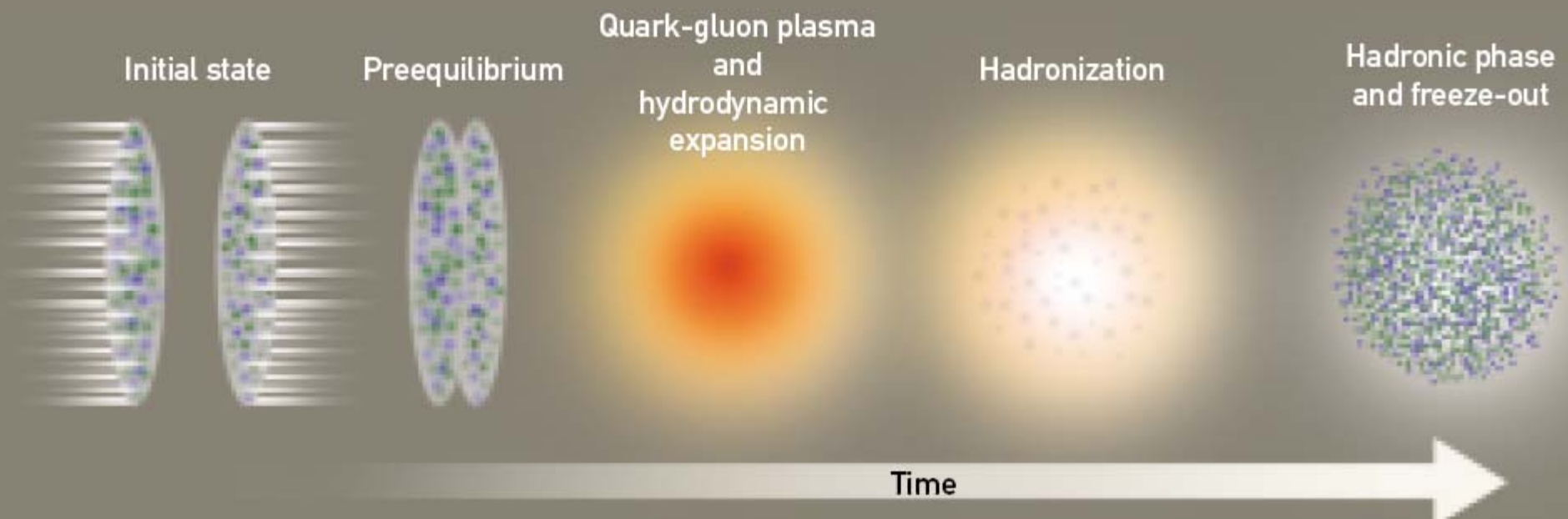
Optics for LHC Commissioning and Operation with Pb Ions

John Jowett



Nominal scheme parameters (Design Report)

		Injection	Collision
Beam parameters			
Lead ion energy	[GeV]	36900	574000
Lead ion energy/nucleon	[GeV]	177.4	2759.
Relativistic "gamma" factor		190.5	2963.5
Number of ions per bunch		$7. \times 10^7$	
Number of bunches		592	
Transverse normalized emittance	[μm]	1.4[a]	1.5
Peak RF voltage (400 MHz system)	[MV]	8	16
Synchrotron frequency	[Hz]	63.7	23.0
RF bucket half-height		1.04×10^{-3}	3.56×10^{-4}
Longitudinal emittance (4σ)	[eV s/charge]	0.7	2.5[b]
RF bucket filling factor		0.472	0.316
RMS bunch length[c]	[cm]	9.97	7.94
Circulating beam current	[mA]	6.12	
Stored energy per beam	[MJ]	0.245	3.81
Twiss function $\beta_x = \beta_y = \beta^*$ at IP2	[m]	10.0	0.5
RMS beam size at IP2	μm	280.6	15.9
Geometric luminosity reduction factor F[d]		-	1
Peak luminosity at IP2	[$\mathrm{cm}^{-2}\mathrm{sec}^{-1}$]	-	$1. \times 10^{27}$

Nominal scheme, lifetime parameters (Design Report)

2 experiments

		Injection	Collision
Interaction data			
Total cross section	[mb]	-	514000
Beam current lifetime (due to beam-beam)[a]	[h]	-	11.2
Intra Beam Scattering			
RMS beam size in arc	[mm]	1.19	0.3
RMS energy spread $\delta E/E_0$	$[10^{-4}]$	3.9	1.10
RMS bunch length	[cm]	9.97	7.94
Longitudinal emittance growth time	[hour]	3	7.7
Horizontal emittance growth time[b]	[hour]	6.5	13
Radiation			
	[W]	3.5×10^{-14}	2.0×10^{-9}
	[Wm^{-1}]	8×10^{-8}	0.005
	[W]	1.4×10^{-3}	83.9
	[eV]	19.2	1.12×10^{6}
	[eV]	7.3×10^{-4}	2.77
	[hour]	23749	6.3
	[hour]	47498	12.6
Variation of longitudinal damping partition number[c]		230	230
Initial beam and luminosity lifetimes			
Beam current lifetime (due to residual gas scattering)[d]	[hour]	?	?
Beam current lifetime (beam-beam, residual gas)	[hour]	-	< 11.2
Luminosity lifetime[e]	[hour]	-	< 5.6

Since the LHC Design Report was published, it has become clear that we will have 3 experiments (ALICE, ATLAS, CMS) taking data.

