LHC a detektor ATLAS
stav a nová fyzika

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CERN

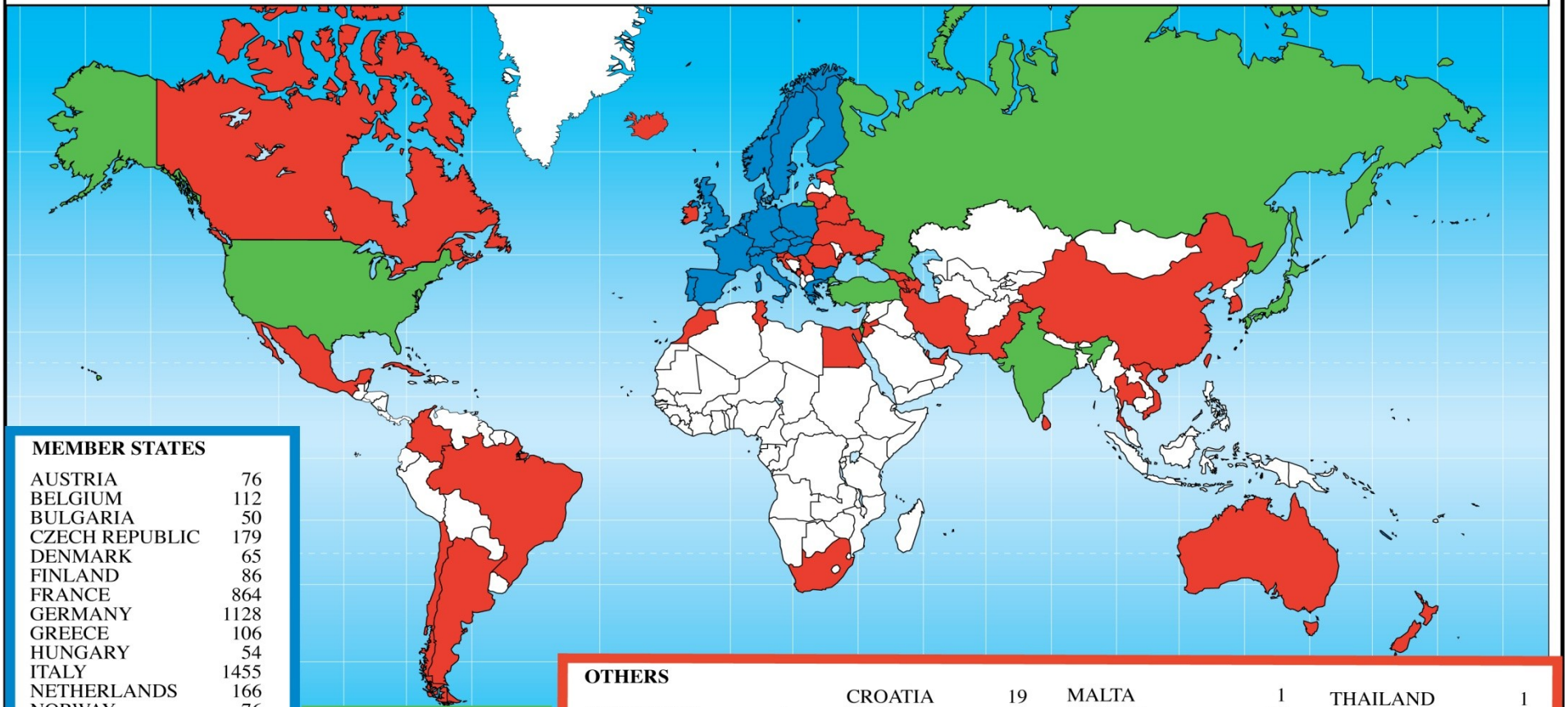
European Organization for Nuclear Research
Organisation Européenne pour la Recherche Nucléaire

CERN in Numbers

- 2256 staff
- ~700 other paid personnel
- ~9500 users
- Budget (2009) 1100 MCHF

- **20 Member States:** Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.
- **1 Candidate for Accession to Membership of CERN:** Romania
- **8 Observers to Council:** India, Israel, Japan, the Russian Federation, the United States of America, Turkey, the European Commission and Unesco

Distribution of All CERN Users by Nation of Institute on 27 October 2009



MEMBER STATES

AUSTRIA	76
BELGIUM	112
BULGARIA	50
CZECH REPUBLIC	179
DENMARK	65
FINLAND	86
FRANCE	864
GERMANY	1128
GREECE	106
HUNGARY	54
ITALY	1455
NETHERLANDS	166
NORWAY	76
POLAND	190
PORTUGAL	123
SLOVAKIA	56
SPAIN	303
SWEDEN	72
SWITZERLAND	363
UNITED KINGDOM	728

6252

OBSERVER STATES

INDIA	97
ISRAEL	55
JAPAN	203
RUSSIA	915
TURKEY	64
USA	1629

2963

OTHERS

ARGENTINA	8	CROATIA	19	MALTA	1	THAILAND	1
ARMENIA	15	CUBA	4	MEXICO	30	TUNISIA	1
AUSTRALIA	15	CYPRUS	8	MONTENEGRO	1	UKRAINE	17
AZERBAIJAN	1	EGYPT	2	MOROCCO	5	U.A.E.	1
BELARUS	19	ESTONIA	11	NEW ZEALAND	8	VIETNAM	1
BRAZIL	71	GEORGIA	10	PAKISTAN	18		
CANADA	143	ICELAND	1	QATAR	1		
CHILE	3	IRAN	12	ROMANIA	53		
CHINA	85	IRELAND	13	SERBIA	20		
CHINA (TAIPEI)	57	JORDAN	1	SLOVENIA	17		
COLOMBIA	12	KOREA	61	SOUTH AFRICA	9		
		LITHUANIA	6	SRI LANKA	1		

759

Conseil Européen pour la Recherche Nucléaire

1973: The discovery of neutral currents in the Gargamelle bubble chamber.

1983: The discovery of W and Z bosons in the UA1 and UA2 experiments.

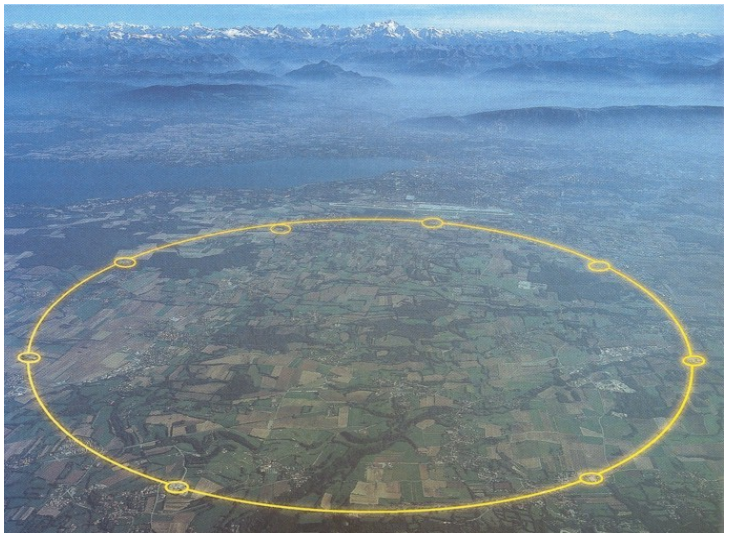
1989: The determination of the number of neutrino families at the Large Electron Positron Collider (LEP) operating on the Z boson peak.

1995: The first creation of antihydrogen atoms in the PS210 experiment.

2001: The discovery of direct CP-violation in the NA48 experiments.

+ ISOLDE
+ CNGS
+ nTOF
+ R&D
+ ....

High energy physics today



Large Hadron Collider

- Length of 27 km.
- Has 4 large detectors.
- Unprecedented energy scales.
- It is most complex human-built machine.

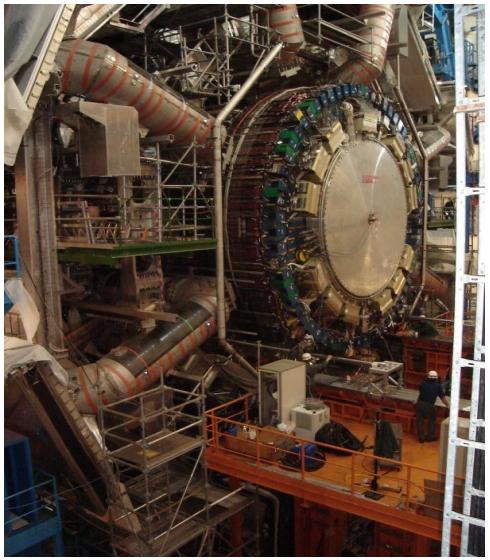
Fundamental questions:

What is the origin of mass?

Why there was less antimatter than matter?

What is dark matter and dark energy?

Are there extra dimensions?



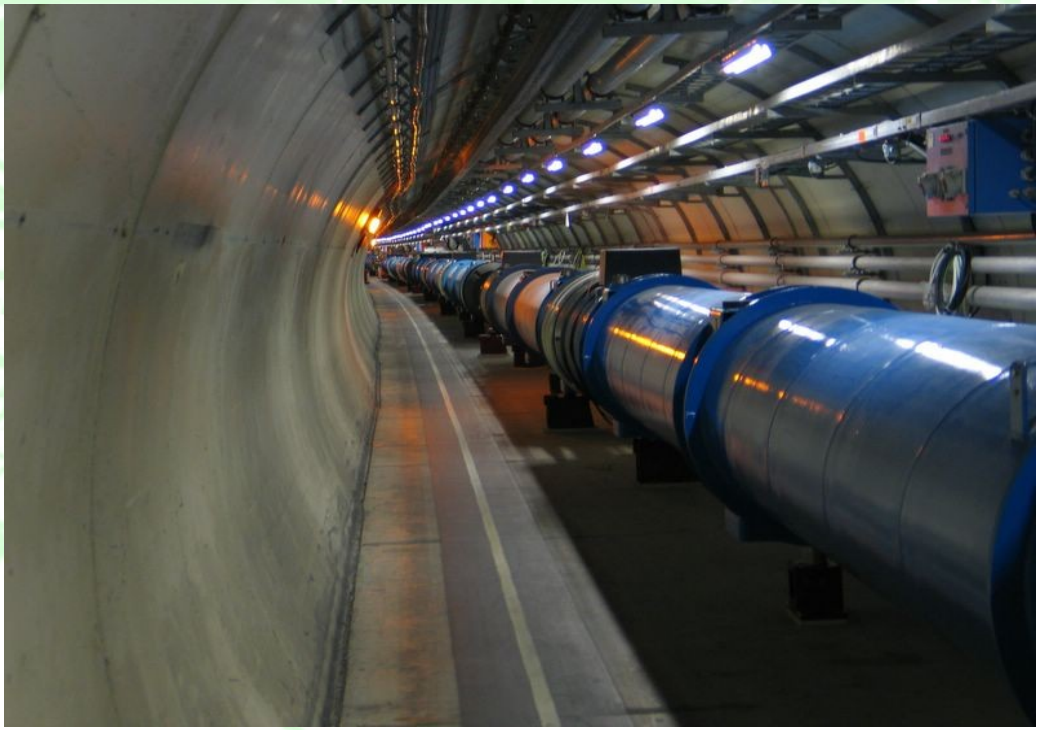
Also, new technologies emerge:
- The WWW
- The GRID
- Medical applications
- Storage challenge
- Data processing
- Superconductors, electronics, etc.

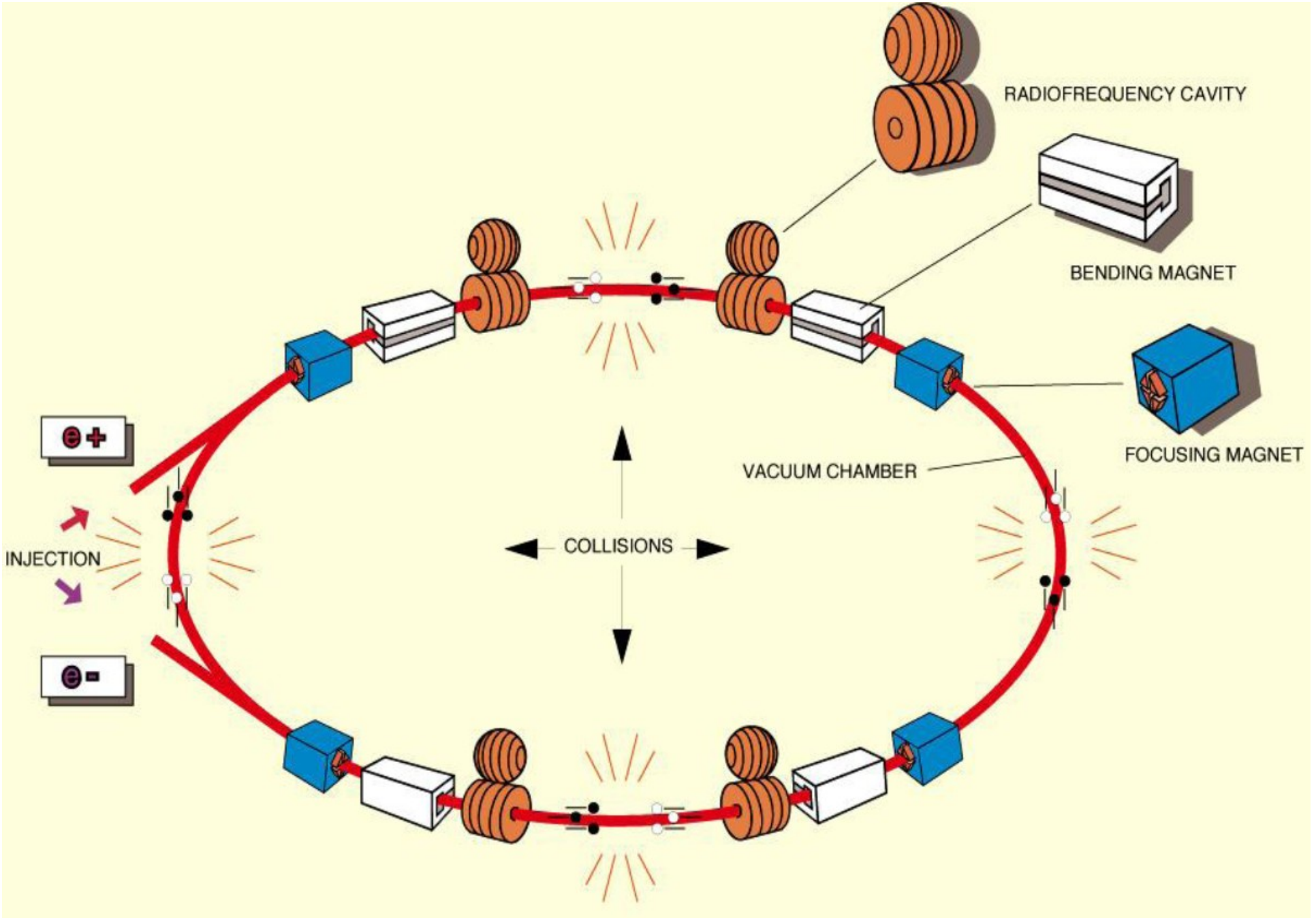
LHC

The Large Hadron Collider (LHC) is 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.

It is designed to collide two counter circulating beams of bunches of protons or heavy ions. Proton-proton collisions are foreseen at an energy of 7 TeV per beam with a start-up in ~~middle 2008~~.

LHC has a total stored beam energy:
10^{14} protons of $14 \cdot 10^{12}$ eV $\sim 10^{8}$ J
...or, if you like one 100 T truck
at 100 km/h



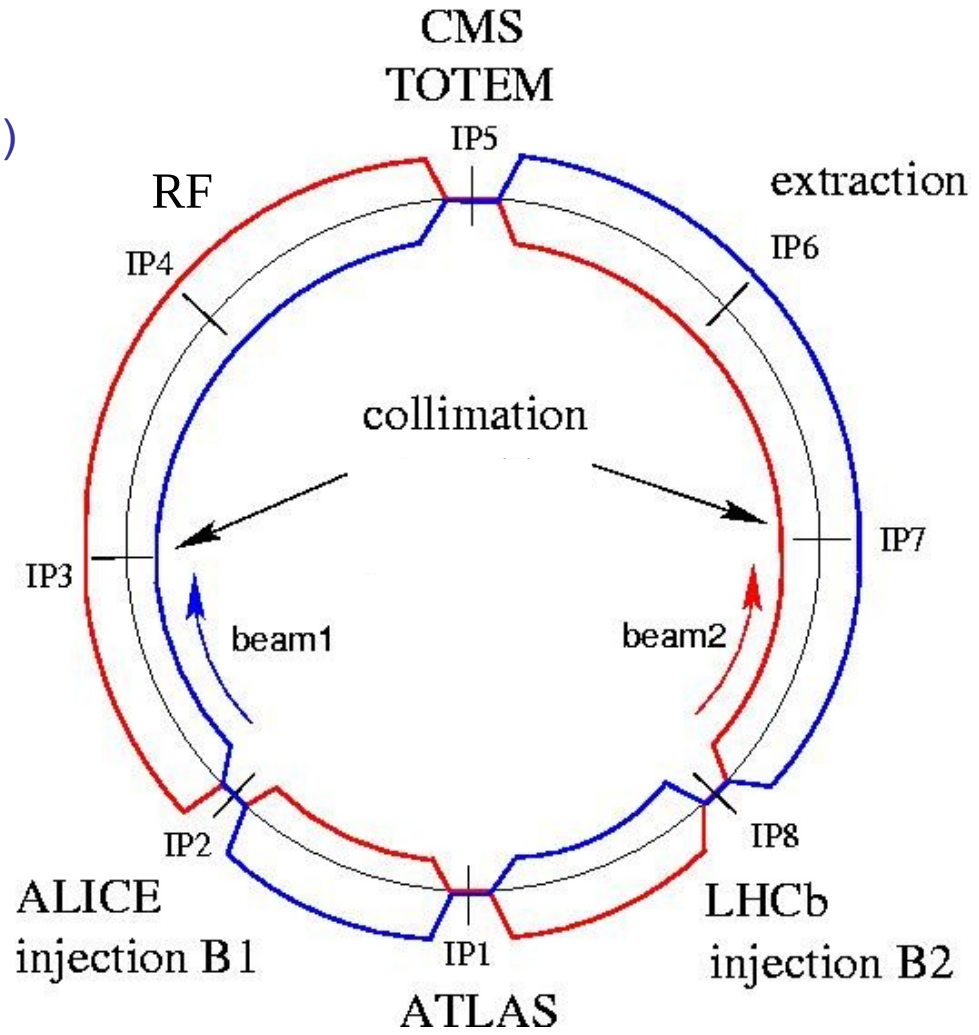

RADIOFREQUENCY CAVITY
BENDING MAGNET
FOCUSING MAGNET
VACUUM CHAMBER
COLLISIONS
INJECTION
e+
e-

LHC layout and parameters

- 8 arcs (sectors), ~3 km each
- 8 long straight sections (700 m each)
- beams cross in 4 points
- 2-in-1 magnet design with separate vacuum chambers → *p-p* collisions

Nominal LHC parameters	
Beam energy (TeV)	7.0
No. of particles per bunch	1.15×10^{11}
No. of bunches per beam	2808
Stored beam energy (MJ)	362
Transverse emittance (μm)	3.75
Bunch length (cm)	7.6

- $\beta^* = 0.55$ m (beam size =17μm)
- Crossing angle = 285 μrad
- $L = 10^{34}$ cm^{-2} s^{-1}



CERN Accelerators
(not to scale)

0.999999c by here

0.87c by here

0.3c by here

LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso

Rudolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Div.,
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01

Start the protons out here

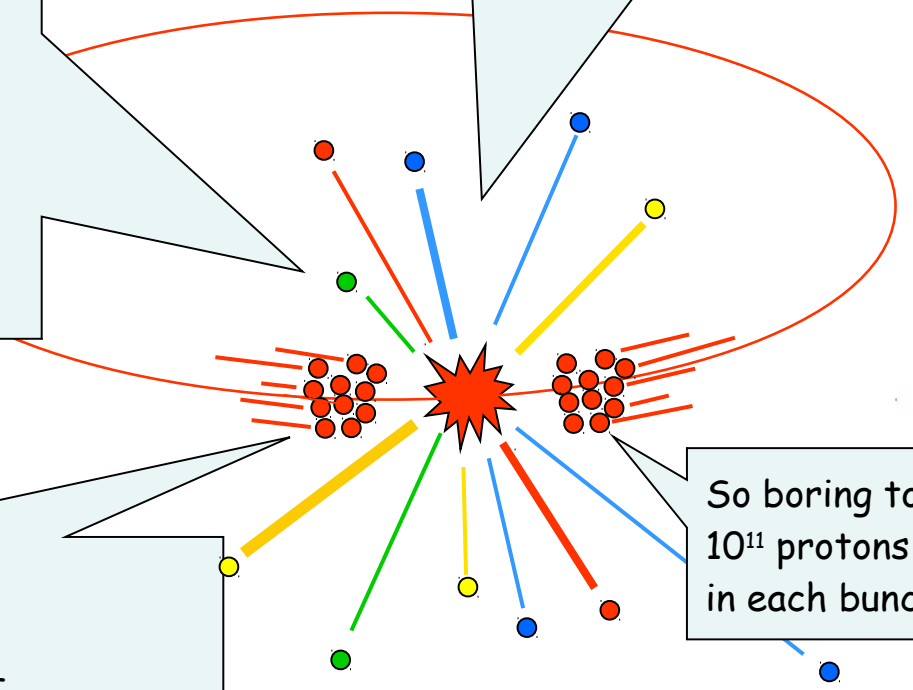
Zrážky u LHC.

The collision point is "watched" by surrounding detector.

Some particles just escaped from the collision zone, the next collision threatens.

The detector should:
- have large coverage (4π ideal)
- be precise
- be fast (and cheap and ...)

