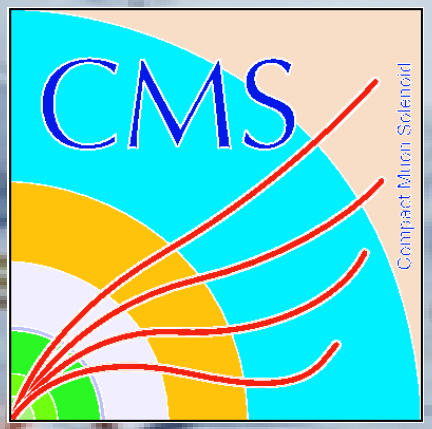
TOP Properties at CMS

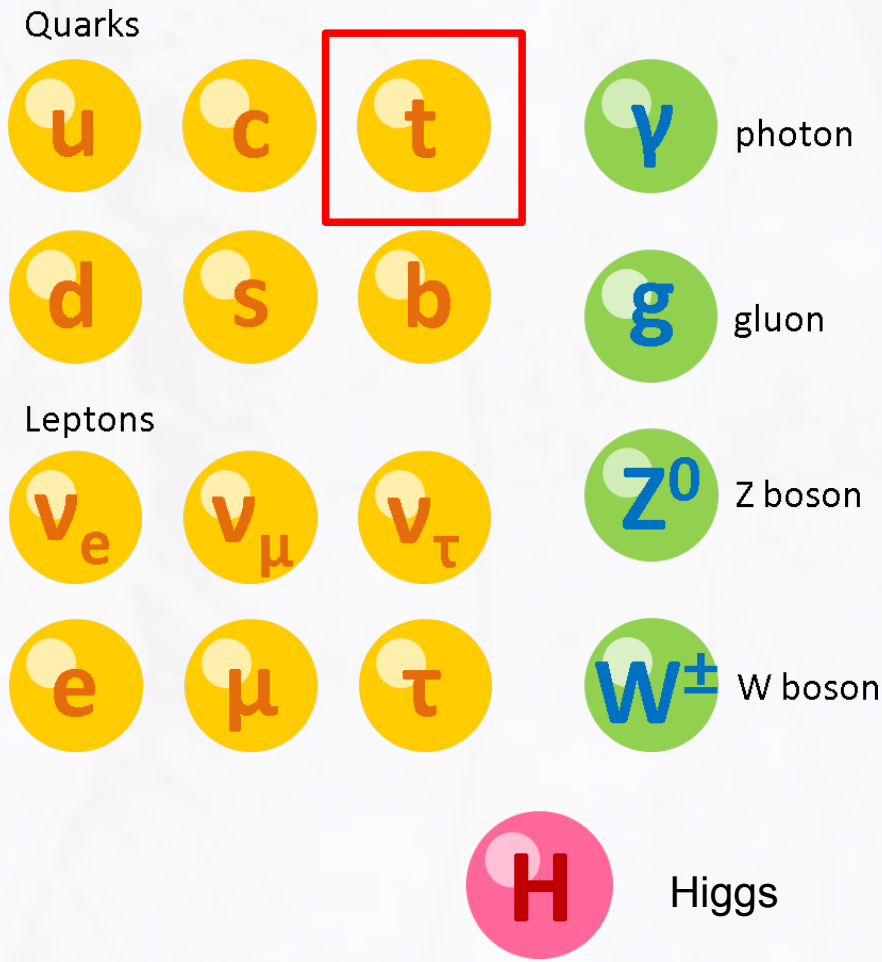


Yuan CHAO,
(National Taiwan University, TW)
On behalf of the CMS collaboration

Les Rencontres de Physique
de La Vallée d'Aoste La Thuile
2014/02/23-03/01

Introduction

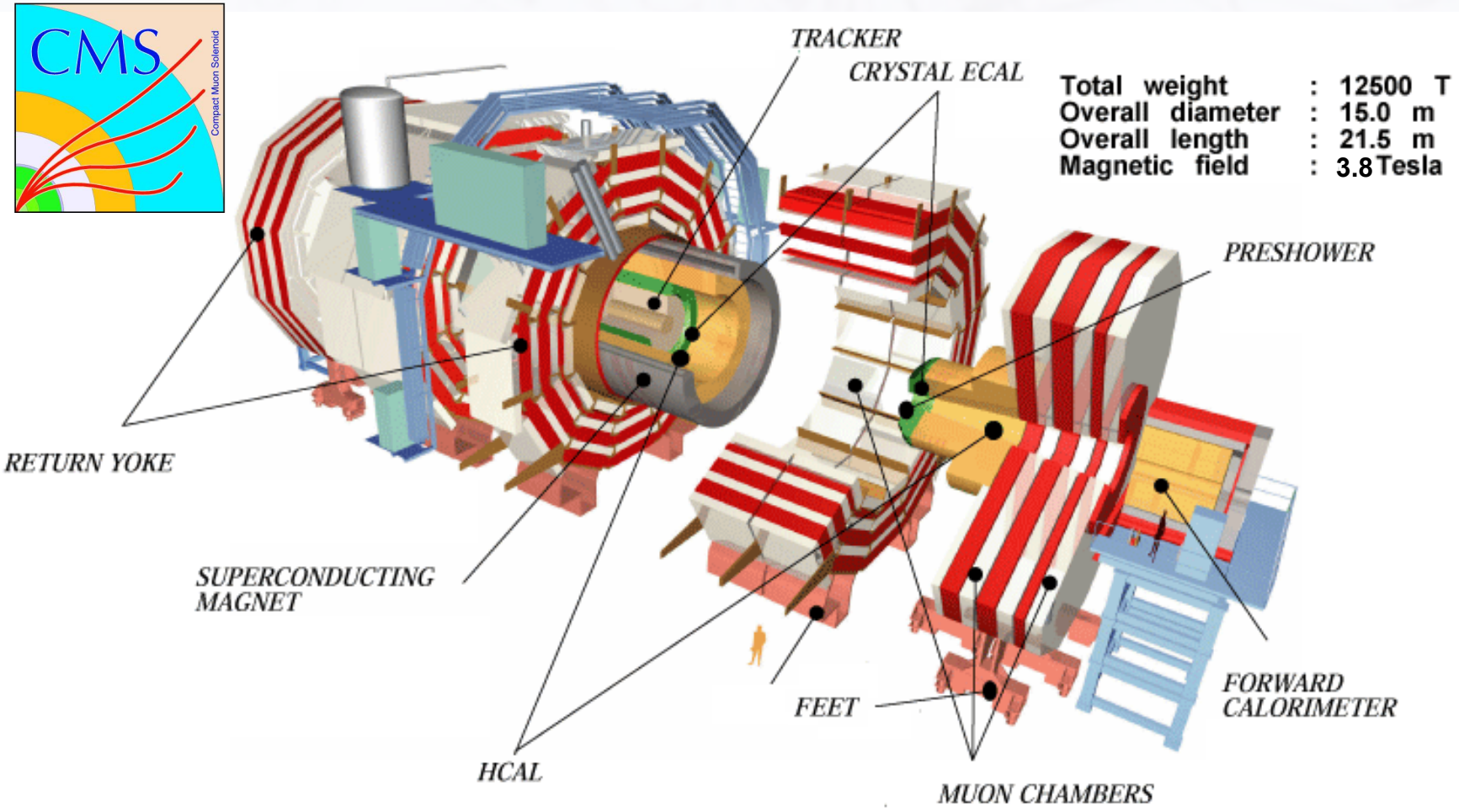
- Top quark is unique!
  - The **heaviest** particle found so far since 1995
  - Decays before hadronization for its **short lifetime**
  - Precision measurements on **QCD properties**
  - Possible probe to **new physics**
  - Major background of physics **beyond standard model (BSM)** searches
- Thanks to LHC
  - Recorded **2 orders** of magnitude more data in the last two years
  - Allowing unprecedented tests and precision measurements



