Beyond the LHCb Phase-1 Upgrade
Elba, 30/5/2017

Magnet Stations Overview and Tracking Studies

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Outline

Physics Motivation

Reminder

- Low-momentum tracks reconstruction
- Proposed Implementation

New Ideas

- A slightly different implementation

Performance

- Momentum resolution
- Pattern Recognition

Physics Motivation

Potential

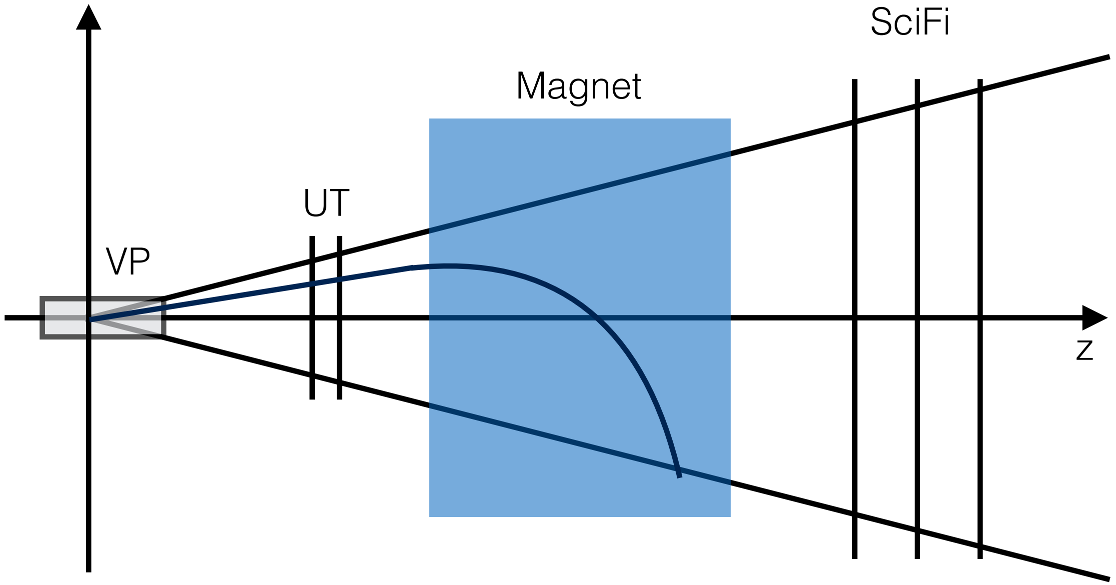
- **There are many physics channels that could benefit of an improved resolution on the momentum of soft tracks**
  Multi-Body decays: $B_s^0 \to D_s^+ D_s^-$, $D \to hhhh$
  Charm Physics: $D^{*+} \to D^0 \pi^+$
  b-baryons: $\Sigma_b^+ \to \Lambda_b^0 \pi^+$
  Spectroscopy: $B \to D\bar{D}K$, $B_c^* \to B_c \pi\pi$
- **Such tracks could also pave avenue to completely new topics for LHCb**
  Search for gluon saturation transition (needs soft particles from small Q^2)

Follow next talk from Marcin for further details

The Problem

Low-Momentum Tracks

- **A lot of low-momentum tracks get lost in the internal sides of the magnet**
- **The current (Upgrade) tracking uses residual magnetic field in UT to guess momentum with ~20% uncertainty for VeloUT tracks**
  Not enough for most physics analyses
- **Tracks are substantially lost**

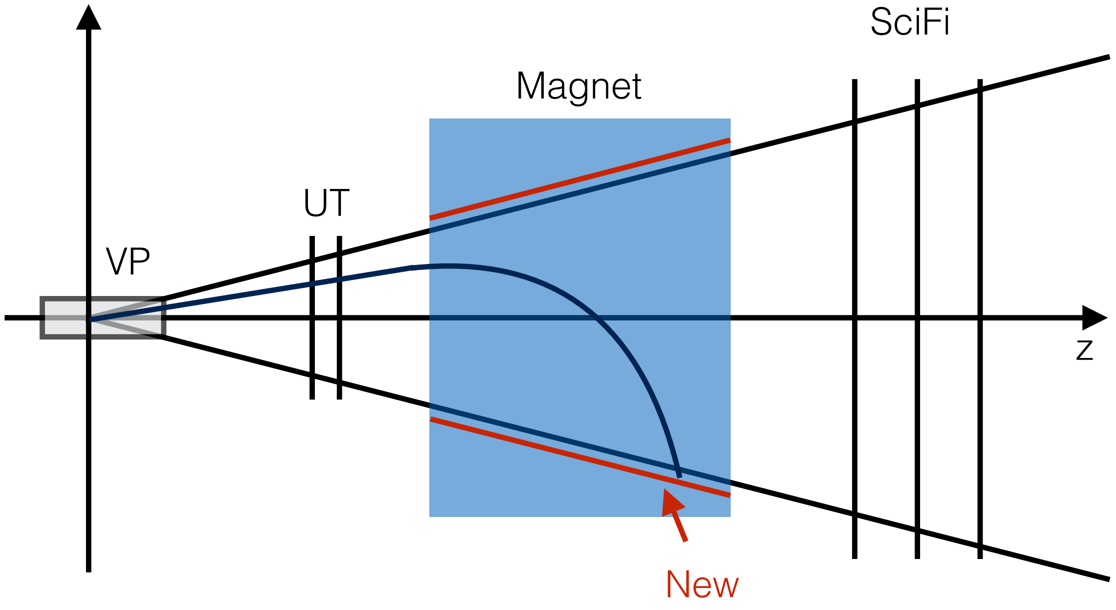


LHCb Upgrade

The Solution

Instrument the Internal Sides of the Magnet

- Adding a measurement after the magnet bending will improve momentum resolution
- A large fraction of the otherwise lost tracks will be recovered
- Possibly further widening LHCb physics program (see next talk)

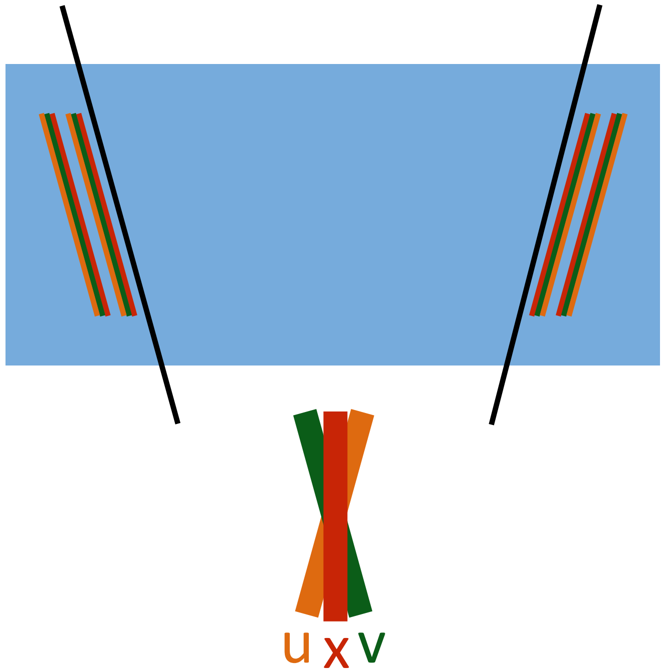


LHCb Upgrade

Implementation - Technology

Requirements

- **Preliminary tracking studies demonstrated that σ_z~1mm $\Longrightarrow$ σ_p/p<1%**
- **Also σ_y~10mm is needed to reduce candidates in pattern recognition**
- **Furthermore, a second station separated by few mm would greatly benefit ghost rejection**
- **Operate in large magnetic field**