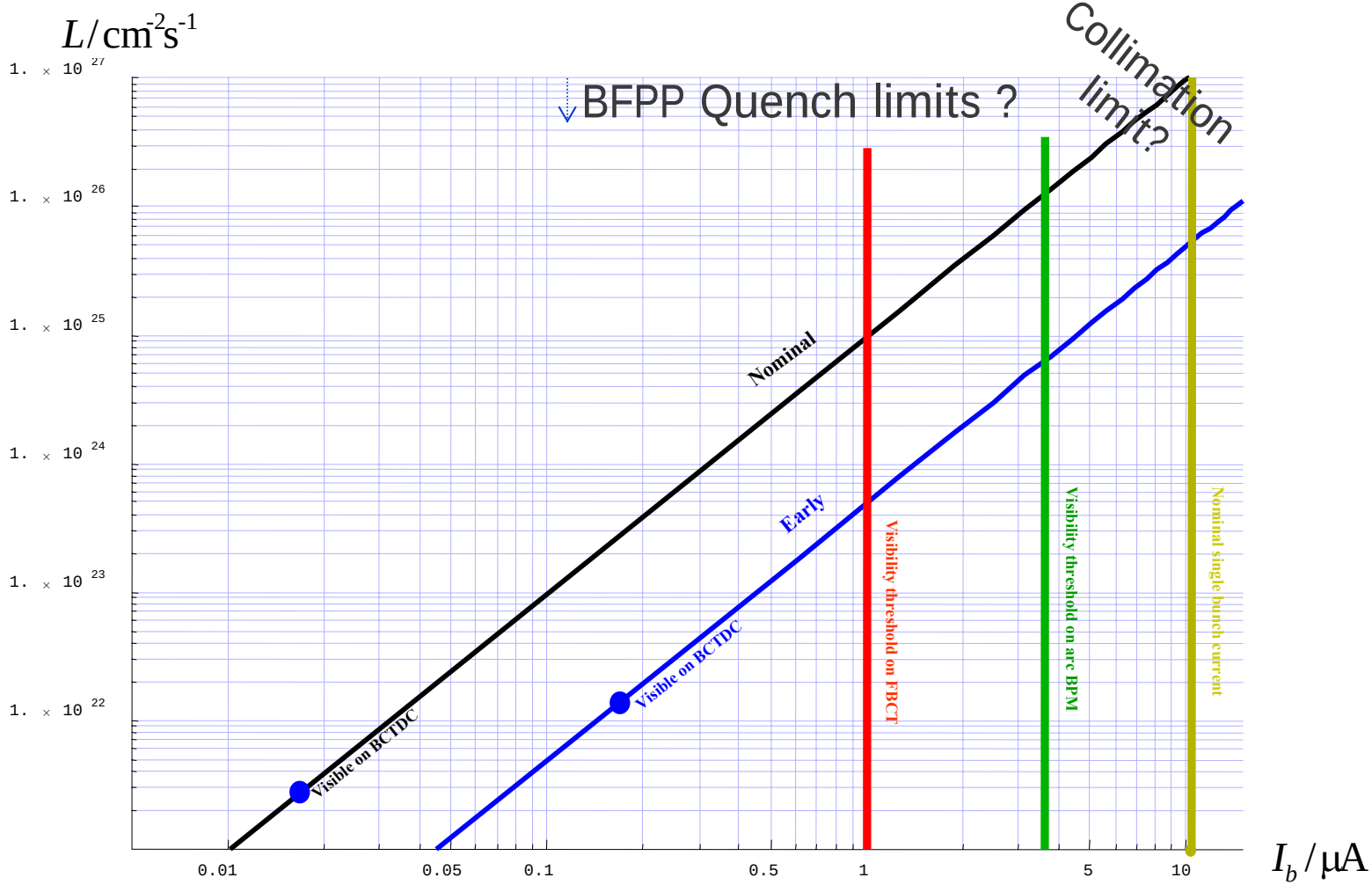
Early scheme Parameters (Design Report)

2 experiments

		Injection	Collision
Beam parameters			
Number of bunches		62	
Circulating beam current	[mA]	0.641	
Stored energy per beam	[MJ]	0.0248	0.386
Twiss function $\beta_x = \beta_y = \beta^*$ at IP2	[m]	10.0	1.0
RMS beam size at IP2 [e]	[μm]	280.6	22.5
Peak luminosity at IP2	[$\mathrm{cm}^{-2}\mathrm{sec}^{-1}$]	-	5.4×10^{25}
Interaction data			
Beam current lifetime (due to beam-beam)[a]	[h]	-	21.8
Synchrotron Radiation			
Power loss per metre in main bends	[Wm^{-1}]	8.5×10^{-9}	5.0×10^{-4}
Synchrotron radiation power per ring	[W]	1.5×10^{-4}	8.8
Initial beam and luminosity lifetimes			
Beam current lifetime (beam-beam, residual gas)	[hour]	-	< 21.8
Luminosity lifetime (as in Table 21.3)	[hour]	-	< 11.2

Only show parameters that are different from nominal scheme

Operational Parameter Space for Pb Ions



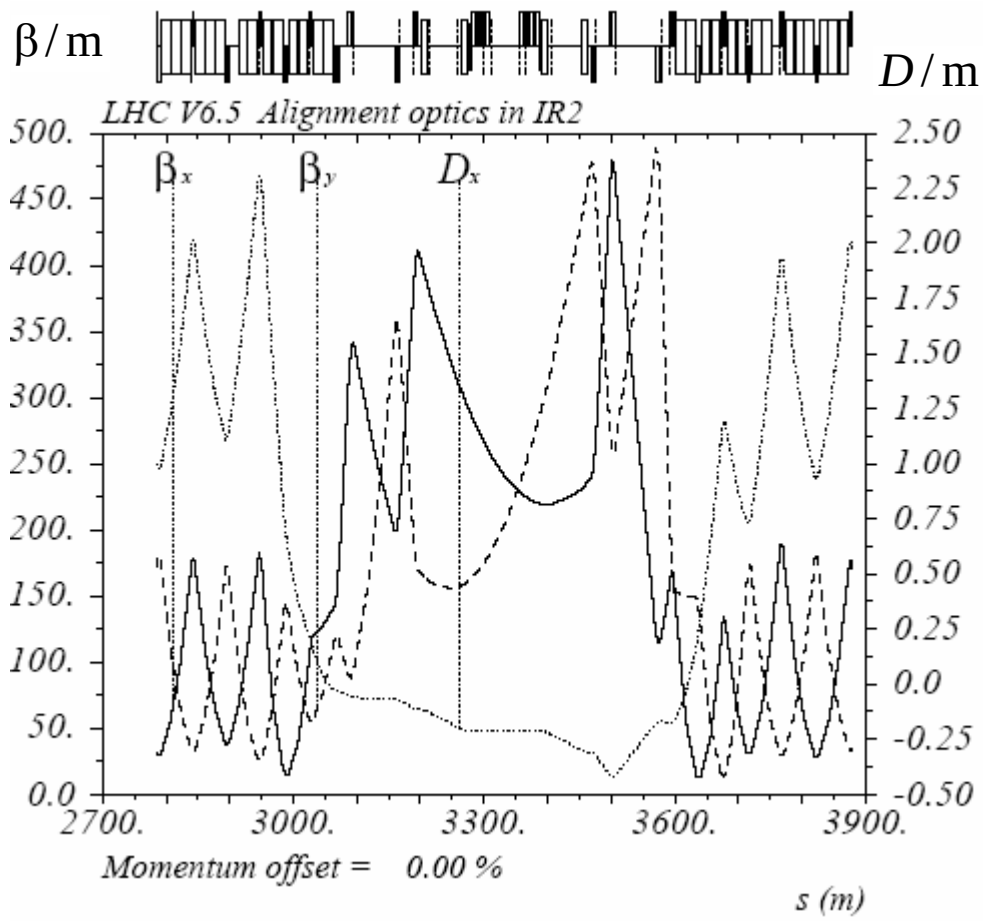
Thresholds for visibility on BPMs and BCTs.

