LHC a detektor ATLAS
stav a nová fyzika

Michal Marcisovsky, FzU AV CR, v.v.i. & FJFI CVUT

CERN

European Organization for Nuclear Research

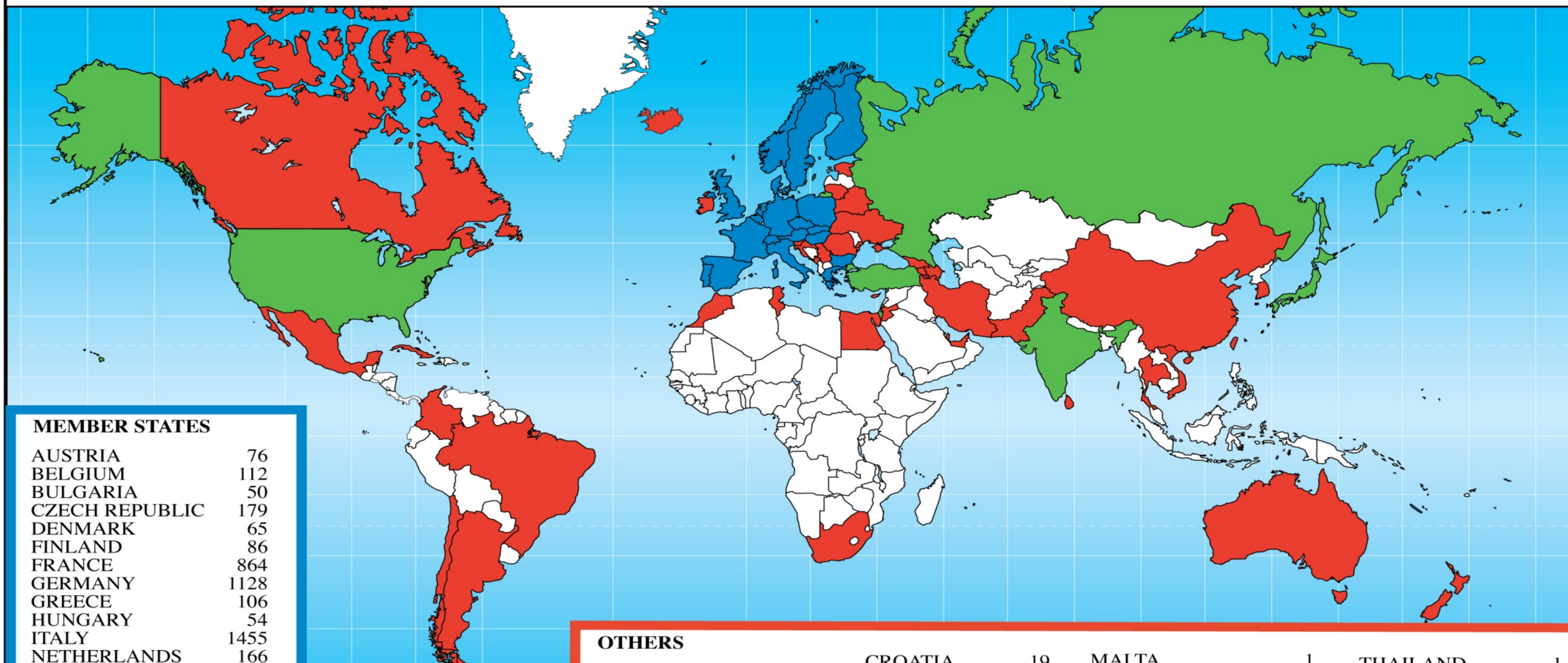
Organisation Européenne pour la Recherche Nucléaire

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

Do konce roku budeme vědět, zda existuje "božská částice", zní z CERNu

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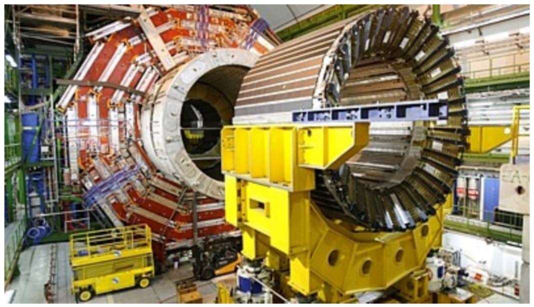

Magnet v urychlovači CERN
FOTO: Reuters

Ženeva - V obřím podzemním prstencovém urychlovači u švýcarské Ženevy několik dní létaly proti sobě svazky urychlených protonů. Zatím se o dva milimetry míjely, dnes se protony s velmi vysokou energií měly srazit. Netrpělivě očekávaný epochální experiment Evropské organizace pro jaderný výzkum (CERN) se však poněkud zpožďuje. Svazky protonů se ztratily,

CERN vyžaduje extrémně jasné důkazy, než případně oficiálně oznámí existenci "božské částice". Oznámí to však jen v případě, že bude pravděpodobnost omylu pouze jedna ku třem miliónům či menší.

Názor s nejvíce souhlasnými hlasy (79)

David Hanák, Prostějov

Neděle, 3.června 2012, 07:25:52 | Souhlasím | Nesouhlasím | +79

Zase je plná obloha chemtrails.
Kdo to má furt dýchat to jejich sviňstvo.Se pak divíme,že nárust rakovin prudce narostl a onkologický průmysl si mne ruce.proč veřejně nevystoupí vláda v televizi a neřekne na rovinu co do těch letatadel cpou za sviňstva,že se ta vodní pára vůbec nerozpouští?Zase jenom vláda mlží a lže.Já od jiných vím,že tam cpou bárium,trimethylaluminium a další škodlivé látky,které musíme dýchat.Média jsou plné Rátha a o takových důležitých věcech se vůbec nemluví,jsou to prolhanci a spiklenci proti nám.

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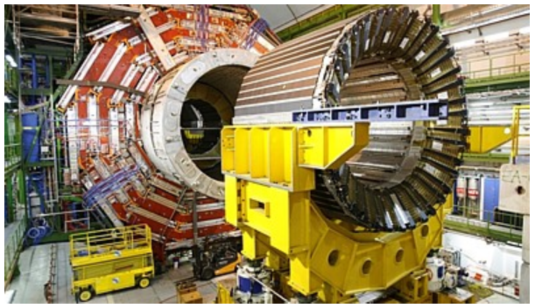

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FOTO: Reuters

Lederman said he gave the Higgs boson the nickname "The God Particle" because the particle is "so central to the state of physics today, so crucial to our final understanding of the structure of matter, yet so elusive," but jokingly added that a second reason was because "**the publisher wouldn't let us call it the Goddamn Particle**, though that might be a more appropriate title, given its villainous nature and the expense it is causing."

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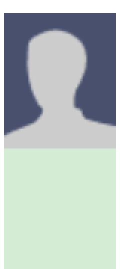

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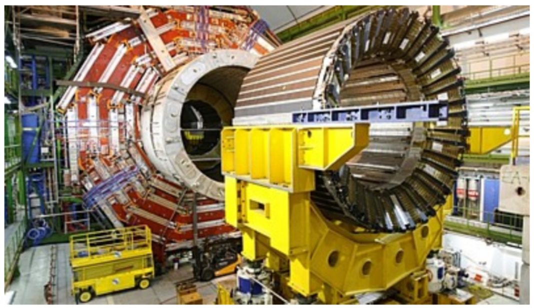

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Chyba aj na našej strane, nepodávame informácie dostatočne jasne. Tiež novinári sú polovzdelaní kokoti.

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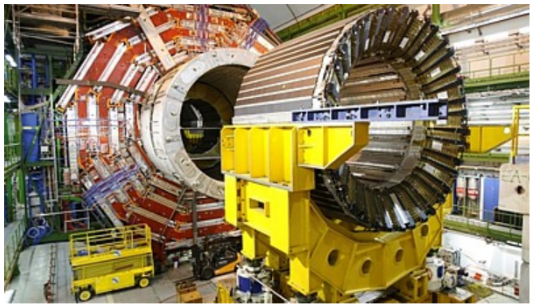

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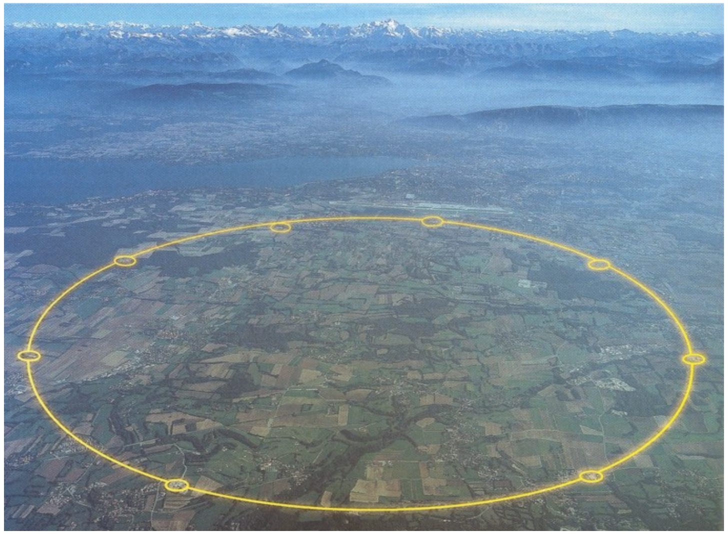
Obyčejní lidi sú taky kokoti.

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.

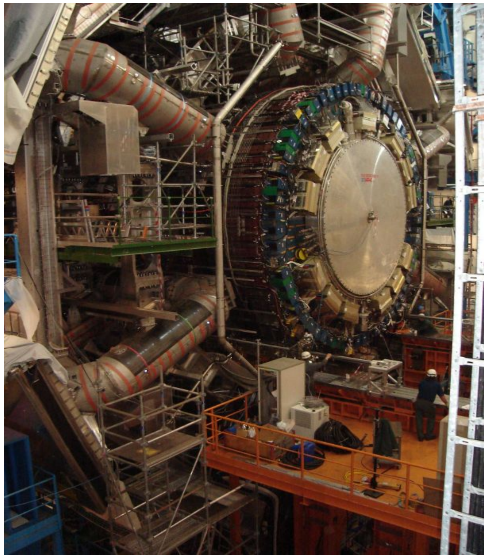
Fundamental questions:

What is the origin of mass?

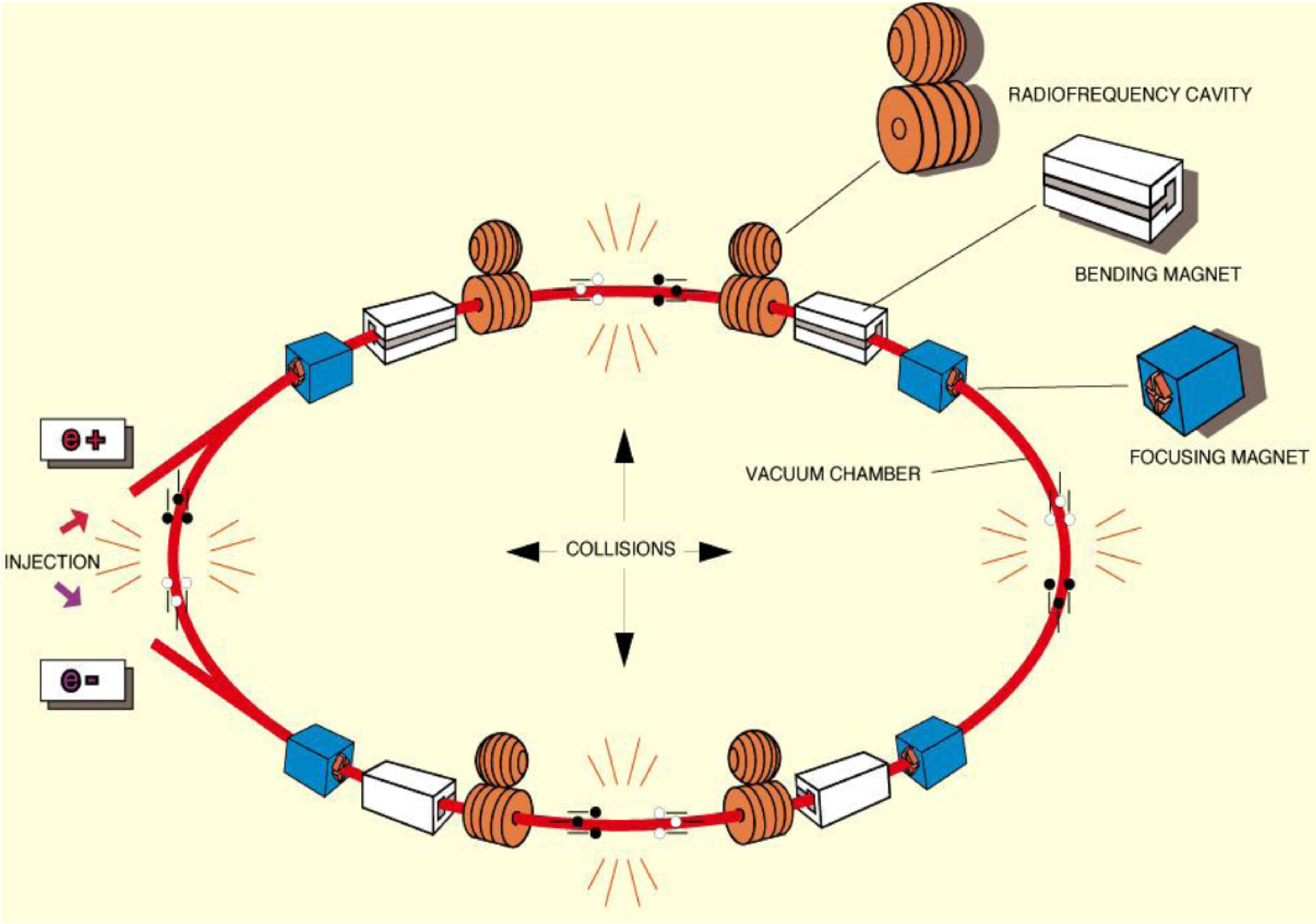
Why there was less antimatter than matter?

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.

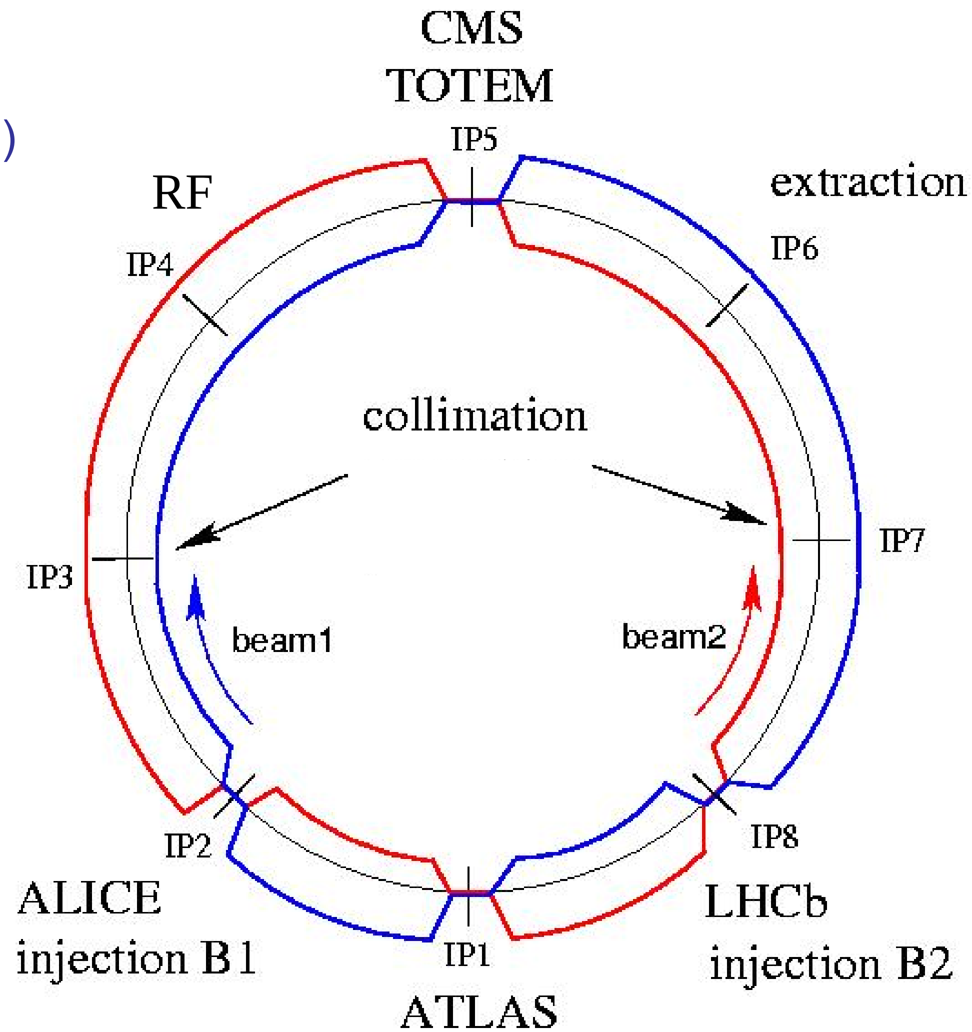

RADIOFREQUENCY CAVITY
BENDING MAGNET
FOCUSING MAGNET
VACUUM CHAMBER
COLLISIONS
INJECTION
e+
e-

LHC layout and parameters

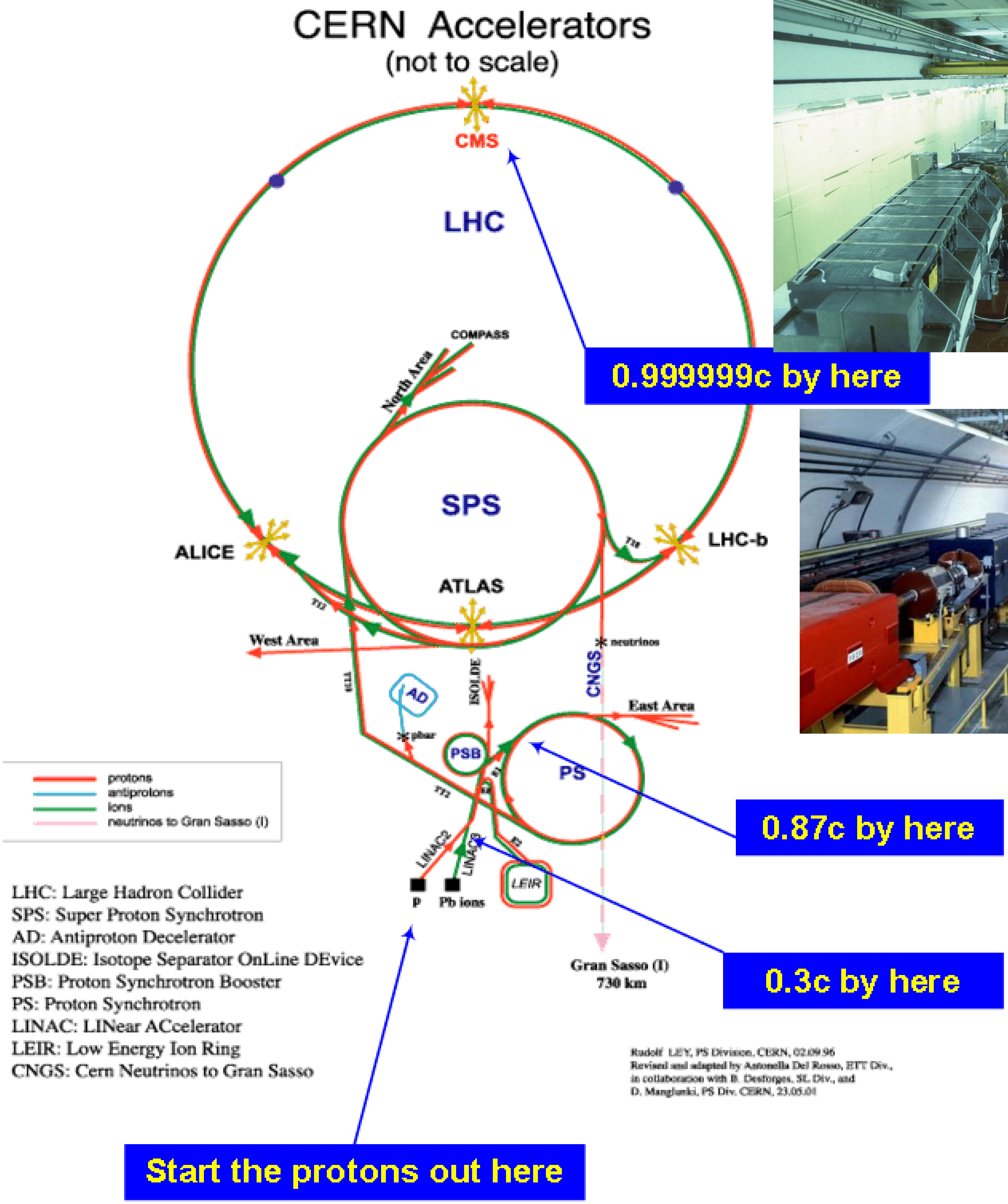
- 8 arcs (sectors), ~3 km each
- 8 long straight sections (700 m each)
- beams cross in 4 points
- 2-in-1 magnet design with separate vacuum chambers → *p-p* collisions

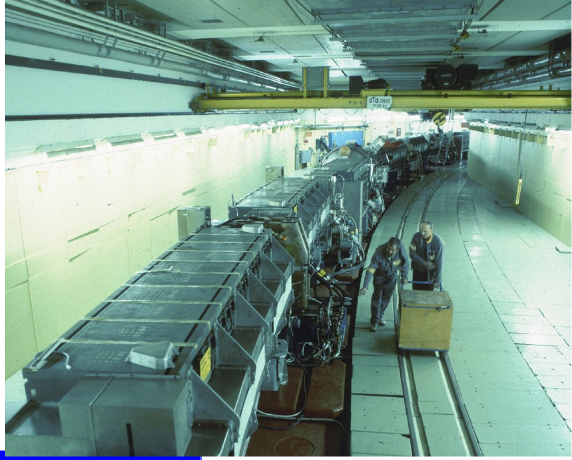
Nominal LHC parameters	
Beam energy (TeV)	7.0
No. of particles per bunch	1.15×10^{11}
No. of bunches per beam	2808
Stored beam energy (MJ)	362
Transverse emittance (μm)	3.75
Bunch length (cm)	7.6

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




PREINJECTEUR
LINAC 2


CERN Accelerators
(not to scale)
CMS
LHC
COMPASS
North Area
SPS
ALICE
ATLAS
LHC-b
West Area
neutrinos
CNGS
ISOLDE
AD
pbar
PSB
PS
East Area
LINAC2
LINAC3
LEIR
p
Pb ions
Gran Sasso (I)
730 km
protons
antiprotons
ions
neutrinos to Gran Sasso (I)
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
0.999999c by here
0.87c by here
0.3c by here
Start the protons out here



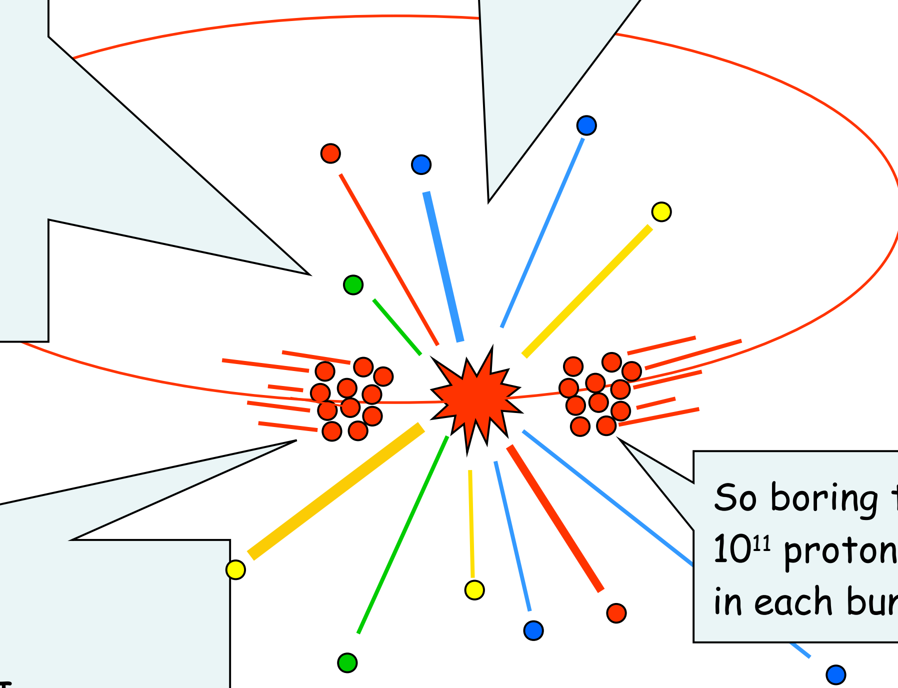
Zrážky u LHC.

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 ...)

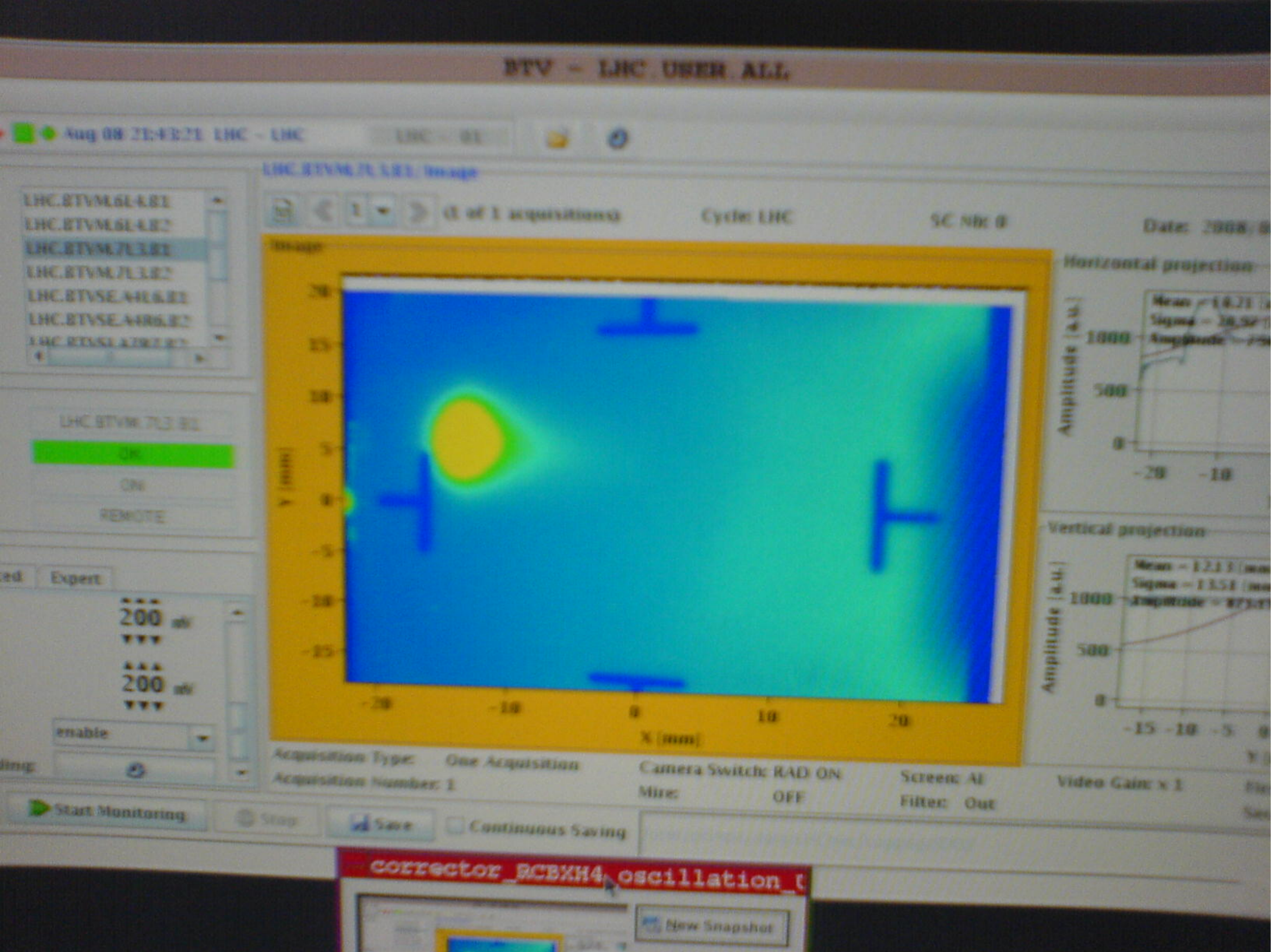
Each meeting of two bunches results in about 23 proton-proton collisions. The mean number of particles born in all these collisions is about 1500. The detector should record as many of them as possible.



