Beyond the SM searches with top quark pairs produced in p-p collisions at the LHC

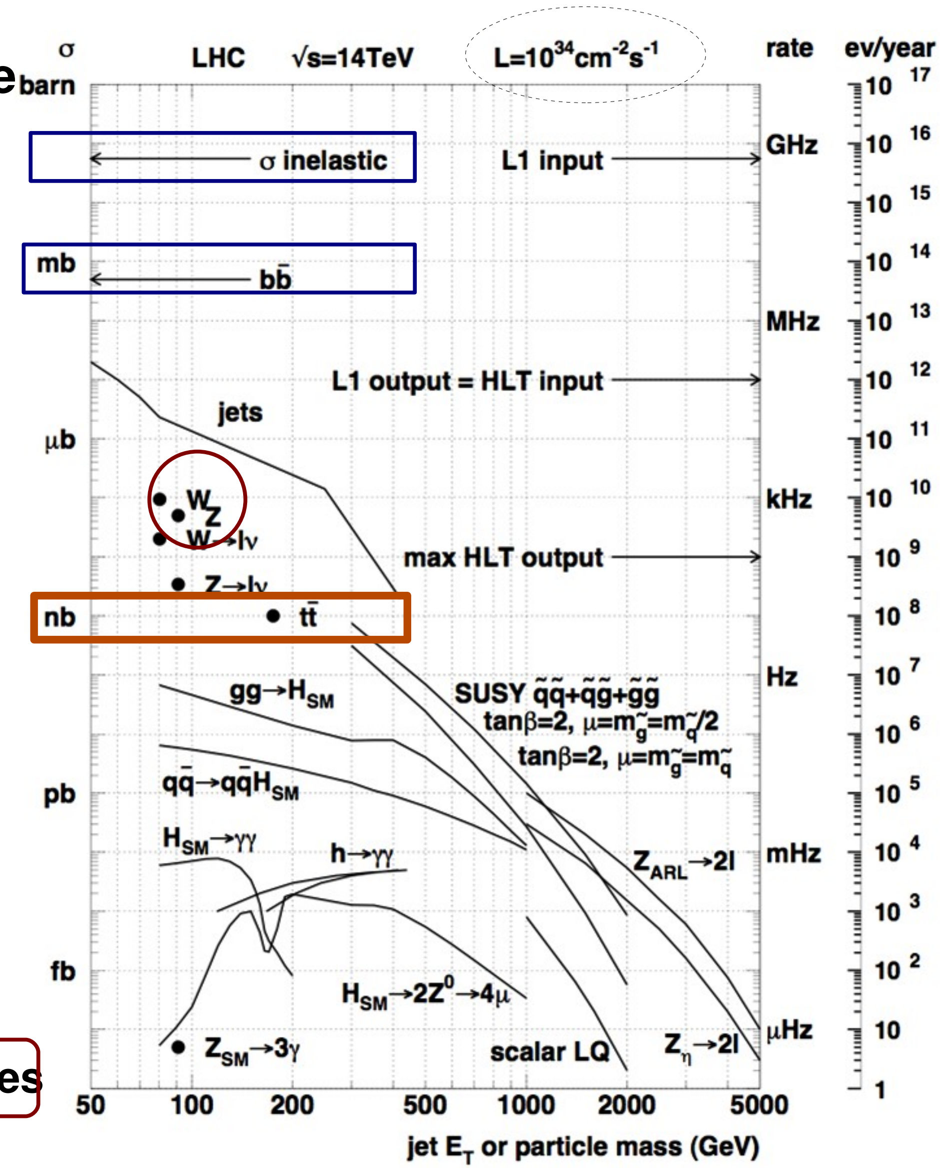
on behalf of ATLAS and CMS collaborations

P. Ferreira da Silva (LIP/CMS)

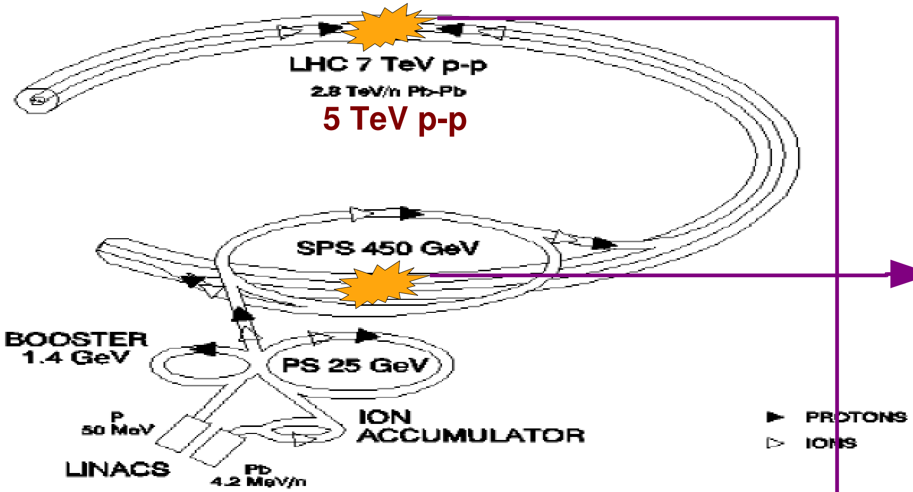
Standard Model Electroweak Physics Session @ *EPS HEP 2009*

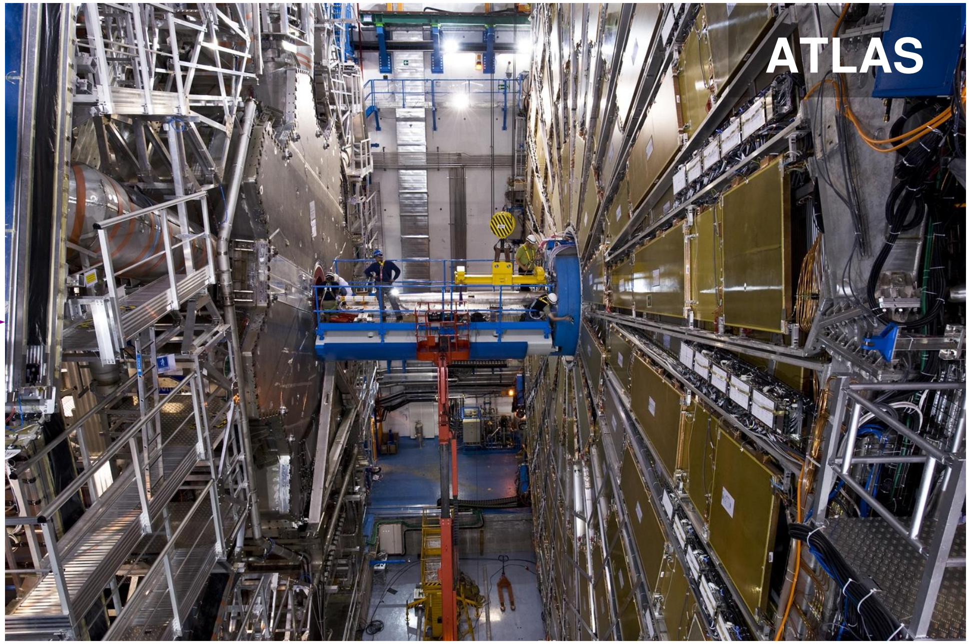
Experimental challenges

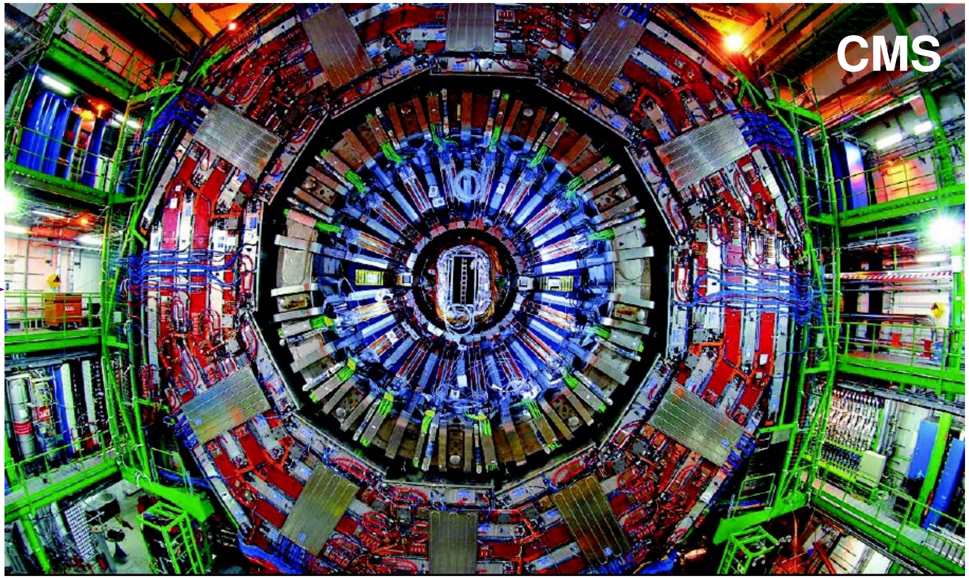
- LHC suited to **explore physics at the TeV scale**
- **Experimental challenges:**
  - High cross section and luminosity
    - ⇒ high trigger efficiency
    - ⇒ need radiation hard detectors
  - Short time between collisions (~25 ns)
    - ⇒ fast readout
    - ⇒ high granularity to reduce occupancy
    - ⇒ synchronization
- **Physics challenges:**
  - Probe short-distance parton structure of hadrons
  - Hadronic jets, **heavy quark production dominates**
  - **New physics underlies** beneath, **to be found**



The collider and the detectors



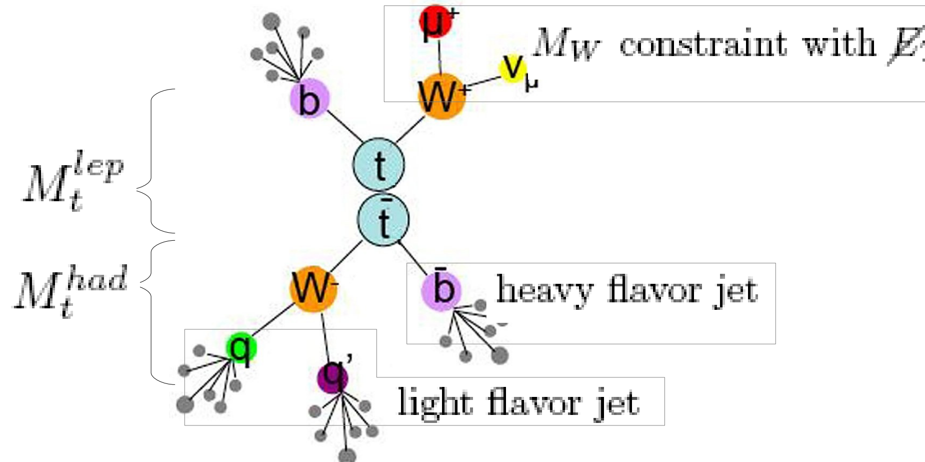


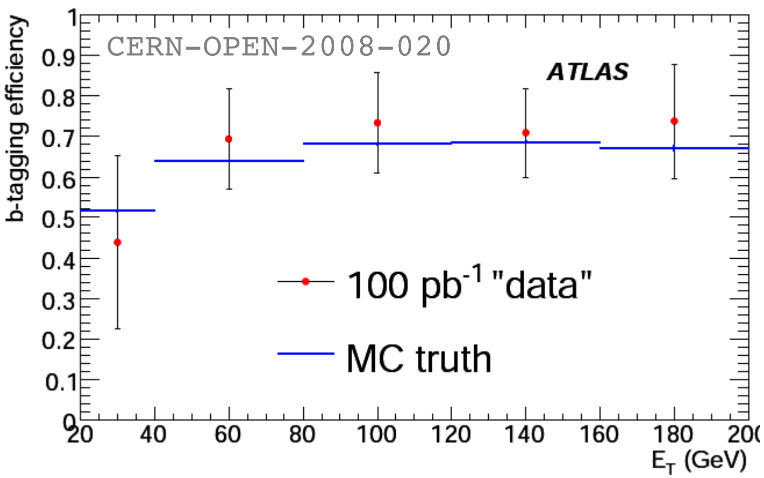


- **Focus on p-p collisions @ 10 TeV**
  - $\sigma_{SM\ t\bar{t}}$ ~ **414 pb** (~90% gg fusion)
  - $\mathcal{L}$=1pb^{-1} @ 14 TeV ~ $\mathcal{L}$=2.5 pb^{-1} @ 10 TeV (for SM $t\bar{t}$ production)
- Detailed description of detectors by:
  - F. Gianotti, L. Masetti, G. Tartarelli (ATLAS)
  - J. Virdee, C. Civinini, T.Orimoto (CMS)

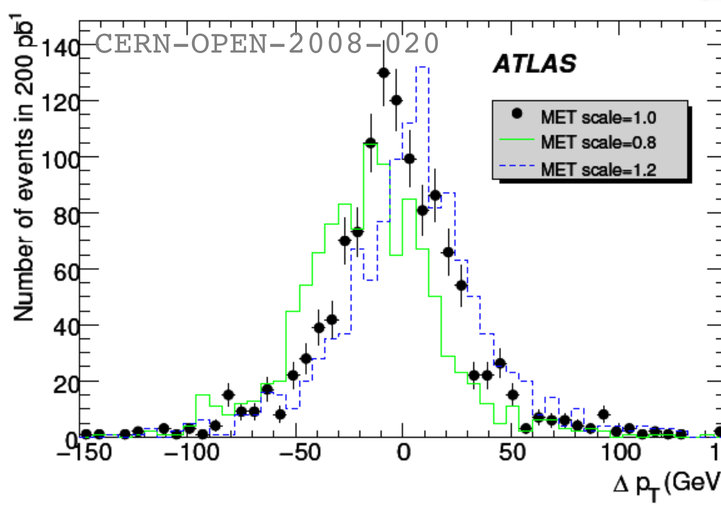
What can we learn with first data?

