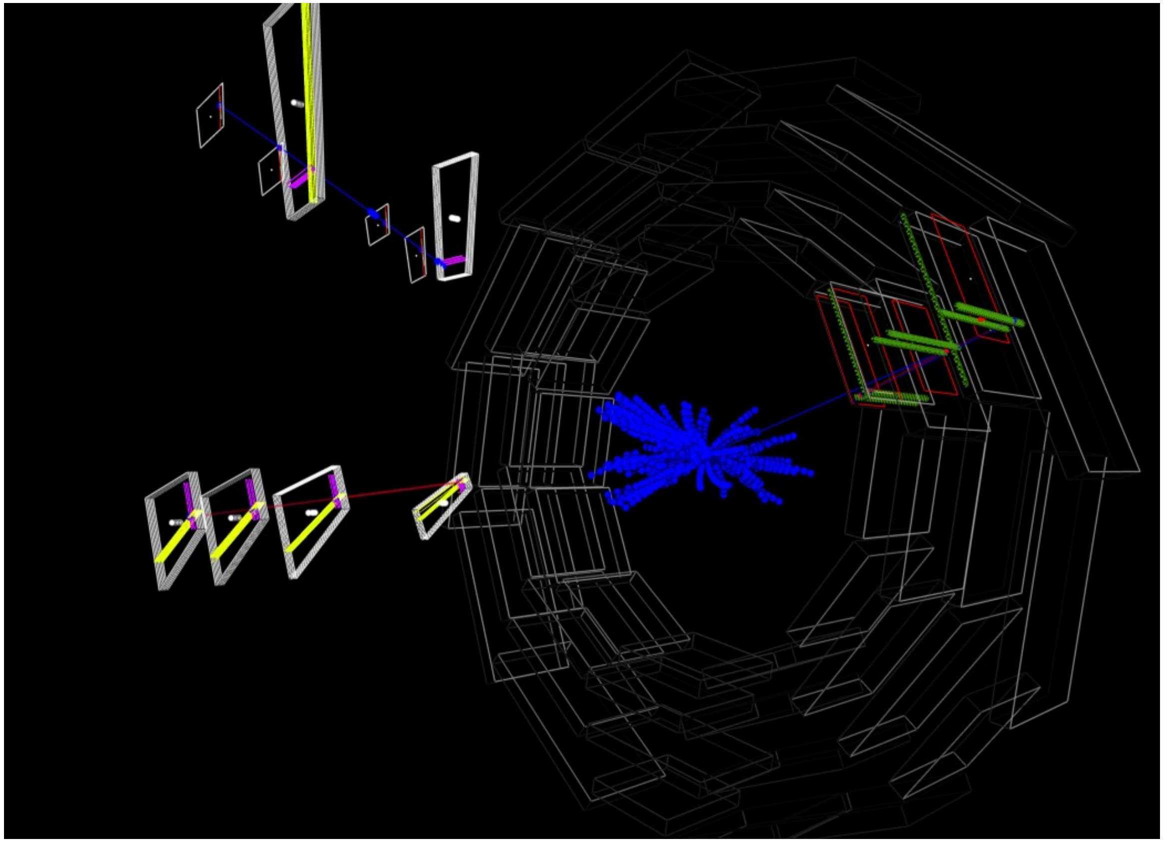
Top physics with the CMS detector
from re-discovery to new physics

Andrea Giammanco
CP3 / UCL, Louvain-la-neuve, Belgium



Dimuonic ttbar event in CMS
courtesy of Martijn Mulders

Strasbourg, 1 feb. 2008

General philosophy of this talk

- I will try to make a case for a continuous line of research which starts with the re-observation of top quarks with very early data, and ends with searches, in the top sector, for phenomena forbidden in the SM
- This talk is explicitly biased towards my own past and present research interests

Examples: I will not talk about the measurement of the **mass** (although it's one of the most important top quark studies) nor about **resonances in M(tt)** (although it's a well-motivated search for new physics)

Outline

- **Part I: why and how?**
  - top physics at LHC, in a nutshell
  - CMS as a tool for top physics
- **Part II: expectations for CMS analysis**
  - Reassessing the Standard Model
  - Precision top physics
  - Looking for new phenomena in the top sector

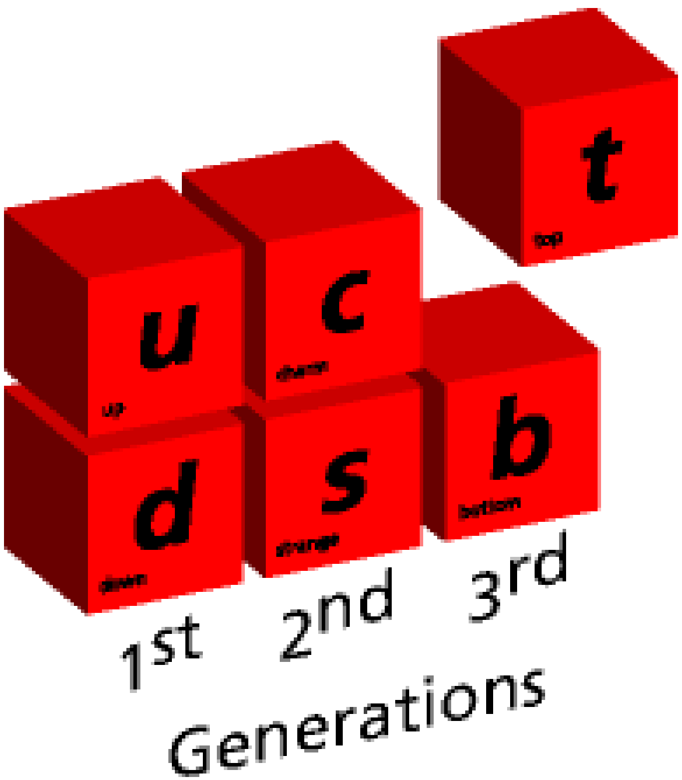
Part I

Why top physics?

Why at LHC?

Is CMS fit and ready?

What is Top



- A 3rd generation quark
- Charge +2/3 (*)
- Lifetime: ~ 10^{-25} s
- Mass: 170.9±1.8 GeV (~ M_{au})
- BR($t \rightarrow Wb$)~100% (**)

(*) this has been established at 90%CL only in 2006! Before, it was mainly "theoretical prejudice" to favour +2/3 over the -4/3 assignment.

(**) mostly from CKM unitarity assumption. I will come back to this later.

Why should we study Top?
(the point of view of precision physics)

- It exists
  - But it's the less known quark: room for improvement
  - Its mass is already precise enough (~1%) to make it useful as a "standard candle"
- $M_t > M_W$: this means that the W is not virtual
  - Γ proportional to G_F, not G_F^2. Result: $\tau_{decay} < \tau_{hadr}$
  - **Even "standard" top physics is unusual!**
- Through its decays, we probe a "naked" quark
- $\tau_{decoherence} > \tau_{hadr} > \tau_{decay}$: polarization is measurable(*)

(*) I will not talk about that in this seminar, but **polarization in single top, spin correlations in ttbar and W polarization** are sensitive to non-EW contributions to couplings

Why should we study Top?

(the point of view of discovery physics)

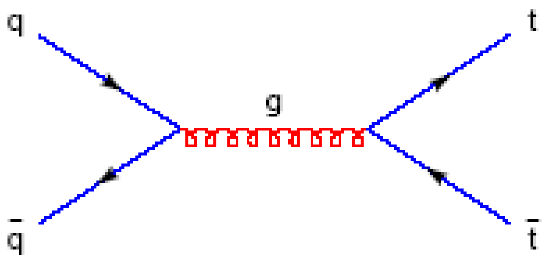
- It's the highest mass fermion: the Higgs likes a lot to couple with a top
- New particles may decay preferentially into top, especially in models which try to explain the “coincidence” $y_t \sim 1$
- Top may decay in new particles (e.g., a light charged H) or through new processes (e.g., FCNC enhanced by SUSY)

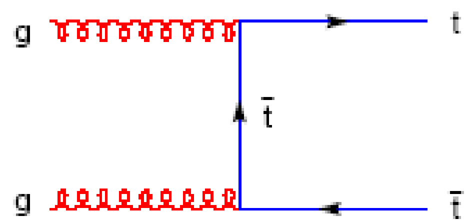
<u>On the other hand:</u>

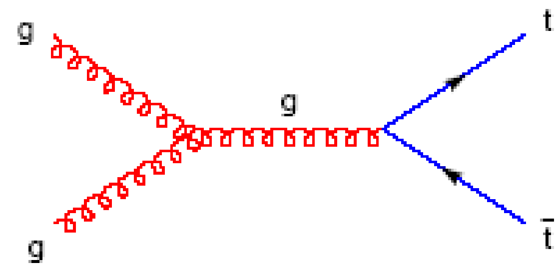
- Top is a **major background** for a lot of “new physics” signatures: until you know its phenomenology in detail, very hard to make serious claims for discoveries
  - Memento UA1: after W and Z, in 1984 it “discovered” the top at 40 GeV and SUSY at the 100 GeV scale (culprits: W/Z+jets)
  - Concrete example: ttH→ttbb (we need to know ttjj)

LHC is a Top factory

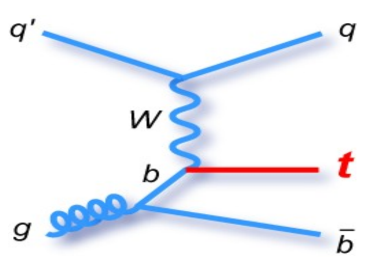
- $t\bar{t}$: gluon fusion (90%) or $q\bar{q}$ annihilation (10%)
  $\sigma_{NLL} = 833^{+52}_{-39}$ pb



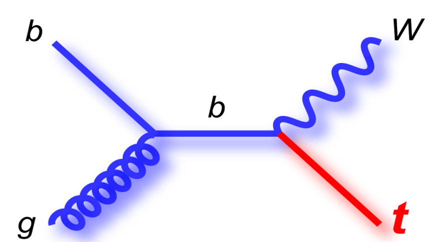




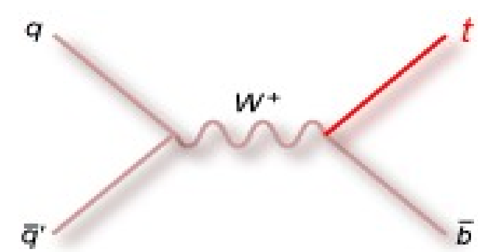
- Electroweak production ("single top") is not negligible:



t-channel
(σ_{SM} ~ 240pb)



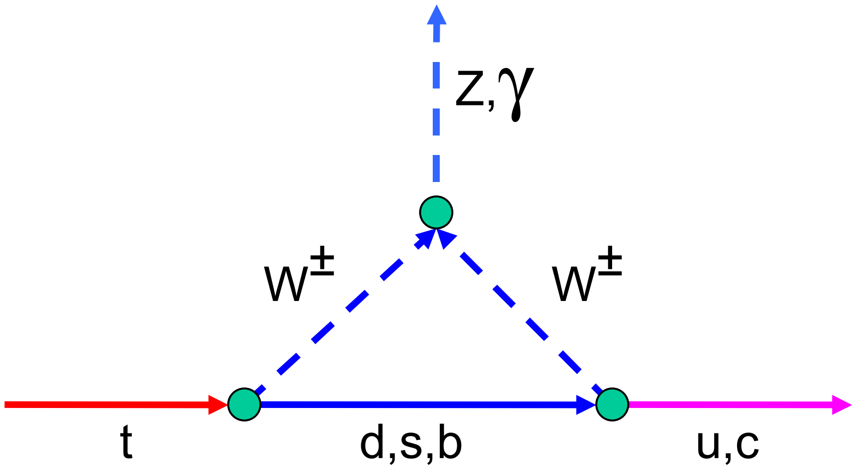
Wt production
(σ_{SM} ~ 60pb)

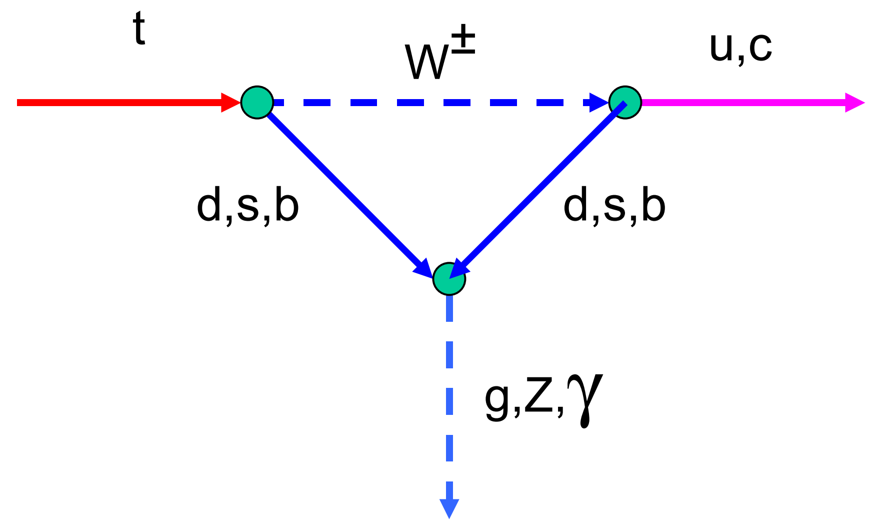


s-channel
(σ_{SM} ~ 10pb)

11 million top events/year
(>1 event/second) at $L=10^{33}cm^{-2}s^{-1}$

GIM-suppressed decays (FCNC)





FCNC decay	BR in SM	BR in 2HDM-II	BR in 2HDM-III	BR in MSSM	BR in MSSM + R violation
$t \to \gamma q$	$4.6\ 10^{-14}$	$\sim 10^{-7}$	$9\ 10^{-4}$	$\sim 10^{-6}$	$\sim 10^{-5}$
$t \to Zq$	10^{-14}	$\sim 10^{-8}$	$\sim 10^{-6}$	$\sim 10^{-5}$	$\sim 10^{-4}$
$t \to g\, q$	$4.6\ 10^{-12}$	$\sim 10^{-5}$	$\sim 10^{-4}$	$\sim 10^{-4}$	$\sim 10^{-3}$

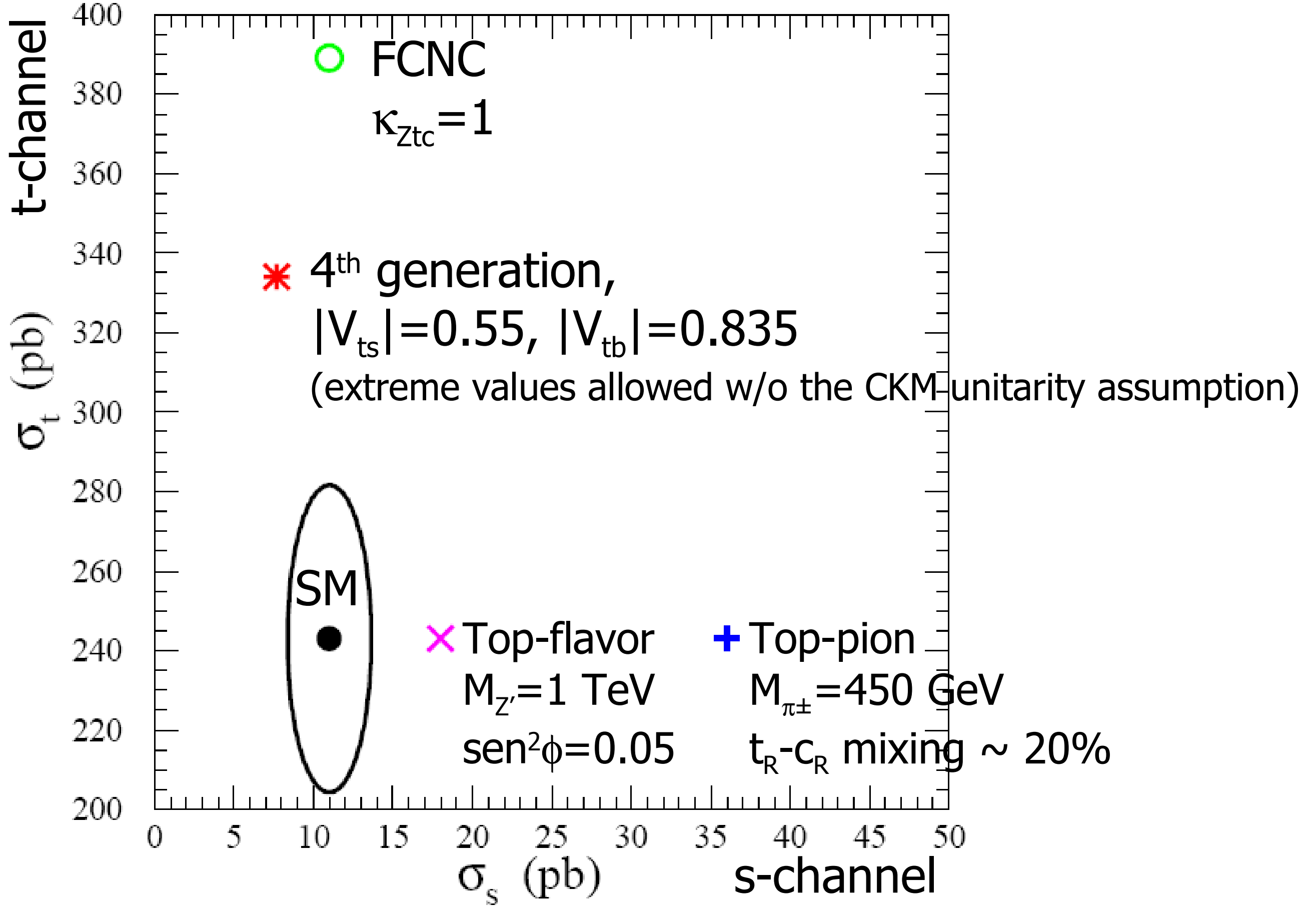
BR in TC	BR in LR	BR in QS	Exp. Limits (95% CL)	FCNC decay
$5\ 10^{-7}$	$9\ 10^{-6}$	$\sim 10^{-8}$	$< 5.9\ 10^{-3}$ ($t\gamma u$) (ZEUS)	$t \to \gamma q$
10^{-4}	$\sim 10^{-4}$	$\sim 10^{-4}$	$< 10.6\ 10^{-2}$ (CDF, Summer '07)	$t \to Zq$
$5\ 10^{-3}$	$\sim 10^{-5}$	$\sim 10^{-7}$	$< 3.7\ 10^{-2}$ (tgu), $< 15\ 10^{-2}$ (tgc) (D0)	$t \to g\, q$

Single Top and new physics

- The same final states of the SM single top (i.e. tq, tb, Wt) can come from non-SM fundamental processes
- t': if $M_{b'}>M_{t'}$, main decay is Wb
  - And for $M_{t'}>270$ GeV, the t'q production mode is favored over $t'\bar{t}'$: enhancement of t-channel at high mass/HT
- W' or W_{KK} would enhance the s-channel
  - If their coupling is SM, they will be observed in leptonic decays much earlier than in single top
  - But the W' b.r.'s are model dependent, and in some models the coupling to leptons is suppressed (W_R: “wrong” helicity!)
- Any model with FCNC (e.g. SUSY) enhances t-channel: while SM needs a **b** in the initial state, FCNC can have a **u**

t- vs s-channel

T.Tait, C.-P.Yuan, Phys.Rev. D63 (2001) 0140018



Wt gets sizable virtual corrections (up to +13%) from colored SUSY particles (Beccaria et al., EPJ C53 (2008))

V_{tb} in a 4x4 or 4x3 matrix

- SM, 3x3: $0.9990<|V_{tb}|<0.9992$ @90%CL
- In hep-ph/0607115 (EPJ C 2007) we reexamined the direct and indirect experimental constraints when CKM is minimally extended to a 4th family, or to a single pseudo-vector quark (b'/t')
- $V_{tb} \sim V_{tb}^{CKM}\cos\theta$; θ: t-t' mixing angle (u-t' and c-t' mixings are very tightly constrained by experiments); limits depend on $M_{t'}$ (Tevatron limit: $M_{t'}/M_t>1.5$)
- With 4th family: $V_{tb}>0.93$
- With pseudo-vector t': $V_{tb}>0.91$

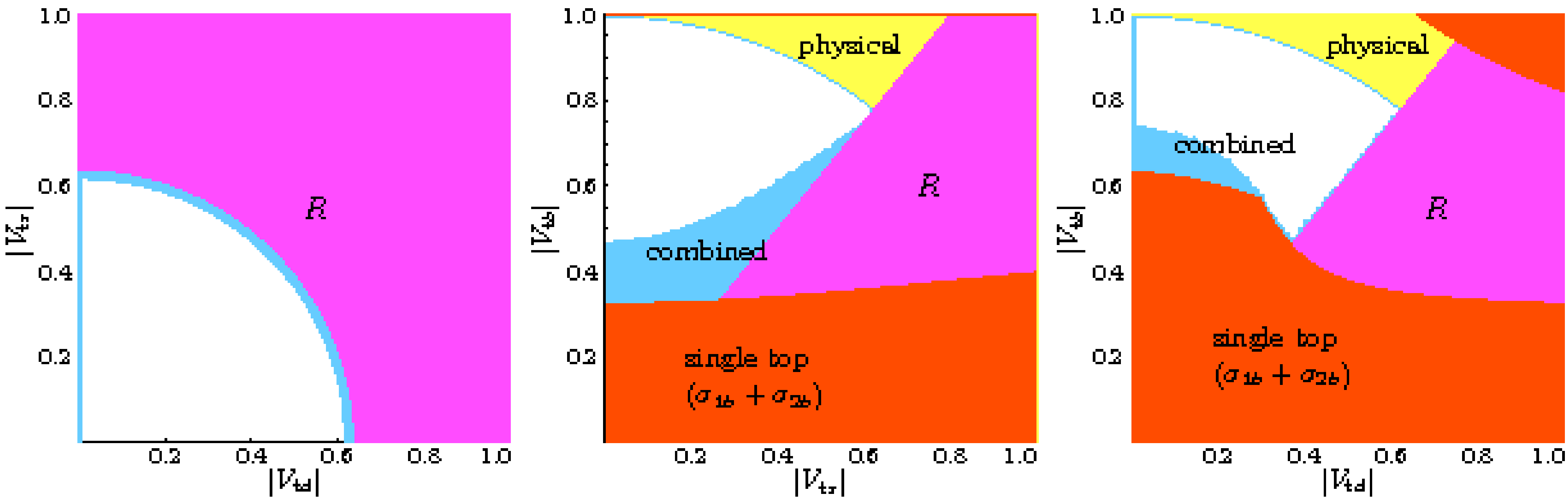
This sets a clear goal for the precision that we want to achieve on Vtb

- Nota bene: here is assumed that no other particles exist; a more rich zoology at low energy can further relax the limits

Limits on V_{ti} from R and single top

R = BR(t→Wb) / BR(t→W + any quark)

$$R = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{td}|^2 + |V_{ts}|^2}$$



Study from hep-ph/0607115 updated in arXiv:0801.1800 [hep-ph],
"Collider aspects of flavour physics at high Q"
using Tevatron data on single top and R

From Tevatron to LHC

	1.96 TeV	14 TeV	
ttbar pairs	$5.06^{+0.13}_{-0.36}$ pb	833^{+52}_{-39} pb	(x170)
Single top (s-channel)	0.88±0.06 pb	10.7±0.7 pb	**(x10)**
Single top (t-channel)	1.98±0.14 pb	247±10 pb	(x120)
Single top (Wt channel)	0.15±0.04 pb	66±2 pb will be discovered at LHC	(x400)
Wjj (*)	~1200 pb	~7500 pb	(x6)
bb+other jets (*)	$\sim 2.4 \times 10^5$ pb	$\sim 5 \times 10^5$ pb	(x2)

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

Analyses will be quite different from Tevatron

CMS and top physics

Top physics is like pentathlon for athletics: it doesn't necessarily require an outstanding performance from a single subdetector (like, e.g., $B_s \to \mu\mu$ or $H \to \gamma\gamma$) but all the subdetectors have to be quite good.