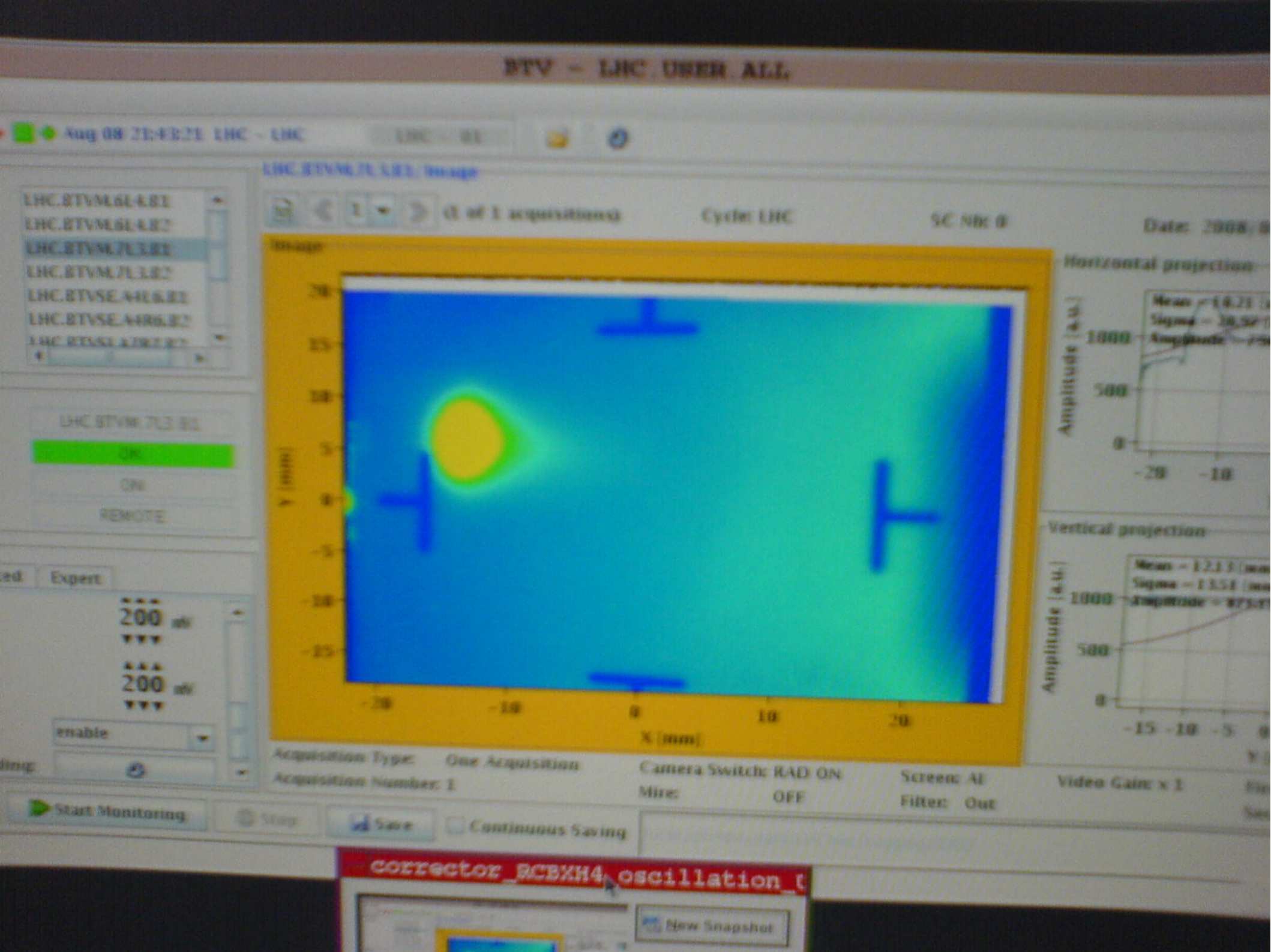
Each meeting of two bunches results in about 23 proton-proton collisions. The mean number of particles born in all these collisions is about 1500. The detector should record as many of them as possible.



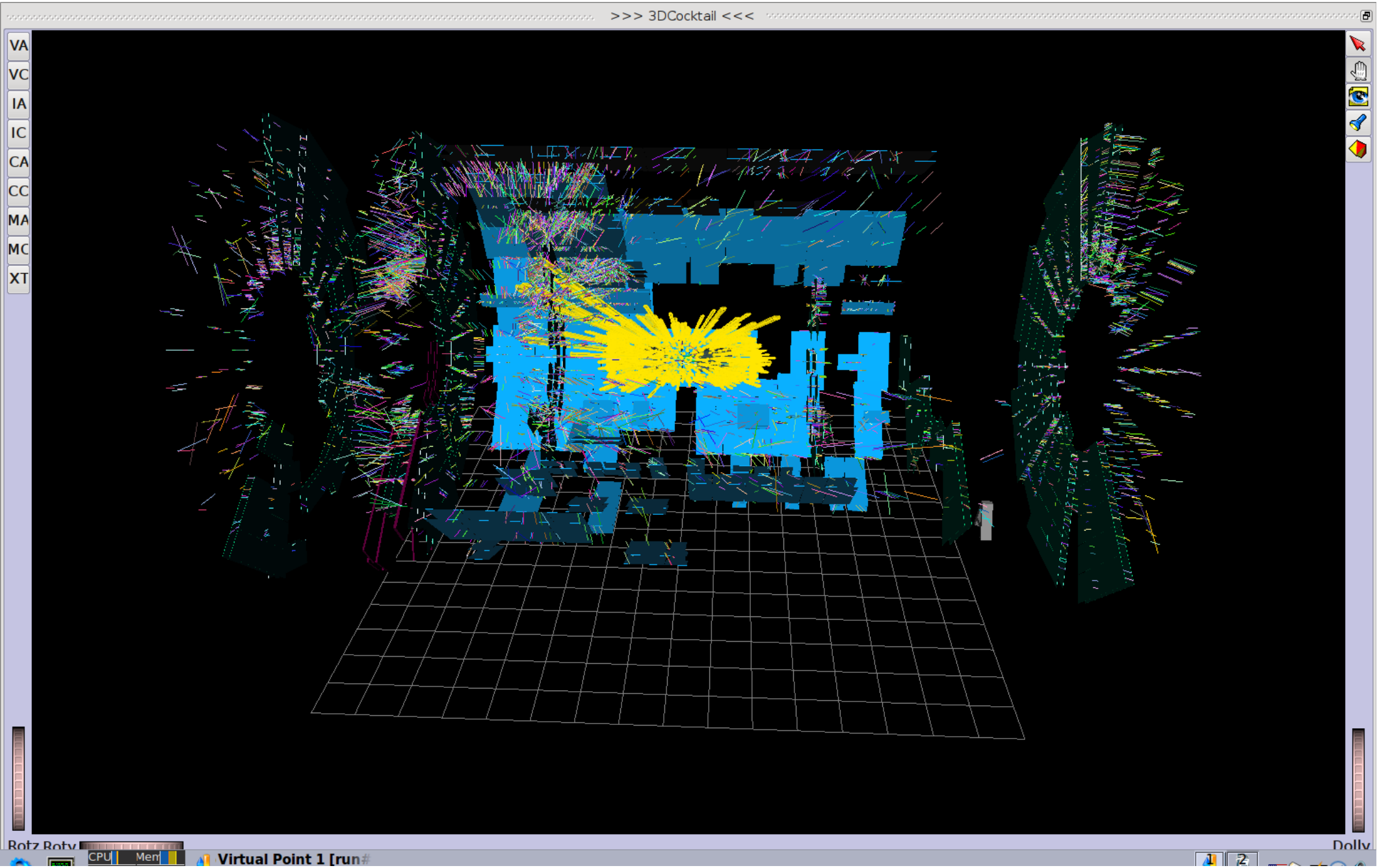
So boring to paint 10^{11} protons in each bunch ...

Each proton carries energy 7 TeV.
So each bunch with 10^{11} protons carries energy $10^{11} \times 7 \times 10^{12}$ eV = 7×10^{23} eV = 44 kJ.
This is a macroscopic energy!!!
In order to reach such kinetic energy on a bike, you go with a speed of more than 30 km/h!

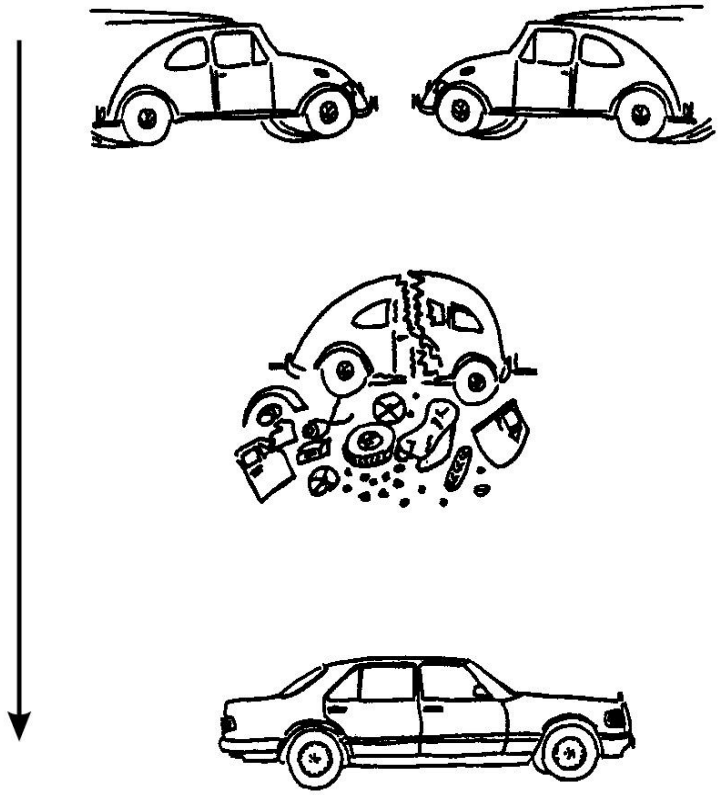
- 7+7 TeV ($p^+ + p^+$)
- 1150+1150 TeV ($Pb^{207} + Pb^{207}$)

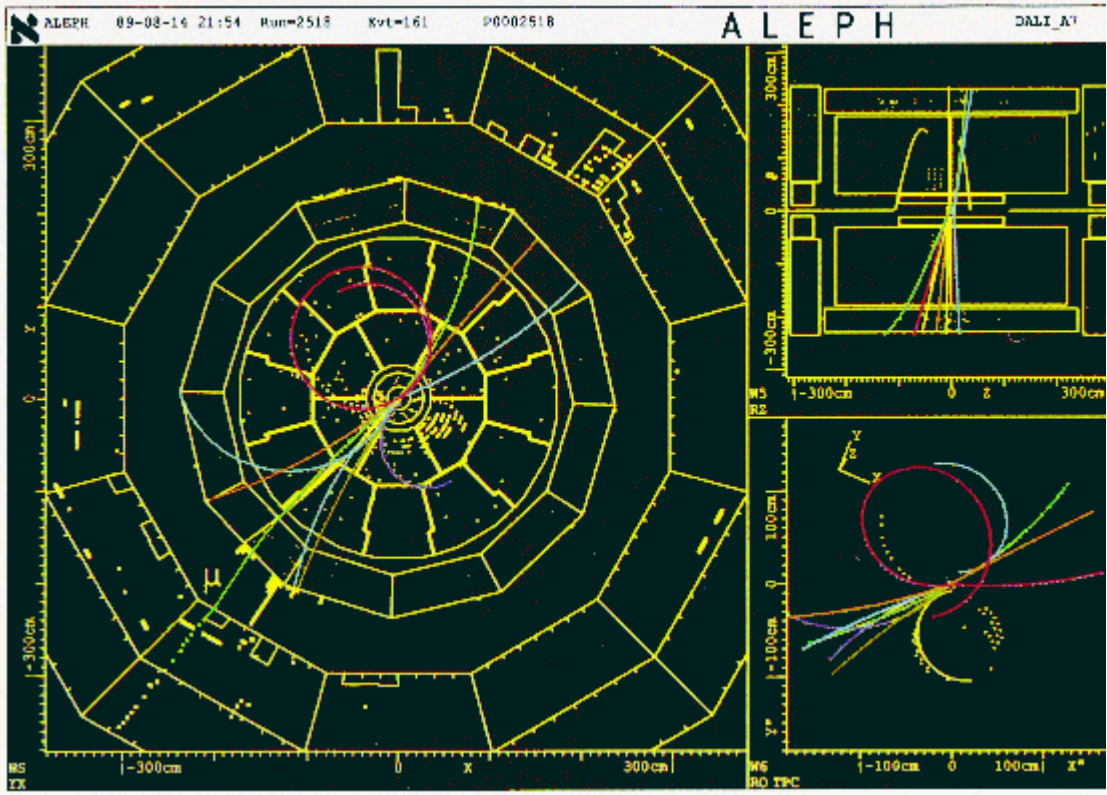

BTV - LHC.USER.ALL
Horizontal projection
Vertical projection
Amplitude [a.u.]
X [mm]
Y [mm]
Start Monitoring
Stop
Save
Continuous Saving
New Snapshot

ATLAS beam splash

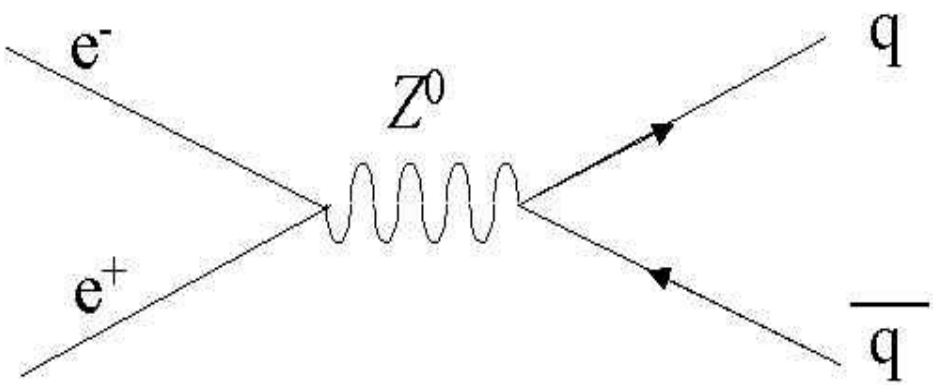


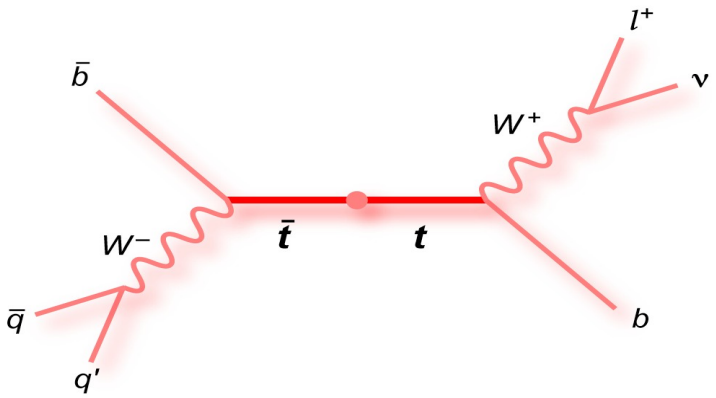
Collider

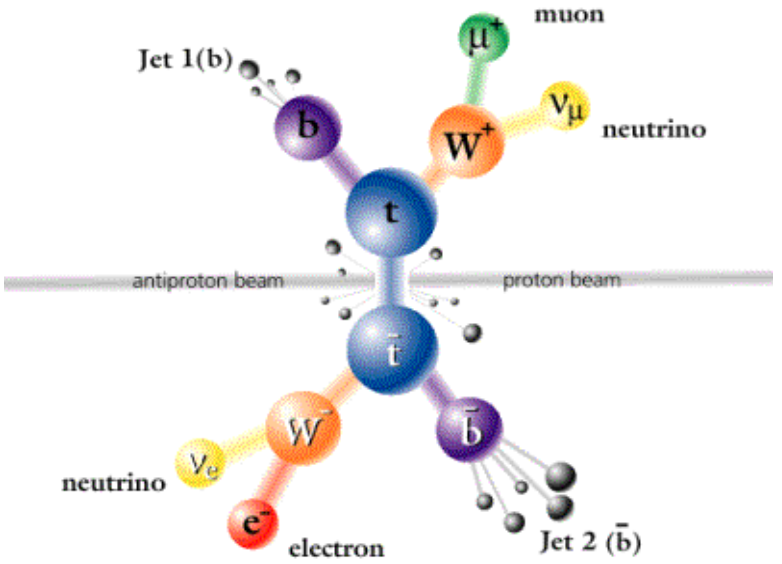


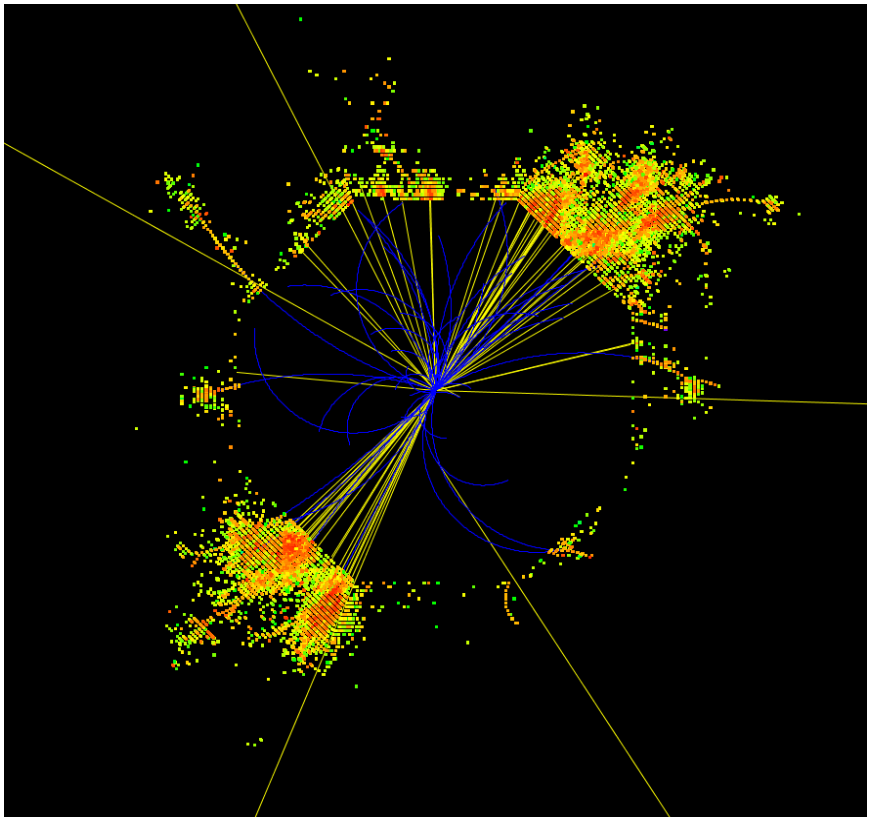


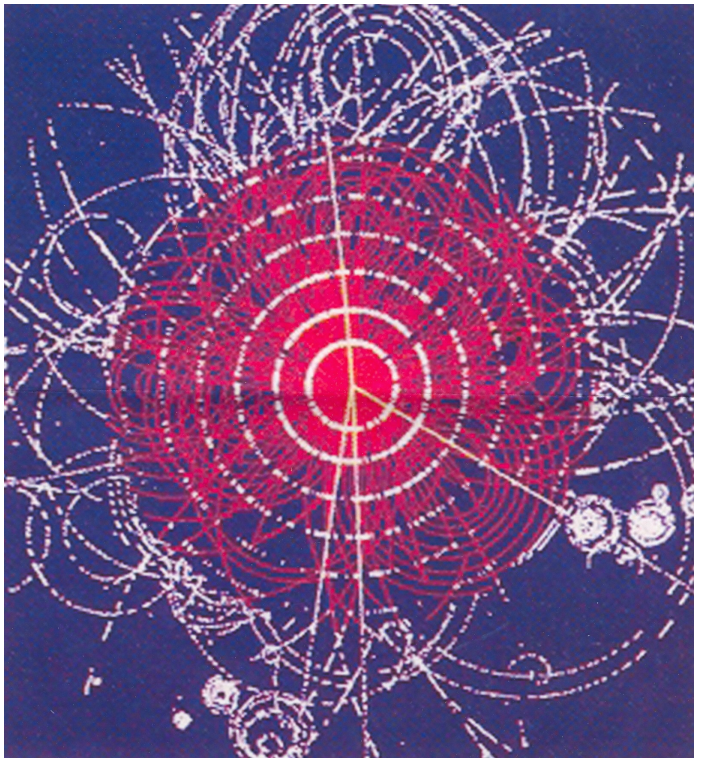
Higgs production in e^+e^- collisions:

