TOP + SM
CMS

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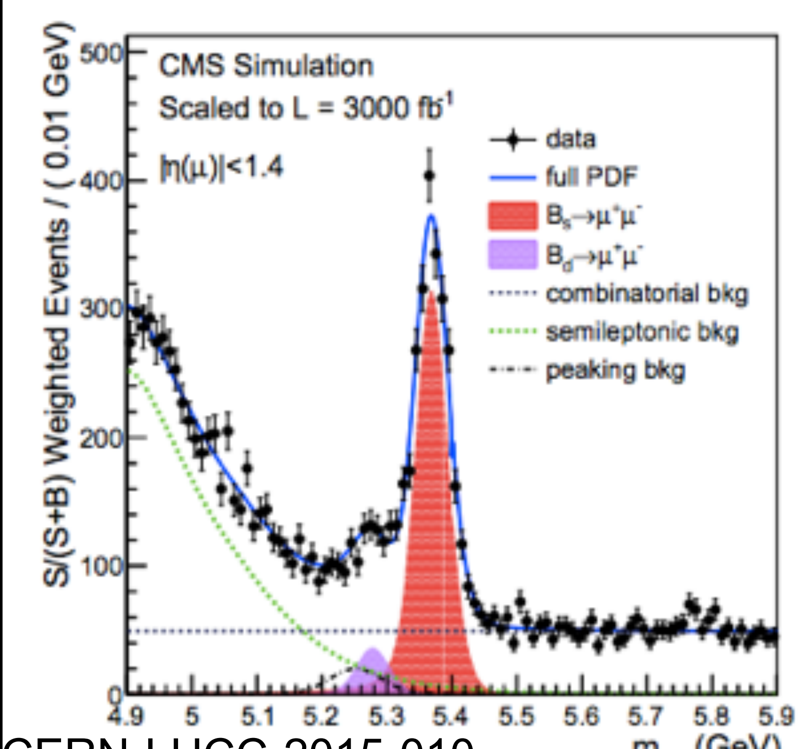
CMS internal work in progress.
Not for distribution

$B_{s,d} \rightarrow \mu\mu$

- very rare in SM
- B_d cross section 30 time slower than B_s
- Excellent benchmark for mass resolution (tracker), background rejection (track trigger)
- B_s will become precision measurement
- B_d significance up to 7σ with 3 ab^{-1}

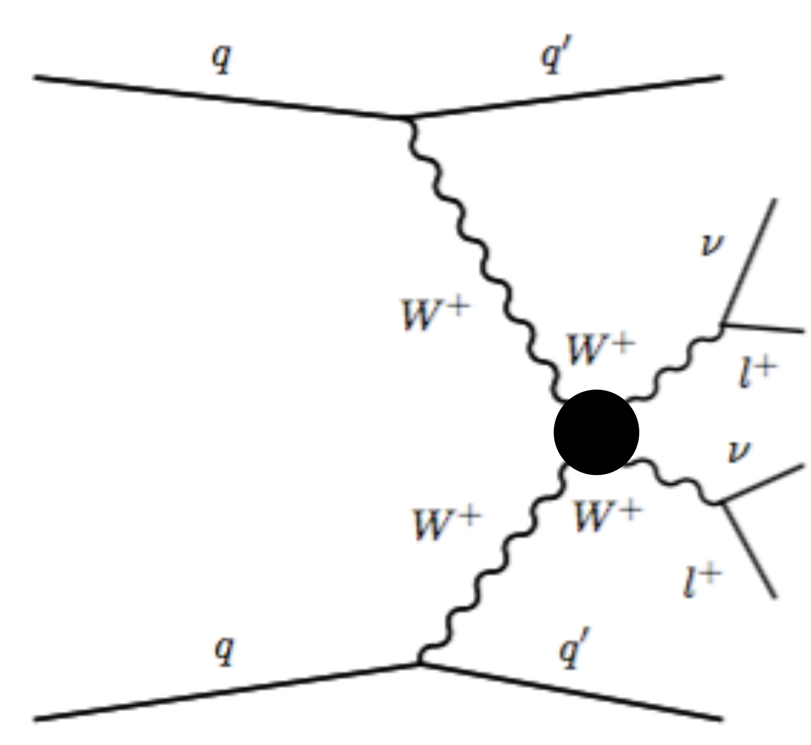


CERN-LHCC-2015-010

Vector boson scattering

- Currently unobserved
- Precisely calculable in SM
- Very sensitive to new physics (in part. LL mode) (resonances, other contrib.)

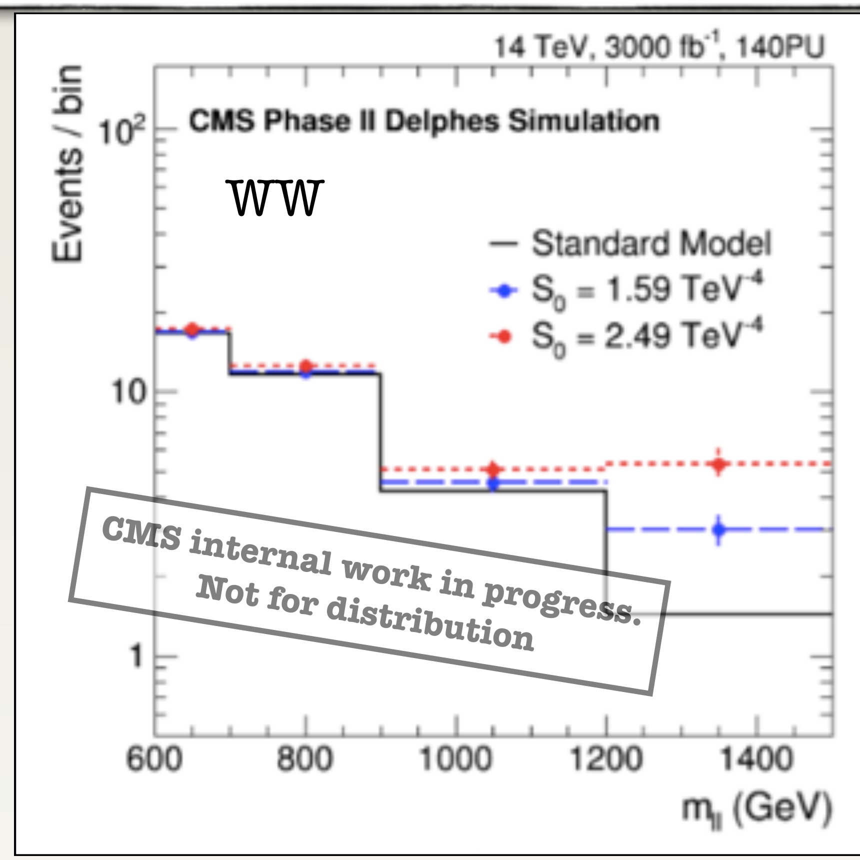
- Leptonic decays of V-Bosons
  - use forward jets to tag event (large $\Delta\eta$, high m_{jj})
  - exact number isolated high-p_T leptons
  - veto additional leptons
  - reconstruct vector bosons
  - many additional requirements

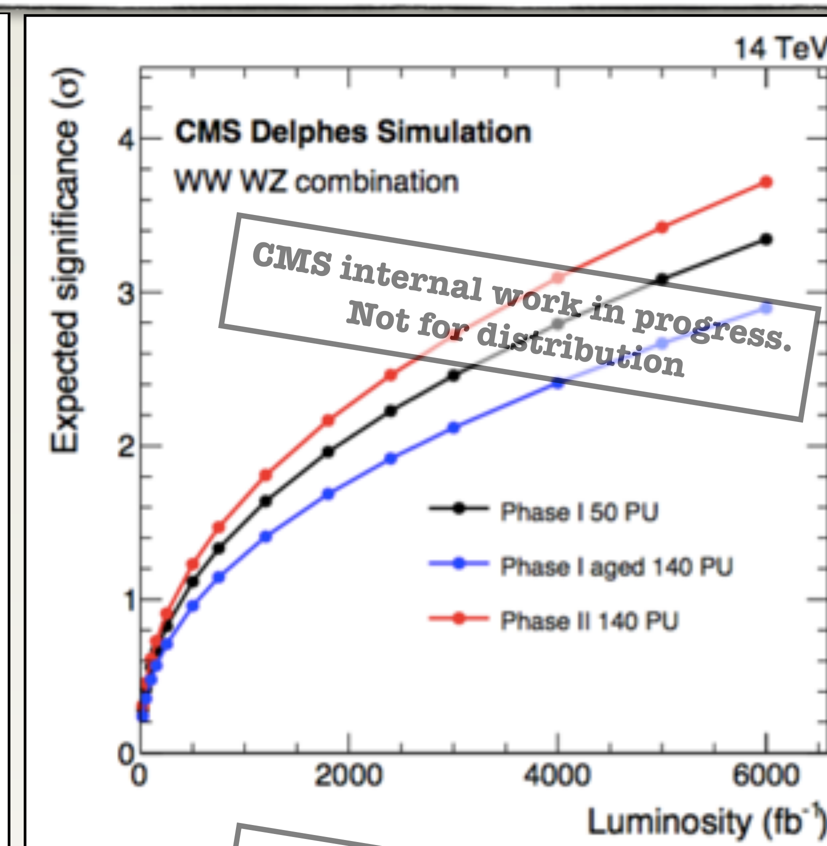


Vector Boson Scattering (beyond TP)

