Luminosity Optimization

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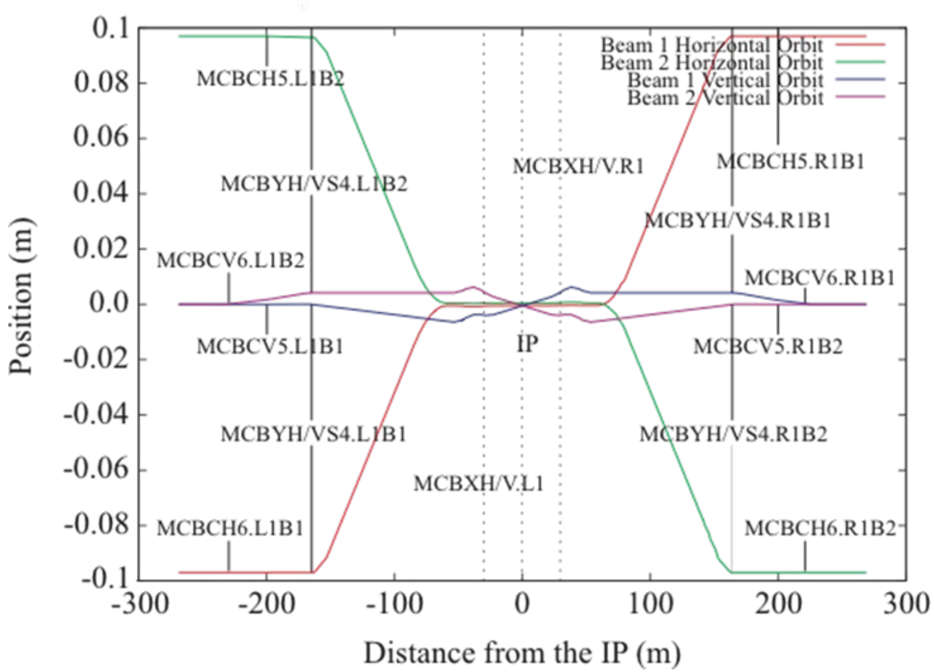
IR Layout and Bumps



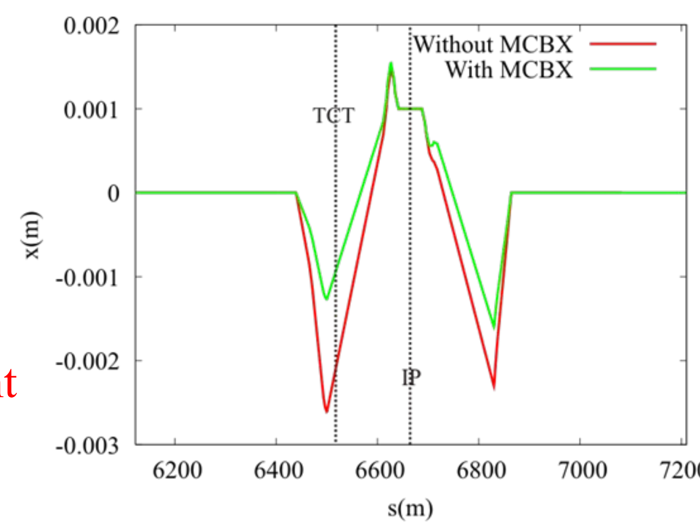
MCBX in triplet - important for crossing angle and aperture at injection. Act on both beams and planes at the same time.

MCBC and MCBY only for one beam allow to drive the beams independently.

⇒ A bump including MCBX magnets will either separate or bring the beams together.
⇒ An offset of the IP can only be corrected with MCBC and MCBY.

Example of an IP bump with and without MCBX:

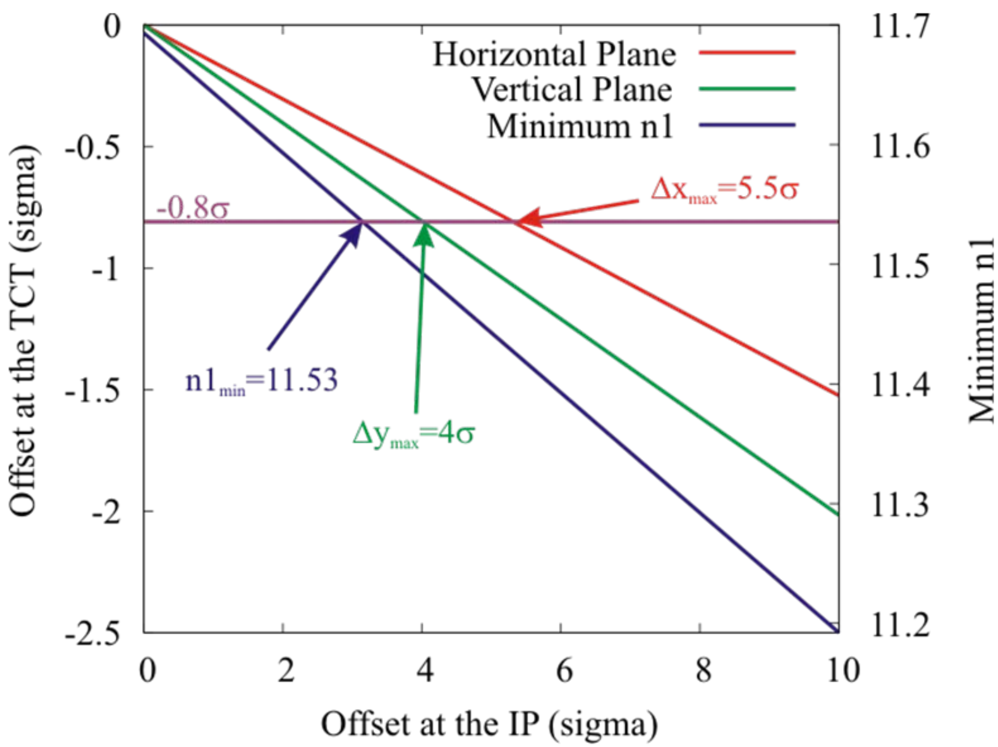
⇒ Creates a large offset in the TCT region.
⇒ This offset can be reduced by using MCBX.
⇒ MCBC and MCBY bumps are not suited for large corrections. They should only be used for fine tuning.
⇒ A large transverse offset of the IP should be corrected by different means (global correction).



• An orbit offset at the TCT can comprise the collimators efficiency to protect the triplets. In order to correctly shadow the triplets the two following conditions should be fulfilled:

$$\left|\Delta x_{TCT}[\sigma]\right| < n\sigma_{QX} - n\sigma_{TCT} \quad , \quad n1_{min} > 10.5$$

Worst case scenario: $\beta^* = 2$ m at IP5. For a half gap of 12.8 σ at the TCT: $\Delta x_{max} \sim 1.2\ \sigma$ with separation bump on and ~1.8 σ with separation off. 1 σ for collimators operation → 0.8 σ is left for optimization.



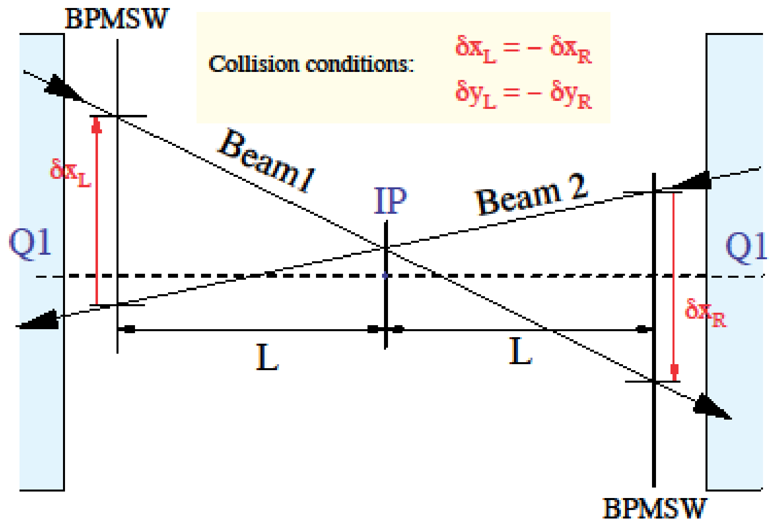
⇒ There should be enough space for optimization. Solutions to be discussed for wider scans.
⇒ Increasing β^* would increase the allowed scan range, but requires larger bumps.
⇒These bumps should be tested with safe beam in order to avoid any unpredicted limitations.
⇒Set limits according to simulations and measurements in the steering software.
⇒ If the allowed scan range is not sufficient this can be overcome by moving the two beams.

IP5 : margin of at least 4σ in vertical and 5.5σ in horizontal. Numbers are similar or better for other IPs.

