Results from the CMS Experiment
The March Meeting Attack

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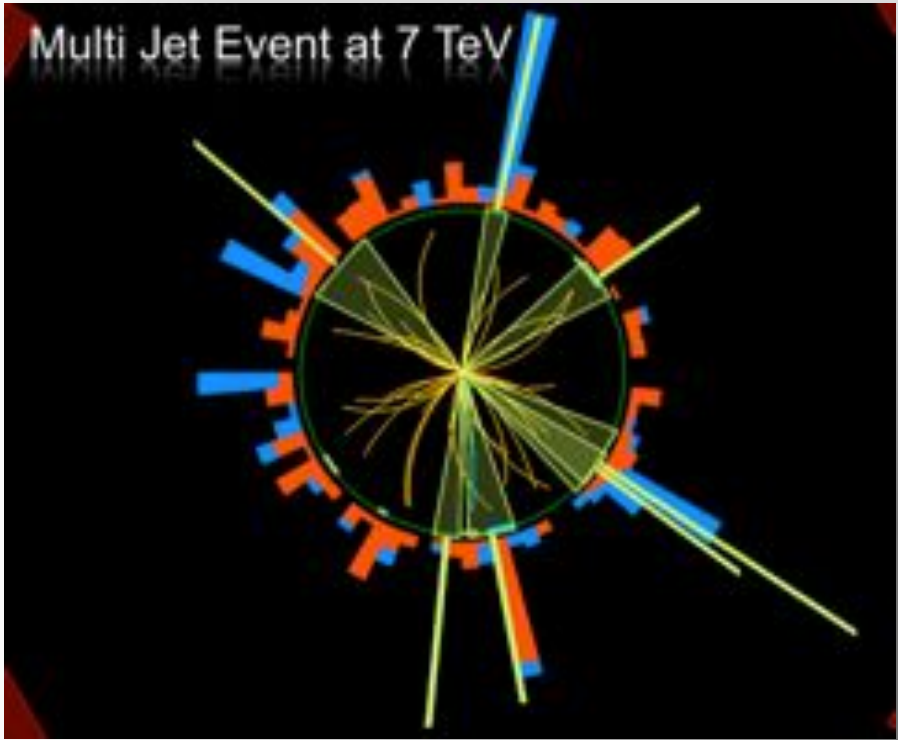
CERN, Geneva, Switzerland and

University of Antwerp & UC Davis & IPPP Durham UK

UCDAVIS PHYSICS



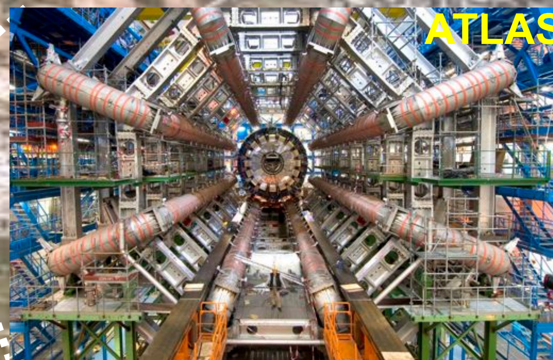
Outline

- Introduction
- LHC & CMS Operations
- New 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

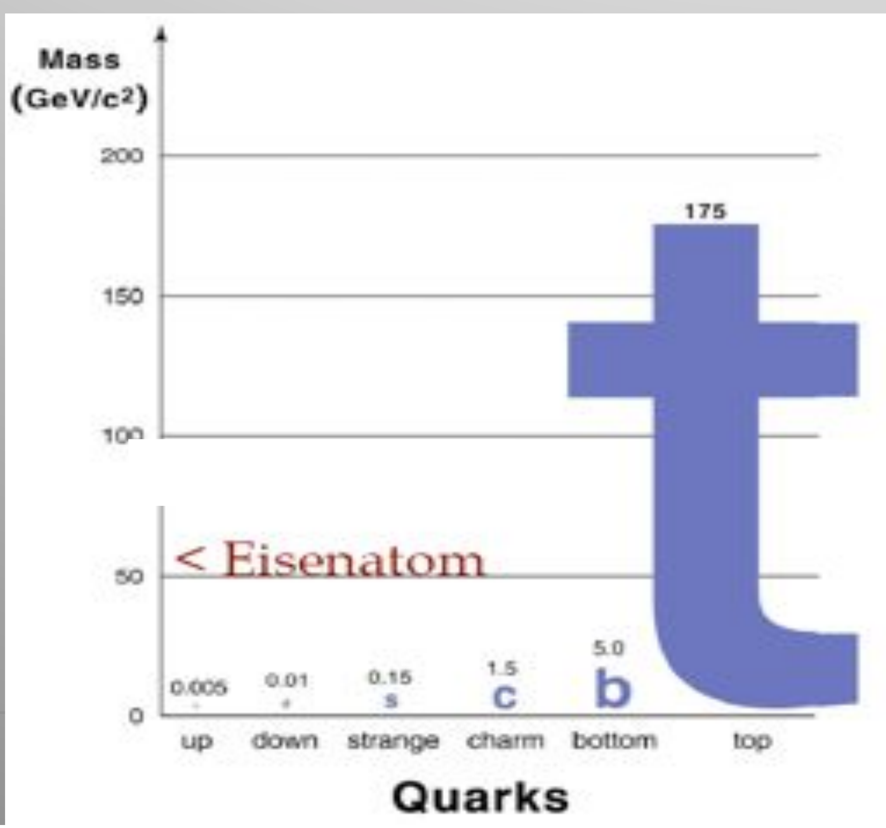


The Origin of Particle Masses

A most basic question is why particles (and matter) have masses (and so different masses)

Peter Higgs

The mass mystery could be solved with the 'Higgs mechanism' which predicts the existence of a new elementary particle, the 'Higgs' particle (theory 1964, P. Higgs, R. Brout and F. Englert)



The Higgs (H) particle has been searched for since decades at accelerators, but not yet found…

The LHC will have sufficient energy to produce it for sure, if it exists

Francois Englert

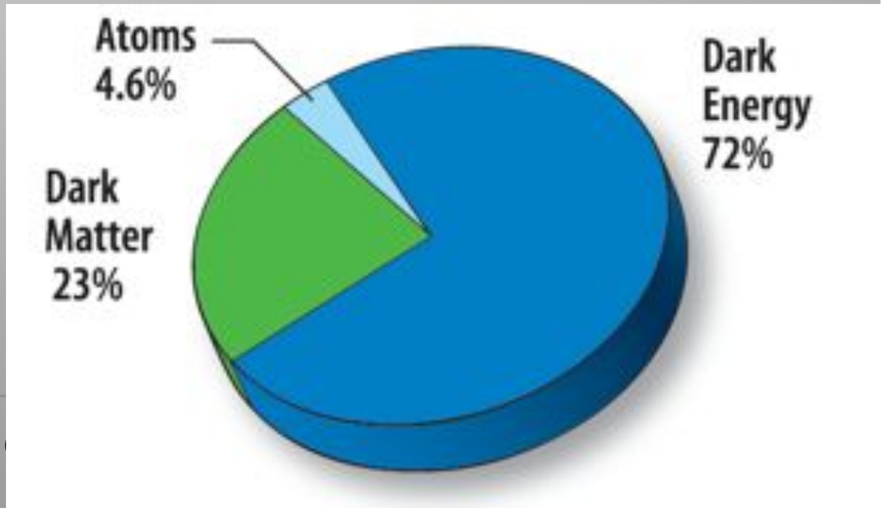
Dark Matter in the Universe

Astronomers say that most of the matter in the Universe is invisible Dark Matter

'Supersymmetric' particles ?

We shall look for them with the LHC


F. Zwicky 1898-1974

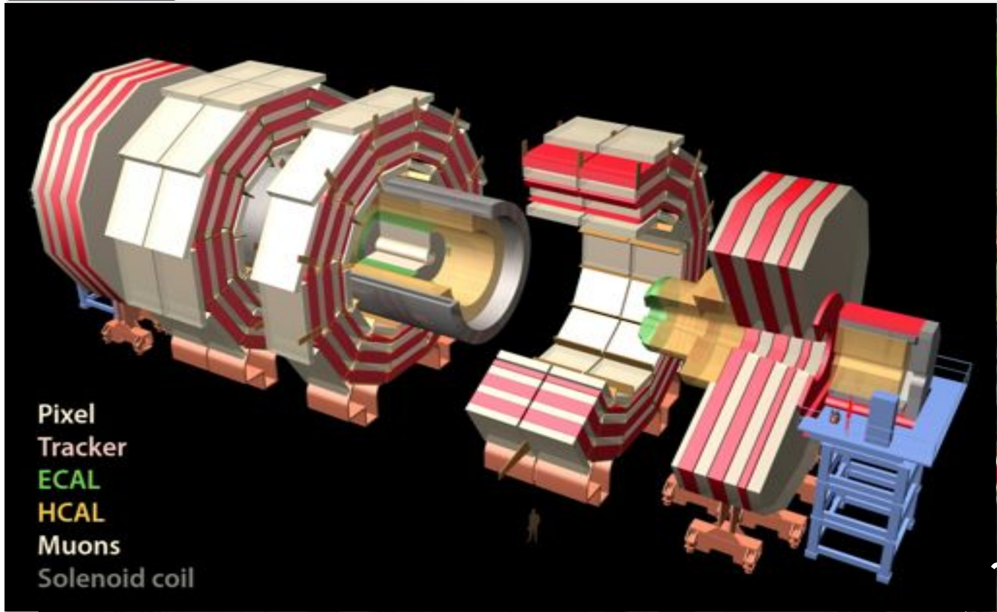


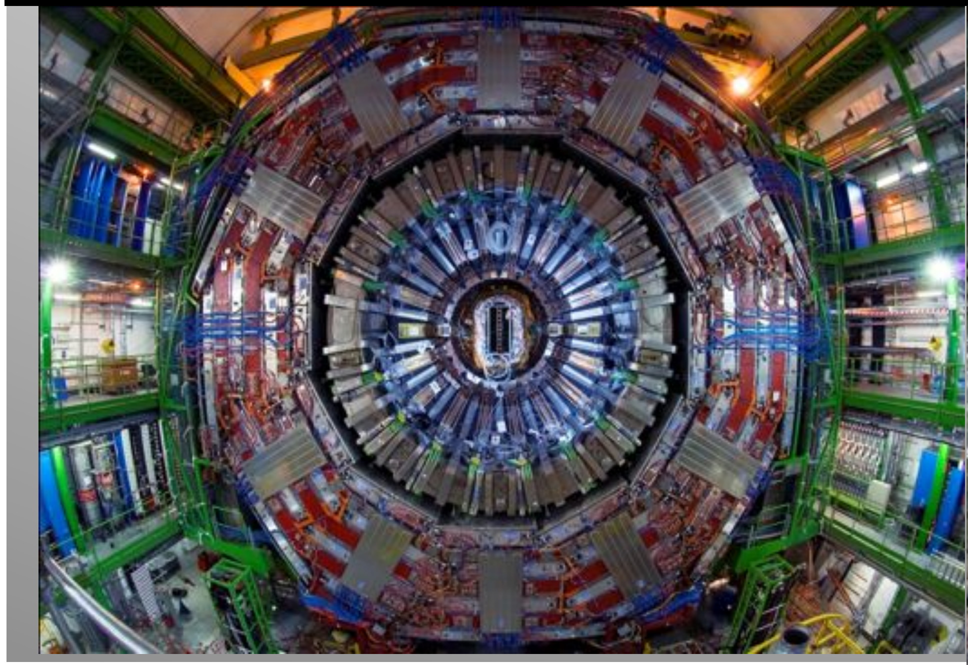
Beyond the SM? Ask a Theorist

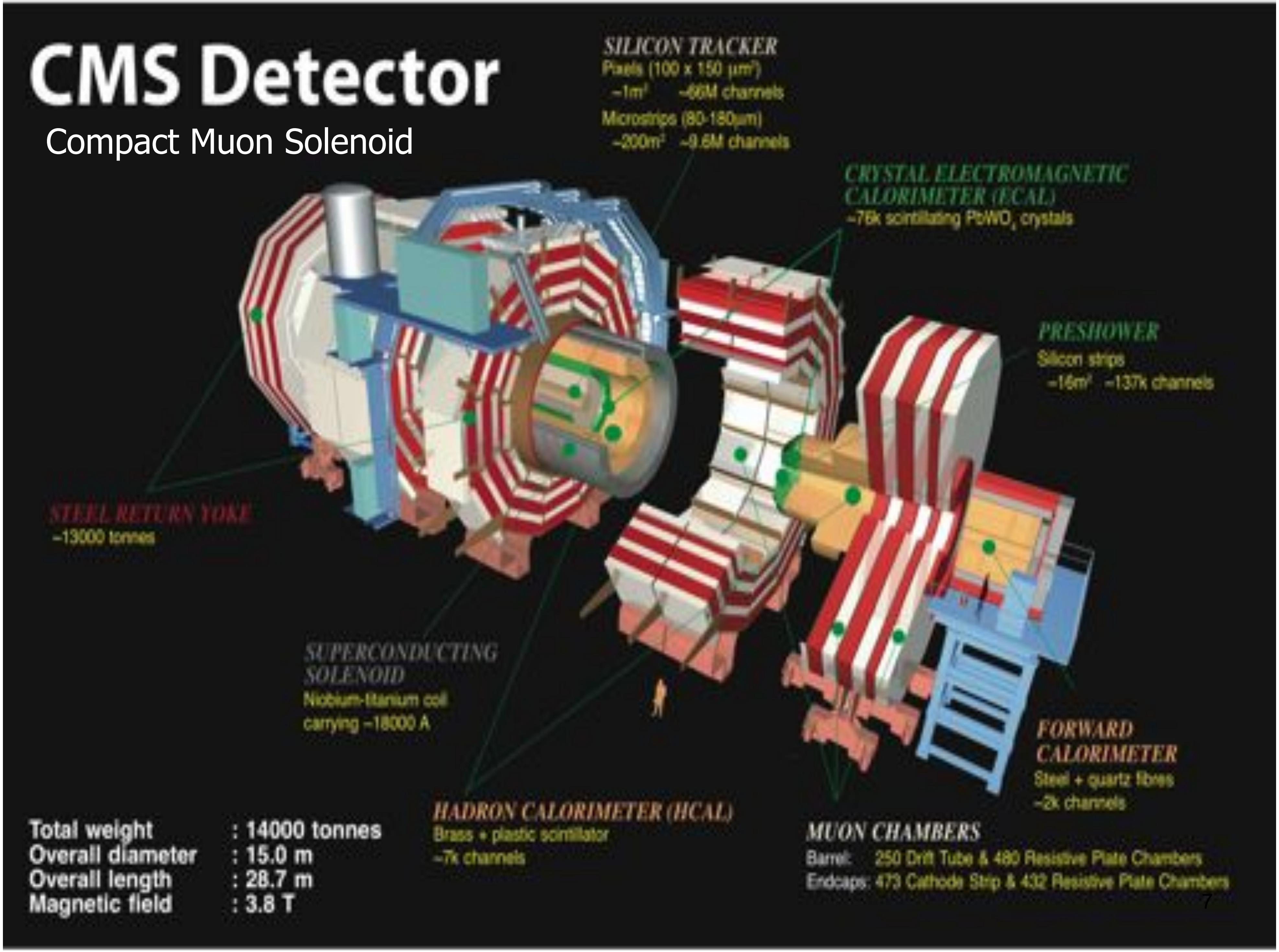
Or maybe not…☺

During the last 2-3 years we –LHC experimentalists- got more models to deal with than we needed…
Some theorists found it a challenge to invent a model with signatures difficult for the experiments:
heavy stable charged particles, hidden valley models, Quirks…

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

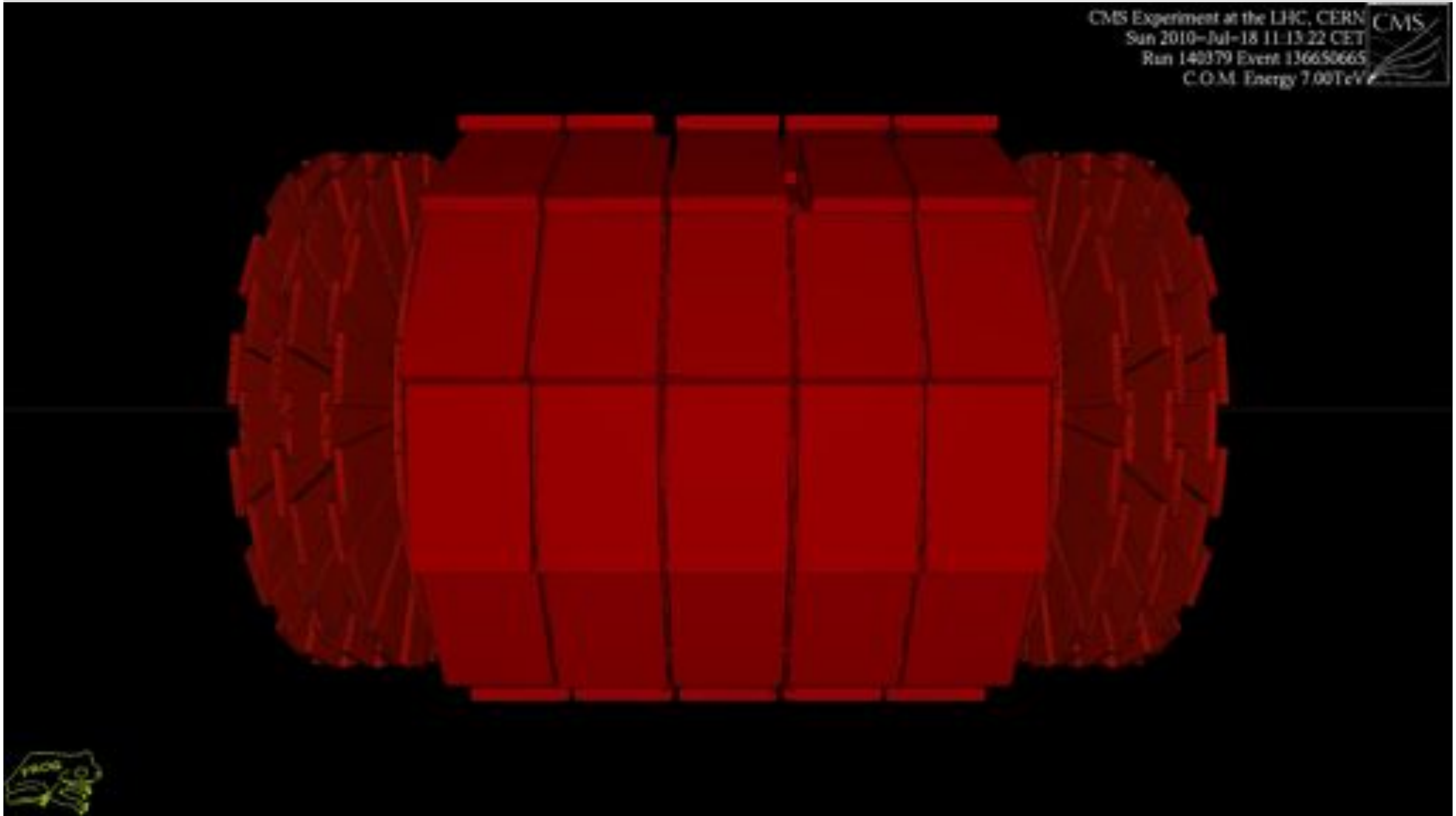




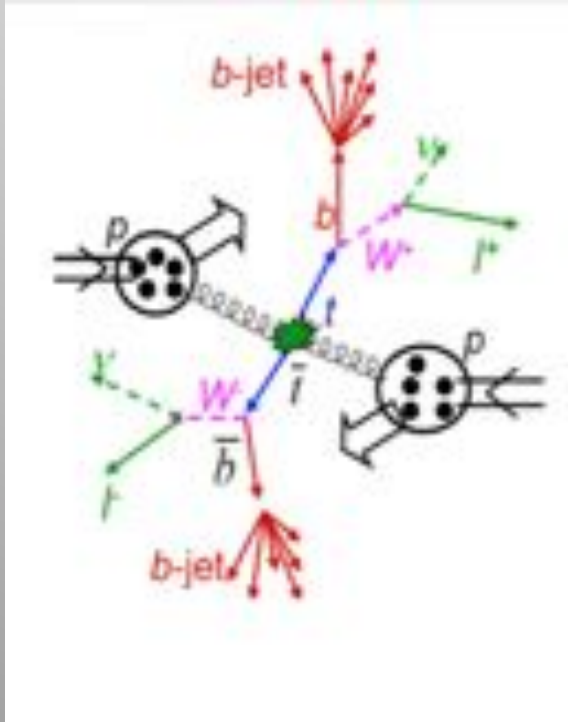

CMS Detector
Compact Muon Solenoid
SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating PbWO₄ crystals
PRESHOWER
Silicon strips
~16m² ~137k channels
STEEL RETURN YOKE
~13000 tonnes
SUPERCONDUCTING 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

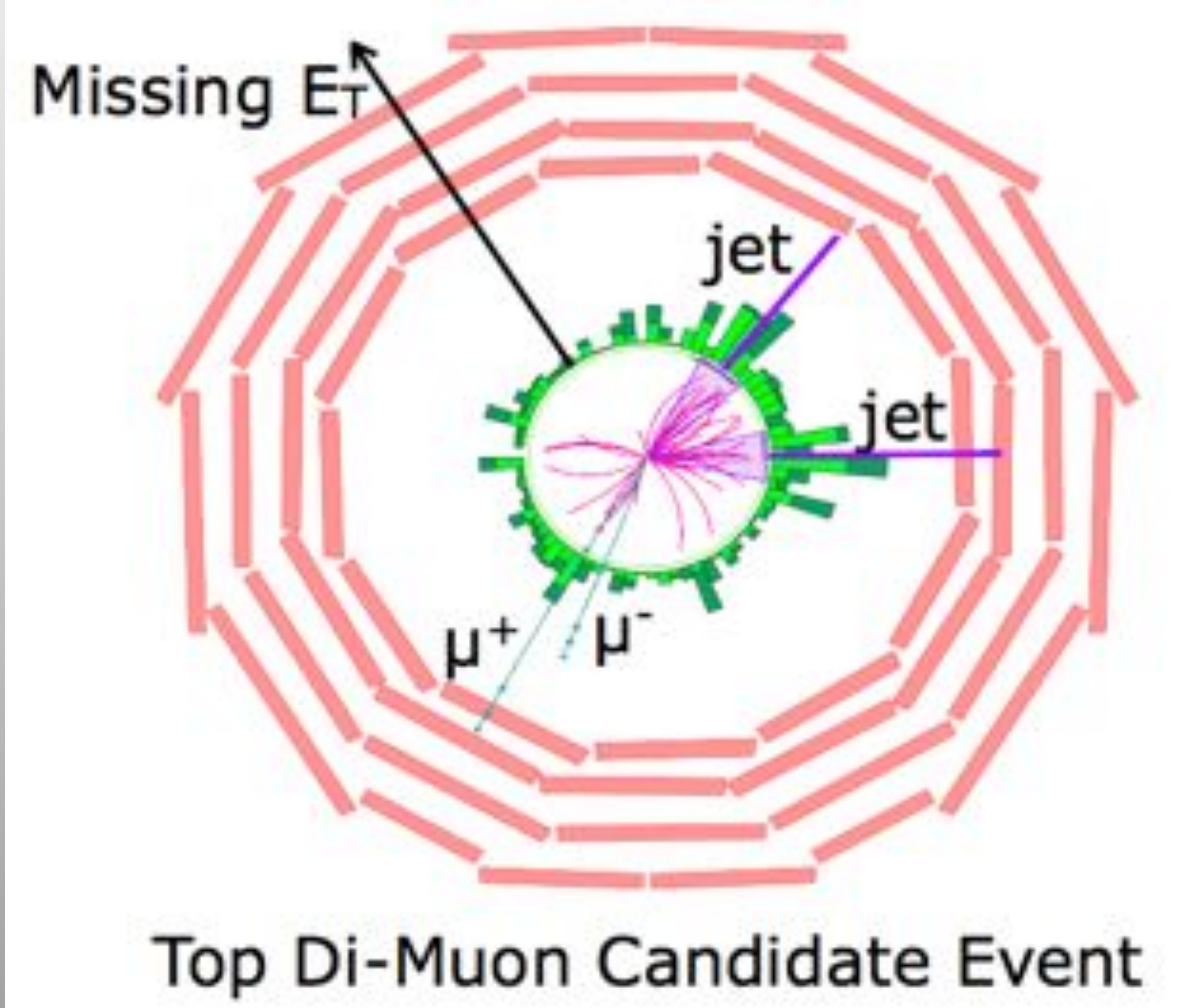
Great Moments

Some of the key moments the last years

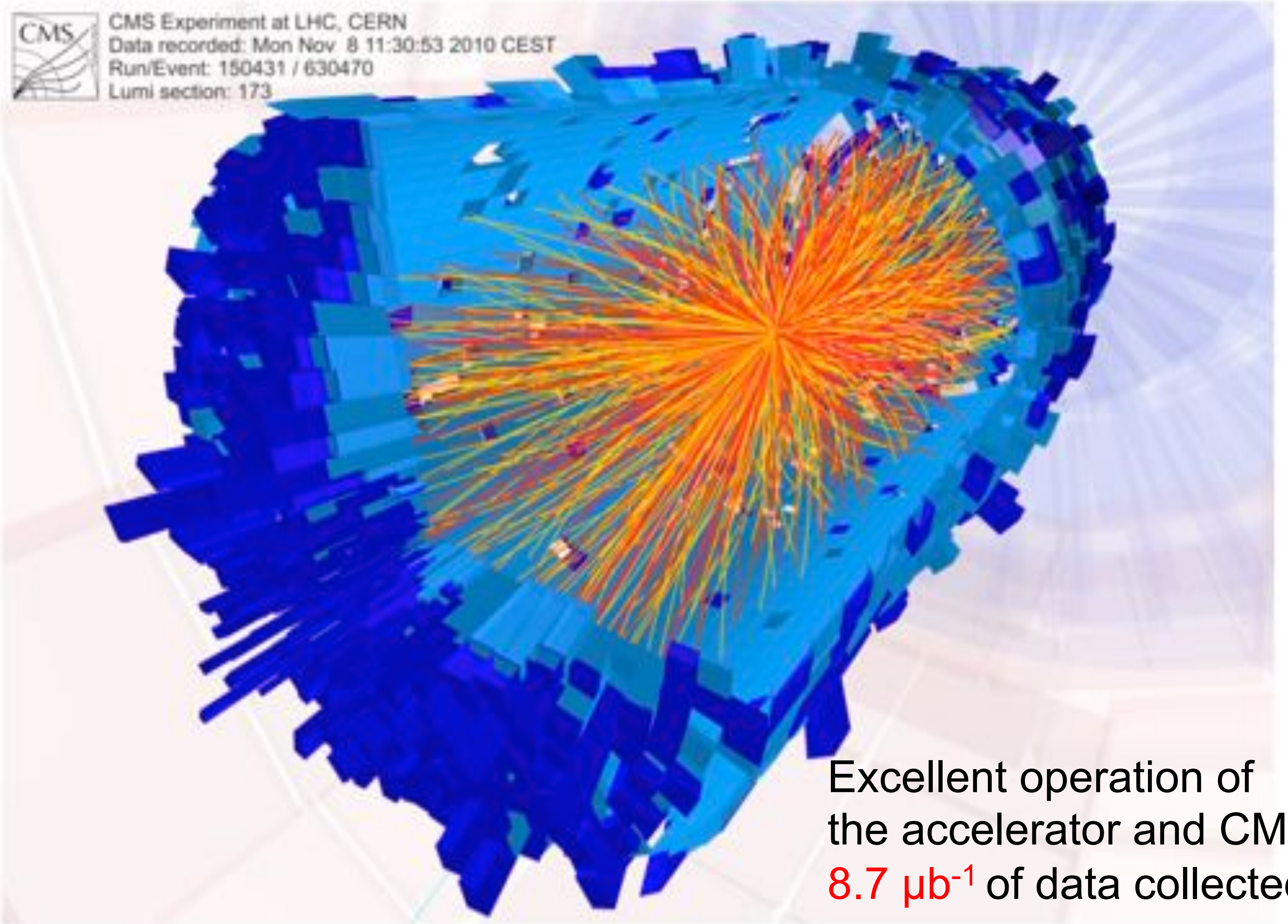

CMS Experiment at the LHC, CERN
Sun 2010-Jul-18 11:13:22 CET
Run 140379 Event 136650665
C.O.M. Energy 7.00TeV

Candidate Event for Top Production





November: Heavy Ion Collisions

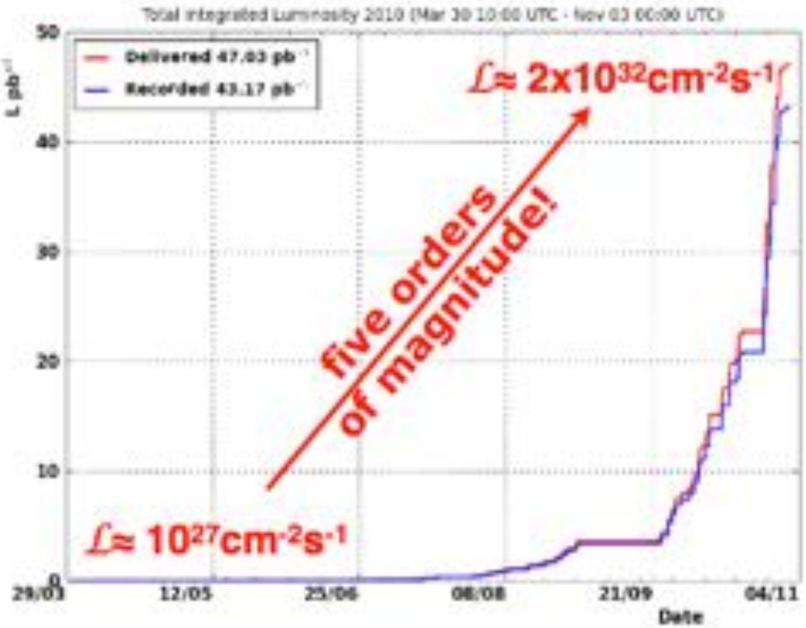


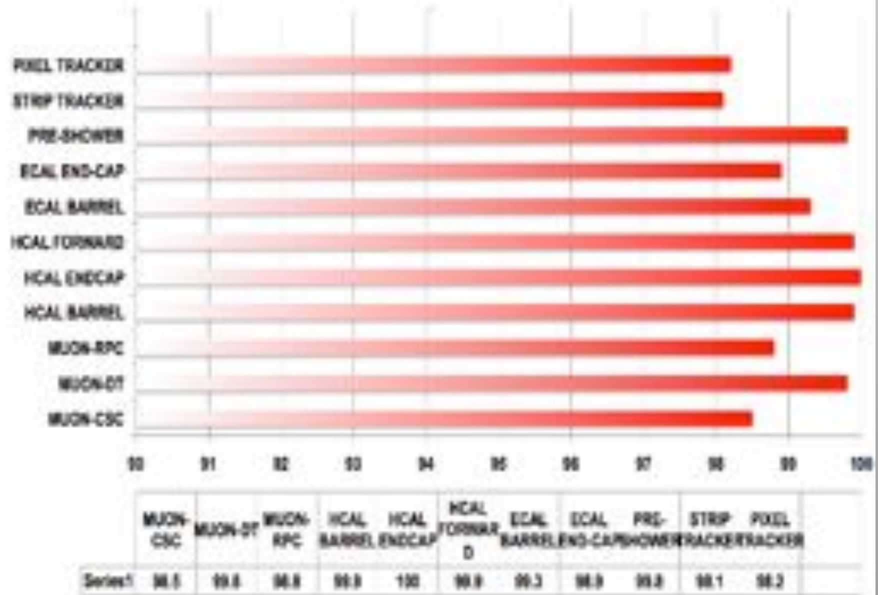
Excellent operation of the accelerator and CMS

8.7 μb^{-1} of data collected

2010: Luminosity and Operation

- ~47pb^{-1} delivered by LHC and ~43pb^{-1} collected by CMS ($\varepsilon \approx 92\%$)
- 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!





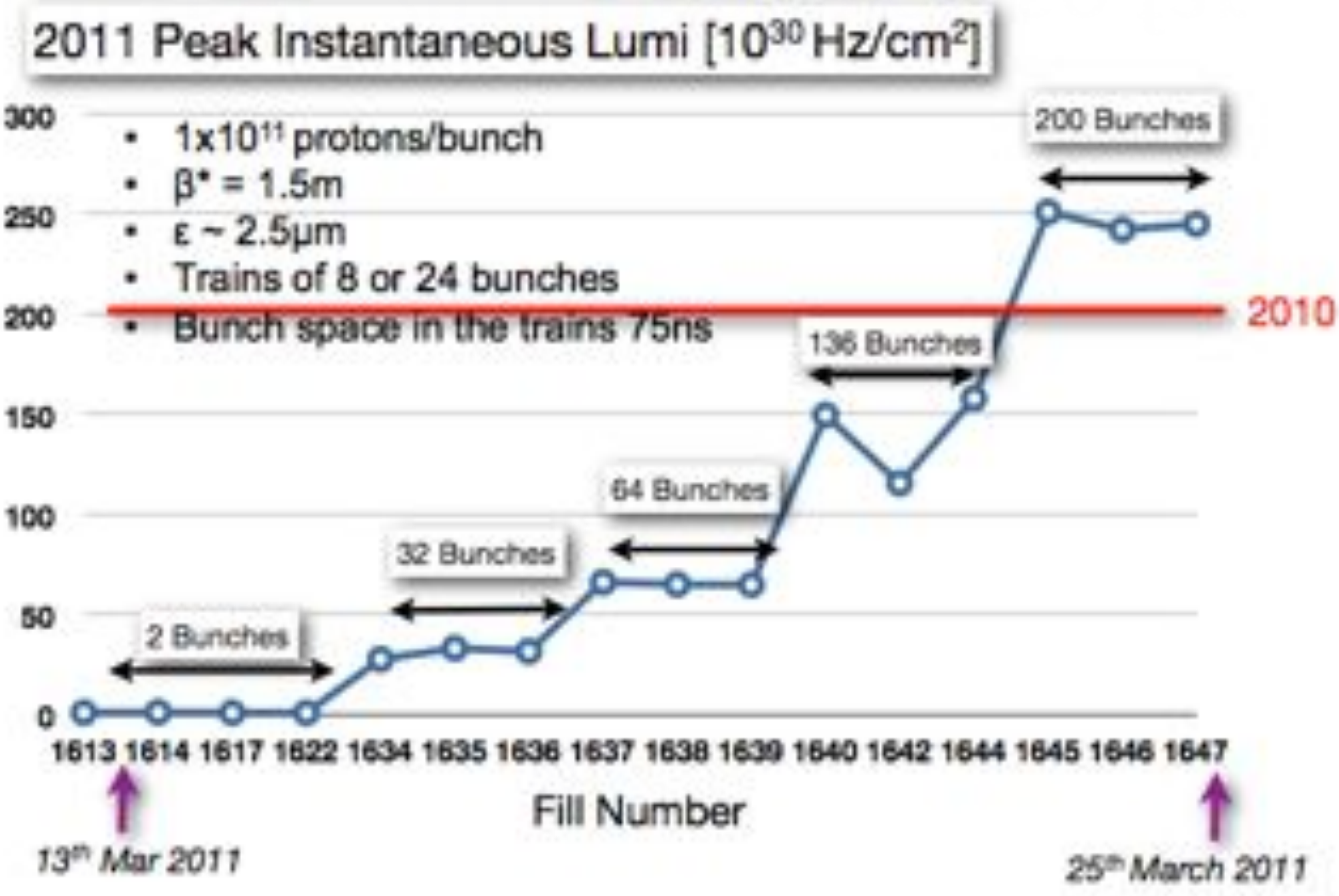
- Max instanteneous luminosity now ~ $2.04 \cdot 10^{32}cm^{-2}s^{-1}$
- The aim for this year was $10^{32}cm^{-2}s^{-1}$…

LHC Start-up in 2011

- LHC teams worked very efficiently from 20th Feb until 13th March on commissioning the LHC for the new settings

- Main changes with respect to last year:
  - Beta*=1.5m (instead of 3.5m)→ pile up will be more than twice
  - Will operate with 75 ns (or 50ns) spacing between the bunches→ last year 150 ns
    - Max: 936 bunches (75ns) or 1400 bunches (50ns)
  - Optimization of the turnaround time: aim for ~2h between two stable beams
    - Ramp up/down ~20min, squeeze in 10 min

LHC 2011 Operation so far



936 bunches/10^{33} $cm^{-2}s^{-1}$ by end of April? ➔ 1 fb^{-1} already by this summer!!

Expected Performance

Intensity ramp-up

- 32 bunches $\mathcal{L} \approx 0.35 \times 10^{32} cm^{-2}s^{-1}$
- 64 bunches $\mathcal{L} \approx 0.7 \times 10^{32} cm^{-2}s^{-1}$
- 136 bunches $\mathcal{L} \approx 1.6 \times 10^{32} cm^{-2}s^{-1}$
- 200 bunches $\mathcal{L} \approx 2.5 \times 10^{32} cm^{-2}s^{-}$

If we extrapolate up to 936 bunches

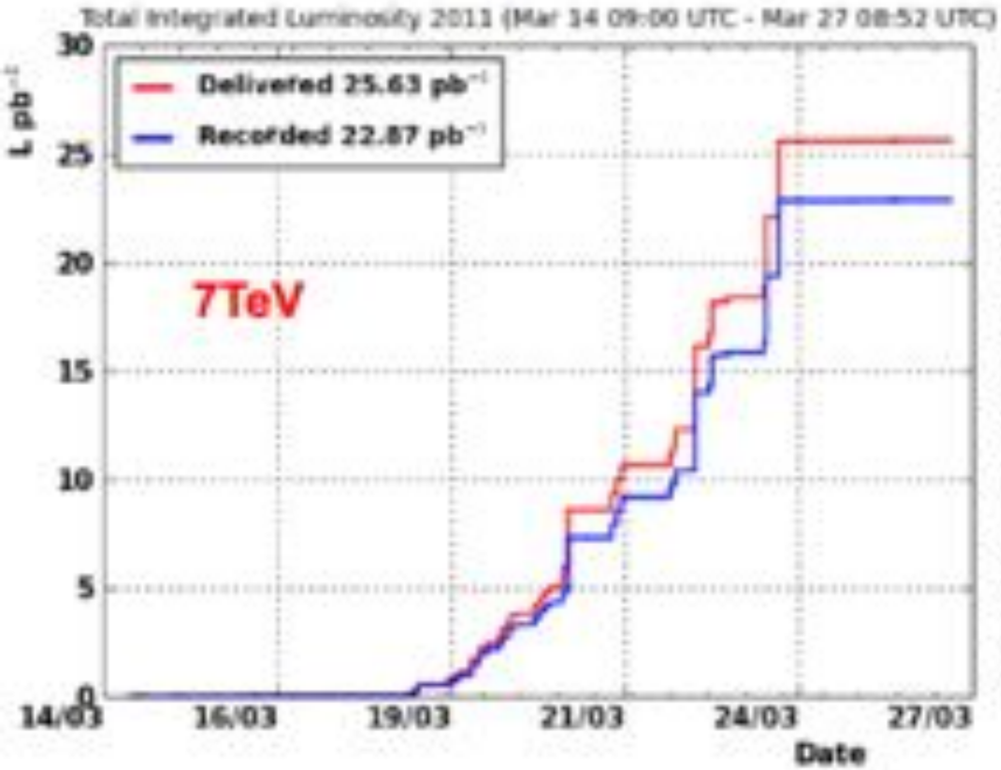
$\mathcal{L} > 1 \times 10^{33} cm^{-2}s^{-1}$ in April?!