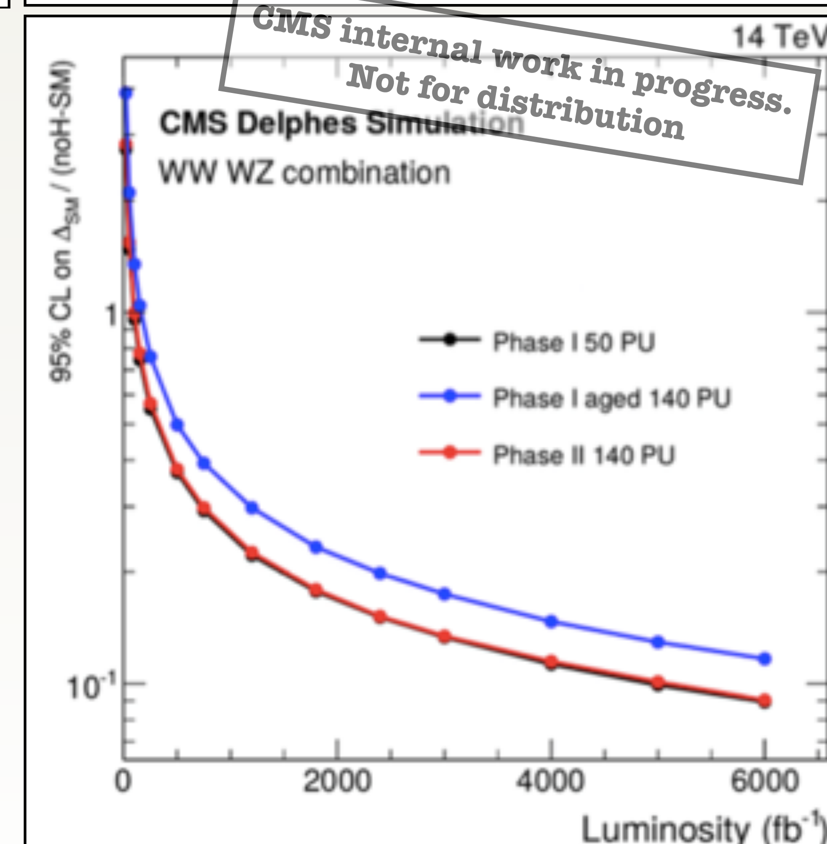
WW - same sign
- 2 leptons, same sign
- Missing E_T

WZ
- 3 leptons
- pair leptons to Z, assign remaining to W
- Missing E_T





Extraction
- 2D Fit of jet and lepton observables

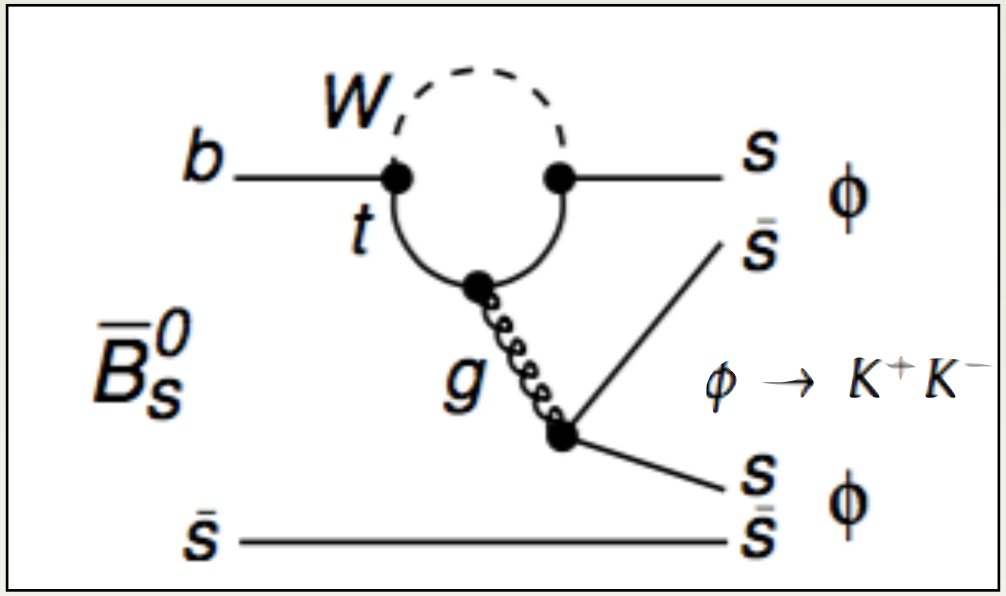


3 scenarios

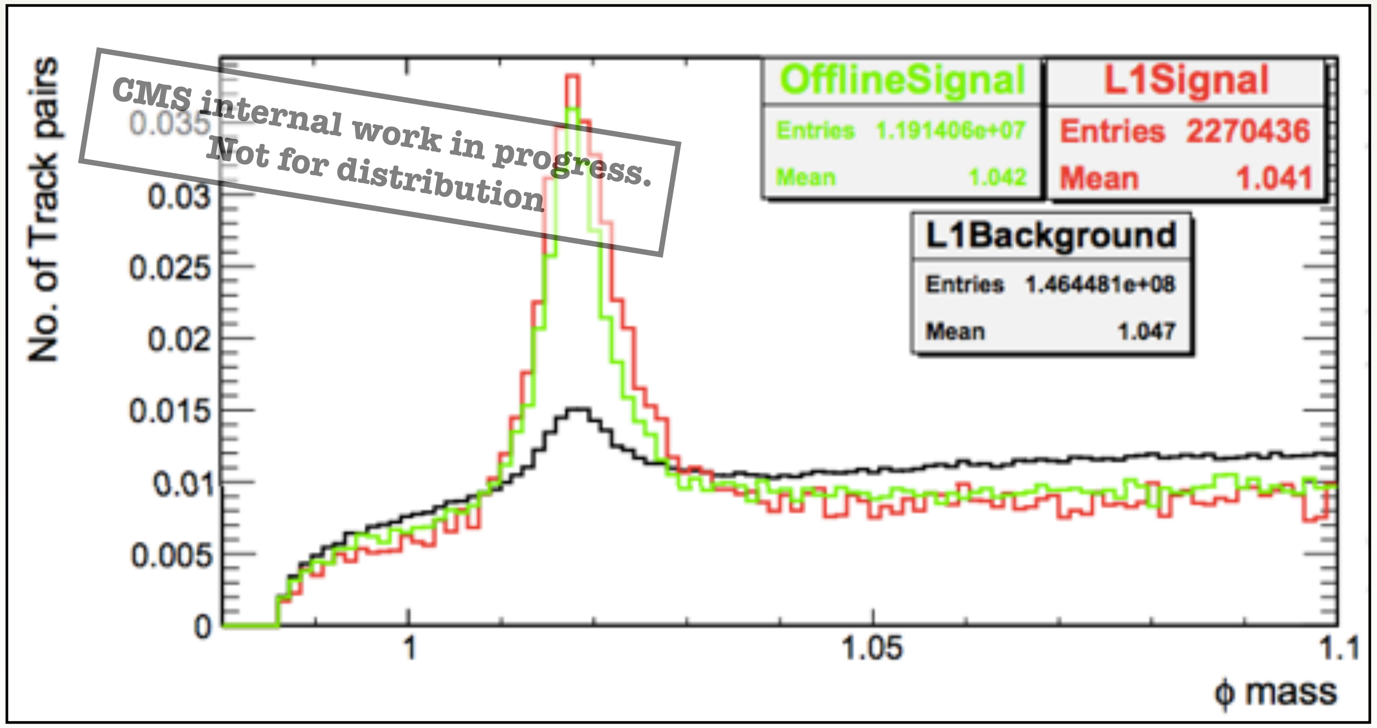
	Phase I	Phase II	Phase I aged
noH 95% CL exclusion	0.14	0.14	0.20
LL scattering discovery significance	2.50	2.75	2.14

for same luminosity

$B_s \to \varphi\varphi$



- Rare process in SM
- Can be used to measure CP-violating phase Φ_s
- For this decay $\Phi_s < 0.02$ in SM
- Deviations (Φ_s or cross-section) can indicate BSM physics at higher scales than directly accessible
- Excellent to benchmark tracking / track trigger performance
  - Level-1 trigger tracks $p_T > 2$ GeV
  - Reconstruct Kaons from pairings
    - Impose quality criteria on Kaon vertices
  - Reconstruct Φ from Kaon combinations
    - Impose quality criteria on Φ vertices
  - Reconstruct B_s



