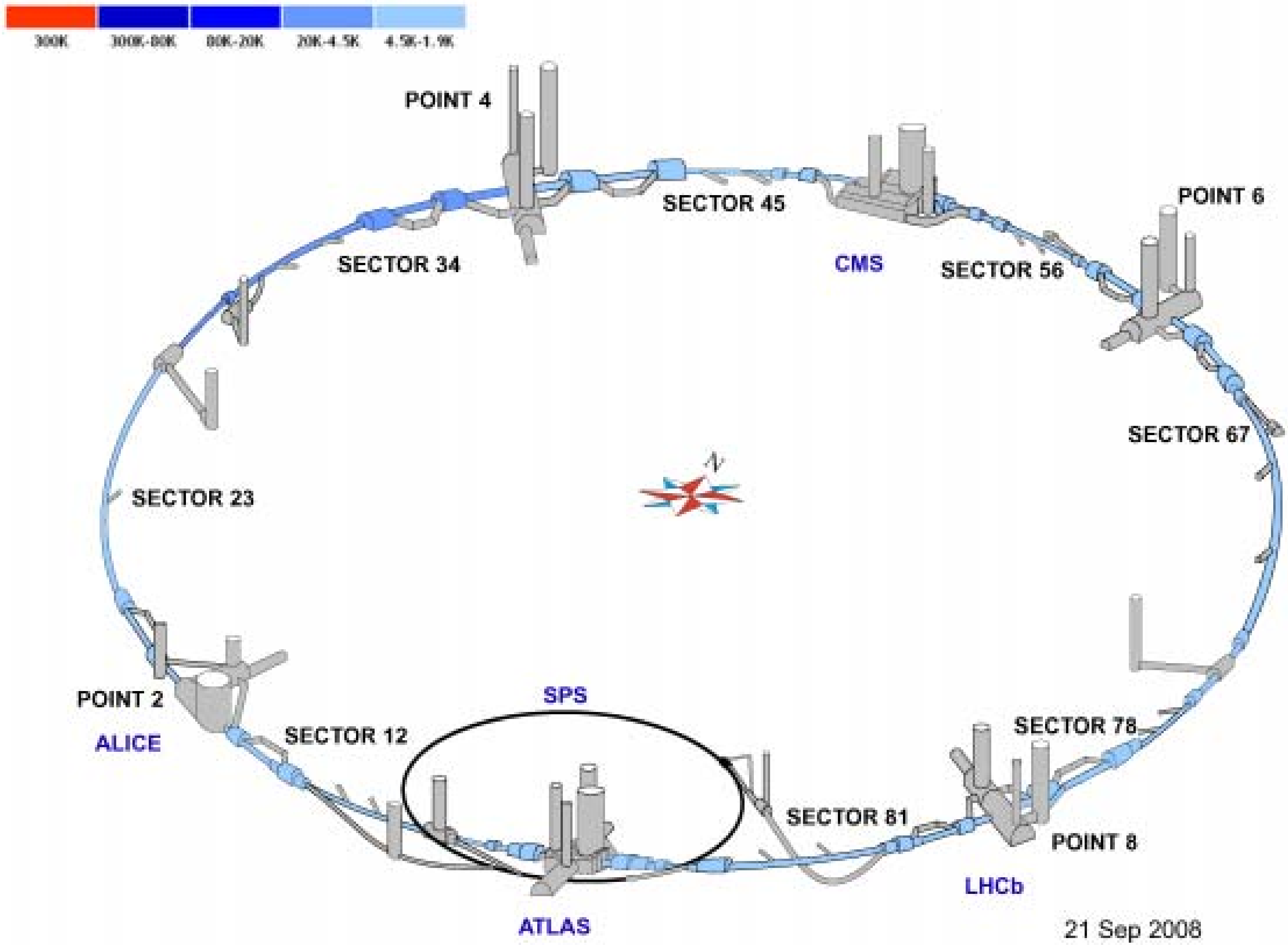
Большой адронный коллайдер и его детекторы

Проф. Л.Н.Смирнова

23 сентября 2008г.

Географическое положение

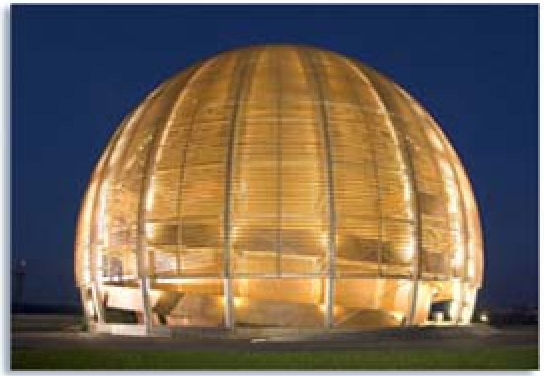
Схема кольца ускорителя БАК



10 сентября – старт БАК

- Geneva, 10 September 2008. The first beam in the Large Hadron Collider at CERN was successfully steered around the full 27 kilometres of the world's most powerful particle accelerator at 10h28 this morning. This historic event marks a key moment in the transition from over two decades of preparation to a new era of scientific discovery.

Центр управления БАК в момент запуска



Globe – информационный центр ЦЕРН

Панорама ЦЕРН с видом на Globe. Вблизи находится главный вход в ЦЕРН (слева) и наземный комплекс АТЛАС(справа)

Результаты первой недели работы БАК

- **LHC progress report, week 1**

- Geneva, 18 September 2008. After a spectacular start on 10 September, the LHC enjoyed a mixed first week of commissioning with beam. To get beams around the ring in both directions on the first day exceeded all expectations, and the success continued through the night, with several hundred orbits being achieved.
- The next step in the commissioning process is to bring in the radio-frequency (RF) system that keeps the beams bunched, rather than spreading out around the ring, and will eventually accelerate them to 7 TeV. The RF system works by ‘capturing’ the beam, speeding up the slower moving particles and slowing down the faster ones so that the beam remains bunched into fine threads about 11 cm long. Without it, the beam quickly dissipates and cannot be used for physics.
- On Thursday night, 11 September, beam two, the anti-clockwise beam, was captured and circulated for over half an hour before being safely extracted from the LHC. The next step is to repeat the process for beam one, and that is set to begin this week.
- The intervening time has been spent recovering cryogenic conditions after the failure of a power transformer on one of the surface points of the LHC switched off the main compressors of the cryogenics for two sectors of the machine. The transformer, weighing 30 tonnes and with a rating of 12 MVA, was exchanged over the weekend. During this process, the cryogenics system was put into a standby mode with the two sectors kept at around 4.5 K. Since the beginning of the week the cryogenics team have been busy re-cooling the magnets and preparing for operation with beam, which is currently forecast for today. The next stage of the commissioning will be single turn studies using beam one, followed by RF capture and circulating beam in both rings.
- The LHC is on course for first collisions in a matter of weeks. Next update 24 September at the latest.

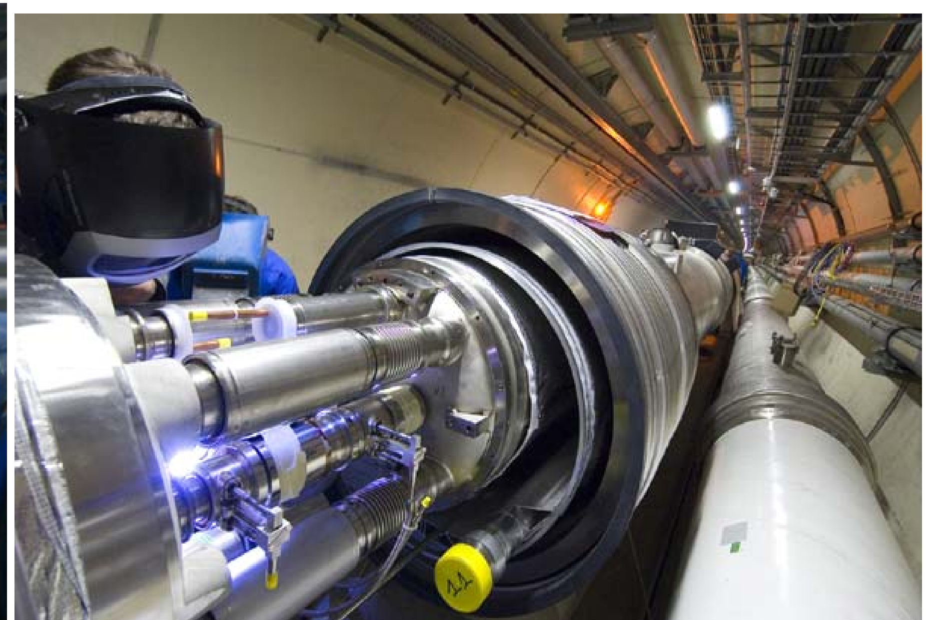
Проблемы:

- PR09.08
  20.09.2008
- **Incident in LHC sector 34**
- Geneva, 20 September 2008. During commissioning (without beam) of the final LHC sector (sector 34) at high current for operation at 5 TeV, an incident occurred at mid-day on Friday 19 September resulting in a large helium leak into the tunnel. Preliminary investigations indicate that the most likely cause of the problem was a faulty electrical connection between two magnets, which probably melted at high current leading to mechanical failure. CERN's strict safety regulations ensured that at no time was there any risk to people.
- A full investigation is underway, but it is already clear that the sector will have to be warmed up for repairs to take place. This implies a minimum of two months down time for LHC operation. For the same fault, not uncommon in a normally conducting machine, the repair time would be a matter of days.
- Further details will be made available as soon as they are known.

Монтаж коллайдера

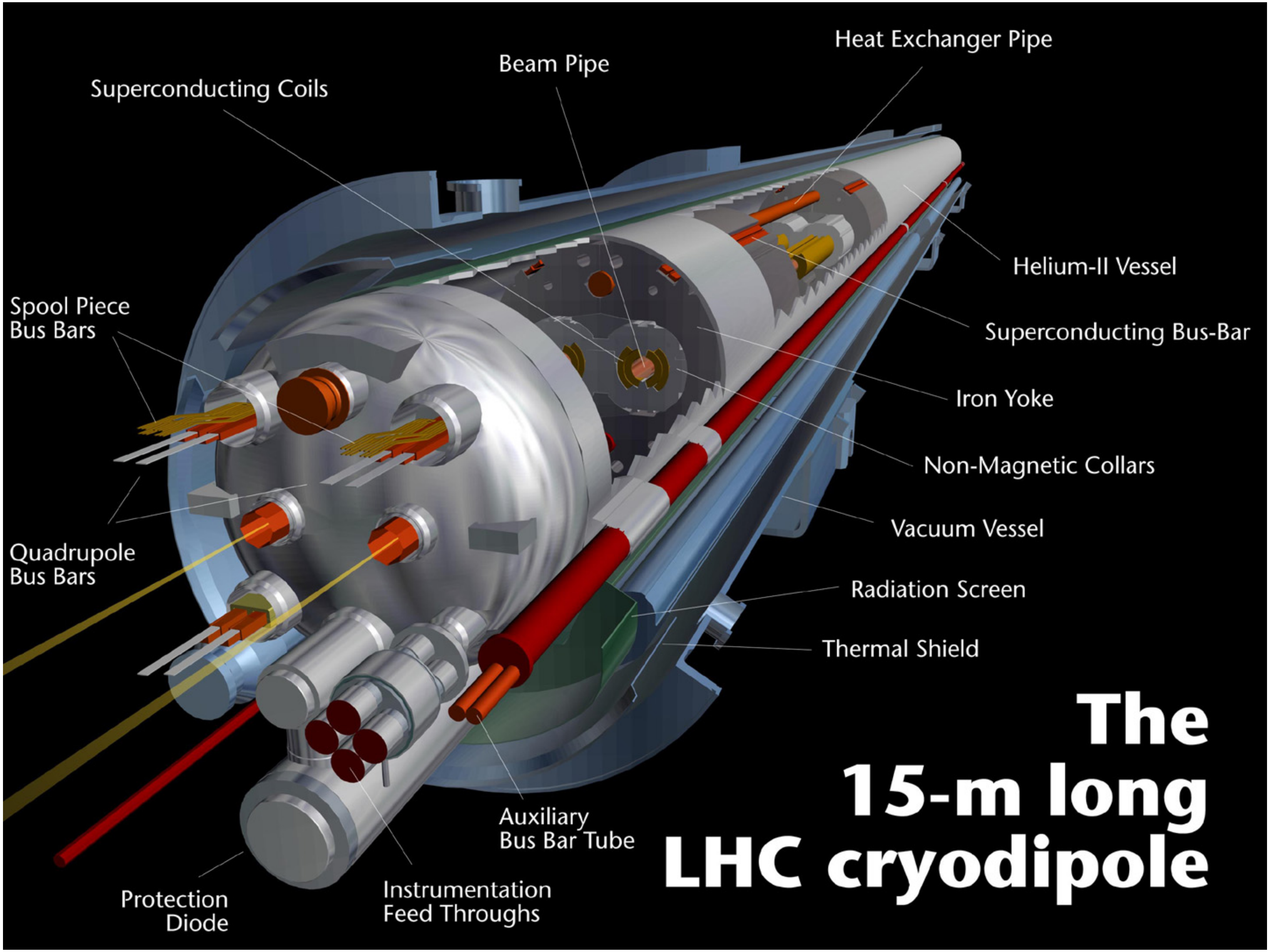
Вид тоннеля – сектор 81

Соединение секций магнитов

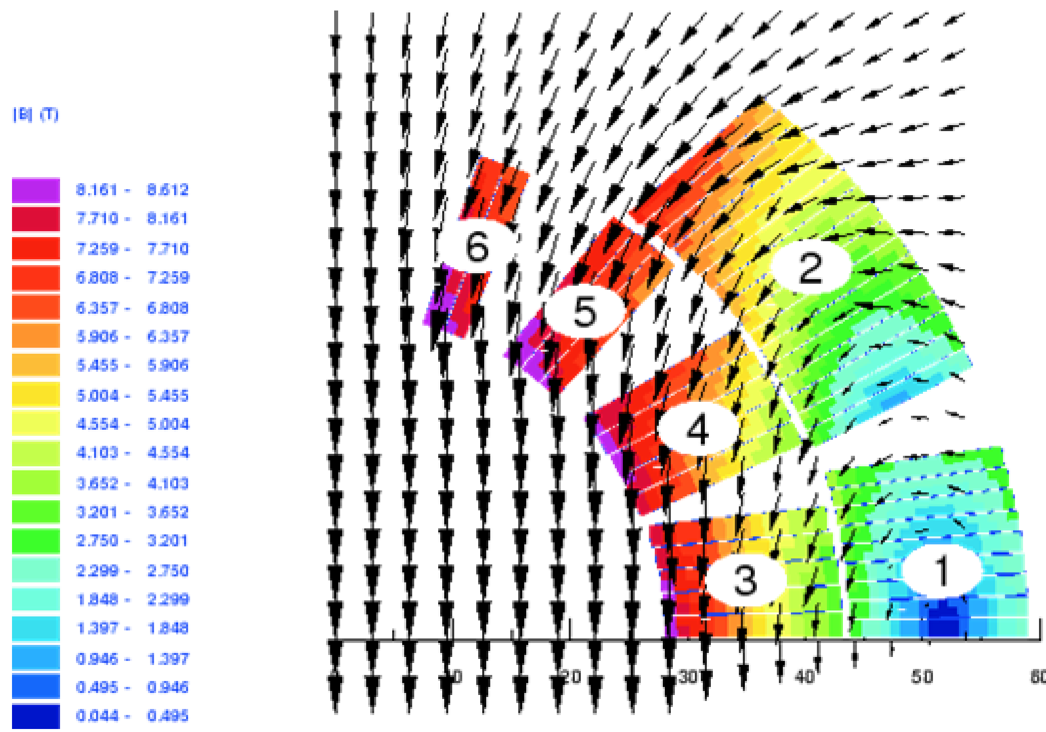


Параметры основного диполя БАК

- **Main Dipoles**
- The main budget item and a serious technological challenge are the superconducting (1.9 K) dipoles which bend the beams around the 27 km circumference of the LHC. At 7 TeV these magnets have to produce a field of around 8.4 Tesla at a current of around 11,700 A. The magnets have two apertures, one for each of the counter-rotating beams. Each one is 14.3 m long. A total of 1232 are needed.
- Vertical B field in the dipole bends the beam round via the Lorentz force
- Need very strong magnets to get the high energy beam around the circle. Superconducting (1.9 K) dipoles producing a field of 8.3 T - current 11,850A
- 2-in-1 magnet design.
- Bending magnets (dipoles): 14.3 m long. Cost: ~ 0.5 million CHF each. Need 1232 of them
- Quads etc to keep beam focused and the motion stable
- Stored magnetic energy up to 1.29 GJ per sector. Total stored energy in magnets = 11GJ
- One dipole weighs around 35 tonnes.


Heat Exchanger Pipe
Beam Pipe
Superconducting Coils
Helium-II Vessel
Spool Piece
Bus Bars
Superconducting Bus-Bar
Iron Yoke
Non-Magnetic Collars
Vacuum Vessel
Quadrupole
Bus Bars
Radiation Screen
Thermal Shield
Auxiliary
Bus Bar Tube
Protection
Diode
Instrumentation
Feed Throughs
The
15-m long
LHC cryodipole

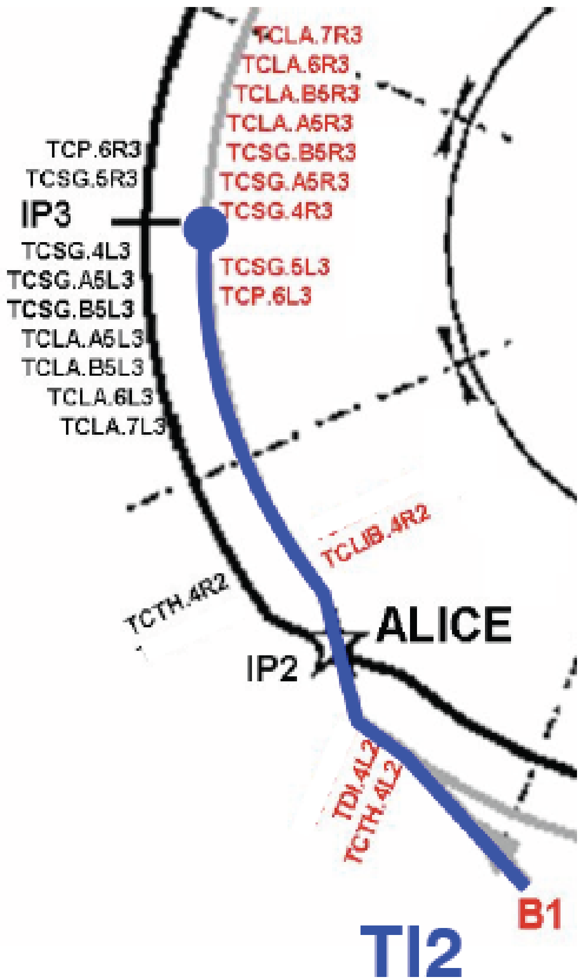
Диполь БАК

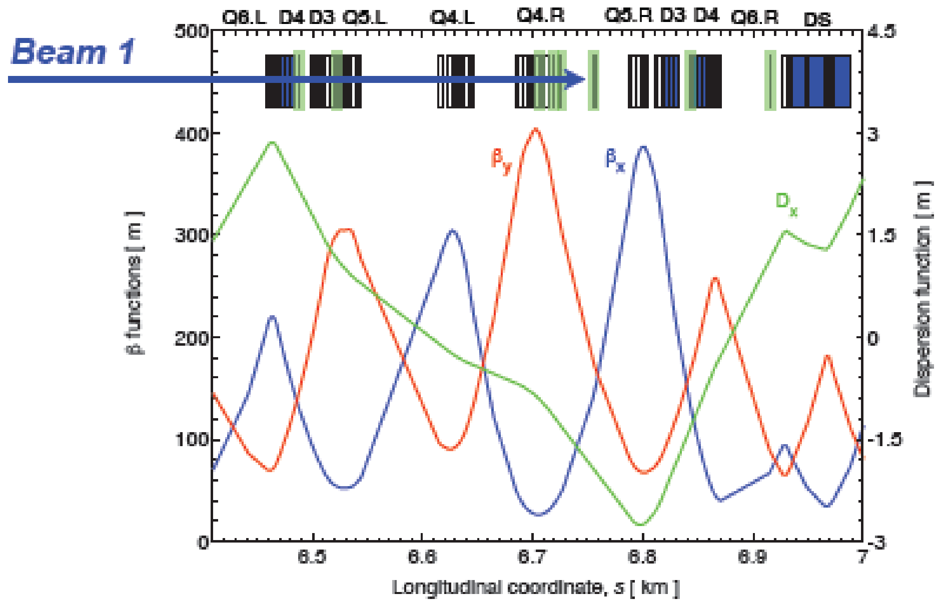


|B| (T)
8.161 - 8.612
7.710 - 8.161
7.259 - 7.710
6.808 - 7.259
6.357 - 6.808
5.906 - 6.357
5.455 - 5.906
5.004 - 5.455
4.554 - 5.004
4.103 - 4.554
3.652 - 4.103
3.201 - 3.652
2.750 - 3.201
2.299 - 2.750
1.848 - 2.299
1.397 - 1.848
0.946 - 1.397
0.495 - 0.946
0.044 - 0.495
6
5
2
4
3
1
20
30
40
50

Тесты пучка БАК в августе 2008г.