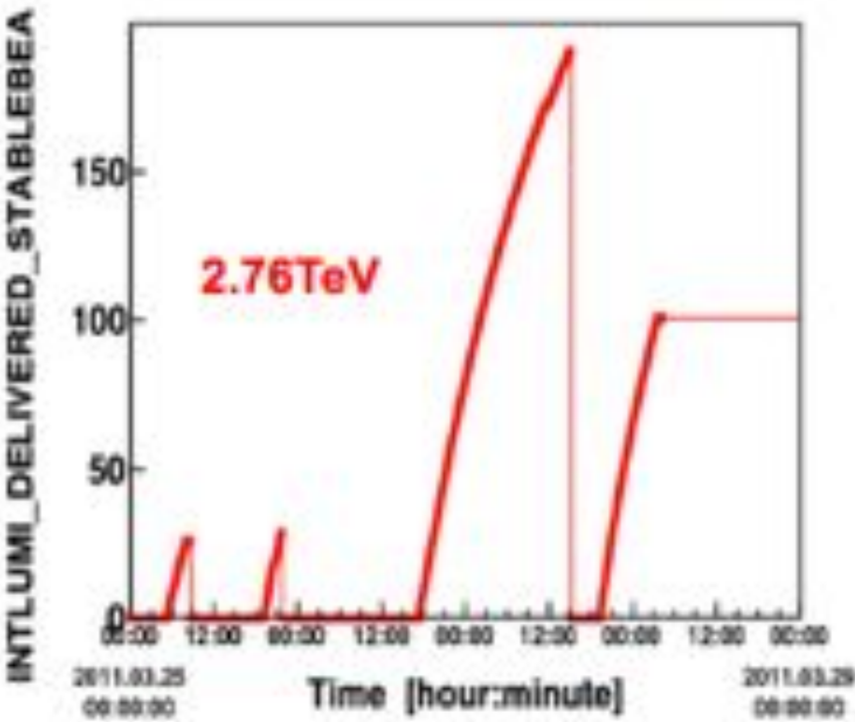
but scrubbing, SEU, unknowns etc

If **10^{33}** achieved by the end of April **~1fb^{-1}** before the end of June becomes a realistic goal.

Delivered so far in 2011

~26pb⁻¹ delivered by LHC at 7 TeV and **~23pb⁻¹** collected by CMS. Overall data taking efficiency **~89%.** Many calibration and timing runs

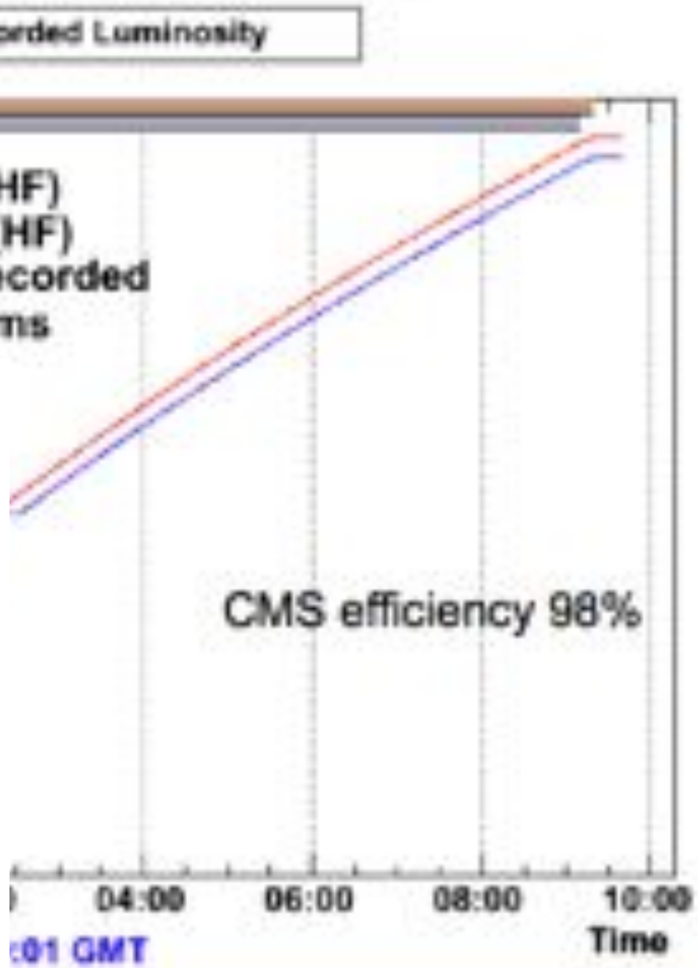




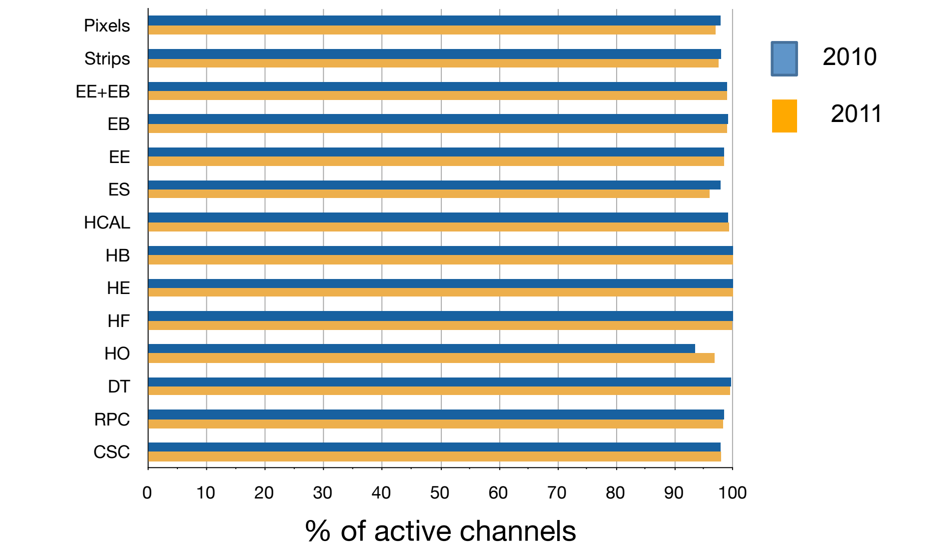
~345nb⁻¹ delivered at low energy (2.76TeV) **~330nb⁻¹** recorded by CMS

Efficiency of the experiment

~7pb-1 delivered in one fill with peak lumi at the beginning of the fill ~2.5×10^{32} Hz/cm^2

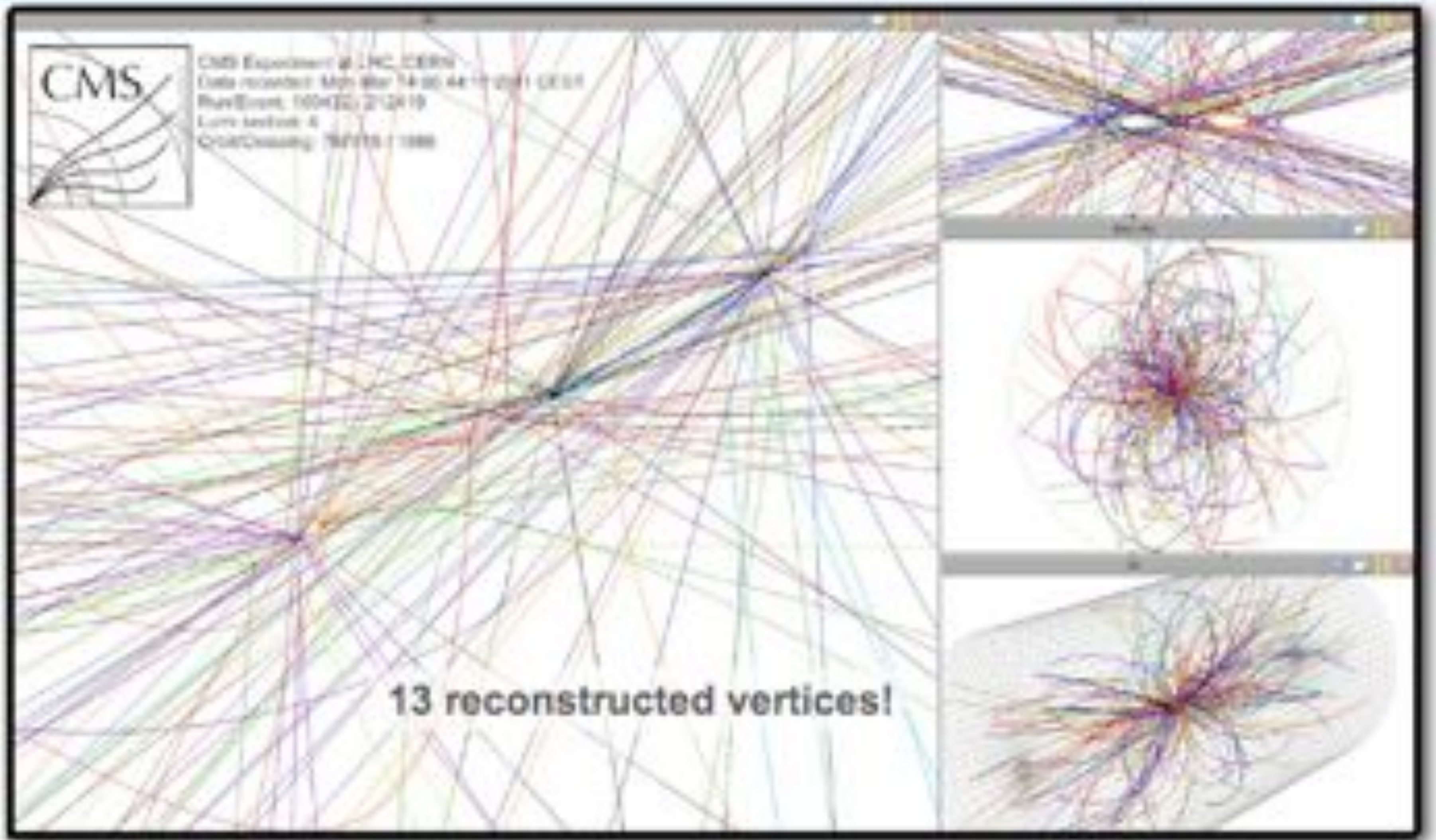


Fraction of CMS alive channels



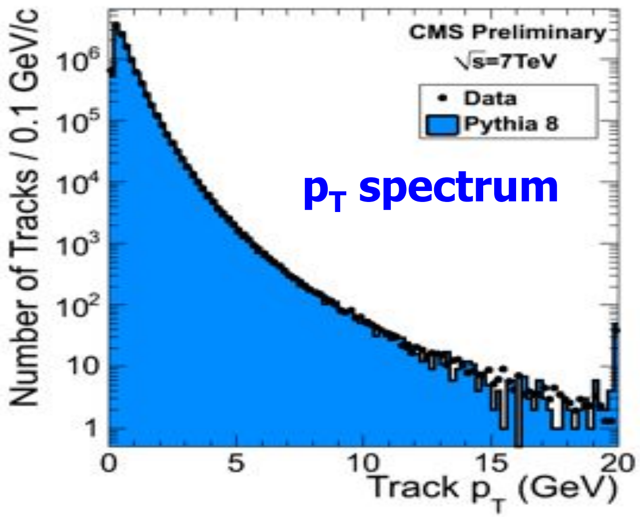
The experiment is alive and well!!

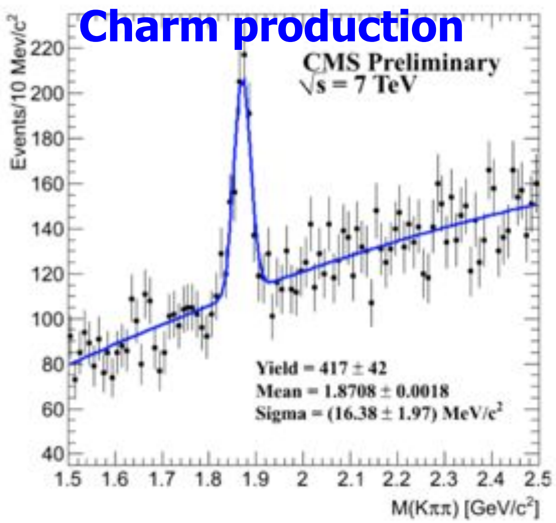
The New Challenge

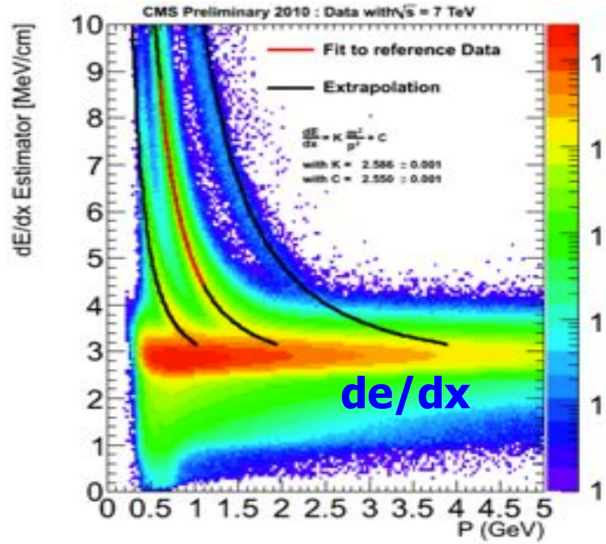


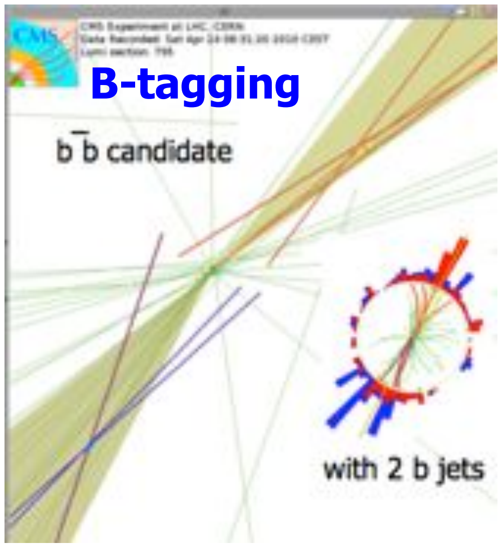
Pile-up!!!

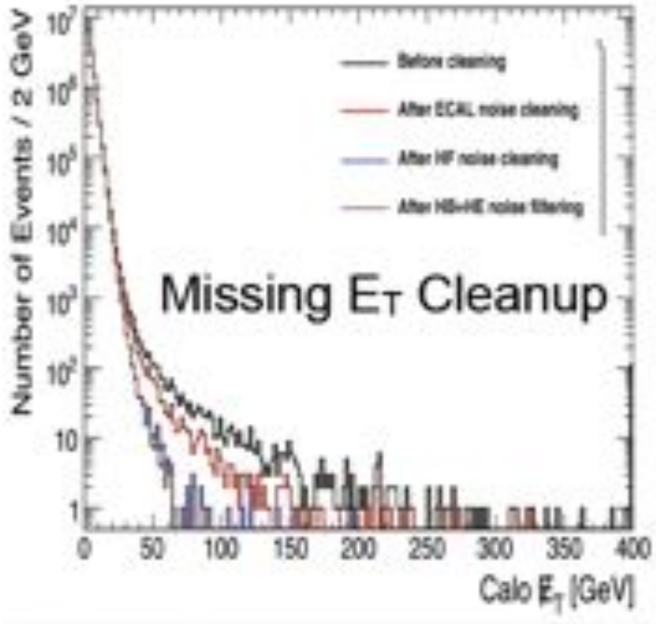
Detector Performance: Tracks & Jets

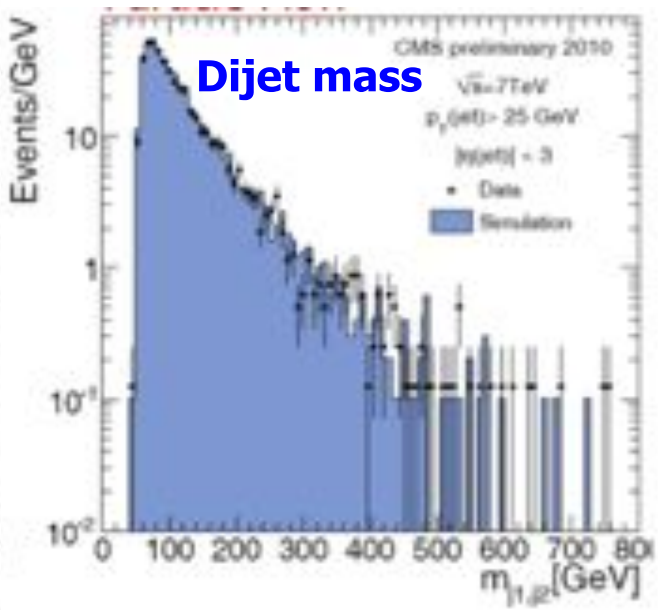






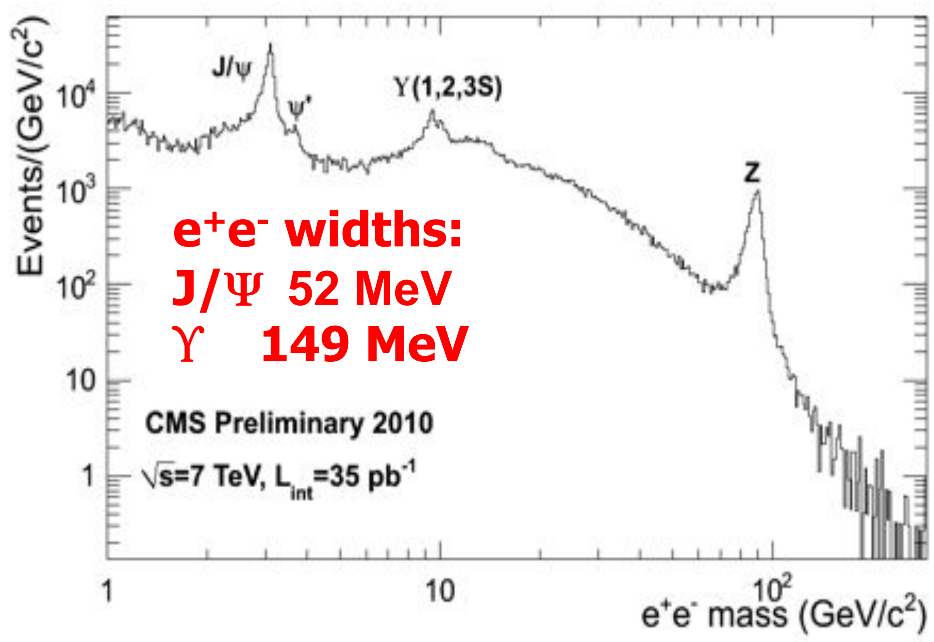


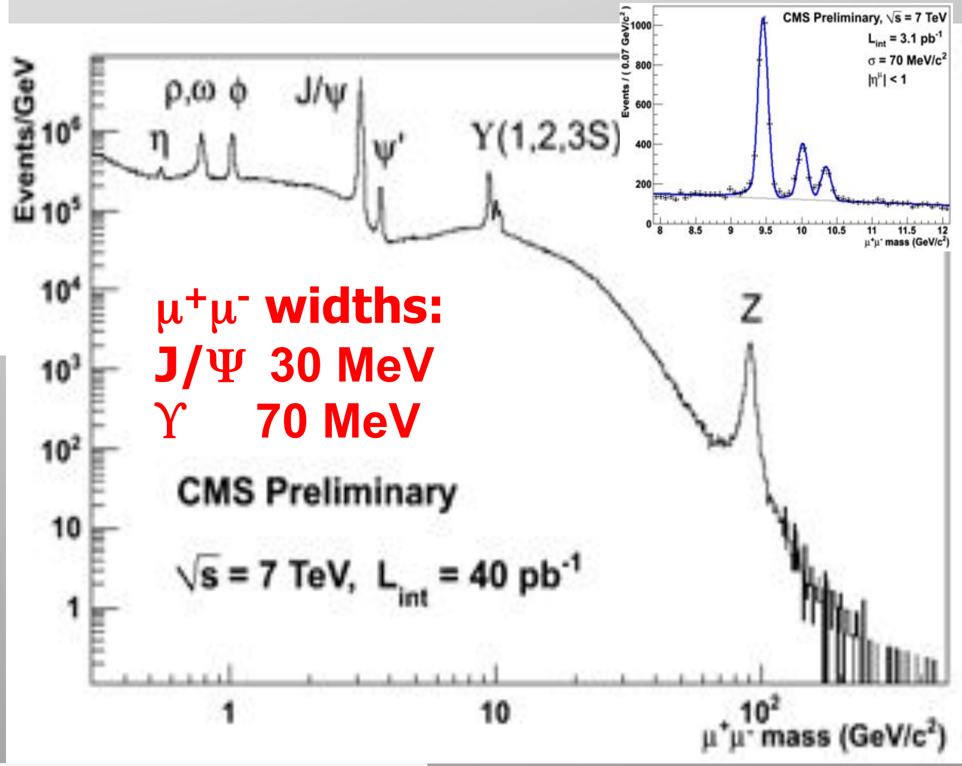




Re-discovery of Standard Model at 7 TeV

Di-electron and di-muon invariant mass spectra

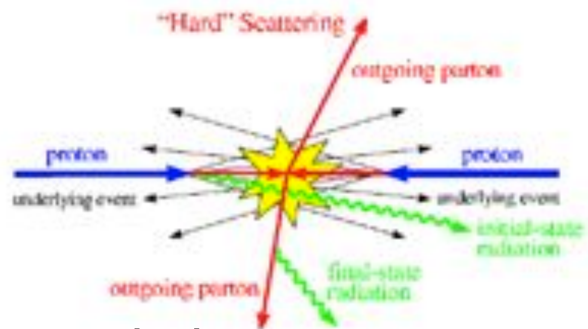




The CMS detector works beautifully!!!

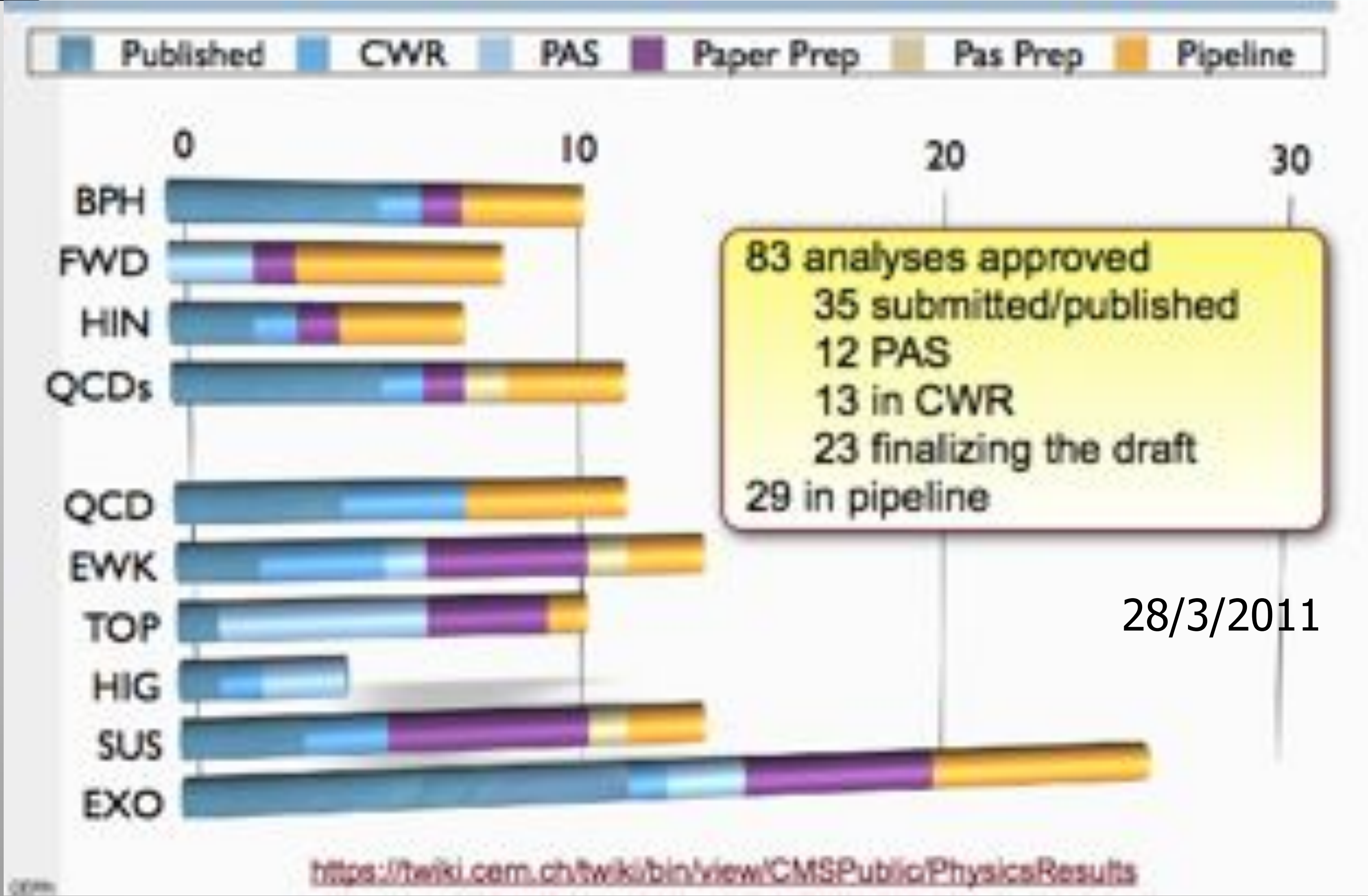
Physics Results

- Studies of general characteristics of minimum bias events (our future pile-up)
- Study of the underlying event in collisions with a hard scattering
- Resonances/known particles
- 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

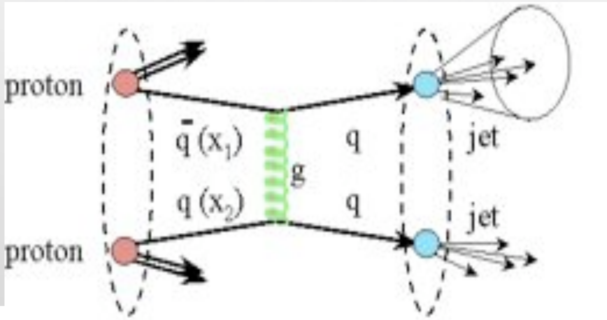
Physics Results



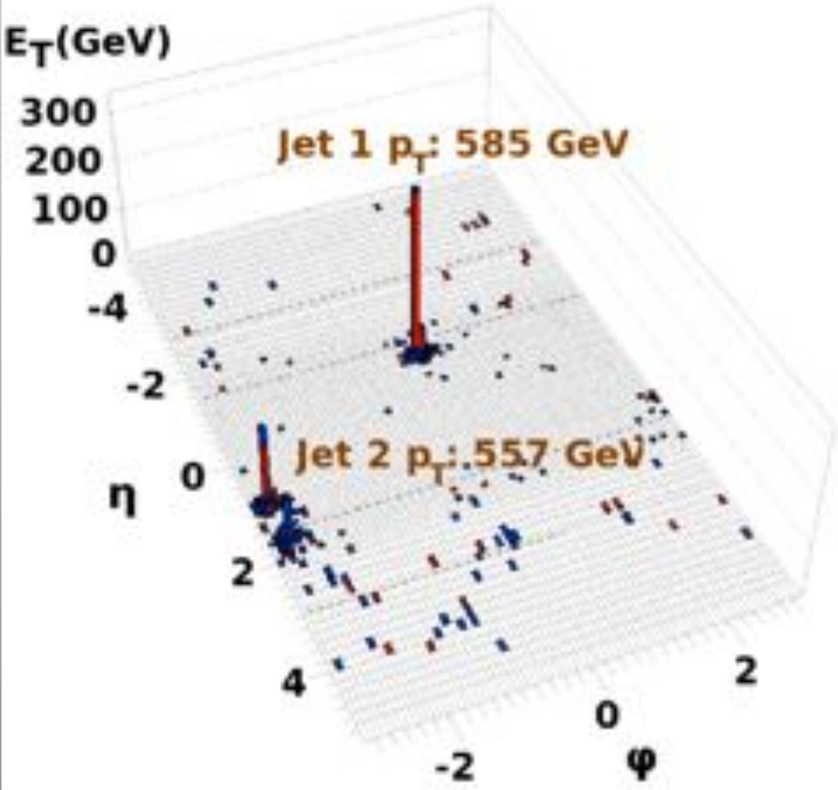
28/3/2011

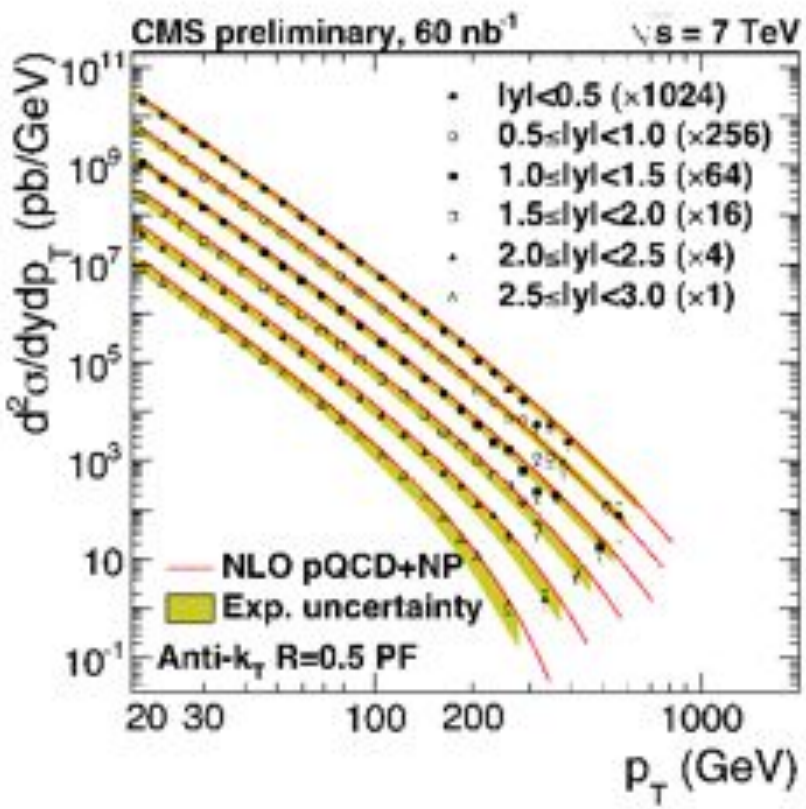
Standard Model

Jet Production at 7 TeV



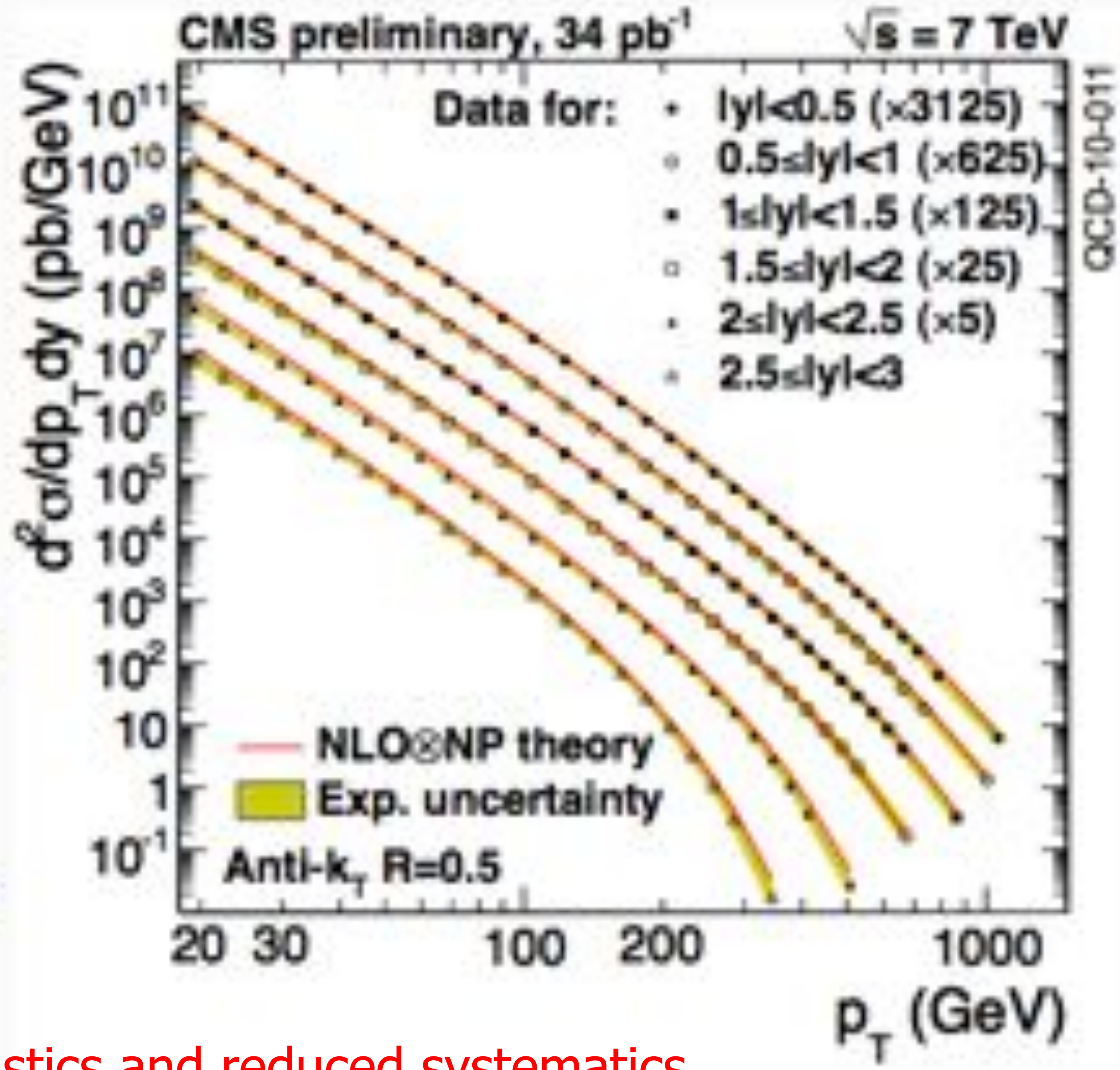
ICHEP 2010





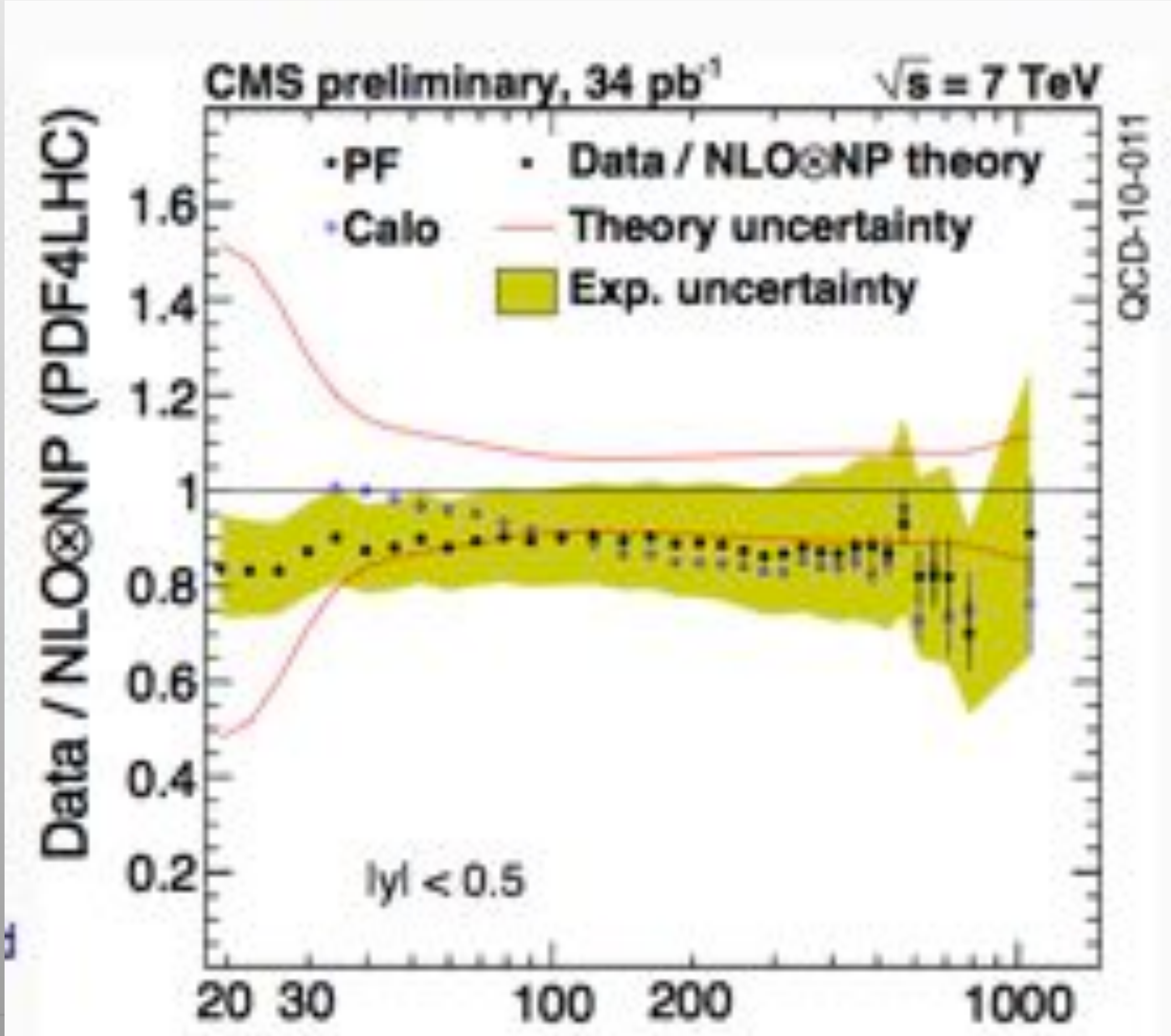
Inclusive Jet Cross Sections

- From p_T=18 GeV to p_T~1 TeV!
- Extending to very low p_T thanks to Particle Flow
- JES uncertainties: ~3-5 %
- Corrected to particle level
- Inclusive jet p_T spectra are in **good agreement with NLO QCD**
- Consistent results obtained using calo-jets

