The CMS Experiment
The First Year of Physics

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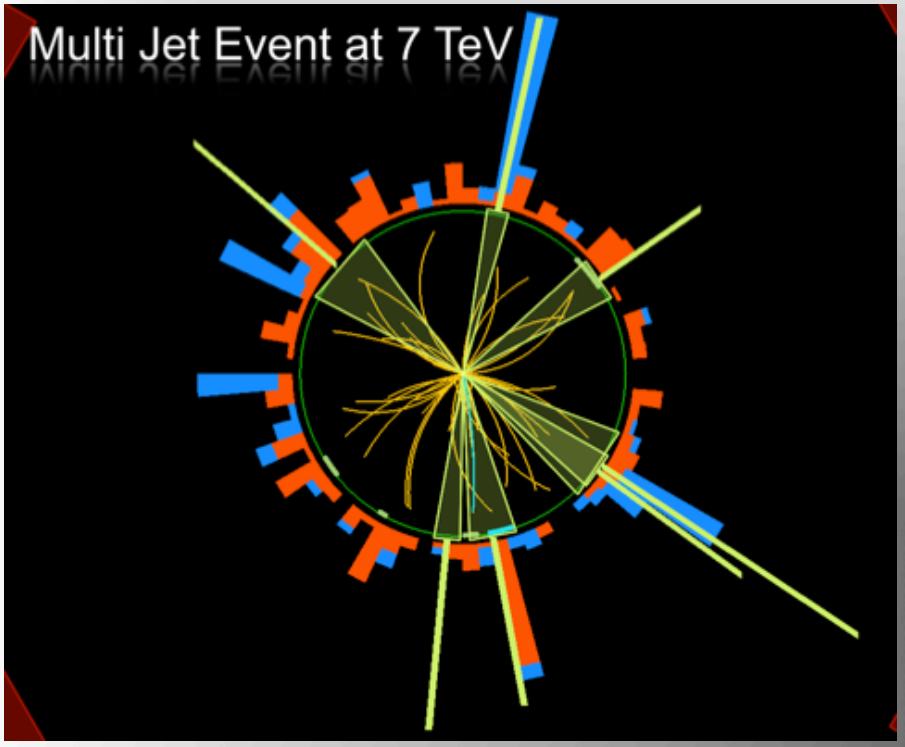
2011中華民國物理年會暨成果發表會

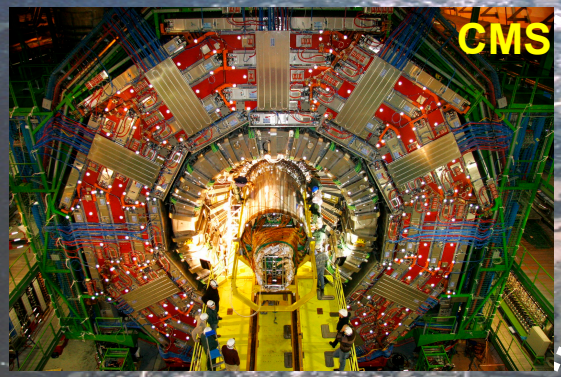


Outline

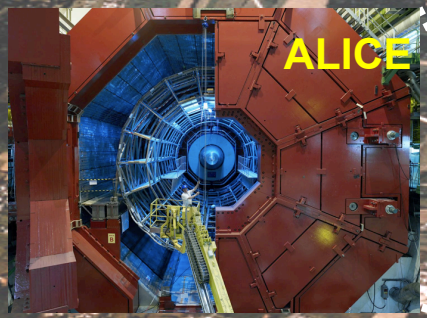
- Introduction
- LHC & CMS Operations
- CMS Performance
- Physics results at 7 TeV
- Summary & outlook for 2011

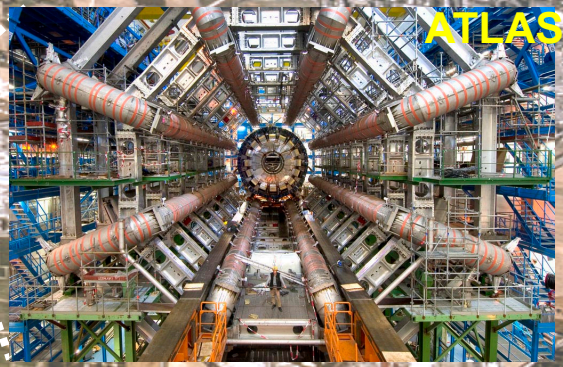
With LHC we are entering a New Era in Fundamental Science

The Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is a turning point in modern physics.



The exploration of a new energy frontier just started
pp collisions at a centre of mass energy of 7 TeV



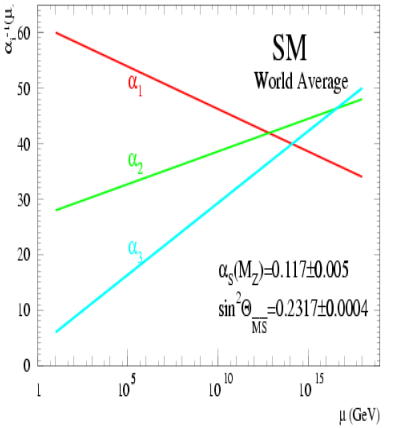


Physics case for new High Energy Machines

Understand the mechanism Electroweak Symmetry Breaking

Discover physics beyond the Standard Model

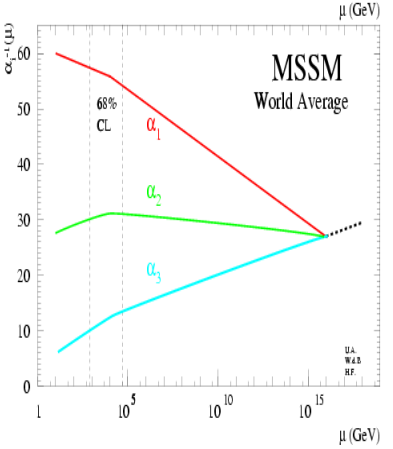
Reminder: The Standard Model
- tells us how but not why
  3 flavour families? Mass spectra? Hierarchy?
- needs fine tuning of parameters to level of 10^{-30} !
- has no connection with gravity. Dark matter, energy?
- no unification of the forces at high energy



SM

Most popular extensions these days

If a Higgs field exists:
- Supersymmetry
- Extra space dimensions



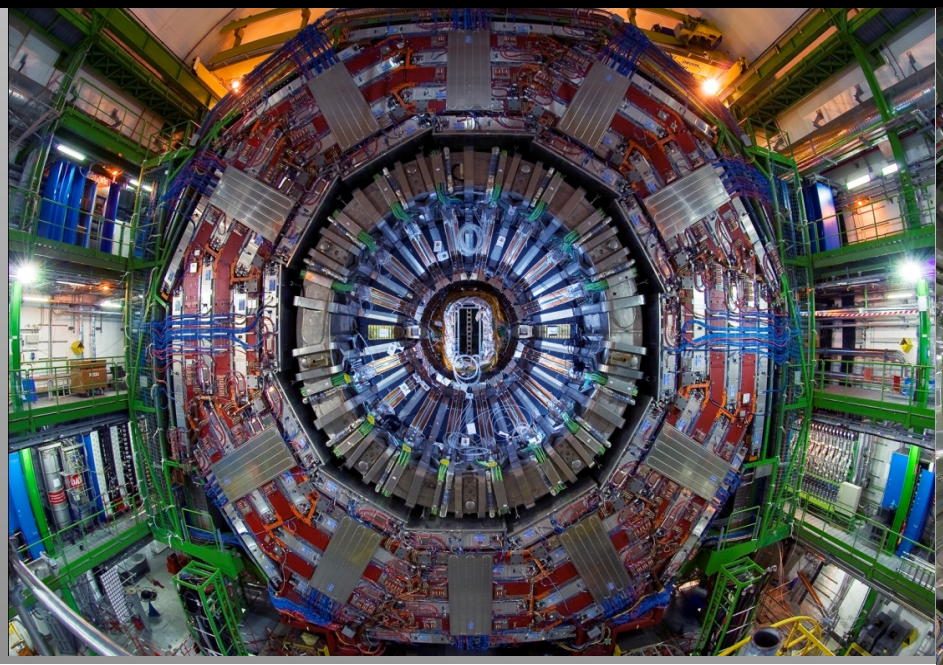
JST

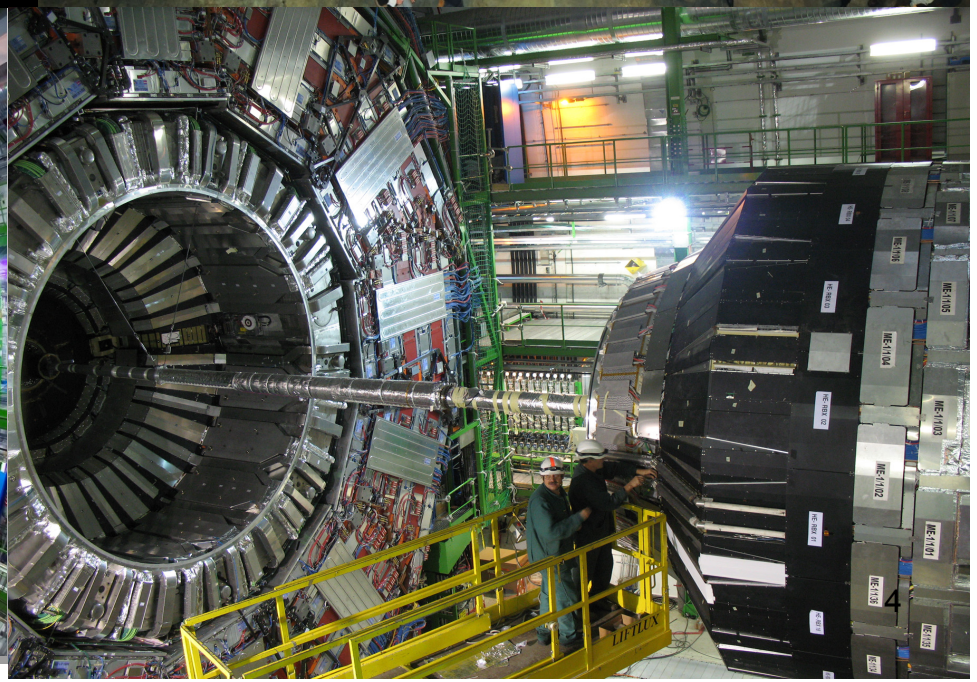
If there is no Higgs below ~ 700 GeV
- Strong electroweak symmetry breaking around 1 TeV

Other ideas: more gauge bosons/quark & lepton substructure,
Little Higgs models, Technicolor, GUT...

The CMS Collaboration: >3170 scientists and engineers, >800 students from 182 Institutions in 39 countries .

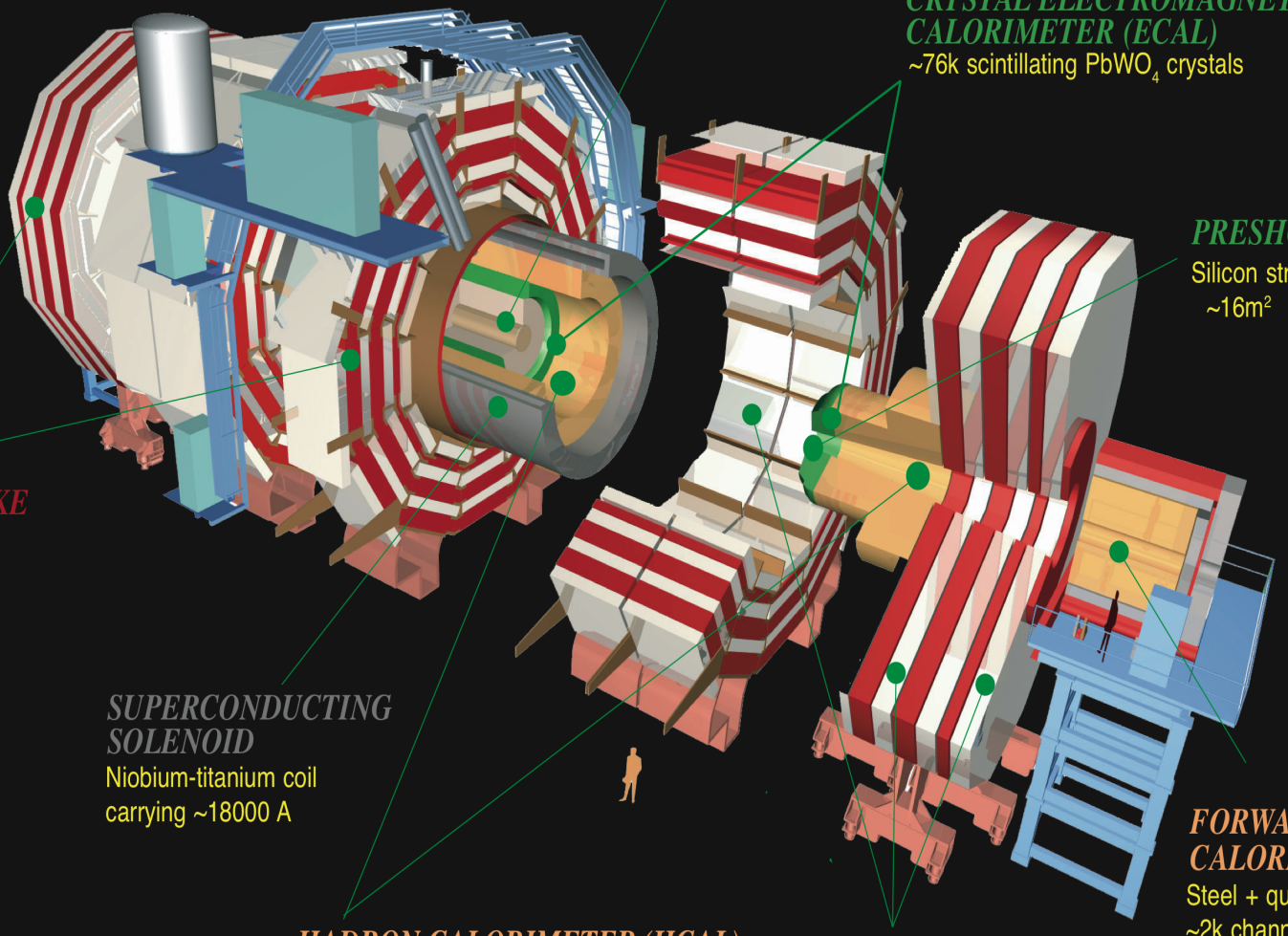
~ 1/4 of the people who made CMS possible





CMS Detector

Compact Muon Solenoid



SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating $PbWO_4$ crystals

PRESHOWER
Silicon strips
~16m² ~137k channels

STEEL RETURN YOKE
~13000 tonnes

SUPERCONDUCTING SOLENOID
Niobium-titanium coil
carrying ~18000 A

FORWARD CALORIMETER
Steel + quartz fibres
~2k channels

HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels

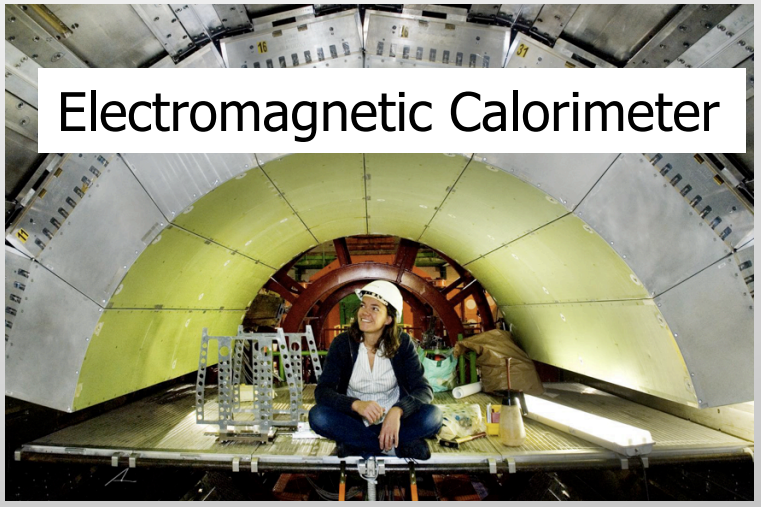
MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 473 Cathode Strip & 432 Resistive Plate Chambers

Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

A few Detector Pictures

Inner Tracker

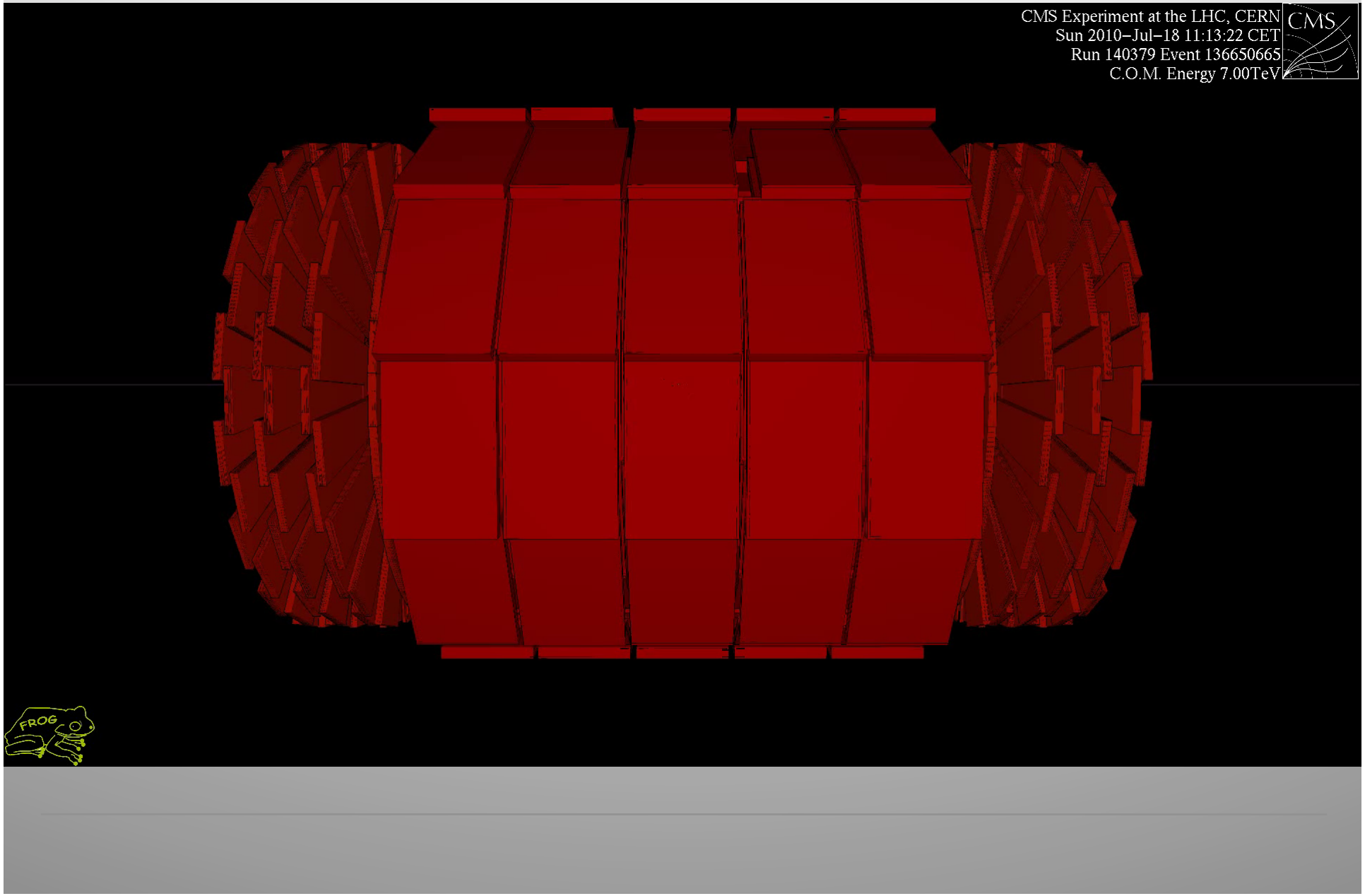
Electromagnetic Calorimeter



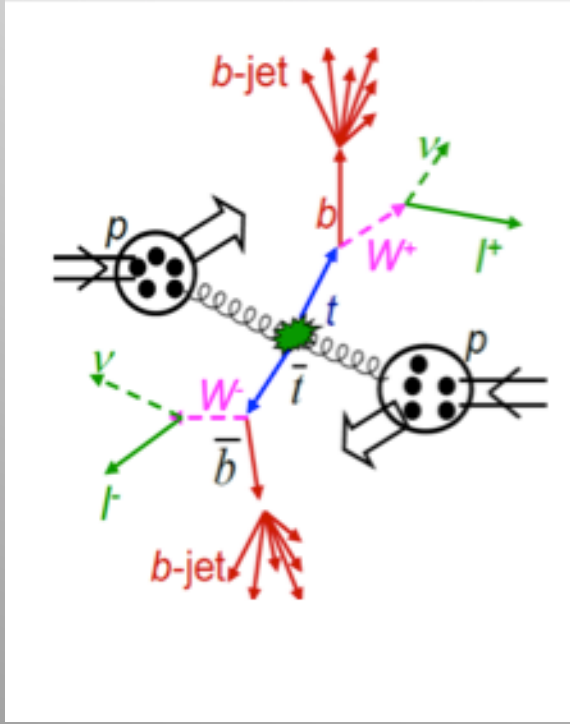
Hadronic Calorimeter

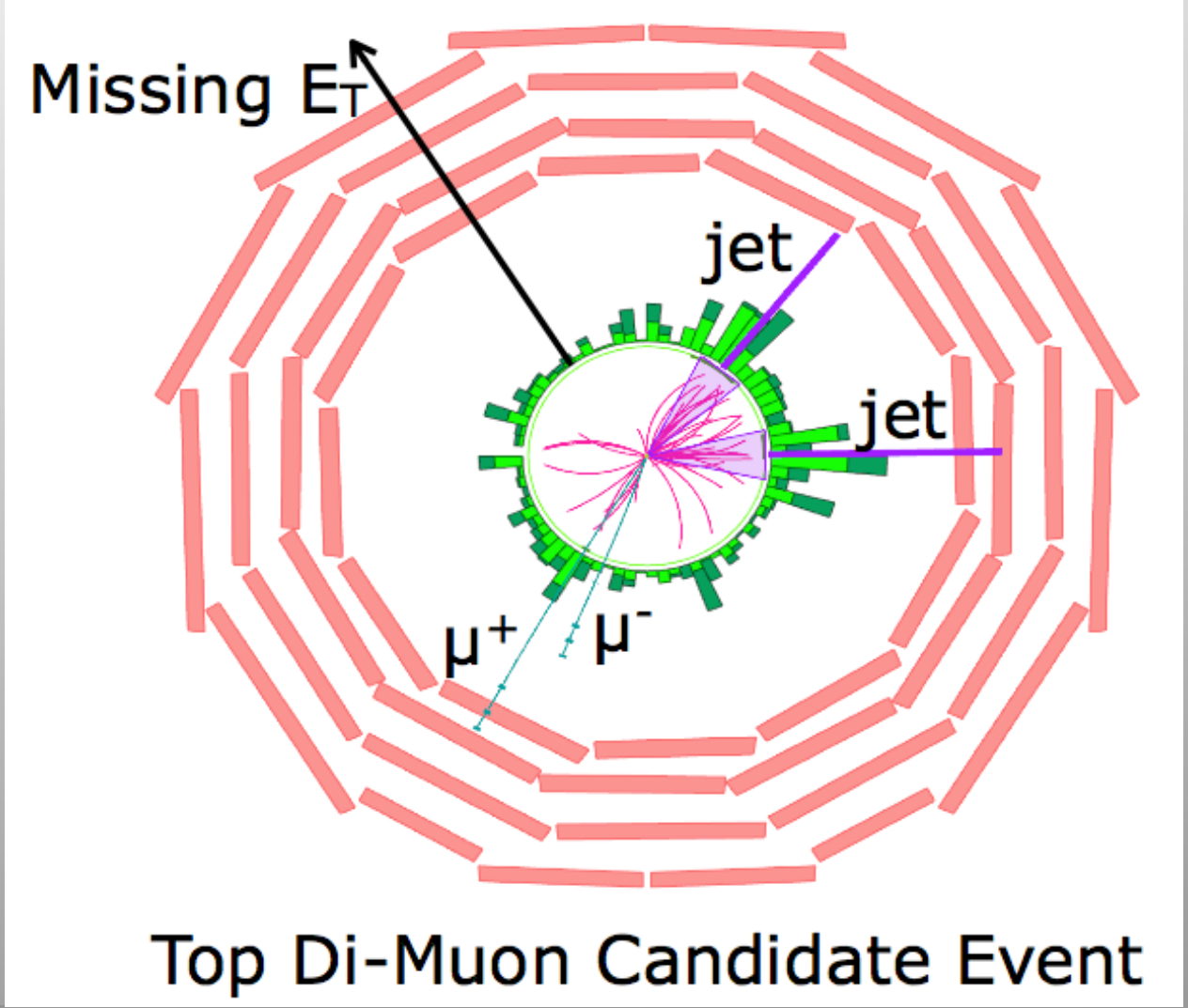
Muon Detectors

March 30: Start of the 7 TeV Run



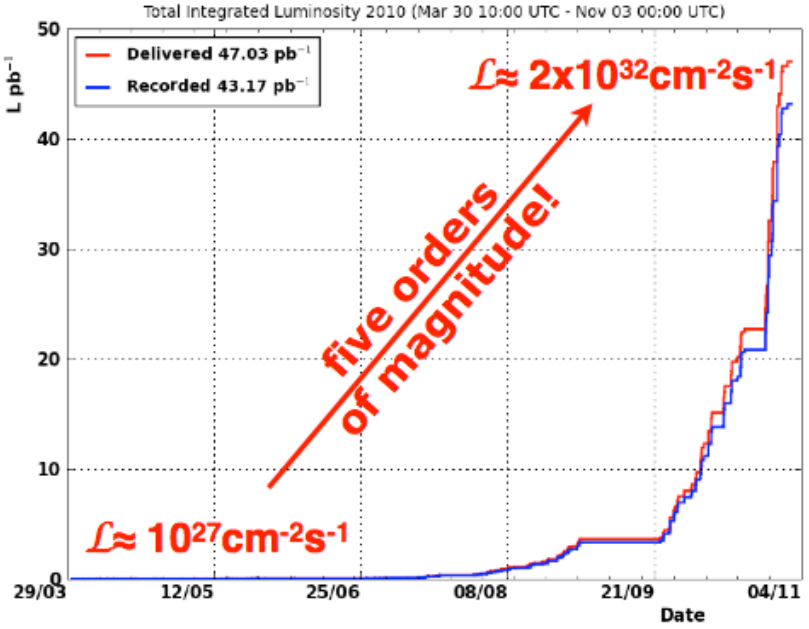
Candidate Event for Top Production

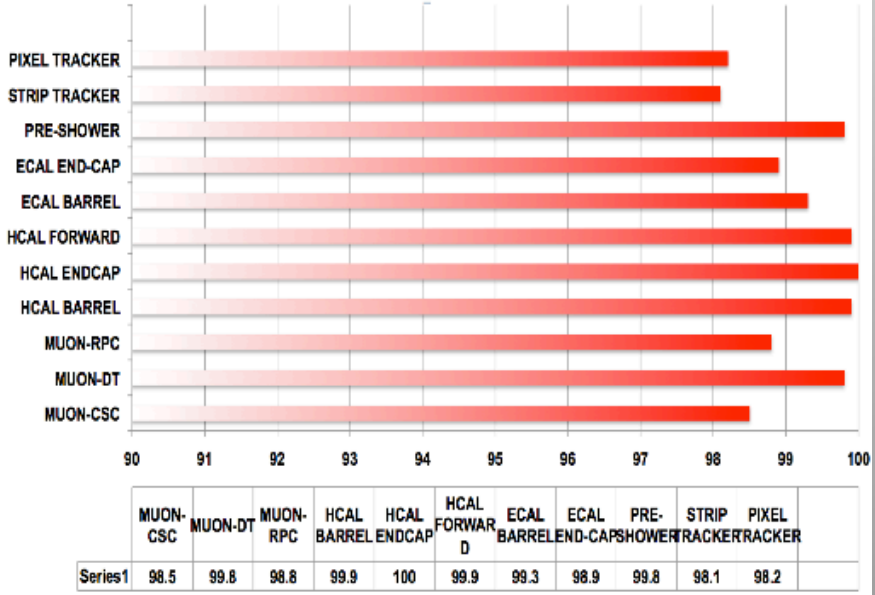




2010: Luminosity and Operation

- ~47pb^{-1} delivered by LHC and ~43pb^{-1} collected by CMS (ε≈92%)
- Average fraction of operational channels per CMS sub-system >99%
- Good performance, handled increase of more than 5 orders of magnitude in instantaneous luminosity over 7 months!

