New Results from CMS experiment at LHC

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On behalf of the CMS Collaboration

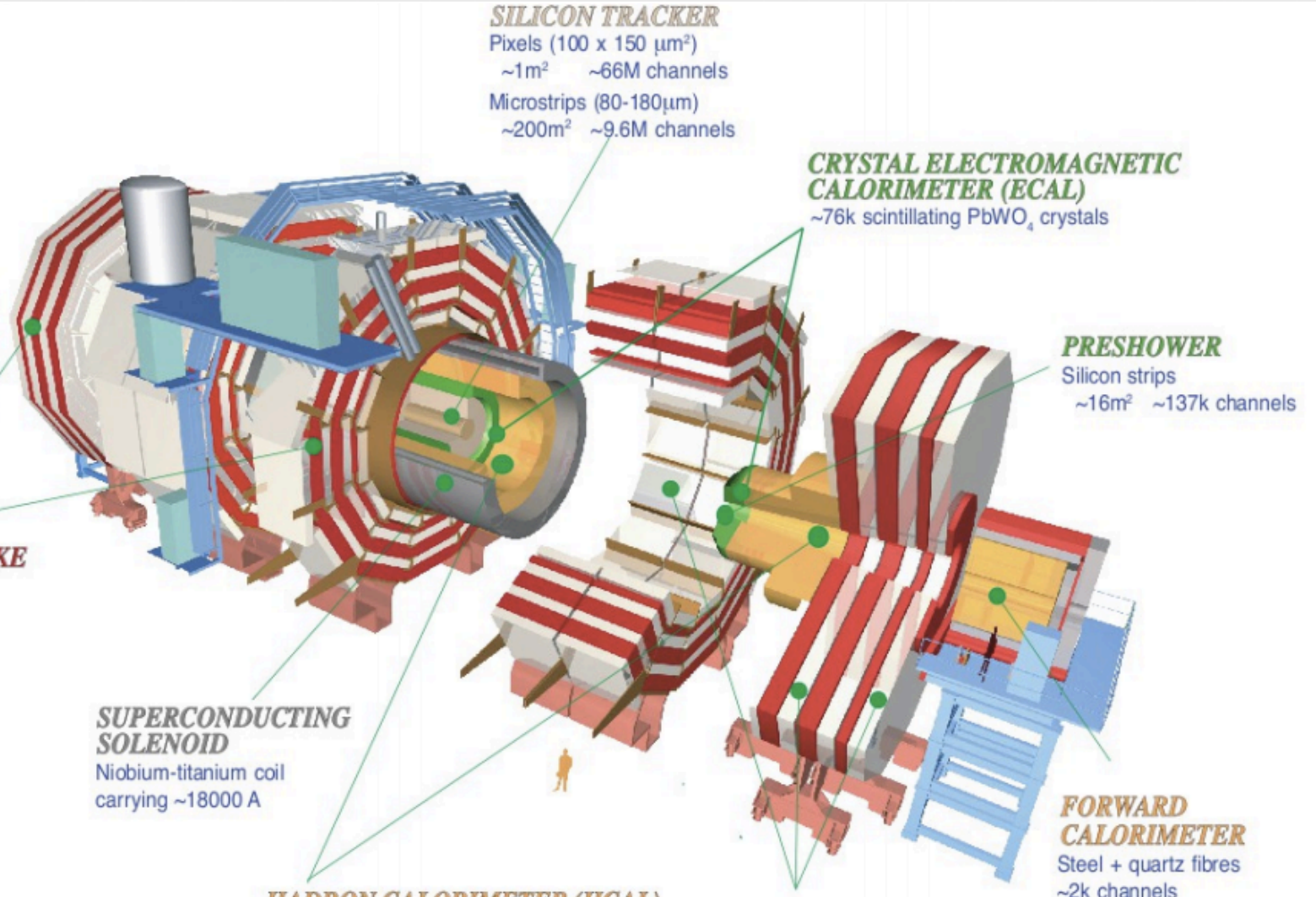
QFTHEP 2013

XXI International Workshop

St. Petersburg, Russia

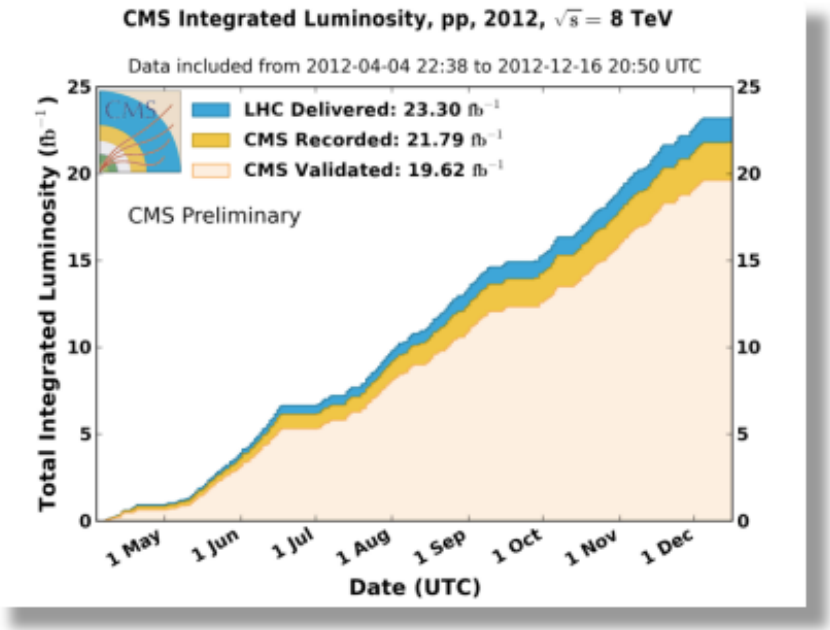
June 26, 2013

CMS Detector

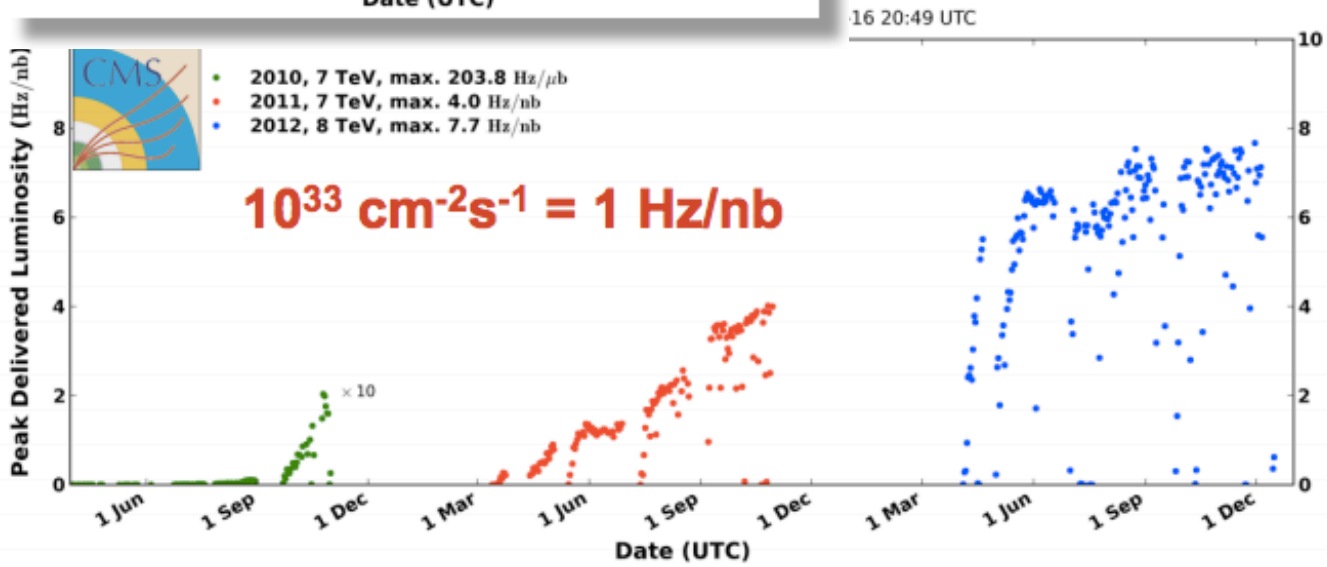


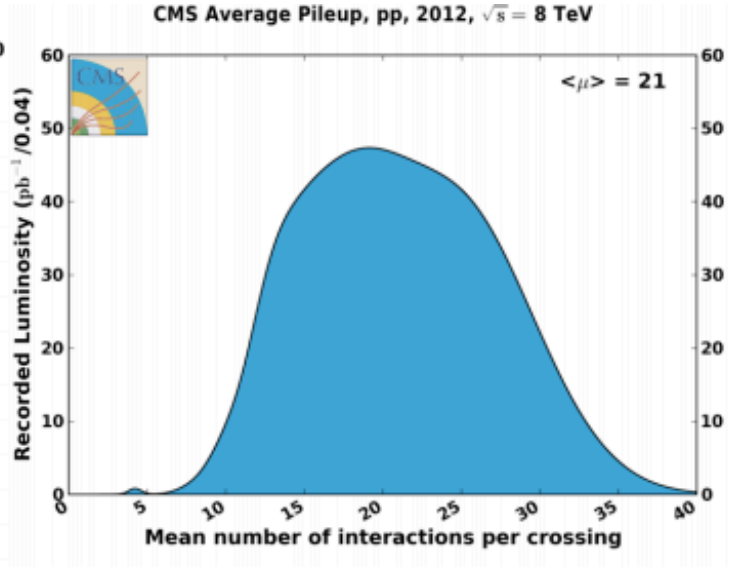
Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

LHC Run 1



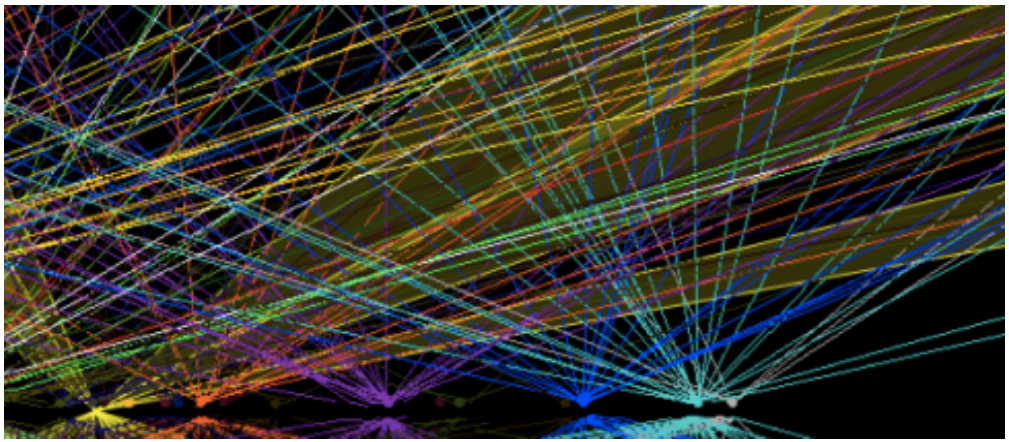
- Total Recorded Luminosity
  - in 2011 ~5 /fb at √s = 7 TeV
  - in 2012 ~22 /fb at √s = 8 TeV
- Excellent detector performance
- Very high data-taking efficiency
  - ~ 95% of delivered data are recorded
  - ~ 95% if those are certified and used for physics



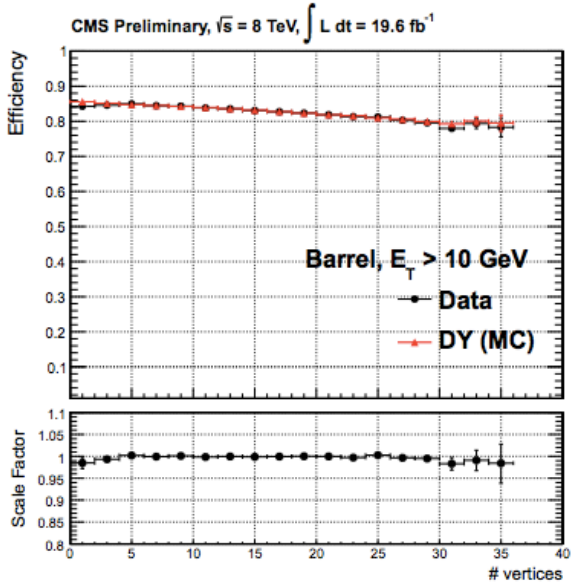


Successful Pileup Mitigation

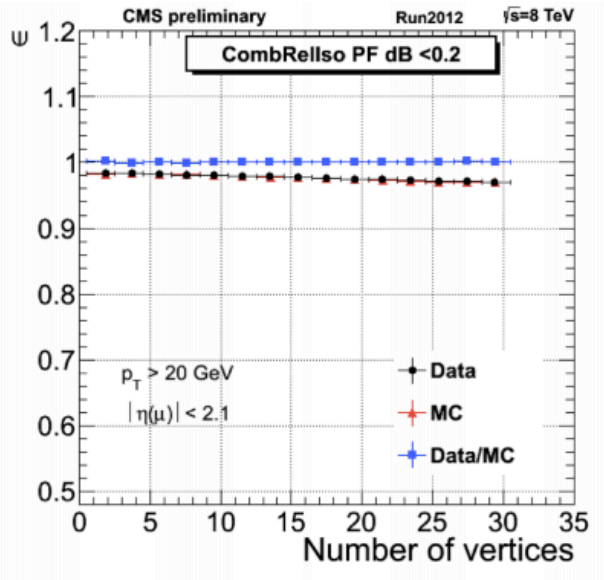
- LHC reached nominal pileup rate of ~ 20 events
- The experiment copes up well !



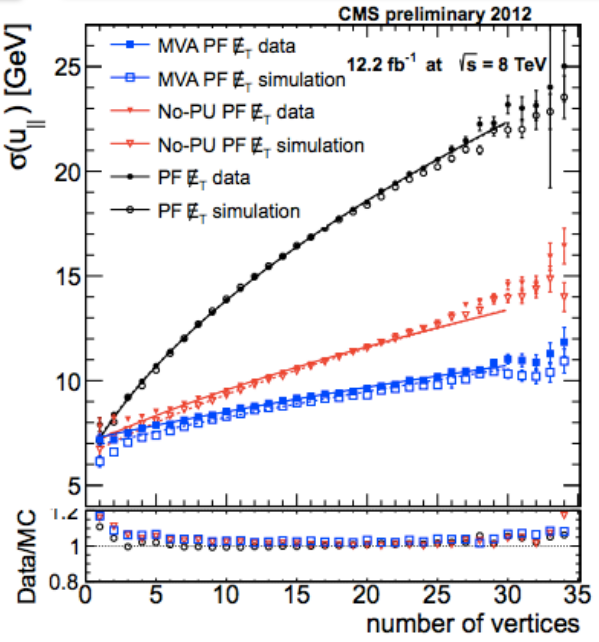
Electron Efficiency



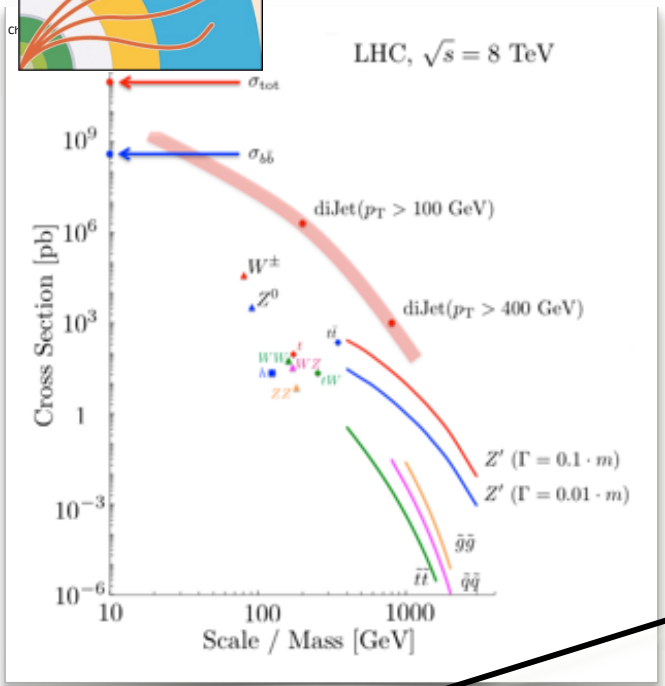
Muon Efficiency

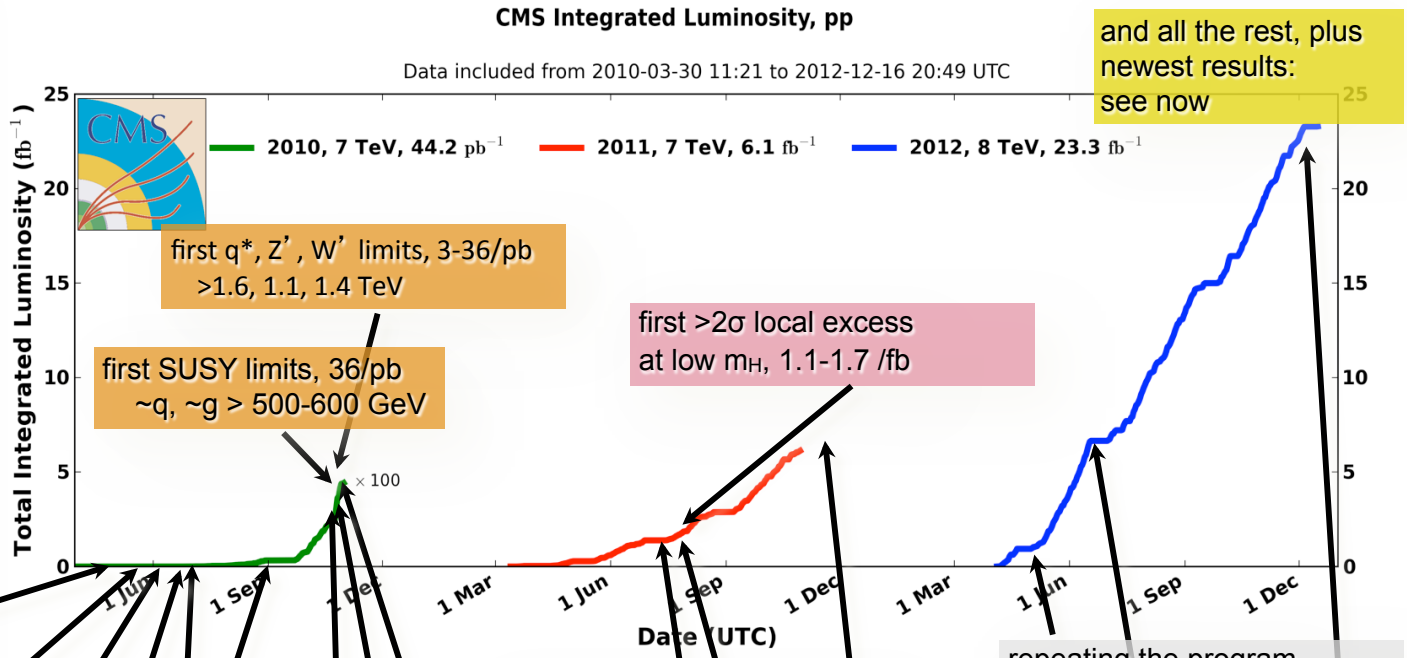


Missing E_T Resolution



Three years of constant physics results





and all the rest, plus newest results: see now

first q*, Z', W' limits, 3-36/pb >1.6, 1.1, 1.4 TeV

first SUSY limits, 36/pb ~q, ~g > 500-600 GeV

first >2σ local excess at low m_H, 1.1-1.7 /fb

repeating the program at 8 TeV

first MinBias / UE studies, particle multiplicities

first top xsec, 3/pb δ ~ 40%

first ZZ xsec, 1.1 /fb δ ~ 40%

going more differential, e.g. Z/W + j,b,c

a new boson is announced, 5 /fb

first incl. b x-section, 8/nb δ ~ 15 %

first single top xsec, t-chan., 36/pb δ ~ 36%

first significant limit on $B_s \to \mu\mu$, BR<1.9x10^{-8}

first incl. jet x-section, PF jets 60/nb δ ~ 20-30%

first m_{top}, 36/pb Δ ~ 6.5 GeV

first particle discovered by CMS: Ξ_b

first incl. W/Z x-sections, 200/nb δ ~ 4-6%, +11% lumi

first WW xsec, 36/pb δ ~ 40% first limit on HWW

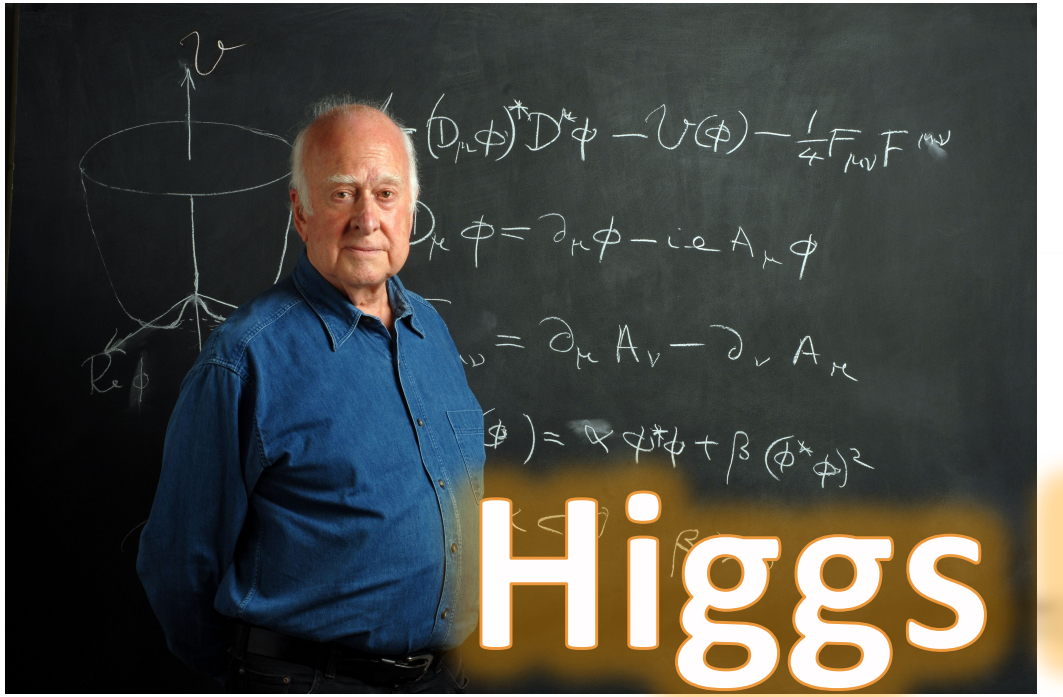
BSM searches continue, limits pushed

first spin parity analysis of the boson, 17 /fb

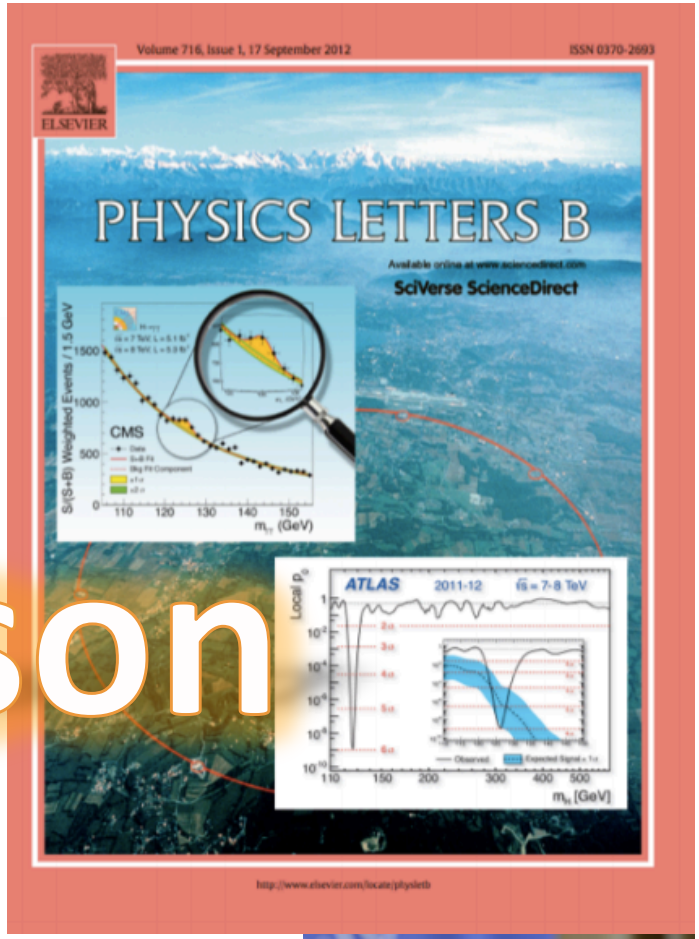
first incl. J/Ψ x-section, 100/nb δ ~ 20%

From G. Dissertori (ETH)

δ .. relative uncert.
Δ .. absolute uncert.



Higgs Boson


Volume 716, Issue 1, 17 September 2012
ISSN 0370-2693
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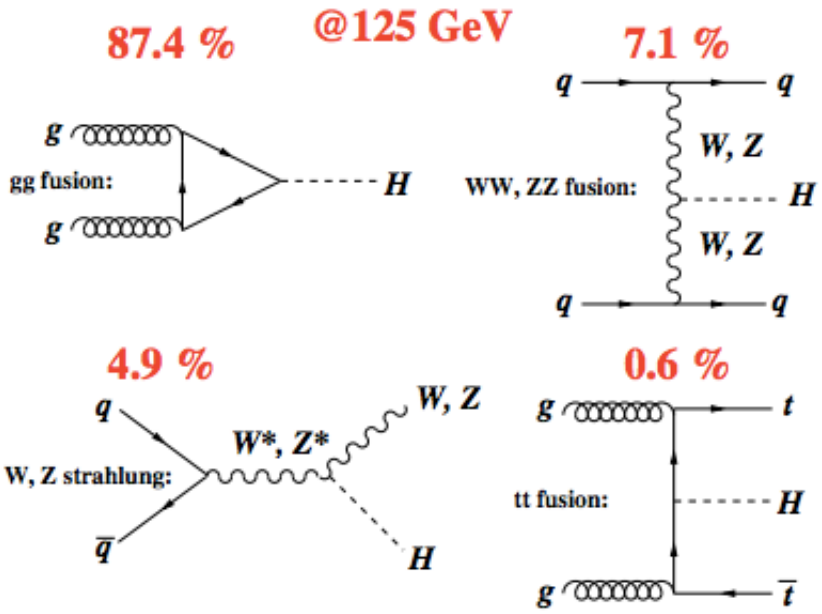
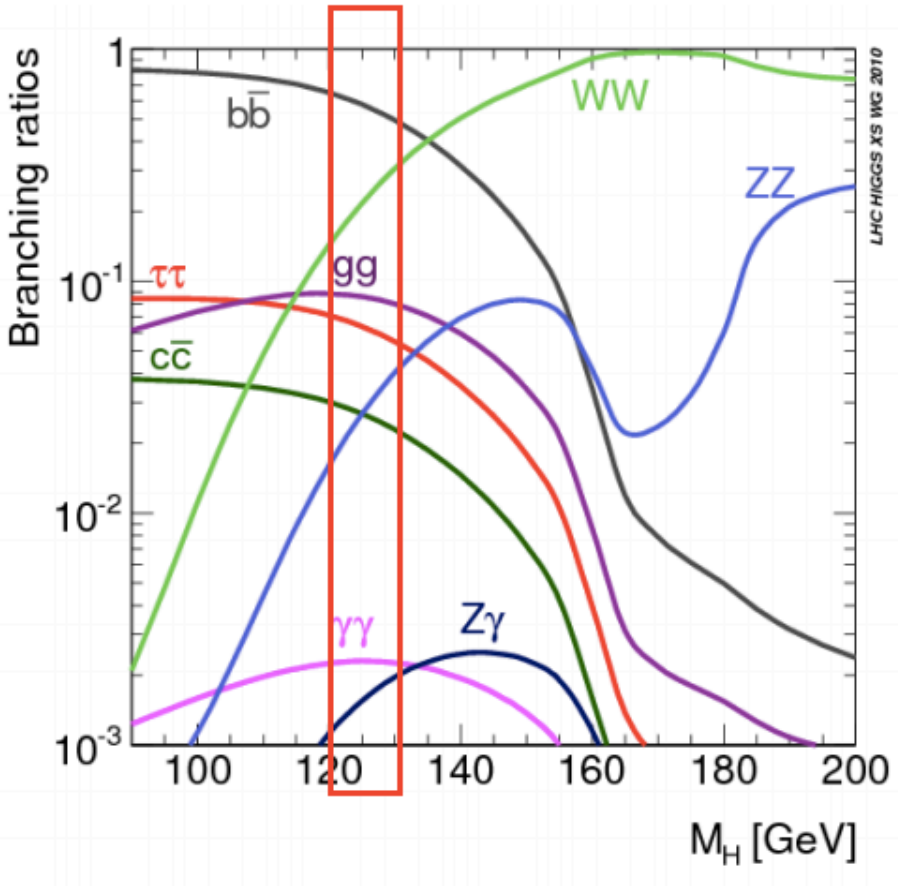
PHYSICS LETTERS B
SciVerse ScienceDirect
CMS
ATLAS
2011-12
$\sqrt{s}$ = 7-8 TeV
m_H [GeV]

