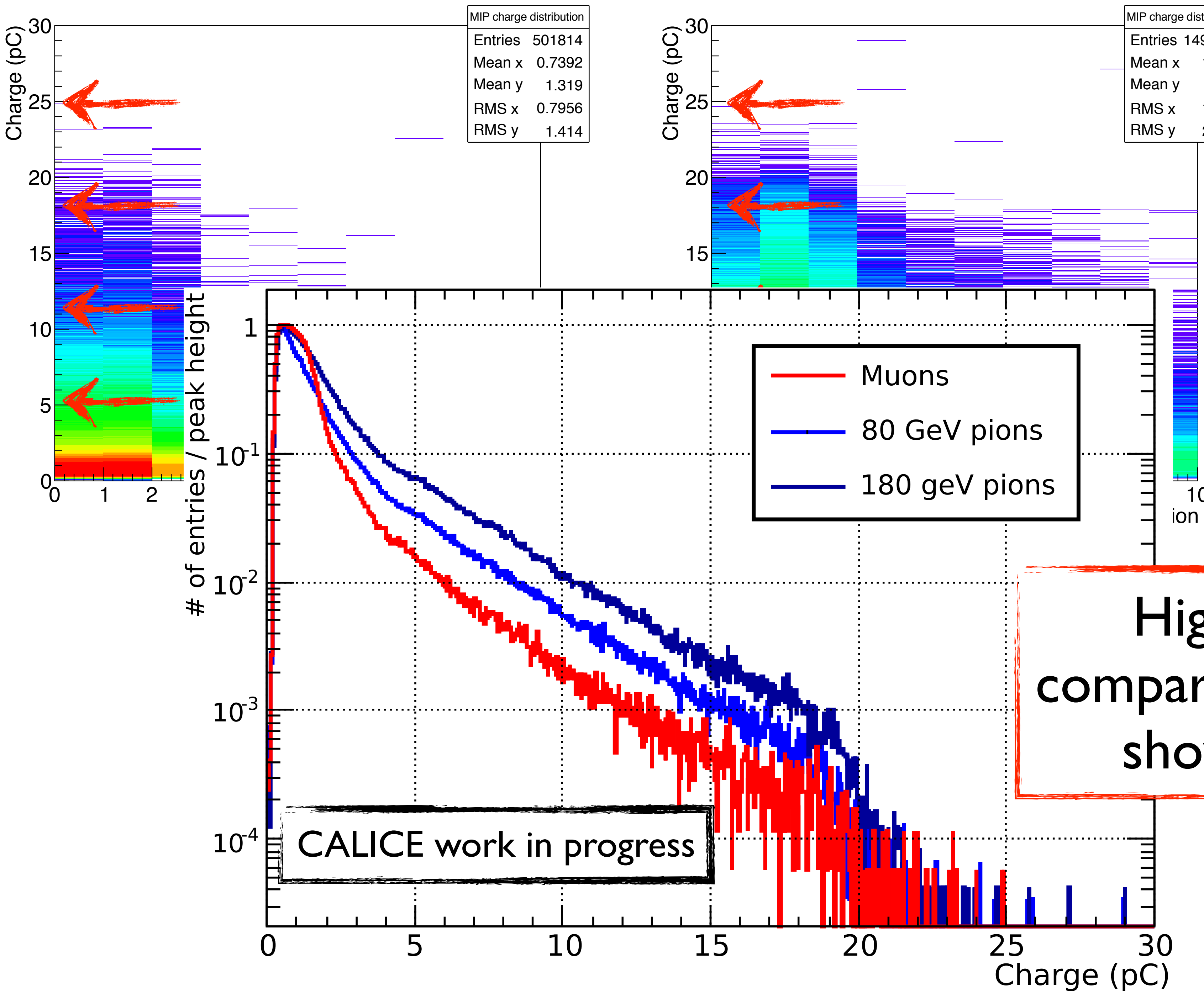
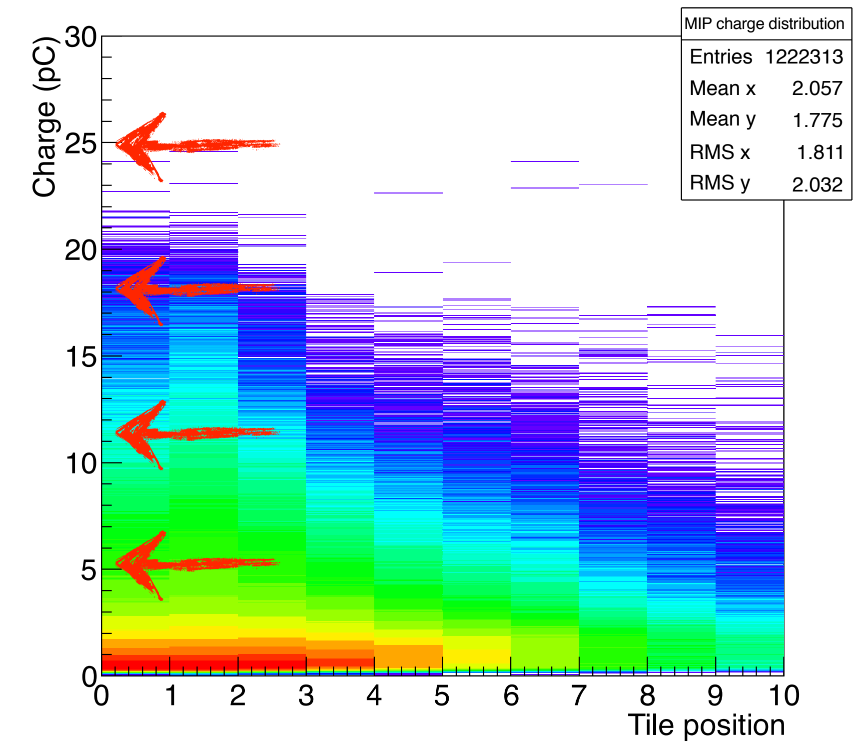


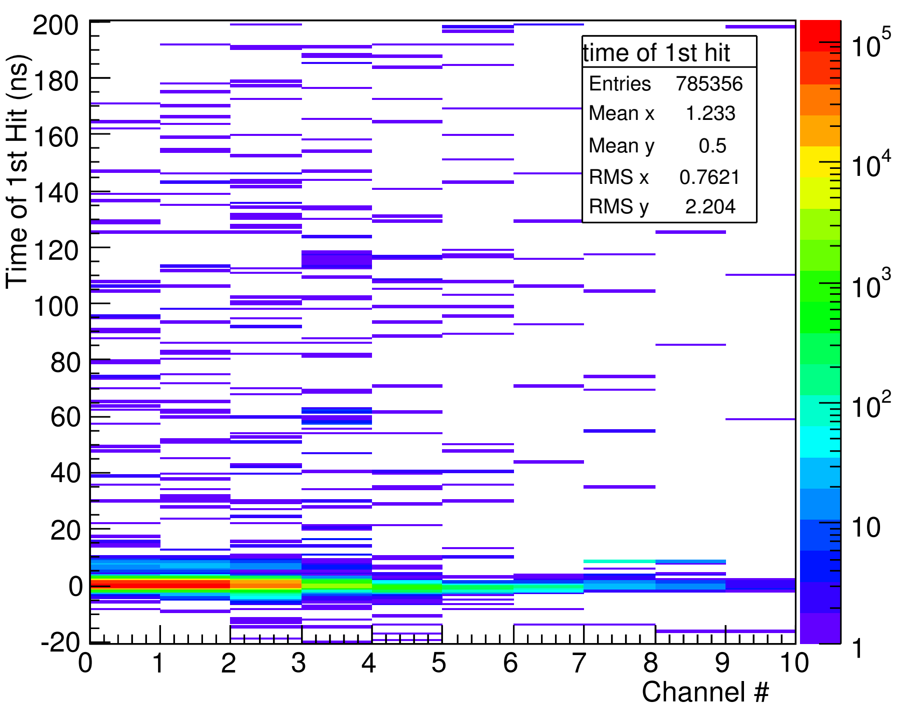


Higher Amplitudes compared to muons: dense shower component

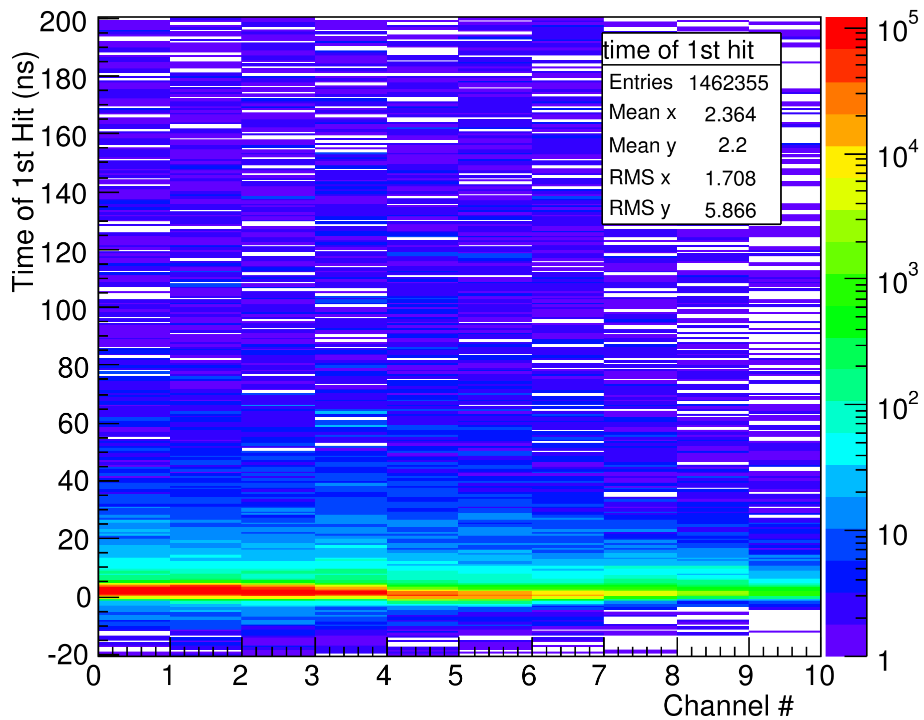
Good agreement with previous measurements from the Argonne group (NIMA A 578:1,88-97(2007)

Data Analysis:
Time of 1st Hit

Muons



80GeV pions



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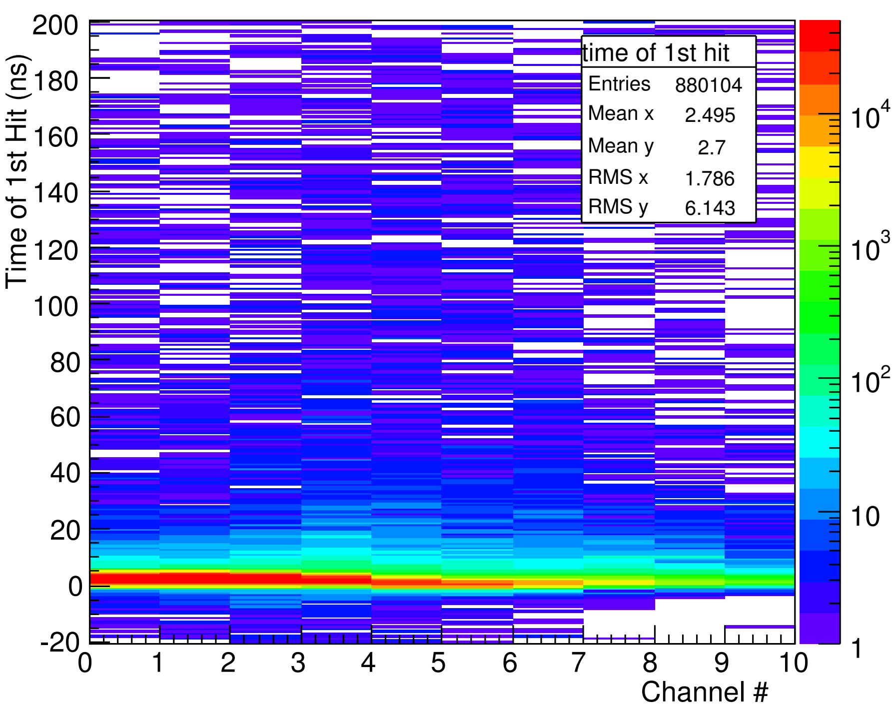
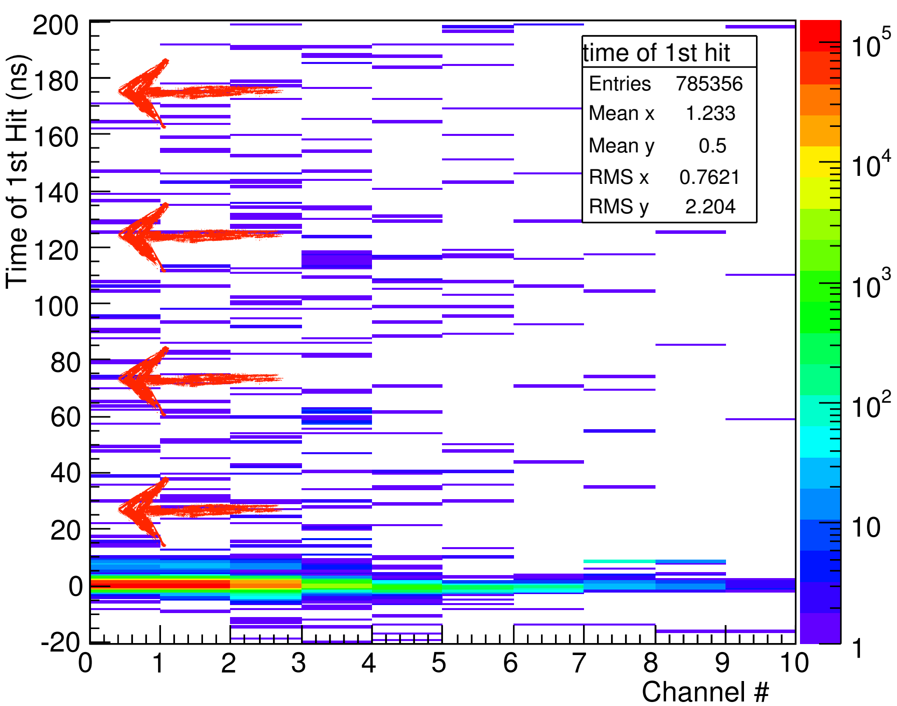


CALICE work in progress

- Muons are instantaneous
- Hadronic showers show substantial late contribution

Time of 1st Hit

Muons



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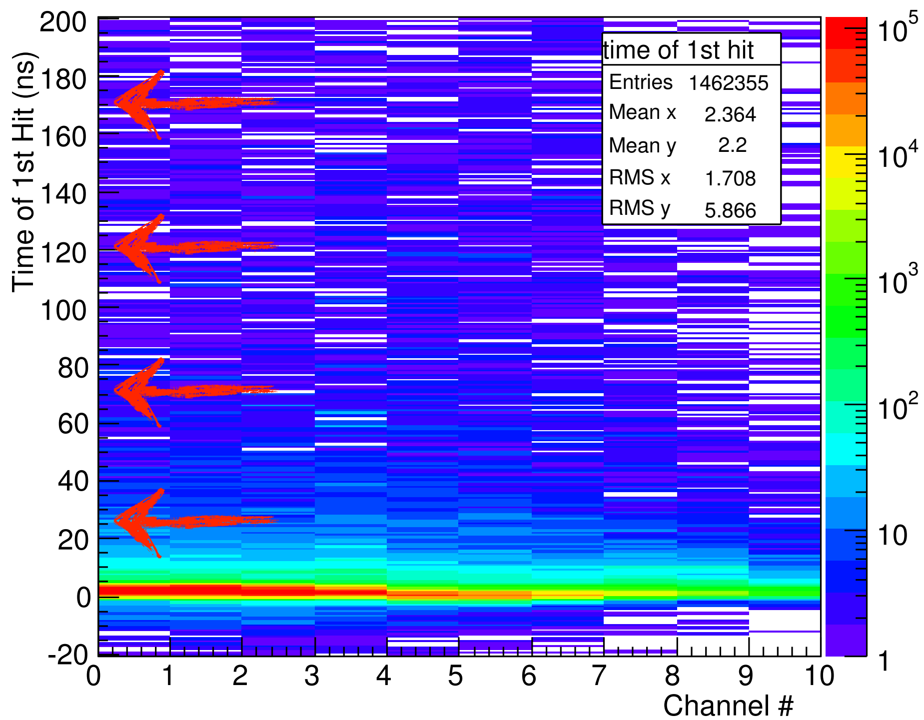

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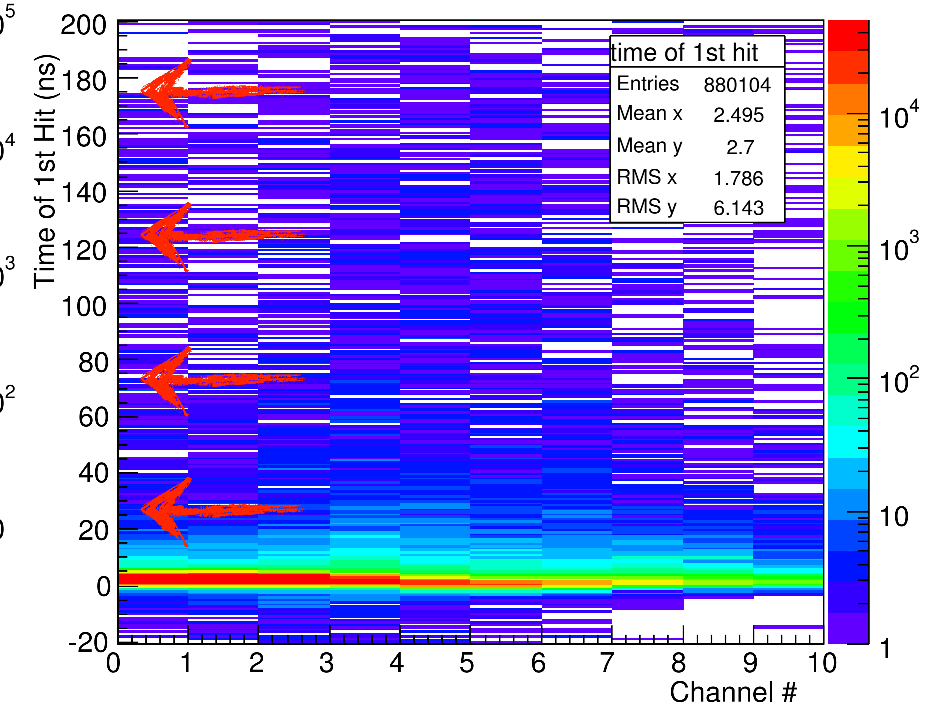

