BGV detector design and considerations of possible locations for its installation

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BGV meeting

16 January 2013

Outline

1. Beam optics and detector vertexing precision
2. Possible locations for BGV installation

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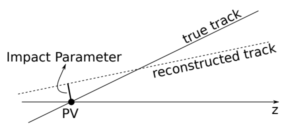
1. **Beam optics and detector vertexing precision**
2. Possible locations for BGV installation

Requirements influencing the detector design (1)

- Cover $3 < \eta < 5$ $(99.5 > \theta > 13.5$ mrad$)$
  - best η range depends on the target-gas atomic mass
  - greater η coverage $\Rightarrow$ more beam-gas products will be detected $\Rightarrow$ larger F_{good} (fraction of events with at least X tracks)
- Beam shape syst. uncertainty due to vertex resolution $\delta\sigma_{\text{beam}}/\sigma_{\text{beam}} \approx 3\%$
  - Goal is emittance syst. uncertainty < 5%, which includes uncertainty on β and all other (yet unknown) syst. errors in the beam shape measurements
  - Requirement on the vertex resolution σ_{resol}:
    - Use $\frac{\delta\sigma_{\text{beam}}}{\sigma_{\text{beam}}} = \frac{\sigma^2_{\text{resol}}}{\sigma^2_{\text{beam}}} \frac{\delta\sigma_{\text{resol}}}{\sigma_{\text{resol}}}$
    - Assume $\delta\sigma_{\text{resol}}/\sigma_{\text{resol}} = 10\%$ (accuracy of vertex resolution parametrization)
    - Therefore, we need: $\sigma_{\text{resol}}/\sigma_{\text{beam}} < 0.55$
  - Keep in mind that the vertex resolution depends on N_{Tr} and on z_{vtx}
    - N_{Tr}: number of tracks making up the vertex

Requirements influencing the detector design (2)

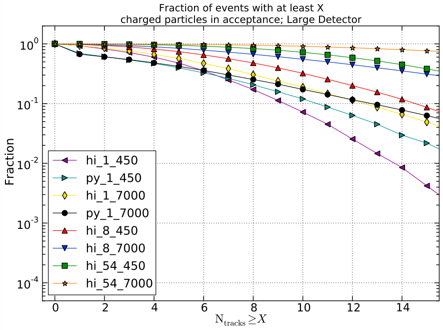
- With our Toy MC we can evaluate the detector "precision" for any detector layout
  - The "precision" is determined by the tracks impact parameter due to multiple scattering (MS) and "extrapolation" (sensors hit resolution and lever arm)



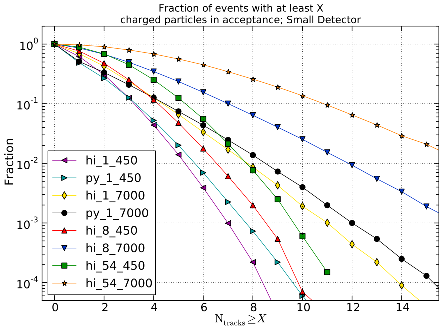
  - Track impact parameter: $\sigma_{\mathrm{IP}} = \sqrt{\sigma^2_{\mathrm{MS}} + \sigma^2_{\mathrm{extrap}}}$
  - We have a vertex fitting algorithm, but more work is needed to understand its performance
    - Currently don't have estimates of σ_{resol}
  - However, by assuming that $\sigma_{\mathrm{resol}} = \sigma_{\mathrm{IP}}/\sqrt{N_{\mathrm{Tr}}}$, we can use σ_{IP} instead of σ_{resol}
  - If we assume $N_{\mathrm{Tr}} = 5\,(10)$, the requirement for the detector precision becomes:

$$\sigma_{\mathrm{IP}}/\sigma_{\mathrm{beam}} < 1.23\,(1.74)$$

LargeDet
(Layout shown on the next slide)



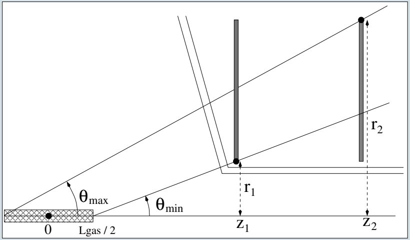
SmallDet
(not discussed later in this talk)



