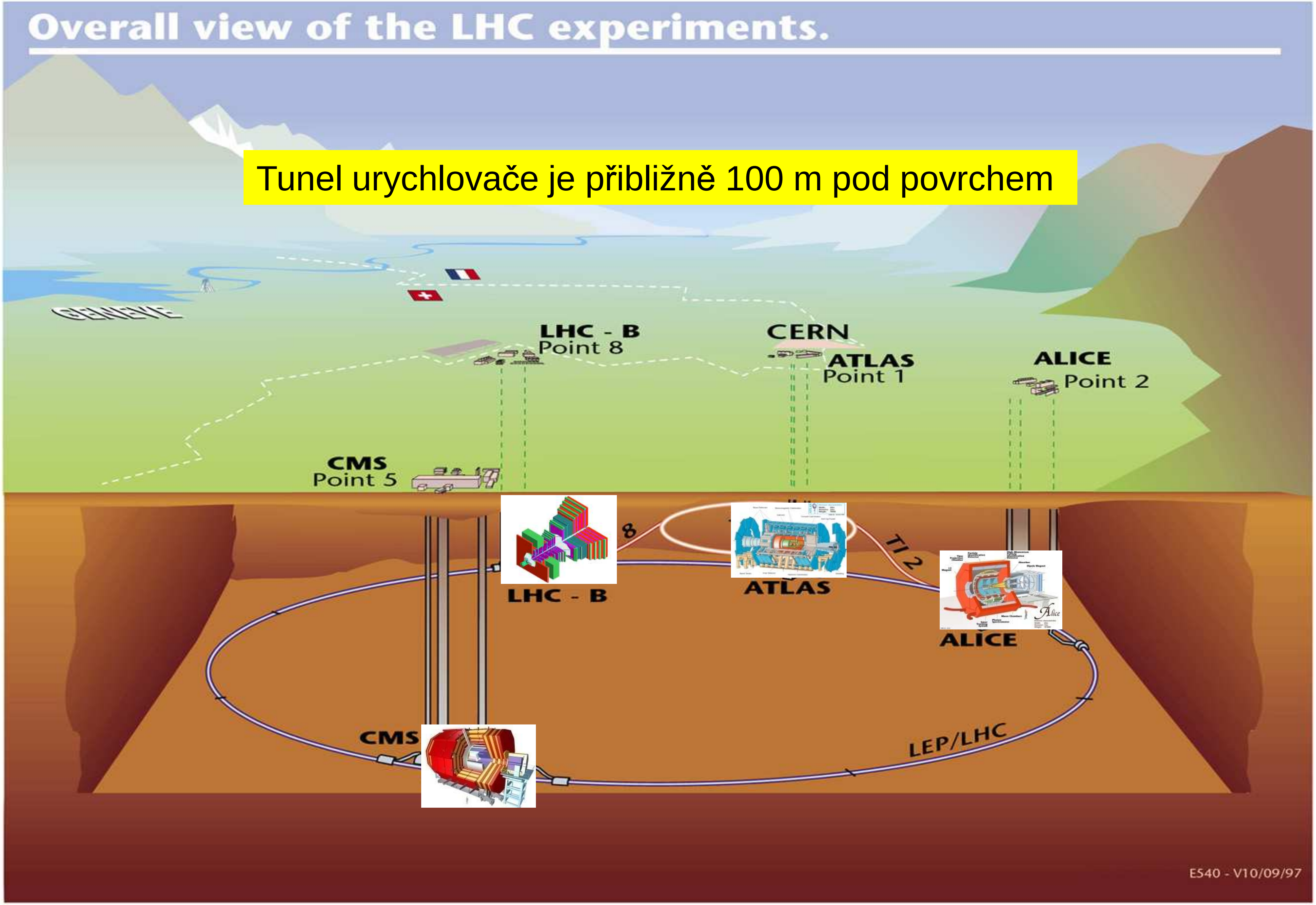
Detektor ATLAS na urychlovači LHC

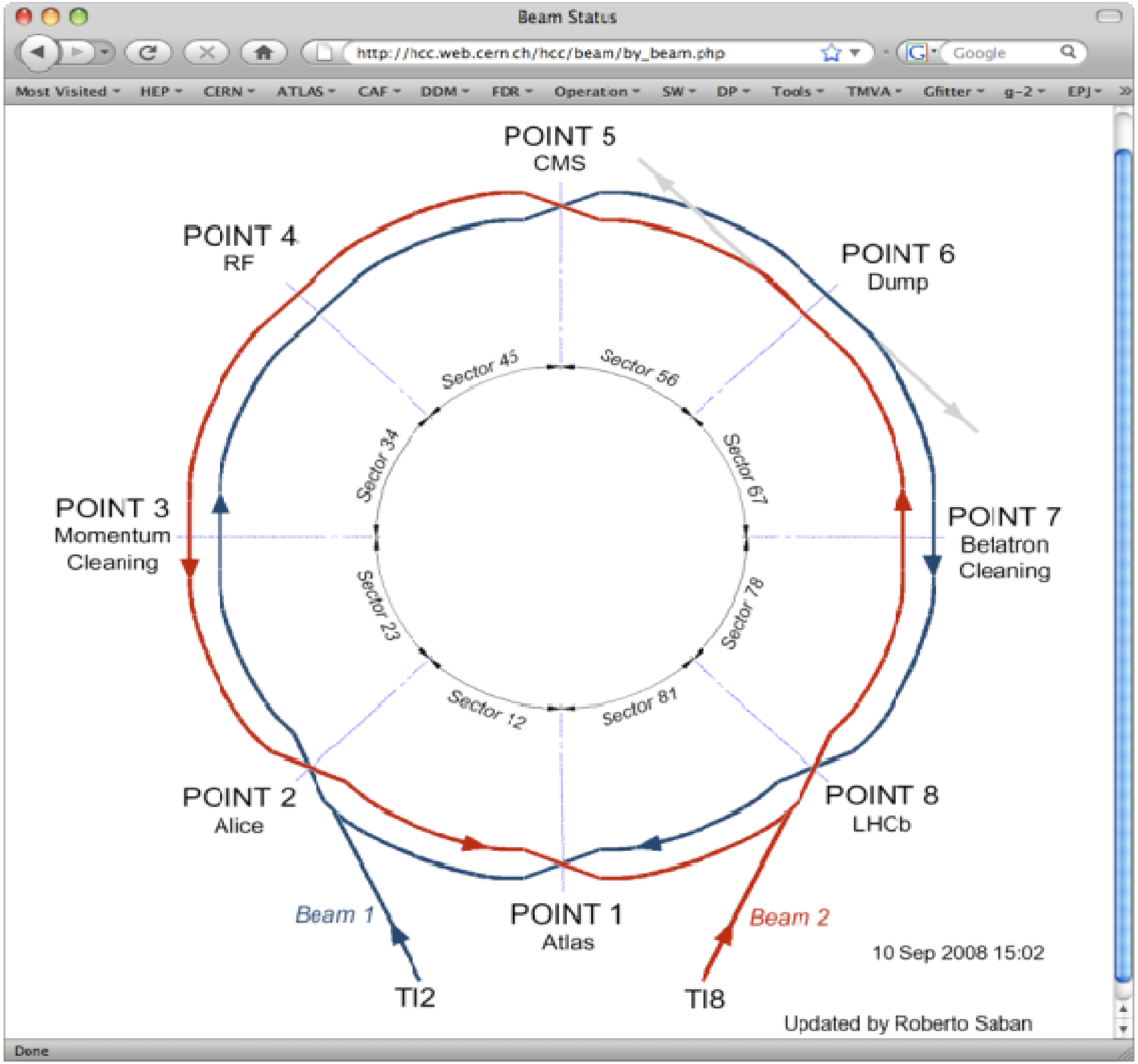
Rupert Leitner, ÚČJF MFF UK
seminář ÚTF MFF UK, 8.12.2009

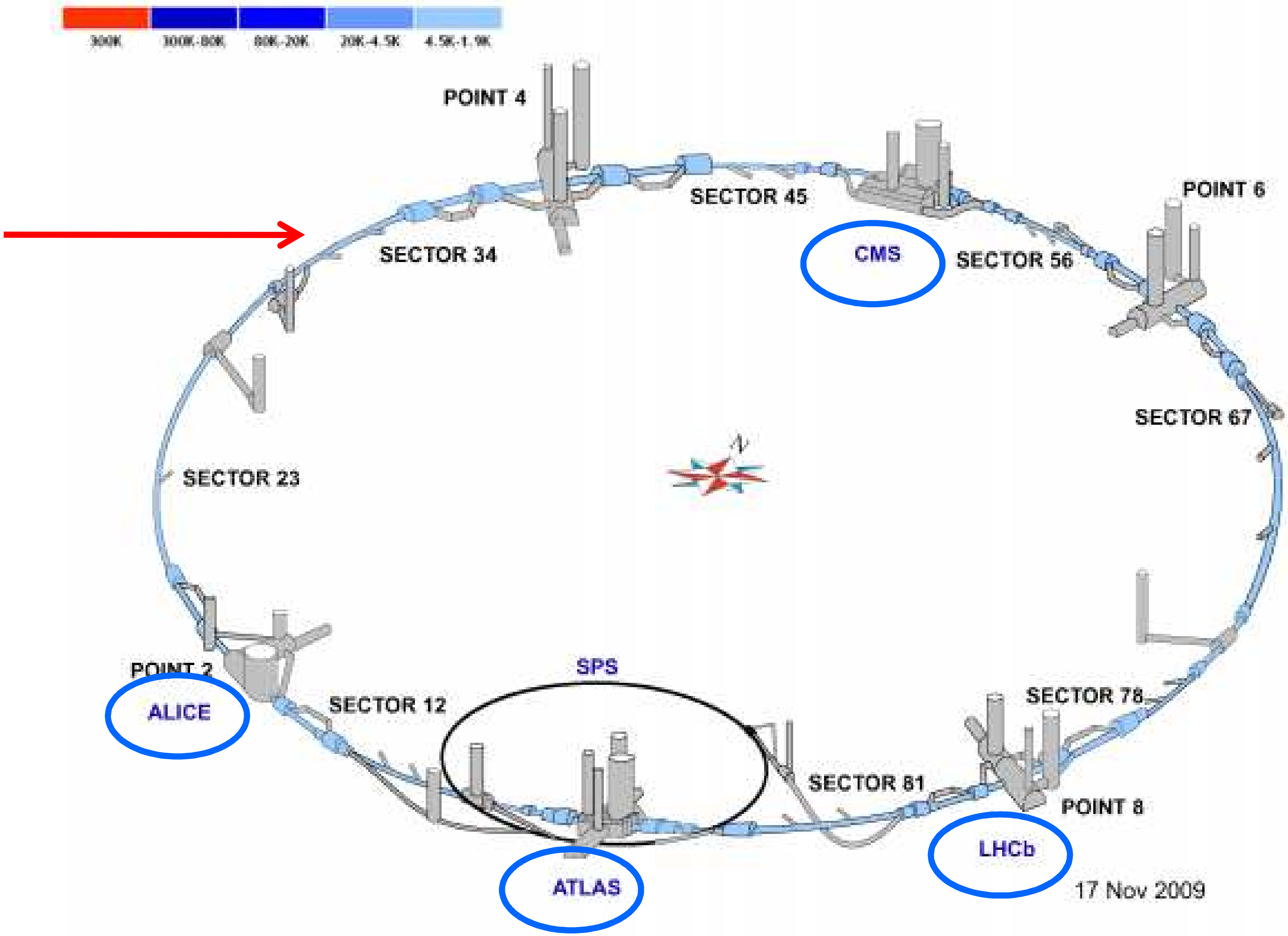
- Parametry urychlovače LHC
- Detektor ATLAS
- Příklady zkoumání fyzikálních procesů pomocí ATLAS
- Současný stav LHC

Urychlovač LHC Large Hadron Collider

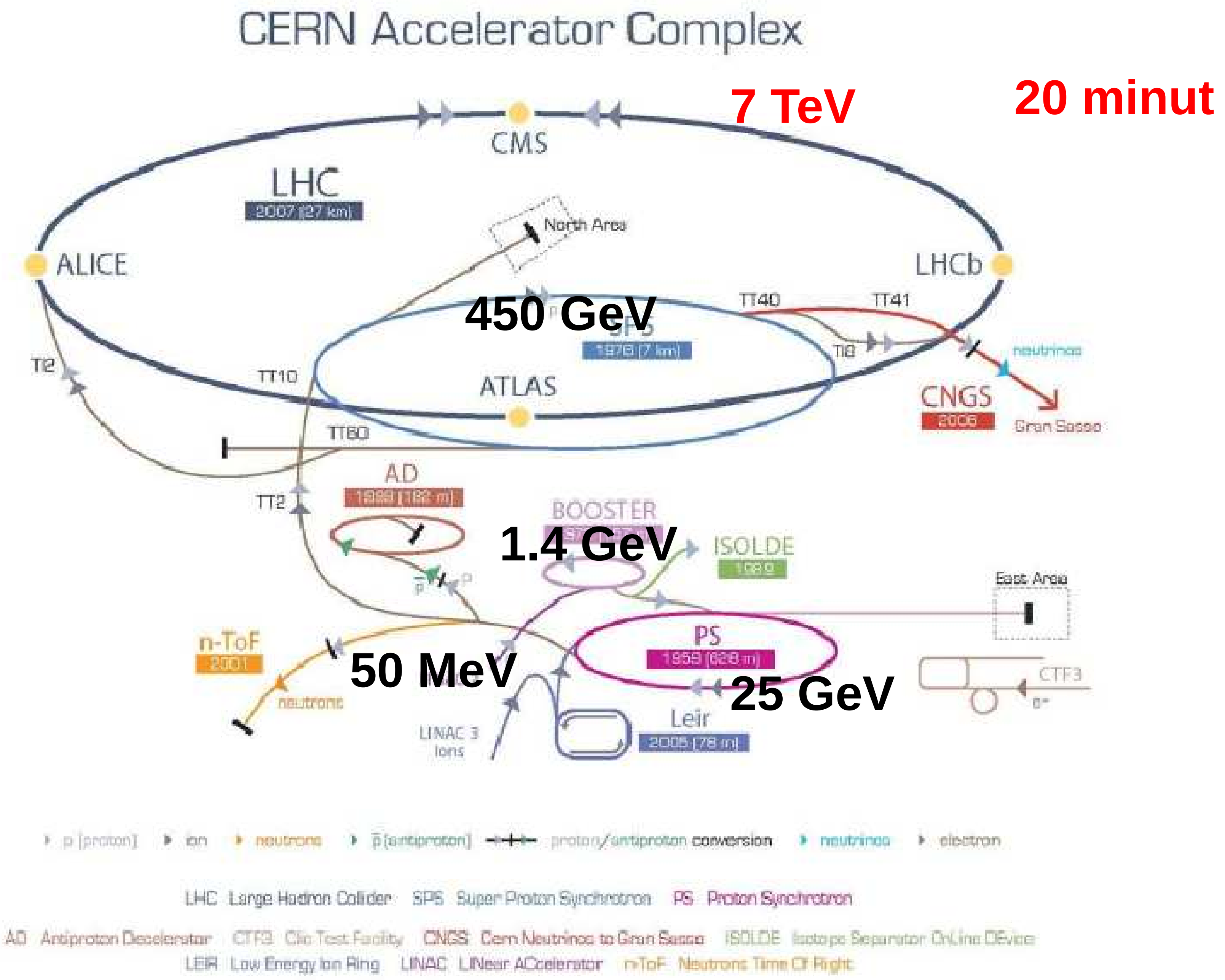
Obvod 27 km, sráží se protony s protony s energií 7 TeV


Overall view of the LHC experiments.
Tunel urychlovače je přibližně 100 m pod povrchem
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC
ES40 - V10/09/97

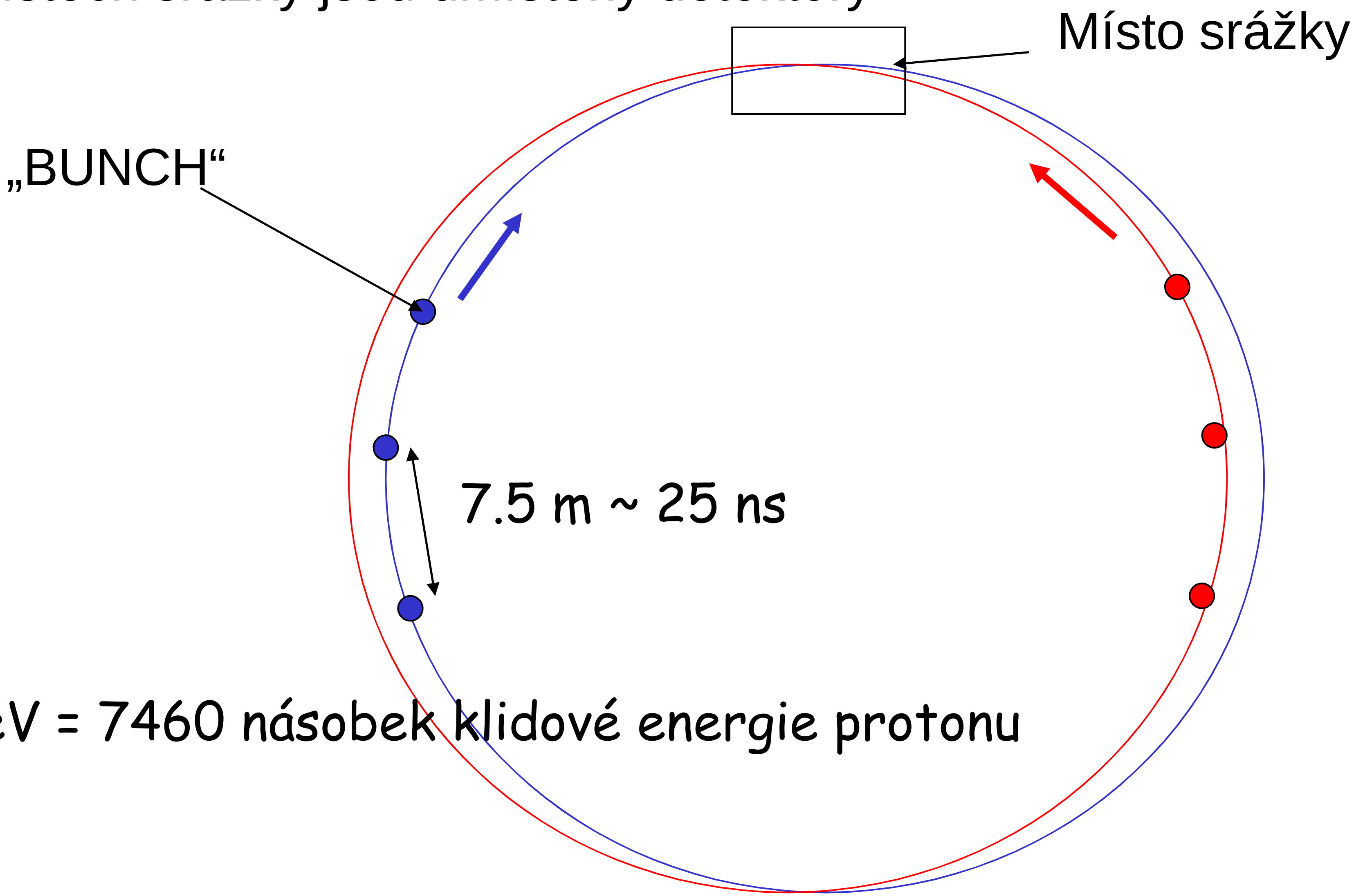

Beam Status
http://hcc.web.cern.ch/hcc/beam/by_beam.php
Google
Most Visited HEP CERN ATLAS CAF DDM FDR Operation SW DP Tools TMVA Gfitter g-2 EPJ
POINT 5
CMS
POINT 4
RF
POINT 6
Dump
Sector 45
Sector 56
Sector 34
Sector 67
POINT 3
Momentum
Cleaning
POINT 7
Betatron
Cleaning
Sector 23
Sector 78
Sector 12
Sector 81
POINT 2
Alice
POINT 8
LHCb
Beam 1
POINT 1
Atlas
Beam 2
10 Sep 2008 15:02
TI2
TI8
Updated by Roberto Saban
Done



300K
300K-80K
80K-20K
20K-4.5K
4.5K-1.9K
POINT 4
SECTOR 45
SECTOR 34
CMS
SECTOR 56
POINT 6
SECTOR 67
SECTOR 23
SPS
POINT 2
ALICE
SECTOR 12
SECTOR 78
SECTOR 81
POINT 8
LHCb
ATLAS
17 Nov 2009


CERN Accelerator Complex
7 TeV
20 minut
CMS
LHC
2007 (27 km)
North Area
ALICE
LHCb
450 GeV
SPS
1976 (7 km)
TT40
TT41
TI8
neutrinos
T12
TT10
ATLAS
CNGS
2006
Gran Sasso
TT60
AD
1999 (182 m)
TT2
BOOSTER
1.4 GeV
ISOLDE
1989
East Area
n-ToF
2001
50 MeV
PS
1959 (628 m)
25 GeV
CTF3
e–
neutrons
LINAC 3
Ions
Leir
2005 (78 m)
p (proton)
ion
neutrons
p̄ (antiproton)
proton/antiproton conversion
neutrinos
electron
LHC Large Hadron Collider
SPS Super Proton Synchrotron
PS Proton Synchrotron
AD Antiproton Decelerator
CTF3 Clic Test Facility
CNGS Cern Neutrinos to Gran Sasso
ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring
LINAC LINear ACcelerator
n-ToF Neutrons Time Of Flight

V **LHC** tvoří urychlené protony celkem 2808 „bunches“ protonů urychlených na energii 7 TeV a vzdálených od sebe 7.5 m, v místech srážky jsou umístěny detektory



7 TeV = 7460 násobek klidové energie protonu

Obvod urychlovače LHC, energie protonů a magnetické pole

$$m\frac{v^2}{R} = e \cdot v \cdot B$$

$$m \cdot v = e \cdot B \cdot R$$

Pro udržení na kruhové dráze platí následující vztah mezi hybností p, poloměrem dráhy R a velikostí magnetického pole B.

$$p = e \cdot B \cdot R$$

$$\frac{p \cdot c}{e} = c \cdot B \cdot R$$

$$pc[GeV] = 0.3 \cdot B[T] \cdot R[m]$$

$$\underline{pc[TeV] = 0.3 \cdot B[T] \cdot R[km]}$$

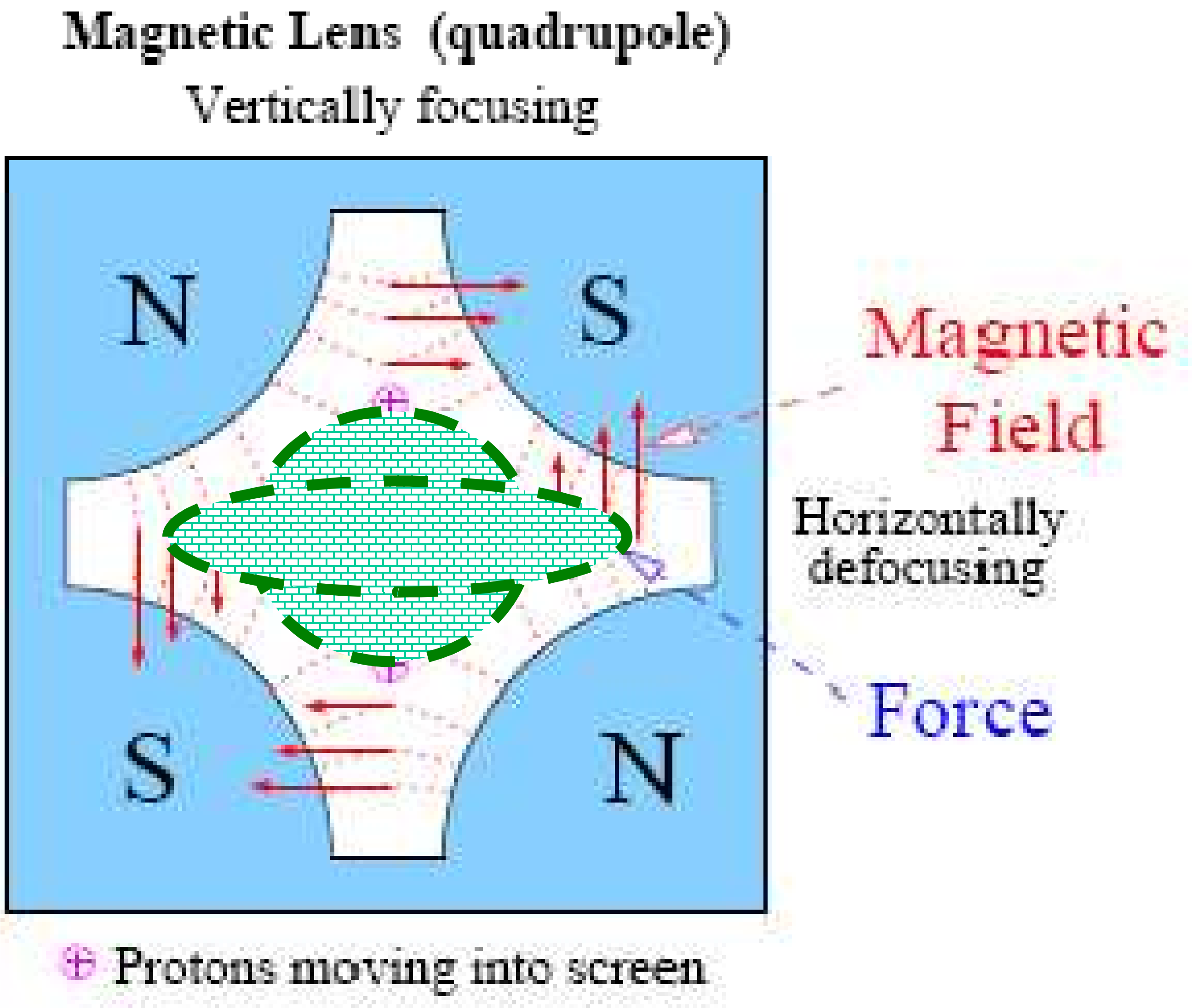
Protony jsou na kruhové dráze udržovány pomocí 1232 dipólových magnetů