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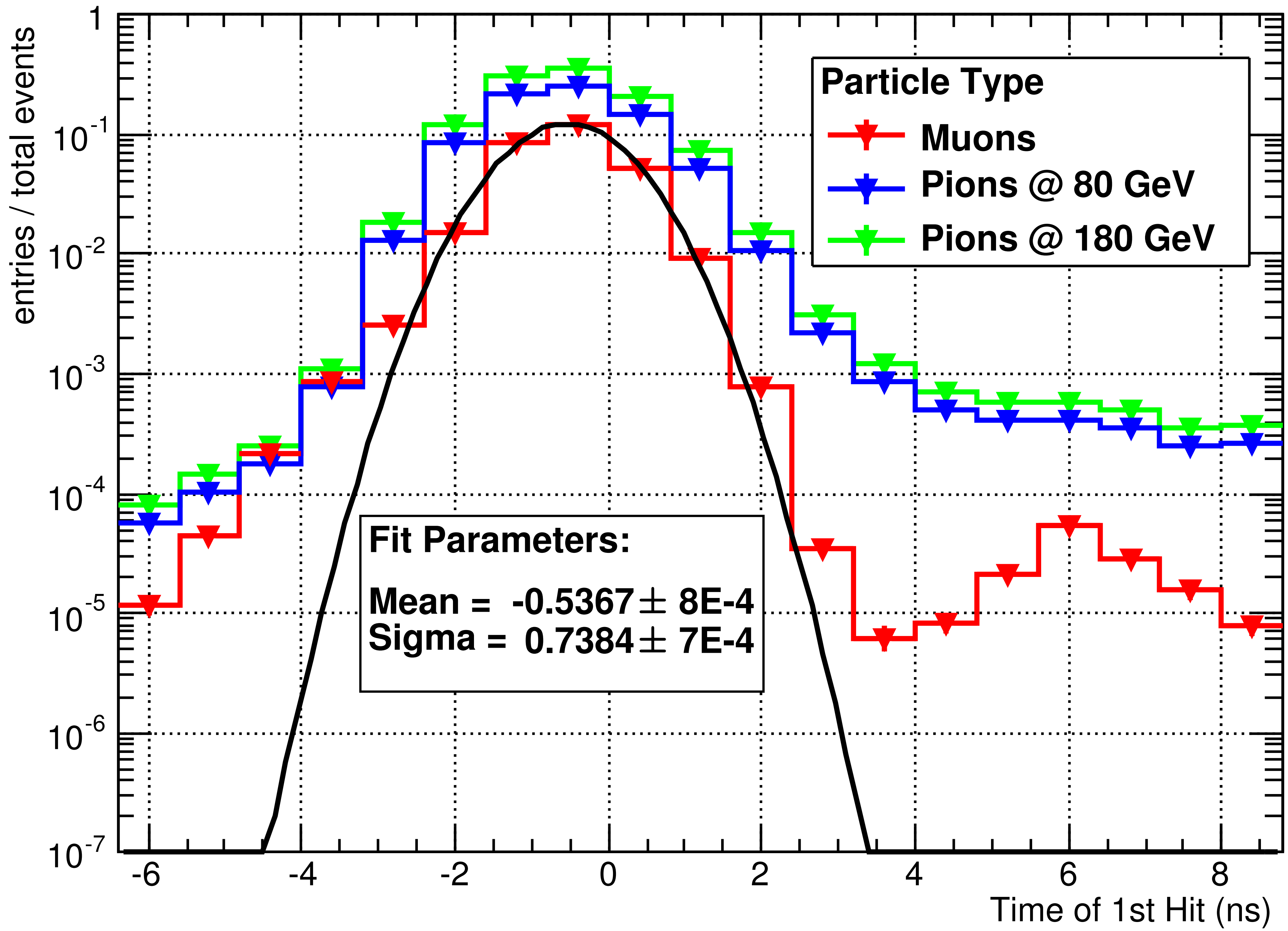
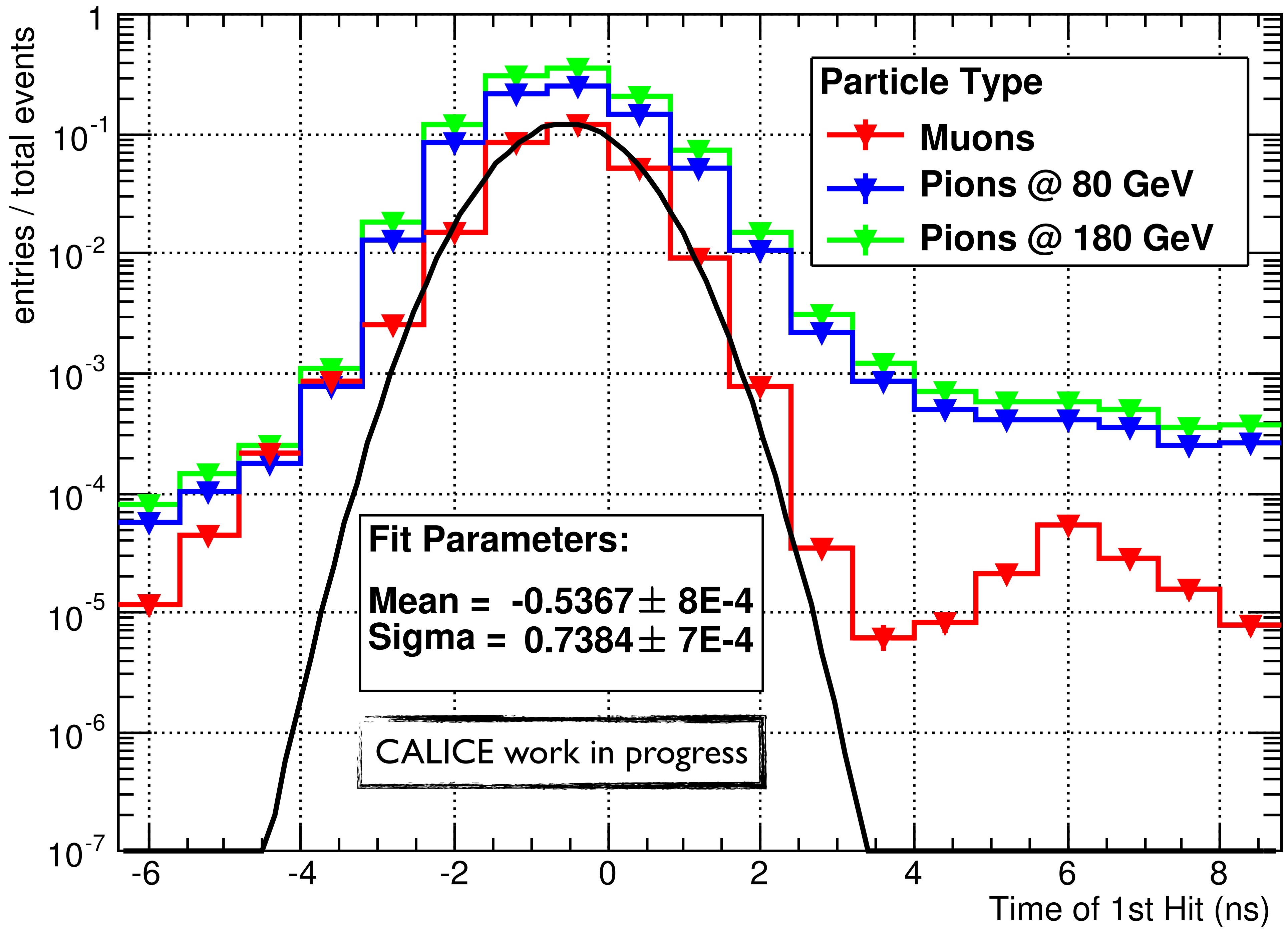
Data Analysis:

Time Resolution



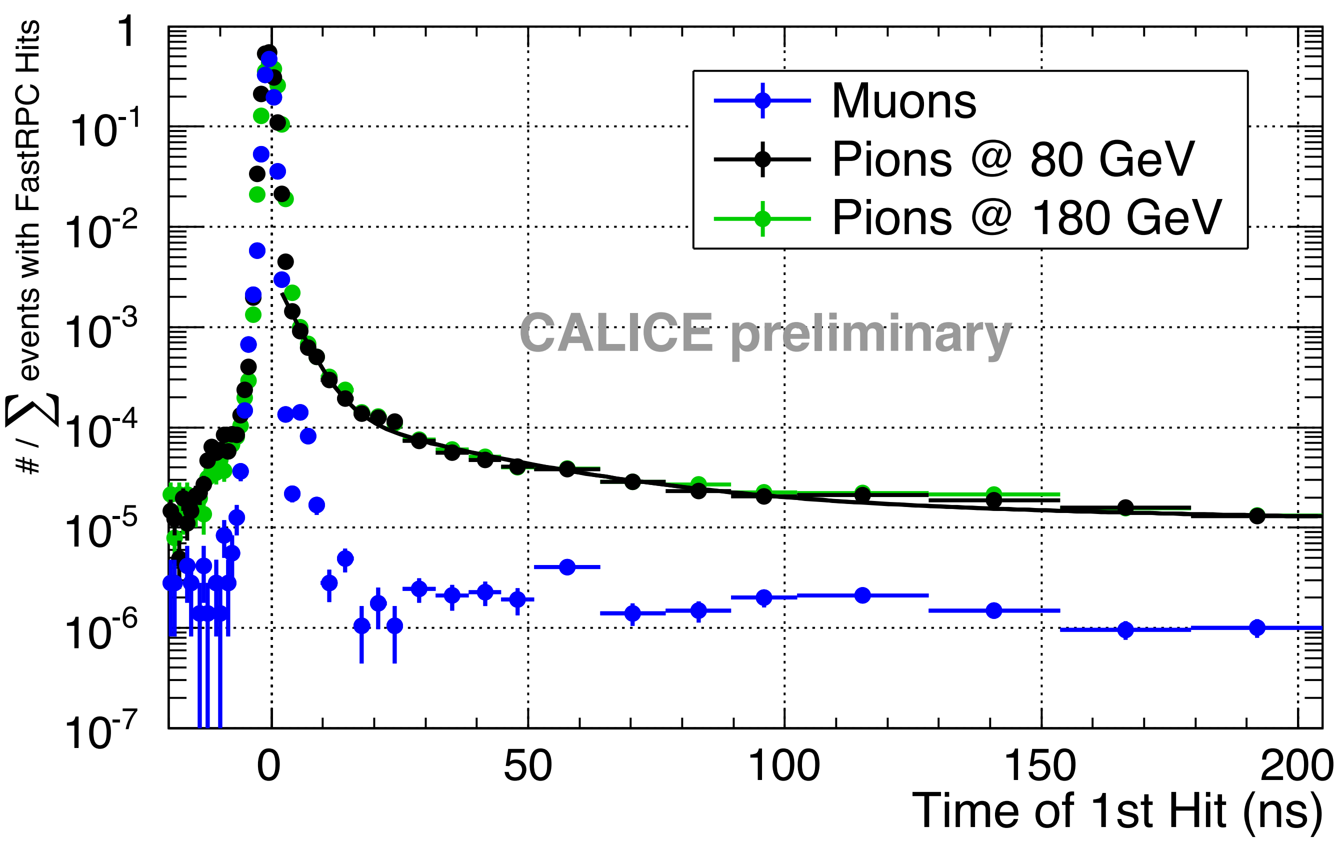
Dominated by jitter in the triggers

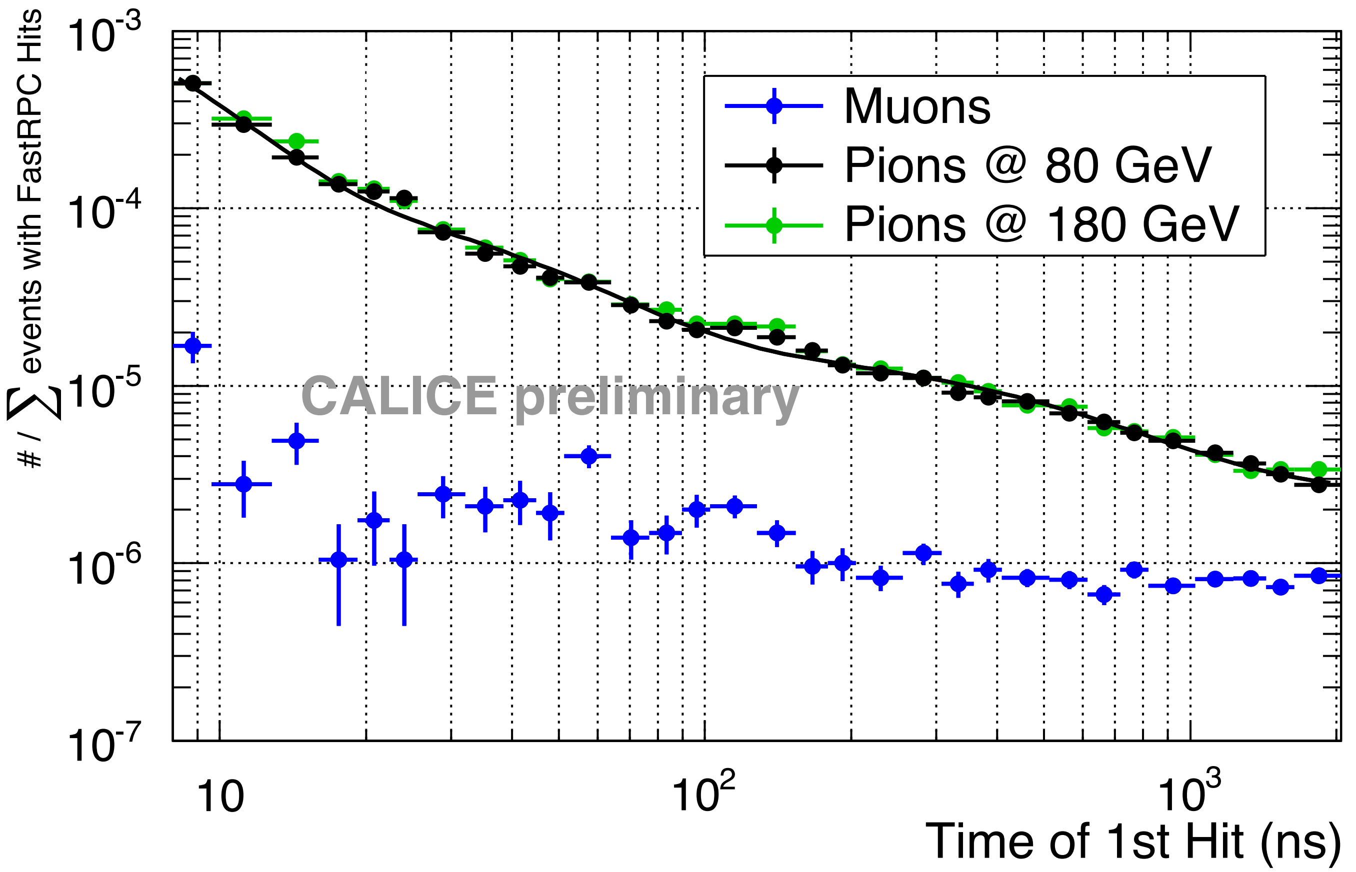
Time Resolution



Dominated by jitter in the triggers

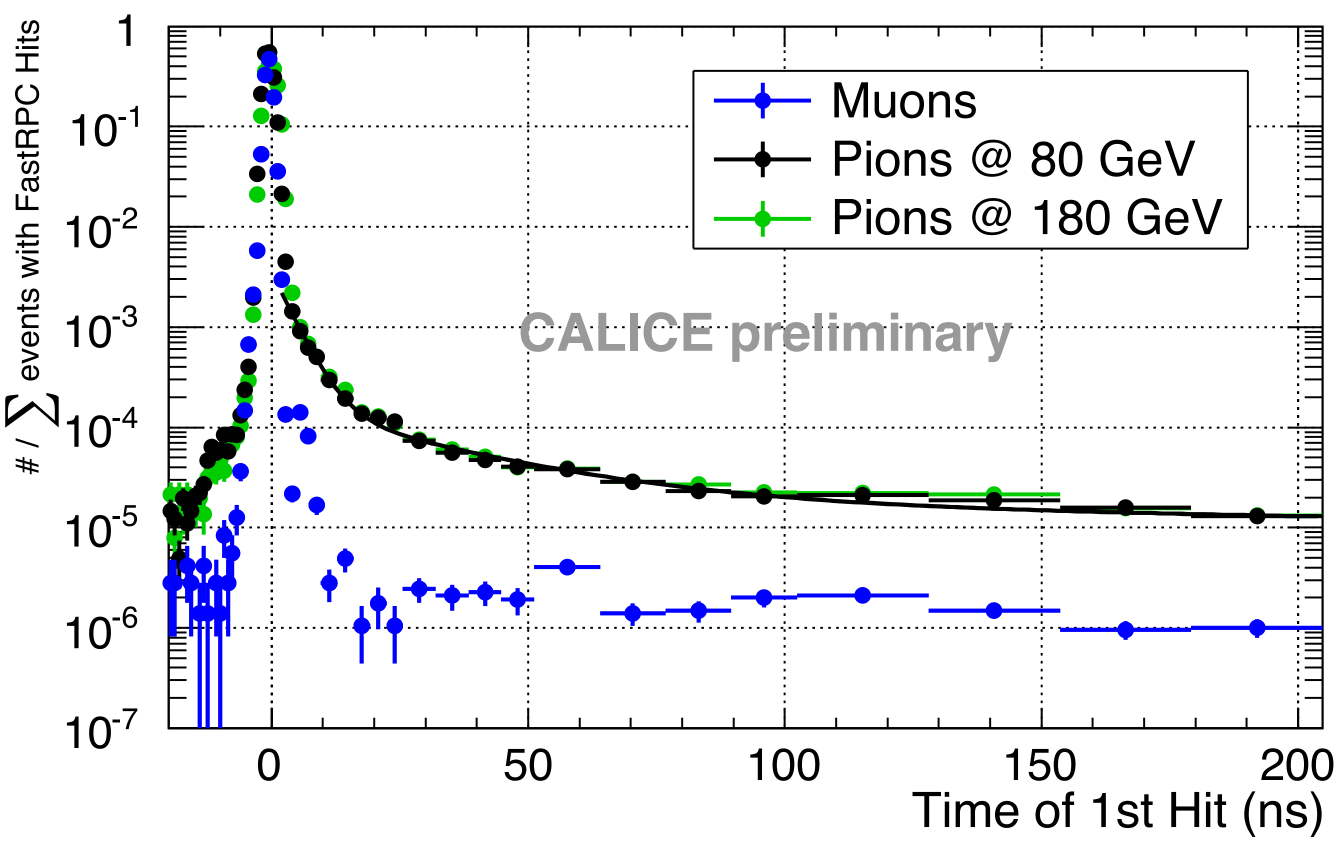
Data Analysis:
ToFH - Projection & Fit

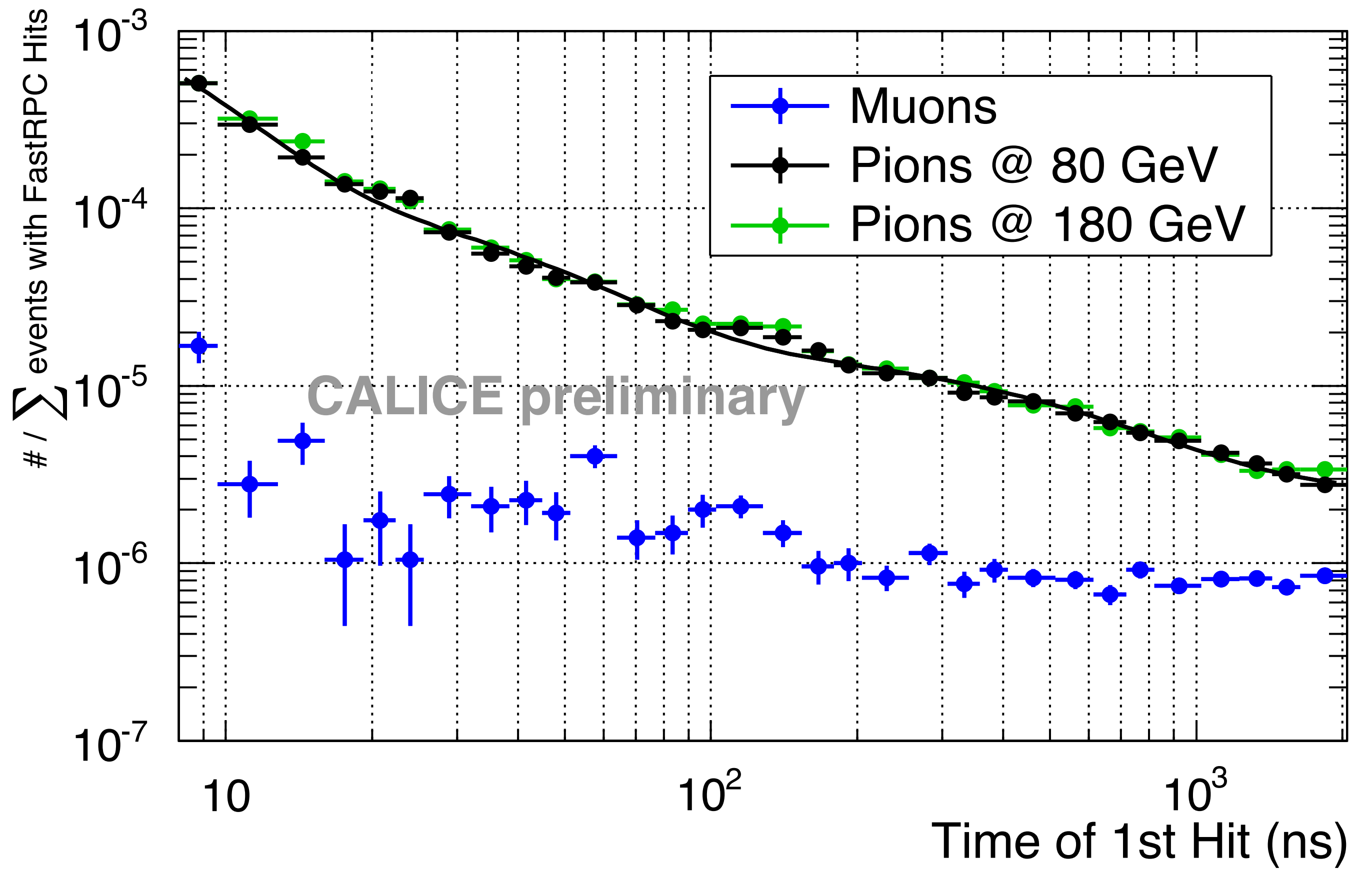




Data Analysis:

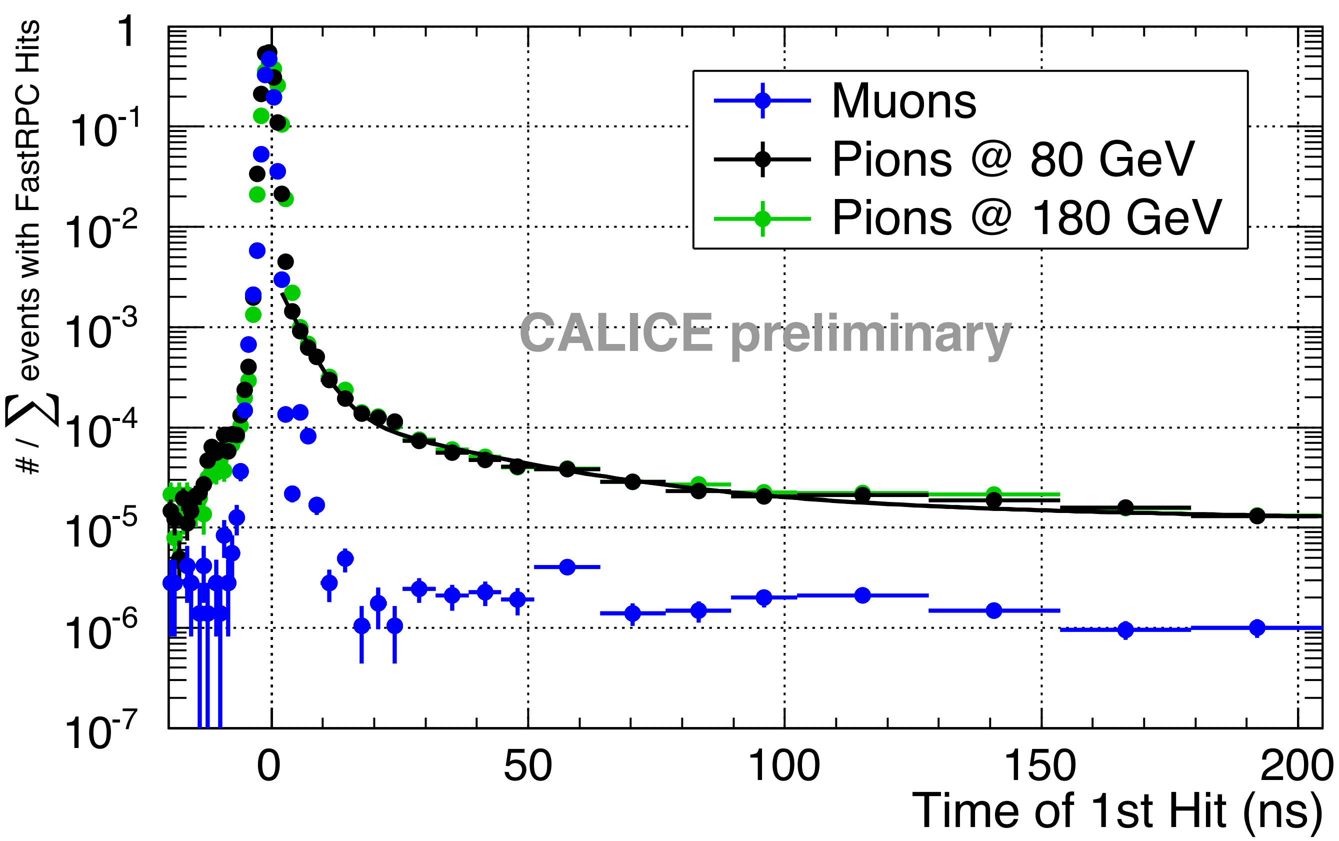
ToFH - Projection & Fit

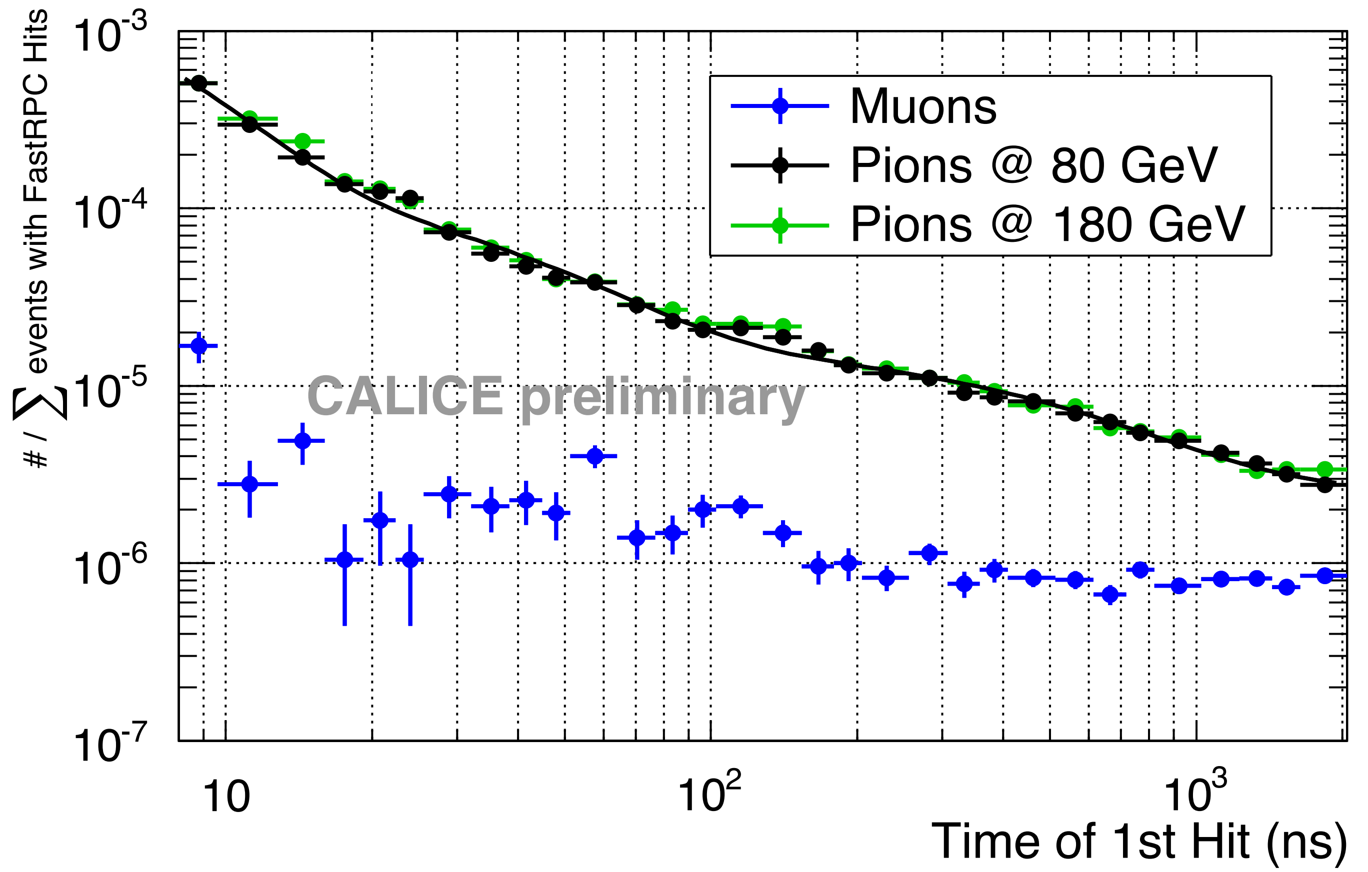




Time structure is independent from energy of the incoming particle

Data Analysis:
ToFH - Projection & Fit



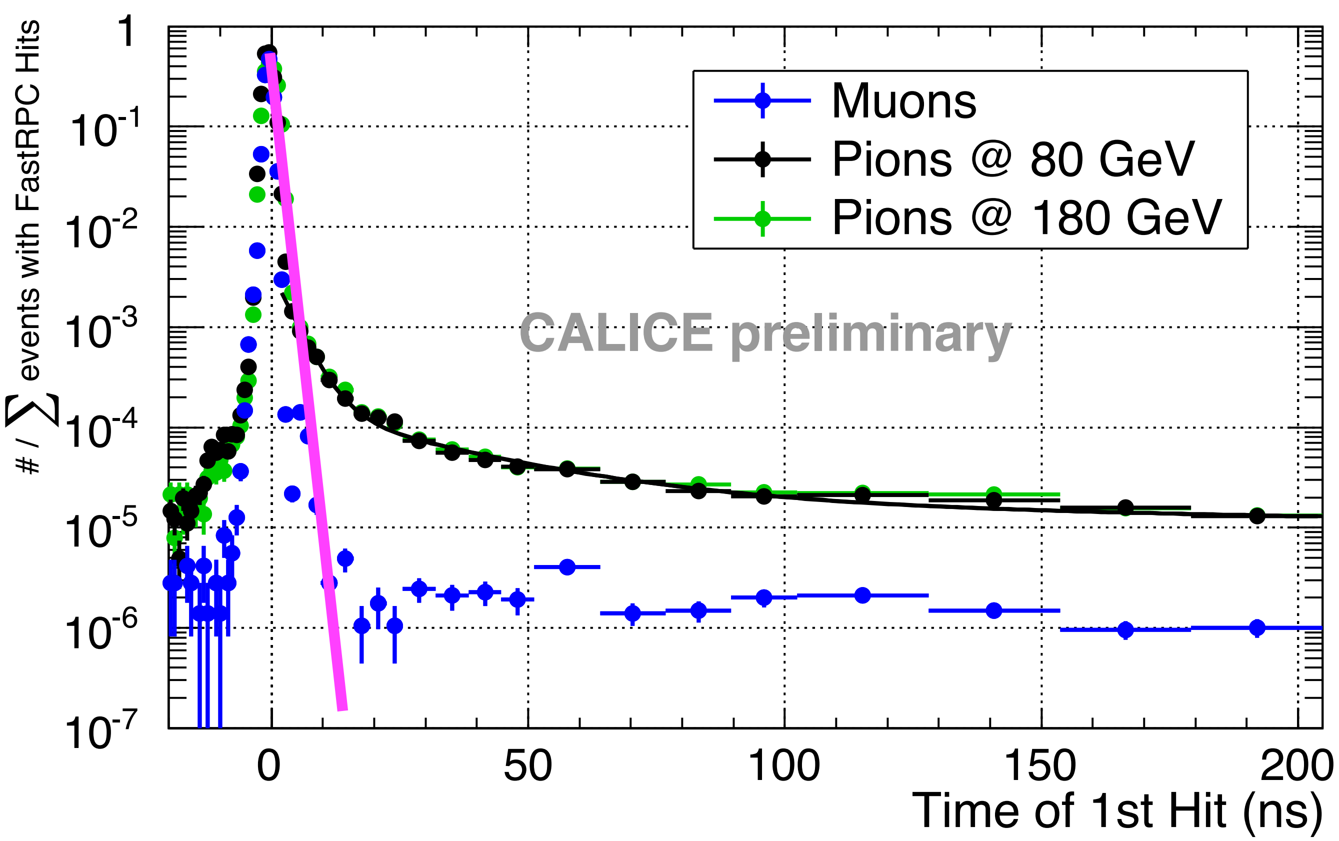


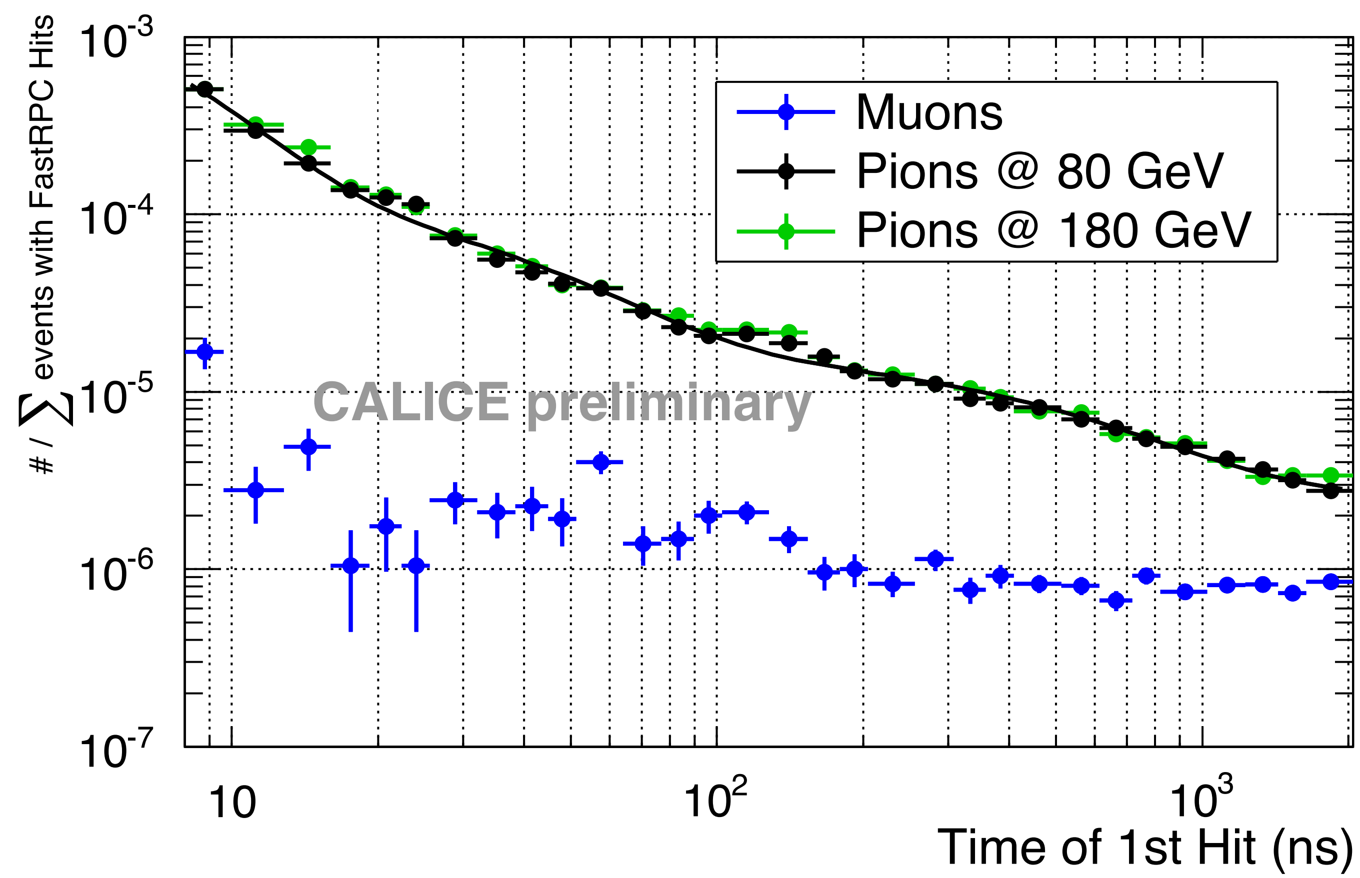
Time structure is independent from energy of the incoming particle

$$A_1 \cdot \exp\left(-\frac{t}{\tau_1}\right) + A_2 \cdot \exp\left(-\frac{t}{\tau_2}\right) + A_3 \cdot \exp\left(-\frac{t}{\tau_3}\right) + c$$

Data Analysis:

ToFH - Projection & Fit



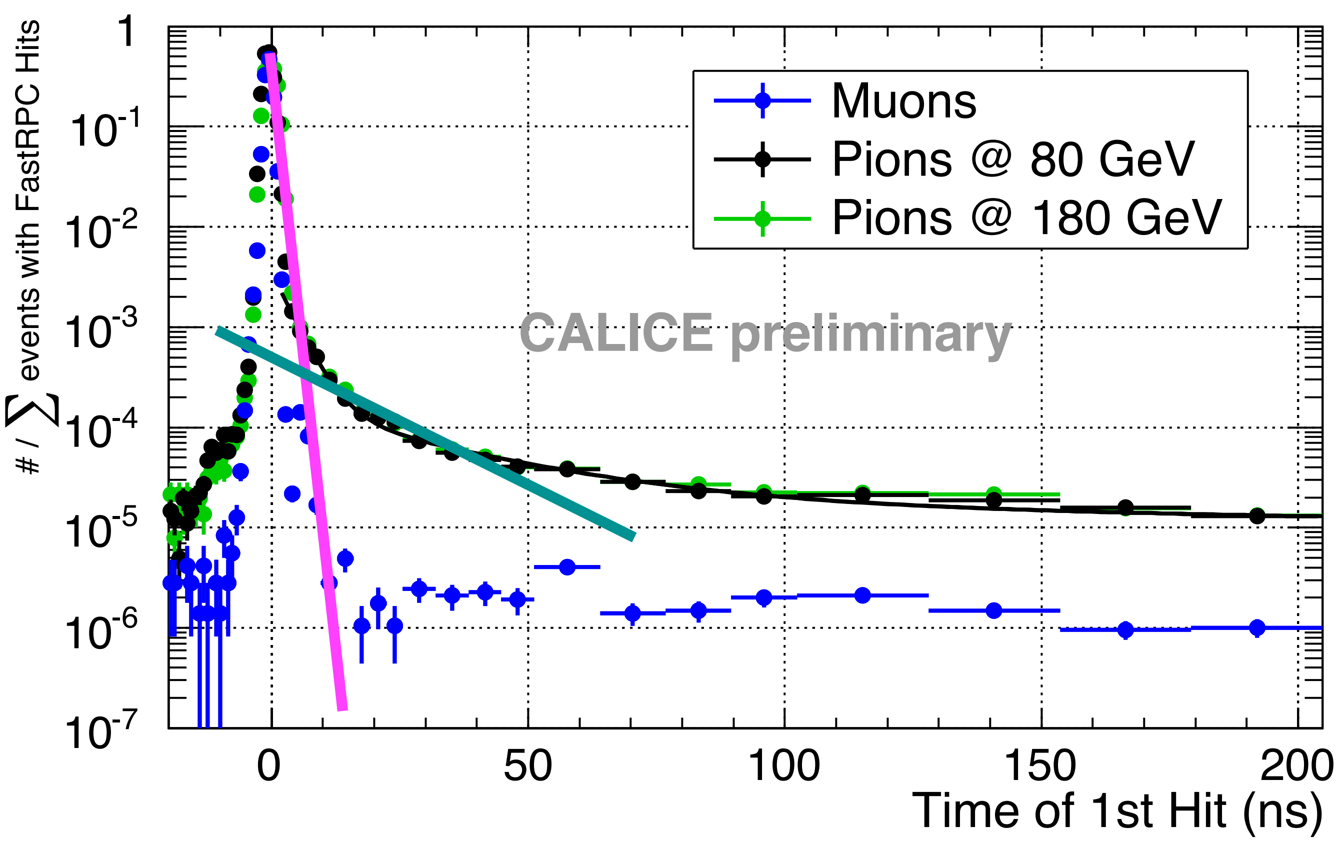


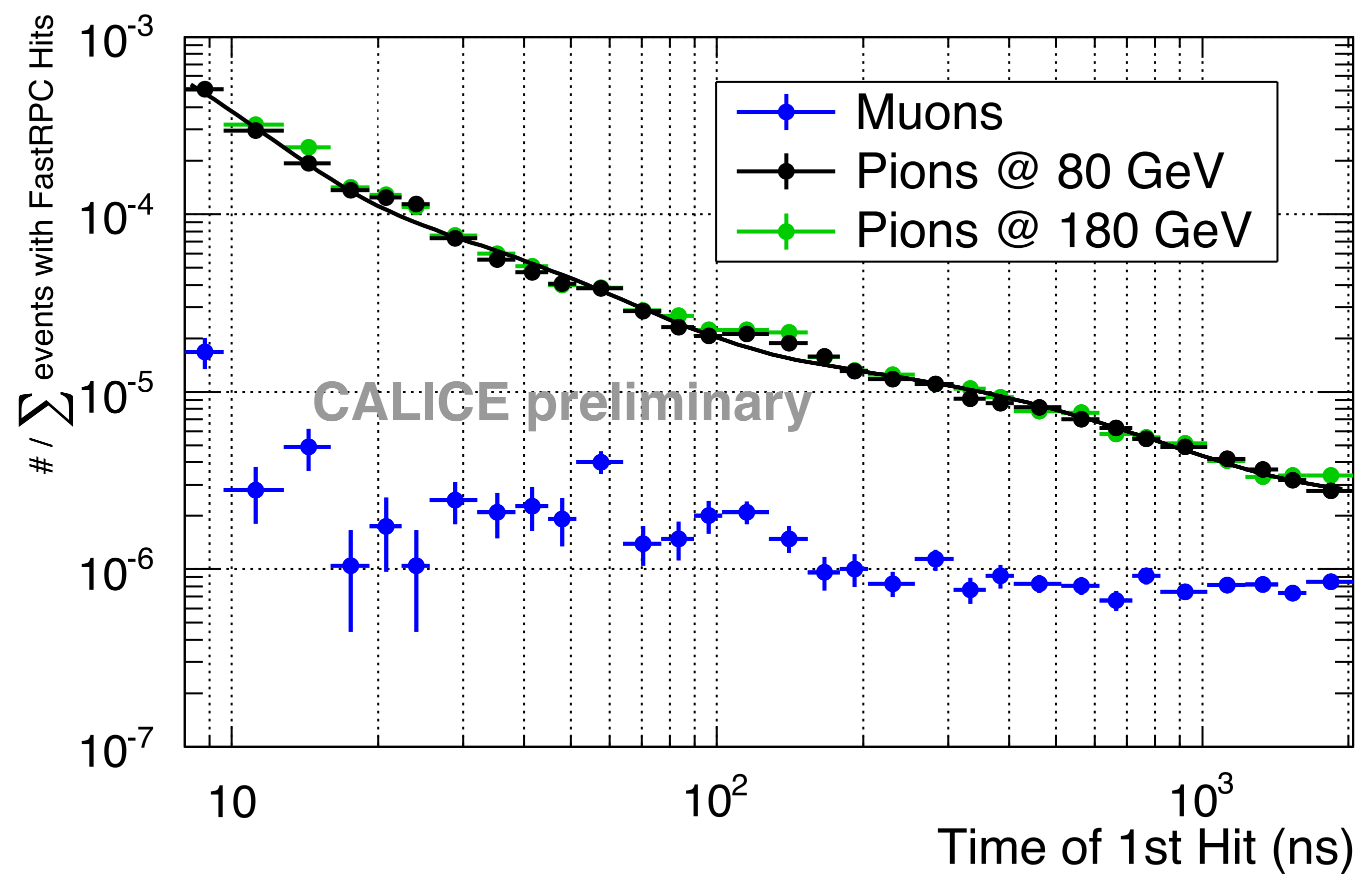
Time structure is independent from energy of the incoming particle

$A_1 = 3.8 \times 10^{-3}$ □= 4.1 ns

$$A_1 \cdot \exp\left(-\frac{t}{\tau_1}\right) + A_2 \cdot \exp\left(-\frac{t}{\tau_2}\right) + A_3 \cdot \exp\left(-\frac{t}{\tau_3}\right) + c$$

ToFH - Projection & Fit





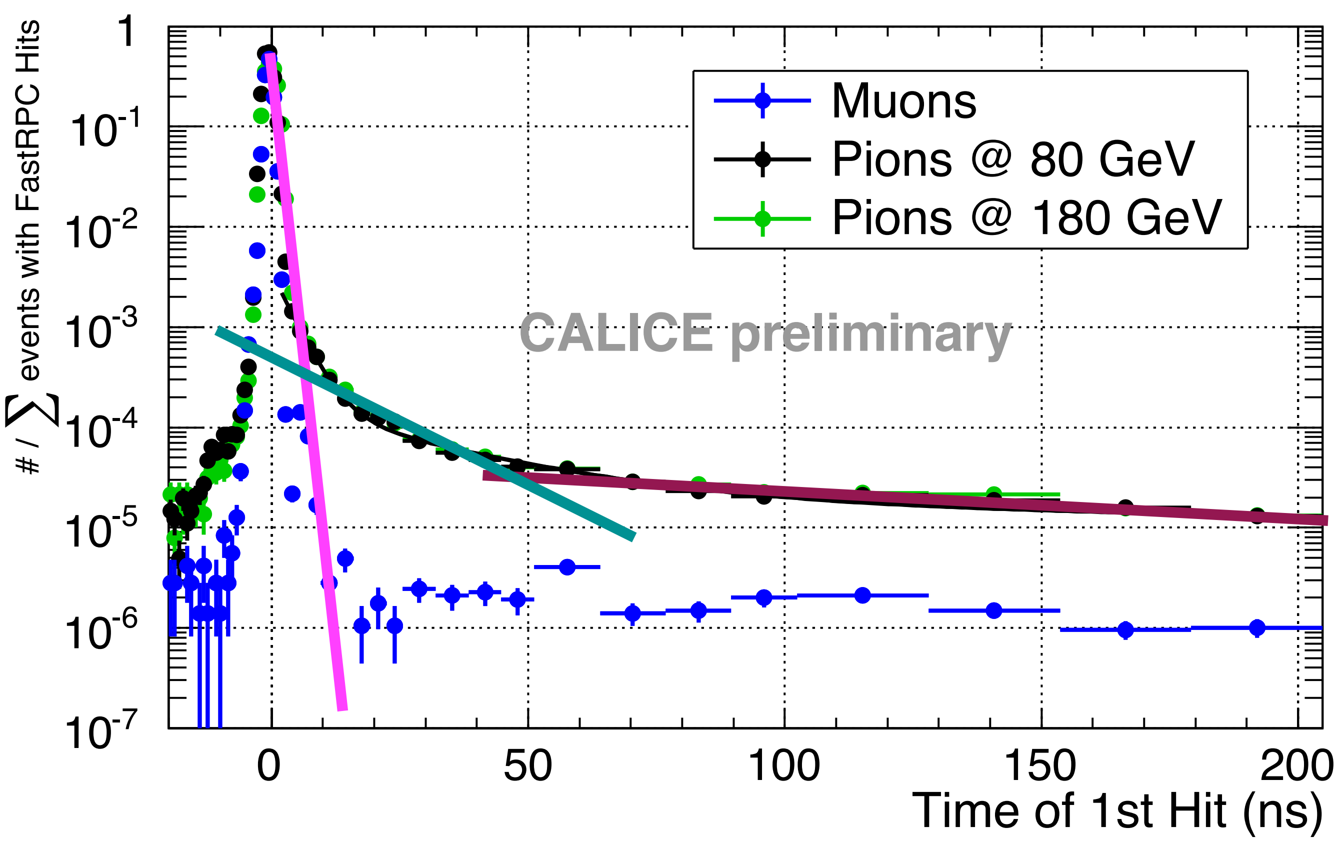
Time structure is independent from energy of the incoming particle

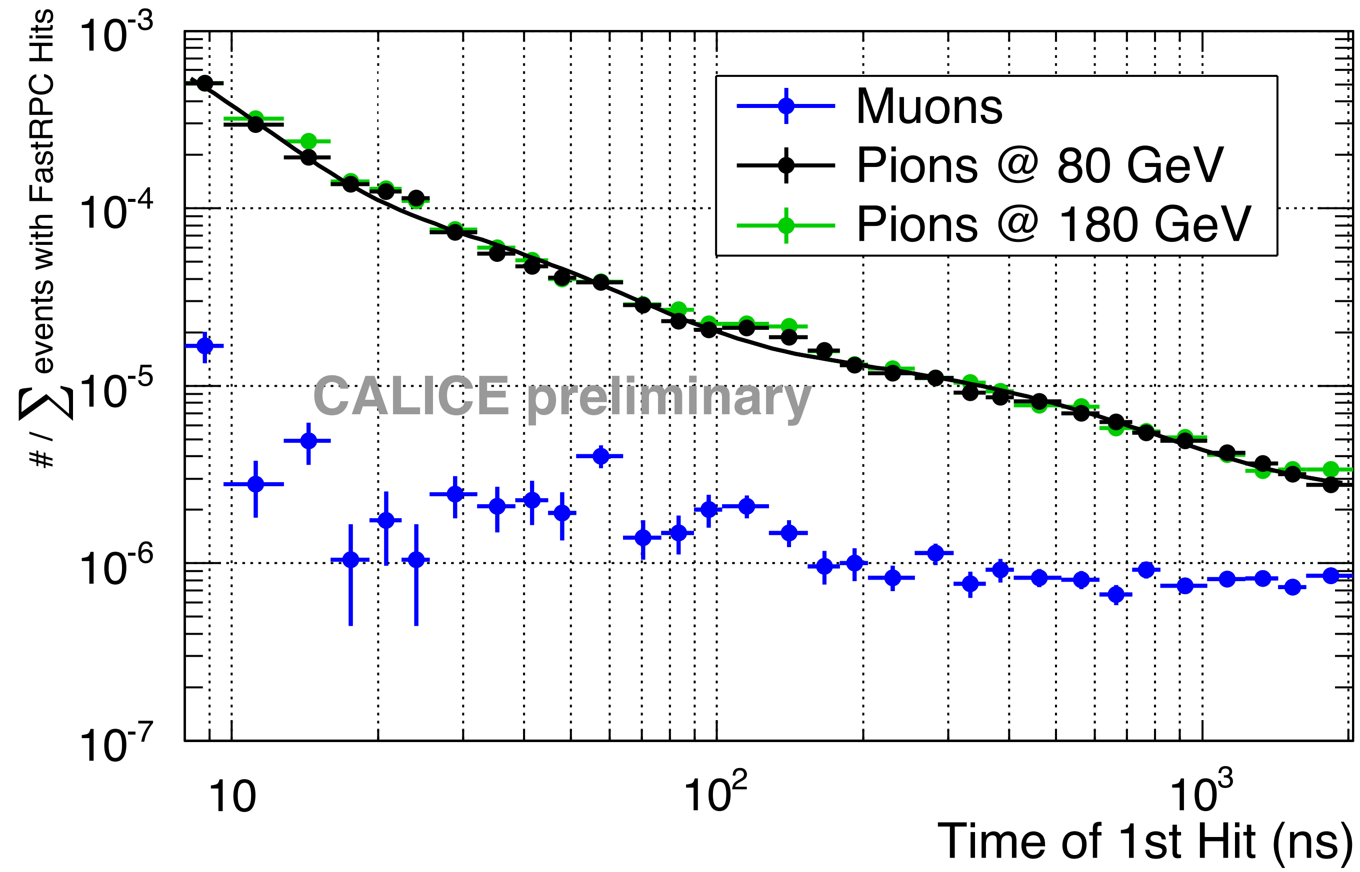
$$A_1 \cdot \exp\left(-\frac{t}{\tau_1}\right) + A_2 \cdot \exp\left(-\frac{t}{\tau_2}\right) + A_3 \cdot \exp\left(-\frac{t}{\tau_3}\right) + c$$

$A_1 = 3.8 \times 10^{-3}$ $\tau_1 = 4.1$ ns

$A_2 = 1.4 \times 10^{-4}$ $\tau_2 = 33$ ns

Data Analysis:
ToFH - Projection & Fit





Time structure is independent from energy of the incoming particle

$$A_1 \cdot \exp\left(-\frac{t}{\tau_1}\right) + A_2 \cdot \exp\left(-\frac{t}{\tau_2}\right) + A_3 \cdot \exp\left(-\frac{t}{\tau_3}\right) + c$$

$A_1 = 3.8 \times 10^{-3}$ $\tau_1 = 4.1$ ns

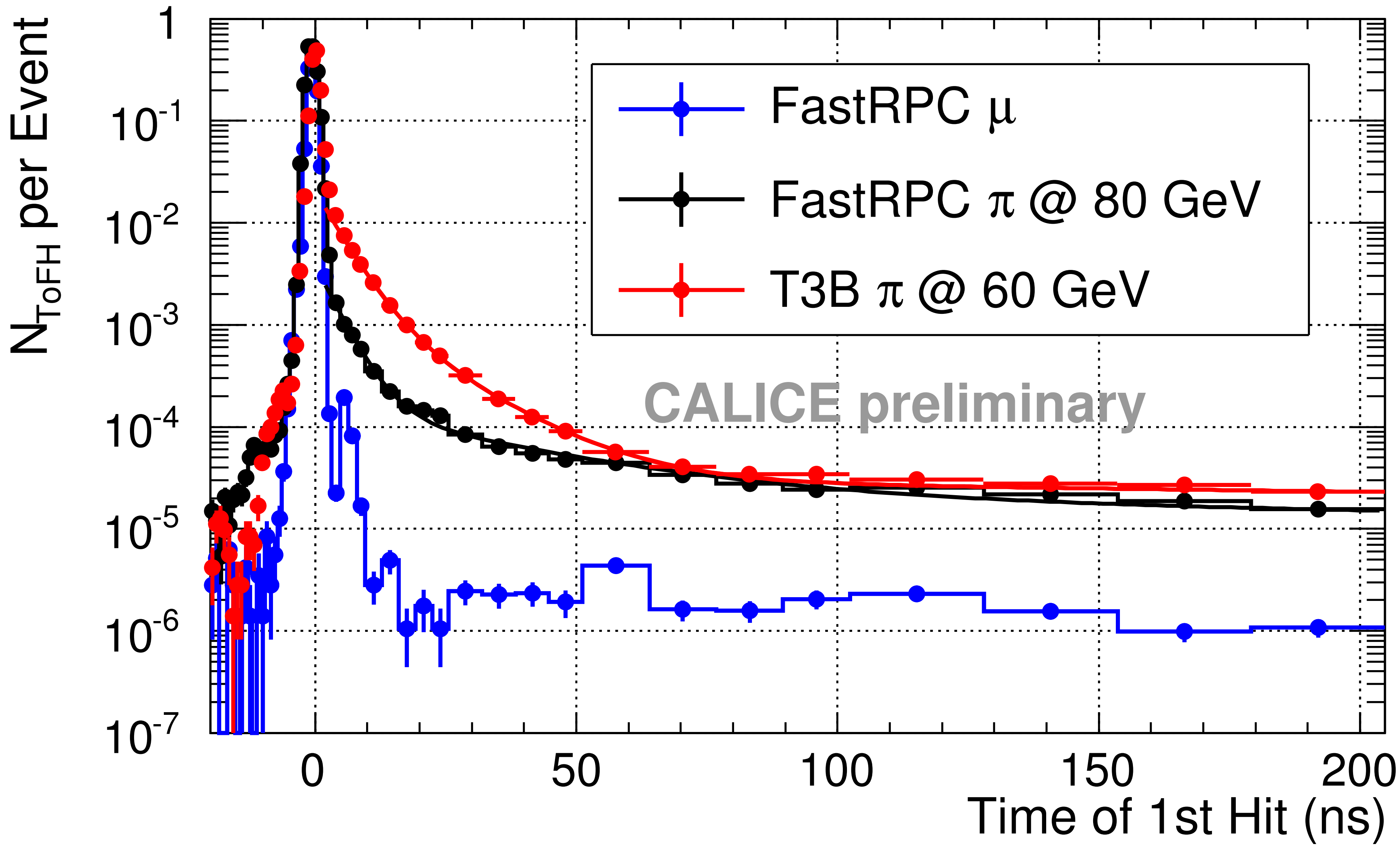
$A_2 = 1.4 \times 10^{-4}$ $\tau_2 = 33$ ns

