Measurement of the Top Quark Pair Production Cross Section in $\sqrt{s}$ = 7 TeV pp Collisions in CMS

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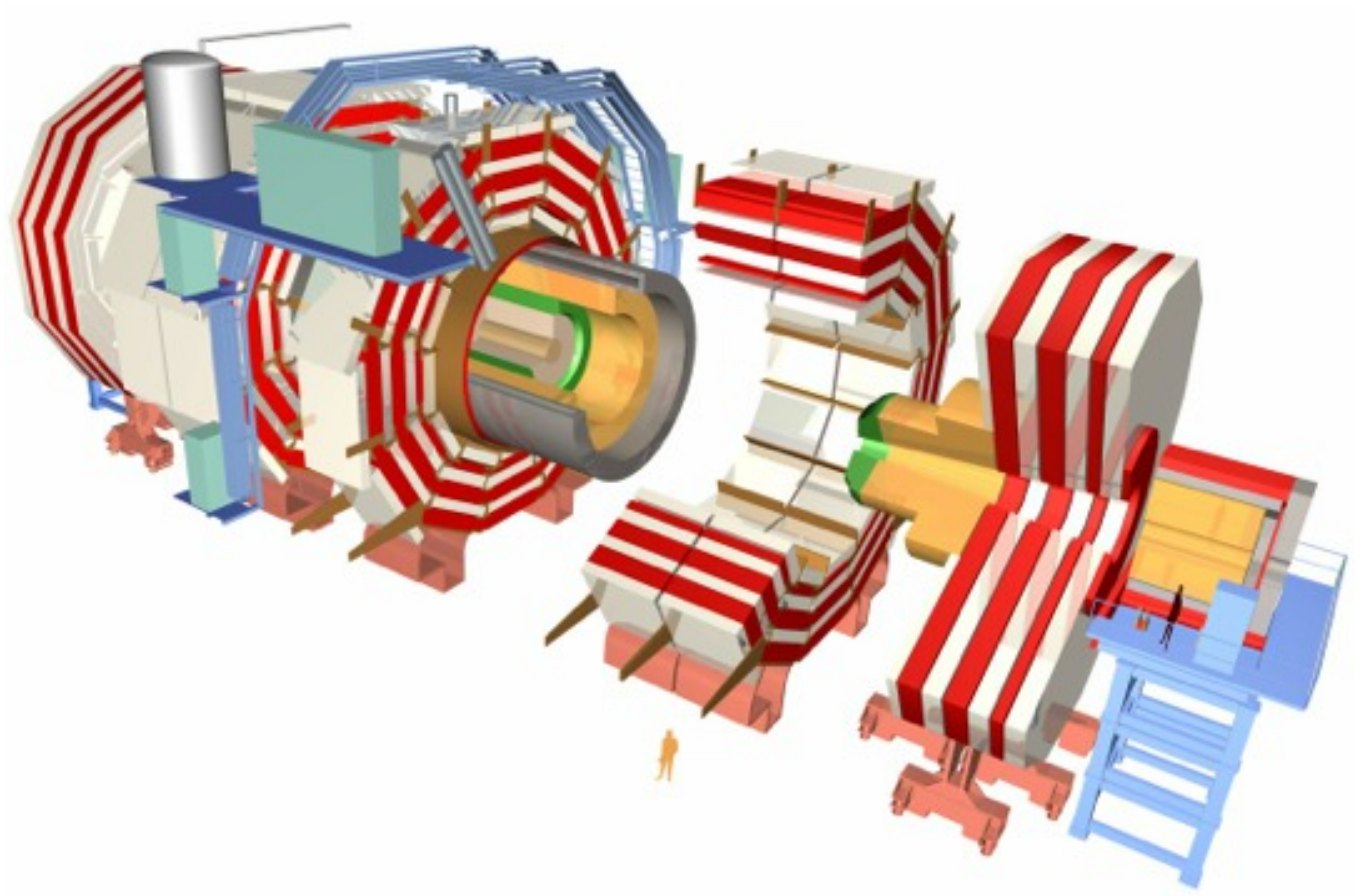
PhD Seminar
28 August 2012

CMS Detector

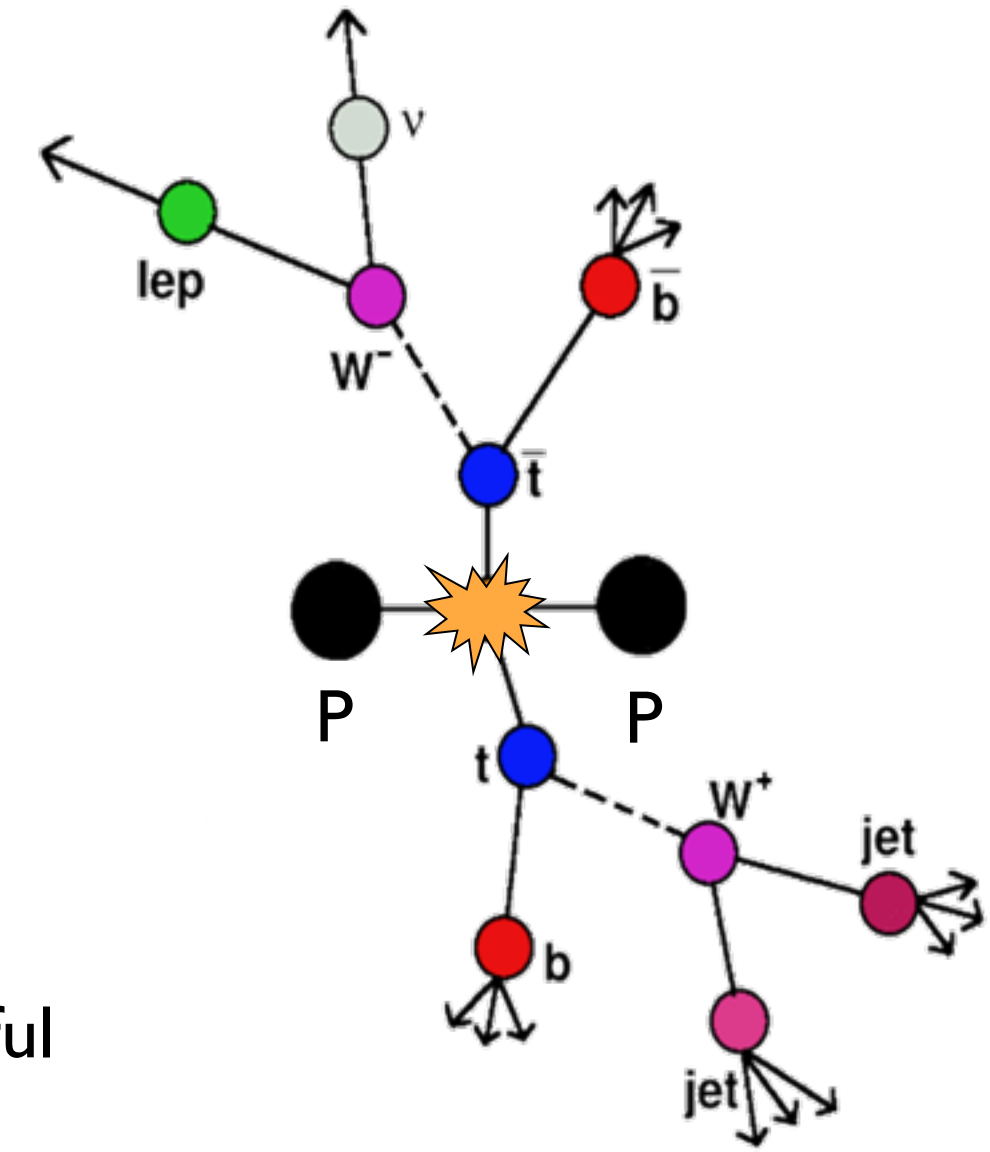


Most important parts for this analysis:

- tracker to identify secondary vertices
- muon chambers
- electromagnetic and hadronic calorimeters

Introduction

- Top pair decay modes
  - dileptonic
  - all hadronic
  - lepton + jets
- lepton + jets channel has a very characteristic signature
  - 2 b-jets
  - 2 other jets
  - neutrino (MET)
  - muon, electron
- Top quark production cross section is useful for a lot of things
  - parton distribution function (PDFs)
  - New physics probes
  - SM consistency