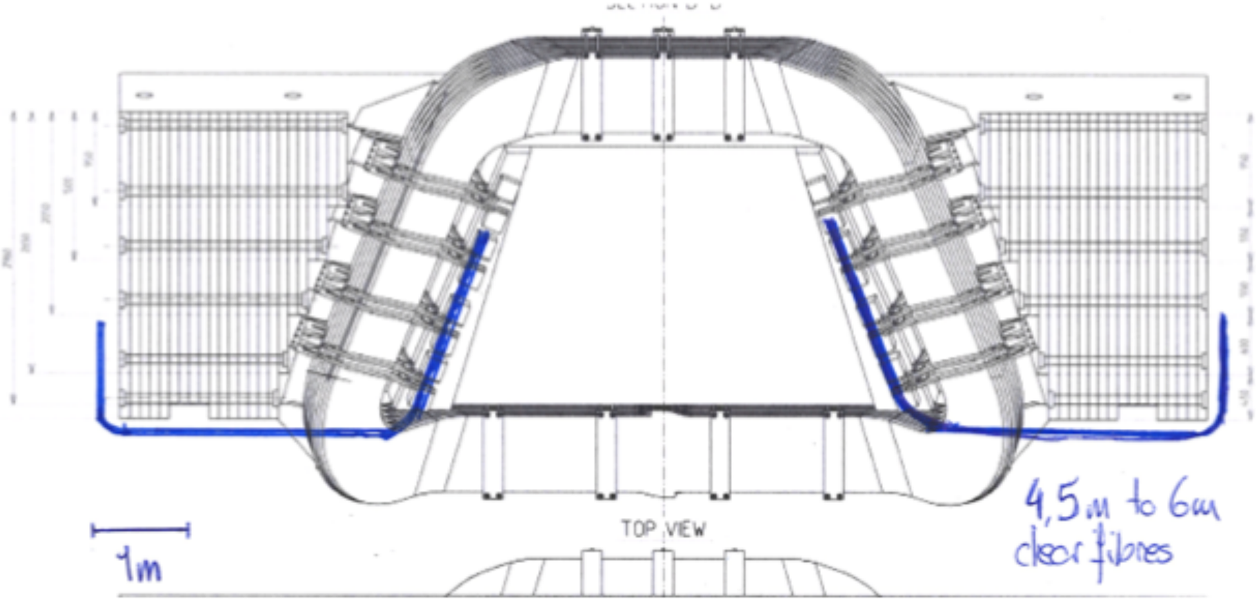
Detector options

- **Considered different options**
  Strawfibres, GEM, MWPC, Silicon, Fibres
- **Fibres**
  Extensive R&D in LHCb for FT
  Resolution requirements (~1mm) achievable
  Y segmentation with stereo arrangements
  SiPM insensitive to magnetic field

Implementation - Readout

SiPM

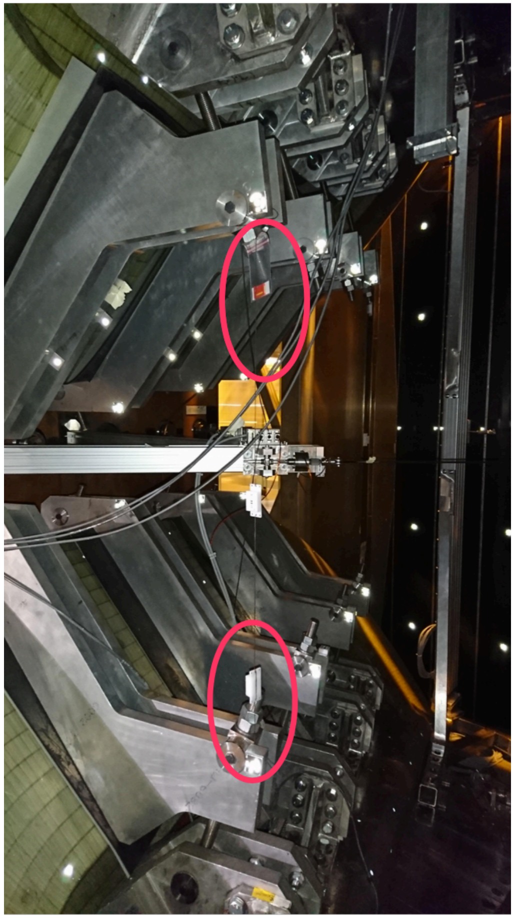
- **Benefit from FT R&D**
- **Insensitive to magnetic field**
- **… but sensitive to radiation damage**
  Estimated $5x10^{12}$ neq/cm^2 inside magnet → would require shielding and cooling
- **Need to be placed outside the magnet behind iron yoke**
  ~$2x10^{10}$ neq/cm^2 → need to route photons with clean fibres

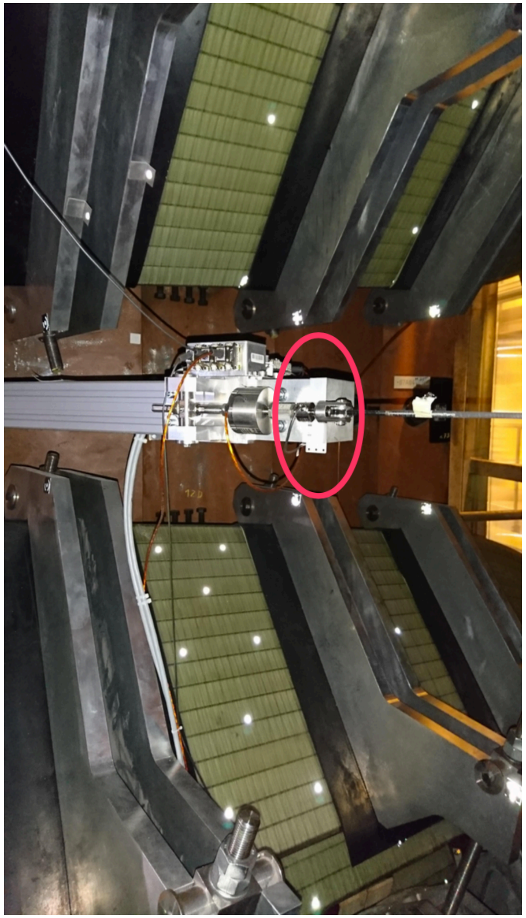


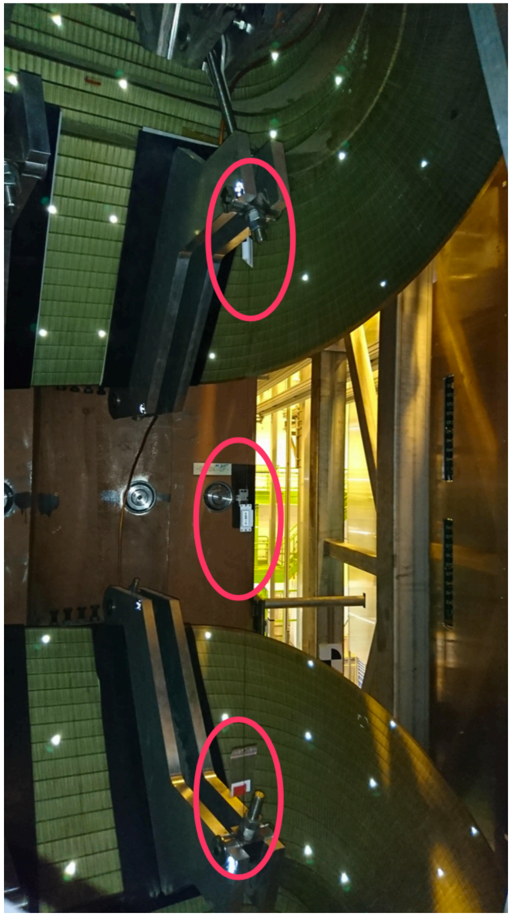
Dosimetry

Installed Dosimeters Inside Magnet

- The numbers we used to estimate the dose have large uncertainty
- Installed dosimeters in the magnet during winter shutdown to obtain precise measurements