Layout of beam path





(1) Commission end of TI2

(beam on TDI on IP2-left)

(2) Steer beam up to IR3

(3) Stop beam on the collimators

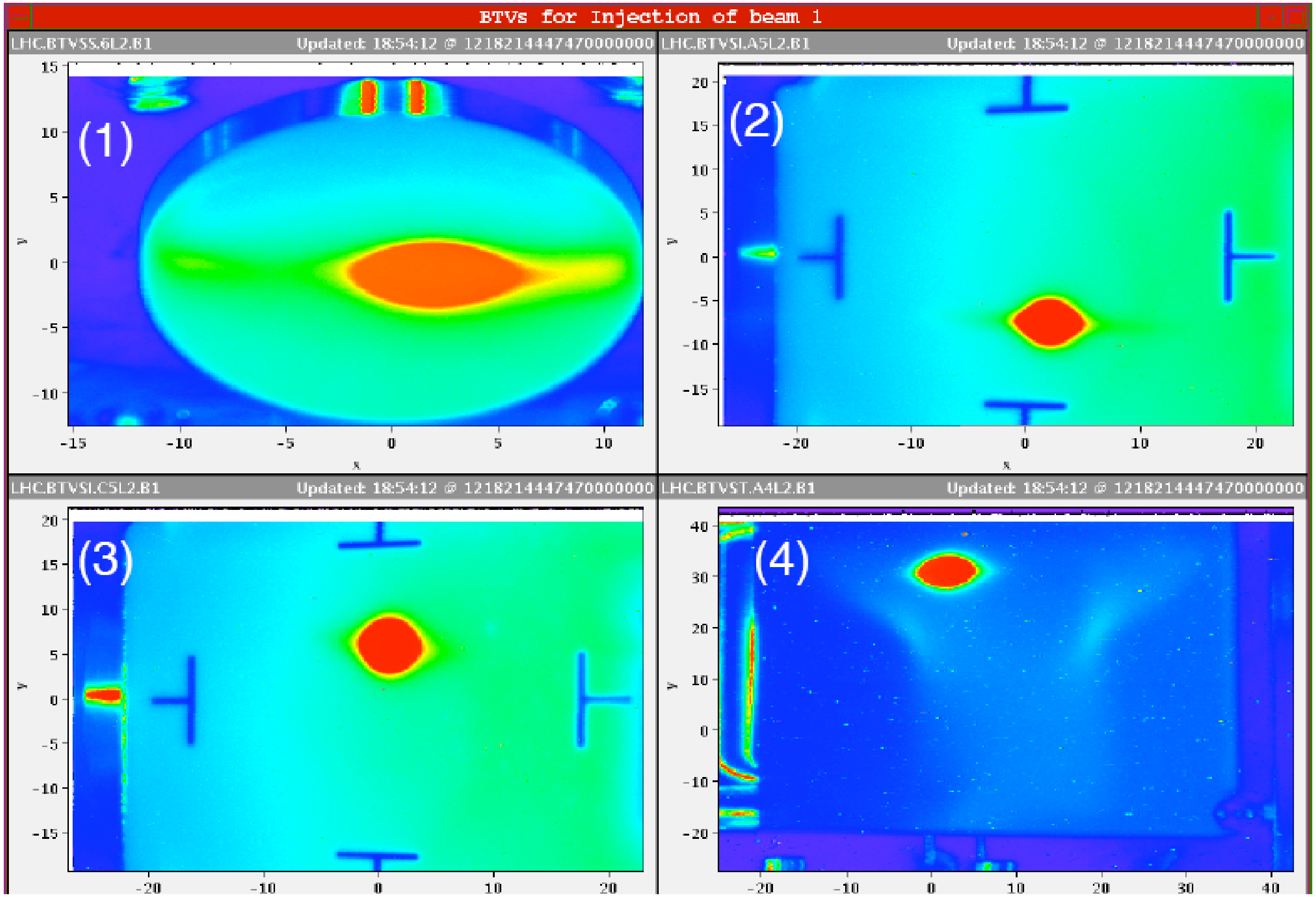
(5 Carbon primary+secondary colls; 4 Tungsten absorbers)

Goals of beam test

		Duration	Intensity	# shots	∫Intensity	Comments
		h	p+		p+	
1	End TI2, Injection Steering, commission BDI, timing	4	5E+09	100	5.0E+11	TDI in, protecting Alice
2	Trajectory acquisition commissioning, trajectory correction, threading	6	5E+09	200	1.0E+12	To IR3 collimators
3	Momentum matching (if required)	1	5E+09	50	2.5E+11	
	RECYCLE & recover	2				
4	Kick response	3	5E+09	300	1.5E+12	Data used for, coupling, BPM polarity checks, corrector polarity checks
5	Injection region aperture	3	5E+09	300	1.5E+12	TDI in, protecting Alice
6	Screens	2	5E+09	50	2.5E+11	
7	Dispersion	1	5E+09	200	1.0E+12	Pi bumps, BLMs, BCT
8	Check BLM system		5E+09	100	5.0E+11	
9	Higher order polarity checks	3	5E+09	150	7.5E+11	
10	Aperture - oscillations	4	5E+09	300	1.5E+12	
11	Aperture - sliding bumps where required	6	5E+09	150	7.5E+11	
12	Momentum aperture	2	5E+09	100	5.0E+11	
13	Effects of magnetic cycle, variations during decay, reproducibility	6	5E+09	100	5.0E+11	Reserve
	TOTAL	43		2100	9.0E+12	On to TCP
	DAYS	2			5.0E+11	On to TDI

M. Lamont: http://lhc-injection-test.web.cern.ch/lhc%2Dinjection%2Dtest/

Изображения пучка в области инжектора



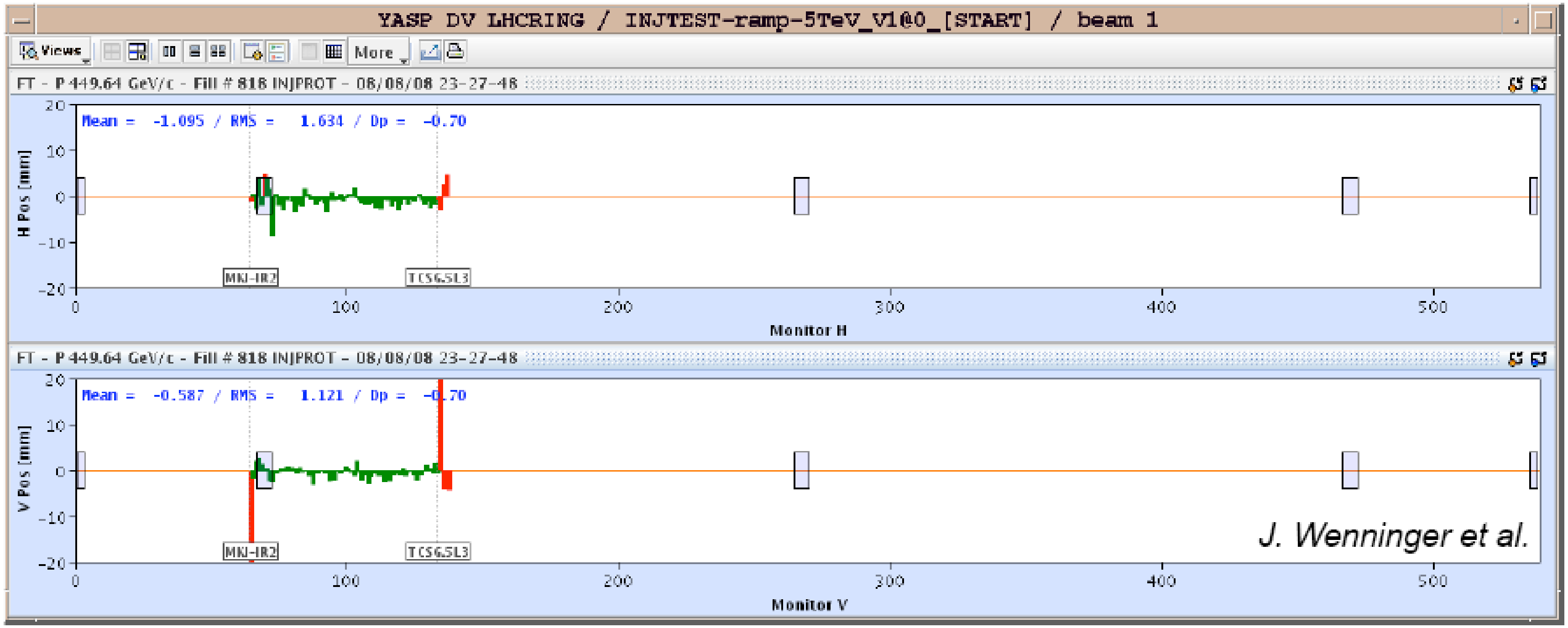
First trajectory (after a few corrections)

J. Wenninger et al

Beam position monitors (BPM's) triggered at the first passage (asynchronous acq.)

Orbit correction to ***± 10 mm*** *in both planes within a few shots!*

First optimized trajectory



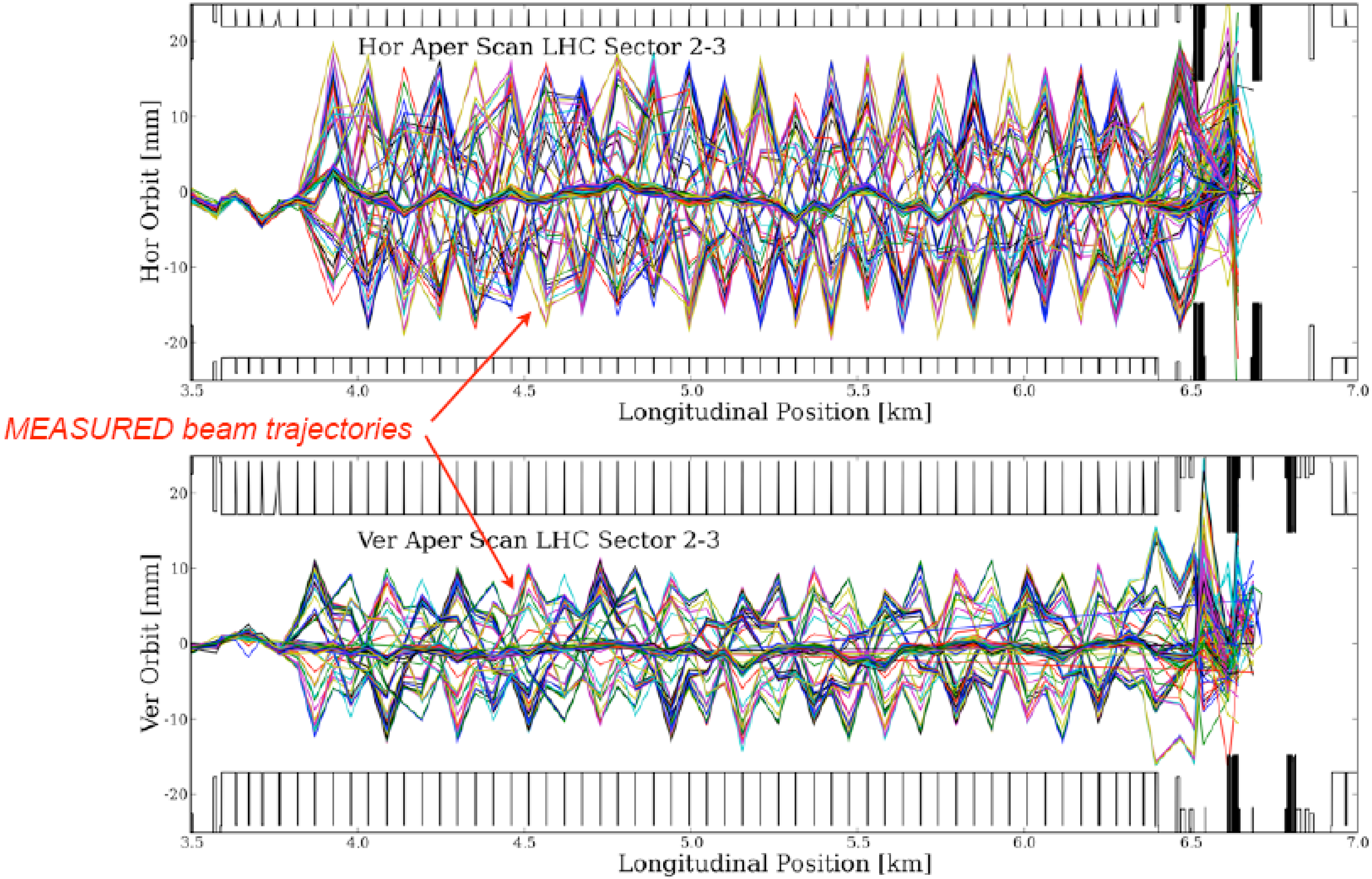
*Peak-to-peak: **± 3 mm** (LHC design specs: ± 4mm!)*

First aperture scan...

LHC Project Report 44 (1996)
"The intensity of the bunch shall therefore not be much larger than 3 10^9 protons."

Indeed, we quenched a main dipole in the region Q8→Q7 left of IP3 with a pilot beam of less than 4 x 10^9p!!

Arc aperture measurements



Horizontal arc aperture of 18-20 mm!!
Vertical limitation at Q8/Q7-L3 of about 10 mm.

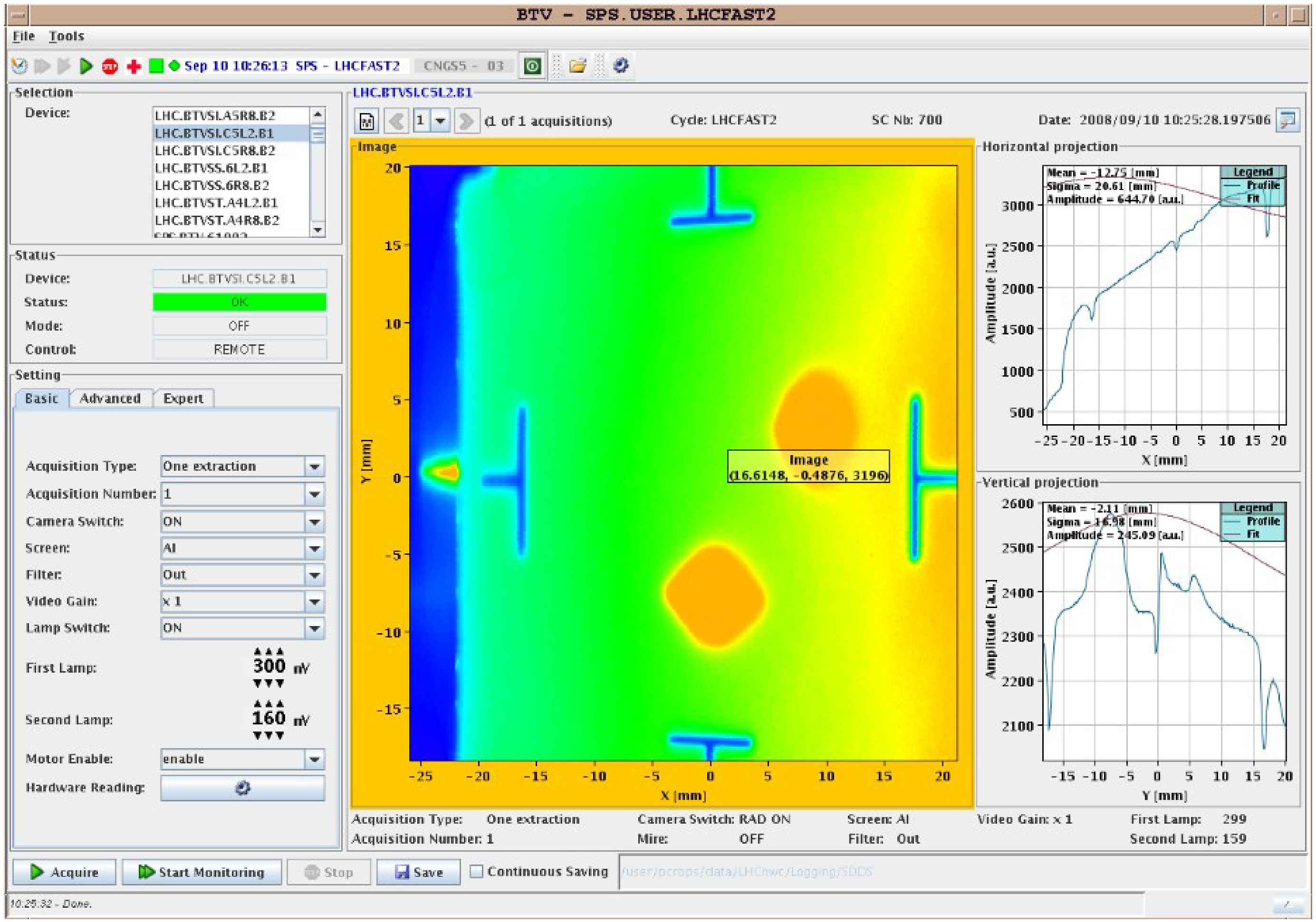
Итоги тестов августа 2008г.

- ☑ Access system looks good
- ☑ Very good condition during the weekend
  - *CRYO, QPS, PIC, BIS, power converters*
- ☑ Aperture looks very good
  - ☐ *No significant limitations found in the arc 23*
  - ☐ *Bottle neck in injection region now fixed*
  - ☐ *No time to measure the insertions*
- ☑ Optics looks good
  - ☐ *Small phase advance error in arc*
  - ☐ *Something suspicious left of 3.*
- ☑ Instrumentation looks very good
  - ☐ *BPMs in asynchronous mode*
  - ☐ *BLMs up and running from first shot*
  - ☐ *Screens etc*
- ☑ Magnet model looks good
- ☑ Controls/Databases looks good (some features…)
- ☑ Beam transfer, RF synchronization looks good

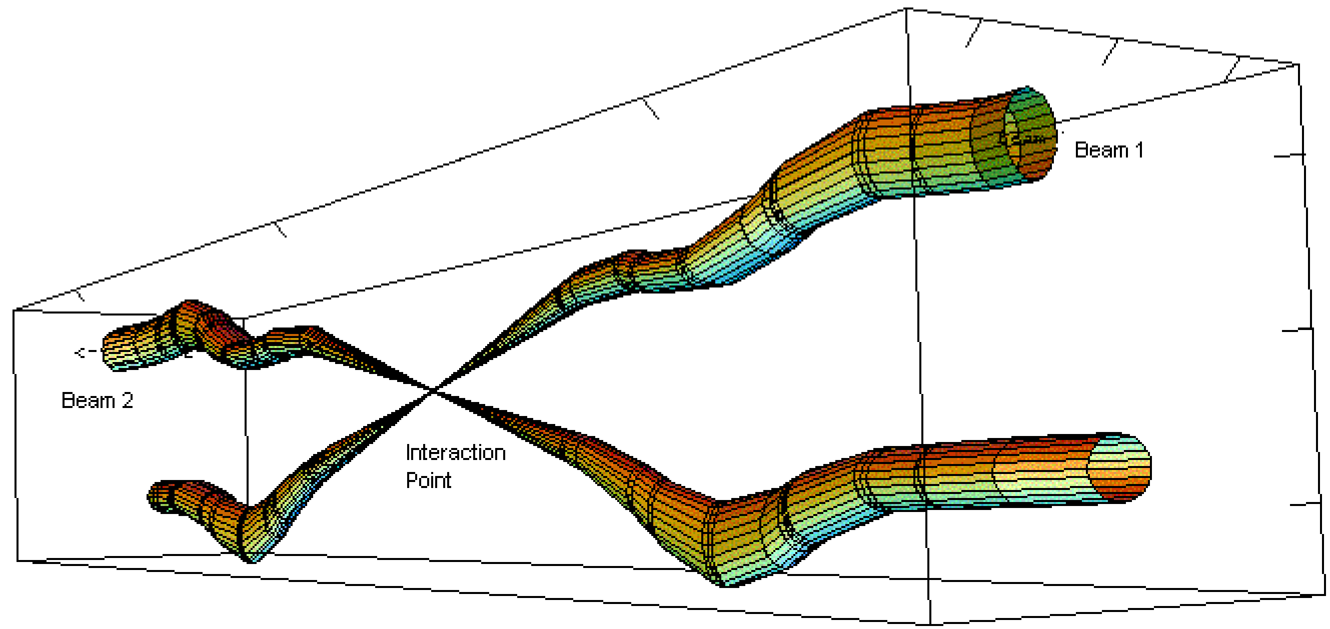
IS Comm, 12-08-2008

For physicists and many news media, it was fantastic to be here at CERN to witness the startup of the LHC. At 10:25am (CERN time), after only an hour of tuning the beam, they circulated the beam all the way around the 27 km ring. This was seen as a cross-section of the beampipe in which one dot was the

injection into the ring and a second dot was the beam returning to that same location (see the photo).



