Top quark physics in CMS

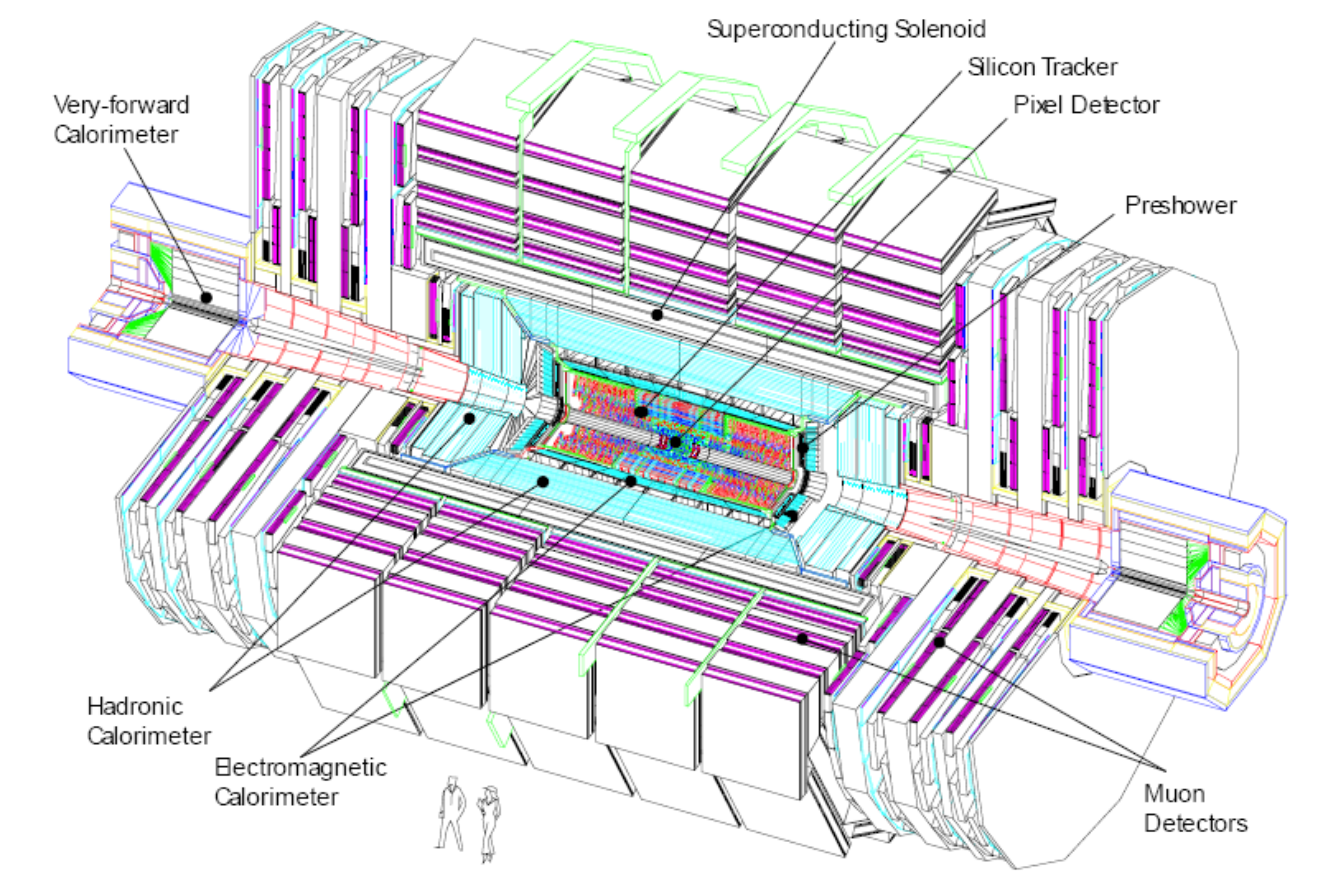
- How to prepare for top quark physics in CMS
  - *key aspects of the CMS detector relevant for top quark physics*
  - *strategy deployed by the CMS collaboration towards data*
- Obtaining a top quark sample
  - *event selection (data driven background estimates in progress)*
- First physics analyses exploring the top quark domain
  - *using top quarks for calibration, differential distributions, …*