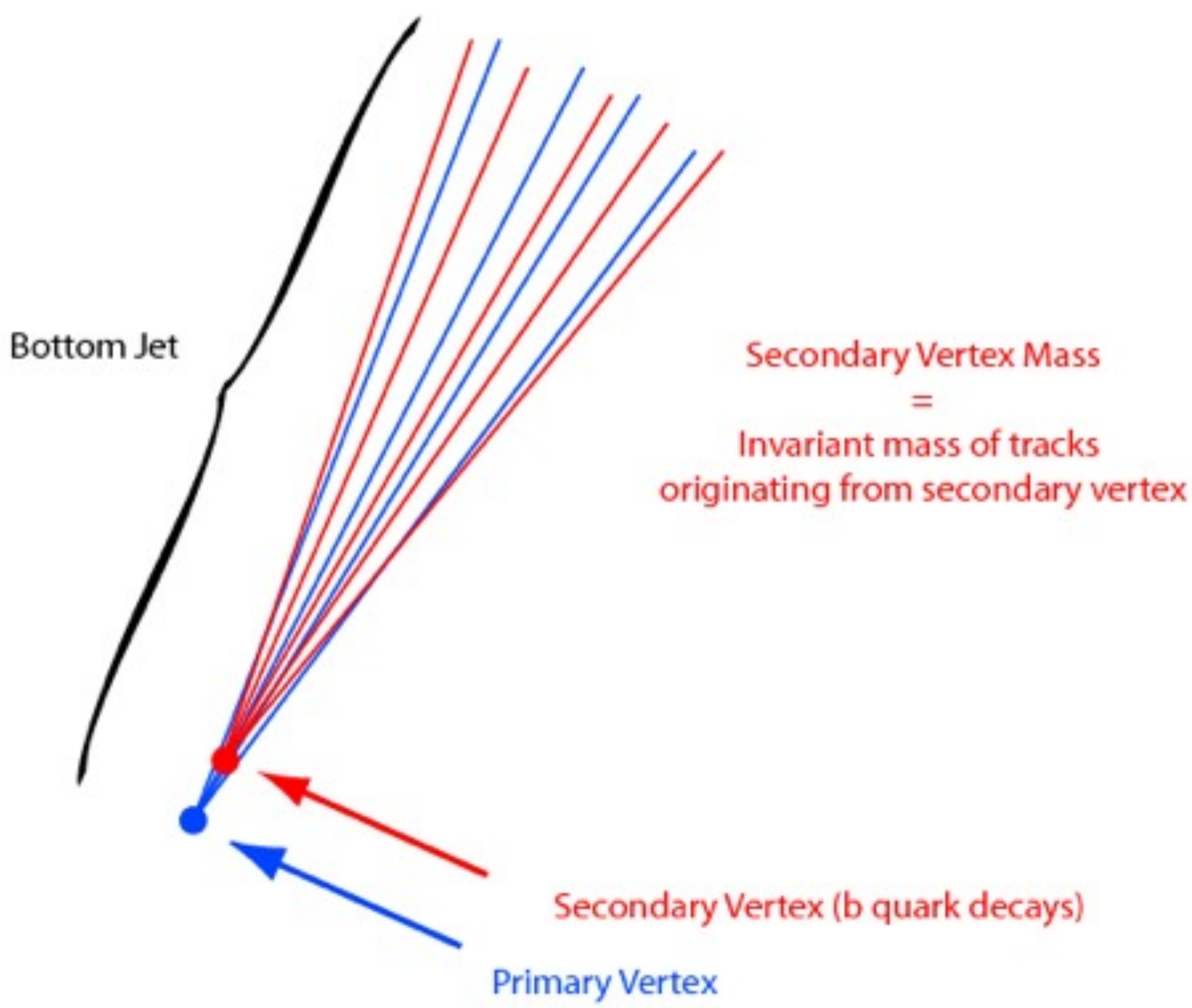


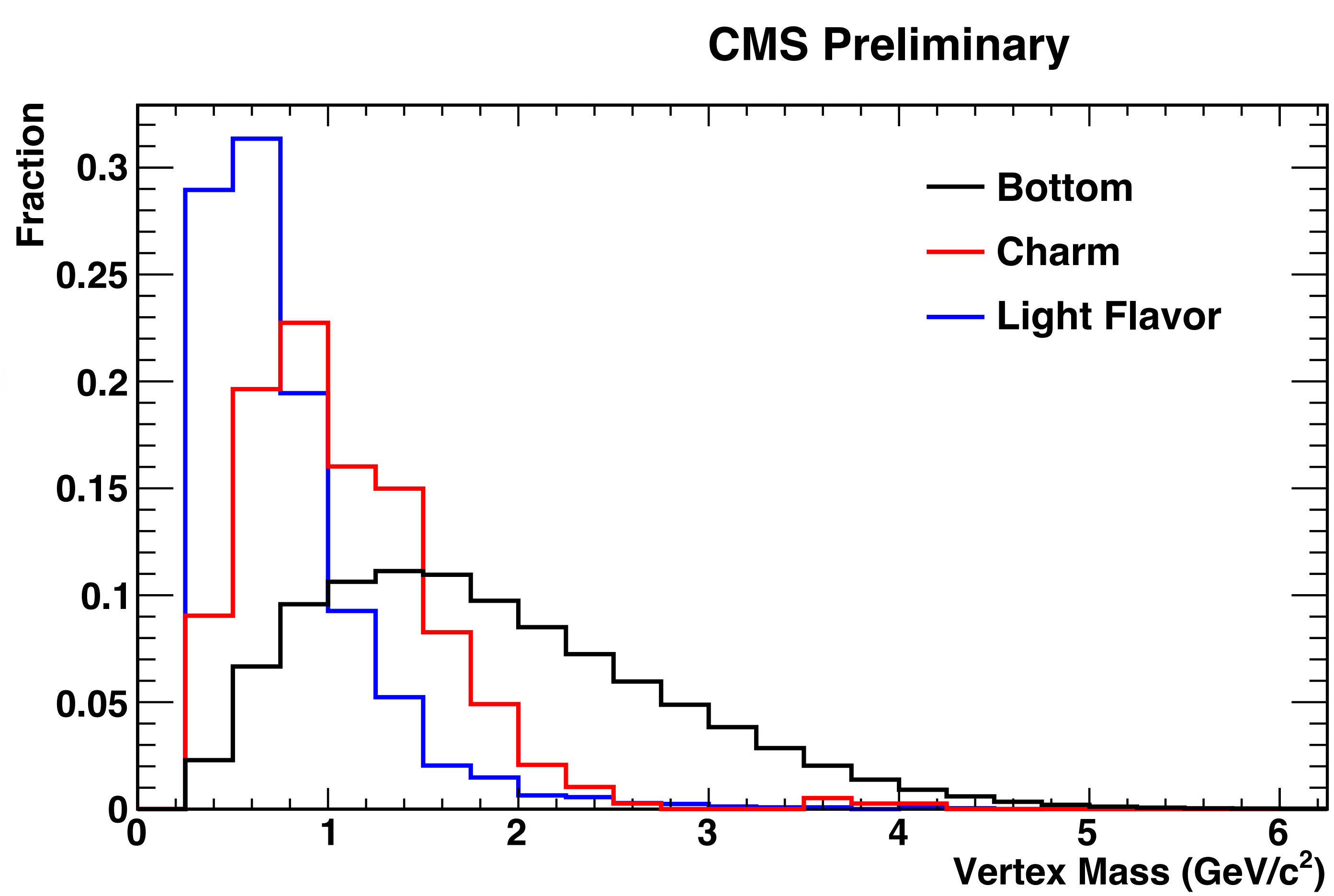
challenges of a cross section measurement

- backgrounds
  - Single Top
  - W+Jets (Wcx, Wbx, W + light flavor)
  - Z+Jets
  - QCD
- accurate integrated luminosity measurement
- acceptance and efficiencies in data
  - apply cuts to monte carlo
  - b-tagging (data to mc scale factor correction *in the fit*)
  - trigger efficiency
- understanding jet energy scale (JES) (*in the fit*)
- accuracy of monte carlo modeling
  - W+Jets Q^2 (*in the fit*)
  - ttbar+Jets Q^2