Costs

	1mm fibres (2)	1mm fibres (3)	2mm fibres (2)
# channels	[48, 64] k	[72, 96] k	[24, 32] k
Scintillating fibres	[104, 138] kCHF	[156, 208] kCHF	[262, 348] kCHF
Clear fibres	[446, 595] kCHF	[670, 892] kCHF	[1400, 1500] kCHF
SiPM (assuming same price for 2mm)	[396, 492] kCHF	[554, 739] kCHF	~[184, 246] kCHF
Electronics PACIFIC, Tell40, others (10CHF/channel from SciFi TDR)	[480, 640] kCHF	[720, 960] kCHF	[240, 320] kCHF
infrastructure, cooling	200kCHF	200kCHF	200kCHF
total total (no clear fibres)	1.6 - 2.1 MCHF 1.2 - 1.4 MCHF	2.3 - 3 MCHF 1.6 – 2.1 MCHF	2.8 -3.2 MCHF 1 – 1.1 MCHF

Costs

1/3 cost from clear fibres

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Costs

1/3 cost from clear fibres

-25% with less chambers

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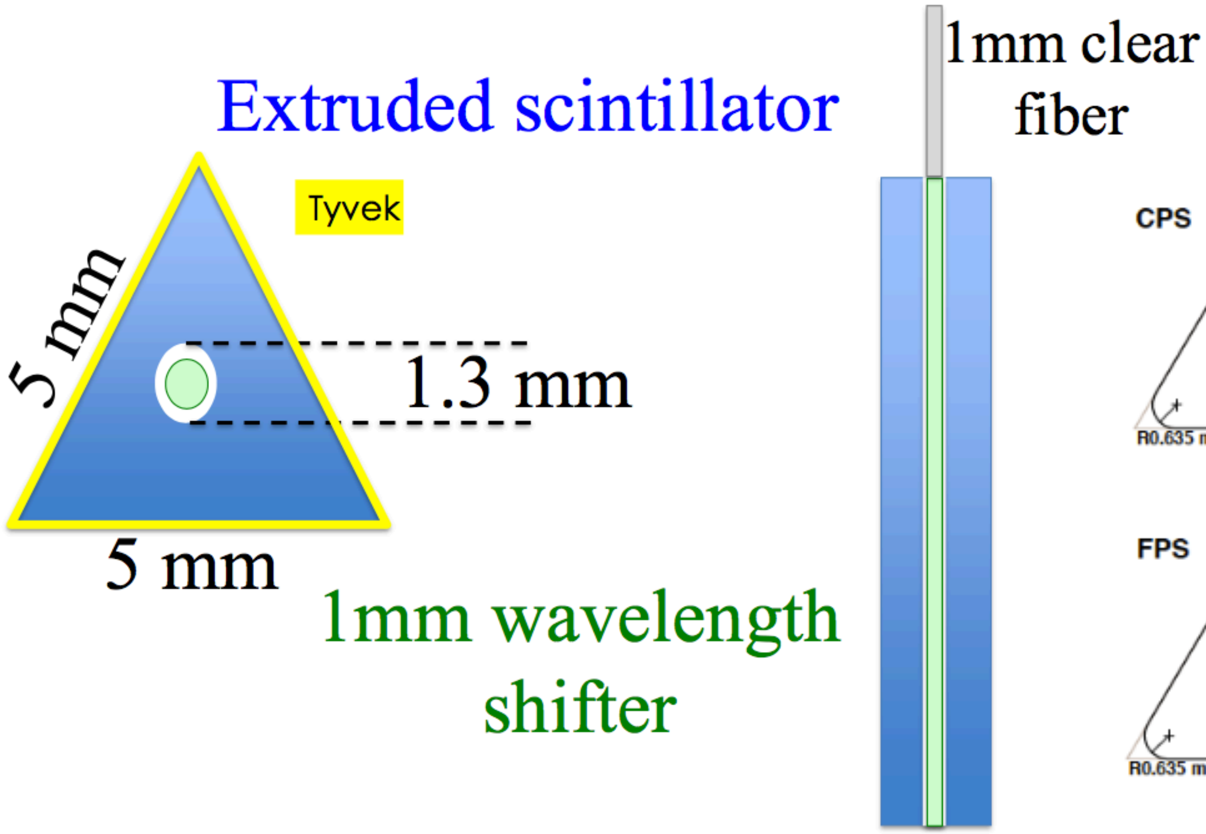
A Slightly Different Implementation

Cesar Da Silva (Los Alamos) recently joined the collaboration to study QGP notably using the Magnet Station

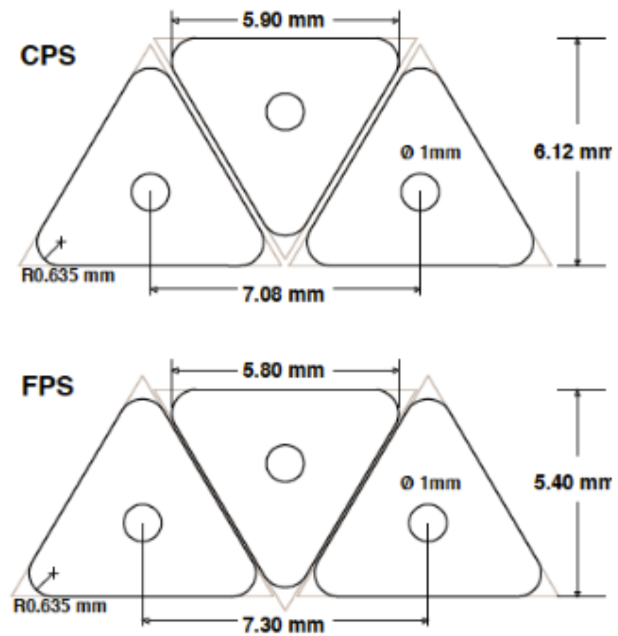
Too Many Channels?

- **Previously shown costs could be greatly reduced with fewer channels (=less fibres and SiPMs)**