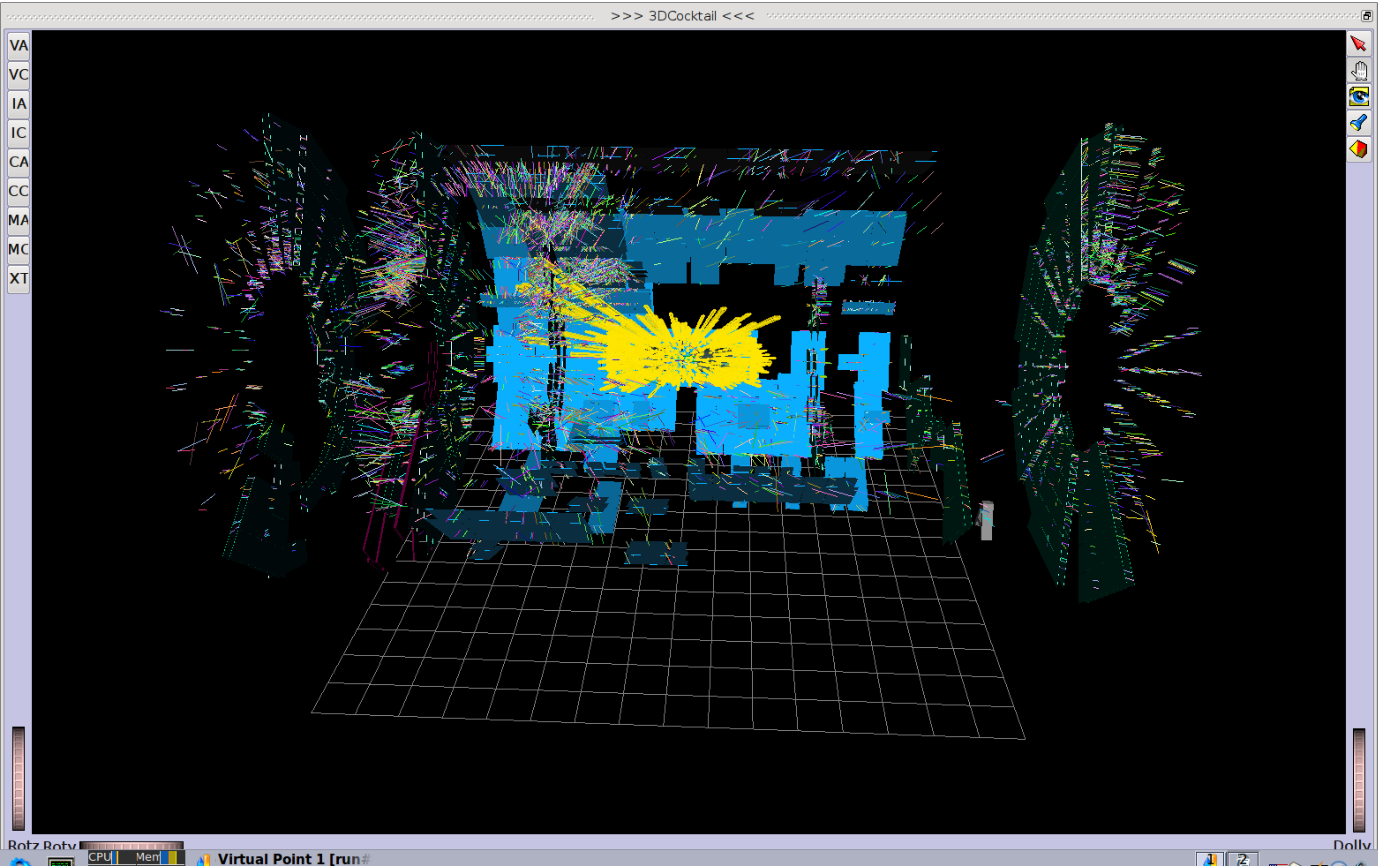
Each proton carries energy 7 TeV.
So each bunch with 10^{11} protons carries energy $10^{11} \times 7 \times 10^{12}$ eV = 7×10^{23} eV = 44 kJ.
This is a macroscopic energy!!!
In order to reach such kinetic energy on a bike, you go with a speed of more than 30 km/h!

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

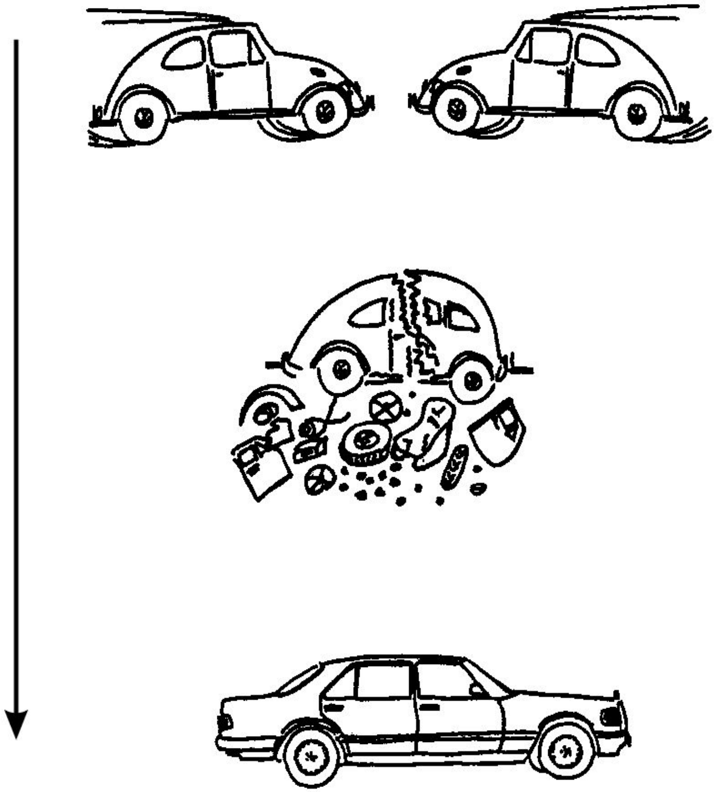
- 7+7 TeV ($p^{+}+p^{+}$)
- 1150+1150 TeV ($Pb^{207}+Pb^{207}$)

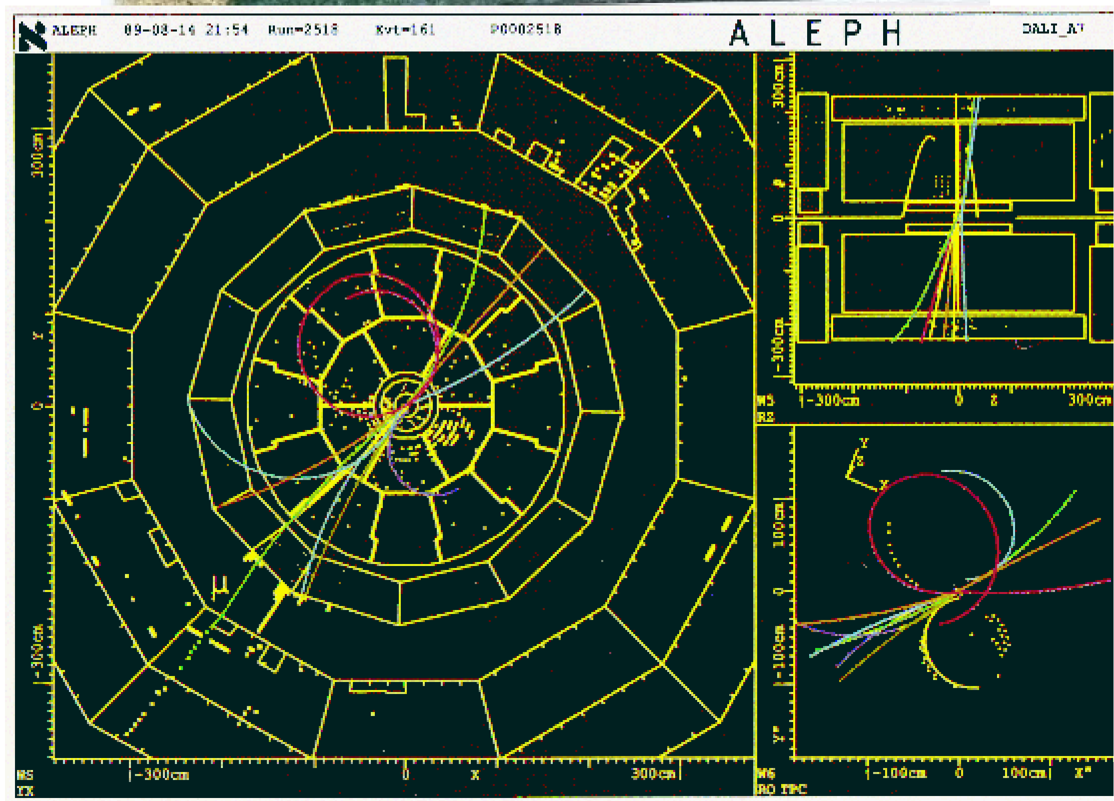

BTV - LHC USER ALL
Aug 08 21:43:21 LHC - LHC
LHC.BTVM.7L3.B1
OK
ON
REMOTE
Expert
200
200
enable
(1 of 1 acquisitions)
Cycle: LHC
Image
Y [mm]
X [mm]
Horizontal projection
Amplitude [a.u.]
Vertical projection
Acquisition Type: One Acquisition
Acquisition Number: 1
Camera Switch: RAD ON
Mire: OFF
Screen: Al
Filter: Out
Video Gain: x 1
Start Monitoring
Stop
Save
Continuous Saving
corrector_RCBXH4_oscillation_
New Snapshot

ATLAS beam splash

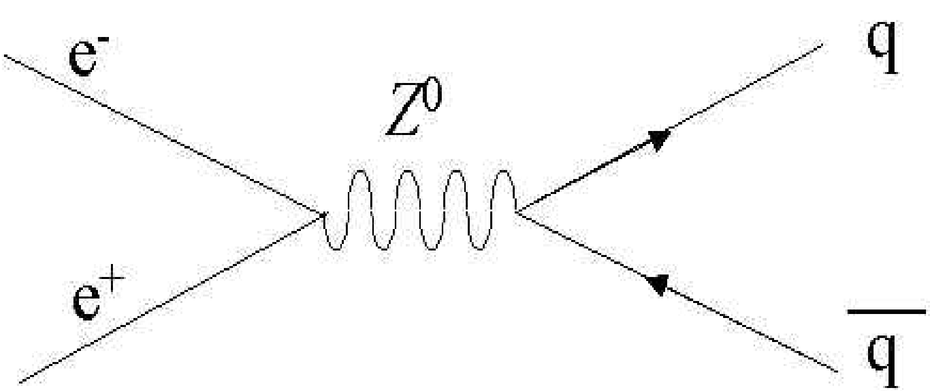


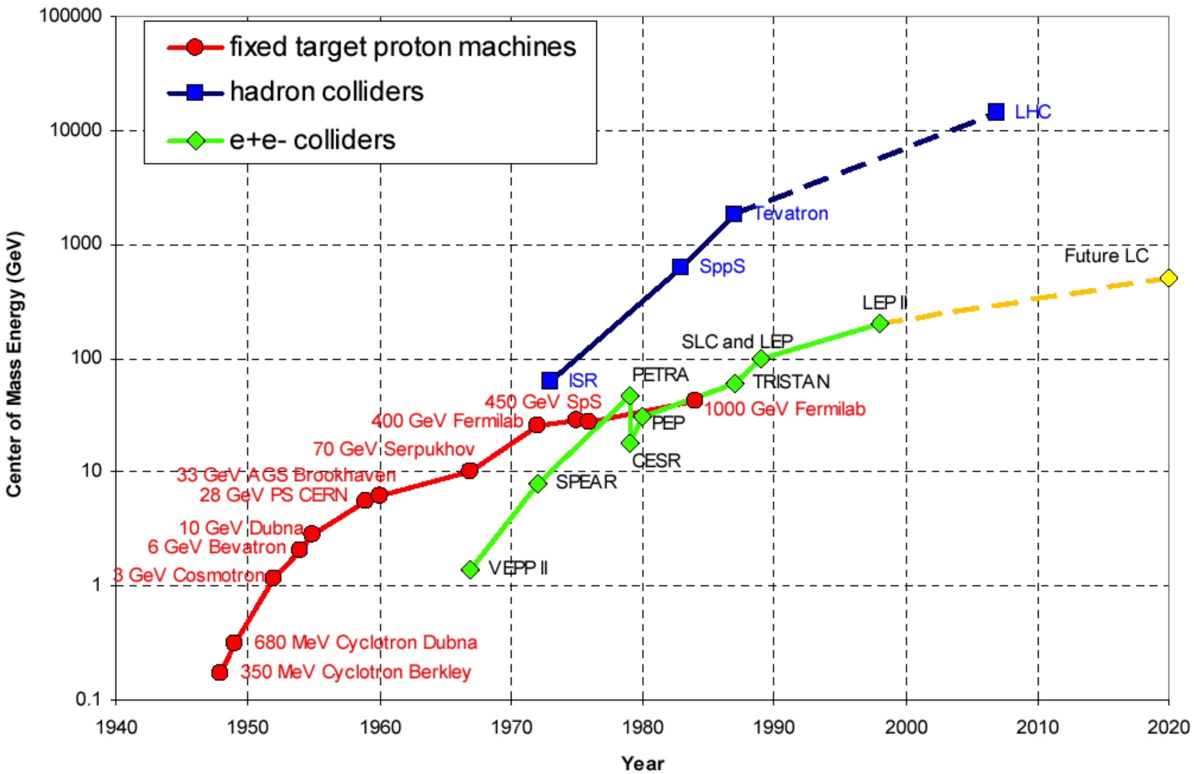
Collider

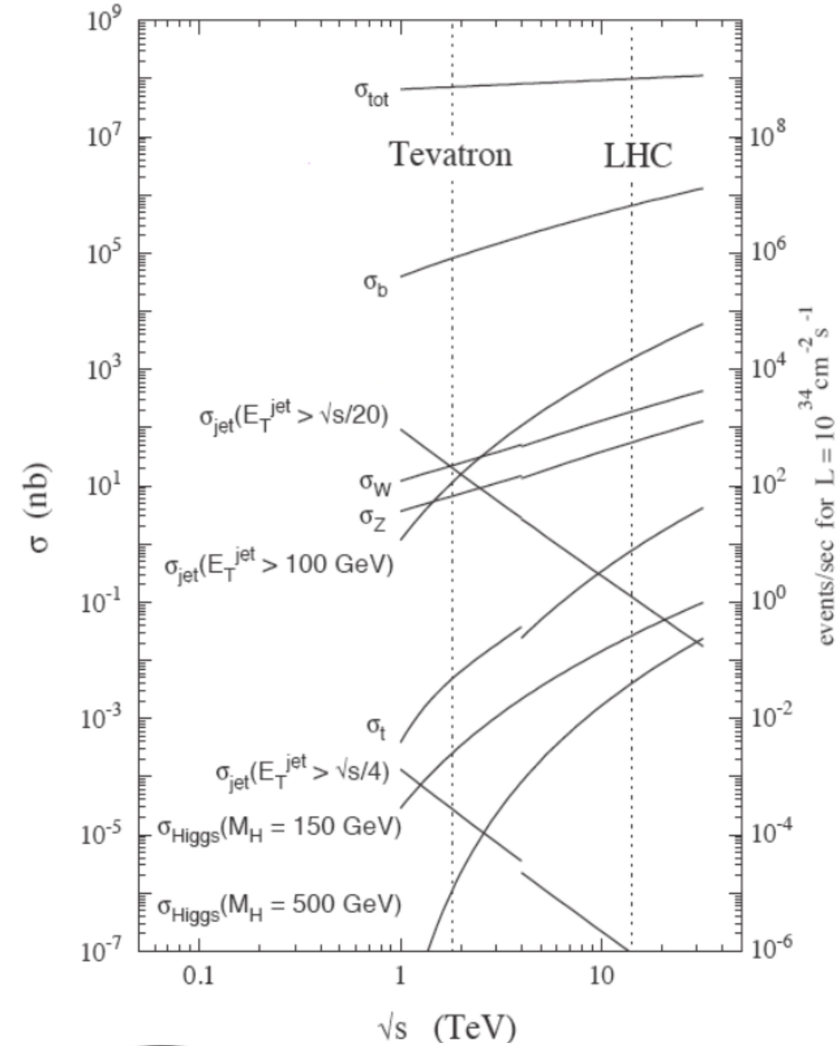


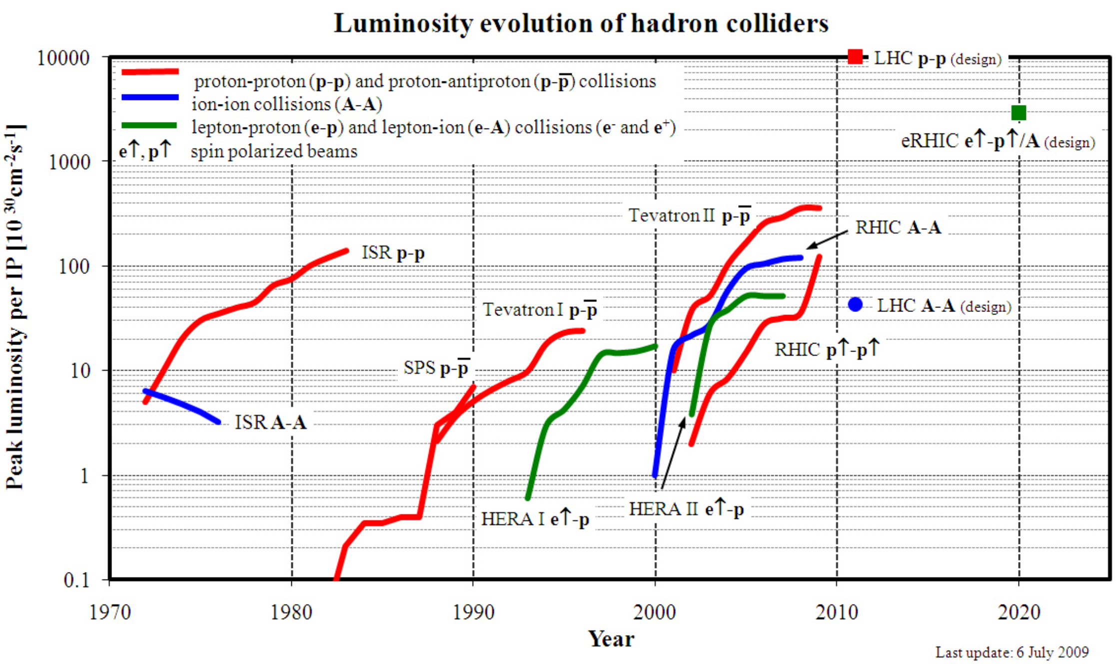


Higgs production in e^+e^- collisions:

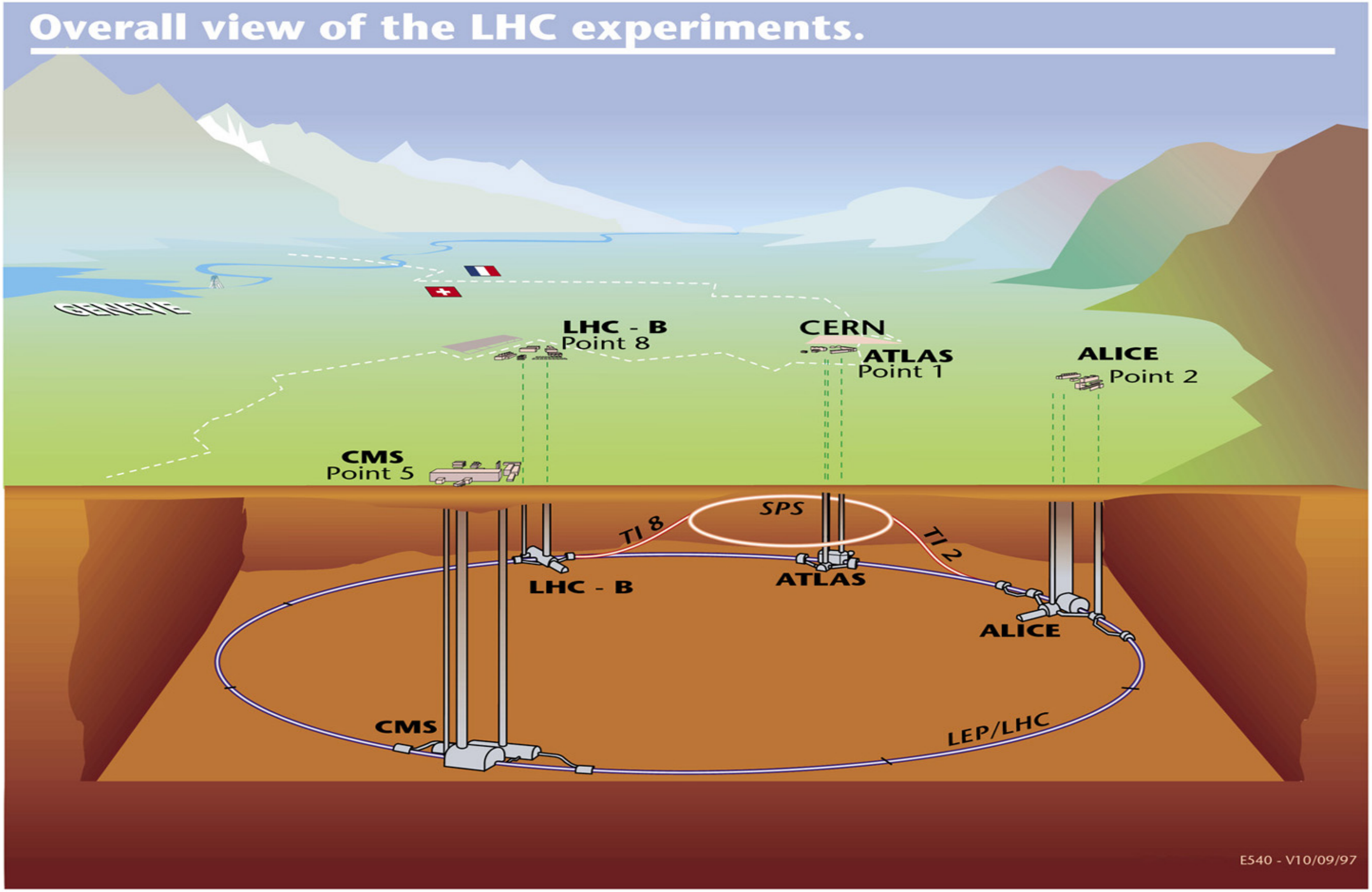






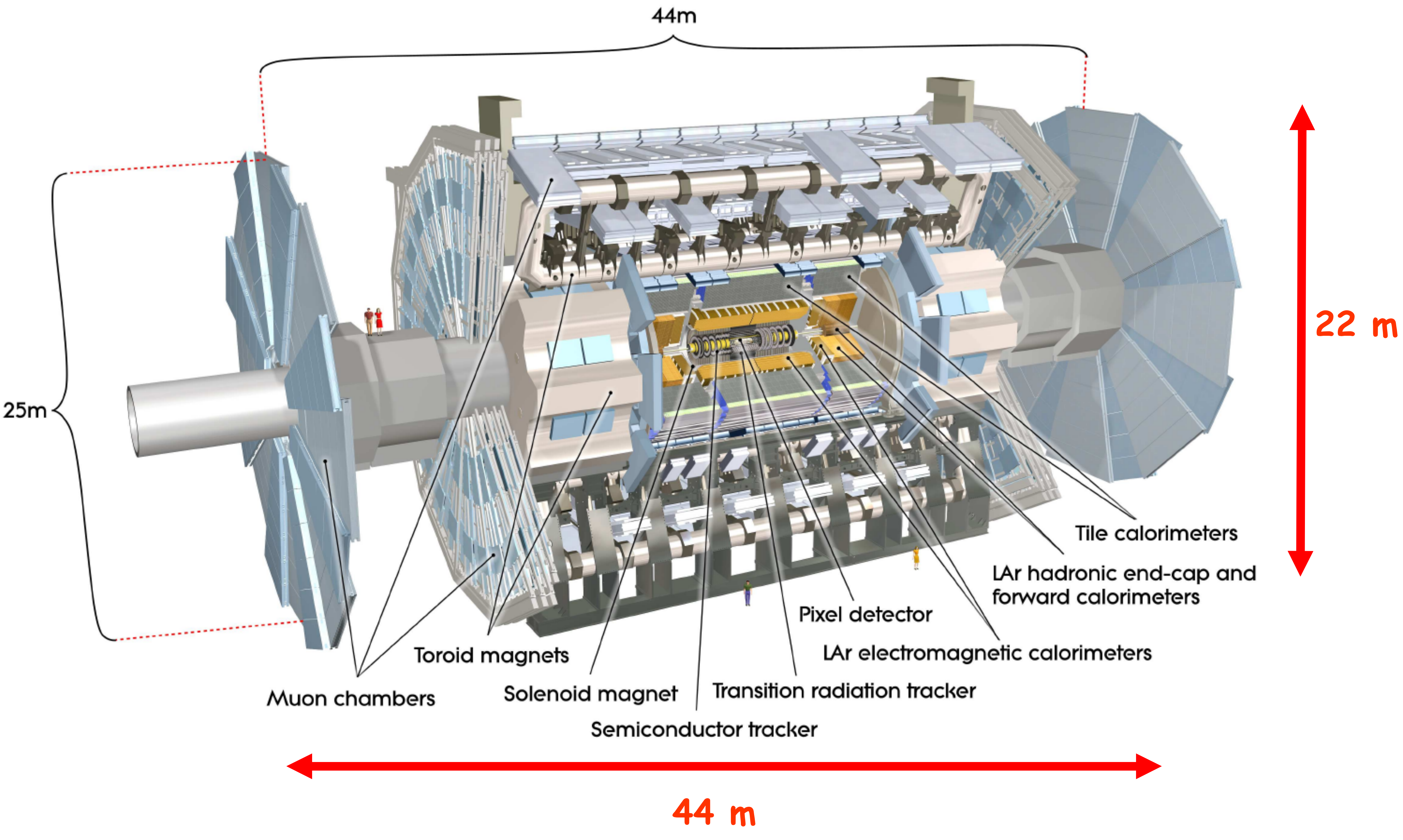


$R = \sigma \times L.$

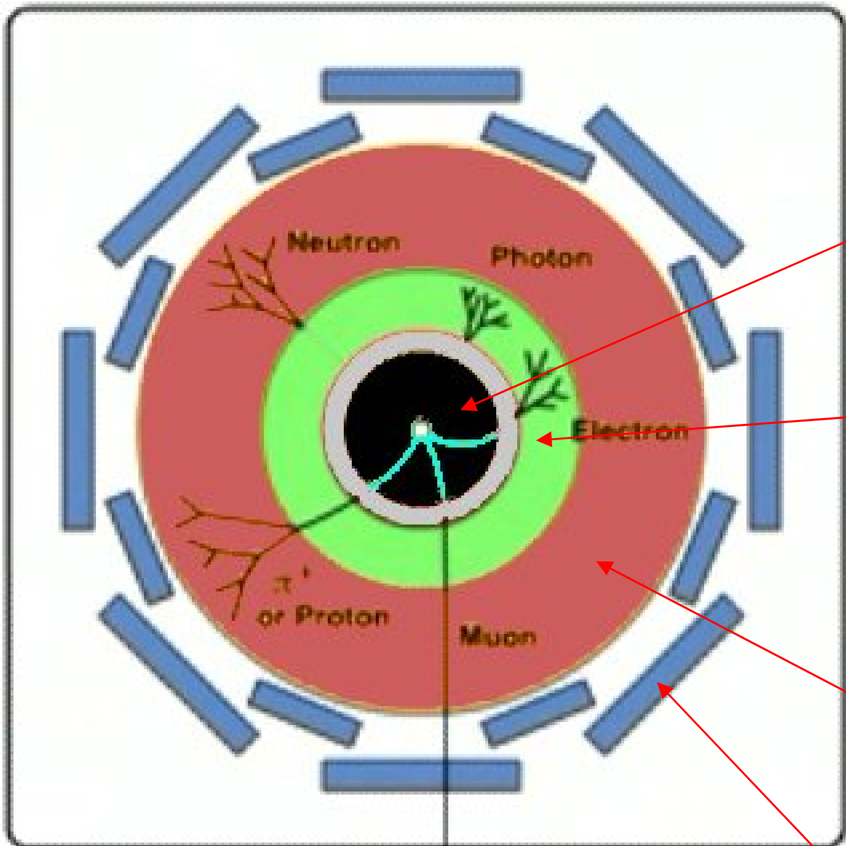

Overall view of the LHC experiments.
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC
E540 - V10/09/97