$A_3 = 1.8 \times 10^{-5}$ $\tau_3 = 480$ ns

Data Analysis:

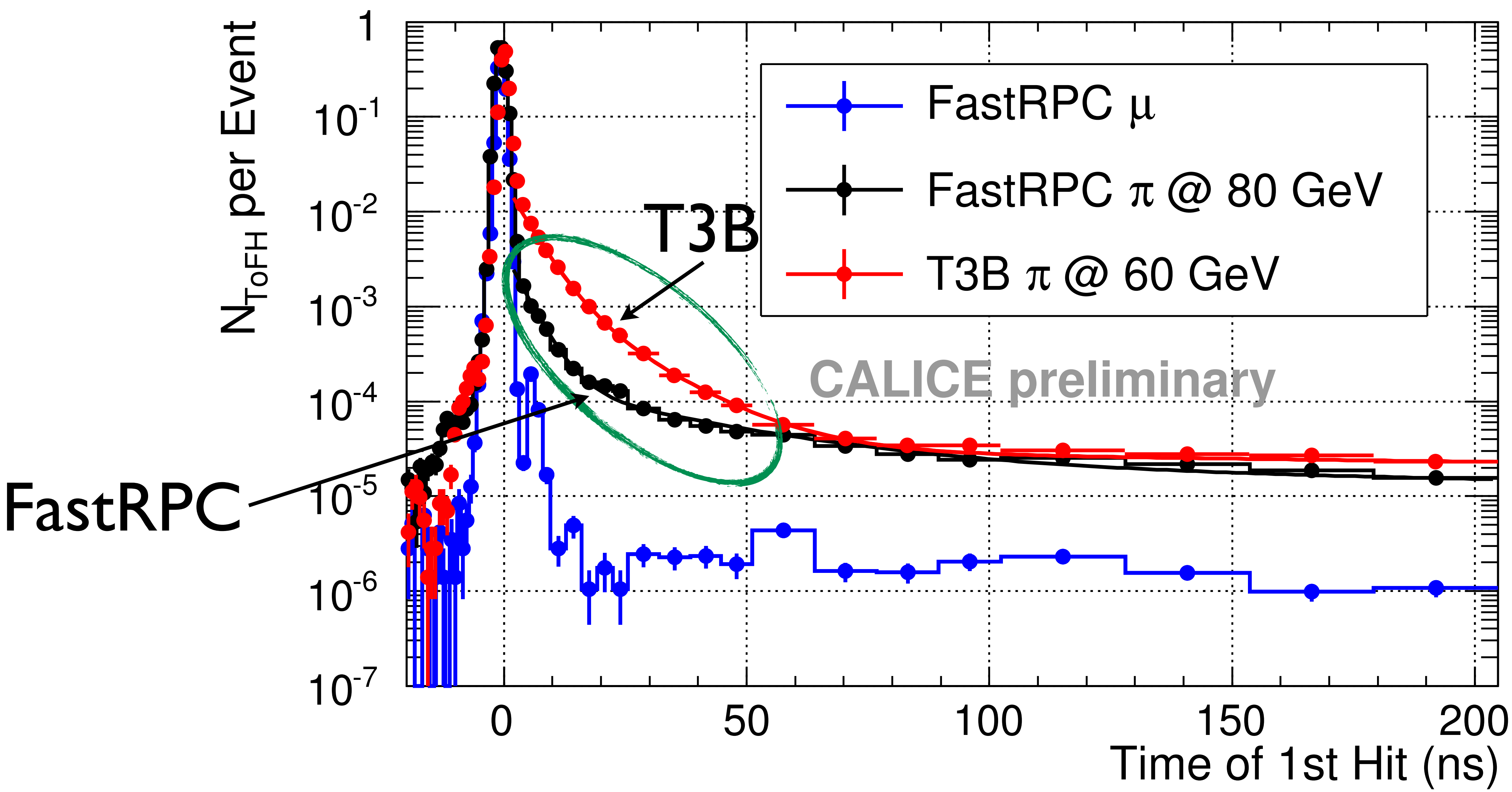
Comparison with Plastic Scintillators

Similar experiment T3B = same readout and absorber BUT plastic scintillators as active layer



Comparison with Plastic Scintillators

Similar experiment T3B = same readout and absorber BUT plastic scintillators as active layer

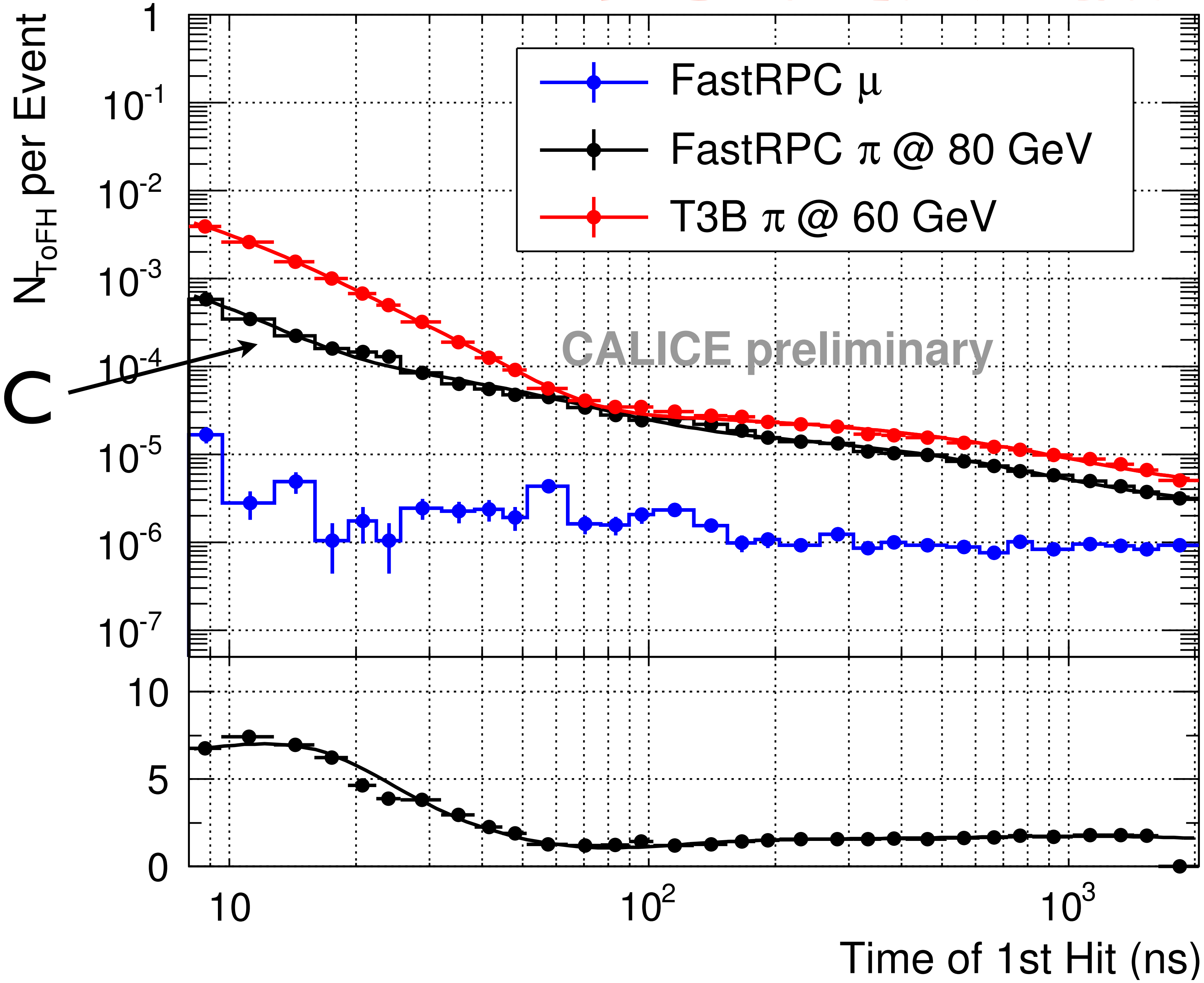


RPC suppress intermediate components [10,50] ns from neutron elastic scattering

Comparison with Plastic Scintillators

Similar experiment T3B = same readout and absorber BUT plastic scintillators as active layer

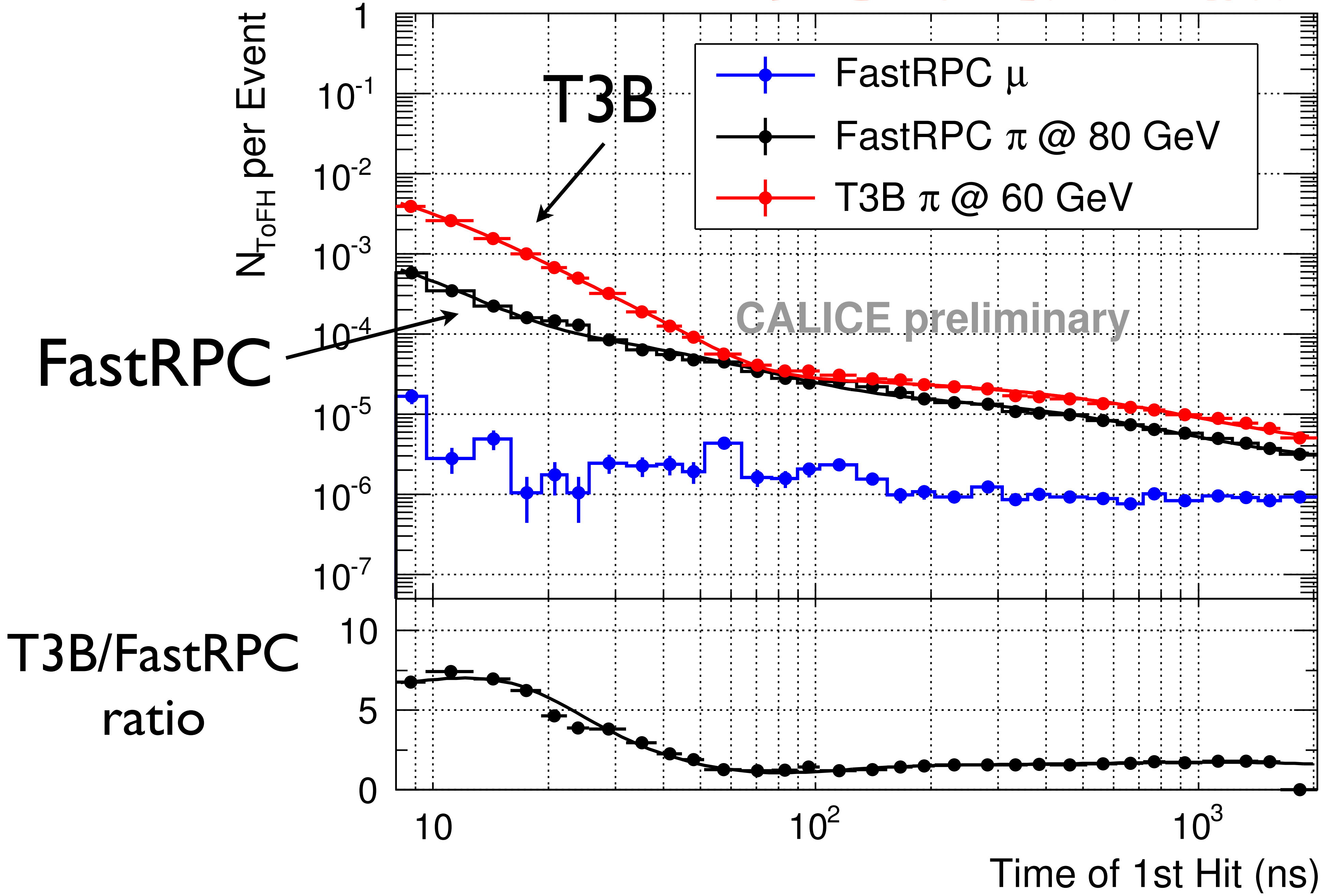
FastRPC



Data Analysis:

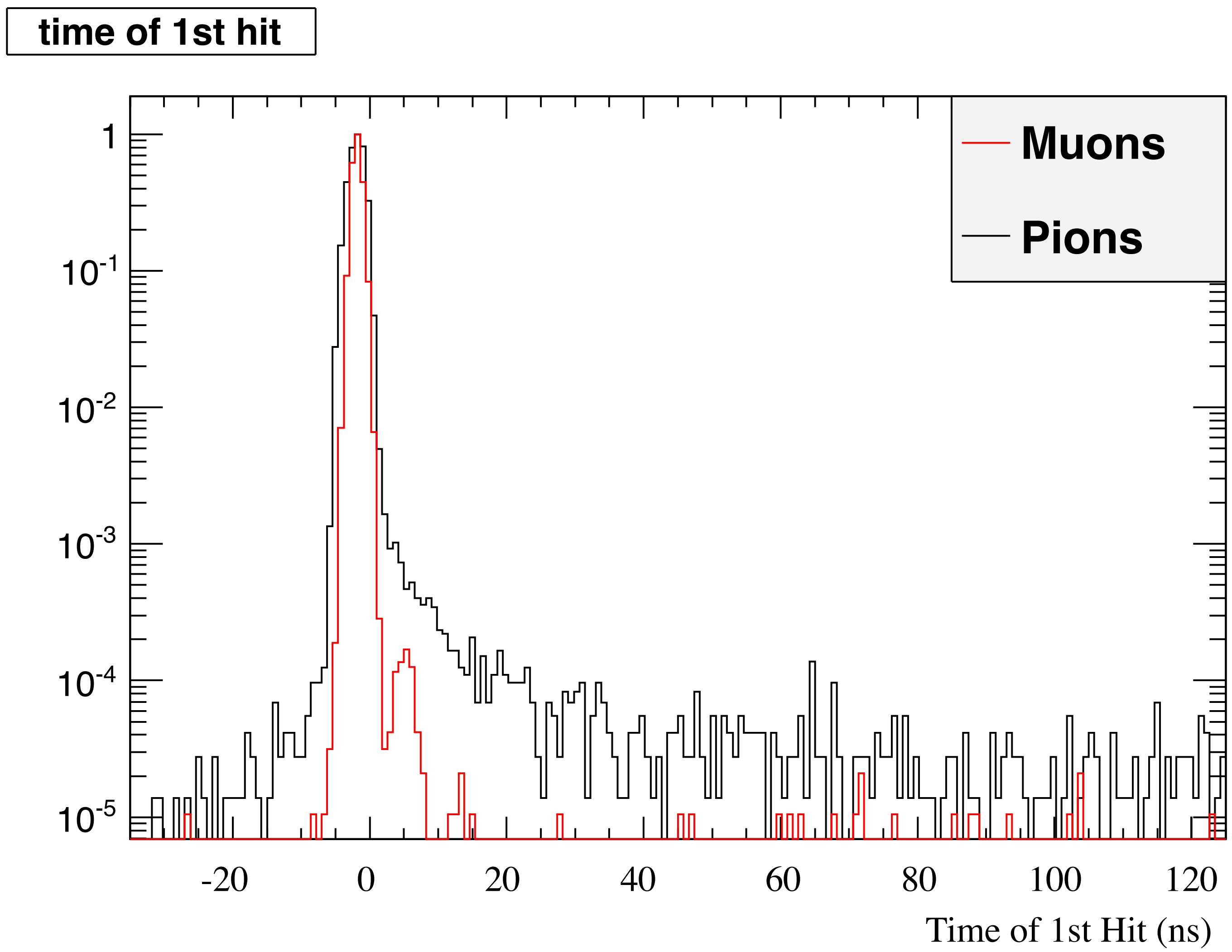
Comparison with Plastic Scintillators

Similar experiment T3B = same readout and absorber BUT plastic scintillators as active layer



RPC suppress intermediate components [10,100] ns from neutron elastic scattering

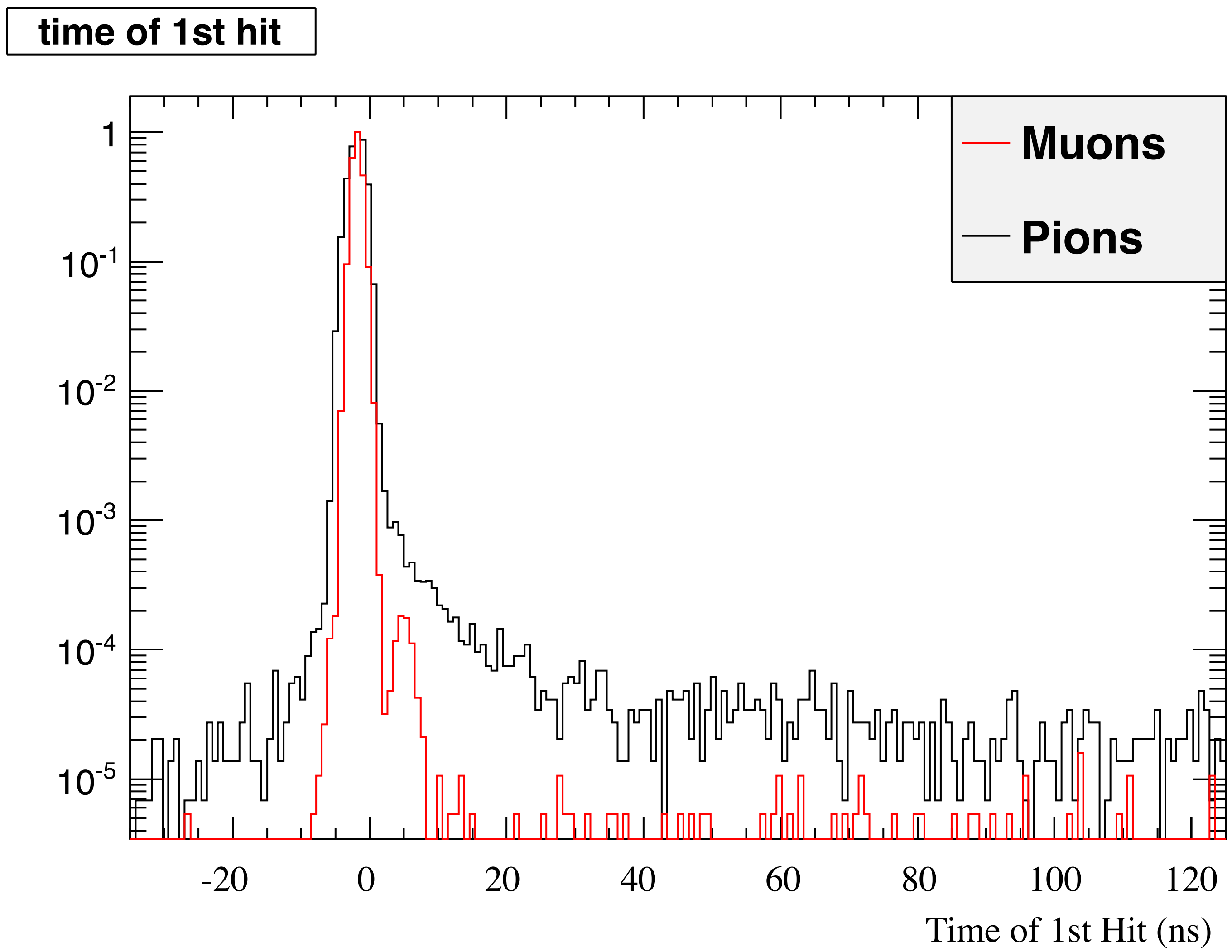
ToFH - Radial



Center of the shower: Dominated by instantaneous contribution from relativistic particles, including muons and punch-through pions

