Introduction to H4 for NP04

Beam instrumentation WG

- Joint NP02 and NP04
- Co-conveners: Y. Karyotakis (NP02, CERN), P. Sala (NP04, CERN), J. Paley (NP04, FNAL)
- Choose, develop, install, readout devices for beam monitoring, momentum measurement, particle identification in the H2 and H4 very low energy beamlines
- Development of hardware
- Beam simulations
- Beam halo/ shielding simulation and design
- Detector simulations
- DAQ interface

Web page

- https://twiki.cern.ch/twiki/bin/view/CENF/DUNEProtSPBeamInstr
- Or : from www.cern.ch/cenf --> projects → np04 → subprojects

Welcome to the NP04/ProtoDUNE-SP Beam Instrumentation TWiki Home page

General

BIG is the Joint Beam Instrumentation working group, charged to design and implement the bea instrumentation for the two Protodunes, and to perform beam simulations

Conveners : Yannis Karyotakis , Jon Paley, Paola Sala

Beam Simulations

G4 simulations

G4 simulations for H4, optics 22, zero current in the least bending magnet are available on the Neutrino Cluster, thanks to Nikos and Yannis :

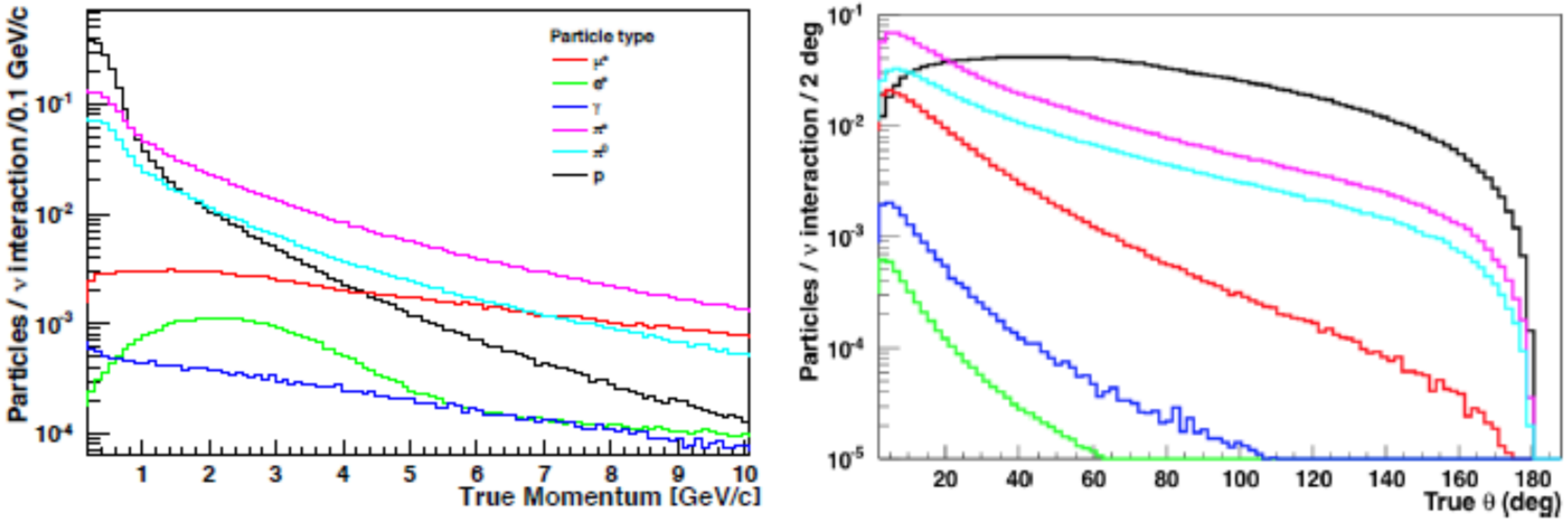
Files available on eos **eos ls /eos/neutplatform/experiments/ProtoDUNEsBeams/SP/TILT22**

- H4_TILT22_APR_FTFP_BERT_1GeV_6M.root

DUNE-PT Charged Particle Requirements

Expected secondary particle spectra in DUNE far detector; uses ν-beam flux as input

(forward horn current)



Also looked at atmospheric neutrino flux based on Bartol 3D flux
GENIE to simulate interactions (Ar 40 cross section) and final states

Relevant charged particles to be studied in CERN beam test

→Energy ranges of : sub-GeV to several GeV

→Angular range: few – 40 deg

Similar for NP02

NP04 : p,π,K,e
0.5- 7 GeV/c

NP02: p,π,K,e
1- 10 GeV/c

Rate: ≈25-50 Hz

Requirements from TDR

Table 6.1: Particle beam requirements. (Kaon rate is low for beam momentum below 2 GeV/c.)

Parameter	Requirements
Particle Types	$e^{\pm}, \mu^{\pm}, \pi^{\pm}, (K), p$
Momentum Range	0.5 - 7 GeV/c
Momentum Resolution	$\Delta p/p \leq 3$ %
Transverse Beam Size	RMS(x,y) $\approx$ 1 cm (At the entrance face of the LAr cryostat)
Beam Entrance Position	Beam # 3 (Figure 6.1) - Saleve side TPC
Rates	$\sim 25 - \sim 100$ Hz

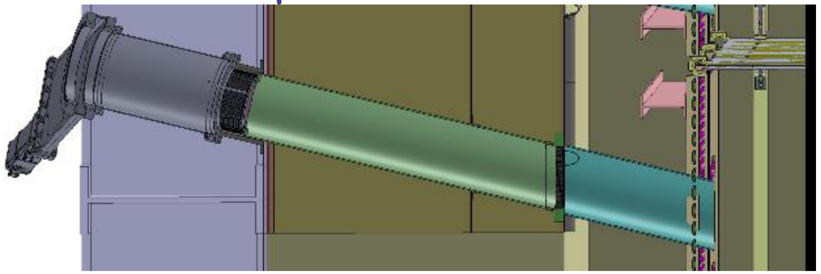
ProtoDUNE Single-Phase Technical Design Report

Phyisics might need better (~1%), measure with spectrometer

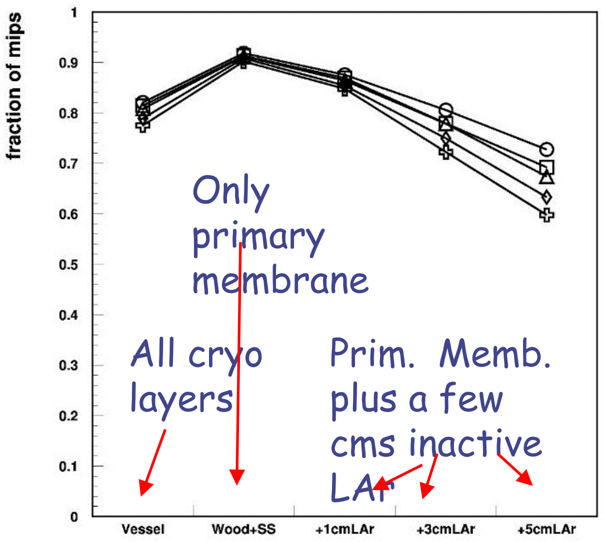
Beam window is much larger (~20 cm diameter). Particle track

In addition, from LAR1AT experience: particle trajectory to match LAr track

Beam penetrations



Penetration in the insulation and Plug in LAr up to active Lar
Necessary for electrons and low mom Hadrons
Only for one of the beam spots



