Beam line instrumentation

Joint beam instrumentation wg

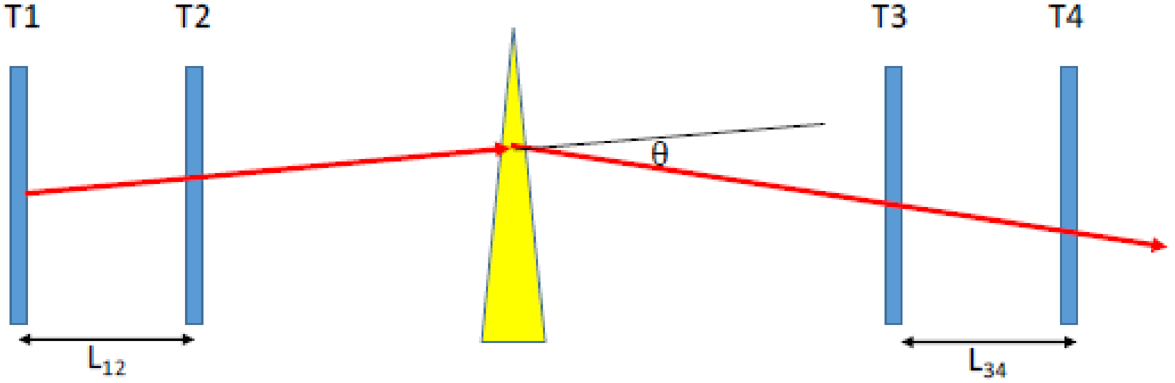
Working group

- Joint working group for the two ProtoDUNEs
- Investigate and propose beam line instrumentation solutions
- Take care of its realization
- Also of DAQ

- Conveners: Yannis Kariotakis, Jon Paley, Paola Sala
- Mailing list : DUNE-PROTO-BEAMINSTRUMENTATION at FNAL

Momentum determination and beam monitoring

- To reduce momentum spread: spectrometer (at high energies might also work with collimators. to be studied)



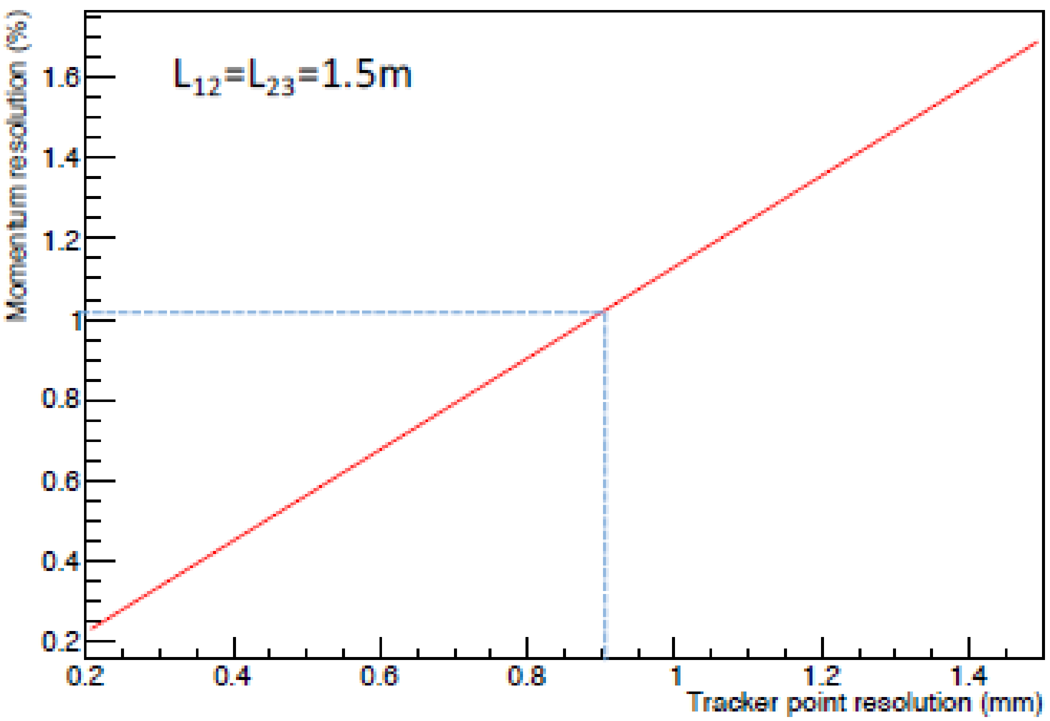
σ_x (mm)= point resolution of T1-4 trackers
$\theta \approx 0.118\ rad$ (nominal bend angle for H4 beamline)
$\Delta\theta_{12}(rad)$=angular uncertainty of T1 to T2 vector
$\Delta\theta_{34}(rad)$=angular uncertainty of T3 to T4 vector

Cheng-Ju

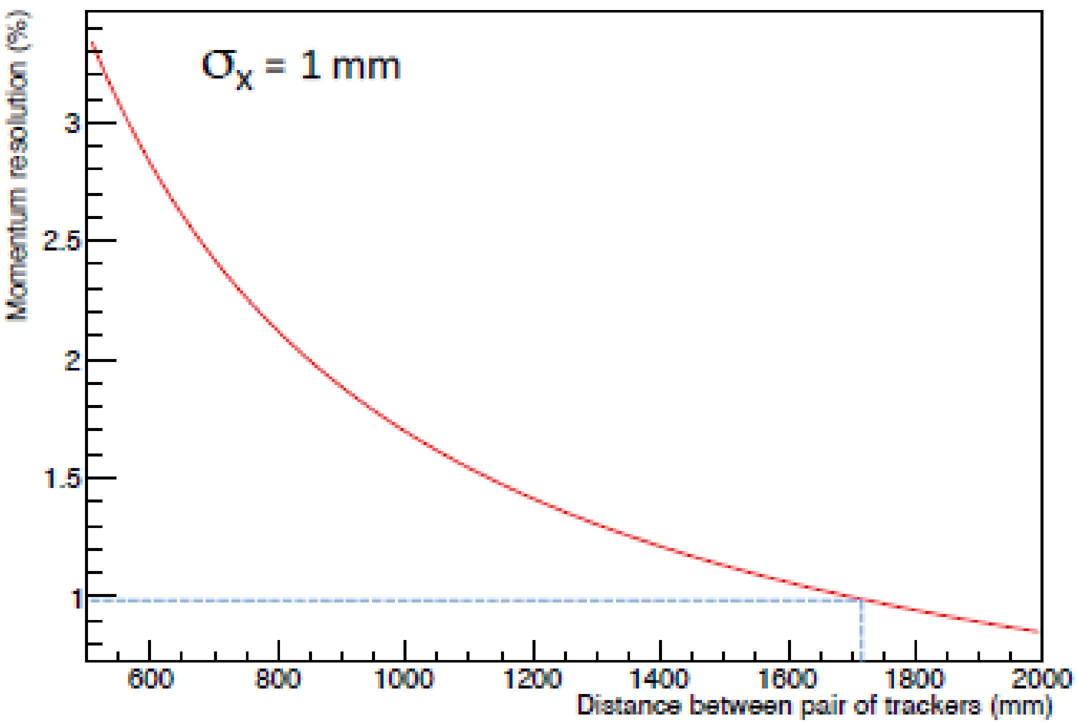
$$\Delta\theta = \sqrt{\Delta\theta_{12}^2 + \Delta\theta_{23}^2} = \sqrt{2\left(\frac{\sigma_x}{L_{12}}\right)^2 + 2\left(\frac{\sigma_x}{L_{34}}\right)^2}$$

$$\frac{\Delta P}{P} = \frac{\Delta\theta}{\theta} \approx \frac{\sqrt{2\left(\frac{\sigma_x}{L_{12}}\right)^2 + 2\left(\frac{\sigma_x}{L_{34}}\right)^2}}{0.118\ rad}$$

Dependence on the Point Resolution of Tracker



Dependence on the Distance Between Pair of Tracker



Momentum resolution (to first order):

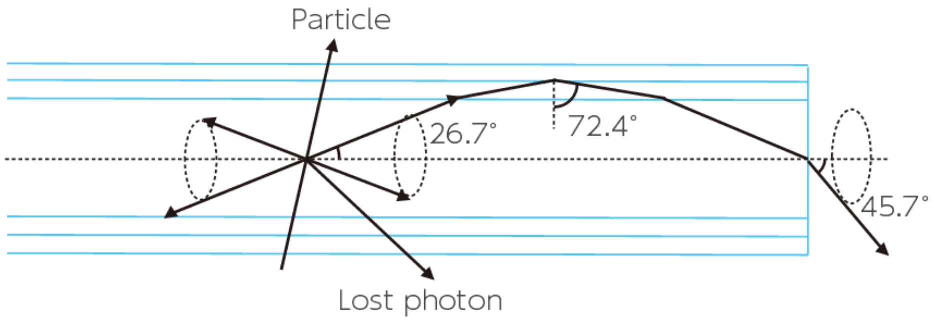
- scales linearly with the point resolution of the tracker
- Inversely proportional to the distance between the trackers
- largely independent of the distance of the trackers from the dipole magnet

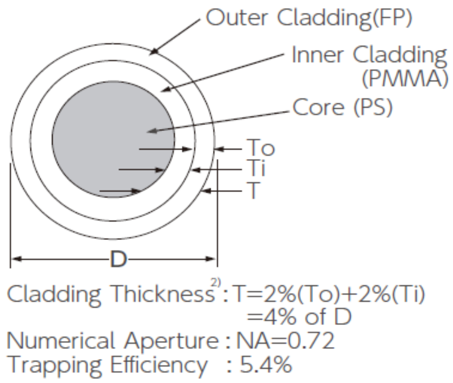
Cheng-Ju

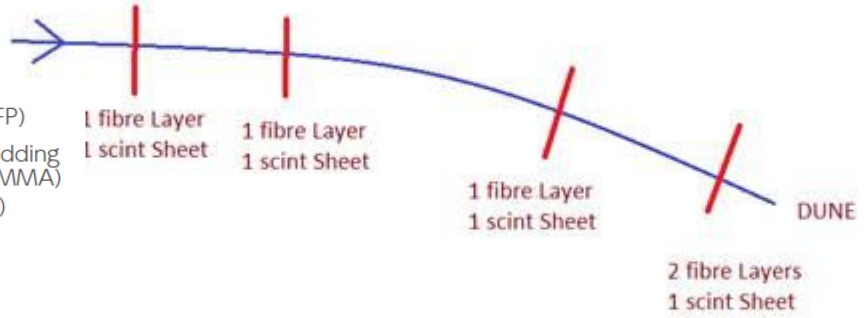
To be checked with full sim (multiple scattering)

Proposed devices (CERN BI group)

- layers of scintillating fibres
- Polystyrene, 0.5 or 1mm square fibres, X and Y layer
- Can cover whole beamline area
- Inserted in beamline with special flange
- 4 devices for spectrometer,
- 1 device beam monitor (and trigger)







Monitor proposal

Overall design:

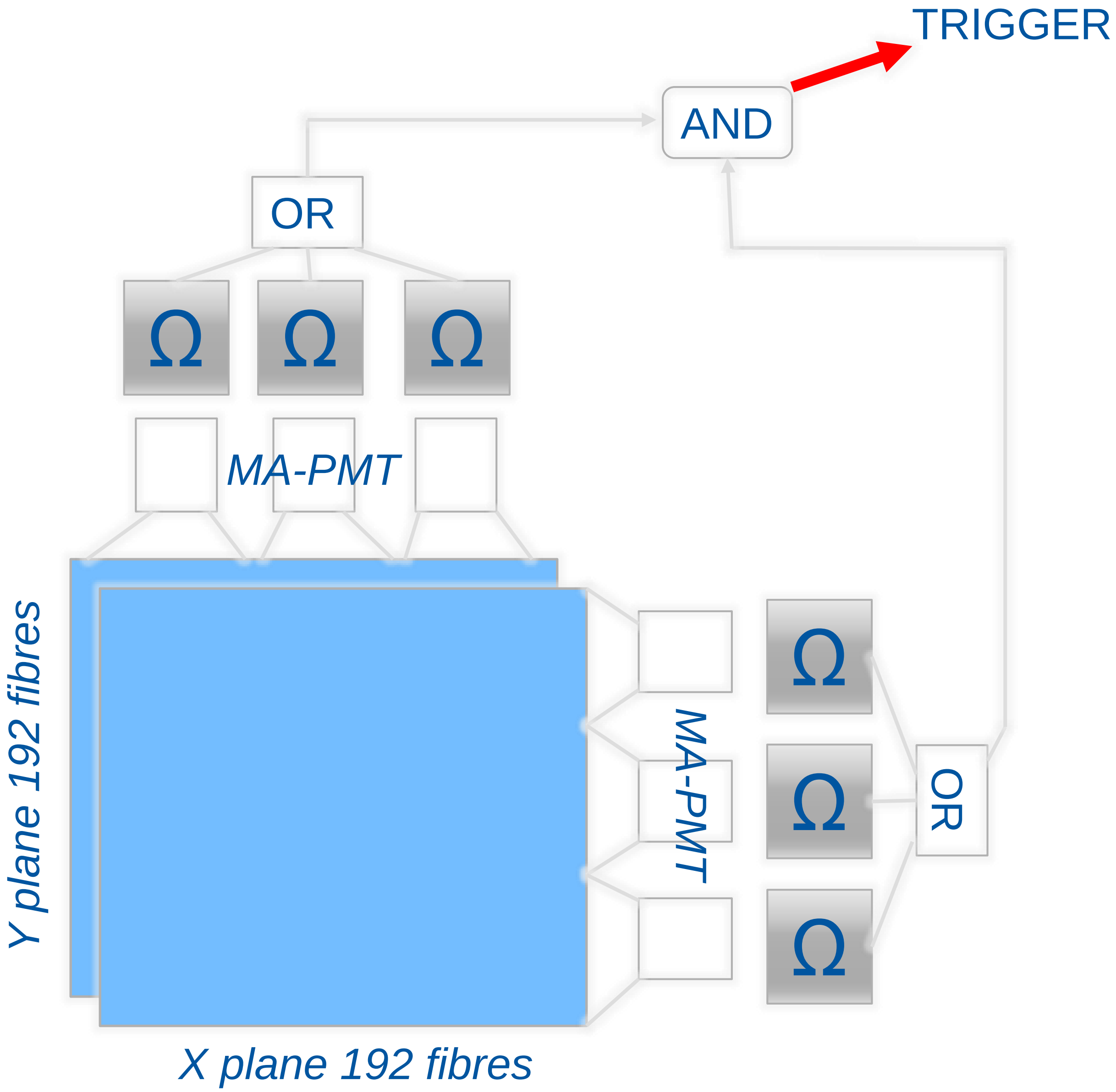
- 1mm square fibres
- 2 planes X&Y: 2mm of Polystyrene per detector.
- 192 fibres per plane with no space between them -> 192mmx192mm covered area
- A mirror on one end to increase light collection
- Light read with MA-PMT
- Front-end electronics including MAROC and FPGA

We can offer a trigger to the experiment:

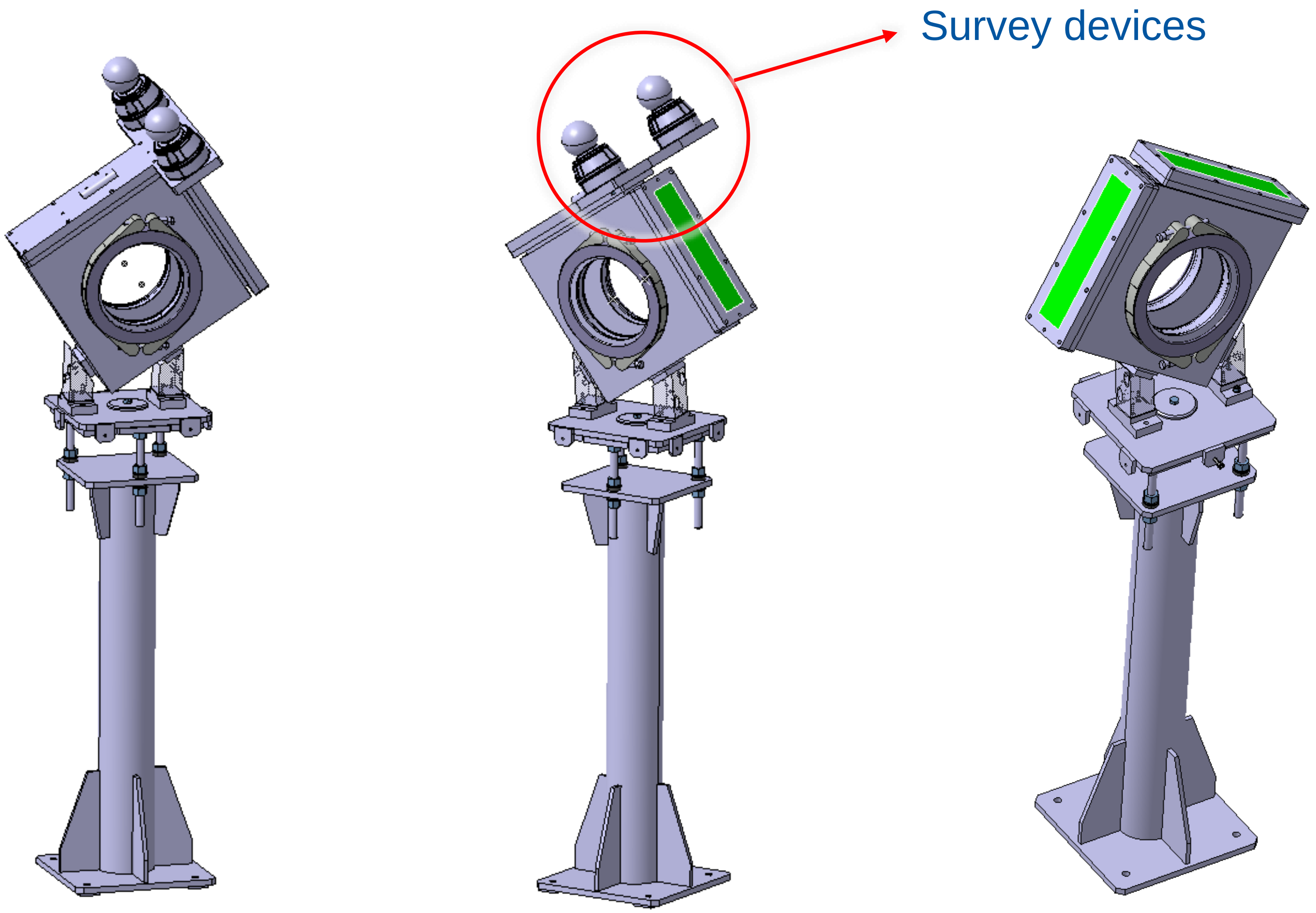
- Required timing?
- Timing precision?

Additionally we can offer:

- Time stamp in the events respect to the beginning of the spill with 10ns precision
- Fibre stamp

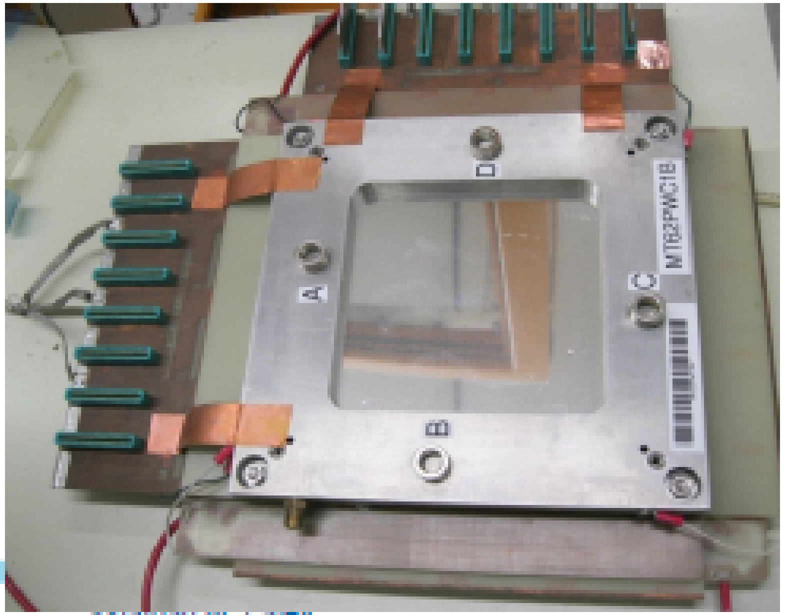


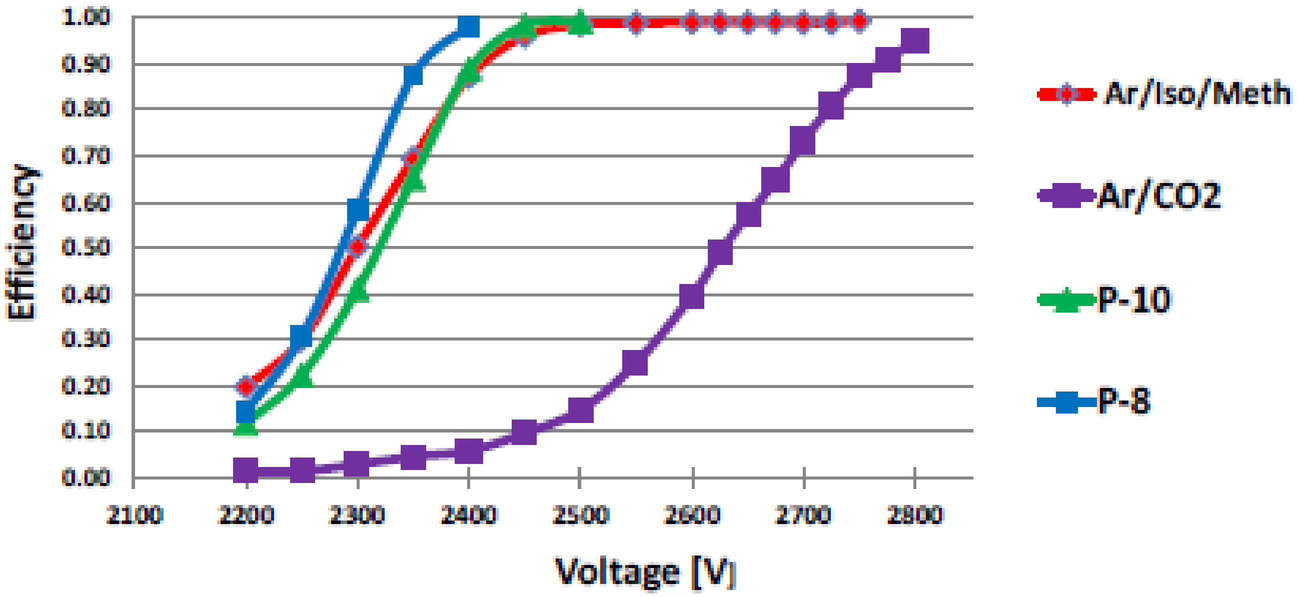
Modular design: planes easily replaceable



Alternative for spectrometer: FNAL wire ch.

