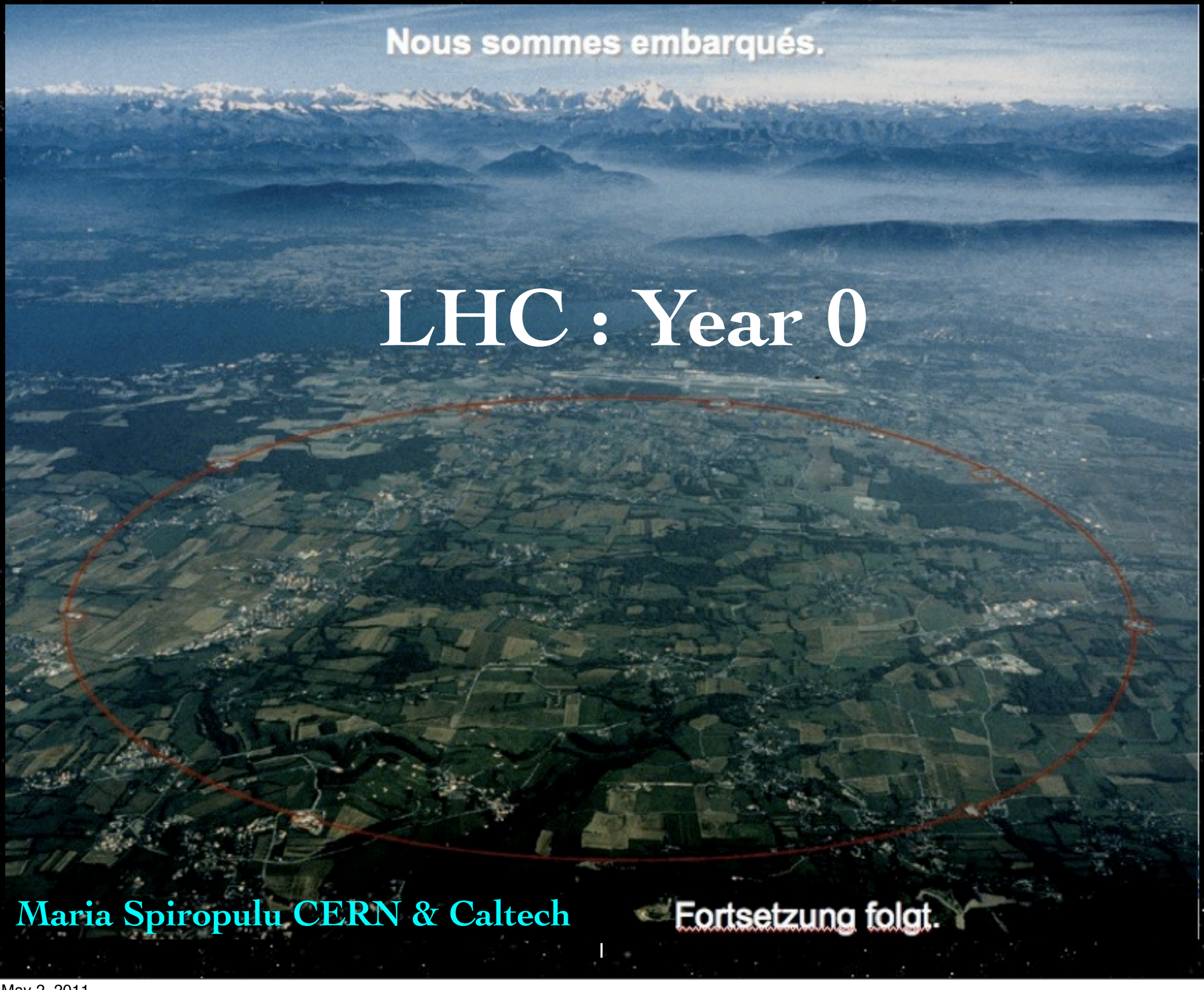
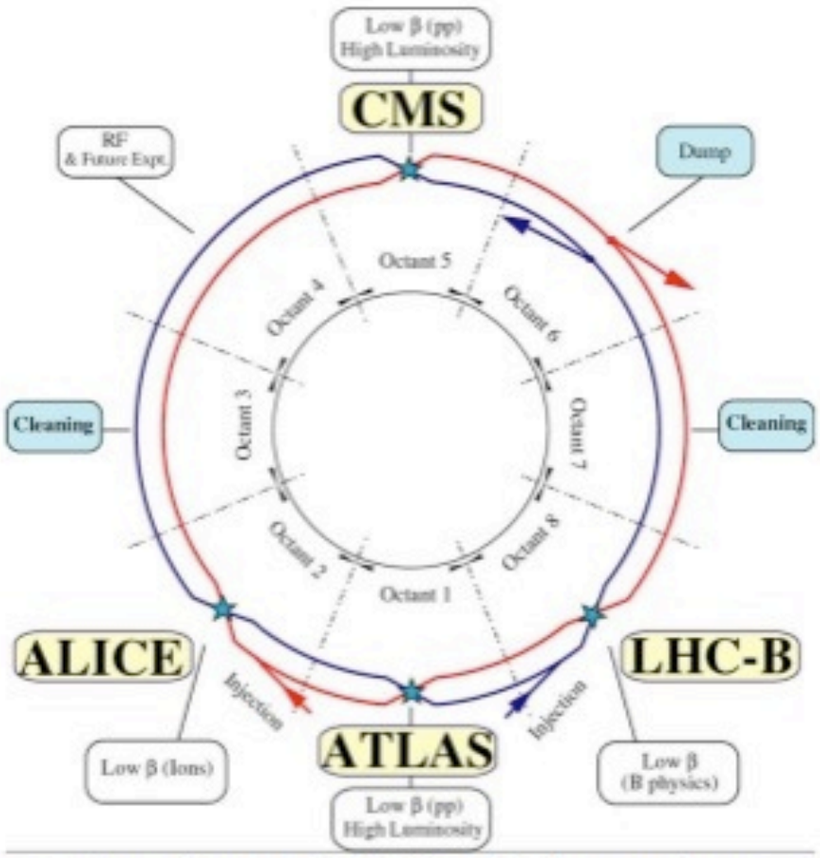

Nous sommes embarqués.
LHC : Year 0
Maria Spiropulu CERN & Caltech
Fortsetzung folgt.

The Large Hadron Collider is a dual synchrotron particle accelerator

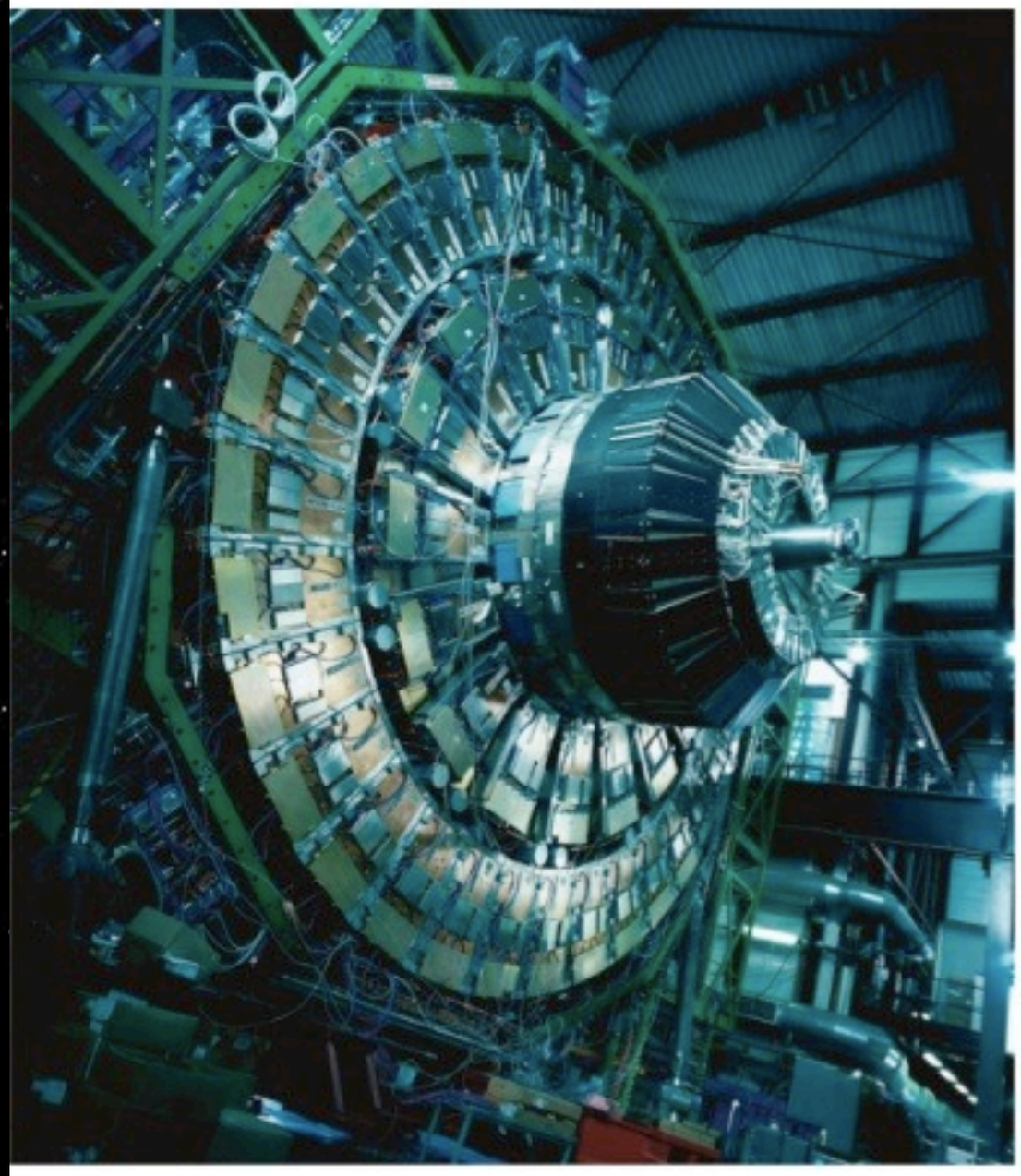
- It is designed to achieve 14 TeV proton-proton collisions at a rate of one billion per second
- (US equivalent) Cost: $ 10 billion
- Location: the CERN laboratory outside Geneva, Switzerland

Schematic View of the LHC

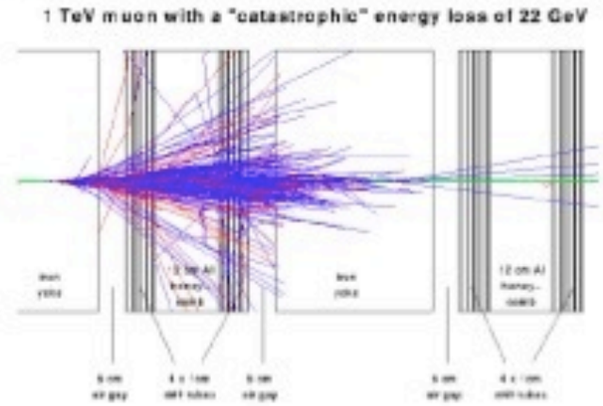


- IP1=ATLAS (general purpose)
- IP5=CMS (general purpose)
- IP2=ALICE (ion-ion, p-ion)
- IP8=LHCb (pp, B-physics, CP-violation)

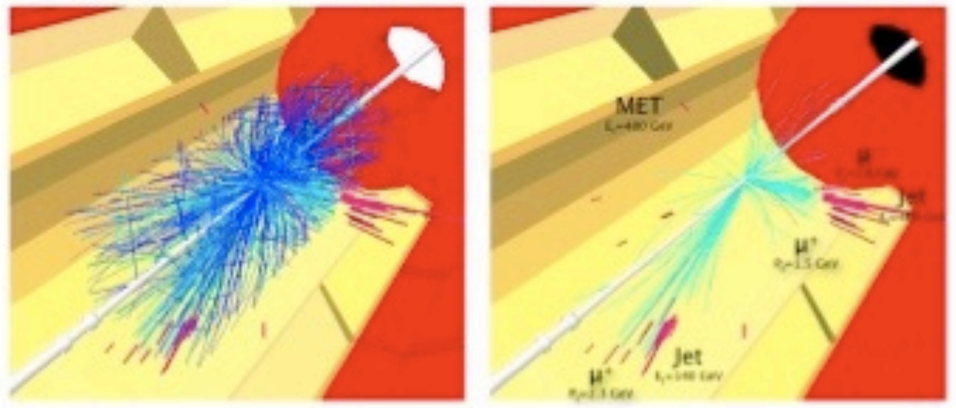
- Design: 2808×2 bunches of protons, 10^{11} protons/bunch accelerated to 7 TeV; The total energy of each beam: 2808 × 1.15 × 10^{11} protons per bunch × 7 TeV = 0.185 M_{Planck} = 362 MJoules ⟶ :



- high energy



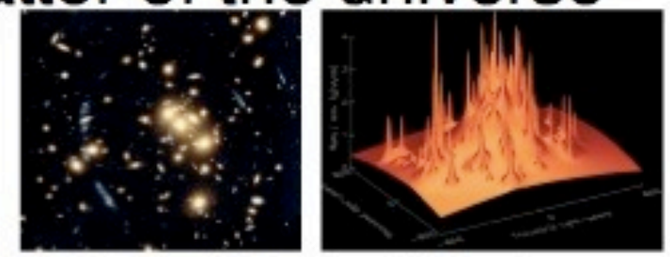
- high luminosity



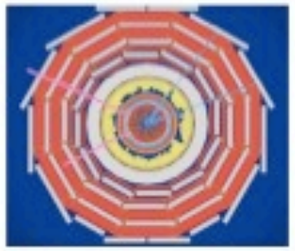
- high data rates (trigger, GRID)
- ...not a walk in the park

The Discovery Physics Scope of the LHC

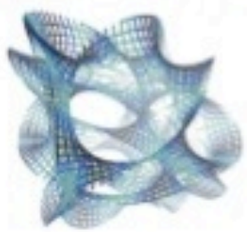
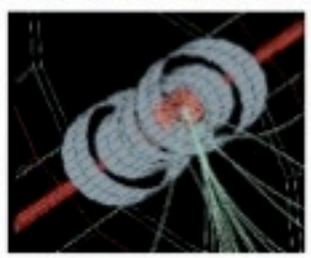
- Find and characterize the new particles that compose the dark matter of the universe

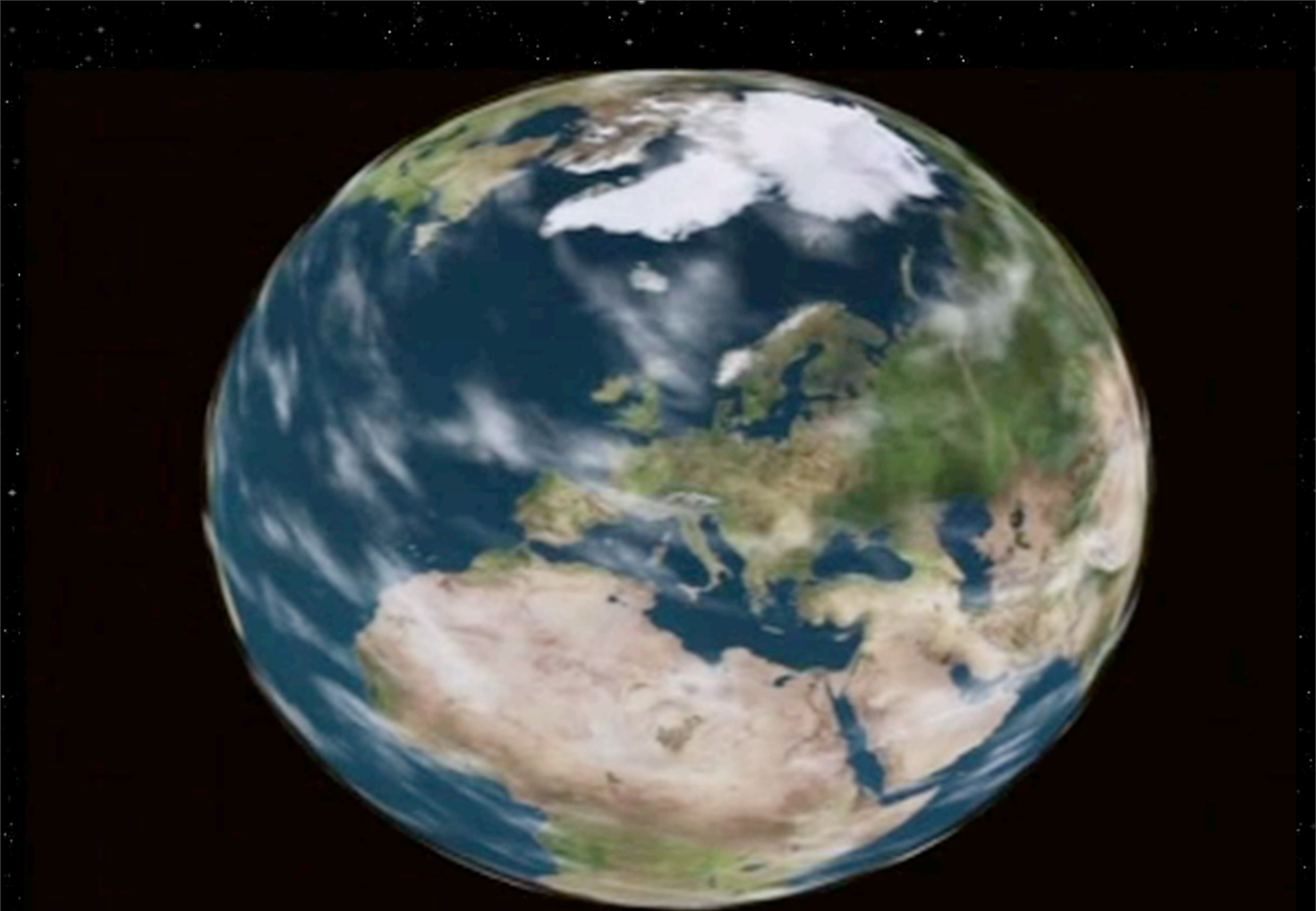



- Find the Higgs particle

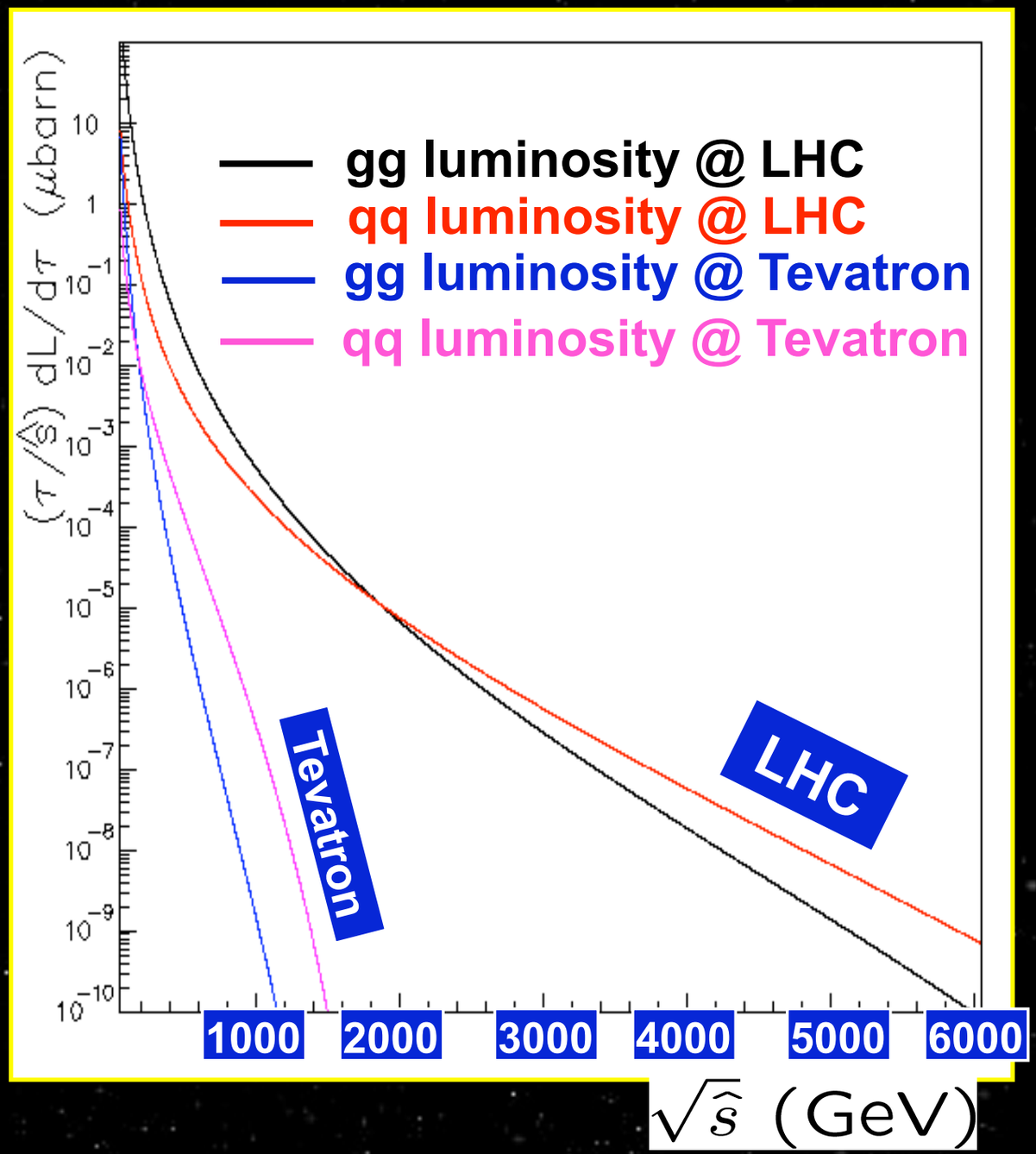


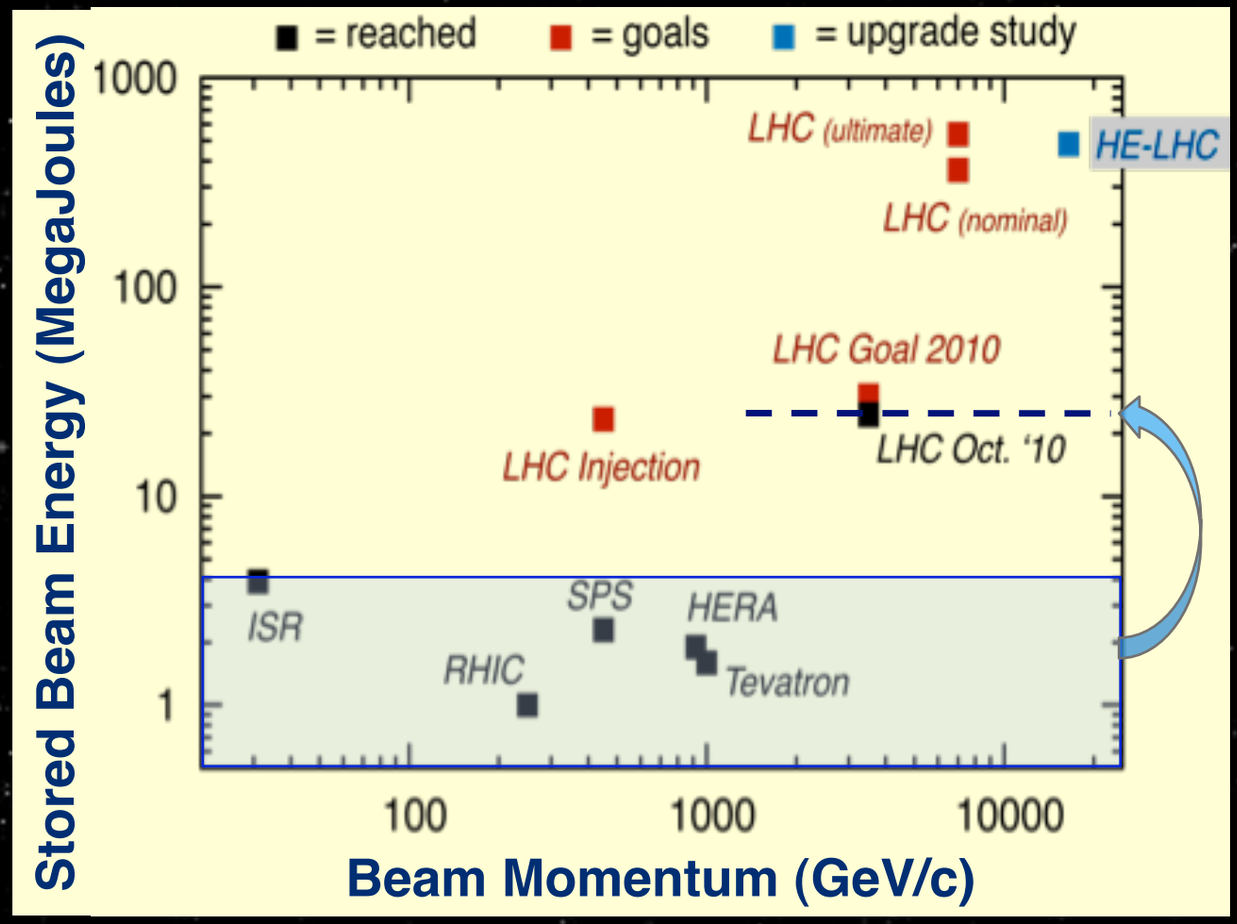
- Find new particles, forces, extra dimensions of space