R&D for DØ preshower

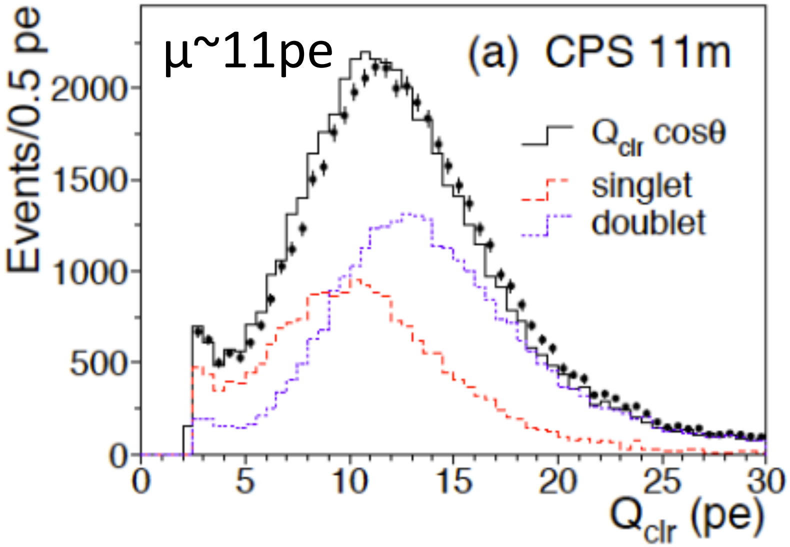
NIM A 469 (2001) 295–310



D0 R&D - Comparison and Light Yield

Comparison with Magnet Stations Option

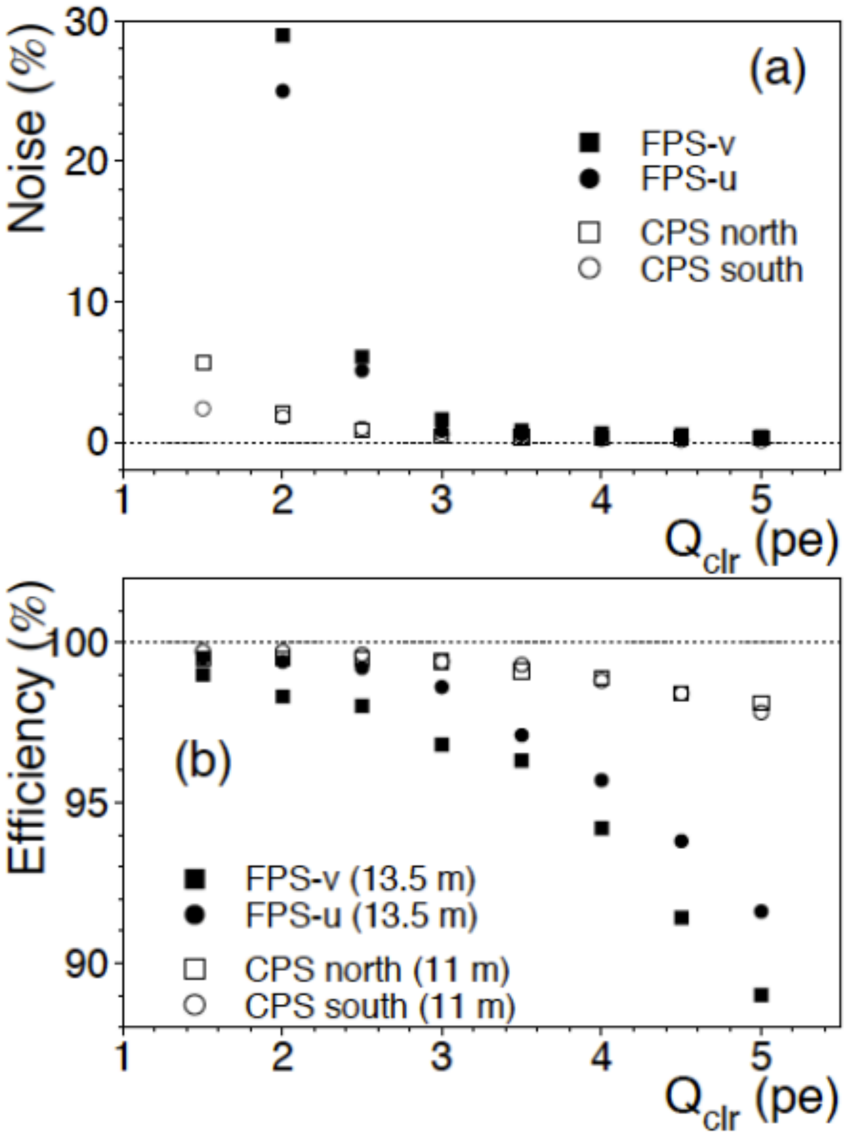
	D0	Magnet Station
Triangular bar side	5.8mm - 5.9mm	5mm
Bar length	CPS:2.4/2 m, FPS:10-30cm	30cm-70cm
N planes	CPS: 1, FPS: 2(uv stereo)	3 xuv
Light guide	11m - 13m	<6m
photodetection	VLPC (at 9K 80% QE)	SiPM (room T 40% QE)



$$\mathrm{LY(MS/D0)} = \frac{0.4QE}{0.8QE}\frac{e^{-6m/10m}}{e^{-11m/10m}} = 82\%$$

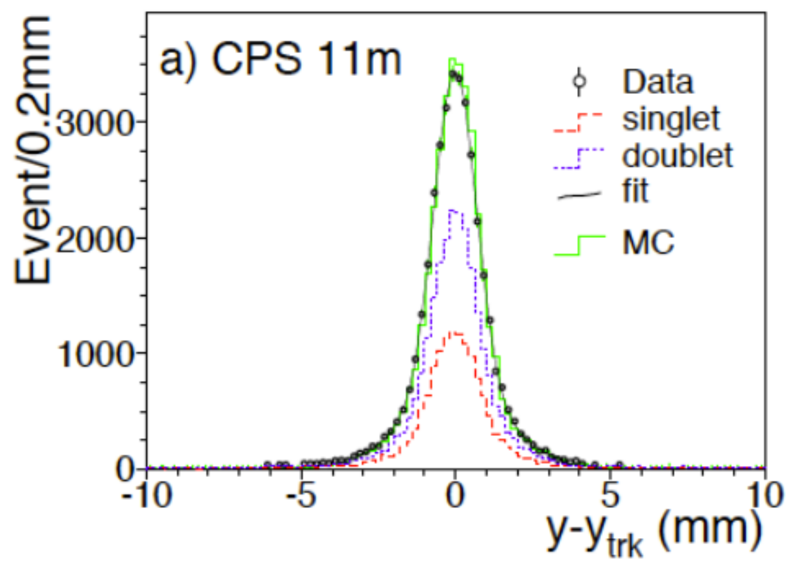
~9-11 p.e.

D0 R&D - Efficiency, Noise and Resolution



- Depend on cluster amplitude cut
- Expect larger noise in MS due to SiPM at room temperature
- But efficiency can be > 95%

- Resolution:
  σ_z~0.6mm → σ_y~3mm (θ=12˚)



Extruded Scintillators Costs

Quantities for ΔZ=2m MS

Los Alamos NATIONAL LABORATORY EST. 1943

- 200 cm * 4 bars/cm * 4 y segments * 6 planes * 2 magnet sides = 38.4K channels

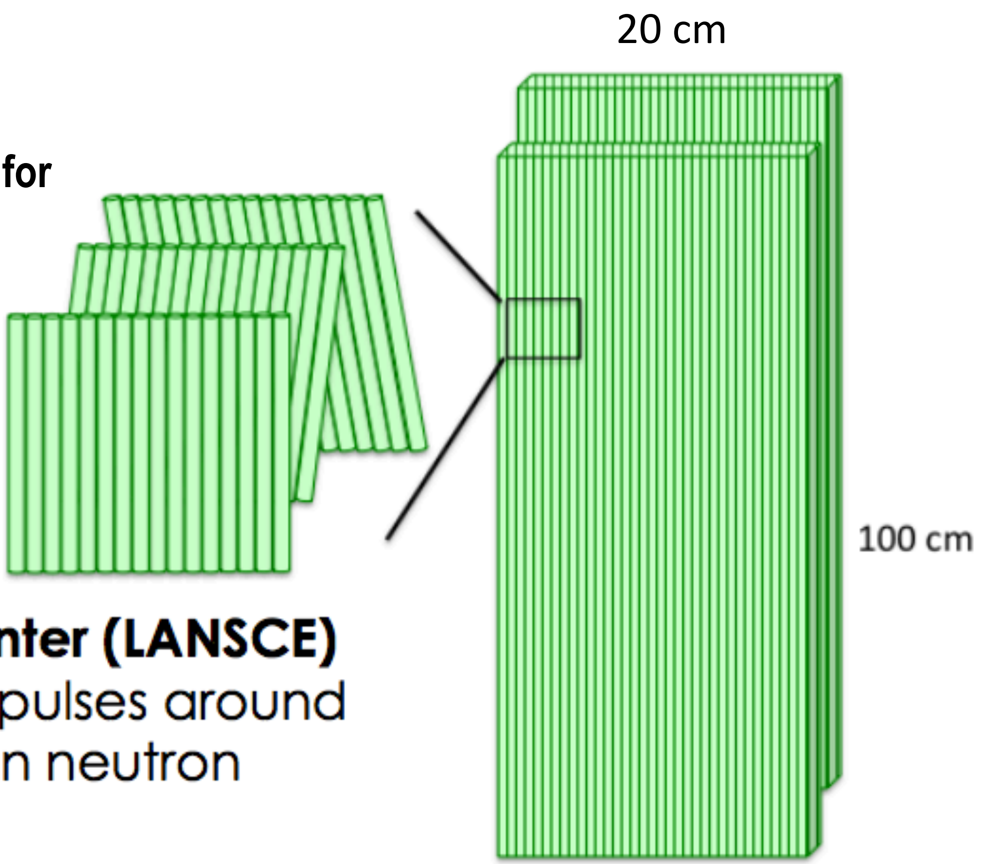
  Main proposal: 2

- Expected 64K channels if using 1mm fiber
- Uses 1mm clear fiber and 1.3*1.3 cm^2 SiPM
- Will contact Fermilab fabric for cost and feasibility of 5mm triangular bars
- Each 1m bar was ~US$3 for a recent project our team just finished
- Total material cost could be ~ US$1.2M