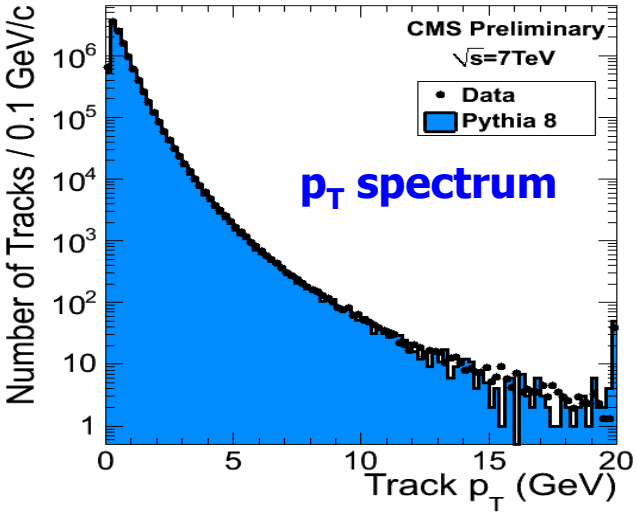


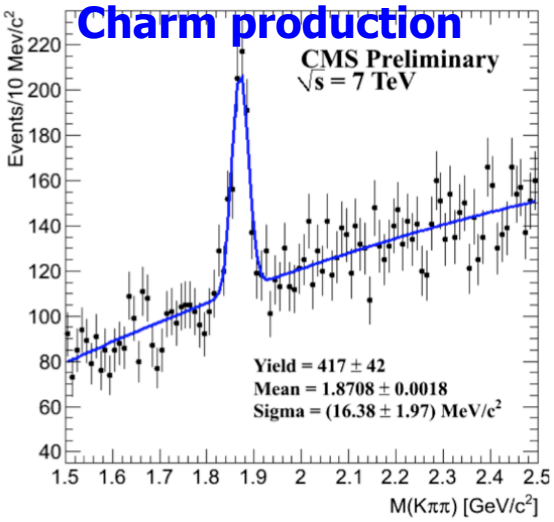


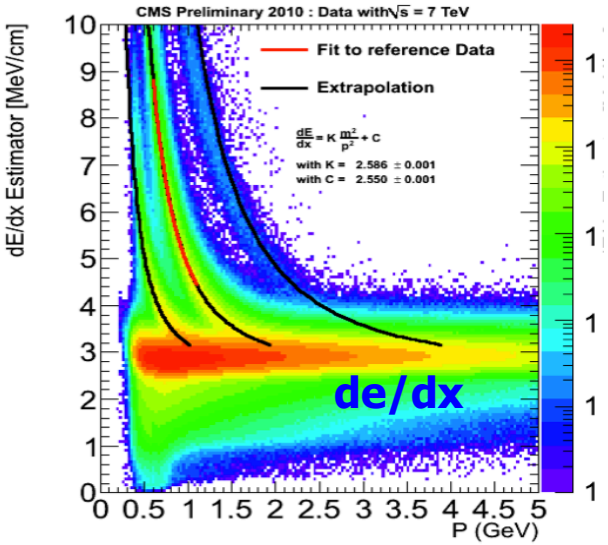
	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2

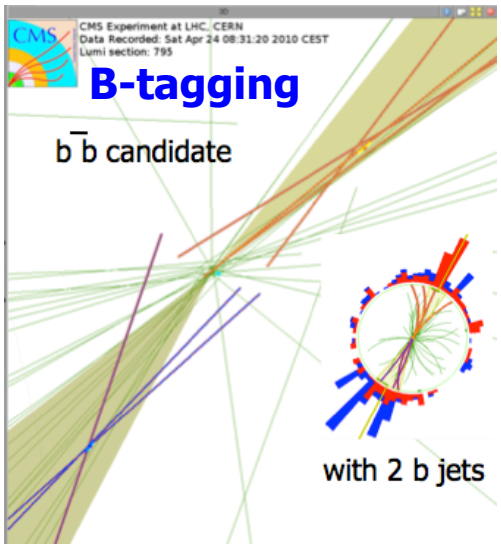
- Max instanteneous luminosity now ~ 2.04•10^{32}cm^{-2}s^{-1}
- The aim for this year was 10^{32}cm^{-2}s^{-1}…

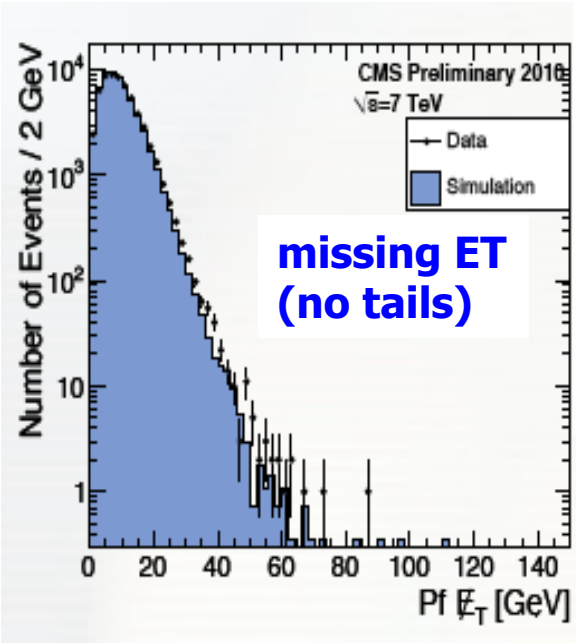
Detector Performance: Tracks & Jets

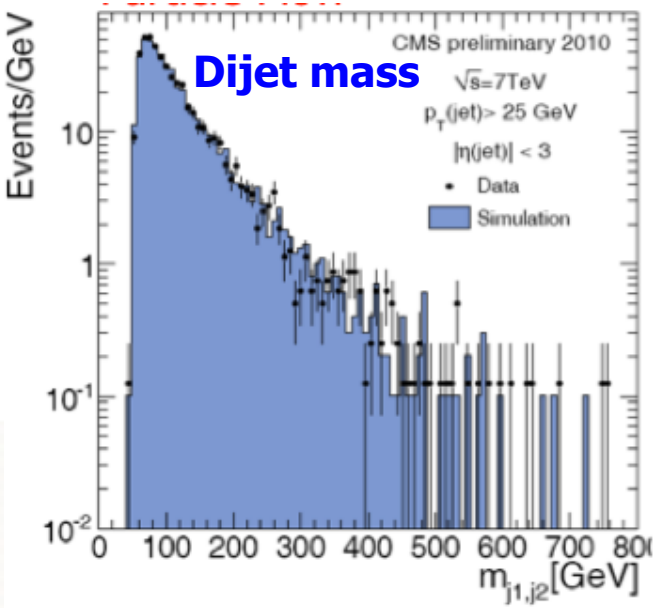




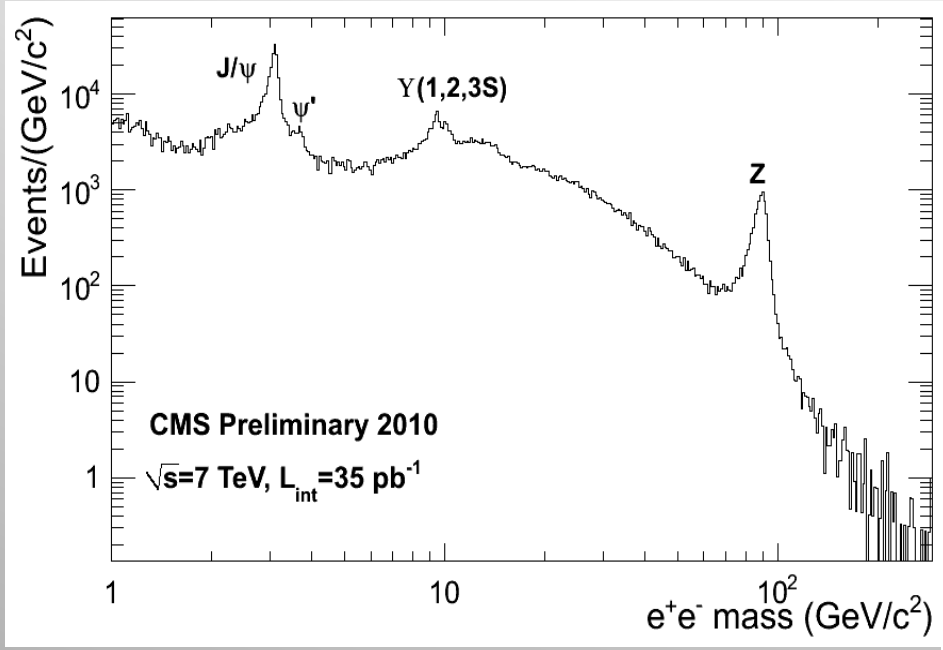




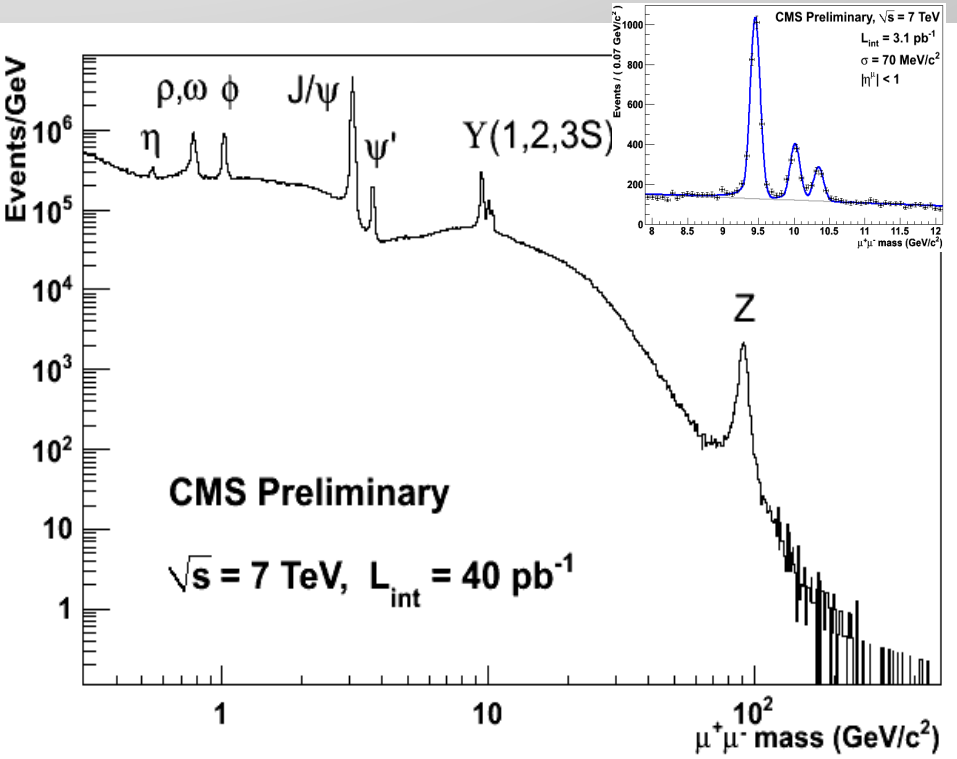




Re-discovery of Standard Model at 7 TeV



Di-electron and di-muon invariant mass spectra



The CMS detector works beautifully!!!

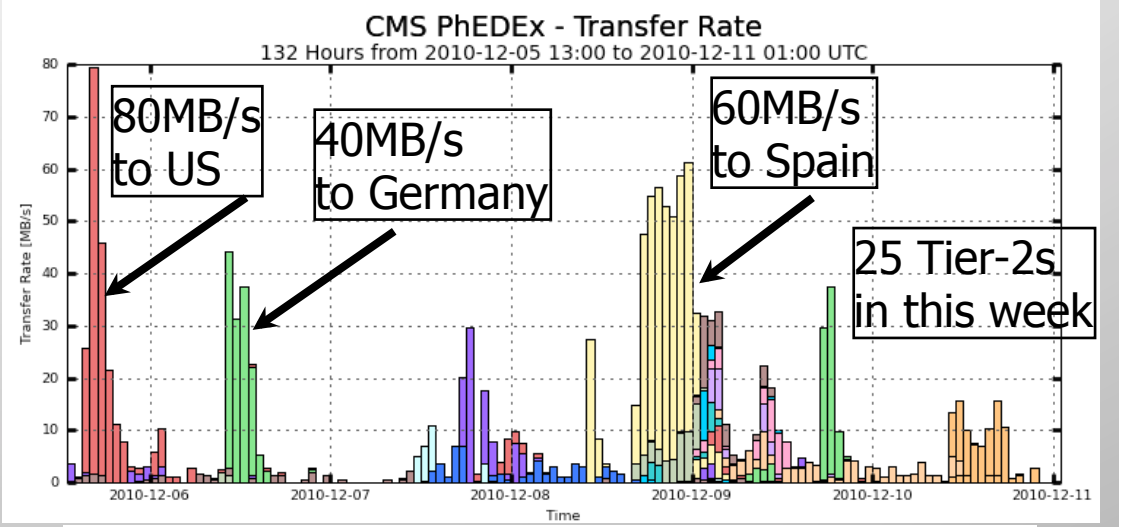
Taiwan @ CMS

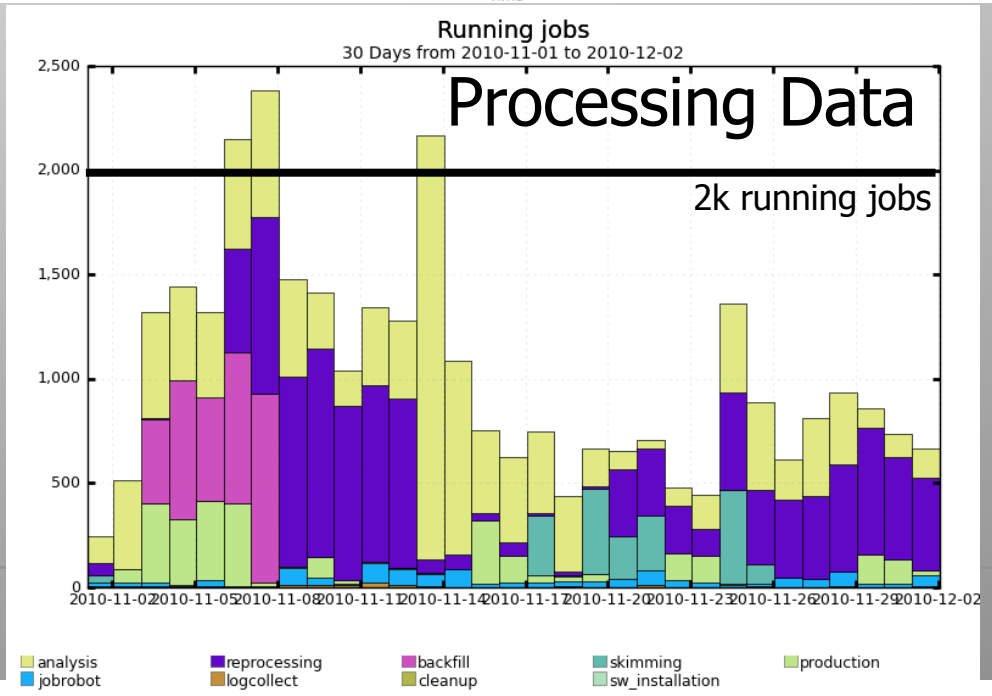
- Groups and contributions
  - National Taiwan University (NTU) (Team leader: George Wei-Shu Hou)
  - National Central University (NCU) (Team leader: Yuan-Hann Chang)
  - A Tier 1 center hosted by Academia Sinica Grid Center (ASGC).
  - About 10~14 people stationed at CERN for detector and other on-site work
- Hardware contributions:
  - Present detector: ECAL/Preshower. NTU produced all of the ES system motherboards and NCU handled 1/4 of the silicon sensors. Further assembly, testing, installation, integration, and software (DAQ/DQM/DB/ etc). Now performance studies (alignment, calibration, E/gamma objects)
  - CMS upgrade (2013-2020): Pixel upgrade work (in preparation)
- Physics contributions
  - QCD Underlying events:
  - EXO 4th generation
  - QCD photon:
  - E/gamma objects:
  - EWK Vgamma: Higgs->2gamma:

The Taiwan Tier1 in CMS

- In CMS each Tier-1 takes a share of the data
  - Served to Tier-2s for analysis
    - ASGC serving to Asia, Europe, and the US
  - Skimmed and reprocessed using Tier-1 Computing
    - Data stored on tape and reprocessed for analysis

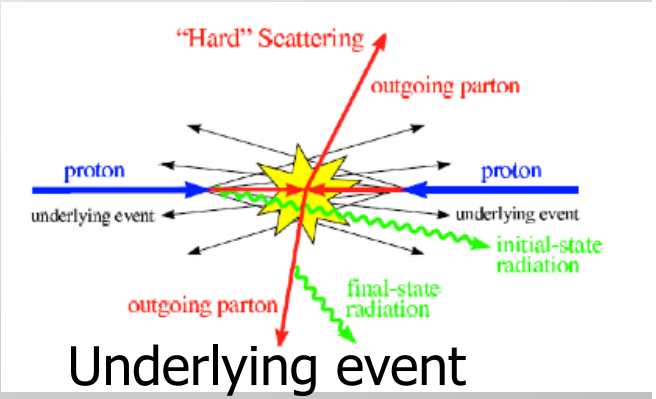
ASGC as a Source





Physics Results

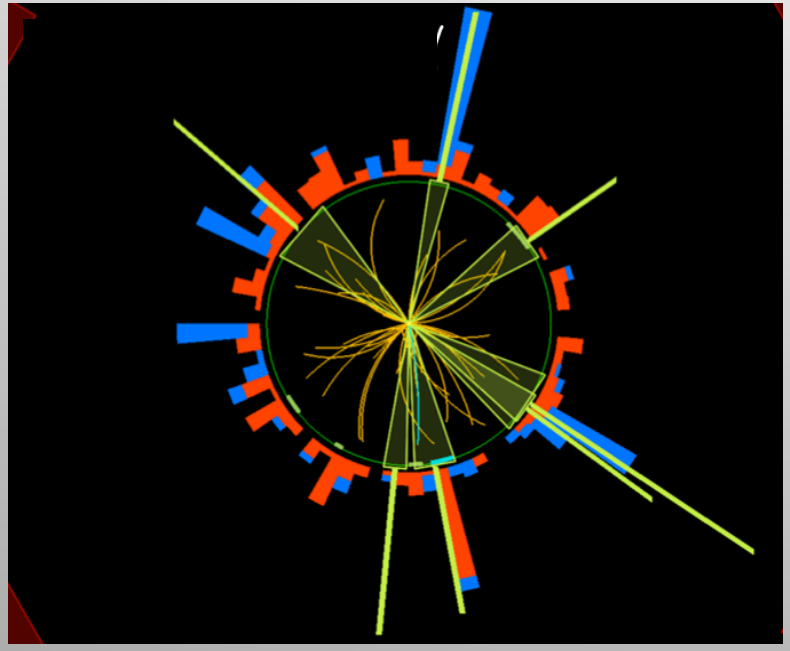
- Studies of general characteristics of minimum bias events (our future pile-up)
- Study of the underlying event in collisions with a hard scattering
- Jet physics & QCD
- B-physics
- W,Z boson production at 7 TeV
- Top at 7 TeV
- Searches for new physics
- New: Heavy Ion collisions at 2.76 TeV
- …



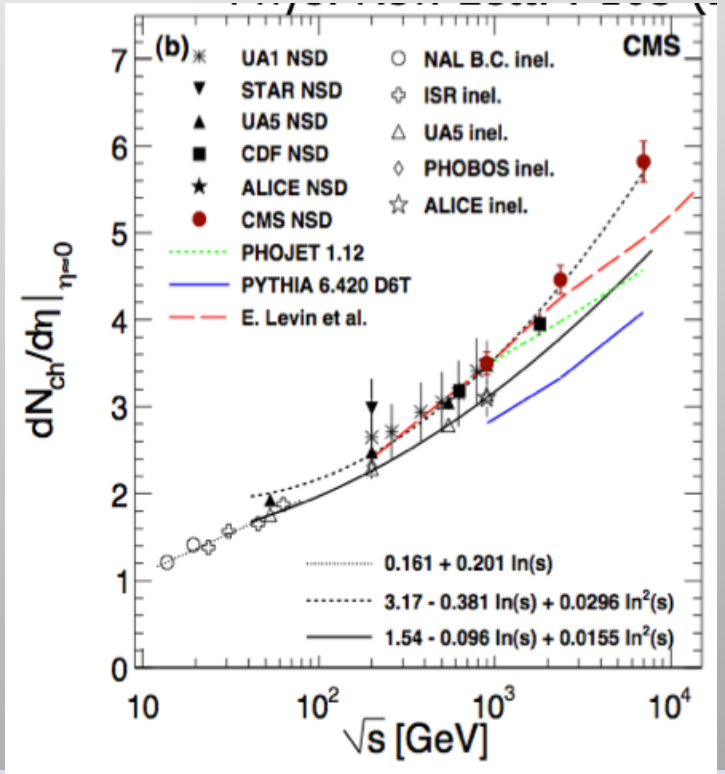
Underlying event

7 TeV Early Analysis

We also learn a lot of particle production at the highest energies!!