http://www.u-tokyo.ac.jp/cms/wp-content/uploads/2012/01/Fig1_SM_en.png

CMS Detector

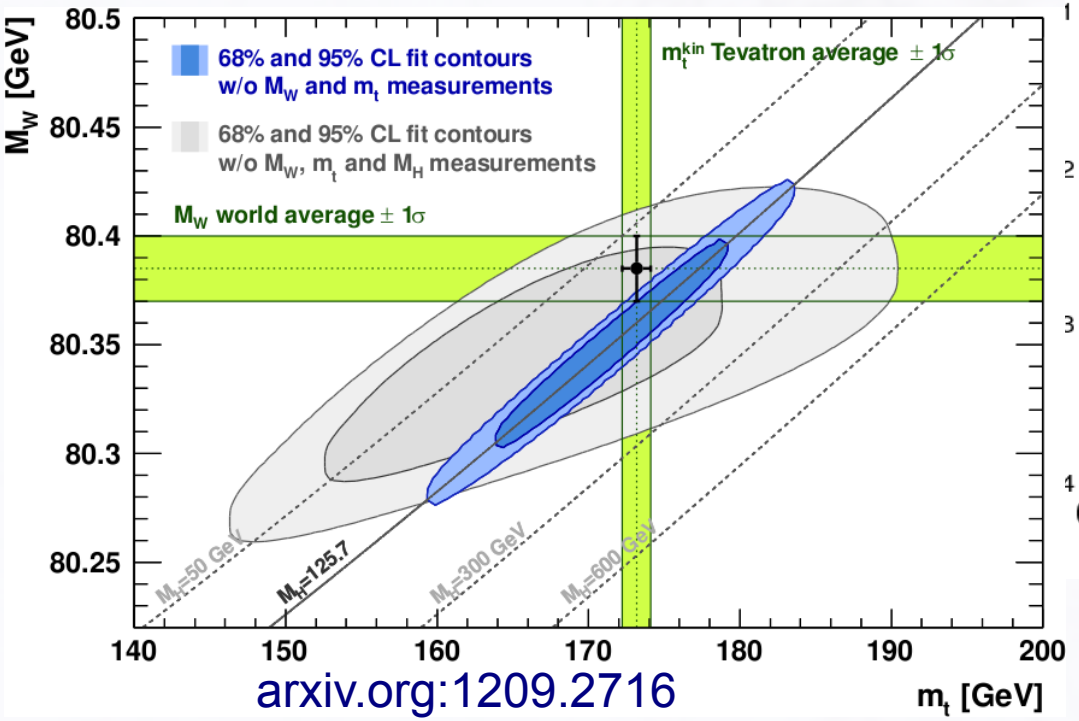
- Compact Muon Solenoid
  - A general purpose detector




Top Mass
http://www.snow-forecast.com/resorts/La-Thuile/photos/6437

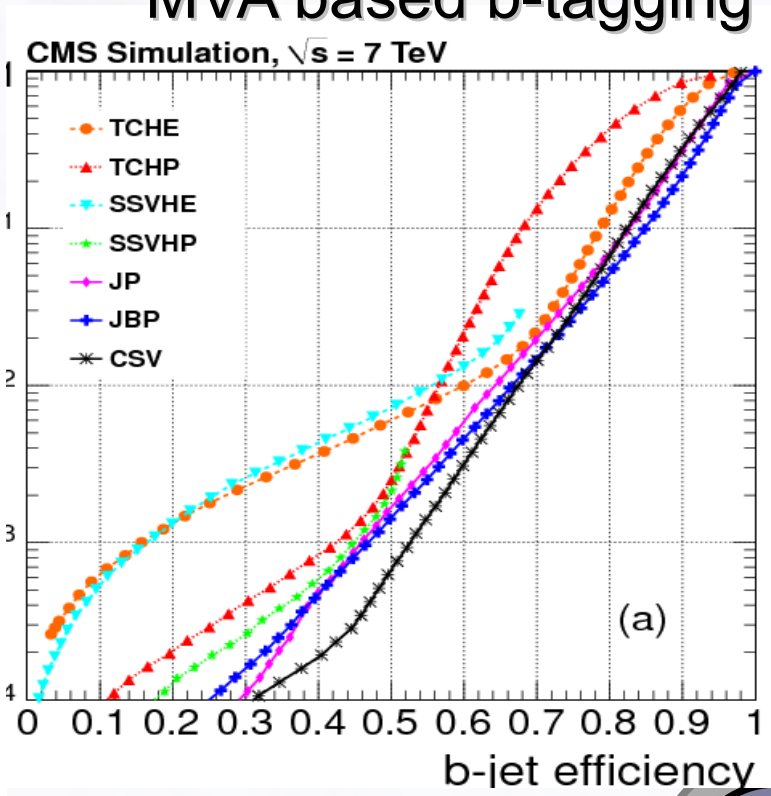
Top Mass

- Top mass measurements
  - Need for **precision** for EWK constraints
    with Higgs mass and m_W → check consistency of SM
  - Mass of a free, non-confined particle
    - Scheme-dependence
    - Non-perturbative effects of order Λ_{QCD}
  - Relies on good jet recon. & b-tagging

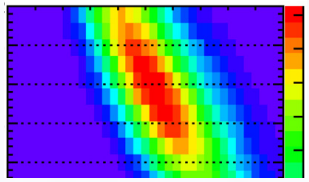
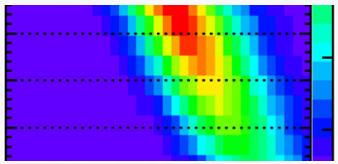


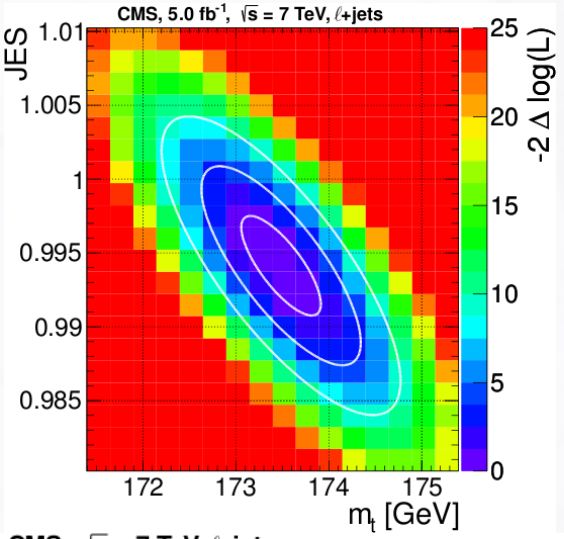
arxiv.org:1209.2716

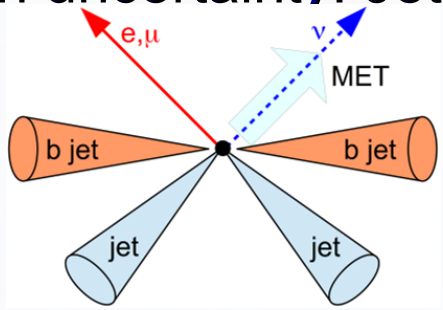
MVA based b-tagging



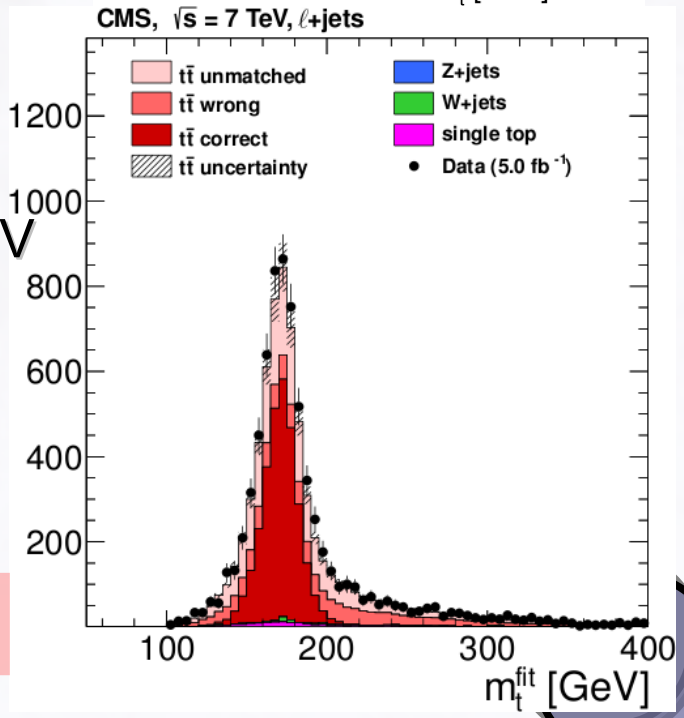
Top Mass (cont.)