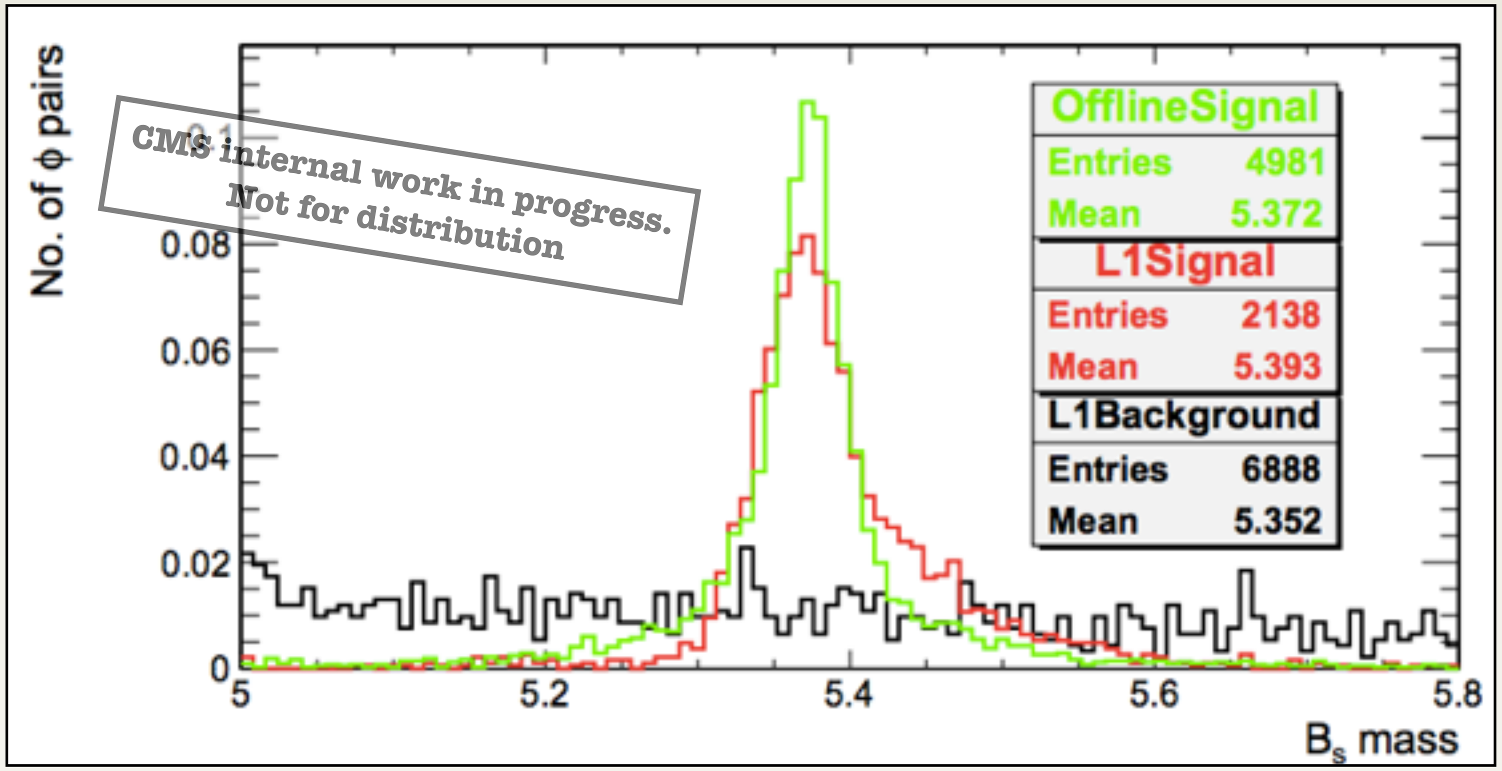
$B_s \to \varphi\varphi$

- Specify different working points and corresponding trigger rates

- 'Loose' working point
  - Track $p_T > 2$ GeV
  - $0.2 < \Delta R(\Phi) < 1$
  - $\Delta R(K) < 0.12$
  - vertices $d_{xy}, d_z < 1$cm
  - $0.99 < m_{KK} < 1.04$ GeV
  - $5.27 < m_{\Phi\Phi} < 5.49$

- 'Tight' working point
  - 'loose' criteria
  - $1.00 < m_{KK} < 1.03$ GeV
  - $5.29 < m_{\Phi\Phi} < 5.48$

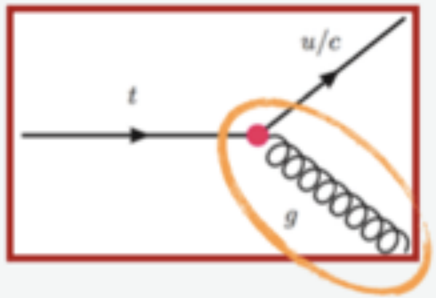
➡Reasonable efficiency and trigger rate

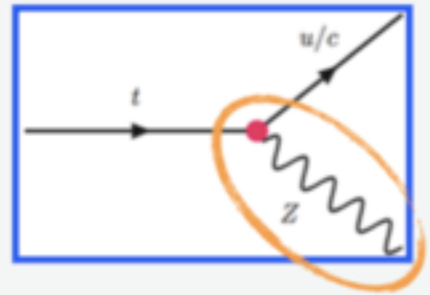


Loose Dataset	Efficiency (%)	Rate (kHz)
L1 Tracks	41.6 ± 1.2	27.9 ± 1.7
Offline Tracks	64.6 ± 1.4	n/a

Tight Dataset	Efficiency (%)	Rate (kHz)
L1 Tracks	36.6 ± 1.1	13.3 ± 1.2
Offline Tracks	57.7 ± 1.3	n/a

Top + gluon

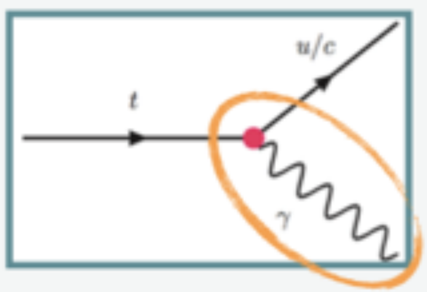


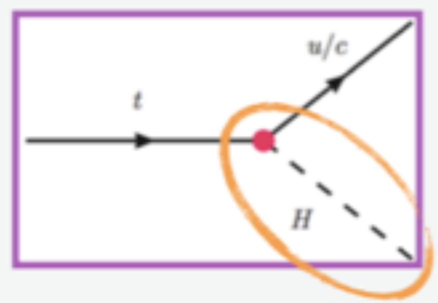


Top + Z

$$\mathcal{L} = \sum_{q=u,c} \Big[\sqrt{2} g_s \frac{\kappa_{gqt}}{\Lambda} \bar{t} \sigma^{\mu\nu} T_a (f^L_{Gq} P_L + f^R_{Gq} P_R) q G^a_{\mu\nu} + \frac{g}{\sqrt{2} c_W} \frac{\kappa_{zqt}}{\Lambda} \bar{t} \sigma^{\mu\nu} (f^L_{Zq} P_L + f^R_{Zq} P_R) q Z_{\mu\nu} - e \frac{\kappa_{\gamma qt}}{\Lambda} \bar{t} \sigma^{\mu\nu} (f^L_{\gamma q} P_L + f^R_{\gamma q} P_R) q A_{\mu\nu} + \frac{g}{\sqrt{2}} \bar{t} \kappa_{Hqt} (f^L_{Hq} P_L + f^R_{Hq} P_R) q H \Big] + \text{h.c.}$$