Phys. Rev. Lett. 105 (2010)



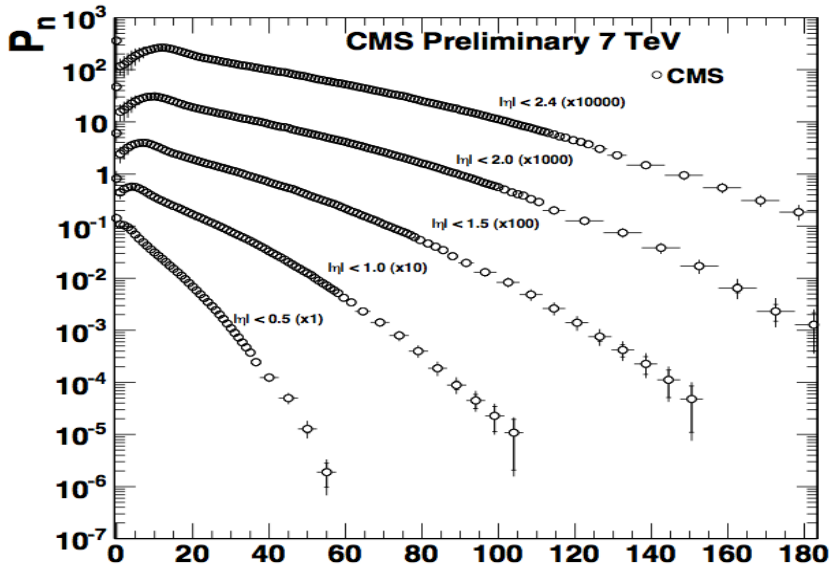
Measurement of the charged particle density in proton proton collisions at 7 TeV

Strong rise of the central particle density with energy

Multiplicity Distributions

Count the number of Charged particle particles in each proton-proton collision

- Minimum Bias event selection
- Unfolded charged particle multiplicity distributions (down to p_T = 0 GeV/c)
- <pT> versus multiplicity



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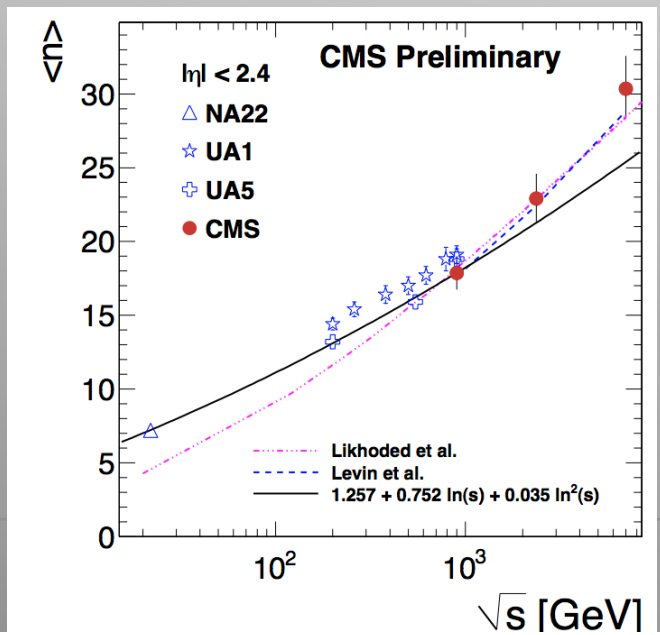
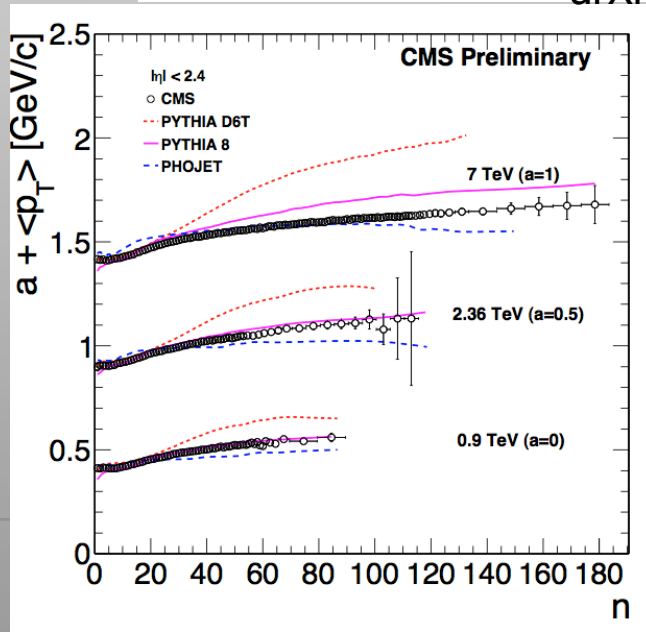




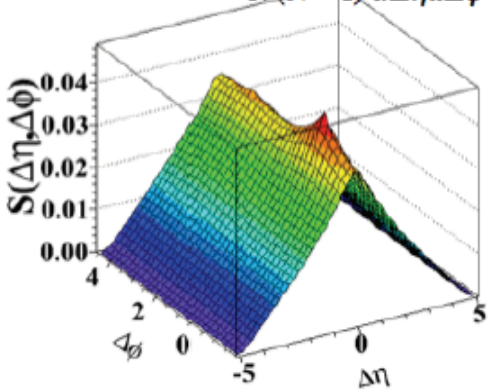
A challenge for the models…

Two Particle Correlations

Two particle angular correlations

Signal distribution:

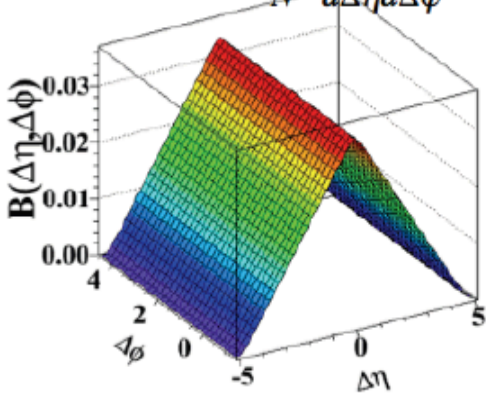
$$S_N(\Delta\eta,\Delta\varphi) = \frac{1}{N(N-1)}\frac{d^2N^{signal}}{d\Delta\eta d\Delta\varphi}$$



Same event pairs

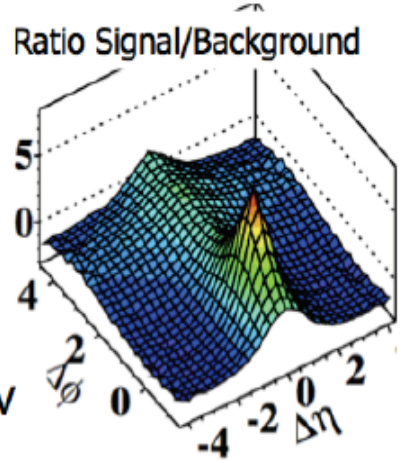
Background distribution:

$$B_N(\Delta\eta,\Delta\varphi) = \frac{1}{N^2}\frac{d^2N^{bkg}}{d\Delta\eta d\Delta\varphi}$$



Mixed event pairs

Ratio Signal/Background



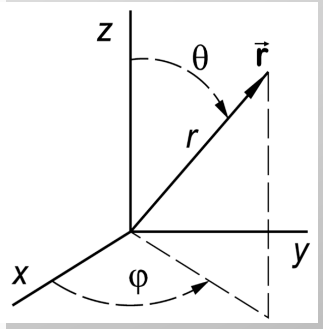
$$R(\Delta\eta,\Delta\varphi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)} - 1\right)\right\rangle_N$$

p_T-inclusive two-particle angular correlations in min bias collisions

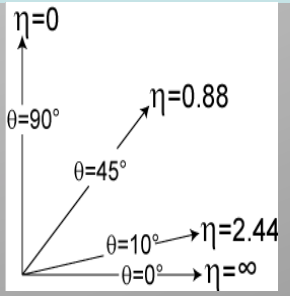
$\Delta\eta = \eta_1 - \eta_2$

$\Delta\varphi = \varphi_1 - \varphi_2$

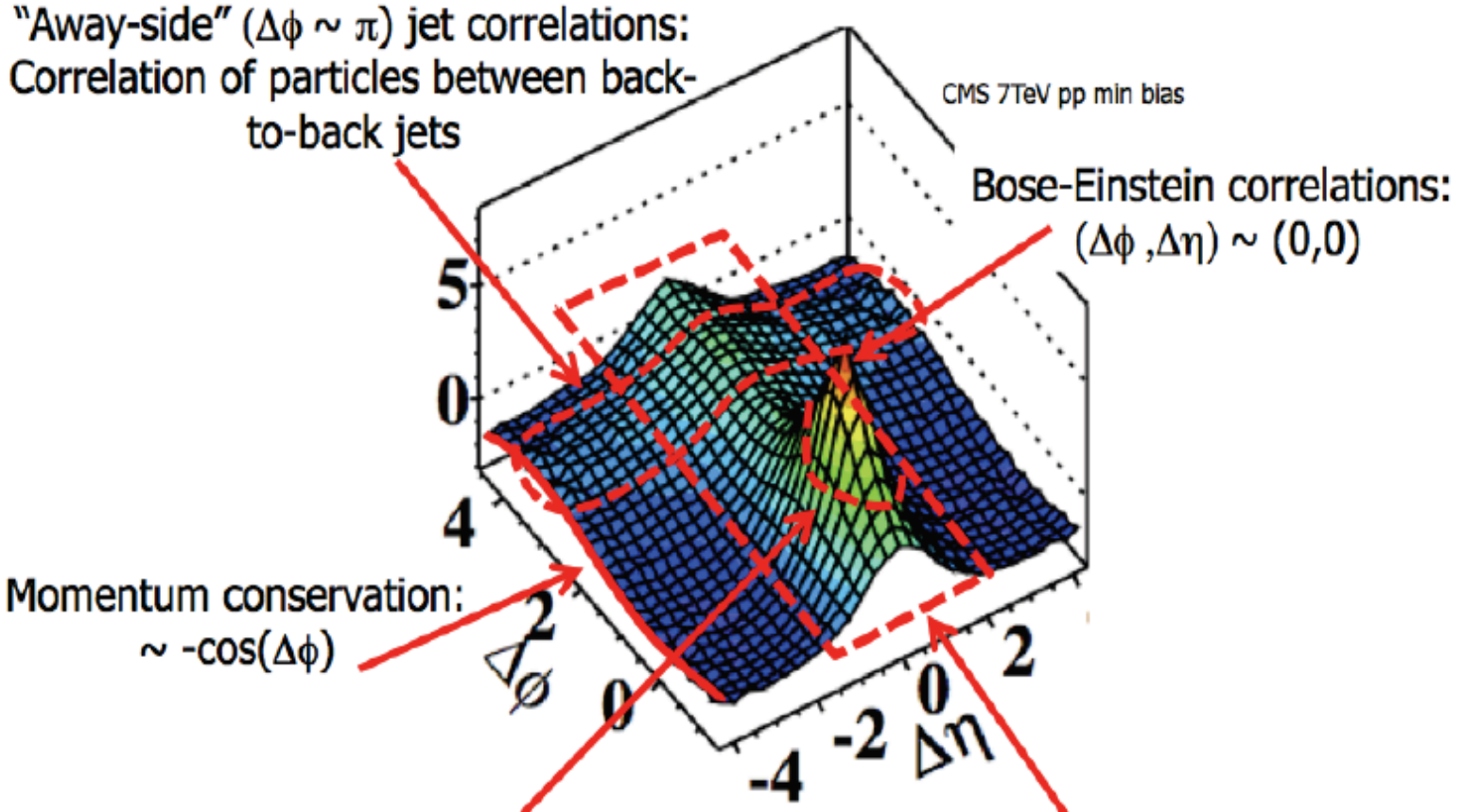
CMS pp 7TeV



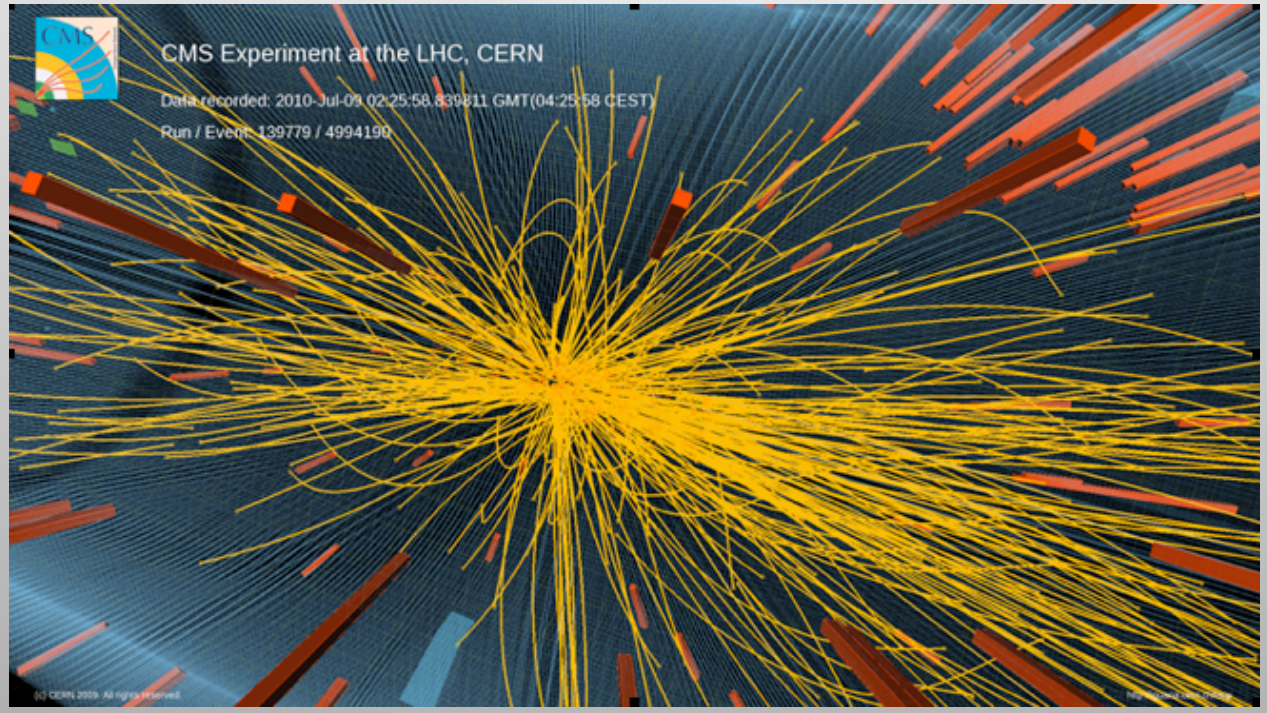
$\eta = -\ln \tan \theta/2$



Two Particle Correlations



…and correlations can be interesting ☺



Collisions at 7 TeV with very high charged particle multiplicity (> 100)

Two Particle Correlations

CMS Collab.. arXiv:1009.4122, accept. for publ. in JHEP!

Intermediate p_T: 1-3 GeV/c

MinBias

(b) MinBias, 1.0GeV/c<p_T<3.0GeV/c

high multiplicity (N>110)

(d) N>110, 1.0GeV/c<p_T<3.0GeV/c

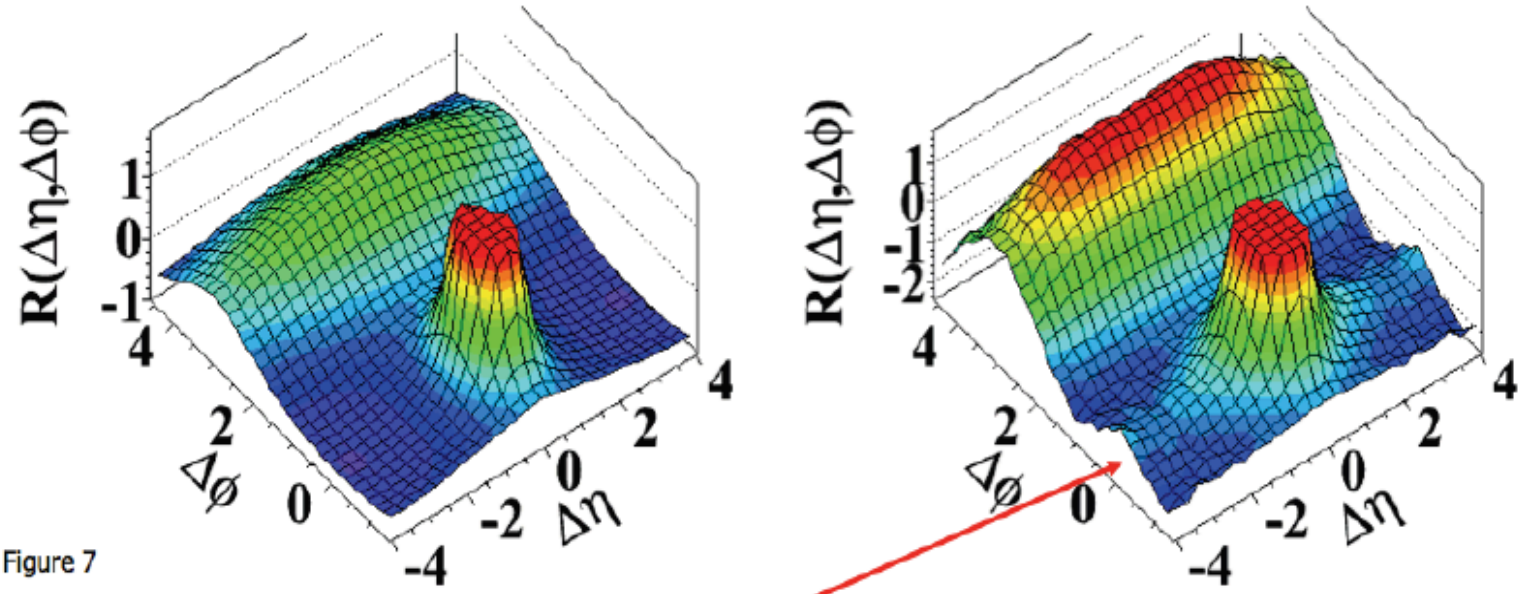
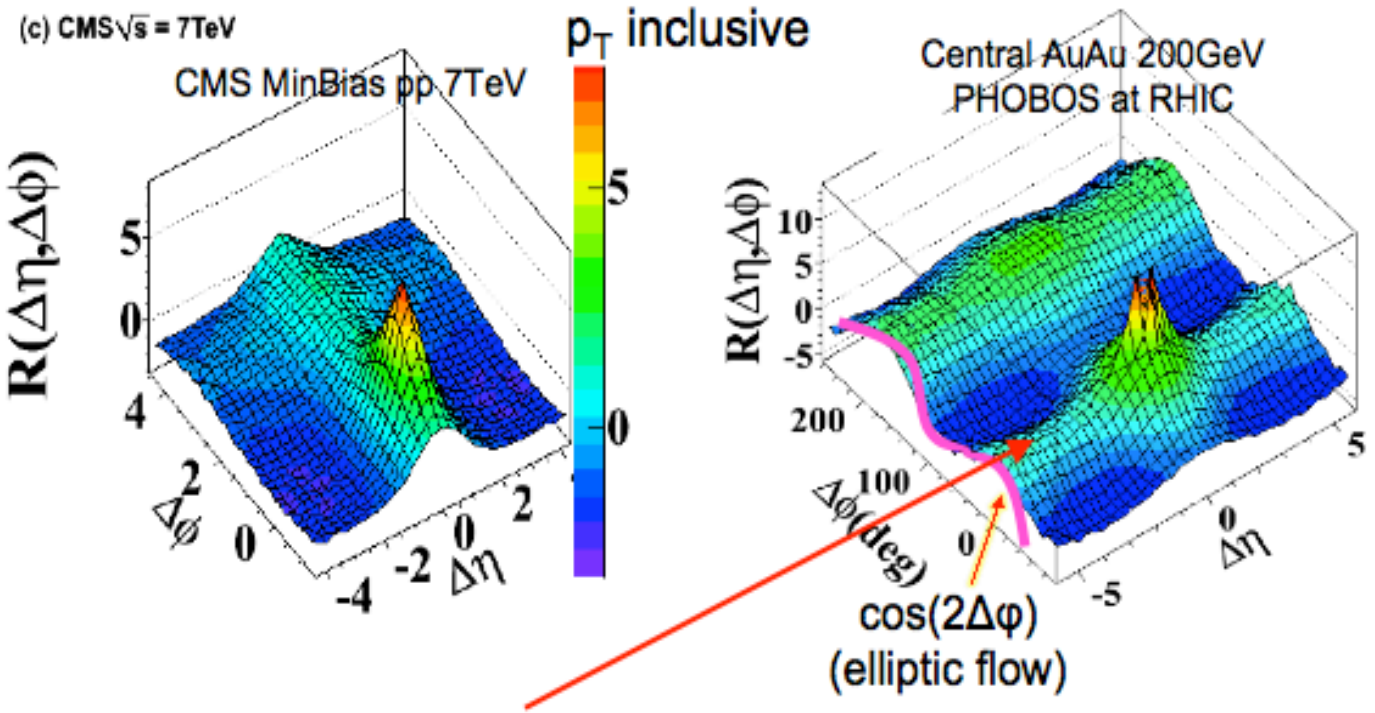


Figure 7

Pronounced structure at large δη around δφ ~ 0 !

A similar –stronger- effect has been observed in Heavy Ion collisions
The origin of the phenomenon is still unclear

Correlations in Heavy Ion Collisions



Long-range "Ridge"-like structure in Δη:

- Believed to be mainly hydrodynamic flow from "Perfect Liquid"
- Most important HI results in the past 10 years
- Several papers (exp. and theo.) with 400-700 citations

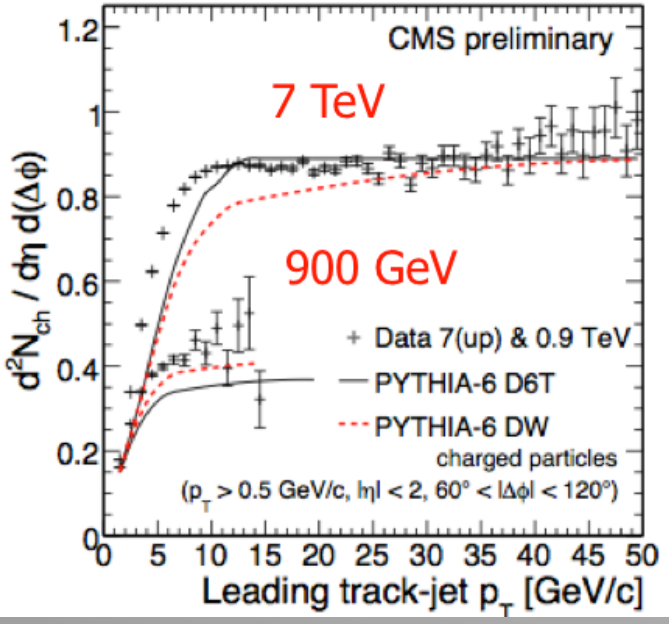
Similarity with the effect observed in pp
Origin of the phenomenon is still unclear

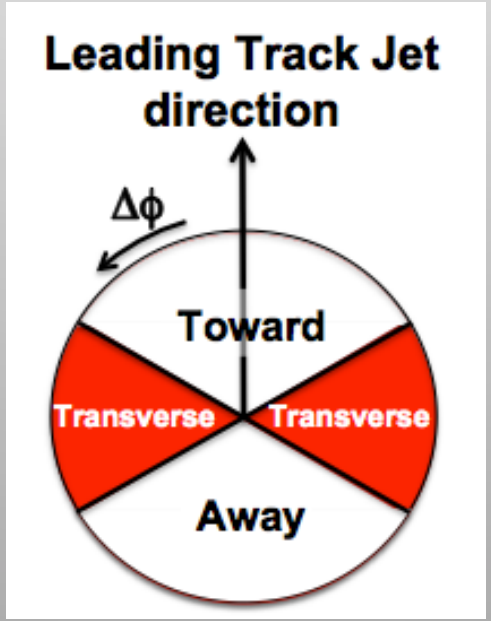
Underlying Event Studies

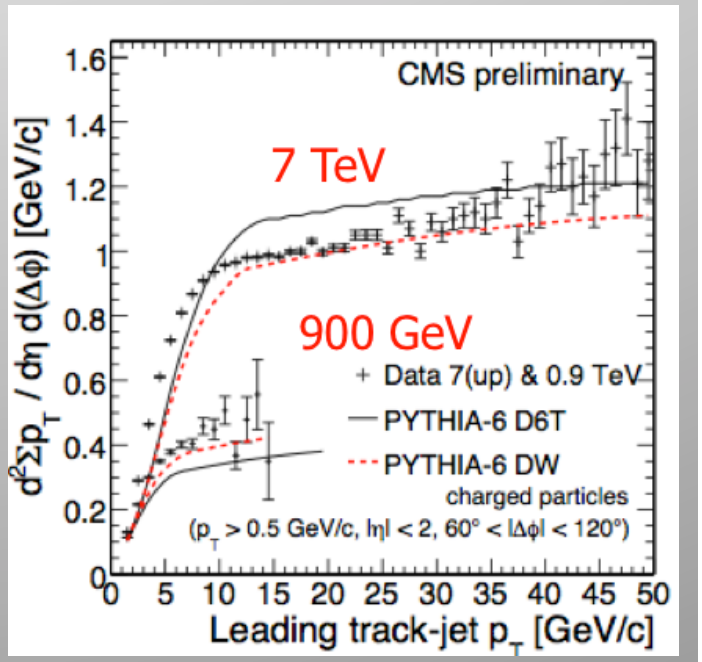
Underlying event activity at $\sqrt{s}$ = 0.9 and 7 TeV

- MinBias event selection, with additional requirement of a 'hard' scattering via a track jet with $p_T > 3$ GeV
- Study the particle density and scalar p_T sum in the transverse region, for particles with $|\eta| < 2$ and $p_T > 0.5$ GeV (uncorrected data)

- Study led by Taiwan Physicists

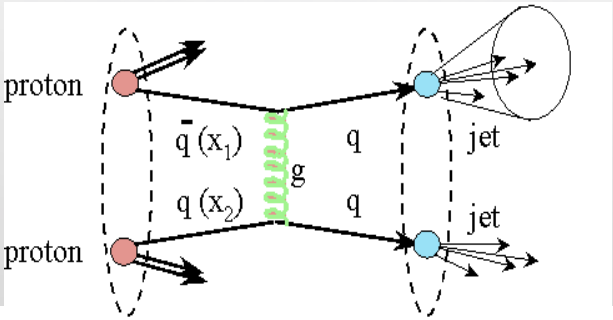




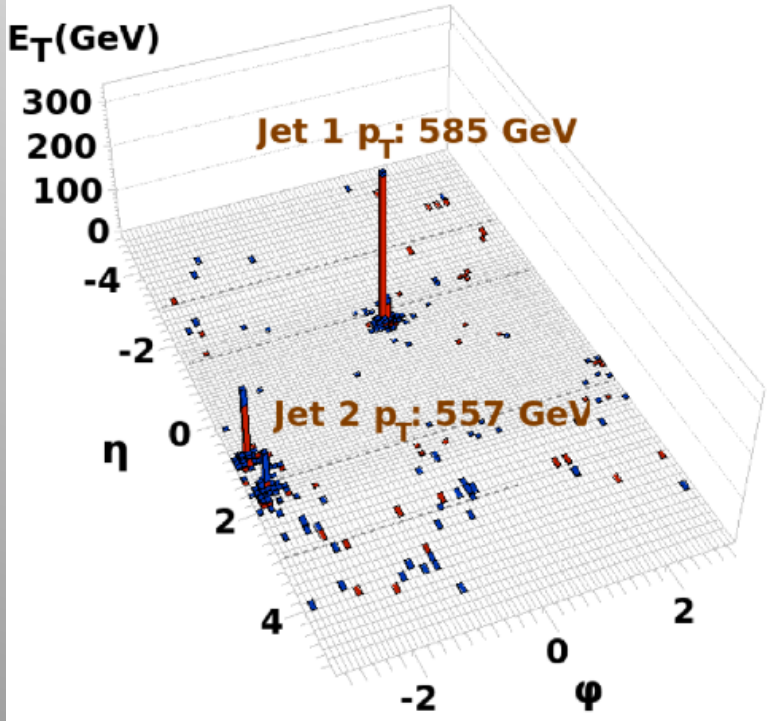


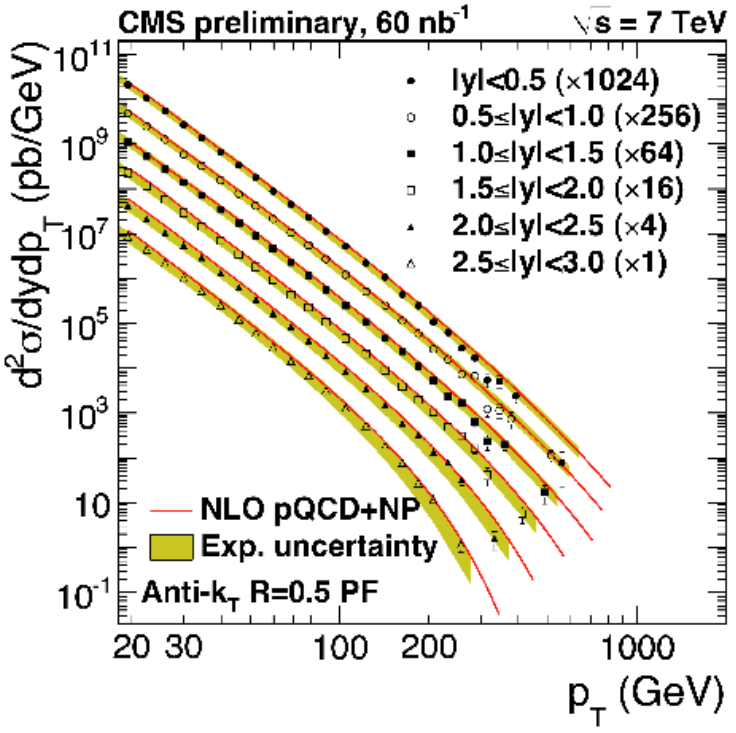
Underlying event activity increases with factor ~2 at 7 TeV
Significant increase of multi-parton interactions?

