Low Material Budget Floating Strip Micromegas for Ion Transmission Radiography

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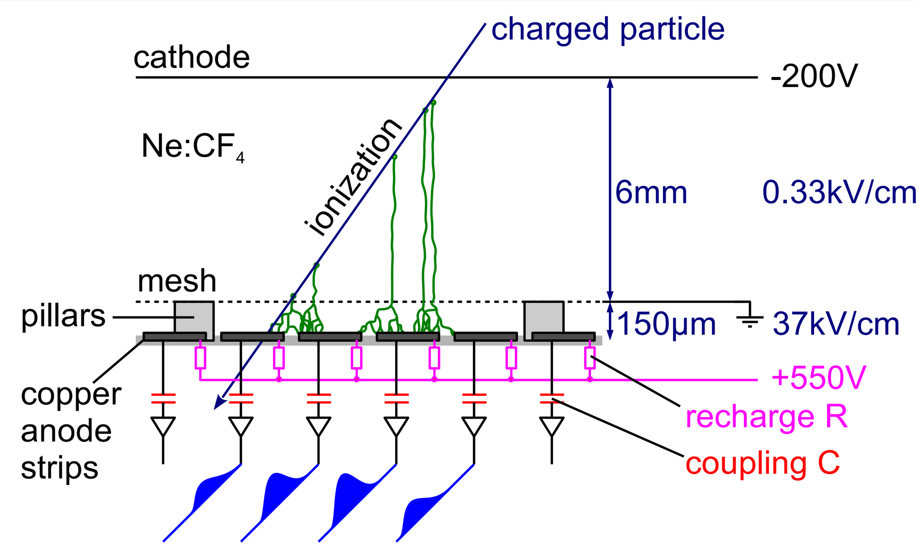
FLOATING STRIP MICROMEGAS DETECTOR

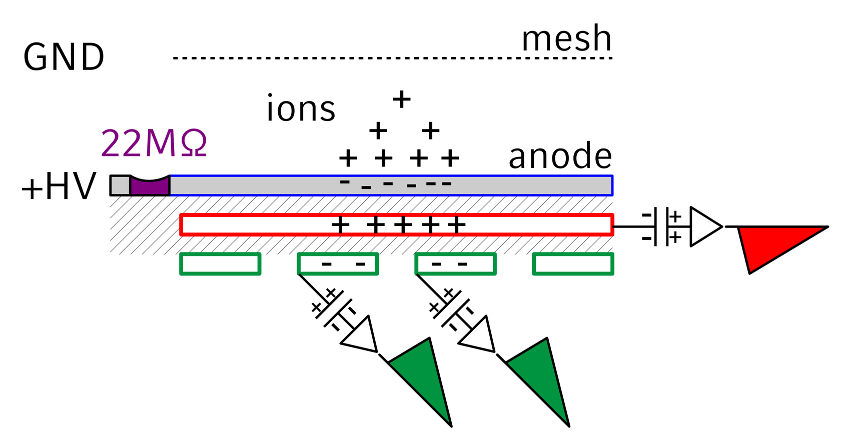
Micromegas principle
- charged particles
  → ionization
- gas amplification 10^3
- charge signal on strips
- single strip readout
  → spatial resolution O(50μm)
  → timing O(ns)
- thin amplification region & fine segmentation
  → fast drain of positive ions
  → high-rate capability



challenge: discharges
- charge density ≥ $2\cdot10^6$ e/0.01mm² (Raether limit)
  → streamer development
- conductive channel between mesh & anode
  → potentials between mesh & anode equalize
- non-destructive, but creating dead time
  → efficiency drop, especially at high particle rates or in high-rate background environments