Относительные размеры пучков в области соударений в точке P1 (АТЛАС)

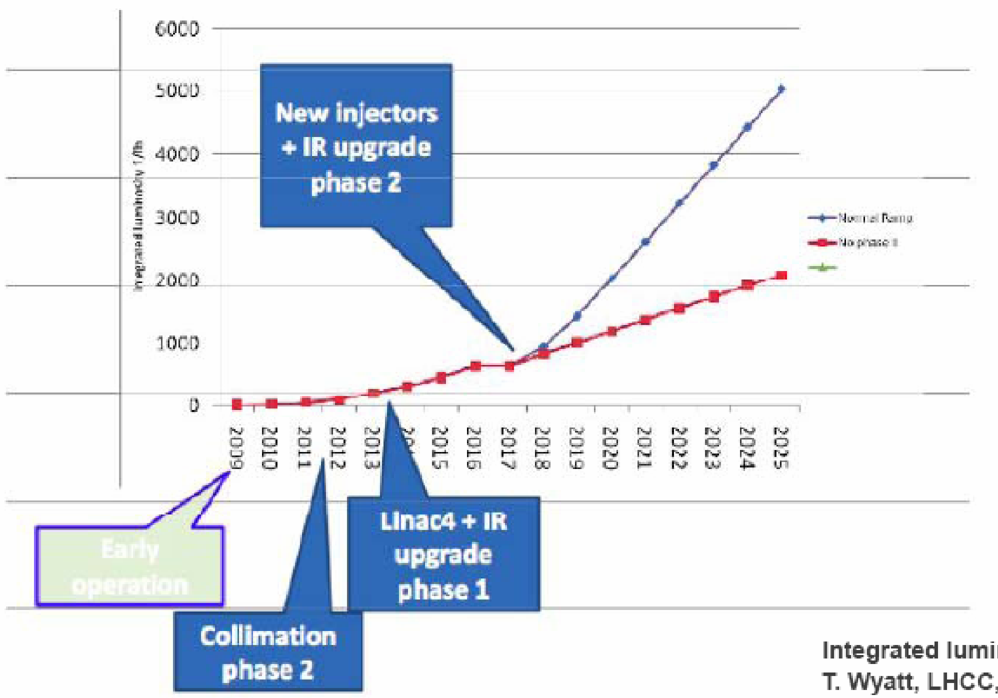


Relative beam sizes around IP1 (Atlas) in collision

Перспективы БАК

A luminosity profile and expected machine upgrades

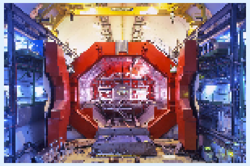
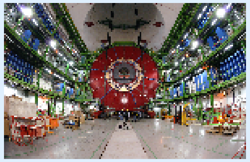
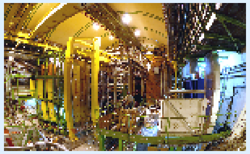
Expected integrated luminosity is a key ingredient relating to recommendations



Integrated luminosity
T. Wyatt, LHCC, 2 July 2008

Эксперименты БАК (LHC)

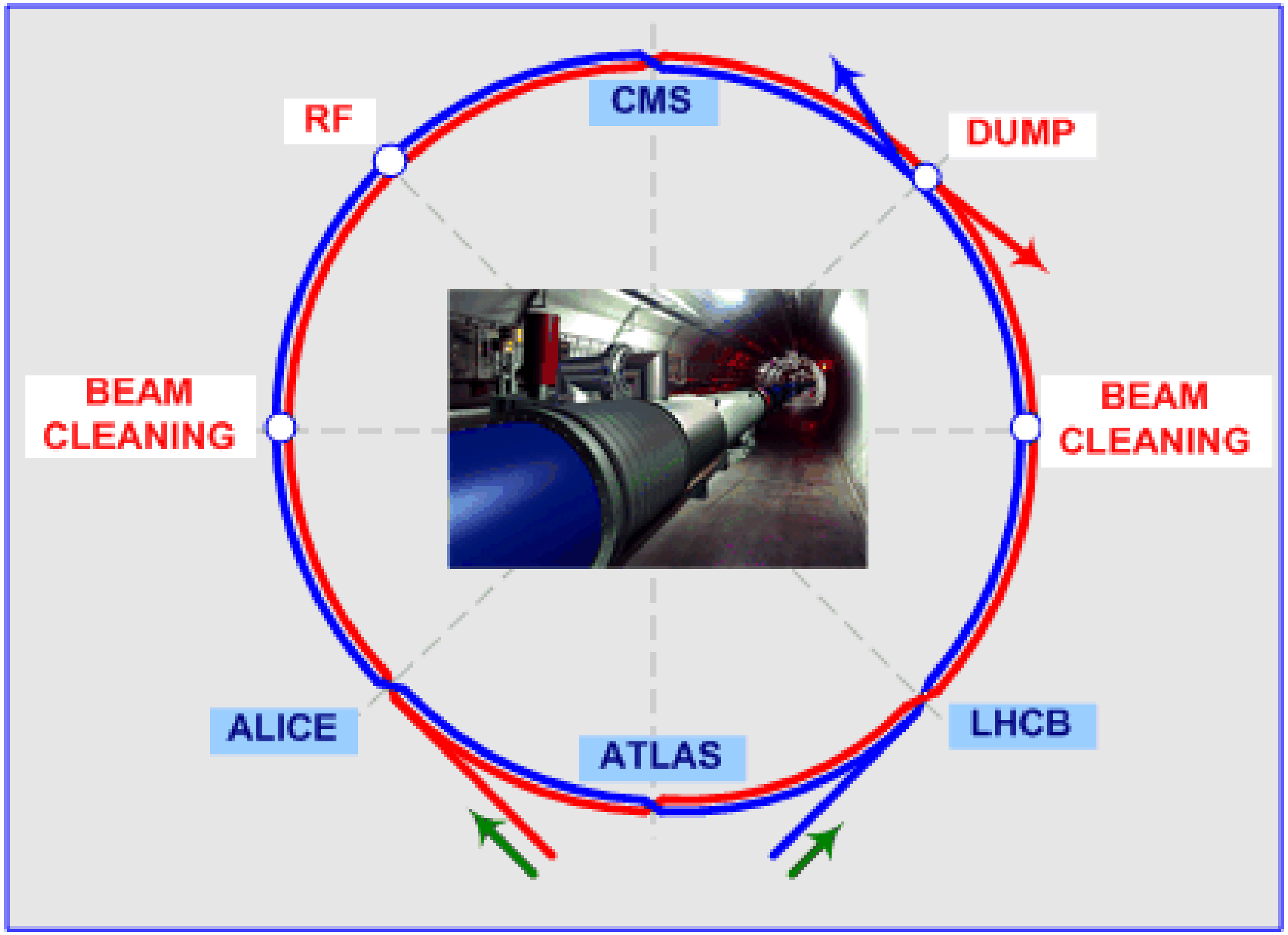
LHC EXPERIMENTS

ALICE	A Large Ion Collider Experiment at CERN LHC	
ATLAS	A large Toroidal LHC ApparatuS	
CMS	The Compact Muon Solenoid an Experiment for the Large Hadron Collider at CERN	
LHCb	Large Hadron Collider beauty experiment	
TOTEM	Total Cross Section, Elastic Scattering and Diffraction Dissociation at the LHC	

LHCf

Схема размещения установок

The Large Hadron Collider (LHC) is being built in a circular tunnel 27 km in circumference. The tunnel is buried around 50 to 175 m. underground. It straddles the Swiss and French borders on the outskirts of Geneva



ALICE

- *Поиск новых состояний материи – кварк-глюонной плазмы;*
- *Изучение распространения кварков в ядерной среде;*
- *Поиск коллективных эффектов в ядерном веществе и т.д.*

Особенности изучения A-A соударений

При энергии LHC впервые процессы в большими P_t, будут иметь значительный вклад в сечение AA соударений. Струи с большими P_t станут пробником изучения кварк-глюонной плазмы (QGP, или КГП). Важно, что методы выделения струй и анализа будут сопоставимы с данными для pp соударений и независимых измерений AA соударений на ATLAS, CMS и позволят эффективно подавлять фон.

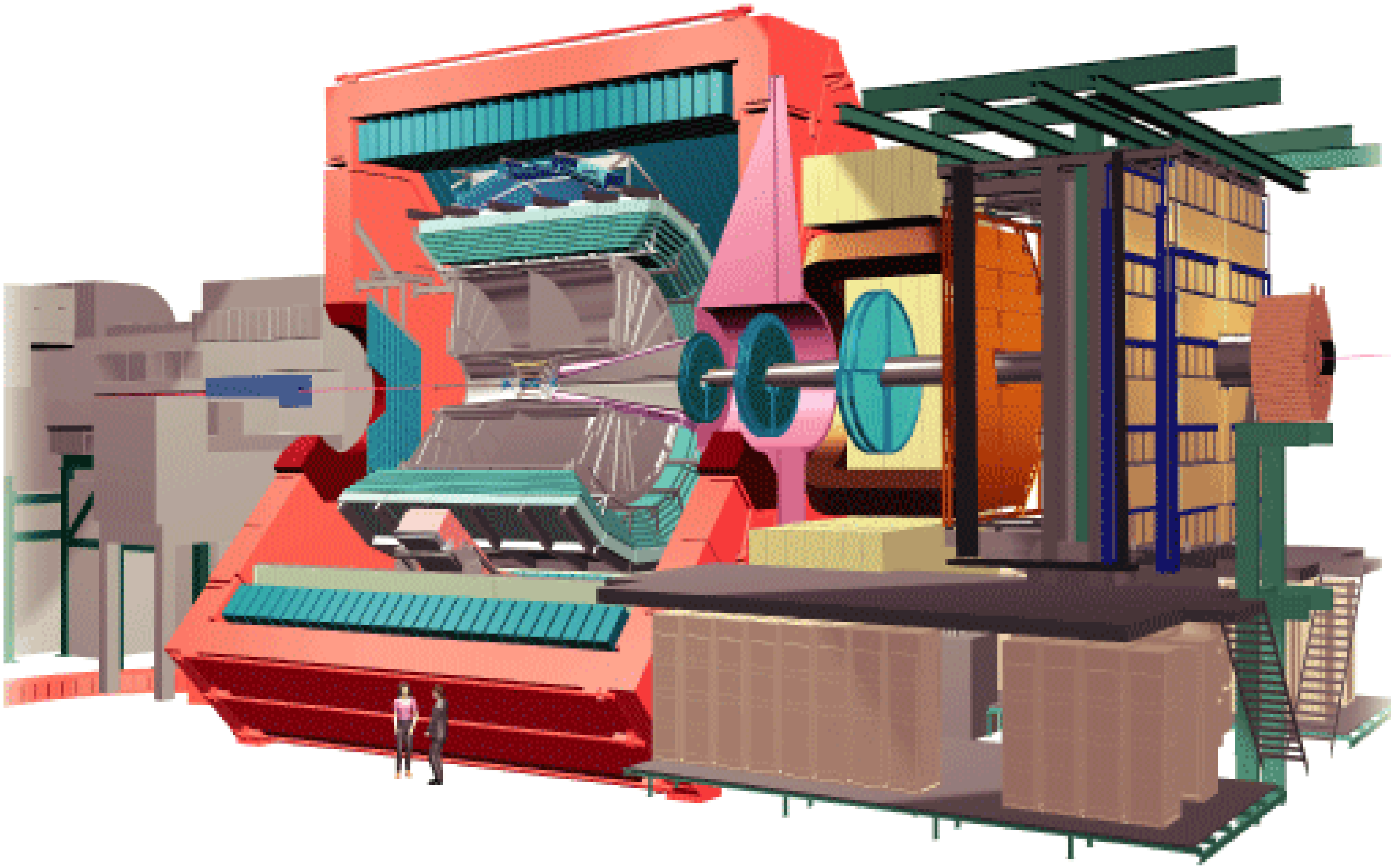
На сегодня установлено существование подавления выхода частиц с большими P_t и корреляций по азимутальному углу вылета частиц, отличия в структуре струй в ядерном веществе (за счет потерь энергии партонами в плотном веществе путем испускания глюонов в соответствии с предсказаниями пертурбативной КХД).

ATLAS и CMS имеют более мощную в сравнении с ALICE калориметрию и смогут измерять струи до 350 ГэВ в центральных соударениях ионов свинца. ALICE использует мощную систему центрального трекера с электромагнитным калориметром для измерения струй до 200 ГэВ. Преимущество ALICE состоит в измерении частиц и струй с относительно малыми P_t и идентификации частиц. Будет возможно измерение фрагментационных функций до малых долей импульса и определять состав струй, т.е. изучать достаточно тонкие эффекты.

Общий вид установки ALICE

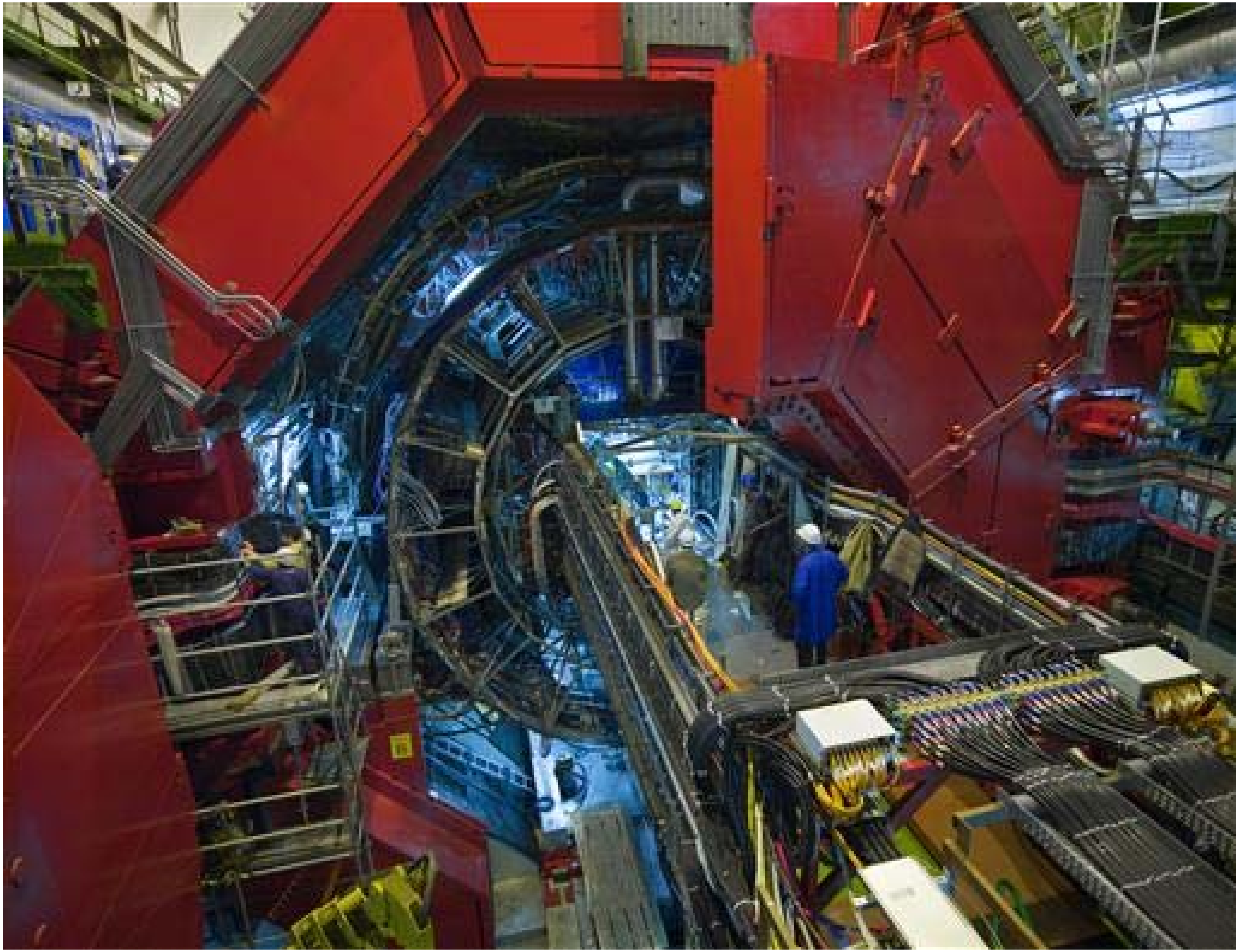
- Aerial view of the ALICE site in Saint-Genis-Pouilly, (France, Ain), 2 km from CERN and the Swiss border

ALICE detector

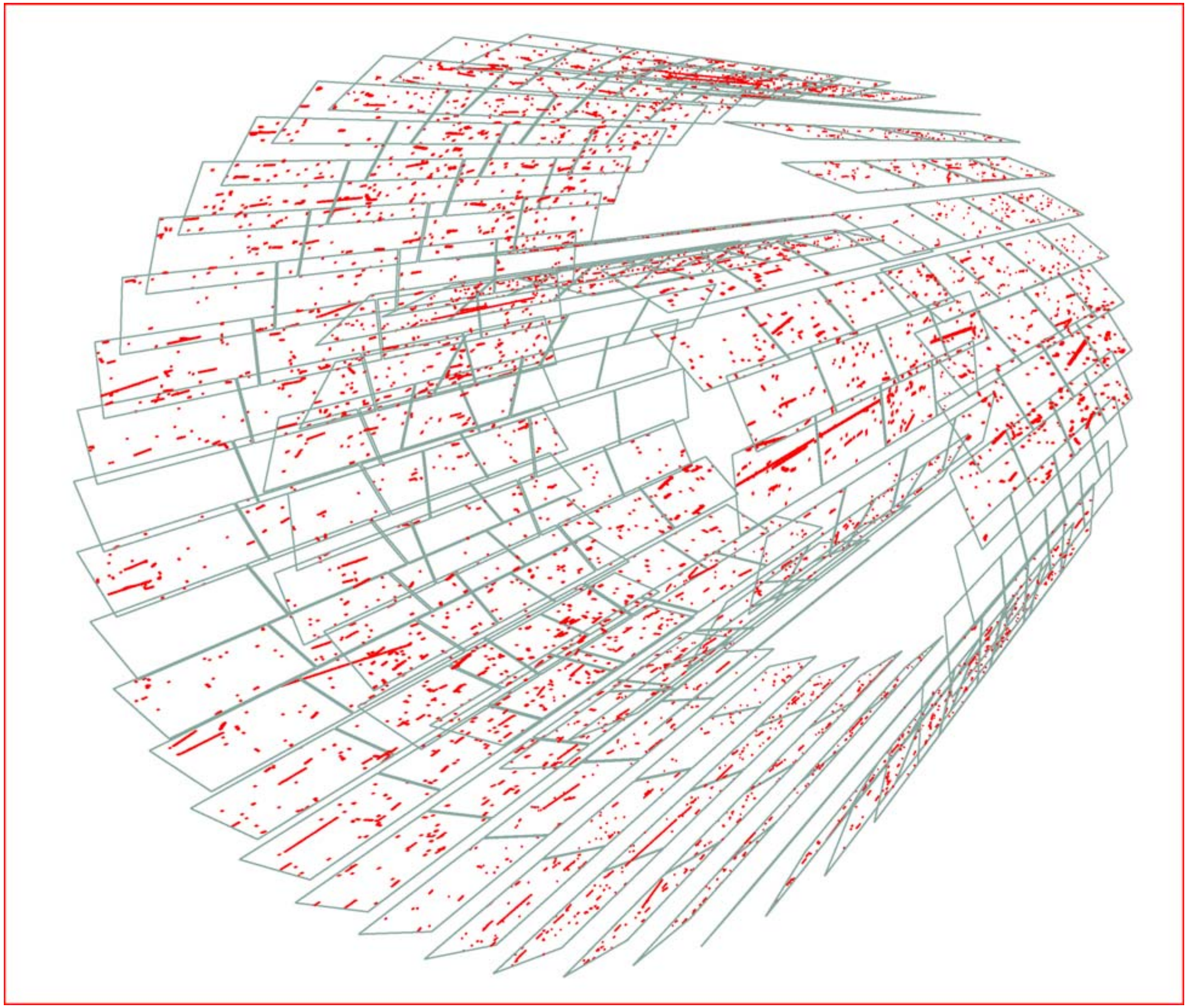


Установка ALICE июнь 2006г.