Prototyping Plans (@LANL)

Cosmic Tests

- 20cm wide, 1m long station with 6 planes
- Purchased 600 2mm*2mm SiPMs
- Obtaining bars from Fermilab factory
- May need 1/4 of a readout board developed for FT or ~3-10 PACIFIC4 chips
- GEANT detector simulation ongoing gives resolution consistent with DØ R&D



Beam Tests / Irradiation

- Likely one day of beam time at LANSCE
- UC Davis another option

Los Alamos Neutron Science Center (LANSCE)
800 MeV proton beam, variable pulses around 10^11p/cm2/s, and spallation neutron beamlines

University of California at Davis
76 inch cyclotron, 67 MeV protons up to ~10^13

Tracking Studies

A: Access (x>0)

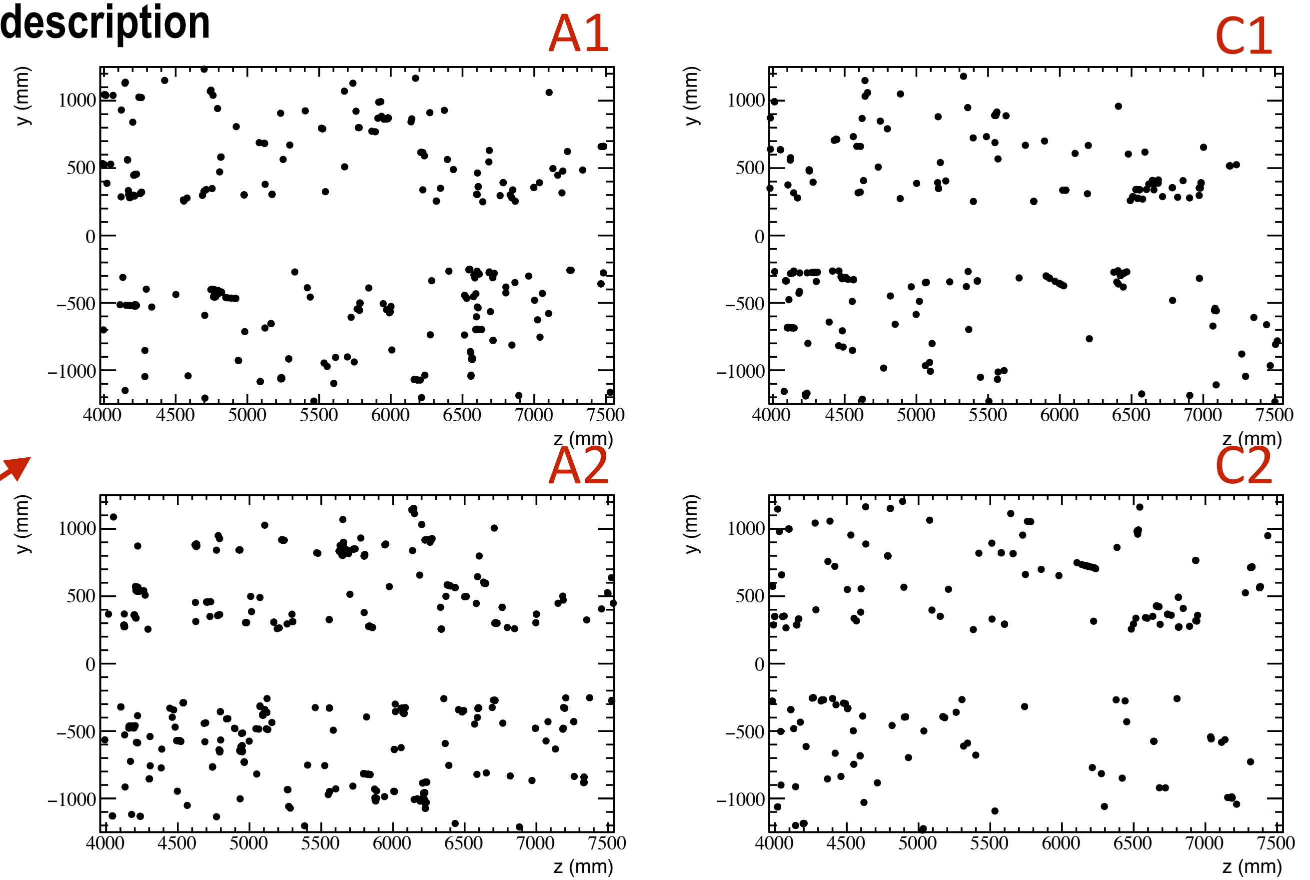
C: Cryo (x<0)

Simulation

- **Minimum Bias in Upgrade conditions**
- **Magnet stations simulated as planes of fibres**
  Interaction with the detector and multiple scattering between the stations
- **Missing proper detector description**
  Will wait for final decision

Studies

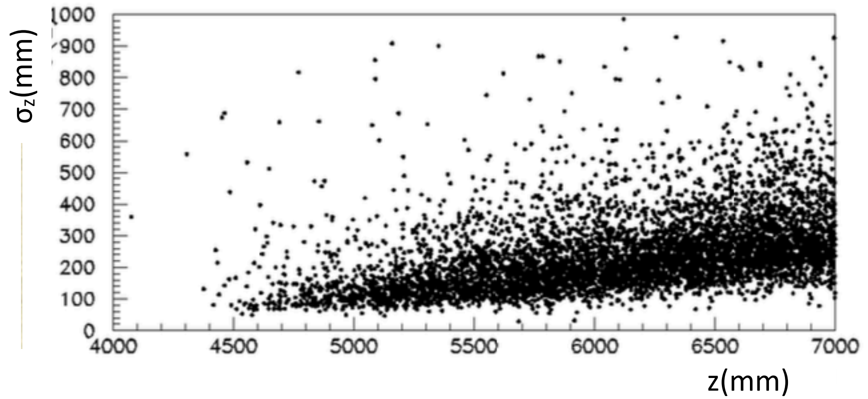
- **Momentum resolution**
- **Pattern recognition**
- **Used VeloUT tracks as starting point**