A Toroidal LHC ApparatuS

ATLAS



A Typical Detector



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

Inner detector (Tracker)

Measures charge and momentum of charged particles in magnetic field

Electro-magnetic calorimeter

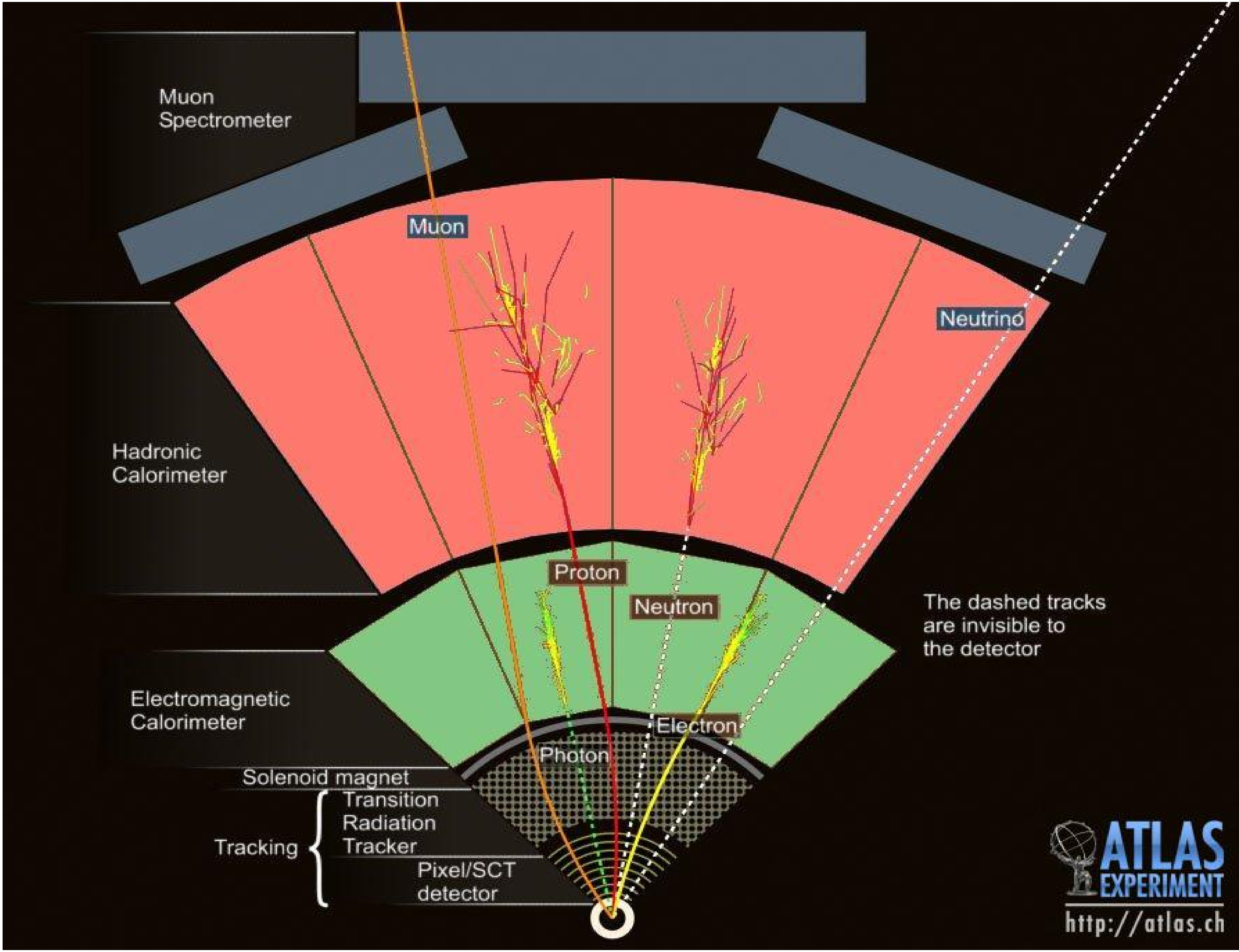
Measures energy of electrons, positrons and photons

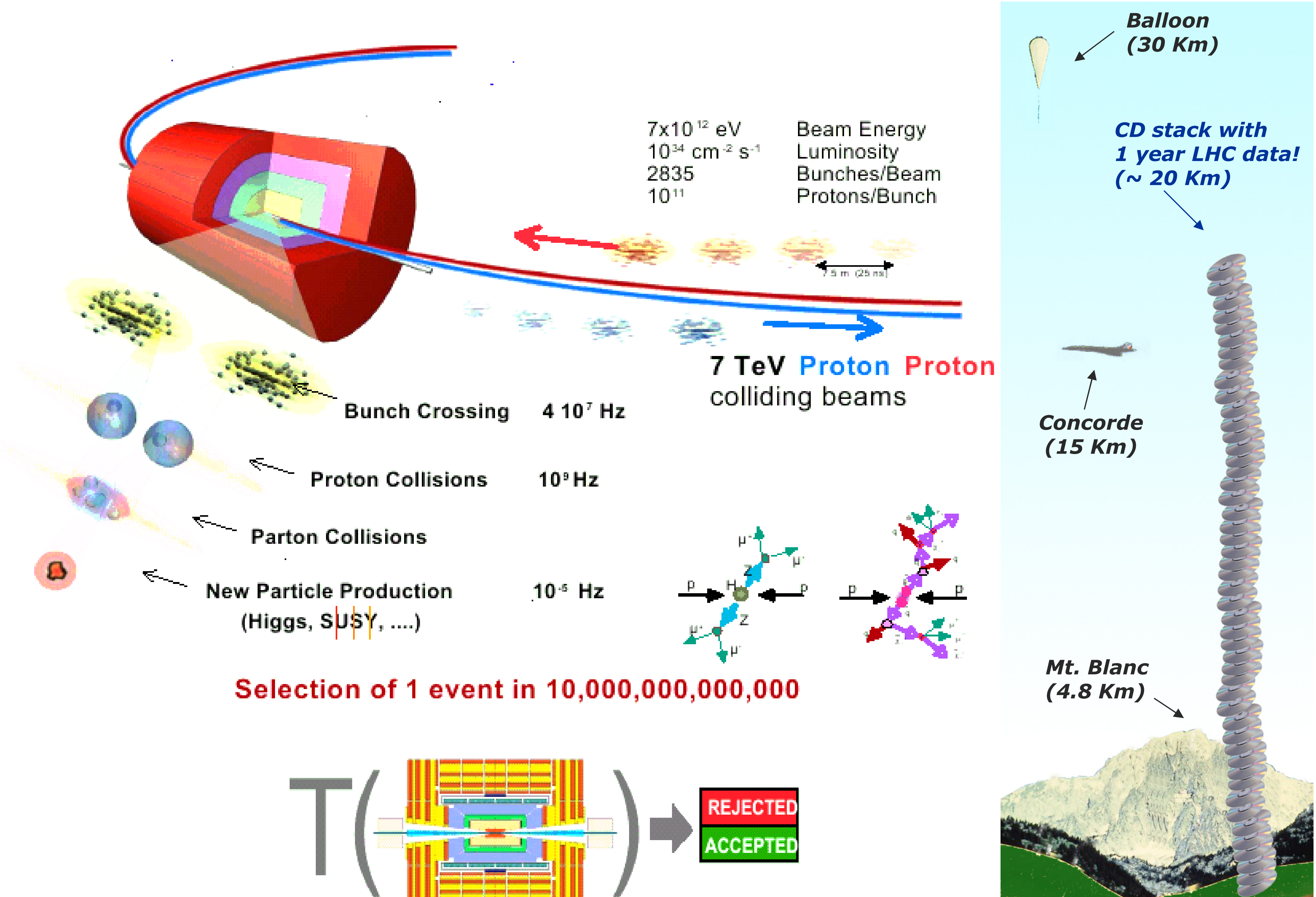
Hadronic calorimeter

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

Muon detector

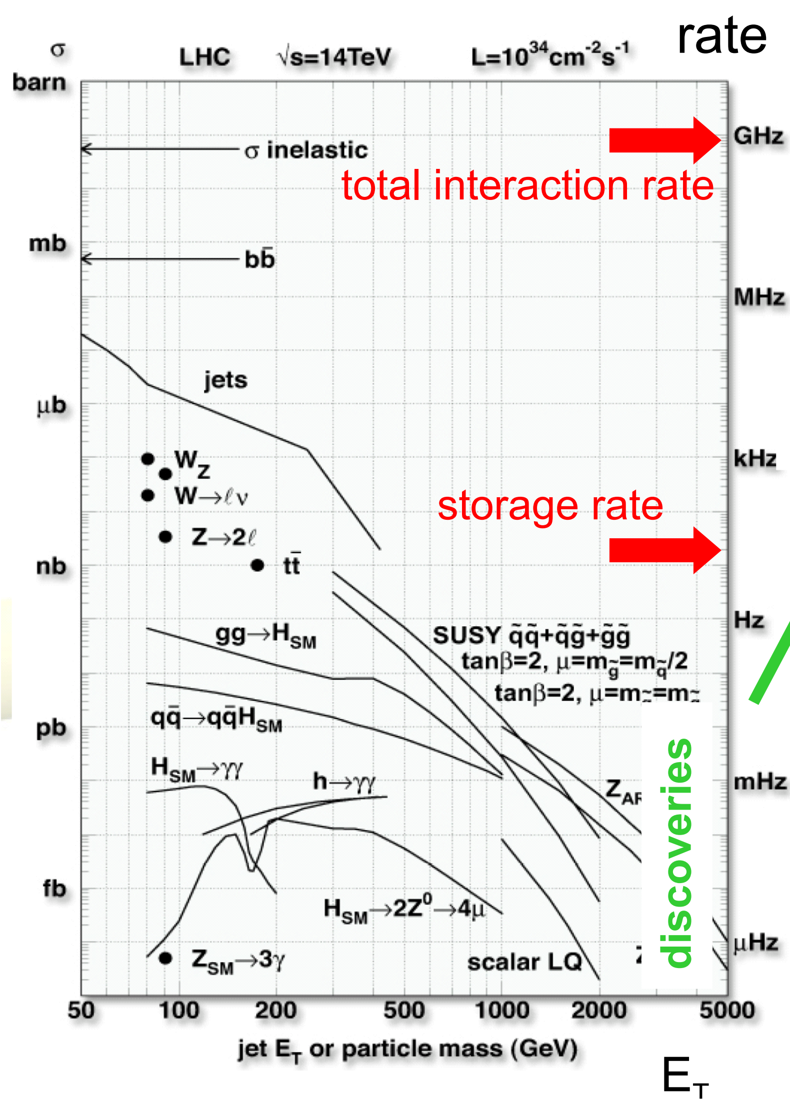
Measures charge and momentum of muons


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



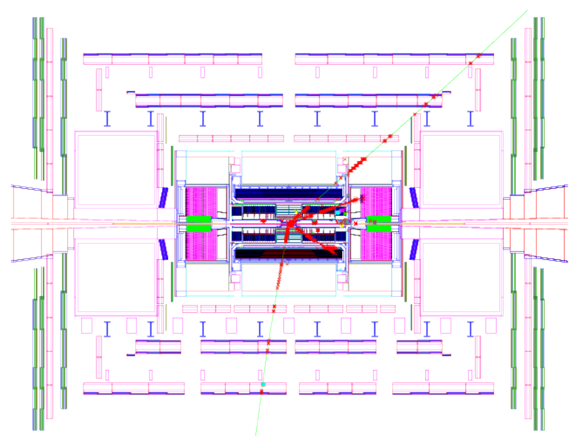
$7x10^{12}$ eV Beam Energy
10^{34} cm^{-2} s^{-1} Luminosity
2835 Bunches/Beam
10^{11} Protons/Bunch
7 TeV Proton Proton colliding beams
Bunch Crossing $4\ 10^{7}$ Hz
Proton Collisions 10^{9} Hz
Parton Collisions
New Particle Production 10^{-5} Hz
(Higgs, SUSY, ...)
Selection of 1 event in 10,000,000,000,000
T
REJECTED
ACCEPTED
Balloon (30 Km)
CD stack with 1 year LHC data! (~ 20 Km)
Concorde (15 Km)
Mt. Blanc (4.8 Km)

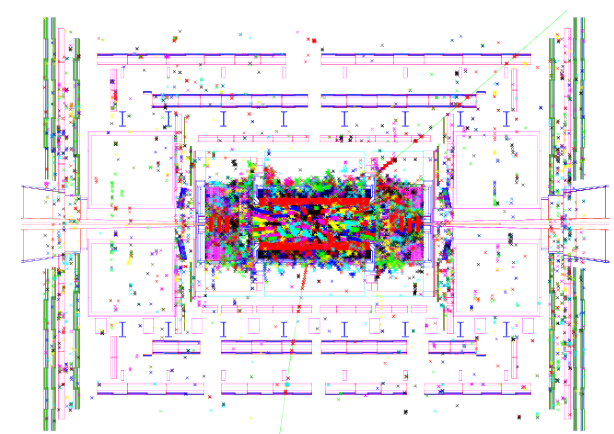
Trigger motivation



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

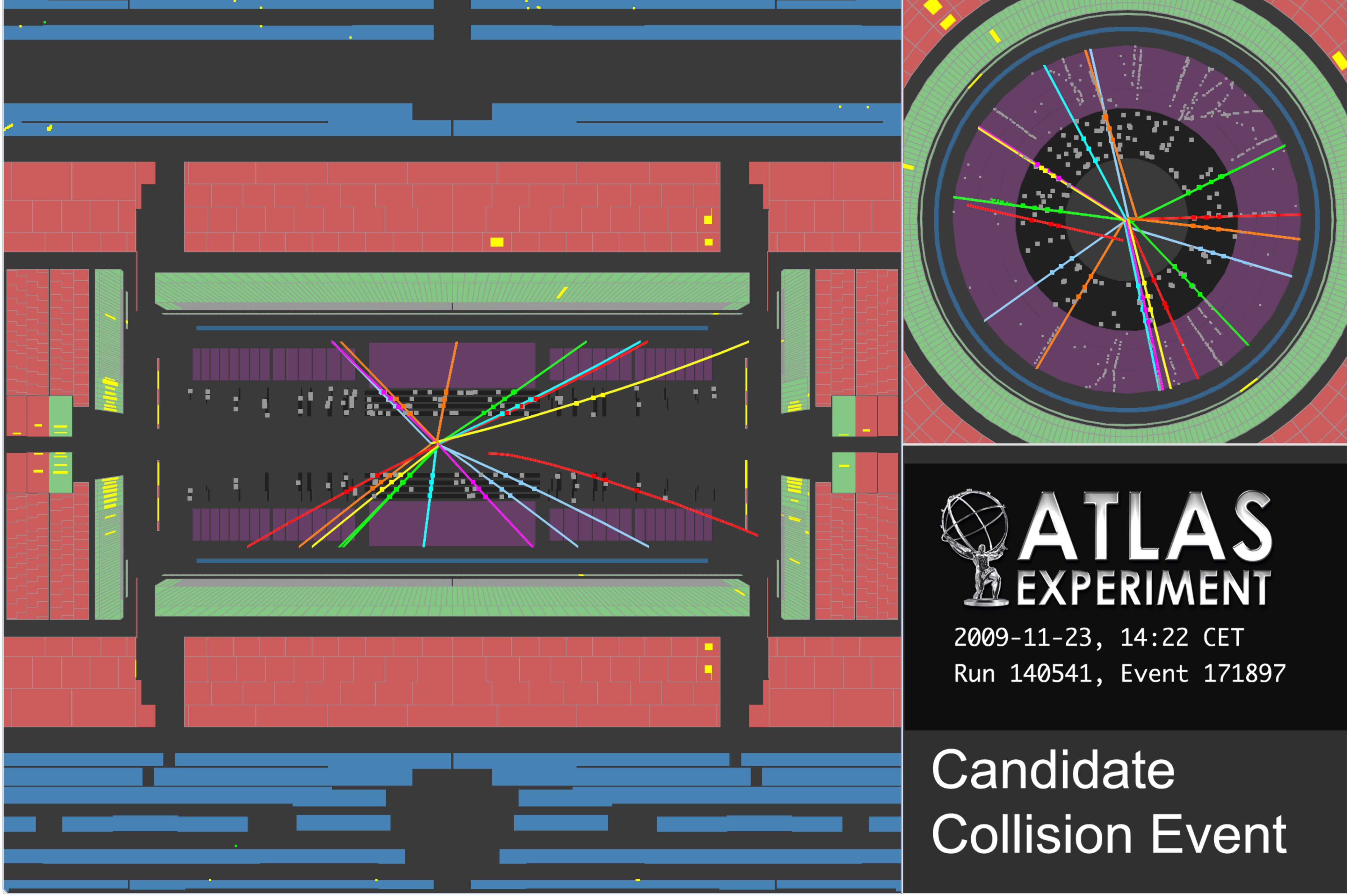




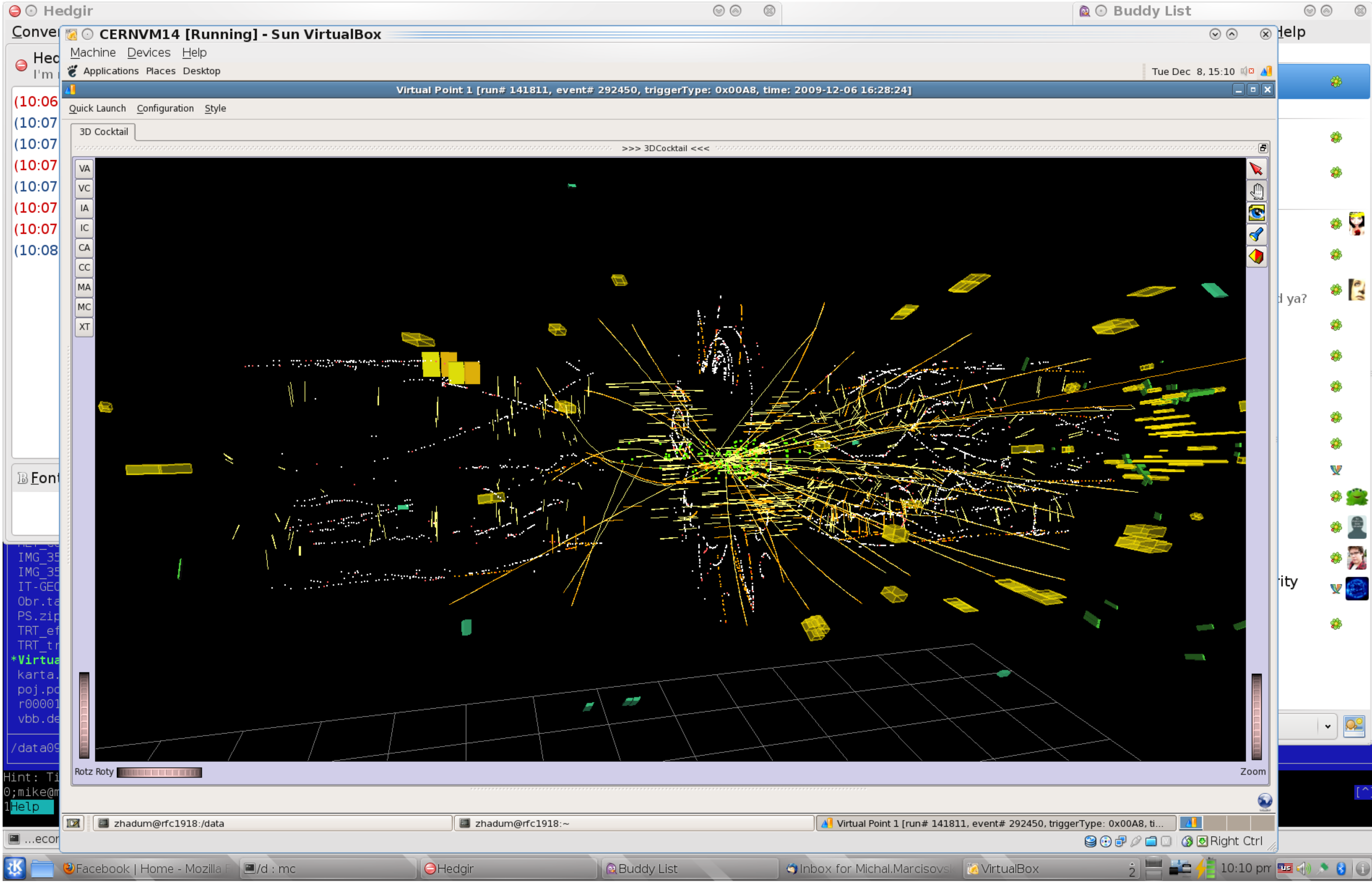
23 min. bias events:
~ 1725 particles/BC

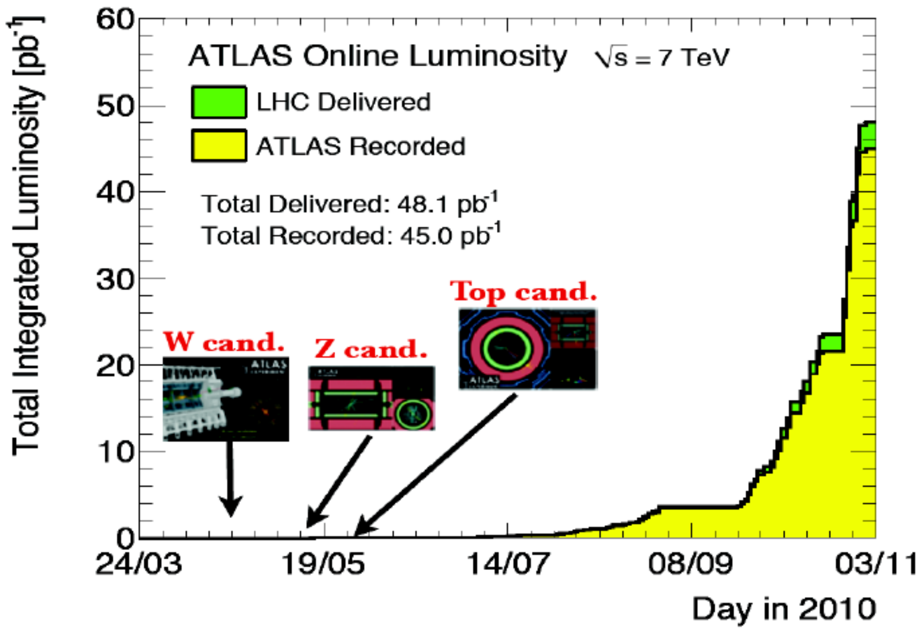
powerful trigger needed

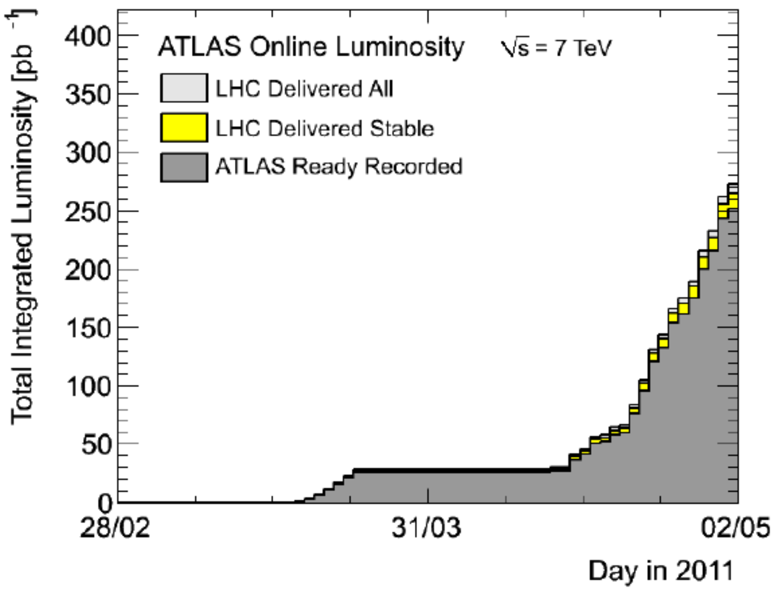
- Enormous rate reduction
- Retaining the rare events in the very tough LHC environment
- Sharing in between physics and technical triggers