- **At the LHC top will**
  - need to **be rediscovered**
  - **be a background** for many physics analysis
  - **be used as** a **calibration tool** ▼

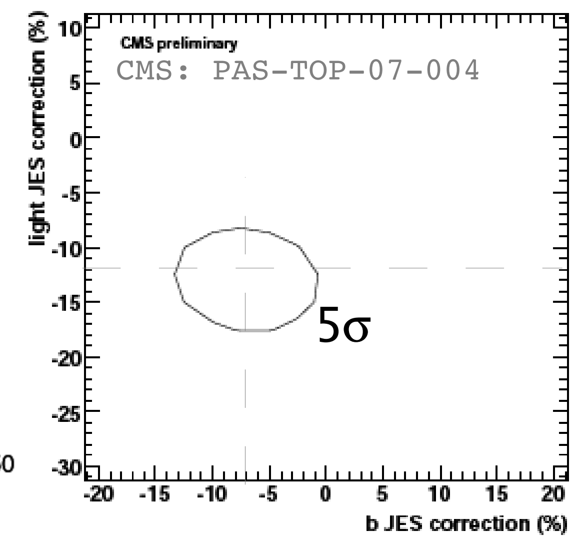




b-tagging efficiency



Missing transverse energy scale

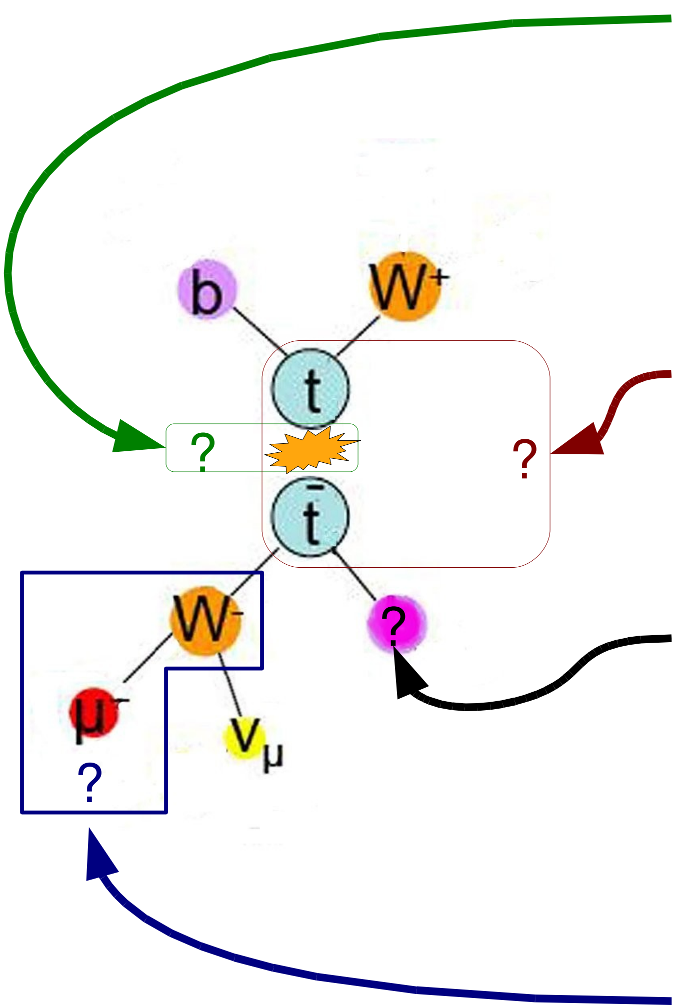


Jet energy scale

What new can we learn from $t\,\bar{t}$ events?

New Physics in $t\,\bar{t}$ events

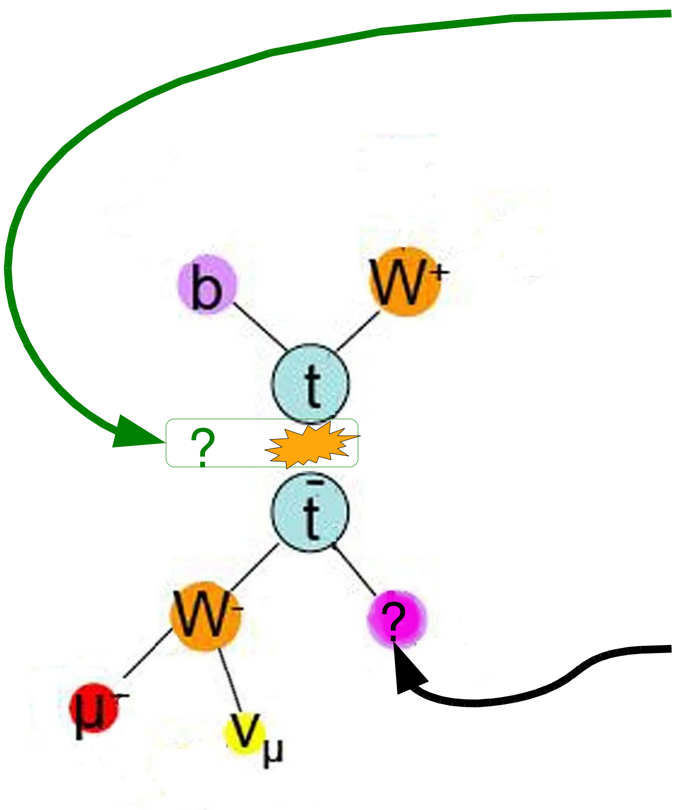
...a non extensive list



- **New mechanisms** might generate $t\,\bar{t}$ pairs
  - High-mass resonances (doi:10.1016/0370-2693(94)01660-5, hep-ph: 0612015)
  - 4th generation: b'b'→ $t\,\bar{t}$ W^+W^- (CMS: PAS-EXO-08-009)
- Top's role in **Electro-Weak Sym. Breaking** mechanism
  - Condensate of top quarks ~ Higgs mechanism (hep-ph: 9702381)
- Rare **top decays**
  - Is V_{tb}=1 ? (hep-ph: 0607115)
  - Flavor Changing Neutral Currents (γq, qZ, qg final states) (hep-ph: 08022075)
- Top quark **polarization**
  - do anomalous couplings occur in Wtb vertex? (hep-ph: 0605190)

New Physics in $t\ \bar{t}$ events

...roadmap for two specific searches



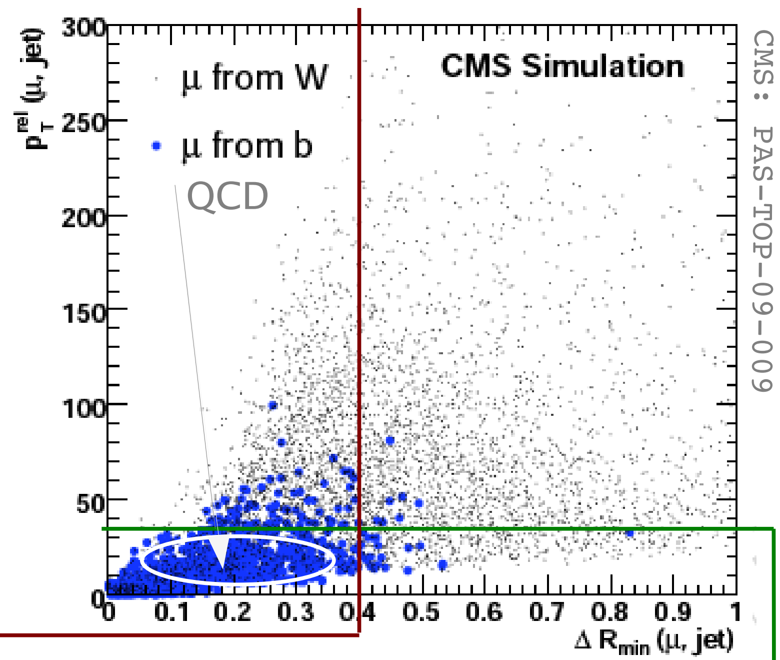
- **New mechanisms** might generate $t\ \bar{t}$ pairs
  - High-mass resonances
    - ⇒ boosted $t\ \bar{t}$ system
  - Collimated decay products can be clustered as single jet
    - ⇒ *(boosted) top*-jet tagging
- Rare **top decays**
  - simple *b* jet counting can probe B(t→Wb)
  - *b* jets often contain secondary vertices and soft leptons
    - ⇒ *b*-jet tagging

Resonances in $t\bar{t}$ spectrum

- The **μ+jets channel** can be used to probe “safely” **heavy resonances** in $t\bar{t}$ events
  - **Large statistics**: ~414 x 29/81 x ½ = 74 pb @ 10 TeV
  - **Single μ trigger** is robust over a large $M_{t\bar{t}}$ range (no isolation)
  - **1 μ** — $p_T > 35$ GeV/c $|\eta|<2.1$
  - no other isolated leptons — $p_T > 10$ GeV/c
  - **at least 4 jets** — $E_T > 35$ GeV/c $|\eta|<2.4$, Iterative Cone (ΔR=0.5)
  - ***$t\bar{t}$* - like topology**

SM $t\bar{t}$
⇒ isolated muons — $\Delta R(\mu,\text{jet}) > 0.4$

Higher masses
⇒ collimated decay products — $p_T^{rel}(\mu,\text{jet}) > 35$ GeV/c