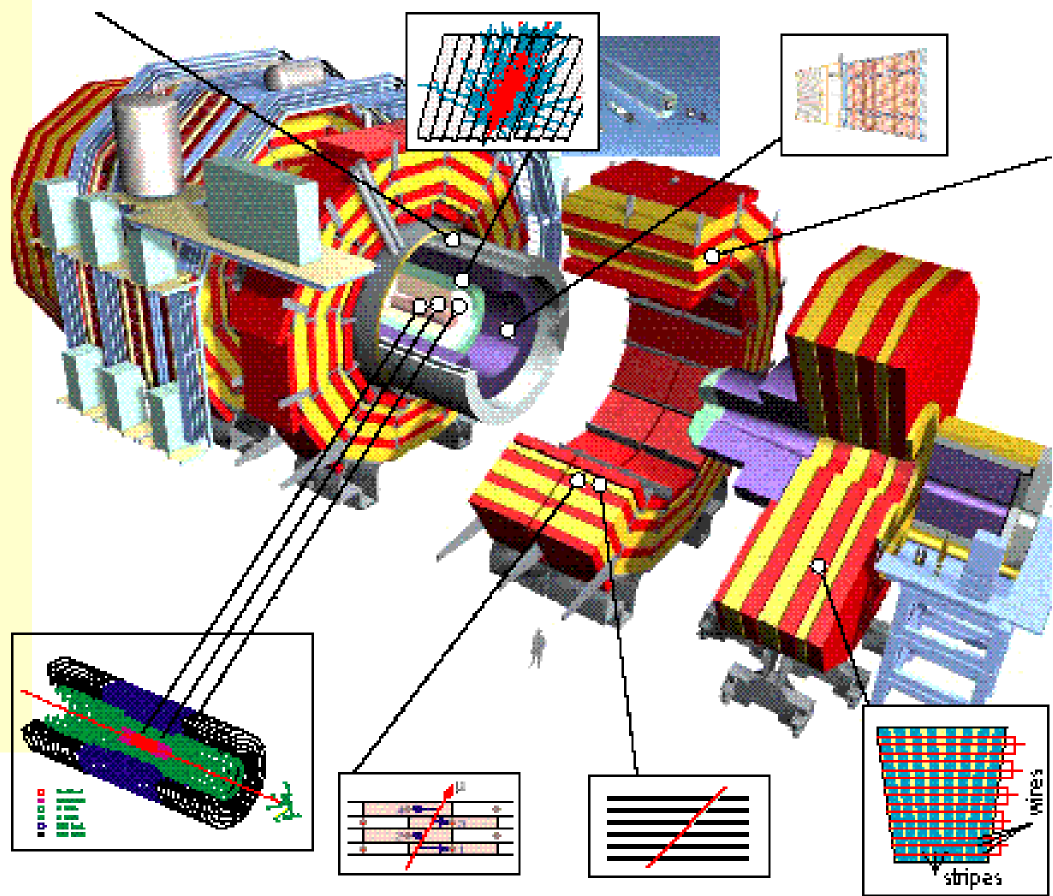
A semileptonic top decay gives:

- an electron (ECAL+Tracker)

or a muon (Muon chamb.+Tracker)

or a tau (Tracker + HCAL + ECAL)

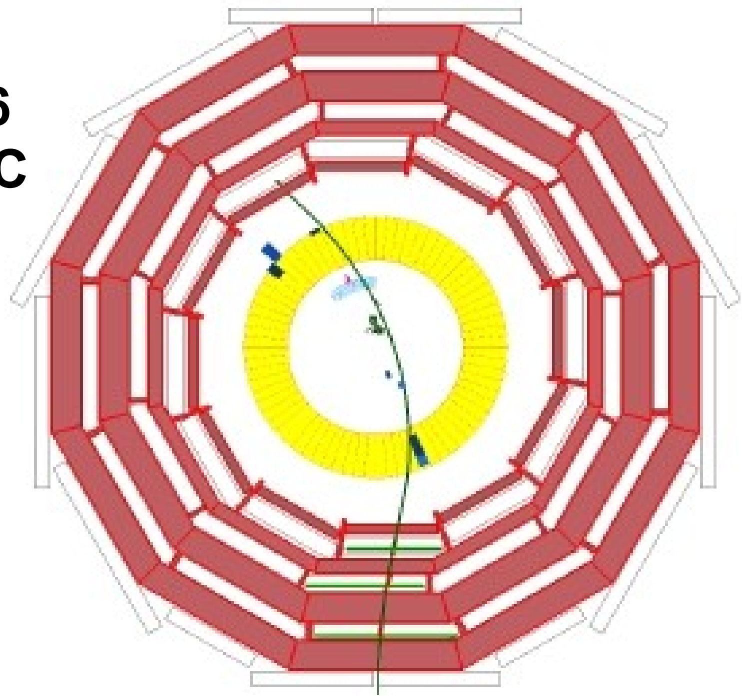
- jets (HCAL+ECAL)
- secondary vertexes (Tracker, in particular Pixels)
- missing energy (HCAL+ECAL)



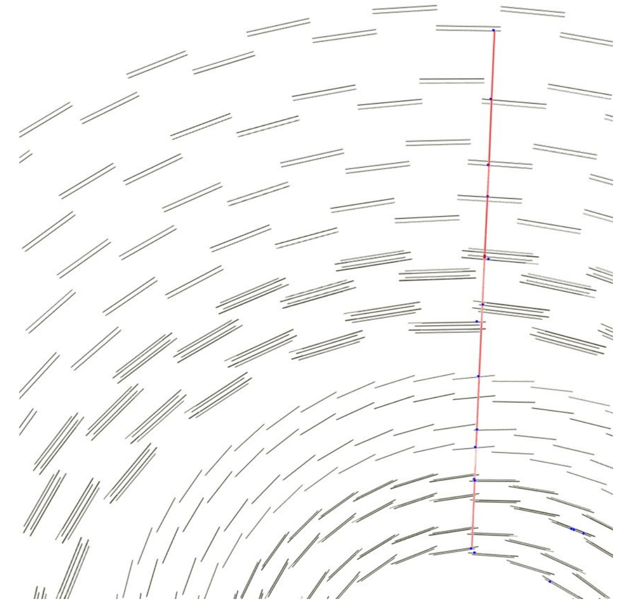
With ParticleFlow, the Tracker improves significantly jets/MET/taus

Getting ready: Magnet Test / Cosmic Challenge, Slice Test, etc.

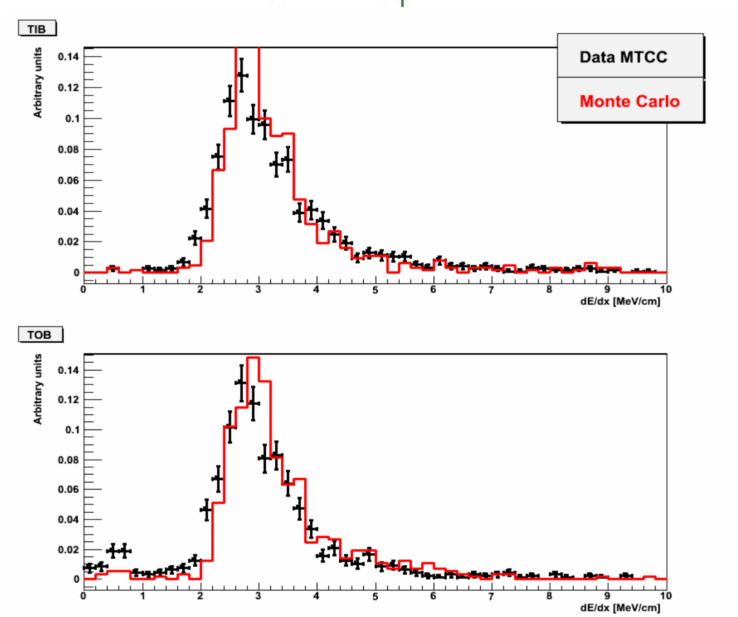
2006
MTCC



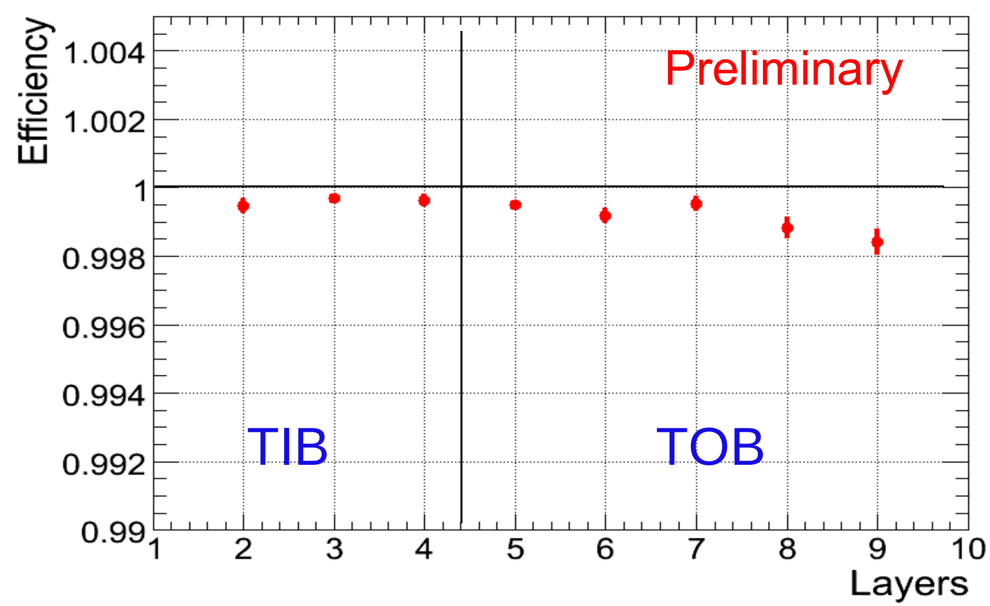
2007
ST (TIF)



MC validation @MTCC: dE/dx

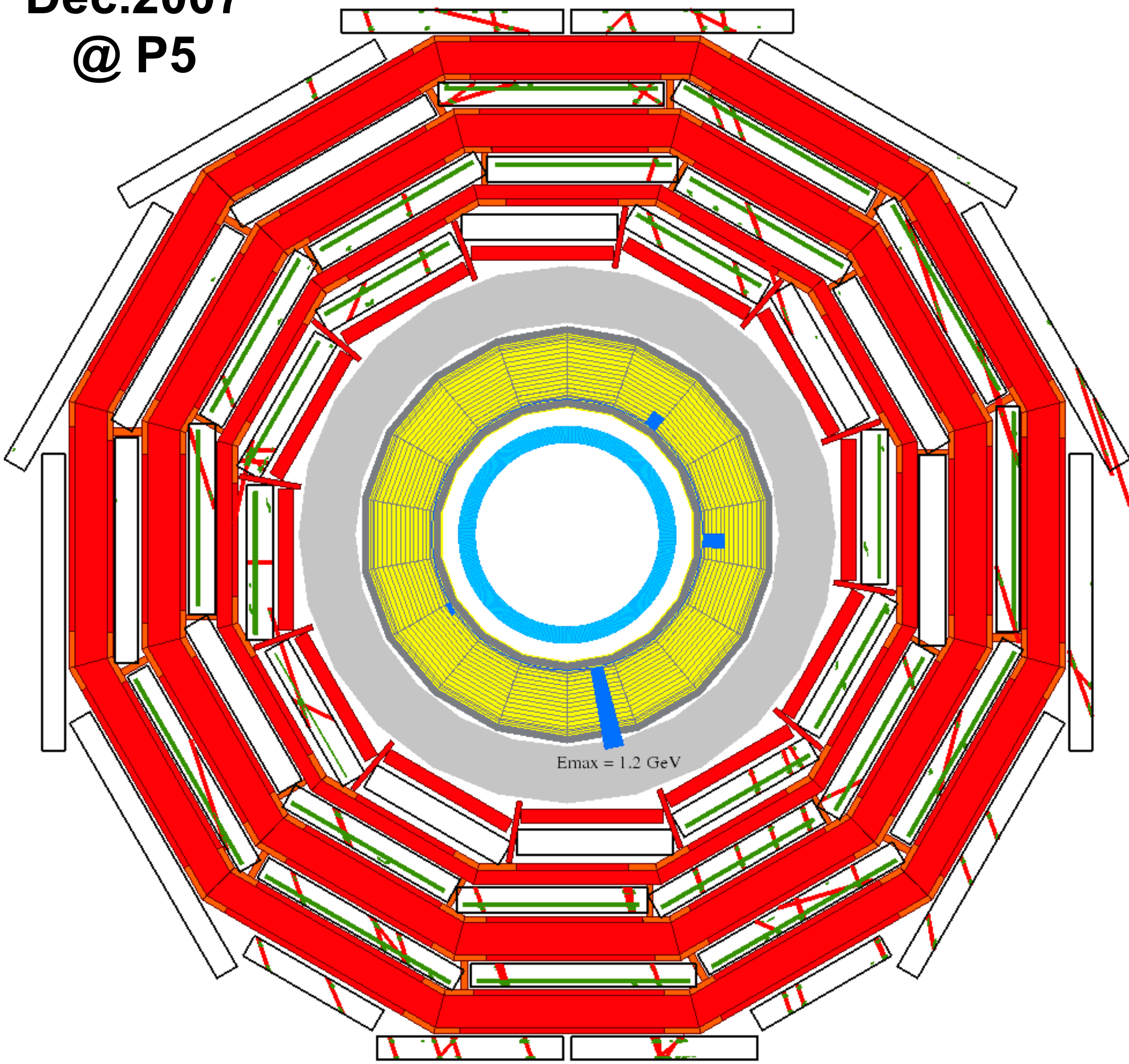


Module efficiency @TIF Slice Test



Almost there

Dec.2007
@ P5



- 100% of HB
- 50% of HF, HE
- 20% of DT, HO
- 10% of barrel RPC, EB (for a few days)
- 0.04% of strip tracker (6 modules)
- First HLT tests

A cosmic shower seen in HCAL and the Drift Tubes, triggered by RPCs

Part II

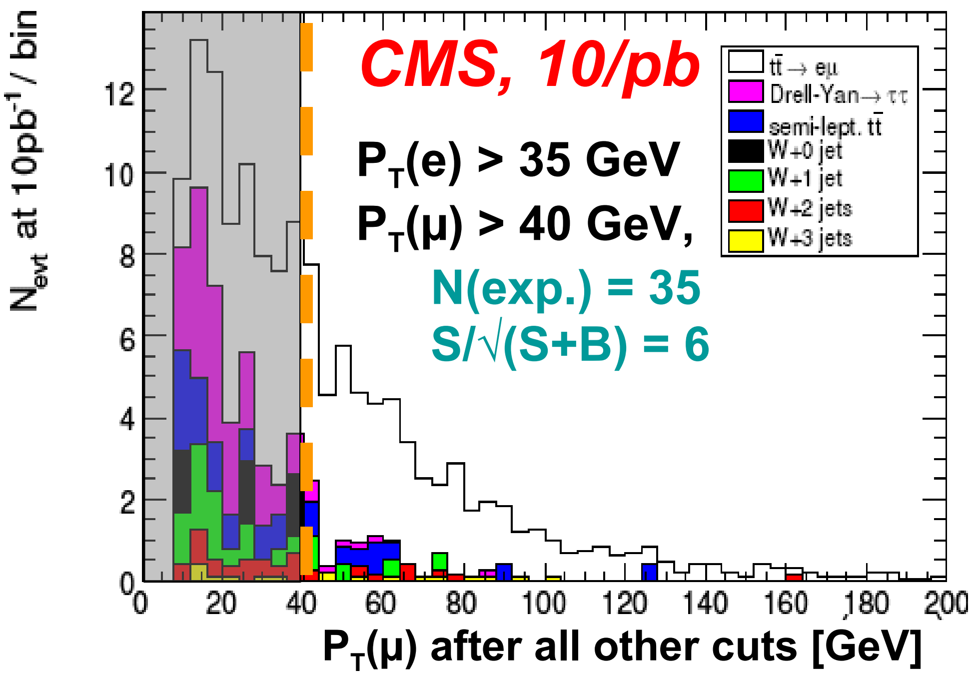
Prospects for CMS,
based on published or ongoing MC analyses

Rediscovering top

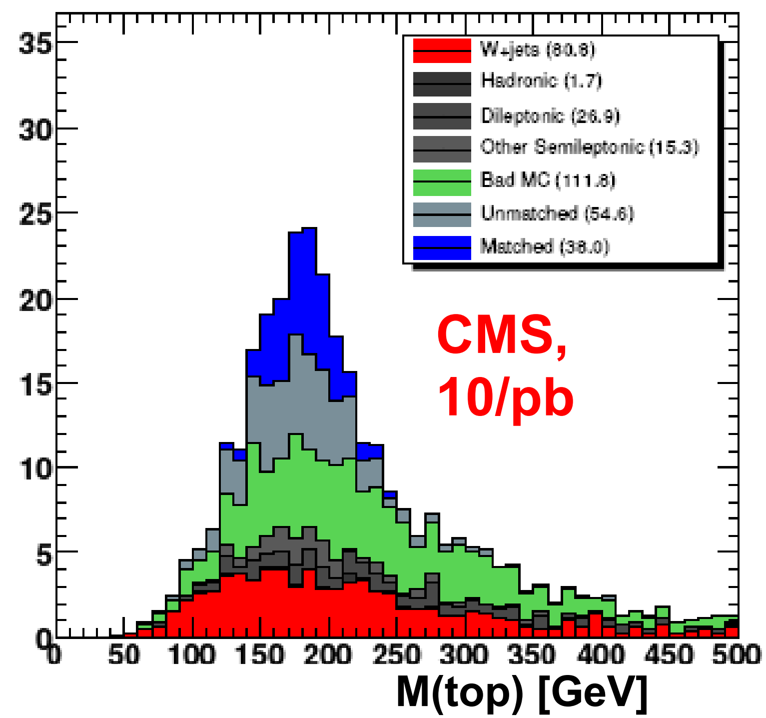
- Although not scientifically very relevant *per se*, the "re-discovery" of the SM particles will constitute an important benchmark for the LHC experiments
- While W and Z will be very simple from the point of view of the event selection, top quark will be the first complex final state to be studied
- Only "easy" topologies will be exploited at this stage: single-leptonic (high BR, reasonable S/B), and di-leptonic, in particular eμ (small BR, but high S/B)
- This is the topic of our "2007 paper" **AN-2007/022**, *"Early measurements of top quark pair events with the first data of CMS"*