Identifying b-quark jets

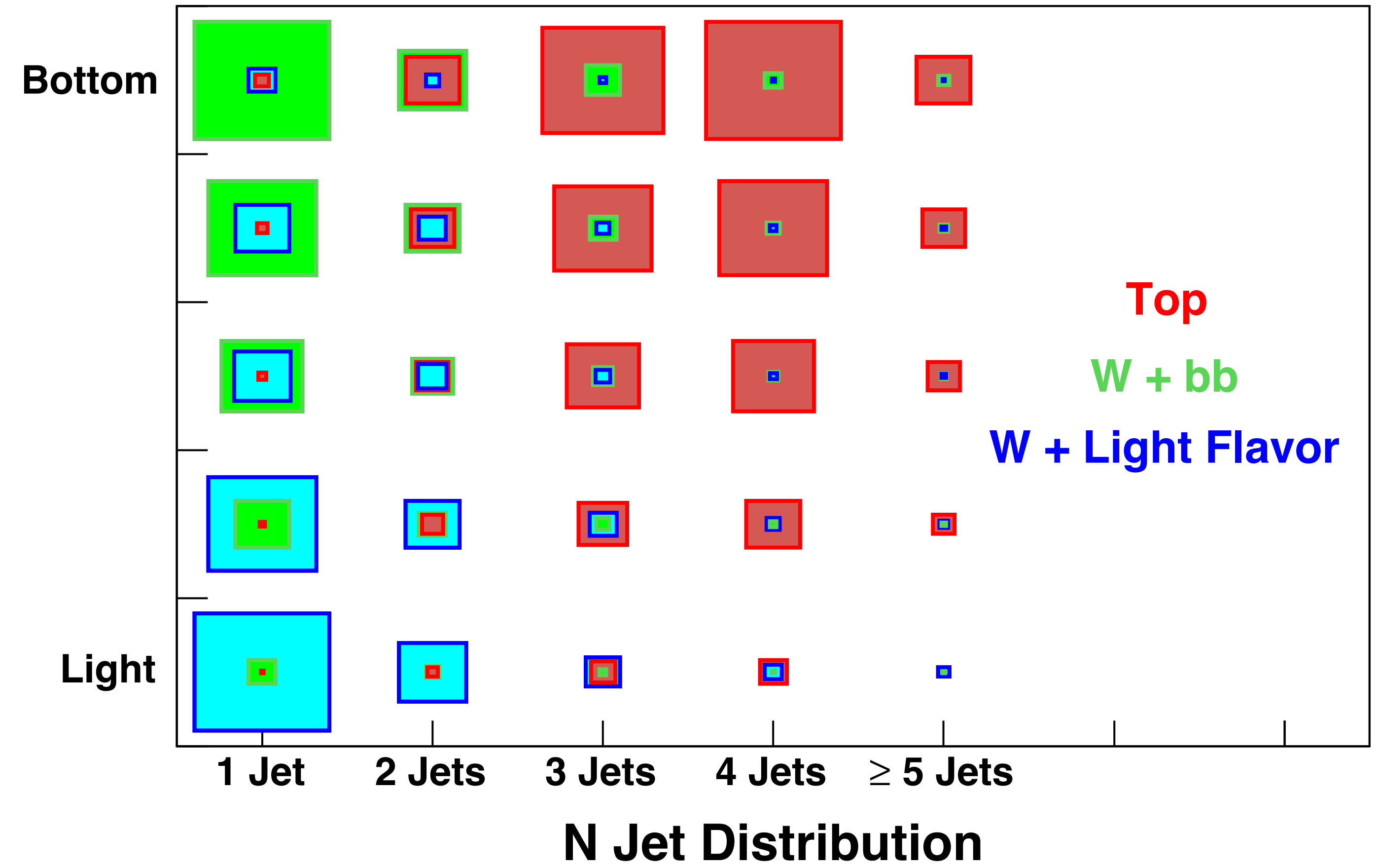
- B hadrons are long lived
- Secondary vertex (secvtx) mass – invariant mass of tracks originating at identified secondary vertex.
- Good separation of bottom from charm and light flavor jets.





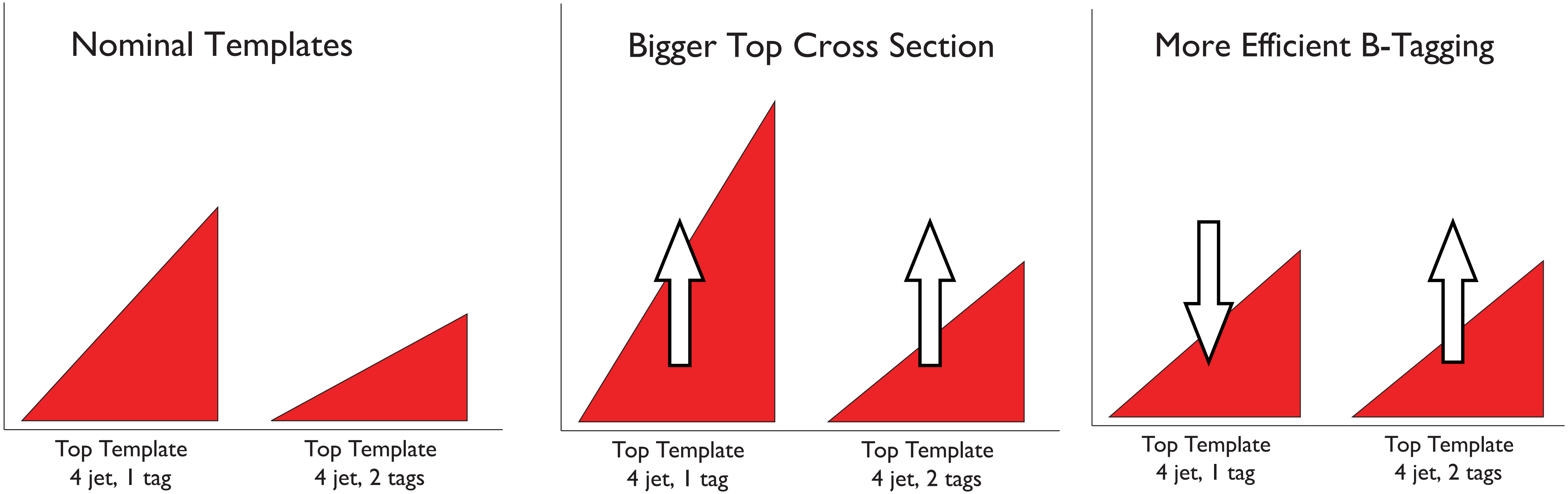
Simultaneous Heavy Flavor and Top Fit

- What discriminating variables are available:
  - Number of jets: Distinguish Top from W+Jets
  - Number of b-tags, secondary vertex mass: Distinguish Wbx from Wcx and W+Light Flavor
- Using this sample, *SHyFT* allows us to measure:
  - Physics observables:
    - Top pair cross section
    - Single top cross section
    - Wbb cross section
    - W + charm cross section
  - Calibration observables
    - B-tag "scale factor"
    - Mistag "scale factor"
    - JES
    - WJets Q^2



SHyFT Introduction, continued

- Split events into jet-tag bins
- Fit SecVtxMass
  - Different pieces of same templates are tied together by the cross section parameters.
  - Only systematic uncertainties can change relative sizes of templates



In Likelihood Form

The simultaneous part

$$\ln L = \sum_{\ell}^{\text{lepton}} \sum_{i,j}^{\text{tag,jet}} \sum_{k}^{\text{bins}} (\ln \mathcal{P}(N_k^{\text{obs}}(i,j,\ell), N_k^{\text{pred}}(i,j,\ell))) - \frac{1}{2} \sum_{l}^{\text{constraints}} \frac{(C_X - \hat{C}_X)^2}{\sigma_{C_X}^2}$$

- Top

$$N_{t\bar{t}}^{\text{pred}}(i,j,\ell) = \sigma_{t\bar{t}} \cdot N_{t\bar{t}}^{\text{MC}}(i,j,\ell) \cdot$$
$$p_{t\bar{t}}^{\text{Btag}}(i,j,\ell,R_{\text{Btag}}) \cdot p_{t\bar{t}}^{\text{Mistag}}(i,j,\ell,R_{\text{Mistag}}) \cdot p_{t\bar{t}}^{\text{JES}}(i,j,\ell,R_{\text{JES}})$$

  - njet dependence: JES
  - ntag dependence: b-tag efficiency (and mis-id)

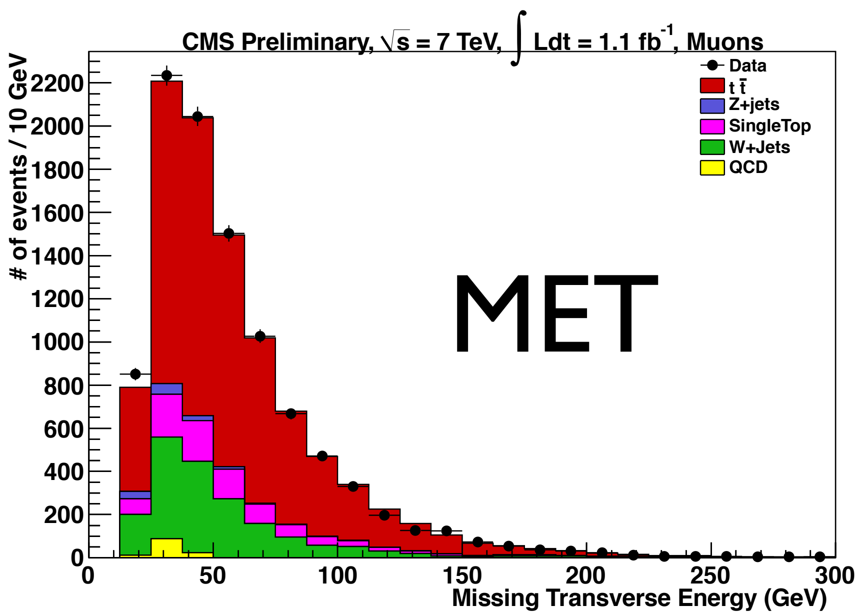
Profile likelihood details

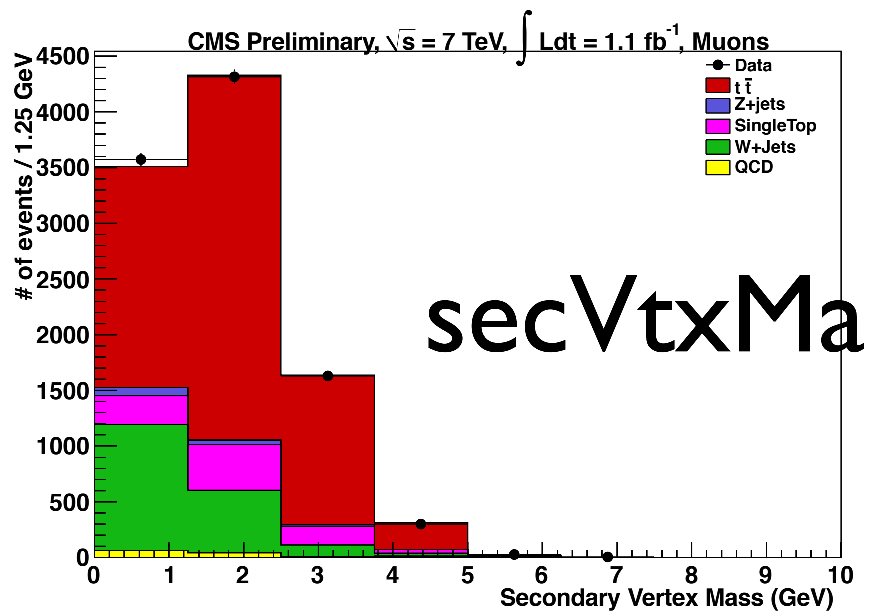
Quantity	Constraint (%)
b-tag Efficiency Scale Factor	100 ± 10
b-tag Mistag Scale Factor	100 ± 10
Jet energy scale relative to nominal	100 ± 3 (η,p_T dependent)
W+jets renormalization/factorization scales	100^{+100}_{-50}
W+jets background normalization	unconstrained
QCD background normalization	100 ± 100
Single-top background normalization	100 ± 30
Z+jets background normalization	100 ± 30

