Requirements from BI and new instruments after LS1

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Content

- Specification LHC and Injectors
- Wire scanners
- Beam Gas Vertex Detector
- Betatron function measurements

Specifications

Functional Specification

(EDMS n. 772786)

MEASUREMENT OF THE TRANSVERSE BEAM DISTRIBUTION IN THE LHC INJECTORS

5.1.3.1 PROFILE MONITOR FOR EMITTANCE COMPARISON AND CALIBRATION

The main use of the circulating beam profile monitors is to provide accurate profile measurements to determine accurately the beam emittance for comparison purposes between different machines to detect possible blow-up during extraction and/or injection.

The required accuracy in the beam size measurement is of few percents if accuracies in the range of 5% have to be achieved for the emittance measurement as required for the LHC proton and ion beams with nominal intensity. This level of accuracy requires a very good measurement of the optics properties at the beam profile monitor which might demand the

Functional Specification

MEASUREMENT OF THE TRANSVERSE BEAM DISTRIBUTION IN THE LHC RINGS

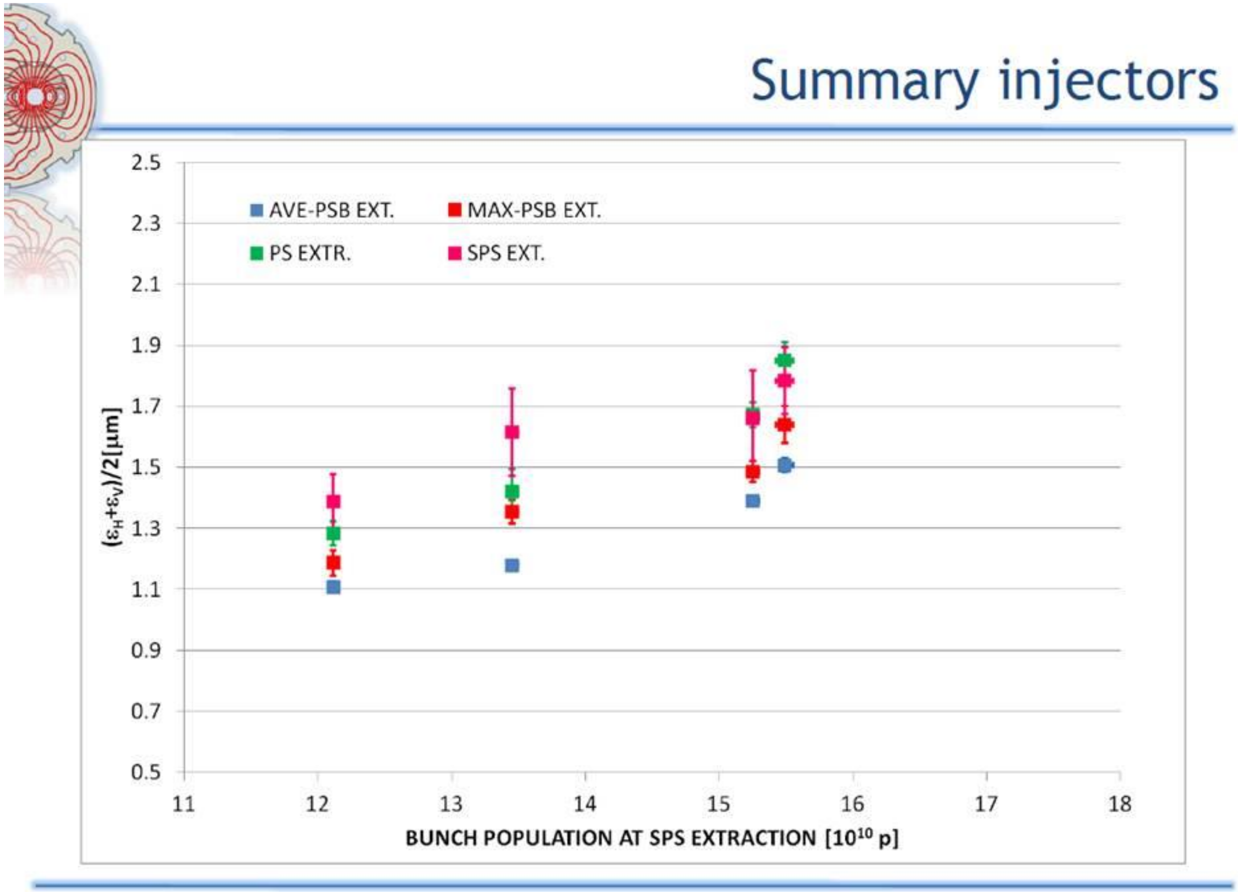
EDMS Document No.

328147

Monitor type/mode		Beam scenario	Observation mode	Precision mode/value
Single-pass to Few-pass	Beam spot	1 pilot to 1 nominal SPS batch	Turn-by-turn	Accuracy: • 20% rms on σ • average position: ≈ 300 µm rms
Single-pass to Few-pass	matching	1 intermediate bunch to SPS batch	Turn-by-turn over 20 turns	Resolution: ± 20% on σ
Circulating	matching	Intermediate to ultimate SPS batch	Turn-by-turn over 20 turns	Resolution: ± 20% on σ
Circulating	beam size and profile	Pilot to intermediate beam	10^3 turns	Resolution: 10% rms on beam σ
Circulating	beam size and profile	intermediate to ultimate beam	10^3 turns	Resolution: • 1% rms on beam σ • 5% rms on bunch σ • 10% rms on transv. distribution points • (± σ/10 in beam position)
Circulating	beam size and profile	intermediate to ultimate beam	10^2 turns	Resolution: 5% rms on beam σ
Circulating	Beam emittance		10^3 turns	Accuracy: ± 5% on beam σ
Circulating	tail	intermediate to ultimate beam	10^4 turns	Resolution: 10% rms on transv. distribution points

