Single top in CMS: an early data strategy

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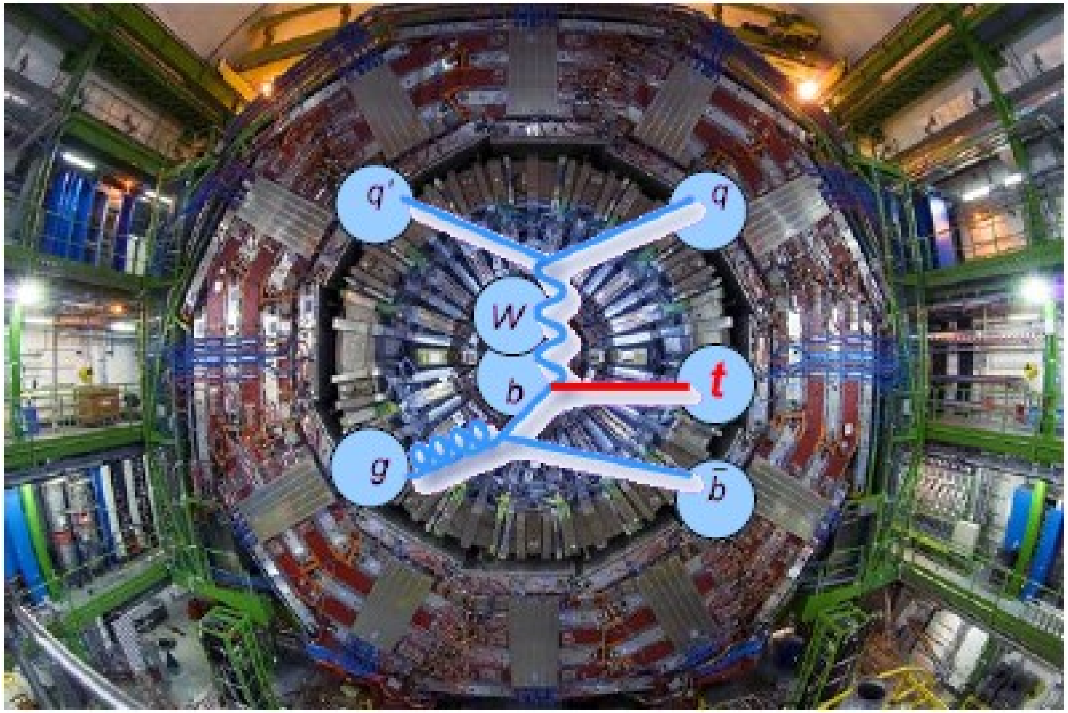


Mostly based on **CMS-PAS-TOP-09-005**,
"Prospects for a measurement of the single top t-channel cross section in the muon channel, with the first 200 pb^{-1} of CMS data at 10 TeV"

Outline

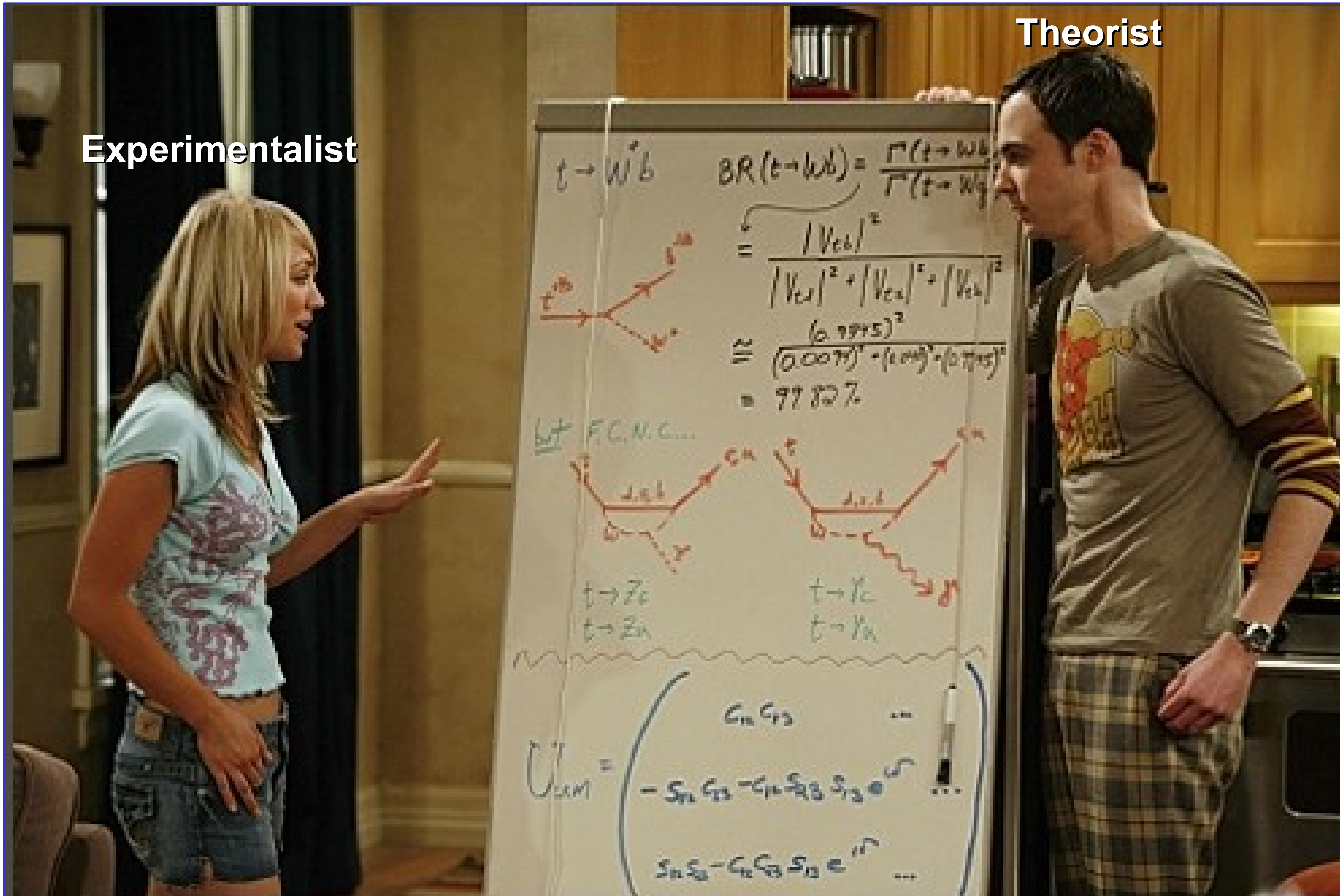
- **Theory**
  - Signal definition
  - Single top and CKM
- **Experimental setup**
  - CMS status
  - LHC news
- **Single top analysis**
  - Event selection
  - Estimating QCD *in situ*
  - Signal extraction
  - Prospects at 7 TeV

Acknowledgements:
Julia Bauer, Jeannine Wagner-Kuhr, Dmitri Konstantinov, Fabio Maltoni, Rikkert Frederix

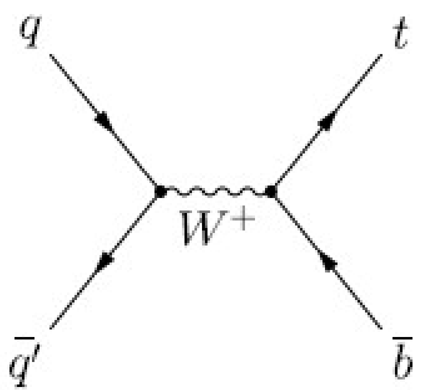
Main references of this talk:

- CMS-PAS-TOP-09-005
  - http://cms-physics.web.cern.ch/cms-physics/public/TOP-09-005-pas.pdf
- *"Is $V_{tb} \approx 1$?"*, arXiv:hep-ph/0607115, Eur.Phys.J. C49 (2007) 791

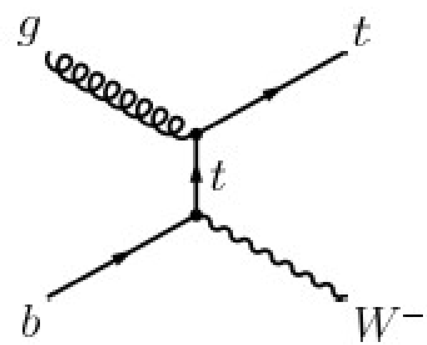
Part I: Theory



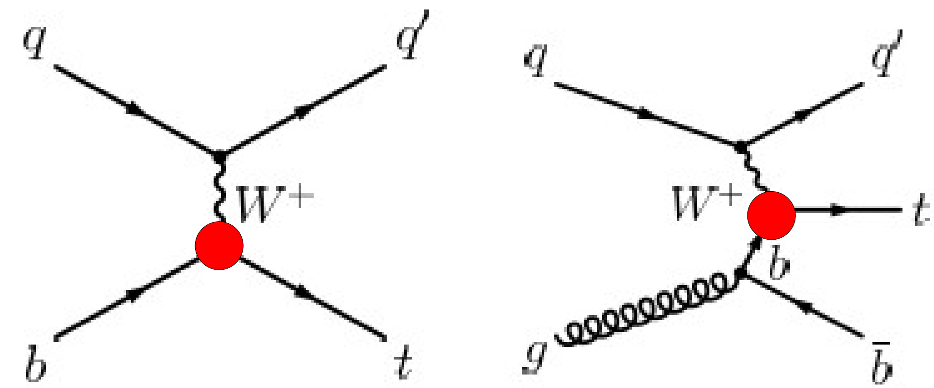
What we talk about, when we talk about single top



s channel
(4 pb @ 7 TeV)



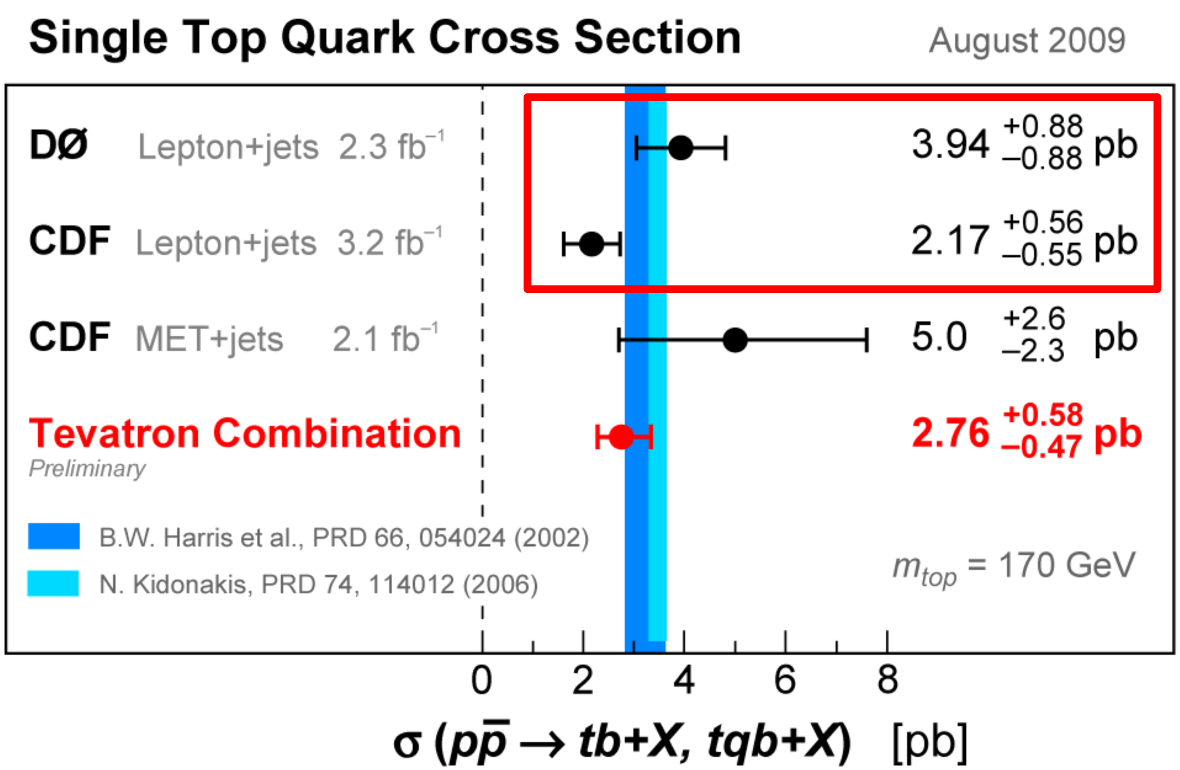
tW
(11 pb @ 7 TeV)

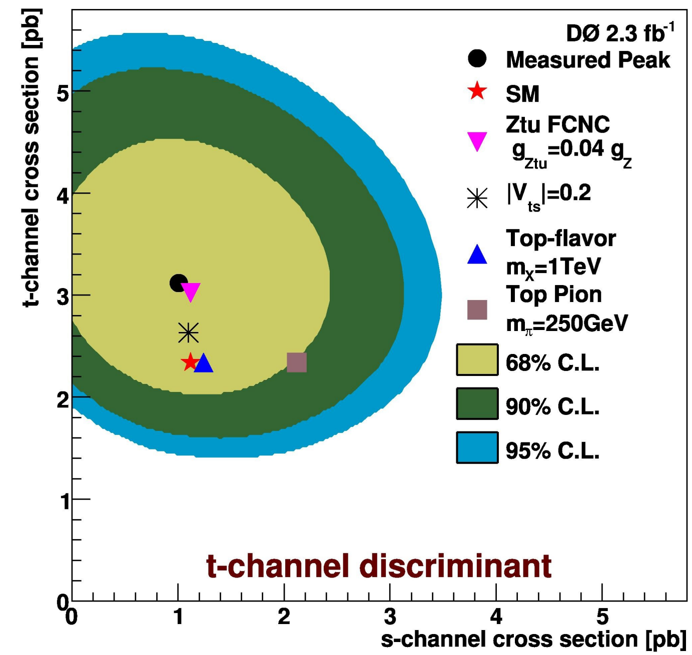


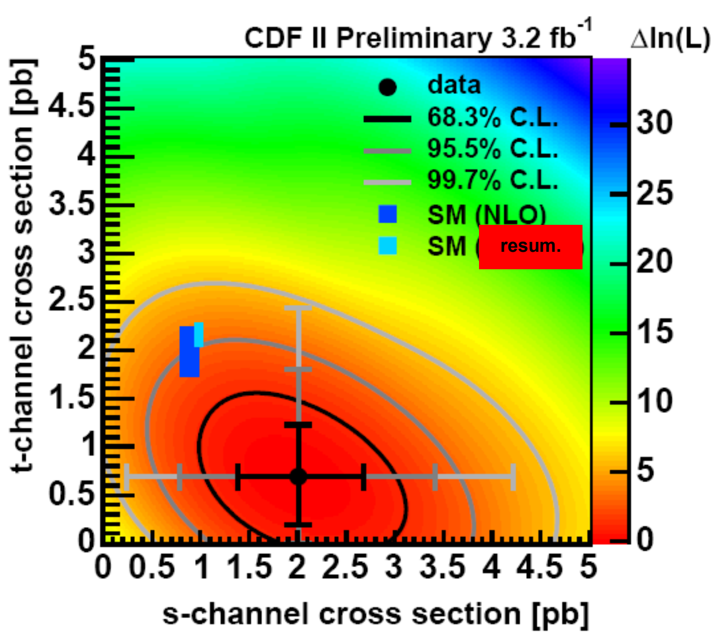
t channel
(65 pb @ 7 TeV)

- Tevatron: recent 5σ observation in s+t channels (~1+2 pb)
  - tW negligible at 1.96 TeV
- LHC, 7 TeV: t channel dominant
- s channel & tW are treated as backgrounds in this talk
- Goals (increasing stat & E_{cm}):
  - **Confirmation of Tevatron**
  - Cross section @ 7 and 14 TeV
  - Competitive constraint on $|V_{tb}|$ ⇒ limit on 4th quark family
  - FCNC, charged resonances, etc.; the three channels offer complementarity

State of the art







The CKM matrix

$$\begin{bmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{bmatrix} .$$

- It is **unitary**, meaning that:
  - Any two rows or columns are orthogonal; verified in K and B exps
  - The scalar product of any row and any column by its own complex conjugate is **1**; if less $\Rightarrow$ evidence for new quarks
- Very precise direct measurements of the 1st and 2nd rows:
  - $|V_{ud}|$: from $0^+ \to 0^+$ β decays
  - $|V_{us}|$: mostly from semileptonic K decays
  - $|V_{ci}|$ (i=d,s): from D, D_s decays; $|V_{cd}|$ also from $\nu d \to \mu^- c$
  - $|V_{ib}|$ (i=u,c): from B decays

What do we know about the 3rd row

- First two rows + Standard Model + 3x3 unitarity ⇒

$$|V_{td}| \simeq 0.0069 - 0.0088$$
$$|V_{ts}| \simeq 0.0401 - 0.0418$$
$$|V_{tb}| \simeq 0.9990 - 0.9992$$

(at 2σ level)

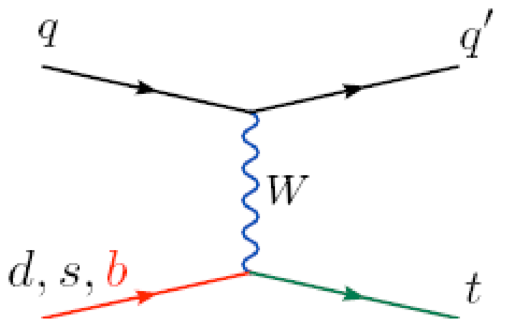
- Measurements of ΔM_{Bs} and ΔM_{Bd} constrain $|V_{td}/V_{ts}|$
- Measuring R measures $|V_{tb}|$ only if 3x3 unitarity is assumed

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

Popular simplifying assumption: $|V_{ti}| \ll |V_{tb}|$ ($i=d,s$) even if a 4th family exists

but D0 limit R> 0.79 only implies $|V_{tb}| > 1.9\sqrt{|V_{td}|^2+|V_{ts}|^2}$

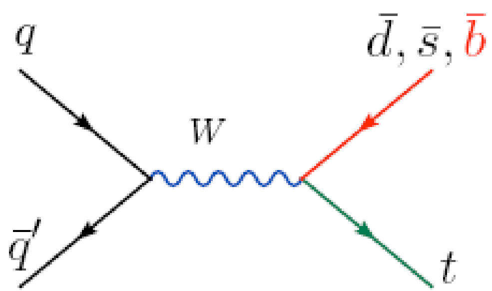
Direct constraints on $|V_{ti}|$, Tevatron



$$\sim |V_{td}|^2 \sigma_d^{\text{t-ch}} + |V_{ts}|^2 \sigma_s^{\text{t-ch}} + |V_{tb}|^2 \sigma_b^{\text{t-ch}}$$

Enhancement due to large *d* and *s* densities

(By the way: for the same reason, this is a good place to look for FCNC (*u* density))



$$\sim (|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2)\sigma^{\text{s-ch}}$$

Signal becomes similar to t-channel (only 1 *b*-jet)

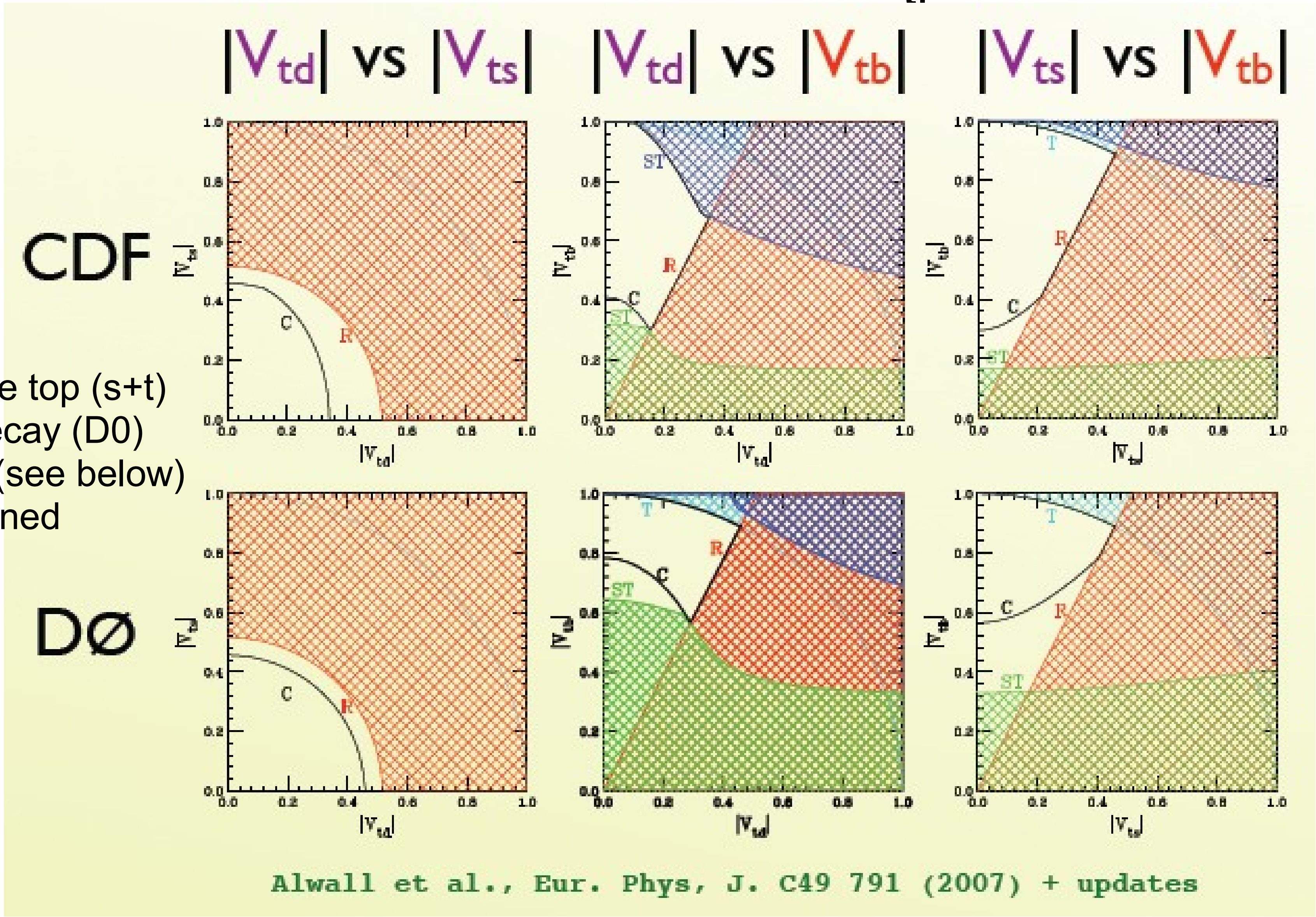
Very simplified meta-analysis of Tevatron results (ignoring differences in kinematics/topology – we would need access to the ntuples to do better):

$$\sigma_{1b\text{-tag}} = R\left\{\sum_{i=b,s,d} |V_{ti}|^2 \sigma_i^{\mathrm{t-ch}} + 2(|V_{td}|^2 + |V_{ts}|^2)\sigma^{\mathrm{s-ch}}\right\}$$

$$\sigma_{2b\text{-tag}} = R\,|V_{tb}|^2\,\sigma^{\mathrm{s-ch}}$$

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

Direct constraints on $|V_{ti}|$, Tevatron



ST: single top (s+t)
R: top decay (D0)
T: trivial (see below)
C: combined

Simplifying assumption: no other new physics apart from new quarks
→ trivial constraint from Pythagoras' theorem

Direct constraints on $|V_{ti}|$, LHC

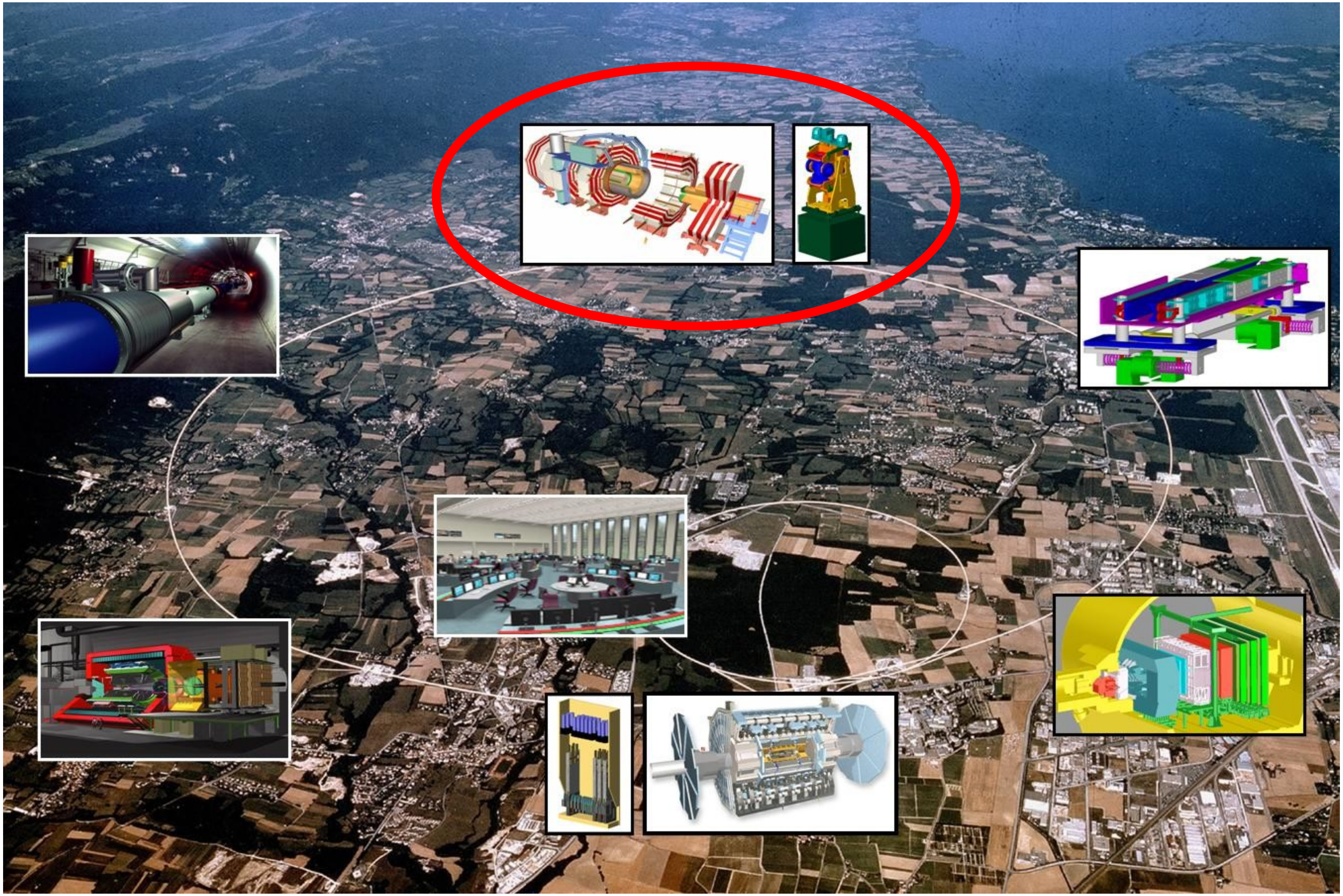
$$\sigma_{1b\text{-tag}} = R\left\{\sum_{i=b,s,d} |V_{ti}|^2 \sigma_i^{t-ch} + \cancel{2(|V_{td}|^2 + |V_{ts}|^2)\sigma^{s-ch}}\right\}$$

$$\cancel{\sigma_{2b\text{-tag}} = R\,|V_{tb}|^2\,\sigma^{s-ch}}$$

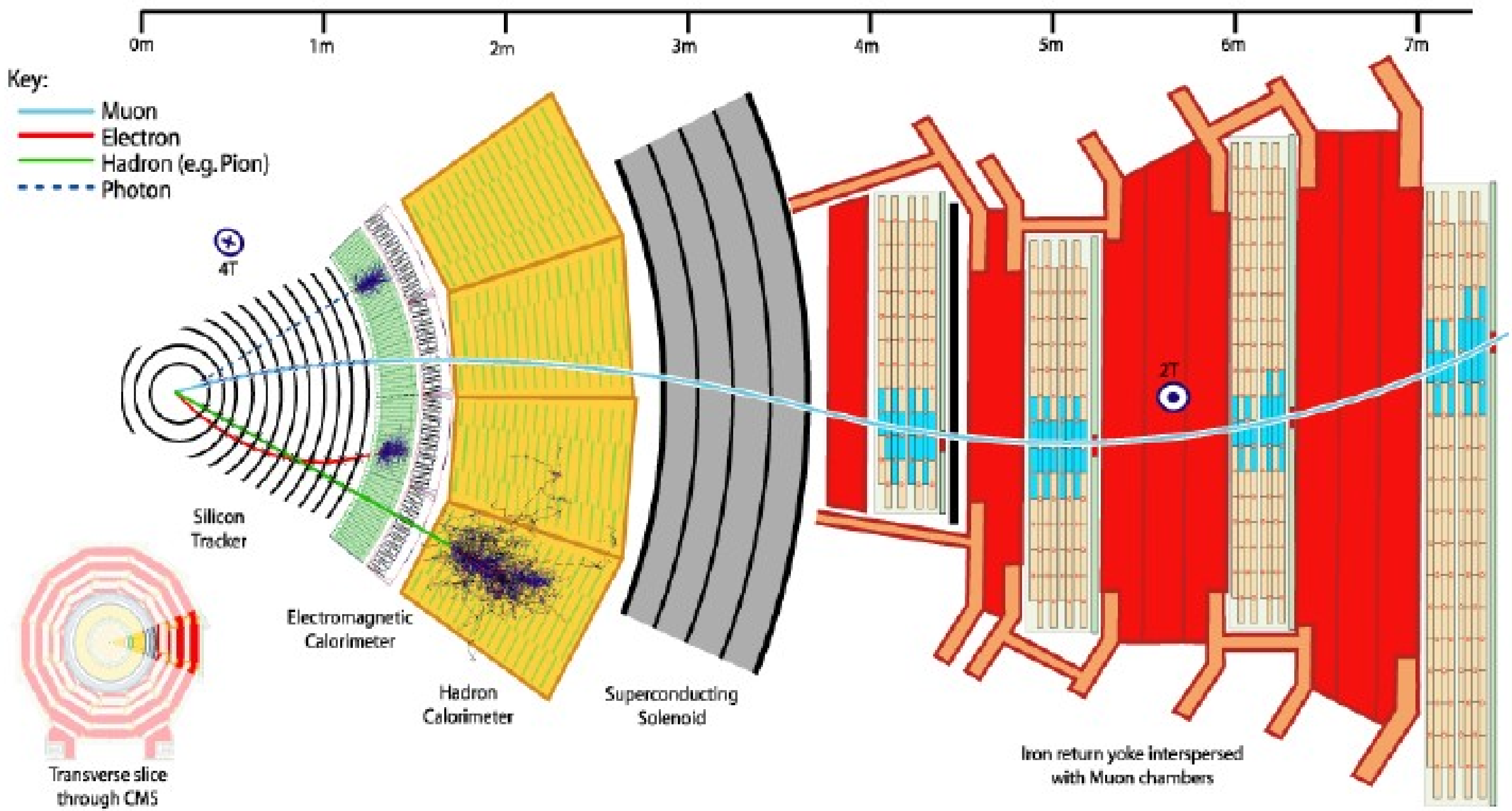
$$R = \frac{\Gamma(t \to Wb)}{\Gamma(t \to Wq(=d,s,b))} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$