Higgs Production and Decay



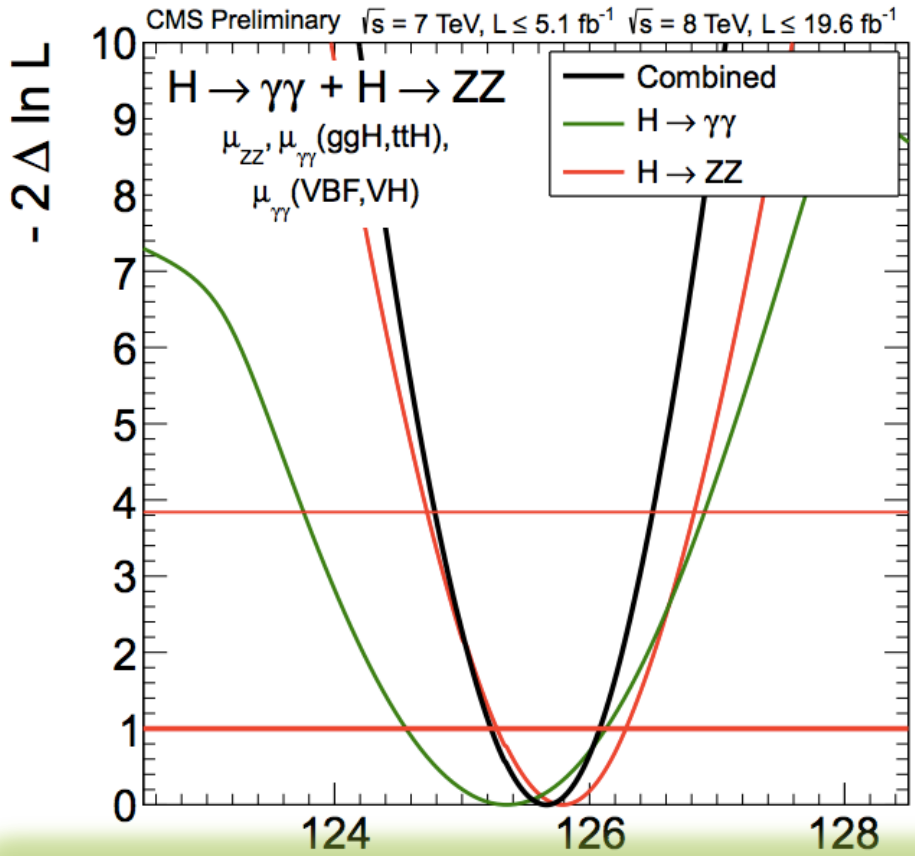
Decay	Exp. Sign. at 125.7 GeV	σ_M/M
H→ γγ	3.9	1-2%
H→ZZ→4l	7.1	1-2%
H→WW→2l2ν	5.3	20%
H→bb	2.2	10%
H→ττ	2.6	10%



- Five decay modes exploited: γγ, ZZ - best resolution, WW, ττ, bb

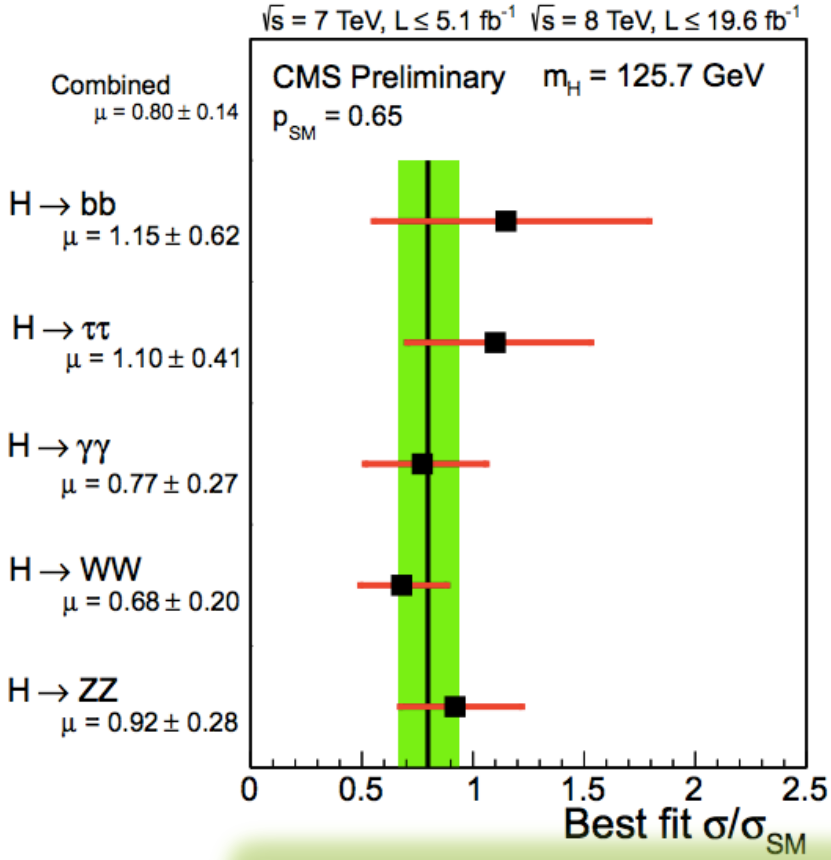
Higgs Combination

- Two best resolution channels: γγ, ZZ for mass measurement



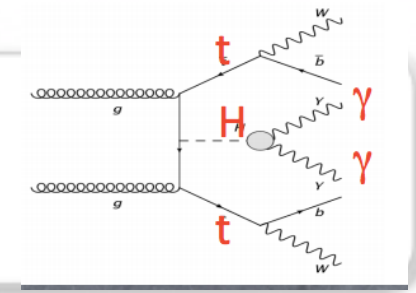
m_H = 125.7 ± 0.3(stat) ± 0.3(syst) GeV

- Consistent event yields in different production and decay modes

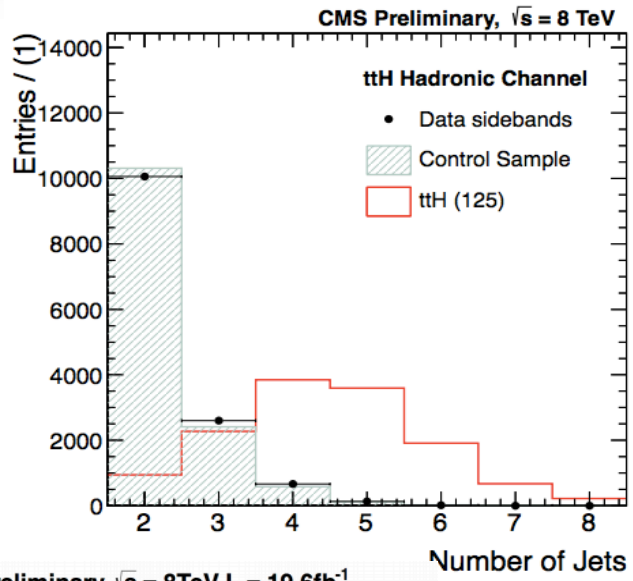


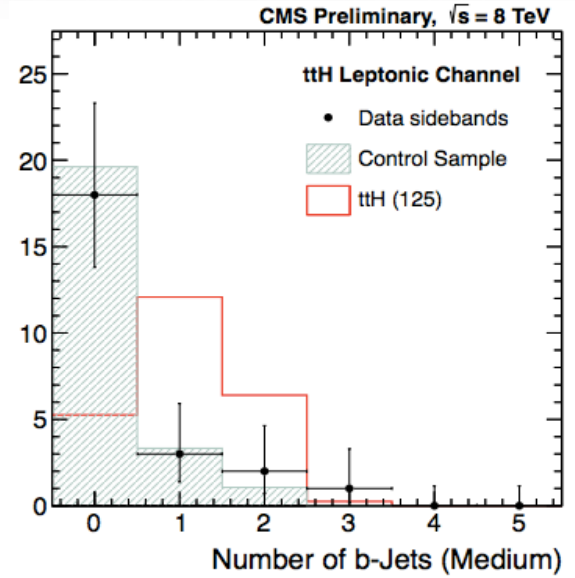
σ/σ_{SM} = 0.80 ± 0.14

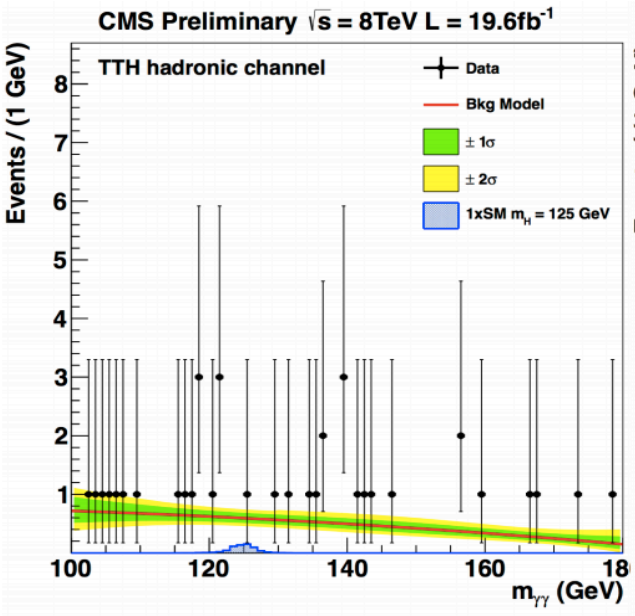
Search for ttH, H →γγ

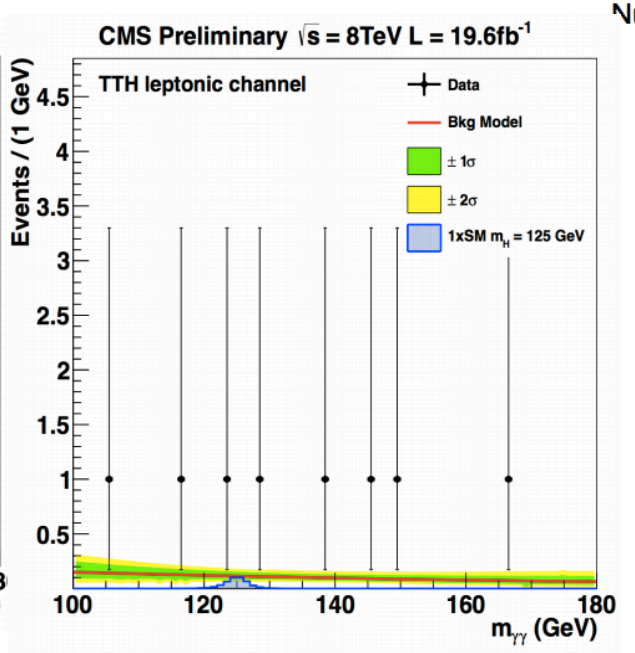


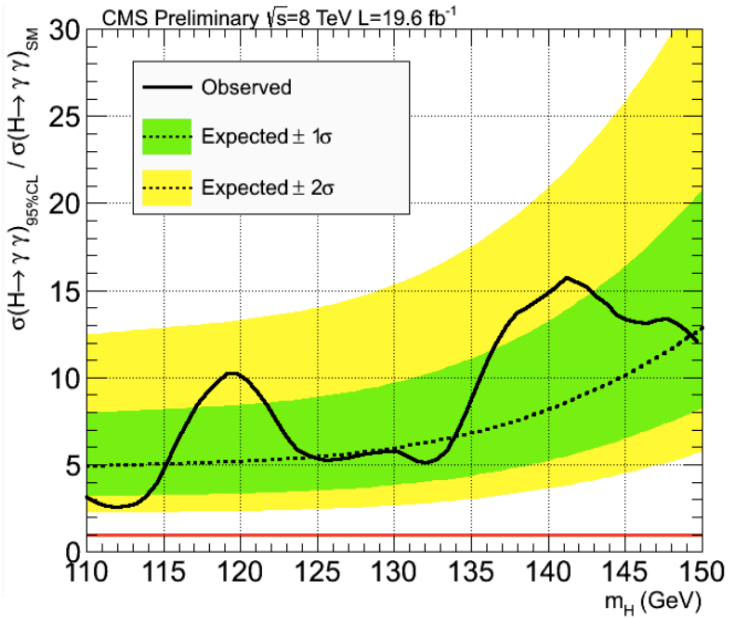
- Separately optimize for all-hadronic and semi-leptonic top decays
- Sensitivity at 5.4 (5.3 expected) x SM



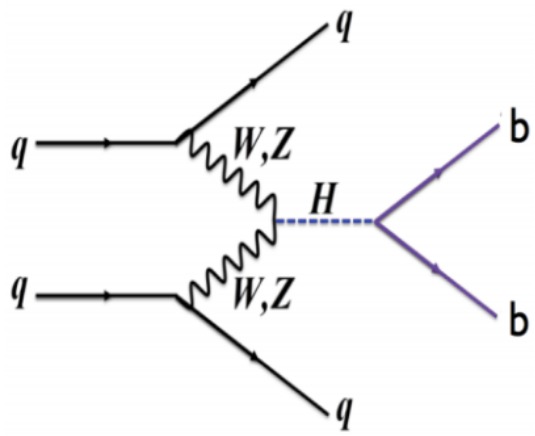




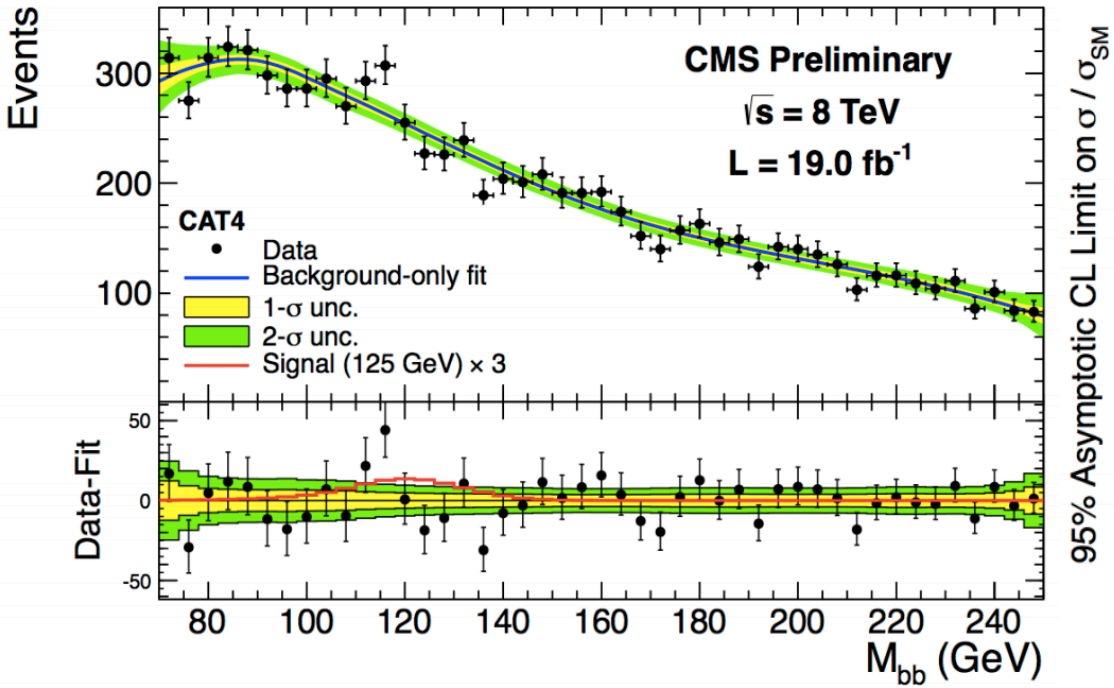


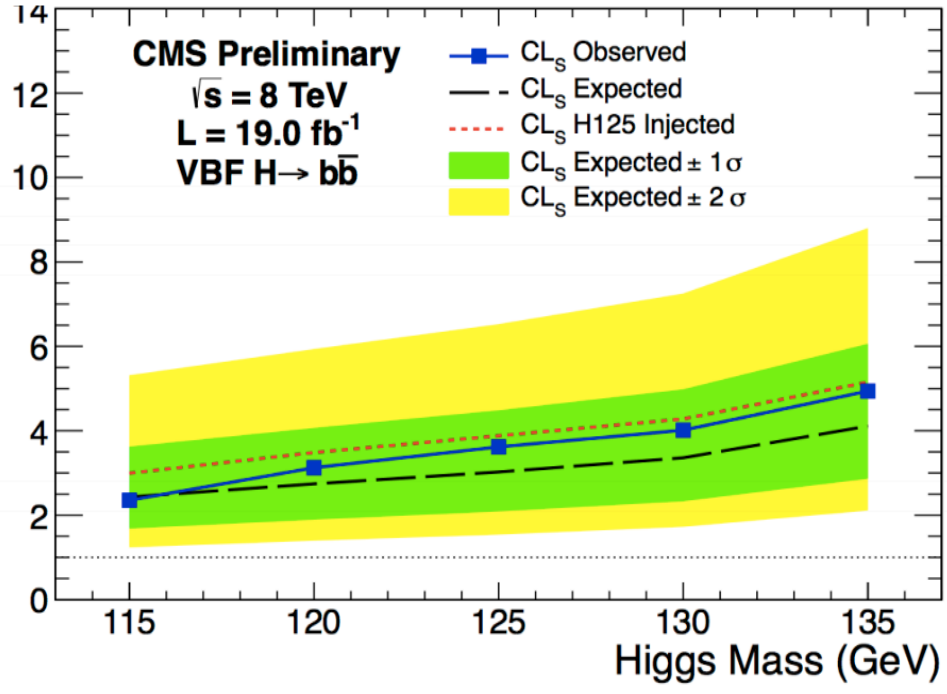


Vector Boson Fusion with H → bb



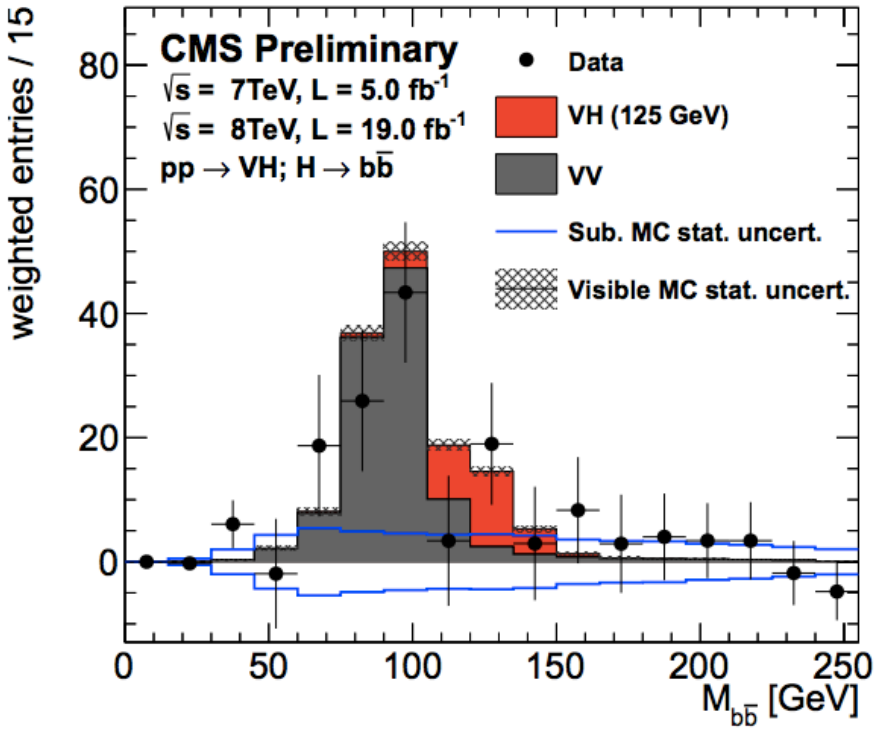
- Full-hadronic final state, main background is QCD
- Employ NN to separate gluons from quark jets, and signal kinematics from background
- Use mass of di-bjet to separate a signal from residual background
- Observed limit at 3.6 (3.0 expected) x SM

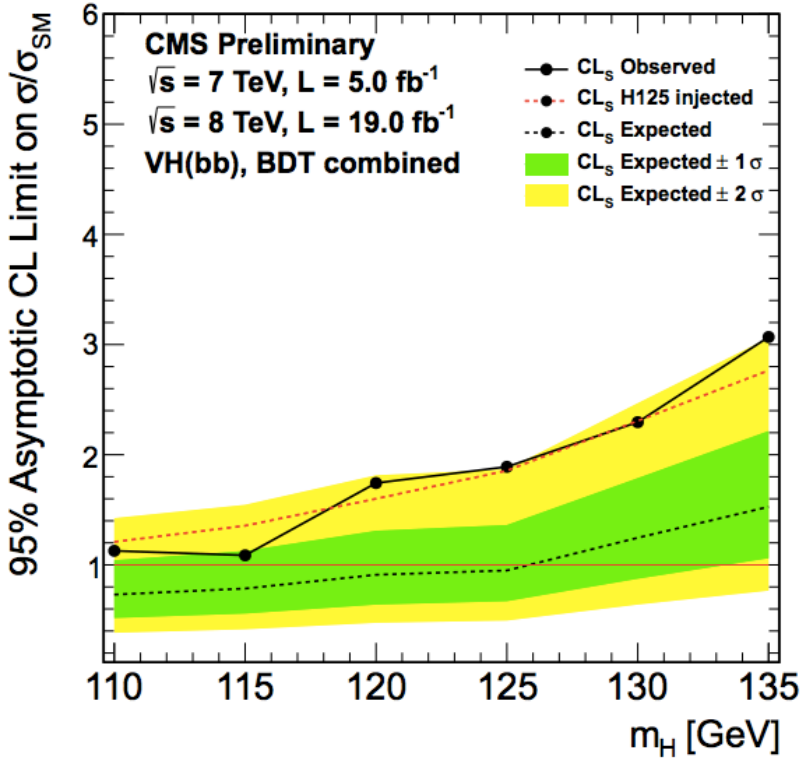




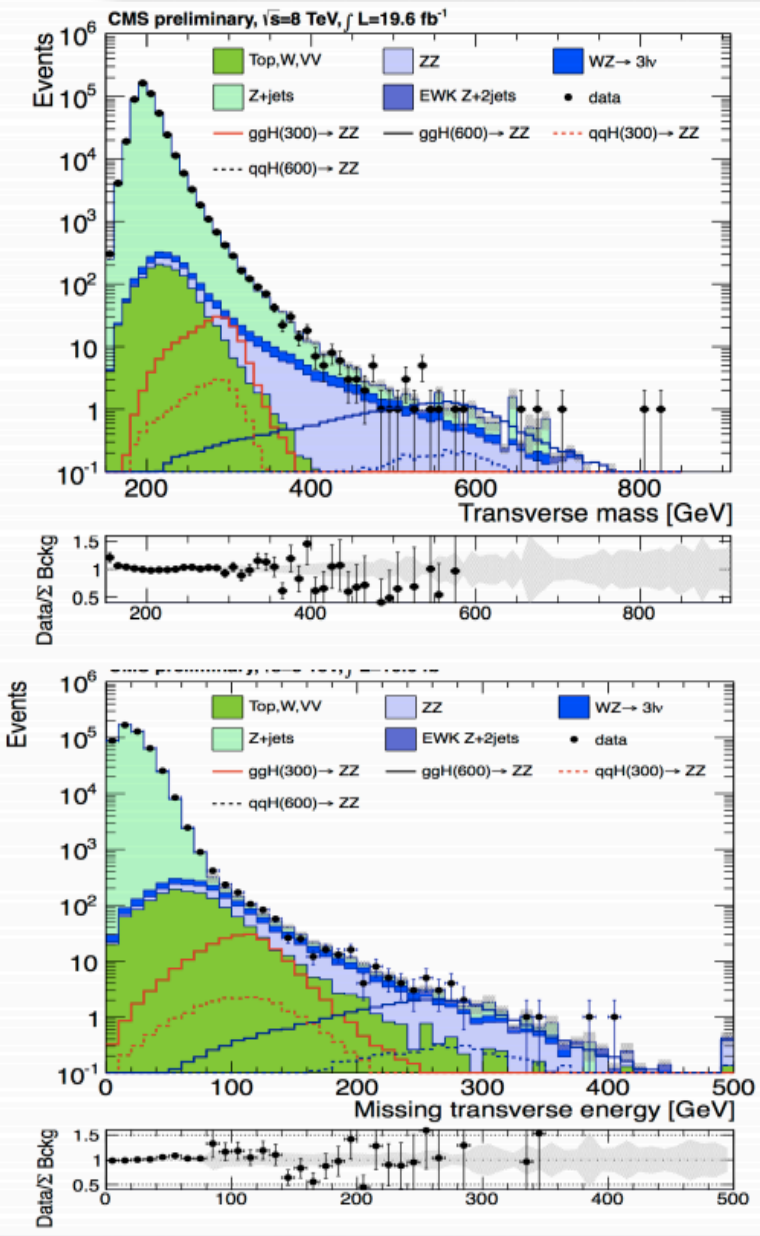
Search for H →bb in VH

- Employ the recoil from V(W,Z) boson, boosted regime
- Consider W->$\ell\nu$, Z->$\ell\ell$, Z->$\nu\nu$
- Trigger on lepton or missing E_T
- Use jets, V-kinematics and b-tagging in BDT
- Di-bjet invariant mass (9% resolution) to characterize the signal
- Observe 2.1 σ excess compatible with the SM Higgs

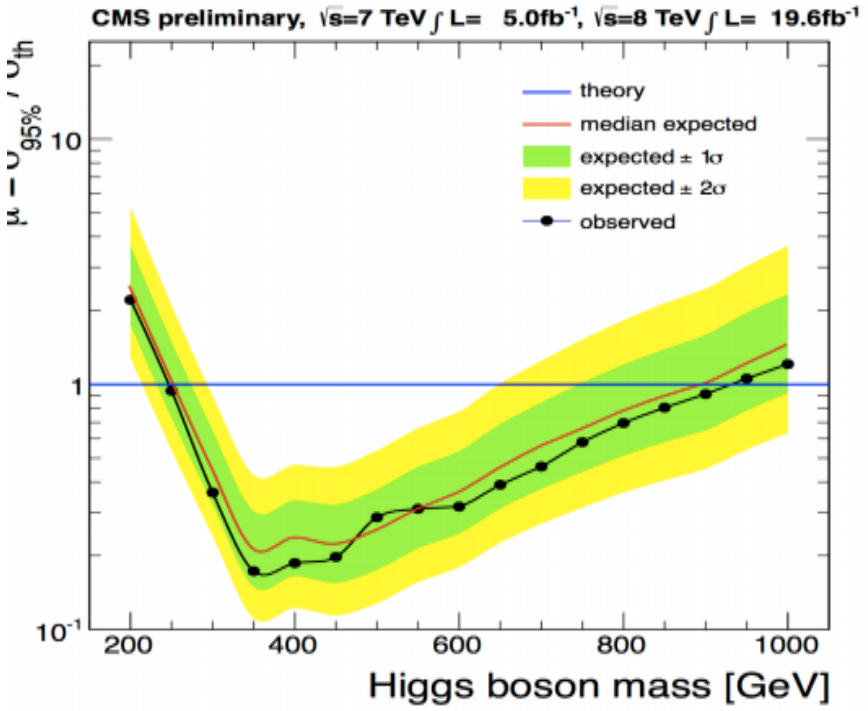




Search for H → ZZ → $\ell\ell\nu\nu$



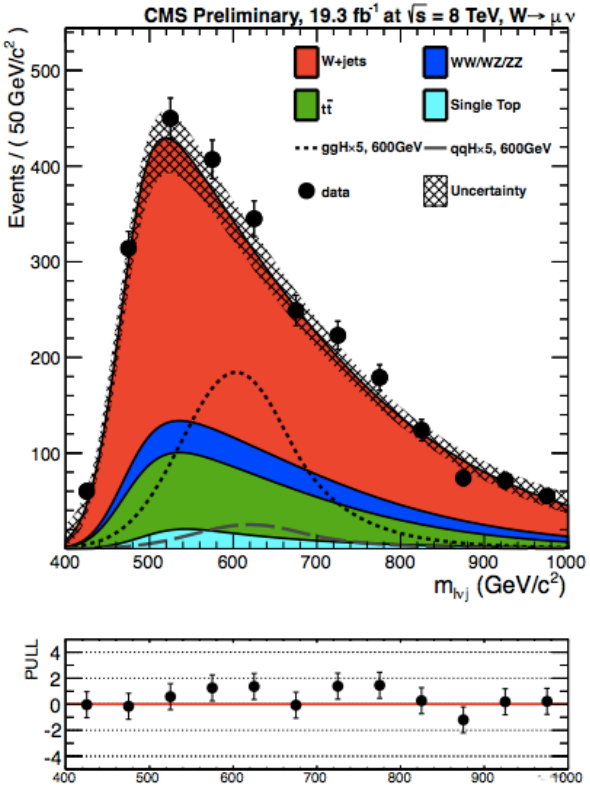
- Search for high mass Higgs
- 2 opposite-charge same-flavor leptons (ee, μμ), 2ν
- B-tag veto to suppress the top background
- Separately optimized for vector boson and gluon fusion production processes