Corrections Using BPM measurements

- Residual separation before corrections. Large offsets were observed in some cases.

	Horizontal [mm]	Vertical [mm]
IP1	1.15	1.34
IP2	0.5	1.2
IP5	2.35	0.85
IP8	0.3	0.75



⇒ Correcting the offsets to align beams based on BPM measurements with local closed orbit bumps was sufficient to establish collisions at the four IPs.

⇒ This might not be the case for higher energies/smaller beams → at 3.5TeV. Van Der Meer scans could be necessary to find the beams.

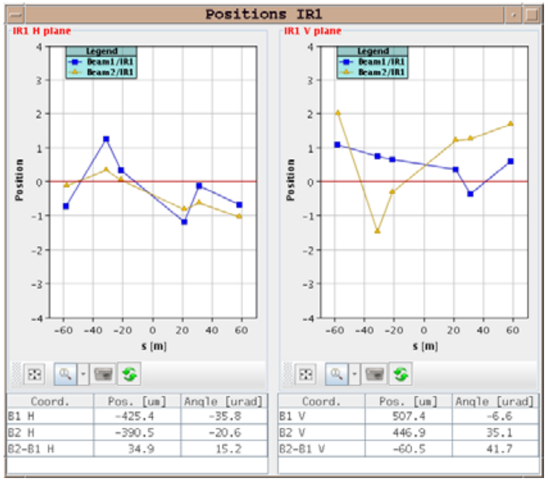
Special case of IP1 and IP5:

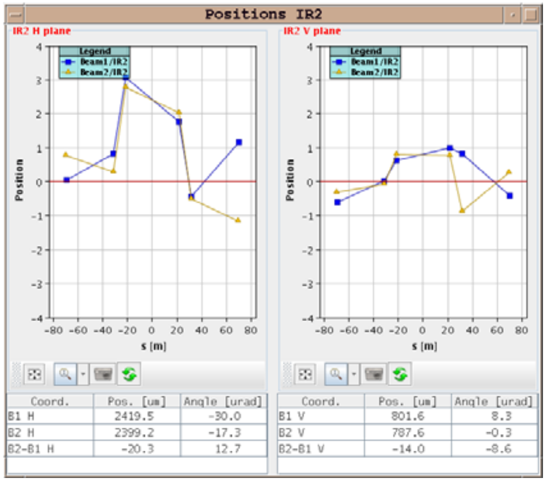
Button pick-ups with higher resolution were installed in IP5 and IP1 which directly measure the separation in Q1.

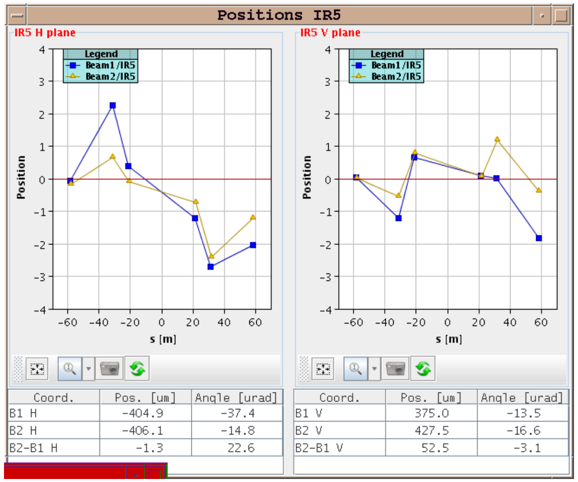
⇒ Not used in 2009 (only BPMSW) → we could possibly reach a better alignment using these.

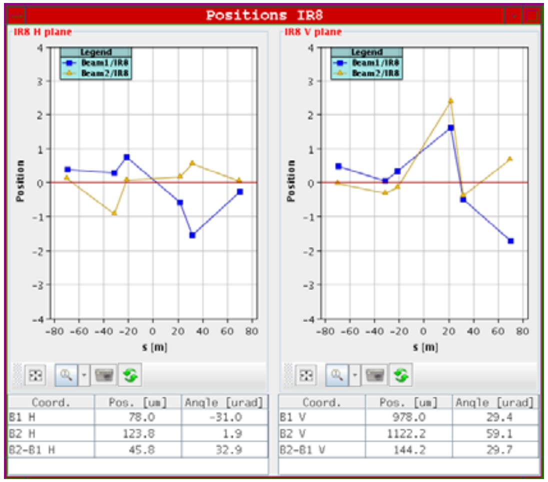
⇒ Implement a display in the software.