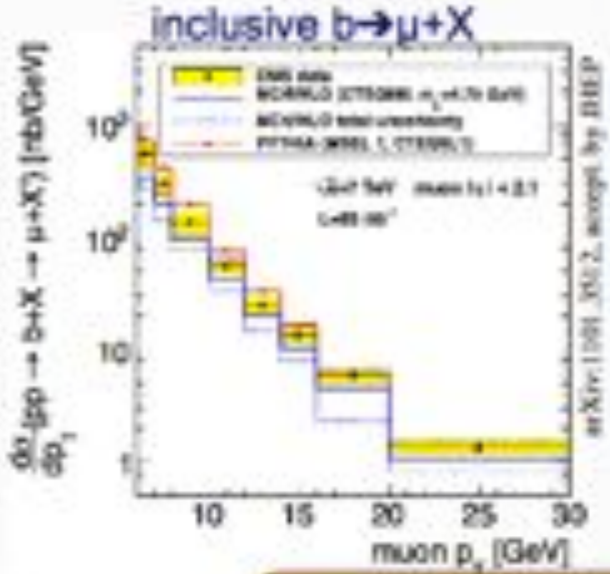


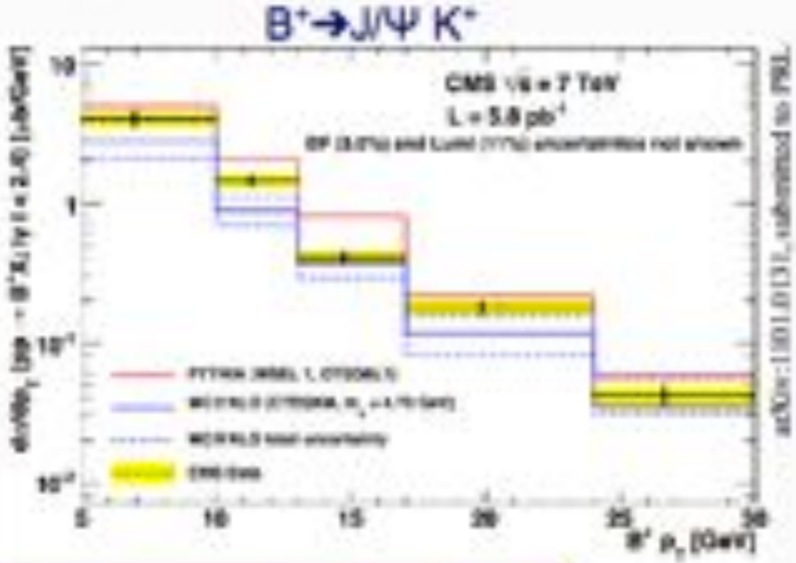
Higher Statistics and reduced systematics

Inclusive Jet Cross Sections

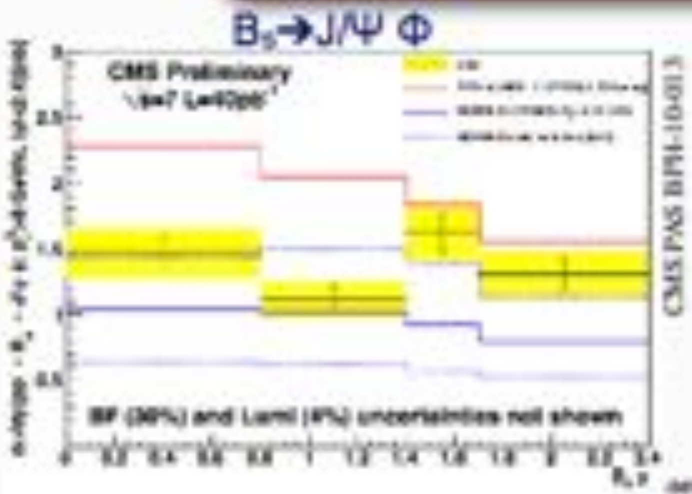


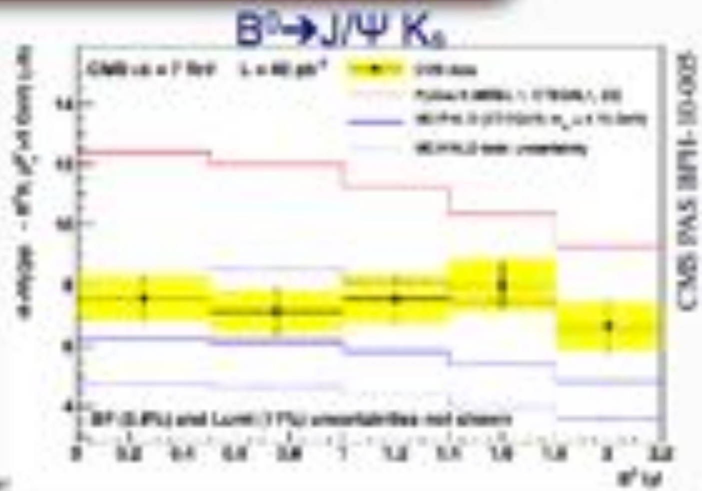
B-physics Results



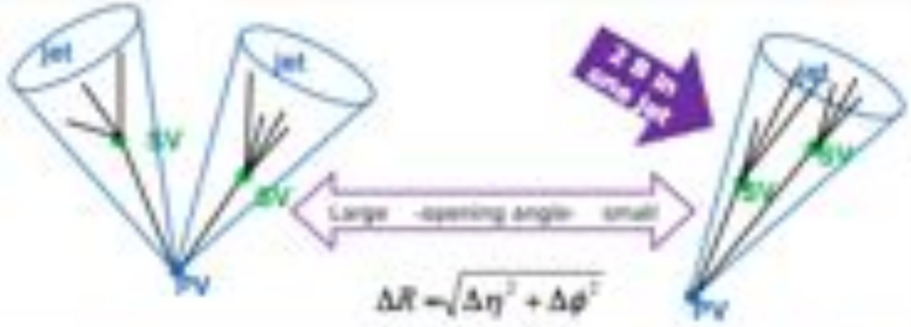


Extensive studies of b/B production. Consistent picture in all channels:
Data between predictions of MC@NLO and Pythia;
differences in shape, both for p_T and rapidity distributions.

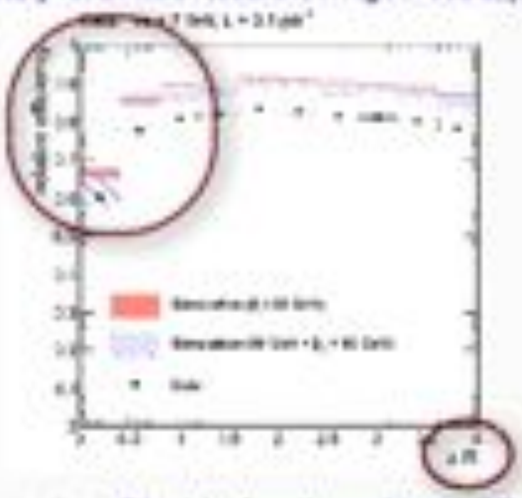


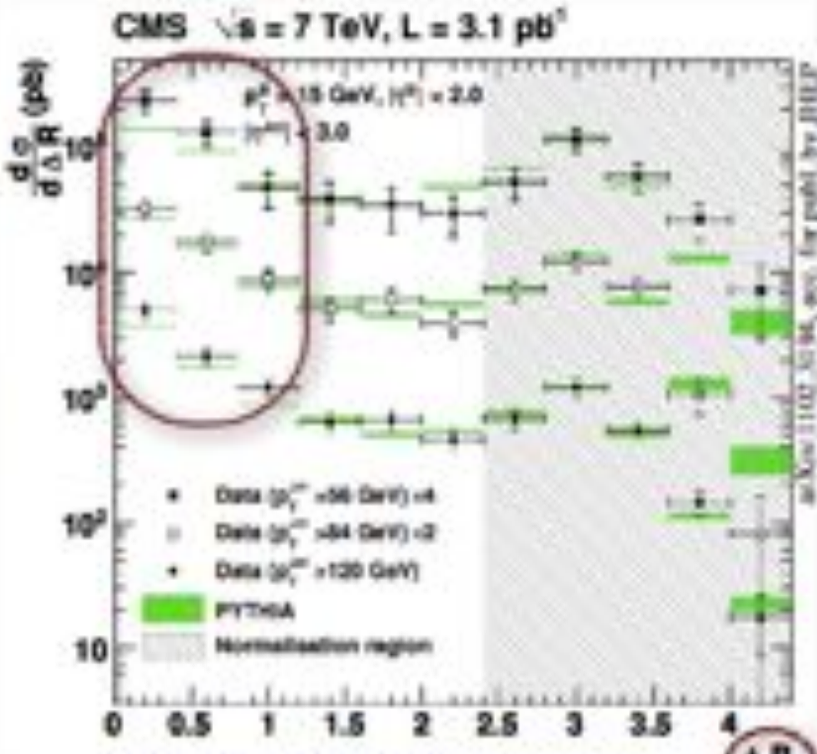


B-jets: Two Bs in one jet



New: Secondary vertex finder seeded with high IP tracks, jet independent





MC normalized to shaded region for shape comparison in the collinear BB region

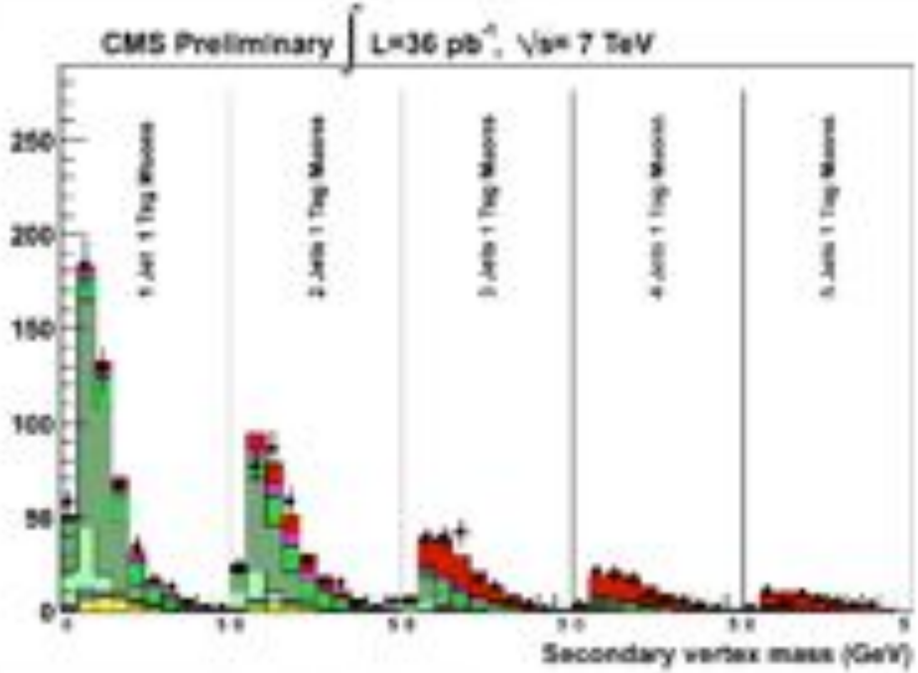
- Sizable fraction of total BB cross section from collinear B-hadron pairs
- Fraction of collinear BB production increases with leading jet p_T

> Extremely important groundwork for upcoming searches with (boosted) bb final states.
> In particular: low-mass Higgs!

Top Cross Sections

New Analysis: Lepton+jets, b-tagged

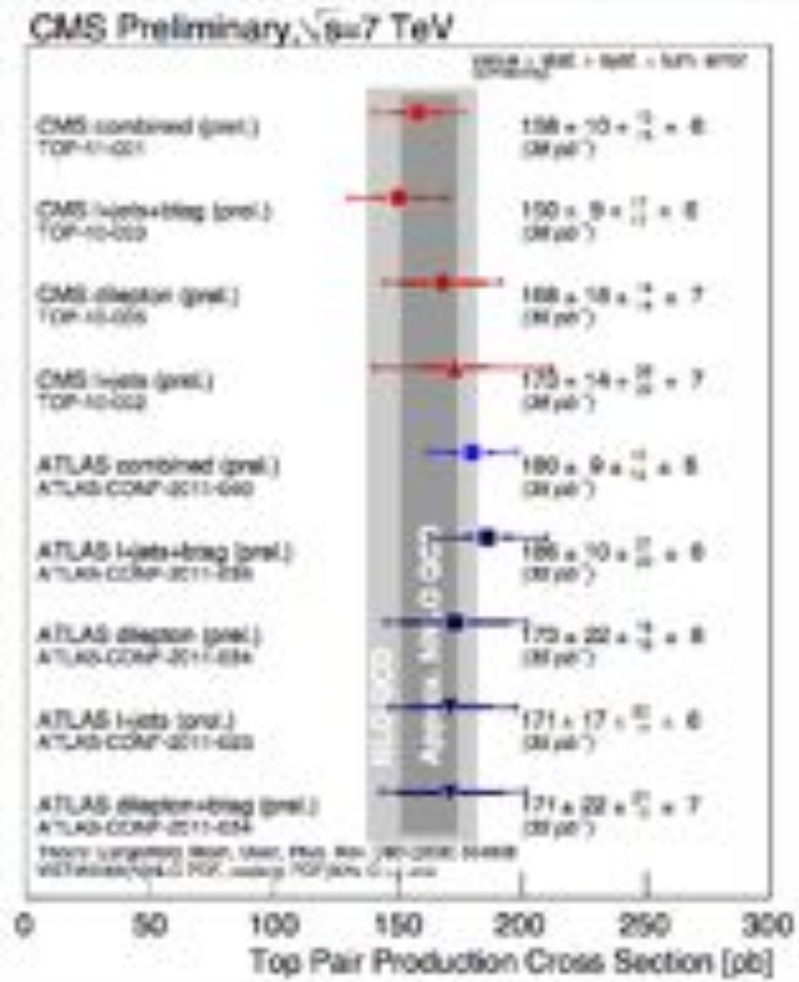
- divide sample into distinct categories: Nr. jets, Nr. of b-tags, electrons, muons
- fit the secondary vertex mass distribution, using templates, simultaneously in all categories
- let also data/MC scale factors (JES, b-tag eff, W+j Q^2-scale) float in the fit
- **Result:**
  - top cross section, with overall **11% syst. uncert.**
  - scale factors consistent with 1, within the fit error

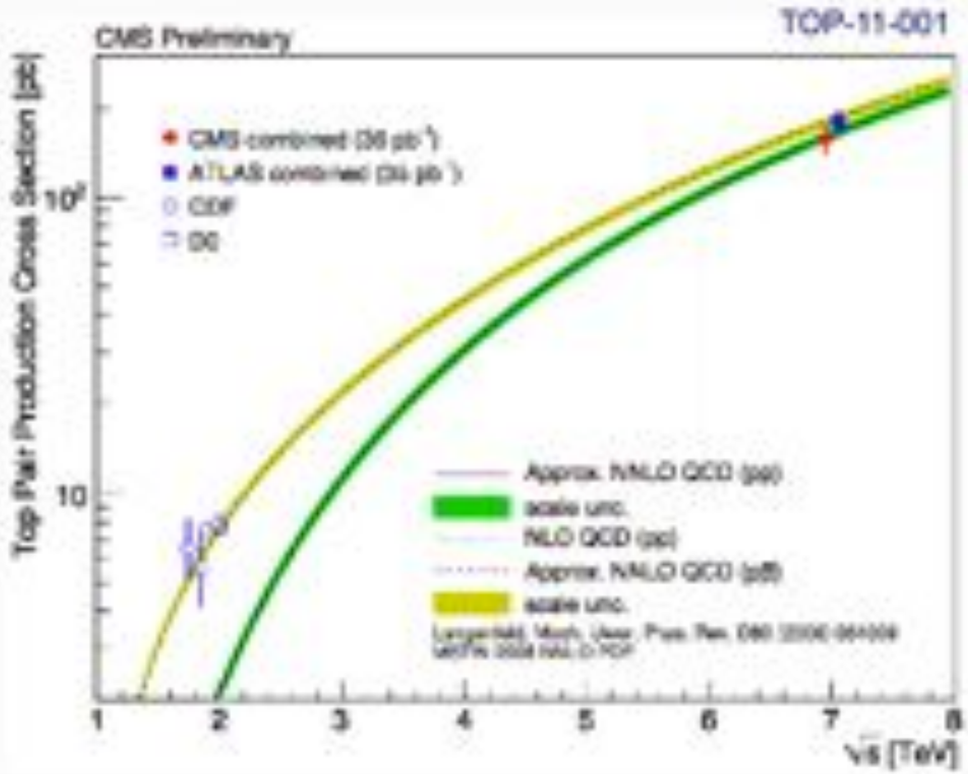


Source	Uncertainty (%)
Systematic uncertainties	
Lepton ID/reco/trigger	3
Unclustered E_T^{miss} resolution	< 1
$t\bar{t}$+ Jets Q^2-scale	2
ISR/FSR	2
ME to PS matching	2
PDF	3.4
Profile likelihood parameters	
Jet energy scale and resolution	7.0
b tag efficiency	7.5
W+Jets Q^2-scale	9.1
Combined	11.6

A fantastic proof of the excellent understanding of all relevant physics objects, and of their outstanding MC description

Top Production Cross Sections



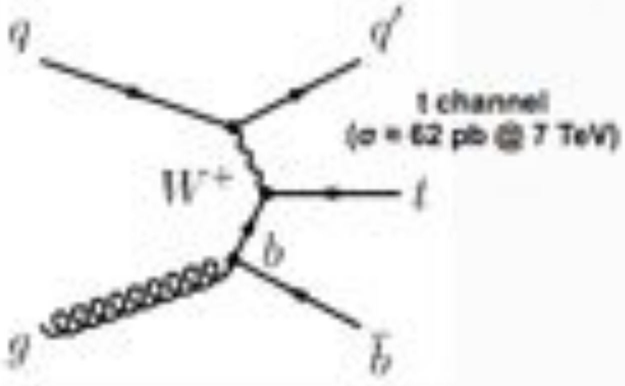


TOP mass: dilepton
TOP-10-006

Method	Measured m_{top} (in GeV/c^2)	Weight
AMWT	$173.8 \pm 4.9(stat) \pm 4.3(syst)$	0.65
KINb	$174.8 \pm 5.5(stat)^{+4.5}_{-5.0}(syst)$	0.35
combined	$175.5 \pm 4.6(stat) \pm 4.6(syst)$	$\chi^2/dof = 0.040$ (p-value=0.84)

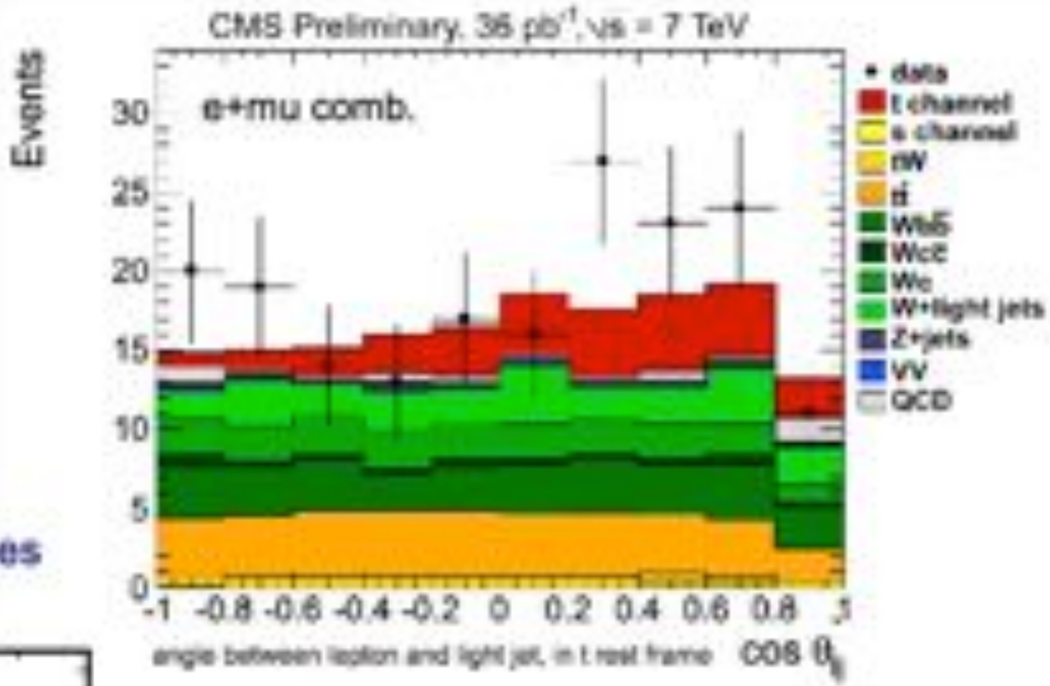
Syst. uncertainty dominated by:
JES (3.1 GeV)
b-JES (2.5 GeV)

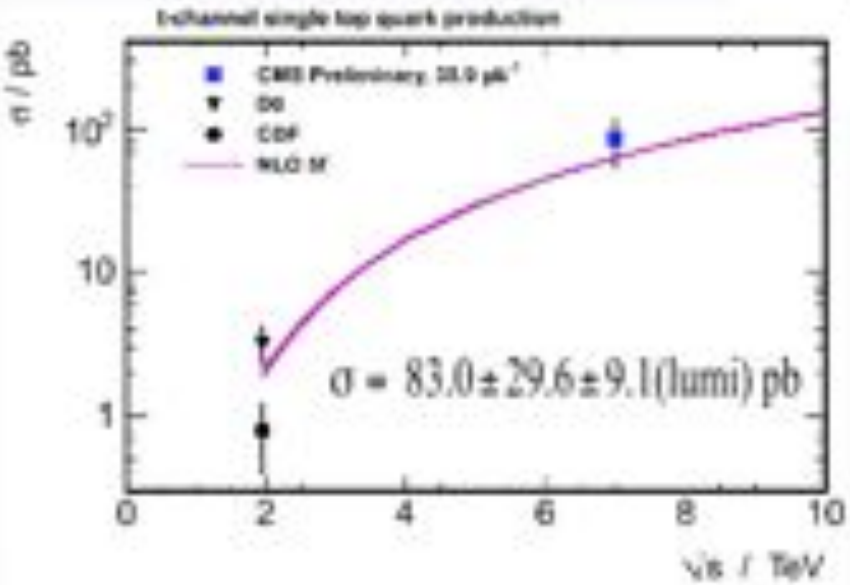
Single Top Production



Two methods employed:

- Cut based using angular info
- BDT, based on kinematic observables

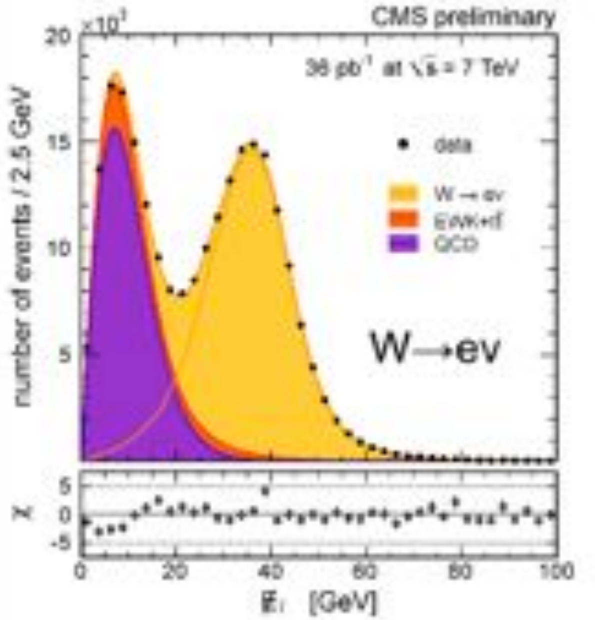


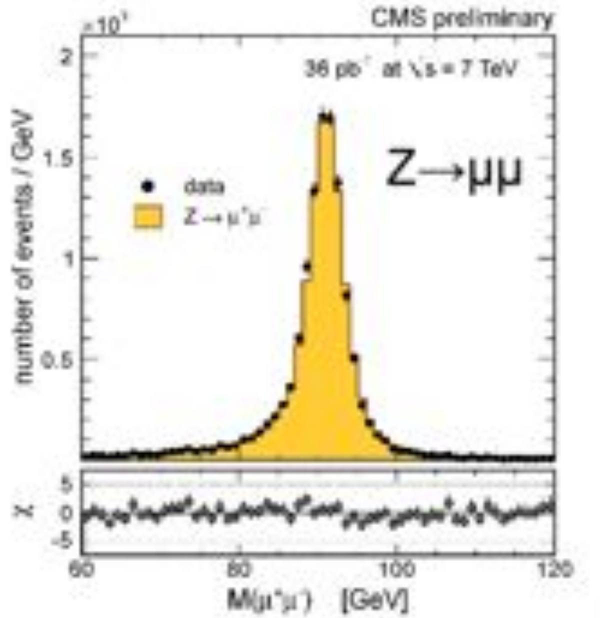


An example of finding **tiny** signals with leptons, MET, b-tag & jets

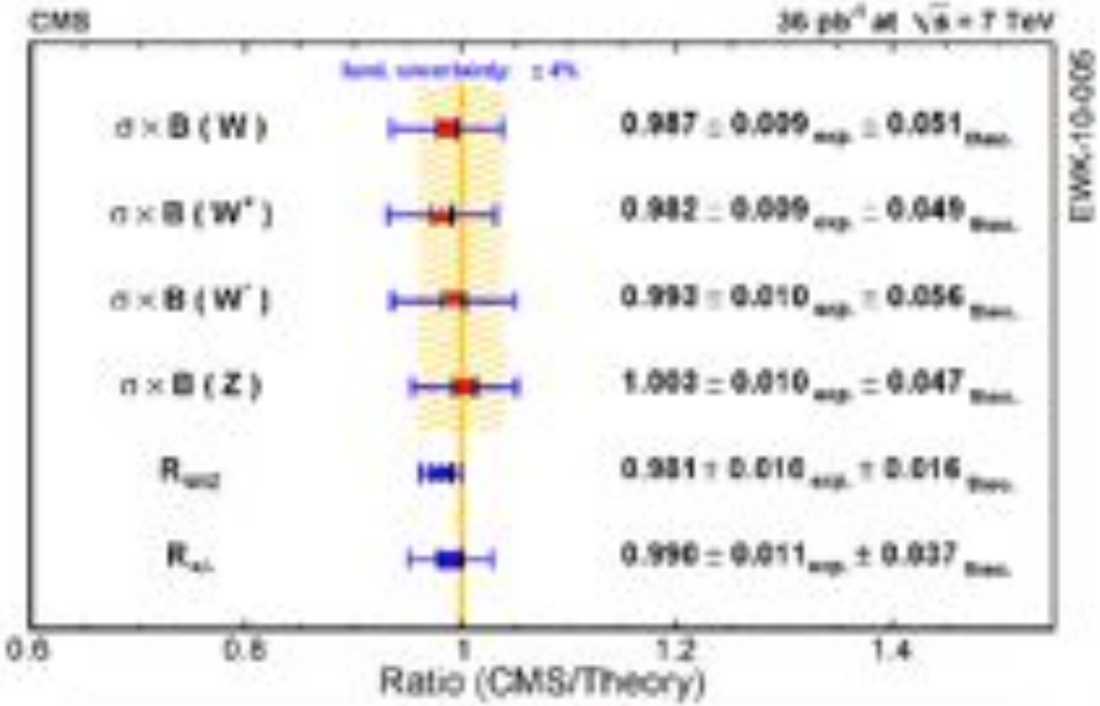
Showing the readiness for challenging searches such as low-mass Higgs

Vector Boson Production



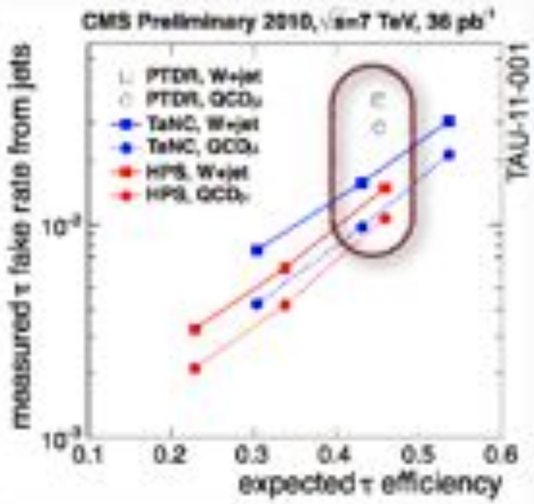


- 3 pb^{-1} results published,JHEP01(2011)080
- new prelim. results for 36 pb^{-1}
- Z important tool : data-driven methods for controlling lepton eff, scale, resolution, E_{Tmiss} (hadronic recoil).
- In general excellent data-MC agreement

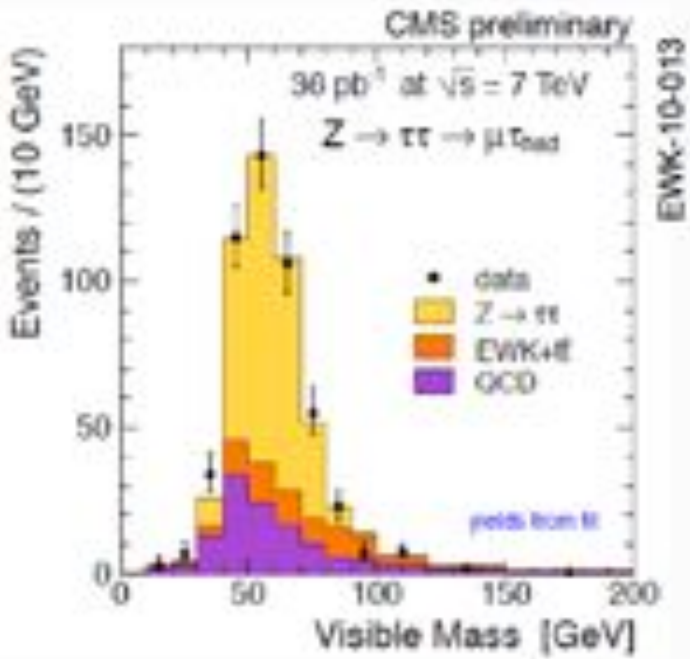


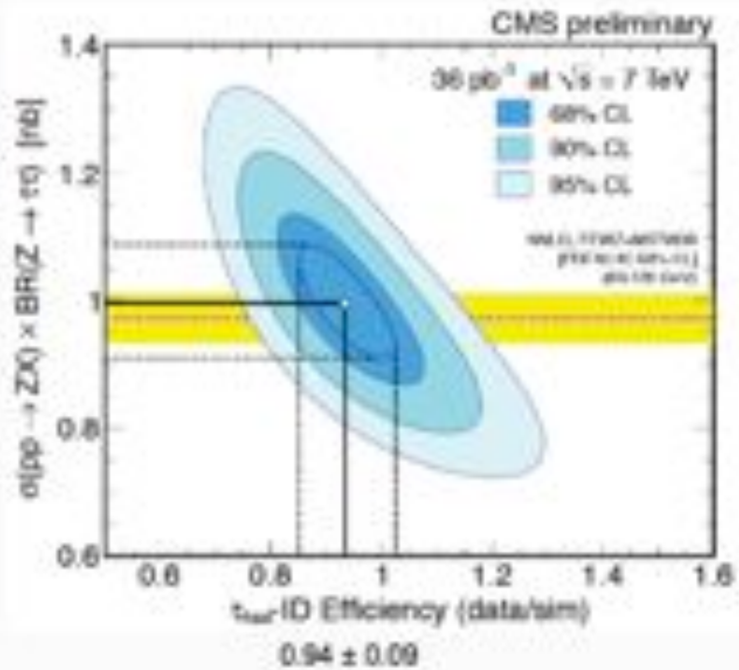
Amazing precision reached (~1% experimental !)
Start to put important constraints on theory (NNLO, PDFs)

Vector Boson Production

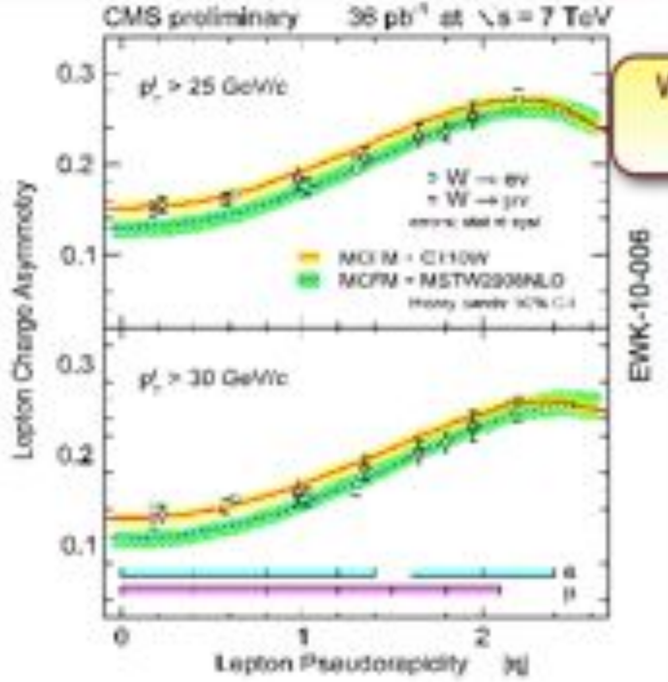


- **Improvement in CMS Tau Identification Performance**
- due to reconstruction of individual decay modes (vector meson resonances), **based on Particle Flow**
- for same efficiency, fake rate reduced by factor of 3
- **for the Z analysis included:** mu+had, e+had, e+mu, mu+mu (~55% of total BR)
- had-tau eff. constrained by ratio lept/semi-lept channels

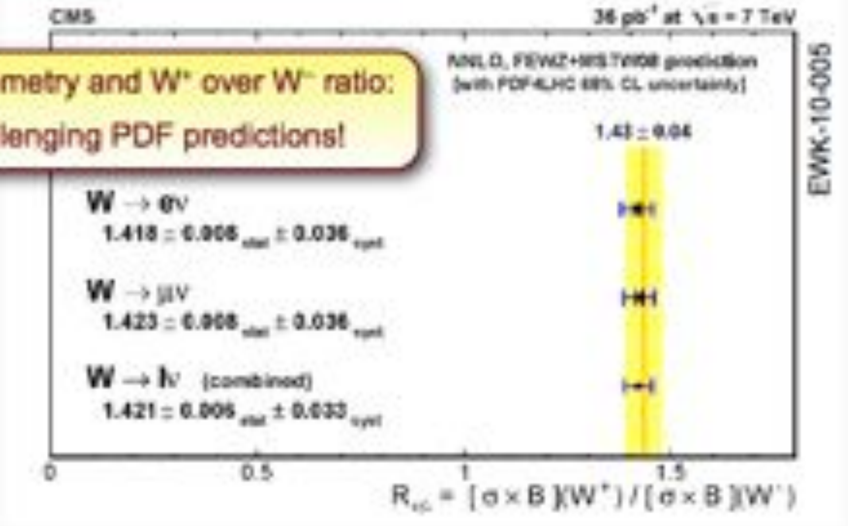


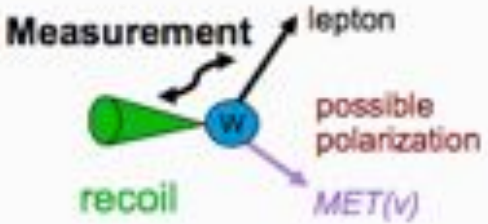


W charge asymmetry and Polarization



W asymmetry and W$^+$ over W$^-$ ratio:
Challenging PDF predictions!