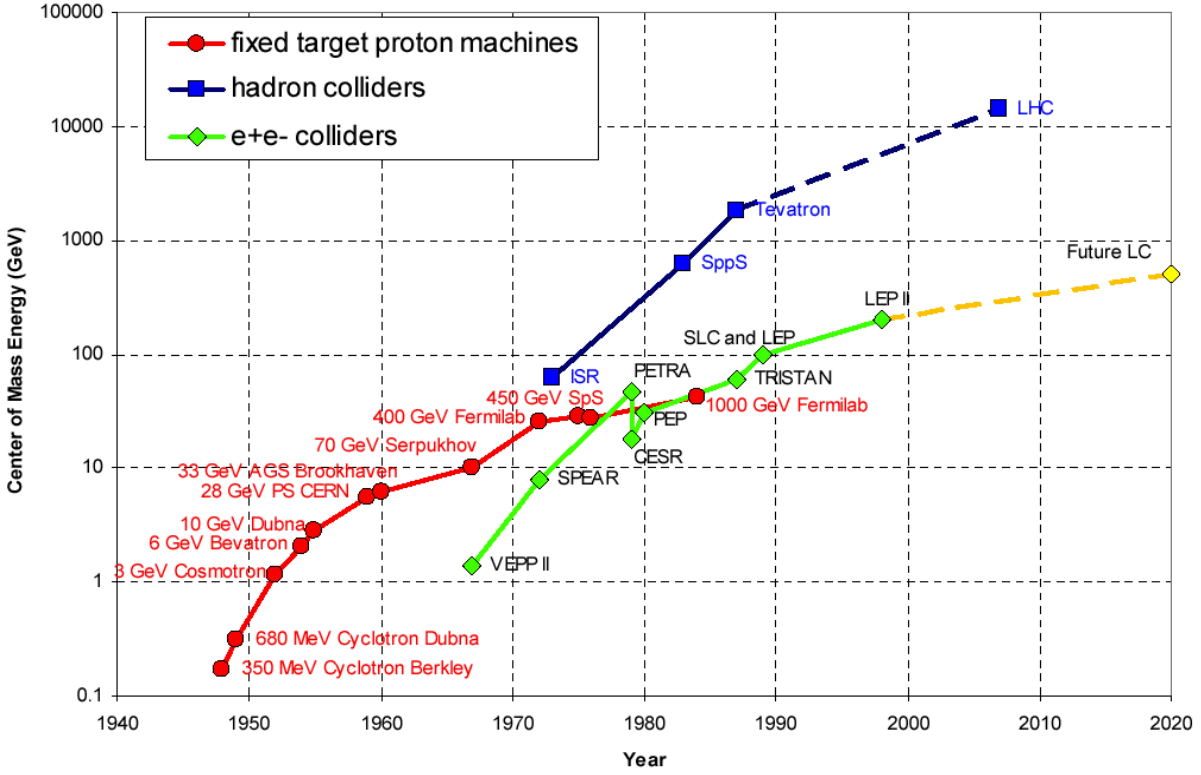


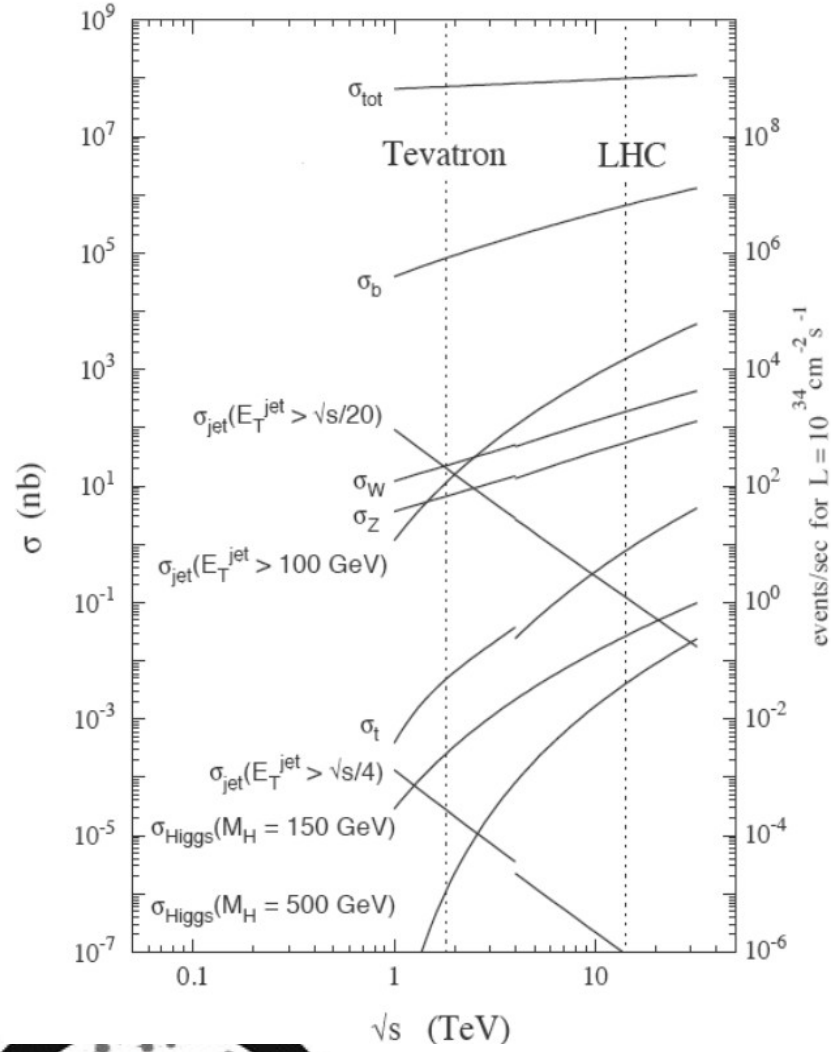

$\bar{b}$
l^+
ν
W^+
W^-
$\bar{t}$
t
$\bar{q}$
q'
b

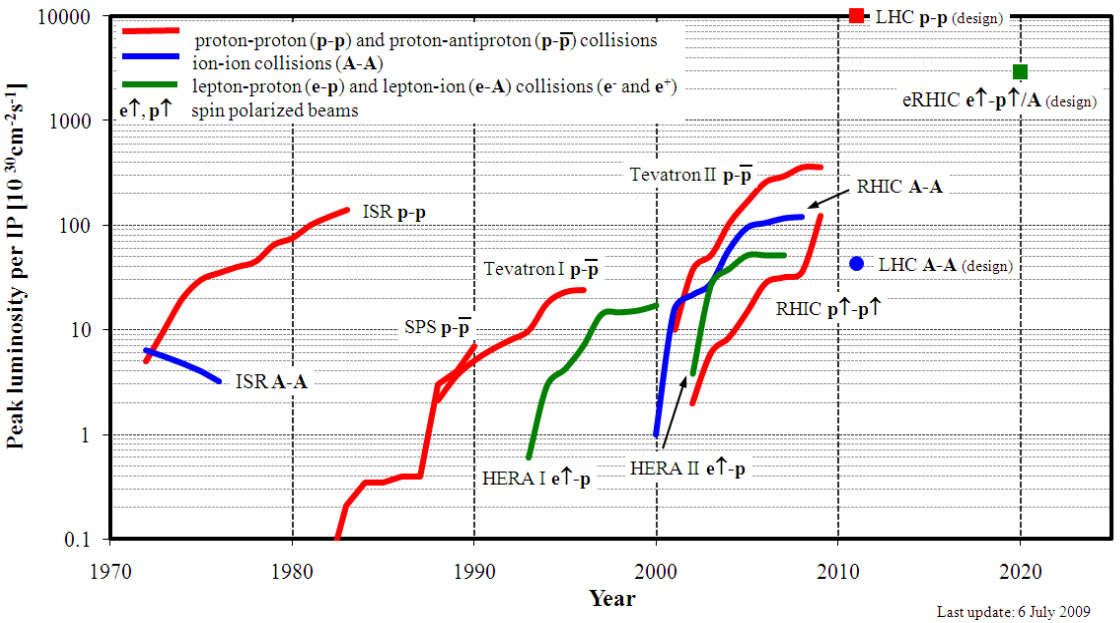

Jet 1(b)
muon
μ^+
ν_μ
neutrino
b
W^+
t
antiproton beam
proton beam
$\bar{t}$
W^-
$\bar{b}$
ν_e
neutrino
e^-
electron
Jet 2 ($\bar{b}$)



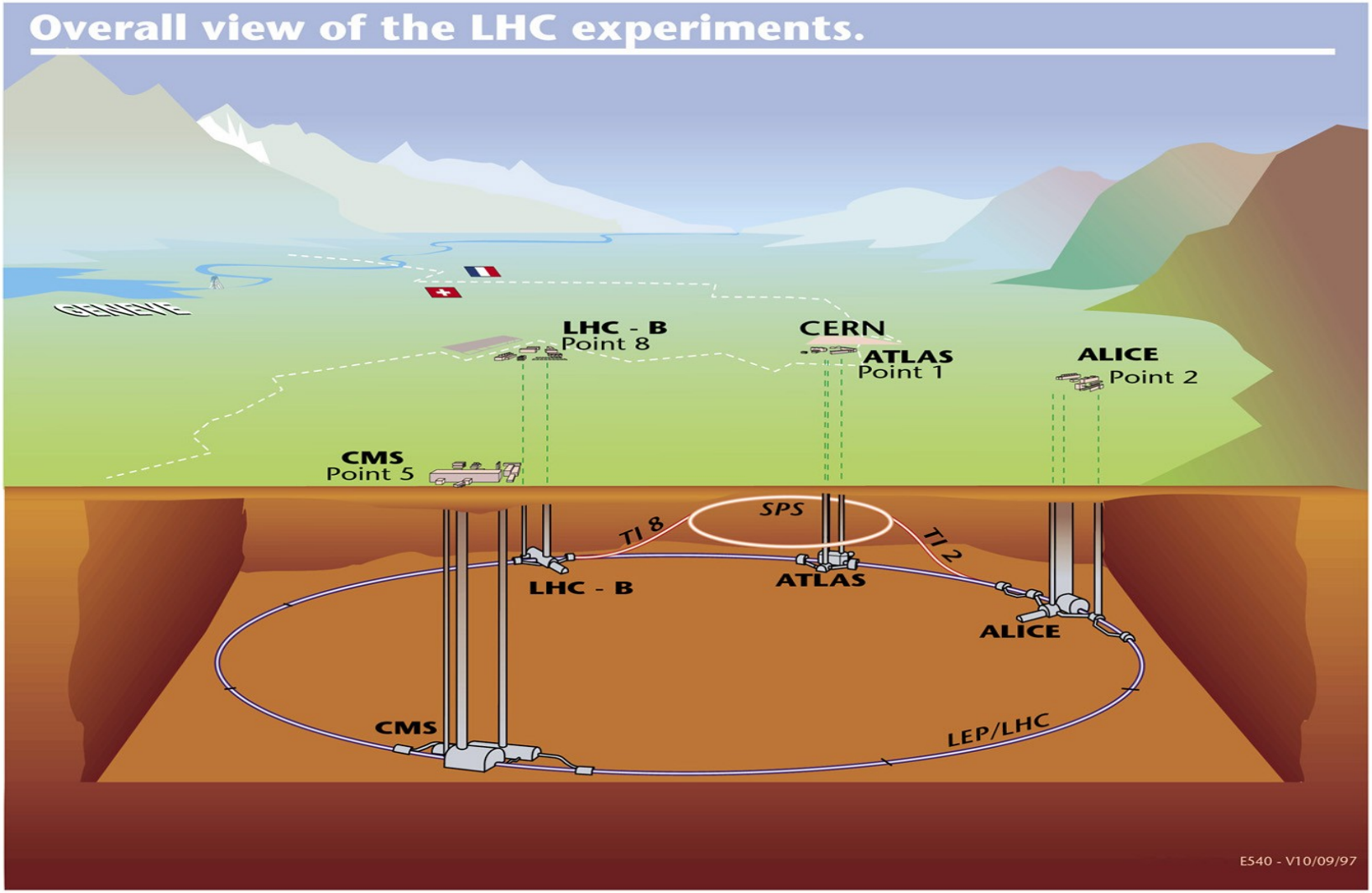






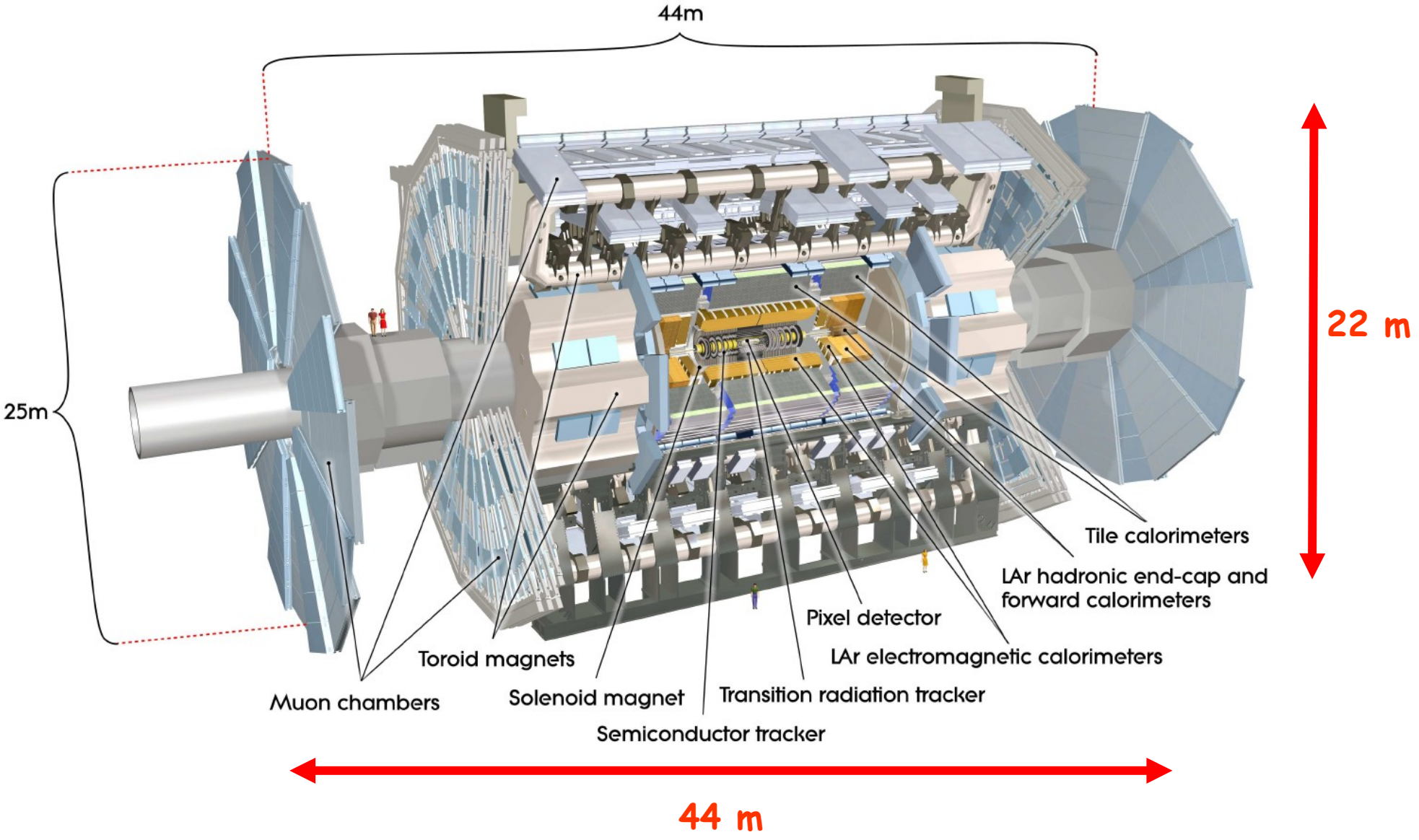


$R = \sigma \times L.$

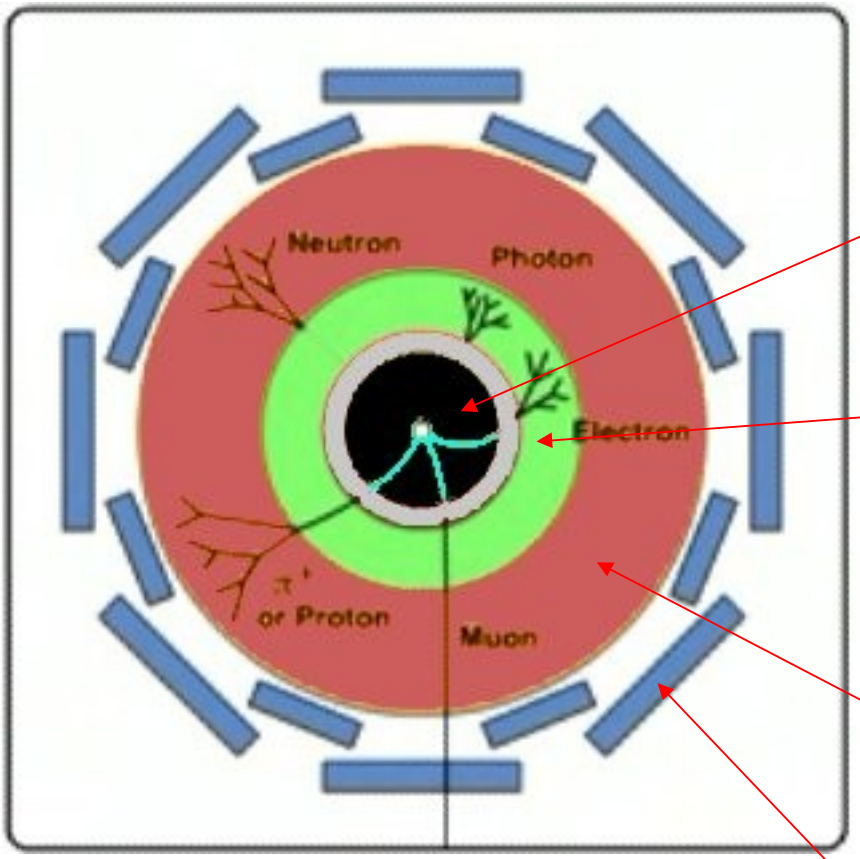

Overall view of the LHC experiments.
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC
E540 - V10/09/97

A Toroidal LHC ApparatuS

ATLAS



A Typical Detector



Inner detector (Tracker)

Measures charge and momentum of charged particles in magnetic field

Electro-magnetic calorimeter

Measures energy of electrons, positrons and photons

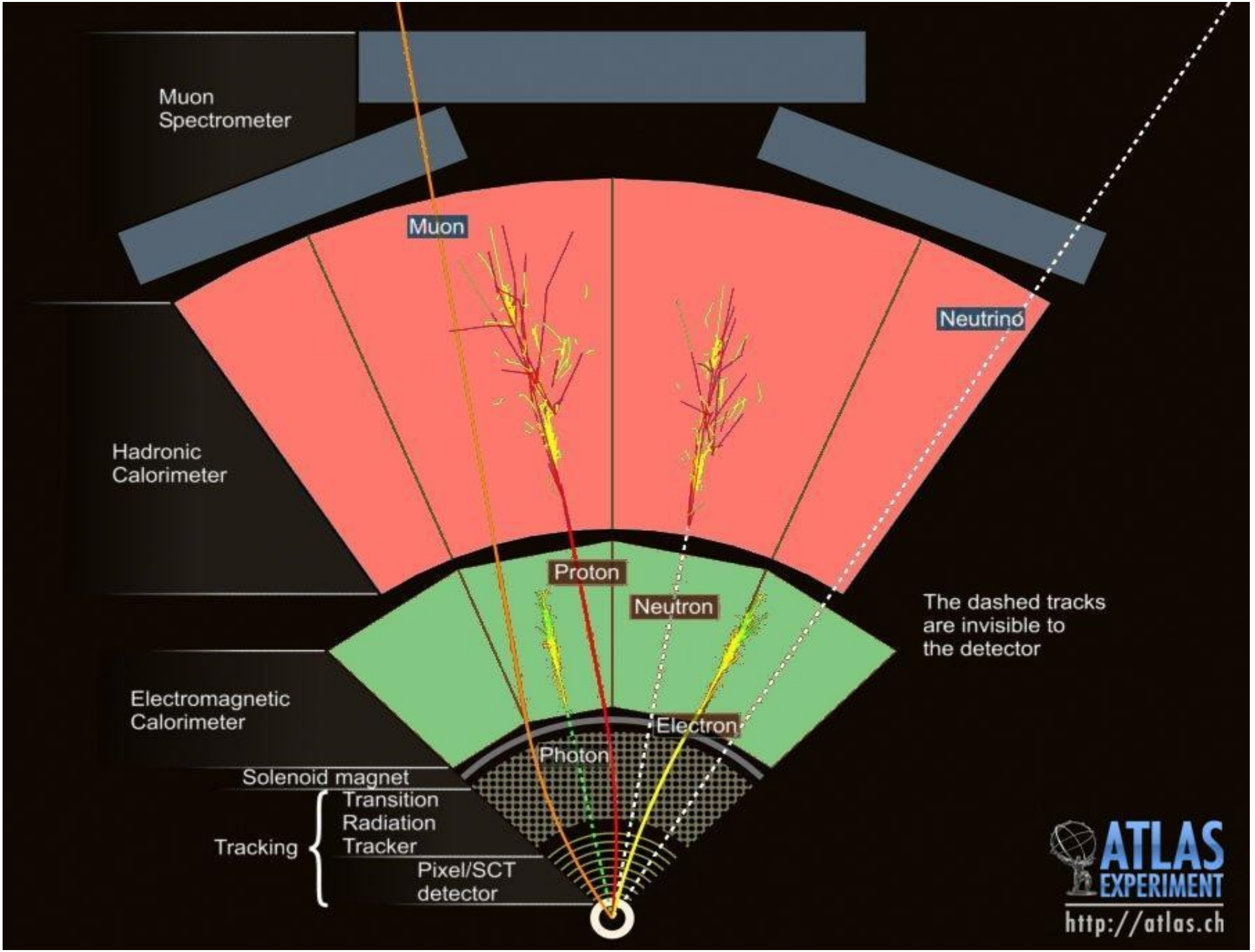
Hadronic calorimeter

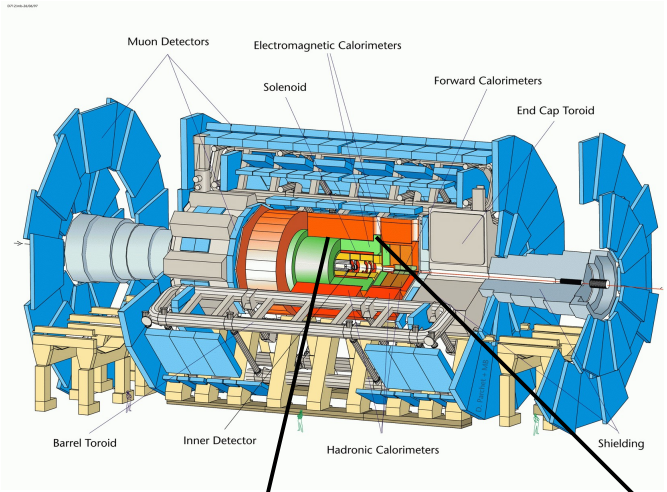
Measures energy of hadrons (particles containing quarks), such as protons, neutrons, pions, etc.

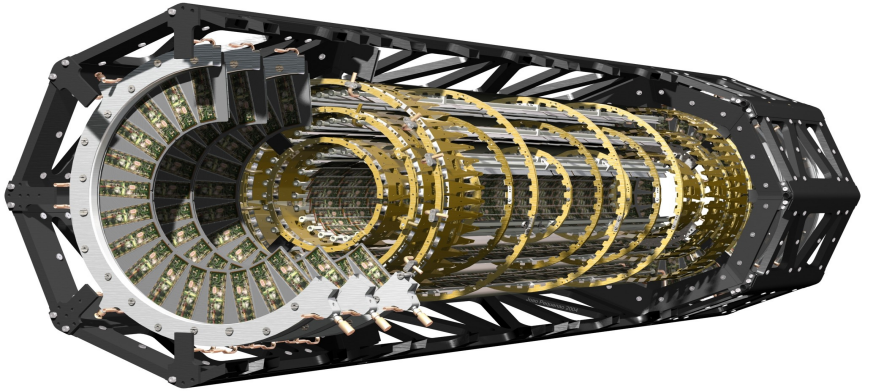
Muon detector

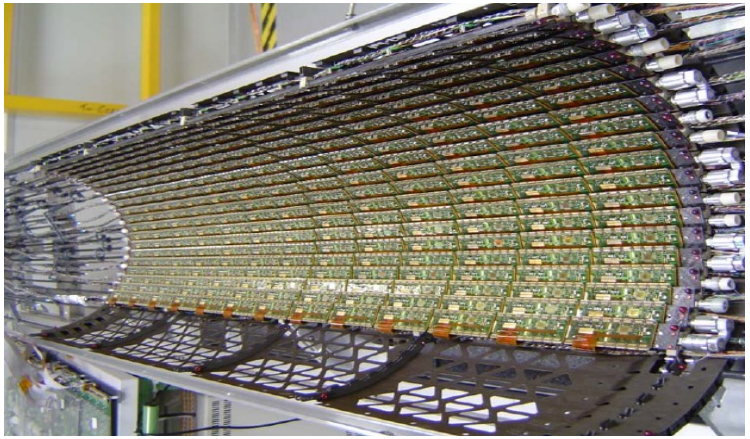
Measures charge and momentum of muons

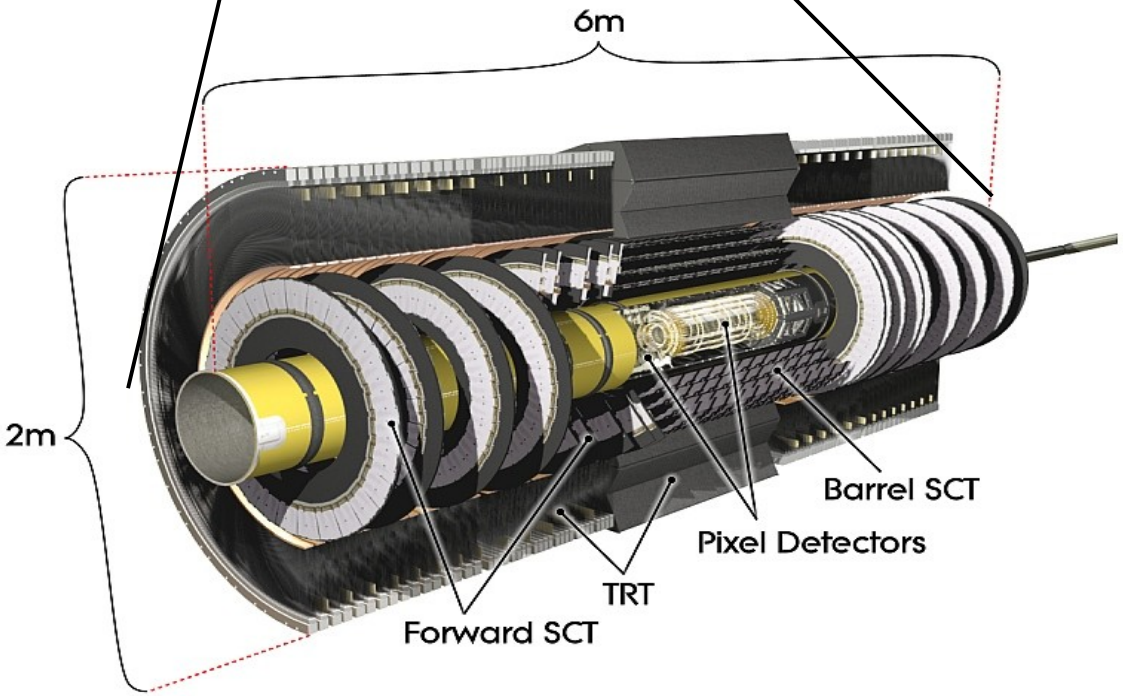
Neutrinos are only detected indirectly via 'missing energy' not recorded in the calorimeters