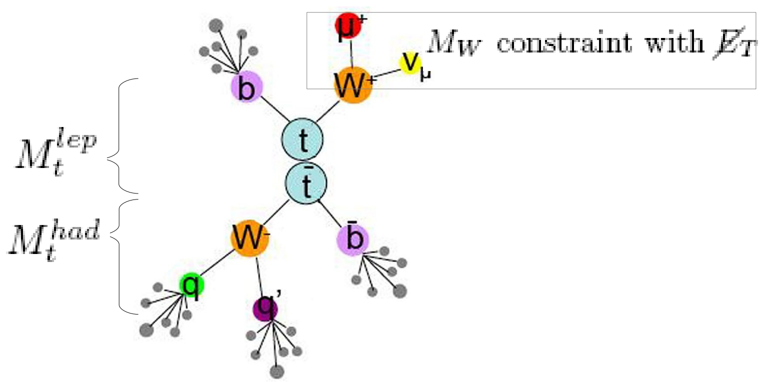


On the road to discovery

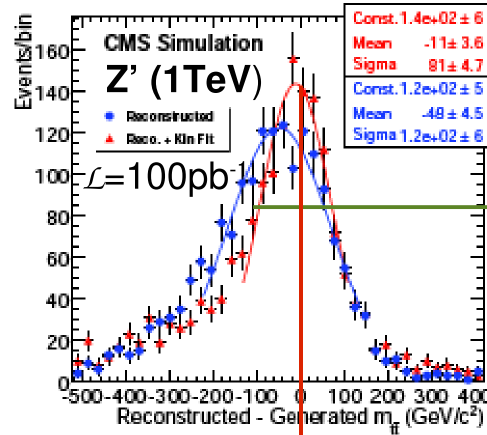
Mass reconstruction

1) use a χ^2 **sorting** method

min $\chi^2(M_t^{had}, M_t^{lep}, M_W, H_T, \ldots)$ = **4 best jets**

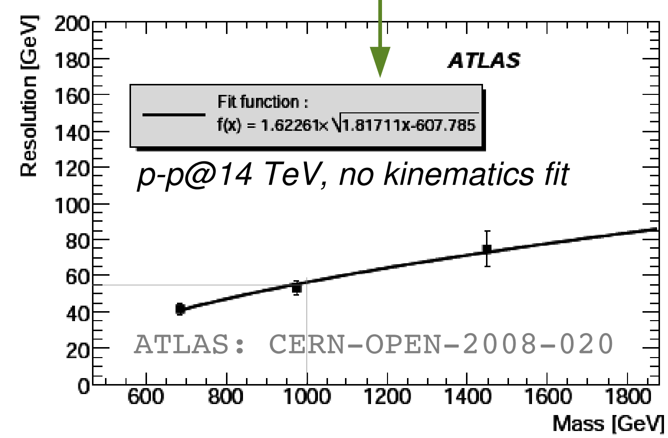


CMS: PAS-TOP-09-009



resolution

~5-8% @ M=1TeV

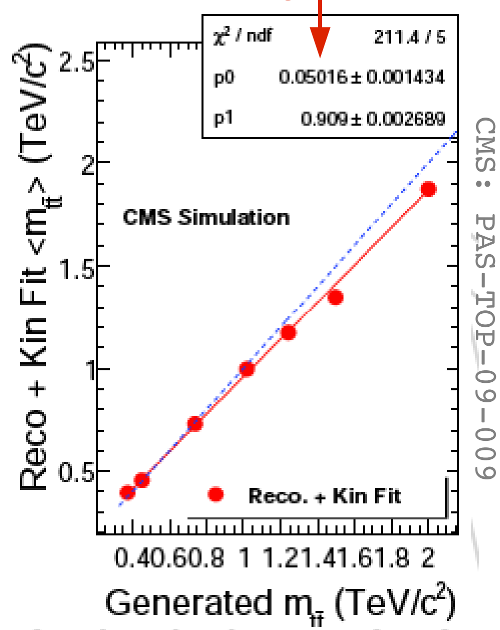


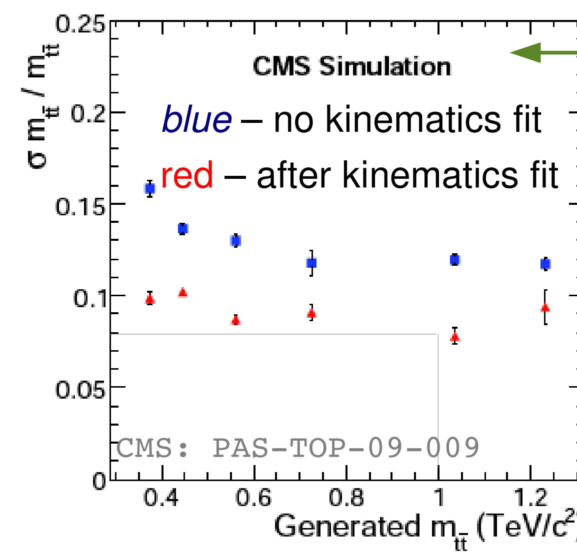
linearity

2) reconstruct $M_{t\bar{t}}$ after kinematics fit

constraints: M_t, $M_{\bar{t}}$, M_W

⇒ find best out of 12 combinations

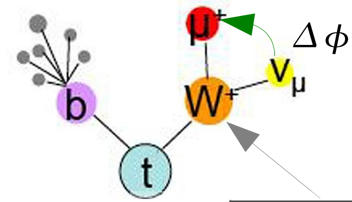




Procedure improves reconstruction of $M_{t\bar{t}}$

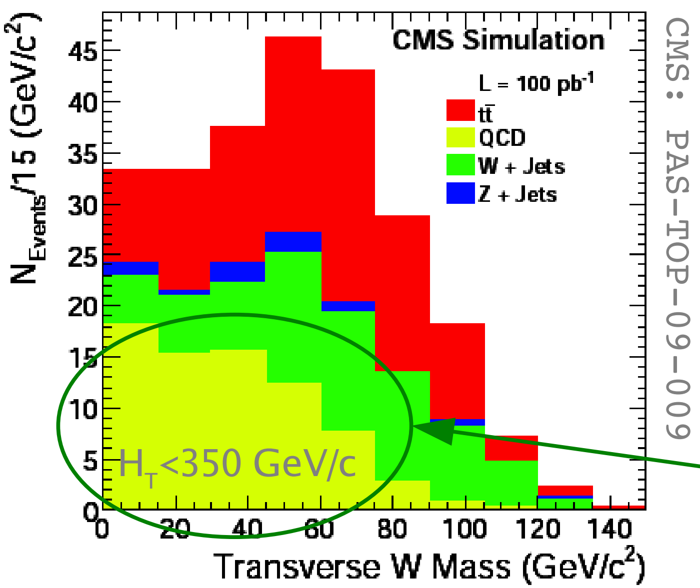
Background control from data

- Find strategies to **control QCD from data** (e.g. M_T^W)
  - In parallel: tune QCD simulations to first data...



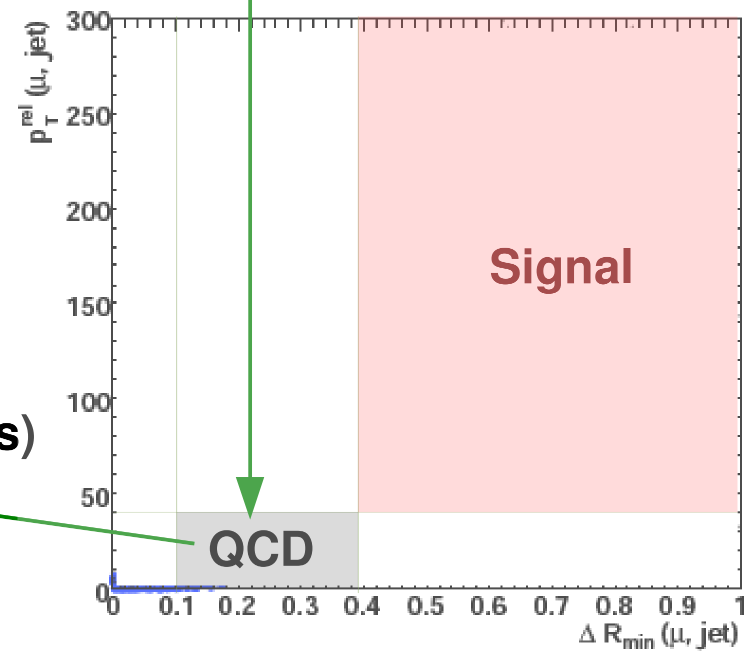
$m_T^W = \sqrt{2\ MET\ p_T^\mu (1-\cos\Delta\phi)}$

- **Get M_T^W** shape **in** a **QCD dominated region**



Fit N(QCD) + N(W+jets)

in **low H_T** events



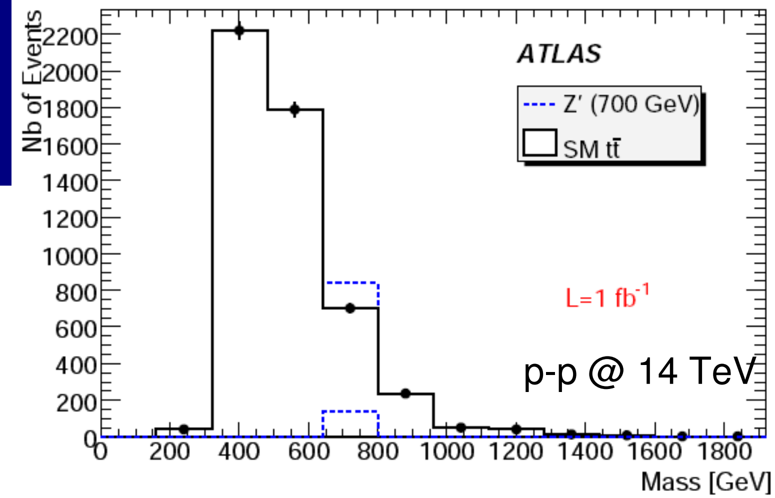
- **Re-scale** fit results **to signal region**
  - **QCD: 23% (stat) ⊕ 25% (syst)**
  - W+jets: 20% (stat) ⊕ 20% (syst)
  - systematics dominated by JES + top background

On the road to discovery

Reach for Z'

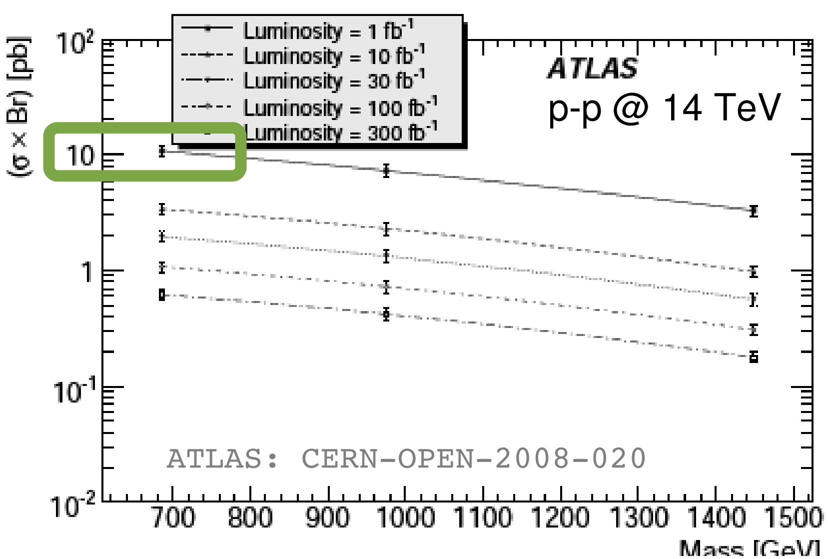
- **Upper limits on $\sigma_{Z'}$ from mass spectrum ▶**
  - count events in $M_{t\bar{t}}$ sliding window;
  - consider background (=SM) only hypothesis;

ATLAS: CERN-OPEN-2008-020



ATLAS

- Find **minimum $\sigma_{Z'}$** for **5σ** deviation
  ⇒ **discovery potential**
- **Systematics < 14%**
  (rec. efficiency, resolution, bckg contribution)



CMS

- Integrate binned likelihood in signal up to 95%
  ⇒ **upper limit for $\sigma_{Z'}$**
- **Systematics** accounted for by pseudo-experiments
  (JES, bckg contribution, ISR/FSR)

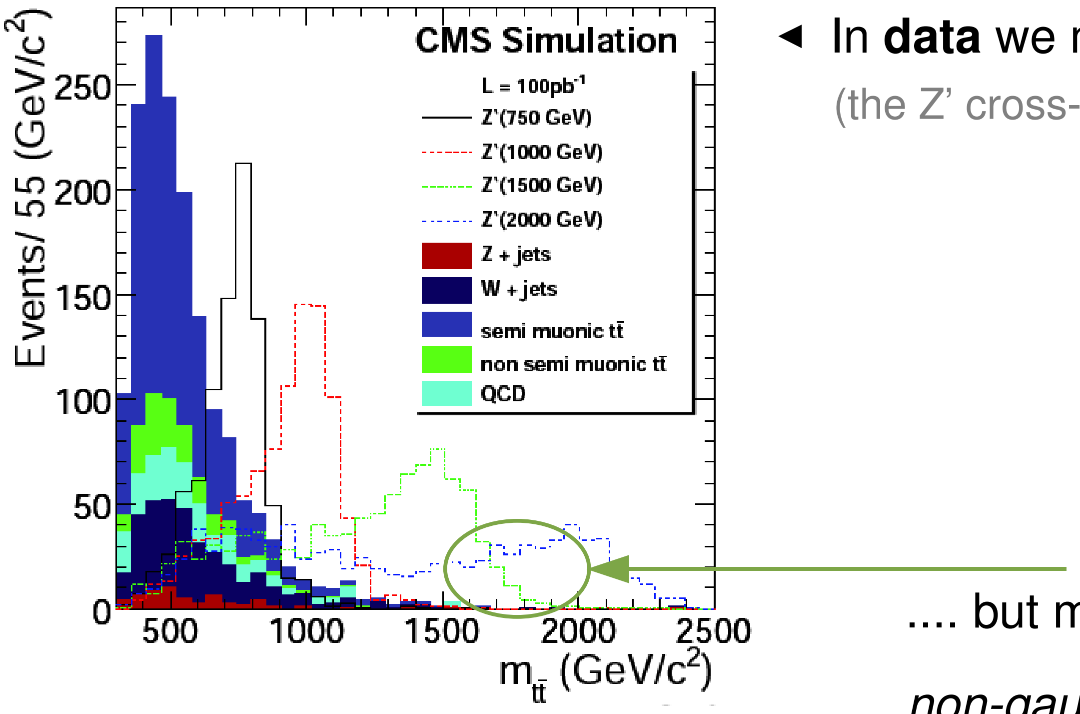
$\mathcal{L}$ = 100pb^{-1}
(p-p @ 10 TeV)