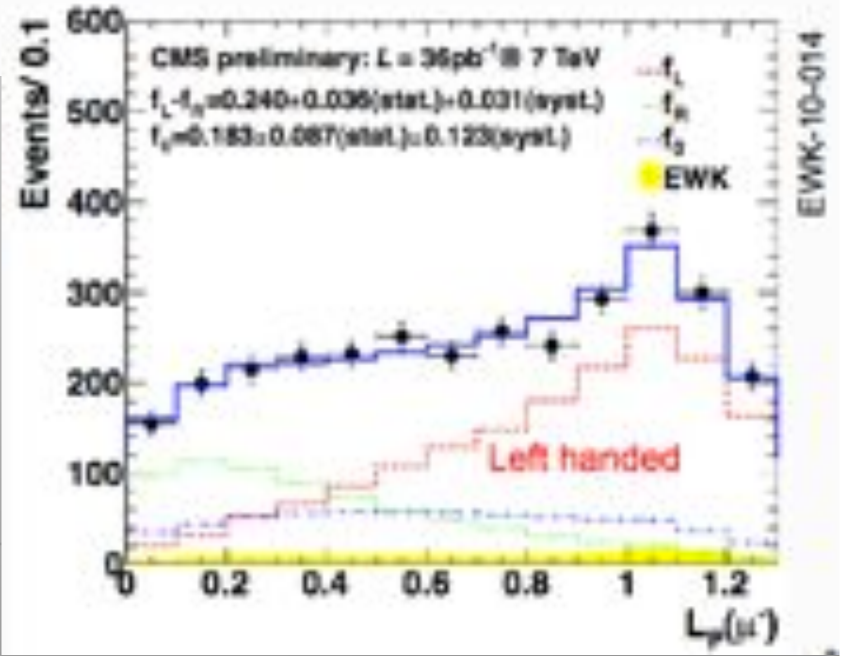




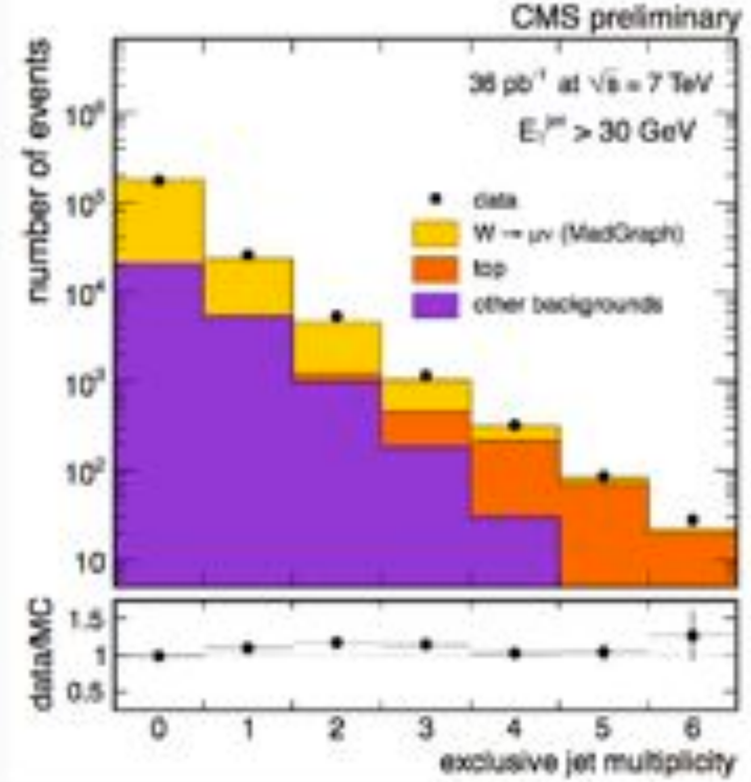
$$\mathrm{LP} = \frac{\vec{p}_T(\ell)\cdot\vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$

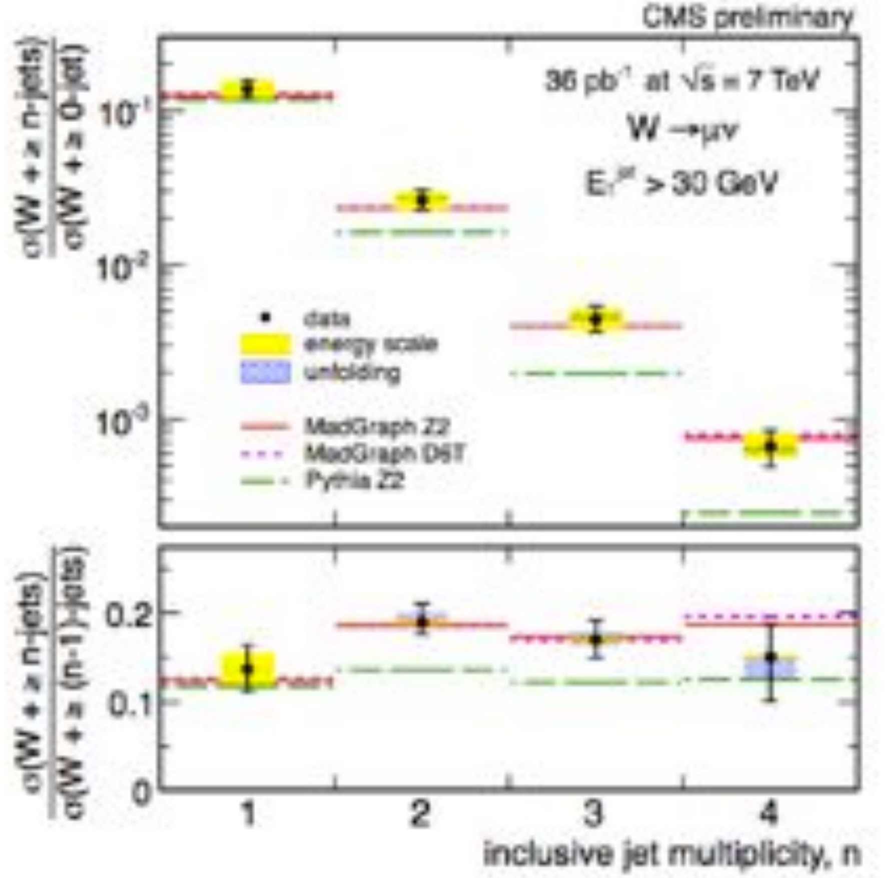
$$p_T(W) > 50\ \mathrm{GeV}$$

First measurement of W polarization:
both W$^+$ and W$^-$ preferred left-handed



Preparing for Searches: W+ Jets





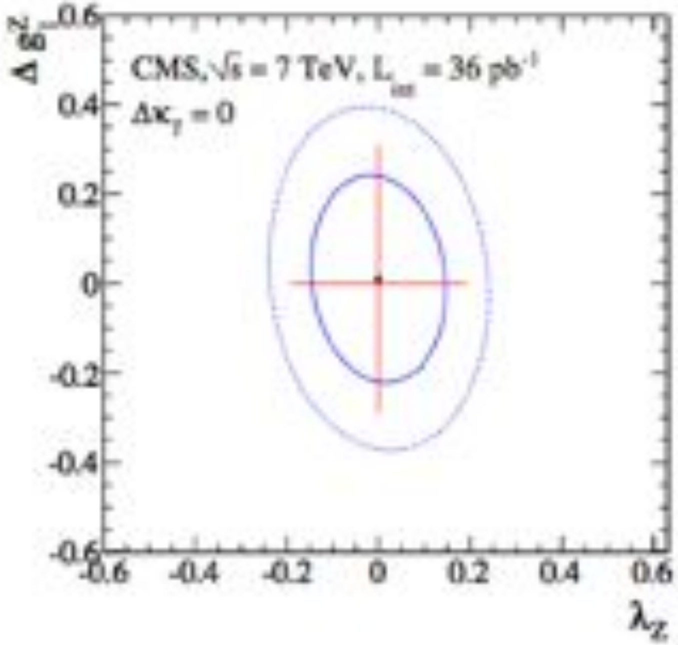
- **simultaneous** extraction of W signal and top background
  - 2D fit to M_T and N_{bjets} distributions
- final distributions: **unfolded to particle level**
- presented for experimental lepton and jet acceptance, eg. p_{Tjet} > 30 GeV

Excellent agreement with ME+PS matched Monte Carlo model.

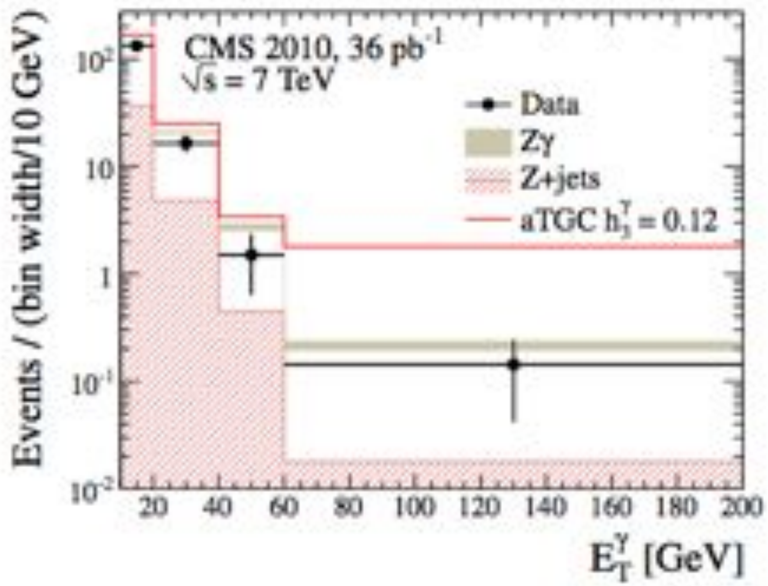
Also tested: Berends-Giele scaling

Di-Boson Production

- **WW** (arXiv:1102.5429, subm. to PLB)
  - same pre-selection as for HWW search, including a jet veto
  - WW cross section and WW/W ratio in agreement with SM exp.
  - limits on TGC from fit to leading lepton p_T
    - consistent with LEP results and similar sensitivity as Tevatron

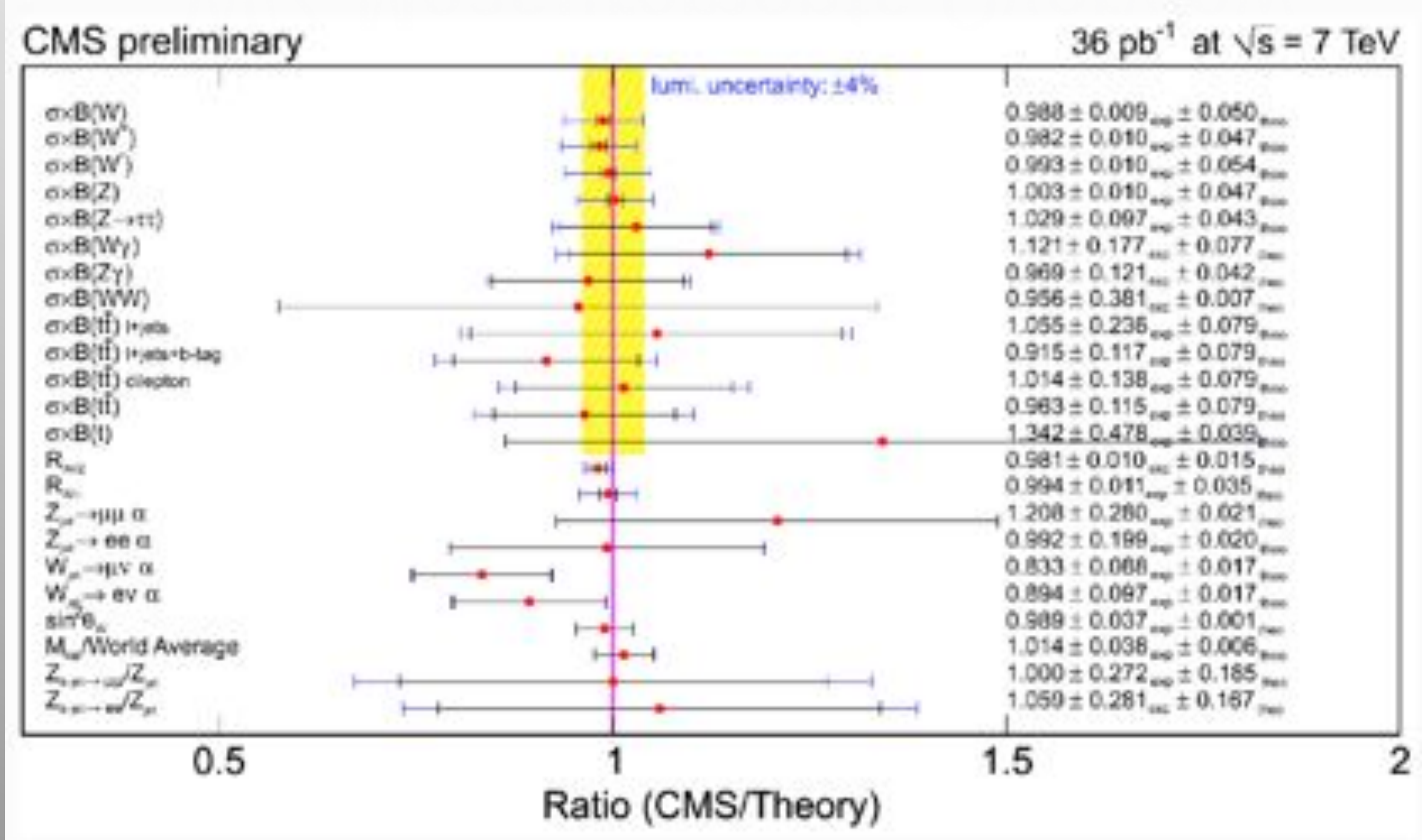


- **Wγ and Zγ**
  - cross sections measured for $E_{T\gamma}$> 10 GeV and dR(lept,γ)> 0.7
  - cross sections in agreement with SM predictions
  - first limits on WWγ,ZZγ,Zγγ TGC at 7 TeV



Measurements of Di-Boson production established.
First limits on TGCs
Groundwork for HWW search!

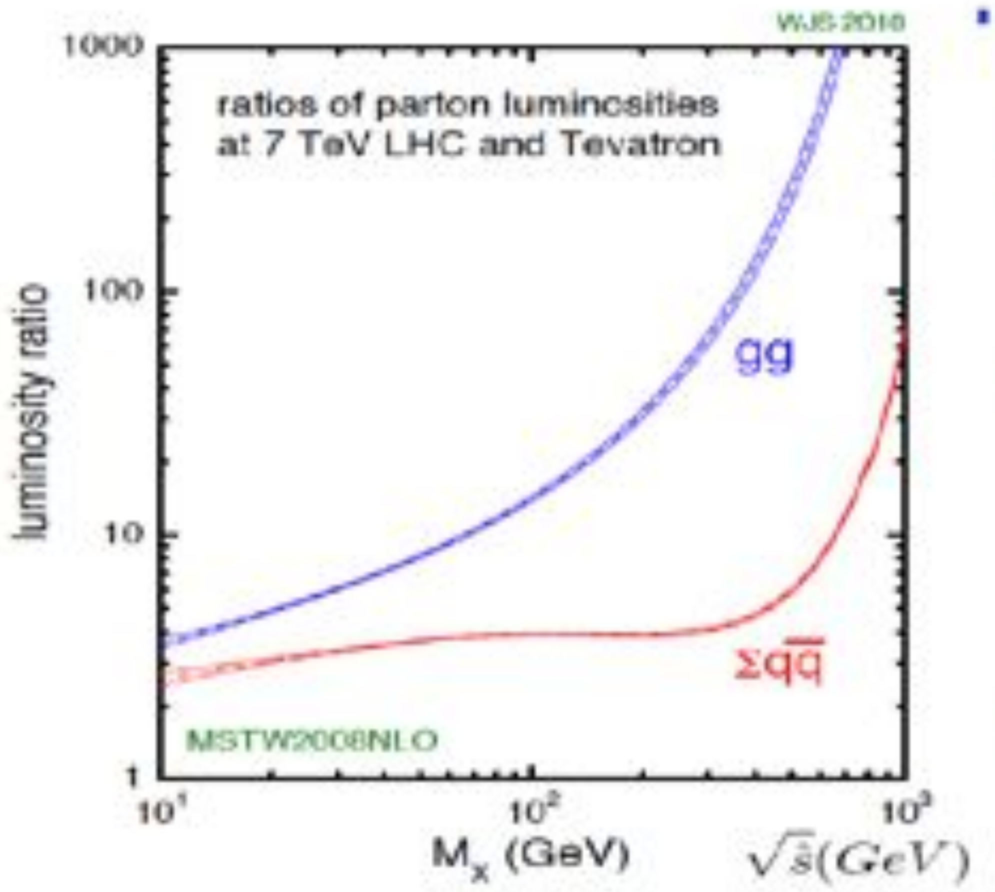
W/Z Measurements Overview



Note: the luminosity uncertainty is now 4%

Searches for New Physics

Can LHC compete with the Tevatron? Yes we can!



- The LHC at $\sqrt{s}$= 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)

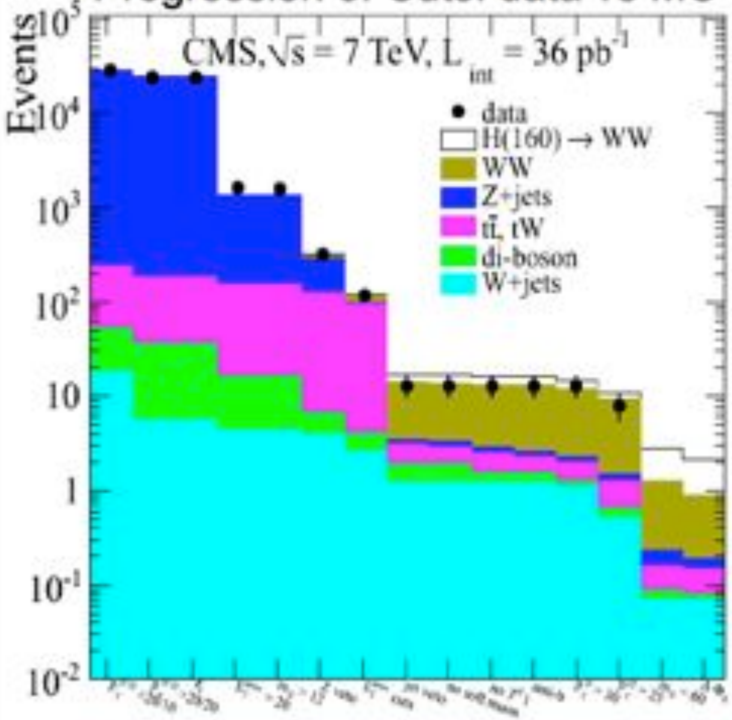
Higgs

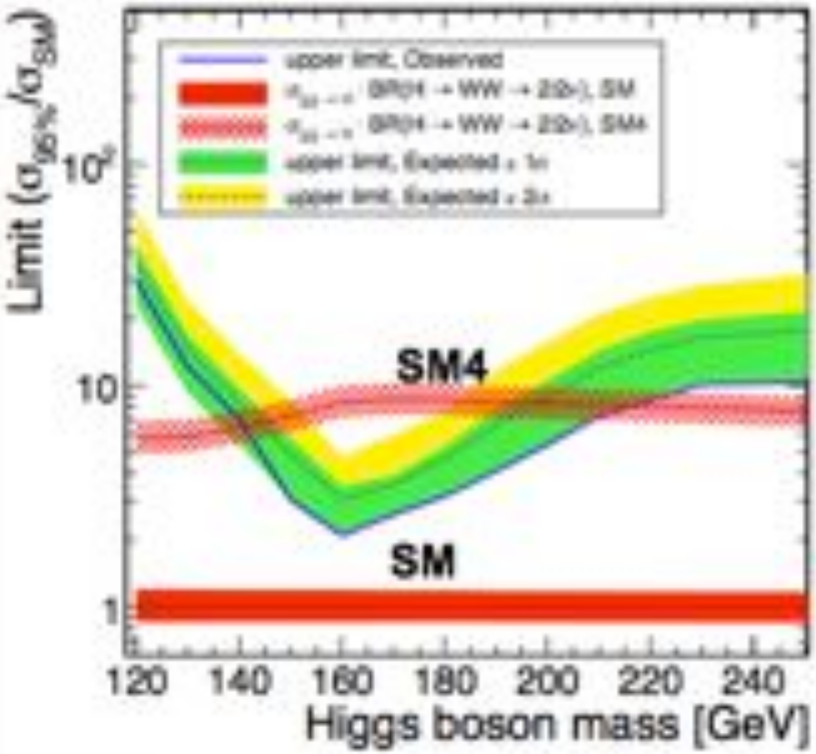
Search for Higgs Decaying to WW

(arXiv:1102.5429, subm. to PLB)

- same pre-selection as for WW analysis, including a jet veto
- Then : 2 analyses
  - cut-based (lepton ΔΦ, lepton mom.)
  - Boosted Decision Tree with 15% higher eff. for same bkgnd

Progression of Cuts: data vs MC



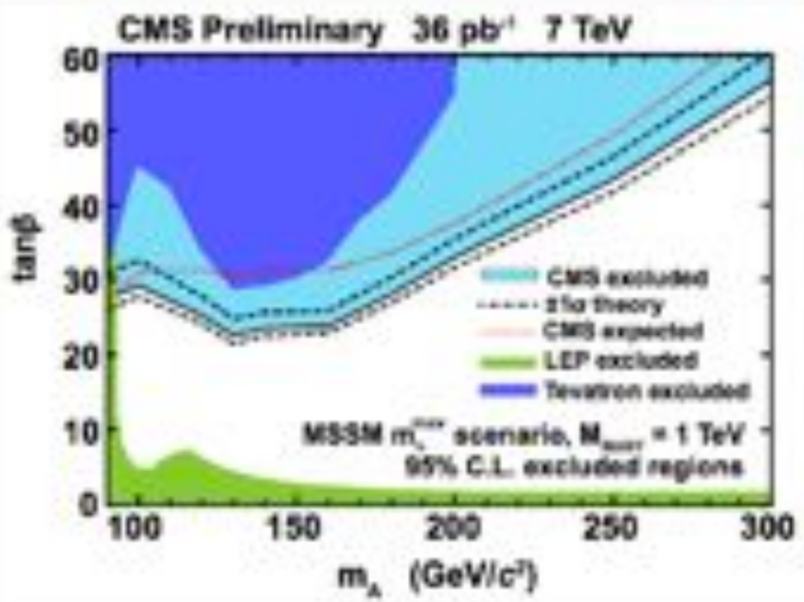


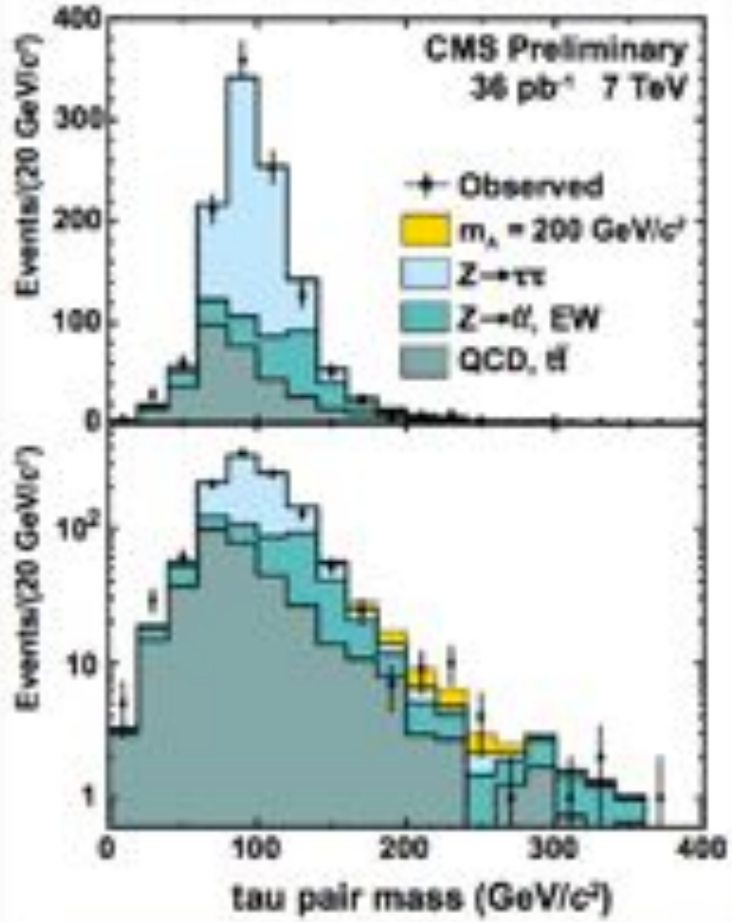
95% CL Limit for MH=160 GeV	CMS (Bayesian)
Expected	3 x SM
Observed	2.1x SM

SM-like Higgs in 4-gen model excluded for (144 < M_H < 207) GeV

Search for Higgs Decaying to TauTau

- Channels used: e-mu, e-had, mu-had
- improved mass reconstruction (better resolution) using likelihood, based on tau decay kinematics of visible decay products and E_{Tmiss}
- first limits on MSSM Higgs production, already improving on the Tevatron results

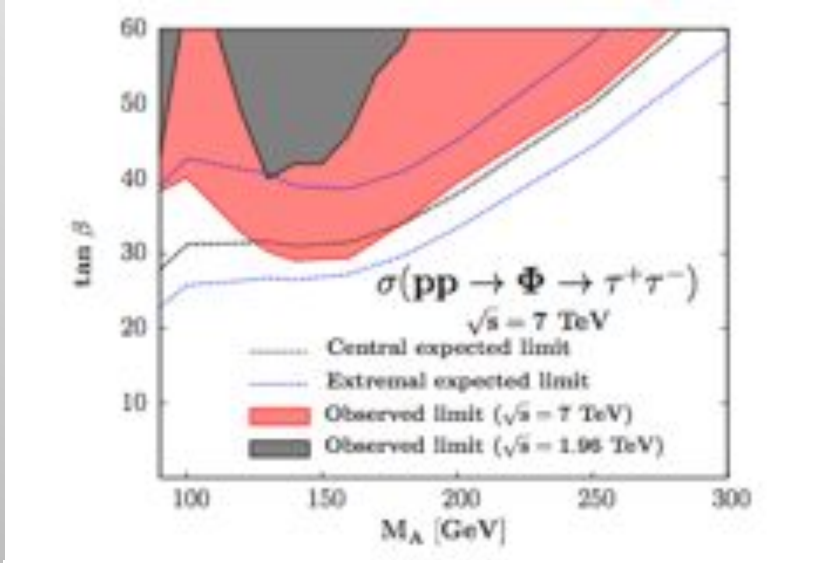




The hunt for MSSM Higgs(es) is open.
Tau channel will play prominent role.

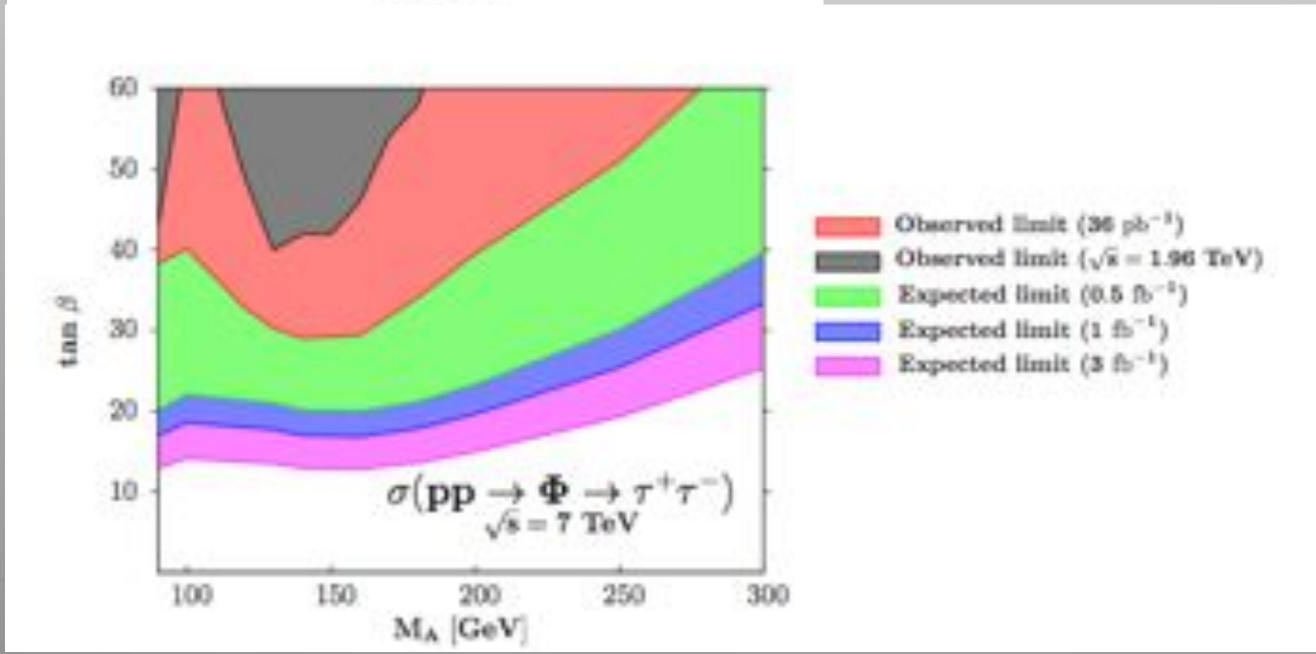
Beautiful analysis… Strong involvement of the UC-Davis group

Theory Discussions



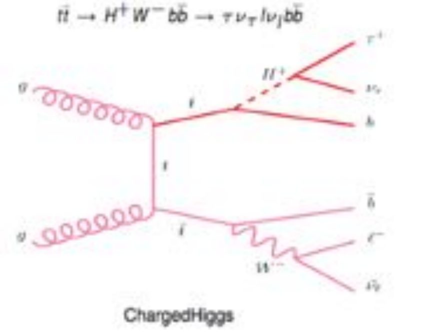
These first results already triggered Quite a bit of discussion eg arXiv:1103.6247 (A Djouadi et al.)

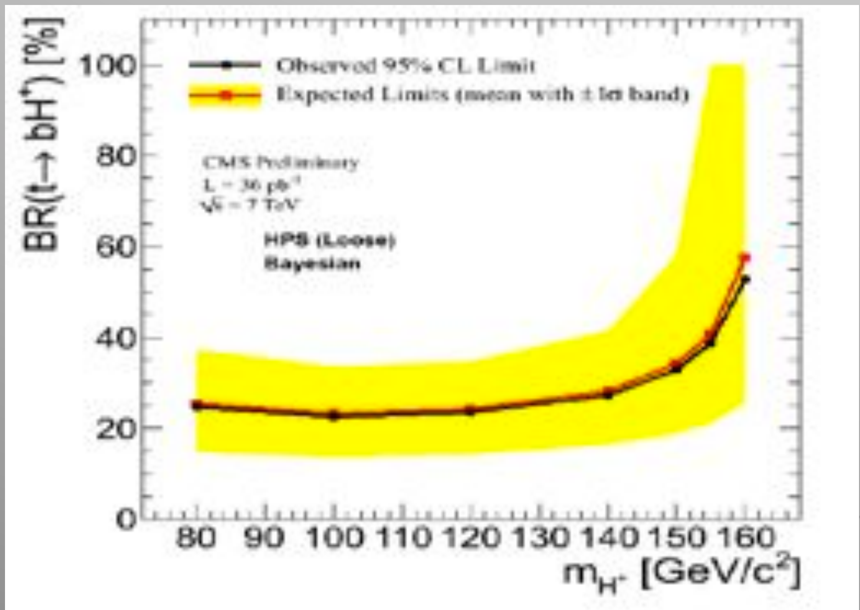
- Competitiveness & robustness
- Model parameter independence
- Usefulness for the SM Higgs search



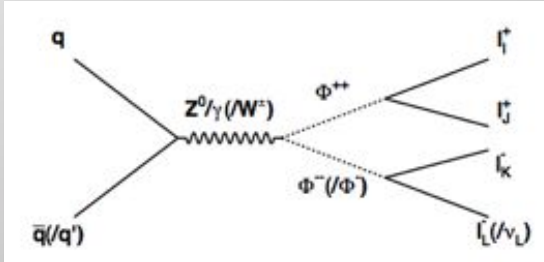
More Higgs Searches

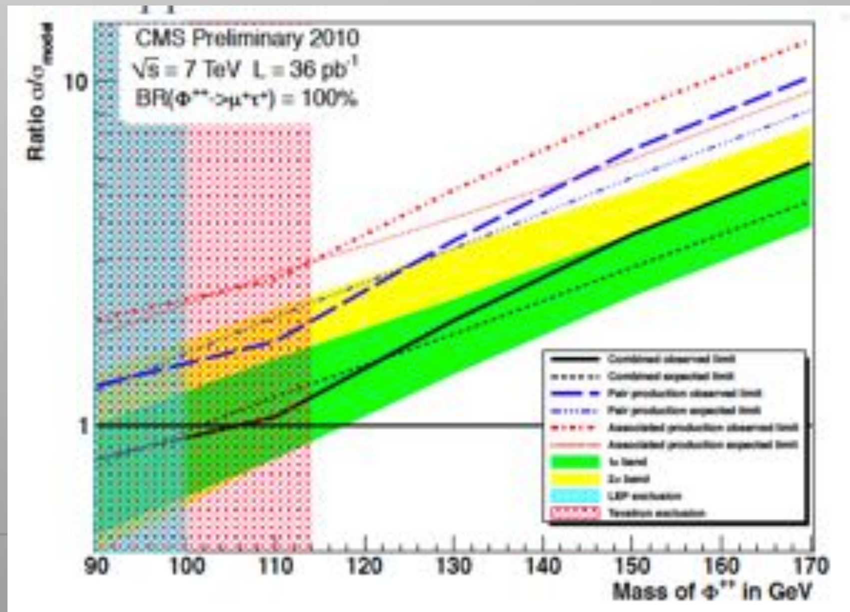
Search for charged Higgs boson in $e\tau$ and $\mu\tau$ dilepton channels of Top quark pair decays in pp collisions at $s^{1/2}$=7 TeV





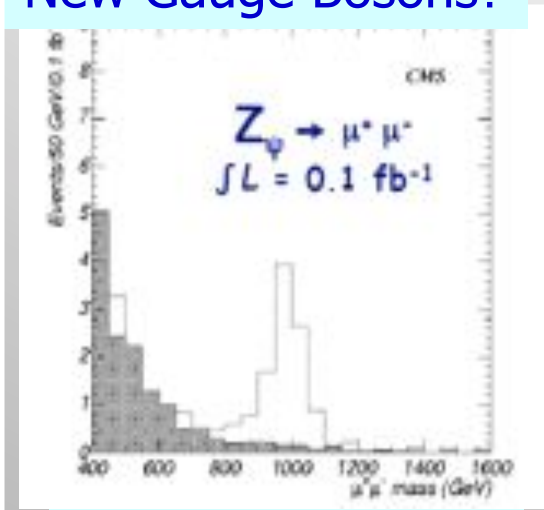
Inclusive search for $\Phi^{\pm\pm}$ in leptonic final states at $\sqrt{s}$=7 TeV in 2010



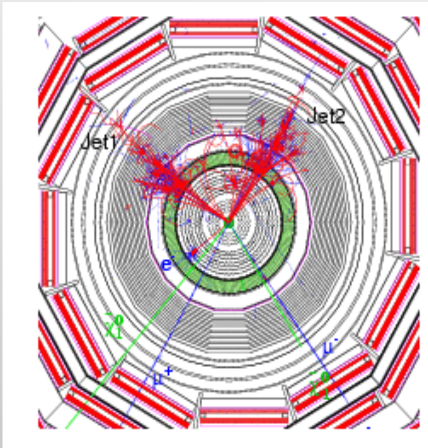


Physics Beyond the Standard Model

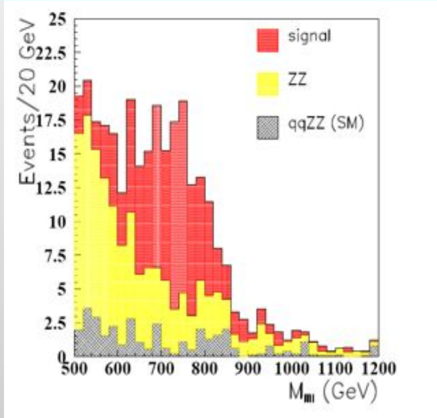
New Gauge Bosons?



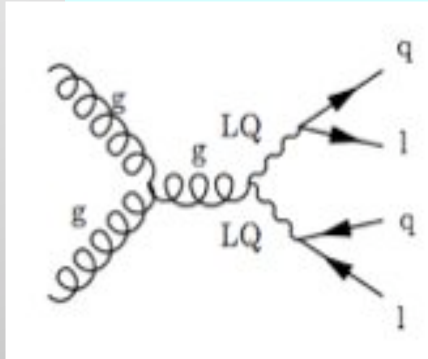
Supersymmetry



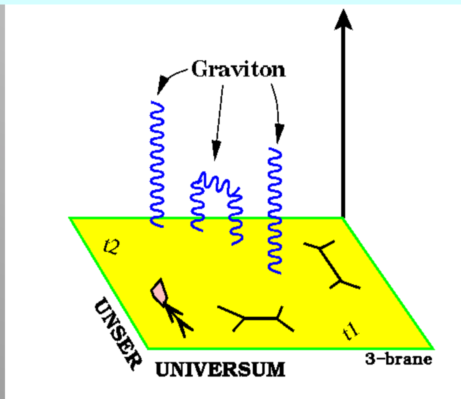
ZZ/WW resonances?



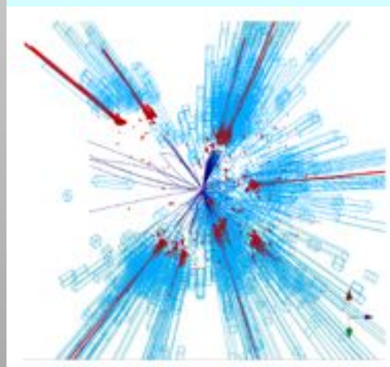
Leptoquarks?



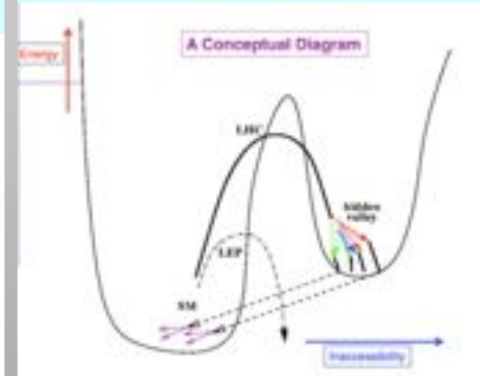
Extra Dimensions?



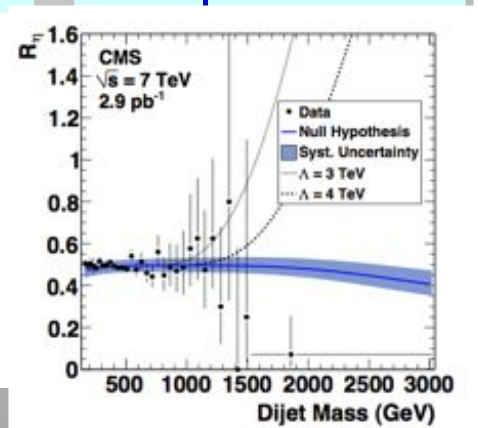
Black Holes???



Long lived particles?



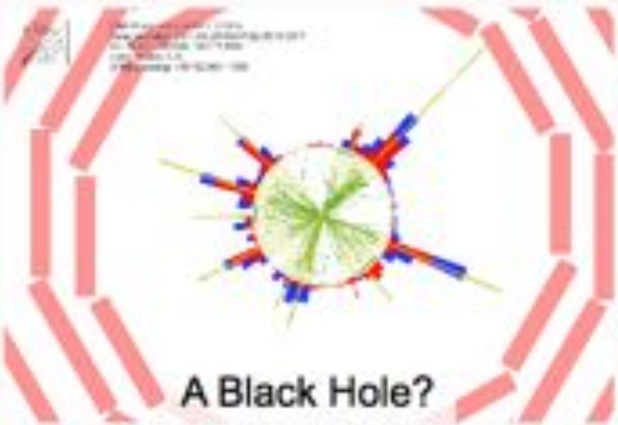
Compositeness?