Jorgen D’Hondt

Vrije Universiteit Brussel – IIHE

Top Institute CERN – May 25, 2009 – CERN

The CMS detector in a nutshell



CMS versus ATLAS

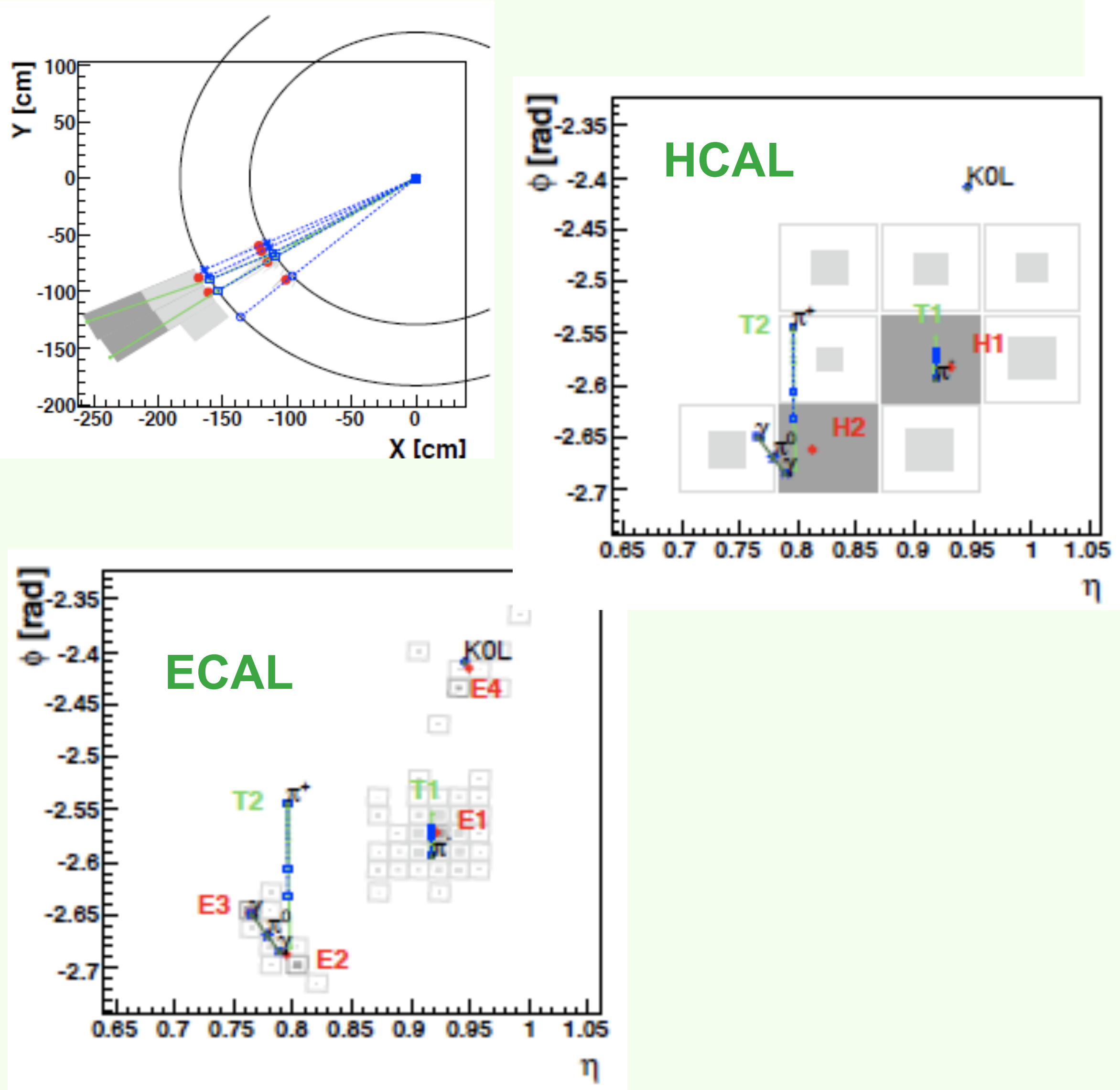
Rick Cavanaugh

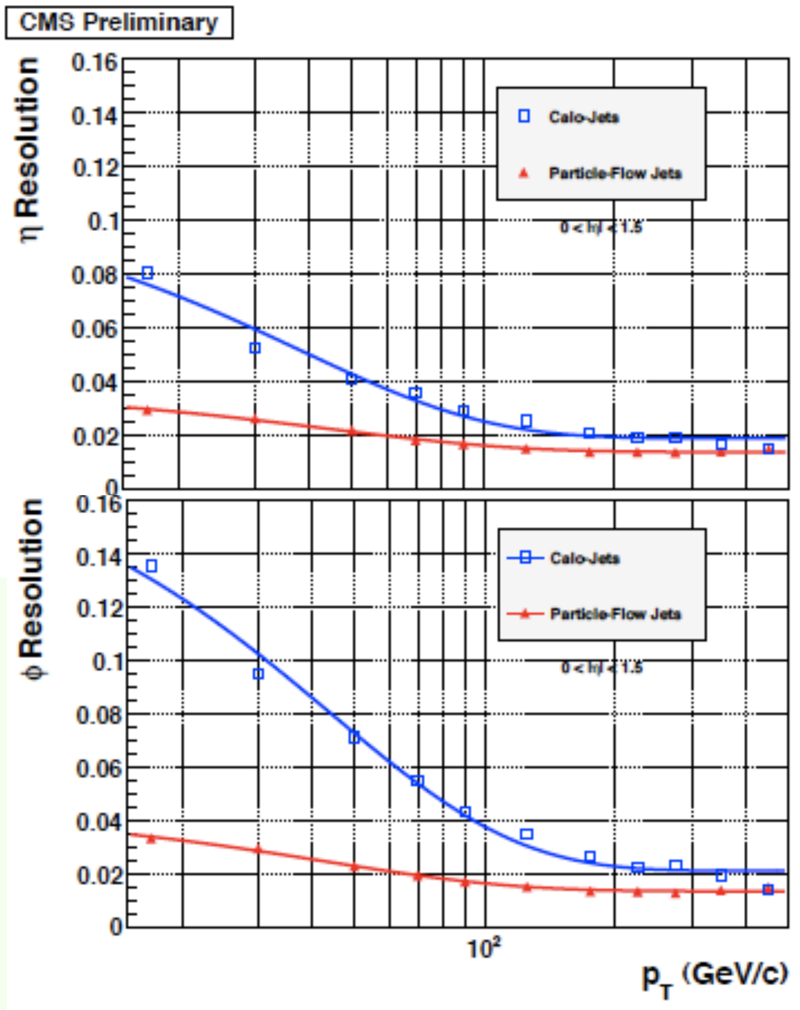
	ATLAS	CMS
Ecal+Hcal pion resolution	$\frac{\sigma}{E} = \left(\frac{41.9\%}{\sqrt{E}} + 1.8\%\right) \oplus \frac{1.8}{E}$	$\frac{\sigma}{E} = \frac{90\%}{\sqrt{E}} \oplus 7\%$ *e/h calibrated*
MET resolution (TDR)	$\sigma(\not{E}_T)/\Sigma E_T \approx 53\%/\sqrt{\Sigma E_T}$ *e/h calibrated*	$\sigma(\not{E}_T)/\Sigma E_T \approx 123\%/\sqrt{\Sigma E_T} + 2\%$ *e/h uncalibrated*
Inner tracker resolution (TDR)	$\sigma(p_T)/p_T = 1.8\% + 60\%\ p_T$ (p_T in TeV)	$\sigma(p_T)/p_T = 0.5\% + 15\%\ p_T$ (p_T in TeV)
B field inner region	2 Tesla : p_T swept < 350 MeV	4 Tesla : p_T swept < 700 MeV

ATLAS has 2x better calorimetry, CMS has 4x better tracking!

Motivation to implement Particle Flow tools combining the calorimeter with the tracking system. Today all main analyses are using only the calorimeter information to reconstruct jets.