Fermilab has multi-wire proportional chambers (MWPCs) with X-Y sense plane readout, approximately 128 mm x 128 mm, readily available that can be used in addition to the XBPF. Chambers add 0.002 nuclear collision lengths and 0.007 radiation lengths. These chambers have a long history, so installation, integration and commissioning should be straightforward.





Installation in air, need to break vacuum

Instrumentation: PID

- Mixed hadron beam: protons, kaons, pions (+electrons)
- Two possibilities for ID: Threshold Cerenkov (good at high P) and ToF (good at low P)
- For Cerenkov to work, i.e. enough photons, need high density gas and/or high pressure.
  - Might use Freon (or equivalent). Limited in pressure by liquefaction at 5 atm
  - Might use high pressure CO_2 (10-15 bars) . Not in the range of standard CERN detectors (<3 bar) but already used in the past, design exists

→ In both cases : high material budget

- Need two devices, one selects pions, the other pions+kaons → work in and/or

Thoughts on requirements:

From proposal requirement table:

- Protons from 0.7 GeV/c
- Pions+- from 0.2 GeV/c
- Electrons from 0.2 GeV/c
- Kaons+ from 1 GeV/c

Do we really need these low energies? And can we get them?

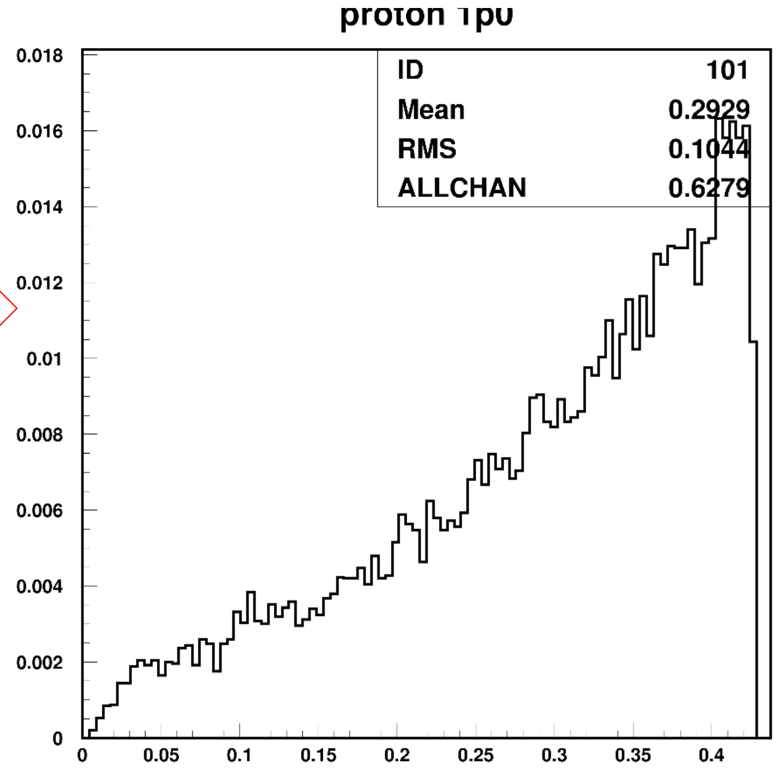
In the following a few ideas, also based on full FLUKA simulations in the full ProtoDUNE detector geometry

These are my personal thoughts, not discussed within the wg

Protons: was 0.7 GeV/c

- We need interacting and stopping particles.
- For stopping, the "initial "energy has small meaning
- At 1 GeV/c, still 35% of protons do stop. (only 5 per mill at 2 GeV/c) AND, 1 GeV/c the protons interact at all energies, from max down to "zero" :

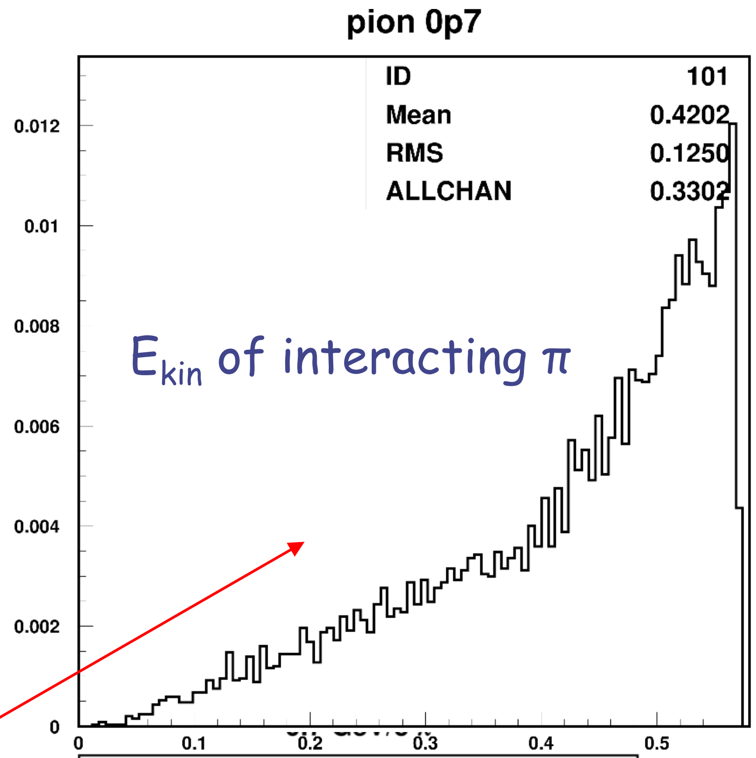
Kinetic energy of protons at the point of interaction in PD active LAr Original momentum is 1GeV/c

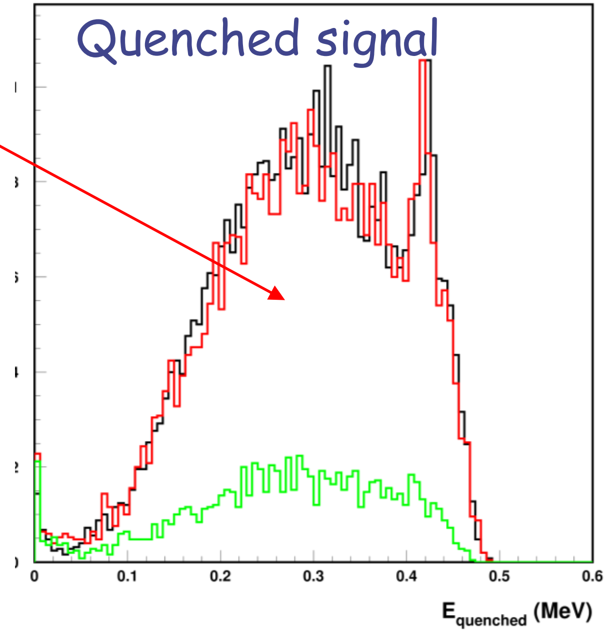


NO NEED to go below 1 GeV/c?

Pions: was 0.2 GeV/c

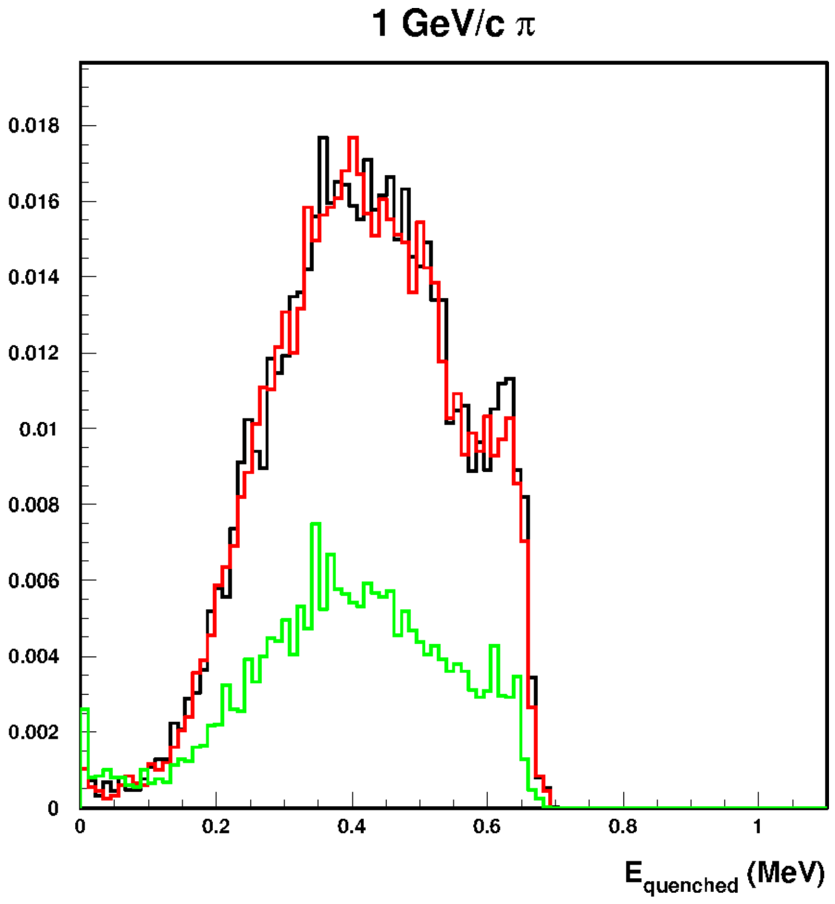
- Need interactions, decay, decay-at-rest (for quenching meas.)
- Pions decay along the beamline
- For a 37m beam line, at 0.2 GeV/c only 4% of the π reach the detector
- The fraction of (stopping π)/(from target π) is 2% at p=0.2, 1.3% at p=0.7. (To be selected from many more interacting π)
- As for protons, there are still interactions all the way from Emax to zero.
- ➔ consider having pions above p≈0.7GeV/c as first priority ?