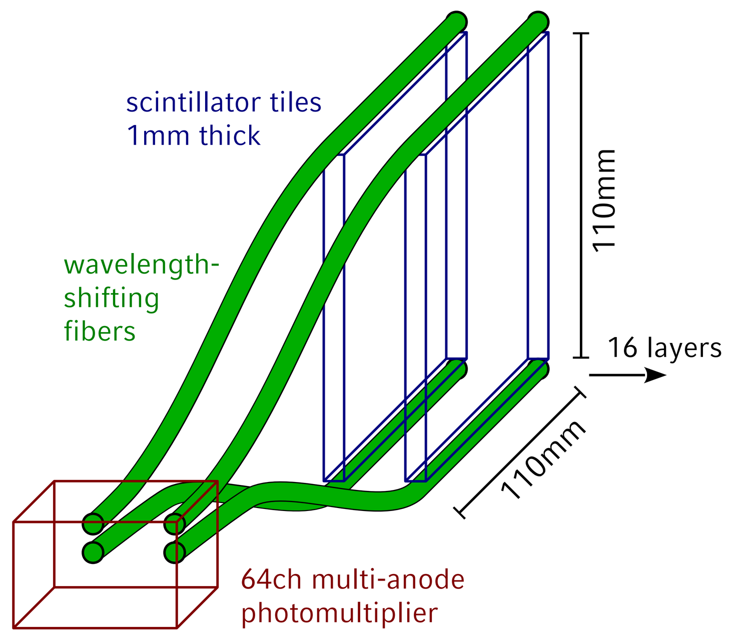
solution: floating strip Micromegas
- strips individually connected to HV via 22MΩ resistors
- readout electronics coupled via pF capacitors
  → strips can "float" in a discharge
  → fast streamer quenching
  → only one to three strips affected
  → fast recovery

TWO-DIMENSIONAL READOUT STRUCTURE



- conventional three-layer Kapton printed circuit board
- active area 64 x 64 mm²
- material budget: x/X0 = 0.011 or 0.4mm WET
- 128 copper anode strips
  - 500μm pitch & 300μm width
  - connected individually to HV via screen printed resistors
- 128 x-readout strips, copper
  - 500μm pitch & 80μm width
  → negative charge signals
- 128 y-readout strips, copper
  - 500μm pitch & 400μm width
  → positive charge signals

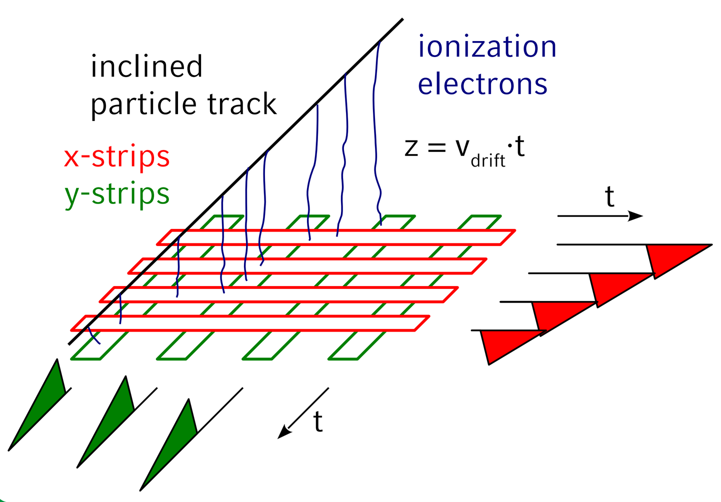
SCINTILLATOR RANGE TELESCOPE (SRT)



- 18 plastic scintillator tiles, 1mm thick, Envinet SP32
- light collection by two wavelength-shifting fibers per tile Saint Gobain BCF 92
- light detection by multi-anode photomultiplier 64 channels, Hamamatsu H75468
- tiles optically insulated with 30μm aluminum foil
- enclosed in light-tight aluminum case, 30μm entrance windows
- fast custom amplifier for signal shaping

range definition
- binary (hit/miss information per layer)
- calorimetric (summed pulse height in all layers)
- weighted range = 0.5 $range_{binary}$ + 0.5 $range_{calo}$