Jet Production at 7 TeV



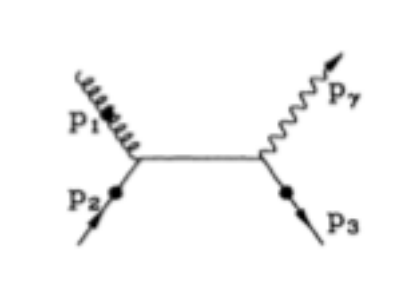
Measurement of inclusive jet cross sections



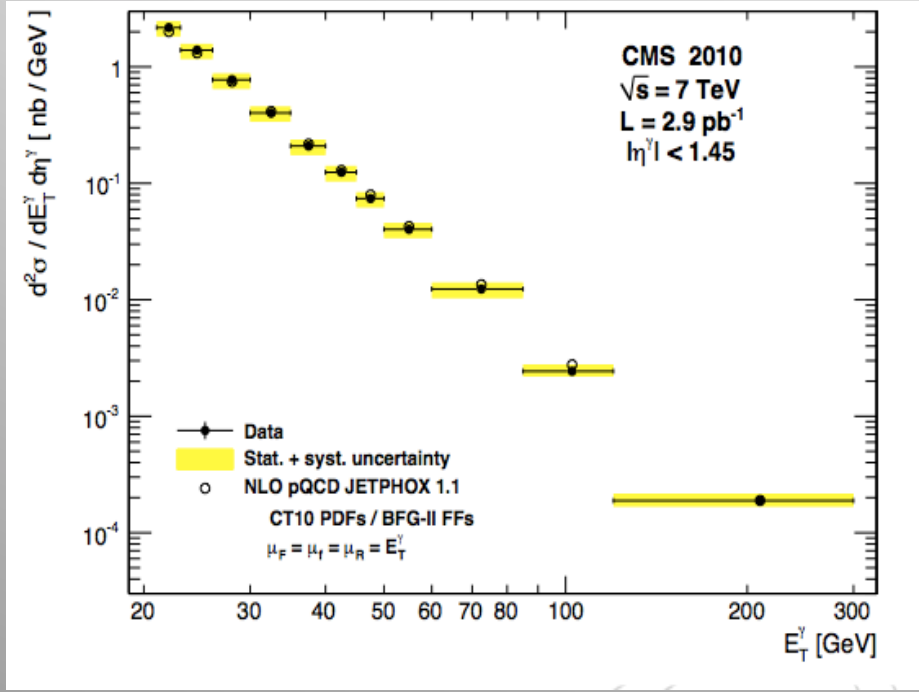


+ many studies performed on QCD and physics with heavy flavors

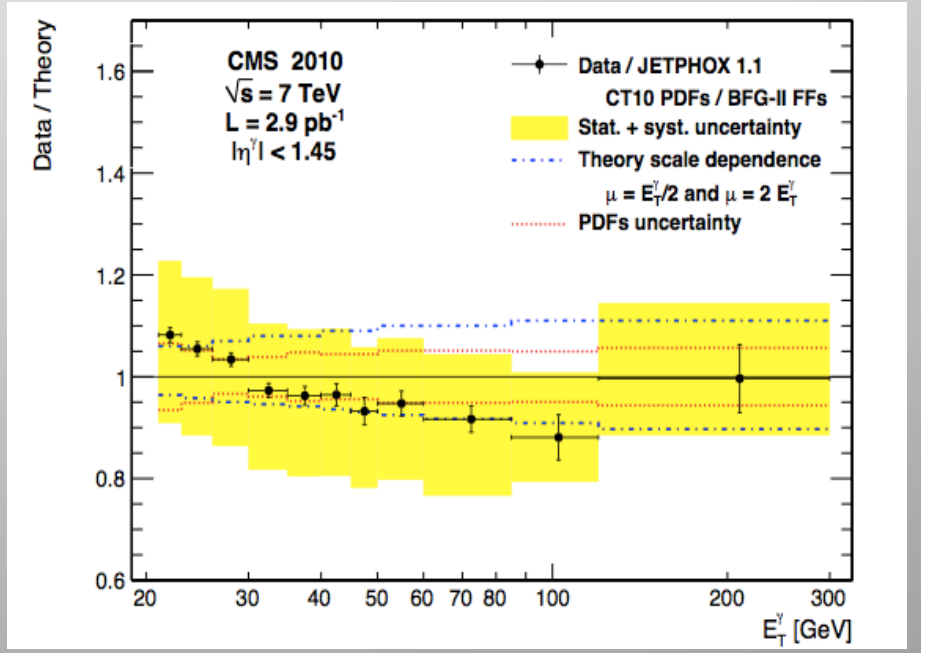
QCD: isolated photon production



Strong involvement of groups from Taiwan



Comparison with theory

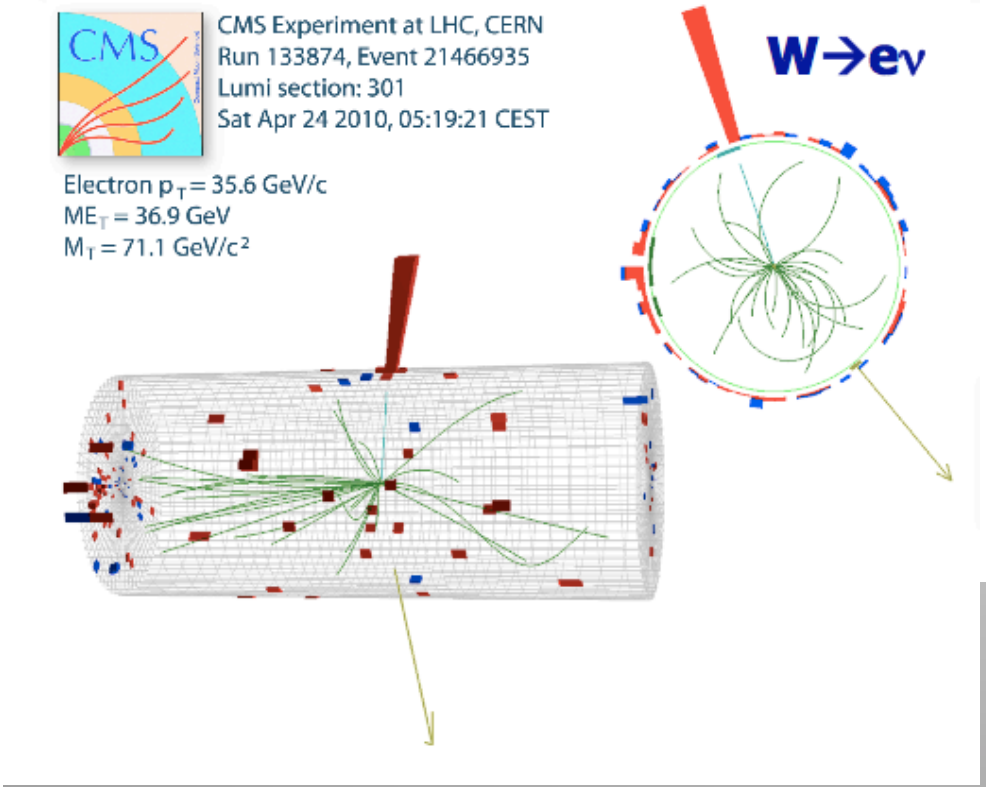


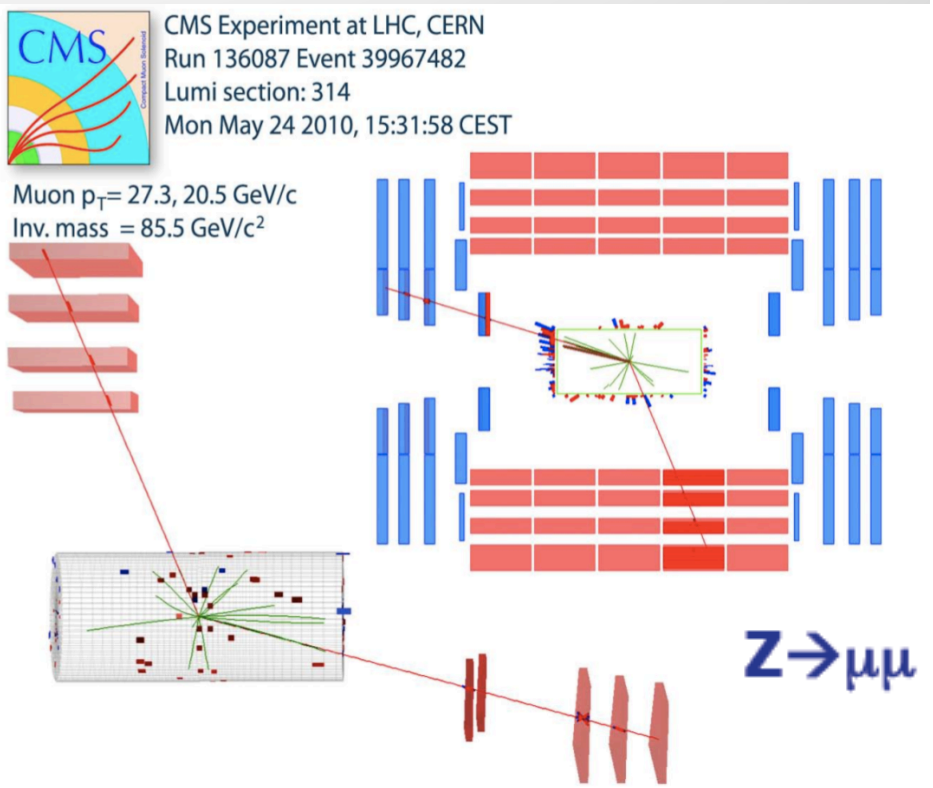
Measurement at higher Q^2 and lower $x_T=2E_T/\sqrt{s}$ wrt the Tevatron.

Lumi error (11%) not included

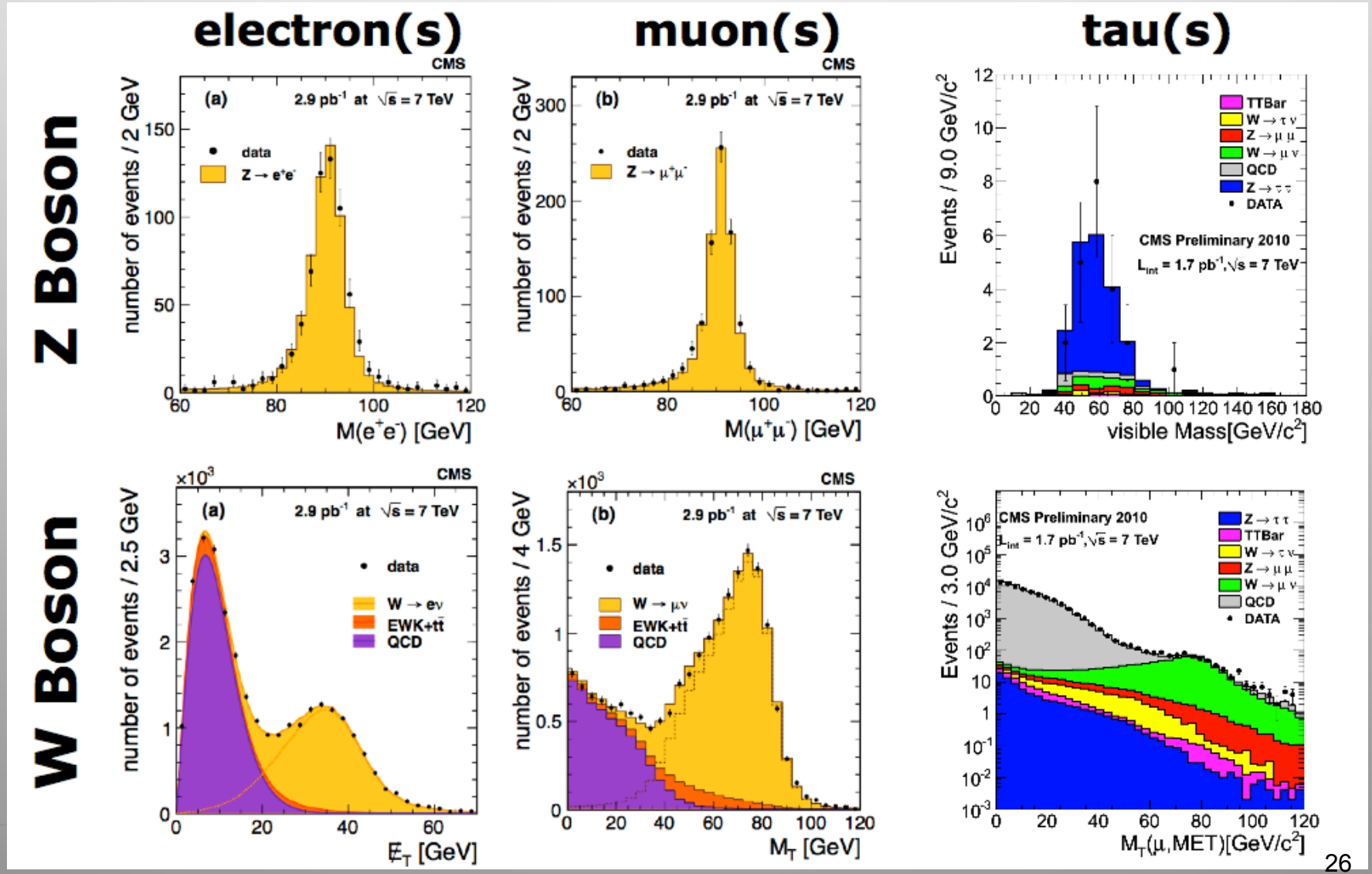
W and Z Boson Production

As of May last year...

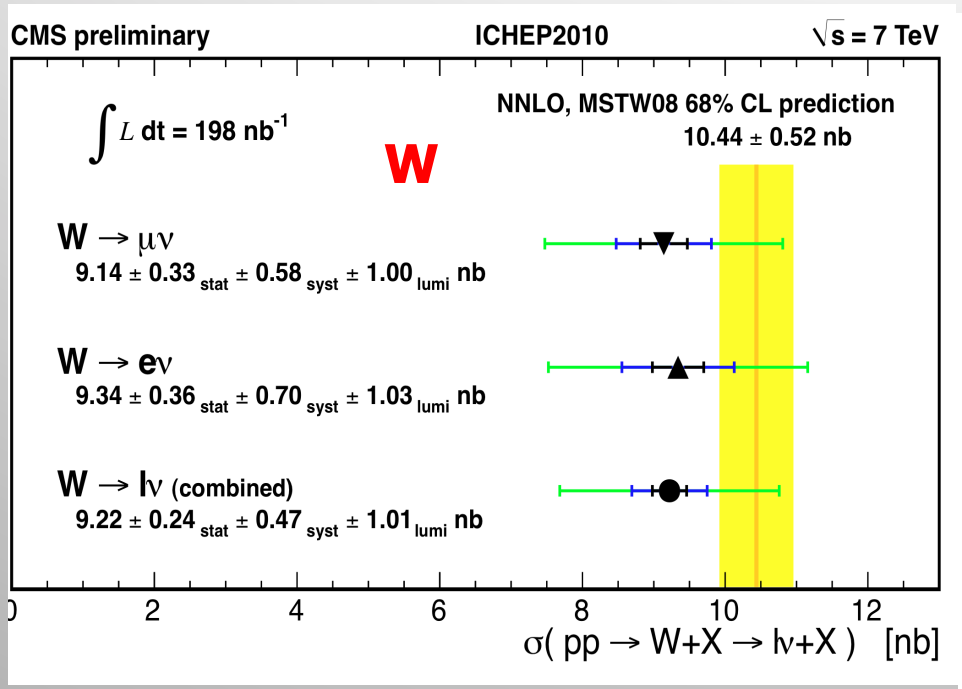


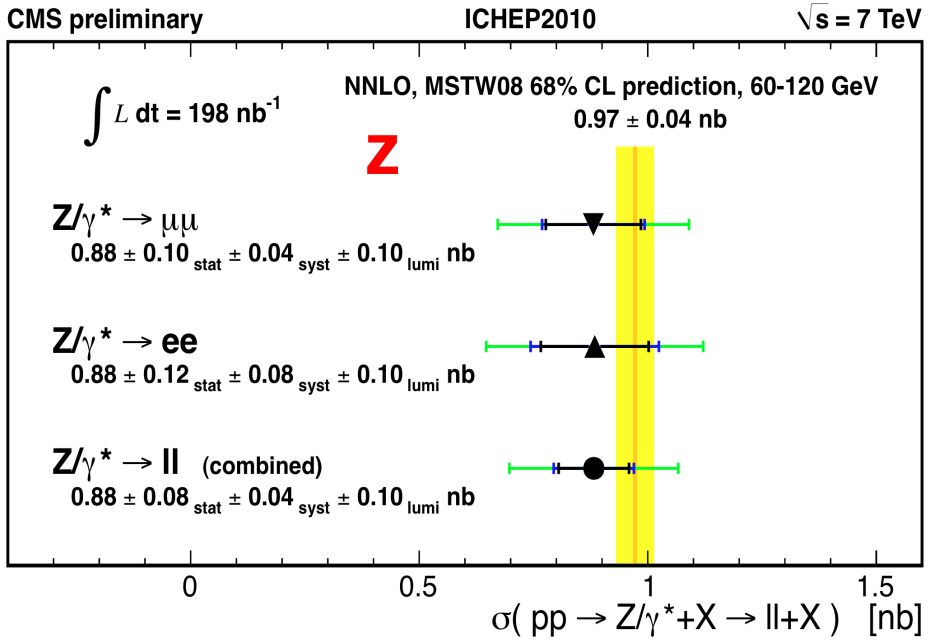


W and Z Boson Production



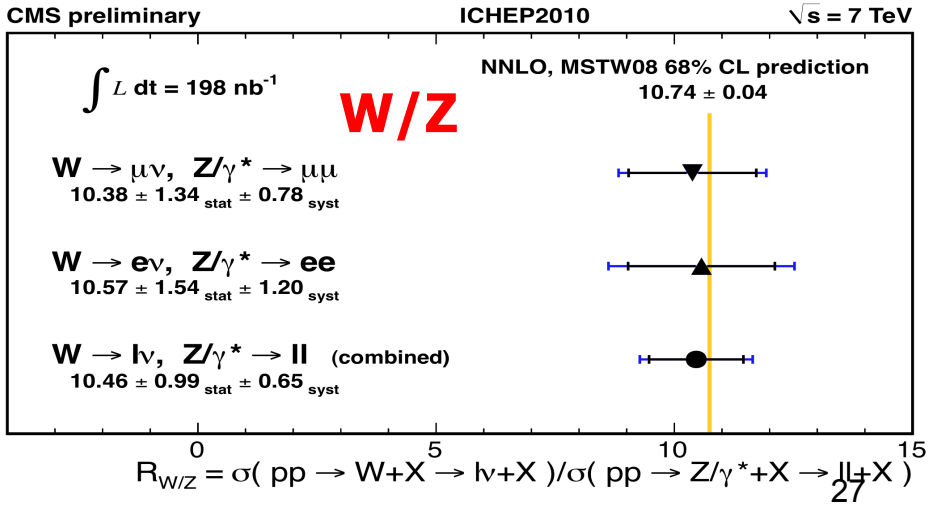
W/Z Cross Sections



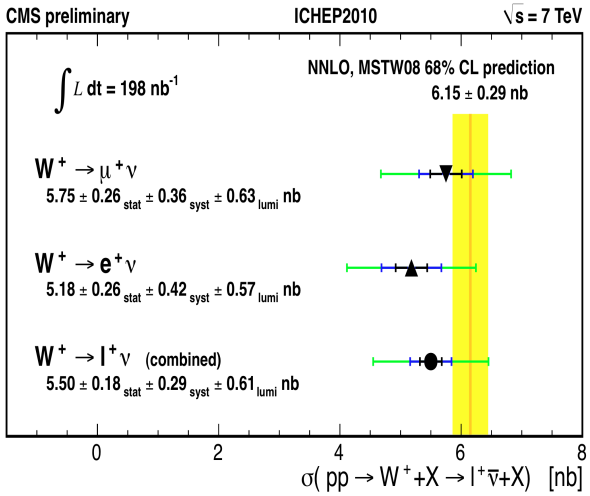


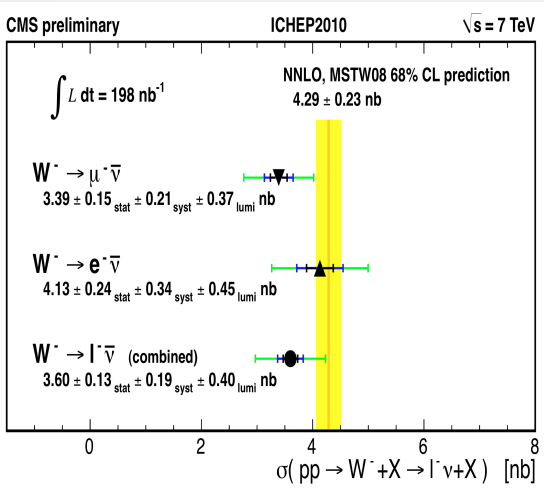
arXiv:1012.2466

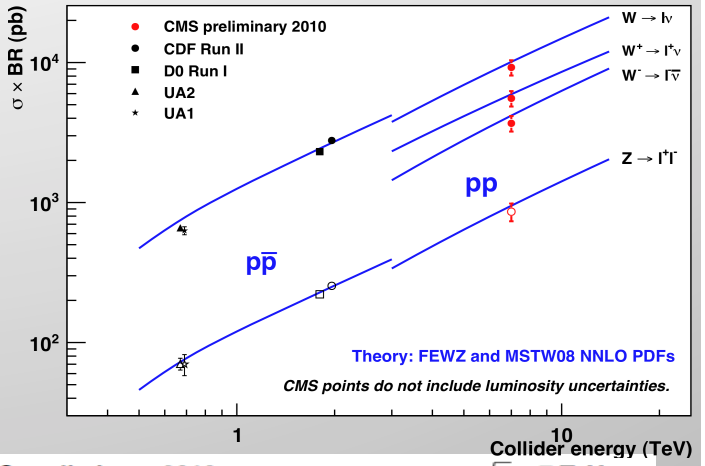
Notice: ~all major components of the measurements (efficiency, background, systematic errors etc) are carefully evaluated using data driven methods.

