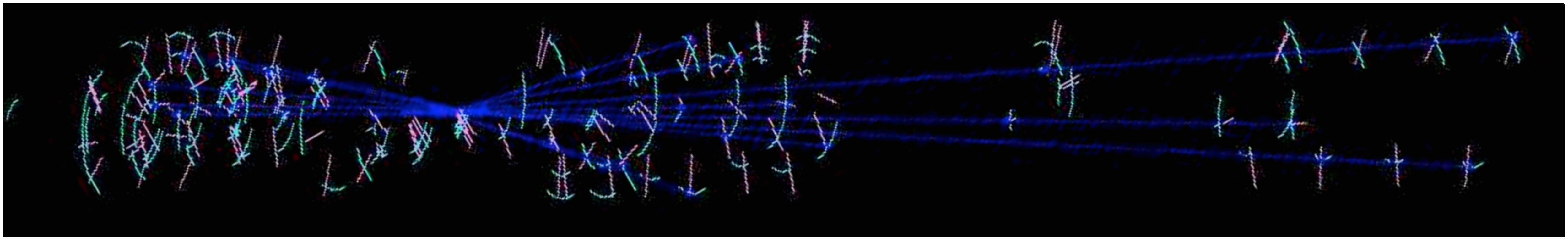
VELO closing control, vertex resolution and luminosity measurement



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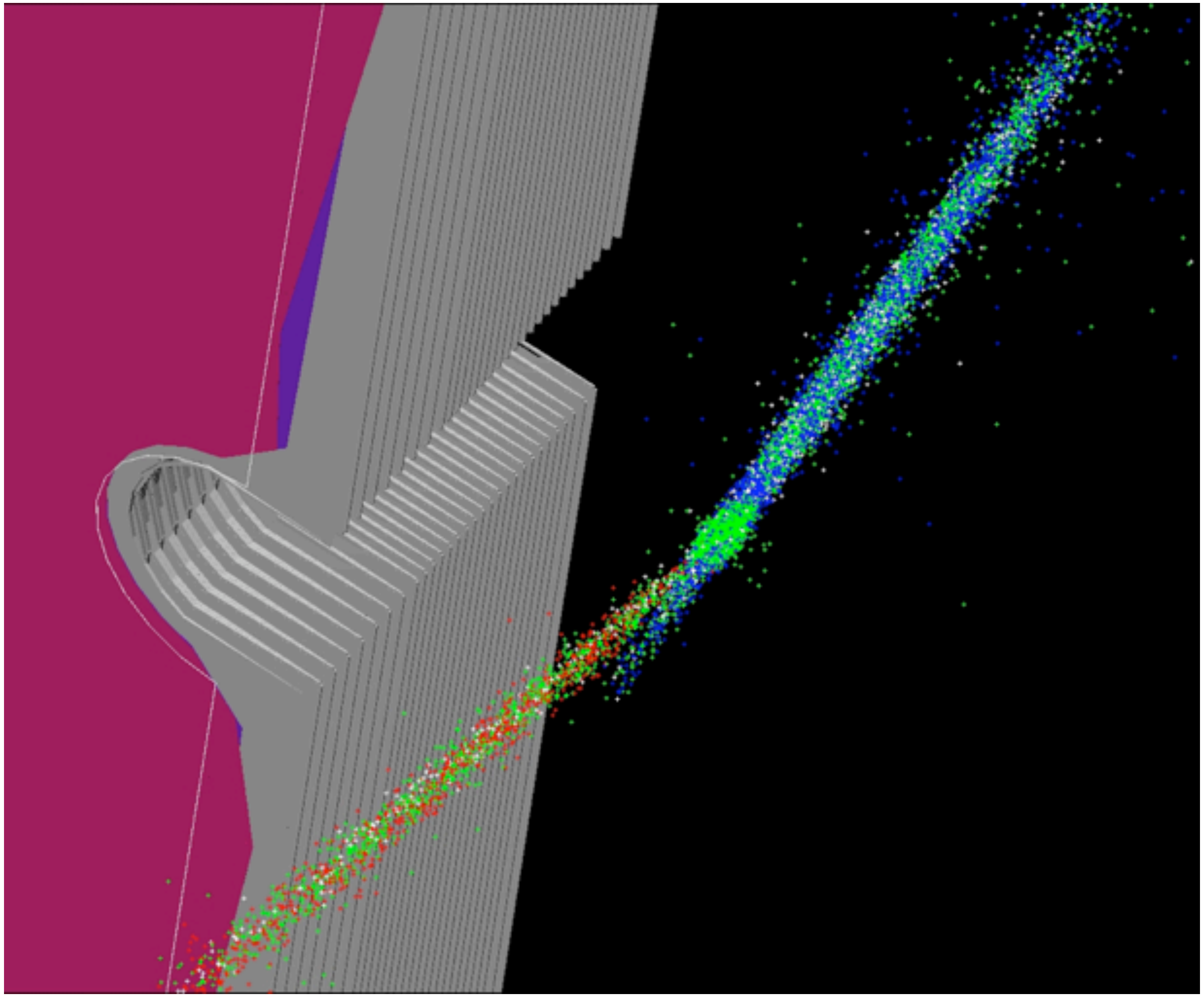
For the LHCb collaboration

Outline

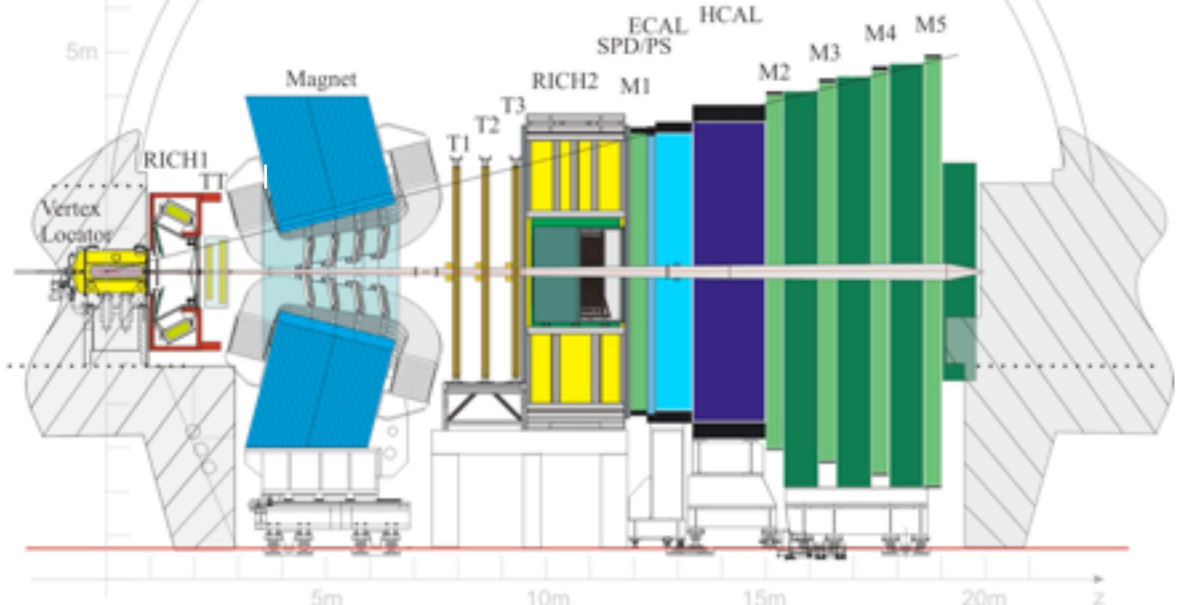
- VELO re-introduction
- Closing
- Beam monitoring
- Vertex resolution
- Luminosity measurement



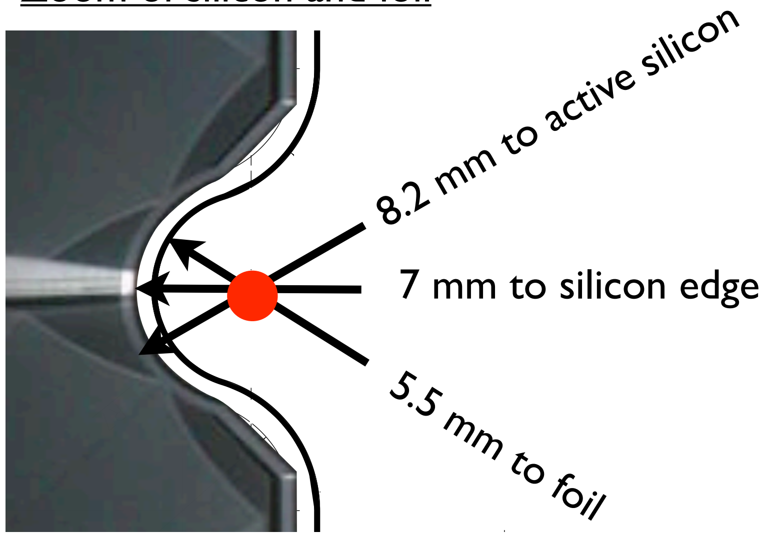
Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.

Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

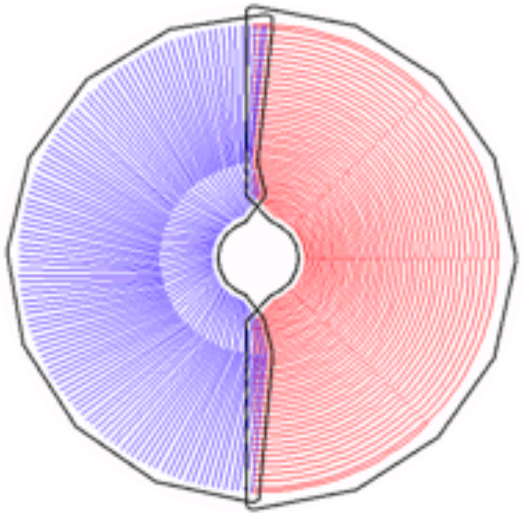
VELO re-introduction

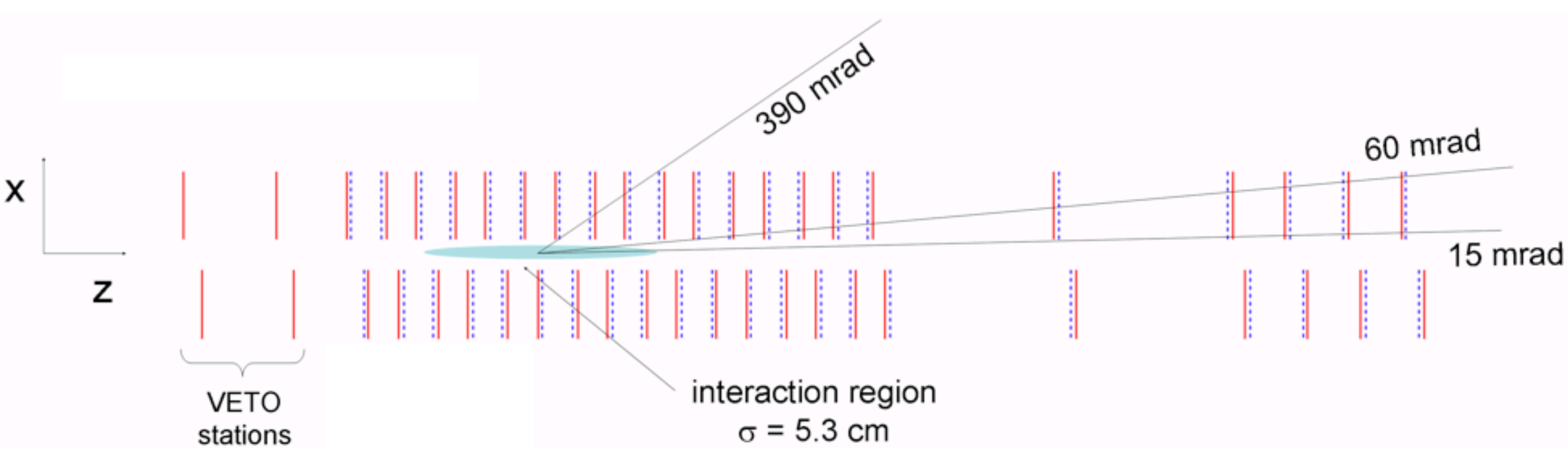


Zoom of silicon and foil



- The VELO - a VErtex LOcator for the LHCb experiment
- 42 silicon micro-strip modules, with r-phi geometry
- Modules are arranged in two halves
- It moves! Two halves move horizontally and vertically to centre around the interaction point