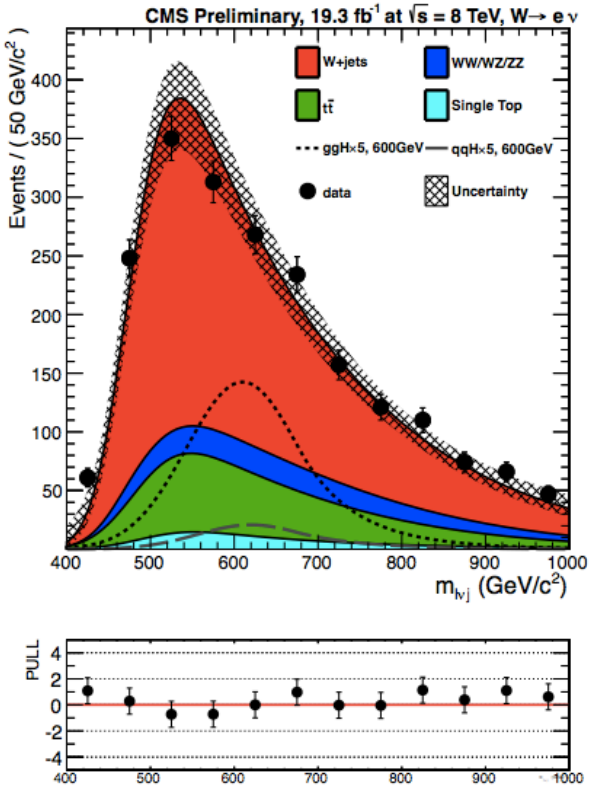


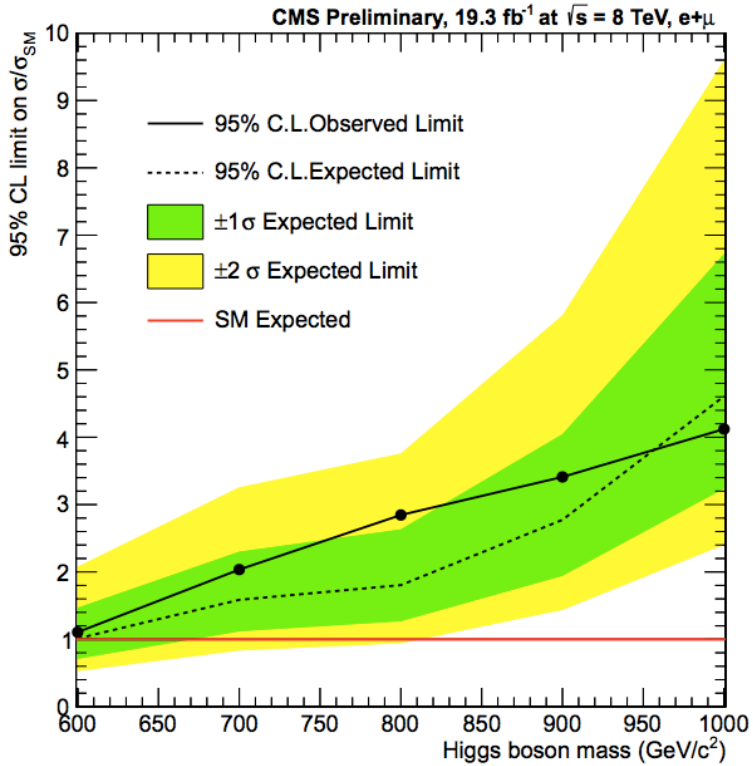
Search for H → WW → $\ell\nu$qq

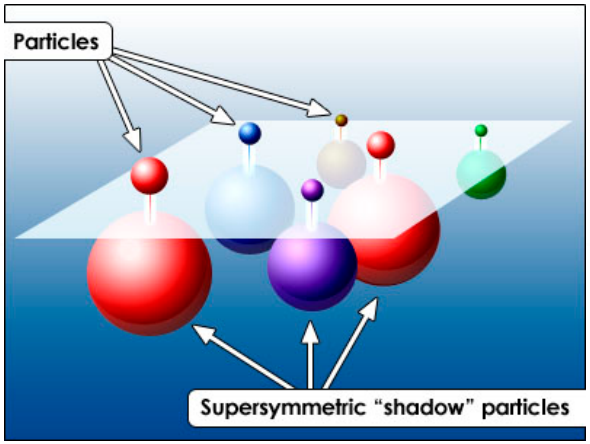
- Search for high mass Higgs with a boosted hadronic W boson
- Employ jet substructure techniques to identify hadronic W
- Fit to the three-body $m_{\ell\nu J}$ distribution
- Extract the main W+jets background shape from side-band region

m_J=[40,65] GeV

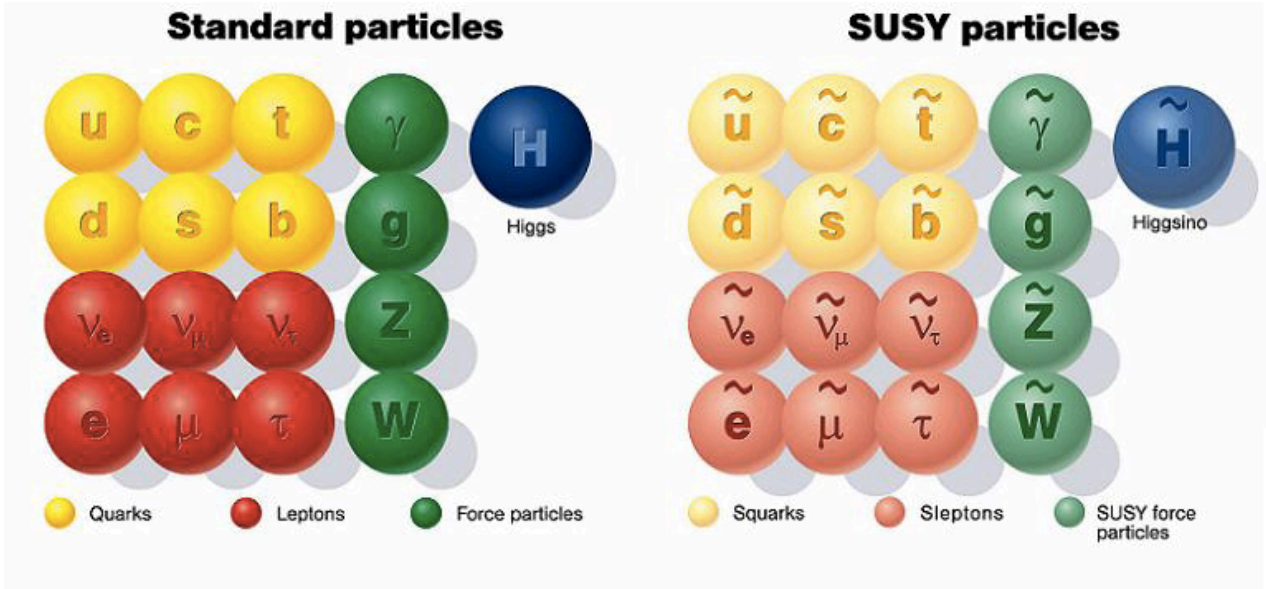


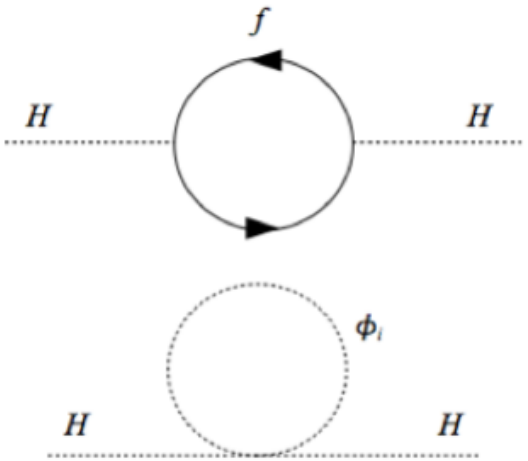






SUSY





$$\Delta M_H^2 \sim \frac{\lambda_f^2}{4\pi^2}[(m_f^2 - m_S^2)\log(\frac{\Lambda}{m_S})]$$

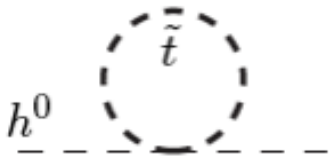
Is the weak scale natural ?

[arXiv:1110.6926]

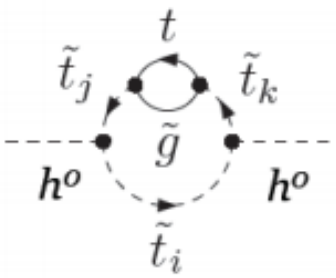
tree level

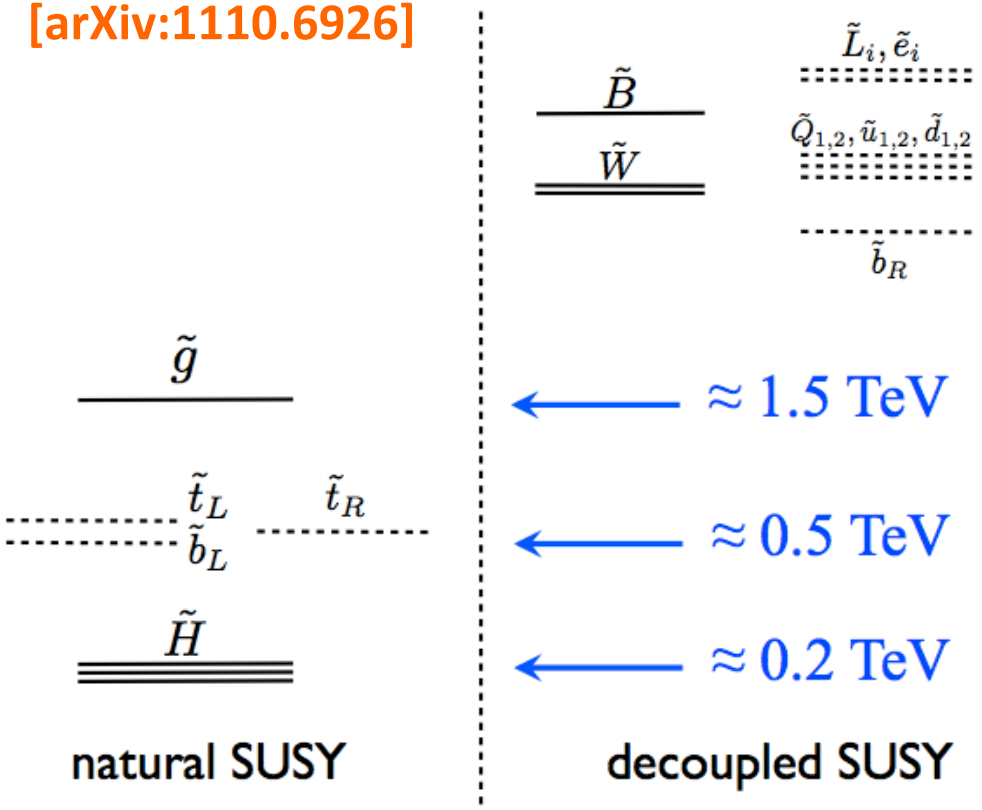
$$-\frac{m_Z^2}{2} = |\mu|^2 + m_{H_u}^2$$

1-loop



2-loop

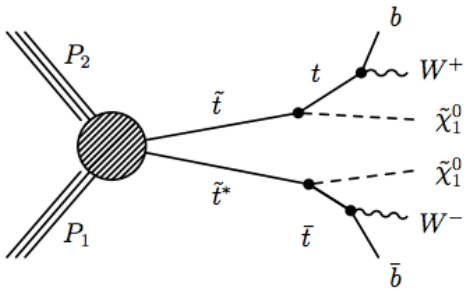




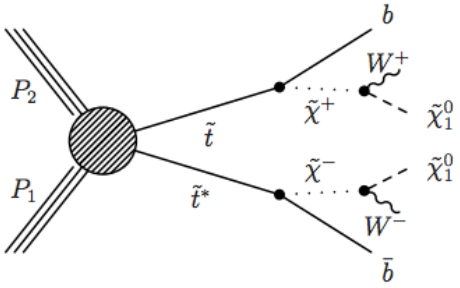
- 1st and 2nd generation squarks, bino/wino, sleptons can be heavy without compromising naturalness

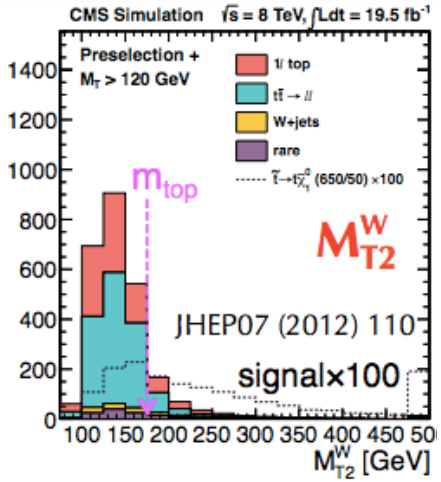
Search for Direct Stop Quark Production

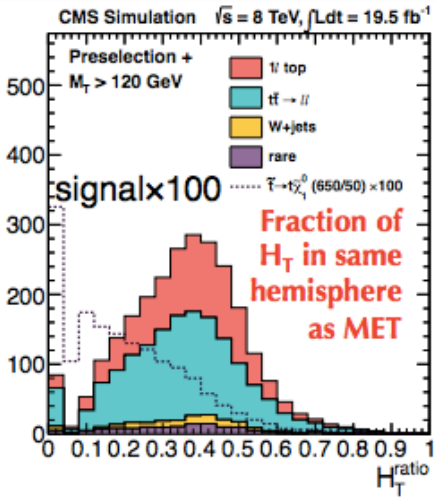
$\tilde{t}\bar{\tilde{t}} \to t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0$

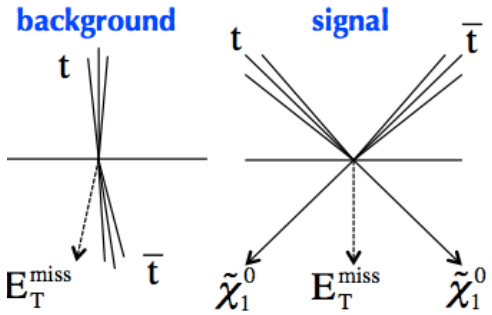


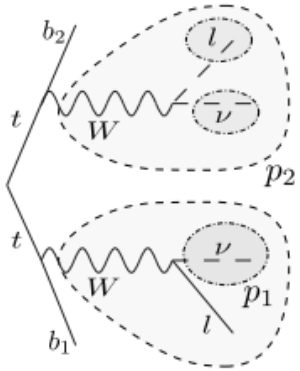
$\tilde{t}\bar{\tilde{t}} \to b\bar{b}\tilde{\chi}_1^+\tilde{\chi}_1^- \to b\bar{b}W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$

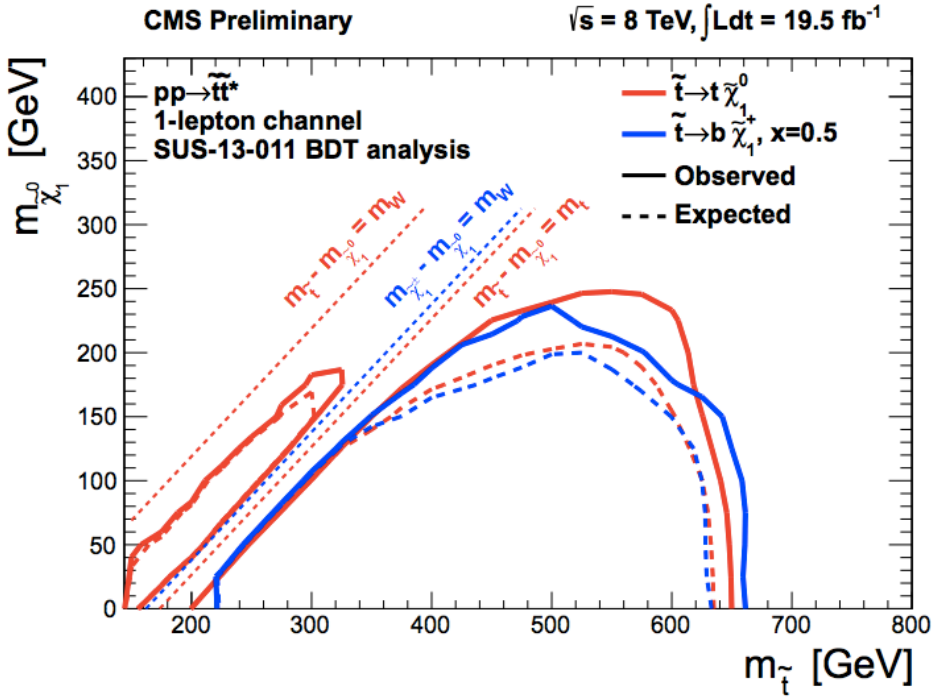








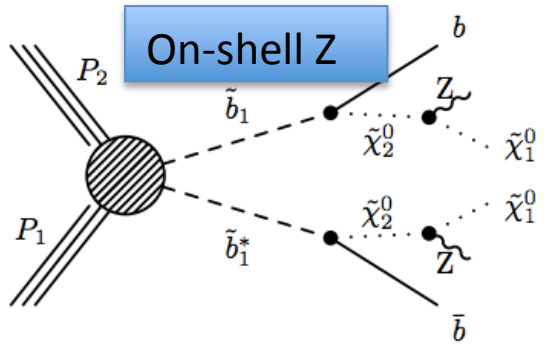


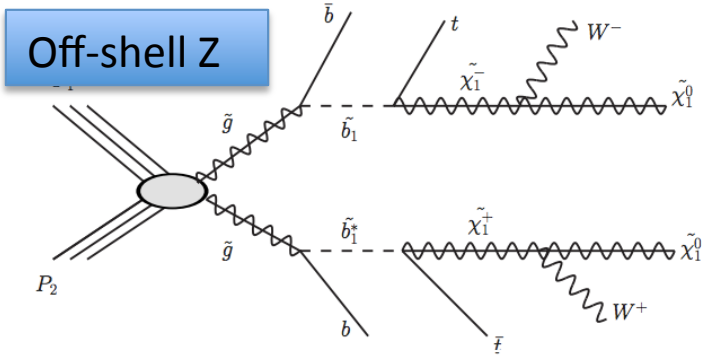


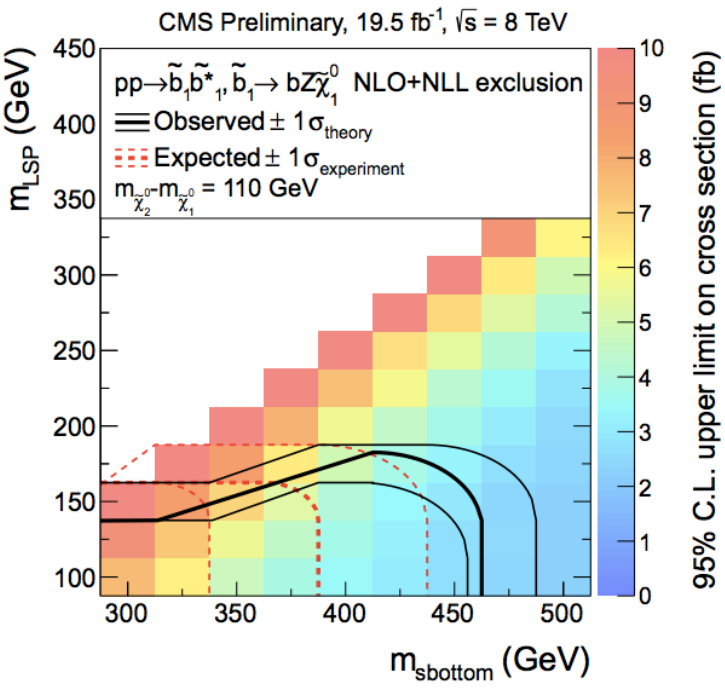
- Single-lepton channel
- Main background is semi-leptonic and dilepton top
- Employ stransverse mass and other clever variables to reduce background
- Combine them into BDT

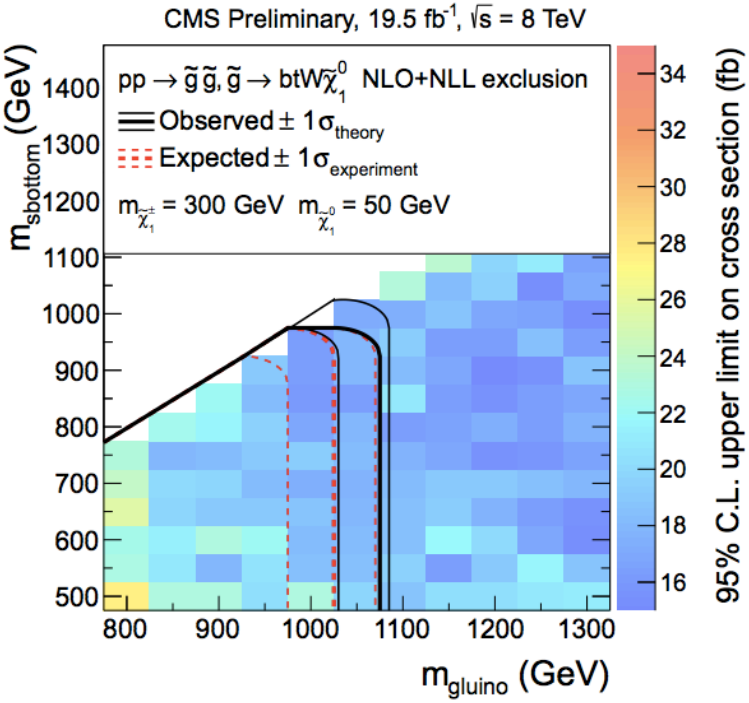
Search for Direct and Gluino-Mediated Sbottom Production

- Search in tri-lepton + >=1 b final state
- Clean signature, low background
- Simultaneous event counting in several regions
- Categorize events based on presence of Z, N jets and b-tags



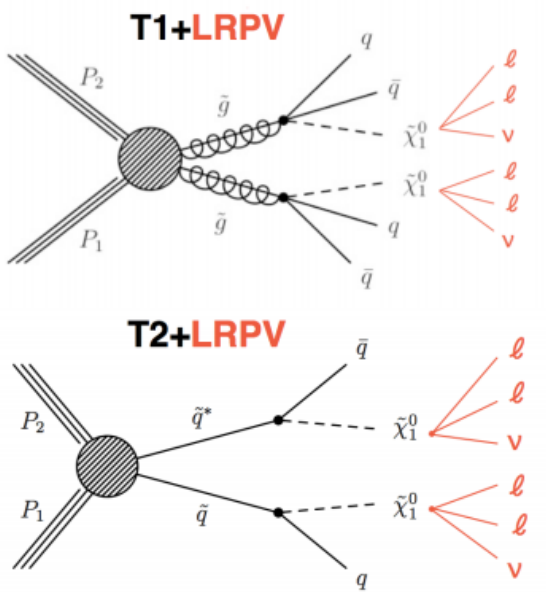




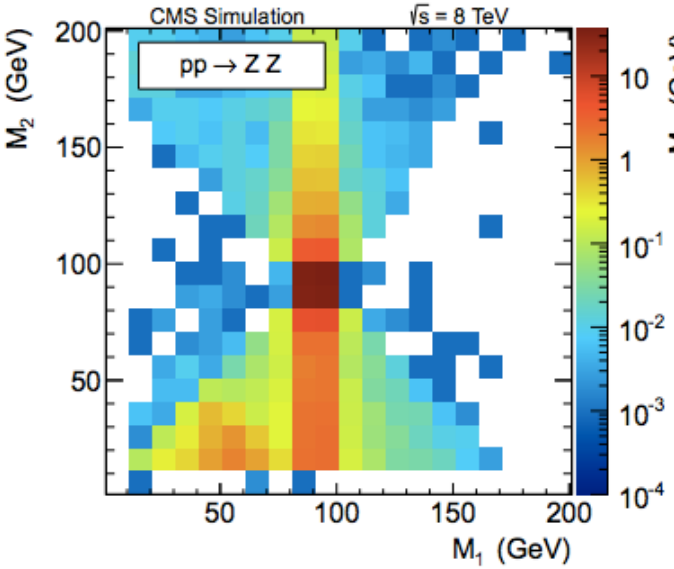


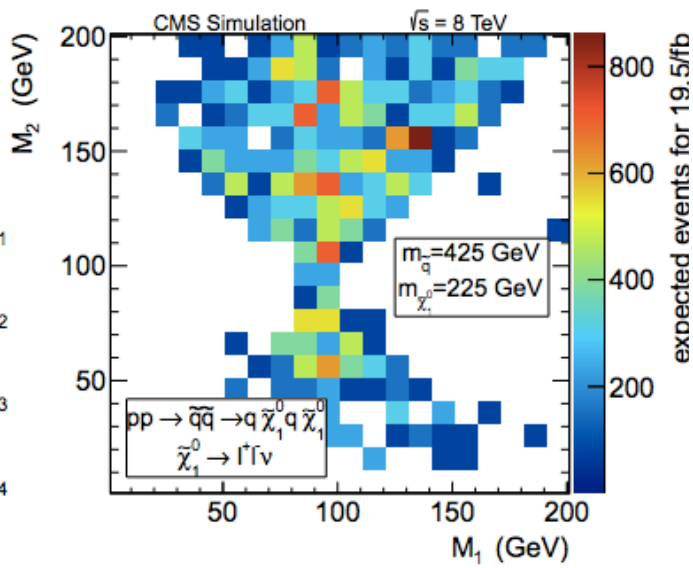
Search for R-Parity Violating SUSY

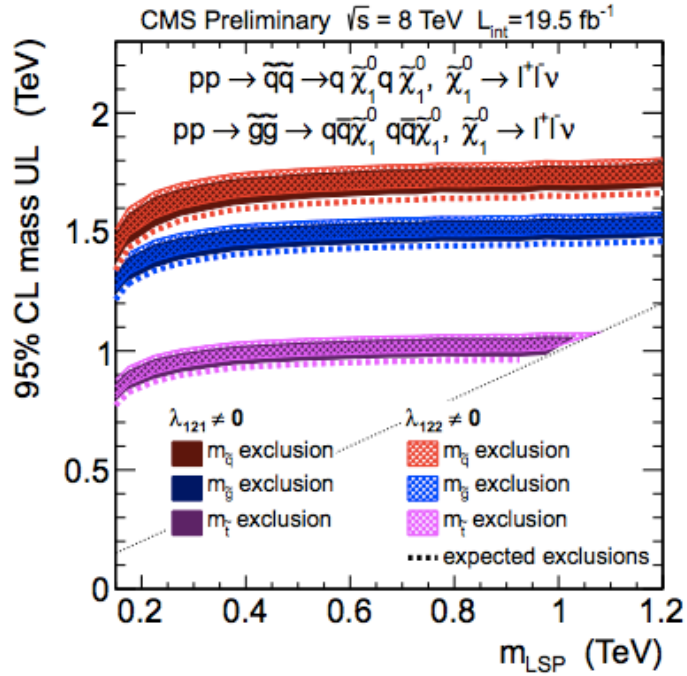
$\tilde{\chi}_1^0\tilde{\chi}_1^0 \to 4l$



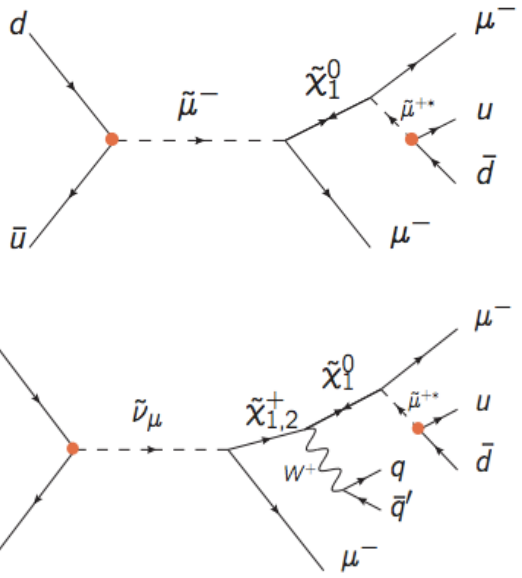
- Search in four-lepton final state
- Define 9 signal regions in M_2 vs M_1 plane
- M_1 – mass of opposite-charge, same-flavor dilepton pair around M_Z
- M_2 – mass of the other lepton pair
- Suppress ZZ background





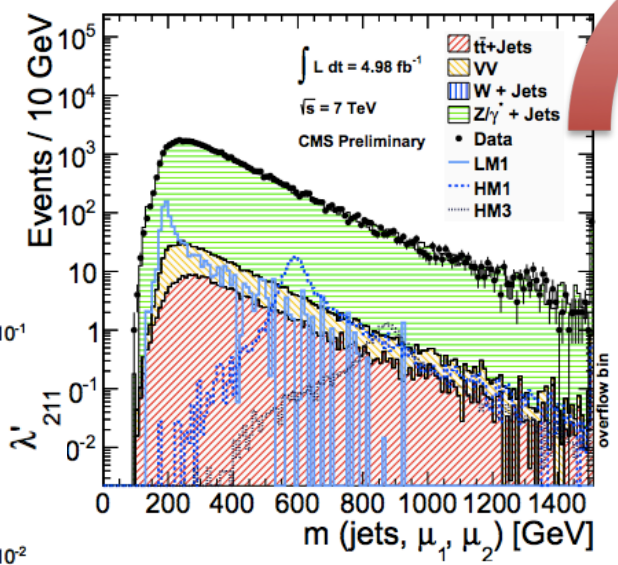


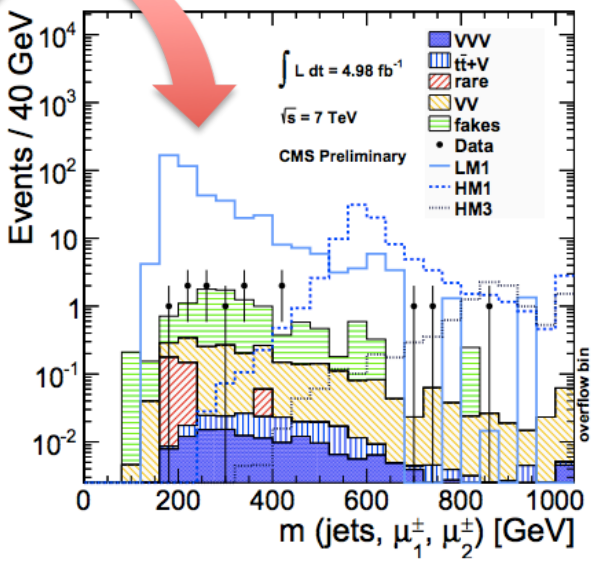
Search for Resonant Smuon Production

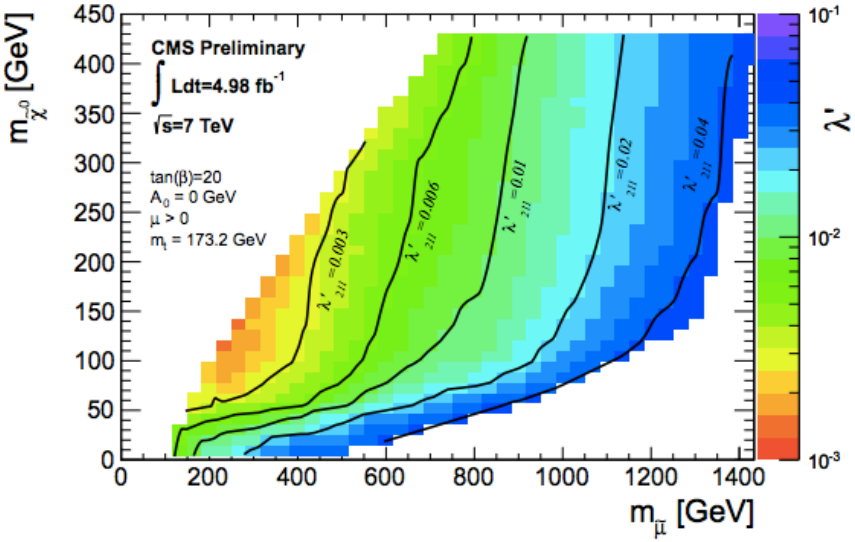


- Signature : like-sign μμ + 2 jets, b-tag veto
- Normalize DY to OS di-muon events

