Physics in Top Quark decays

- the decay of the top quark in the Standard Model and beyond
- using b-tagging to study the decay t→Wb
    1. measuring the branching ratio
    2. using BR(t→Wb) as a constraint to measure the b-tagging efficiency
- obtaining Jet Energy Scale corrections from mass constraints
- resonances in the top quark pair mass spectrum

Somewhere in India anno 2006

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Workshop on LHC Physics – Mumbai 21-27 October 2009

The Top Quark in the Standard Model

❶ **In the Standard Model the quarks obtain their mass via EW symmetry breaking**

$$\mathcal{L}_Y = \sum_{ij} y_{ij}^D \, \bar{D}_R^i \, \Phi^\dagger \, Q_L^j \; + \; \sum_{ij} y_{ij}^U \, \bar{U}_R^i \, \bar{\Phi}^\dagger \, Q_L^j \; + \; \text{h.c.}$$

- ✓ *where Φ is a doublet under SU(2) and has hypercharge ½*
- ✓ *when $\Phi^\dagger = (\,0 \;\; v\,)$ these interactions give masses to the quarks as $m_q = y_q v$*
- ✓ *collecting all the mass terms leads to the CKM matrix, a unitary matrix that couples top and W to all the down, strange and bottom quarks : $\mathcal{A}(t \rightarrow Wq) \propto V_{tq}$*
- ✓ *we can study the Standard Model production of top quarks or top quark pairs*

❷ **'Theorists at work' : replace this structure with something else …**

- ✖ *most of the times with more fields*
- ✓ *the top quark couples most strongly to the EW symmetry breaking sector*

❸ **The large mass leads to a large top quark width (Γ_t ~ 1.5 GeV)**

- ✓ *the top quark lifetime is shorter than the typical hadronization time (Λ_{QCD}^{-1})*
  - ⇨ *within the SM = 4×10^{-25} s $< \tau_{hadr.} \sim 28 \times 10^{-25}$ s*
- ✓ *one can study the bare quark properties (no confinement)*
- ✓ *the weak interactions are strong and the strong interactions are weak…*

The decay of the top quark

PRODUCTION

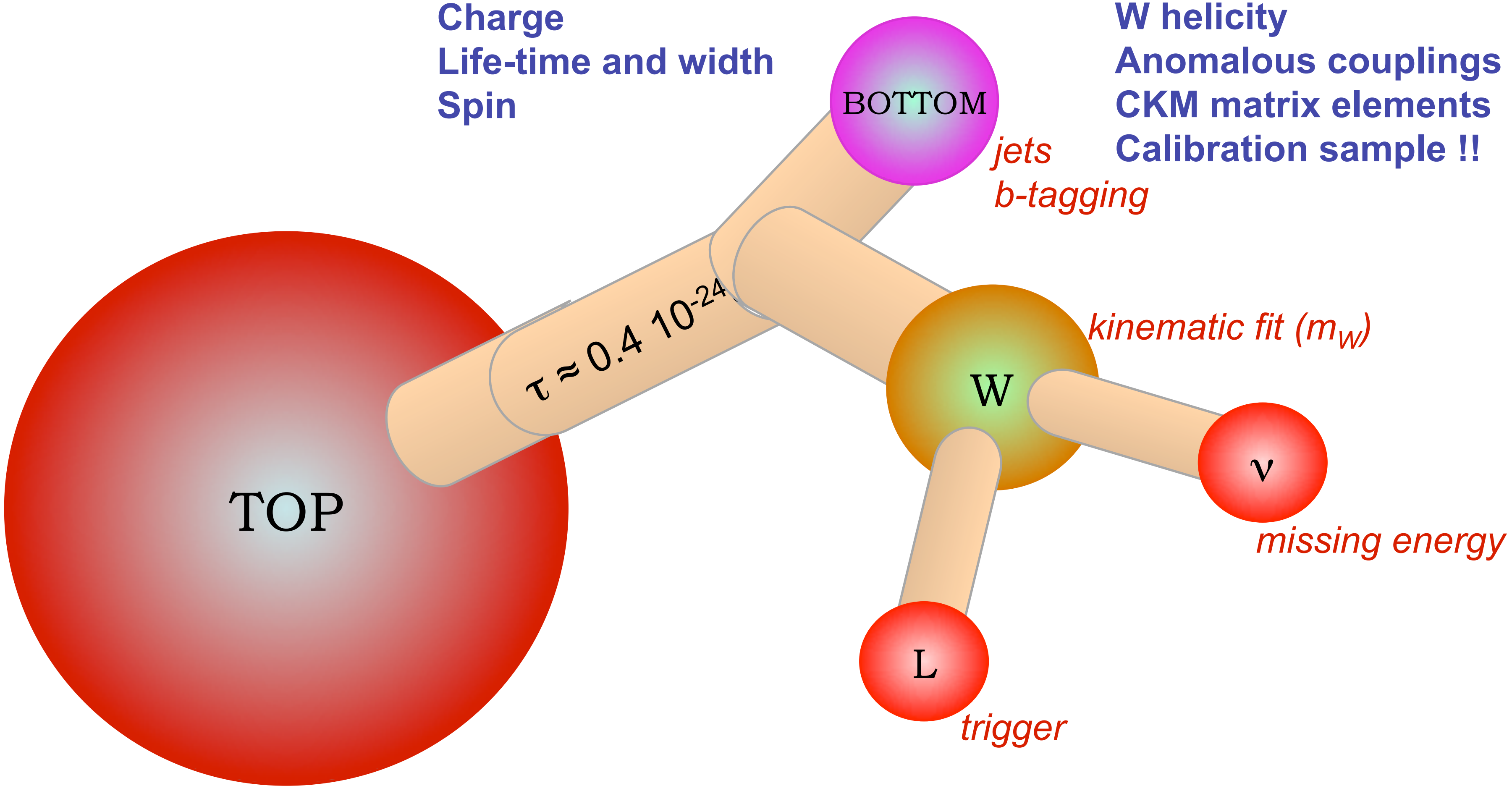
Cross section

PROPERTIES

Mass (matter vs. anti-matter)
Charge
Life-time and width
Spin

DECAY

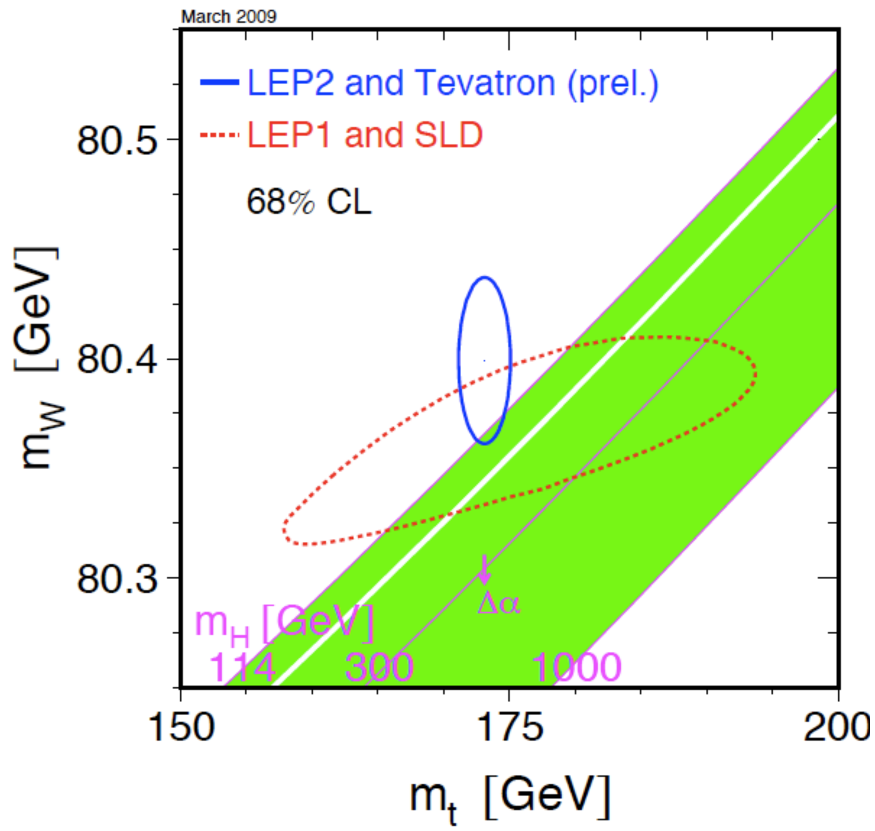
Charged Higgs
W helicity
Anomalous couplings
CKM matrix elements
Calibration sample !!



The LHC data will extend the Tevatron precision reach and allow new topics.

Tevatron knowledge

- **First measurements achieved at the Tevatron (only a selection!)**



Parameter	**CDF**	95% CL	**D0**
mass (comb)	**173.1±0.6±1.1 GeV**		
width	< 13.1 GeV		
lifetime	$c\tau_{top}<52.2\ \mu m$		
charge	excl. -4/3 @ 87%		excl. -4/3 @ 92%
BR(t→Wb)/ BR(t→Wq)	> 0.61		> 0.79
F0	0.66±0.16±0.05		0.49±0.11±0.09
F+	< 0.27		0.11±0.06±0.05

D0 : m(top) – m(anti-top) = 3.8 ± 3.7 GeV

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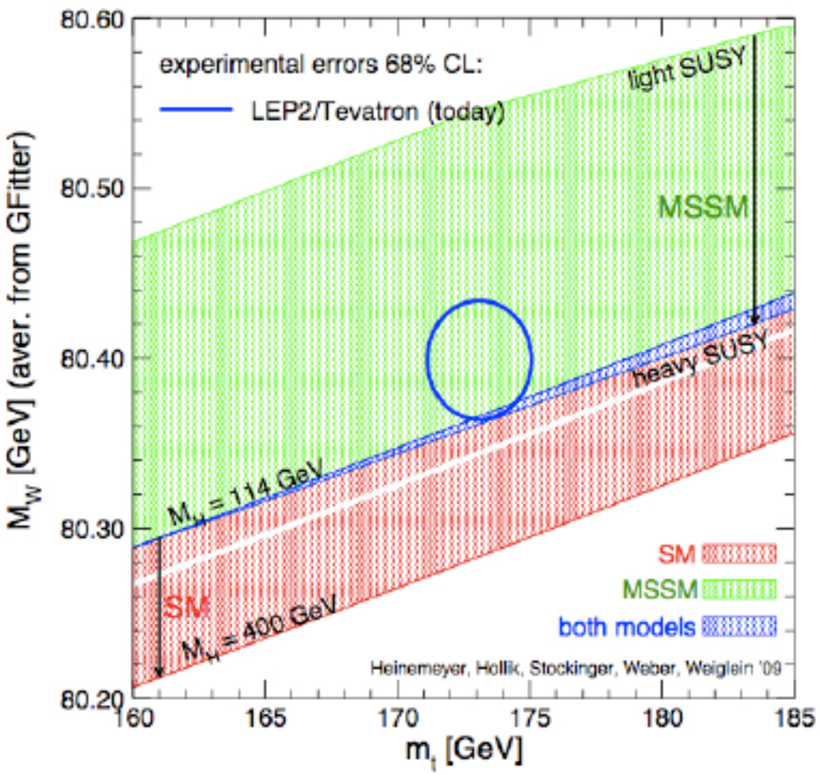

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How to define the Top Quark mass?

eg. arXiv:0906.5273v2

- **What is the real theoretical uncertainty (or error even) on m_{top}?**
- **Which kind of top quark mass do we measure, examples:**
  - **Pole mass (m_t^{pole}): Breit-Wigner pole**
  - **1S mass scheme (m_t^{1S}): threshold mass eg. in $e^+e^- \rightarrow$ttbar**
  - **MS-bar mass ($m_t^{MS}(\mu)$): preferred by theorists**
- **Theoretical differences can be large…**

- **A calculation from the Tevatron cross section resulted in a 8 GeV difference between the pole mass and the running top quark mass (MS-bar).**

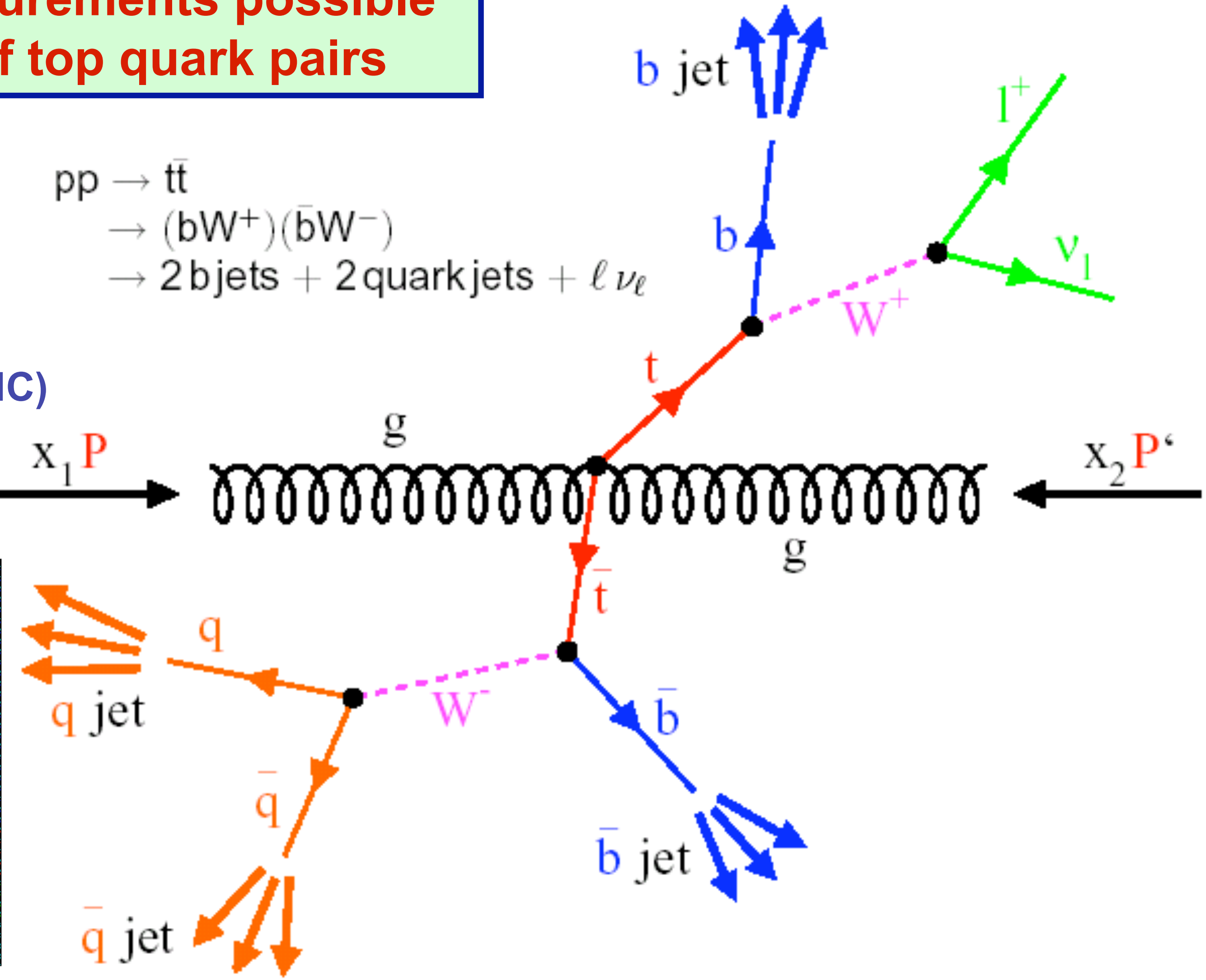
	$\overline{m}$ [GeV]	m_t [GeV]
LO	$159.2^{+3.5}_{-3.4}$	$159.2^{+3.5}_{-3.4}$
NLO	$159.8^{+3.3}_{-3.3}$	$165.8^{+3.5}_{-3.5}$
NNLO	$160.0^{+3.3}_{-3.2}$	$168.2^{+3.6}_{-3.5}$

Numbers obtained from the measured Tevatron cross section σ=8.18pb, uncertainties are experimental.

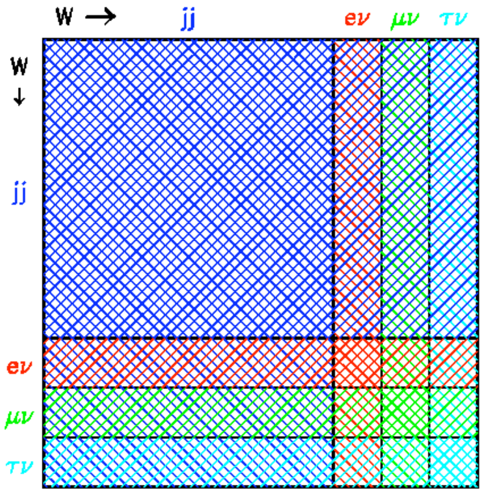
Decay of top quark pairs

Many new measurements possible in the decay of top quark pairs

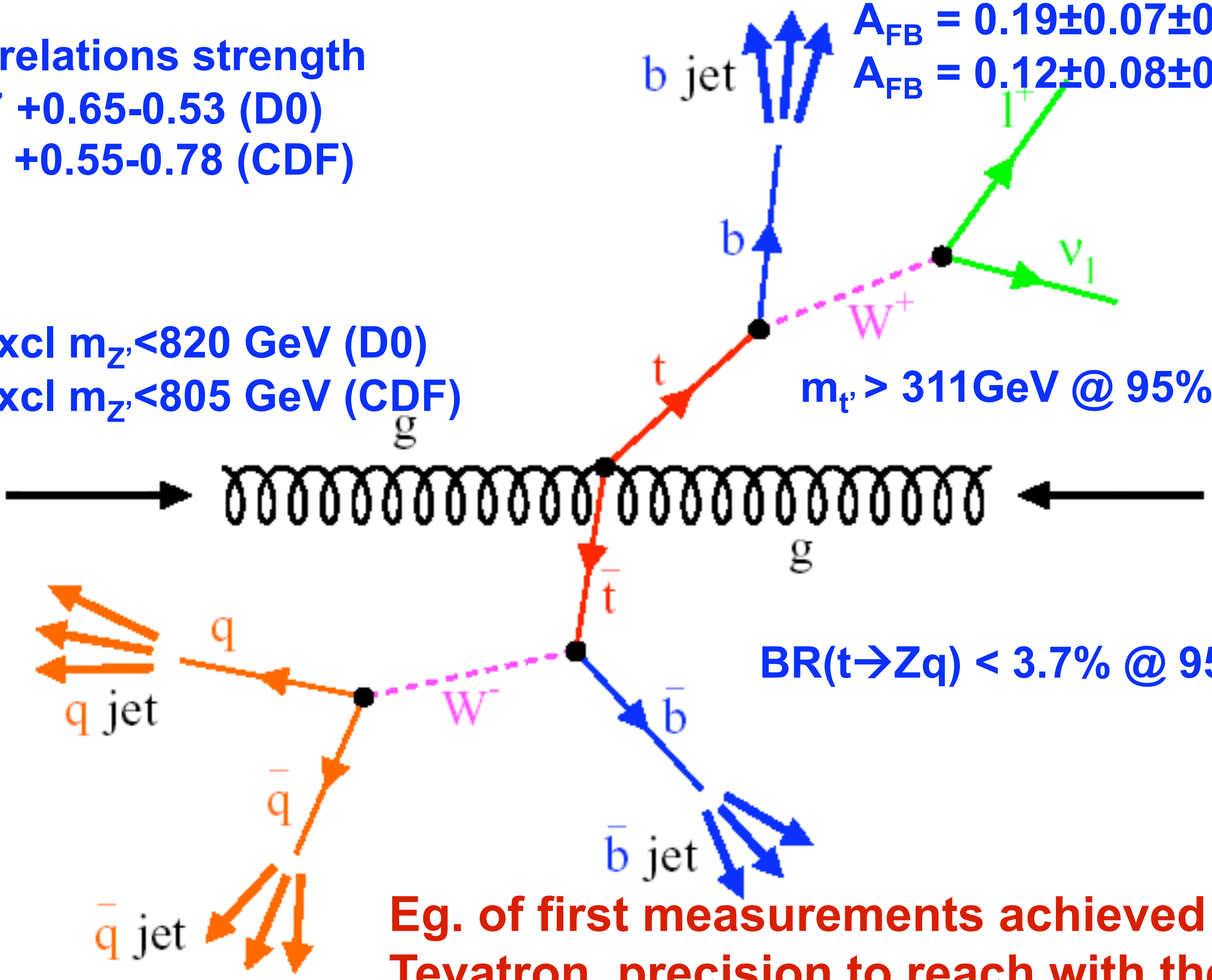
Spin-correlations
Resonances X→tt
Fourth generation t'
New physics (SUSY)
Flavour physics (FCNC)



$$pp \to t\bar{t} \to (bW^+)(\bar{b}W^-) \to 2\,\mathrm{b\,jets} + 2\,\mathrm{quark\,jets} + \ell\,\nu_\ell$$



Tevatron knowledge



Spin correlations strength
K = -0.17 +0.65-0.53 (D0)
K = 0.32 +0.55-0.78 (CDF)

A_{FB} = 0.19±0.07±0.02 (CDF)
A_{FB} = 0.12±0.08±0.01 (D0)

excl $m_{Z'}$<820 GeV (D0)
excl $m_{Z'}$<805 GeV (CDF)

$m_{t'}$ > 311GeV @ 95% CL (CDF)

BR(t→Zq) < 3.7% @ 95% CL (CDF)

Eg. of first measurements achieved at the Tevatron, precision to reach with the LHC data

The decay of the top quark

arXiv:hep-ph/0607115v2

- **Also new phenomena can be hidden in the top decay…**
- **Flavour changing processes in the Standard Model**

$$J_\mu^+ = \bar{u}_L \gamma_\mu d_L \xrightarrow{\text{mass eigenstates}} J_\mu^+ = \bar{U}_L \gamma_\mu V_{\mathrm{CKM}} D_L$$

$$|\mathbf{V}_{\mathrm{CKM}}| = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$= \begin{pmatrix} 0.9738 \pm 0.0005 & 0.2200 \pm 0.0026 & (3.67 \pm 0.47) \times 10^{-3} \\ 0.224 \pm 0.012 & 0.996 \pm 0.013 & (41.3 \pm 1.5) \times 10^{-3} \\ ? & ? & ? \end{pmatrix}$$

- **There can be new physics in $|V_{tb}|$, eg. charged Higgs $t \rightarrow H^+ b$ or an extended quark flavour section (4th generation)…**
- **Direct constraints via**

b-tagging!!