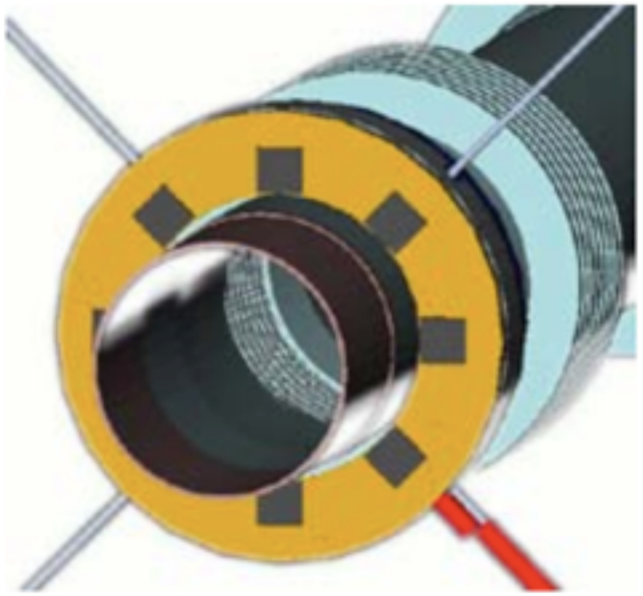
Closing procedure

PROTON PHYSICS: STABLE BEAMS

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	true	true
Global Beam Permit	true	true
Setup Beam	false	false
Beam Presence	true	true
Moveable Devices Allowed In	true	true
Stable Beams	true	true

- Wait for Page 1 flags: stable beams, and movable devices allowed in
- Power - check temperatures, bias currents, occupancies
- Closing manager automatically (under supervision) closes the VELO
- Four steps in x: 29 mm - 14 mm - 5 mm - 1 mm - closed
    - Automatic verification of safety checklist
    - Lookup/calculation of next position
    - Human confirmation
    - Movement in x, movement in y if request > 50 microns

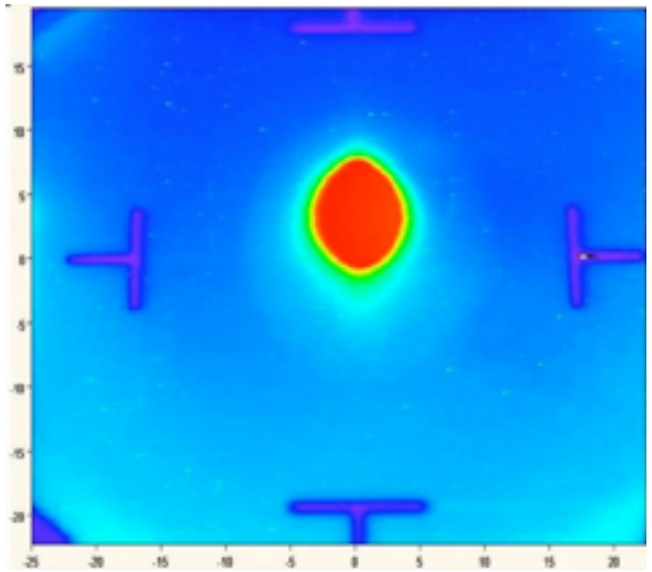
Closing safety checks



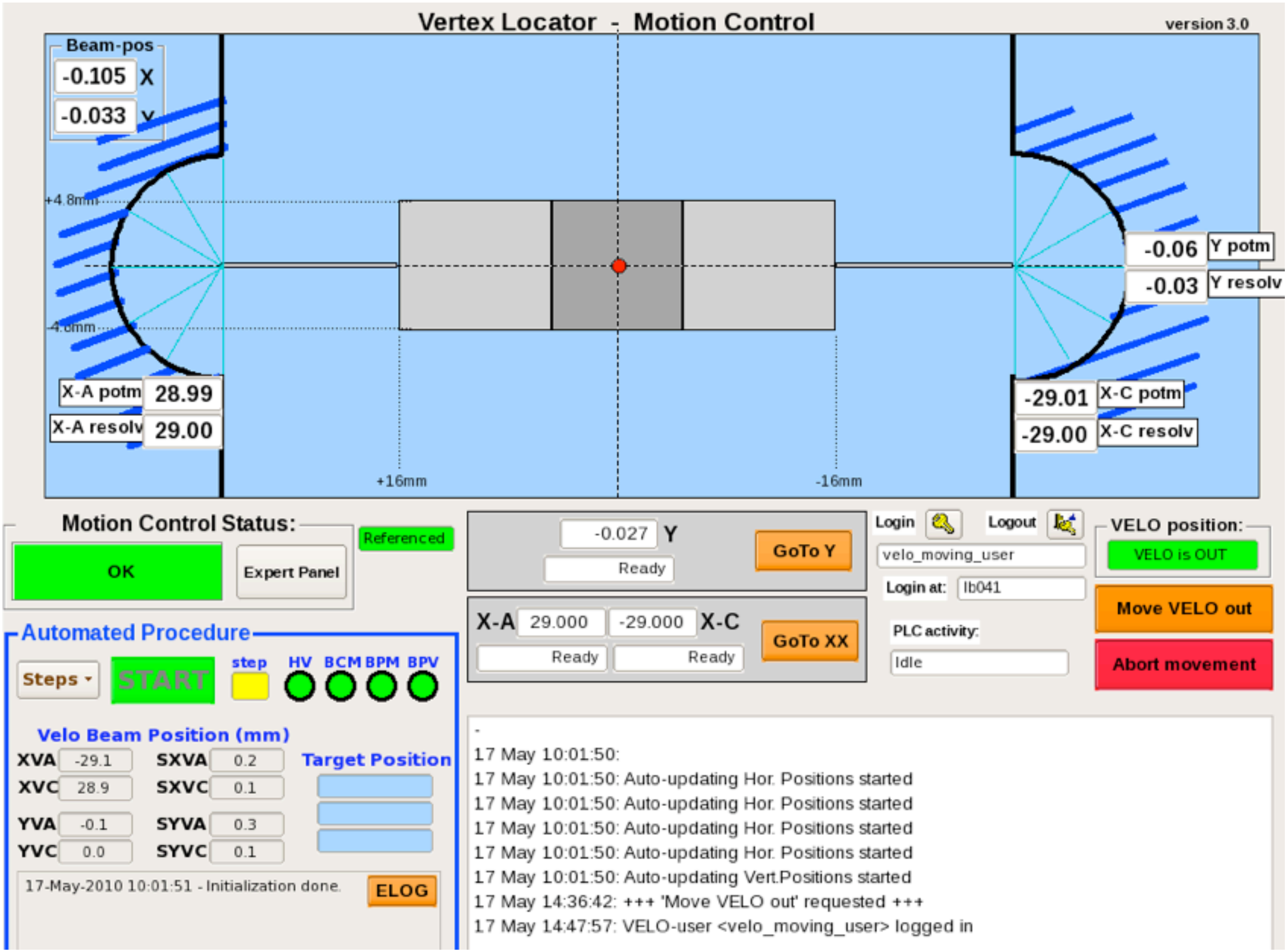
How to maintain detector security:

- Silicon bias currents - hardware measurement, very reliable
- Beam condition monitors - made of radiation hard diamond
- Beam position measurements - their absolute values and rate of change of position
- Reconstructed beam position and width - straight line VELO tracks loosely vertexed

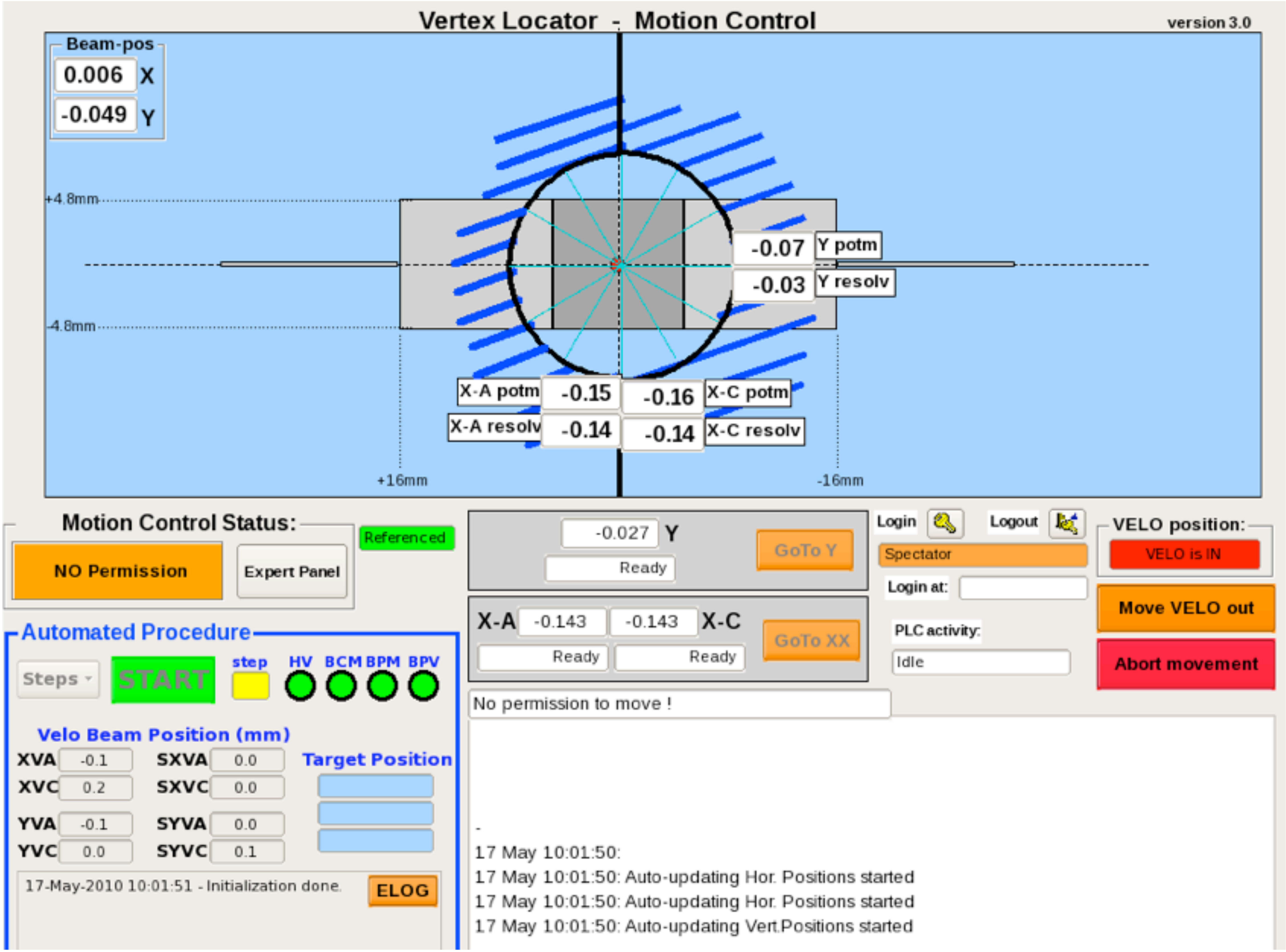
#	Quantity	ActualValue	Criterion	Status
1.	I VL01AB	2.8 uA	< 3 uA	OK
2.	I VL01CB	0.6 uA	< 5.5 uA	OK
3.	I VL02AT	3.2 uA	< 4.5 uA	OK
4.	I VL02CT	5.4 uA	< 7.5 uA	OK
5.	D(B1L8H), D(B1R8H)	0 um, 0 um	< 200 um	OK
6.	D(B1L8V), D(B1R8V)	2 um, 3 um	< 200 um	OK
7.	D(B2L8H), D(B2R8H)	10 um, 2 um	< 200 um	OK
8.	D(B2L8V), D(B2R8V)	3 um, 10 um	< 200 um	OK
9.	|XVA + XVC|	14.8 um	< 200 um	OK