Toward the outside of the shower, the late energy deposition component fraction gets bigger and bigger

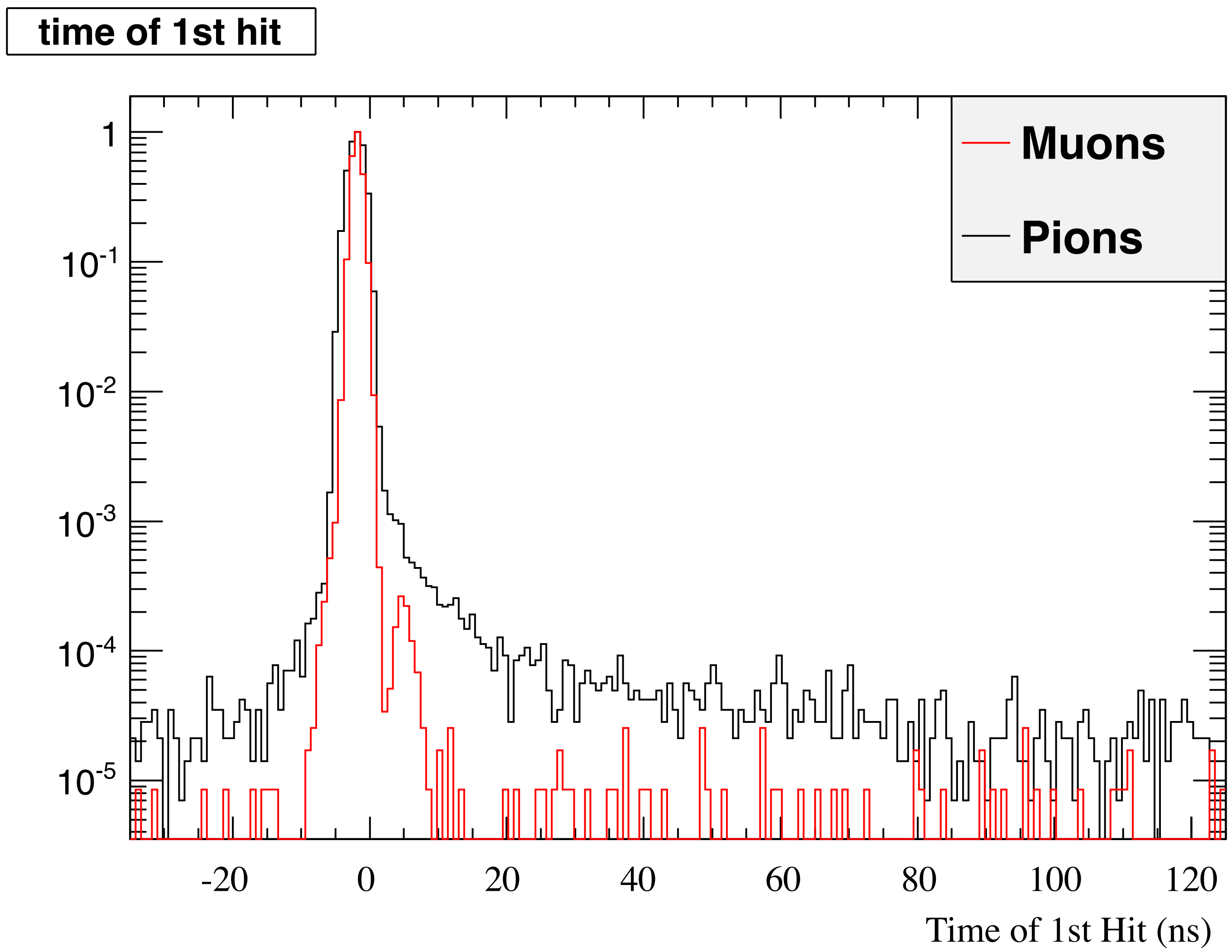
ToFH - Radial



3cm from center:
still lot dominated by
instantaneous components

Toward the outside of the shower, the late energy deposition component fraction gets bigger and bigger

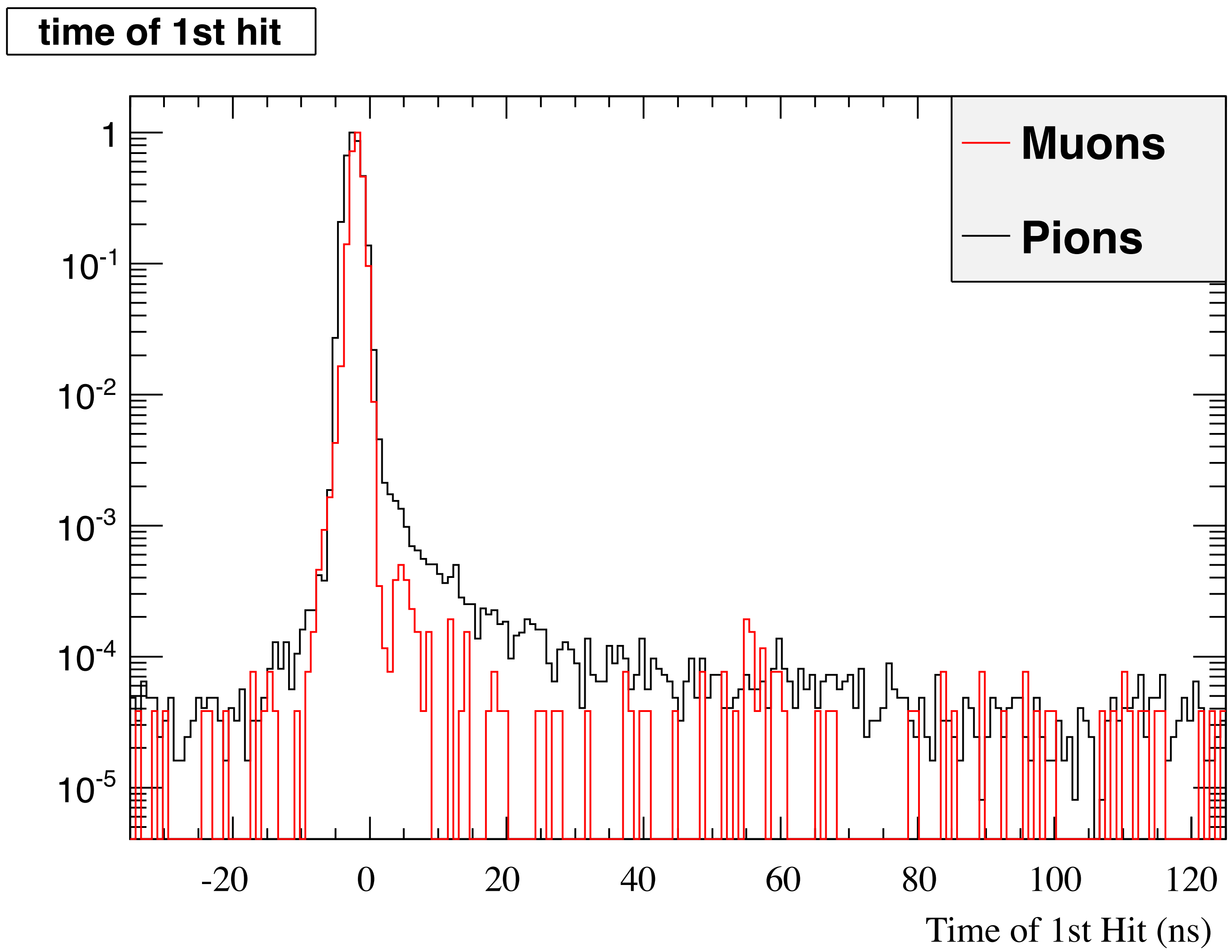
ToFH - Radial



6cm from center

Toward the outside of the shower, the late energy deposition component fraction gets bigger and bigger

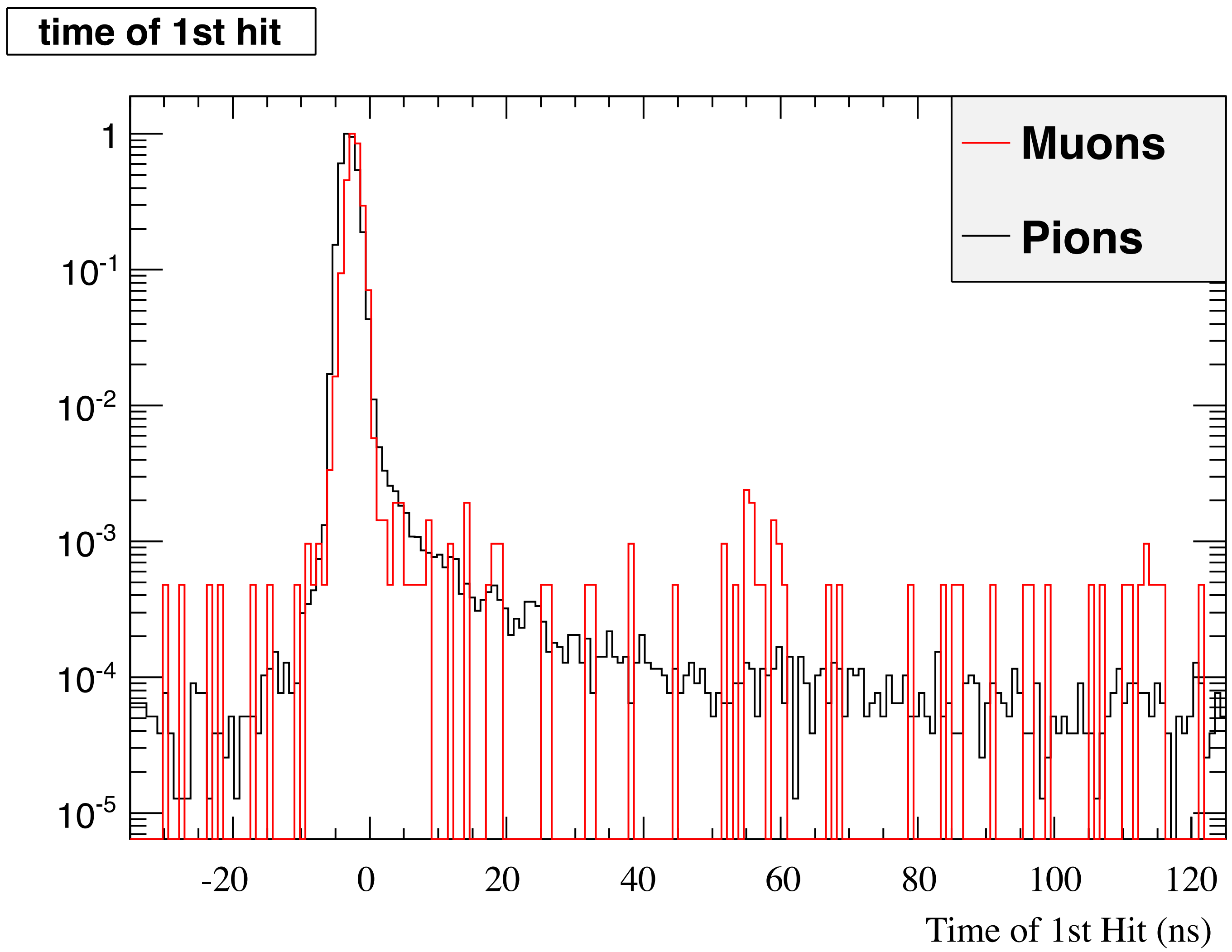
Data Analysis:
ToFH - Radial



9cm from center

Toward the outside of the shower, the late energy deposition component fraction gets bigger and bigger

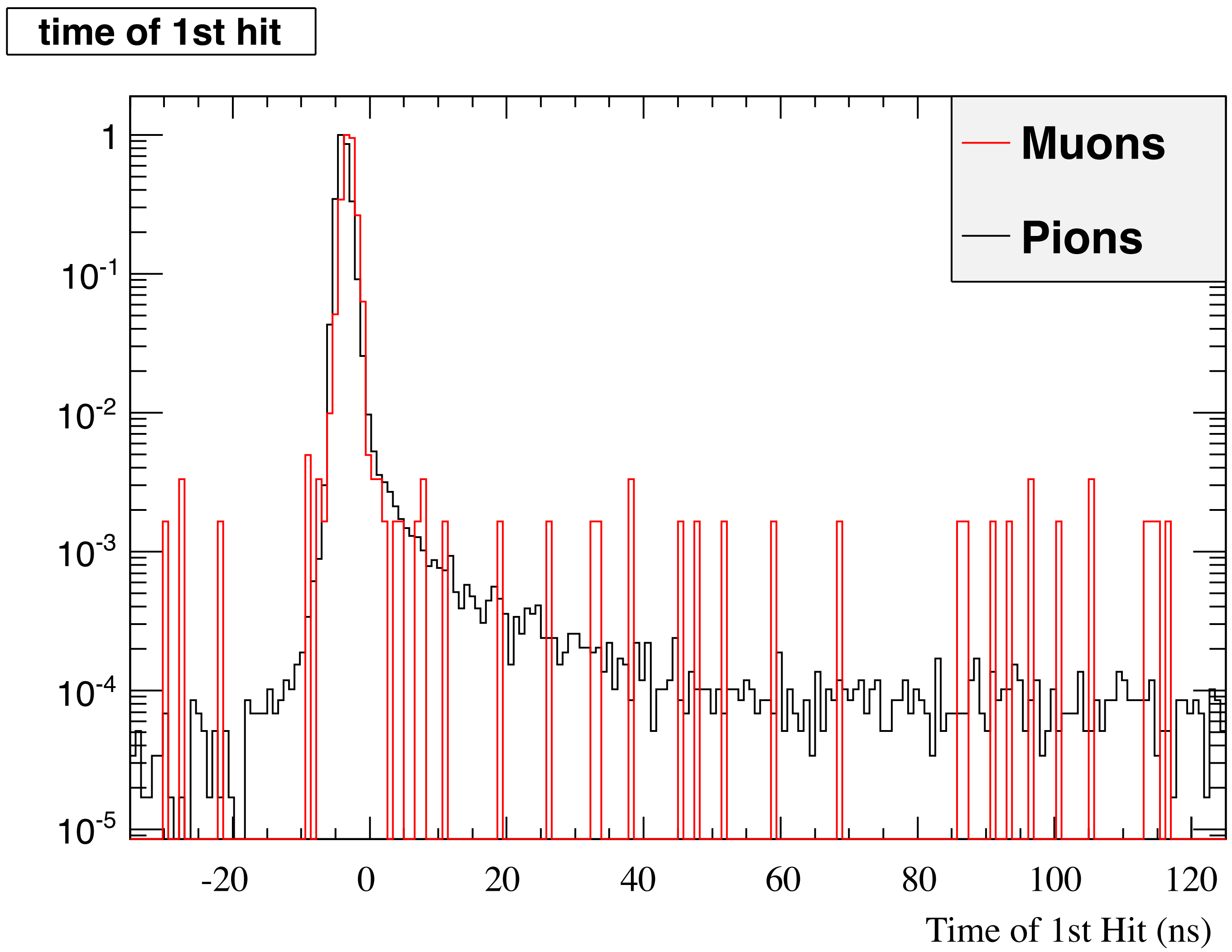
ToFH - Radial



12cm from center

Toward the outside of the shower, the late energy deposition component fraction gets bigger and bigger

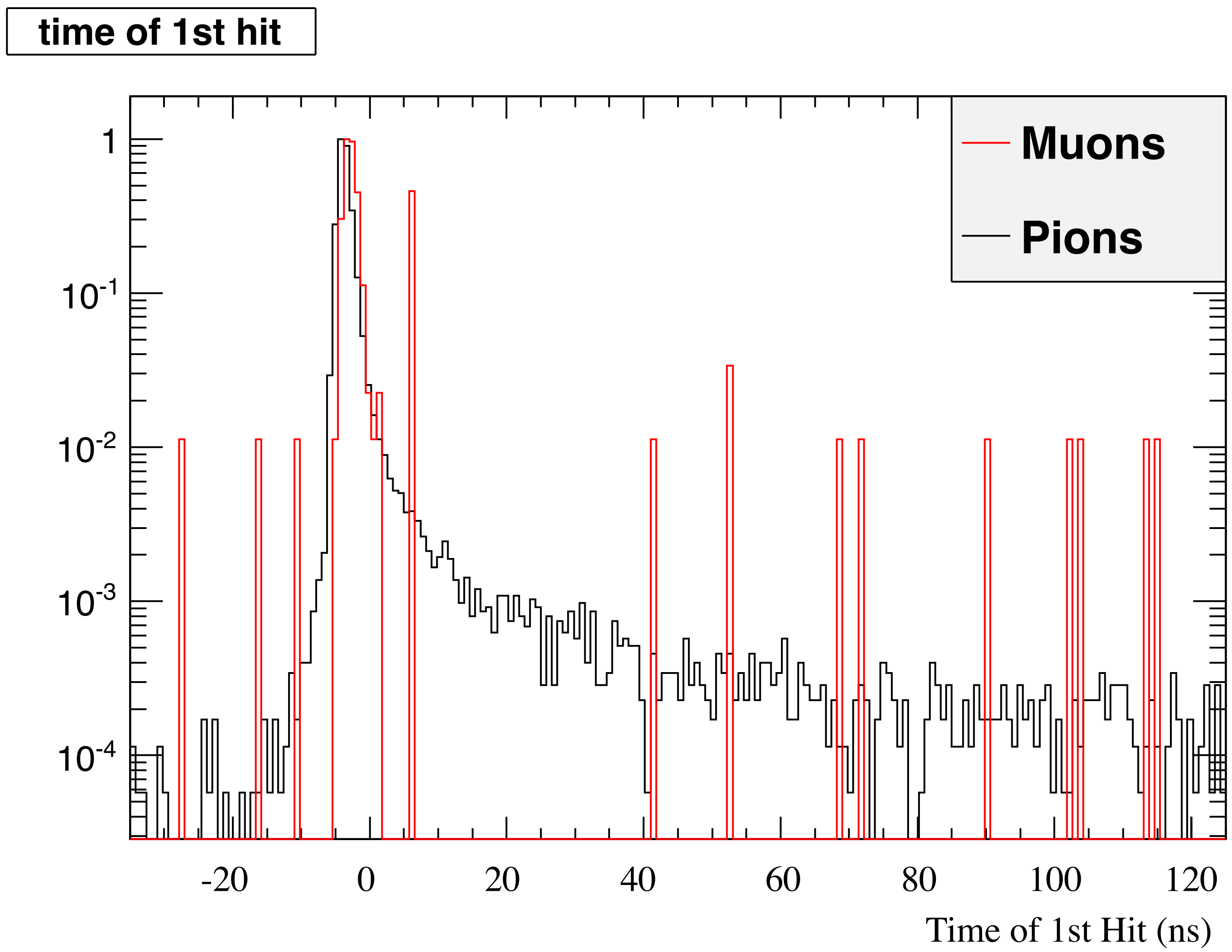
Data Analysis:
ToFH - Radial



15cm from center

Toward the outside of the shower, the late energy deposition component fraction gets bigger and bigger