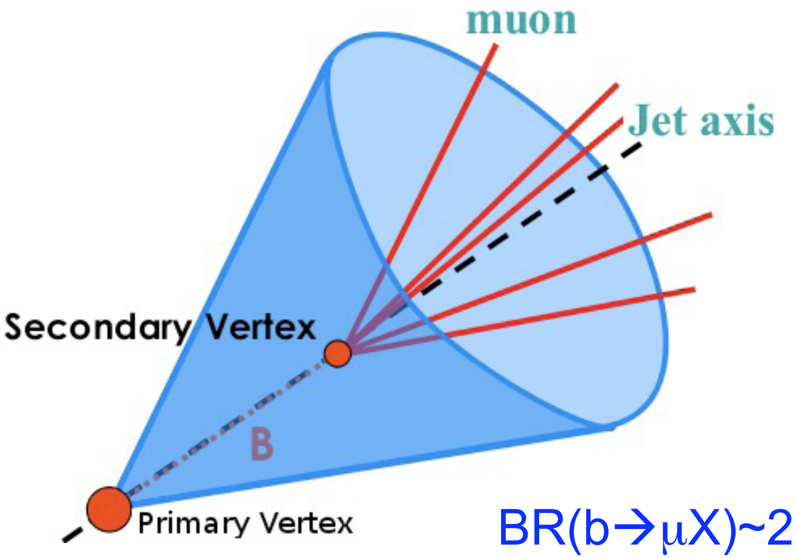
$$\boxed{R = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq(= d, s, b))} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}}$$

B-tagging in CMS

- **B-tagging tools make use of the Tracking devices to search in a jet for displaced vertices, soft (low p_T) leptons and/or tracks not originating from the primary collision vertex**

Example of observables used:

- Impact parameter and its significance
- Decay lengths
- Presence of secondary vertex
- Vertex mass
- Number of tracks at vertex
- Ratio of je energy to energy associated to secondary vertex
- Presence of soft-leptons



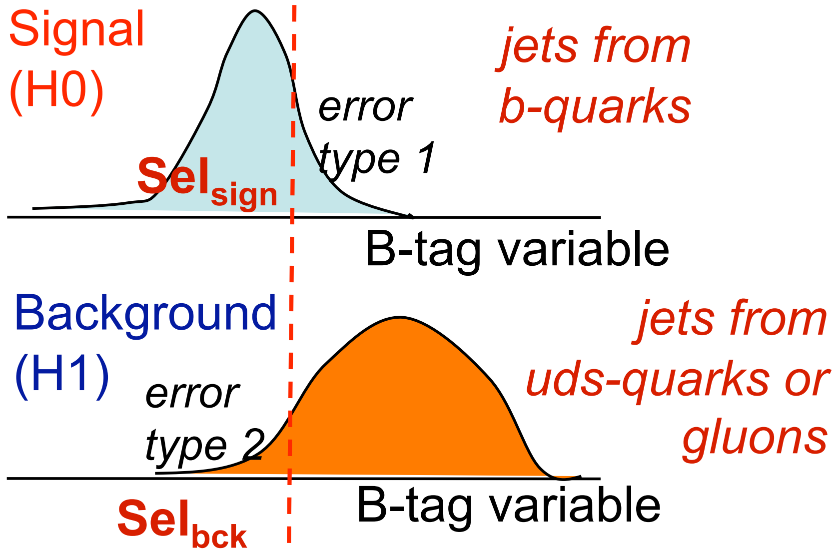
BR(b→μX)~20%

Example b-tagger (*track counting*):
Jet is b-tagged if at least N tracks have a impact parameter significance above S.

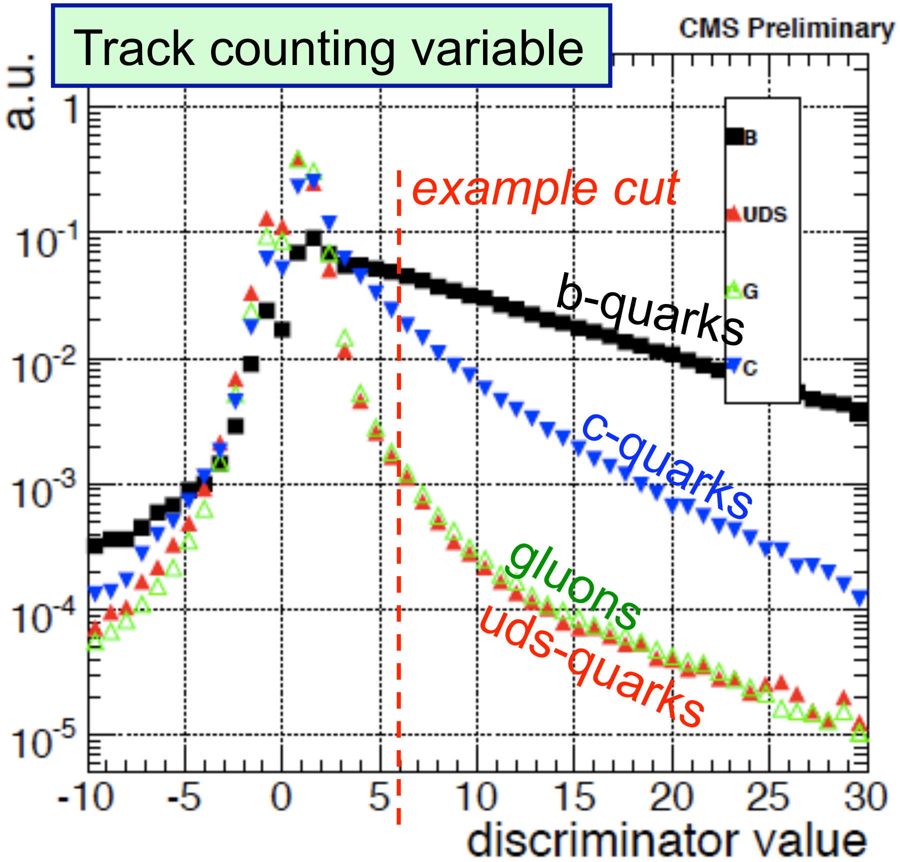
One should not forget to include quality cuts on the tracks to consider in the jet

B-tagging in CMS

- **The performance of these different b-taggers is quantified as a typical hypothesis test.**



cut (= *"working point"*)


Track counting variable

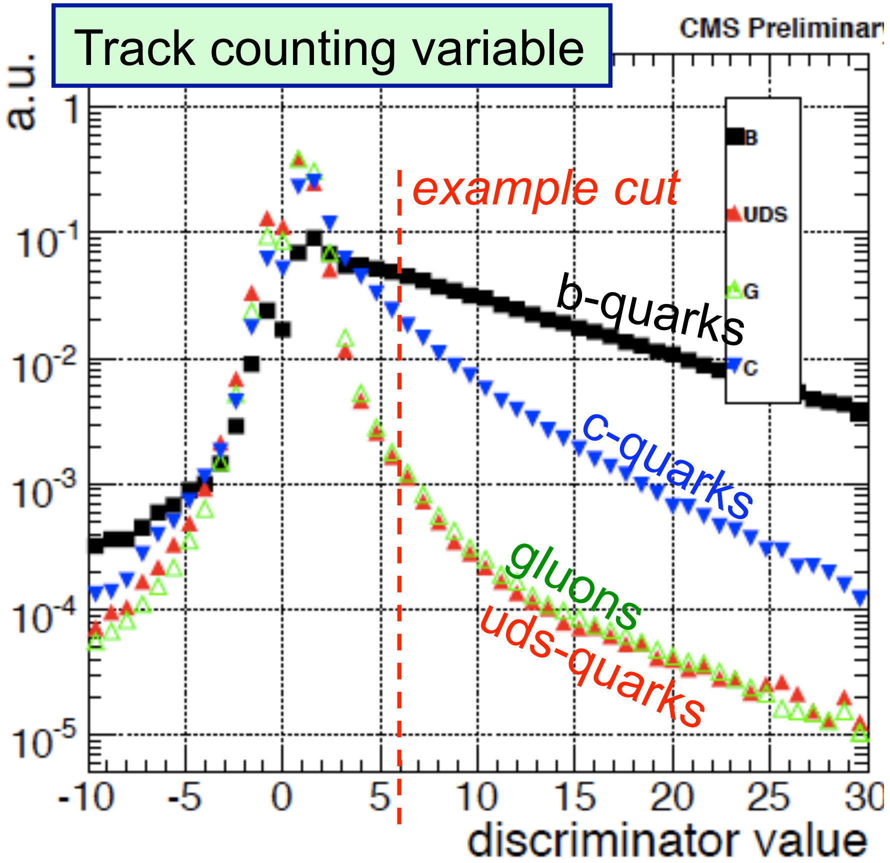
Error of type-1: rejecting a real b-quark jet
Error of type-2: accepting a non b-quark jet

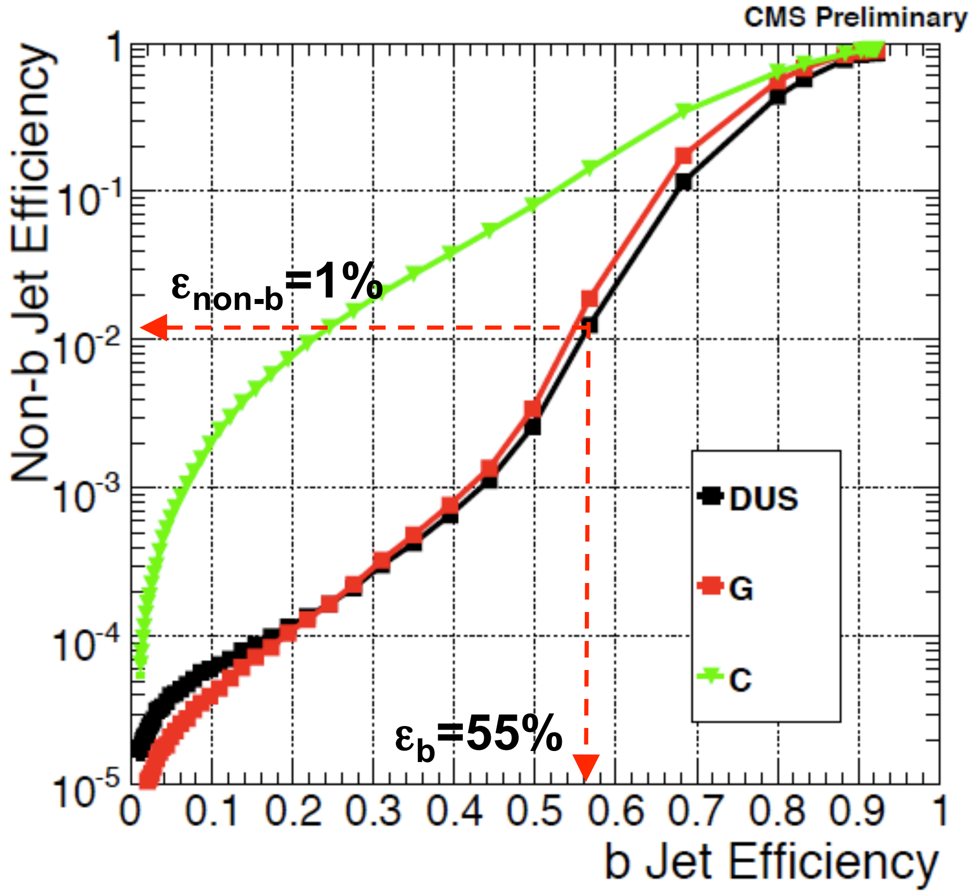
or

ε_b = b-tagging efficiency = # Sel$_{sign}$ / total # b-quark jets
$\varepsilon_{non\text{-}b}$ = Mis-tagging efficiency = # Sel$_{bck}$ / total # non-b-quark jets

B-tagging in CMS

- **An example (track counting variable)**

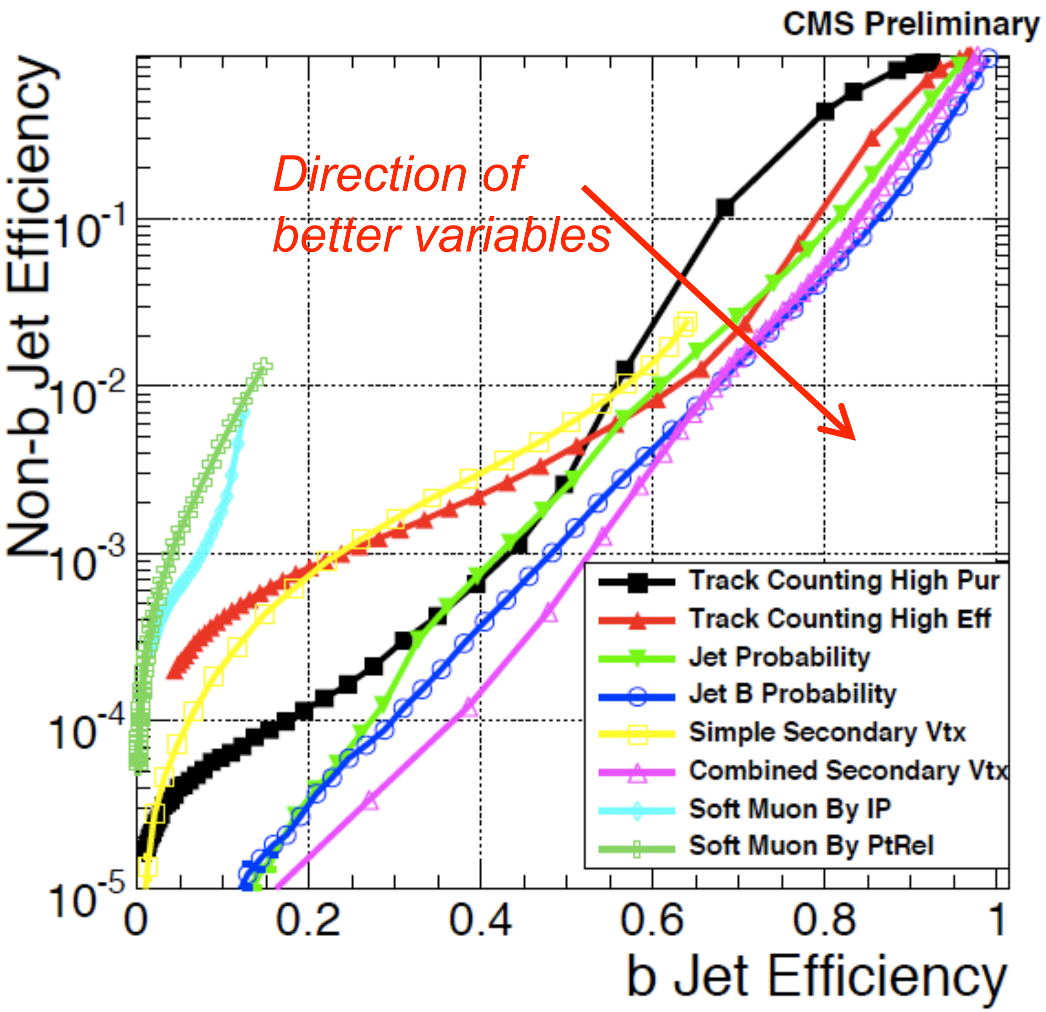




- **These efficiencies depend on the η-value and p_T-value of the jet**

B-tagging in CMS

- **Comparing all methods (all b-tag discriminators/variables)**

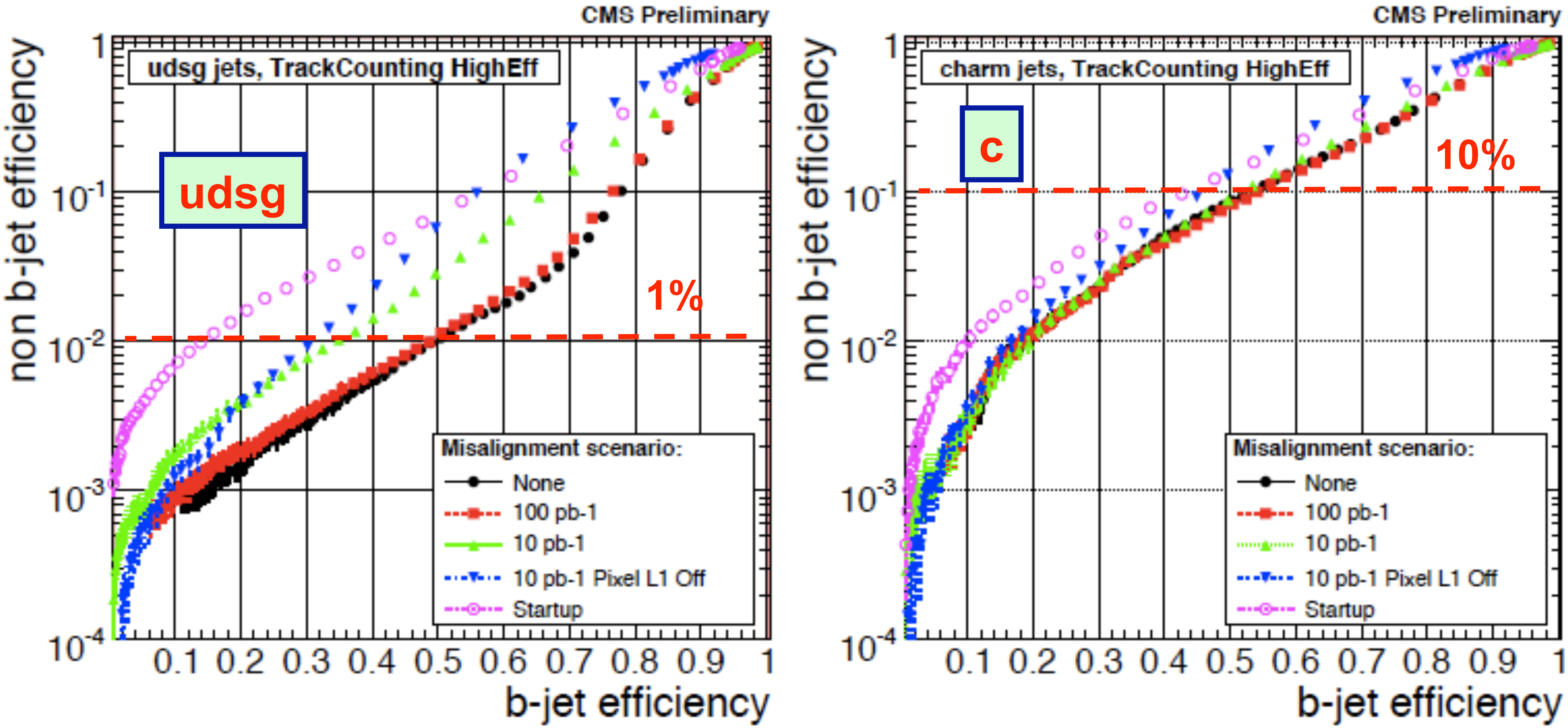


- The better algorithm is the most complex one to master, namely the “Combined Secondary Vertex” variable.
- At 60% efficiency the non-b-quark efficiency of mis-tag efficiency can vary between 0.4% and 3%.
- Soft-lepton taggers can only reach efficiencies up to ~20% because of the branching ratio of b-quarks into these leptons.