Closing manager



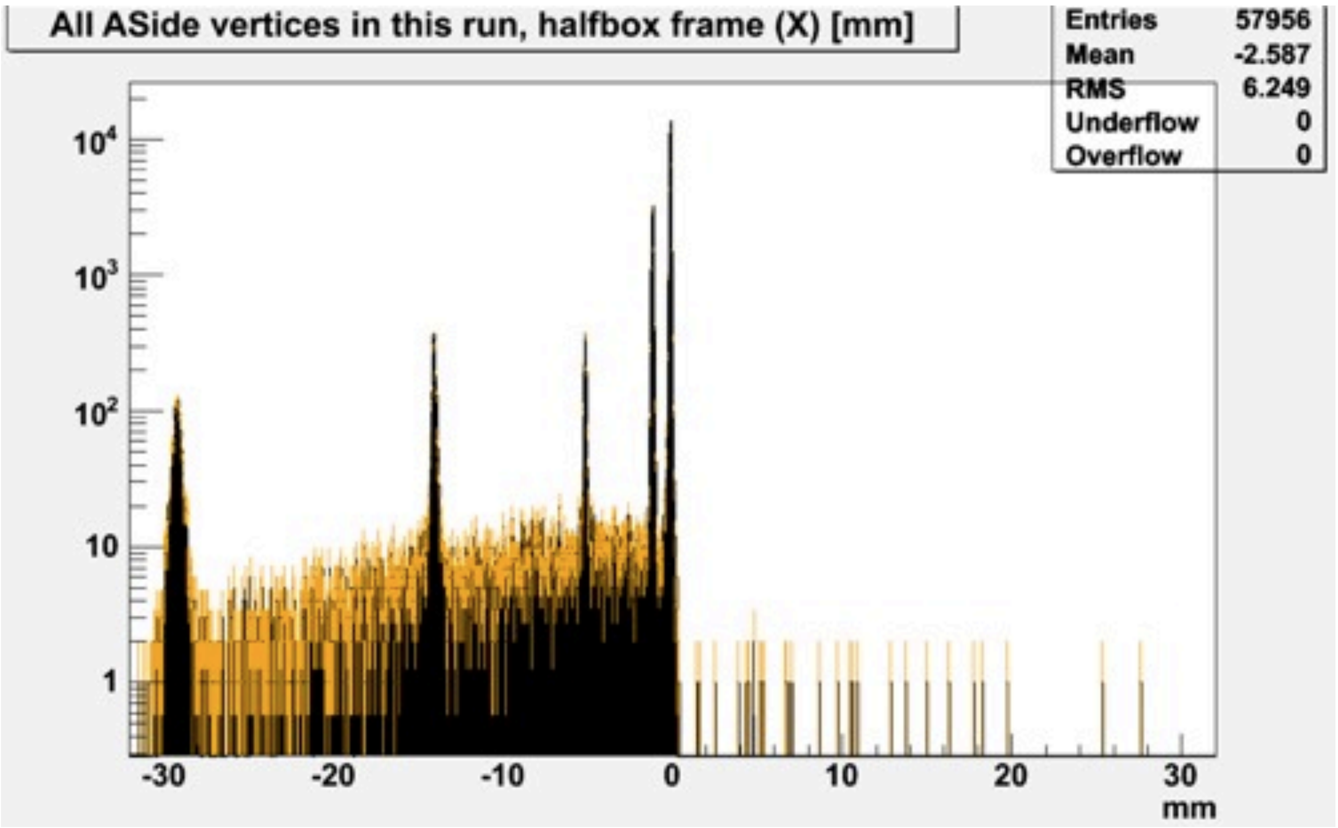
Closing manager

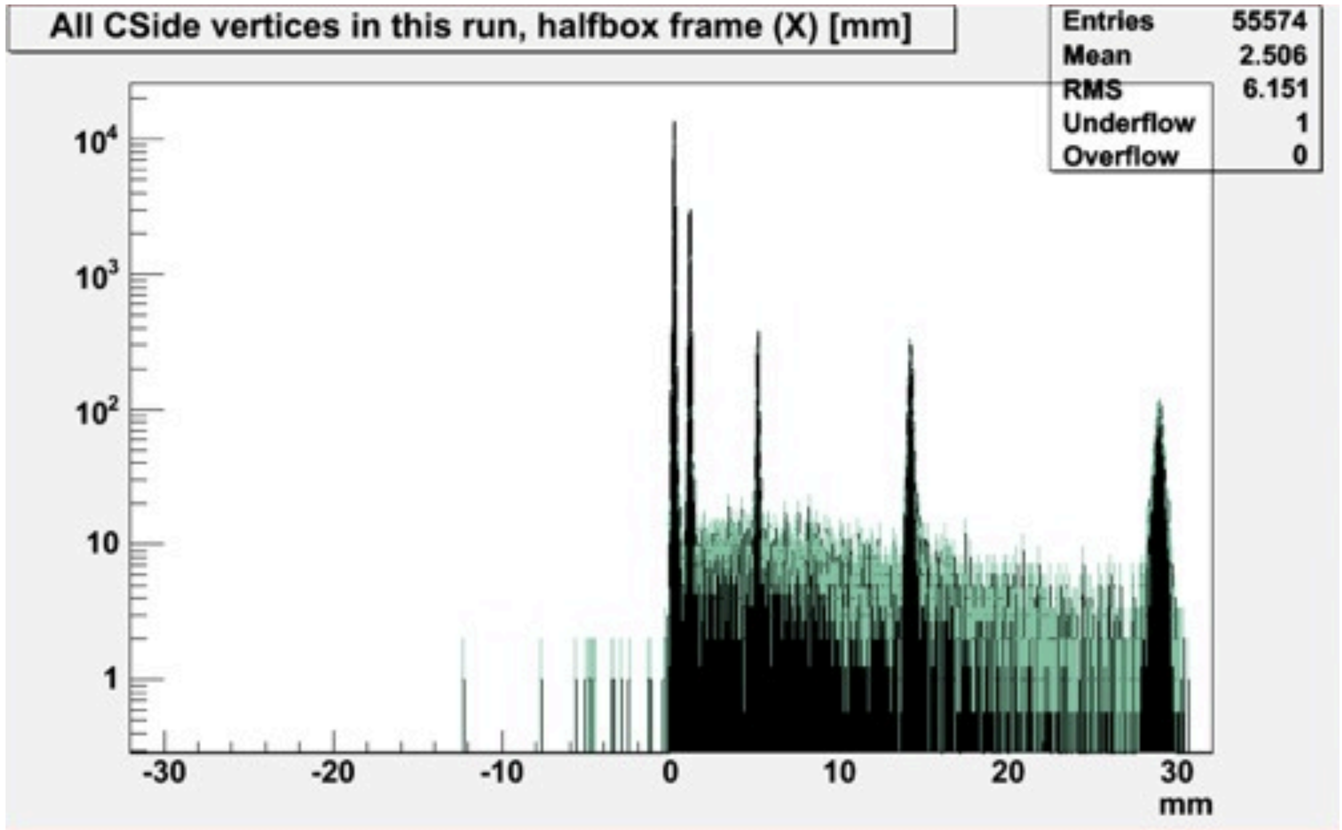


Vertex position during closing

What the VELO sees as it closes:

- Taken in the local frame of each VELO half
- Peaks where VELO paused to check safety and optimal position
- Smear of vertices reconstructed during movement
- Reconstruction rate and resolution improves as VELO approaches beam

