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Selected Highlights from the LHC

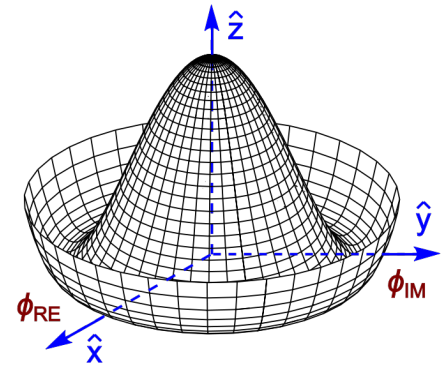
*Christian Sander
on behalf of ATLAS, CMS, and LHCb*

Jahrestagung der DPG – März 2013 – Dresden

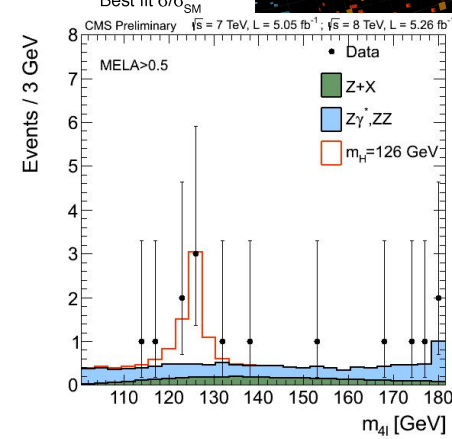
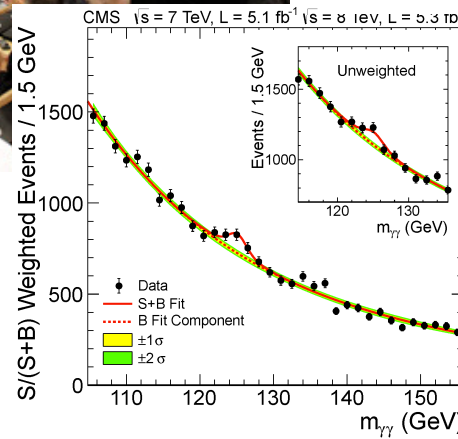
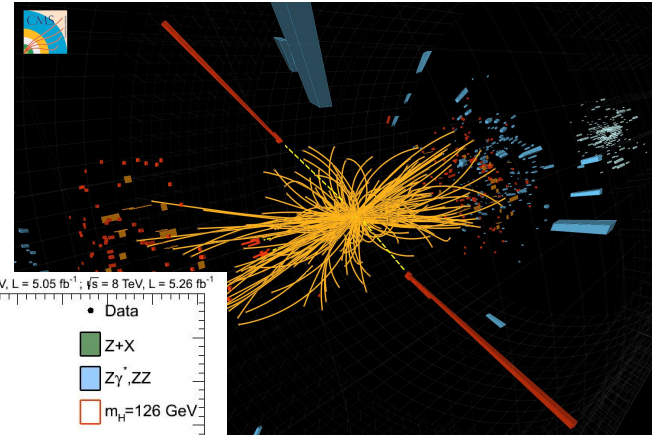
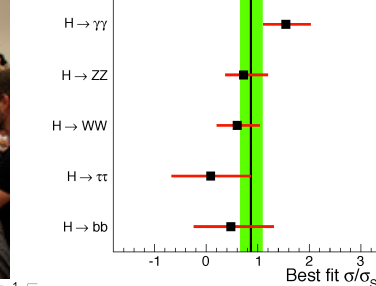
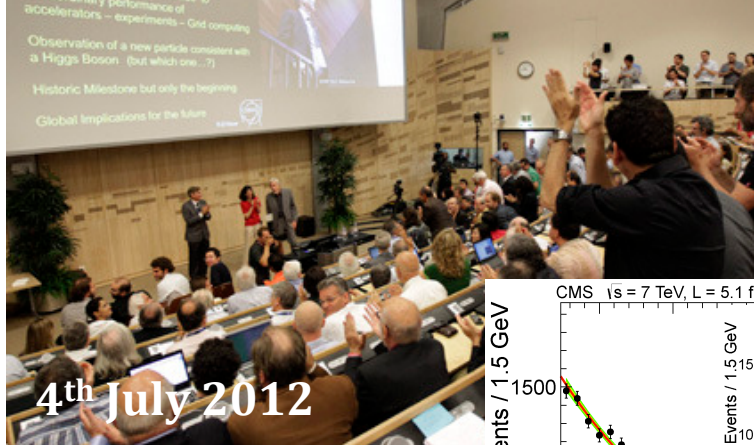
The LHC – A Great Success

Pre-LHC: Origin of Electroweak symmetry breaking?

→ Search for the Higgs at LHC



$$V_{\text{Higgs}} = -\mu \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$



See Symposium "Ursprung der Masse" and plenary talk by K. Jakobs on Wednesday on the Higgs discovery and implications

Introduction

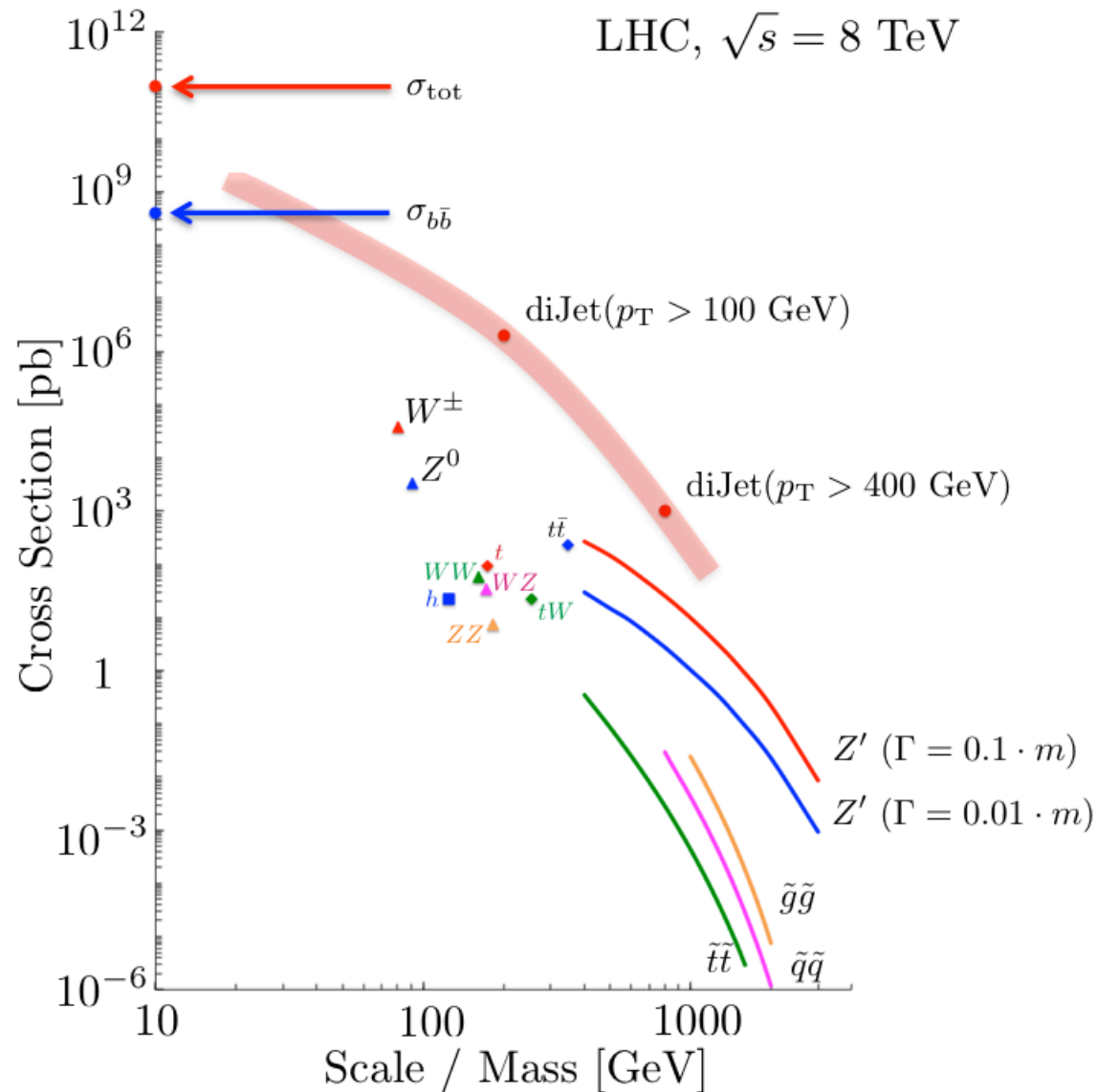
Standard Model

- QCD
- Flavour physics
- Top physics
- Electroweak gauge boson production

Beyond the SM

- Supersymmetry
- Exotica

Disclaimer: Personal selection out of few hundred public results; comparable results from the other experiment(s) for almost each shown analysis

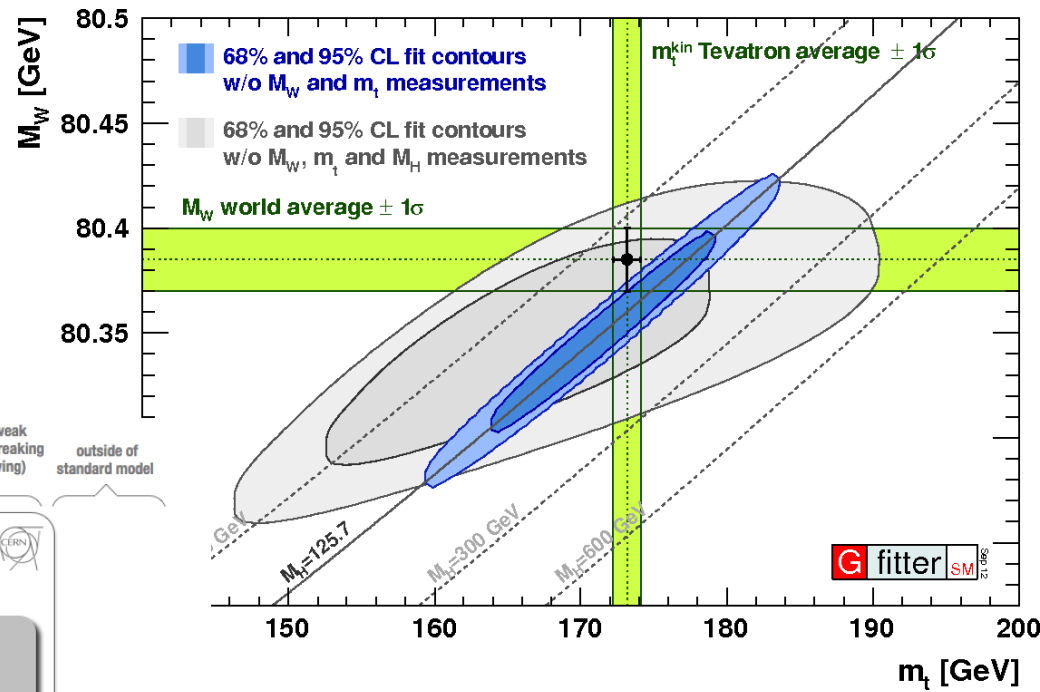


The Standard Model

Particle interactions described by gauge groups:

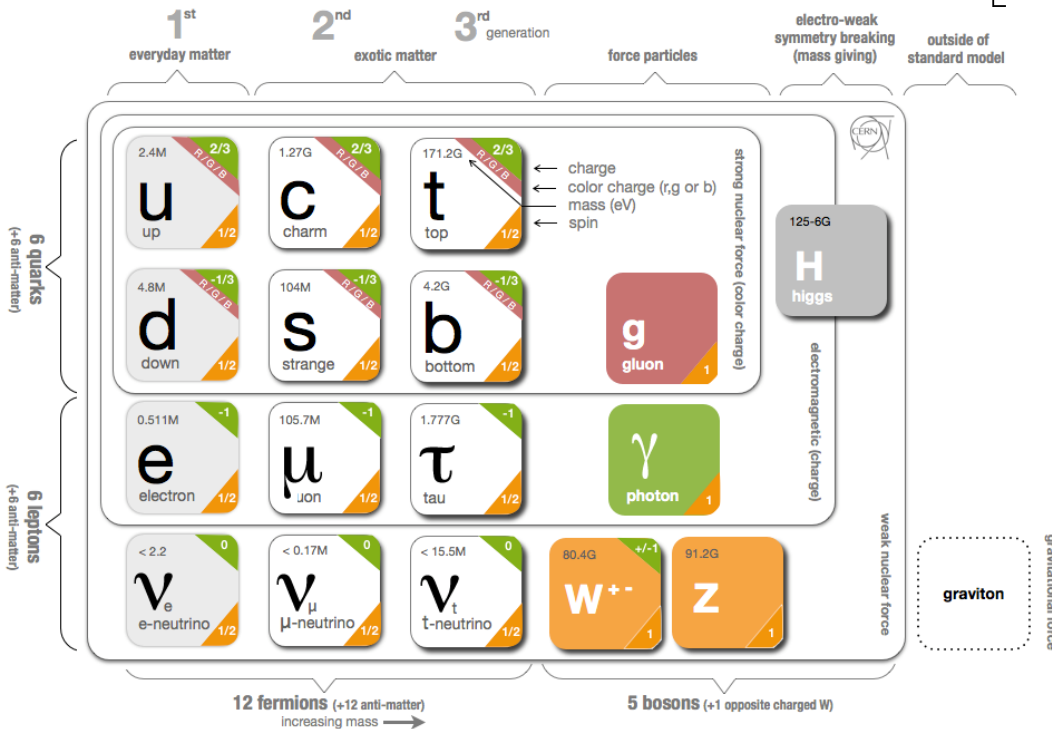
$$U_Y(1) \otimes SU(2)_L \otimes SU(3)_C$$

All collider data in very good agreement with SM prediction



Current global fit is compatible with Standard Model ($p \sim 8\%$)

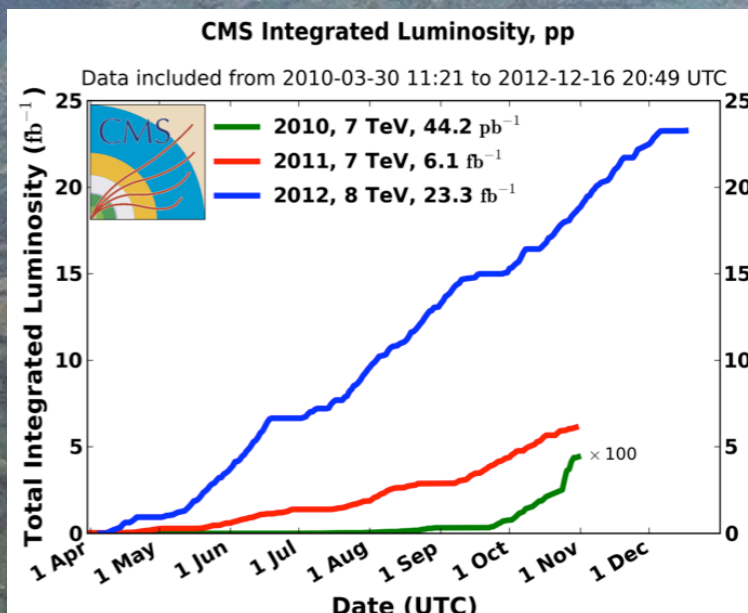
New input from $m_H \rightarrow$ more precise results (in particular for m_t and m_W)





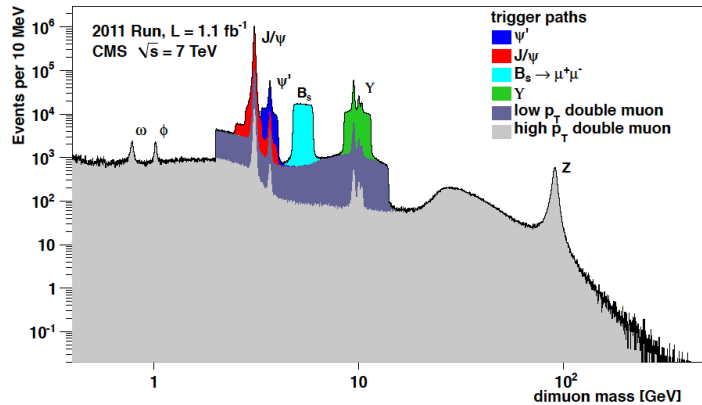
The LHC

Excellent performance of the machine → Large data sets collected at 7 and 8 TeV (pp)





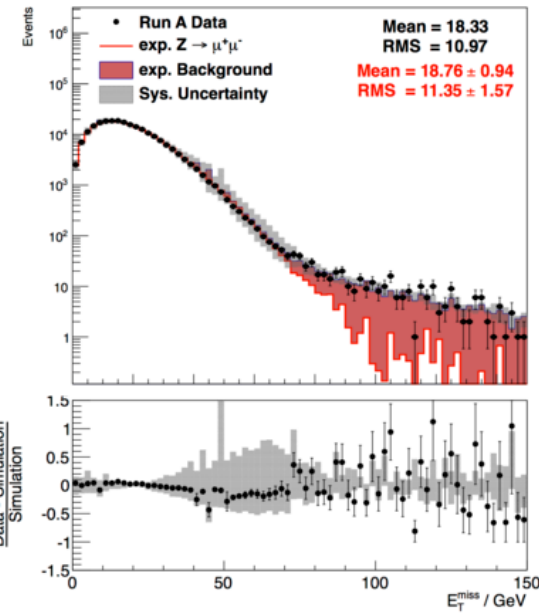
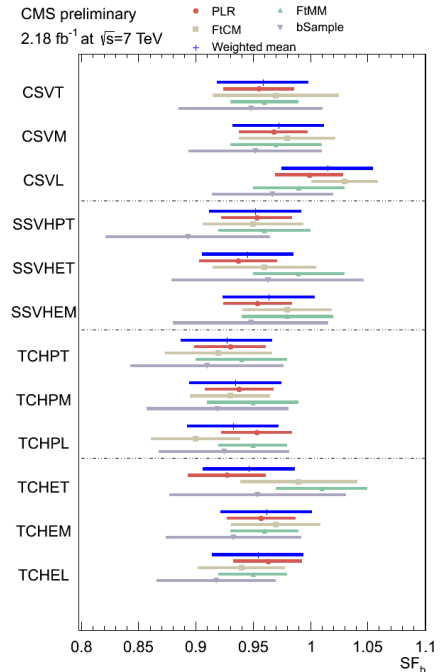
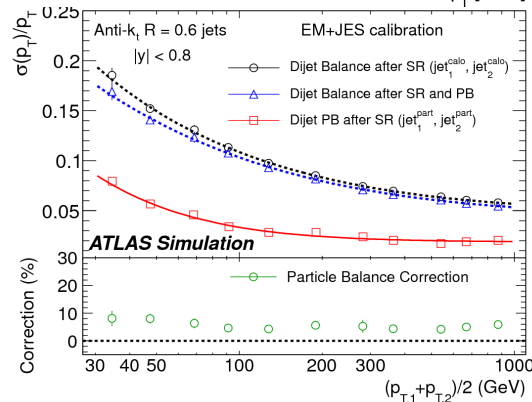
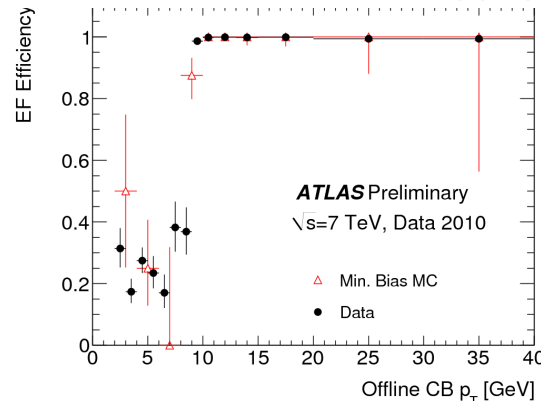
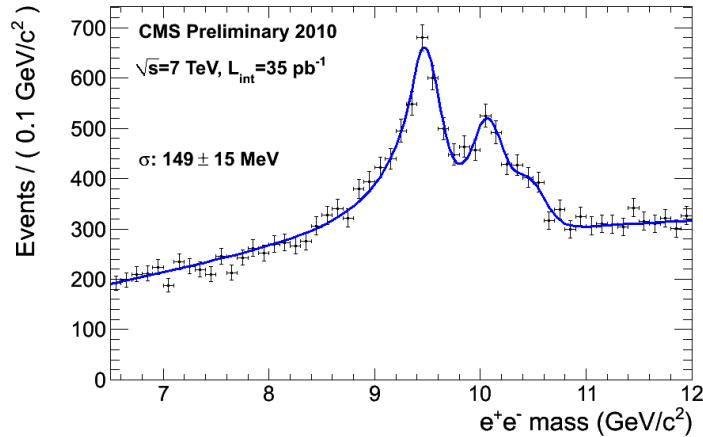
Experiments – Performance



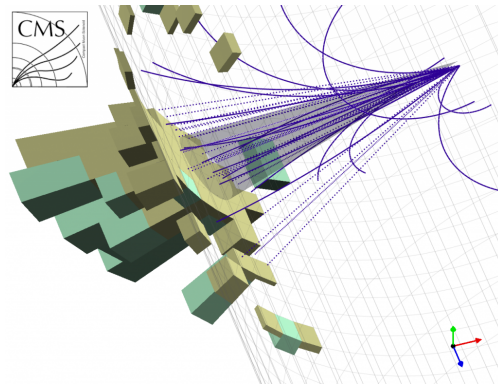
ATLAS detector operation efficiency:

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	98.3%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	100%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	96.0%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	98.2%

Excellent performance of
triggers, DAQ, sub-detectors,
reconstruction, ...