The Power and the Glory of the LHC

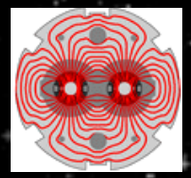


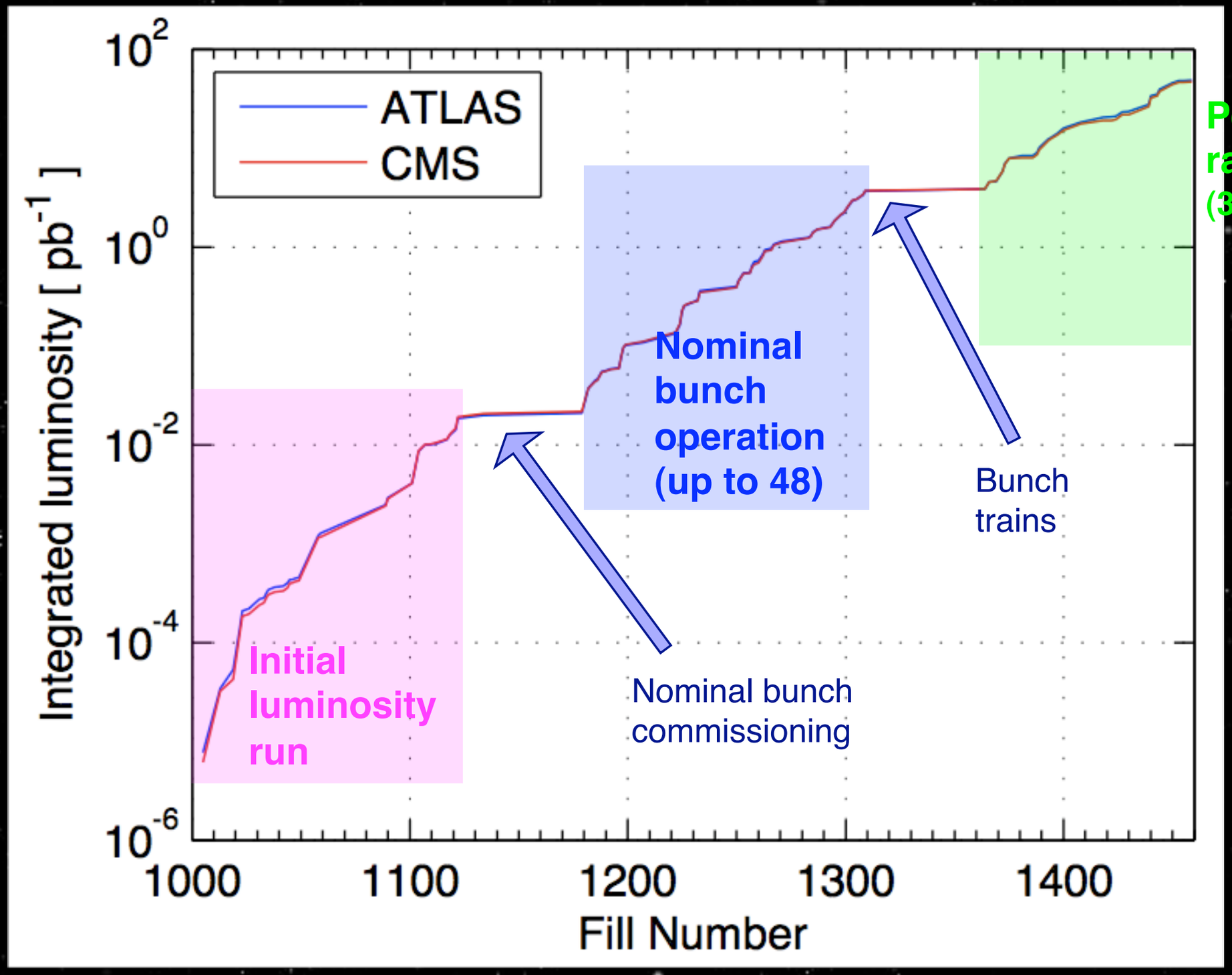


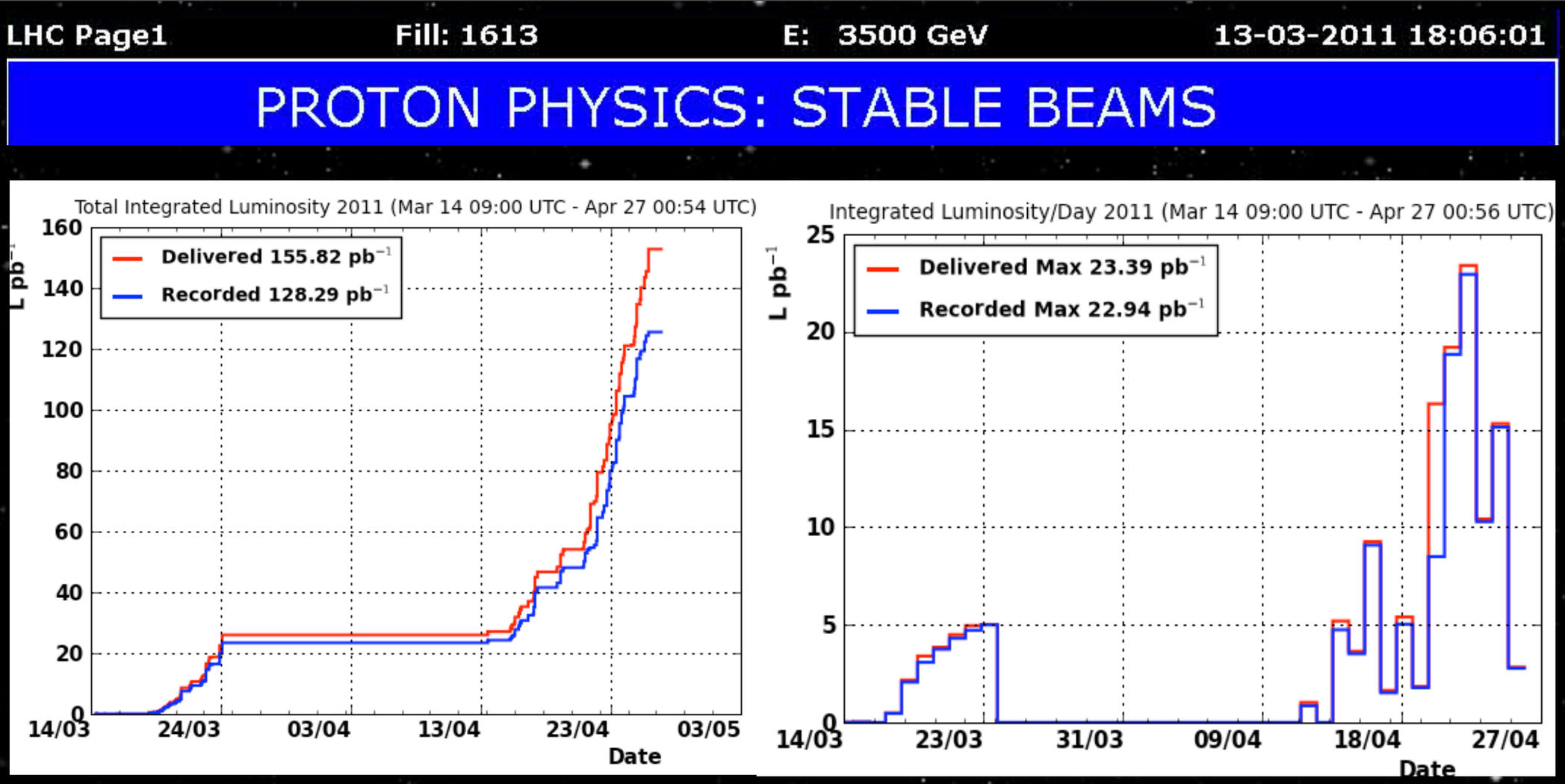
In the first year of operation achieved

- factor of 10 above the state-of-the-art
- 28 MJ, (24 MJ w/ collisions)

- Discovery Machine
- Probing deep into the terascale
- Good reasons to expect new physics




ATLAS
CMS
Integrated luminosity [pb^{-1}]
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
1000
1100
1200
1300
1400
Fill Number
Initial luminosity run
Nominal bunch commissioning
Nominal bunch operation (up to 48)
Bunch trains
Performance ramp-up (368 bunches)



- $\sim$ 156 pb^{-1} delivered by the LHC since the March 13 2011 startup. Over 20 pb^{-1}/day!
- Over 100 pb^{-1} of data delivered in a week.

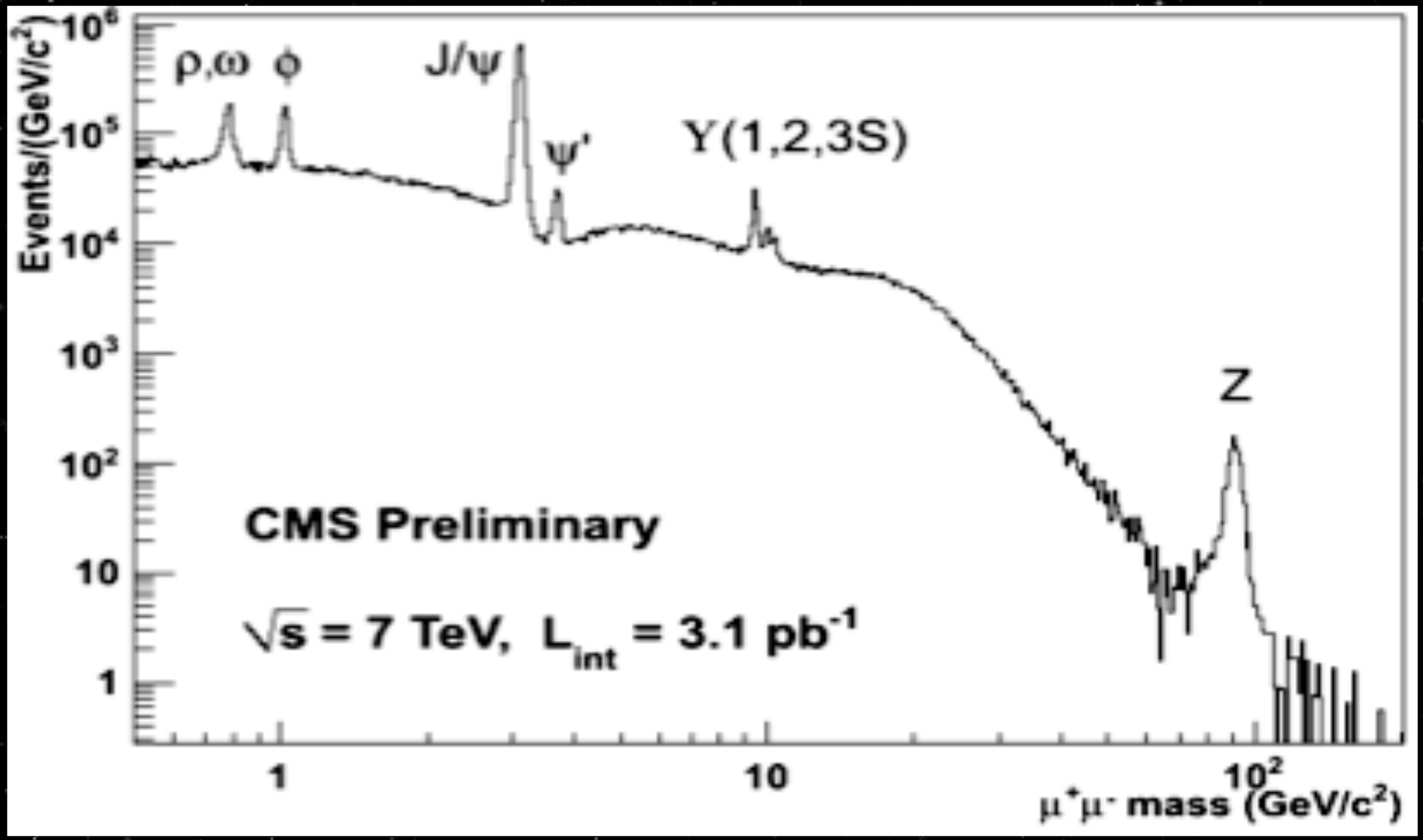
2011: more more more

- 75/50 ns bunch spacing
- 930/1400 bunches
- good for $> 10^{33}$ cm^{-2}s^{-1} and more than 1 fb^{-1}

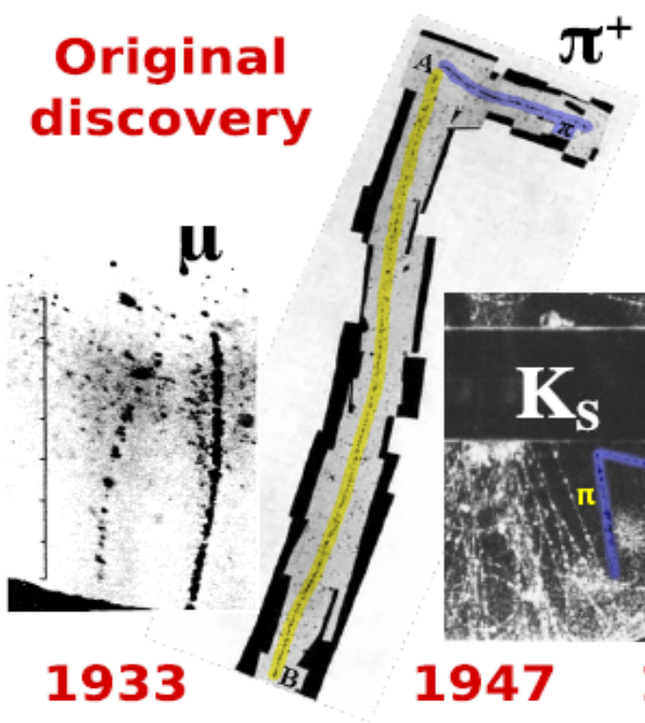
2010 harvest: $\sim$ 40 pb^{-1}

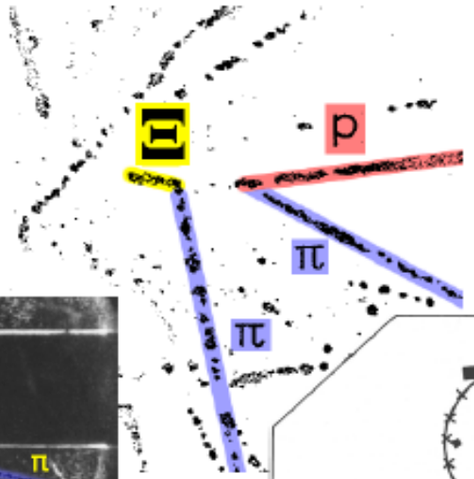
- **about 4 trillion collisions total**
- **4 million W bosons**
- **1 million Z bosons**
- **8,000 top quark pairs**
- **maybe 500 Higgs bosons**
- **maybe 200 dark matter particles**

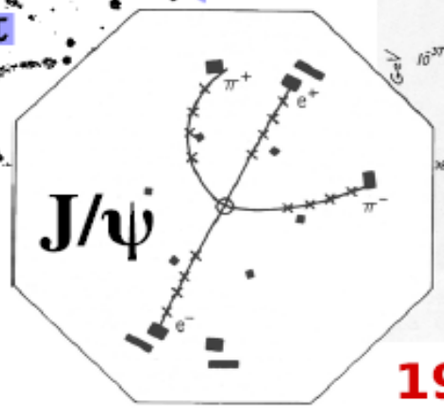
- **results on processes with rates that span 11 orders of magnidute**

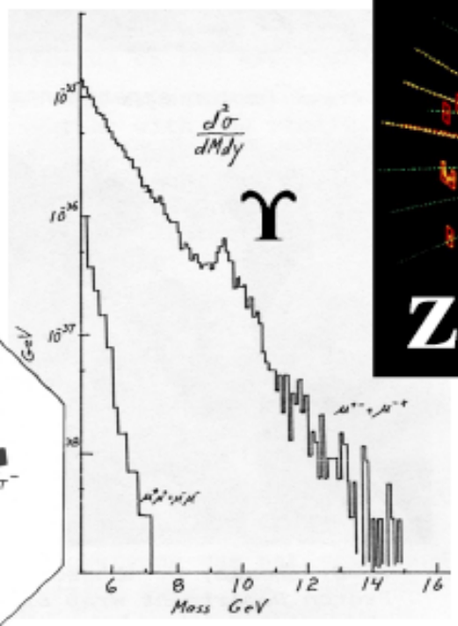

Events/(GeV/c²)
10⁶
10⁵
10⁴
10³
10²
10
1
ρ,ω
ϕ
J/ψ
ψ'
Υ(1,2,3S)
Z
CMS Preliminary
√s = 7 TeV, L_int = 3.1 pb⁻¹
1
10
10²
μ⁺μ⁻ mass (GeV/c²)

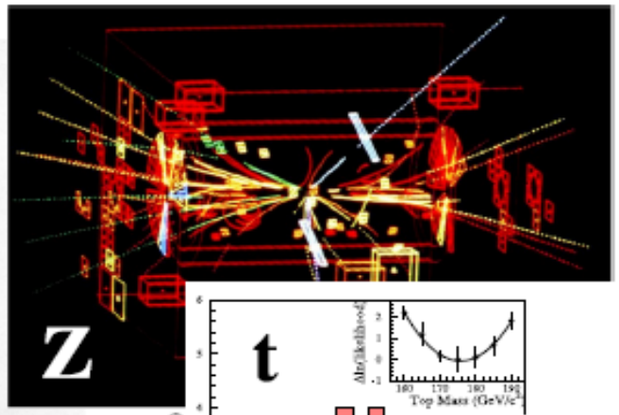
Original discovery

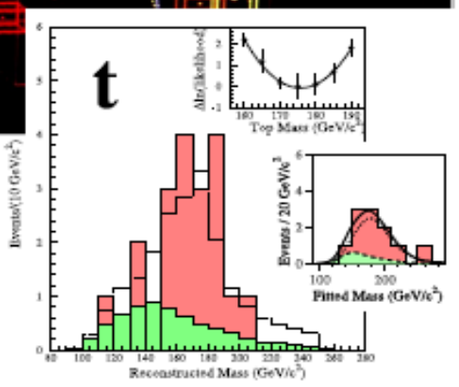






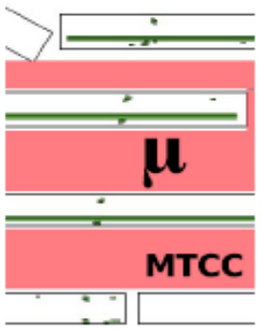


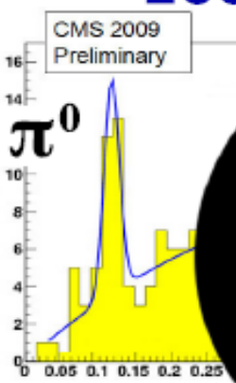


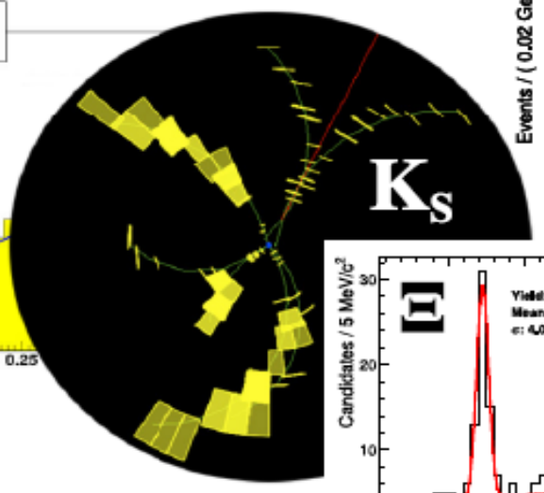


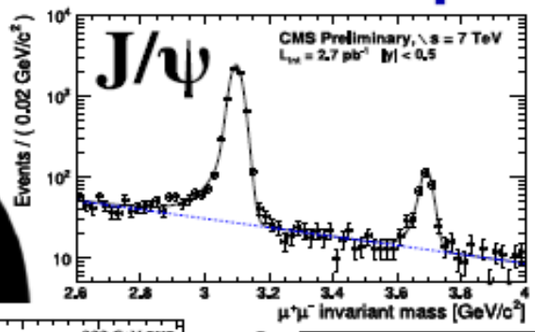
1933 1947 1964 1974 1977 1983 1995

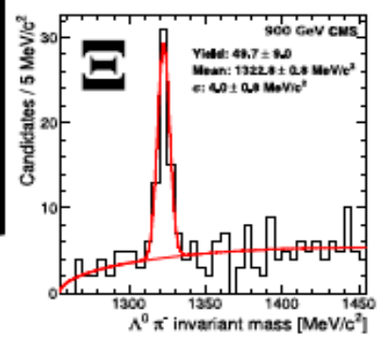
2006 Dec 2009 Jan 2010 Feb Mar Apr May Jun Jul 2010

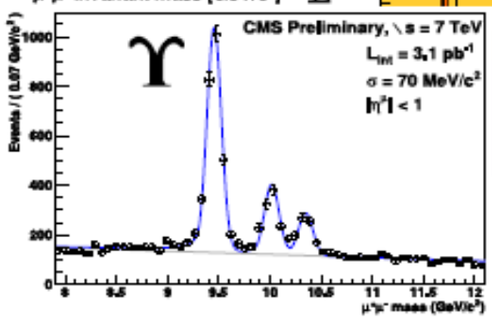


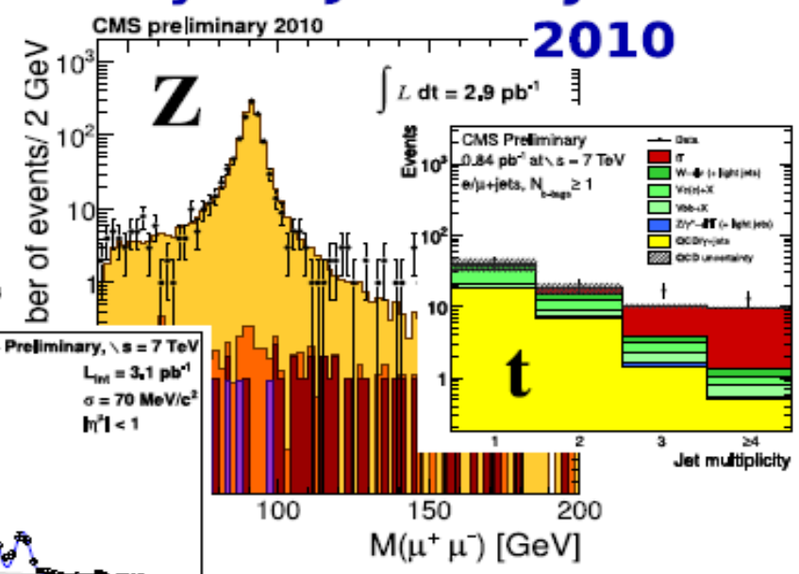




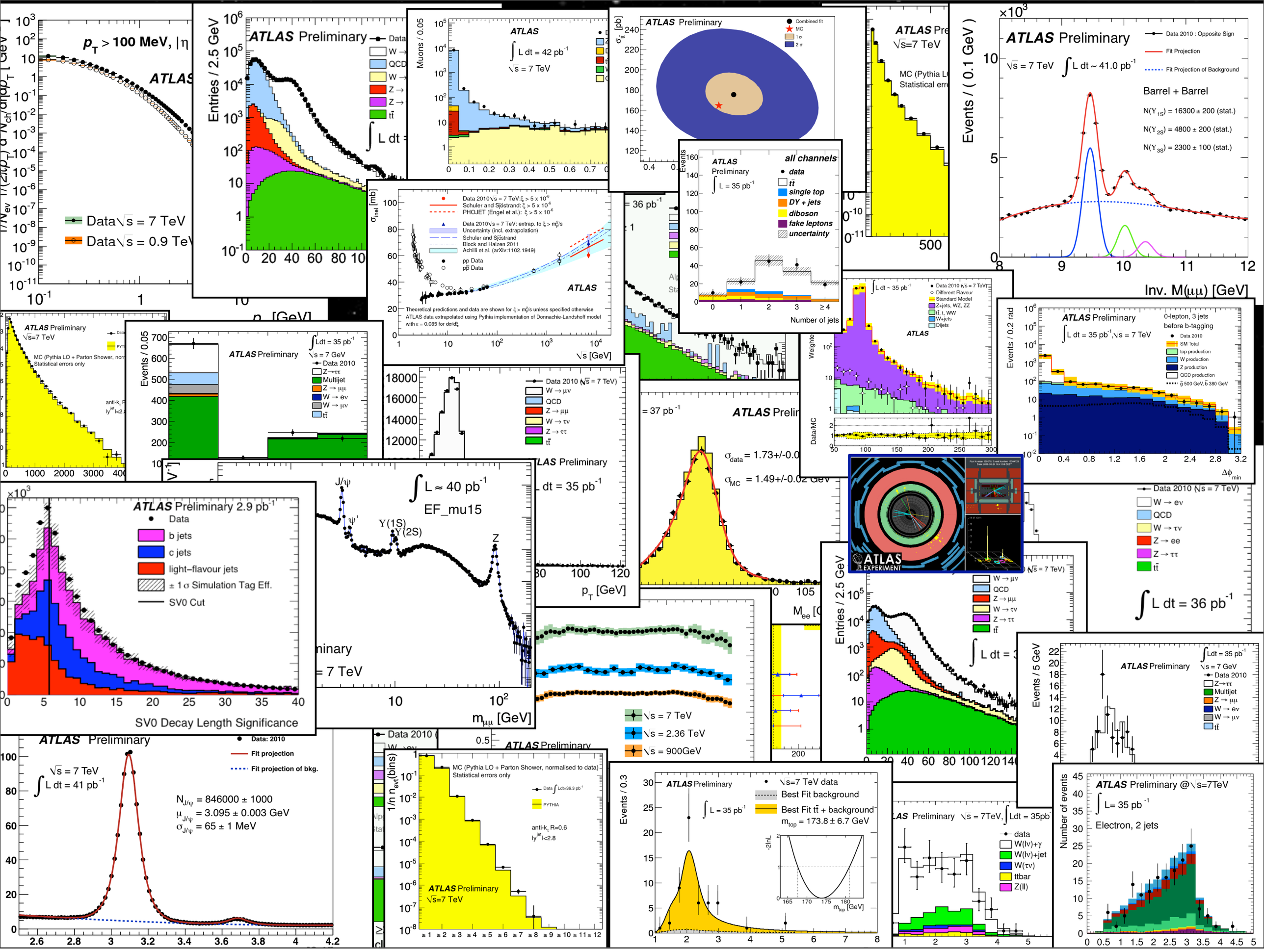








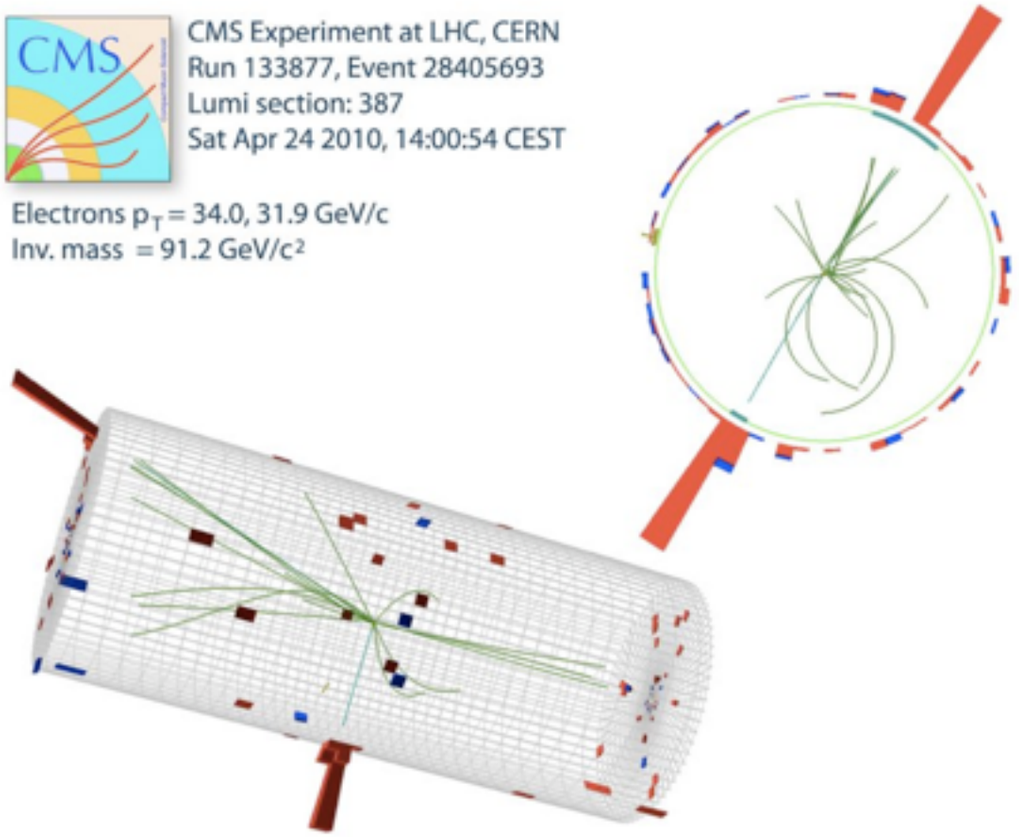
"Rediscovery" in CMS (dates approximate)