Effect of mis-alignment on b-tagging

CMS PAS BTV-07-003

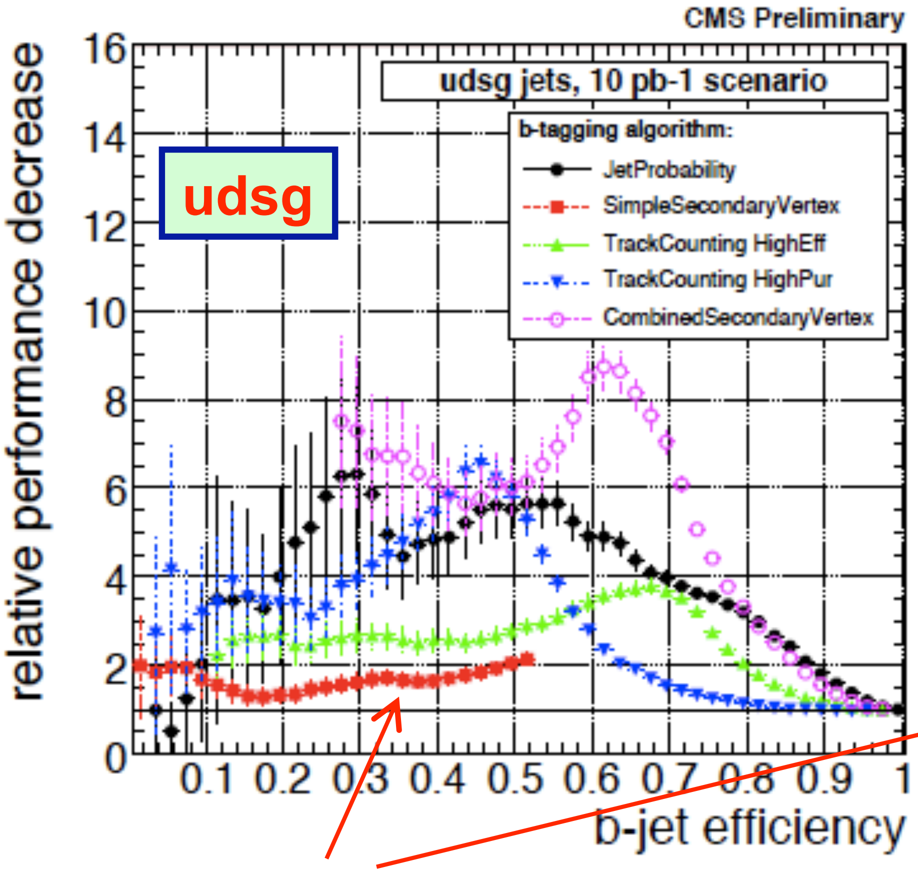
- The true performance of the b-tagging algorithms will depend on how

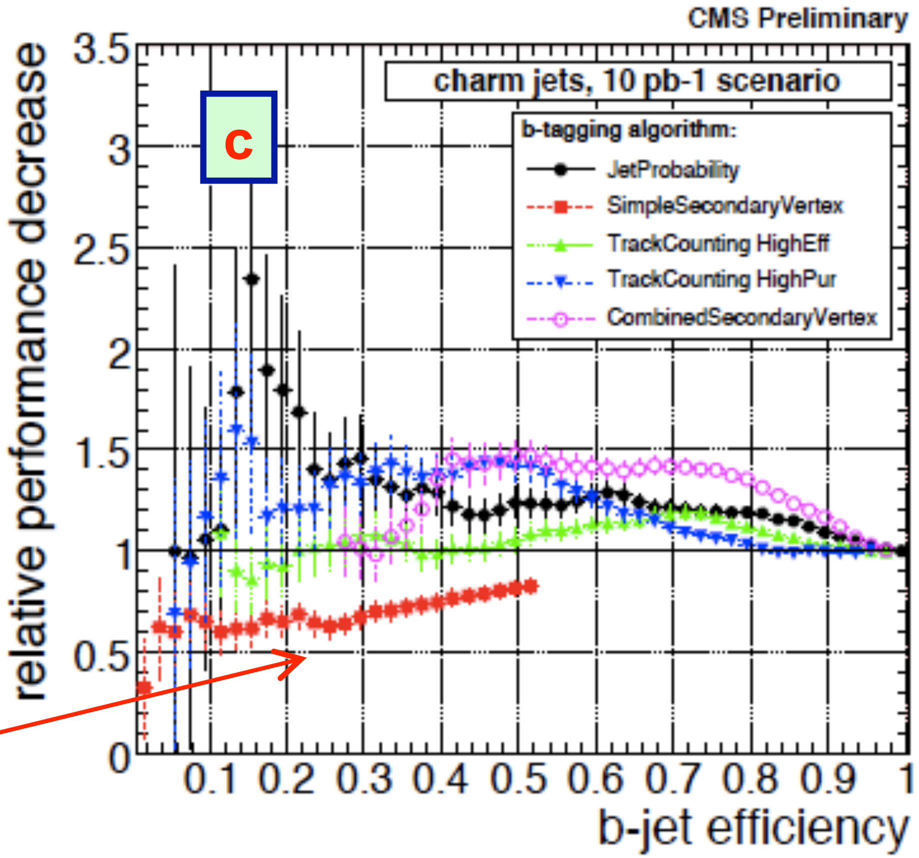


- Steep improvement in performance from start to 100/pb

Effect of mis-alignment on b-tagging

- **Decrease in performance depends of course on the b-tagger used**





- **"*Simple secondary vertex*" variable most robust (eg. 10/pb)**

Measuring the top's branching ratios

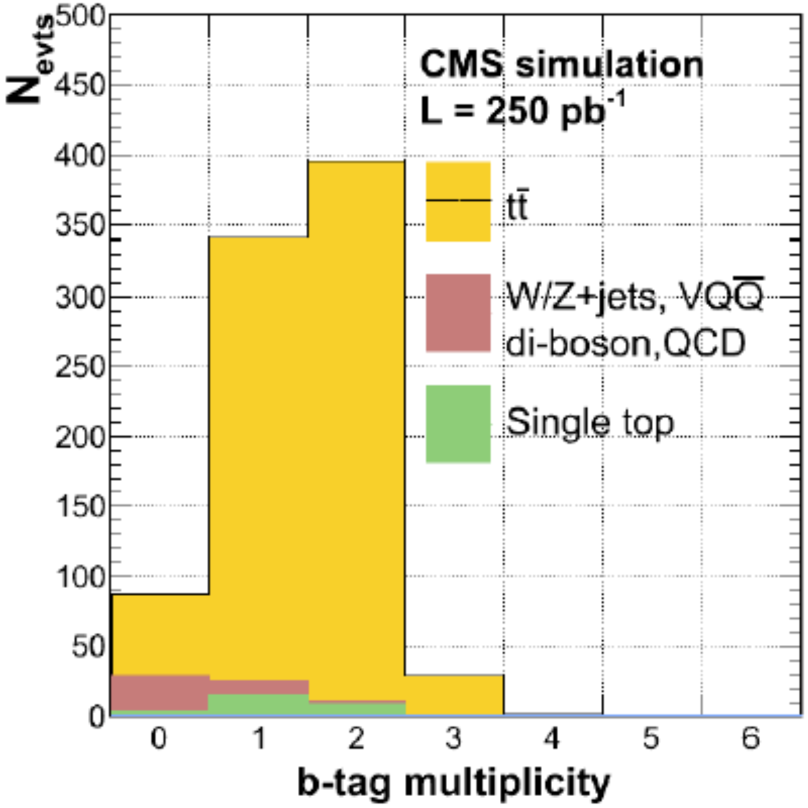
[CMS PAS TOP-09-007](#)
[CMS PAS TOP-09-001](#)

- **Important to test the $|V_{tb}|\sim1$ of the Standard Model**

  (remember Tevatron gives $|V_{tb}| = 1.0 \pm 0.1$ … personal poor mans combination as an illustration of the current precision from direct measurements)

- **Likelihood fit of the b-tag multiplicity spectra with a function depending o**

  is-tag efficiency $\varepsilon_{non\text{-}b}$

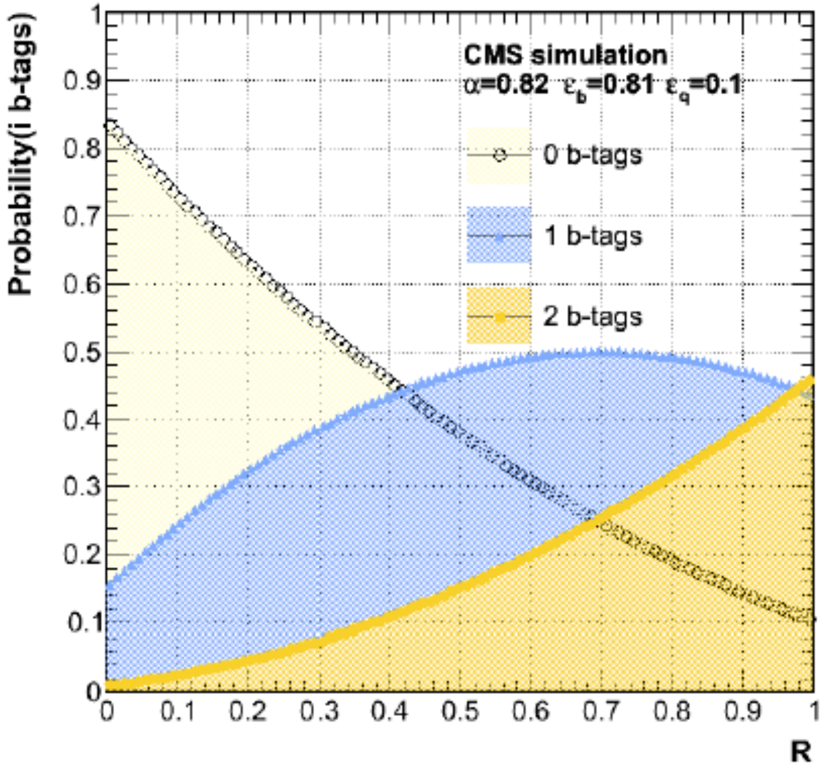


Example with di-lepton events

1. Choose a b-tagging algorithm and a working point
2. If the discriminator value is above a certain threshold then we consider the jet to be tagged
3. Count the number of tagged jets per event

Measuring the top’s branching ratios

- Fit function uses the probability P_k of observing k b-tags in an event



- The top quark pairs decay to 2 b-jets
- Expect 2 b-tags in the event from:

$$P(t\rightarrow Wb;t\rightarrow Wb) \sim R^2\,\varepsilon_b^{\,2}$$
$$+\,P(t\rightarrow Wb;t\rightarrow Wq) \sim 2\,R\,(1\text{-}R)\,\varepsilon_b\,\varepsilon_q$$
$$+\,P(t\rightarrow Wq;t\rightarrow Wq) \sim (1\text{-}R)^2\,\varepsilon_q^{\,2}$$

- In general the probability to observe k b-tags in the events is:

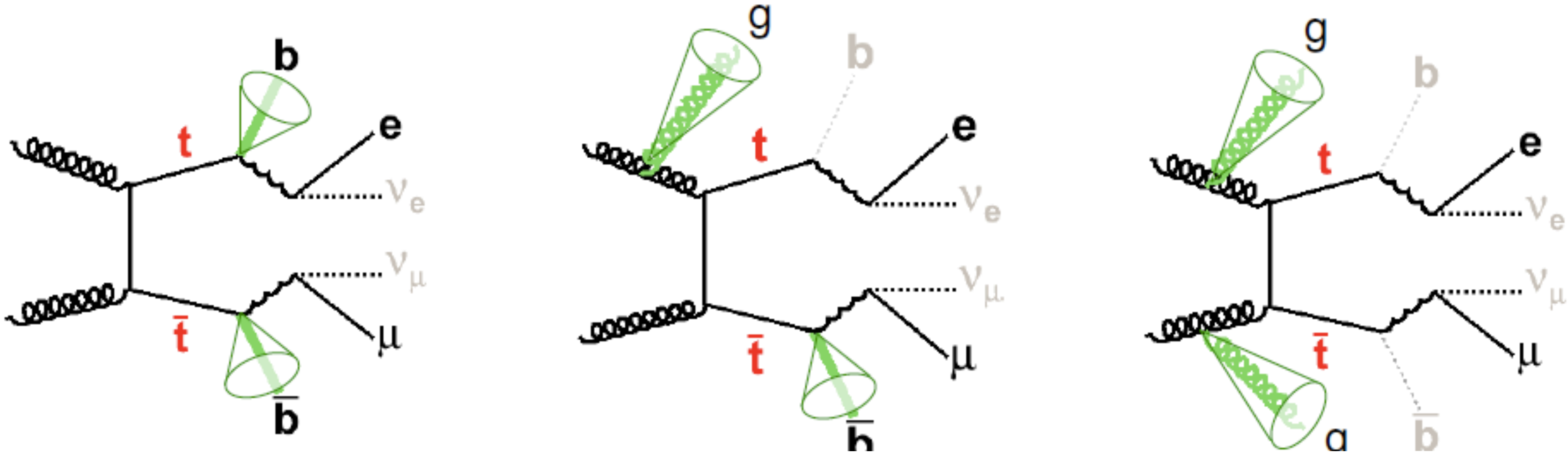
$$P_k = R^2\,P_k(bb) + 2R(1\text{-}R)\,P_k(bq) + (1\text{-}R)2\,P_k(qq)$$

- The probability functions P_k are parametrized by α, ε_b, ε_q and R
- The probability α that a jet from a top decay is reconstructed and selected is evaluated from data

Measuring the top’s branching ratios

- **Probability that 2, 1 or 0 b-jets are reconstructed and selected**

2 reconstructed b-jets (α_2)	1 reconstructed b-jet (α_1)	no reconstructed b-jets (α_0)

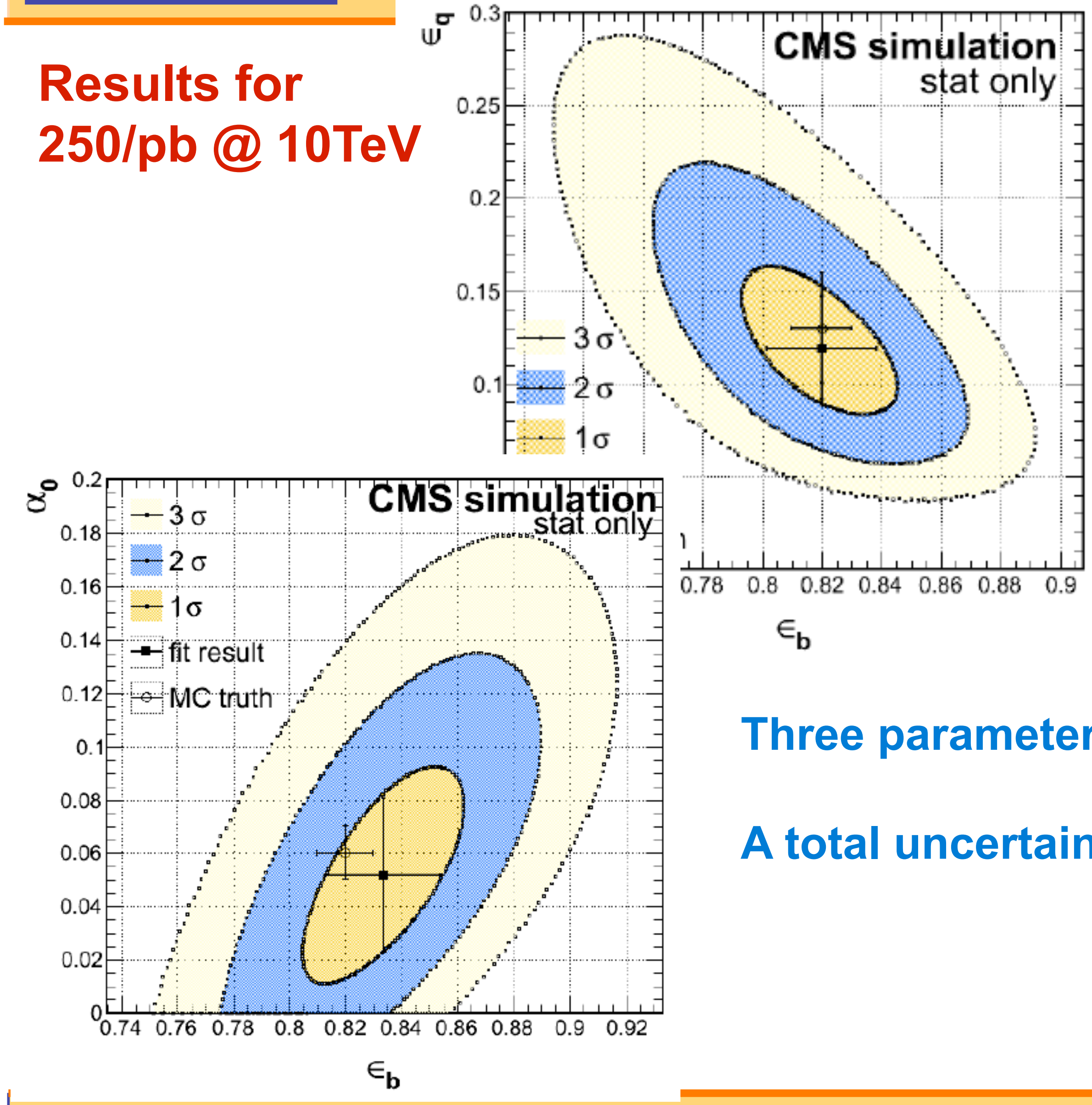


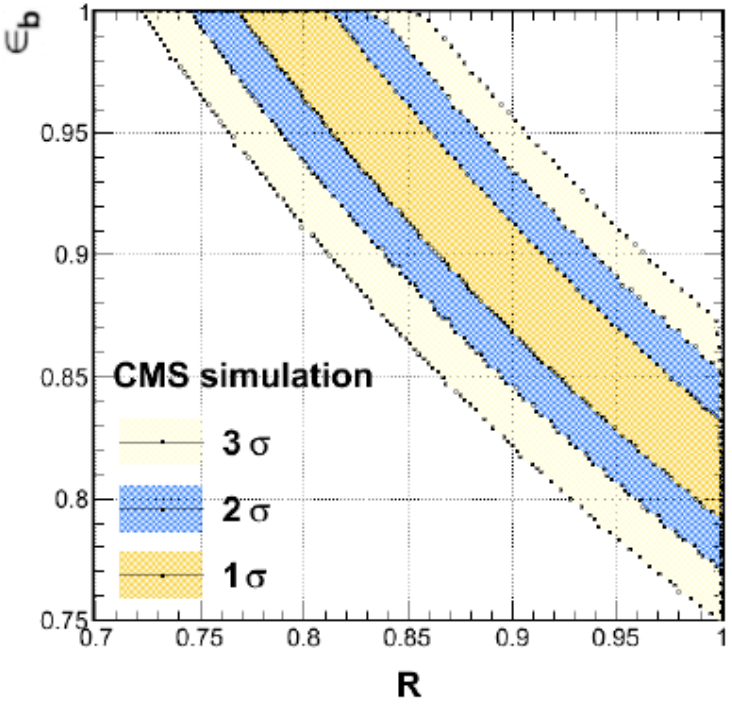
$\alpha_2 = \alpha^2$ probability to find 2 jets	$\alpha_1 = 2\,\alpha\,(1-\alpha)$ probability to miss 1 jet	$\alpha_0 = (1-\alpha)^2$ probability to miss 2 jets