Optics for the Early and Nominal Ion Schemes

- Same *geometrical* transverse beam size and emittance
  - Optics, dynamic aperture, mechanical acceptance, etc. similar to protons.
- Injection and ramp done with **exactly the same** optics, orbits, corrections, etc. as for protons
  - Should shorten ion commissioning time considerably!
- Colliding in ATLAS, CMS $\Rightarrow$ same squeeze as protons
- Leave IR8 in injection configuration
- Main difference is that IR2 is squeezed to $\beta^* = 2., 1., 0.5$ m
  - May - or may not - be operationally convenient to commission the ion optics first with low-intensity protons.
- Crossing angle at IP2 (1,5?) may be small (includes ALICE muon spectrometer, details in Design Report)
  - Aperture requirements somewhat relaxed w.r.t. protons
  - Operational time for polarity reversals

Alignment of IR2 Quadrupole Triplets

- Procedure
  - K-modulation to find quadrupole centres w.r.t. BPMs
  - Alignment with special optics, triplet quads off
- Only possible with Beam 2
  - Phase advance injection kicker to TDI
- May not be necessary in first year
  - Can be done with protons
  - Consider scheduling together with other IRs?



New alignment optics for IR2 (+IR1, IR5)

A. Verdier

Plan for Commissioning LHC Rings with Lead Ions (1)

- Assume that protons can be collided
  - **Injection, ramp, squeeze (where applicable) are set up**
- Re-commission injection and first turns with single ion "pilot" bunch (close to nominal intensity)
  - Adjust BST
  - Energy matching to different SPS cycle, each ring
  - Should go quickly (magnetic reproducibility...)
  - Deal with any difference of geometric beam size from protons (collimator settings, etc.)
- Set up RF and capture ("few shifts"), instrumentation

Plan for Commissioning LHC Rings with Lead Ions (2)

- Re-commission ramp
  - Should also go quickly (magnetic reproducibility again)
  - Deal with any difference of geometric beam size from protons (collimator settings, etc.)
- Commission squeeze of IP2 (if applicable)
  - Including crossing angle with ALICE spectrometer bump
  - (Alignment of IR2 triplet quadrupoles?)
  - Could take a few days (see experience with IP1 and IP5)
- Collide Pb-Pb
  - Re-optimise collimation (how?), measurements, etc.

Need to review time requirements with proton experience.

Provide > 4 weeks of physics with Early Scheme for ALICE, ATLAS, CMS.

Don't forget MD time ($\rightarrow$ Nominal Scheme) with Pb ions

Optical Parameters at the IPs (Nominal)

```
IPopticsTable["CollisionIons", "LHCB1"]
```

|//NumberForm=

	IP1	IP2	IP5	IP8	IP1.L1
β_x/m	0.55	0.5	0.55	10.	0.55
β_y/m	0.55	0.5	0.55	10.	0.55
x_c/mm	1.1×10^{-9}	-3.59×10^{-9}	0.5	-3.18×10^{-9}	1.1×10^{-9}
y_c/mm	−0.5	5.77×10^{-9}	2.08×10^{-9}	−0.5	−0.5
p_{xc}/μrad	-2.95×10^{-6}	2.63×10^{-6}	142.	−210.	-2.95×10^{-6}
p_{yc}/μrad	143.	−10.	-7.9×10^{-6}	-1.81×10^{-7}	143.

```
IPopticsTable["CollisionIons", "LHCB2"]
```

|//NumberForm=

	IP1	IP2	IP5	IP8	IP1.L1
β_x/m	0.55	0.5	0.55	10.	0.55
β_y/m	0.55	0.5	0.55	10.	0.55
x_c/mm	4.11×10^{-9}	3.94×10^{-9}	0.5	-2.43×10^{-8}	4.11×10^{-9}
y_c/mm	−0.5	-6.01×10^{-9}	-2.72×10^{-9}	0.5	−0.5
p_{xc}/μrad	-2.79×10^{-6}	5.5×10^{-6}	−142.	210.	-2.79×10^{-6}
p_{yc}/μrad	−142.	10.	−0.0000107	-2.69×10^{-6}	−142.

Optical Parameters at the IPs (Early)

```
IPopticsTable["EarlyCollisionIons", "LHCB1"]
```

/NumberForm=

	IP1	IP2	IP5	IP8	IP1.L1
β_x/m	2.	1.	2.	10.	2.
β_y/m	2.	1.	2.	10.	2.
x_c/mm	-1.11×10^{-9}	2.29×10^{-9}	0.322	1.78×10^{-9}	3.08×10^{-9}
y_c/mm	−0.322	2.78×10^{-9}	3.61×10^{-10}	−2.	−0.322
p_{xc}/μrad	2.37×10^{-6}	-1.83×10^{-6}	92.	−170.	1.86×10^{-6}
p_{yc}/μrad	92.	-2.13×10^{-6}	-1.98×10^{-6}	8.67×10^{-7}	92.

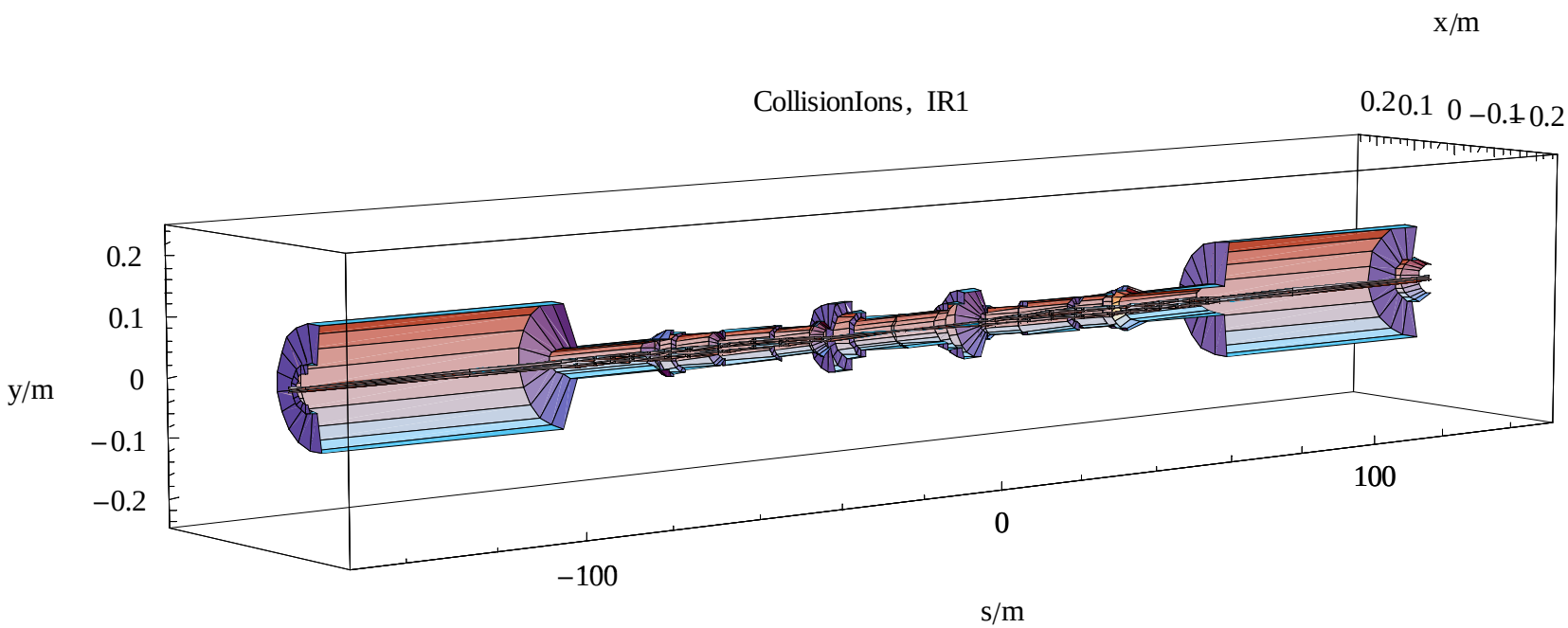
```
IPopticsTable["EarlyCollisionIons", "LHCB2"]
```