Fraction of non-showering electrons

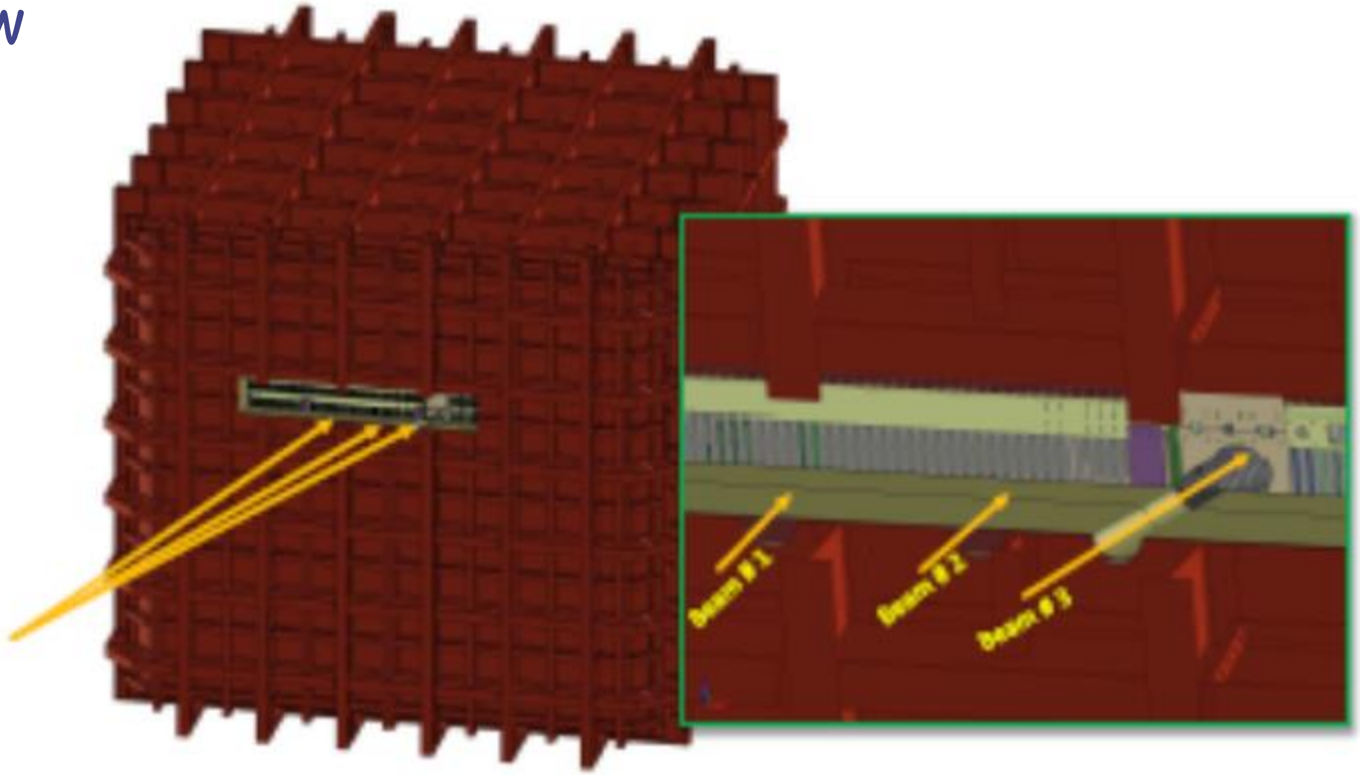
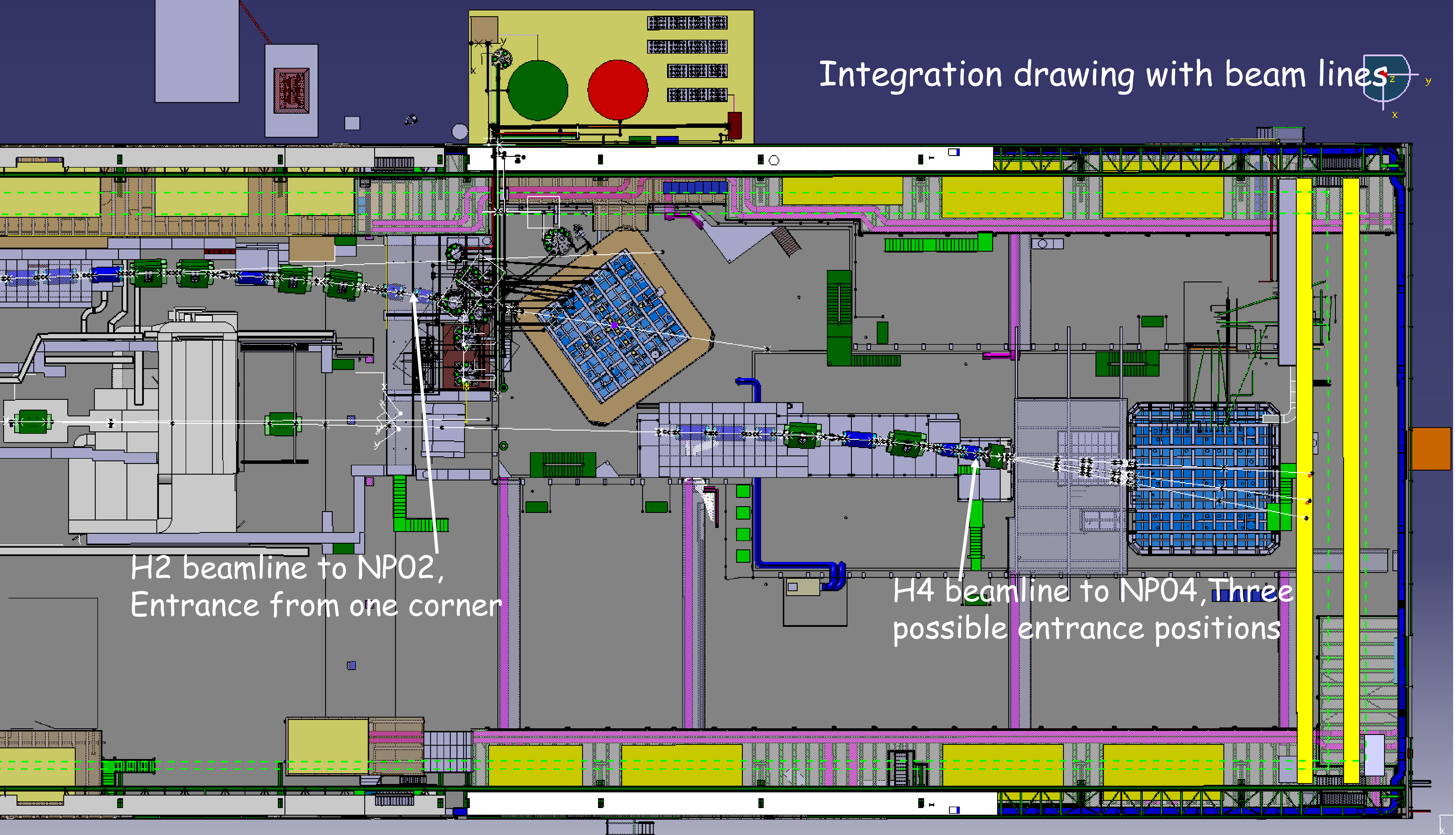


Figure 5.1: Three possible beam injection points. The cryostat support structures near the beam injection points are removed in the Figure to show the interior. Beam window and beam plug are installed only for beam # 3.

Beam holes NP04

- December 2016:Two beam holes drilled and measured by survey group
- New version of the optics (27)

Integration drawing with beam lines



H2 beamline to NP02, Entrance from one corner

H4 beamline to NP04, Three possible entrance positions

Hadron beam

- Full details in Nikos talk

- Hadron rate: few Hz at 0.5 GeV/c , ~150 Hz at 7 GeV
- Mixed composition, however few Kaons at low momenta (decay…)
- Overwhelming electromagnetic contamination at low momenta
- Intrinsic momentum spread ~5%, to be reduced with collimator closing or measured with spectrometer

Electron beam

- Full details in Nikos talk

- Expected 99% purity

Needs/constraints for beam instrumentation

- Beam steering and monitoring
- Trigger of BI itself and ProtoDUNE
- Momentum measurement to reduce the momentum spread
- Particle ID : electron veto, pion/K/p separation
- Particle tracking to match track in ProtoDUNE (only NP04)

- Low material budget
- Large area (beam pipe ~200mm diameter, can be filled by beam envelope)
- Fit in short and crowded beam line (total length approx. 32m)

Monitor/ tracking devices CERN BI group

- layers of scintillating fibres
- Polystyrene, 1mm square fibres, one or two (X and Y) layers
- Can cover whole beamline area
- Inserted in beamline with special flange, do not break vacuum
- 3 devices for spectrometer, single layer, oriented according to deflection
- 2 device beam monitor, two layers
- 1 device tracking, two layers
- Will give sub-millimetre space resolution
- Might do ToF 1ns