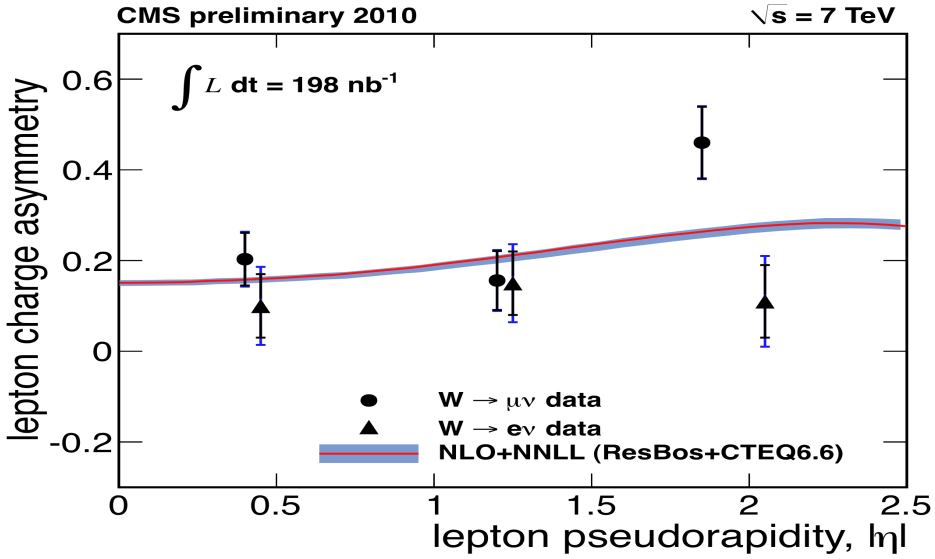


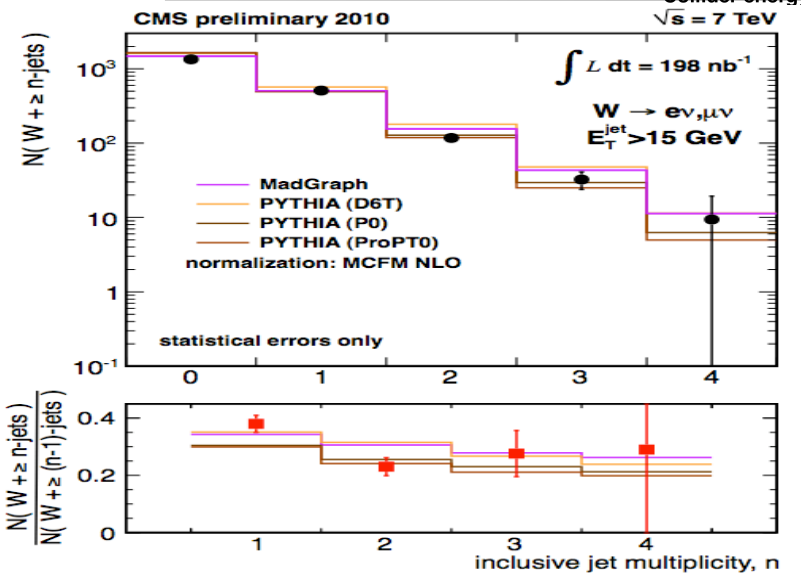
Charge asymmetry and W+jets







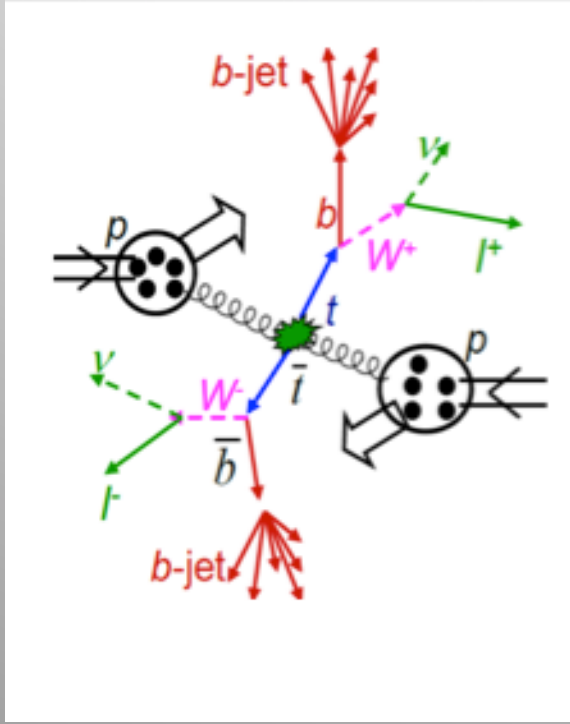


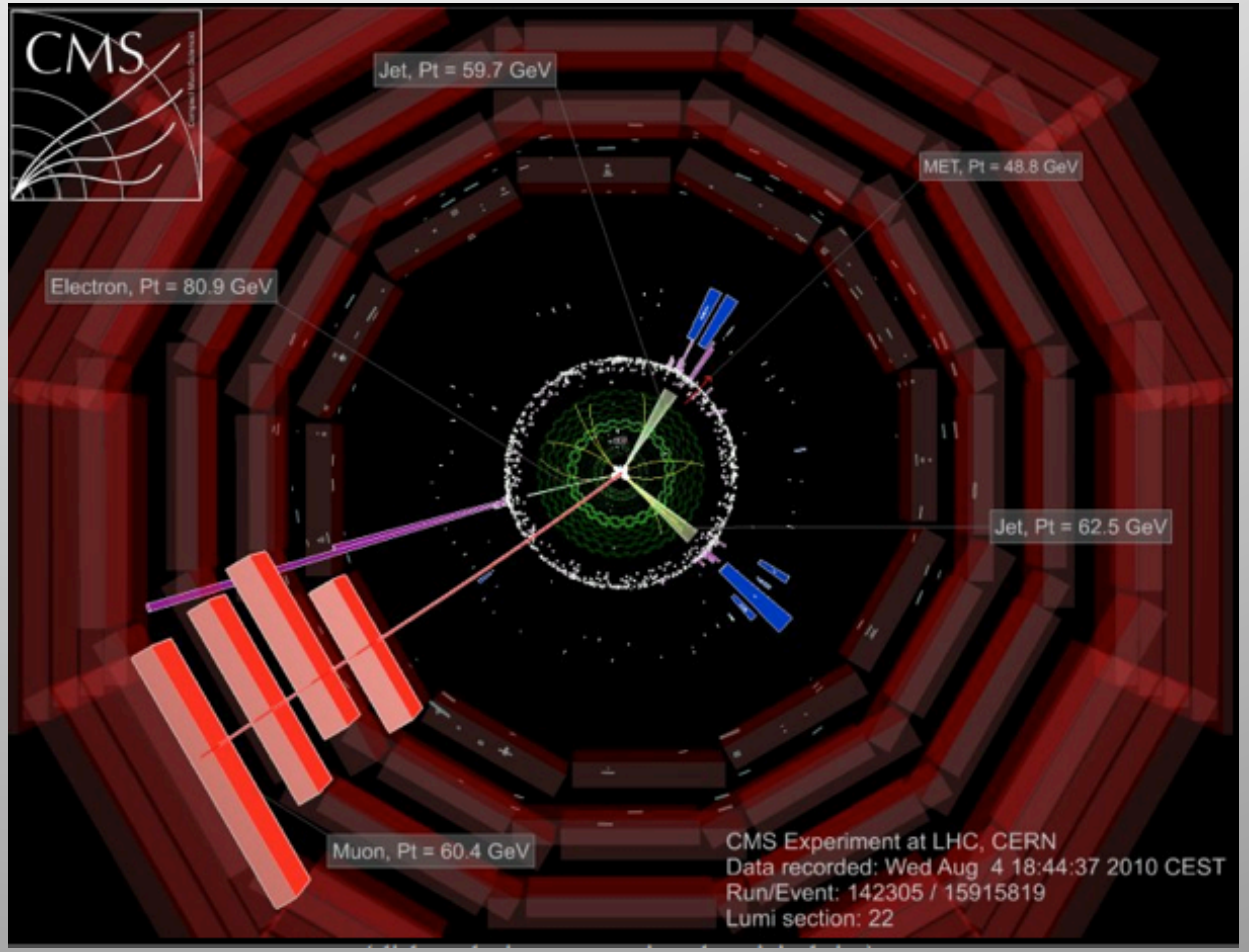


…And now we deploy everything for hunting the top

Top Signals in CMS

Electron+muon + 2 b-quark jets + missing transverse momentum



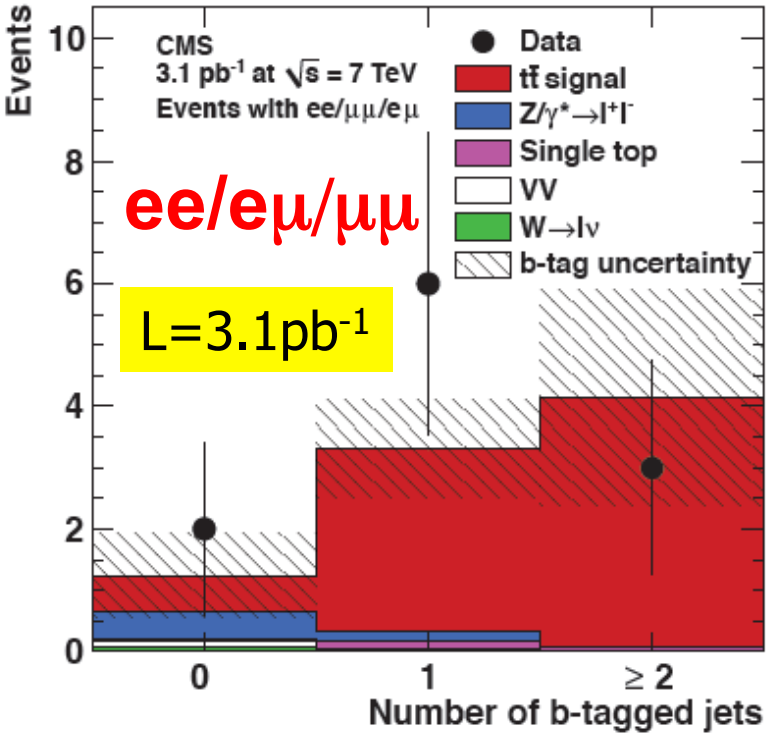


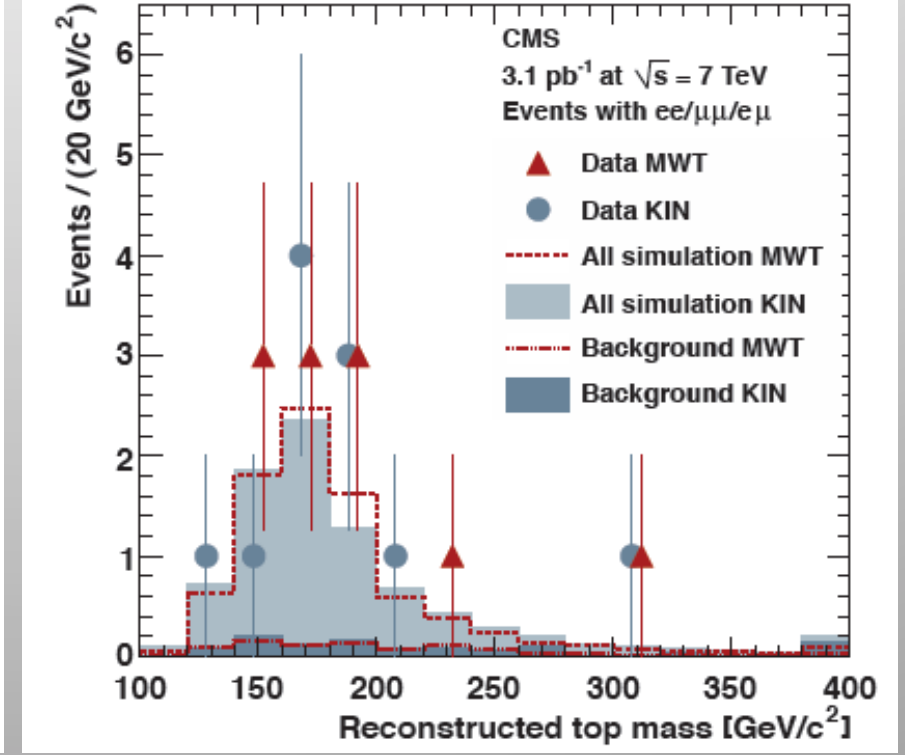
Other decay channels studied as well

Di-Leptons + Jet Top Selection

- Full selection applied: Z-bosonVeto, |M(ll)-M(Z)|>15 GeV
- MET >30 (20) GeV in ee,μμ, (eμ); N(jets)≥2

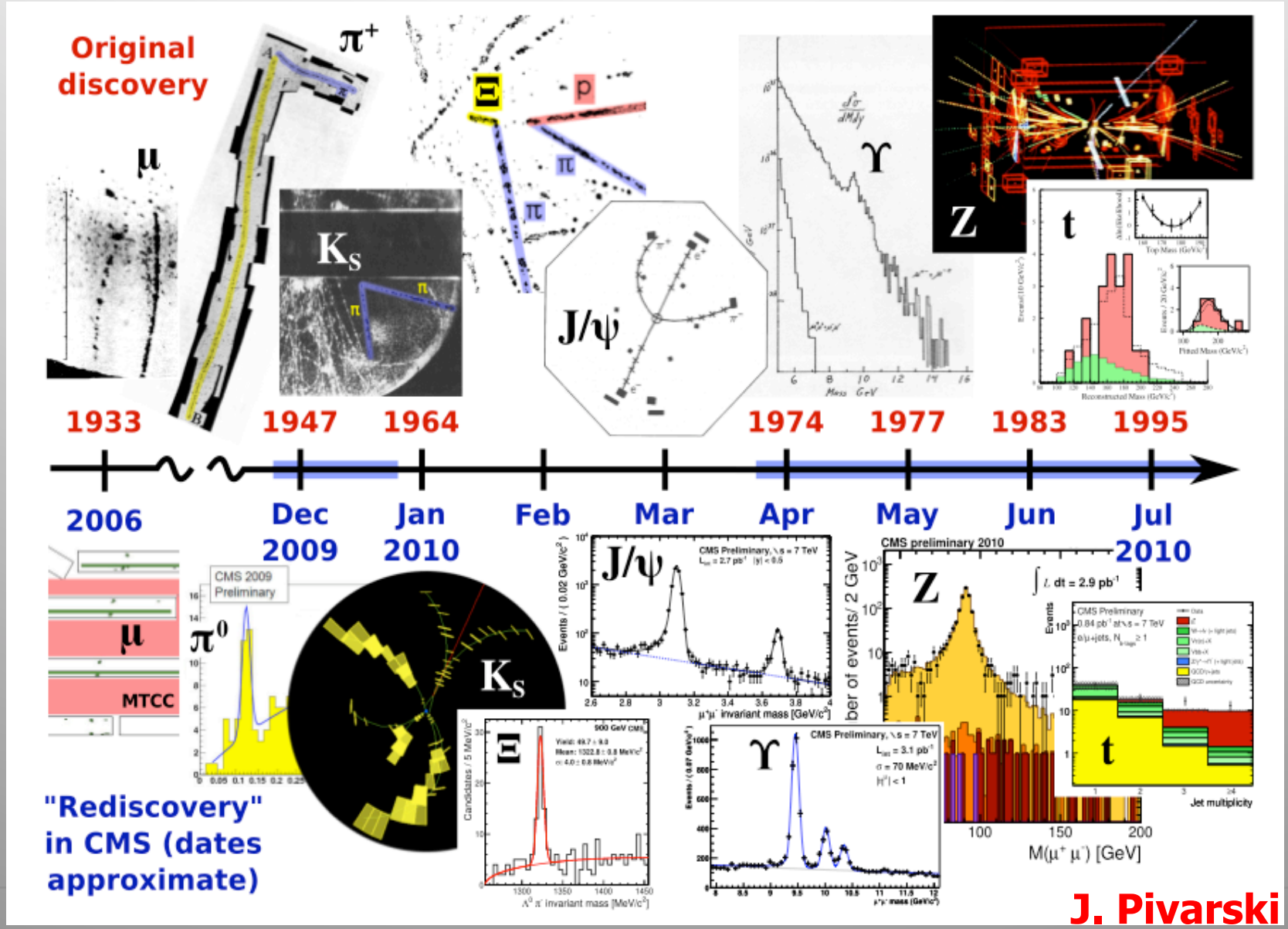
arXiv:1010.5994





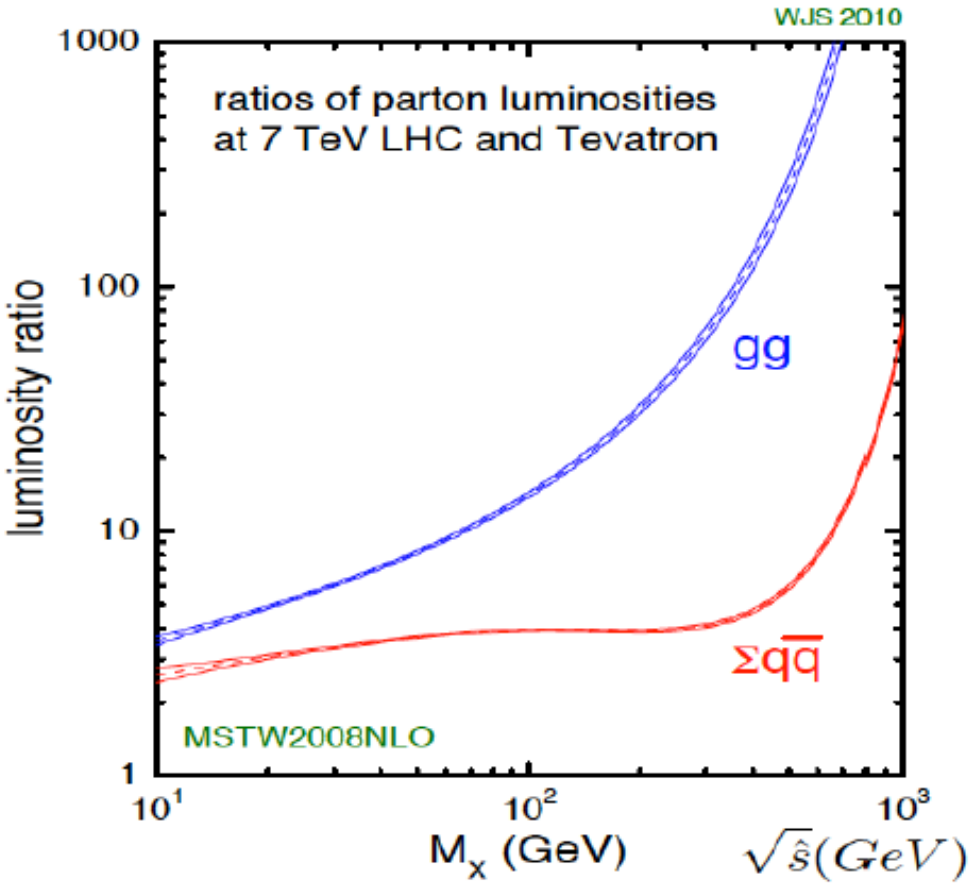
$\sigma(pp \rightarrow t\bar{t}) = 194 \pm 72(stat.) \pm 24(syst.) \pm 21(lumi.)$ pb.
Consistent with NLO prediction of 157.5 (+23.2 −24.4) pb for a top quark mass of $m_t = 172.5$ GeV/c^2

Re-discovery of the Standard Model at 7 TeV



Searches for New Physics

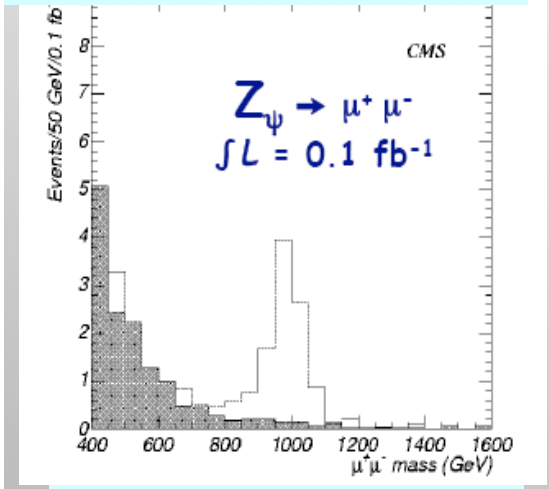
Can LHC compete with the Tevatron? Yes we can!



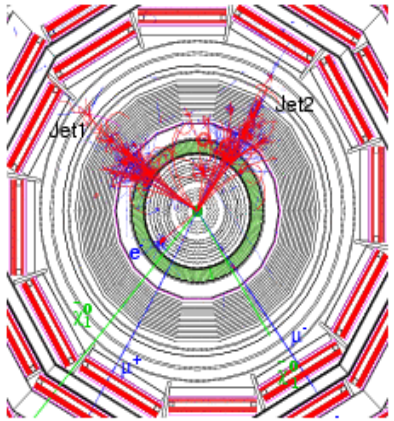
- The LHC at √s= 7 TeV offers (with respect to Tevatron):
  - Higher center-of-mass energy → access to new physics scales, even with very low luminosities
  - ~ 10 times more gluon-gluon initial state → top factory, more Higgs cross section, also larger QCD backgrounds
  - ~ 3 times more $q\bar{q}'$ initial state → larger W/Z production in general (inclusive or associated)

Physics Beyond the Standard Model

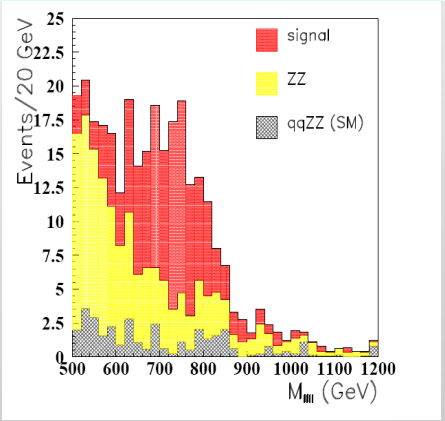
New Gauge Bosons?



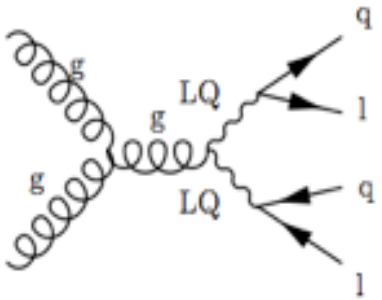
Supersymmetry



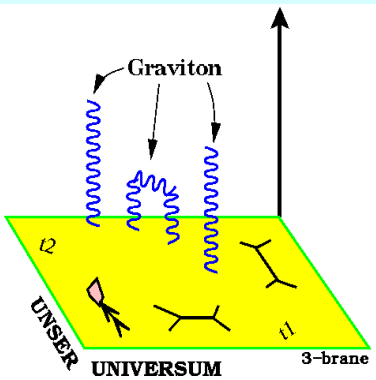
ZZ/WW resonances?



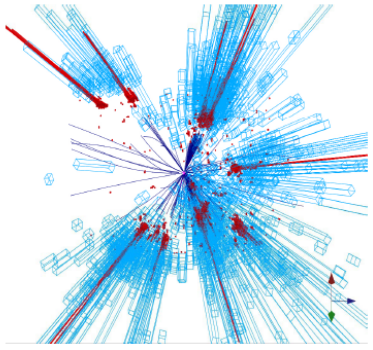
Leptoquarks?



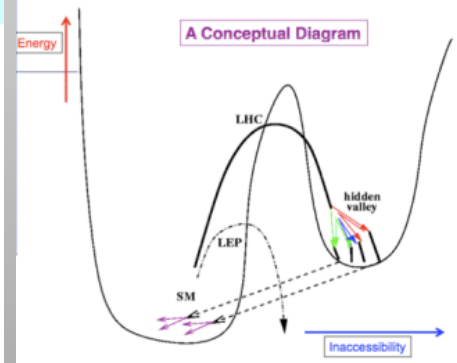
Extra Dimensions?



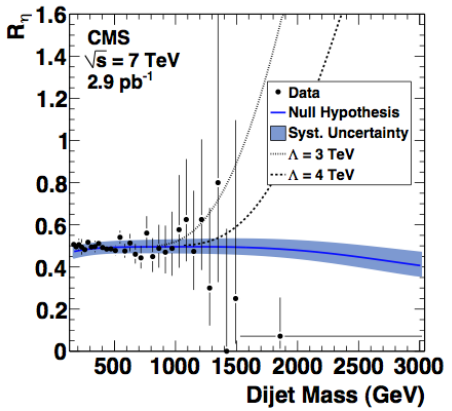
Black Holes???



Long lived particles?



Compositness?



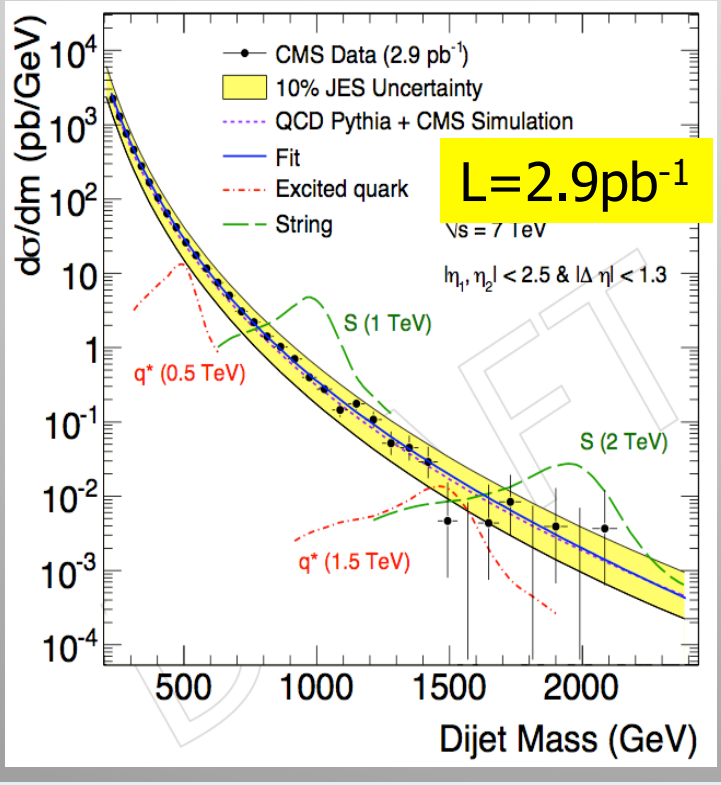
We do not know what is out there for us…
A large variety of possible signals. We have to be ready for that

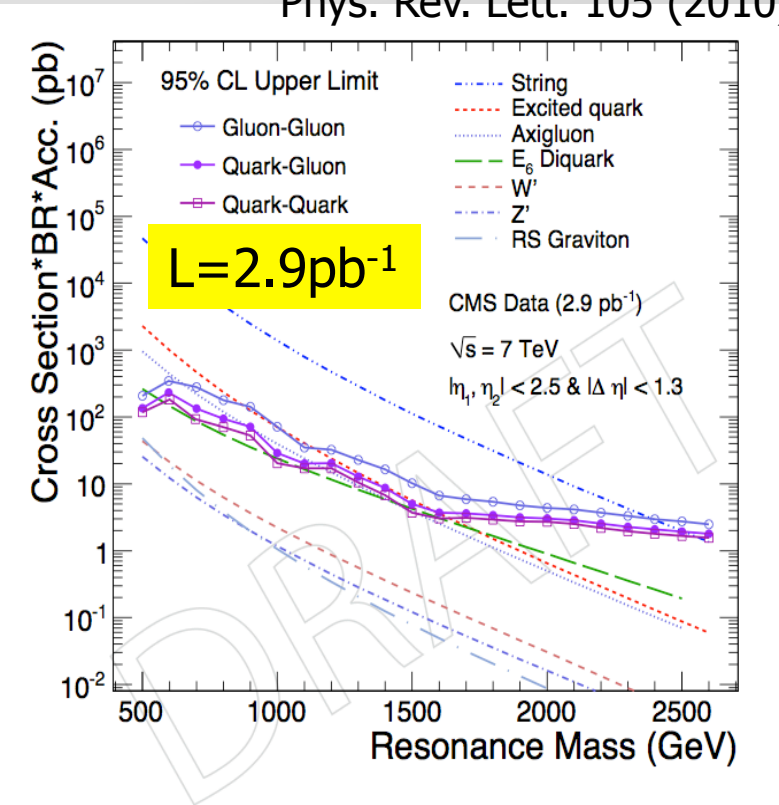
Exploring New Territory: Di-jets

Search for narrow resonances in di-jet final states.