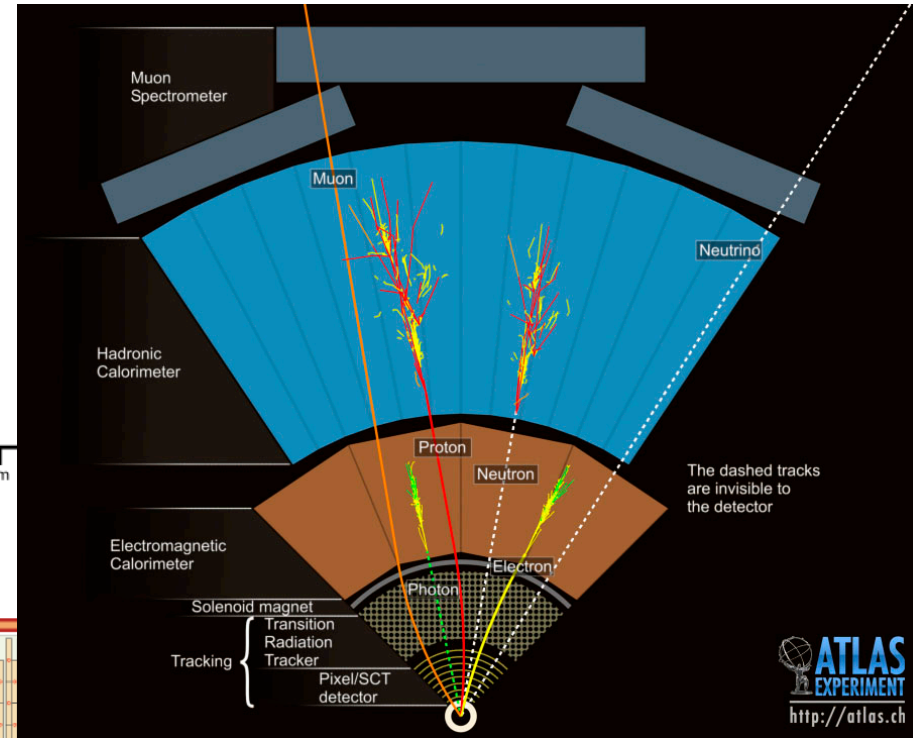
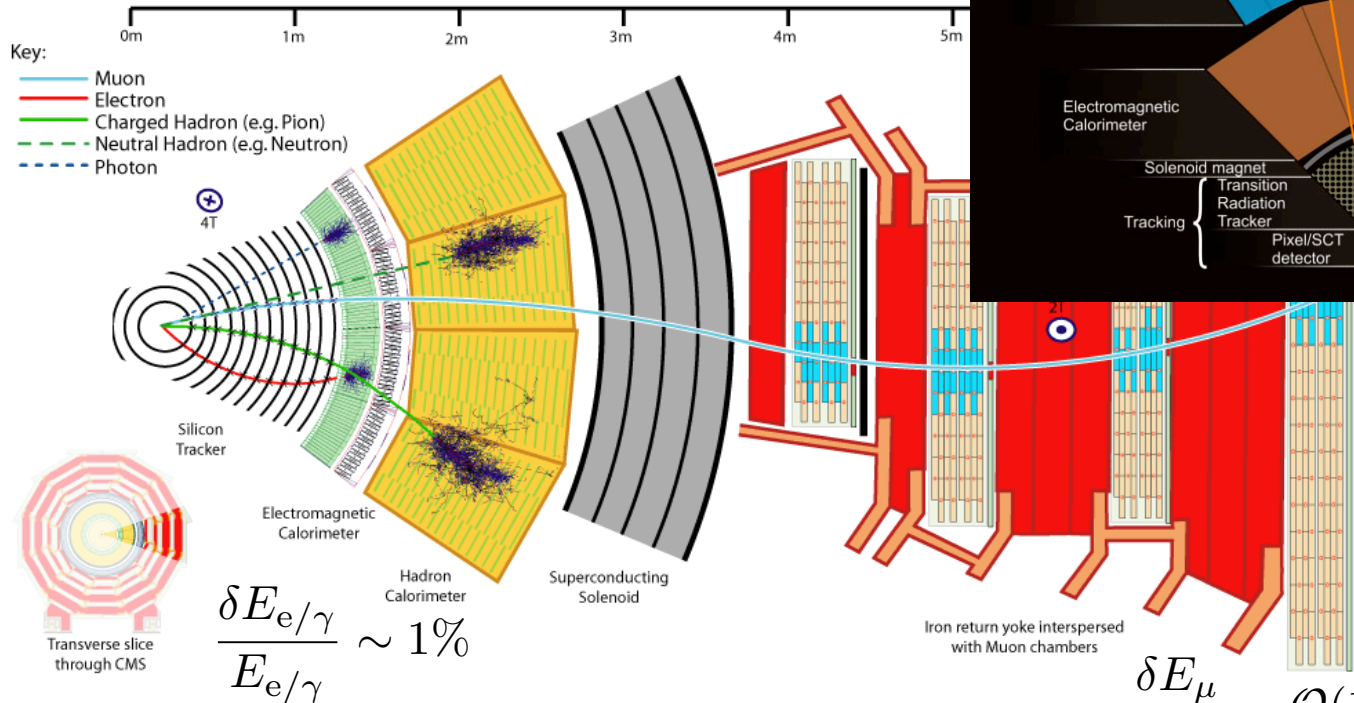
Detectors & Physic Objects



$$\frac{\delta E_{\text{jet}}}{E_{\text{jet}}} \sim 5 - 15\%$$

Key:

- Muon
- Electron
- Charged Hadron (e.g. Pion)
- - - Neutral Hadron (e.g. Neutron)
- - - Photon



$$\frac{\delta E_{\mu}}{E_{\mu}} \sim \mathcal{O}(1\%) \text{ for } p_T^{\mu} \lesssim 100 \text{ GeV}$$

QCD – Jet Cross Sections

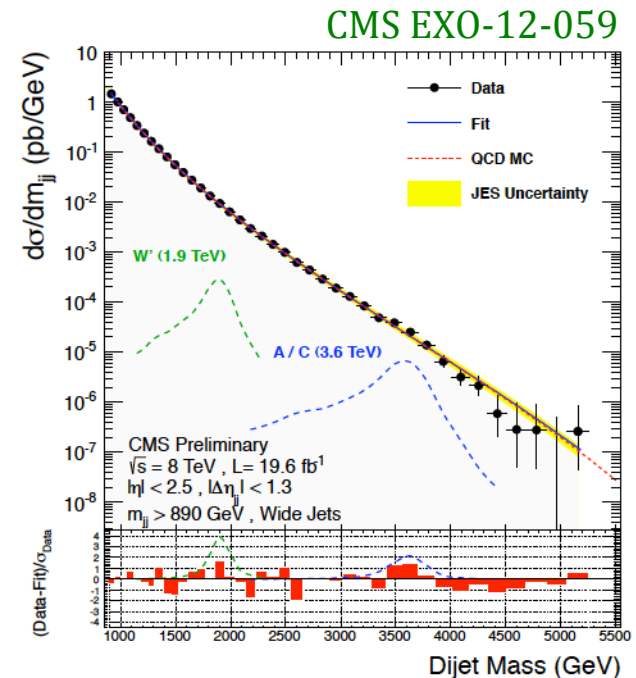
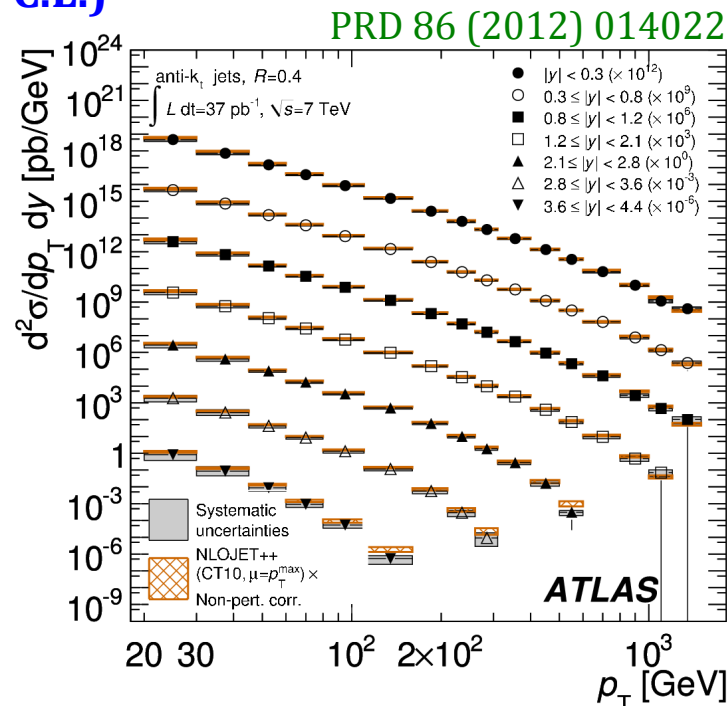
Almost every collision at LHC is QCD process

Significant developments in understanding of QCD in various areas:

- Matrix element generators, approximate NNLO, heavy flavour production, parton showering, pdfs ...

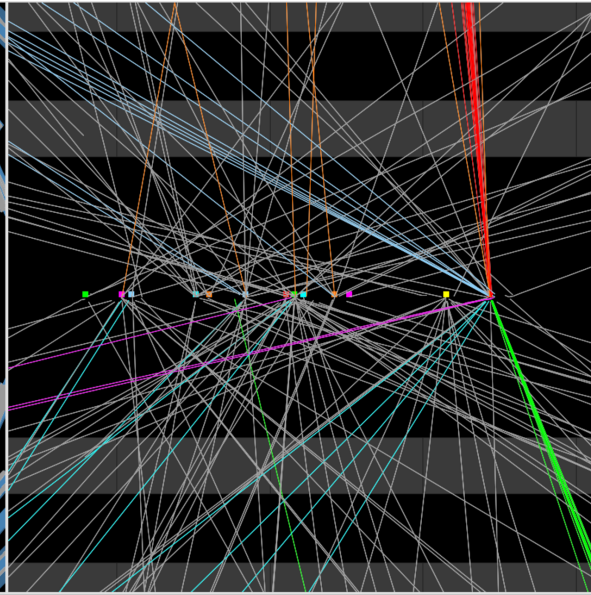
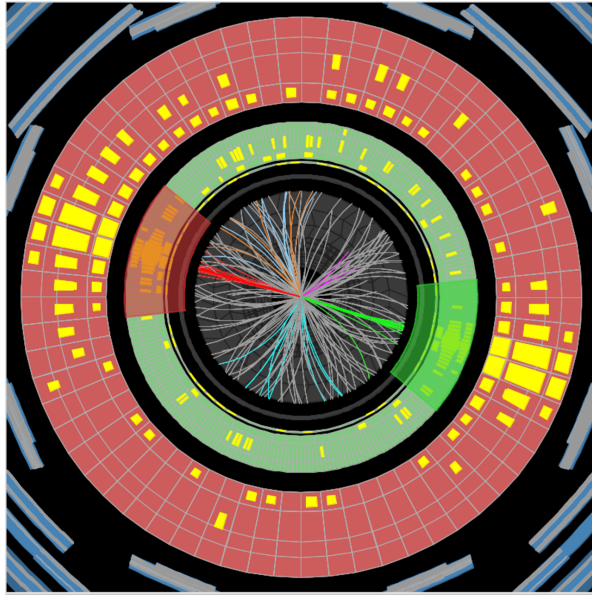
Di-Jet events allow to probe QCD at highest scales:

- No resonance in di-jet mass distribution → **Limits, e.g. excited quarks $m_{q^*} > 3.8$ TeV (95% C.L.)**





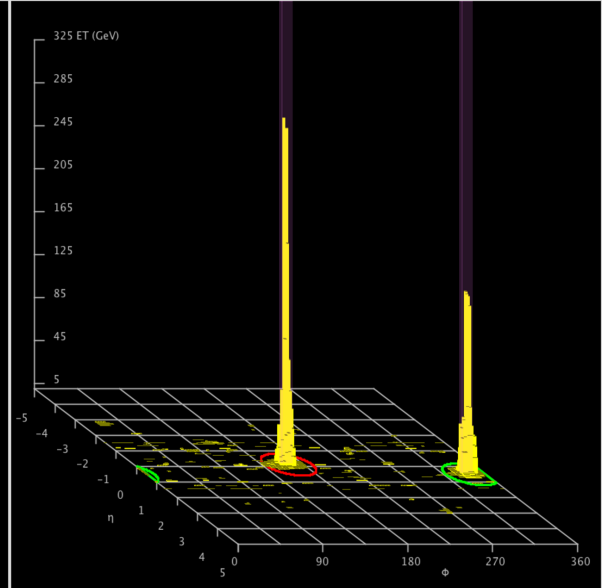
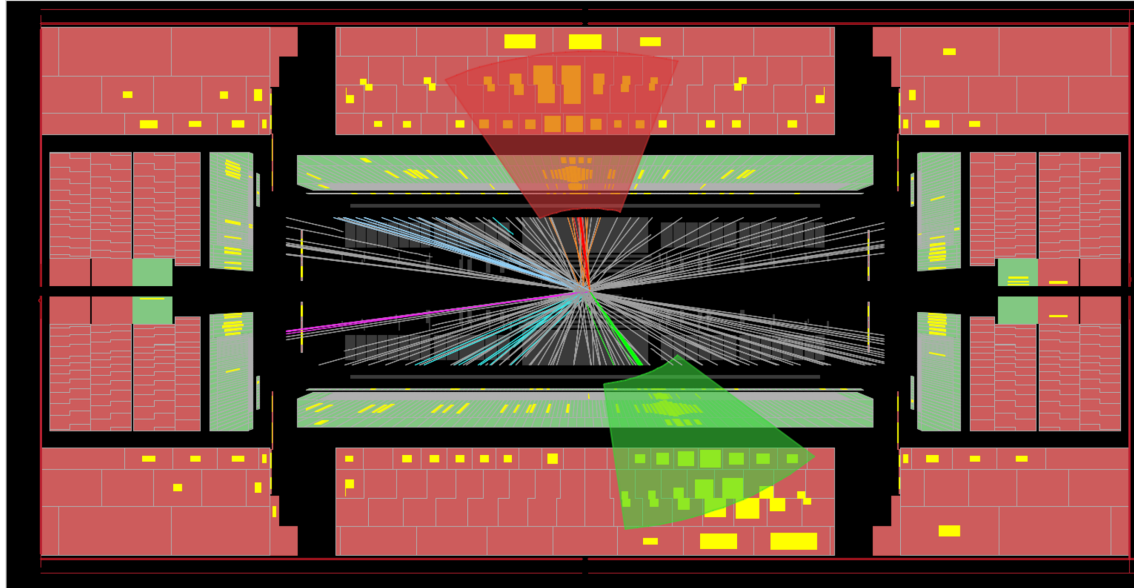
$m_{jj} = 4.69 \text{ TeV}$



ATLAS
EXPERIMENT

Run Number: 209580, Event Number: 179229707

Date: 2012-08-31 20:24:29 CEST



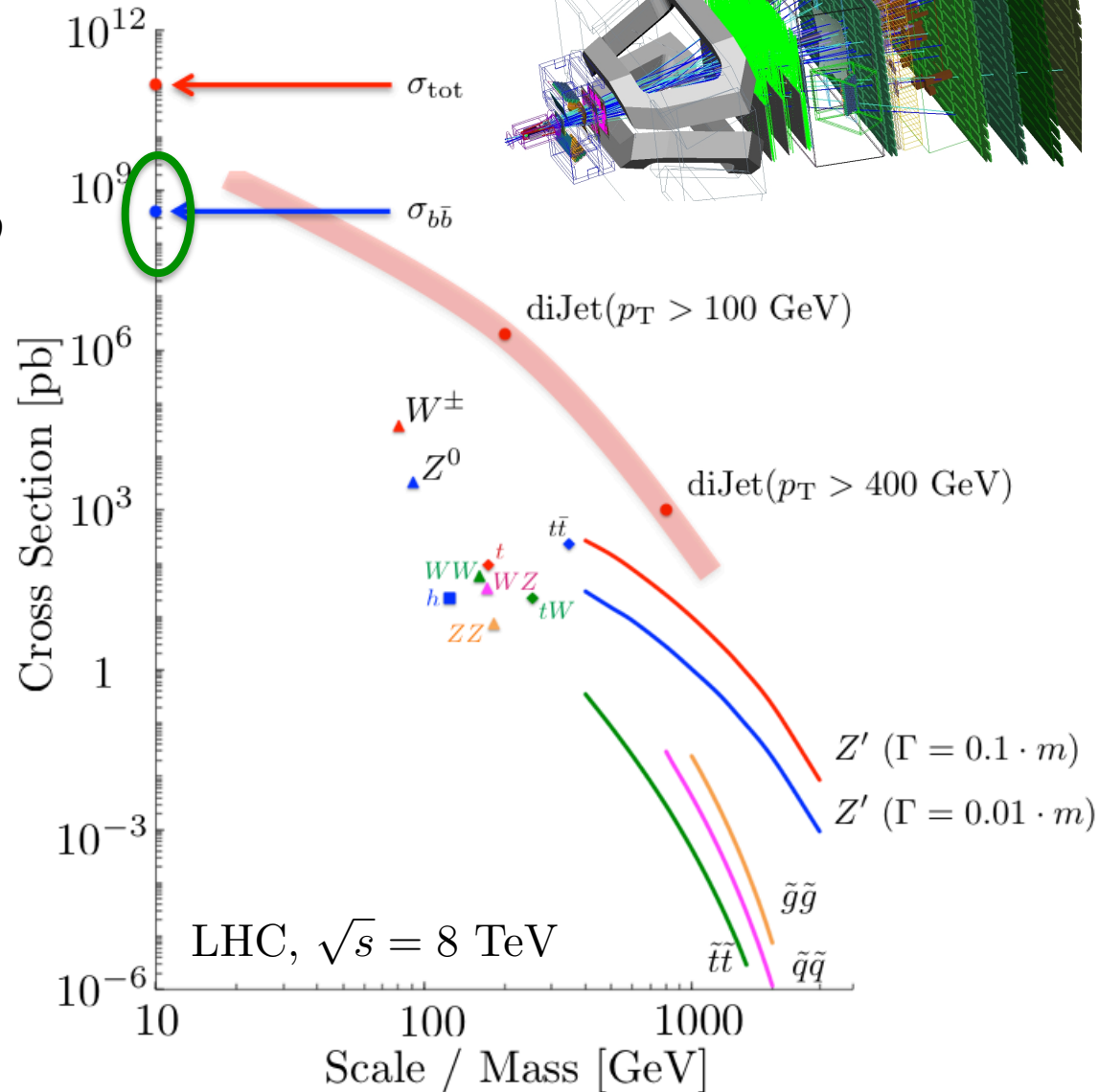
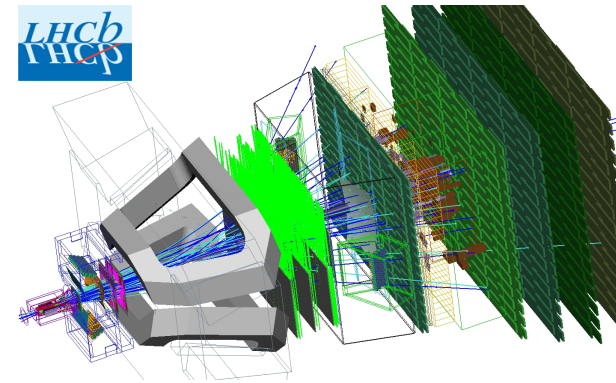
Flavour Physics

More than 10^{12} $b\bar{b}/c\bar{c}$ events produced at LHC

LHCb (+ ATLAS & CMS) search for rare decays or asymmetries of B/D ... hadrons

- Search for CPV in B and D systems
- Mixing in B and D systems
- Measurement of γ (see EV by M. Karbach on Tue.)
- B and D decays in neutral K (EV by M. Britsch on Thu.)
- $Br(B_s \rightarrow \mu^+ \mu^-)$
- ...

See HV "Summary on Flavour Physics" (HV by J. Albrecht on Fri.)





$$B_s^0 \rightarrow J/\Psi \phi$$

Assumed to be golden mode to measure CPV in B_s
(sensitive to New Physics)

$$\phi_s^{\text{SM}} = -2\beta_s \sim -0.03 \text{ with } \beta = \arg \left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} \right)$$

Time dependent fit to various decay angles, proper
time distributions, candidate mass ...

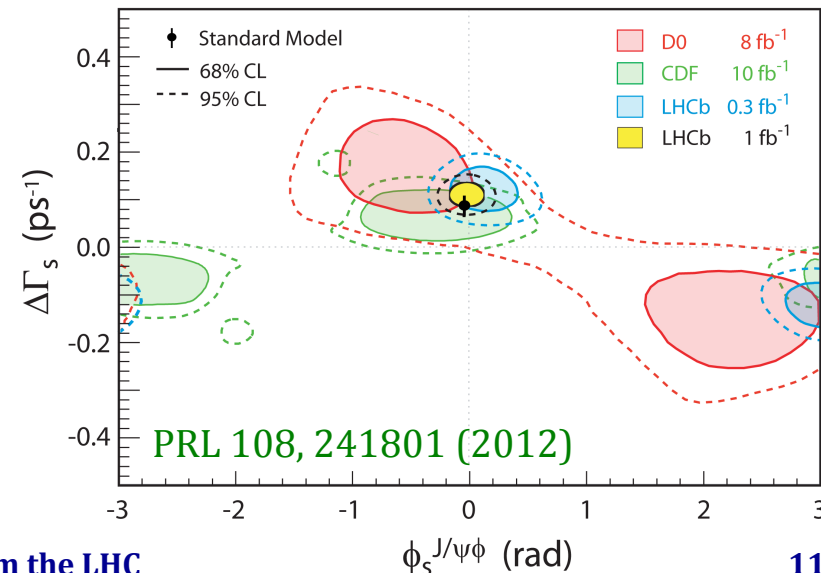
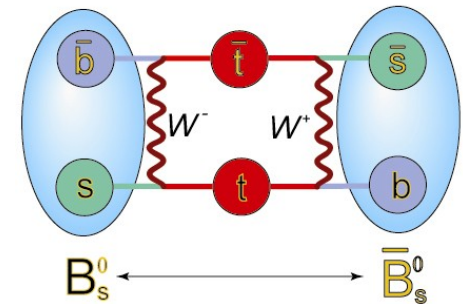
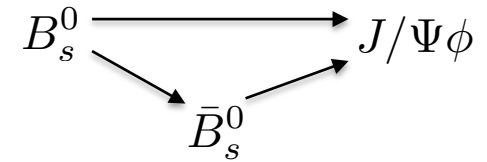
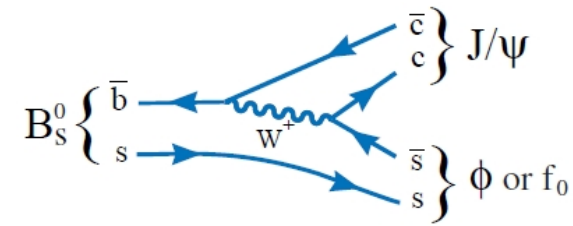
$$\phi_s = -0.001 \pm 0.101(\text{stat.}) \pm 0.027(\text{syst.})$$

Most precise measurement of ϕ_s , but no
evidence for CP violation so far!