- In collaboration with EP-DT

See talk by Inaki

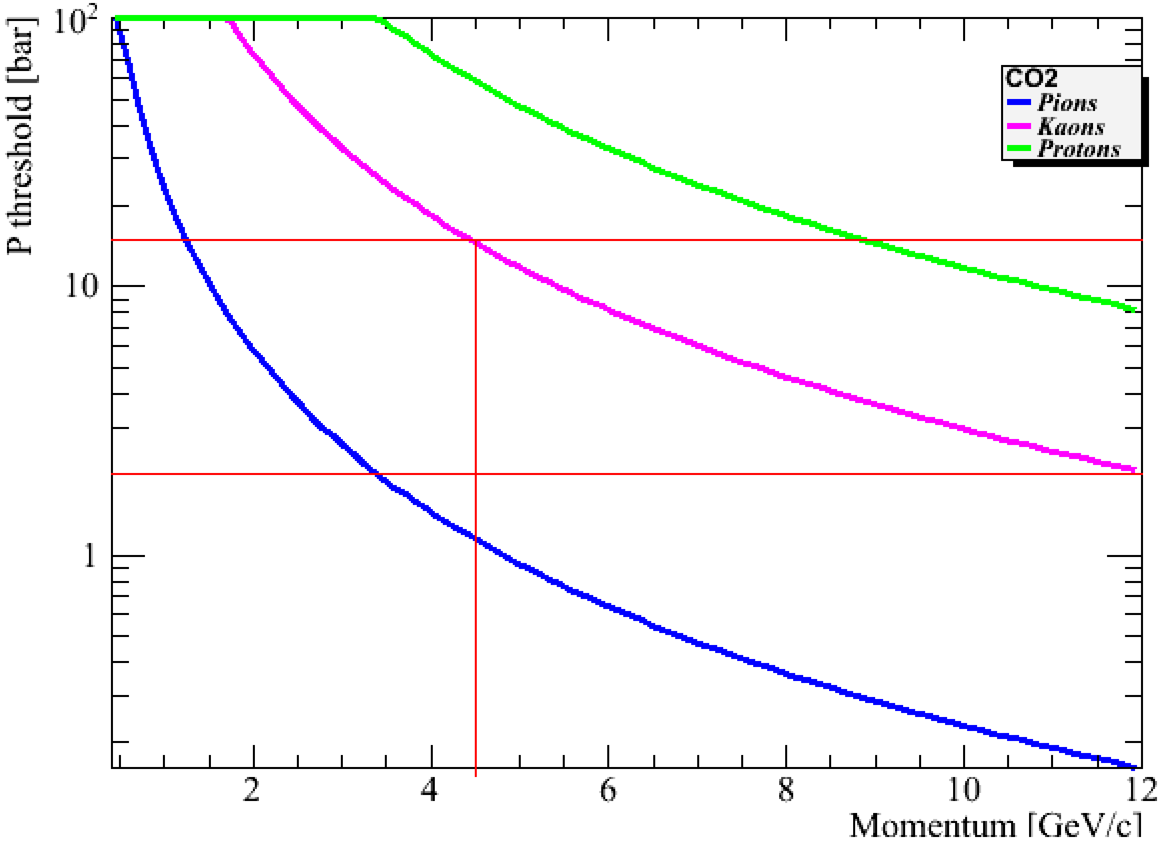
PID

Two possibilities:
Cherenkov and ToF

Cherenkov works for electrons
For Pions only above 2 GeV
For Kaons only above 5 GeV

Here: threshold pressure for Cv emission vs particle momentum, CO_2
Max pressure 15 bar, standard <3.5

Need ToF for low momenta!



Investigations ongoing with different gases (Freon-like)

Note: high-pressure CV will NOT be in the beamline for low momenta runs

Requirements for ToF

Needed resolution for 4 σ discrimination, assuming 23 m ToF (ps)

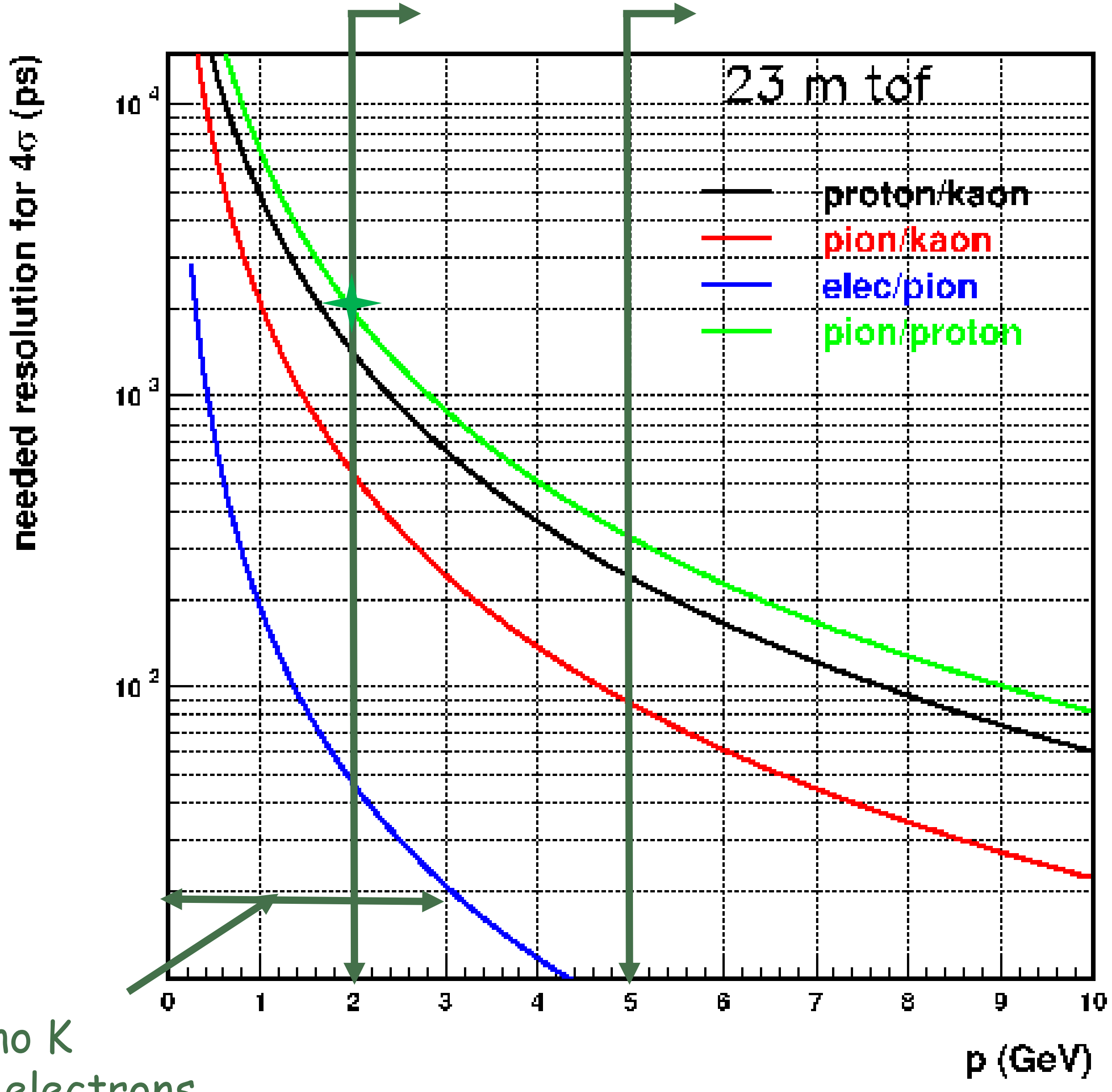
Below 2 GeV : pion/proton need ~ns

2-5 GeV : kaon/proton needs ~100 ps

With a 50ps device pion/kaon up to 6 GeV
proton/k up to 10 GeV

From here π with Cv

From here K with Cv



Here almost no K
1 Cv used for electrons

PID-Tof

- Proposal from FNAL: pLAPPD
- better than 50 ps timing resolution
- ≈ 1mm position resolution
- 6x6cm area
- Hope to integrate in the same box as beam monitors
- Under test see Jon's talk

- Alternative for low p (1ns timing)
- Same devices as for beam monitors
- Different electronics: ASIC for SiPM readout, called STiC, https://www.kip.uni-heidelberg.de/hep-detektoren/readout?lang=en