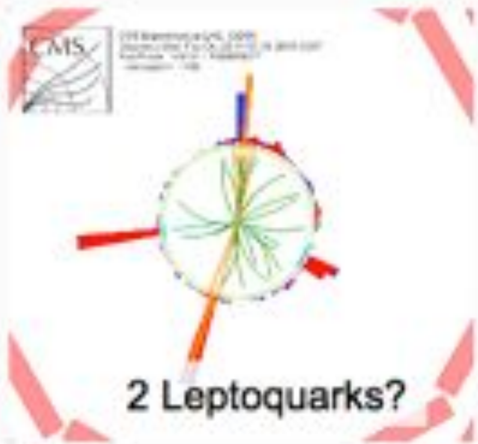


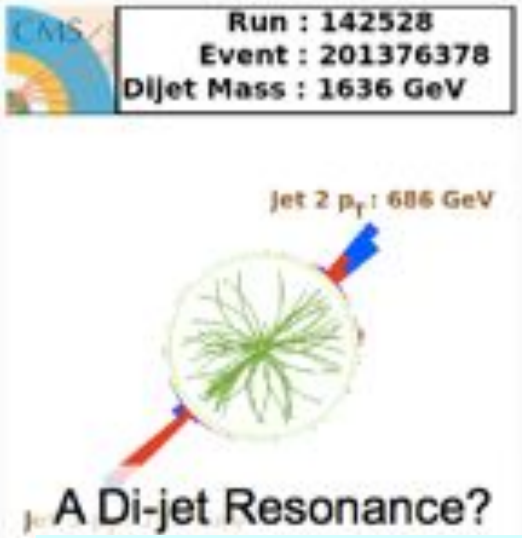
We do not know what is out there for us…
A large variety of possible signals. We have to be ready for that

Exotica

Searches for Exotica







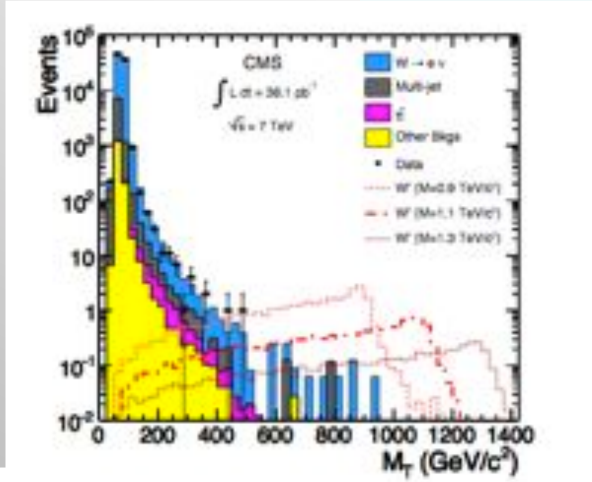
see also talk by F. Santanastasio, Moriond EWK-11

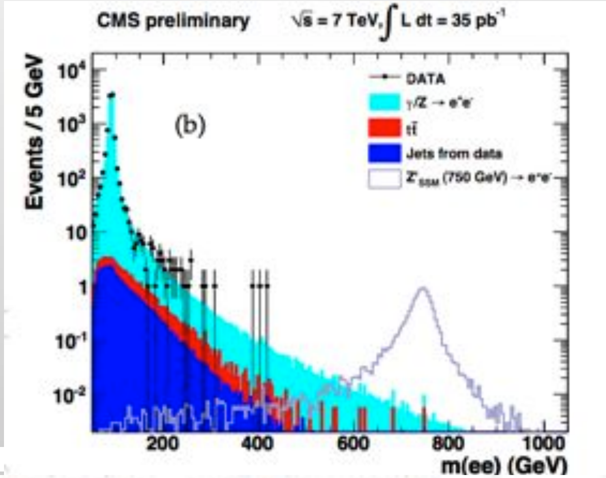
We do not know what is out there for us…
A large variety of possible signals. We have to be ready for that

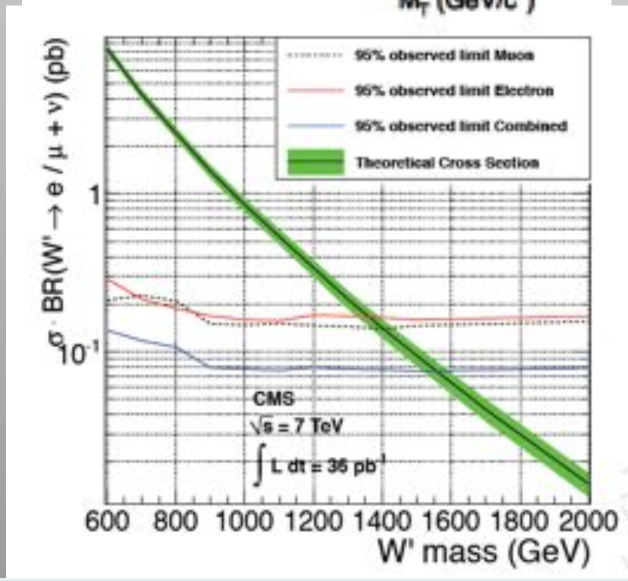
Search for New Gauge Bosons

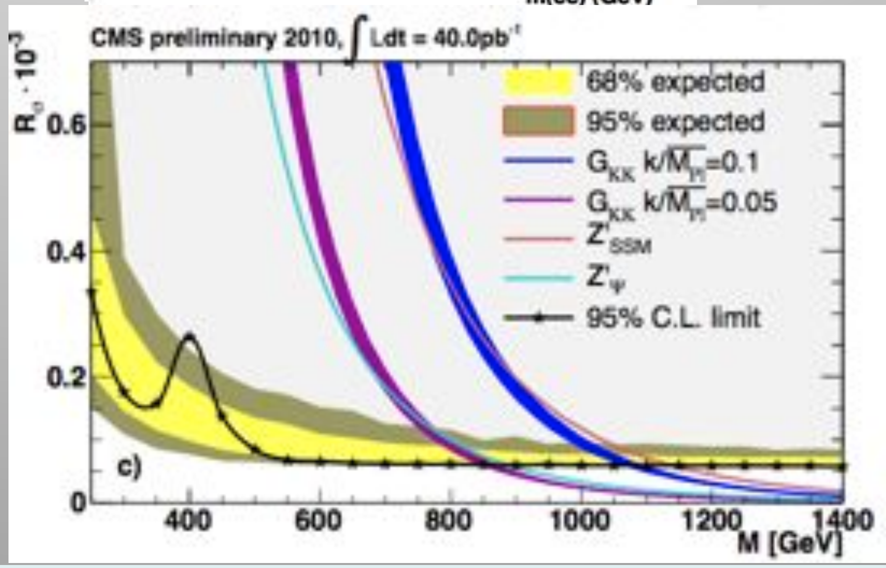
arXiv:1012.5945

Study of the channels W′→ μ ν ,e ν and Z′→ μ μ , ee



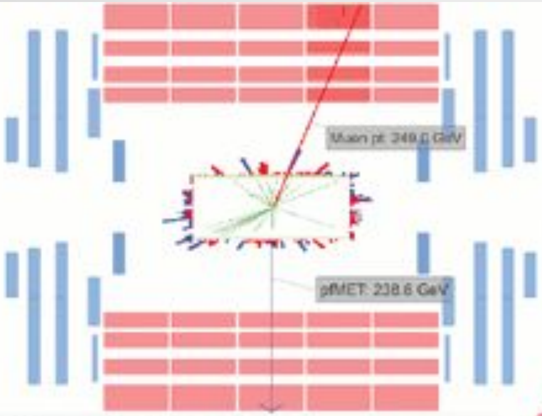


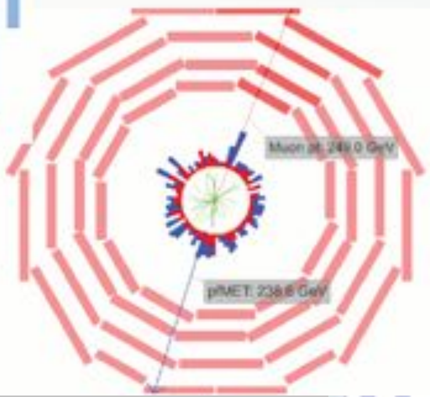




Exclude a new gauge bosons up to 1.58 TeV (W′) and 1.1TeV (Z′) @ 95% CL
This goes beyond the Tevatron timits of ~ 1.1 (W′) and 1.0 (Z′) TeV

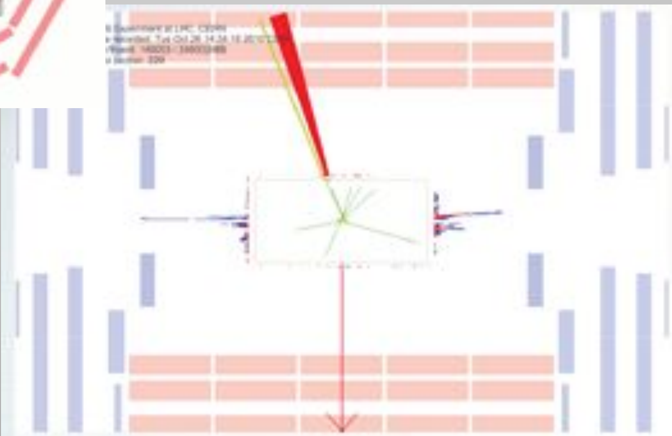
Highest M_T Candidates

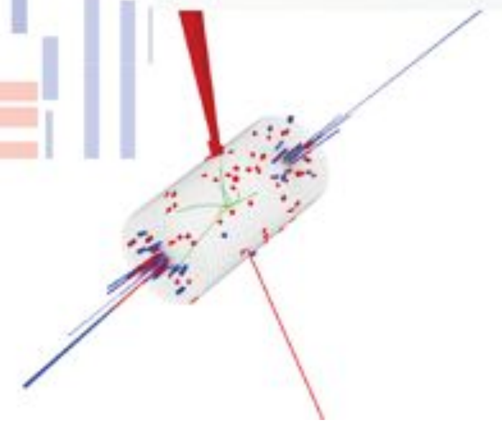




- M_T = 487 GeV candidate event

Muon event

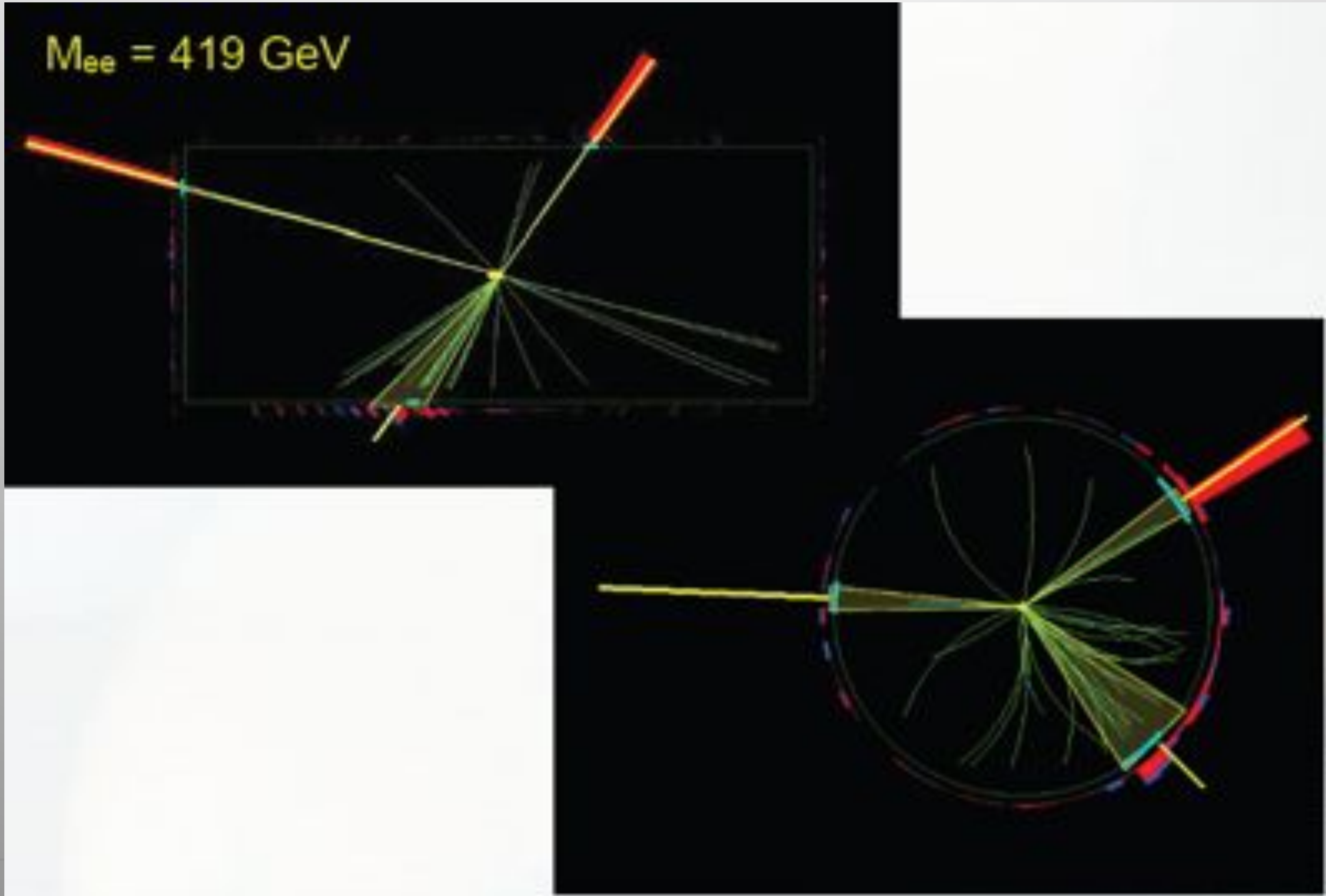




- M_T = 493 GeV candidate event

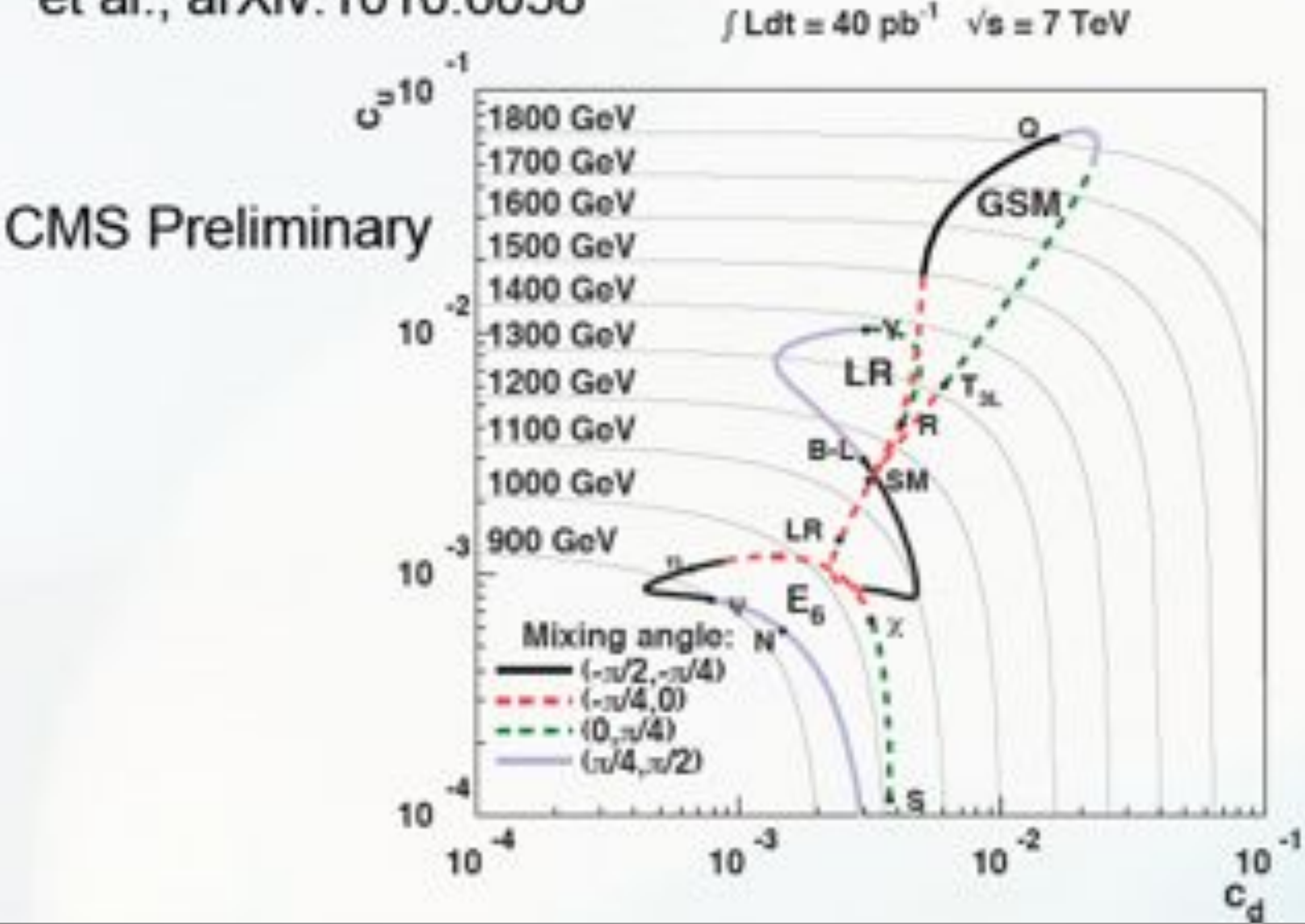
Electron event

Di-Electron Event Candidates



Alternative Limit Presentation

- Expressed in terms of couplings to up and down quarks: c_u, c_d
- Carena et al., Phys. Rev. D **70**, 093009 (2004) and Accomando et al., arXiv:1010.6058



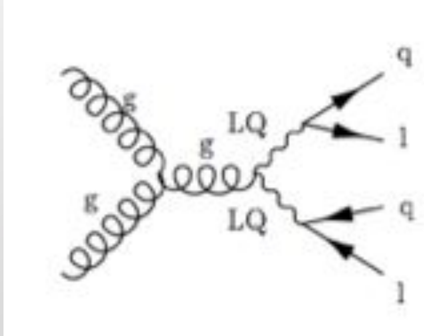
Searches: Leptoquarks

GUT inspired models predict new particles with lepton and quark properties

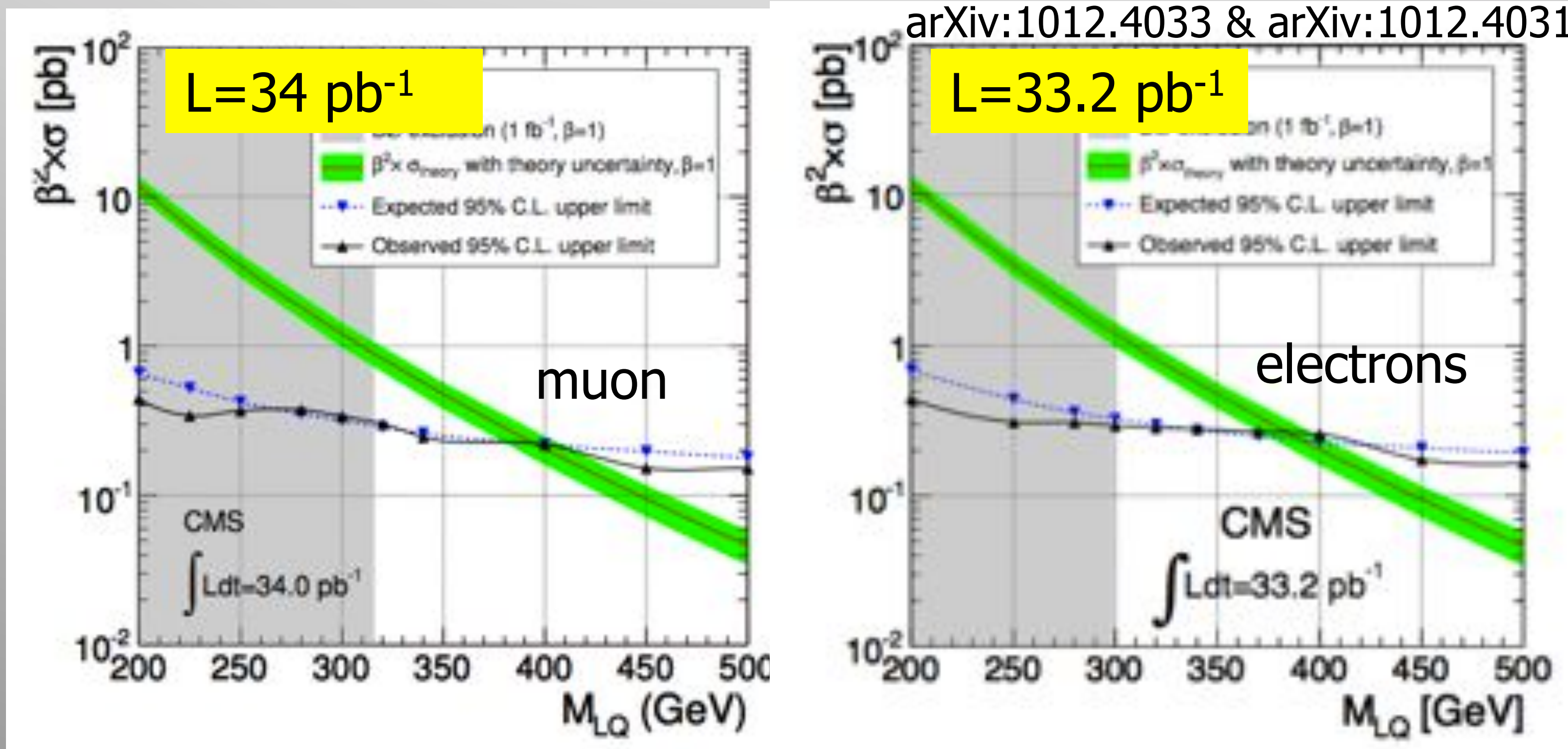
*Some excitement at HERA in ’97 (M~ 200 GeV)

Search in muon or electron + jet final states

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



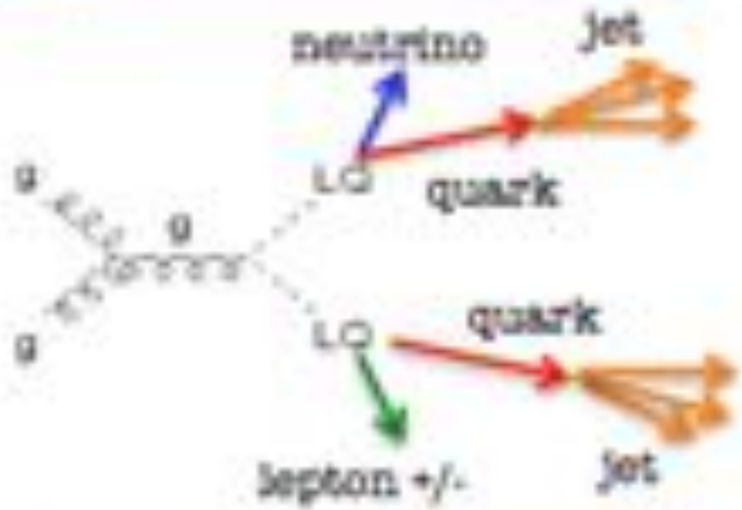
arXiv:1012.4033 & arXiv:1012.4031



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

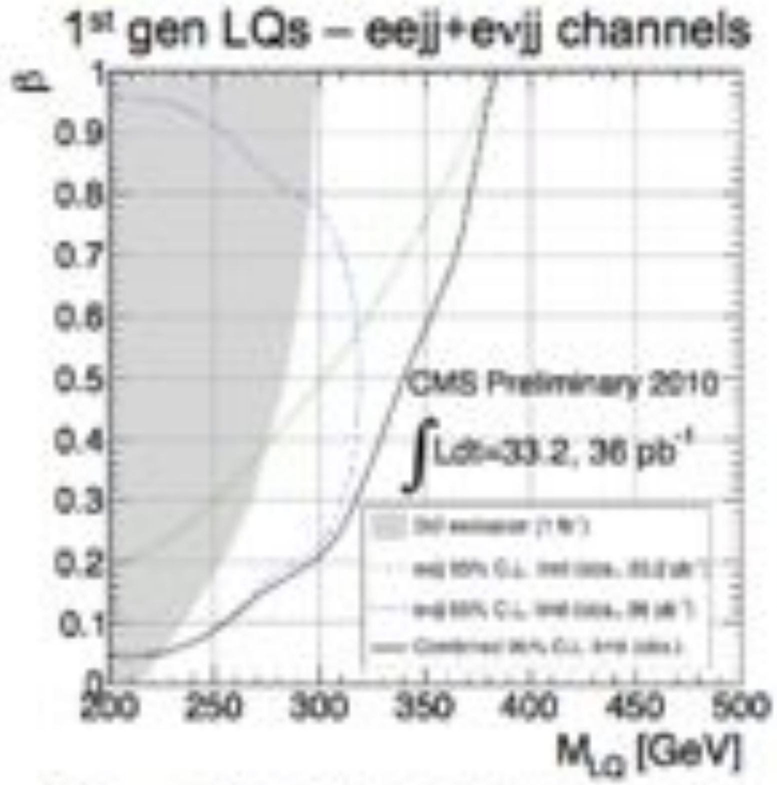
Searches: Leptoquarks

lνjj channel – 2β(1-β)



$$S_T = p_T^{l1} + MET + p_T^{j1} + p_T^{j2}$$

eejj : arXiv:1012.4031, accepted by PRL
eνjj + comb. : EXO-10-006



$M_{LQ} > 340, 384$ GeV for $\beta = 0.5, 1$

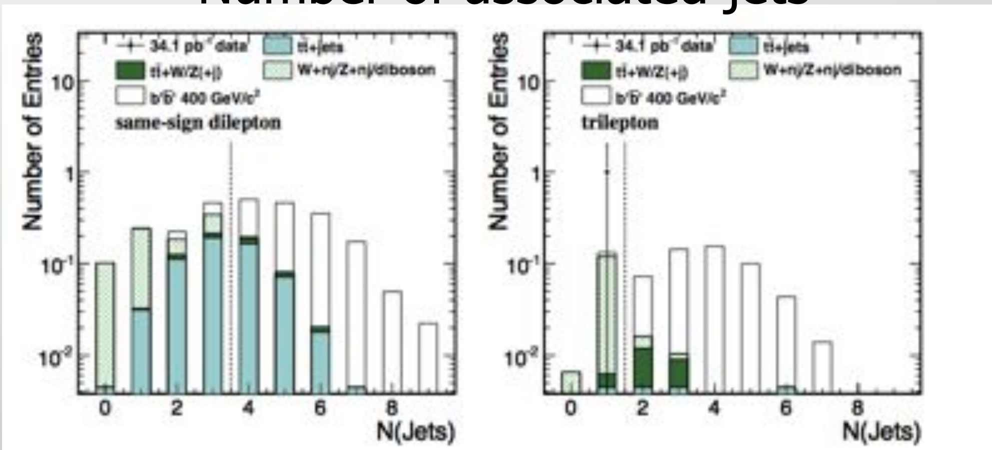
A Fourth Quark Flavor Generation?

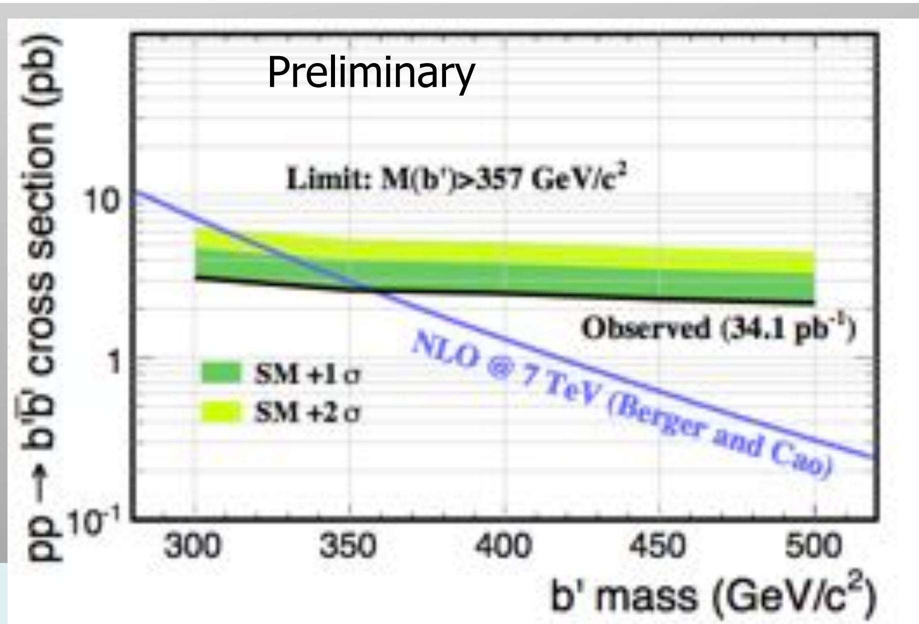
We can't be sure that there are only 3 generations (u,d) (s,c) (b,t). A possible new generation should be heavy!

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

Number of associated jets

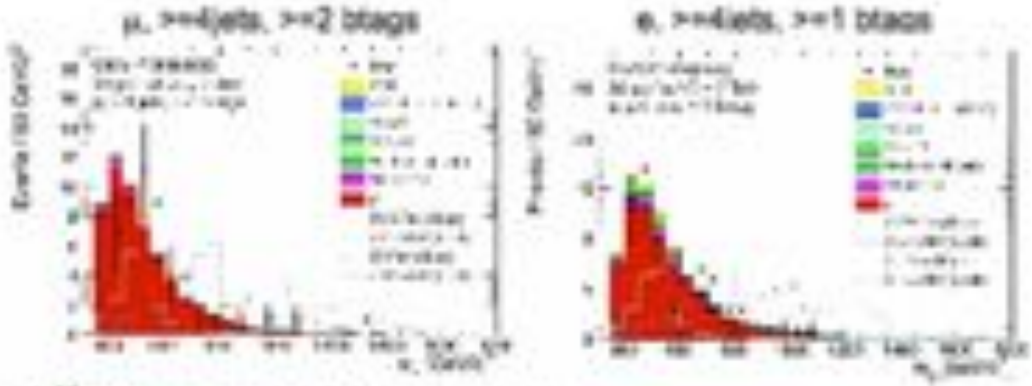


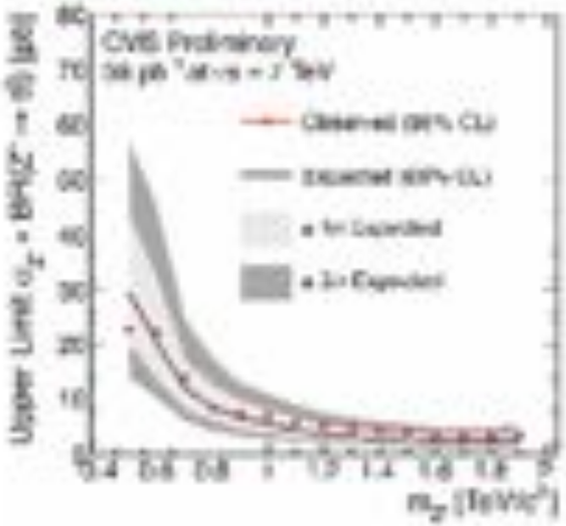


CMS limit: M(b') > 357 GeV 95% CL
Tevatron M(b') > 338 (372) GeV 95% CL

Searches for Top Resonances

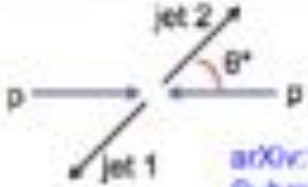
- **Bump hunt in M(ttbar) spectrum**
- Lepton+jets channels (e and μ)
- No bump seen in data
- Set limits, competitive with Tevatron





TOP-10-007,
EXO-10-023

Searches with Jets

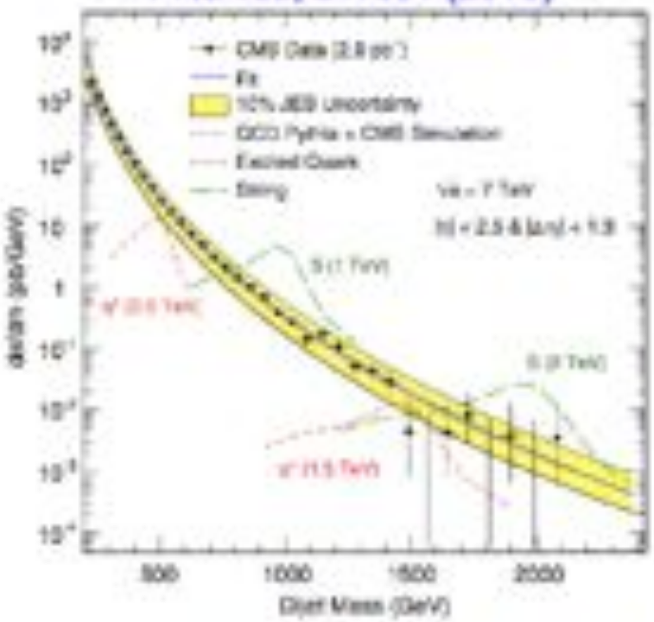


$$\chi = e^{2y^*} = \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}$$

1) **Di-jet mass spectrum** (→ narrow resonances)
2) **Di-jet angular distributions** (→ contact interactions)

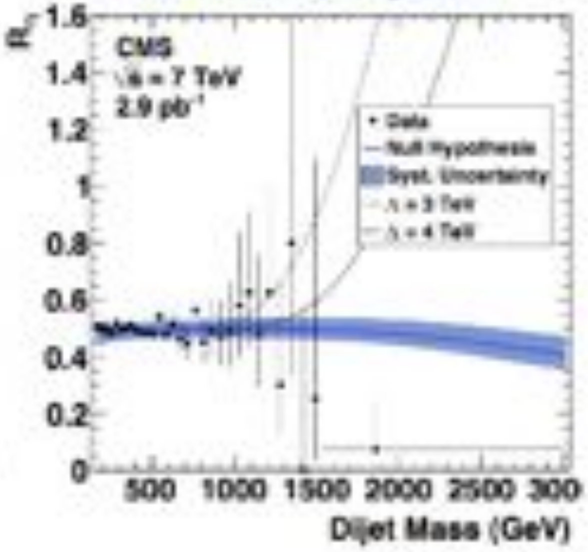
arXiv:1102.2020, Submitted to PRL

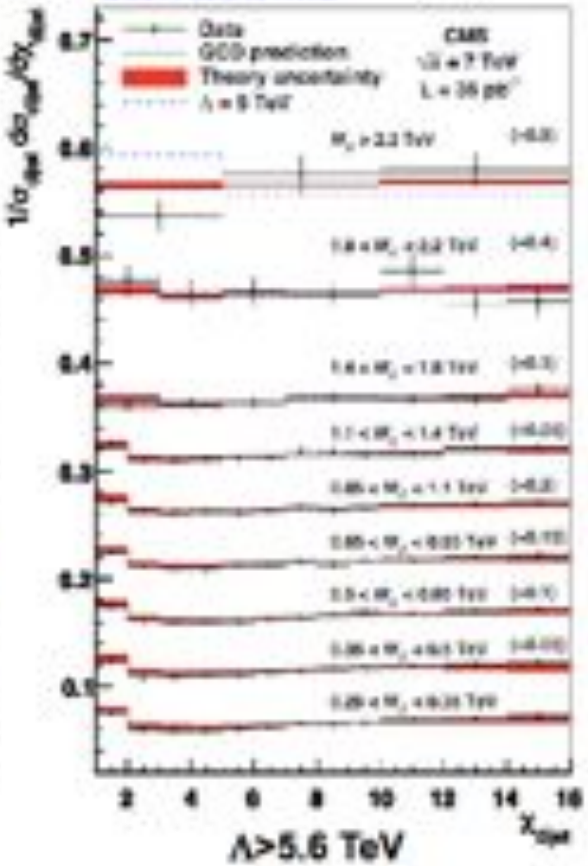
PRL 105, 211801 (2010)



$$R_\eta \equiv \frac{N_{2j}(|\eta| < 0.7)}{N_{2j}(0.7 < |\eta| < 1.3)}$$

PRL 105:262001,2010





M_{String}>2.5 TeV M_{q^*}>1.58 TeV
$M_{q^*} = \Lambda,\ f = f' = f_s = 1$

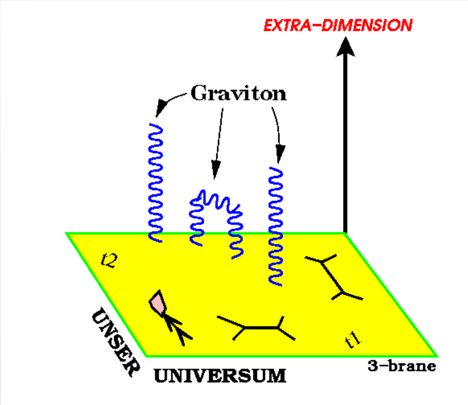
Λ>4 TeV
(expected Λ>2.9 TeV)

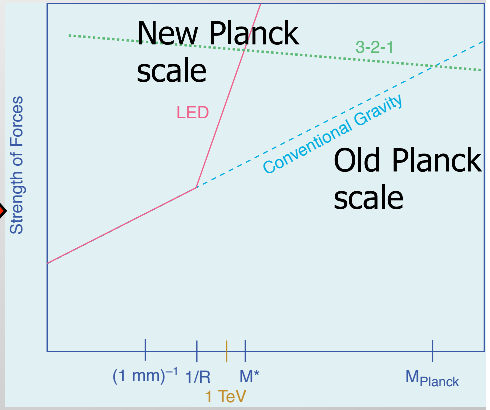
Λ>5.6 TeV
(expected Λ>5 TeV)

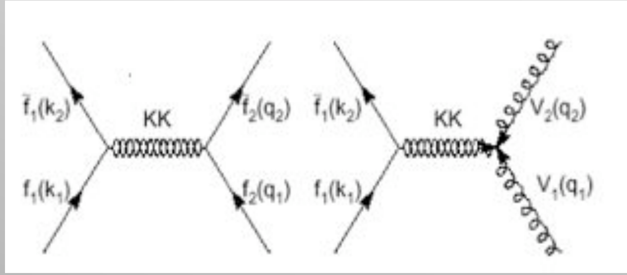
Search for Extra Dimensions

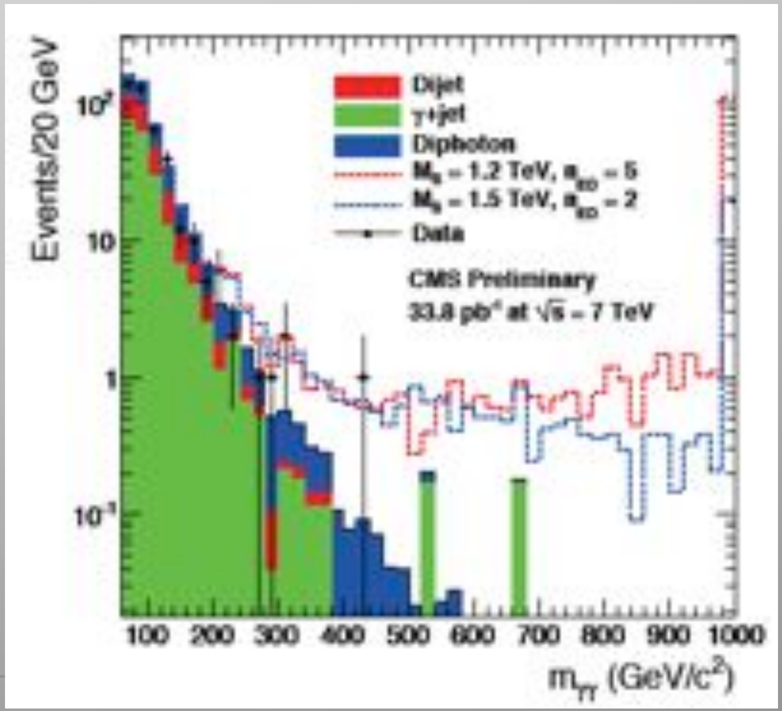
Are there extra space dimensions that open at higher energies?