Top + gamma





Top + Higgs

	SM	2HDM	MSSM
BR(t→cg)	$\simeq 5 \times 10^{-12}$	10^{-8} - 10^{-4}	10^{-7} - 10^{-6}
BR(t→cZ)	$\simeq 1 \times 10^{-14}$	10^{-10} - 10^{-6}	10^{-7} - 10^{-6}
BR(t→cγ)	$\simeq 5 \times 10^{-14}$	10^{-9} - 10^{-7}	10^{-9} - 10^{-8}
BR(t→cH)	$\simeq 3 \times 10^{-15}$	10^{-5} - 10^{-3}	10^{-9} - 10^{-5}

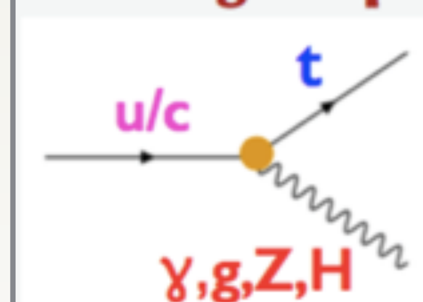
In SM

- Forbidden at tree level
- Only via loops, but highly suppressed

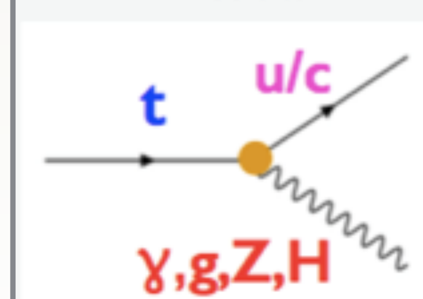
Search

- Single top (production)
- Top-pair (decay)