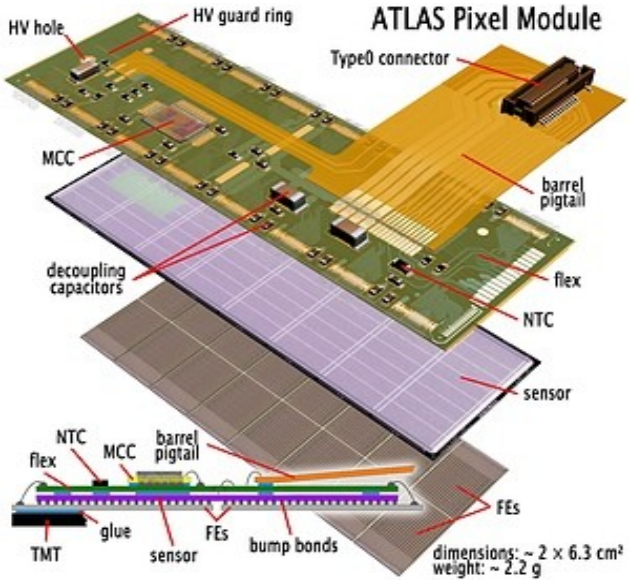

Muon
Spectrometer
Muon
Neutrino
Hadronic
Calorimeter
Proton
Neutron
The dashed tracks
are invisible to
the detector
Electromagnetic
Calorimeter
Electron
Photon
Solenoid magnet
Tracking
Transition
Radiation
Tracker
Pixel/SCT
detector
ATLAS
EXPERIMENT
http://atlas.ch

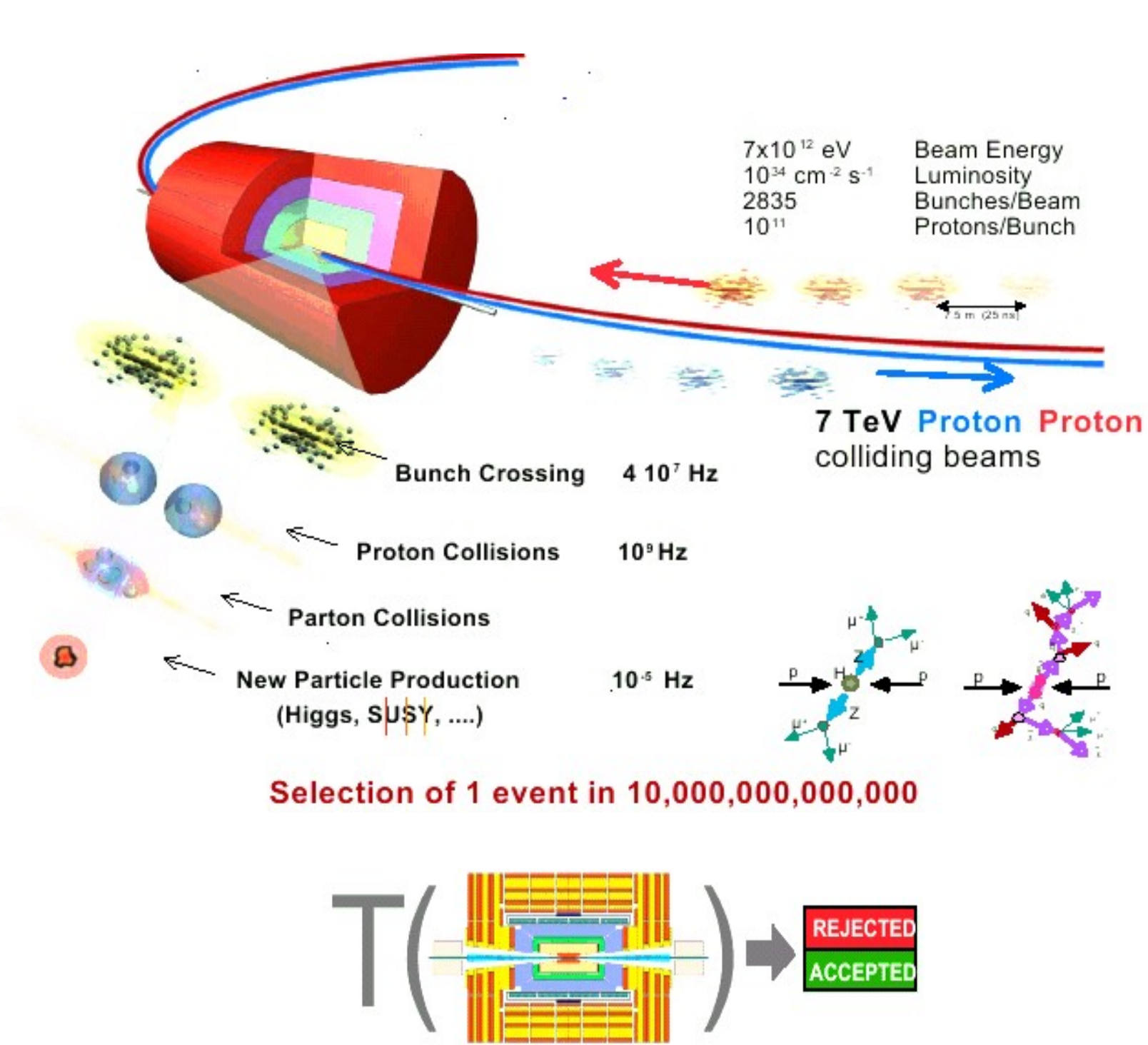

Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

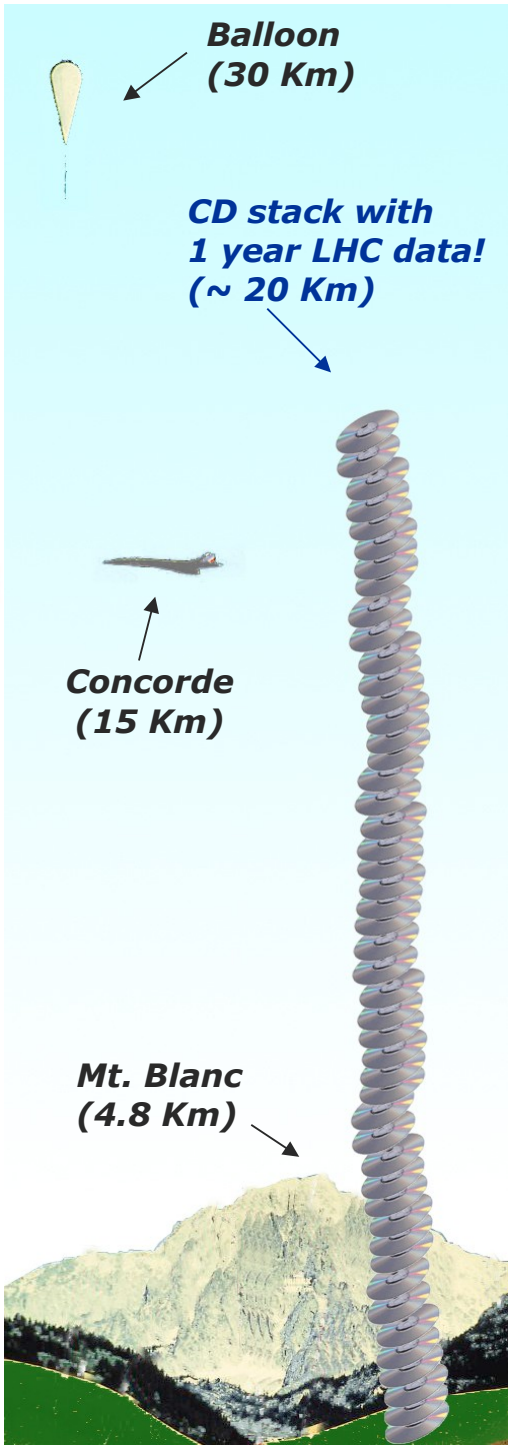





6m
2m
Barrel SCT
Pixel Detectors
TRT
Forward SCT

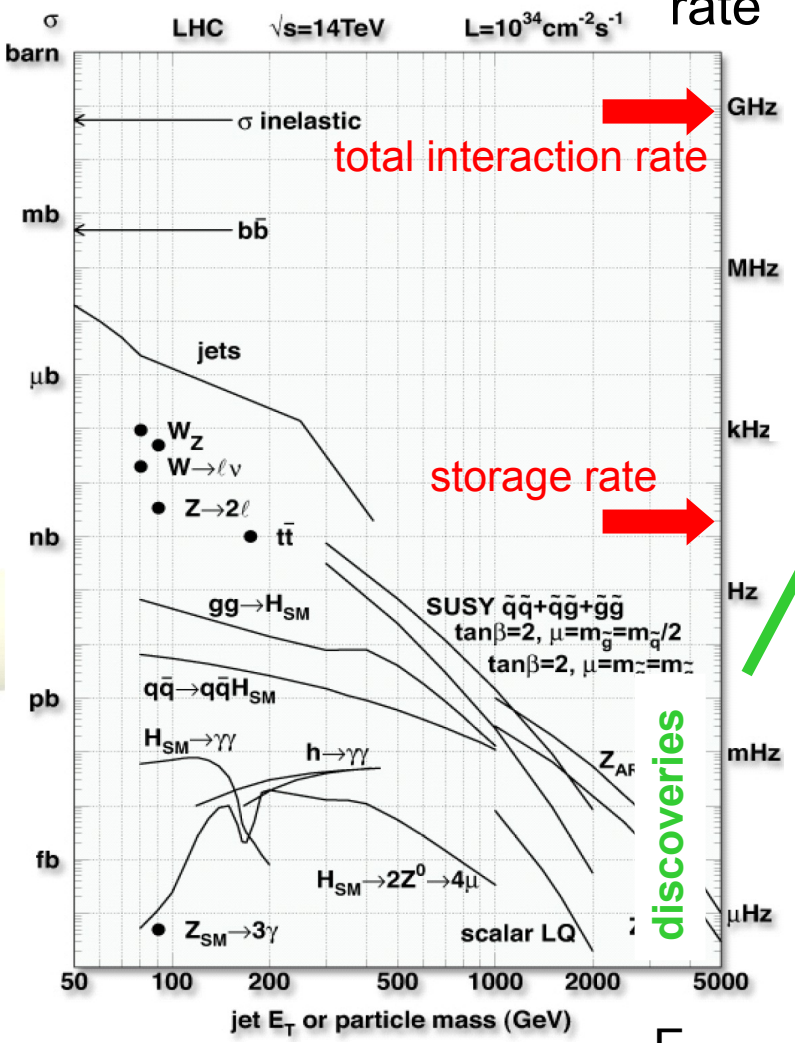

ATLAS Pixel Module
HV hole
HV guard ring
Type0 connector
MCC
barrel pigtail
decoupling capacitors
flex
NTC
sensor
NTC
flex
MCC
barrel pigtail
FEs
glue
TMT
sensor
FEs
bump bonds
dimensions: ~ 2 x 6.3 cm²
weight: ~ 2.2 g


7x10 12 eV
Beam Energy
10 34 cm -2 s -1
Luminosity
2835
Bunches/Beam
10 11
Protons/Bunch
7 TeV Proton Proton
colliding beams
Bunch Crossing
4 10 7 Hz
Proton Collisions
10 9 Hz
Parton Collisions
New Particle Production
(Higgs, SUSY, ...)
10 -5 Hz
Selection of 1 event in 10,000,000,000,000
REJECTED
ACCEPTED


Balloon
(30 Km)
CD stack with
1 year LHC data!
(~ 20 Km)
Concorde
(15 Km)
Mt. Blanc
(4.8 Km)

Trigger motivation

rate



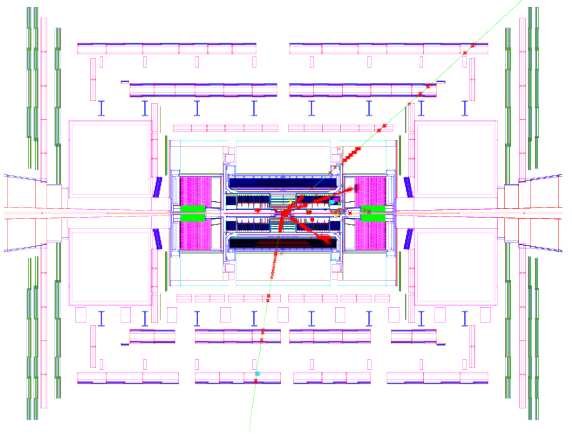
total interaction rate

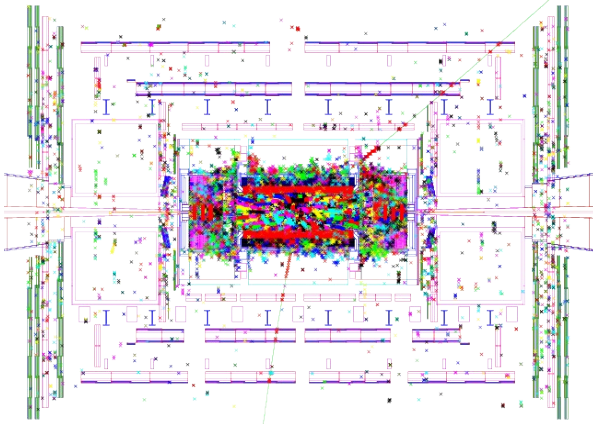
storage rate

E_T

bunch crossing rate: 40 MHz
total interaction rate: ~ 1 GHz
event size: ~ 1.5 MB
affordable: ~ 300 MB/s
storage rate: ~ 200 Hz
→ online rejection: 99.9995%

e.g.: Higgs → ZZ → 2e+2μ

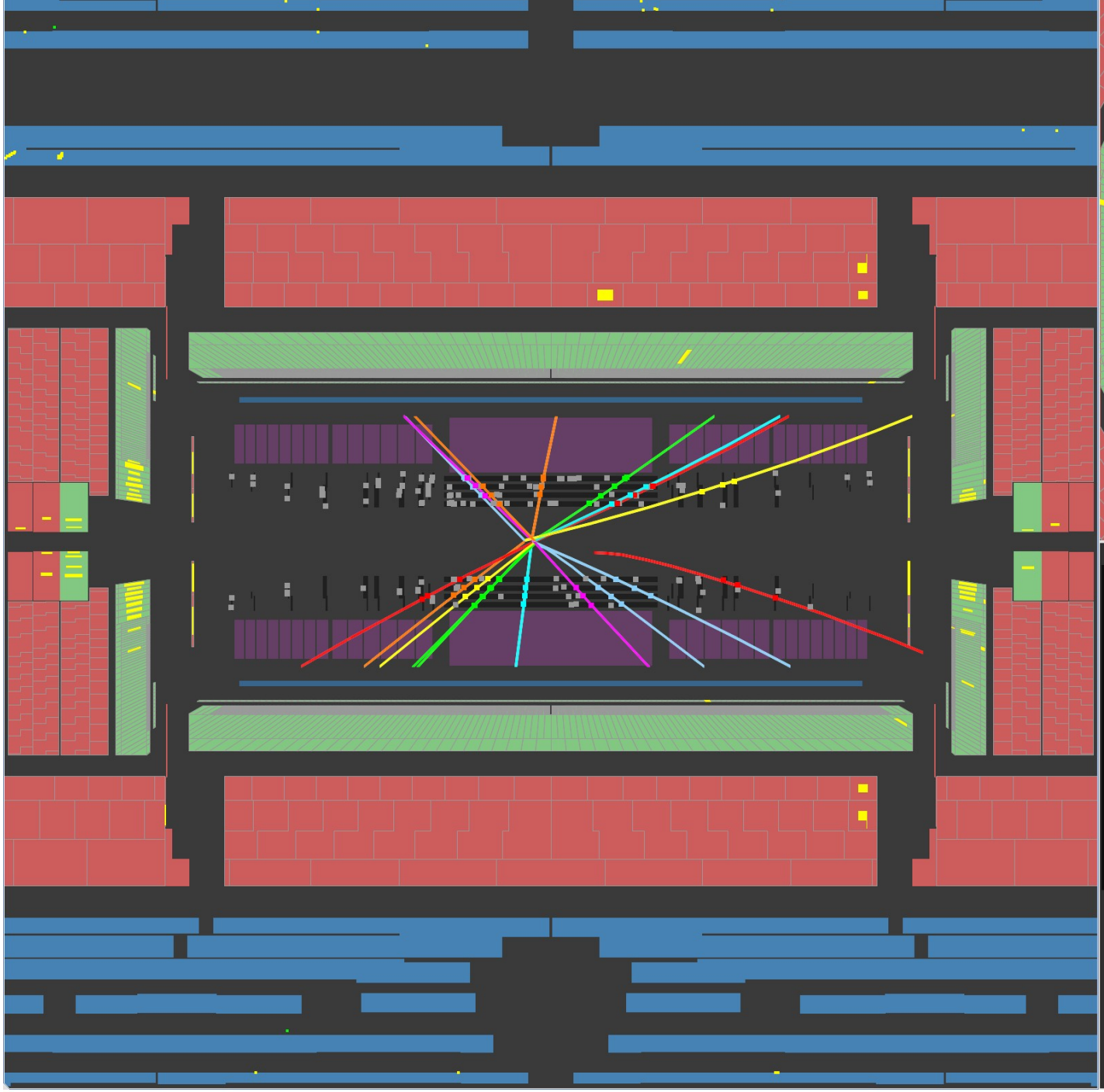


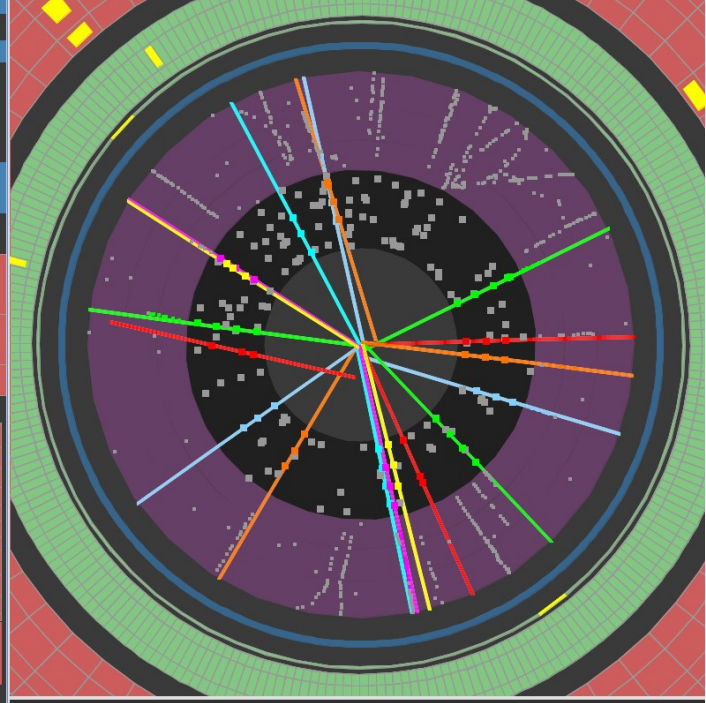


23 min. bias events:
~ 1725 particles/BC

powerful trigger needed

- Enormous rate reduction
- Retaining the rare events in the very tough LHC environment
- Sharing in between physics and technical triggers





ATLAS EXPERIMENT

2009-11-23, 14:22 CET

Run 140541, Event 171897

Candidate Collision Event

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

OP Vistars - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://op-webtools.web.cern.ch/op-webtools/Vistar/vistars.php?usr=LHC1

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LHC1

OP Vistars

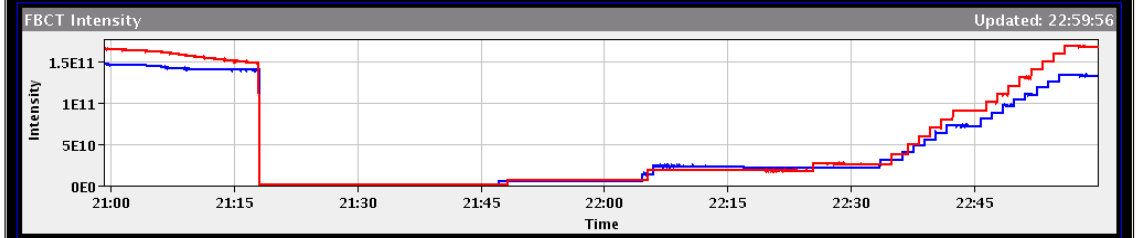
LHC Page1	Fill: 918.0	E: 450 GeV	14-12-2009 22:59:56

BEAM SETUP: INJECTION PROBE BEAM

BCT TI2:	0.00e+00	BCT TI8:	0.00e+00	I(B1):	1.69e+11	I(B2):	1.85e+11

TED TI2 position:	BEAM	TED TI8 position:	BEAM

TDI P2 gaps/mm	upstream:	9.45	downstream:	9.43
TDI P8 gaps/mm	upstream:	8.50	downstream:	8.55



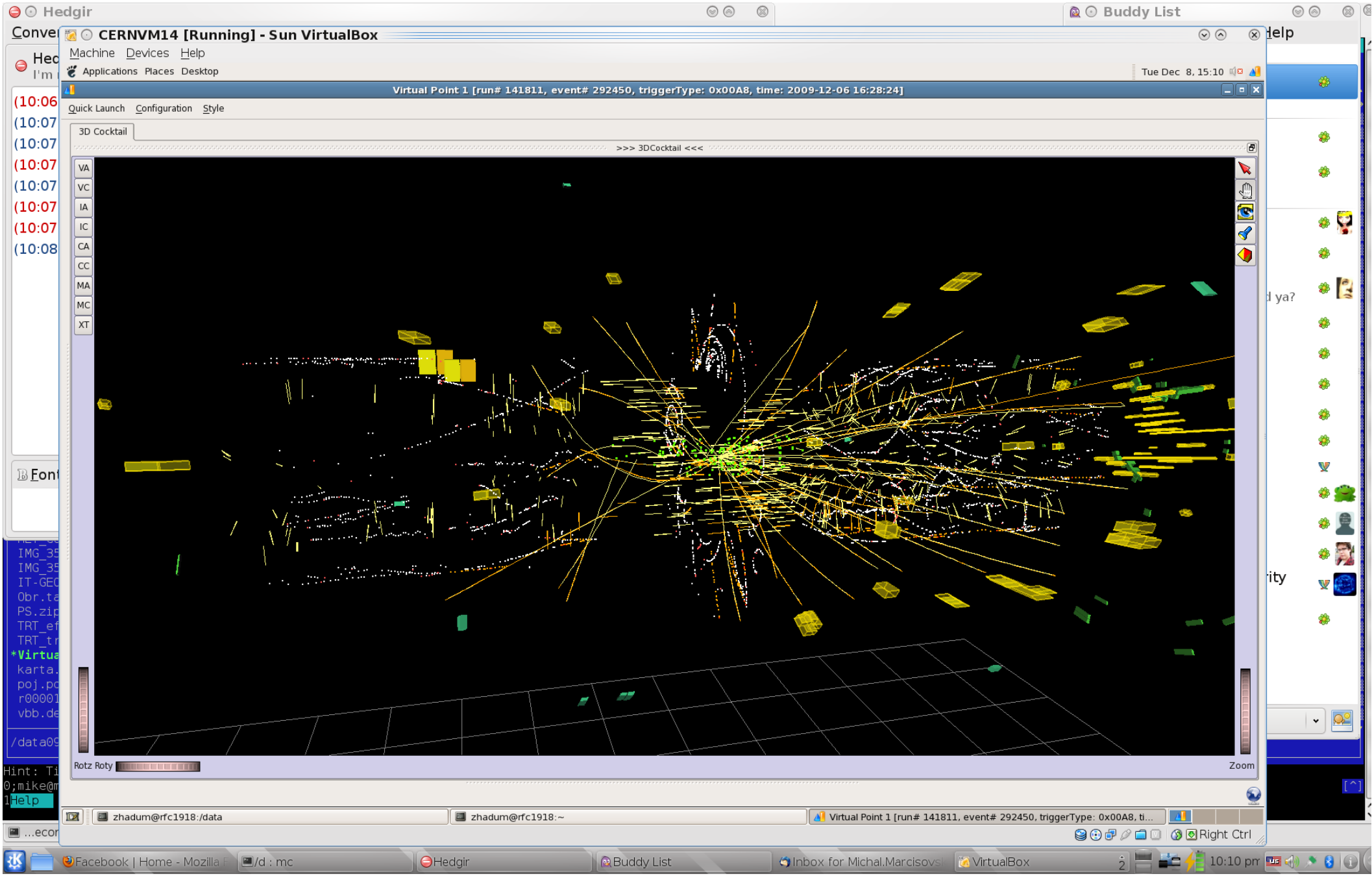
Comments 14-12-2009 22:59:14 :	SMP Flags	B1	B2
16x16 injected	Channel Link Status A-B B-A	false	false
Collapsing separation bumps	Global Beam Permit	true	true
	Setup Beam	true	true
	Beam Presence	true	true
	Moveable Devices Allowed In	false	false
	Stable Beams	false	false