LS + b-tag veto



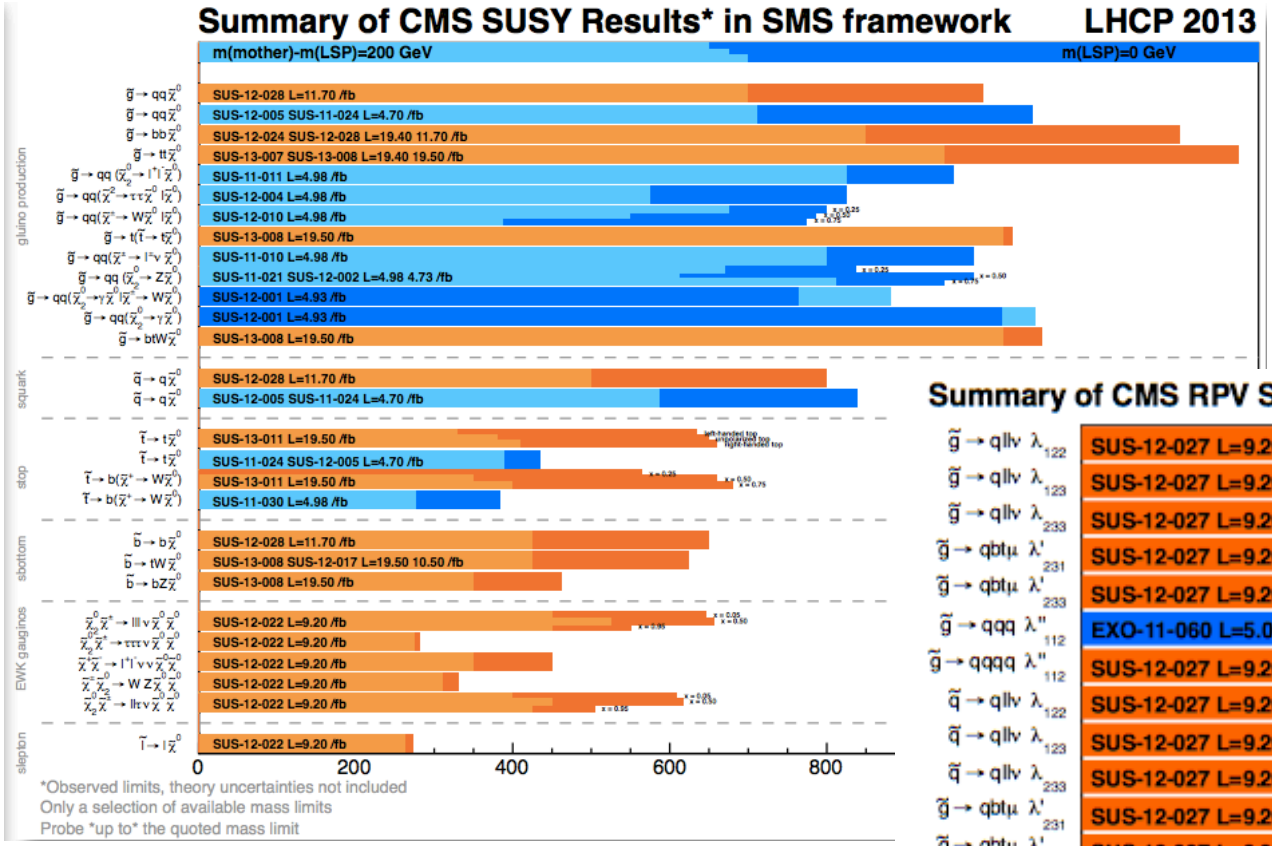




- 13 events observed, 10.7 expected

Summary of SUSY Results

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

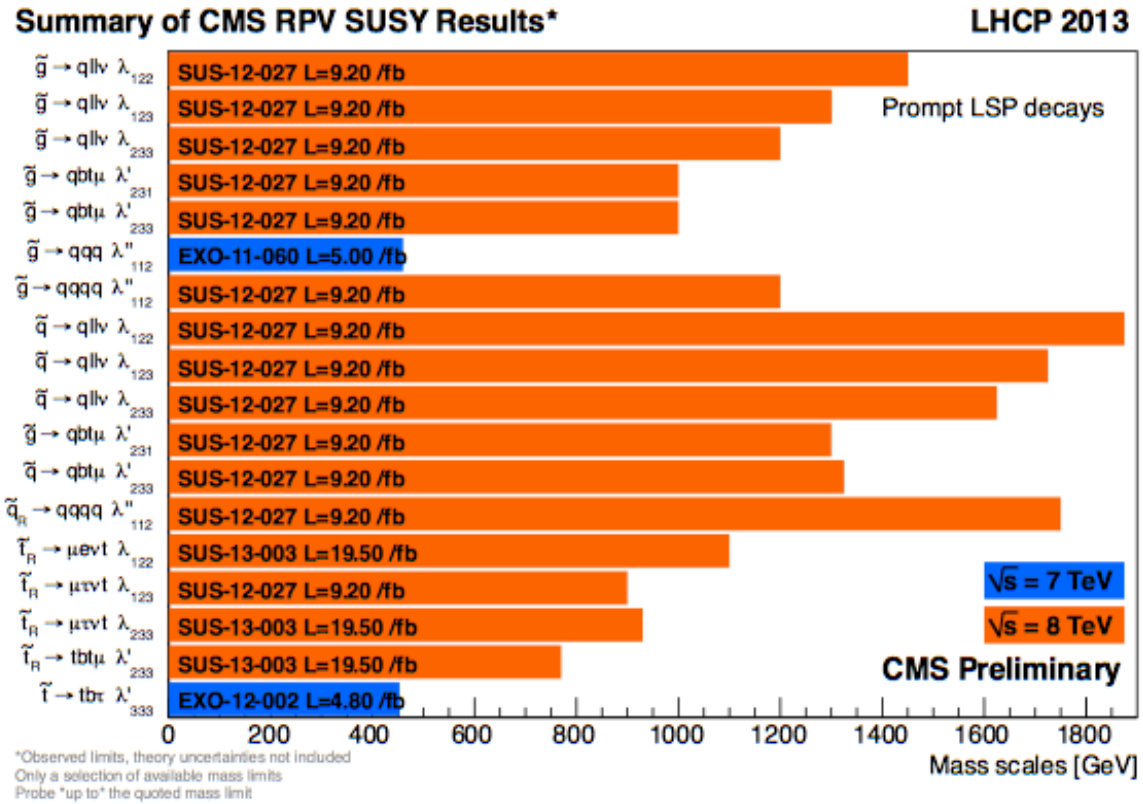


√s = 7 TeV

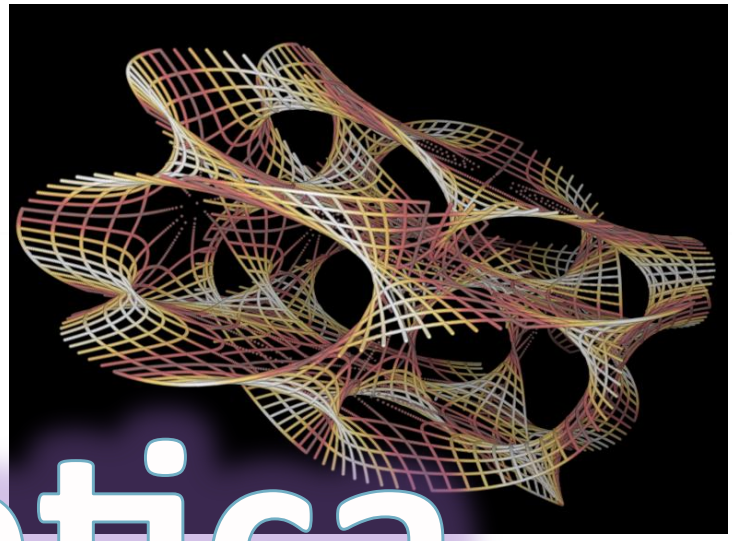
√s = 8 TeV

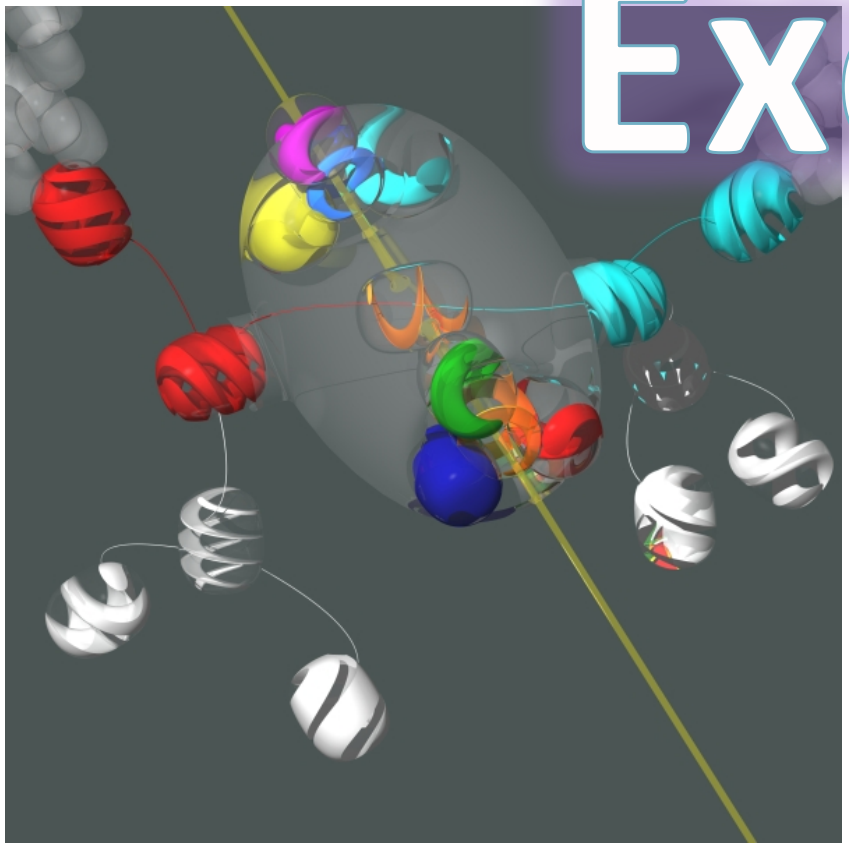
CMS Preliminary

For decays with intermediate mass,
$m_{intermediate} = x \cdot m_{mother} + (1-x) \cdot m_{lsp}$



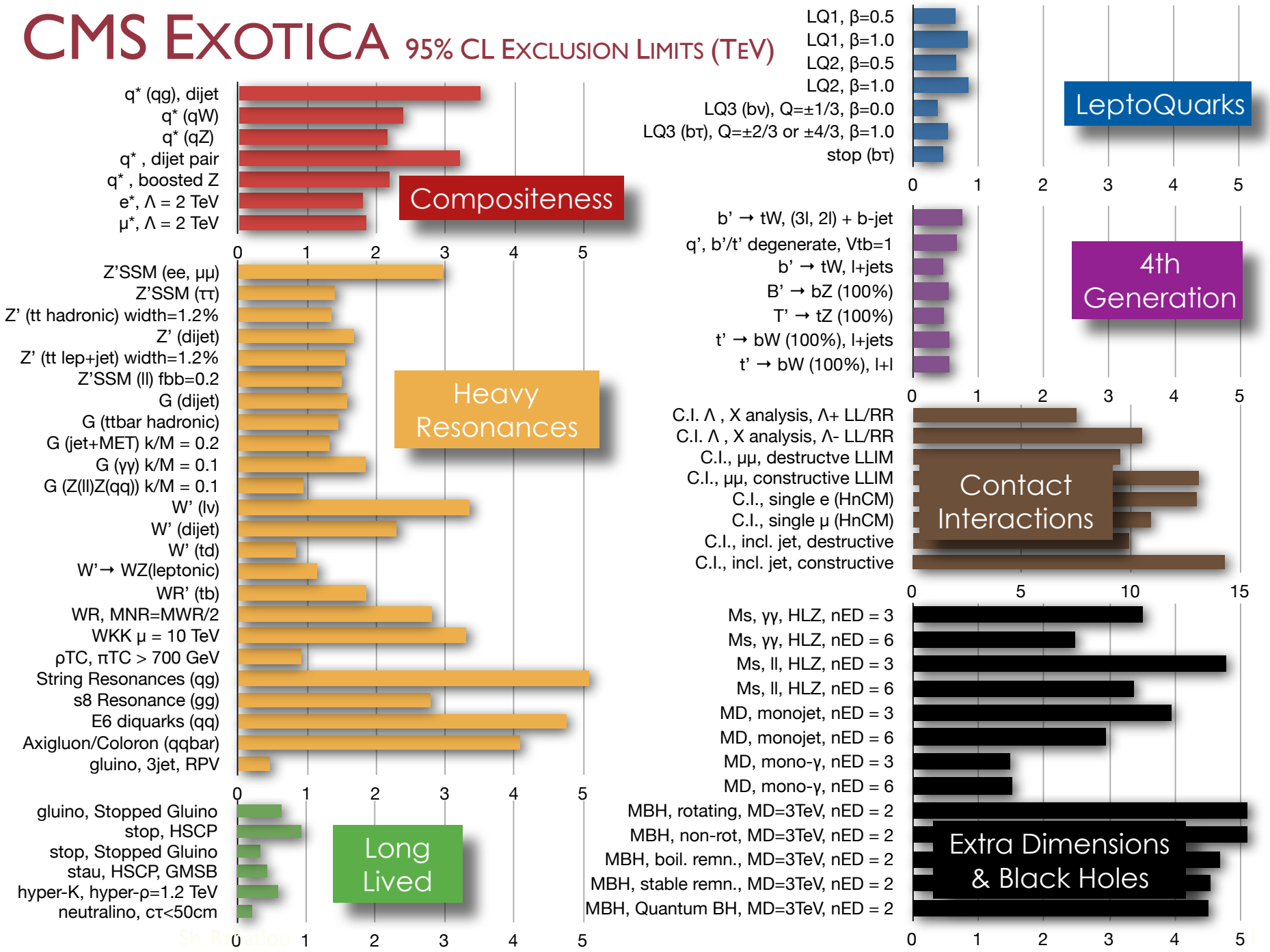
Exotica





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

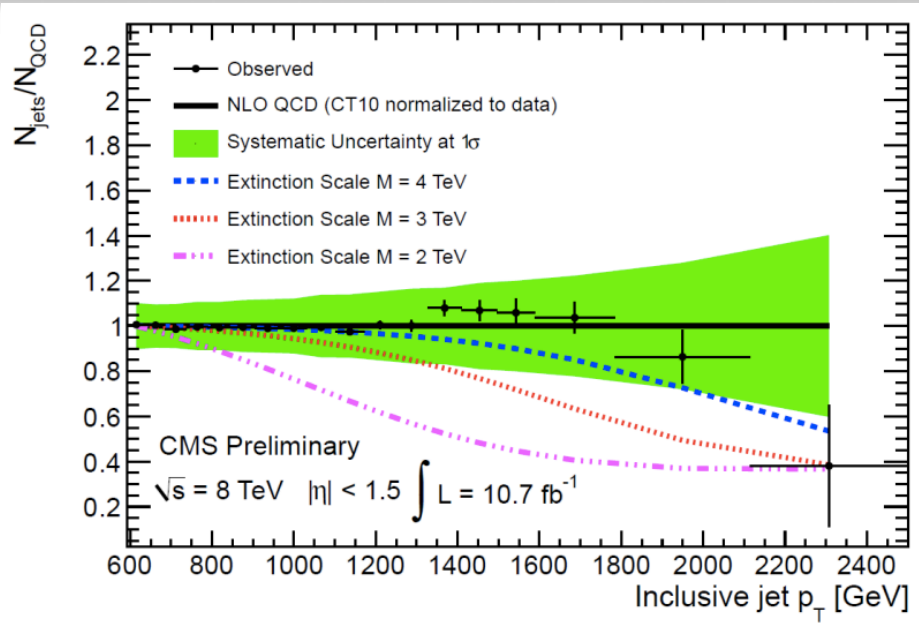
CMS EXOTICA 95% CL EXCLUSION LIMITS (TEV)

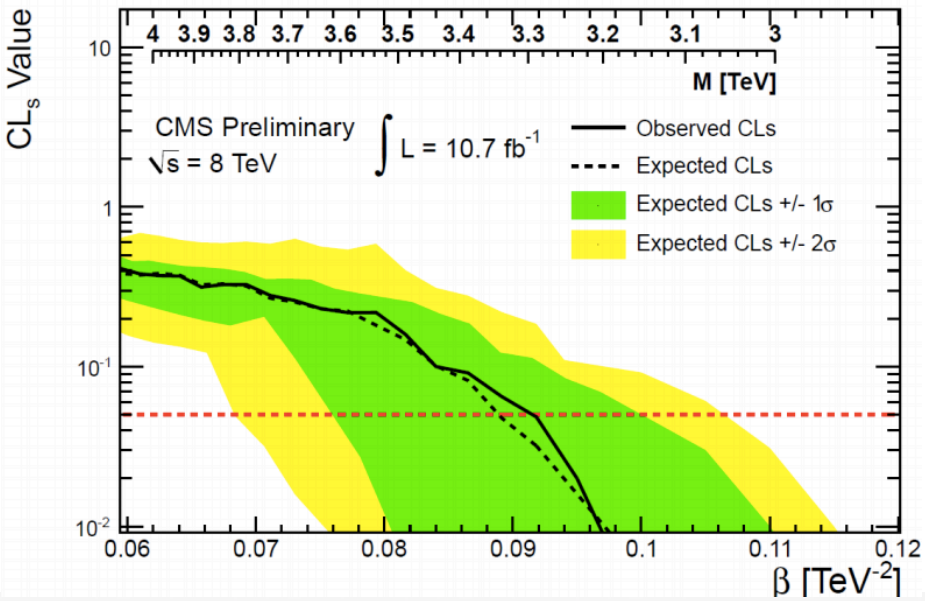


Search for Jet Extinction

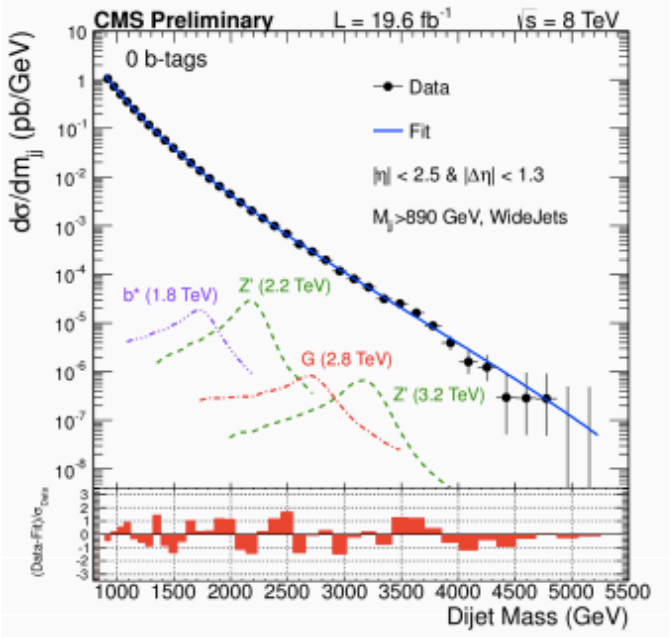
- Search for signatures of the terascale gravity
- The string model predicts suppression of all high transverse momentum SM processes beyond a certain energy scale
- Motivated by [arXiv:1207.3525]
- Look for extinction of inclusive jet production
- Use central jets with

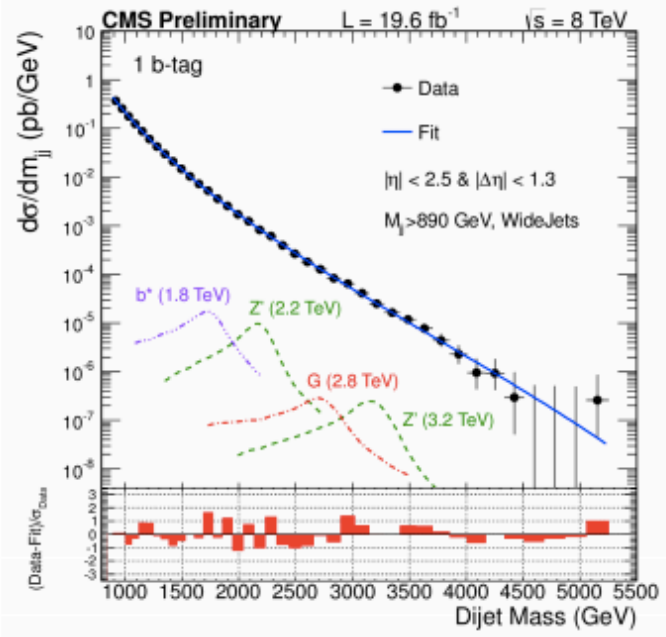
  $p_T > 592$ GeV, $|\eta| < 1.5$
- Exclude the extinction energy scale < 3.3 TeV

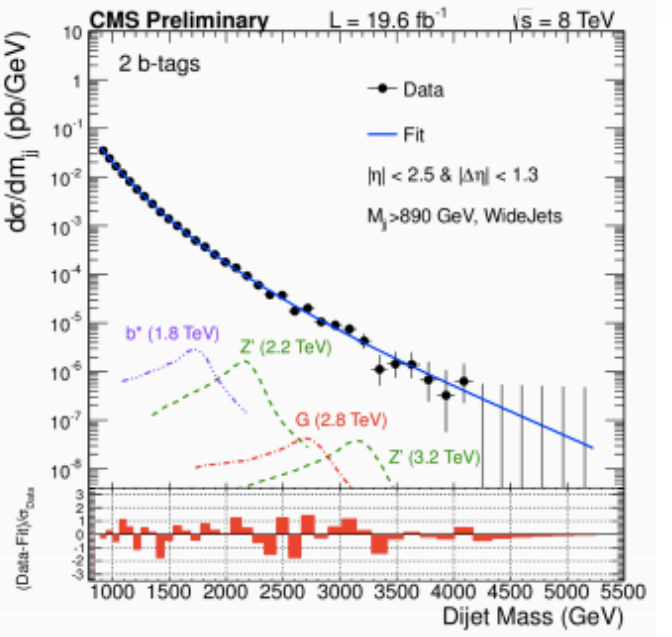




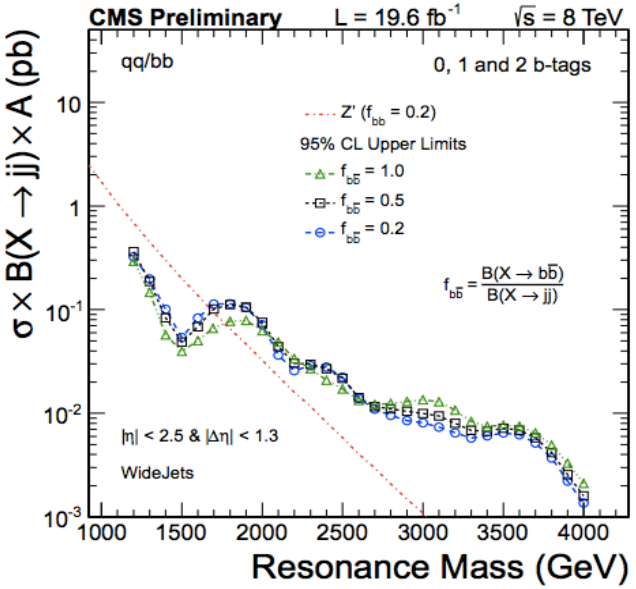
Search for $b\bar{b}$ and bg Resonances

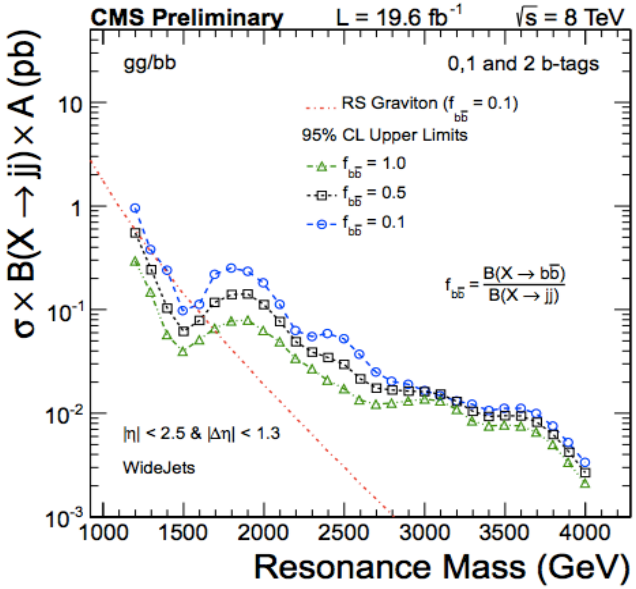






- Search for a new gauge boson Z′ with enhanced couplings to b quarks (as a SM Z !)
- Events are split into 3 exclusive categories
- Limits on Z′ and RS Graviton for different ratios $f_{b\bar{b}}$

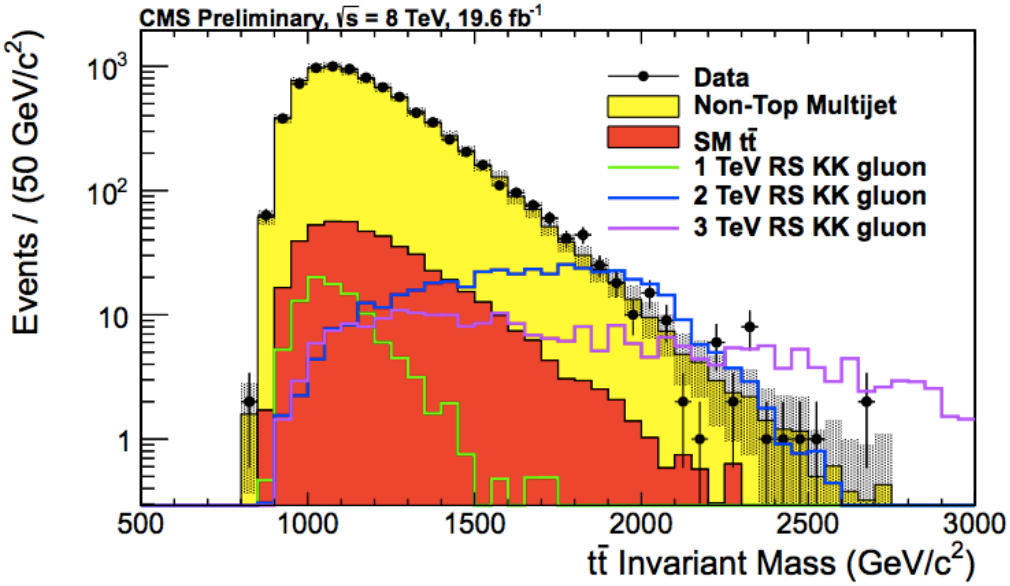


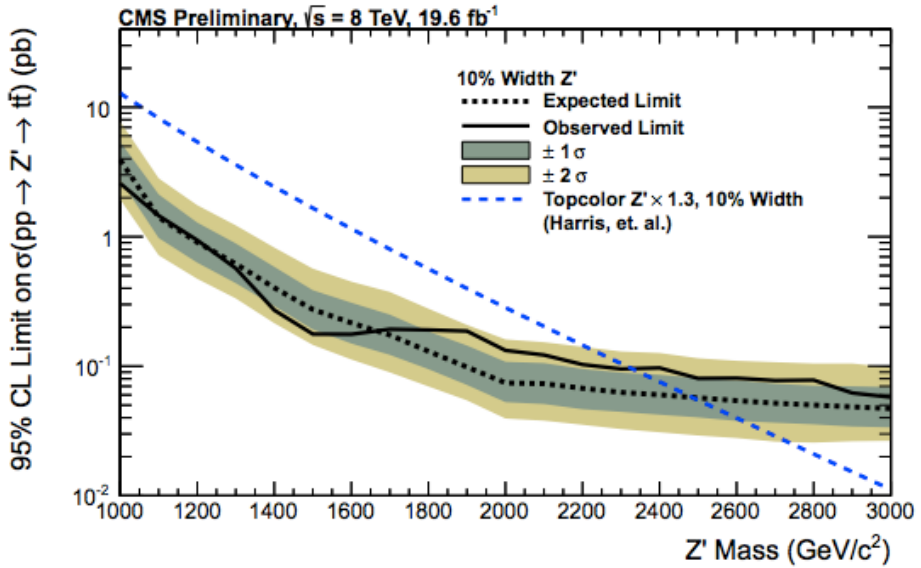


Search for Z′ → $t\bar{t}$ –all-hadronic

- Highly boosted topologies : 2 fat jets in the final state with mass [140,250] GeV, consistent with top
- And >=3 subjets with minimum pair-wise mass > 50 GeV consistent with W
- Main background is QCD obtained from data by inverting pair-wise mass cut