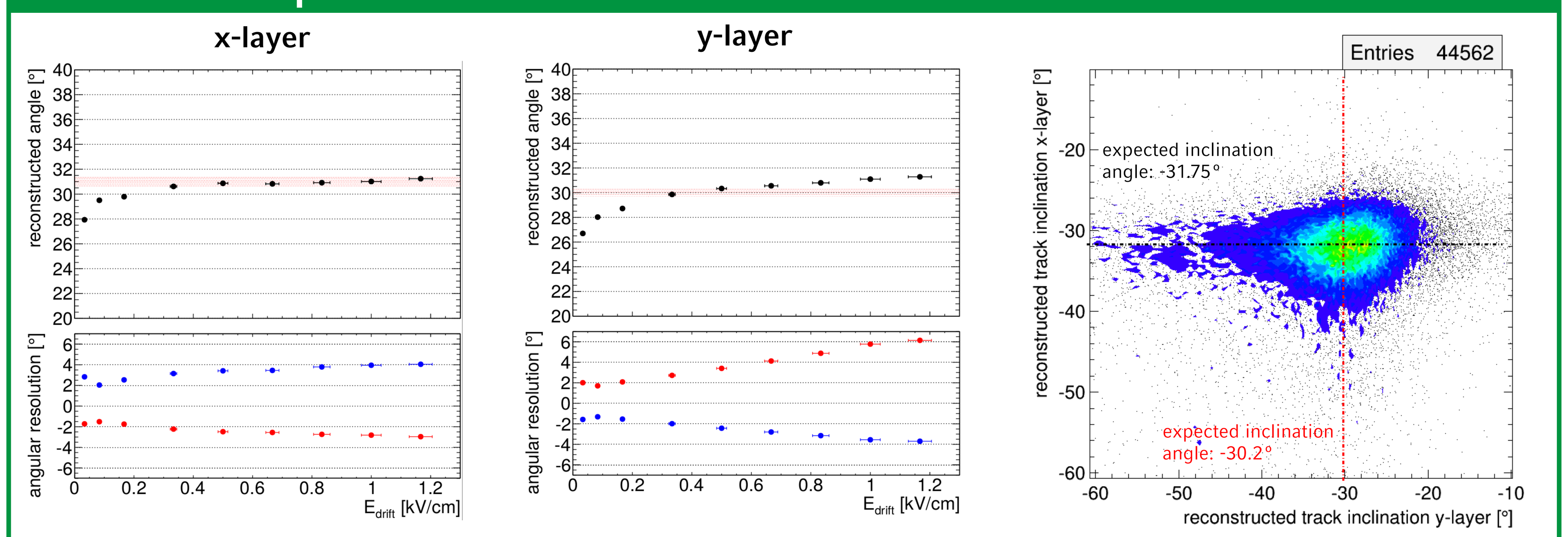
THREE-DIMENSIONAL μTPC RECONSTRUCTION



method
- arrival time ↔ drift distance
  $v_{drift}\cdot t = z$
- measure arrival time of charge signal on strips
  → signal timing t_0
- linear fit to time-strip data points
  → track inclination
  → alternative hit position
  → drift velocity

systematics
- capacitive coupling of signals onto neighboring strips
  → can be simulated with LTSpice