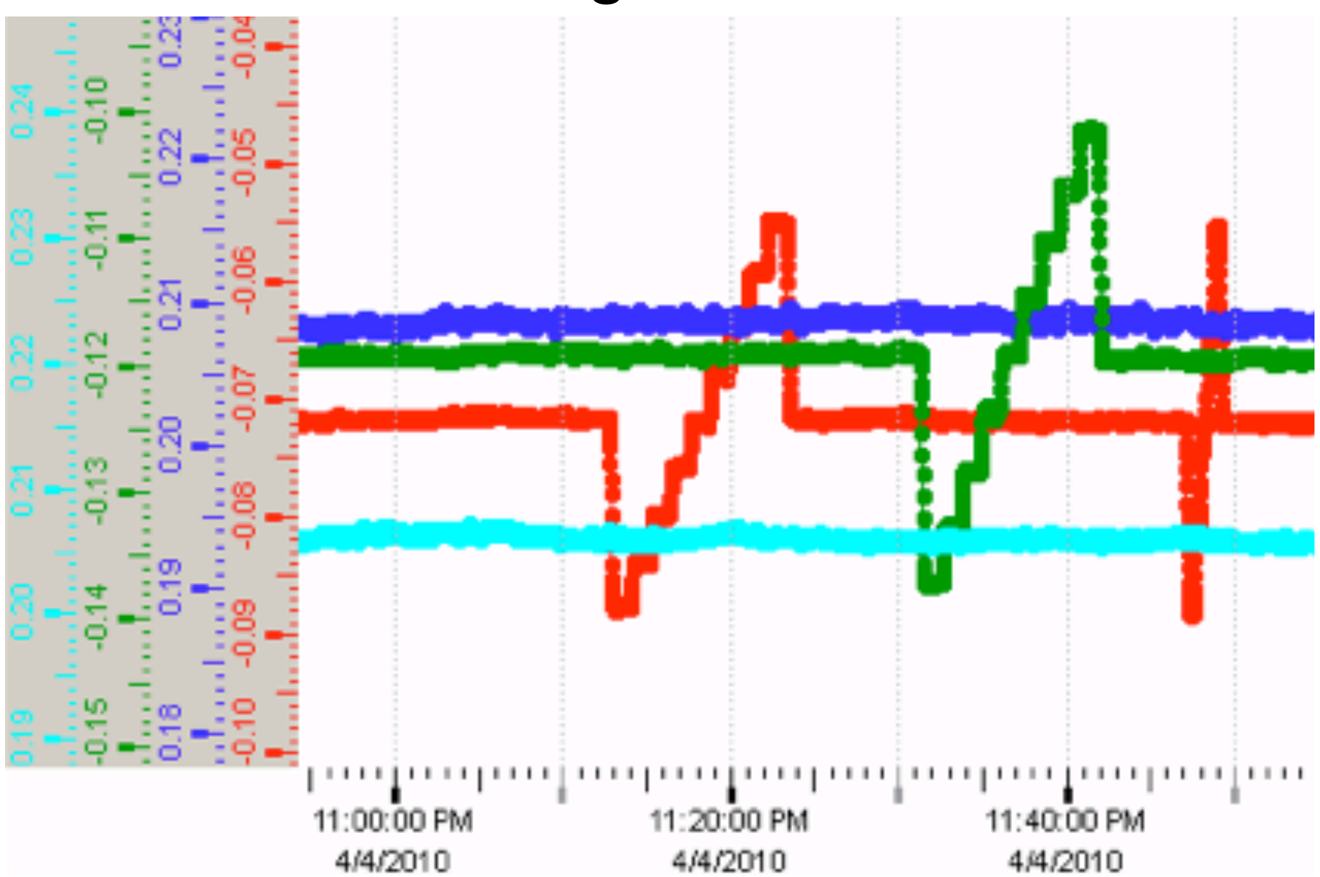




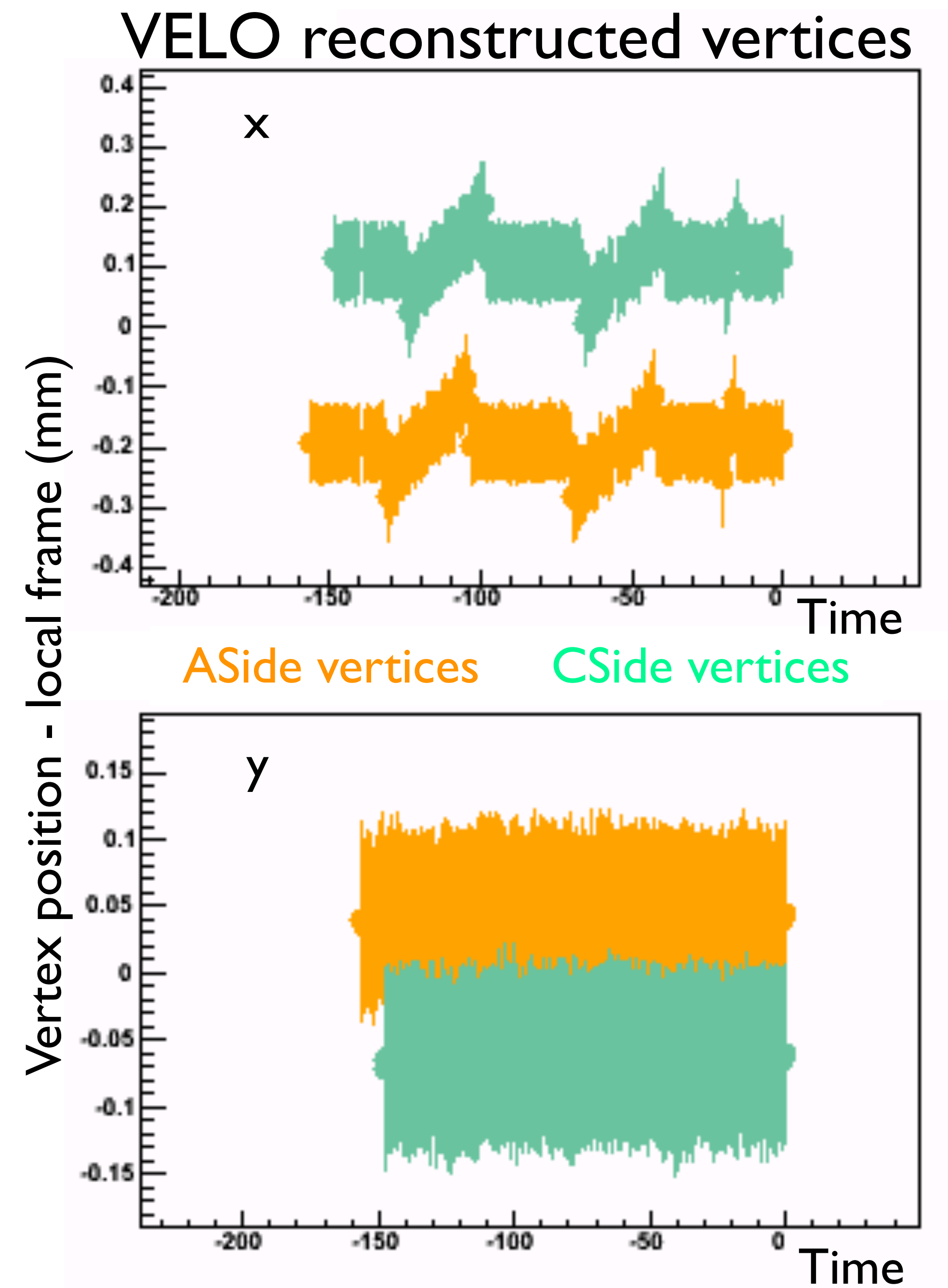
Beam monitoring

- Once the VELO is closed, it continues to monitor beam stability
- During luminosity scans the two beams are adjusted to find the point of highest rate
- We see the movement of the BPM values mirrored in the reconstructed vertex position

BPMs at edge of LHCb cavern



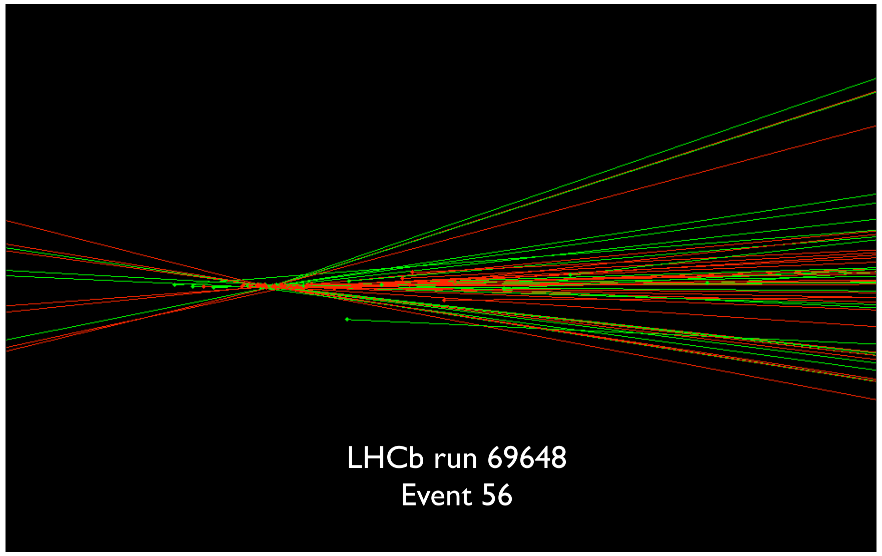
Beam1 - horizontal (cm)
Beam2 - horizontal (cm)
Beam1 - vertical (cm)
Beam2 - vertical (cm)

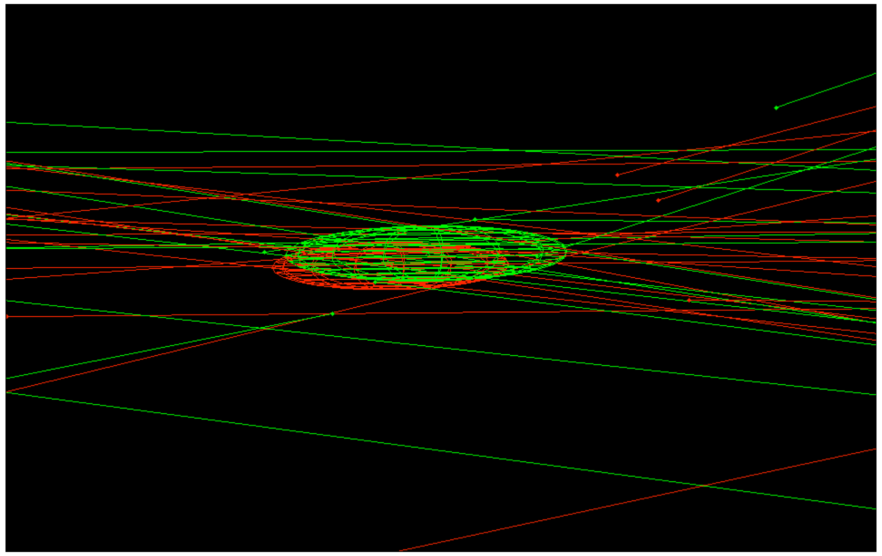


Vertex resolution method

Primary vertex resolution is dominated by the number of tracks used in the vertex. Method:

1. For each event, split the set of tracks into two
2. Make a vertex from each new set of tracks
3. If the number of tracks used to make each vertex is the same, take the difference between their positions
4. Fill a residual histogram for each nTracks
5. Fit this with a Gaussian
6. Resolution for this number of tracks is the Gaussian sigma / sqrt(2)





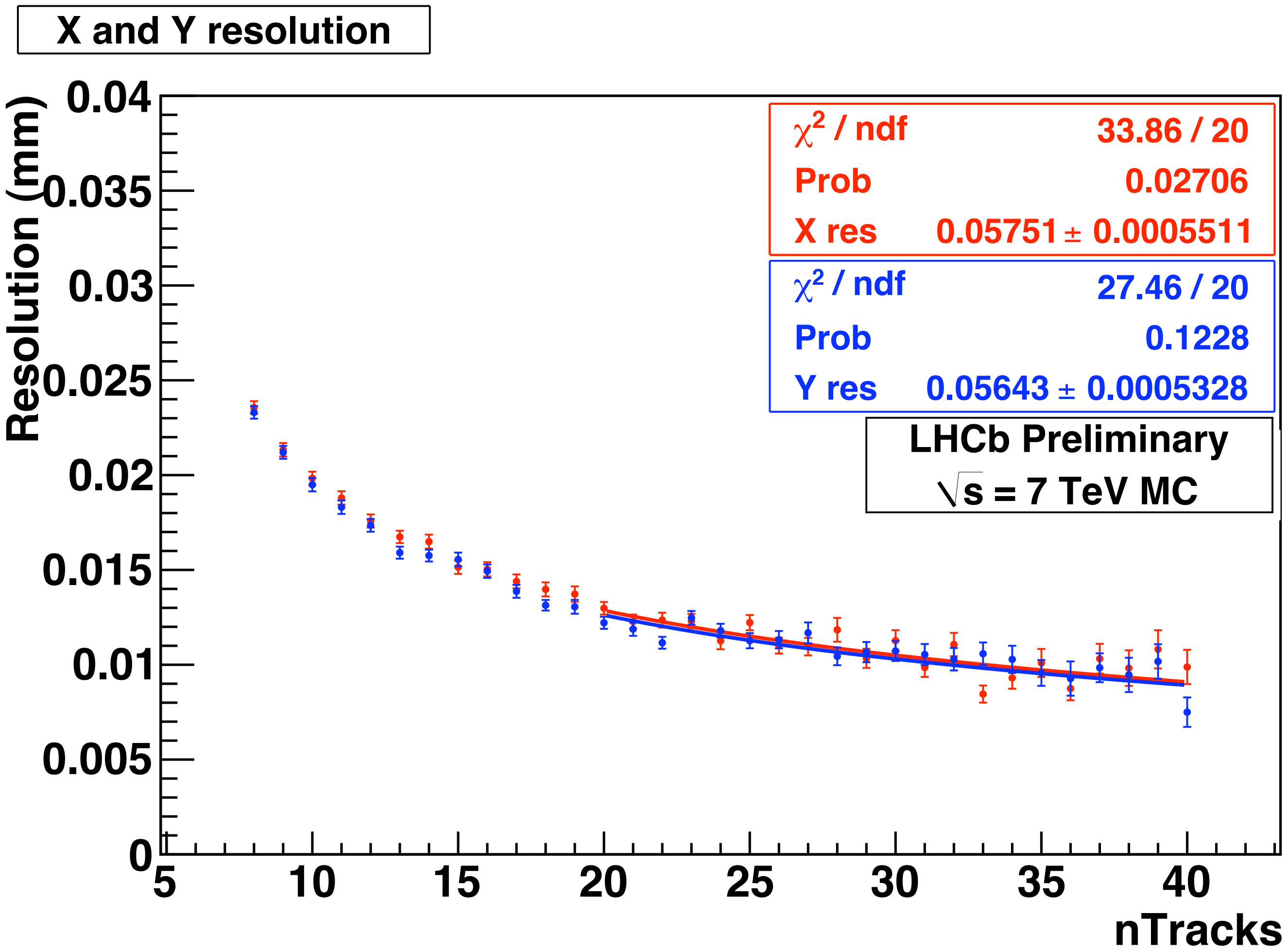
$$
\begin{aligned}
x_r &= x_1 - x_2 \\
\sigma_{x_r}^2 &= \sigma_{x_1}^2 + \sigma_{x_2}^2 = 2\sigma_x^2 \\
\sigma_x &= \frac{\sigma_{x_r}}{\sqrt{2}}
\end{aligned}
$$