Pions 1 GeV/c

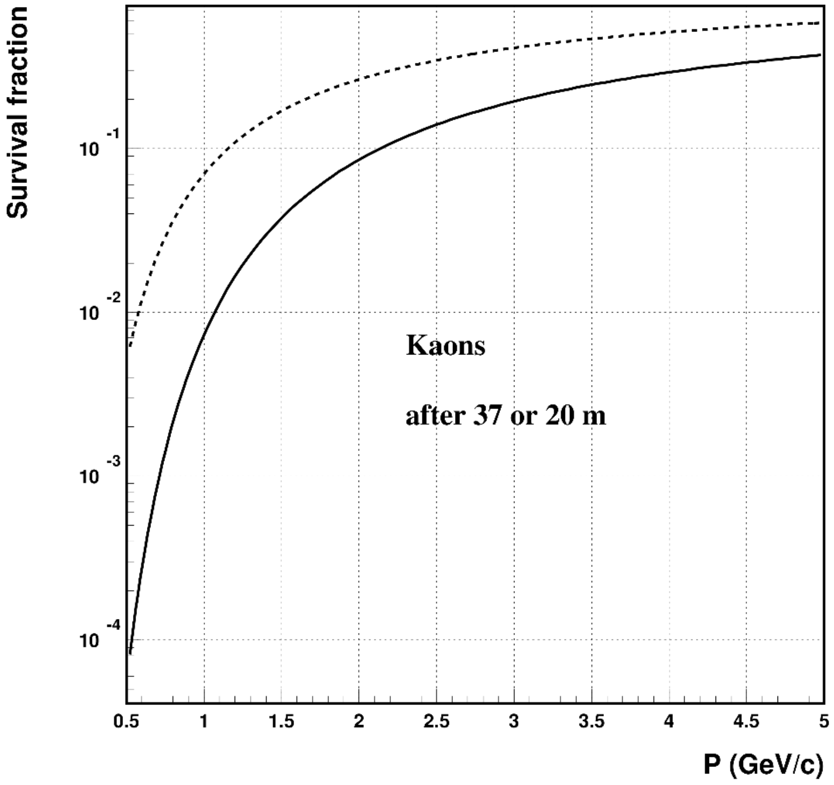
- Very few stopping pions (around 2% of the initial ones, 4% of the detected ones)

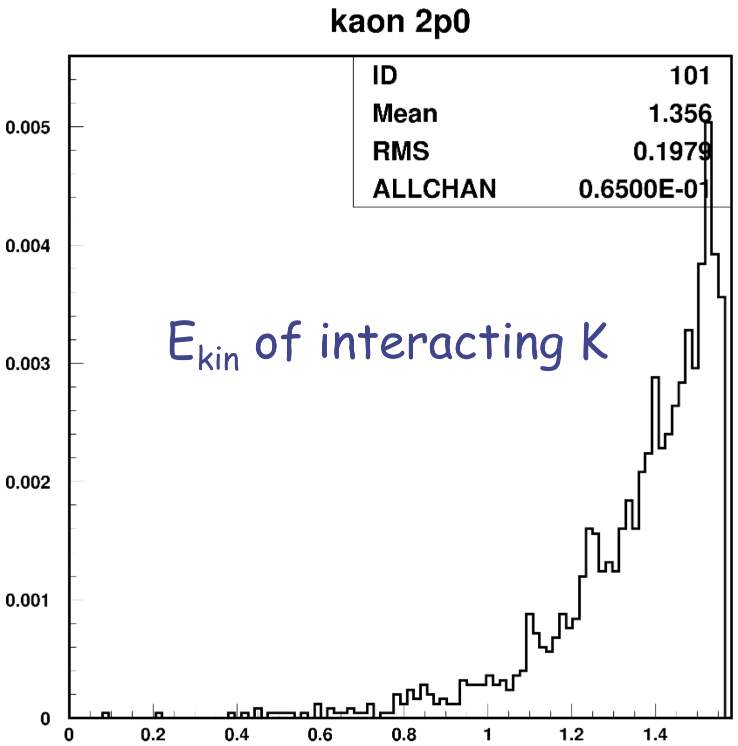


Black: only beam monitor
Red: BM + spectrometer
Green: BM+spectrometer+ToF

Kaons: was 1GeV

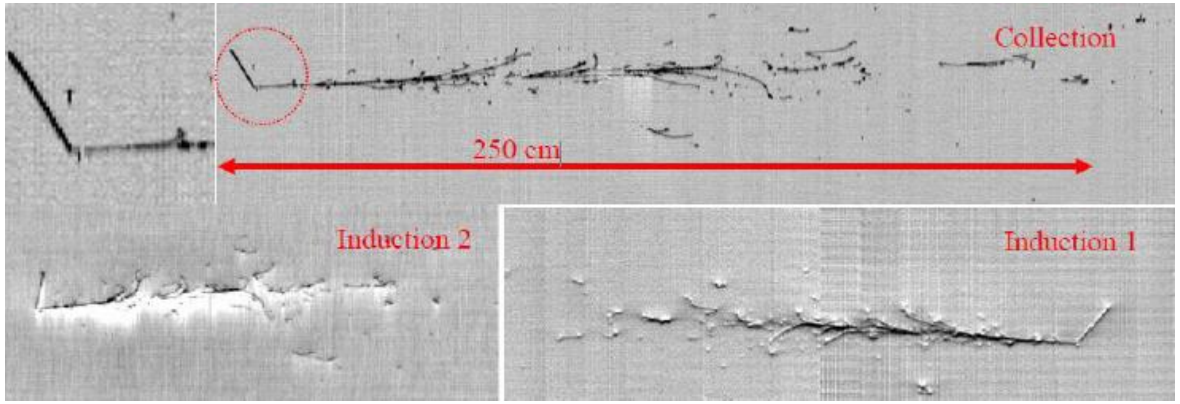
- And one would like to have.. But…no hope below 2 ≈GeV/c or more
- There will be no decay at rest
- And only “high”energy interactions





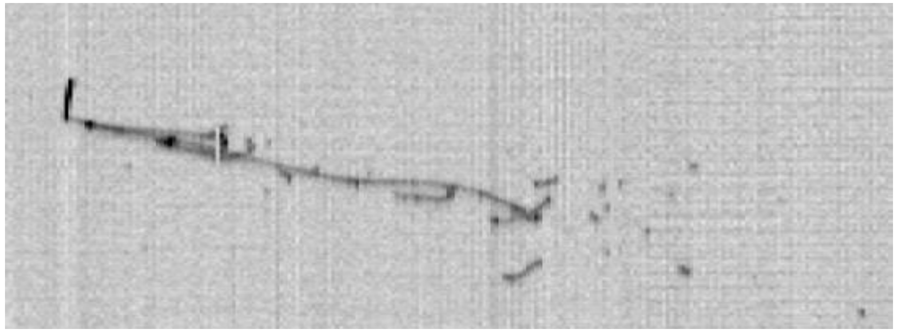
Electrons: was 0.2 GeV/c

- At low energy, topology is different from standard shower
- Would like to check ID and reco