- Ideogram Method to get top mass:
  - $L(m_t, JES|sample) \sim \Pi_{evt} L(evt|m_t, JES)^{Pgof}$
    $= \Pi_{evt} P(m_t^{fit}, m_W^{reco}|m_t, JES)^{Pgof}$
  - -2 ln( x  x …) =
- Extract mt and JES after calibration
- Lepton + Jets channel as an example
  - One isol. e/μ, >=4 jets, >= 2 b-tagged jets
  - Result on 5.0/fb @ 7 TeV with 2D ideogram:
    - M_t = 173.49 ± 0.43 (stat.+JES) ± 0.98 (syst.) GeV
    - JES = 0.994 ± 0.003 (stat.) ± 0.008 (syst.)
  - Main uncertainty: Jet energy scale (JES)





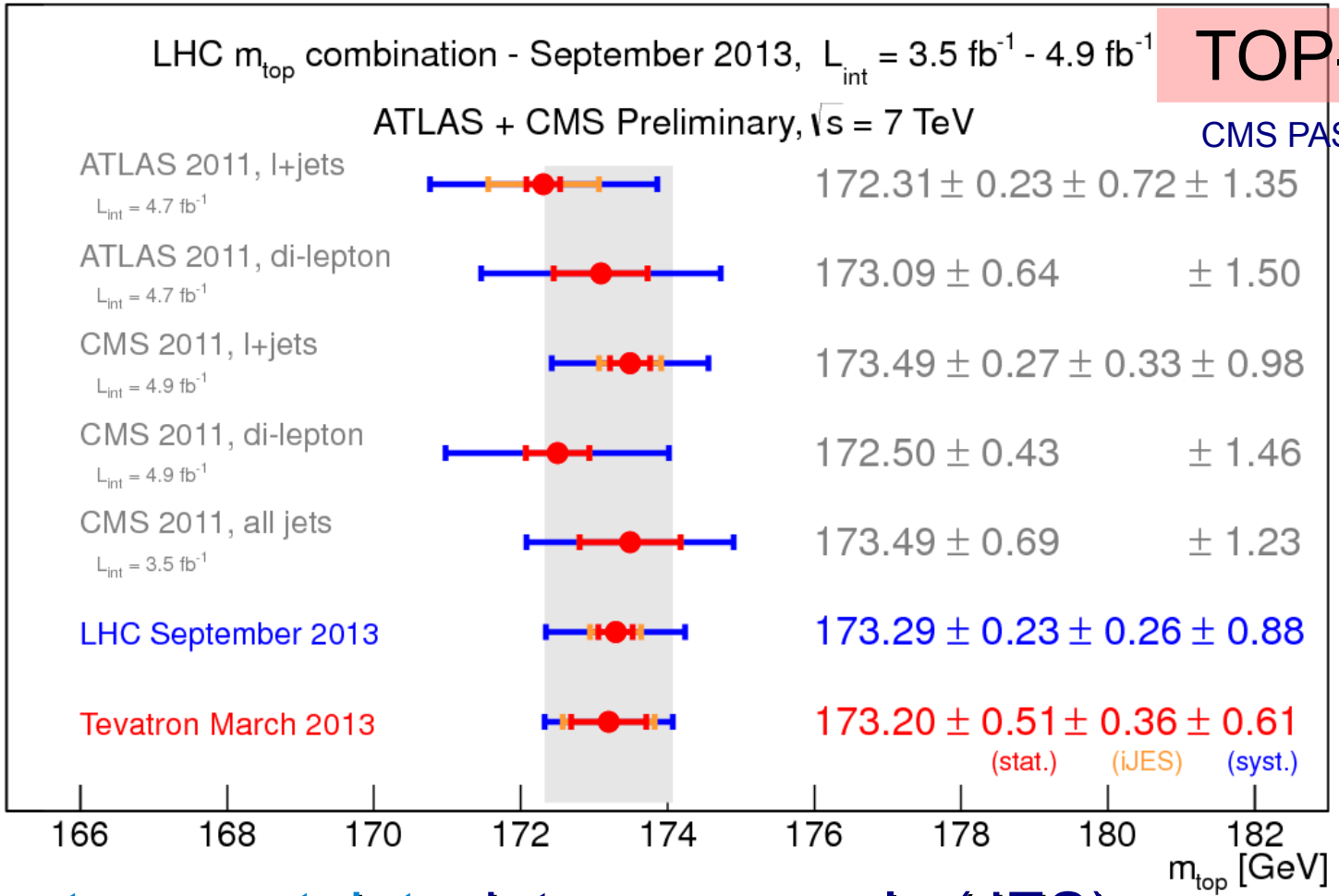
TOP-11-015



Top Mass combination

m_t = 173.29±0.23(stat.)±0.26(JES)±0.88(syst.) GeV

in situ calibration using the W mass constraint



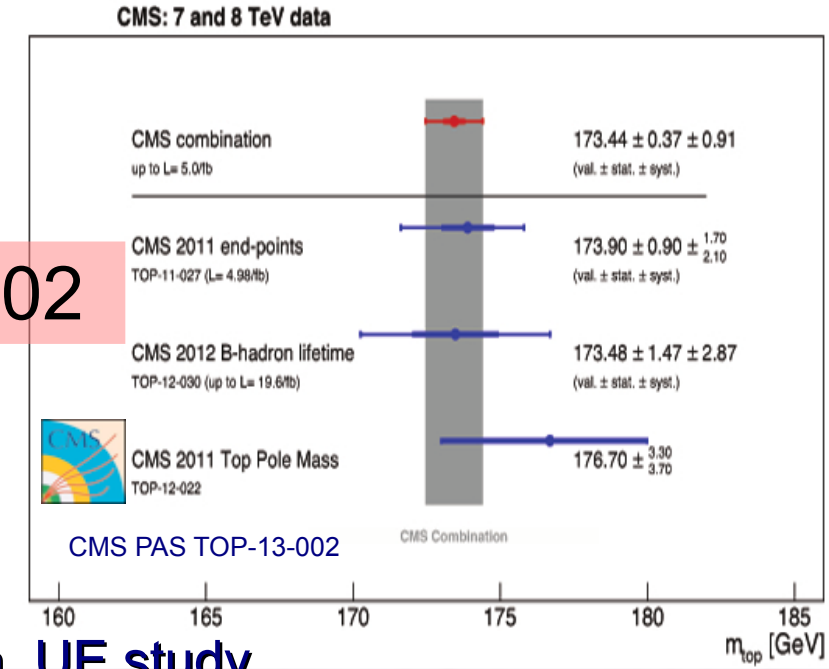
- Dominate uncertainty: jet energy scale (JES)

Top Mass in CMS (cont.)

- CMS has alternative ways on top mass measurement
  - Kinematic end-point
  - B-meson lifetime
  - Top pole mass

TOP-13-002

CMS: m_{top}=173.44 ± 0.37$_{stat}$ ± 0.91$_{syst}$



CMS PAS TOP-13-002

- Outlooks:
  - Focus on reduction of systematics
    - More data, J/ψ in $t\bar{t}$, color recombination, UE study

arXiv:hep-ph/9912320

	Current	Future			Comment
Center-of-mass energy	8 TeV	13 TeV	14 TeV	14 TeV	
	$e\mu$				
Integrated luminosity	20 fb^{-1}	30 fb^{-1}	300 fb^{-1}	3000 fb^{-1}	
b fragmentation/hadronization	0.8	0.4	0.4	0.3	improve with data
Top p_T modeling	2.4	0.2	0.2	0.2	improve at NNLO
Other systematic uncertainties	1.1	0.3	0.2	0.2	improve with data
Systematic	2.8	0.6	0.5	0.4	
Statistical	2.0	1.1	0.4	0.1	
Total	3.4	1.3	0.6	0.4	