- Specification
  - Bunch by bunch resolution of 5 % in 0.1s
  - Accuracy 5 % on emittance in 0.1s
    => assumption 3.5% contribution from beam size and 3.5 % from beta function uncertenty
    => 1.8 % beam size accuracy
    (dsig/sig=1/2 depsi/epsi)

Injectors Wire Scanner Measurements

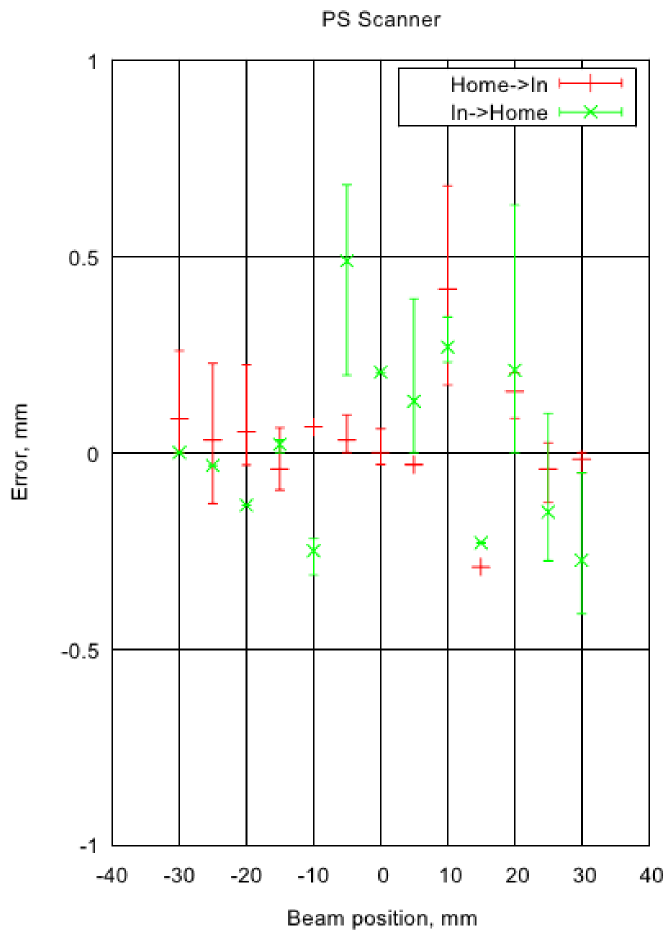


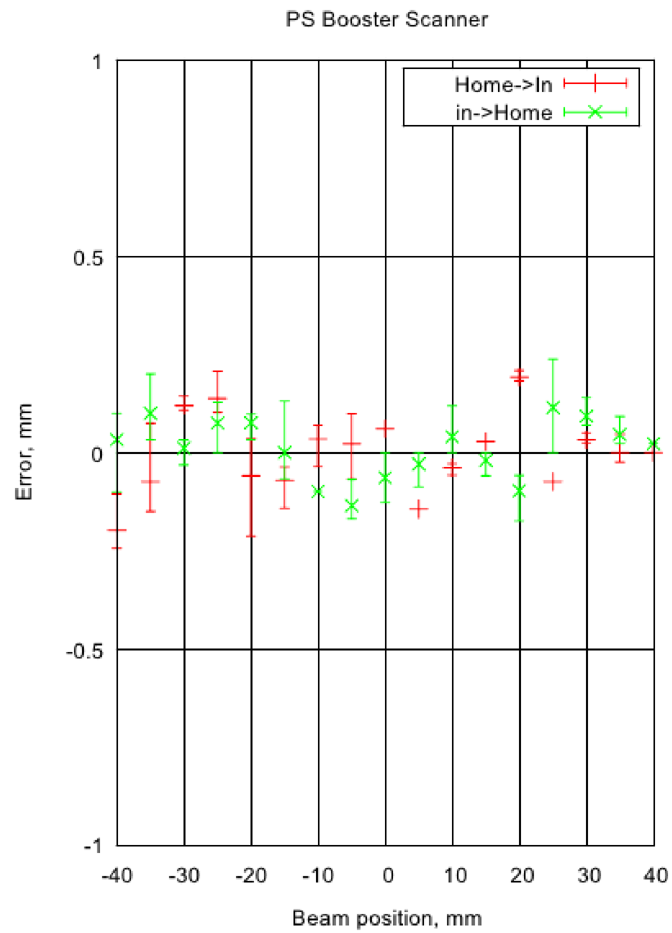
LMC summary on injector emittance measurements (G. Arduini)

Order (PSB, PS, SPS) of measurements more convincing at low beam intensities

LASER beam reproducibility test measurements

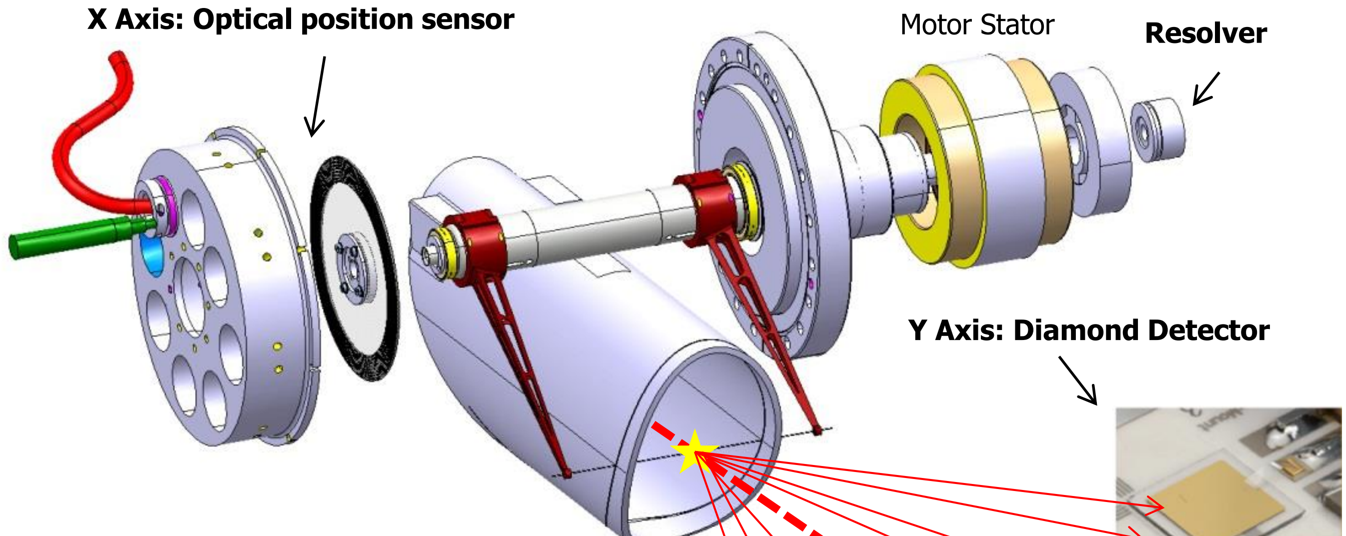
Verification measurement accuracy after having introduced calibration data