Z' mass [TeV]	Expected Limit [pb]: no systematics	Expected Limit [pb]: with systematics	$\sigma_{Z'}^{TopColor}$ [pb]
0.75	$11.48\,^{+7.31}_{-4.27}$	$16.06\,^{+5.58}_{-2.50}$	13.17
1.00	$6.94\,^{+4.26}_{-2.80}$	$8.89\,^{+4.02}_{-2.23}$	3.28
1.25	$6.76\,^{+3.81}_{-2.75}$	$8.18\,^{+3.41}_{-2.11}$	1.53
1.50	$6.04\,^{+4.26}_{-2.41}$	$7.09\,^{+4.52}_{-1.98}$	0.56
2.00	$7.40\,^{+3.78}_{-3.39}$	$8.26\,^{+4.70}_{-3.18}$	0.13

CMS: PAS-TOP-09-009

On the way to high masses

CMS: PAS-TOP-09-009



- In **data** we might get one out of these scenarios
  (the Z' cross-sections have been rescaled to $t\ \bar{t}$)

.... but method **breaks down at high-masses**

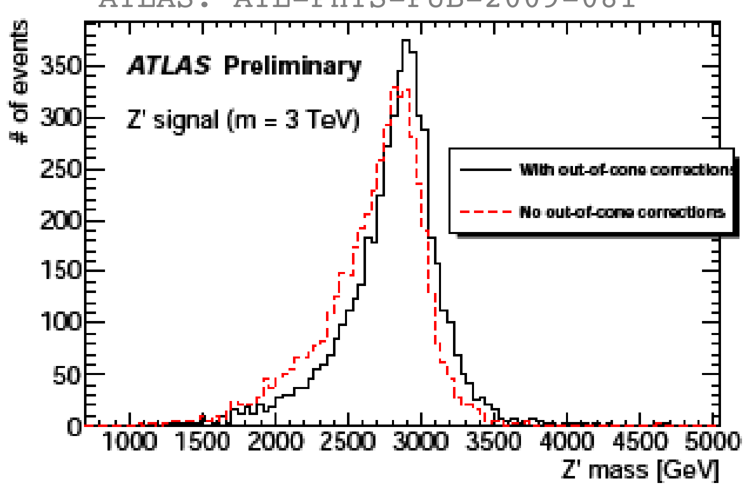
non-gaussian tails ⇒ alternative needed

Corrections for mass reconstruction

- **Out-of-cone** (0.7<R<1.2)
  - Look-elsewhere in the events (ΔR=0.4)

    ⇒ exclude detector effects

ATLAS: ATL-PHYS-PUB-2009-081

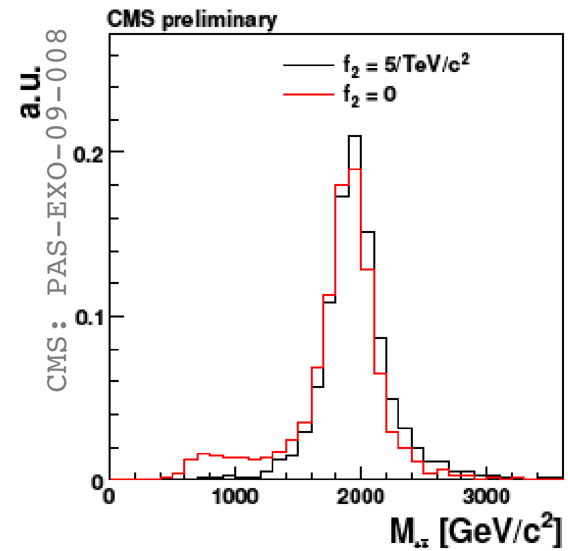


$\mathcal{L}$=1fb^{-1} (p-p @ 14 TeV)

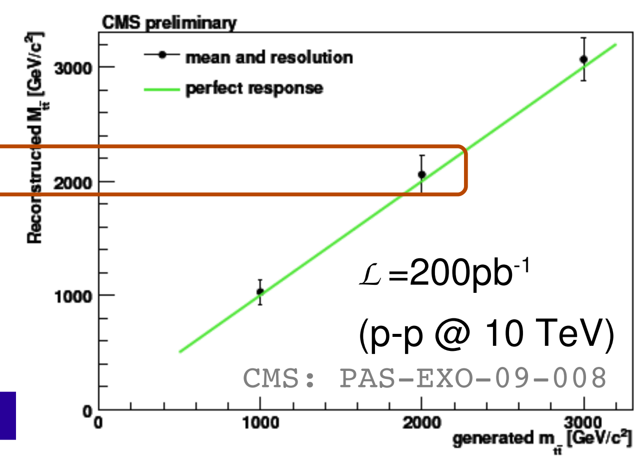
m(Z') (TeV/c^2)	$m_{gen} - m_{reco}$ (GeV/c^2)	σ (GeV/c^2)
2	44	98
3	93	154

Improved Z' **resolution, reduced** non-Gaussian **tails**

- **Event topology** (distance in phase-space)
  - minimize $\Delta R(t_{lep},\mu)+\Delta R(t_{lep},\nu_\mu)+\Delta R(t_{lep},b)$
    $-f_1\Delta R(t_{lep},t_{had})-f_2 M_{t\bar{t}}$



Adjust f_1, f_2 from MC



$\mathcal{L}$=200pb^{-1}

(p-p @ 10 TeV)

CMS: PAS-EXO-09-008

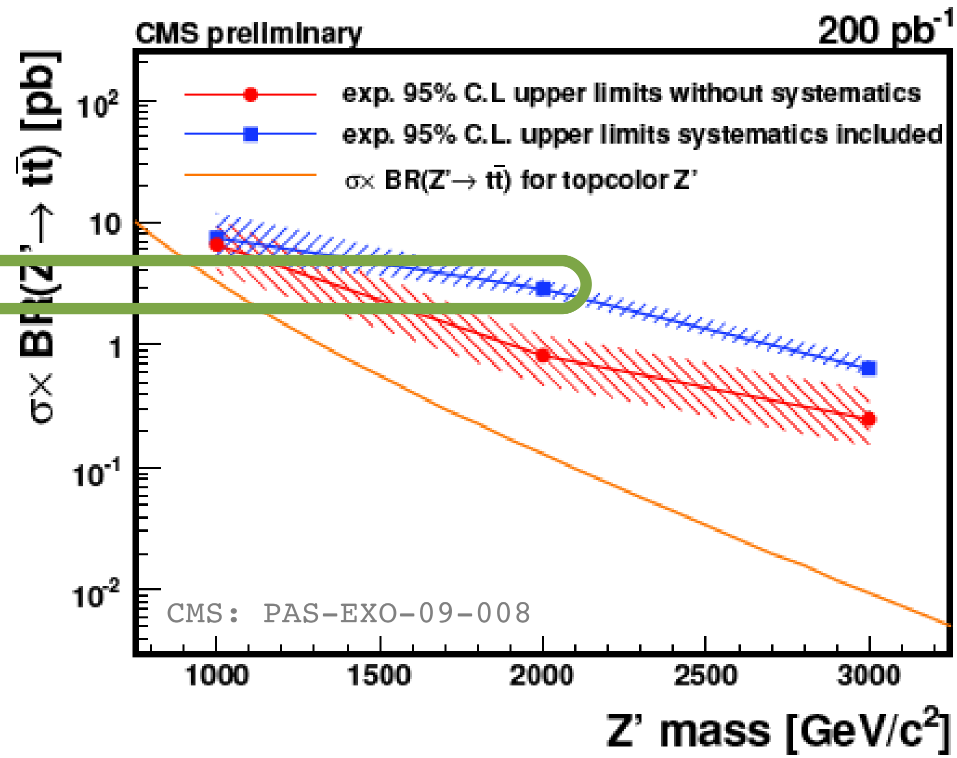
Reach for High-Mass Z'

- A **likelihood ratio*** method can be used
  - **N_{events}(signal) ~ 9 %**
  - N(QCD + SM $t\bar{t}$) ~ 20 events
- For L=**1 fb^{-1}** of data (@ **14 TeV** collisions)
  - Upper limit of ~ 5.5 pb is expected

95% C.L. limits on σ x BR($t\bar{t}$) (fb)	$y_L > 0.6$	$y_L > 0.9$	$y_L > 1.2$
$m = 2$ TeV	550	650	1400
$m = 3$ TeV	160	180	450

ATLAS: ATL-PHYS-PUB-2009-081

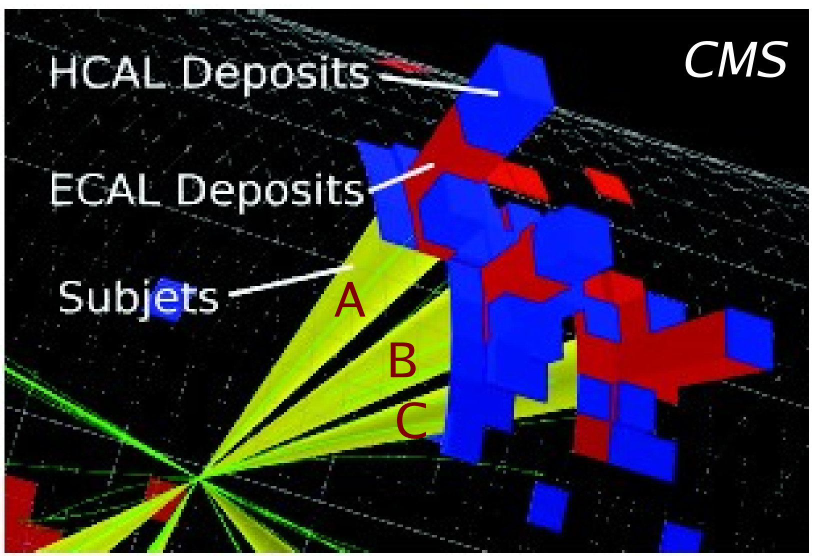
- **Background** contamination can be extracted **from $M_{t\bar{t}}$ sidebands** (see slide 9)
  - Low H_T^{lep} region (<200 GeV/c²)
  - $0.1<\Delta R(\mu,jet)<0.4 \wedge p_T^{rel}(\mu,jet)<35 GeV/c^2$



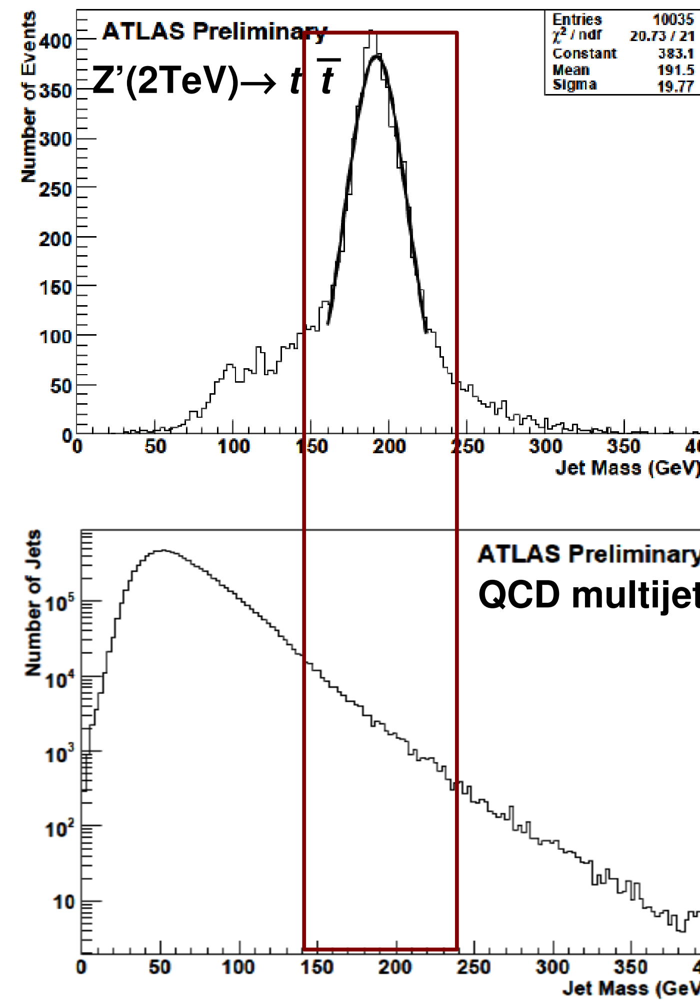
* The *likelihood ratio* (y_L) uses $m_{top\ monojet}$ (next slide) and the the first scales for the k_T-algorithm splitting as variables. Hadronic top monojets are required to have y_L>0.6