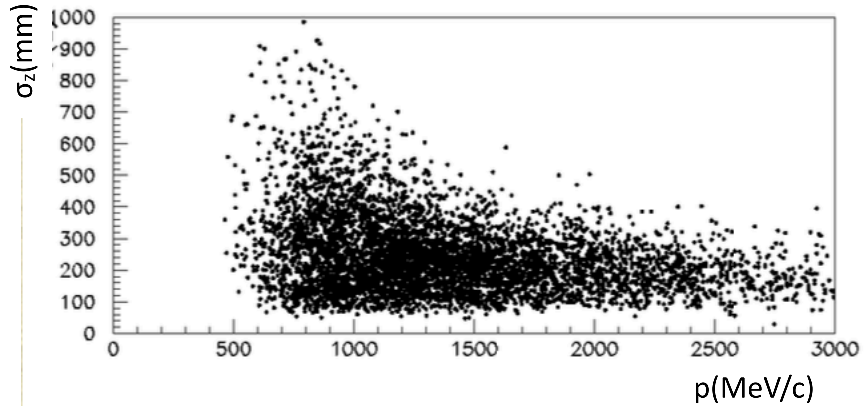


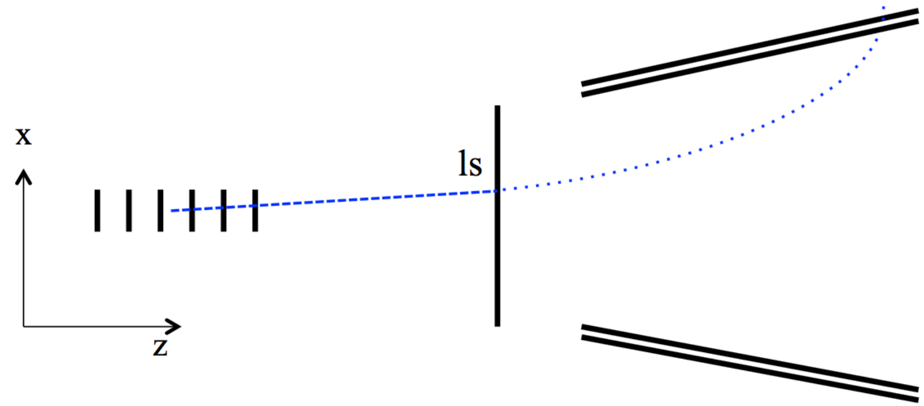
One random Minimum Bias event

Extrapolation

- Start from VeloUT track state at last point and magnetic field
- Multiple scattering simulated with a numerical approach
- Error matrices based on (x,y,t_x,t_y) at z_{ls} and (z,y,t_z,t_y) at magnet station plane
- Uncertainties on z increase with z and decrease with p





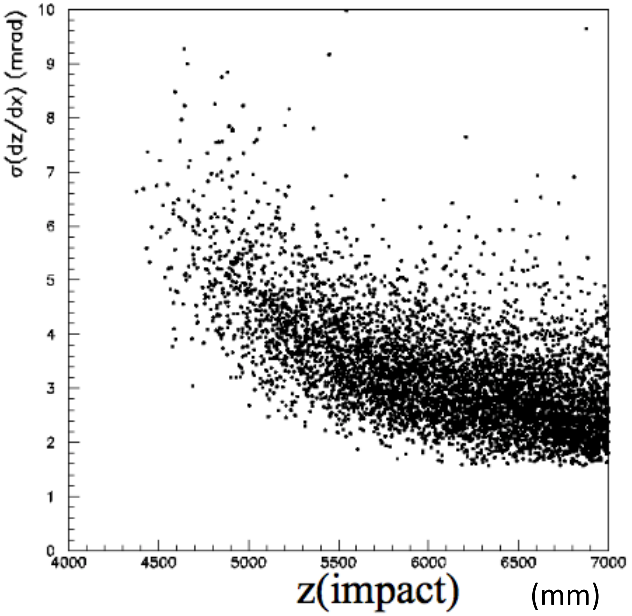


The Second Station

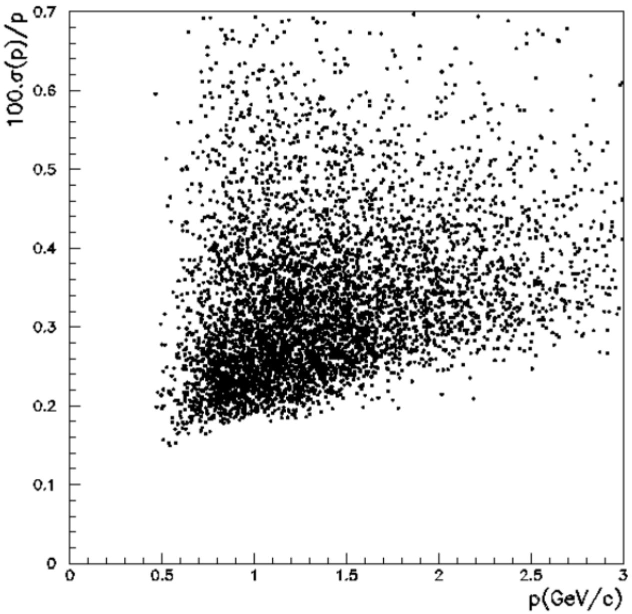
Prediction

- With the first station extrapolation one can predict the position on the second layer within 1mm
- With two points, the uncertainty on the momentum becomes < 1%

σ(t_z)



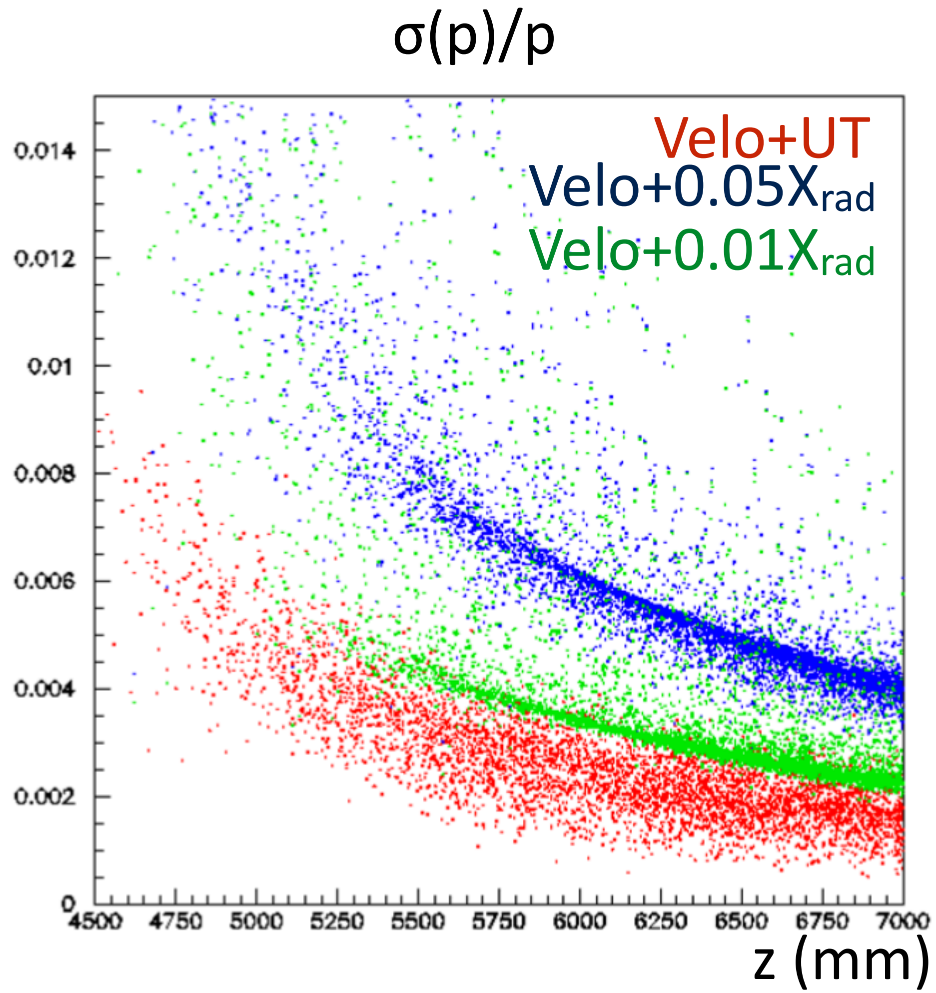
σ(p)/p



Second Station - Velo Tracks

Start from Velo Tracks

- Assuming the pattern is correctly found, similar results are possible by starting from a Velo track
- One could think of a search algorithm that starts from Velo tracks and some assumption based on t_x and t_y
- This could be run after running the algorithm that starts from VeloUT