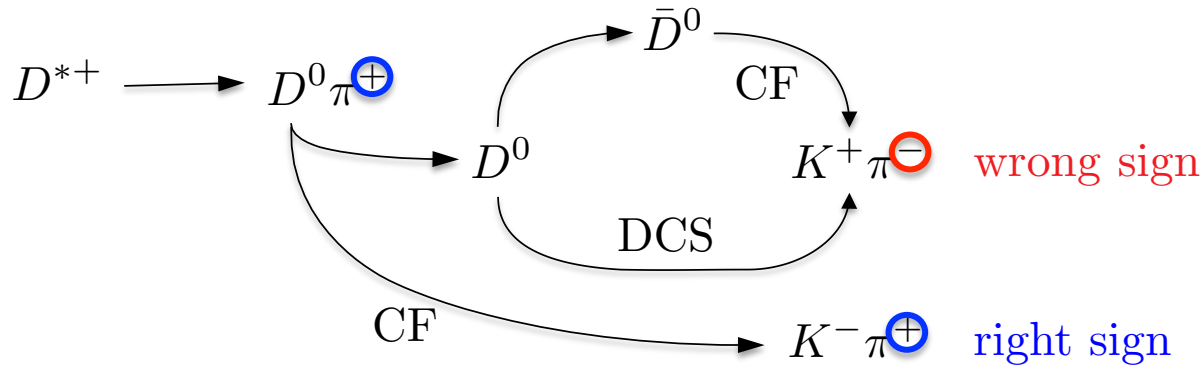
$$\Delta\Gamma_s = 0.116 \pm 0.018(\text{stat.}) \pm 0.006(\text{syst.}) \text{ ps}^{-1}$$

First 5σ evidence of width difference

Results in agreement with Standard Model



Charm Mixing

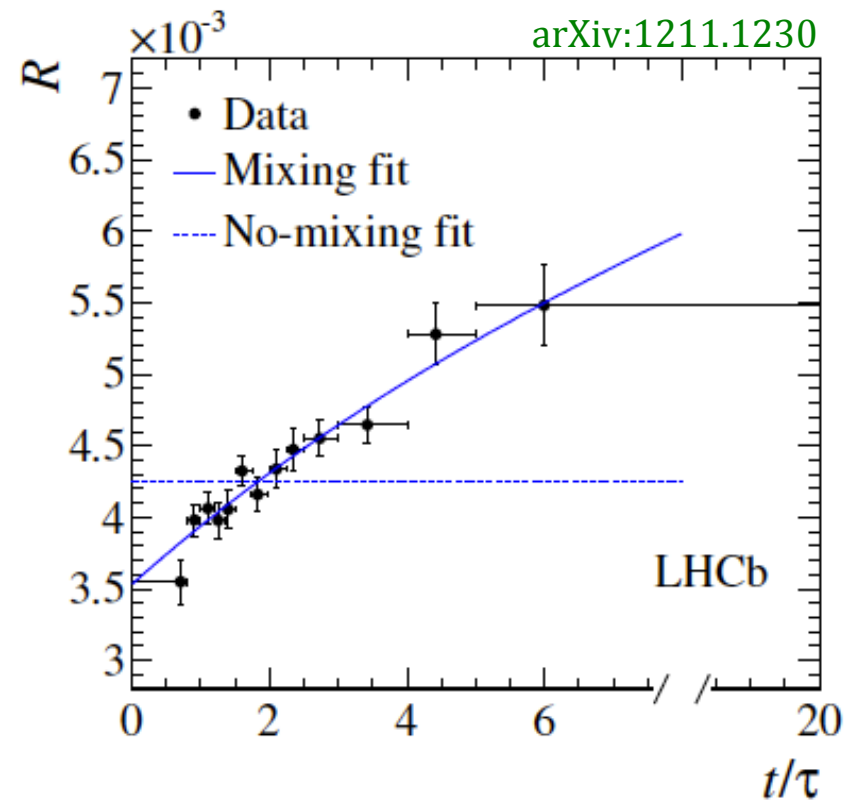


Analysis idea: Fit ratio of wrong and right sign events in various bins of decay time

$$R(t) = \frac{N_{\text{wrong}}(t)}{N_{\text{right}}(t)}$$

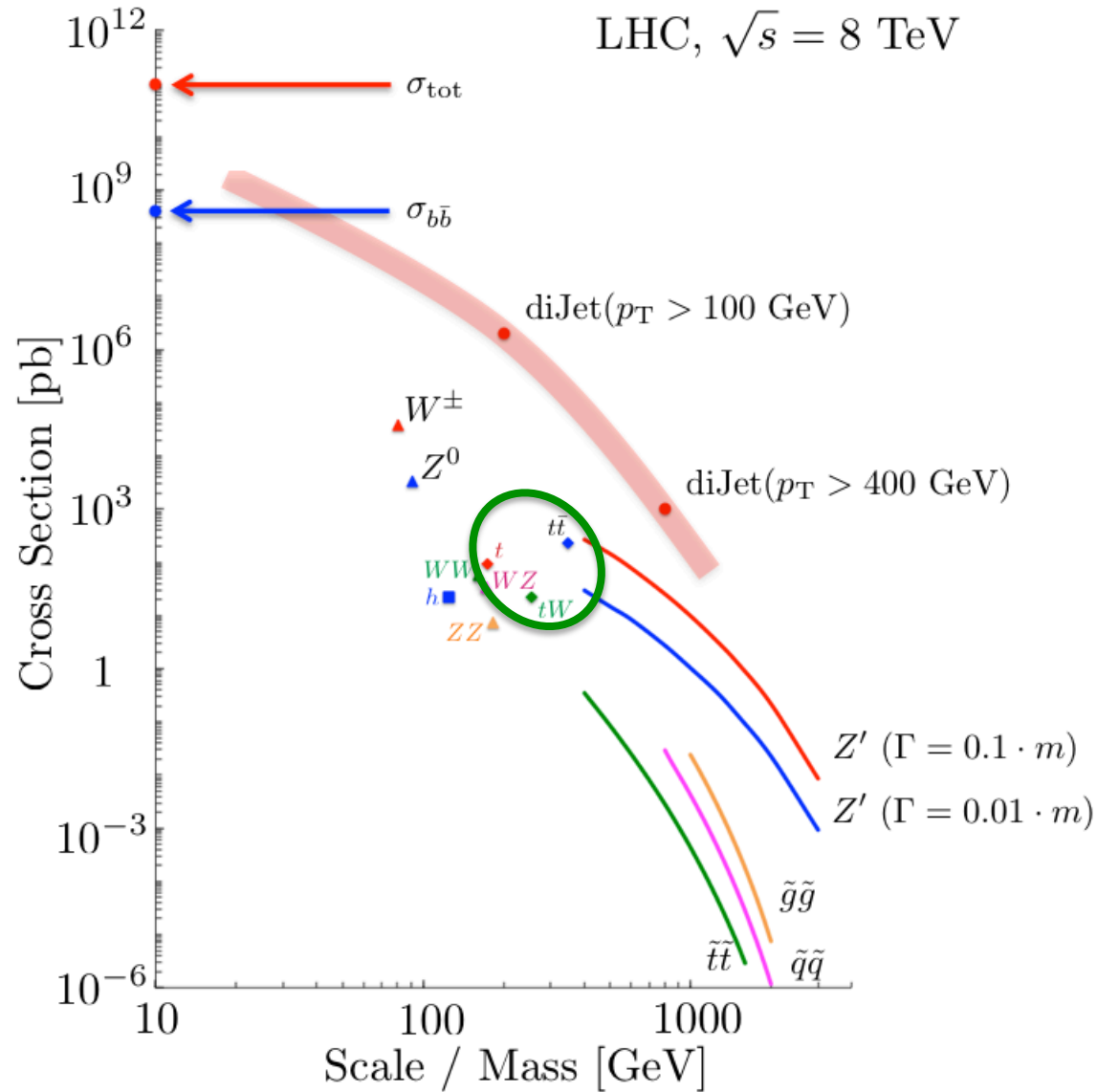
No mixing hypothesis rejected at 9.1σ

Previously excluded only by combination of experiments



Top Physics

- Inclusive and differential cross section
- Mass measurement
- Single top
- $t\bar{t}Z/t\bar{t}W$
- FCNC in t decays
- $Z' \rightarrow t\bar{t}$
- Charge asymmetry
- Spin correlations
- ...



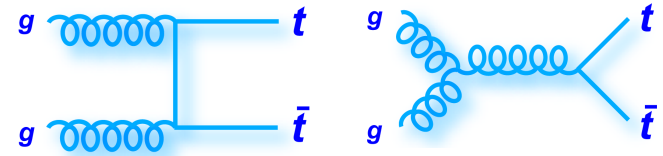
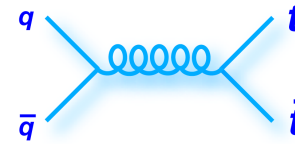
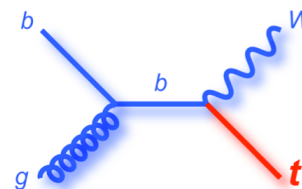
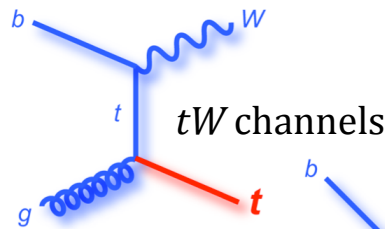
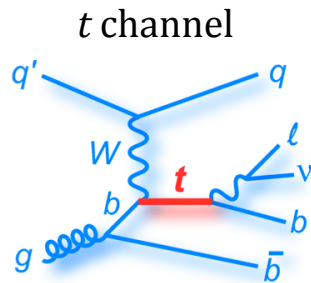
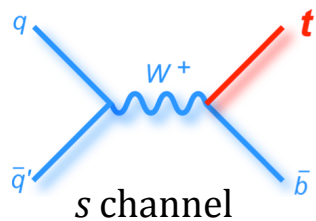
The Top Quark

- LHC is a “Top Factory”
- Top decays before hadronization ($\tau \sim 5 \cdot 10^{-25}$ s)
- “Top physics” is “Higgs physics”
- $t\bar{t}$ important background for many BSM searches

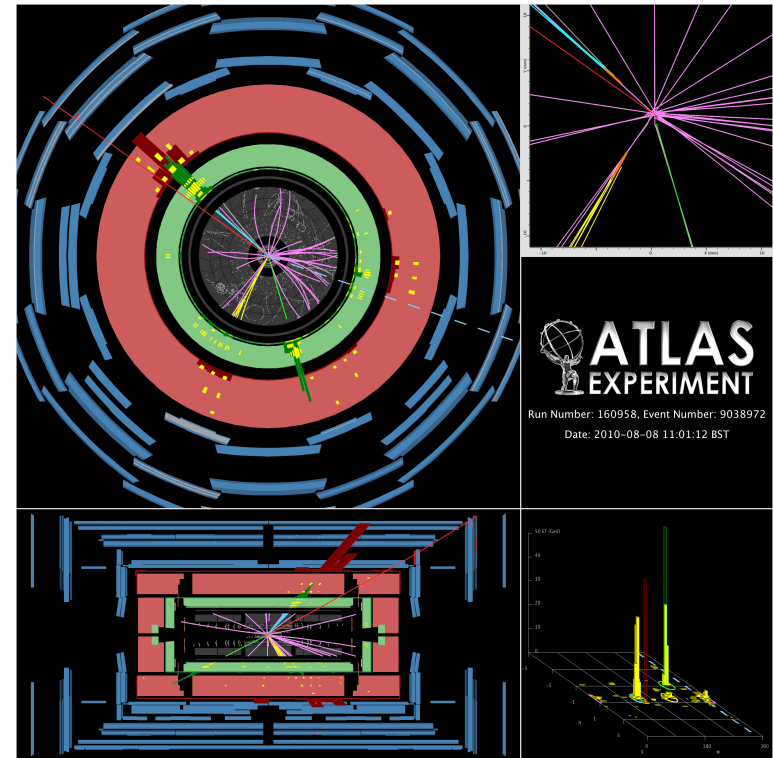
Used physics objects: jets, electrons, muons, taus, b -tags, MET

Single Top:

- Test of electroweak interactions (V_{tb})
- Sensitivity to b -pdf
- Probe for new physics (e. g. 4th generation)



See EV by
M. Aldaya (Tuesday) and
D. Hirschbühl (Tuesday)



Event display of
Di-leptonic $t\bar{t}$ event

Top – Cross Section

Inclusive cross section in good agreement with SM
Differential cross sections in various quantities

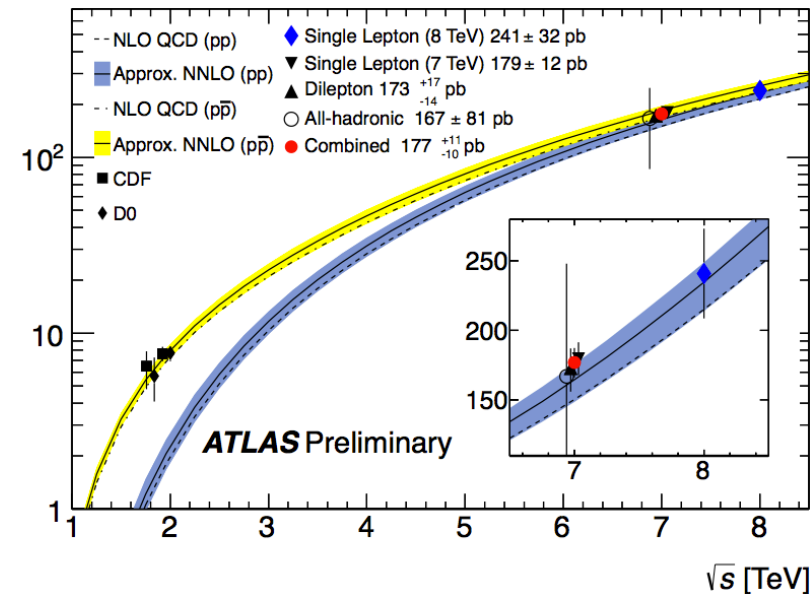
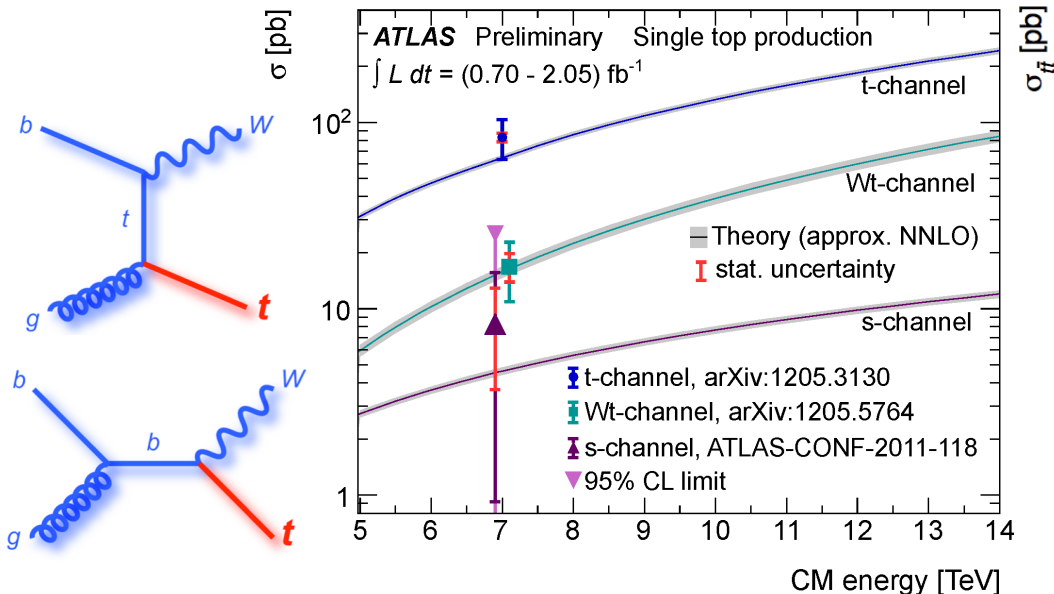
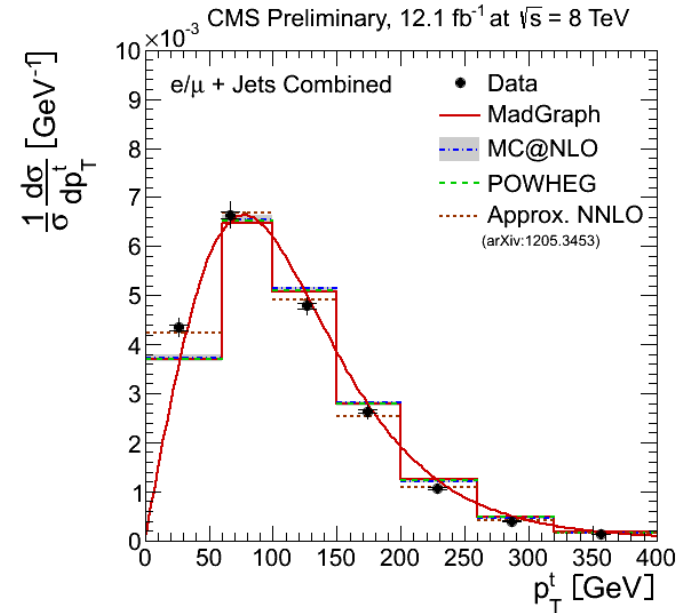
- Test of perturbative QCD

→ **Good agreement of data and simulation!**

Single Top: first measurement of tW channel

- ATLAS: $\sigma_{Wt} = 16.8 \pm 2.9(\text{stat.}) \pm 4.9(\text{syst.}) \text{ pb}$
- CMS: $\sigma_{Wt} = 16_{-4}^{+5} \text{ pb}$
- SM: $\sigma_{Wt} = 15.6 \pm 0.4(\text{scale})_{-1.2}^{+1.0}(\text{pdf}) \text{ pb}$

CMS TOP-12-027



Top - Mass

Important input to Higgs physics, SM vacuum stability, ...

Accurate measurement using “Ideogram method”:

- Combine reconstruction of $t\bar{t}$ by kinematic fit with scan of top mass and jet energy scale of light quark jets

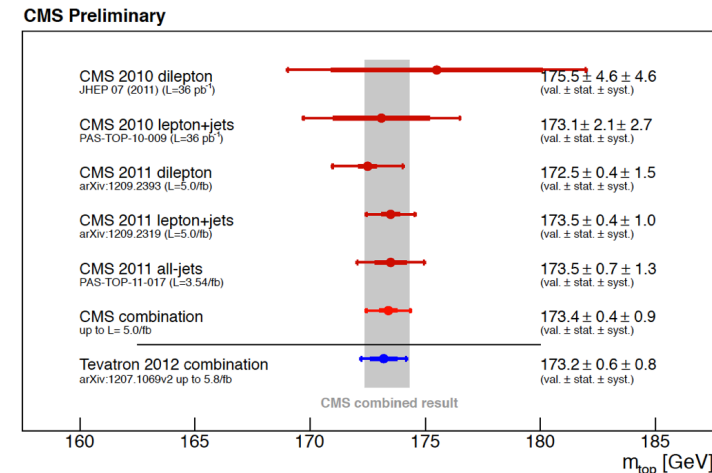
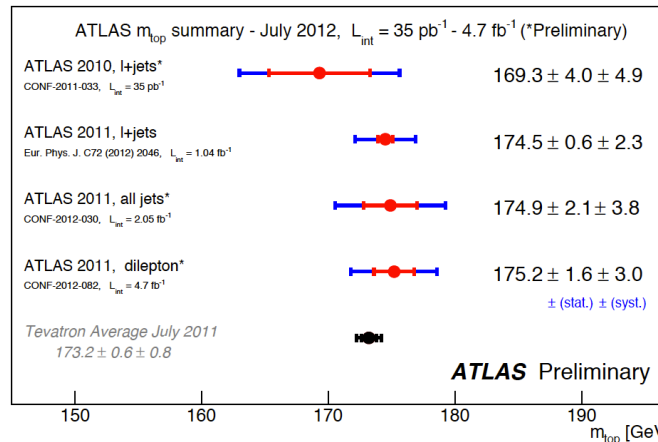
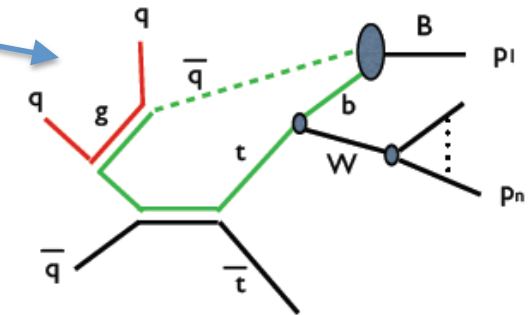
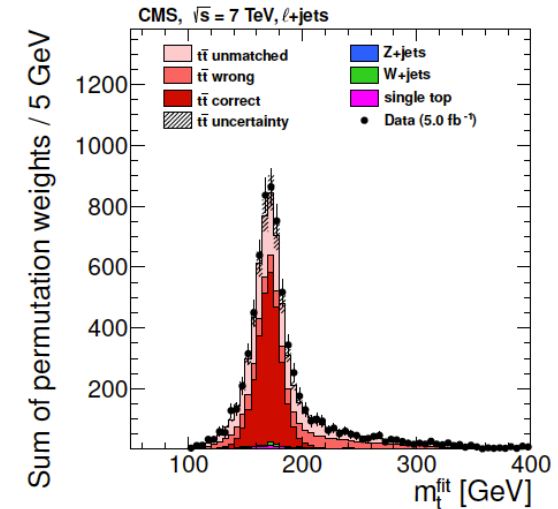
$$m_t = 173.49 \pm 0.43(\text{stat.} + \text{JES}) \pm 0.98(\text{syst.}) \text{ GeV}$$

- Dominant uncertainties:

- Color reconnection (0.54 GeV)
- b -jet energy scale (0.61 GeV)

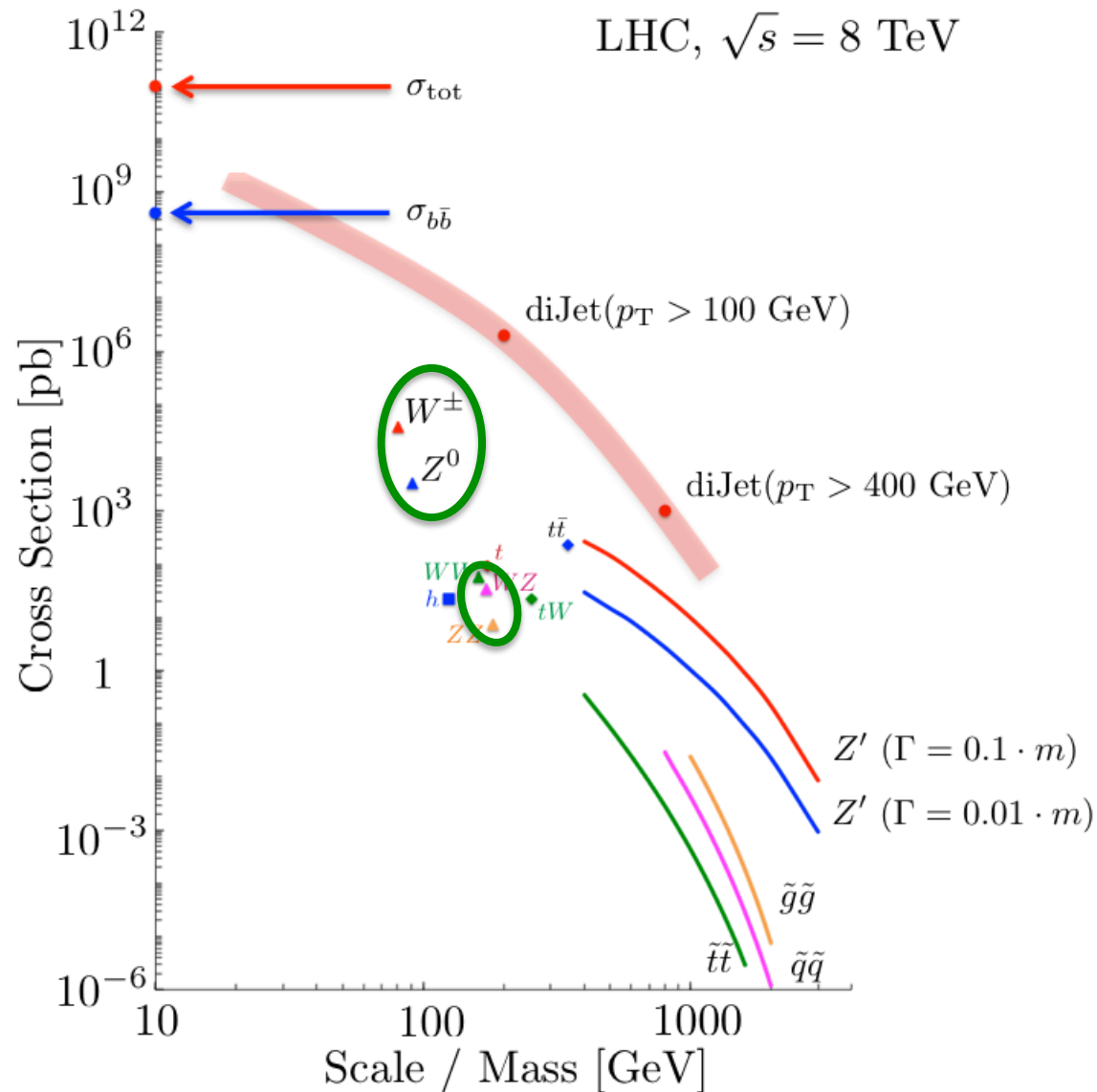
→ LHC experiments reach Tevatron accuracy!

Reduction of systematic uncertainties will be big challenge for future



Electroweak Physics

- W / Z mass
- Inclusive and differential cross sections
- W charge asymmetry
- W polarization
- DY forward backward asymmetry
- $V + \text{jets}$
- WW / ZZ
- VVV
- $WWWW$
- ...