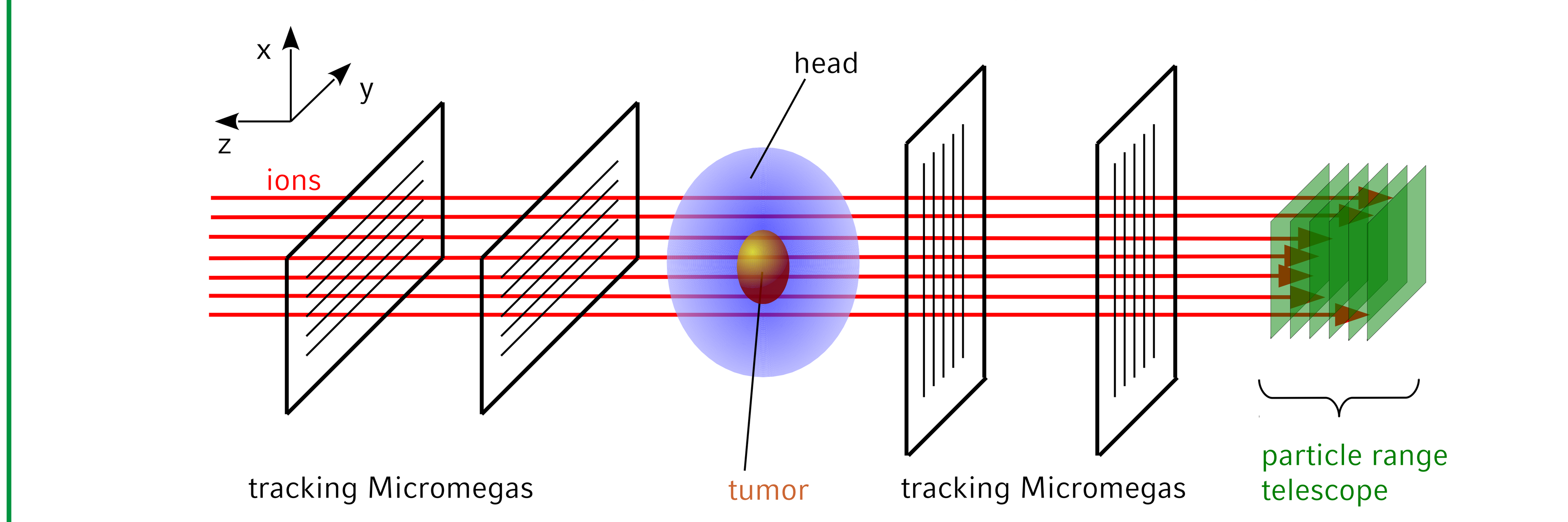
RESULTS: μTPC RECONSTRUCTION FOR 20MeV PROTONS



→ **three-dimensional μTPC reconstruction with angular resolution of $^{+3°}_{-2°}$ in both layers**

ION TRANSMISSION RADIOGRAPHY

medical imaging with transmitted ions
advantageous before and during particle therapy
- O(1%) radiation dose compared to conventional X-ray CT
- avoid calibration uncertainty: photon energy loss (X-ray CT for planning) ↔ particle energy loss (treatment)