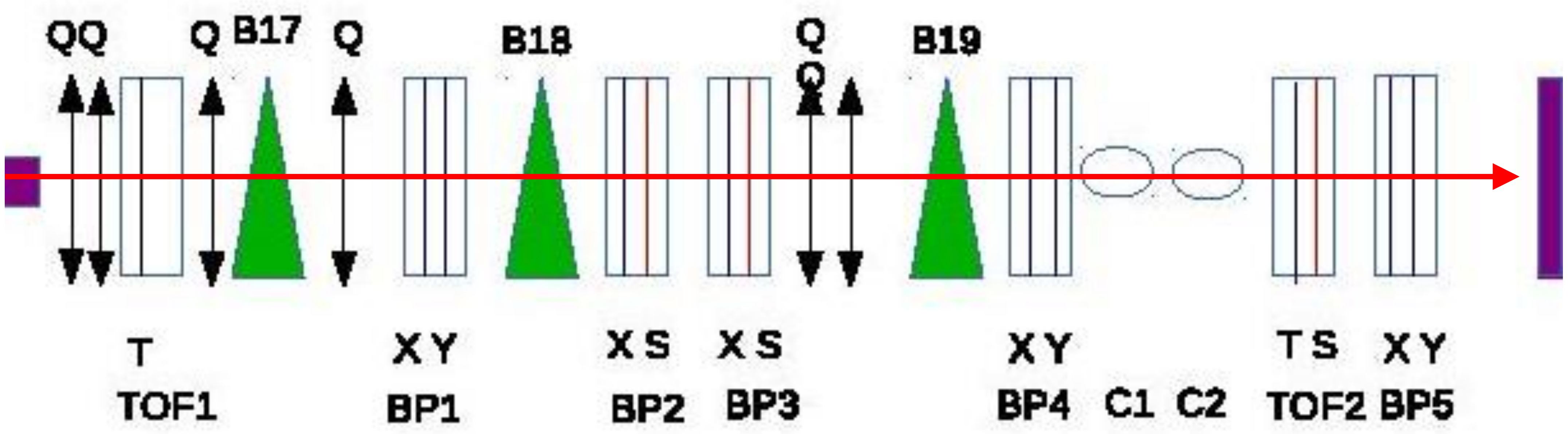
(implementation in Daq to be studied)

- Or simply readout by fast PMT

Why two tof systems?

- Material budget: pLAPPD too thick at low p
- Efficiency: small area, again a problem for low intensity low momentum (see later)

Layout of H4-VLE



XY = layers of scifi monitors
S =scifi for trigger
T = ToF system, either scintillator or pLAPPD
C=Cherenkov, one or two, depending on selected momentum/available ToF

H4 det. layout, option 1 – with pLAPPD

All tracking and trigger monitors will be always present in the beamline, for a total of 8 sci (XBPF) layers and three trigger planes

For PiD:

- $p \leq 2$GeV/c : XBPF ToF + standard CO2 Cherenkov for electron discrimination
- $2 < p \leq 7$GeV/c : pLAPPD ToF + standard CO2 Cherenkov for electron discrimination

Total instrumentation needed: 8 XBPF layers with standard electronics, 2 XBPF layers with ToF electronics, two pLAPPD stations, one standard Cerenkov, and three trigger planes, plus spares.

H4 det. Layout, option 2 – without pLAPPD

For PiD:

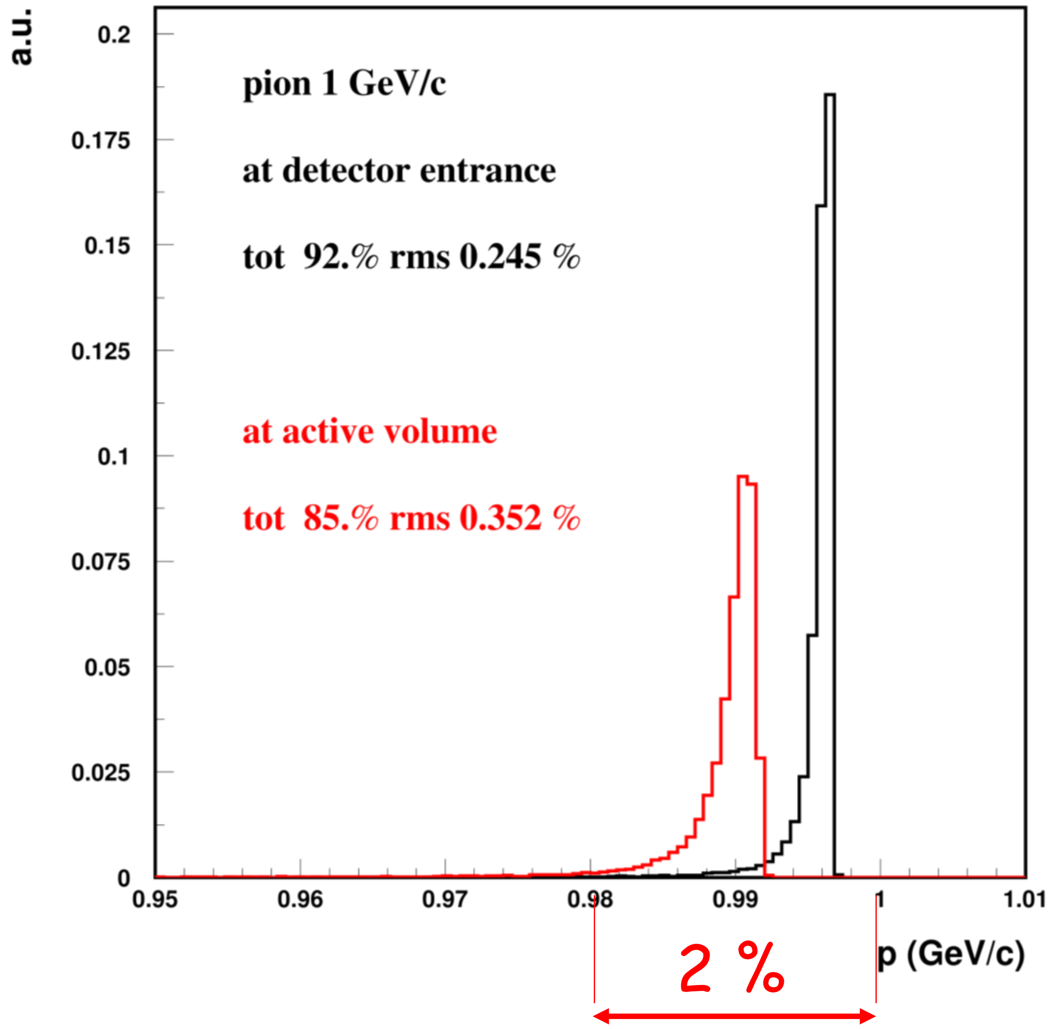
- $p \leq 2GeV/c$: XBPF ToF + standard CO2 Cherenkov for electron discrimination
- $2 < p \leq 3GeV/c$: XBPF ToF + standard CO2 Cherenkov for electron discrimination. Kaons cannot be distinguished from protons
- $3 \leq p \leq 5GeV/c$: standard CO2 Cherenkov for electrons, high pressure Cherenkov for π(< 10 bar) **Kaons cannot be distinguished from protons**
- $p > 5GeV/c$: standard CO2 Cherenkov for pions, high pressure (10-15 bar) CO2 Cherenkov for kaons. Electron content will not be tagged.