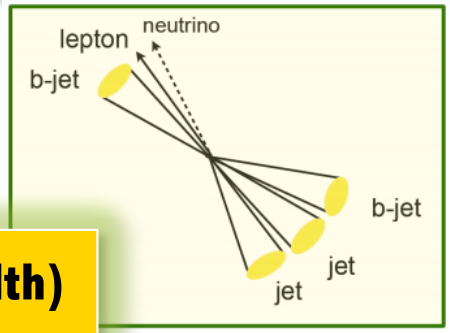
$M_{Z'}$ > 1.6 TeV (1.2% width)
$M_{Z'}$ > 2.3 TeV (10% width)
$M_{g(KK)}$ > 1.8 TeV



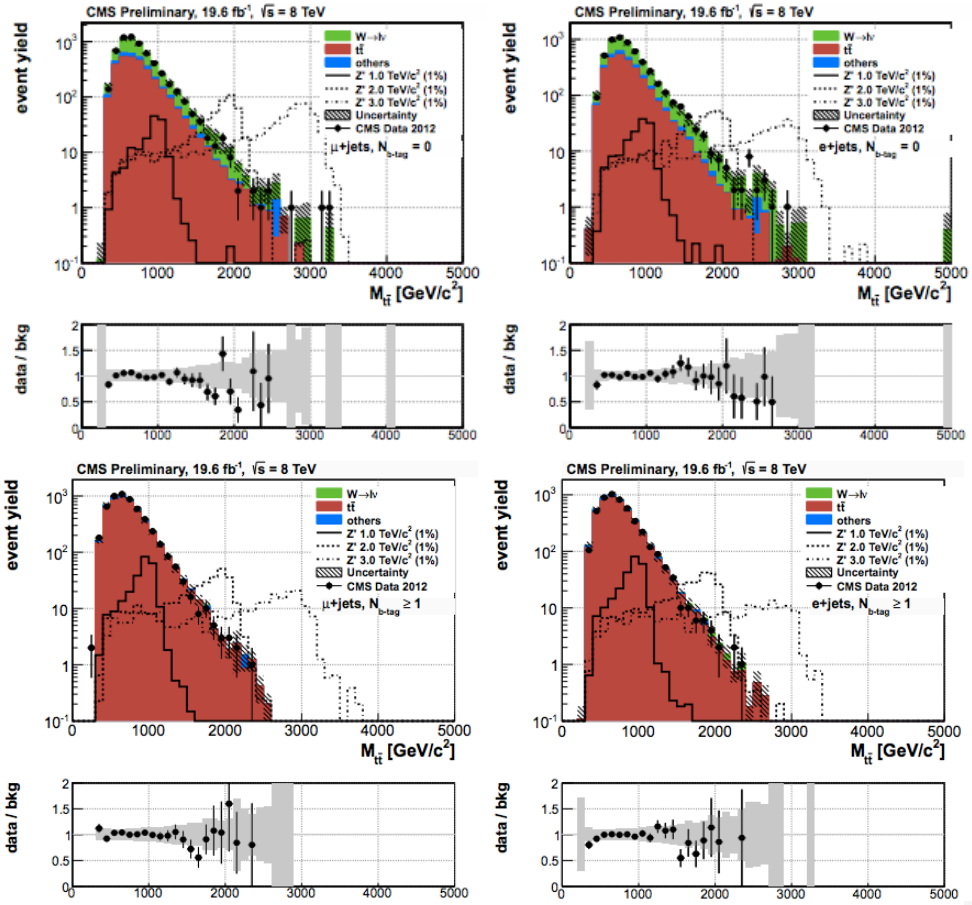


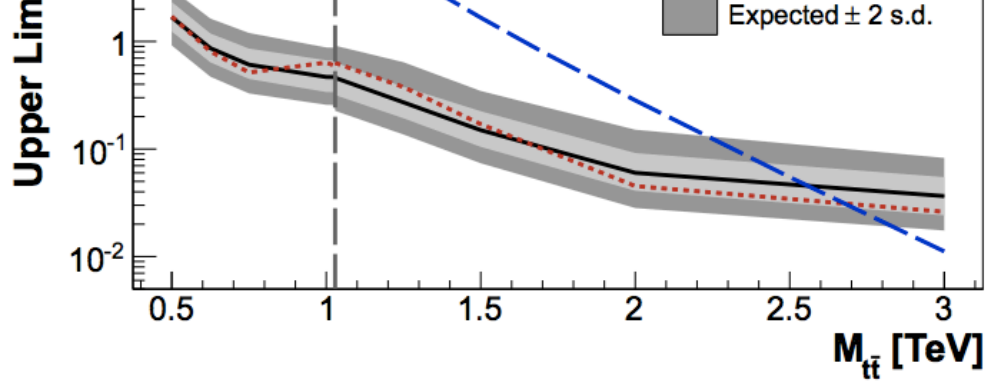
Search for Z′ → $t\bar{t}$ –semi-leptonic

- Separately optimized for low (non-boosted) and high-mass (boosted) regime
- Split into 0 or 1 b-tag
- Define χ^2 for top hypothesis



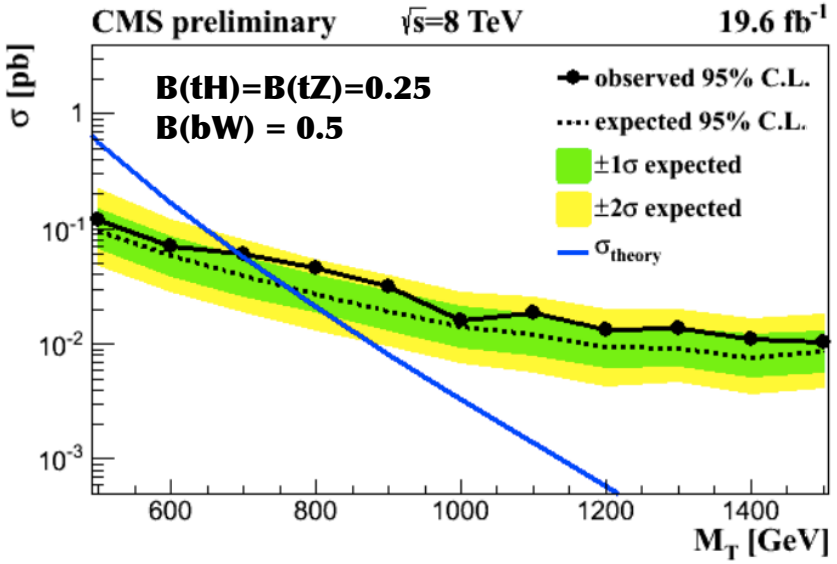
$M_{Z'}$ > 2.1 TeV (1.2% width)
$M_{Z'}$ > 2.7 TeV (10% width)
$M_{g(KK)}$ > 2.5 TeV

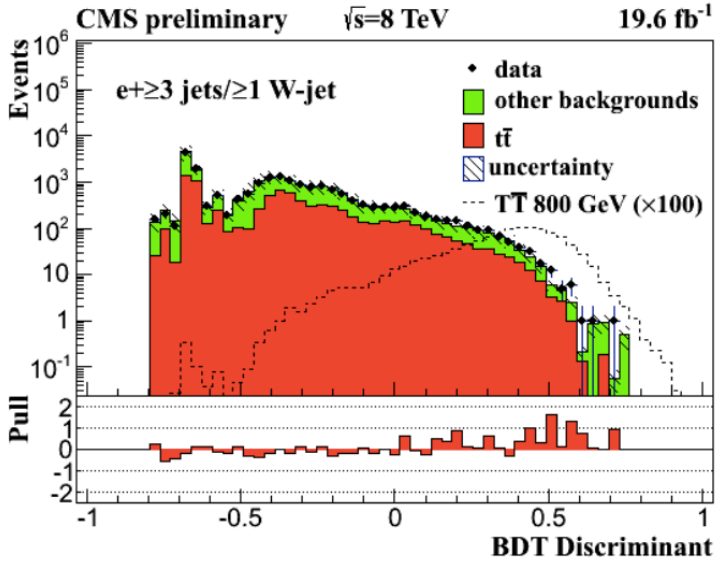


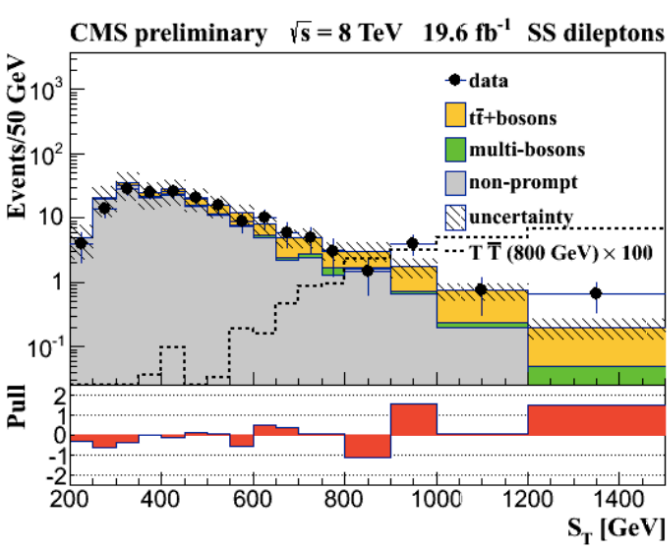


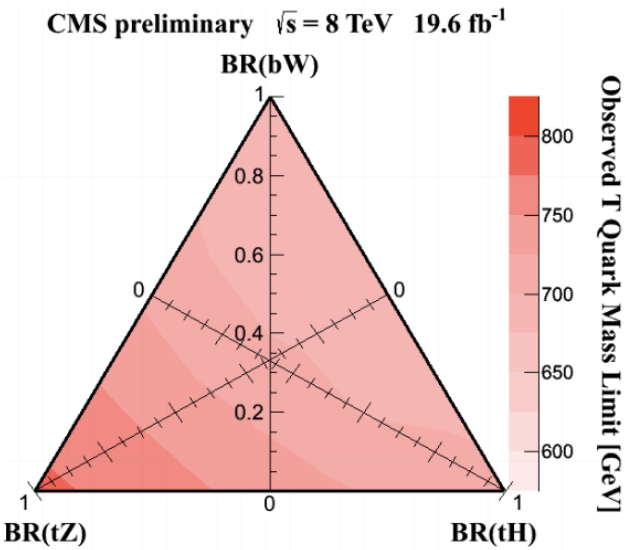
Search for vector-like t′ quark

- In most BSM theories couples to thrd generation quarks, can experience FCNC decays: bW, tZ, tH
- Simultaneous search in several channels: semi-leptonic, opposite-sign and same-sign charge dilepton and trilepton channels
- Set limits for different branching ratios

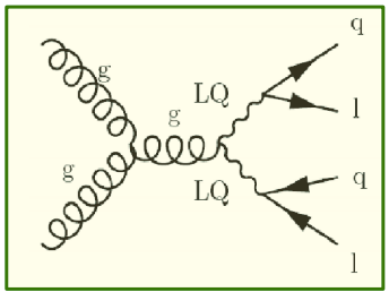




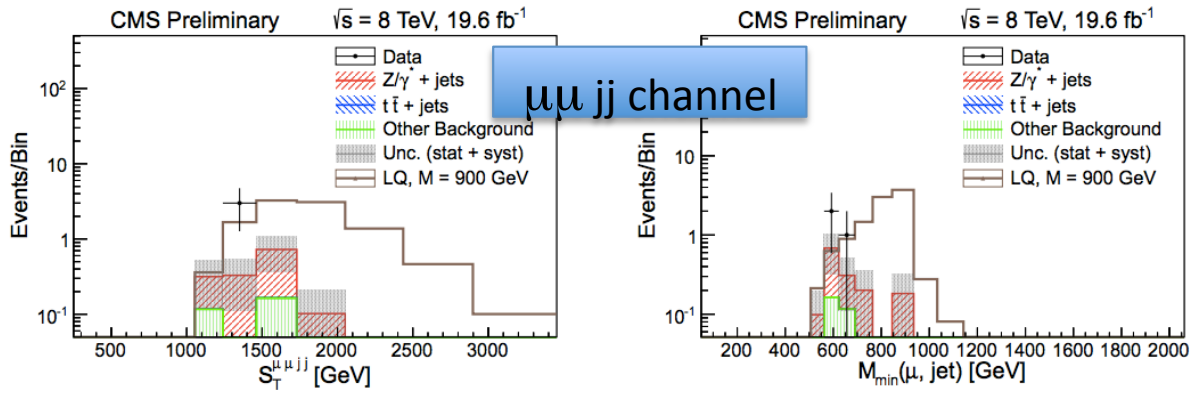


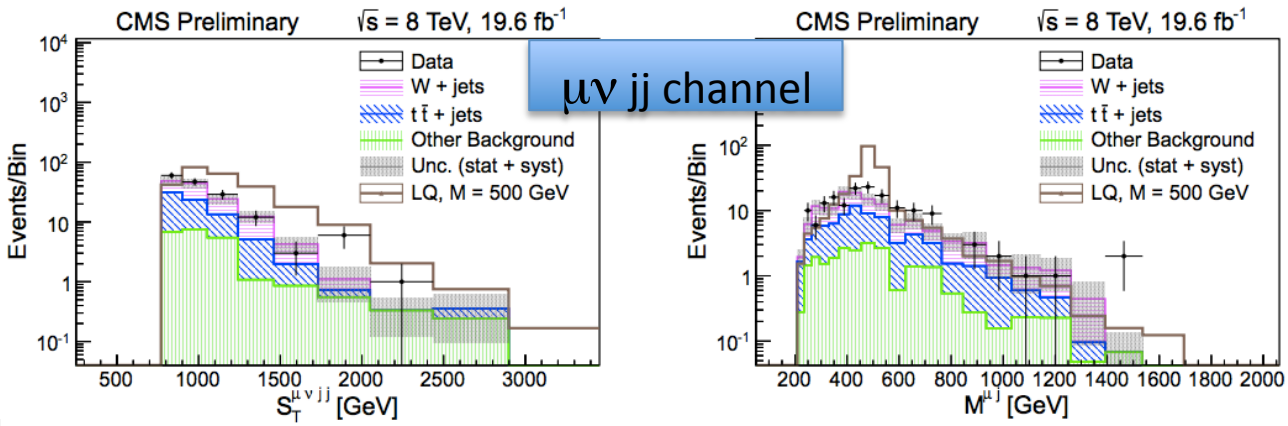


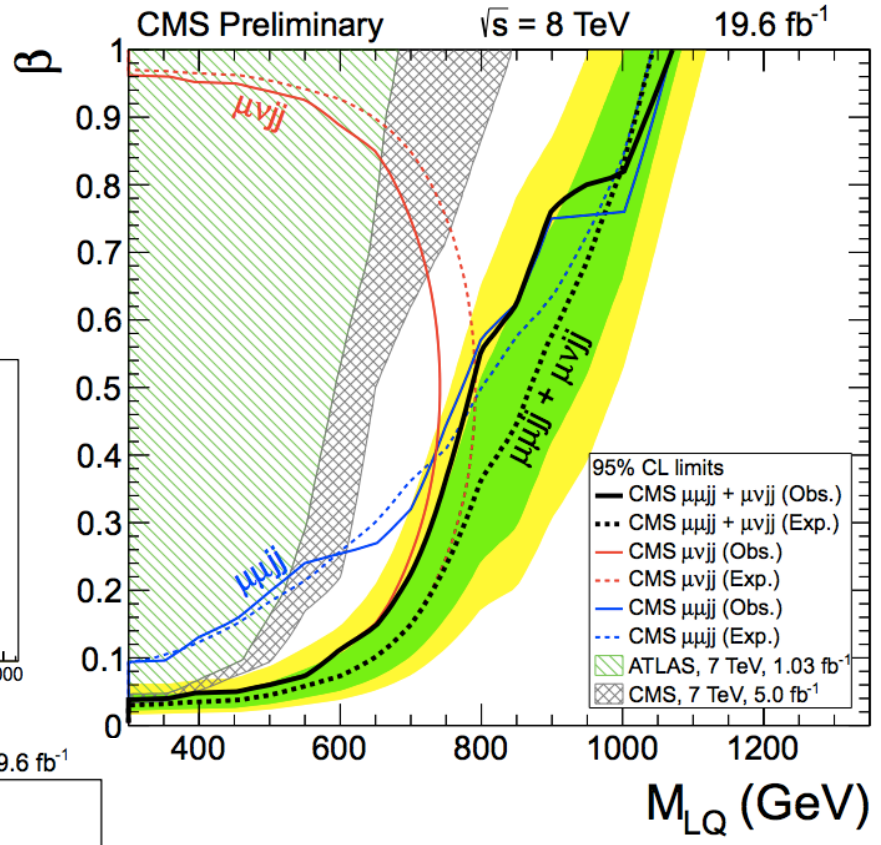
Search for LQ2 (μν+jj, μμ+jj)



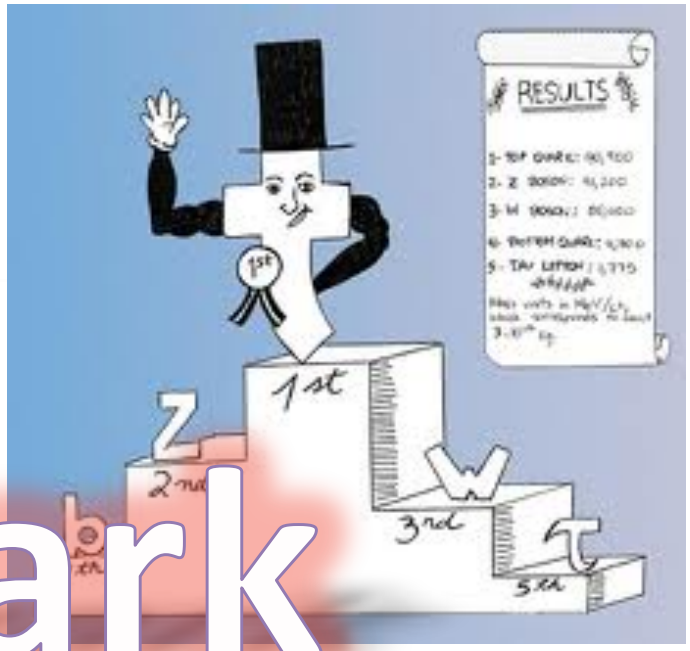
- Search for second generation lepto-quarks
- Set a mass limit as a function of BR



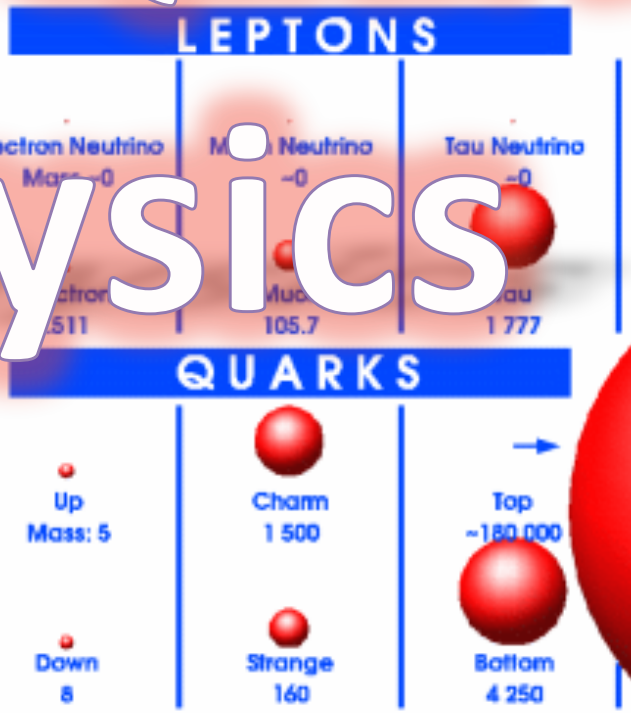


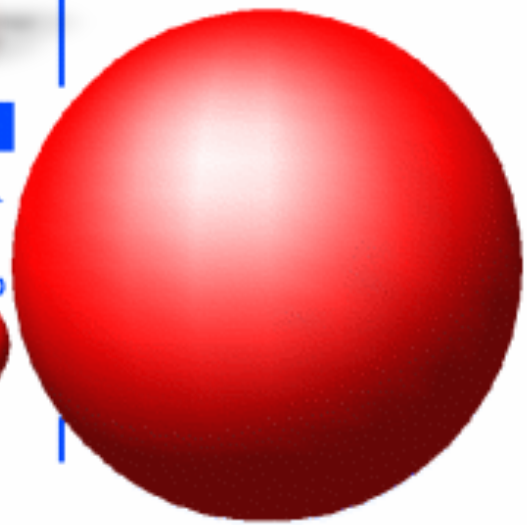


M_{LQ2} > 1070 (785) GeV for B(LQ2 → μq) = 1 (0.5)



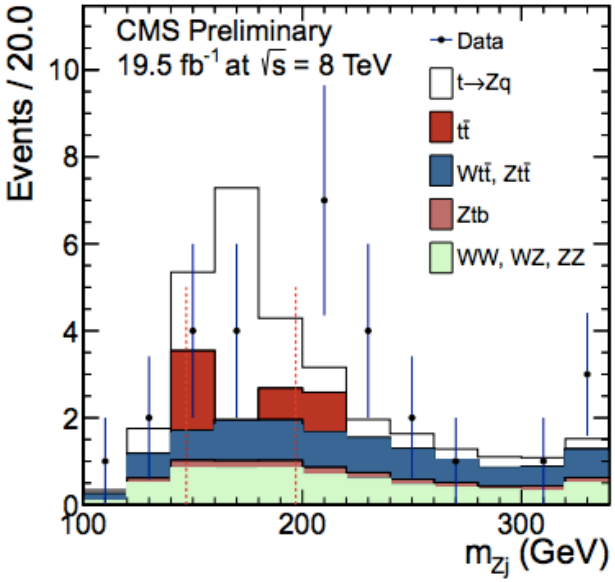
Top Quark Physics

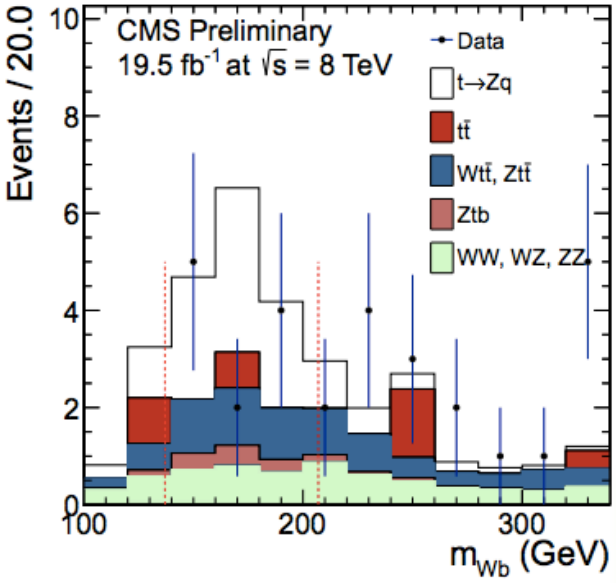


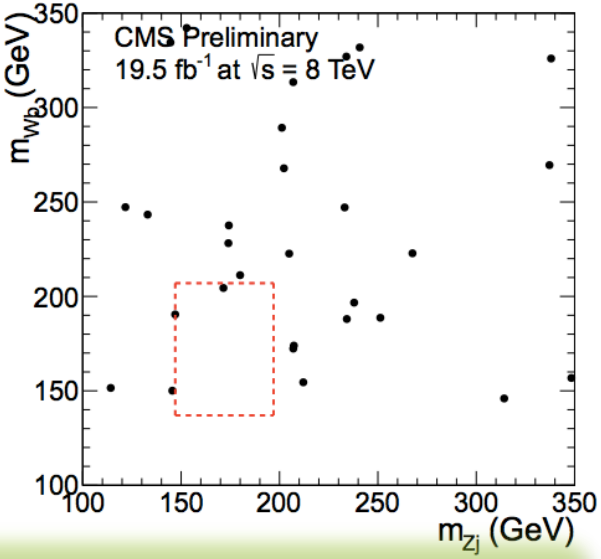


Search for FCNC Top Decays

- t->Zq decays are highly suppressed in the SM by GIM mechanism ~O(10^{-14})
- Can be enhanced in R-parity violating SUSY, top color assisted technicolor models up to O(10^{-4})
- Search in tri-lepton + >= 1 btag events with a dilepton pair consistent with Z
- Signal region: 3.1 ± 5.1 expected, 1 event observed



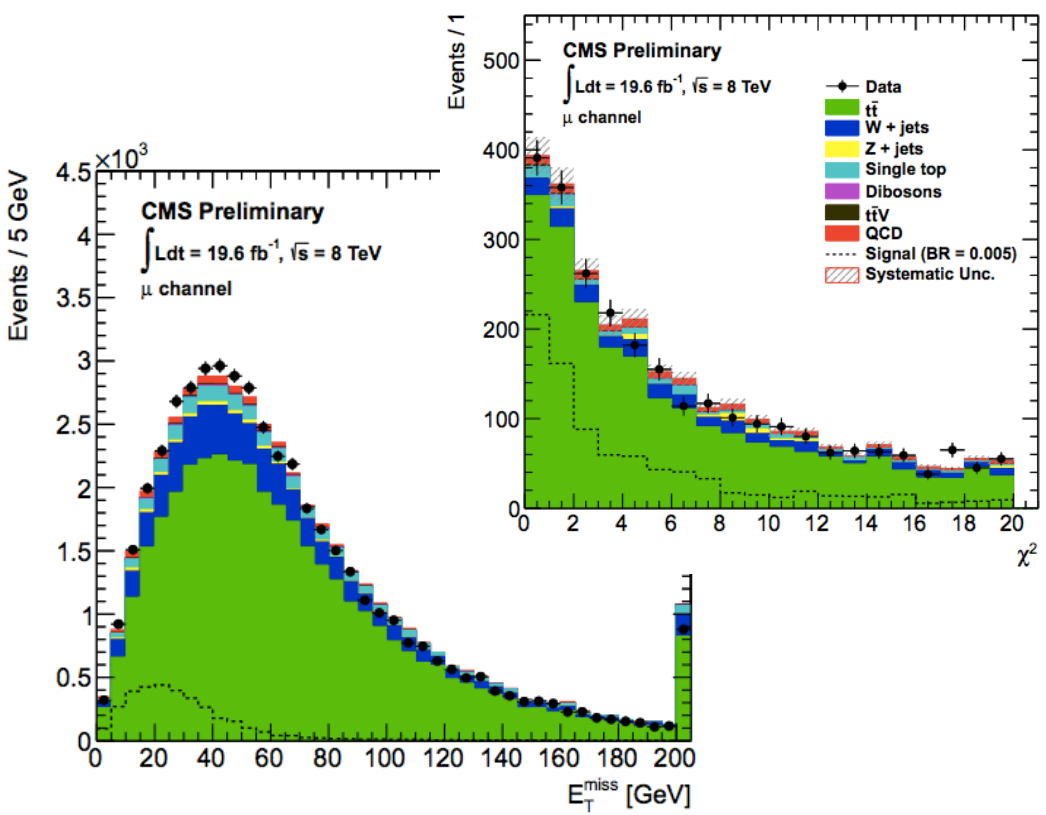


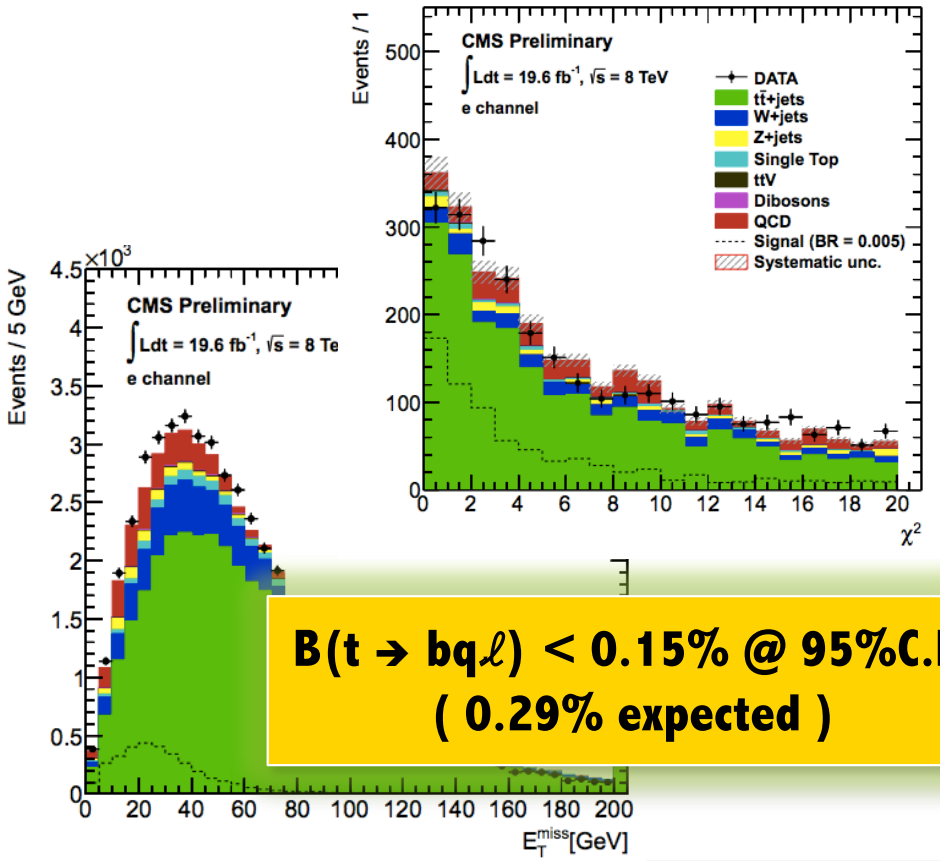


B(t → Zq) < 0.07% @ 95%C.L.
(0.11% expected)

Search for BNV Top Decays

- $t \to \bar{b}\bar{q}\ell$ (q = c,u) decays with baryon number violation can occur in SUSY, GUT and black-hole physics scenarios
- Reconstruct tt events under BNV decay hypothesis
- Search in low-Missing E_T