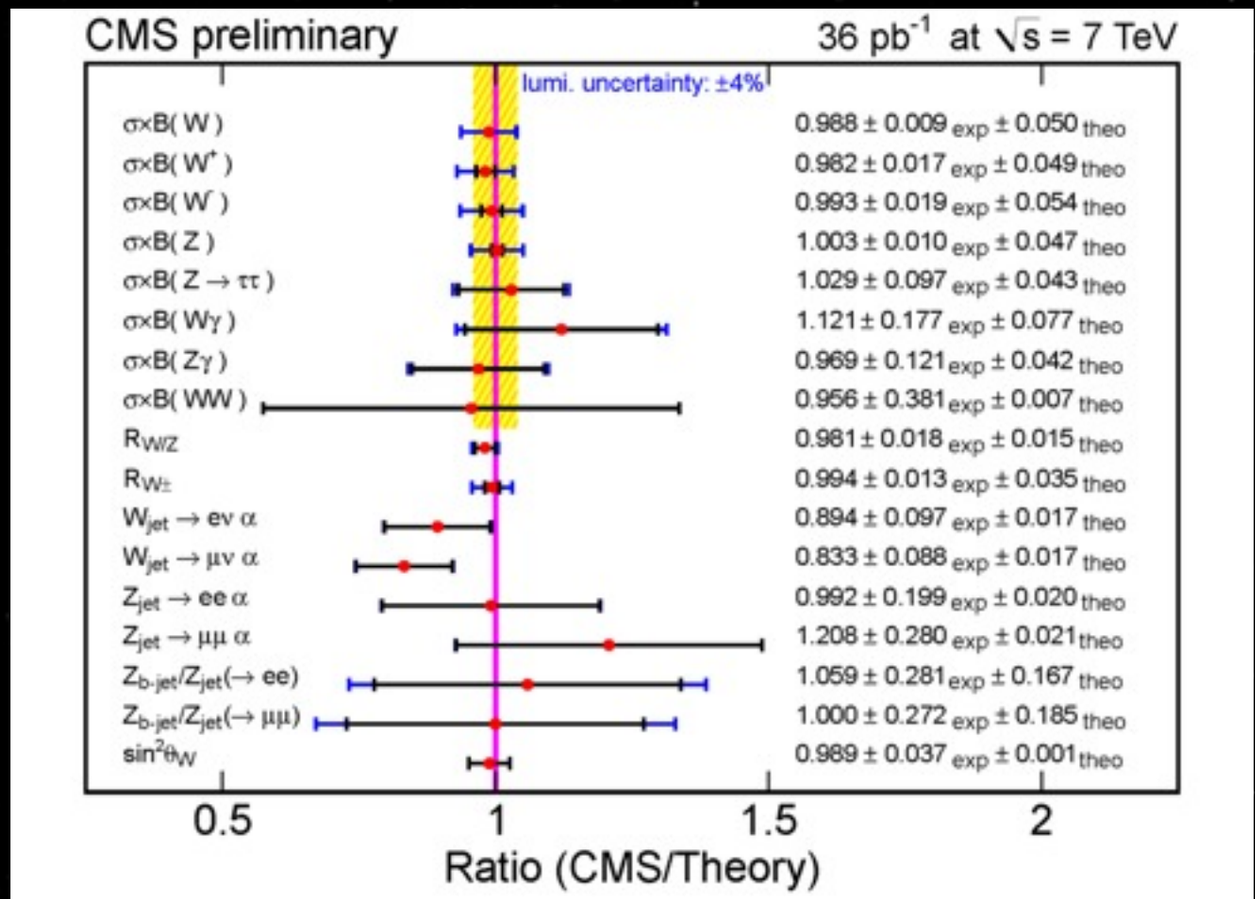

ATLAS Preliminary
Data\s = 7 TeV
Data\s = 0.9 TeV
Data 2010\s = 7 TeV: ξ > 5 x 10^-6
Schuler and Sjöstrand: ξ > 5 x 10^-6
PHOJET (Engel et al.): ξ > 5 x 10^-6
Data 2010\s = 7 TeV: extrap. to ξ > m_p^2/s
Uncertainty (incl. extrapolation)
Schuler and Sjöstrand
Block and Halzen 2011
Achilli et al. (arXiv:1102.1949)
pp Data
pp̄ Data
Theoretical predictions and data are shown for ξ > m_p^2/s unless specified otherwise
ATLAS data extrapolated using Pythia implementation of Donnachie-Landshoff model
with ε = 0.085 for dσ/dξ
σ_inel [mb]
\s [GeV]
all channels
data
tt̄
single top
DY + jets
diboson
fake leptons
uncertainty
Number of jets
Data 2010 : Opposite Sign
Fit Projection
Fit Projection of Background
Barrel + Barrel
N(Υ1S) = 16300 ± 200 (stat.)
N(Υ2S) = 4800 ± 200 (stat.)
N(Υ3S) = 2300 ± 100 (stat.)
Events / (0.1 GeV)
Inv. M(μμ) [GeV]
Data 2010 (\s = 7 TeV)
Different Flavour
Standard Model
Z+jets, WZ, ZZ
tt̄, t, WW
W+jets
Dijets
Data/MC
0-lepton, 3 jets
before b-tagging
SM Total
top production
W production
Z production
QCD production
g̃ 500 GeV, b̃ 380 GeV
Δφ_min
Events / 0.2 rad
Multijet
Z → μμ
W → eν
W → μν
W → τν
Z → ee
Z → ττ
tt̄
Entries / 2.5 GeV
Events / 5 GeV
Ldt = 35 pb^-1
\s = 7 GeV
Z→ττ
σ_data = 1.73+/-0.0
σ_MC = 1.49+/-0.02 GeV
J/ψ
ψ'
Υ(1S)
Υ(2S)
Z
L ≈ 40 pb^-1
EF_mu15
m_μμ [GeV]
p_T [GeV]
M_ee [
ATLAS Preliminary 2.9 pb^-1
Data
b jets
c jets
light−flavour jets
± 1 σ Simulation Tag Eff.
SV0 Cut
SV0 Decay Length Significance
Data: 2010
Fit projection
Fit projection of bkg.
\s = 7 TeV
L dt = 41 pb^-1
N_J/ψ = 846000 ± 1000
μ_J/ψ = 3.095 ± 0.003 GeV
σ_J/ψ = 65 ± 1 MeV
\s = 7 TeV
\s = 2.36 TeV
\s = 900GeV
MC (Pythia LO + Parton Shower, normalised to data)
Statistical errors only
anti-k_t R=0.6
1/n n_evt(bins)
\s=7 TeV data
Best Fit background
Best Fit tt̄ + background
m_top = 173.8 ± 6.7 GeV
m_top [GeV]
-2lnL
Events / 0.3
data
W(lν)+γ
W(lν)+jet
W(τν)
ttbar
Z(ll)
Number of events
Electron, 2 jets
Monday, May 2, 2011

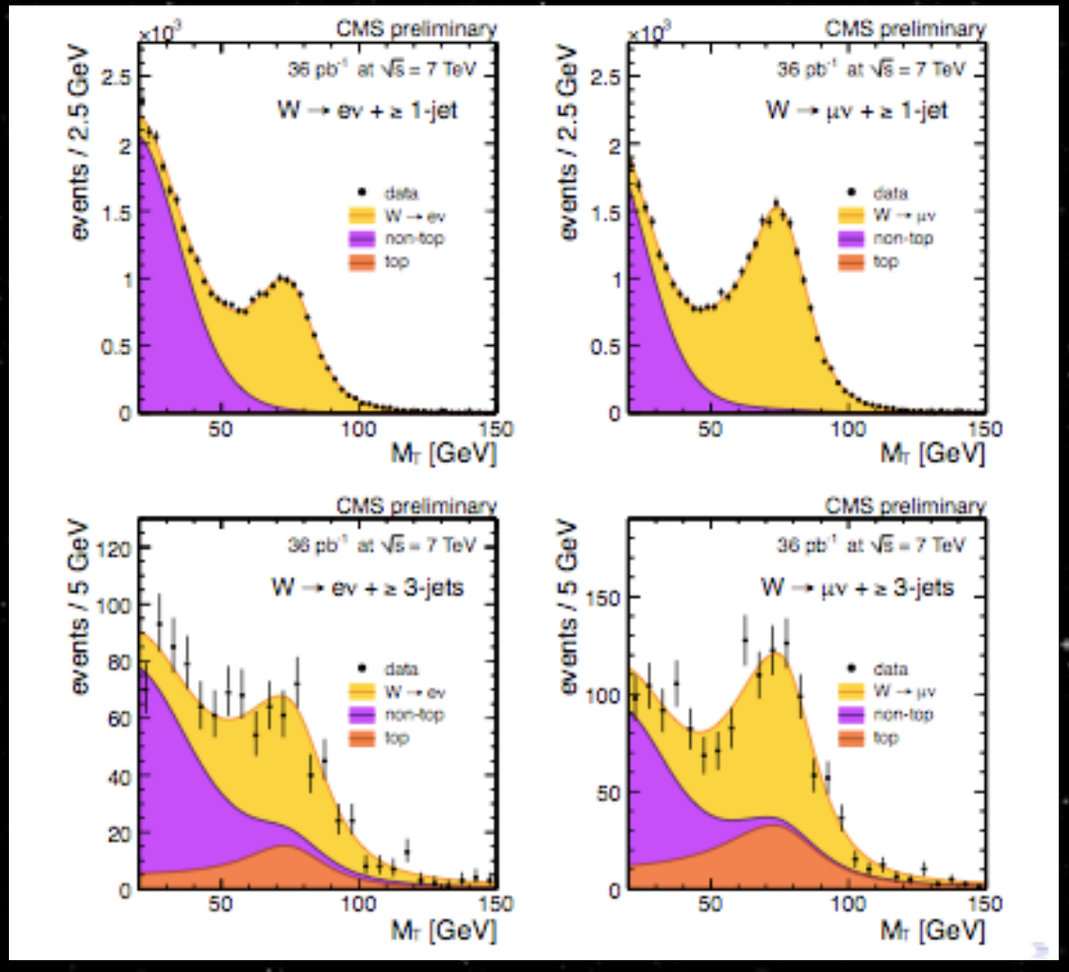
Fabiola Gianotti

CMS Experiment at LHC, CERN
Run 133877, Event 28405693
Lumi section: 387
Sat Apr 24 2010, 14:00:54 CEST

Electrons p_T = 34.0, 31.9 GeV/c
Inv. mass = 91.2 GeV/c²







EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2011-043
2011/04/20

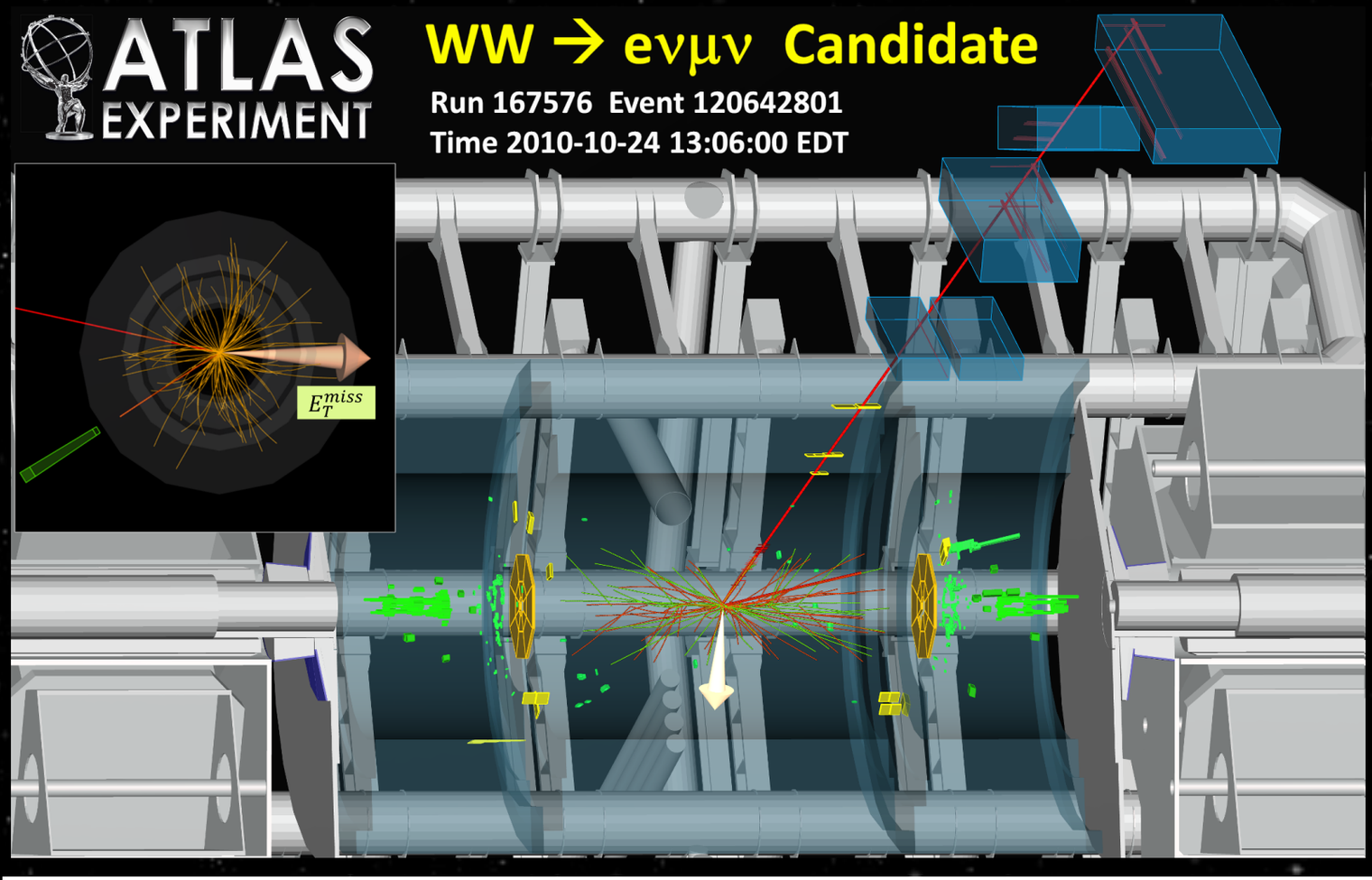
CMS-EWK-10-014

Measurement of the Polarization of W Bosons with Large Transverse Momenta in W+Jets Events at the LHC

The CMS Collaboration*

19 Apr 2011

- https://twiki.cern.ch/twiki/bin/view/AtlasPublic



CERN-PH-EP-2011-054; submitted to PRL

Measurement of the W^+W^- cross section in $\sqrt{s} = 7$ TeV pp collisions with ATLAS

ATLAS Collaboration

This Letter presents a measurement of the W^+W^- production cross section in $\sqrt{s} = 7$ TeV pp collisions by the ATLAS experiment, using 34 pb^{-1} of integrated luminosity produced by the Large Hadron Collider at CERN. Selecting events with two isolated leptons, each either an electron or a muon, 8 candidate events are observed with an expected background of 1.7 ± 0.6 events. The measured cross section is $41^{+20}_{-16}(\text{stat.}) \pm 5(\text{syst.}) \pm 1(\text{lumi.})$ pb, which is consistent with the standard model prediction of 44 ± 3 pb calculated at next-to-leading order in QCD.

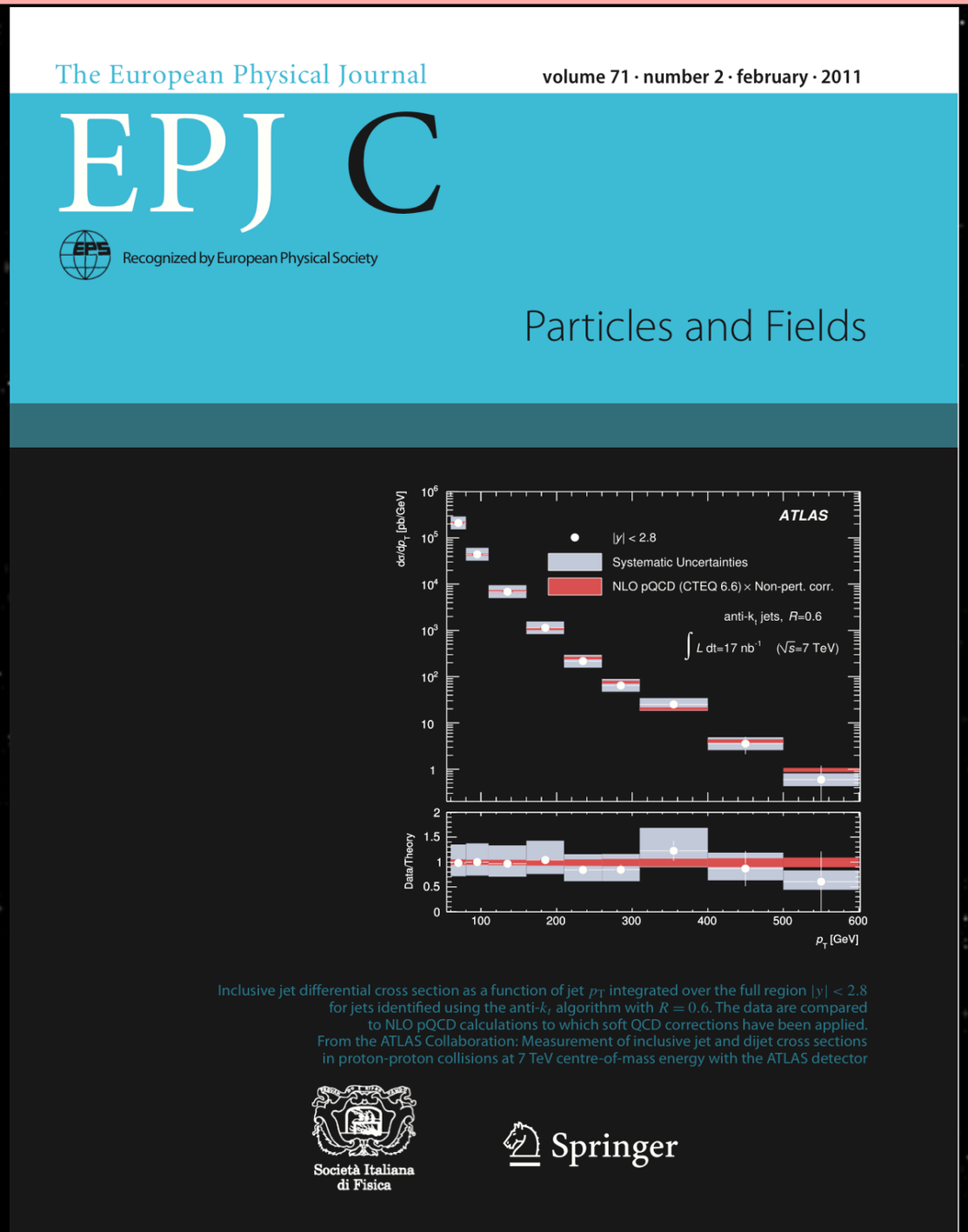
PACS numbers: 14.70.Fm, 13.38.Be, 13.85.Qk

The W^+W^- process plays an important role in electroweak physics. The production rate and kinematic distributions of W^+W^- are sensitive to the triple gauge couplings of the W boson [1, 2] and W^+W^- production is an important background to standard model Higgs boson searches. For these reasons, the measurement of the W^+W^- production cross section in 7 TeV pp collisions is a milestone in the Large Hadron Collider (LHC) physics program. W^+W^- production has been previously measured in both e^+e^- collisions [1] and $p\bar{p}$ collisions [2],

cision tracking for charged particles for $|\eta| < 2.5$. It consists of silicon pixel and strip detectors surrounded by a straw tube tracker that also provides transition radiation measurements for electron identification. The calorimeter system covers the pseudorapidity range $|\eta| < 4.9$. For $|\eta| < 2.5$, the electromagnetic calorimeter is finely segmented and plays an important role in electron identification. The muon spectrometer has separate trigger and high-precision tracking chambers covering $|\eta| < 2.7$. The transverse energy E_T is defined to be $E \sin\theta$, where

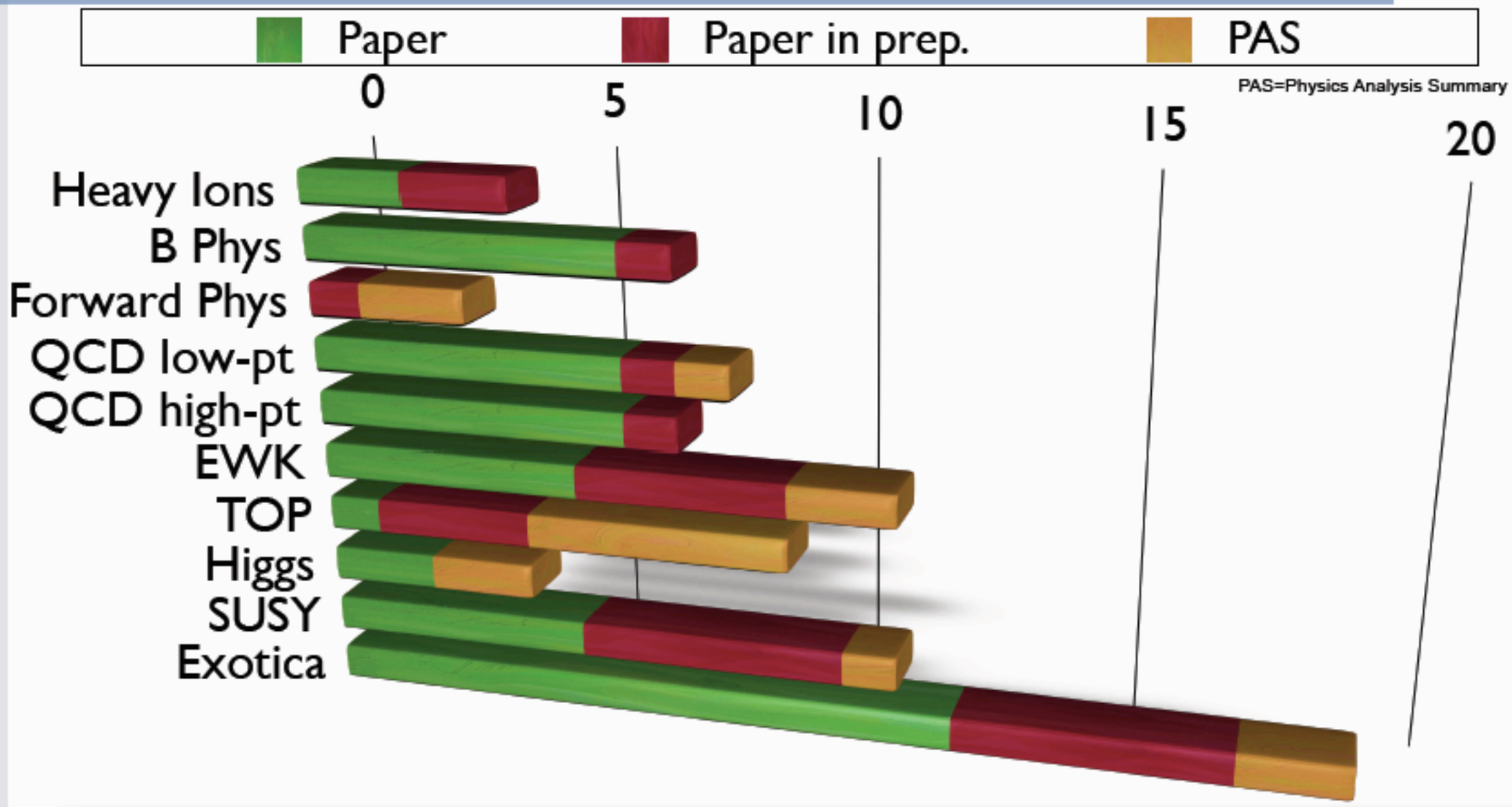
Based on these data:

- 31 papers submitted for publication (21 published or accepted, 10 under journal's review) and 5 more in the final Collaboration review stage
- Huge number of physics results presented at 2010-2011 Winter Conferences
  → documented in ~150 CONF-notes



Inclusive jet differential cross section as a function of jet p_T integrated over the full region $|y| < 2.8$ for jets identified using the anti-k_t algorithm with $R = 0.6$. The data are compared to NLO pQCD calculations to which soft QCD corrections have been applied. From the ATLAS Collaboration: Measurement of inclusive jet and dijet cross sections in proton-proton collisions at 7 TeV centre-of-mass energy with the ATLAS detector

List of physics analyses so far

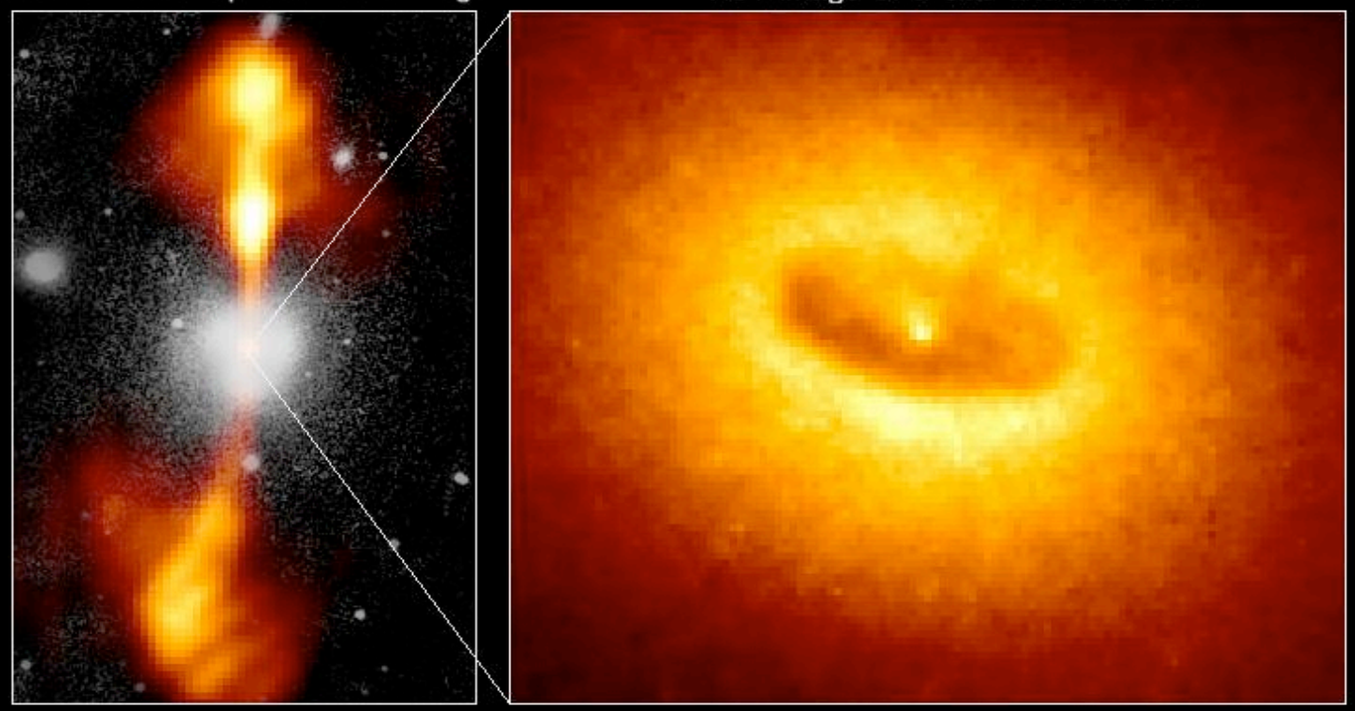


In total : **83** physics analyses, based on 2010 data, approved so far
45 papers completed (published, submitted, or close to submission)
23 papers in preparation
24 analyses to be approved soon

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

what does the Standard Model not explain ?