- **Každý dipól má délku 15 m, tj. celkem tvoří kruh o obvodu 1232 x 15 = 18,5 km a poloměru 2.9 km.**

- **Každý dipól ohýbá dráhu částice o 6.28/1232 = 5.1 mili radiánu**

- **Je nutné magnetické pole 8 T podle vztahu: 0,3 x 8 (T) x 2.9 (km) = 7 TeV**

Fokusace svazků pomocí kvadrupólových magnetů



Fokusace svazků v místě interakce

- **Z příčného rozměru 1x1 mm na 17x17 mikrometru**

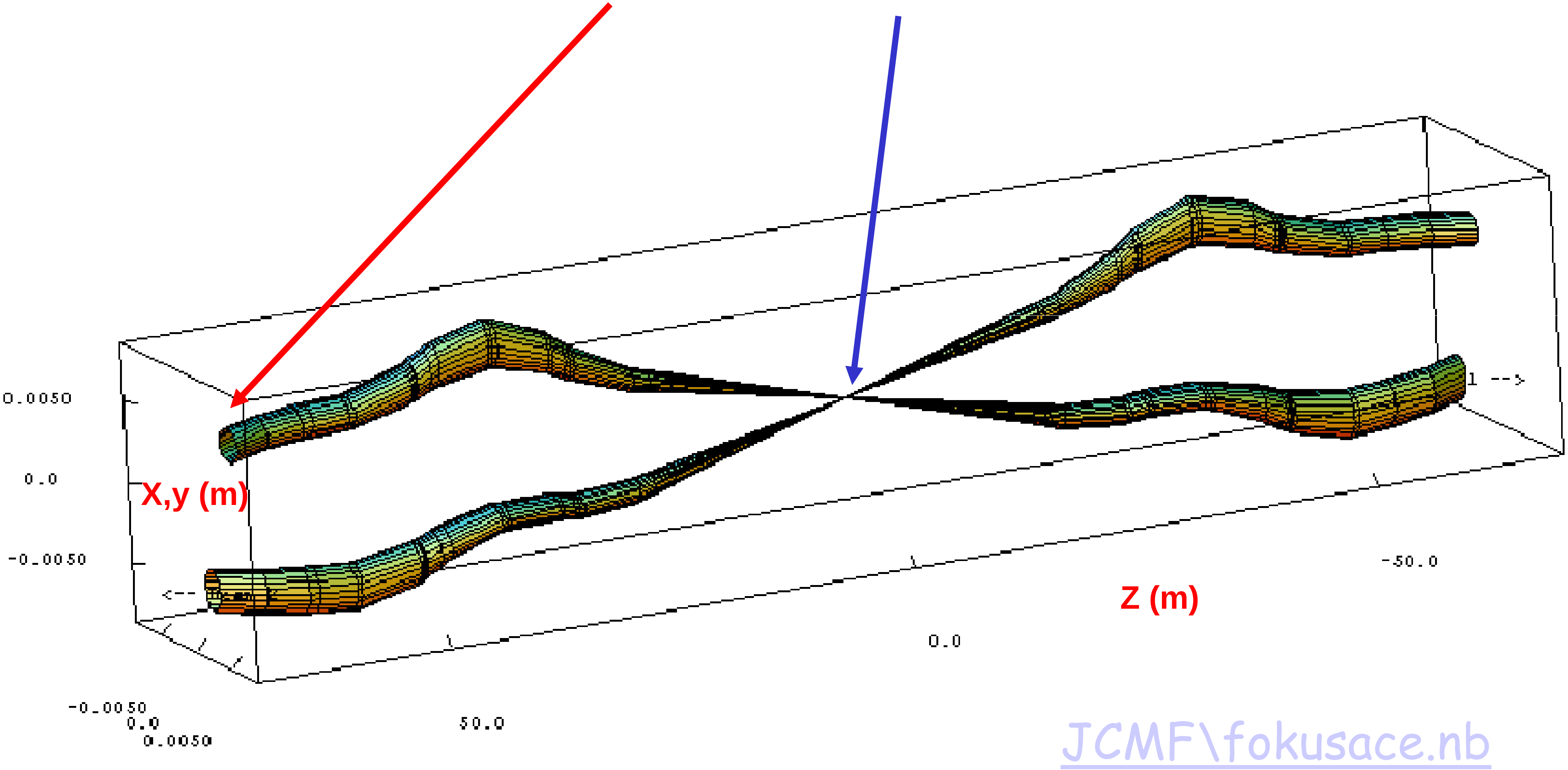


Table 2.1: LHC beam parameters relevant for the peak luminosity

		Injection	Collision
Beam Data			
Proton energy	[GeV]	450	7000
Relativistic gamma		479.6	7461
Number of particles per bunch		1.15×10^{11}	
Number of bunches		2808	
Longitudinal emittance (4σ)	[eVs]	1.0	2.5^a
Transverse normalized emittance	[μm rad]	3.5^b	3.75
Circulating beam current	[A]	0.582	
Stored energy per beam	[MJ]	23.3	362
Peak Luminosity Related Data			
RMS bunch length[c]	cm	11.24	7.55
RMS beam size at the IP1 and IP5[d]	μm	375.2	16.7
RMS beam size at the IP2 and IP8[e]	μm	279.6	70.9
Geometric luminosity reduction factor F[f]		-	0.836
Peak luminosity in IP1 and IP5	[$cm^{-2}sec^{-1}$]	-	1.0×10^{34}
Peak luminosity per bunch crossing in IP1 and IP5	[$cm^{-2}sec^{-1}$]	-	3.56×10^{30}

Počet inerakcí za 1 s

$$L_{\max} \cong 10^{34} cm^{-2} s^{-1}$$

$$\sigma_{tot} = 100 mbarn = 100 \cdot 10^{-27} cm^{2}$$

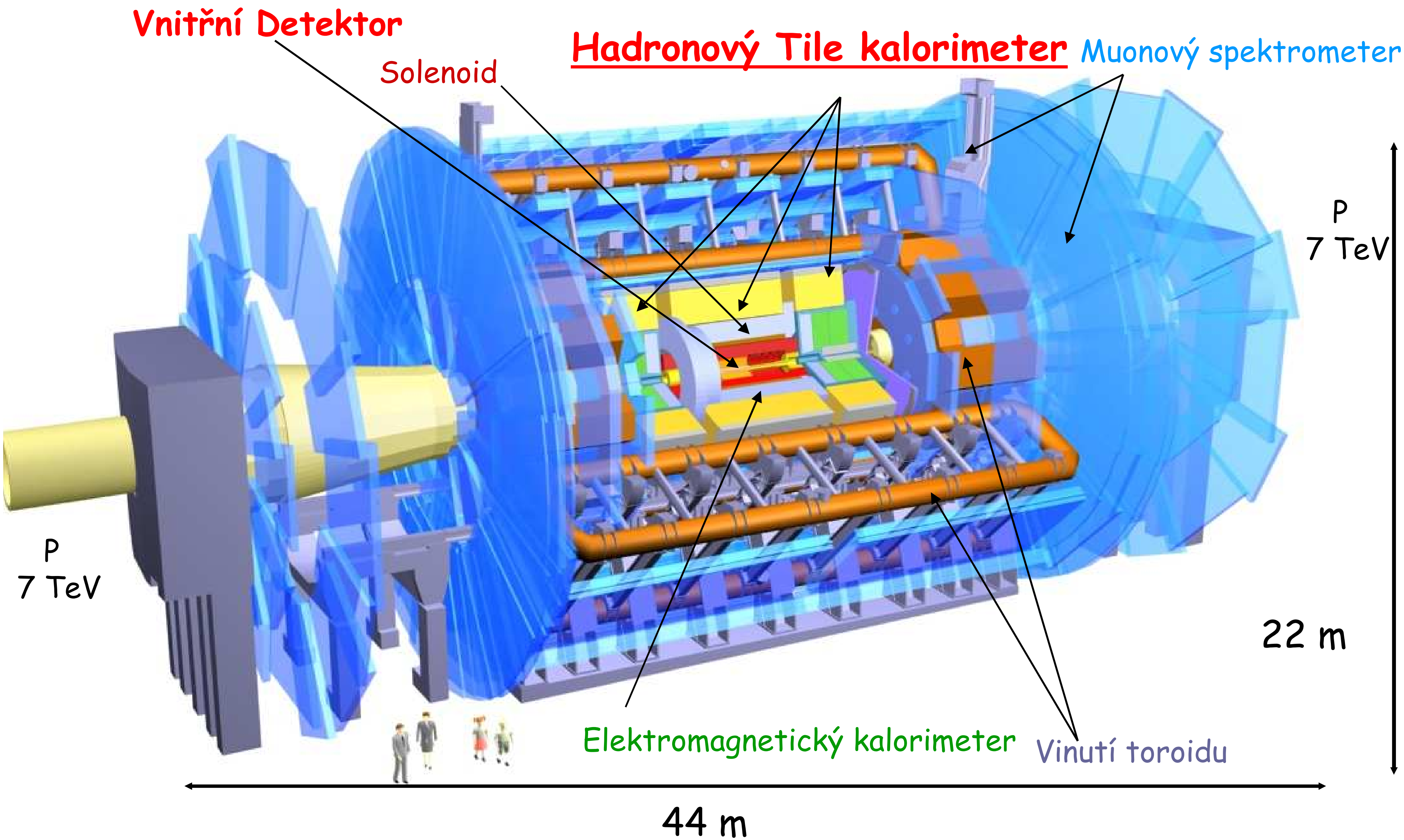
$$L_{\max} \cdot \sigma_{tot} = 10^{9} / s$$

Pomocí triggeru se vybere „pouhých“ 100 interakcí za 1 s, tj. jen jedna z 10 milionu.

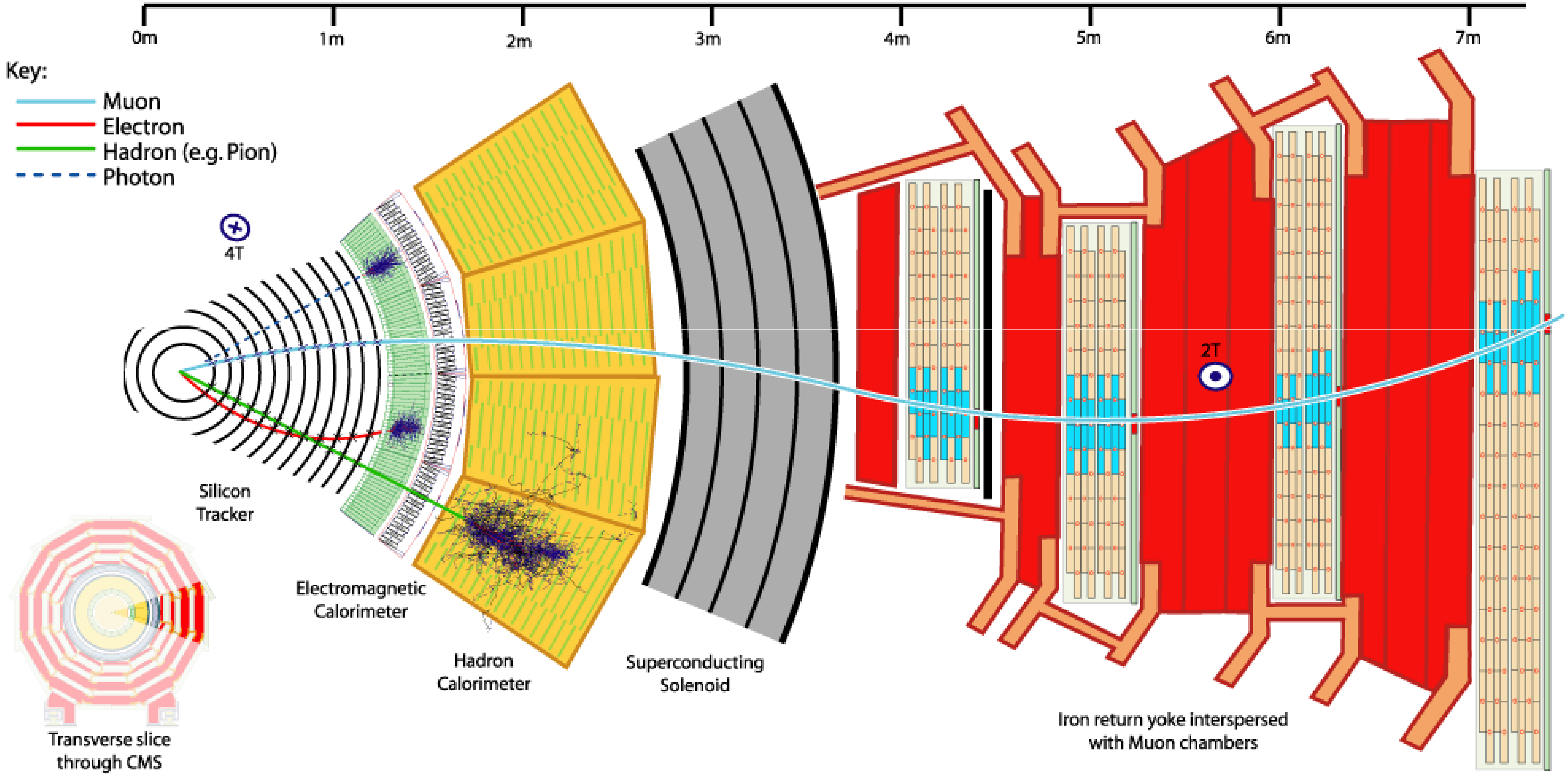
I tak se za 1 rok zaznamená 1 miliarda interakcí, každá z nich je popsána přibližně 2 MB údajů, celkem tedy asi 2 PetaByty informace.

Detektor ATLAS

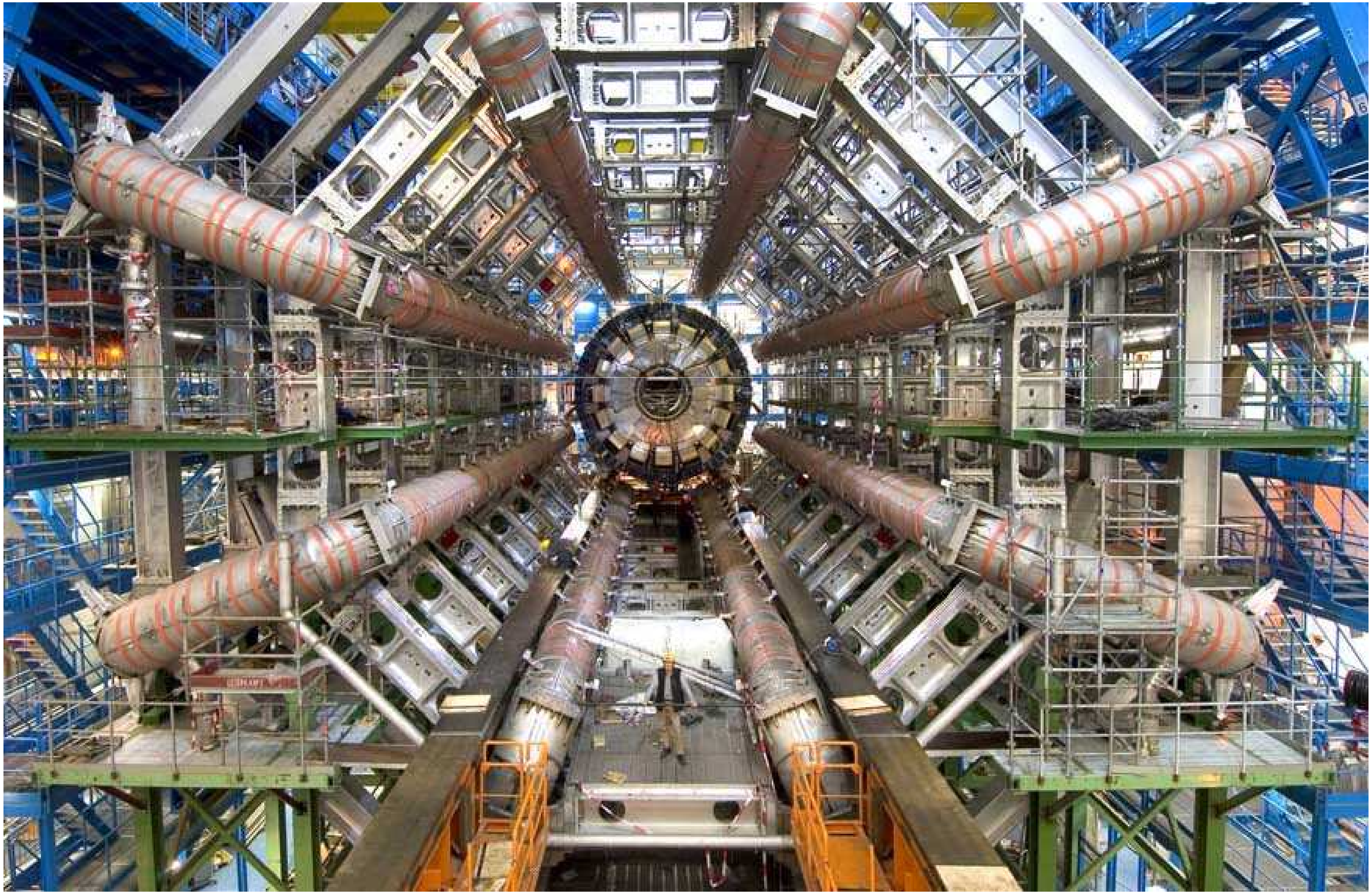
Celková váha ~ 7000 t



Detektory slouží pro měření energie, hybnosti a identifikaci částic,



Rozměry ATLAS jsou určeny detektorem mionů a kalorimetry



Měření hybnosti mionů

$$sagita = R - \sqrt{R^2 - (L/2)^2} \cong R - R(1 - \frac{1}{2}\frac{L^2}{4R^2}) = \frac{L^2}{8R}$$

$$0{,}3BR = pc \Rightarrow R = \frac{pc}{0{,}3B}$$

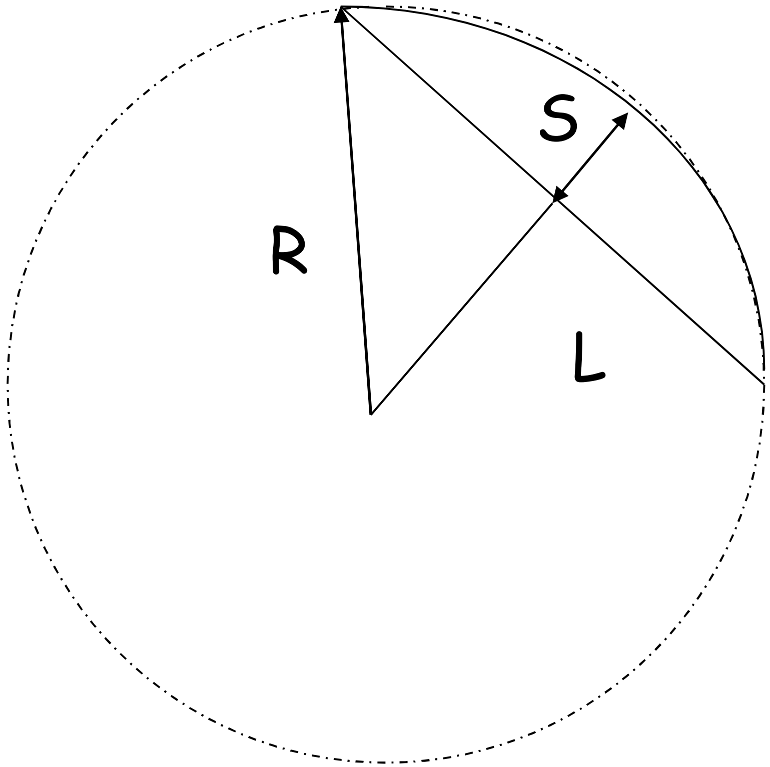
$$sagita = \frac{0{,}3}{8} BL \cdot L \frac{1}{pc}$$

$$pc = 1TeV$$

$$L = 5m$$

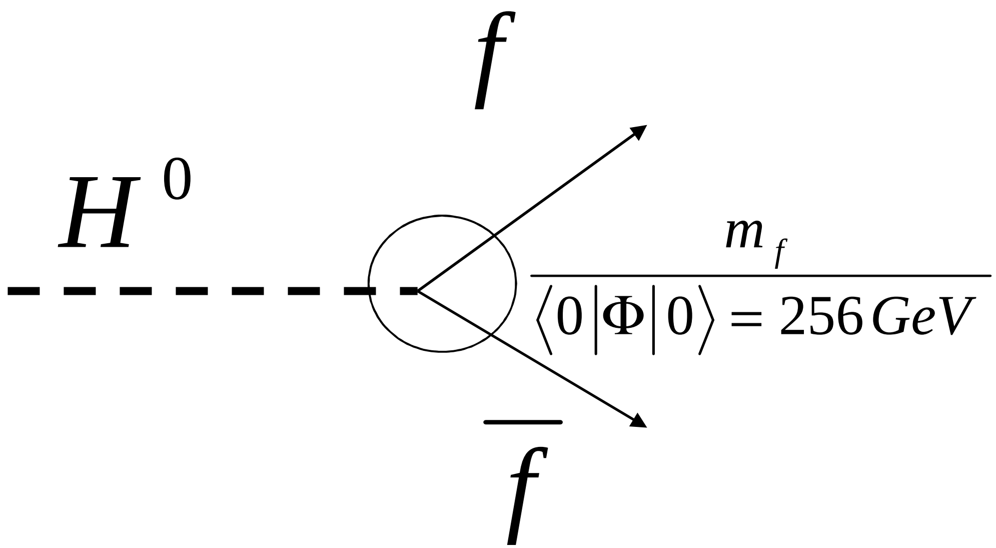
$$BL = 8Tm$$

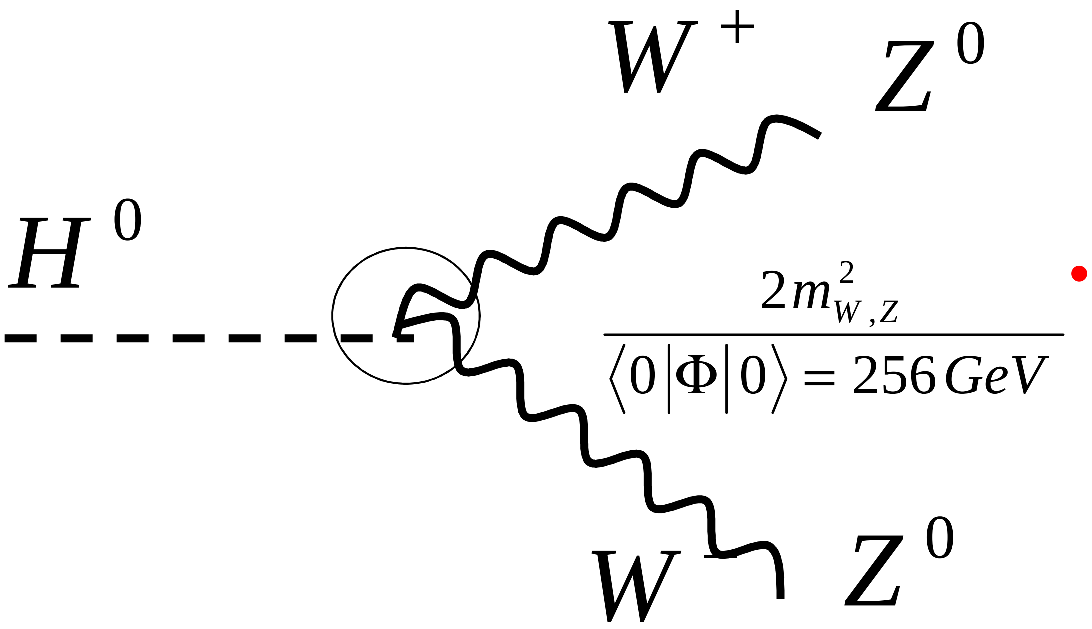
$$S = \frac{0{,}3}{8} 8Tm \cdot 2{,}5m \frac{1}{1000GeV} = 750 \mu m$$



Chceme-li měřit hybnost mionů s přesností 10%, pak musíme být schopni změřit sagitu s přesností 75 mikronů.