Status after Corrections









⇒ (Large) IP transverse offset remaining. Difficult to correct using closed orbit bumps because of aperture limitations.
⇒ Largest measured crossing angle ~40 murad. Luminosity reduction negligible.
⇒ IP2/IP8 smaller offsets : MCBX magnets were not used.
⇒ IP5 some magnets were not commissioned: injection separation bumps magnets were used as a temporary solution.

⇒ The actual settings are not optimized in terms of IP position and aperture.
⇒ Re-optimize all IPs starting from a "cleaner" situation and reset collimators afterwards.

Luminosity Optimization

Principle

$$L_0 = \frac{N_1 N_2 n_b f}{4\pi\sigma_x\sigma_y} \quad \text{and} \quad \frac{L}{L_0} = \exp\left[-\left(\frac{\delta x}{2\sigma_x}\right)^2 - \left(\frac{\delta y}{2\sigma_y}\right)^2\right]$$

Luminosity and evolution as a function of the separation for equal Gaussian beams.

⇒ Transverse separation scans allow to find an optimum and give a measurement of the beam sizes at the IP.

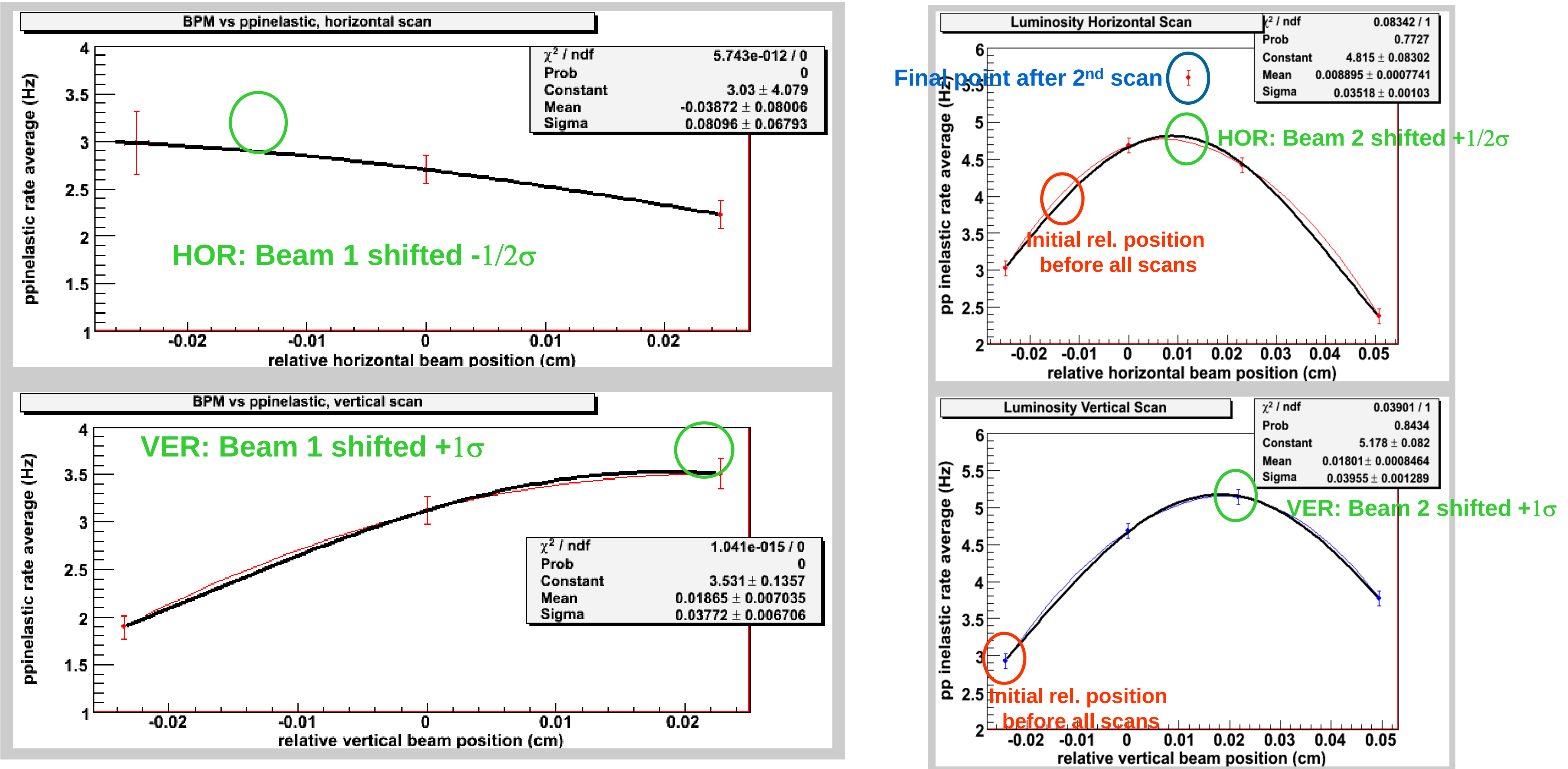
Run '09

- Mini-scans were performed in all IPs during STABLE BEAMS.
- All scans done manually with 3 points for a range of +/- 1 σ.
- ~40 minutes per IP due to the very low rates.

- The software interlock system limits the changes in strength in the orbit correctors.

⇒ Default settings were too tight → had to be manually released to allow for scans of +/- 1σ.
⇒ Could go up to +/- 2σ by moving the two beams.

First Results (LHCb)

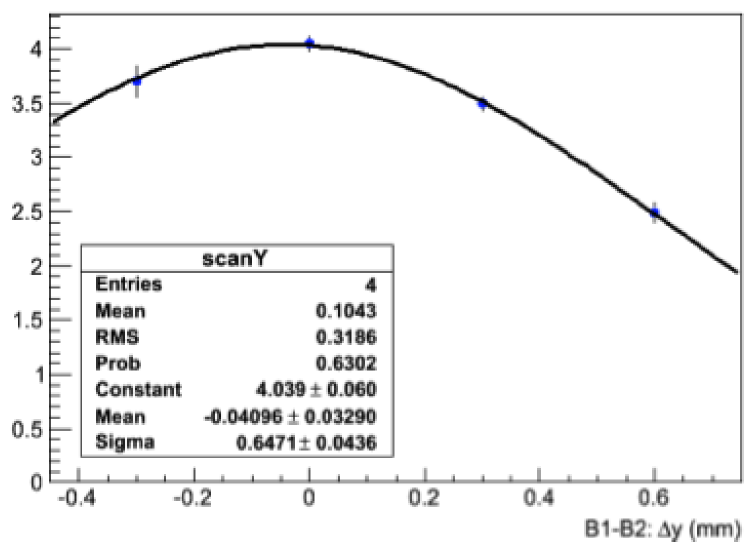


Courtesy of R. Jacobsson

- Measurements done in LHCb. Because of limited scan range several iterations were necessary to find the peak and reach the optimum settings. Gain of ~ 40% overall.

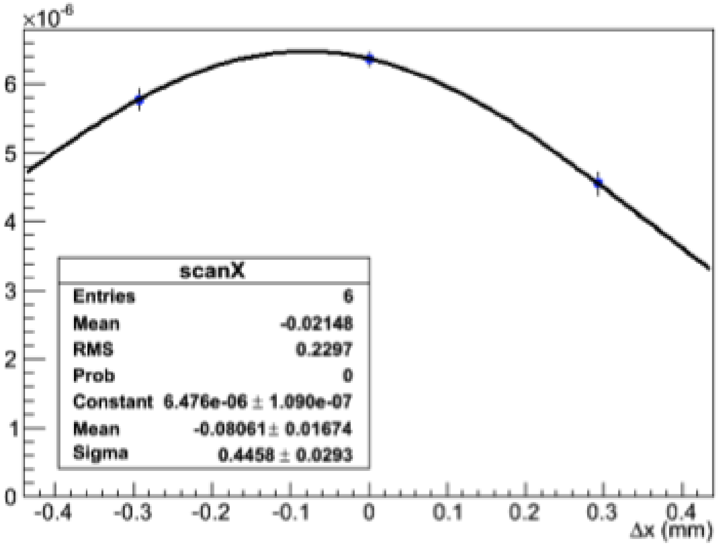
First Results (CMS)

BSC: Y scan



σy = 0.04575688 +/- 0.003082986 [cm]