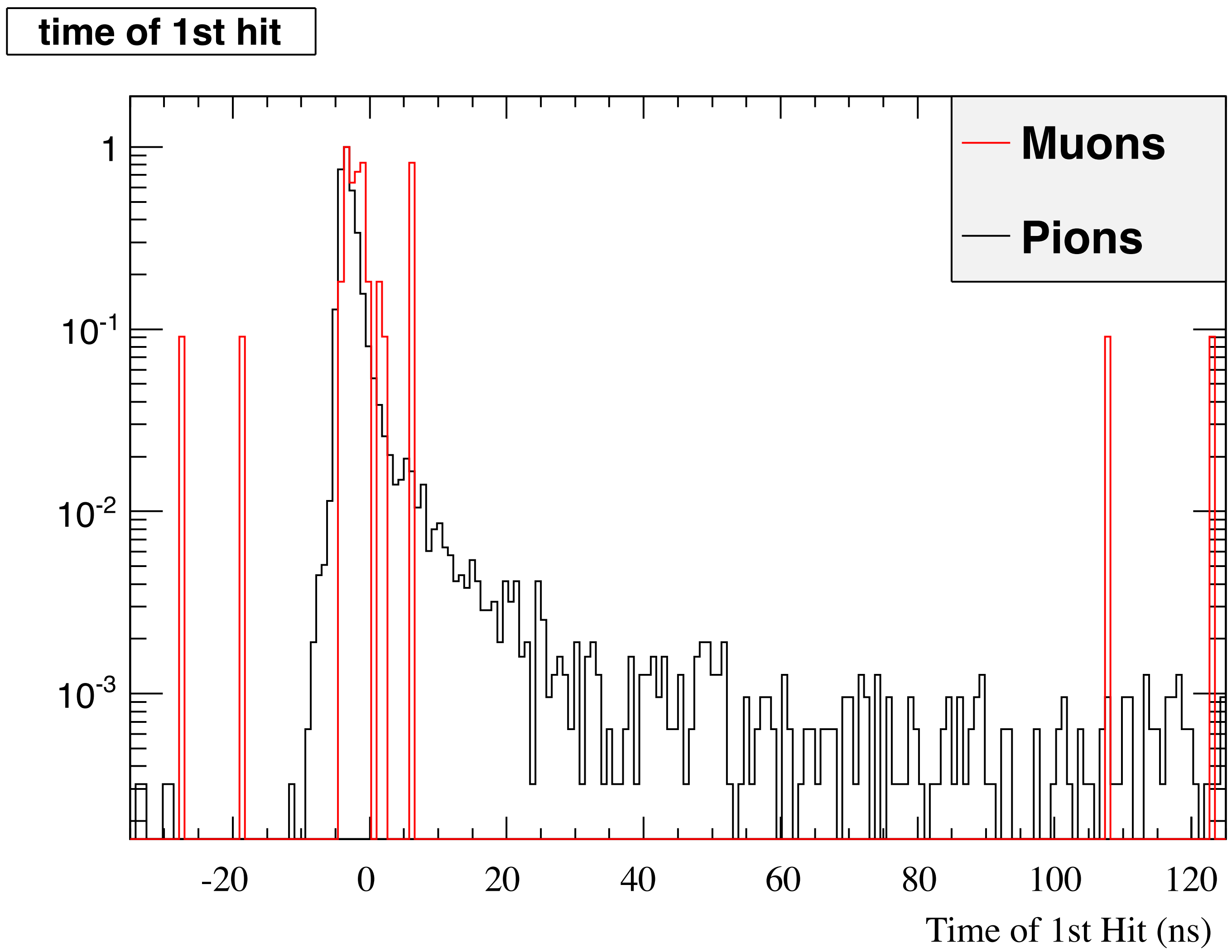
Data Analysis:
ToFH - Radial



21cm from center

Toward the outside of the shower, the late energy deposition component fraction gets bigger and bigger

Data Analysis:
ToFH - Radial

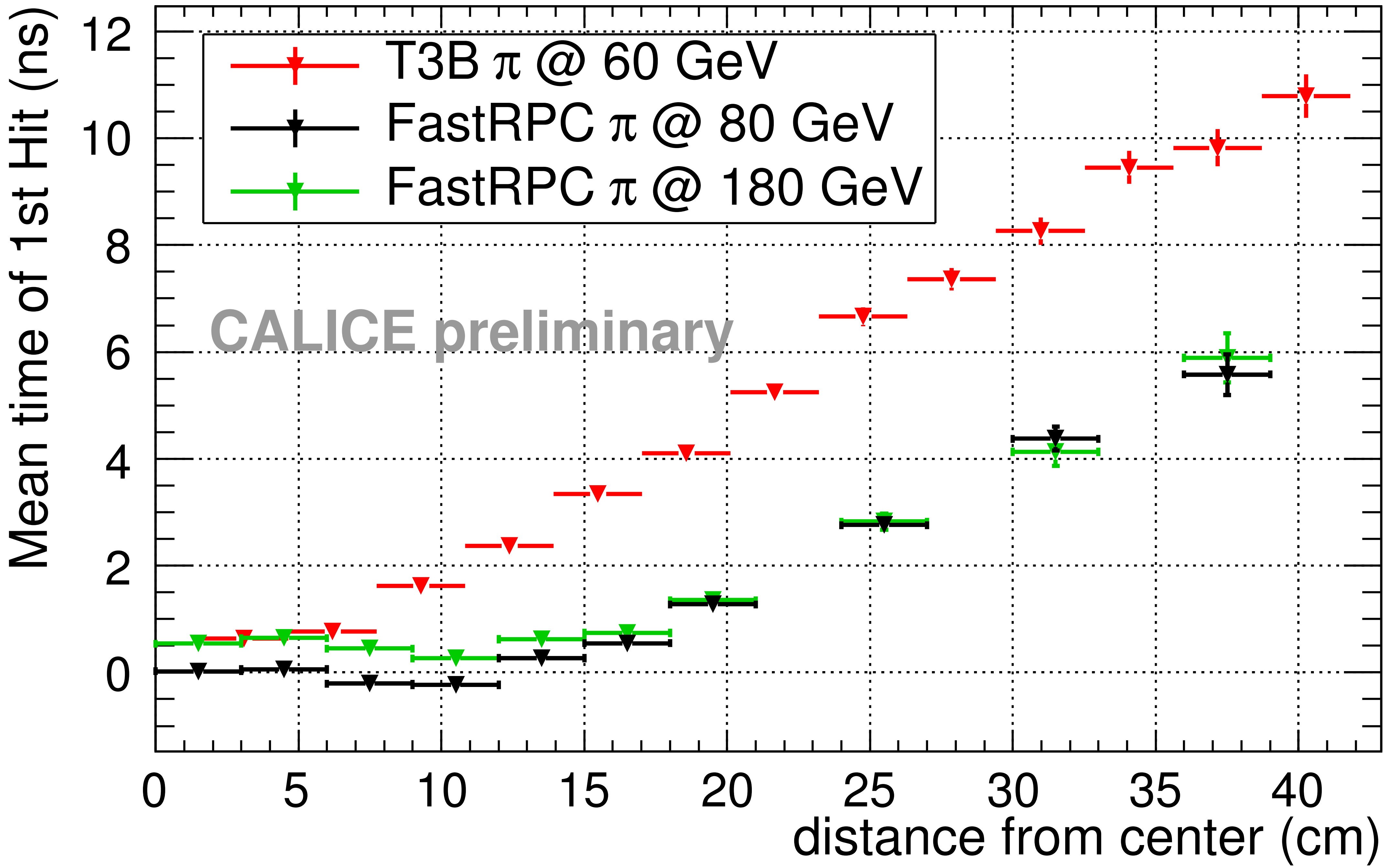


27cm from center

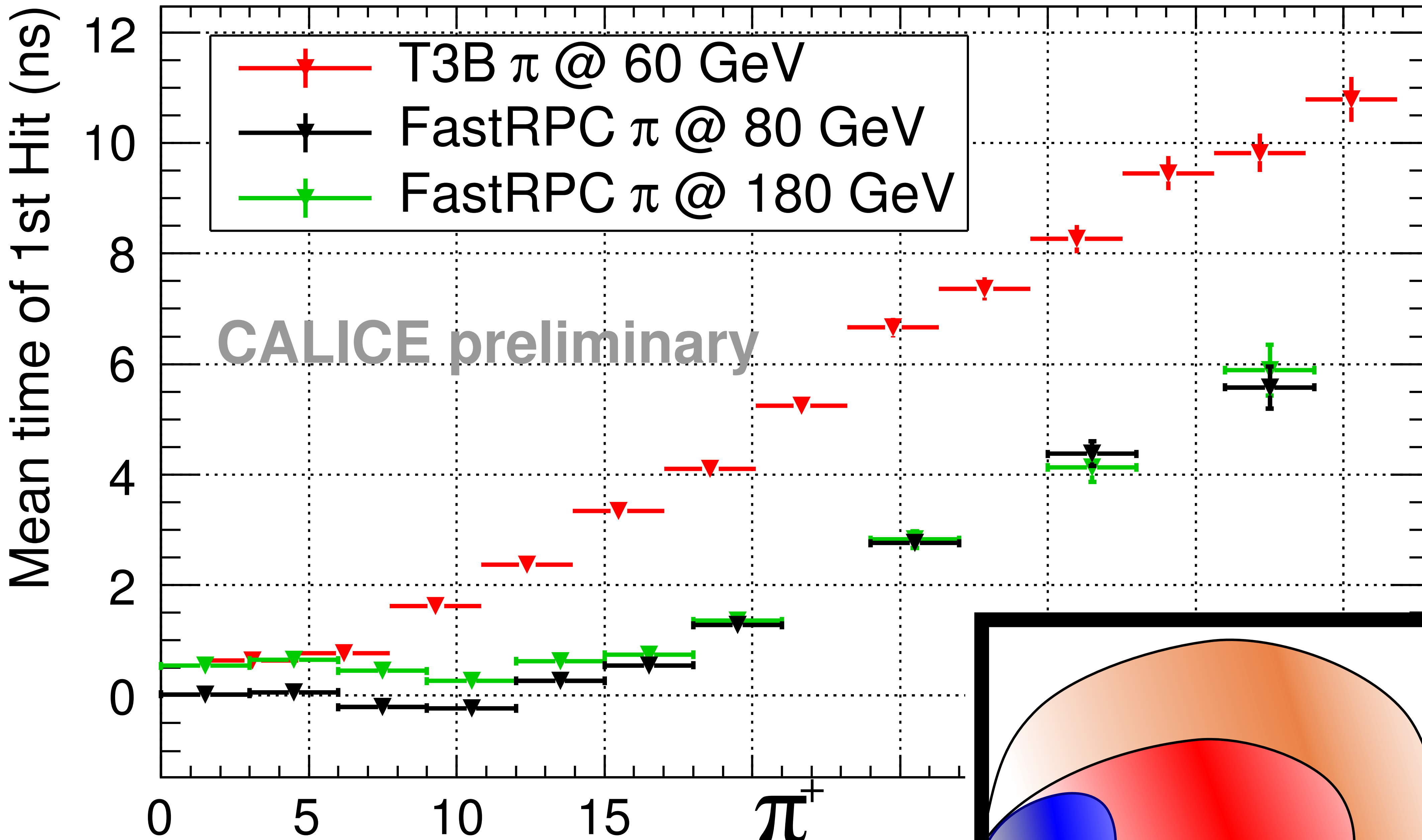
Toward the outside of the shower, the late energy deposition component fraction gets bigger and bigger

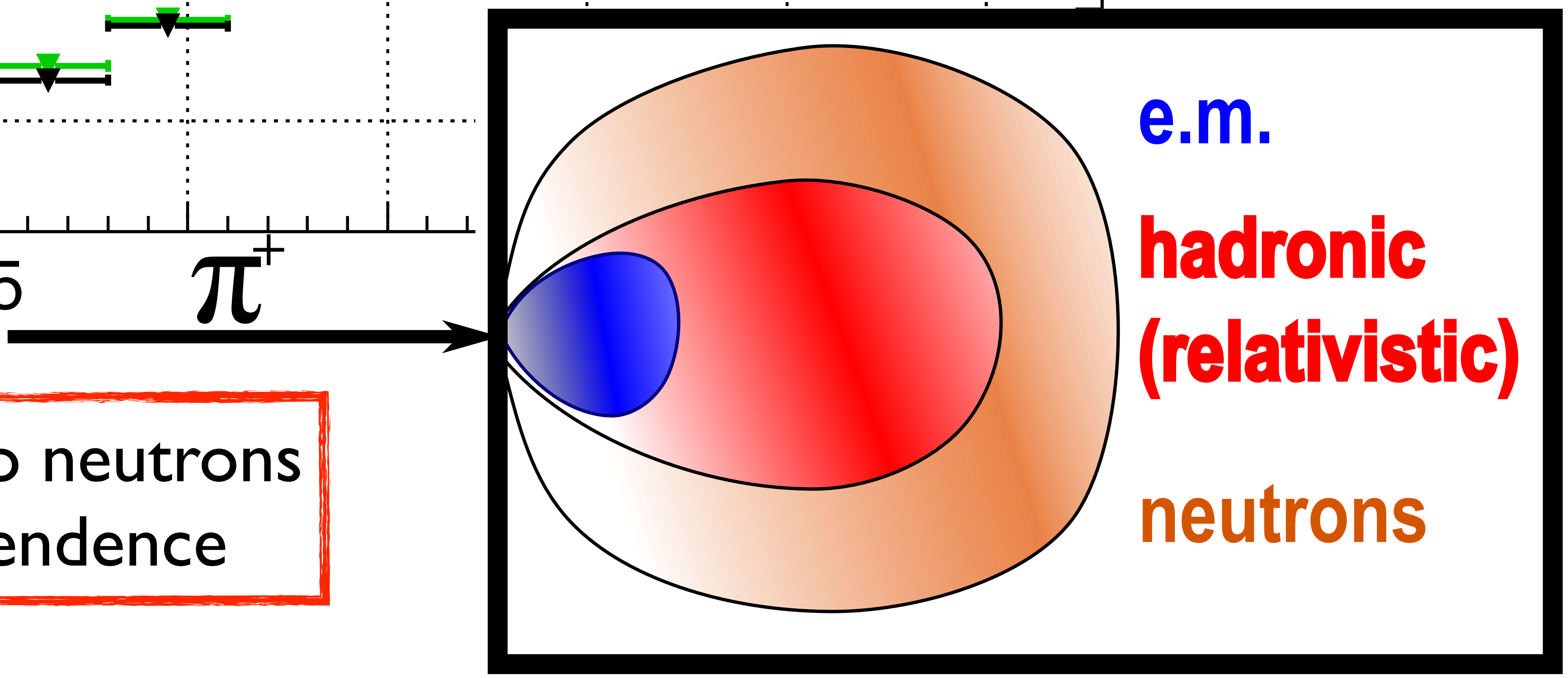
We can tune the radial extension of the shower by the choice of the time window
➔ offers interesting possibilities for particle flow optimization and shower separation

Radial Distribution - Mean ToFH



Radial Distribution - Mean ToFH





RPC are less sensitive to neutrons
→ less radial time dependence

Conclusions

- Lepton colliders are a key tool to explore the Higgs sector and physics at the TeV scale

- Development of the FastRPC detector to study the time structure of hadronic showers in a tungsten HCAL

- Commissioning and data taking campaign at CERN PS and SPS facility for almost 5 weeks of beam time

- Data Analysis - RPC are:
  - sensitive to late components of the showers, 3 time components from different underlying processes in the shower
  - comparison with plastic scintillators shows suppression of intermediate components from neutron elastic scattering on H nuclei

Conclusions & Outlook

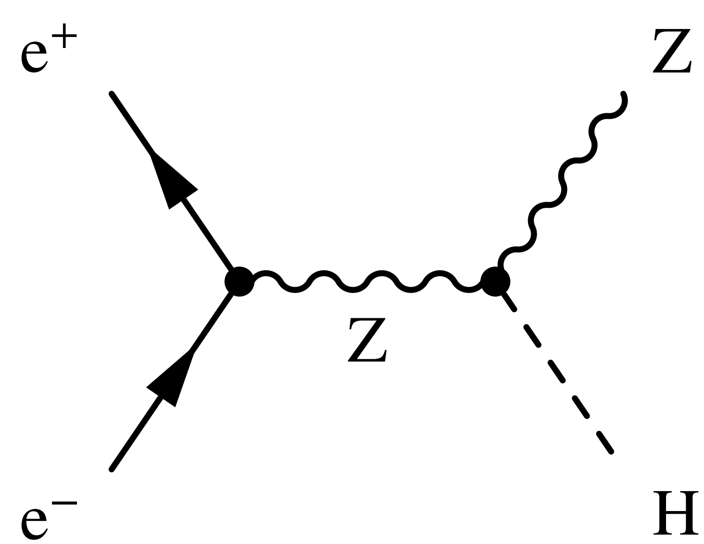
- This work has been internally peer reviewed by the CALICE collaboration and is now available as a Calice Analysis Note (CAN-043) at: https://twiki.cern.ch/twiki/pub/CALICE/CaliceAnalysisNotes/CAN-043.pdf