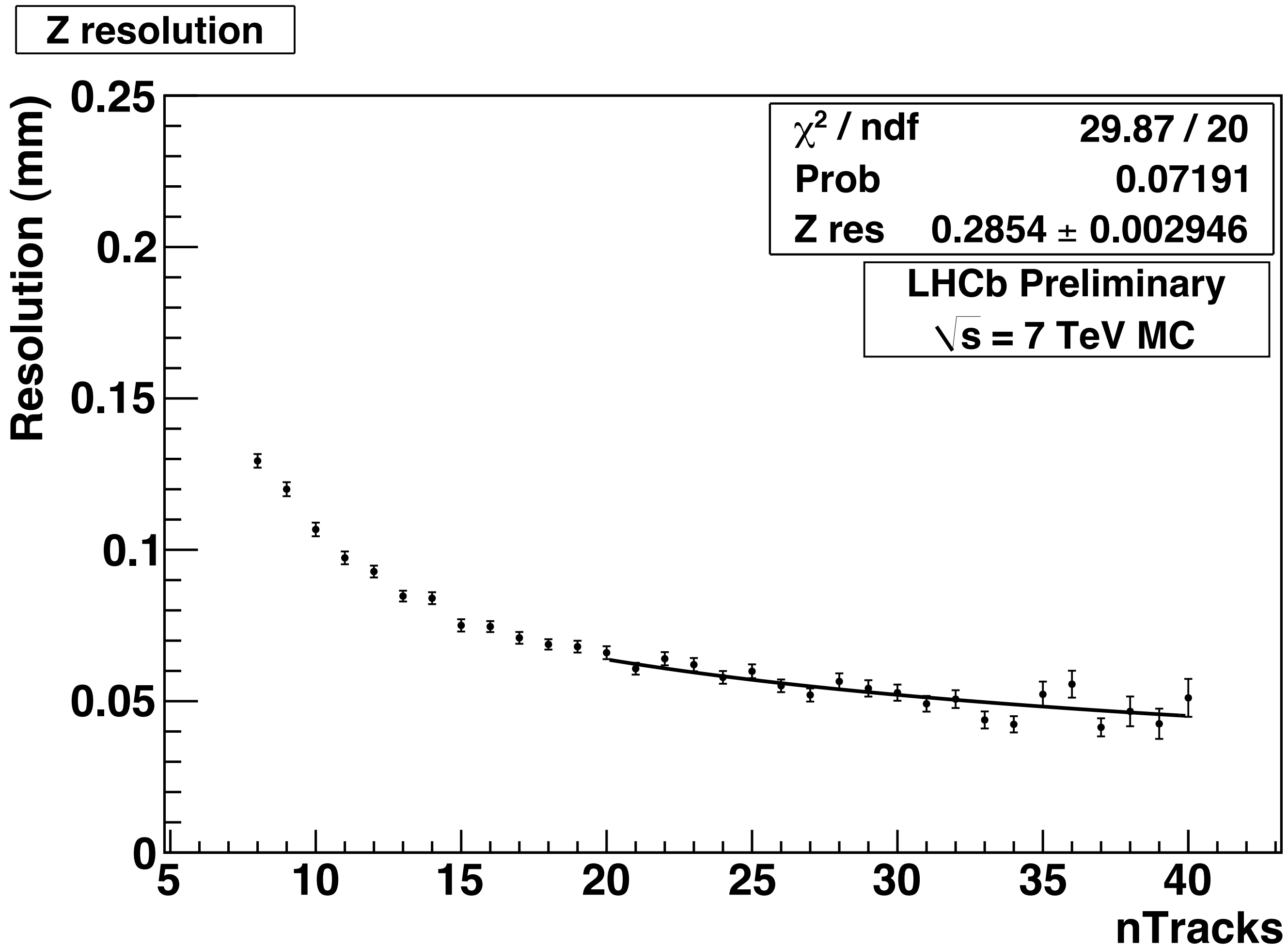
Vertex resolution in MC

Monte Carlo confirmed the strong dependence on the number of tracks per vertex

- The systematic uncertainty due to half misalignment was calculated as 1 microns
- The systematic uncertainty due to sensor misalignment is deemed to be 3 microns
- For an average vertex with nTracks = 25, resolutions are :

x: 11.5 microns, y: 11.3 microns, z: 57 microns





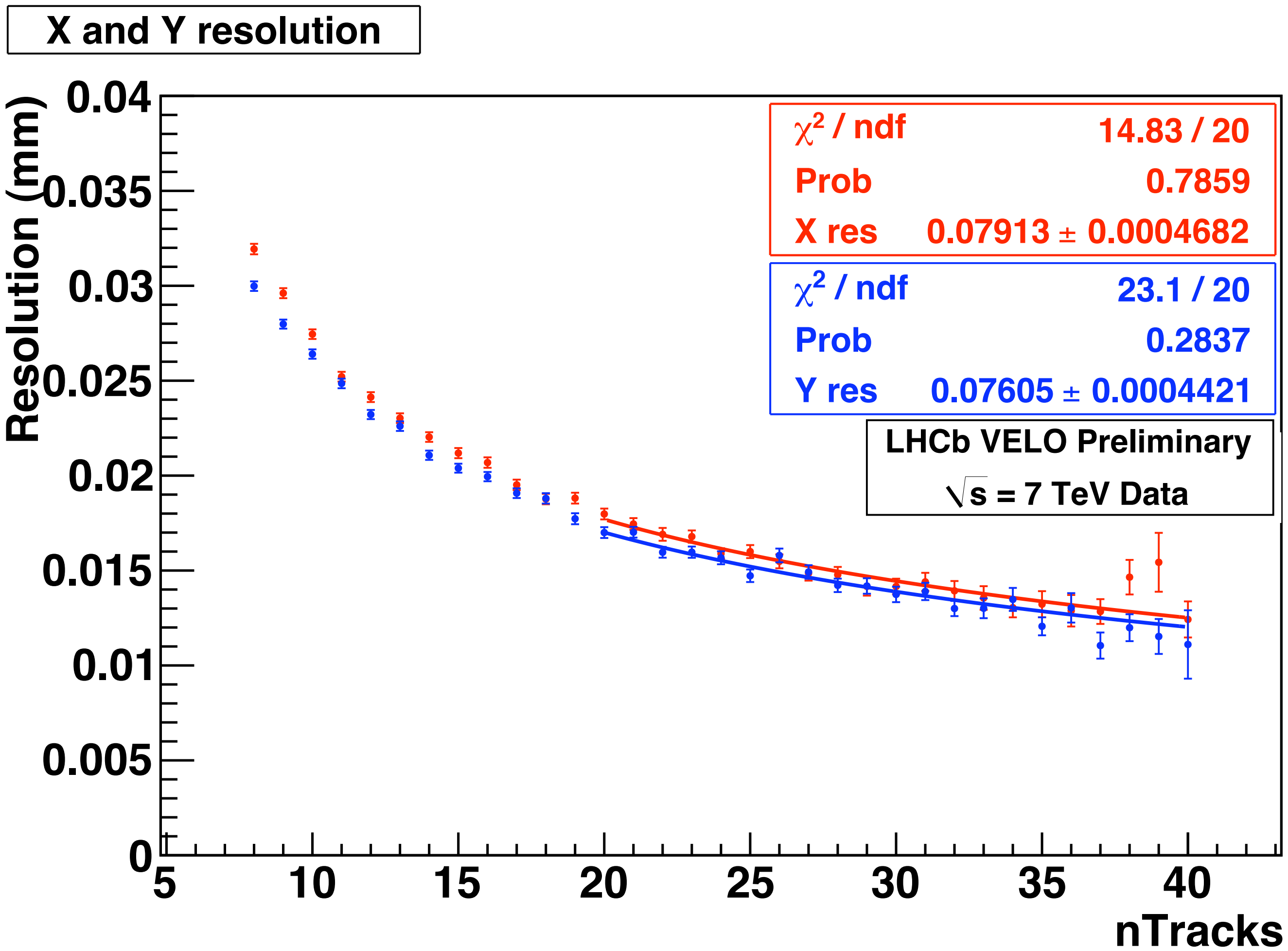
Measurements fitted with constant/$\sqrt{\text{nTracks}}$ from 20 to 40 tracks