How we will observe the first european top quarks

DILEPTONIC



SEMI-LEPTONIC



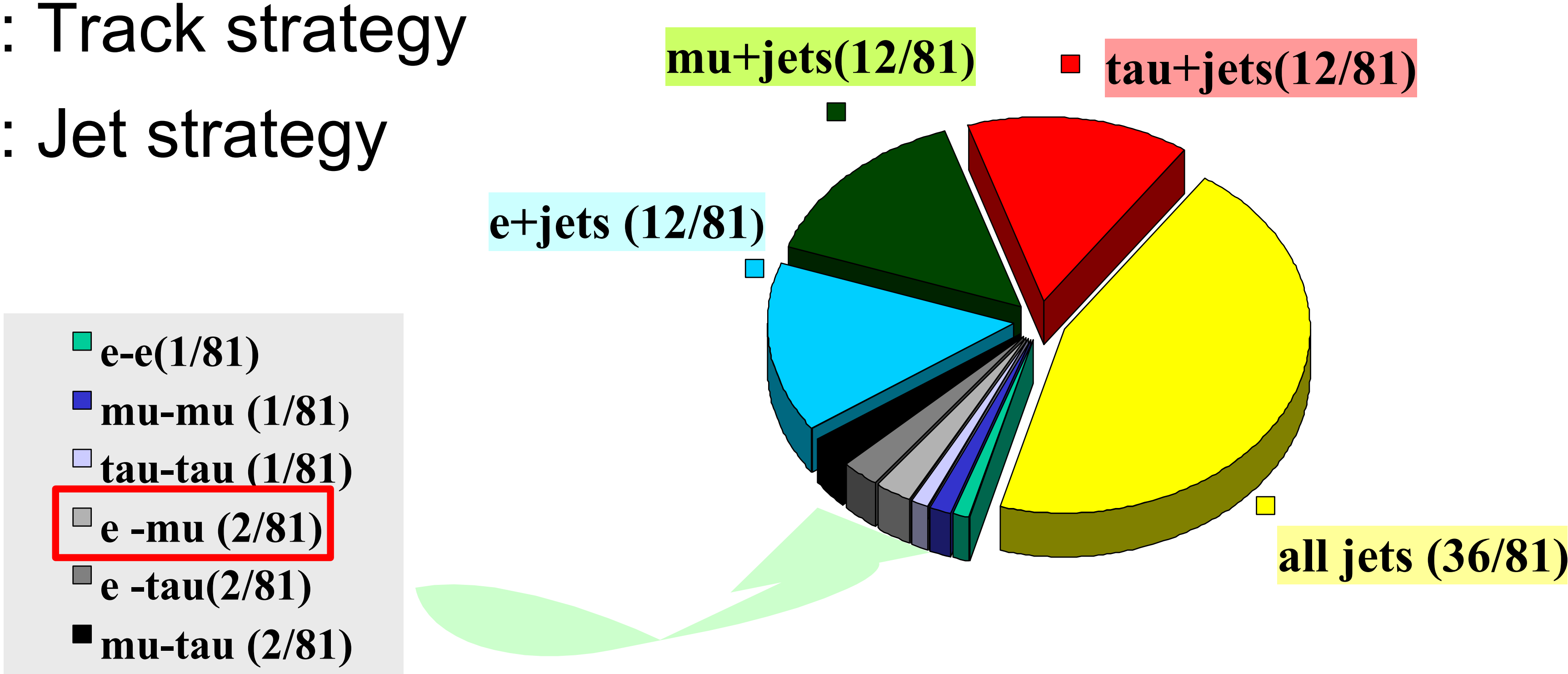
No b-tag; highest-pt combination of 3j; angular selection for jets from W (other options in a backup slide)

CMS AN 2007/022 in progress

J.Caudron, AG, D.Kcira, V.Lemaitre, in CMS AN 2007/022

The eμ channel

- b-tagging is not used (in order to minimize impact of Tracker misalignment)
- Three complementary strategies are being explored:
  - M1: Inclusive leptonic strategy
  - M2: Track strategy
  - M3: Jet strategy



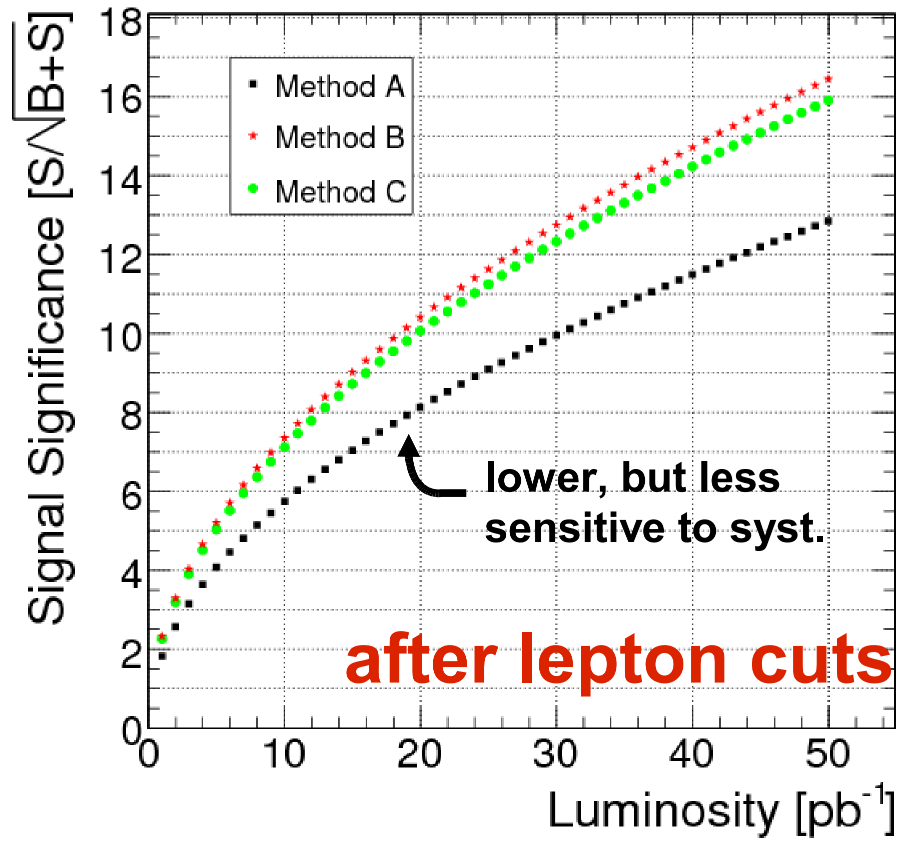
Lepton selection

- **Transverse momentum:**
  p_T(electrons) > 40., 25., 17. GeV
  p_T(muons) > 35., 20., 15. GeV
- **Tracker isolation:**
  iso (R=0.3) < 3., 3., 3. GeV

strat. M1, stringent cuts

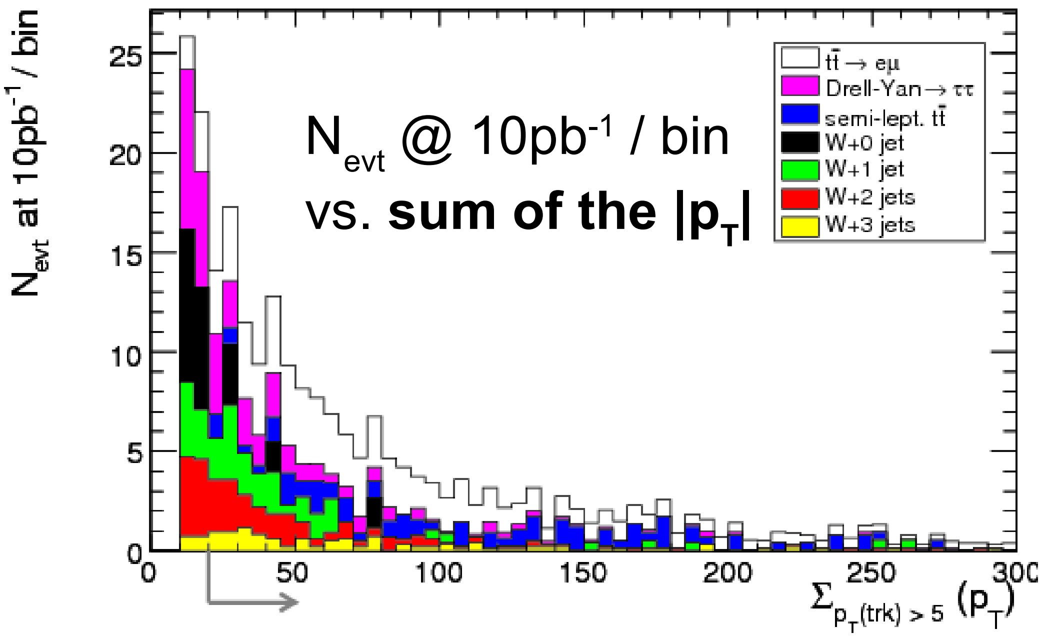
strat. M2, medium cuts

strat. M3, loose cuts



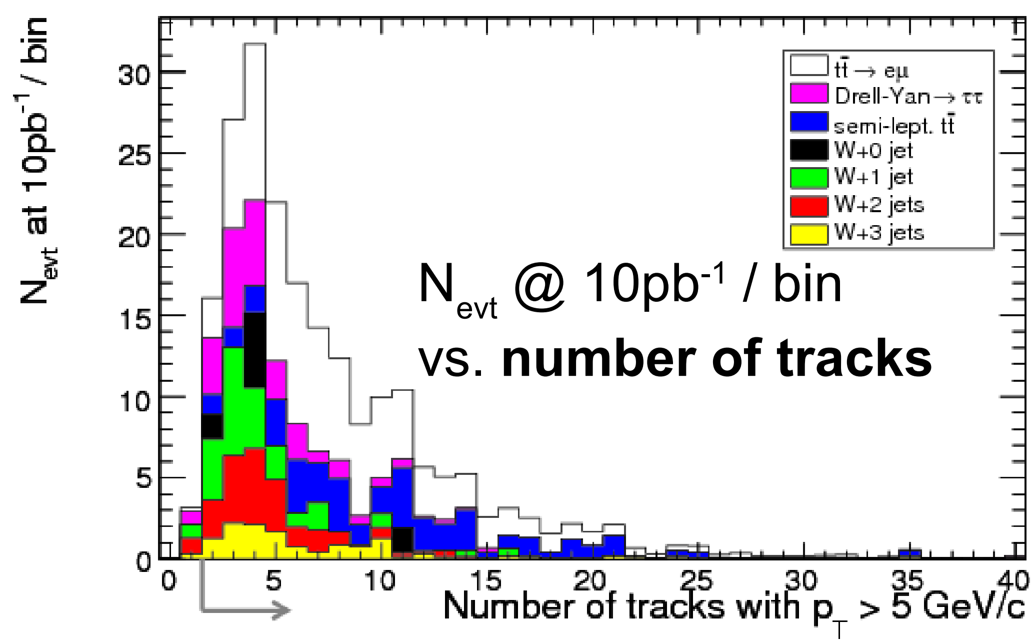
	signal	W+0jet	W+1jet	W+2jets	W+3jets	semi-leptonic $t\bar{t}$	DY
before cuts: N_{evts}	5668	195933	191996	180937	68199	8738	546000
cross-section (pb)	18.5	30000	8000	2500	722	360	7559
A) stringent lepton cuts: cross-section (pb)	3.48±0.11	< 0.15	< 0.04	< 0.01	0.021±0.015	0.12±0.07	0.042±0.024
B) medium lepton cuts: cross-section (pb)	6.59±0.15	< 0.15	0.083±0.059	0.14±0.04	0.064±0.026	0.41±0.13	0.73±0.10
C) loose lepton cuts: cross-section (pb)	8.16±0.16	0.31±0.22	0.71±0.17	0.43±0.08	0.15±0.04	0.87±0.19	2.55±0.19

M2: track-based event variables

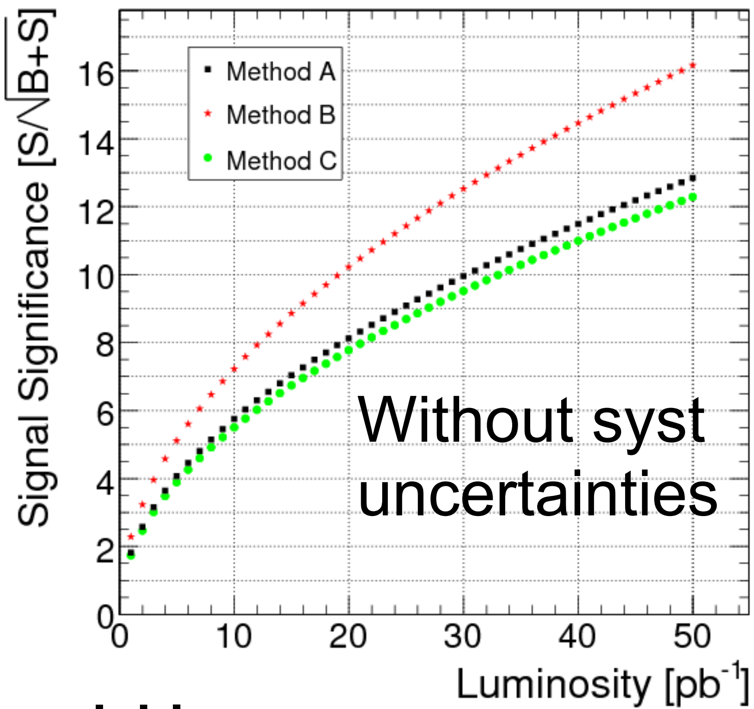


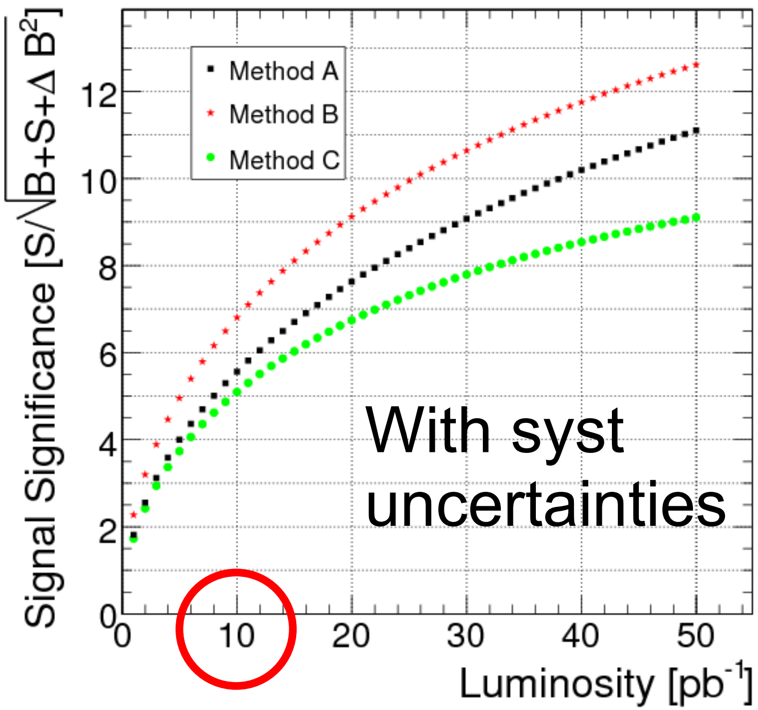
The track associated to the lepton is excluded

Other variables were also considered: aplanarity, sphericity, circularity, centrality



Results

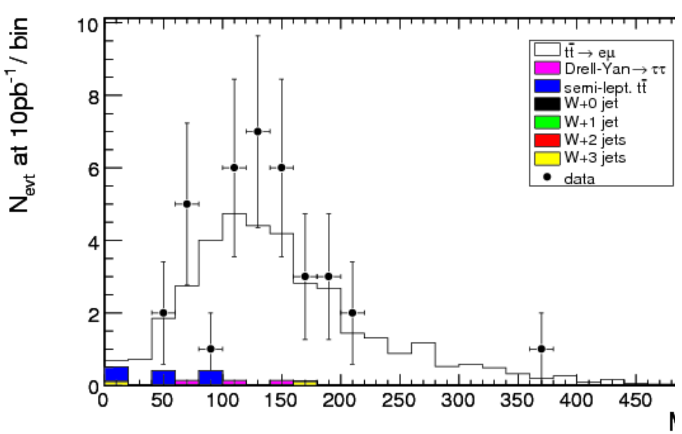




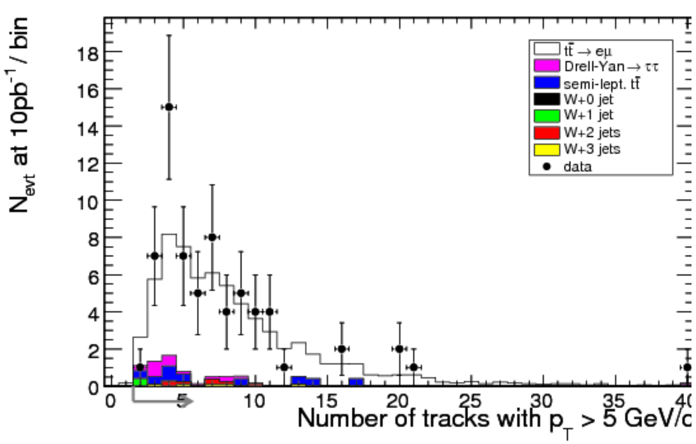
Systematics not yet final

Final variables:

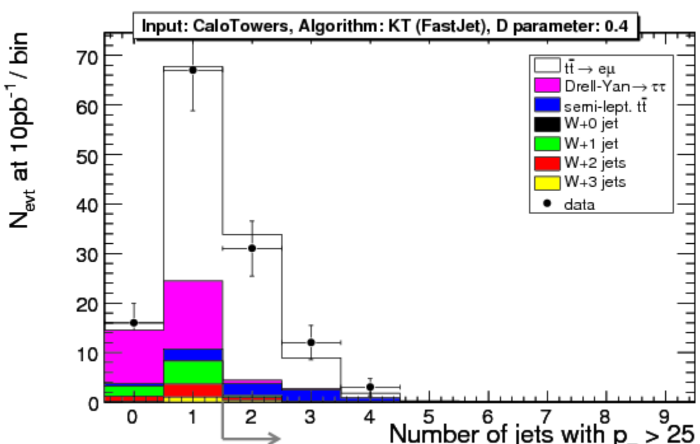
M1, dileptonic mass



M2, number of tracks



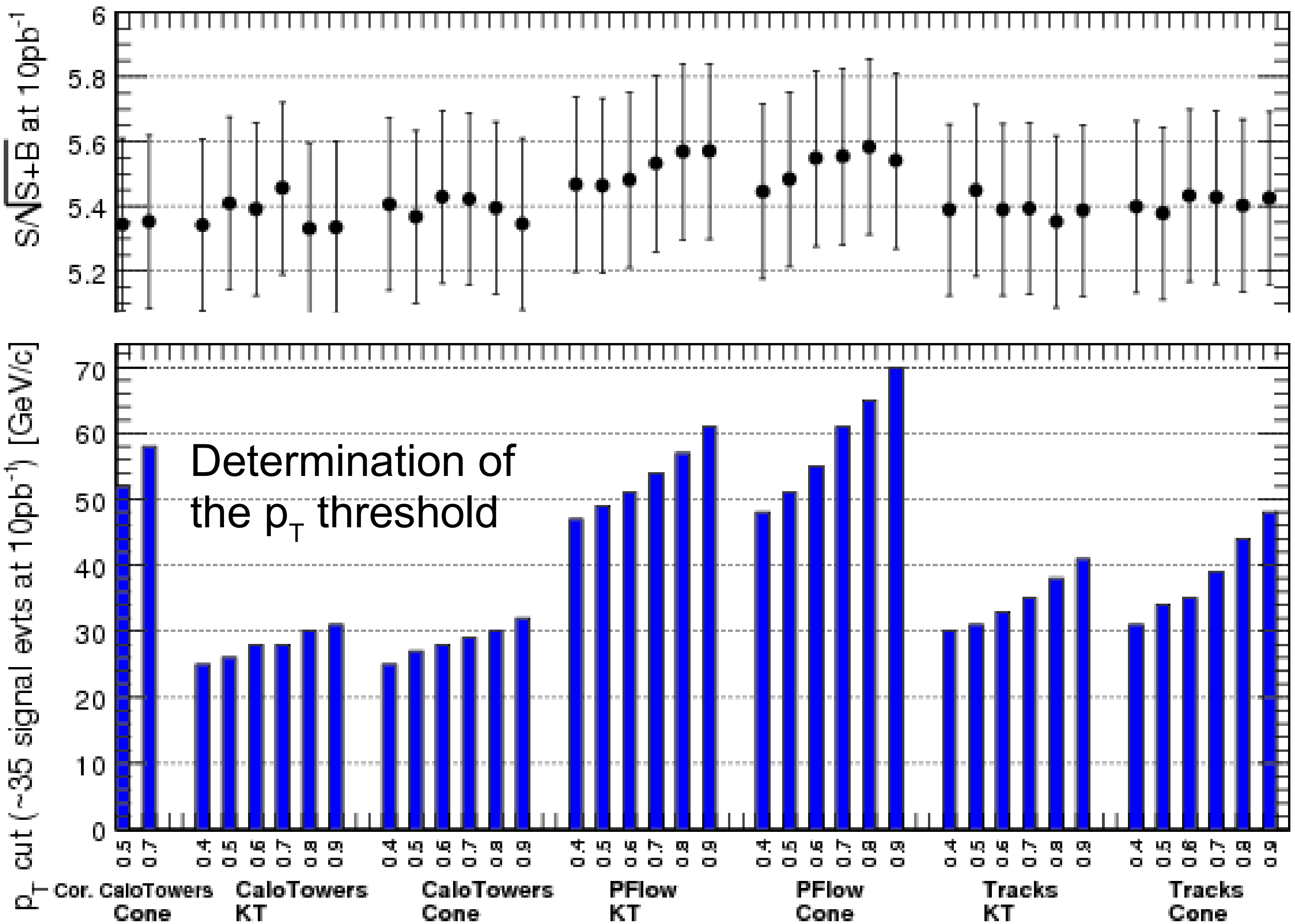
M3, number of jets



M2 & M3: background shapes and normalization from μ+μ– sample

M3: jet selection

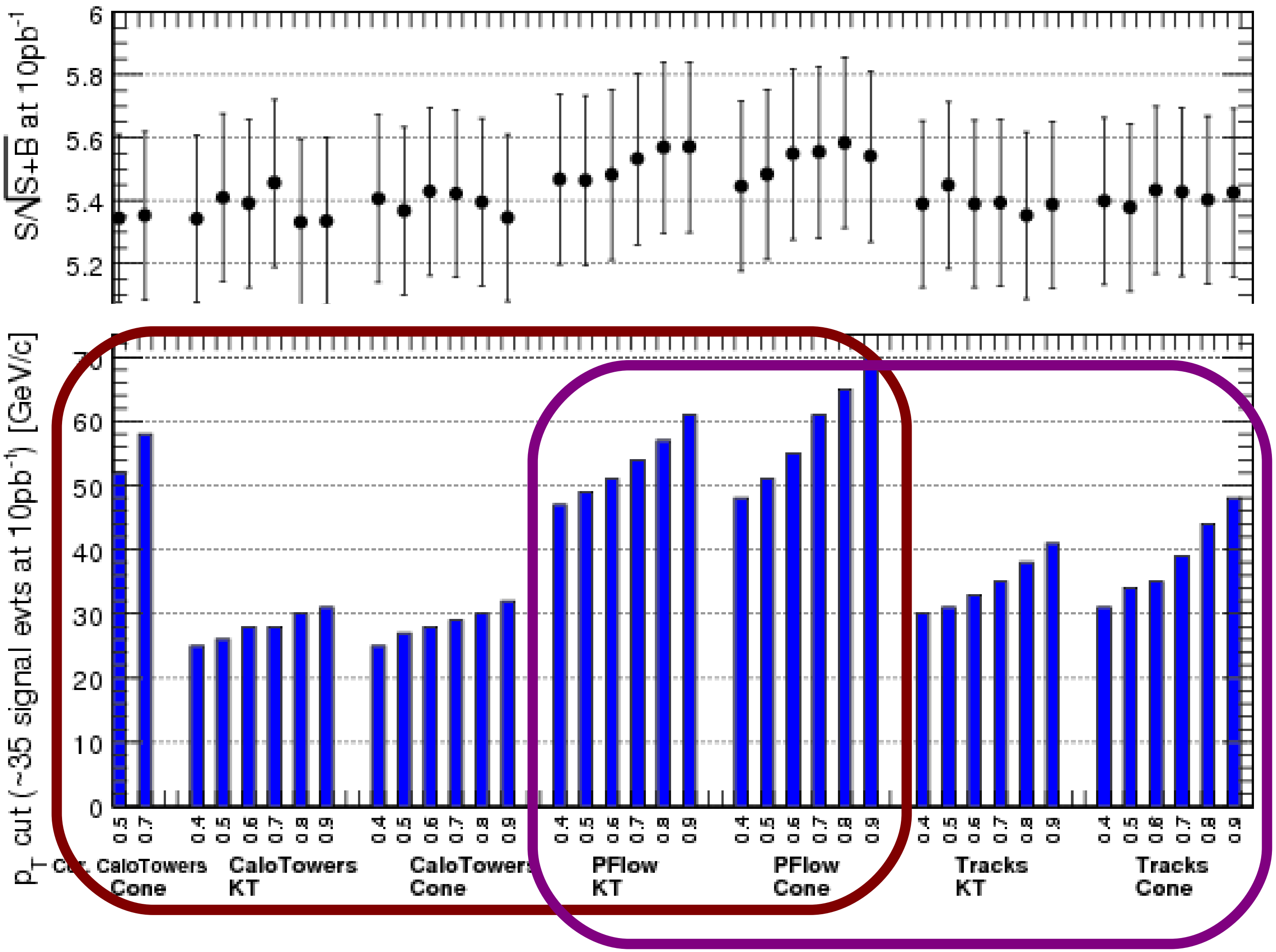
- **$|\eta^{jet}|<2.4$**
- **Remove jets that match isolated electrons**
- **At least 2 jets with p_T higher than a given threshold**
- **Different jet algorithms, with different inputs (tracks, calo towers, even PF objects if considered reliable): differently affected by different syst.**



Note: we are not reconstructing mass peaks, so jet→parton calibration is not an issue

Calo vs Tracker

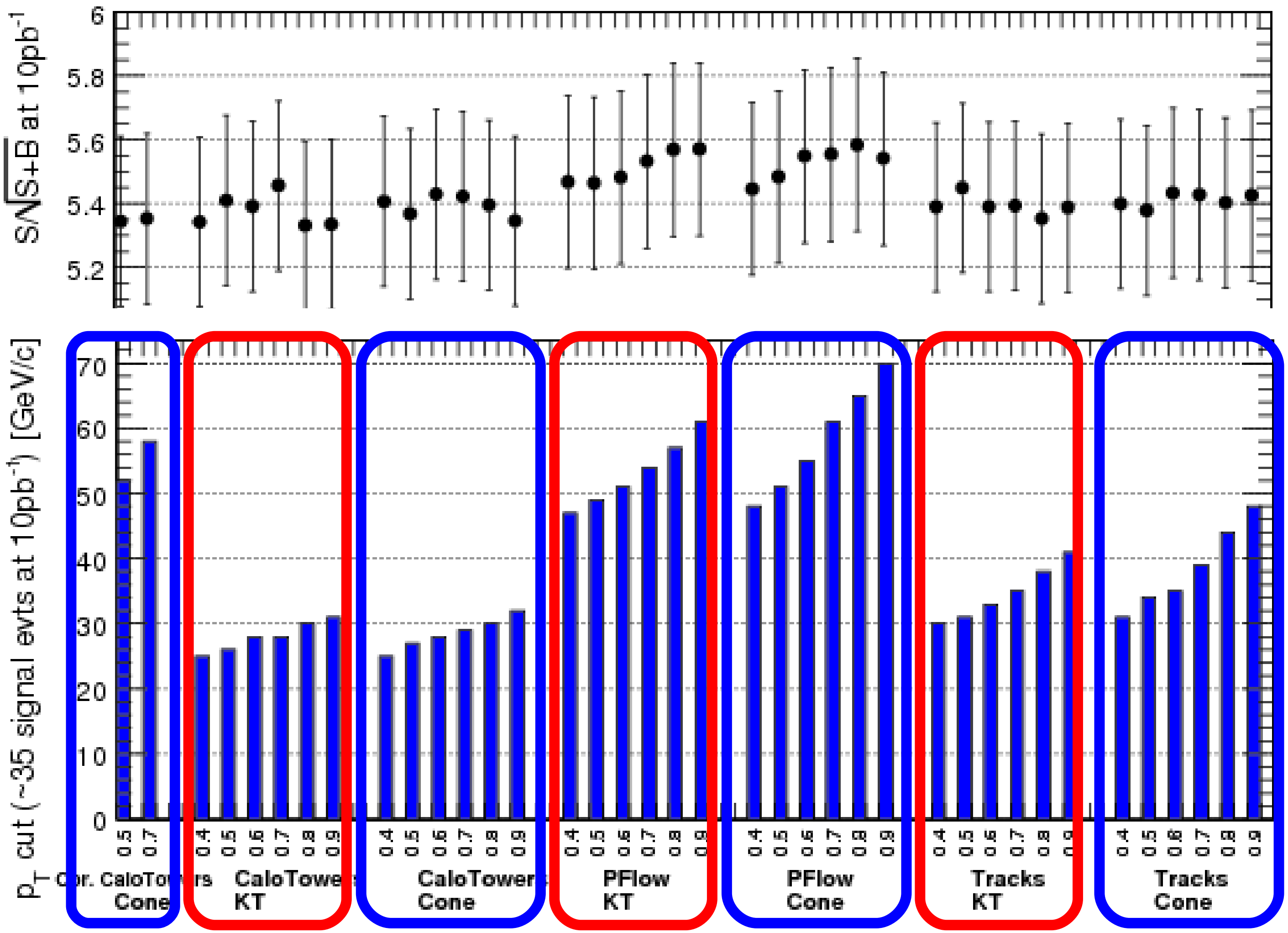
We need the analysis to be robust against the eventuality of "catastrofic" malfunctioning of one of the sub-detectors. Luckily, we found that jet selections based on calorimeter and on tracking informations have rather similar significancies.



Not surprisingly, the best significance is with Pflow: it combines the maximum amount of information

Different jet clustering algorithms

Extrapolating our soft-QCD models to LHC gives very large variations on the expected levels of gluon radiation and Underlying Event (UE). And wildly variating inst. lumi at the beginning will affect Pile-Up (PU). Different algorithms with different parameters will have different sensitivities to physics systematics
(AG et al. in Les Houches 2005, hep-ph/0604120)



Bonus for (fast-)KT algo: event-by-event UE/PU-subtraction (Cacciari, Salam 2005)

First “useful” top measurements

- Cross sections in various final states (semi-lep and dilep, including taus) are the topic of our “2007 paper” **AN-2007/025**, *“Measurements of the top quark pair production cross section with L=100 pb^{-1} using the CMS detector”*
- One section is devoted to the exclusive cross section tt+Nj, in the dileptonic channel
  - Important *per se* as a study of radiation
  - Even more important if seen as a way to deduce the irreducible $t\bar{t}b\bar{b}$ background to $t\bar{t}H$

CMS AN 2007/025
in progress

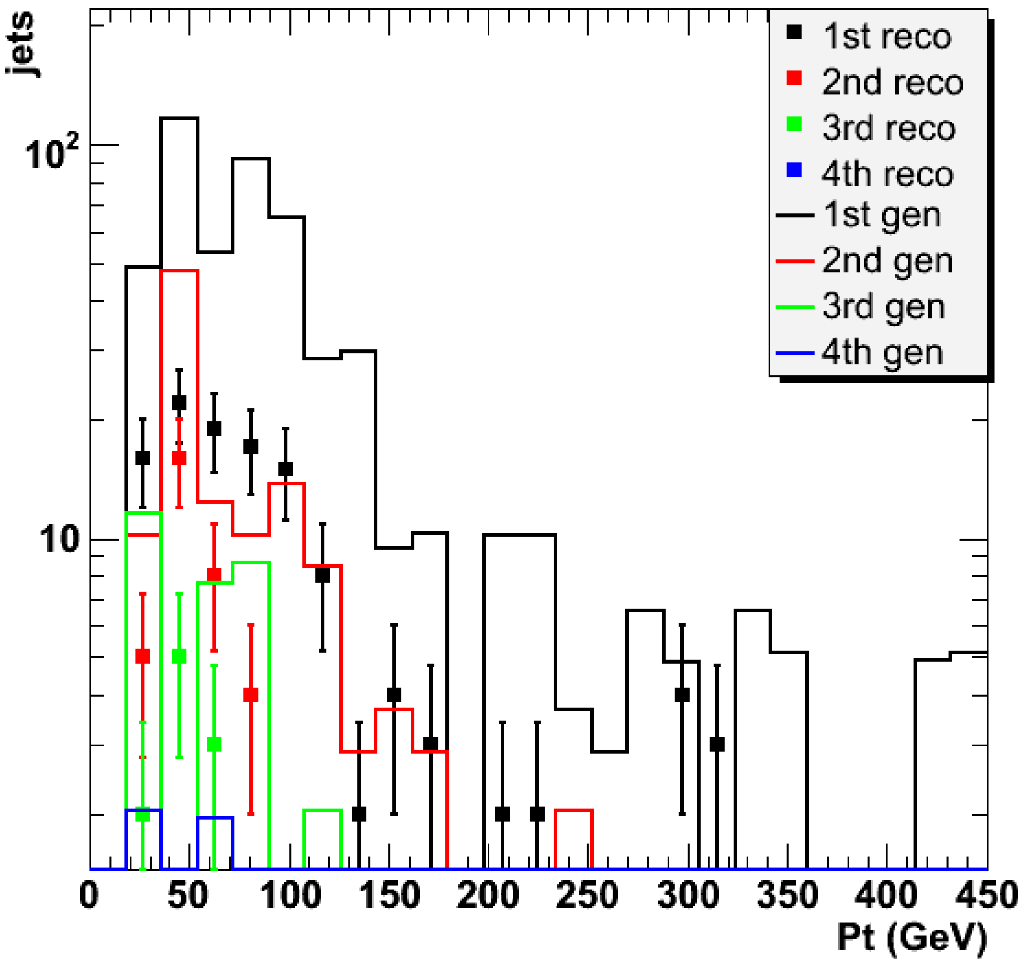
Strategy for tt+Nj

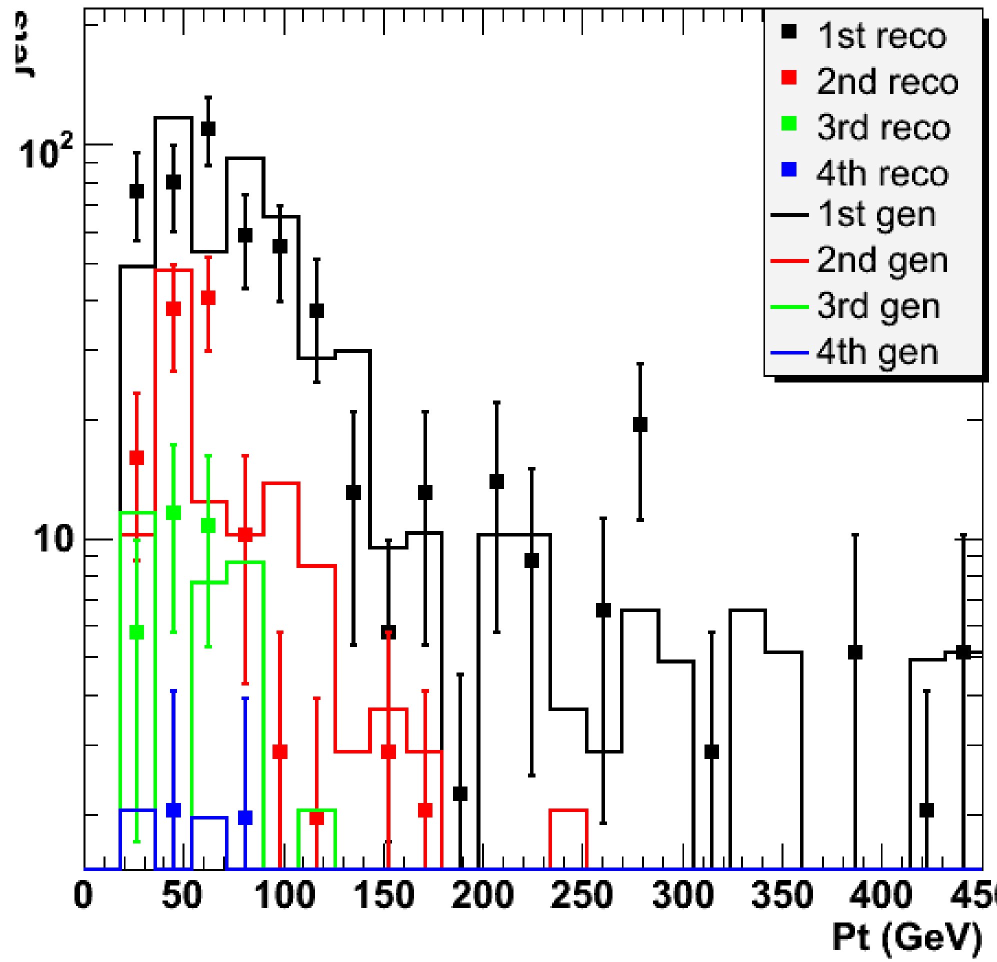
- Select dileptonic events
  - Clean event selection (2l, Z-veto, MET, 2j, mild b-tagging)
  - Easy “extra-jet” definition: a non-b jet (from 3rd jet onward, in b-tag ordering)
- Clean up the jet sample
  - avoid fakes or pathological jets
- Unfolding: correct reco jet Pt to the GenJet Pt
  - Binned unfolding function trained on MC (validated on indep. MC)
- Correct for selection efficiency and background
  - Both as functions of Njets (reco)
  - for W+jets we use Z($\rightarrow\mu\mu$)+jets and apply a scale factor

Extra-jet$^{(*)}$ spectra with 100/pb

$^{(*)}$ = non-tagged

AG in CMS AN 2007/025



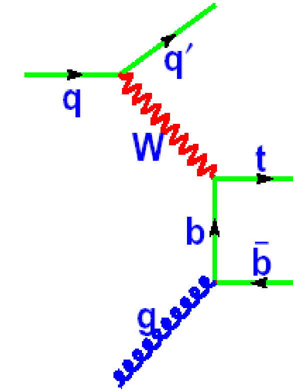


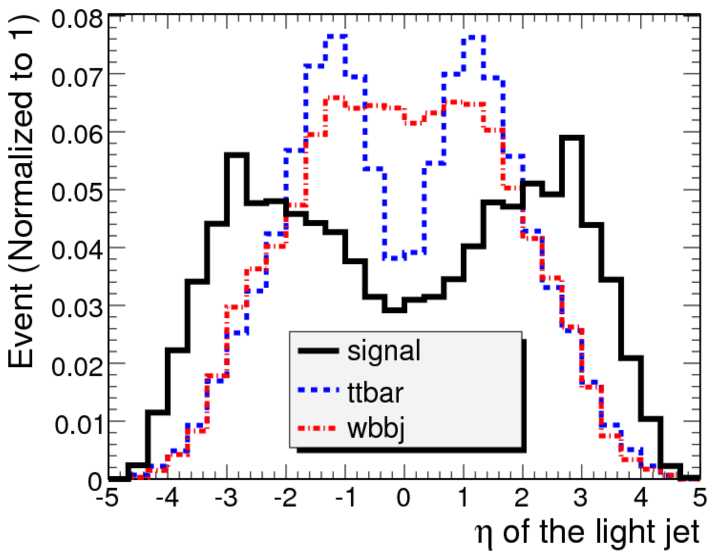
Raw "data" (AlpGen) vs MC truth, stat error only

After efficiency correction and unfolding extracted from "MC"
(here "MC" and "data" are independent)

CMS NOTE 2006/084
PhysTDR vol.2

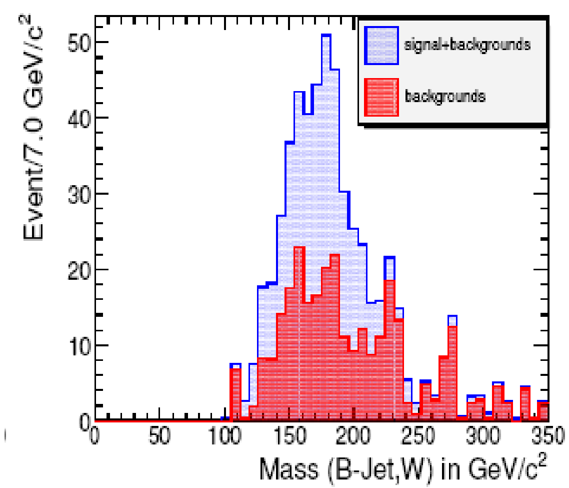
Single top: t-channel





Selection:

- 1 muon (isolated), MET (type I), 2 jets
- 1 jet b-tagged and central, 1 jet forward
- Σ_T is defined as vectorial sum of transverse momenta (including MET)
- Cuts on Σ_T, M_T^W and M_{top}
- **S/B=1.3**

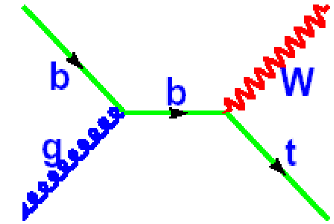


sample	selected	ΔN_{th}	ΔN_{Lum}	$\Delta N_{\mathrm{b-tag}}$	JES	tot.	ΔN_{stat}
t-channel	2330	93.2	116	93.2	26	177.5	48.3
$t\bar{t}$	1147	80.3	57.3	45.9	84	137.5	33.9
$Wb\bar{b}j$	188	32	9.4	7.5	4.5	34.5	13.7
Wjj	402	20	20	16.1	0	32.6	20

$\Delta\sigma/\sigma$ = 2.7% (stat) + 8.1% (syst) + 5% (lumi) = 9.9% @10fb^{-1}

CMS NOTE 2006/086
PhysTDR vol.2

Single top: W-associated



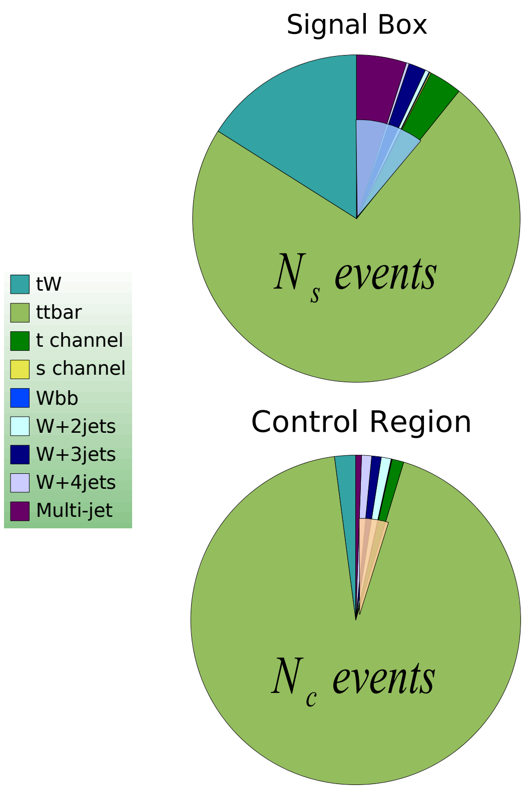
Selection (dileptonic):

- $1e+1\mu$ (isolated), MET
- 1 jet, b-tagged
- **S/B=1/3**

In both cases, almost all the surviving background is ttbar; normalization over data (control samples with one more jet, in both channels) cancels out most of the systematics.