- At LHC, $\sigma^{s\text{-}ch} << \sigma^{t\text{-}ch}$
  - The 3rd channel, tW, is non negligible now; but it's “1b” too
- 2 measurements (σ: single top, and R: from $t\bar{t}$) for 3 unknowns: top-only constraint of the entire 3rd row impossible
  - but we can use $|V_{td}/V_{ts}|$ from ΔM_{Bd} and ΔM_{Bs}

Part II: Experimental setup



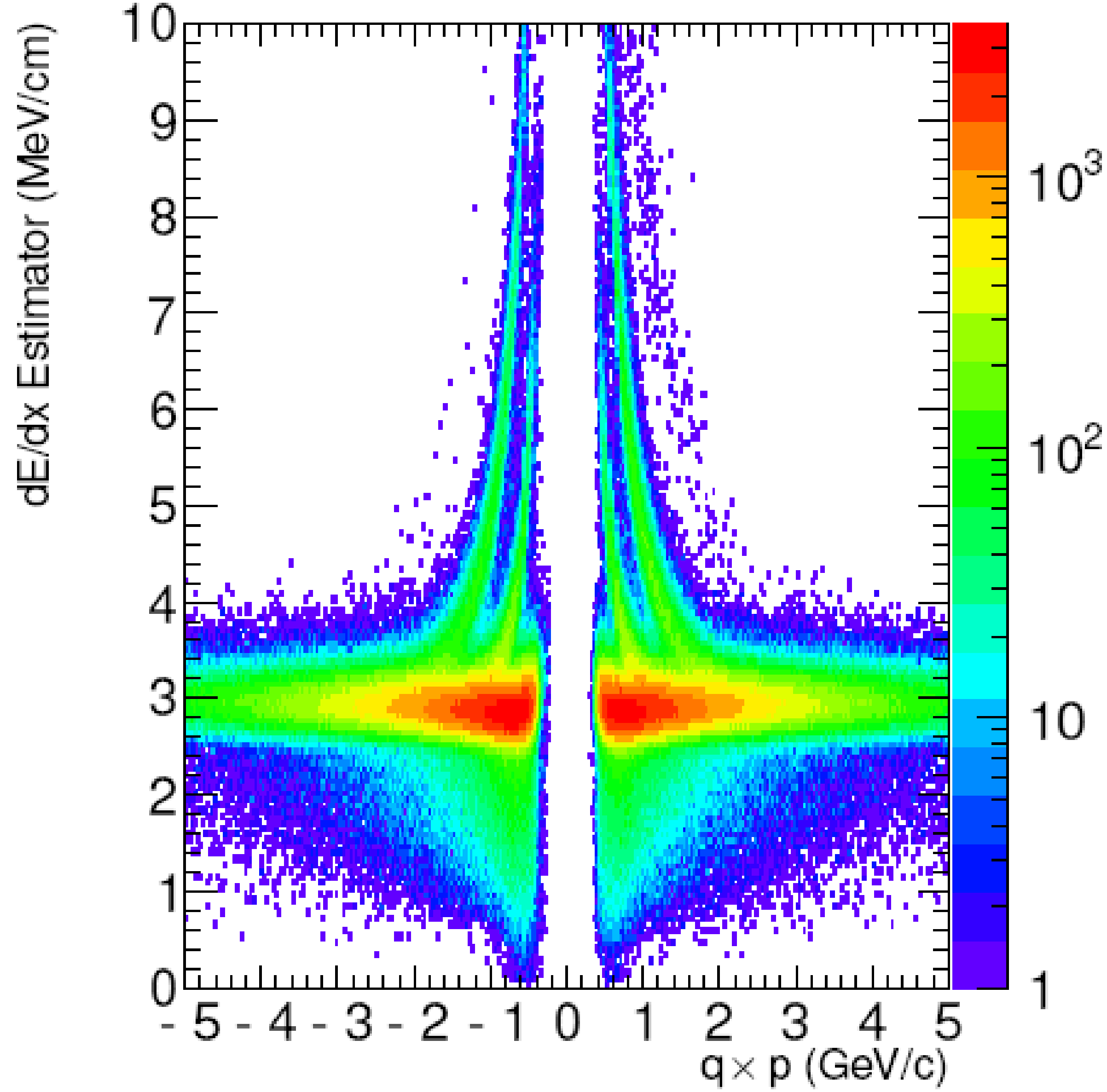
CMS detector: general concept



In→out: Si Pixels, Si Strips, EM calorimeter (PbWO), Hadron calorimeter (brass+scint.), Solenoid (3.8 T), Muon system (RPCs, drift tubes in barrel, CSCs in endcaps)

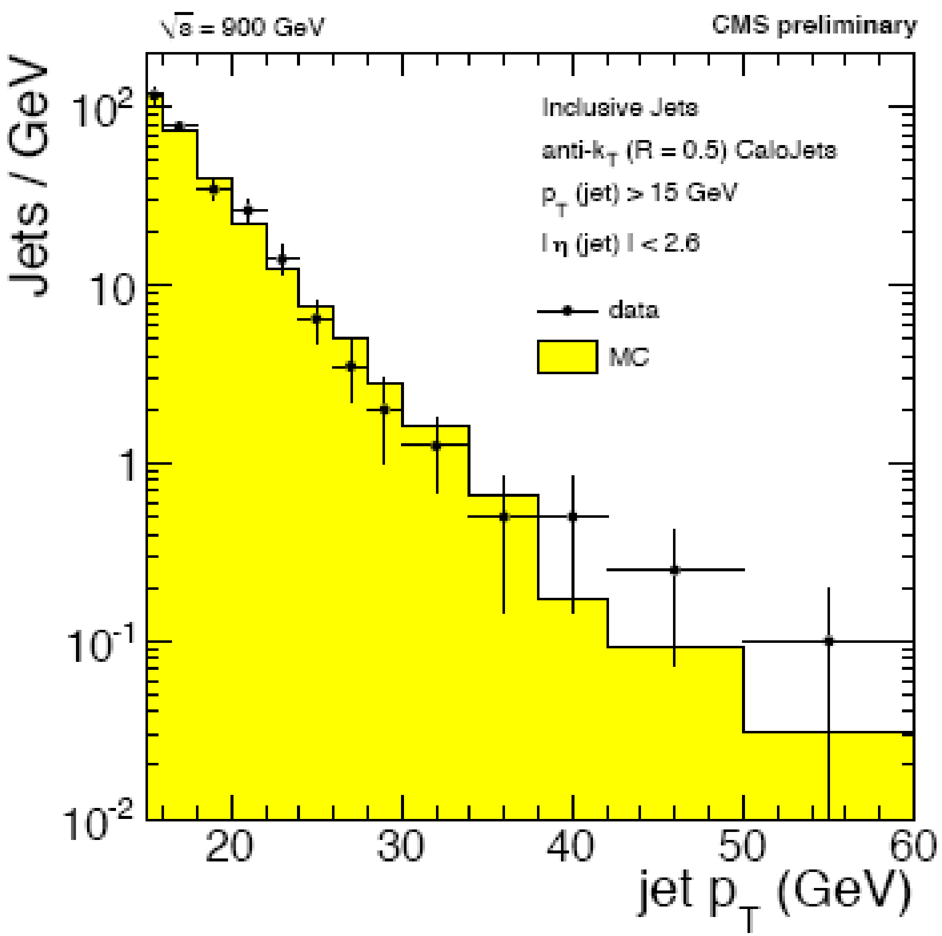
Neutrinos: no interaction → momentum imbalance → MET

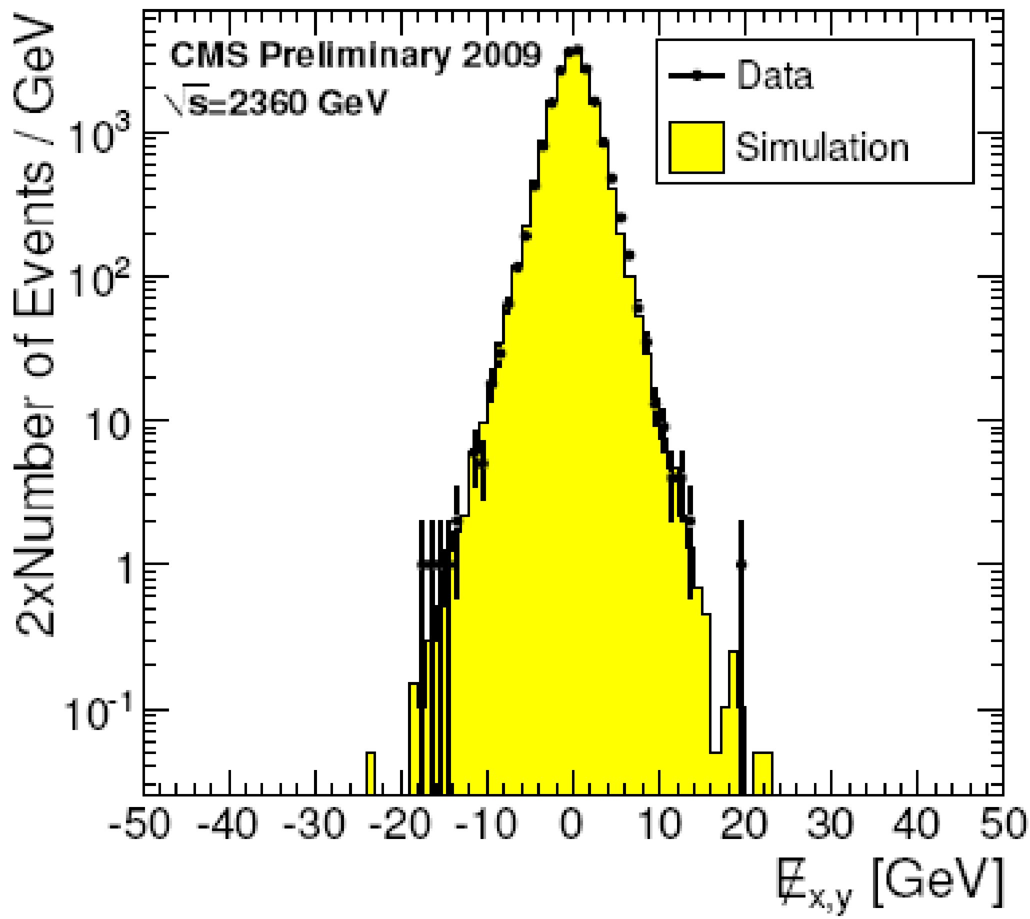
Readiness of CMS: 0.9 TeV data



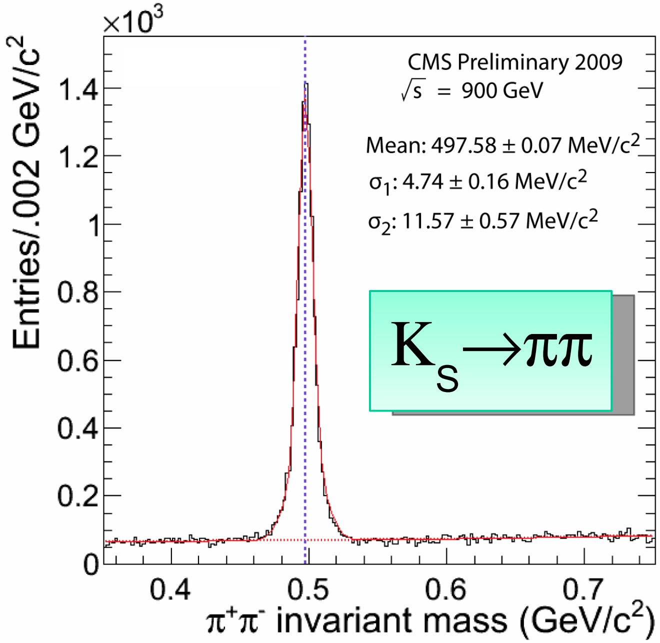
Readiness of CMS: 0.9 and 2.36 TeV data

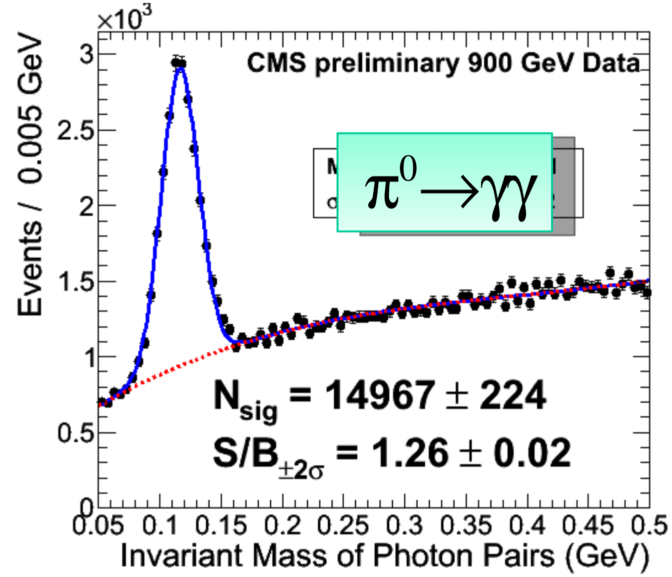
PAS JME-10-001
PAS JME-10-002

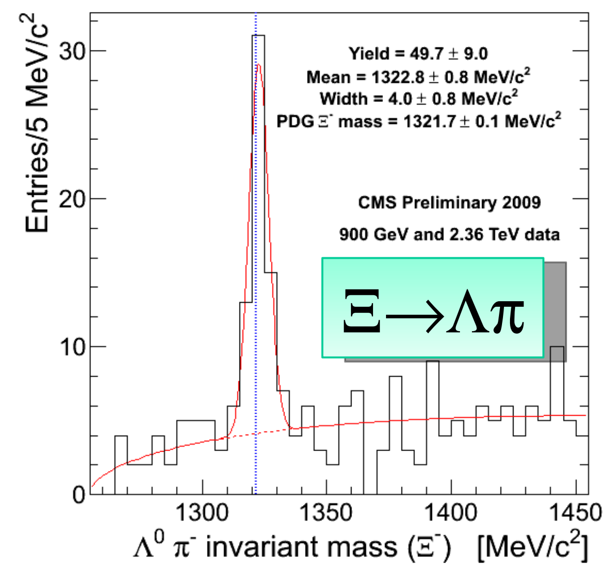


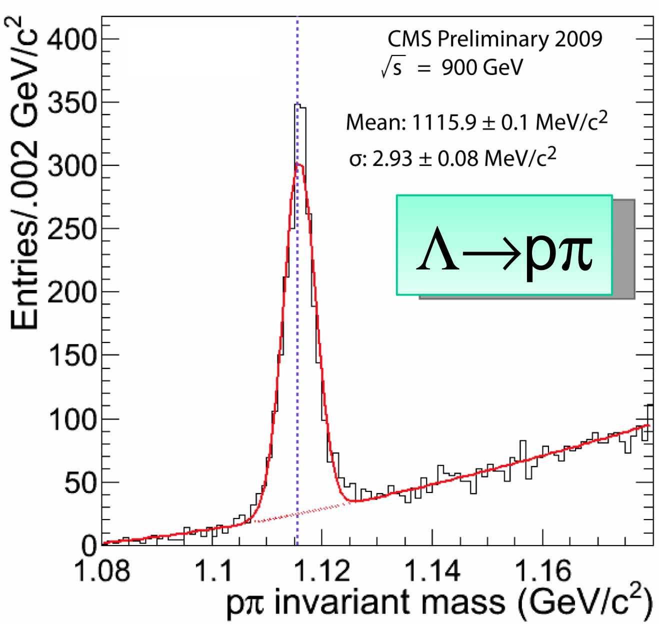


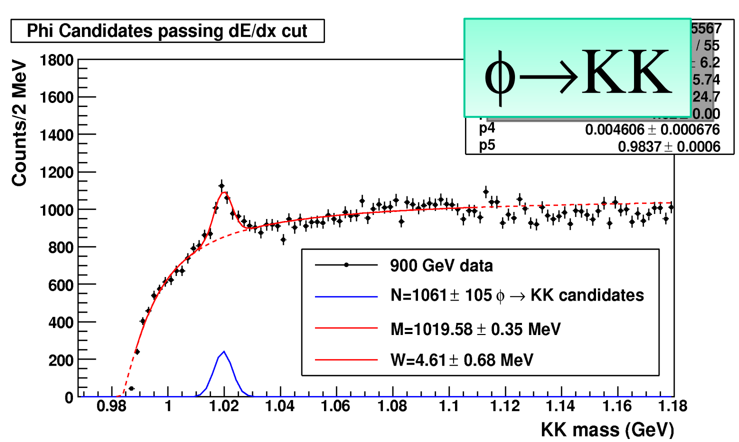
With the 2009 data: like doing physics in the 50's, with fast-forward











Standard Candles

Peak positions agree with PDG; resolutions agree with MC

⇒

Impressive validation of alignment and calibration

LHC plans for 2010-2011

Mail by Steve Myers to all CERN, Feb.3rd 2010:

(...) The most important decision we reached last week is to run the LHC for **18 to 24 months** at a collision energy of **7 TeV (3.5 TeV per beam)**. After that, we'll go into a long shutdown in which we'll do all the necessary work to allow us to reach the LHC's design collision energy of **14 TeV for the next run**. This means that when beams go back into the LHC later this month, we'll be entering the longest phase of accelerator operation in CERN's history, scheduled to take us into summer or autumn 2011.

Note: all the MC prospects that I'm going to show assumed the old schedule of 200 pb^{-1} at 10 TeV; MC at 7 TeV is already available

Scenario A: sort splices out in one go

Mike Lamont

- Two years at 3.5 TeV
- 2010: should peak at 10^{32} and yield up to 0.5 fb^{-1}
- 2011: ~1 fb^{-1} at 3.5 TeV
- 2012: splice consolidation (and cryo collimator prep.)
- 2013: 6.5 TeV - 25% nominal intensity
- 2014: 7 TeV – 50% nominal intensity

Aggressive

Year	Months	energy	beta	ib	nb	Peak Lumi	Lumi per month	Int Lumi Year	Int Lumi Cul
2010	8	3.5	2.5	7 e10	720	1.2 e32	-	0.2	0.2
2011	8	3.5	2.5	7 e10	720	1.2 e32	0.1	0.8	1.0
2012									
2013	6	6.5	1	1.1 e11	720	1.4 e33	1.1	7	8
2014	7	7	1	1.1 e11	1404	3.0 e33	2.3	16	24

Previous schedule: ~50/pb @ 7 TeV, then 200-300/pb @ 10-8 TeV (2010-2011), then pause 1 year

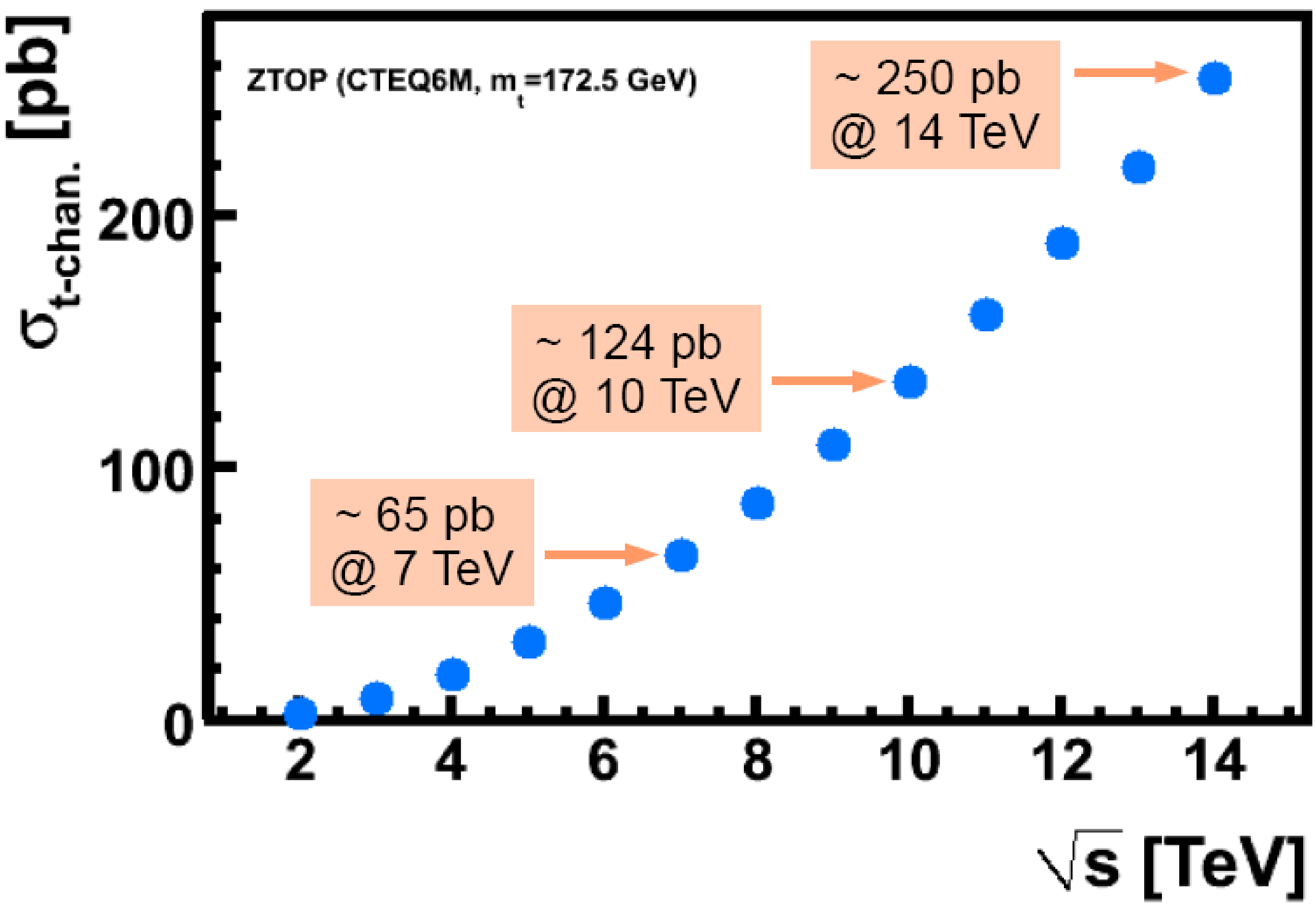
Independent estimate

Courtesy of a rather pessimistic but perhaps more realistic Massi Ferro-Luzzi

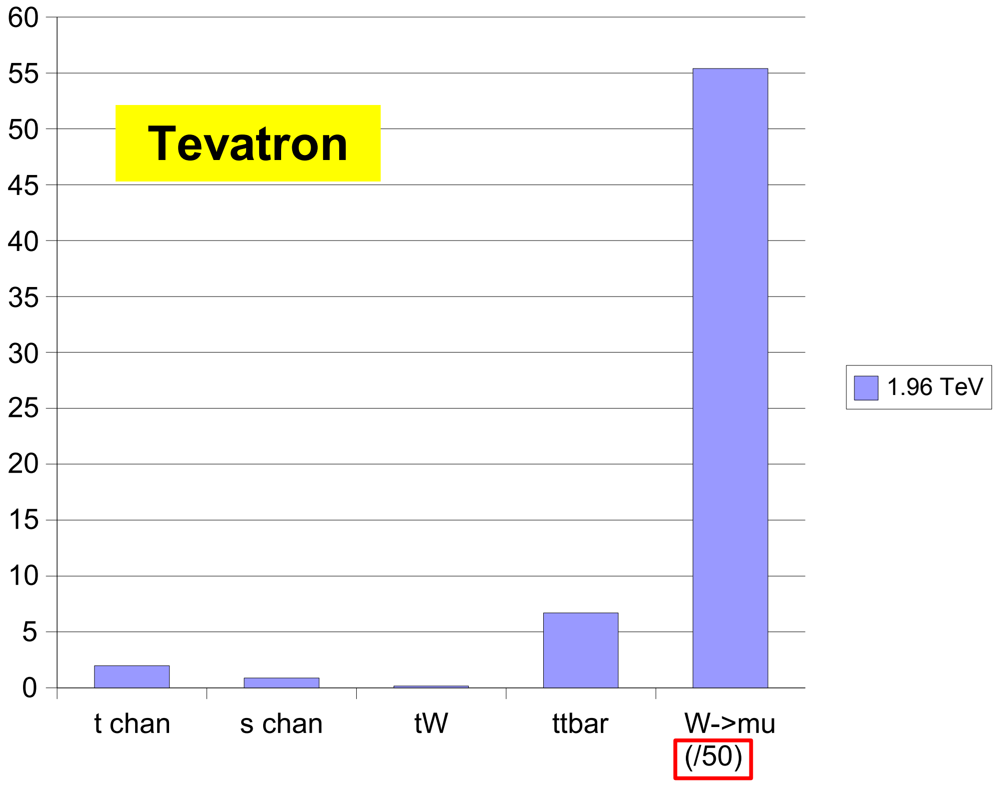
Year	Months	energy	beta	ib	nb	Peak Lumi	Lumi per month	Int Lumi Year	Int Lumi Cul
2010	6	3.5	2.5	7 e10	720	1.0 e32	-	0.1	0.1
2011	9	3.5	2.5	9 e10	720	2.0 e32	0.1	1	1.1
2012									
2013	6	6.5	1	9 e10	720	9 e32	0.45	2.7	3.8
2014	9	6.5	1	9 e10	1404	1.7 e33	0.6	5.3	9.1