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

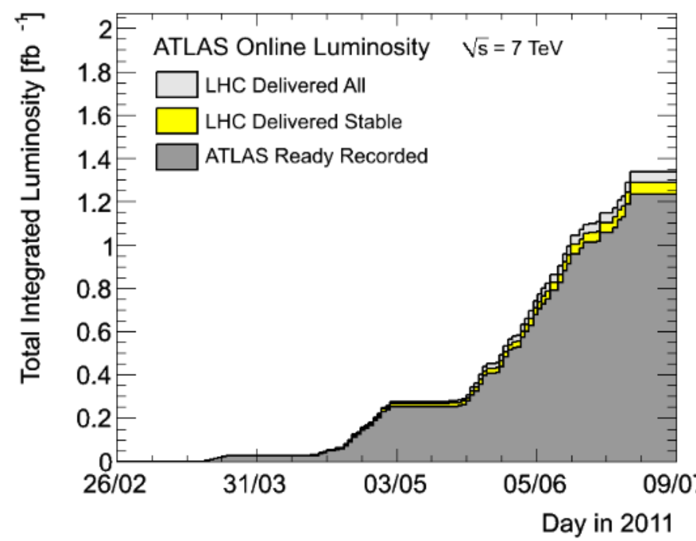

Hedgir
Buddy List
CERNVM14 [Running] - Sun VirtualBox
Machine Devices Help
Applications Places Desktop
Tue Dec 8, 15:10
Virtual Point 1 [run# 141811, event# 292450, triggerType: 0x00A8, time: 2009-12-06 16:28:24]
Quick Launch Configuration Style
3D Cocktail
>>> 3DCocktail <<<
VA
VC
IA
IC
CA
CC
MA
MC
XT
Rotz Roty
Zoom
zhadum@rfc1918:/data
zhadum@rfc1918:~
Right Ctrl
Facebook | Home - Mozilla
/d : mc
Hedgir
Buddy List
VirtualBox
10:10 pm

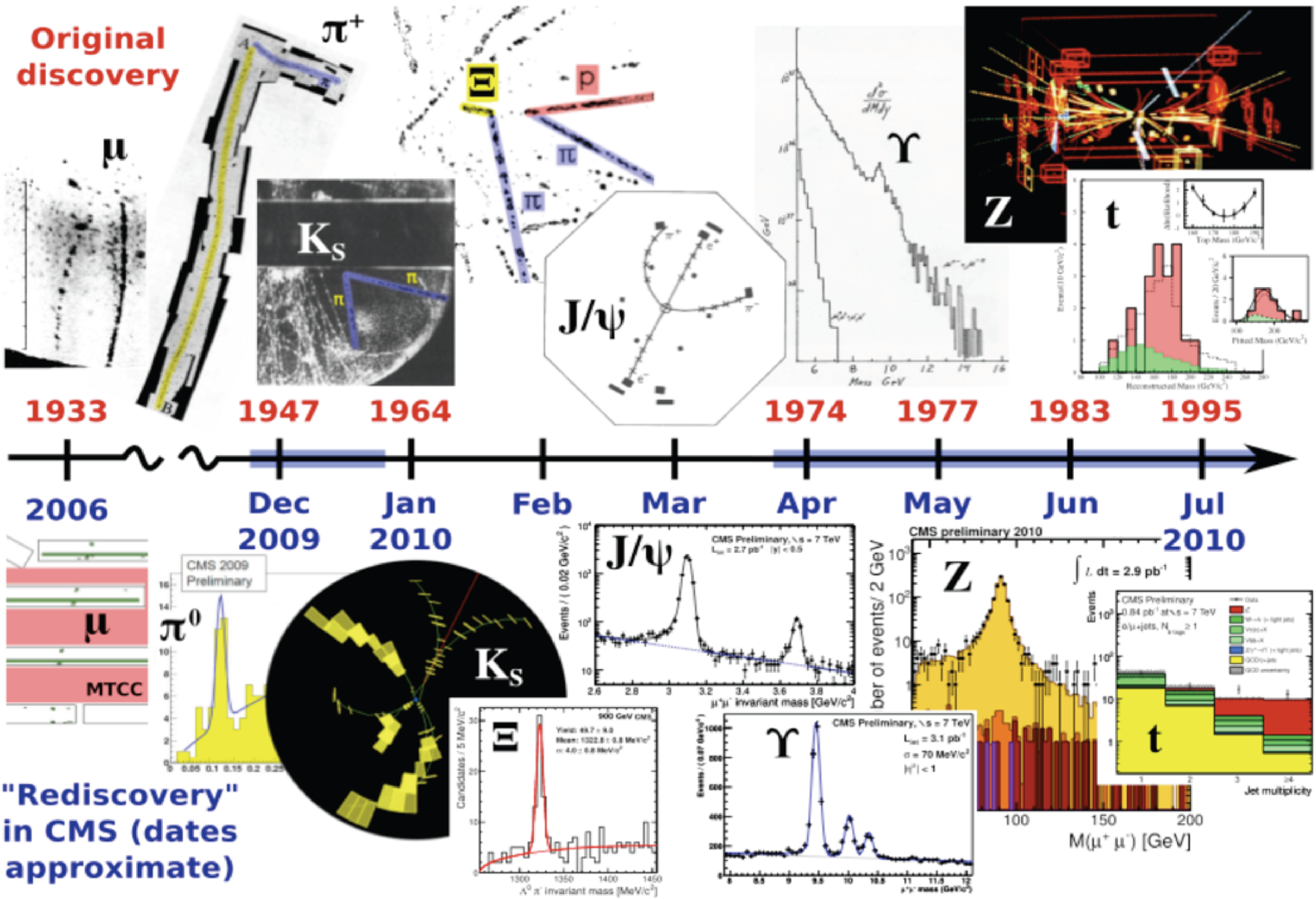




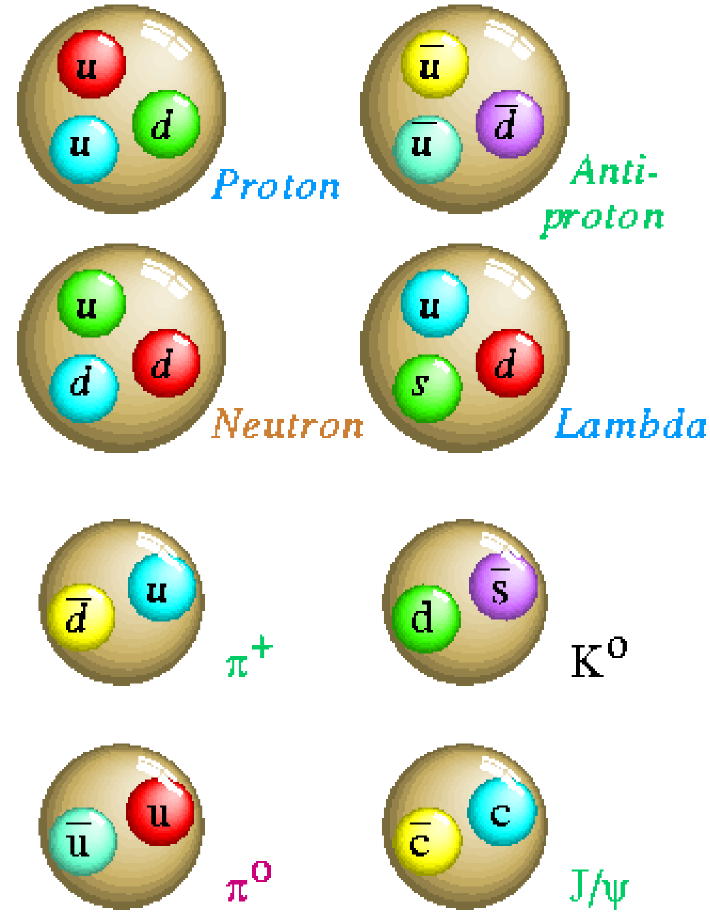
2010 was a great year

- 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

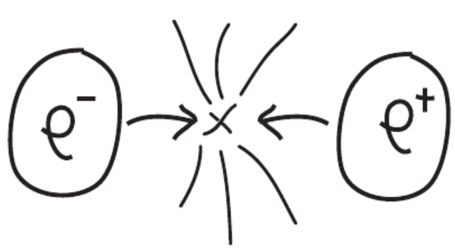


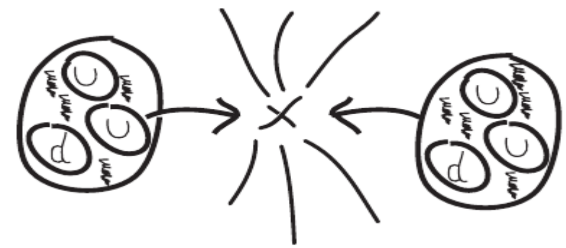

Original discovery
1933
1947
1964
1974
1977
1983
1995
2006
Dec 2009
Jan 2010
Feb
Mar
Apr
May
Jun
Jul 2010
MTCC
CMS 2009 Preliminary
"Rediscovery" in CMS (dates approximate)
CMS Preliminary, √s = 7 TeV
μ⁺μ⁻ invariant mass [GeV/c²]
CMS preliminary 2010
M(μ⁺ μ⁻) [GeV]
Jet multiplicity


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


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

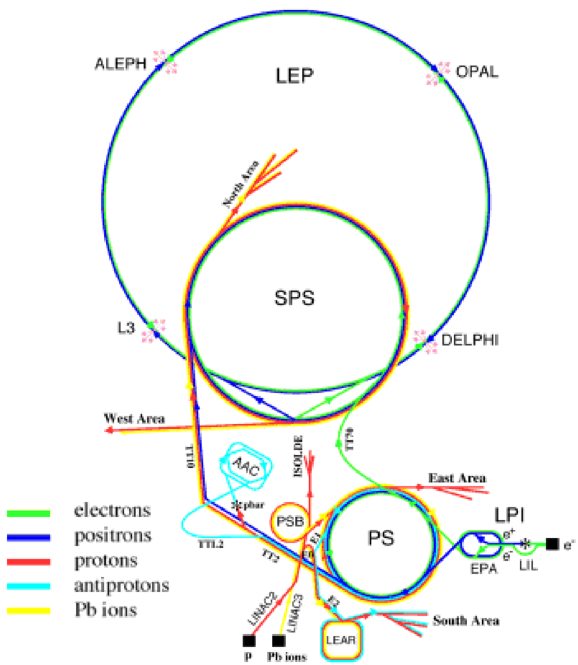
Hadrónové vs leptónové collidery

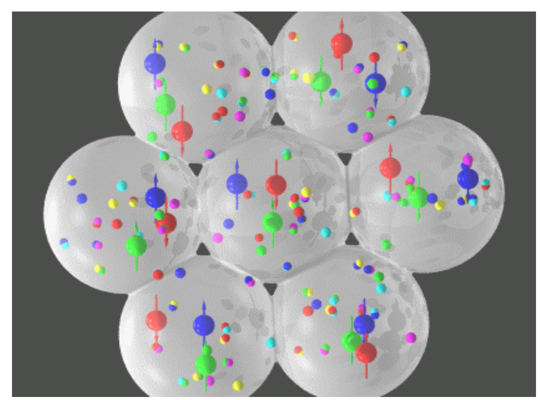


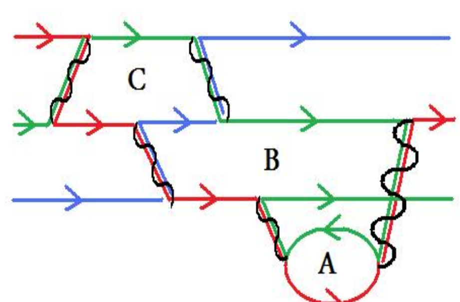


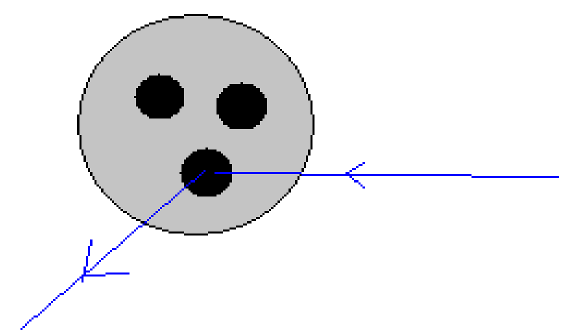
• Precízne energetické scany.
• Při vyšších energiách stráta energie vyžarovaním.

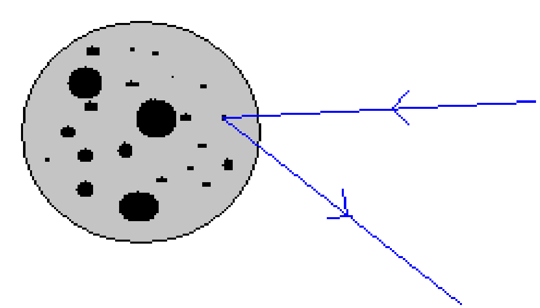
• Distribúcia energie medzi partóny. (PDF)
• S jednou energiou scanovanie širokého spektra energií.

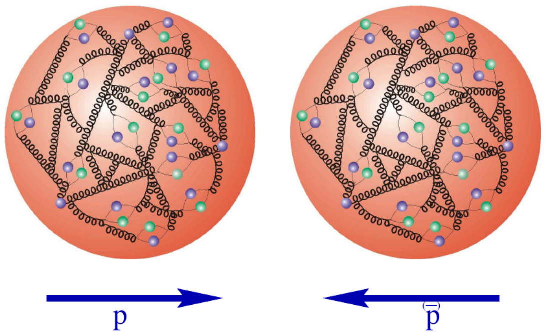


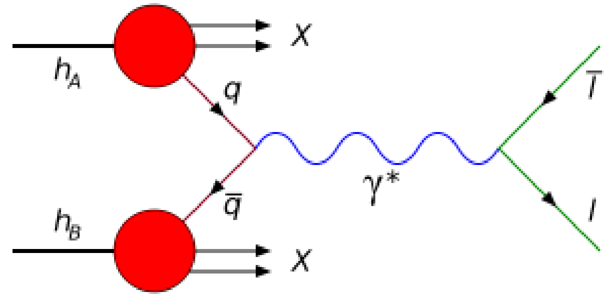




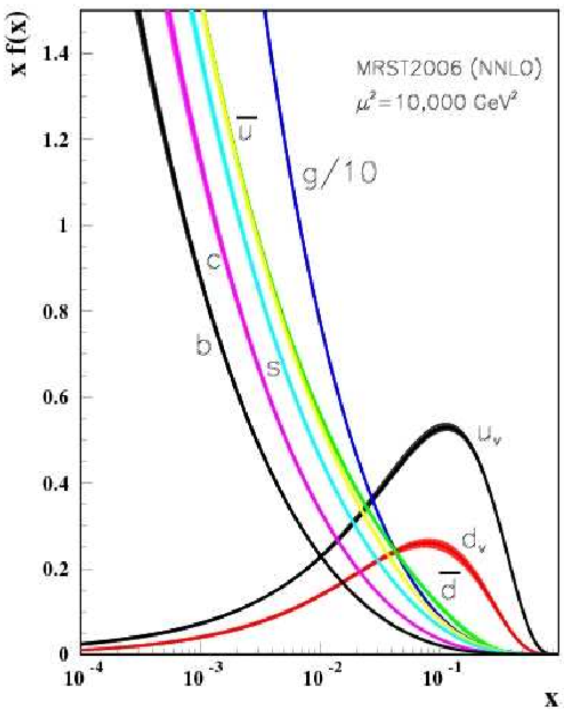


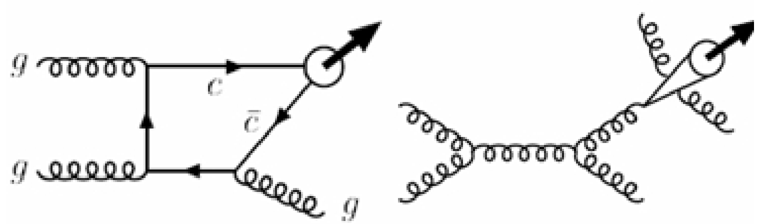


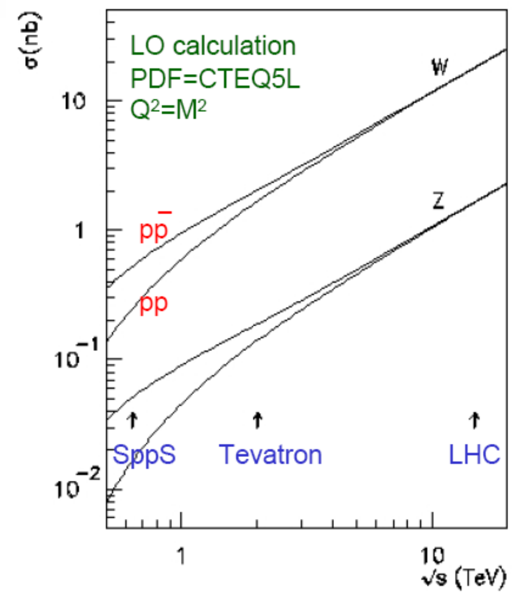




$$\sigma_X = \sum_{a,b} \int_0^1 dx_a dx_b f(x_a, flav_a, Q^2) f(x_b, flav_b, Q^2) \cdot \sigma_{ab \to X}(x_a, x_b, Q^2).$$

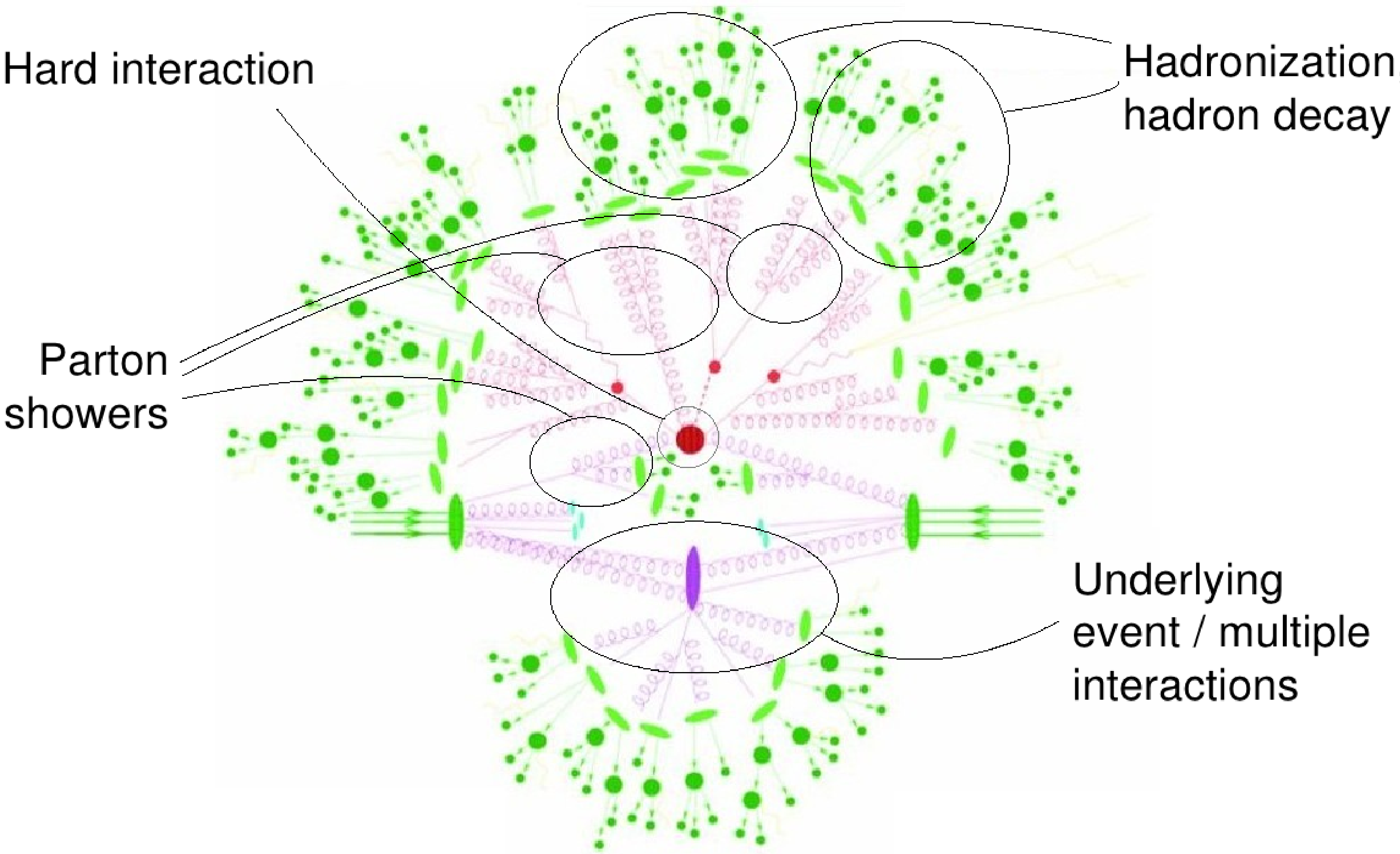


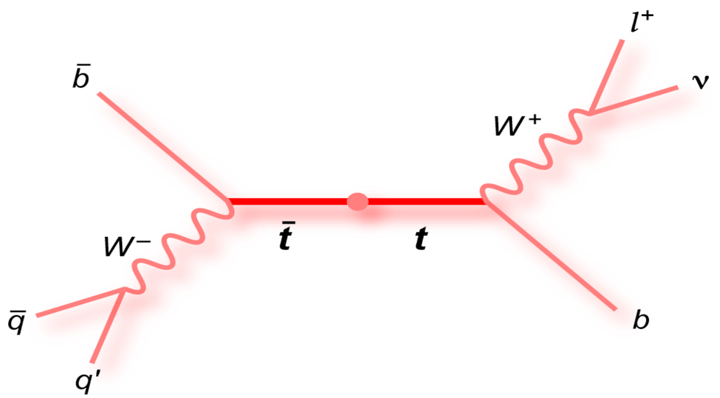


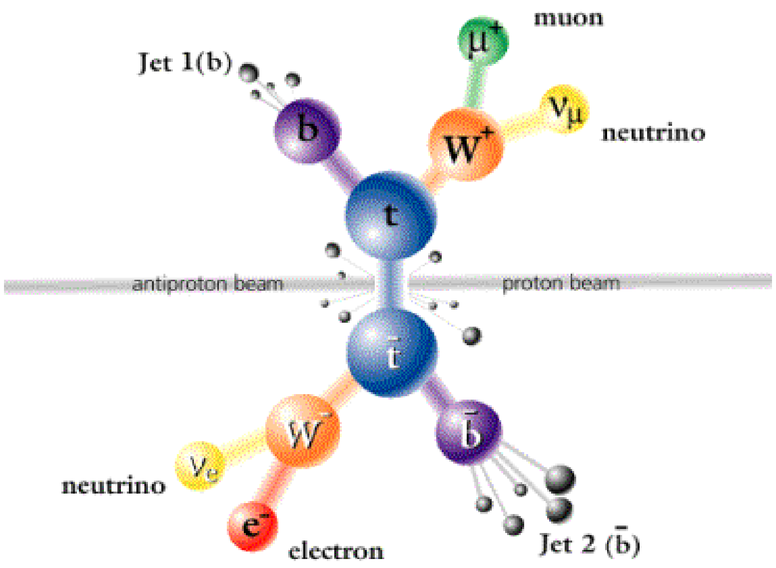


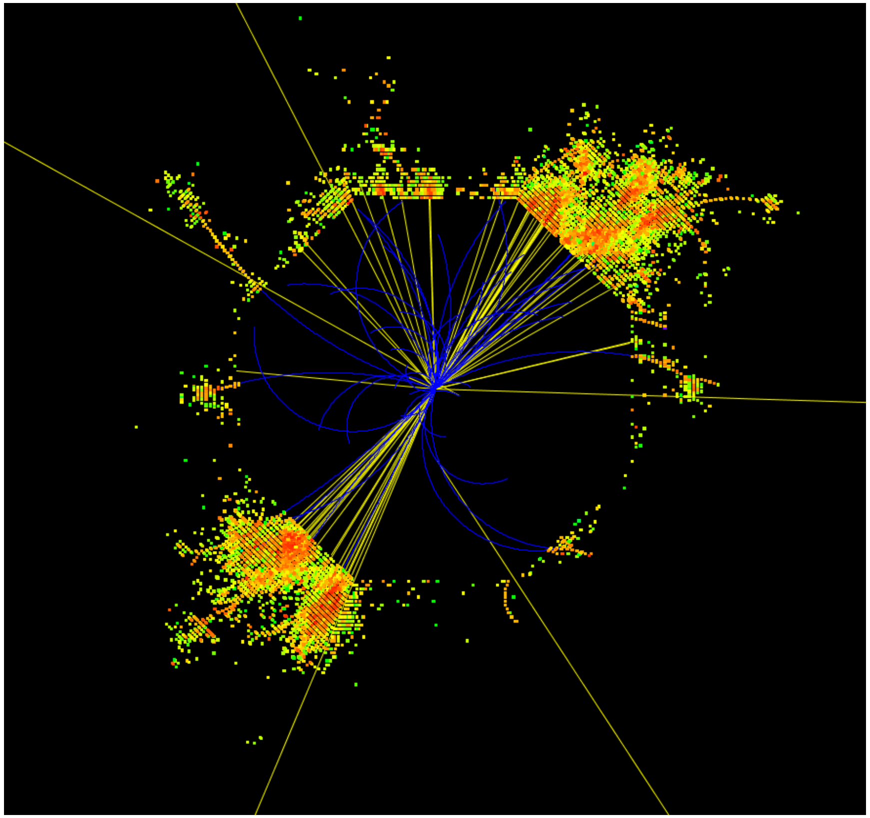
- In principle want to annihilate particles with antiparticles
- Generation of antiprotons is very expensive and limits luminosity
- At high energy PDFs anyway dominated by gluon and sea-quarks
- (almost) no difference between pp and $p\bar{p}$ cross sections