in single top



in ttbar

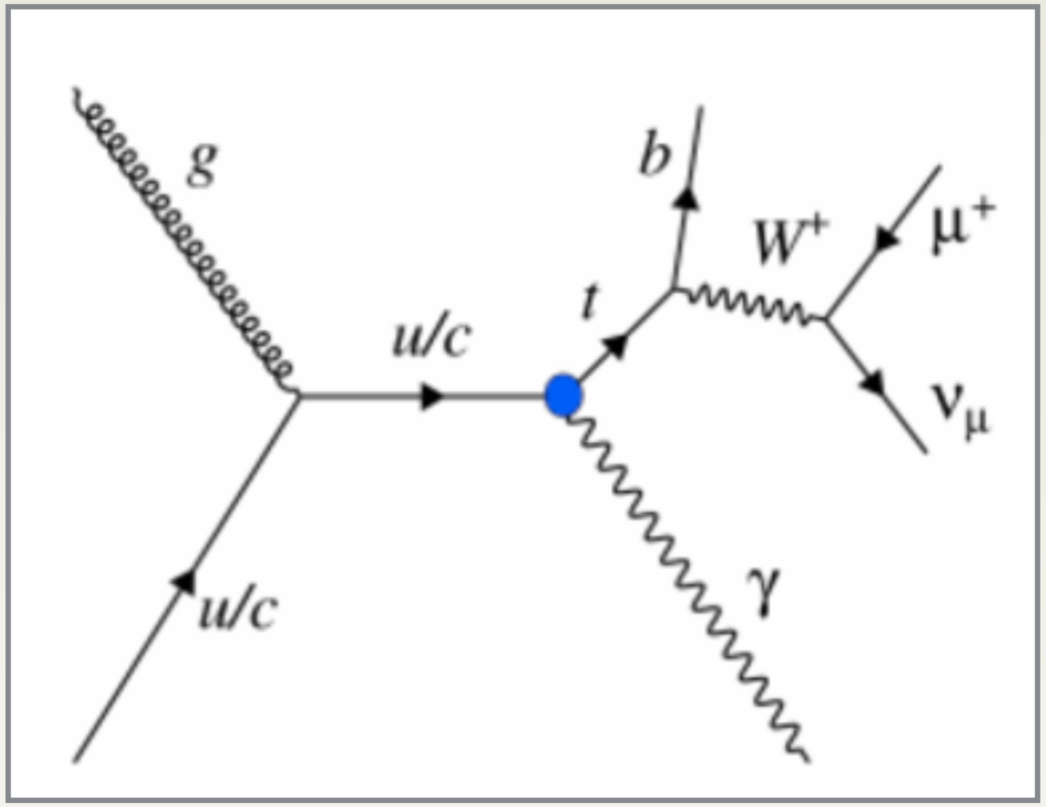


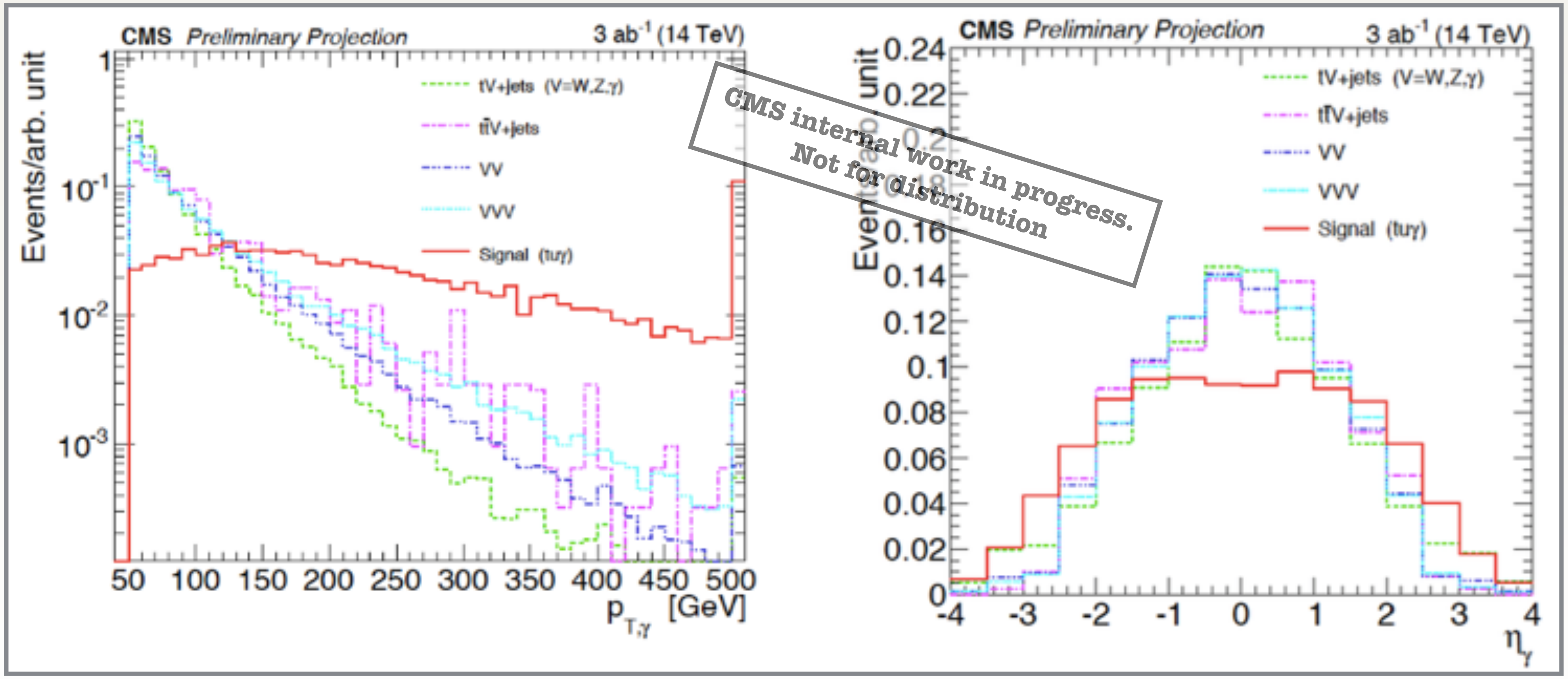
FCNC tqγ

- Following published 8 TeV analysis (arXiv:1511.03951) → but Cut and Count

Selection

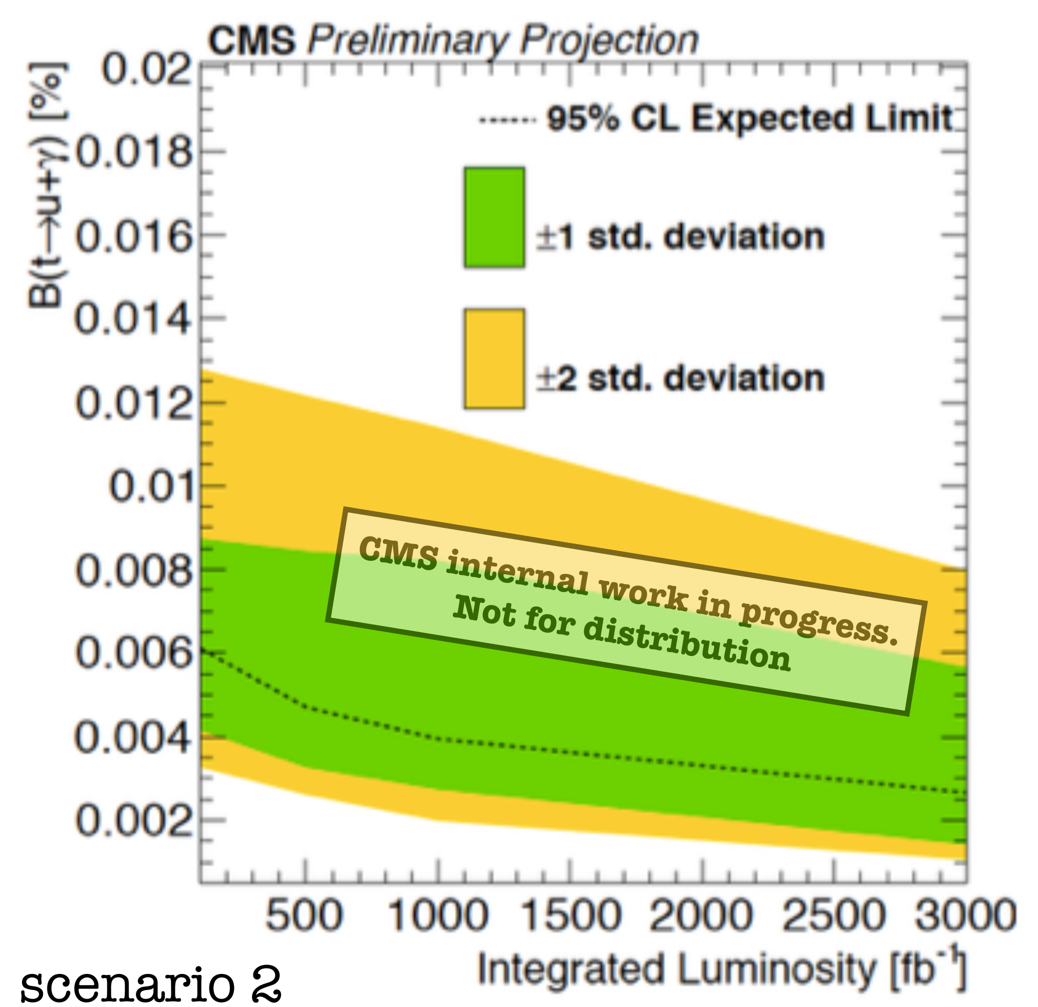
- Exactly 1 tight, isolated μ
  - Veto loose μ/e
- Exactly 1 b-tagged jet
- Exactly 1 isolated high E_T photon
  - well separated from jet and μ ΔR=0.7
- Reconstructed $130 < m_t < 220$ GeV





FCNC tqγ

- Dominant contributions from backgrounds
  - Assumed to be controllable with large statistics from 3 ab^{-1}
- Consider two scenarios for systematics
  - 1) No change w.r.t public 8 TeV
  - 2) Based on estimates/studies for an improvement with Phase II detector / statistics



scenario 2

Table 4: Upper limits at the 95% CL for $B(t \to u + \gamma)$ and $B(t \to c + \gamma)$, including the results obtained in 8 TeV data, which corresponds to an integrated luminosity of 19.7 fb^{-1} and the expected limits for 14 TeV with an integrated luminosity up to 3000 fb^{-1} using CMS DELPHES simulation for two scenarios for considering systematic uncertainties.

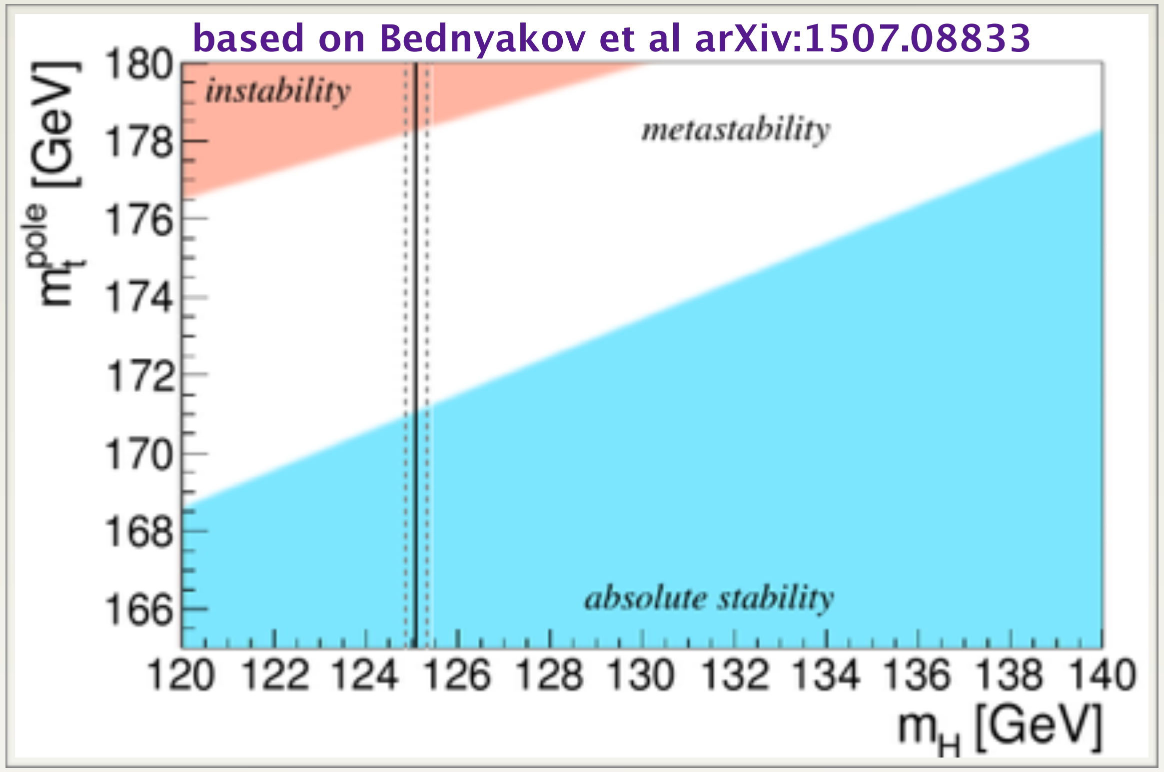
$B(t \to q + \gamma)$	19.7 fb^{-1} at 8 TeV	3 ab^{-1} at 14 TeV (Scenario 1)	3 ab^{-1} at 14 TeV (Scenario 2)
$B(t \to u + \gamma)$	1.7×10^{-4}	4.6×10^{-5}	2.7×10^{-5}
$B(t \to c + \gamma)$	2.2×10^{-3}	3.4×10^{-4}	2.0×10^{-4}

➡Sensitivity increase by factor 3 to 10 (depending on channel and scenario)

The Top-Quark Mass

The top-quark mass - theory perspective

- Parameter in the Lagrangian
- Beyond LO: renormalisation
- Definition becomes scheme dependent (pole, MSR MSbar…)
- Essential for EWK precision fits, EWK vacuum stability



The top-quark mass - experimental perspective

- Highly precise MC mass measurements
- Pole mass measurements with increasing precision
- Work ongoing to relate both

Worth to continue measuring the top-quark (MC) mass with HL-LHC?