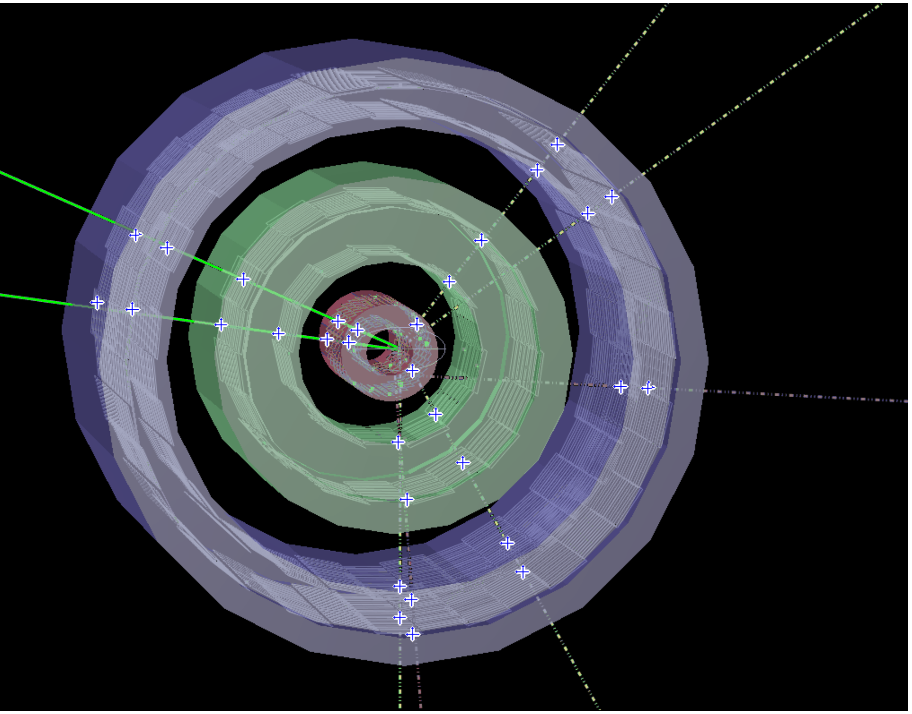
ALICE в конце сборки



Изображение первого события в ALICE

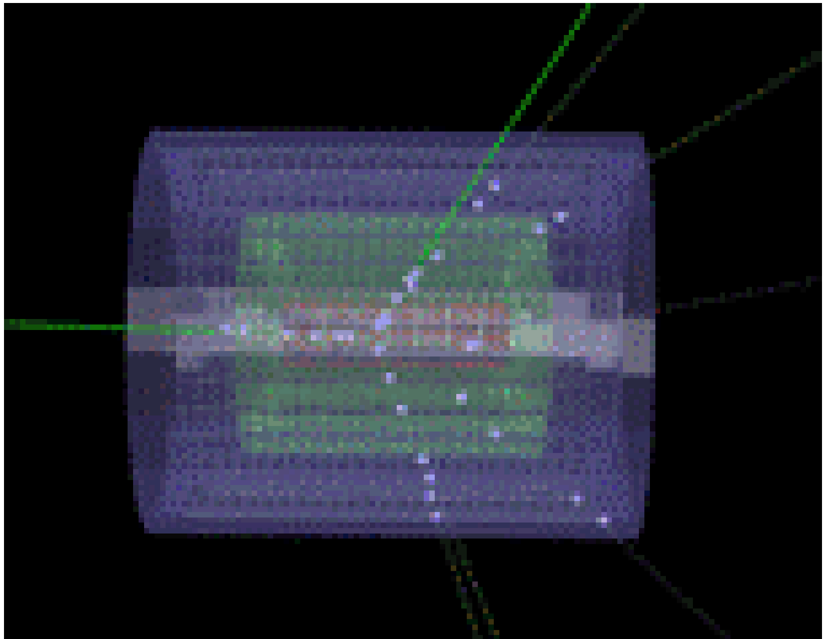


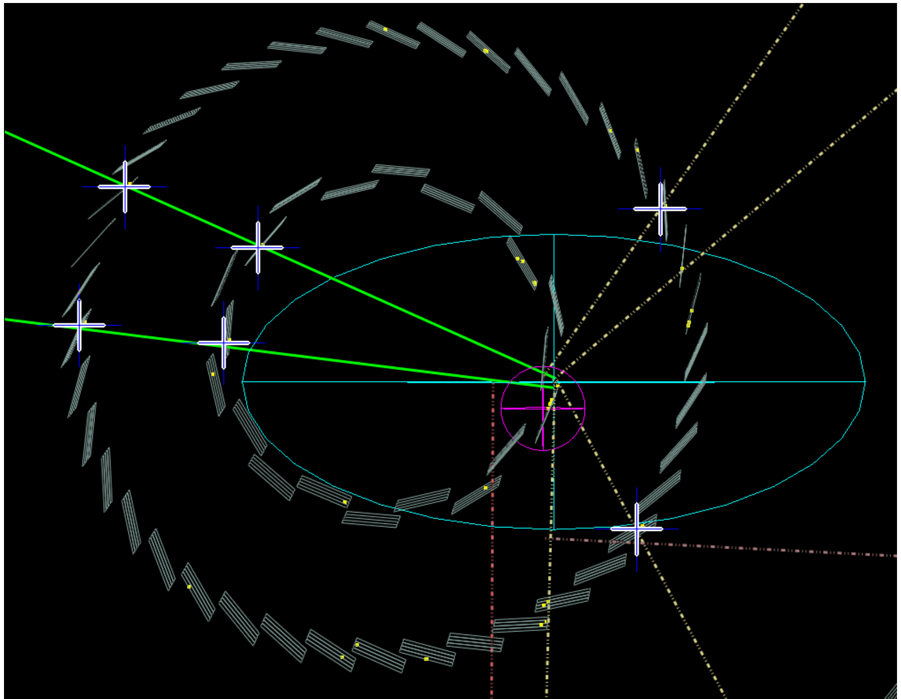
- **On the evening of June 15, 2008, ALICE physicists saw the first tracks at LHC during the first injection test in transfer line TI 2. The Silicon Pixel detector recorded muon tracks produced in the beam dump near Point 2 of the LHC.**
- **© CERN**



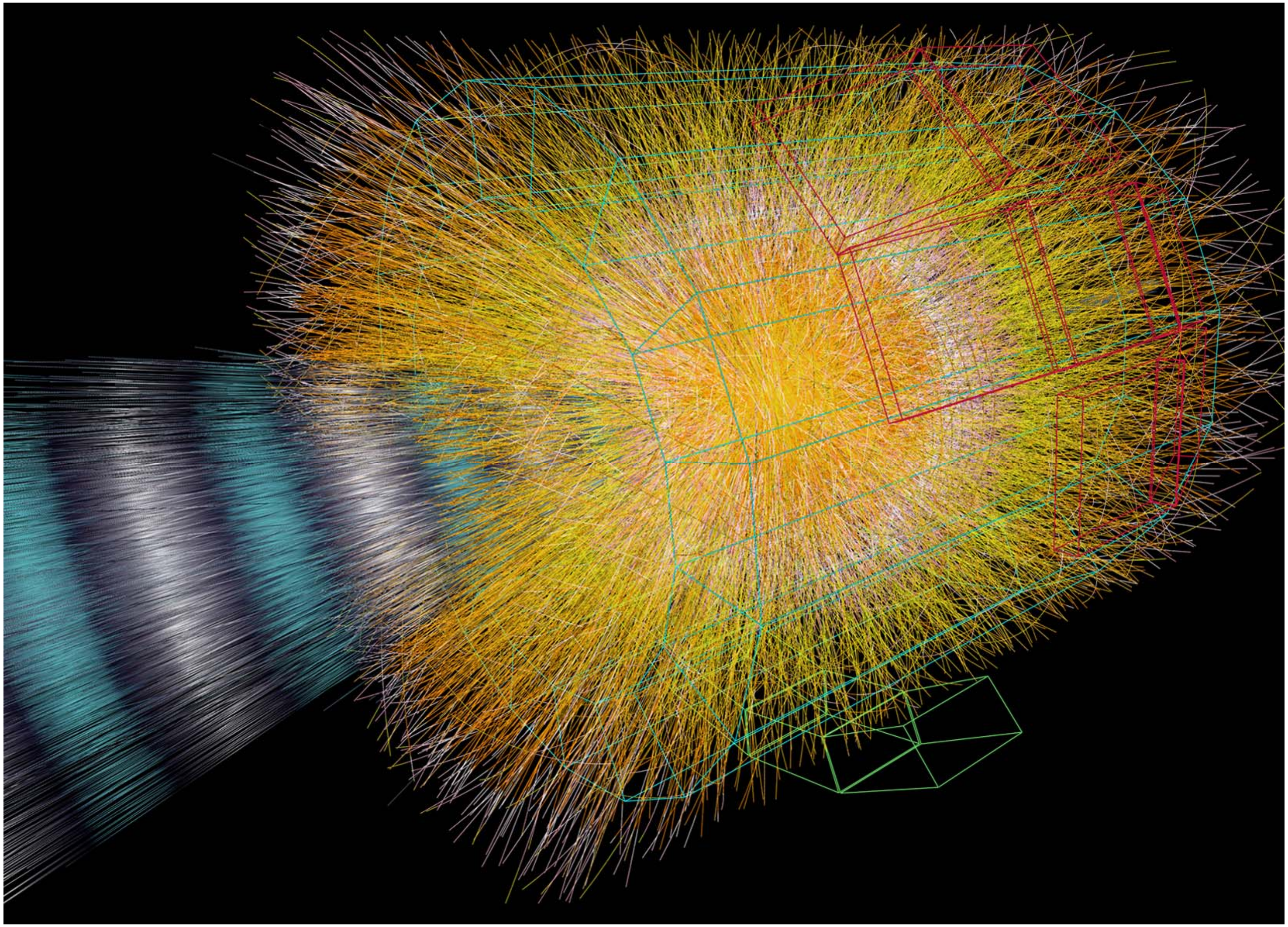
Первые события на ALICE

- **Beam 2** was circulated for a while in the night 11/12 September.
  In the figure, one of the few clean events with 7 tracks from a collision.





Моделирование соударения ядер свинца



LHC b

Исследуются распады c и b-кварков с точки зрения проверки СМ и поиск новой физики через виртуальное проявление новых частиц в характеристиках распадов.

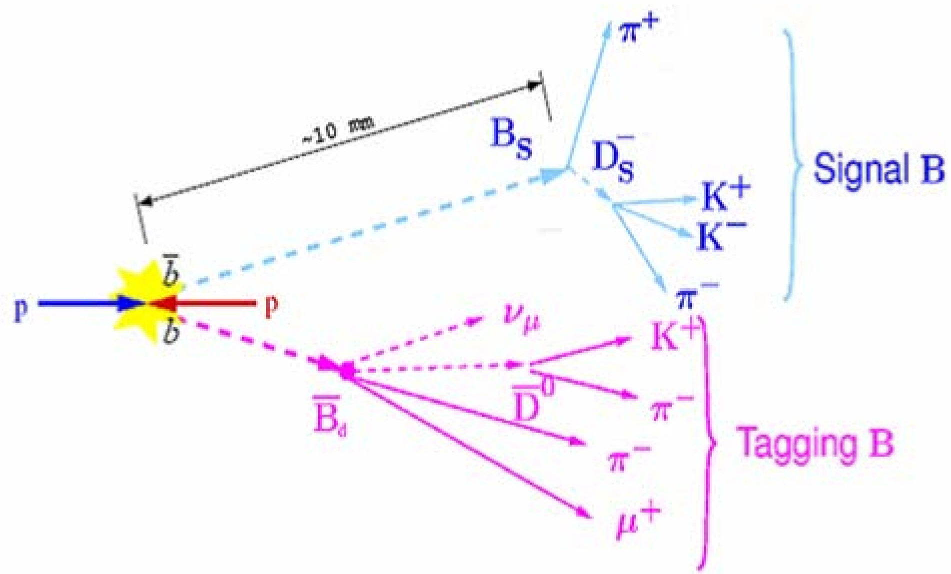
LHCb особенности

- Оптимальная светимость <L> ≅ $2 \cdot 10^{32}$

что обеспечивает рождение 10^{12} $b\tilde{b}$ пар в год (10^7сек).
- Триггер эффективен как для лептонных, так и адронных мод распадов.
- Возможна идентификация пионов и каонов при импульсах от ~1ГэВ/с до ~100ГэВ/с
- Высокое временное разрешение для измерения осцилляций в системе B_s-мезонов
- Асимметрия столкновений

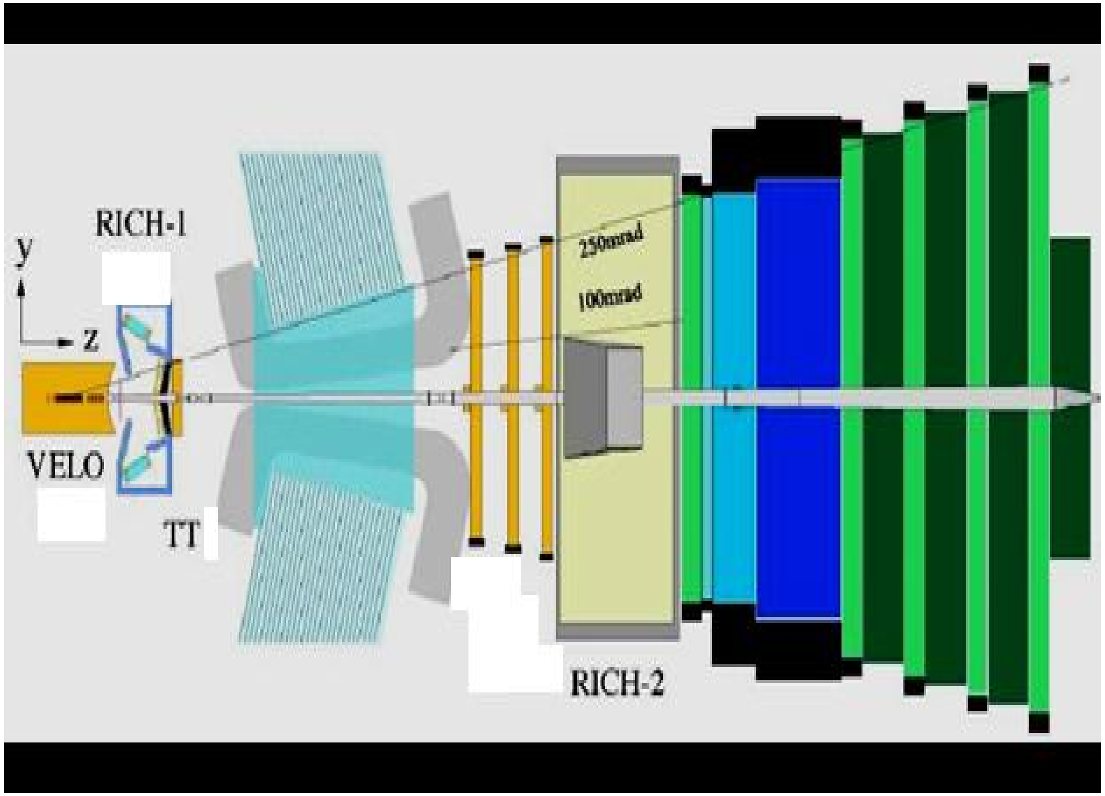
LHC b – *эксперимент для изучения свойств симметрии пространства и материи*

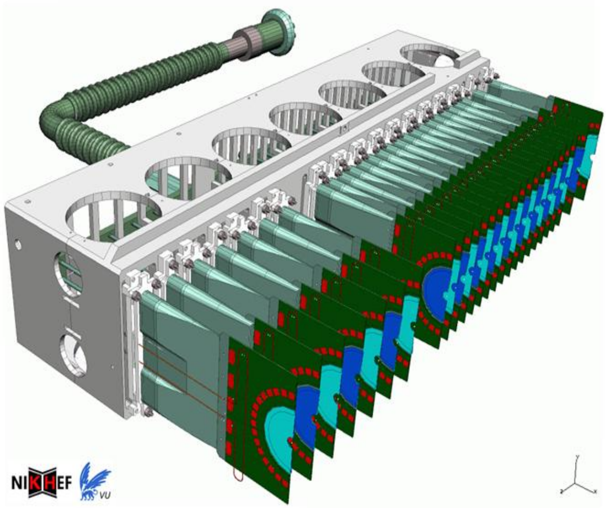
- The VErtex LOcator is the part of the detector closest to the collisions at the LHC. Its sensitive elements are Si detectors and during operation these are only 8mm away from the beam. Its proximity to the interactions allows physicists to observe the decays of short lived particles, called *B*-mesons.

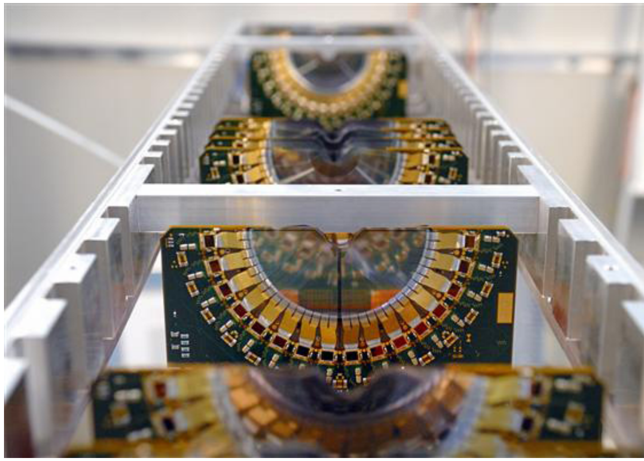


The VELO is a precise particle tracking detector which surrounds the proton proton collision point inside LHCb. It is composed of 42 silicon "modules", which are spread along both sides of the proton beam (21 each side). The whole device is about a metre long.