FTR-13-017

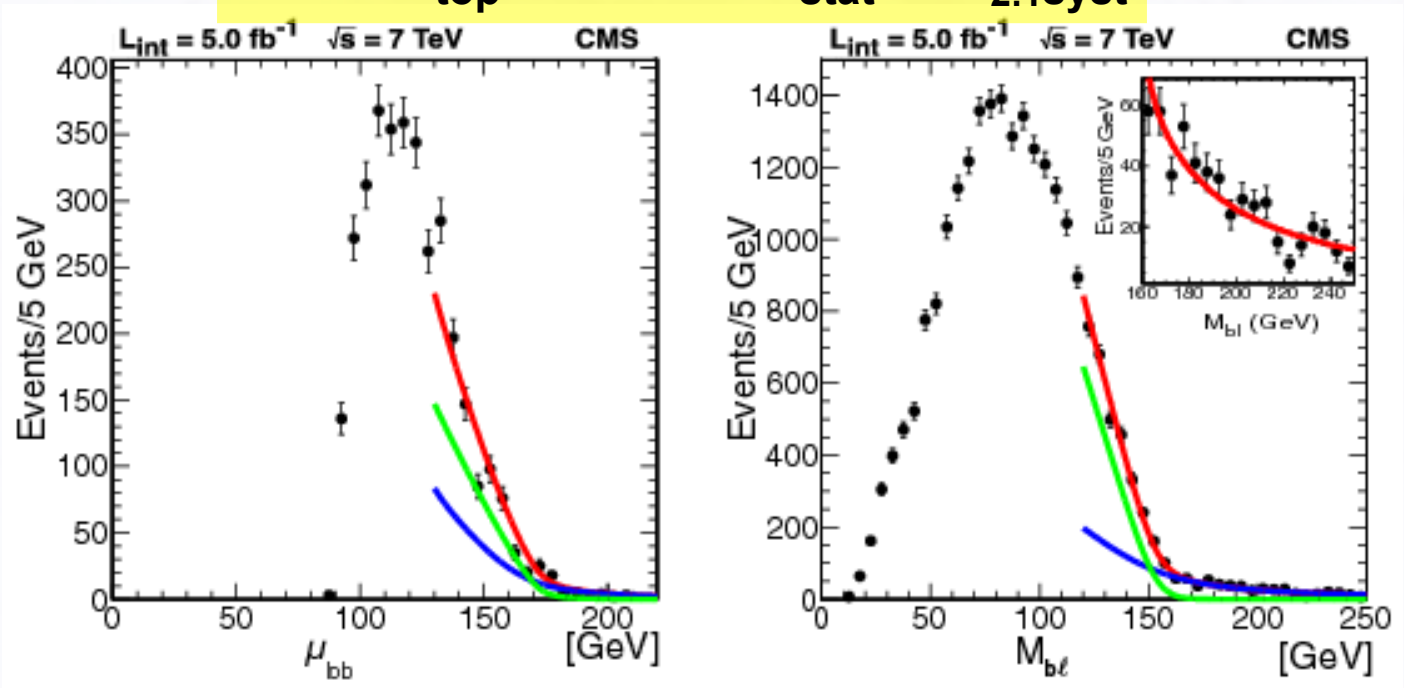
Top Mass in CMS (cont.)

- Kinematic end-points
  - Invariant / transverse mass sensitive to M_t
  - Using 5.0/fb data @ 7 TeV
  - Looking at events ==2 isol. e/m, >=2 b-tagged jets

TOP-11-027

Eur. Phys. J. C73 (2013) 2494

CMS: $m_{top}=173.9 \pm 0.9_{stat}\ ^{+1.7}_{-2.1syst}$



$$\mu_{bb}^{\max} = \frac{M_t}{2}(1-\frac{M_W^2}{M_t^2}) + \sqrt{\frac{M_t^2}{4}(1-\frac{M_W^2}{M_t^2})^2 + \widetilde{M}_W^2} \qquad M_{bl}^{\max} = \sqrt{m_b^2 + (1-\frac{M_\nu^2}{m_W^2})(E_W^* + p^*)(E_b^* + p^*)}$$

Top Mass in CMS (cont.)

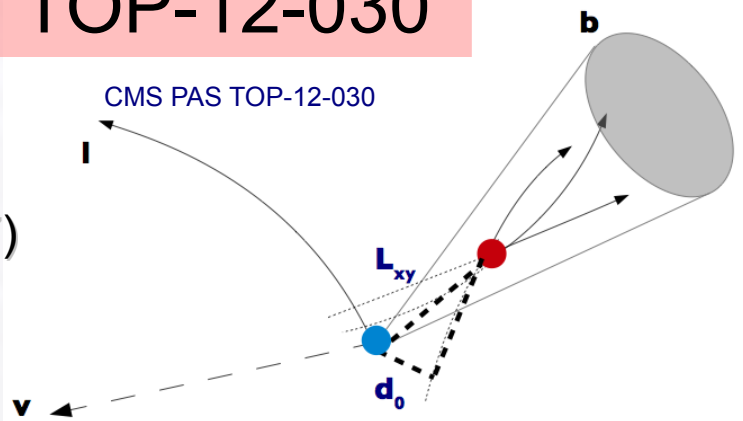
- Top mass from *b* decay length
  - Using ***b* hadron life-time based** technique
    $$L_{xy} = \gamma_b \beta_B \tau_B \sim 0.4 \frac{m_t}{m_B} \beta_B \tau_B$$
  - First done in CDF Phys. Rev. D75, 071102 (2007)
  - Has linear **top mass** dependency
    $$\Delta L_{xy}/\mathrm{GeV} = 25 - 30 \mu m$$
- Complementary **systematics** to traditional measurements (**JES**)
- Select secondary vertex with largest L_{xy}
- Median L_{xy} is used to **extract m_t**

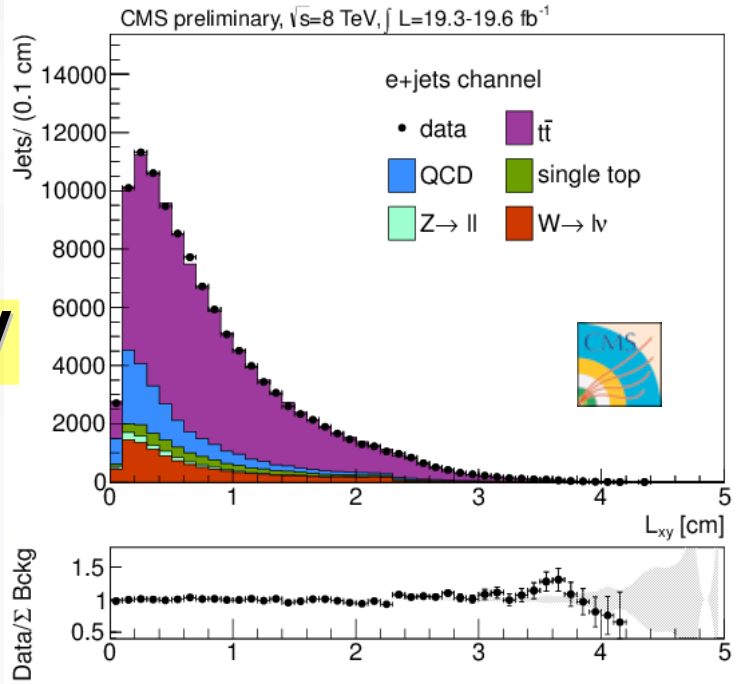
m_t = 173.5±1.5(stat.)±1.3(syst.)±2.6($p_T(t)$) GeV