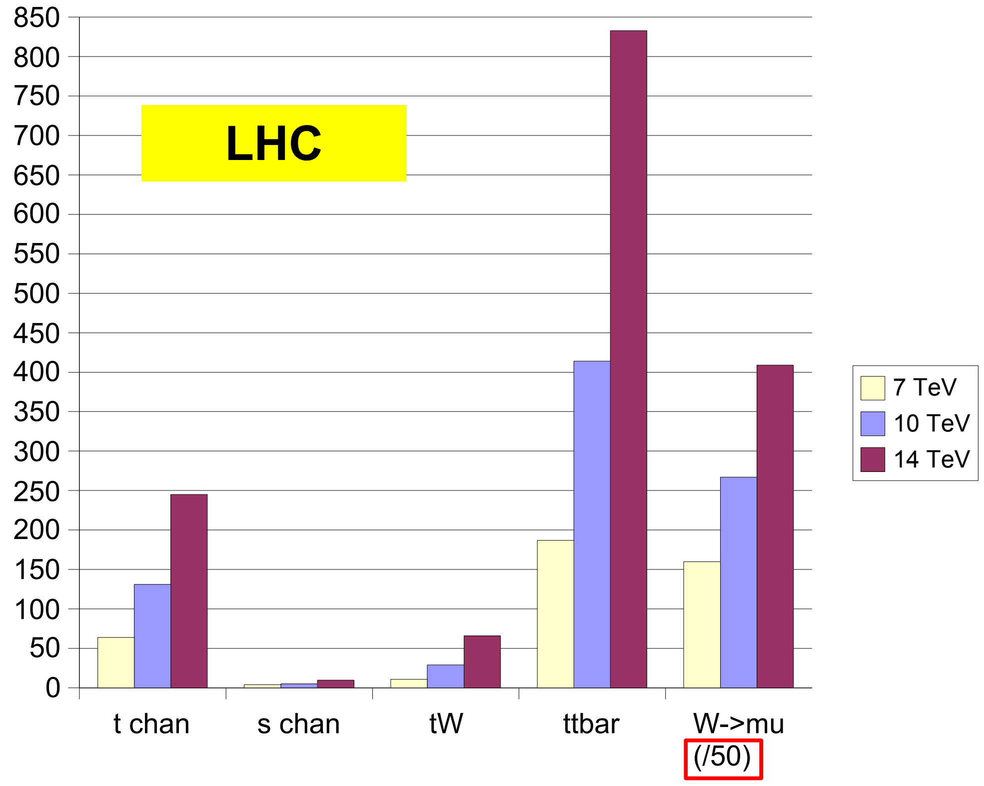
At least in the same ball park

Single top (t channel) cross section as a function of √s



Cross sections (pb):



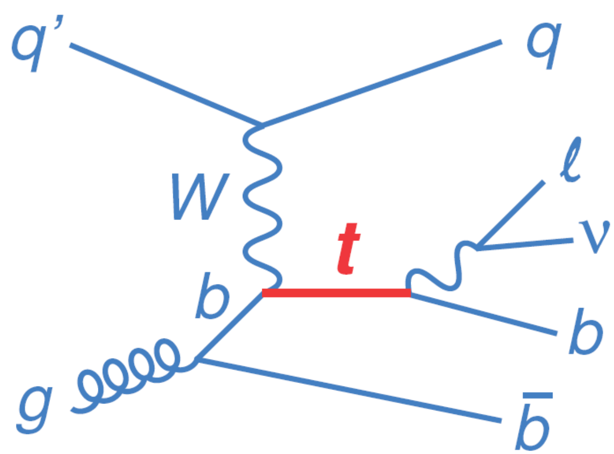


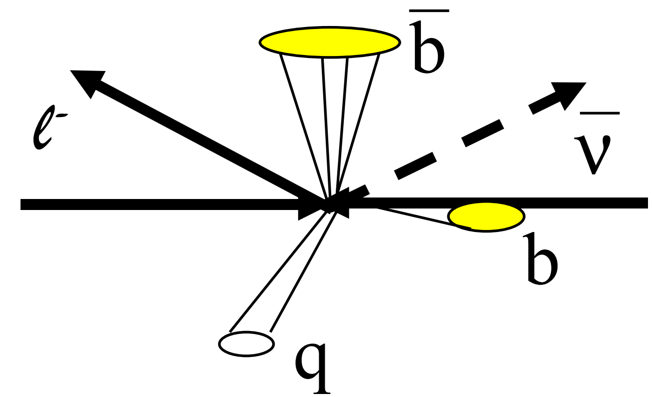
General rule: the heavier the final state, the steeper the cross section growth with E_{cm}

Part III: Single top search @ 10 TeV

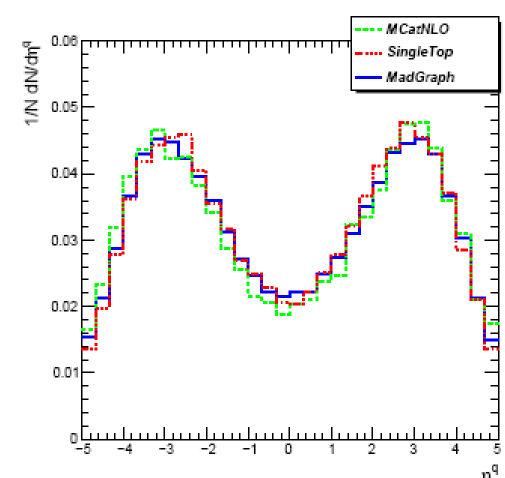
Hunts Needle in a Haystack

Event selection

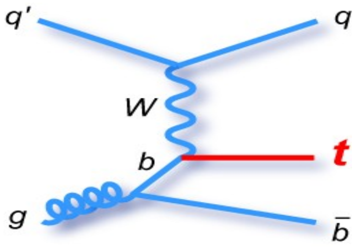




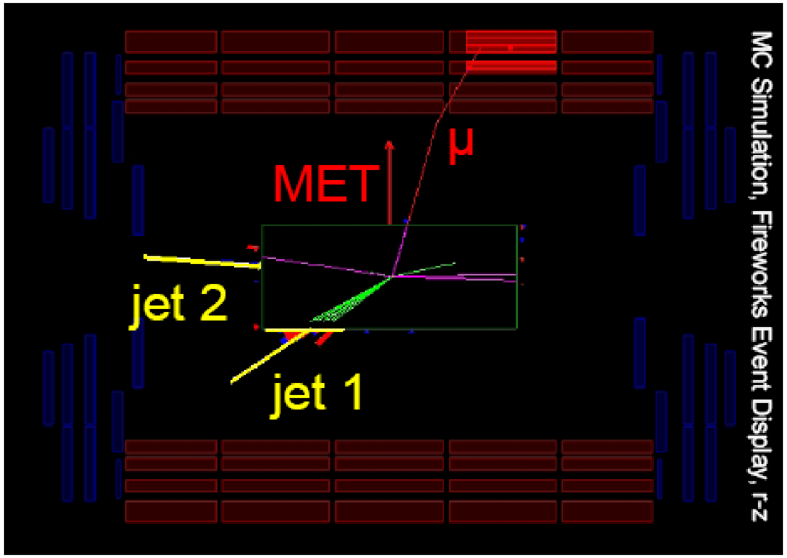
- Main features of t-channel events:
  - Real W from t ($m_t > m_W$)
    - decaying 1/9 of the times into μν
  - Central b jet from t
  - Light jet from recoil, rather forward
  - Additional b jet has a very soft p_T spectrum



Cuts overview

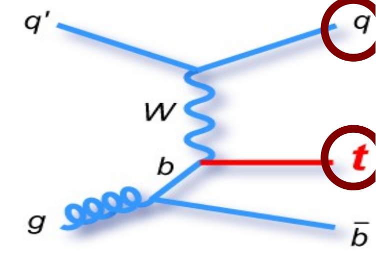


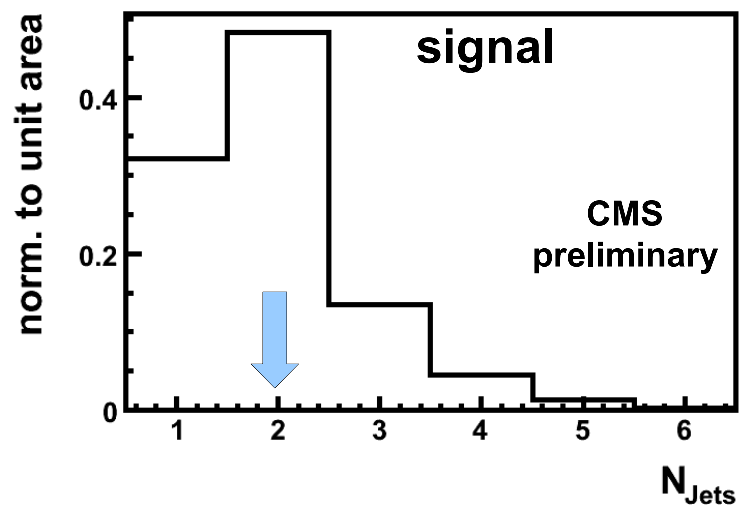
- **Single muon, di-lepton veto**
  - 1μ (p_T>20 GeV, |η|<2.1, plus some quality cuts)
  - 0e (p_T>20 GeV, |η|<2.4, plus tight identification cuts)
  - This muon is isolated
- **Two jets, far from the muon**
  - Iterative cone R=0.5 (not critical)
  - p_T>30 GeV, |η|<5
  - ΔR(μ,jets)>0.3 otherwise the event is discarded ("near-jet veto")

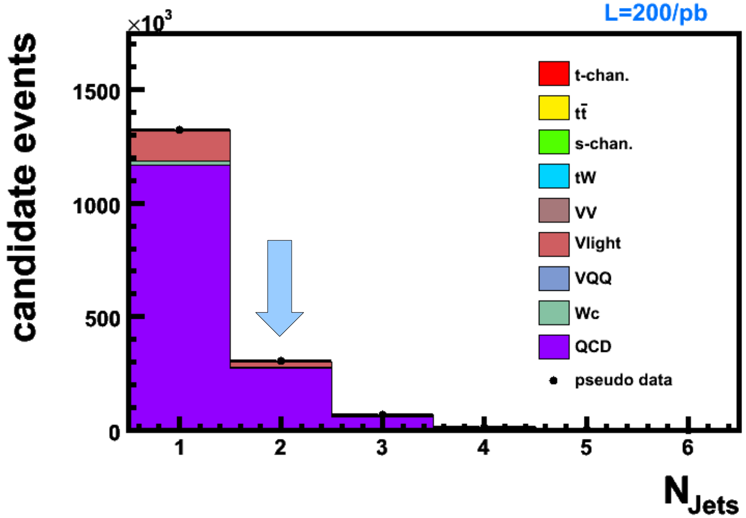


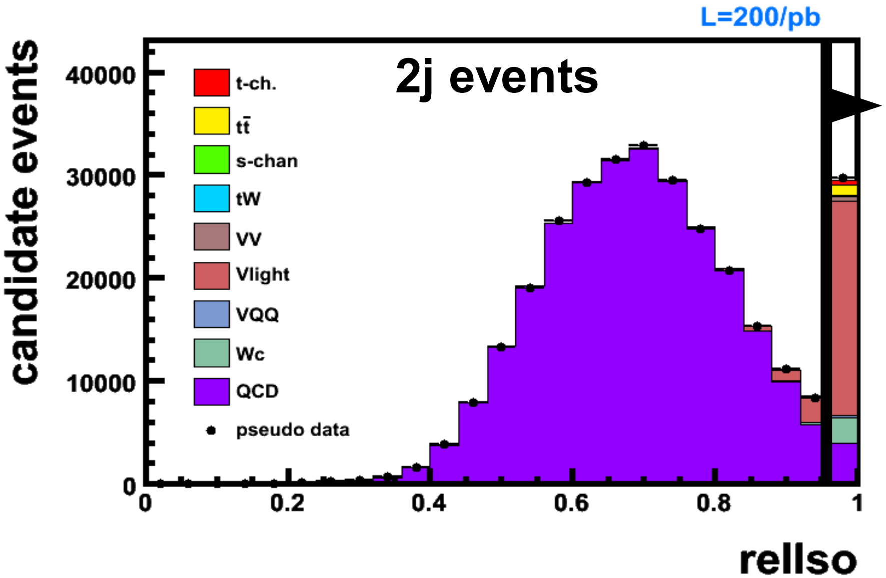
- **One b jet**
  - "Track counting" tagger
  - 1j passing a tight selection
  - 2nd jet: it must fail a loose selection
- **On-shell W boson (t→Wb)**
  - M_T>50 GeV

After lepton and jet counting (1μ, 0e, 2j), the sample is still QCD-dominated









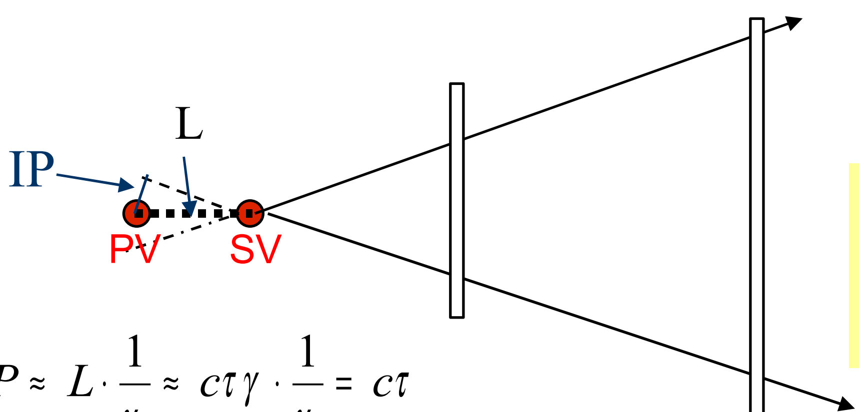
$$relIso = \frac{p_{T,\mu}}{p_{T,\mu} + tkIso + caloIso}$$

tkIso and caloIso are the sums of transverse momenta/energies in a cone (R<0.3) around the muon direction, in Tracker and Calos

After the isolation request, it is W-dominated

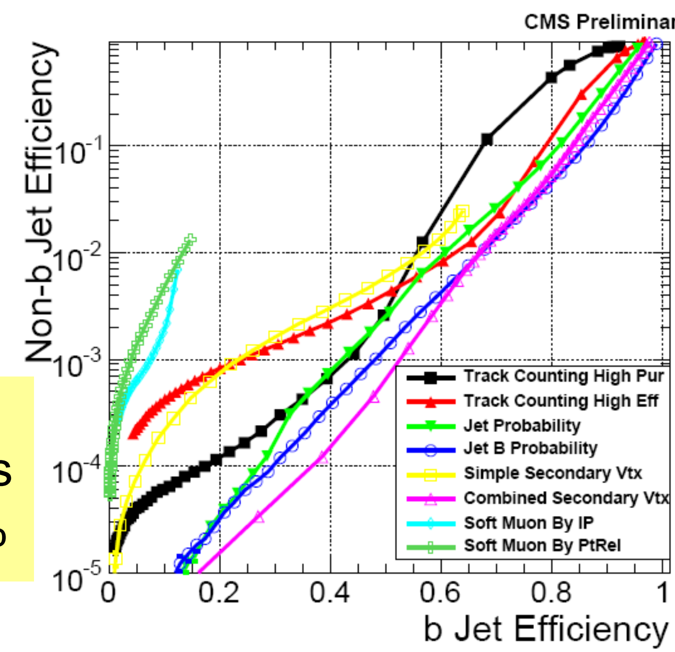
b tagging

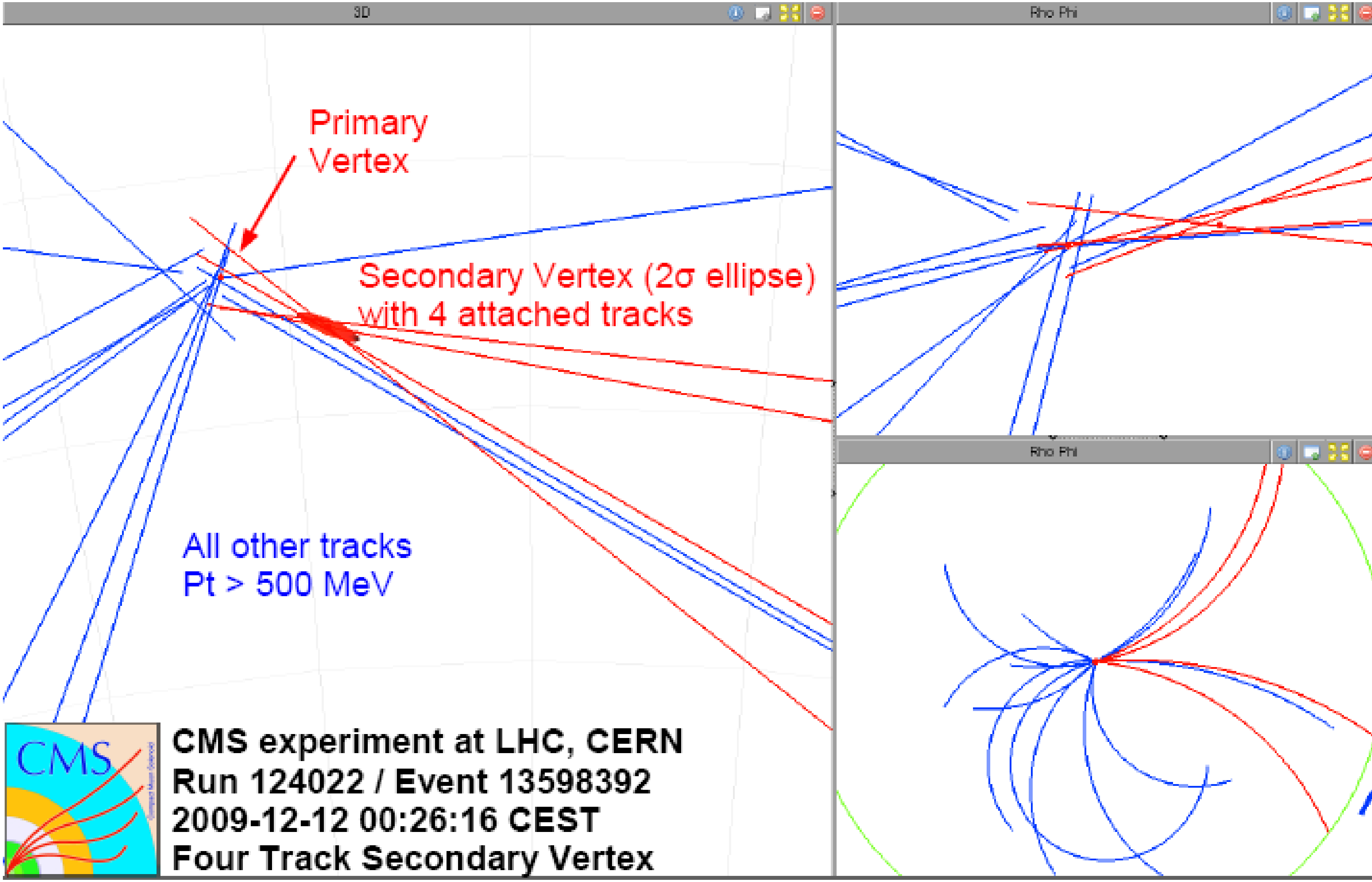
- Based on "soft" leptons
  - BR($b \rightarrow e/\mu + X$)~20%, but e/μ not isolated, therefore tougher to identify
- Based on Impact Parameter (IP)
  - "Track counting": require at least N tracks with IP/σ_{IP}>cut
  - Combination of the IP incompatibility with 0 of all the tracks in the jet
- Based on secondary vertex (SV) reconstruction
  - Explicit search for the b decay point



$$IP \approx L \cdot \frac{1}{\gamma} \approx c\tau\gamma \cdot \frac{1}{\gamma} = c\tau$$

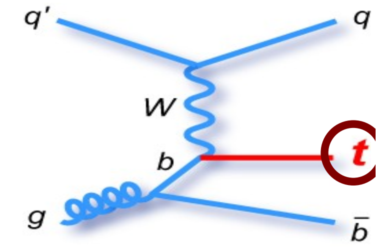
Requiring a rejection factor of 100 for light jets usually gives ε_b~50-70%

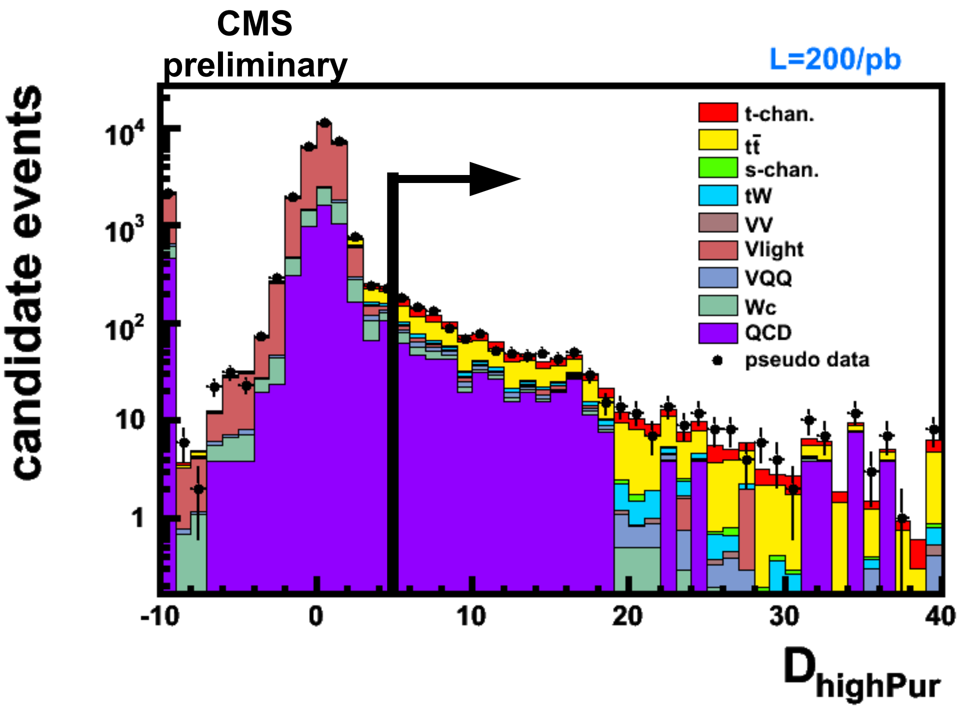




(this is not Monte Carlo)

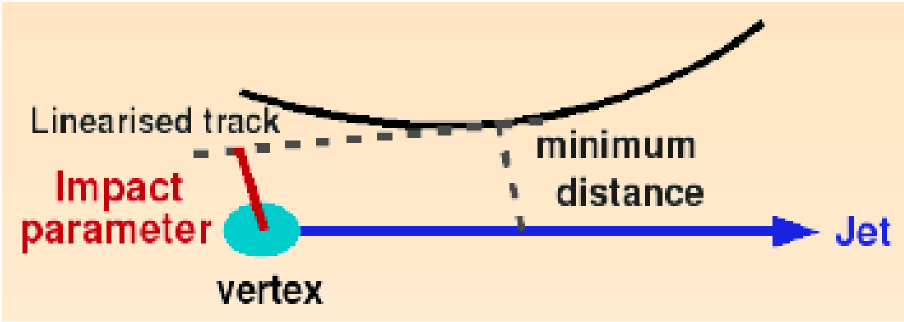
Getting rid of W+jets: tight b tagging



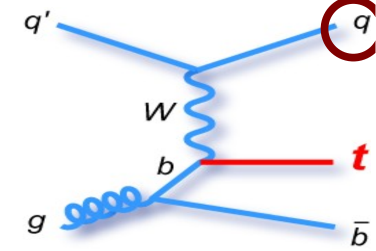


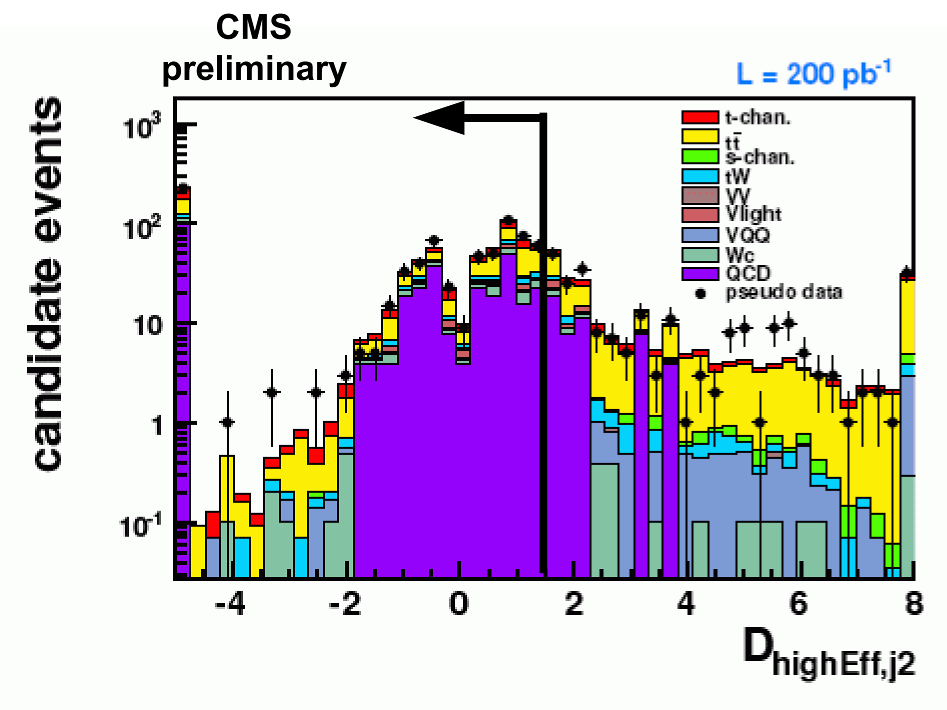
High-purity track-counting algorithm, i.e. 3rd track IP/σ_{IP} in the jet

We chose a “tight working point”, defined as to have a rejection factor of 1/1000 for light jets in di-jet events



Signal has 1b only, most bkgs 2b: veto on 2nd b-jet, <u>loose</u> b tagging



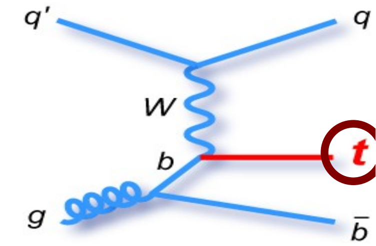


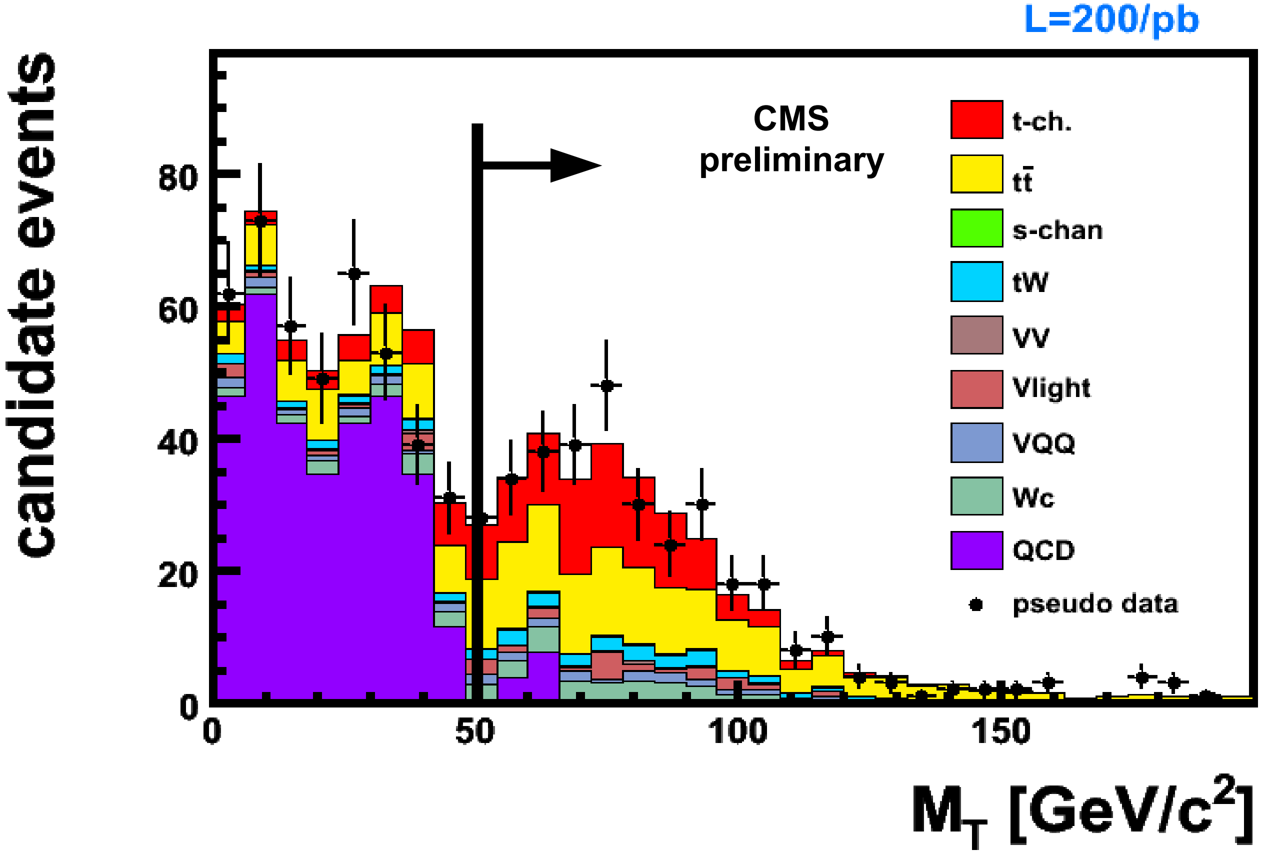
High-efficiency track-counting algorithm, i.e. 2rd track IP/σ_{IP} in the jet