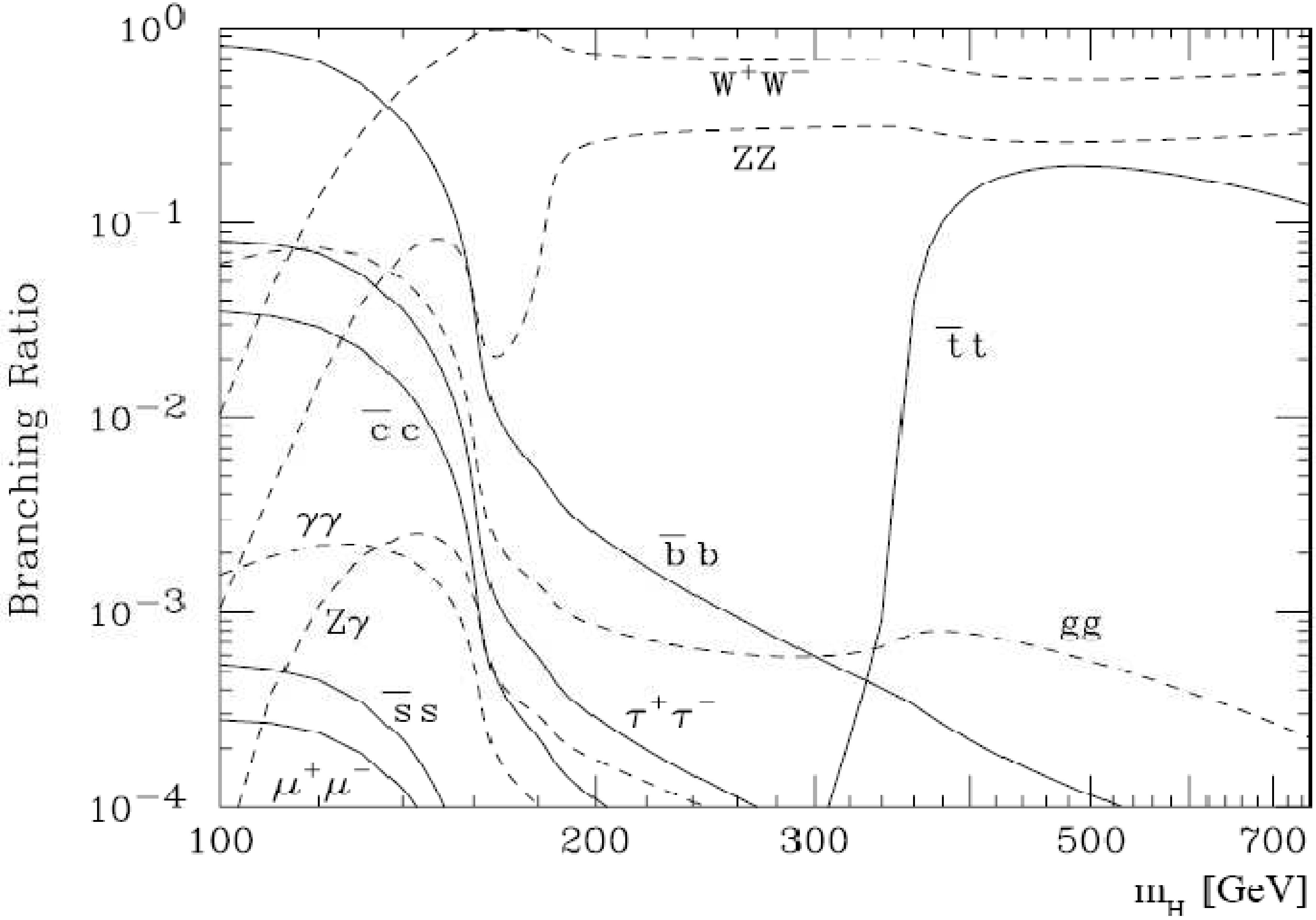
HLEDÁNÍ HIGGSOVA BOSONU



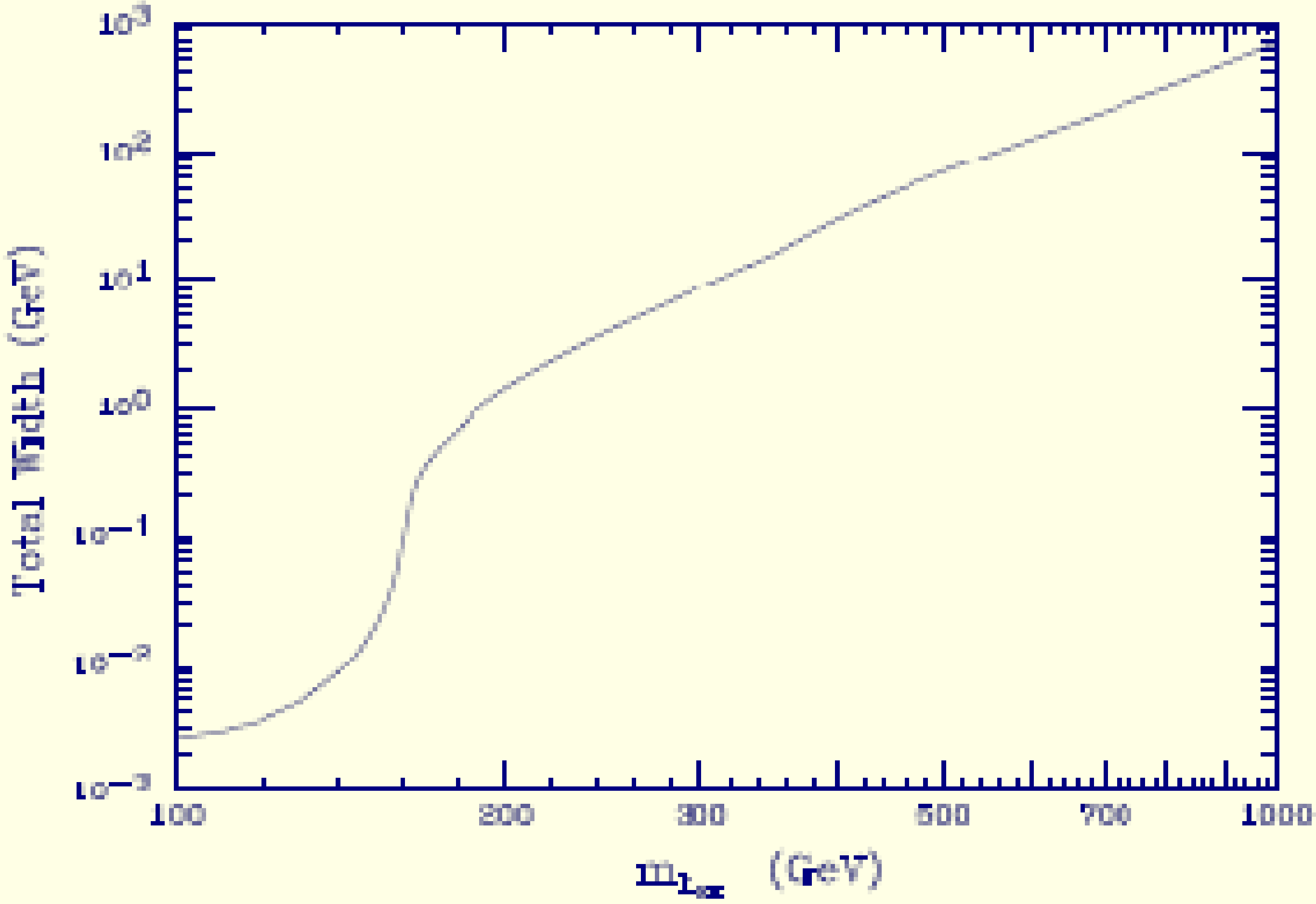


- Higgsův boson je hmotná částice se spinem 0, dosud neobjevená
- V nejjednodušší verzi existuje jeden H s nulovým nábojem a spinem 0
- Amplituda rozpadu H je úměrná hmotě částic na něž se může Higgsův boson rozpadnout
- **Higgsův boson se rozpadá na nejtěžší částice na něž se může rozpadnout**

- Higgsův boson se rozpadá především na nejtěžší částice na něž se může rozpadnout



- Šířka Higgsova bosonu závisí na jeho hmotě
- Pod prahem rozpadu na WW je menší než GeV
- Nad prahem WW prudce roste a pro MH=1000 GeV je 500 GeV!

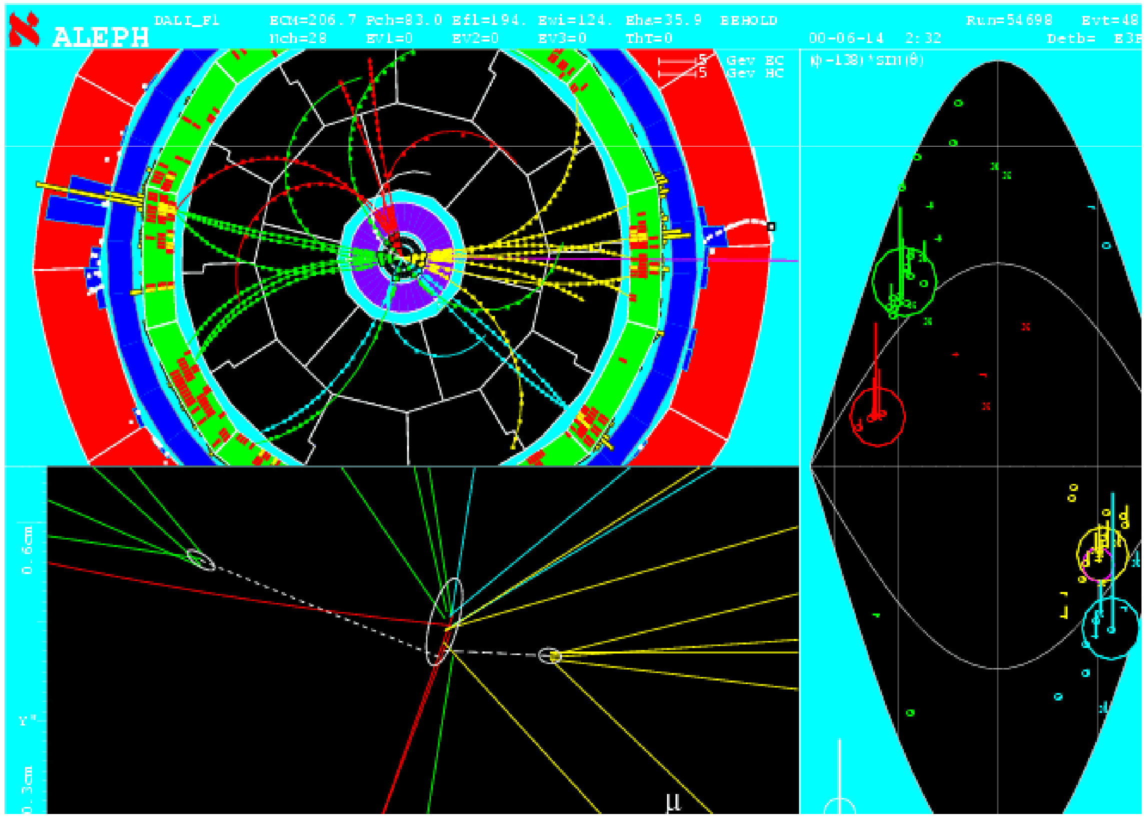


Byl v experimentech na LEP v závěru roku 2000 pozorován Higgsův boson ?

$$e^+ e^- \rightarrow H\,Z \rightarrow q\bar{q}$$
$$H \rightarrow b\bar{b}$$

Projev existence Higgsova bosonu je zvýšená produkce b-jetů

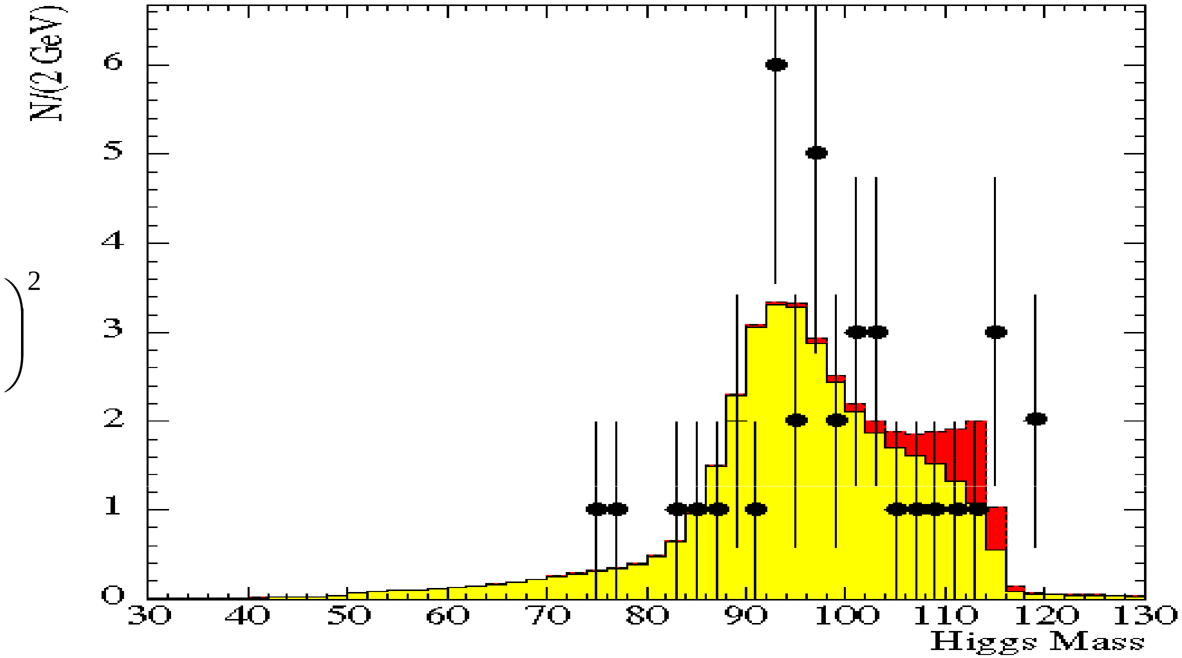
Příznak **b-jetu** je existence tzv. **sekundárních vrcholů** v jetu, jejichž původ je v rozpadech relativně dlouhožijících B mezonů



Rozdělení invariantní hmoty páru b-jetů v experimentu ALEPH

$$(E, \vec{p}) = (E_1, \vec{p}_1) + (E_2, \vec{p}_2)$$

$$M^2 = E^2 - \left(\vec{p}\right)^2 = \left(E_1 + E_2\right)^2 - \left(\vec{p}_1 + \vec{p}_2\right)^2$$



Publikace:

ALEPH Coll., Observation of an Excess in the Search for the Standard Model Higgs Boson at ALEPH, CERN-EP/2000-138

L3 Coll., Higgs Candidates in e+e- Interactions at sqrt(s)=206.6 GeV, CERN-EP/2000-140, Phys. Lett. B, 495 (2000) 18.

Experimenty DELPHI a OPAL tento efekt nepozorovaly.

Higgs nebyl pozorován a jeho hmota je větší než 114 GeV

Nepřímé určení hmoty Higgsova bosonu:

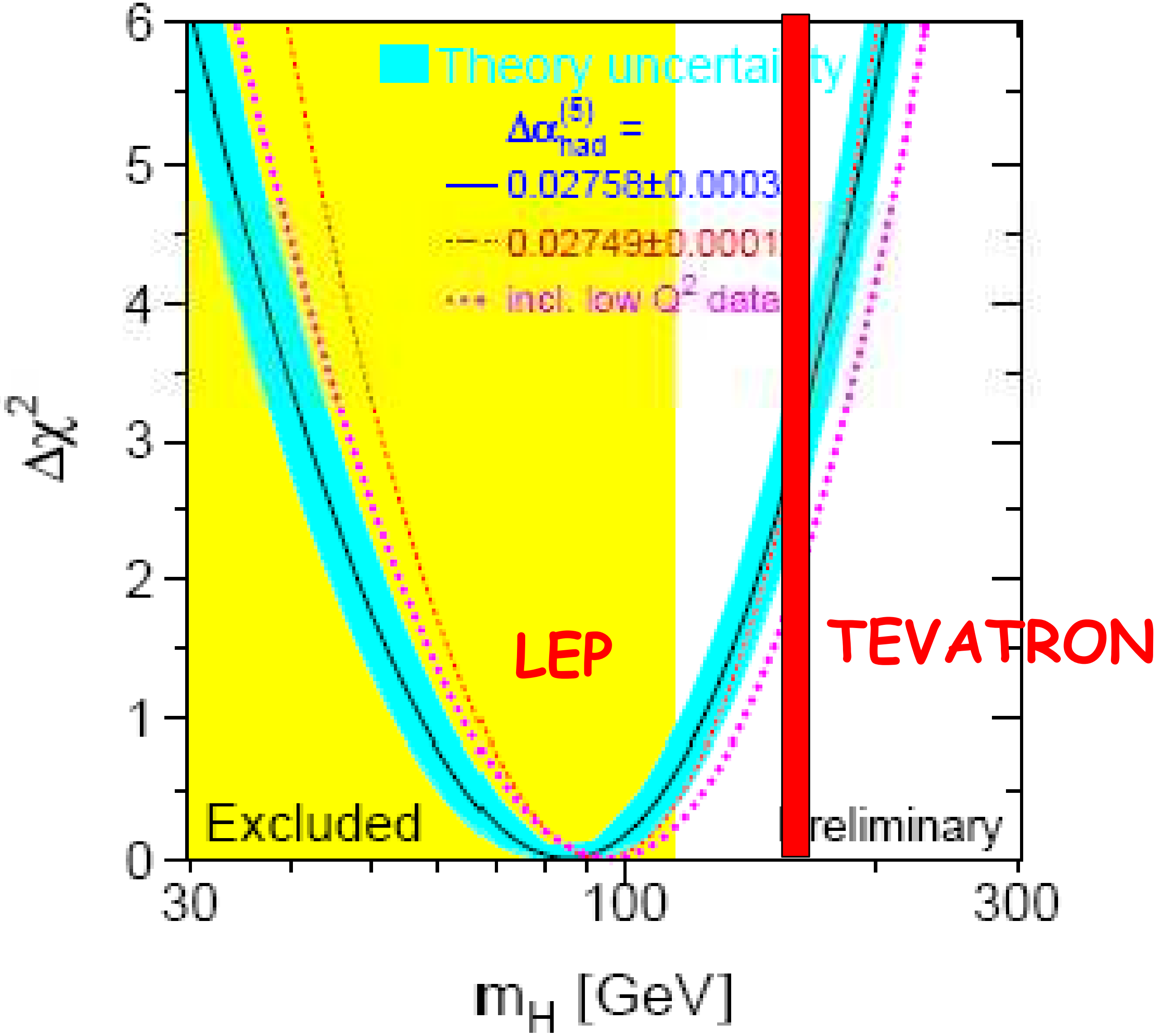
$$M_W^2 = \frac{\pi\alpha}{\sqrt{2}G_F \sin^2\theta_W}\frac{1}{1-\Delta r(M_t, M_h)}$$

$$M_W[GeV] = f(m_t, M_H)$$

$$M_W = 80.3827 - 0.0579 \ln\left(\frac{M_H}{100\ \mathrm{GeV}}\right) - 0.008 \ln^2\left(\frac{M_H}{100\ \mathrm{GeV}}\right)$$

$$+0.543\left(\left(\frac{m_t}{175\ \mathrm{GeV}}\right)^2 - 1\right) - 0.517\left(\frac{\Delta\alpha_{had}^{(5)}(M_Z)}{0.0280} - 1\right) - 0.085\left(\frac{\alpha_s(M_Z)}{0.118} - 1\right)$$

Hledání Higgsova Bosonu – současný stav



Hledání Higgsova bosonu v experimentech CDF a D0 na Tevatron

$$N_{H\to final\ state}(M_H) = L \times \sigma(M_H) \times BR(M_H)_{H\to final\ state}$$

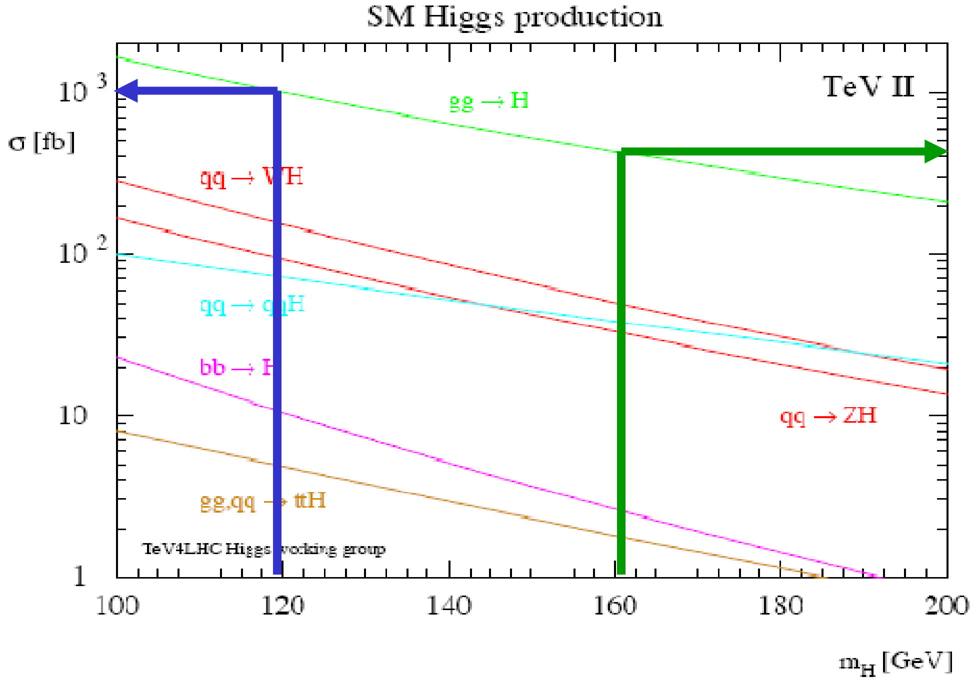
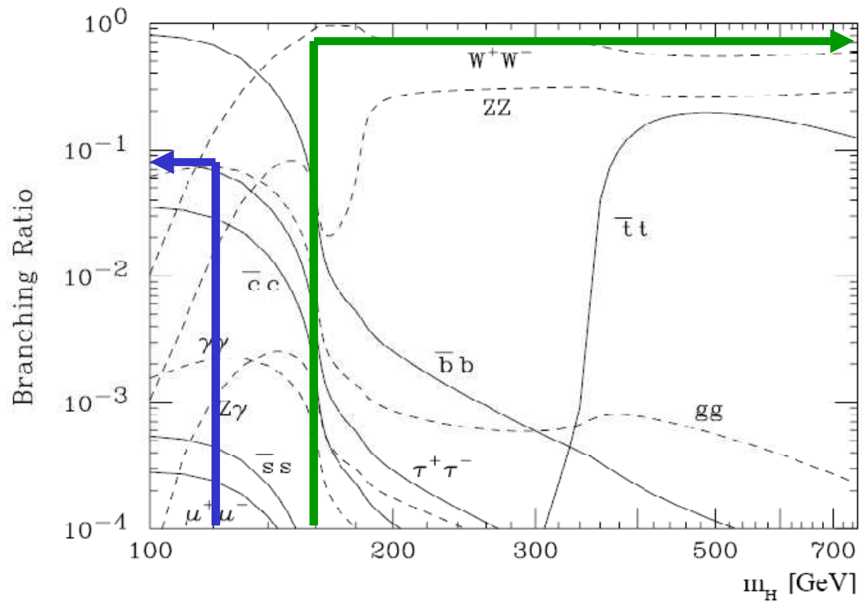


Figure 1: SM Higgs production cross sections for $p\overline{p}$ collisions at 1.96 TeV [26]. Color version at end of book.



$$N_{H\to\tau\tau}(M_H = 120\,GeV) = 5\,fb^{-1} \times 1000\ fb \times 0.08 = 400$$

$$N_{H\to WW}(M_H = 160\,GeV) = 5\,fb^{-1} \times 450\ fb \times 0.9 = 2025$$

Hledání Higgsova bosonu v experimentech ATLAS a CMS na LHC

$$N_{H\to final\ state}(M_H) = L \times \sigma(M_H) \times BR(M_H)_{H\to final\ state}$$