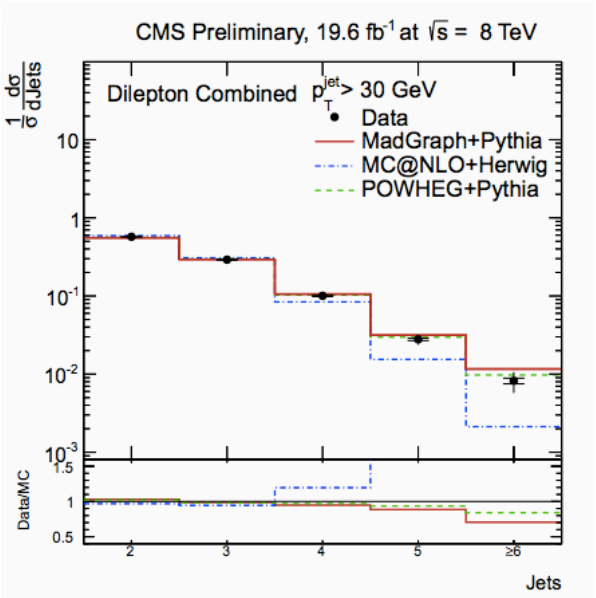


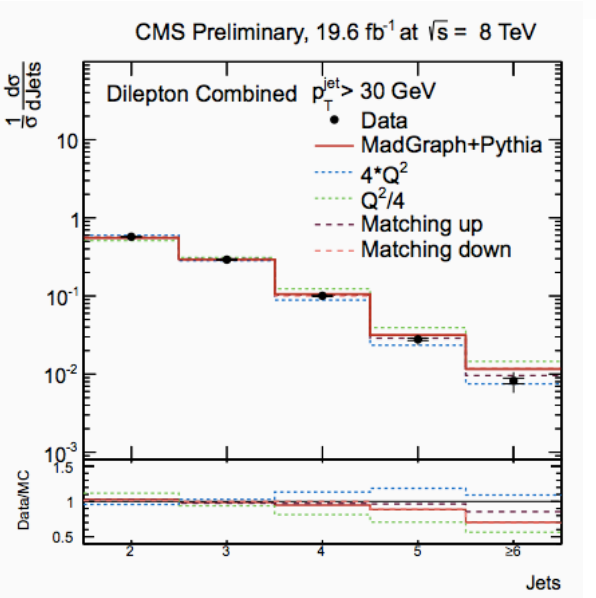


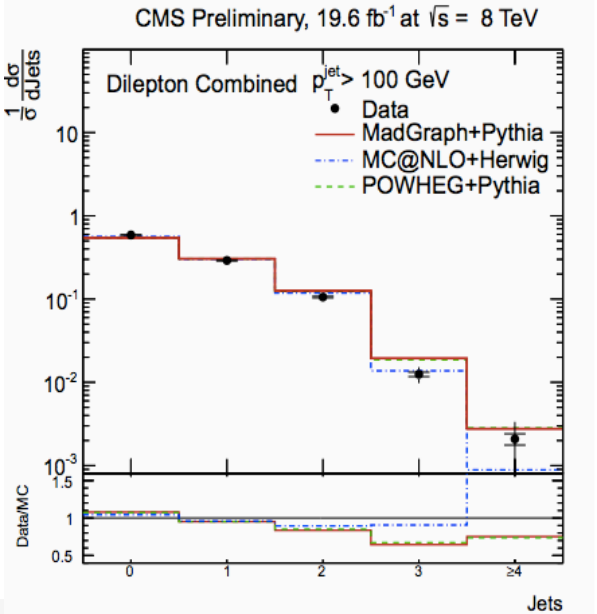
B(t → bqℓ) < 0.15% @ 95%C.L.
(0.29% expected)

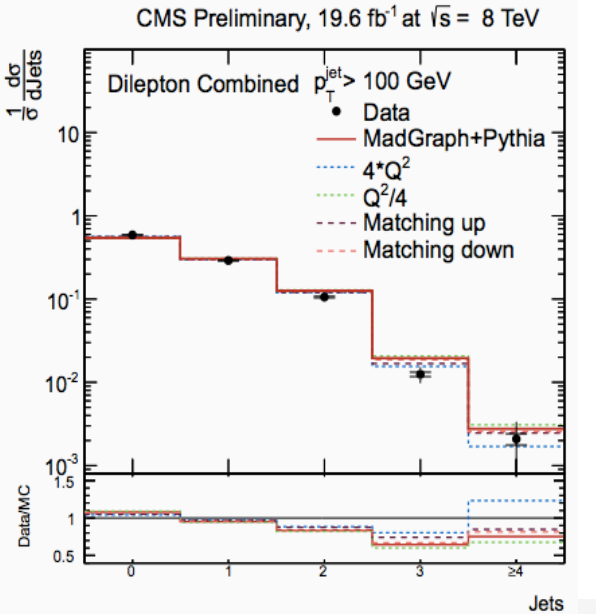
Jet Multiplicity in Top Dilepton

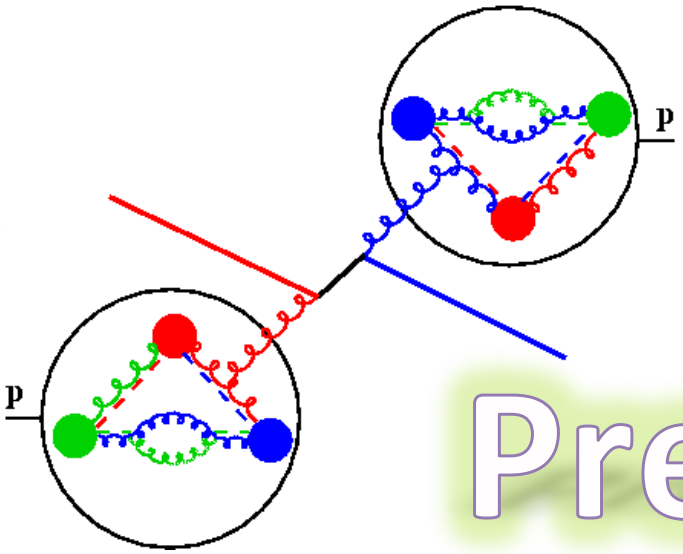
- Test of higher order QCD calculations
- Detector effects unfolded to particle level
- Test different jet p_T thresholds: 30, 60, 100 GeV (anti-k_T, $\Delta R = 0.5$)
- Comparison with Madgraph, POWHEG, MC@NLO MC generators

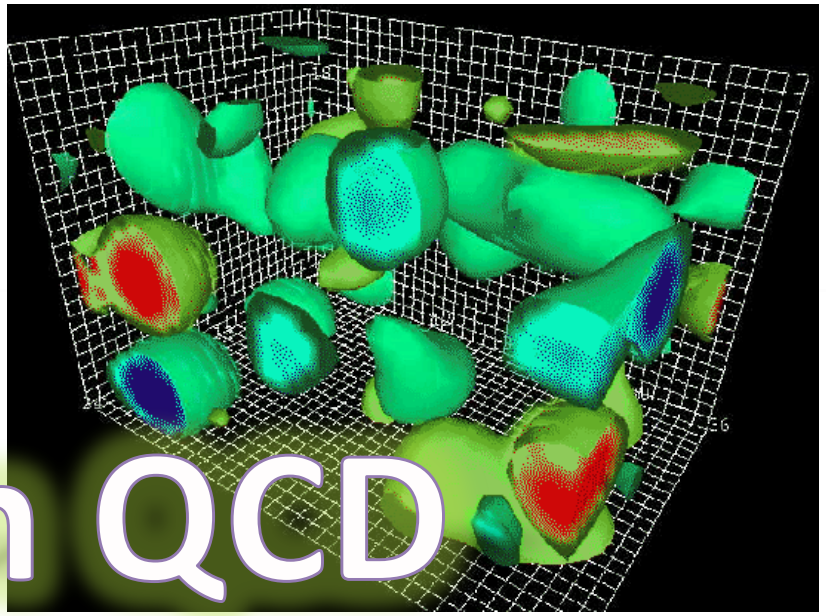








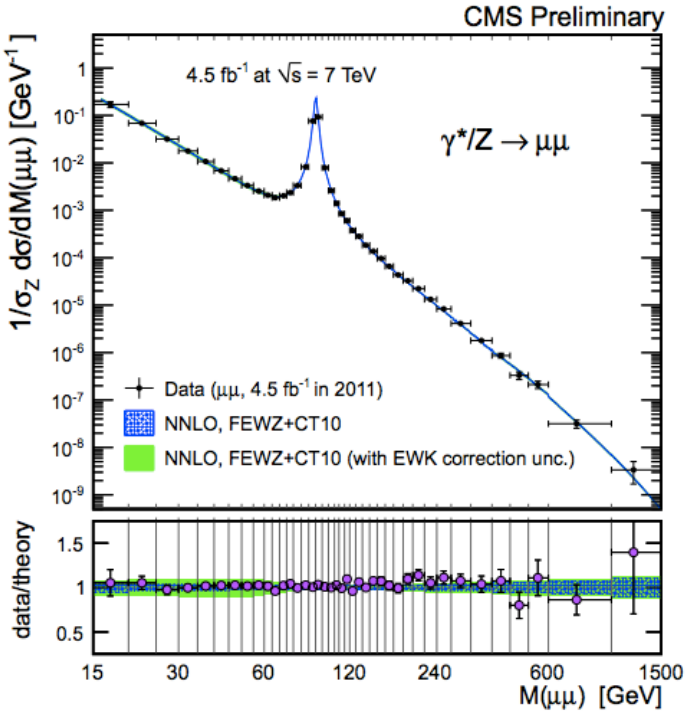


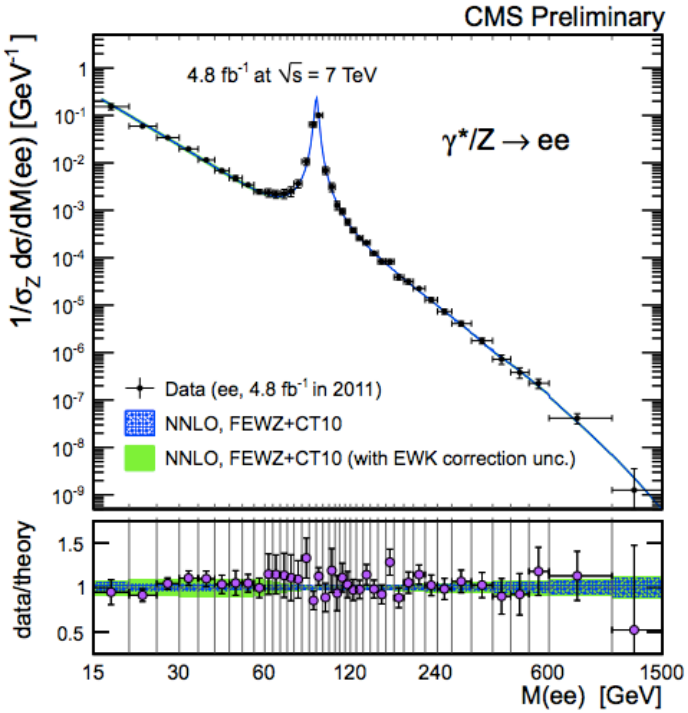


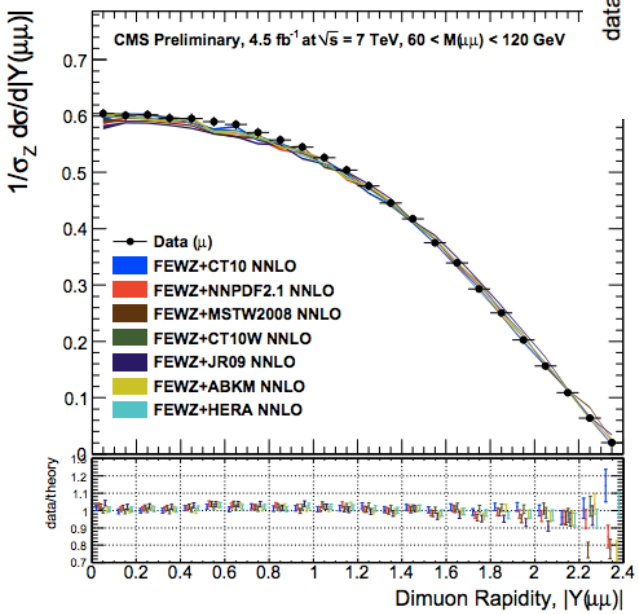
Precision QCD and EWK Measurements

Differential DY Cross Section

- First CMS results on full 2011 dataset
- Good agreement with NNLO predictions computed with FEWZ



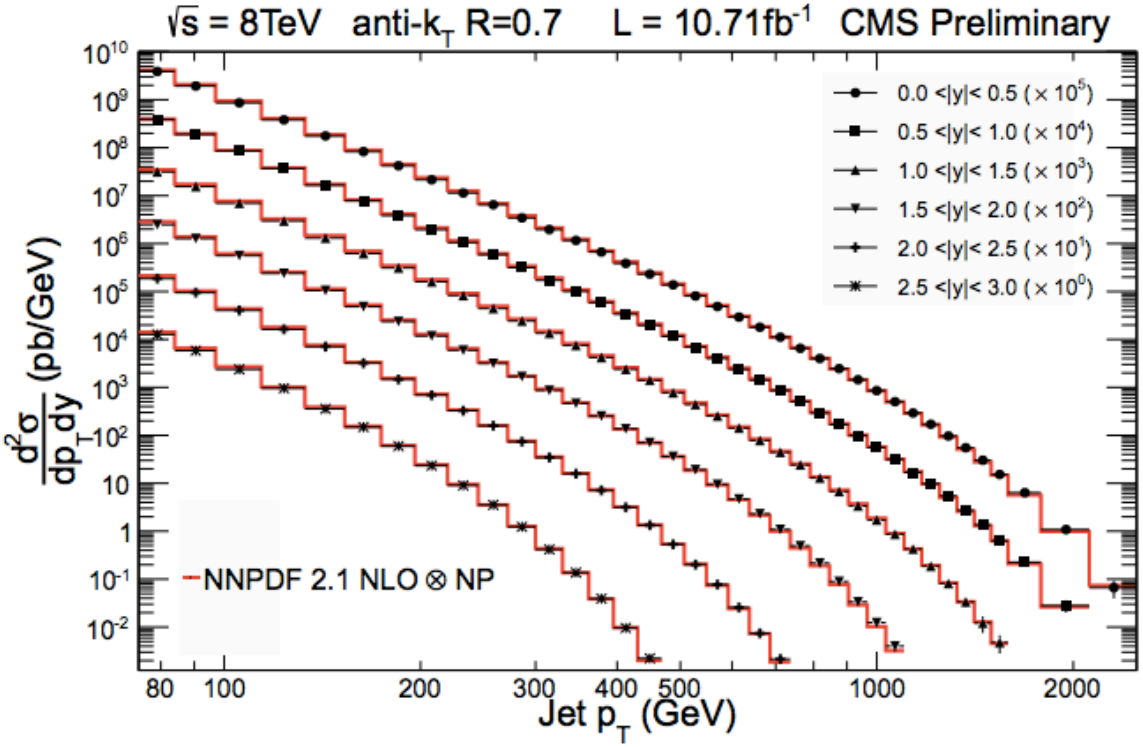


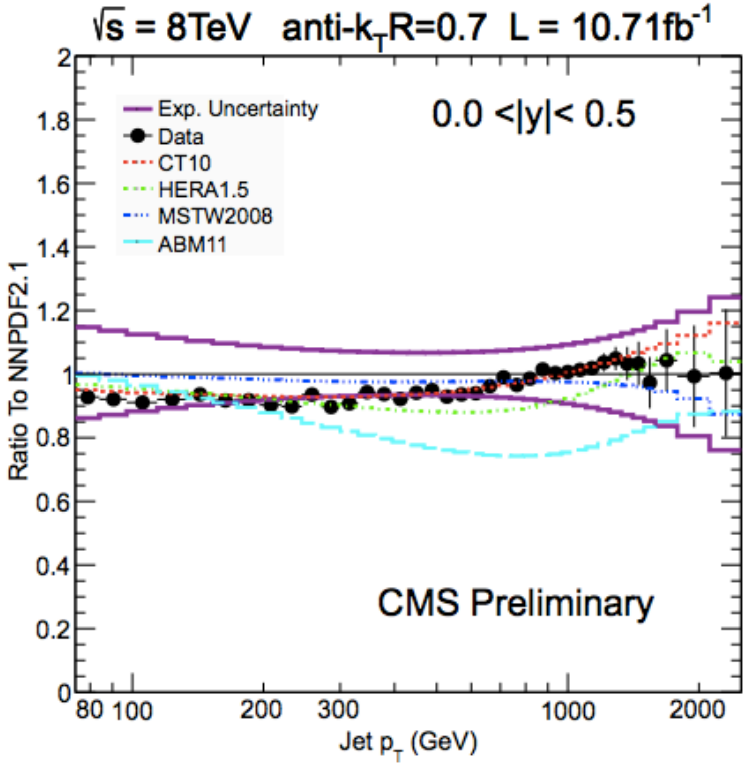


- Double-differential measurement $d^2\sigma/dMdY$
- Valuable input to future global PDF fits

Inclusive Jet Cross Section

- Useful for constraining PDFs and determining α_s
- NLO prediction in good agreement with data over many orders of magnitude
- Most NLO PDFs agree with data within uncertainties



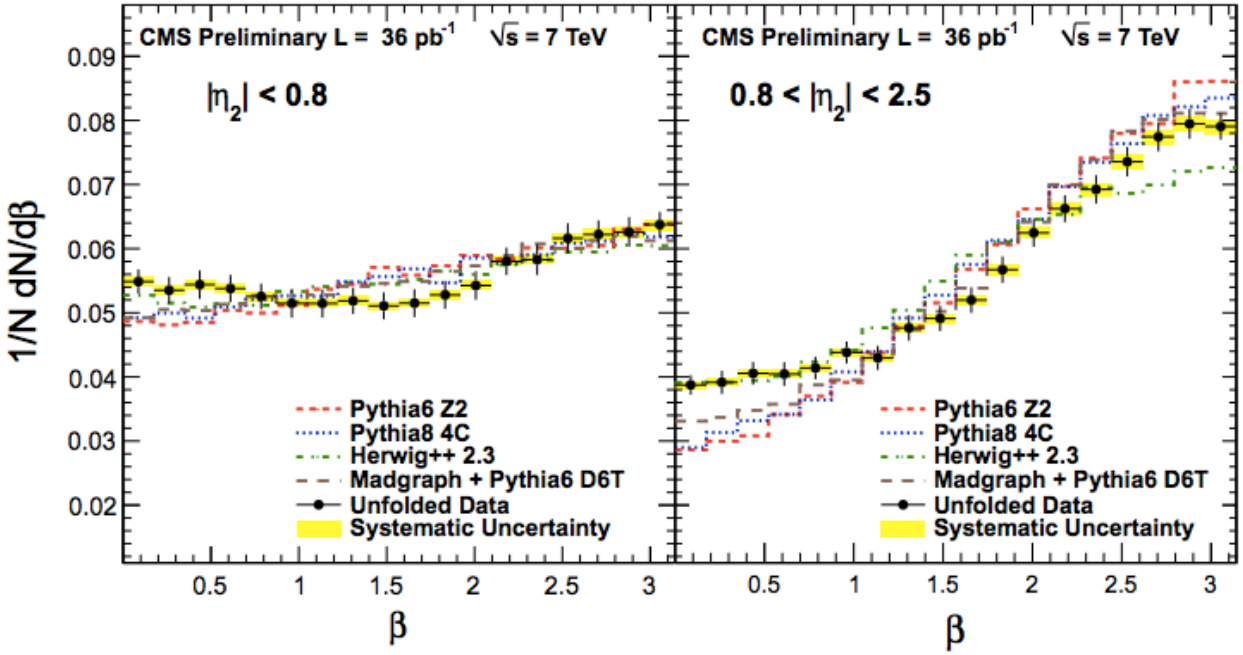


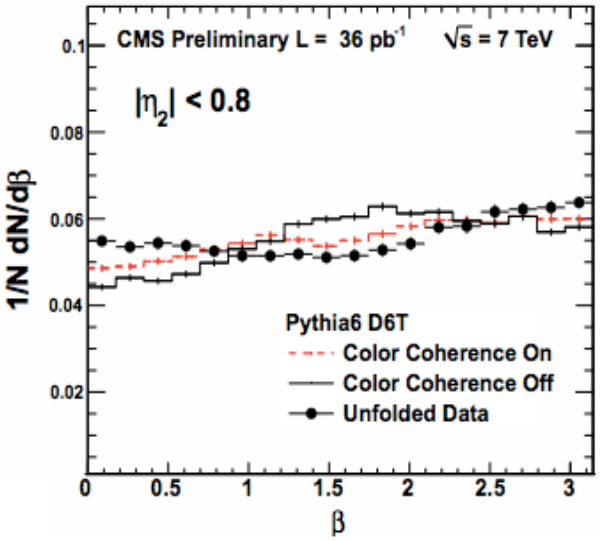
Color Coherence Effects

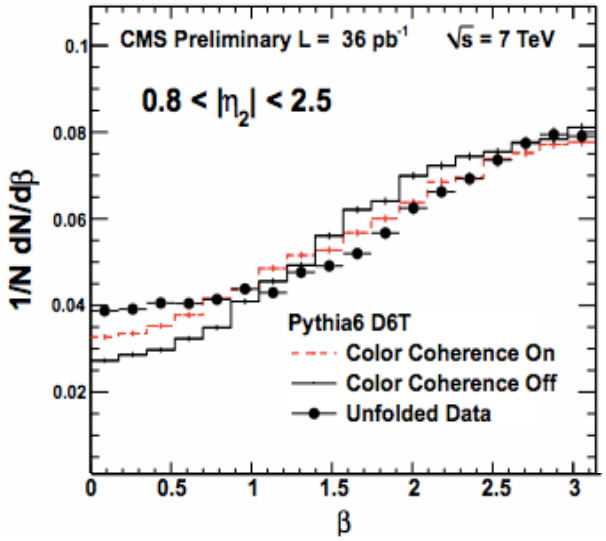
- Study of interference of outgoing partons from hard interaction using 2010 dataset
- Require two back-to-back leading jets
- Analysis of angular correlation between 2nd and 3rd jets

$$\beta = |\text{atan2}(\Delta\phi_{23}, \Delta\eta_{23})|$$

- Better modeling with newer MC generators and newer UE tunes
- Data supports larger coherence effects that are incorporated into MC

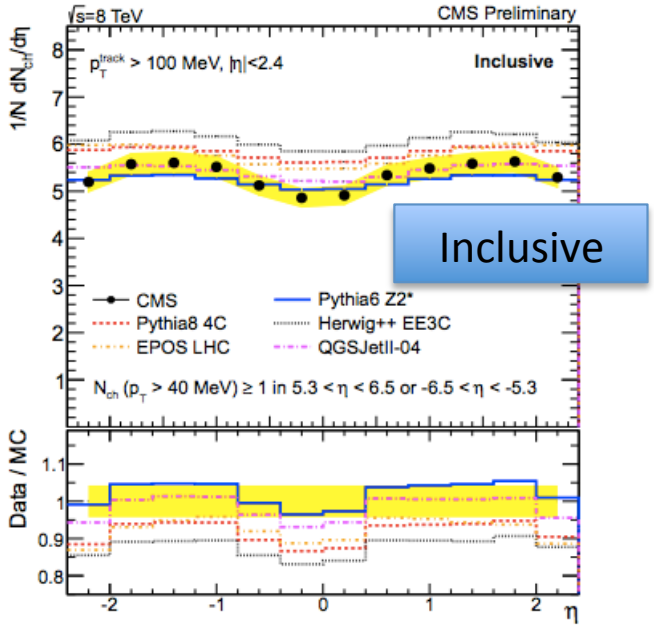




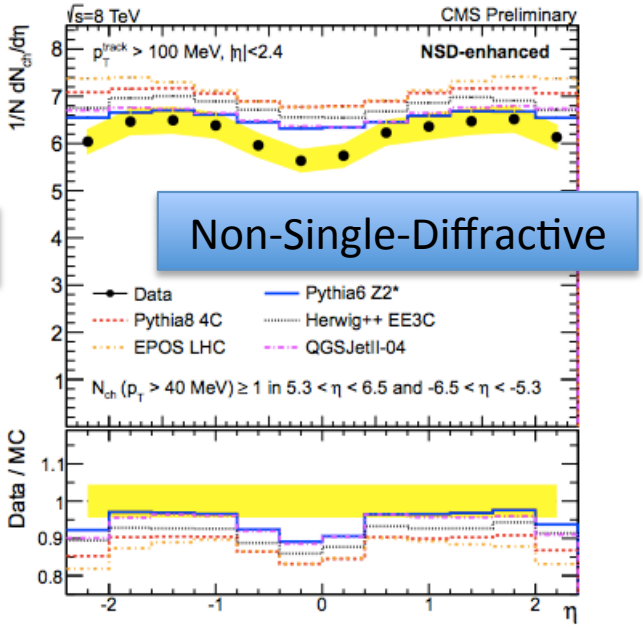


Hadron Production

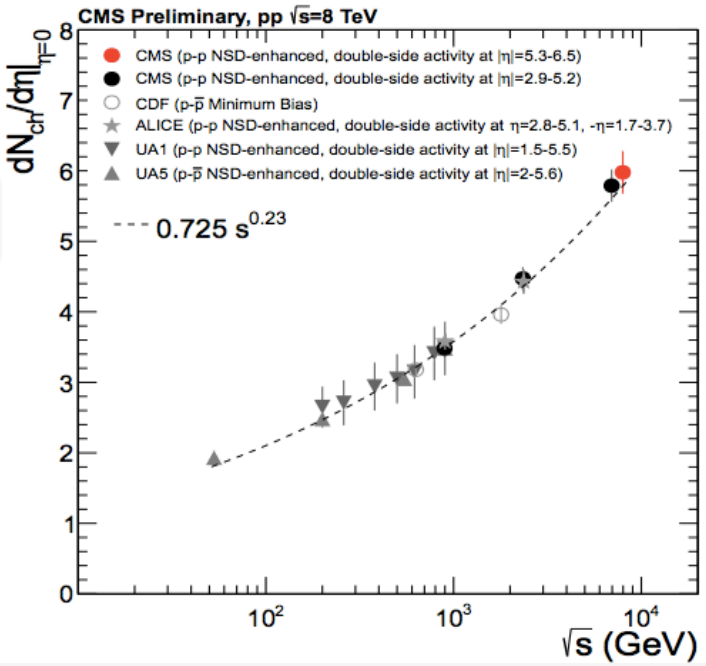
- Measurement of charged-particle densities in minimum-bias events triggered based on charged track $p_T > 0.1$ GeV in at least one or both hemispheres by forward detectors (TOTEM telescopes $5.3 < |\eta| < 6.5$)
- Pythia Z2* and QGSJetII-04 well describe data for inclusive selection
- All models overestimate data by up to 20% in non-single-diffractve enhanced sample
- Particle production follows power-law center-of-mass energy dependence



Inclusive



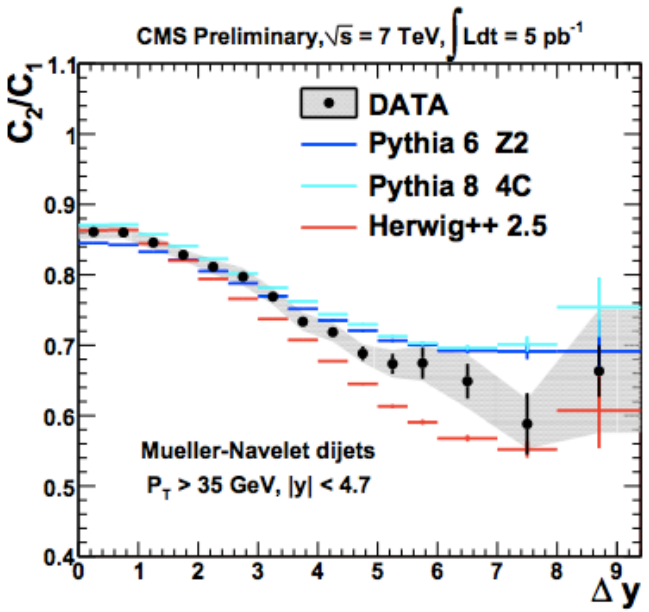
Non-Single-Diffractive

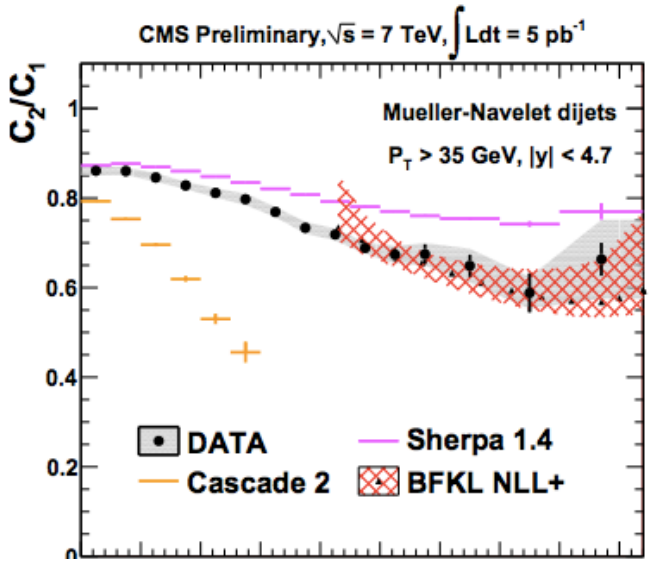


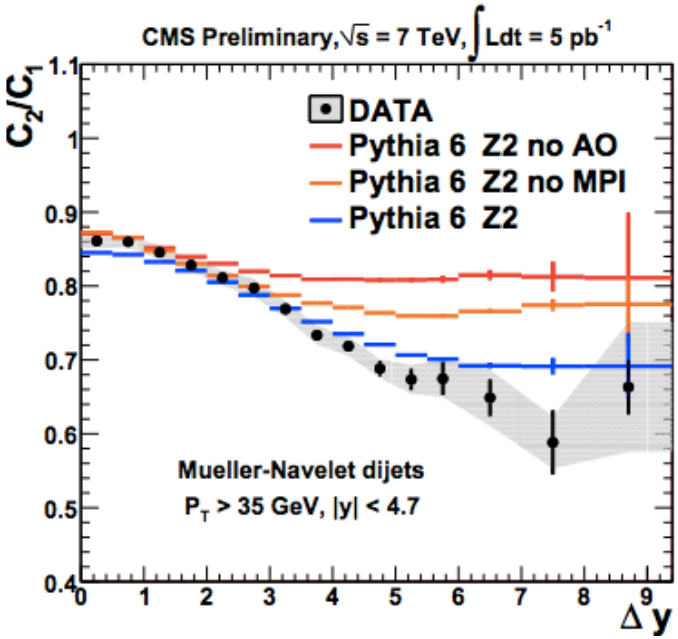
Mueller-Navelet Dijet Azimuthal Decorrelations