We chose a "loose working point", defined as to have a rejection factor of 1/10 for light jets in di-jet events

Note: our choice of the "track-counting algo" was based on very conservative assumptions for the start-up misalignment (reasonable in June 2009).
Long cosmic data-taking in Summer 2009 ⇒ excellent alignment already in early data (see backup) ⇒ vertex-based algos will be our default choice

Invariant transverse mass (M_T): QCD has no Jacobian peak



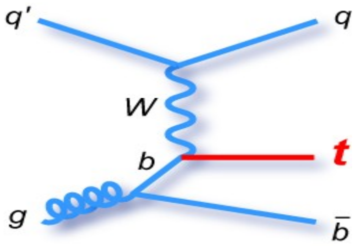


For an on-shell W boson:

$$M_T = \sqrt{(p_{T,\mu} + p_{T,\nu})^2 - (p_{x,\mu} + p_{x,\nu})^2 - (p_{y,\mu} + p_{y,\nu})^2}$$

$P_{x,\nu}$ and $P_{y,\nu}$ from the components of MET (corrected for muons and jets)

Expected yield in 200/pb @ 10 TeV



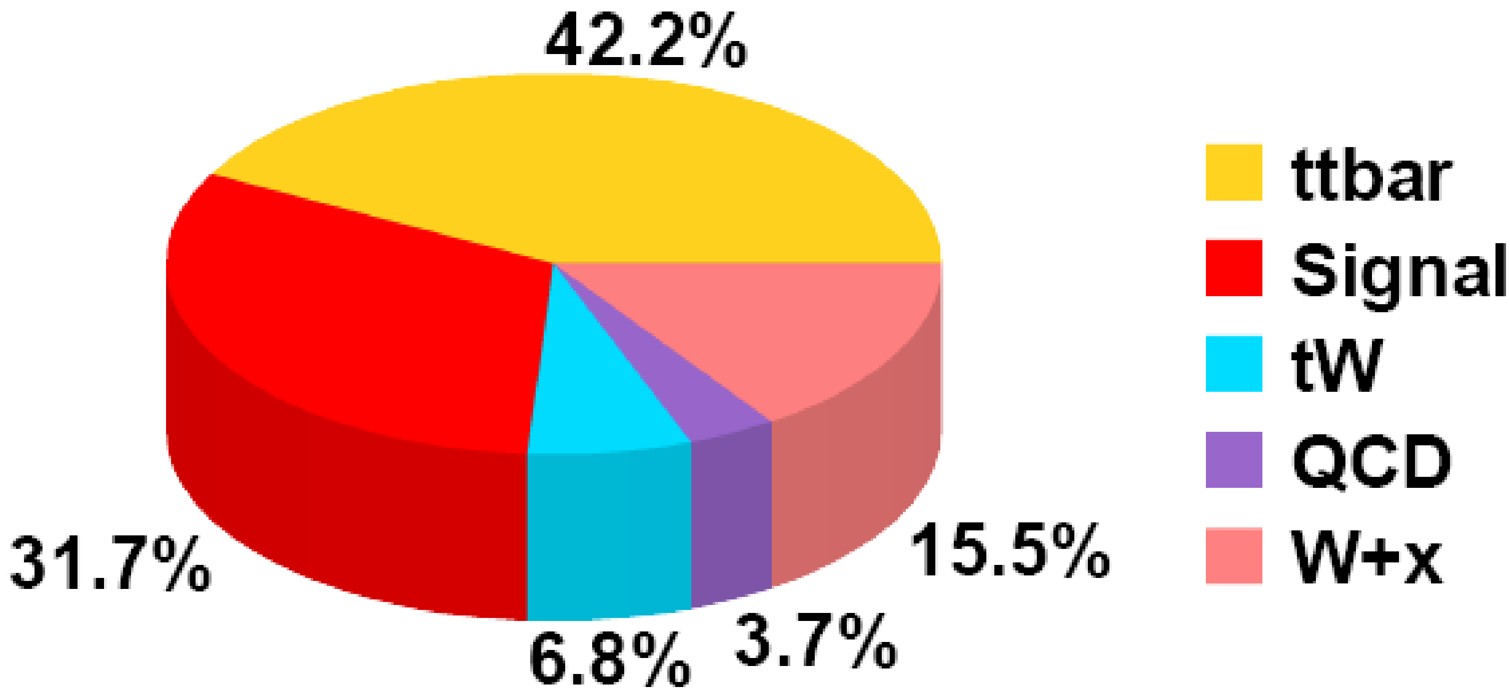
Process	$\sigma \times$ BR[pb]	L $[fb^{-1}]$	N_{evt} in 200 pb^{-1}
single top, t channel ($W \to l\nu, l = e, \mu, \tau$)	42.9 (NLO)	6.6	102±1.8
single top, s channel ($W \to l\nu, l = e, \mu, \tau$)	1.6 (NLO)	7.5	1.8±0.2
single top, tW	29 (NLO)	5.8	22.3± 0.9
$t\bar{t}$	414 (NLO+NLL)	2.2	136.0±3.5
QCD multi-jet (μ-enriched)	121675(LO)	0.05	12±6.7
Wc ($W \to l\nu, l = e, \mu, \tau$)	1 490 (LO)	2.0	29±1.7
$Wb\bar{b}$ ($W \to l\nu, l = e, \mu, \tau$)	54.2 (LO)	2.9	8.0±0.7
$Wc\bar{c}$ ($W \to l\nu, l = e, \mu, \tau$)	118.8 (LO)	4.5	1.2±0.2
$W+$ light partons ($W \to l\nu, l = e, \mu, \tau$)	40 000 (LO)	0.24	12±2.6
$Zb\bar{b}$ ($Z \to ll, l = e, \mu, \tau$)	44.4 (LO)	3.5	2.7±0.4
$Zc\bar{c}$ ($Z \to ll, l = e, \mu, \tau$)	71.7 (LO)	5.0	0.2±0.1
$Z+$ light partons ($Z \to ll, l = e, \mu, \tau$)	3 700 (LO)	0.33	2±1.2
WW	74 (LO)	2.8	0.9±0.3
WZ	32 (LO)	7.4	1.2±0.2
ZZ	10.5 (LO)	19.0	0.17±0.04
Total Background			229±8.4

S/B=0.45
S/√B=6.7
S/√S+B=5.6

Not bad, but a <u>counting experiment</u> requires a very good level of knowledge of B abundance.

First data in a new energy regime: must minimize assumptions about B

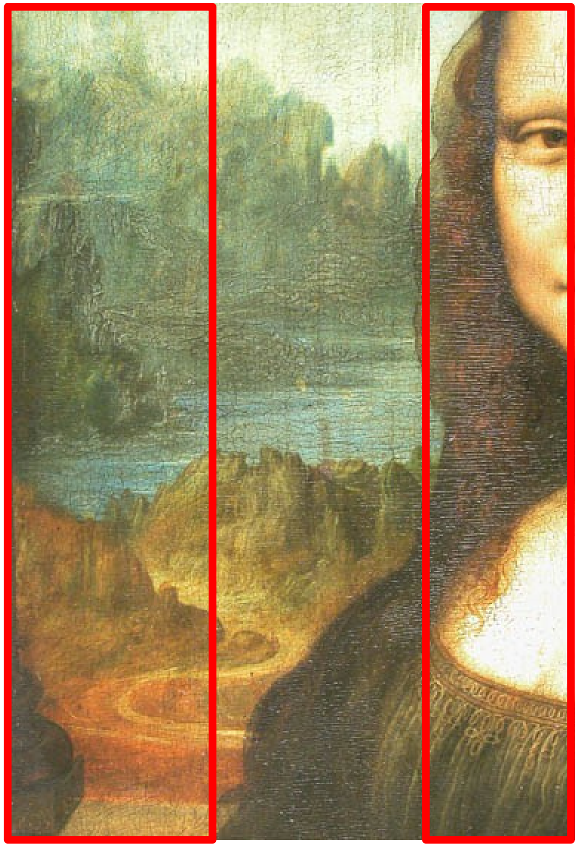
Expected yield in 200/pb @ 10 TeV



QCD is not the dominant background (in MC!) but it's the least predictable one

And cross section uncertainty is not even the end of the story, I'm mostly concerned about the shapes of the discriminating variables: how to trust MC? Any QCD event able to pass our selection is a <u>very atypical</u> one...

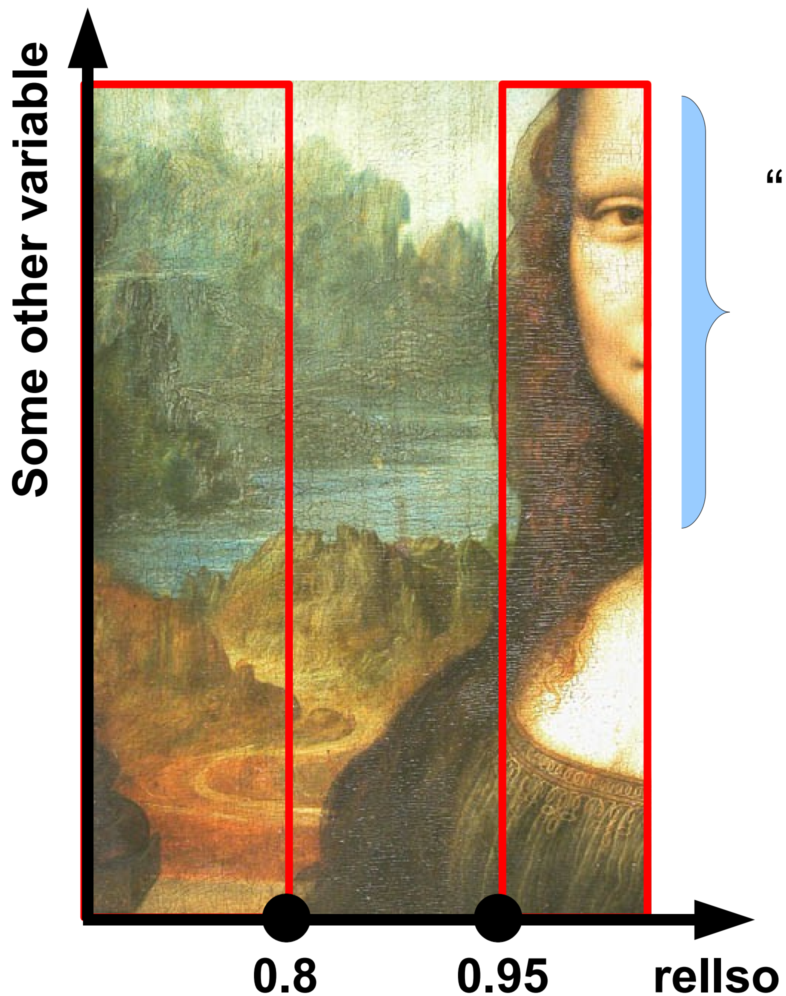
Multi-jet QCD estimation



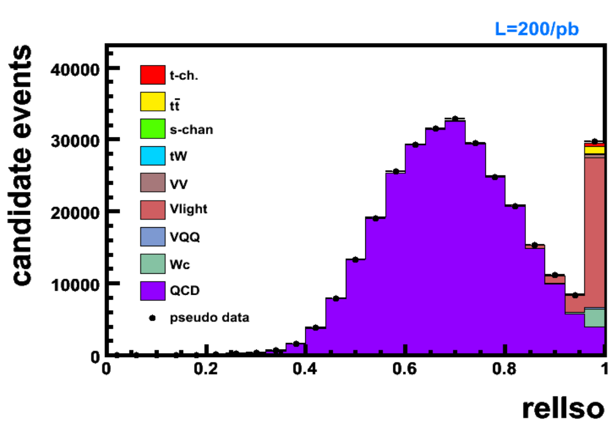
Control region

Analysis region

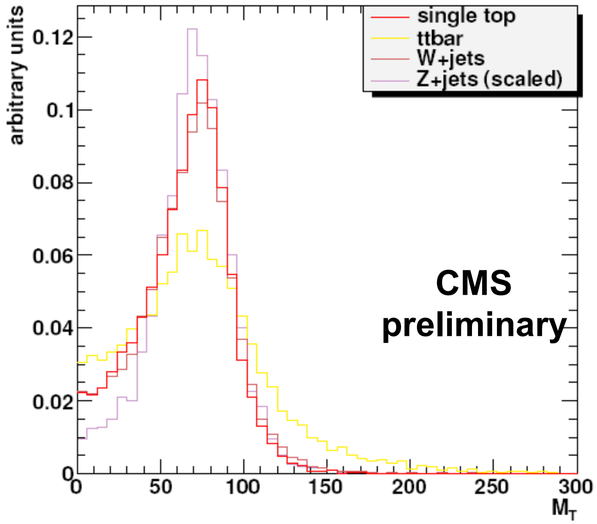
Multi-jet QCD estimation



"Background estimation": behind Monna Lisa's head there is probably water, and behind her body probably land

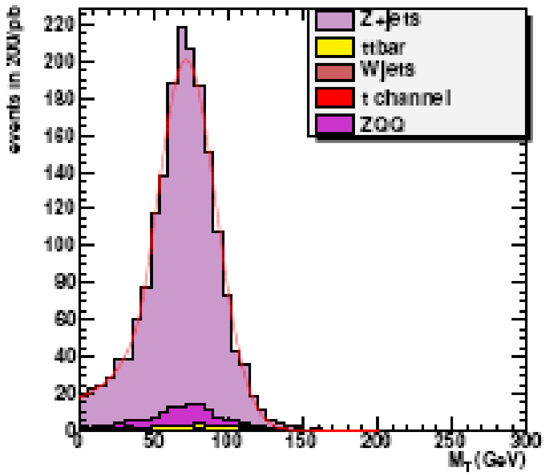


In practice



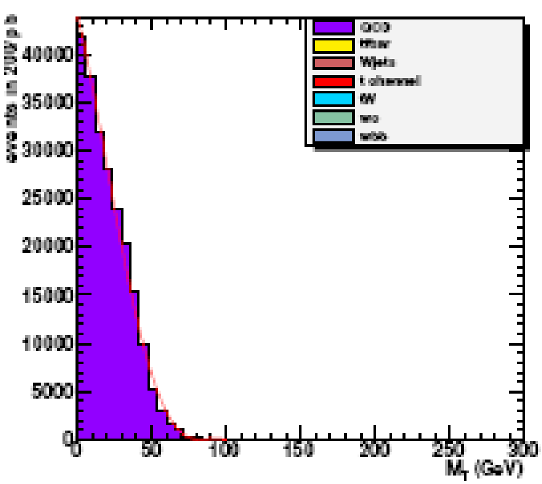
- Signal/tW/$t\bar{t}$/WX roughly similar in $\mathbf{M_T}$
- After full sel., fit to $F(M_T)=aS(M_T)+bB(M_T)$
- Minimize model assumptions:
  - shapes $S(M_T)$, $B(M_T)$ are both taken from **control samples:**
  - QCD-enriched: no b-tag cut, relIso<0.8, all the rest the same
  - Z-enriched: 2μ, 2j, no b-tag cut, $76<M_{\mu\mu}<106$ GeV
    - Muon momenta rescaled by M_W/M_Z
    - A μ, randomly chosen, is treated as a ν (summed to MET)
    - Purity very high, and M_T shape resembles signal enough
  - Alternative $S(M_T)$ models: MC truth, or W-enriched (no btag)

Control samples ⇒ prediction



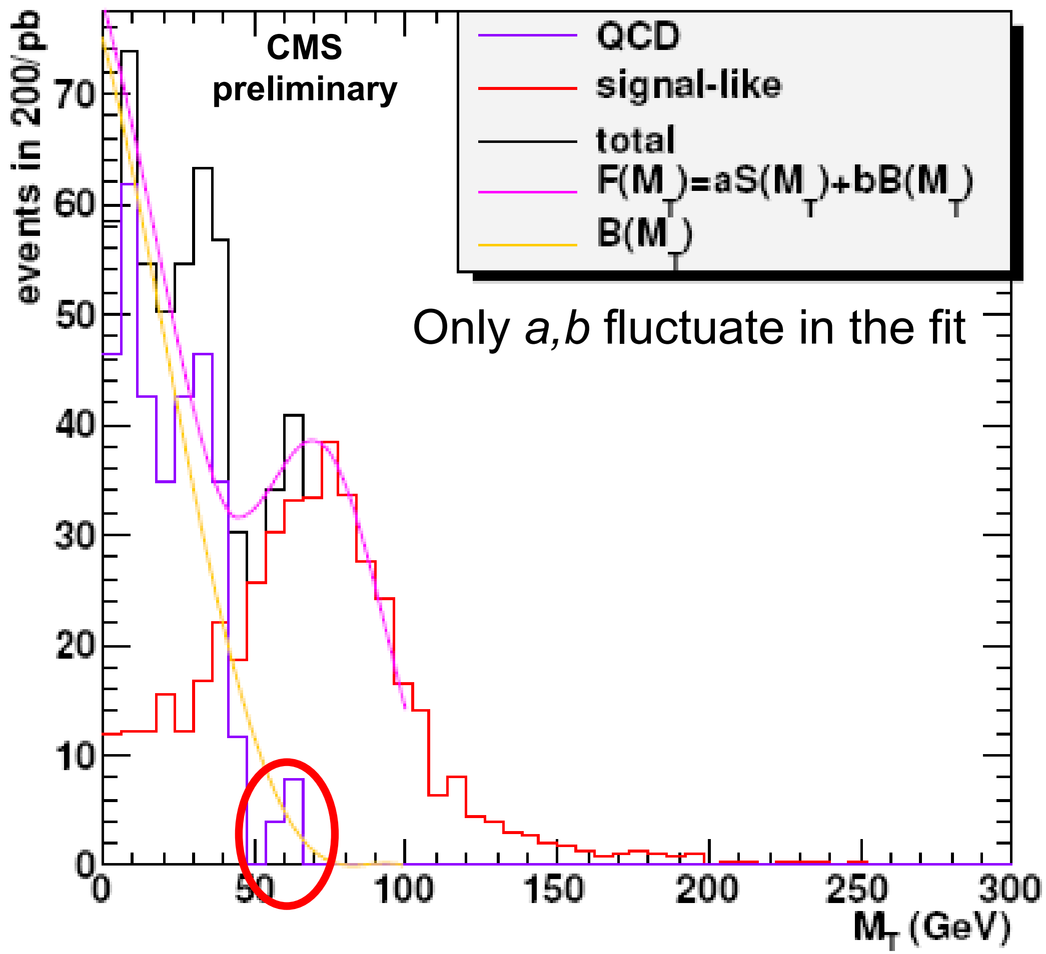
S(M_T): Z-enriched sample

fitted to a “Crystal ball” function



B(M_T): QCD-enriched sample

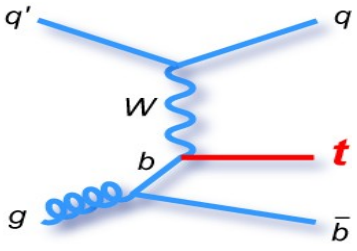
fitted to a polynomial of rank 4



Result: 22.0 QCD events predicted for M_T>50 GeV, versus 12±7 actual. Stat.error from the fit: 6%.

If S(M_T) from W-enriched: 15.1; pure MC: 19.7

Plan: use this method to optimise the cut



The last step

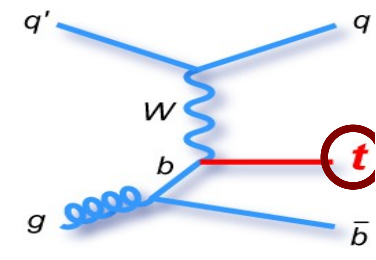
Some observables, for XXX pb^{-1} of data passing full selection

Our sausage machine could be a simple "cut and count", a powerful MVA technique, or whatever; and dozens of discriminating variables could be its input. Our choices were driven by the specificities of an "early data" scenario.

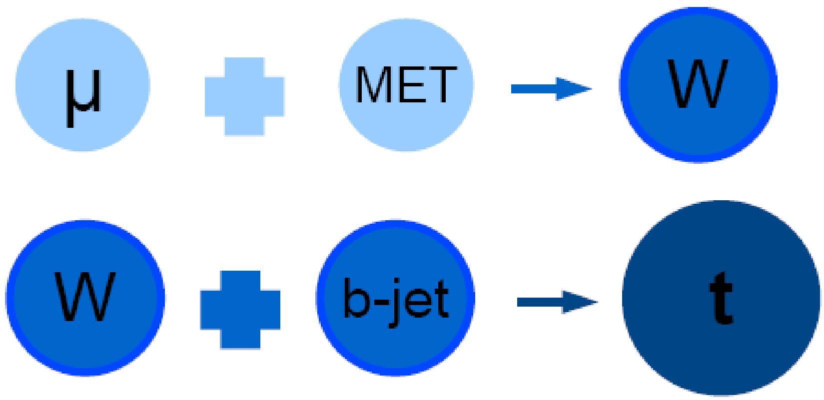
Background-only hypothesis is excluded at Nσ level (eventually, cross section measurement)

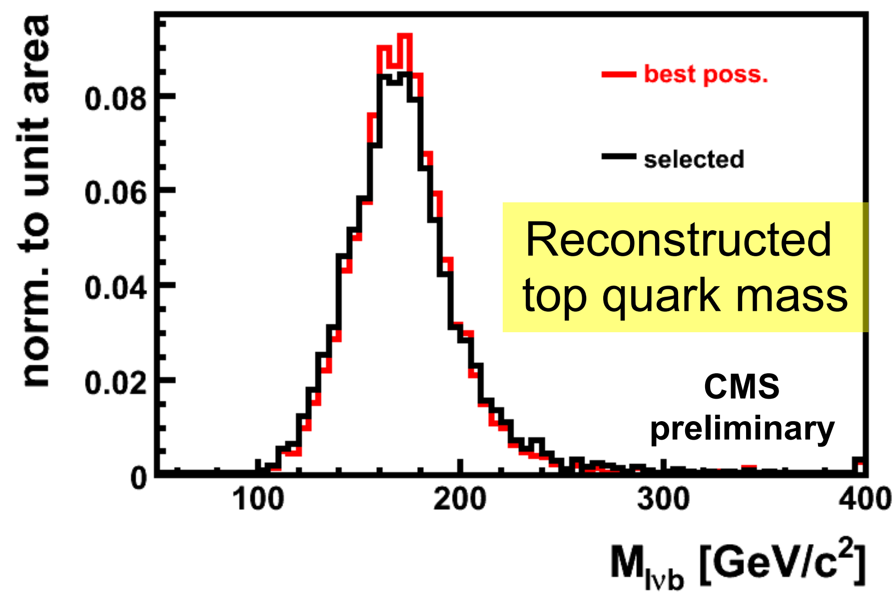
We chose, for start-up, to base everything on **<u>the</u>** most "robust" out of 4 observables that we studied in depth

Top quark reconstruction

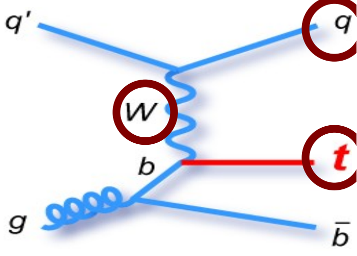


- W boson reconstruction:
  - W mass constraint
  - 2nd order equation in $P_{z,\nu}$
  - 36% of signal has no real solutions
    - Impose $M_T=M_W \Leftrightarrow \mathrm{Img}(P_{z,\nu})=0$
  - 64% of signal has two real solutions
    - Pick the one with smallest $P_{z,\nu}$
- Pairing with a b:
  - Just take the b-tagged jet
  - Correct in 92.2% of selected events
  - The associated b accounts only for 4.0%





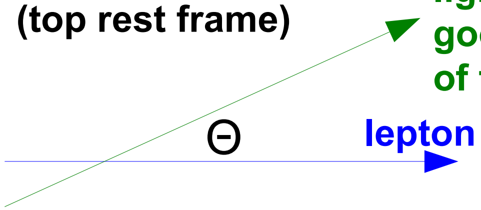
"Best possible" means minimal distance (ΔR) of ν_{reco}, b_{reco} from ν_{true}, b_{true}



Polarization

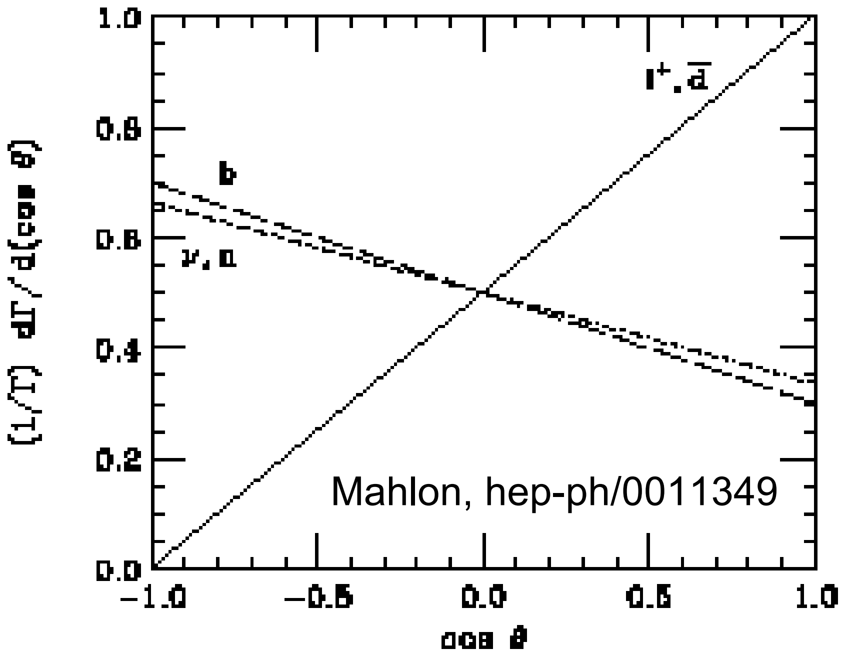
Most characteristic feature of single top quarks, stemming from the V-A nature of the Wtb coupling; **propagated to decay products**

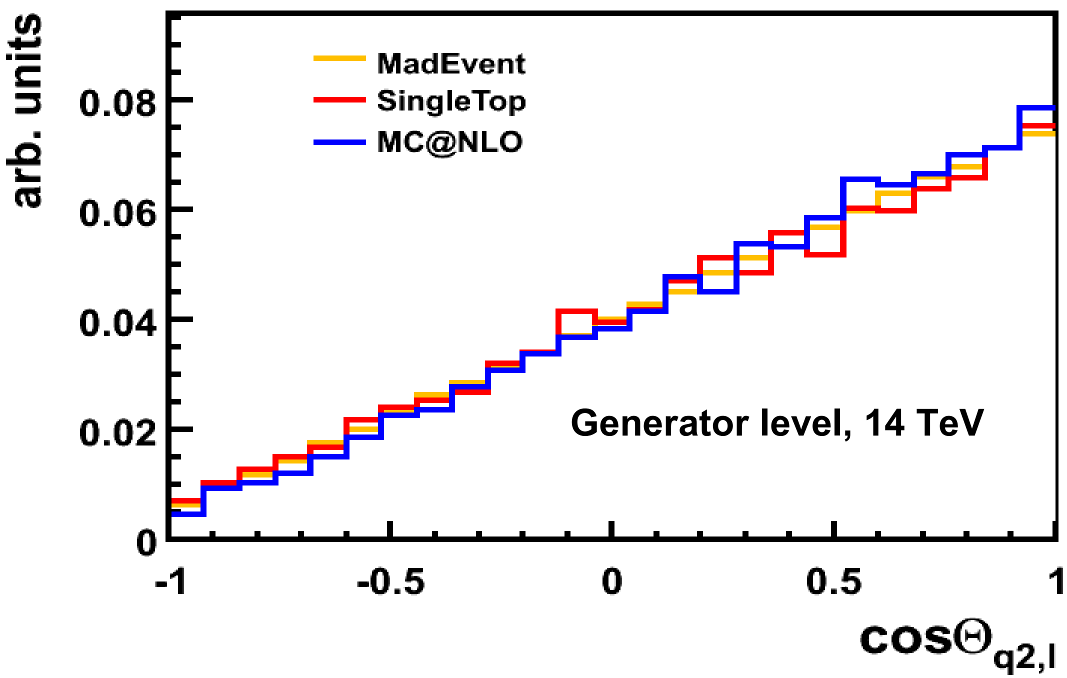
(top rest frame)

