AFP Alignment

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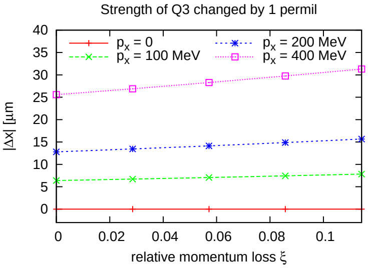
Introduction

Contents

Uncertainty on magnets strengths

- Alignment makes sense only if the optics is well understood
- Is optics calibration needed? How stable the optics is?
- Typical claim of the magnet strength precision is 10^{-4}
- Detailed investigation shows that this number is underestimated for quadrupoles
- The present study for AFP:
  quadrupole strength precision of 1 ‰

Results on optics stability



- Change of magnets strengths leads to shift of proton position
- The effect depends mainly on p_T of the proton (increases with p_T for x and decreases for y), less on ξ
- For p_T < 200 MeV the effect on horizontal position is of the order of 10 – 15 μm

- Shift is small – stability of optics is good
- A need for calibration is not to be expected
- The effect on physics should be small (steep p_T distribution)

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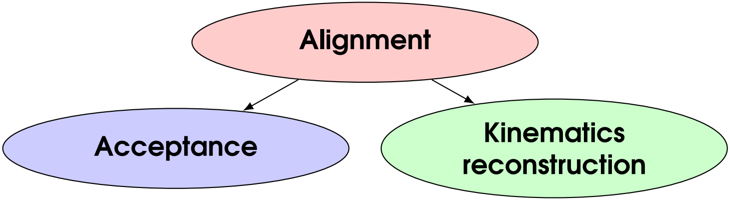
Effect of AFP misalignment



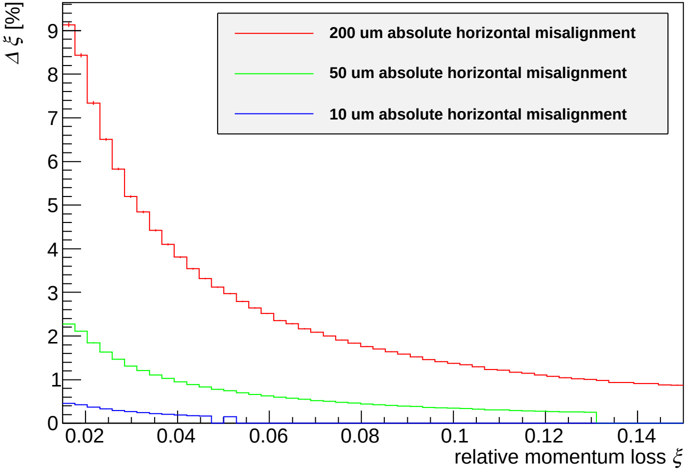
Effect via acceptance

- Wrong alignment = wrong assumption on acceptance
- Leads to uncertainty on acceptance correction or theoretical prediction (depending on approach)
- Affects all measurements
- 100 µm horiz. shift results in cross section change by:
  - 1.5 % for processes with single tag
  - 2 % for processes with double tag
- Alignment w.r.t. the actual beam position needed

Degrees of freedom

- AFP detectors measure position and direction of proton trajectory (position measurements in two planes)
- Alignment – precise knowledge about the position of the detectors, needed to determine proton trajectory parameters
- Relative alignment between stations – affects trajectory direction
- Absolute alignment – affects trajectory position
- Rotations of stations (in xy, xz and yz planes)
- Longitudinal alignment – very precise from survey

Effect of absolute alignment



Affects small ξ values.