Icarus T600 2.1 GeV electron

Real data, atm nu events , from SPSC presentation

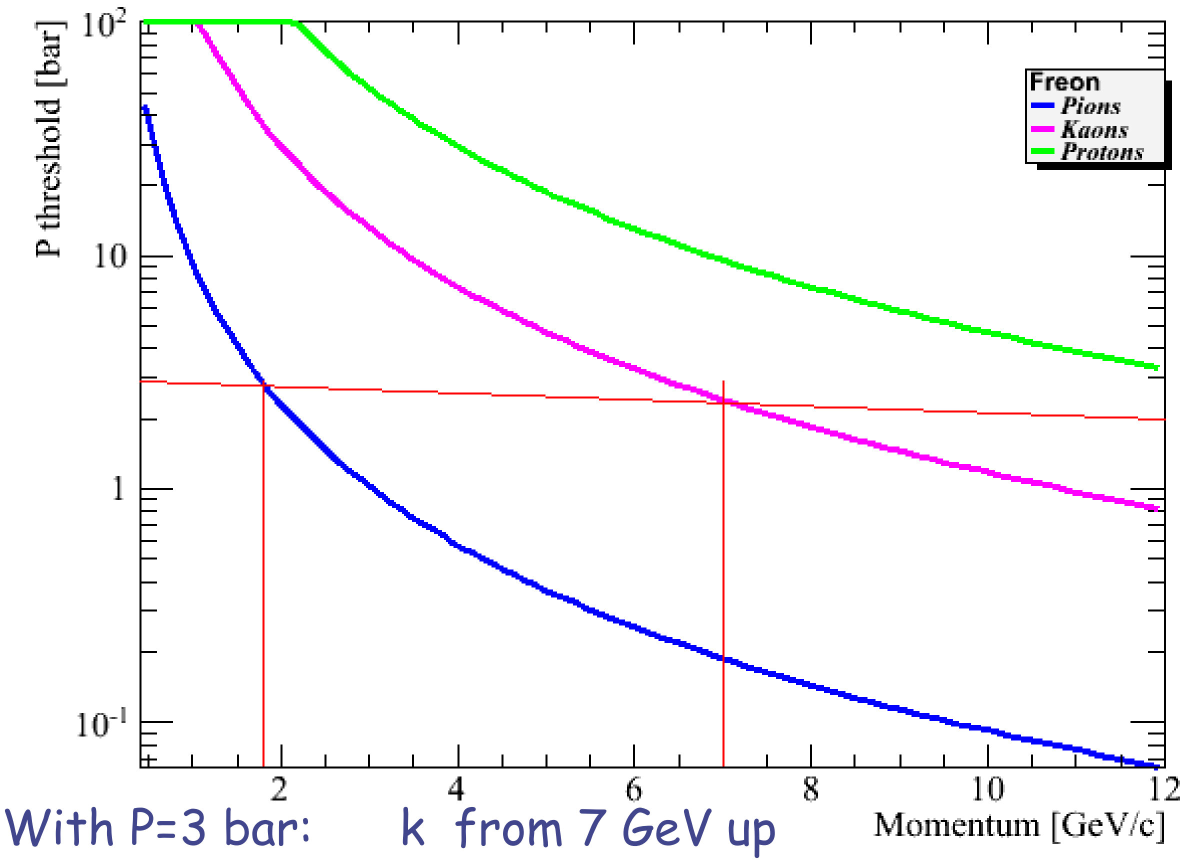


Icarus T600 0.2 GeV electron

- main argument to keep low material budget

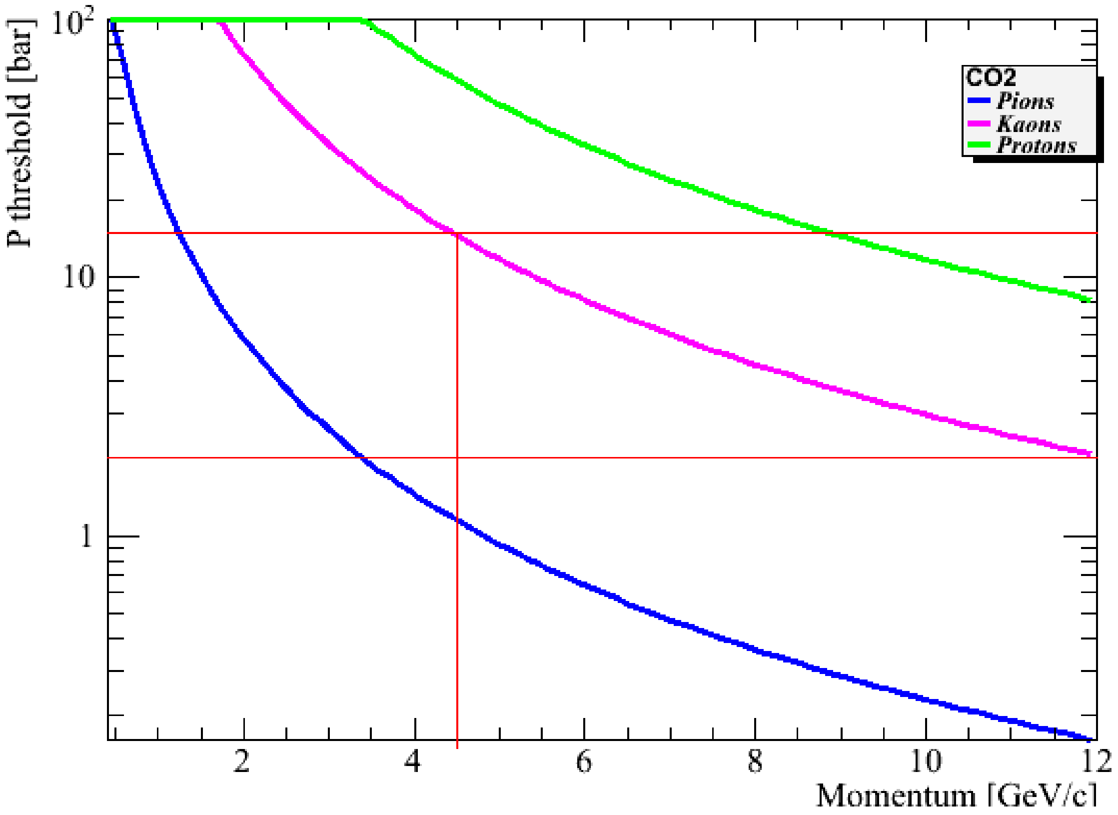
PID-Cerenkov

From Yannis Kariotakis (WA105):
Needed Cerenkov pressure to produce at least 10 optical photons as a function of particle momentum using FREON-12



With P=3 bar: k from 7 GeV up
π from 2 GeV up
With P=1 bar : π from 3 GeV up

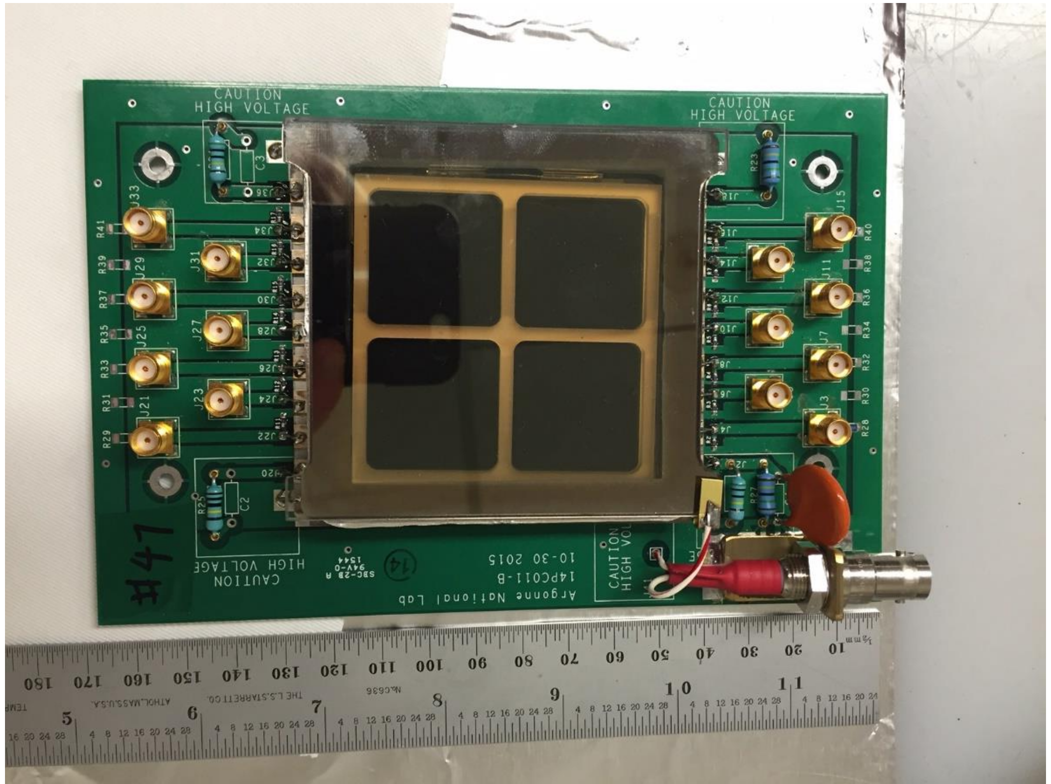
Same, CO_2

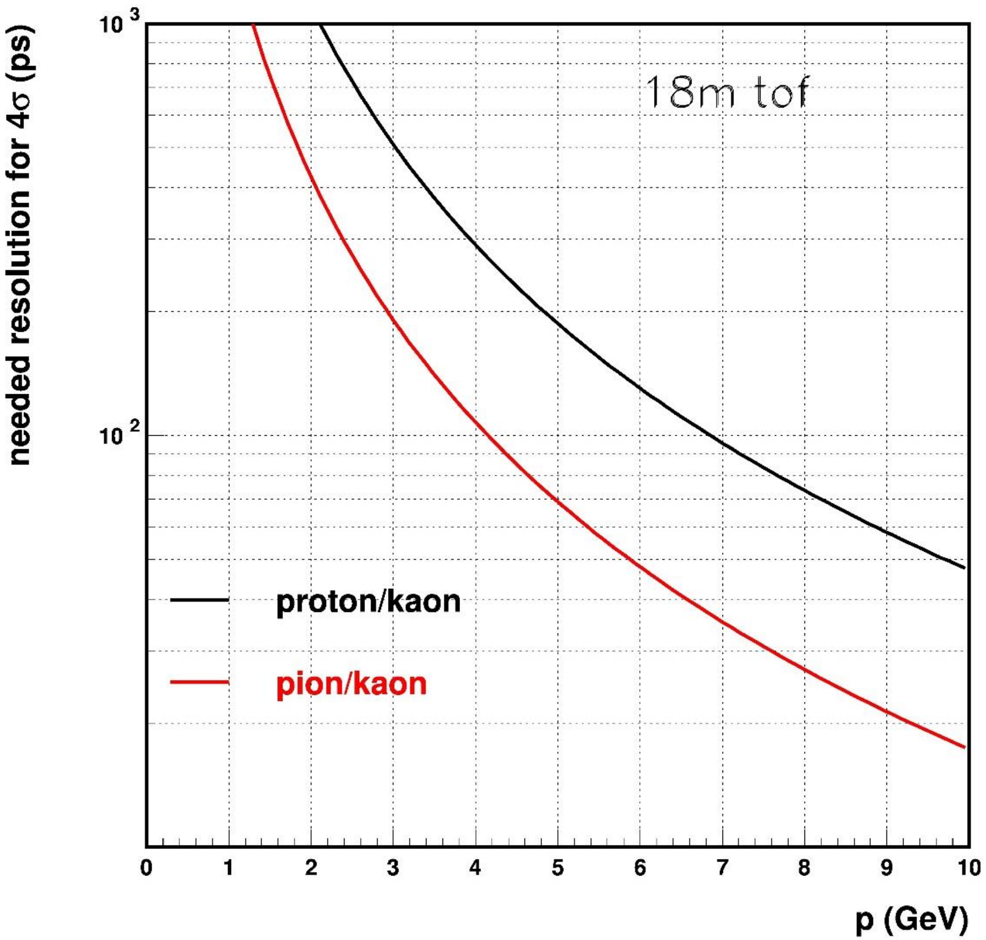


C2 @ <=15 bars CO2 identifies Kaons above 4.5 GeV

PID-Tof

- At lower energies: tof
- Proposal from FNAL: LAPPD
- better than 50 ps timing resolution
- ≈ 1mm position resolution
- 6x6cm area





Needed resolution for 4 σ discrimination, assuming 18 m tof
With a 50ps device pion/kaon below 6 GeV
proton/k below 10 GeV

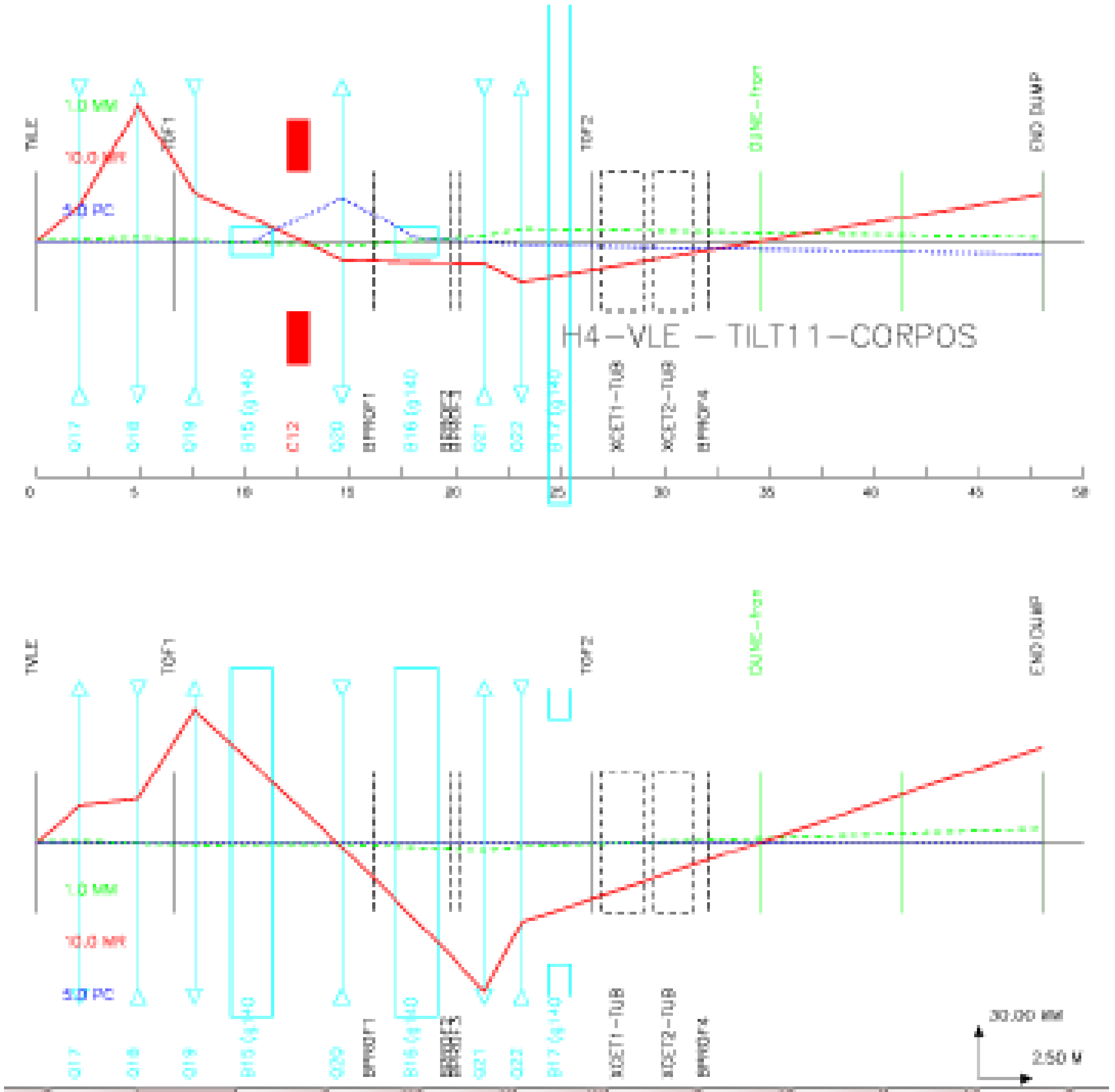
PID: summary

- PID feasible with
- 2 Cerenkov
- ToF with resolution better than 100 ps and path around 20 m
- Materials??