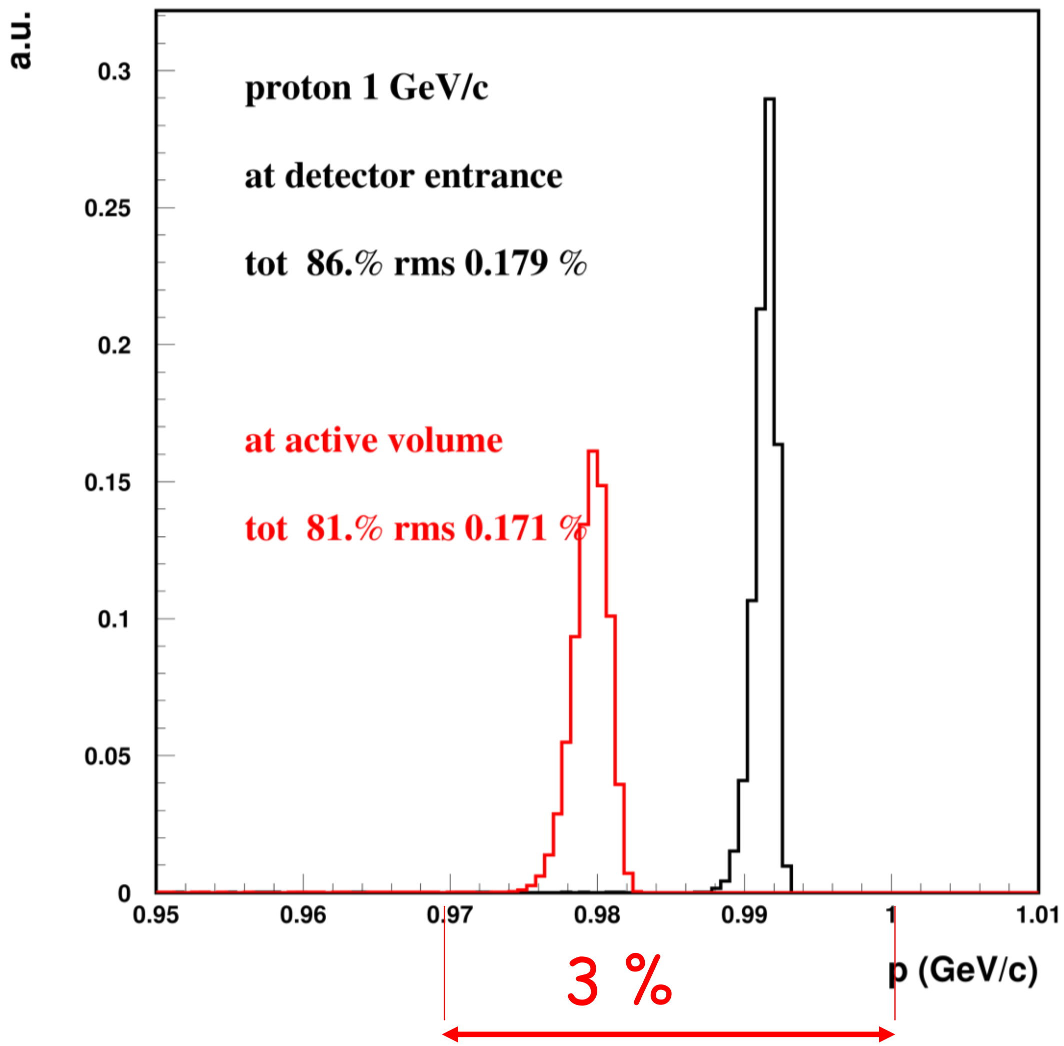
Total instrumentation needed: 8 XBPF layers with standard electronics, 2 XBPF layers with ToF electronics, one standard Cherenkov, one high pressure Cerenkov with non-standard distribution system, and three trigger planes, plus spares.

Effect of materials on beam quality

- Full FLUKA simulation of beam line, beam materials, cryo, beam windows
- To evaluate effect of materials: inject beam just downstream of target
  - Monochromatic
  - Parallel
  - 1cm diameter
- Spectra at cryo face and at LAr active surface (after beam window)
- Attenuation with respect to "no materials" (counting "good" particles)

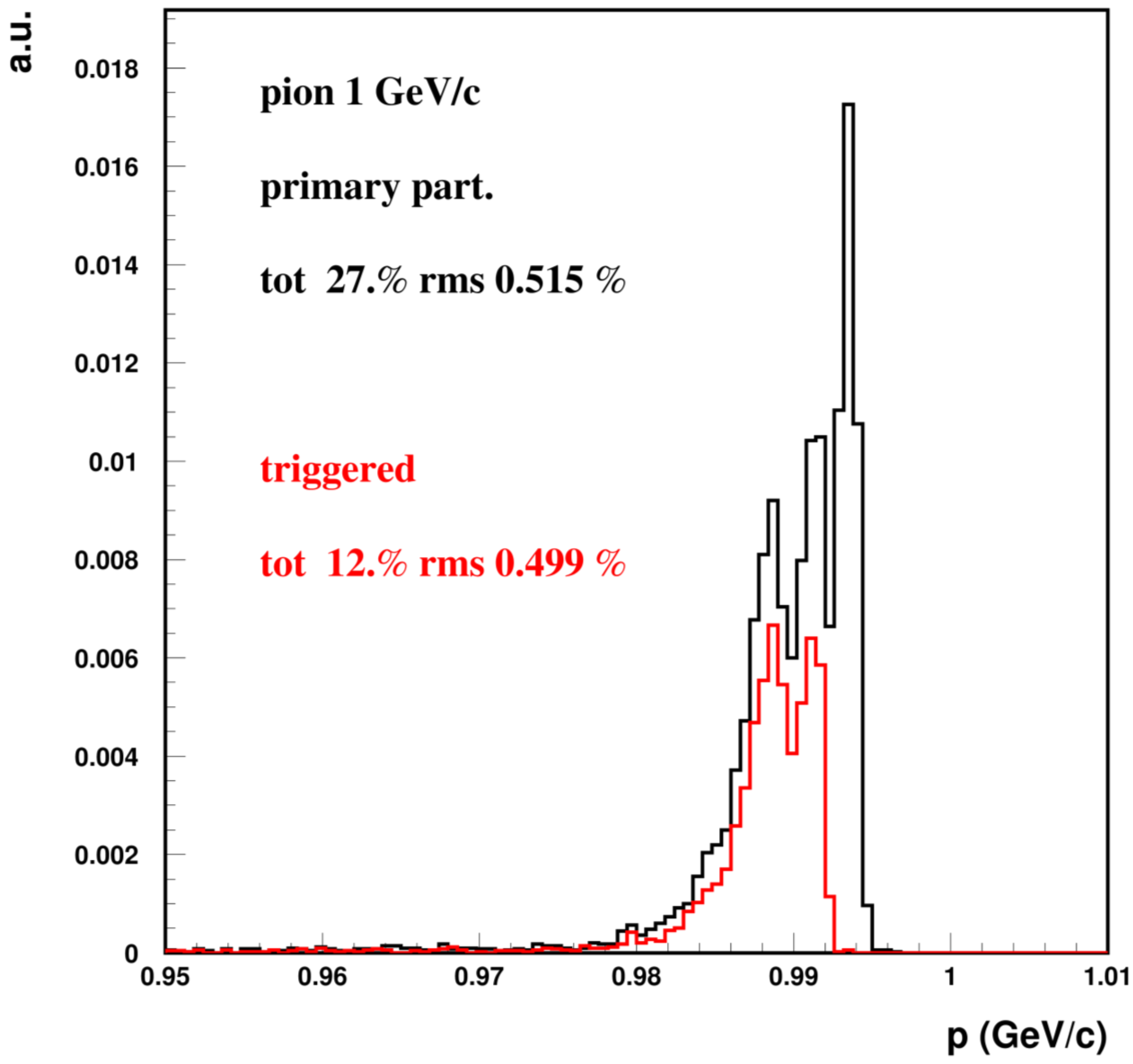
Low momenta: scintillators + low pressure CV





Small energy degradation – can be corrected by MC with small uncertainty
Momentum spread < 1% - small (15-20 %) intensity reduction

What if pLAPPD?