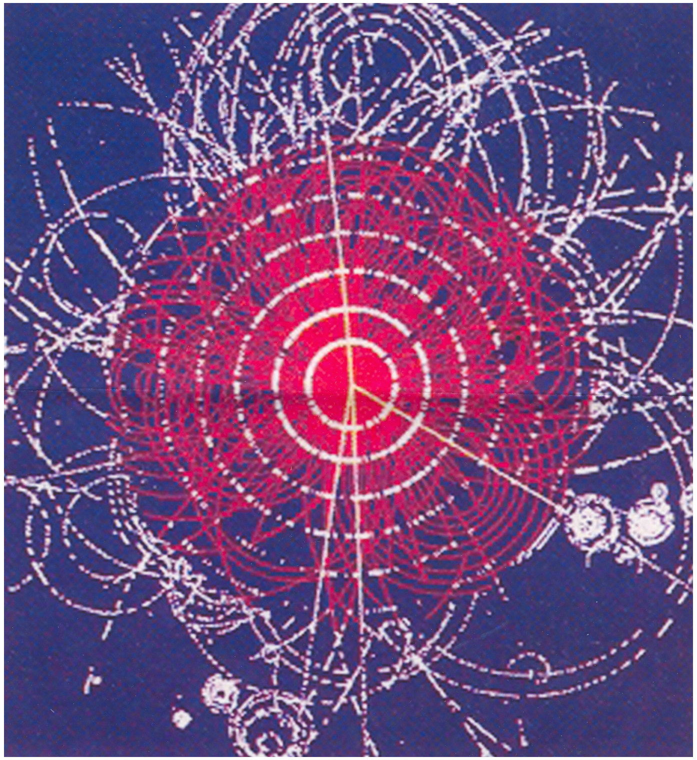
Simulation of LHC collision

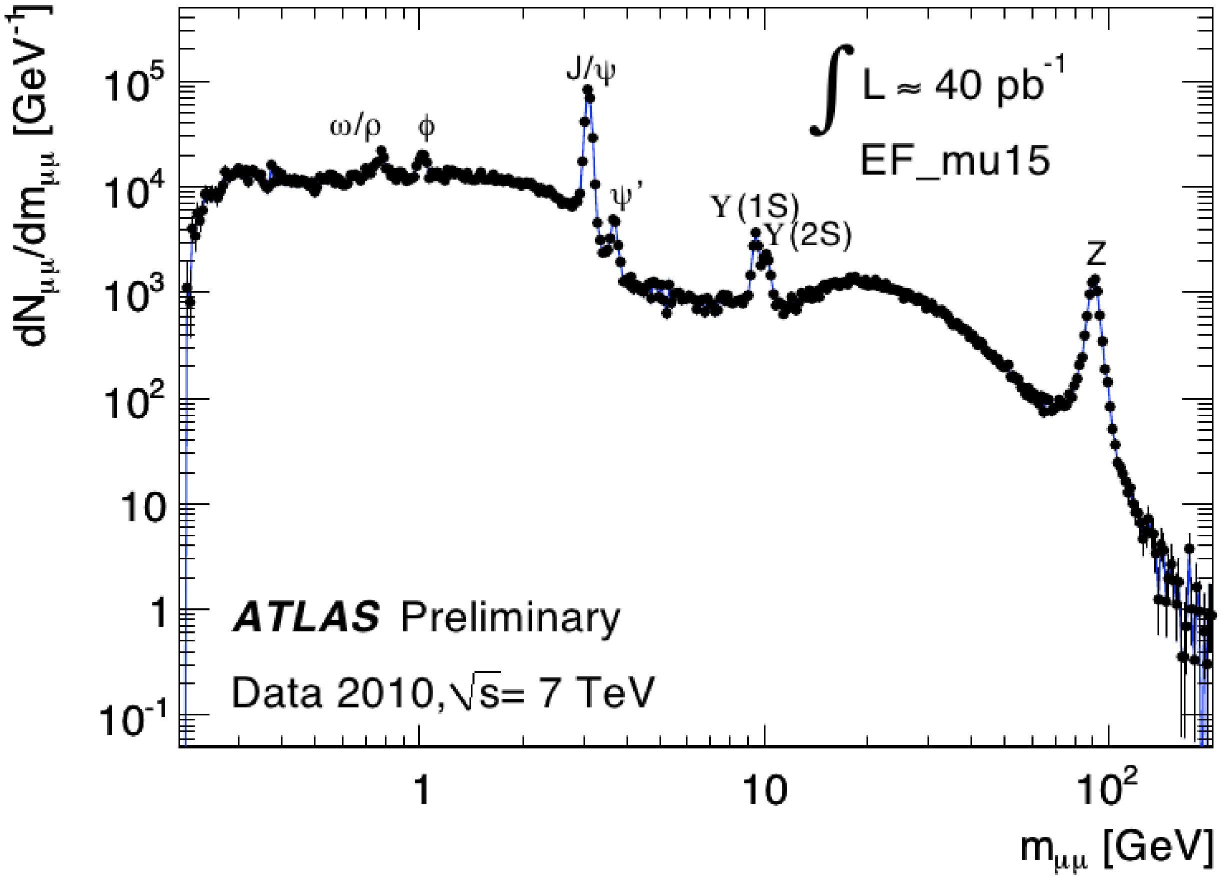


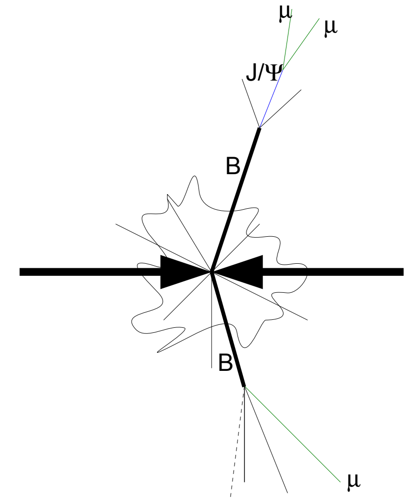

$\bar{b}$
l^+
ν
W^+
W^-
$\bar{t}$
t
$\bar{q}$
q'
b

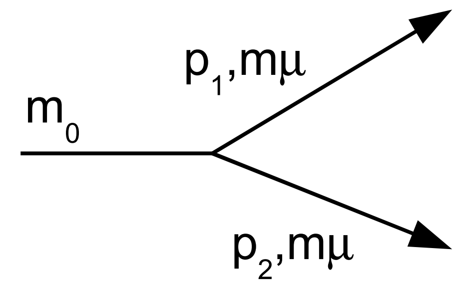

muon
Jet 1(b)
neutrino
antiproton beam
proton beam
neutrino
electron
Jet 2 ($\bar{b}$)

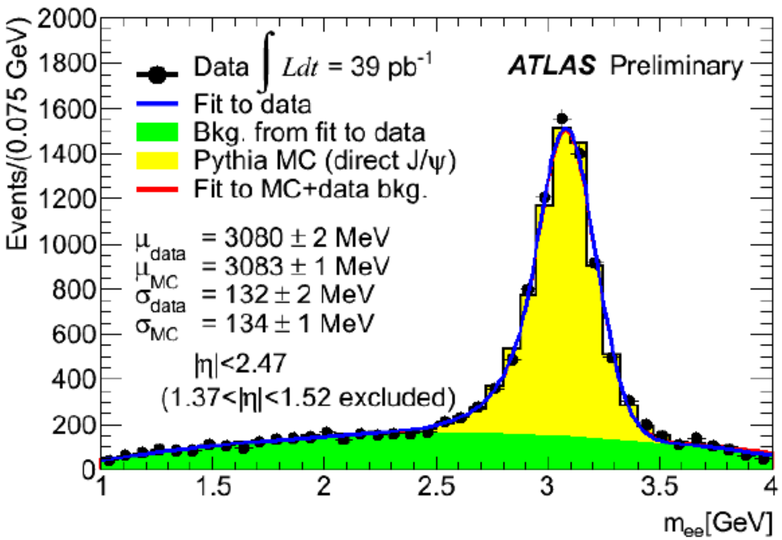












$$m_0^2 = E^2 - p^2$$

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

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

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

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

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. W. HIGGS
Tait Institute of Mathematical Physics, University of Edinburgh, Scotland

Received 27 July 1964

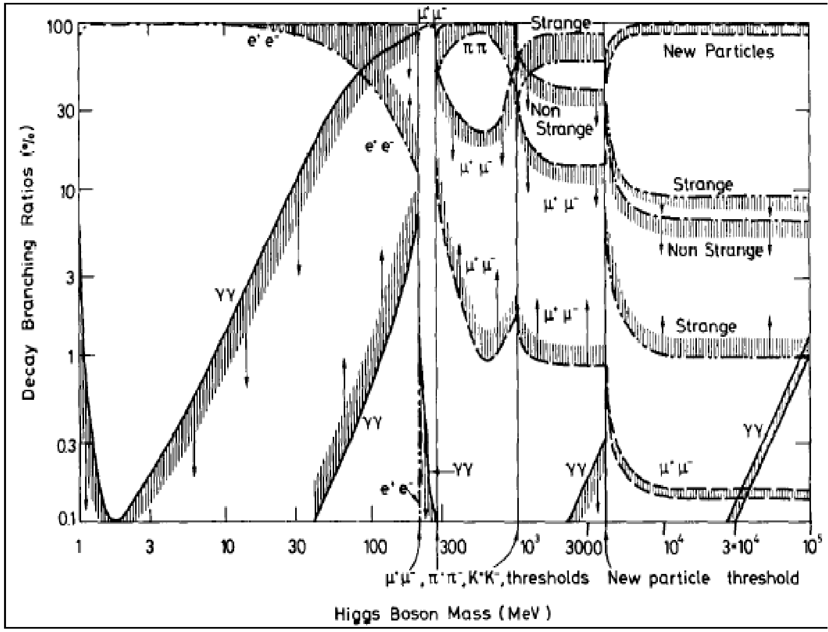
VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

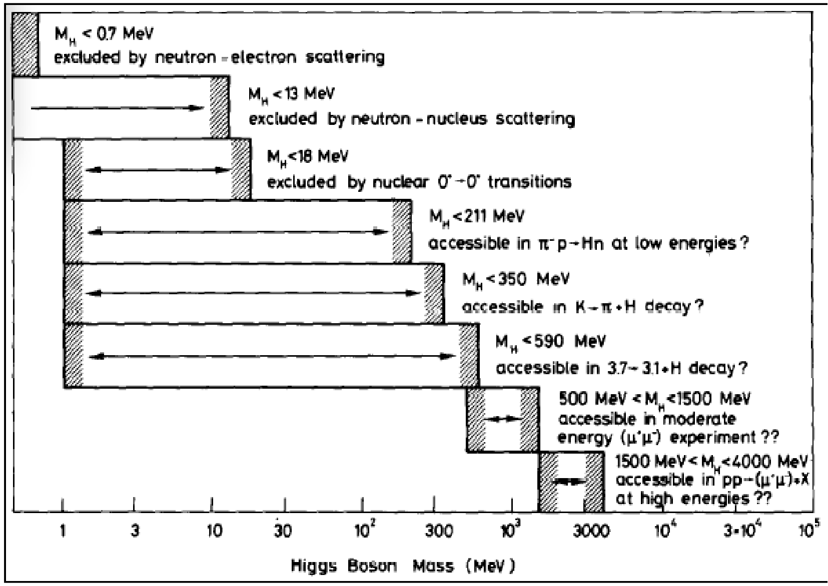
BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

G. S. Guralnik,† C. R. Hagen,‡ and T. W. B. Kibble
Department of Physics, Imperial College, London, England
(Received 12 October 1964)





We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

Maxwellove rovnice:

$$\nabla \cdot \boldsymbol{E} = \rho \quad ; \quad \nabla \cdot \boldsymbol{B} = 0$$

$$\nabla \times \boldsymbol{B} - \frac{\partial \boldsymbol{E}}{\partial t} = \boldsymbol{J} \quad ; \quad \nabla \times \boldsymbol{E} + \frac{\partial \boldsymbol{B}}{\partial t} = 0$$

$$A^{\mu} \equiv (\phi, \boldsymbol{A}) \quad ; \quad J^{\mu} \equiv (\rho, \boldsymbol{J})$$

$$\boldsymbol{E} = -\nabla \phi - \frac{\partial \boldsymbol{A}}{\partial t} \quad ; \quad \boldsymbol{B} = \nabla \times \boldsymbol{A}$$

$$F^{\mu\nu} \equiv \partial^{\mu} A^{\nu} - \partial^{\nu} A^{\mu} = \begin{bmatrix} 0 & -E_1 & -E_2 & -E_3 \\ E_1 & 0 & -B_3 & B_2 \\ E_2 & B_3 & 0 & -B_1 \\ E_3 & -B_2 & B_1 & 0 \end{bmatrix}$$

$$\partial_{\mu} F^{\mu\nu} = \partial_{\mu} \partial^{\mu} A^{\nu} - \partial^{\nu} (\partial_{\mu} A^{\mu}) = J^{\nu}$$

Lorenzova kalibračná podmienka: $\partial_{\mu} A^{\mu} = 0$

$$\partial_{\mu} \partial_{\nu} F^{\mu\nu} = 0 \;\rightarrow\; \partial_{\mu} J^{\mu} = 0$$

Zachovanie elektromagnetického naboja
(rovnica kontinuity)

$$(\partial^{\mu} \partial_{\mu}) A^{\mu} = J^{\mu}$$

$$A'^{\mu} \equiv A^{\mu} + \partial^{\mu} \Lambda$$

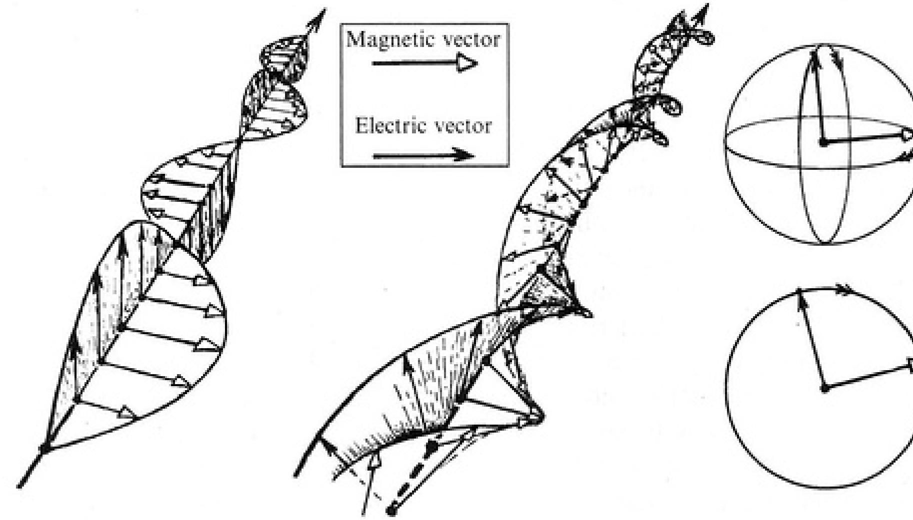
Existuje mnoho potenciálov
popisujúcich stejnú fyziku.

Ak prostredie bez zdrojov:

$\partial_\mu A^\mu = 0 \quad J^\mu = 0$

Potom platí: $\left(\partial^\mu \partial_\mu\right) A^\mu = 0$

Čo je Klein-Gordonova rovnica pre nehmotnú časticu.



(a) (b) (c)

4-vektor má 4 stupne volnosti, ale:

Lorenzova (Ludvik) kalibračná podmienka: $\partial_\mu A^\mu = 0$
a

Reziduálna invariancia $A'^\mu \equiv A^\mu + \partial^\mu \Lambda$
Vyžerú 2 stupne voľnosti. Preto má nehmotný fotón 2 tranzverzálne polarizácie.

Nerelativisticky:

$$p = -i\nabla \quad ; \quad E = i\frac{\partial}{\partial t}$$

$$E = \frac{p^2}{2\mathrm{m}}$$

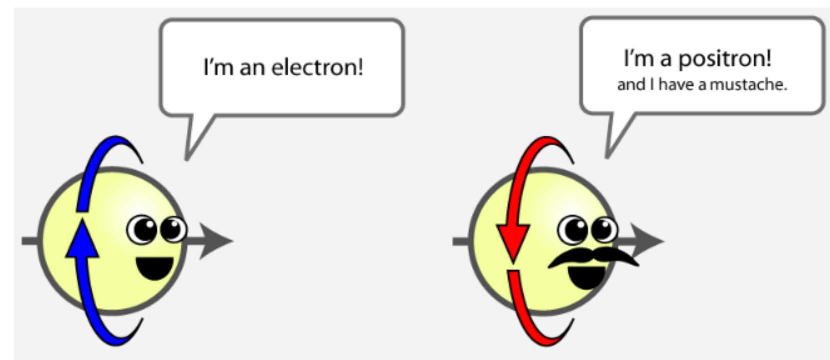
$$i\frac{\partial \Psi}{\partial t} = -\frac{\nabla^2}{2\mathrm{m}}\Psi$$

Relativisticky:

$$p^\mu = -i\,\partial^\mu = i g^{\mu\nu}\frac{\partial}{\partial x^\nu}$$

$$E^2 = p^2 + m^2$$

$$(\partial^\mu \partial_\mu + m^2)\Phi = 0$$



Electrons (left-chiral) and positrons (right-chiral) are two completely different particles, as evidenced by the positron's mustache.

Spin 1/2

$$(i\gamma^\mu \partial_\mu - m)\Psi = 0$$

$$-(i\gamma^\nu \partial_\nu + m)[(i\gamma^\mu \partial_\mu - m)\Psi] = 0 \;\equiv\; (\partial^\mu \partial_\mu + m^2)\Psi$$

$$\{\gamma^\mu, \gamma^\nu\} = 2g^{\mu\nu}$$

$$\gamma^0 = \begin{pmatrix} I & 0 \\ 0 & -I \end{pmatrix}; \quad \gamma^k = \begin{pmatrix} 0 & \sigma_k \\ -\sigma_k & 0 \end{pmatrix}$$

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

$$\sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

$$\sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$S=\int \mathscr{L}(\phi,\partial_\mu\phi)d^4x \qquad \delta S=0 \longrightarrow \frac{\partial\mathscr{L}}{\partial\phi}-\partial^\mu\left(\frac{\partial\mathscr{L}}{\partial(\partial^\mu\phi)}\right)=0$$

$$(i\gamma^\mu\partial_\mu-m)\Psi=0 \qquad \bar{\Psi}=\Psi^\dagger\gamma^0 \longrightarrow \mathscr{L}=\bar{\Psi}(i\gamma^\mu\partial_\mu-m)\Psi$$

Chceme aby bol Lagrangian invariantný voči otočeniu fázy o Θ(x). (tzv. $U(1)_{LOC}$ symetria)

$$\Psi\rightarrow\Psi'=e^{iQ\Theta(x)}\Psi$$
$$\bar{\Psi}\rightarrow\bar{\Psi}'=e^{-iQ\Theta(x)}\bar{\Psi}$$

$$\mathscr{L}'=e^{-iQ\Theta(x)}\bar{\Psi}(i\gamma^\mu\partial_\mu)e^{iQ\Theta(x)}\Psi-me^{-iQ\Theta(x)}e^{iQ\Theta(x)}\bar{\Psi}\Psi$$
$$\partial_\mu\Psi\rightarrow e^{iQ\Theta(x)}(\partial_\mu+iQ\partial_\mu\Theta(x))\Psi$$

Musíme pridať člen ktorý to kompenzuje.

Zavedieme tzv. Kovarianú deriváciu

$$\mathscr{L}=\bar{\Psi}(i\gamma^\mu D_\mu-m)\Psi \quad ; \quad D_\mu\equiv(\partial_\mu-ieQA_\mu)$$
$$\mathscr{L}=\bar{\Psi}(i\gamma^\mu\partial_\mu-m)\Psi+eQA_\mu(\bar{\Psi}\gamma^\mu\Psi)$$

Z požiadavku na zachovanie lokálnej invariancie nám vznikne vektorové pole (spin 1) – fotón.

$$A'_\mu\equiv A_\mu+\frac{1}{e}\partial_\mu\Theta(x)$$

Electron kinetic term

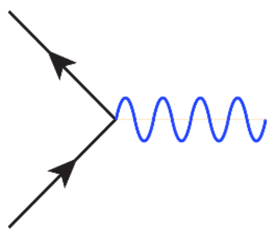
e$^-$ mass term

$$\mathscr{L} = i\bar{\Psi}(\gamma^{\mu}\partial_{\mu})\Psi + eQ A_{\mu}\bar{\Psi}\gamma^{\mu}\Psi - m\bar{\Psi}\Psi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$

QED

interaction term

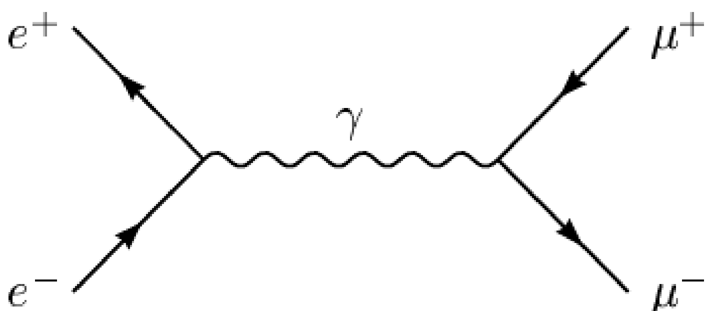
kinetic term for elmag. field



$$(\partial^{\mu}\partial_{\mu})A^{\mu} = J^{\mu}$$

Z M.R.

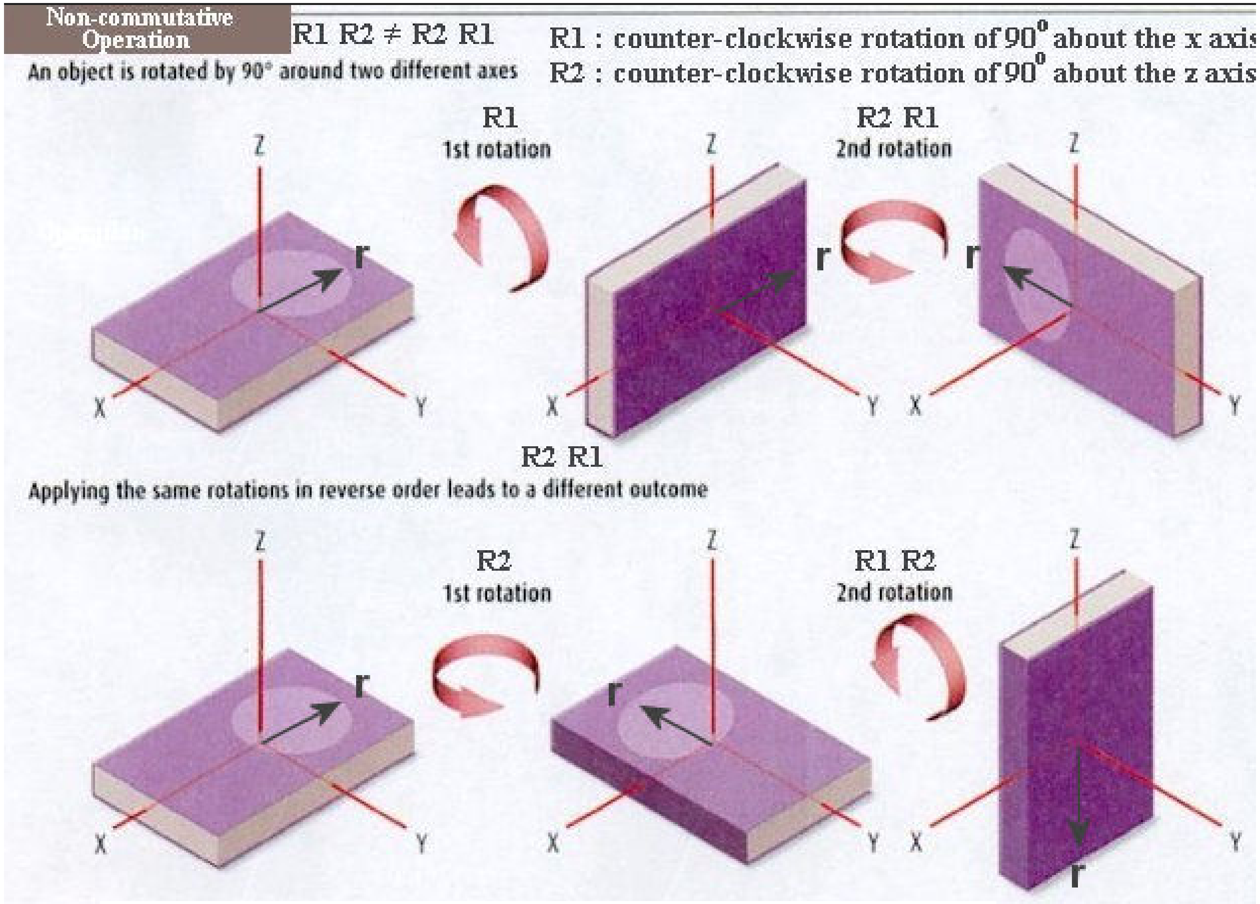
$$(\partial^{\mu}\partial_{\mu})A^{\mu} = J^{\mu} = e\bar{\Psi}\gamma^{\mu}\Psi$$

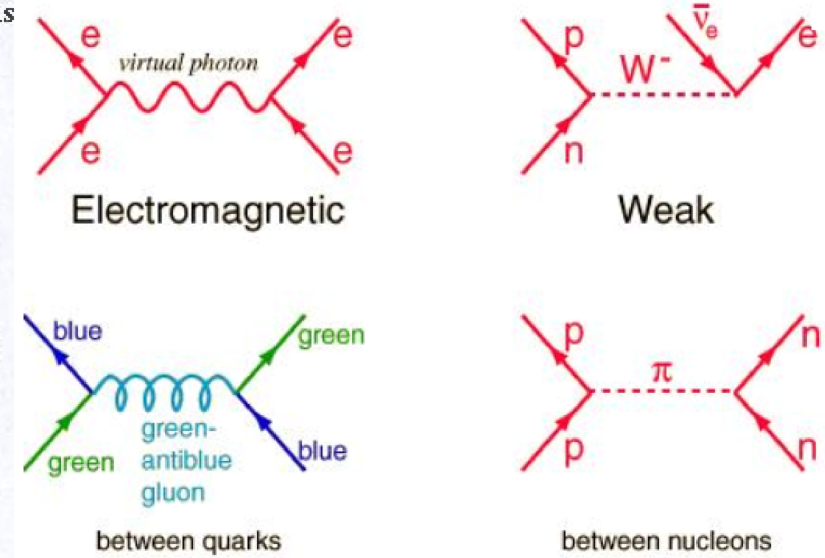


(a)

$$i\mathcal{M}_{fi} = (-ie)\,\overline{u}(p_c)\gamma^{\mu}u(p_a)\left(\frac{-ig_{\mu\nu}}{q^2}\right)(-ie)\,\overline{u}(p_d)\gamma^{\nu}u(p_b).$$

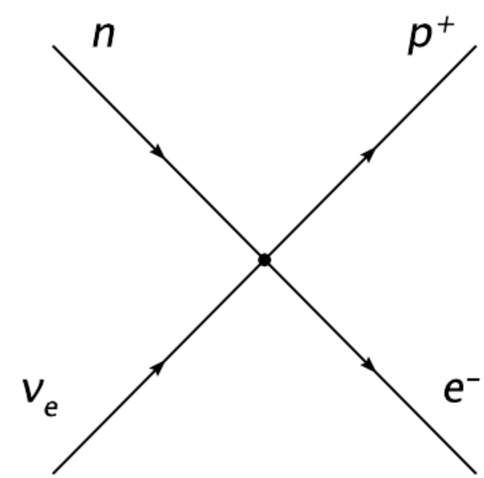
$$SU(2)_L \times U(1)_Y$$





$$D_\mu = \partial_\mu - ig\frac{1}{2}\vec{\tau}\cdot\vec{W}_\mu - ig'\frac{1}{2}YB_\mu$$

$$D_\mu\begin{pmatrix}\nu_L\\ e_L\end{pmatrix} = \left[\partial_\mu - \frac{ig_1}{2}B_\mu + \frac{ig_2}{2}\mathbf{W}_\mu\right]\begin{pmatrix}\nu_L\\ e_L\end{pmatrix}$$



$$M = \frac{G_F}{\sqrt{2}}[\overline{u_P}\gamma^\mu u_N][\overline{u_e}\gamma^\nu u_\nu]$$

$$SU(2)_L \times U(1)_Y$$

Neabelovská grupa → self interaction.