Top quark p_T re-weighting

- Syst. dominated by **W+jet normalization**

TOP-12-030



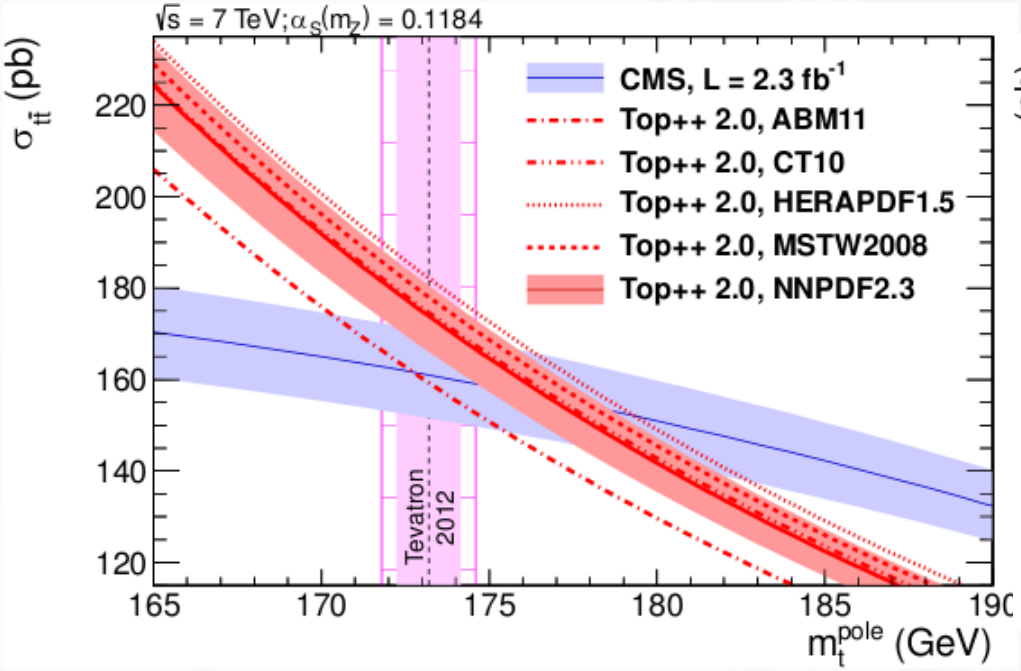


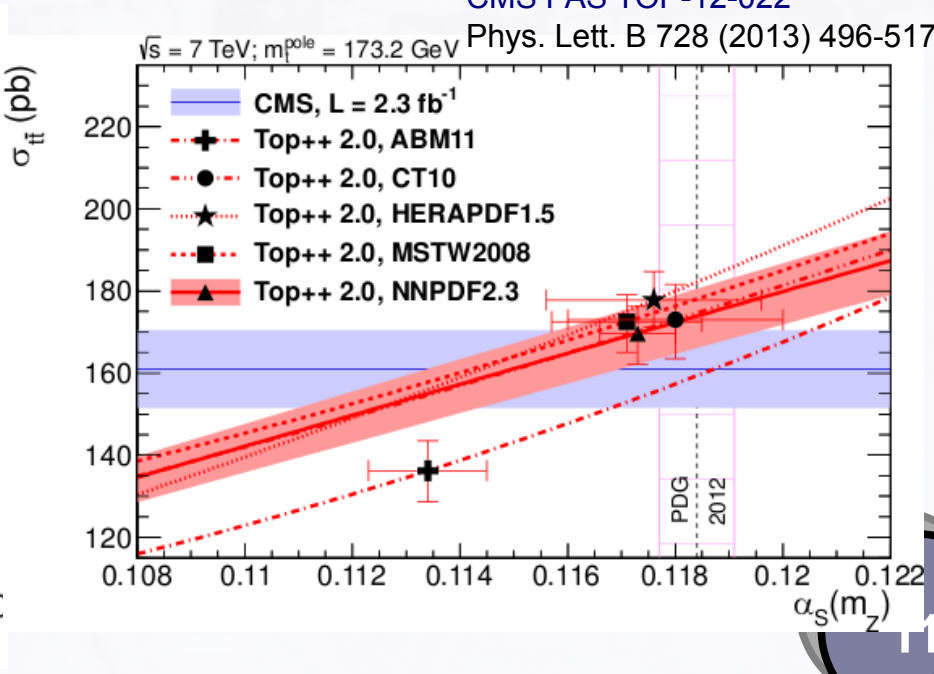
Top Mass in CMS (cont.)

TOP-12-022

- Mass from top cross section
  - Measuring m_t^{pole} is theoretical well understood / motivated
  - Based on most precise $\sigma_{t\bar{t}}$ JHEP 11 (2012) 067
  - Constrain with theoretical $\sigma_{t\bar{t}}$ (m_t^{pole}, α_s) @ NNLO
  - Results with NNPDF2.3:
    - $m_t^{pole} = 176.7^{+3.8}_{-3.4}$ GeV ($m_t^{pole} = m_t^{Tevatron}$ =173.2 GeV)
    - $\alpha_s(m_Z) = 0.1151^{+0.0033}_{-0.0032}$ (PDG α_s: 0.1184)

CMS PAS TOP-12-022
Phys. Lett. B 728 (2013) 496-517

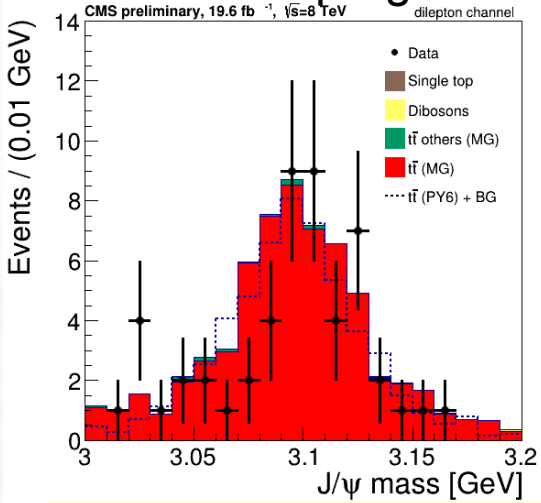


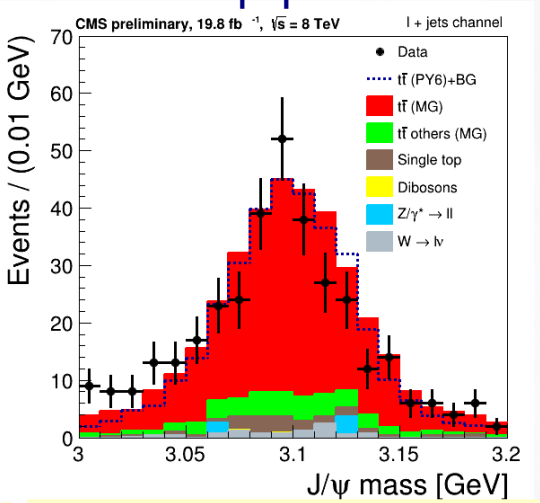


Further Studies (alt. mass)

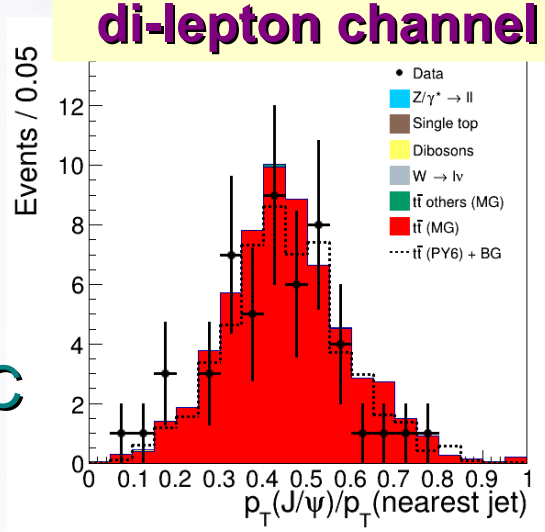
- Study J/ψ in $t\bar{t}$ events
  - Look for **leptonic** $t\bar{t}$ with J/ψ from b-jet
    - Use isolated lepton / dilepton with **full 2012 data**
    - Select $J/\psi \rightarrow \mu^+ \mu^-$
    - Model background and b-hadron fragmentation
    - Study J/ψ properties
- Most J/ψ found in a jet
  - Distance agree with MC
- Most jet p_T can be attributed to the J/ψ
  - Fair agreement with default MC
- Towards **alternative** mass measurements