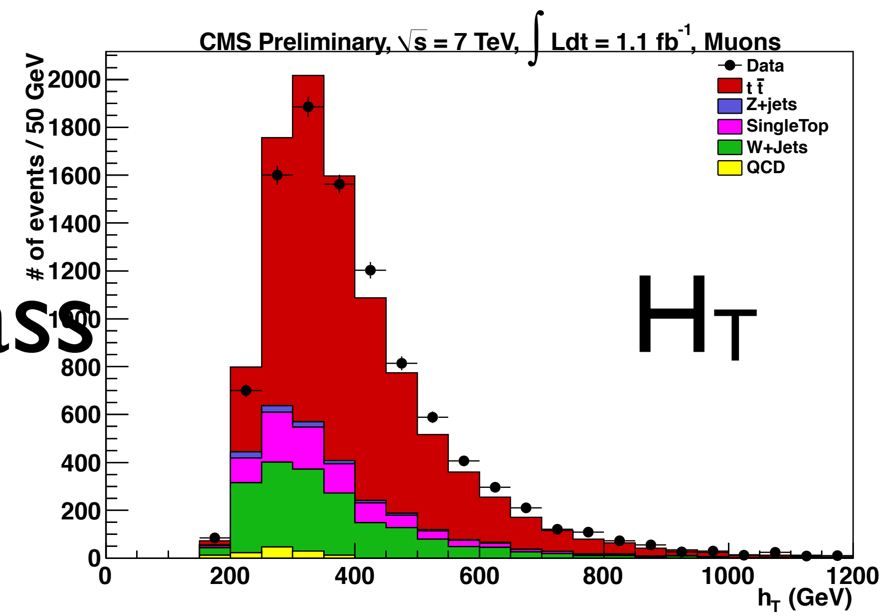
- these are starting points
- the fitter returns an uncertainty for each parameter in the fit

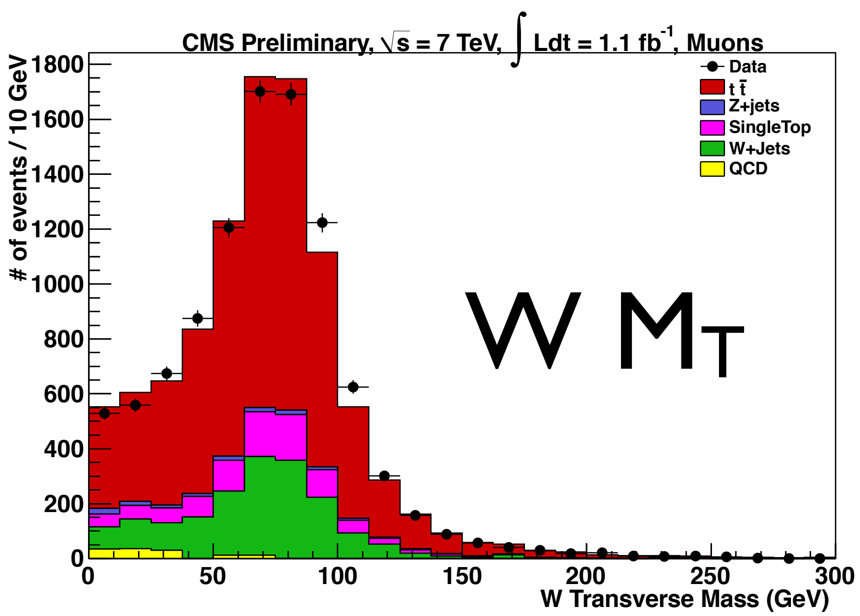
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP11003