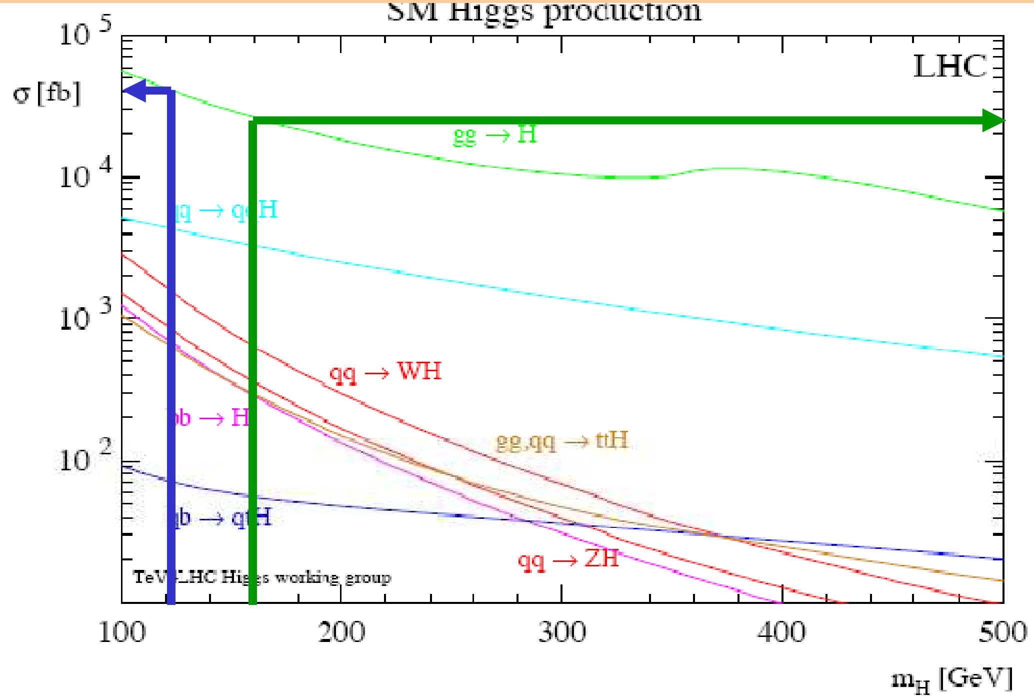
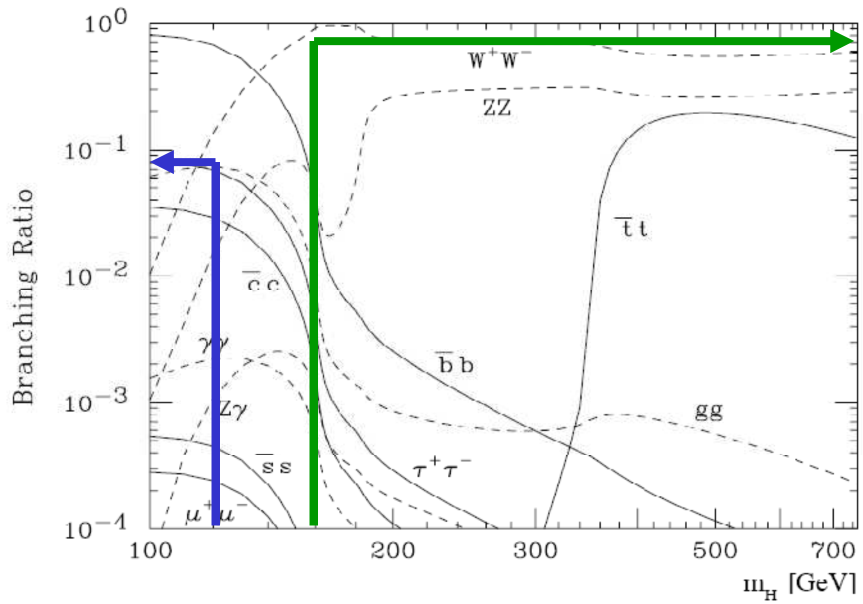
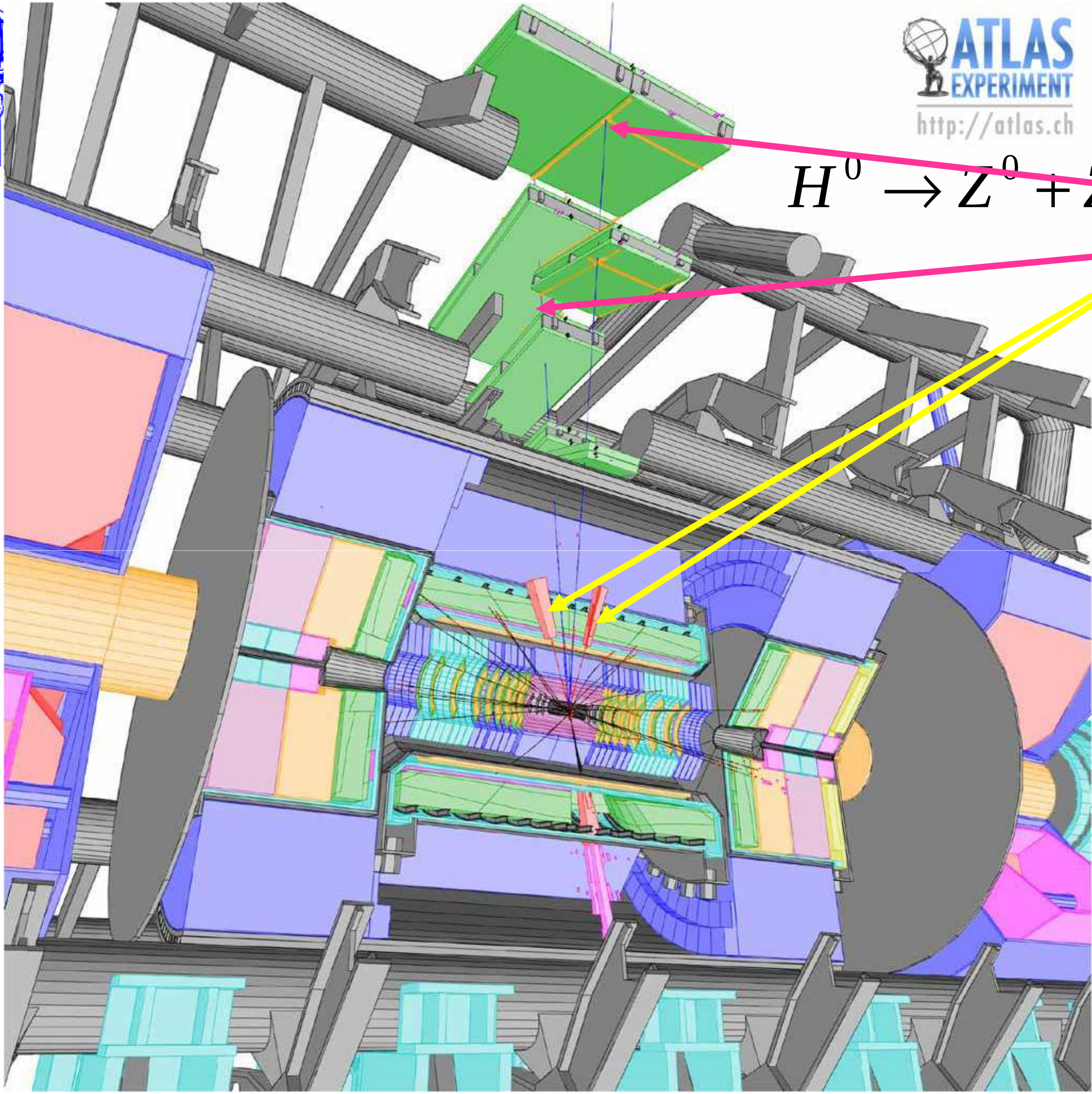


Figure 2: SM Higgs production cross sections for *pp* collisions at 14 TeV [26]. Color version at end of book.



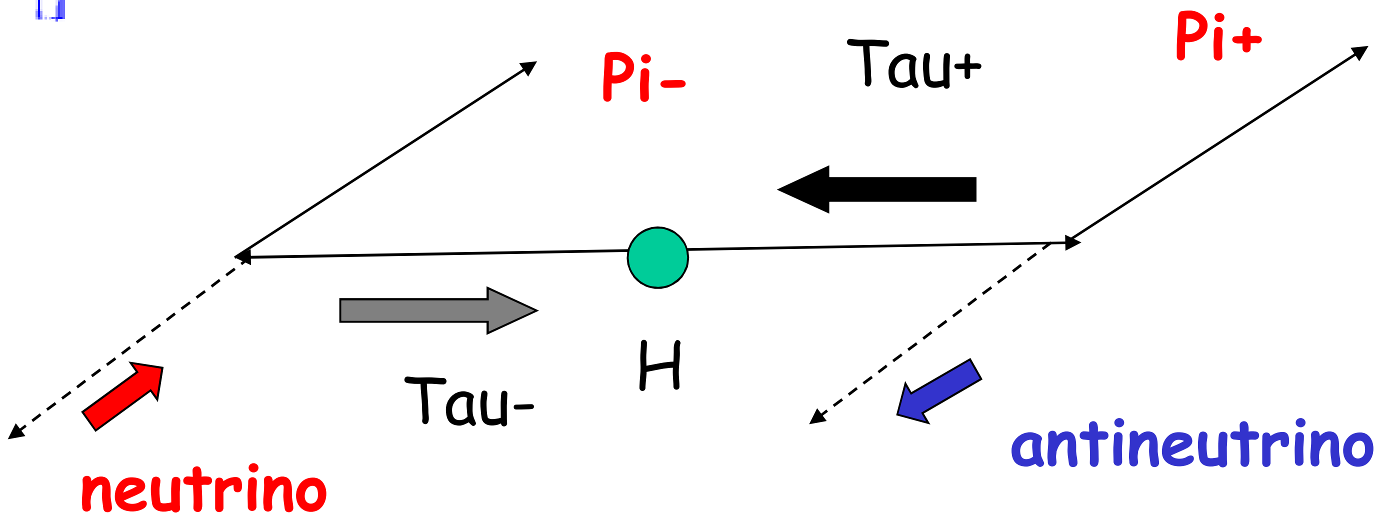
$$N_{H\to\tau\tau}(M_H = 120\,GeV) = 100\ fb^{-1} \times 40000\ fb \times 0.08 = 320.000$$

$$N_{H\to WW}(M_H = 160\,GeV) = 100\ fb^{-1} \times 25000\ fb \times 0.9 = 2.250.000$$

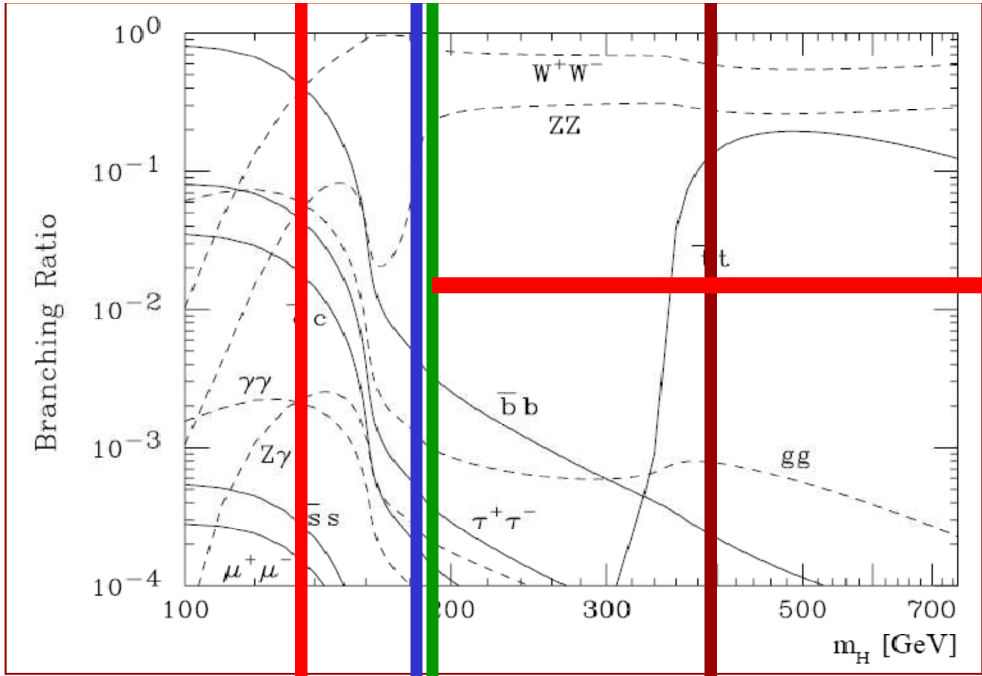


$$H^0 \rightarrow Z^0 + Z^0 \rightarrow e^+e^- + \mu^+\mu^-$$

Určení spinu Lehkého Higgsova bosonu



Velká energie Pi+
a malá energie Pi-



Determination of Higgs spin using H->ZZ->LL LL channel

$M_H < 2M_W$

$H \to b\bar{b}$

$H \to \tau^+\tau^-$

$2M_W < M_H < 2M_Z$

$H \to W^+W^-$

$2M_t < M_H$

$H \to W^+W^-, Z^0Z^0, t\bar{t}$

$2M_Z < M_H$

$H \to W^+W^-, Z^0Z^0$

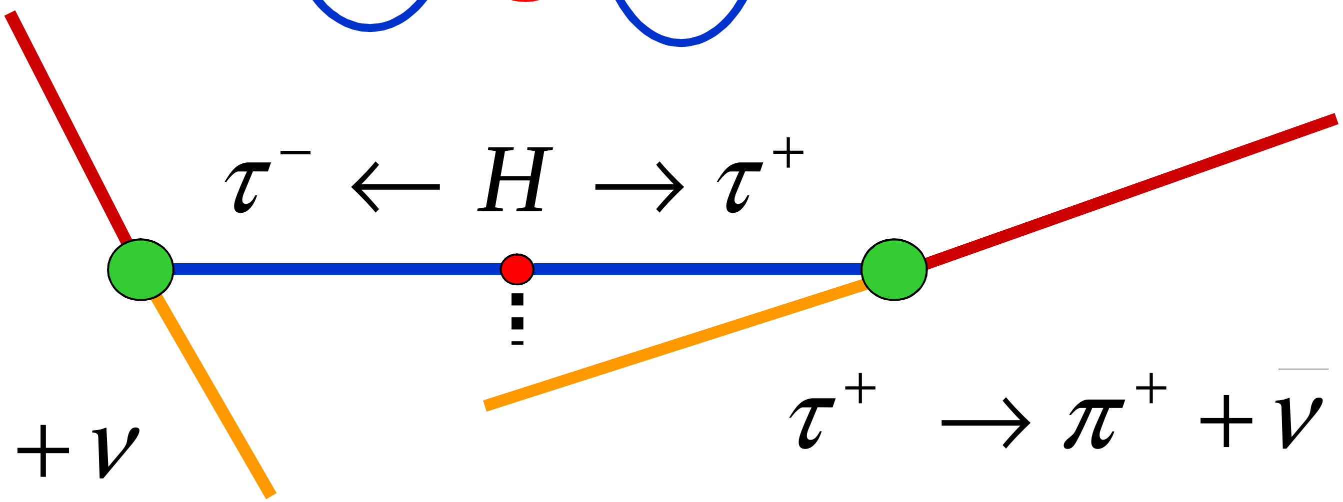
Měření spinu lehkého Higgsova bosonu

$$\pi^- + \nu \;\leftarrow\; \tau^- \leftarrow H \rightarrow \tau^+ \;\rightarrow \pi^+ + \bar{\nu}$$

$$p + k \;\leftarrow\; q \leftarrow P \rightarrow q' \;\rightarrow p' + k'$$

$$iM =$$

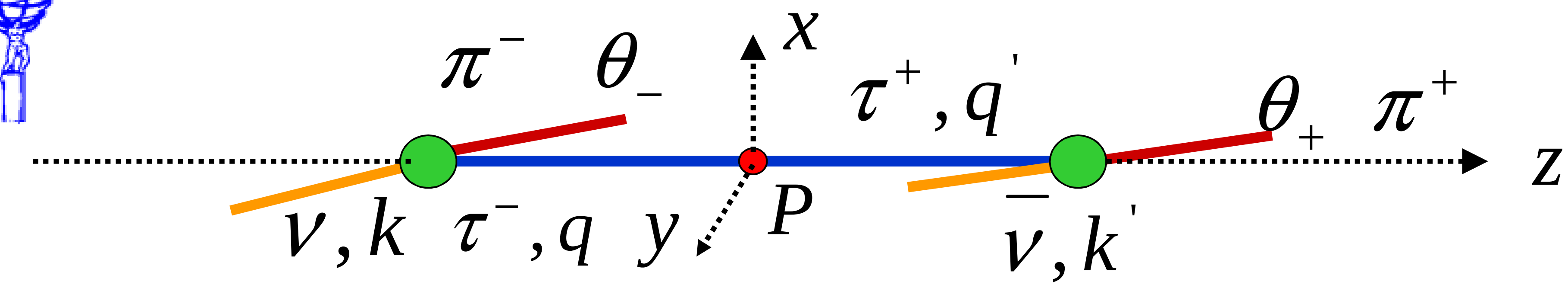
$$\bar{u}(k)\gamma_\mu(1-\gamma_5)p^\mu\left(-i\frac{G_F}{\sqrt{2}}\cos\theta_C F_\pi\right)\frac{i}{\hat{q}-m_\tau}\,\frac{-igm_\tau}{2m_W}\,\frac{i}{\hat{q}'-m_\tau}\left(-i\frac{G_F}{\sqrt{2}}\cos\theta_C F_\pi\right)p'^\nu\gamma_\nu(1-\gamma_5)v(k')$$

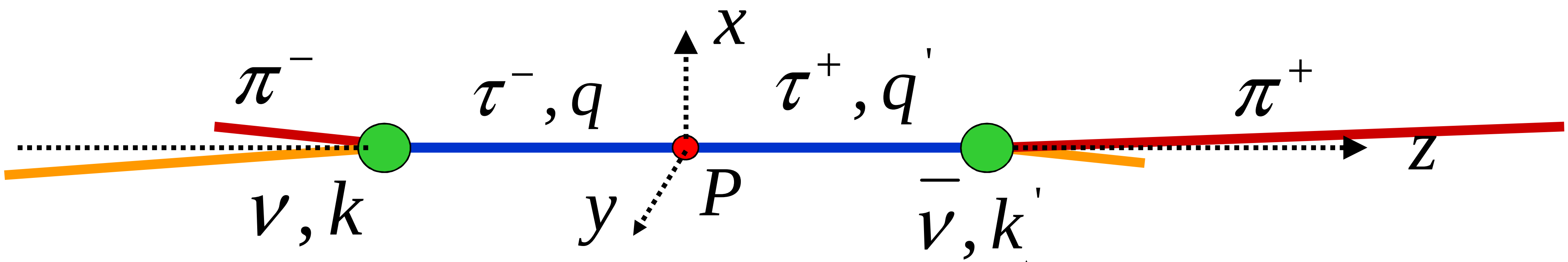


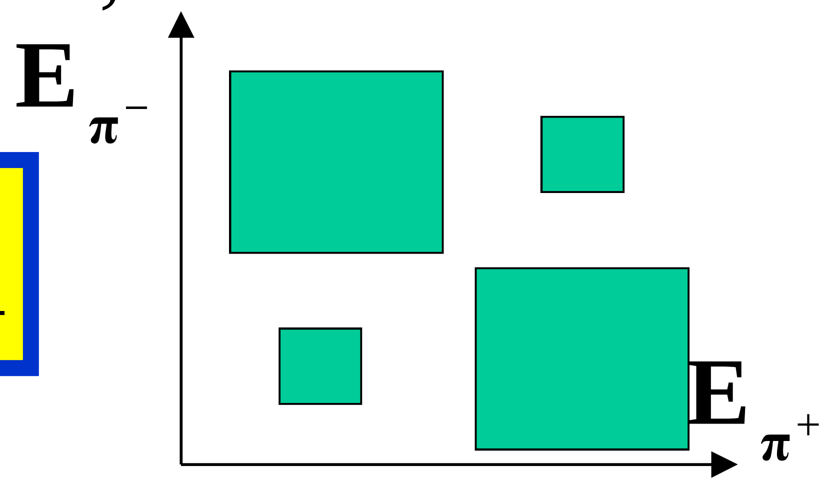
$$\tau^- \leftarrow H \rightarrow \tau^+$$

$$\tau^+ \;\rightarrow \pi^+ + \bar{\nu}$$

$$\tau^- \;\rightarrow \pi^- + \nu$$







$$\left|M\right|_S^2 \approx 1 + \cos\theta_+ \cos\theta_-$$

HLEDÁNÍ TĚŽKÝCH ČÁSTIC S DLOUHOU DOBOU ŽIVOTA

SUSY částice

Particle	Symbol	Spin	Superparticle	Symbol	Spin
Quark	q	1/2	Squark	$\tilde{q}$	0
Electron	e	1/2	Selectron	$\tilde{e}$	0
Muon	μ	1/2	Smuon	$\tilde{\mu}$	0
Tauon	τ	1/2	Stauon	$\tilde{\tau}$	0
W	W	1	Wino	$\tilde{W}$	1/2
Z	Z	1	Zino	$\tilde{Z}$	1/2
Photon	γ	1	Photino	$\tilde{\gamma}$	1/2
Gluon	g	1	Gluino	$\tilde{g}$	1/2
Higgs	H	0	Higgsino	$\tilde{H}$	1/2

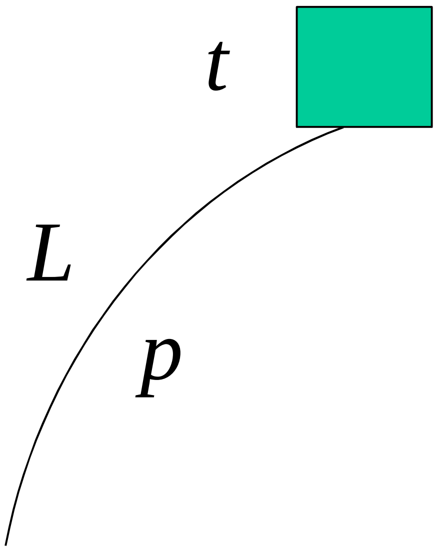
Existence tzv. **Supersymetrických (SUSY)** partnerů „obyčejných částic“ je jednou z možností jak vysvětlit temnou hmotu.
LSP = Lightest Suspersymmetric Particle

Ve většině SUSY teorií je LSP neutralino, sneutrino or gravitino

Existují ale teorie, kde je LSP sgluino
Pak by mohly existovat stabilní tzv. R-hadrony
Mezony = kvark antikvark a sgluino
Baryony = 3 kvarky a sgluino

Pokud je LSP gravitino, tak NLSP (Next to LSP) může mít dostatečně dlouhou dobu života (větší než průlet detektorem)

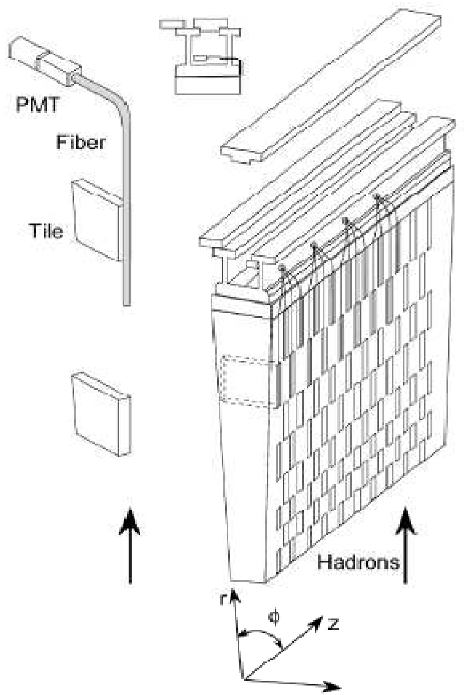
Oba tyto případy lze odhalit měřením doby letu částice



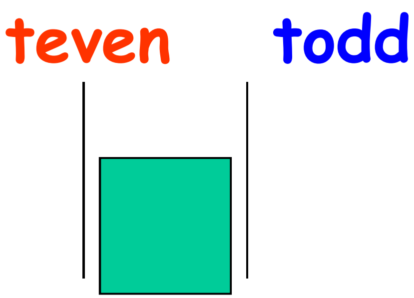
$$\beta = \frac{L}{ct} = \frac{t_0}{t} \qquad t_0 = \frac{L}{c}$$

$$\beta = \frac{p}{E} = \frac{p}{\sqrt{p^2 + m^2}}$$

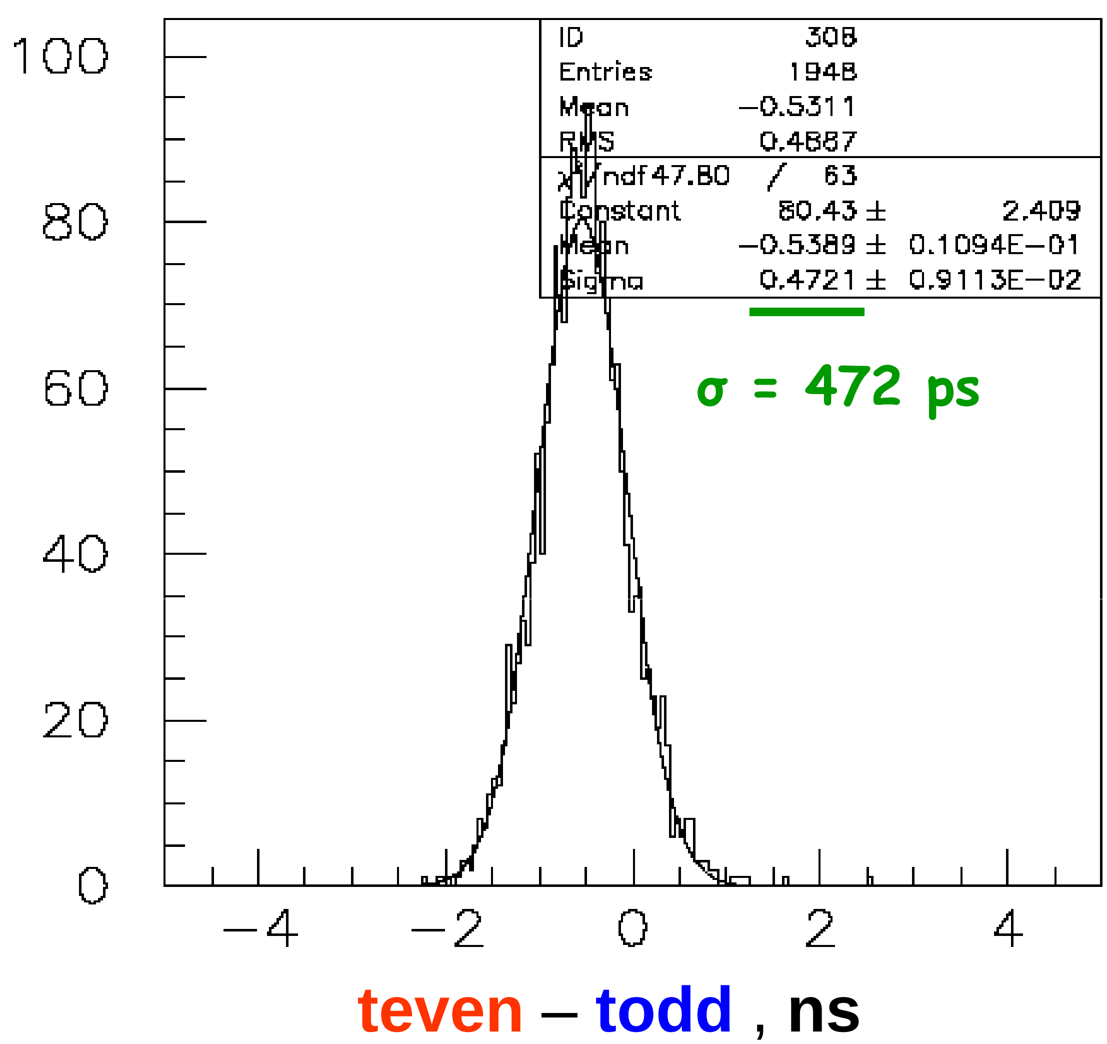
$$m = p\,\frac{\sqrt{t^2 - t_0^2}}{t_0}$$