- Possible to go (multi) differential measurements
  - Gain insight into tunes, different corners of phase space
- Almost unlimited possibilities for data-driven constraints

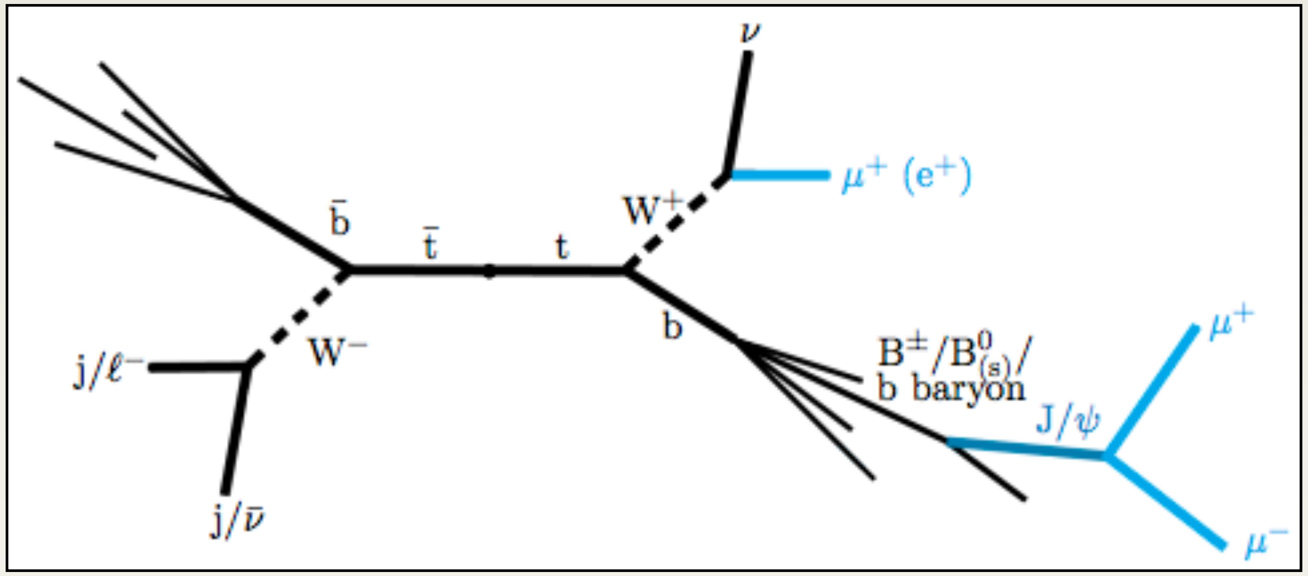
Strategies considered

'Standard' methods

- Reconstruct invariant 3-jet mass (l+jets / all-jets)

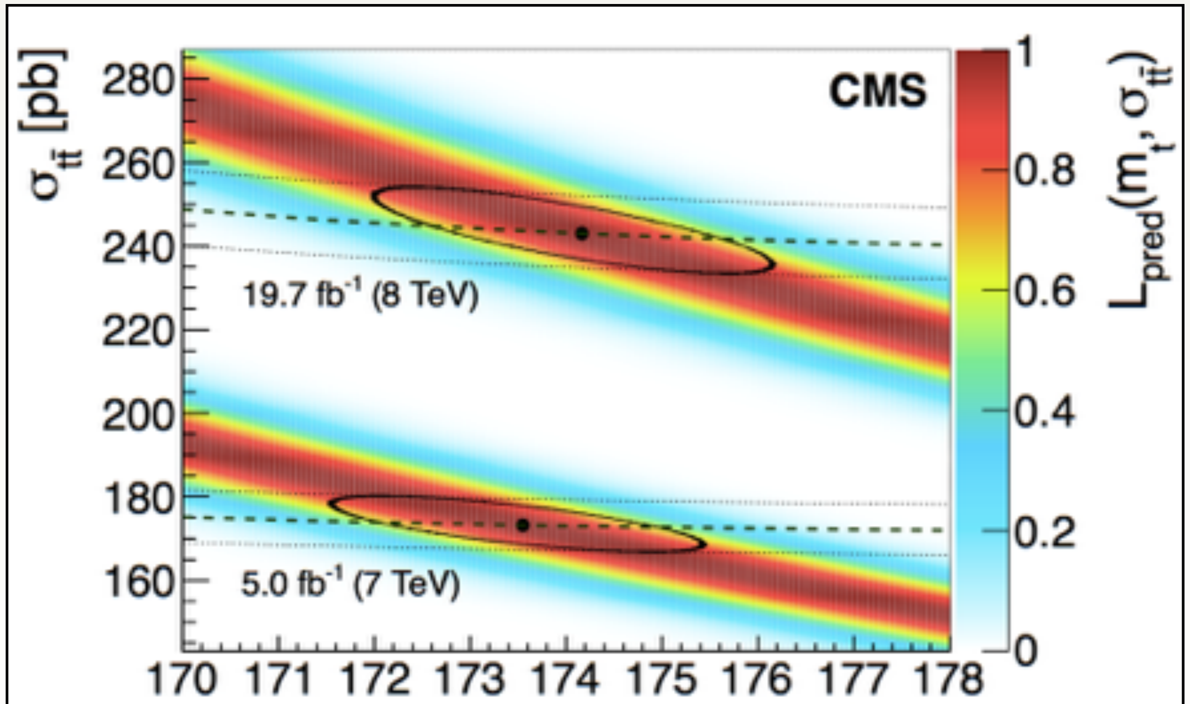
Track-based observables

- Use tracking and vertices
- J/Psi, m_{svl}



Pole mass from cross-section

- Use dependence of NNLO prediction on the top-quark pole mass



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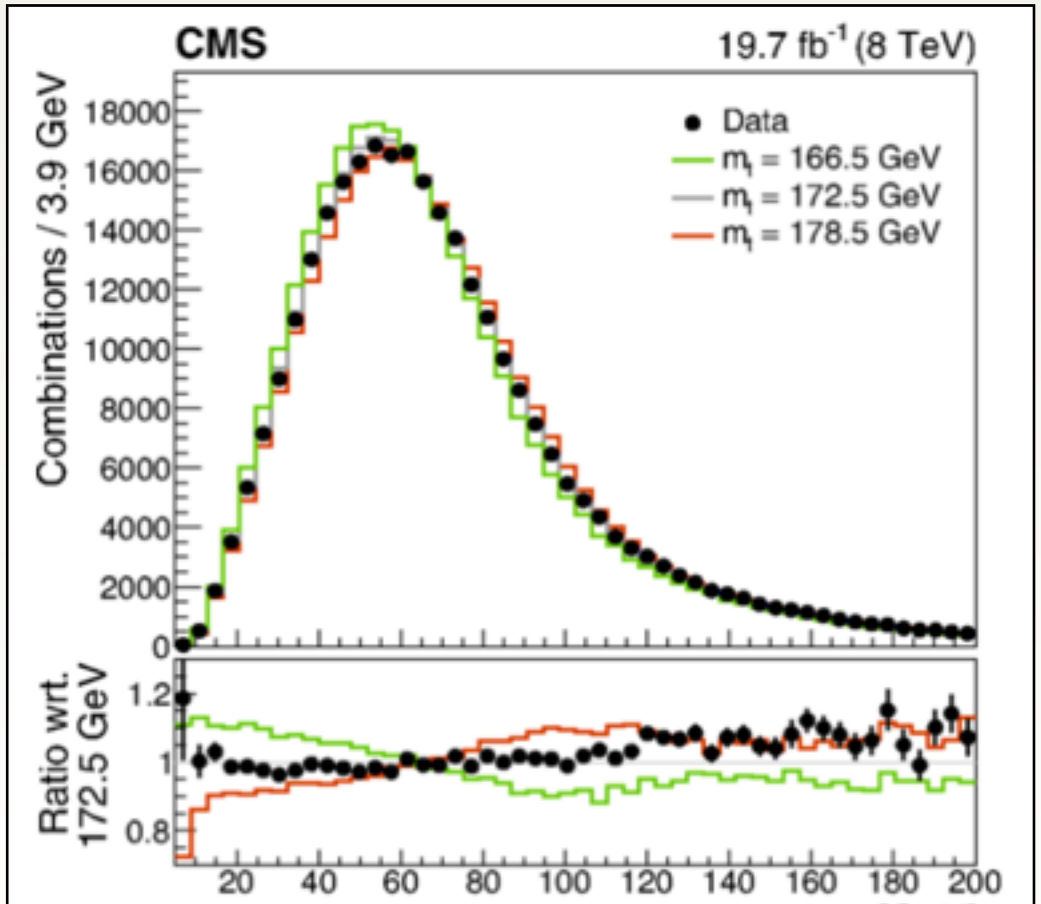