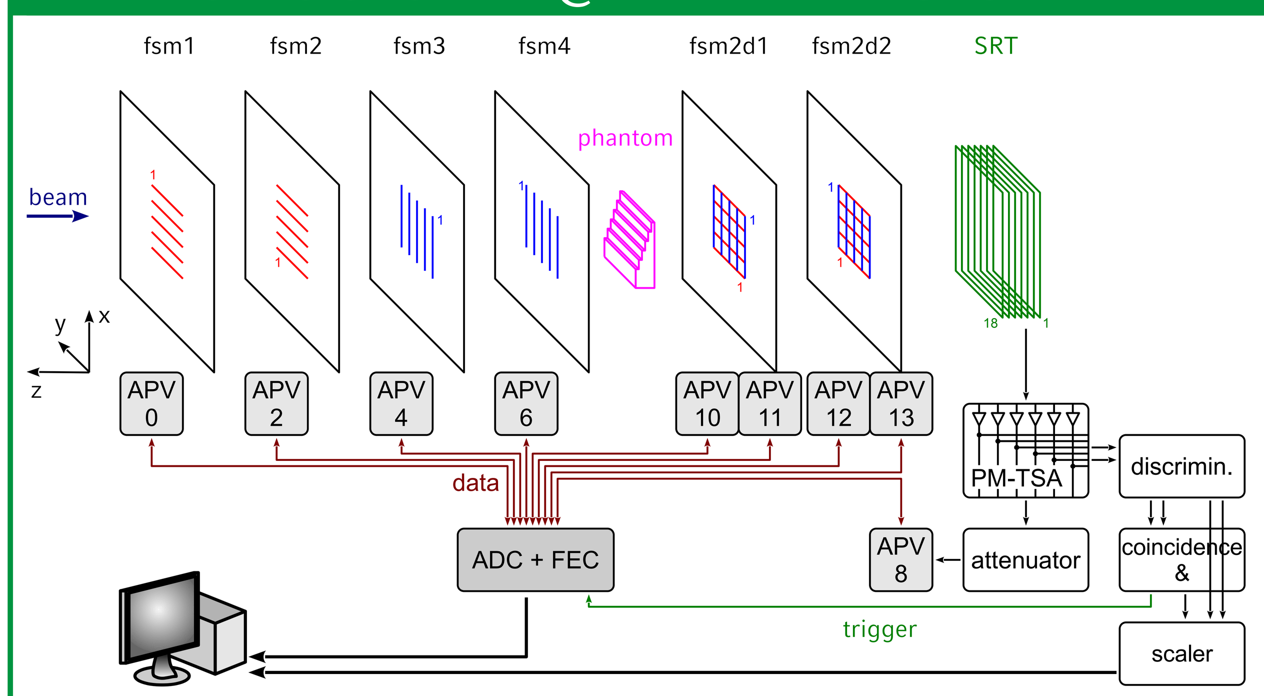


x- & y-information
floating strip Micromegas
- high-resolution
- highly efficient
  → minimize radiation dose
- low material budget
  → minimize multiple scattering

contrast information
$\Delta E = E_{initial} - E_{final}$
↓
multi-layer scintillator range telescope

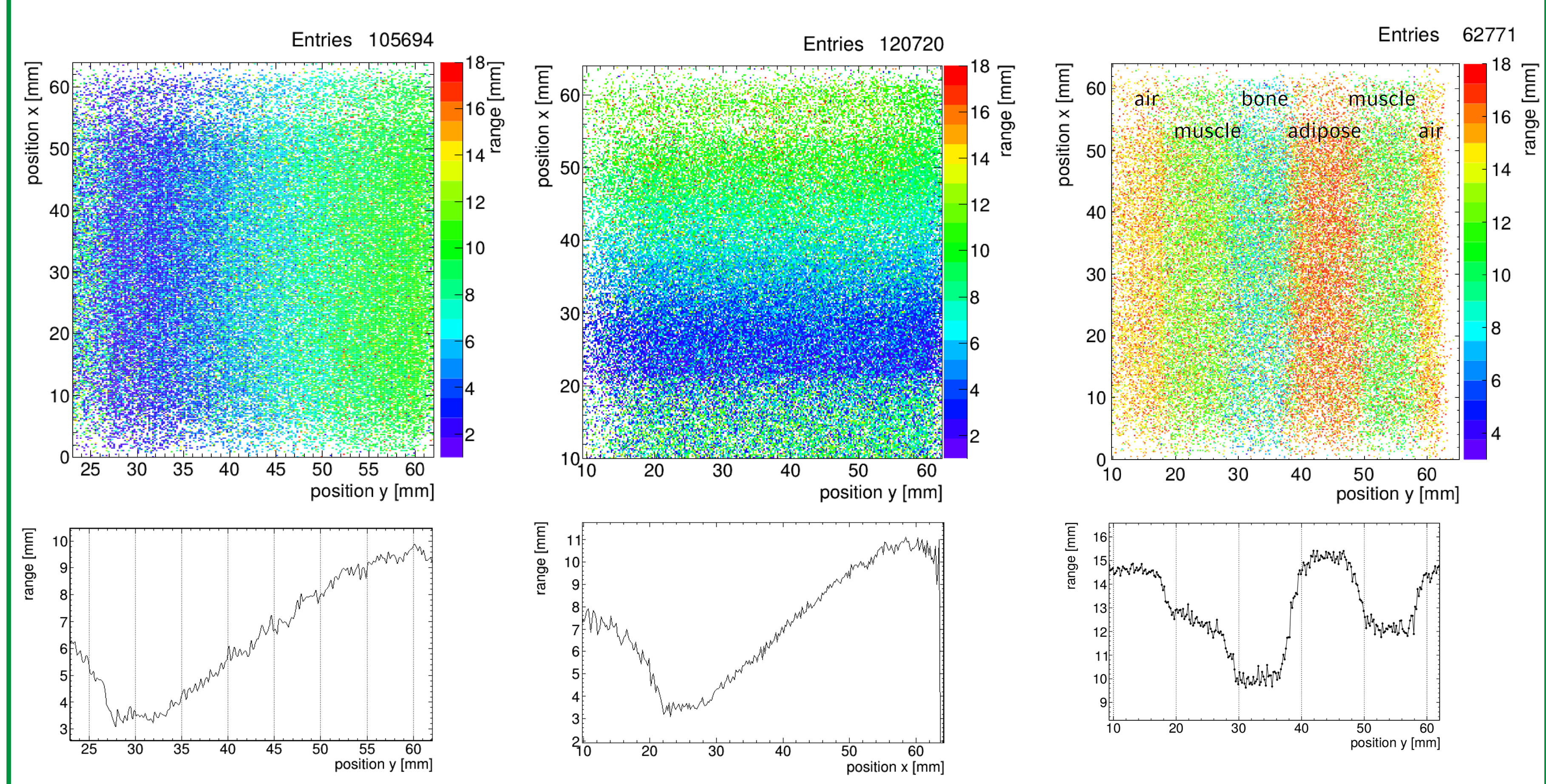
Kalman filter based track reconstruction
- reliable identification of particle hits
- correct treatment of multiple scattering
  → track is not necessarily straight
  → scattering in phantom as additional contrast information