PMT
Fiber
Tile
Hadrons
r
ϕ
z

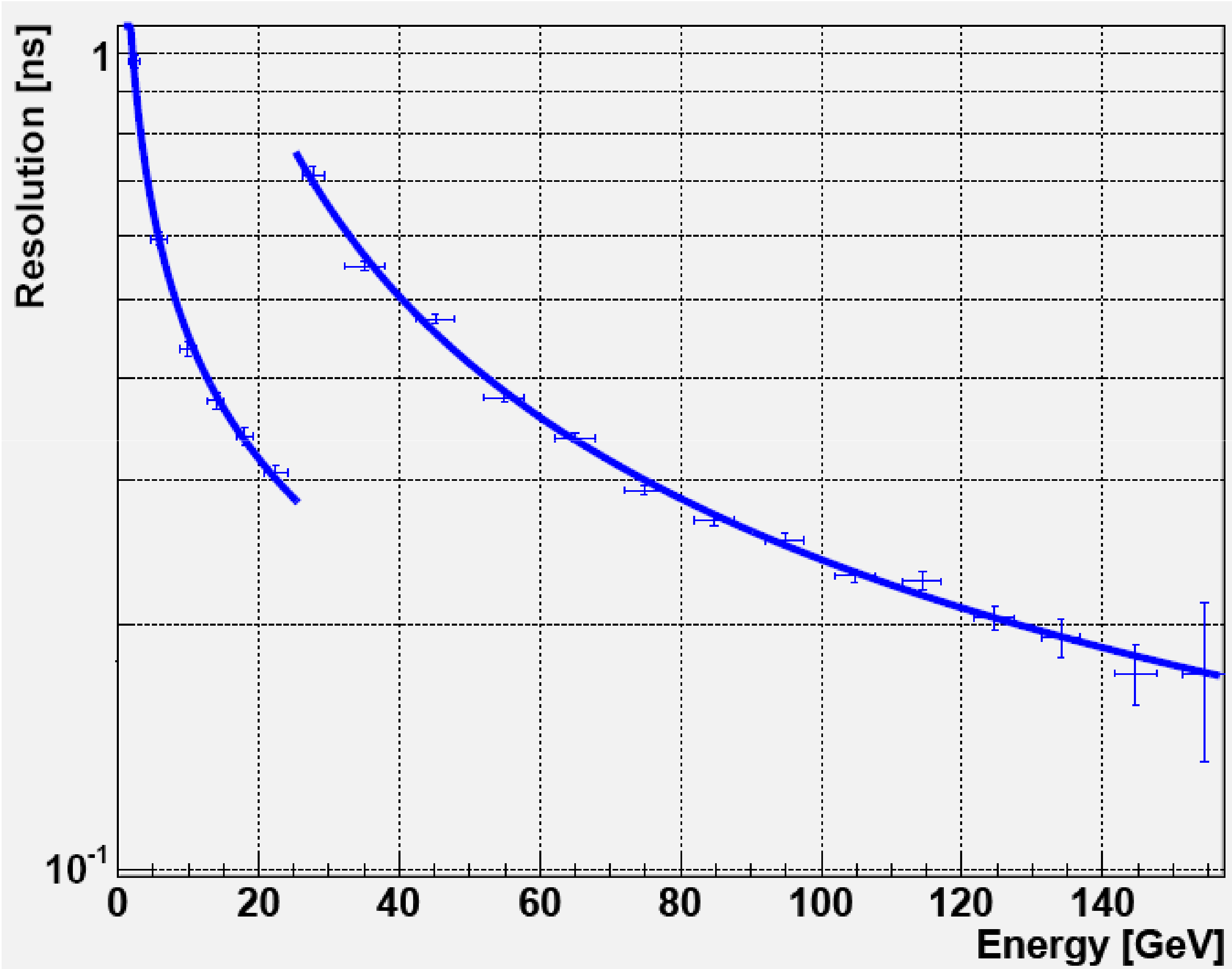


teven
todd



ID 308
Entries 1948
Mean −0.5311
RMS 0.4887
χ²/ndf 47.80 / 63
Constant 80.43 ± 2.409
Mean −0.5389 ± 0.1094E−01
Sigma 0.4721 ± 0.9113E−02
σ = 472 ps
100
80
60
40
20
0
−4
−2
0
2
4
teven – todd , ns

Výsledky z testů detektoru na svazku částic:

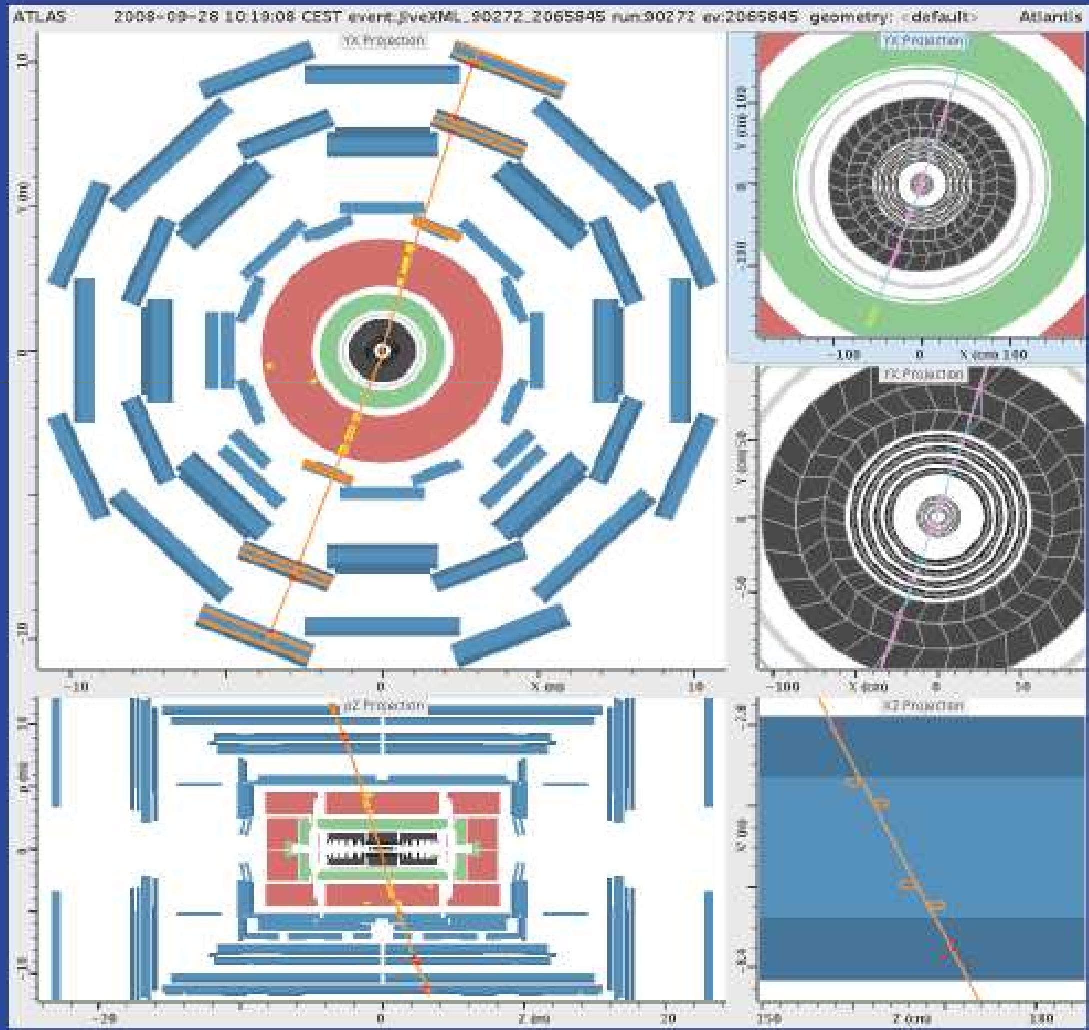


ATLAS vidí kosmické záření

Prompt offline processing @ Tier0

For cosmic data

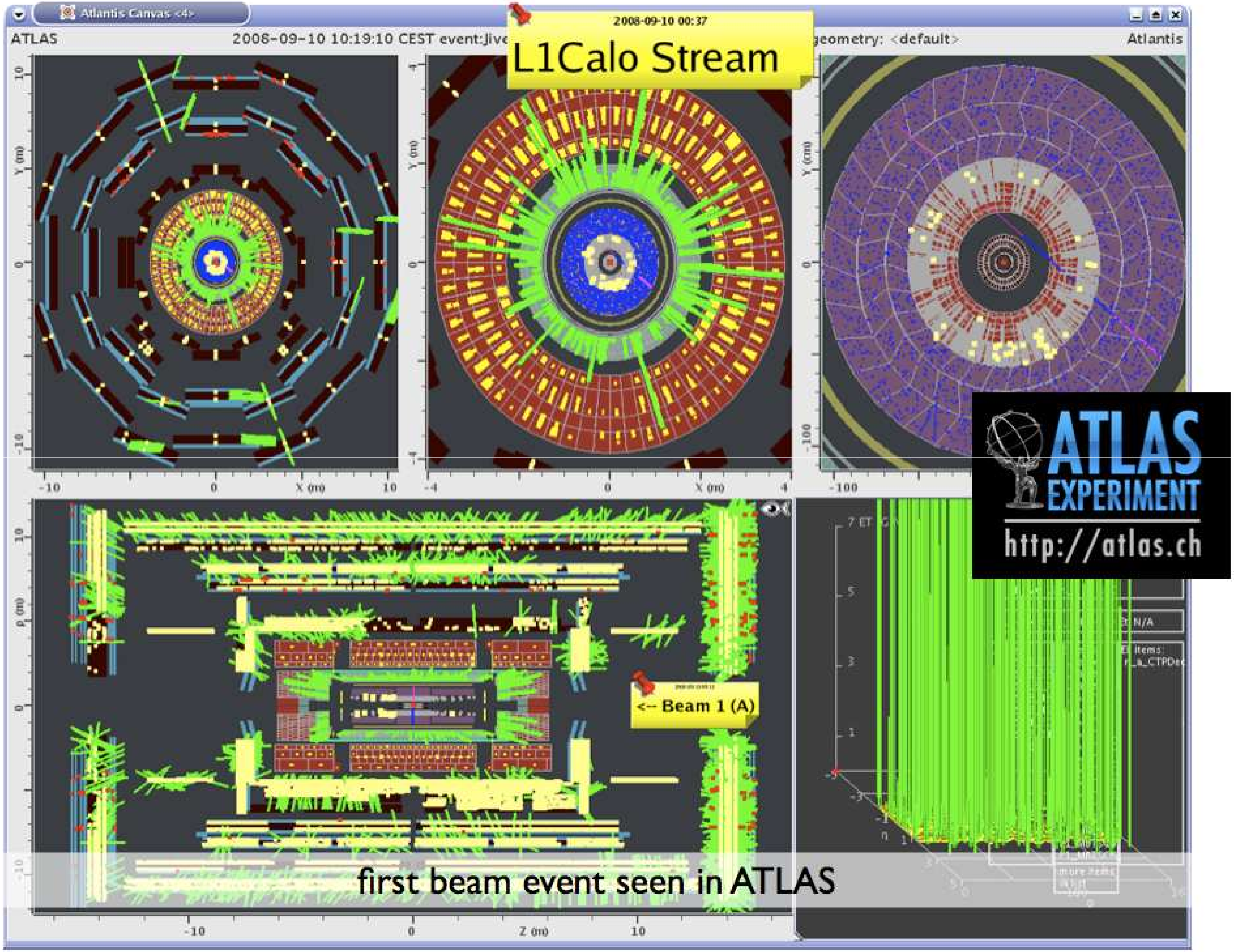
- Reconstruction in good shape for different magnet and detector configurations
  - Solenoid only field needs final validation
  - Conditions are continuously updated

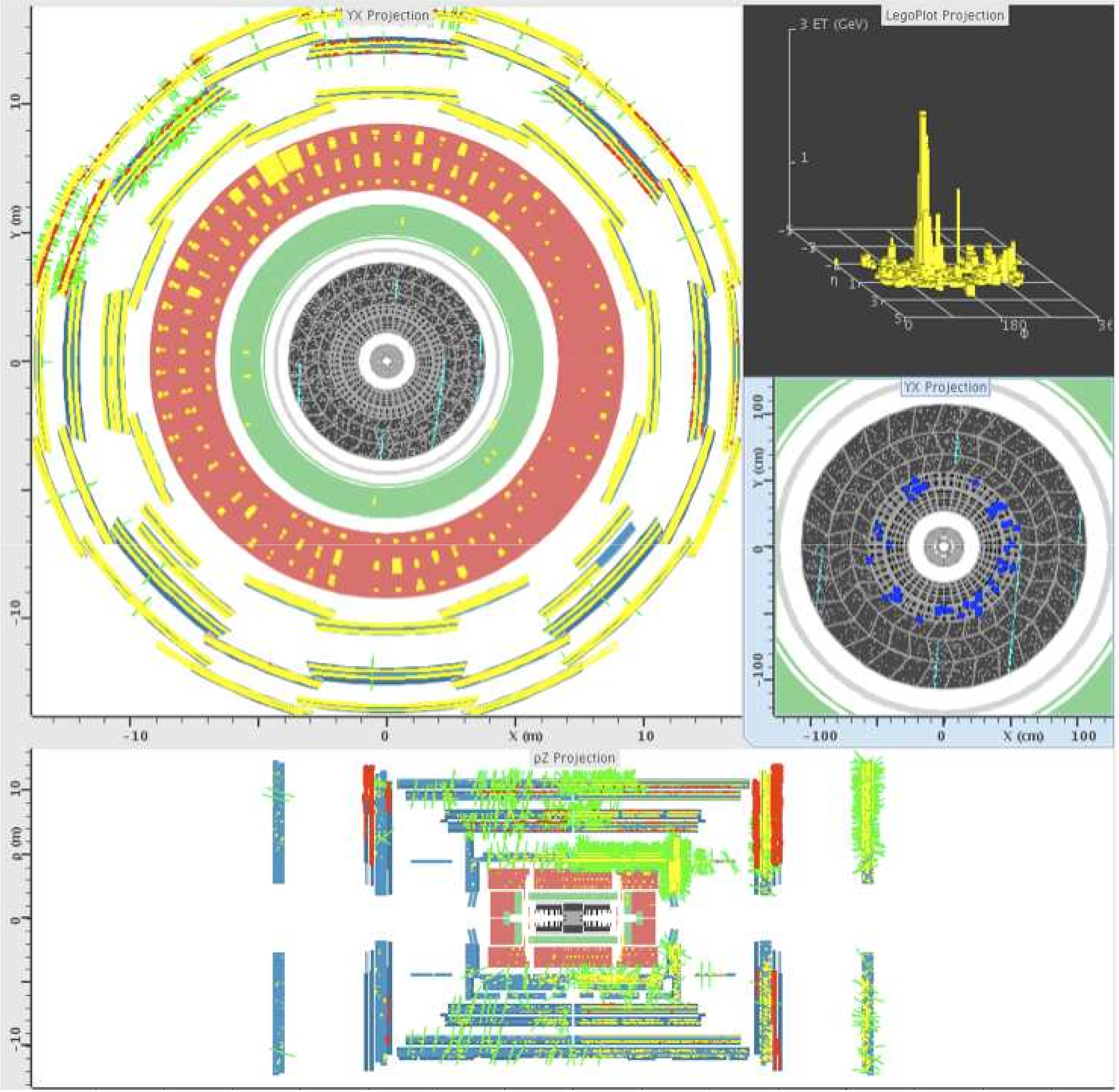


Atlantis Event Display
Cosmic run 90272
Full magnetic field
All systems in
(except CSC)

ATLAS a spuštění LHC 10.9.2008

První projevy svazku v detektoru ATLAS 10.9.2008





event from
2nd beam
seen in ATLAS

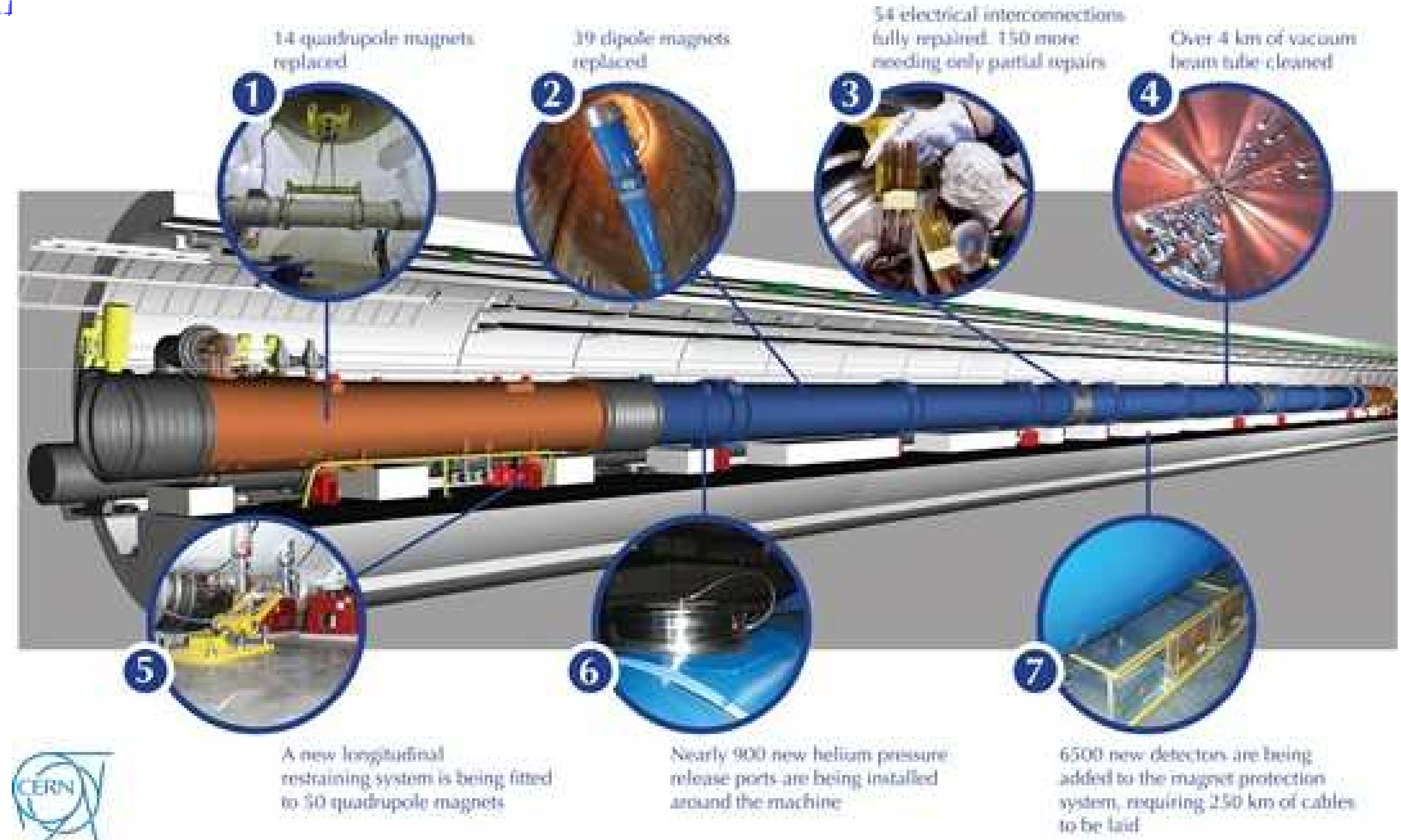
Incident in LHC sector 3-4

Geneva, 20 September 2008. During commissioning (without beam) of the final LHC sector (sector 3-4) 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.

The LHC repairs in detail



The LHC is back

Geneva, 20 November 2009. Particle beams are once again circulating in the world's most powerful particle accelerator, CERN[1]'s Large Hadron Collider (LHC). This news comes after the machine was handed over for operation on Wednesday morning. A clockwise circulating beam was established at ten o'clock this evening. This is an important milestone on the road towards first physics at the LHC, expected in 2010.

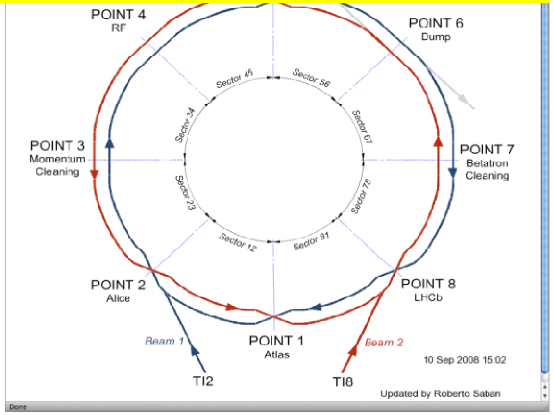
The LHC is back. Geneva, 20 November 2009.

Friday November 20

18:30 Beam 1

- 19.00 beam through CMS (23, 34, 45)
  - beam1 through to IP6 19.55 Starting again injection of Beam1
  - corrected beam to IP6, 7, 8, 1
- 20.40 Beam 1 makes 2 turns
  - Working on tune measurement, or
  - Beam makes several hundred turns (not captured)
    - Integers 64 59, fractional around .3 (Qv trimmed up .1)
- 20.50 Beam 1 on beam dump at point 6
- 21.50 Beam 1 captured

2h10 for 27km: 12.5km/h average speed



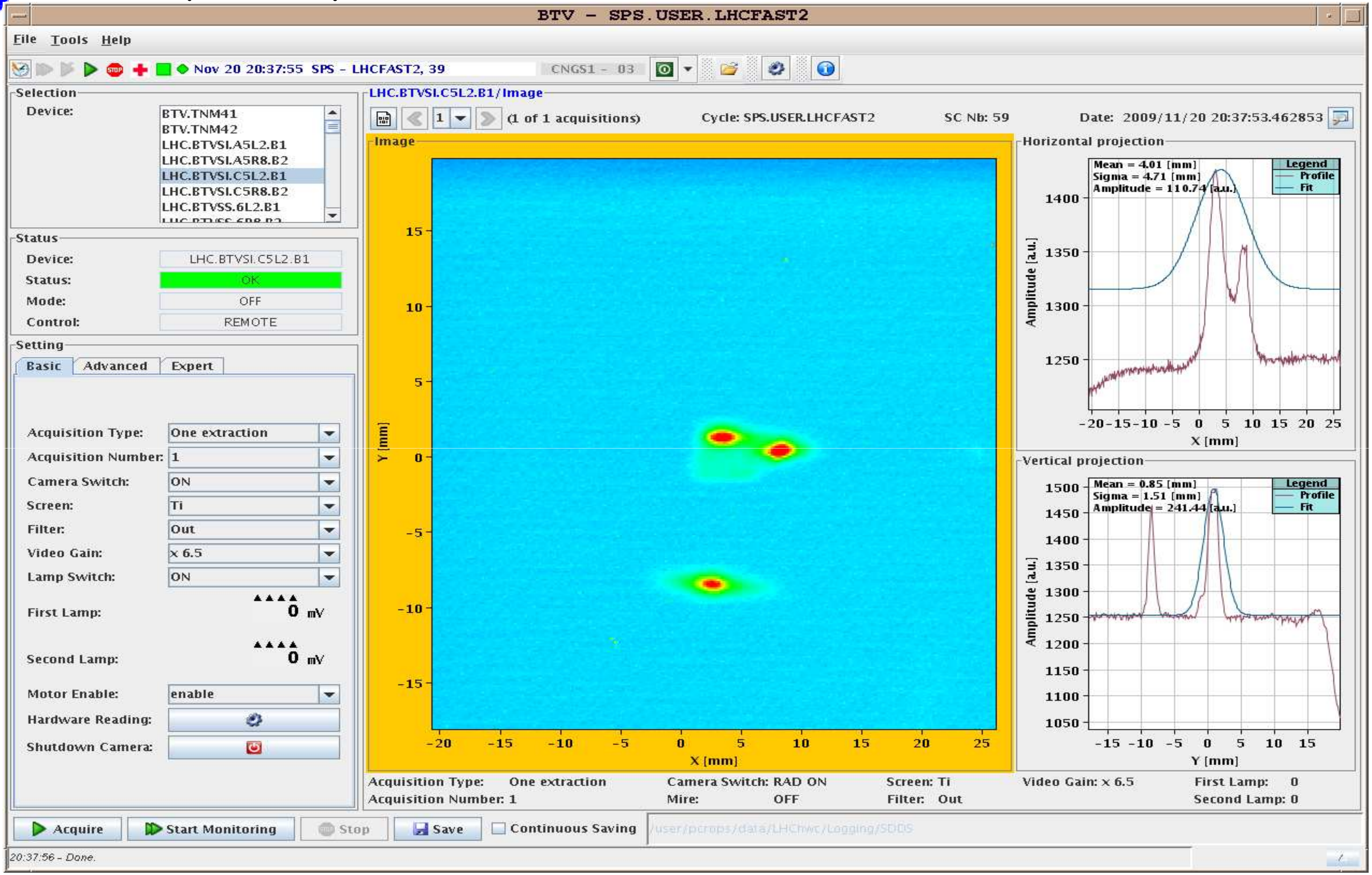
22:15 Beam2

- 23.10 Start threading Beam2
  - Round to 7 6 5 2 1
- 23.40 First Turn Beam2
  - Working on tune measurement, orbit, dump and RF
  - Beam makes several hundred turns (not captured)
    - Integers 64 59, fractional around .3 (Qv trimmed up .05)
- 24.10 Beam 2 captured