Boosted top jet tagging

- **Boosted tops produce broader jets** ($\Delta R>0.5$)
  - $\mathbf{M_{jet} \to M_{top}}$ (in contrast with $M_{jet} \propto p_T^{jet}$ in QCD). ▸
  - **contains** all **top decay products** (b + W-decay);
  - decomposable in 3 (or 4) sub-jets: A,B,C (D);



  - ***min*** $\mathbf{\{M_{A,B};M_{A,C};M_{B,C}\} \sim M_W}$ (b sub-jet leads in p_T)



ATLAS: ATL-PHYS-CONF-2008-008

- Efficiency: ~46% + **fake rate: ~2% derivable from data**

...more details check S. Rappoccio (CMS)

On the road to discovery

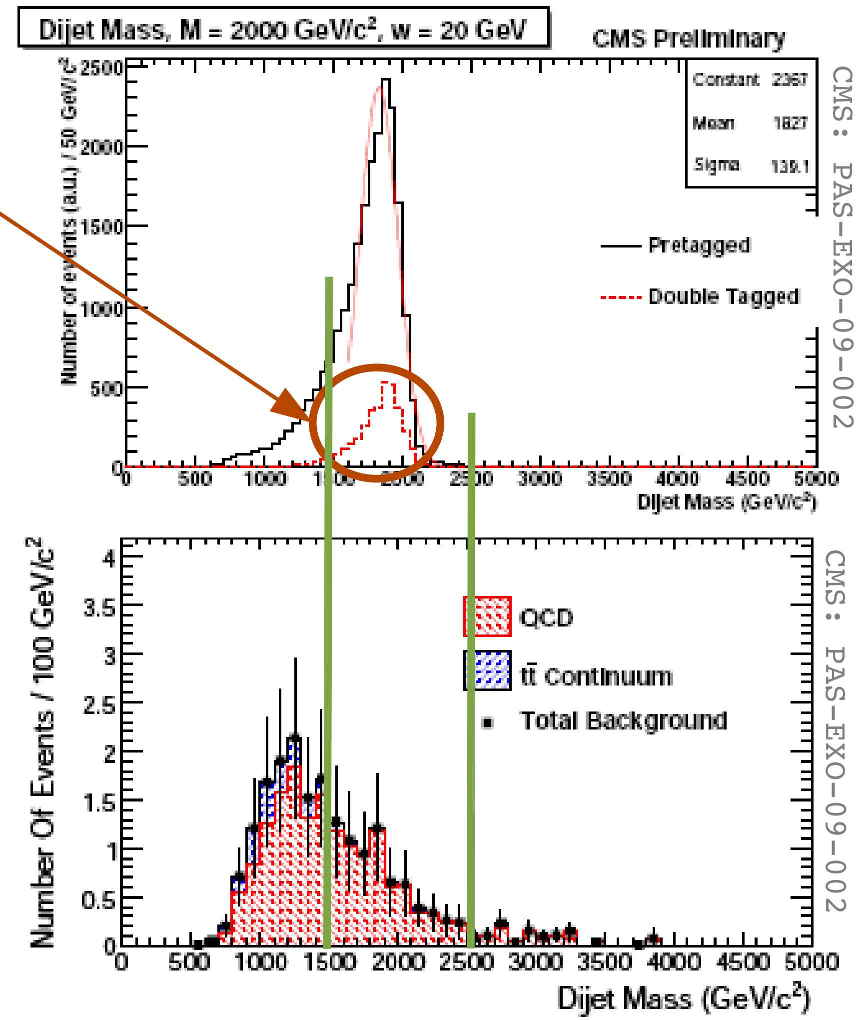
Di-(top) jet resonances

- Construct **di-jet mass** from pre-tagged sample (p_T > 250GeV/c ; $|\eta|$<2.5)
- **Signal** estimated **after double tag**:

$$S(m_0)=L\times\sigma(M)\times B(t\bar{t}\rightarrow jets)\times\int_{M-2\sigma}^{M+2\sigma} dm \frac{N_{2-tags}(m)}{N_{total}(m)}$$

- **Background** can be **estimated from data:**
  - **mistag parameterization predicts** background (= double mistags)

Quantity	Relative Uncertainty	Uncertainty on S and B at $m_0 = 2$ TeV/c^2
Signal Uncertainties		
Top Tagging Efficiency	6.5%	13%
JES Uncertainty on Acceptance	5%	5%
Total Signal Uncertainty		14%
Background Uncertainties		
Statistical uncertainty	10%	10%
JES Uncertainty on QCD Background	35%	33%
$t\bar{t}$ Continuum Contribution	100%	5%
Luminosity	10%	10%
Total Background Uncertainty		36%



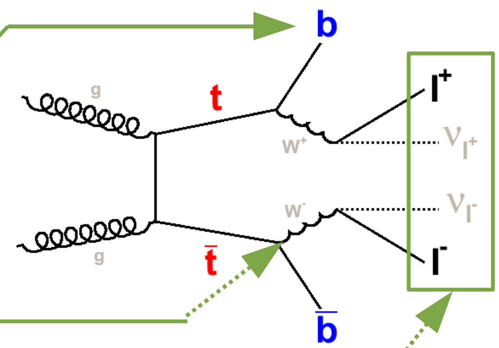
On the road to discovery

Top decays

- $t\bar{t}$ **decays produce 2 *b* jets** in the final state

2 *b* jets = $t\bar{t}$ experimental signature?

b-tagging



⇒ Unique **handle against background**

Is V_{tb}=1?

branching fraction

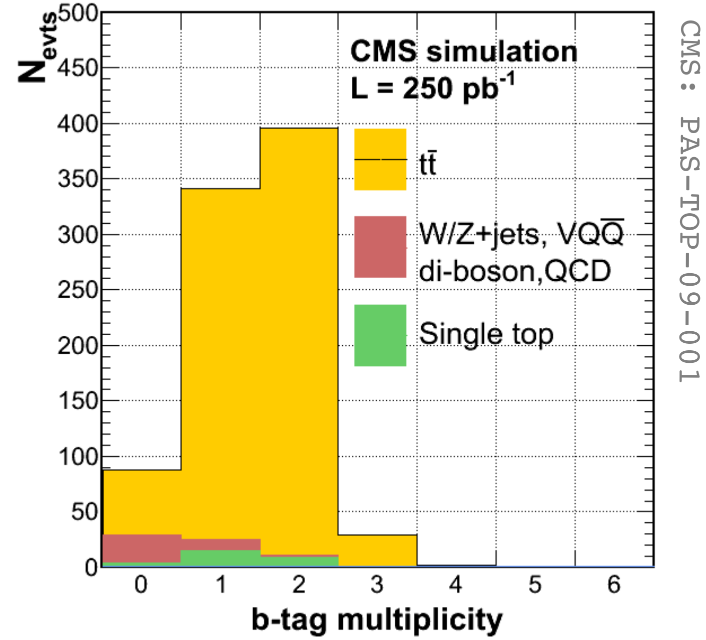
⇒ $\mathcal{O}(0.1)$ deviations may evidence **new physics**

- **Dilepton $t\bar{t}$ channel** may **provide clean answer with early data** (L=250 pb^{-1})
  - **Orthogonal** to beyond SM searches in other $t\bar{t}$ channels
  - **e-μ** final state **provides** a **clean signature**, almost background free (S/B ~ 10)

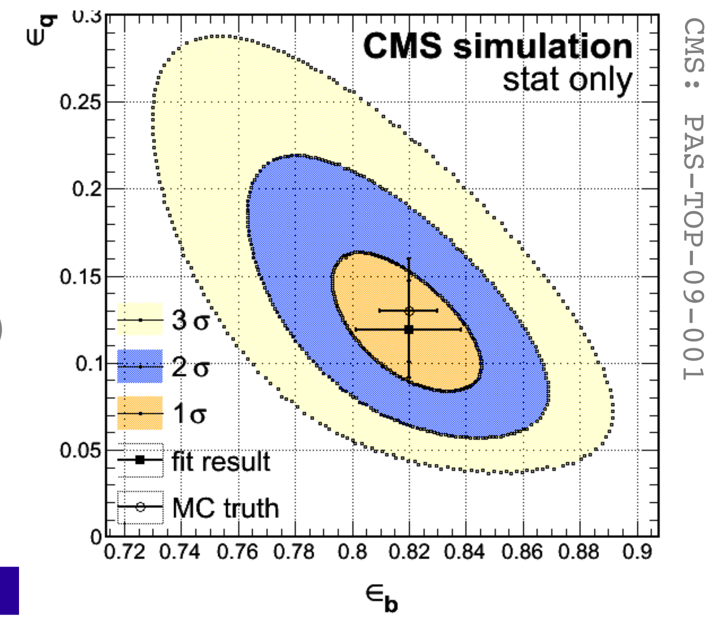
On the road to discovery

b - tagging efficiency in $t\,\bar{t}$

- Analyze ***b*-tag multiplicity** of dilepton events:
  - Use simple algorithms based on impact parameters
  - **Count** the number of **b-tags** per event
  - **Compare with expections** based on
    - $\boldsymbol{\varepsilon_b}$ (ε_q) - b-tag (mistag) rates
    - **R** = B(t→Wb) / B(t→Wq)
    - jet misassignment fraction;



- *b*-tagging efficiency is computed (assume R=1, SM inspired)
  - **2%(stat) ⊕ 4%(syst)** uncertainty
  - higher statistics yield $\varepsilon_b=\varepsilon_b(p_T)$, see slide 3 (ATLAS results)
  - Why not use b-tagging as handle against QCD background with first data?



On the road to discovery

ISR/FSR control

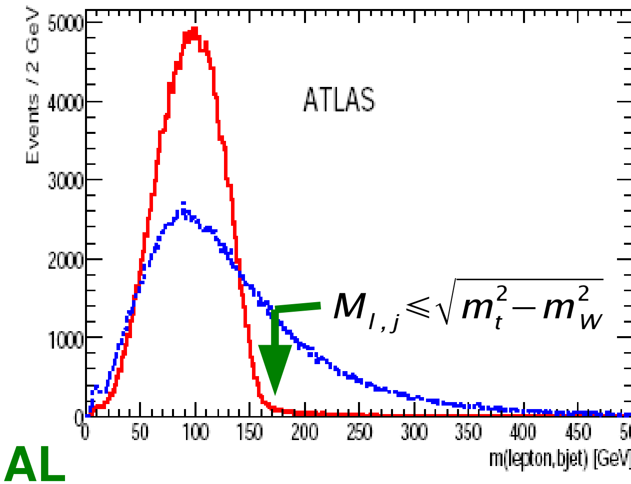
- **Correct** lepton-jet **assignments** have M_{lj}<156 GeV/c² ▶

- **Tail in mass spectrum controls ISR/FSR from data**
  - **Combinatorial assignments** modeled by:
    - **Swap**: pair leptons and jets from different events;
    - **Random rotation** of the leptons;
  - Normalization: scale shape at high masses. ▶

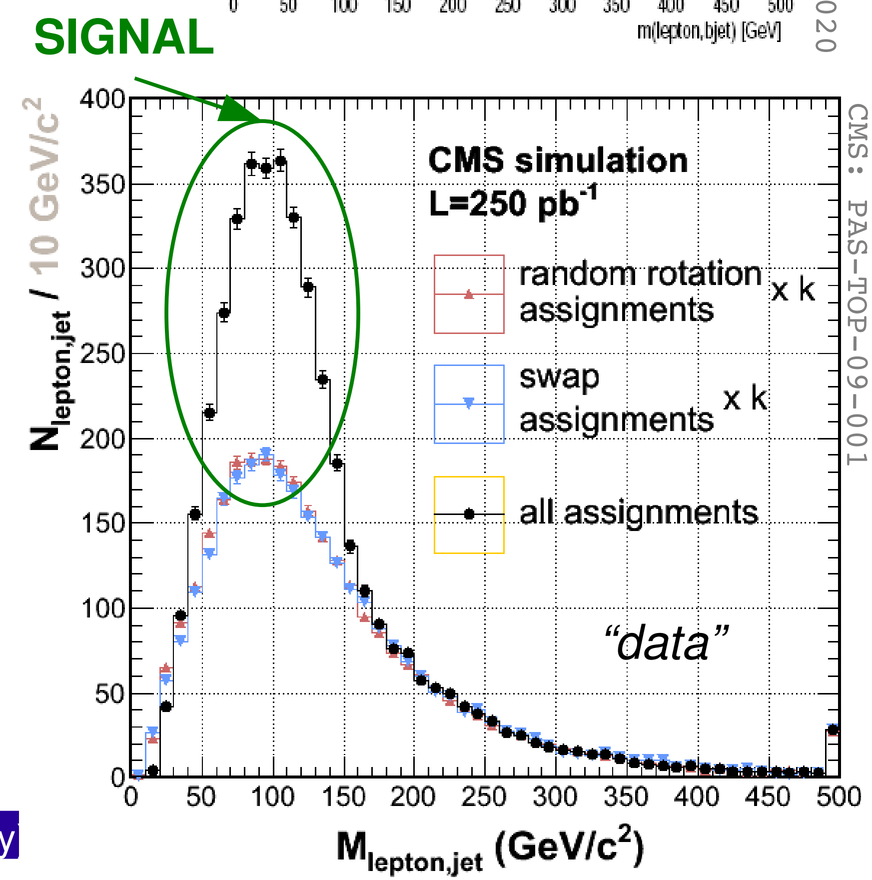
- Method **determines the fraction of jets from** $t\bar{t}$
  - correctly reconstructed and selected;
  - **dominated by statistical uncertainty** ▶