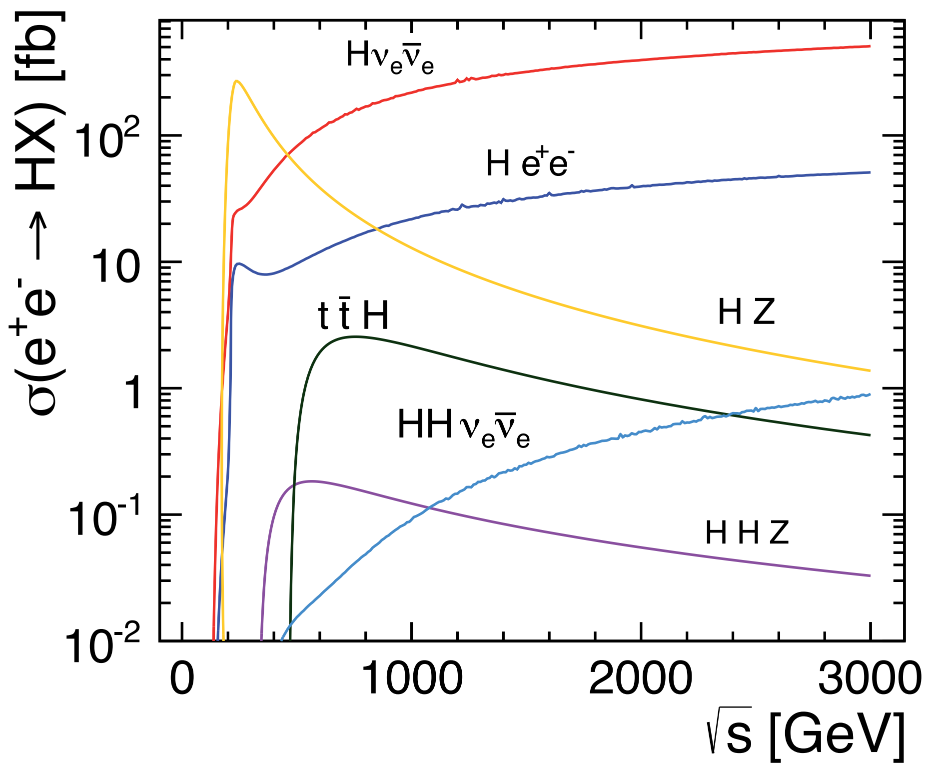
Outlook

- Full event synchronization with the DHCAL
- Comparison with MC data

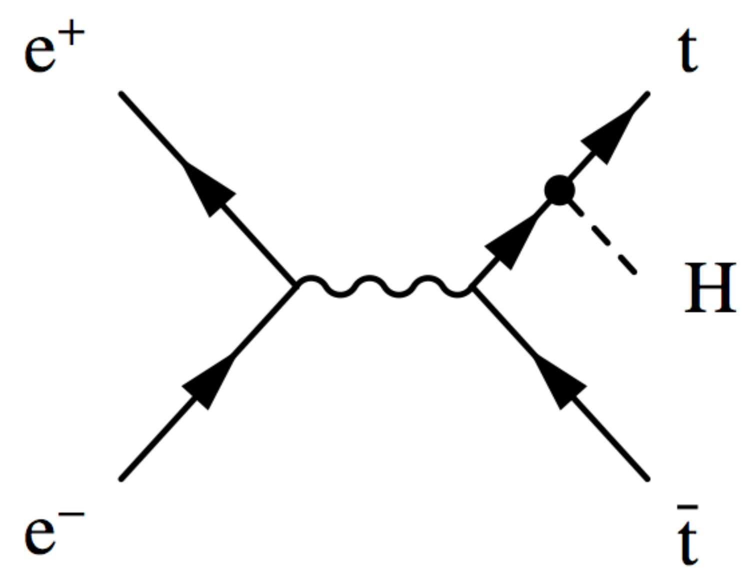
Backup

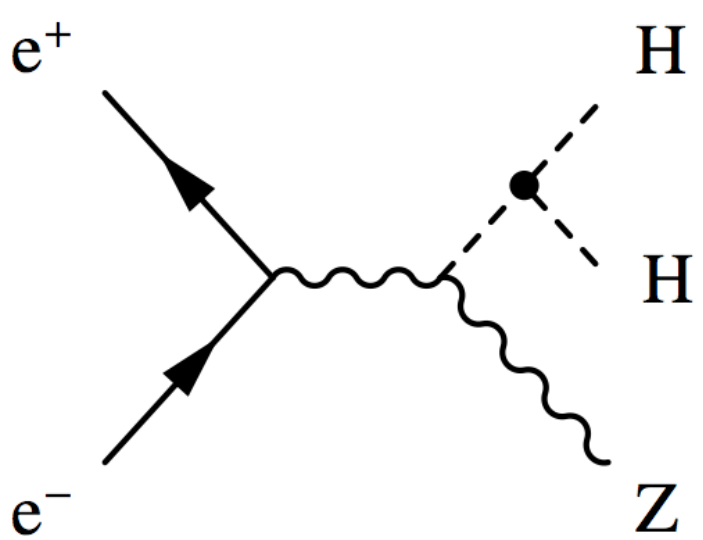
Backup:
Physics processes LC

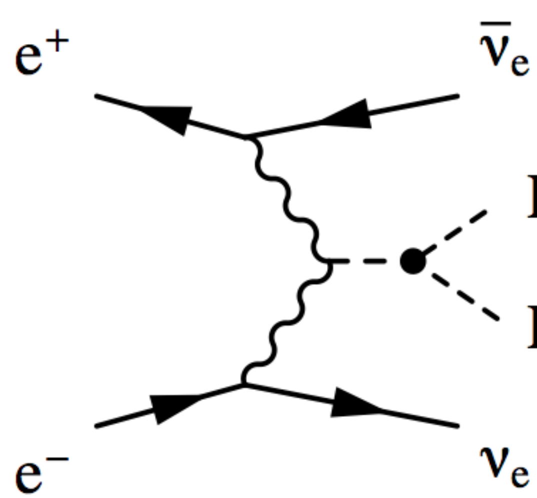


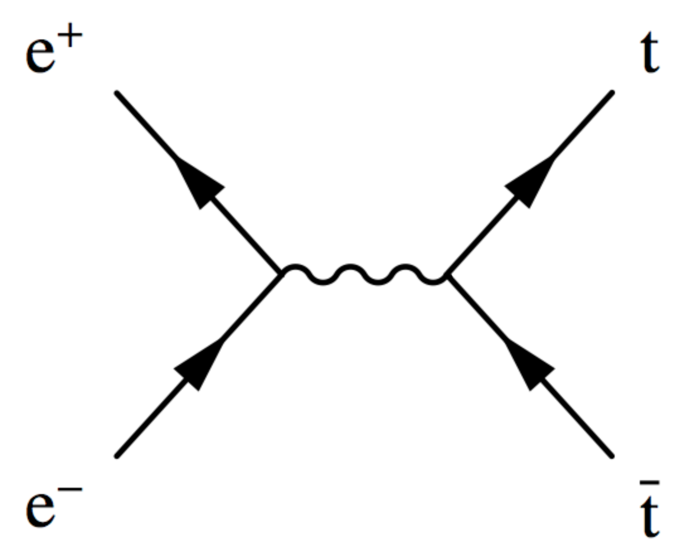


source: Frank Simon - arXiv:1211.7242

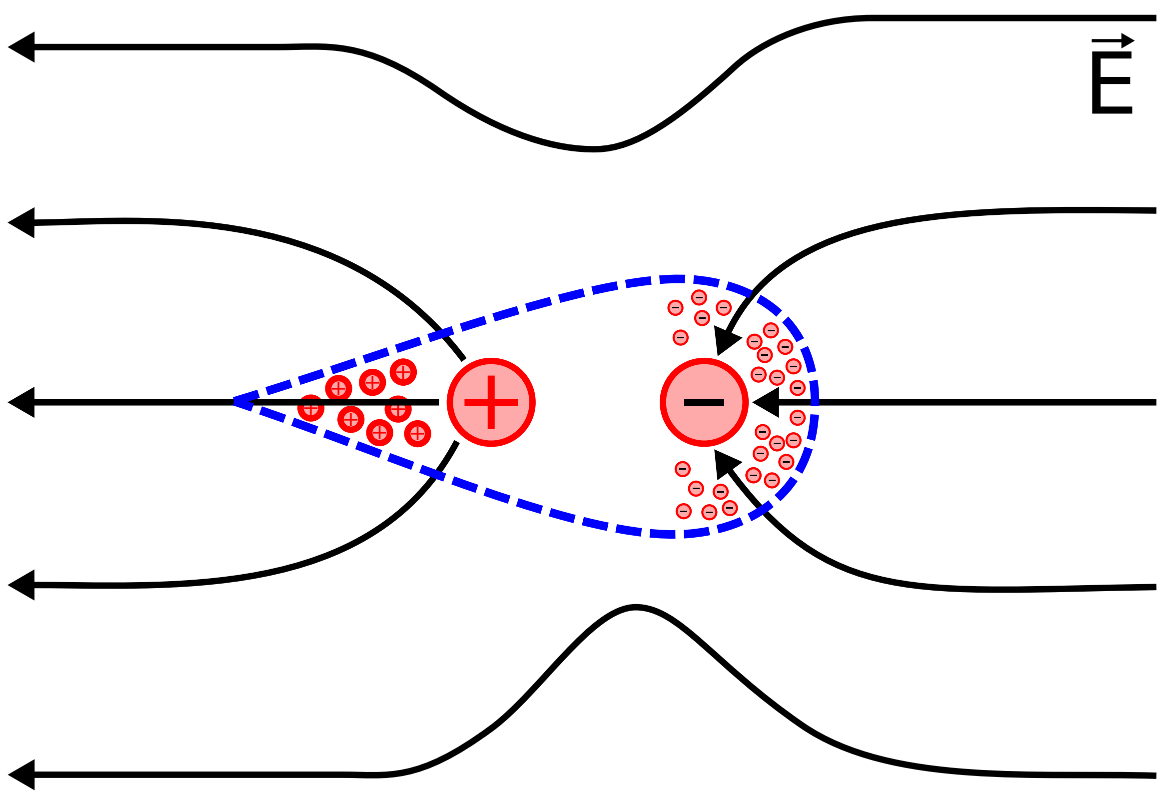


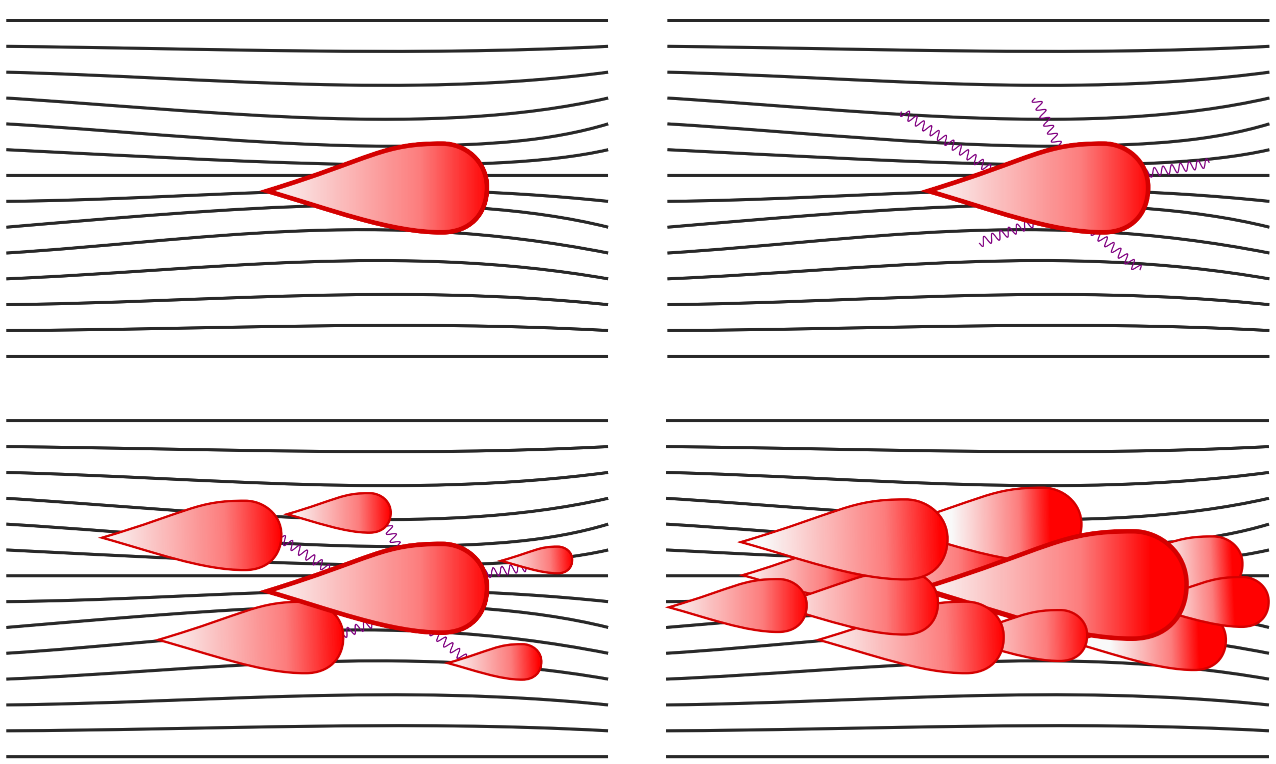


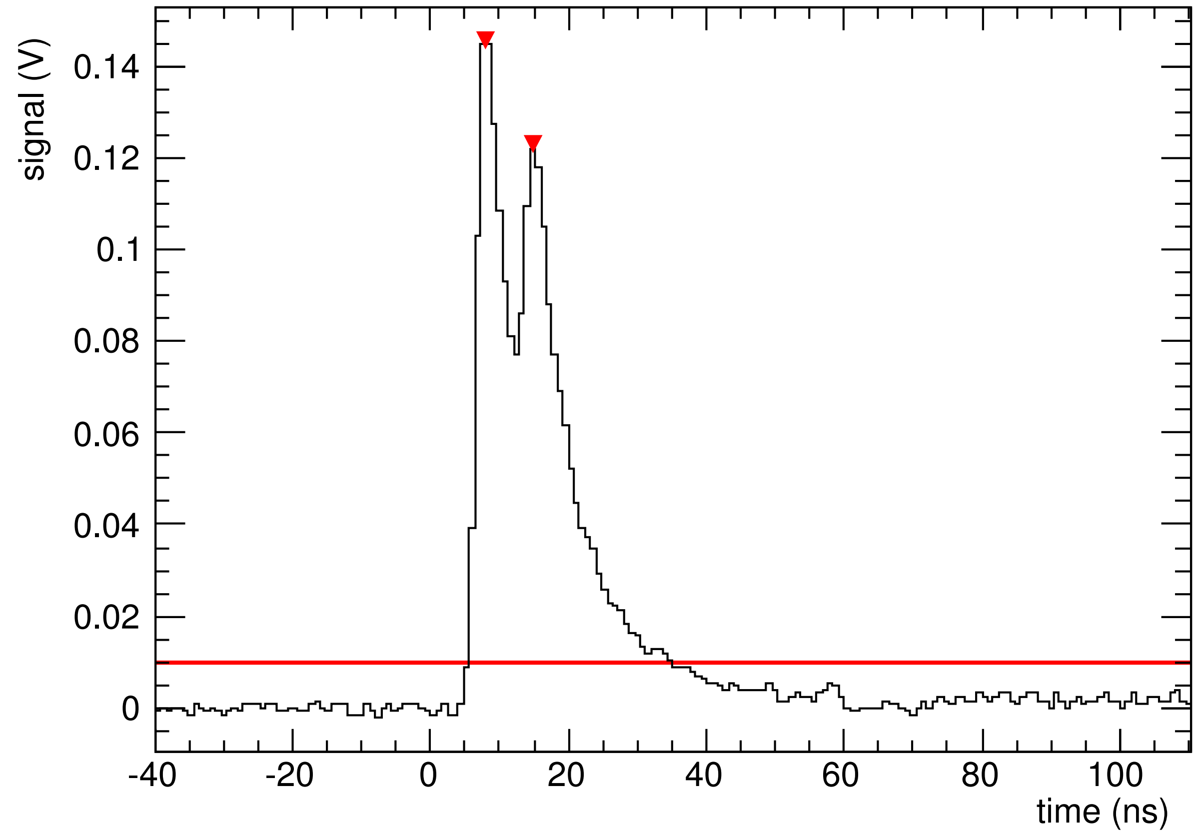


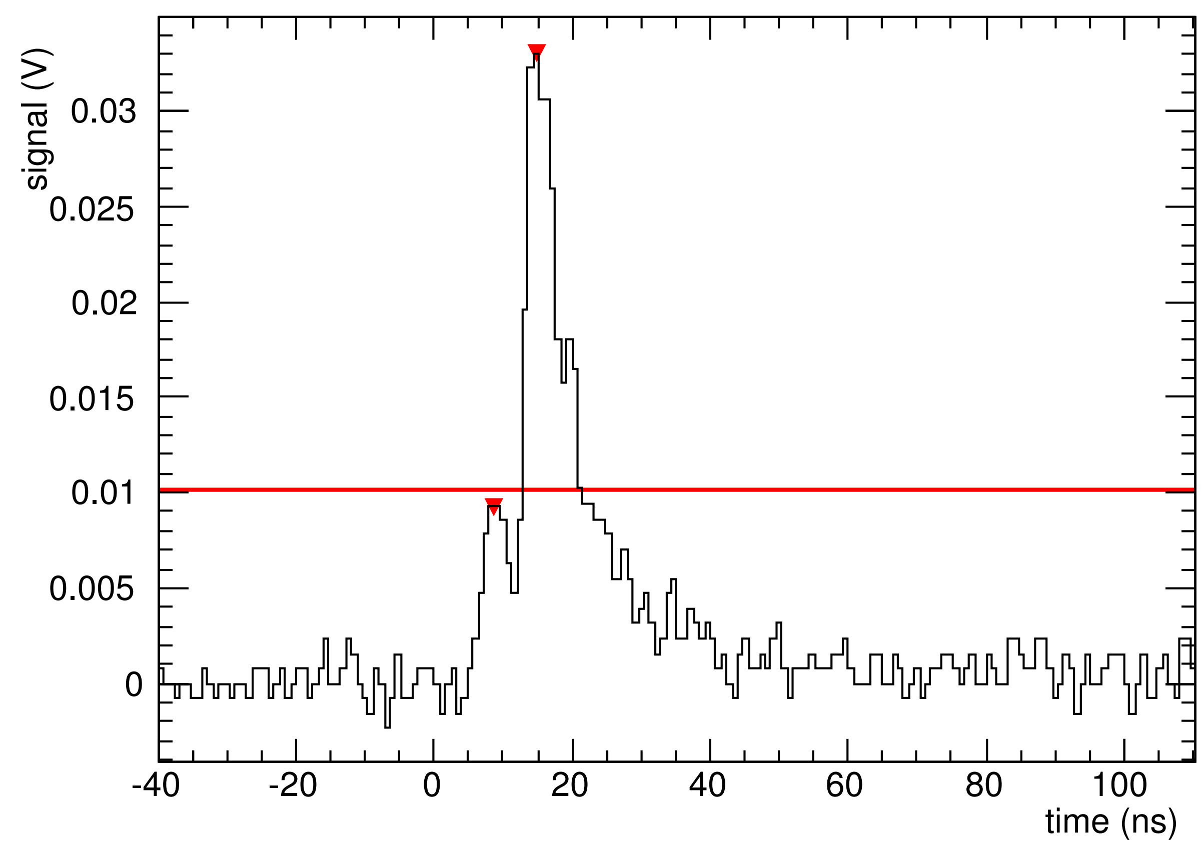


Streamers


E




signal (V)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-40
-20
0
20
40
60
80
100
time (ns)


signal (V)
0.03
0.025
0.02
0.015
0.01
0.005
0
-40
-20
0
20
40
60
80
100
time (ns)

Backup:

pedestal subtracted comparison