World first of J/ψ signal in $t\bar{t}$! arXiv:hep-ph/9912320

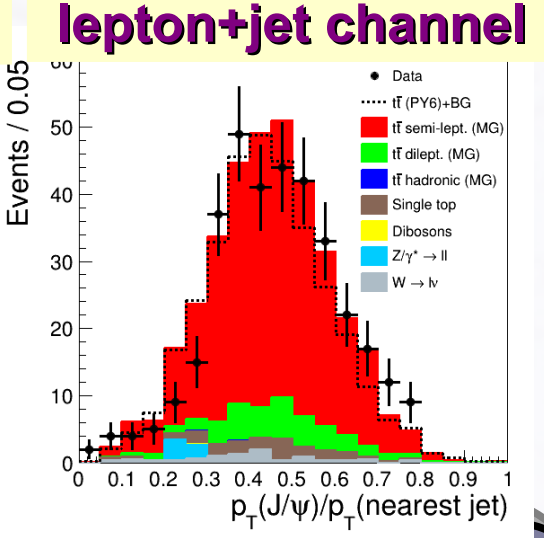




di-lepton channel



lepton+jet channel



TOP-13-007

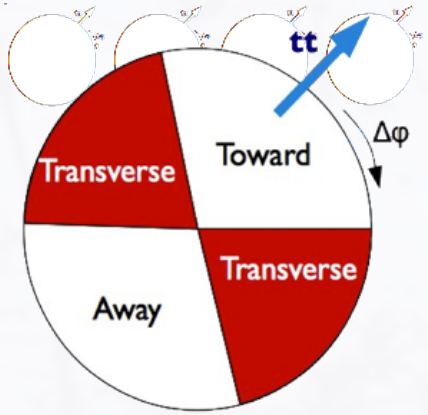
CMS PAS TOP-13-007

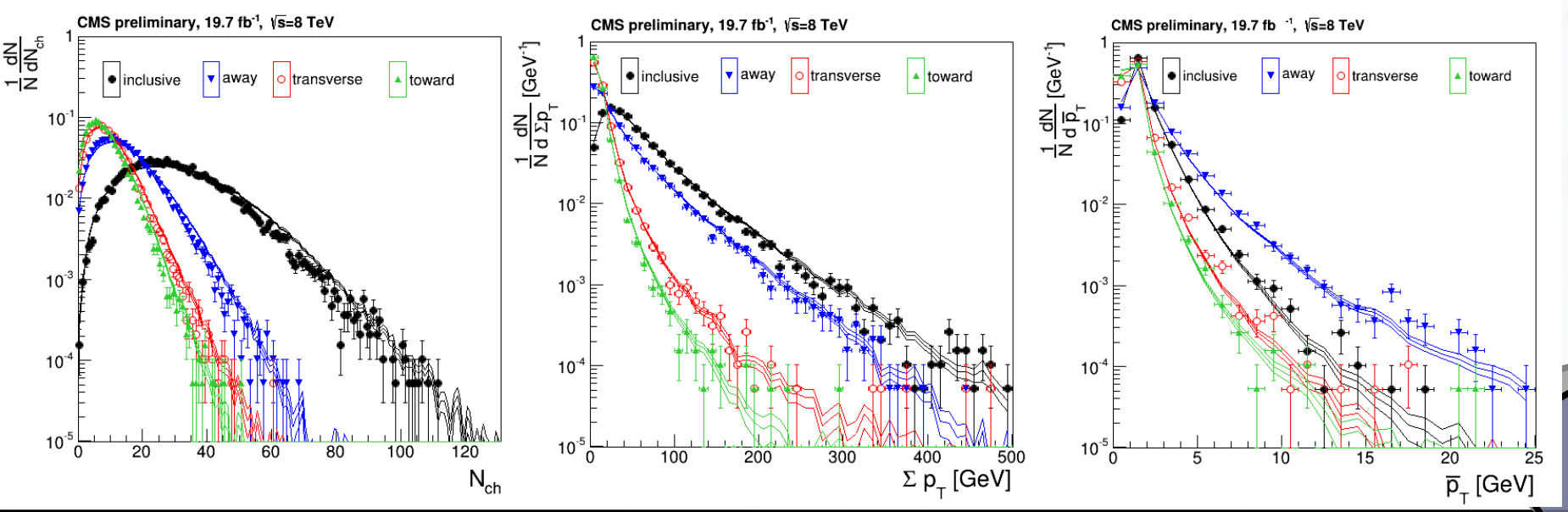
Further Studies (CR, Q^2)

- UE in $t\bar{t}$ events with **full 2012 data**
  Hadron activity of ISR/FSR, MPI and beam remnants
  - Towards constraining **MC modeling** systematics
  - Using eμ high purity sample S/(S+B) ~ 0.96
  - Charged **PF candidates** not used in jet clusters
  - Charged particle profile at reco. Level
    - Background subtracted with MC
    - Top as event-by-event reference axis
    - Compare normalized distributions: Nch, ΣpT, <pT>

TOP-13-007

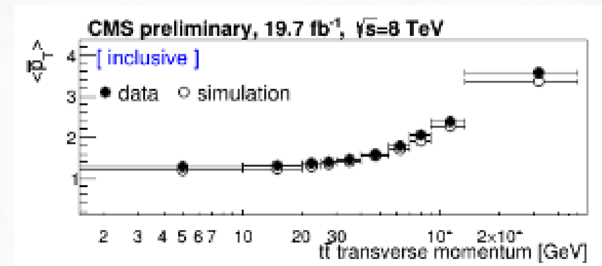
CMS PAS TOP-13-007

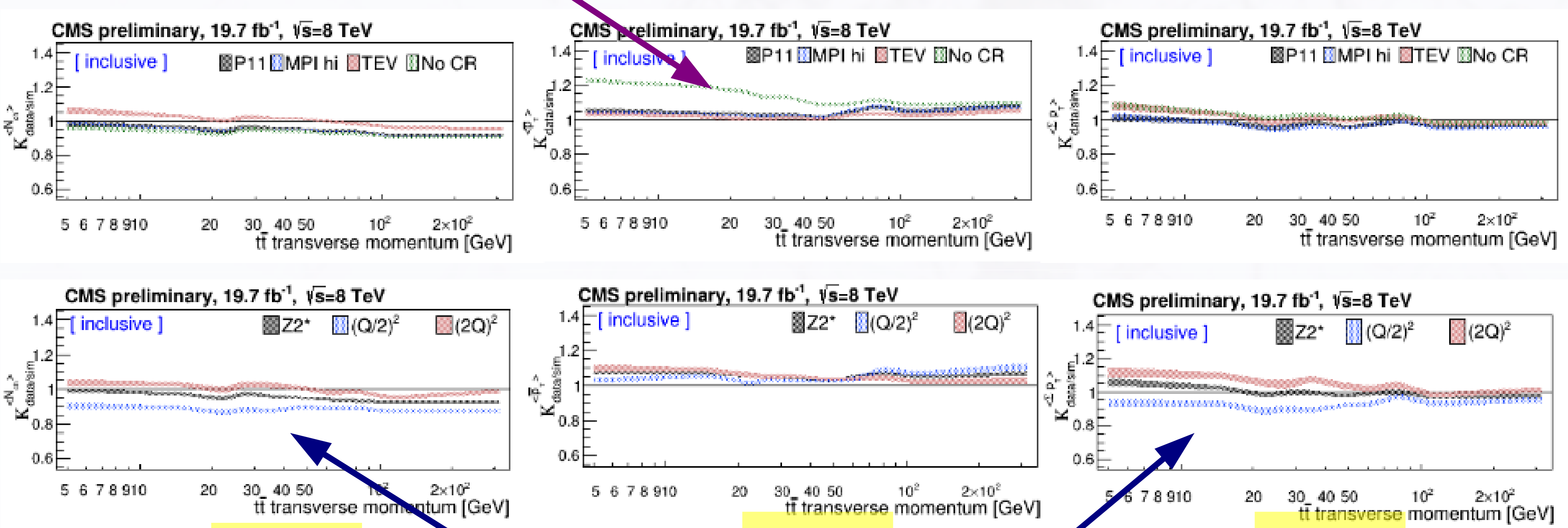




Further Studies (CR, Q^2)

- Checking all toward, transverse, away regions
  - Event axis to factorize ISR
  - Validity of Pythia **Z2* and P11** tunes
  - Role of Q^2 in the event (higher on average)
  - Effect of color reconnection can be isolated





Nch

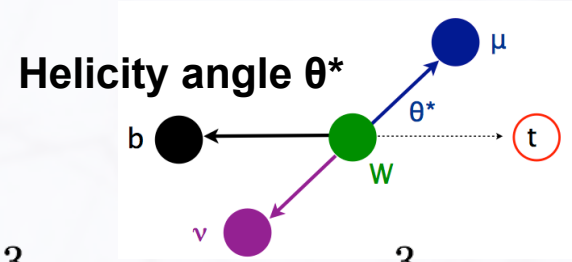
ΣpT

<pT>


Top Properties
http://www.snow-forecast.com/resorts/La-Thuile/photos/6437

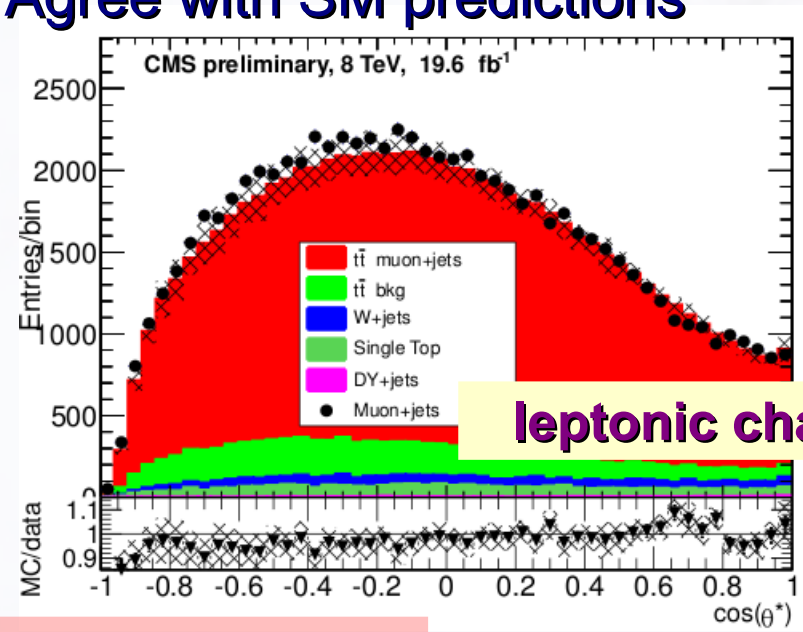
Top Properties – W helicity

- W helicity in top pair events
  - Results of 7 TeV have been published JHEP 10 (2013) 167
  - 8 TeV study update:
    → improved precision
  - Agree with SM predictions