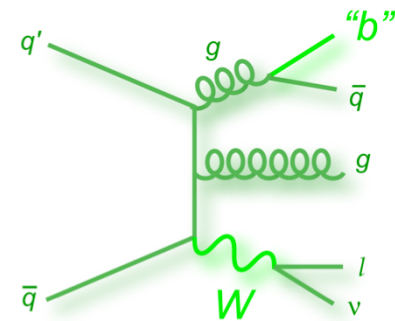
W / Z Production

Clean signatures → Demonstration of excellent detector performance

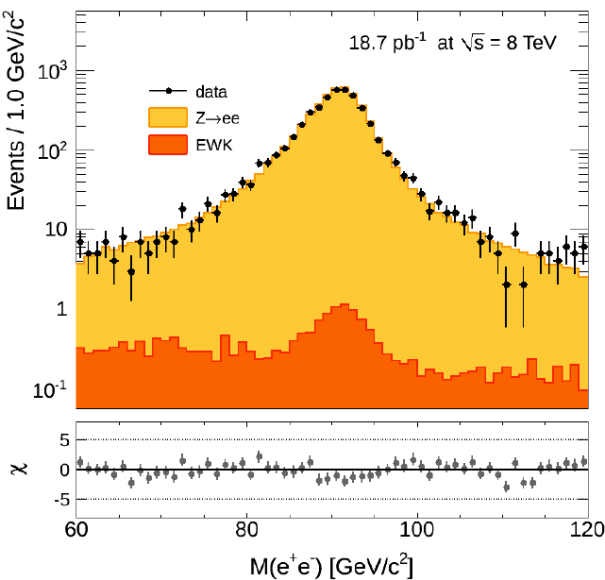
Precision tests of SM

Sensitivity to proton structure: W charge asymmetry (in particular LHCb at large $|\eta|$)

Break through in theory: V +jets accurately modelled by matrix element generators (MadGraph, ALPGEN, ...) → Precision tests of pQCD



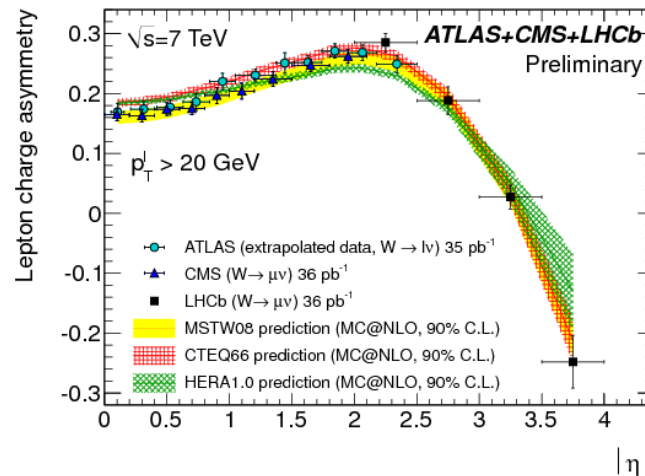
CMS SMP-12-011 CMS Preliminary



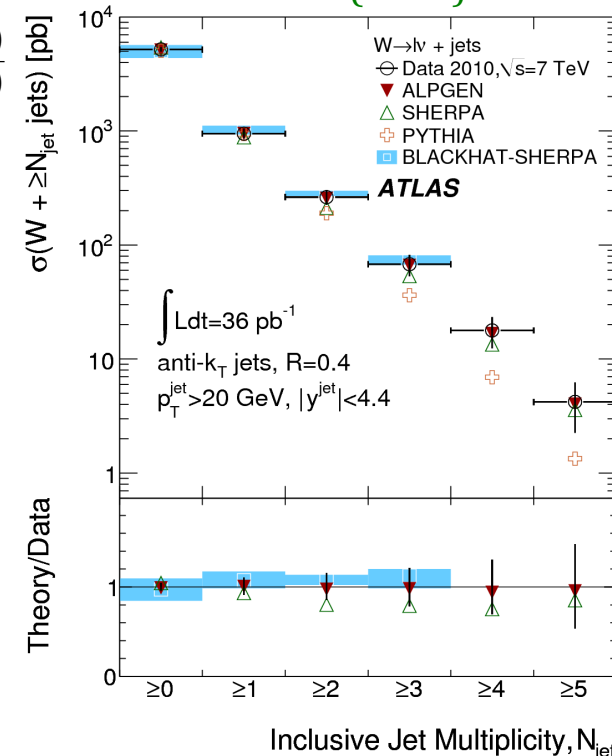
$$\sigma_{Z \rightarrow l+l-} = 1.12 \pm 0.01_{\text{stat}} \pm 0.02_{\text{syst}} \pm 0.05_{\text{lumi}} \text{ nb}$$

$$\sigma_{Z \rightarrow l+l-}^{\text{SM}} = 1.13 \pm 0.04 \text{ nb}$$

$$A(\eta) = \frac{d\sigma/d\eta(W^+ \rightarrow l^+\nu) - d\sigma/d\eta(W^- \rightarrow l^-\nu)}{d\sigma/d\eta(W^+ \rightarrow l^+\nu) + d\sigma/d\eta(W^- \rightarrow l^-\nu)}$$



PRD 85 (2012) 092002



Di-Boson Production: WW / ZZ

- Test of SU(2) structure
- Background for BSM searches
- Sensitive to New Physics: Triple Gauge Couplings (TGC, in SM: $WW\gamma$ and WWZ only)

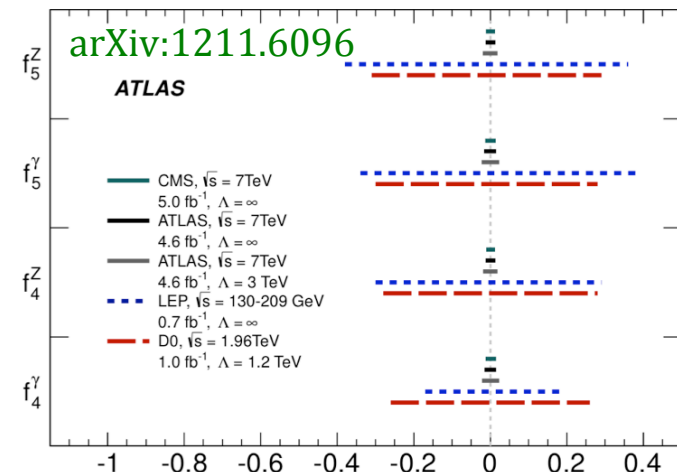
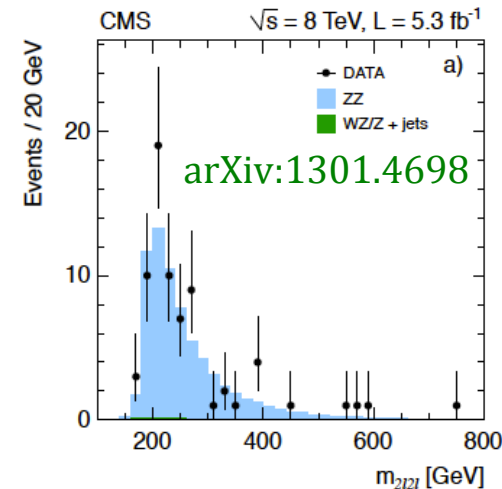
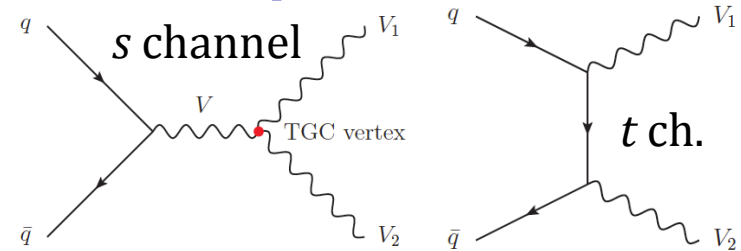
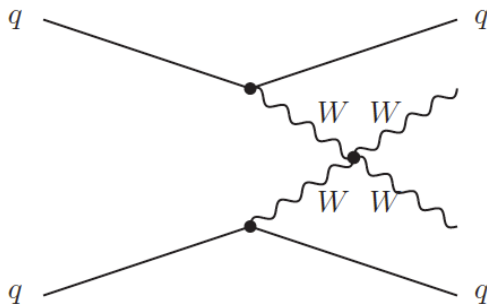
Example: ZZ cross section sensitive to ZZZ and $ZZ\gamma$

$$g_{ZZV}\Gamma_{ZZV}^{\alpha\beta\mu} = e \frac{P^2 - M_V^2}{M_Z^2} (if_4^V (P^\alpha g^{\mu\beta} + P^\beta g^{\mu\alpha} + if_5^V \epsilon^{\mu\alpha\beta\rho} (q_1 - q_2)_\rho)$$

No significant deviation $\rightarrow$ Limits on f_5^V (CP conserving) and f_4^V (CP violating) parameters (=0 in SM)

Improved limits by ~1 magnitude compared to LEP/TeVatron

Outlook: WW final state sensitive to WW scattering

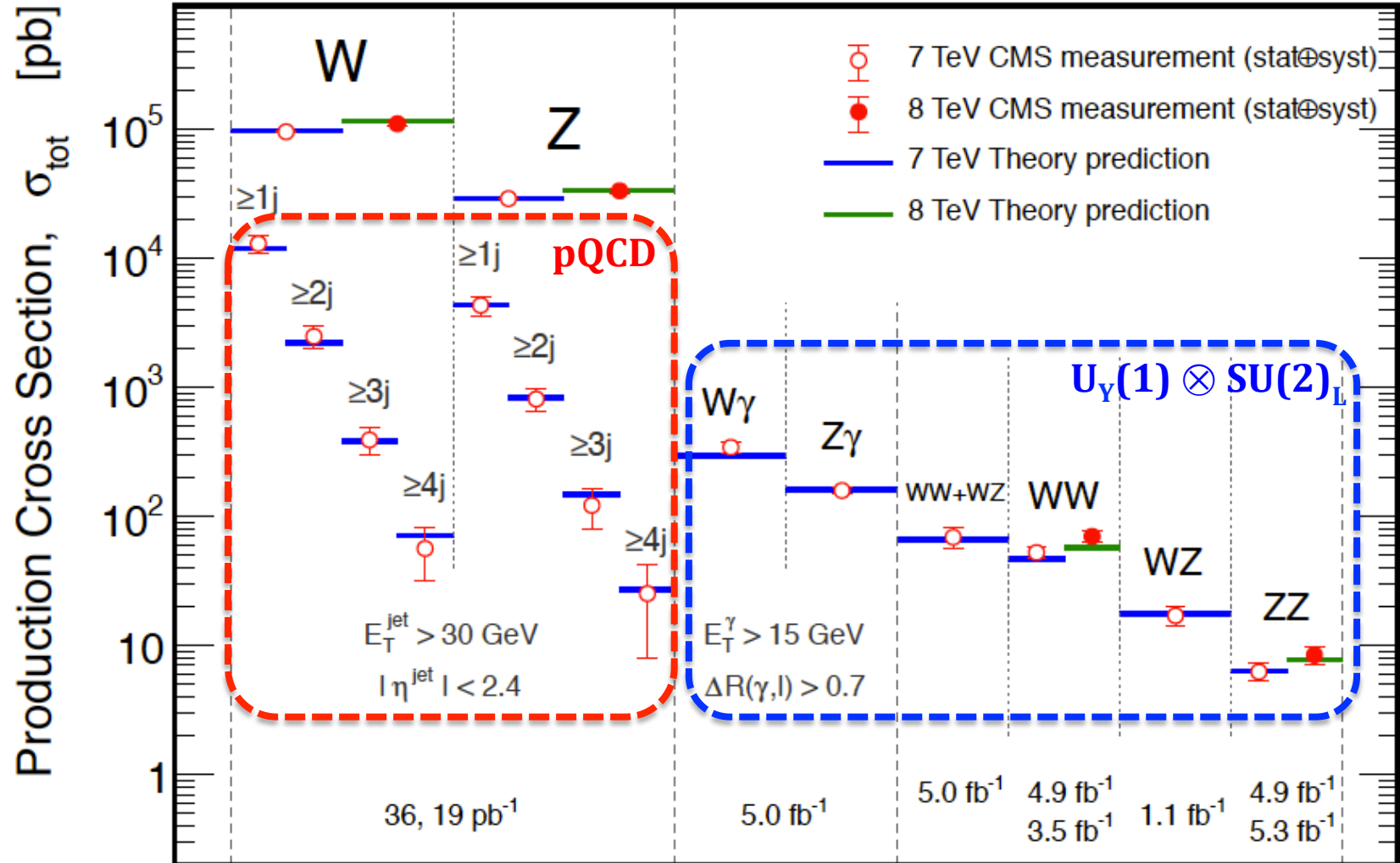


Electroweak Summary

See HV by
M. Schott (Monday)

CMS

Nov 2012



JHEP10(2011)132

JHEP01(2012)010

CMS-PAS-SMP-12-011 (W/Z 8 TeV)

CMS EWK-11-009

CMS-PAS-EWK-11-010 (WZ)

CMS-PAS-SMP-12-005 (WW7),

007(ZZ7), 013(WW8), 014(ZZ8), 015(WV)

x 136.5 mm

Physics Beyond the SM

New Physics expected at TeV scale

- “Fine tuning” problem

→ SUSY / Technicolour ...

- Hierarchy problem

→ Large Extra Dimensions / SUSY ...

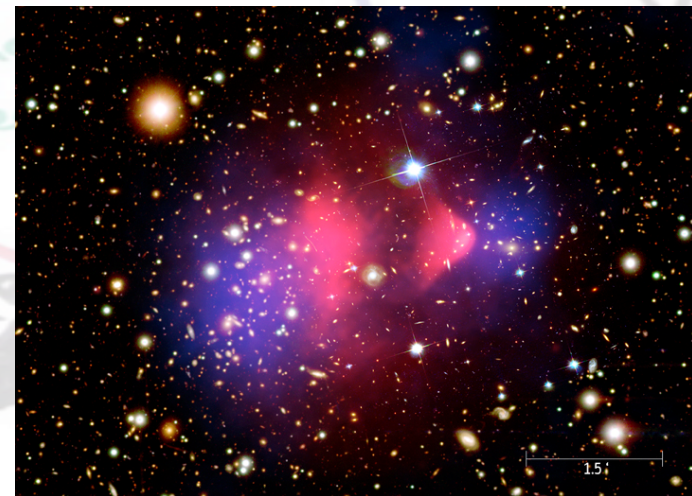
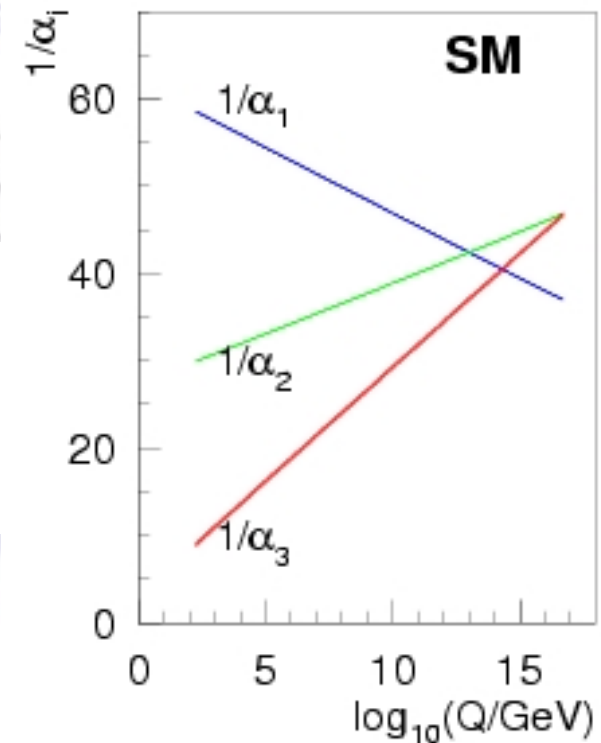
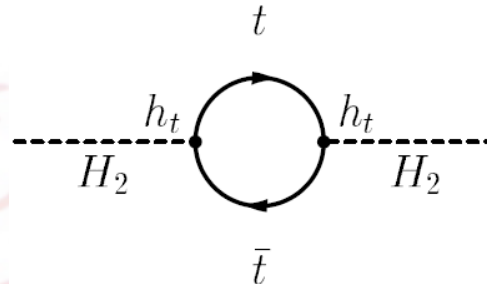
- Dark Matter

→ SUSY / Extra Dimensions ...

- Unification of gauge couplings

→ Supersymmetry / Leptoquarks ...

Best place to search → LHC



Supersymmetry



Last possible extension of Poincare group: Symmetry between fermions and bosons

Each SM particle gets SUSY partner

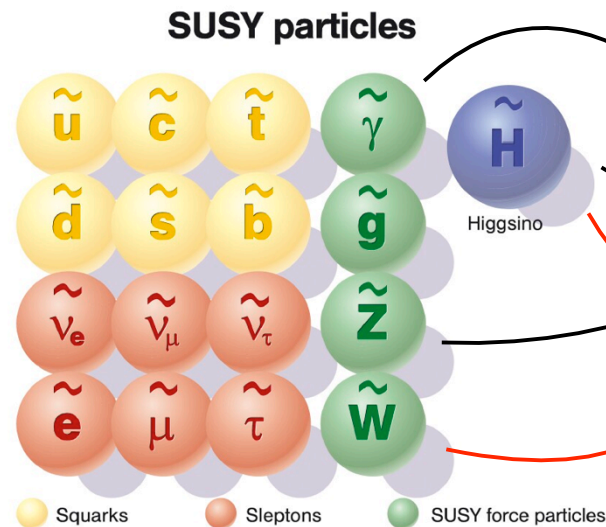
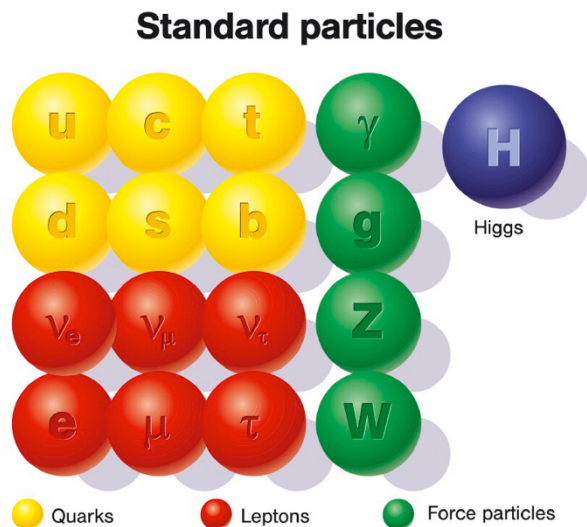
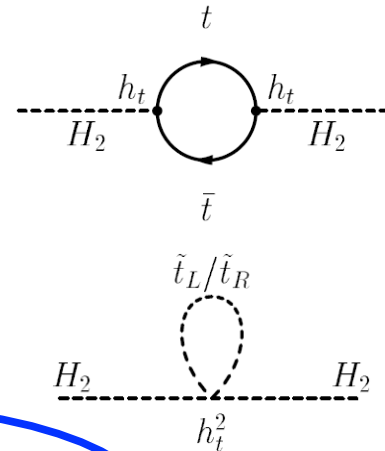
Solve “Fine Tuning” by opposite sign SUSY contributions

No SUSY particle discovered → SUSY is broken (heavy particles)

Conserved quantum number R parity: $R = (-1)^{3(B-L)+2S}$

→ SUSY particles are only produced in pairs or associated

→ **Lightest SUSY particle (LSP) is stable → DM candidate**

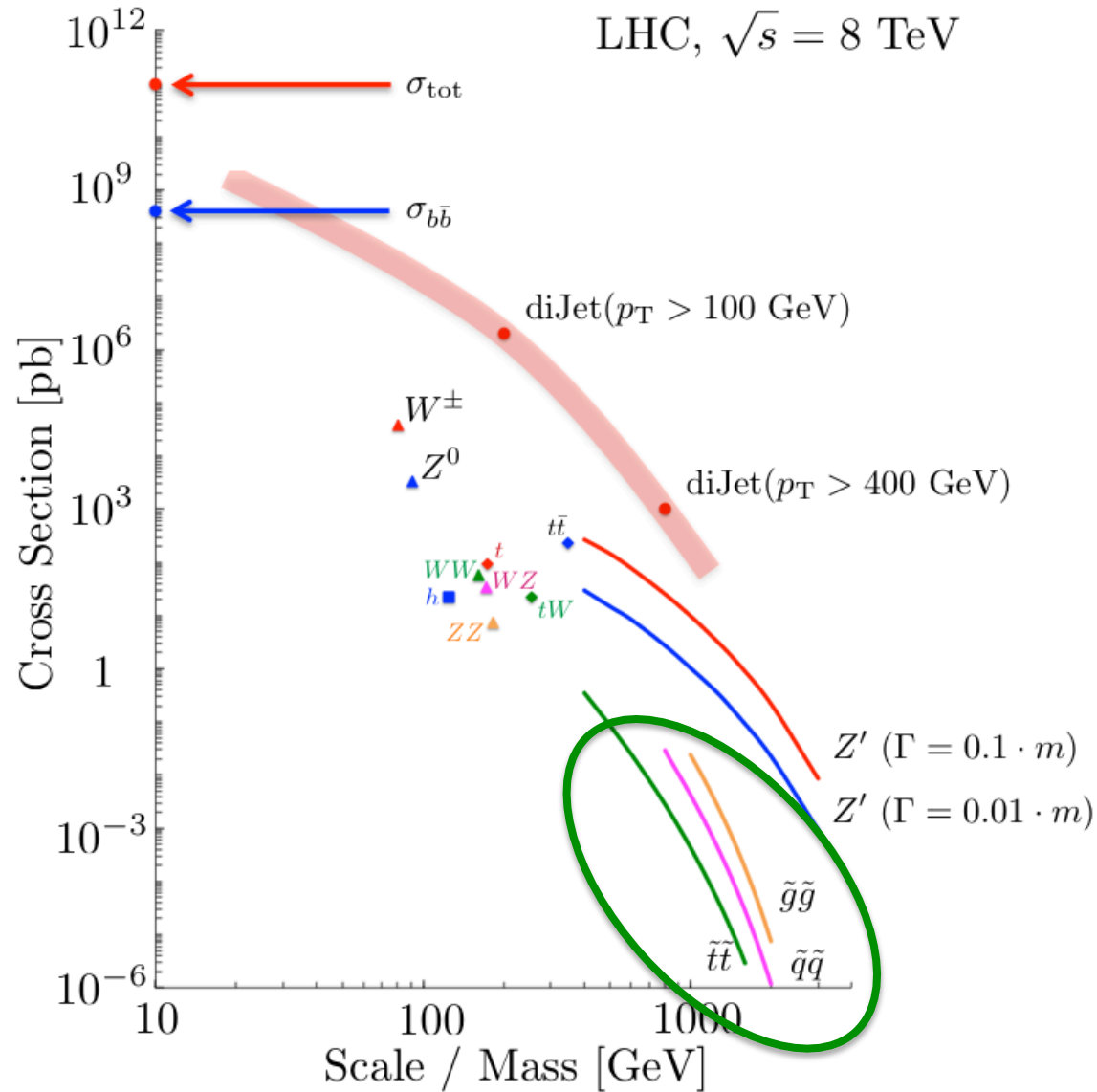


$\tilde{\chi}_{1,2,3,4}^0$
Neutralinos

$\tilde{\chi}_{1,2}^\pm$
Charginos

Supersymmetry

- Inclusive searches: Squarks / gluinos or charginos / neutralinos
- Mass edges
- Searches for 3rd generation superpartners (e. g. “natural SUSY”)
- Searches with photons, taus, Zs, ...
- RPV searches
- Long living NLSPs (heavy stable charged particles)
- ...