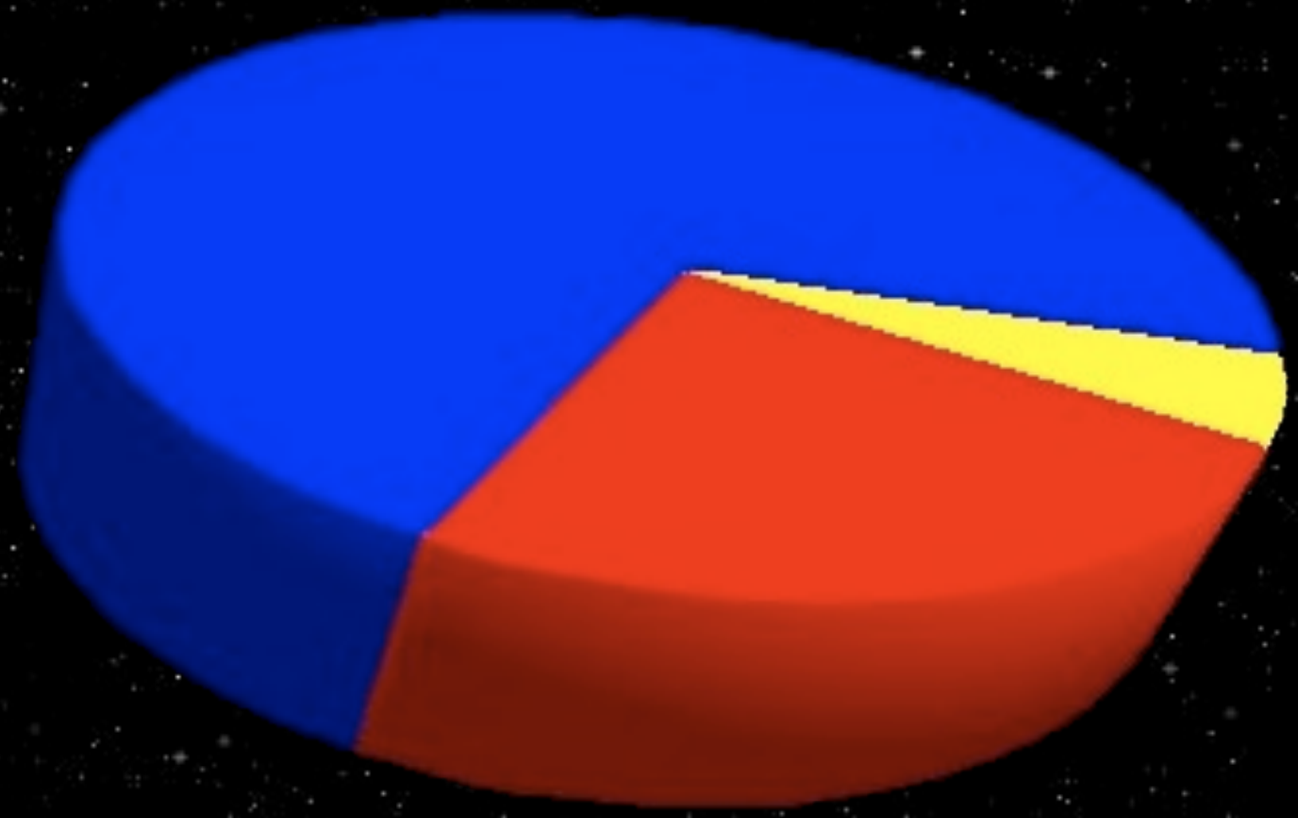
- quantum gravity



HST image of an 800 light-year wide spiral shaped disk of dust fueling a 1.2x10^9 solar mass black hole in the center of NGC 4261

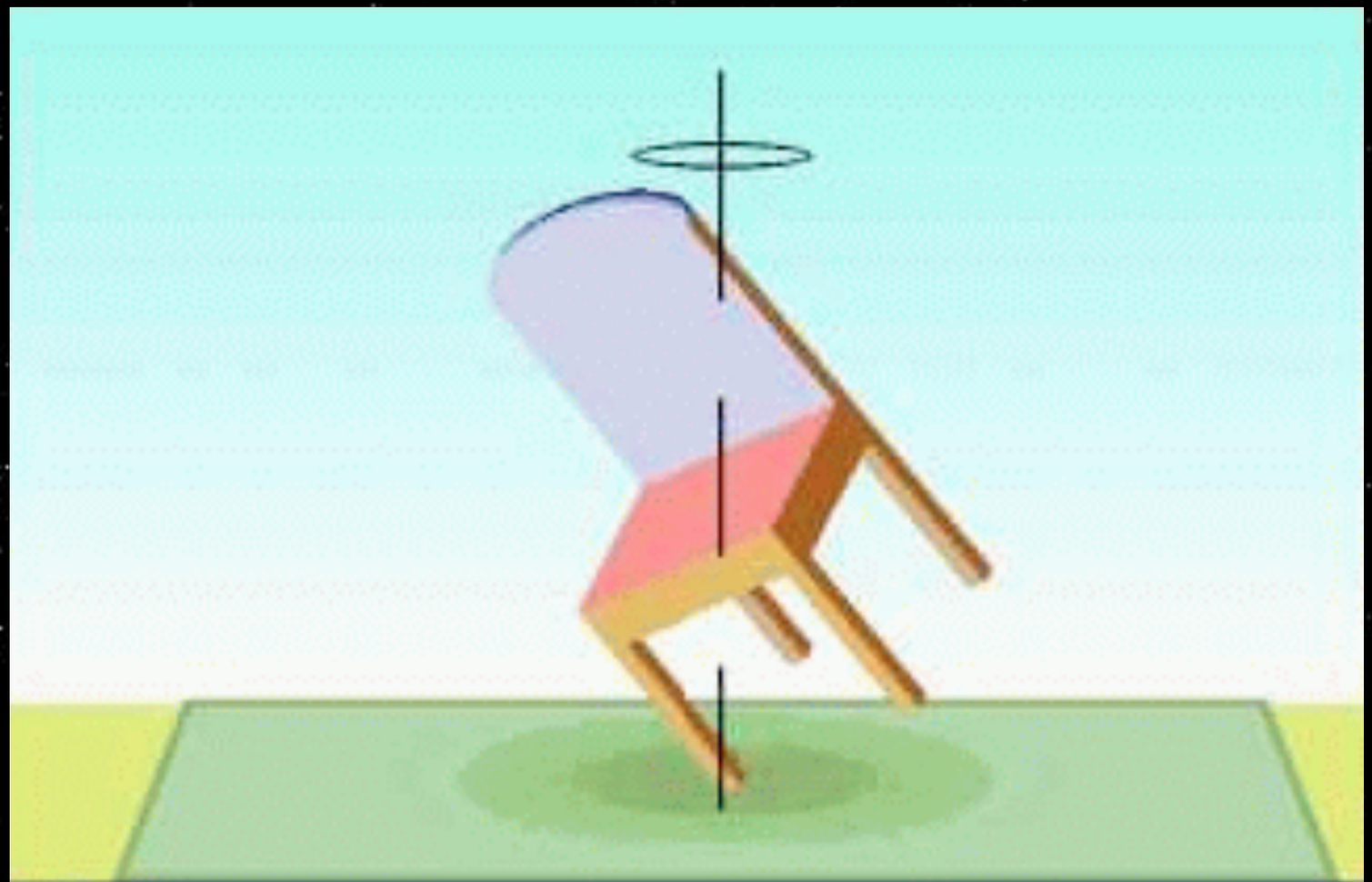
what does the Standard Model not explain ?

- dark matter and dark energy



what does the Standard Model not explain ?

- quantum gravity
- dark matter and dark energy
- **Higgs**



Arrange it so delicately that it will fall down in 19 minutes.

95% CL excluded mass range LEP+Tevatron

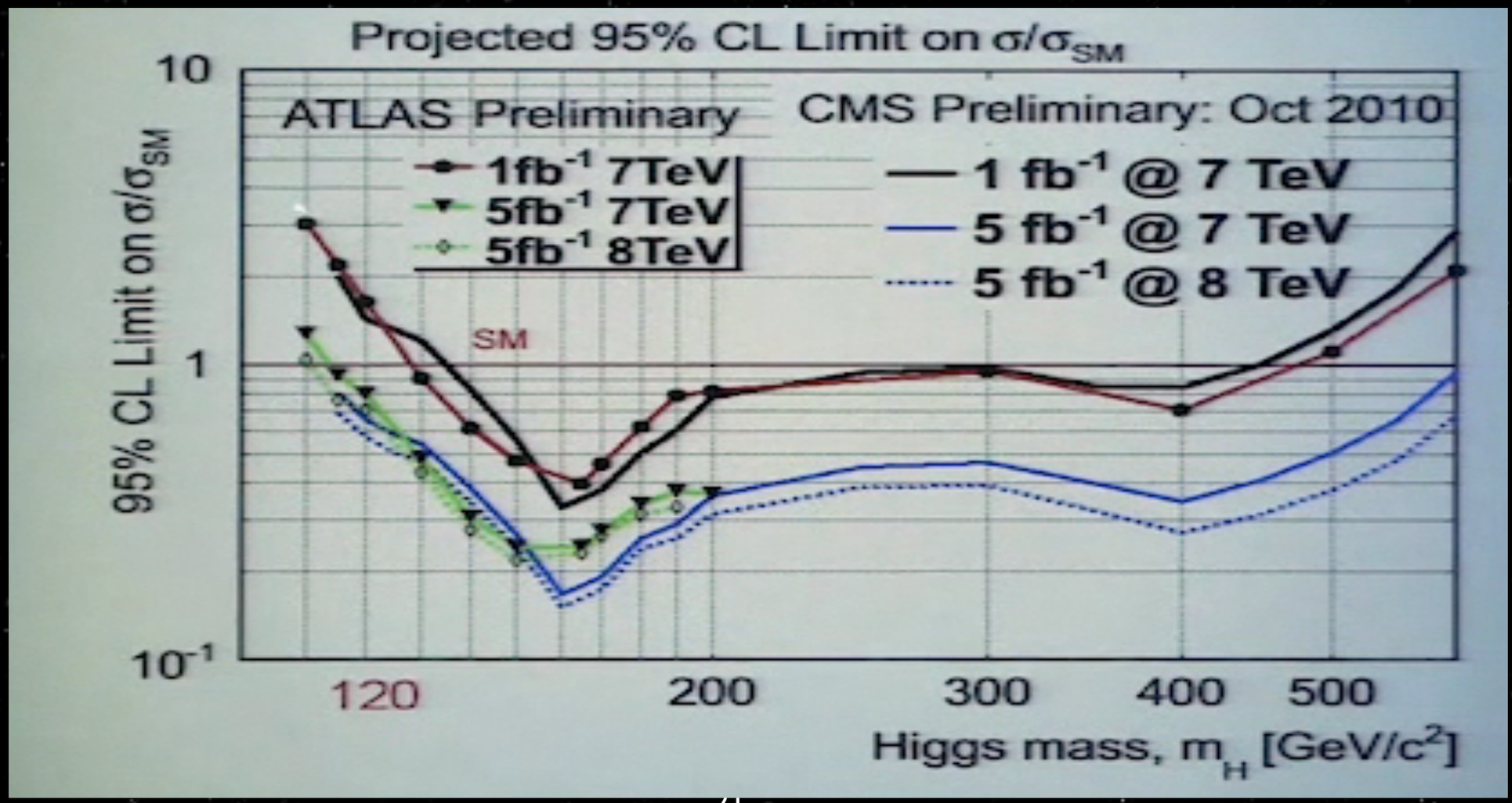
158 173

300

600

114

Rolf Heuer



SM Higgs Search Prospects (Mass in GeV)			
ATLAS + CMS ≈ 2 x CMS	95% CL exclusion	3 σ sensitivity	5 σ sensitivity
1 fb^{-1}	120 - 530	135 - 475	152 - 175
2 fb^{-1}	114 - 585	120 - 545	140 - 200
5 fb^{-1}	114 - 600	114 - 600	128 - 482
10 fb^{-1}	114 - 600	114 - 600	117 - 535

Higgs Boson: if it exists with mass between 114-600 GeV it will be either discovered or ruled out in the next ~ two years

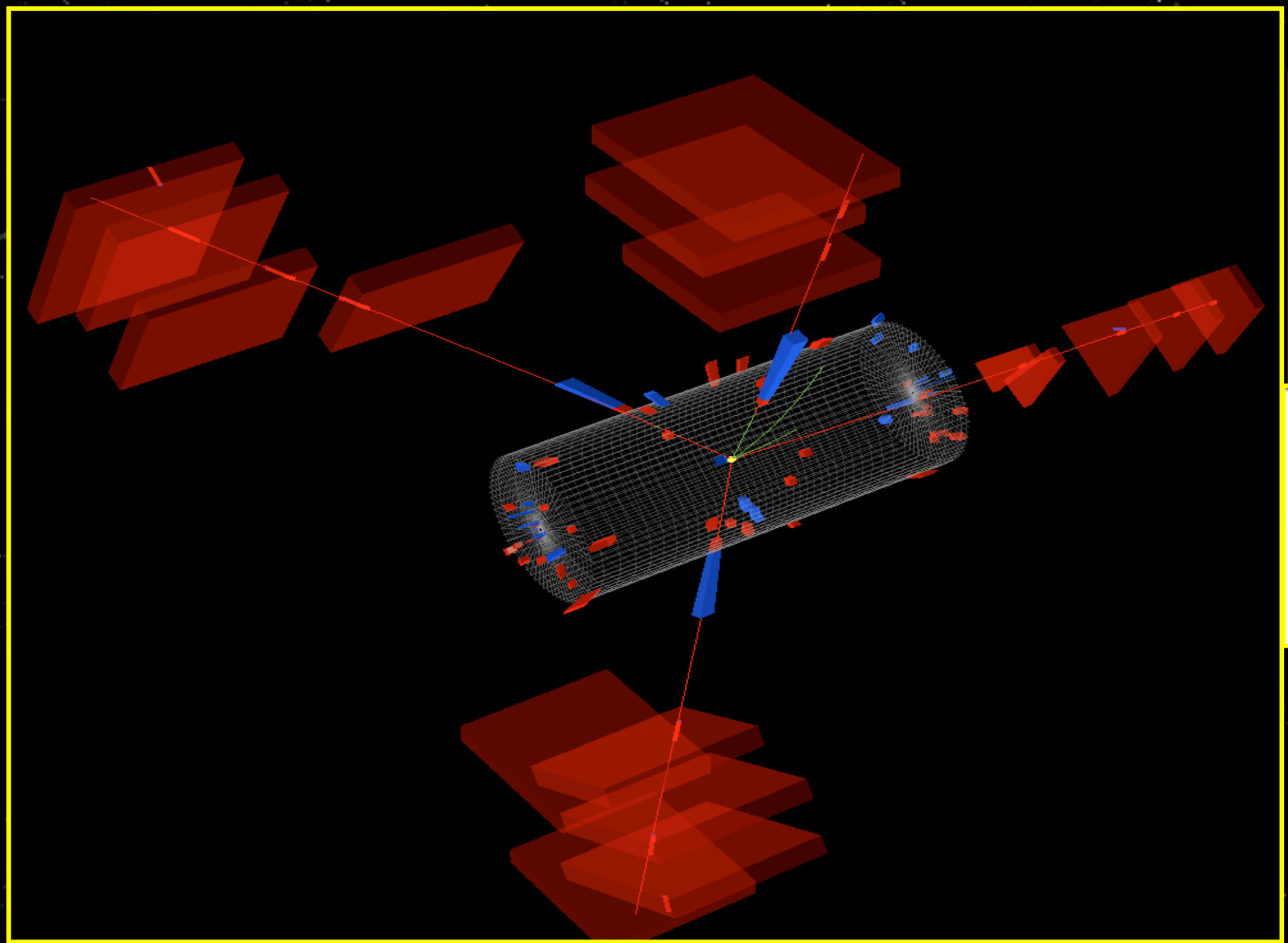
Operate LHC in 2011 and 2012 Rolf Heuer

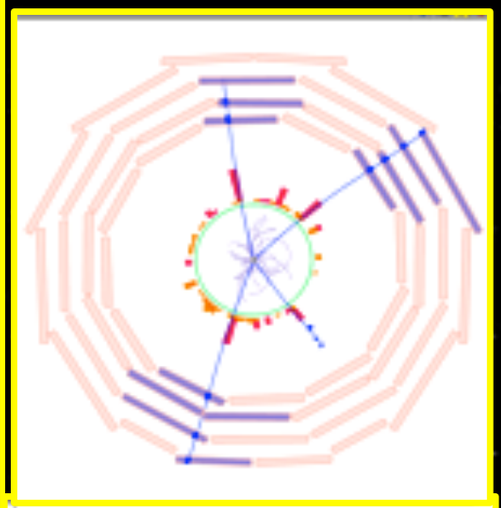
2011 : E = 7 TeV ; expect 1 fb^{-1} (baseline) hope for more

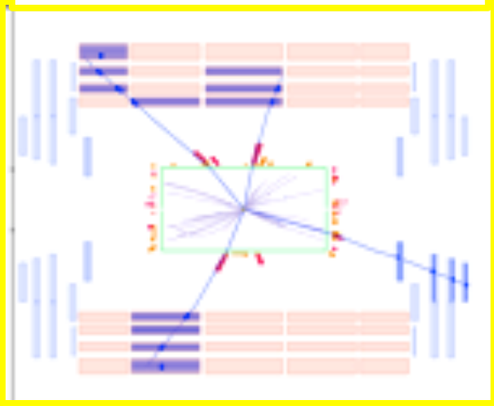
2012 : Lint increase by a factor of two

2013/14 shutdown (15 mo) to prepare ~14 TeV operation

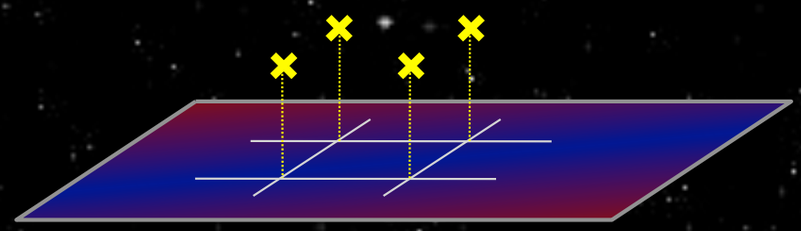
A beautiful, clean, rare 4-muon event



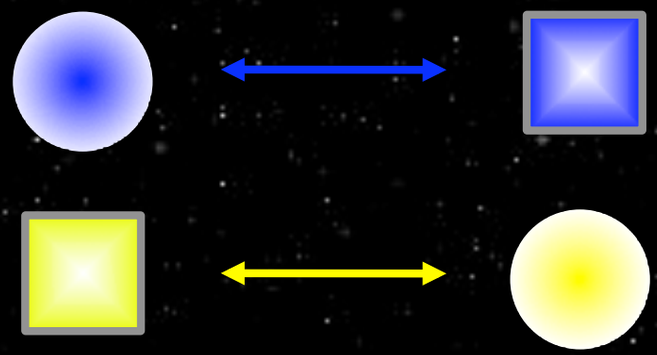




Super dimensions!

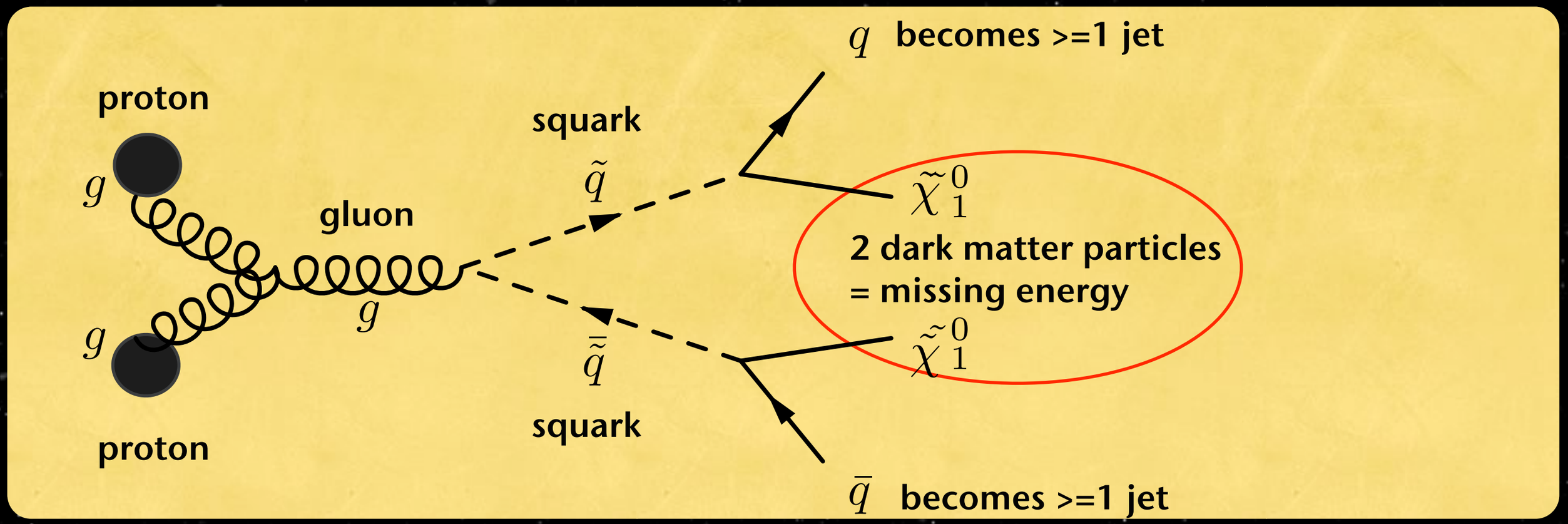


Idea: extra dimensions of zero size, with the funny property that bosons can vibrate in the new directions and become fermions, and vice-versa.



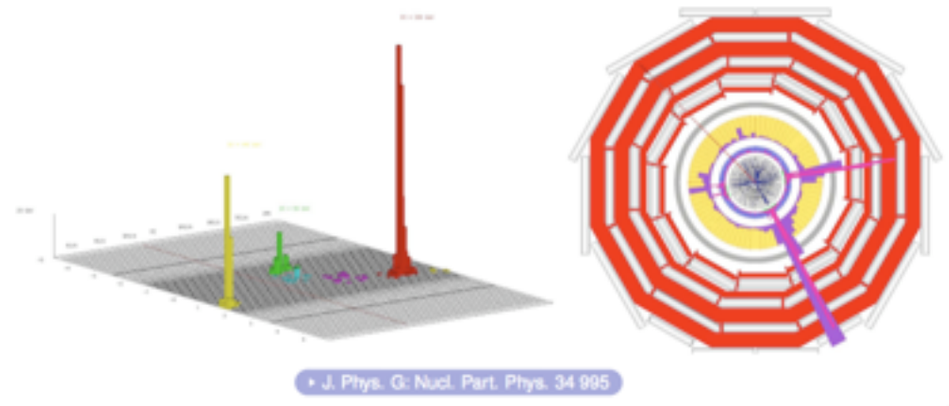
There can be a symmetry between ordinary and super-dimensions (just as there already is among ordinary dimensions): Supersymmetry!