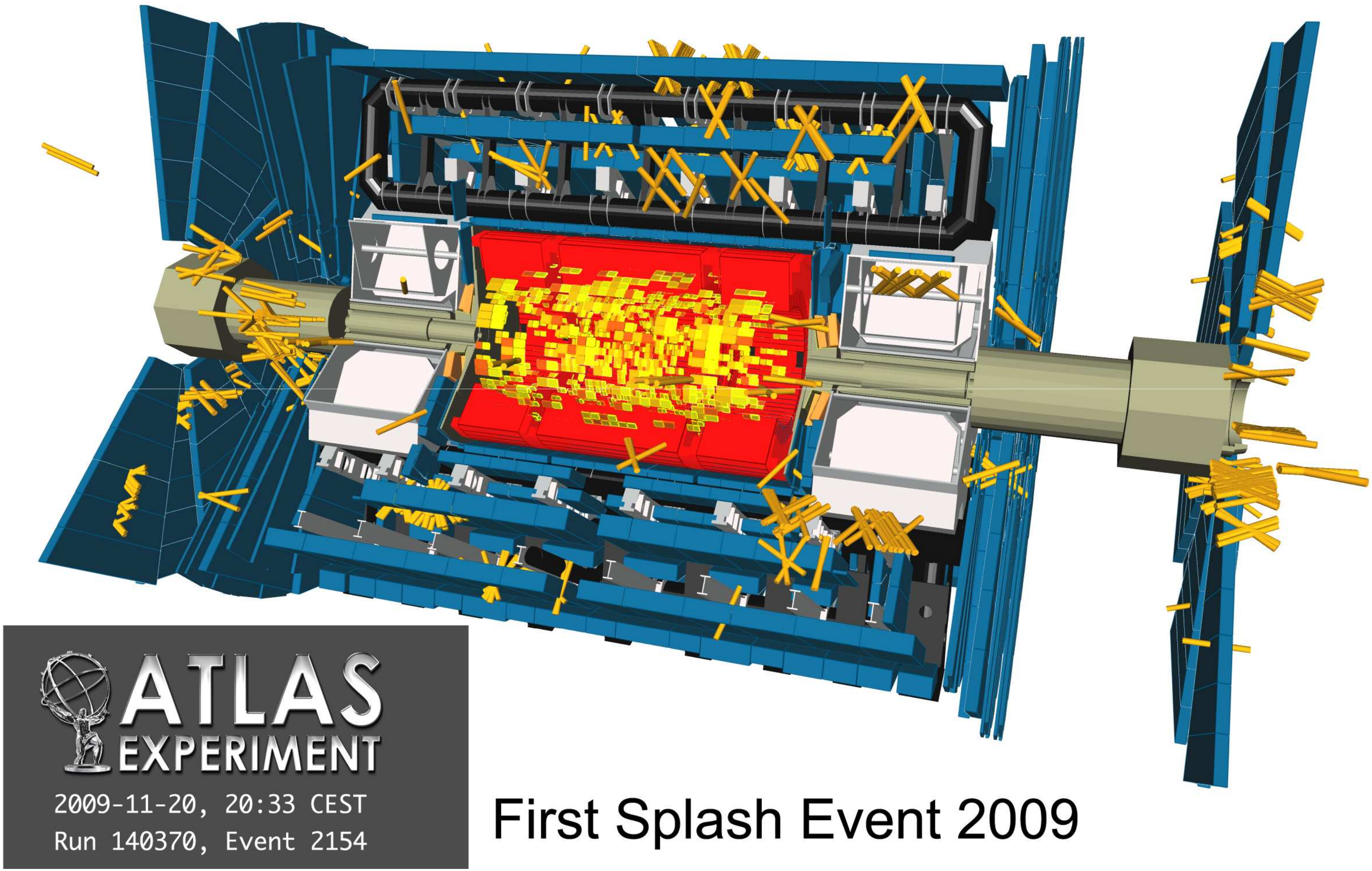
1h25 for 27km: a bit faster

From R. Heuer's lecture given at CERN on 3rd December 2009

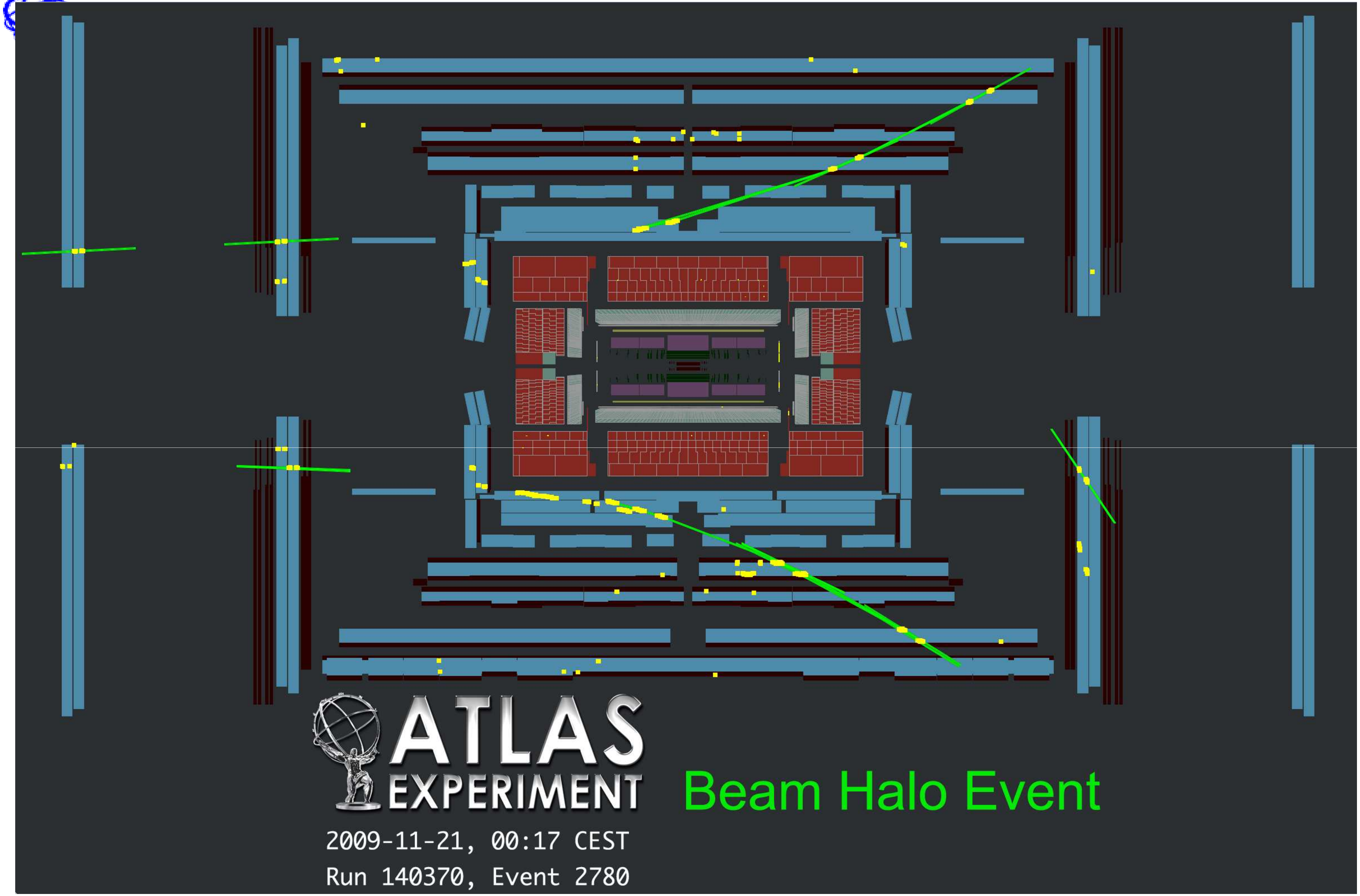
Friday: 8:15pm: Beam 1 First 2 turns



From R. Heuer's lecture given at CERN on 3rd December 2009



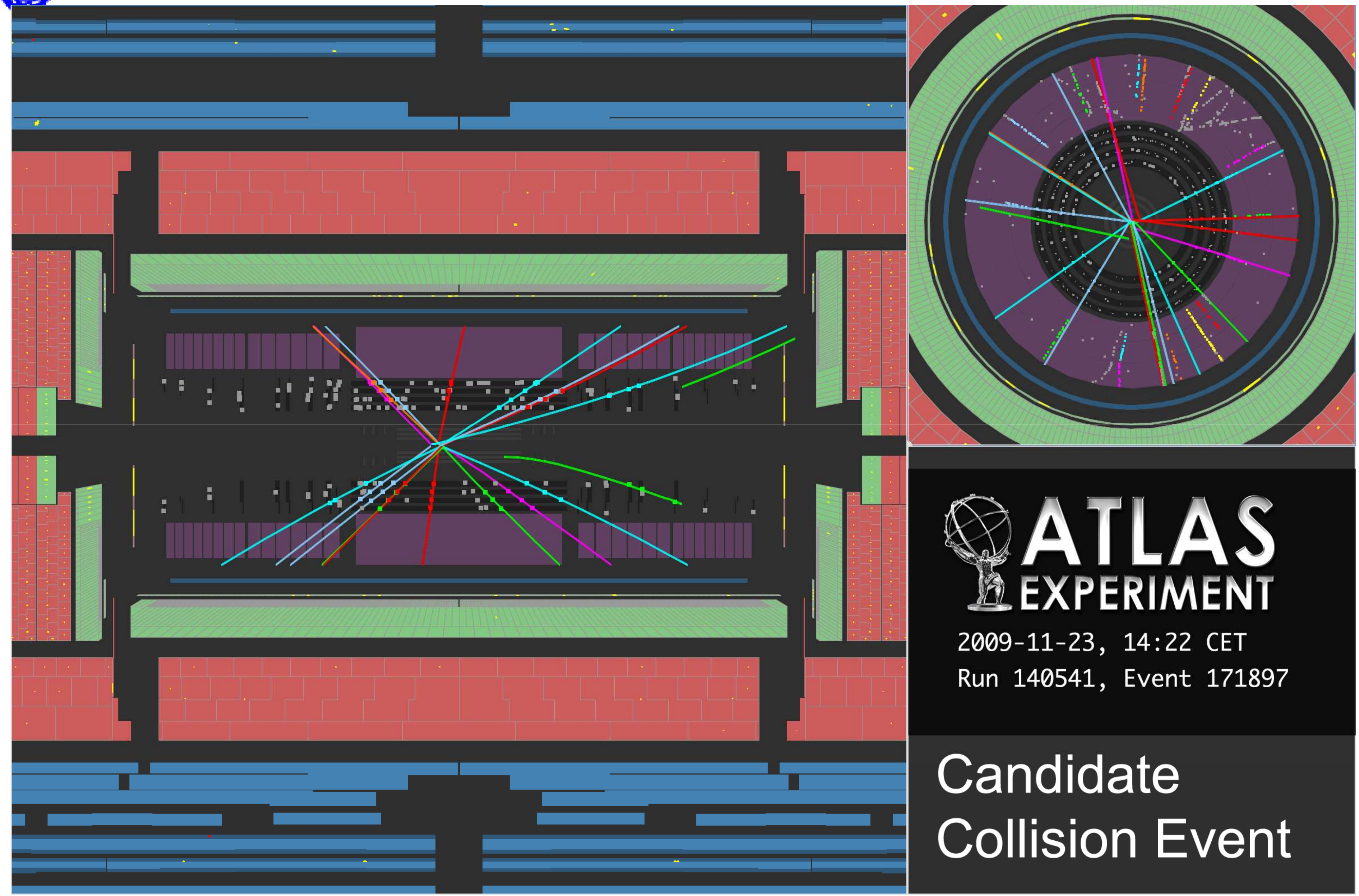
First Splash Event 2009


ATLAS
EXPERIMENT
Beam Halo Event
2009-11-21, 00:17 CEST
Run 140370, Event 2780

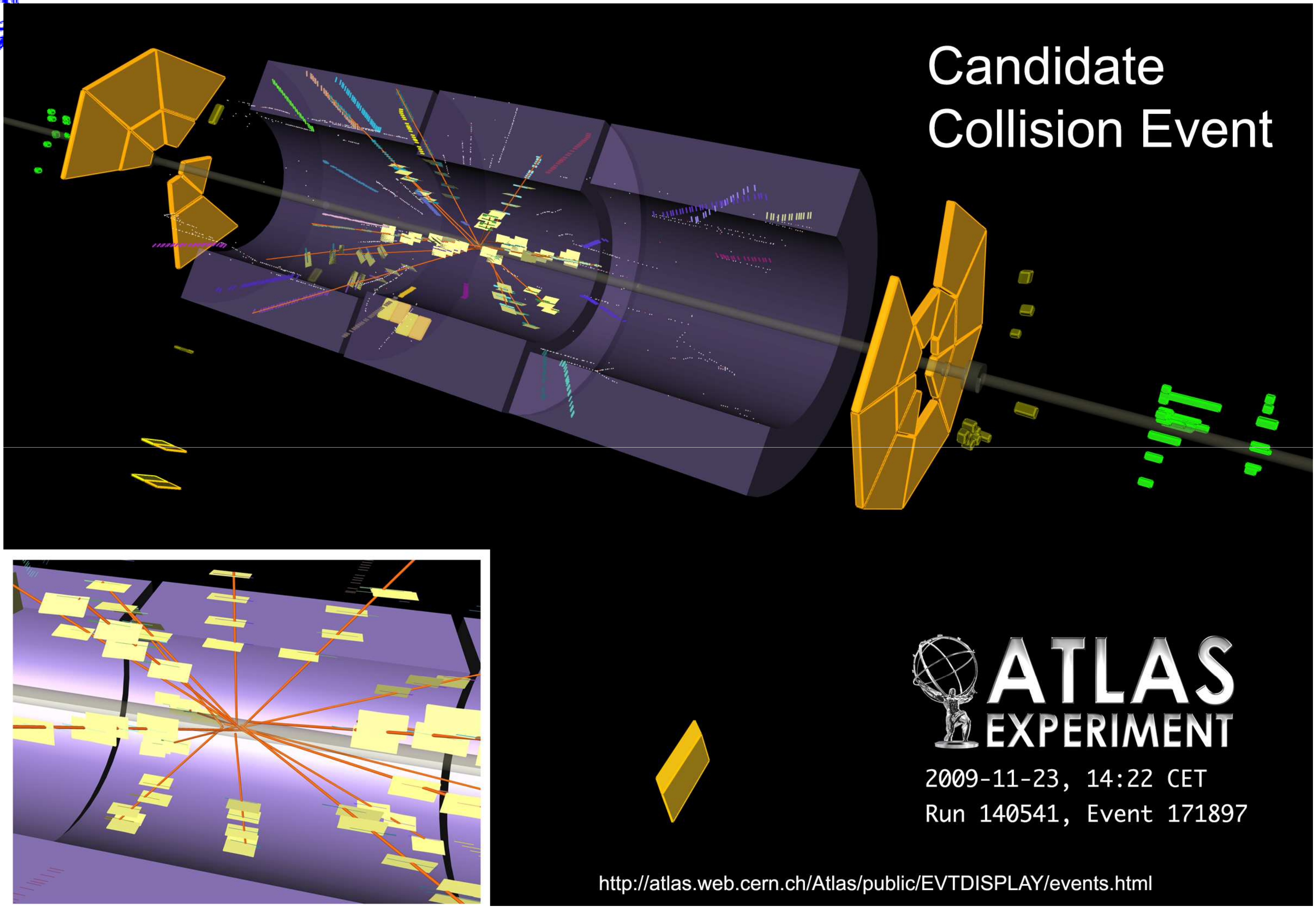
Two circulating beams bring first collisions in the LHC

Geneva, 23 November 2009. Today the LHC circulated two beams simultaneously for the first time, allowing the operators to test the synchronization of the beams and giving the experiments their first chance to look for proton-proton collisions. With just one bunch of particles circulating in each direction, the beams can be made to cross in up to two places in the ring. From early in the afternoon, the beams were made to cross at points 1 and 5, home to the ATLAS and CMS detectors, both of which were on the look out for collisions. Later, beams crossed at points 2 and 8, ALICE and LHCb.

23.11.2009 První srážky zaznamenané v ATLAS



http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html


Candidate
Collision Event
ATLAS
EXPERIMENT
2009-11-23, 14:22 CET
Run 140541, Event 171897
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

Monday, 23rd afternoon

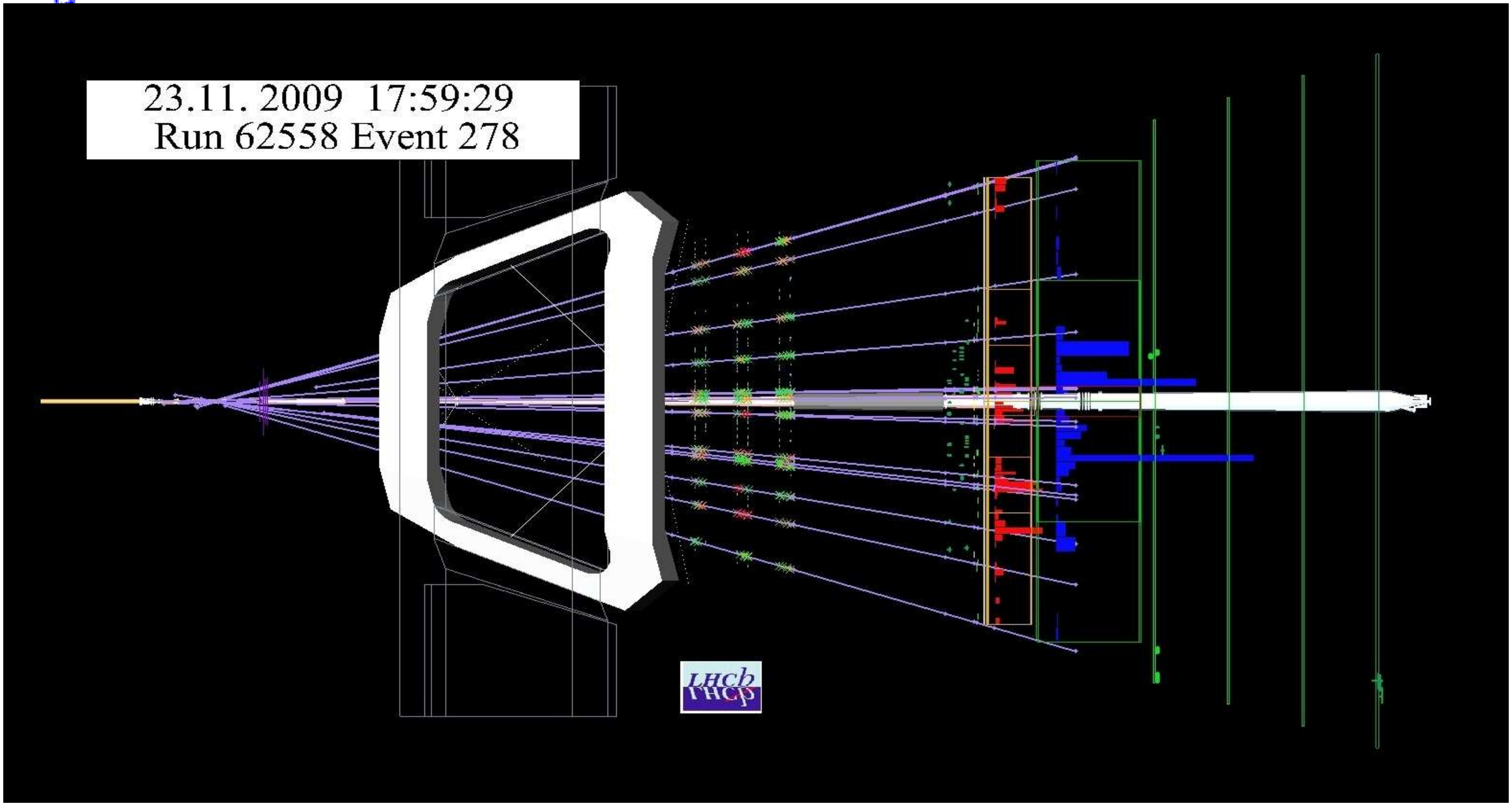
- Recorded collision events in ATLAS and CMS

- From 16:00
  - Two beams in LHC at buckets 1 and 8911
  - Quiet beams for ALICE
  - Then 2 beams in LHC at buckets 1 and 26701
  - Quiet beams for LHCb
- Recorded collision events in ALICE and LHCb

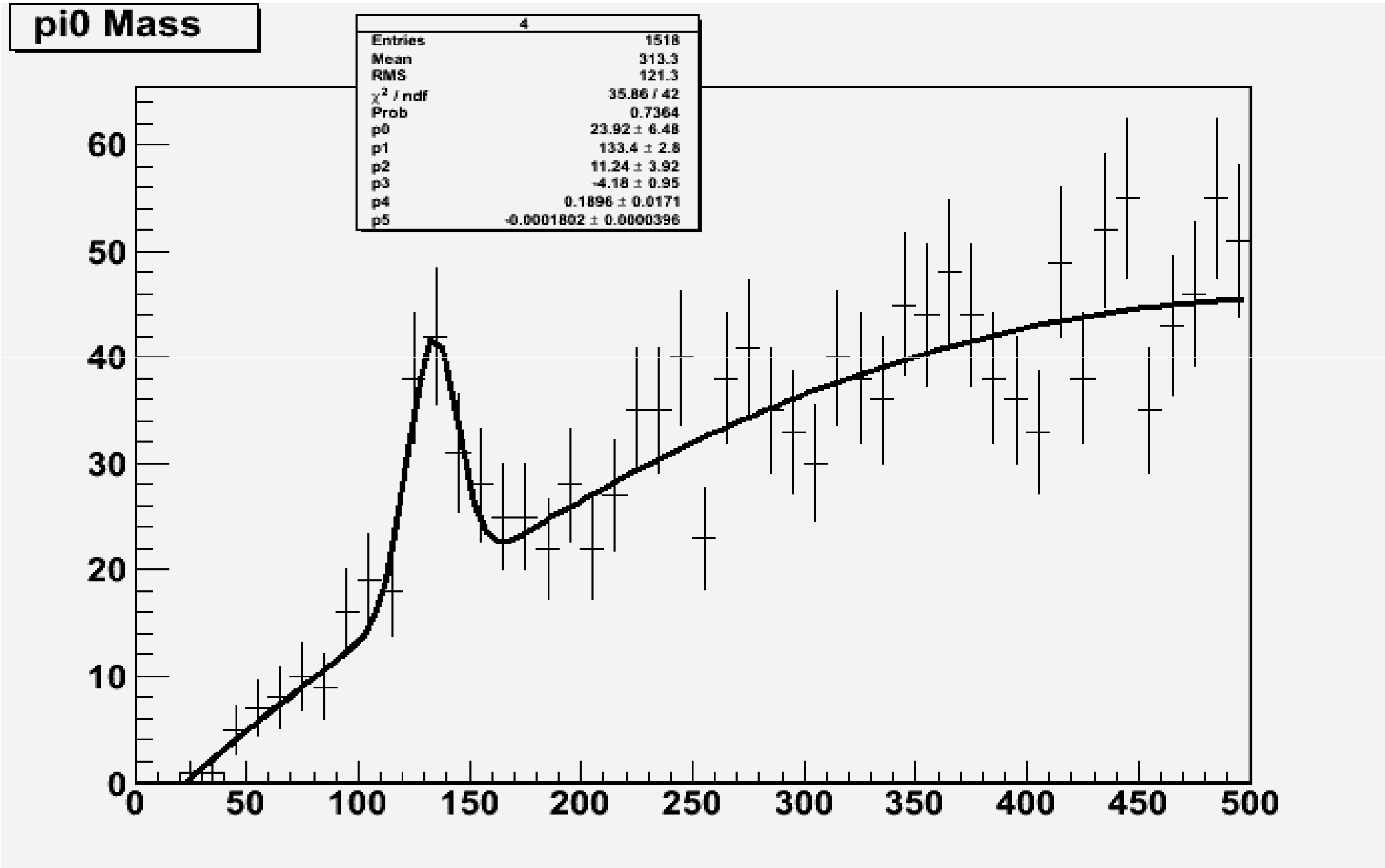
Monday, 30th at 0:42

- Both beams at 1.18 TeV

- Events have nice vertices (extrapolating OT tracks)