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









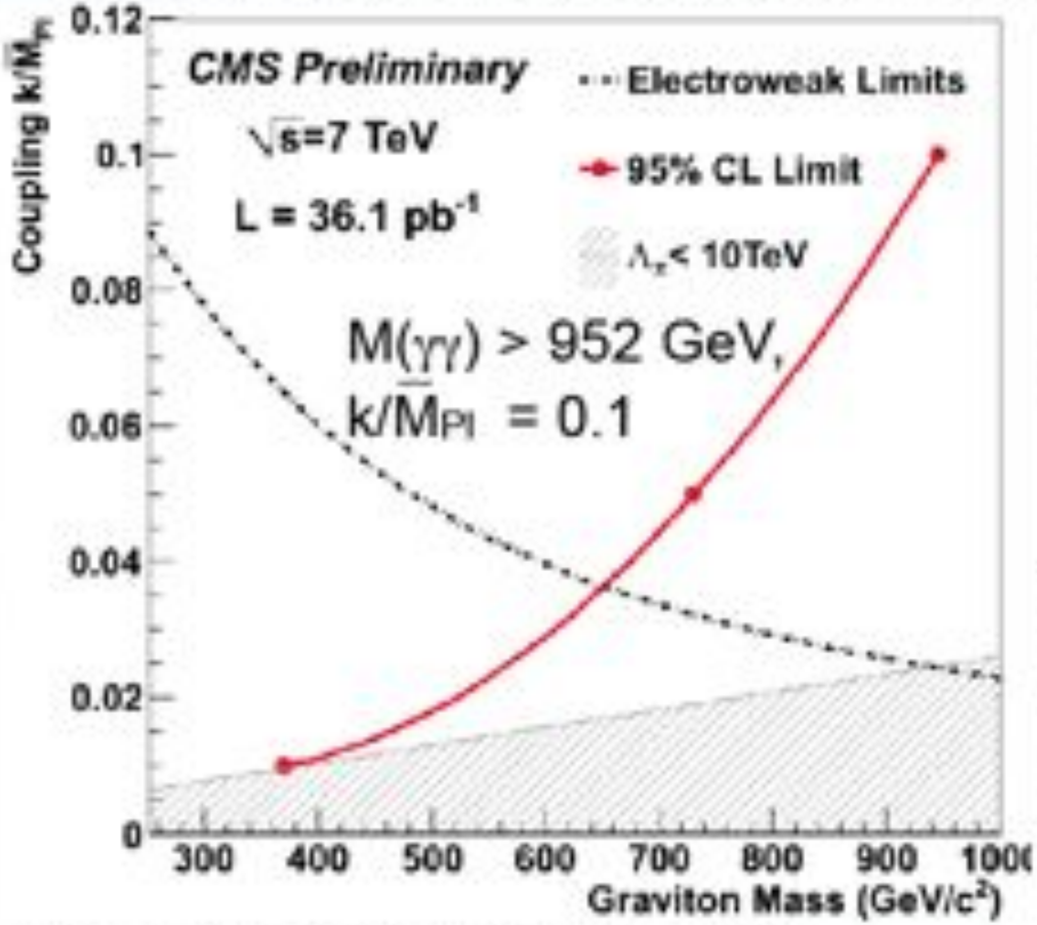
Results

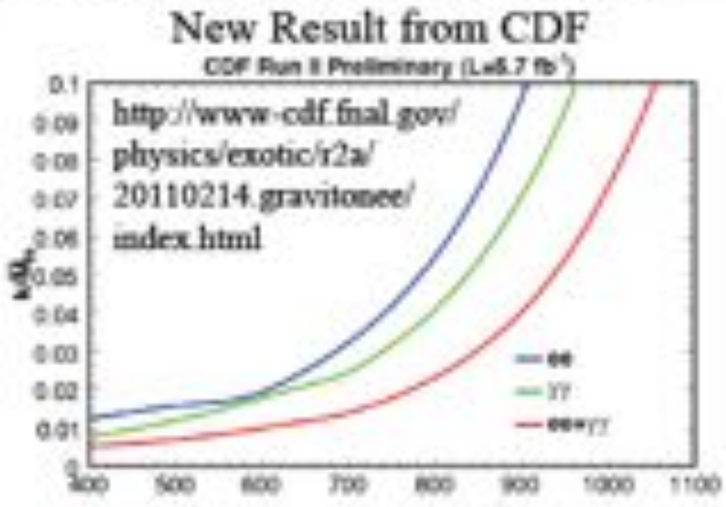
$n_{ED}=2$	$n_{ED}=3$	$n_{ED}=4$	$n_{ED}=5$	$n_{ED}=6$	$n_{ED}=7$
1.88	2.29	1.93	1.74	1.62	1.53

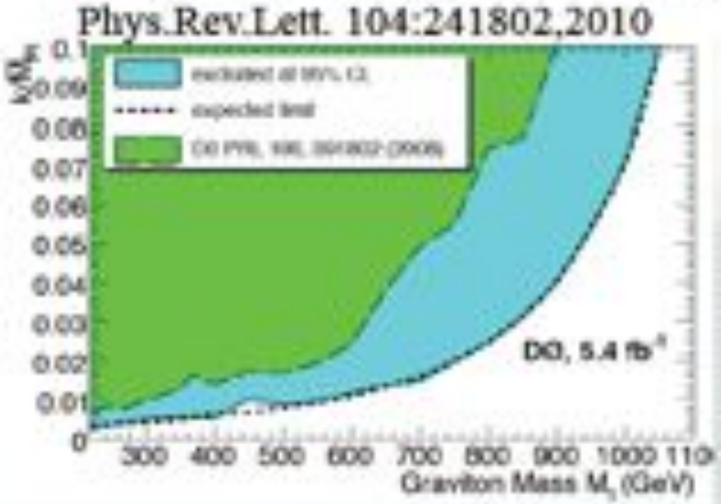
New mass scale larger than 1.5-2.3 TeV depending on the number of extra Dimensions (similar in the $\mu\mu$ channel)
Tighter limits than at the Tevatron

Randal-Sundrum Graviton Search

- Same analysis can be reinterpreted as search for resonances decaying into pair of photons (e.g., GKK)
- Just shy of the Tevatron limits (expect to exceed in combination)







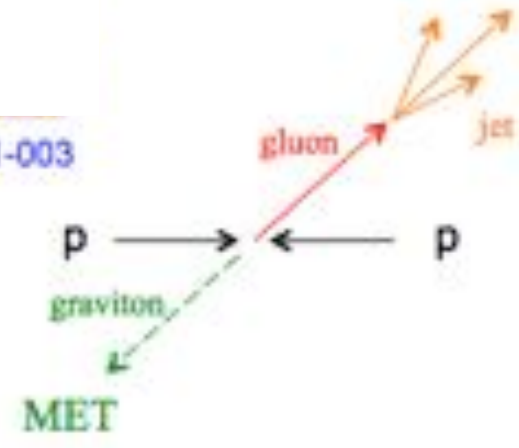
M(ee+μμ) > 1079 GeV, k/M̄Pl = 0.1

Searches for Extra Dimensions

Mono-jet final states

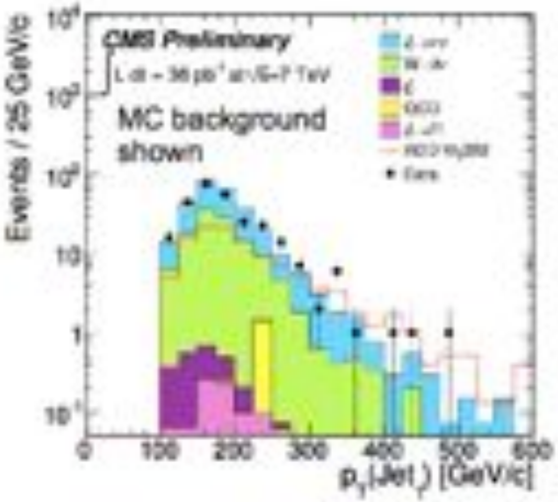
- **One high p_T jet + large MET + no leptons**
- Suppress cosmic/beam halo/instrumental backgrounds
- Data-driven estimate for $Z \rightarrow \nu\nu$ + jets background
- Data consistent with SM, set limits on M_D vs δ

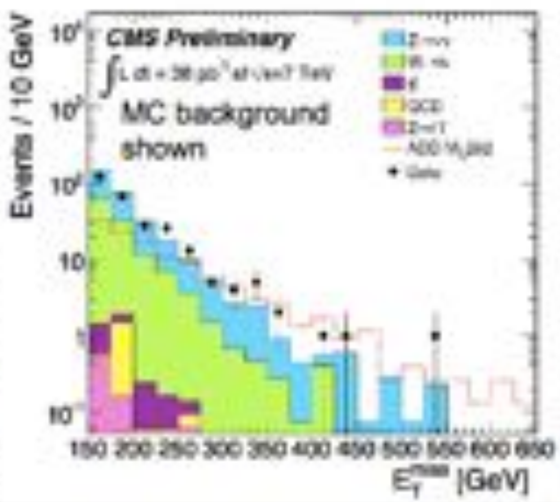
EXO-11-003



N_{DATA}	275
N_{BKG} (data-driven)	297 +/- 45
$N_{SIGNAL}(M_D=2, \delta=2)$	115.2

M_D = "True" Planck scale
δ = number of extra dimensions





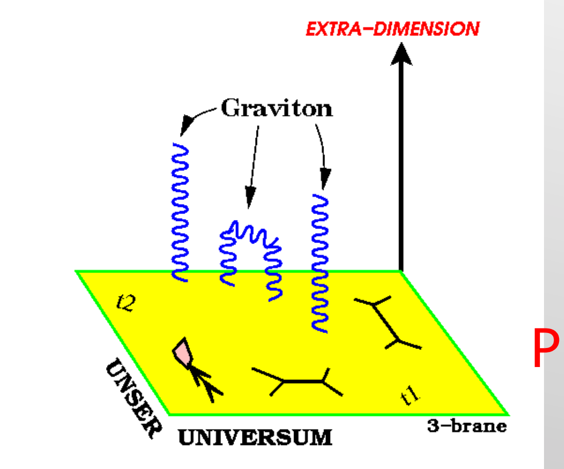
CMS limits on M_D (36 pb^{-1})

δ	With K-Factor**	No K-Factor
2	2.37 TeV	2.16 TeV
3	1.98 TeV	1.83 TeV
4	1.77 TeV	1.67 TeV

** = 1.5 (1.4) for δ=2,3 (4)

δ	CDF	LEP
2	1.4 TeV	1.6 TeV
3	1.15 TeV	1.2 TeV
4	1.04 TeV	0.94 TeV

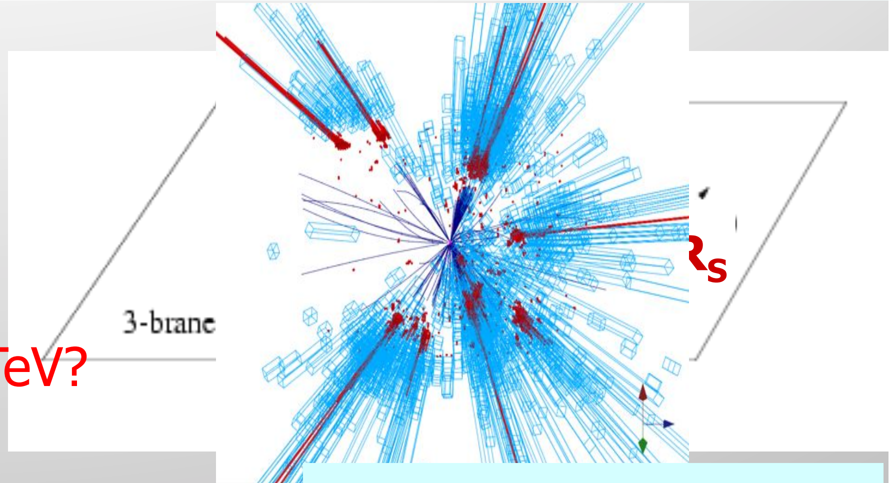
Search for Micro-Black Holes



arXiv:1012.3375

Extra Dimensions!

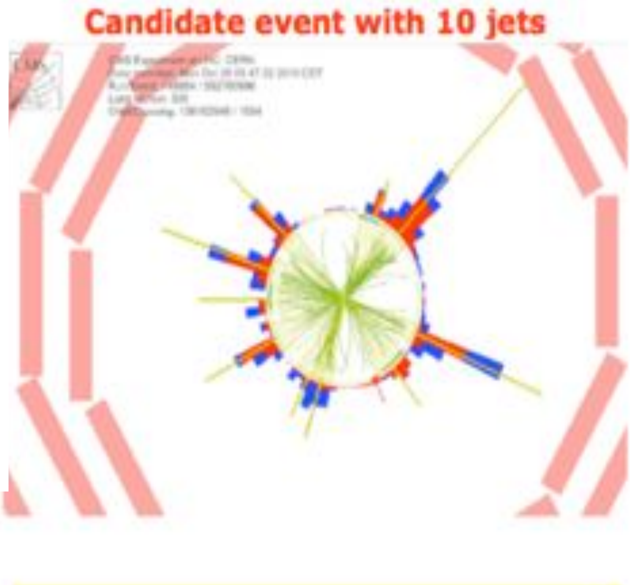
Planck scale a few TeV?

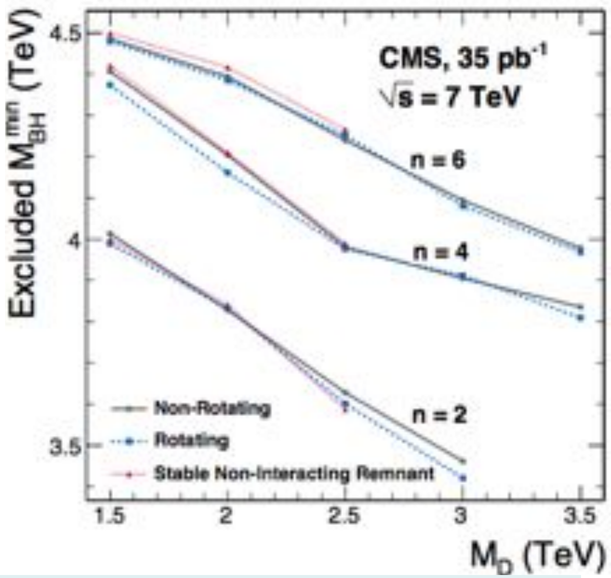


Evaporates in 10^{-27} sec

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

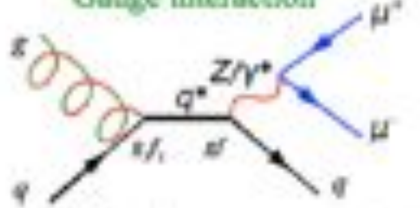




Black hole masses excluded in range 3-4.5 TeV depending on assumptions

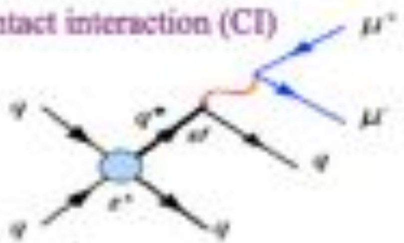
Quark Compositness (q*->qZ)

Gauge interaction



$$L_{trans} = \frac{1}{2\Lambda}\bar{f}_R^* \sigma^{\mu\nu}\left(g_s f_s \frac{\lambda^a}{2} G^a_{\mu\nu} + g f \frac{\tau}{2} W_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu}\right) f_L$$

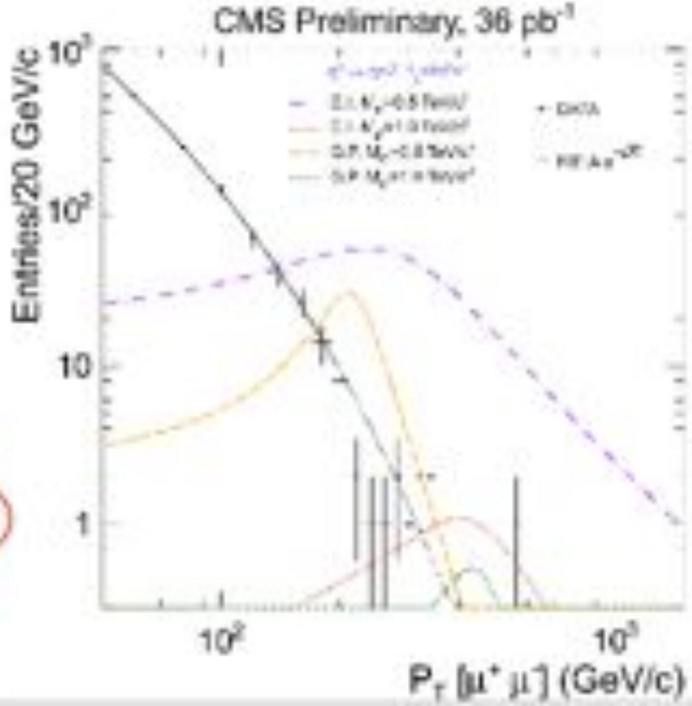
Contact interaction (CI)



$$L_{q^*} = \frac{g^2}{2\Lambda}(\bar{q}\gamma^\mu q)(\bar{q}^*\gamma_\mu q)$$

EXO-10-025

- Complementary to q*→jj decay channel
- **Search for bump/deviations in Z p_T spectrum**
- No deviation from SM prediction, set limits



Gauge Interactions

$M_{q^*} = \Lambda,\ f = f' = f_S = 1$

$M_{q^*} > 0.91$ TeV

Contact Interactions

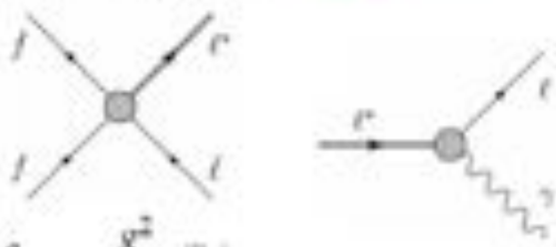
$M_{q^*} = \Lambda,\ f = f' = 1, f_S = 0$

$M_{q^*} > 1.17$ TeV

(H1 limit, 475 pb^{-1}, gauge int., f_S=0, M_{q^*}>252 GeV)

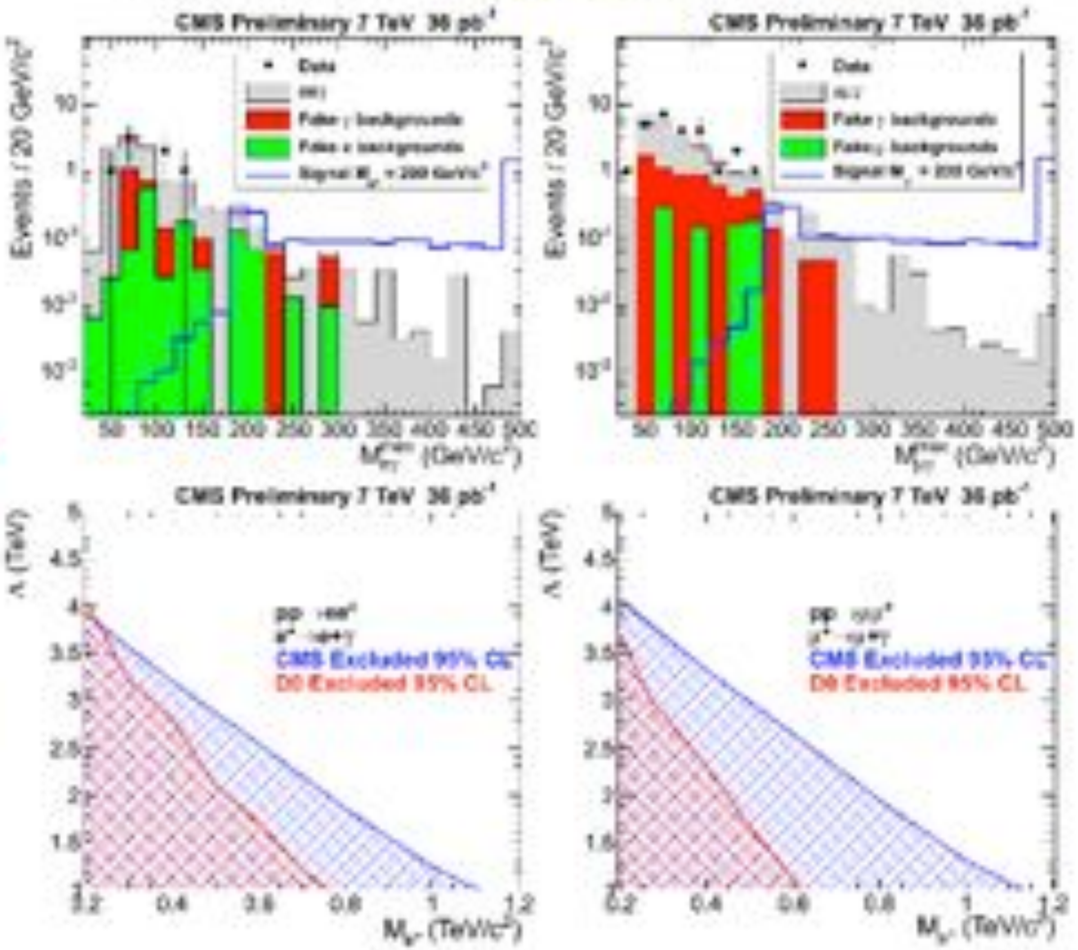
Excited Leptons

Production via new contact interaction → Decay



$$\mathcal{L}_{CI} = \frac{g^2}{2\Lambda^2} j^\mu j_\mu$$

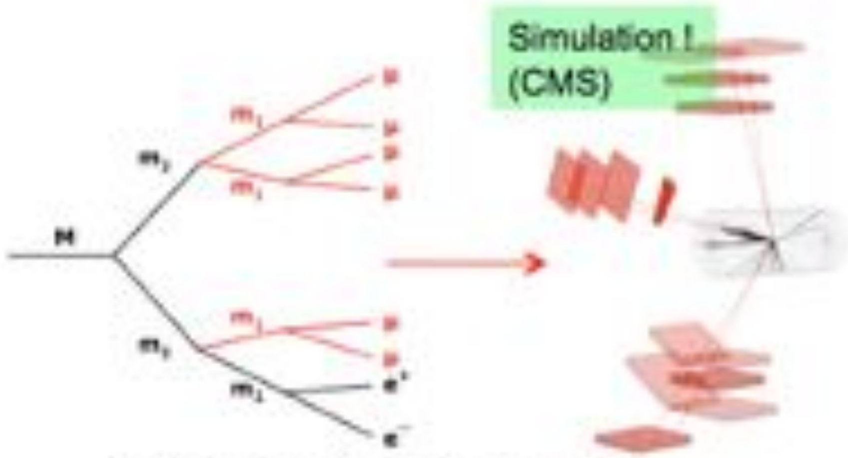
qq→ee*→eeγ EXO-10-016 qq→μμ*→μμγ



- **Search for excess in data at high M(eγ) or M(μγ)**
- Reducible backgrounds from data
  - Fake γ : Z+jets (l^+l^- + fake γ)
  - Fake l : Wγ+jets (l + fake l + γ)
- 0 events observed at high M(lγ)
- Set limits, exceed Tevatron

Also excited quarks in q*-> qZ channel => m_{q*}> 1.17 TeV

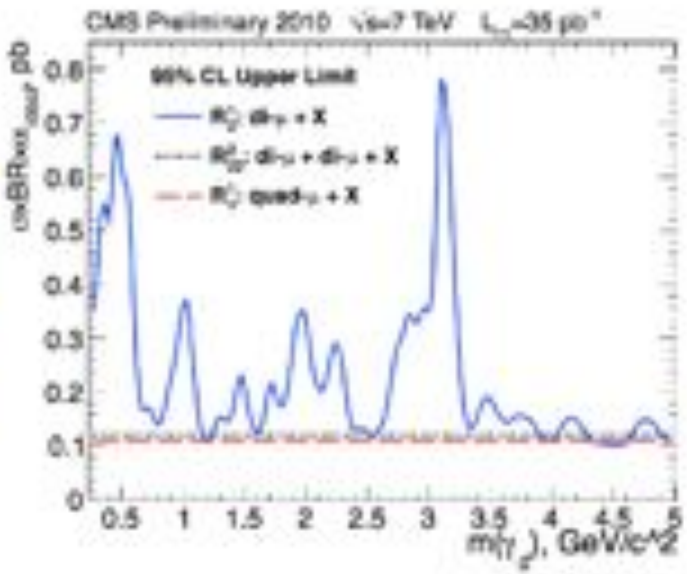
Lepton Jets (Hidden Valleys)



- Hidden sector contains a new low mass particle (m_1 ~ few GeV)
- It decays into SM pairs (i.e. μμ)
- **Collimated groups of di-muons [μμ]**
  - opposite charge, $m_{\mu\mu}$<9 GeV, consistent vertex
- Search for new μμ resonances in various event topologies: [μμ], [μμ][μμ], etc.

EXO-11-013

- **No new μμ resonance seen**
- Set model independent upper limits on σ x BR x α (~0.1–0.5 pb)
- Verified sensitivity in various benchmark models (ex. NMSSM Higgs, MSSM + γ_{DARK})



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.

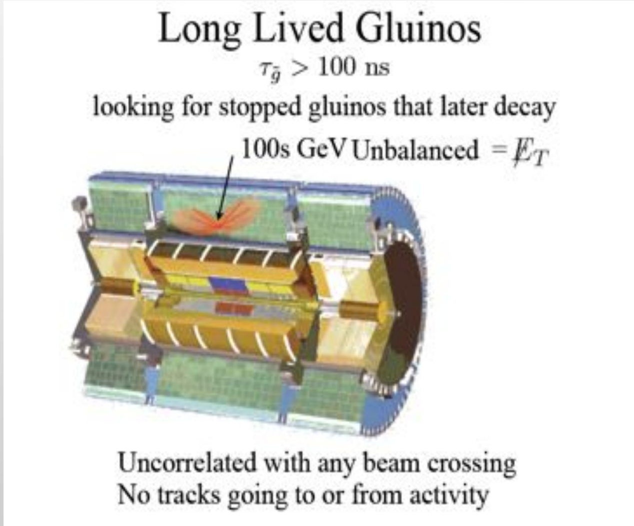
  Unusual interactions with material

  eg. with the calorimeters of the experiments!

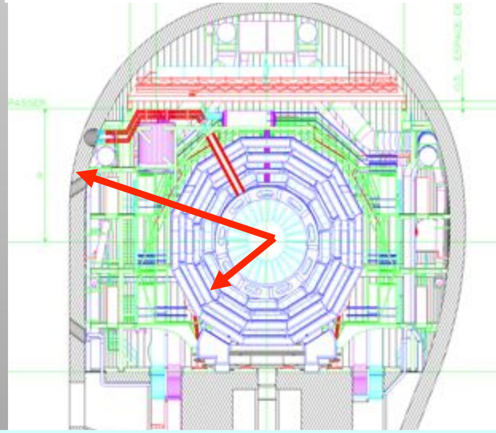
Gravitino Dark Matter and GMSB

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

⇒Challenge to the experiments!

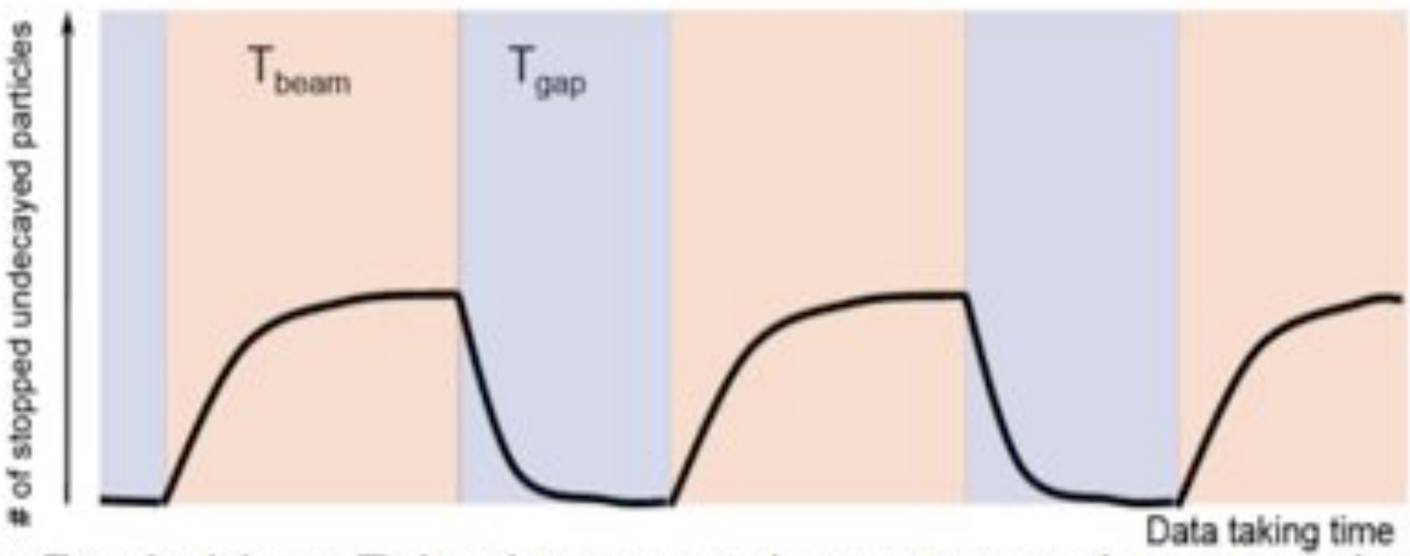


K. Hamaguchi,M Nijori,ADR hep-ph/0612060
ADR, J. Ellis et al. hep-ph/0508198



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

Stopped gluinos



- Basic idea: R-hadrons can loose enough energy in the detector to stop somewhere inside (usually calorimeters)

Eg when there is no beam!

- Sooner or later they must decay
- Trigger: (jet) && !(beam)
- Only possible backgrounds: cosmics and noise
  - Being already studied with CRAFT data

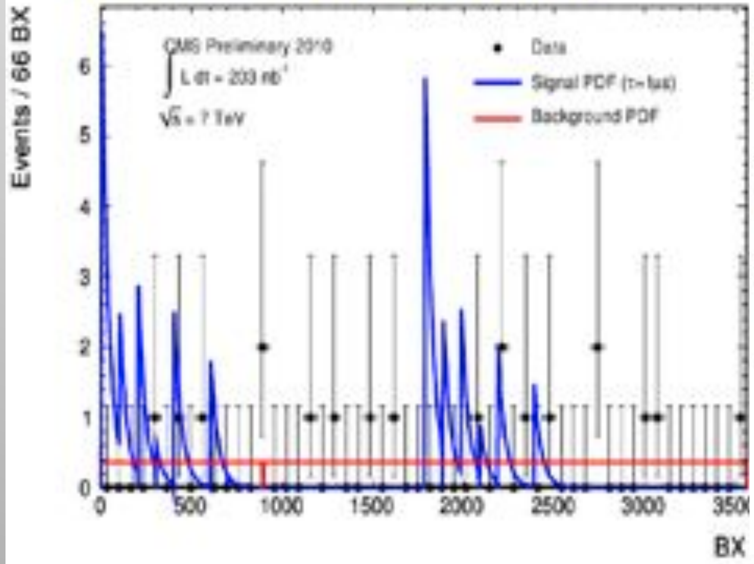
12

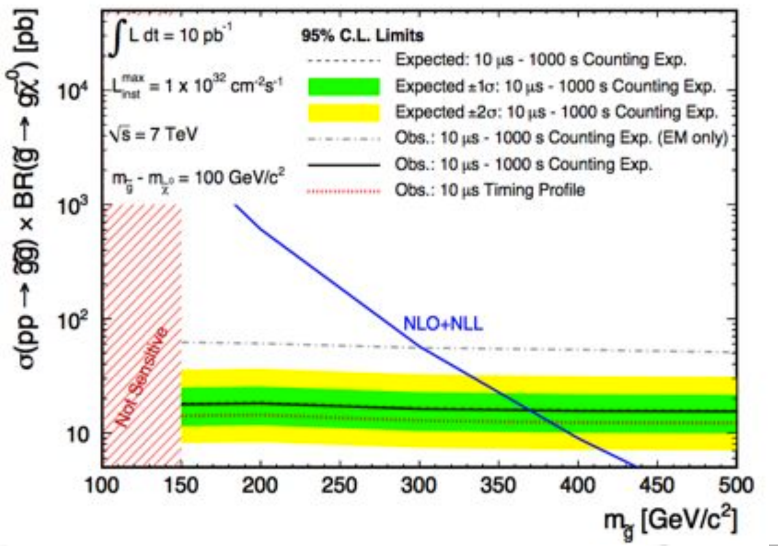
Searches: Stopped Gluinos

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

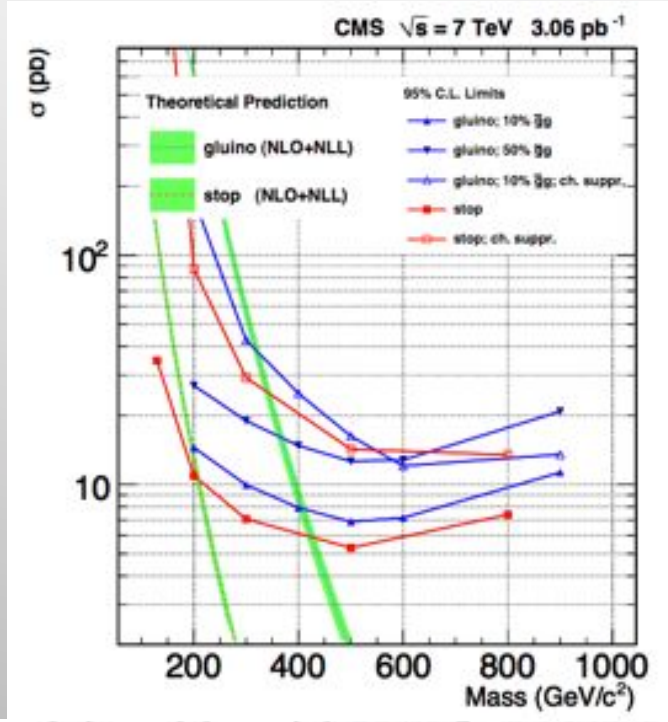
Counting experiment (10 μs - 1000s)
exclude $m_{\tilde{g}}$ < 370 GeV

Heavy Stable Charged Particles

arXiv:1101.1645

Stable particles that traverse the detector

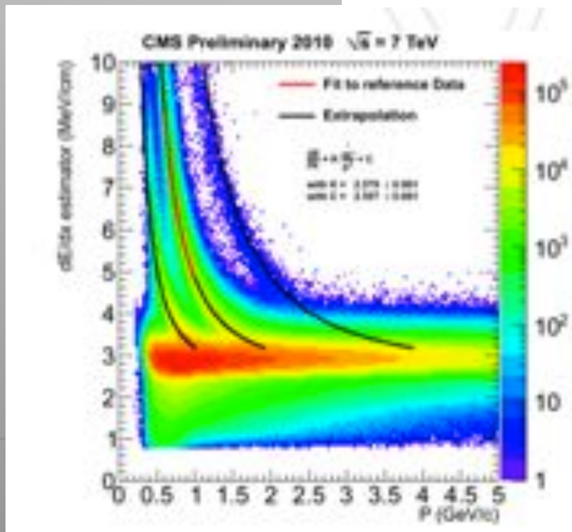
Eg heavy stable gluino (R-hadron) or stop/stau