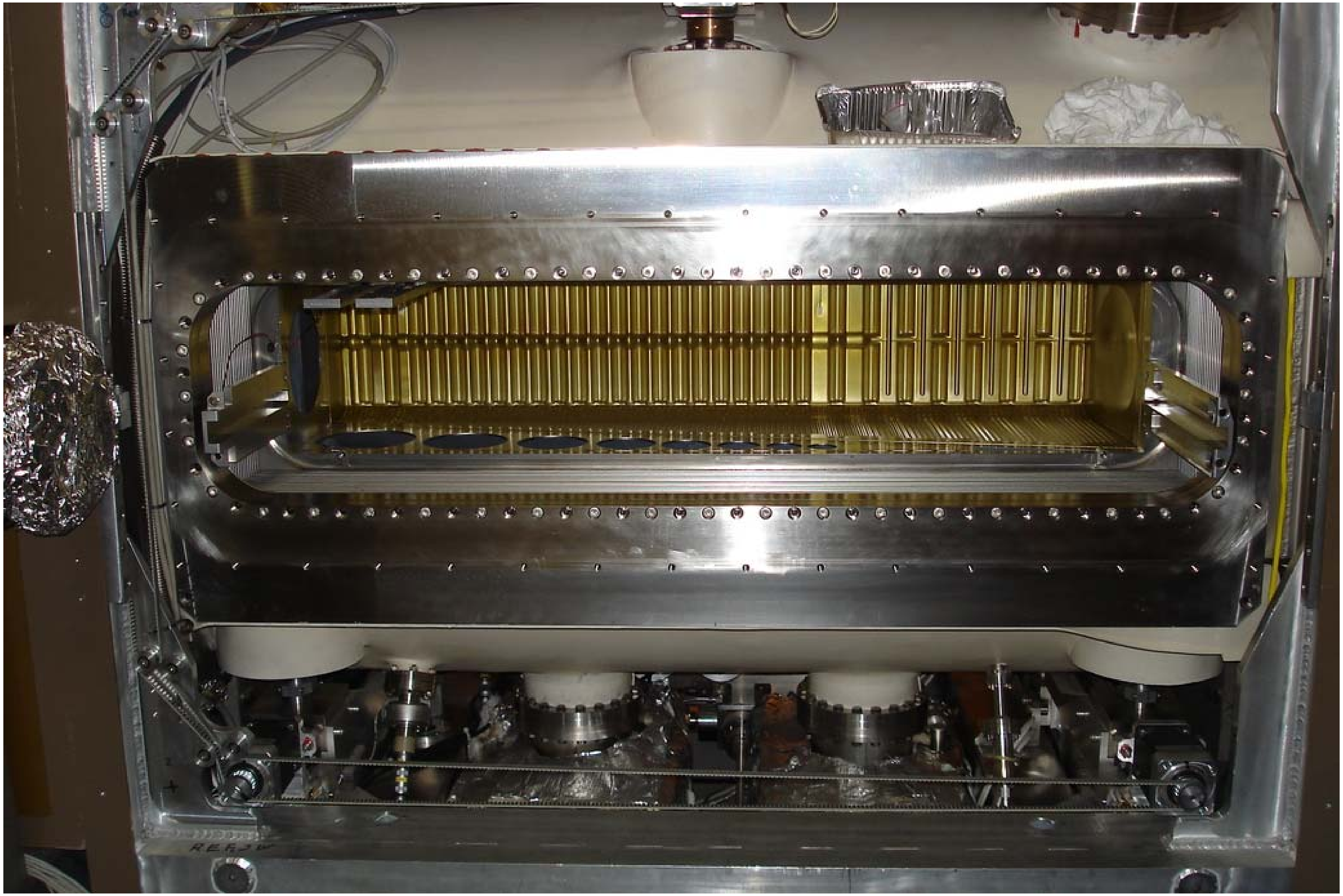
- Схема детектора и VELO





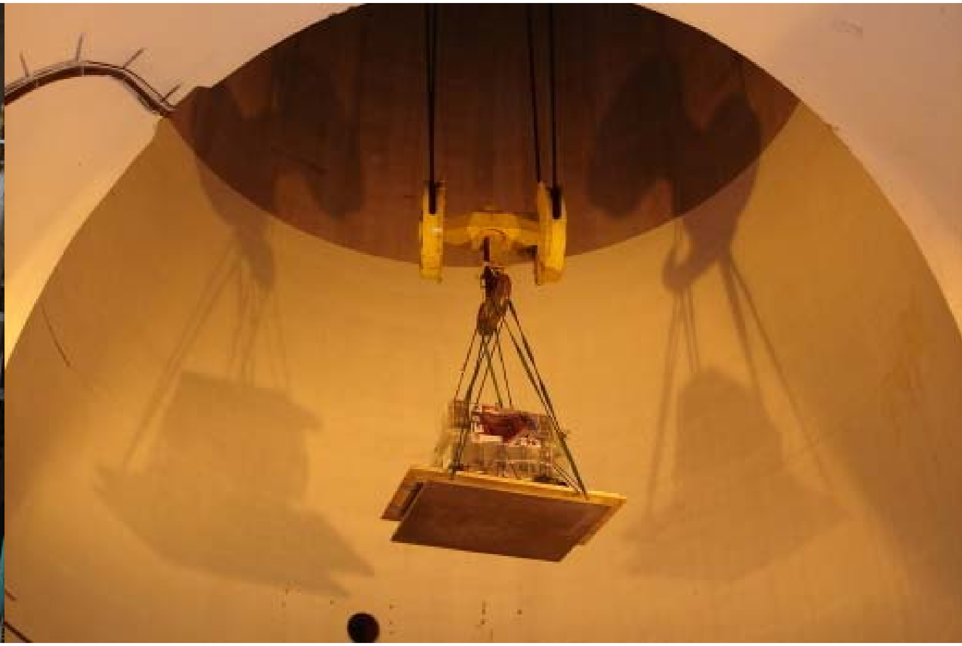


VELO – LHC b

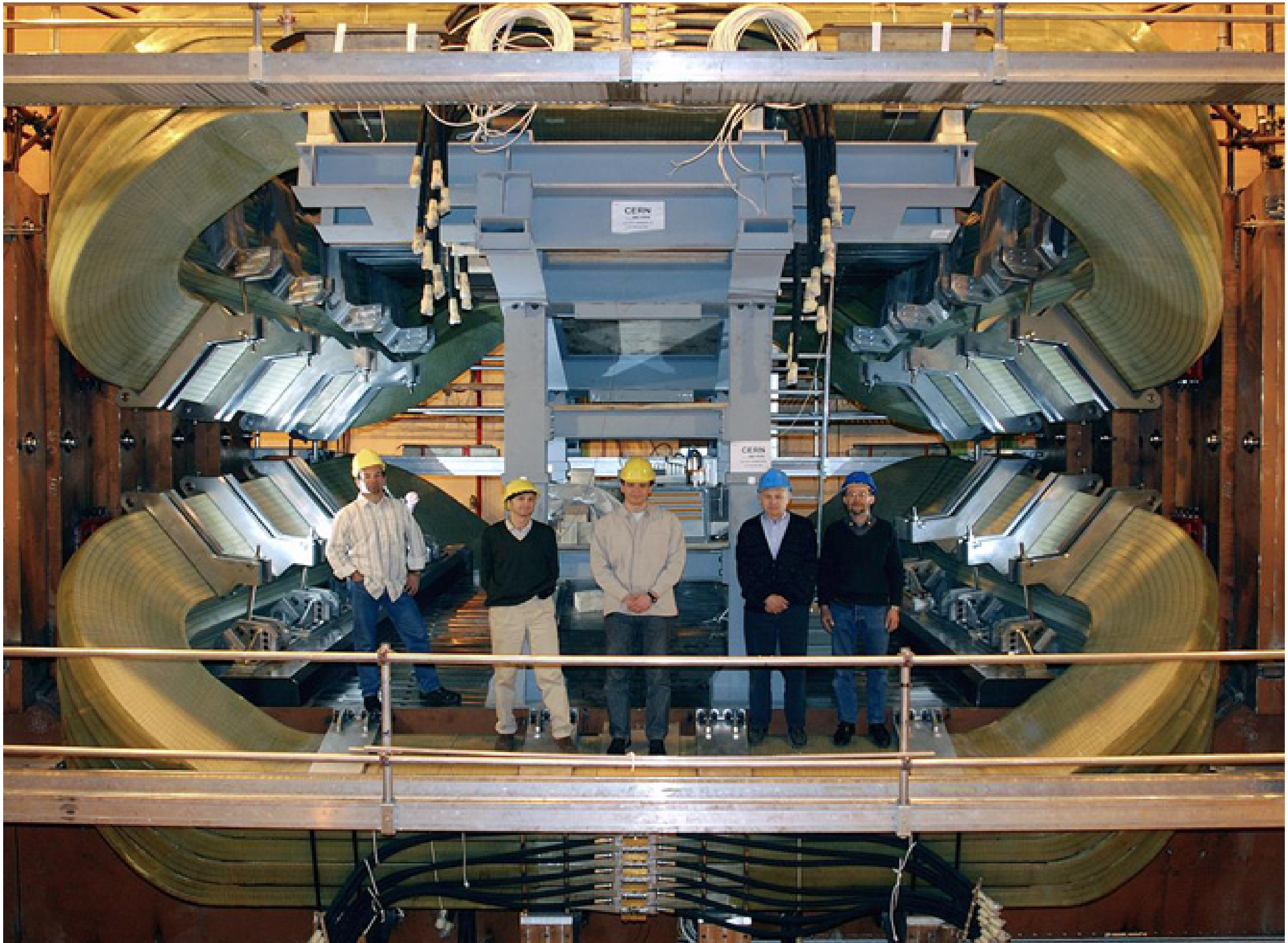


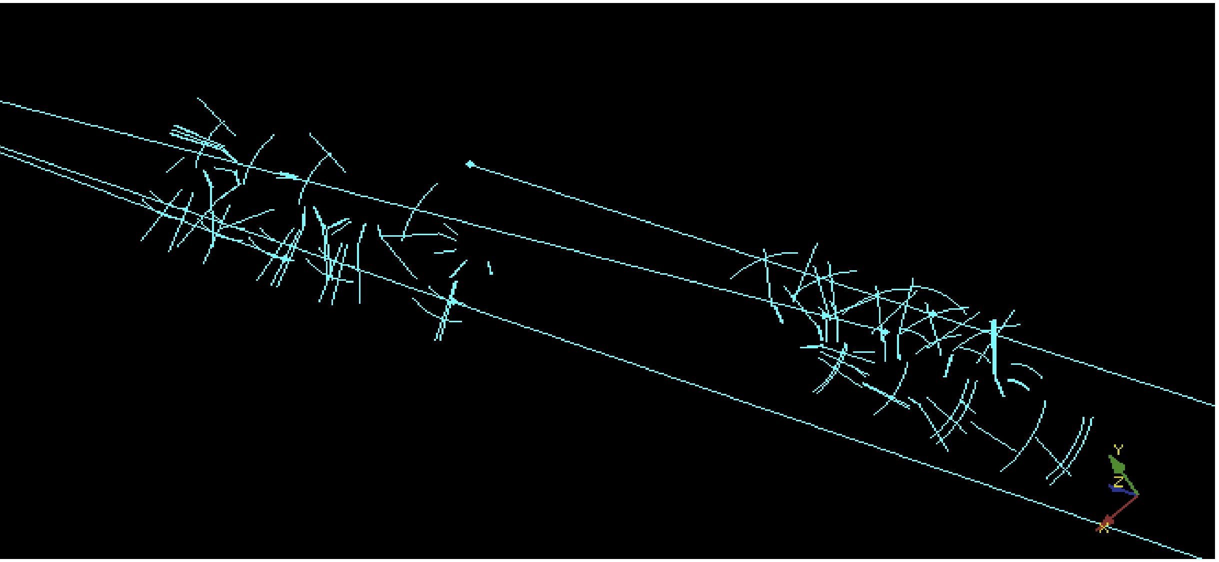
LHC b

- Транспортировка VELO к установке в точке 8
- Спуск в шахту



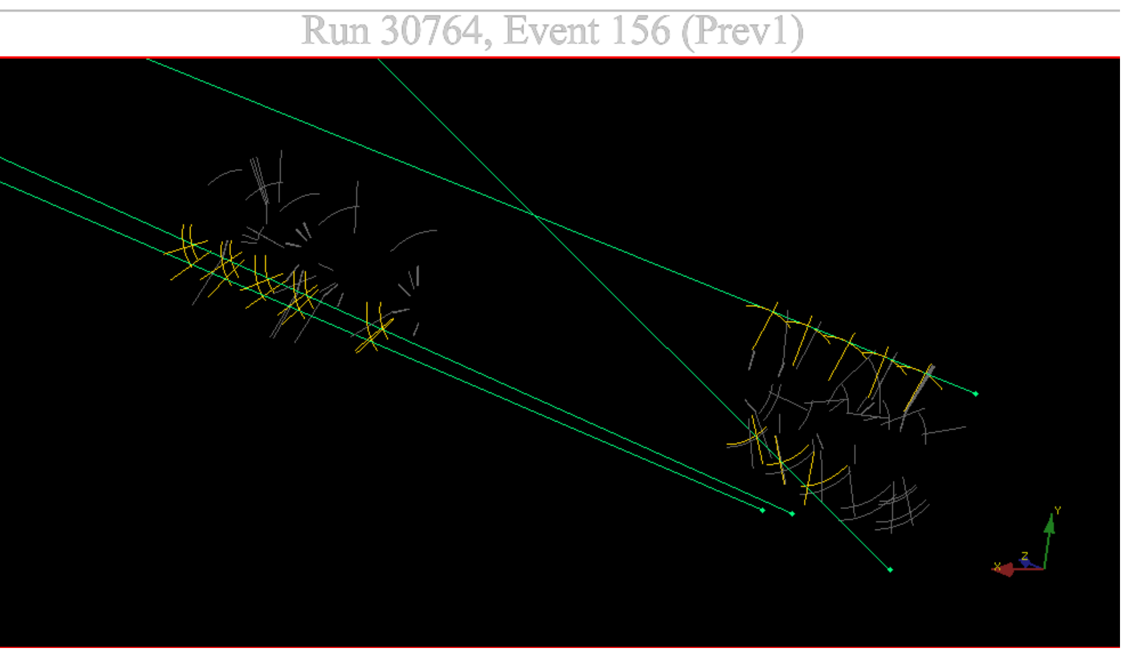
Он же после сборки детектора





FIRST EVENTS FROM LHC at LHCb

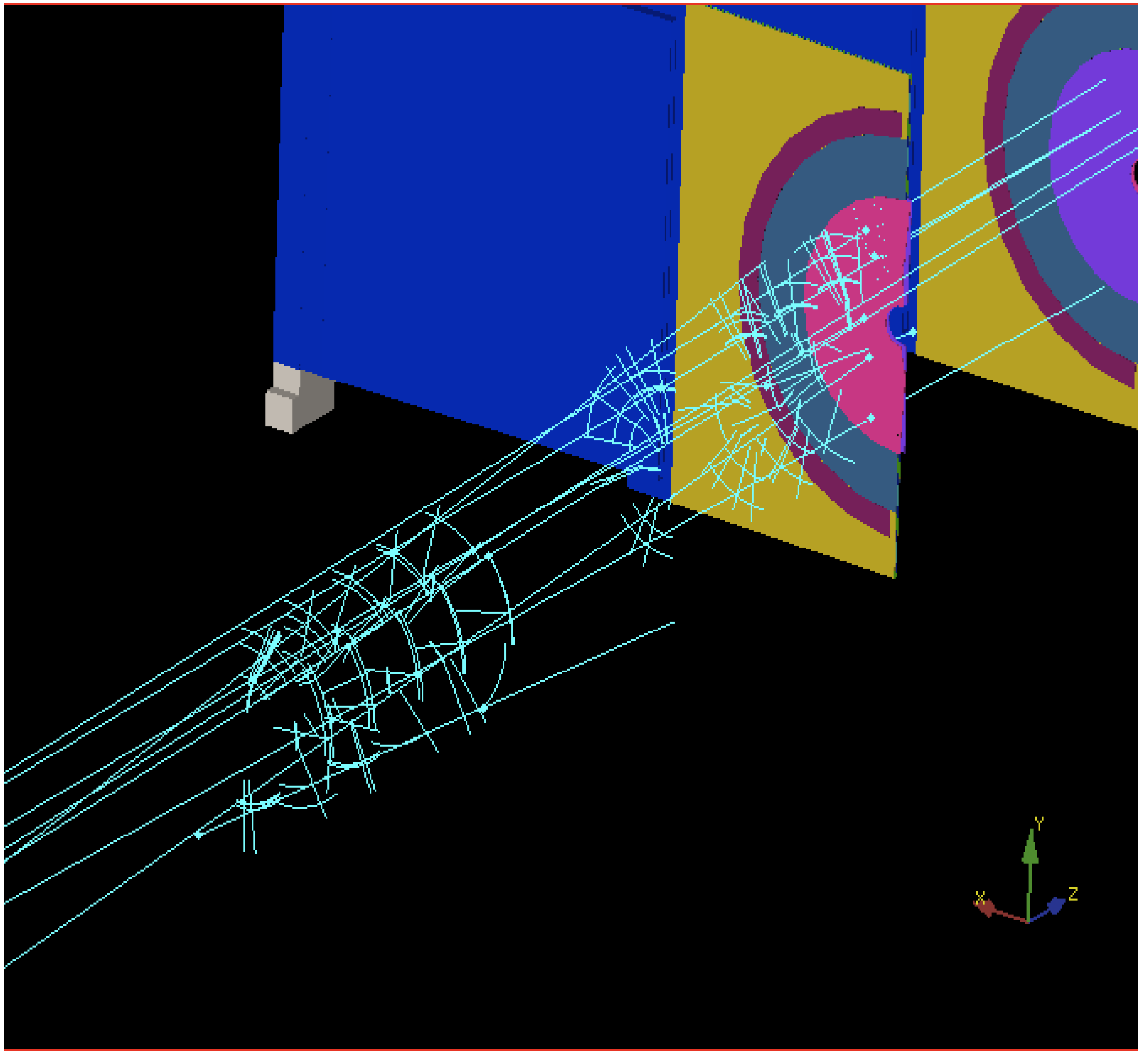
At 17:30 on Friday 22 August 2008 the LHCb VELO recorded events from an injection test at IP8. About 1/4 of the VELO detector was turned on and events were immediately reconstructed. First couple of events are shown below.



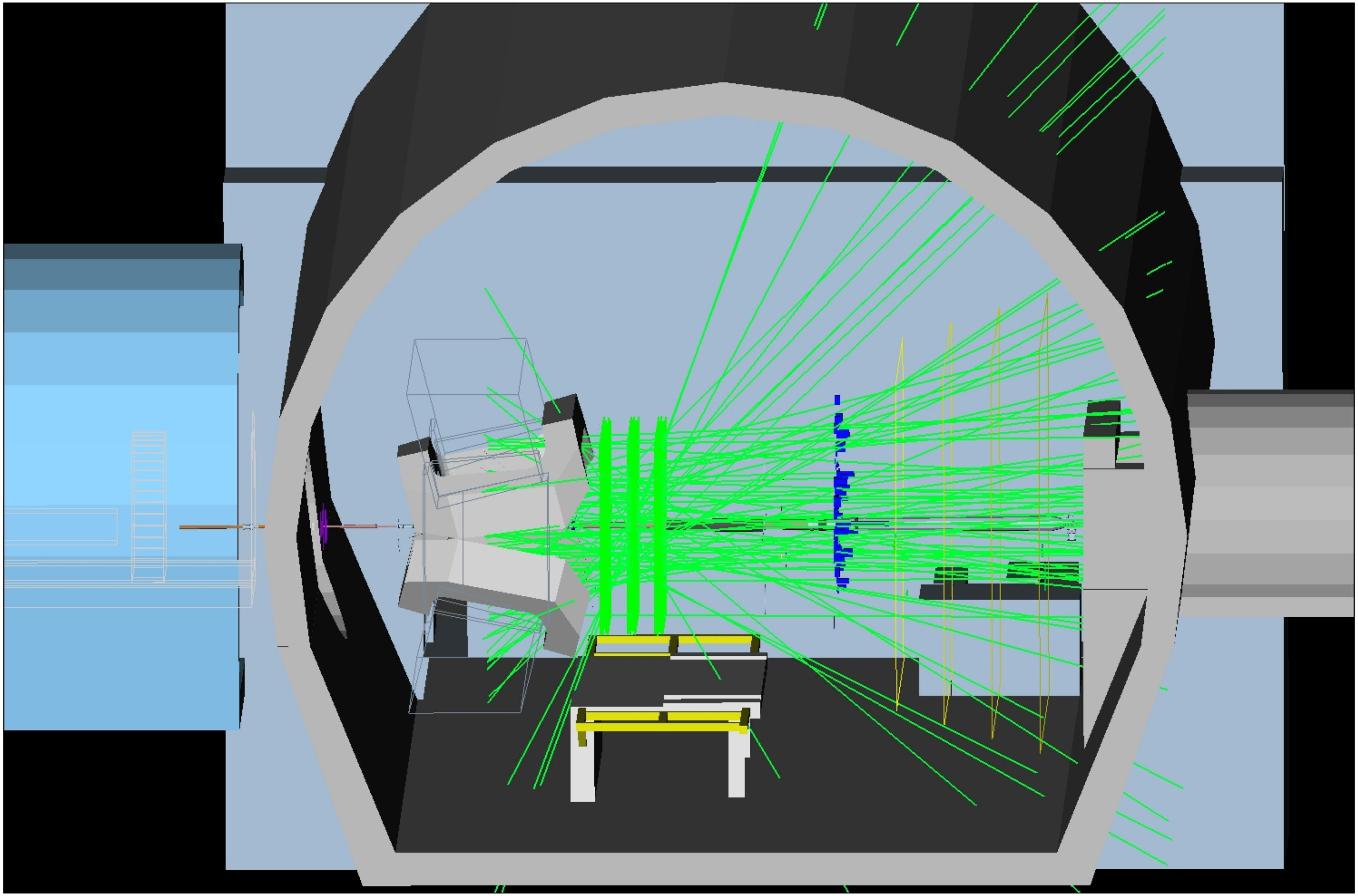
Событие

дня

Аналогичное событие



Выброс частиц в детектор



- 10 сентября

Эксперимента LHCb

TOTEM

- **Total Cross Section, Elastic Scattering and Diffraction Dissociation at the LHC**

The TOTEM experiment will measure the total pp cross section and study elastic scattering and diffractive dissociation at the LHC. More specifically, TOTEM will measure:

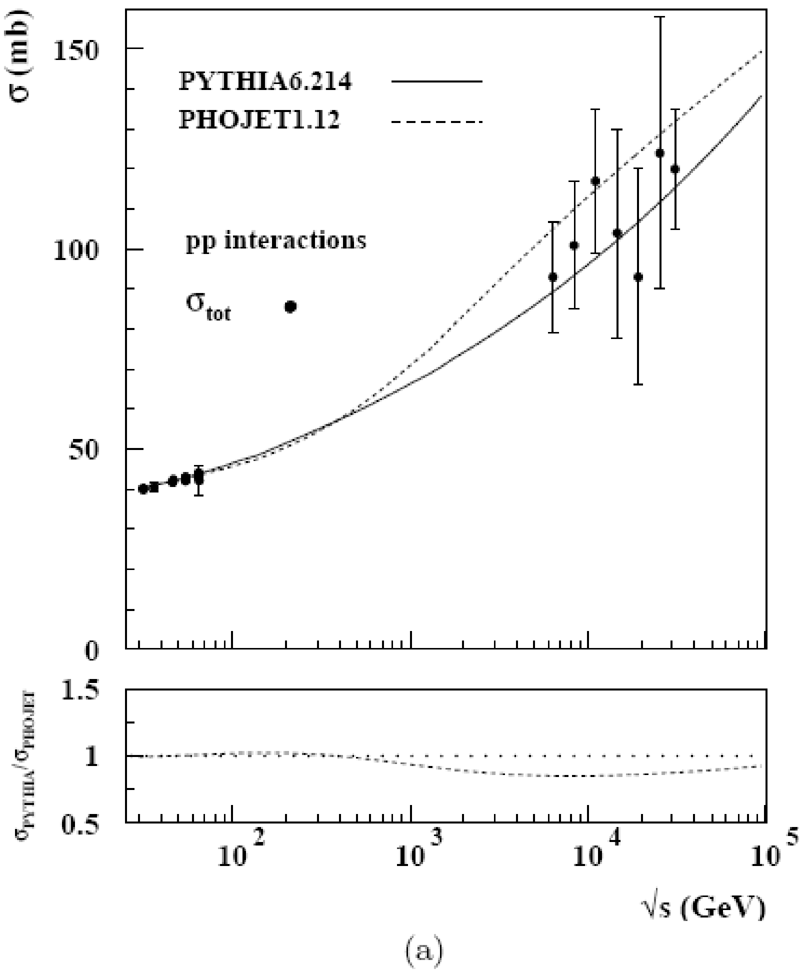
* the total cross-section with an absolute error of 1 mb by using the luminosity independent method. This requires the simultaneous measurement of the elastic pp scattering down to the four-momentum transfer of $-t \approx 10^{-3}\,\mathrm{GeV}^2$ and of the inelastic pp interaction rate with an adequate acceptance in the forward region;