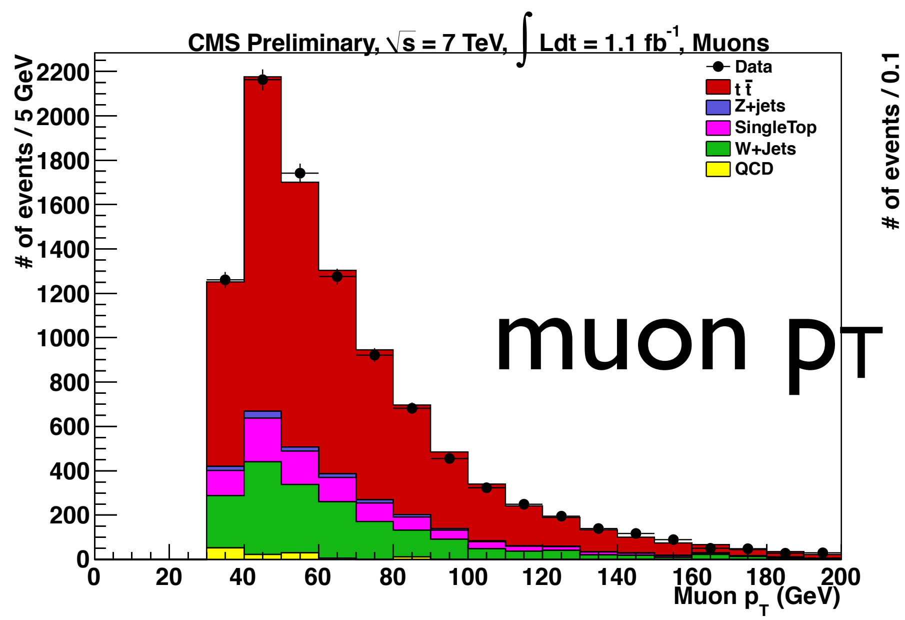
Muon kinematic plots

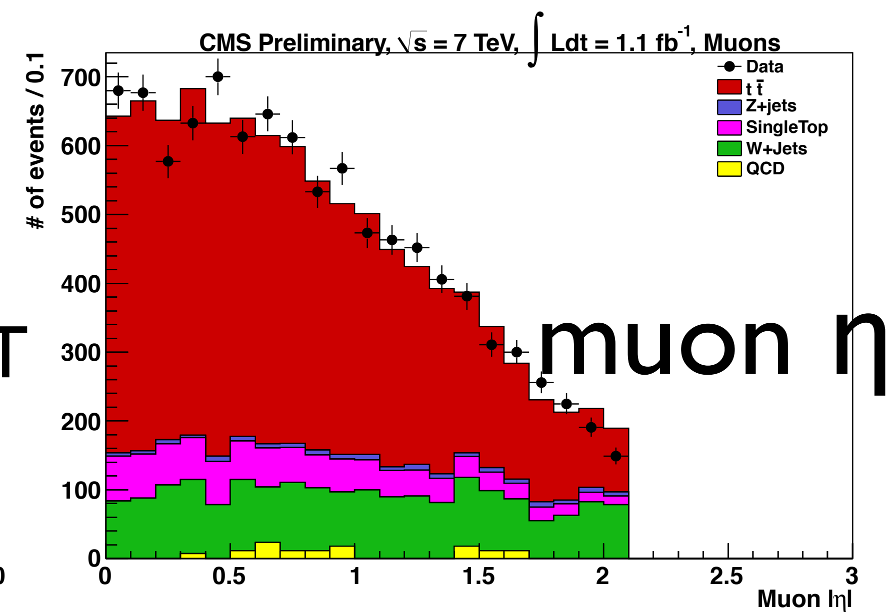












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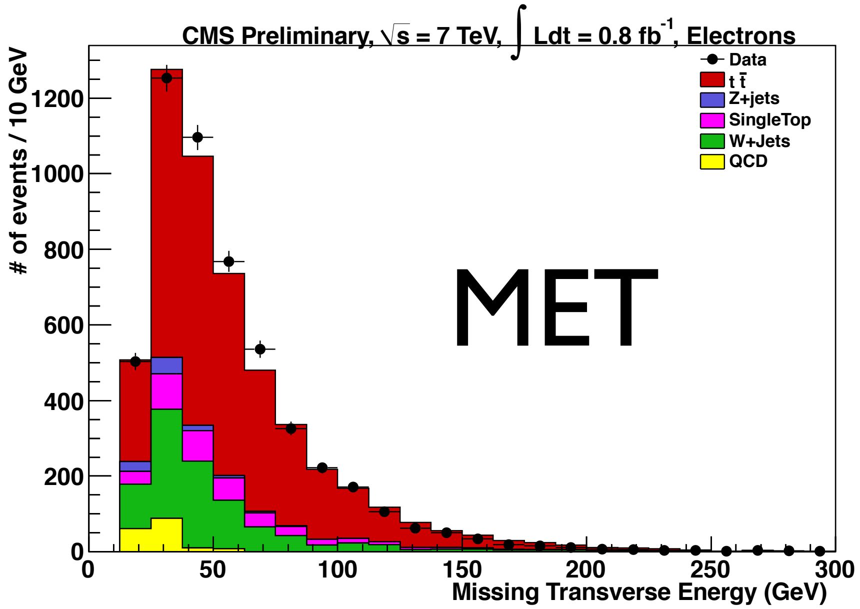
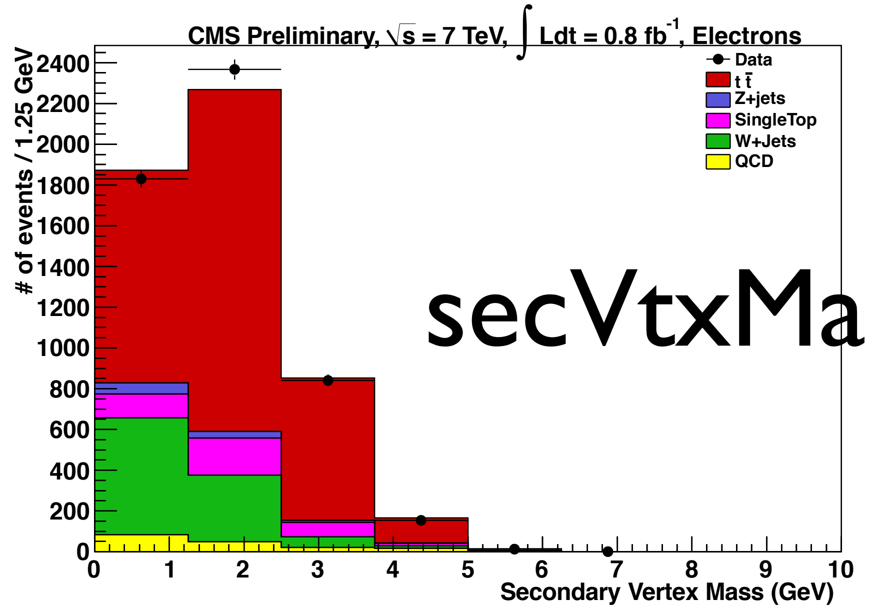
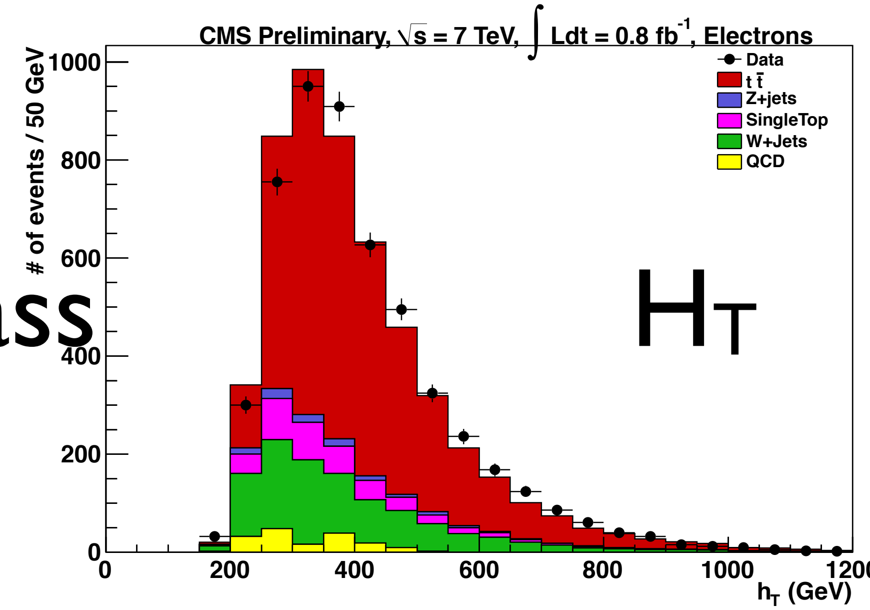
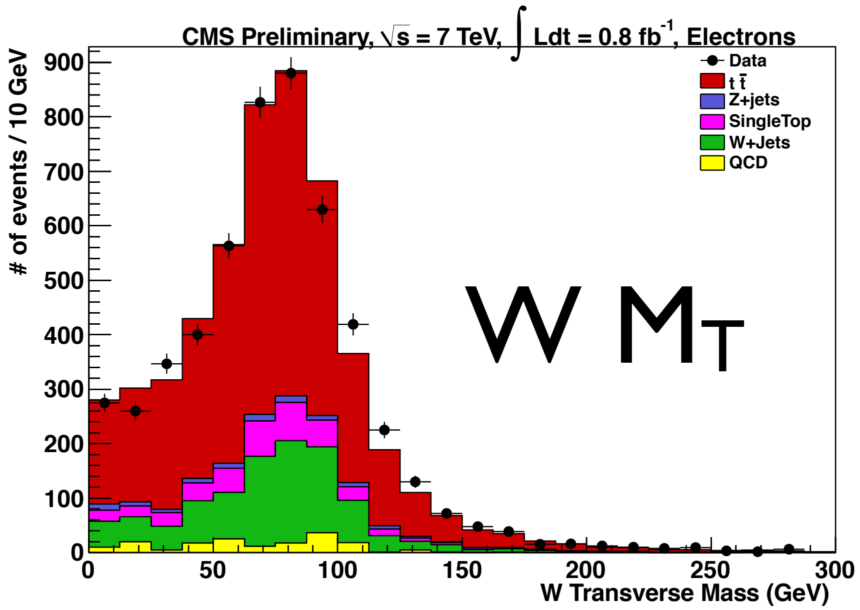
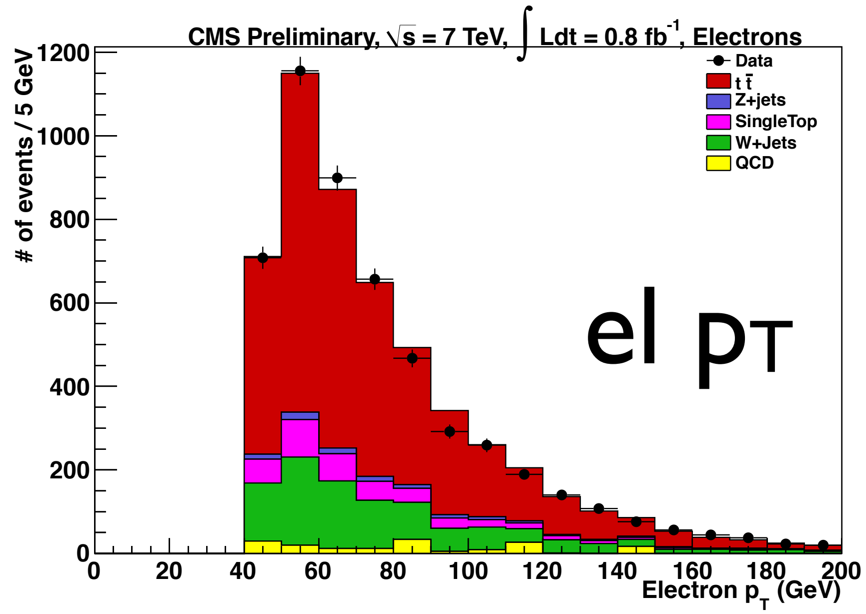
Electron kinematic plots

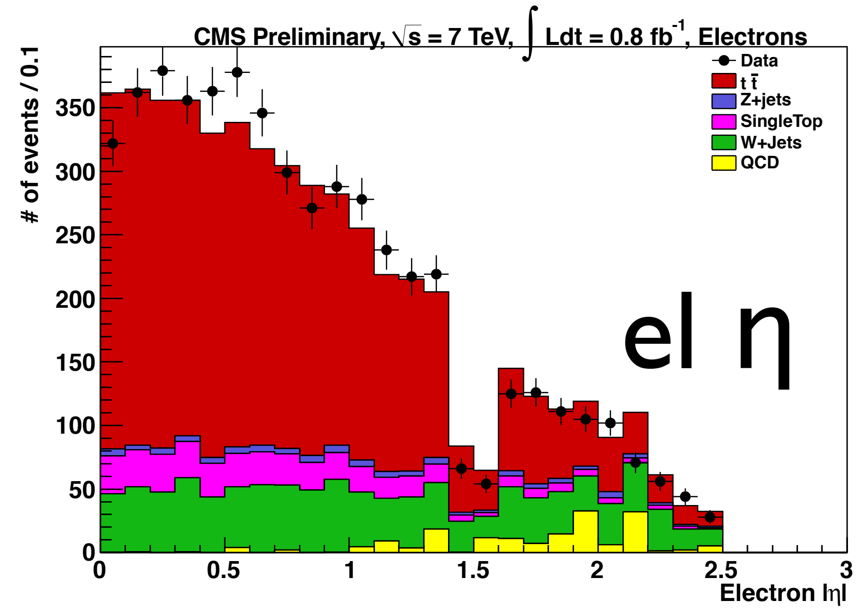












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Systematics uncertainties

Source	Muon Analysis	Electron Analysis	Combined Analysis
Quantity	Uncertainty (%)		
Lepton ID/reco/trigger	3.4	3	3.4
$\not\!\!E_{\mathrm{T}}$resolution due to unclustered energy	< 1	< 1	< 1
$t\bar{t}$+jets Q^2 scale	2	2	2
ISR/FSR	2	2	2
ME to PS matching	2	2	2
Pile-up	2.5	2.6	2.6
PDF	3.4	3.4	3.4
Profile Likelihood Parameter	Uncertainty (%)		
Jet energy scale and resolution	4.2	4.2	3.1
b-tag efficiency	3.3	3.4	2.4
W+jets Q^2 scale	0.9	0.8	0.7
Combined	7.8	7.8	7.3

estimated using PEs

included in the fit

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP11003

what do we mean by pseudo experiments (PEs)?