LHC Operation in CCC : 77600, 70480	PM Status B1	ENABLED	PM Status B2	ENABLED

by E.Matli

Done

OP Vistars - Mozilla Firefox | B5 : bash | rybinin | Buddy List | Inbox for Michal.Marcisovsky@ce | 01:12 am


Hedgir
Buddy List
CERNVM14 [Running] - Sun VirtualBox
Machine Devices Help
Applications Places Desktop
Tue Dec 8, 15:10
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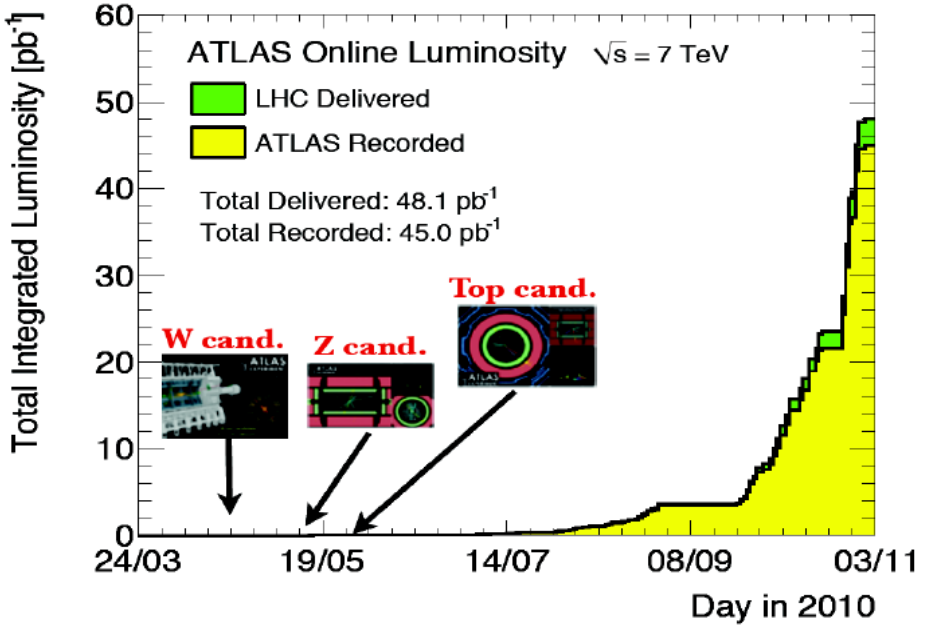
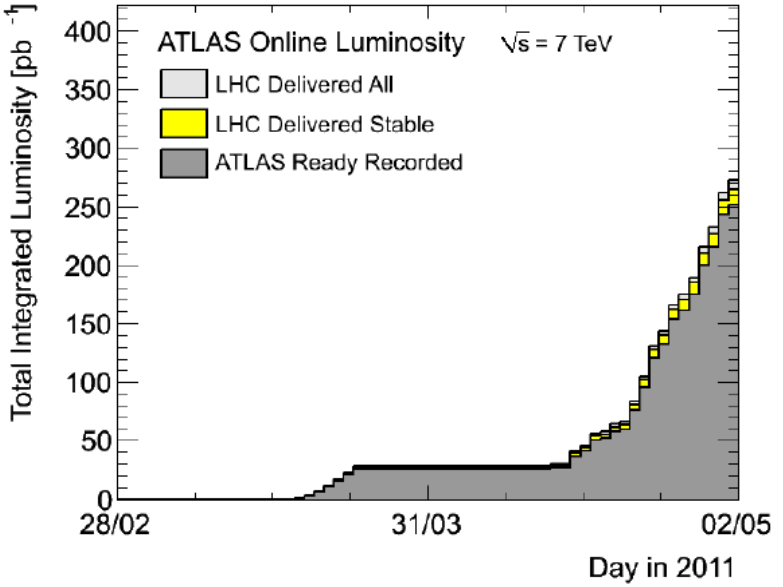
Quick Launch Configuration Style
3D Cocktail
>>> 3DCocktail <<<
VA
VC
IA
IC
CA
CC
MA
MC
XT
Rotz Roty
Zoom
zhadum@rfc1918:/data
zhadum@rfc1918:~
Virtual Point 1 [run# 141811, event# 292450, triggerType: 0x00A8, ti...
Right Ctrl
Facebook | Home - Mozilla
/d : mc
Hedgir
Buddy List
Inbox for Michal.Marcisovs
VirtualBox
10:10 pm

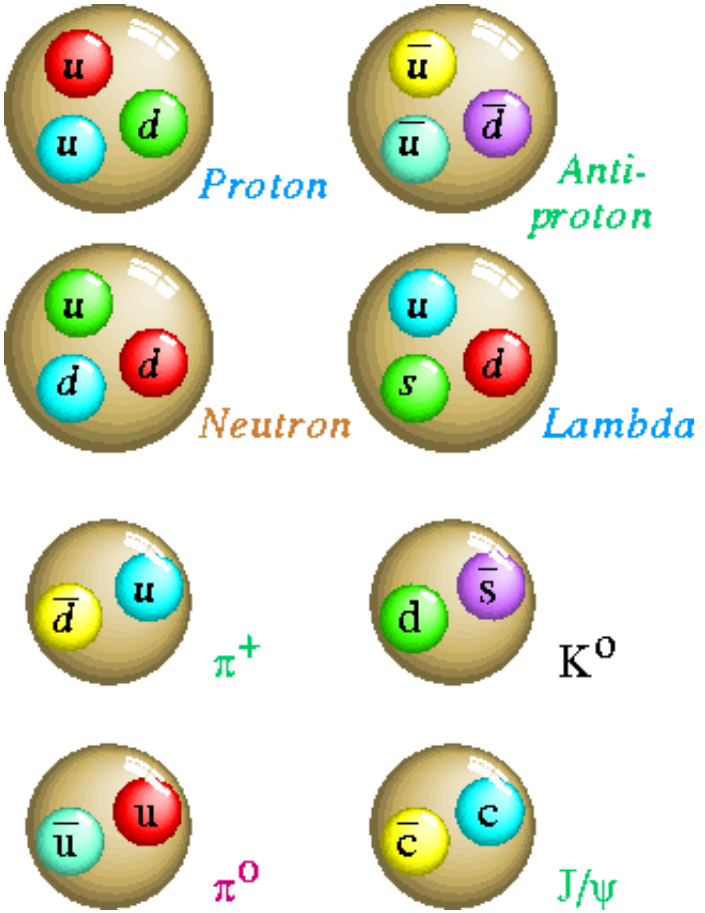


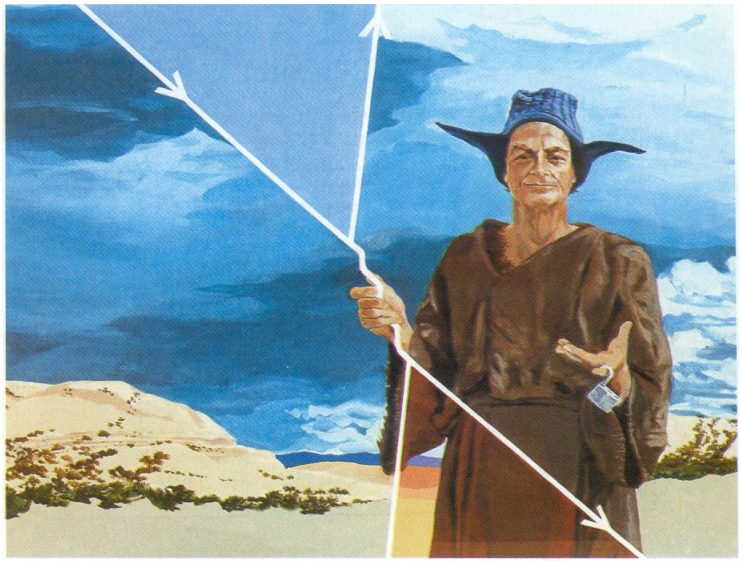


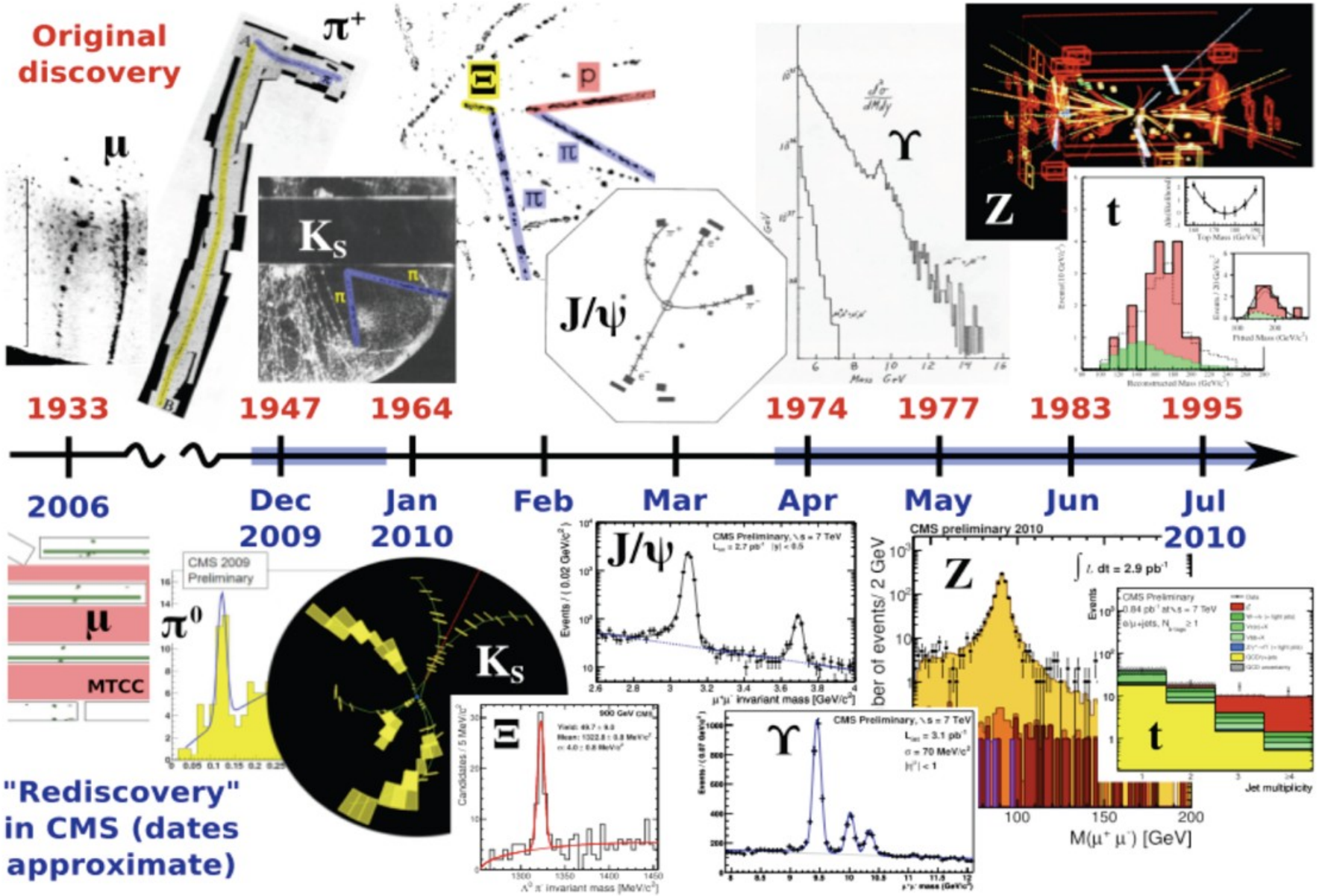
2010 was a great year

- Calibrating ATLAS at 7 TeV
- “Rediscovering” the SM.
- The first W, Z, top candidates observed one year ago
- Lots of data in uncharted territory, 35-40 pb^{-1} for analyses

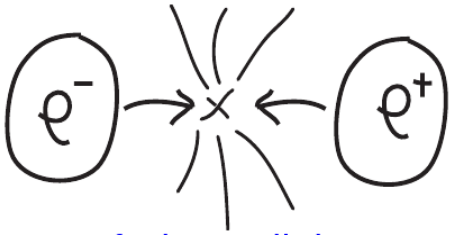

Quarks
Leptons
Bosons
up
down
electron
neutrino e
photon
charm
strange
muon
neutrino μ
gluon
Z⁰ W±
top
beauty
tau
neutrino τ
Higgs


u
d
u
Proton
ū
d̄
ū
Anti-proton
u
d
d
Neutron
u
s
d
Lambda
d̄
u
π+
d
s̄
K⁰
ū
u
π⁰
c̄
c
J/ψ



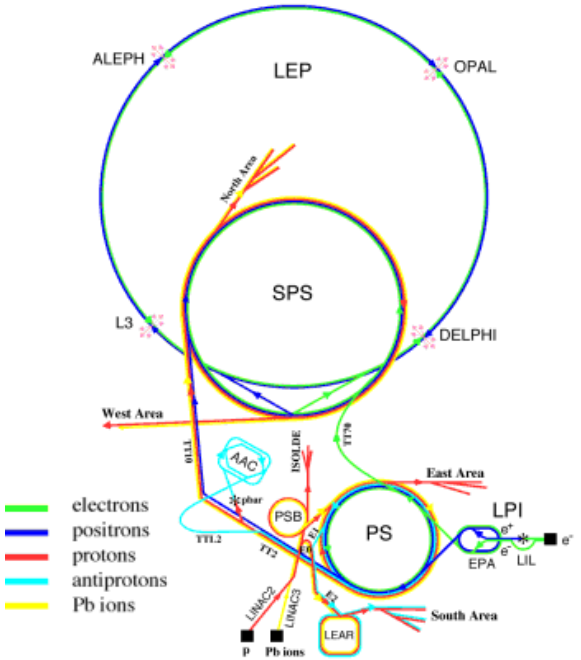

Original discovery
μ
π+
Ks
π
π
Ξ
p
π
π
J/ψ
Υ
Z
t
1933
1947
1964
1974
1977
1983
1995
2006
Dec 2009
Jan 2010
Feb
Mar
Apr
May
Jun
Jul 2010
μ
MTCC
CMS 2009 Preliminary
π0
Ks
J/ψ
CMS Preliminary, √s = 7 TeV
μ+μ- invariant mass [GeV/c2]
CMS preliminary 2010
Z
t
Jet multiplicity
M(μ+ μ-) [GeV]
Ξ
Λ0 π- invariant mass [MeV/c2]
Υ
CMS Preliminary, √s = 7 TeV
"Rediscovery" in CMS (dates approximate)

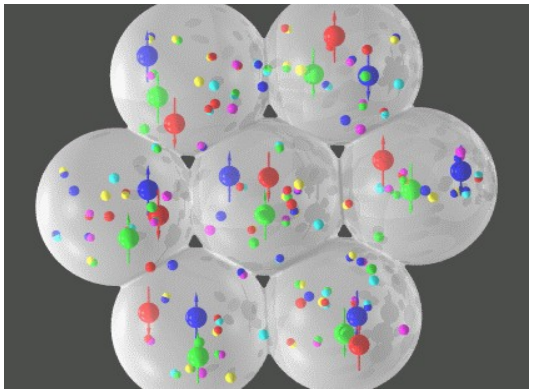
Hadrónové vs leptónové collidery

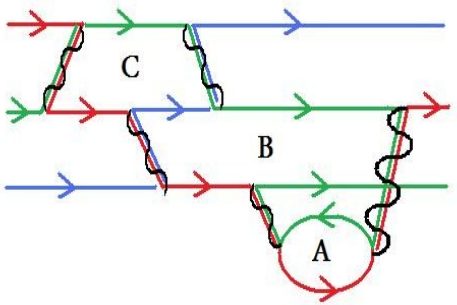


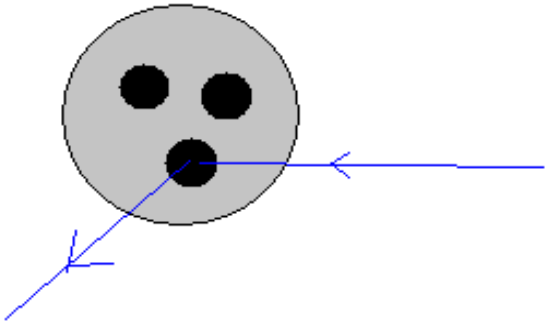
- Precízne energetické scany.
- Při vyšších energiách stráta energie vyžarovaním.

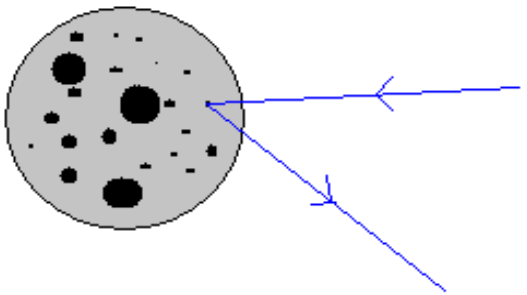
- Distribúcia energie medzi partóny. (PDF)
- S jednou energiou scanovanie širokého spektra energií.

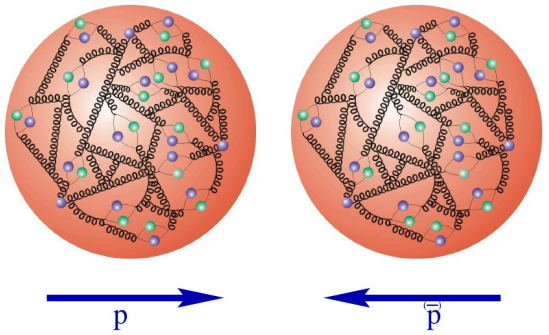


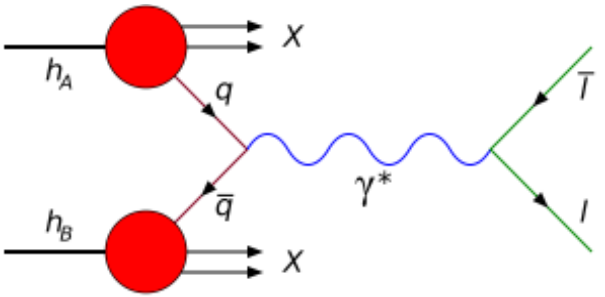


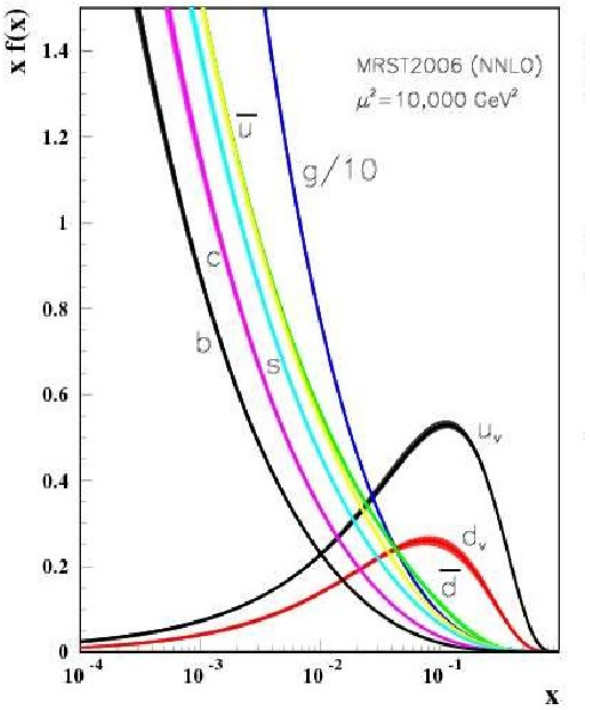




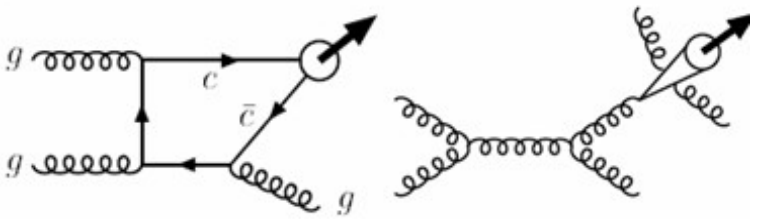


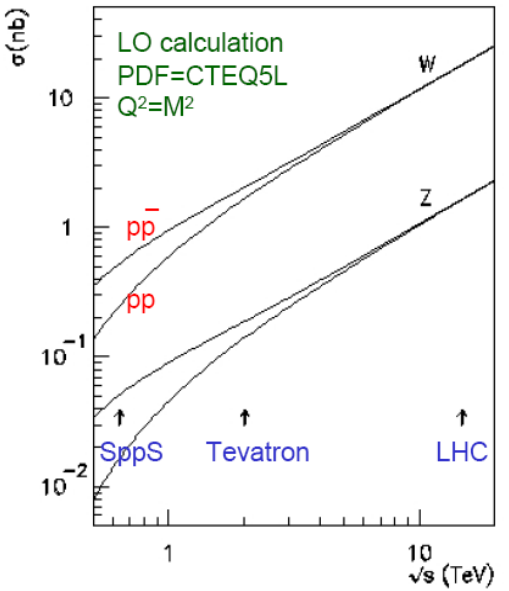




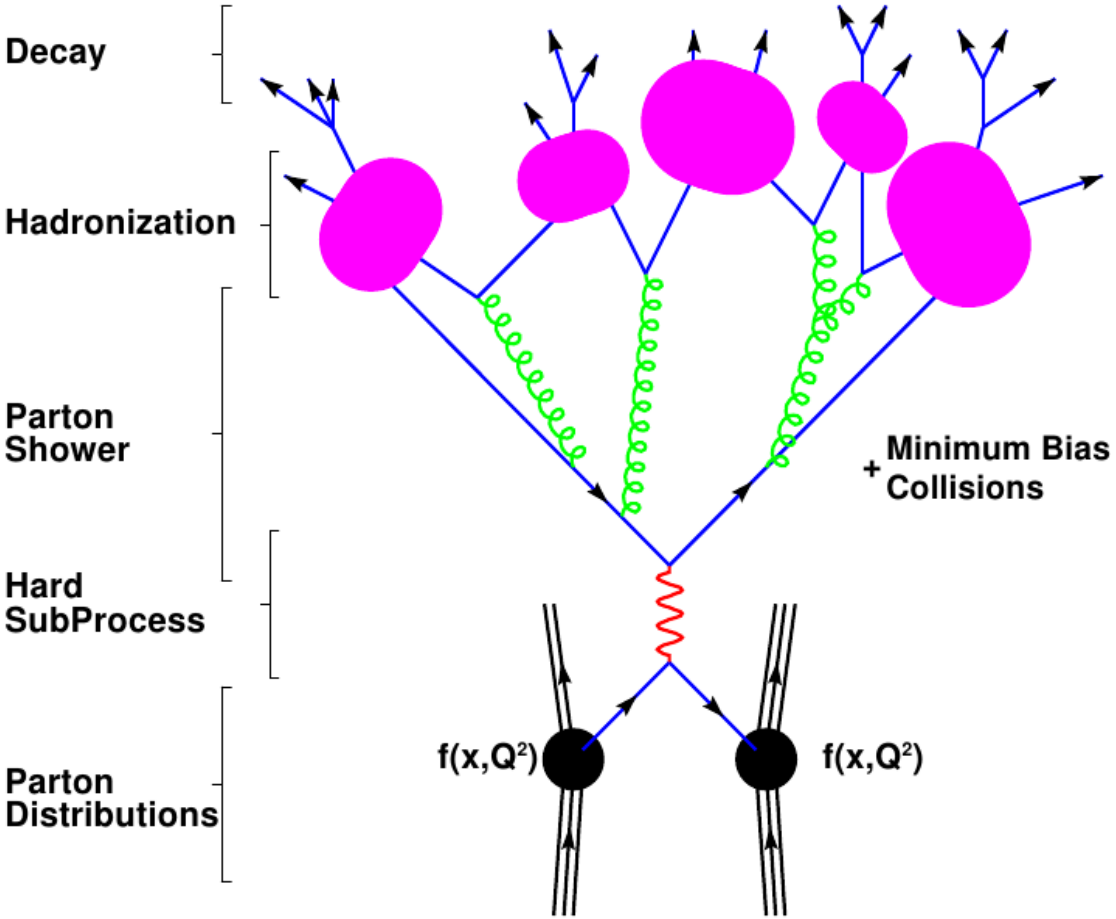


$$\sigma_X = \sum_{a,b} \int_0^1 dx_a dx_b f(x_a, flav_a, Q^2) f(x_b, flav_b, Q^2) \cdot \sigma_{ab\to X}(x_a, x_b, Q^2).$$