/NumberForm=

	IP1	IP2	IP5	IP8	IP1.L1
β_x/m	2.	1.	2.	10.	2.
β_y/m	2.	1.	2.	10.	2.
x_c/mm	3.94×10^{-9}	3.09×10^{-9}	0.322	-8.36×10^{-9}	3.94×10^{-9}
y_c/mm	−0.322	-4.5×10^{-9}	-5.35×10^{-9}	2.	−0.322
p_{xc}/μrad	-1.74×10^{-6}	1.11×10^{-8}	−92.	170.	-1.74×10^{-6}
p_{yc}/μrad	−92.	-3.55×10^{-7}	-1.07×10^{-6}	-1.13×10^{-6}	−92.

Beams crossing inside LHC aperture, Nominal, IR1

```
IRcrossingPlot3D["CollisionIons", "IR1", 2, 0.25]
```



Beams crossing, Nominal, IR1, closer view (2σ beam)

```
IRcrossingPlot3D["CollisionIons", "IR1", 2, 0.015]
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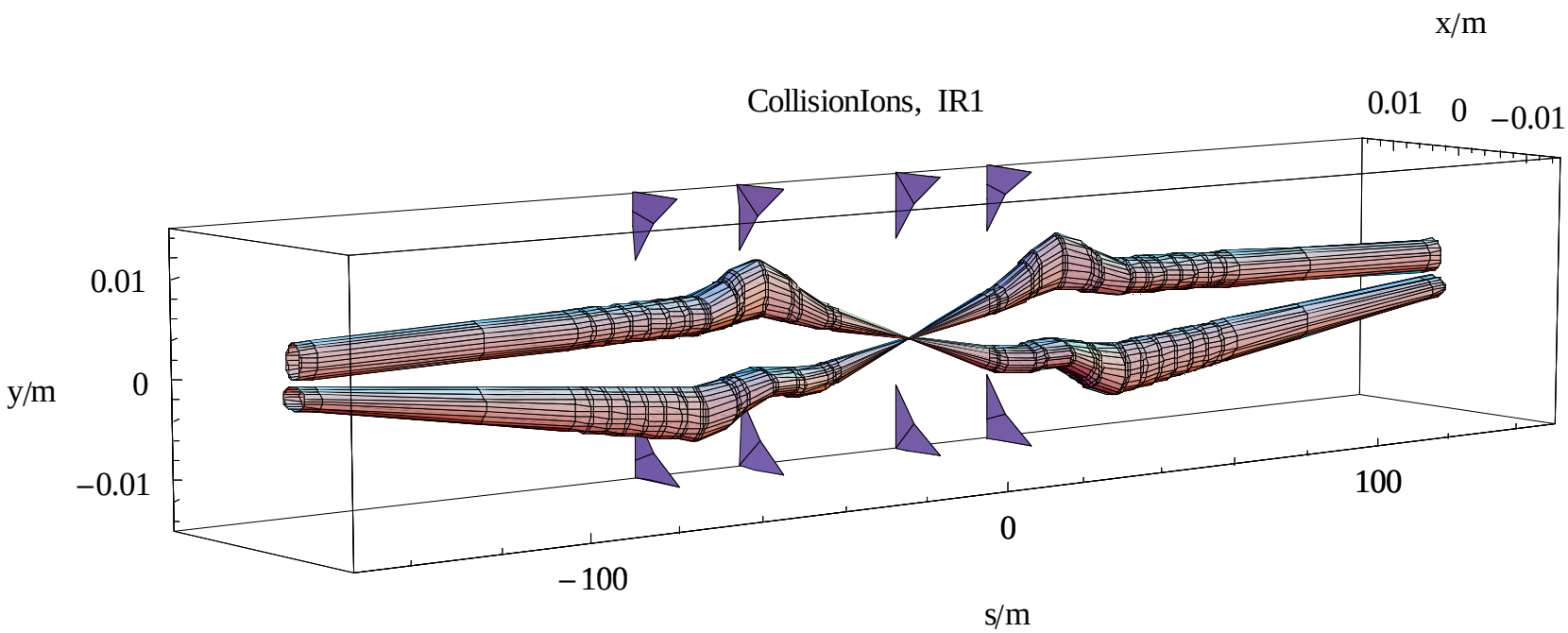
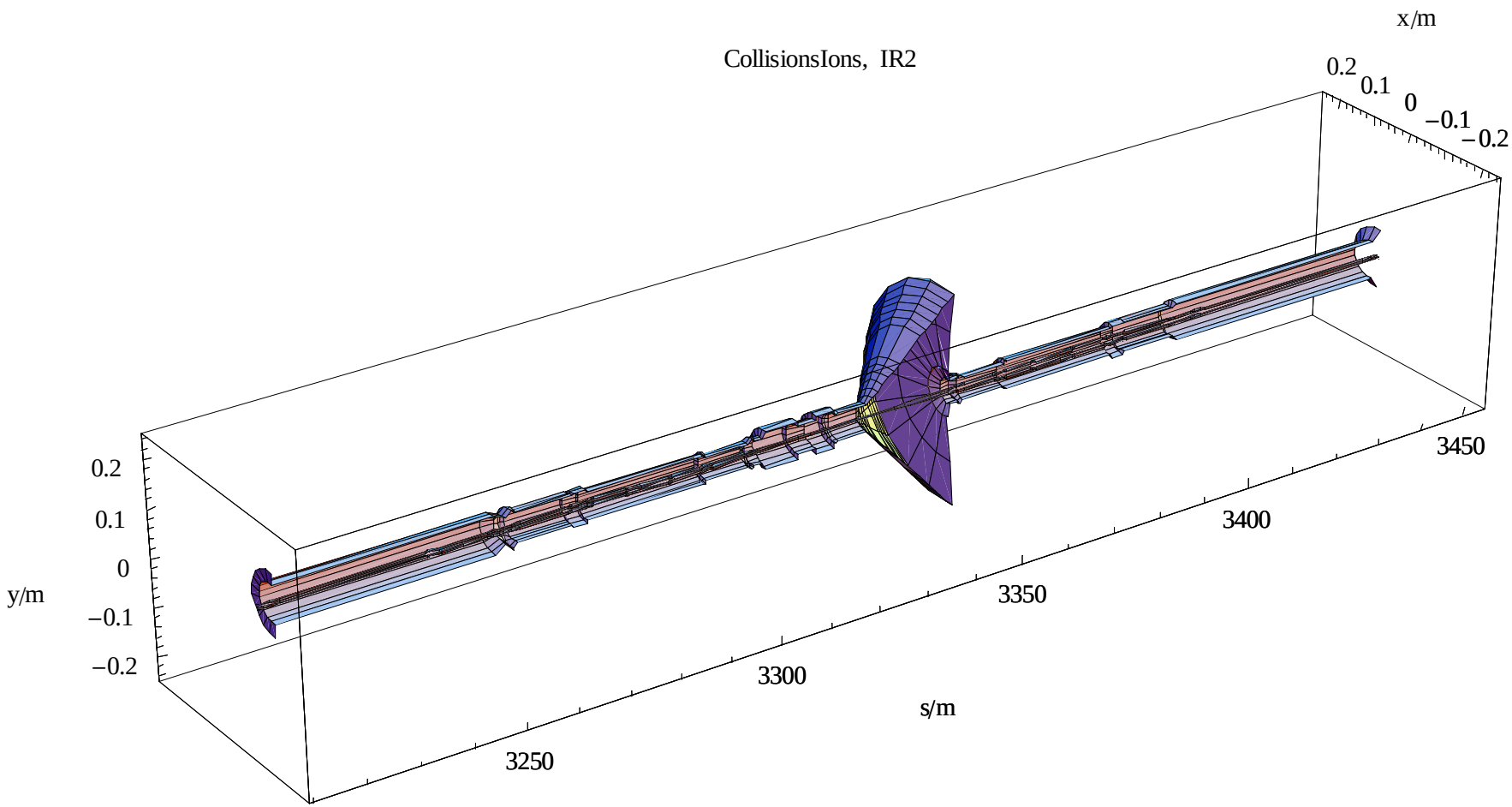


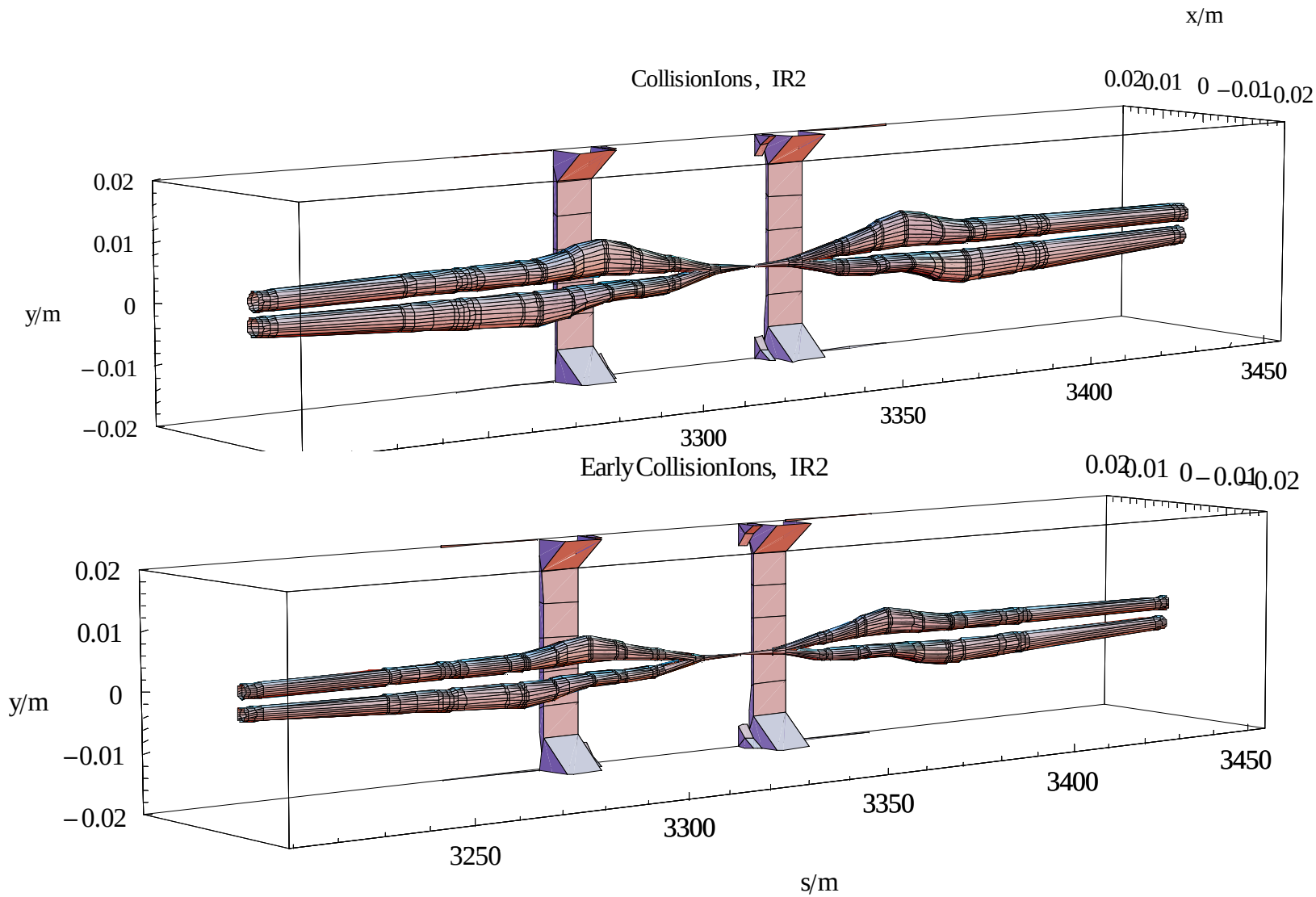
Beams crossing inside LHC aperture, Nominal, IR2