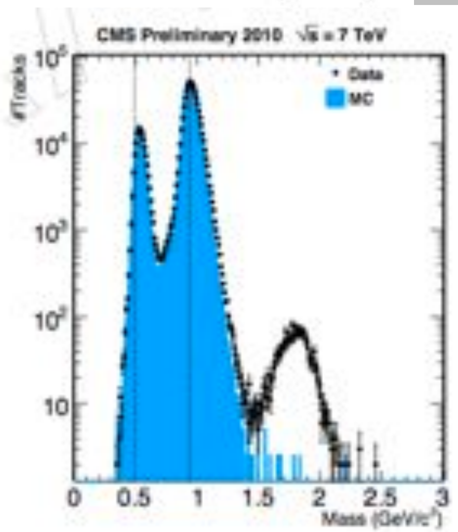


First search limits using tracker de/dx and muon identification

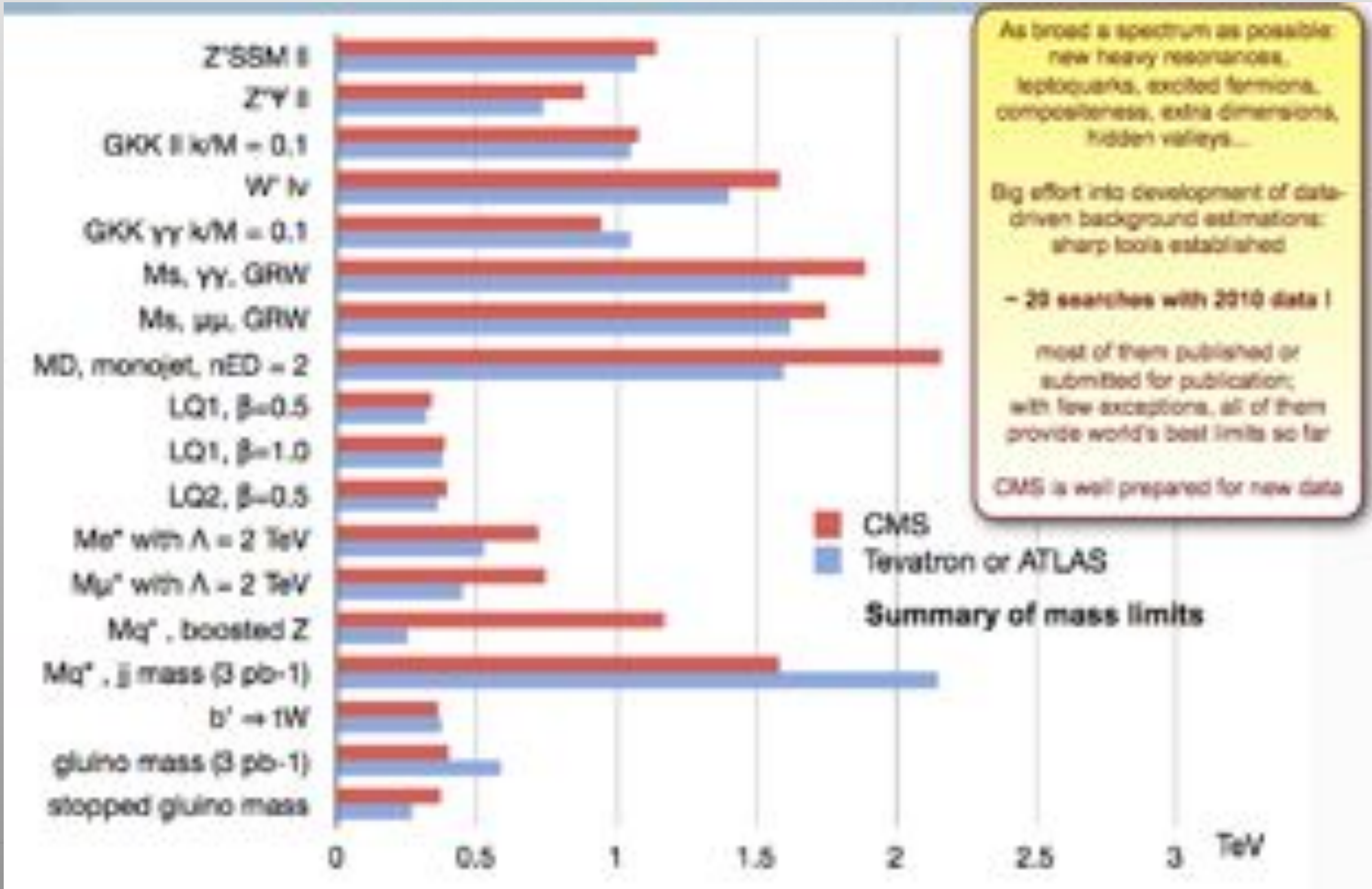
Result for 3.1 pb^{-1}
0 events after cuts

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



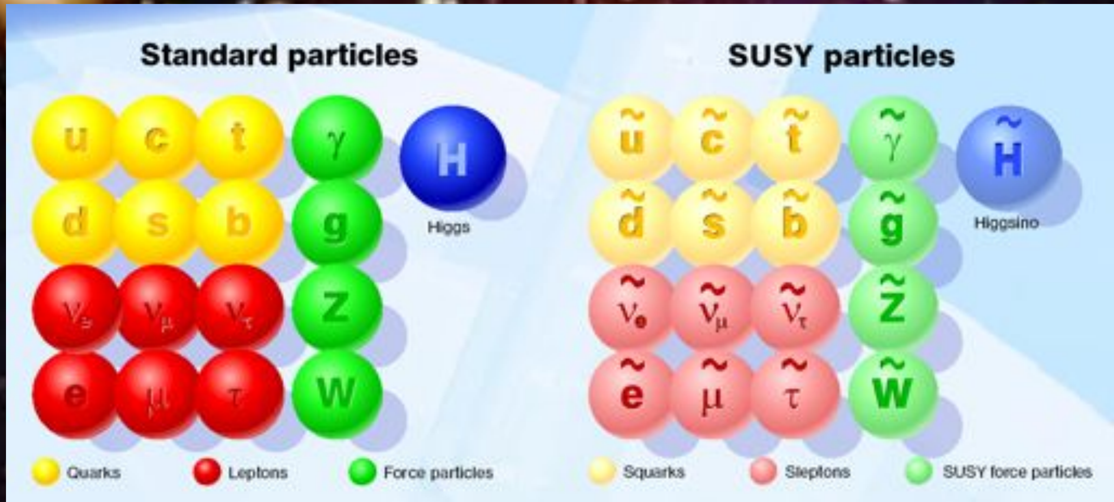


Reach Overview

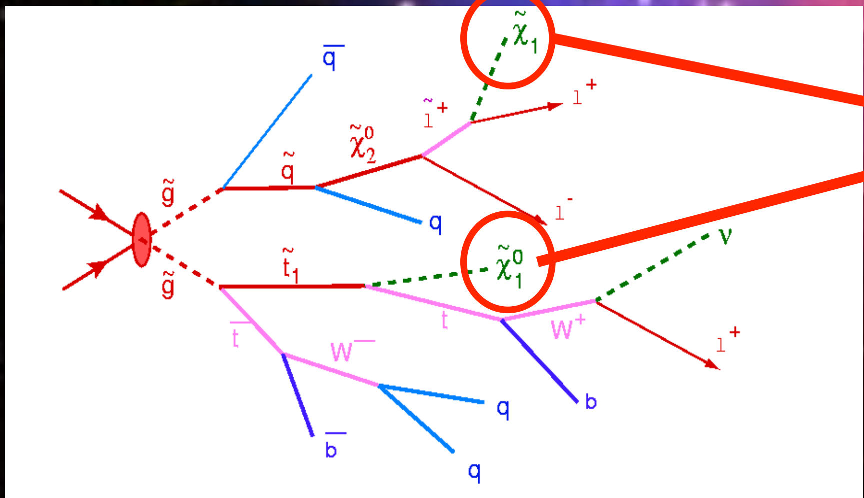


Supersymmetry

Supersymmetry: a new symmetry of Nature?

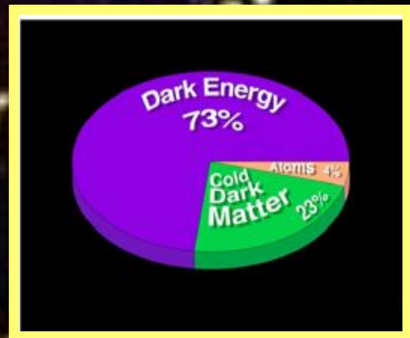


Candidate particles for Dark Matter
⇒ Produce Dark Matter in the lab



SUSY particle production at the LHC

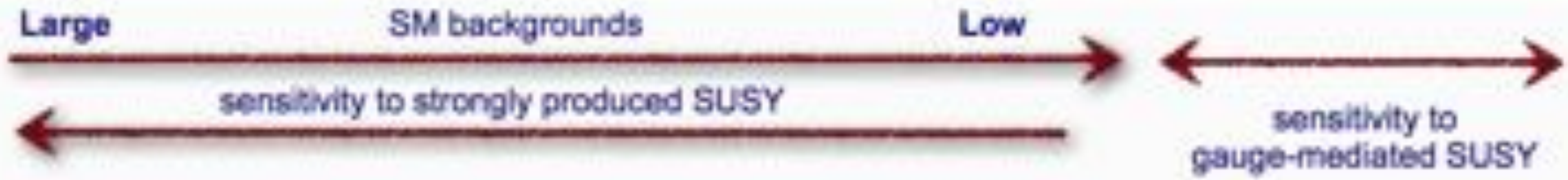
+ 2 b-jets
+ 4 jets



ac

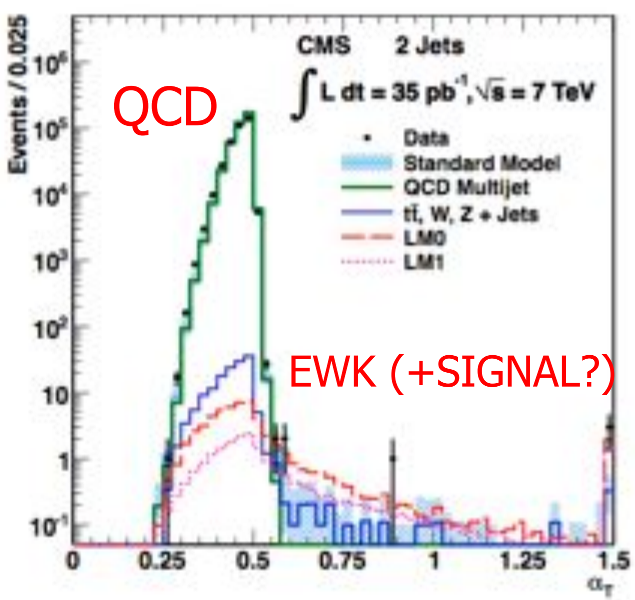
Searches for SUSY

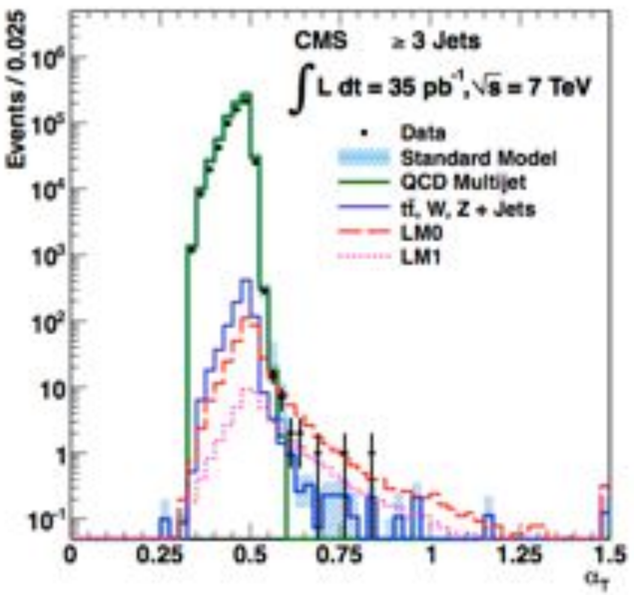
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET



- **Focus on signatures (topologies)**, use different approaches/observables
  - alpha_T, "Razor", HT, MHT, ...
- Established many different **data-driven techniques** to derive backgrounds
  - jet smearing and re-balancing, ABCD, fakeable-object technique to estimate fake lepton rates, generic properties of lepton p_T spectra, generic properties of falling SM spectra
- Different trigger paths (all hadronic HT-based, leptonic)
- Not necessarily optimized for best excl. limits, but sharpened tools for discovery!
- **cross check, cross check, cross check....**

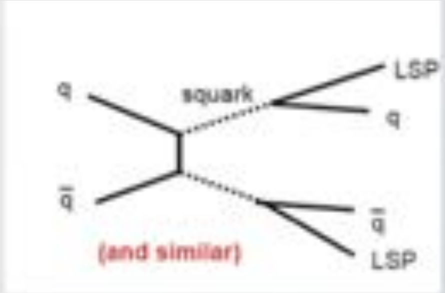
Search for SUSY

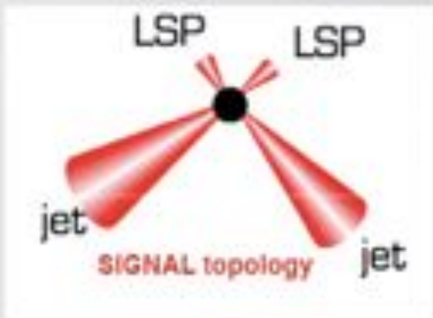




arXiv:1101.1628

All Hadronic Channel:
Jets + Missing Transverse Energy





$$\alpha_T = \frac{E_{T\,j2}}{M_{T\,j1j2}} = \frac{\sqrt{E_{T\,j2}/E_{T\,j1}}}{\sqrt{2(1-\cos\Delta\varphi)}}$$

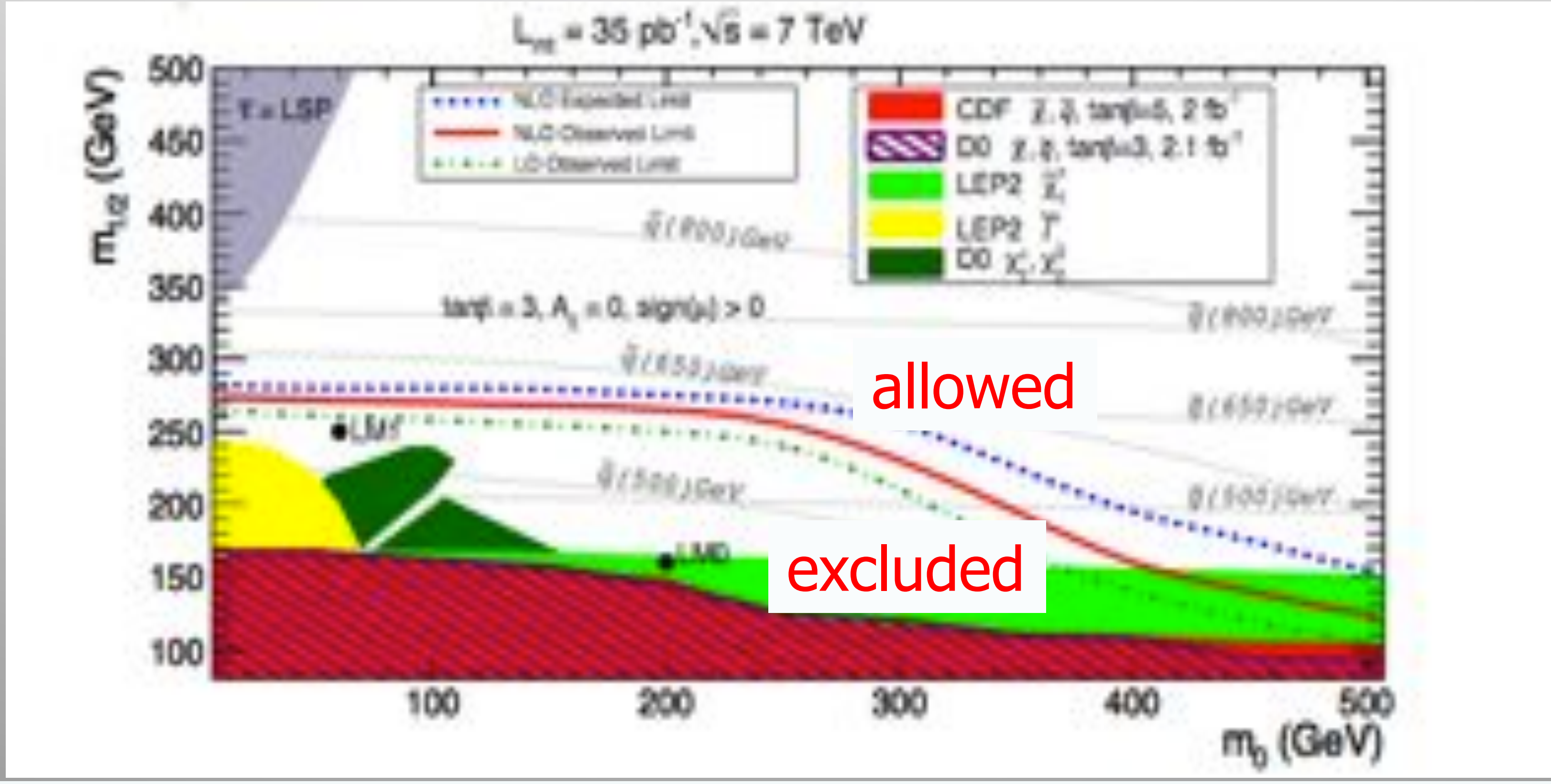
Control QCD with the α_T variable
No QCD expected for $\alpha_T > 0.5$

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

First SUSY Search Result

-All 2010 data included: ~10-12 Events expected/ 13 observed

No discovery of supersymmetry yet… Stronger exclusion limits



Masses of squarks/gluinos > ~600 GeV!!! (in the CMSSM)

m_0 amd $m_{1/2}$ are universal scalar and gaugino masses at the GUT scale

Where do we expect SUSY?

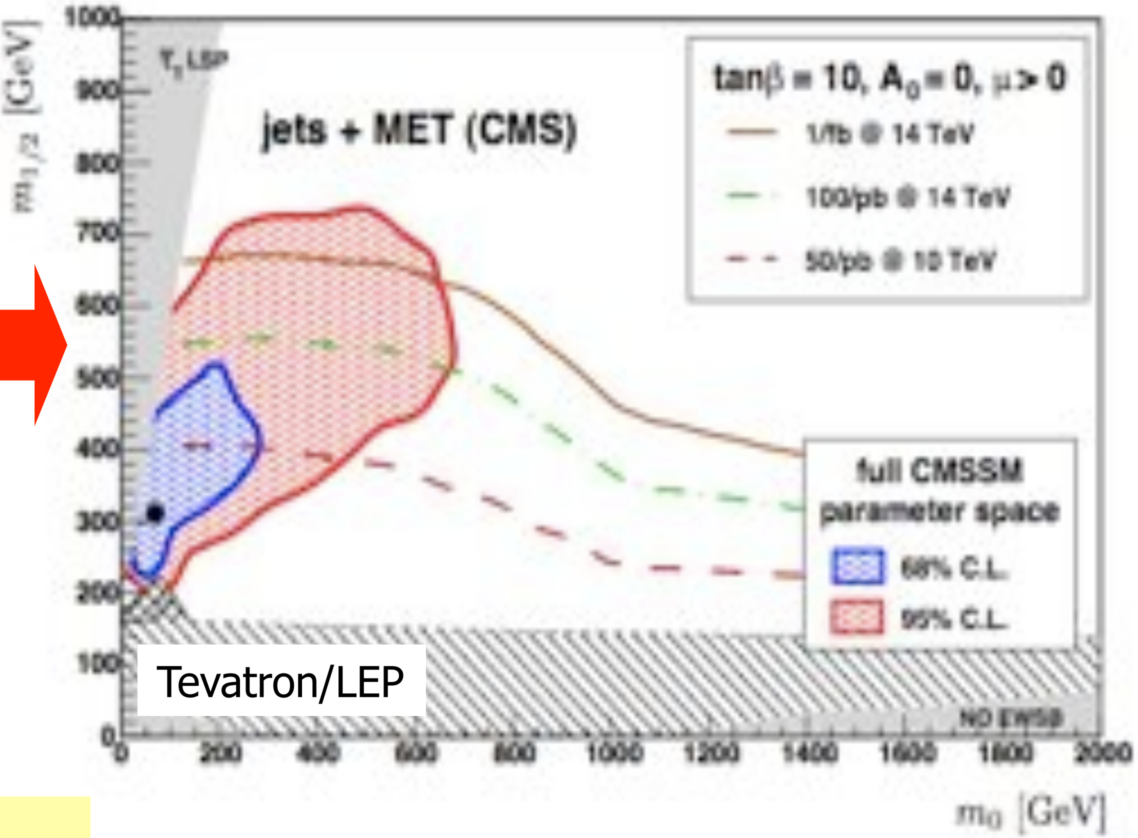
O. Buchmuller et al
arXiv:0808.4128

OB, R.Cavanaugh, A.De Roeck,
J.R.Ellis, H.-Flaecher, S.-Heineme
G.Isidor, K.A.Olive, P.Paradini,
F.J.Ronga, G.Weiglein

Simultaneous fit of CMSSM parameters m_0, $m_{1/2}$, A_0, tan (μ>0) to more than 30 collide and cosmology data (e.g. M, M_{top}, g-2, BR(B→Xγ), relic density)

Precision measurements
Heavy flavour observables

"LHC Weather Forecast"



"CMSSM fit clearly favors low-mass SUSY - Evidence that a signal might show up very early?!"

"Predict" on the basis of present data what the preferred region for SUSY is (in constrained MSSM SUSY)

Many other groups attempt to make similar predictions

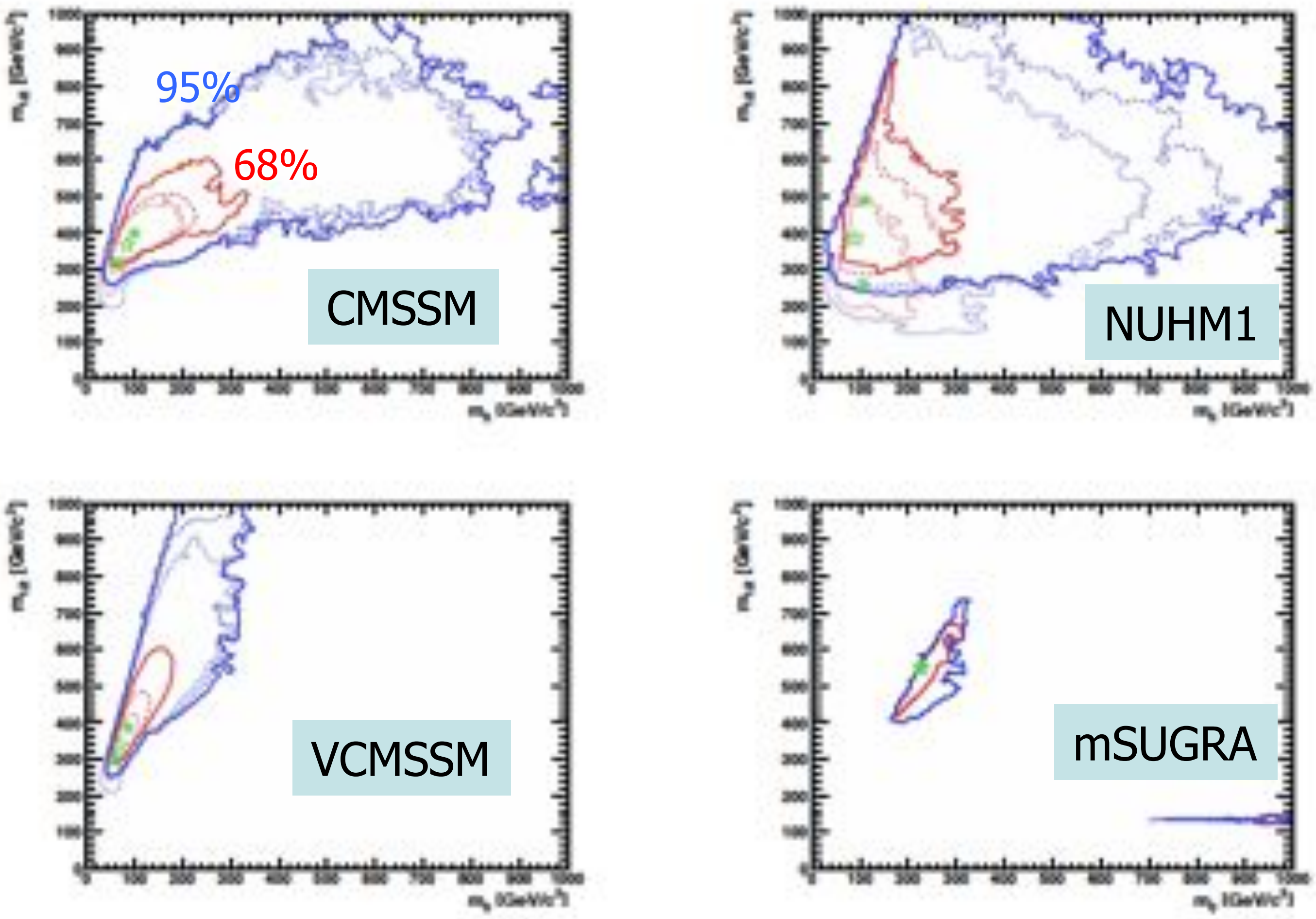
Impact of First SUSY Limits

Implications of Initial LHC Searches for Supersymmetry

O. Buchmueller[a], R. Cavanaugh[b,c], D. Colling[a], A. De Roeck[d,e], M.J. Dolan[f], J.R. Ellis[d,g], H. Flächer[h], S. Heinemeyer[i], G. Isidori[j], K. Olive[k], S. Rogerson[a], F. Ronga[l], G. Weiglein[m]

Add the new CMS/ATLAS cesults to the constraints

arXiv:1102.4585



Original: dotted

+CMS:dashed

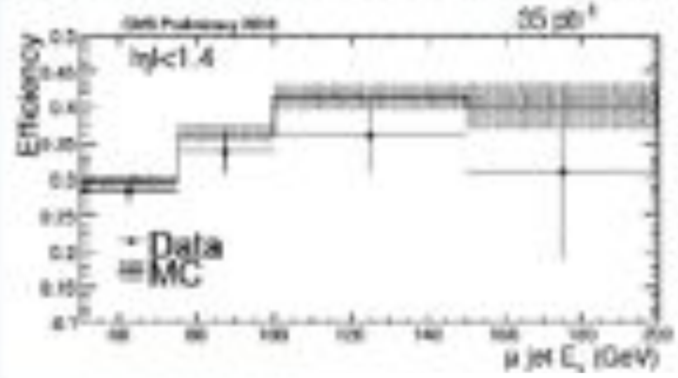
+ATLAS: solid

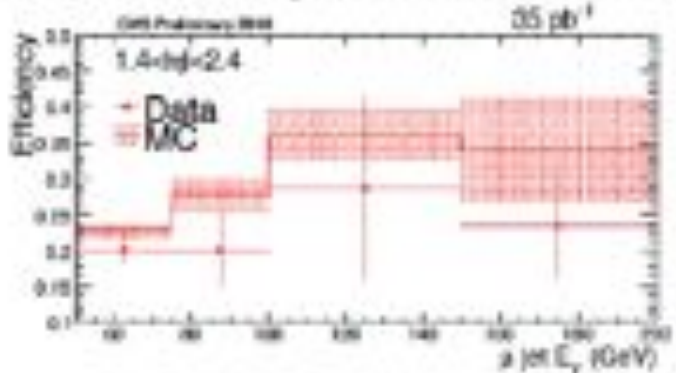
Changes in for the « Best Point »

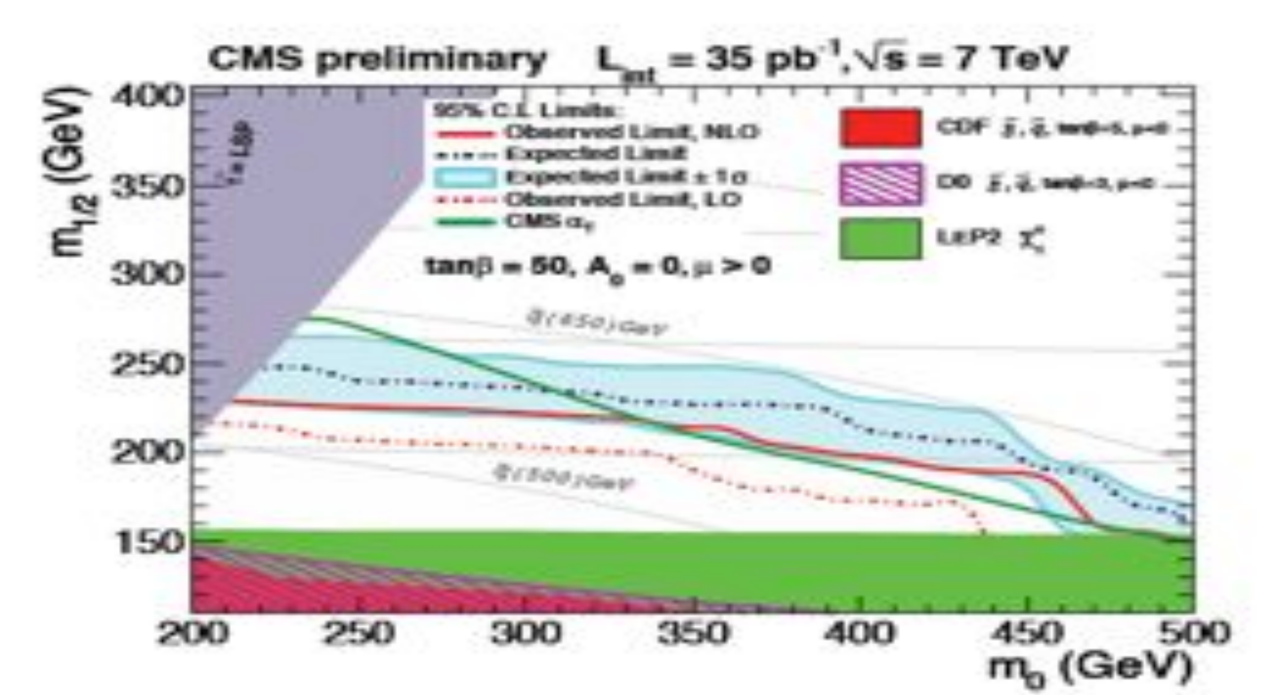
Model	Minimum χ^2	Probability	$m_{1/2}$ (GeV)	m_0 (GeV)	A_0 (GeV)	$\tan\beta$	M_h (no LEP) (GeV)
CMSSM	(21.3)	(32%)	(320)	(60)	(-170)	(11)	(107.9)
with CMS	22.0	29%	370	80	-340	14	112.6
with ATLAS	24.9	16%	400	100	-430	16	112.8
NUHM1	(19.3)	(31%)	(260)	(110)	(1010)	(8)	(121.9)
with CMS	20.9	28%	380	90	70	14	113.5
with ATLAS	23.3	18%	490	110	-630	25	116.5
VCMSSM	(22.5)	(31%)	(300)	(60)	(30)	(9)	(109.3)
with CMS	23.8	25%	340	70	50	9	115.5
with ATLAS	27.1	13%	390	90	70	11	117.0
mSUGRA	(29.4)	(6.1%)	(550)	(230)	(430)	(28)	(107.8)
with CMS	29.4	6.1%	550	230	430	28	121.2
with ATLAS	30.9	5.7%	550	230	430	28	121.2

Search using B-jets + MET

- Extension of the α_T analysis to b-jets
- Improved sensitivity at large tanβ and m_0 (tanβ > 50)

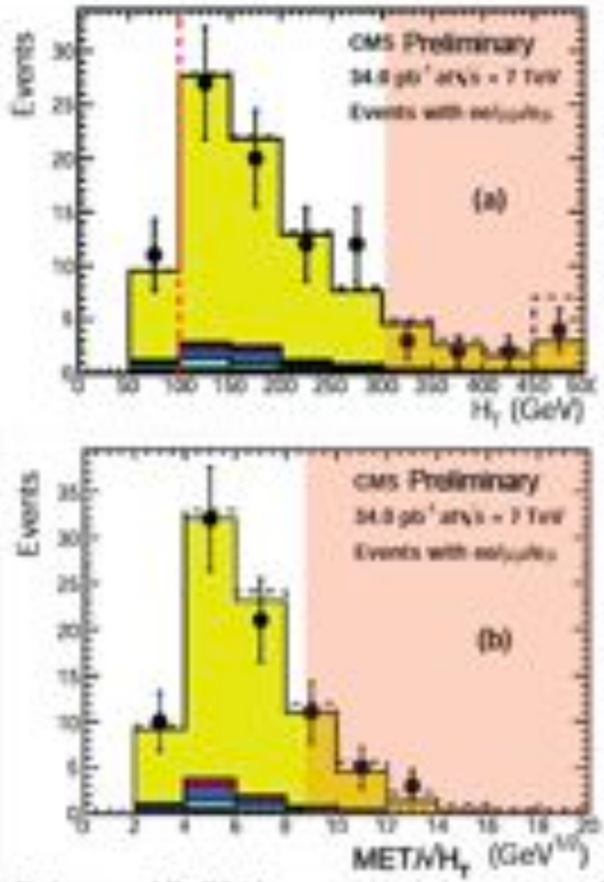


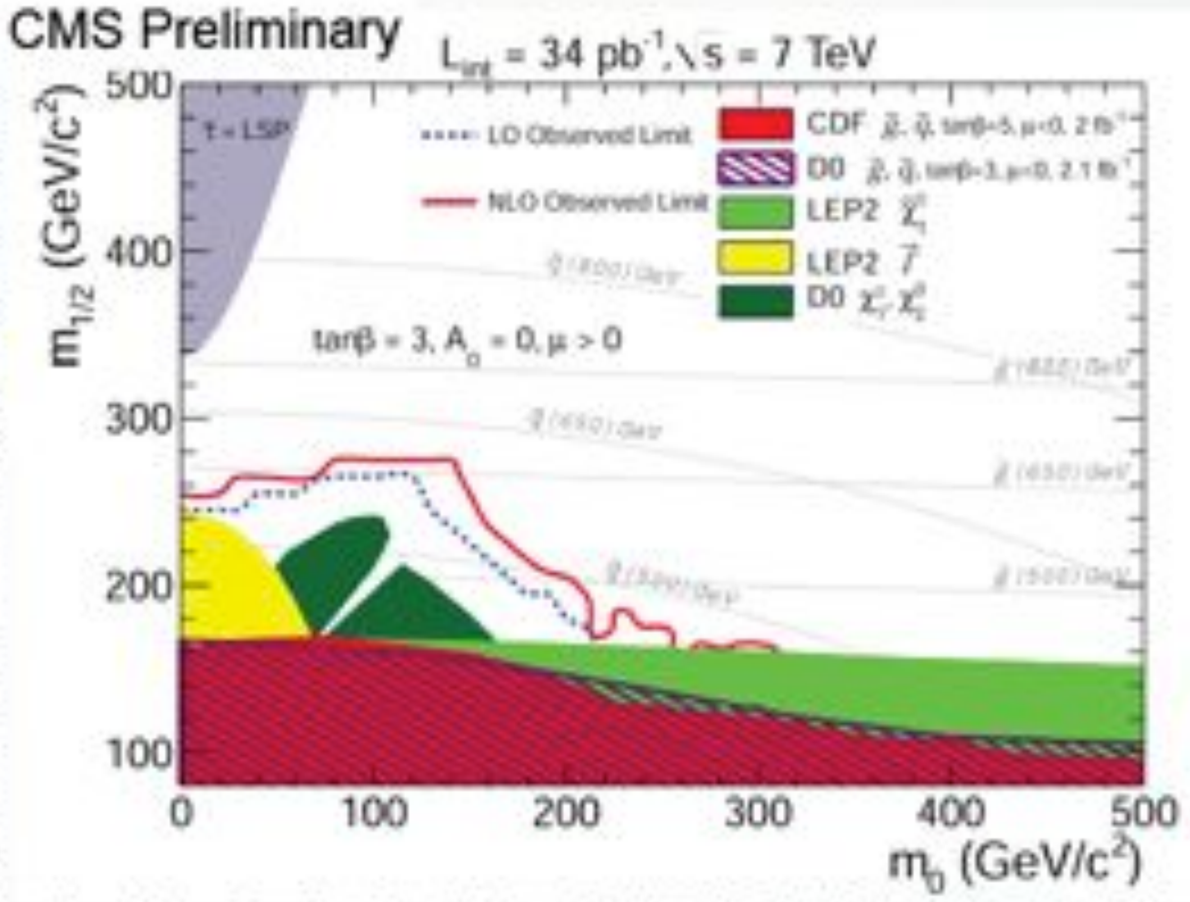




SUSY: OS Di-Leptons + jets + MET

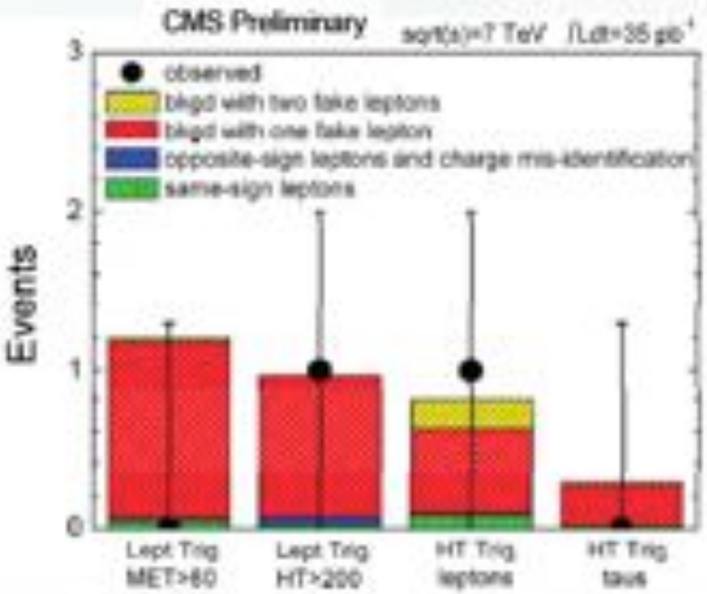
- Two opposite-sign leptons (e^+e^-, $\mu^+\mu^-$, $e^\mp\mu^\pm$)
- Dominant background: top-pair production
- Estimated via matrix method: 1.4 ± 0.8 events predicted, 1 observed