W – weak isospin, 3 komponenty W^1, W^2, W^3
B – hypercharge

$$D_\mu = \partial_\mu - ig\frac{1}{2}\vec{\tau}\cdot\vec{W}_\mu - ig'\frac{1}{2}YB_\mu$$

$$\mathcal{L}_{int}^{\mathrm{EW}} = \mathcal{L}_{int}^{\mathrm{QED}} + \mathcal{L}_{int}^{\mathrm{CC}} + \mathcal{L}_{int}^{\mathrm{NC}}$$

$$\mathcal{L}_{int}^{\mathrm{EW}} = -igj_\mu^i W^{i\mu} - i\frac{g'}{2}j_\mu^Y B^\mu,$$

$$A^\mu = B^\mu \cos\theta_w + W^{3\mu}\sin\theta_w$$

$$Z^\mu = -B^\mu \sin\theta_w + W^{3\mu}\cos\theta_w$$

$$W^{\pm\mu} = \frac{1}{\sqrt{2}}(W^{1\mu} \mp iW^{2\mu})$$

$$\mathcal{L}_{matter} = \sum_L \bar{L}\gamma^\mu\left(i\partial_\mu + g\frac{1}{2}\vec{\tau}\cdot\vec{W}_\mu + g'\frac{Y}{2}B_\mu\right)L + \sum_R \bar{R}\gamma^\mu\left(i\partial_\mu + g'\frac{Y}{2}B_\mu\right)R$$

$$-igj_\mu^3 W^{3\mu} - i\frac{g'}{2}j_\mu^Y B^\mu = -i\left(g\sin\theta_w j_\mu^3 + g'\cos\theta_w\frac{j_\mu^Y}{2}\right)A^\mu$$

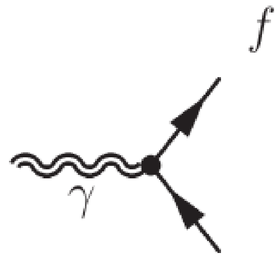
$$-i\left(g\cos\theta_w j_\mu^3 - g'\sin\theta_w\frac{j_\mu^Y}{2}\right)Z^\mu$$

$$i\mathcal{L}_{int}^{\text{QED}} = -ie\bar{\psi}_f \gamma_\mu Q \psi_f A^\mu$$

$$\chi_L \equiv \begin{pmatrix} \nu_l \\ l \end{pmatrix}_L = \frac{1-\gamma^5}{2} \begin{pmatrix} \nu_l \\ l \end{pmatrix}$$

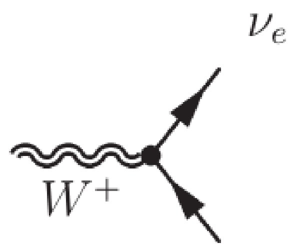
$$c_V^f = T_3^f - 2\sin^2\theta_w Q^f$$
$$c_A^f = T_3^f .$$

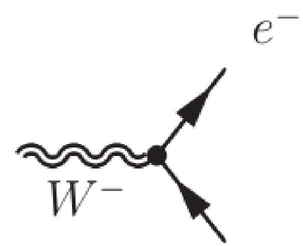
	Q^f	c_V^f	c_A^f
ν	0	$1/2$	$1/2$
e	-1	$-1/2 + 2\sin^2\theta_w$	$-1/2$
u	$2/3$	$1/2 - 4/3\sin^2\theta_w$	$1/2$
d	$-1/3$	$-1/2 + 2/3\sin^2\theta_w$	$-1/2$

$\Rightarrow$ 

$= -ieQ_f\gamma_\mu$

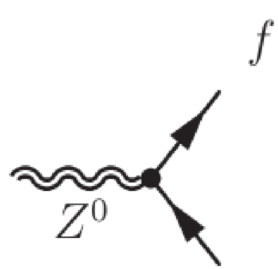
$$i\mathcal{L}_{int}^{\text{CC}} = -i\frac{g}{\sqrt{2}}(\bar{\chi}_L\gamma_\mu\tau_+\chi_L)W^{+\mu} - i\frac{g}{\sqrt{2}}(\bar{\chi}_L\gamma_\mu\tau_-\chi_L)W^{-\mu}$$
$$= -i\frac{g}{\sqrt{2}}\bar{\nu}\gamma_\mu\left(\frac{1-\gamma_5}{2}\right)eW^{+\mu} - i\frac{g}{\sqrt{2}}\bar{e}\gamma_\mu\left(\frac{1-\gamma_5}{2}\right)\nu W^{-\mu}$$

$\Rightarrow$ 

$=$ 

$= -i\frac{g}{\sqrt{2}}\gamma_\mu\left(\frac{1-\gamma_5}{2}\right)$

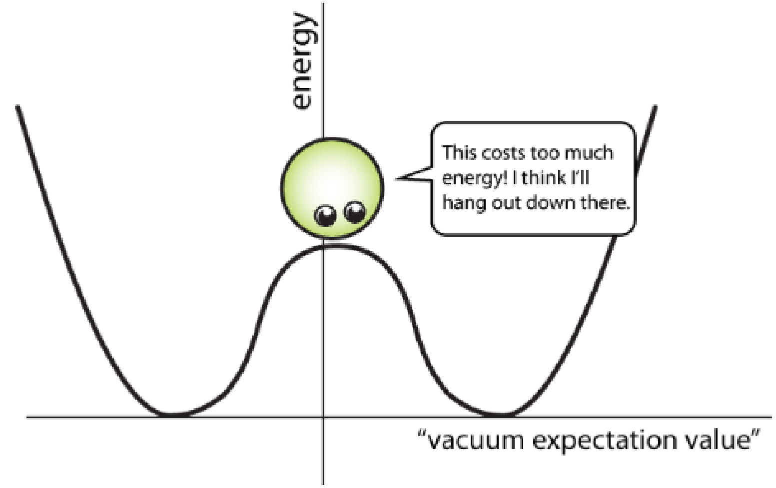
$$i\mathcal{L}_{int}^{\text{NC}} = -i\frac{g}{\cos\theta_w}\bar{\psi}_f\gamma_\mu\left[\left(\frac{1-\gamma_5}{2}\right)T_3 - \sin^2\theta_w Q\right]\psi_f Z^\mu$$
$$= -i\frac{g}{\cos\theta_w}\bar{\psi}_f\gamma_\mu\frac{1}{2}(c_V^f - c_A^f\gamma_5)\psi_f Z^\mu$$

$\Rightarrow$ 

$= -i\frac{g}{\cos\theta_w}\gamma_\mu\frac{1}{2}(c_V^f - c_A^f\gamma_5)$

Klasické vloženie mass termu do Lagranžiánu spôsobí zrušenie kalibračnej symetrie

$$\mathcal{L}_M = -\frac{m^2}{2} A_\mu A^\mu$$



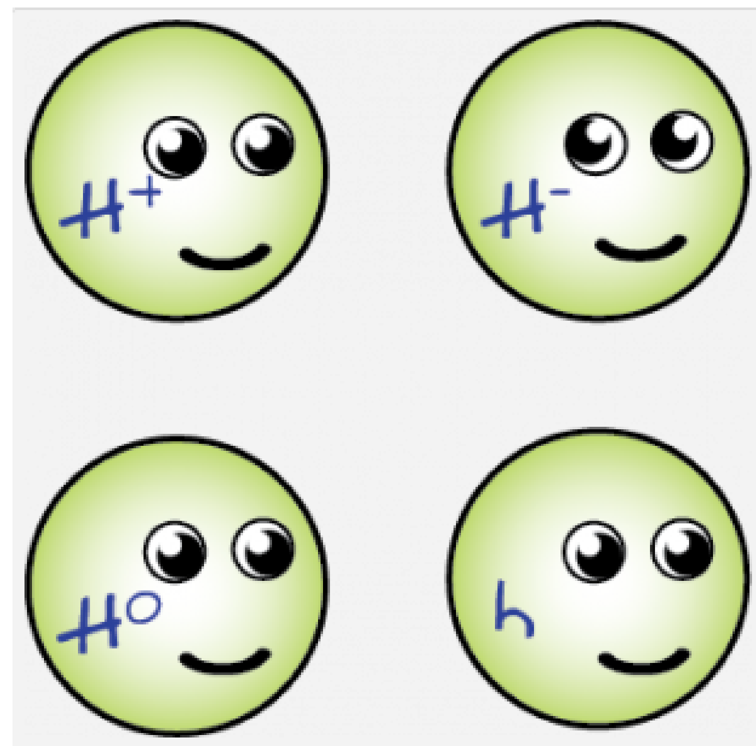
Ak ale však do SM vložíme komplexný doublet

$$\phi = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi_1 + i\phi_2 \\ \phi_3 + i\phi_4 \end{pmatrix} = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

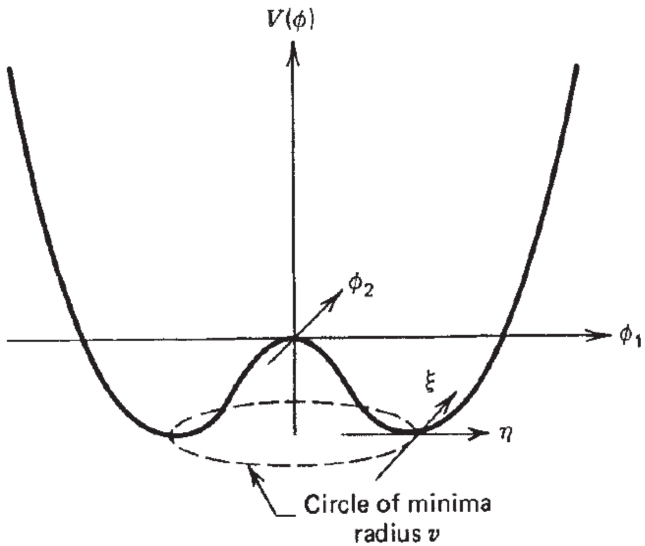
So symetriou $SU(2)_L \times U(1)_Y$

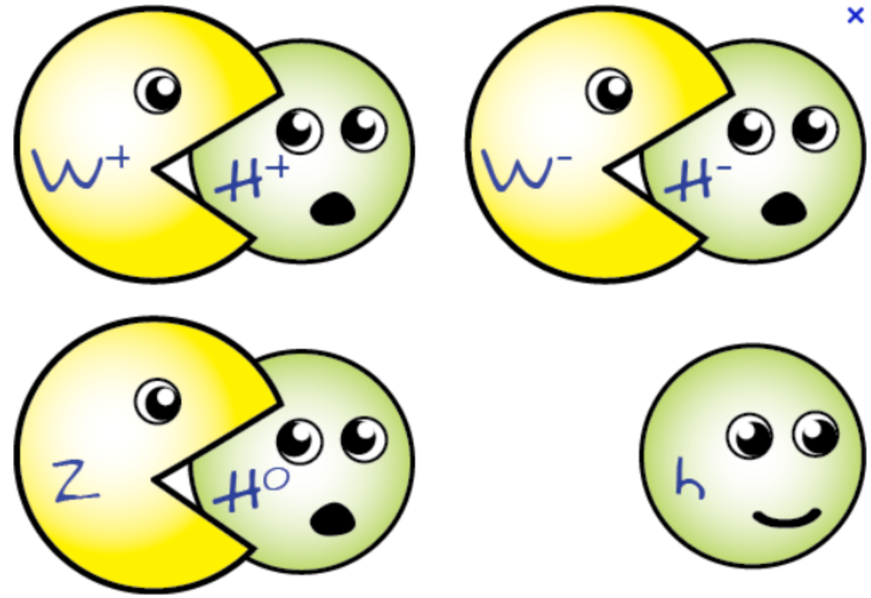
$$D_\mu = \partial_\mu - ig\frac{1}{2}\vec{\tau} \cdot \vec{W}_\mu - ig'\frac{1}{2} Y B_\mu$$

$$\mathcal{L} = [iD^\mu \phi]^\dagger [iD_\mu \phi] - \mu^2 \phi^\dagger \phi - \lambda [\phi^\dagger \phi]^2$$



"The Four Higgses of the Standard Model," biblical pun intended





Uvažujme $\mu^2 < 0$ a $\lambda > 0$ a vyberme si stav vakua $\Phi_1 = \Phi_2 = \Phi_4 = 0$ a $\Phi_3 = v$, potom

$$v^2 = -\frac{\mu^2}{\lambda} \qquad \phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix}$$

$$\begin{aligned} \left| \left(-i\frac{g}{2}\vec{\tau} \cdot \vec{W}_\mu - i\frac{g'}{2} B_\mu \right) \phi \right|^2 &= \frac{1}{8} \left| \begin{pmatrix} gW^3_\mu + g'B_\mu & g(W^1_\mu - iW^2_\mu) \\ g(W^1_\mu + iW^2_\mu) & -gW^3_\mu + g'B_\mu \end{pmatrix} \begin{pmatrix} 0 \\ v \end{pmatrix} \right|^2 \\ &= \frac{1}{8} v^2 g^2 \left| (W^1)^2 + (W^2_\mu)^2 \right| + \frac{1}{8} v^2 (g'B_\mu - gW^3_\mu)(g'B^\mu - gW^{3\mu}) \\ &= \left(\frac{1}{2} vg \right)^2 W^+_\mu W^{-\mu} + \frac{1}{8} v^2 (g'B_\mu - gW^3_\mu)^2 \end{aligned}$$

$$\mathcal{L}_{GWS} = \sum_f (\bar{\Psi}_f(i\gamma^\mu \partial\mu - m_f)\Psi_f - eQ_f\bar{\Psi}_f\gamma^\mu\Psi_f A_\mu) +$$

$$+\frac{g}{\sqrt{2}}\sum_i(\bar{a}_L^i\gamma^\mu b_L^i W_\mu^+ + \bar{b}_L^i\gamma^\mu a_L^i W_\mu^-) + \frac{g}{2c_w}\sum_f \bar{\Psi}_f\gamma^\mu(I_f^3 - 2s_w^2 Q_f - I_f^3\gamma_5)\Psi_f Z_\mu +$$

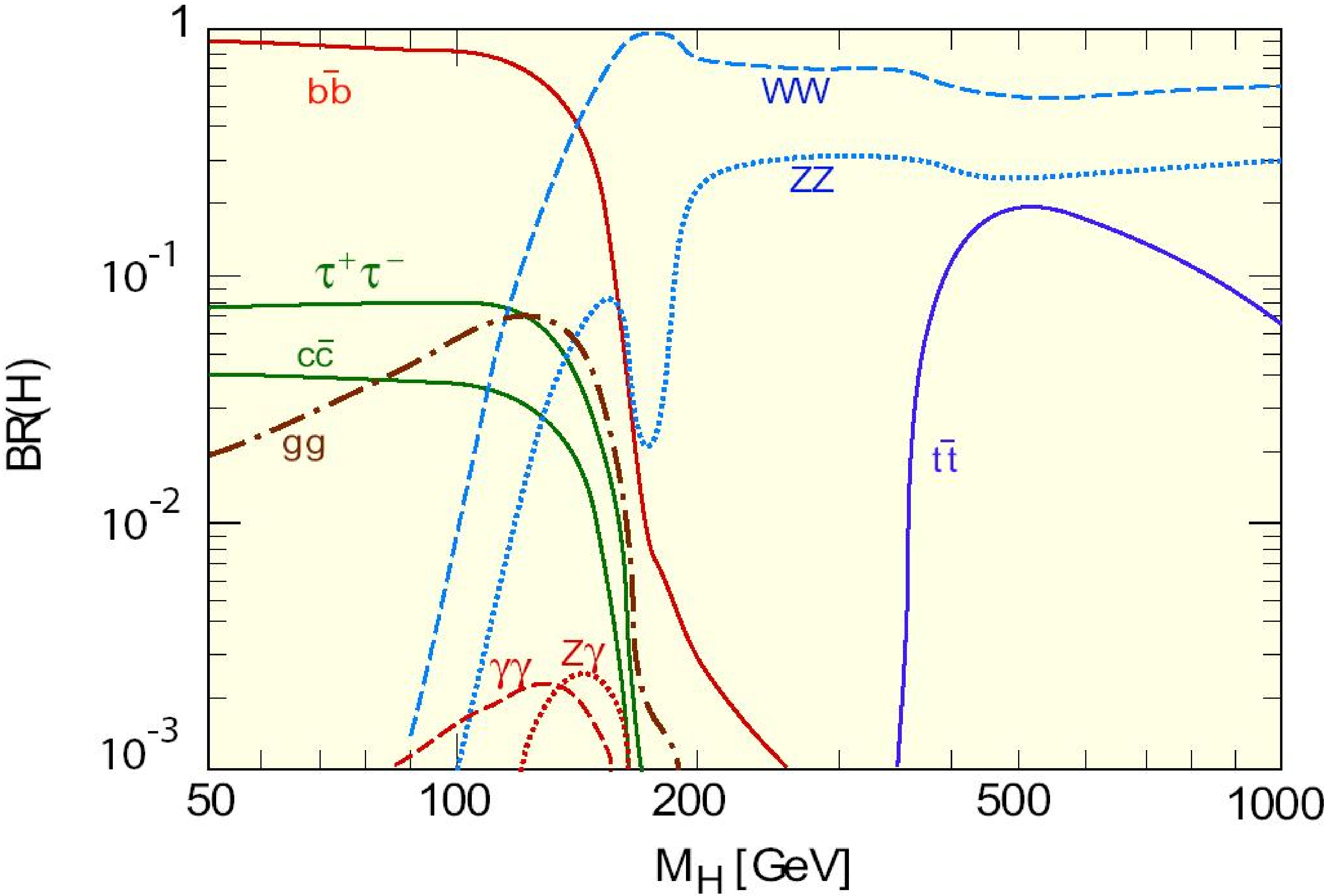
$$-\frac{1}{4}|\partial_\mu A_\nu - \partial_\nu A_\mu - ie(W_\mu^- W_\nu^+ - W_\mu^+ W_\nu^-)|^2 - \frac{1}{2}|\partial_\mu W_\nu^+ - \partial_\nu W_\mu^+ +$$

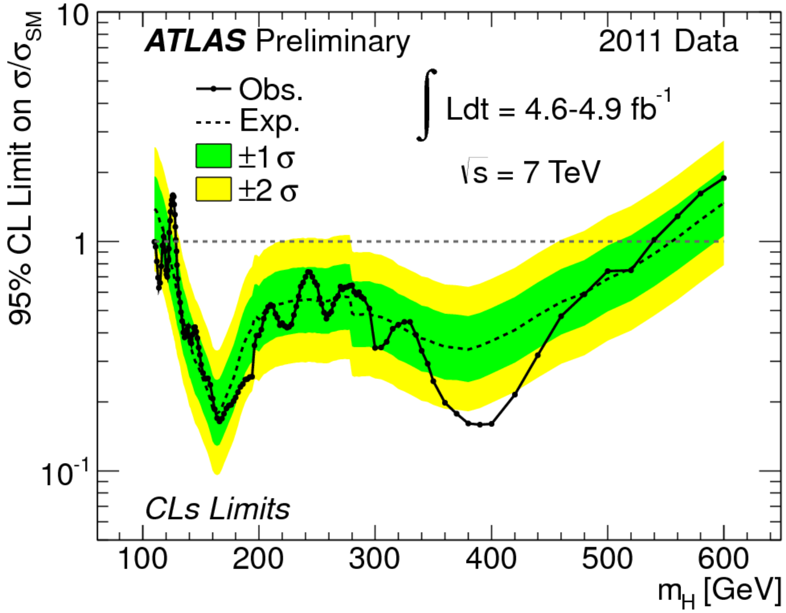
$$-ie(W_\mu^+ A_\nu - W_\nu^+ A_\mu) + ig' c_w(W_\mu^+ Z_\nu - W_\nu^+ Z_\mu|^2 +$$

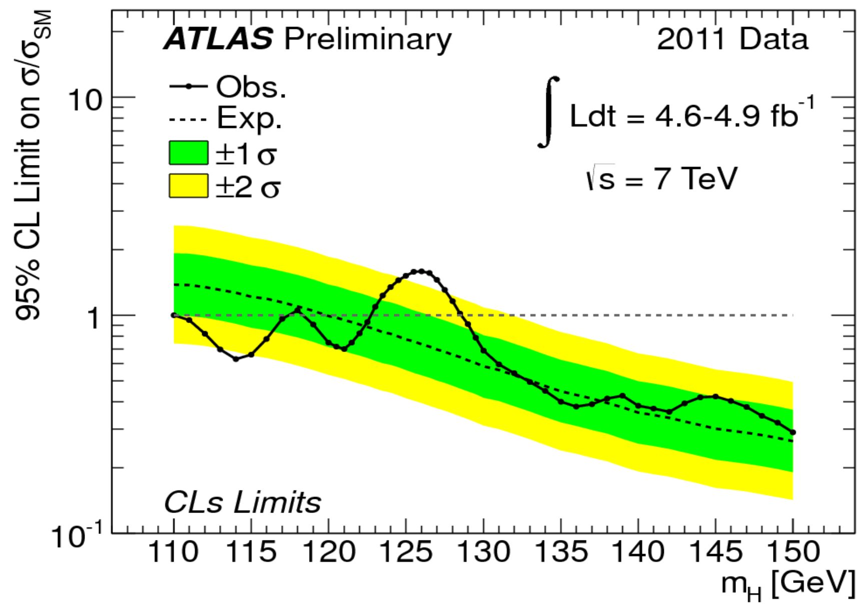
$$-\frac{1}{4}|\partial_\mu Z_\nu - \partial_\nu Z_\mu + ig' c_w(W_\mu^- W_\nu^+ - W_\mu^+ W_\nu^-)|^2 +$$

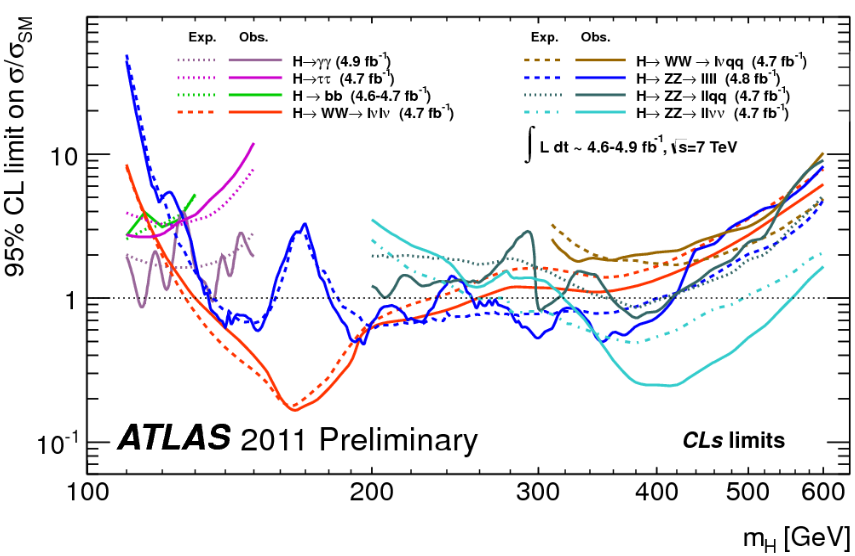
$$-\frac{1}{2}M_\eta^2\eta^2 - \frac{gM_\eta^2}{8M_W}\eta^3 - \frac{g'^2 M_\eta^2}{32M_W}\eta^4 + |M_W W_\mu^+ + \frac{g}{2}\eta W_\mu^+|^2 +$$

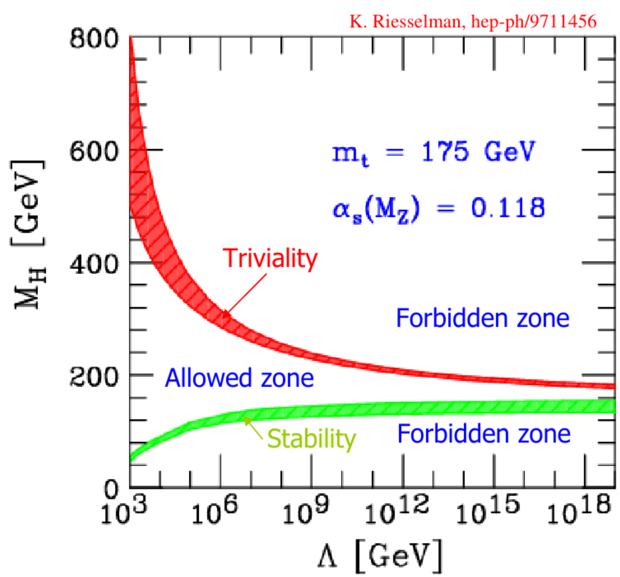
$$+\frac{1}{2}|\partial_\mu\eta + iM_Z Z_\mu + \frac{ig}{2c_w}\eta Z_\mu|^2 - \sum_f \frac{g}{2}\frac{m_f}{M_W}\bar{\Psi}_f\Psi_f\eta$$


1
10-1
10-2
10-3
BR(H)
50
100
200
500
1000
M_H [GeV]
bb̄
WW
ZZ
τ+τ−
cc̄
gg
tt̄
γγ
Zγ

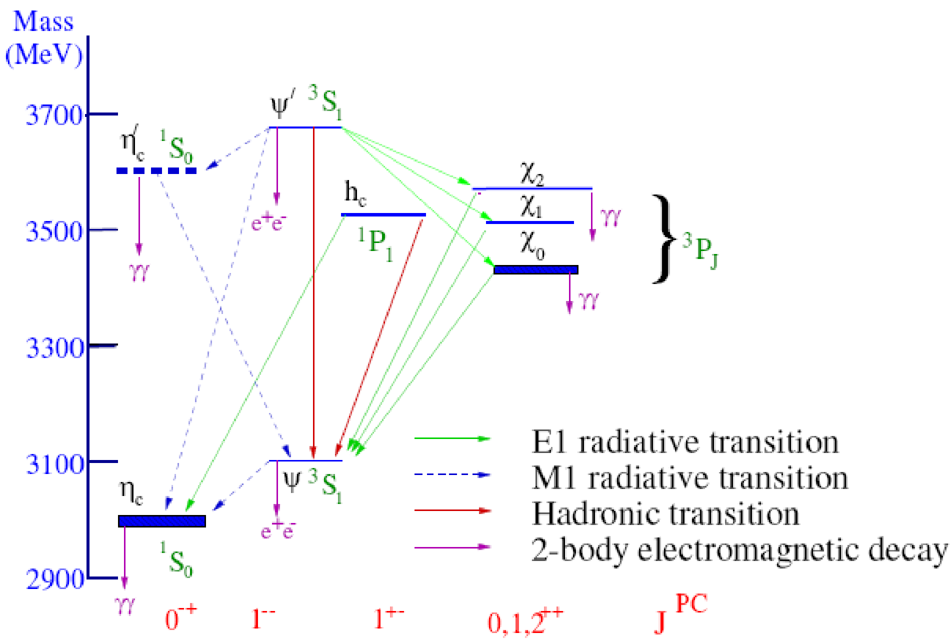

ATLAS Preliminary
2011 Data
Obs.
Exp.
±1 σ
±2 σ
∫ Ldt = 4.6-4.9 fb⁻¹
√s = 7 TeV
CLs Limits
95% CL Limit on σ/σSM
mH [GeV]