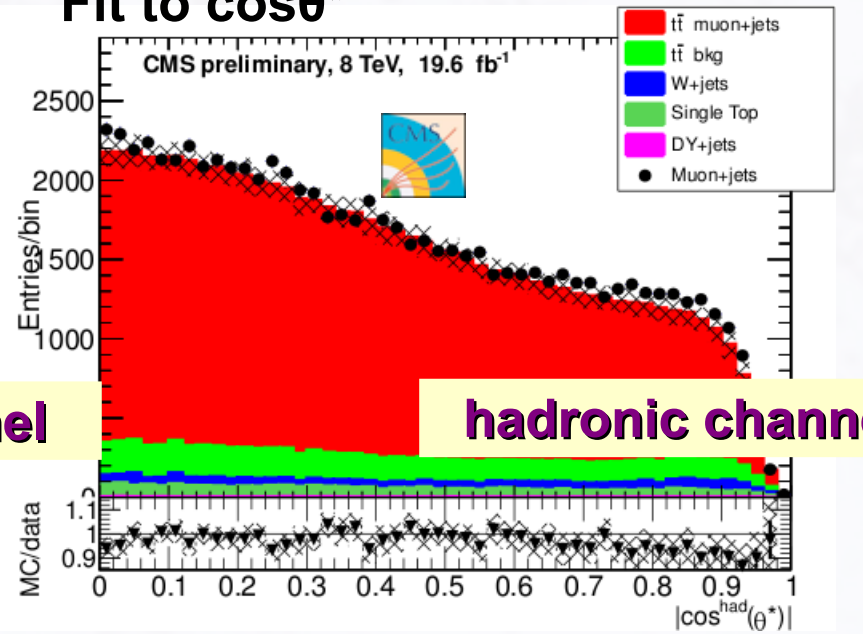


$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{8}(1+\cos\theta^*)^2 F_R + \frac{3}{4}(\sin\theta^*) F_0$$

Fit to cosθ*



leptonic channel



hadronic channel

TOP-13-008

CMS PAS TOP-13-008

$F_L + F_0 + F_R = 1$

$F_0 = 0.659 \pm 0.015(\text{stat}) \pm 0.023(\text{syst})$

$F_L = 0.350 \pm 0.010(\text{stat}) \pm 0.024(\text{syst})$

$\rightarrow F_R = -0.009 \pm 0.006(\text{stat}) \pm 0.020(\text{syst})$

Top FCNC Searches

- Top flavor-changing neutral-current decays
  - Highly suppressed in SM O(10^{-15})
  - Could be enhanced ex. 2HDM, RS...

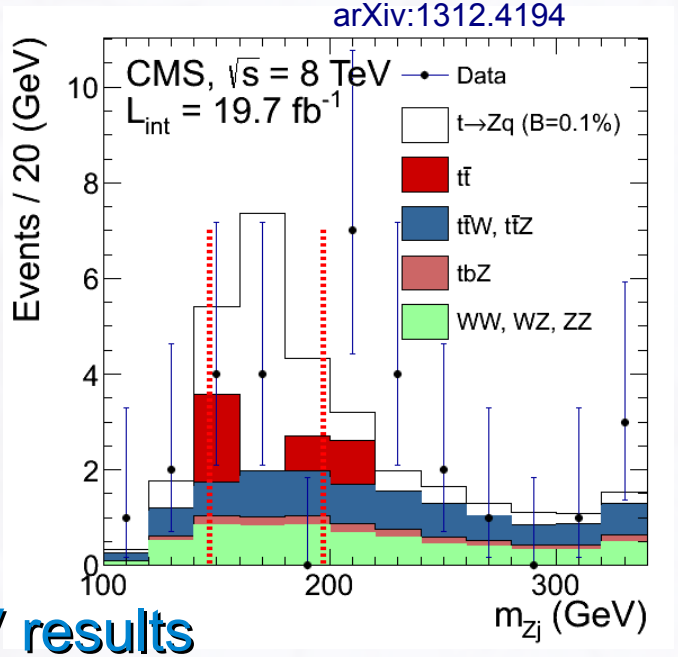
Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

up to ~O(10^{-3})

arXiv: 1311.2028v1 (2013)

TOP-12-037

arXiv:1312.4194



- Search for $t \to Zq$ decays
  - Looking at trilepton channels with full 2012 data on $t\bar{t} \to WbZq \to bj\ell^+\ell^-\ell'$
  - Journal paper submitted combining 7 + 8 TeV results
    => BR(t → Zq) < 0.05% with 25/fb (best limit)
- Future projections: → Would need more improvements

$\mathcal{B}(t \to Zq)$	300 fb^{-1} @ 14 TeV	3000 fb^{-1} @ 14 TeV
Exp. bkg. yield	26.8	268
Expected limit	$< 0.027\%$	$< 0.010\%$
$1\,\sigma$ range	$0.018 - 0.038\%$	$0.007 - 0.014\%$
$2\,\sigma$ range	$0.013 - 0.051\%$	$0.005 - 0.020\%$

FTR-13-016

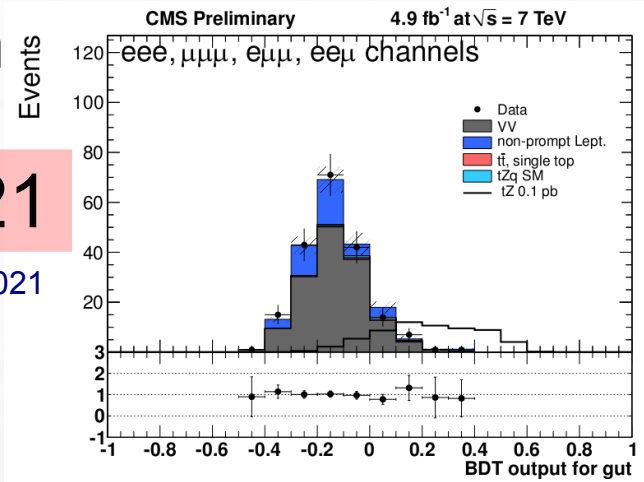
CMS PAS FTR-13-016

Top FCNC Searches (cont.)

- Search for $t \to Vq$ in single top production
  - Looking at trilepton channels with 5/fb data at 7 TeV:
    $B(t \to gu) \leq 0.56\%$, $B(t \to gc) \leq 7.12\%$,
    $B(t \to Zu) \leq 0.51\%$, $B(t \to Zc) \leq 11.40\%$.

TOP-12-021

CMS PAS TOP-12-021



- Search for $t \to Hq$ decays
  - Direct search
    - Looking at different Higgs decay channels
  - Alt. way deriving from SUSY studies:
    - Re-interpret the multi-lepton searches
    - Looing at 10 most sensitive channels
    - All signal regions:
      3 leptons, no OSSF or
      an OSSF pair off Z and a b-taged jet
    - Complement to $H \to \gamma\gamma$
      with limit at 95% C.L. given:

$$\mathcal{B}(t \to cH) < 1.28\%, \sqrt{|\lambda^h_{tc}|^2 + |\lambda^h_{ct}|^2} < 0.21$$

OSSF pair	$N_{\tau_{had}}$	E_T^{miss} [GeV]	H_T [GeV]	$N_{b\text{-jets}}$	data	background	signal
below Z	0	50–100	0–200	≥ 1	48	48 ± 23	9.5 ± 2.3
n/a	0	50–100	0–200	≥ 1	29	26 ± 13	5.9 ± 1.3
below Z	0	0–50	0–200	≥ 1	34	42 ± 11	5.9 ± 1.2
n/a	0	0–50	0–200	≥ 1	29	23 ± 10	4.3 ± 1.1
below Z	0	50–100	> 200	≥ 1	10	9.9 ± 3.7	3.0 ± 1.1
below Z	0	0–50	> 200	≥ 1	5	10 ± 2.5	2.8 ± 0.8
below Z	0	50–100	0–200	0	142	125 ± 27	9.7 ± 2.1
n/a	1	0–50	0–200	≥ 1	237	240 ± 113	13.1 ± 2.6
n/a	0	50–100	0–200	0	35	38 ± 15	4.3 ± 1.1
above Z	0	0–50	0–200	≥ 1	17	18 ± 6.7	2.8 ± 0.8