- all this assumes that the elecrons present in the hadron beam are identified in the detector. Otherwise, we'll have to keep one Cerenkov, low pressure, to discriminate electrons in low-energy hadron beams. This conficuration is not yet included in simulations

Beam line possible layout

Nikos, old plot, not to be considered as real, it only gives possible positions for the instrumentation

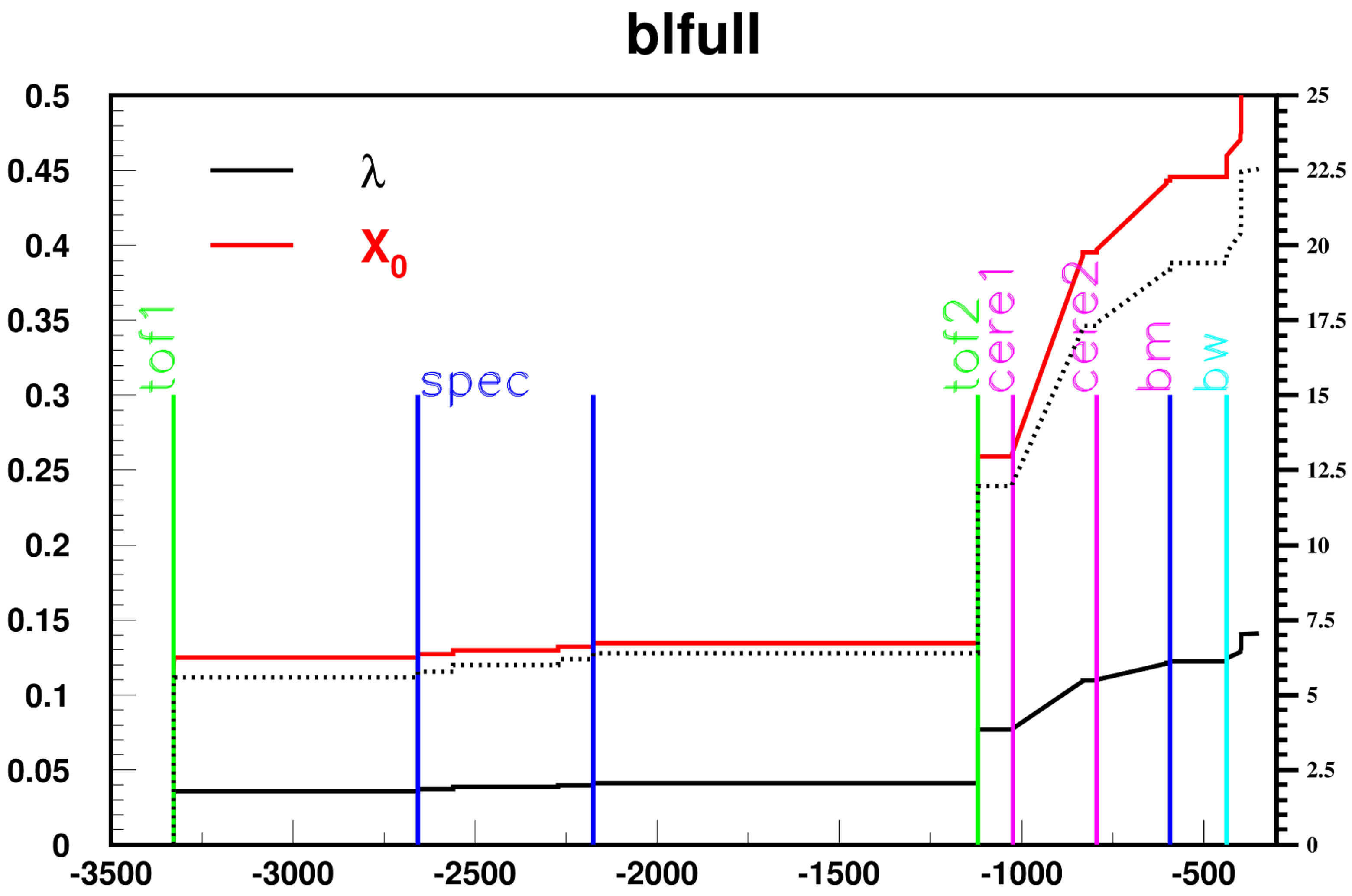


Simulations

- Simulations of the effect of beam line materials started
- Using the full ProtoDUNE geometry, in FLUKA
- In the beam line: material layers, not yet the magnetic elements
- ➔ tricks
  - Discard particles exiting from the beam line before the last bend
  - Dut on particle momentum at the last bend, xx around the nominal beam
- Recostruction.. Waiting for the interface.. Using directly the MonteCarlo results

- Work just started..more to do

Material budget



If one puts all the instrumentation in the beamline:
number of interaction lengths,
of radiation lengths ,
energy loss for a mip (dotted line right axis)

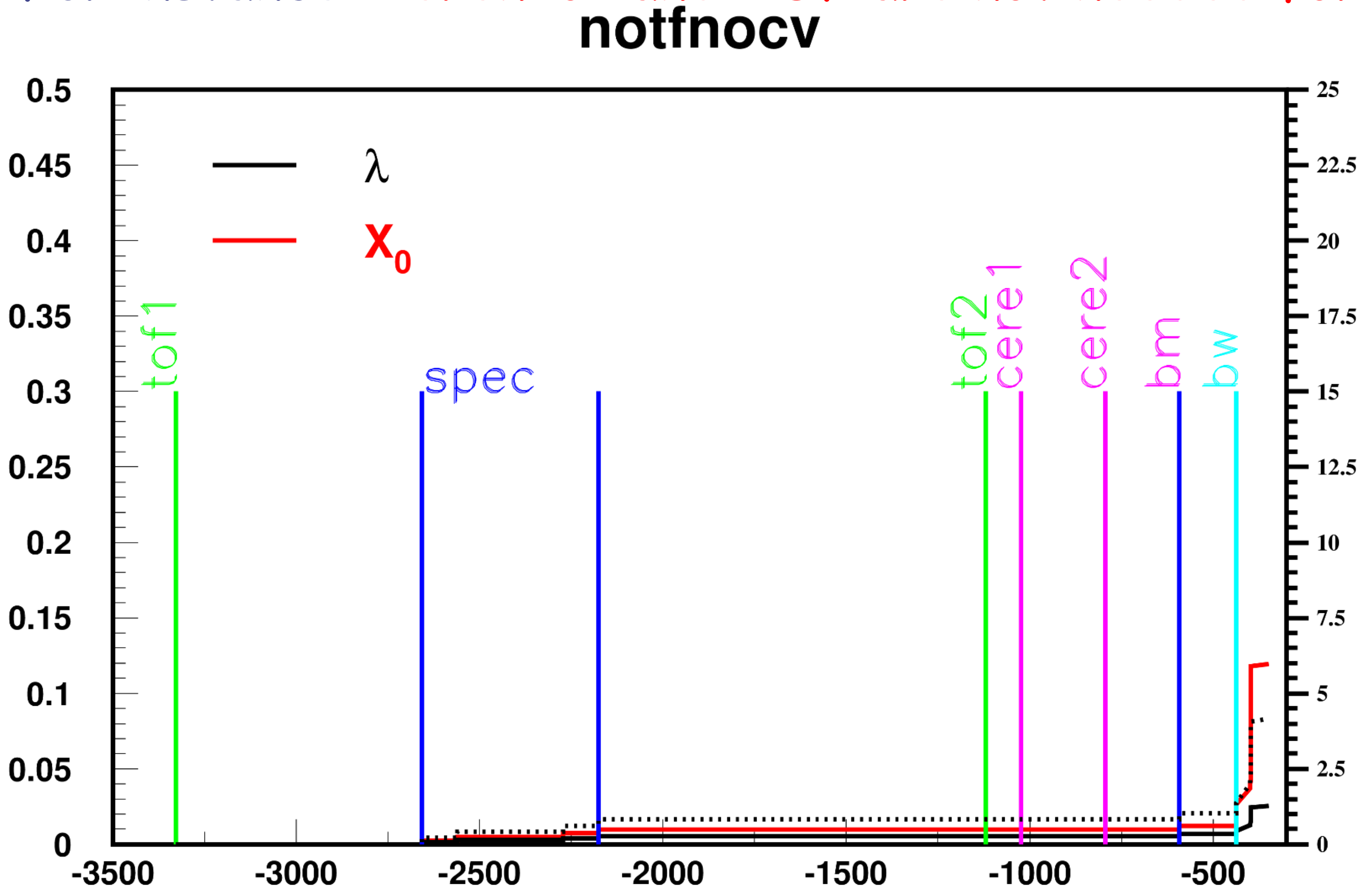
➔ 0.5 X0
➔ 0.15 λ
➔ 25 MeV

Mostly from tof and Cerenkov (here very conservative Cer., with 3 and 1 bar..).

Pions are scattered and lost. At 0.7 GeV, roughly factor 5 reduction + energy spread
Almost no electrons stay mip..