- **Obtained from the tail of the $m_{\text{lepton,jet}}$ spectrum (→ wrong b-jets in tail)**

Measuring the top's branching ratios

Results for 250/pb @ 10TeV





Three parameters are involved and are correlated

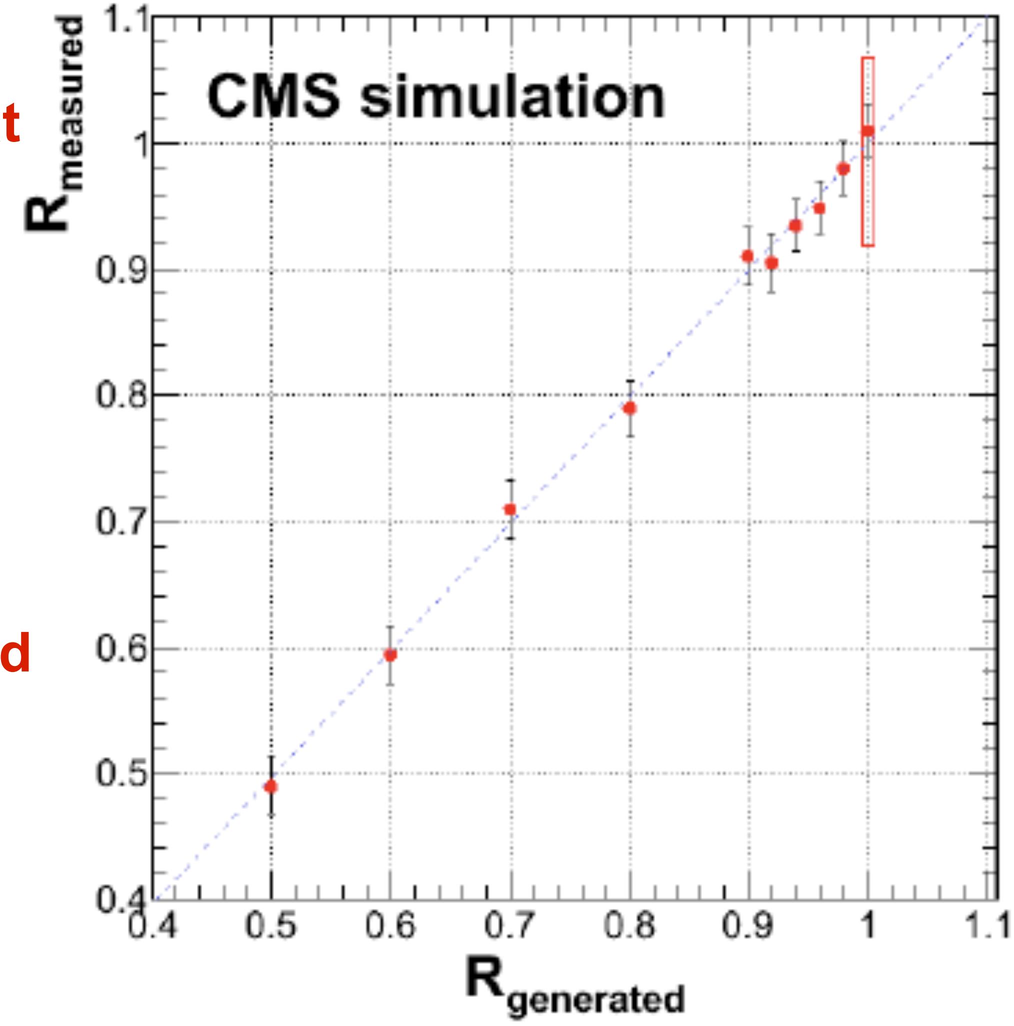
A total uncertainty of 9% can be reached on R.

Measuring the top's branching ratios

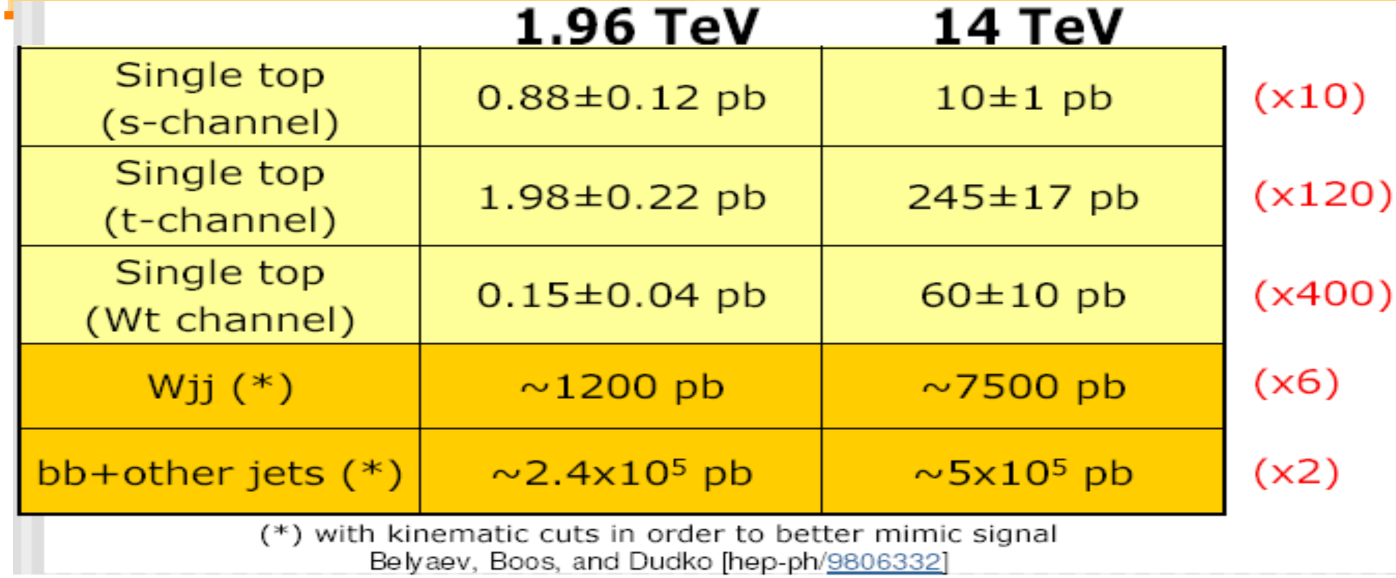
- **Always check the bias of your method (what you put in, is what you should get out)…**

- **Also check that your estimator has a linear behaviour with respect to the input parameter value to measure**

- **This is to be done with simulated events**

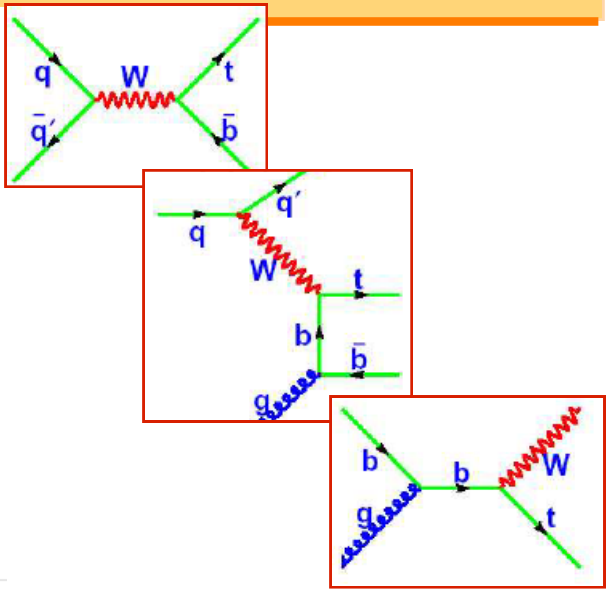


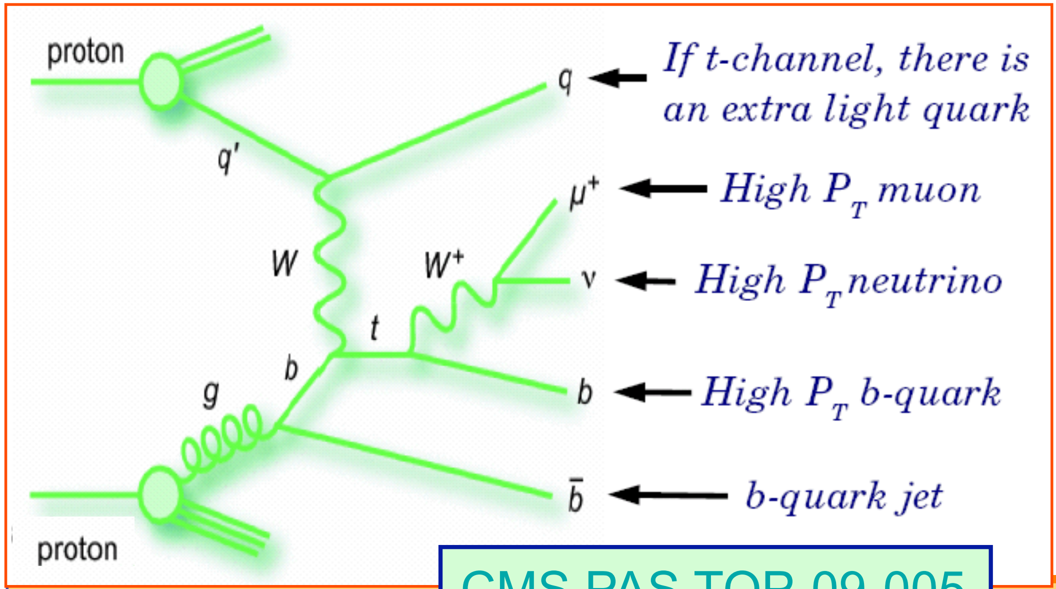
… also from single-top events



	1.96 TeV	14 TeV	
Single top (s-channel)	0.88±0.12 pb	10±1 pb	(x10)
Single top (t-channel)	1.98±0.22 pb	245±17 pb	(x120)
Single top (Wt channel)	0.15±0.04 pb	60±10 pb	(x400)
Wjj (*)	~1200 pb	~7500 pb	(x6)
bb+other jets (*)	~2.4x10⁵ pb	~5x10⁵ pb	(x2)

(*) with kinematic cuts in order to better mimic signal
Belyaev, Boos, and Dudko [hep-ph/9806332]





CMS PAS TOP-09-005

Each channel sensitive to different signals

- heavy W' → s-channel
- FCNC → t-channel
- H± → Wt-channel

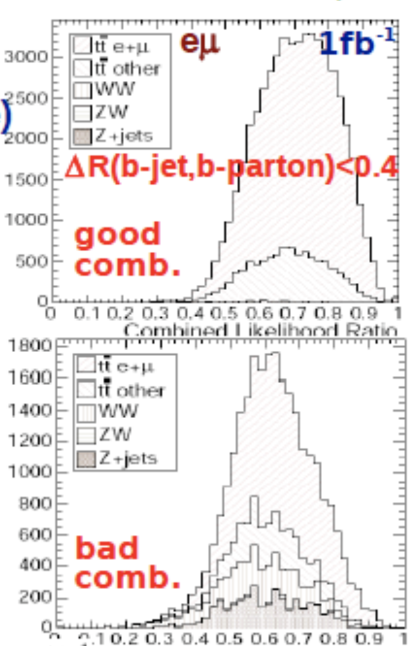
Also directly related to $|V_{tb}|$ to percent level (s-channel preferred, t-channel dominated by PDF scale uncertainties of ~10%)

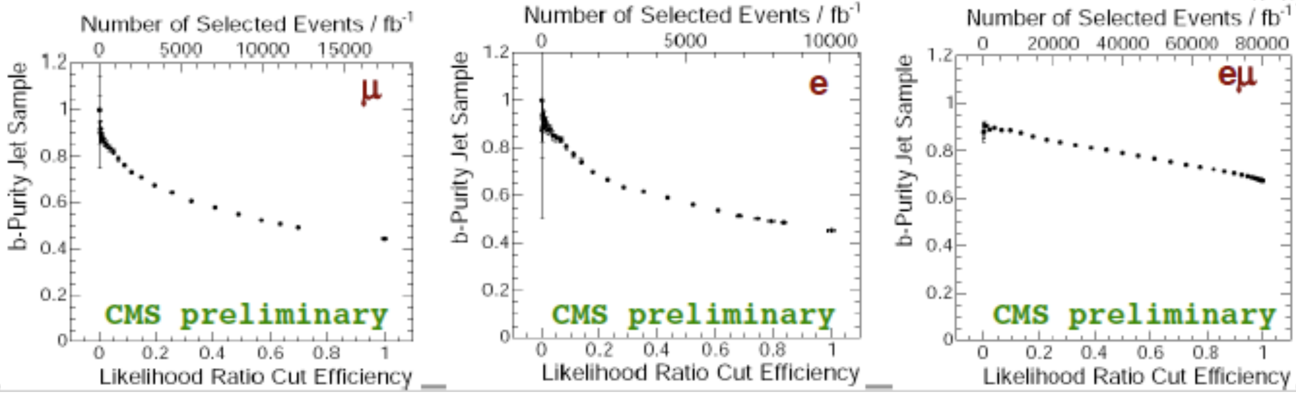
$$R = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

Using the constraint BR(t→Wb)=1

CMS Note 2006/013

- **We can do the inverse: assume $|V_{tb}|=1$ and obtain the b-tag efficiency**
  - Extra selection cuts:
    - Jets from pile-up vetoed using a track-based method
    - Lepton+jets: S/B ~ 60 (50) for μ (e) events (1 b-tag on hadronic side)
    - Fully leptonic (μe): leptons opposite charge → S/B ~ 4 (no b-tag)
  - Selection of b-enriched sample:
    - Several observables x_i are able to discriminate between good and bad jet associations
    - Each $x_i \rightarrow \mathcal{L}_i(x_i)=(S_i/B_i)$, with S_i good and B_i bad jet combinations **(back-up 28-33)**
    - Comb. Likelihood Ratio $\mathcal{L} = \Pi\ \mathcal{L}_i(x_i)$ for each jet combination **(35-36)**
    - With a cut on $\mathcal{L}$ it is possible to increase the b-jet content of the jet sample



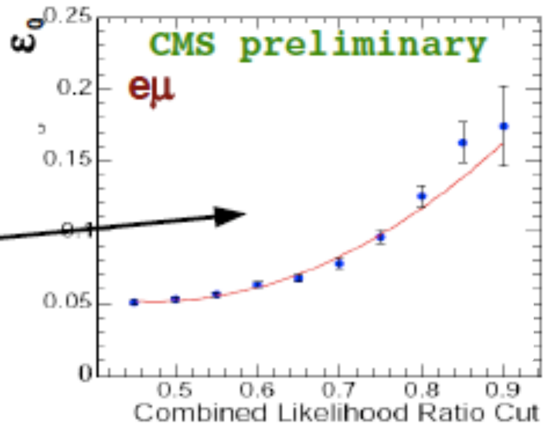


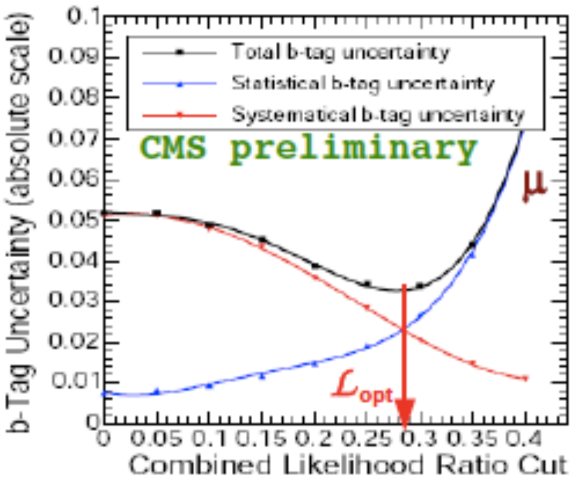
Using the constraint BR(t→Wb)=1

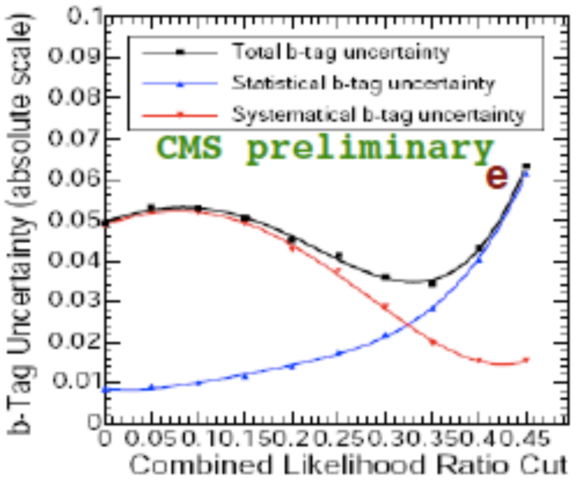
- When a b-tagging algorithm is applied on a sample, a fraction x_{tag} of the jets will be tagged

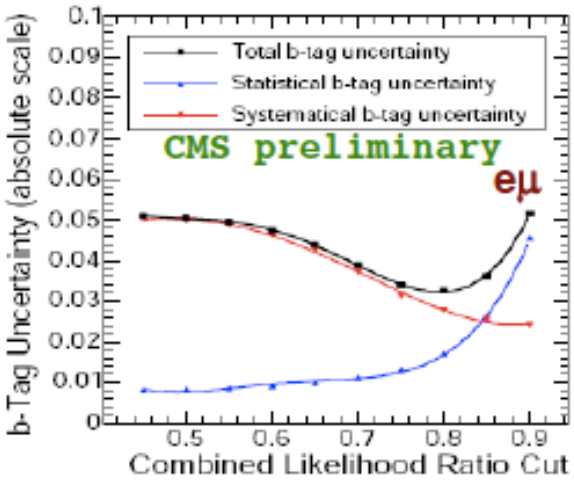
$$x_{tag} = \varepsilon_b x_b + \varepsilon_c x_c + \varepsilon_l x_l = \varepsilon_b x_b + \varepsilon_0 (1 - x_b)$$

- For certain values of the cut on $\mathcal{L}$, $\varepsilon_0(\mathcal{L})$ was determined from simulation
- To find the optimal value for the cut on $\mathcal{L} = \mathcal{L}_{opt}$, the total uncertainty is calculated:







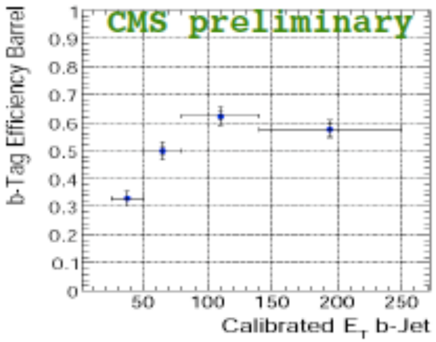


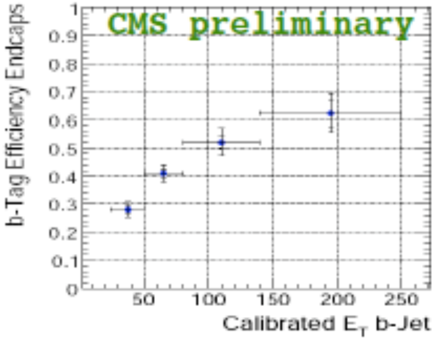
- Main systematic uncertainty: ISR/FSR and signal and background cross sections (fully lep)
- ISR/FSR and the b-tag efficiency for tagging the b-jet in the event selection (semilep)
- x_{tag} contributes to the statistical uncertainty

Using the constraint BR(t→Wb)=1

CMS Note 2006/013

- Etimation of ε_b for 1 fb^{-1}:
  - μ sample $\varepsilon_b = 58.0 \pm 2.2$ %
  - e sample $\varepsilon_b = 58.7 \pm 2.6$ %
  - eμ sample $\varepsilon_b = 59.2 \pm 3.3$ %
- These results can be combined (systematic uncertainties fully correlated)
- ε_b has to be parametrized as function of E_T and η of the jet for sample independent ε_b

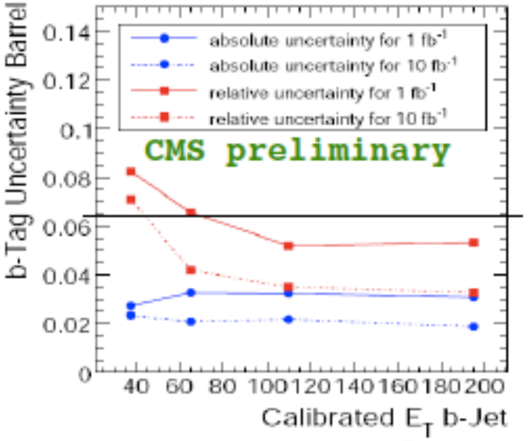


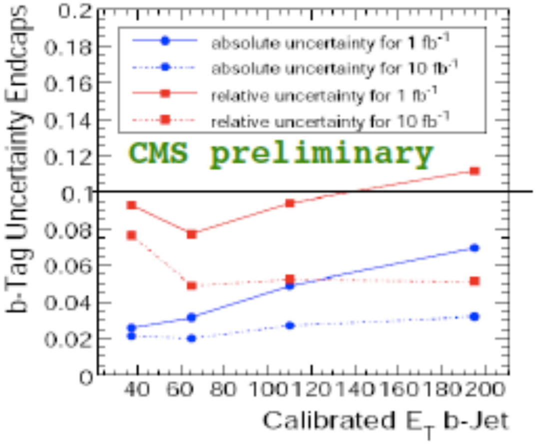


(back-up 38)

barrel $|\eta|<1.5$

endcap $|\eta|>1.5$



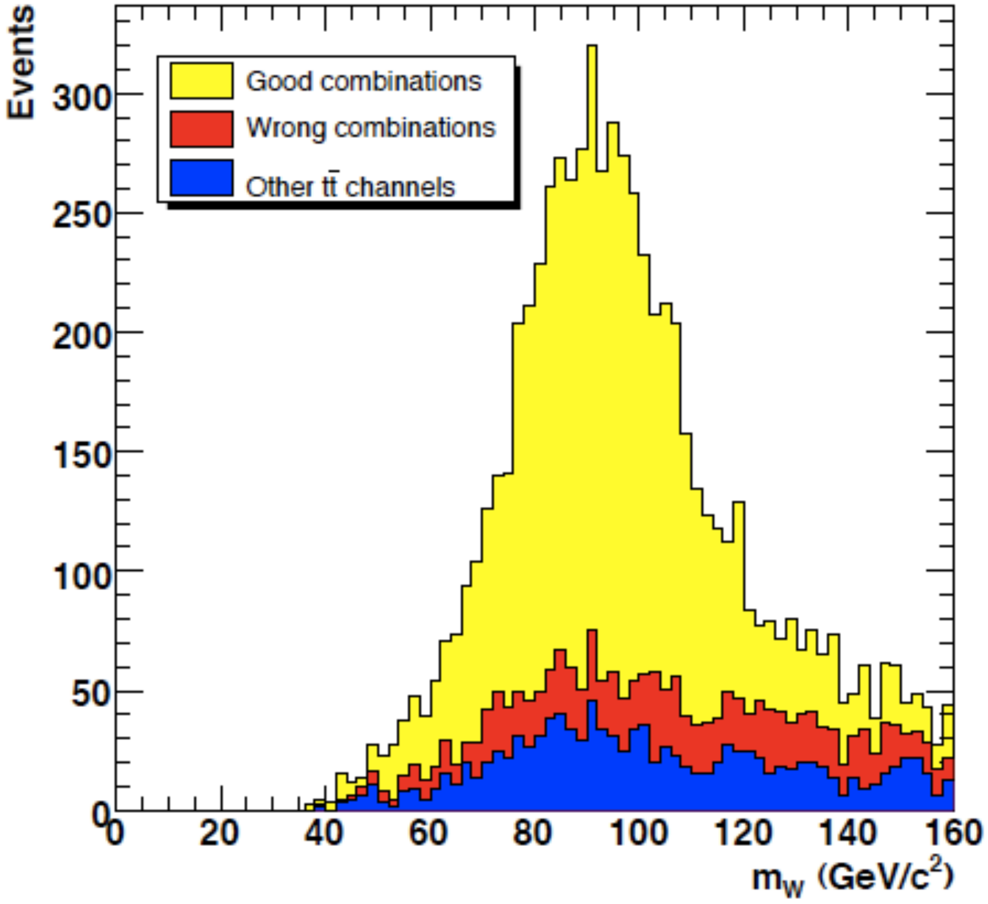


- The relative uncertainty for 1 fb^{-1} on the estimated b-tag efficiency is expected to be about 6 % in the barrel and 10% in the endcaps

@ 14 TeV

Jet corrections from top events

- **Also here we can do the inverse: assume the top quark mass as measured by Tevatron experiments and obtain Jet Energy Corrections**



- Reconstruct the W boson mass in the t→Wb decay (with W→qq) and measure the shift.
- Transform this into a shift on the energy scale of the individual jets.

$$E_{\text{new}} = (1 + \Delta C) \cdot E_{\text{jet}}$$

- Statistical precision of <1% can be obtained, but at this precision the delicate systematic effects are important…
- More clever: event-by-event rather than one distribution over all events.

Jet corrections from top events

- **More advanced, perform an event-by-event kinematic fit on t→Wb**
  - **Our knowledge of the observed event comes from measured objects in the final state (i = jets, lepton, 'neutrino').**
    - this can be summarized as $\mathbf{p}_i = \{ E_i, \theta_i, \varphi_i \}$ (for example)
    - together with the covariance matrix $\mathbf{V}_i$ for each object i
  - **Extend this knowledge p_i and V_i by assuming some hypothesis for the event**
    - for example : $m_{jj} = m_W$ & $m_{jjb} = m_t$
  - **Add Lagrange multipliers λ_k in the χ^2 equation to incorporate these hypothesed constraints in our knowledge of the event ($\Delta p = p^{fit} - p^{measured}$)**

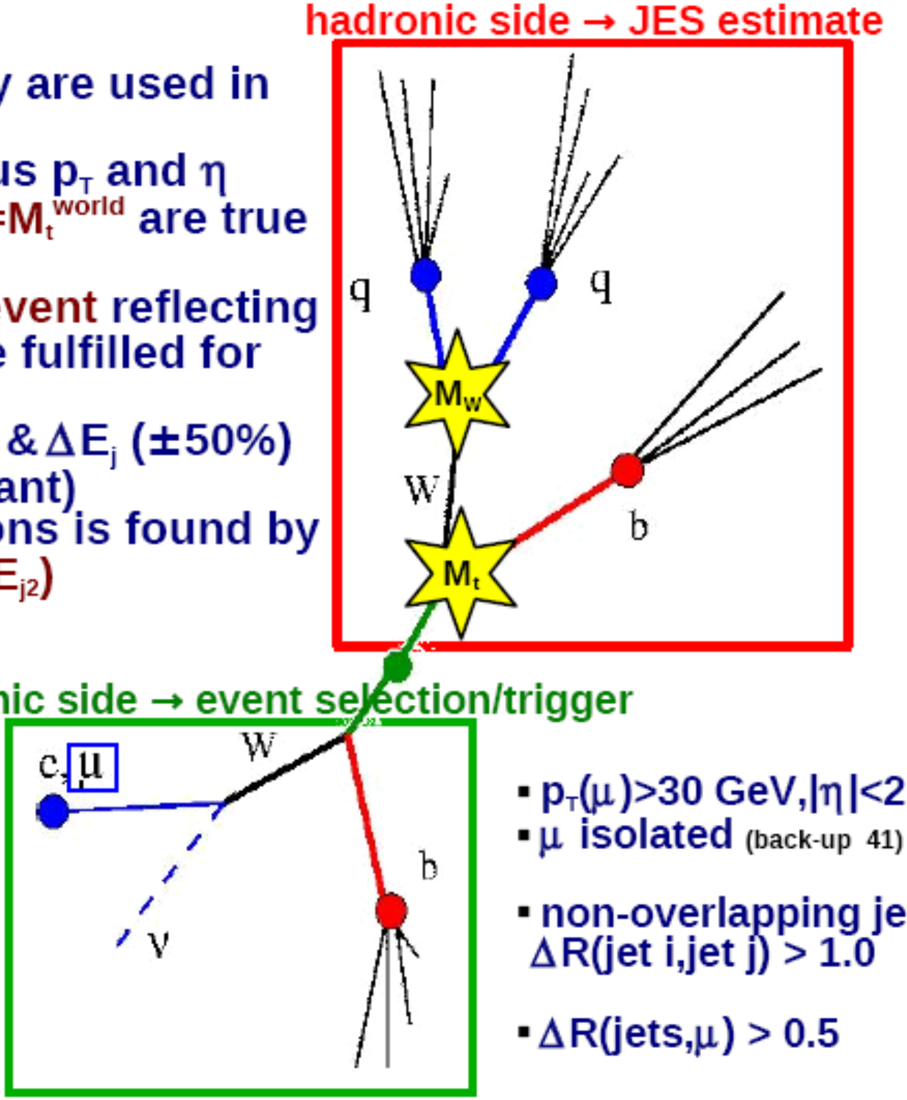
$$\chi^2(\mathbf{p}^{fit}) = \Delta\mathbf{p}^T\, \mathbf{V}^{-1}\, \Delta\mathbf{p} + 2 \sum \lambda_k\, f_k(\mathbf{p}^{fit}, \mathbf{a})$$

    - where we have the *m* constraint functions f_k and unmeasured parameters $\mathbf{a}$
    - for the true measured and unmeasured parameters → $f_k(\mathbf{p}_{true}, \mathbf{a}_{true}) = 0$
  - **If the constraints are non-linear an iterative procedure is used to solve them**
    - the equation $f_k(\mathbf{p},\mathbf{a})=0$ are linearized in each iteration step (*Taylor expansion*)
    - the χ^2 equation is minimized ($\partial\chi^2/\partial\mathbf{p}=0$, $\partial\chi^2/\partial\mathbf{a}=0$, $\partial\chi^2/\partial\lambda_k=0$) and solved
    - the iteration stops when some pre-defined convergence criteria are fulfilled
  - **A $P(\chi^2)$ is returned by the kinematic fit, reflecting the probability that the constraints are fulfilled**

Jet corrections from top events

CMS PAS TOP-07-004

- The 3 jets from the hadronic top decay are used in an event-by-event kinematic fit
- Jet resolutions are parametrized versus p_T and η
- The constraints $m_W^{rec}=M_W^{world}$ and $m_t^{rec}=M_t^{world}$ are true at parton level
- Kinematic fit returns a $P(\chi^2)$ for each event reflecting the probability that the constraints are fulfilled for this event
- A whole range of JES corrections ΔE_b & ΔE_j (±50%) is scanned for each event (E/|p| constant)
- The best estimate of the JES corrections is found by minimizing the function $\chi^2(\Delta E_b, \Delta E_{j1}=\Delta E_{j2})$



hadronic side → JES estimate

leptonic side → event selection/trigger

- To reduce the process background a tight event selection is applied
- A likelihood ratio is constructed to identify the correct jet combination
- A cut on this likelihood ratio is made to reduce combinatorial background
- To reduce contributions from mis-reconstructed events cuts are made on the probability of the kinematic fit

- $p_T(\mu)>30$ GeV, $|\eta|<2.1$
- μ isolated (back-up 41)
- non-overlapping jets: ΔR(jet i,jet j) > 1.0
- ΔR(jets,μ) > 0.5

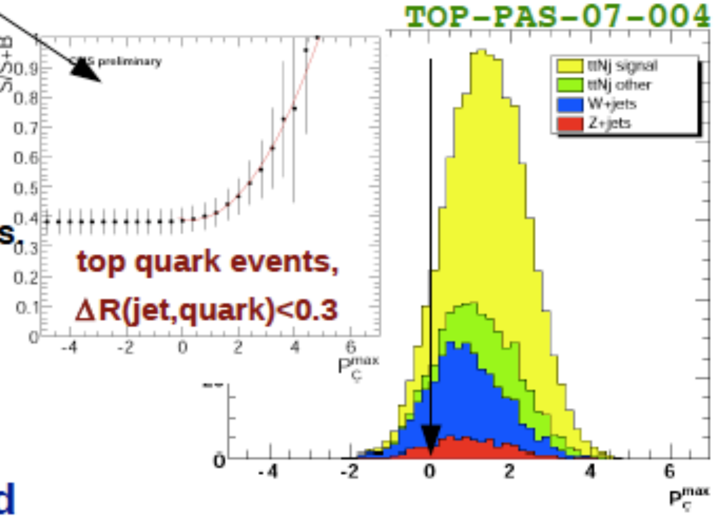
Jet corrections from top events

- To identify the correct jet combination four observables are combined into a LR:
  - $p_T^{had\ top}/\langle p_T^{had\ top}\rangle$
  - $(p_T^{b1}+p_T^{b2})/(p_T^{l1}+p_T^{l2})$
  - $\Delta R(l1,l2)$
  - b-value(b1)+b-value(b2)

S: correct jet comb.
B: wrong jet comb.

- $P_c^{max}=\max(\sum_i \log(L_i(x_i)))$ with $L_i(x_i)=S_i(x_i)/B_i(x_i)$, i=obs.
- To purify event sample: $P_c^{max} > 0$

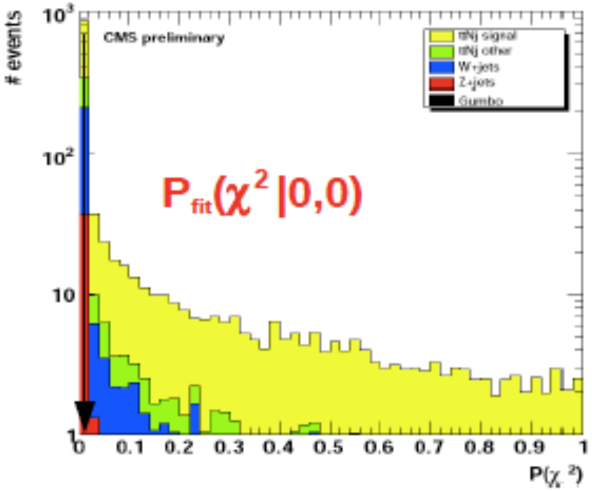
TOP-PAS-07-004



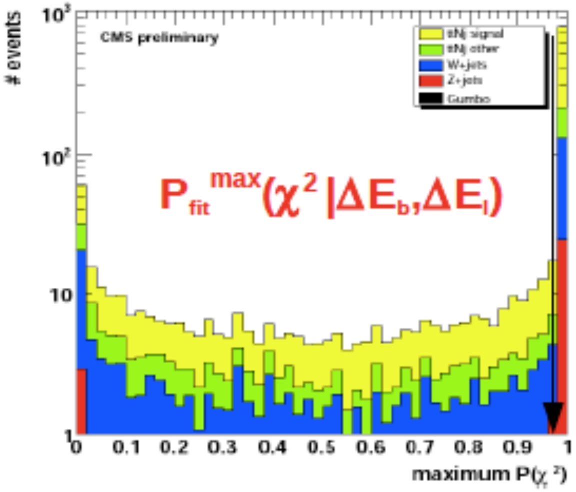
top quark events, ΔR(jet,quark)<0.3

- For each event $P_{fit}(\chi^2|0,0)$ (no JES corrections)
- For each event and over whole scanned JES corrections range $P_{fit}^{max}(\chi^2\,|\Delta E_b,\Delta E_l)$ is calculated

- Removal of mis-reconstructed events: $P_{fit}(\chi^2|0,0) > 0.01$
- Requiring the JES corrections are found in the scanned range: $P_{fit}^{max}(\chi^2\,|\Delta E_b,\Delta E_l) > 0.98$



$P_{fit}(\chi^2\,|0,0)$

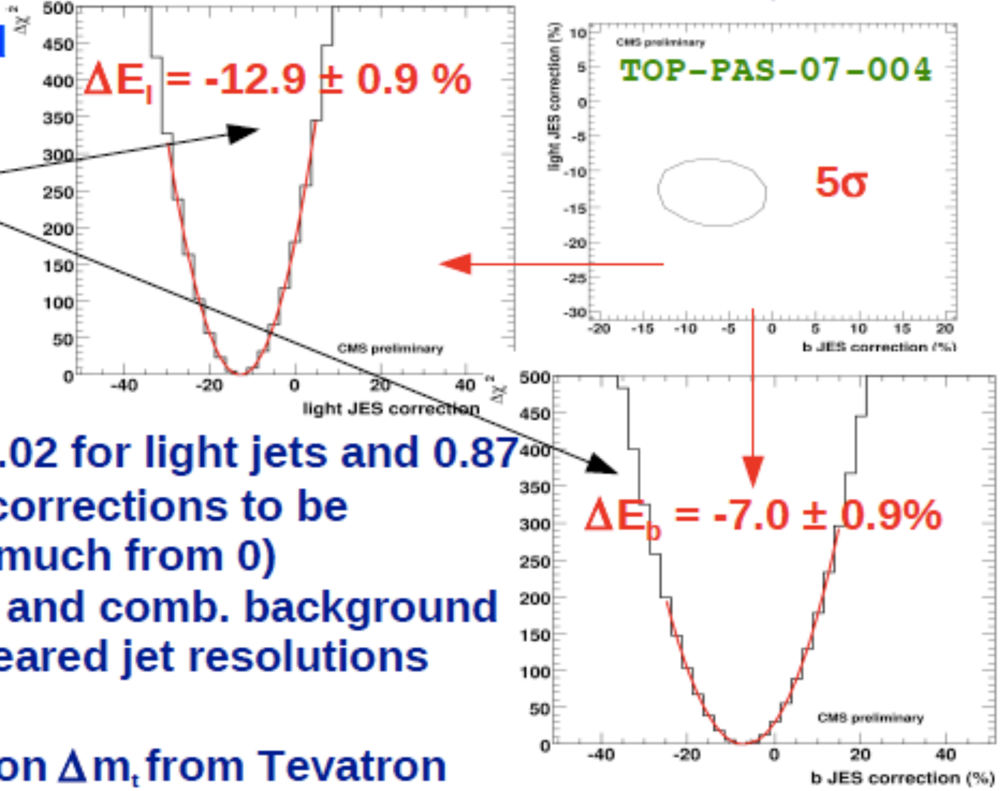


$P_{fit}^{max}(\chi^2\,|\Delta E_b,\Delta E_l)$

Jet corrections from top events

- For each event we have an estimate of the JES corrections, $\Delta E_{b,i}$ and $\Delta E_{l,i}$ (i=event)
- Events for which $\Delta E_{b,i}$ or $\Delta E_{l,i} > \pm 20\%$ w.r.t first estimate are removed:
- The relative difference between the fitted expectation value of the m_W distribution and M_W^{world} is taken as a first estimate for light jets: $\Delta E_{l,incl.}$
- Difference between MC expectation values of light and b JES corrections (7%) is used to obtain the first estimate for b jets $\Delta E_{b,incl.}$ from $\Delta E_{l,incl.}$