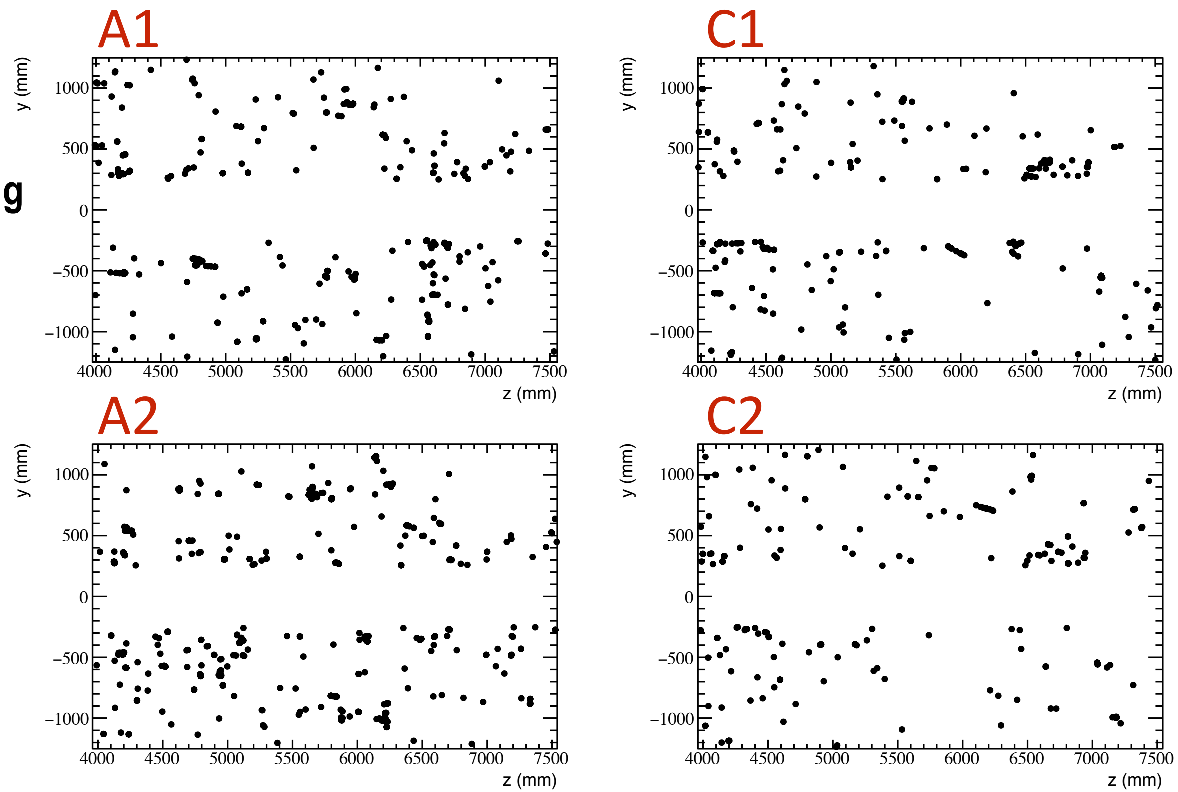
Pattern Recognition

Clustering

- **We don't have a real clustering yet**
  We miss the a proper detector description within LHCb framework
- **Used energy deposit from MC particles as a starting point**
- **Planes divided in 1mm^2 bins in z-y**

Strategy

- **Extrapolate VeloUT to stations**
- **Open a window to collect matching clusters**
- **Fit q/p using z from each cluster**
- **With updated q/p open another window in the second station**
- **Build a track candidate**



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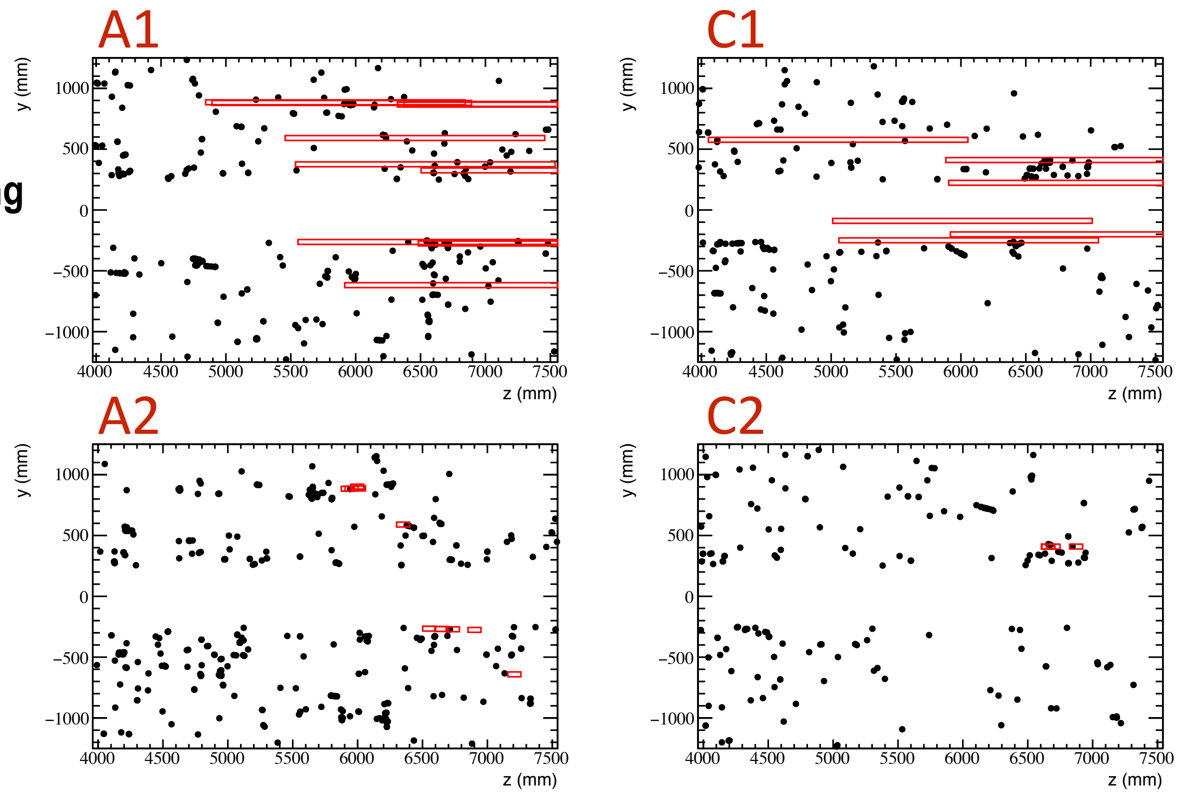
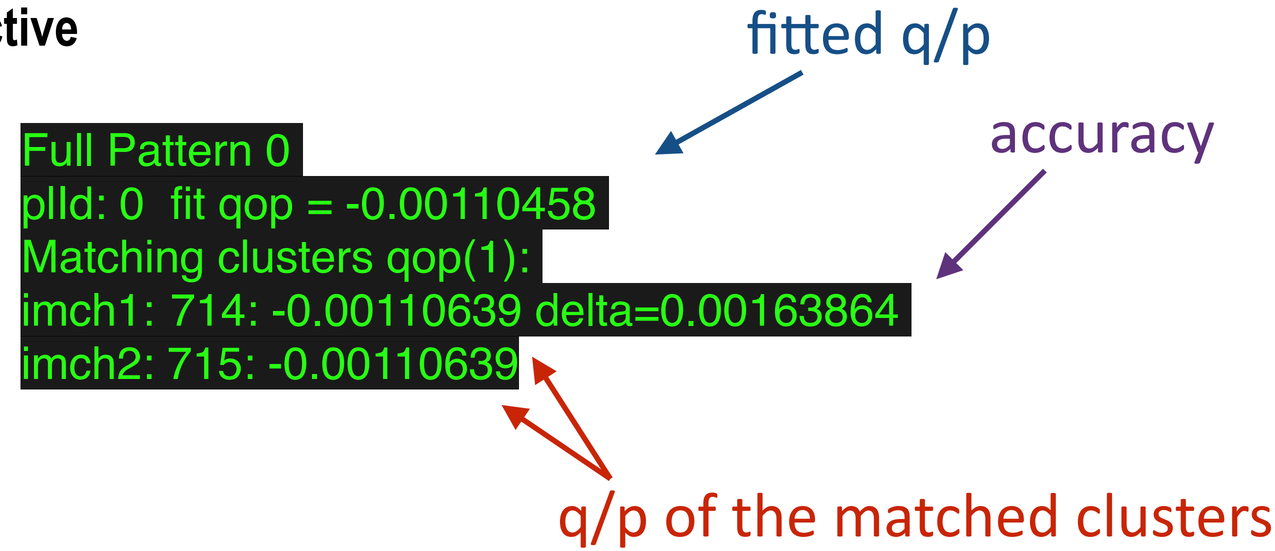