Selection (single lepton):

- 1 e/μ (isolated), MET
- 3 jets, 1 b-tagged
- Cuts on M_T^W, M(jj), M_{top} and other topological variables
- **S/B=1/5**

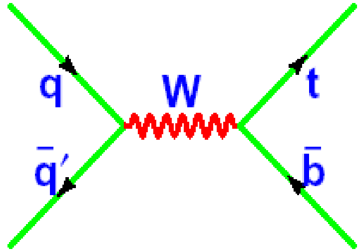


$\Delta\sigma/\sigma$ (2l)=8.8%(stat)+23.9%(syst)+5%(lumi)

$\Delta\sigma/\sigma$ (1l)=7.5%(stat)+16.8%(syst)+5%(lumi)

CMS NOTE 2006/084
PhysTDR vol.2

Single top: s-channel



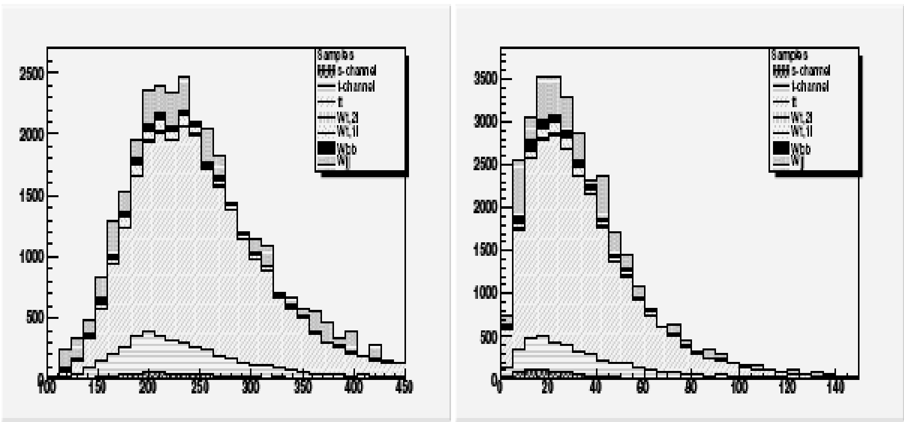


Figure 13: Distribution of the scalar (left) and of the vectorial (right) sum in the transverse plane of the momenta of the lepton, of the $\not{E}_T$ and of the two b-jets.

Selection:

- 1 e/μ (isolated), MET)
- 2 jets, both b-tagged
- Cuts on Σ_T, M_T^W, M_{top} and other topological variables
- **S/B=1/7**

- s-channel: 273±3(JES)±11(btag)±1.5(M_{top})±2(PDF)±1.5(ISR/FSR)
- t-channel: 629±25(theo)±8(JES)±25(btag)
- ttbar: 1258±63(theo)±75(JES)±50(btag)
- Wbb: 155±8(theo)±7(JES)±6(btag)

A normalization over data had to be developed (two control samples: one for tt->1l, one for tt->2l) in order to keep under control the tt background and cancel most of the systematics. What remains is mostly due to the JES systematic alone.

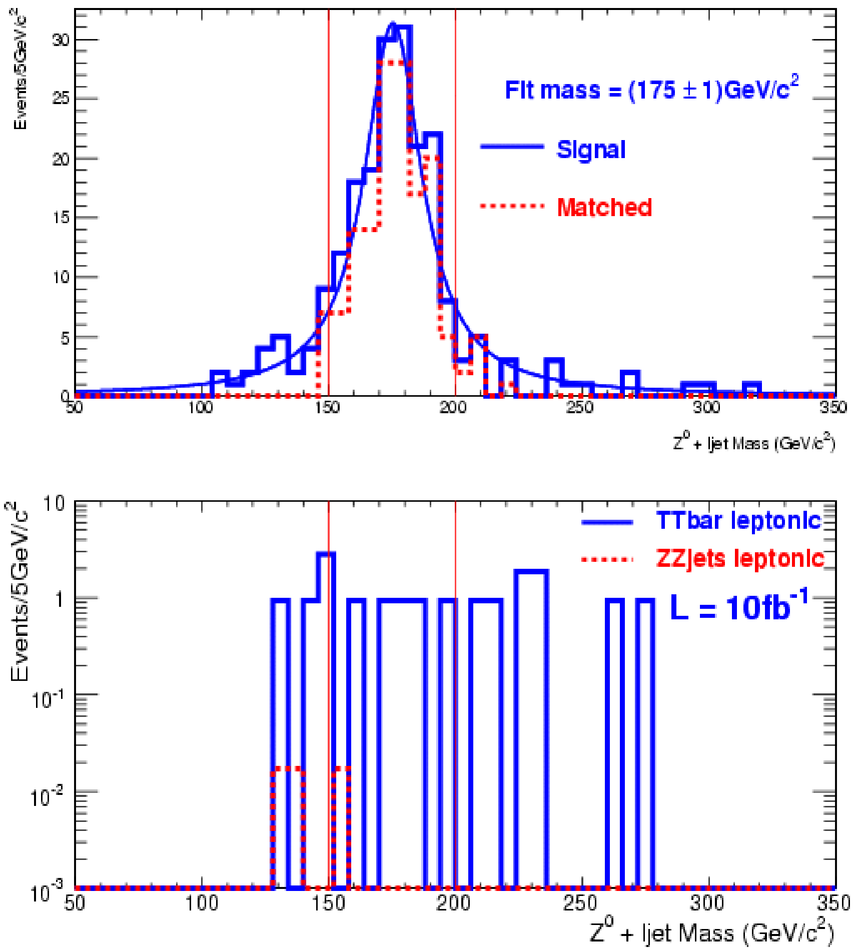
$\Delta\sigma/\sigma$ = 18% (stat) + 31% (syst) + 5% (lumi) = 36% @10fb^{-1}

R=BR(t→Wb)/BR(t→W+any)

- Analysis boils down to counting the number of b-tags
  - ε^{btag} and mistag rate to be estimated from other samples
  - In semilep channel, jet assignment based on kinematic fit
  - Bkg subtraction by flipping the leading jet dir. in the kin.fit
  - Result expected after 1 fb^{-1}: $\Delta R = \pm 0.08(stat) \pm 0.09(syst)$
  - Dileptonic: lower statistics but better purity; easier to classify jets from t→q (no W→q$\bar{q}$, other jets come from rad/UE/PU)
- Worst bkg is “internal”: gluon splitting in tt events (g→c$\bar{c}$,b$\bar{b}$)
  - Very hard to measure independently (even at LEP it was tough!)
  - Parton Showers underestimate it: need t$\bar{t}$b$\bar{b}$ diagram
  - It can mask New Physics! t$\bar{t}$→b$\bar{q}$ may be interpreted as t$\bar{t}$→b$\bar{b}$

CMS NOTE 2006/093
PhysTDR vol.2

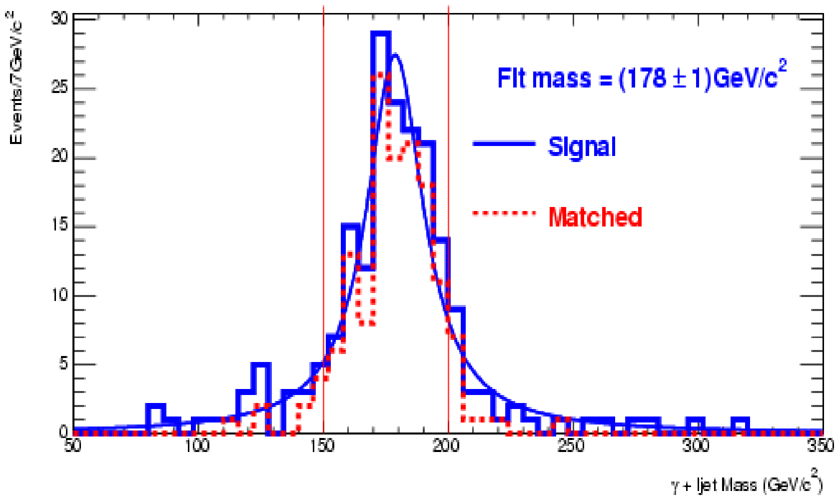
FCNC: $t \to Zq$

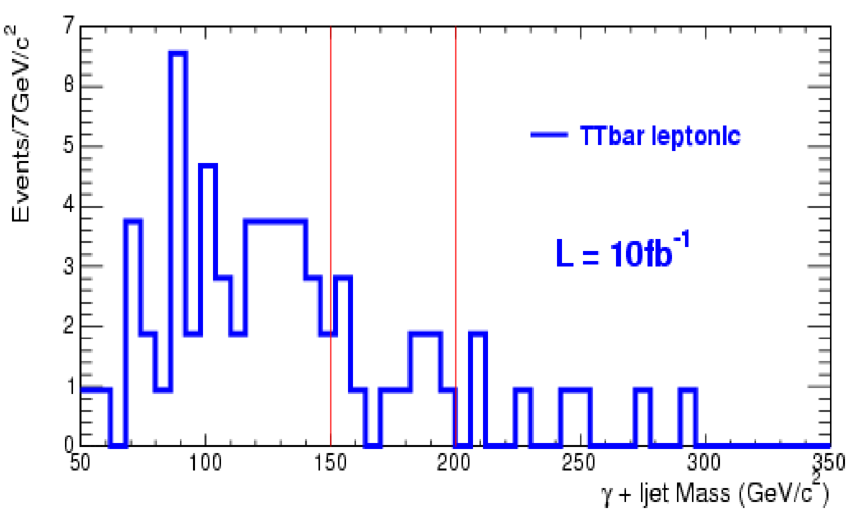


- BR=1.3×10^{-13} in SM, $<10^{-4}$ in SUSY with R-parity violation, $<10^{-2}$ with new quarks; limit <0.14@95% (LEP2), <0.106@95% (CDF)
- 3 isolated leptons
- "SM side":
  - $M_T(l,MET) \sim M_W$
  - $M(l,\nu,b) \sim M_t$
- "FCNC side":
  - $M(l^+l^-) \sim M_Z$
  - $M(l^+l^-,q) \sim M_t$
- Main bkg: SM $t\bar{t} \to 2l$ (+1l from b)
- Fragmentation is an important syst
- Sensitivity (5σ):
  - ~1.5×10^{-3} (L=10 fb^{-1})
  - ~4×10^{-4} (L=100 fb^{-1})

CMS NOTE 2006/093
PhysTDR vol.2

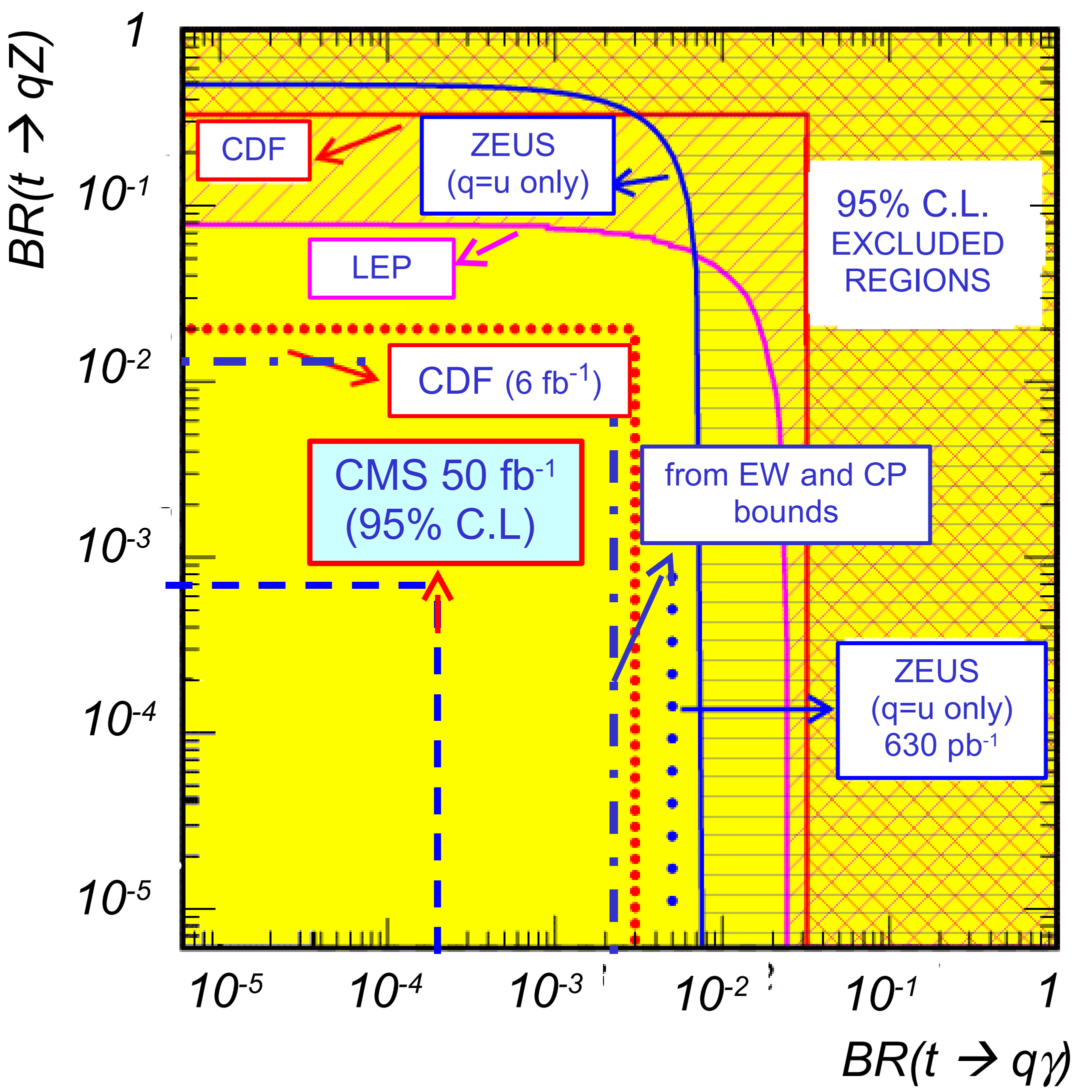
FCNC: $t \to \gamma q$





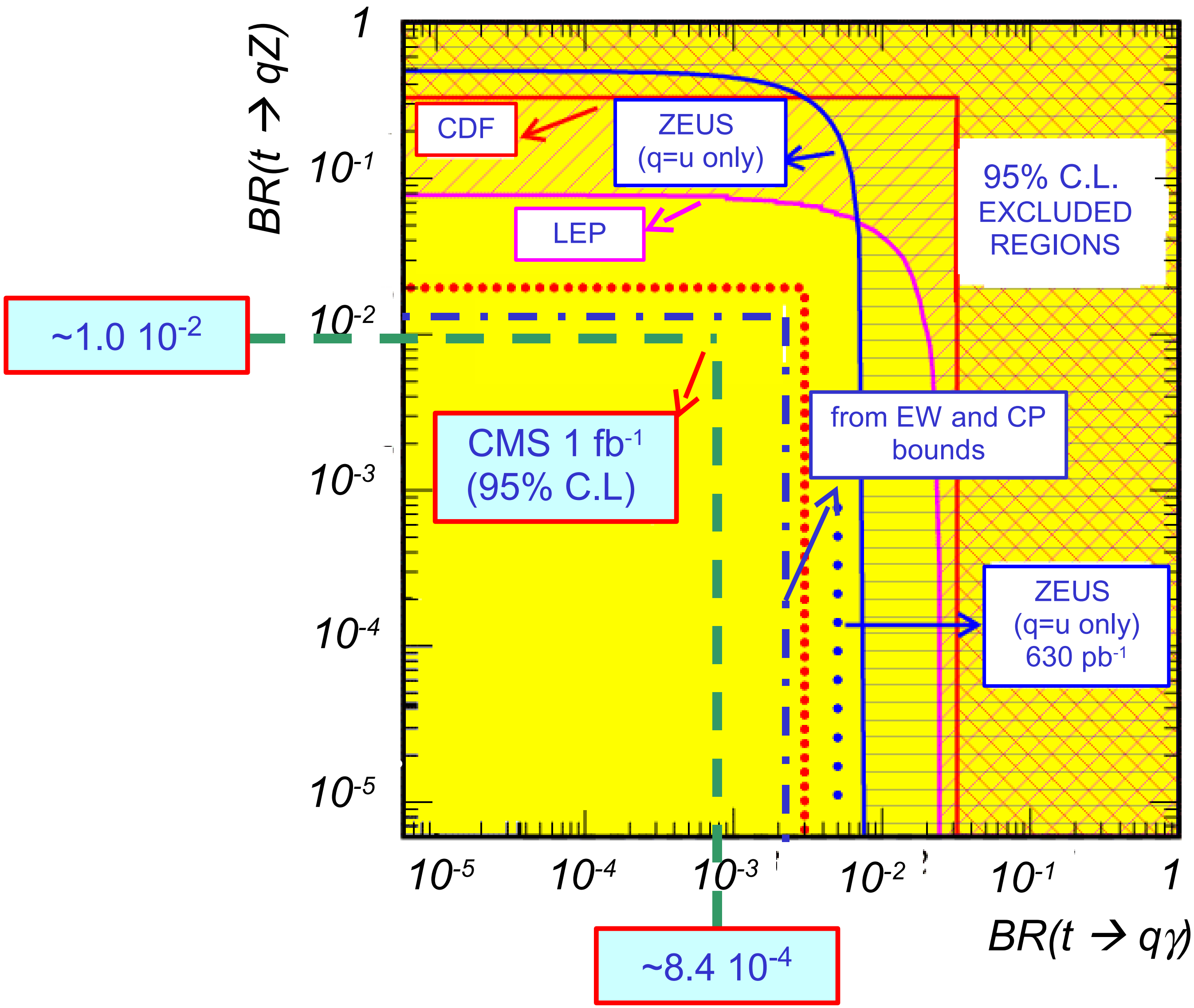
- BR=5×10^{-13} in SM, $<10^{-5}$ in SUSY with R-parity violation, $<10^{-5}$ with new quarks; limit<0.0059@95% (HERA)
- 1 isolated lepton, 1 isolated high-pt γ
- "SM side":
  - M_T(l,MET)~M_W
  - M(l,ν,b)~M_t
- "FCNC side":
  - M(γ,q)~M_t
- Main bkg: SM tt, single top
- Sensitivity (5σ):
  - ~8×10^{-4} (L=10 fb^{-1})
  - ~3×10^{-4} (L=100 fb^{-1})