Higgs Decay Mode		obs	exp	1σ range
$h \to WW^*$	(BR = 23.1 %)	1.58 %	1.57 %	(1.02–2.22) %
$h \to \tau\tau$	(BR = 6.15 %)	7.01 %	4.99 %	(3.53–7.74) %
$h \to ZZ^*$	(BR = 2.89 %)	5.31 %	4.11 %	(2.85–6.45) %
combined		1.28 %	1.17 %	(0.85–1.73) %

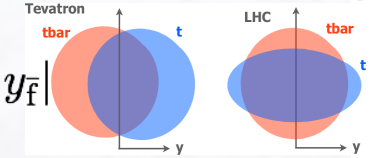
SUS-13-002

PAS-SUS-13-002

Top Charge Asymmetry

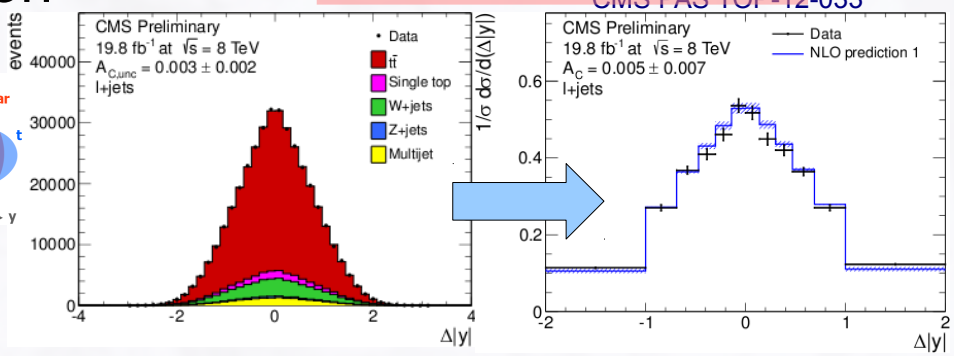
- Charge asymmetry in lepton + jet
  - An 8 TeV update of 7 TeV publication
  - Unfolded to parton level

$$A_C = \frac{N^+ - N^-}{N^+ + N^-}, \Delta|y| = |y_t| - |y_{\bar{t}}|$$



TOP-12-033

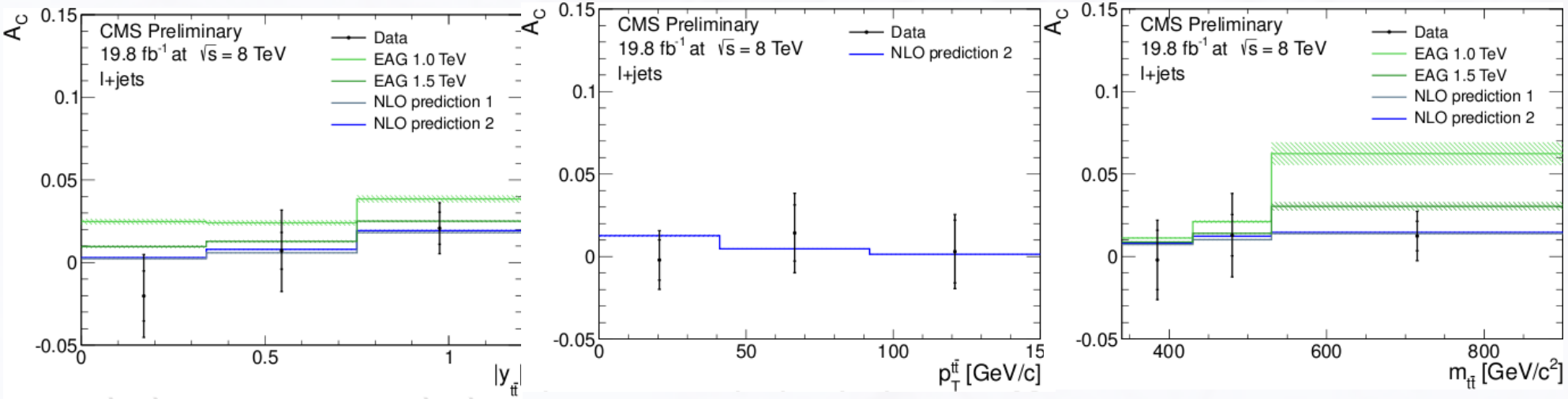
CMS PAS TOP-12-033



- Measured asymmetry:

  0.005 ± 0.007 (stat.) ± 0.006 (syst.)

  - No indication of BSM



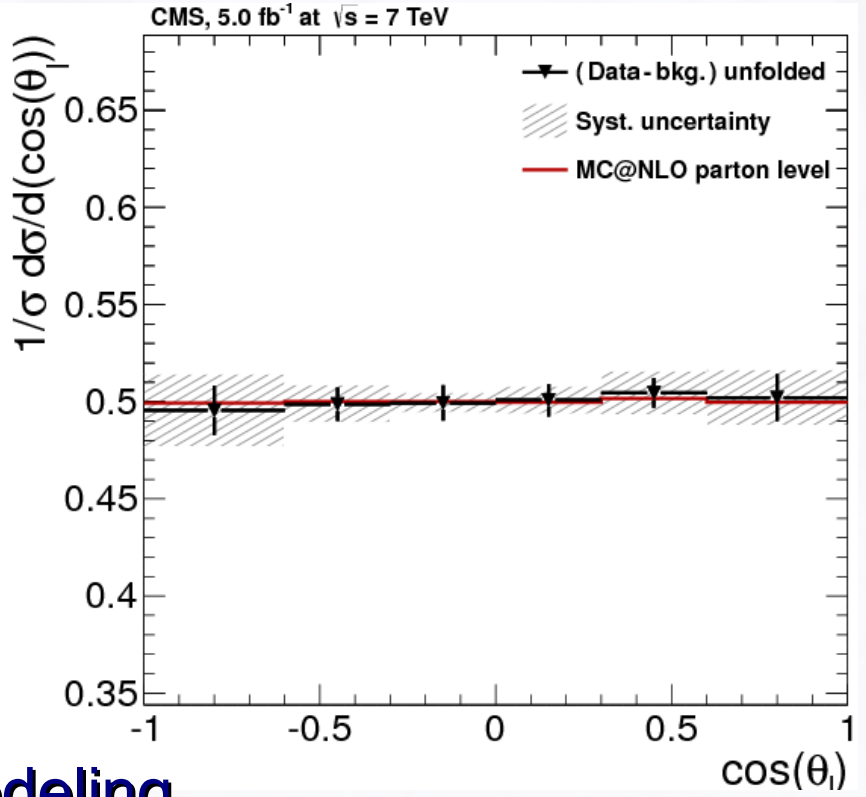
- Largest syst. from JES and MC Modeling

Top-quark Polarization

- Results on charge asymmetry, spin-correlation, polarization
  - Using 5/fb at 7 TeV data
  - Looking at dilepton events
- Top polarization
  - Background subtracted, unfolded to parton level
    (singular value decomposition)

$$A_P = \frac{N(\cos(\theta_l) > 0) - N(\cos(\theta_l) < 0)}{N(\cos(\theta_l) > 0) + N(\cos(\theta_l) < 0)}$$

$A_P = 0.005 \pm 0.013(\text{stat}) \pm 0.020(\text{syst}) \pm 0.008(p_T)$



- Largest syst. from JES and MC Modeling
- Agree with SM

TOP-13-003

arXiv:1311.3924


Summary
http://www.snow-forecast.com/resorts/La-Thuile/photos/6437

Summary and Prospects

- Studies of top-quark properties:
  - Many precise and exciting results from CMS
  - Thanks for LHC providing excellent data
- Top mass measurements
  - Combination of LHC
  - End point, b life-time, pole mass...: to improve systematics
- Top properties
  - W helicity
  - Charge asymmetries, spin correlation, polarization
  - FCNC / FCNH searches
- To find possible deviation via precision measurements
  - So far results agree with Standard Model
- New milestone ahead
  - Still many studies to finish up with the full 7+8 TeV data
  - LHC to restart in 2015 after LS1
  - Stay tuned for the new results!

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

Grazie

Thank YOU!

謝謝

Merci de Votre Attention