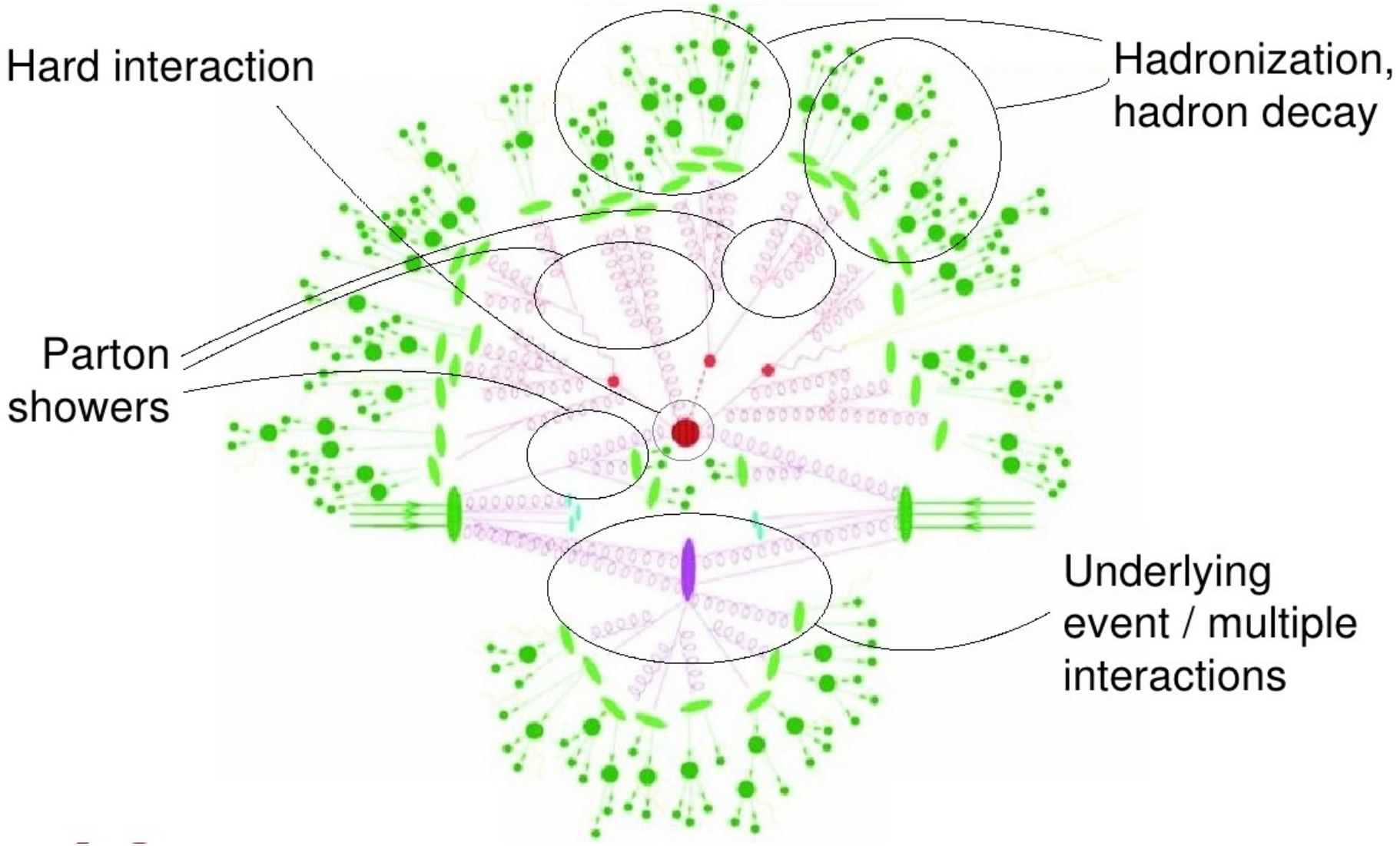


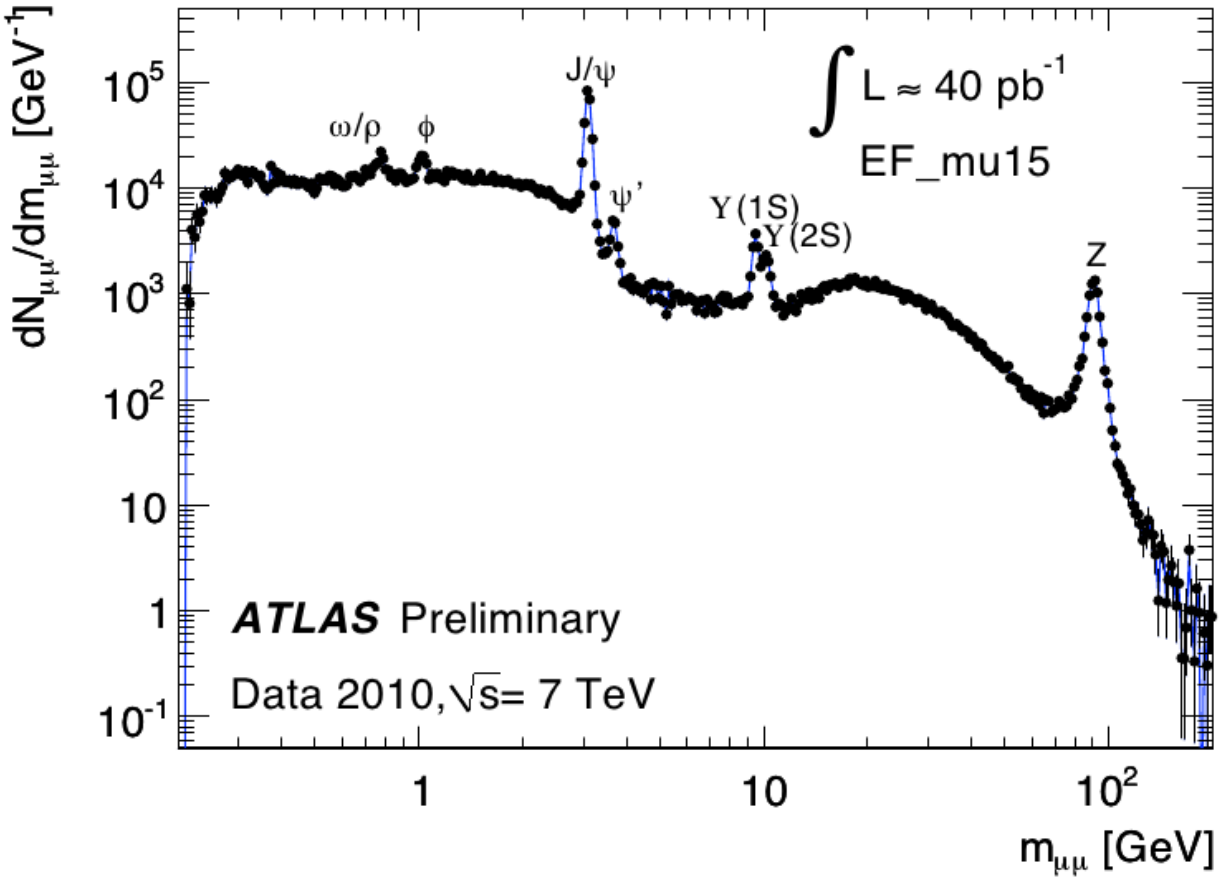


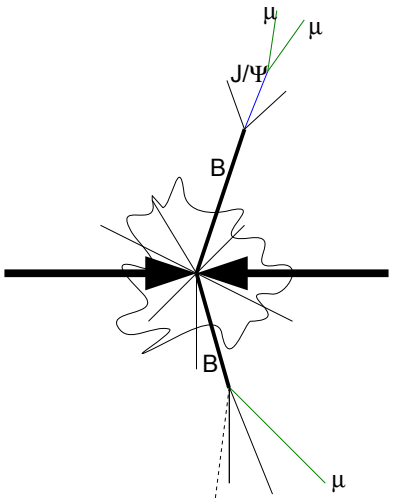
- In principle want to annihilate particles with antiparticles
- Generation of antiprotons is very expensive and limits luminosity
- At high energy PDFs anyway dominated by gluon and sea-quarks
- (almost) no difference between pp and $p\bar{p}$ cross sections

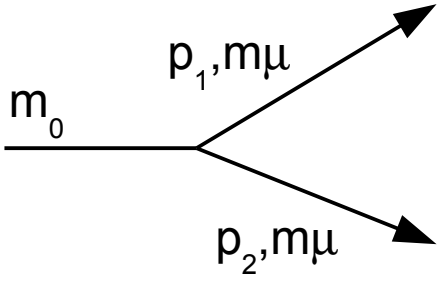

Decay
Hadronization
Parton
Shower
Hard
SubProcess
Parton
Distributions
+ Minimum Bias
Collisions
f(x,Q²)
f(x,Q²)

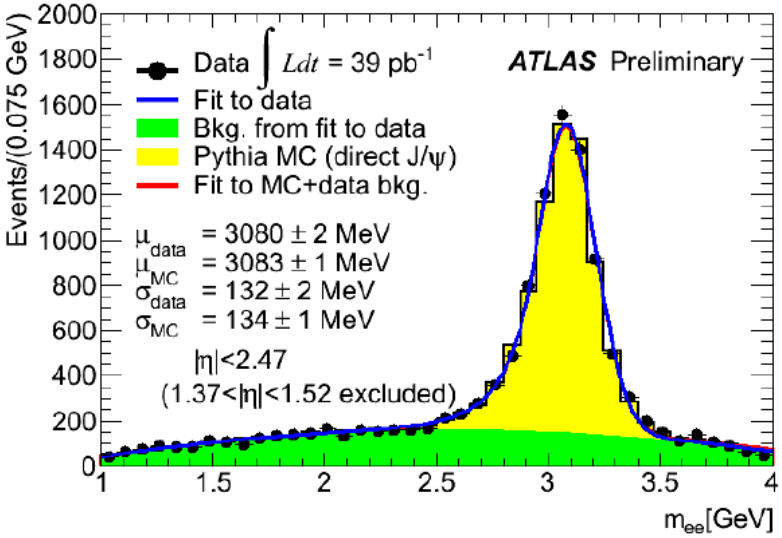
Simulation of LHC collision











$$m_0^2 = E^2 - p^2$$

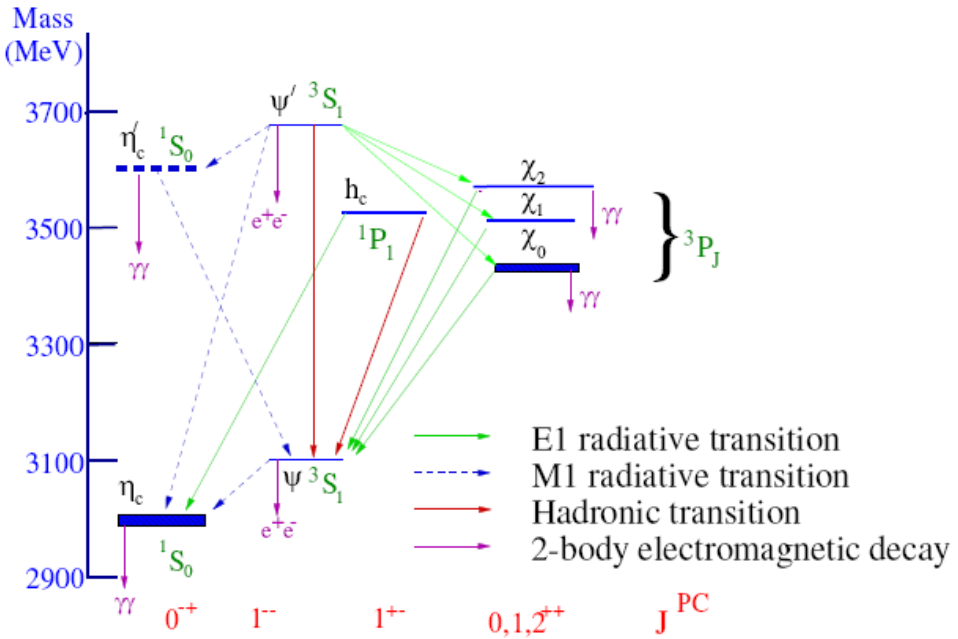
$$m_0^2 = (E_1 + E_2)^2 - (p_1 + p_2)^2$$

$$m_0^2 = \left(\sqrt{p_1^2 + m_\mu^2} + \sqrt{p_2^2 + m_\mu^2}\right)^2 - (p_1 + p_2)^2$$

$$m_0^2 = \left(p_1^2 + p_2^2 + 2m_\mu^2 + 2\sqrt{p_1^2 + m_\mu^2}\sqrt{p_2^2 + m_\mu^2}\right) - \left(p_1^2 + p_2^2 + 2p_1 \cdot p_2\right)$$

$$m_0^2 = \left(2m_\mu^2 + 2\sqrt{p_1^2 + m_\mu^2} \cdot \sqrt{p_2^2 + m_\mu^2}\right)^2 - (2p_1\, p_2)\cos(\alpha)$$

Charmonium is a bound state of a charmed quark and antiquark. It is "almost nonrelativistic": $\beta \sim 0.4$:
Hence the hydrogen atom-like spectrum

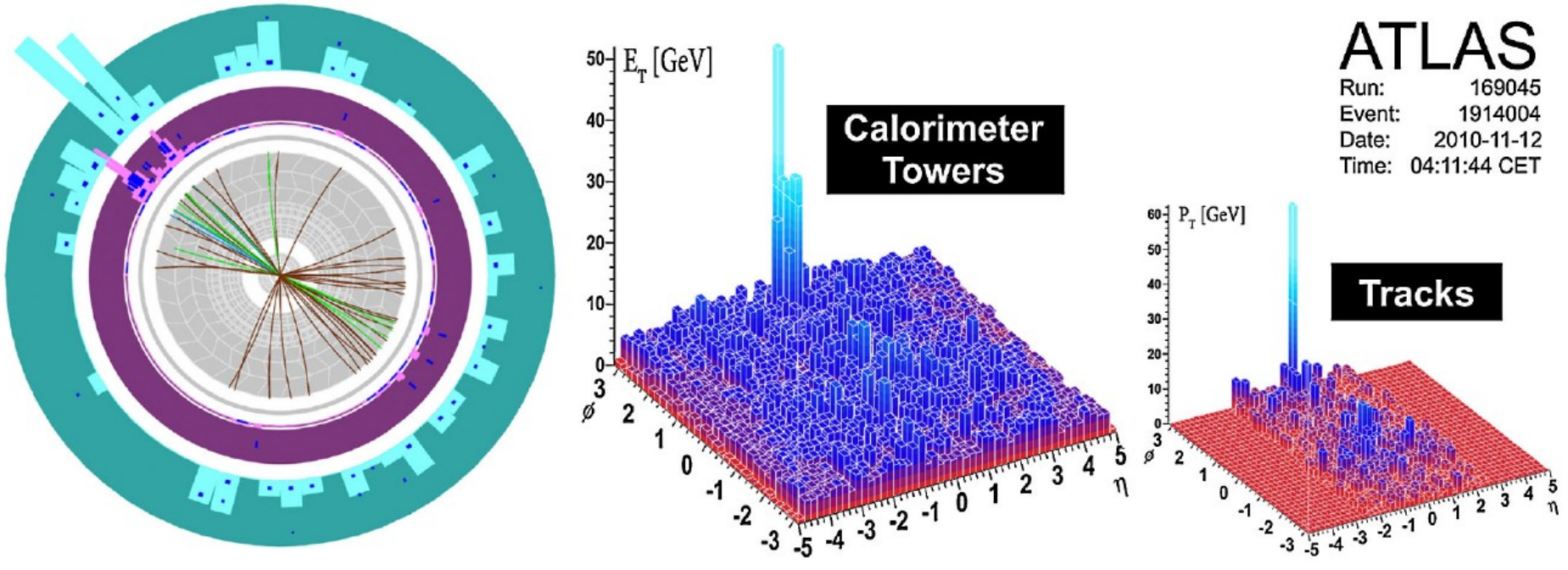


m_0 [MeV]	Γ [MeV]	$J^{PC} = 0^{+-}$	1^{--}	$0, 1, 2^{++}$	1^{+-}
2979.6	17.3	$\eta_c(1^1S_0)$			
3096.91	0.091		$J/\Psi(1^3S_1)$		
3415.19	10.1			$\chi_{c0}(1^3P_0)$	
3510.59	0.91			$\chi_{c1}(1^3P_1)$	
3526.21	< 1.1				$h_c(1^1P_1)$
3556.26	2.11			$\chi_{c2}(1^3P_2)$	
3654	~ 17	$\eta_c'(2^1S_0)$			
3686.09	0.281		$\Psi'(2^3S_1)$		
~ 3740	——— $D\bar{D}$-threshold ———				
3770.0	23.6		$\Psi(3770)(3^3S_1)$		
4040	52		$\Psi(4040)(4^3S_1)$		
4160	78		$\Psi(4160)(5^3S_1)$		
4415	43		$\Psi(4415)(6^3S_1)$		

$$J/\psi = {}^3S_1 \qquad J^{PC} = 1^{--}$$

Means:
- Spin=1 (3 = 2 x 1 + 1, (2S+1))
- Orbital Ang. Mom. = 0 (S,P,D,F,...)
- Total J/ψ angular momentum = 1 (j=s+l)

Means:
- Total J/ψ Spin = 1
- Parity is Odd
- Charge Conjugation is Odd



Collisions of heavy ions at ultrarelativistic energies are expected to produce an evanescent hot, dense state, with temperatures exceeding 2 $\times 10^{12}$ K, in which the relevant degrees of freedom are not hadrons but quarks and gluons. In this medium, high-energy quarks and gluons are expected to transfer energy to the medium by multiple interactions with the ambient plasma. There is a rich theoretical literature on in-medium QCD energy loss extending back to Bjorken, who proposed to look for ‘‘jet quenching’’ in proton-proton collisions.

The LHC heavy ion program was foreseen to provide an opportunity to study jet quenching at much higher jet energies than achieved at the Relativistic Heavy Ion Collider.

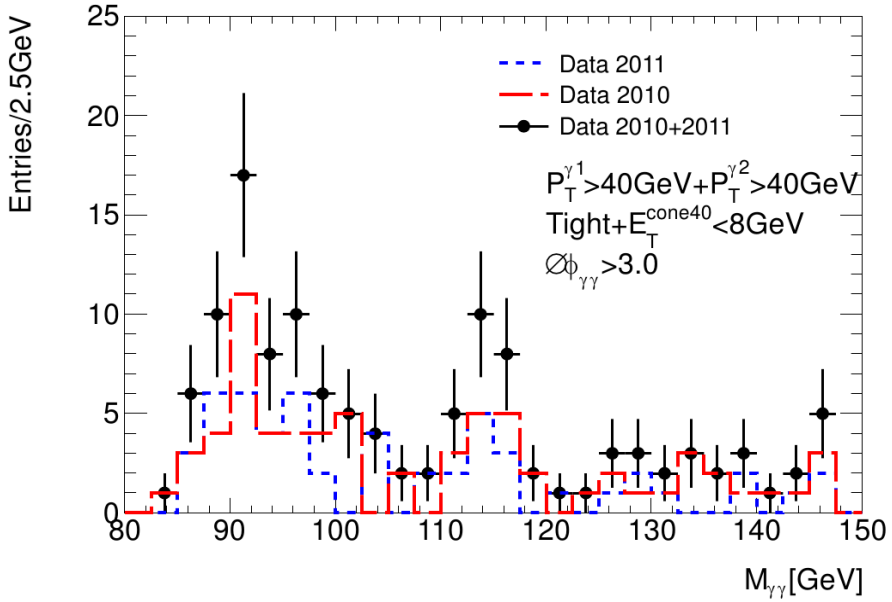
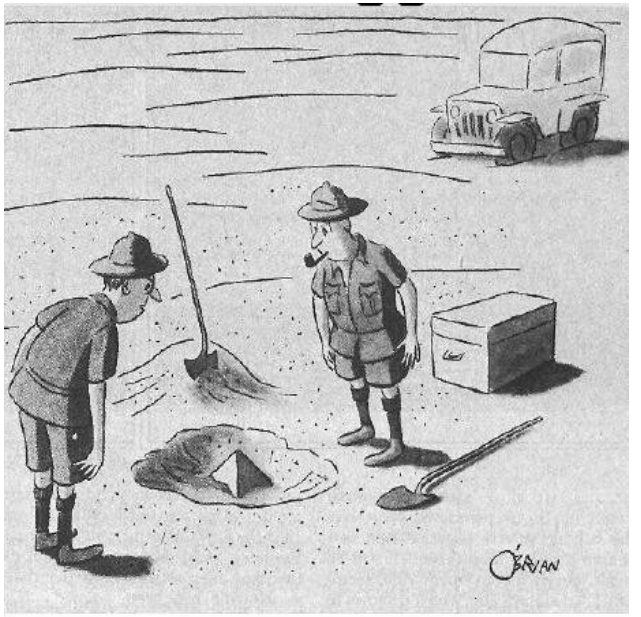


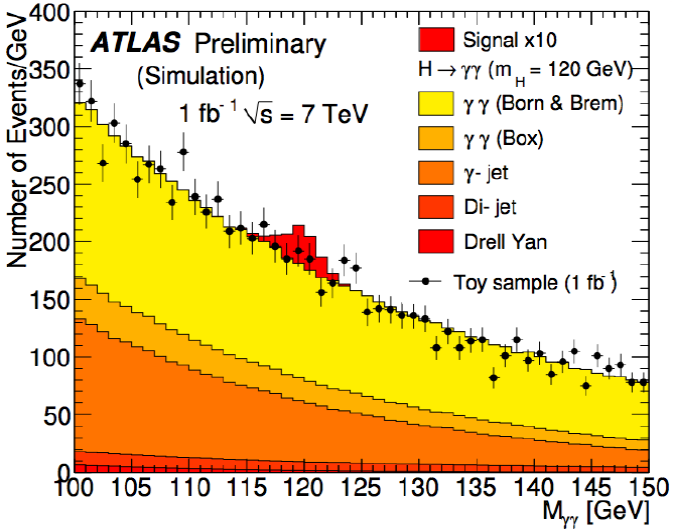
Figure 5: Comparison of the diphoton invariant mass distributions between 2010 (line), 2011 (dashed line), and all data (points).