* elastic proton scattering over a wide range in momentum transfer up to $-t \approx 10\,\mathrm{GeV}^2$;

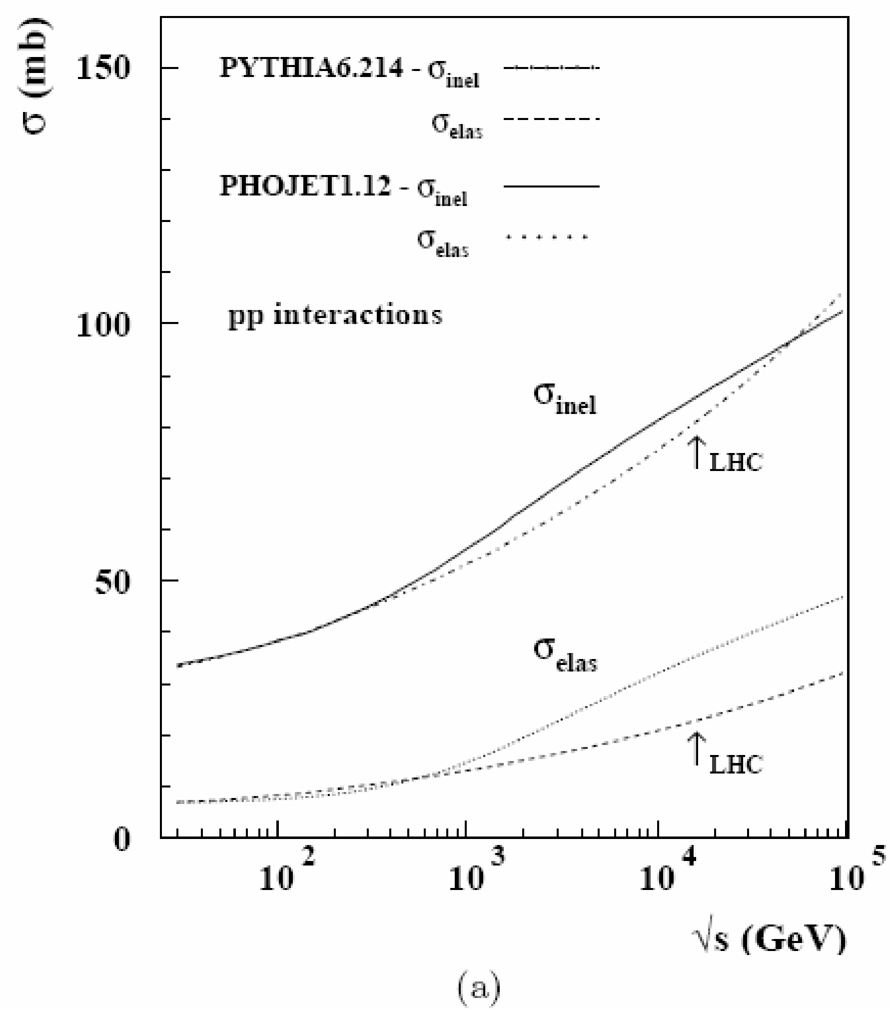
* diffractive dissociation, including single, double and central diffraction topologies using the forward inelastic detectors in combination with one of the large LHC detectors.

TOTEM was proposed in 1997 [1]. Having received favourable consideration from the LHCC and the Research Board, the Collaboration prepared a Technical Proposal [2] in 1999 in which they identified CMS as the optimal host experiment for TOTEM.

Параметризация сечений : полного, упругого и неупругого

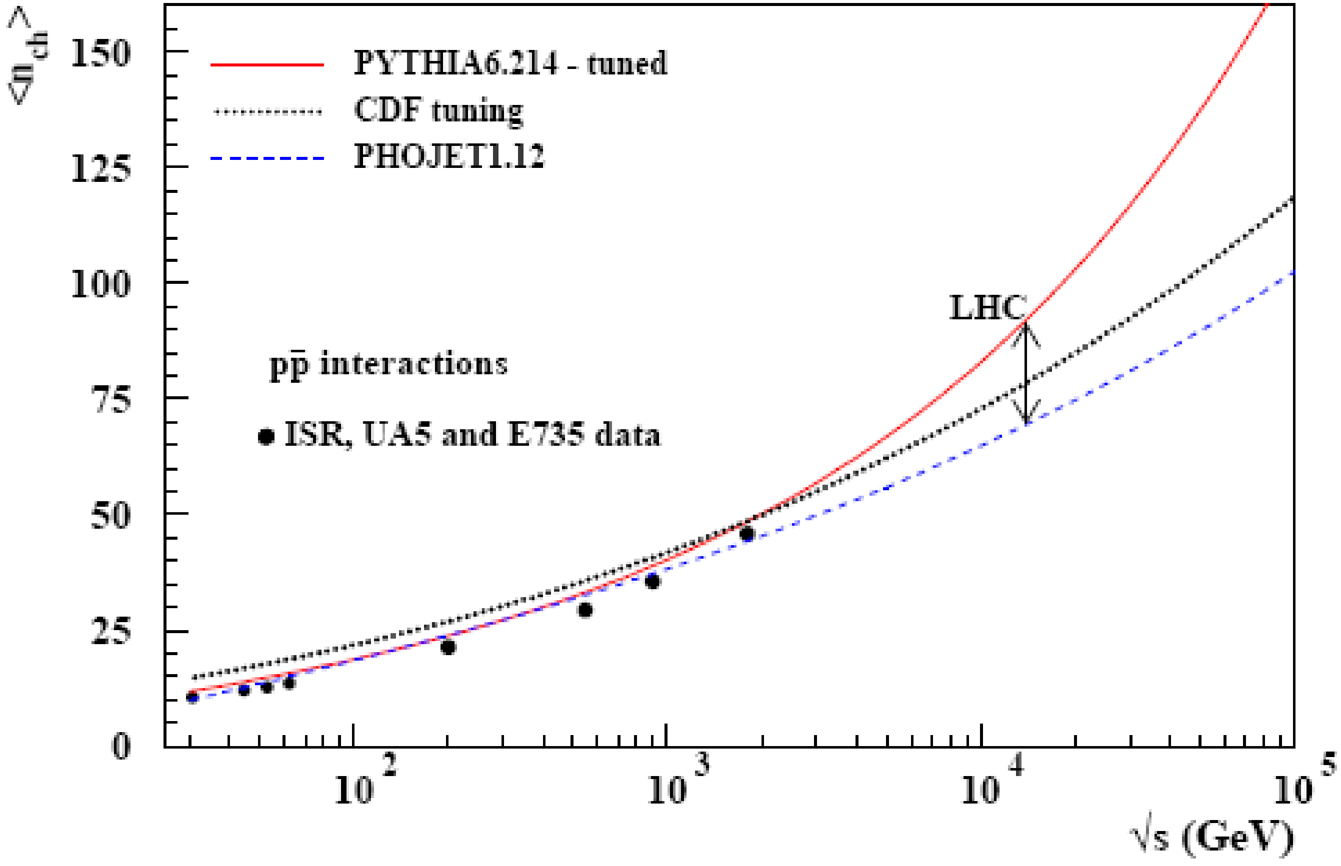


(a)



(a)

Предсказания для средней множественности заряженных частиц



(a)

As noted above, TOTEM has to measure the inelastic pp interaction with adequate acceptance in the forward region. Two tracking telescopes, T1 and T2, installed on each side of the IP in a manner compatible with the CMS detector, will provide this coverage (Fig. 1.1). The T1 telescope will be placed in the CMS endcaps, while T2 will be in the shielding behind the CMS Hadronic Forward (HF) calorimeter. T1 and T2 add charged particle tracking and trigger capabilities to the CMS experiment over a rapidity interval $3 \leq | \eta | \leq 6.8$. A fully inclusive trigger, including single and double diffraction, can be provided with an expected loss in the inelastic rate of less than 5%.

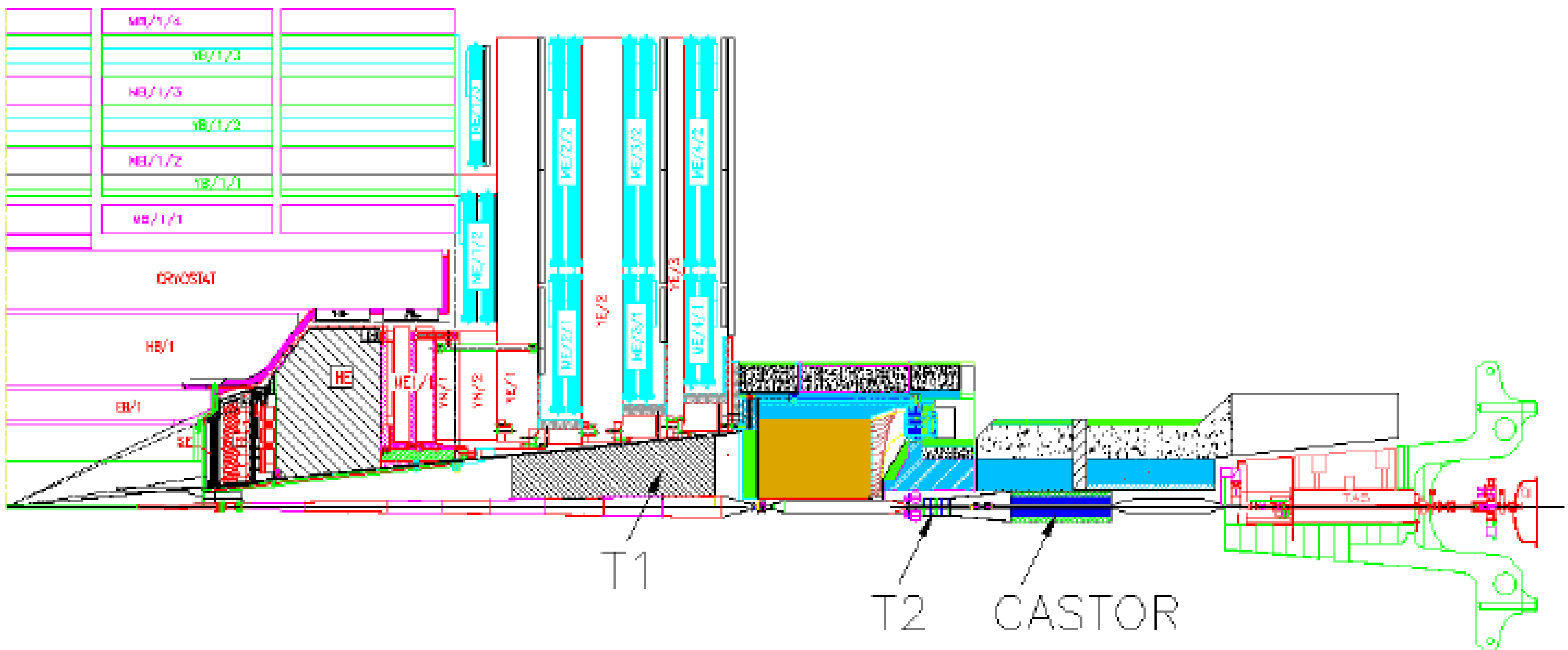


Figure 1.1: The TOTEM detectors are installed in the CMS forward region

Схема электроники TOTEM

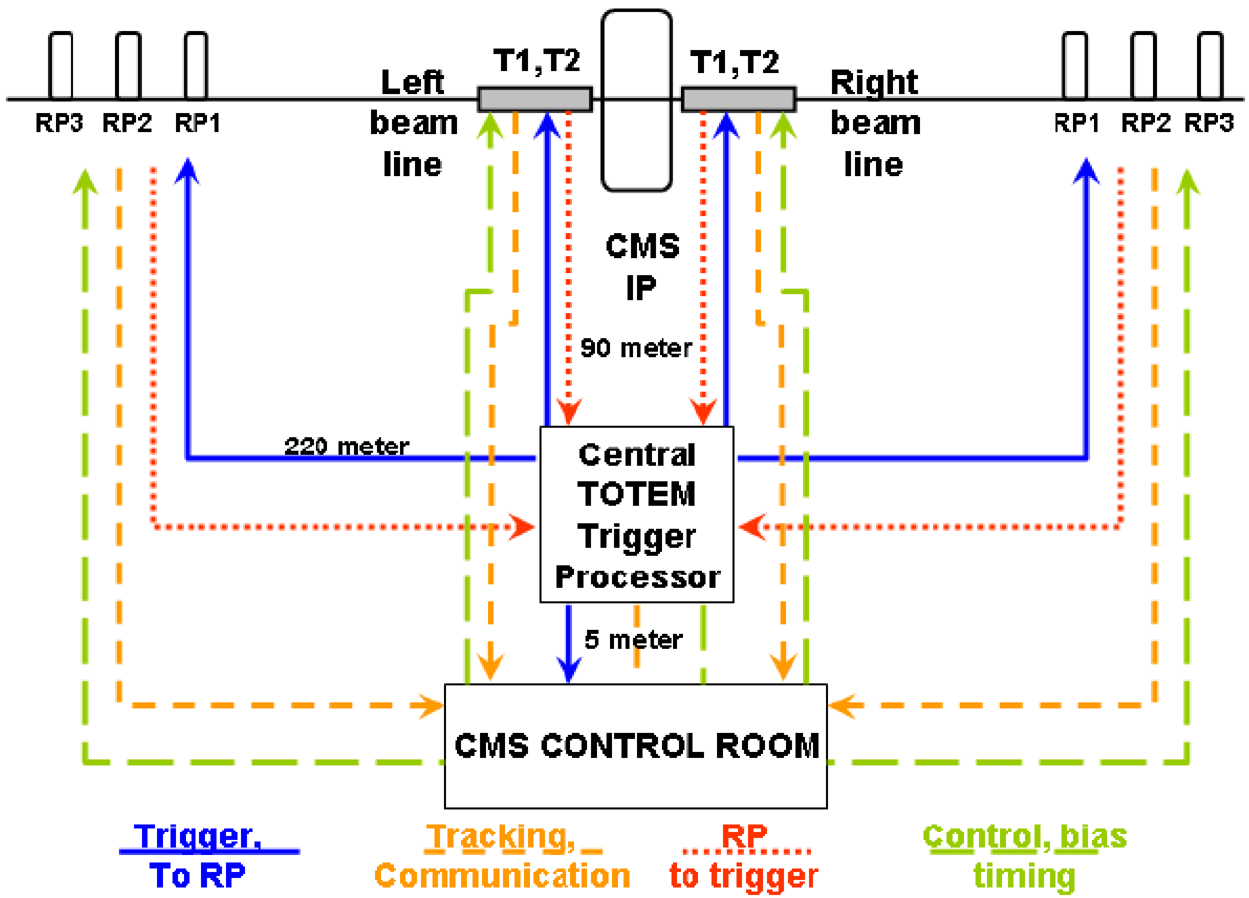


Таблица ожидаемых значений общих параметров pp-взаимодействий при14 ТэВ и диапазон их неопределенностей

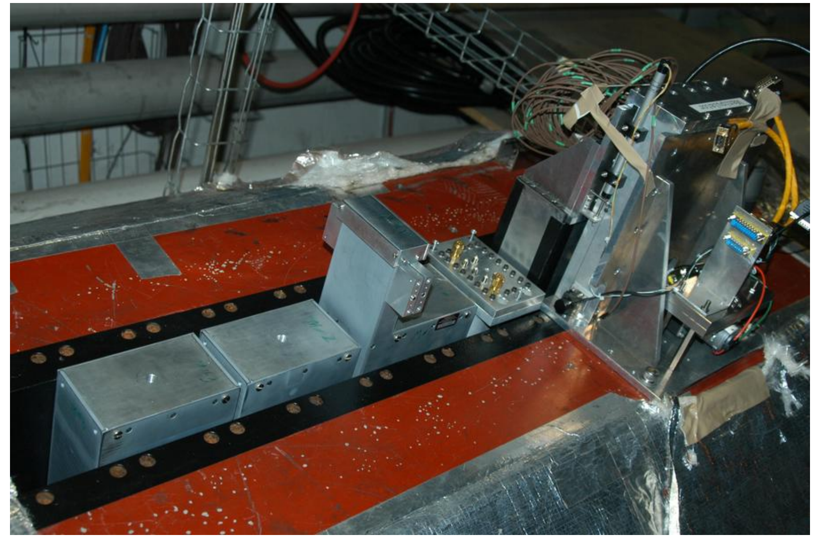
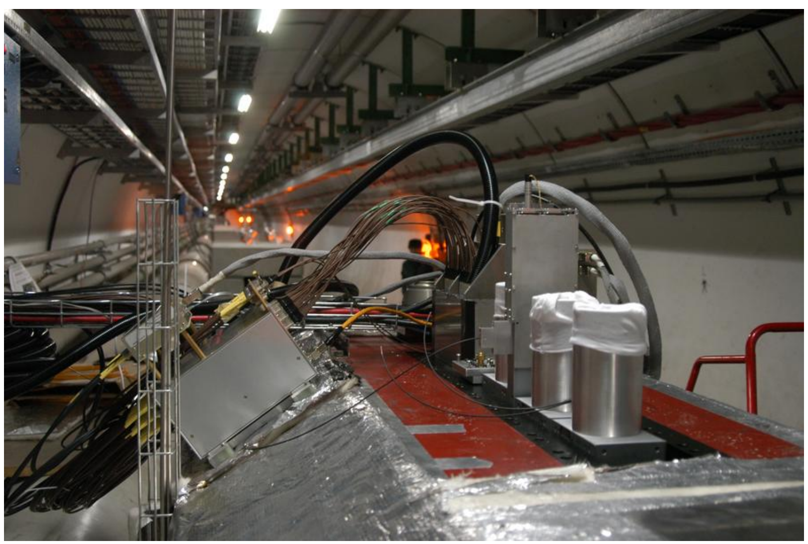
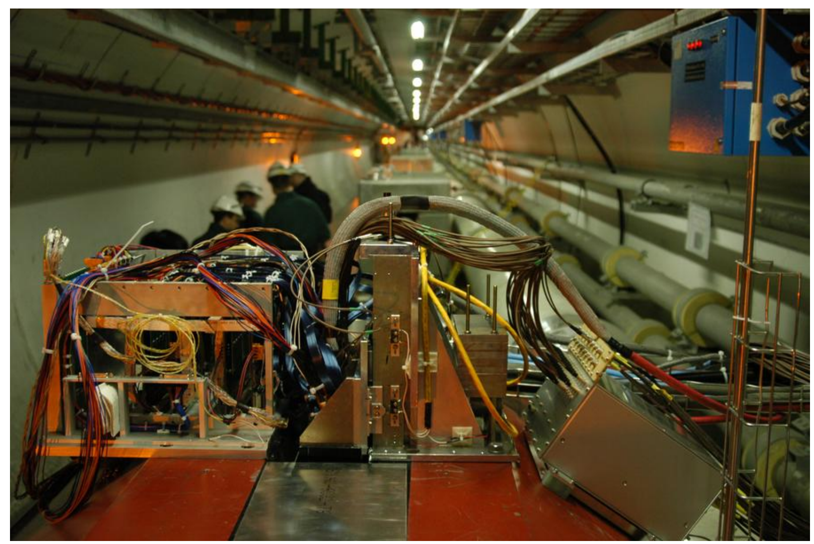
Observable	PYTHIA6.214 - tuned	PHOJET1.12	$\Delta\ \% = \frac{(X_{high} - Y_{low}) \times 100}{Y_{low}}$
σ_{tot} (mb)	101.5	119.1	17.3
σ_{elas} (mb)	22.5	34.5	53.3
σ_{nsd} (mb)	65.7	73.8	12.3
Minimum bias Predictions			
$\langle n_{ch} \rangle$	91.0	69.6	30.7
$dN_{ch}/d\eta$ plateau for $\|\eta\| < 2.5$	~ 7.0	~ 5.5	27.3
$dN_{ch}/d\eta$ at $\eta = 0$	6.8	5.1	33.3
$\langle p_t \rangle$ at $\eta = 0$ (GeV)	0.55	0.64	16.4
$\mathrm{n_{tot}}$ ($\|\eta\| < 15$) per pp event	158.4	115.1	37.6
$\mathrm{n_{tot}}$ ($\|\eta\| < 2.5$) per pp event	60.9	45.5	33.8
Underlying Event Predictions (approx. values)			
$\langle N_{\mathrm{chg}} \rangle$ $\mathrm{P_{t_{1jet}}} > 10$ GeV	6.5	3.0	~ 115
$\langle \mathrm{p}_{t_{\mathrm{sum}}} \rangle$ $\mathrm{P_{t_{1jet}}} > 10$ GeV	7.5	3.5	~ 115
$dN_{ch}/d\eta$ for $\mathrm{P_{t_{1jet}}} > 10$ GeV	29.0	13.3	~ 120
UE/Min-bias $\mathrm{P_{t_{1jet}}} > 10$ GeV	4	2	100

Table 10. PYTHIA6.214 - tuned and PHOJET1.12 results for pp collisions event generation at $\sqrt{s} = 14$ TeV.