FCNC prospects



Courtesy of Leonardo Benucci

FCNC prospects



Courtesy of Leonardo Benucci

Conclusions

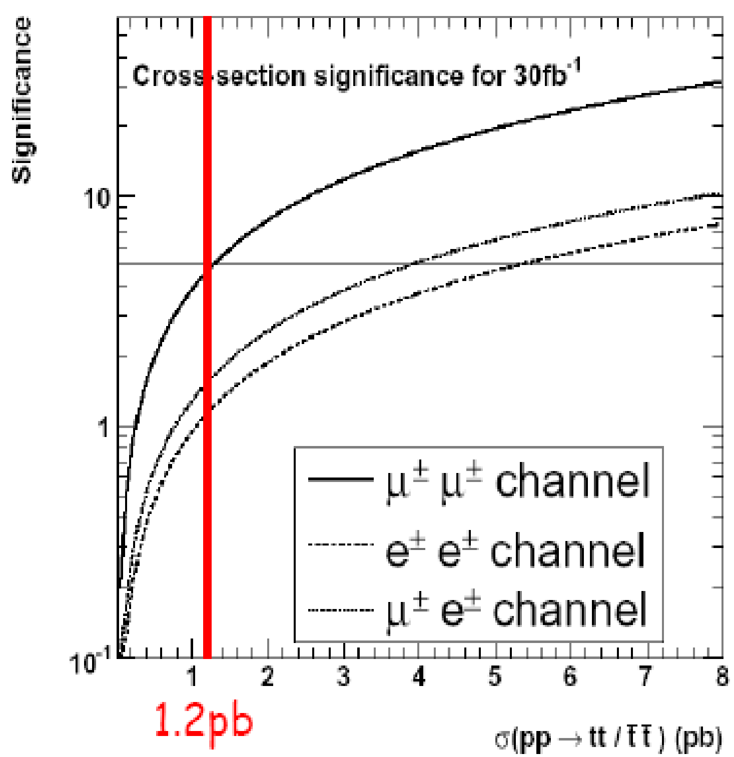
- LHC analyses will have first to re-establish the "known knowns", then measure the "known unknowns", and at last (logically, not necessarily chronologically) quest for the Unknown
  - re-discover top and make sure that everything makes sense (fix calibrations / bugs / biases in selection / etc.), check models in small phase space corners (especially if sampled by other analyses), measure observables sensitive to deviations from SM
- The top sector could be a window on new physics
  - V_{tb} at 5% ($\Delta\sigma/\sigma, \Delta R \sim 10\%$) is THE goal for single top & R
- Note: CMS is designed to be particularly strong in muon/electron/photon final states
  - We are in the best position to explore FCNC decays

BACKUP SLIDES

FCNC: Same-sign pair production

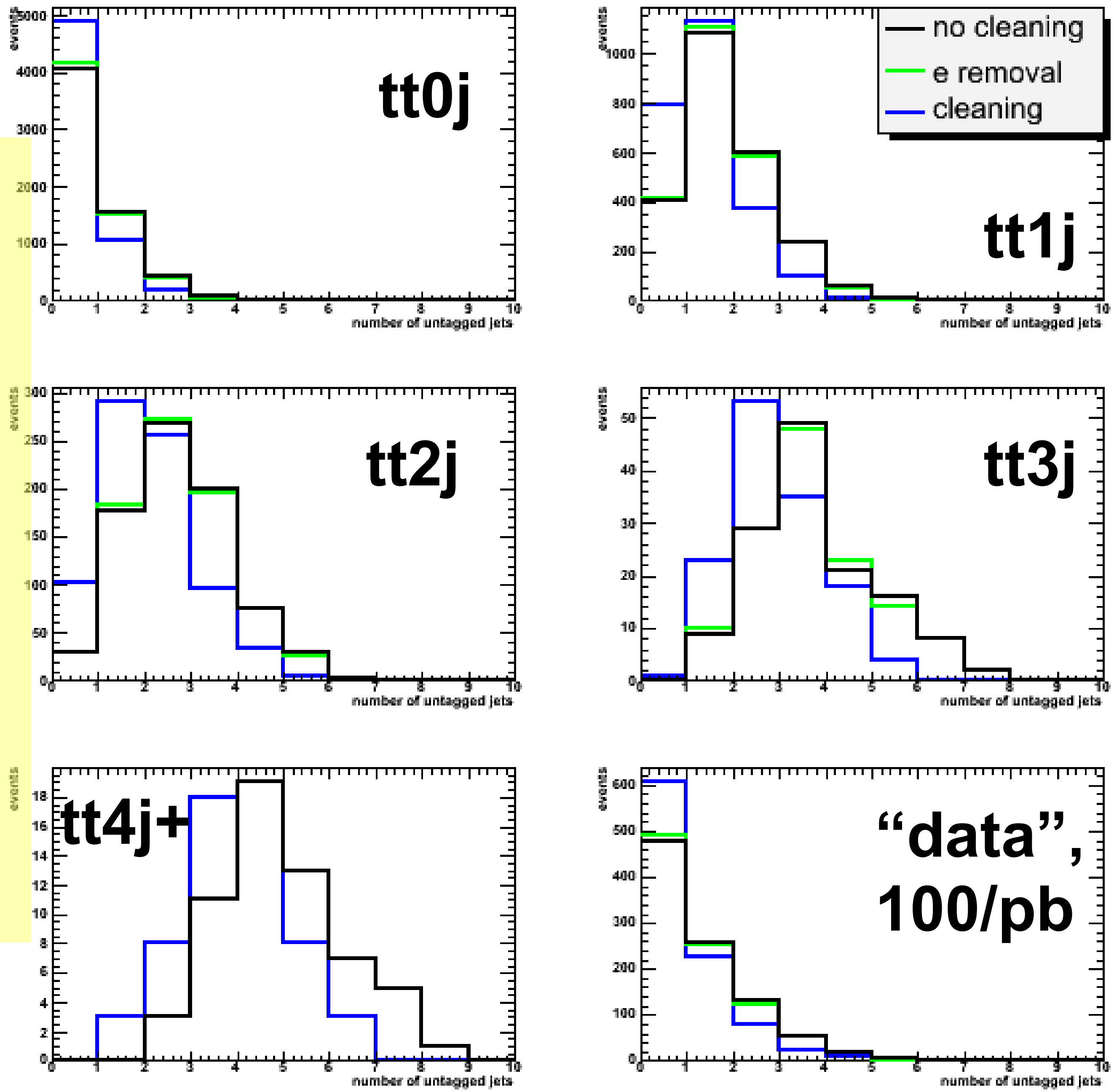
- No hope to constrain the FCNC *tgu* coupling in decays, but in production spectacular uu→tt signature
  - Additional motivation: SUSY cascades
- Standard di-leptonic selection (ee, eμ, μμ), measurement of $R=N_{SS}/N_{OS}$
- Main bkg's: fake leptons, charge misid.
- In MC, under the assumption of SM:
  - $R_{\mu\mu}=0.0027\pm0.0007$
  - $R_{ee}=0.0389\pm0.0033$
  - $R_{e\mu}=0.0128\pm0.0013$

significance vs. SS tt x-sec.

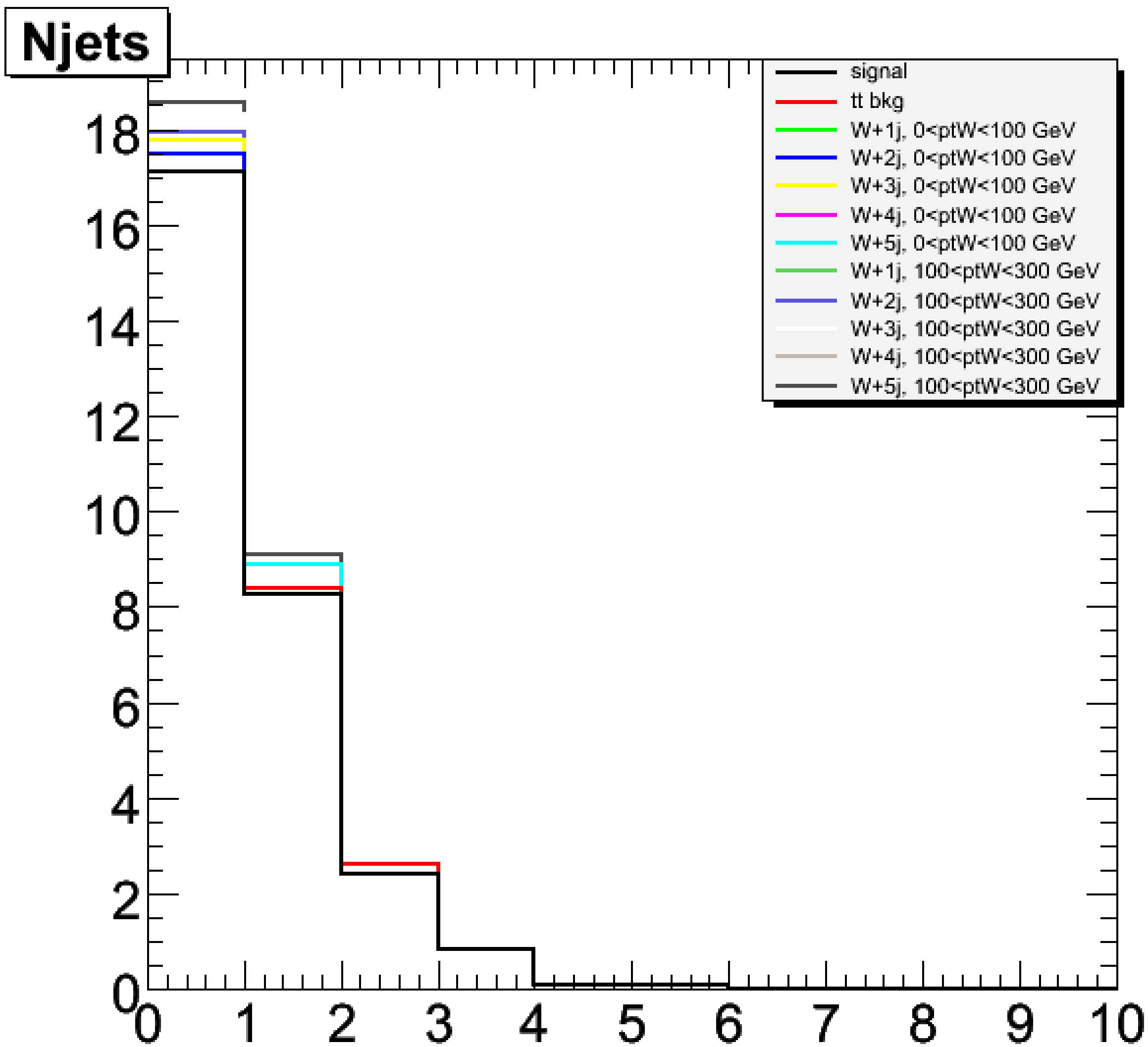


Counting the “interesting” jets

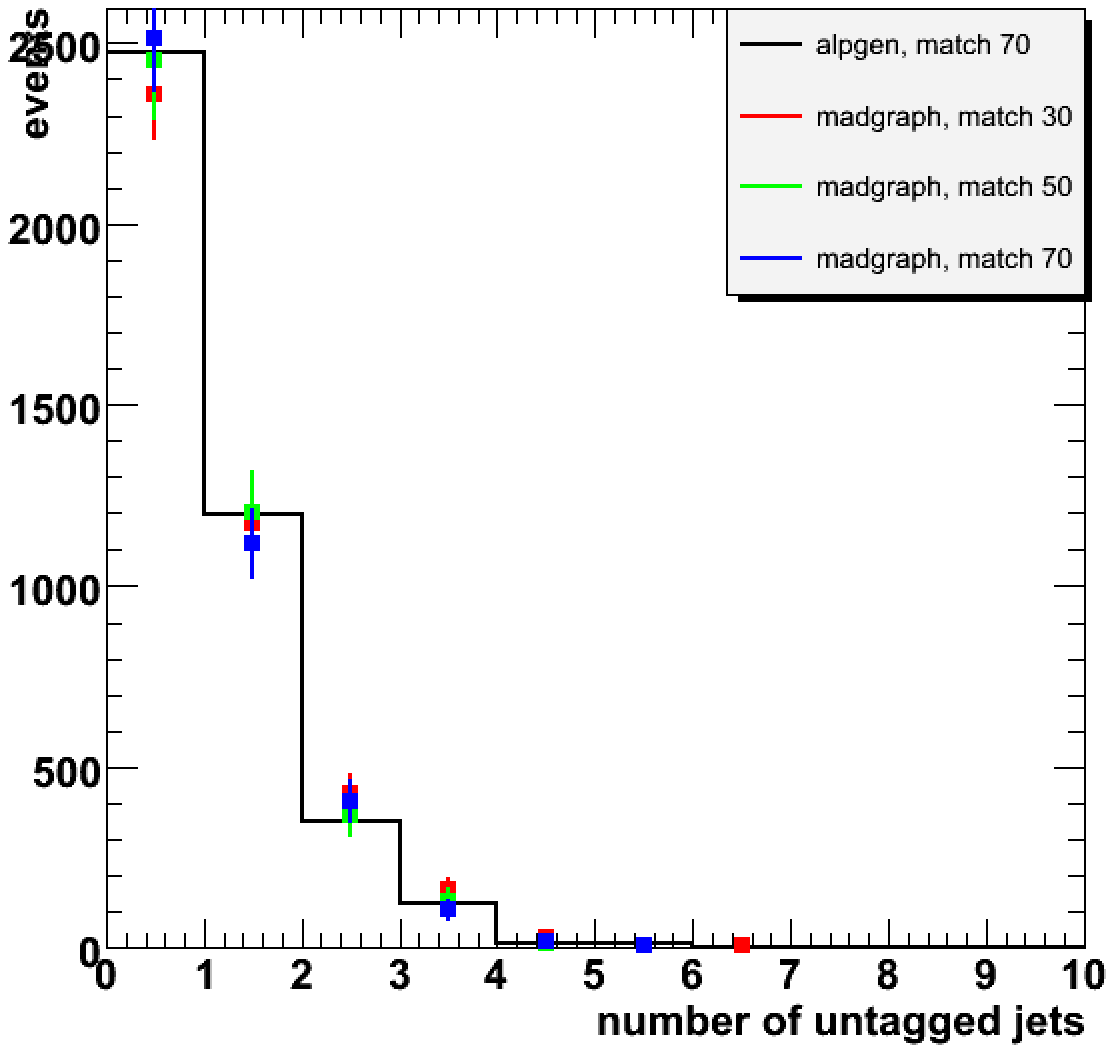
- These are reco jets
- The 2 highest-btag jets are ignored
- Et>30 GeV, |η|<2.4
- No correction for selection efficiency in this slide
- “data”: alpgen ttbar samples mixed with proper proportions



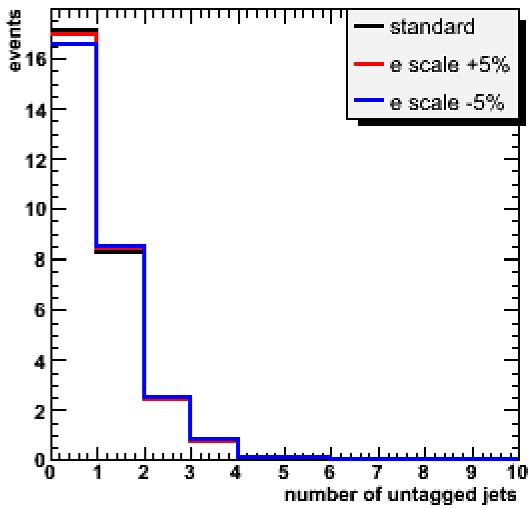
Bkg vs extra jets number

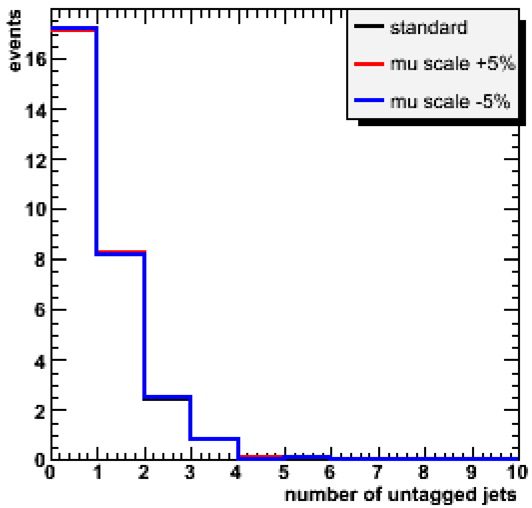


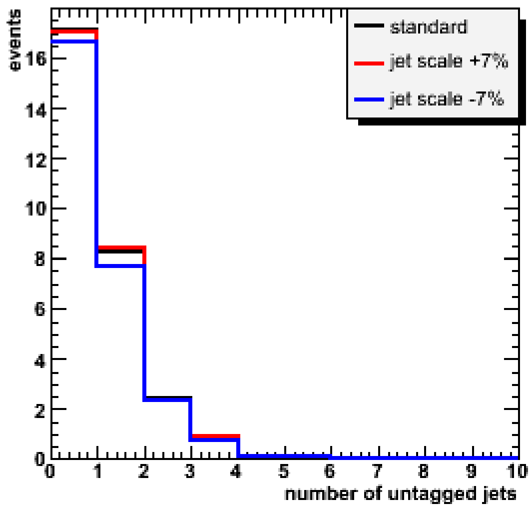
Njets vs model



Njets vs miscalibrations

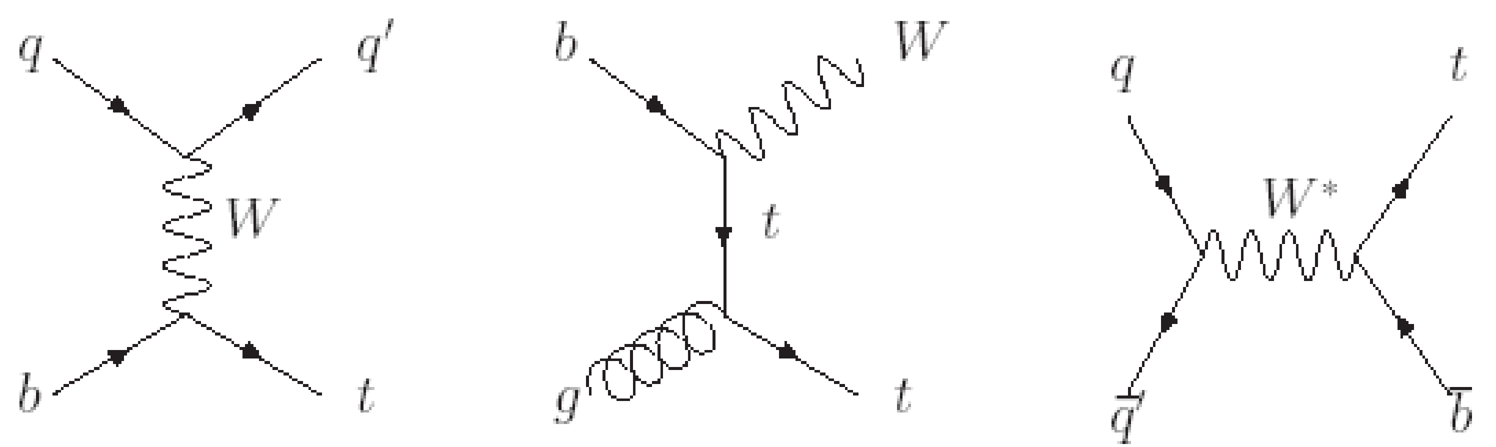






Single Top

Three "single top" production modes in the Standard Model:



t-channel (245 pb) W-associated (60 pb) s-channel (10 pb)

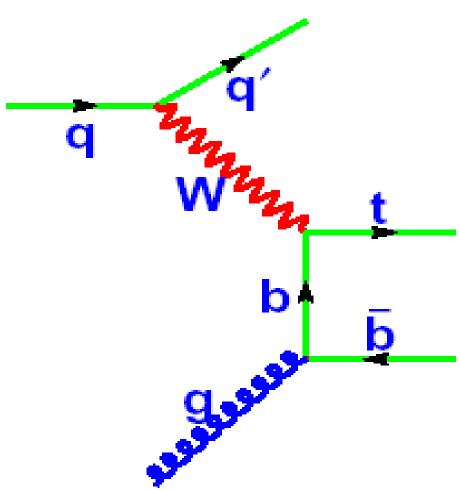
- Directly related to $|V_{tb}|$, not a ratio
- Possibility to study top properties (mass, polarization, charge) with less reconstruction ambiguities than in ttbar
- Wt is out of Tevatron reach, but it will be accessible to LHC
- Together the 3 channels provide complementary informations on Wtb coupling, since they probe it for $q^2<0$, $q^2>0$, $q^2=0$

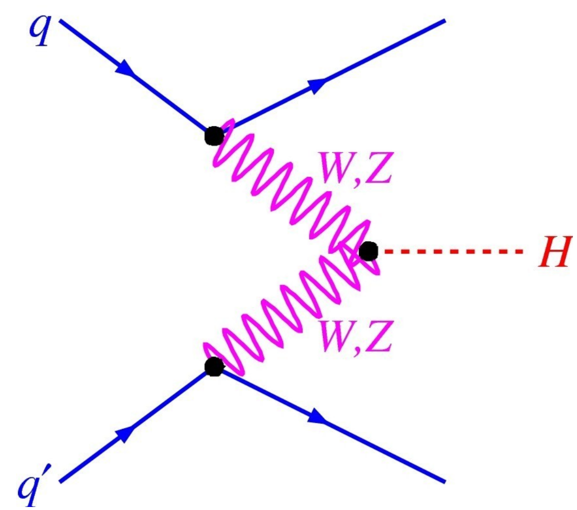
Single Top as noise

- In the $H \to WW \to l\nu l\nu$ search, after jet veto the Wt/tt ratio increases
  - Wt becomes a significant contamination
  - Difficult to extract it from dedicated control samples, we currently rely on NLO estimates to disentangle it from the "tt control sample"
    - Campbell et al., Les Houches 2005 report: hep-ph/0604120
- In the $gb \to H^{\pm}t$ search ($H \to \tau\nu$), $gb \to Wt$ ($W \to \tau\nu$) can only be reduced by exploiting the spin difference (tau spectrum and/or angular distribution)
- In general, whatever has ttbar as background (eg SUSY) has also a single top contamination

Single Top as a benchmark

- The most abundant production mode, t-channel, is characterized by its forward energetic jet
- Precious signature for isolating it from background, but also quite complicated η region, for both detector (HF) and phenomenology (UE, PU, ...)
- But it's mandatory to understand this region as soon as possible: forward jets are also the signature of VBF



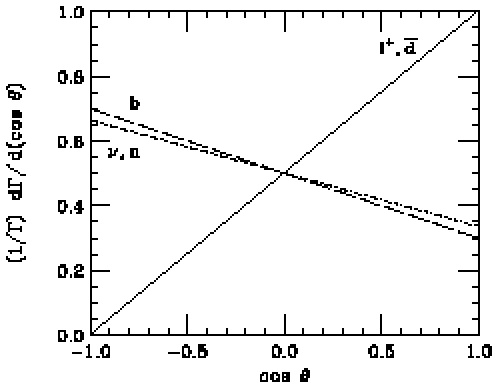


Single top after the TDR

- G.Petrucciani and AG in summer 2006 further refined all 3 analyses, in particular:
  - Jet collection cleaning, e.g. use of tracks from prim.vtx
  - More control samples for bkg normalization
  - **More systematics and backgrounds**
  - Improvements: t-channel 10%→8%, Wt(SL) 19%→14%, Wt(DL) 25%→18%, s-channel 36%→24%
  - Still with the old software (ORCA+FAMOS)
  - http://indico.cern.ch/conferenceDisplay.py?confId=4945
  - Note: Particle Flow shown to have great impact in the pt region where the bulk of our signal is; in the to-do list!