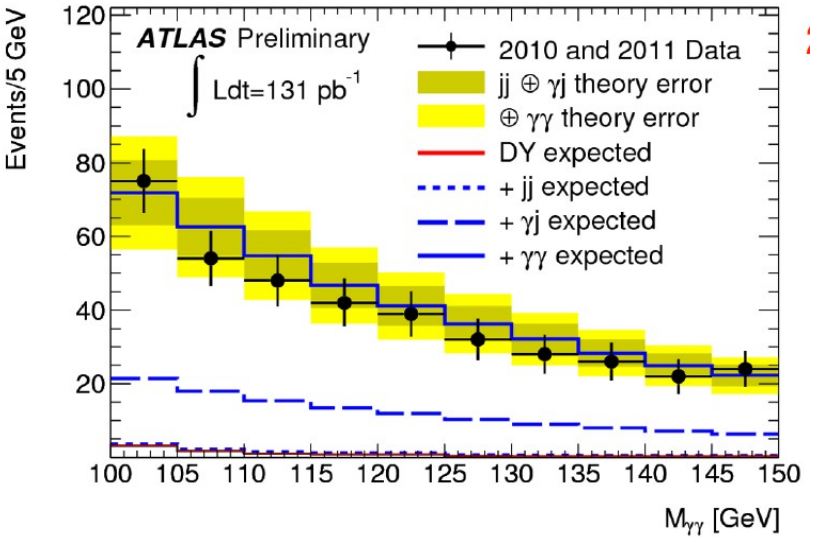
Author(s) Fang, Y (-) ; Flores Castillo, L R (-) ; Wang, H (-) ; Wu, S L (University of Wisconsin-Madison)

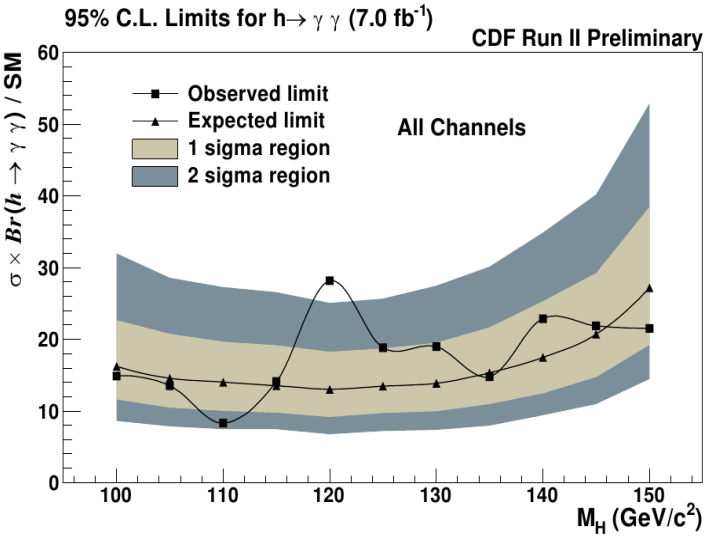


"This could be the discovery of the century. Depending, of course, on how far down it goes."

Gang of four was the name given to a political faction composed of four Chinese Communist Party officials. They came to prominence during the Cultural Revolution (1966–76) and were subsequently charged with a series of treasonous crimes. The name was given to the group by Mao Zedong in what seemed like a warning to Jiang Qing during which Mao stated, "Do not try to begin a gang of four to accumulate power".





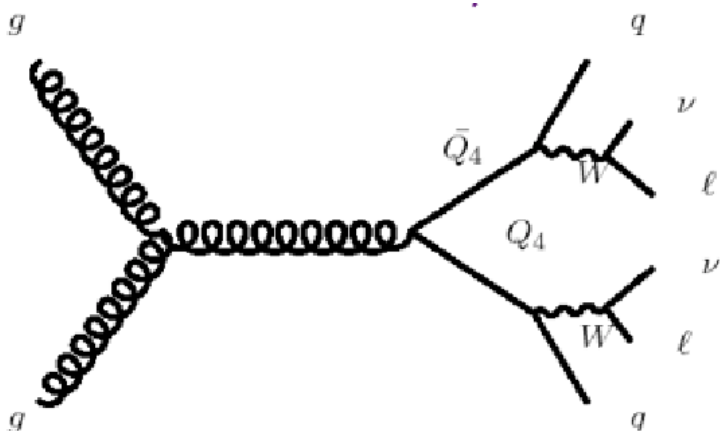


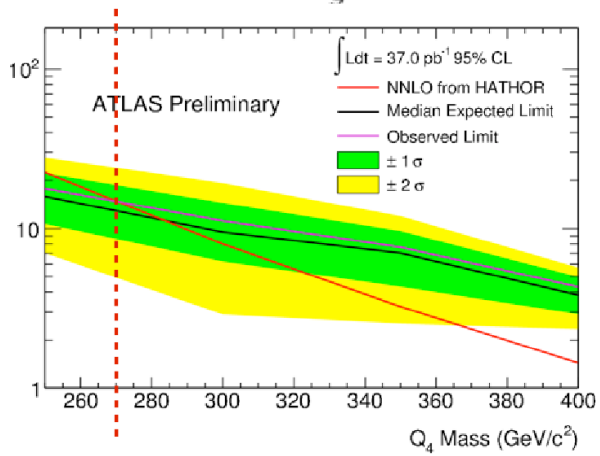
With few inverse pico-barns of integrated luminosity ATLAS has already been able to produce high quality results, competitive with searches performed at other facilities O(1-3) fb-1 are expected in 2011 and more in 2012 → full access to the multi-TeV scale

WWjj

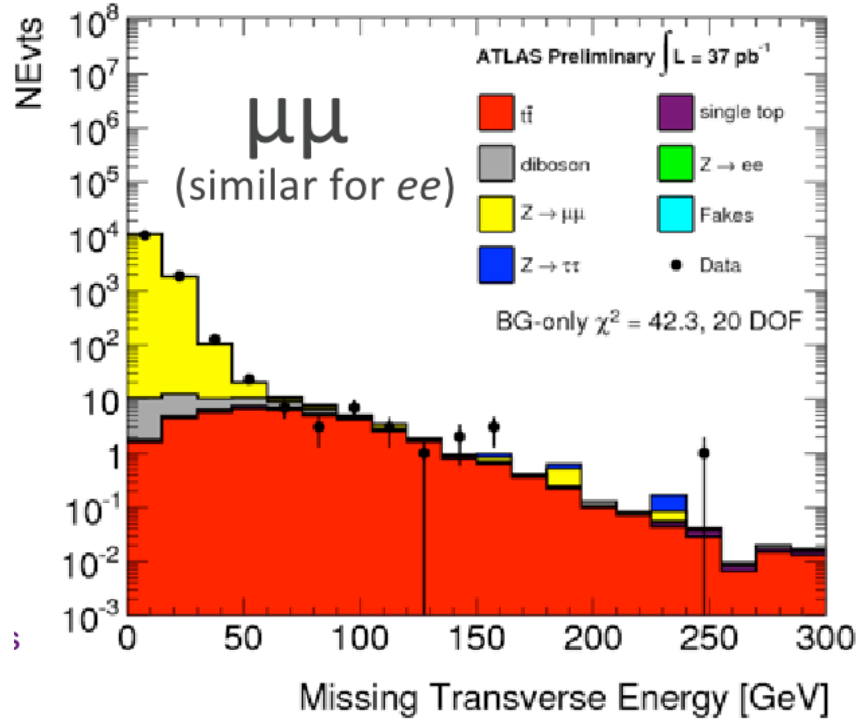
Search for 4th quark generation
all leptonic (e and μ)
opposite sign leptons

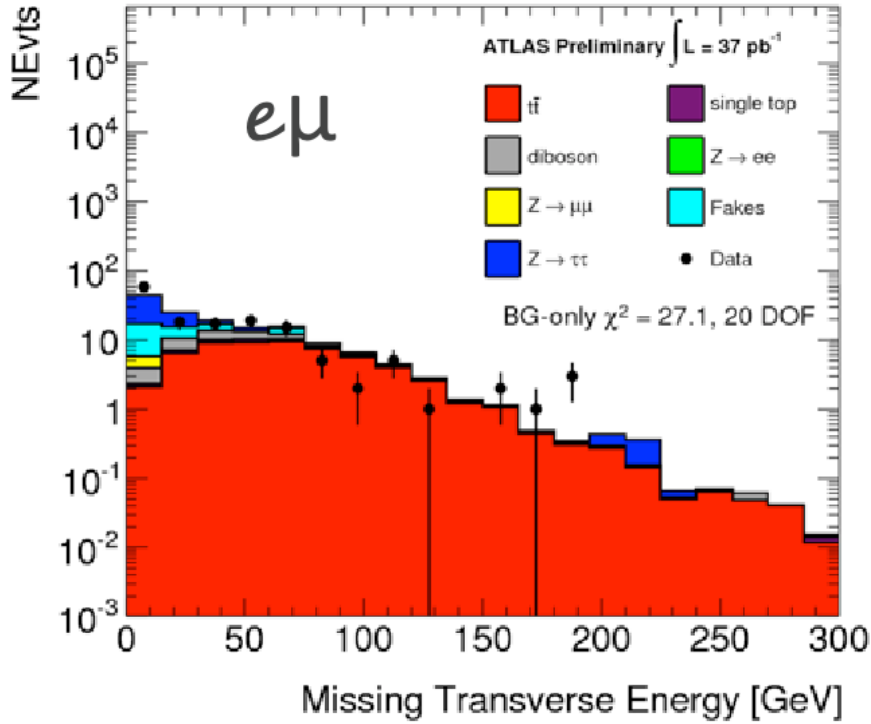
Main background after cuts
t t-bar





m_{Q4} >270 GeV@95% C.L



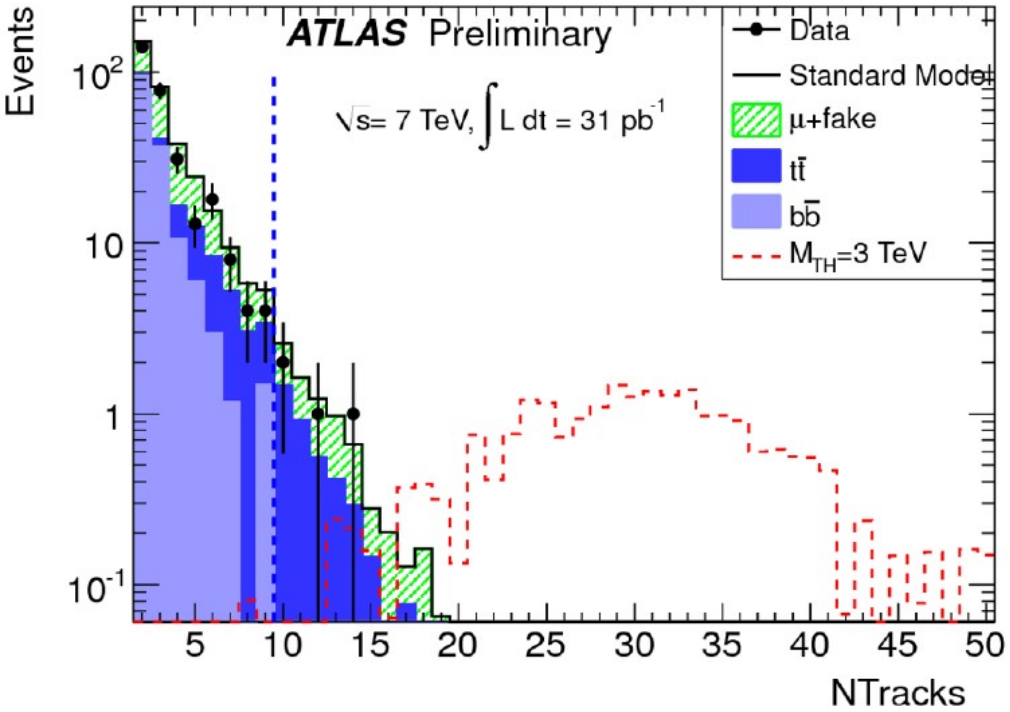


Black holes

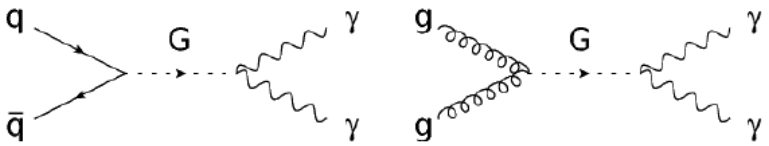
- striking signatures: multiple high pT objects
- background further reduced searching in like-sign di-muon decays

Strategy:

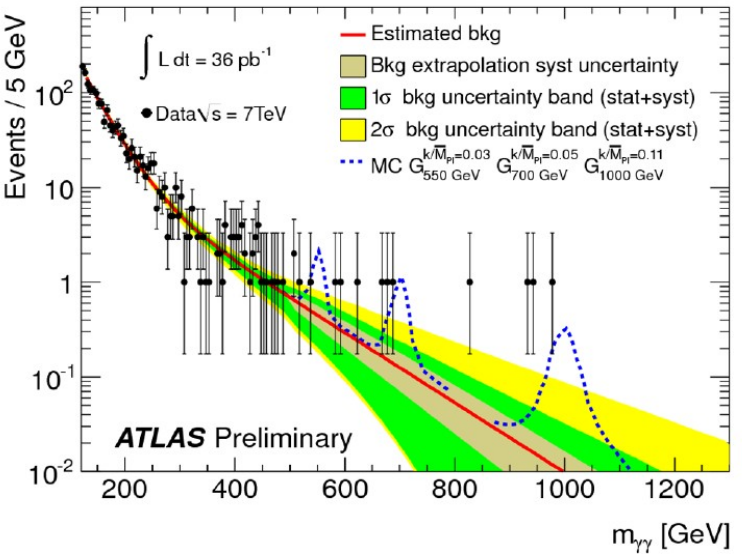
- high pT track multiplicity discriminates signal and background effectively
- counting experiment in a pre-defined signal region
- muon+fake background from data using per-track fake rate
- other backgrounds (tt, bb) from MC

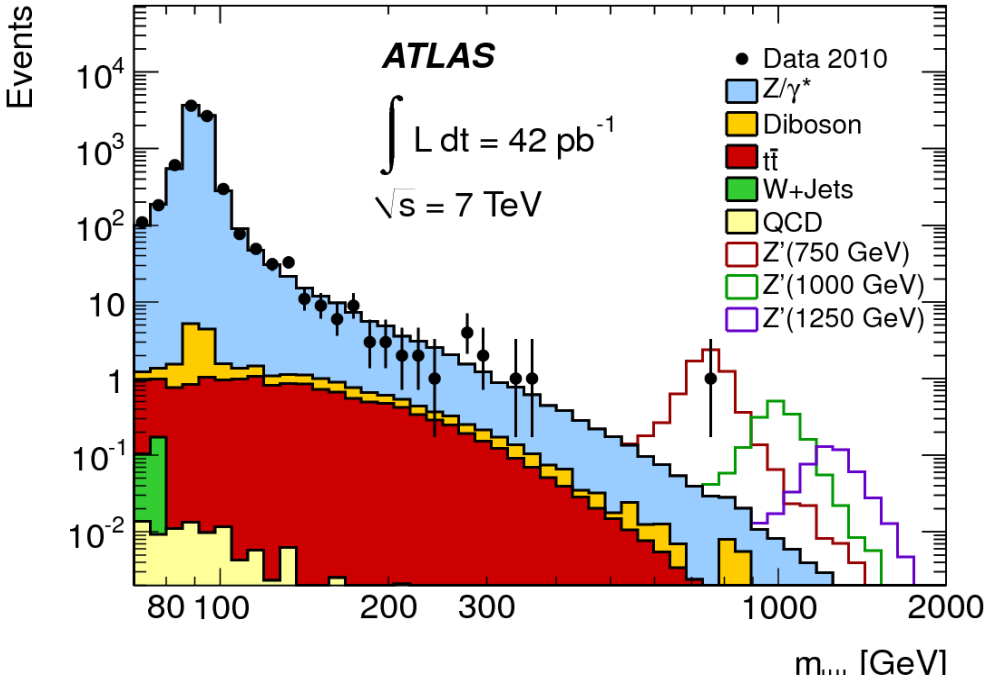


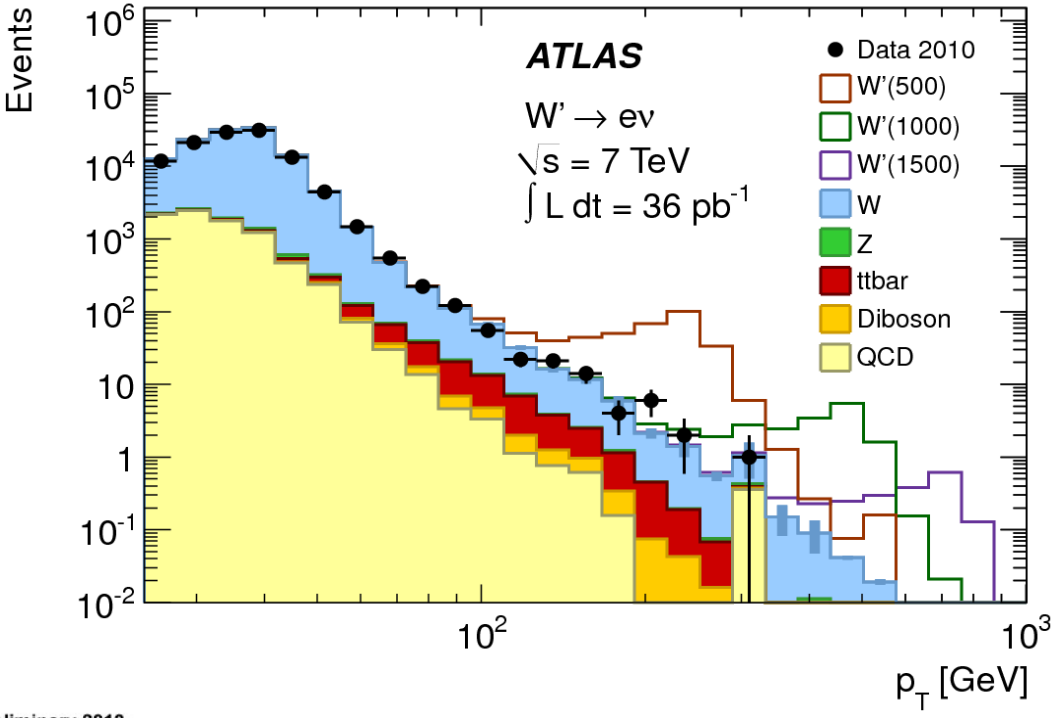
Gravitons

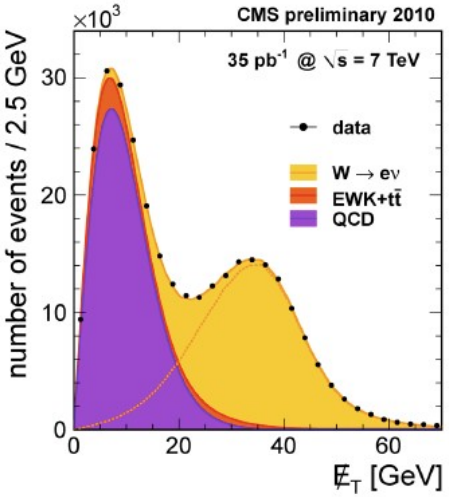


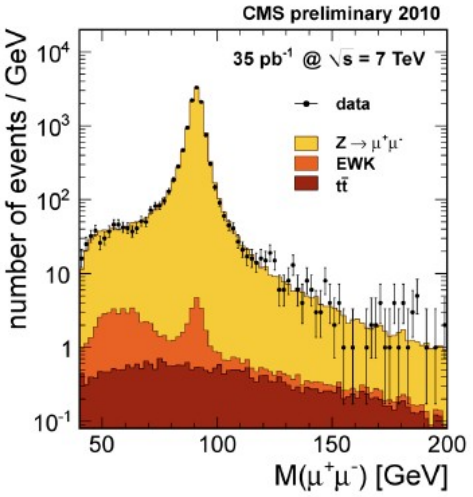
Graviton excitations expected in the di-photon spectrum in R-S warped extra dimension models