Supersymmetry predicts "squarks" = heavy partners of quarks, and "neutralinos", the lightest of which could be dark matter



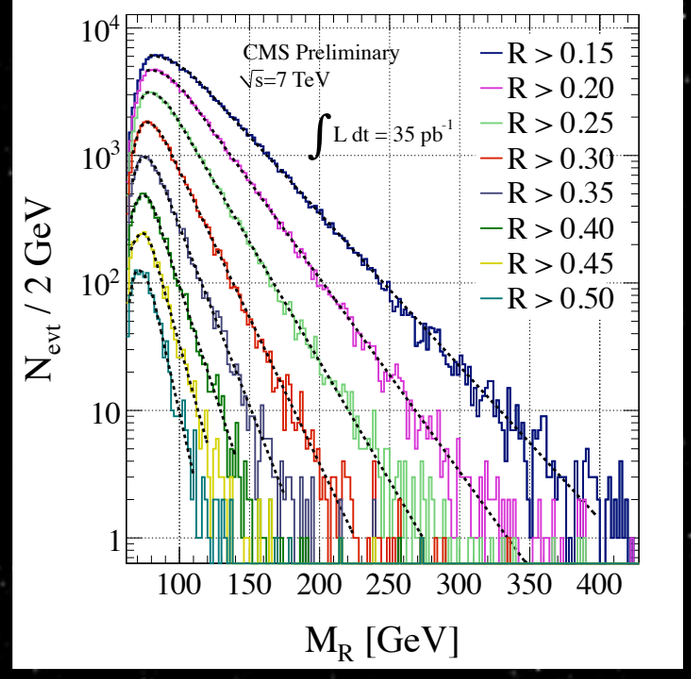
Canonical Dark Matter Searches Using Missing Energy

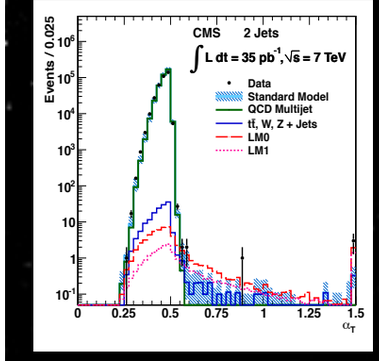
E_T^{miss}=360 GeV, E_T(1)=330 GeV, E_T(2)=140 GeV, E_T(3)=60 GeV

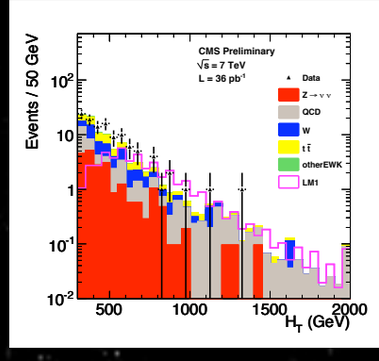


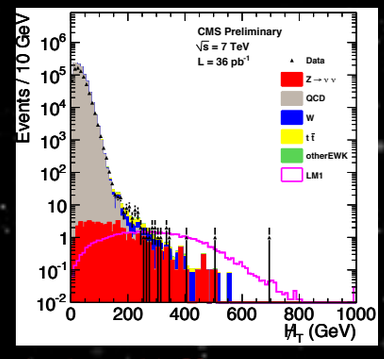
J. Phys. G: Nucl. Part. Phys. 34 995

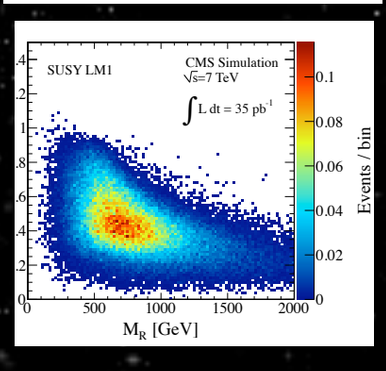
at 7 TeV 1,000 to 10,000 events in the first year





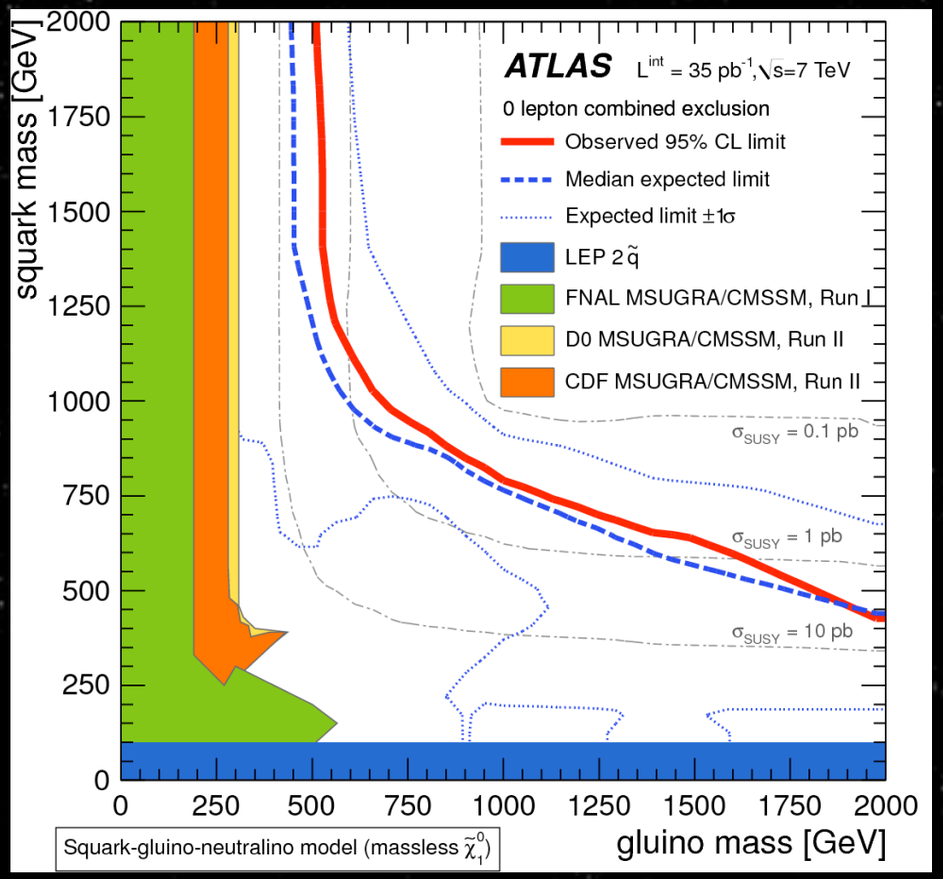


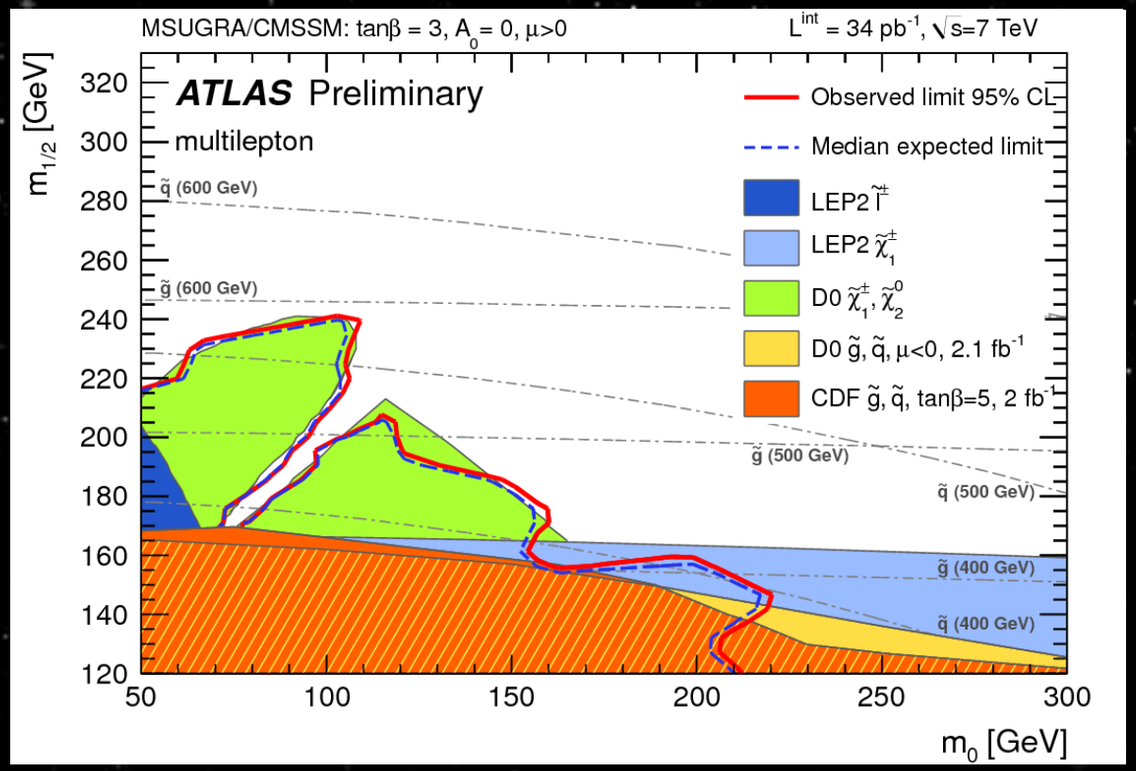


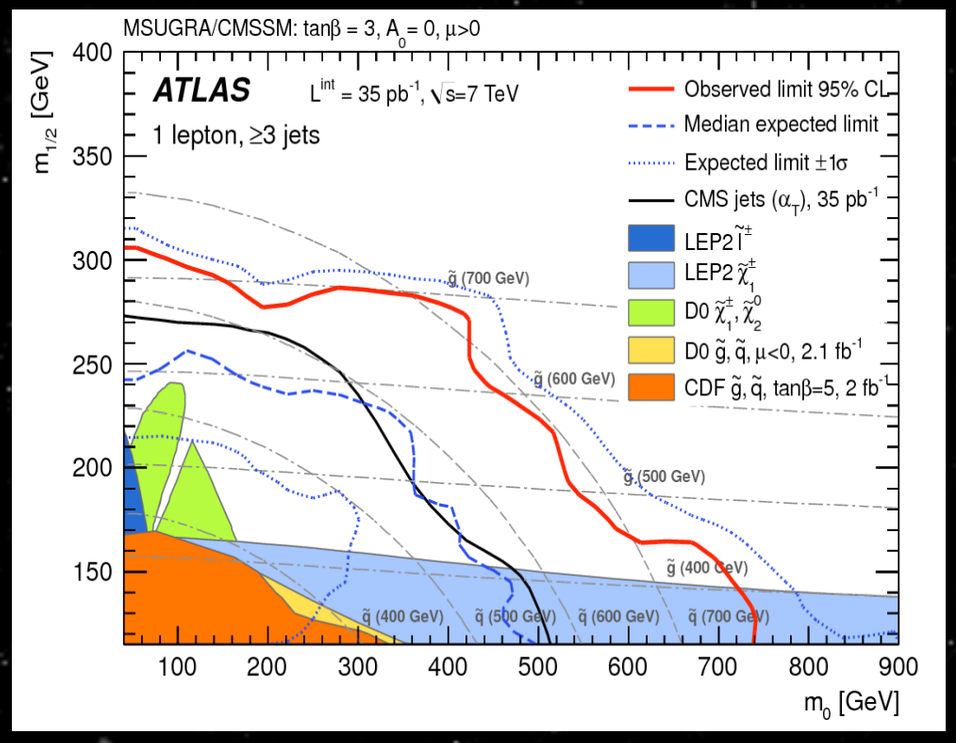


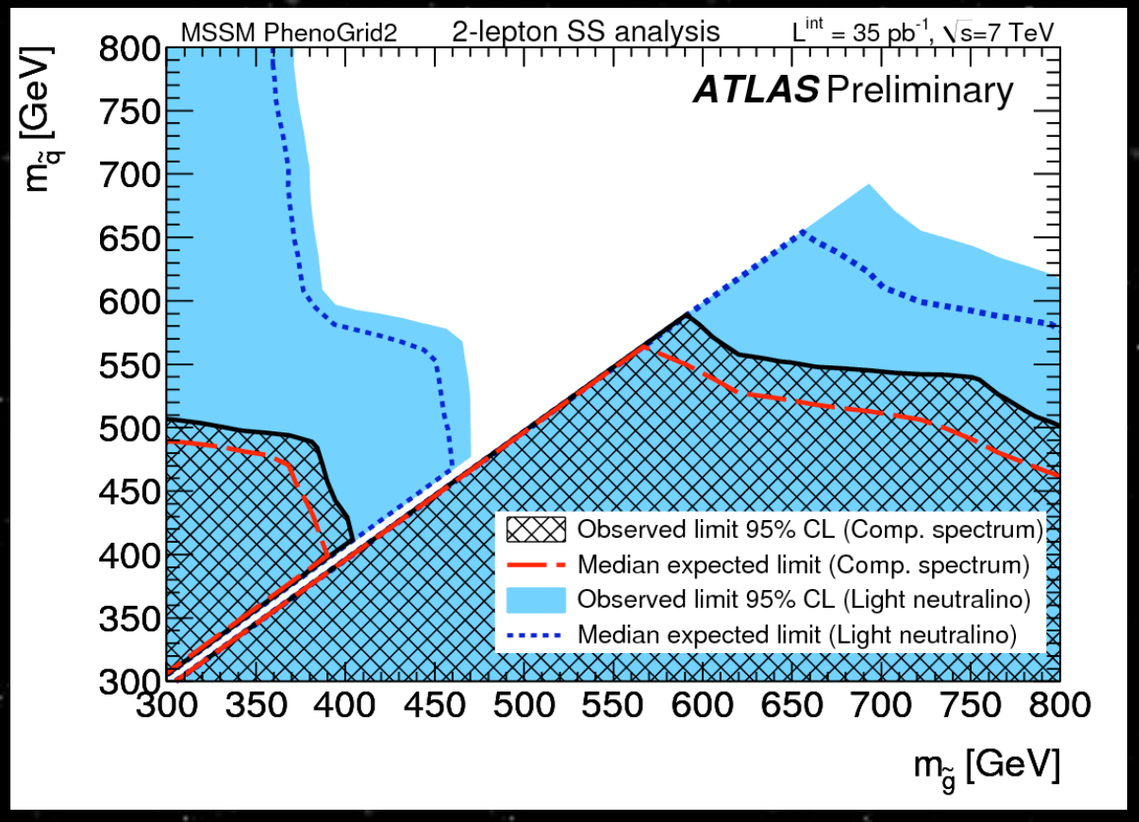
- There are an infinite number of different models with different superpartner masses and decay patterns
- Design *inclusive* searches to look for most of them, plus a few *exclusive* searches to cover special cases

• ATLAS SUSY searches results









Razor kinematics

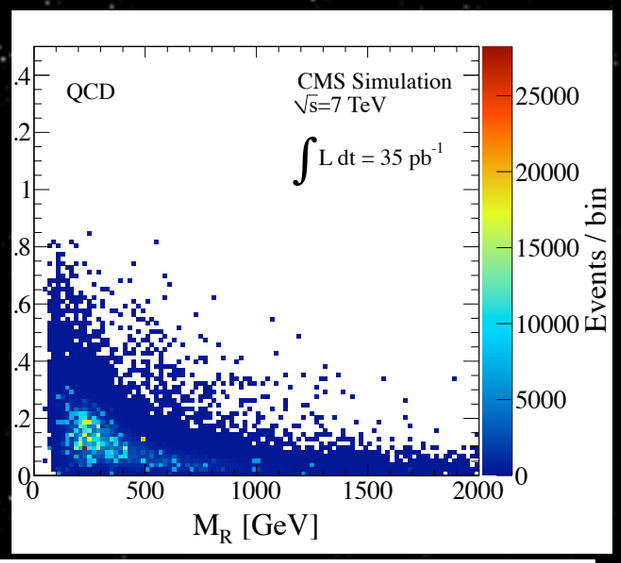
Scale:

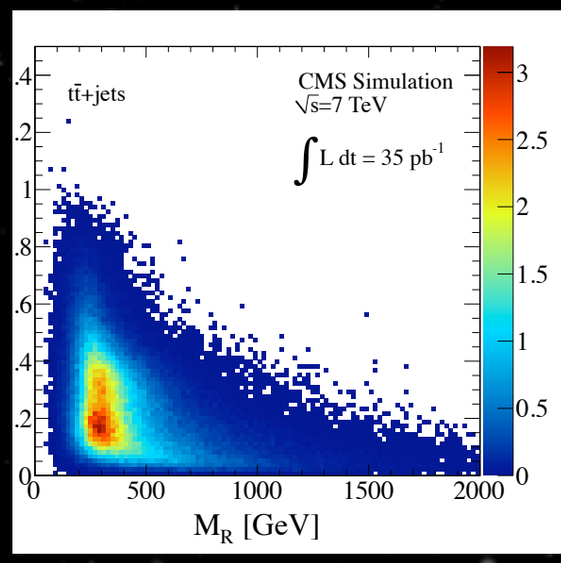
$$M_R = 2\sqrt{\frac{(|\vec{p}|q_z - |\vec{q}|p_z)^2}{(p_z - q_z)^2 - (|\vec{p}| - |\vec{q}|)^2}}$$

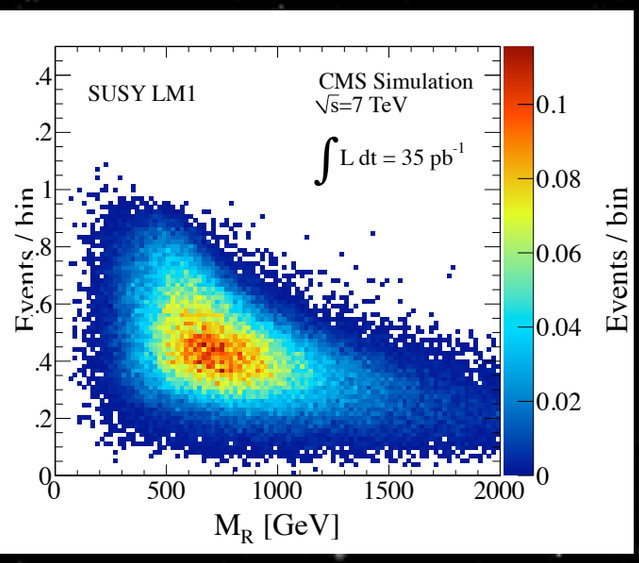
$$M_T^R = \sqrt{\frac{|\vec{M}|(|\vec{p}| + |\vec{q}|) - \vec{M}\cdot(\vec{p}+\vec{q})}{2}}$$

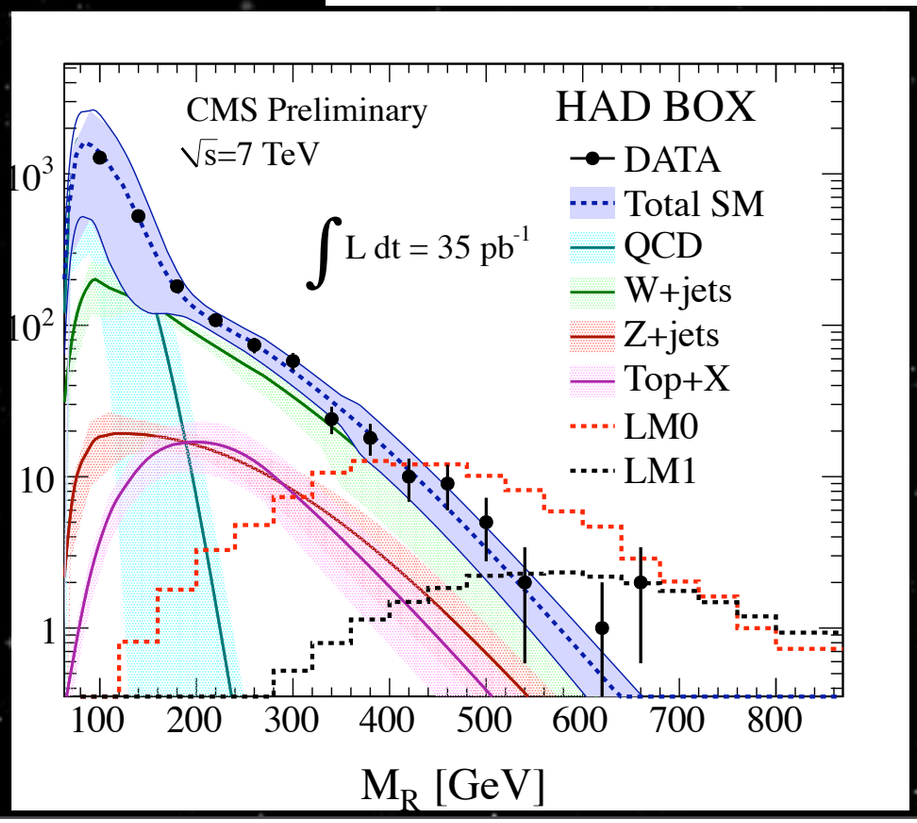
Angle:

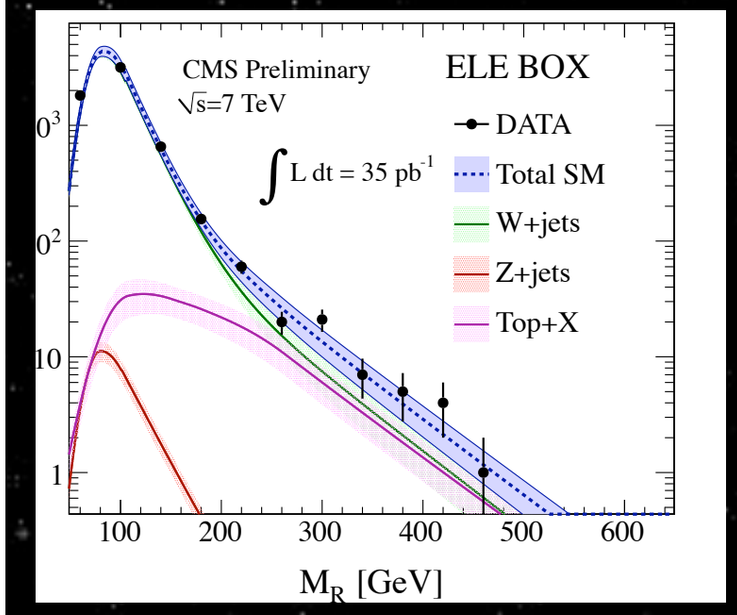
$$R = \frac{M_T^R}{M_R}$$

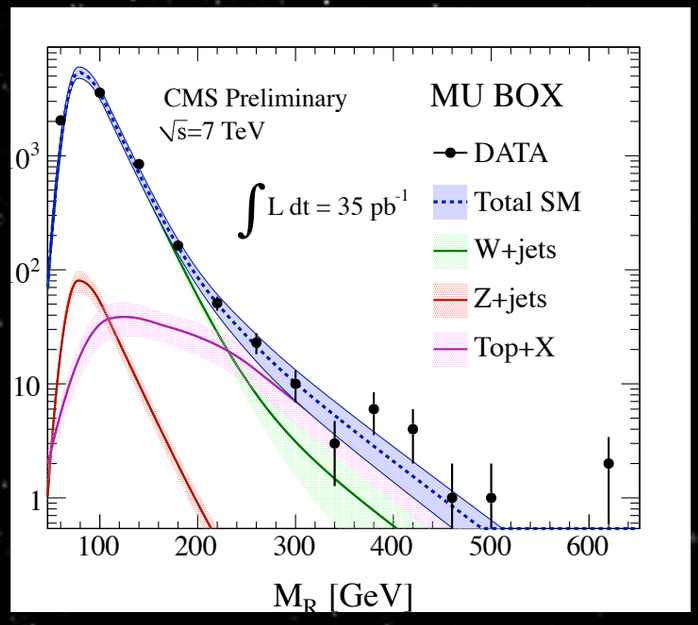




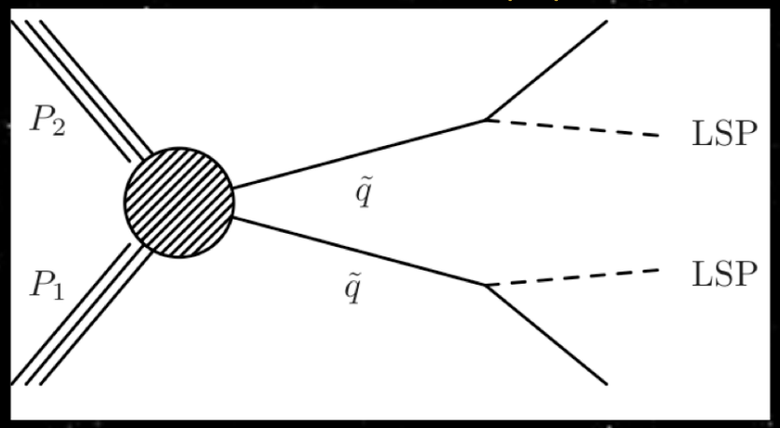


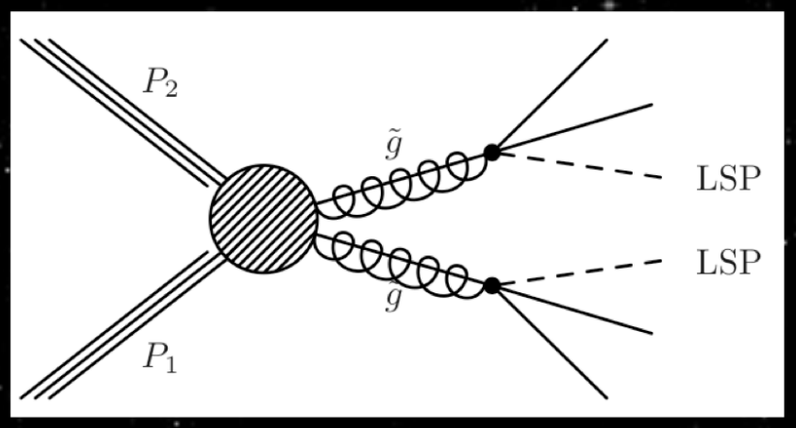




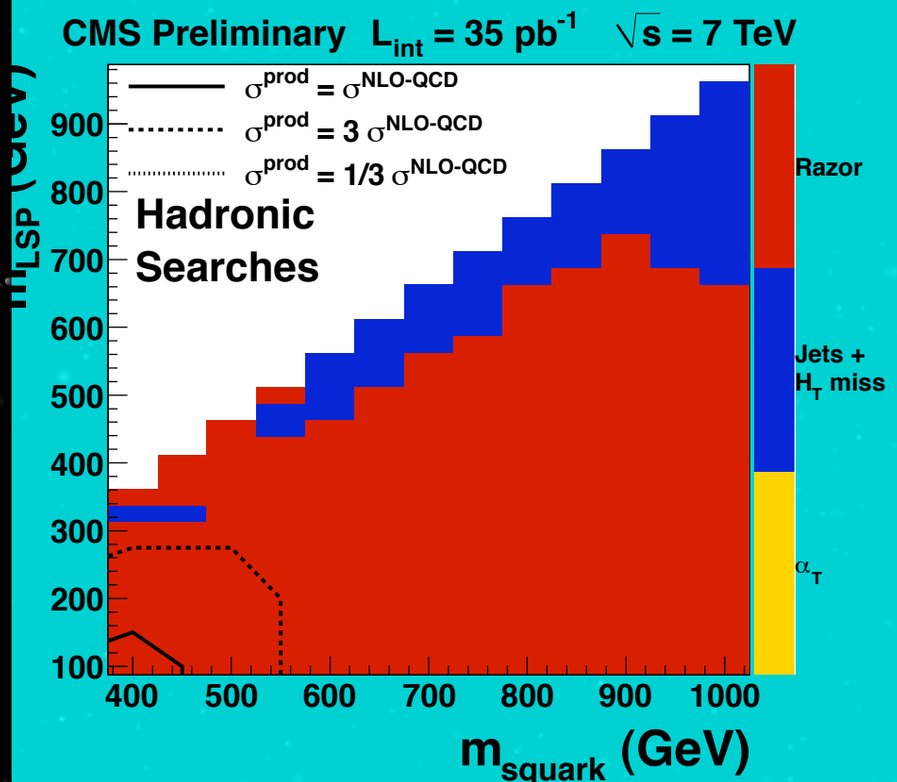


- http://www.lhcnewphysics.org

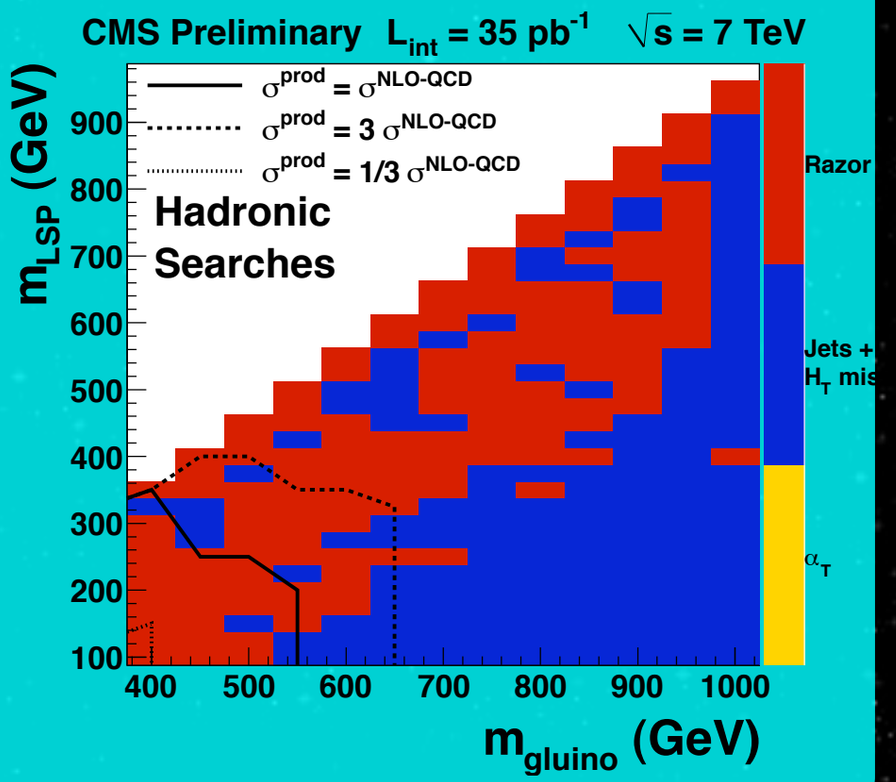




$\tilde{q}\tilde{q} \rightarrow (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0)$

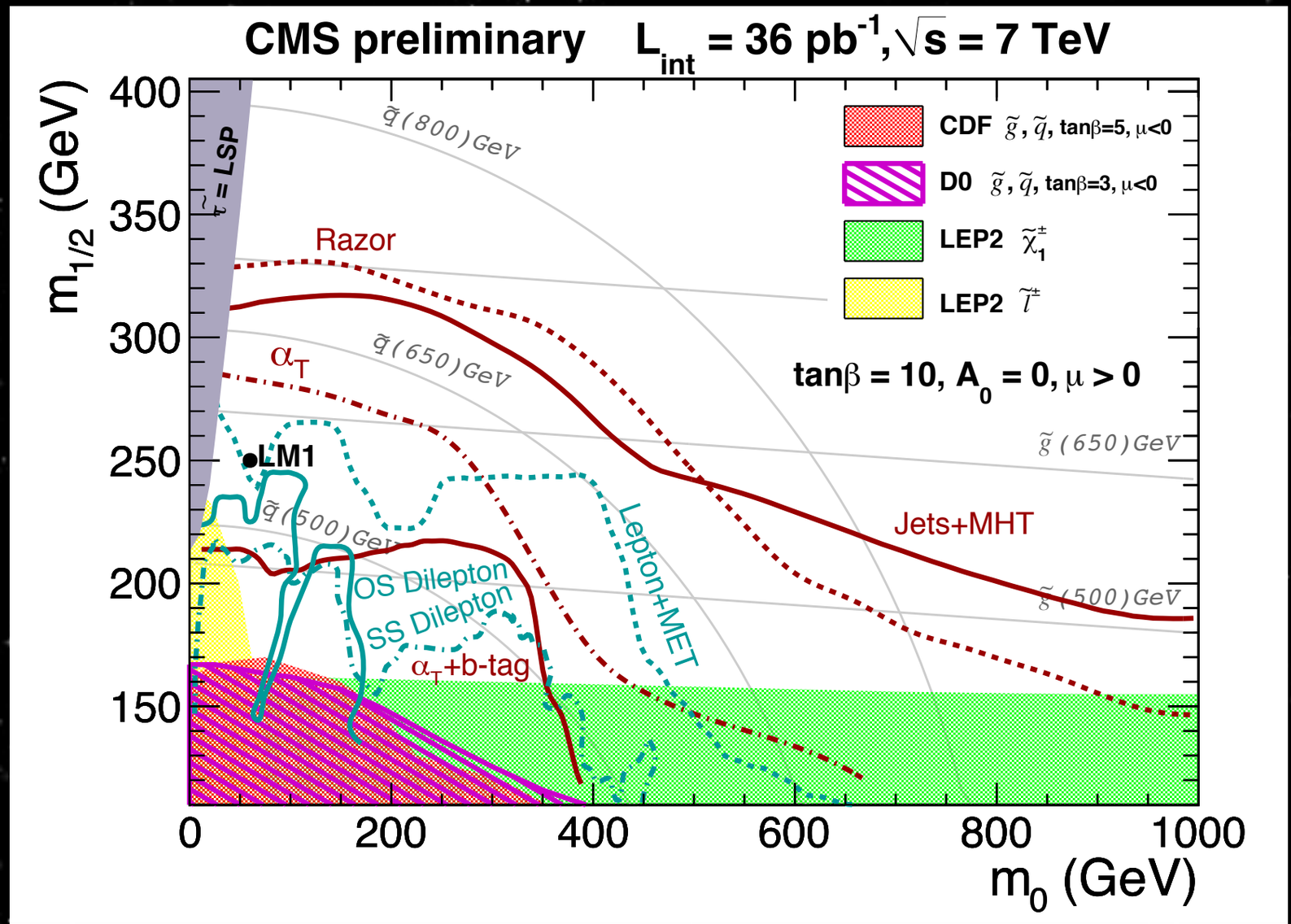


$\tilde{g}\tilde{g} \rightarrow (qq\tilde{\chi}_1^0)(qq\tilde{\chi}_1^0)$



Advantages in an LHC search for dark matter:

- Produce dark matter in the laboratory and study it under controlled conditions.
- Study the new unstable "relatives" of dark matter particles, giving a much broader and deeper picture of the "dark sector".



Limitations:

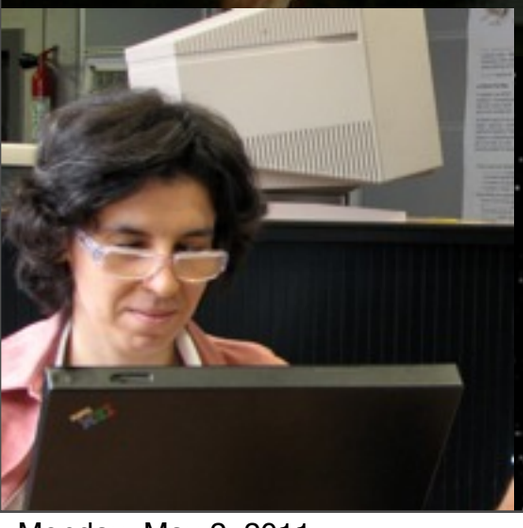
- Inference of dark matter properties from other particles

- ❒ **2011** Run got extended into 2012 (to get ~10/fb)
- ❒ **2013 : Splice consolidation**
- ❒ **2014 – 2015: to 13+ TeV**
- ❒ **2016+: Gear up for L = 10^{34}**
  - Phase 2 Collimators; SPS Upg.; Improved Injection System; New Pixel Detectors
- ❒ **2017-2019*: Reach Design Lumi.***
  - New Linac + Booster Upgrade
  - Prepare for crab Cavities; Cryo. System Upgrades
  - *[330/fb by end 2019]*
- ❒ **2020-21: Transition to *HL-LHC***
  - Lower β Large Insertions; Crab Cavities; SPS Enhancements; Major Detector Upgrades: Pixels, Tracker, Fwd Calorimetry
  - *[3000/fb by 2030]*
- ❒ **~2035: *HE LHC* (~33 TeV)**

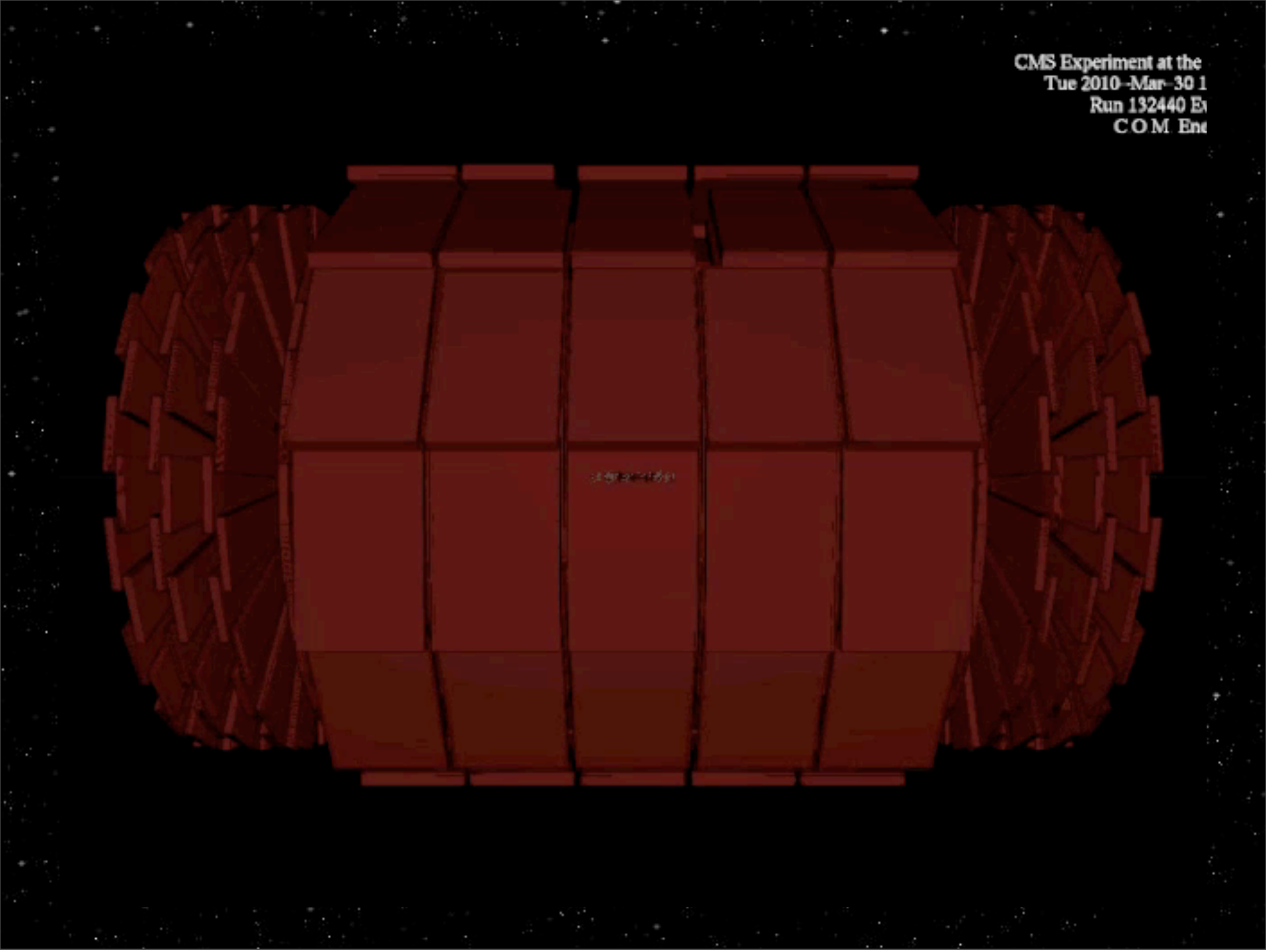
Expect the unexpected


New physics


Jak zobaczyć ciemną materię



D. Gross


CMS Experiment at the
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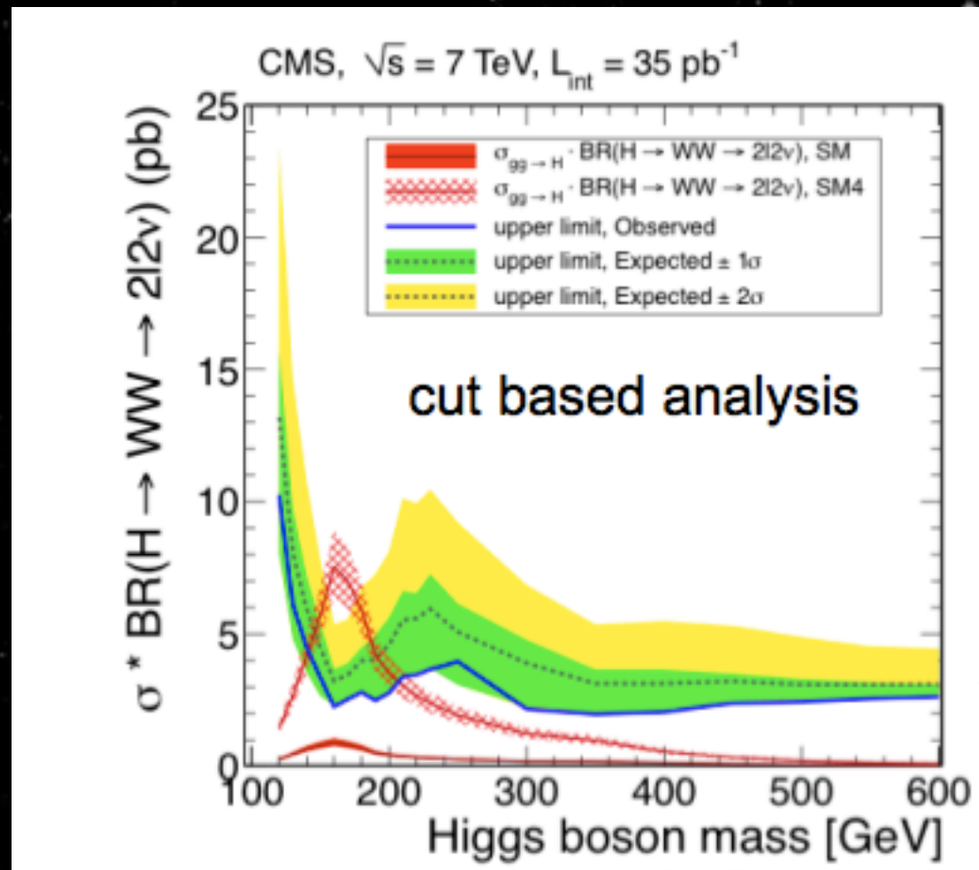
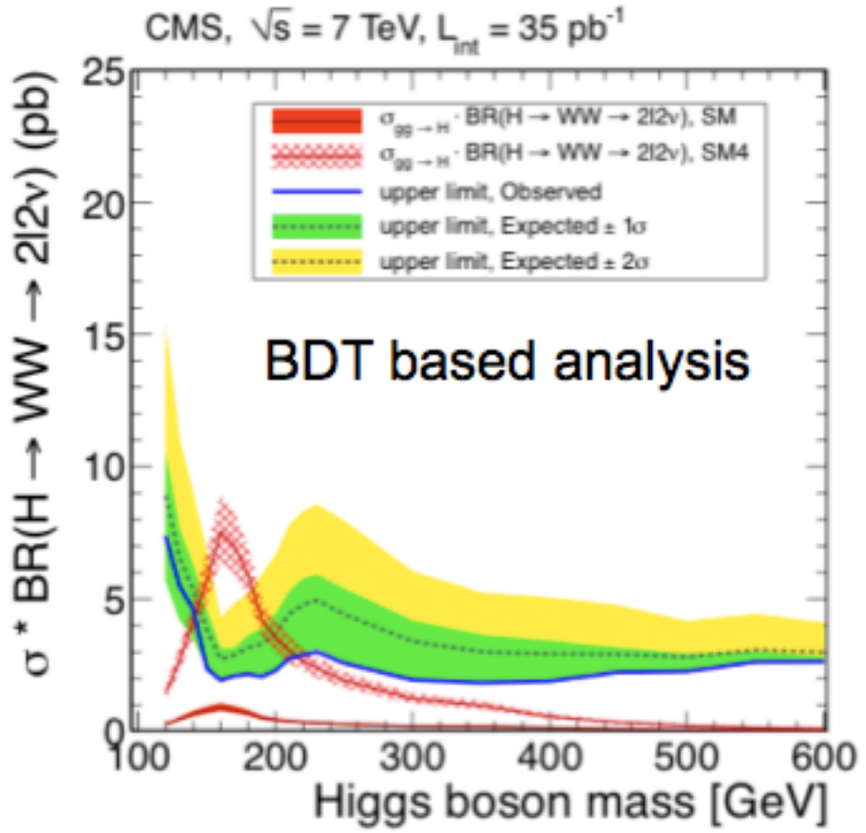
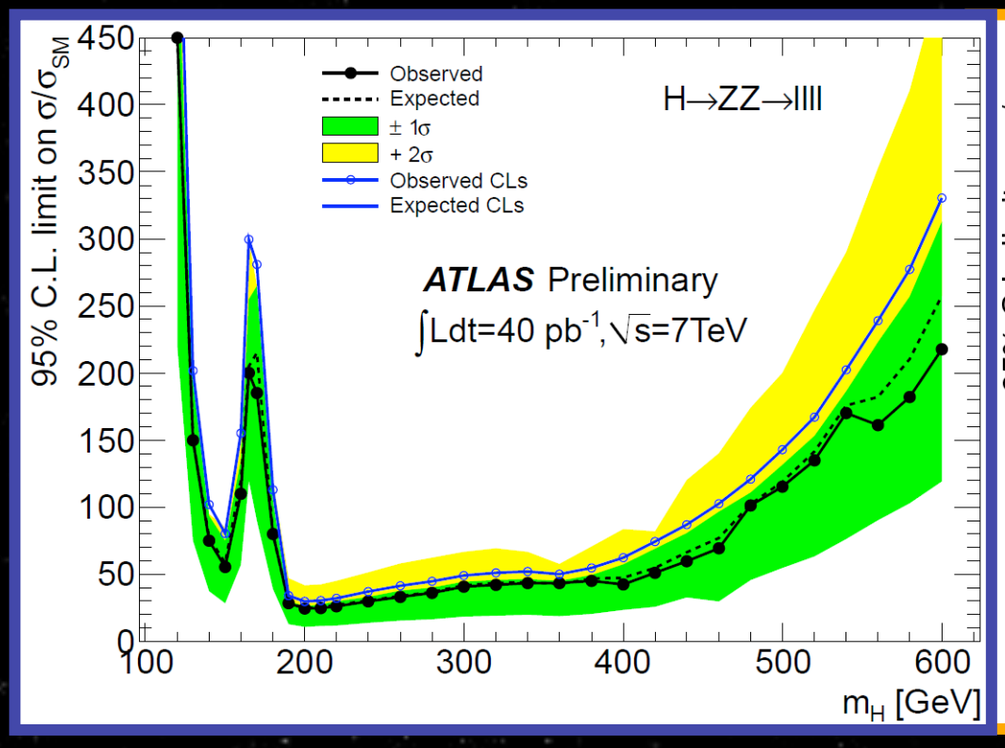
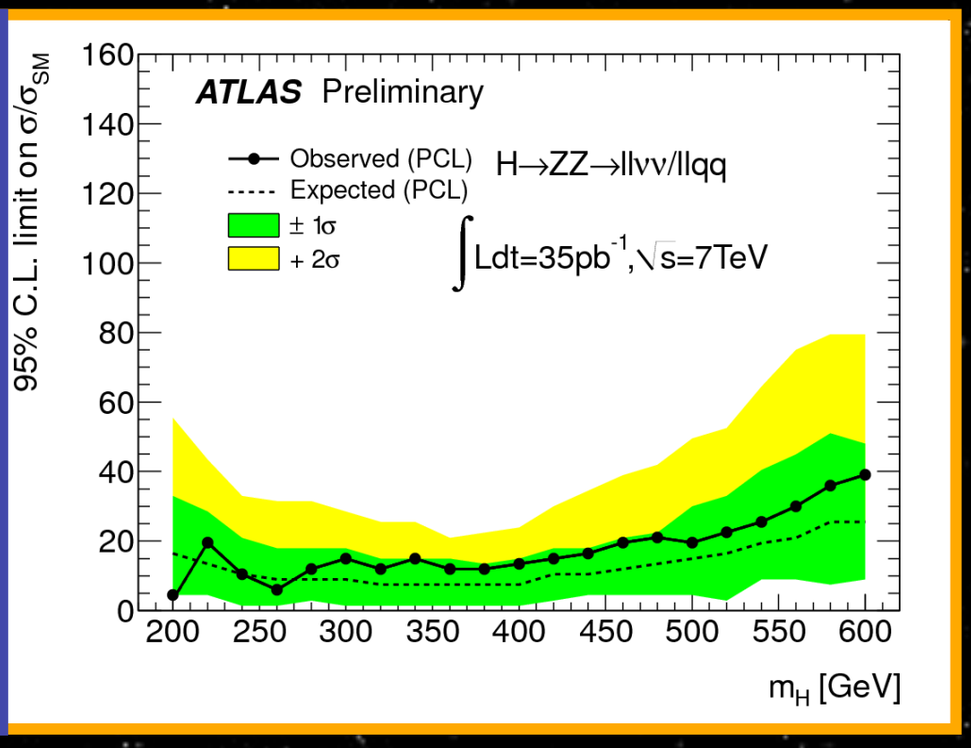
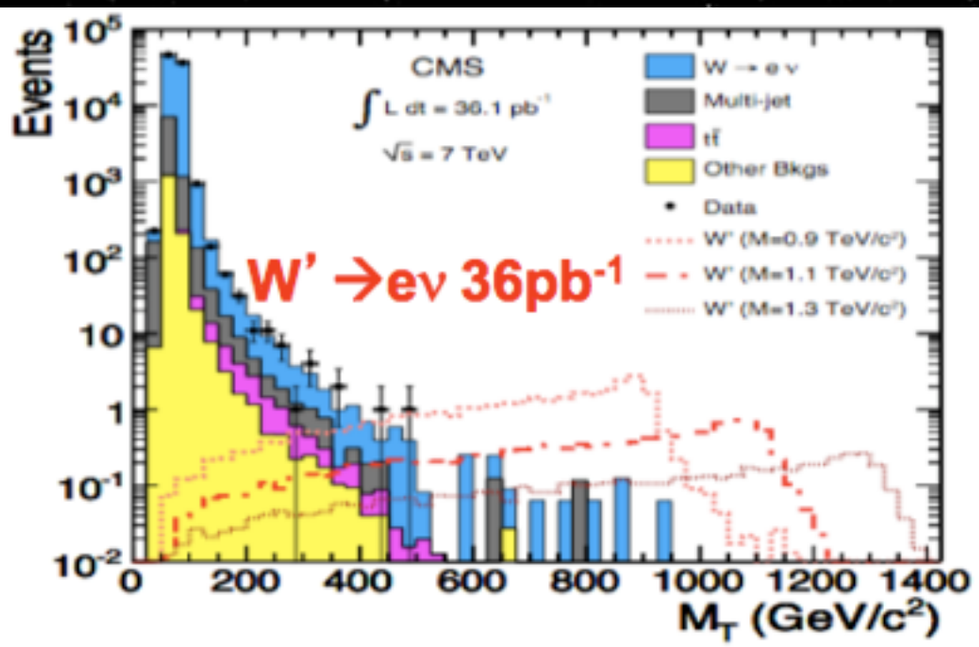
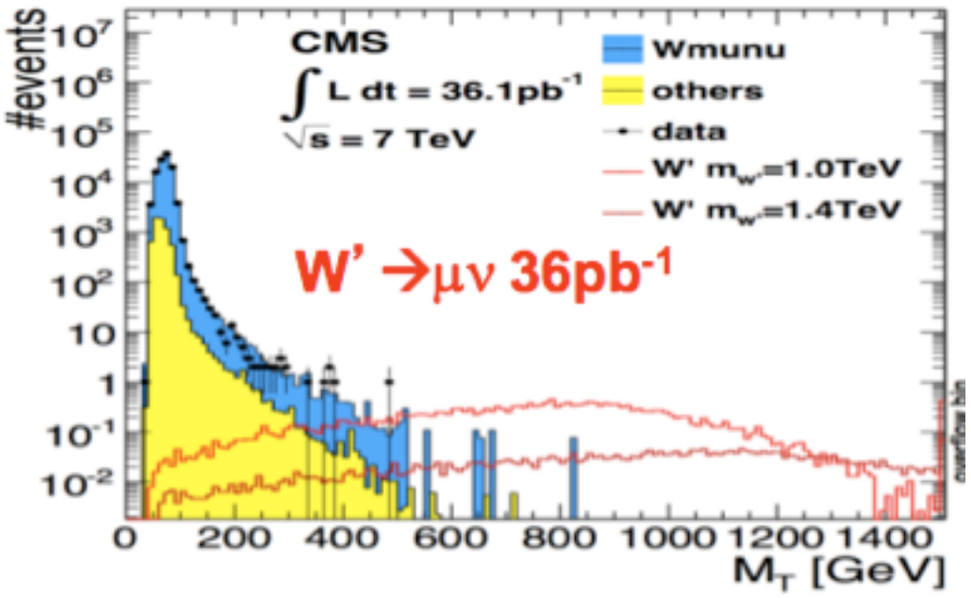