- Reminder: The fraction of good events (F_{good}) and the gas pressure determine the time needed to achieve certain statistical precision on the measured σ_{beam}
- F_{good} itself depends on several parameters, including detector geometry and cut on N_{Tr}

Detector layout

- Determine the position and the size of the sensors, needed to cover certain η range and certain target length



Fixed parameters (example study):

- $\mathrm{L_{gas}} = 1000$ mm
- Cover $3 < \eta < 5$ $(99.5 > \theta > 13.5$ mrad)
- Distance between first and last sensor: $z_2 - z_1 = 1000$ mm
- r_1 determined from aperture restrictions (see later)
- For calculating multiple scattering use $x/X_0 = 3\%$ (includes 0.5mm Al wall, 2*0.5mm Si sensors, 70um copper wakefield suppressor at 20° wrt beam axis)

Derived parameters:

- $z_1 = \frac{\mathrm{L_{gas}}}{2} + \frac{r_1}{\tan\theta_{\mathrm{min}}}$
- $r_2 = \left(z_2 + \frac{\mathrm{L_{gas}}}{2}\right) \tan\theta_{\mathrm{max}}$

- With these layout parameters, is it better to install the detector in a location with smaller or larger β?
  - Larger β implies larger beam (good), but also larger r_1 (bad)

Optics and detector design

β [m]	Aperture [mm]	σ_{beam}^{7000} [mm]	Detector Layout [mm]				Impact Parameter [mm]			$\sigma_{\mathrm{IP}}/\sigma_{beam}^{7000}$
			z_1	z_2	r_1	r_2	σ_{MS}	σ_{extrap}	σ_{IP}	
100	18.0	0.116	1835	2835	18.0	333.0	0.106	0.196	0.223	1.93
200	25.5	0.164	2389	3389	25.5	388.3	0.150	0.241	0.284	1.73
300	31.2	0.200	2813	3813	31.2	430.7	0.184	0.275	0.331	1.65
400	36.1	0.232	3171	4171	36.1	466.4	0.212	0.304	0.371	1.60
500	40.3	0.259	3487	4487	40.3	497.9	0.238	0.330	0.406	1.57

- Aperture = $17 \times 1.2 \times \sigma_{beam}^{450}$
  - $\sigma_{beam}^{450} = \sqrt{\beta\epsilon_n/\gamma}$, with $E_{beam} = 450$ GeV and $\epsilon_n = 3.75\ \mu$m
- σ_{beam}^{7000} calculated with $E_{beam} = 7000$ GeV and $\epsilon_n = 1.0\ \mu$m
- Detector layout (see previous slide)
- Impact parameter
  - Multiple scattering: $\sigma_{\mathrm{MS}} \approx r_1 \times 13.6/p_T \times \sqrt{x/X_0}$
    - Use $p_T = 400$ MeV and $x/X_0 = 3\%$
  - Extrapolation: $\sigma_{\mathrm{extrap}} \approx \sqrt{\dfrac{z_1^2\,\sigma_2^2 + z_2^2\,\sigma_1^2}{(z_2 - z_1)^2}}$, with $\sigma_1 = \sigma_2 = 58\ \mu$m (hit resolution of LHCb IT silicon sensors)