***R*-Parity conserved SUSY:**

- If $\tilde{q}$ and $\tilde{g}$ not much heavier than other sparticles $\rightarrow$ Strong production dominates
 - (Long) decay chains down to LSP
 - LSP stable $\rightarrow$ Missing transverse energy
- Possible diagram:**
-
- The diagram illustrates a production and decay process in supersymmetry. A gluon (g) and a top quark (t) meet at a vertex to produce a gluino ($\tilde{g}$) and a top squark ($\tilde{t}$). The gluino then decays into a top quark and a gluon, and the top squark decays into a top quark and a gluon. The final state consists of two top quarks and two gluons.

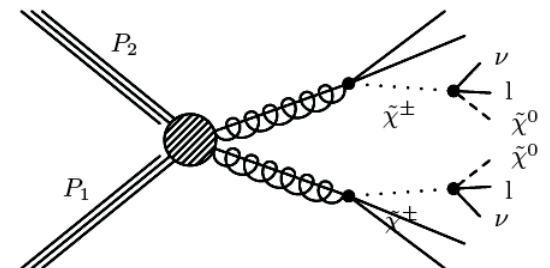
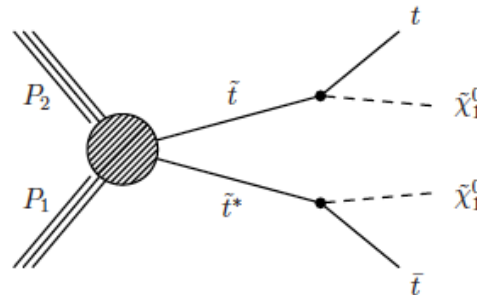
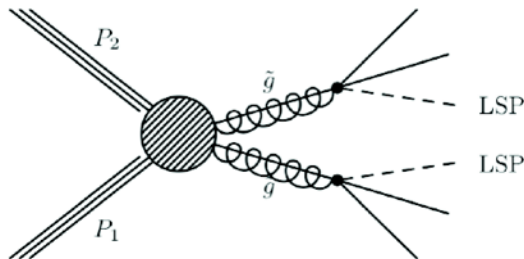
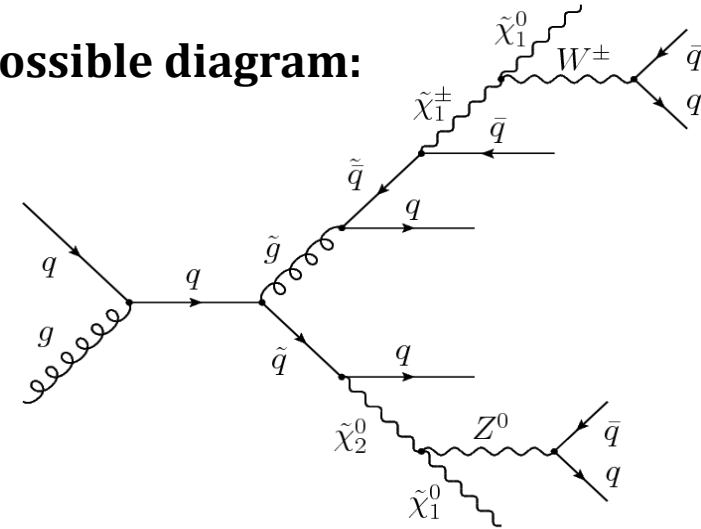
Realized final states very model dependent

Past: Interpretation in specific SUSY breaking models

Present: Interpretation mostly in simplified models (decay topologies)

→ As model independent as possible

Possible diagram:



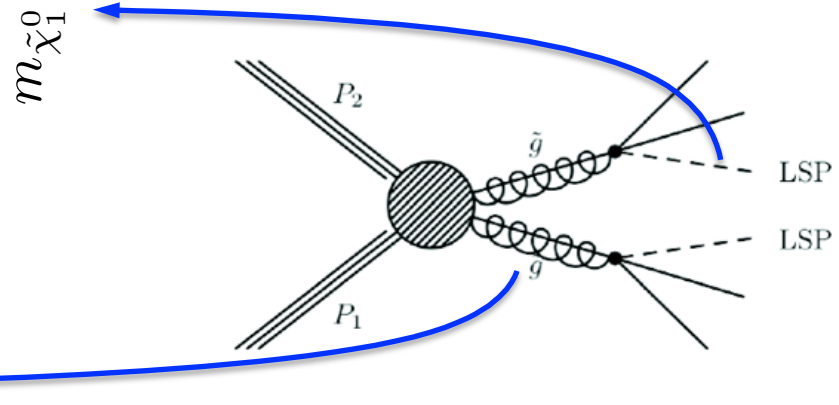
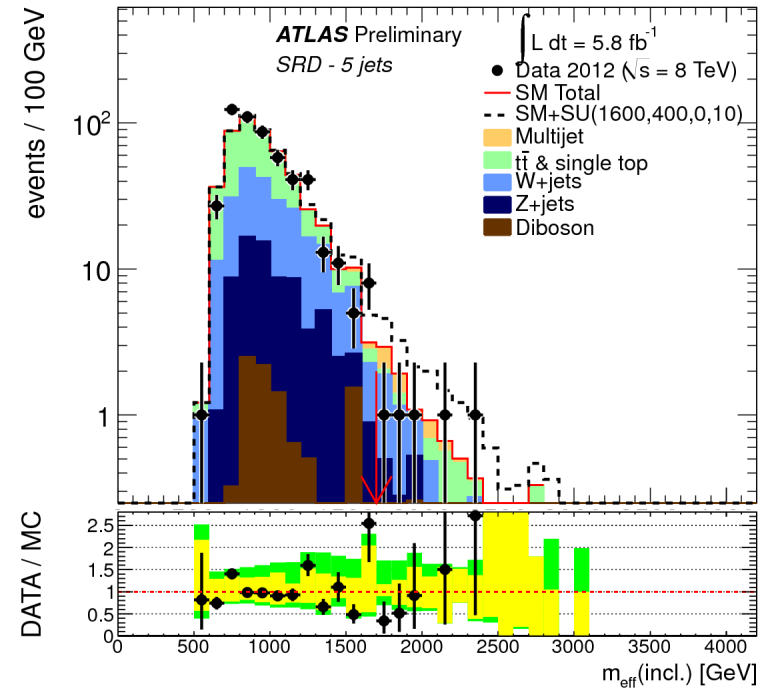
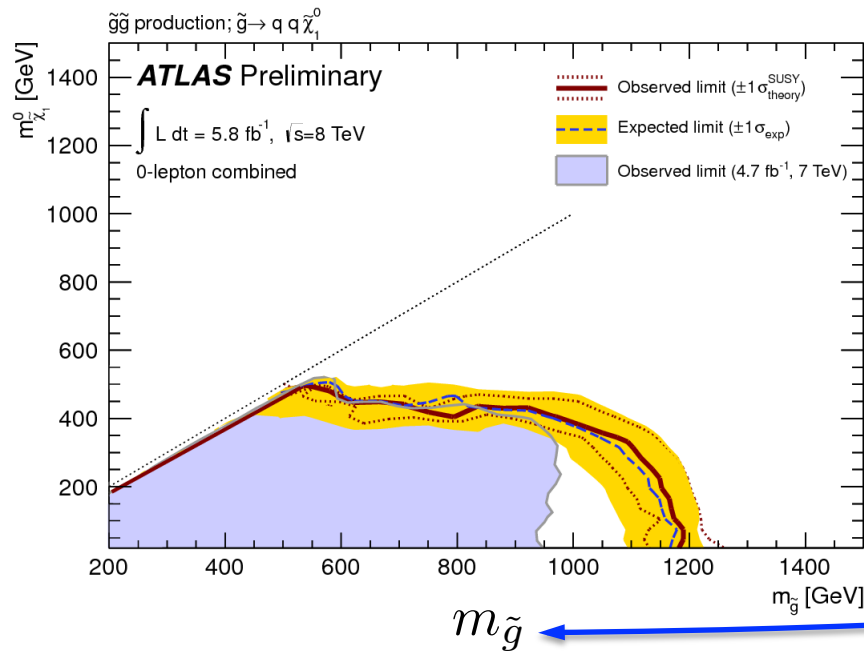
Supersymmetry – Fully Hadronic

ATLAS-CONF-2012-109

In many models: Fully hadronic final states have largest BR

Final state: jets + MET or $m_{\text{eff}} = \sum_{\text{jets}} |p_T| + E_T^{\text{miss}}$

No excess $\rightarrow$ Strong limits on 1st and 2nd generation squark and gluinos in various simplified models



Direct $\tilde{\chi}^0, \tilde{\chi}^\pm$ Production

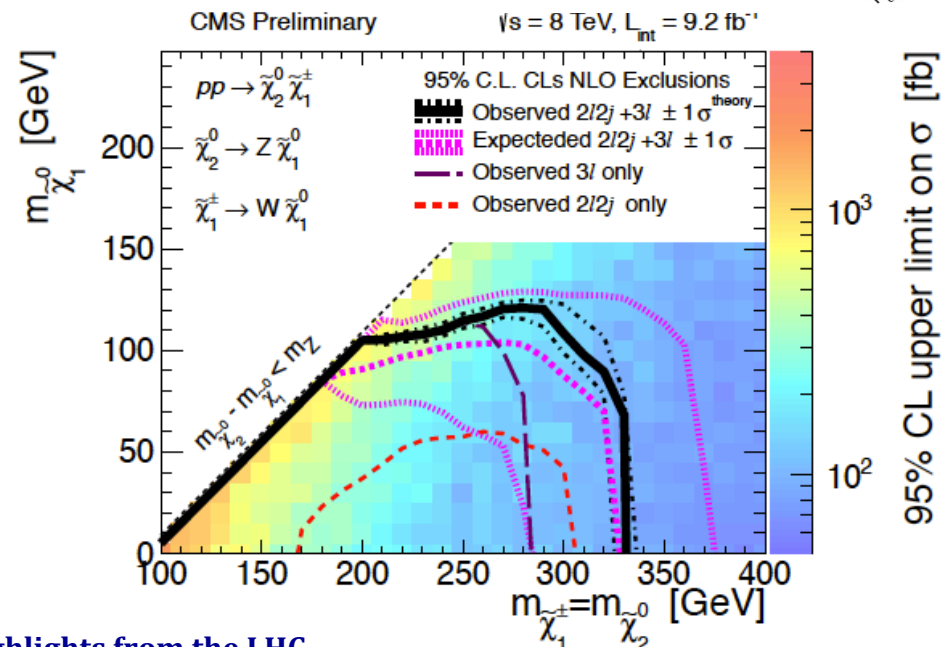
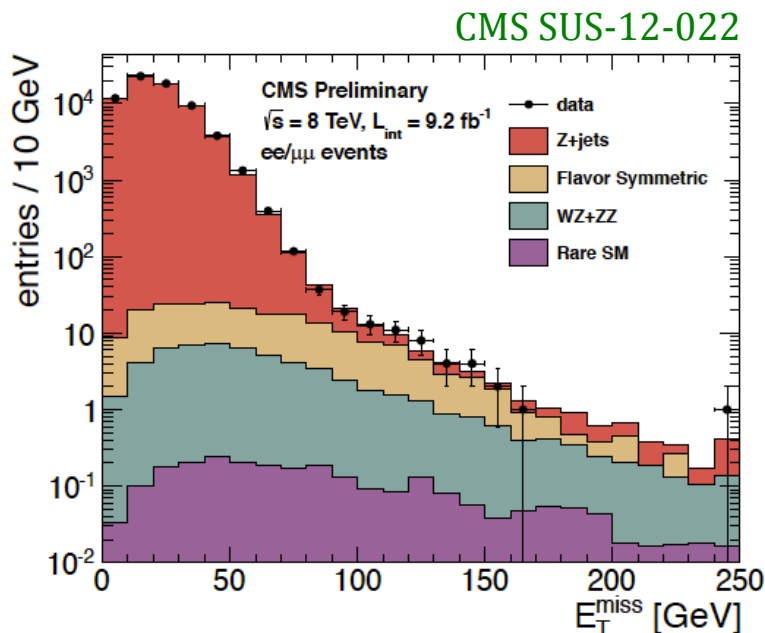
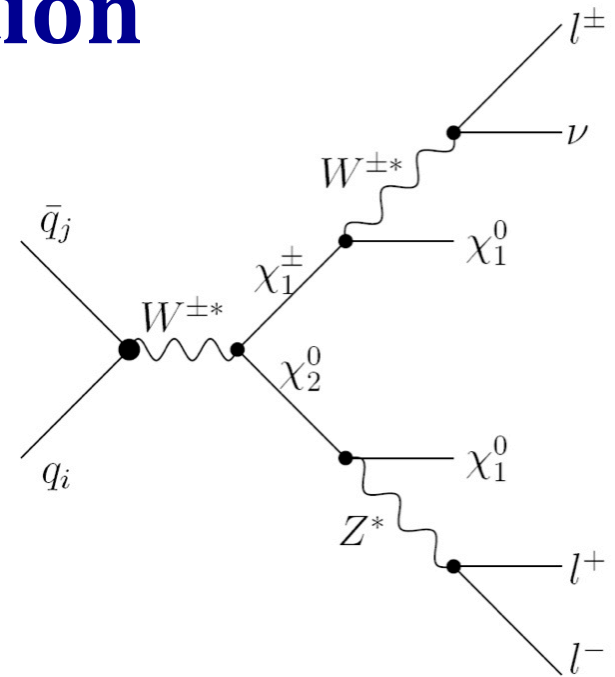
If $\tilde{q}$ and $\tilde{g}$ much heavier than $\tilde{\chi}^0, \tilde{\chi}^\pm$

→ **Direct chargino and/or neutralino production**

Leptonic decay modes provide clean signature:

- Many leptons (up to 4) + MET
- Possible opposite sign same flavour pairs with $m_{ll} = m_Z$
- Small jet activity

No excess → Limits





Relic density $\Omega_{\text{DM}} h^2 \sim 0.12$

- Either sufficient annihilation: $\tilde{\chi}_0 \tilde{\chi}_0 \rightarrow f \bar{f}$
- Or co-annihilation: $\tilde{\chi}_0 \tilde{\tau}_1 \rightarrow \tau \gamma$

In cMSSM: $\tilde{\tau}$ is often lightest sfermion

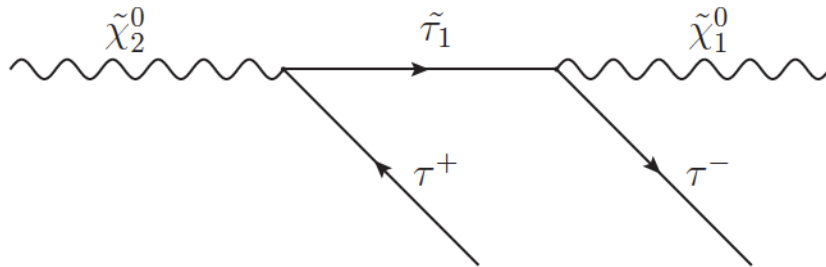
Cosmologically favoured region: $\tilde{\chi}_0 \approx \tilde{\tau}_1$

→ Chargino/neutralino decay dominantly via $\tilde{\tau}$

→ Copious production of taus in decay chains

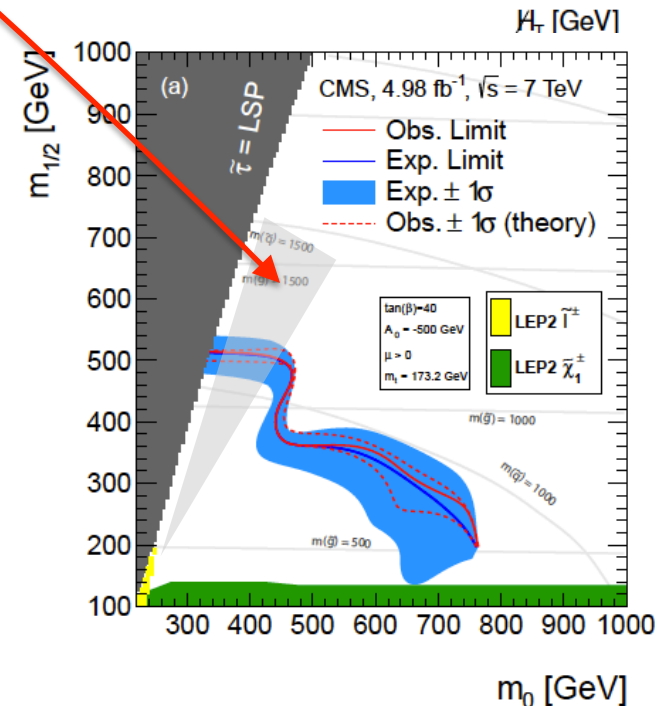
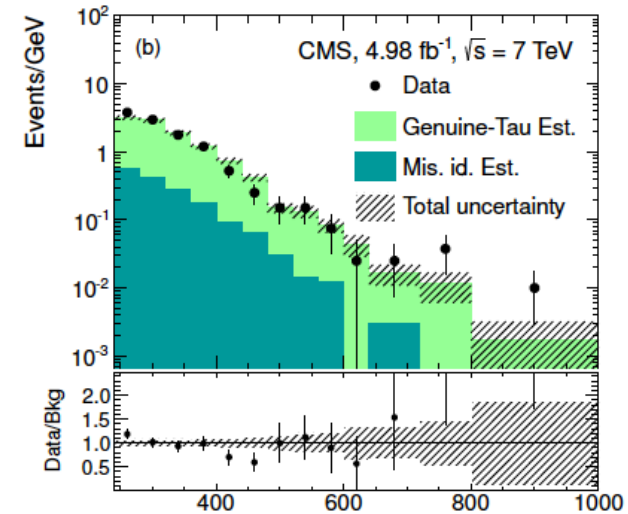
→ Search for final states with Jets + τ + MET

No excess observed → Strong exclusion in “co-annihilation region”



“Second” τ could be soft if $\Delta M(\tilde{\tau}_1, \tilde{\chi}_1^0) \lesssim 5 \text{ GeV}$

arXiv:1301.3792



Supersymmetry-Higgs Interplay

Arbey, Battaglia, Djouadi, Mahmoudi, Quevillon
arXiv:1112.3028

Implications of 125 GeV Higgs:

- Either stops are heavy ($\gg 1$ TeV) $\rightarrow$ Tension to “naturalness” ($\rightarrow$ some amount of fine tuning)

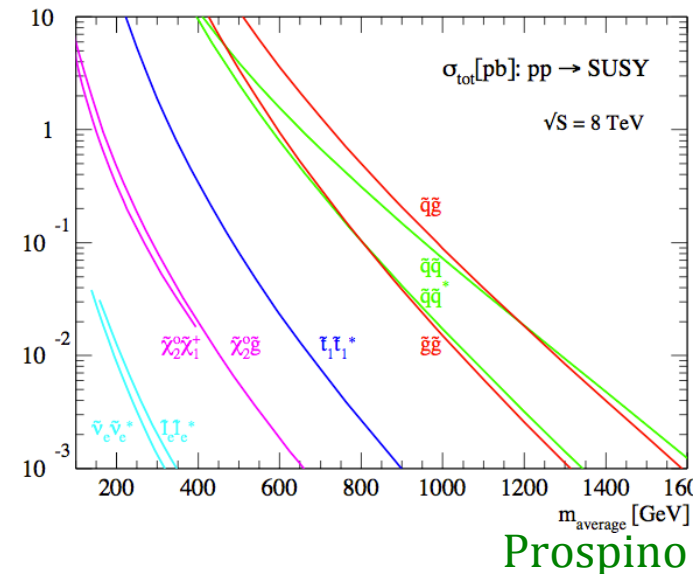
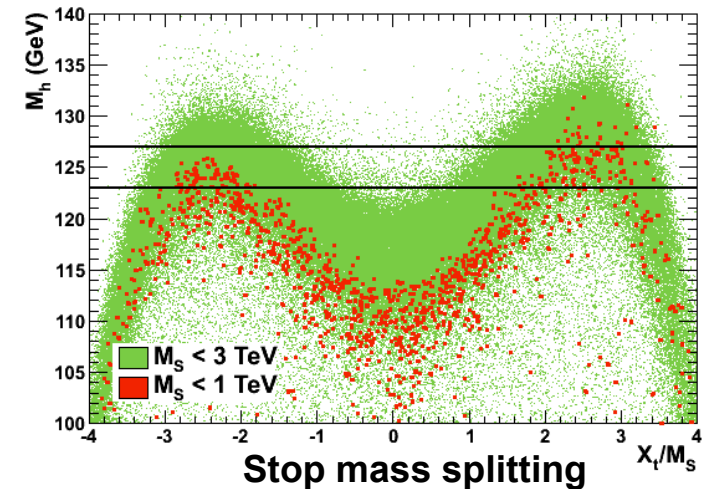
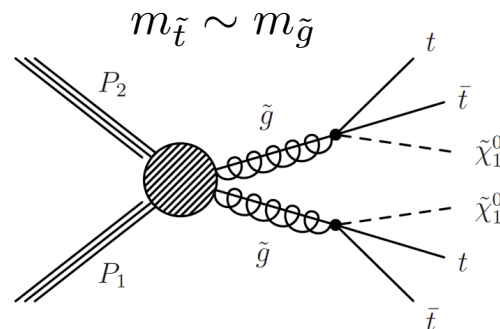
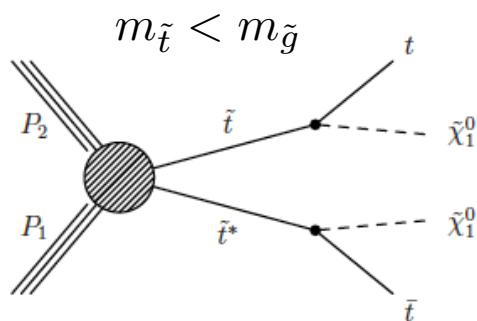
$$\frac{M_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d) - (m_{H_u}^2 + \Sigma_u) \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2$$

Radiative EWSB

- or large stop mass splitting (“Maximal mixing”)

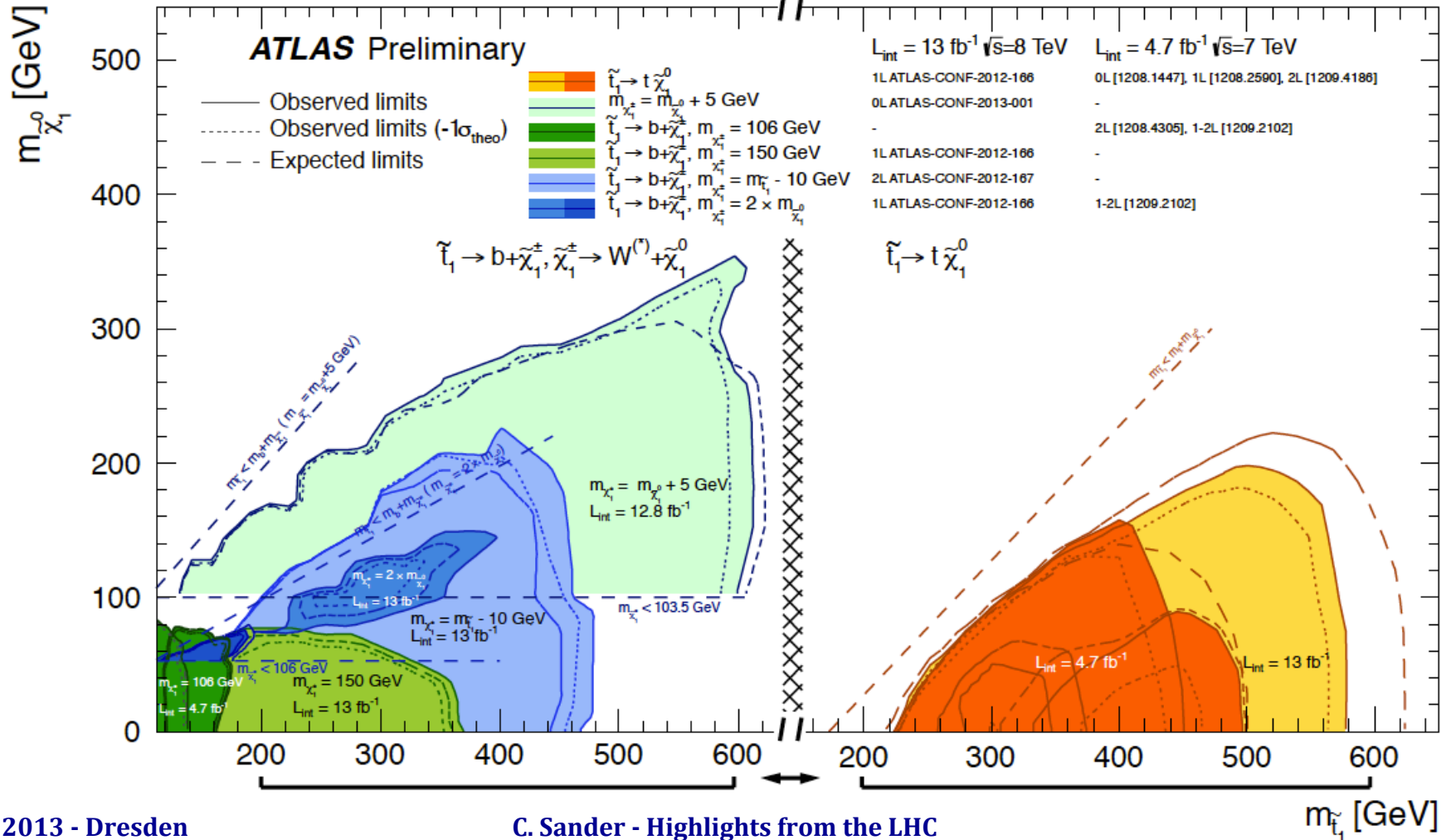
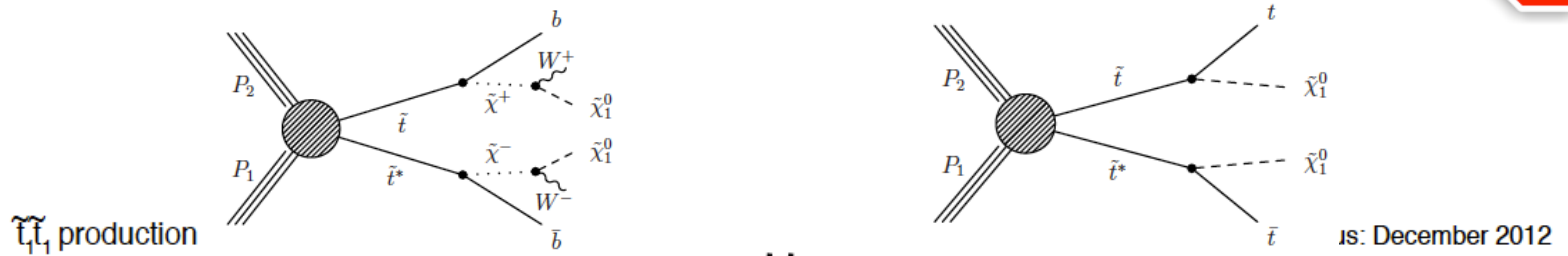
$\rightarrow$ Stop quarks can be much lighter than 1st and 2nd generation squarks!