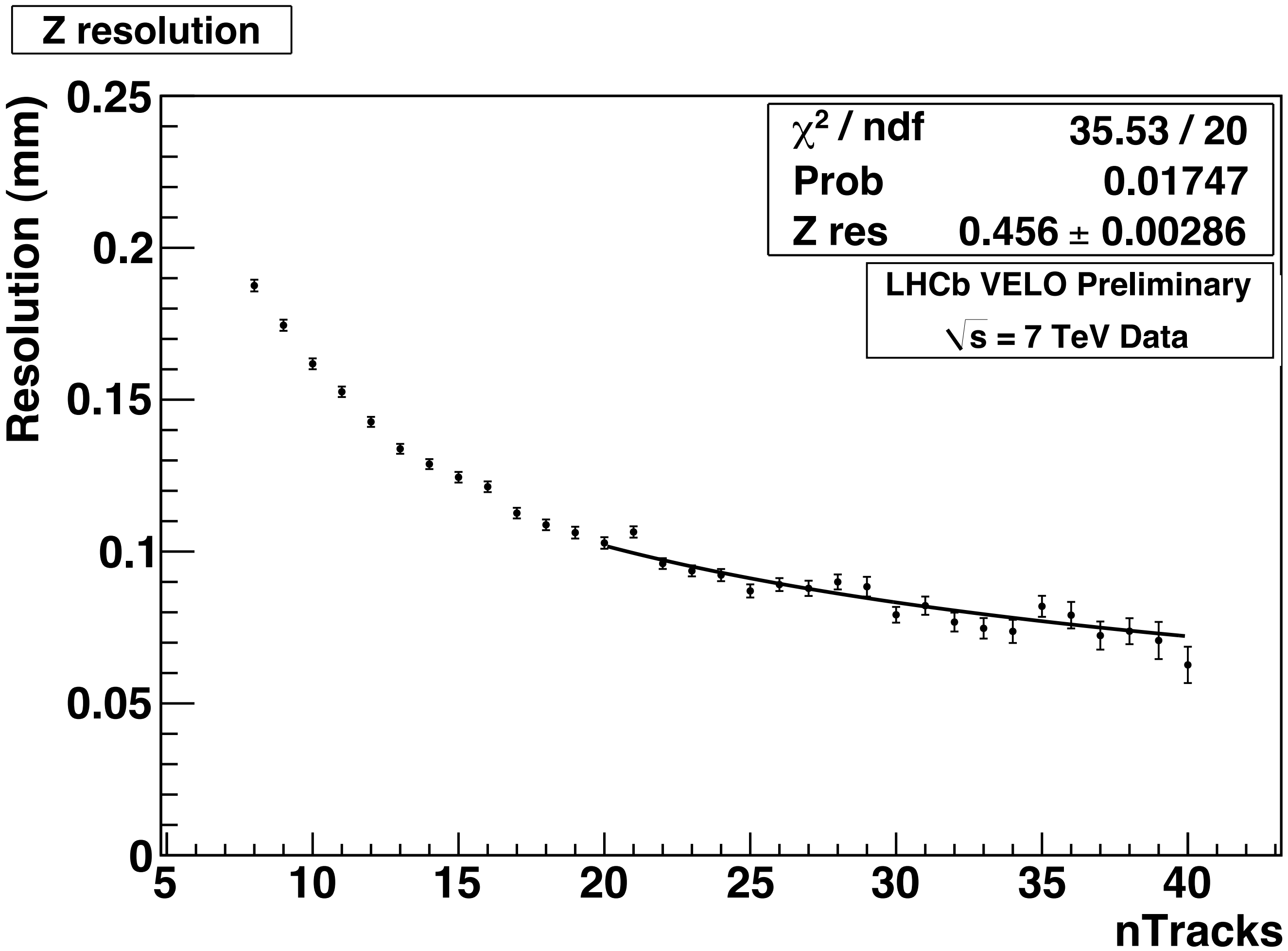
Vertex resolution in data

In data, the dependence on number of tracks is maintained, however resolutions are slightly larger than in MC

- Resolution in y is marginally better than in x
- For an average vertex with nTracks = 25, resolutions are :

x: 16 microns, y: 15 microns, z: 93 microns



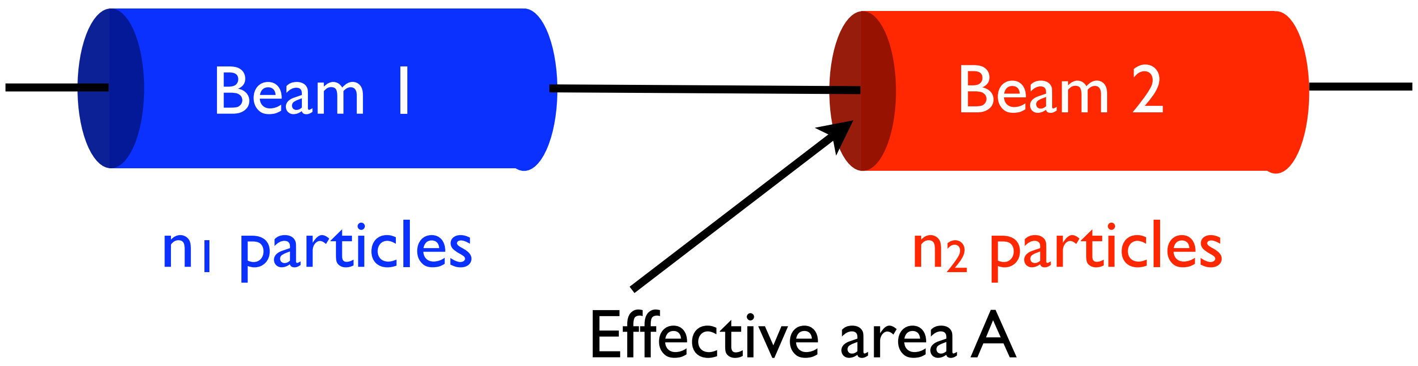


Measurements fitted with constant/$\sqrt{\text{nTracks}}$ from 20 to 40 tracks

Luminosity measurement

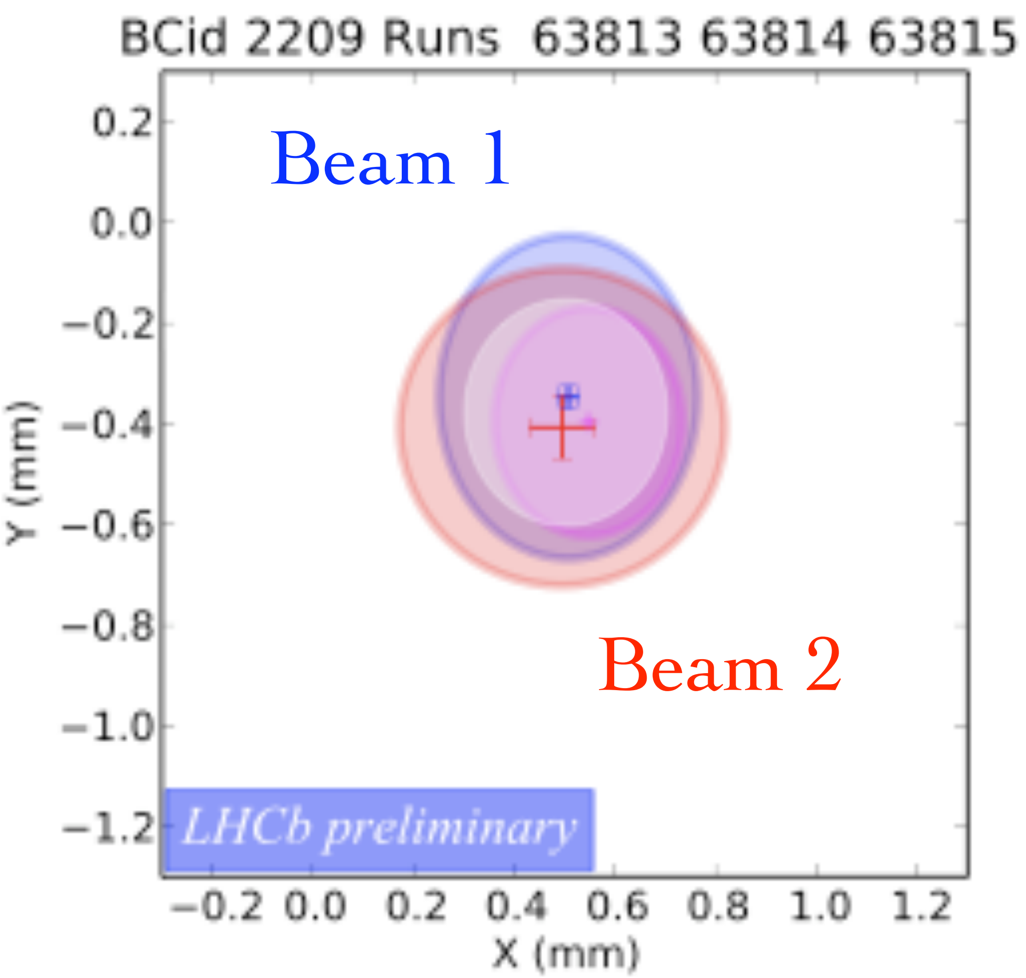
To measure the 2009 450 GeV run luminosity from beam parameters:

- Measure the effective area of the two beams by calculating their overlap integral
- Combine with beam-current information from the LHC to find luminosity
- Revolution frequency of 11 kHz, multiplied by number of colliding bunches



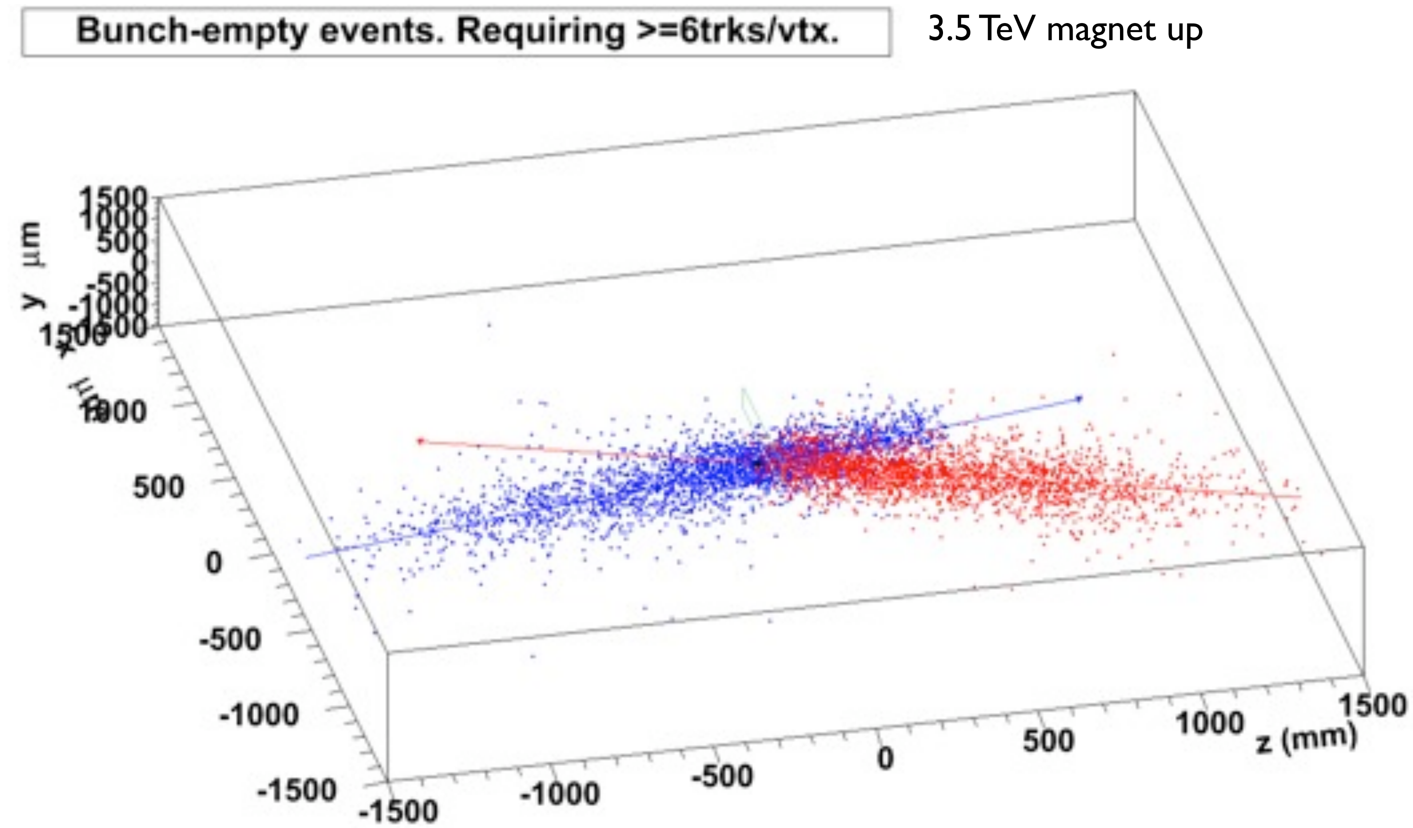
$$\mathcal{L} = \frac{n_1 n_2 f}{A}$$

f : collision frequency
n : number of particles per bunch
A : area of beam overlap