Effect of relative alignment

AFP Alignment

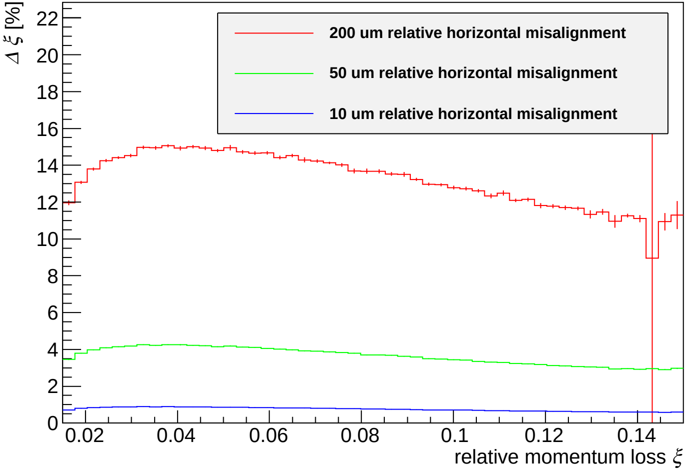
R. Staszewski

Optics stability

Alignment Precision

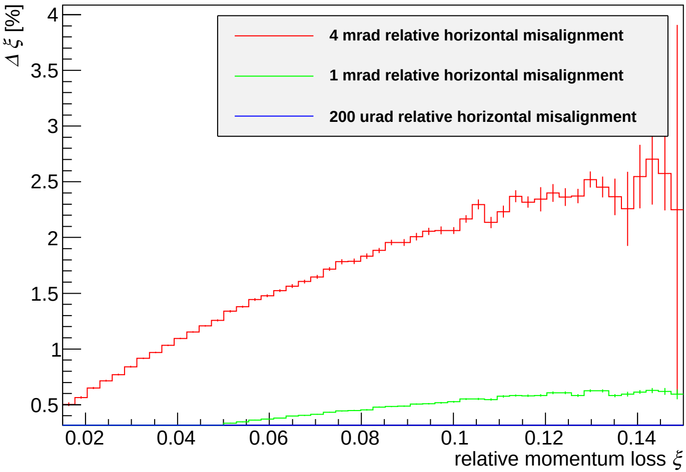
Alignment Methods

Summary



Affects whole ξ range.

Effect of rotations



Small effect on ξ.

Effect on physics

lumi	tag only	poor alignment	good alignment
low and medium	– measurement with single and double tag request – cross sections – charged particle multiplicity – gap survival probability – jet, photon p_T distributions – event shapes, jet structure – W charge asymmetry – cross section ratios	measurements for "tag only", but in few bins of ξ, t, M (possible even with 500 µm precision)	precise ξ, t, M distributions
high	not possible	not possible†	needed for all measurements†

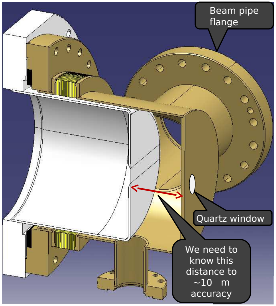
† to be verified what precision is needed for high luminosity

Contents

Hardware: BPM and LVDT

BPM (Beam Position Monitor):

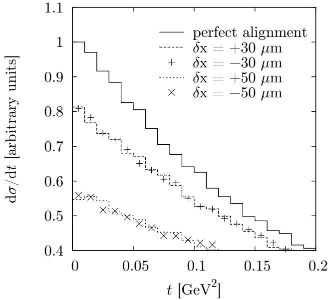
- Measures the AFP position w.r.t. the actual beam
- Dedicated readout electronic for better precision
- Sub-μm precision expected
- BPM → RP → detector calibration less accurate (100 μm?), possible improvement with quartz window (fine with the LHC!)

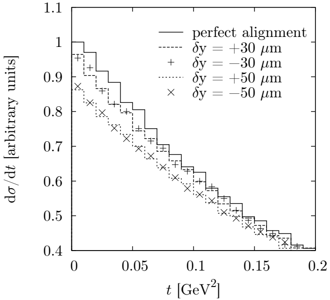


LVDT (Linear Variable Differential Transformer):

- Fixed reference frame
- ALFA experience:
  - 35 μm for pr ecision
  - 250 μm for calibration

Kinematic peak method





- Principle: reconstruct t distribution with different assumptions on detector position
- Successfully used in CDF experiment
- At the LHC sensitive to relative alignment between stations
- Better sensitivity in horizontal direction due to better spatial resolution
- 100 K soft SD events $\rightarrow$ 30 μm precision (preliminary)

Hot spot method (M. Bruschi, P. Bussey)

Left plot: hit pattern in AFP has a complex structure with a characteristic dense area (hot spot)

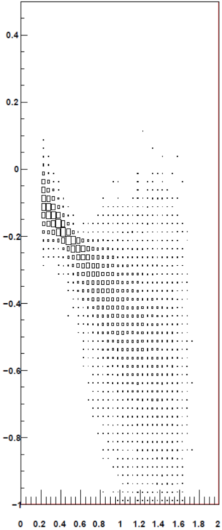
Right plot: rms width of the y distribution as a function of bins in x

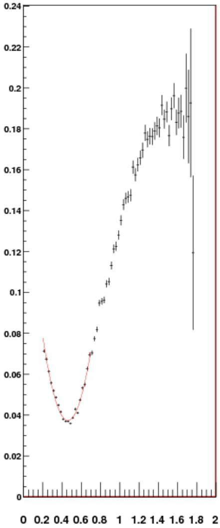
Clear minimum corresponding to the hot spot position

100K events $\rightarrow$ 8 µm precision!