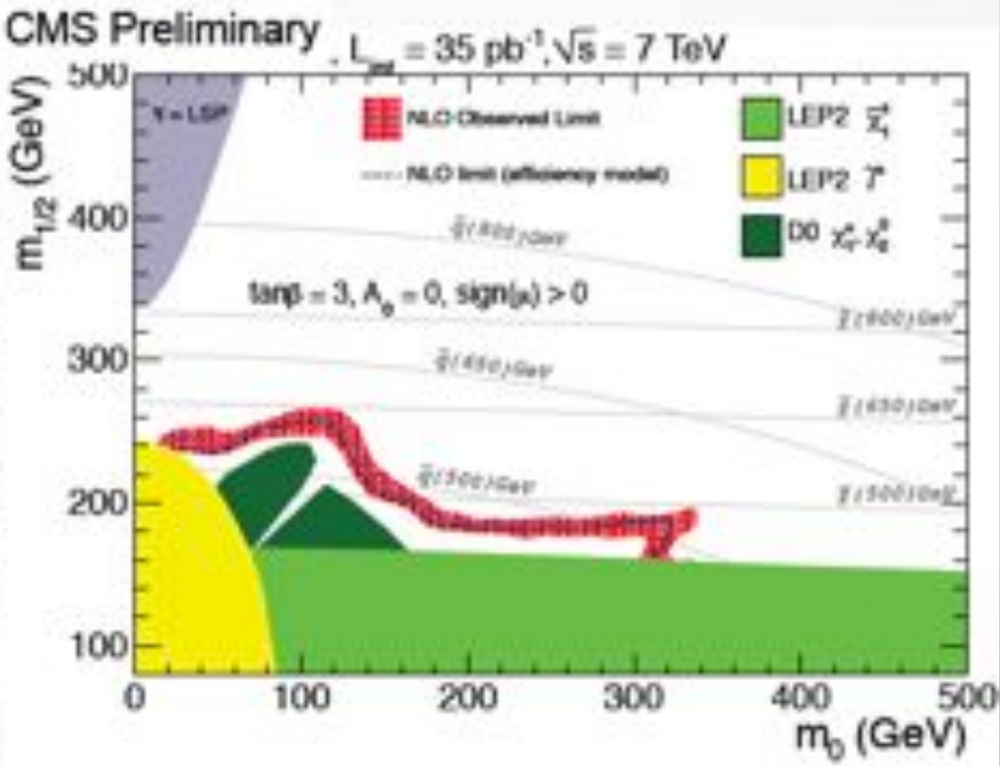




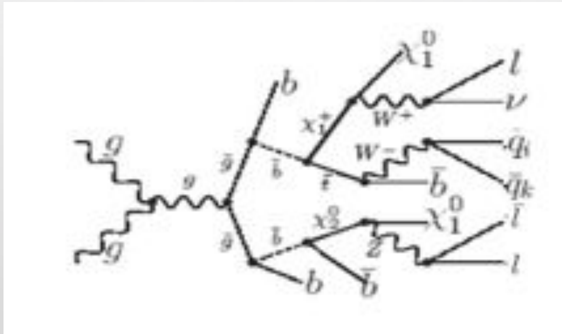
SUSY: SS Di-Leptons + jets +MET

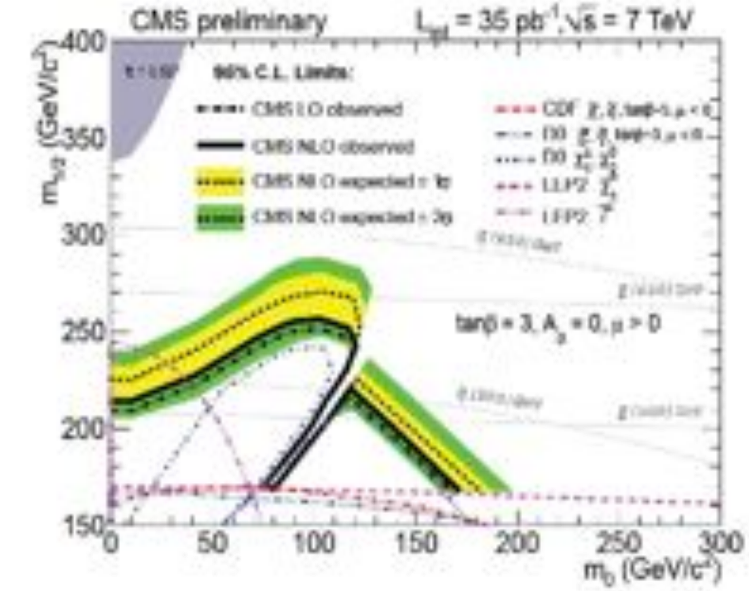
- Two same-sign leptons ($e^\pm e^\pm$, $\mu^\pm\mu^\pm$, $e^\pm\mu^\pm$, $e^\pm\tau^\pm$, $\mu^\pm\tau^\pm$, $\tau^\pm\tau^\pm$)
- Dominant background: misidentified leptons
- Similar sensitivity as in the OS channel for small tanβ
- Tau channels are not yet included in the limit; will be for large tanβ

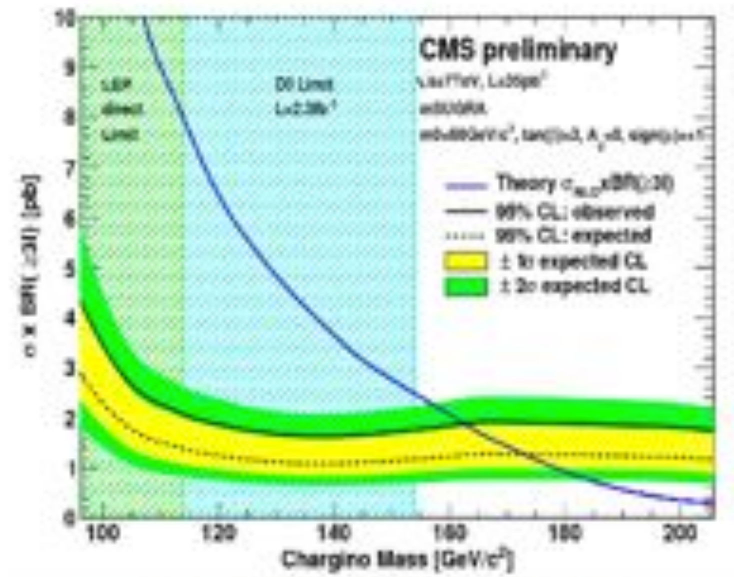




SUSY: Multipleptons







Chargino mass >170 GeV/c² for this particular value of m_0, tanβ

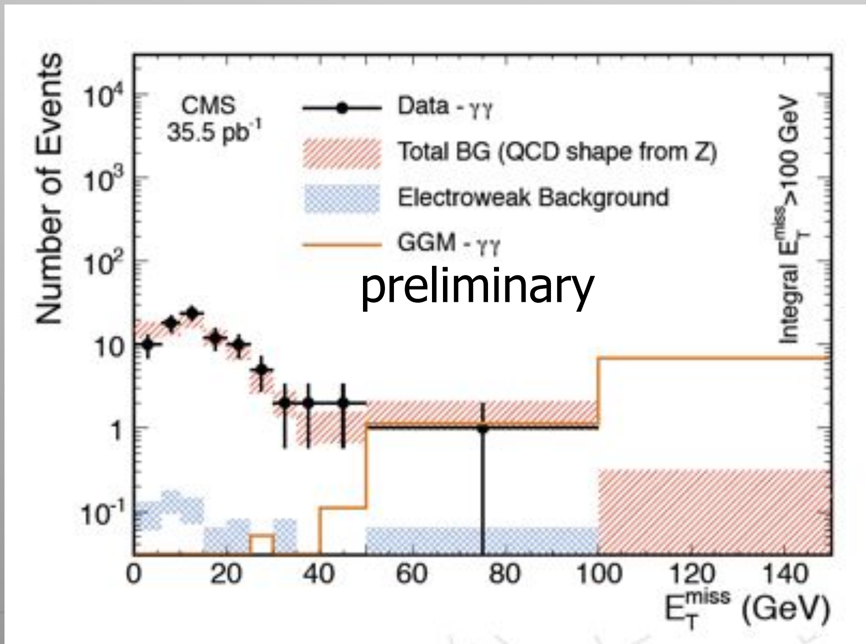
Gluino mass > 690 for m_0=100 GeV/c²

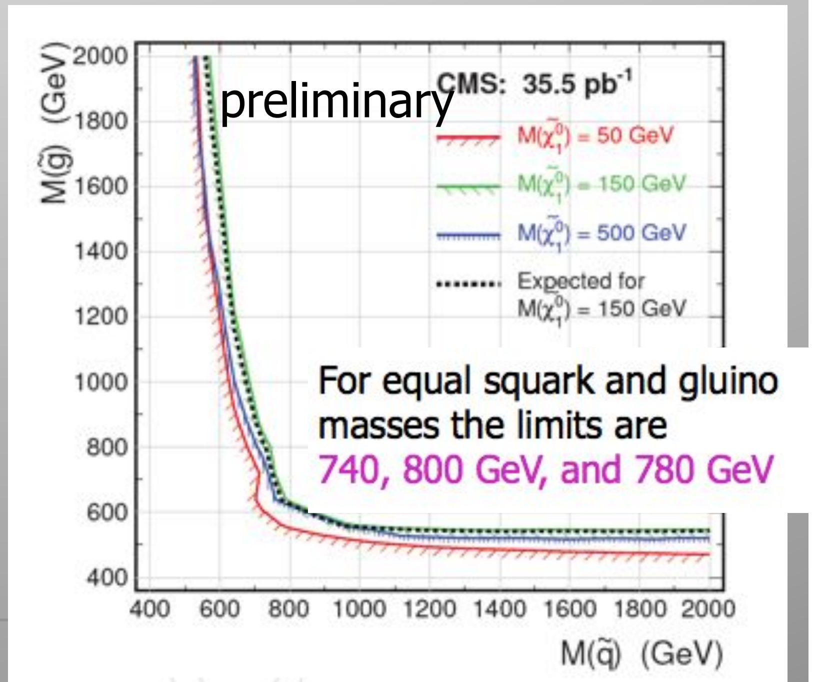
GMSB SUSY Searches

Gauge Mediated SUSY breaking: LSP is the Gravitino

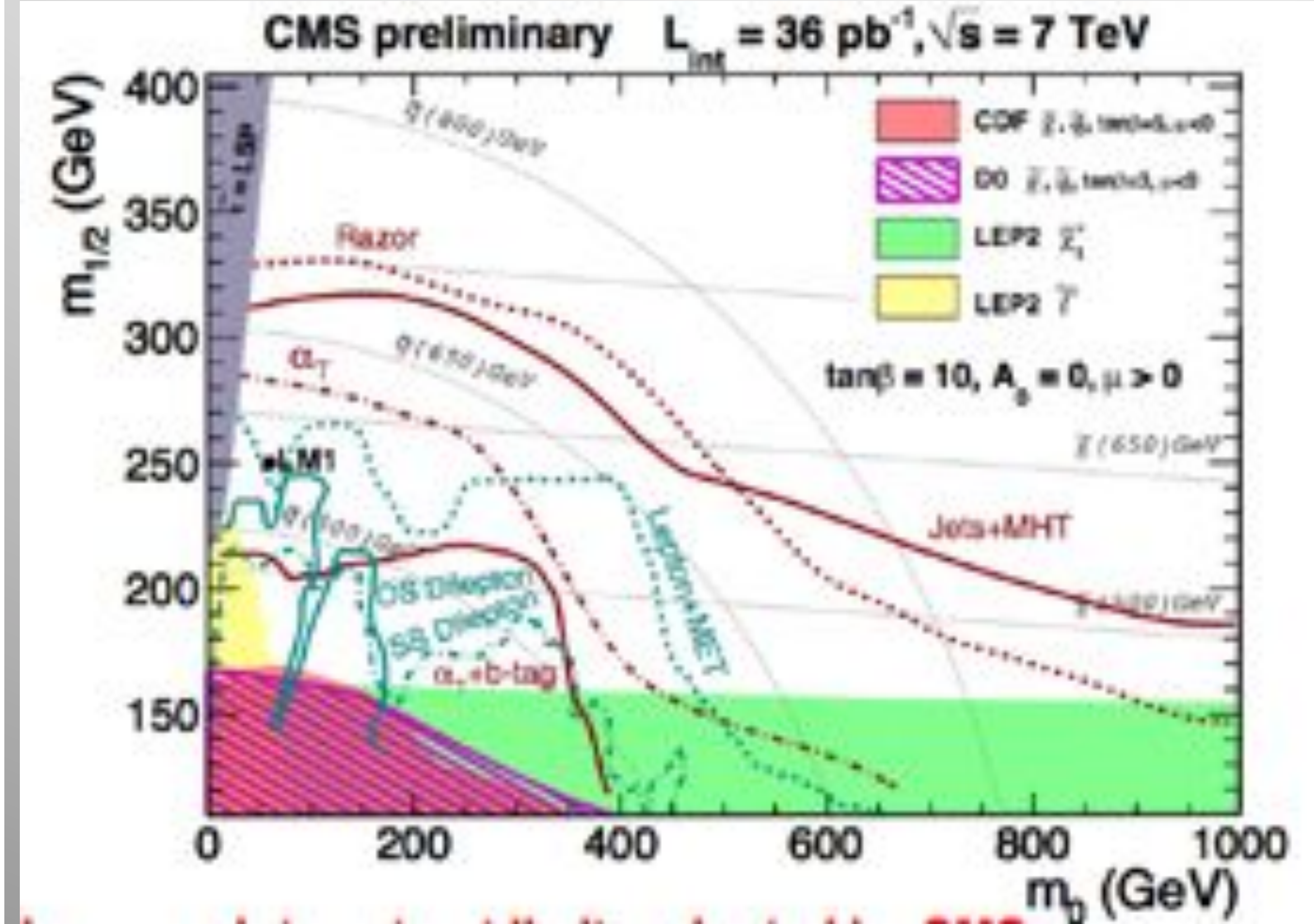
- Phenomenology depends on NLSP
  - if neutralino, decays into gravitino and γ, Z^0, or h^0 (depending on neutralino mixing)

Here analyse collisions with:
two hard photons (30 GeV) , missing transverse momentum and jets





Summary of Search Channels



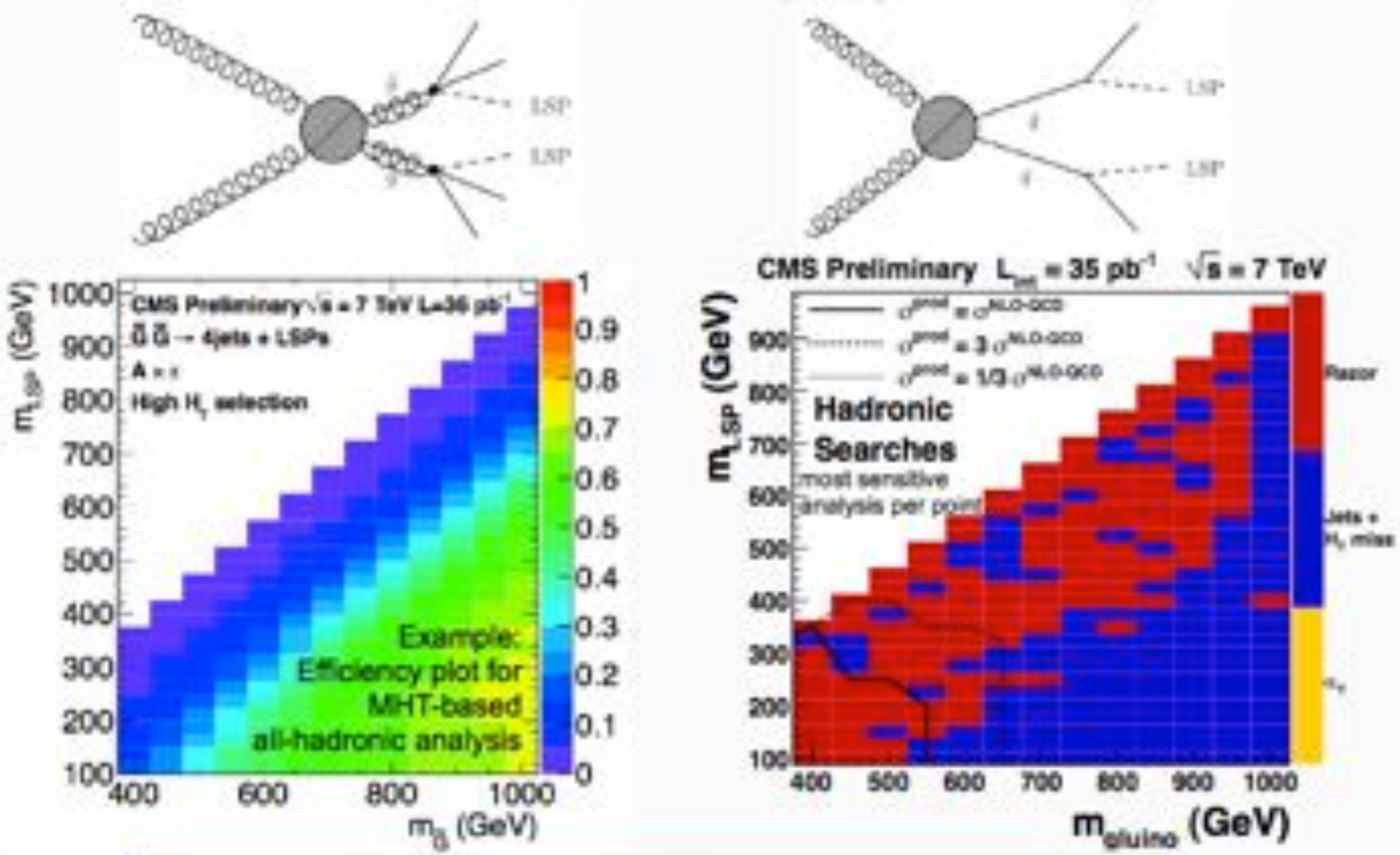
Channels with

- Jets only
- Single leptons
- Di-leptons
- Photons

In this model the squarks/gluinos get excluded for masses below 600-700 GeV

Results as Simplified Models

Models proposed at: http://www.lhcnewphysics.org



Shows complementarity of hadronic analyses.
CMS will provide these results electronically.
Feedback is welcome.

The World is Watching (I)

The fine-tuning price of the early LHC

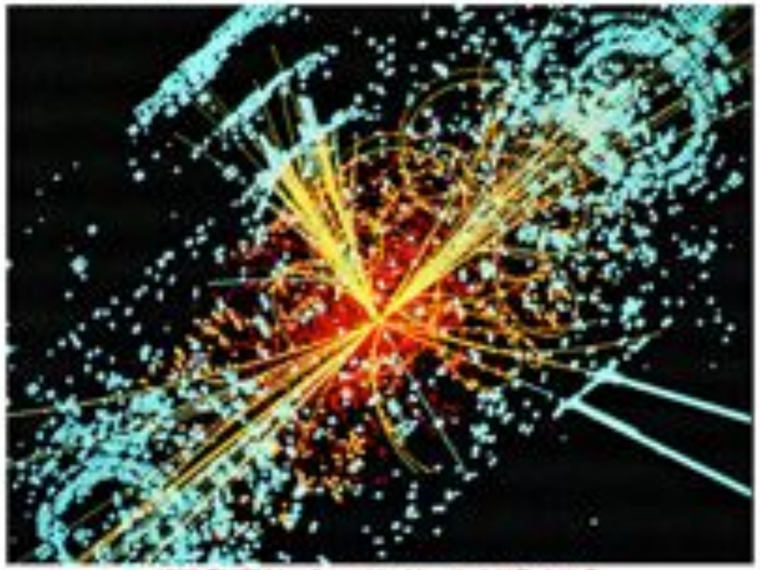
Alessandro Strumia

(Submitted on 11 Jan 2011 (v1), last revised 20 Feb 2011 (this version, v2))

LHC already probed and excluded half of the parameter space of the Constrained Minimal Supersymmetric Standard Model allowed by previous experiments. Only about 0.7% of the CMSSM parameter space survives. This fraction rises to about 2% if the bound on the Higgs mass can be circumvented.

Will the LHC find supersymmetry?

Feb 22, 2011 5 comments



Will SUSY be found lurking in LHC data?

The first results on supersymmetry from the Large Hadron Collider (LHC) have been analysed by physicists and some are suggesting that the theory may be in trouble. Data from proton collisions in both the Compact Muon Solenoid (CMS) and ATLAS experiments have shown no evidence for supersymmetric particles – or sparticles – that are predicted by this extension to the Standard Model of particle physics.

Nature

Beautiful theory collides with smashing particle data

Latest results from the LHC are casting doubt on the theory of supersymmetry.

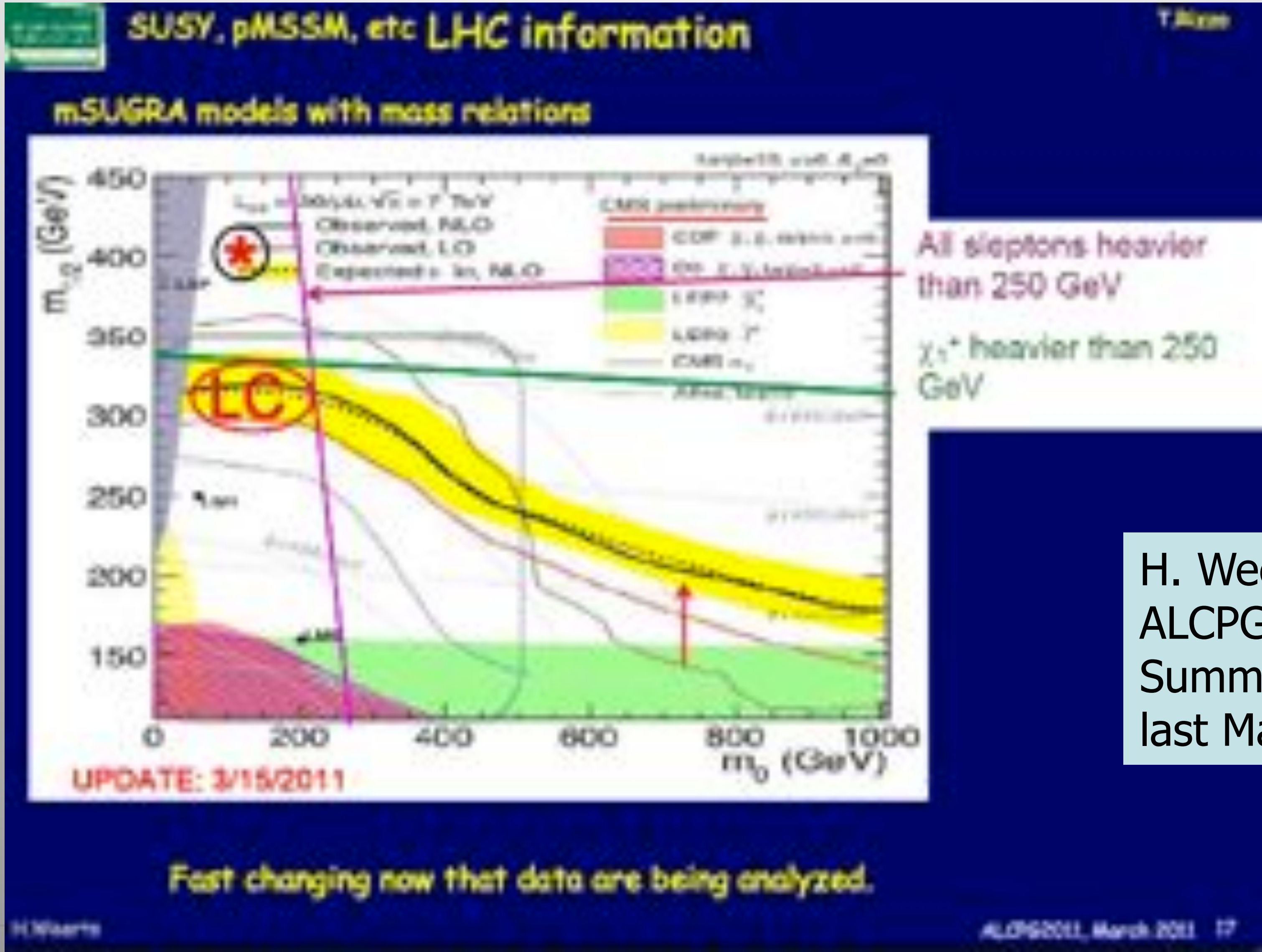
Geoff Brumfiel

"Wonderful, beautiful and unique" is how Gordon Kane describes supersymmetry theory. Kane, a theoretical physicist at the University of Michigan in Ann Arbor, has spent about 30 years working on supersymmetry, a theory that he and many others believe solves a host of problems with our understanding of the subatomic world.

"Any squarks in here?" The ATLAS detector (above) at the Large Hadron Collider has failed to find predicted 'super partners' of fundamental particles. C. MARCELLONI/CERN

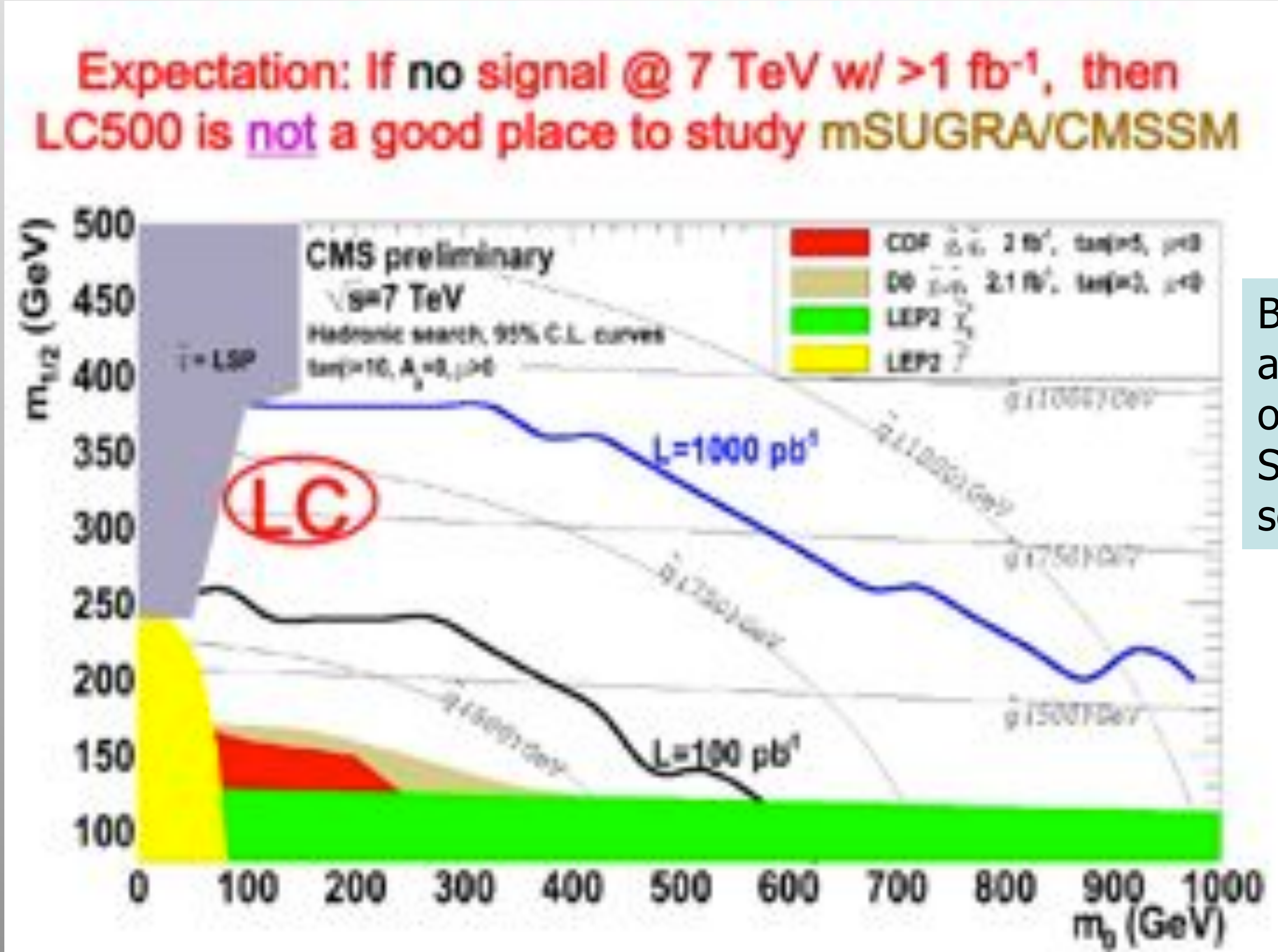
A slight wave of panic???

Panic for a 500GeV Linear Collider?



H. Weerts
ALCPG Meeting
Summary talk
last March

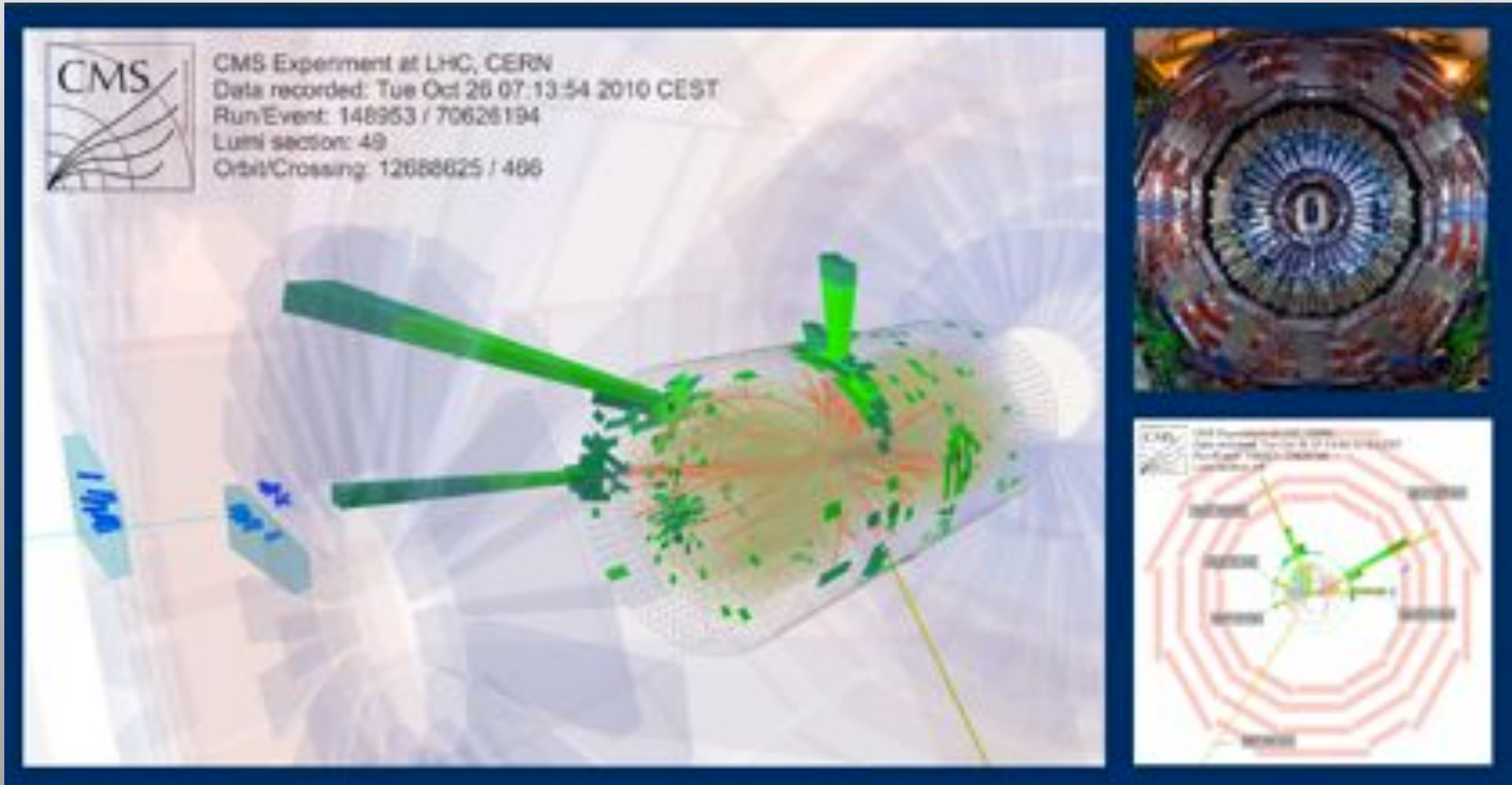
Panic for a 500GeV Linear Collider?



T. Rizzo

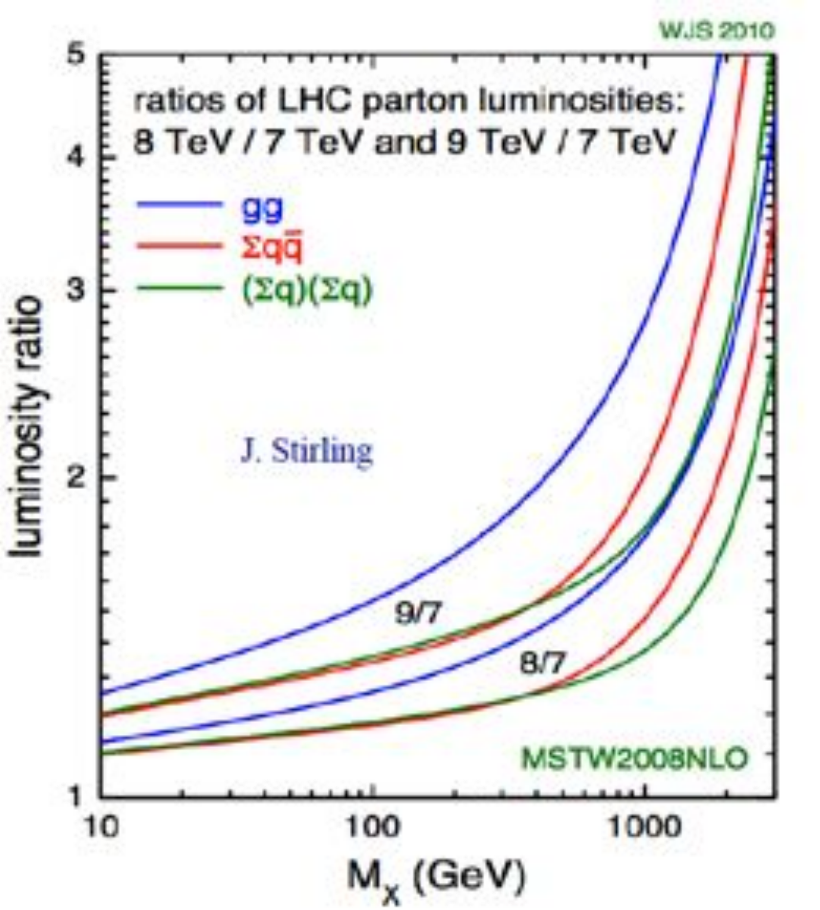
But there are other of course SUSY scenarios..

And we want more of these events…



New proposal for a CMS postcard:
Total H_T= 1132 GeV   Missing H_T = 693 GeV
Be prepared for discoveries…

The Future: 2011-2012 Run



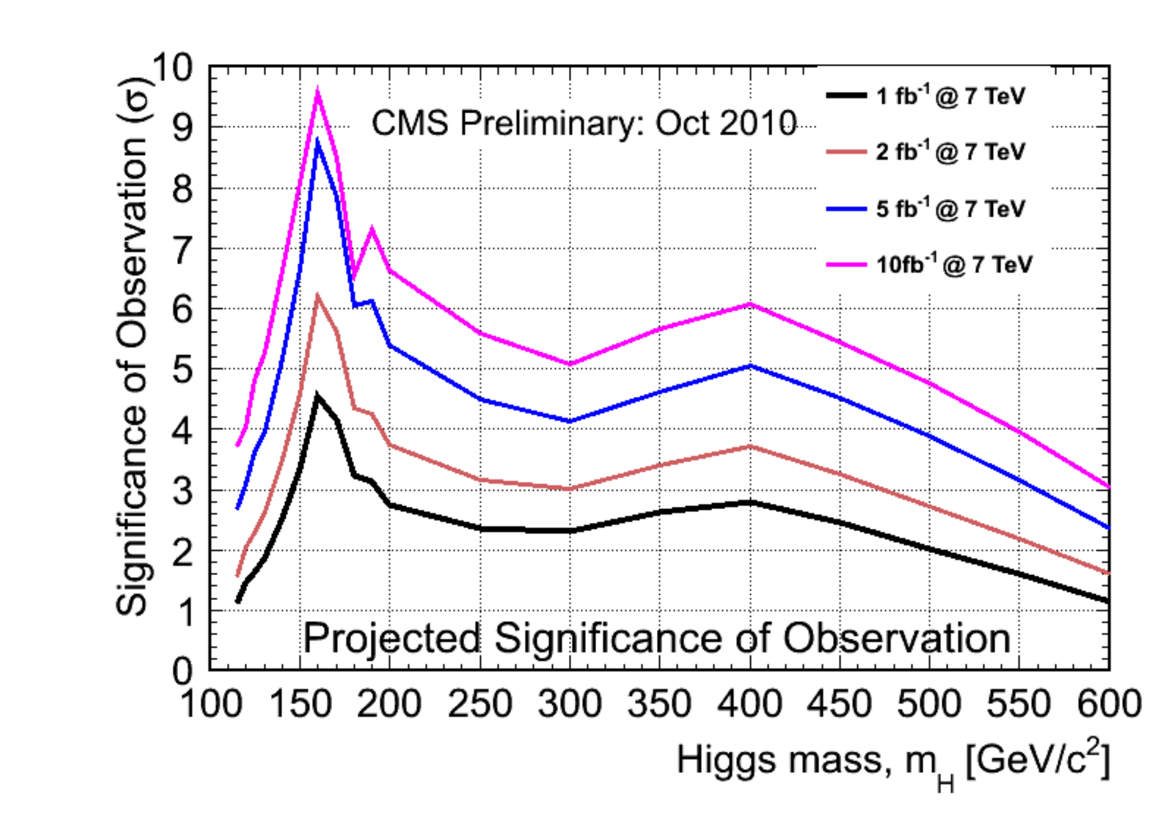
- The Machine is back for the 2011 run since March 13
- Run both years 2011 and 2012
  - Higher energy in 2012?
  - Long shutdown after 2012 run
- Minimal promised scenario: 7 TeV and 1 fb^{-1} of data by end of 2011, but:
- Very likely to get more
  - More bunches (up to 900/1400?)
  - Beta* (squeeze) from 3.5 m to 1.5 m already operational
- ⇨ A few fb^{-1}, perhaps 5 fb^{-1} /exp not excluded!

GOOD NEWS FOR HIGGS HUNTERS

But: no higher beam energy in 2011

2011: Project Higgs!

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



The hunt for the elusive Higgs boson has definitely started in 2011 at the LHC!!

Summary: It's been a Great Year

- CMS is very well advanced with the detector commissioning and calibration
- Physics papers being completed on the 2010 7 TeV collisions. Lots of results on QCD, EWK, B-physics, and the top. Many 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…
- CMS is ready for the 'real game' ie searches for new physics, and for the Higgs…. Possibly already in 2011
- The LHC is doing its part with a great start-up!!!