Method	$N_{mis}^{M>190}$ / N_{mis}	α
$t\bar{t}$ events from MadGraph		
average	0.21 ± 0.01	0.82 ± 0.04
MC truth	0.20 ± 0.01	0.80 ± 0.01

CMS: PAS-TOP-09-001



ATLAS: CERN-OPEN-2008-020



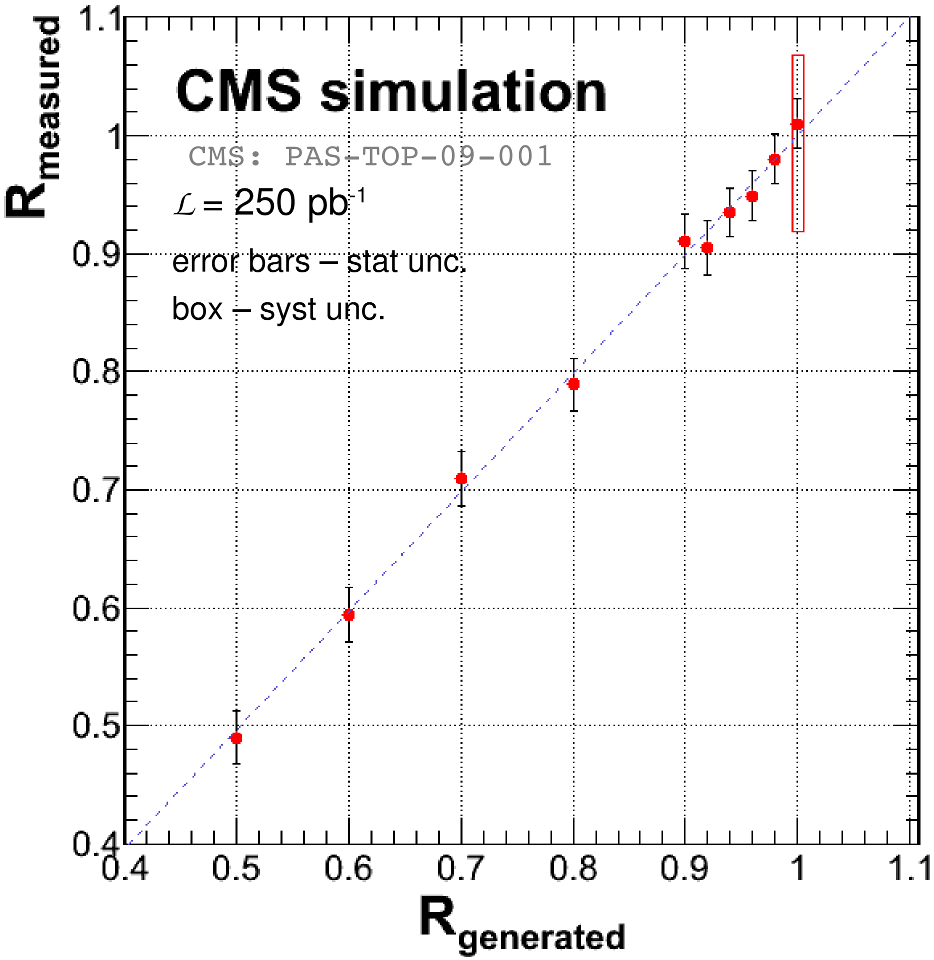
CMS: PAS-TOP-09-001

Measurement of R=B(t→Wb)/B(t→Wq)

- **Total uncertainty ~ 9% (stat+syst)**
  - dominated by uncertainty in ε_b
    (if L=10pb^{-1} is used for $\sigma_{\varepsilon b} \Rightarrow \sigma_R$~14%)
  - the variation of ISR/FSR is controlled (σ_R<1%)

- **Systematic uncertainty can be reduced** with **10x more data $\Delta\varepsilon_b/\varepsilon_b$** = 10% → **5%**

- Combined measurement with lepton+jets channel may also help reducing common uncertainties



Conclusions

- With the upcoming LHC collider ***$t\bar{t}$* will be re-discovered** in distinct ways:
  - bridge with Tevatron discovery;
  - **provide callibration for** the ATLAS and CMS **detectors** (energy scales, b-tagging, etc.);
  - appear as **background** / **open window for new physics** searches

- Focused on the **searches for heavy resonances** in $t\bar{t}$ production:
  - Intermediate and High-Mass resonance searches (can aim for σxBR~8pb discovery with ~100 pb^{-1});
  - **Data-driven background estimation** is crucial before detectors are understood+MC is tuned;
  - **Jet tagging algorithms are powerful tools** against background rejection
    - Top jet tagging identifies the unique signature of collimated top jet decays (stay tuned for next talk)
    - *b*-jet tagging identifies the unique signature of the b-jets from top decays
    - **Efficiencies can be derived from data** and be used with early data

Backup slides

- Look for the original analysis in:

ATLAS Physics Results

CERN-OPEN-2008-020

ATL-PHYS-PUB-2009-081

ATL-PHYS-CONF-2008-008

CMS Physics Results

CMS-PAS-TOP-09-009

CMS-PAS-EXO-09-002

CMS-PAS-EXO-09-008

CMS-PAS-JME-09-001

CMS-PAS-BTV-07-001

CMS-PAS-BTV-07-002

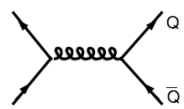
CMS-PAS-BTV-07-003

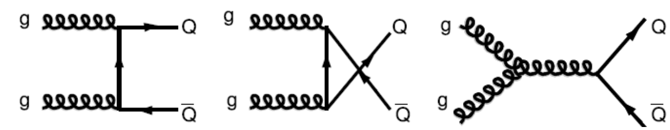
CMS-PAS-TOP-09-001

CMS-PAS-TOP-09-007

Top Quark Production

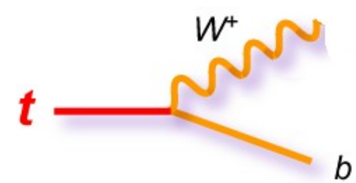
- **Top** quark can be **produced in pairs**

quark annihilation ▸ 

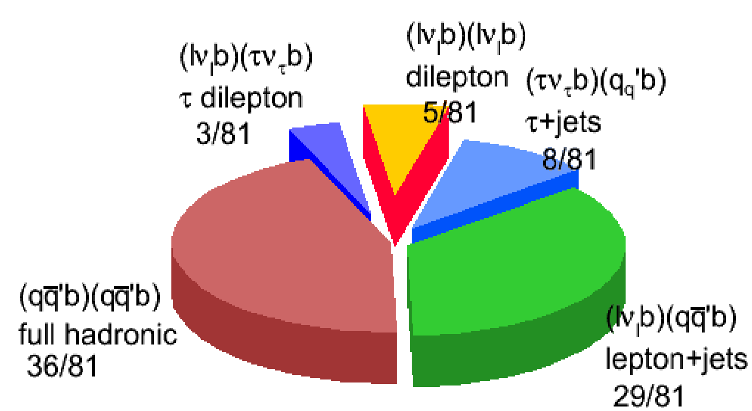
gluon fusion ▸ 

Collider	Collisions	When	$\sigma_{t\bar{t}}$ (pb)	Production Ch.
Tevatron	$p - \bar{p}$	Run I	5.0	$\approx 90\%\ q\bar{q}$
		Run II	7.5	$\approx 85\%\ q\bar{q}$
LHC	$p - p$	first data	414	$\approx 90\%$ gg
		full operation	911	$\approx 95\%$ gg

- **Decays promptly, coupling** preferentially **to the b-quark** ▸



- **Decay** channel **of the W-boson identifies the $t\bar{t}$ system decay channel** ▸
  - each channel offers specific experimental challenges



On the road to discovery

Event yields for Z' search

- **Selection efficiencies** for $t\ \bar{t}$ and Z' events for L = 100pb^{-1}

$m_{t\bar{t}}$	500 GeV	750 GeV	1000 GeV	1250 GeV	1500 GeV	2000 GeV
ϵ(SM $t\bar{t}$) (%)	15.3 ± 0.2	17.3 ± 0.5	16.9 ± 0.5	16.2 ± 0.6	15.5 ± 1.0	12.7 ± 2.7
$\epsilon(Z')$ (%)	13.6 ± 0.4	21.3 ± 0.6	23.9 ± 0.6	24.6 ± 0.6	25.4 ± 0.6	24.0 ± 0.6

CMS: PAS-TOP-09-009

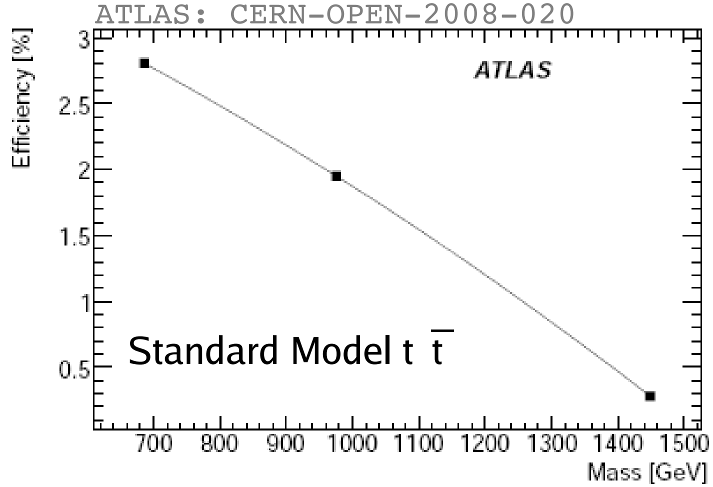
- Event yields after full event selection for **SM processes** (L=100pb^{-1})

requirement	tt $bq\bar{q}\bar{b}\mu\nu$	Other tt	W+jets	Z+jets	QCD
Events in 100/pb	6255	35K	4.1M	370K	>12M
Muon trigger	4966	6926	767K	102K	9.7M
Muon selection	2891	1538	387K	61K	46K
Veto second lepton	2816	1242	386K	33K	46K
4jets with $E_T > 35$ GeV	932	160	352	62	188
Fit convergence	910±2	147±1	317±14	58±6	183±20

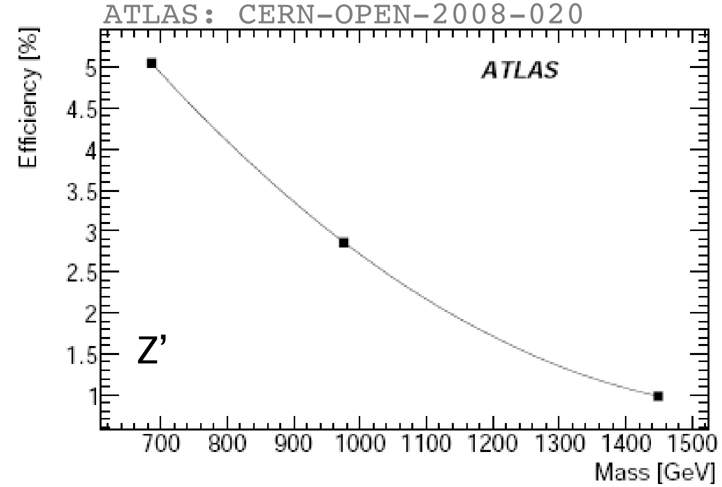
CMS: PAS-TOP-09-009

- Reconstruction efficiencies compared:

ATLAS: CERN-OPEN-2008-020



ATLAS: CERN-OPEN-2008-020

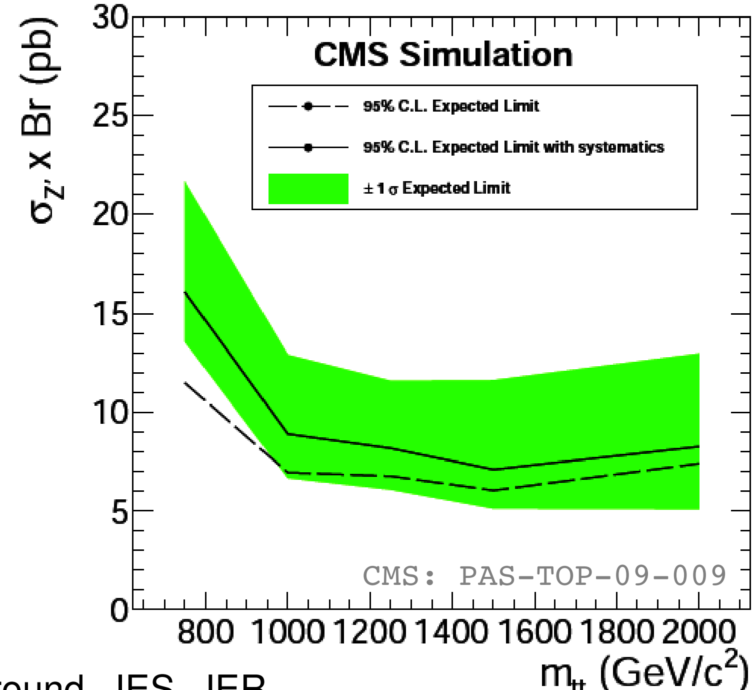


Binned likelihood for $\sigma_{Z'}$

$$L=\prod_{i=1}^{N_{evts}} P(M_i|N_S,\beta_S,\beta_{t\bar{t}},\beta_{QCD},\beta_{W+jets})\, G(\beta_{t\bar{t}}|1,\Delta_{\beta_{t\bar{t}}})\, G(\beta_{QCD}|1,\Delta_{\beta_{QCD}})\, G(\beta_{W+jets}|1,\Delta_{\beta_{W+jets}})$$

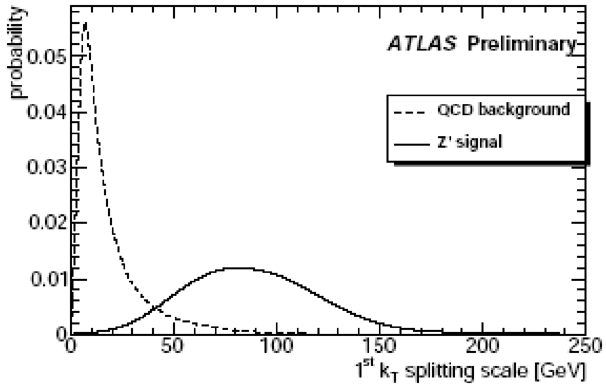
- M_i: reconstructed $t\bar{t}$ invariant mass in event i
- N_S: number of signal (Z') events
- $\beta=\frac{\sigma(measured)}{\sigma(expected)}$
- G: Gaussian distribution
- Δ_β: uncertainties in the accepted predicted σs sample by sample

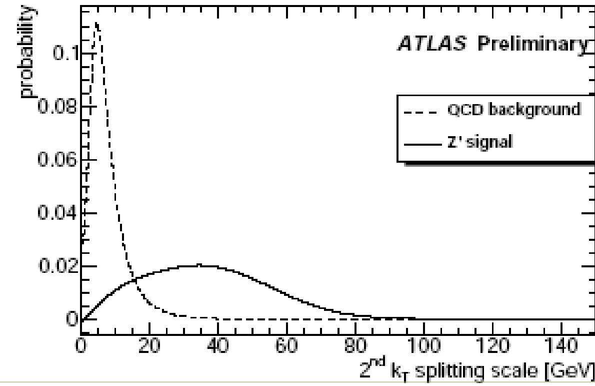
- The likelihood is profiled in β_S (signal only) by minimizing w.r.t to the backgrounds
- The upper limit on $\sigma_{Z'}$ obtained integrating L(β_s) to 95%
- Upper limit distribution obtained by pseudo-experiments
  - Dice the background contributions from the MC expectations
  - use β_s median as estimator for U.L. (34% interval=1σ error band)
  - Systematics induce variations of β_s and are taken into account by pseudo-experiments
    - accepted background cross sections, ISR/FSR, QCD multijet background, JES, JER

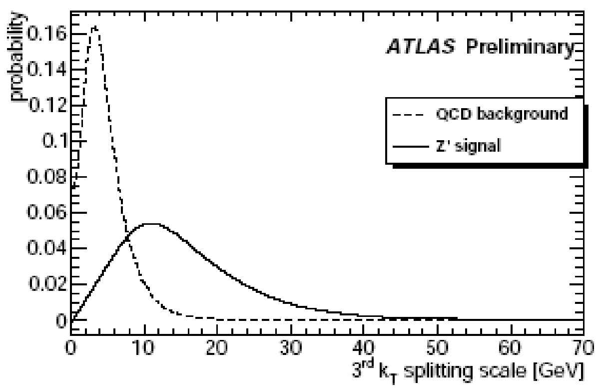


Likelihood for high mass Z’ searches

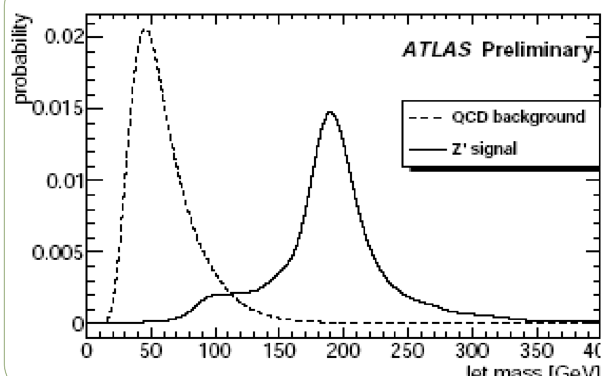
- The pdf’s for signal and backgrounds are built out of 4 variables





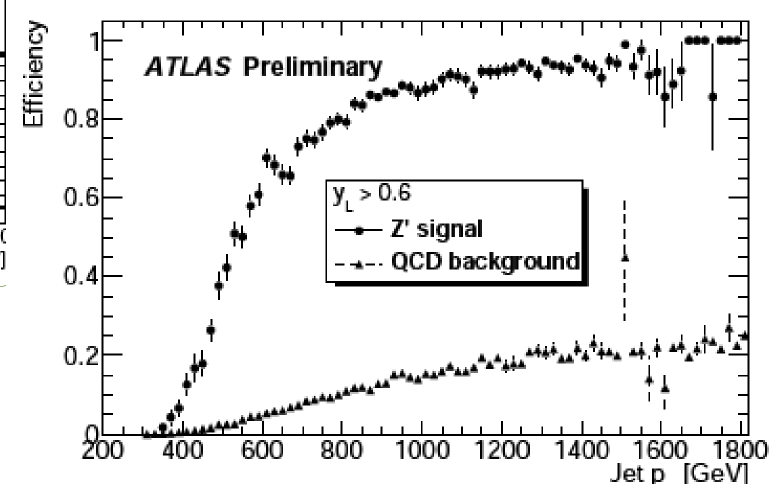


First k_T splitting variables

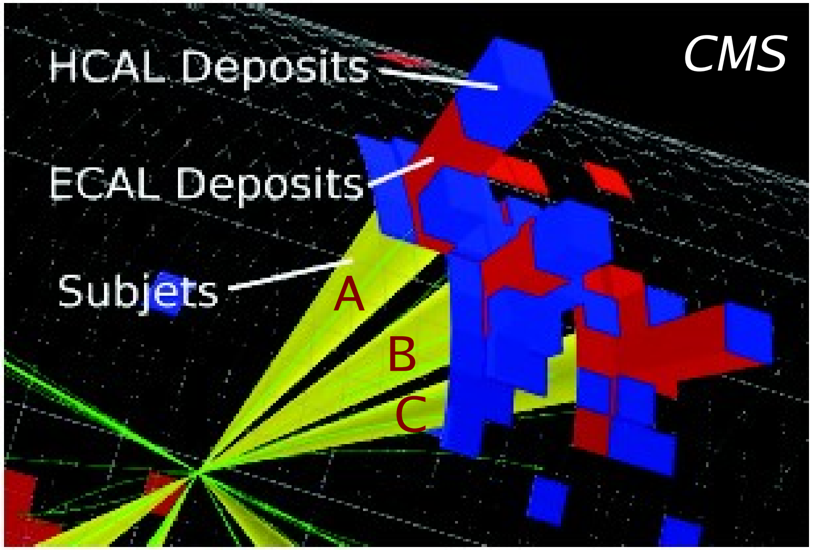


Top monojet mass

$$y_L(i) = \frac{\ln\left(L_S(i)/L_B(i)\right)}{15}$$

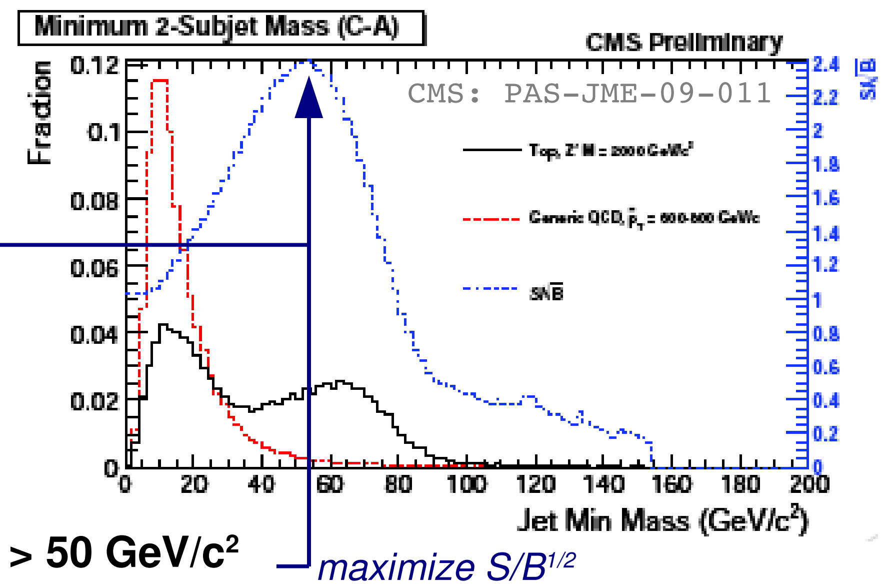


Boosted top jet tagging



- **Broader jet contains** all **top decay products**
  - $\mathbf{M_{jet} \rightarrow M_{top}}$ (in constrast with $M_{jet} \propto p_T^{jet}$ in QCD).
  - decomposable in 3 (or 4) sub-jets: A,B,C (D);
  - ***min*** $\mathbf{\{M_{A,B};M_{A,C};M_{B,C}\} \sim M_W}$ (*b* sub-jet leads in p_T)

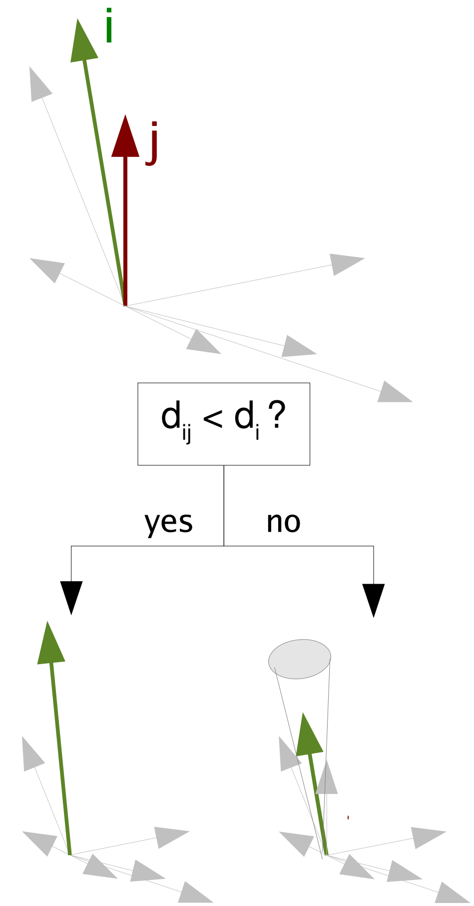
- In CMS boosted top jets are tagged with:
  - **Cambridge-Aachen** algorithm with **R=0.8**;
  - **sub-clusters** must have **> 5%** $\mathbf{p_T^{jet}}$;
  - consistent with top: $\mathbf{100 < M_{jet} < 250}$ **GeV/c²**
  - di-subjet consistent with *W* must be found: ***min*** $\mathbf{M_{A,B} > 50}$ **GeV/c²**