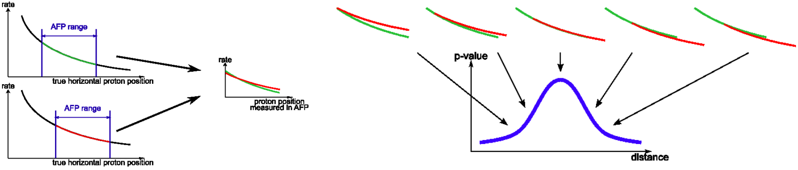
Small sensitivity to physics model and optics changes

Very promising! To be studied in more detail (*e.g.* effect of beam background)





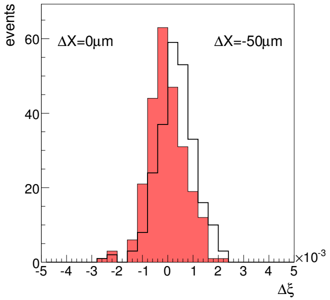
Distribution shift method



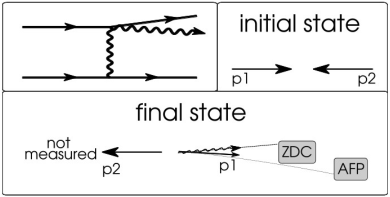
- Comparing distributions of the horizontal positions of registered protons from two runs (time periods) using the Wilcoxon-Mann-Whitney statistical test
- Search for translation that equalises distributions shapes
- Precision: 13 μm for 1M events, 25 μm for 100K, 100μm for 10K
- Relative alignment between runs and alignment stability tests
- No assumption on optics and physics
- No sensitivity to background, if constant in time
- New method, promising especially for stability tests
- Possible extension to 2D comparison

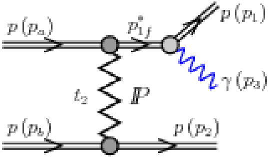
Exclusive $\gamma\gamma \rightarrow \mu\mu$ (O. Kepka)

- Process measured in CMS without proton tagging (track based exclusivity cuts)
- Additional single proton tag
- Alignment is based on exclusivity of the event
- Comparison ξ measured in AFP with ξ from muon pair
- 100 events needed for 10 μm alignment precision
- Small cross section: 40 fb (pT > 10 GeV for both muons, AFP 2 mm from the beam)
- Optics calibration possible with sufficient statistics



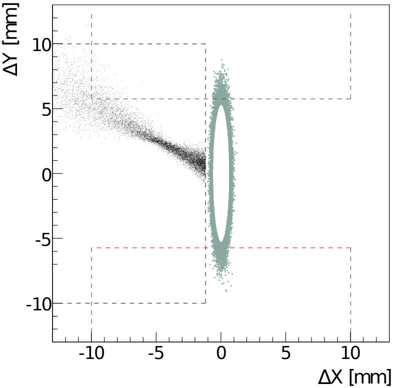
Bremsstrahlung





- Comparing AFP position to ZDC energy
- Very large cross section $\rightarrow$ no problem with statistics
- Large backgrounds, but should be manageable
- Can provide precise alignment and precise calibration

ALFA / vertical pots (A. Kupco)



- Elastic scattering: very strongly correlated kinematics: left and right sides, trajectory position and direction – very good for alignment
- Align vertical pots with elastic scattering
- Use overlapping acceptance region between horizontal and vertical pots to align the horizontal ones

- Either dedicated vertical pots or common run with ALFA (more difficult due to Q6 magnet between AFP and ALFA)

Contents

Summary

- Poor alignment (200 μm) leads to:
  - systematic uncertainty on ξ reconstruction: below 10 %
  - systematic uncertainty on cross sections (via acceptance): 3 % (single tag), 4 % (double tag)
- Majority of measurements at low and medium luminosity does not need very precise alignment
- Present estimates for the alignment precision:
  - **Hot spot method**: 10 μm for absolute alignment (100K ev)
  - **Kinematic peak method**: 30 μm for relative alignment between stations (100K events)
  - **Distribution shift**: 25 μm for relative movement
  - **Exclusive muons**: 10 μm for 100 events
  - **LVDT**: 35 μm
  - **BPM**: 1 μm
  - **BPM and LVDT calibration**: 100 – 200 μm (possible improvement with quartz window)