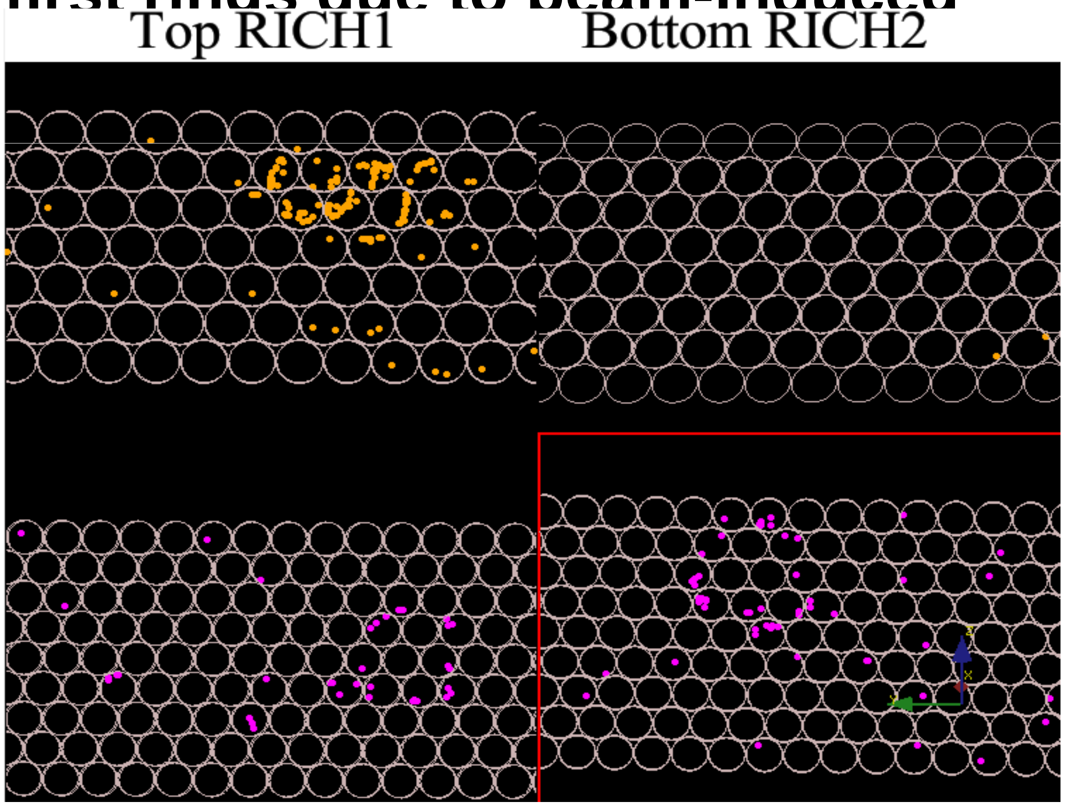
- π^0 have been reconstructed in the calorimeter



From R. Heuer's lecture given at CERN on 3rd December 2009

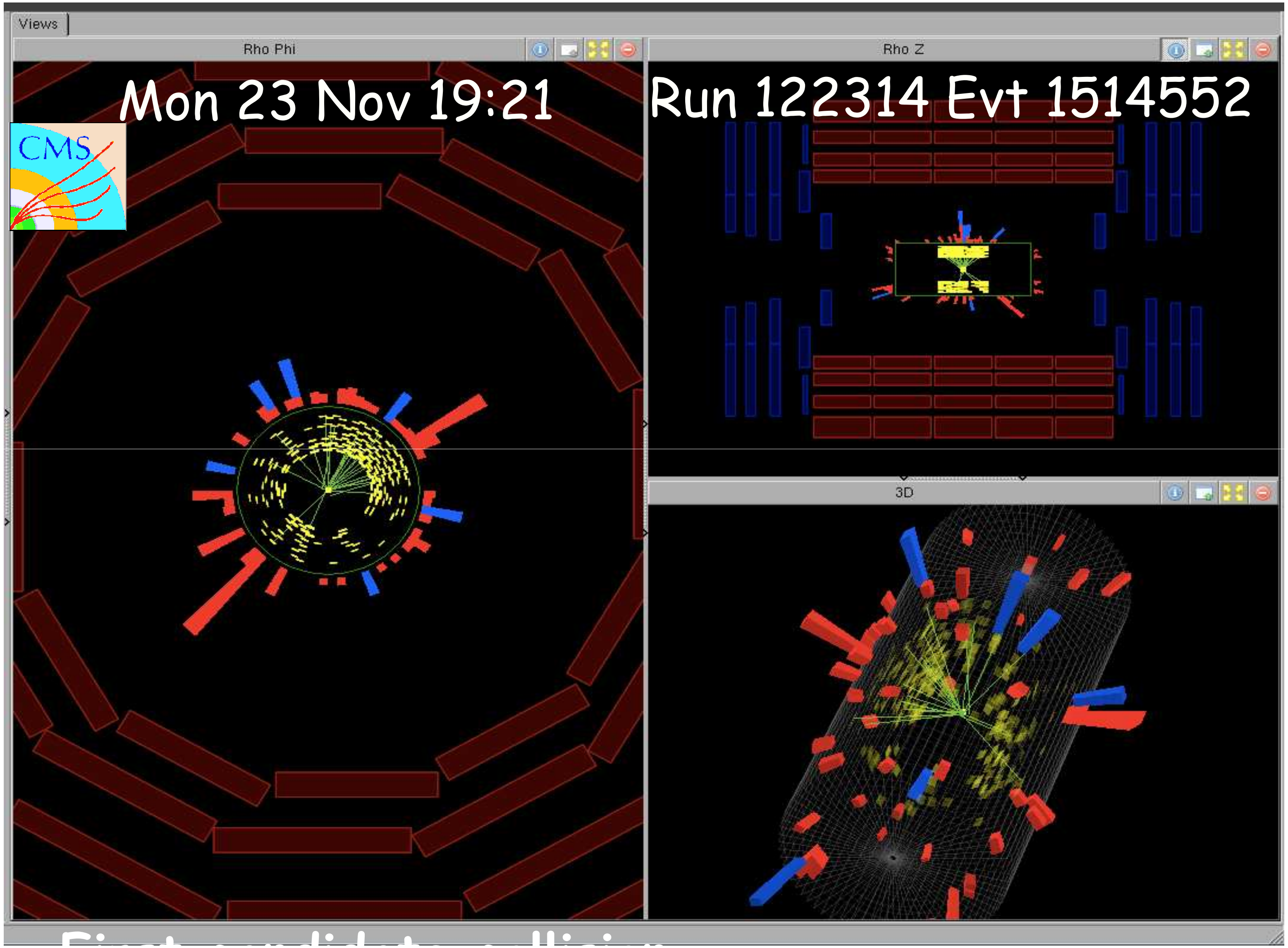
Towards collisions

- **Monday 23 November afternoon was fantastic**
  - **First some "quiet" beam while beams were colliding in Atlas and CMS, then when colliding in Alice**
  - **The RICH got its first rings due to beam-induced particles**



From R. Heuer's lecture given at CERN on 3rd December 2009

An event from the Evening Fill

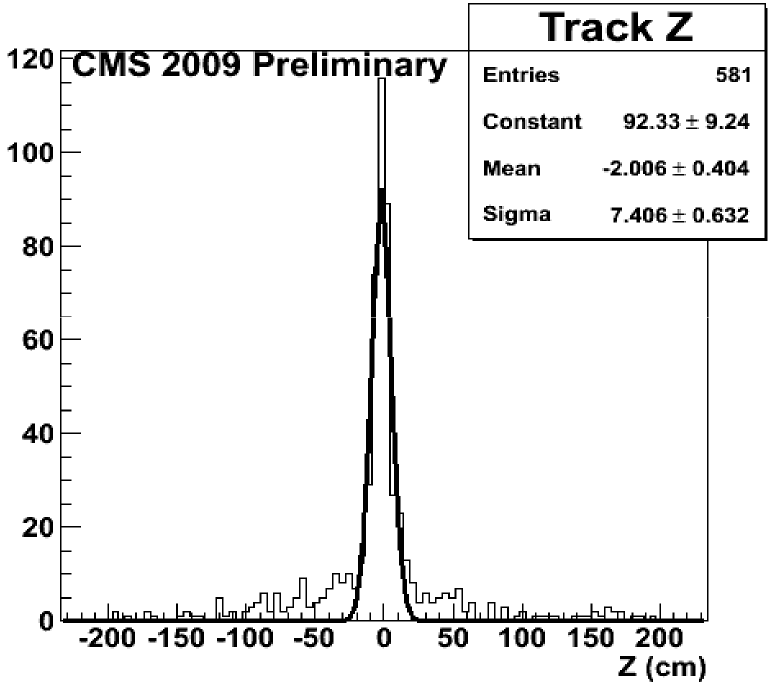


From R. Heuer's lecture given at CERN on 3rd December 2009

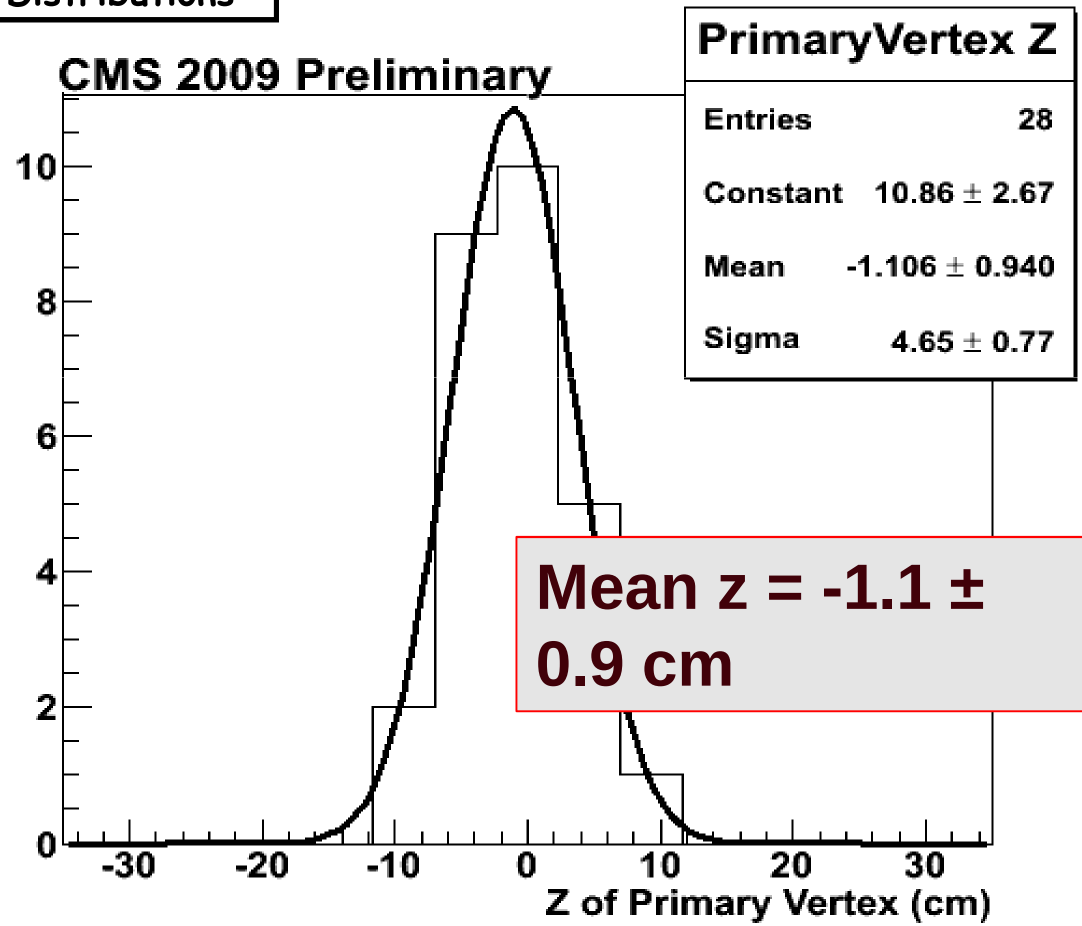
Reconstructed vertices using TOB

CMS 2009 Preliminary
Uncorrected Distributions

Evening Fill



All tracks with > 6 hits and $\chi^2 < 10$



Mean z = -1.1 ± 0.9 cm

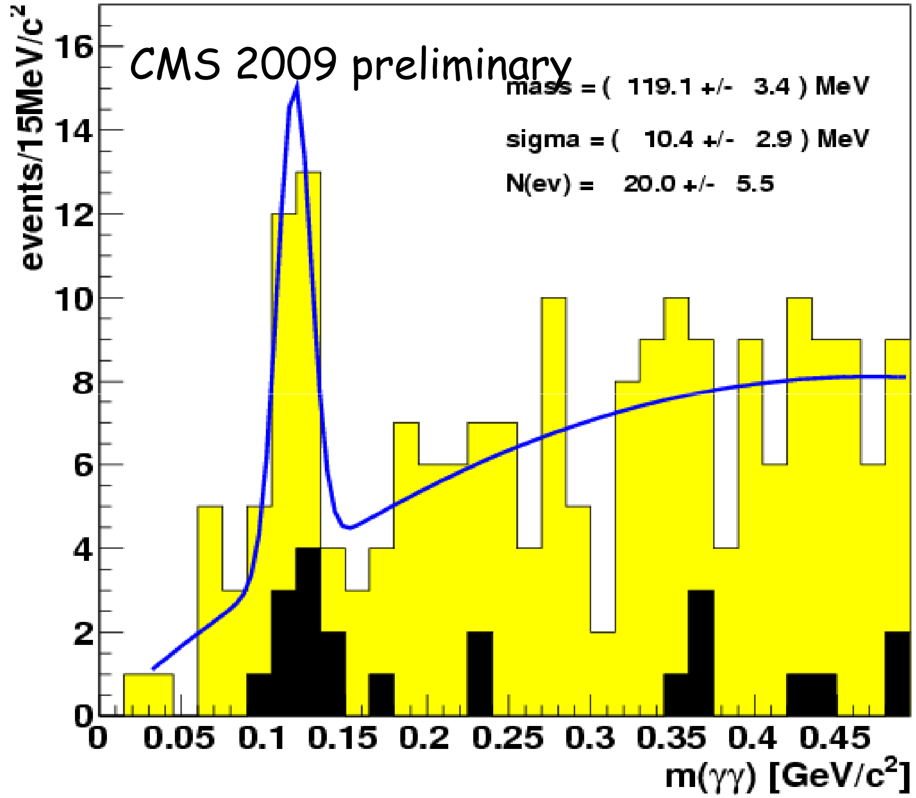
Clean vertices (≥ 3 tracks)

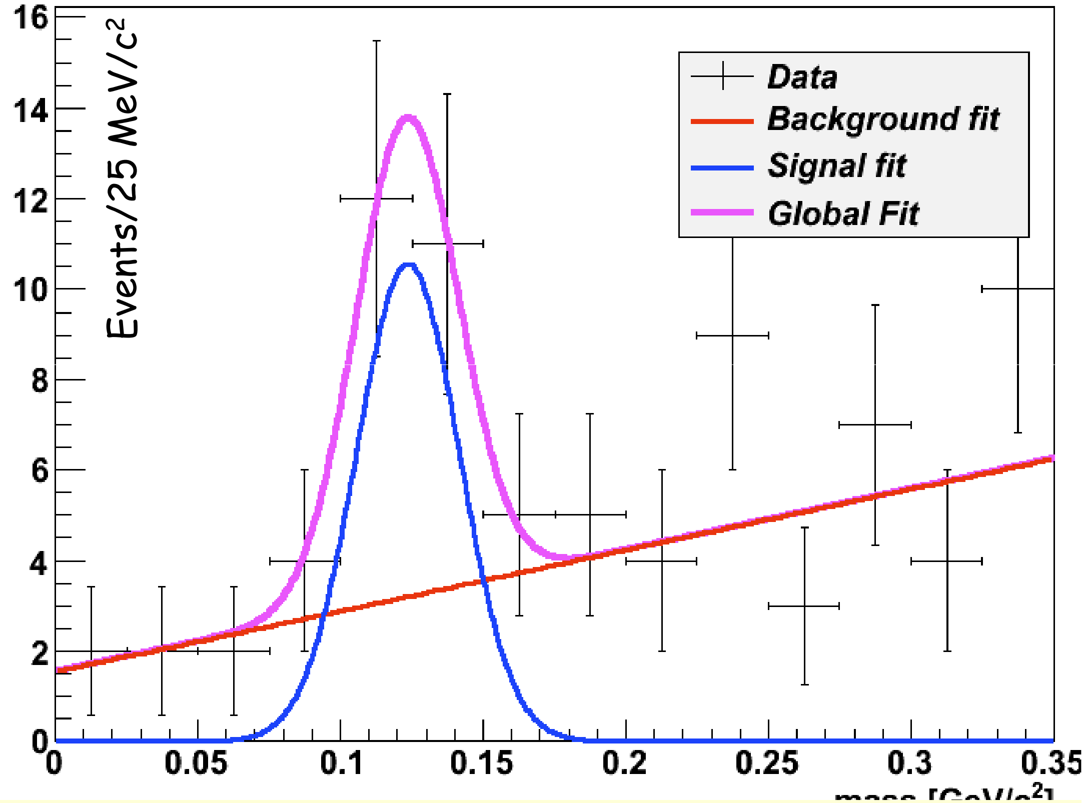
From R. Heuer's lecture given at CERN on 3rd December 2009

CMS 2009 Preliminary
Uncorrected Distribution

Evening Fill

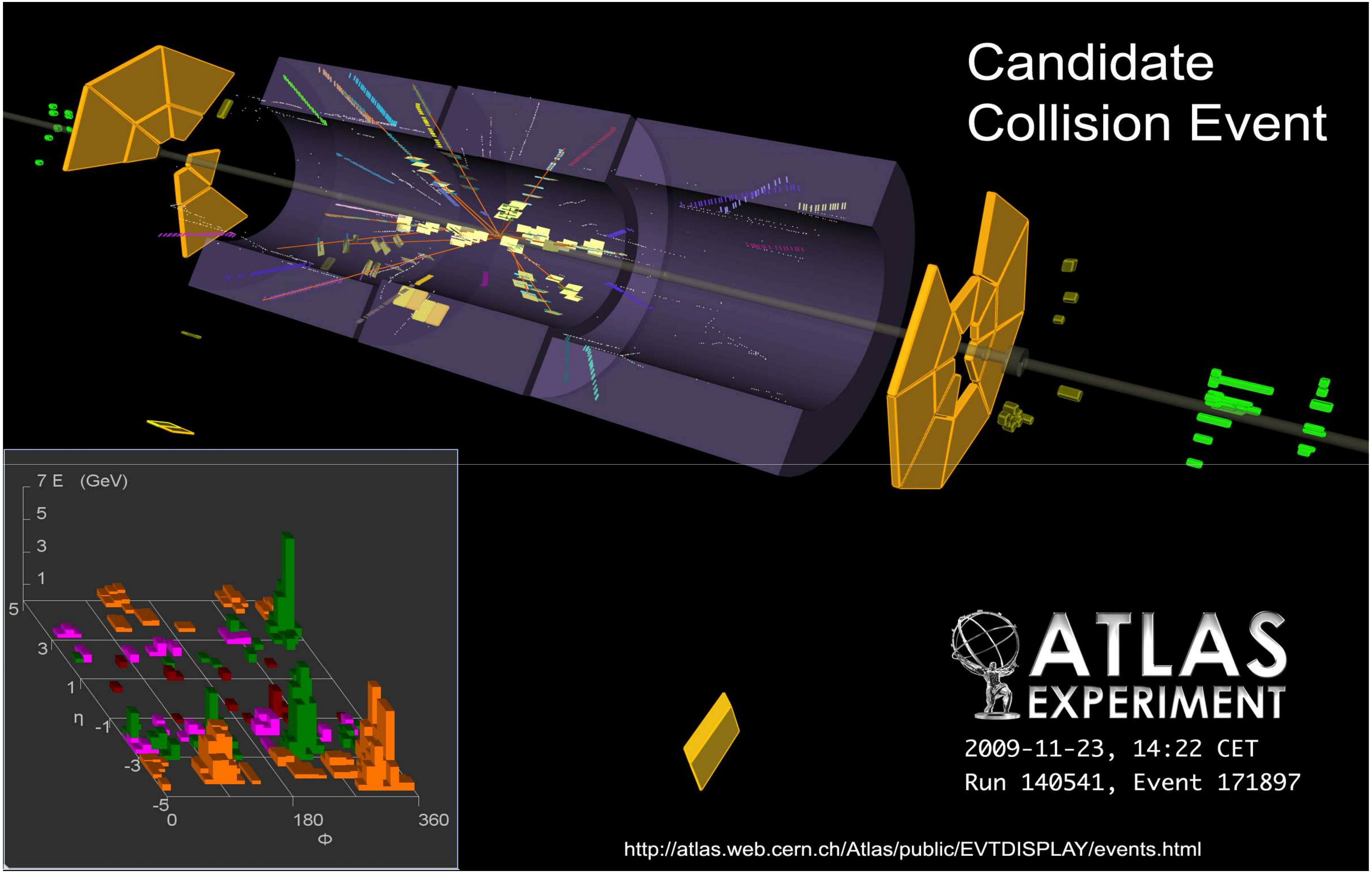
First Di-photon Distribution in CMS





- M(pi^0) is lower in both data and MC
- Mostly due to the readout threshold (100 MeV/Crystal).
- Conversions: part of the energy is deposited upstream of ECAL.
- Event timing is consistent

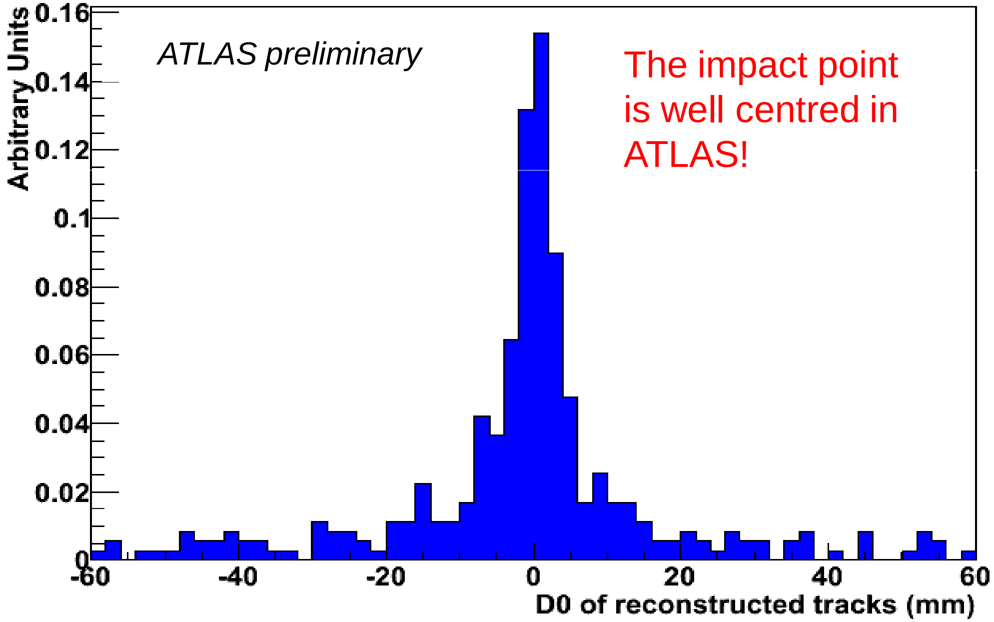
From R. Heuer's lecture given at CERN on 3rd December 2009



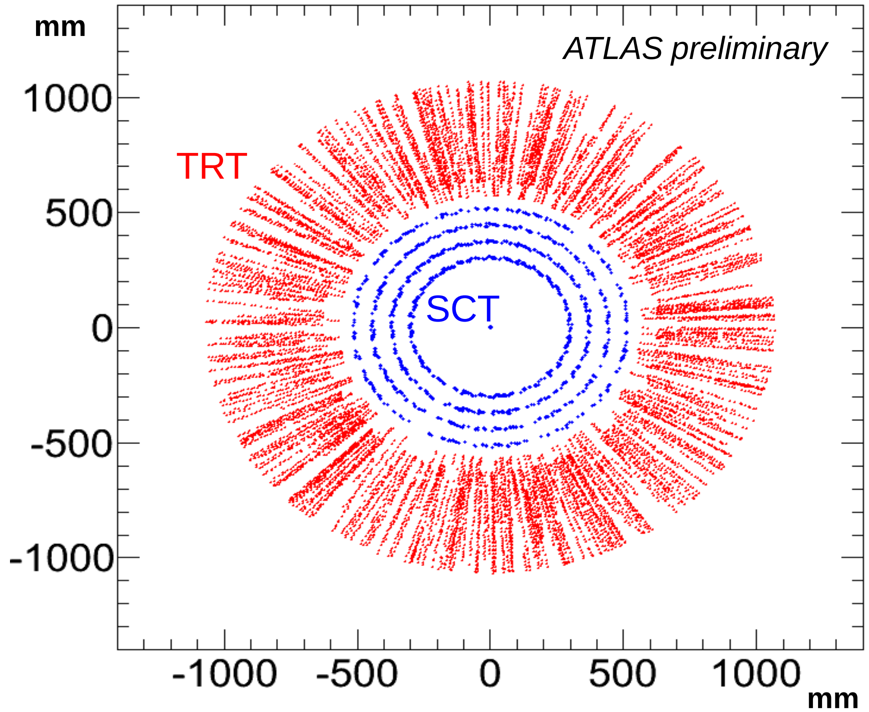
From R. Heuer's lecture given at CERN on 3rd December 2009

Tracking (challenging w/o Pixel, limited SCT and solenoid field off!)