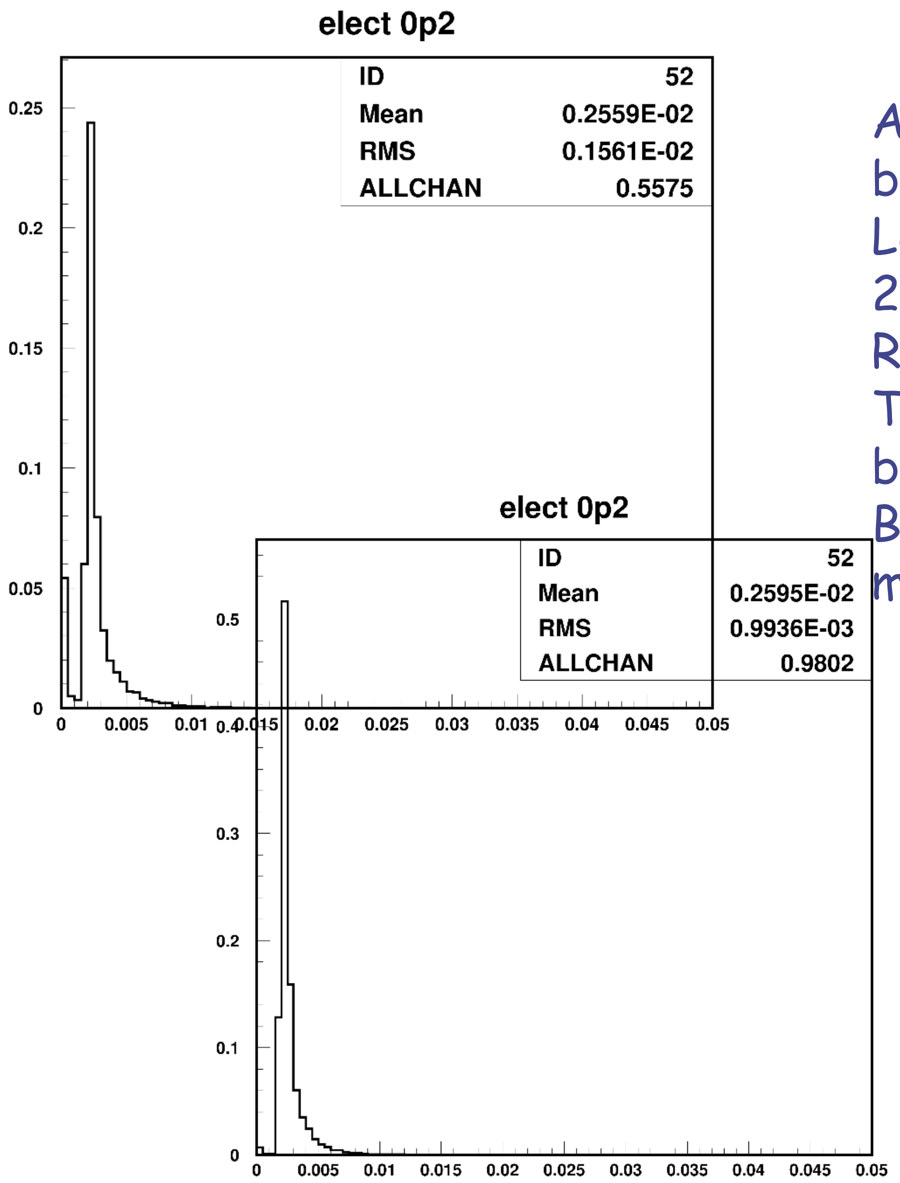
A plug-and-play beam line

- Try to have elements that can be extracted from the beam line if needed.
- For instance: Cerenkov and TOF are not needed for electron beams

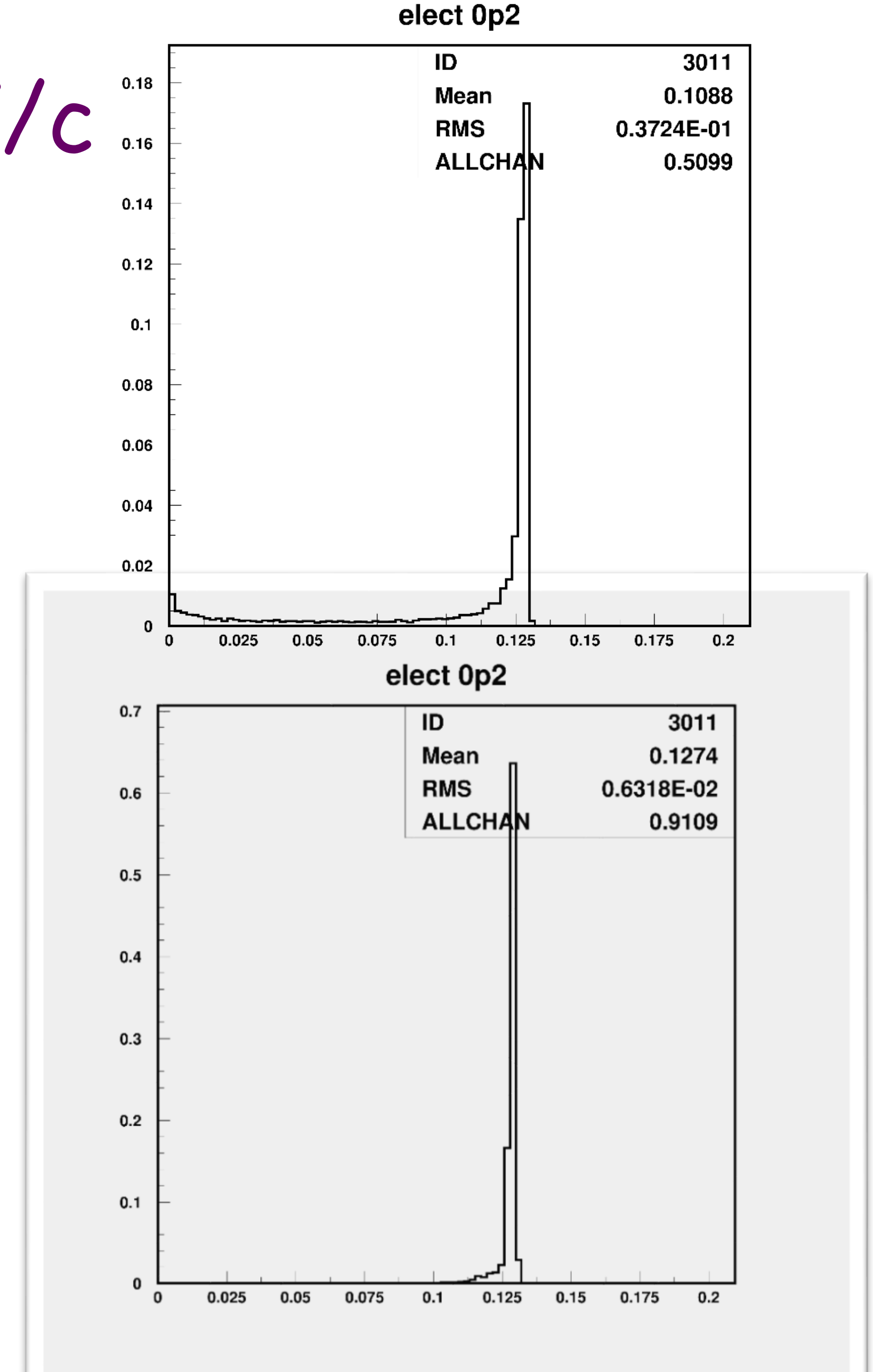


No TOF,
No Cerenkov
In this configuration, scatterings in the spectrometer elements harms a bit, reducing by a factor 2 the "good" electrons wrt the situation with beam window only.

No tof, no cv, electrons, 0.2GeV/c

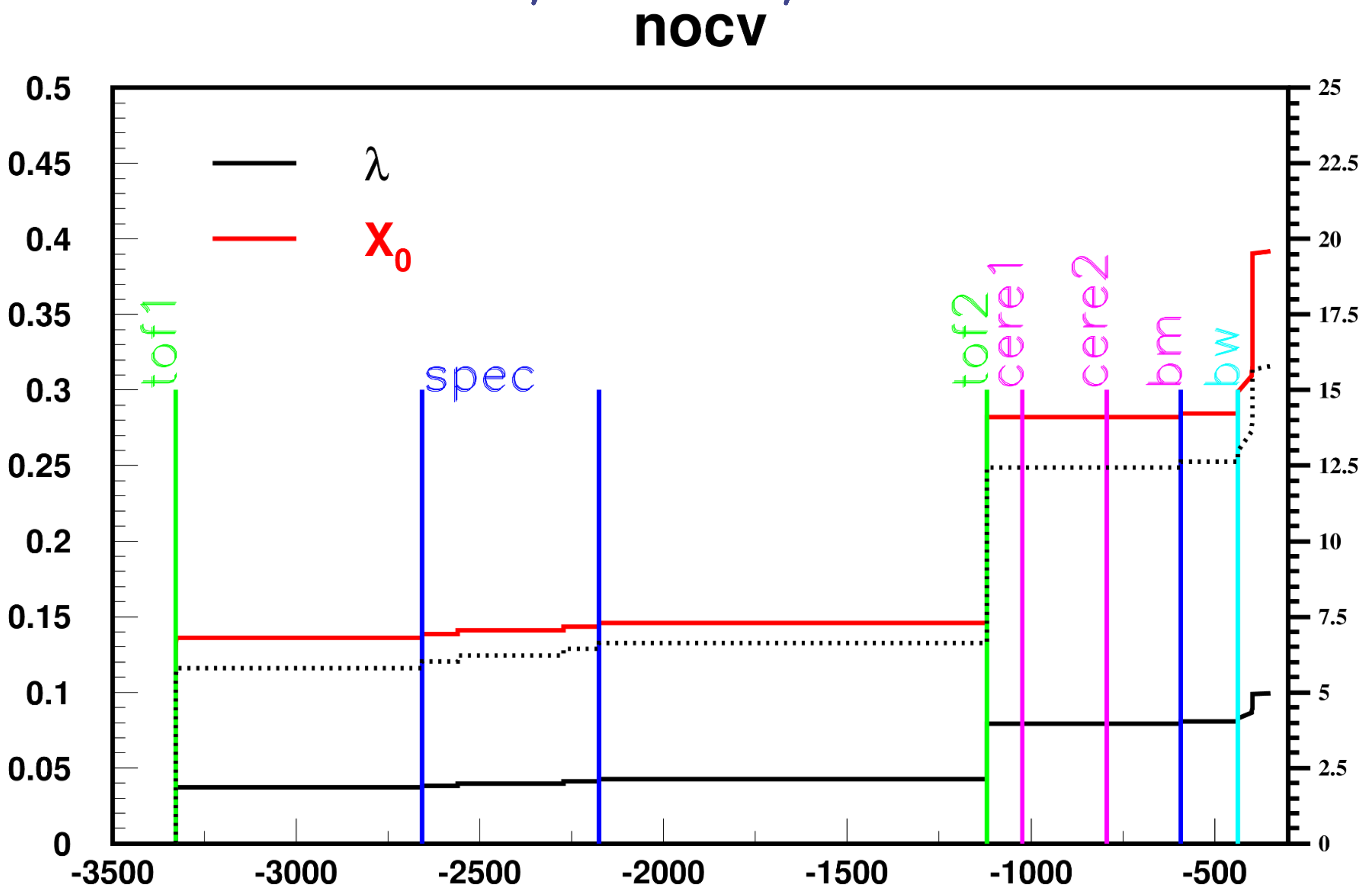


Asking a "mip"in the beam monitor
Left: de/dx in first 2 cm Lar
Right: visible energy
Top: spectrometer+ beam monitor
Bottom: only beam monitor