HF: X Scan



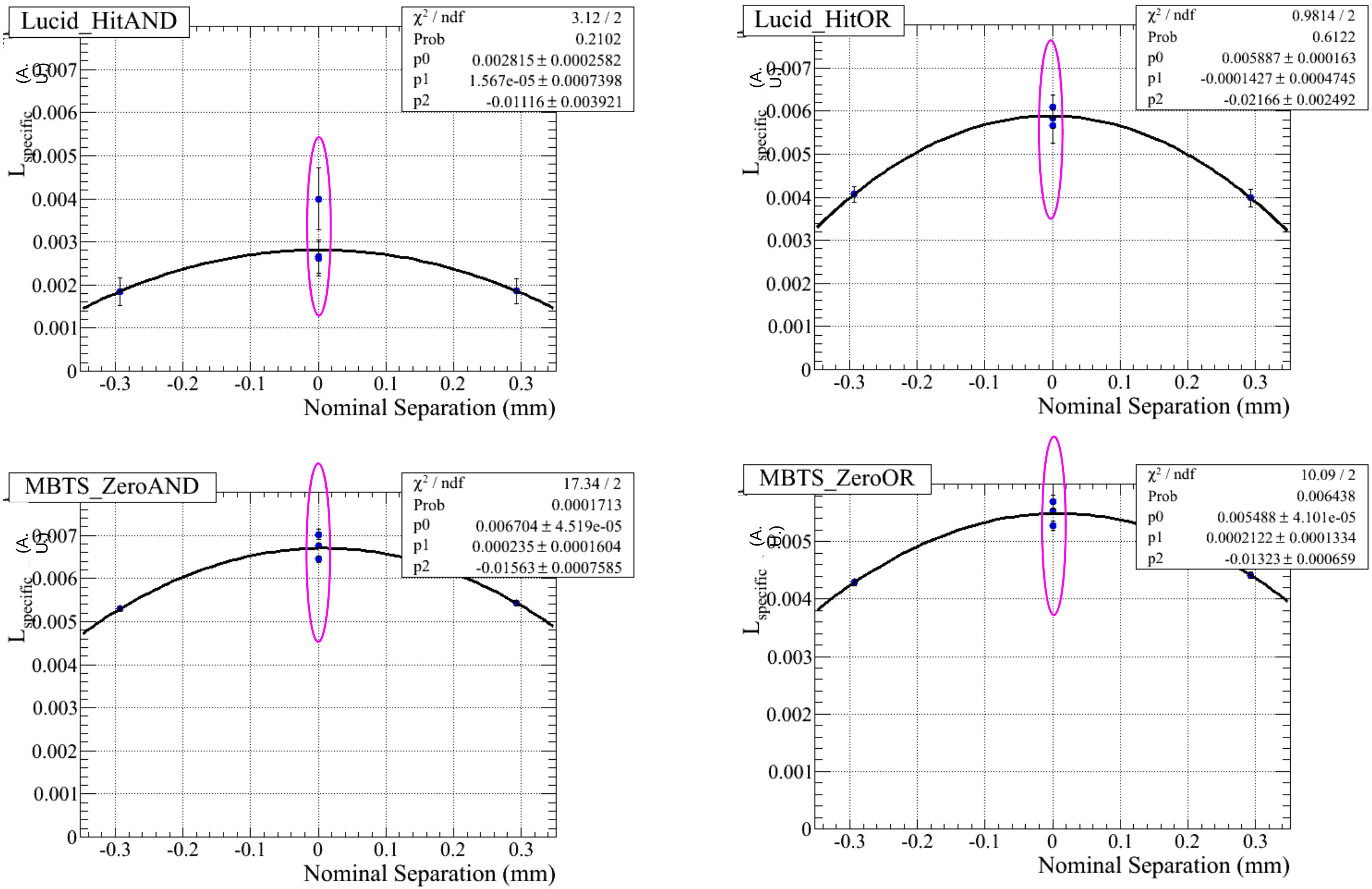
σx = 0.03152282 +/- 0.002071823

- Both HF and BSC were used during the scan
- The 3 point scans were found to be extremely valuable and improved the accuracy on the CMS luminosity

Courtesy of T. Camporesi

- Measurements done in CMS. Because of limited scan range several iterations were necessary to find the peak and reach the optimum settings. Gain of a factor ~2 overall.