- Testing the BFKL regime by using di-jets with similar p_T and large Δy (MN-jets)
- Study azimuthal dependence using ratio of Fourier coefficients with expected suppression of DGLAP evolution

$$\frac{1}{\sigma}\frac{d\sigma}{d(\Delta\phi)}(\Delta y, p_{\mathrm{Tmin}}) = \frac{1}{2\pi}\left[1 + 2\sum_{n=1}^{\infty} C_n(\Delta y, p_{\mathrm{Tmin}}) \cdot \cos(n(\pi - \Delta\phi))\right]$$

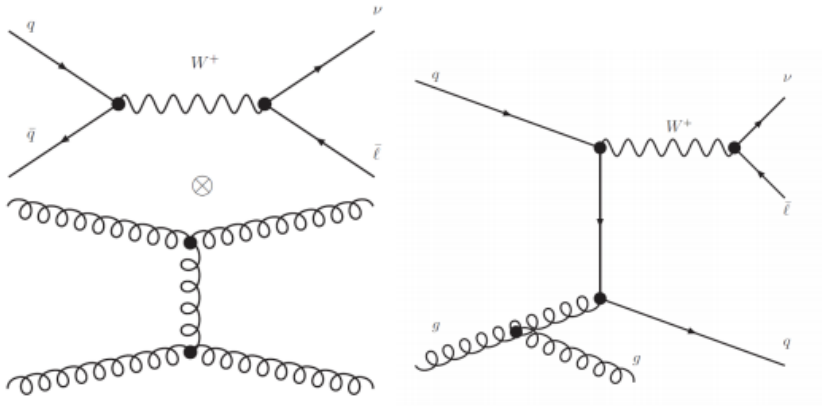






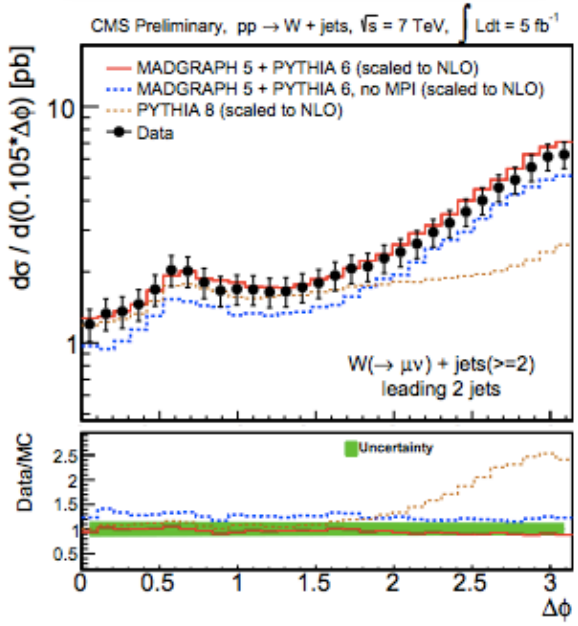
- Perturbative calculations based on DGLAP do not describe data, significant variations by MC
- BFKL-inspired Cascade2 predicts far too strong decorrelations
- Data agrees with analytical NLL BFKL calculations
- Polar angle ordering in parton showering and MPI are important for better agreement with data

Double Parton Scattering in W + Di-jet

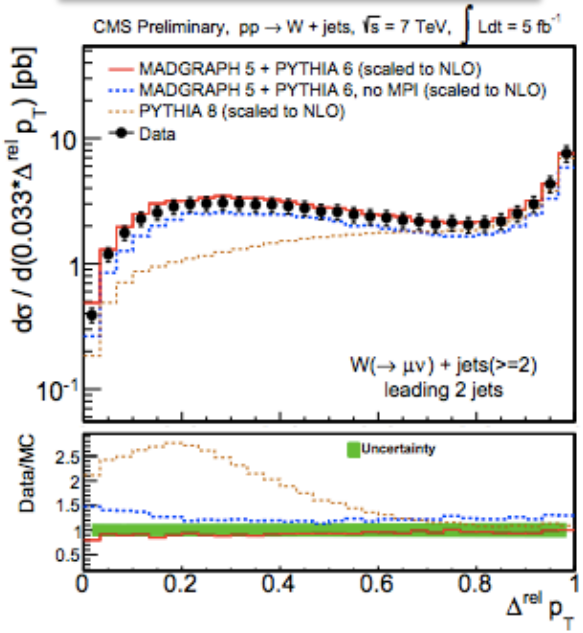


- Study of observables sensitive to identifying contribution of two hard scatterings in single pp-interaction
- Good agreement of Madgraph with data
- MPI are important

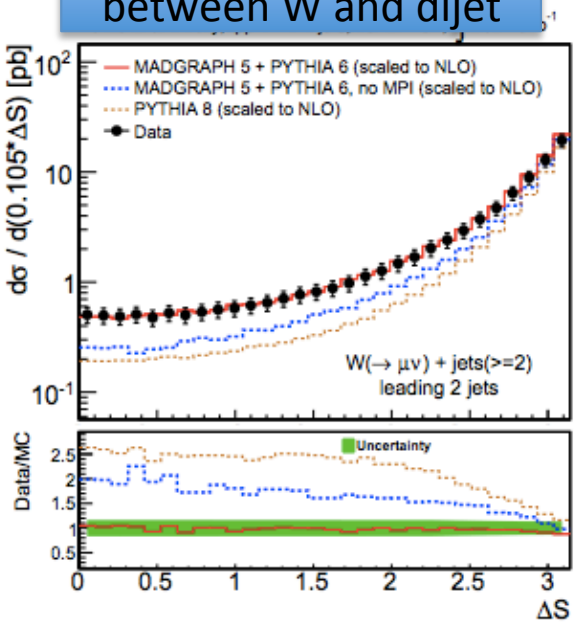
Azimuthal Separtion



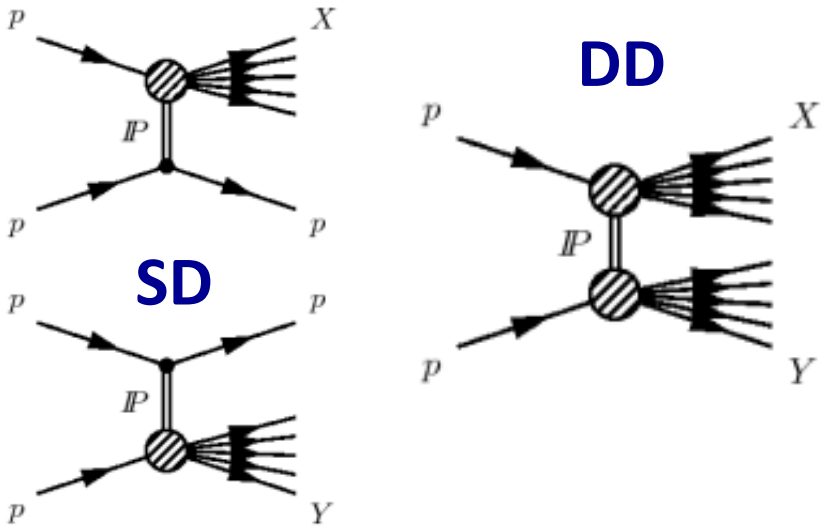
Relative p_T



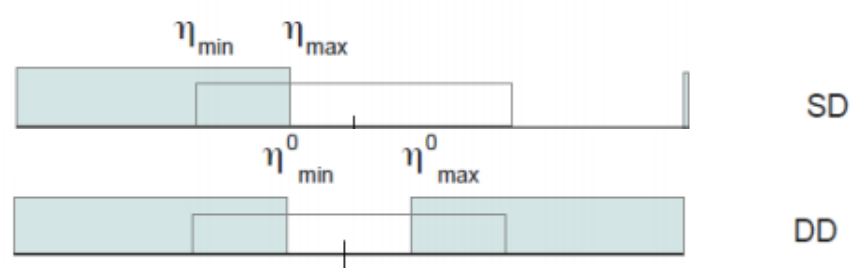
Azimuthal angle between W and dijet



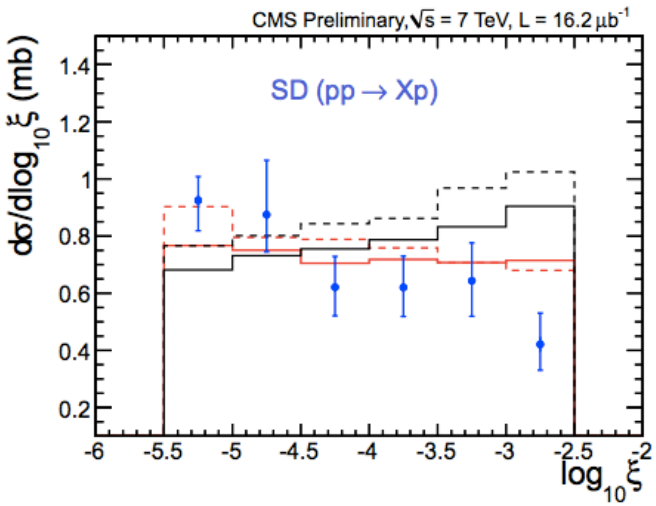
Soft Diffraction

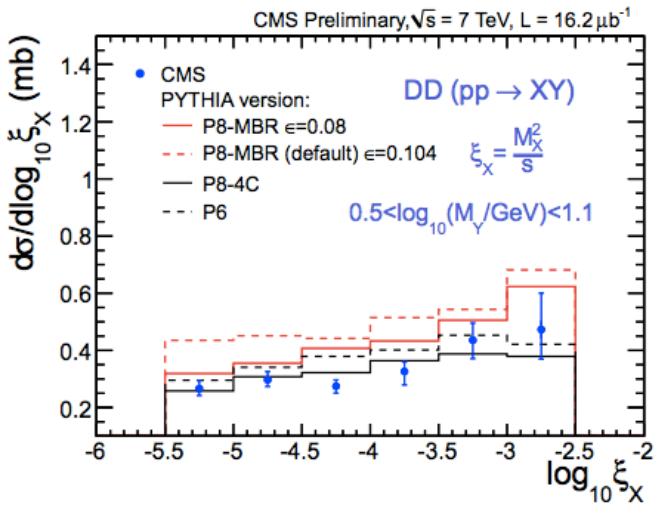


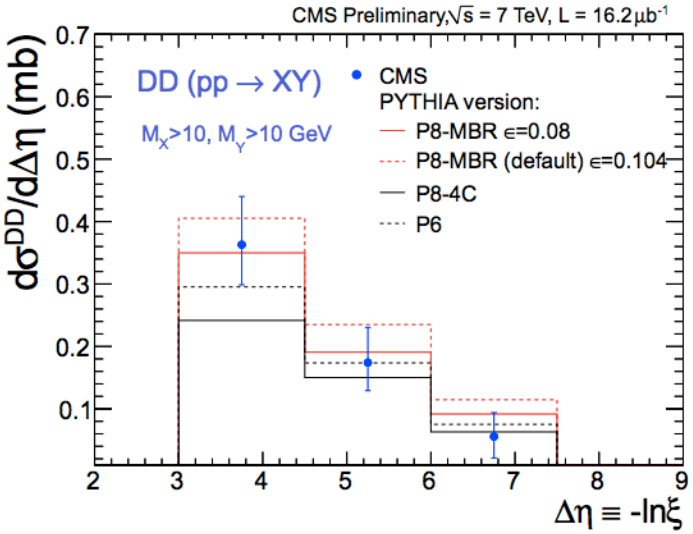
- Measurement based on 2010 data in low-pileup
- Final State: large rapidity gap



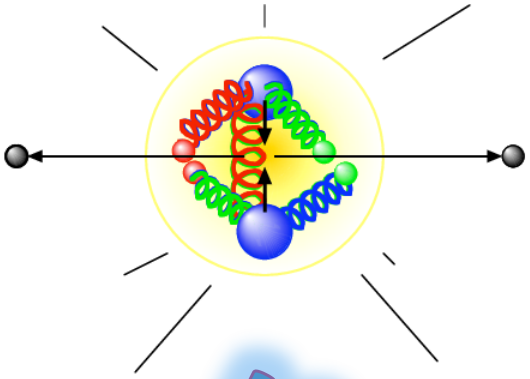
- Pythia 8 shows good description of data

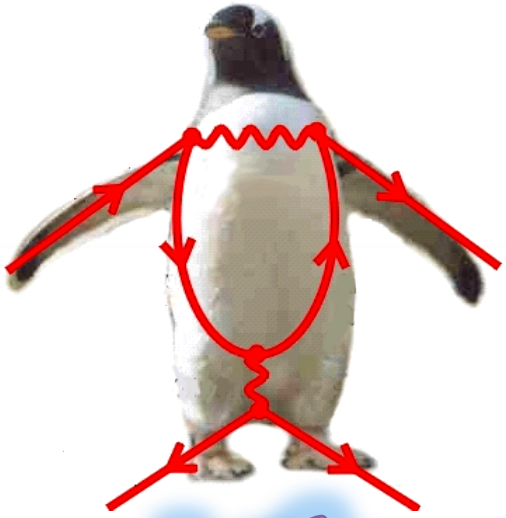




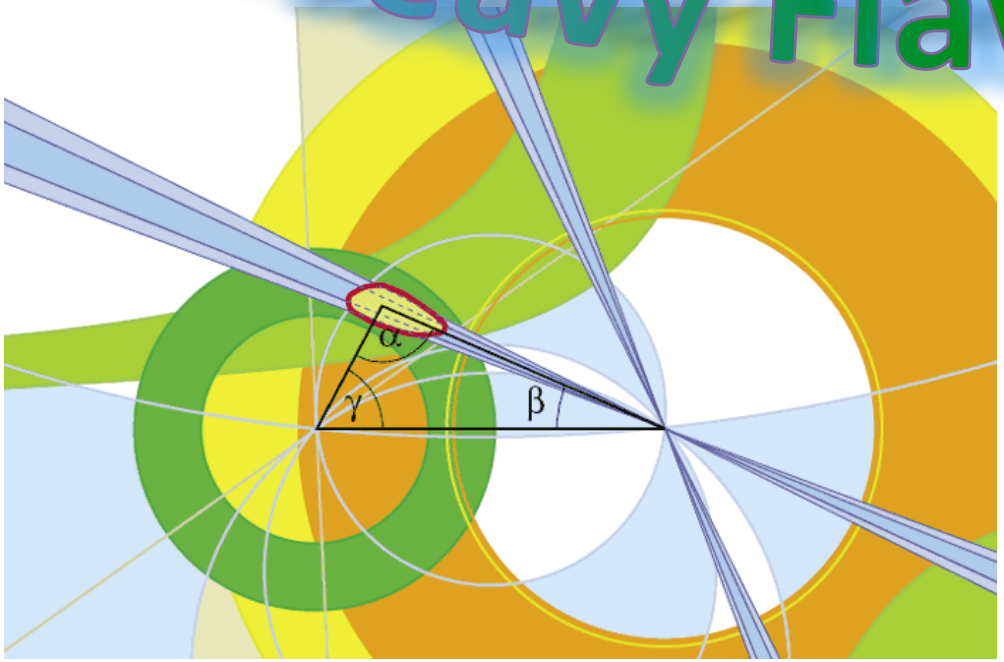


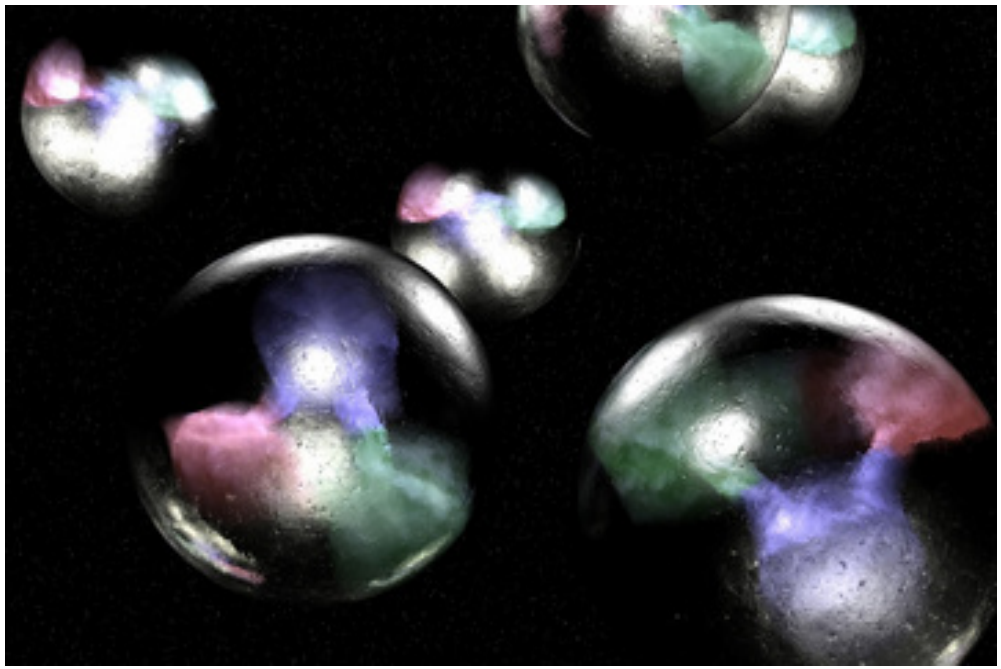
ξ – forward momentum loss of incoming parton





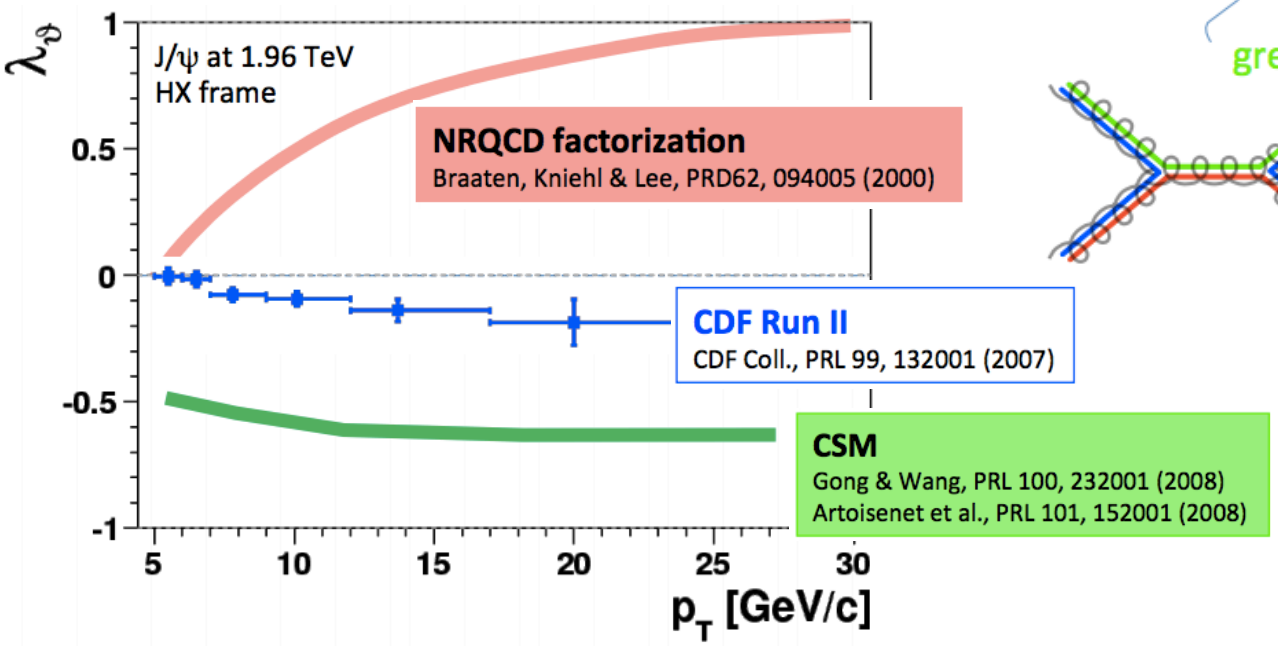
Heavy Flavor Physics

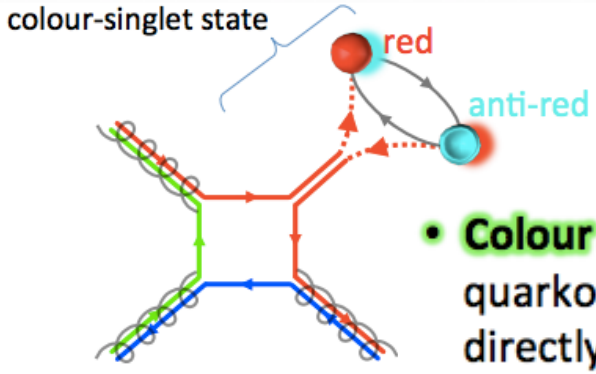




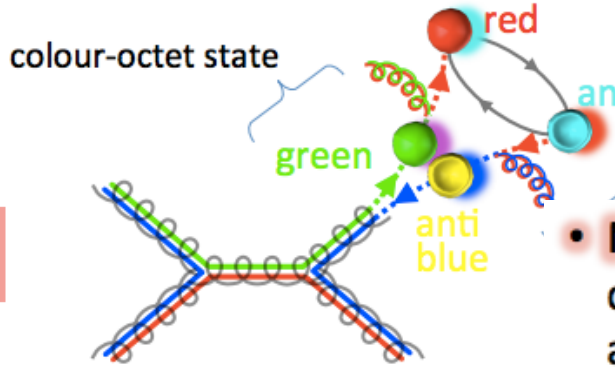
Quarkonium Studies

- Production mechanism for heavy quarkonium states is not fully understood
- Models predicts strong polarizations



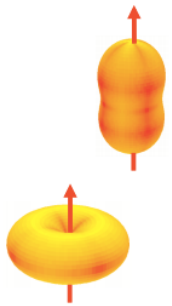


- **Colour Singlet Model**: quarkonia always produced directly as observable ***colour-neutral*** Q-Qbar pairs



Non-pertutbative transition

- **NRQCD factorization**: quarkonia also produced as ***coloured*** Q-Qbar pairs *of any possible quantum numbers*



$J_z = \pm 1 \rightarrow \lambda_\vartheta = +1$
"transverse" polarization

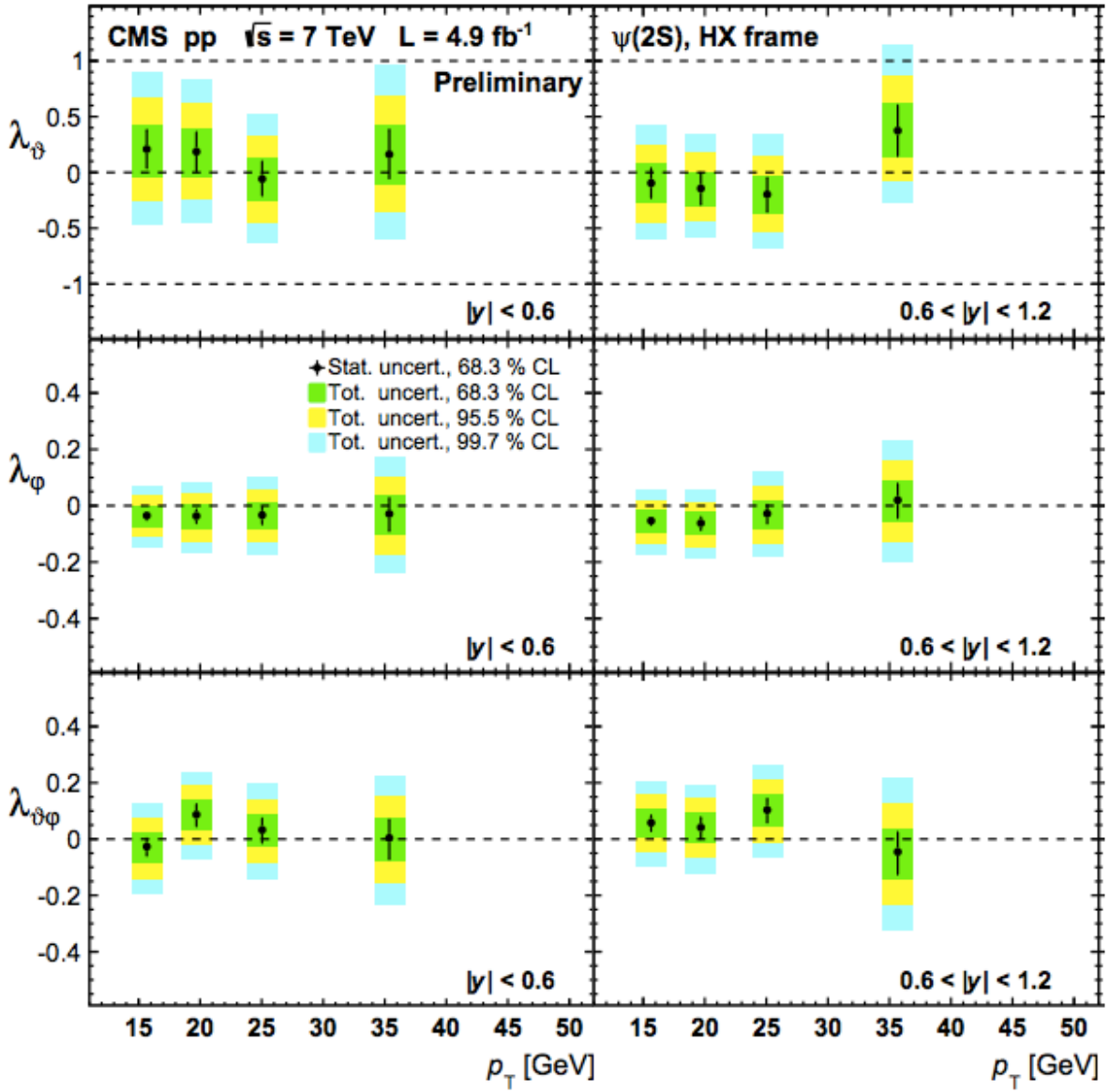
$J_z = 0 \rightarrow \lambda_\vartheta = -1$:
longitudinal polarization

Prompt ψ(2S) Polarization

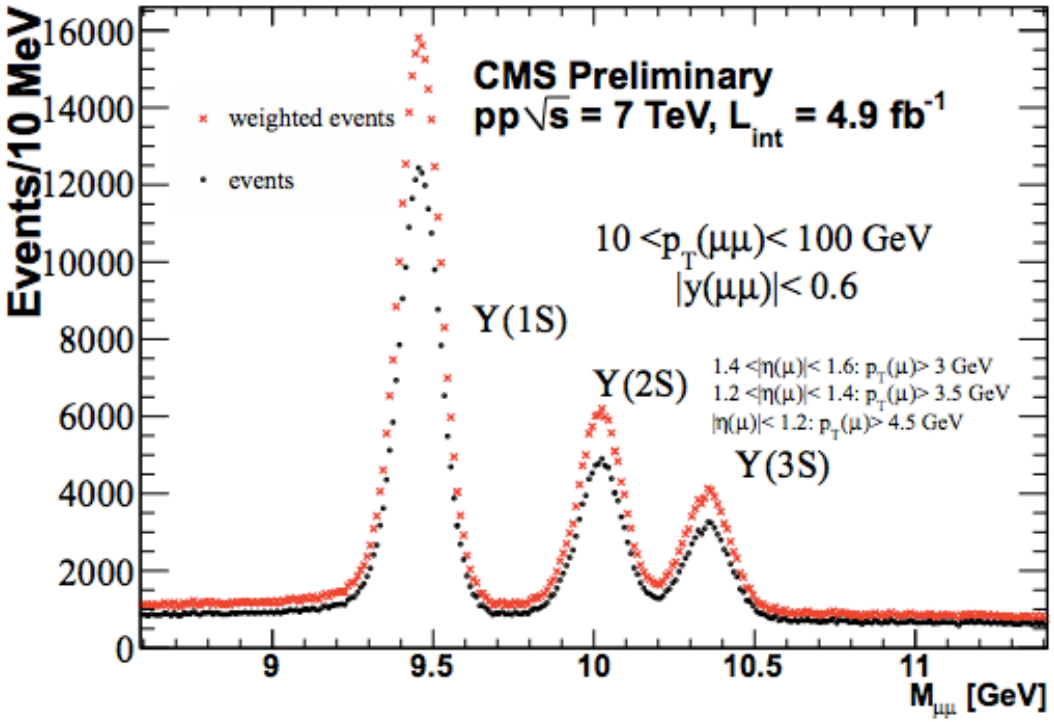
- Measure polarization of quarkonium state through angular distributions of muons in different polarization frames