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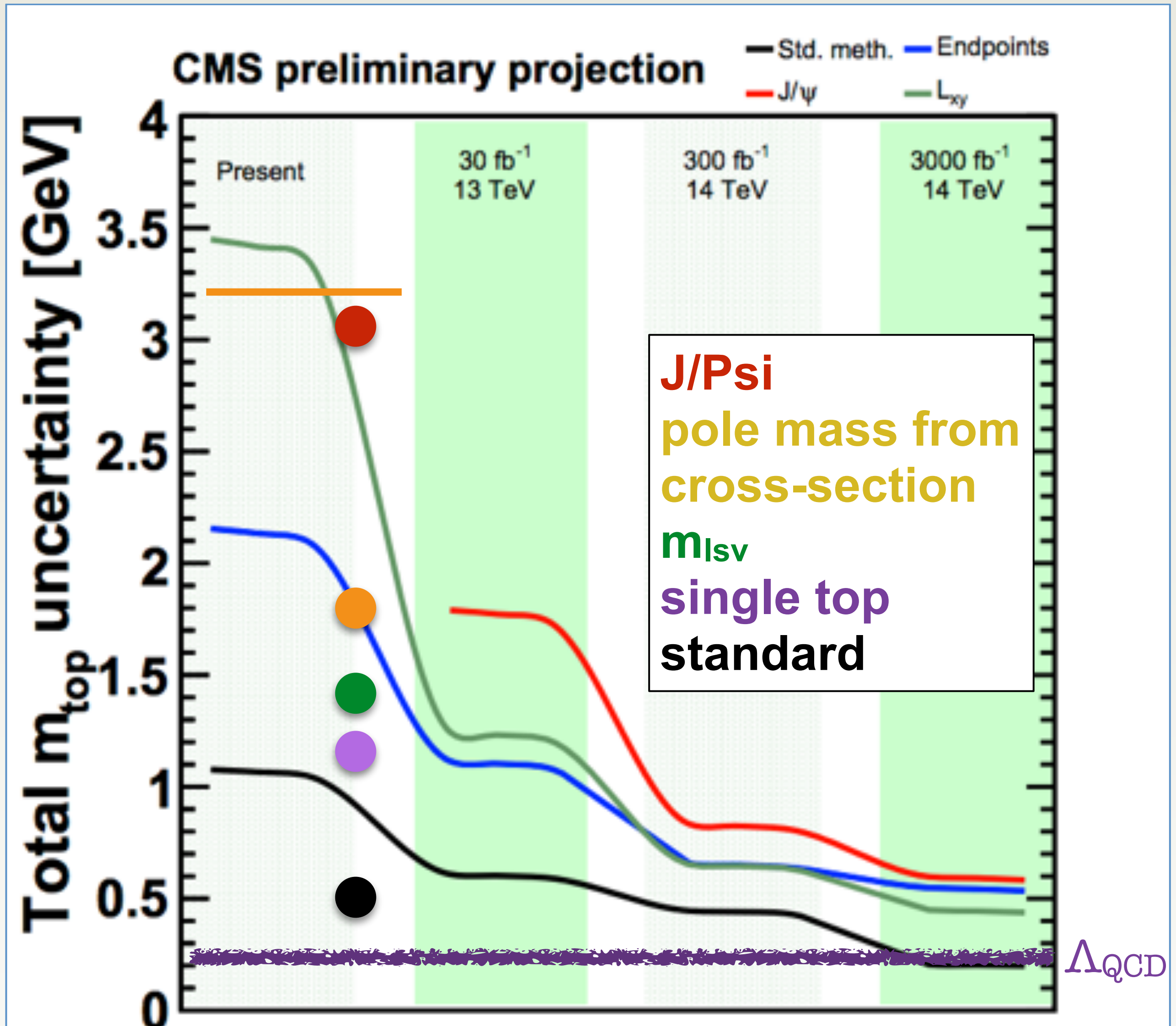
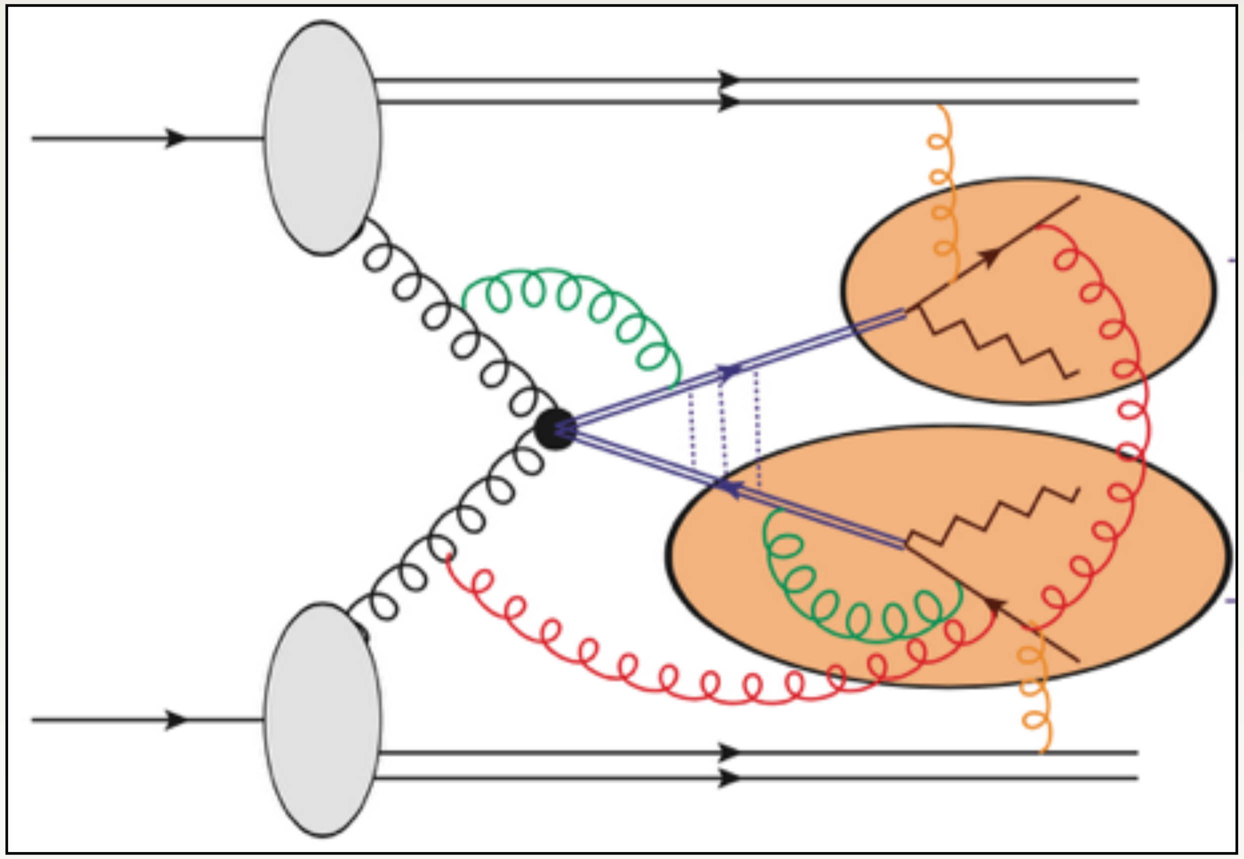


CMS-PAS-FTR-**13**-017 (heavily modified)

- What do we expect for the HL LHC given the experience we gained?
- Simple scaling gives estimate of status today
  - Estimates of relative uncertainties w.r.t other analysis techniques were right!
- All analyses may enter scales of Λ_{QCD}

Systematic uncertainties

- Common
  - Jet energy scale
  - B-hadron branching ratios (B → υ + X)
  - ME generator choice
  - Renorm. and factorisation scales
  - Modeling of hadronisation
- Track-based observables (m_{lSV}, J/Psi,...)
  - Lepton energy scales
  - Top-quark p_T modelling
- Single top
  - Background contributions
  - Fit calibration