First Results (ATLAS)

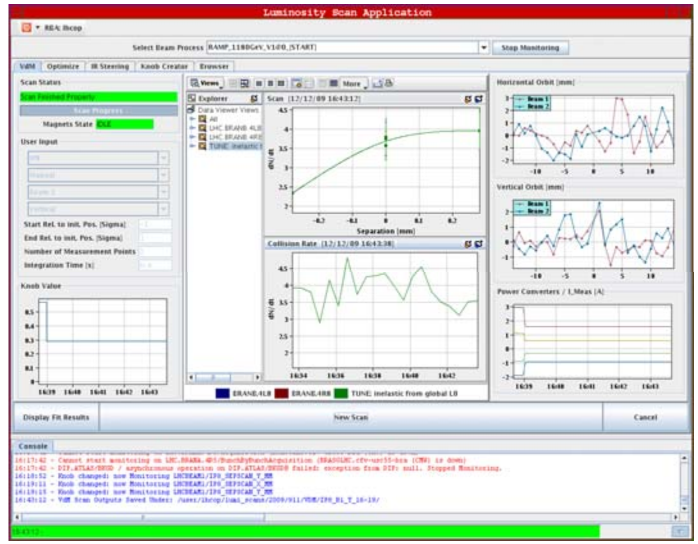


Courtesy of W. Kozanecki

- Measurements done in ATLAS only one set of scans was performed that shown no clear evidence for misalignments. Results were similar for ALICE.

Software and Data Exchange

- The same software was used for IR steering and to perform the mini-scans.



- Screen shots of the panels used for IR steering and luminosity scans.
Here is an example of a scan performed in LHCb.

- The data exchange with the experiments was done via DIP and was rather successful.
- Fully automated scans routine are implemented and were tested during the dry runs.
- Single beam knobs generated with online model for all IPs/beams/planes. Template script available: can easily be generated for any optics.

To be implemented:
⇒ Database access (work in progress will be ready for start-up).
⇒ Ability to drive both beams at once (implement knobs and script for online model).
⇒ Improved online analysis tools.

Lessons and Possible Improvements

- Duration of a scan:

⇒ Very low rates → step trough the different separations manually in order to allow the experiments to collect enough statistics : several minutes per point for a total duration of ~20 minutes per plane.
⇒ Move on to a fully automated procedure.
⇒ Once we have higher rates the limitation will come from the magnet ramping rates.

- Online analysis:

⇒ No detailed analysis provided online → had to wait for the experiments feedback.
⇒ Improve online analysis tools → the operator should be able to perform a scan and re-align the beams without feedback from the experiments.

- Scan range:

⇒ Limited by the software interlock system. Proved to be a real limitation when the peak was out of reach. CMS and LHCb needed several iterations before the optimum could be found.
⇒ Allow for +/- 2σ scan range by default.
⇒ If necessary scan with both beams to minimize offset at the TCT (will also optimize ramping time).
⇒ Avoid using MCBX (larger hysteresis).

Luminosity Calibration

• The Van Der Meer scan method can also be used to determine the absolute luminosity by measuring the beam sizes at the IP. All experiments requested an absolute luminosity calibration.

• Calibration scans have different requirements in order to reduce the systematics:

⇒ Specific measurement → done on request.
⇒ Detailed scan : more points to reduce fit errors and wider range to measure full profile. +/- 5σ should be sufficient (learn with experience).
⇒ Move only one beam.
⇒ Bunch-by-bunch acquisition and analysis.
⇒ No crossing angle and moderate intensity (5e10 p/bunch).
⇒ Can only be done once we have higher statistics and stable optics/beam conditions.
⇒ Once statistic are no longer a limitation a scan is expected to last a few minutes.

• Proposal for the upcoming run:

⇒ Beam parameters are not too far from what is required for the calibration scans → use the end of fills.
⇒ A calibration of the length scale using the beam spot measurements from the experiments could further reduce the uncertainty on the position → dedicated scans with longer steps.
⇒ The procedure and tools are the same as for optimization scans (tested and ready).

Summary

• IR Steering:

⇒ Test bumps for aperture limitations.
⇒ Generate MCBX knobs for all IPs in case large corrections are necessary.
⇒ Re-align all IPs optimizing aperture and IP transverse position.

• Machine Protection:

⇒ Could become a limitation for squeezed optics → to be studied in details together with the collimation team.

• Luminosity Optimization:

⇒ Luminosity optimization using the Van Der Meer method was successfully performed in all IPs.
⇒ The software and data exchange procedure are operational.
⇒ Move on to a fully automated procedure to allow for optimization as a part of routine operation.

• Luminosity Calibration:

⇒ Done on request by the experiments.
⇒ Optimum beam parameters to be determined (learn with experience).