- **Without solenoid field no separation of tracks by momenta**
- **Fit impact parameter in a "silver-plated" sample with SCT >= 20 V and number of SCT hits >= 6 (46 events)**

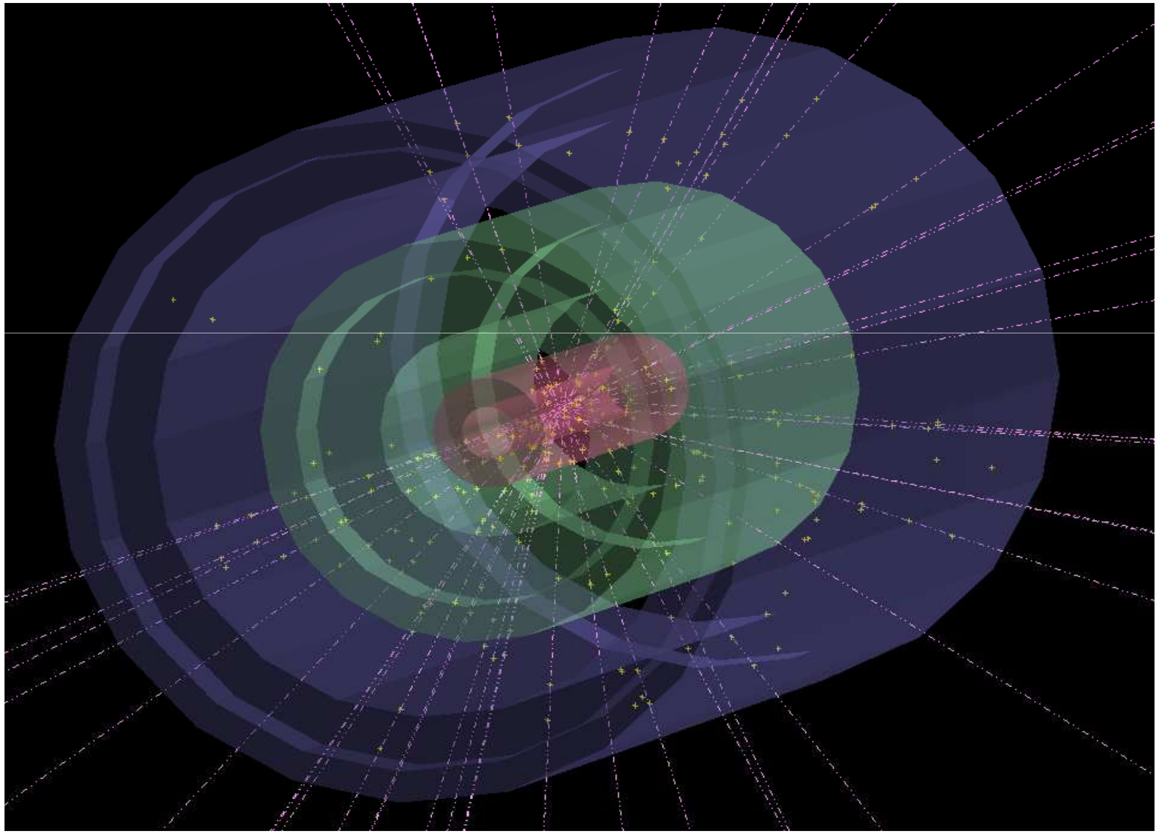


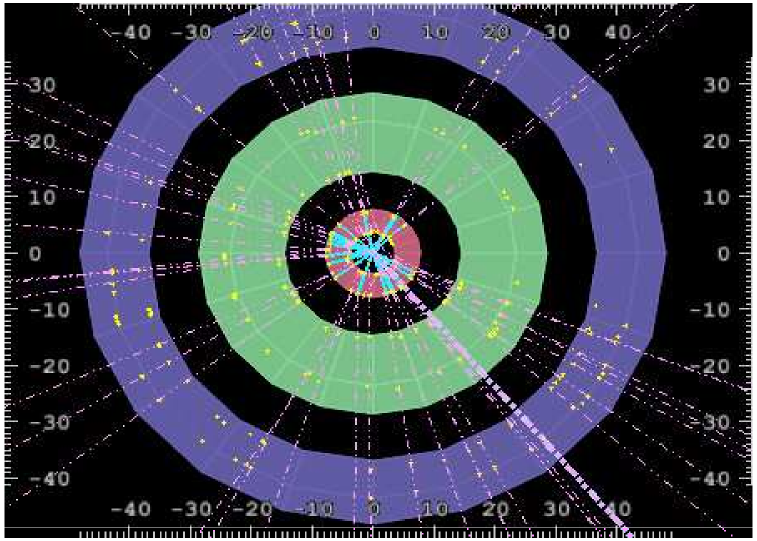
Scatter plot of hits on tracks (barrel, 46 events)

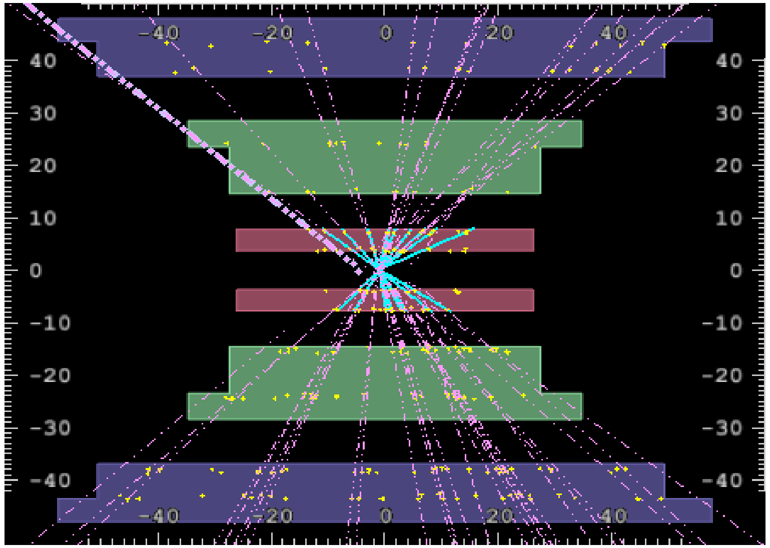


From R. Heuer's lecture given at CERN on 3rd December 2009

ALICE - A high multiplicity event…



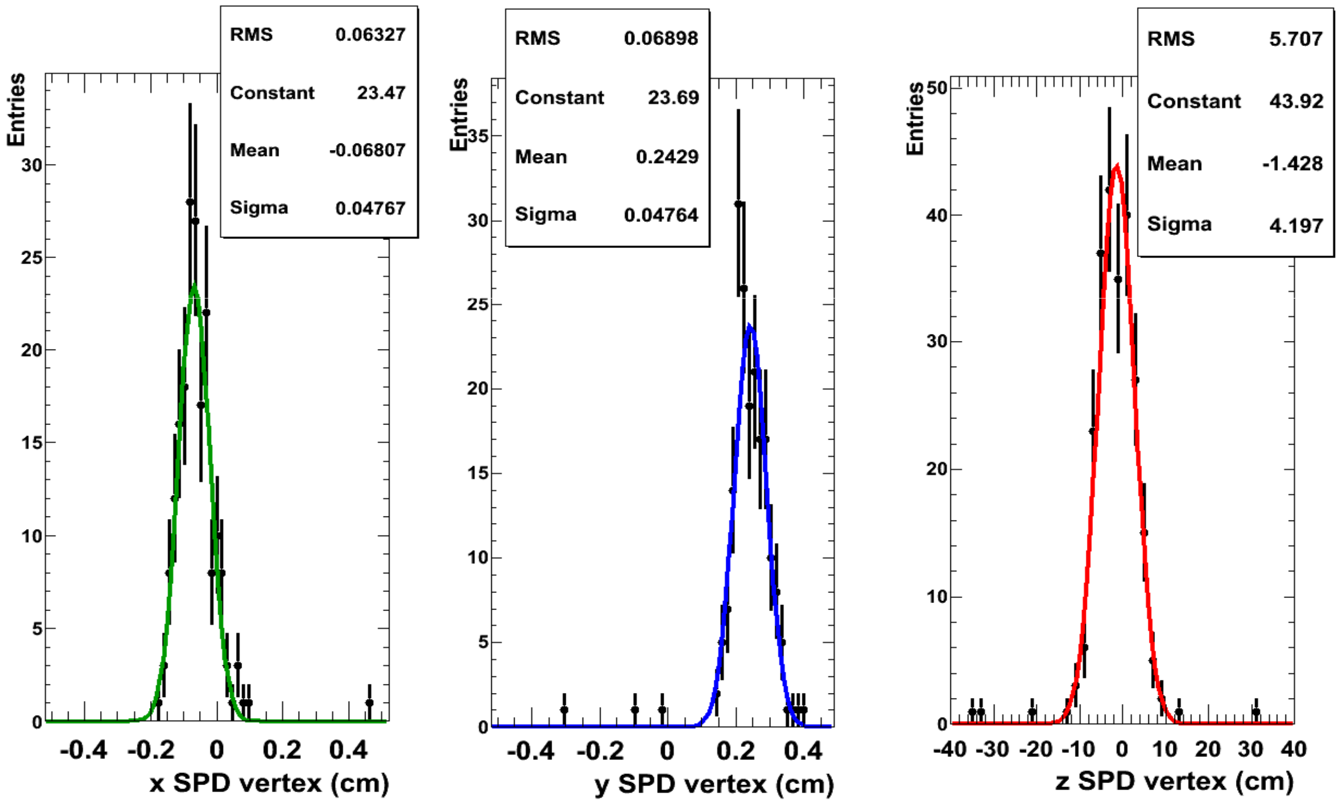




From R. Heuer's lecture given at CERN on 3rd December 2009

Vertex distributions (offline)

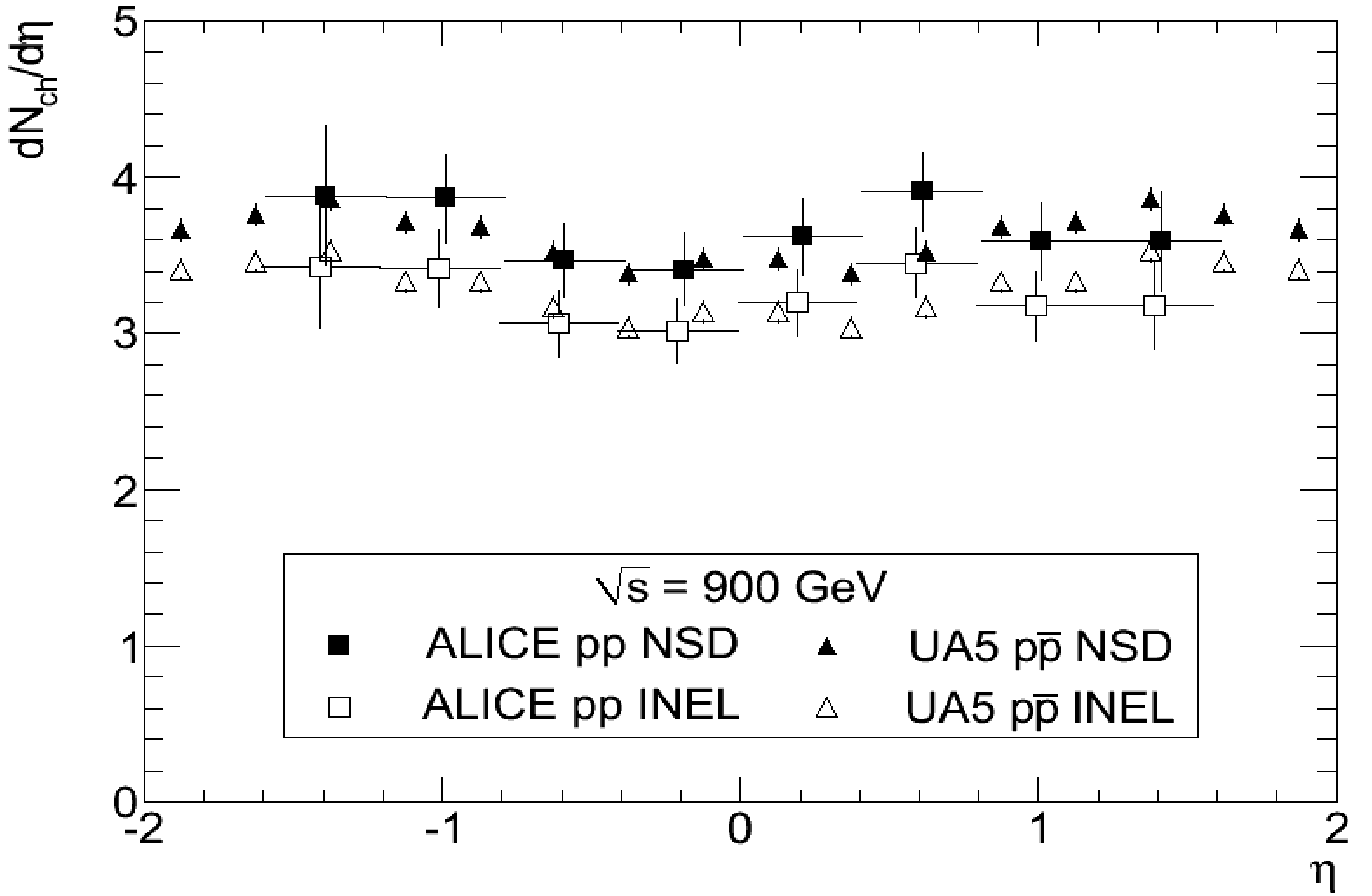
- Detector:



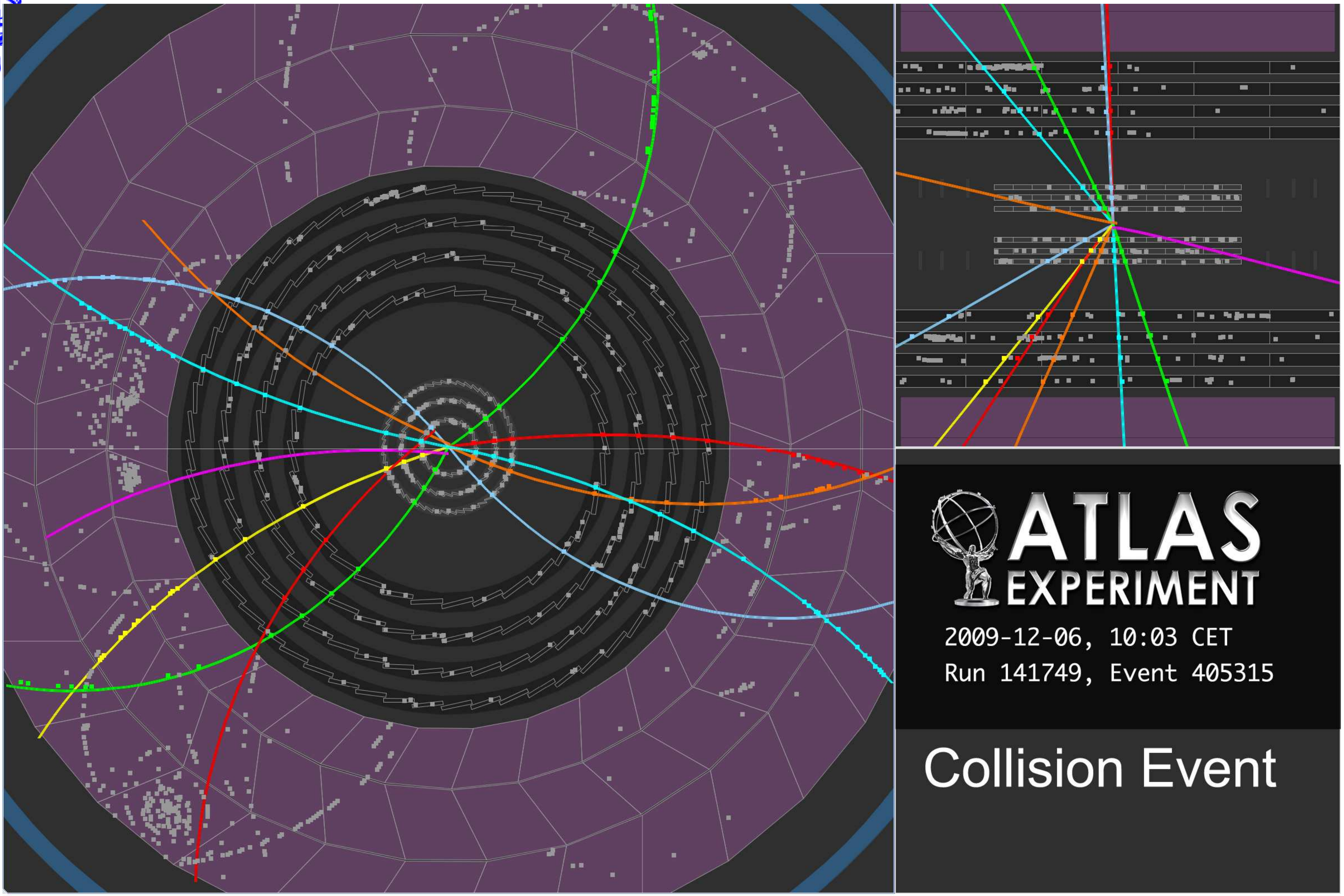
From R. Heuer's lecture given at CERN on 3rd December 2009

First publication, accepted by EPJ

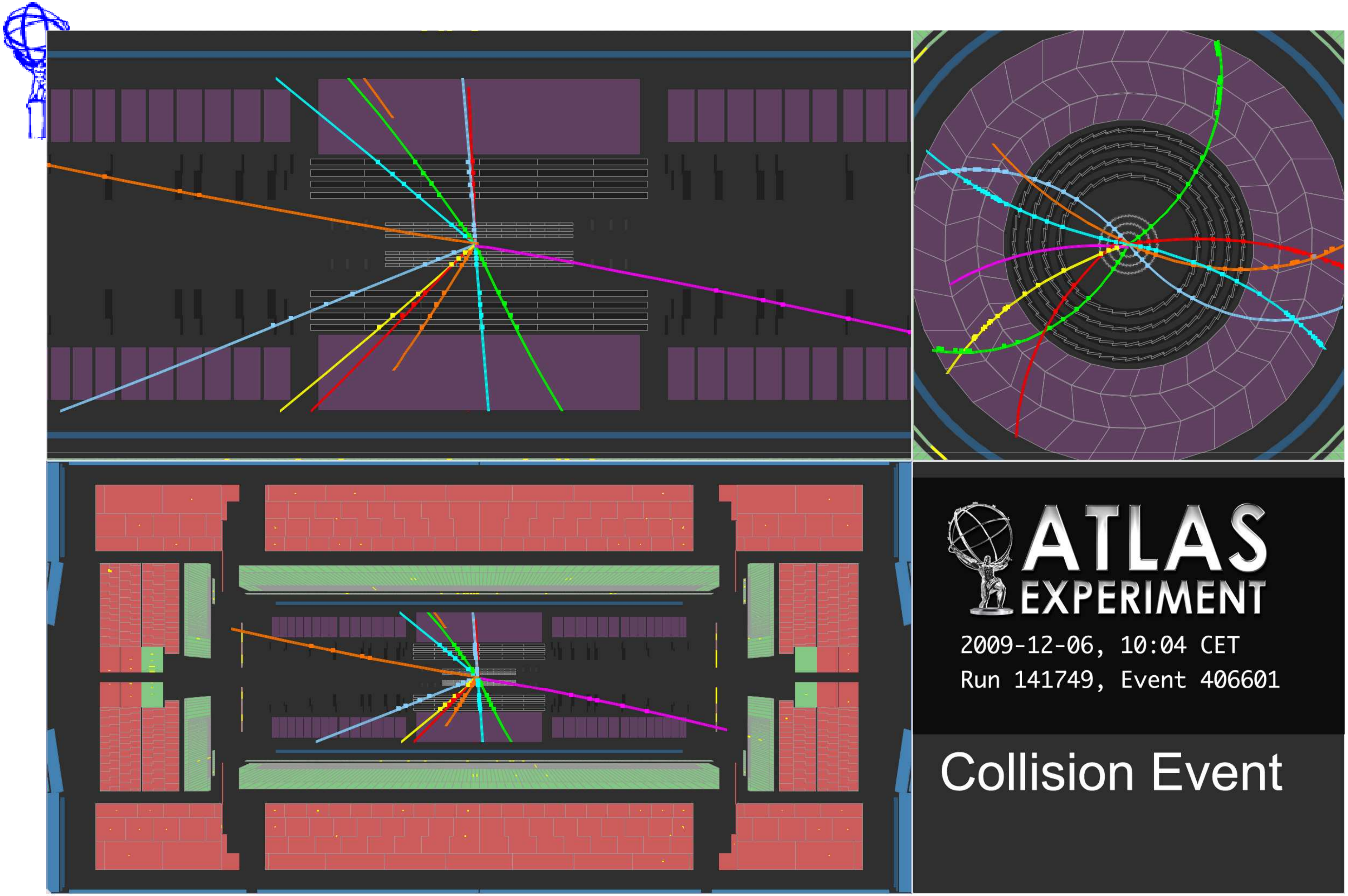
Pseudorapidity distribution



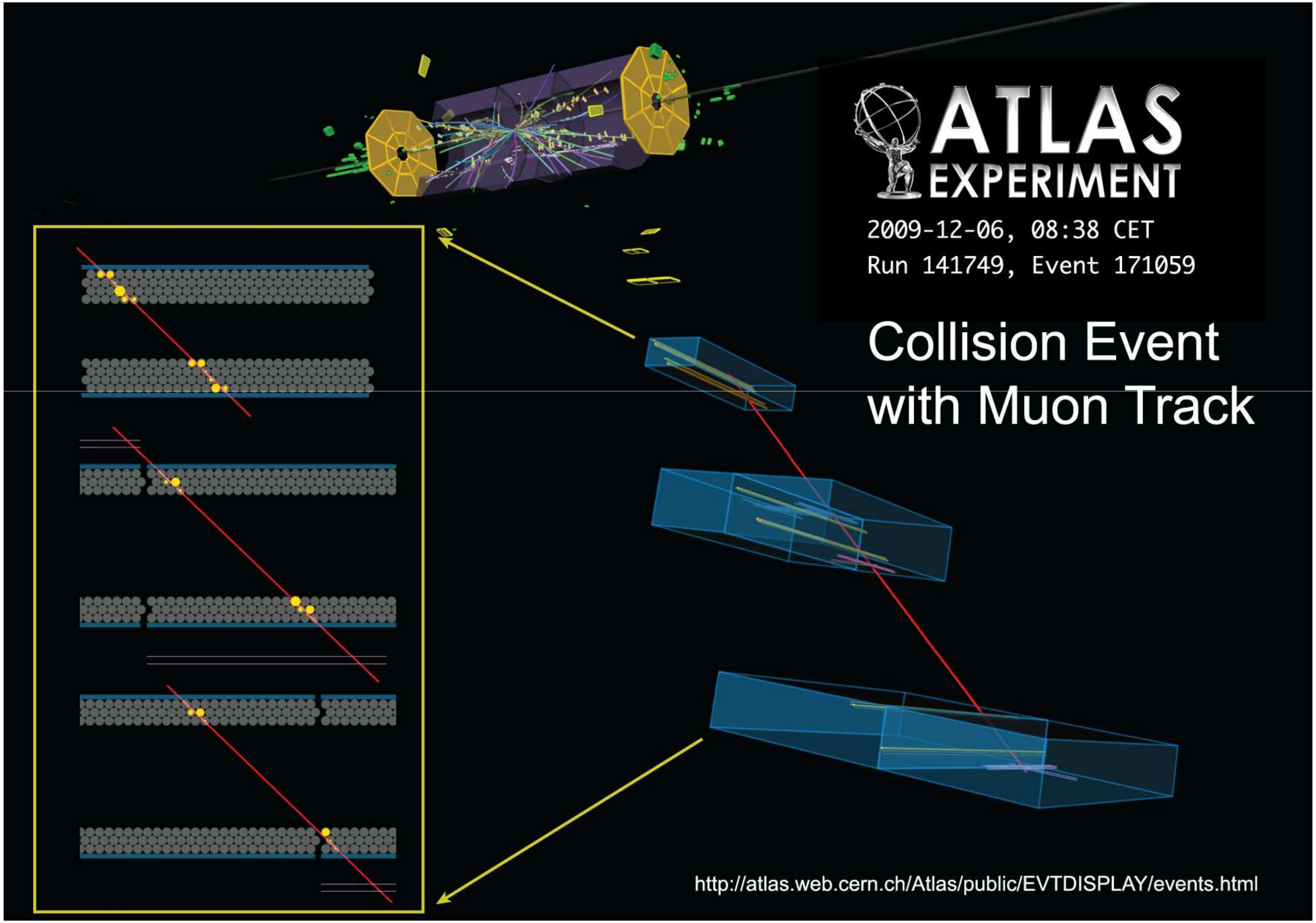
From R. Heuer's lecture given at CERN on 3rd December 2009



http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html



http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html


ATLAS
EXPERIMENT
2009-12-06, 08:38 CET
Run 141749, Event 171059
Collision Event
with Muon Track
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

Discoveries in Physics

Facility		Original purpose, Expert Opinion	Discovery with Precision Instrument
P.S. CERN	(1960's)	π N interactions	Neutral Currents -> Z, W
Brookhaven	(1960's)	π N interactions	ν_e, ν_μ CP violation, J
FNAL	(1970's)	Neutrino physics	*b, t quarks*
SLAC Spear	(1970's)	ep, QED	Scaling, Ψ, τ
PETRA	(1980's)	t quark	*Gluon*
Super Kamiokande	(2000)	Proton decay	Neutrino oscillations

Exploring a new territory with a precision instrument is the key to discovery.

From S.Ting's lecture given at CERN on 4th December 2009

Závěrem

- Plány urychlovače LHC:

  do konce roku 2009 – první srážky 450x450 GeV, pak zvýšit energii až na 1.2 TeVx1.2 TeV

- V roce 2010 srážky při 3.5 TeV x 3.5 TeV a první důležité výsledky(?)

- Experiment Atlas bude hlavním programem experimentální fyziky částic na příštích 15 let