LHCf – проверка моделей взаимодействия частиц космических лучей при 10^17 эВ

- *To understand these high energy cosmic ray phenomena, knowledge of the energy distribution of particles emitted in the very forward region in hadronic interactions is important. Some of the data could be interpreted quite differently depending on the interaction model. We are installing LHCf detectors at +/- 140 m from ATLAS IP and measure high energy photons and neutrons produced near zero degrees. The LHC energy is equivalent to 1017 eV laboratory frame energy. Therefore, the measurement will give an important clue to judging the validity of nuclear interaction models used in Monte Carlo simulations of air showers induced by ultra-high energy cosmic-rays, and thus give a milestone for understanding cosmicray phenomena up to the GZK region.*

Монтаж детектора LHCf

ATLAS и CMS – эксперименты общего назначения

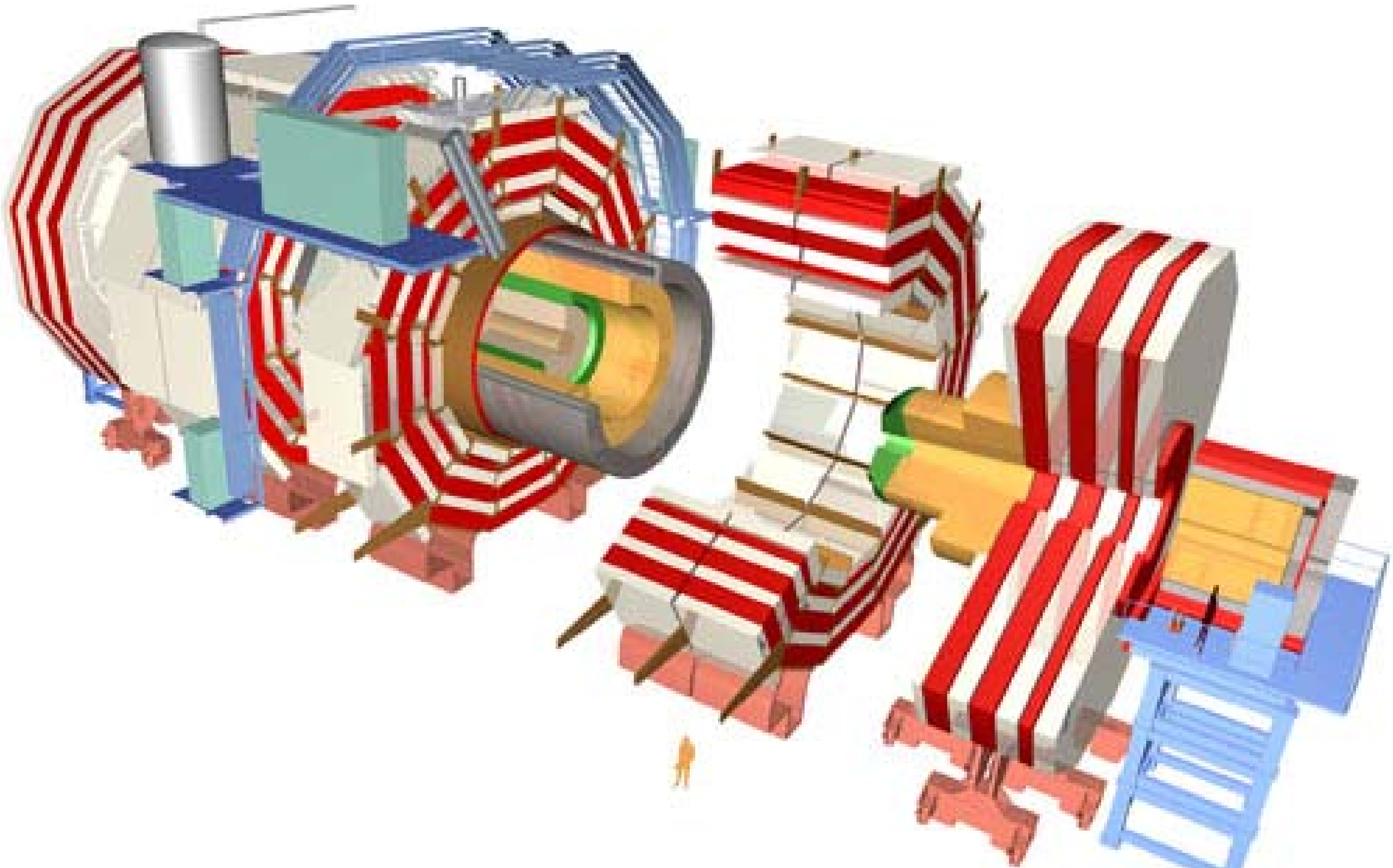
Задачи:

- *Уточнение параметров Стандартной модели и пределов ее применимости; Новая физика;*
- *Исследование свойств тяжелых кварков;*
- *Поиск бозонов Хиггса и суперсимметричных частиц;*
- *Изучение эффектов CP нарушения;*
- *Поиск структуры кварков и лептонов и т.д.*

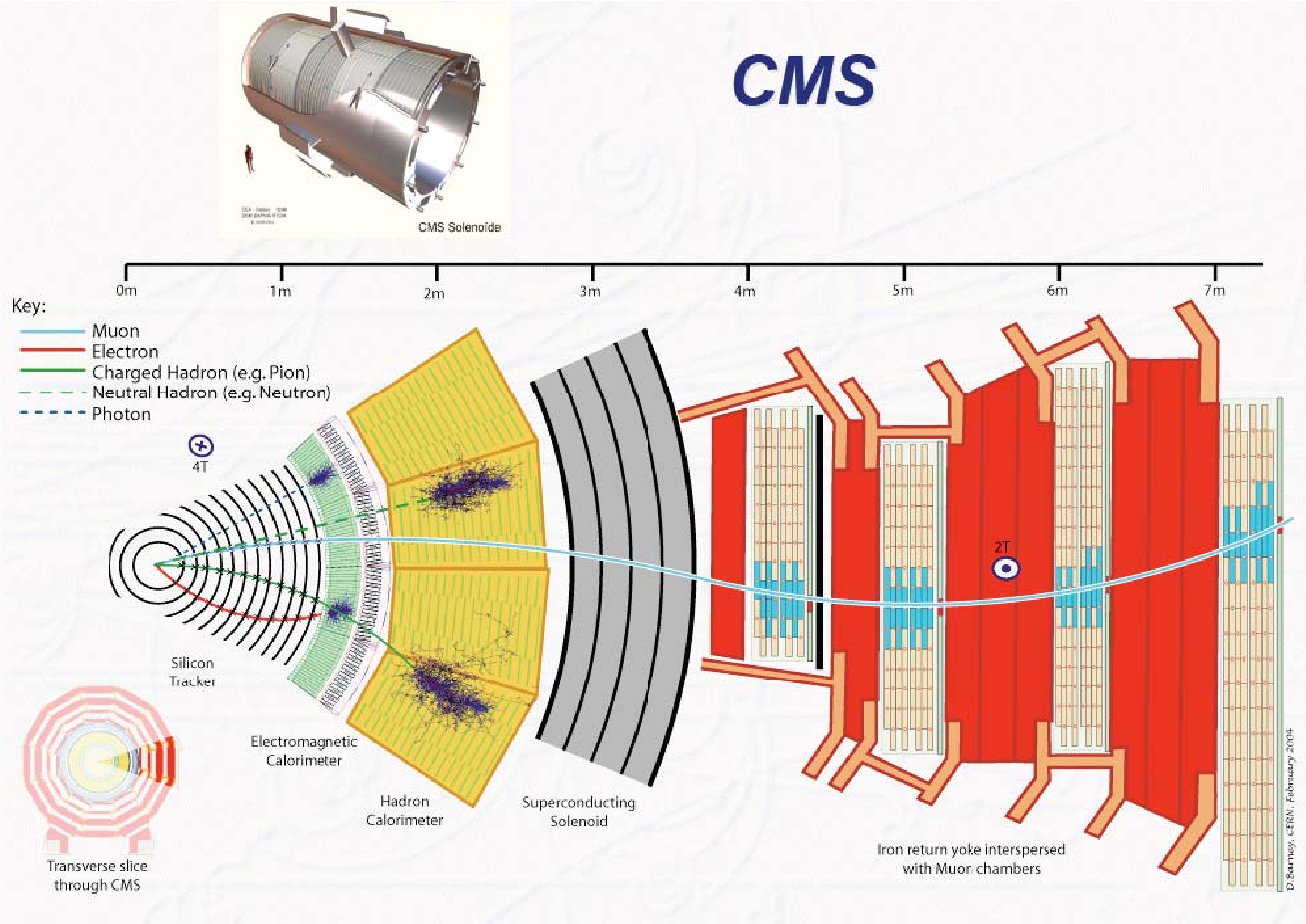
CMS

- The CMS experiment is 21 m long, 15 m wide and 15 m high, and sits in a cavern that could contain all the residents of Geneva; albeit not comfortably.

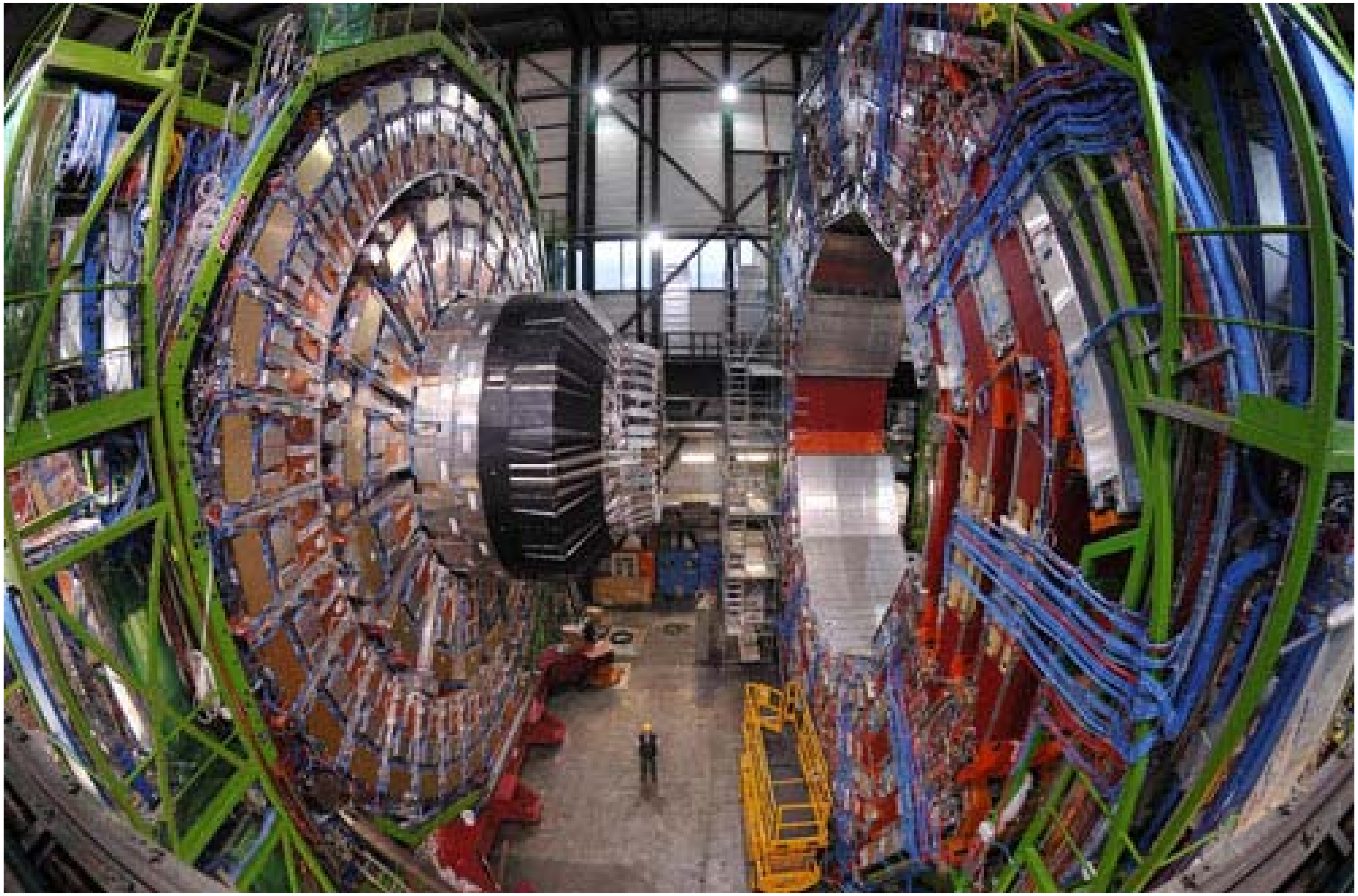
Схема эксперимента CMS



Структура установки CMS

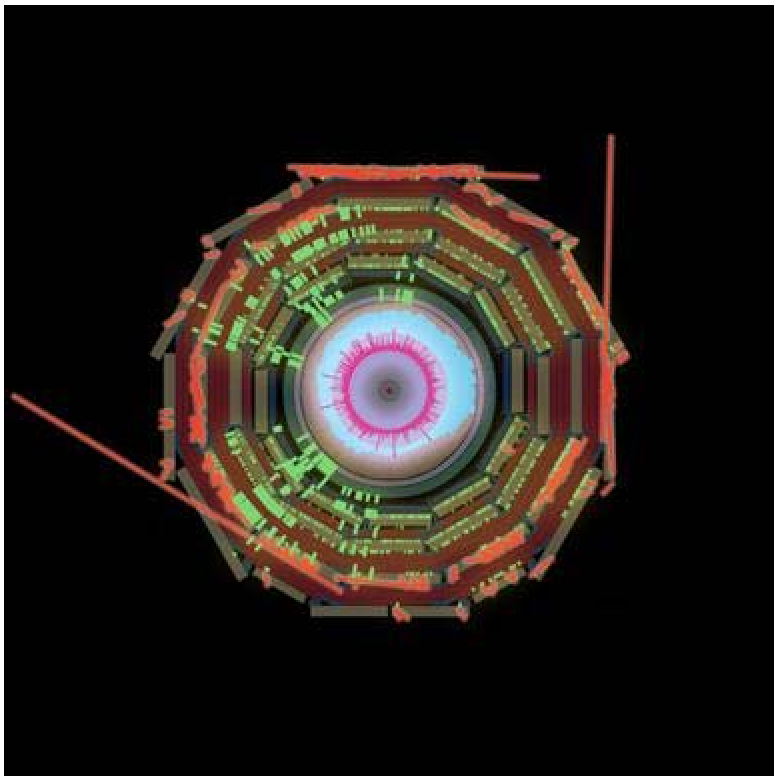


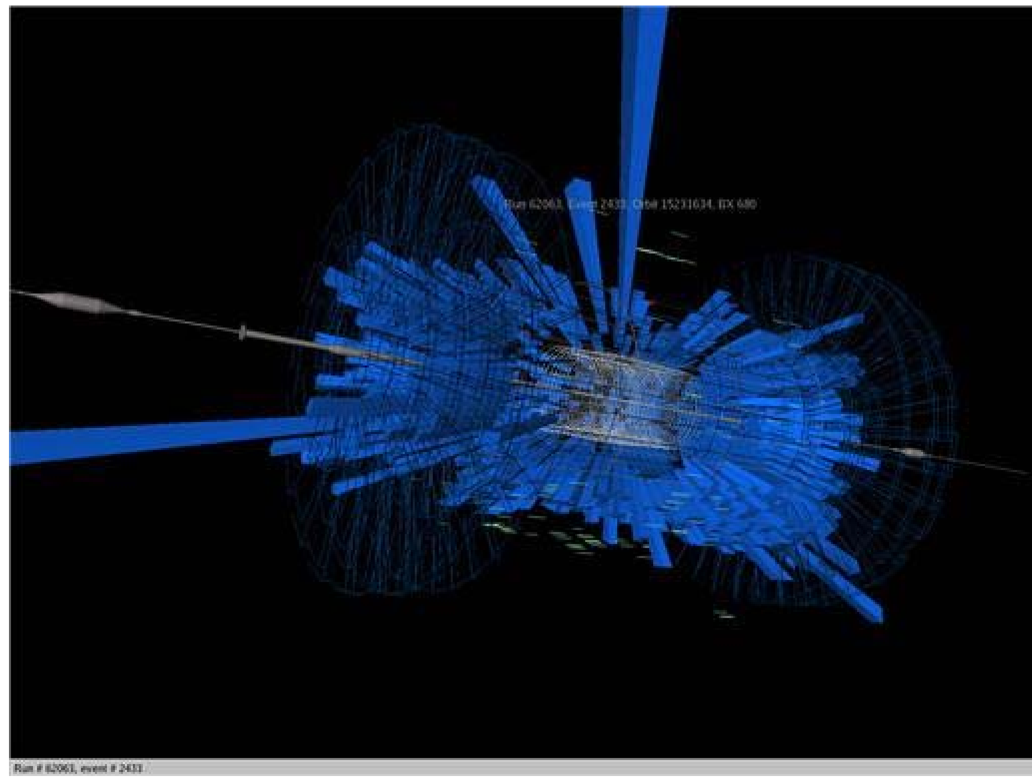
Общий вид установки CMS



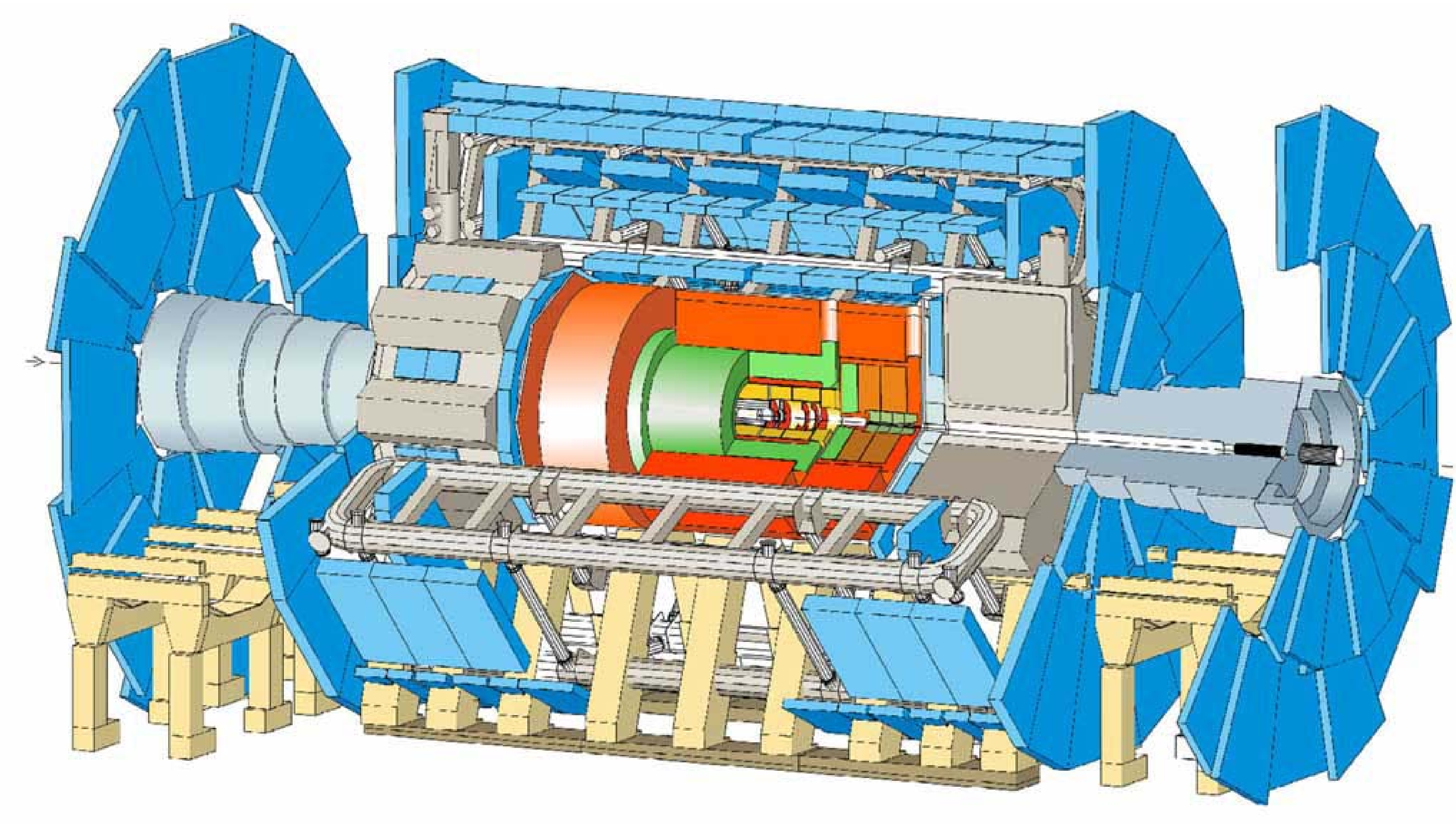
One of the first images from CMS, showing the debris of particles picked up in the detector's calorimeters and muon chambers after the beam was steered into the collimator (tungsten block) at point 5