Optics and detector design

β [m]	Aperture [mm]	σ_{beam}^{7000} [mm]	Detector Layout [mm]				Impact Parameter [mm]			$\sigma_{\mathrm{IP}}/\sigma_{beam}^{7000}$
			z_1	z_2	r_1	r_2	σ_{MS}	σ_{extrap}	σ_{IP}	
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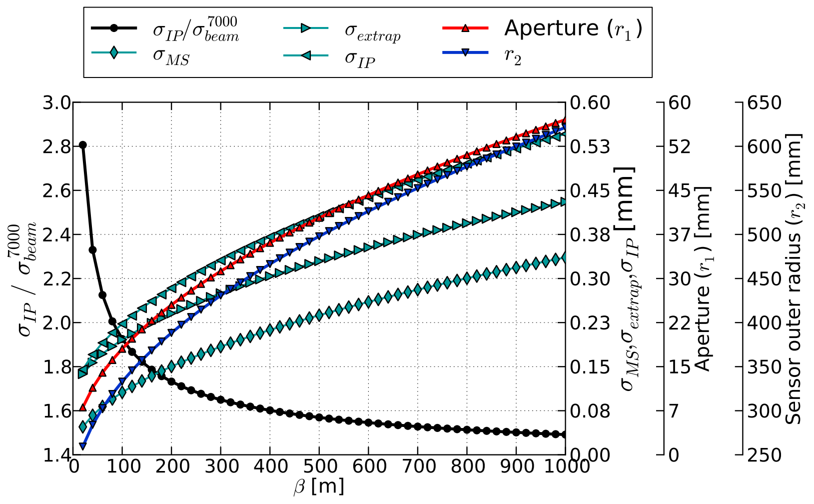
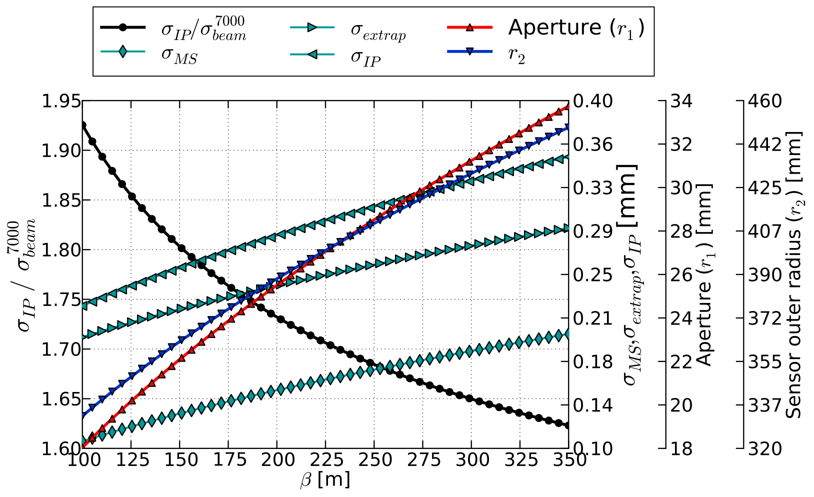
- Reminder: The goal was $\sigma_{\mathrm{IP}}/\sigma_{\mathrm{beam}} < 1.23\,(1.74)$, for $N_{\mathrm{Tr}} = 5\,(10)$
  - Means of improving σ_{IP} (σ_{extrap} dominates!): larger lever arm, better hit resolution
- The improvement of $\sigma_{\mathrm{IP}}/\sigma_{\mathrm{beam}}$ with increasing β is not dramatic
  - It is related to going further away, and having larger sensors
  - σ_{beam} and σ_{MS} are proportional to $\sqrt{\beta}$ ($\sigma_{\mathrm{MS}} \sim r_1 \sim \sigma_{\mathrm{beam}}$), while the σ_{extrap} increase with β is slower
- The sensors outer radius is $30 - 50$ cm
  - Installation restrictions: cut ϕ region for the other beam-pipe; others?
  - Scintillating fibre sensors a more natural choice