We have measured, in 2.9pb^{-1} of data, the dijet mass differential cross section for $|\eta_1,\eta_2|<2.5$ and $|\Delta\eta|<1.3$. The distribution is sensitive to the coupling of any new massive object to quarks and gluons.

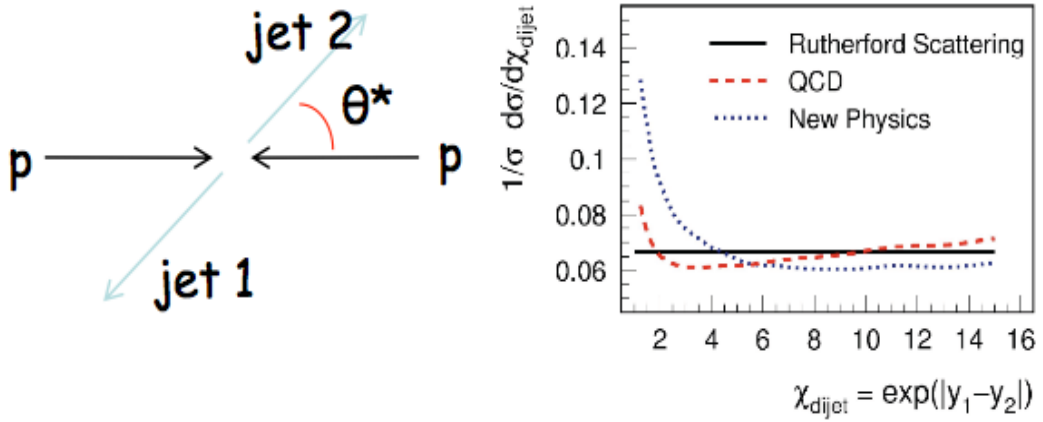
Phys. Rev. Lett. 105 (2010) 211801





95% CL mass limits for new particles decaying to parton pairs:
String resonances >2.5TeV; Excited quarks >1.58TeV (Tevatron: >0.87 TeV)

Di-jet Angular Distributions

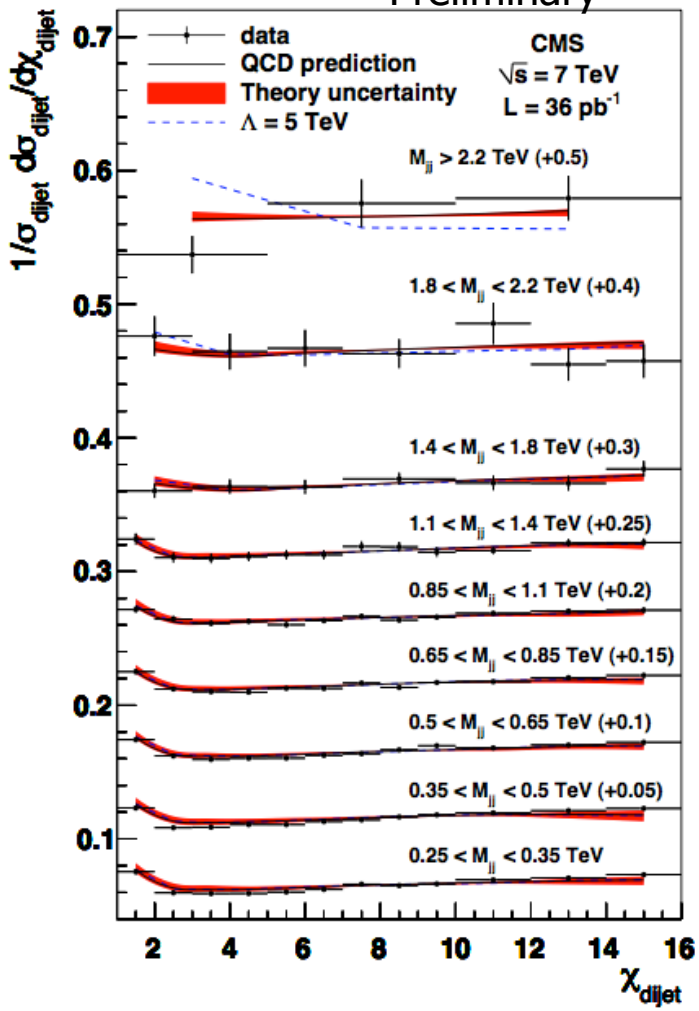


$$\chi_{\text{dijet}} = \exp(2y^*) = (1+\cos\theta^*)/(1-\cos\theta^*)$$

Eg searches for contact interactions at the Tevatron

$\Lambda < 2.8$ TeV - 3 TeV

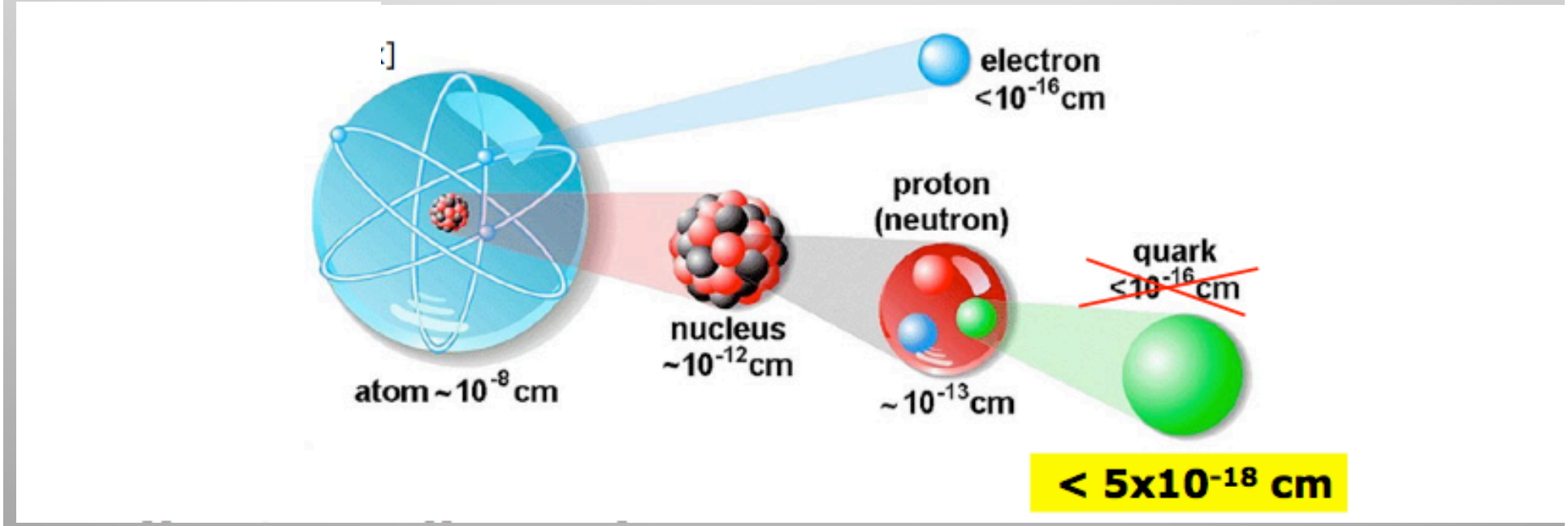
Preliminary



CMS: Exclude @ 95% CL Λ < 5.6 TeV for 36 pb^{-1}

Limits on Quark-Compositness

What do these results teach us?

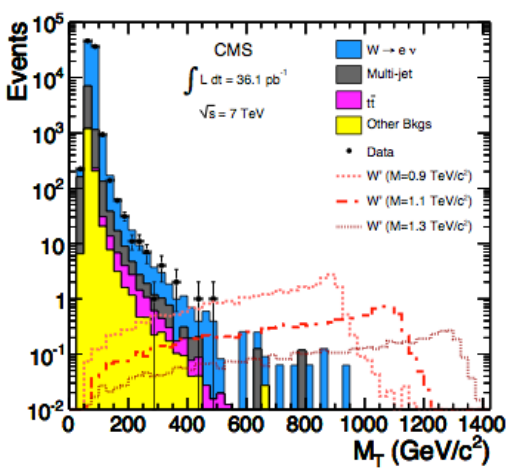


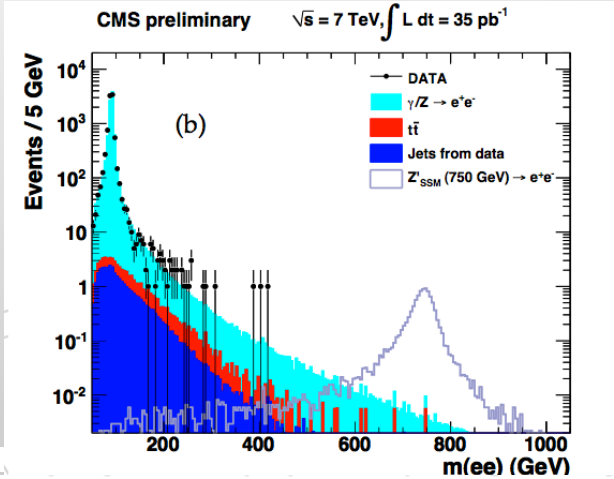
Quarks remain elementary particles after these initial results

Search for New Gauge Bosons

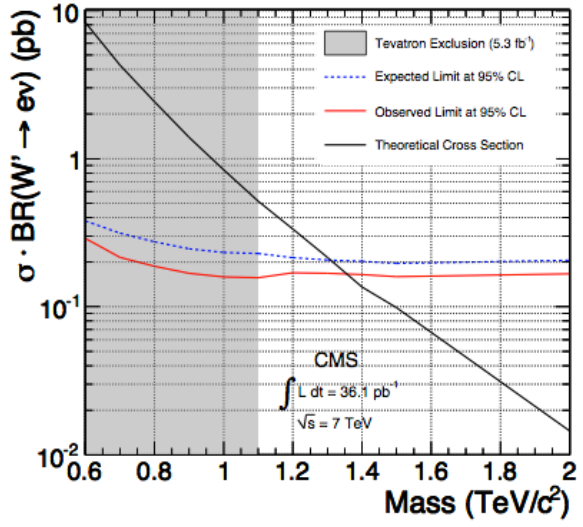
arXiv:1012.5945

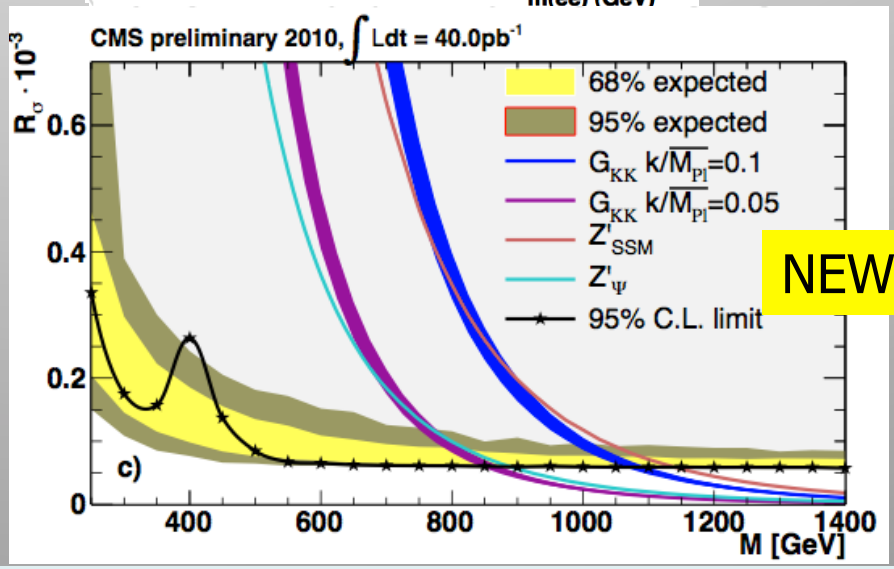
Study of the channels $W' \to \mu\ \nu$, $Z' \to \mu\ \mu$, ee





NEW





NEW

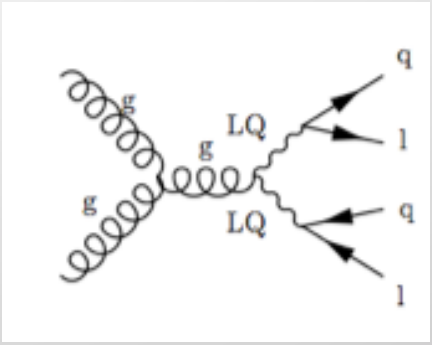
Exclude a new gauge bosons up to 1.3 TeV (W') and 1.1TeV (Z') @ 95% CL

This goes beyond the Tevatron timits of ~ 1.1 (W') and 1.1 (Z') TeV

Searches: Leptoquarks

GUT inspired models predict new particles with lepton and quark properties

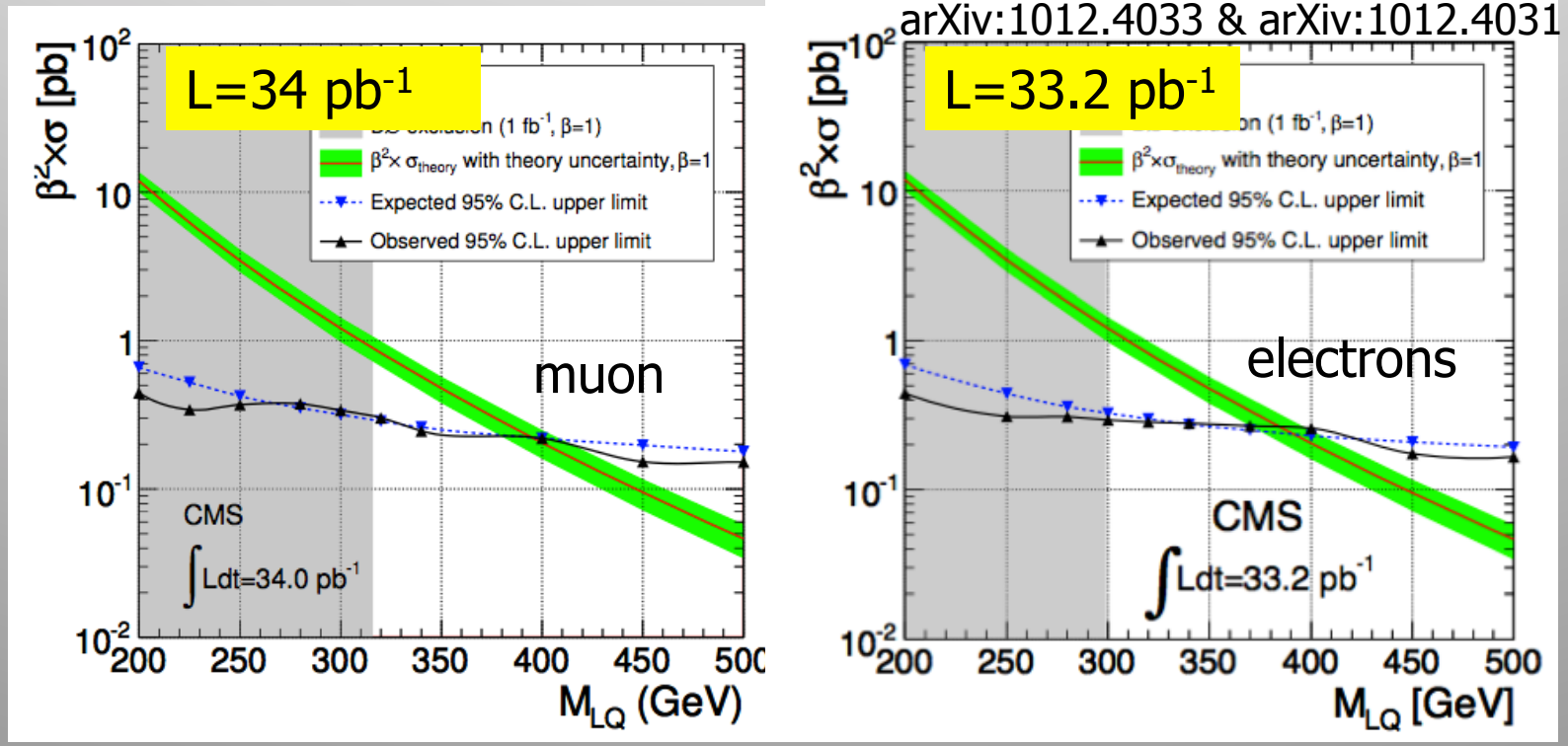
*Some excitement at HERA in '97 (M~ 200 GeV)



Search in muon or electron + jet final states

95% CL limit: 394 GeV (muon) / 384 GeV (electron)

arXiv:1012.4033 & arXiv:1012.4031



CMS limit improves the Tevatron bounds already by about 70-80 GeV

A Fourth Quark Flavor Generation?

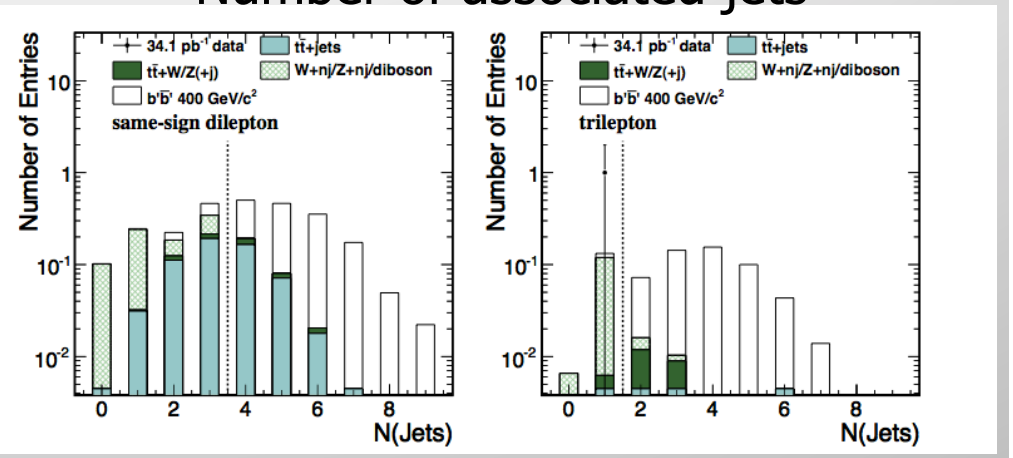
We can't be sure that there are only 3 generations (u,d) (s,c) (b,t). A possible new generation should be heavy!

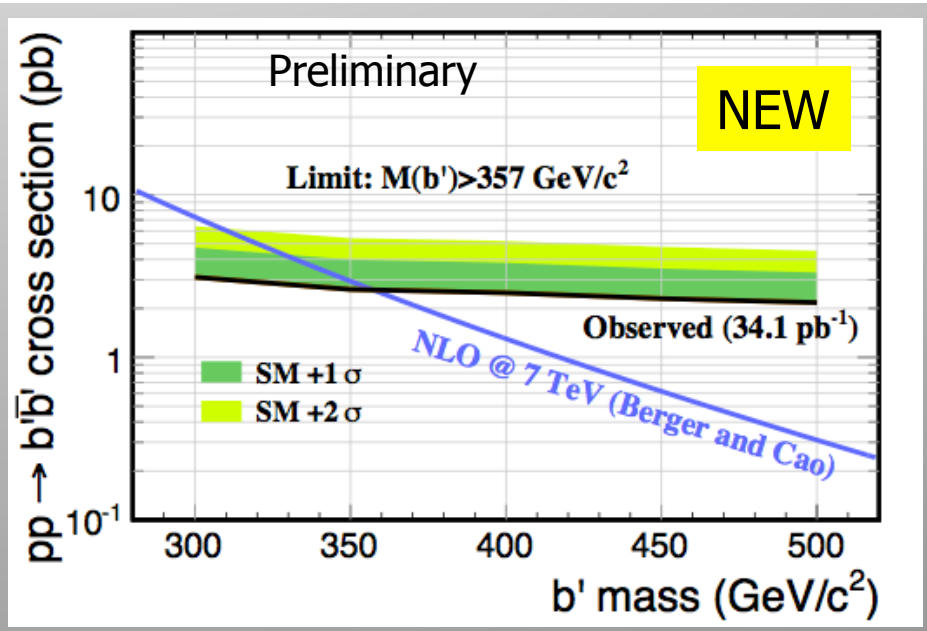
Look for b′ and t′ quarks
This channel: b′→ tW decays
Hence we have b′→ tW→WWb

Utilize the W leptonic decays
Search for same sign di-lepton (+4 jets) for or tri-lepton (+2 jets) events
No events found/background of 0.32 expected from SM processes

CMS limit: M(b′) > 357 GeV 95% CL
Tevatron M(b′) > 338 GeV 95% CL

Number of associated jets



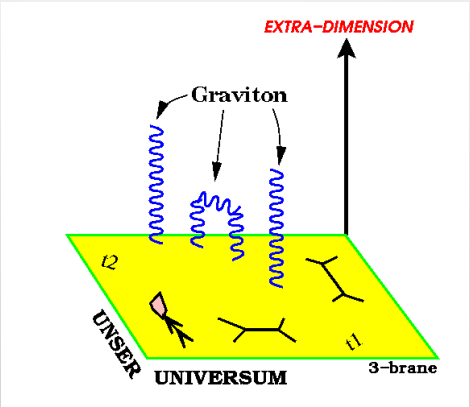


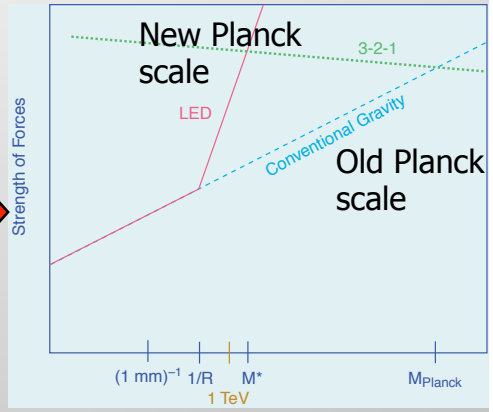
•Study led by Taiwan Physicists

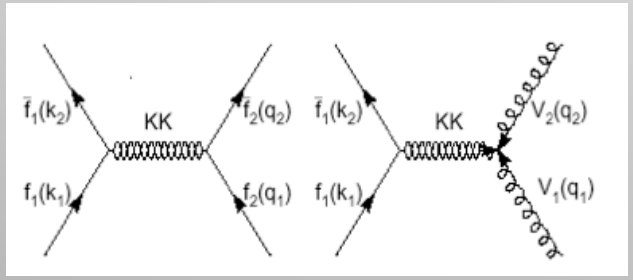
Search for Extra Dimensions

Are there extra space dimensions that open at higher energies?