- generate 4000 reasonable alternate pseudo dataset
- fit with default template
- the bias is the systematic uncertainty

Results

- Fit Result (muon and electron channels combined):

$$\sigma_{t\bar{t}} = 164.4 \pm 2.8(\text{stat.}) \pm 11.9(\text{syst.}) \pm 7.4(\text{lum.})\ \text{pb}$$

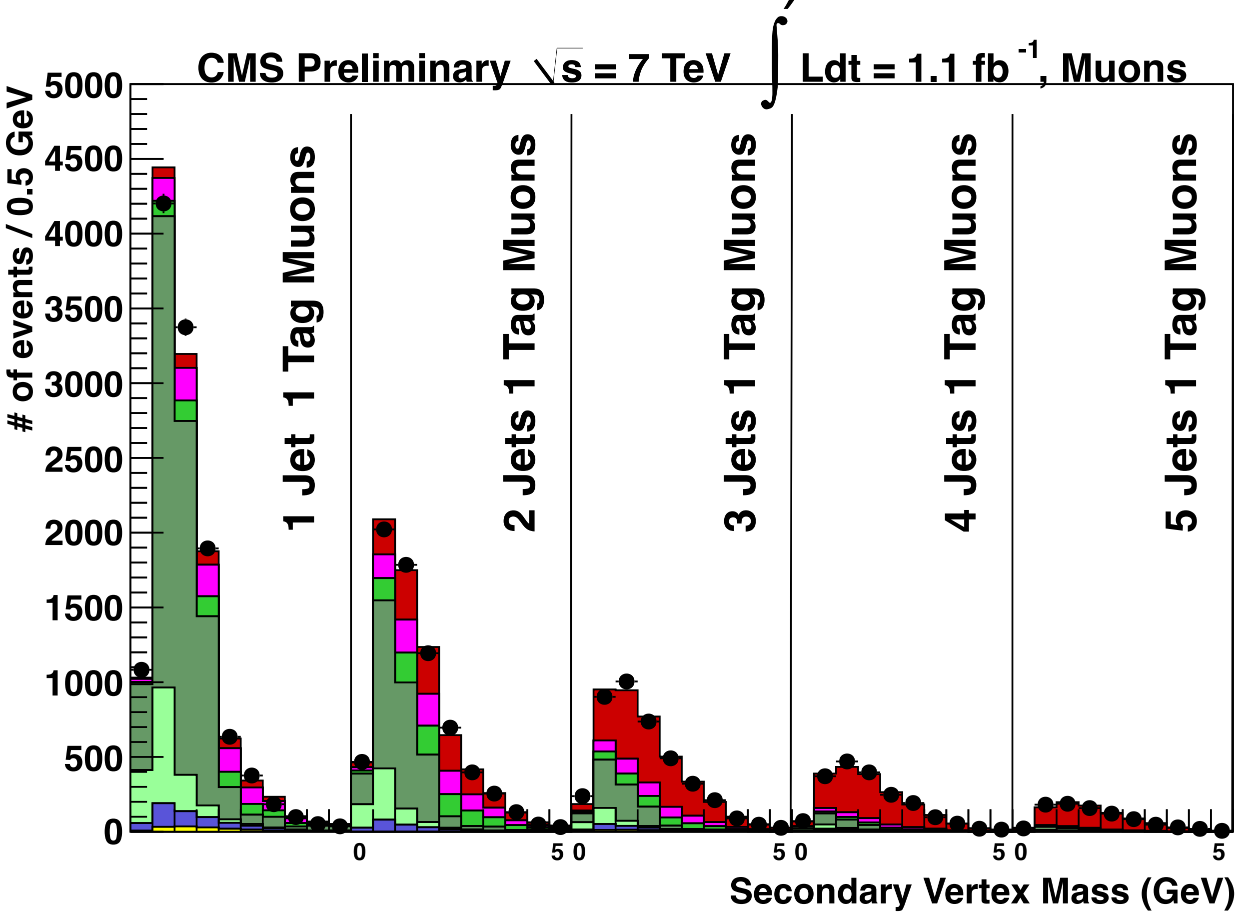
- Fit Result (muon only):

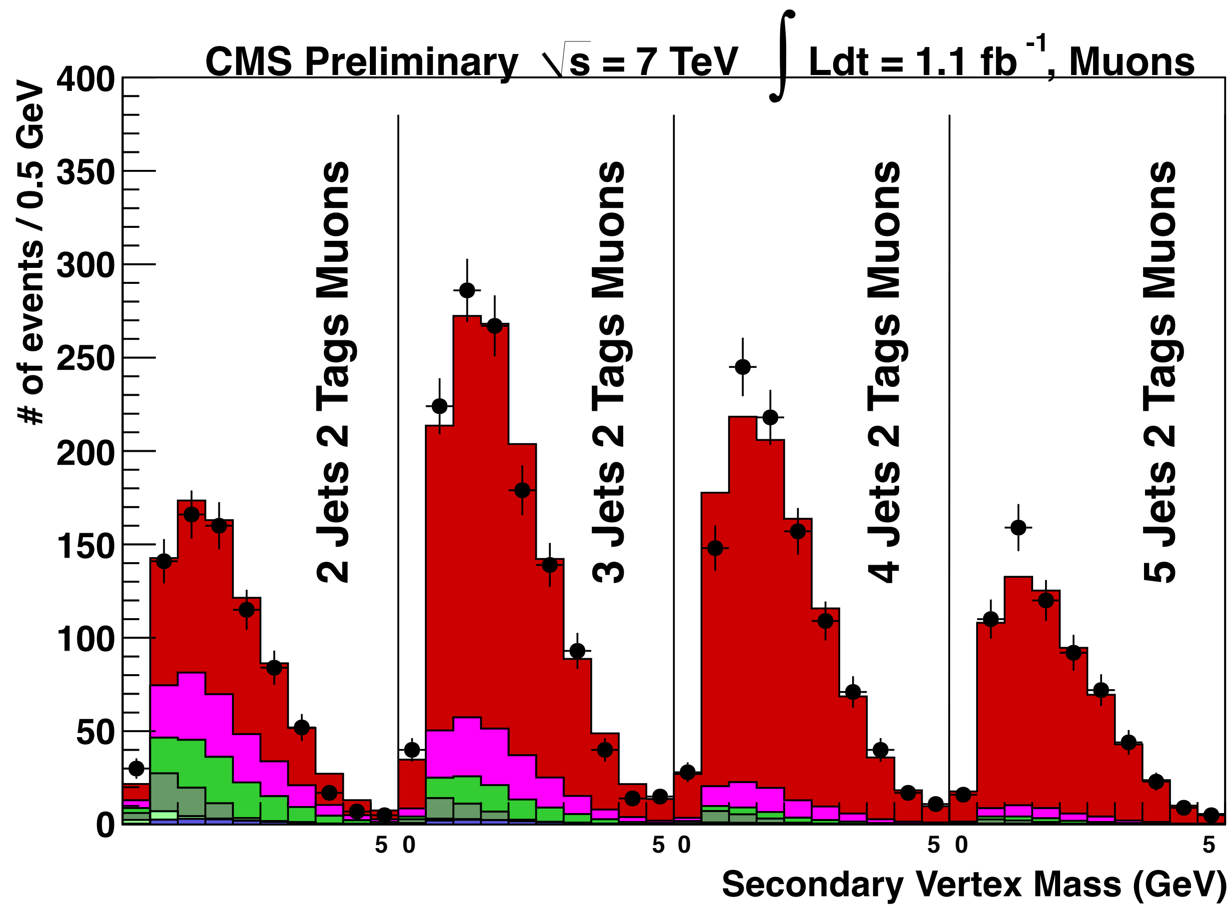
$$\sigma_{t\bar{t}} = 163.2 \pm 3.4(\text{stat.}) \pm 12.7(\text{syst.}) \pm 7.3(\text{lum.})\ \text{pb}$$