Not only x-section: new physics in Polarization

- Top's chirality is 100% left-handed in EWK production
  - $\tau_{decoherence} > \tau_{decay}$: decay products are probes of polarization
  - $(d\Gamma/\Gamma)/d(\cos\theta) = ½(1 + A \cos\theta)$
  - $A(l) = +1$, $A(b) = -0.40$, $A(\nu) = -0.33$

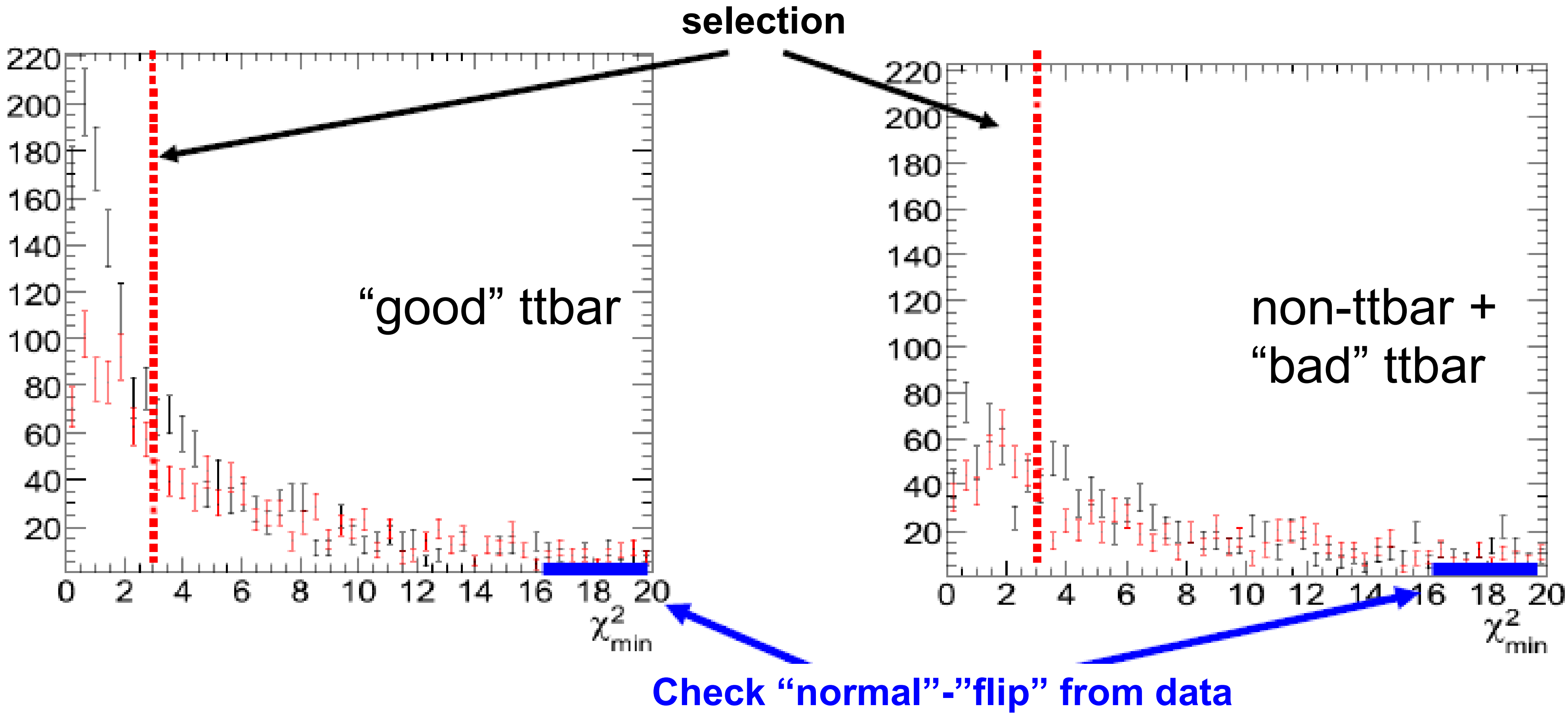


- Problem: at the top mass, helicity ≠ chirality
  - Solution: in the top frame, spin axis ∥ d-type quark direction
  - Which d-type quark?
    - Tevatron, s-channel: take the anti-proton direction (correct in 98% of cases); not applicable at LHC
    - LHC: take the recoil quark's direction in t-channel
    - How-to: boost into reco top frame, plot angle between lepton and untagged jet, correct for acceptance/bkg, extract slope

R: bkg subtraction

χ^2 Normale = f(P1,P2,P3,P4,Met,Lep)

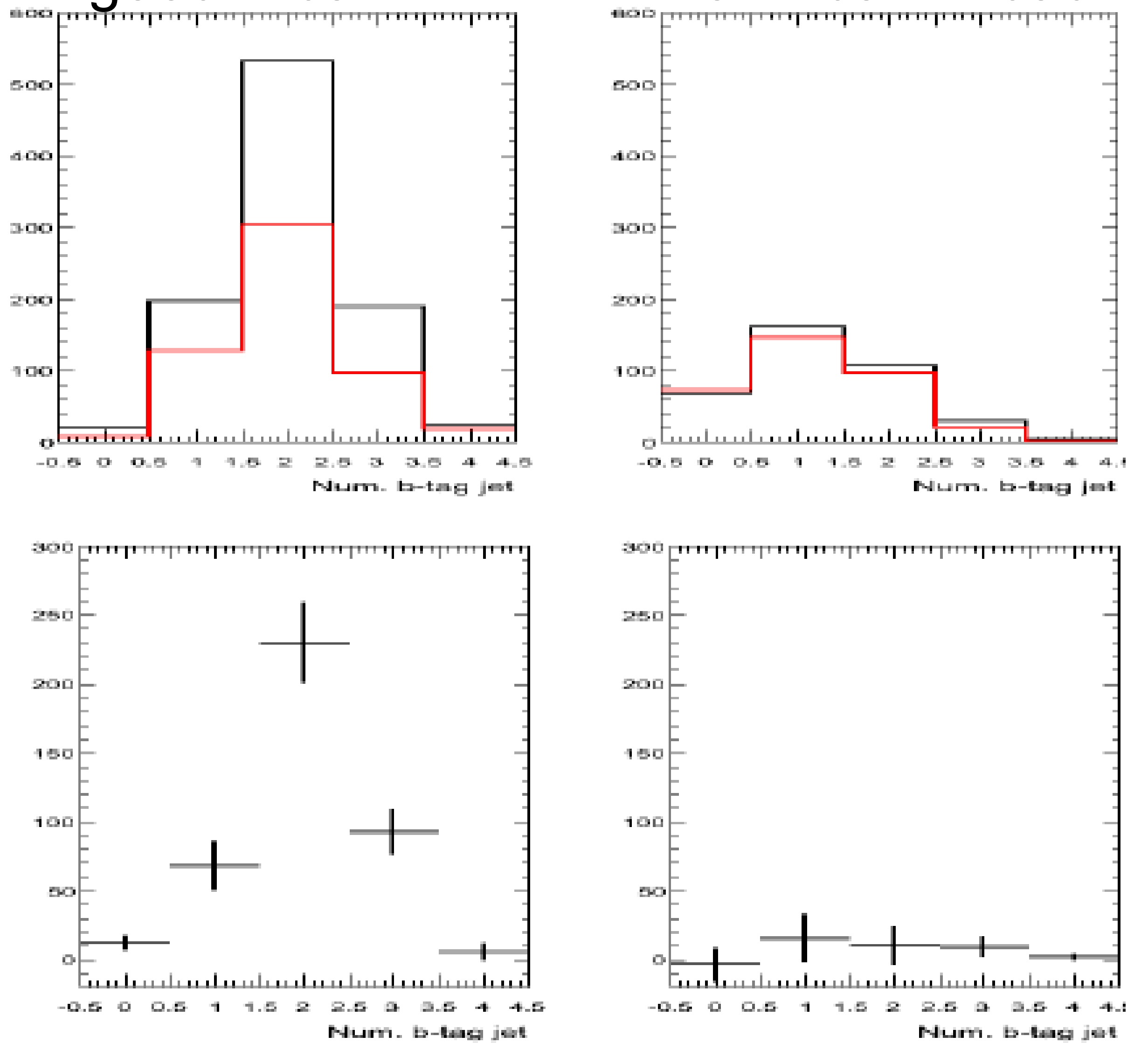
χ^2 Flip = f(-P1,P2,P3,P4,Met,Lep)



R: bkg subtraction

“good” ttbar

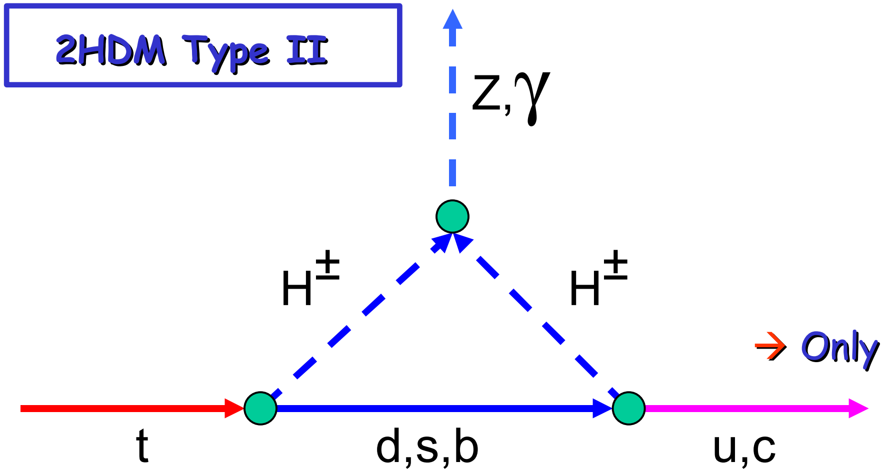
non-ttbar + “bad” ttbar

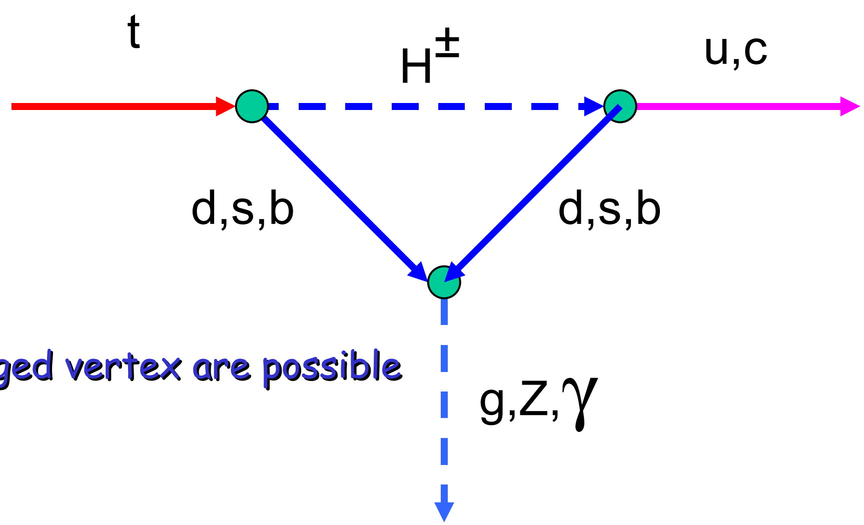


Normal - Flip

FCNC

2HDM Type II

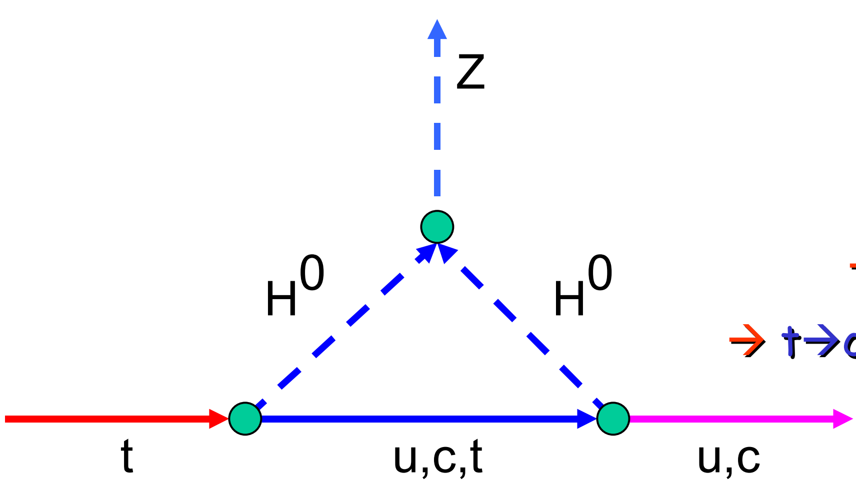


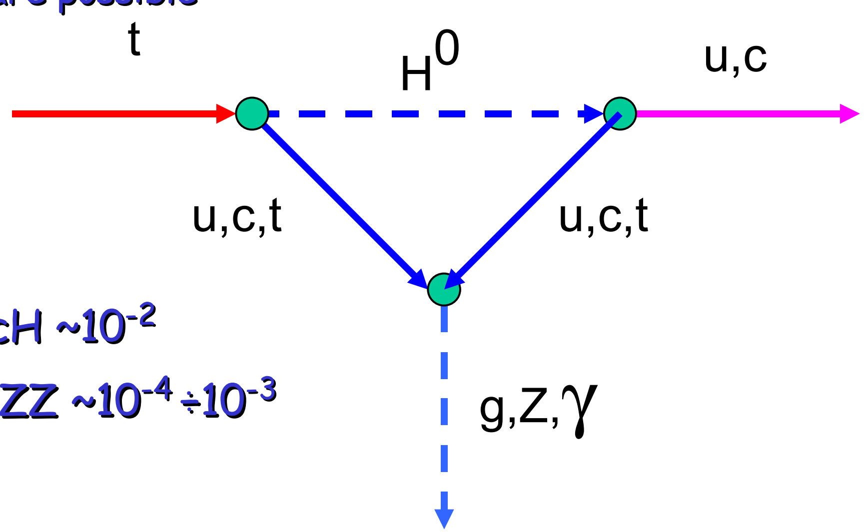


→ *Only charged vertex are possible*

2HDM Type III

→ *Also neutral vertex are possible*





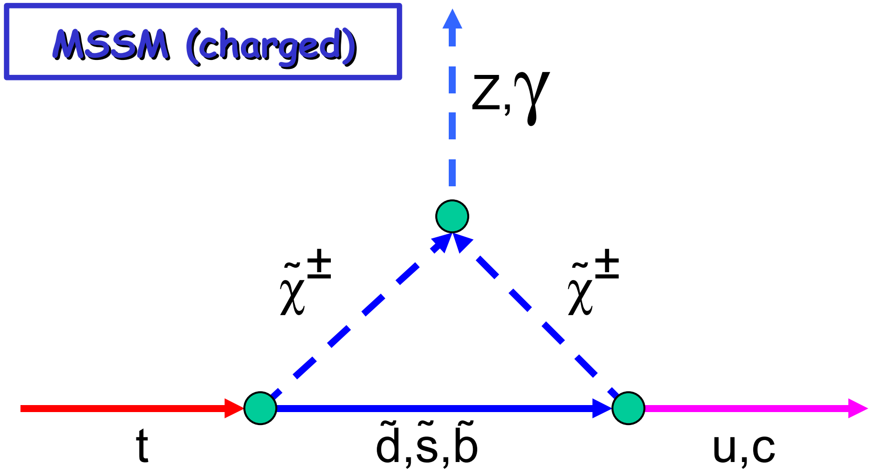
→ $t \to cH \sim 10^{-2}$

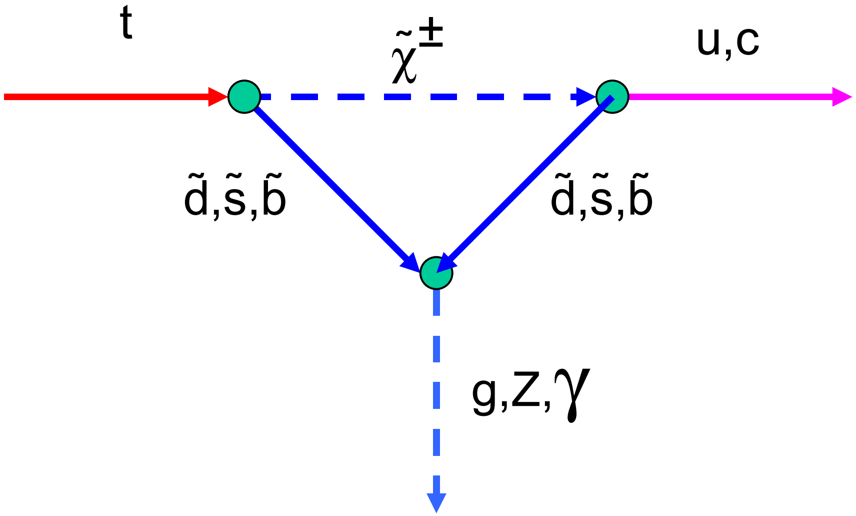
→ $t \to cWW/ZZ \sim 10^{-4} \div 10^{-3}$