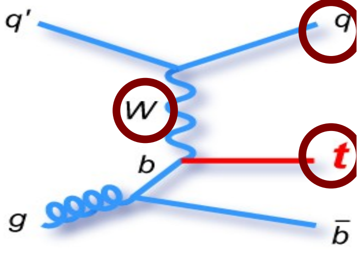


$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{1}{2}(1 + A\cos\theta^*)$$

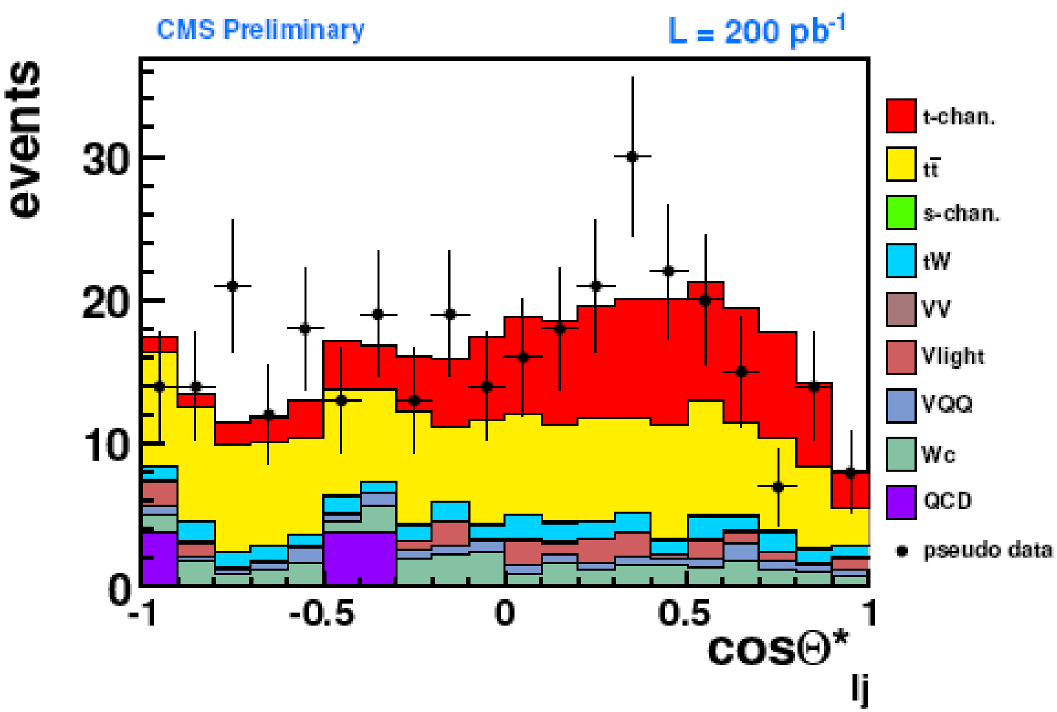
A=+1 for charged leptons

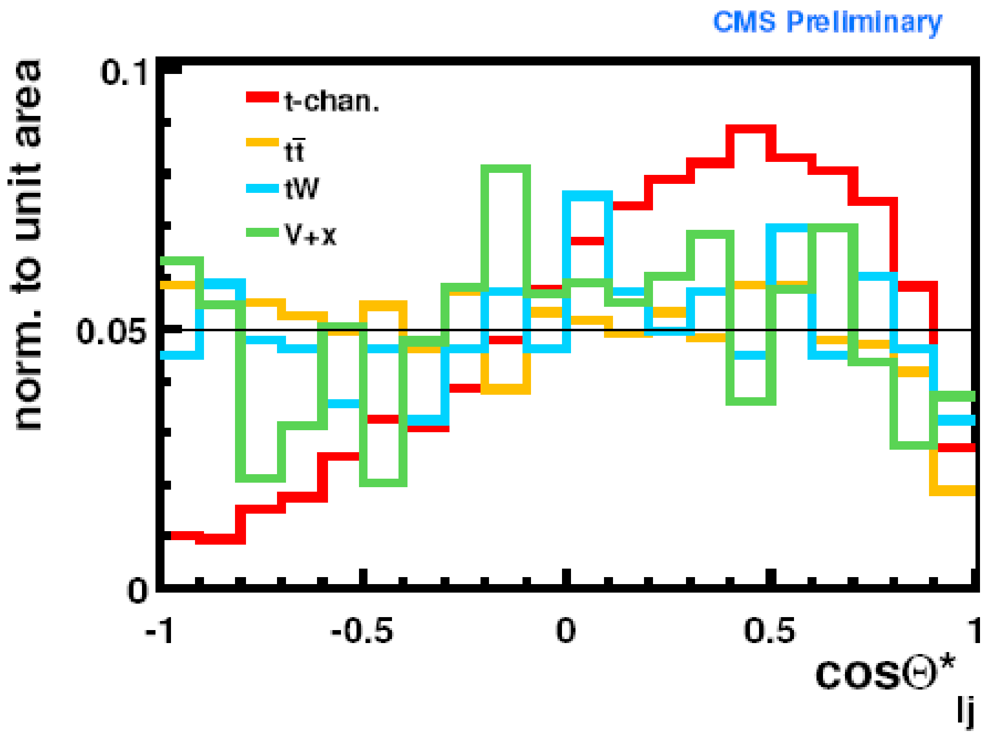






Polarization

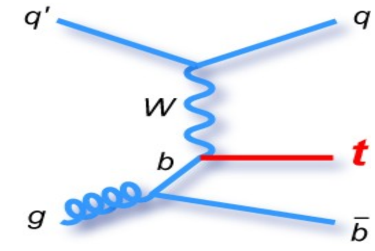




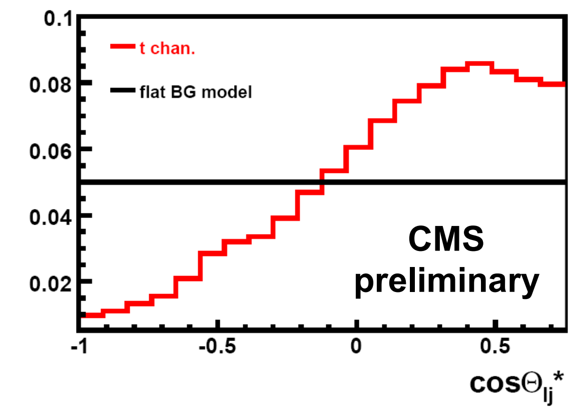
Backgrounds, instead, are remarkably isotropic (cosθ* flat)

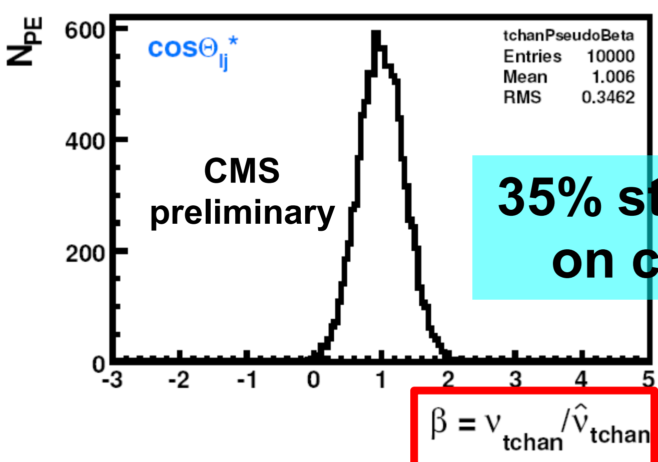
Un-flatness→signal

Template fit

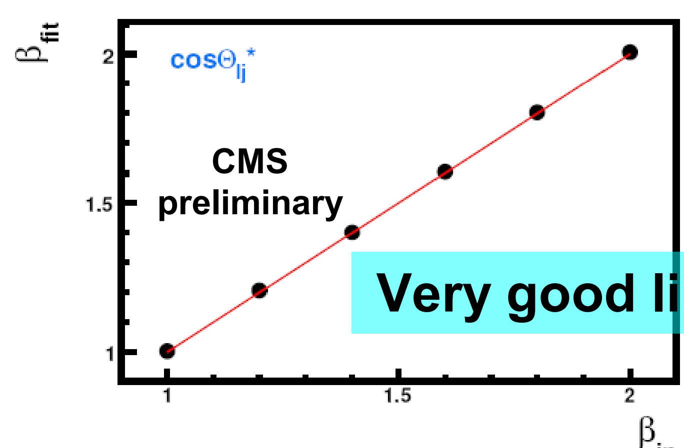


- Binned likelihood fit based on **cosθ* in [-1,¾] range**
- Signal template taken from MC
- **Flat template assumed for sum of bkg**
- Free parameters: β_{signal}, β_{bkg} (β=measured/predicted)
- **No assumption about background size**
  - ±50% variation on bkg size → $\Delta\beta_{signal}$~0%, $\Delta\beta_{bkg}$~±50%



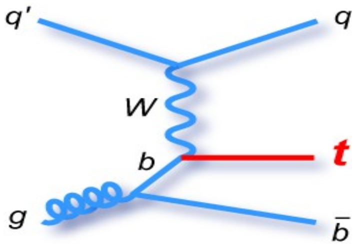


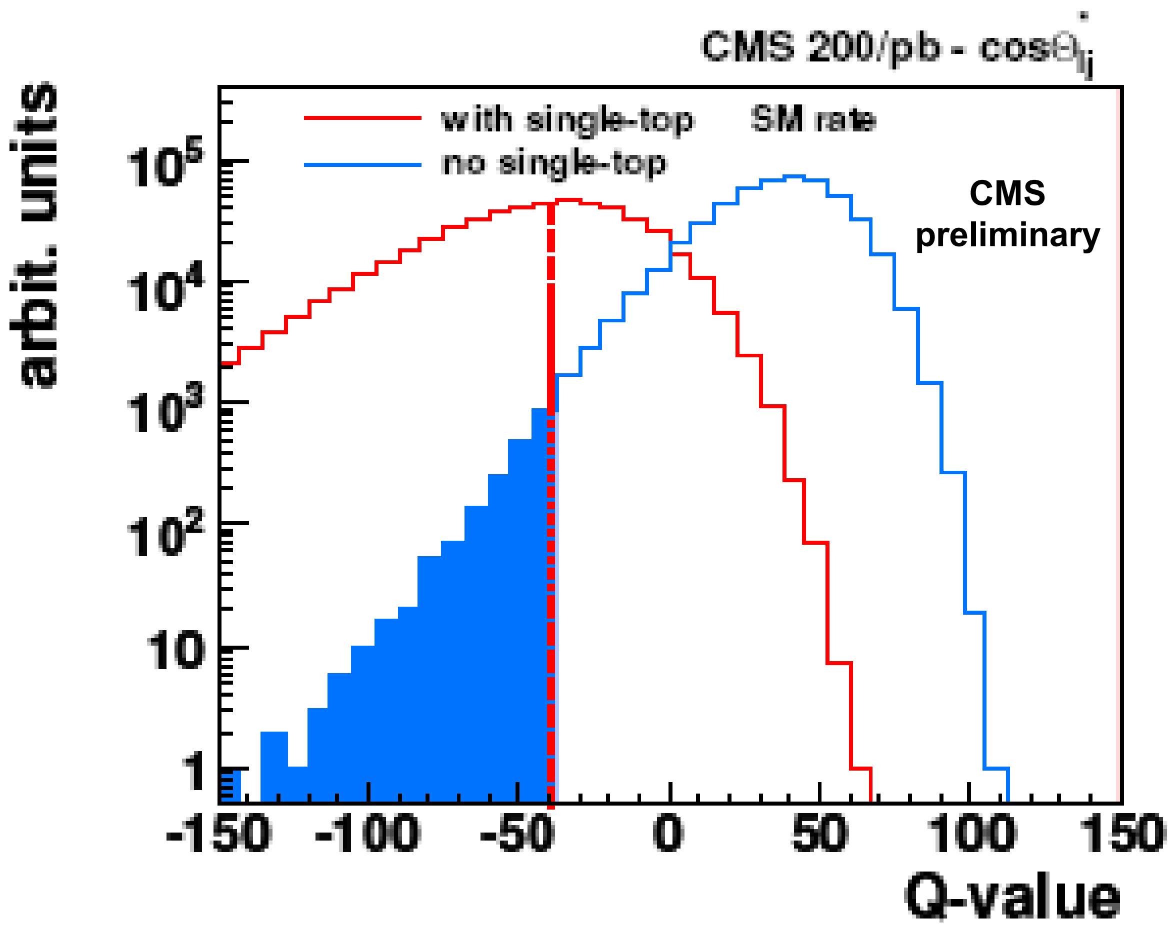
35% stat. uncertainty on cross section



Very good linearity

Expected sensitivity





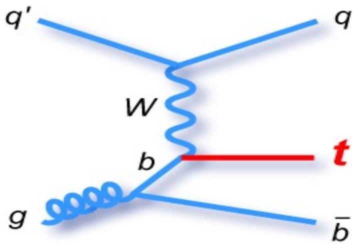
$$Q = -2\ln\left(\frac{L(\hat\beta_1, \hat\beta_2, \ldots, \hat\beta_C)}{L(\beta_1 = 0, \tilde\beta_2, \ldots, \tilde\beta_C)}\right)$$

$$p(Q_m) = \frac{1}{A_q}\cdot\int_{-\infty}^{Q_m} q_0(Q')\,dQ'$$

$$\sigma = \sqrt{2}\cdot Erf^{-1}(1-2(1-p))$$

50k ensemble tests ("toy MC") performed

If both signal and background are described by the SM, there is a 50% probability of excluding the bkg-only hypothesis at 2.8σ level (stat.only) with 200/pb @ 10 TeV

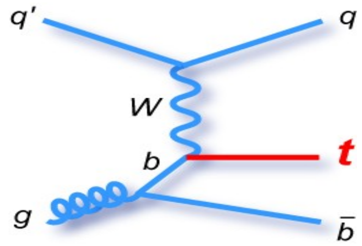


And at 7 TeV?

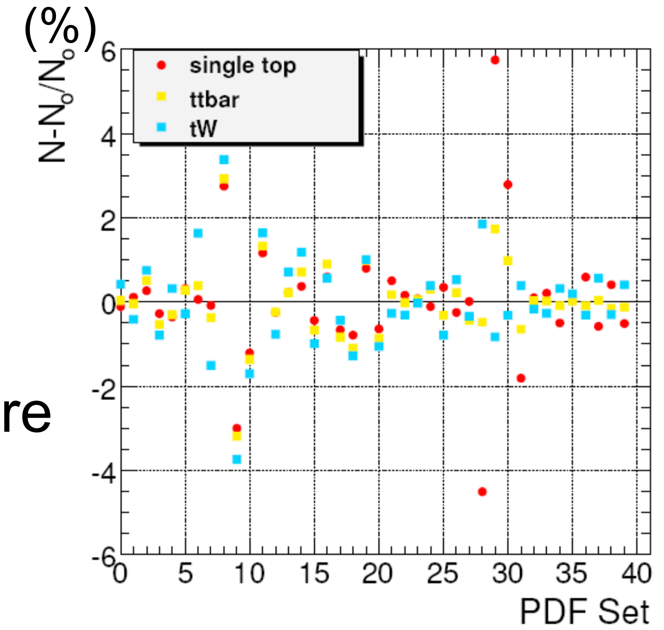
- Naïve rescaling:
  - NLO ratio with MCFM(*) when the proper library is included
  - When not, LO; it is usually ok when it comes to ratios
  - Details in backup

- Result:
  - S→~S/2; remarkably, B→~B/2 too (top-dominated)
  - 1/pb at 10 TeV equivalent to 2.25/pb at 7 TeV
  - 2.8σ in 200/pb @10 TeV → 4σ in 1000/pb @7 TeV

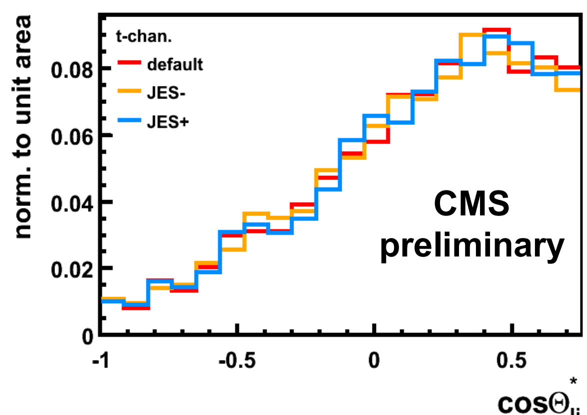
Systematics



- PDF (rate&shape):
  - CTEQ61 weights for signal and 2 major bkg's
  - Shape variations negligible in all cases
  - Rate variations up/down always < 6%; effect on cross-section measurement summed in quadrature

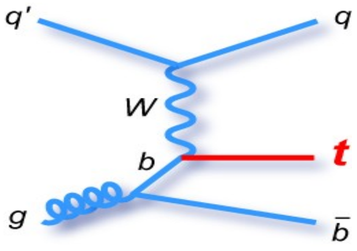


- JES and MET (rate&shape):
  - ±10% on Jet Energy Scale
  - ±10% on the uncorrected MET
- b tagging (rate&shape):
  - ±8.2%(8.0%) on efficiency of tight(loose) cut
  - ±18.1%(3.4%) on mistag prob. of tight(loose) cut
- Luminosity (rate): ±10%



Considering all systematics: 2.8σ → 2.7σ

Plenty of shape variation plots in the backup slides



Conclusions

- **New method** based on fitting the muon/light-jet angle in the reconstructed top rest frame
  - Isotropy of the **overall background**: no a priori assumption on its size, treated as a **free parameter**
  - Make sure that there are no surprises by QCD bkg: *in situ* tuning of the M_T threshold
- This method is robust against systematics
- Plans for 2010-2011 run: **~1000/pb @7 TeV**
  - This μ-only selection can achieve **~4σ**
    - Historical recollection by J.Bauer, who joined CMS at the time: in our kick-off meeting in Apr.2008, we wondered whether ~5σ with ~1000/pb @ 14 TeV was realistic!

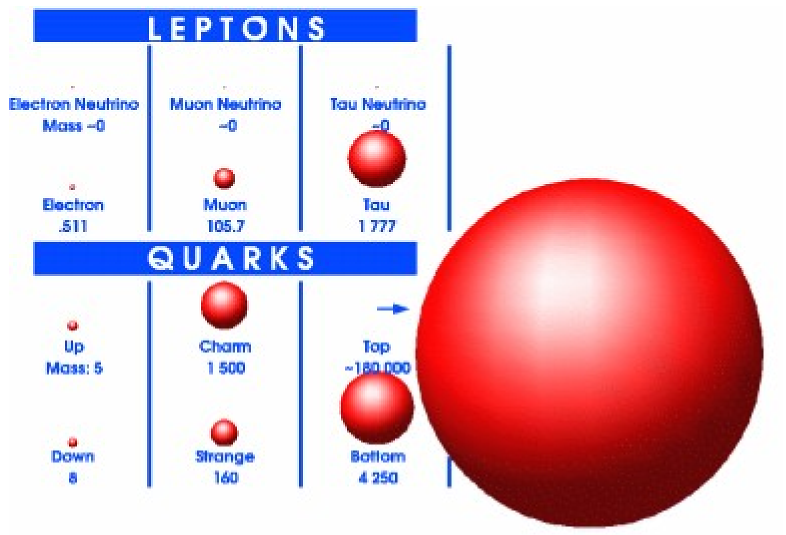
Thanks for you attention!

Digression: *a 4th family? Wasn't it excluded since long time?*

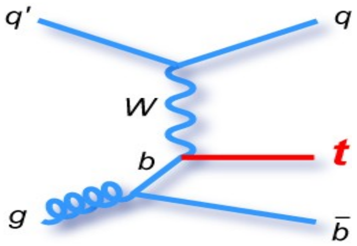
Electroweak precision data [LEPEWWG]

– Particle Data Group:
An extra generation of ordinary fermions is excluded at the 6σ level on the basis of the S parameter alone... [Erler & Langacker]
This result assumes that...any new families are degenerate [Erler & Langacker]
Just as our 3rd generation??? [Holdom; Kribs, TP, Spannowsky, Tait]

Flame-bait by Tilman Plehn



Cross section precision and its limiting factors

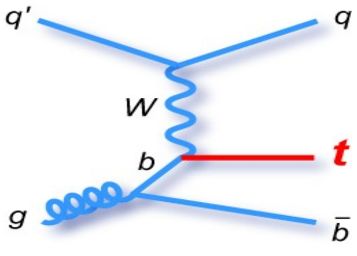


Source of uncertainty	$\Delta\sigma$ [%]	Expected sensitivity
statistical	$\pm$ 35	2.8σ
b tagging	$\pm$ 7.3	2.7σ
mistag	$\pm$ 0.4	2.7σ
JES	$\pm$ 5.5	2.7σ
MET	$\pm$ 9.9	2.7σ
PDF	$\pm$ 5.5	2.7σ
total	$\pm$ 39	2.7σ

(±10% luminosity)

- At 200/pb, by far limited by statistics
- By the time of 1/fb, data-driven methods are expected to improve the knowledge of these sources of systematics as follows:
  - JES uncertainty from ±10% to ±5%, MET *probably* the same
  - b-tagging uncertainty from ±8% to ±5-6%
  - PDF uncertainties reduced by large factors, see e.g. http://cdsweb.cern.ch/record/1117860/files/ATL-SLIDE-2008-079.pdf
  - luminosity uncertainty from ±10% to ±5%

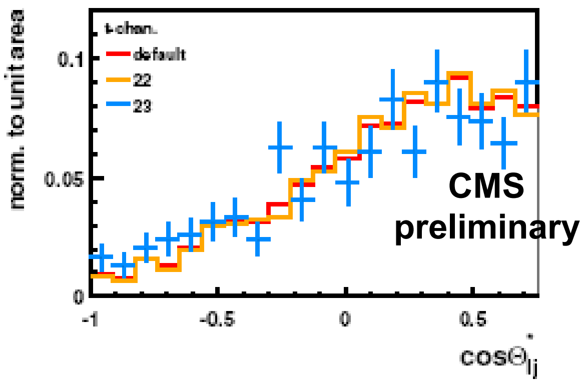
“What happens if...”

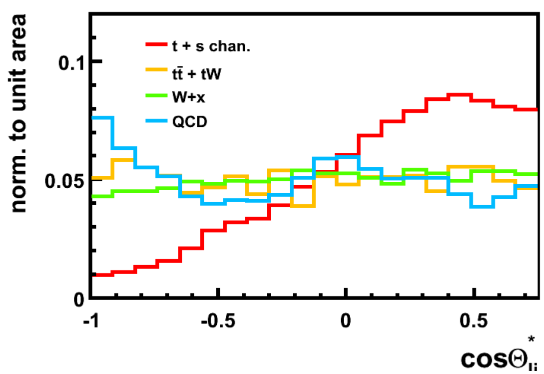


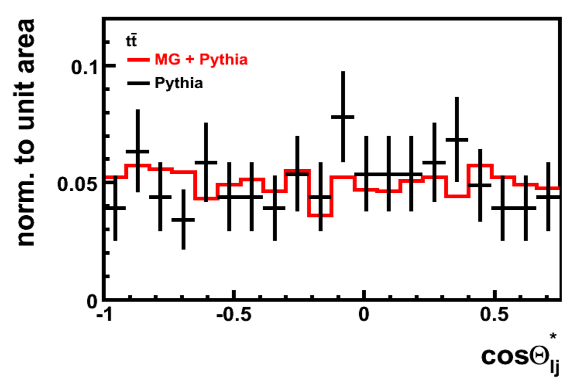
- Signal model (shape): the most extreme variation, a priori, is 2→2(only) vs 2→3(only)
- Bkg model (shape): the actual (?) shape from somewhere else is used in the fit
  - tt&tW: shape from MC; tt flatness checked in “2b”
  - W/Z+X: shape from b-tag-less control sample
  - QCD: from b-tag-less anti-isolated control sample
- Radiation model for $t\bar{t}$ (shape):
  - ISR/FSR up and down
  - MadGraph vs Pythia

The worst difference (QCD shape): 2.7σ → 2.6σ

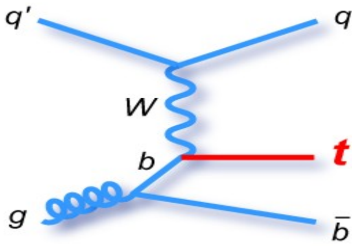
- Overall background rate +/-50%: no significant bias on the measurement, sensitivity 2.2σ / 3.2σ







Scaling to 7 TeV

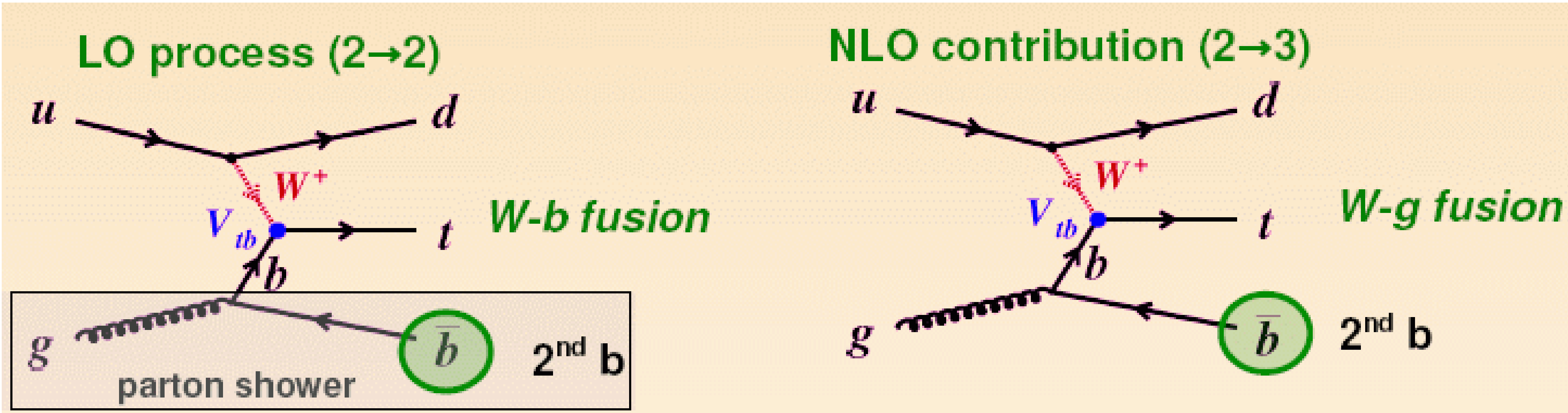


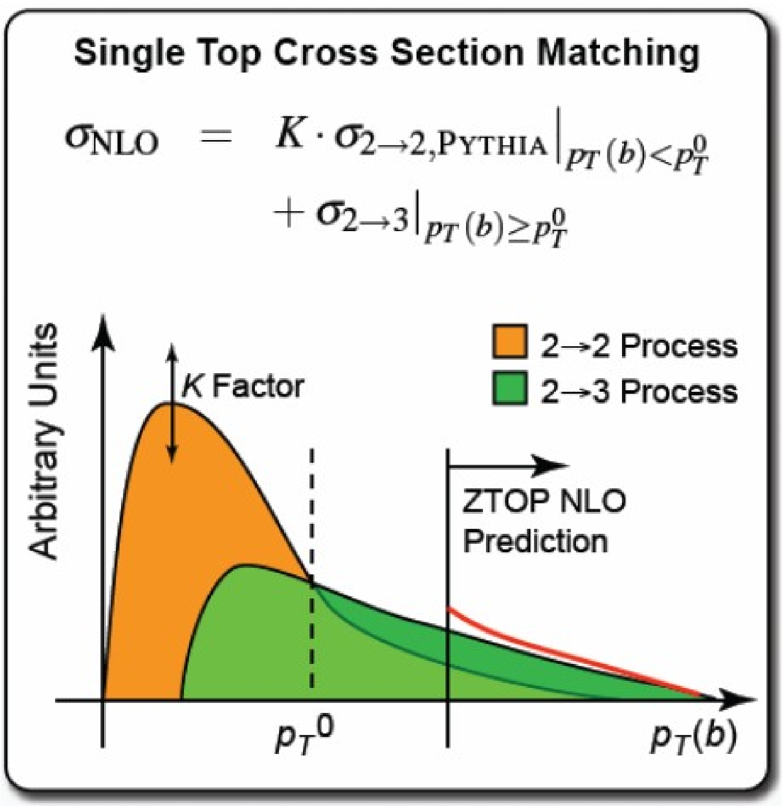
- Using MCFM (NLO, m_t=170 GeV, CTEQ6M):
  - Single top, t: 85.4+47.3 pb (10 TeV) → 42.3+21.9 pb (7 TeV)
  - Wt: 27.3 pb (10 TeV) → 11.1 pb (7 TeV)
  - Pair production: 414 pb (10 TeV) → 186.7 pb (7 TeV)
  - Wc: 3.3 **n**b (10 TeV) → 1.9 **n**b (7 TeV)
  - Wbb: 29.9+19.1 pb (10 TeV) → 16.8+10.1 pb (7 TeV)
  - (LO) W+light partons: 40 **n**b (10 TeV) → 24 **n**b (7 TeV)
  - QCD (12 ev @10 TeV), W+light jets (12 ev @10 TeV), and all minor bkg's (9 ev@10 TeV), all scaled by 50%
- Naïve rescaling of $S/\sqrt{B}$ for the $\cos\theta^*$ method: 200/pb @ 10 TeV → ~450/pb @ 7 TeV

Planned analysis improvements

- Add electron channel
  - ~$\sqrt{2}$ gain in significance unless surprises from QCD force us to tighten the e/j discrimination
- Combine $\cos\theta^*$ and charge asymmetry
  - Uncorrelated properties of the signal
- Add jet-sensitive variables as soon as reliable
  - $M(l\nu b)$ and $|\eta(j_{recoil})|$ already studied in depth
- Particle flow algorithm, when fully validated
  - Better jet & MET resolution, smaller JES syst.
  - Surprisingly good validation results at 900 GeV!