- Fit Result (electron only):

$$\sigma_{t\bar{t}} = 163.0 \pm 4.4(\text{stat.}) \pm 12.7(\text{syst.}) \pm 7.3(\text{lum.})\ \text{pb}$$

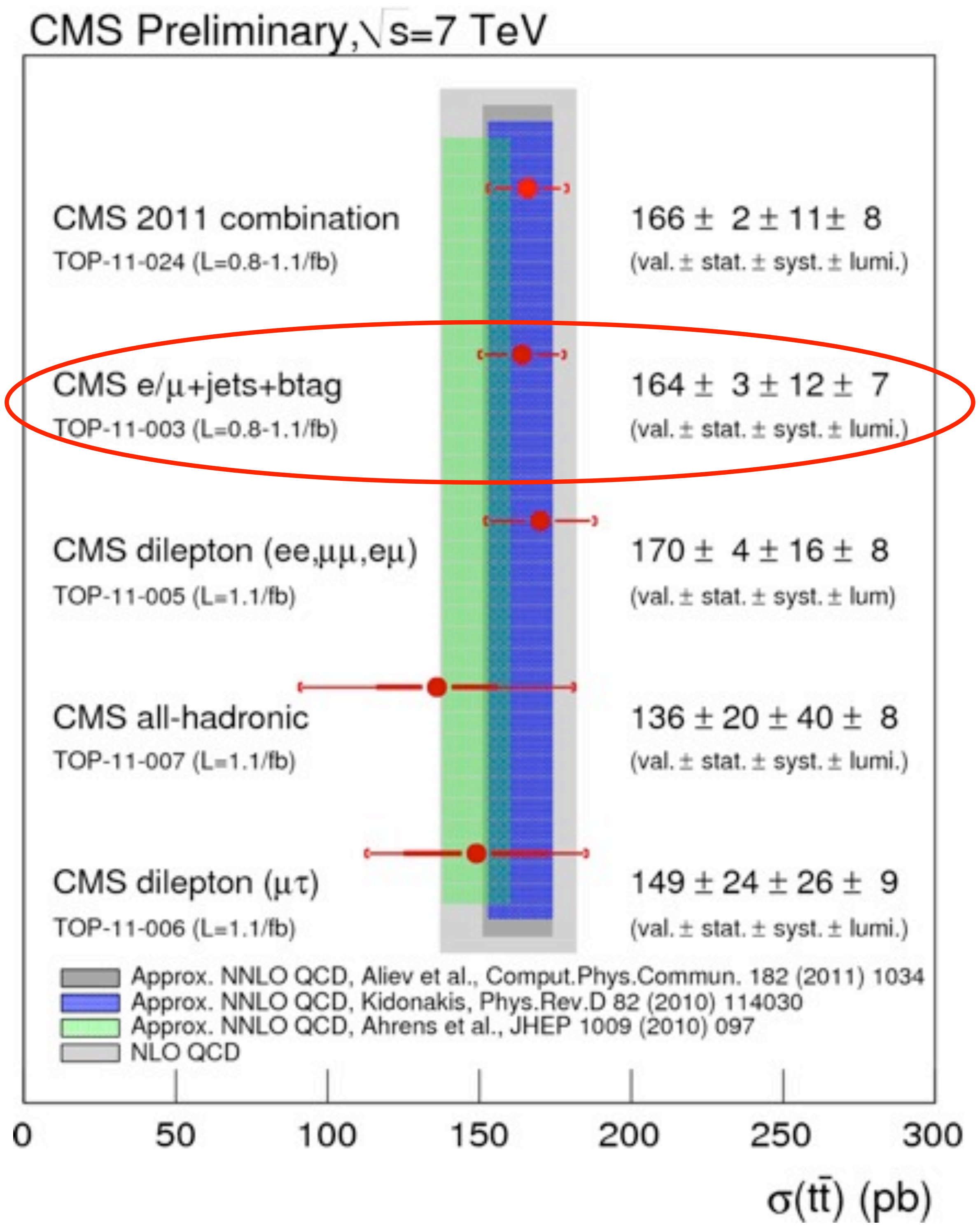
- independent measurement of the btag SF (in excellent agreement with other methods within CMS)





Summary

- ttbar lepton + jets result is in good agreement with other channels and predictions
  - it agrees with standard model prediction
  - no evidence yet of new physics decaying to ttbar
- recently analysis was performed on the full 2011 7 TeV dataset and is being prepared for publication
- analysis continues with 8 TeV data



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP11024

THANK YOU!

Backup

Event counts

	Data	Total Pred	Top	SingleTop	Wbx	Wcx	Wqq	ZJets	QCD
1 Jet 1 Tag Muons	11934	11968.9	426.9	983.8	643.8	7787.7	1499.2	475.6	151.9
2 Jets 1 Tag Muons	7026	7092.4	1500.8	996.0	931.6	2776.7	664.0	294.3	-70.9
3 Jets 1 Tag Muons	4067	4067.7	2101.8	447.7	343.7	797.7	208.5	115.4	53.0
4 Jets 1 Tag Muons	1933	1926.5	1394.6	140.8	81.7	182.0	55.8	33.4	38.0
5 Jets 1 Tag Muons	854	880.7	731.2	43.7	23.8	51.8	9.7	14.5	6.1
2 Jets 2 Tags Muons	777	808.4	448.1	167.8	119.7	50.2	8.7	13.9	0.0
3 Jets 2 Tags Muons	1297	1307.8	1048.3	150.1	68.3	27.3	1.9	11.8	0.0
4 Jets 2 Tags Muons	1044	1041.3	940.9	63.9	17.1	14.9	0.9	3.7	0.0
5 Jets 2 Tags Muons	650	630.5	586.6	26.3	9.8	5.6	0.0	2.2	0.0
1 Jet 1 Tag Electrons	6119	6033.8	227.5	338.4	275.8	3766.4	752.1	229.7	443.9
2 Jets 1 Tag Electrons	3586	3598.4	782.3	382.2	431.3	1430.0	344.8	161.9	65.9
3 Jets 1 Tag Electrons	2142	2109.8	1079.9	198.8	169.5	378.1	90.6	64.1	128.8
4 Jets 1 Tag Electrons	1026	997.3	722.3	67.9	38.1	96.7	32.8	20.4	19.2
5 Jets 1 Tag Electrons	475	466.6	380.2	20.9	15.5	22.3	7.2	6.5	14.1
2 Jets 2 Tags Electrons	383	369.8	225.5	62.9	42.0	23.7	1.3	10.5	3.9
3 Jets 2 Tags Electrons	689	688.1	535.1	62.2	43.0	19.5	0.7	6.1	21.5
4 Jets 2 Tags Electrons	553	545.8	485.3	30.5	13.8	4.1	1.0	3.1	8.0
5 Jets 2 Tags Electrons	319	324.3	301.3	13.4	4.6	1.2	0.3	1.3	2.3
Total	44874	44858.3	13918.7	4197.2	3273.0	17435.9	3679.5	1468.5	885.6

https://twiki.cern.ch/twiki/bin/view/CMS/PasTop11003SupplementaryMaterial

Fit Results

combined electron+muon fit result

Fit factors	
Top	$164.2^{+6.1}_{-5.9}$
SingleTop	$1.44^{+0.27}_{-0.27}$
Wbx	$1.21^{+0.28}_{-0.27}$
Wcx	$1.66^{+0.06}_{-0.06}$
Wqq	$0.58^{+0.08}_{-0.07}$
ZJets	$1.34^{+0.29}_{-0.29}$
Fit Shifts	
Q2	$0.09^{+0.10}_{-0.10}$
btag	$-0.33^{+0.11}_{-0.11}$
jes	$-0.28^{+0.39}_{-0.40}$
lftag	$0.11^{+1.00}_{-1.00}$
qcdConstr_1j_el	$0.60^{+0.34}_{-0.33}$
qcdConstr_1j_mu	$-0.78^{+0.25}_{-0.26}$
qcdConstr_2j_el	$-0.65^{+0.27}_{-0.26}$
qcdConstr_2j_mu	$-1.36^{+0.63}_{-0.63}$
qcdConstr_3j_el	$1.27^{+0.59}_{-0.59}$
qcdConstr_3j_mu	$0.09^{+0.86}_{-0.86}$
qcdConstr_4j_el	$-0.21^{+0.38}_{-0.36}$
qcdConstr_4j_mu	$0.19^{+0.85}_{-0.85}$
qcdConstr_5j_el	$-0.46^{+0.45}_{-0.44}$
qcdConstr_5j_mu	$-0.20^{+0.98}_{-0.98}$