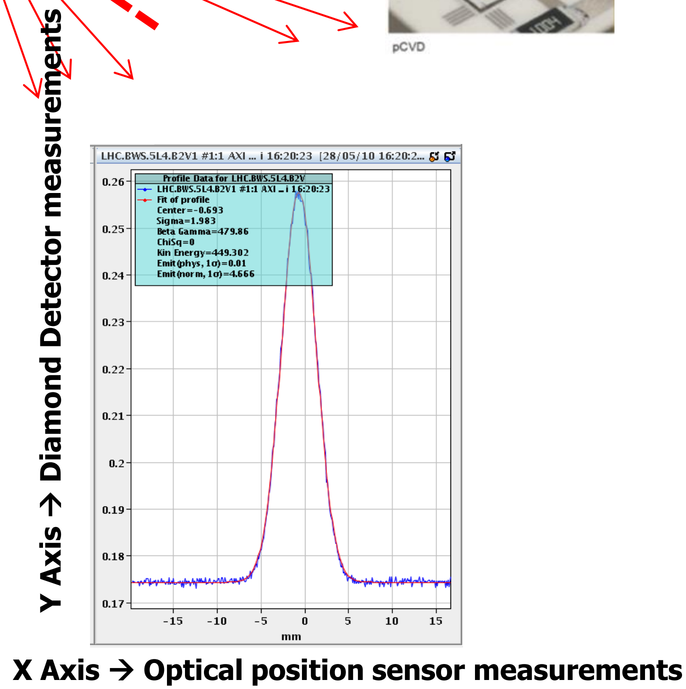
- Fluctuation up to several 100 um
- Fluctuation due to principle of scanner hardware

Schematic and First Design



- Absolute accuracy of beam width determination of about 5 um
  - Reduction of play in mechanical system
    => all elements mounted on same axis
  - Position measurement
    => high accuracy angular position sensor
  - Overcome bellow limitations:
    - Low lifetime
    - Friction

    => Locate all moveable parts in the vacuum
  - Minimize fork and wire deformations
    => Study of dynamic behavior of fork/wire system
    => Vibration mode optimized acceleration profile
- Large dynamic range for secondary particle detection
  => Usage of sensor with large dynamic (diamond)
  => Automatic electronic switching of gain ranges (**range dynamic 1E4**)



1. Optical Position Sensor

1.6 Tests & System performance

- Calibration Results: Speed: **290rad/s** , Alignment: 0.58deg, Spot 20um, Track 10um.

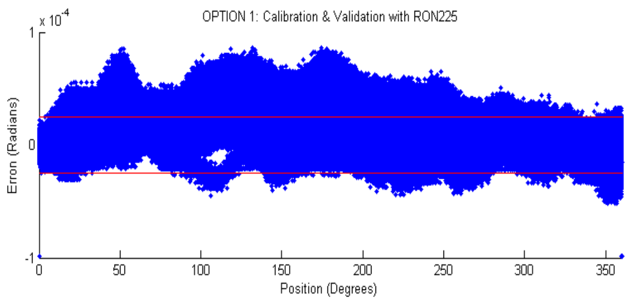
Fork Considered: 10cm

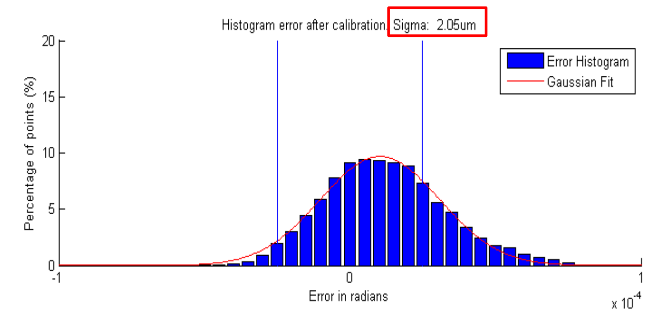
Resolution: **15.7µm**

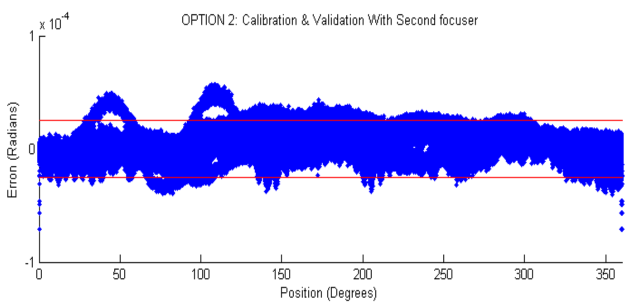
Error Sigma: **< 2.1µm**

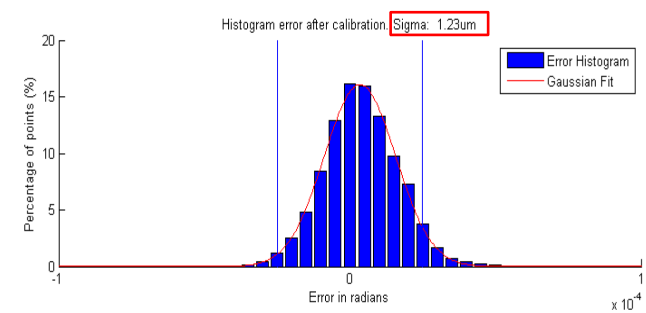
- Results in test-bench
- To be tested in prototype
- Better results expected!