IMAGING SYSTEM @ HEIDELBERG ION THERAPY CENTER



- first test of the imaging system
  - commissioning of range telescope & 2d Micromegas
  - commissioning of SRT readout electronics
- **radiographies of different PMMA step phantoms & tissue-equivalent slab phantom**
- carbon ions
  - up to 2MHz particle rate
  - 100MeV/u to 270MeV/u energy
- protons
  - ~2MHz particle rate
  - 70MeV to 130MeV energy

RESULTS: PHANTOM RADIOGRAPHY WITH CARBON IONS



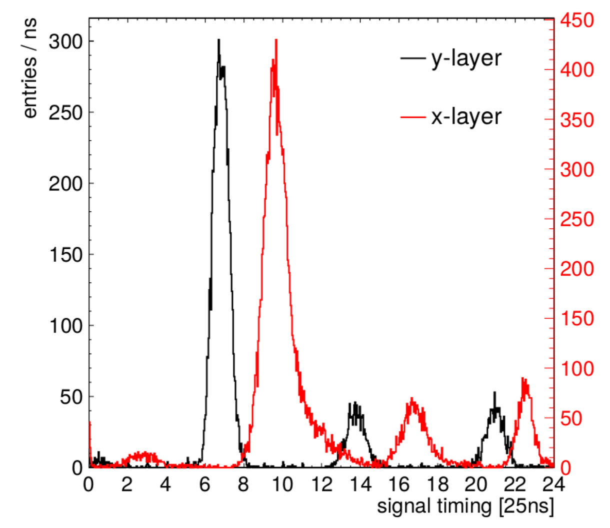
- steps: 3mm x 1mm
- plastic slabs: 10mm x 100mm x 100mm
- longitudinally irradiated

→ **spatial resolution** in y-direction: **O(1mm)**
in x-direction: **O(1.5mm)**
→ **weighted binary & calorimetric range** yields optimum results
→ linear range behavior as expected

SUMMARY

- new floating strip Micromegas detectors with two-dimensional strip readout
  - low material budget
  - track angle reconstruction in both layers with excellent angular resolution
  - excellent timing & multi-hit resolution
- ion transmission radiography
  - intended for medical imaging before and during tumor particle irradiation
  - avoids calibration uncertainties
  - considerably reduced radiation dose
- scintillator range telescope with 18 layers
- prototype imaging system tests at HIT
  - radiographies of phantoms
  → spatial resolution O(mm) with only few ions
  → linear range behavior
  → range resolution O(0.2mm) with only few ions

RESULTS: TIMING @ HIT



- special measurement with vanishing drift field
  → **excellent timing resolution of (7±1)ns**
- excellent multi-hit resolution: detection of particles from preceding & following bunches
- perpendicular y-strips
  - shorter signals due to small strip capacitance
  → **potential use for large-area detectors**