```
IRcrossingPlot3D["CollisionsIons", "IR2", 2, 0.25]
```



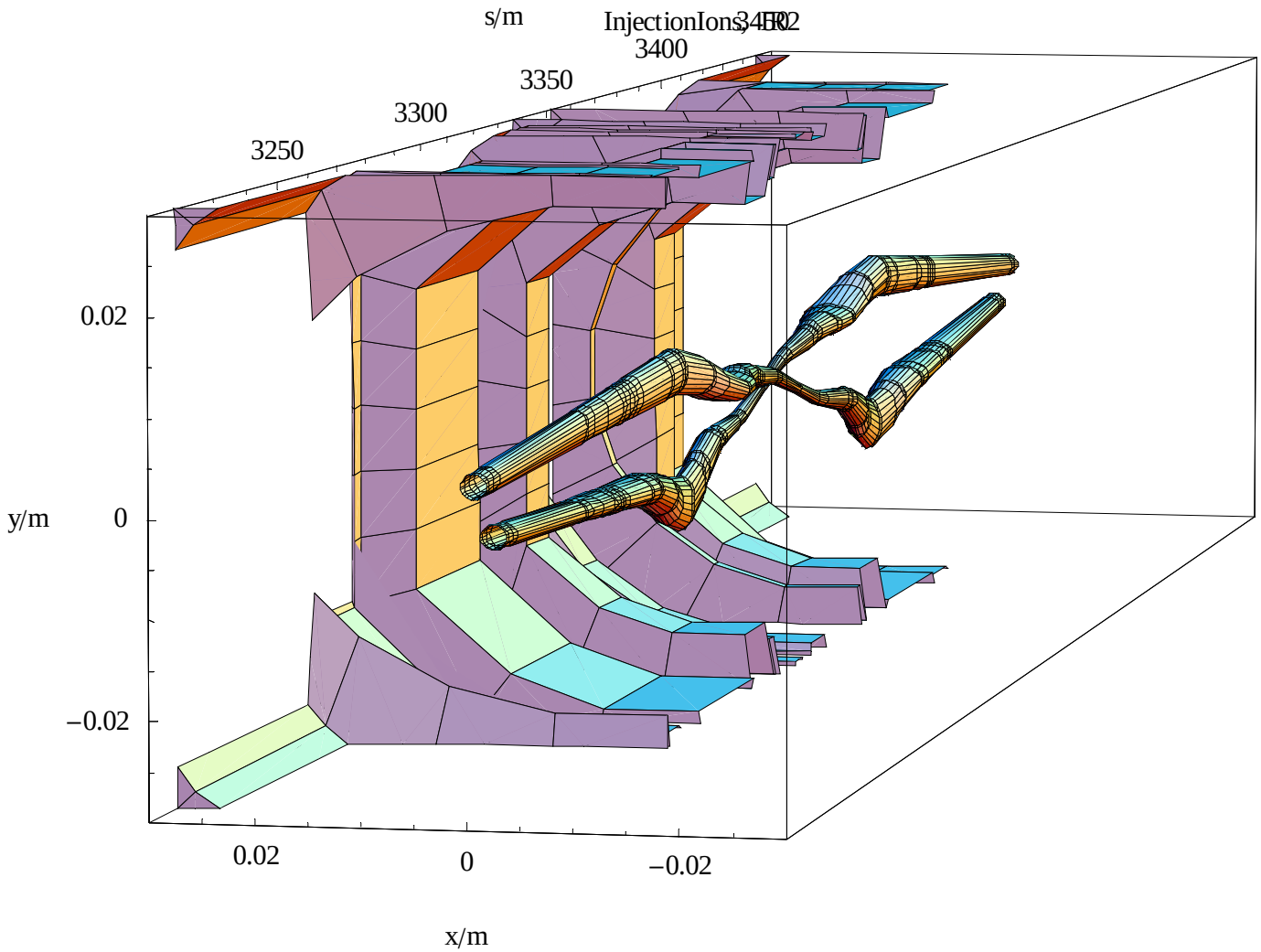
Beams crossing, Nominal+EARLY, IR2 (2σ beam)

```
IRcrossingPlot3D["CollisionIons", "IR2", 2, 0.02]
```



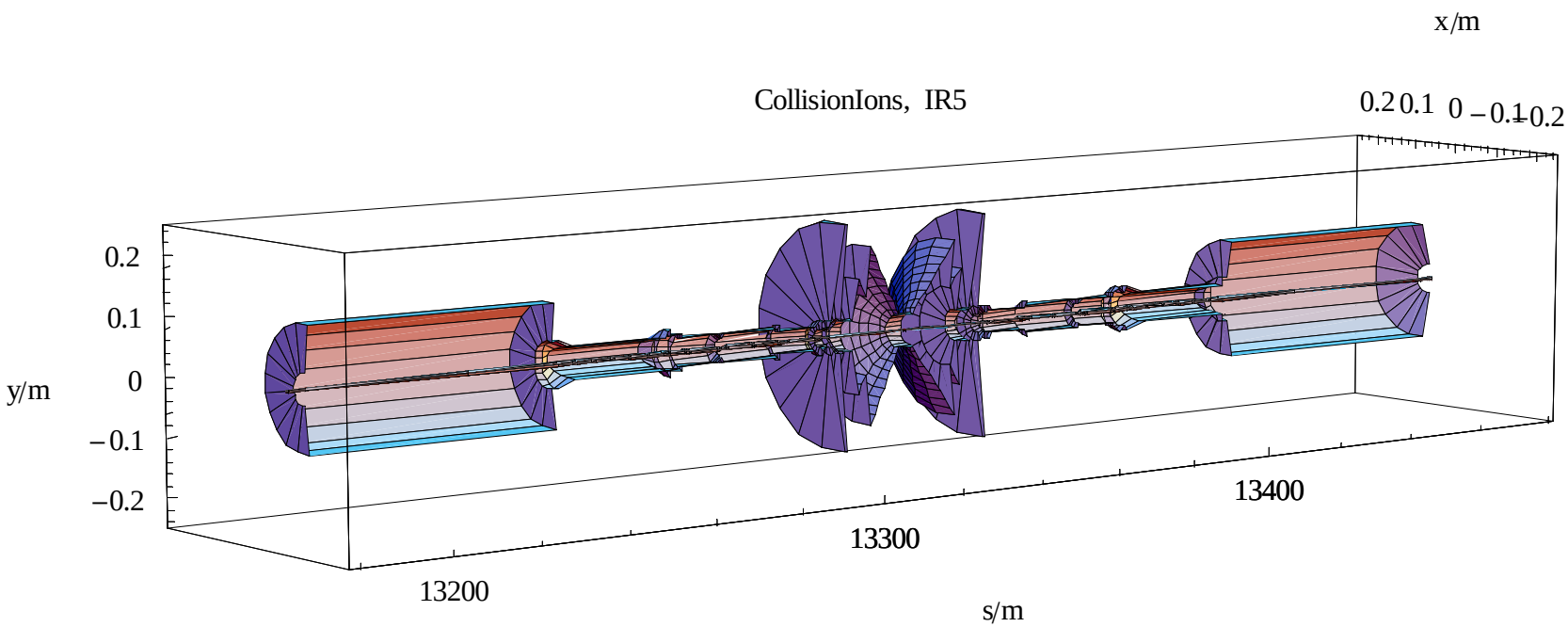
Beams crossing, Injection, IR2 (2σ beam)