CMS, √s = 7 TeV, L_int = 35 pb^-1
σ_gg→H · BR(H → WW → 2l2ν), SM
σ_gg→H · BR(H → WW → 2l2ν), SM4
upper limit, Observed
upper limit, Expected ± 1σ
upper limit, Expected ± 2σ
cut based analysis
σ * BR(H → WW → 2l2ν) (pb)
Higgs boson mass [GeV]

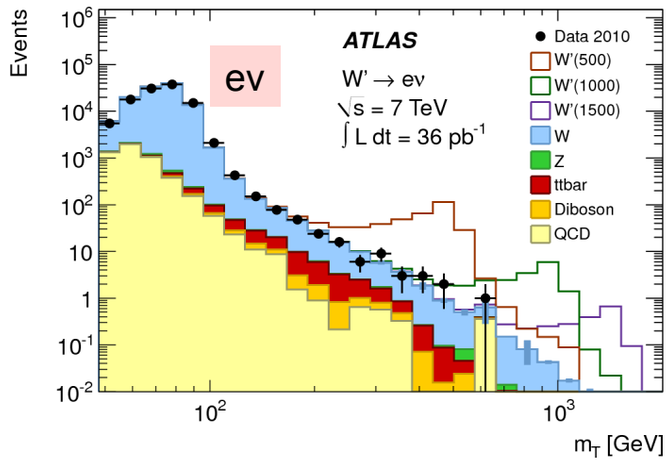

CMS, √s = 7 TeV, L_int = 35 pb^-1
σ_gg→H · BR(H → WW → 2l2ν), SM
σ_gg→H · BR(H → WW → 2l2ν), SM4
upper limit, Observed
upper limit, Expected ± 1σ
upper limit, Expected ± 2σ
BDT based analysis
σ * BR(H → WW → 2l2ν) (pb)
Higgs boson mass [GeV]

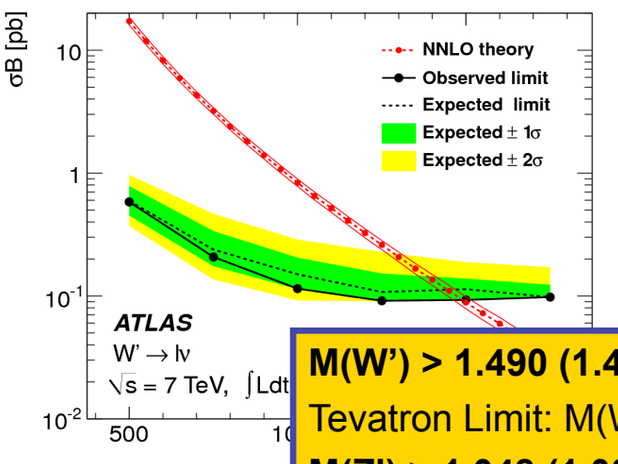

Observed
Expected
± 1σ
+ 2σ
Observed CLs
Expected CLs
H→ZZ→llll
ATLAS Preliminary
∫Ldt=40 pb^-1, √s=7TeV
95% C.L. limit on σ/σ_SM
m_H [GeV]

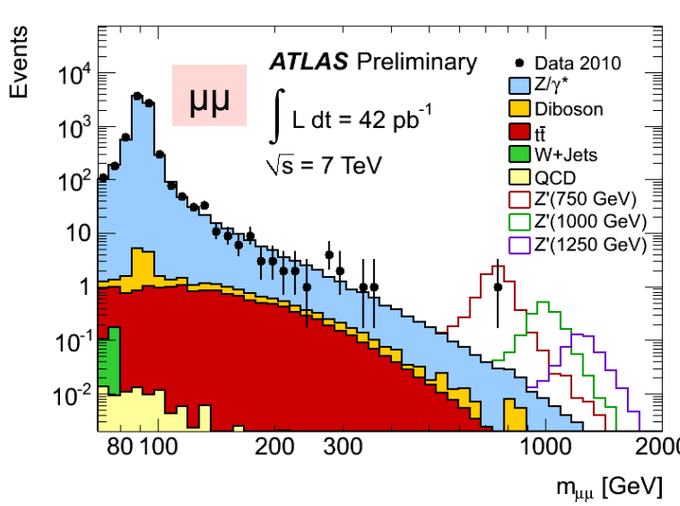

ATLAS Preliminary
Observed (PCL)
Expected (PCL)
± 1σ
+ 2σ
H→ZZ→llνν/llqq
∫Ldt=35pb^-1, √s=7TeV
95% C.L. limit on σ/σ_SM
m_H [GeV]

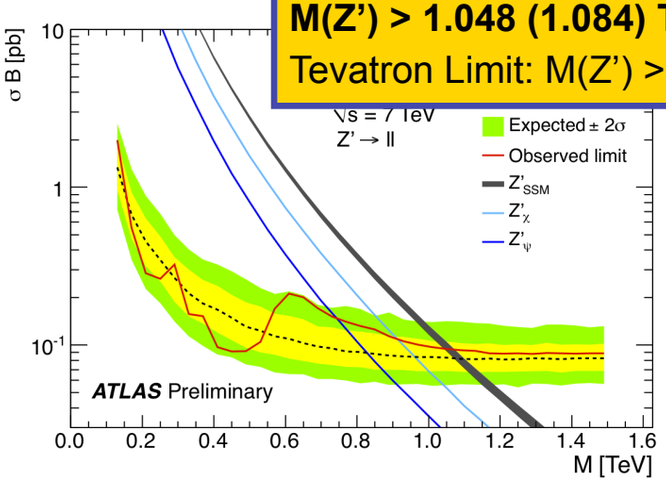








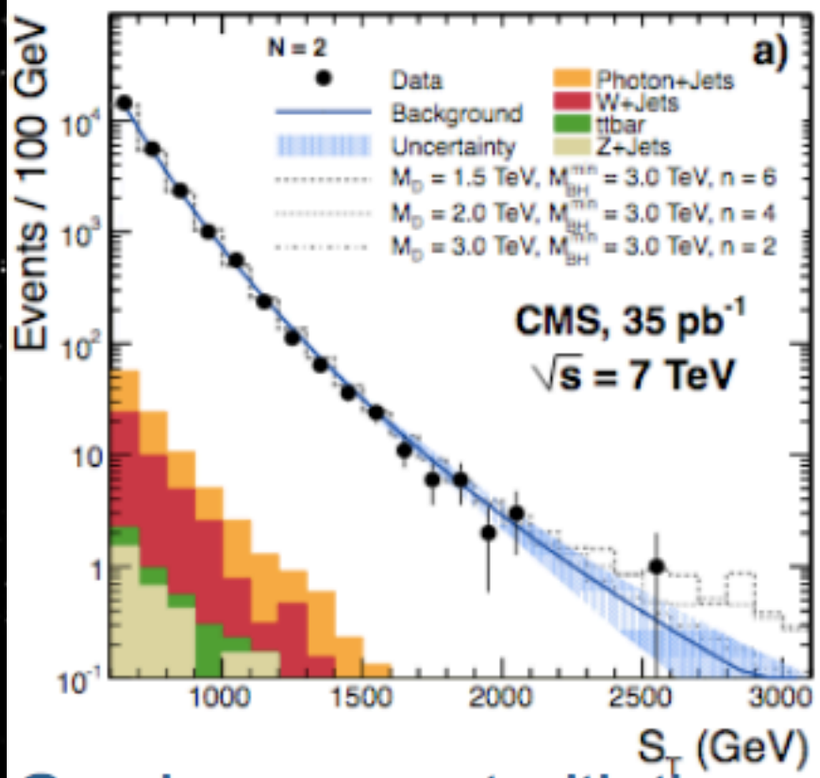


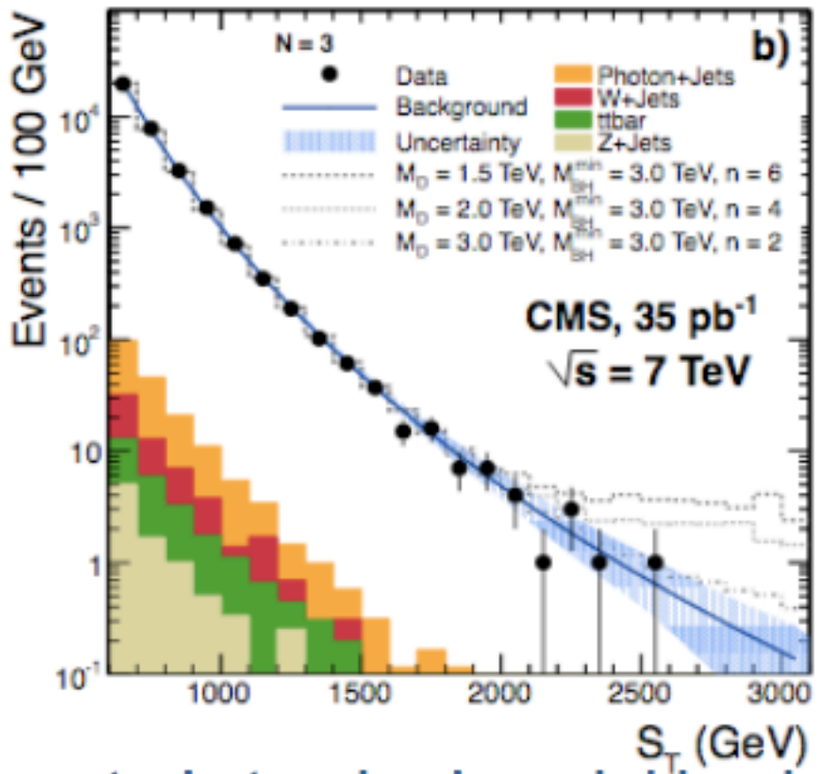


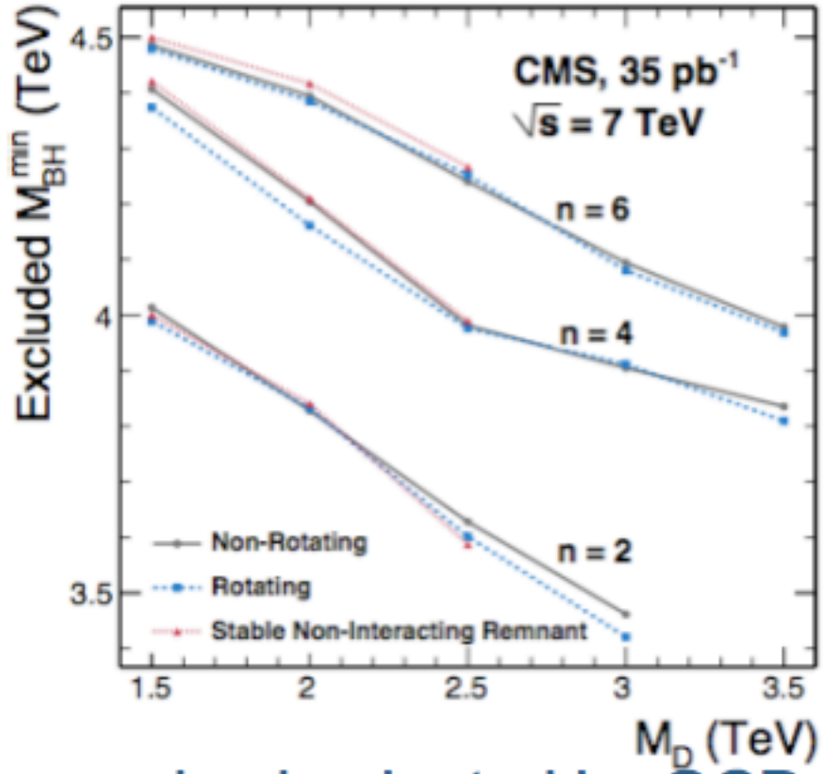
M(W') > 1.490 (1.450) TeV
Tevatron Limit: M(W') > 1.10 TeV
M(Z') > 1.048 (1.084) TeV
Tevatron Limit: M(Z') > 1.071 TeV

First direct search of microscopic black holes signatures at a particle collider.

Events with large total transverse energy are analyzed for the presence of multiple high-energy jets, leptons, and photons, typical signal expected from a microscopic black hole.

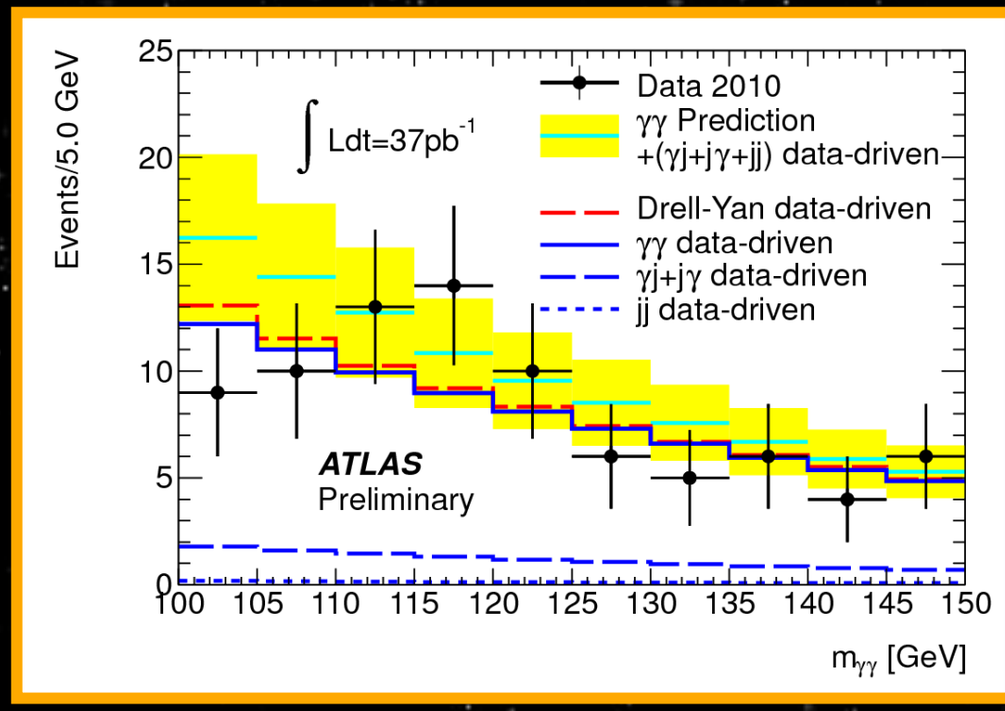


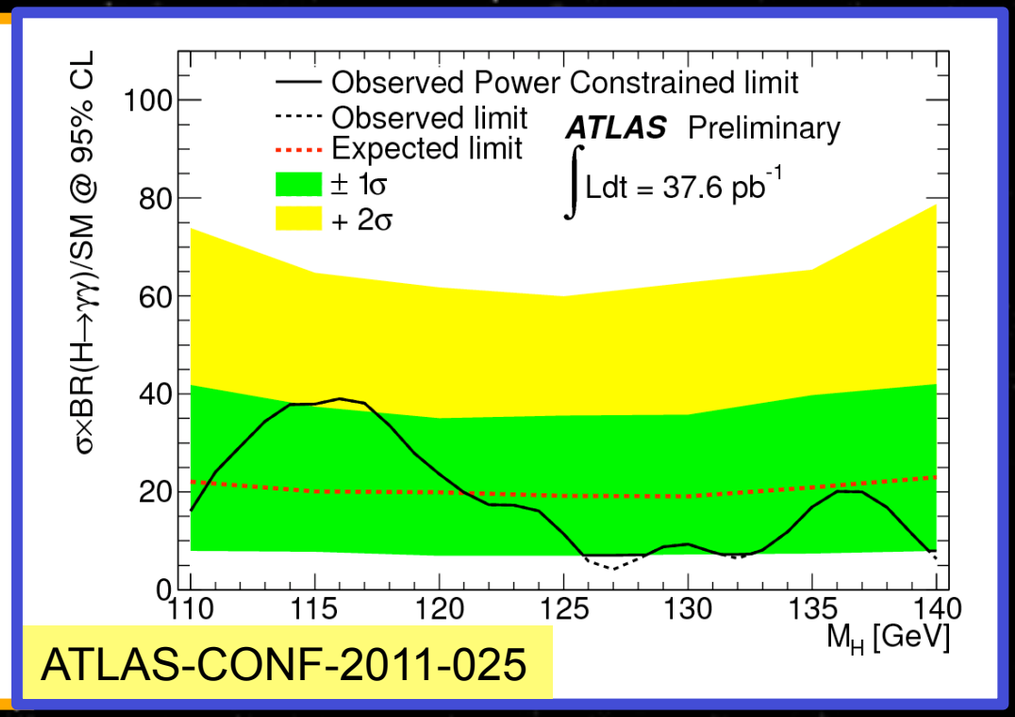




Good agreement with the expected standard model backgrounds, dominated by QCD multijet production, is observed for various final-state multiplicities. Limits on the minimum black hole mass are set, in the range **3.5–4.5 TeV**, for a variety of parameters in a model with large extra dimensions.

arXiv:1012.3375; ***Phys. Lett. B697 (2011)***



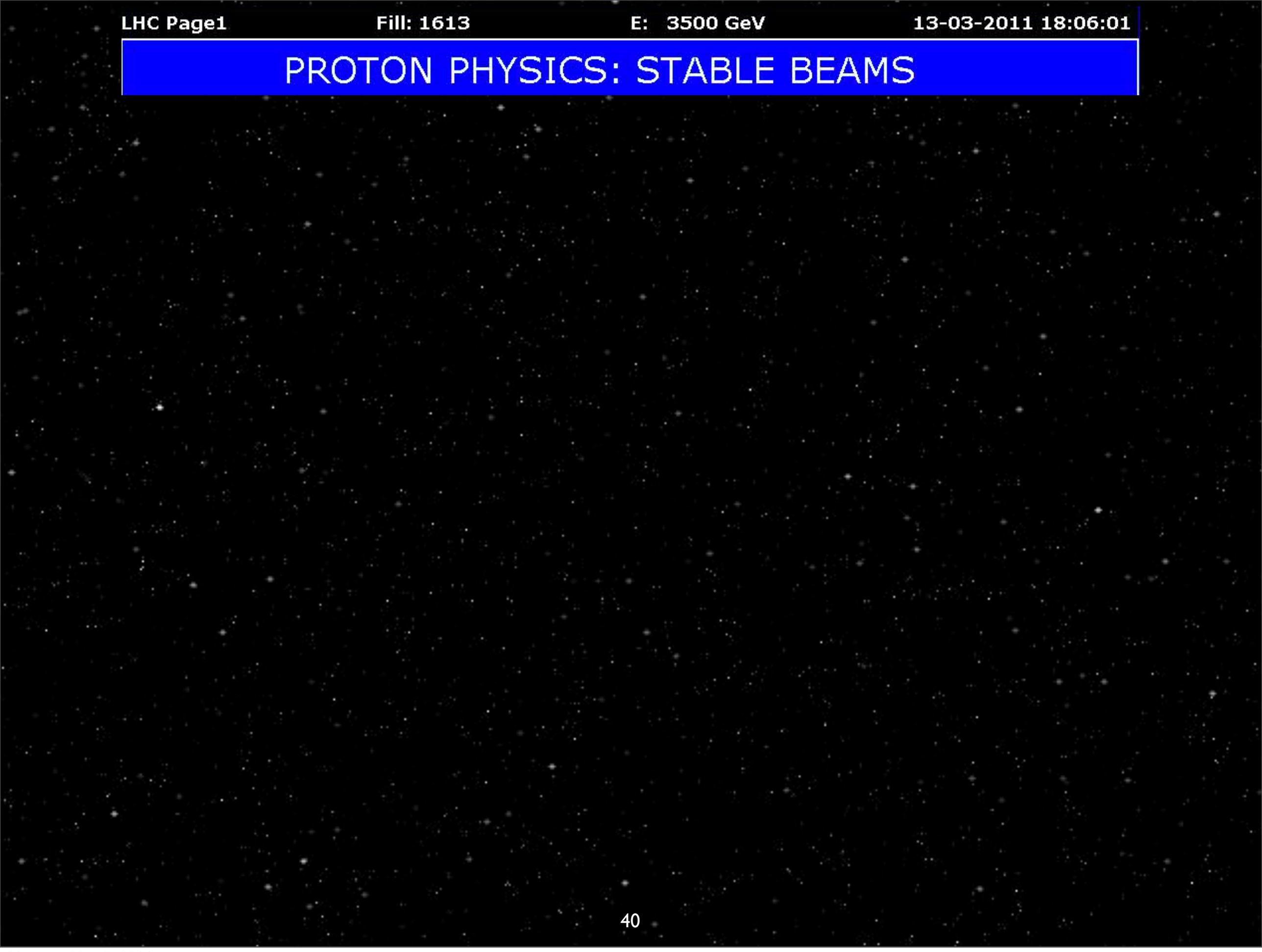


ATLAS-CONF-2011-025

…for any important assertion evidence must be produced;
…prophecies and bugaboos must be subjected to scrutiny;
… guesswork must be replaced by exact count;
….accuracy is a virtue and inquiry is a moral imperative

To the hegemony of science we owe a feeling for which there is no name, but which is akin to the faith of the innocent that the truth will out and vindication will follow. In its purest form science is justice as well as reason.

Jacques Barzun


LHC Page1
Fill: 1613
E: 3500 GeV
13-03-2011 18:06:01
PROTON PHYSICS: STABLE BEAMS

LHC Page1 Fill: 1613 E: 3500 GeV 13-03-2011 18:06:01

PROTON PHYSICS: STABLE BEAMS

CERN CERN

#LHC declared stable beams at 18:05 this evening. 2011 physics running is underway.

13 Mar

LHC Page1 Fill: 1613 E: 3500 GeV 13-03-2011 18:06:01

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18 Mar

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19 Mar

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Great performance last weekend from #LHC, now running with 136 bunches. 2011 data set already approaching 1/5 the total achieved in 2010.
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CERN CERN
#LHC sets new luminosity record of over 2.5x10^32 - peak in 2010 was 2.0x10^32. What does it mean? More data more quickly...
22 Mar

LHC Page1 Fill: 1613 E: 3500 GeV 13-03-2011 18:06:01

PROTON PHYSICS: STABLE BEAMS

CERN CERN
#LHC declared stable beams at 18:05 this evening. 2011 physics running is underway.
13 Mar

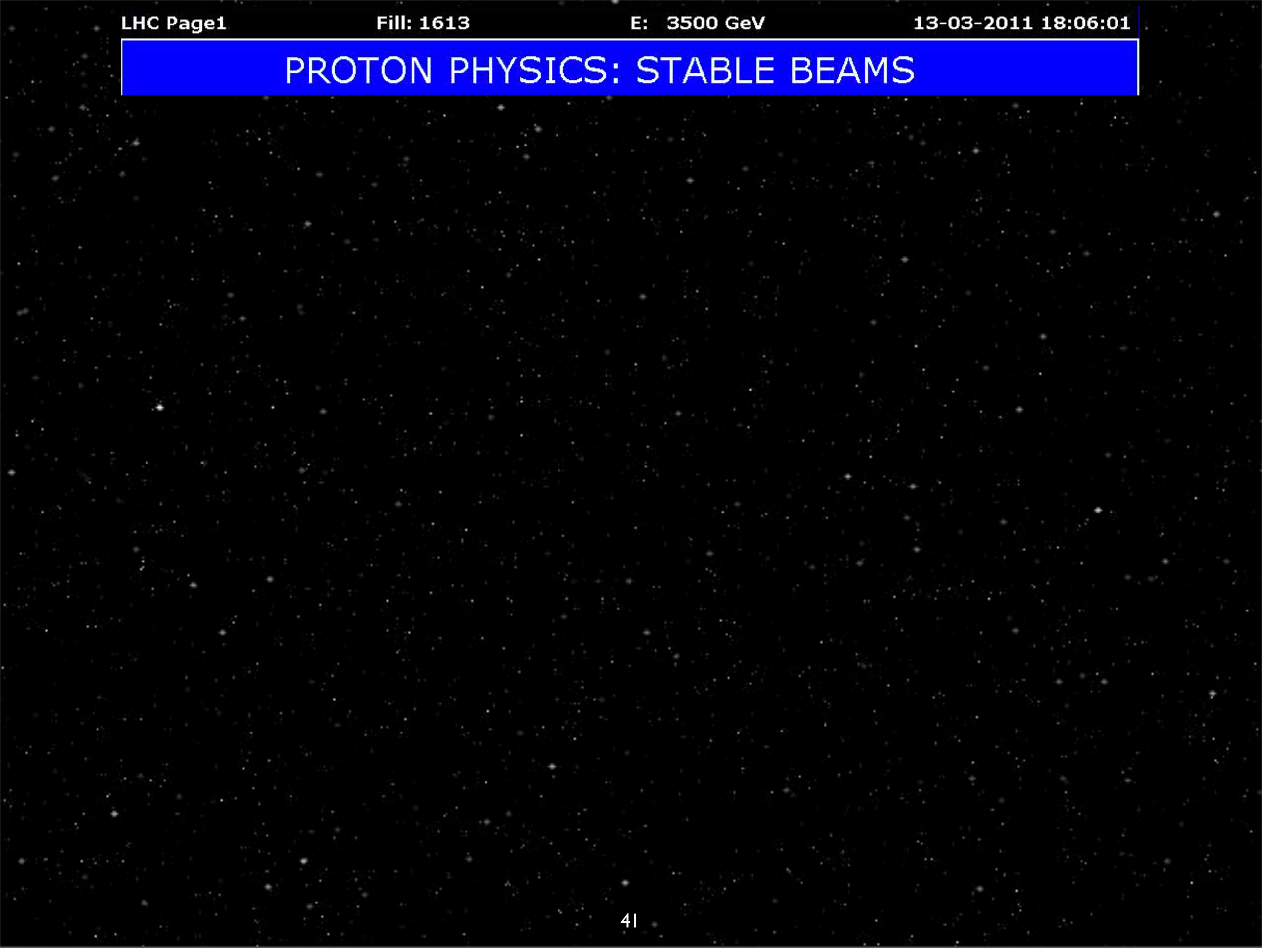
CERN CERN
#LHC is running with 32 bunches. Colliding stable beams.
18 Mar

CERN CERN
#LHC now running with 64 bunches
19 Mar

CERN CERN
Great performance last weekend from #LHC, now running with 136 bunches. 2011 data set already approaching 1/5 the total achieved in 2010.
21 Mar

CERN CERN
#LHC sets new luminosity record of over 2.5x10^32 - peak in 2010 was 2.0x10^32. What does it mean? More data more quickly...