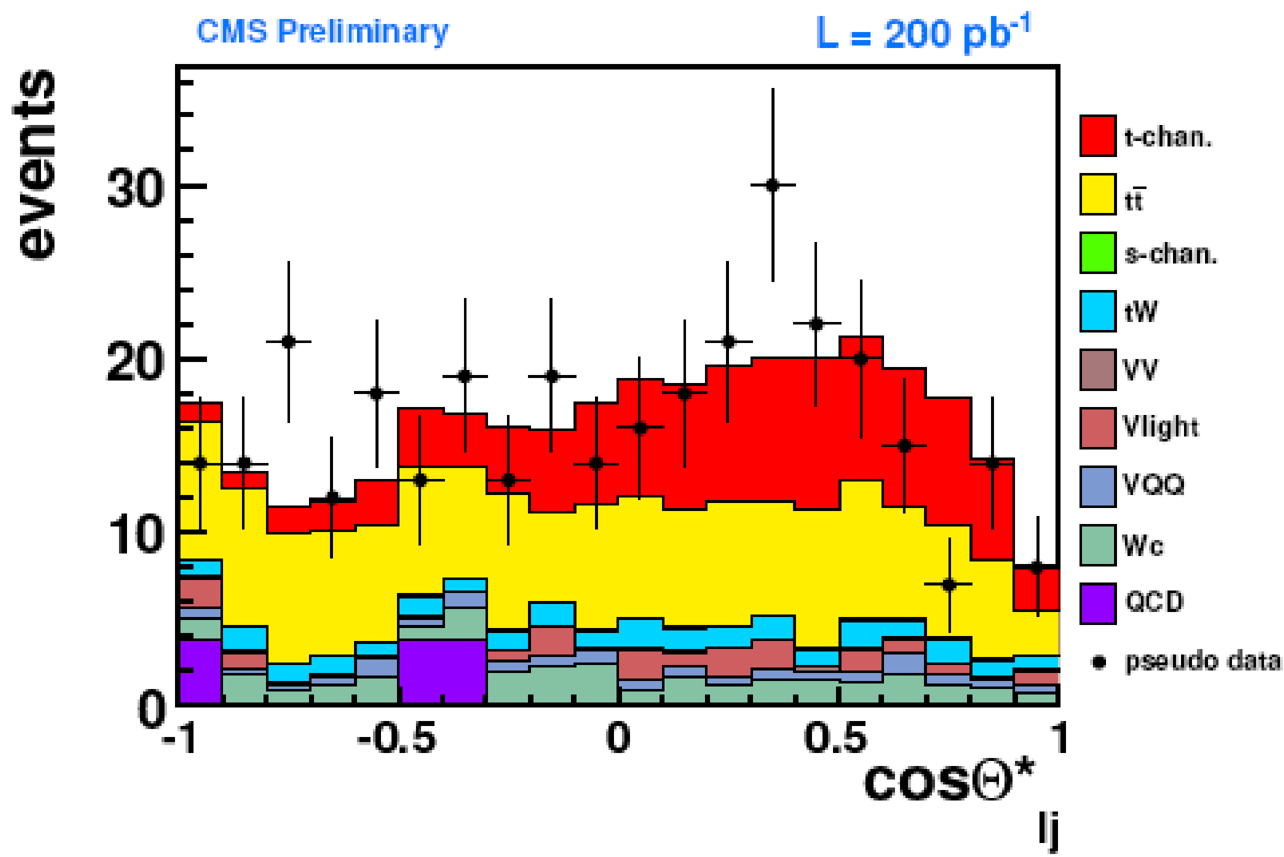
Signal model: 2→2 / 2→3 matching





- Matching in p_T of the associated b
- Original idea: E.Boos, L.Dudko, V.Savrin, CMS NOTE 2000/065 (*SingleTop* gen.)
- Used in CDF (*MadGraph*), D0 (*SingleTop*)
- CMS implementation on top of *MadGraph*
  - ✓ Cross-validated with *SingleTop* and *MC@NLO* (internal note AN2009/024)

Hunting for new physics: first constrain the backgrounds!



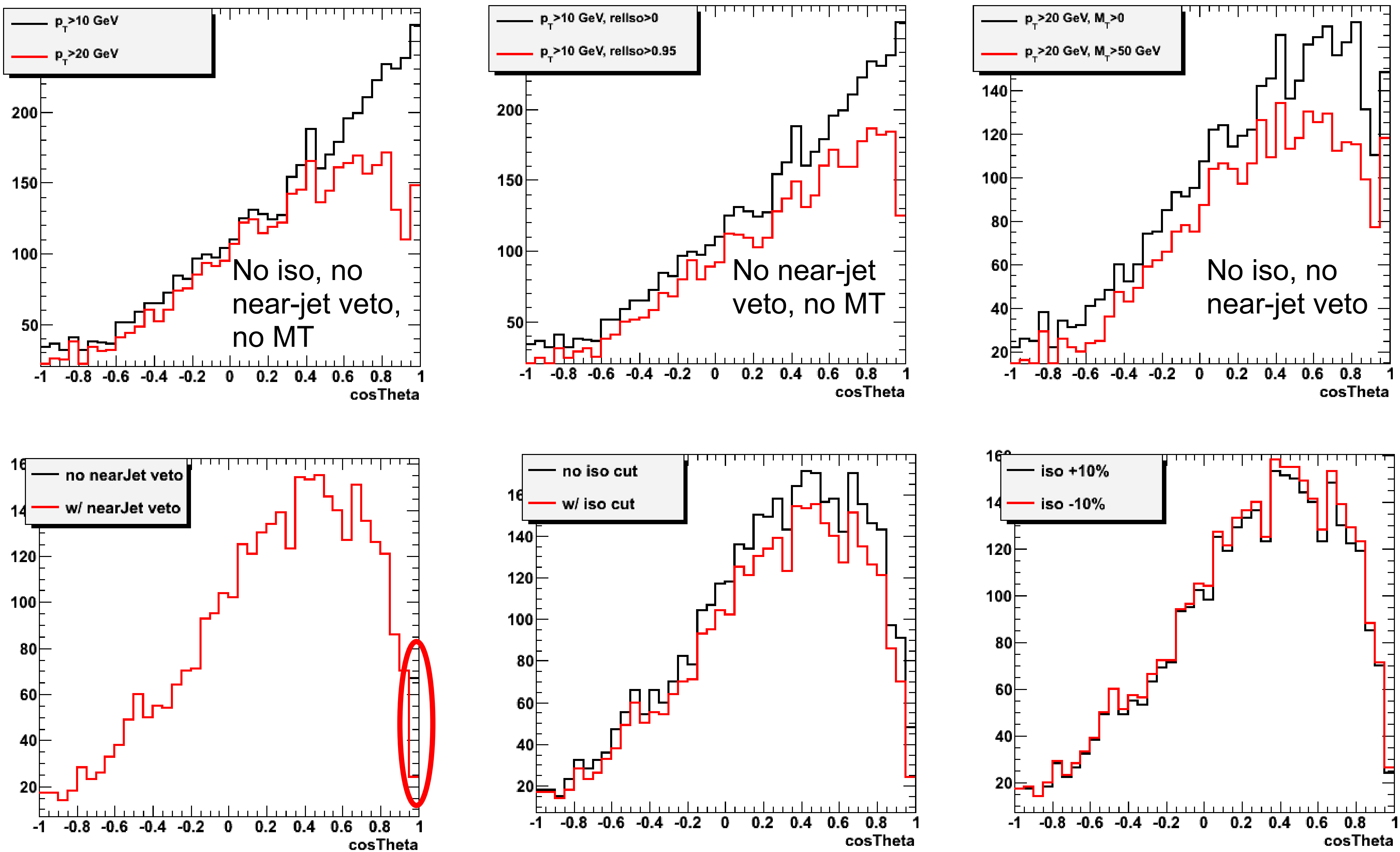
This variable is sensitive to FCNC and anomalous Wtb couplings.
Ideally, independent precise measurements of all SM backgrounds would permit to measure the non-SM component of single top from the remaining pedestal.
But this use is not for early data.

Why M_T instead of MET

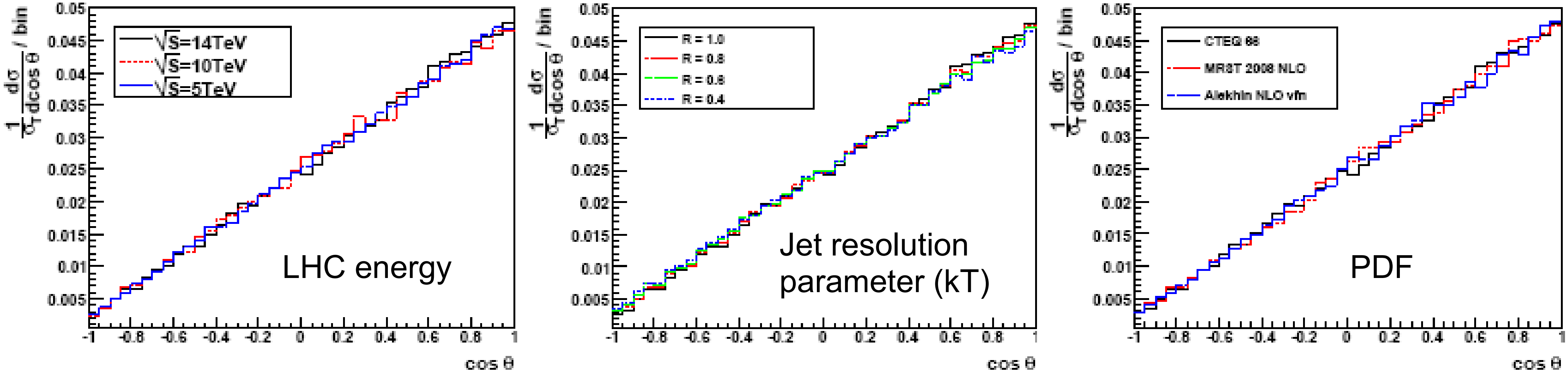
- Better discrimination power in CMS
  - But this could be not true with particle flow
- Better stability vs JES and MET variations
- Easier QCD estimation: all non-QCD processes have a similar M_T shape, not so for MET
- In QCD, MET is correlated with muon momentum and muon isolation (M_T is not), due to the fact that most of the surviving QCD events are bb or cc
  - Probably not true for the electronic channel

What shapes cosθ*

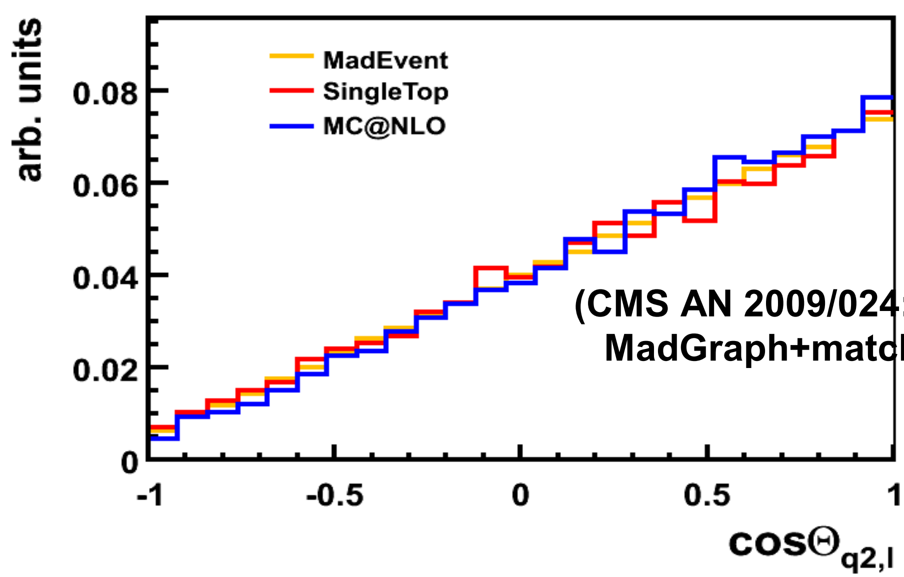
CMS preliminary



At generator level

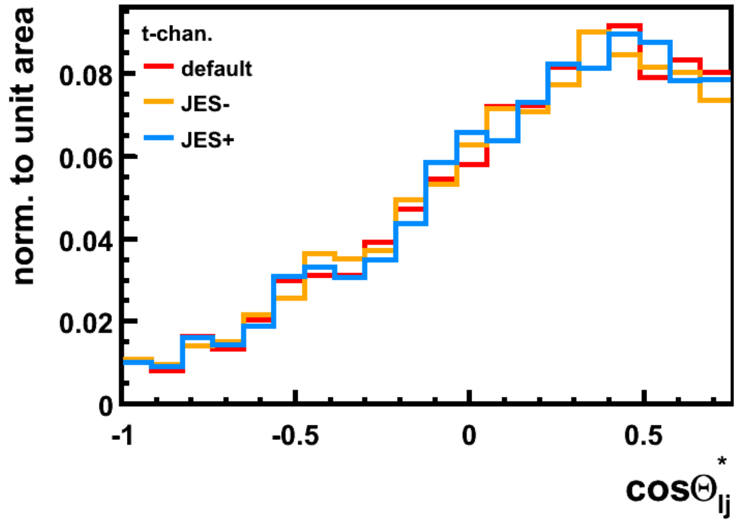


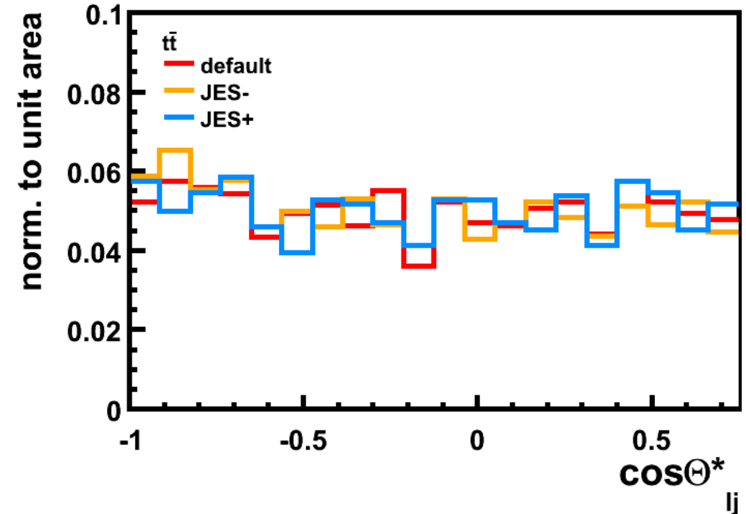
(P.Motylinski, hep-ph:0905.4754)



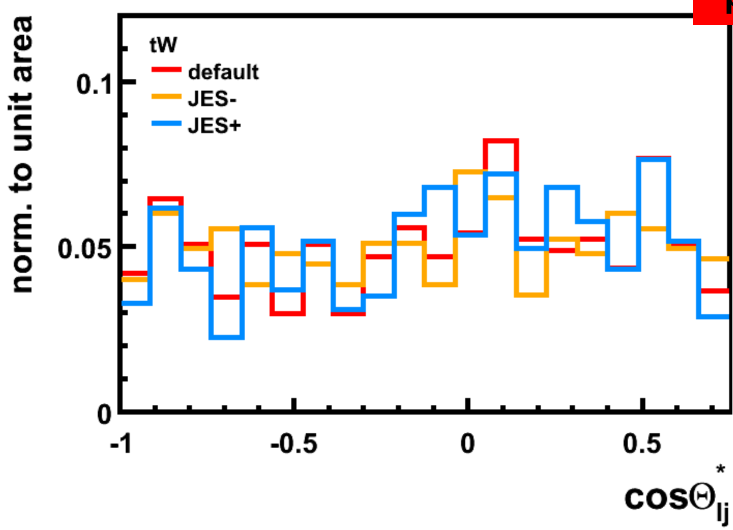
(CMS AN 2009/024: 14 TeV, comparison between MadGraph+matching / SingleTop / MC@NLO)

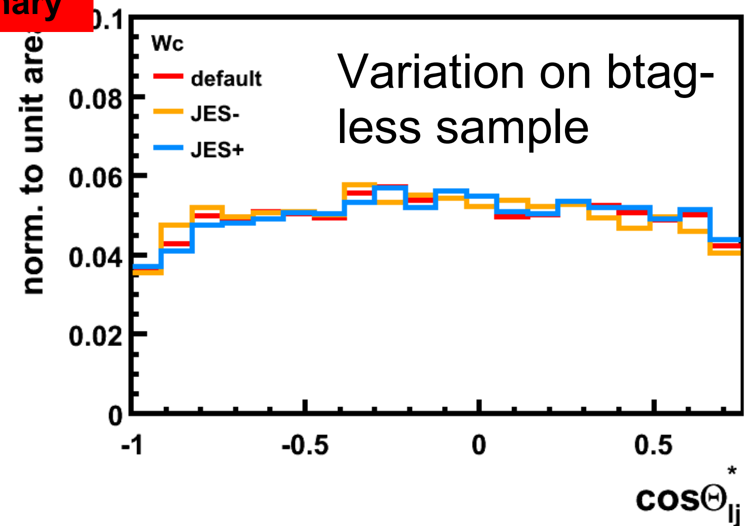
Shape systematics, JES



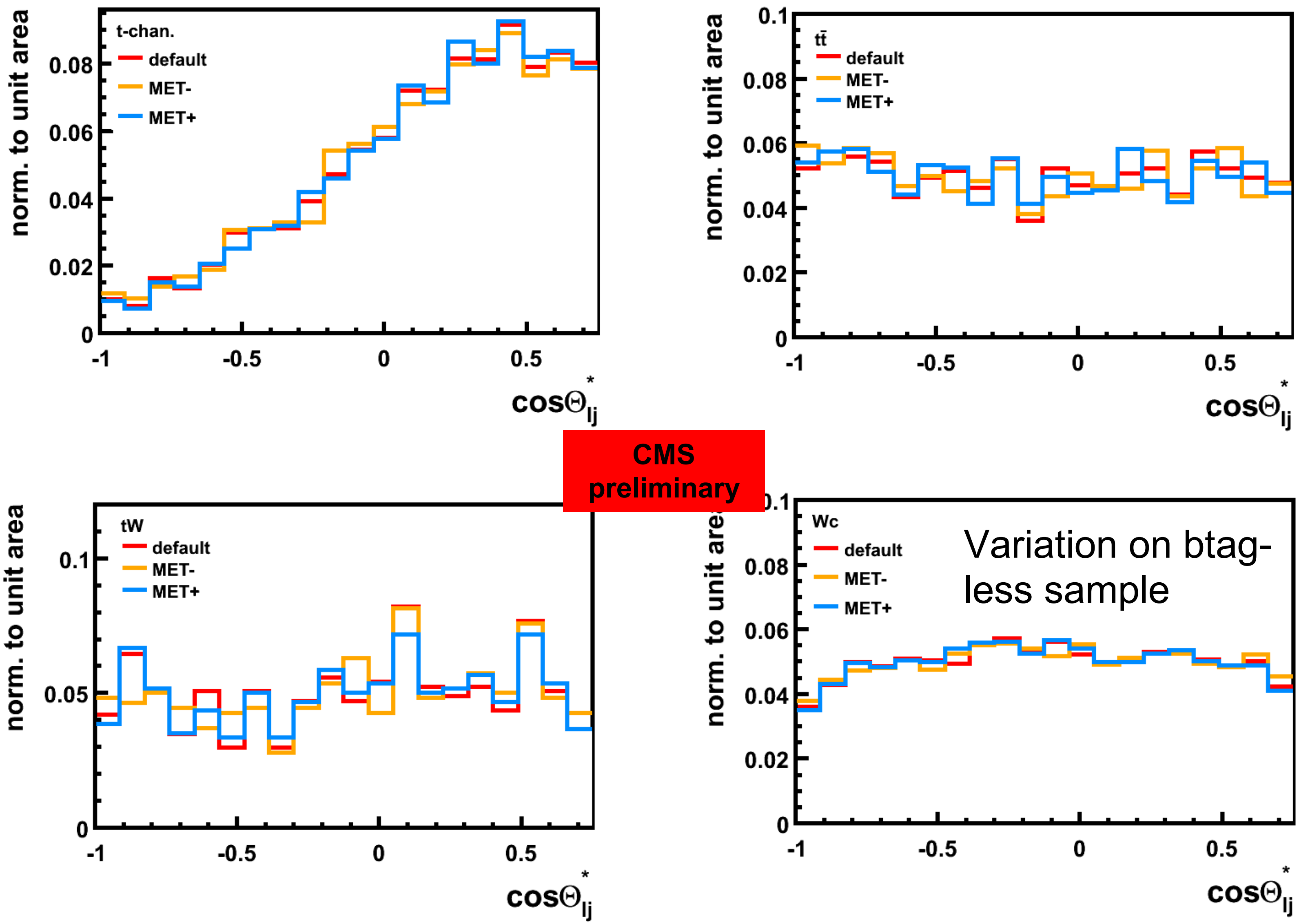


CMS preliminary

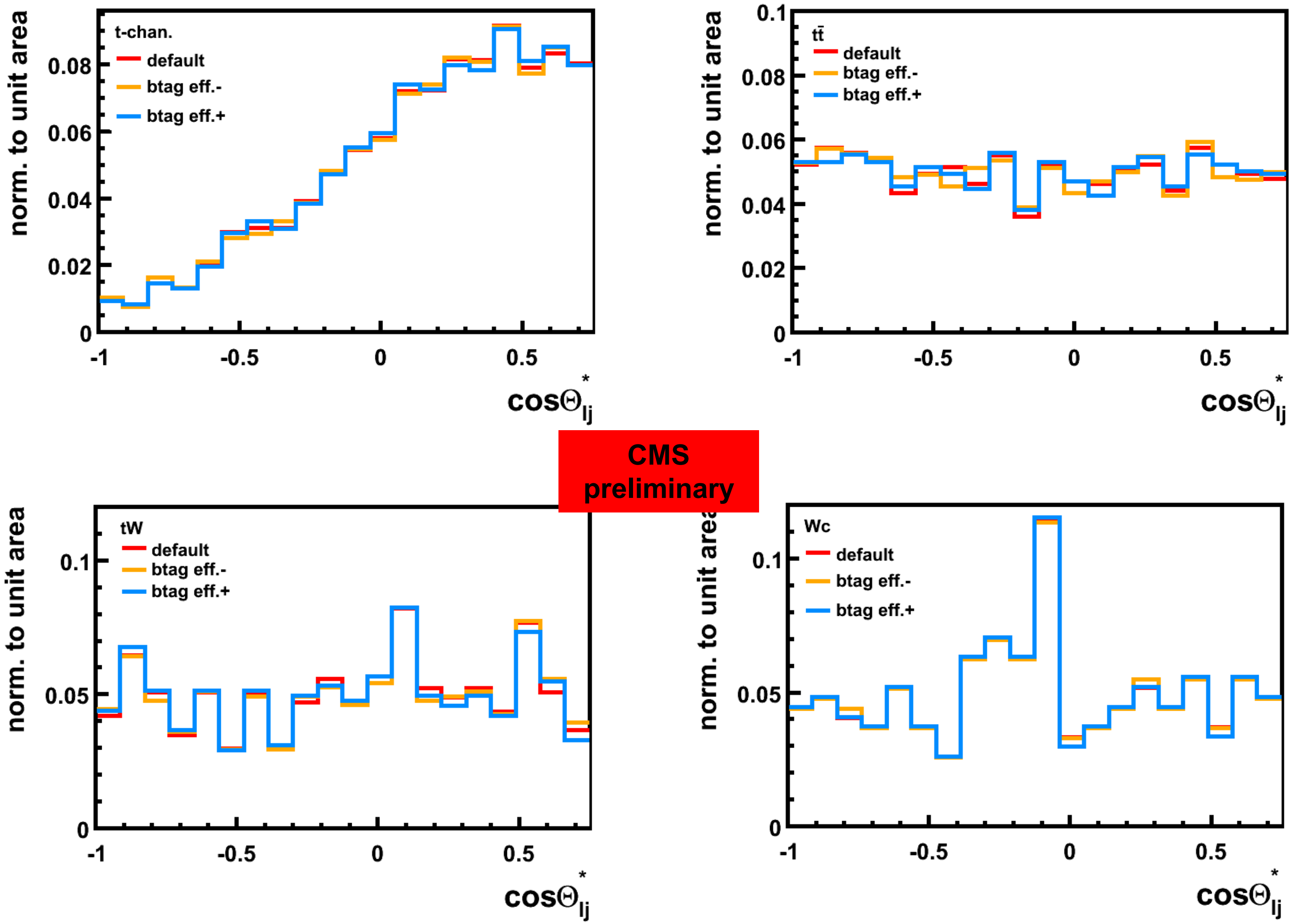




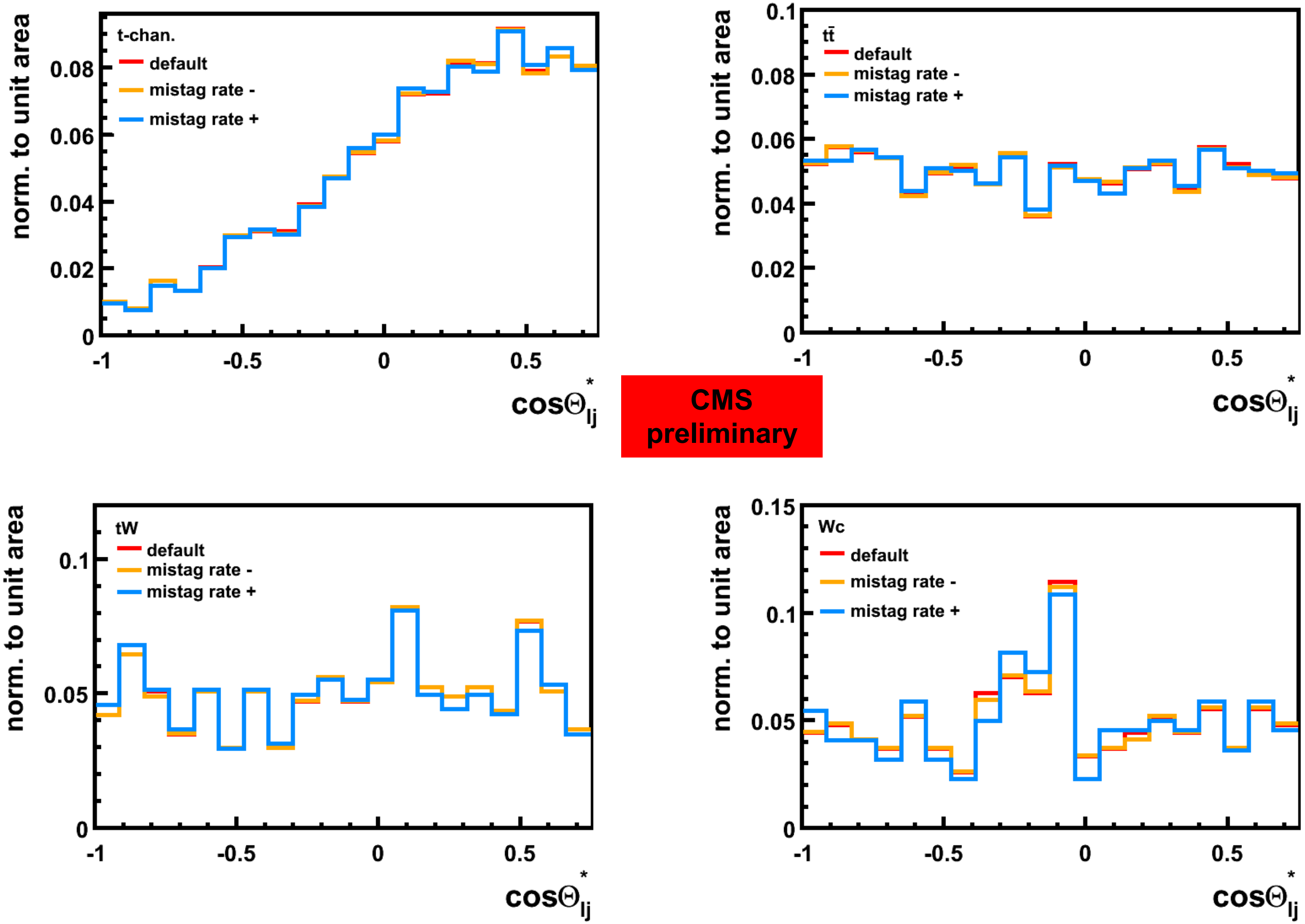
Shape systematics, MET



Shape systematics, b tagging



Shape systematics, mistag



Btag efficiency

- From CMS-PAS-BTV-07-001:

operating point	Loose			Medium			Tight		
Luminosity (pb^{-1})	10	100	1000	10	100	1000	10	100	1000
Systematics (%)									
β	5.8	5.8	2.9	6.3	6.3	3.2	5.7	5.7	2.9
α	0.4	0.4	0.2	0.4	0.4	0.2	0.4	0.4	0.2
κ_b	3.4	3.4	1.7	3.6	3.6	1.8	3.3	3.3	1.7
κ_{cl}	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.2	0.1
$p_{T\,rel}$	2.8	2.8	2.8	2.9	2.9	2.9	3.0	3.0	3.0
statistics MC (%)	2.3	2.3	2.3	2.6	2.6	2.6	2.7	2.7	2.7
statistics data (%)	7.2	2.3	0.7	8.4	2.6	0.8	8.7	2.7	0.9
Total error (%)	10.5	8.0	6.4	11.8	8.6	5.4	11.6	8.2	5.3

Table 6: Summary of uncertainties expected for b-tagging efficiencies measured with the System8 for different luminosity scenarios for the TrackCounting tagger.