Optics and detector design

- $\beta \in [20; 1000]$ m



- $\beta \in [100; 350]$ m

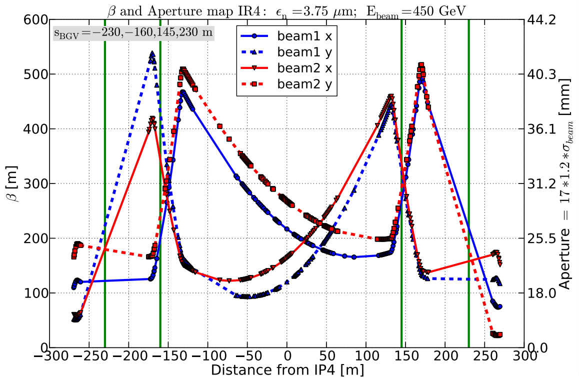


Outline

1. Beam optics and detector vertexing precision
2. **Possible locations for BGV installation**

Best location possibilities in IR4

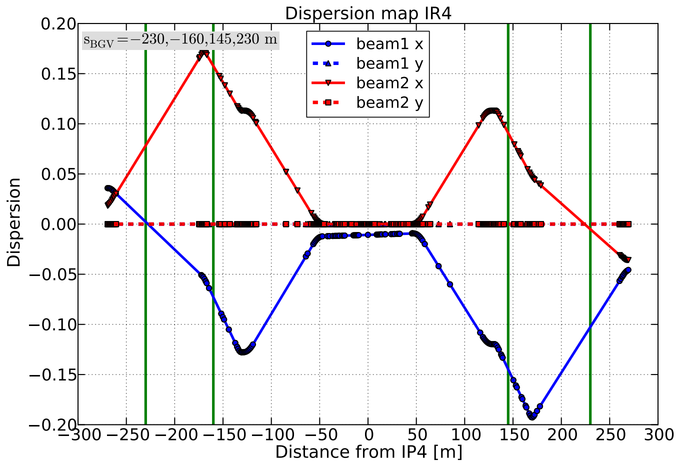
- Initially, investigated the LHC-layout drawings for zones free of equipment
- Went to a visit at IP4 to check on the spot
- Figures, photos and visit notes can be found on the BGV Twiki:
  https://twiki.cern.ch/twiki/bin/view/BGV/Documents
  - some of them are shown and discussed later
- Consider 4 suitable locations with space for at least one BGV system ($\Delta s \geq 7$ m)
  - tbc that it is an exhaustive list (!!!check: $s = 40$ m)



- β / Aperture map in IR4
  - Thanks to M. Giovannozzi for providing a table with machine parameters
  - Minimal allowed approach ("Aperture") to the beam: $17 \times 1.2 \times \sigma_{beam}$
    - β does not change with the beam energy
    - The Aperture should be calculated at injection (largest beam), and with the largest expected emittance (we use $\epsilon_n = 3.75$ μm)

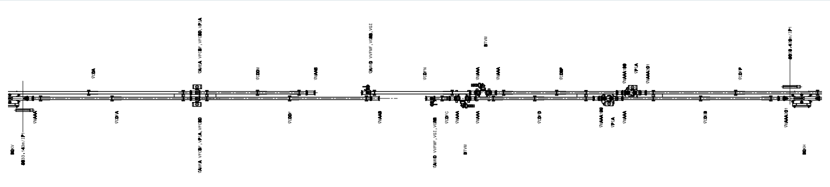
Dispersion

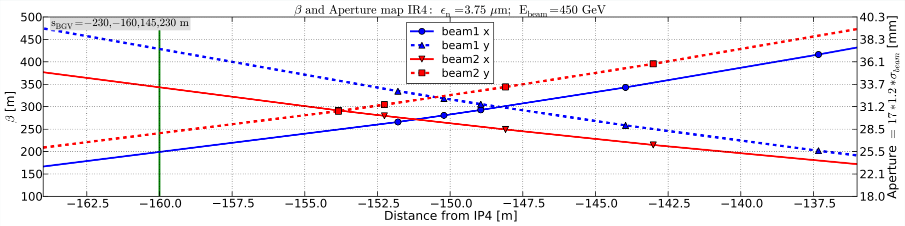
- Missing the data for the y-component of the dispersion (both beams)



Location BGVL1

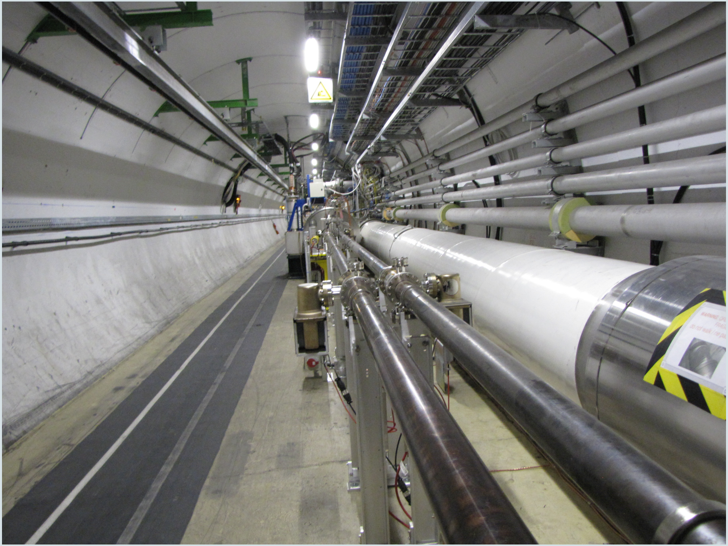
- $s \in [-164; -136]$ m in (C6L4)