CERN CERN
It's a year to the day since the #LHC research programme got underway: http://ow.ly/4pDwV
30 Mar


LHC Page1
Fill: 1613
E: 3500 GeV
13-03-2011 18:06:01
PROTON PHYSICS: STABLE BEAMS

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PROTON PHYSICS: STABLE BEAMS

CERN CERN

LHC topped 1000 bunches and 10^14 particles per beam for the first time over the weekend.

11 Apr

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PROTON PHYSICS: STABLE BEAMS

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11 Apr

CERN CERN

#LHC now running with 336 bunches of particles per beam

16 Apr

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LHC sets world record beam intensity http://bit.ly/dPR3CB
22 Apr

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PROTON PHYSICS: STABLE BEAMS

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CERN CERN
#LHC now running with 624 bunches per beam. Data flowing...
27 Apr

LHC Page1 Fill: 1613 E: 3500 GeV 13-03-2011 18:06:01

PROTON PHYSICS: STABLE BEAMS

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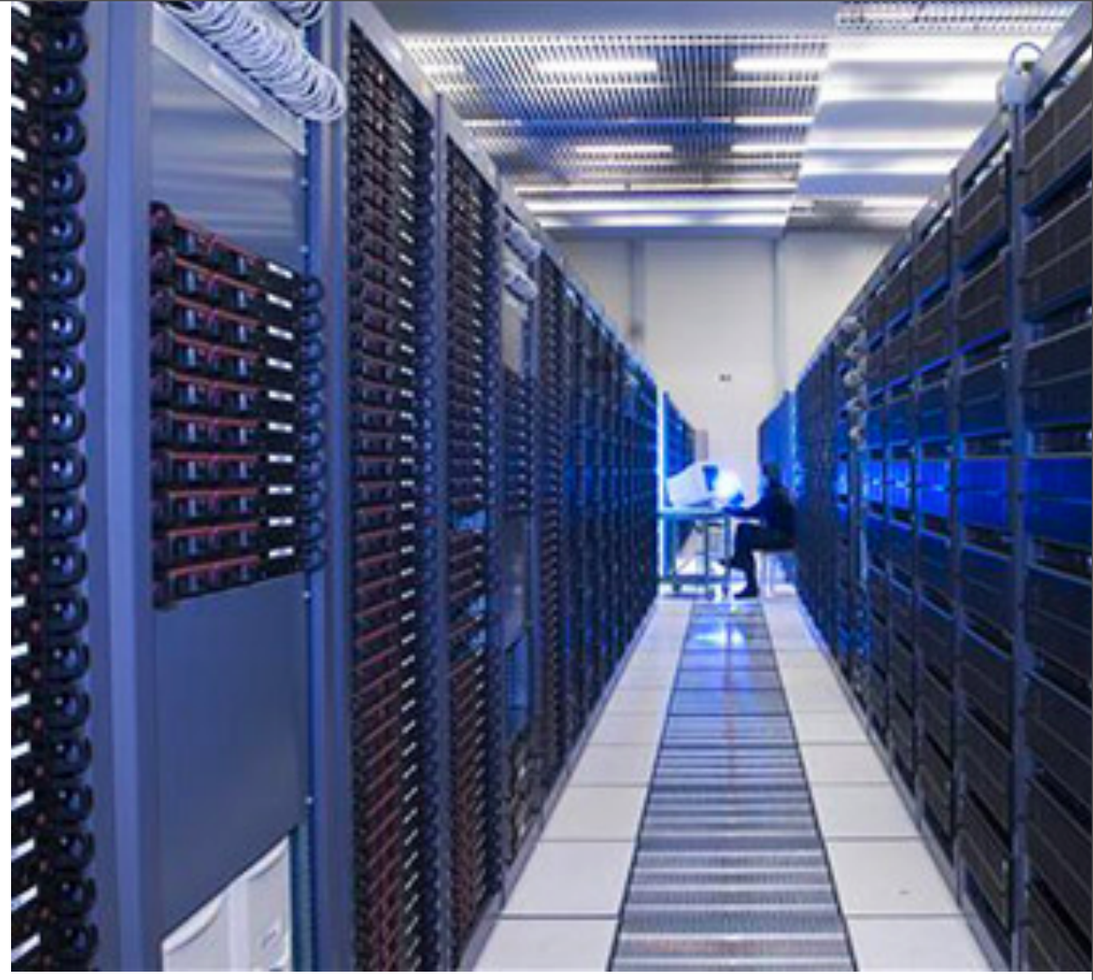
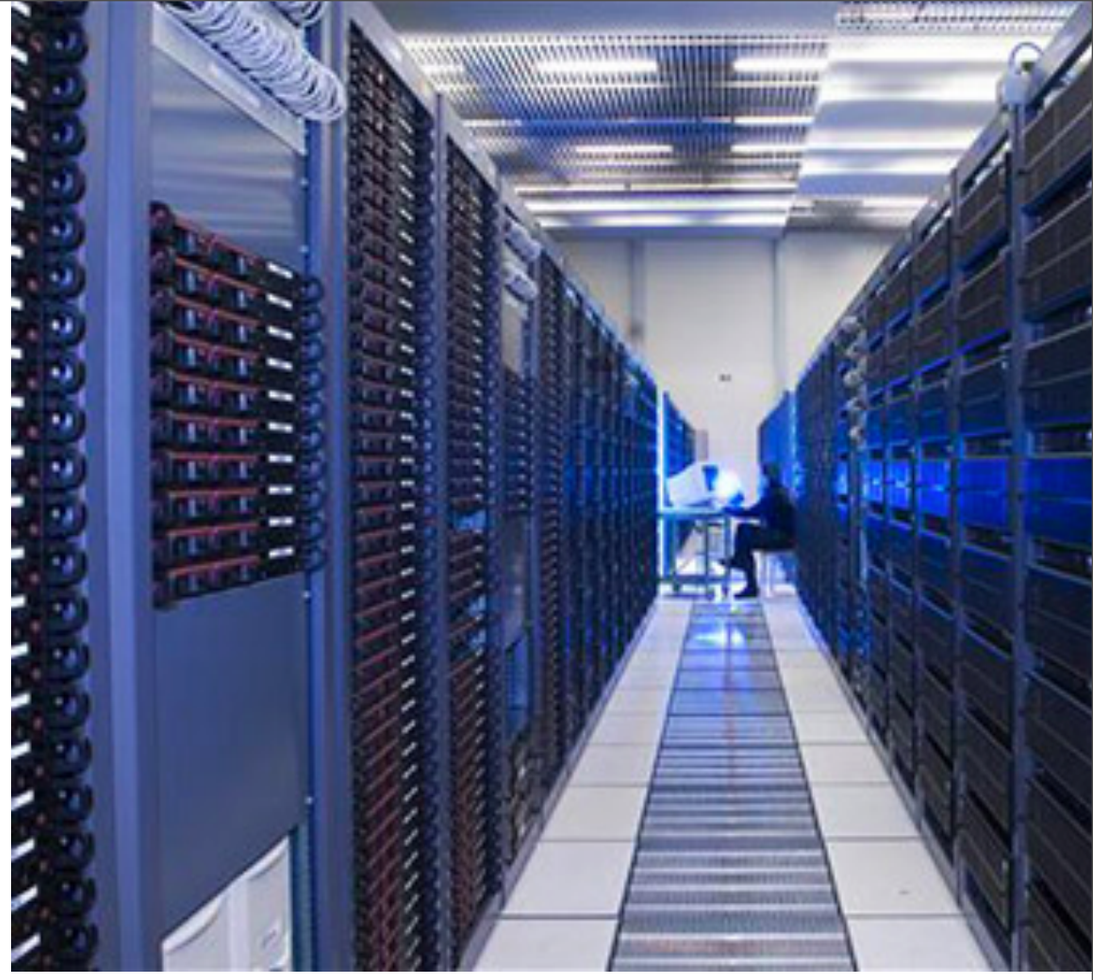
CMS data rate

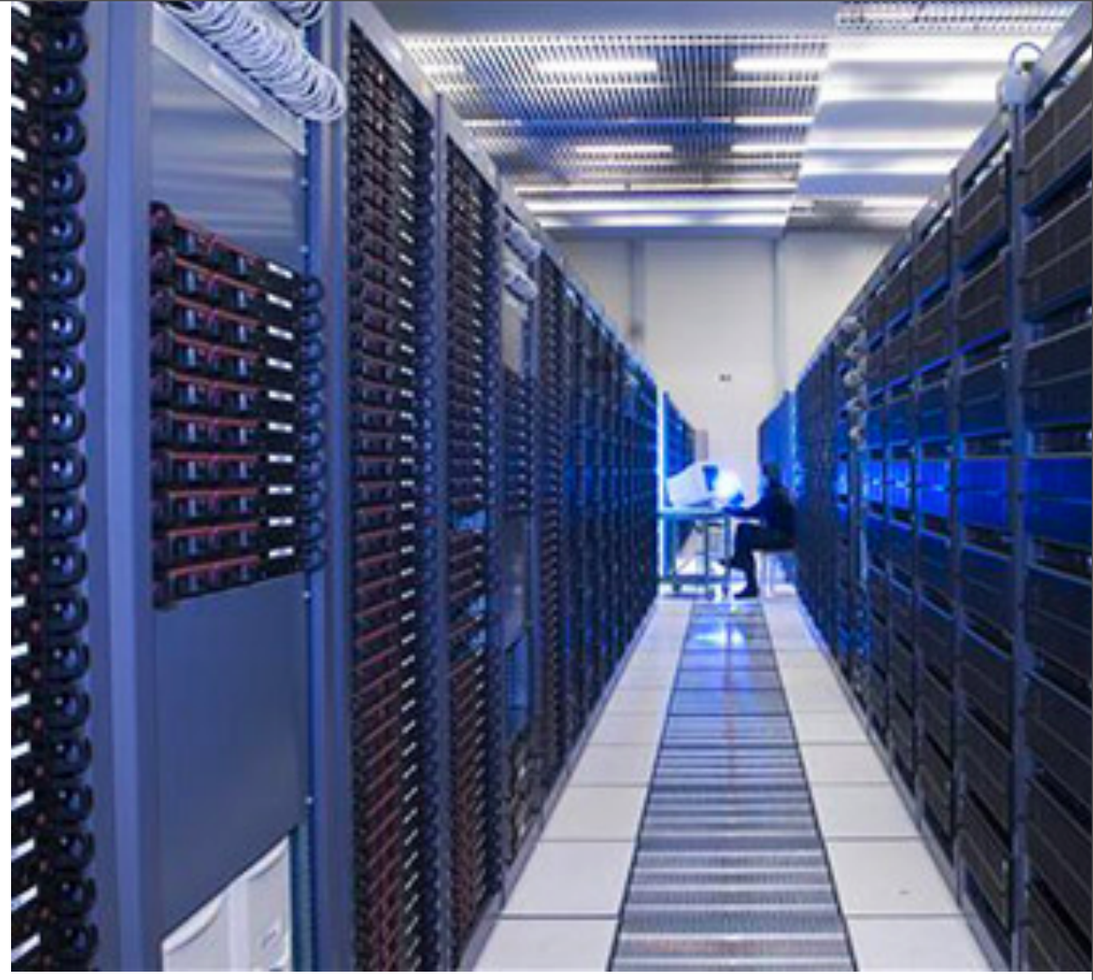


CMS data rate



- The raw data rate is 100 million channels divided by 25 nanoseconds = 1 Petabyte/second

CMS data rate



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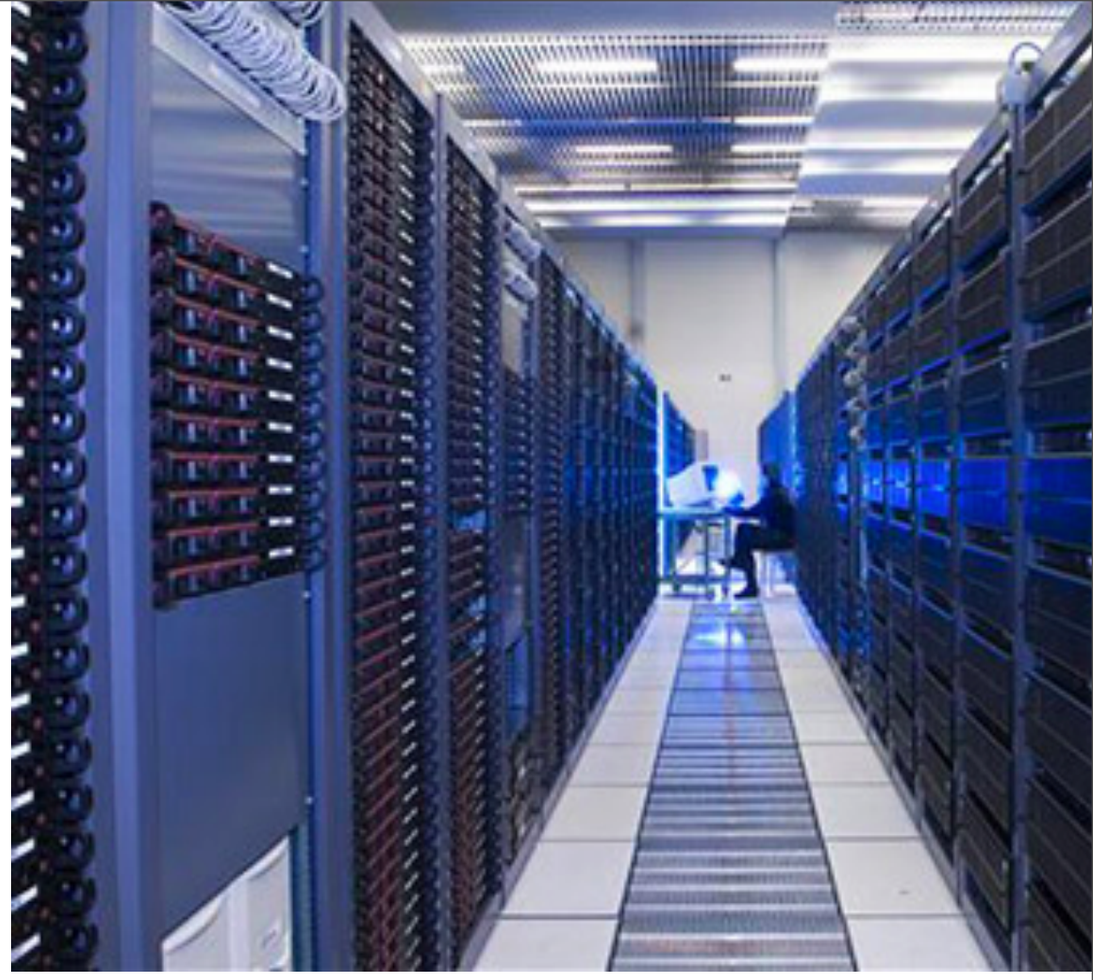
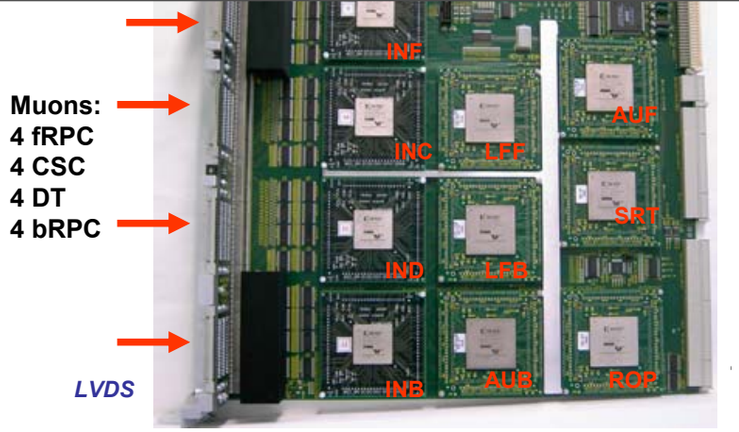
CMS data rate



- The raw data rate is 100 million channels divided by 25 nanoseconds = 1 Petabyte/second
- Compare this to total global WWW traffic = 5 Terabytes/sec
- Compare this data load to Google, which processes 20 Petabytes per day
- Houston, we have a problem

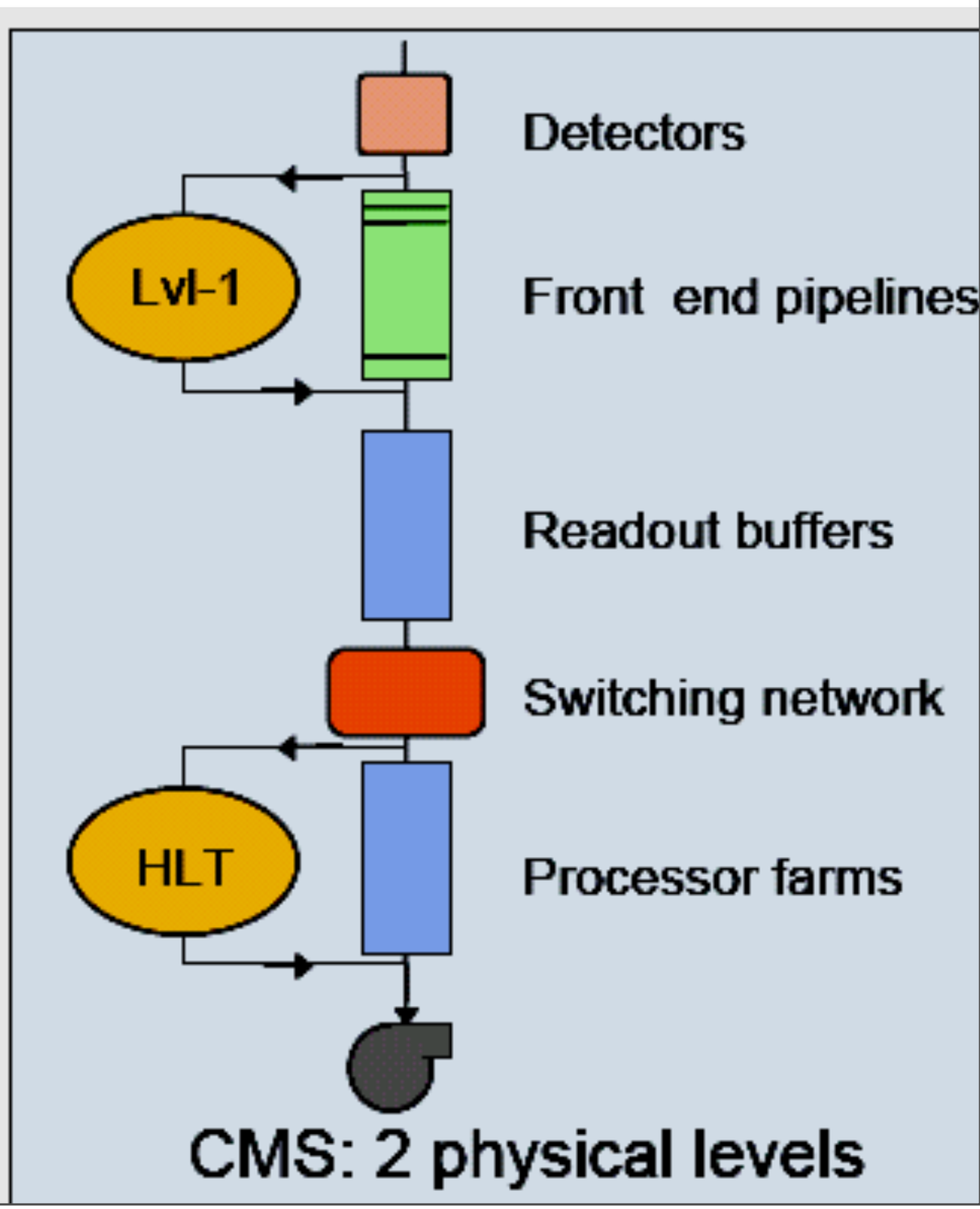


Global Muon Trigger GMT

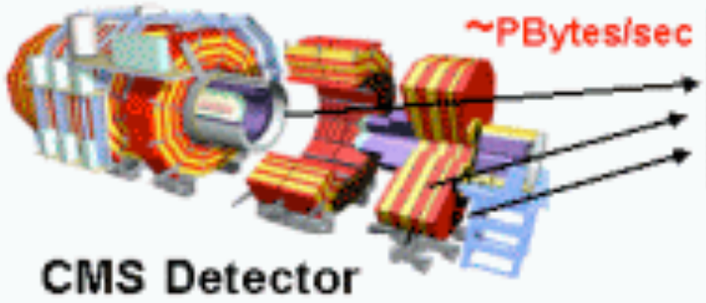
IN chips: LVDS Receiver: 512 bits / 40 MHz
PHASE + BC synchronization
Spy mem, Ringbuffers + FIFOs
LFF/LFB: find matching muons, cancel out logic
order by rank, 1st-sorter stage
AUF/AUB: assign MIP+ISO bits
SRT: Final Sorter, Ringbuffers + FIFOs
ROP: VME decoding, Readout processor

CMS Trigger System

- The Level One trigger uses fast FPGA firmware and selects, on average, one event in 500 for further processing
- Of these, the HLT software triggers in a 1000 node farm select, on average, one event per 200
- ~300 events per second are saved, the rest are gone forever



LHC/CMS Tiered Data System



CMS Detector

~PBytes/sec

Online System
Reconstruction Farm

~0.15/1.5 GBps

Tier 0

CERN Center

>10-40 Gbps

Tier 1

IN2P3 | RAL | INFN | FNAL | ...

~10 Gbps

Tier 2

Physics data cache

Caltech | ue | in | raska | UCSD | ...

~2.5-10 Gbps

Tier 3

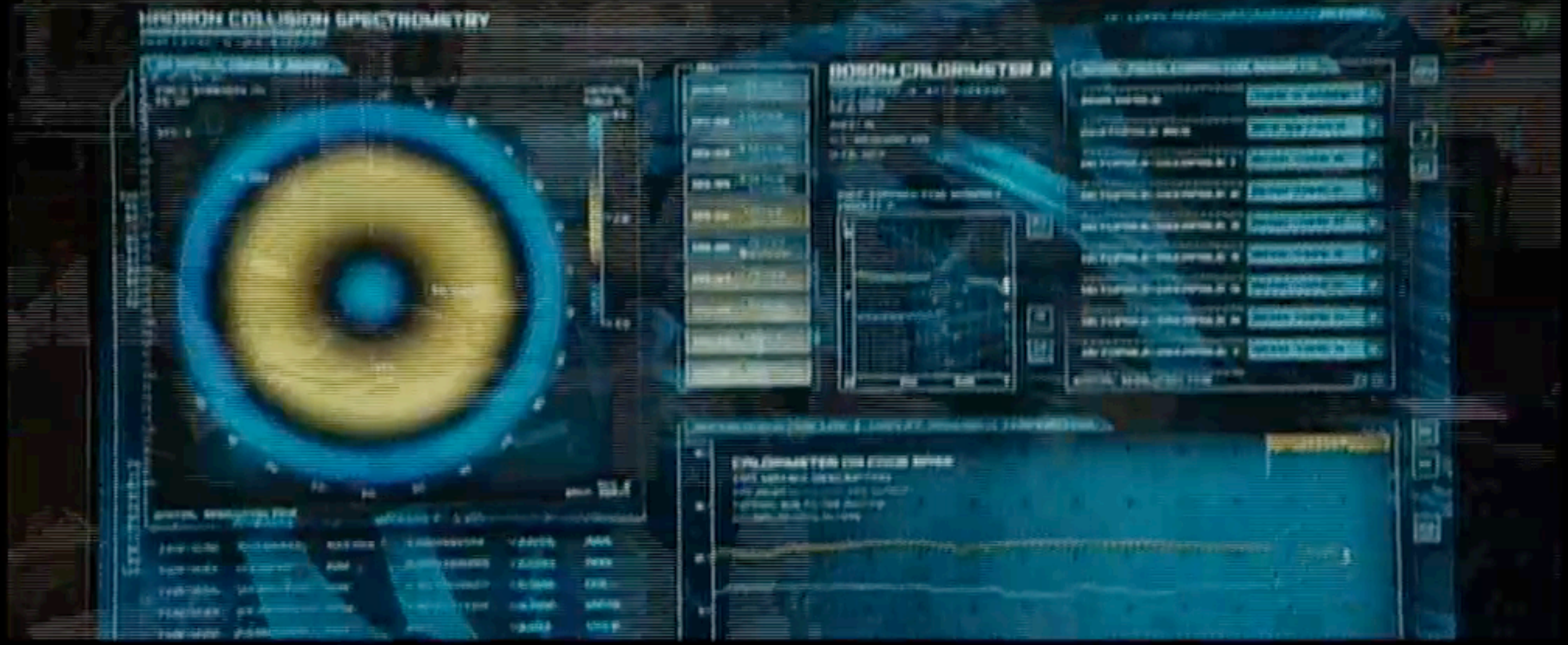
Institute | Institute | Institute | Institute

~0.1-10 Gbps

Tier 4

Physicists' Computers

- ~ 2500 Physicists, ~40 Countries
- ~ Tens of PetaBytes per Year
- ~ ExaBytes in ~ 10 Years


HIGGS COLLISION SPECTROMETRY
HIGGS CALORIMETER II


ANGELS&DEMONS
MAY 2009
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Dipôle