```
IRcrossingPlot3D["InjectionIons", "IR2", 2, 0.03, ViewPoint -> {-3.308, -0.644, 0.312}]
```



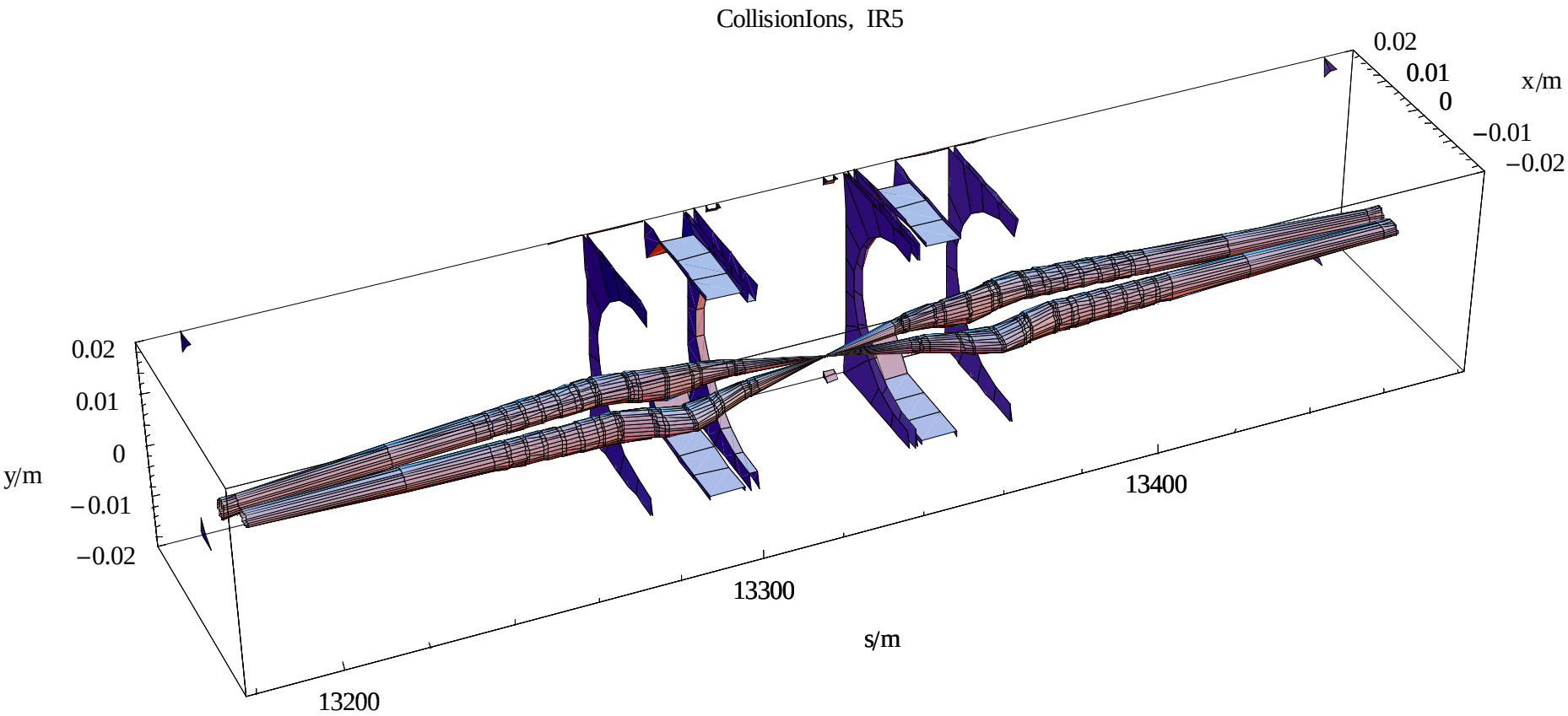
Beams crossing inside LHC aperture, Nominal, IR5

```
IRcrossingPlot3D["CollisionIons", "IR5", 2, 0.25]
```



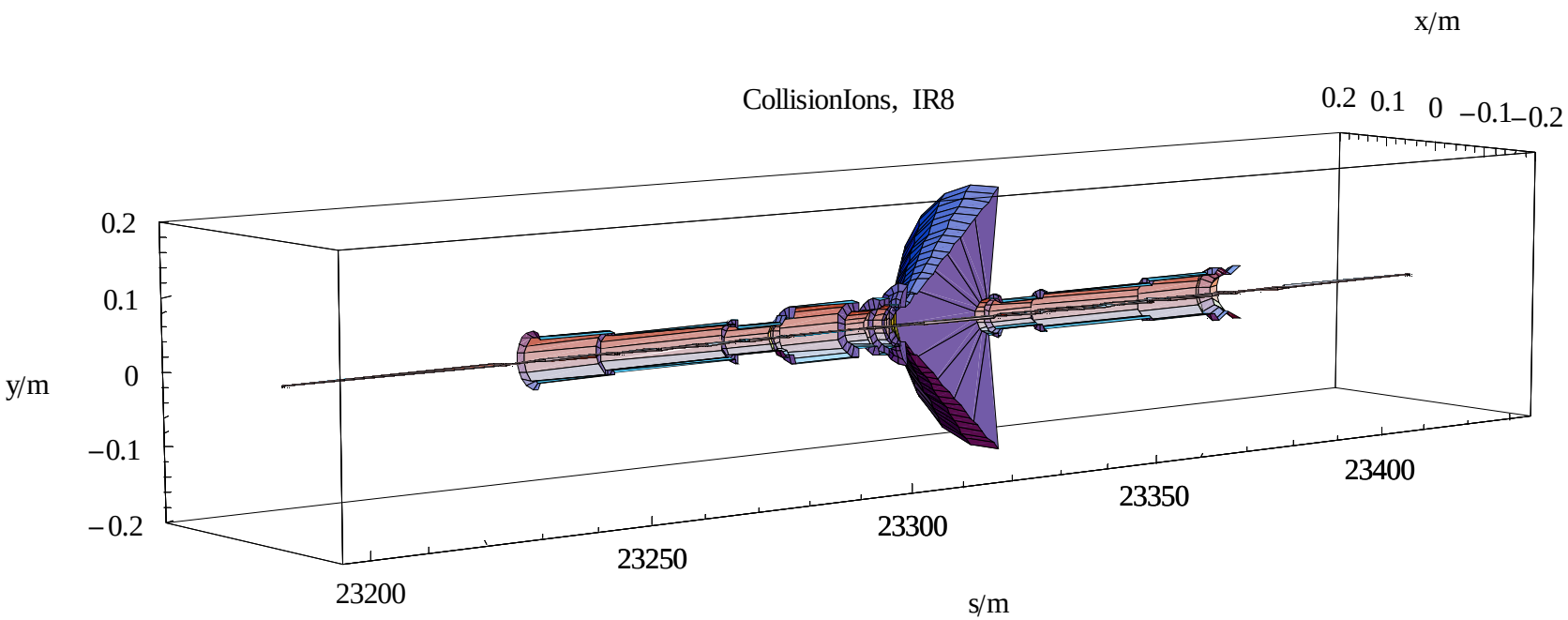
Beams crossing, Nominal, IR5, closer view (2σ beam)

```
IRcrossingPlot3D["CollisionIons", "IR5", 2, 0.02, ViewPoint -> {-1.233, -2.695, 2.165}]
```



Beams crossing inside LHC aperture, Nominal, IR8

```
IRcrossingPlot3D["CollisionIons", "IR8", 2, 0.2]
```



Beams crossing, Nominal, IR8, closer view (2σ beam)