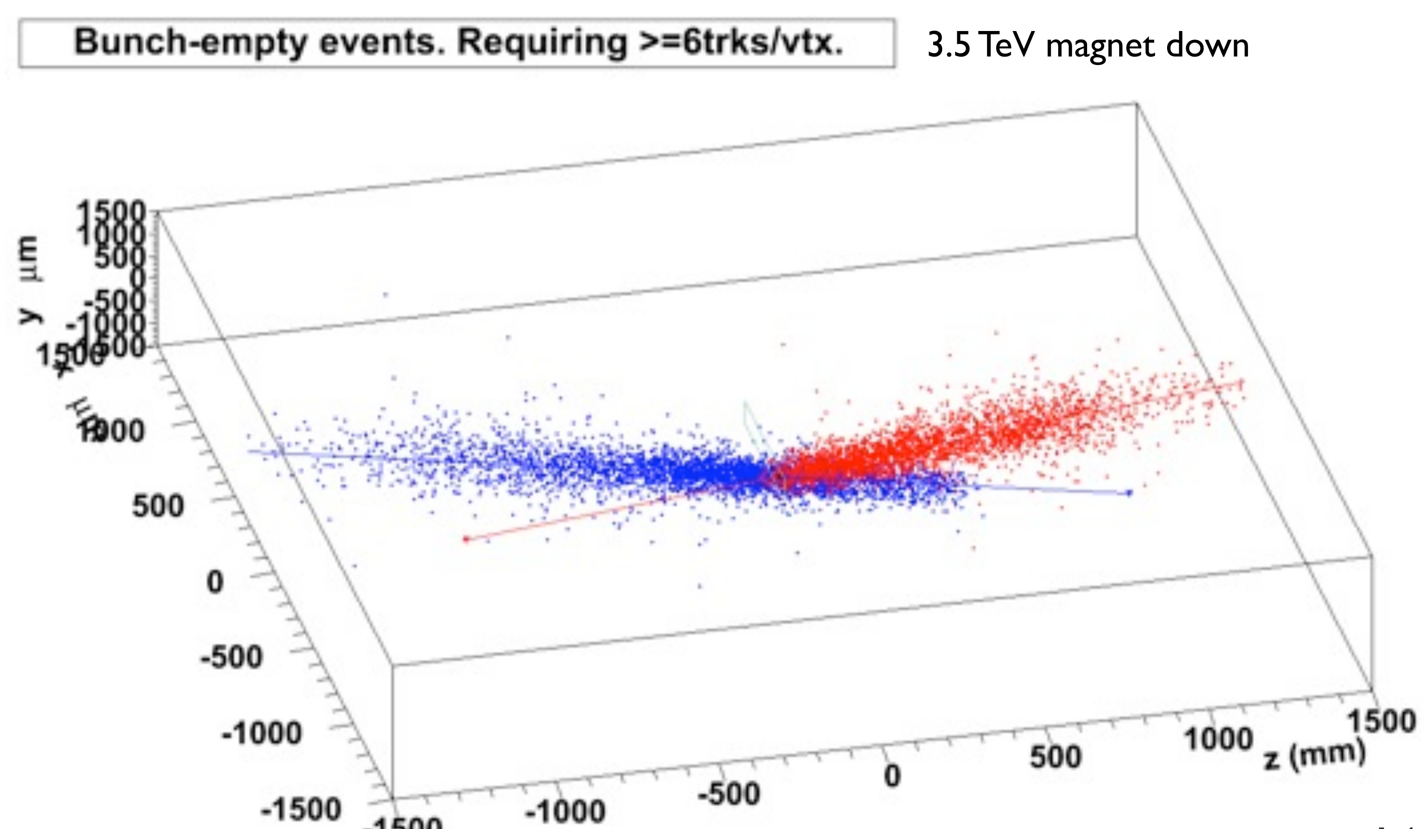


Beam-gas reconstruction

- VELO can reconstruct the two beams separately using beam-gas events
- Gas pressure in beam-pipe is around 10^{-9} millibar
- Resolution depends on number of tracks, and also z position
- Bin events by number of tracks, and z-position
- Beam width, position and resolution calculated for each bin