Low energy pions

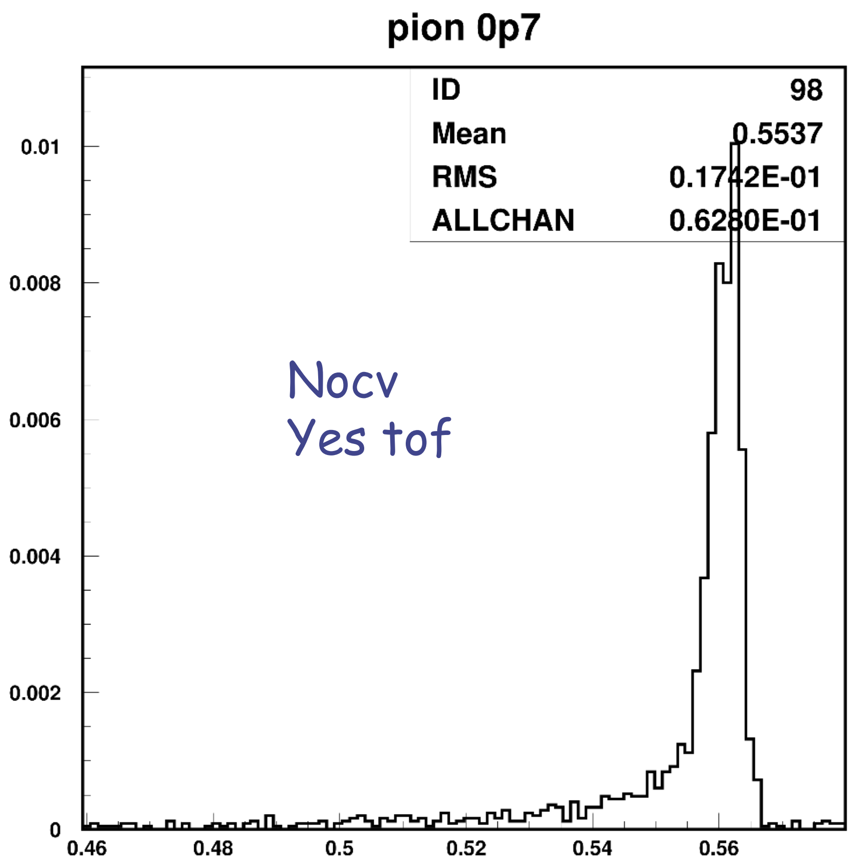
- Below 2-3 GeV/c, use TOF, no Cerenkov

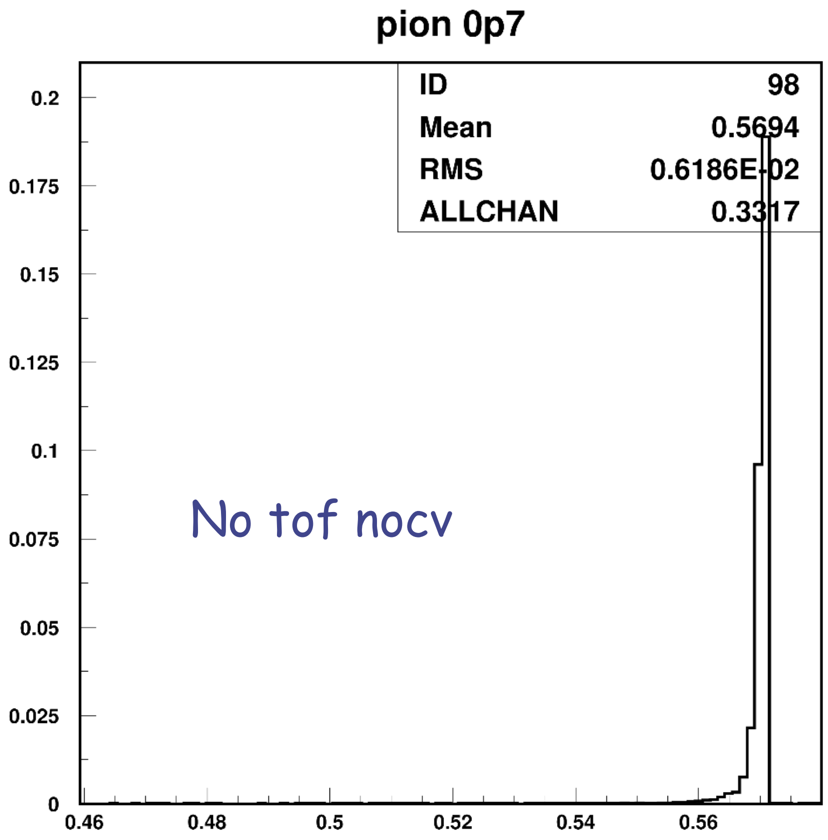


Still a non-negligible effect

0.7 geV/c pions

Kinetic energy of particle entring "alone"in the detector

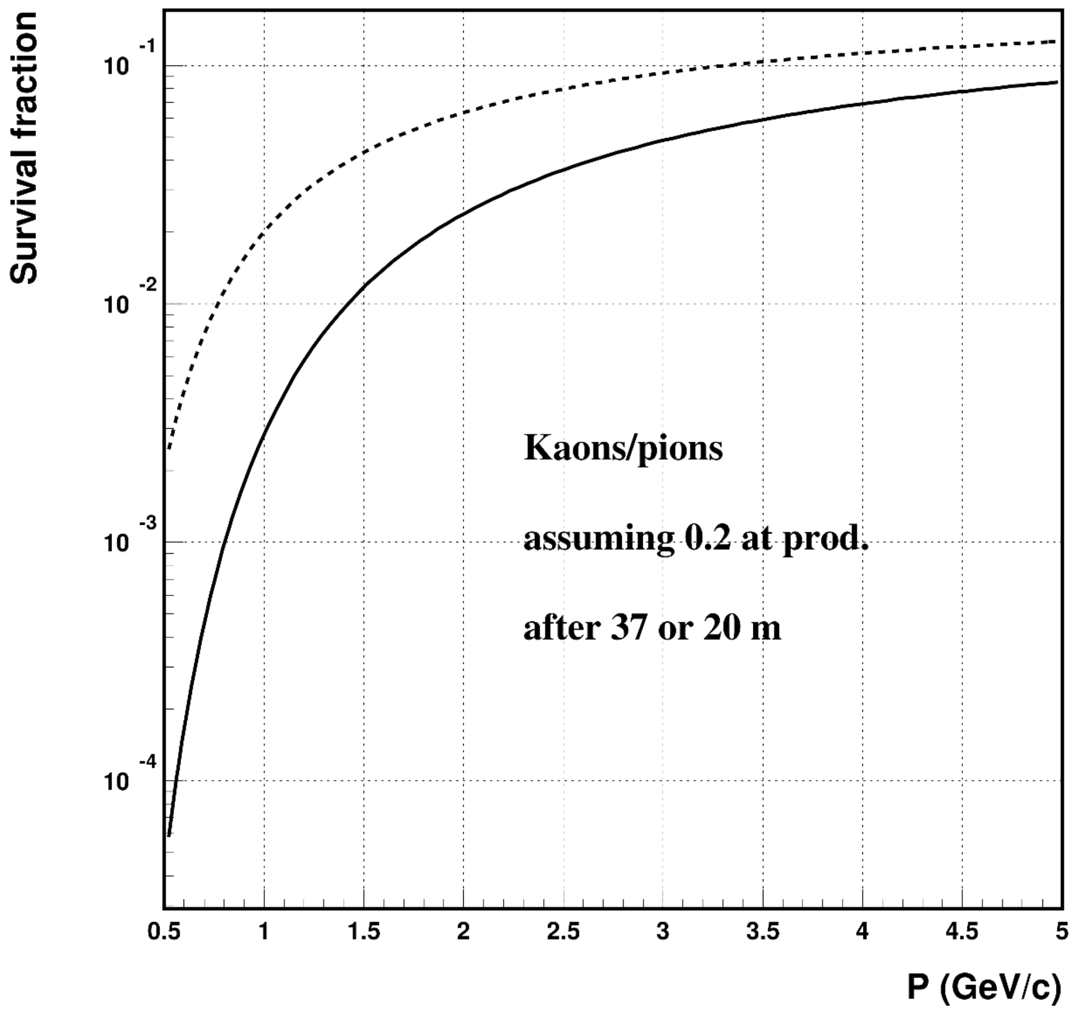




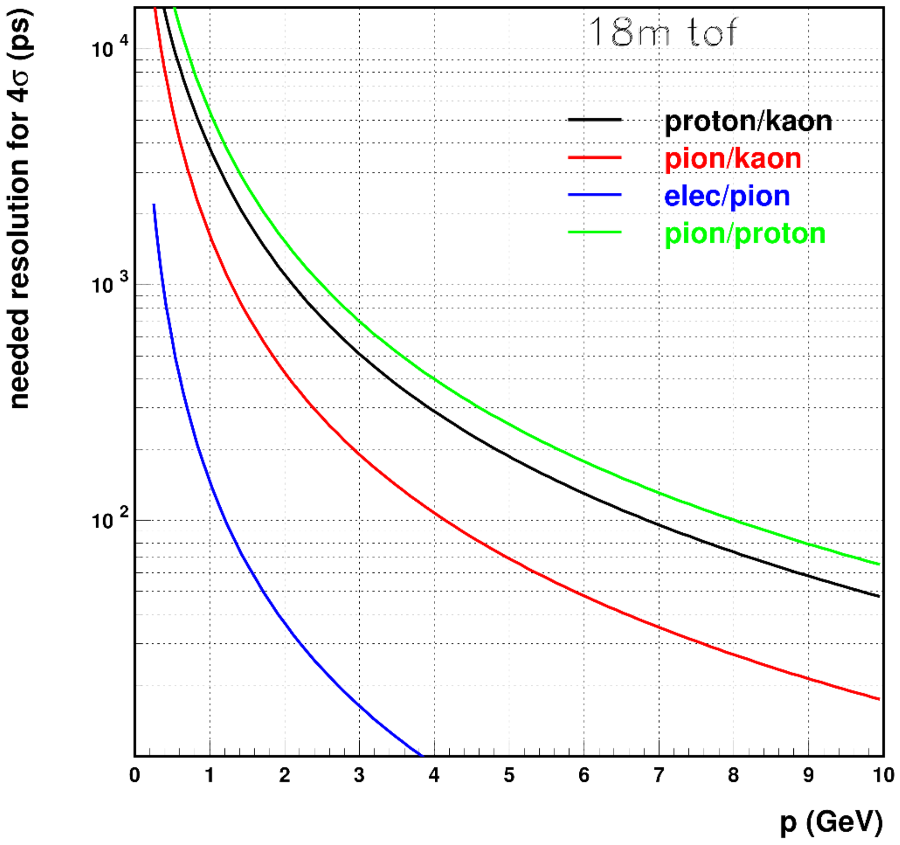
Note the normalization: factor 5 less
Significant distortion of spectrum

To be confirmed introducing magnets
in the simu

However: at low energies, we have no kaons



IF one has just to separate pions from protons below 2 GeV/c, a 1ns timing would be enough
Investigations ongoing



conclusions

- Solution for spectrometer and beam monitor in good shape
- PID will need more work. Surely a plug-and-play beam line, with and without TOF and Cerenkov
- Effects of materials important, simulations ongoing to be confirmed.

No tof, no cv, no spec, electrons. Maybe air?

Air from last bend to secondary membrane (about 9 m, could be elsewhere)