Challenge: Small production cross section (compared to light squark production)



Prospino

Direct Stop – Summary



$Br (B_s \rightarrow \mu^+ \mu^-)$

Very rare process (FCNC and helicity suppressed)

SM prediction:

$$Br(B_s \rightarrow \mu^+ \mu^-) = (3.54 \pm 0.30) \cdot 10^{-9}$$

Measurement: LHCb reported last November first evidence for observation of this final state

$$Br(B_s \rightarrow \mu^+ \mu^-) = (3.2^{+1.5}_{-1.2}) \cdot 10^{-9}$$

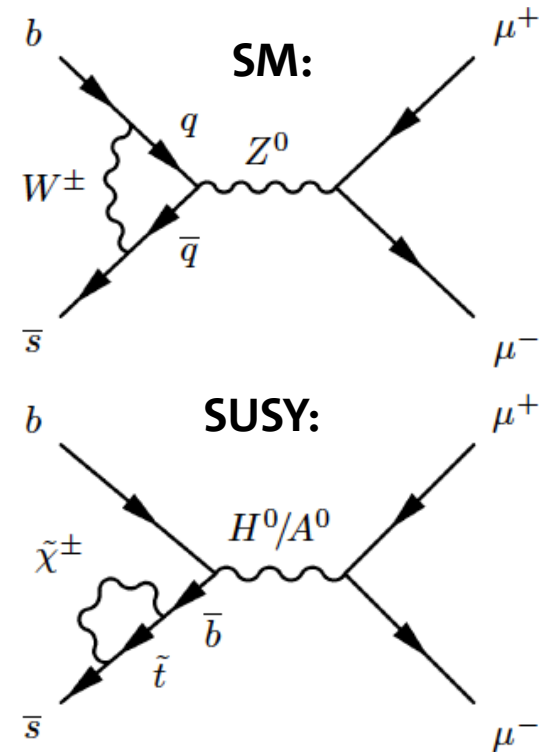
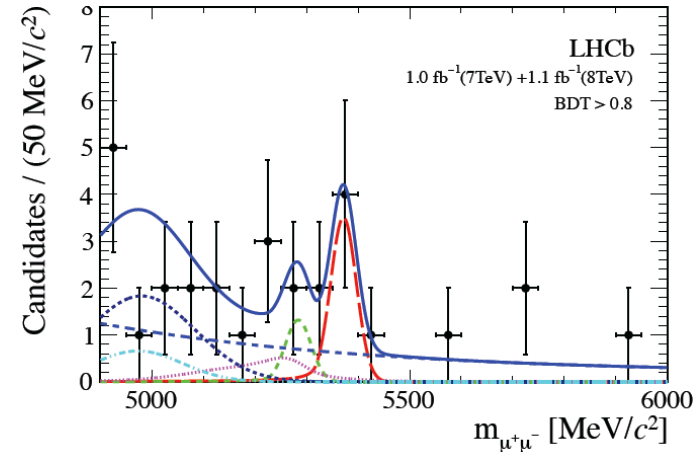
Some extensions of the SM (e.g. SUSY) predict large contributions

These models are now under pressure!!!

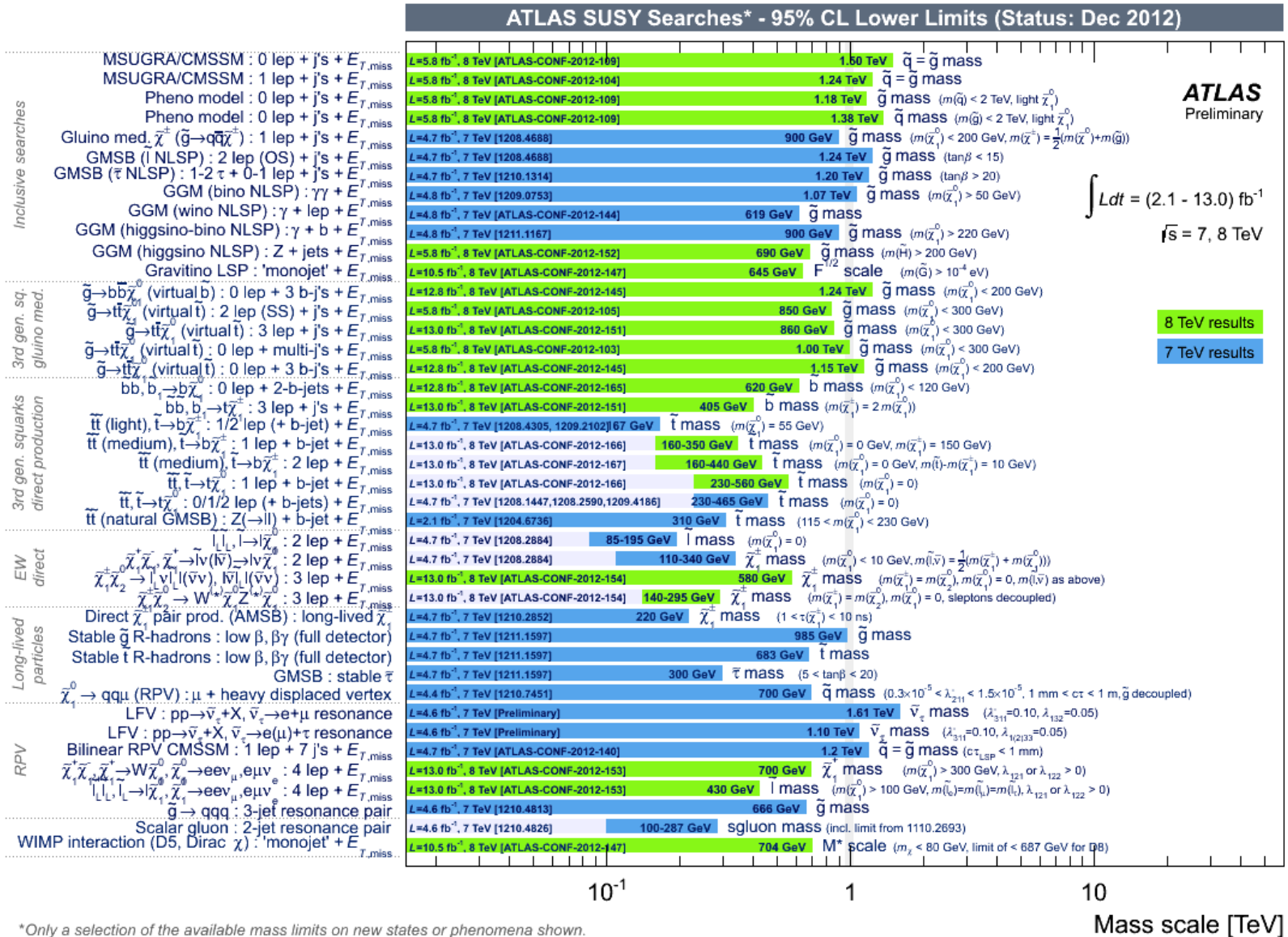
If stop mass splitting is small $\rightarrow$ Dominant SUSY contributions can get small

But: Small splitting disfavoured by natural SUSY

PRL 110, 021801 (2013)



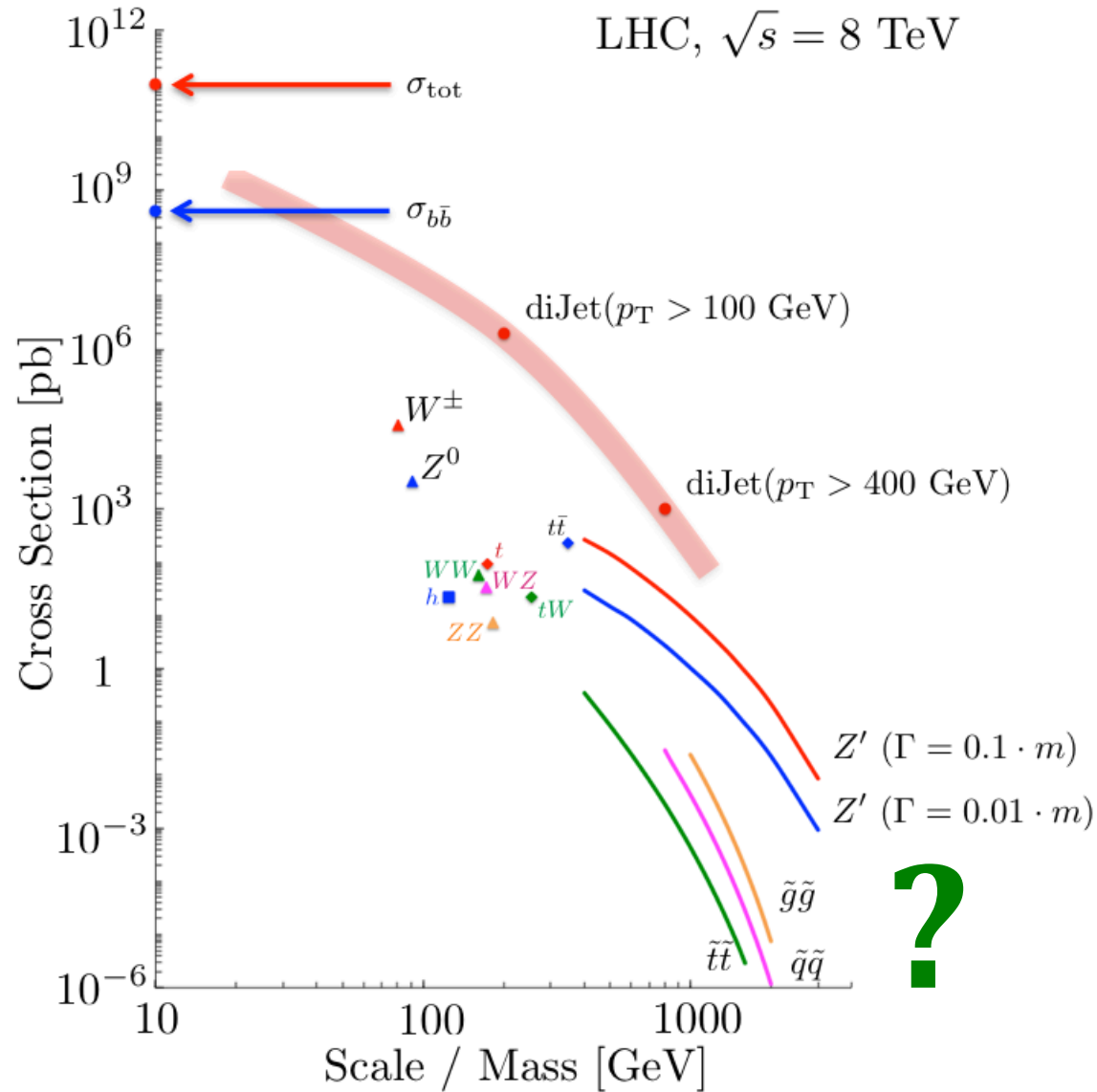
Supersymmetry – Summary



Natural SUSY under Pressure



- Extra dimensions
- Black holes
- **Dark Matter**
- Leptoquarks
- Heavy RH neutrinos
- Stopped gluinos / R -hadrons
- W' / Z'
- 4th generation
- Technicolour
- **Excited quarks**
- Contact interactions
- Un-particles
- ...



Dark Matter Searches

Directly produced DM particles not detectable $\rightarrow$ High p_T initial state radiation (ISR) $\rightarrow$ Signature: “mono-jets” or “mono-photons”

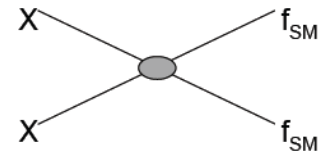
No excess $\rightarrow$ Limits on interaction cross section of DM with nucleons

Very strong limits for:

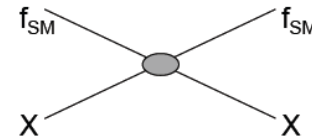
- Low masses DM particles
- Spin-dependent cross section

Direct detection experiments for spin-independent cross section for large WIMP masses superior

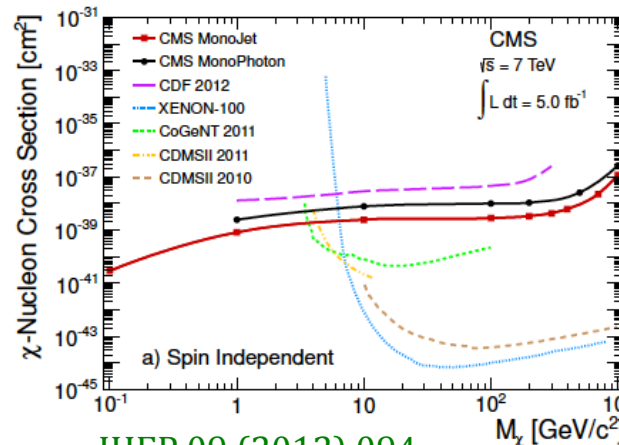
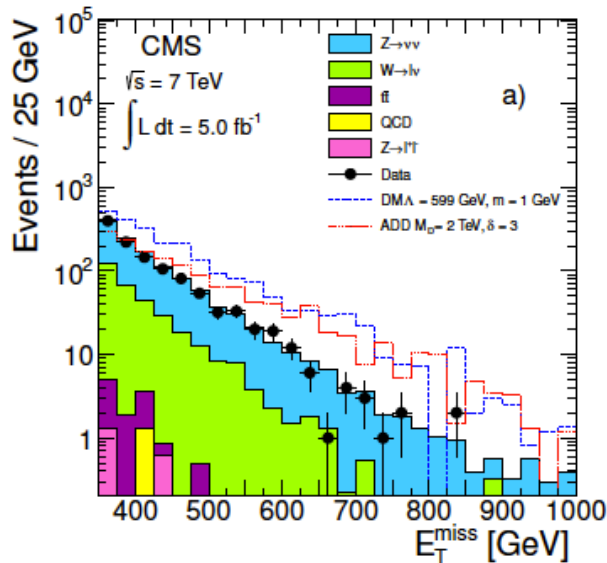
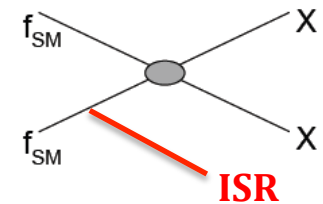
Indirect searches:



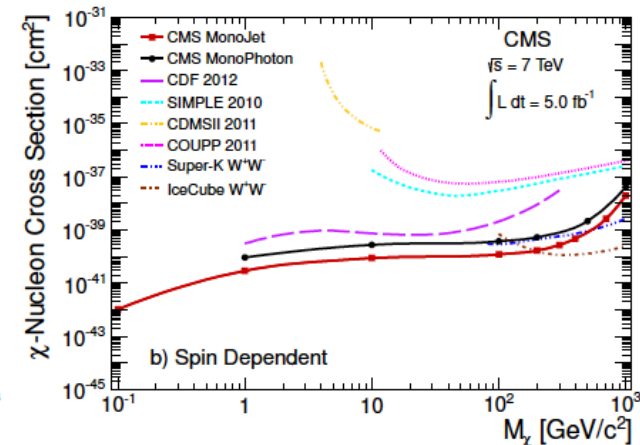
Direct detection:



Collider searches:



JHEP 09 (2012) 094
PRL 108, 261803 (2012)

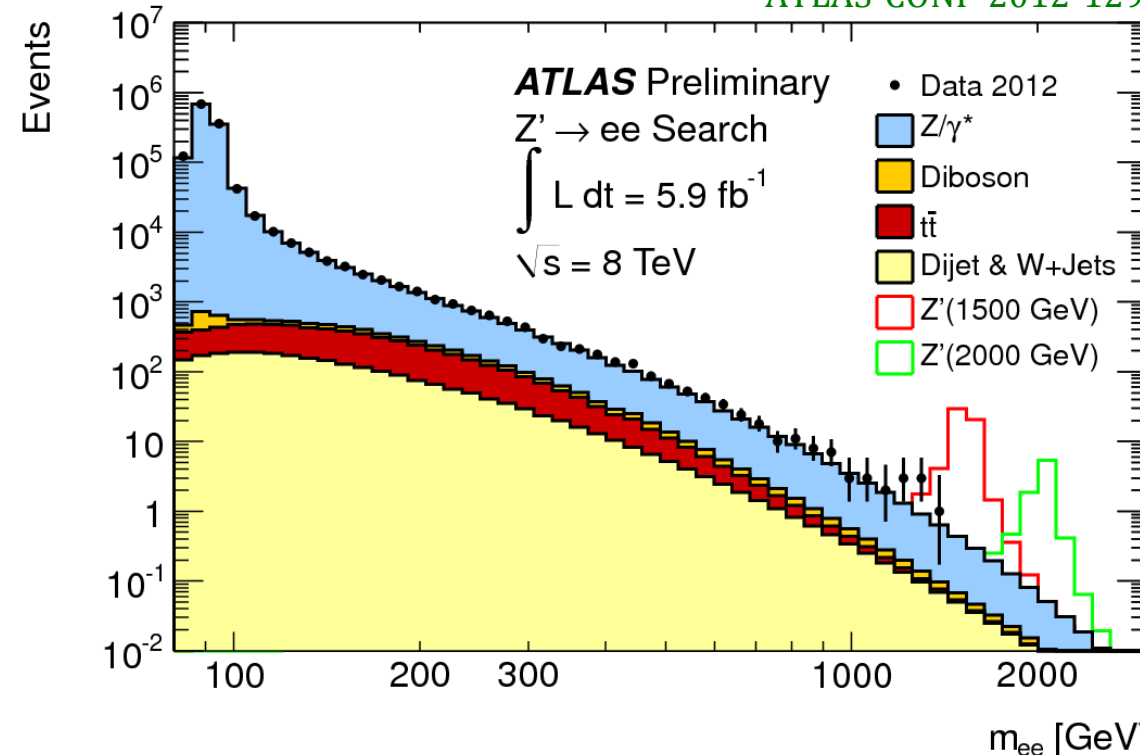


Many SM extensions (universal extra dimensions, sequential SM, ...) predict heavy “copies” of the weak gauge bosons

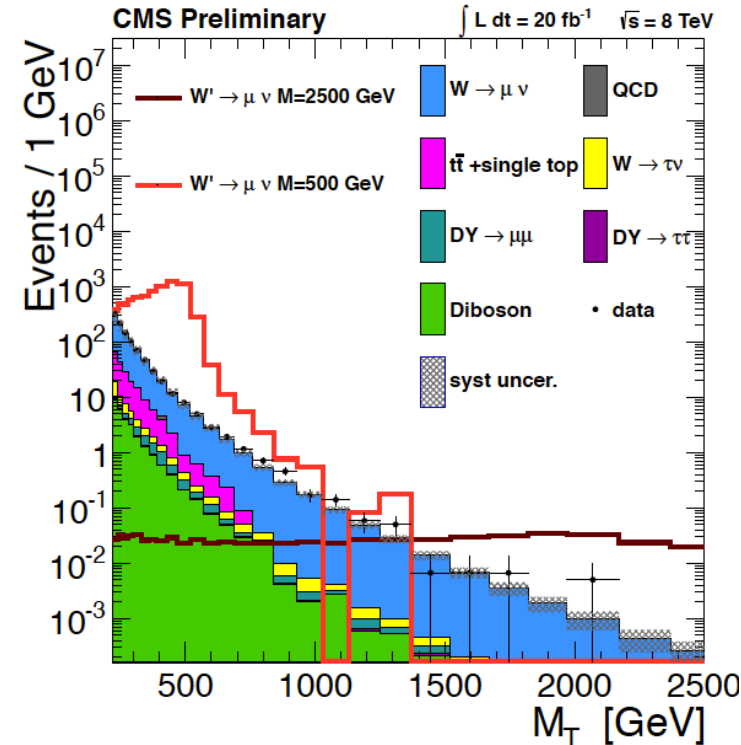
Clean signatures, small backgrounds, no deviation from SM prediction:

- $m_{Z'} < 2.96$ TeV (95% C.L.)
- $m_{W'} < 3.35$ TeV (95% C.L.)