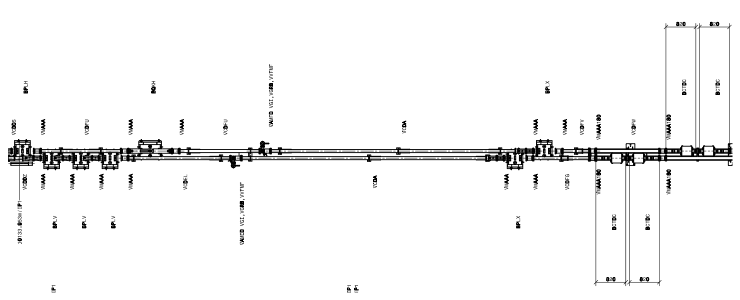
Location BGVL1

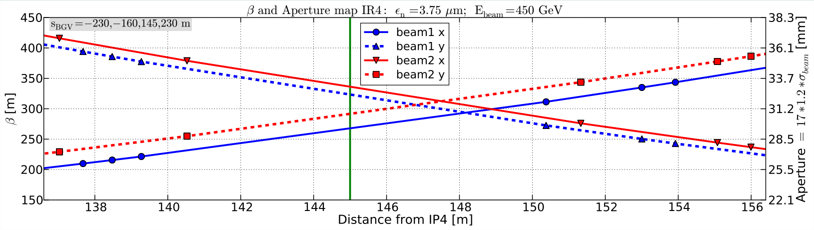
- Position $\sim\ -157$ m



Location BGVR1

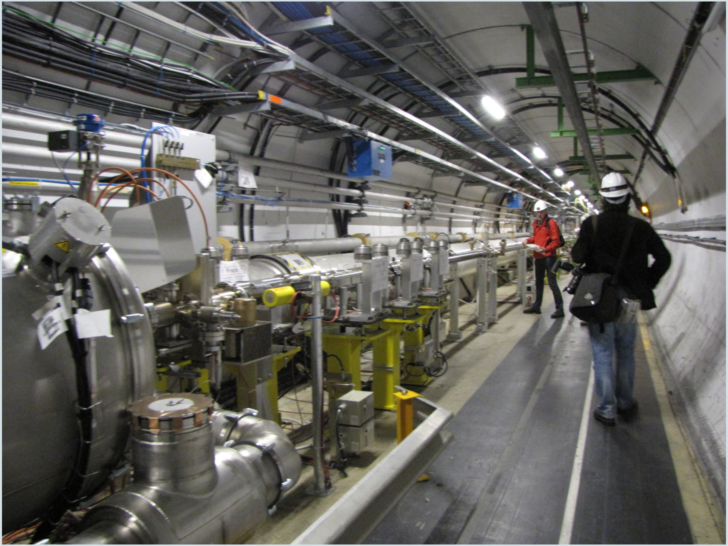
- $s \in [136; 156]$ m in (C6R4)





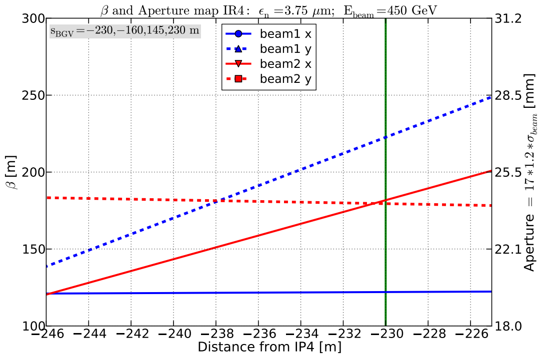
Location BGVR1

- Position $\sim$ 133 m



Location BGVL2

- $s \in [-246; -225]$ m (C7L4)
- Basically, no BI devices or magnets (except at the ends of the cell)