- The $P^{fit}(\chi^2 | \Delta E_b, \Delta E_l)$-values of the remaining events are translated into χ^2-values
  - The χ^2-values are combined and the minimum is searched for
  - Results are corrected for the width of pull distributions
  - The uncertainty reflects the uncertainty for 100 pb^{-1} @ 14 TeV



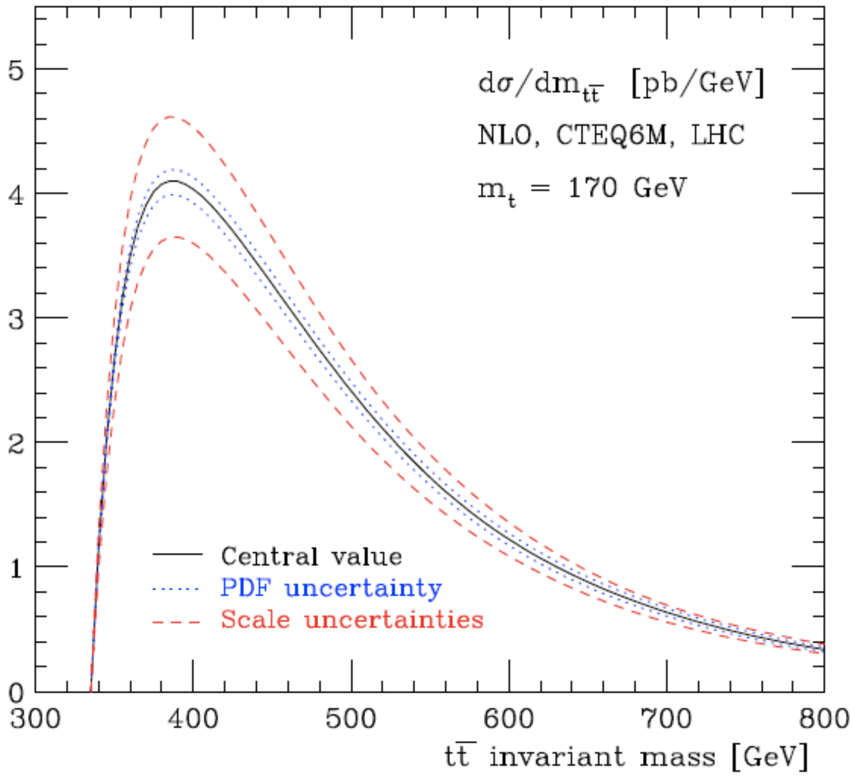
- Method is linear (slope of 0.77± 0.02 for light jets and 0.87 ± 0.03 for b jets → to avoid bias: corrections to be estimated should not deviate too much from 0)
- Method is robust against process and comb. background
- Method is also robust against smeared jet resolutions

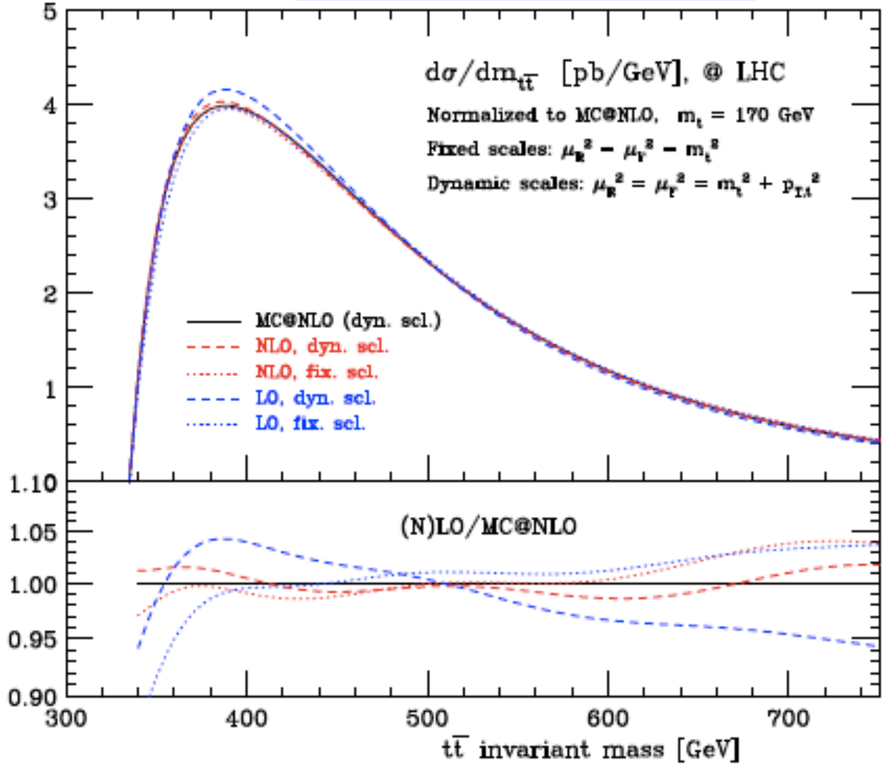
- Performance of method depends on Δm_t from Tevatron

The decay of the top quark (BSM)

- Also new phenomena can be hidden in the top pair decay…
- Effects in the top quark pair mass spectrum

arXiv:0712.2355v3

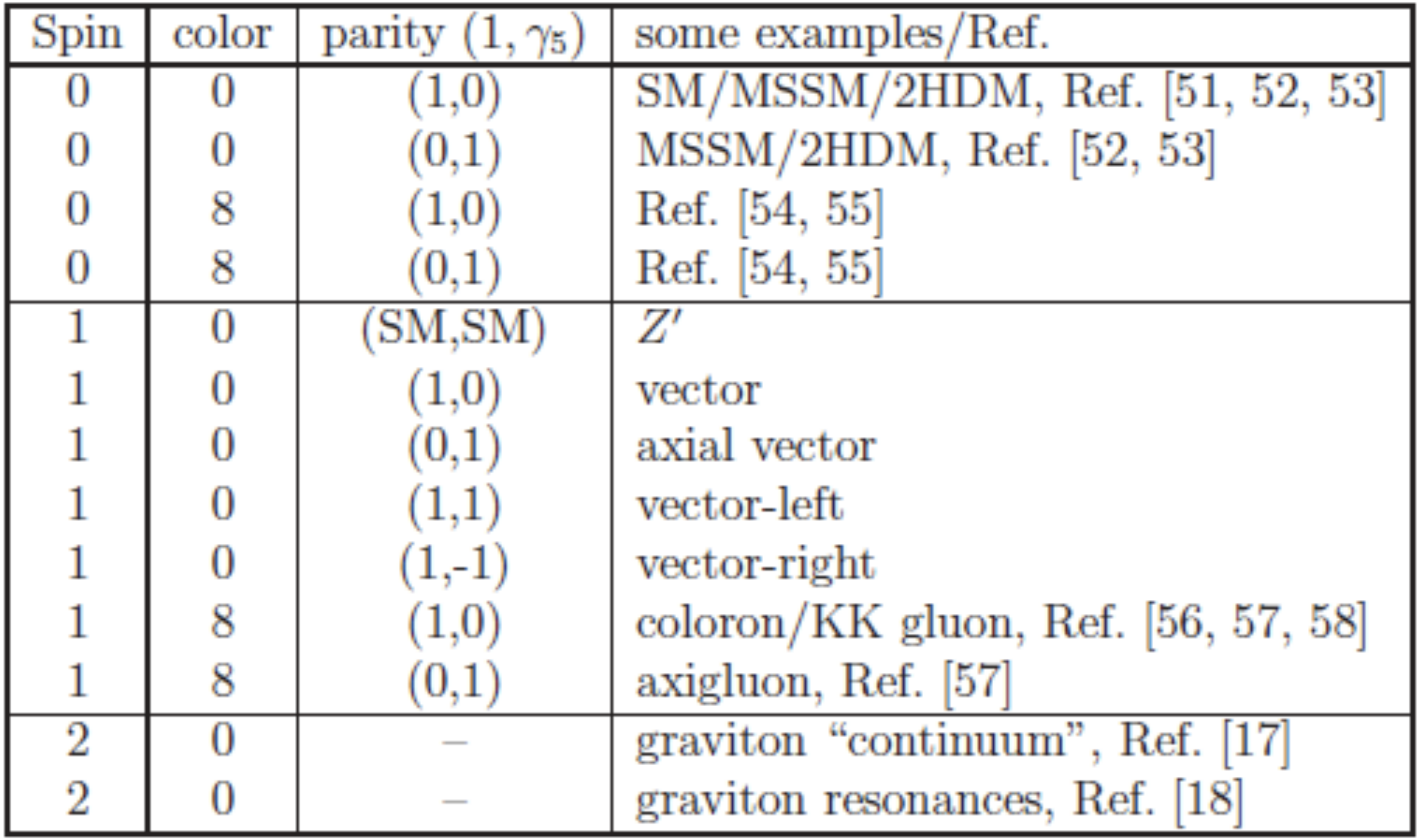




- Lots of theory work needed to control this distribution
- Also lots of experimental work needed to reconstruct this distribution!

The decay of the top quark (BSM)

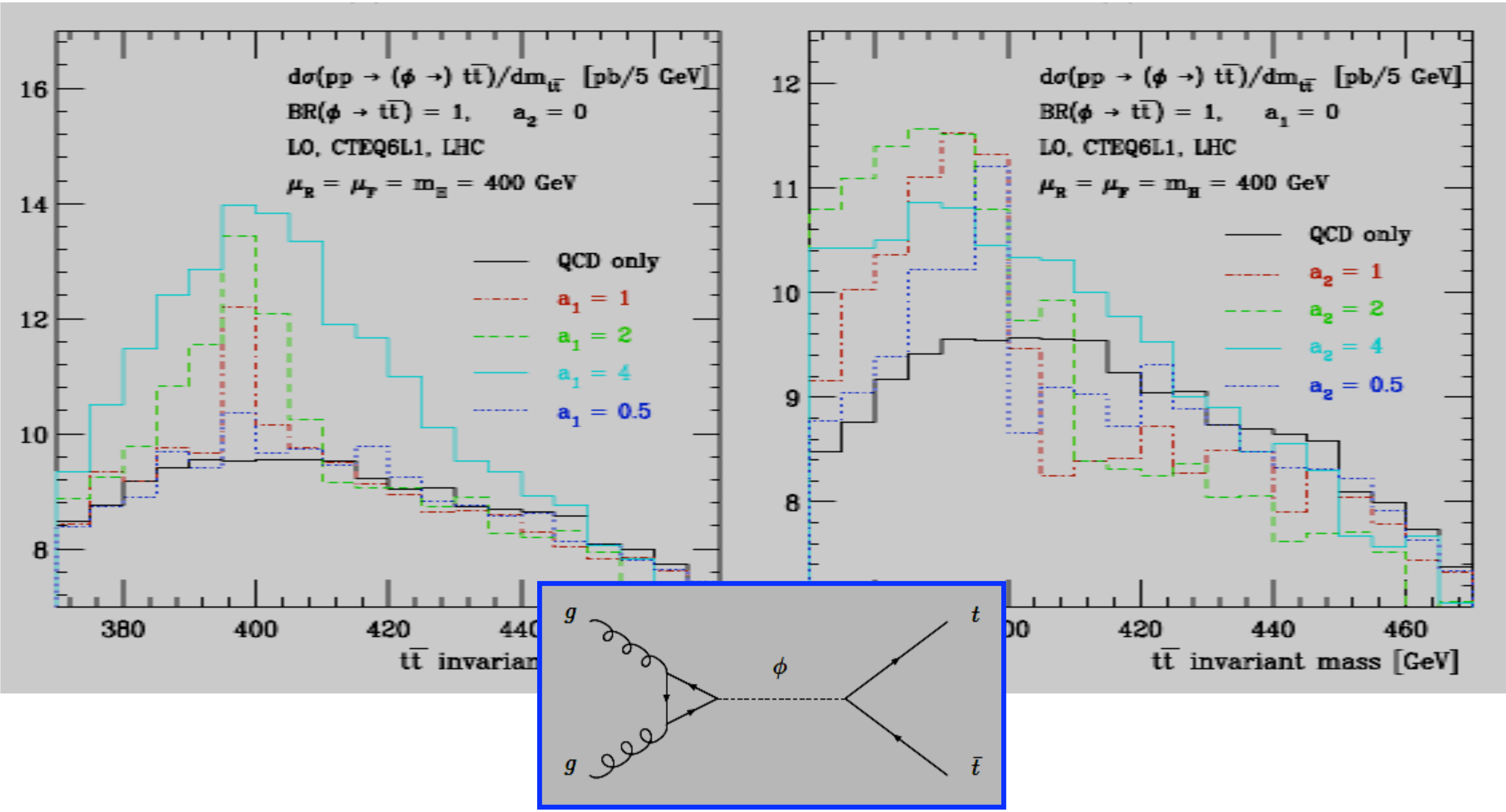
- **Several new models predict resonances in this spectrum**



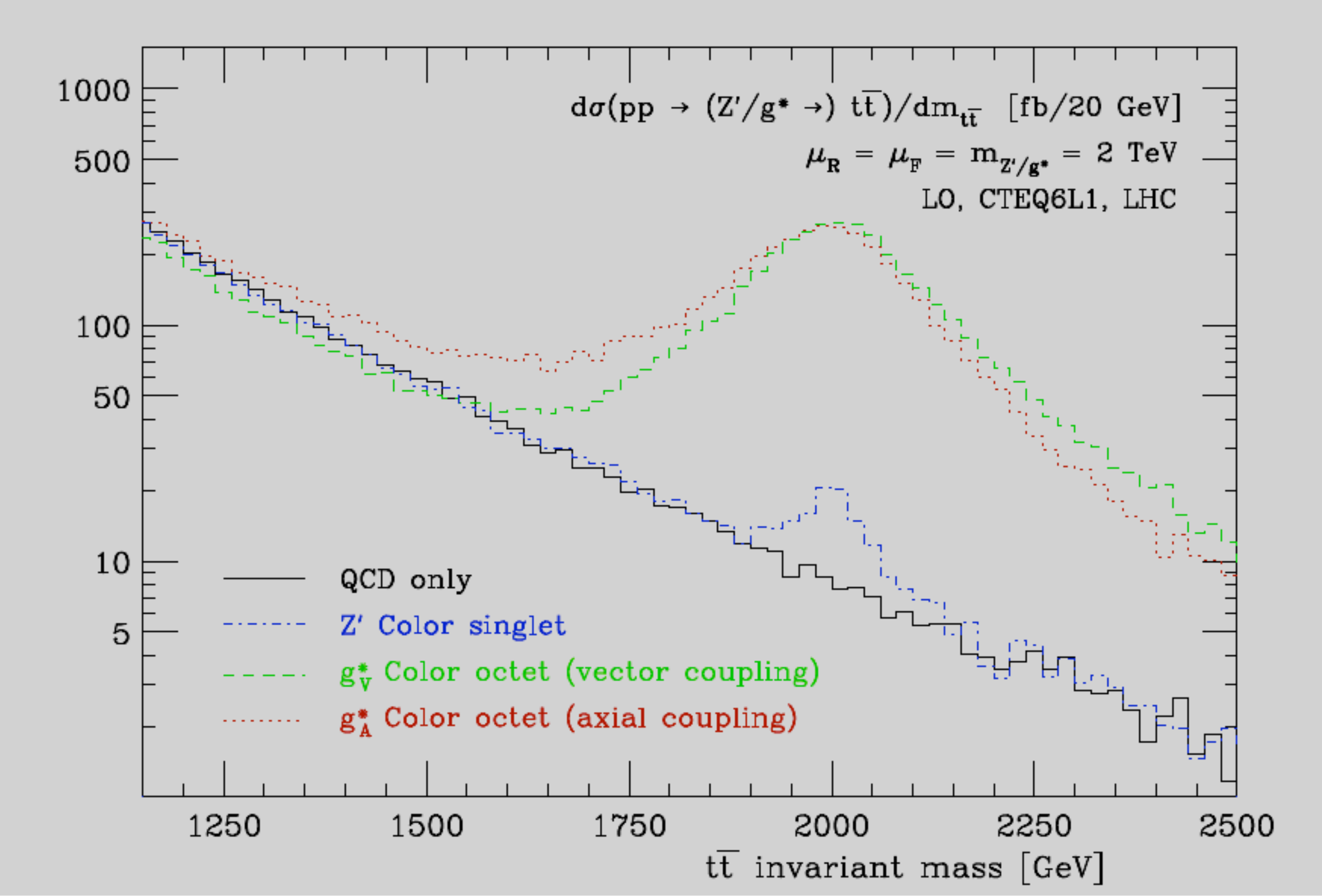
Spin	color	parity $(1, \gamma_5)$	some examples/Ref.
0	0	(1,0)	SM/MSSM/2HDM, Ref. [51, 52, 53]
0	0	(0,1)	MSSM/2HDM, Ref. [52, 53]
0	8	(1,0)	Ref. [54, 55]
0	8	(0,1)	Ref. [54, 55]
1	0	(SM,SM)	Z'
1	0	(1,0)	vector
1	0	(0,1)	axial vector
1	0	(1,1)	vector-left
1	0	(1,-1)	vector-right
1	8	(1,0)	coloron/KK gluon, Ref. [56, 57, 58]
1	8	(0,1)	axigluon, Ref. [57]
2	0	–	graviton “continuum”, Ref. [17]
2	0	–	graviton resonances, Ref. [18]

The decay of the top quark (BSM)

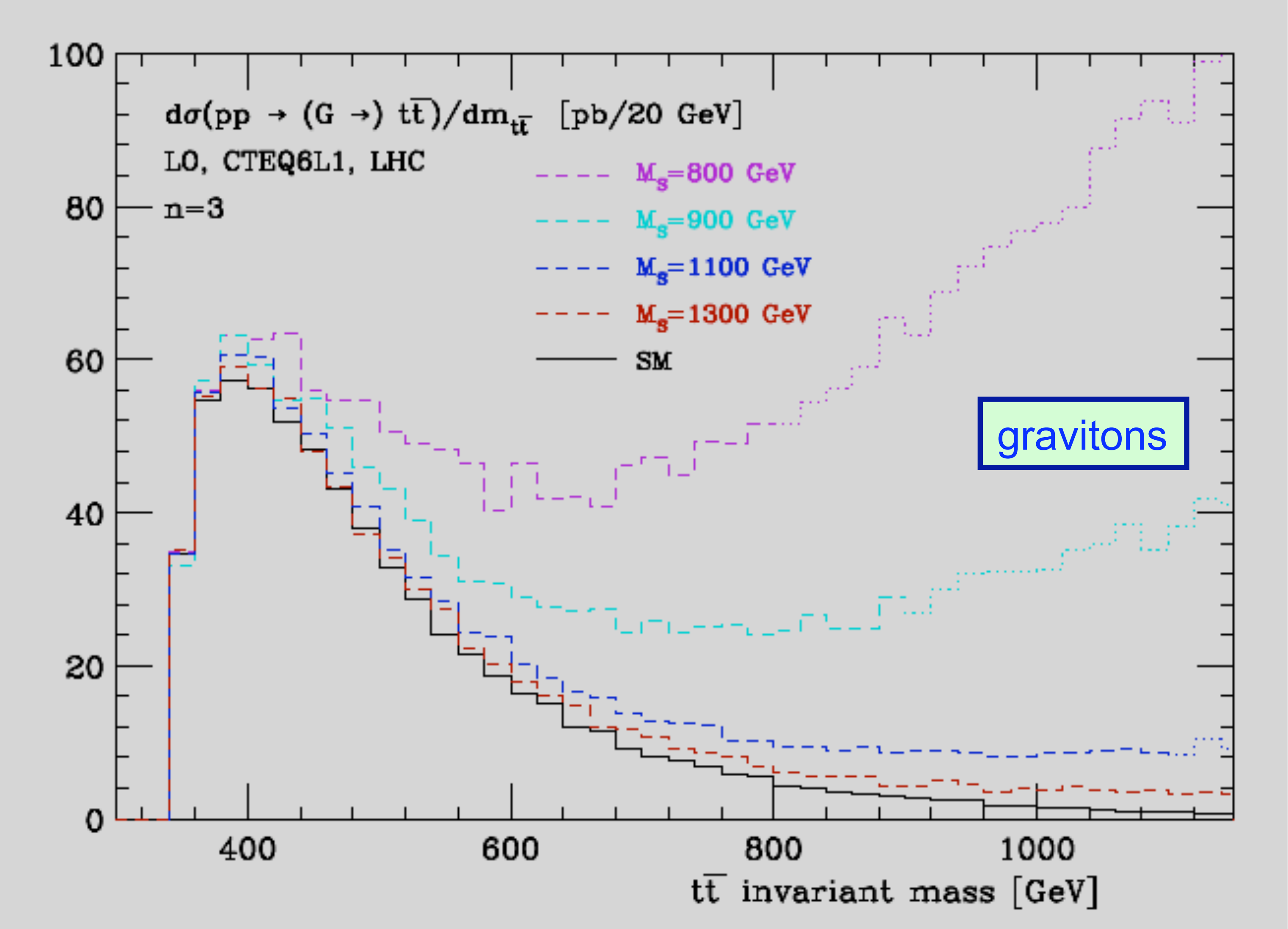
- **Boson-phobic scalar (left) and pseudo-scalar (right)**