...more details in Salvatore Rappoccio's talk

The Cambridge-Aachen algorithm

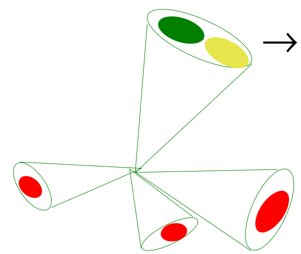
- Recombination type algorithm (arXiv:hep-ph/9707323)
- Pairs of Lorentz vectors are used as input
- Distances* computed as: $d_{ij} = min[k_T^n(i), k_T^n(j)] \frac{\Delta R(i,j)^2}{R^2}$
  - Standard (anti) k_T-algorithm uses N = 2 (-1);
  - **Cambridge-Aachen uses N=0**.
- Distance is gauged with respect to "*beam distance*": $d_i = k_T^n(i)$
- If $\mathbf{d_{ij} < d_i}$ cluster the pairs and proceed iteration
- If $\mathbf{d_{ij} > d_i}$ stop process ⇒ **jet has been reconstructed**
- CMS uses R=0.8 as distance parameter for the *top jet algorithm*



*Distance in detector phase-space is defined as: $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$

Boosted top jet tagger performance

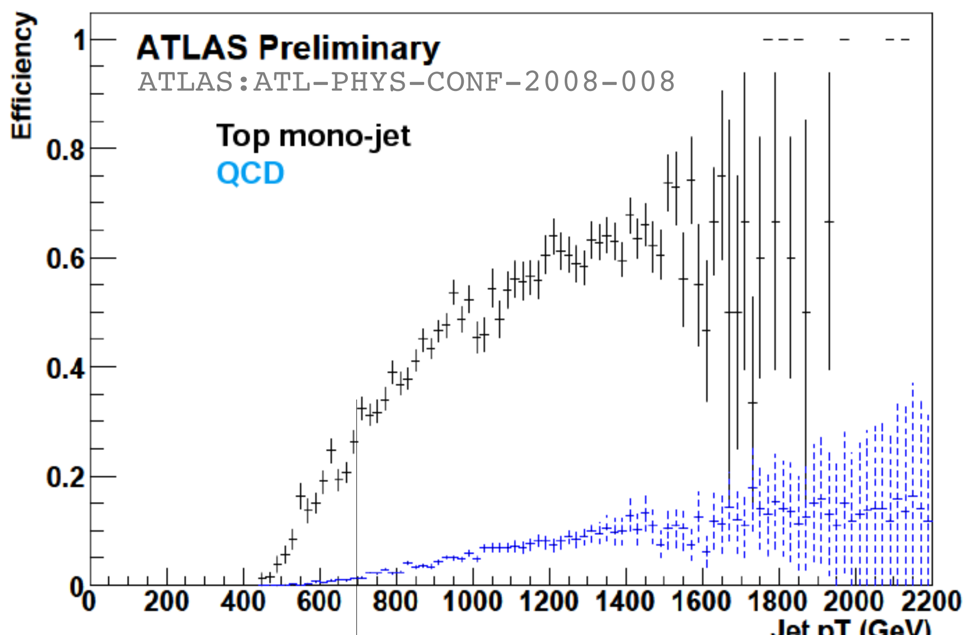
- **Fake rate is measurable from data**
  - measured in **anti-tag + probe** sample

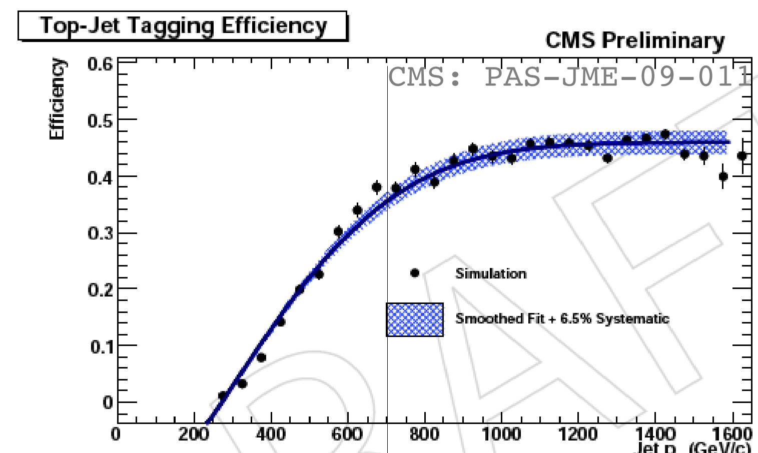


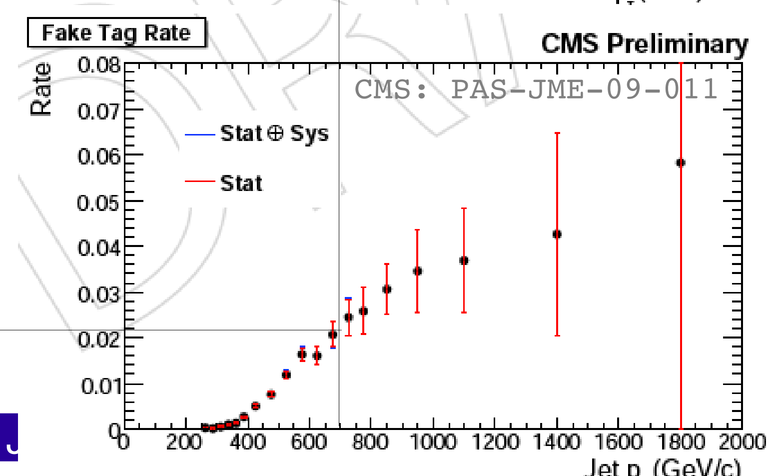
→ $p_T > 250$ GeV/c, $|\eta|<2.5$, **no top tag**

$$\varepsilon = \frac{N_{jets}(tagged)}{N_{jets} \in \{anti-tag\ sample\}}$$

- Efficiency is estimated from MC
  - **Systematic uncertainty ~ 6.5%** (dominated by detector-based uncertainties)





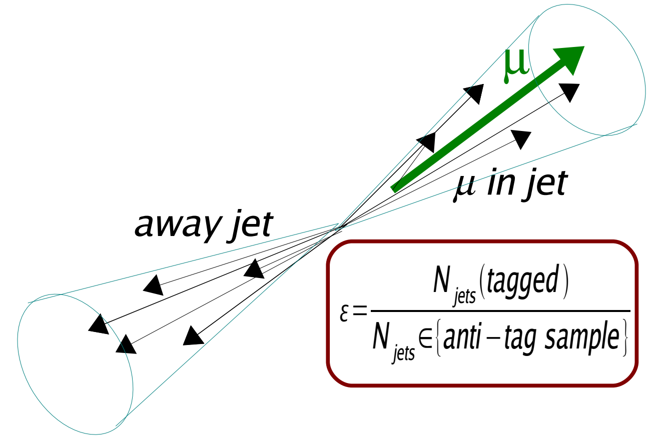


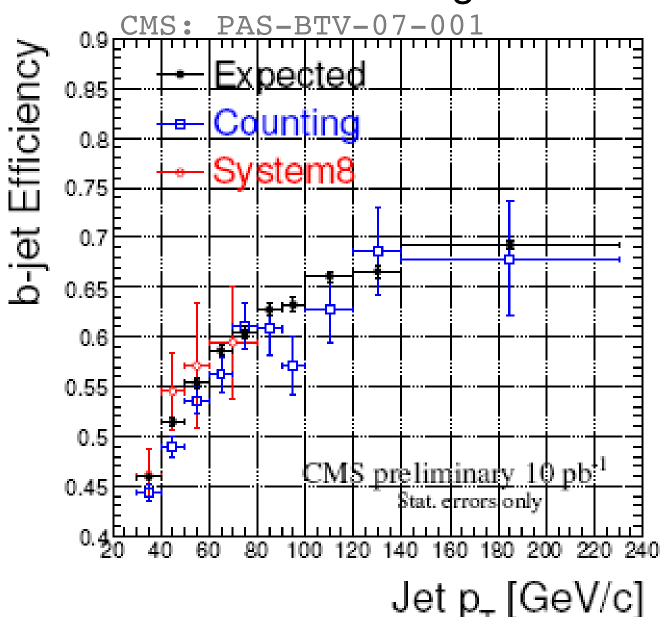
Efficiency: ~*40%*

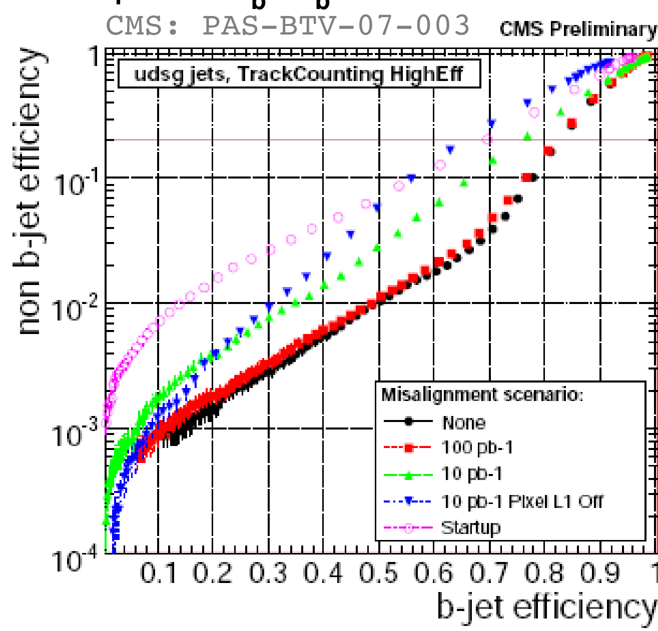
Fake rate: ~*2%*

b tagging performance

- b-tagging efficiency can be measured directly from data
  - **relative p_T** of μ in jets **extracts $N_{b\text{-jets}}$** in sample
  - **b-tagging** the **away jet extracts $N_{b\text{-jets}}$(tagged)**
- **Uncertainties** dominated by:
  - Beam spot, **tracker alignment**, p_T^{rel} template + statistics of (p_T ,η) bins
  - With current alignment scenario expect **$\Delta\varepsilon_b$ / ε_b ~ 10%-15%** at the startup of CMS







<u>Efficiency</u>: ε_b ~ 70%

<u>Fake rate</u>: ε_q ~ 10% **(3%)**

@ startup (ideal conditions)

Event yields for the dilepton (eμ) channel

- **Selection efficiencies** for $t\ \bar{t}$ dilepton channel for L = 250pb^{-1}

Selection	Total	$t\bar{t}$ dileptons
Triggered	$(426 \pm 1) \cdot 10^6$	6251 ± 25
$\geq$ 2 leptons (>20 GeV/c)	$(204.7 \pm 0.5) \cdot 10^3$	2595 ± 16
1 e and 1 μ	2531 ± 32	1344 ± 12
$\geq$ 2 jets (>30 GeV)	1041 ± 12	914 ± 10
$\not{E}_T \geq 30$ GeV	884 ± 10	789 ± 9
Opp. sign leptons	867 ± 10	787 ± 9

CMS: PAS-TOP-09-001

- Event yields for background **SM processes** (L=250pb^{-1})

Selection	Single top	other $t\bar{t}$	Di-boson	W/Z+jets	VQQ	QCD
Triggered	27563 ± 422	42303 ± 77	3400 ± 13	$(4338 \pm 2) \cdot 10^3$	38046 ± 64	$(422 \pm 1) \cdot 10^6$
$\geq$ 2 leptons (>20 GeV/c)	225 ± 10	66 ± 3	620 ± 5	$(193 \pm 0.4) \cdot 10^3$	8170 ± 26	401 ± 183
1 e and 1 μ	122 ± 8	34 ± 2	207 ± 2	749 ± 24	49 ± 2	26 ± 15
$\geq$ 2 jets (>30 GeV)	38 ± 4	27 ± 2	14 ± 1	45 ± 6	2.0 ± 0.4	-
$\not{E}_T \geq 30$ GeV	29 ± 1	23 ± 2	11.6 ± 0.5	30 ± 5	0.7 ± 0.2	-
Opp. sign leptons	29 ± 1	14 ± 1	10.5 ± 0.5	26 ± 5	0.7 ± 0.2	-

CMS: PAS-TOP-09-001