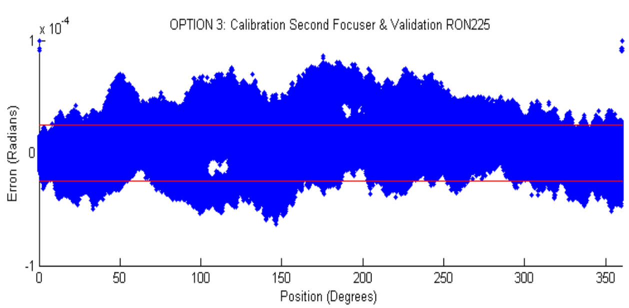
- Which method is more reliable for validation?

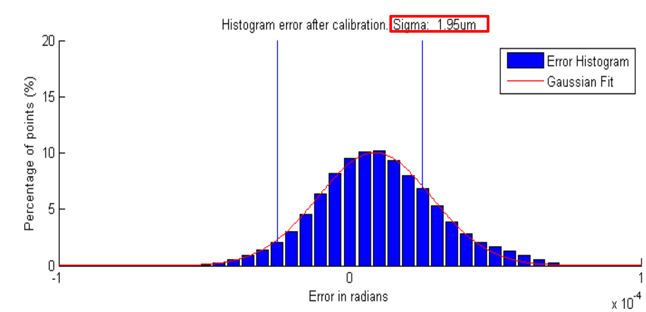








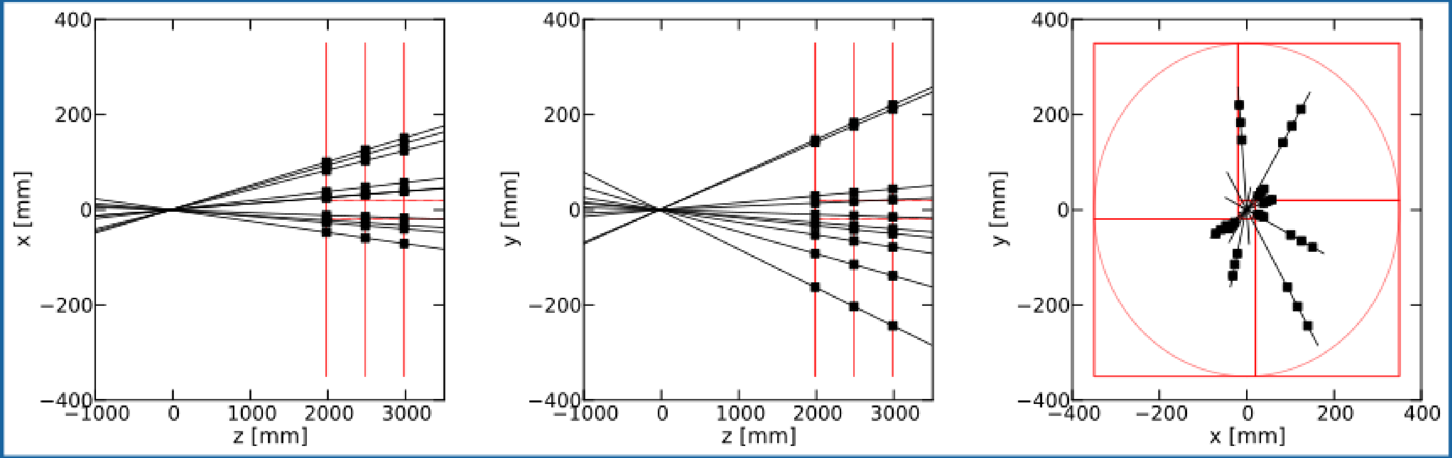




Courtesy J. Sirvent

BGV design studies

- As a minimum, need 2 or 3 measuring planes

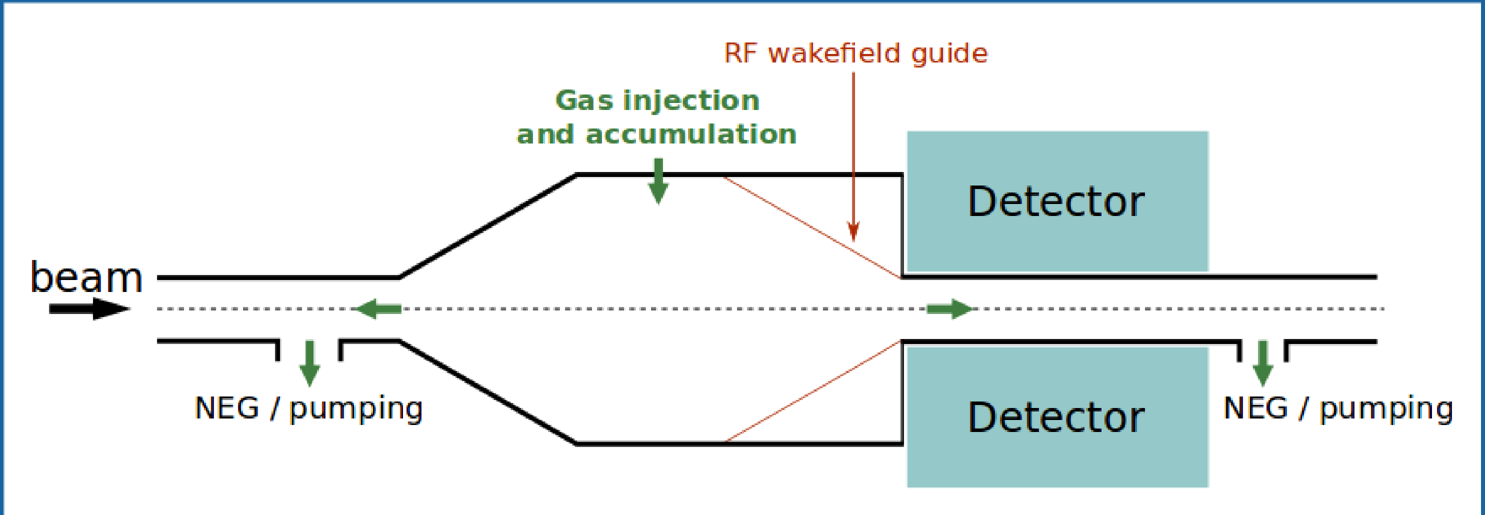


Goal for Beam Gas Vertex detector

bunch by bunch measurement in all operation condition

Absolute accuracy

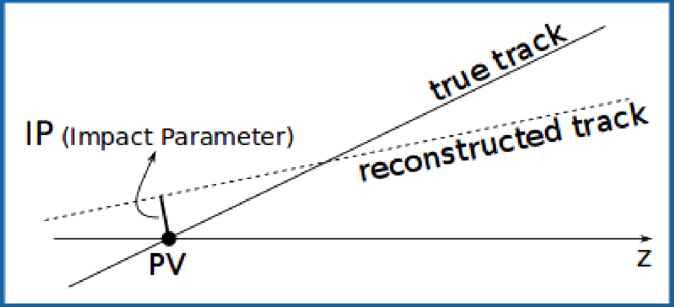
- Need a dedicated pressure bump



Tracking precision

The impact parameter (IP) resolution, σ_{IP}, is determined by:

- σ_{MS} – IP induced by multiple scattering (MS)
- σ_{extrap} – IP induced by detector hit resolution



$$\sigma_{\mathrm{IP}}^2 = \sigma_{\mathrm{MS}}^2 + \sigma_{\mathrm{extrap}}^2$$

$$\sigma_{\mathrm{MS}} \approx r_1 \frac{13.6\ \mathrm{MeV}}{p_T} \sqrt{\frac{x}{X_0}}$$

$$\sigma_{\mathrm{extrap}} \approx \sqrt{\frac{z_1^2 + z_2^2}{(z_2 - z_1)^2}} \cdot \sigma_{\mathrm{hit}}$$

Minimizing vacuum window thickness required

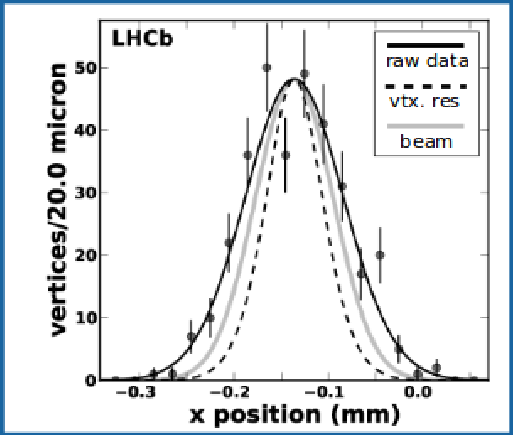
Vertexing precision

- For a beam with Gaussian transverse shape:

$$\sigma^2_{\rm raw} = \sigma^2_{\rm beam} + \sigma^2_{\rm vtx.res}$$

- When $\delta\sigma_{\rm raw}/\sigma_{\rm raw} \to 0$:

$$\frac{\delta\sigma_{\rm beam}}{\sigma_{\rm beam}} = \frac{\sigma^2_{\rm vtx.res}}{\sigma^2_{\rm beam}} \cdot \frac{\delta\sigma_{\rm vtx.res}}{\sigma_{\rm vtx.res}}$$



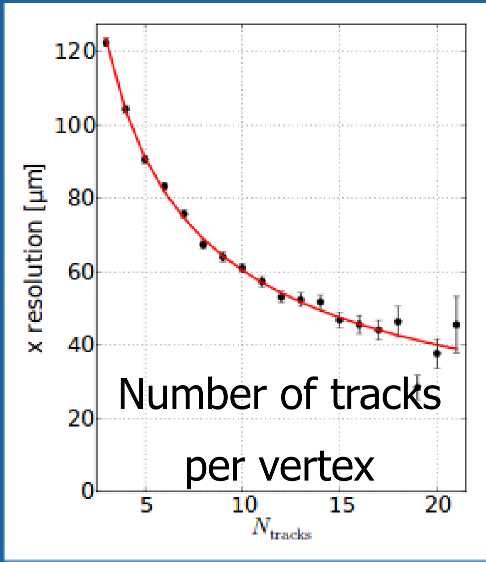
Therefore, it is important to have

- Small $\delta\sigma_{\rm vtx.res}$ / $\sigma_{\rm vtx.res}$: aim at 10 % (LHCb experience)
- Small ratio $\sigma^2_{\rm vtx.res}$ / $\sigma^2_{\rm beam}$: aim at 0.2

- If we assume $\sigma_{\rm vtx.res} = \sigma_{\rm IP}/\sqrt{N_{\rm Tr}} \Rightarrow$

$$\frac{\delta\sigma_{\rm beam}}{\sigma_{\rm beam}} = \frac{\sigma^2_{\rm vtx.res}}{\sigma^2_{\rm beam}} \frac{\delta\sigma_{\rm vtx.res}}{\sigma_{\rm vtx.res}} = \frac{1}{N_{\rm Tr}} \frac{\sigma^2_{\rm IP}}{\sigma^2_{\rm beam}} \frac{\delta\sigma_{\rm vtx.res}}{\sigma_{\rm vtx.res}}$$

- The vertex resolution depends on the z position too



Accuracy goals

- **Initial estimates of what is achievable, based on current knowledge**
  - Values apply for 0.45 to 7 TeV