ATLAS-CONF-2012-129



CMS EXO-12-060



Top-Antitop Resonances

See EV by
E. Kuutmann (Thursday)

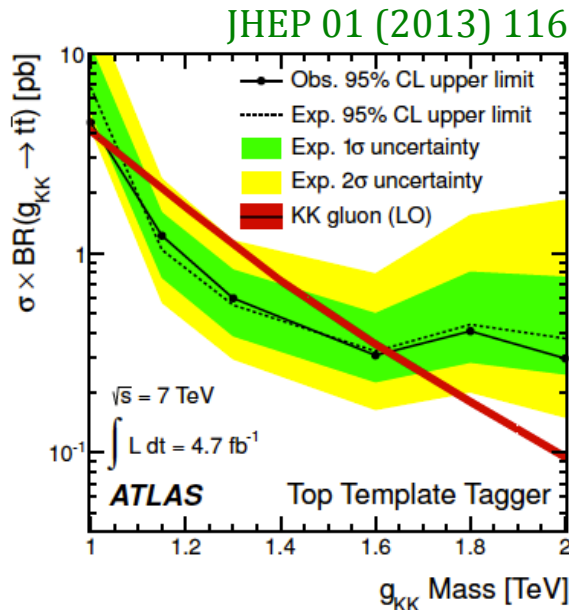
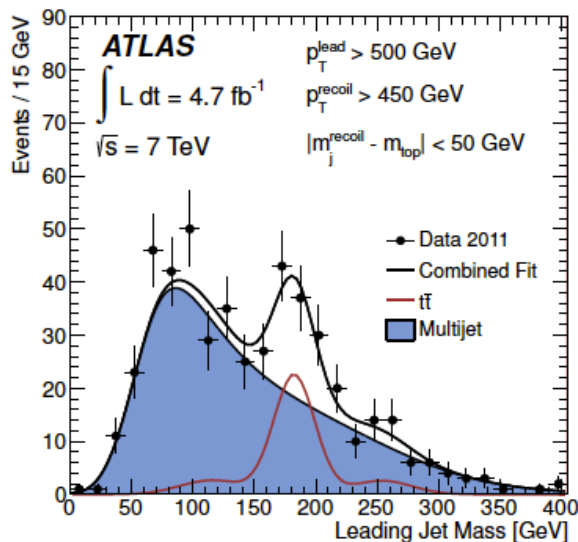
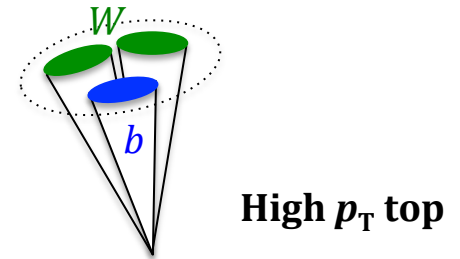
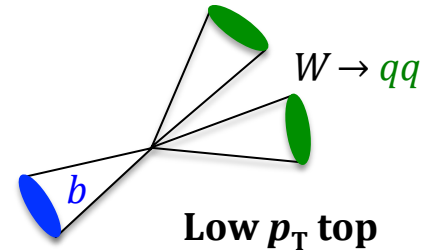
Some new physics models predict highly boosted top-quarks,
e.g. $Z'/g_{KK} \rightarrow t\bar{t}$

$E_{\text{top}} \gtrsim 500 \text{ GeV} \rightarrow$ Decay products merged to one jet

**$\rightarrow$ Search for jets with sub-structure (“top-tagging”) and
jet mass near m_{top}**

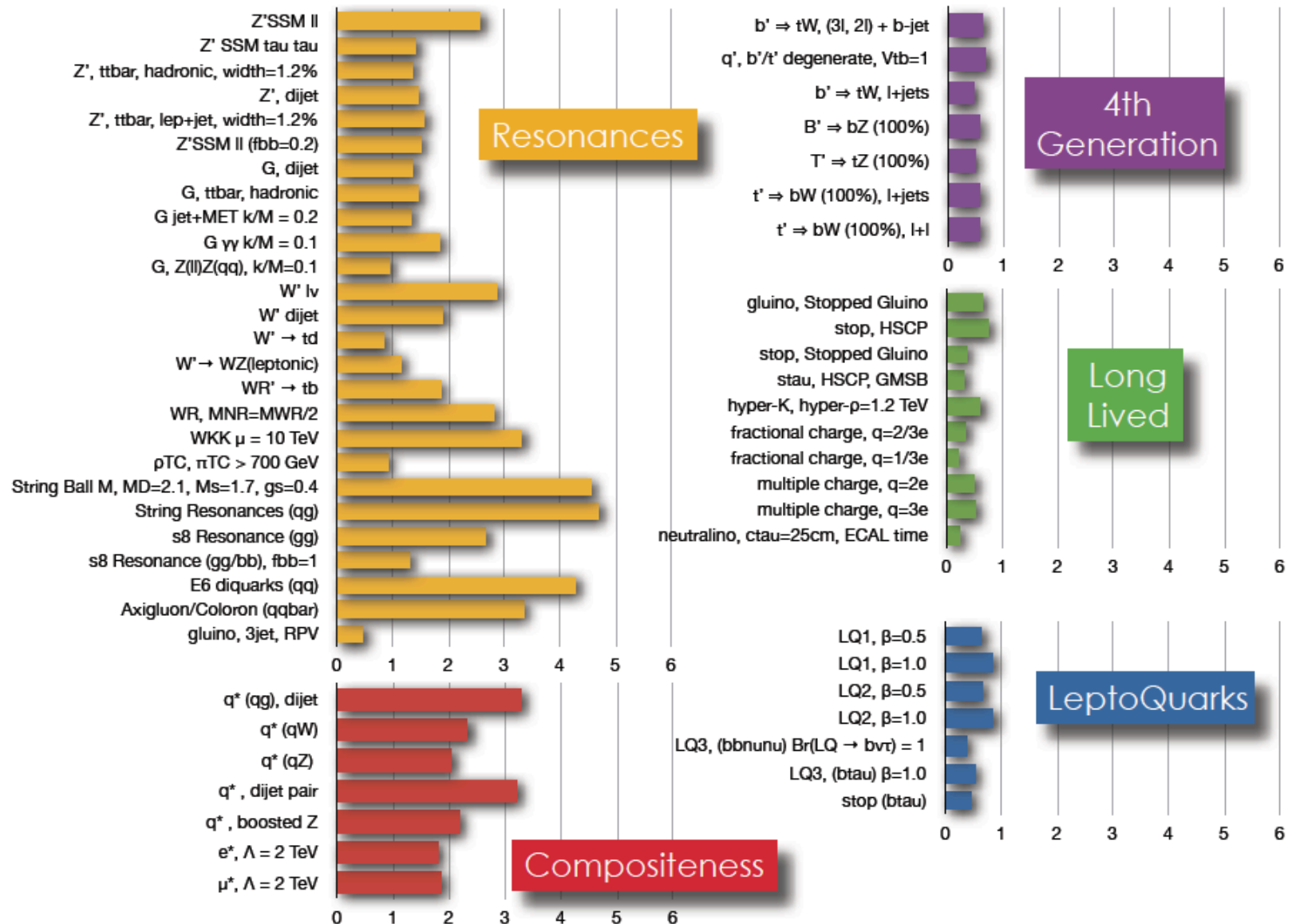
So far no excess in resonant $t\bar{t}$

**Techniques important for future as heavier exotic
particles lead to boosted decay products!**



Exotica – Summary

See HV by Martin Wessels
(Tuesday) and EV by
A. Perieanu (Tuesday)



Conclusion

- Collider and experiments are performing beyond expectation → Golden Era for particle physics
- LHC experiments have delivered ...
 - one of the most important discoveries in particle physics,
 - precise Standard Model measurements, and
 - searches for New Physics.
- So far, no significant deviation from SM observed → Worlds best limits on almost all New Physics models
- Many more ATLAS, CMS, and LHCb results available and more to come from Run 1 dataset → Visit the public result pages
 - <https://twiki.cern.ch/twiki/bin/view/AtlasPublic>
 - <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults>
 - <http://lhcbproject.web.cern.ch/lhcbproject/CDS/cgi-bin/index.php>
- LHC has entered first long shutdown ... to be continued at 13/14 TeV

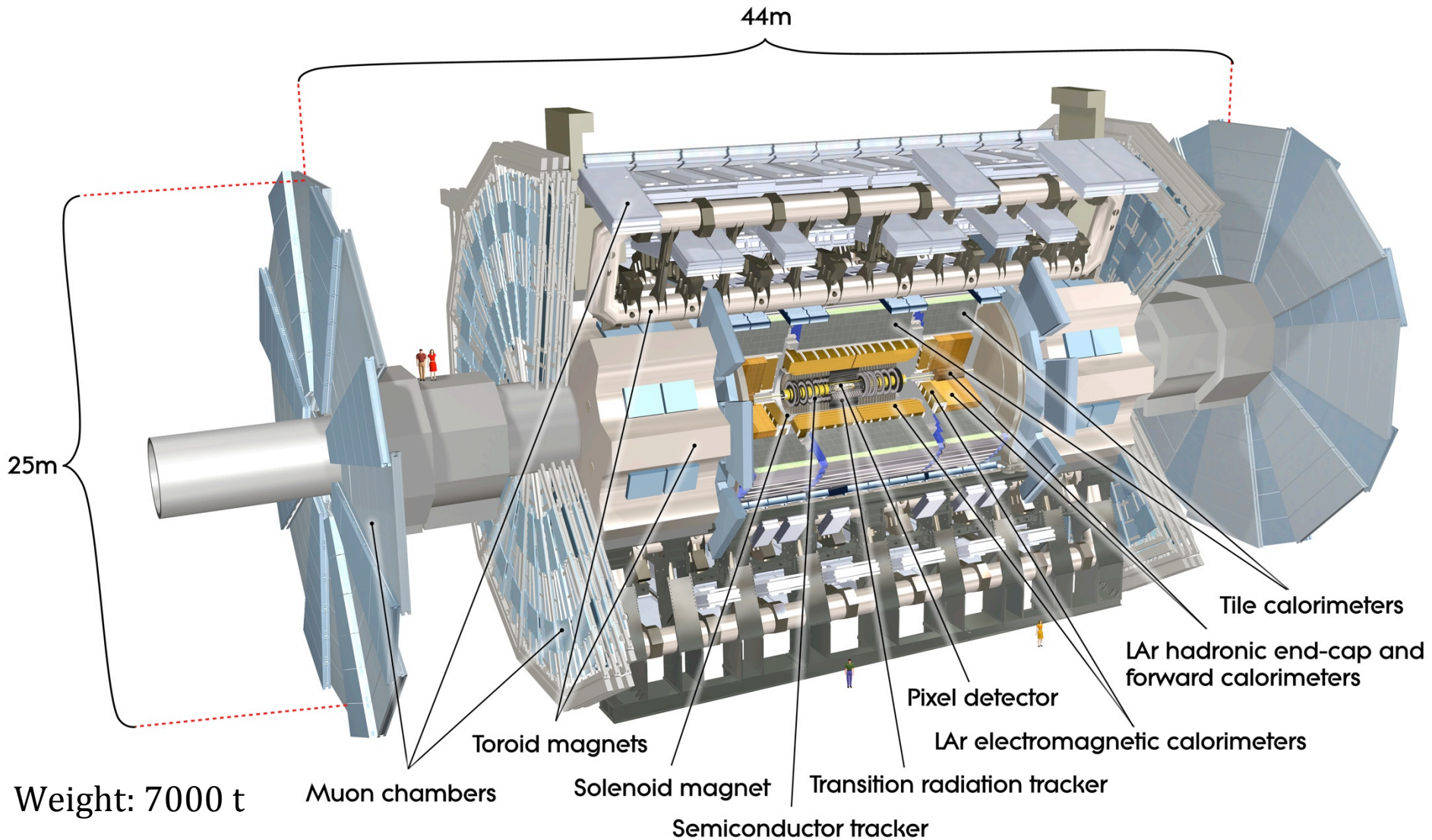
The End

... to be continued

A wooden mannequin torso is displayed on a glass surface. The mannequin is made of polished wood and has a light-colored, textured, ring-like object around its waist. In the background, there are two framed sketches on the wall. The sketch on the left shows a mechanical device with a circular component and a vertical rod. The sketch on the right shows a hand with fingers spread. A person's bag is visible on the right side of the image.

Backup

ATLAS Detector



CMS Detector



SILICON TRACKER

Pixels ($100 \times 150 \mu\text{m}^2$)
~1m² ~66M channels

Microstrips ($80\text{--}180 \mu\text{m}$)
~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

HADRON CALORIMETER (HCAL)

Brass + plastic scintillator
~7k channels

FORWARD CALORIMETER

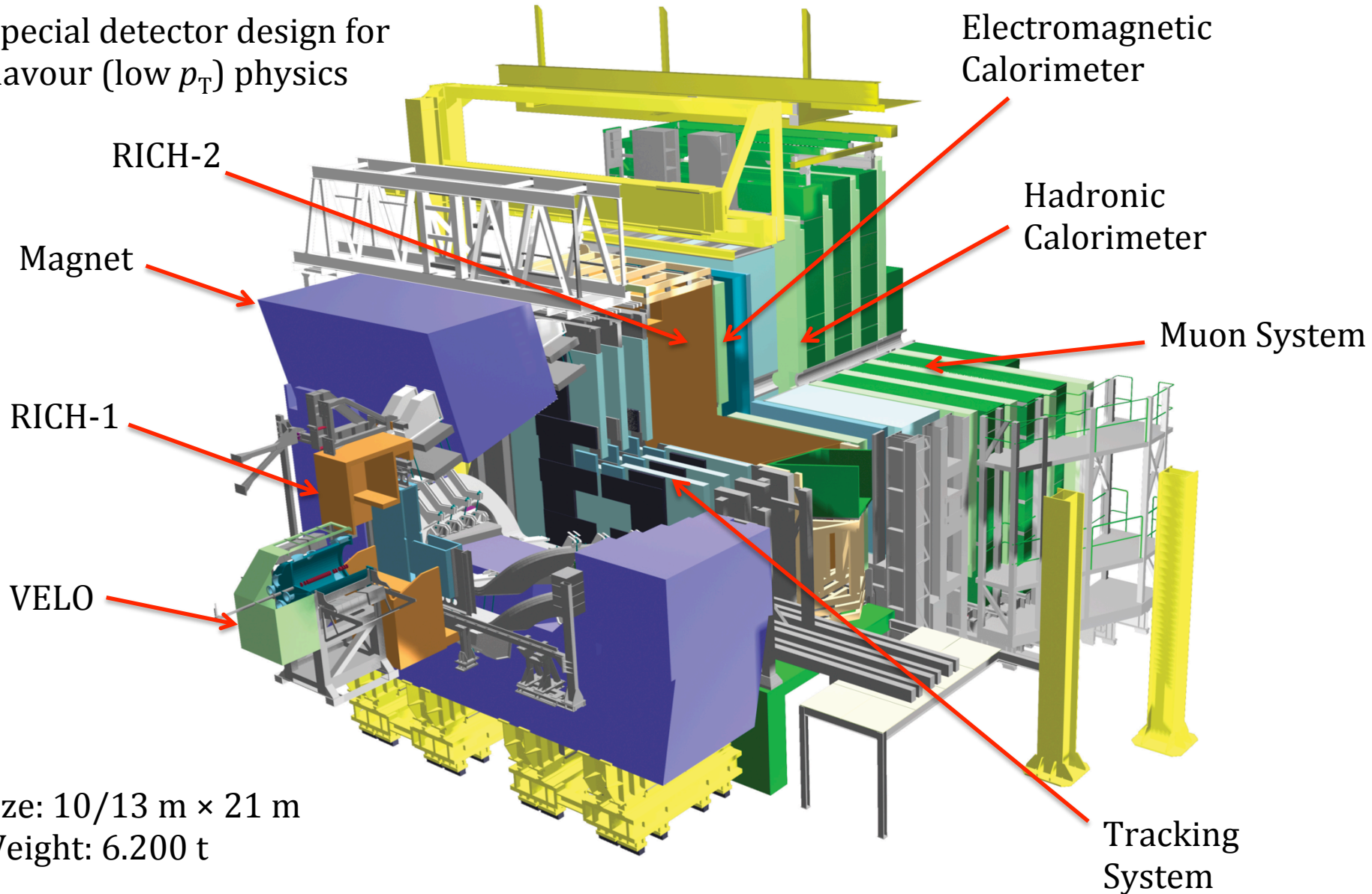
Steel + quartz fibres
~2k channels

MUON CHAMBERS

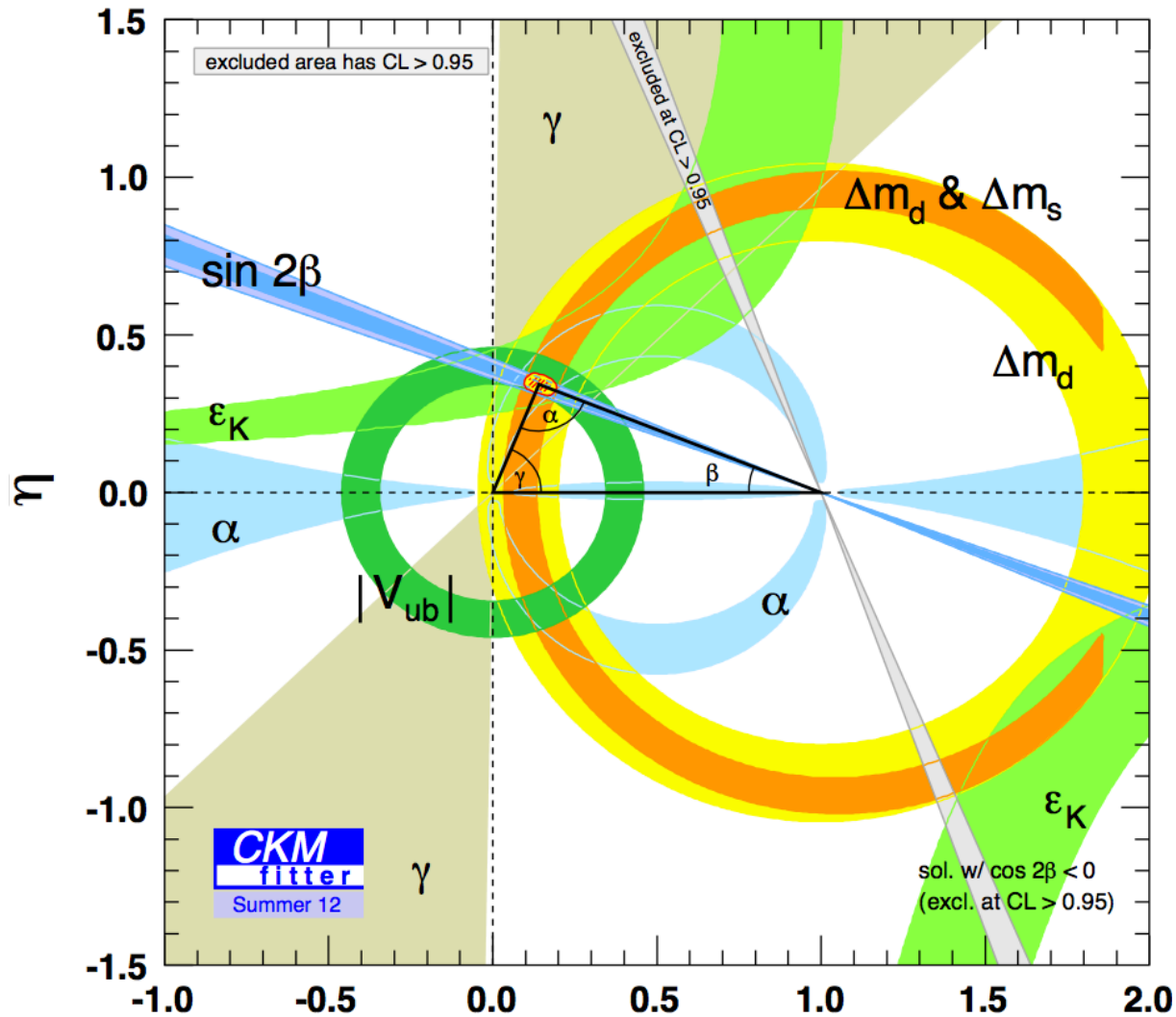
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 473 Cathode Strip & 432 Resistive Plate Chambers

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

Special detector design for
flavour (low p_T) physics



Flavour Physics



Validity of the SM

If $\dim \geq 5$ operators present $\rightarrow$ assume SM is effective theory below cut-off energy Λ

Gedankenexperiment: Check consistency of SM at high energies by calculating amplitude of Higgs scattering $hh \rightarrow hh$

Energy dependent Higgs self interaction λ $\frac{d\lambda(Q)}{d \log Q} = \frac{1}{16\pi^2} (24\lambda^2 + 12\lambda y_t^2 - 6y_t^4) + \dots$

- If $d\lambda(Q)/dQ > 0 \rightarrow \lambda$ can reach values where perturbative calculation breaks down

$\rightarrow \Lambda_+$ (**perturbativity bound**)

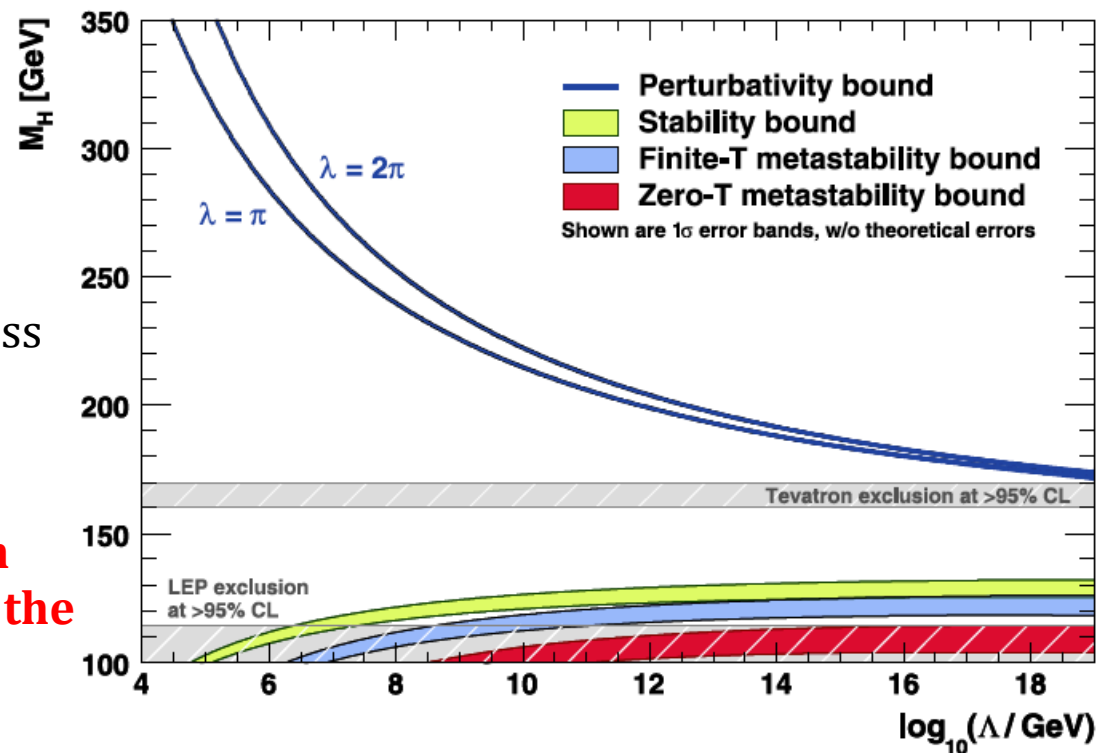
- If $d\lambda(Q)/dQ < 0 \rightarrow \lambda$ can reach negative values, in which the electroweak vacuum is only local minimum $\rightarrow \Lambda_-$ (**stability bound**)

Relating self coupling with Higgs mass

$$M_h = \sqrt{2\lambda(Q \sim M_h)}v$$

Show validity of SM (at Λ) versus M_h

Only in Higgs mass range between 130-170 GeV the SM is valid up to the Planck scale