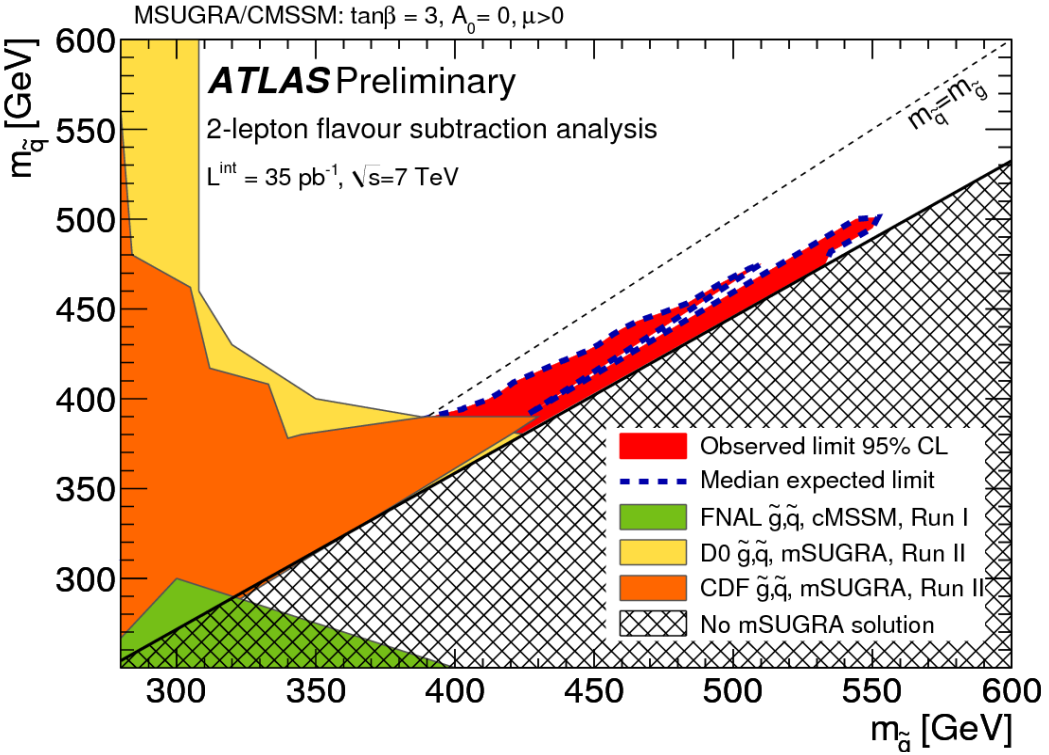


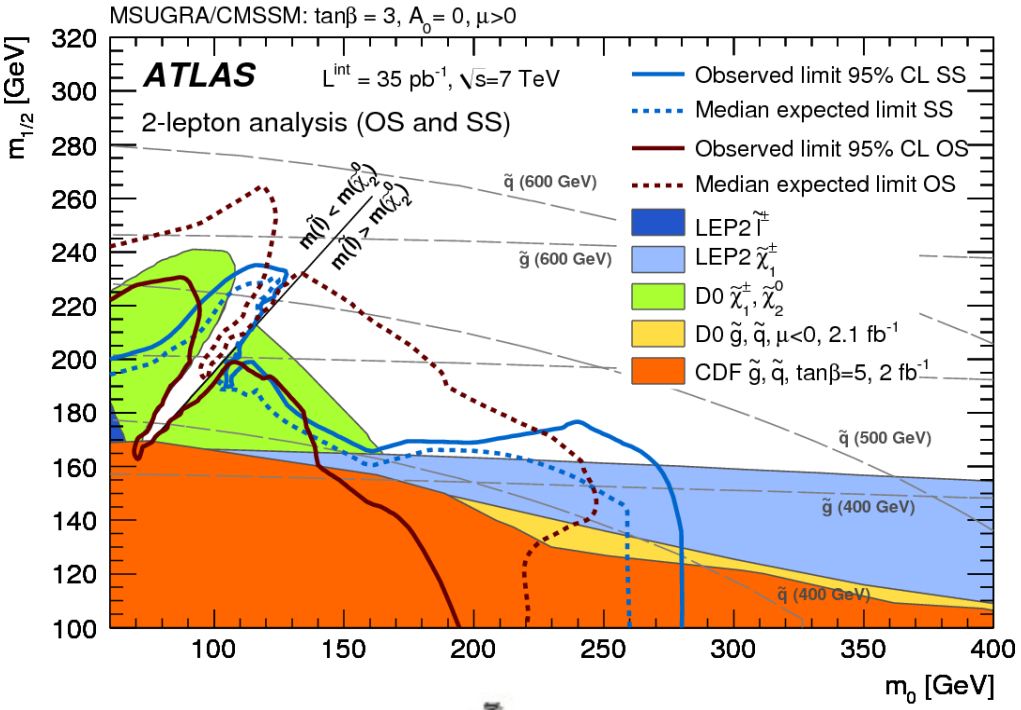




$M_{W'} > 1490$ GeV @95% CL

$M_{Z'} > 1048$ GeV @95% CL





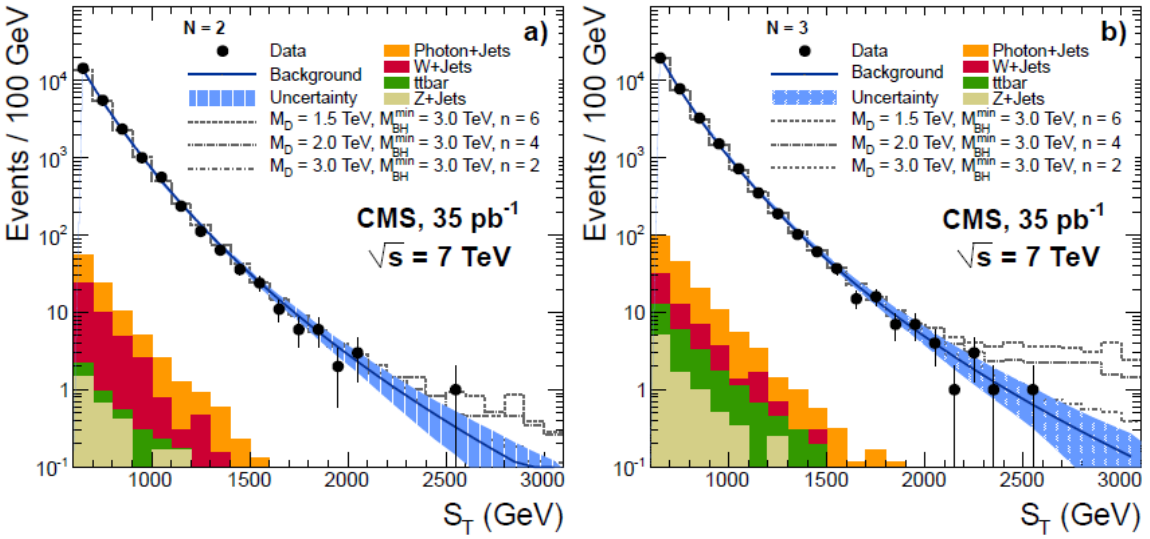
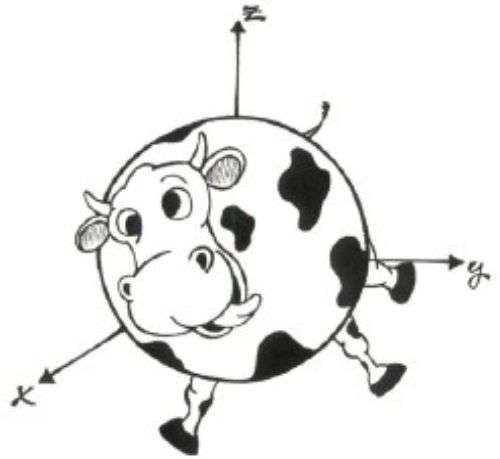
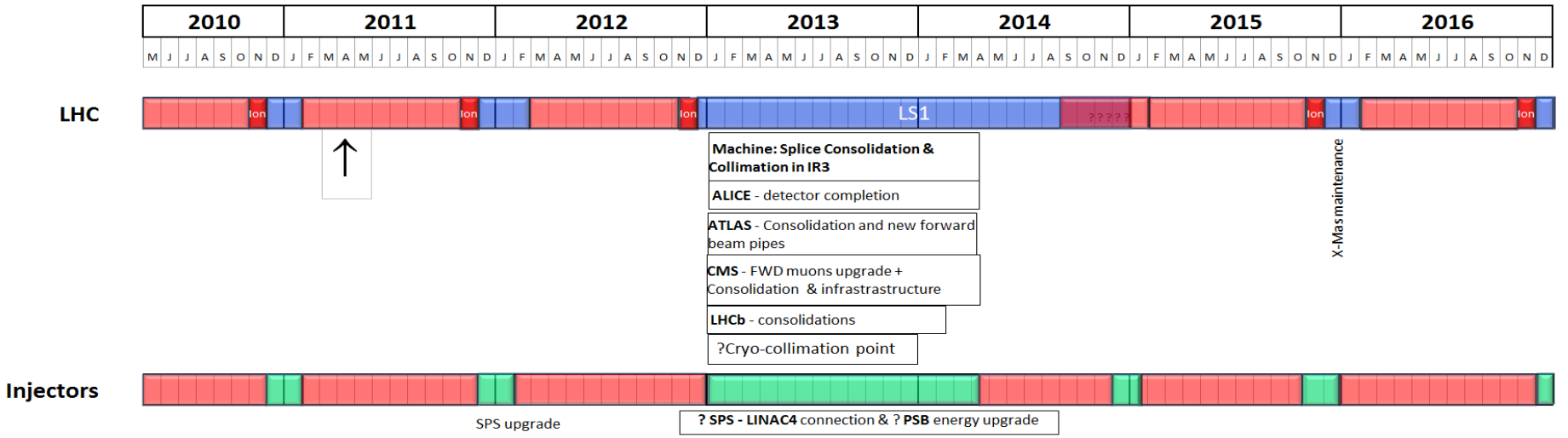


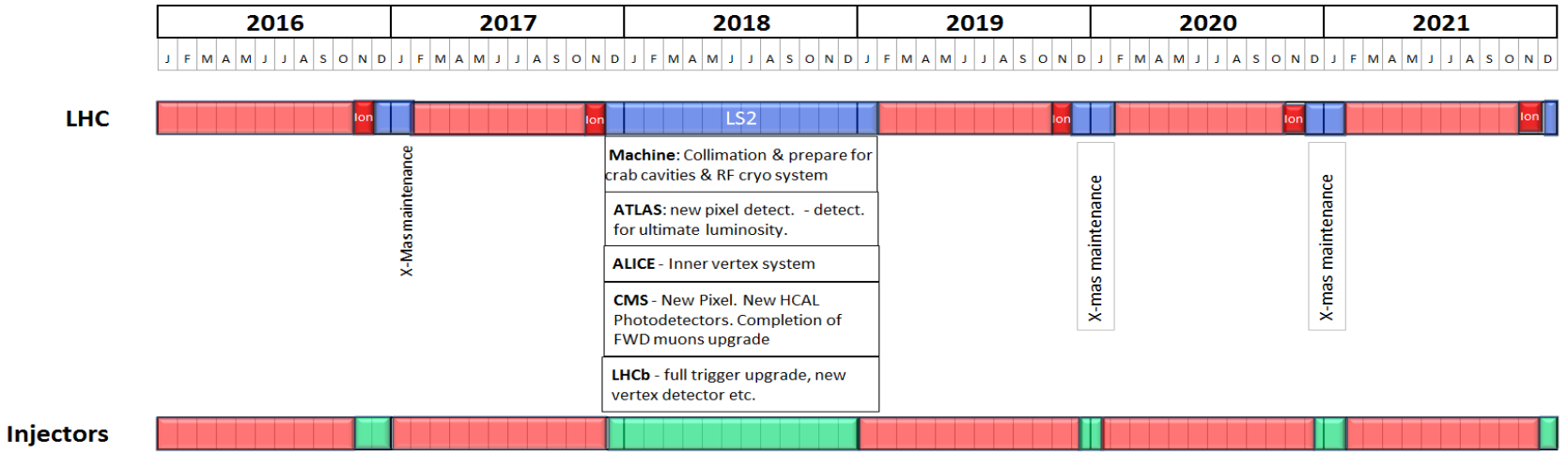
Figure 1: Total transverse energy S_T, for events with the multiplicities of a) $N = 2$, and b) $N = 3$ objects in the final state. Data are depicted as solid circles with error bars; the shaded band is the background prediction obtained from data (solid line) with its uncertainty. Non-multijet backgrounds are shown as colored histograms. Also shown is the predicted black hole signal for three different parameter sets.



We have significant hints for SUSY.
We have significant hints against SUSY.
At some point somebody will understand what is the logic.

New rough draft 10 year plan





Associated LHC parameters

$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y} F = \frac{N^2 k_b f \gamma}{4\pi\beta^* \varepsilon} F$$

Parameter	2010	Nominal	Limited by
Energy	3.5 TeV	7 TeV	Hardware
N (p/bunch)	1.1×10^{11}	1.15×10^{11}	
k_b (no. bunches)	**368 (348 coll/IP)**	**2808**	Machine protection
ε (μm rad)	2.5-5	3.75	
β^* (m)	3.5 (3.5)	0.55 (10)	Aperture, tolerances
Stored energy (MJ)	28	360	
L ($cm^{-2}s^{-1}$)	2×10^{32}	10^{34}	

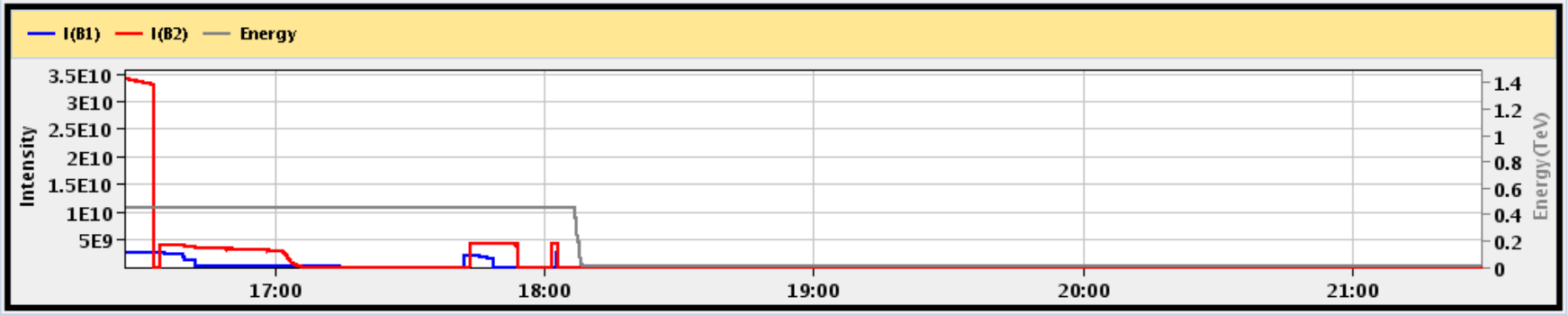
- Squeezing at the IP (β^*) is limited by aperture and tolerances.
  - *Beams are larger at 3.5 TeV ~ 1/γ.*
  - *$\sigma_x = \sigma_y$ = ~45-60 μm - nominal value is 15 μm at 7 TeV.*

16-Dec-2009 21:28:38 | Fill #: 924 | Energy: 0.000 TeV | I(B1): 4.95e+07 | I(B2): 4.99e+07

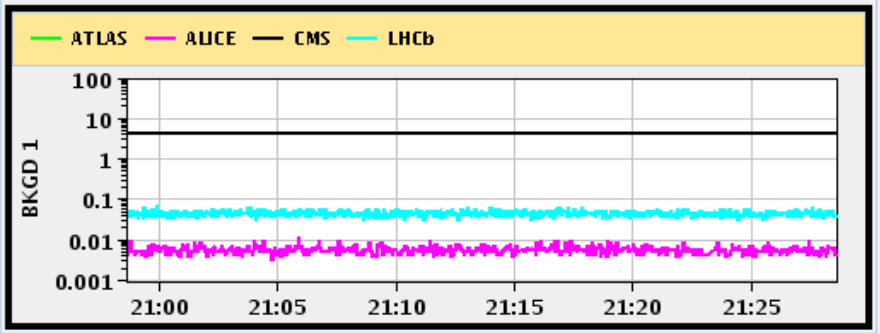
	ATLAS	ALICE	CMS	LHCb
Experiment Status	DRUNK	STANDBY	HIGH	STANDBY
Inst Lumi/CollRate Parameter	0.000e+00	0.000e+00	0.000e+00	9.733e+01
BRAN Count Rate	3.774e-01	7.040e-02	9.962e-01	3.636e-01
BKGD 1	0.000	0.004	4.052	0.038
BKGD 2	4072.500	0.000	0.002	0.050
BKGD 3	0.000	0.011	0.003	0.007

LHCf: No info | No data | LHCb VELO Position: OUT | TOTEM: STANDBY

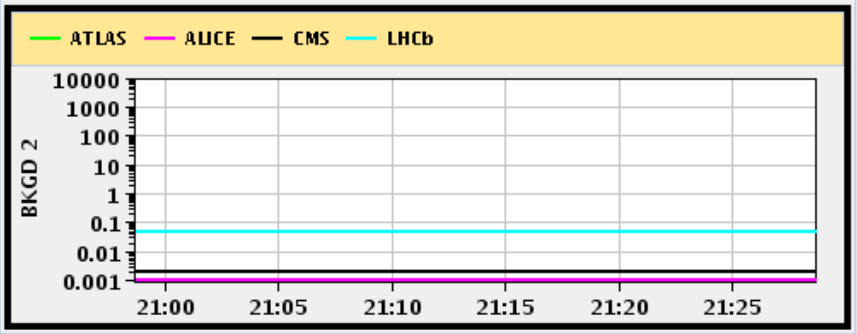
Performance over the last 12 Hrs



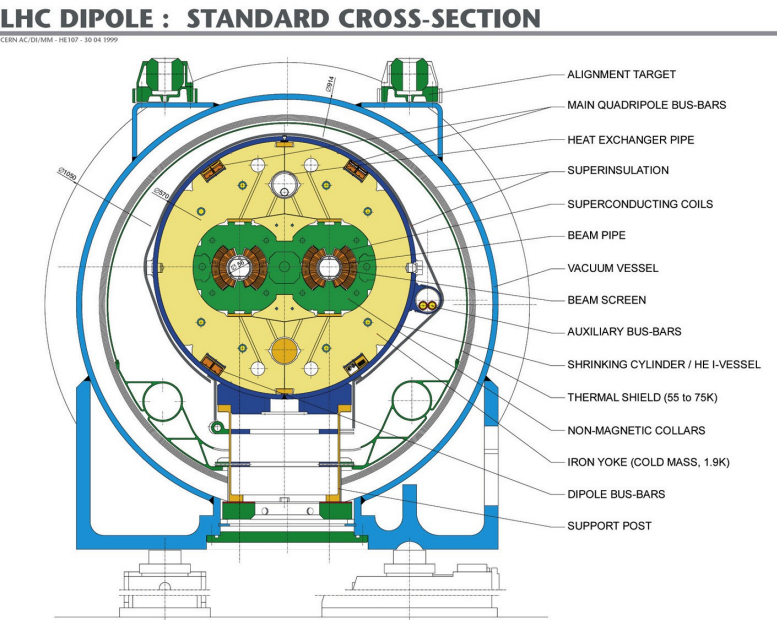
Background 1

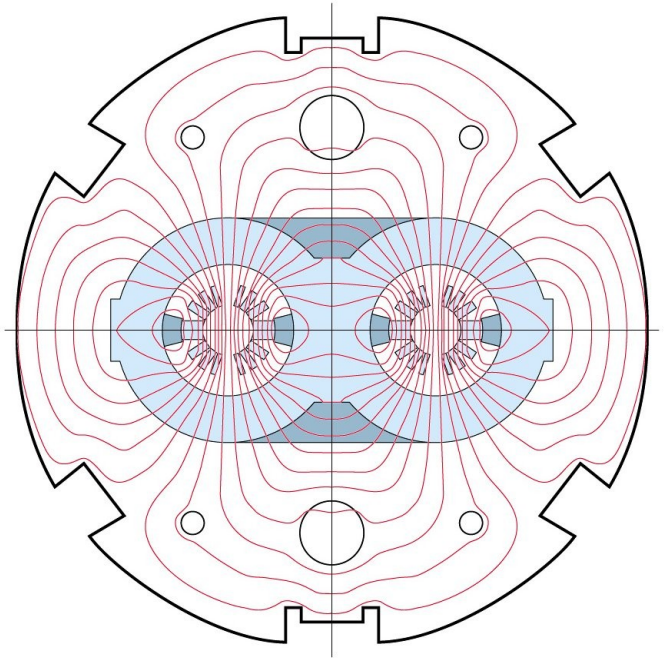


Background 2

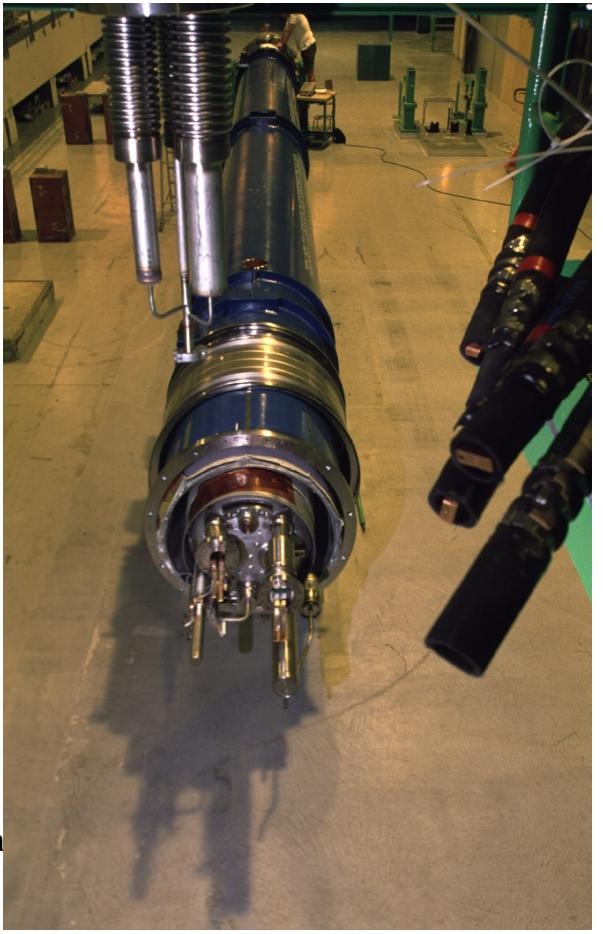


Magnety

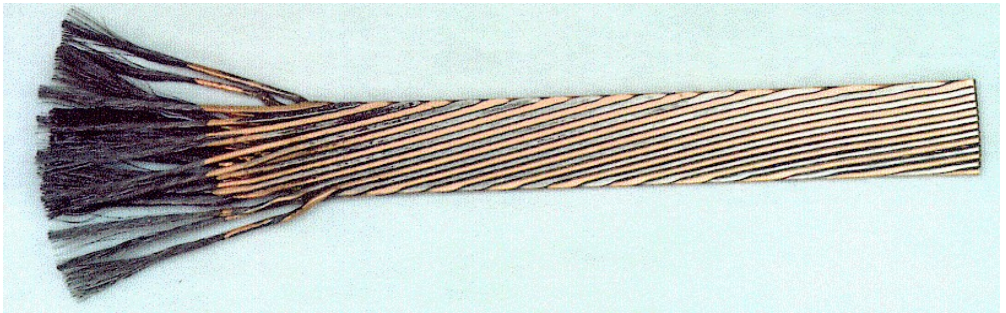


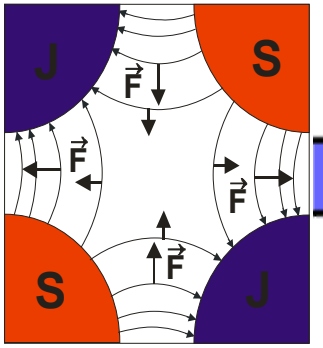


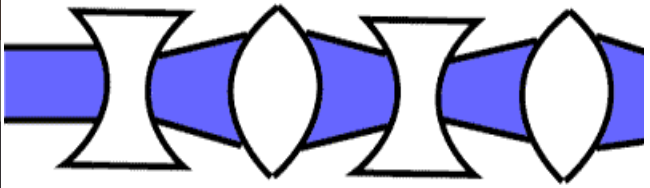
Computed magnetic flux map at B_0=10 Tesla



1232 Dipole magnets
Length about 15 m
Magnetic Field 8.3 T
Two beam-tubes with an opening of 56 mm







Forward spectrometer

$2 < \eta < 5.3$