Quantity	Accuracy	Time interval	Key factors
Relative bunch width Bunch by bunch	$5\ \%$	< 1 min	vertex resolution stability
Absolute average beam width	$2\ \%$	< 1 min	σ_{beam}, σ_{MS}, σ_{extrap} (σ_{hit})

- Of global importance: Rate of "good" events (acceptance, gas type, gas pressure)

❖ **Assuming** $\delta\beta/\beta = 3.5\ \% \Rightarrow \delta\epsilon_{\mathrm{beam}}/\epsilon_{\mathrm{beam}} = 5.3\ \%$

RESULTS

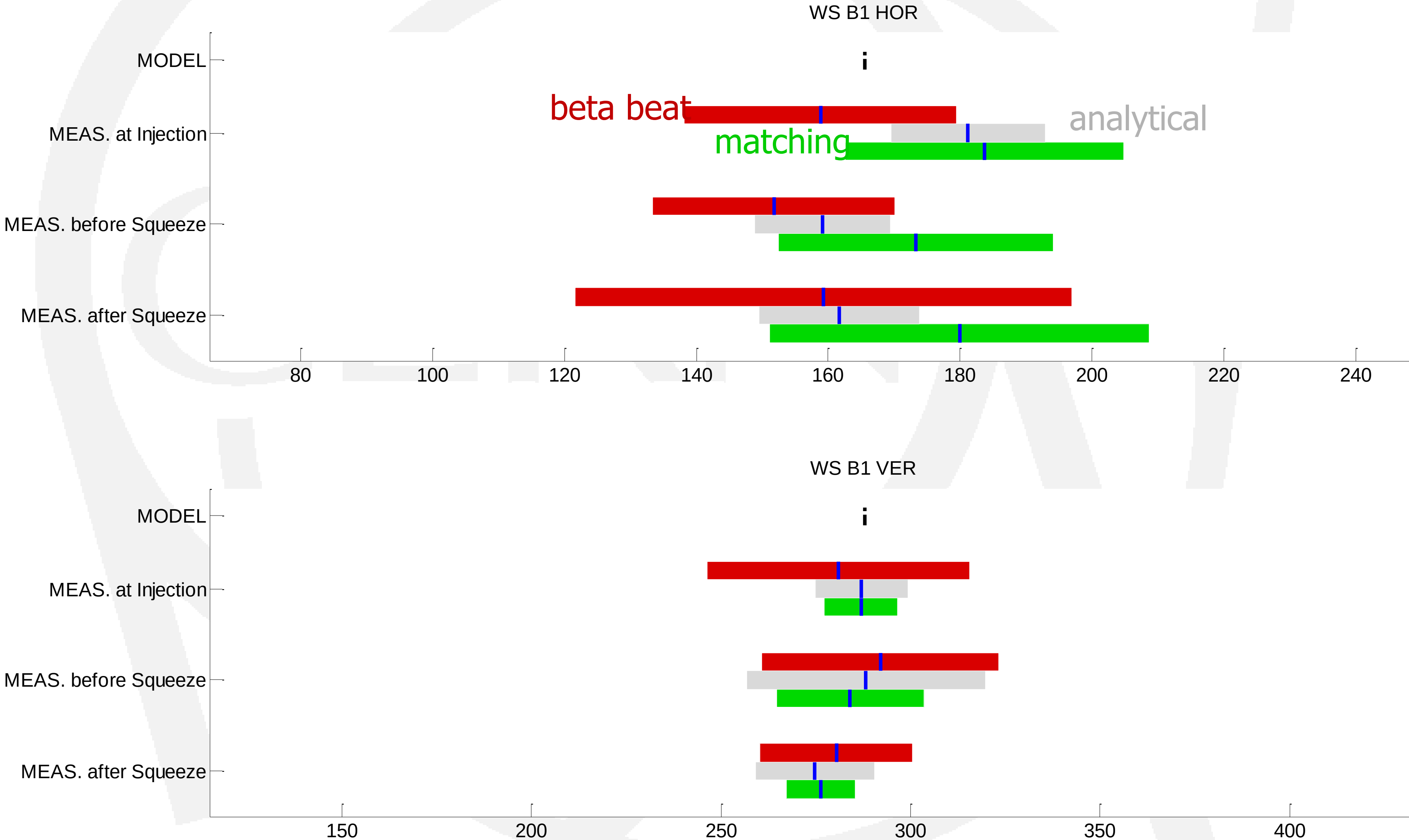
FLATTOP AFTER SQUEEZE

BEAM 1

		MODEL	Beta-beating	Best Analytical	matching
WS	X	165.484	159.27 ± 23.6%	161.7 ± 7.5 %	179.9±16%
	Y	287.814	280.4 ± 7.13%	274.8 ± 5.72%	276.3±3.3%
D3	X	172.967	167.43 ± 24.5%	174.5 ± 7.77%	
	Y	214.595	203.65 ± 11.27%	206.5 ± 4.2%	