Mistag efficiency

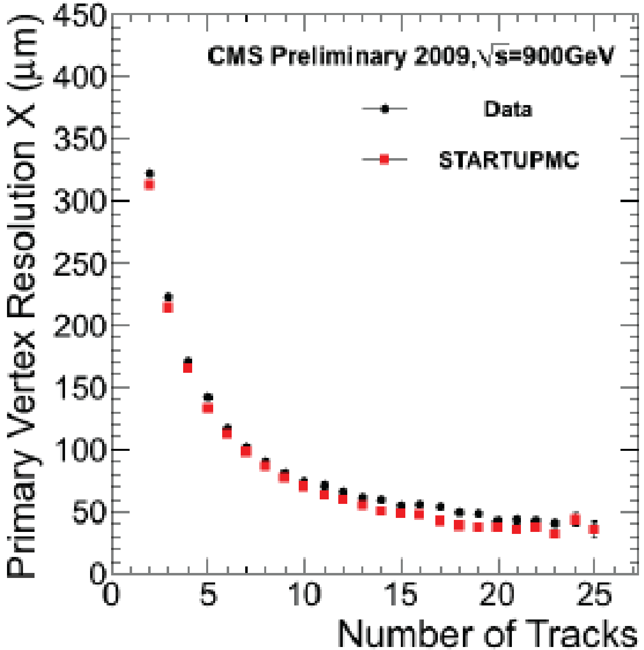
- From CMS-PAS-BTV-07-002:

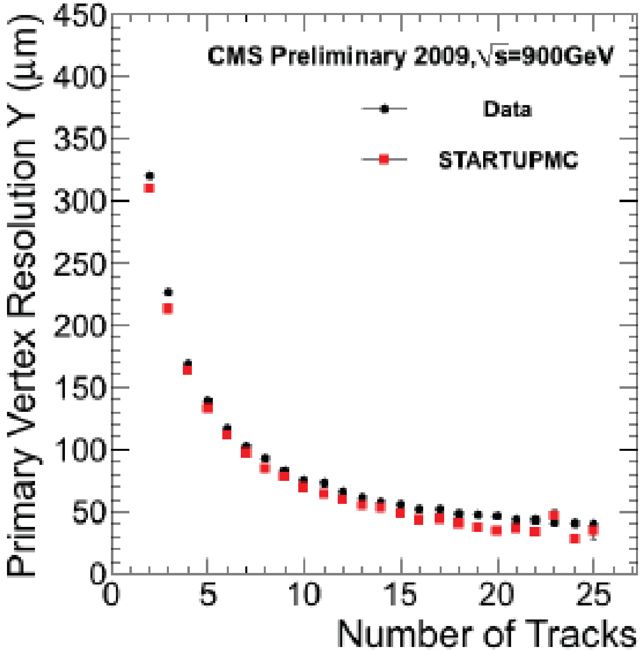
The breakdown of systematic uncertainties is detailed in Table 2. As, according to Figures 8-13 and 24, the systematics depend on the jet p_T and η, they are reported here for $p_T = 100$ GeV, integrating over all η.

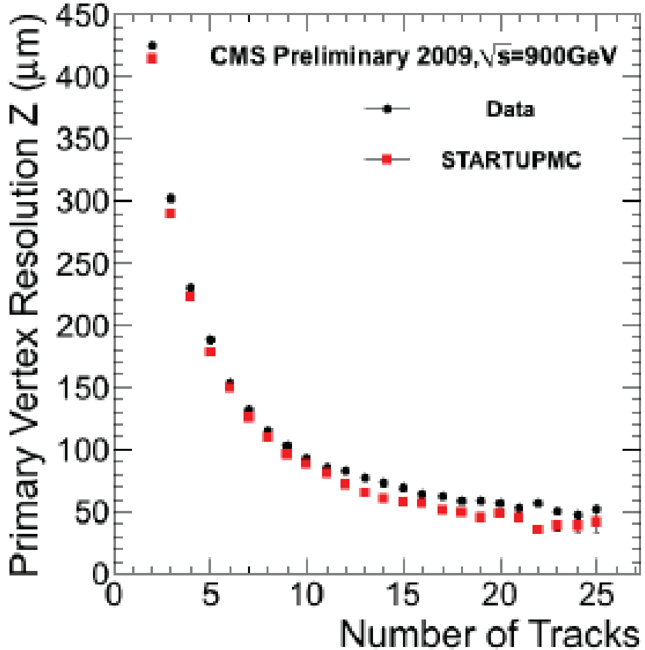
operating point	Loose			Medium			Tight		
Luminosity (pb^{-1})	10	100	1000	10	100	1000	10	100	1000
Systematics (%)									
b fraction	1.4	1.4	0.6	0.8	0.8	0.3	1.2	1.2	0.5
c fraction	0.8	0.8	0.3	0.7	0.7	0.3	1.3	1.3	0.5
g fraction	0.8	0.8	0.4	1.4	1.4	0.7	2.3	2.3	1.2
V^0 fraction	1.4	1.4	0.7	3.6	3.6	1.8	4.6	4.6	2.3
other displaced processes	1.4	1.4	0.7	3.6	3.6	1.8	4.6	4.6	2.3
IP sign flip	0.7	0.3	0.2	4.5	1.9	1.4	24.0	10.2	7.6
statistics MC	0.1	0.1	0.1	0.4	0.4	0.4	1.2	1.2	1.2
statistics data	0.4	0.1	—	1.6	0.5	0.2	5.5	1.7	0.6
sampling	2.0	2.0	2.0	5.0	5.0	5.0	13.0	13.0	13.0
Total syst.	3.4	3.4	2.4	8.8	7.6	5.9	28.7	18.1	15.5

Table 2: Estimated relative systematics (%) on the mistag efficiency for the Track Counting tagger at a jet $p_T = 100$ GeV. Three operating points, corresponding to an average mistag efficiency (in the QCD 80-120 Monte Carlo) of 10%, 1%, 0.1%, respectively, and three luminosity scenarios are considered.

TRK-10-001, primary vertex







TRK-10-001, impact parameter

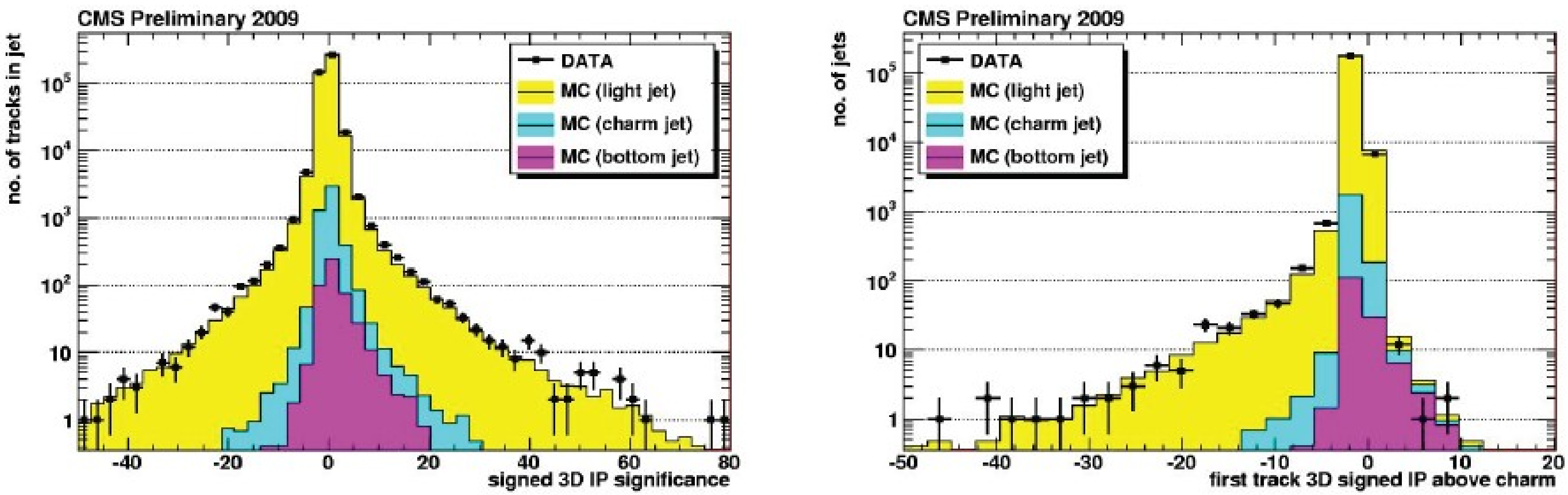
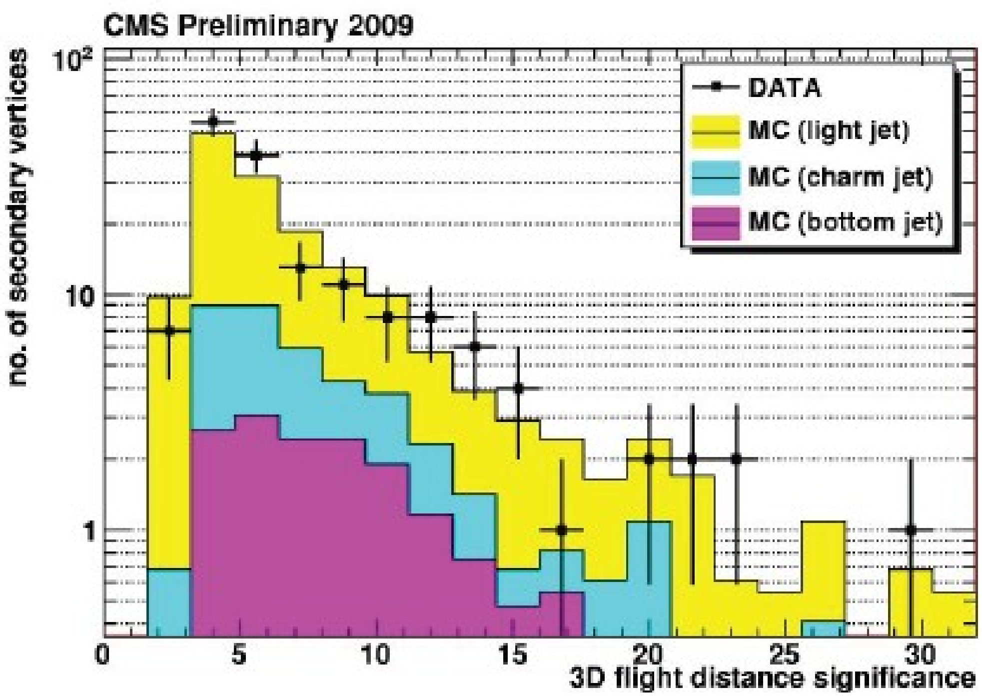
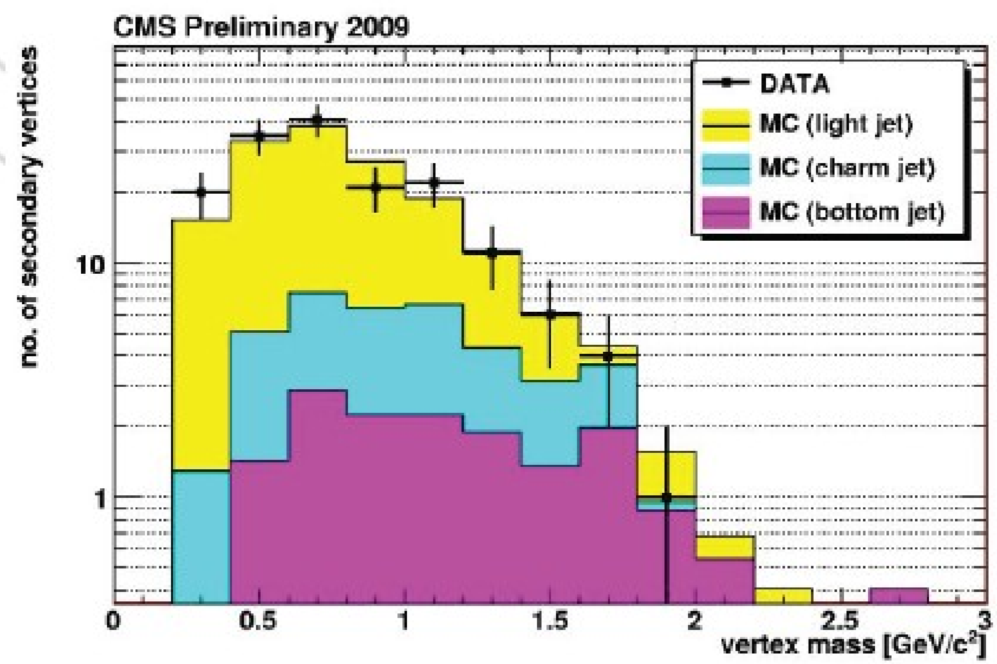


Figure 36: Distribution of the significance of the three dimensional impact parameter for all tracks in the jet (left) and for the first track above 2/3 of charm mass adding tracks in decreasing impact parameter significance order (right). The data is shown as full circles while the Monte Carlo contributions from light flavour, charm and bottom are shown as filled histograms.

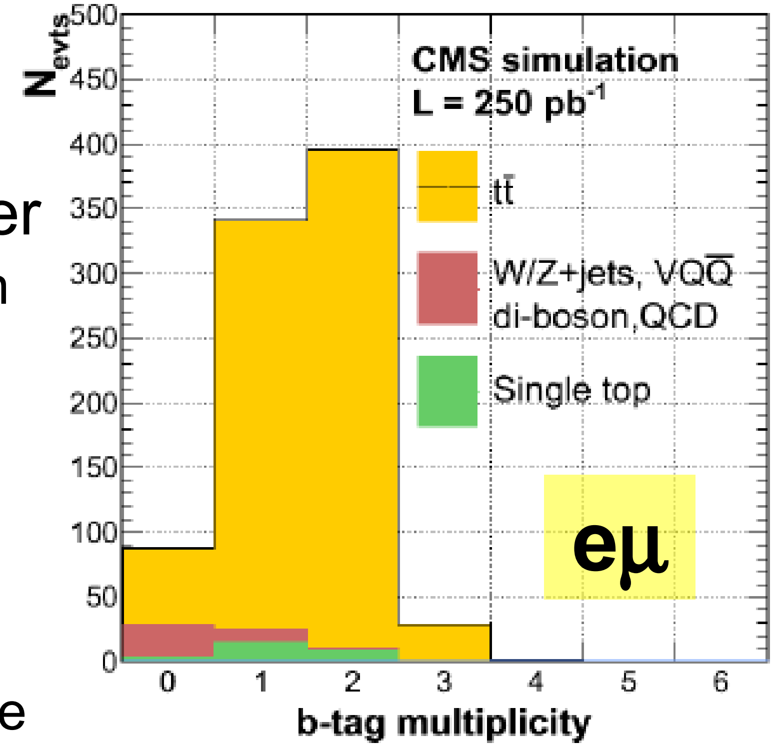
TRK-10-001, secondary vertex



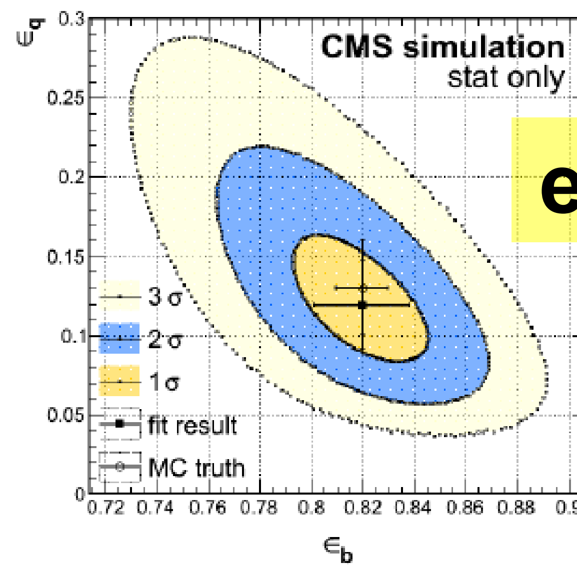


b tagging efficiency or R=BR(t→b)

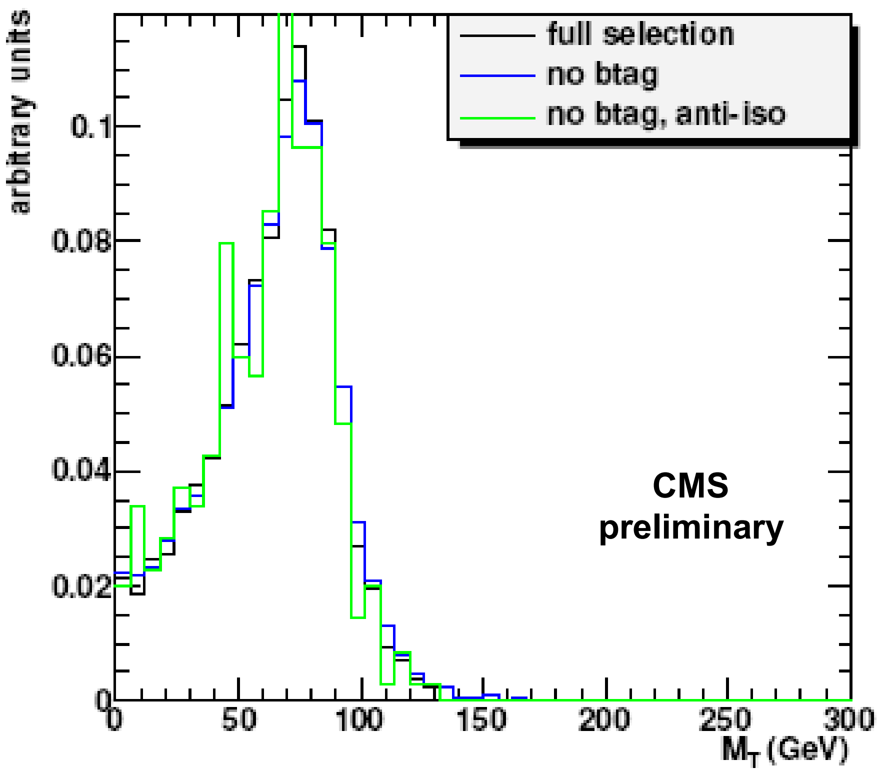
PAS TOP-09-001 (2l)
PAS TOP-09-007 (1l)



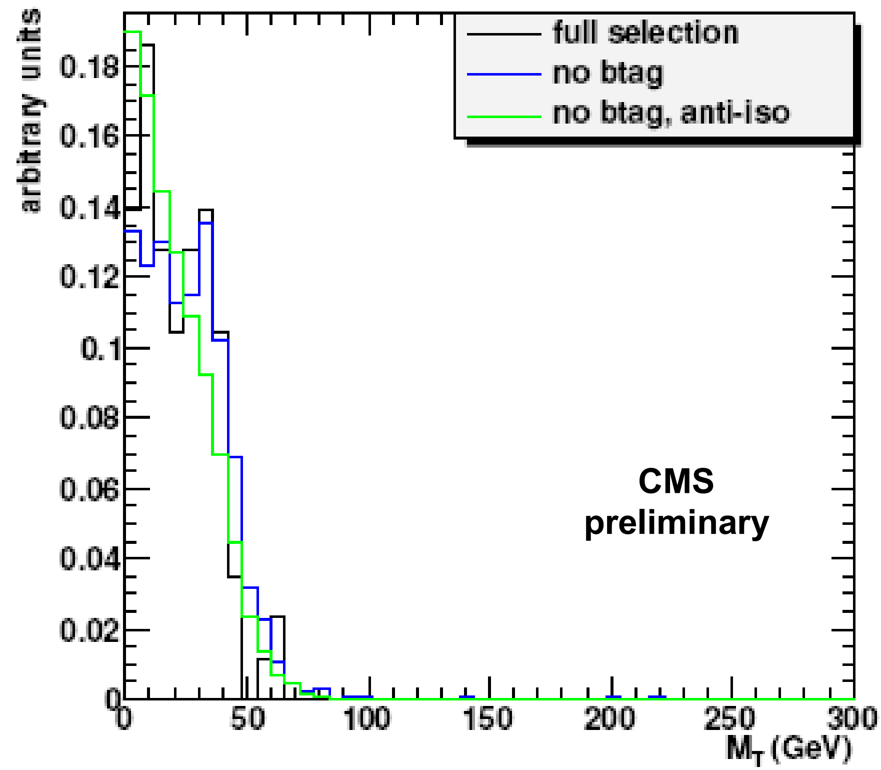
- Start from the standard selection and count the jets above some threshold in some b-tagger
  - A fit to this distribution yields ε_b, with the assumption of SM (R~1), or R if ε_b is estimated independently
  - In this slide a loose b-tagging working point is used, for a combined IP-based algorithm
- In the eμ channel, non-tt background is small
  - The challenge is the *internal* bkg: one b is missed, and a radiation (/pile-up/fake) jet is taken in his place
  - Methods exist to estimate it from the same data
  - Situation is much worse in the l+jets channels
- 250/pb @ 10 TeV: ΔR/R=±2%(stat)±9%(syst)
  - **→~500/pb @ 7 TeV to compete with Tevatron**
  - Dominated by b-tagging uncertainty
  - $\Delta\varepsilon_b/\varepsilon_b$=±1-3%(stat)±4%(syst) if R=1, depending on the threshold and on the tagger



QCD estimation: (in)sensitivity of M_T to btag & iso



Single top, t channel



Multi-jet QCD

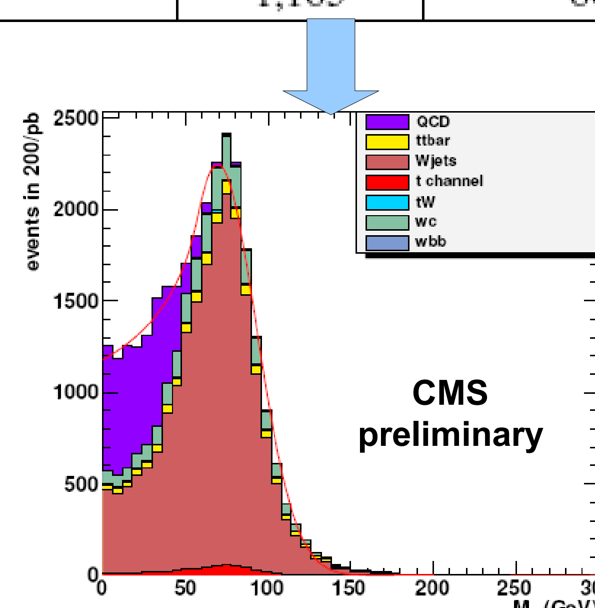
QCD-, W-, Z-enriched control samples: event yields

QCD-enriched

Process	N_{evt} in MC	N_{evt} in 200 pb^{-1}
QCD	56,920	222,036
signal	352	10
$t\bar{t}$	384	30
tW	118	4
$W+$ light partons	417	340
Wc	282	28
$Wb\bar{b}$	21	1

W-enriched

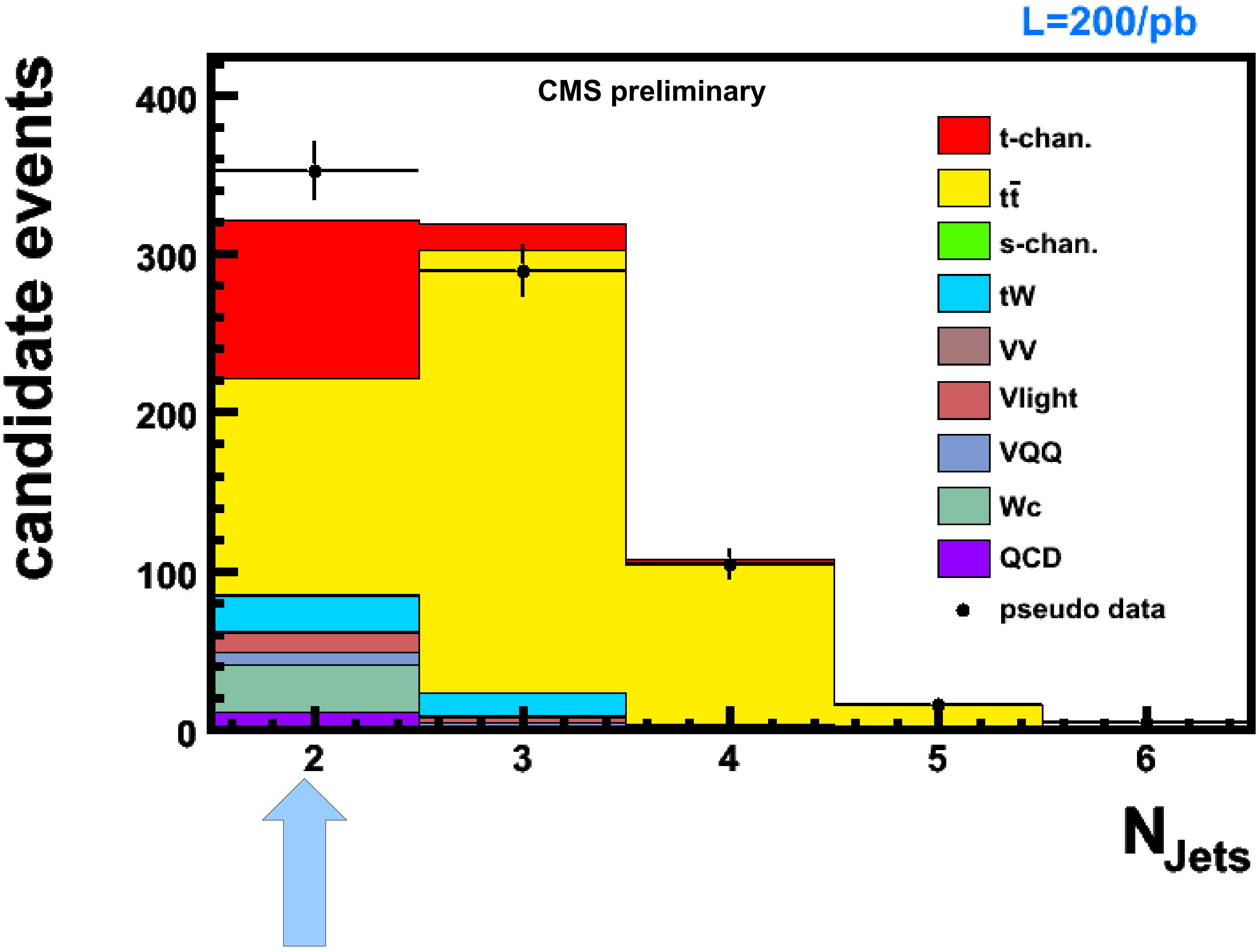
Process	N_{evt} in MC	N_{evt} in 200 pb^{-1}
QCD	1,342	5,235
signal	18,240	544
$t\bar{t}$	10,528	845
tW	4,379	150
$W+$ light partons	23,815	19,439
Wc	25,941	2,567
$Wb\bar{b}$	1,165	80