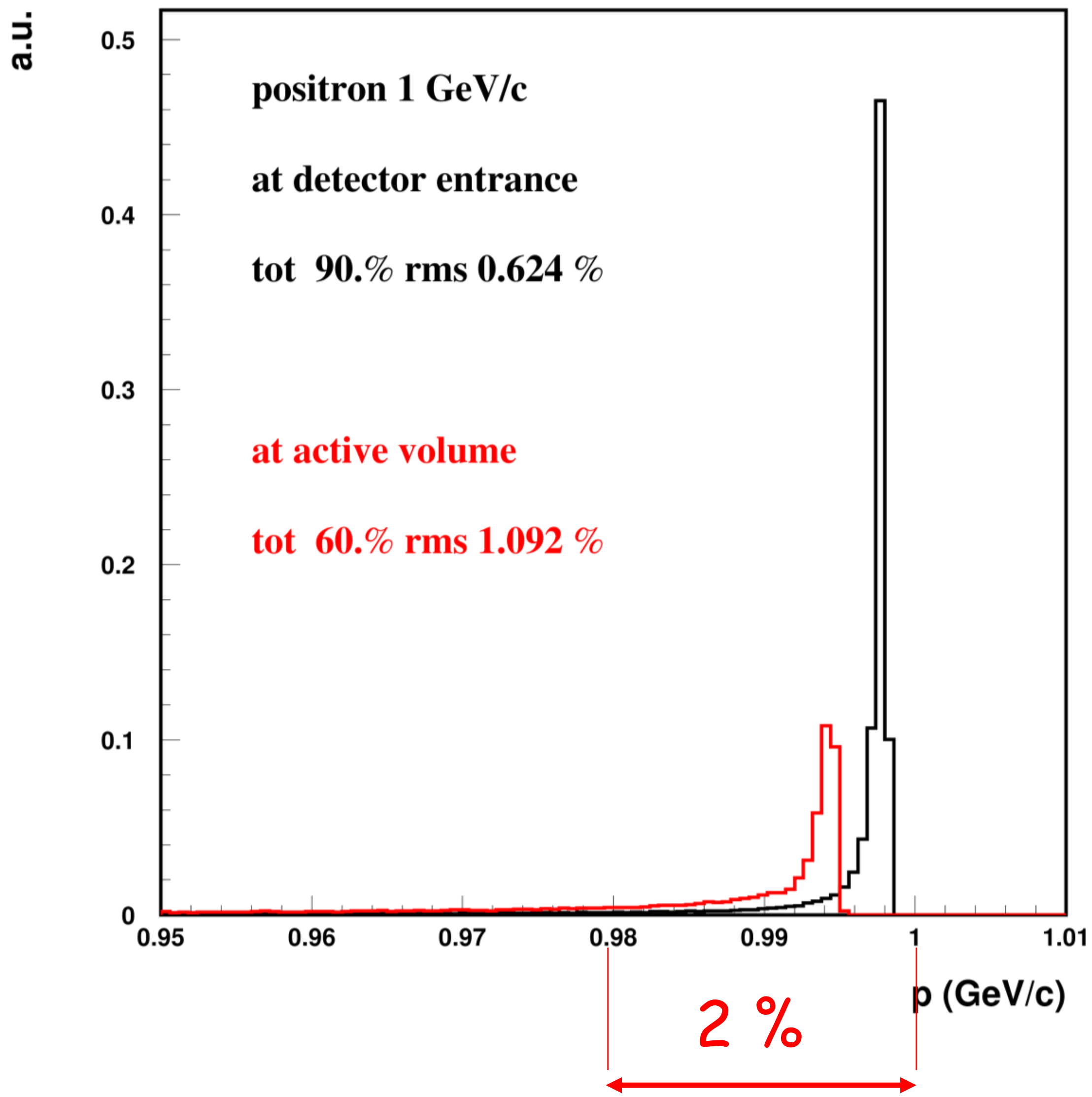


Black: all "good" (uncollided) at cryo
Red: only good that passed through pLAPPD active areas (note: here small parallel beam from target)

➔ Scattering in pLAPPD layers throws pions out of beamline acceptance ➔ only 27% left

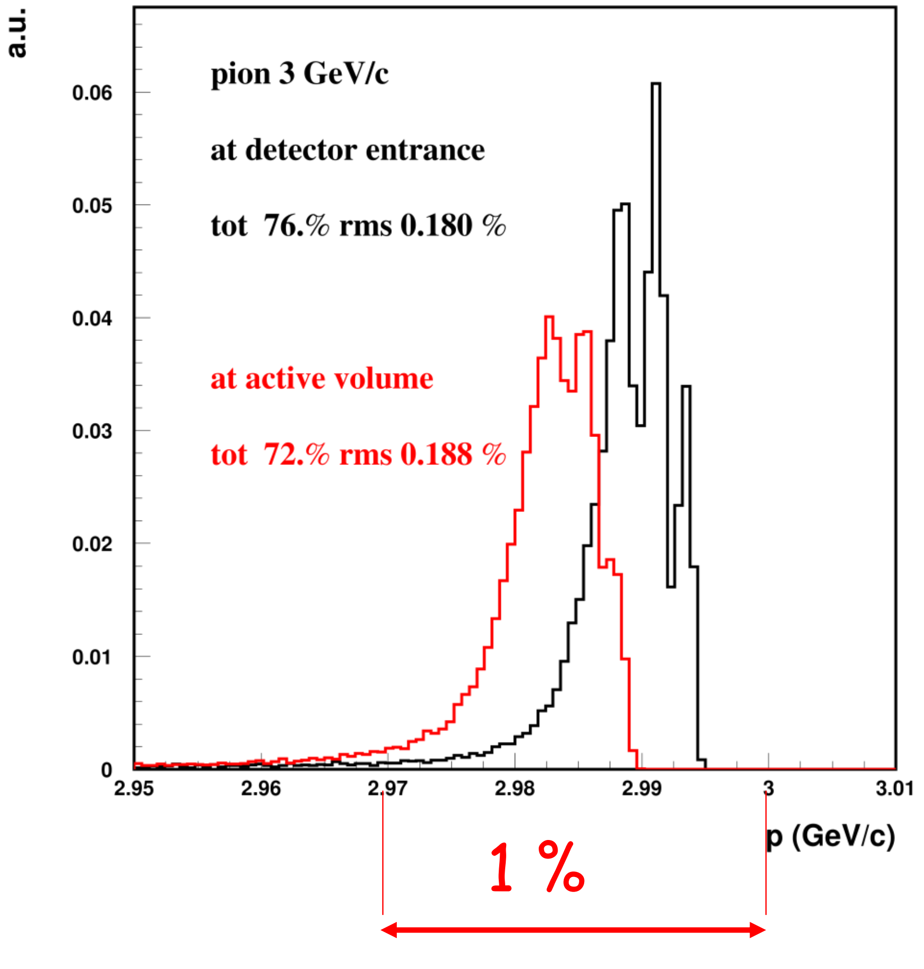
➔ If pads geometrical acceptance included➔ only 12% left (could be improved by doubling the devices)

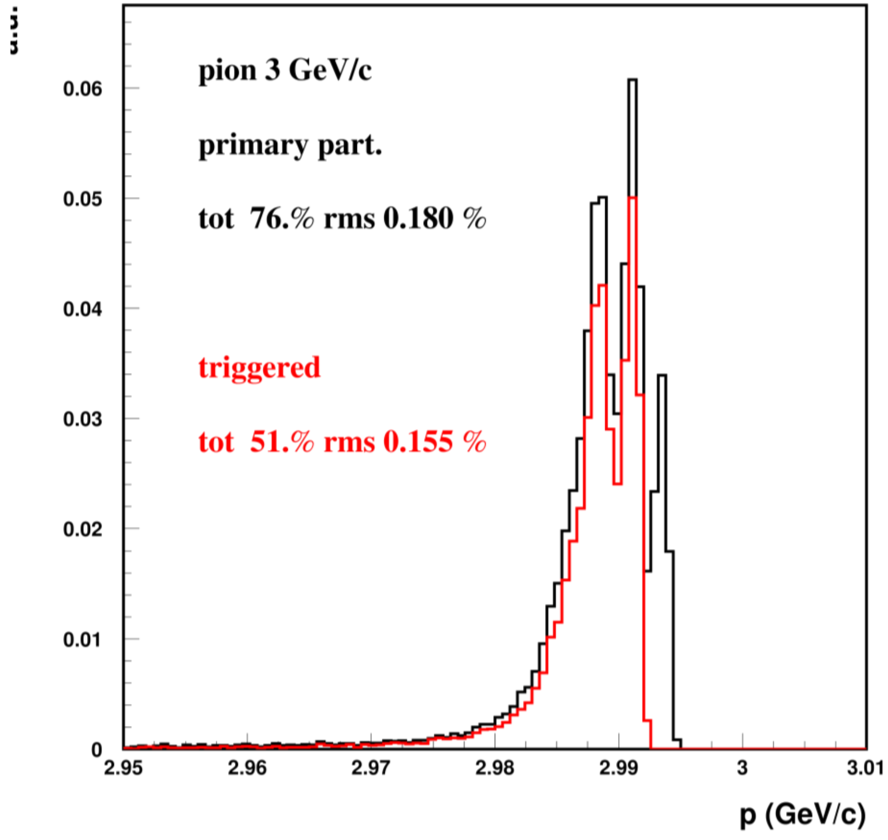
Low momenta: scintillators, electron beam