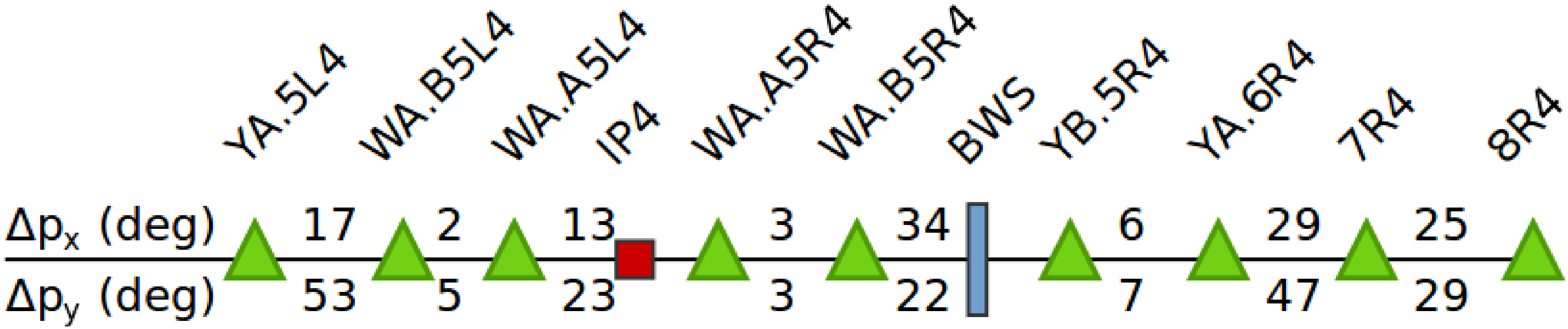
BEAM 2

		MODEL	Beta-beating	Best Analytical	matching
WS	X	123.512	127.52 ± 96.6%	114.3 ± 6.2%	119.1±8.3%
	Y	404.551	413.24 ± 7.18%	410.4 ± 1.33%	413.6±1.6%
D3	X	127.090	126.34 ± 17%	126.2 ± 2.7%	122.3±9.5%
	Y	334.613	358.9 ± 23.72%	340 ± 4.545%	344±2%



Georges Trad

Improvements for IR4.



BPMWA B5R4	Current Algorithm	Optimized BPM sets
β_x (m)	183.1	190.2
$\sigma_1\beta_x$ (m)	23.7	2.1
$\sigma_2\beta_x$ (m)	2.4	0.2
β_y (m)	174.0	167.1
$\sigma_1\beta_y$ (m)	21.5	1.9
$\sigma_2\beta_y$ (m)	4.6	0.2

BPMYB B5R4	Current Algorithm	Optimized BPM sets
β_x (m)	197.6	191.8
$\sigma_1\beta_x$ (m)	15.6	3.0
$\sigma_2\beta_x$ (m)	1.7	0.7
β_y (m)	405.1	407.7
$\sigma_1\beta_y$ (m)	32.9	4.6
$\sigma_2\beta_y$ (m)	9.1	3.3

$\sigma_1 =$ error propagation from ϕ

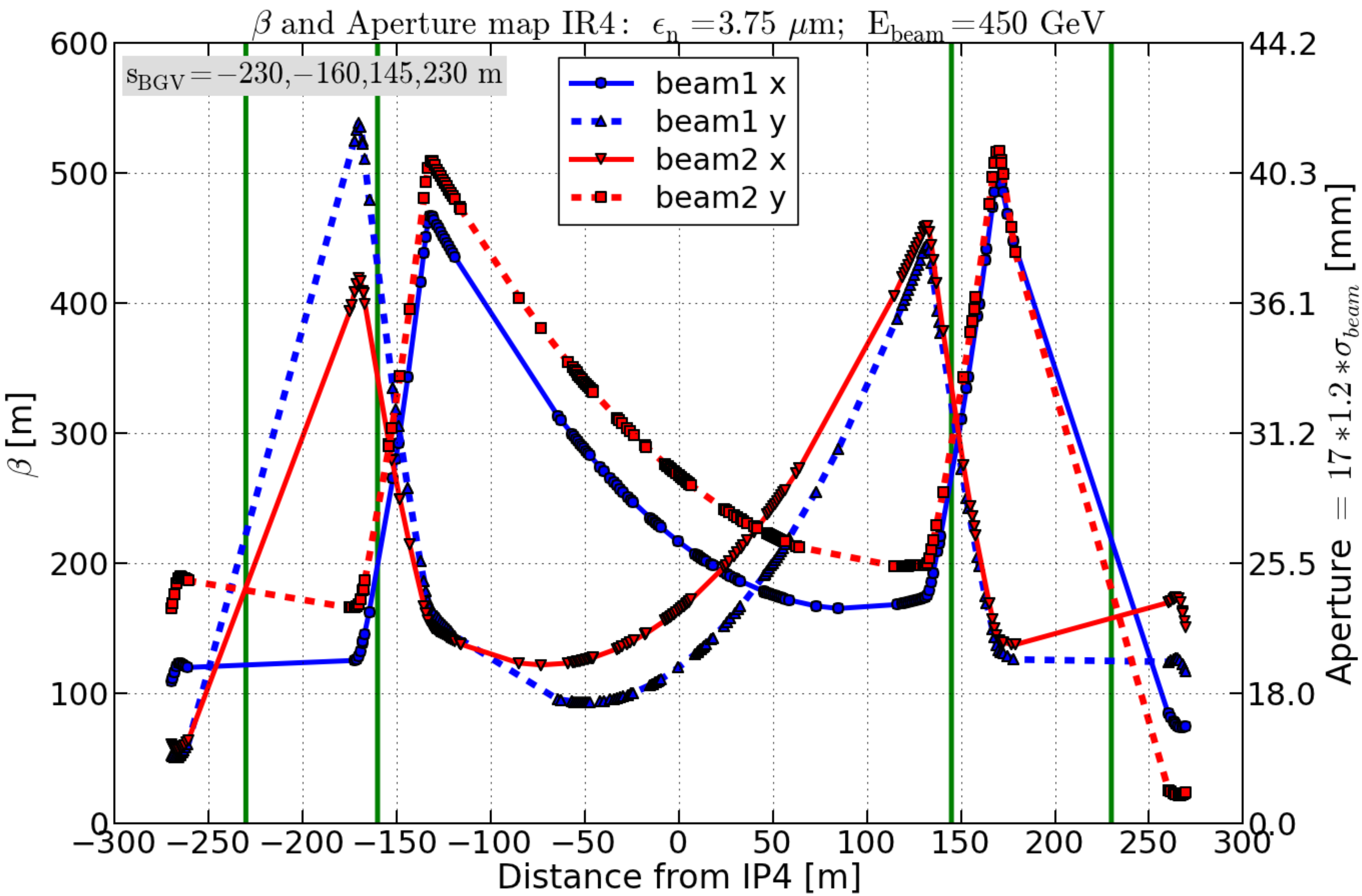
$\sigma_2 =$ standard deviation of using 3 BPM sets