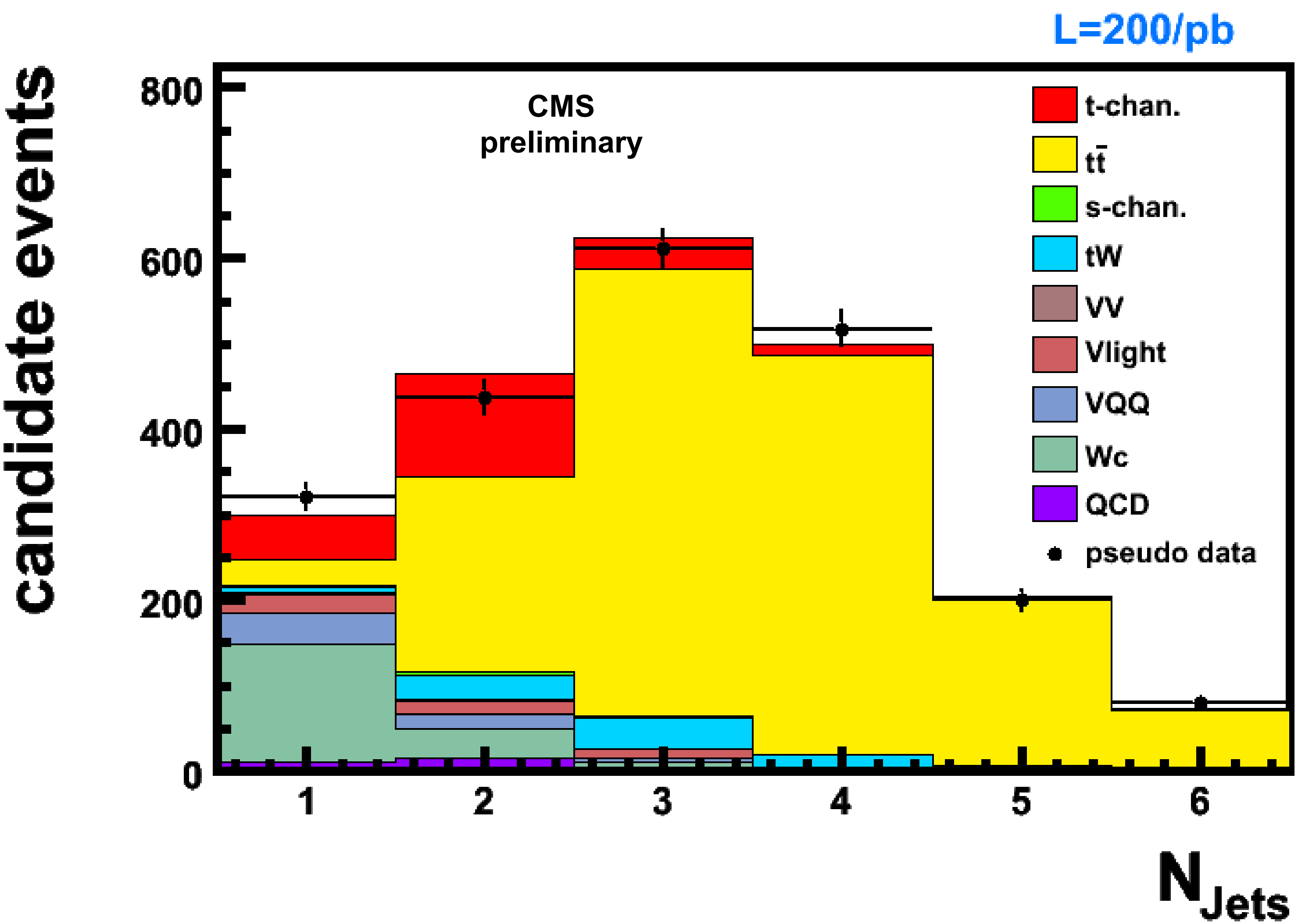
Z-enriched

Process	N_{evt} in MC	N_{evt} in 200 pb^{-1}
$Z+jets$	2,732	1,677
$Zc\bar{c}$	1,198	48
$Zb\bar{b}$	791	45
QCD	1	4
signal	76	2
$t\bar{t}$	530	48
$W+$ light partons	4	3

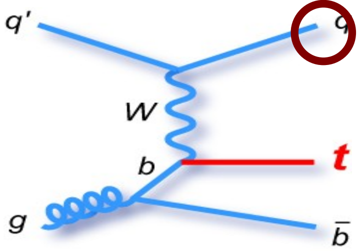
Higher jet multiplicities

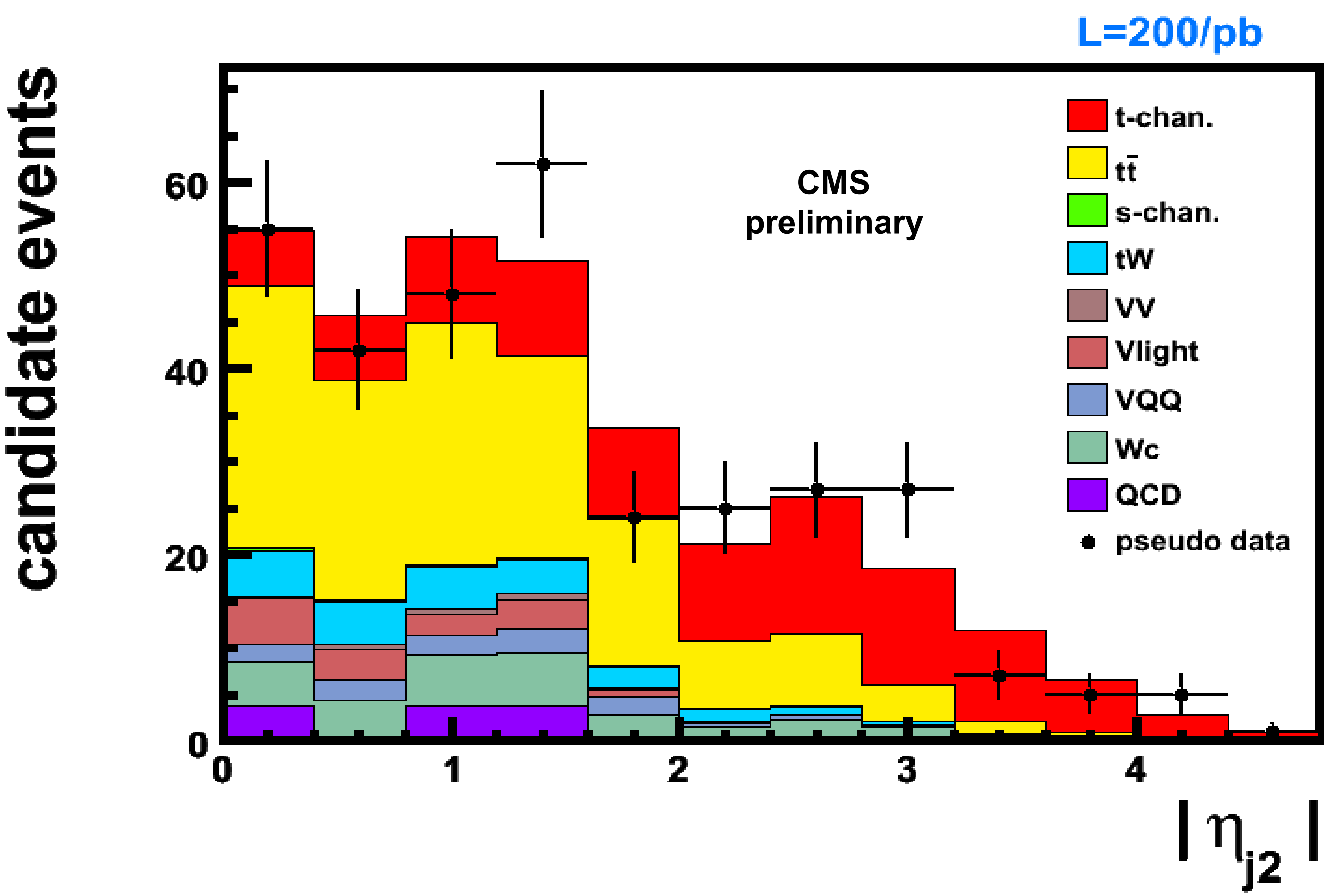


Full selection apart from 2^{nd} b veto

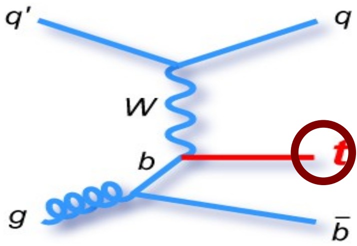


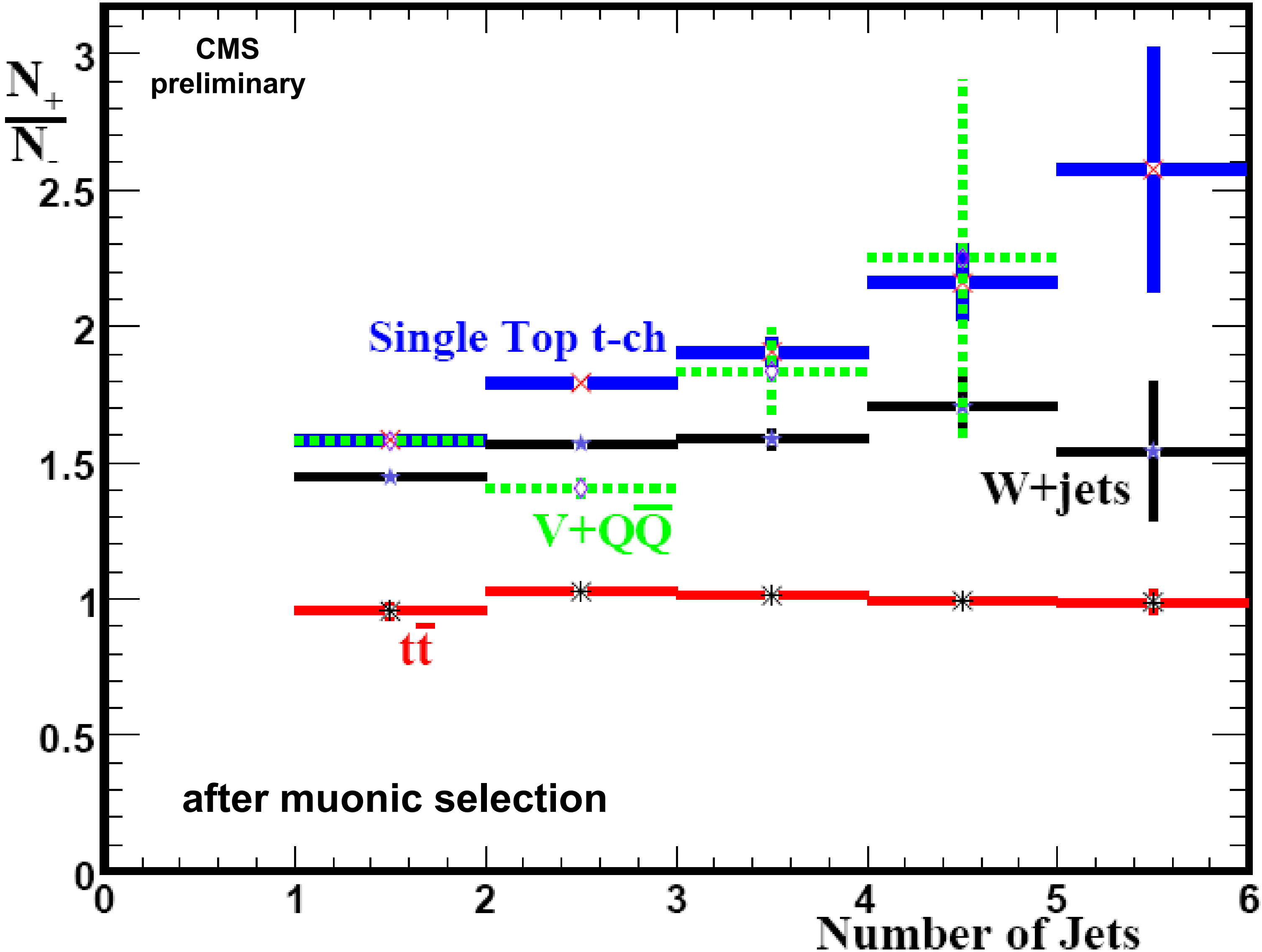
Alternative #1:
η of the "recoil quark"



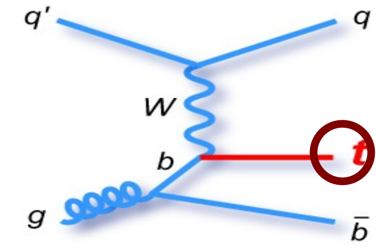


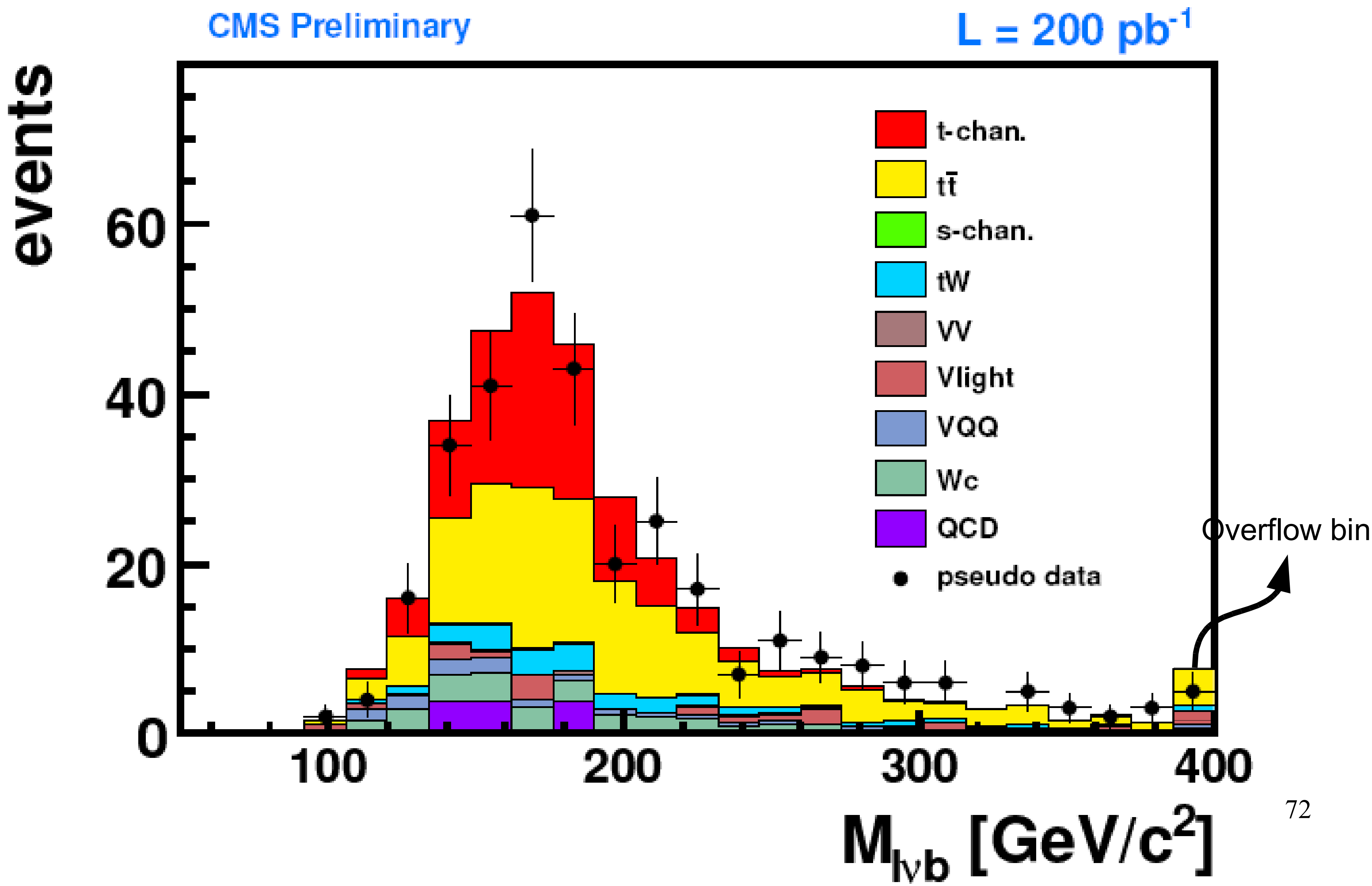
Alternative #2: charge asymmetry



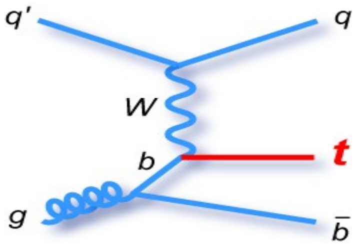


Alternative #3: a peak at the right mass

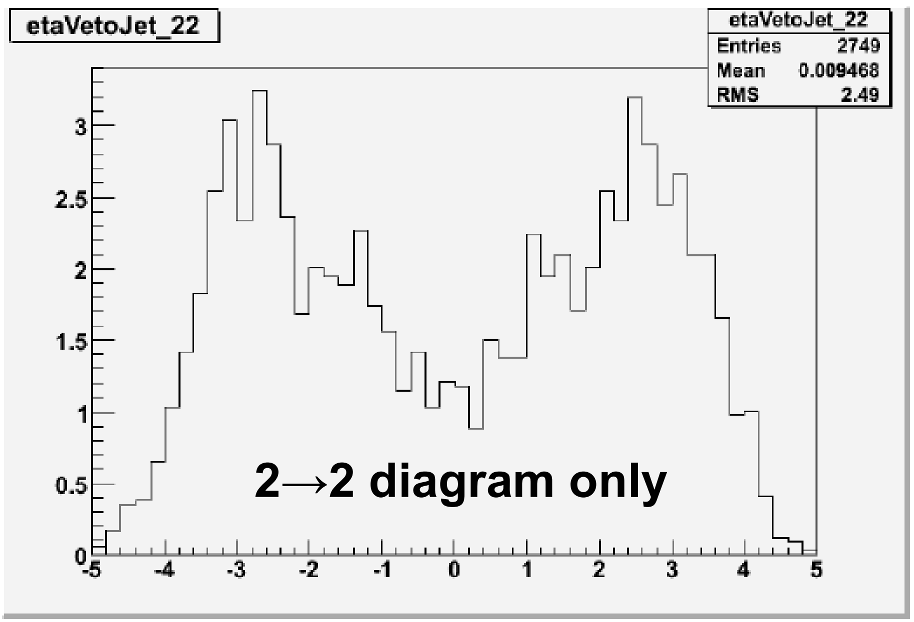


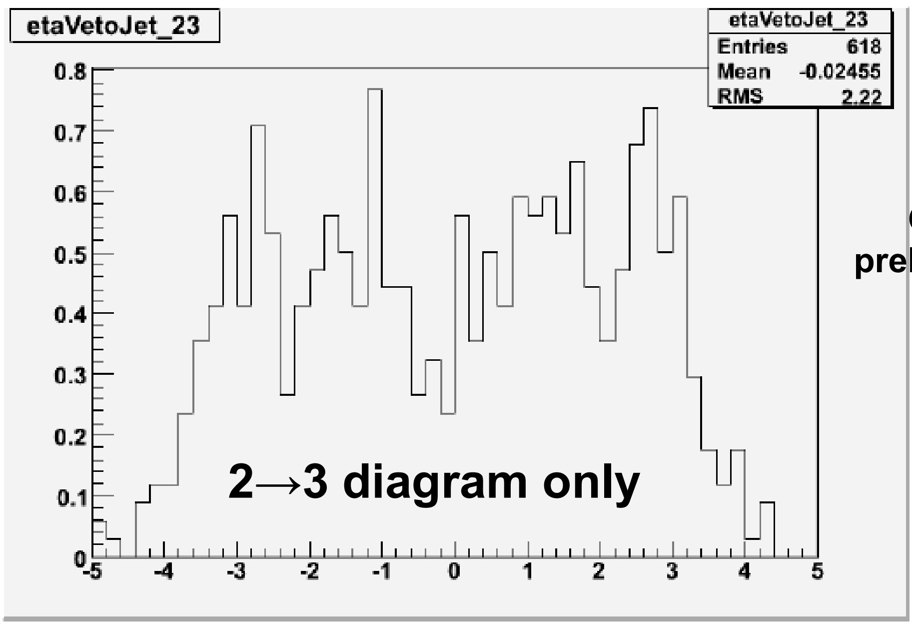


What to choose in a scenario of early data (1)



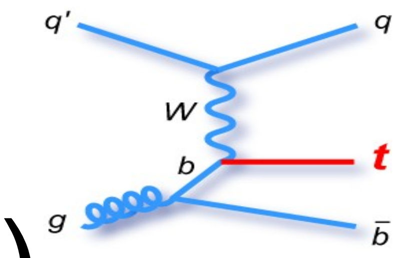
- Pseudorapidity of the recoil quark:
  - **Pro:** excellent discrimination against anything else; S/B>1 for |η|>2
  - **Contra:**
    - Sensitive to signal model
    - Relies critically on forward calorimetry; needs reliable understanding of forward jets, Underlying Event, Minimum Bias Events



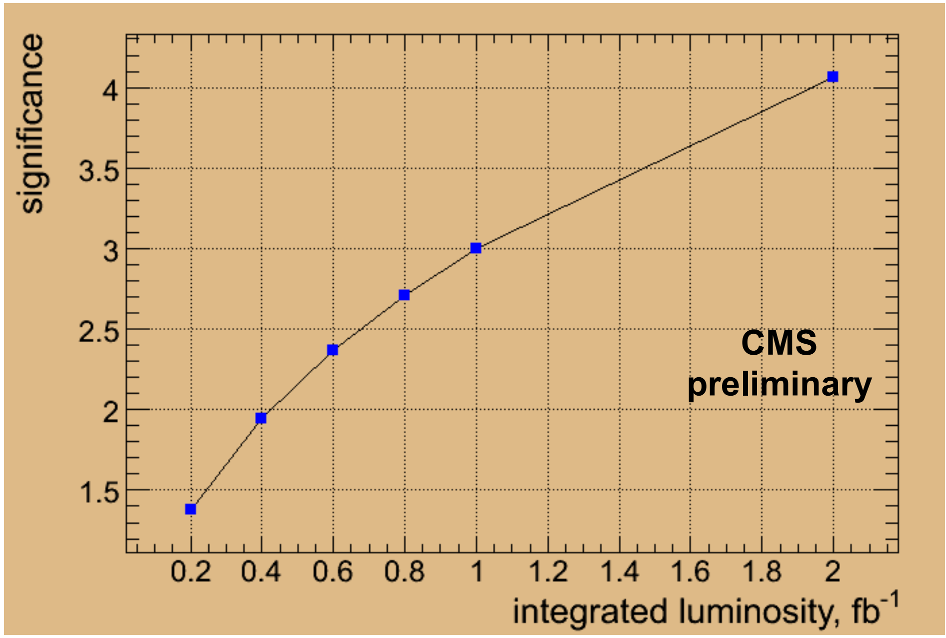


CMS preliminary

What to choose in a scenario of early data (2)

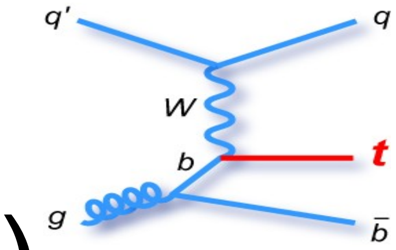


- Charge asymmetry:
  - **Pro:** most backgrounds and most systematics cancel away
  - **Contra:**
    - PDF systematic becomes critical
    - W+jets is charge-asymmetric too, thus it doesn't cancel out; simultaneous data-driven extraction of its **σ*A** is under consideration, but more work needed
    - most of all, statistical error is larger (N^+-N^- ~ N/4)

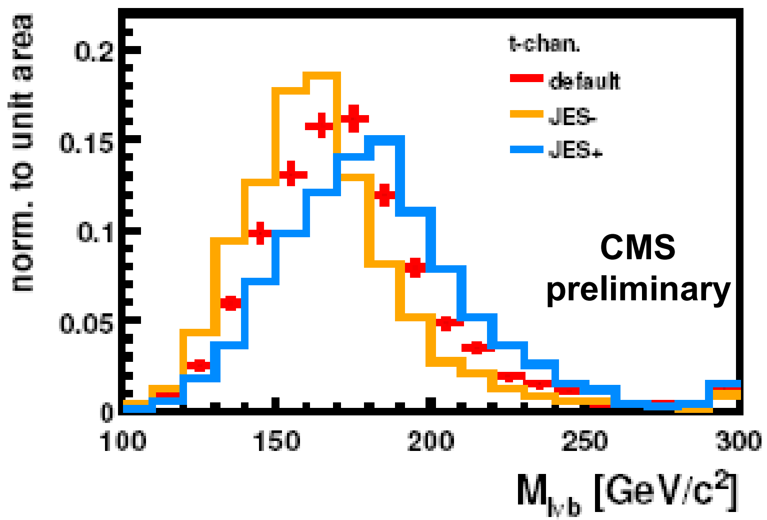


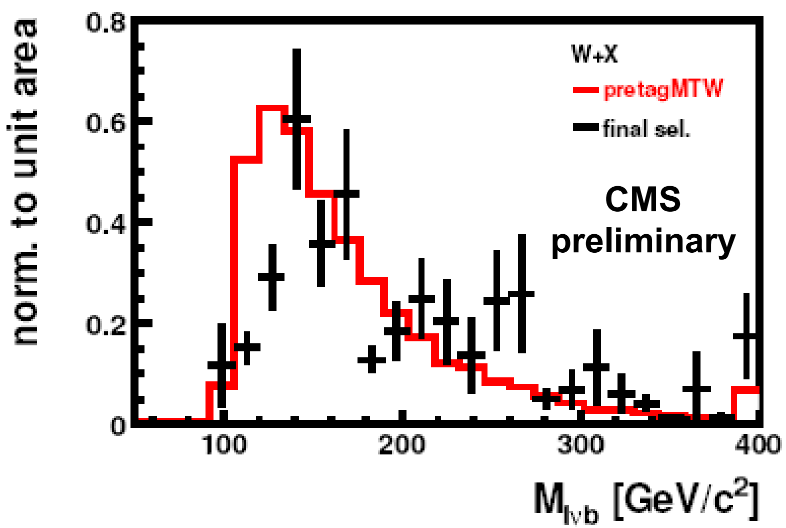
Muon channel only, same event selection, systematics included, uncertainty on the W asymmetry taken equal to what we expect after ~100/pb from the dedicated measurement in the 0j sample (and assumed 100% correlated for signal)

What to choose in a scenario of early data (3)

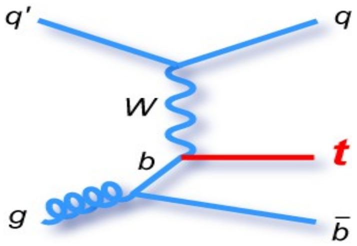


- Reconstructed mass:
  - **Pro:**
    - Boost-invariant
    - Good discrimination; we tried a template fit w/ 3 free parameters (st, tt & tW, W/Z+X; QCD constrained with the method seen before) and it works
  - **Contra:**
    - shape is very sensitive to jet uncertainties and gluon radiation
    - We tried to take W/Z+X and QCD shapes from control samples with relaxed selection, but corrections would be needed





What to choose in a scenario of early data (4)



- Polarization:
  - **Pro:**
    - All backgrounds share the same shape (and it is a very simple one!)
    - Shape is remarkably stable against theory and detector systematics, for both signal and backgrounds
  - **Contra:**
    - Close to ~1, sensitive to kinematic cuts and isolation
    - Complication when used in conjunction with η cut: bias on bkg makes it more signal-like

Know your enemy: what kind of ttbar remains