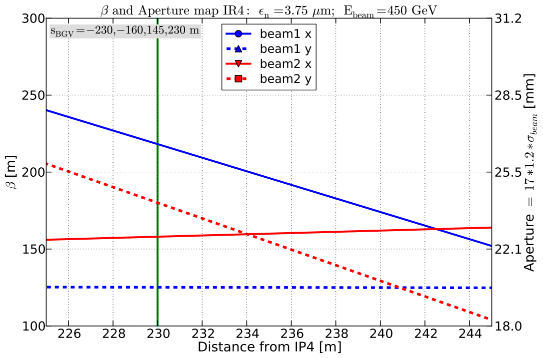


Location BGVL2

- Position ~ -185 m

Location BGVR2

- $s \in [225; 245]$ m (C7L4)
- Basically, no BI devices or magnets (except at the ends of the cell)



Location BGVR2

- Position $\sim$ 200 m

Table of comparison

- Table 1

Location	s wrt IP4	Beam1								Beam2							
		β_x	β_y	$\frac{\delta\beta_x}{\beta_x}$	$\frac{\delta\beta_y}{\beta_y}$	$\sigma_{res\,x}^{syst}$	$\sigma_{res\,y}^{syst}$	D_x	D_y	β_x	β_y	$\frac{\delta\beta_x}{\beta_x}$	$\frac{\delta\beta_y}{\beta_y}$	$\sigma_{res\,x}^{syst}$	$\sigma_{res\,y}^{syst}$	D_x	D_y
	[m]	[m]	[m]	[%]	[%]	[%]	[%]	[m]	[m]	[m]	[m]	[%]	[%]	[%]	[%]	[m]	[m]
BGVL1	–158	210	410			5.0	2.6	–0.07		330	250			2.7	3.5	0.16	
BGVR1	147	285	305			2.9	2.7	–0.15		320	310			2.7	2.8	0.09	
BGVL2A	–243	120	160			4.3	3.2	0.02		130	180			4.3	3.1	0.05	
BGVL2B	–230	120	220			5.4	2.9	0.00		180	180			3.1	3.1	0.08	
BGVR2A	234	200	125			3.0	4.8	–0.10		160	160			3.2	3.2	–0.01	
BGVR2B	242	165	125			3.2	4.2	–0.08		165	120			3.2	4.3	–0.02	

- $\sigma_{res}^{syst} = \delta\sigma_{\text{beam}}/\sigma_{\text{beam}} = \frac{1}{N_{\text{Tr}}}\frac{\sigma_{\text{IP}}^2}{\sigma_{\text{beam}}^2}\frac{\delta\sigma_{\text{resol}}}{\sigma_{\text{resol}}}$
  - For the numbers in the table used $N_{\text{Tr}} = 10$, and assumed $\delta\sigma_{\text{resol}}/\sigma_{\text{resol}} = 10\%$ (accuracy of vertex resolution parametrization)

- Table 2

Location	s wrt IP4	Instrument/Magnet		D_{pipes}	infrastr.	radiation
	[m]	on the left	on the right	[mm]		
BGVL1	–158	BQKV	BTVMs			
BGVR1	147	BPLVs, BQKH	BPLX, DC&FBCT			
BGVL2A	–243	Q7L4	BPLHs			
BGVL2B	–230	Q7L4	BPLHs			
BGVR2A	234	BPLH, BPLV	Q7R4			
BGVR2B	242	BPLH, BPLV	Q7R4			

Conclusion

- Beam optics and detector vertexing precision
  - Slight improvement of ratio $\sigma_{\mathrm{IP}}/\sigma_{\mathrm{beam}}$ with β, at the cost of larger sensors
  - $\beta_x \approx \beta_y$ highly desirable
  - A fairly precise detector of $z_2 - z_1 \approx 1$ m and outer radius of ≈ 40 cm could provide the needed vertex resolution
- Search for possible locations for BGV installation
  - A comparison table taking shape
  - The investigated zones in C7L5 and C7R5 look OK for BGV installation
    - β values not optimal, but plenty of free space
  - The free space in the investigated zones in C6L5 and C6R5 is tight
    - Need to check carefully if it is enough
    - need to check the effect of BGV to the surrounding devices