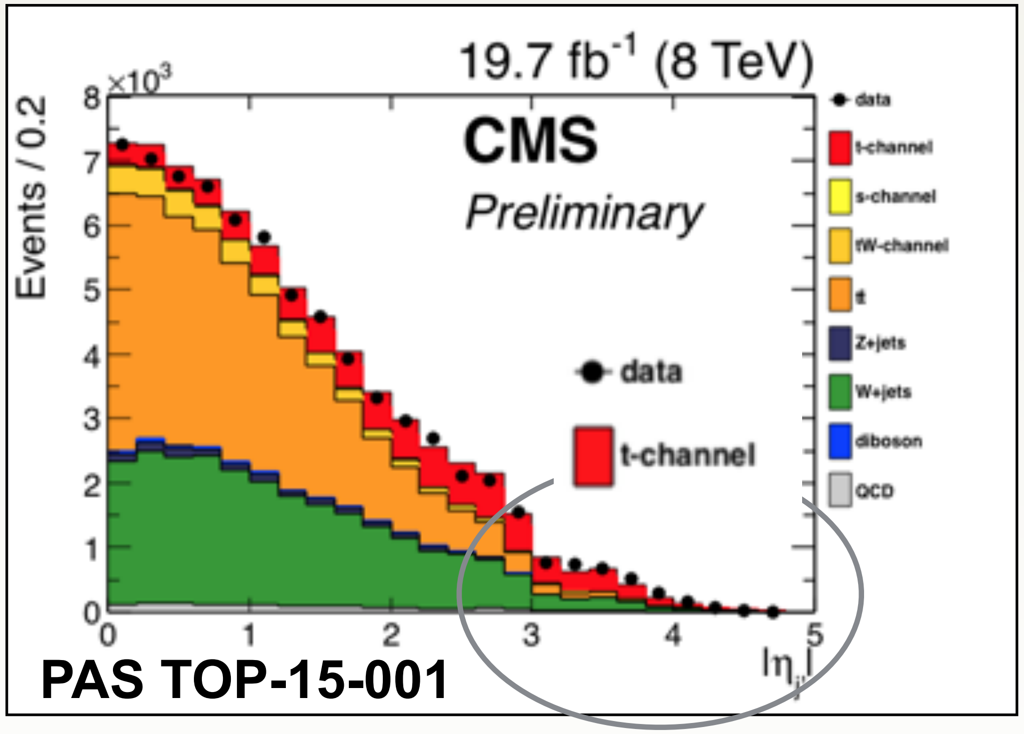


➡Large contribution of modelling uncertainties

Assumptions

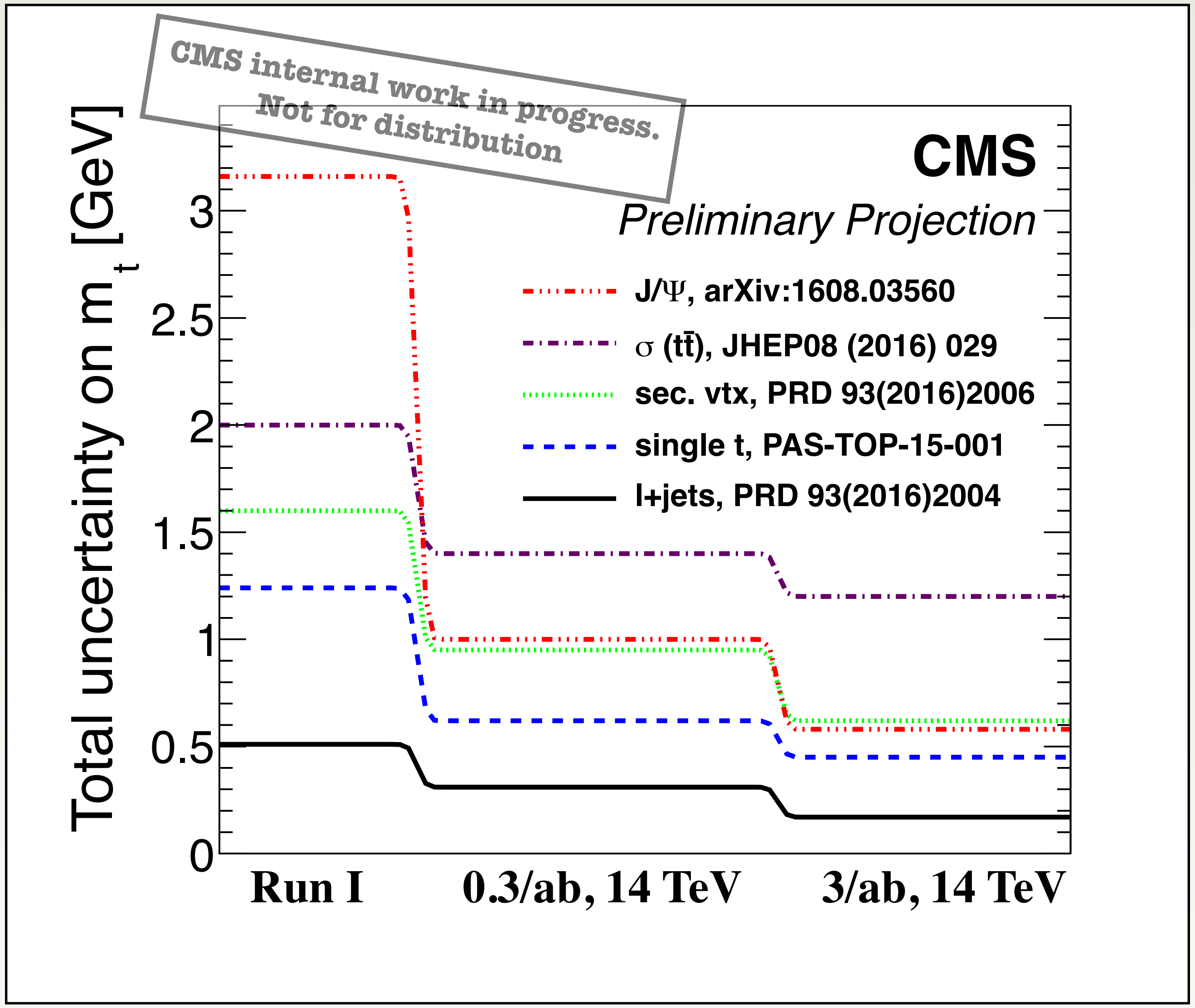
- Modelling (efforts already performed/started)
  - Full NLO MC, well understood and studied
  - Differential studies of the top-quark mass (differential m_t)
    - Better understanding of non-perturbative effects / tunings
  - Measurements of UE and b-fragmentation studies (directly in top-quark events)
  - Differential cross-section measurements
    - Allow to distinguish between NLO generators / constrain them and confirm NNLO predictions
  - Use differential NNLO k-factors to improve NLO MC

- Experimental effects
  - Differential m_t
    - Give insight into JES and detector effects in various corners of phase space.
    - Useful model to estimate how statistical precision of data-driven constraints on experimental systematics evolves.
  - Analysis techniques: 3D, or "nD"-fits (profiling)
    - Many possibilities with high statistics to constrain systematics in-situ
  - New detector components
    - Kinematic coverage, resolutions, ...
  - Increasing pile-up / trigger thresholds
    - Mitigated by cross-section increase



Projections

- Clear benefit from statistics for J/Psi
  - About same as secondary vertices
- Moderate improvement for pole mass from cross sections
  - Ultimately limited by luminosity uncertainty and theory uncertainty (no N^3LO assumed)
- Single top:
  - Benefit from statistics and modelling improvements
- 'standard' l+jets
  - Benefit from differential studies constraining modelling



- All MC mass analysis will go well below 1 GeV uncertainty.
  - Differences in production/decay mechanism may be visible
- Likely even more analyses techniques become available not covered here
  - More in-situ constrains

Summary

$B_{s,d} \to \mu\mu$

- B_s becomes precision measurement, B_d discovery

Vector boson scattering

new w.r.t.
tech. prop.

- High sensitivity to BSM at the EWK scale
- Up to 2.8σ discovery significance for LL-scattering

$B \to \Phi\Phi$

- BSM physics at higher scales than directly accessible
- Dedicated track trigger feasible

FCNC tqγ

- Not yet completely optimised strategy
- Sensitivity increase by factor 3 to 10 (depending on channel and scenario)

Top-mass measurements (mostly systematics)

- J/Psi benefits from statistics
- General precision increase from better understanding of modelling
- Very high potential for in-situ constraints