Track Fit

Very Simple

- **Using the Jacobian of the extrapolation to correct q/p until d(q/p)/(q/p) < 0.001**
  z and q/p are the most correlated terms in the extrapolation
- **Not perfect, but good starting point**
- **Also rather effective**



Tracking - To do

Simulation

- We need proper simulation and clustering
- LANL already has something for plain GEANT and is working to port it to LHCb simulation

Tracking

- Encouraging results obtained from VeloUT extrapolation
- Studies to be repeated with Velo extrapolation
- Some candidates may be eliminated by a detailed fitter

Conclusions

Detector Prototype

- New ideas to reduce the costs
- A prototype of the detector will soon be tested

Tracking

- We are developing the necessary tools and preliminary results are encouraging
- Plan to extend studies to Velo+MS candidates

Simulation

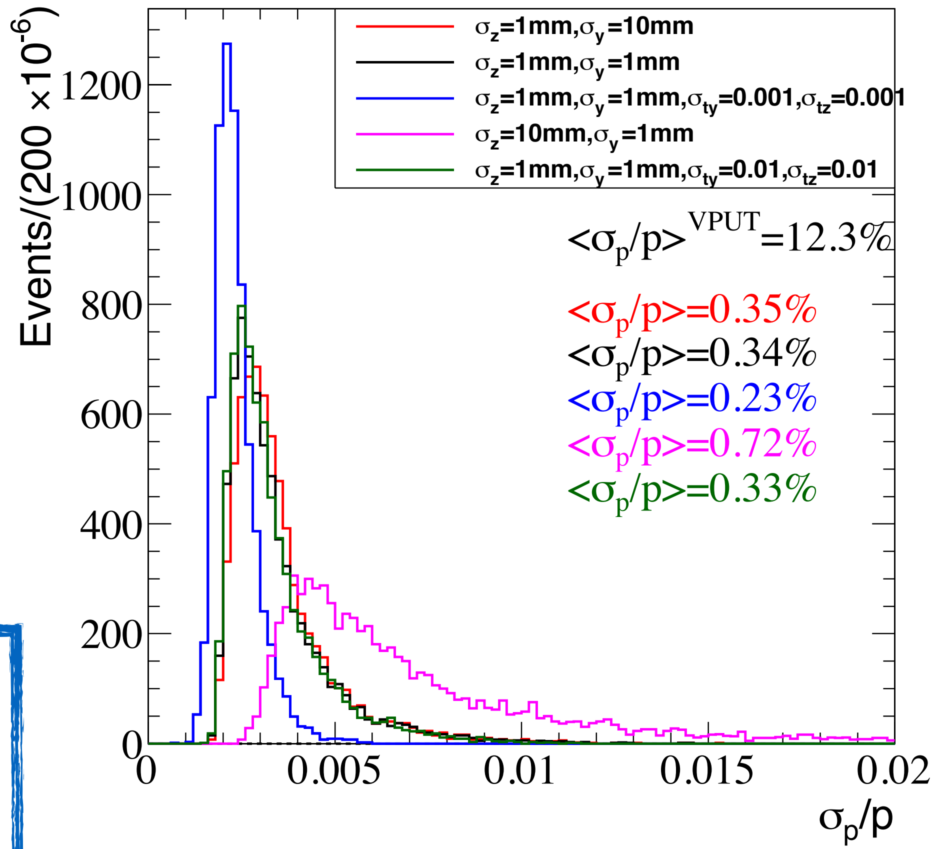
- Work is needed, in particular for defining the detector in LHCb framework
- Any contribution is welcome!

Spares

Resolution Expectations - Results

Scenarios

- **Most likely scenario: red**
  σ_z=1mm, σ_y=1cm
- **Very good y-res: black**
  σ_z=1mm, σ_y=1mm
- **Effect of direction angle: blue**
  σ_z=1mm, σ_y=1mm, σ_{ty}=1mrad, σ_{tz}=1mrad
- **Effect of direction angle (realistic): green**
  σ_z=1mm, σ_y=1mm, σ_{ty}=10mrad, σ_{tz}=10mrad
- **"Poor" z-resolution: magenta**
  σ_z=1cm, σ_y=1mm



Even assuming the estimate wrong by 100%, <1% uncertainty seems possible!

Multiple Scattering

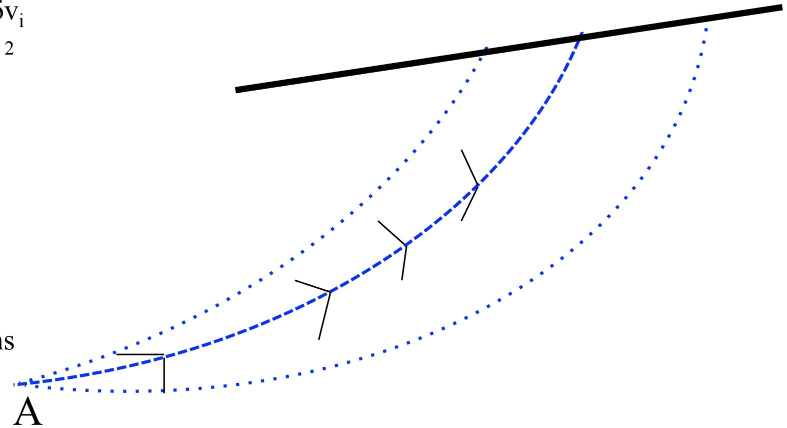
extrapolation of multiple scattering errors

(with $u = t_y = dy/dx$, $v = t_z = dz/dx$)

fully numerical approach:

$$C_i = \begin{matrix} \delta y_i^{\,2} & \delta y_i\,\delta z_i & \delta y_i\,\delta u_i & \delta y_i\,\delta v_i \\ \delta y_i\,\delta z_i & \delta z_i^{2} & \delta z_i\,\delta u_i & \delta z_i\,\delta v_i \\ \delta y_i\,\delta u_i & \delta z_i\delta u_i & \delta u_i^{\,2} & \delta u_i\,\delta v_i \\ \delta y_i\,\delta v_i & \delta z_i\delta v_i & \delta u_i\,\delta v_i & \delta v_i^{\,2} \end{matrix}$$

resulting deviations (δy_i , δz_i , δu_i , δv_i , i=1,2)



with θ^2_{MS} at point A

➔ contribution $(\theta_{MS}/\delta\theta)^2\,(C_1+C_2)$

continuous material (e.g. air):
define a sequence of points $\{A_k\}$
sum up the independent contributions
along the trajectory

deviations of $\delta\theta$ = 1 mrad in two *orthogonal* directions
(may be chosen in an arbitrary way)

06/03/17 P. Billoir , magnet chambers 2