ATLAS Preliminary
2011 Data
Obs.
Exp.
±1 σ
±2 σ
∫ Ldt = 4.6-4.9 fb⁻¹
√s = 7 TeV
CLs Limits
95% CL Limit on σ/σSM
mH [GeV]


Exp. Obs.
H→γγ (4.9 fb⁻¹)
H→ττ (4.7 fb⁻¹)
H→bb (4.6-4.7 fb⁻¹)
H→WW→lνlν (4.7 fb⁻¹)
H→WW→lνqq (4.7 fb⁻¹)
H→ZZ→llll (4.8 fb⁻¹)
H→ZZ→llqq (4.7 fb⁻¹)
H→ZZ→llνν (4.7 fb⁻¹)
∫ L dt ~ 4.6-4.9 fb⁻¹, √s=7 TeV
ATLAS 2011 Preliminary
CLs limits
95% CL limit on σ/σSM
mH [GeV]


K. Riesselman, hep-ph/9711456
mt = 175 GeV
αs(MZ) = 0.118
Triviality
Forbidden zone
Allowed zone
Stability
Forbidden zone
MH [GeV]
Λ [GeV]

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



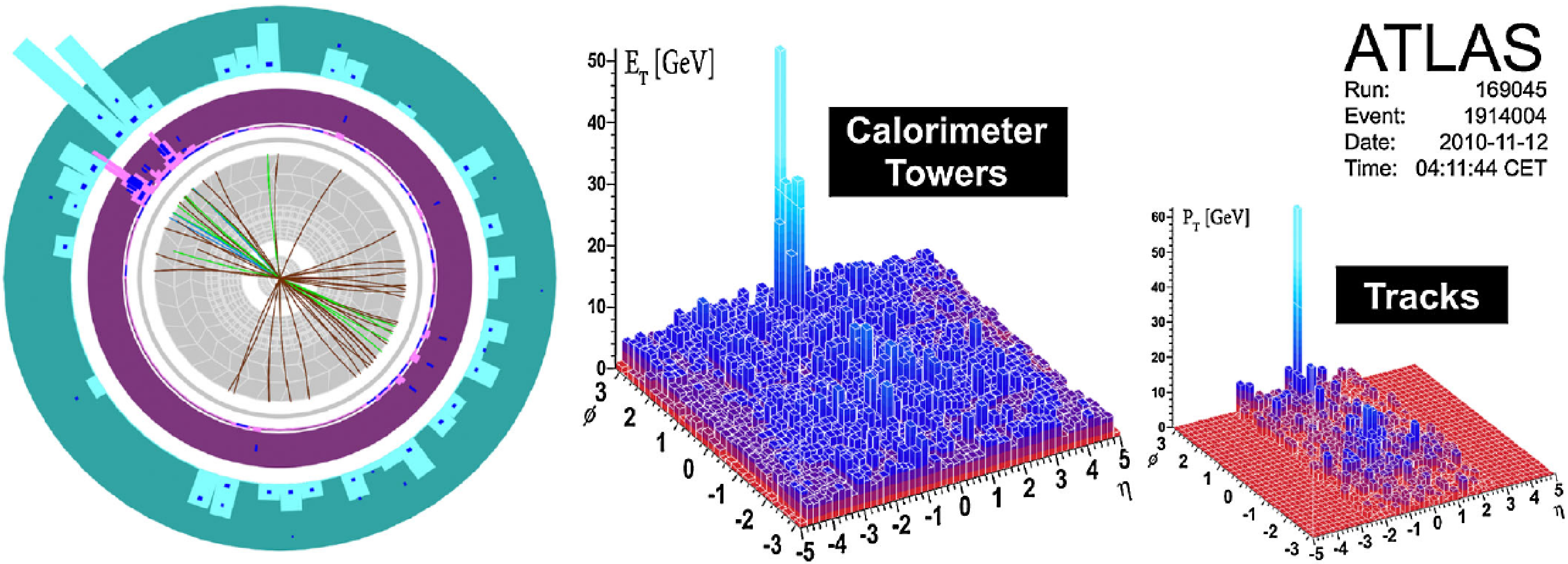
m_0 [MeV]	Γ [MeV]	$J^{PC} = 0^{+-}$	1^{--}	$0,1,2^{++}$	1^{+-}
2979.6	17.3	$\eta_c(1^1S_0)$			
3096.91	0.091		$J/\Psi(1^3S_1)$		
3415.19	10.1			$\chi_{c0}(1^3P_0)$	
3510.59	0.91			$\chi_{c1}(1^3P_1)$	
3526.21	< 1.1				$h_c(1^1P_1)$
3556.26	2.11			$\chi_{c2}(1^3P_2)$	
3654	~ 17	$\eta_c'(2^1S_0)$			
3686.09	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		$\Psi(4415)(6^3S_1)$		

$$J/\psi = {}^3S_1$$

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)

$$J^{PC} = 1^{--}$$

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 2×10^{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.

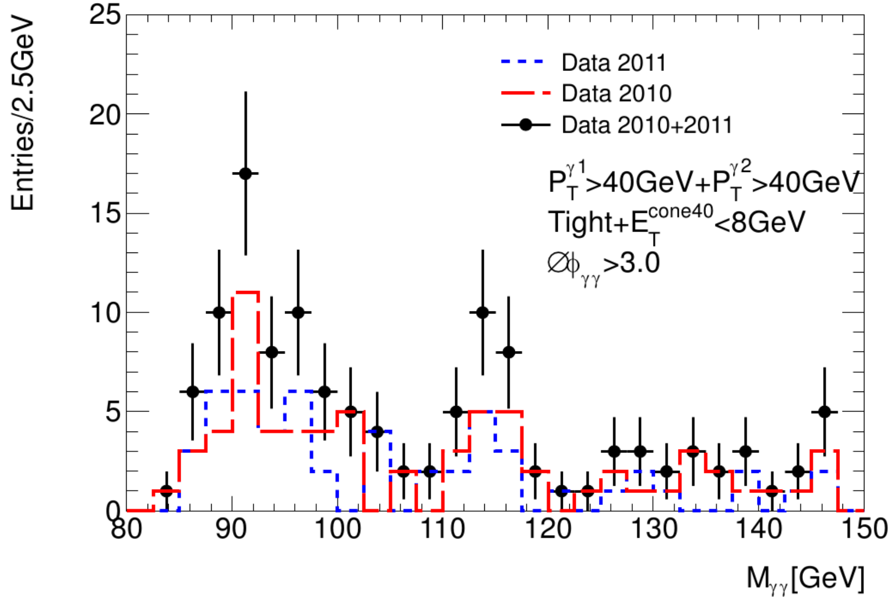
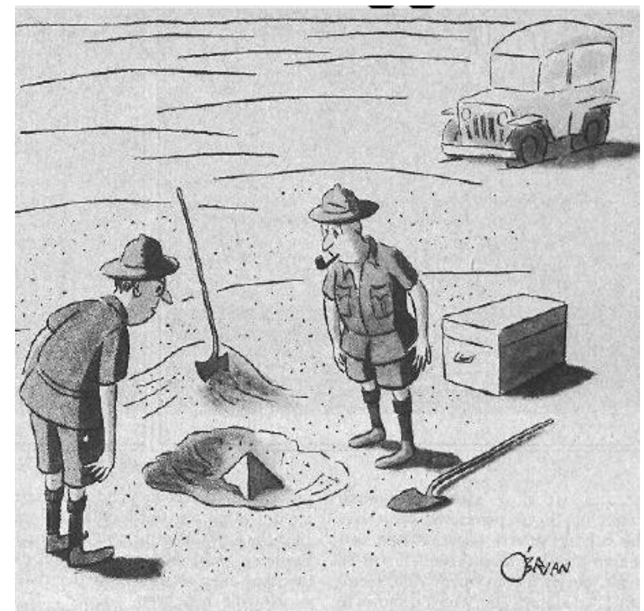


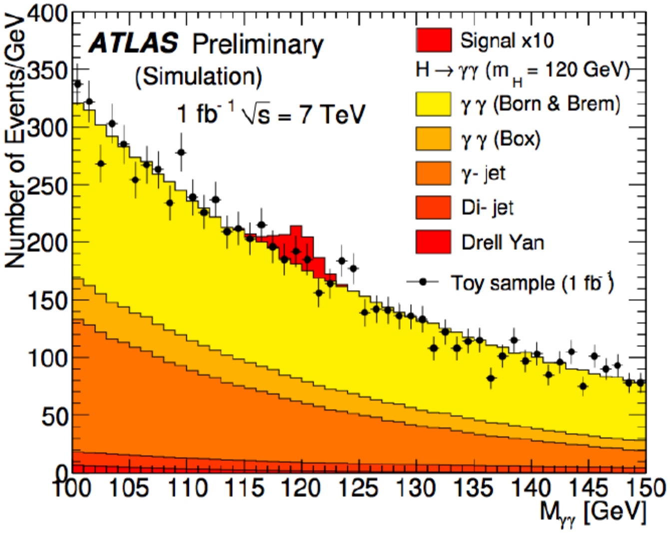
Figure 5: Comparison of the diphoton invariant mass distributions between 2010 (line), 2011 (dashed line), and all data (points).

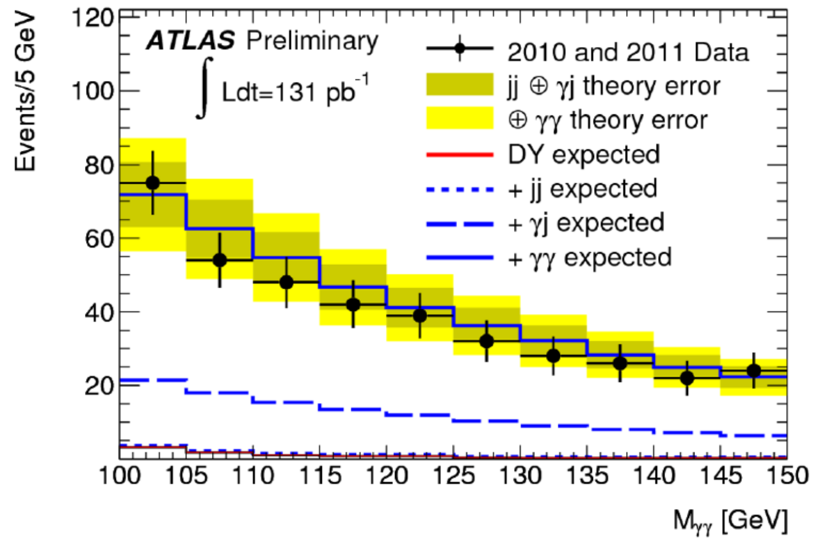


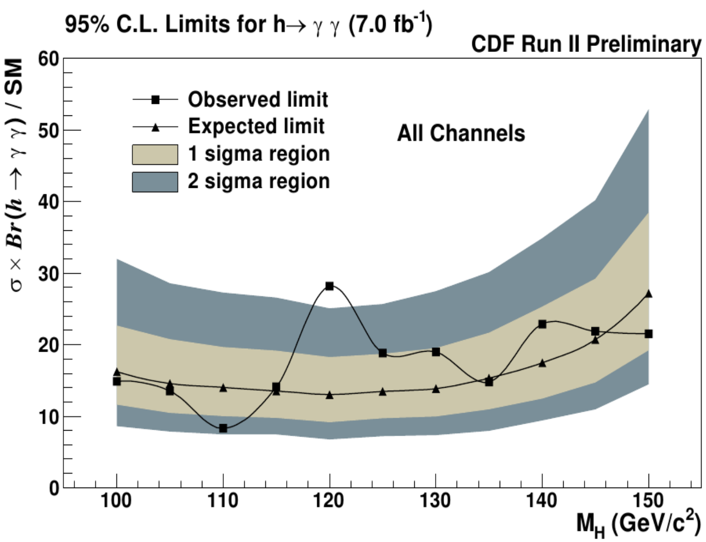
"This could be the discovery of the century. Depending, of course, on how far down it goes."

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

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".





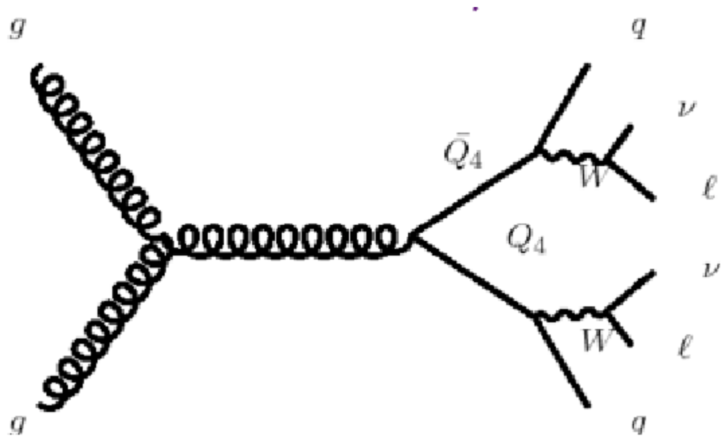


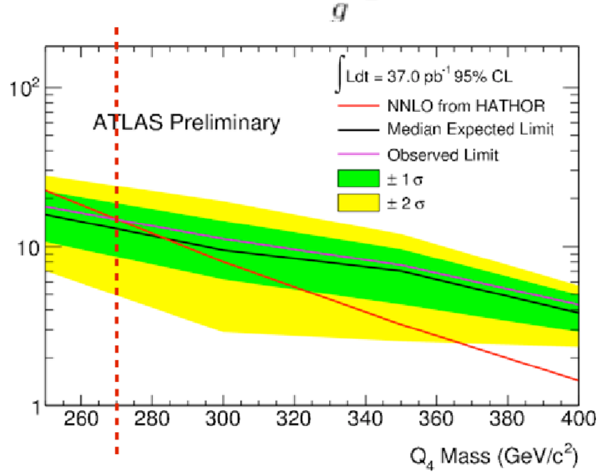
With few inverse pico-barns of integrated luminosity ATLAS has already been able to produce high quality results, competitive with searches performed at other facilities O(1-3) fb-1 are expected in 2011 and more in 2012 → full access to the multi-TeV scale

WWjj

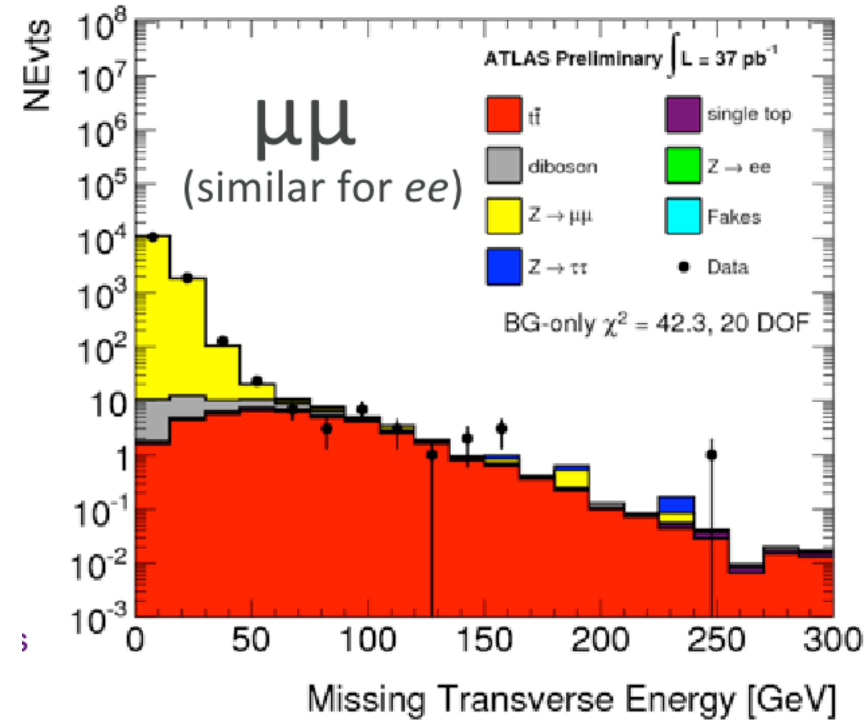
Search for 4th quark generation
all leptonic (e and μ)
opposite sign leptons

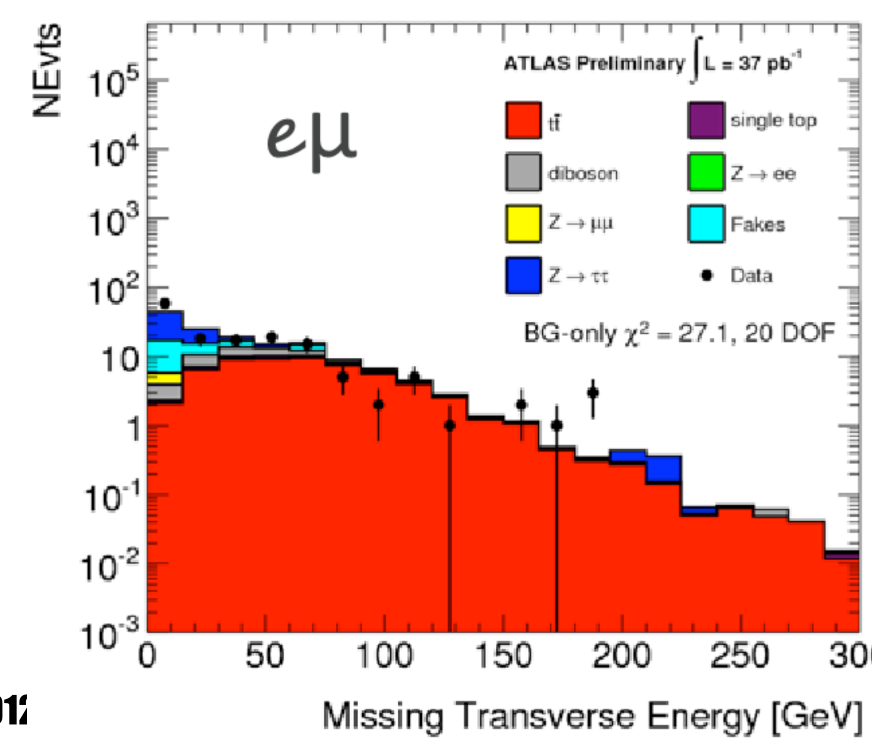
Main background after cuts
t t-bar





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



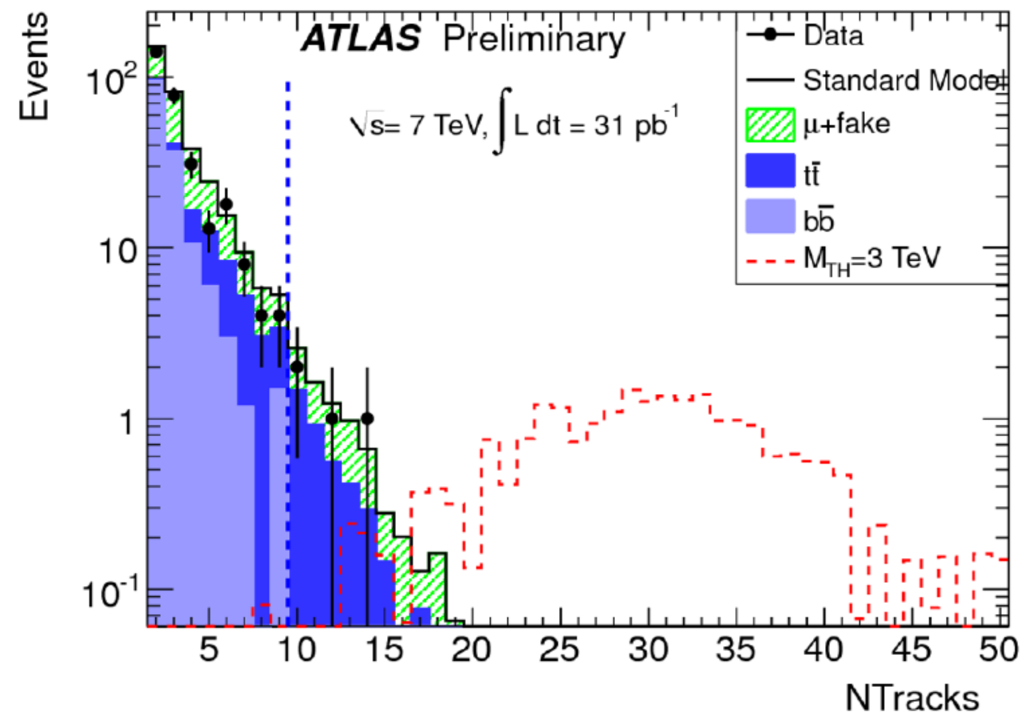


Black holes

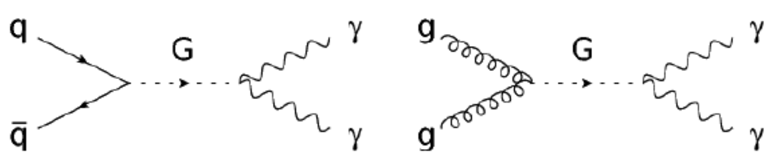
- striking signatures: multiple high pT objects
- background further reduced searching in like-sign di-muon decays

Strategy:

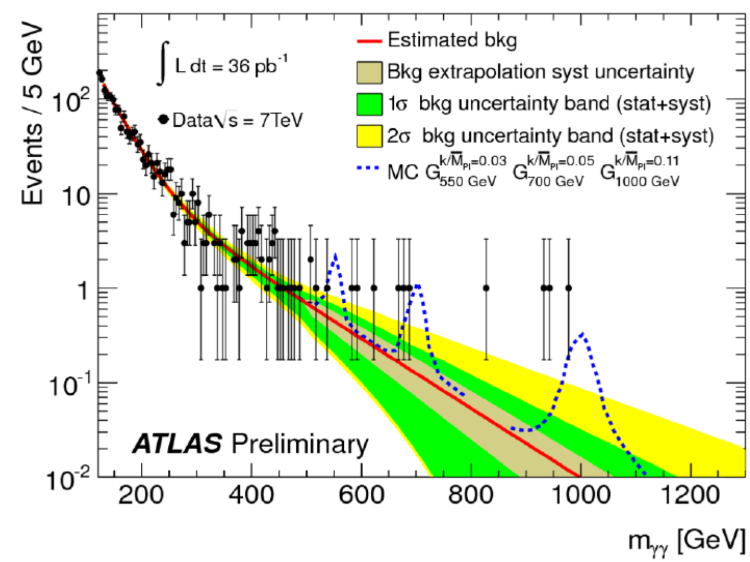
- high pT track multiplicity discriminates signal and background effectively
- counting experiment in a pre-defined signal region
- muon+fake background from data using per-track fake rate
- other backgrounds (tt, bb) from MC

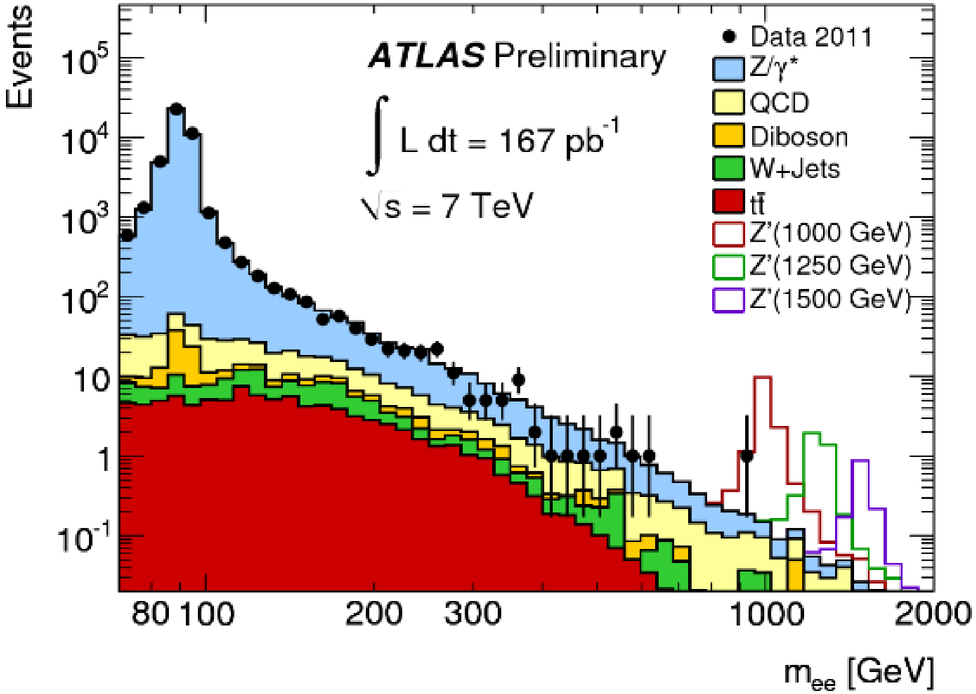


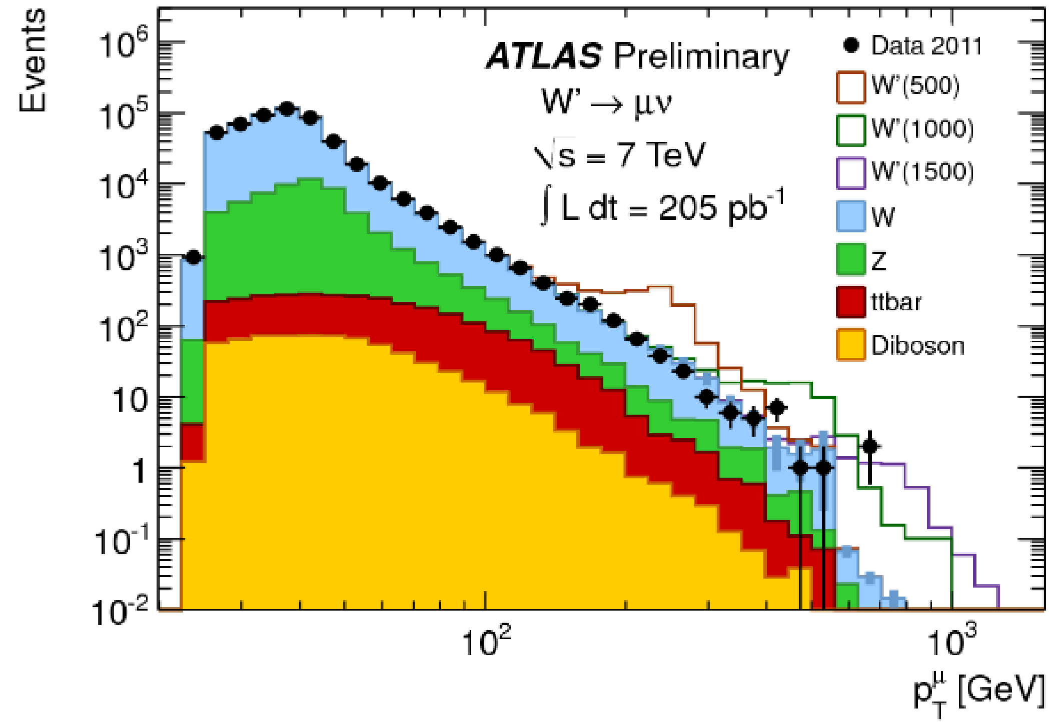
Gravitons

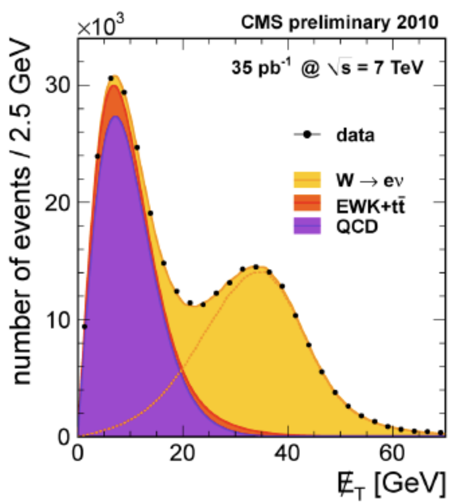


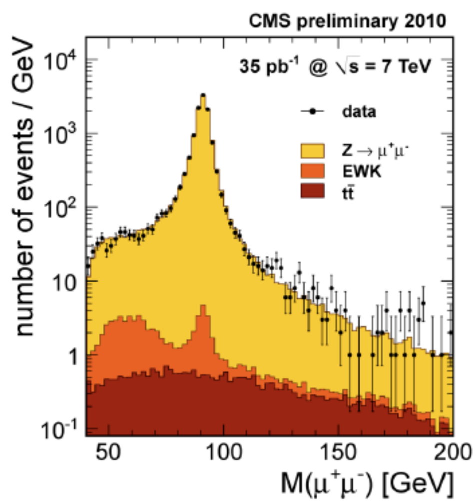
Graviton excitations expected in the di-photon spectrum in R-S warped extra dimension models