Light sTops – Direct Production

$m_{\tilde{t}} < m_{\tilde{g}} \rightarrow$ Direct stop production

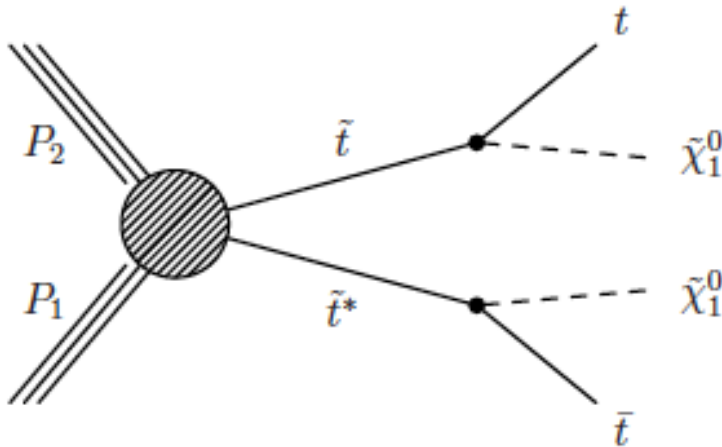
Signature: $t\bar{t}$ + MET

Challenge: dominant background ($t\bar{t}$)
has also genuine MET

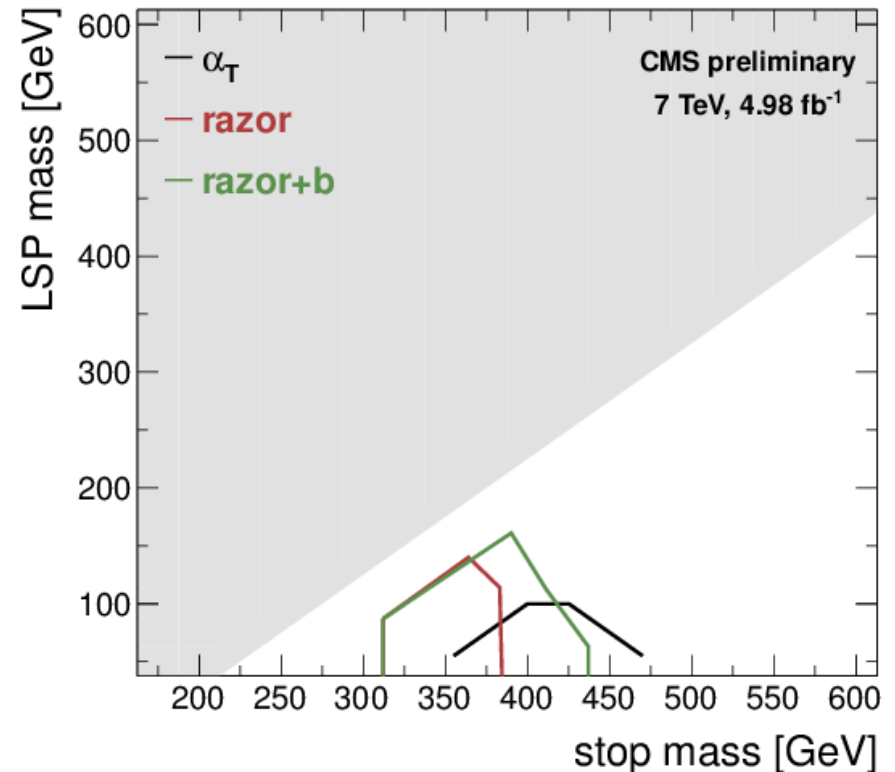
Leptonic and hadronic searches:

No excess above SM expectation

Different decay topology for: $m_{\tilde{t}} < m_t$



95% exclusion limits for $\tilde{t} \rightarrow t \tilde{\chi}_1^0$; $m(\tilde{g}, \tilde{q}) \gg m(\tilde{t})$



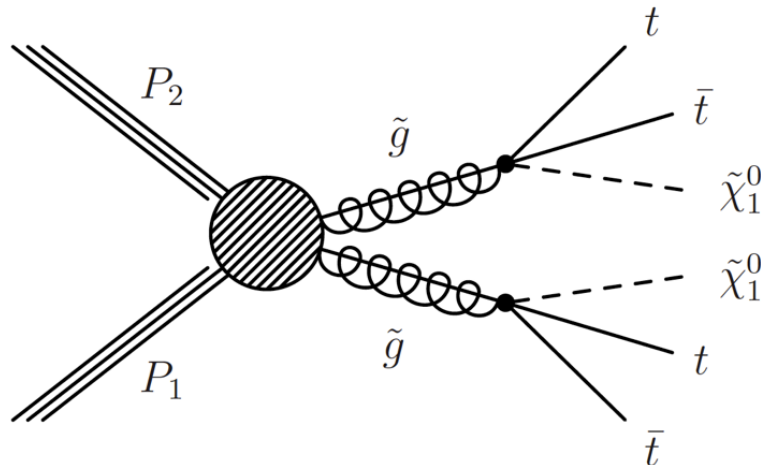
Light sTops – Gluino Induced Production

$m_{\tilde{t}} \sim m_{\tilde{g}} \rightarrow$ “Gluino induced” production

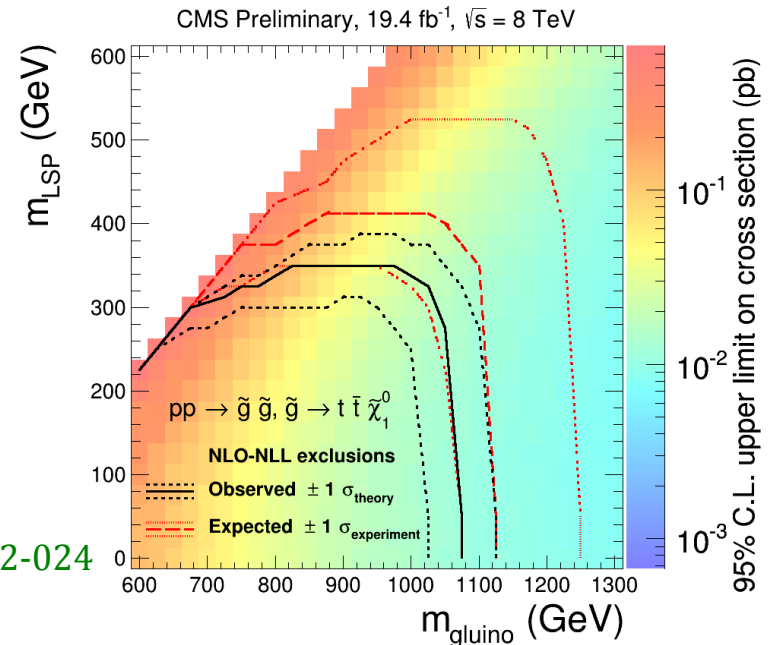
Signature: $t\bar{t}t\bar{t} + \text{MET}$

$\rightarrow$ Up to 12 jets; 4 b -tags; MET

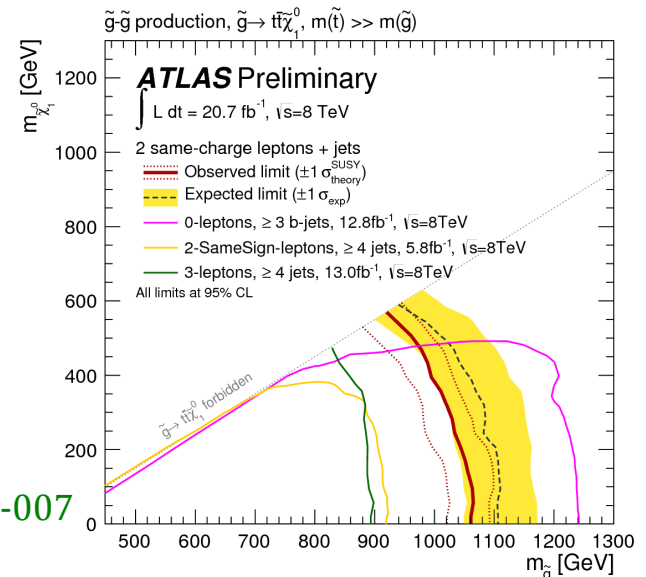
Small backgrounds!



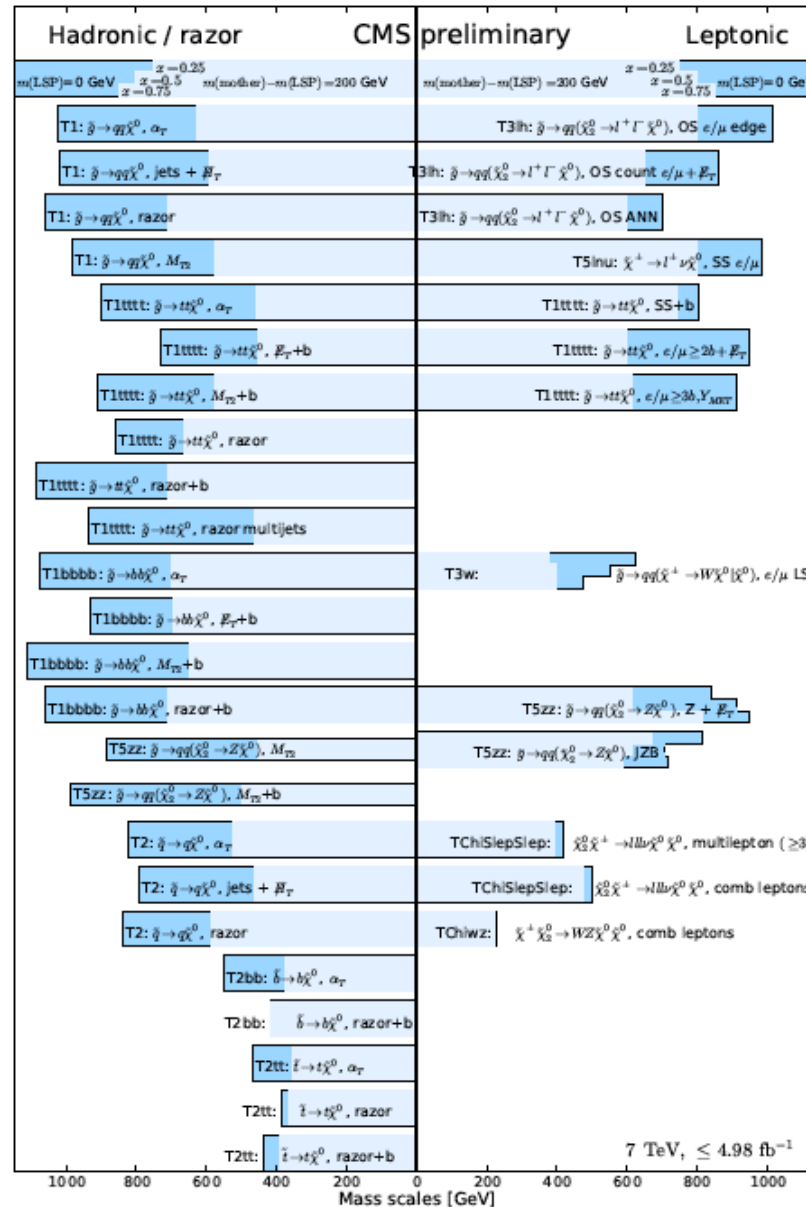
CMS SUS-12-024



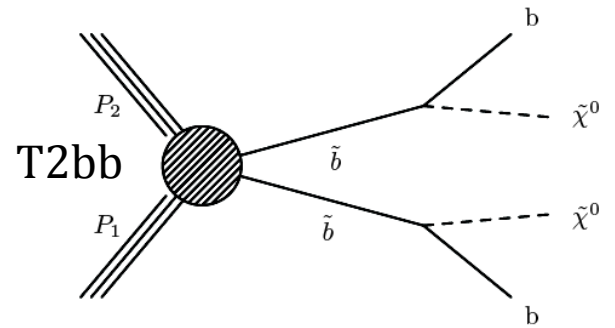
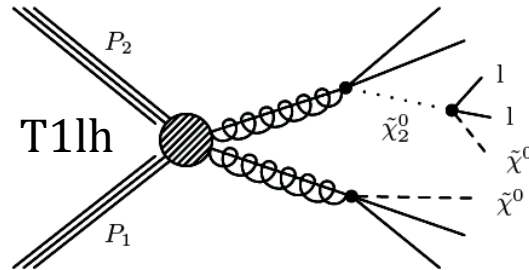
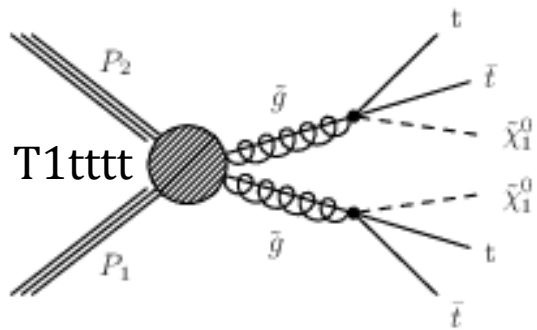
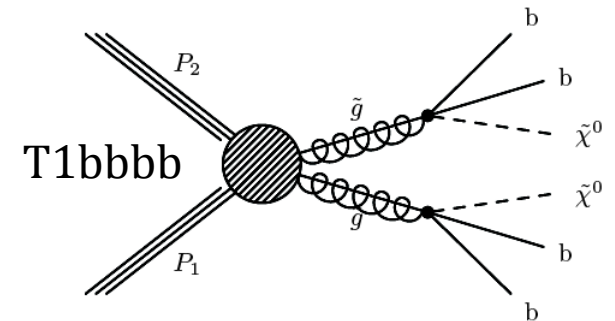
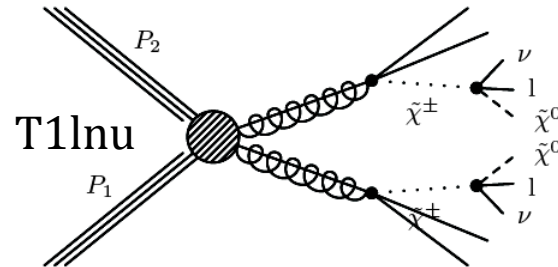
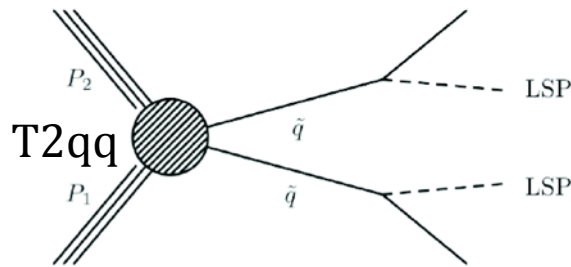
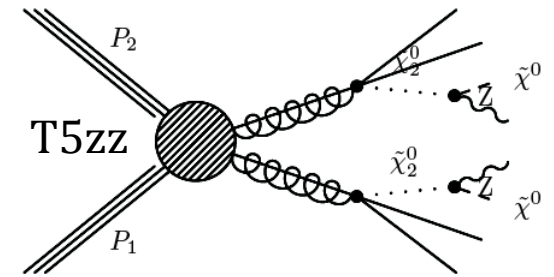
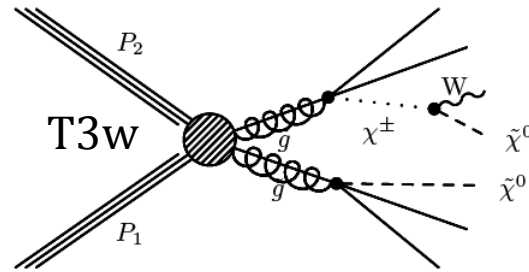
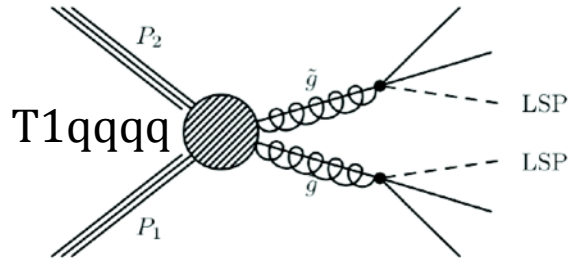
ATLAS-CONF-2013-007



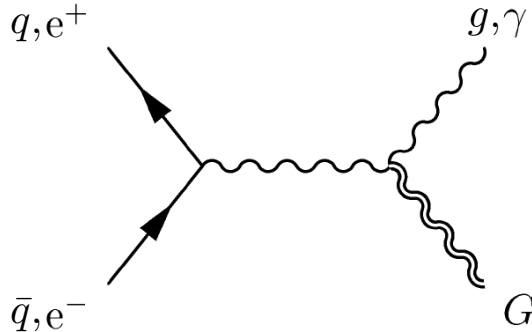
Supersymmetry – Summary (CMS)



Simplified Models – Topologies



Extra Dimensions at the LHC



Why is gravity so weak? → “Thinned out” by extra dimensions (rolled up at small scale $\sim \text{mm}$)

Graviton becomes Kaluza-Klein “tower” of massive equidistant particles

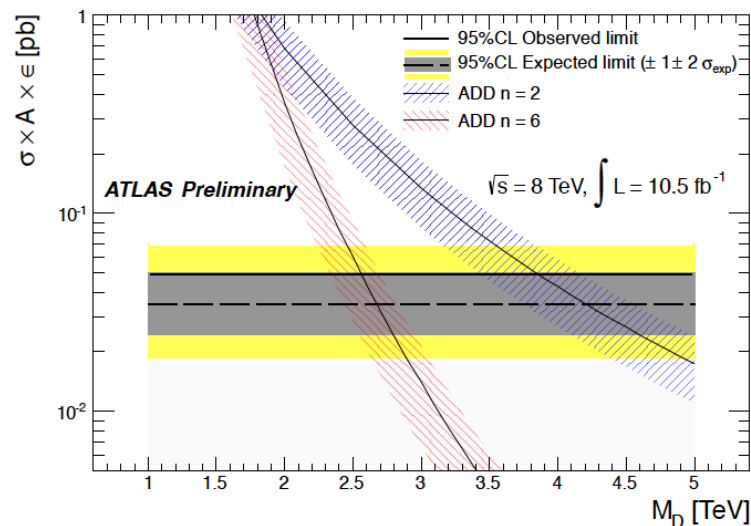
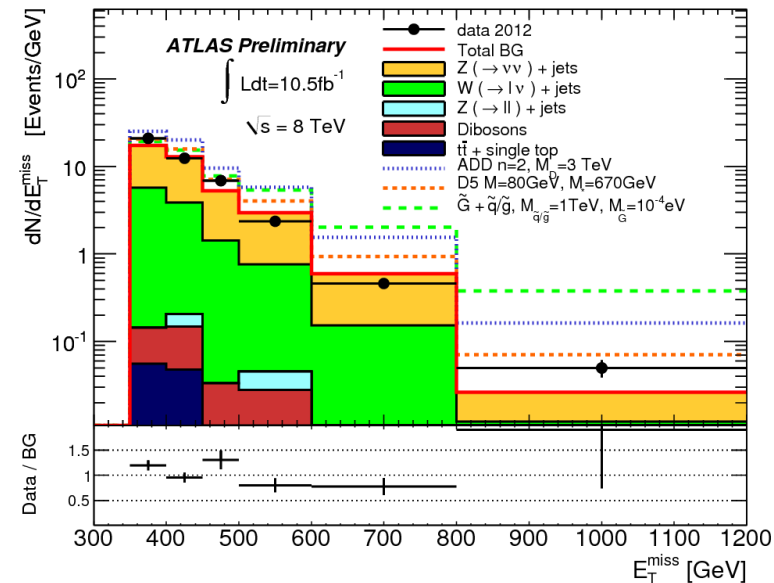
Interaction of KK particles only by gravitation → Suppressed by $1/M_D$ (with M_D reduced Planck scale)

Inclusive processes: sum over all KK states → Cross sections can be large

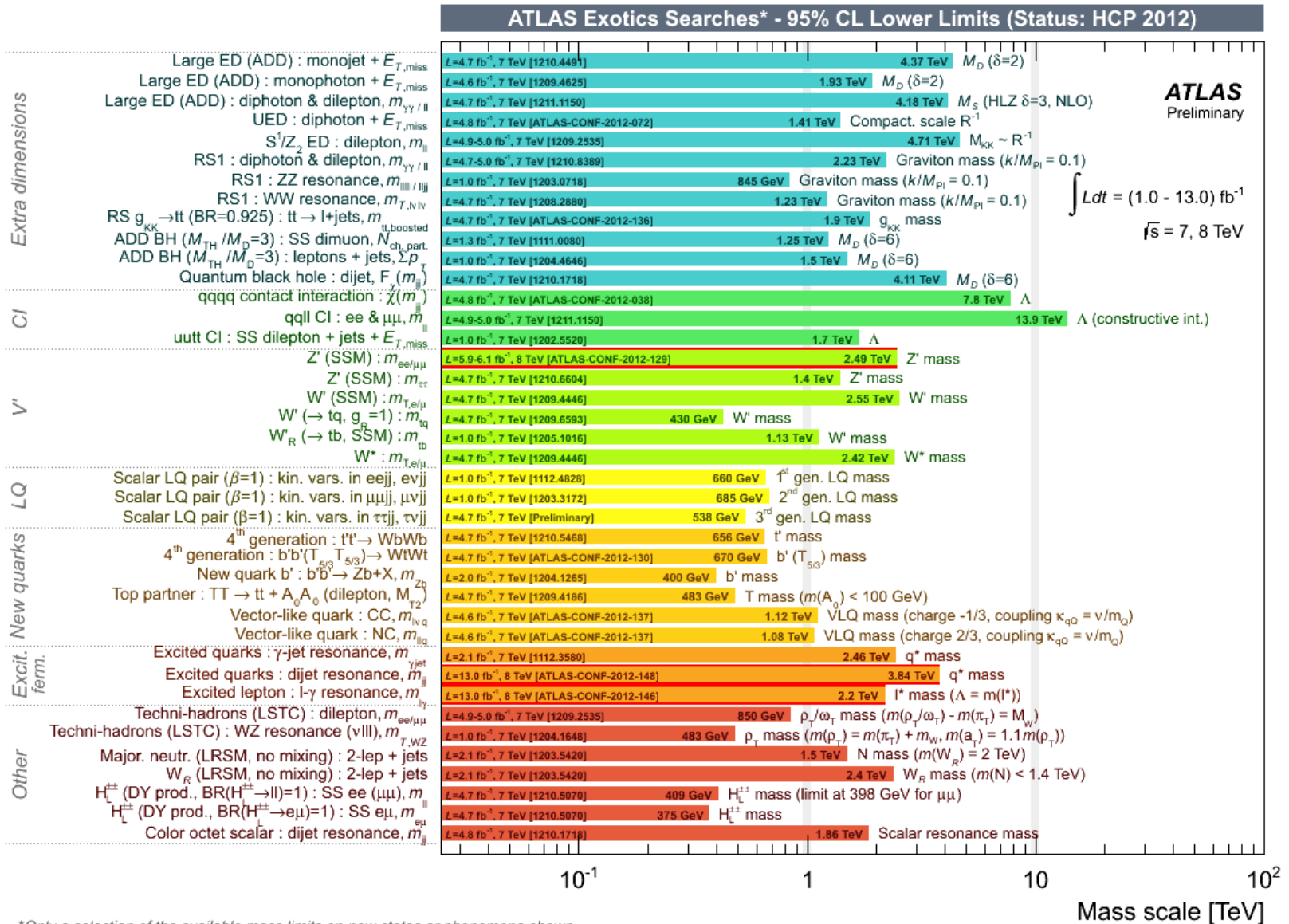
Possible collider signatures: Direct production of KK particle → **Mono-photons** or **mono-jets**

No discrepancy from SM prediction

→ **Limits:** $M_D < 3.9$ (2.5) TeV for $d = 2$ (6)



Exotica- Summary (ATLAS)



*Only a selection of the available mass limits on new states or phenomena shown

Mass scale [TeV]

LHC Cross Sections