Example: Experimental signature affects the di-fermion production
Study here: di- photon production

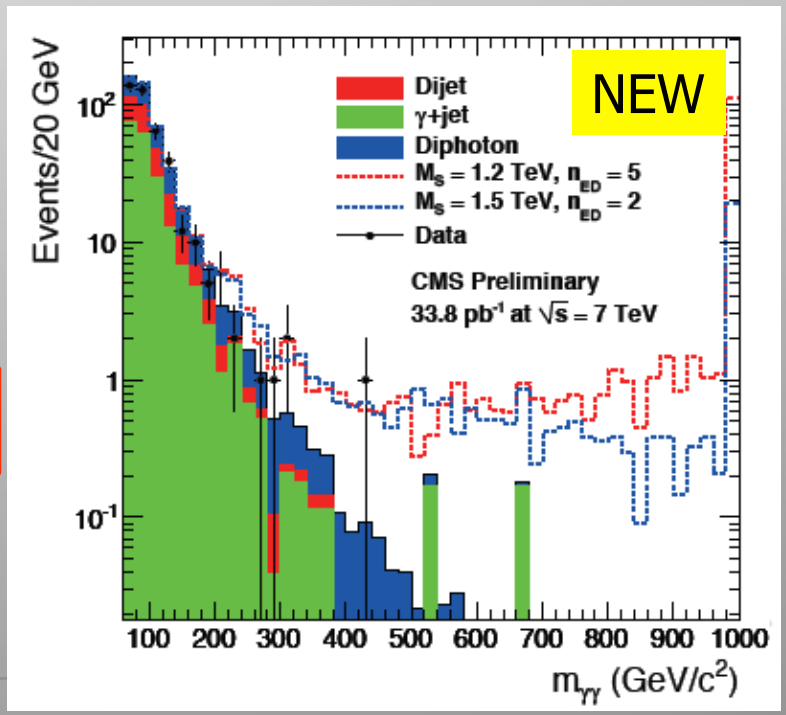






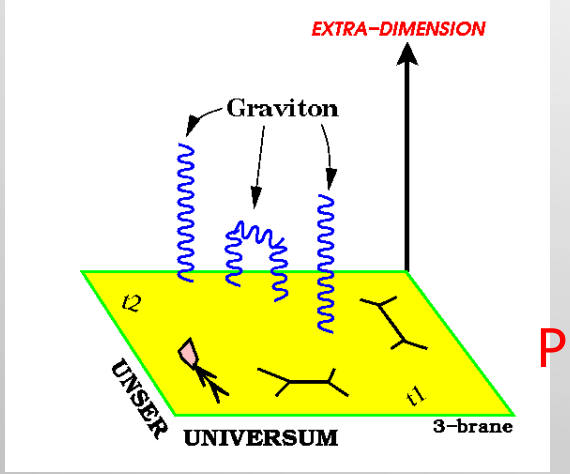
Results

$n_{ED}=2$	$n_{ED}=3$	$n_{ED}=4$	$n_{ED}=5$	$n_{ED}=6$	$n_{ED}=7$
1.88	2.29	1.93	1.74	1.62	1.53



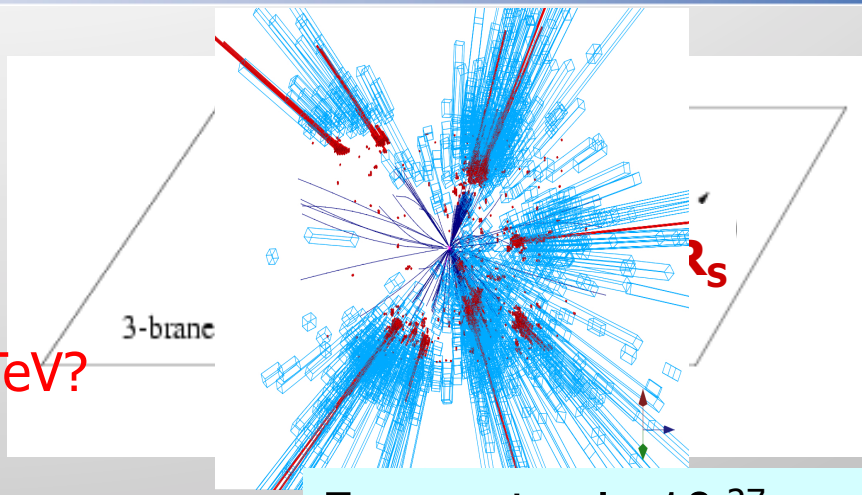
New mass scale larger than 1.5-2.3 TeV depending on the number of extra dimensions
Tighter limits than at the Tevatron

Search for Micro-Black Holes



Extra Dimensions!

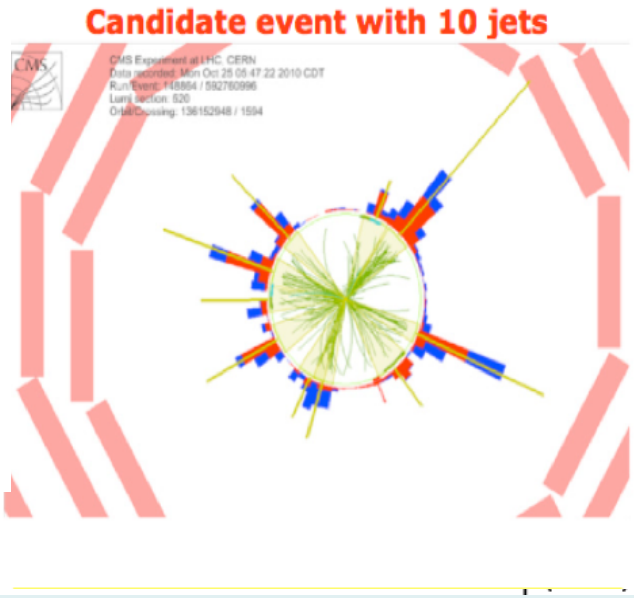
Planck scale a few TeV?

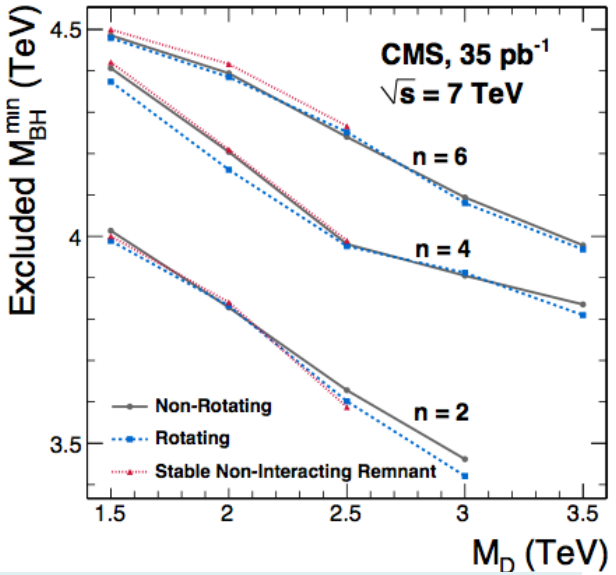


Evaporates in 10^{-27} sec

Look for the decay producs of an evaporating black hole (lifetime ~ 10^{-27} sec)

- Define S_T to be the scalar Sum of all high p_T objects found in the event
- Look for deviations at high S_T





Black hole masses excluded in range 3-4.5 TeV depending on assumptions

Long Lived Particles in Supersymmetry

Split Supersymmetry

- Assumes nature is fine tuned and SUSY is broken at some high scale
- The only light particles are the Higgs and the gauginos

  - Gluino can live long: sec, min, years!
  - R-hadron formation (eg: gluino+ gluon): slow, heavy particles containing a heavy gluino.

  Unusual interactions with material

  eg. with the calorimeters of the experiments!

Gravitino Dark Matter and GMSB

- In some models/phase space the gravitino is the LSP
- ⇒ NLSP (neutralino, stau lepton) can live 'long'
- ⇒ non-pointing photons

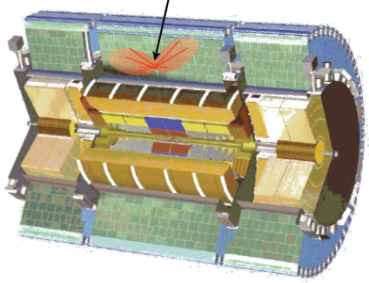
⇒Challenge to the experiments!

Long Lived Gluinos

$\tau_{\tilde{g}} > 100$ ns

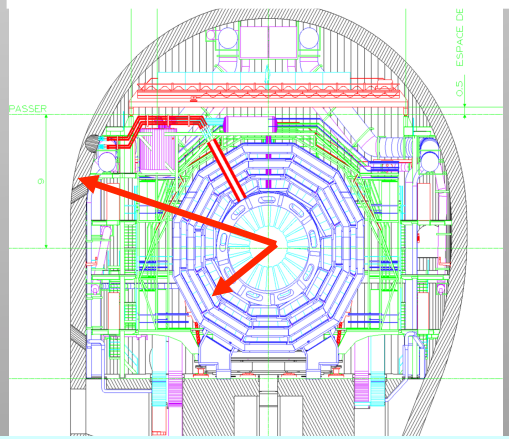
looking for stopped gluinos that later decay

100s GeV Unbalanced $= \not{E}_T$



Uncorrelated with any beam crossing
No tracks going to or from activity

K. Hamaguchi,M Nijori,ADR hep-ph/0612060
ADR, J. Ellis et al. hep-ph/0508198



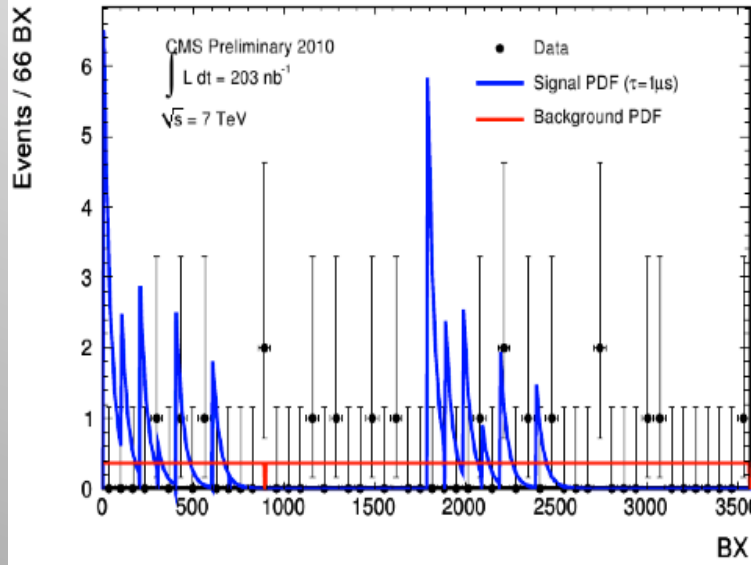
Sparticles stopped in the detector,walls of the cavern, or dense 'stopper' detector. They decay after hours---months...

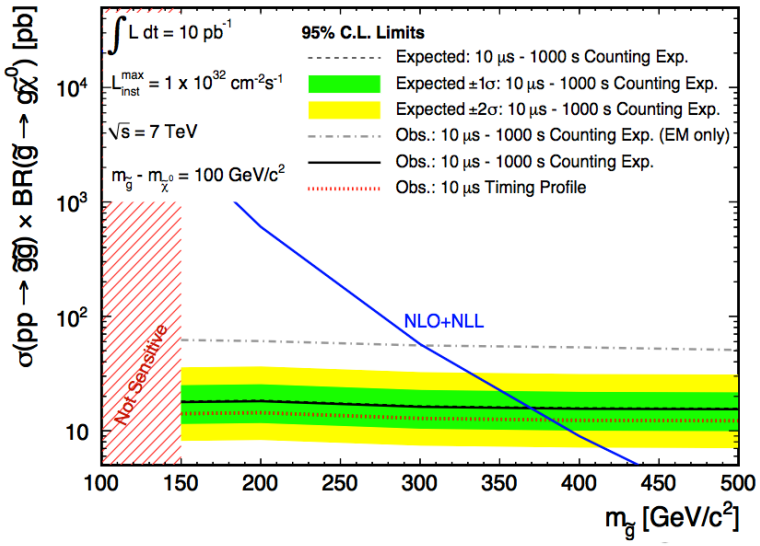
Searches: Stopped Gluinos

Search for Heavy Stable Charged Particles that stop in the detectors and decay a long time afterwards (nsec, sec, hrs…)

Searches for Stopped Gluino

Phys. Rev. Lett. 106 (2010) 01181





- gluino, hadronized into a charged R-hadron, can stop and decay in the calorimeter
- trigger on large "out-of-collision" energy depositions
- sensitive to the large lifetimes
- assume $BR(\tilde{g} \to g\tilde{\chi}^0) = 100\%,\ M_{\tilde{g}} - M_{\tilde{\chi}^0} > 100\ GeV$
- CMS'2010 95% CL limits on gluino lifetime $\tau_{\tilde{g}}$:
  - counting experiment excludes $\tau_{\tilde{g}}$ within [120ns, 6μs]
  - time profile analysis improves low limit down to 75ns

Gluino masses are excluded:

Time profile analysis (10 μs)
exclude $m_{\tilde{g}}$ < 382 GeV

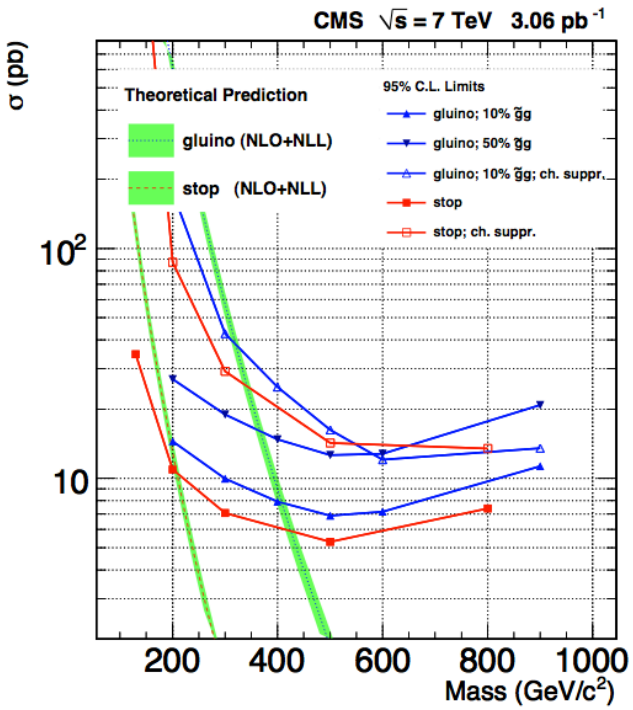
Counting experiment (10 μs - 1000s)
exclude $m_{\tilde{g}}$ < 370 GeV

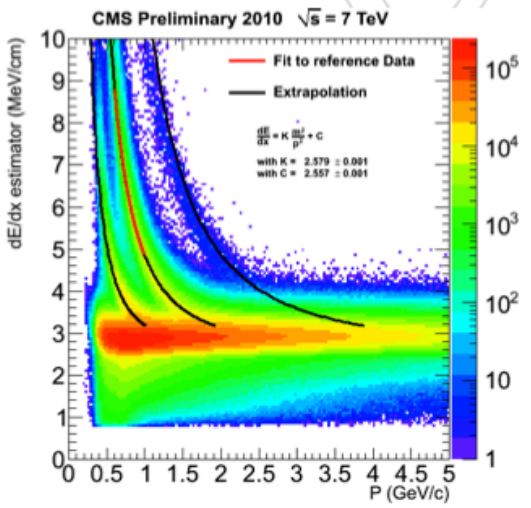
Heavy Stable Charged Particles

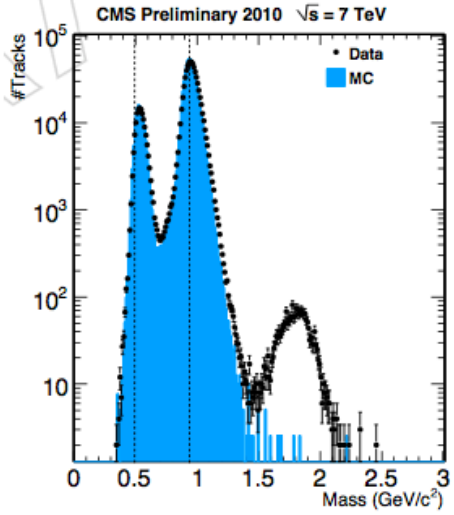
arXiv:1101.1645

Stable particles that traverse the detector

Eg heavy stable gluino (R-hadron) or stop/stau





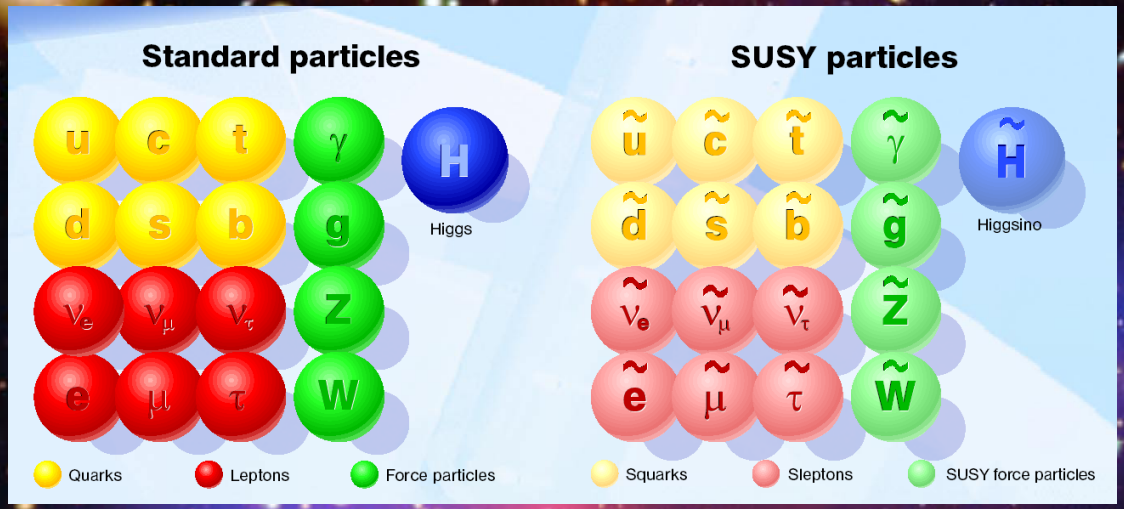


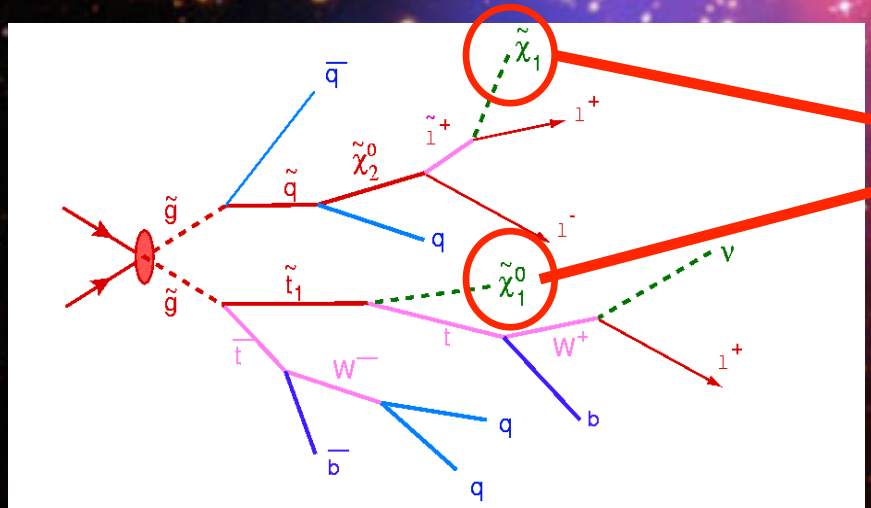
First search limits using tracker de/dx and muon identification

Result for 3.1 pb^{-1}
0 events after cuts

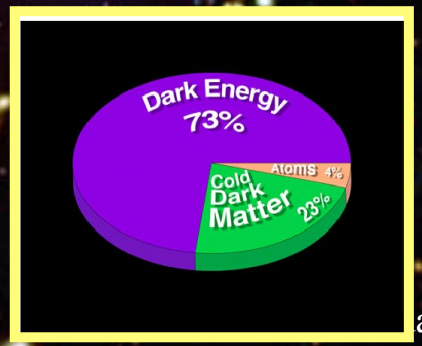
95% CL limits on production cross sections of a few100 pb in the 300-400 GeV mass range
Eg. Gluinos> 398 GeV

Supersymmetry: a new symmetry of Nature?





Candidate particles for Dark Matter
⇒ Produce Dark Matter in the lab

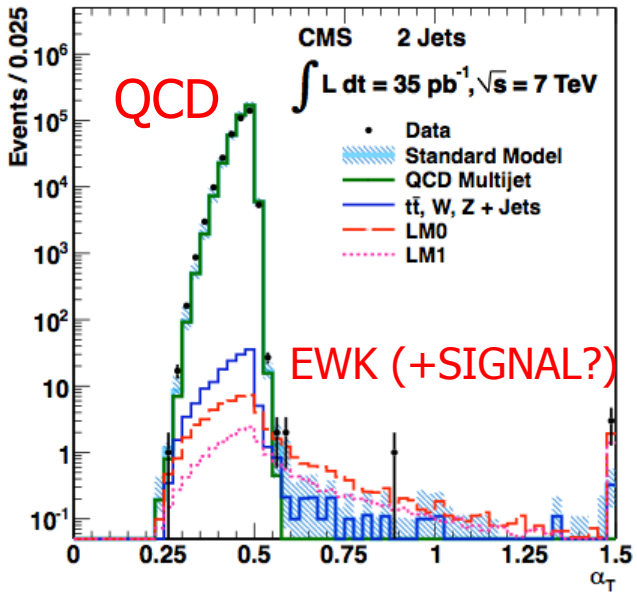


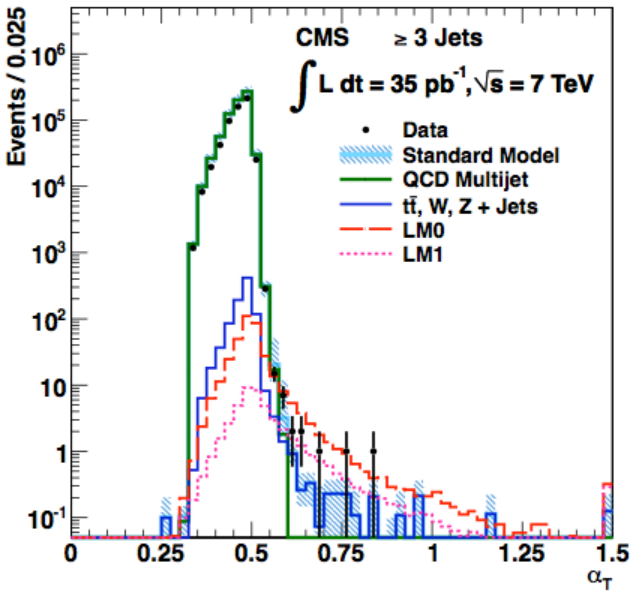
SUSY particle production at the LHC

+ 2 b-jets
+ 4 jets

ac

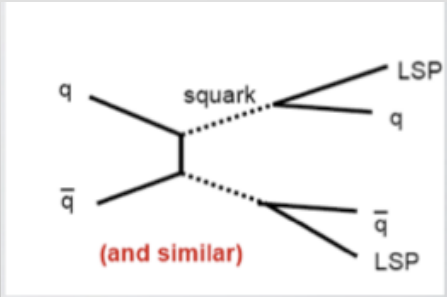
Search for SUSY



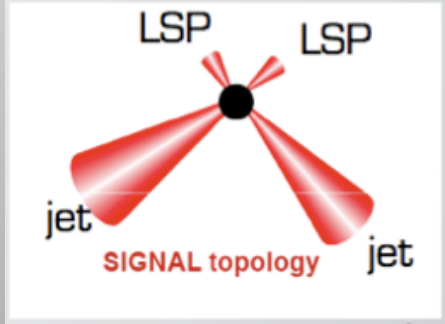


arXiv:1101.1628

All Hadronic Channel:
Jets + Missing Transverse Energy



$$\alpha_T = \frac{E_{T\,j2}}{M_{T\,j1\,j2}} = \frac{\sqrt{E_{T\,j2}/E_{T\,j1}}}{\sqrt{2(1-\cos\Delta\varphi)}}$$