The decay of the top quark (BSM)



The decay of the top quark (BSM)

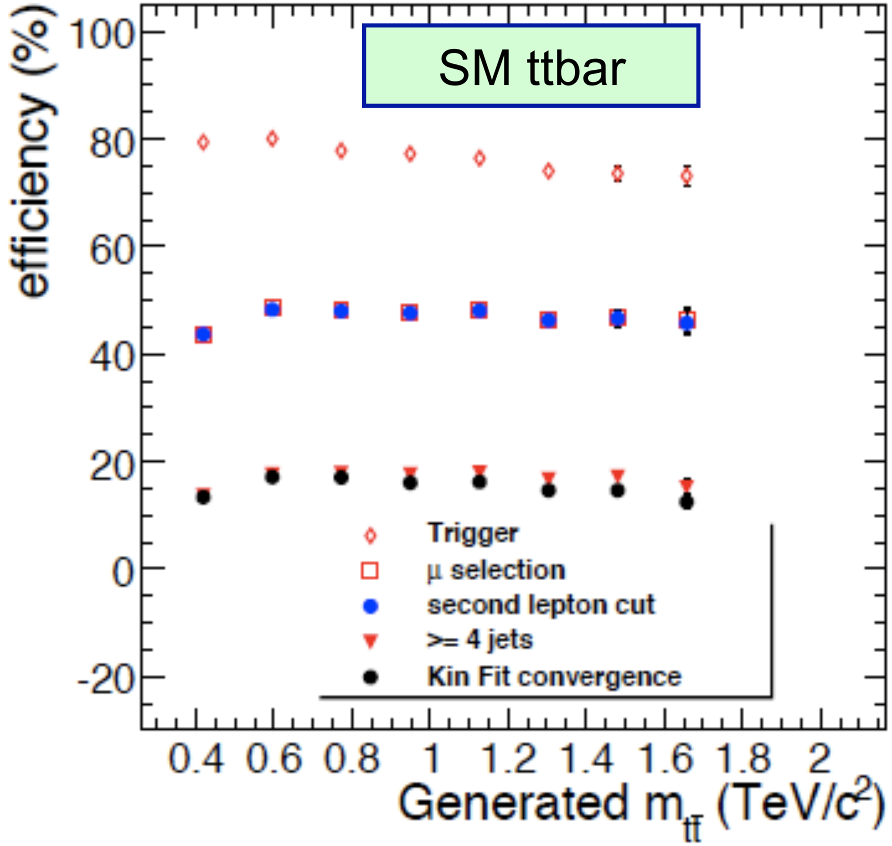


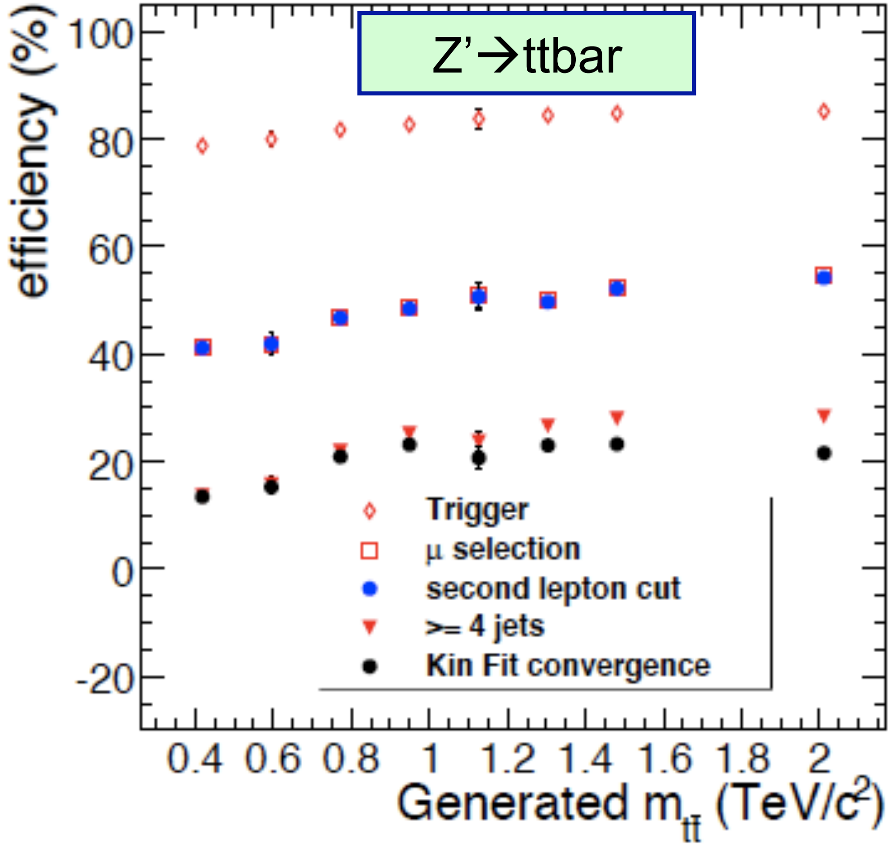
gravitons

Top quark pair resonances

CMS PAS TOP-09-009

- **When reconstructing the full event one can obtain the mass of the top-antitop system and search for resonances X→tt**

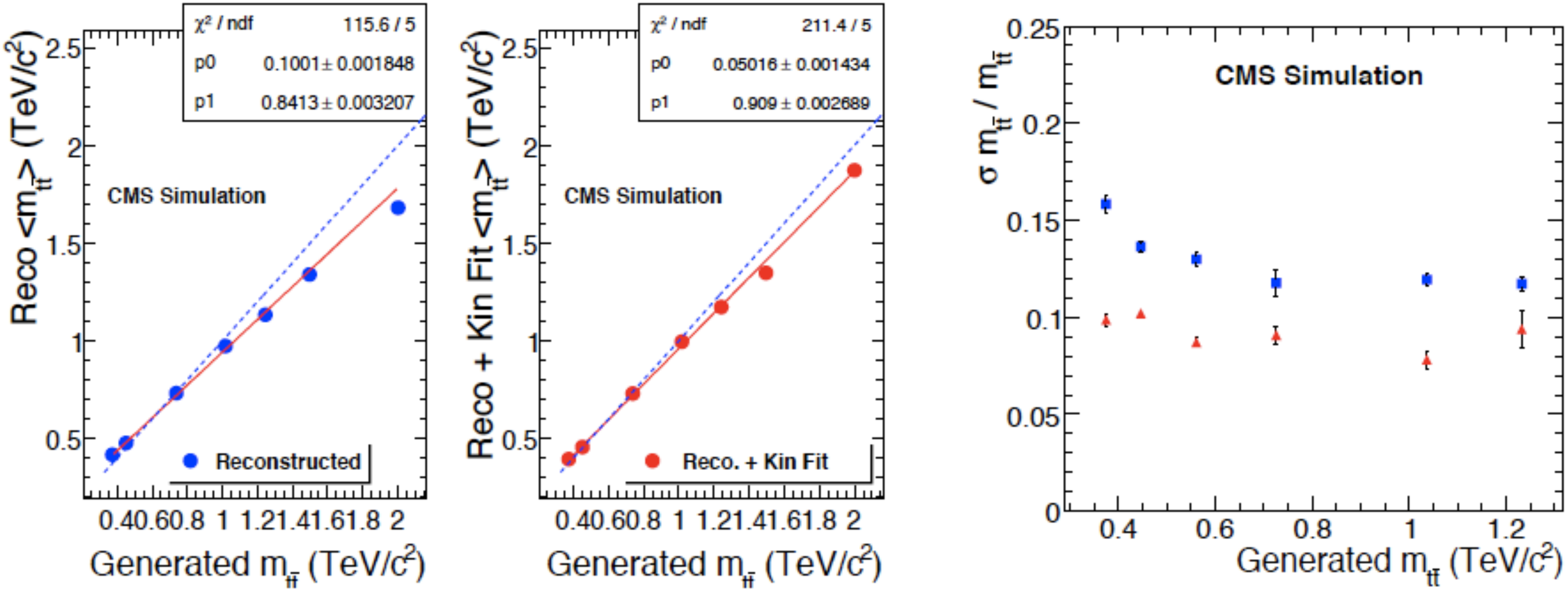




- **Trigger on non-isolated muons not to loose the boosted signal…**

Top quark pair resonances

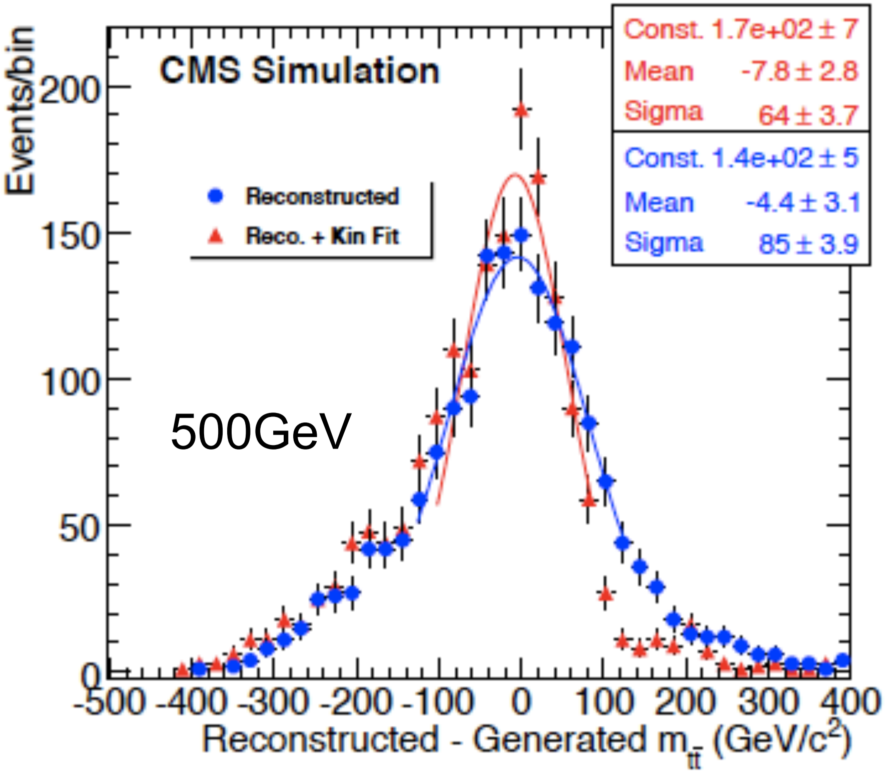
- The jets from the top quark decays in the event are chosen via a χ^2 minimization on the top quark and W boson mass (kinematic fit)
- The resonance mass is measured as the Gaussian fitted average

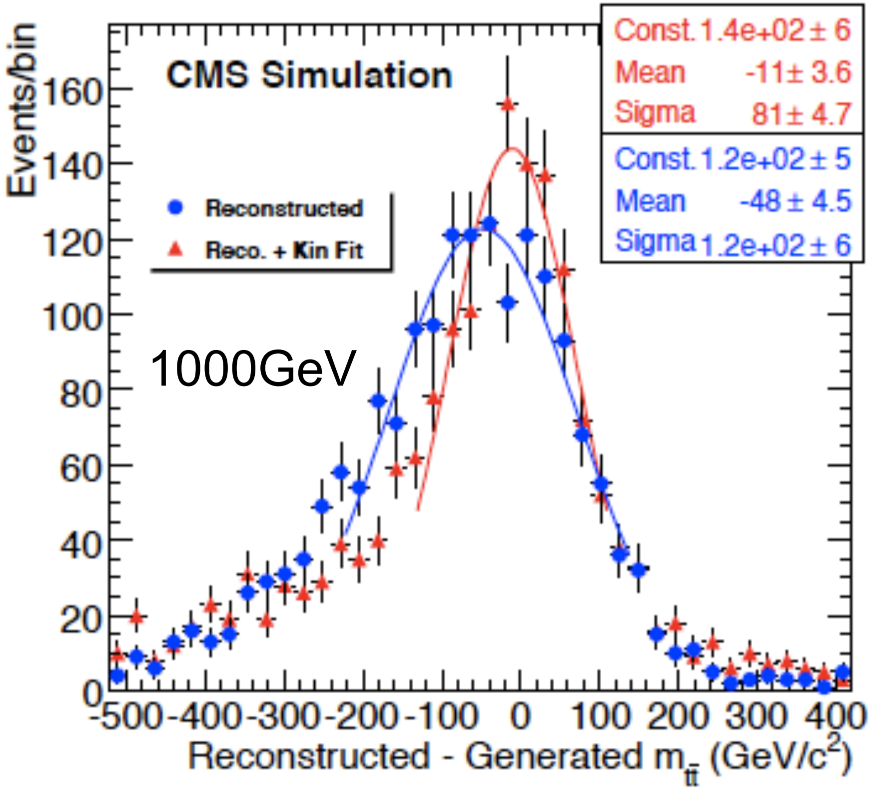


- The jet resolution is relatively improving with ~35% by use of the kinematic fit

Top quark pair resonances

- **The improvement from the kinematic fit visual…**

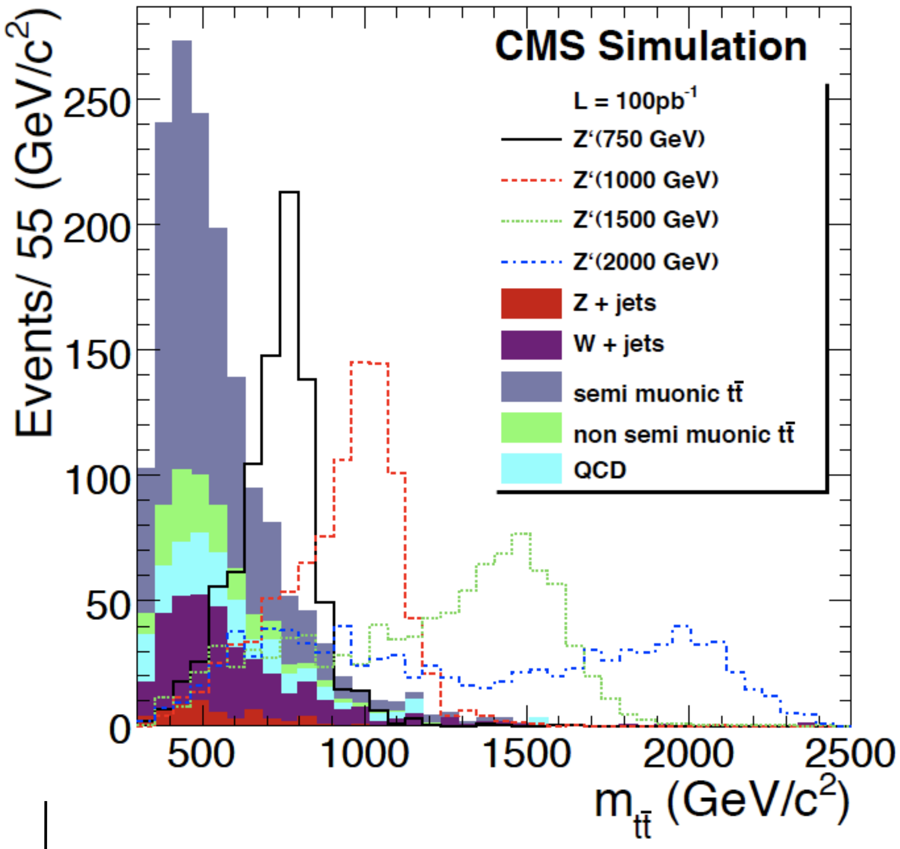


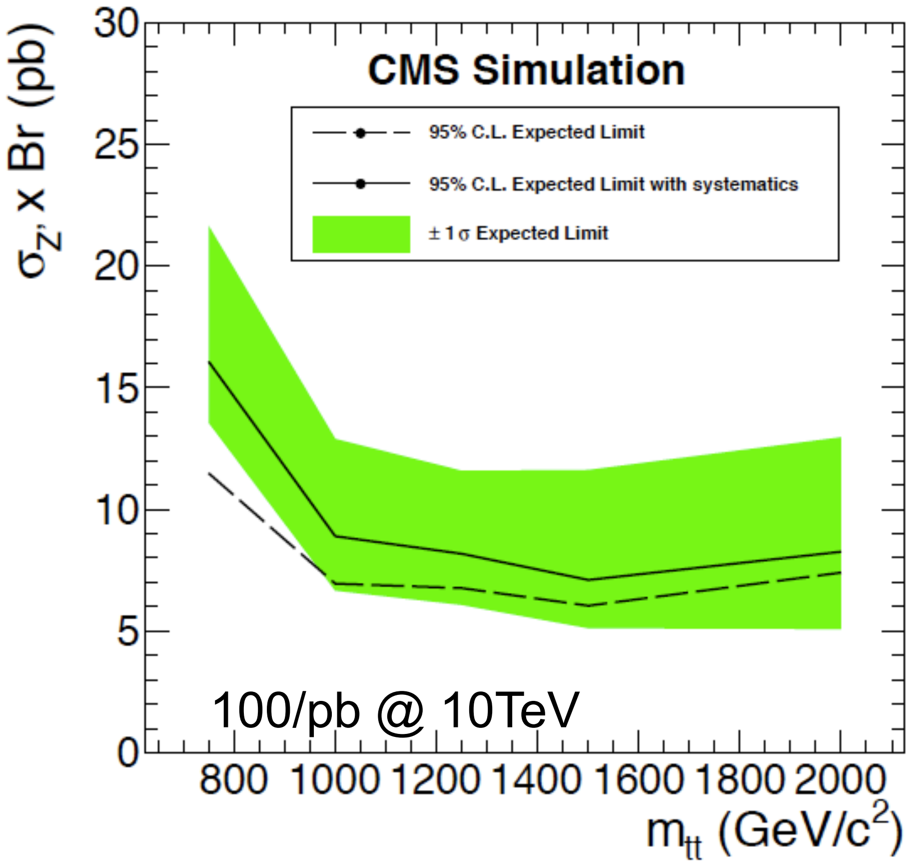


- **The kinematic fit reduces the bias on the measured mttbar and improves the overall resolution**

Top quark pair resonances

- **The new physics is visible above the Standard Model background**





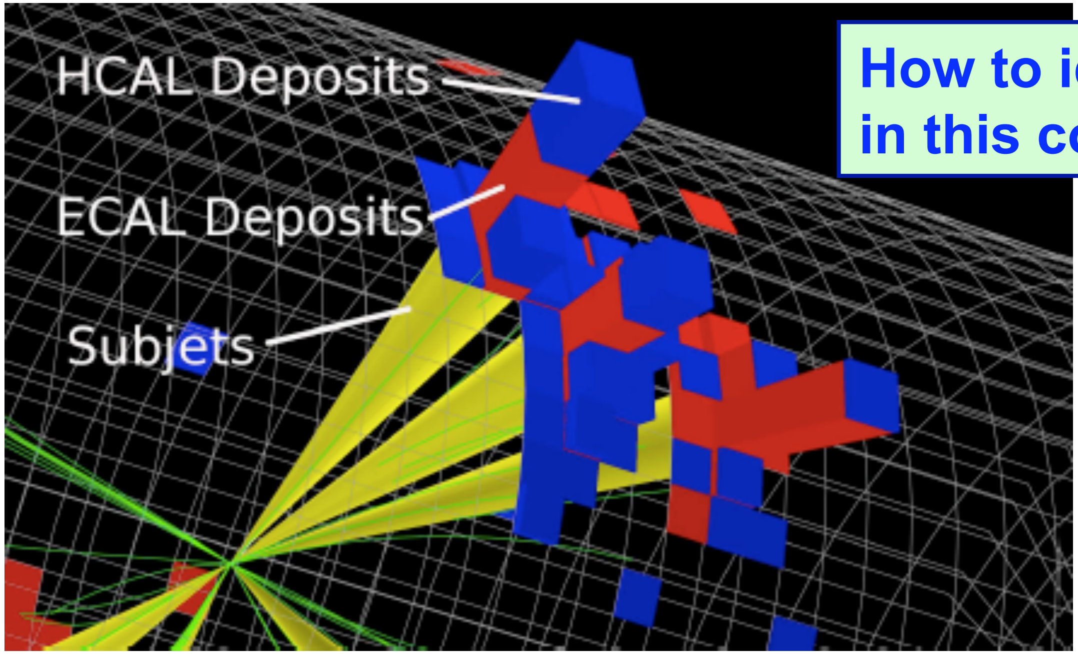
100/pb @ 10TeV

For illustration purpose the Z'→ttbar cross section is set equal to the Standard Model ttbar cross section

Top quark pair resonances

CMS PAS JME-09-001

- Reconstructing and identifying boosted top quarks is not easy



How to identify the decay t→Wb→qqb in this collimated top?