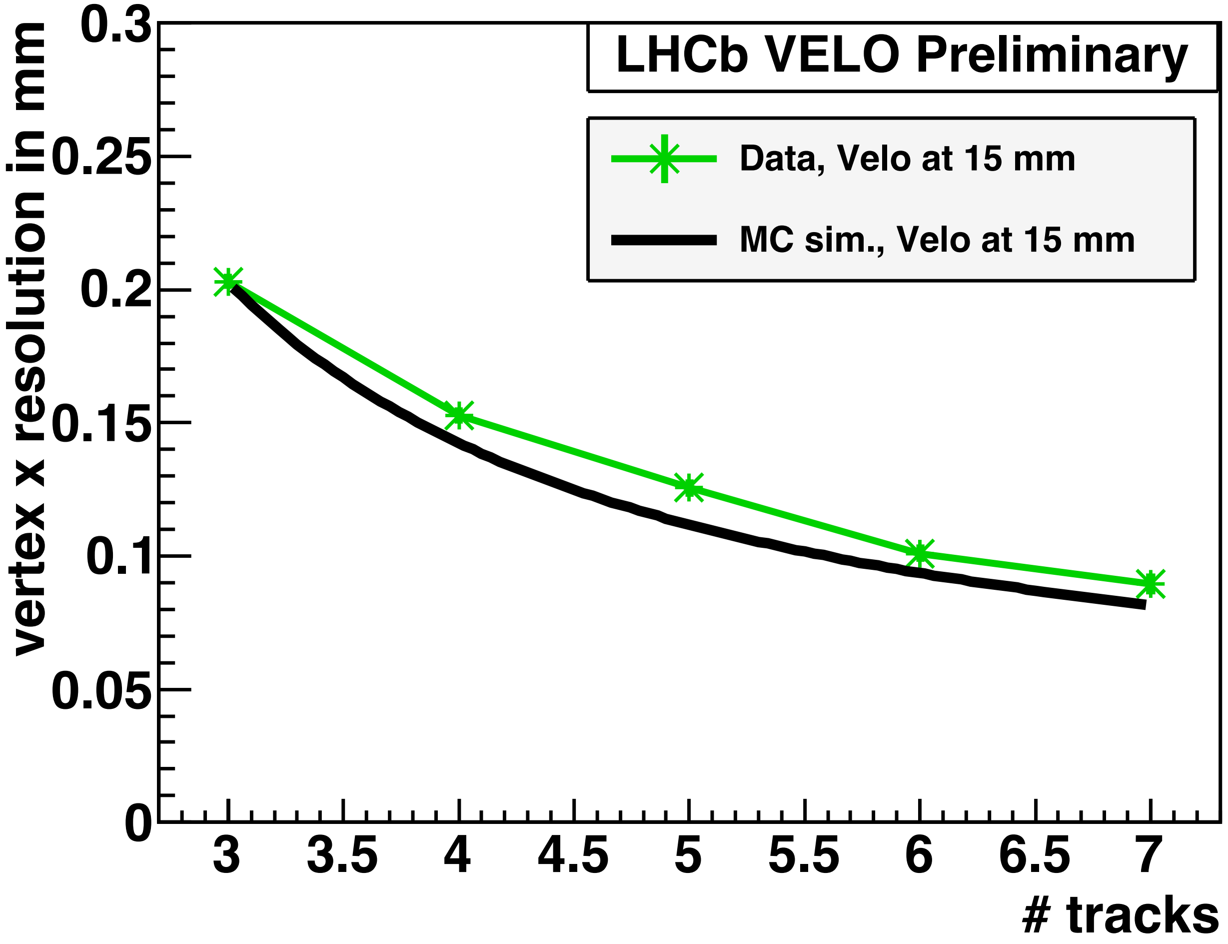
3.5 TeV magnet up

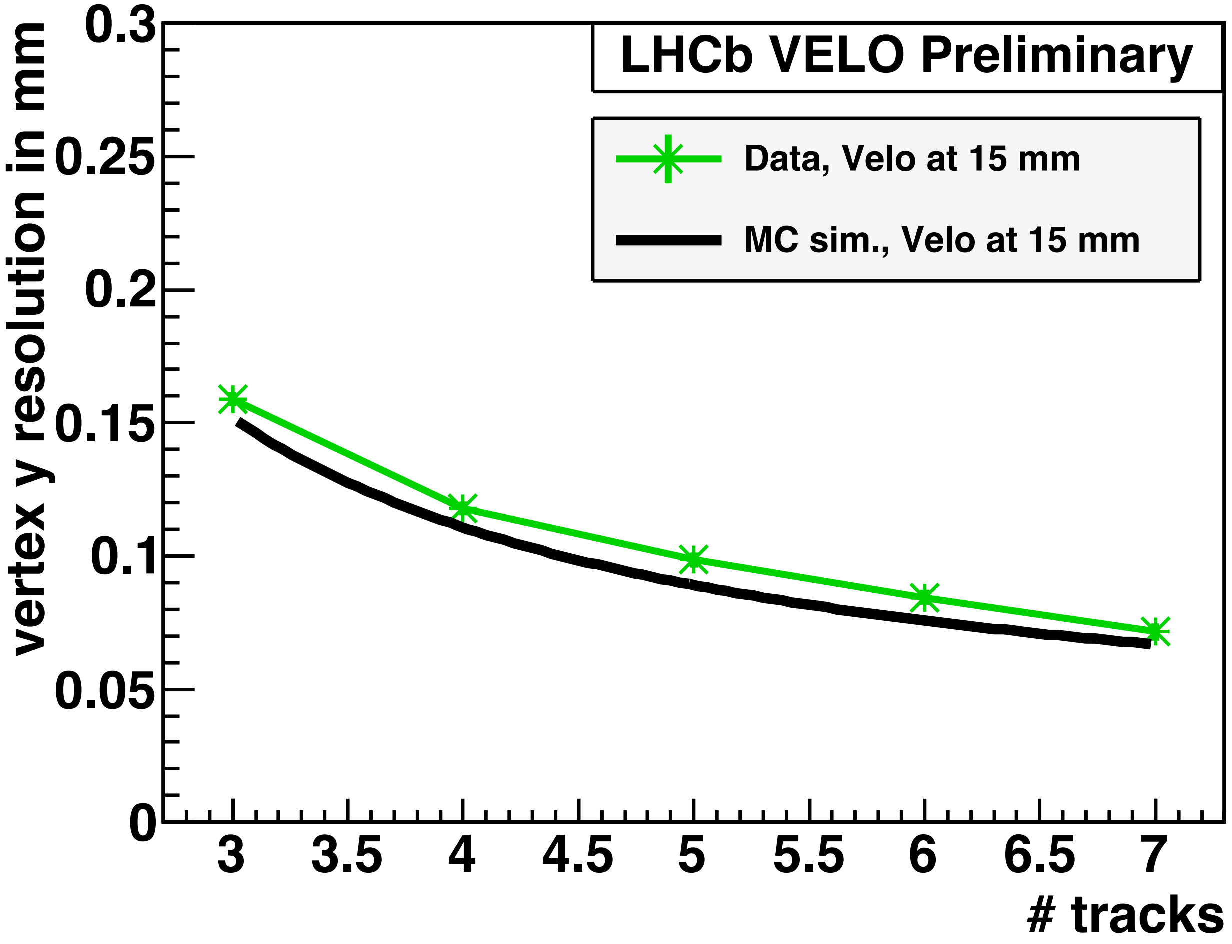


3.5 TeV magnet down

Resolution - track dependence

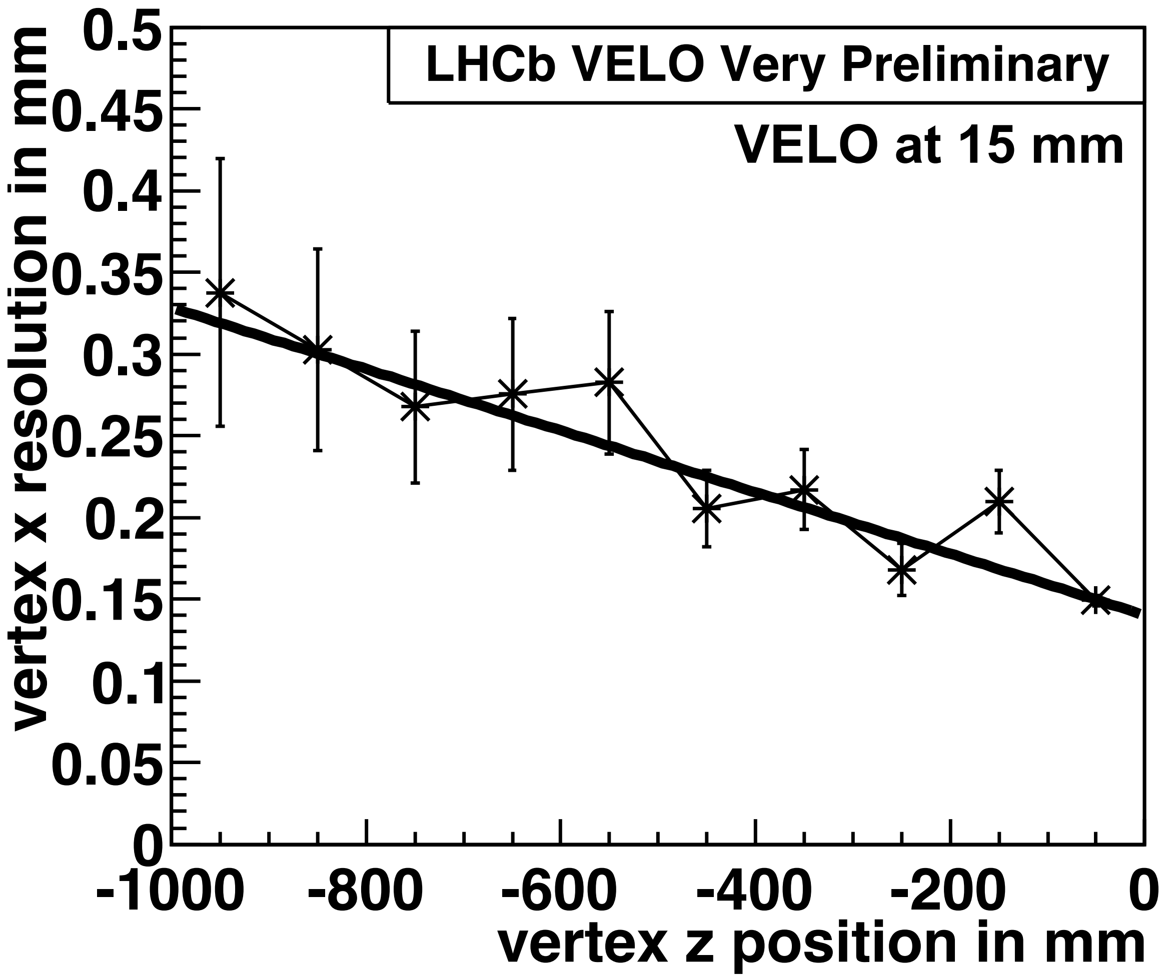
- During the 450 GeV runs, VELO is closed to 15 mm due to larger beam sizes
- MC - data agreement is good
- The resolution is better in y than in x (due to the beam-VELO distance)
- The dependence is approximately $1/\sqrt{nTracks}$

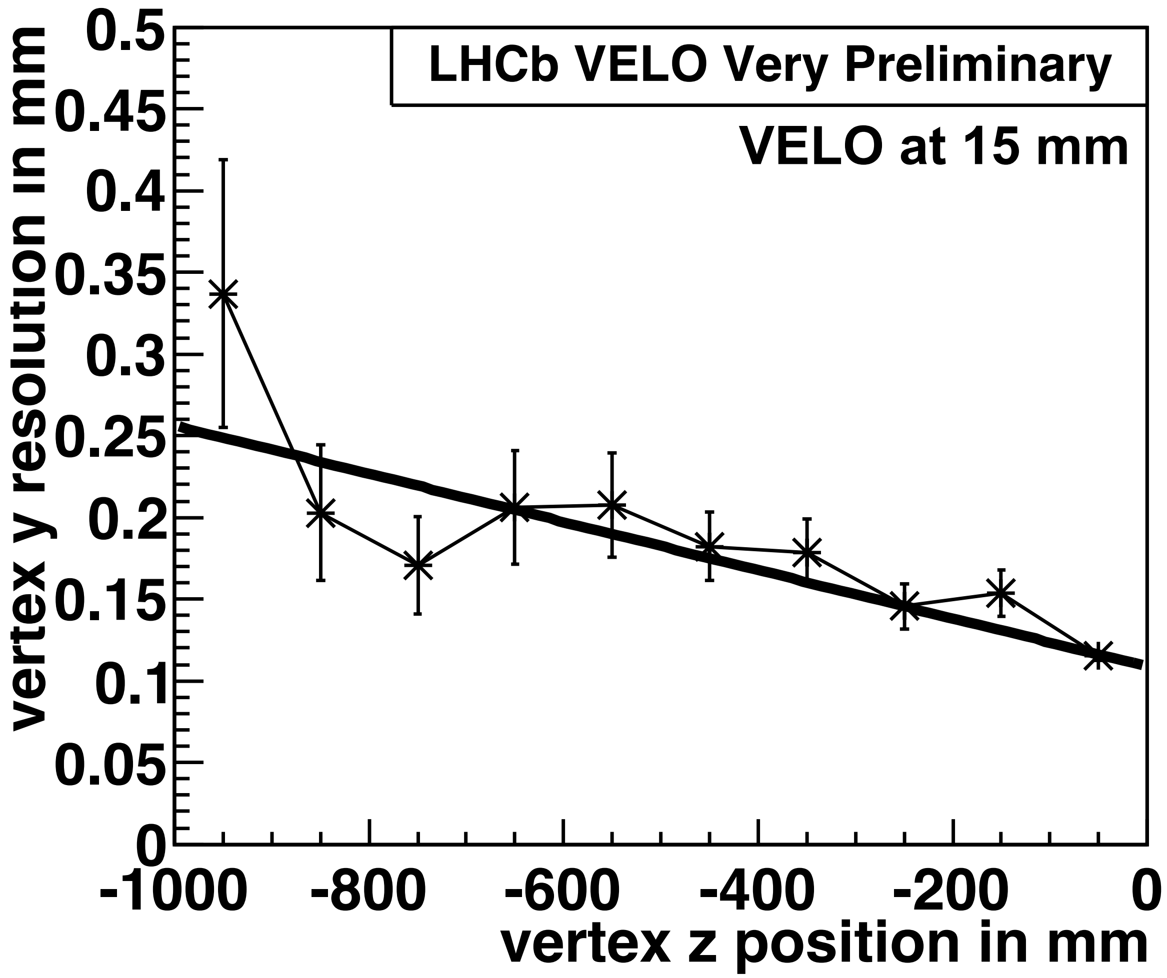




Resolution - z dependence

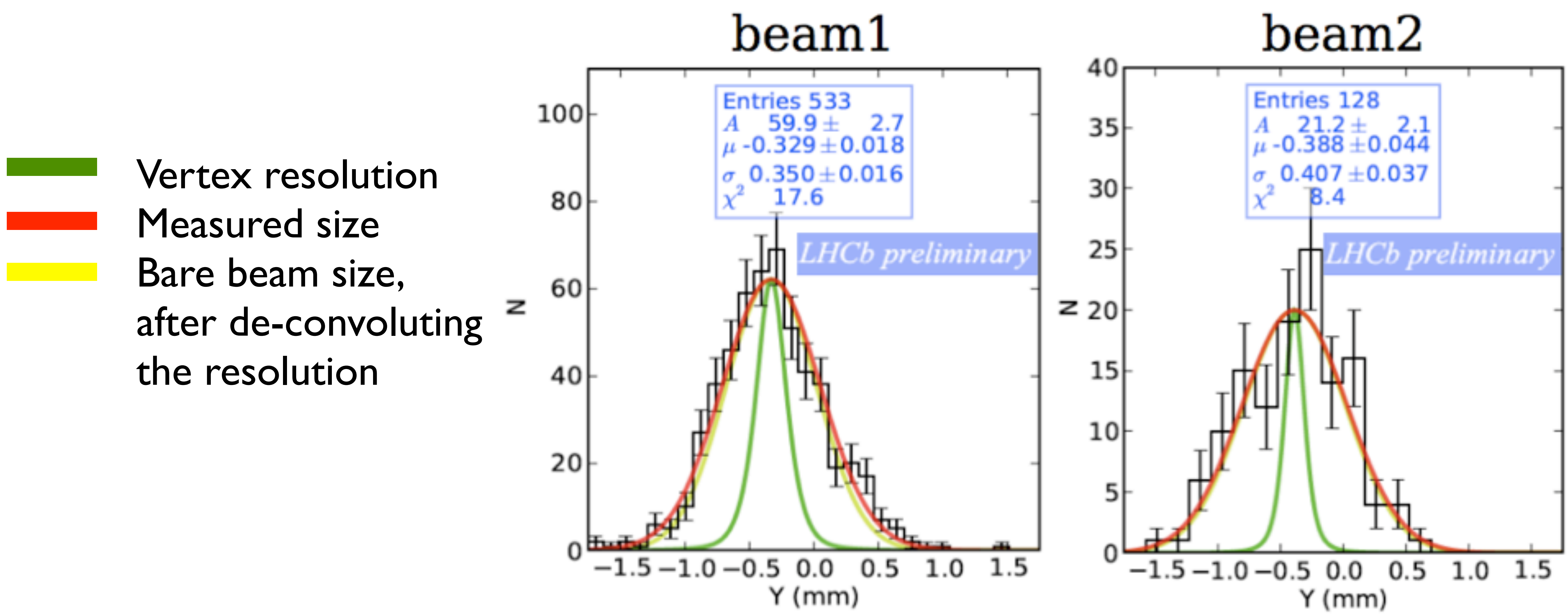
- The resolution varies depending on the position of the vertex along z
- This is due to the geometry of the VELO and track extrapolation distance
- Plotted is the RMS of the vertex residual distribution for 5 track vertices using beam-gas events from beam 1 (in data)
- Dependence is linear and independent of N (within statistics)





Luminosity result

- Resolution measured in bins of z and number of tracks
- Unfold the resolution from the measured width to give the bare beam size
- This is then used in the overlap integral to calculate the effective area



450 GeV 2009 sample has integrated luminosity of 6.8 ± 1 μb^{-1} where the dominant uncertainty comes from the beam-currents

Conclusion

- VELO closing - a tricky job practically impossible to practise without beam - is being perfected and will soon be fully automated
- Currently with human supervision, it takes just over 6 minutes, with an irreducible mechanical background of 2.5 minutes
- Vertex resolution is 16 microns in the transverse plane, 93 microns in z
- Coverage in regions of high pseudo-rapidity allows beam-gas reconstruction
- Crucial component of LHCb luminosity measurement used in the K-short production paper, integrated luminosity in 2009 was 6.8 ± 1 μb^{-1}
- Working on 2010 luminosity measurement