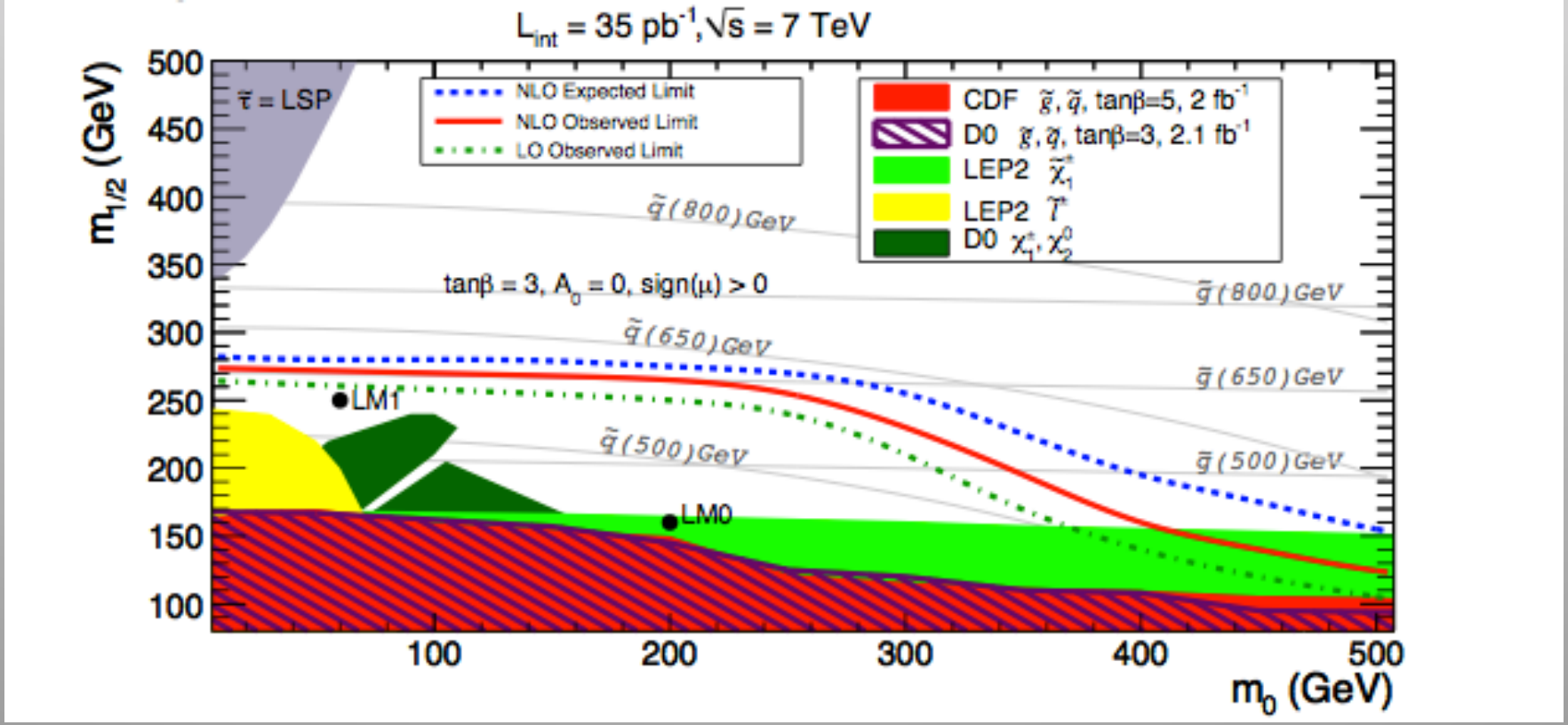


Control QCD with the α_T variable
No QCD expected for $\alpha_T > 0.5$

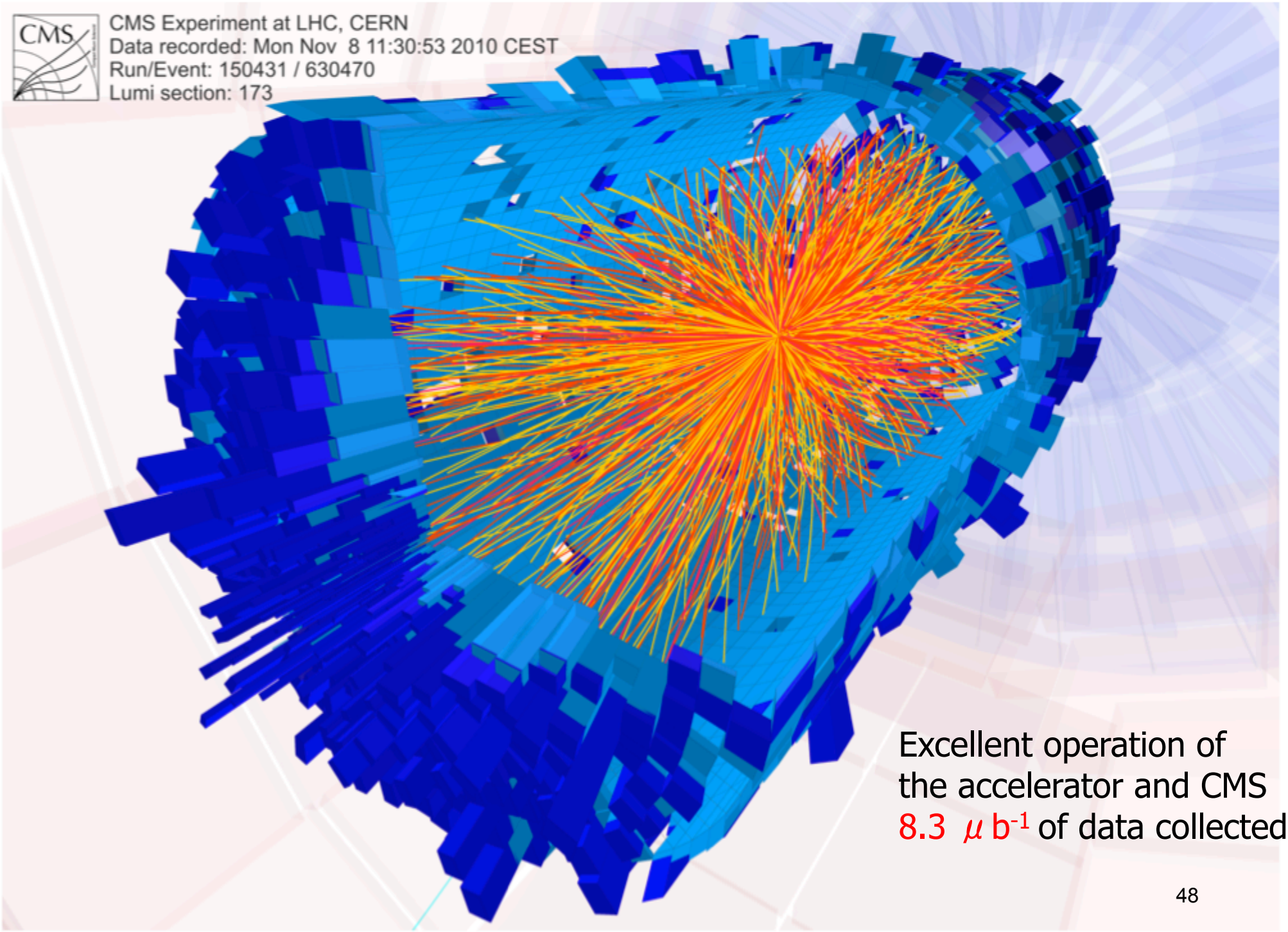
Control EWK backgrounds from data itself using W-> $\mu\ \nu$, γ +jet and other control samples

First SUSY Search Result

-All Hadronic Channel: Jets + Missing Transverse Momentum
-All 2010 data included: ~10-12 Events expected/ 13 observed



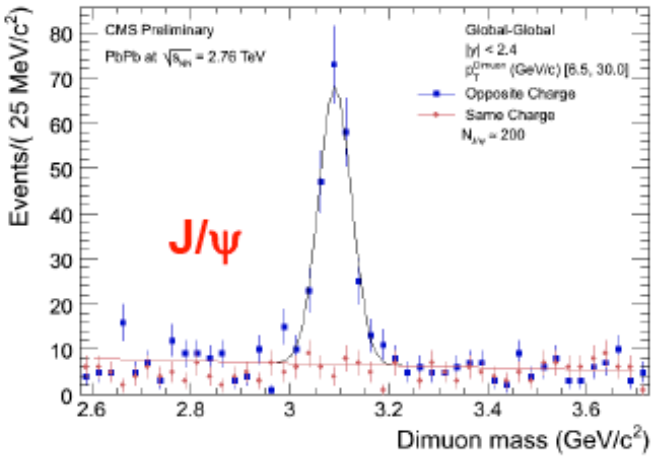
No discovery of supersymmetry yet… Stronger exclusion limits

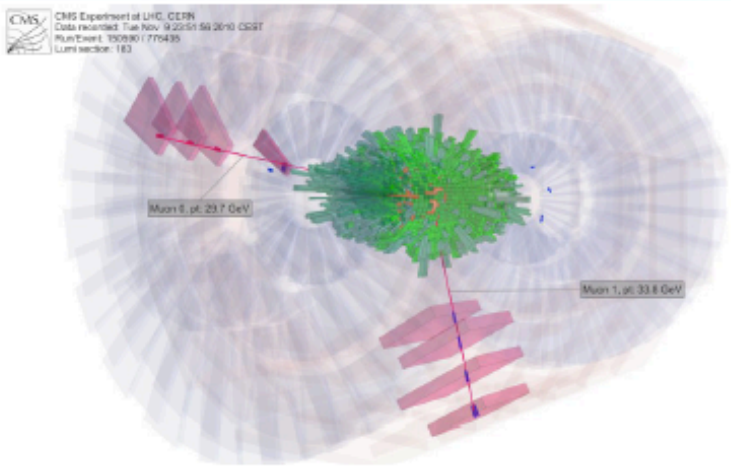


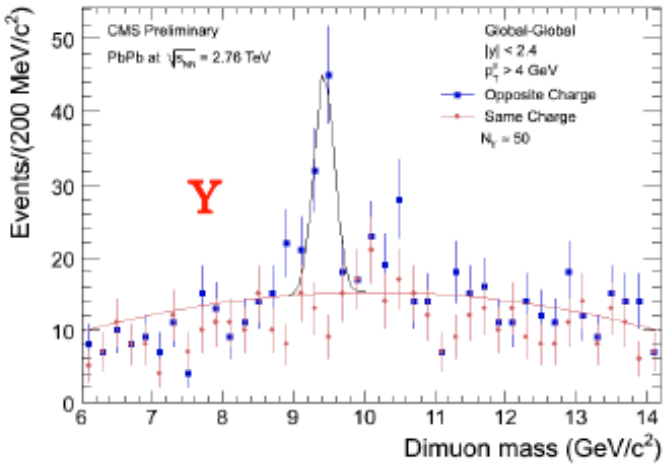
Excellent operation of
the accelerator and CMS
8.3 μb^{-1} of data collected

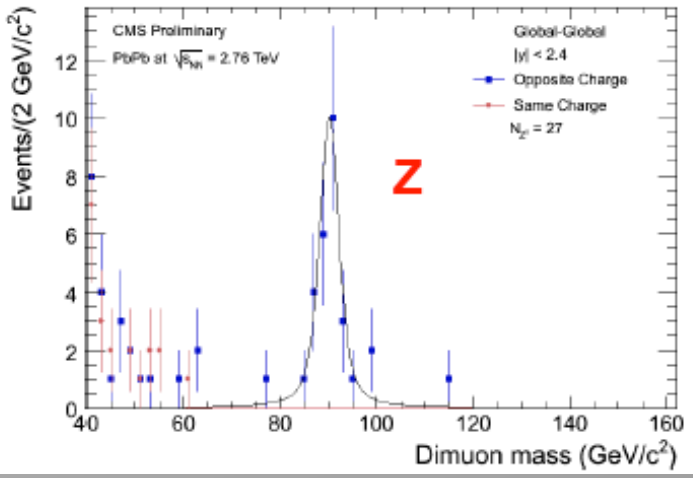
Di-muon signals in Heavy Ions

- Quarkonia should melt down in a quark gluon plasma
- Weak bosons are observed for the first time in HI collisions



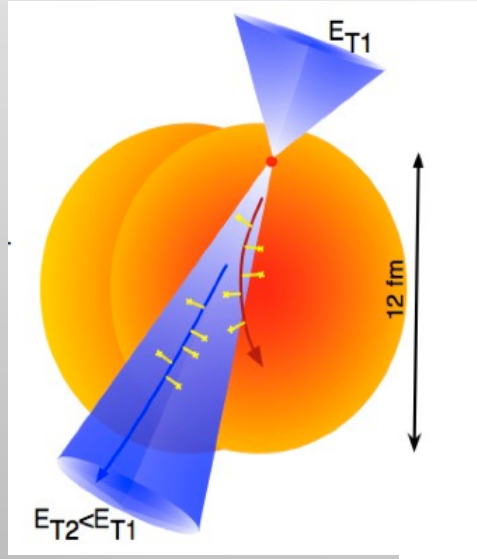




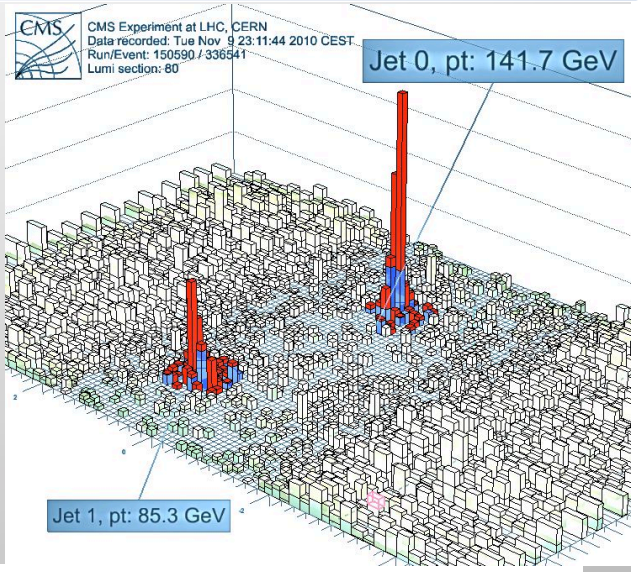


CMS will be able to study this in detail

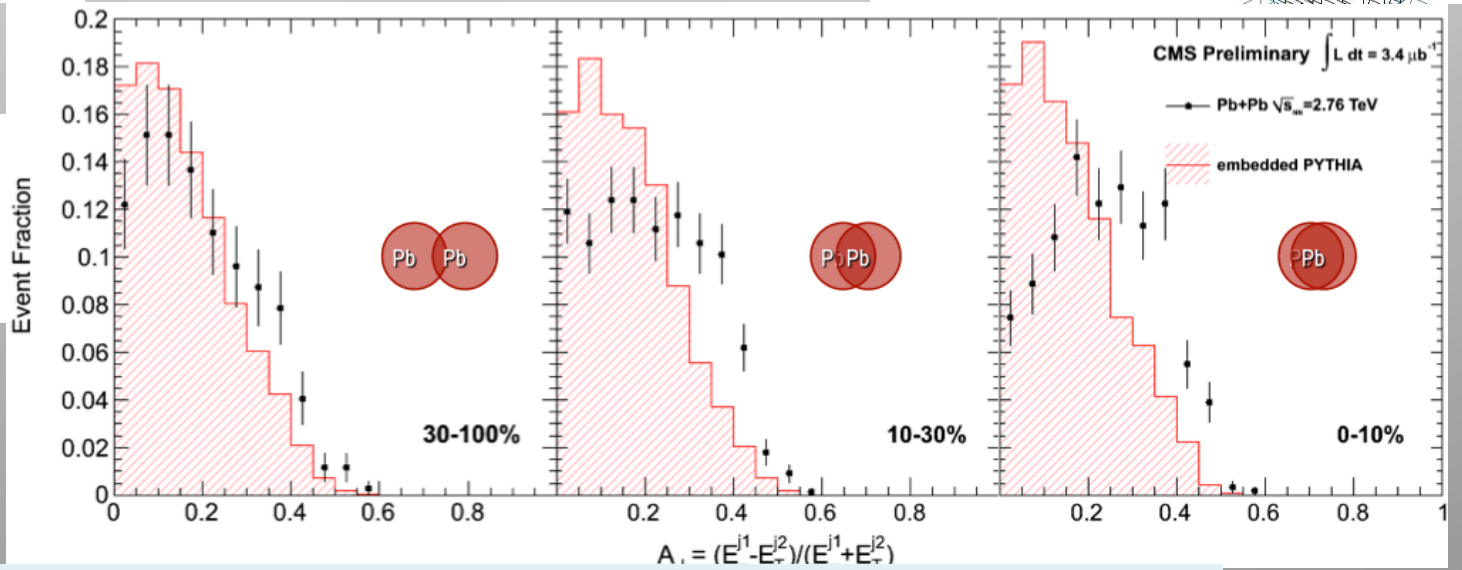
Dijet Energy Imbalance



- Strong quenching effects were observed in at RHIC for single particle spectra and particle correlations
- At the LHC one can fully reconstruct the jets!

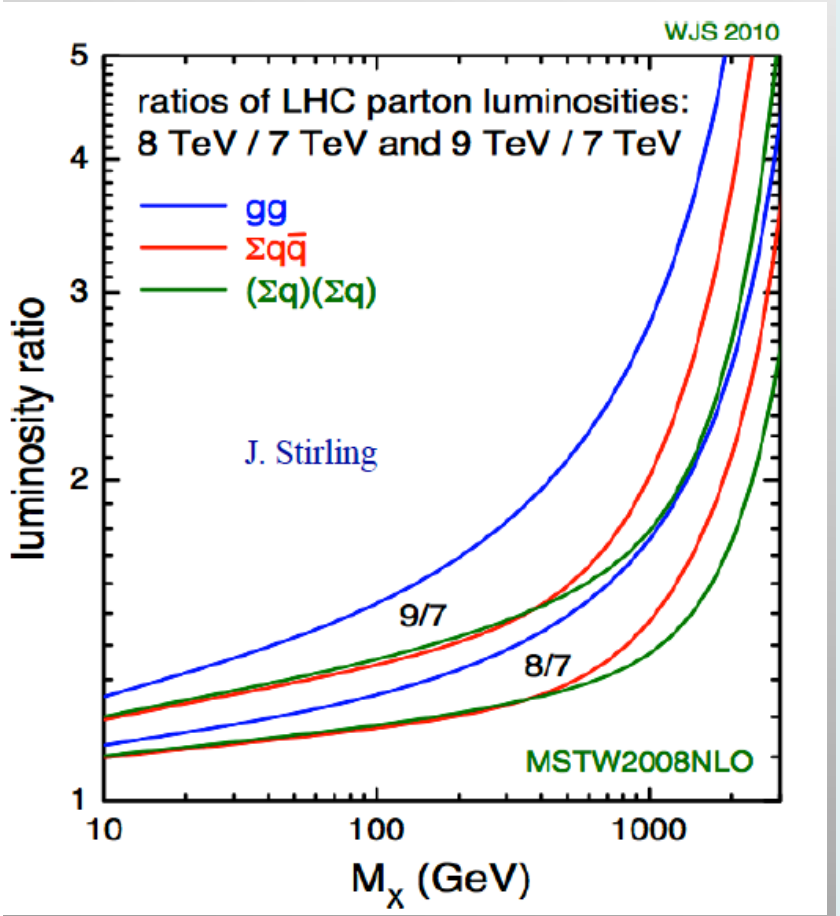


$$A_J = \frac{E_T^{j1} - E_T^{j2}}{E_T^{j1} + E_T^{j2}}$$



A significant dijet imbalance, well beyond that expected from unquenched MC, appears with increasing collision centrality

The Future: 2011 Run

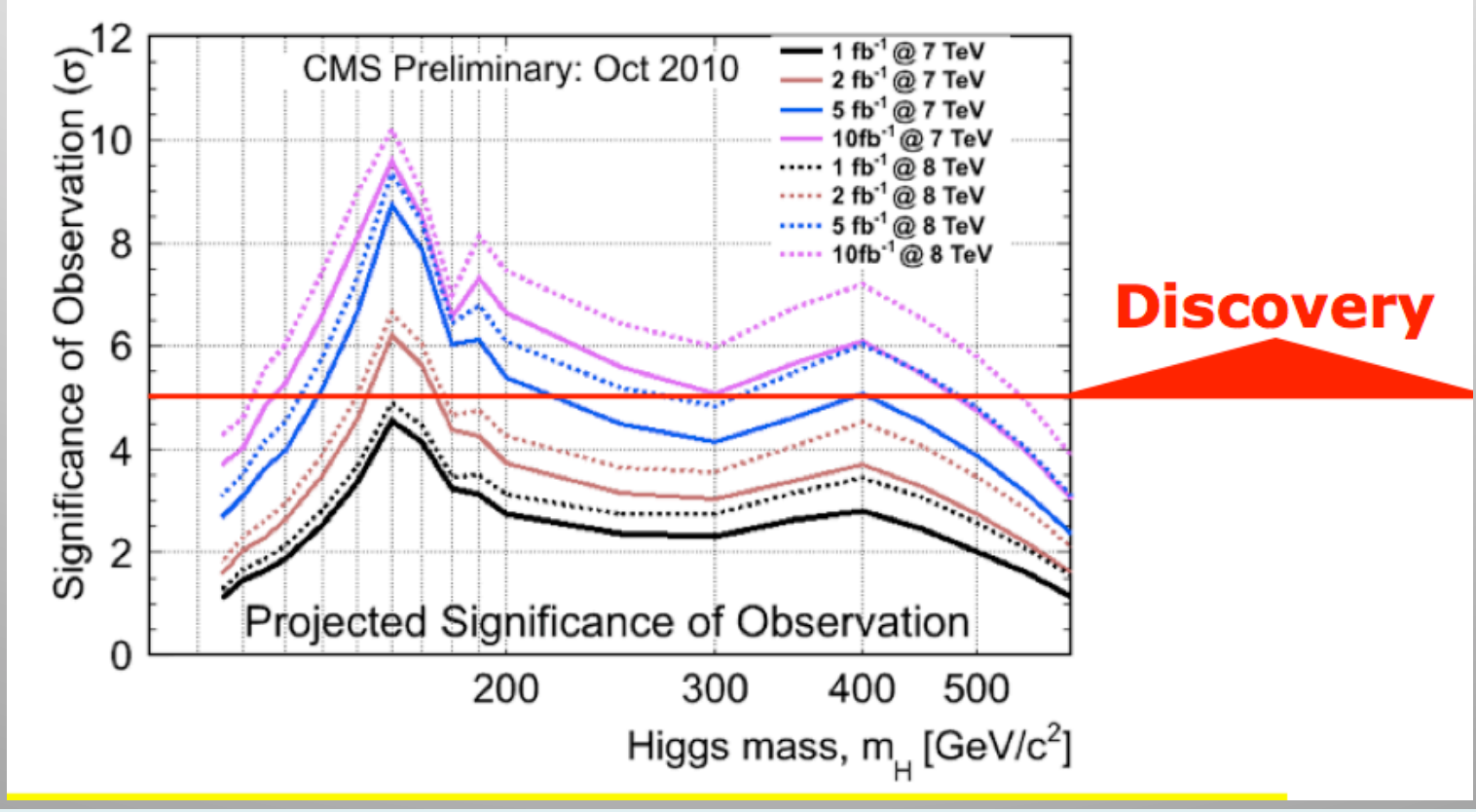


- As of 6 December: Technical stop for 11 weeks till February 18
- Next: Startup of the 2011 run
  - Continue in 2012 or start 1.5y shutdown?
- Minimal scenario: 7 TeV and 1 fb^{-1} of data by end of 2011, but:
- Higher energy (8TeV?) is being discussed
- Higher lumi?
  - More than 400 bunches (up to 900?)
  - Beta* (squeeze) from 3.5 m to 2 m?
- Decision at CERN this week!
- ⇨ A few fb^{-1}, perhaps 5 fb^{-1} /exp not excluded!

GOOD NEWS FOR HIGGS HUNTERS

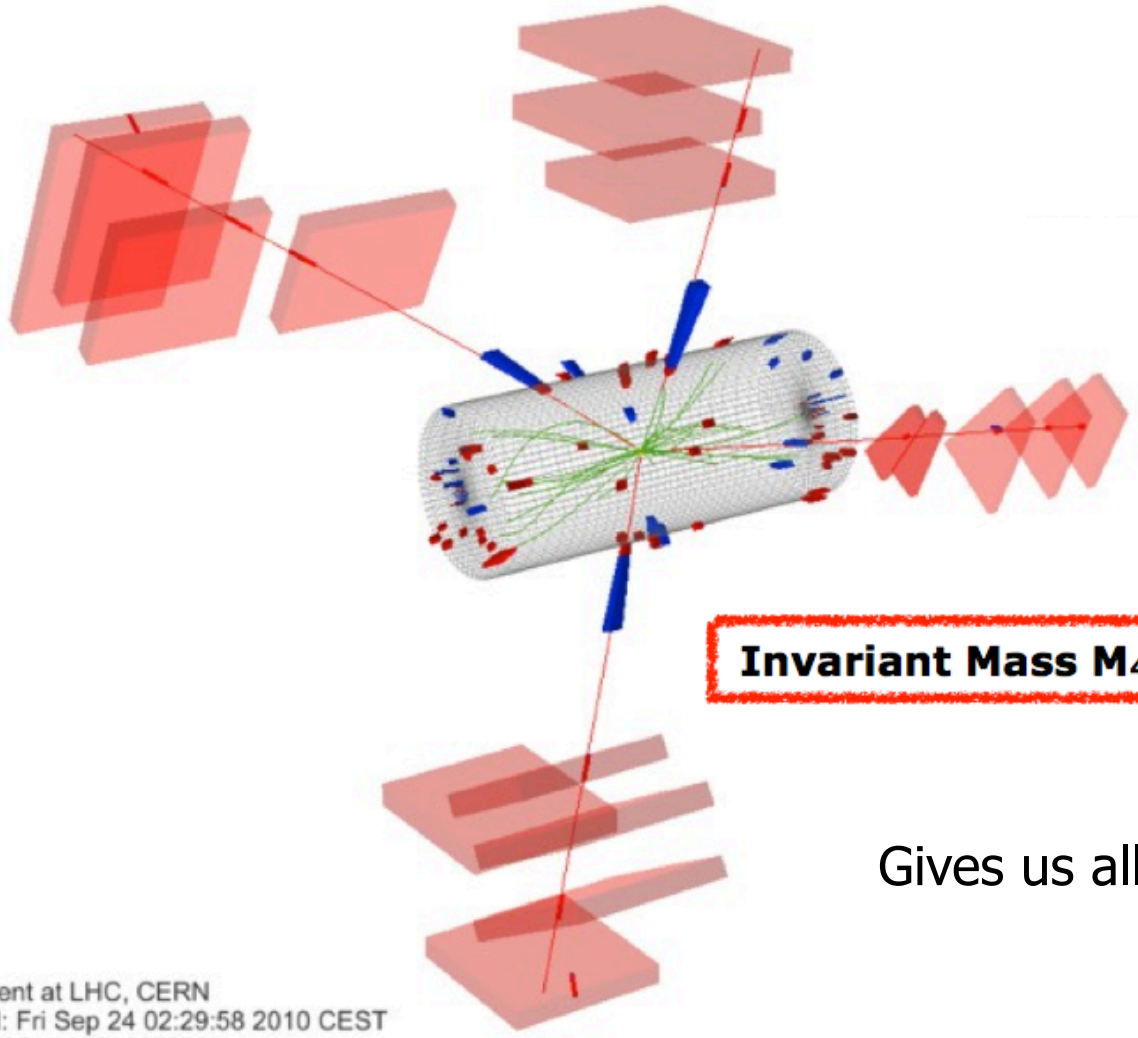
2011: Project Higgs!

New studies including more Higgs decay channels and for several machine scenarios



The hunt for the elusive Higgs boson will definitely start in 2011 at the LHC!!

An interesting event in the 2010 data: pp → ZZ +X →μμμμ + X



Gives us all hope… ☺

Summary: It's been a Great Year

- CMS is well advanced with the detector commissioning and calibration. CMS is being used for physics
- Physics papers being completed on the 2010 7 TeV collisions. Lots of results for ICHEP2010 on QCD, EWK, B-physics, and observation of the top. The first searches for new physics have been made, and most go already beyond the reach of the Tevatron.
- Search papers are now published on full 2010 statistics. No sign of new physics yet - but still looking..
- Mysterious correlations in high multiplicity events
- Direct observation of jet quenching in Heavy Ion collisions
- CMS is ready for the 'real game' ie searches for new physics, and for the Higgs…. Possibly already in 2011

Thank You