Time resolution of the diamond sensors used in the Precision Proton Spectrometer

CMS Collaboration

Abstract

The Precision Proton Spectrometer (PPS) is a forward-proton spectrometer using near-beam detectors (inside Roman Pots, RPs) located symmetrically on both sides of IP5 at a distance of about 220 m. In addition to the tracking system, timing detectors were installed in 2017 to measure the Time-Of-Flight (TOF) of the protons produced in central exclusive interactions. Two cylindrical RPs were equipped with Diamond sensors. In 2018 the TOF system consisted of two single- and two double-diamond planes. This note describes the timing resolution of the sensors, a necessary ingredient to assess the precision of the TOF measurement.
DPS NOTE:
PPS timing detector performance
(2018)

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PPS timing system

LHC sector 45

Plane 0: Single diamond (SD)
Plane 1: Single diamond
Plane 2: Double diamond (DD)
Plane 3: Double diamond

Inside RP
Hybrid board
Preamp
Shaper
NINO Board (x2)

48 individual coax. connections

~1m from the beam pipe

LHC sector 56

2 NINO board
4 NINO chip on each board

2 Digitizer board
4 HPTDC chip on each board

FPGA (SF2)
Optical link (GOH)

48 channels

I2C Interface

Inside RP ~1m from the beam pipe

CR

ROMAN POTs

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Signal digitization

NINO discriminator works on charge. TOT (Time over threshold) dependence on the input amplitude is not linear.

TOT must be used to correct Time Walk effect.

$\text{TOT} = t_t - t_l$

$t_t = k + f(Q)$

$t_l = k + f(Q)$
1. Correction and alignment of measured arrival time w.r.t. signal TOT (each channel independently treated)

Calibration curve example: one run, one channel

![Fit function graph](image)

- Asymptotically limited
- Very good description of the data in the most populated region
- Good for all channels (both double and single diamond)

2. Iterative procedure to compute resolution of each pad.

Fit function:

\[ \langle t_{\text{arr}} \rangle = \frac{p_0}{e(TOT-p_1)/p_2 + 1} + p_3 \]
Calibration effect example: one run, all channels (LHC sector 45)

- No timing calibration. Spike at $t = 0$ corresponds to events with missing leading edge.
- Timing calibrations (from calibration step 1) applied for each channel. Spike at $t = 0$ and tail correspond to events with missing leading/trailing edge.
- Timing calibration with quality cut: only hits with both leading and trailing edges and TOT>0 are considered valid.
- Timing calibration with quality cut and pixel tracks multiplicity selection. Pixel multiplicity selection is used to reduce background.

Calibrated hit distribution shows a reduced RMS (it includes the effect of the beam longitudinal size).
For the 2018 data, the resolution is computed for each pad and used to calculate the track time (weighted mean). Resolutions are computed with iterative procedure, where the weights computed at step n-1 are used the next step:

\[ t_k = \text{corrected time measurement of plane } k \]
\[ w_k^j = \text{weight computed at step } j \text{ for the active pad in plane } k \quad (w = 1/\sigma^2) \]

\[ T_{\text{partial}} = \frac{w_{1}^{n-1}t_1 + w_{2}^{n-1}t_2 + w_{3}^{n-1}t_3}{w_{1}^{n-1} + w_{2}^{n-1} + w_{3}^{n-1}} \]
\[ \sigma_{\text{partial}} = \sqrt{1/(w_{1}^{n-1} + w_{2}^{n-1} + w_{3}^{n-1})} \]

\[ \Delta T = t_0 - T_{\text{partial}} \]
Calibration procedure: channel resolution example

\( \Delta T \) distribution between channel 3 and partial time track computed with the other 3 planes.

Average partial track resolution (\( \sigma_{\text{partial}}(\mu) \)) is deconvoluted from the \( \sigma \) of the \( \Delta T \) distribution.

\[
\sigma_{\text{pad}} = \sqrt{\sigma_{\Delta T}^2 - \sigma_{\text{partial}}(\mu)^2}
\]

Pad resolution

Statistical error negligible.
Systematic uncertainty (on the method) estimated \( \sim 10 \) ps
Resolution vs integrated Luminosity in Run2 (after July 2018)

Calibration data available only after July 2018.

General resolution loss in the range 20-50%: radiation damage on sensor and electronics close to the beam (pre-amplification stage).

In Run 3 performance can be recovered raising the LV of the pre-amplification stage (LV remote control not implemented for Run 2).
For the channels without important localized damage the behavior of TOT is consistent with signal amplitude reduction and resolution loss.

In Run 3 Performance can be recovered raising the LV of the pre-amplification stage (LV remote control not implemented for Run 2).
Similar behavior seen for double (DD) and single (SD) diamond.

Resolution in double diamond expected to be factor 1.7 better

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Comparison of the resolution in two SD planes vs integrated Luminosity in Run2

Plane 0 of each station was already used in 2017, accumulating an integrated luminosity of \( \sim 40 \text{ fb}^{-1} \).

Data from such planes can be used to extend the resolution measurements on SDs up to \( \sim 100 \text{ fb}^{-1} \): the comparison is done for same channels (\( \sim \) same distance w.r.t. the beam) of plane 0 and 1.
Once all channel resolutions are known it is possible to assign a time precision to each timing track. This is a measure of the full station resolution (sensor + front-end + digitization + timing channel calibration and reconstruction procedure).

1 track in both pixel tracker stations & at least 3 diamond planes & 1 pad per plane
Once all channel resolutions are known it is possible to assign a time precision to each timing track. This is a measure of the full station resolution (sensor + front-end + digitization + timing channel calibration and reconstruction procedure).

1 track in both pixel tracker stations & 4 diamond planes & 1 pad per plane
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