Reconstruct a "super-jet" with the Cambridge-Aachen clustering algo with R=0.8 in the algorithm's metric

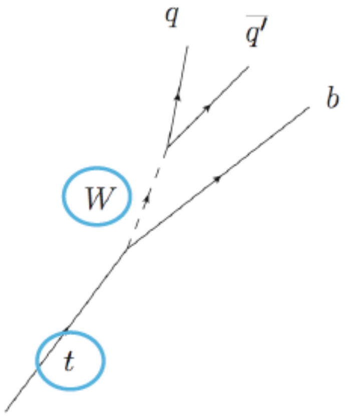
$$d_{ij}=\Delta R_{ij}^2/R^2$$

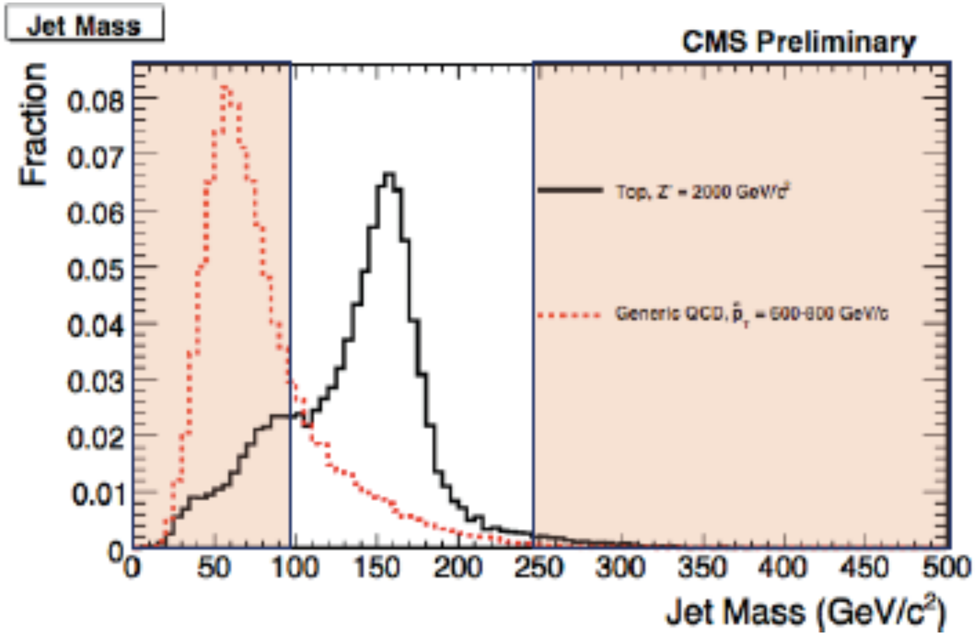
- Now we have the "super-jet" which should reflect the top quark

- Reverse the clustering sequence, by throwing out clusters which are soft (less then 5% of the "super-jets" p_T) and this to find sub-jets in the "super-jet"

Top quark pair resonances

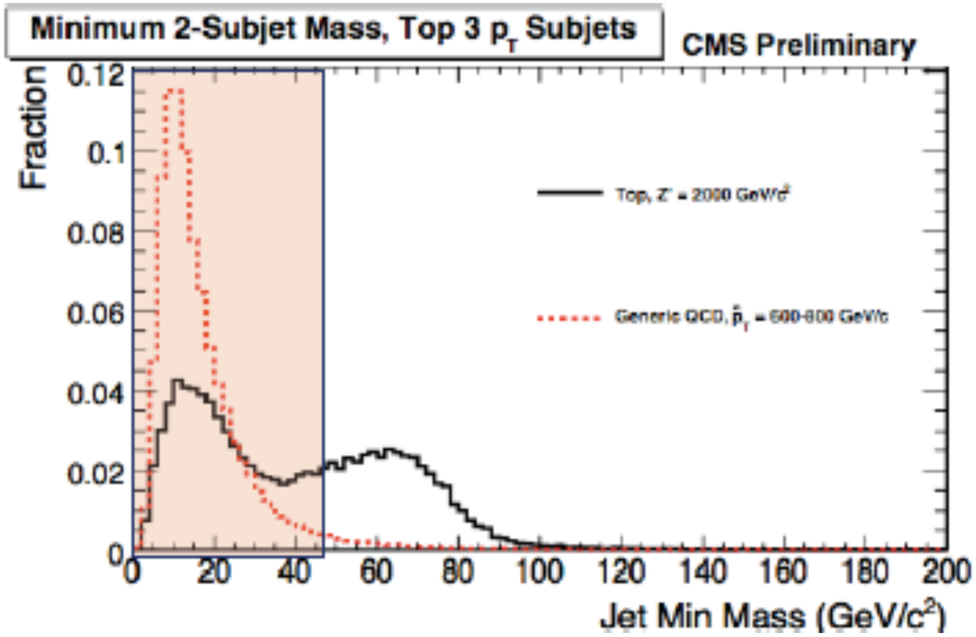
- **Selection window on “top quark” and “W boson” mass**





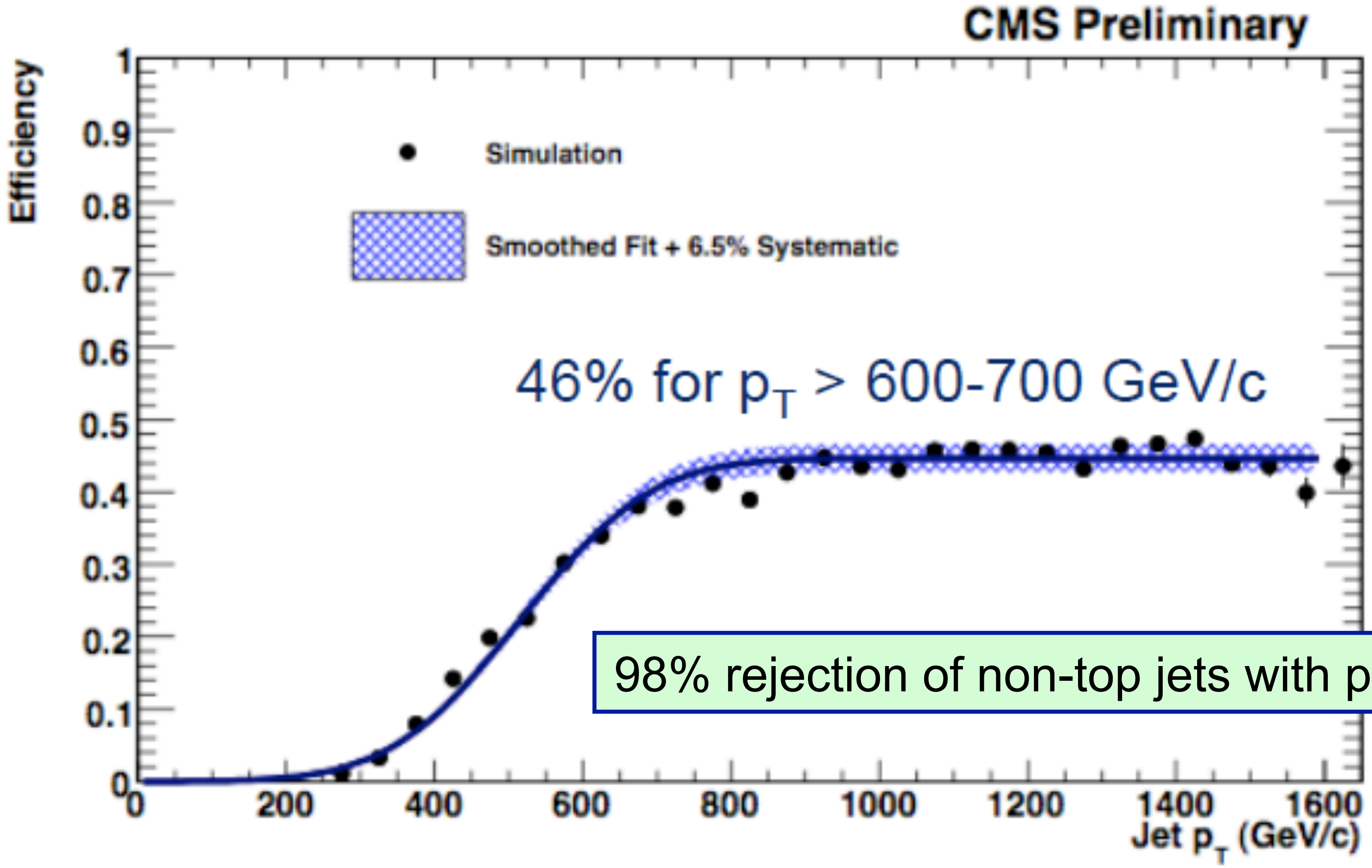
eg. Z’ decay to top pairs

eg. QCD bck (generic)



Top quark pair resonances

- **Resulting top-tagging efficiency reaches ~50% for p_T>700GeV/c**



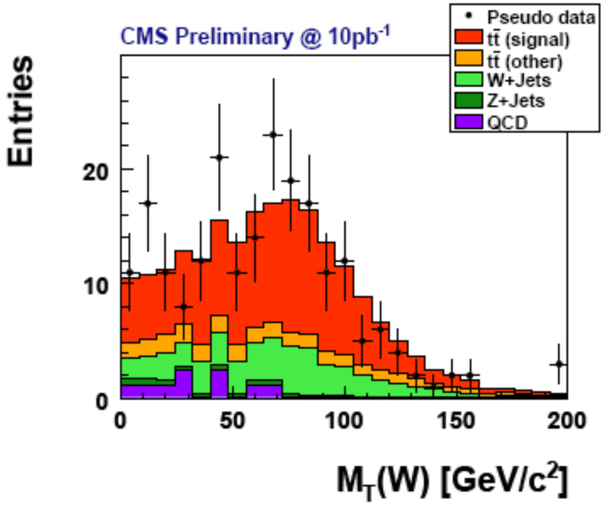
46% for p_T > 600-700 GeV/c

98% rejection of non-top jets with p_T=600GeV/c

- **Mis-tag rate can be controlled via data-driven methods.**

General searches with top events

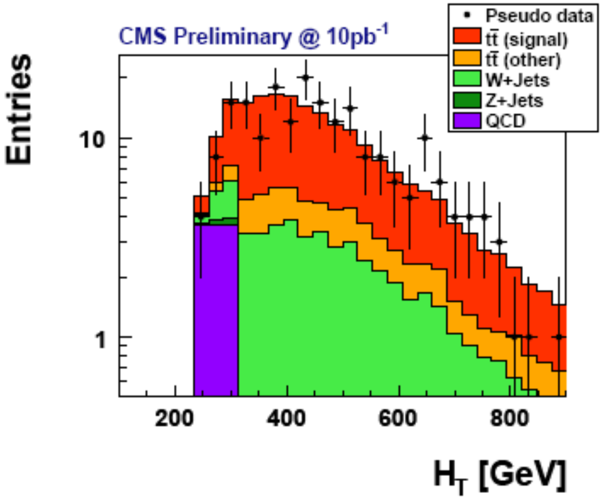
- Several differential distributions can go beyond testing the Standard Model and are sensitive to new physics
- We need to understand the SM part of the distribution before we start looking in the part sensitive to new physics
- Including the systematic effects...

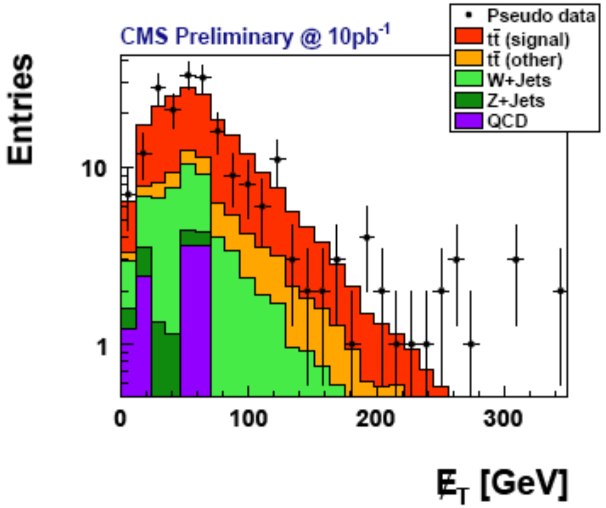


- Examples:

  H_T, MET, p_T^{top}, p_T^{ttbar}, p_T^{lept}, m_{ll}, m_T(l+MET), topo. variables, ...

- Need to increase the activity and ideas in this direction

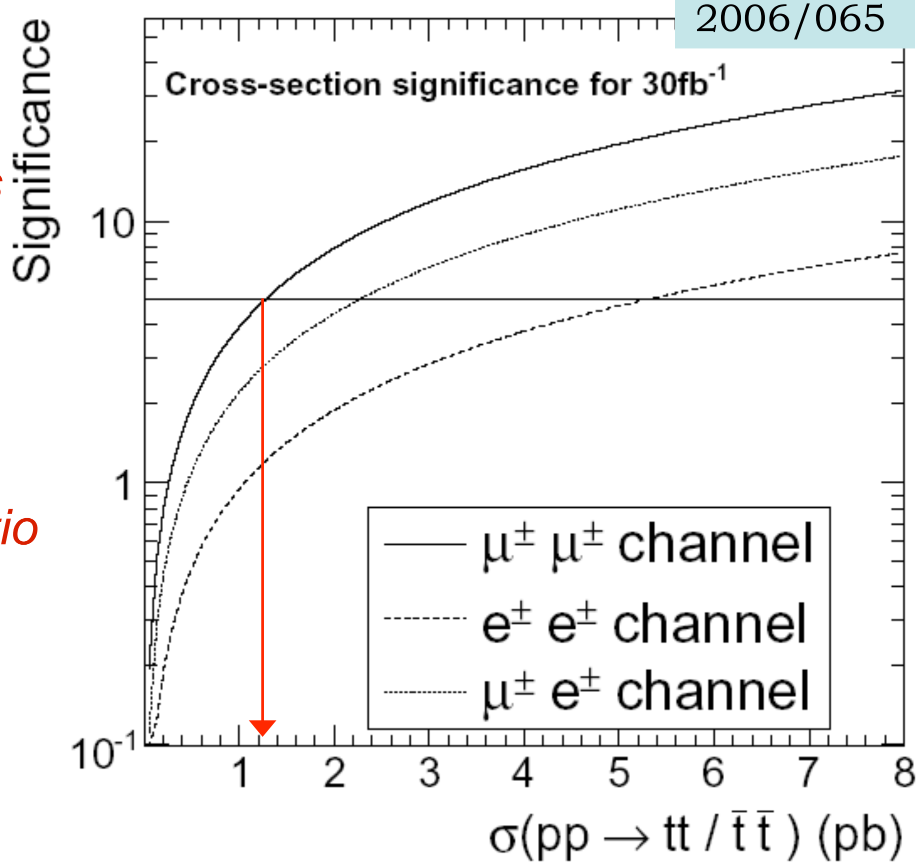




General searches with top events

- **Di-lepton top quark pairs have a clear topology**
  - ☐ *2 b-jet and 2 isolated leptons with a different charge, selected with a large S/N*
  - ☐ *exploit the performance of the lepton isolation criteria (*CMS Note 2006/024*)*
- **Motivation for this search**
  - ☐ *FCNC (in SM suppressed, Z' bosons in Topcolor assisted Technicolor (TC2))*
  - ☐ *from top- and techni-pion in TC2 models*
  - ☐ *in MSSM from for example gluino pairs*
- **Variable to be measured is R = $N^{++,--} / N^{+-}$**
  - ☐ *ratio of events with a pair of leptons with same and different electric charge*
  - ☐ *most of the systematics cancel in the ratio*

CMS Note 2006/065



at 30fb^{-1} a pp→tt cross section of 1pb becomes visible as a 5σ effect on the ratio R

Not covered…

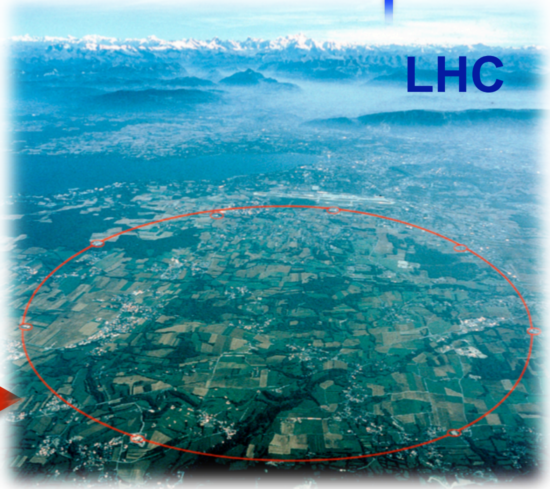
- Many important analyses are not well covered today within CMS, hence consider this as a shopping list for newcomers!

1. W polarization (using the cosθ* distribution)
2. Spin correlations between the top and anti-top quark
3. Mass difference between top and anti-top
4. The electric charge of the top quark
5. Fourth generation quarks (t')
6. The fully hadronic channel
7. Using matrix element tools rather than a kinematic fit
8. Forward-Backward charge asymmetry
9. Top quark width
10. …

- All of these topics cover reconstruction issues, Standard Model issues and can search for new physics phenomena… hence an excellent topic for a small group of students and senior people!
- Most of these analyses are documented at the Tevatron or ATLAS…

Putting the pieces together…

- Top Quark physics is the key topic for the Tevatron and will be the key physics topic for 2-10TeV LHC collisions
- An understanding on the full process, from production over properties to decays, has still to arise
- The first measurements at the Tevatron do not reach the precision to discover new phenomena, the LHC data will open a new window on this heaviest quark
- An important ground for understanding the physics and reconstruction tools in hadron collisions



Some important publicity…

TOP2010 Conference

30th of May – 5th of June 2010
Brugge, Belgium

CP3 - IIHE