σ(Top) in pb

fraction of SM

shift from nominal value [σ]

constrained to 0 ± 1

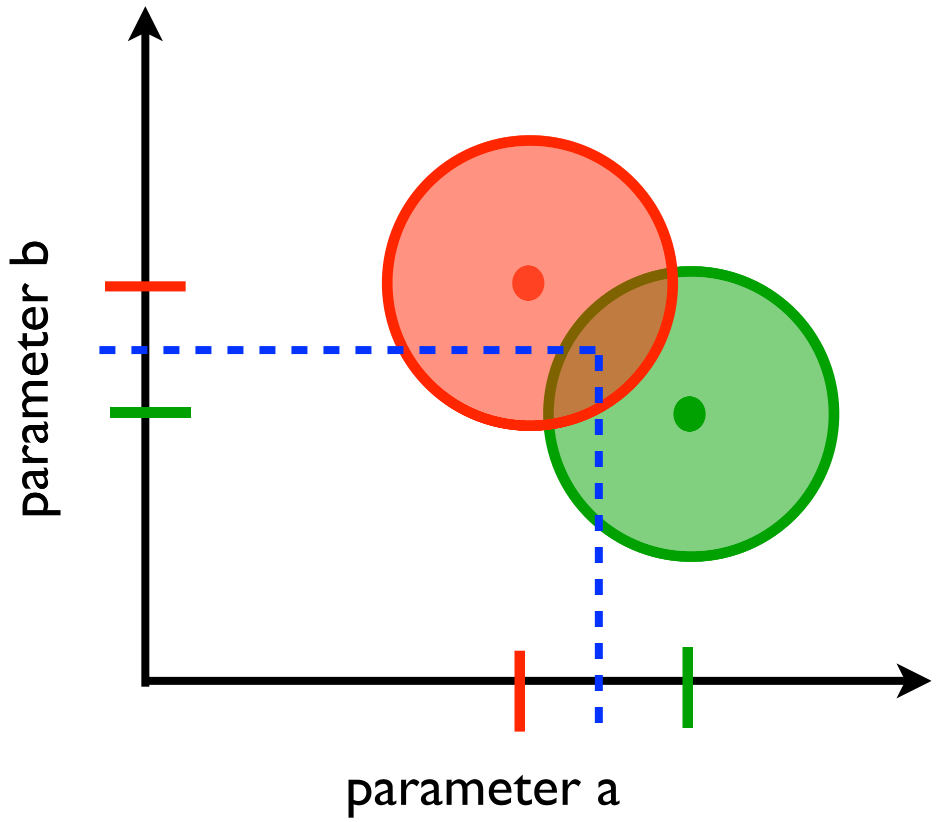
shift from nominal value [σ]

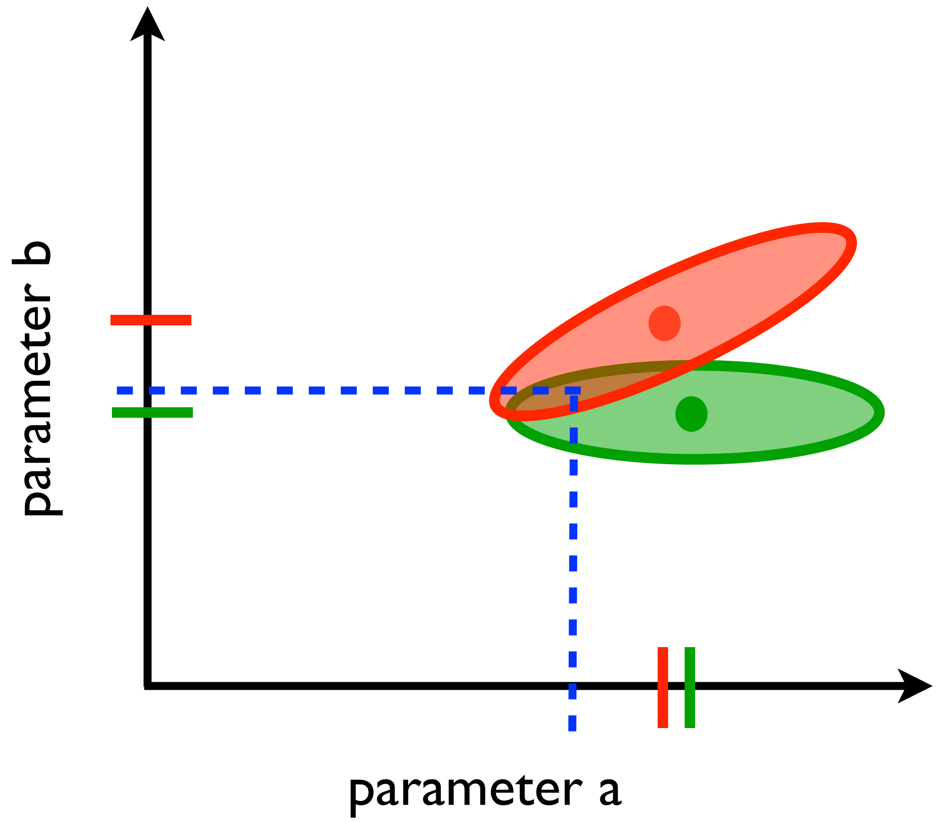
100% uncert. constrained to 0 ± 1

https://twiki.cern.ch/twiki/bin/viewauth/CMS/PasTop11003SupplementaryMaterial

Question: Should the combined result be bracketed?

- In a multiparameter likelihood we shouldn't expect the combination results to be bracketed by the individual results, so being the mean is definitely not certain
- Simple cartoon for building intuition





Example 1: The combination is bracketed by measurements 1 and 2 for both parameters in likelihood

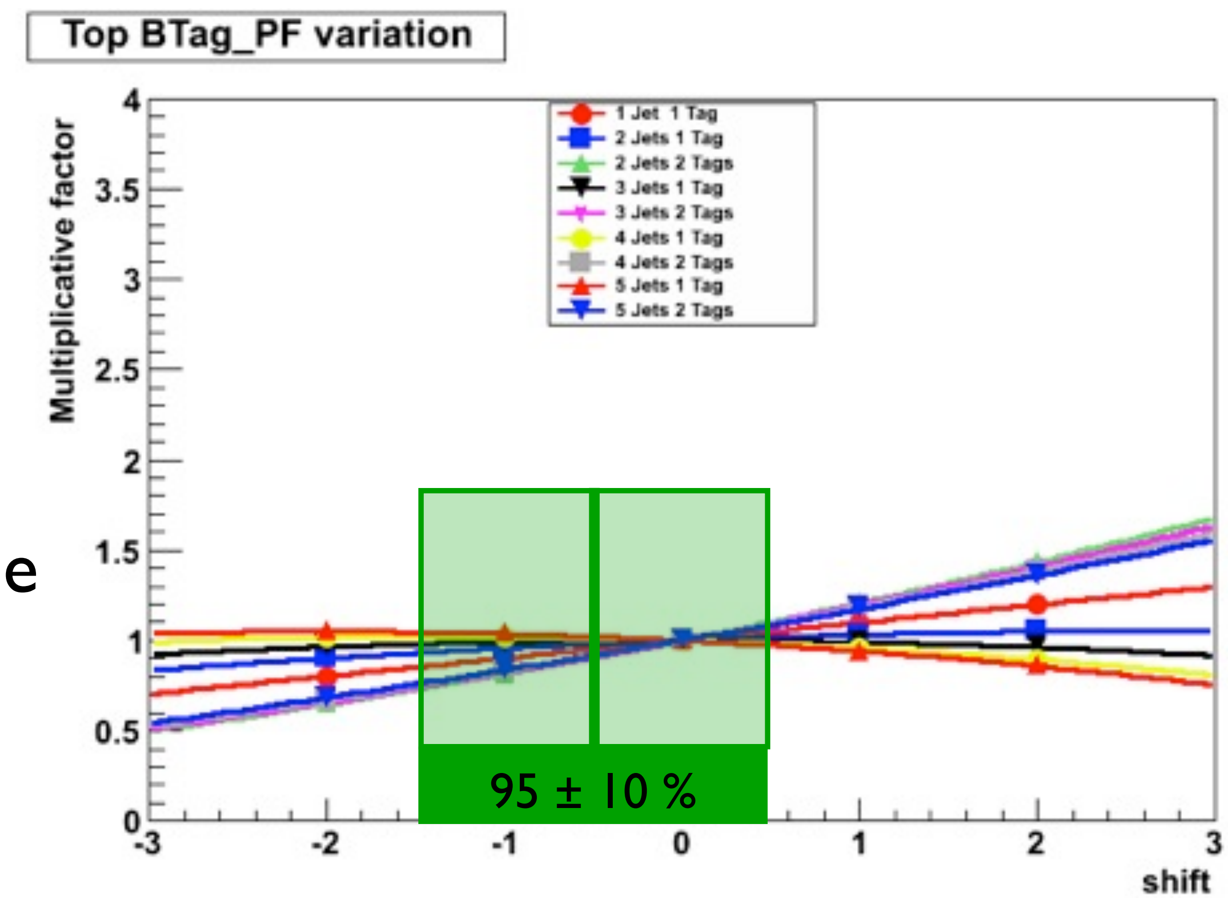
Example 2: The combination is bracketed in parameter b, but not in parameter a

Polynomials for Top B-Tagging

- Use SF = 1.0 ± 0.1 and perform an independent measurement
  - nominal = 0 shift → p=1
  - how much does normalization changes for ± 1σ? ± 2σ?
  - Fit a second degree polynomial to these points

$$p_{t\bar{t}}^{\mathrm{Btag}}(i, j, \ell, R_{\mathrm{Btag}})$$

- R_{Btag} is a parameter of the fitter (the SF is measured!)



Btagging POG SF is within 1 sigma of our starting point