Improvement of one order of magnitude on the error bar

Remarks and Summary

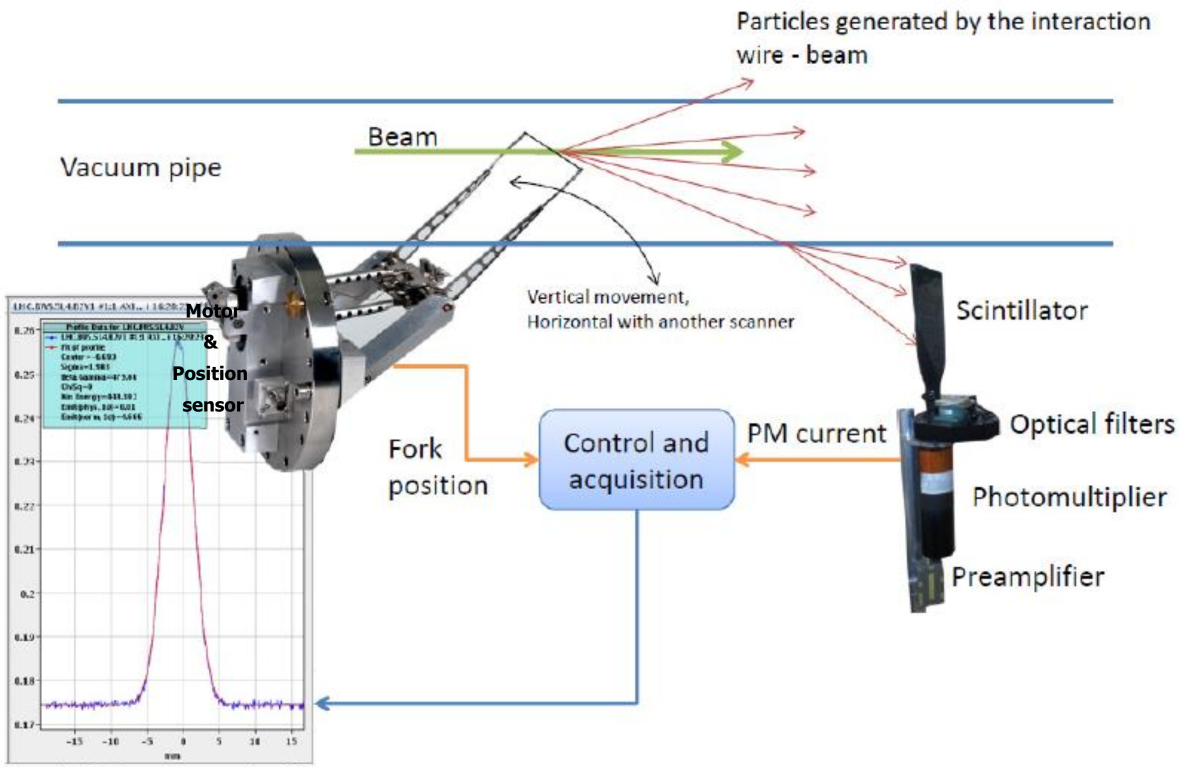
- The new instruments aim for an increased accuracy and faster acquisition time
  - Specified measurement time together with the accuracy limits could only be reached with wire scanners (LHC and SPS usage limited by beam intensity)
  - It is aimed reach the specified accuracy with the beam gas vertex monitor
- The envisaged beta function changes at LHC IP4 at the location of the emittance monitors should result in an increase of the function at all locations (top energy)
- It is foreseen to install a new wire scanner system in the SPS (517) in LS1
- It is foreseen to install a demonstrator beam gas vertex monitor in the LHC IP4 in LS1 (LSC decision pending)
- Many improvements are foreseen to cope with the observed limitations of the existing emittance monitors (BSRT, WS, BGI, IPM)
- To obtain the specified emittance accuracy of 5 % a beta function absolute accuracy of 3.5 % needs to be obtained

LHC IR 4



β and Aperture map IR4: ϵ_n =3.75 μm; E_{beam}=450 GeV
s_{BGV}=−230,−160,145,230 m
beam1 x
beam1 y
beam2 x
beam2 y
β [m]
Aperture = $17*1.2*\sigma_{beam}$ [mm]
Distance from IP4 [m]
0
100
200
300
400
500
600
0.0
18.0
25.5
31.2
36.1
40.3
44.2
−300 −250 −200 −150 −100 −50 0 50 100 150 200 250 300

Limitations



Example of a beam transversal profile

- Reproducibility much larger as required by specification
  - Beam size min LHC 130, PSB 2000 um
  - Flexible design of wire fork
    - Deformation of fork are not measured
  - Angular position measurement outside of vacuum system
    - Lever arm play is not measured
- Speed regulation circuit
  - Analog feedback loop difficult to optimize
- Secondary particle acquisition system
  - Requires accurate adjustment of working range
    - Saturation effect of PM
  - Dynamic of working range small < 200
    - Tail measurement limited by noise
  - High intensity beams cause an increase of background signal
    - Dynamic of working range reduced
- Aging of bellows

Goals

- Scan at least as fast as the existing system (20 m/s needed to avoid wire damage)
  => Rotational system (power ~ inertia ~ m * r^2)
- Absolute accuracy of beam width determination of about 5 um
  - Reduction of play in mechanical system
    => all elements mounted on same axis
  - Position measurement
    => high accuracy angular position sensor
  - Overcome bellow limitations:
    - Low lifetime
    - Friction

    => Locate all moveable parts in the vacuum
  - Minimize fork and wire deformations
    => Study of dynamic behavior of fork/wire system
    => Vibration mode optimized acceleration profile
- Large dynamic range for secondary particle detection
  => Usage of sensor with large dynamic (diamond)
  => Automatic electronic switching of gain ranges (**range dynamic 1E4**)
- Increase MTBF compared with existing systems