Combined effect of Beam Instr + baem window still allows for good statistics of unperturbed electrons

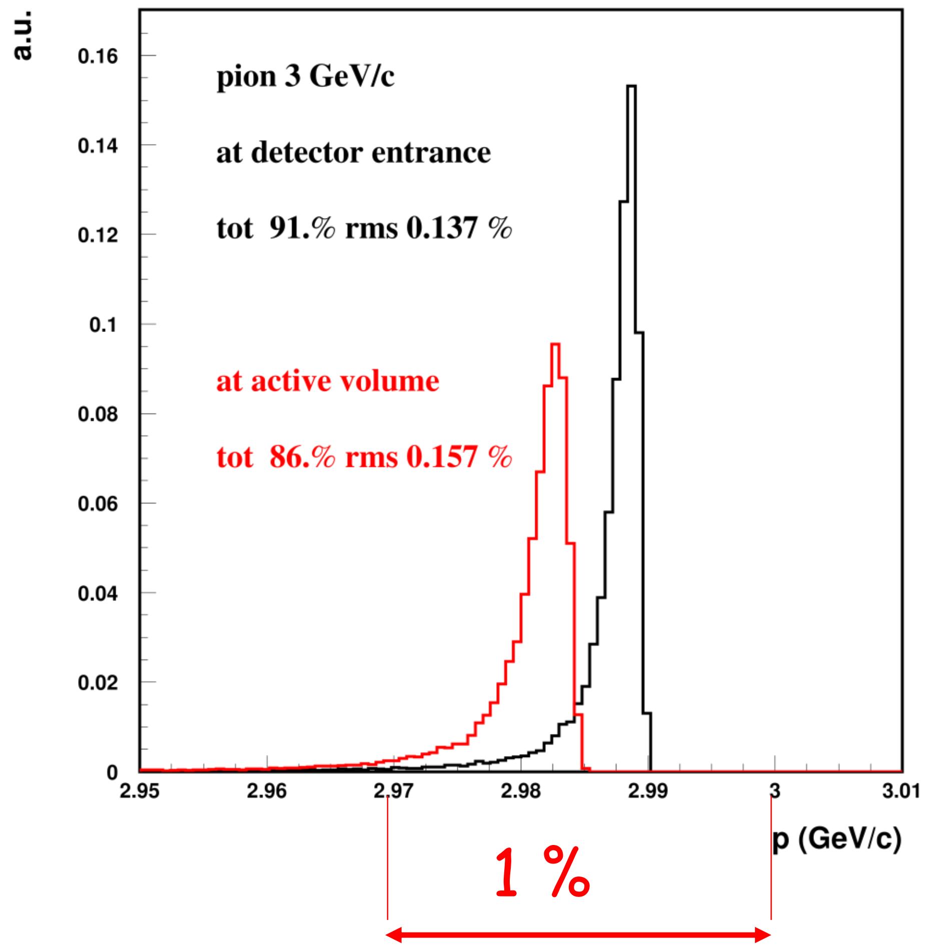
Intermediate: use pLAPPD





Pion scattering acceptable,
Energy loss fine,
efficiency to be checked (double device?)

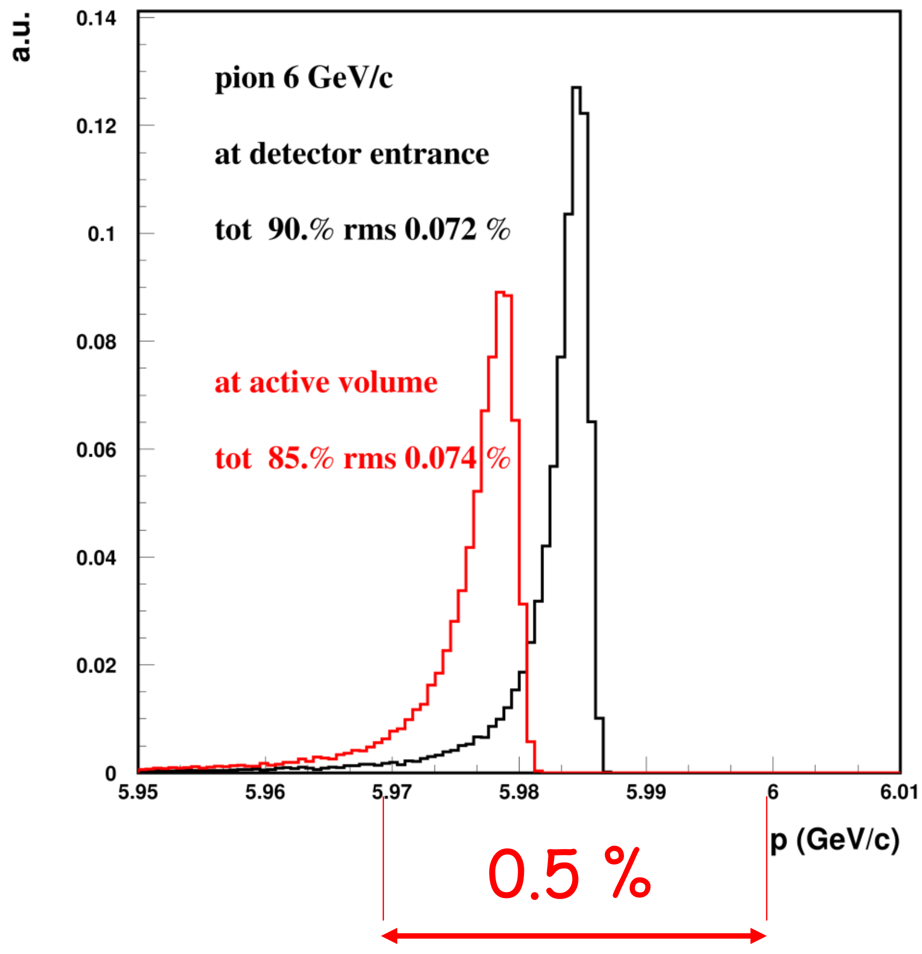
Intermediate: if no pLAPPD : 2 CV



Here:
1 low pressure CV for e^+ discrimination
1 10bar CO_2 CV for pions

Small energy and efficiency degradations

If High pressure CV is needed



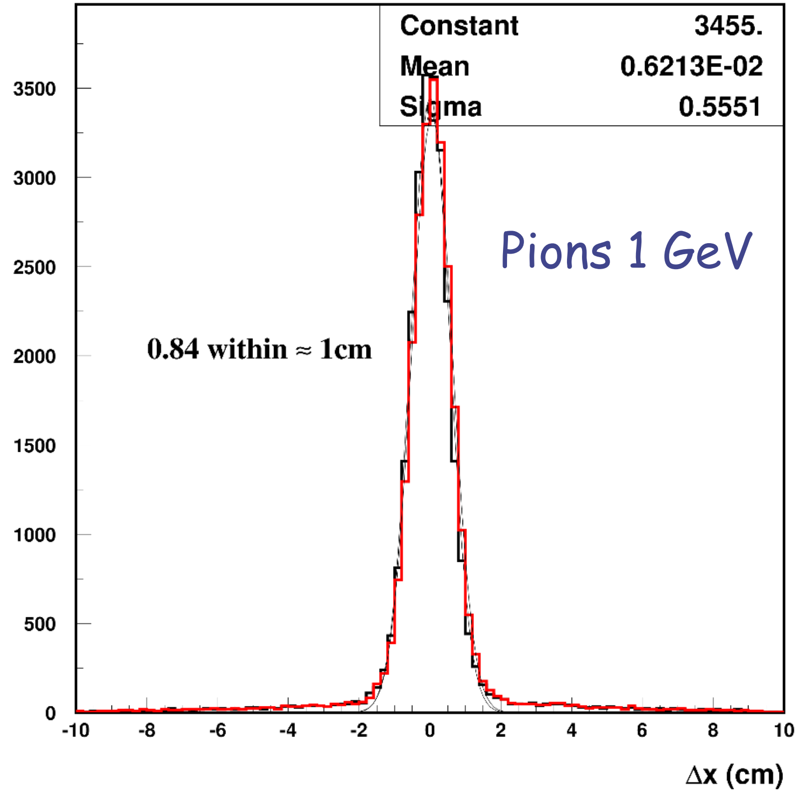
Hig momenta: K id by 15 bar CV if pLAPPD not available: fine