The energy deposits in the electromagnetic (pink) and hadronic (blue) calorimeters are visible. Hits in the resistive plate chamber muon (RPC) system in green and drift-tube (red) are also seen





ATLAS



Центр управления ATLAS

- 10 сентября 2008



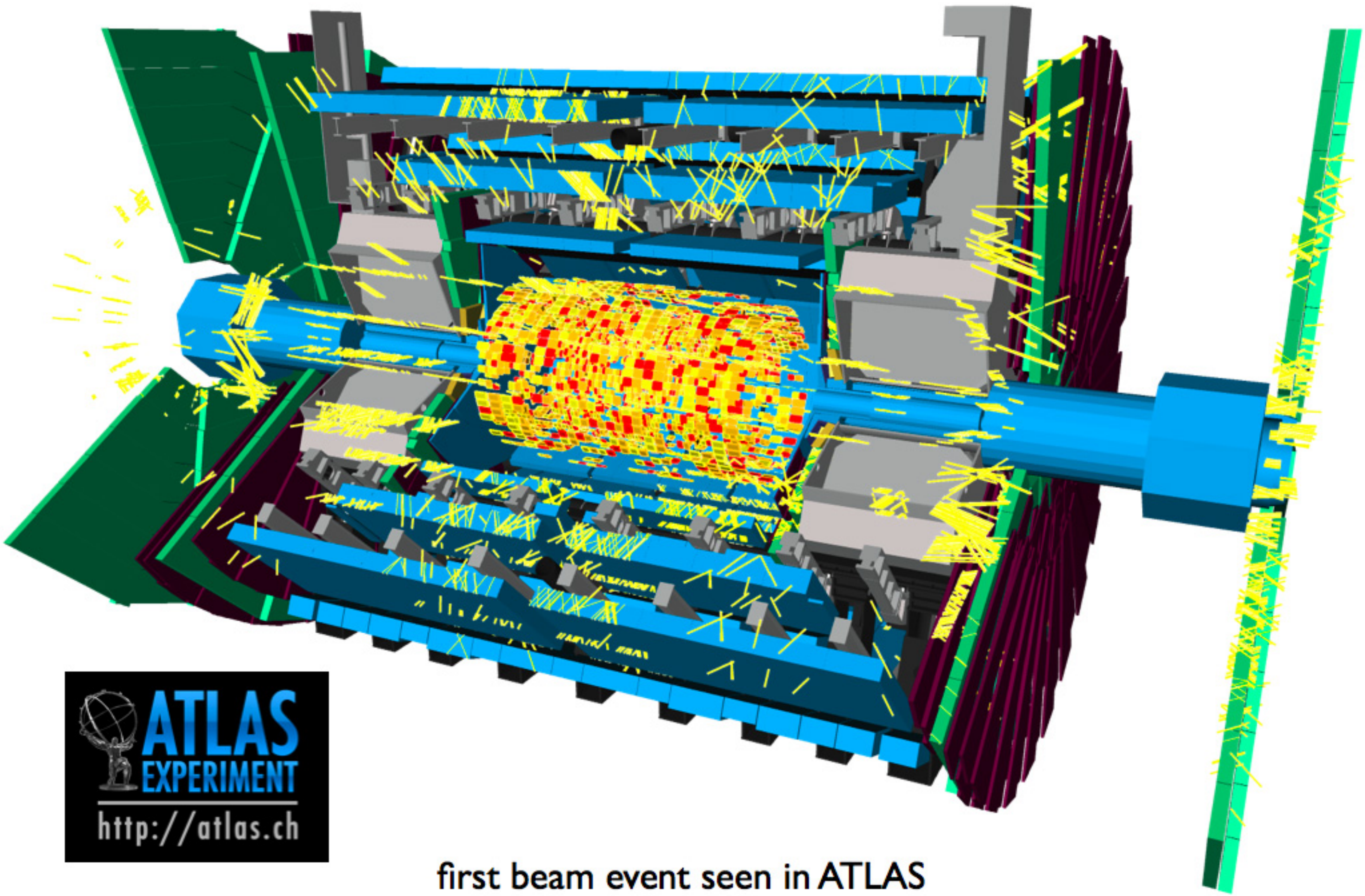
Общественный резонанс

- Despite – or perhaps because – of the court case, a record number of visitors came to CERN. A total of 76,000 people arrived at CERN over the weekend, 31,000 of whom went underground to view one or more of the experiments and the tunnel.
- As expected, ATLAS was one of the most popular sites, with queues to visit the detector itself snaking out onto the street within half an hour of opening on each day. A total of 5,700 individuals were able to go underground - 2,200 friends and family of CERN staff on Saturday, and 3,500 members of the public on Sunday.

Strangers photographing the ATLAS detector are a familiar sight for those working down in the pit. But last month, things were a little bit different: the detector was being photographed in preparation for its Hollywood debut in the dramatisation of Dan Brown's best-seller Angels and Demons.

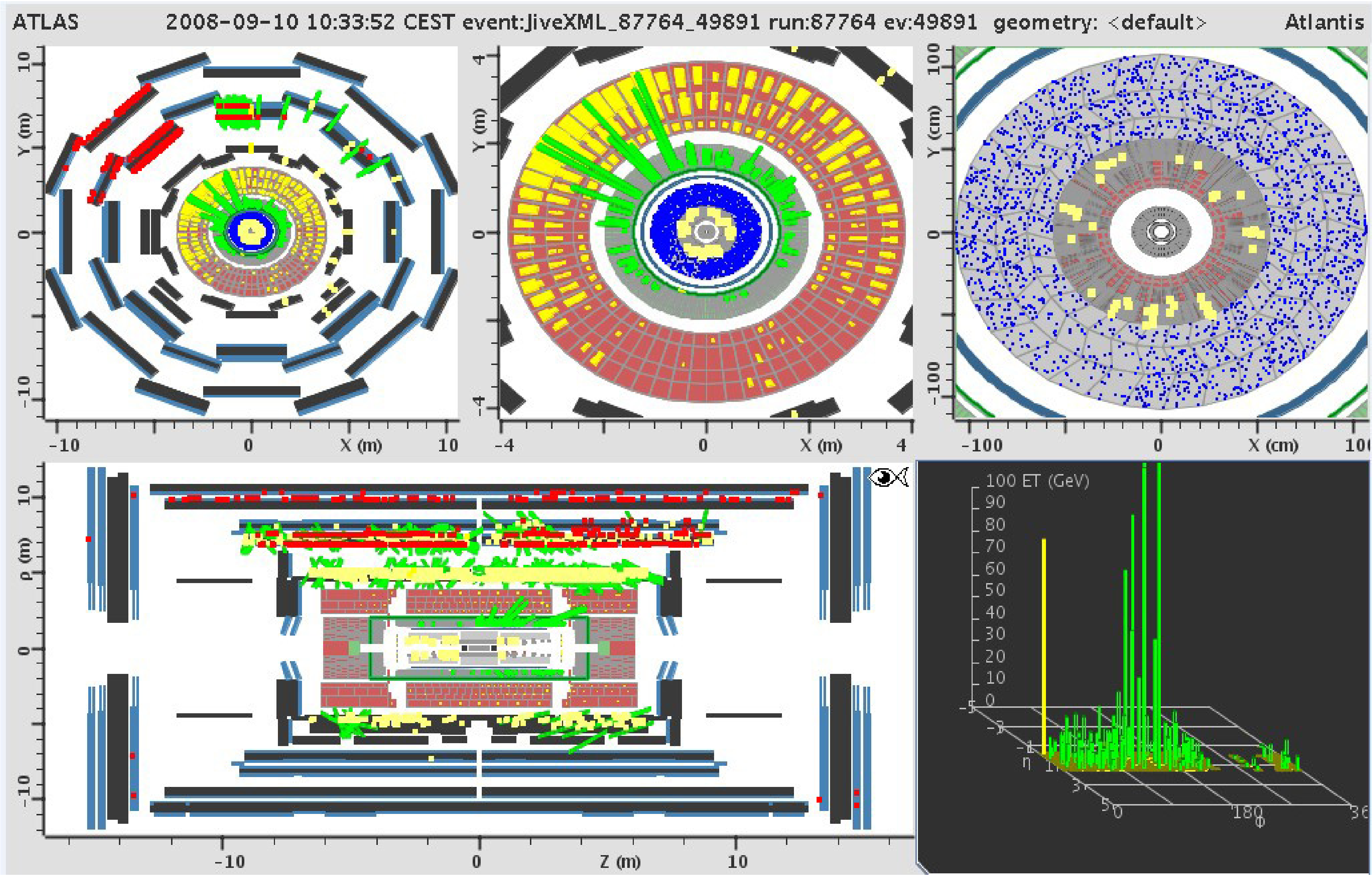
Для Голливуда

Первые частицы от взаимодействия пучка в установке АТЛАС

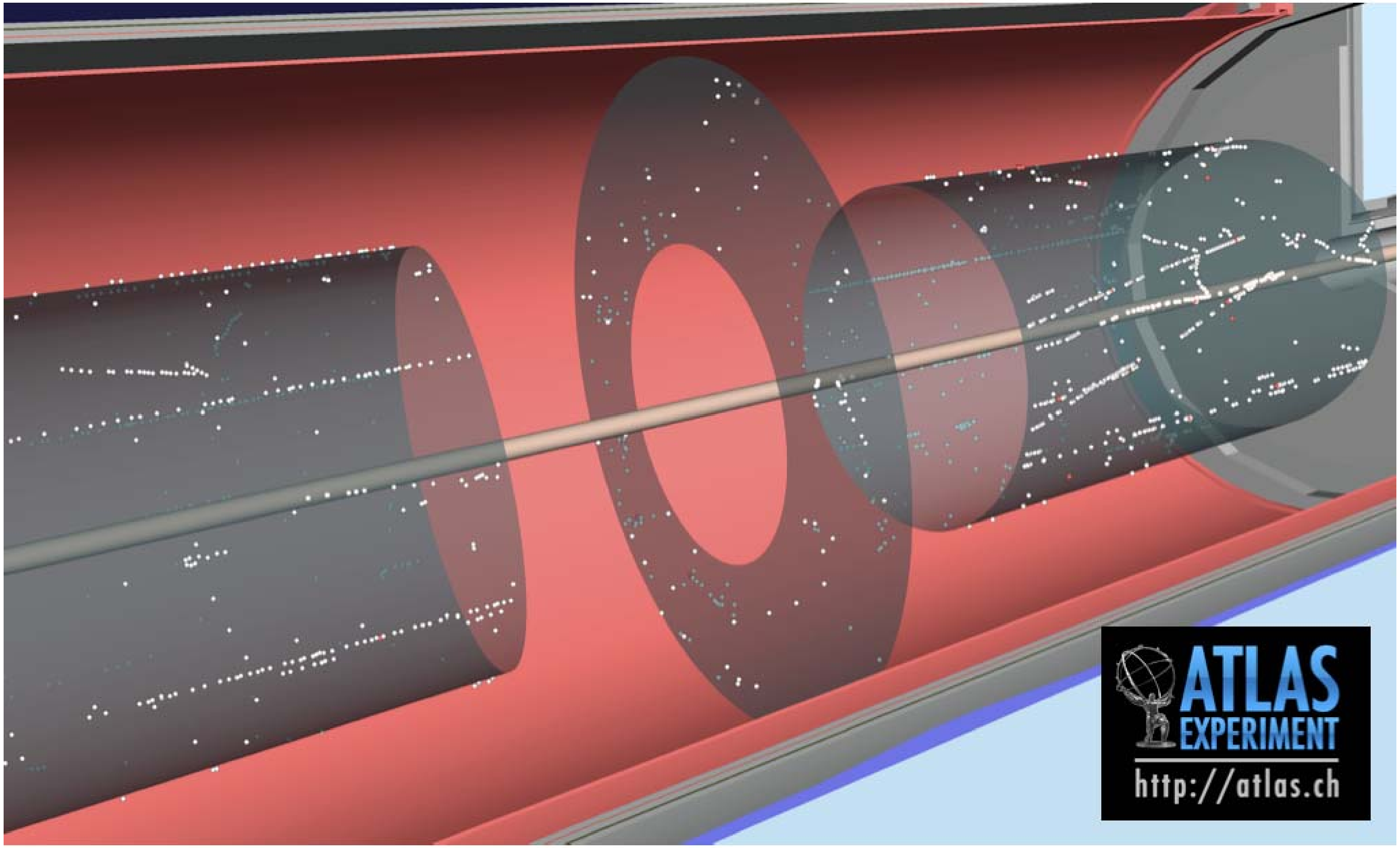


first beam event seen in ATLAS

Отклики детекторов эксперимента АТЛАС

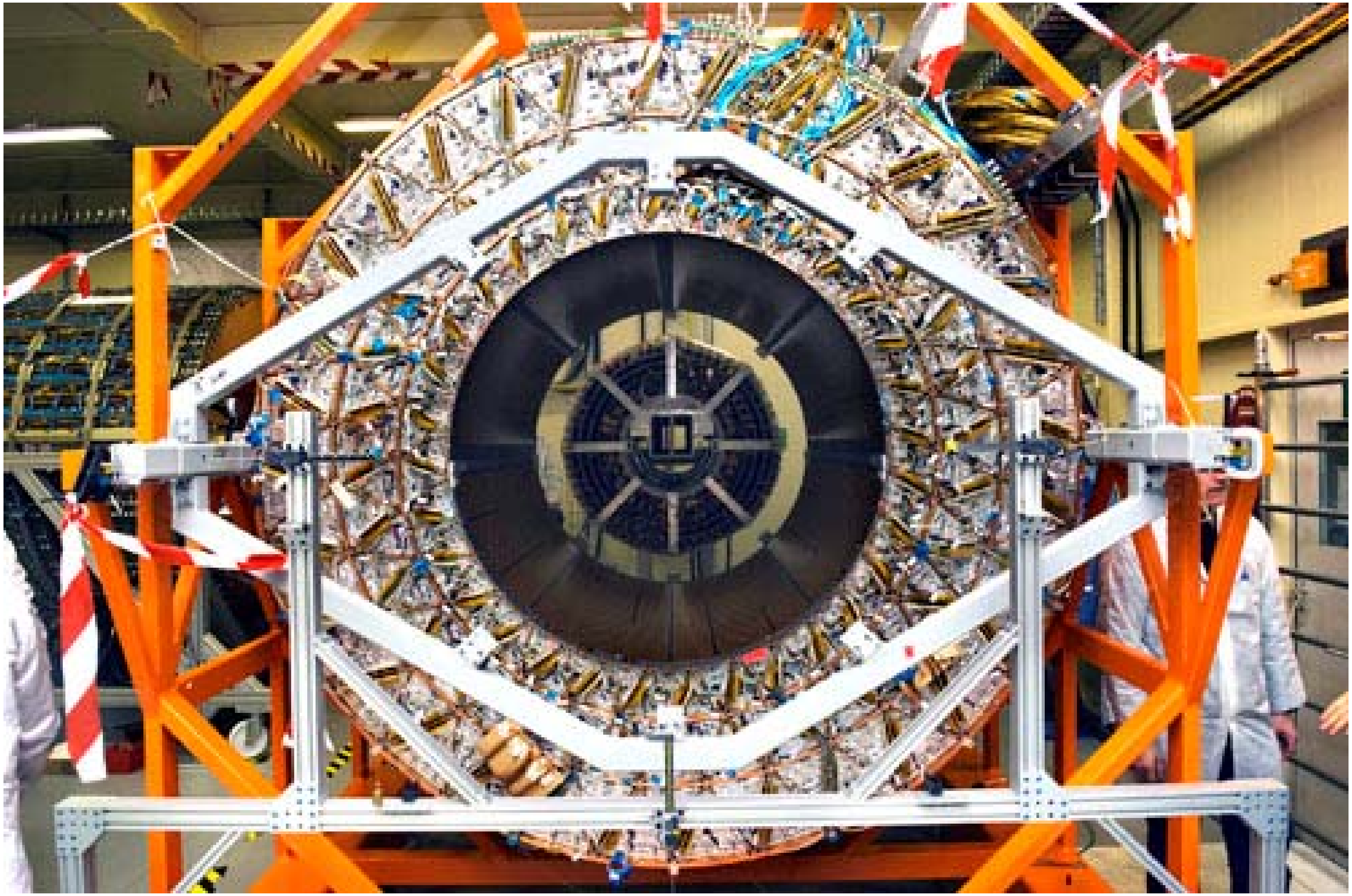


Зарегистрированное событие в TRT

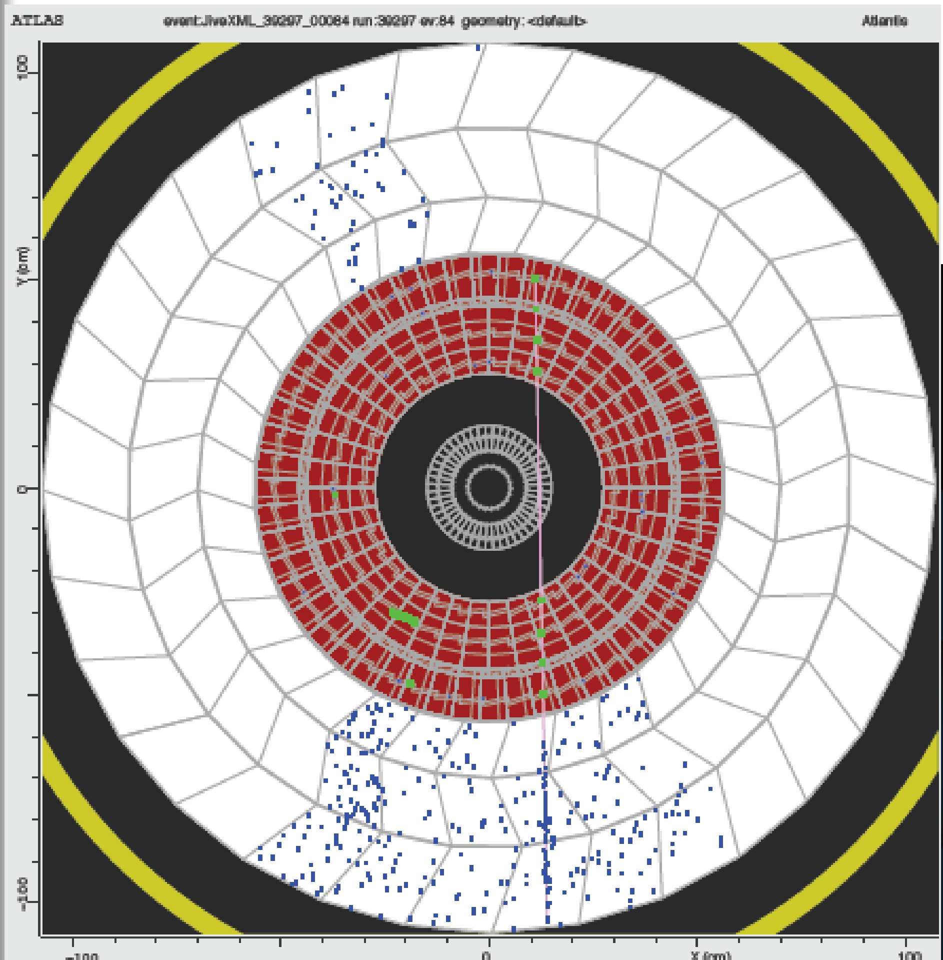


beam halo event seen in ATLAS

Центральная часть TRT



Track from cosmic ray event detected by SCT and TRT systems



- Major milestone in the detector commissioning: combination of DAQ, online and offline software.