```
IRcrossingPlot3D["CollisionIons", "IR8", 2, 0.01, ViewPoint -> {-0.999, 0.046, 0.011}]
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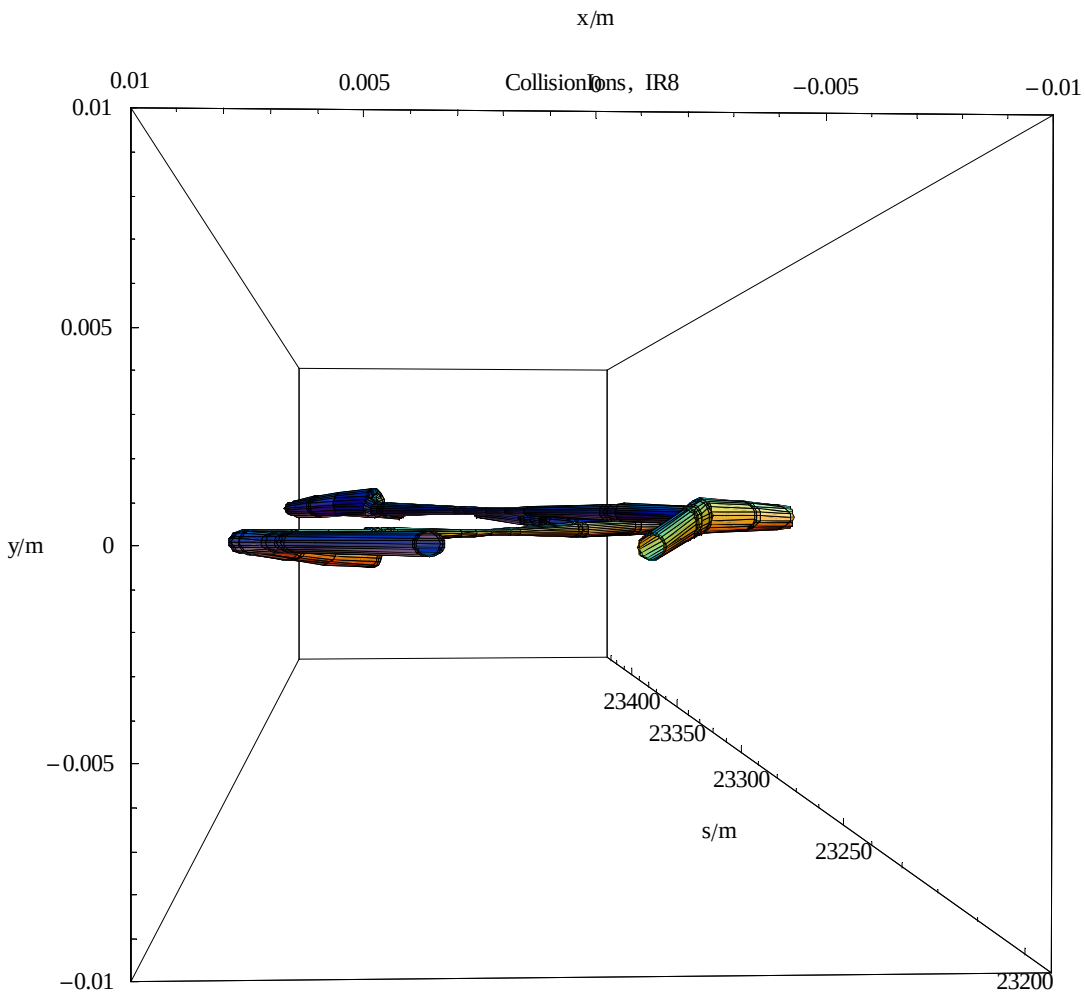
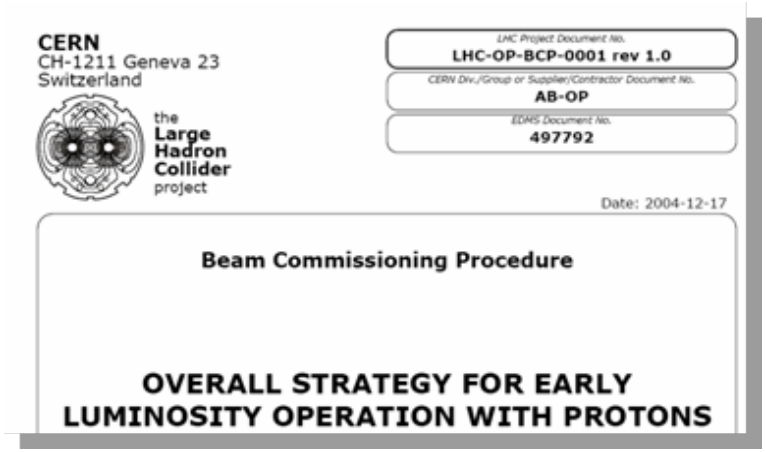


Separation at IP8, similar to injection (but smaller beams)

Minimum Pre-requisites for switching from p-p to Pb-Pb

- Pb-ion injection should be ready
  - Nominally in Spring 2008
- Injection, ramp and collisions work with protons
  - Squeeze is not strictly necessary
  - E.g. conditions of the Pilot Run ...

Optical Conditions in Proton Pilot Run


CERN
CH-1211 Geneva 23
Switzerland

the Large Hadron Collider project

LHC Project Document No.
LHC-OP-BCP-0001 rev 1.0
CERN Div./Group or Supplier/Contractor Document No.
AB-OP
EDMS Document No.
497792

Date: 2004-12-17

Beam Commissioning Procedure

OVERALL STRATEGY FOR EARLY LUMINOSITY OPERATION WITH PROTONS

Initial Pilot Run conditions with Early Ion beam would give Pb-Pb luminosity of:

$$L = (\text{few}) \times 10^{24}\ \text{cm}^{-2}\text{s}^{-1}$$

ALICE will be taking head-on collisions.

Minimum change to LHC configuration.

Beam energy (TeV)	6.0, 6.5 or 7.0	6.0, 6.5 or 7.0	6.0, 6.5 or 7.0
Number of bunches (per beam)	43	43	156
β* in IP 1, 2, 5, 8 (m)	18,10,18,10	2,10,2,10	2,10,2,10
Crossing Angle (μR)	0	0	0
Transverse emittance (μm)	3.75	3.75	3.75
Bunch spacing (μs)	2.025	2.025	0.525
Bunch Intensity	$1\ 10^{10}$	$4\ 10^{10}$	$4\ 10^{10}$
Luminosity in IP 1 & 5 ($cm^{-2}\ s^{-1}$)	$\sim 3\ 10^{28}$	$\sim 5\ 10^{30}$	$\sim 2\ 10^{31}$
Luminosity in IP 2 ($cm^{-2}\ s^{-1}$)	$\sim 6\ 10^{28}$	$\sim 1\ 10^{30}$	$\sim 4\ 10^{30}$