Courtesy of Leonardo Benucci

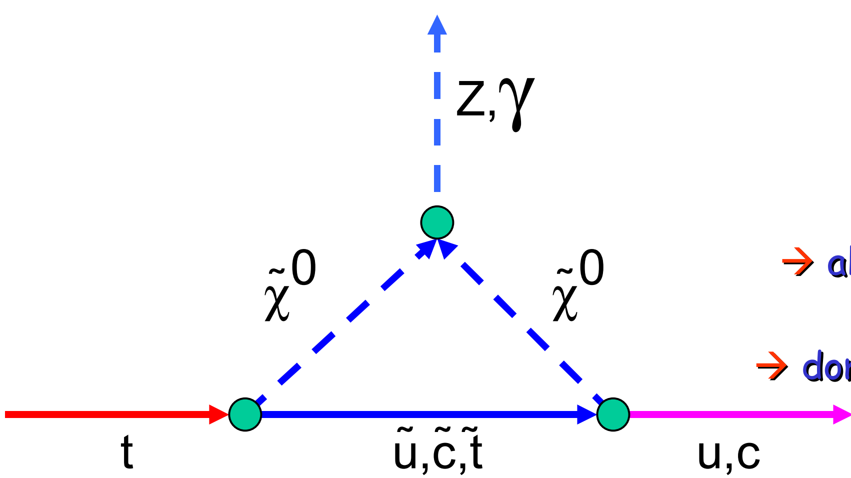
FCNC

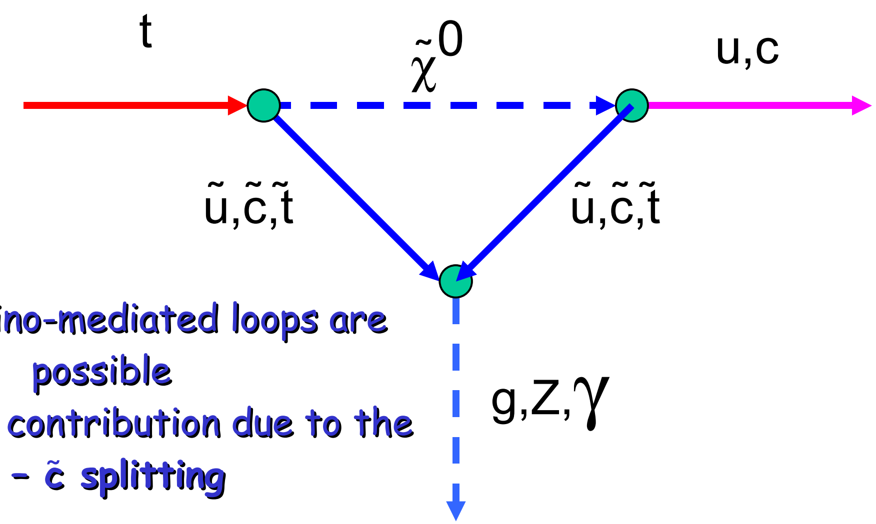
MSSM (charged)





MSSM (neutral)





→ also gluino-mediated loops are possible

→ dominant contribution due to the t̃ – c̃ splitting

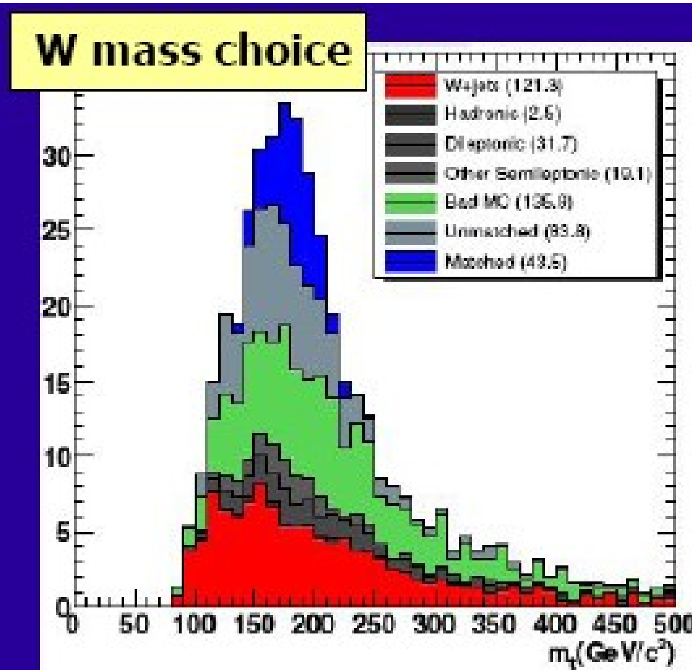
Courtesy of Leonardo Benucci

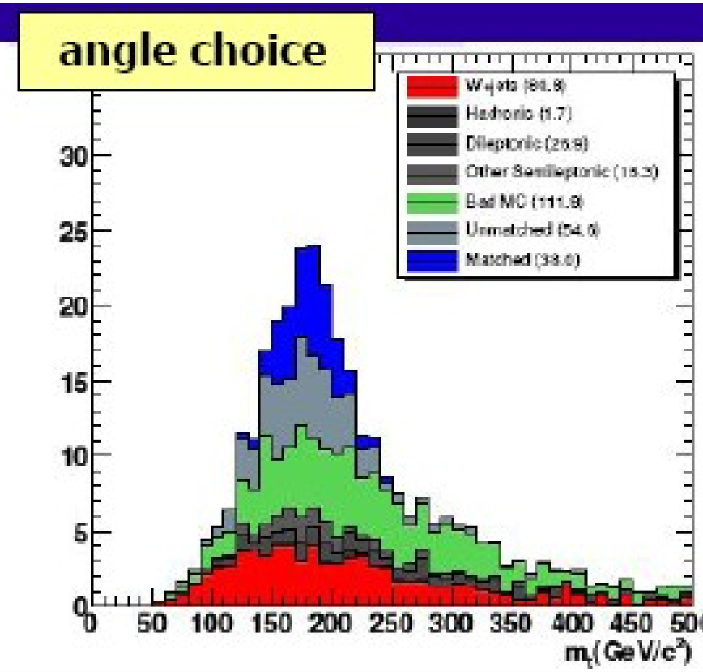
Some non-SUSY models with enhanced FCNC

- 2HDM (2 Higgs Doublet Model)
  - Type II: down quarks couple with only one H doublet
  - Type III: with both doublets
- TC2: technicolor + topcolor
- LR (Left-Right): additional U(1) which gives B-L violations; it has an additional vector-like quark
- QS (Quark Singlet): additional Q=+2/3 quark, singlet under SU(2)

top mass

N_{evt} @ $10pb^{-1}$ / bin

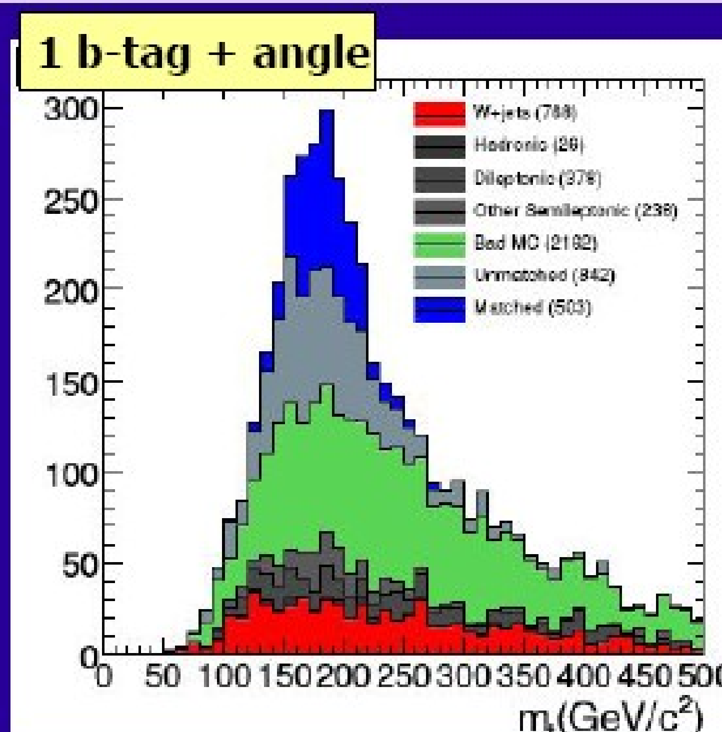


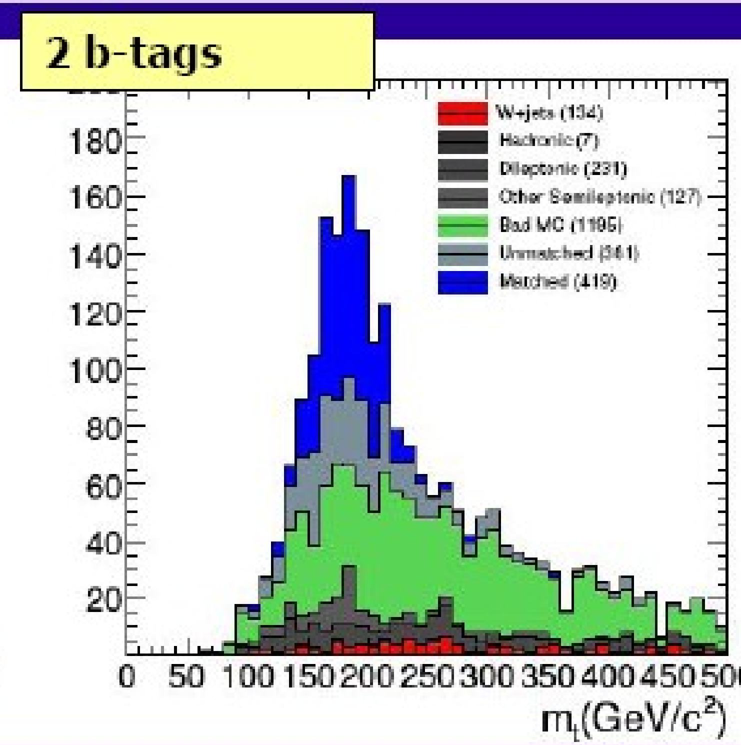


N_{evt} @ $100pb^{-1}$ / bin

(blue area in 1-tag underestimated)

[to be fixed]





Subtracting QCD in semilep events

- Matrix method:
  - Define loose (l) and tight (t) lepton cuts
  - 2 unknowns: “signal” (ttbar but also W), “QCD”
    - $N^{(t,l)}=N_S^{(t,l)}+N_{QCD}^{(t,l)}$
  - Define $\varepsilon^{l\to t}$: fract of l which also pass the t selection
    - $N^l=N_S^l+N_{QCD}^l$
    - $N^t=\varepsilon_S^{l\to t}N_S^l+\varepsilon_{QCD}^{l\to t}N_{QCD}^l$

2 equations
2 unknowns

  - Efficiencies from data:
    - “W-like” leptons from Z→ll (tag & probe)
    - fakes from l+jets events with low MET
      - This point deserves more discussion, see slide “Fake rates...”

Subtracting bkg in dilep events (1)

- Like-sign method:
  - assume SS~OS in bkg; only true for misid hadrons
- Matrix method:
  - Define loose (l), medium (m), tight (t) lepton cuts
  - 3 unknowns: “signal” (ttbar but also Z), “W”, “QCD”
    - $N^{(t,m,l)}=N_S^{(t,m,l)}+N_W^{(t,m,l)}+N_{QCD}^{(t,m,l)}$
  - Efficiencies: $\varepsilon^{l\to m}$, $\varepsilon^{l\to t}$ (fract of l which are also m or t)
    - $N^l=N_S^l+N_W^l+N_{QCD}^l$
    - $N^m=\varepsilon_S^{l\to m}N_S^l+\varepsilon_W^{l\to m}N_W^l+\varepsilon_{QCD}^{l\to m}N_{QCD}^l$
    - $N^t=\varepsilon_S^{l\to t}N_S^l+\varepsilon_W^{l\to t}N_W^l+\varepsilon_{QCD}^{l\to t}N_{QCD}^l$

3 equations
3 unknowns

Subtracting bkg in dilep events (2)

- Matrix method (cont'd):
  - Efficiencies from data:
    - $\varepsilon_S^{l\to m}$, $\varepsilon_S^{l\to t}$: “W-like” leptons from Z→ll (tag & probe)
    - $\varepsilon_{QCD}^{l\to m}$, $\varepsilon_{QCD}^{l\to t}$: fakes from l+jets events with low MET
      - This point deserves more discussion, see slide “Fake rates...”
    - $\varepsilon_W^{l\to m}$, $\varepsilon_W^{l\to t}$ from both of the above (uncorrelated)
  - Solve the system of equations, get N_s^l, N_W^l, N_{QCD}^l
    - Multiply by the $\varepsilon^{l\to t}$'s to get N_s^t, N_W^t, N_{QCD}^t

Fake rates from control regions

- Region C: Isolation > 0.2 and $\not{E}_T > 20$ GeV
- Region D: Isolation < 0.1 and $\not{E}_T > 20$ GeV.

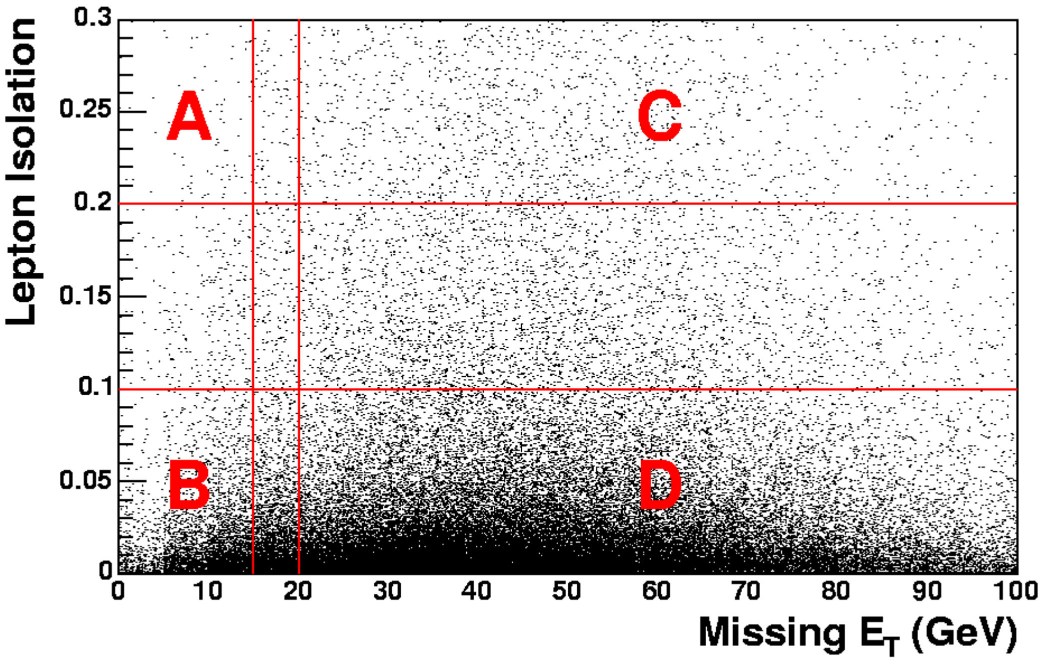
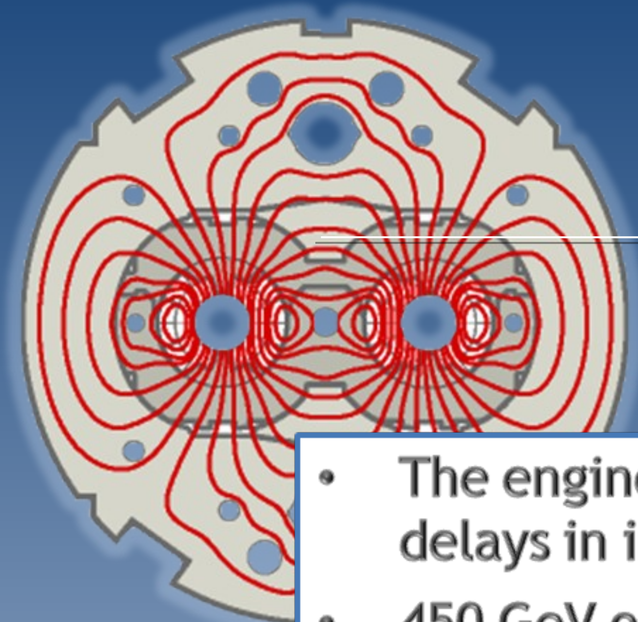


FIG. 15: Definition of the sideband regions used to estimate the non-W background. Lepton isolation *versus* missing transverse energy distribution for $t\bar{t}$ simulated events is also shown.

- All other selection cuts are applied
- Ideally, "W-like" leptons (tt/W/Z events) populate D and are rare in A,B,C
- QCD contamination in D is $N_D^{QCD}=N_C N_B/N_A$
- Caveat: we assume MET and iso uncorrelated
  - MET uncorrected is ok
  - jet misid as electron → pt underestim → wrong MET!

Getting ready for data

- February
  - Magnet test at low current
  - Weekly “private runs” (1 or 2 subdet + Trigger)
  - DAQ/Trigger consolidation
- March
  - End of tracker cabling
  - **Cosmic run at 0T :** TK, DT 3 wheel, ECAL, HCAL, CSC+, RPC
- April
  - Beam pipe closed
  - Pixel system installed
- May
  - Combined Computing Readiness Challenge
  - **Cosmic Run at 4 T. CMS ready for beam, taking cosmics**



LHC General schedule

- The engineering run originally foreseen at end 2007 is precluded by delays in installation and equipment commissioning.
- 450 GeV operation is part of normal setting up procedure for beam commissioning to high-energy
- The general schedule being reassessed, accounting for inner triplet repairs and their impact on sector commissioning
  - Machine closed — April 2008
  - Beam commissioning starts — May 2008
  - First collisions at 14 TeV c.m. — July 2008
  - Pilot run pushed to 156 bunches for reaching $10^{32} cm^{-2} \cdot s^{-1}$ as soon as possible
- No provision for major mishaps, e.g. additional warm-up/cooldown of sector: a success-oriented schedule !

Courtesy R.Aymar

S.Redaelli, 31/1/2008

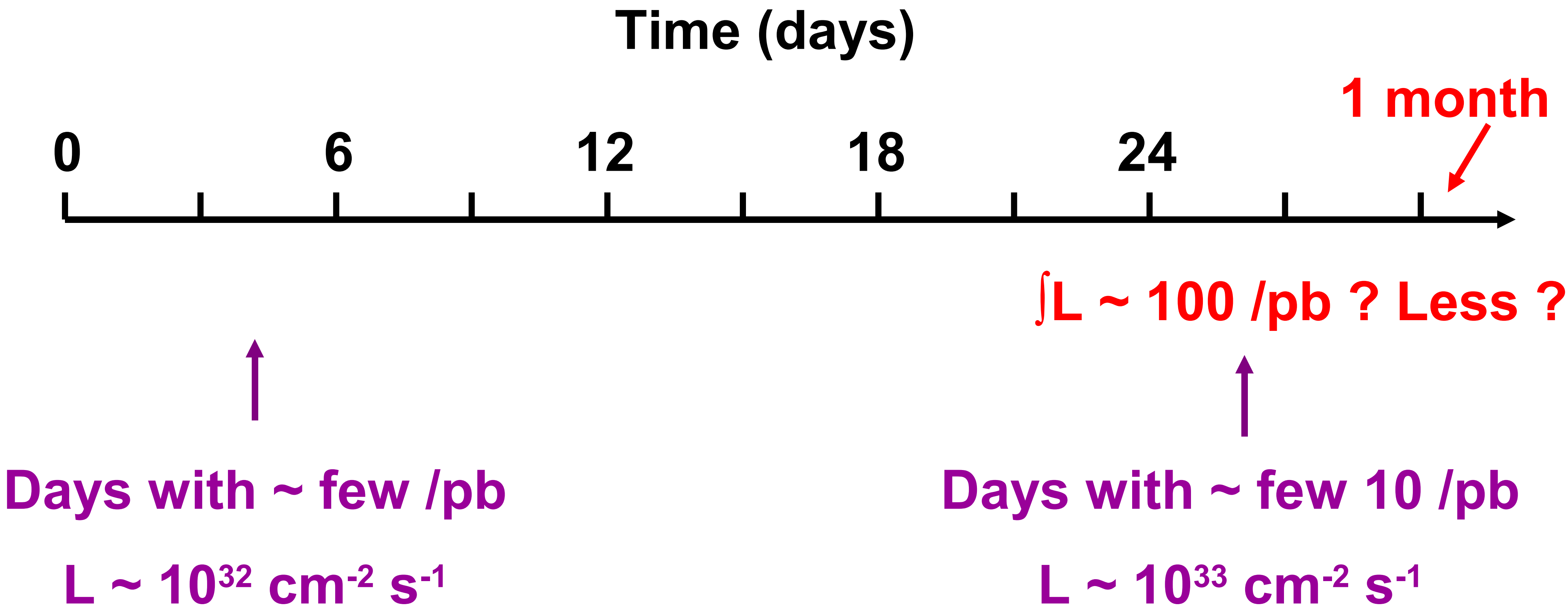
Time scale

(<u>beam time</u> is given, assuming 100% availability)

	Activity	Rings	Beam Time [days]
1	Injection and first turn	2	4
2	Circulating beam	2	3
3	450 GeV – initial commissioning	2	4
4	450 GeV – detailed optics studies	2	5
5	*450 GeV increase intensity*	*2*	*6*
6	450 GeV - two beams	1	1
7	*450 GeV - collisions*	*1*	*2*
8a	Ramp - single beam	[illegible]	8
8b	Ramp - both beams	[illegible]	2
9	7 TeV – top energy checks	[illegible]	2
10	Top energy collisions	1	1
	TOTAL TO FIRST COLLISIONS at 7 TeV		$\boxed{30}$
11	*Commission squeeze*	*2*	*6*
10	*Set-up physics - partially squeezed*	*1*	*2*
	TOTAL TO PILOT PHYSICS RUN		**46**

Approx.
<u>2 months</u> of
elapsed time
(50% effic.)

A hypothetical LHC startup month in 2008...



J.Alcaraz, Moriond 2007