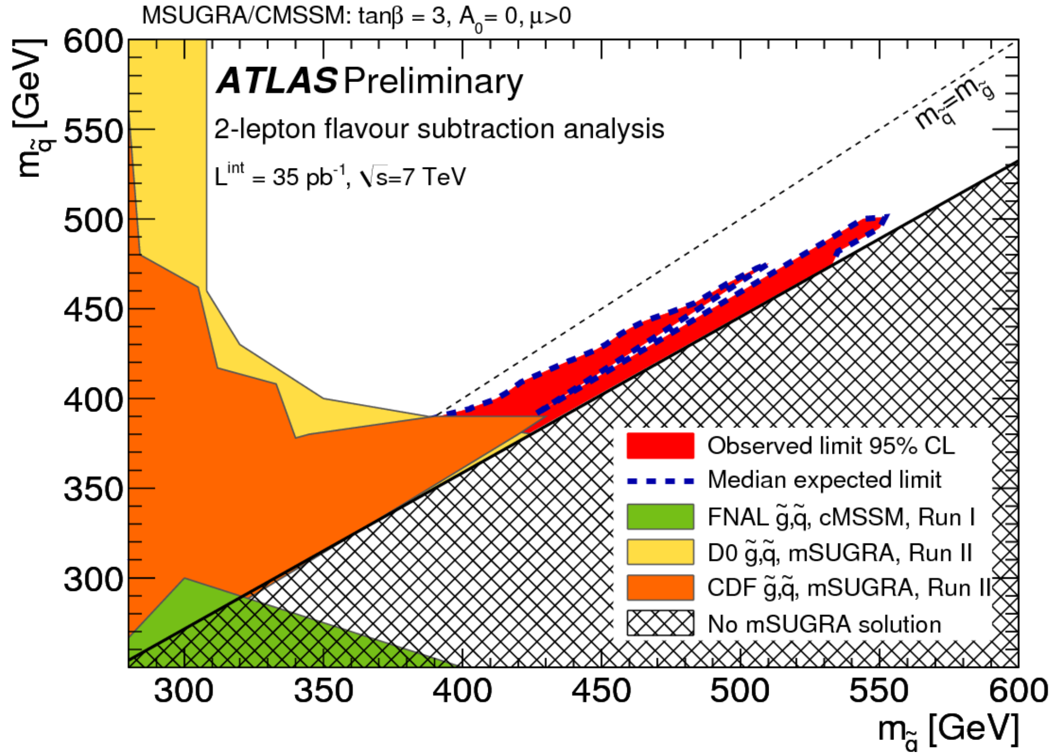


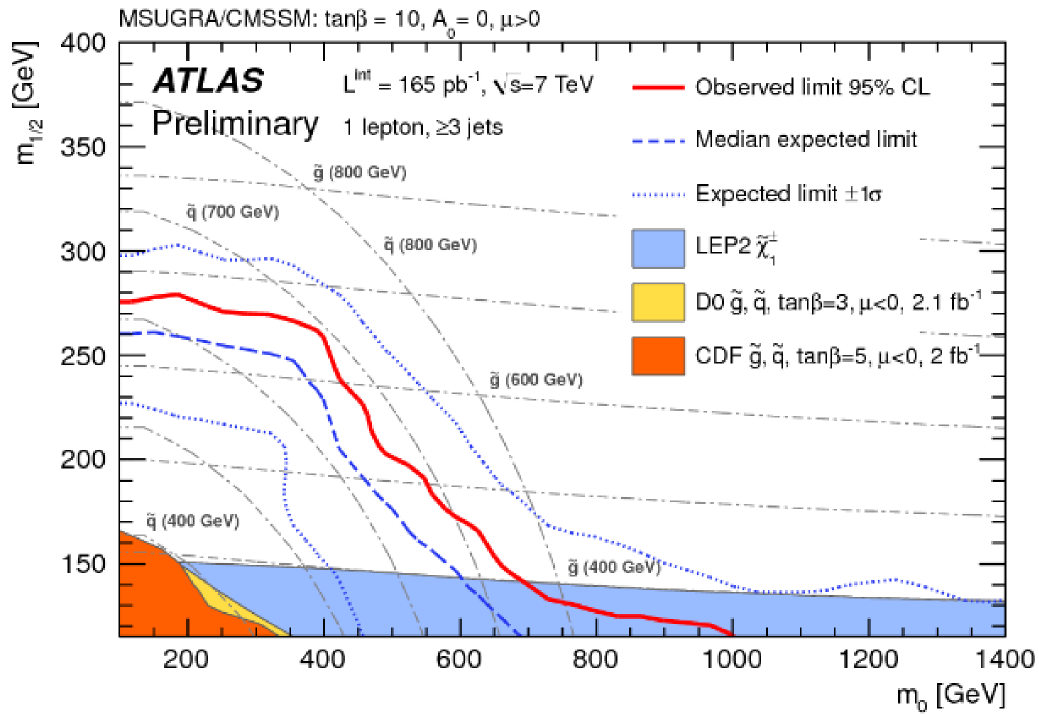




$M_{W'}$ > 1700 GeV @95% CL

$M_{Z'}$ > 1407 GeV @95% CL





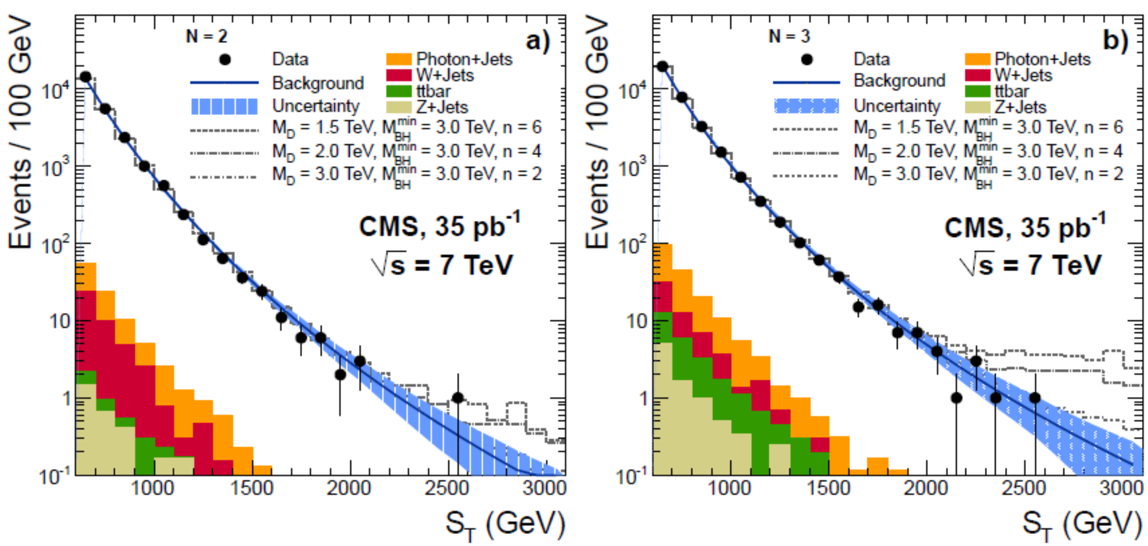
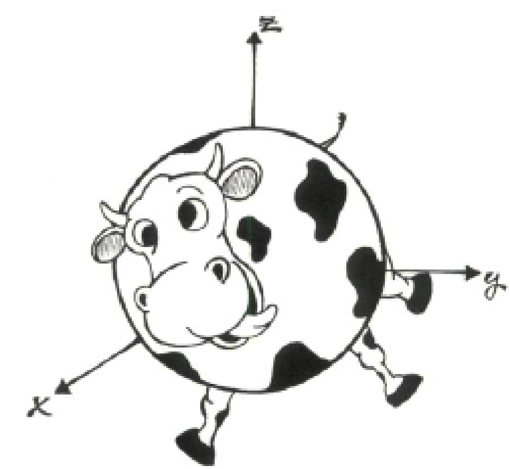
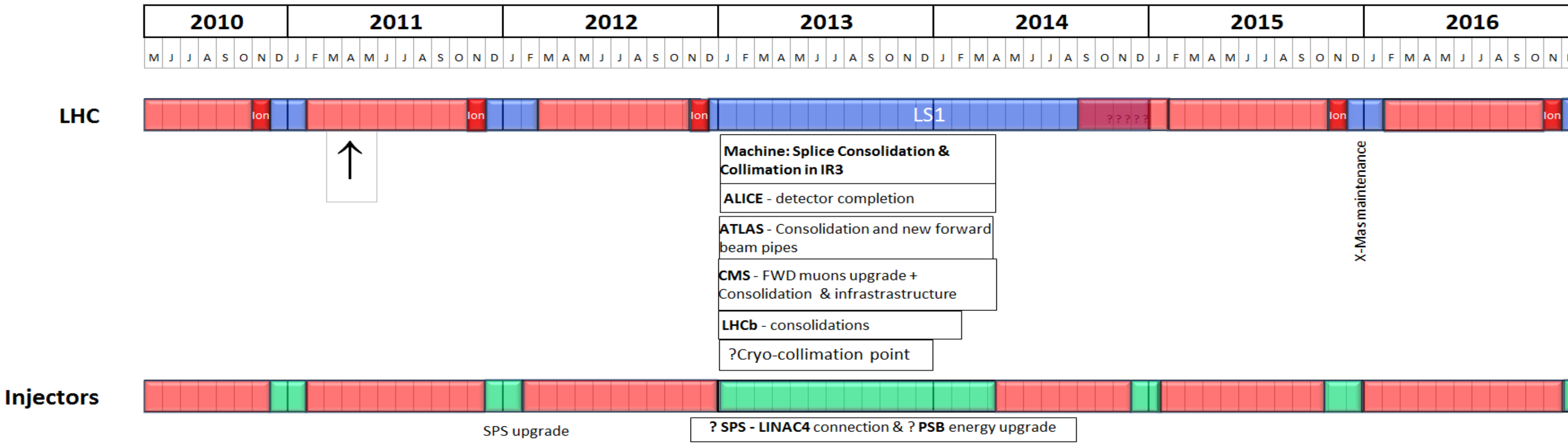


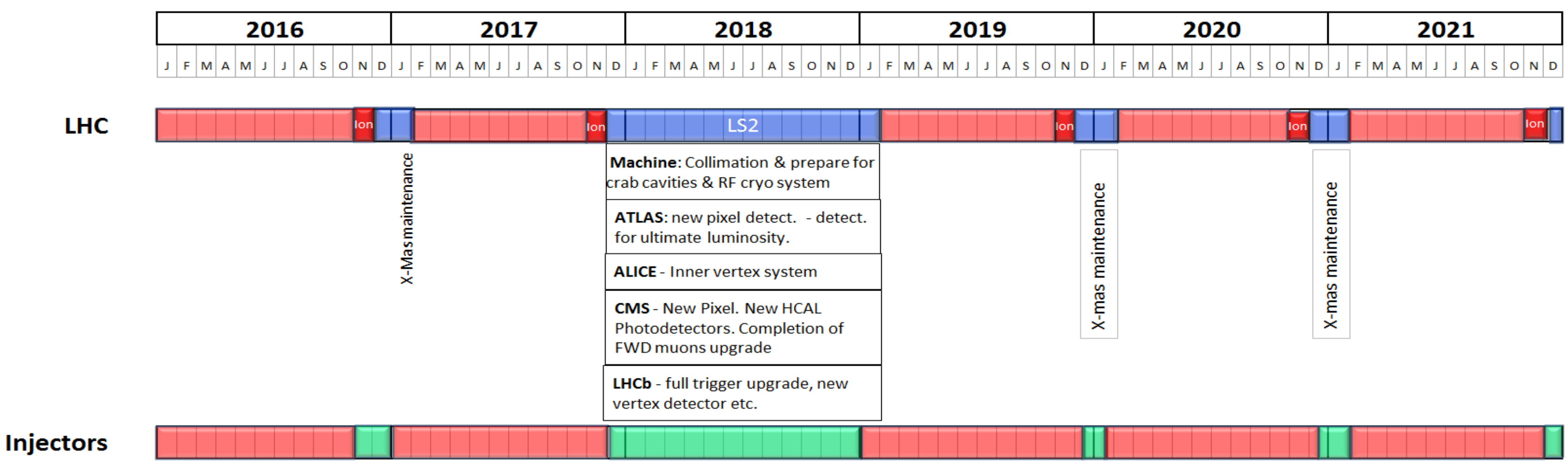
Figure 1: Total transverse energy S_T, for events with the multiplicities of a) $N = 2$, and b) $N = 3$ objects in the final state. Data are depicted as solid circles with error bars; the shaded band is the background prediction obtained from data (solid line) with its uncertainty. Non-multijet backgrounds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



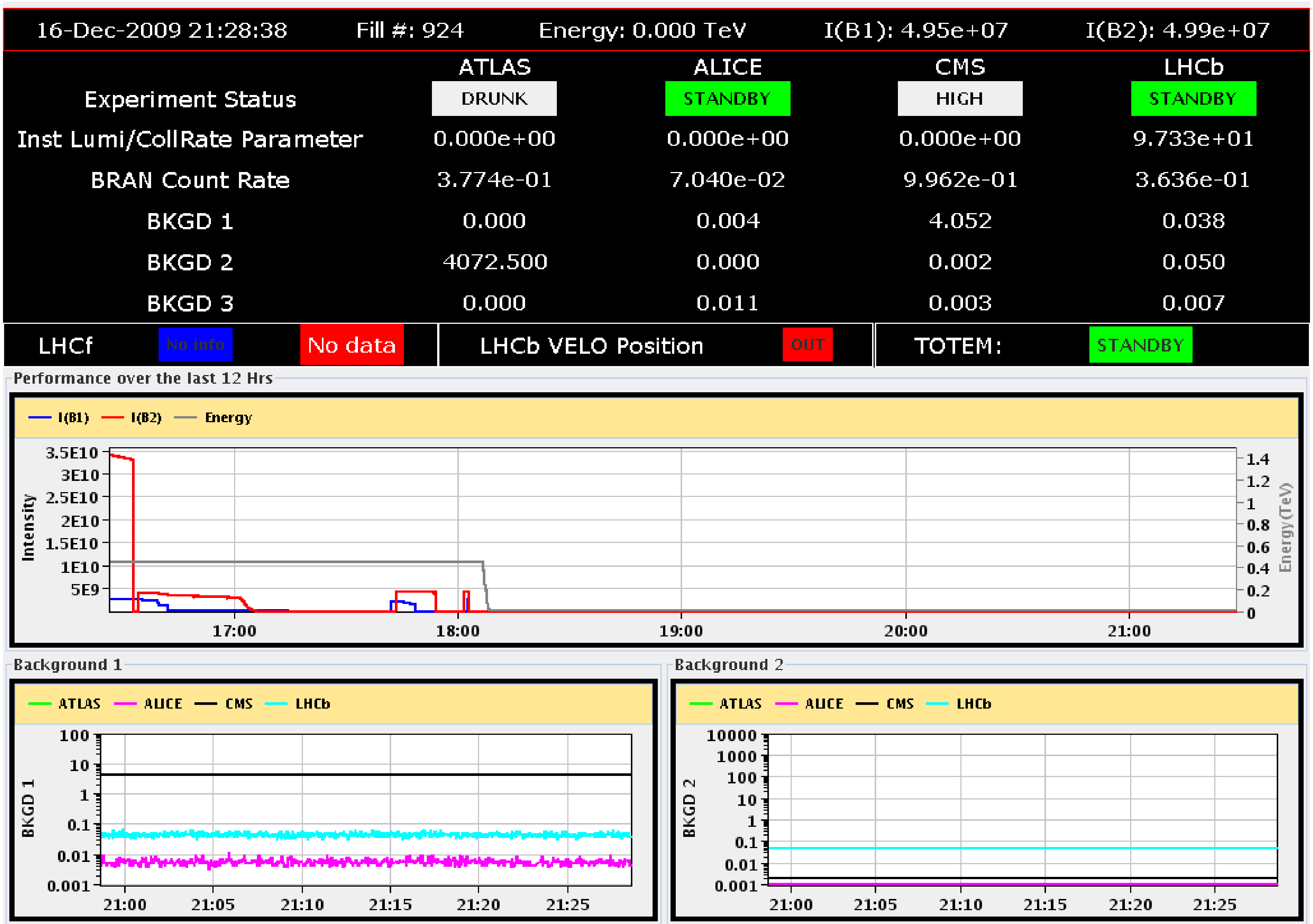


Associated LHC parameters

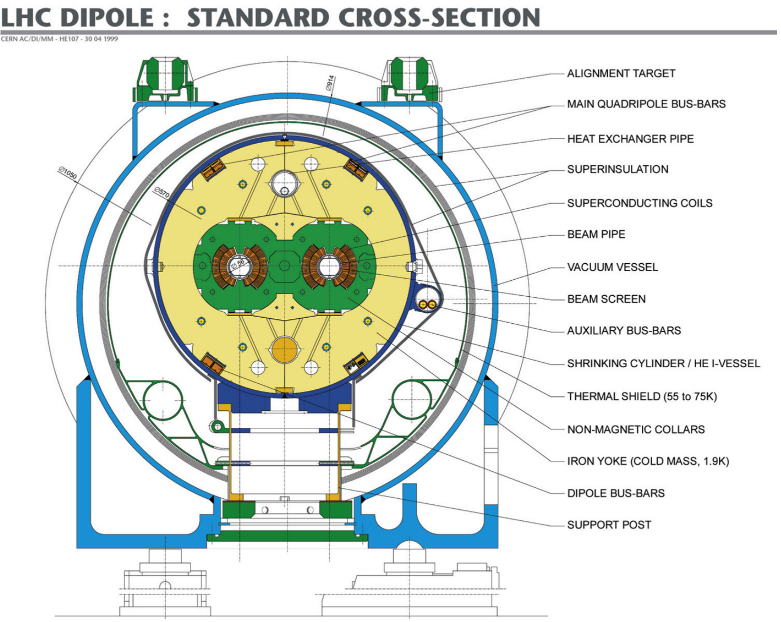
$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y} F = \frac{N^2 k_b f \gamma}{4\pi\beta^* \varepsilon} F$$

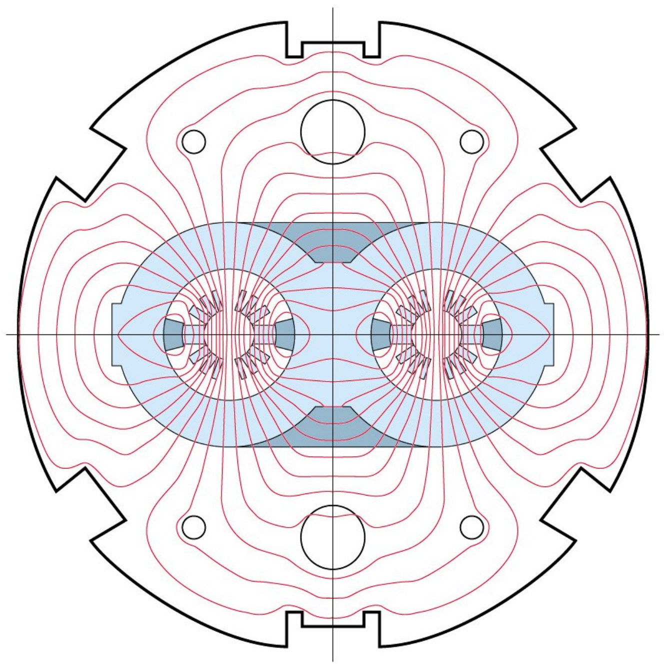
Parameter	2010	Nominal	Limited by
Energy	3.5 TeV	7 TeV	Hardware
N (p/bunch)	1.1×10^{11}	1.15×10^{11}	
k_b (no. bunches)	**368 (348 coll/IP)**	**2808**	Machine protection
ε (μm rad)	2.5-5	3.75	
β^* (m)	3.5 (3.5)	0.55 (10)	Aperture, tolerances
Stored energy (MJ)	28	360	
L ($cm^{-2}s^{-1}$)	2×10^{32}	10^{34}	

- 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.*

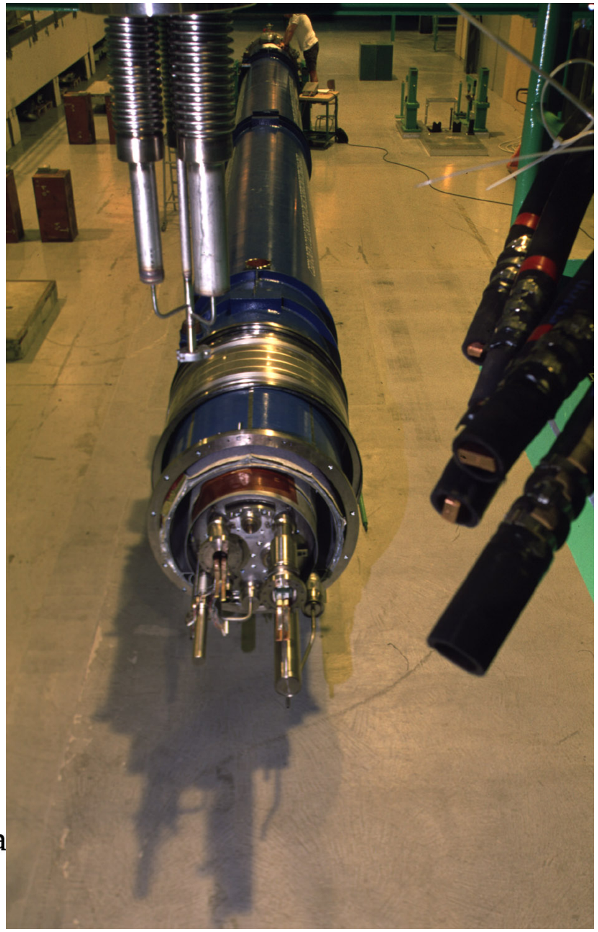

16-Dec-2009 21:28:38
Fill #: 924
Energy: 0.000 TeV
I(B1): 4.95e+07
I(B2): 4.99e+07
ATLAS
ALICE
CMS
LHCb
Experiment Status
DRUNK
STANDBY
HIGH
STANDBY
Inst Lumi/CollRate Parameter
0.000e+00
0.000e+00
0.000e+00
9.733e+01
BRAN Count Rate
3.774e-01
7.040e-02
9.962e-01
3.636e-01
BKGD 1
0.000
0.004
4.052
0.038
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
I(B1)
I(B2)
Energy
Intensity
Energy (TeV)
3.5E10
3E10
2.5E10
2E10
1.5E10
1E10
5E9
1.4
1.2
1
0.8
0.6
0.4
0.2
0
17:00
18:00
19:00
20:00
21:00
Background 1
ATLAS
ALICE
CMS
LHCb
BKGD 1
100
10
1
0.1
0.01
0.001
21:00
21:05
21:10
21:15
21:20
21:25
Background 2
ATLAS
ALICE
CMS
LHCb
BKGD 2
10000
1000
100
10
1
0.1
0.01
0.001
21:00
21:05
21:10
21:15
21:20
21:25

Magnety

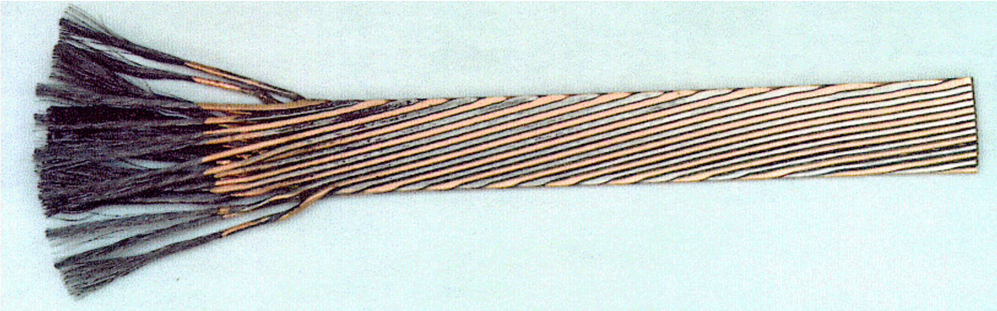


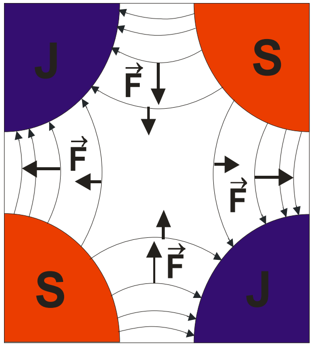


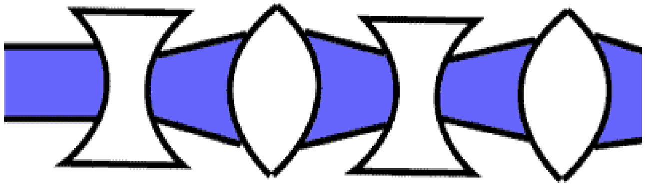
Computed magnetic flux map at B_0=10 Tesla



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







Forward spectrometer $2 < \eta < 5.3$