Conclusion on material budget

- Beam instrumentation and beam window allows to keep the beam quality within requirements

Tracking

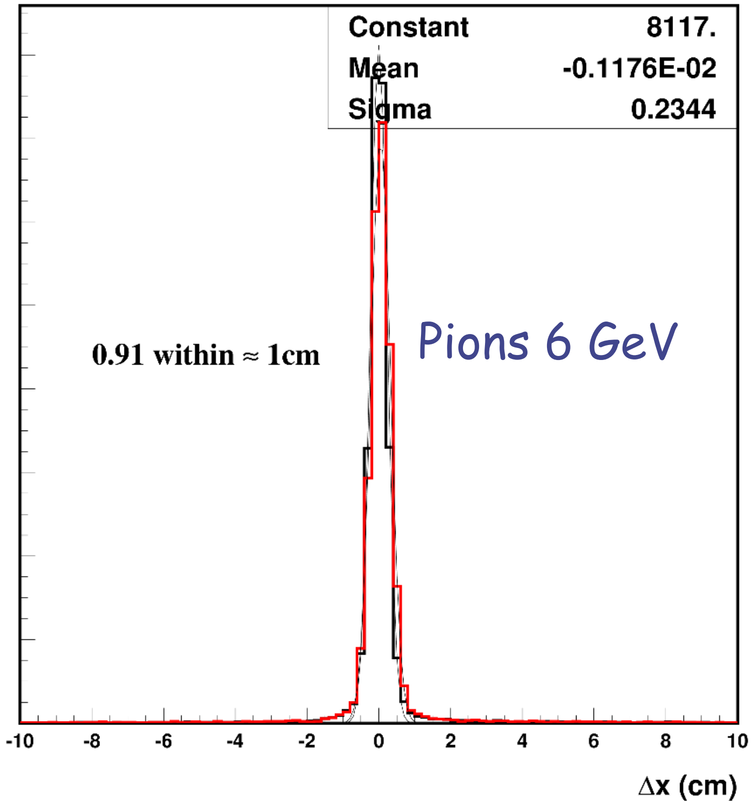
- The two last beam monitors should allow track matching with LAr data
- Possible disruptions: space resolution and scattering in materials



Simulated Difference between x-coordinate at LAr entrance And x extrapolated from last two monitors

For two different energies (and beam line materials)
Red histo: add 1mm rms (huge) smear on monitors

80% to 90 % of events reconstructed within +-1cm



According to simulation, particle track matching is feasible in the current configuration

Momentum selection/measurement

- Details of the methods and preliminary results in Nikos talk
  - Reduction of the momentum spread by closing the collimator: can achieve ~2.5% dp/p with ~factor 3 reduction in particle rate → can be used at high momenta
  - Momentum measurement particle-by-particle with trackers+bending magnet : better than 2% for p>2 GeV/c. Deteriorates at lower momenta due to multiple scattering.
  - In both cases, "downstream" effect of materials to be corrected for

- **→ Momentum determination within 2.5% achievable for p>2GeV/c, will deteriorate up to the intrinsic 5% at lower momenta**

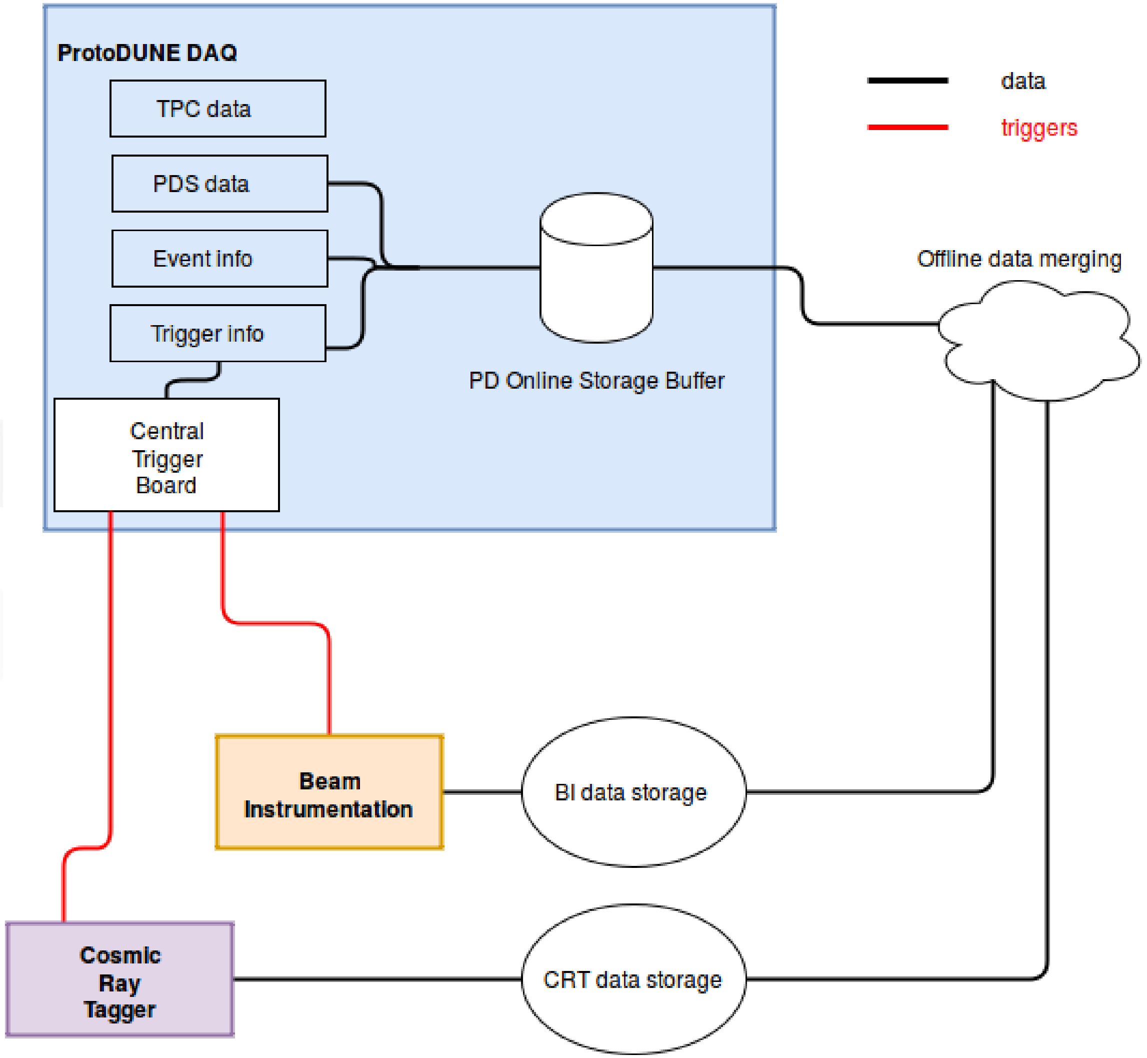
Schedule

- Details in Nikos, Quentin and Inaki's talks
- Beam line + Cerenkovs: spring2018
- Sci-fi : Full prototype by September, test in beam lines Oct-Nov, full production April 2018
- Warning on scint ToF: if custom electronics cannot be integrated, use trigger layers with pLAPPD logic. Decision in next month

Backgrounds

- See dedicated talk.
- Shielding design ongoing, to be validated by integration and RP teams.
- Present guess: about 1kHz charged particles at LAr active face for high p beam, same order of magnitude for fast neutrons,
- High energy muon halo is being evaluated. Will need interaction with the Cosmic Ray Tagger group.

DAQ Architecture



P. Sala Beam Instrumentation trigger and data

Synchronization will be ensured by time stamping of data with the White Rabbit (WR) system

WR timestamps have a precision of +/-700 ps

A common GPS signal will come from a WR master switch in the CCR (Cern Control Room), same GPS as for LHC

Offline interface: see Jon's talk

Trigger signals and Cherenkov logic signals to NP04 trigger board (cables-NIM)

Grounding Isolation