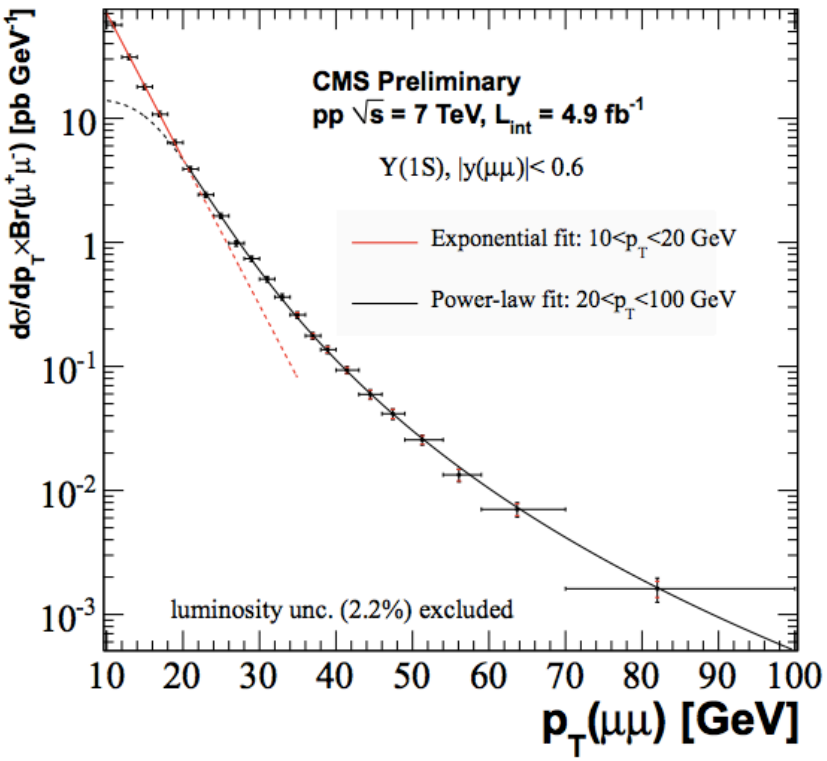
$$\frac{dN}{d\Omega} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos\varphi$$

- NRQCD describes well p_T spectra, but measured polarizations are much weaker than expected by NRQCD



Υ(nS) Cross Section

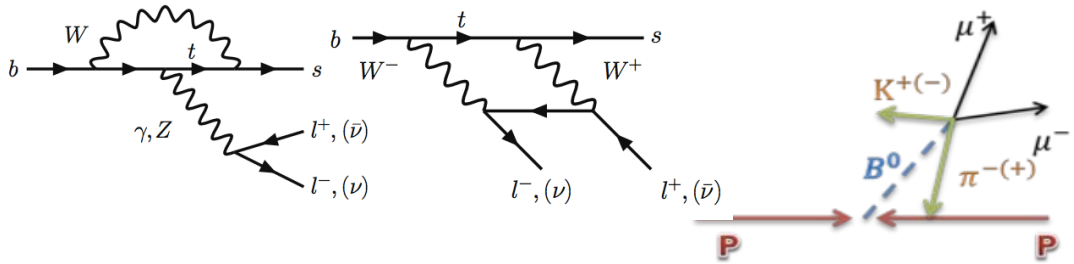




- Stringent test of QCD
- Measure differential cross sections shapes at high momenta
- Shape is well described by a power-law for all three S-states
- Challenge to theoretical models

$$\left.\frac{d\sigma\,(\mathrm{pp}\to\Upsilon(nS))}{dp_{\mathrm{T}}}\right|_{|y|<0.6}\times\mathcal{B}\left(\Upsilon(nS)\to\mu^{+}\mu^{-}\right)=\frac{A}{C+\left(\frac{p_{\mathrm{T}}}{p_o}\right)^{\alpha}}$$

$B^0 \rightarrow K^{*0}\mu^+\mu^-$



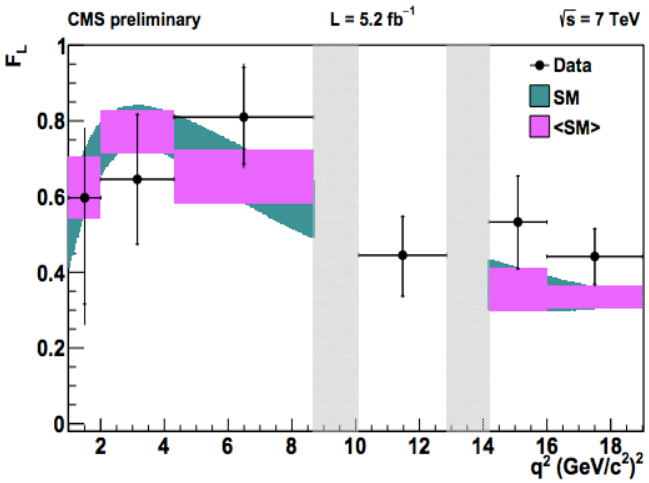
$B^0 \rightarrow K^{*0}(K^+\pi^-)\ J/\psi\ (\mu^+\mu^-)$

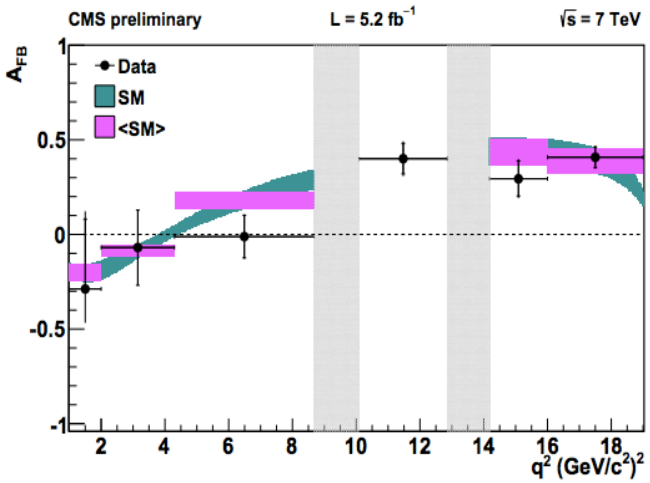
- F_L: 0.554 ± 0.004 (stat) ➜ PDG value 0.570 ± 0.008
- A_{FB}: −0.004 ± 0.004 (stat) ➜ compatible with zero

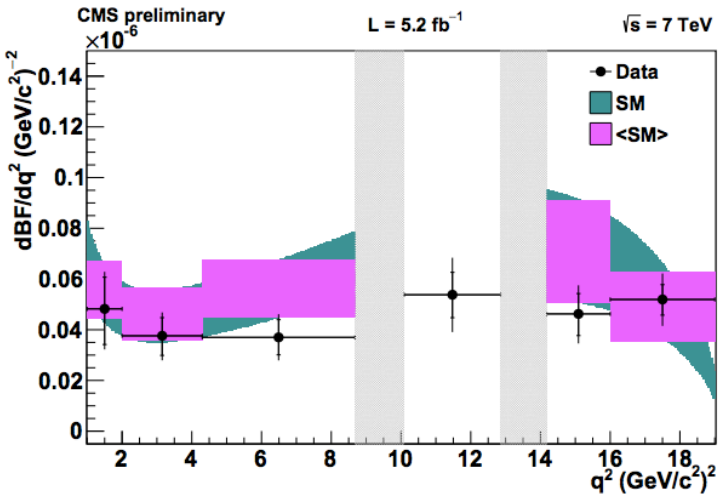
$B^0 \rightarrow K^{*0}(K^+\pi^-)\ \psi(2S)\ (\mu^+\mu^-)$

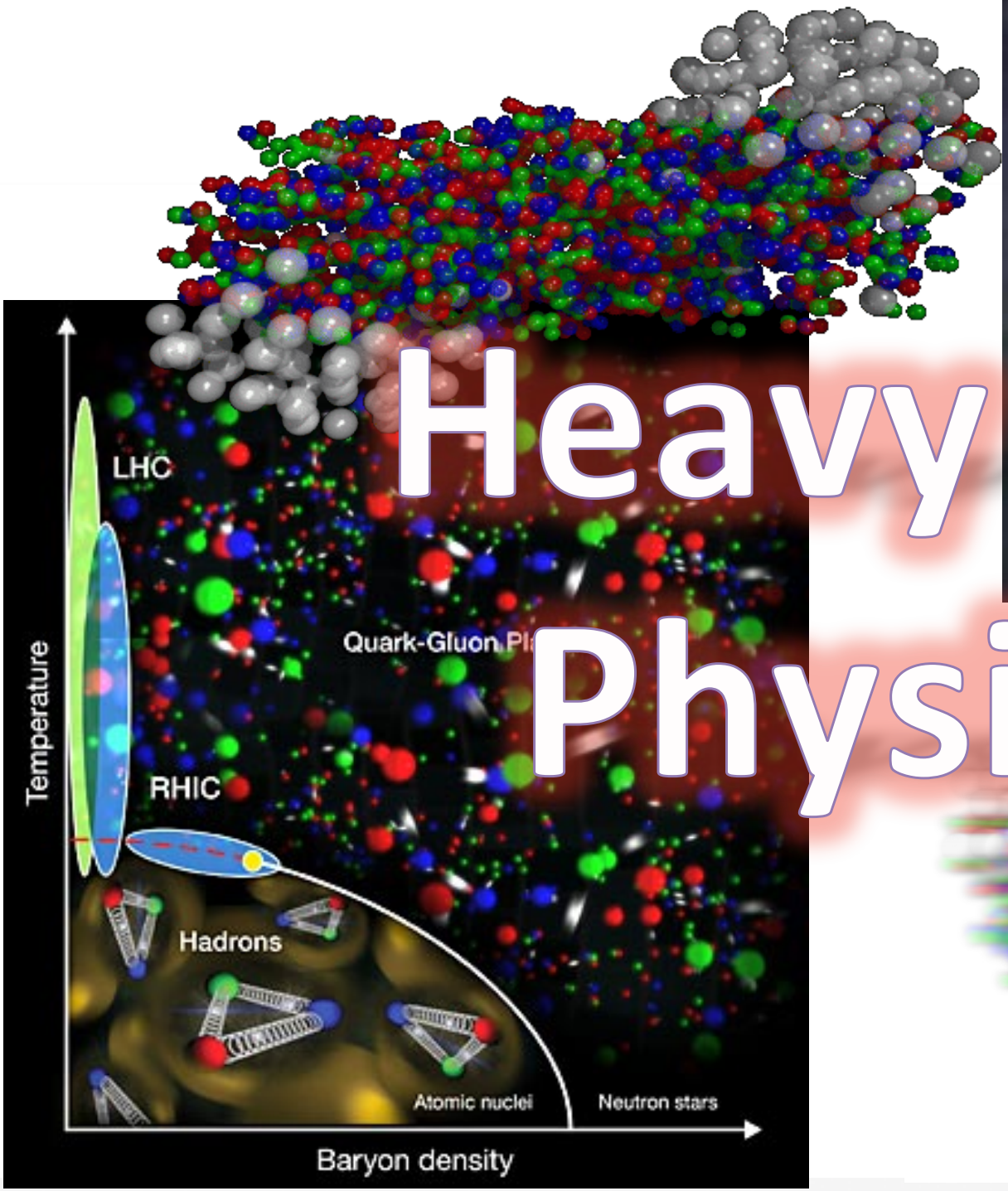
- F_L: 0.509 ± 0.016 (stat) ➜ PDG value 0.46 ± 0.04
- A_{FB}: 0.013 ± 0.014 (stat) ➜ compatible with zero

- The forbidden decay at the tree level in SM, sensitive to new physics
- Measure the branching ratio, the forward-backward asymmetry of muons and the longitudinal polarization of kaons as a function of q^2 – di-muon invariant mass squared
- Results are consistent with the SM

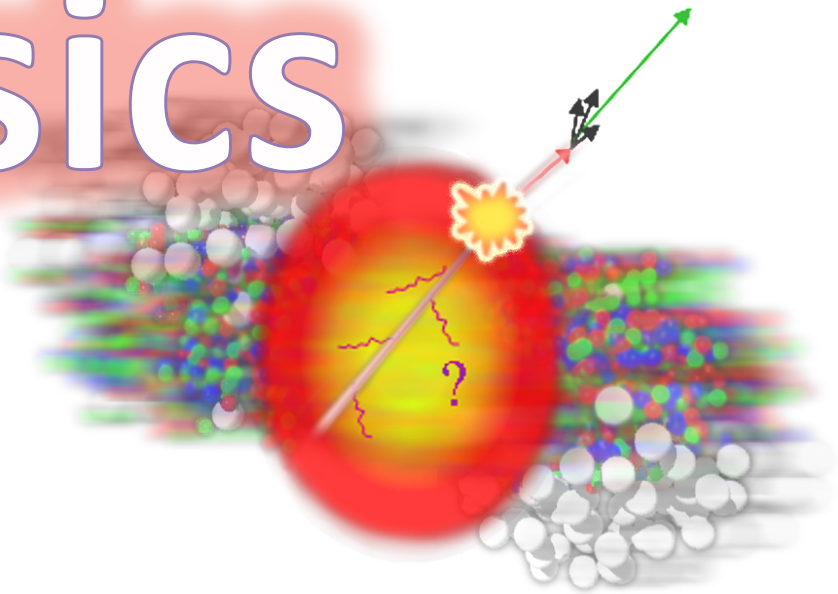








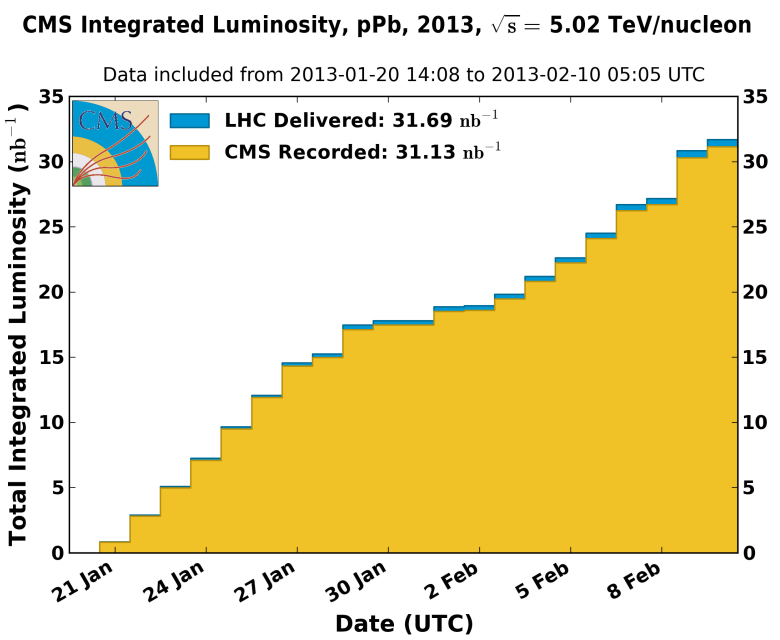
Heavy Ion Physics

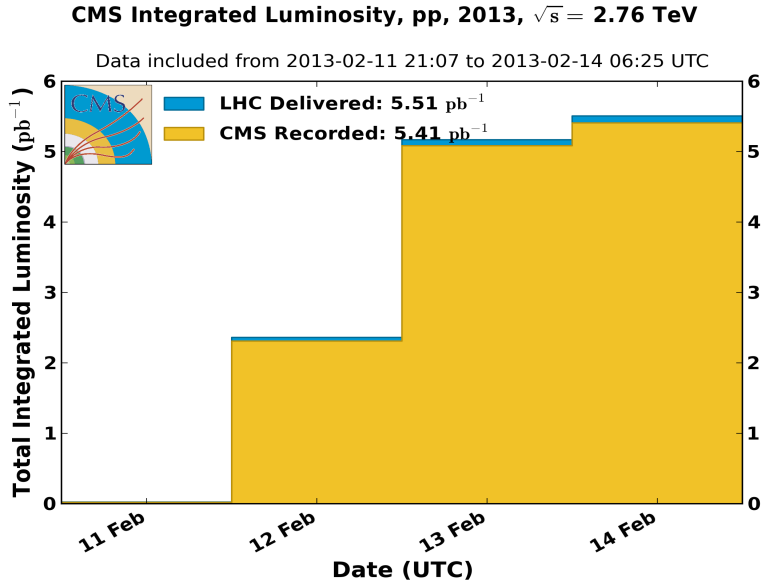


The pPb Run

- pPb is a good system to probe the gluon distribution at very low x, mainly via forward measurements

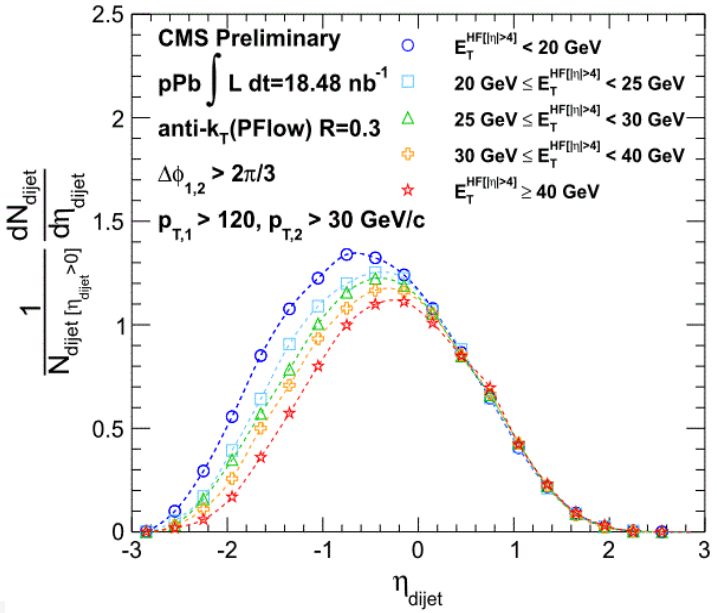
- pPb collisions at 5.02 TeV/nucleon, ~31 /nb recorded
- A short pp run at 2.76 TeV with ~5.5 /pb
- Similar statistics for hard probes in pp, PbPb at 2.76 TeV and pPb at 5.02 TeV

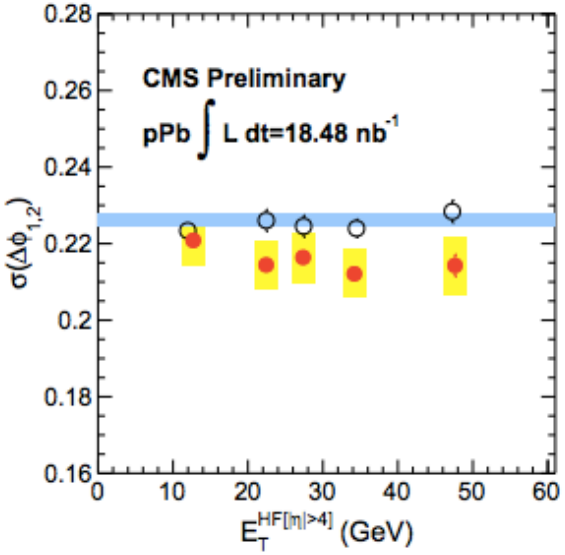


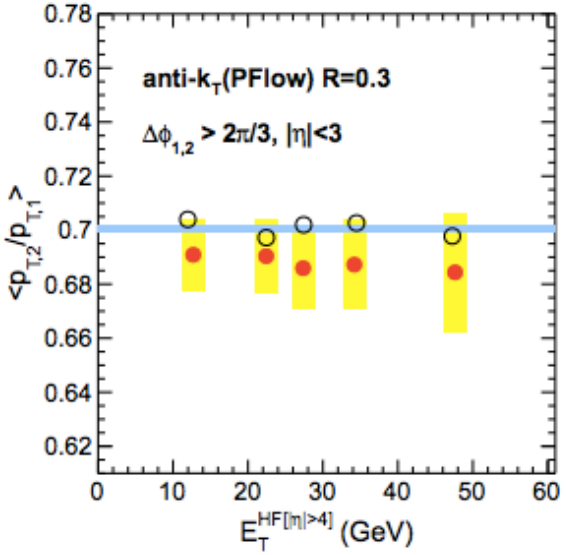


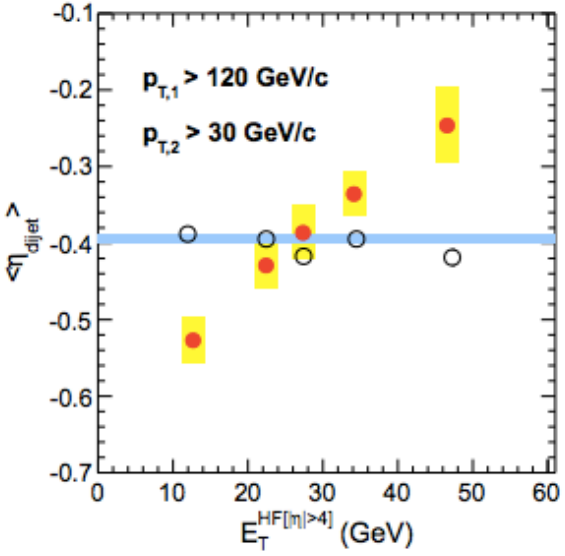
Di-jets in pPb

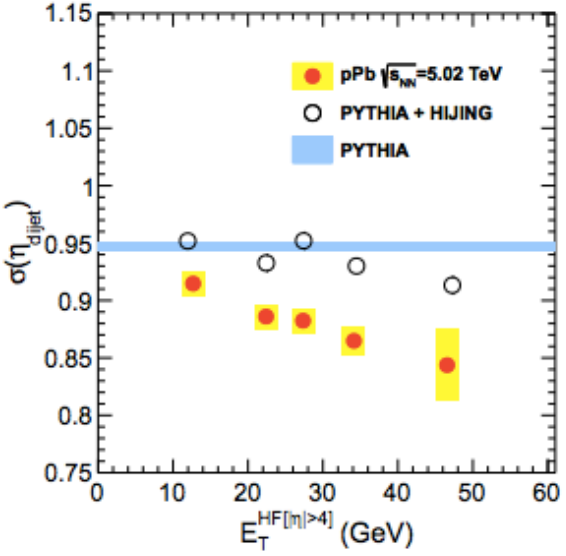
- $p_{T,2}/p_{T,1}$ insensitive to N_{part} in collision, no p_T imbalance
- Jets remain back to back
- Consistent with pp reference
- Strong modification of dijet pseudorapidity



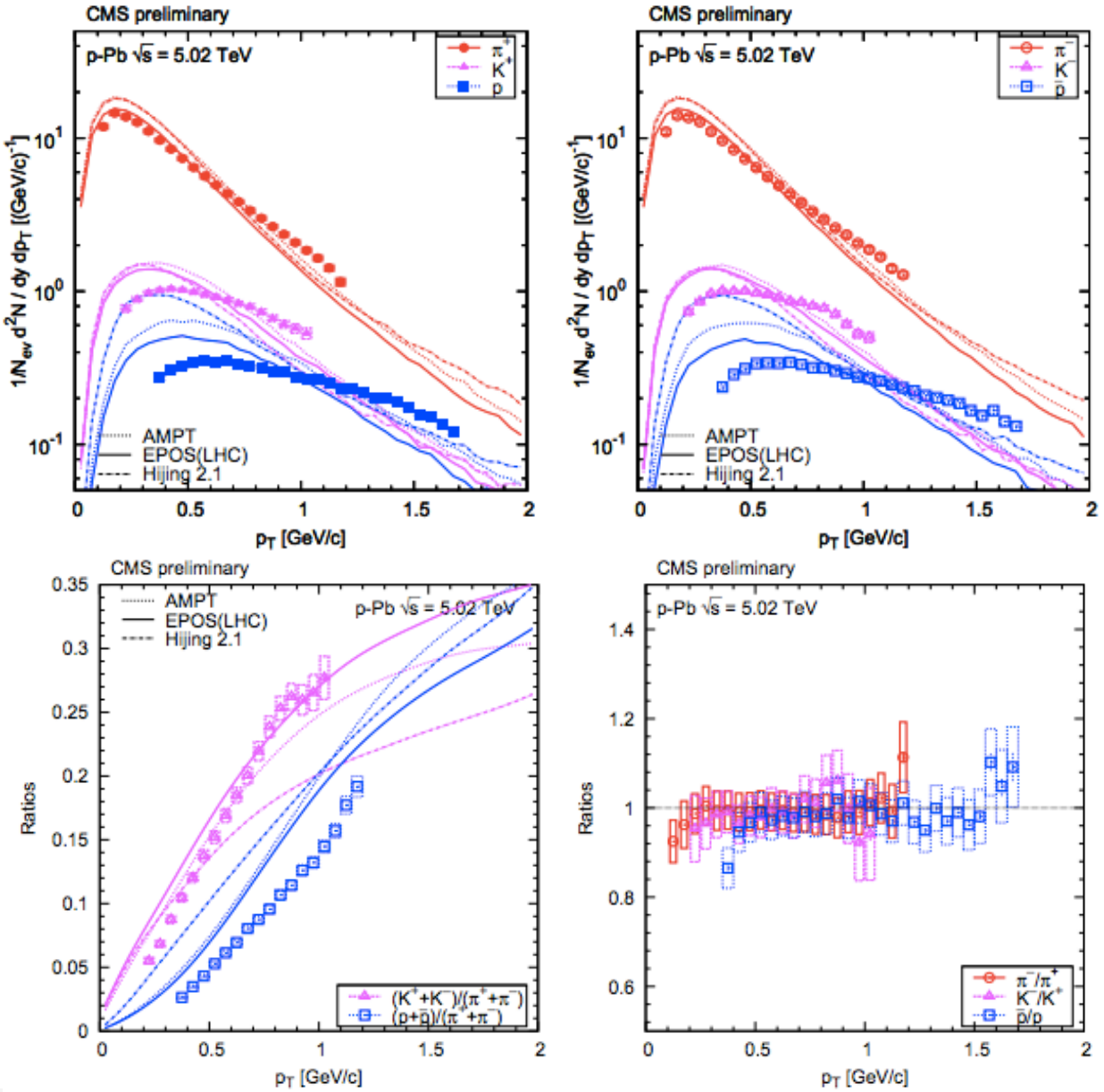








Inclusive Spectra of Charged Particles



- Average p_T increases rapidly with mass of hadron
- Spectrum is fitted to Tsallis-Pareto distribution

$$\frac{d^2N}{dy\,dp_T} = \frac{dN}{dy} \cdot C \cdot p_T \left[1 + \frac{(m_T - m)}{nT}\right]^{-n}$$

- All generators predict steeper p_T spectra
- Characteristics of particle production is strongly correlated with event particle multiplicity

Public CMS Results

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

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

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

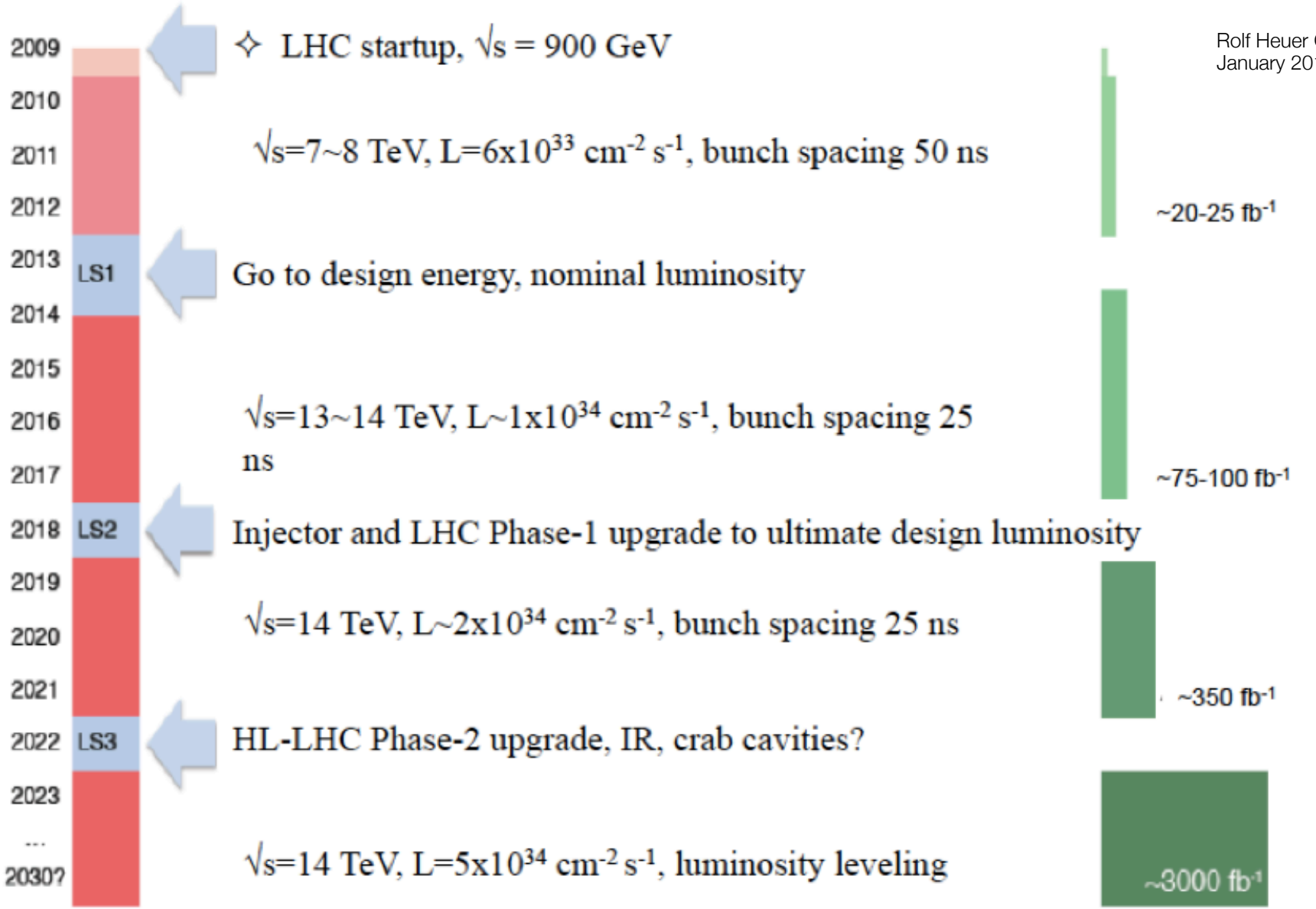
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

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

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

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

The LHC Timeline



Rolf Heuer CERN-DG
January 2013

Conclusions

- Rich physics program at CMS
- Higgs boson looks more and more like a Standard Model Higgs
- Overwhelming number of results, no compelling evidence for BSM physics
- Many new analysis and interpretations using 8 TeV dataset of 20 fb^{-1} are underway
- LHC is prerparing for 14 TeV collisions and high luminosity run
- Stay tuned for new results!