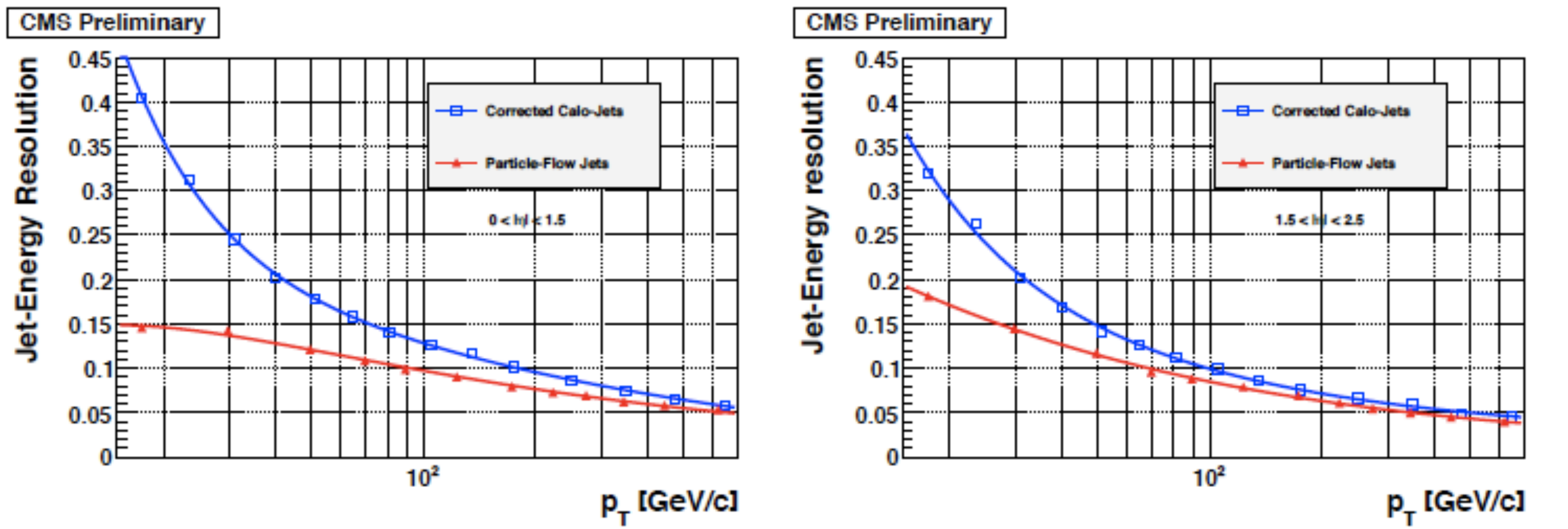
Particle Flow





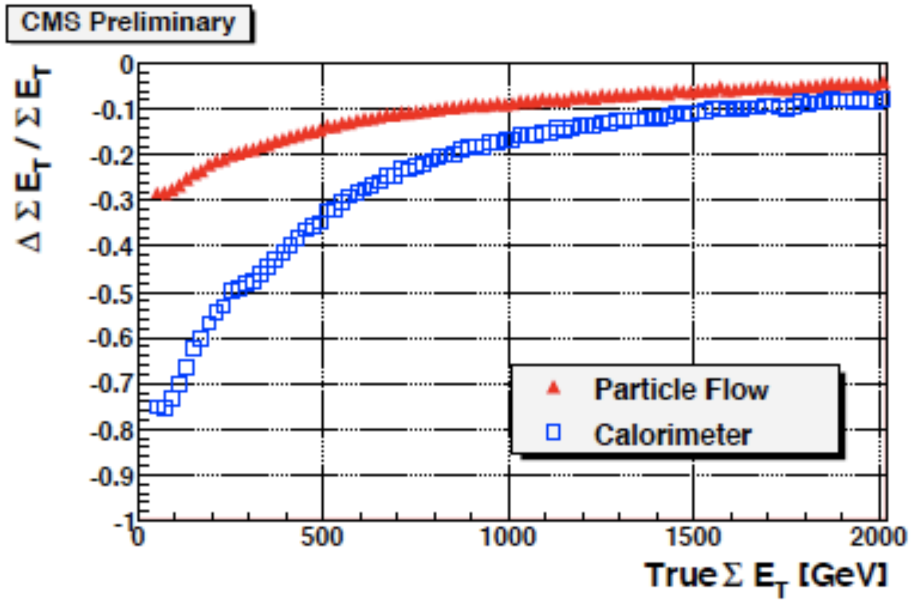
Particle Flow

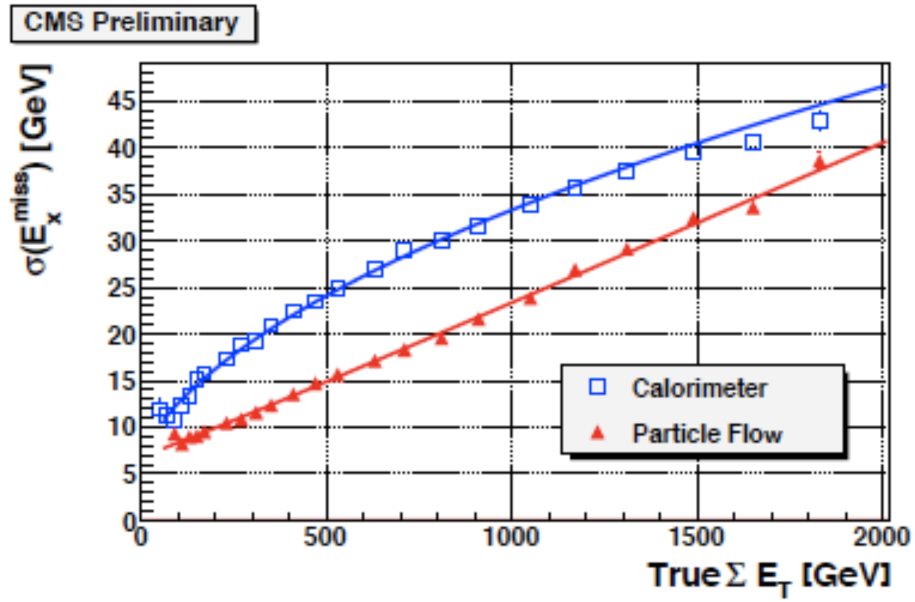
CMS PAS PFT-09/001



(a) Barrel (b) End-Caps

Particle Flow

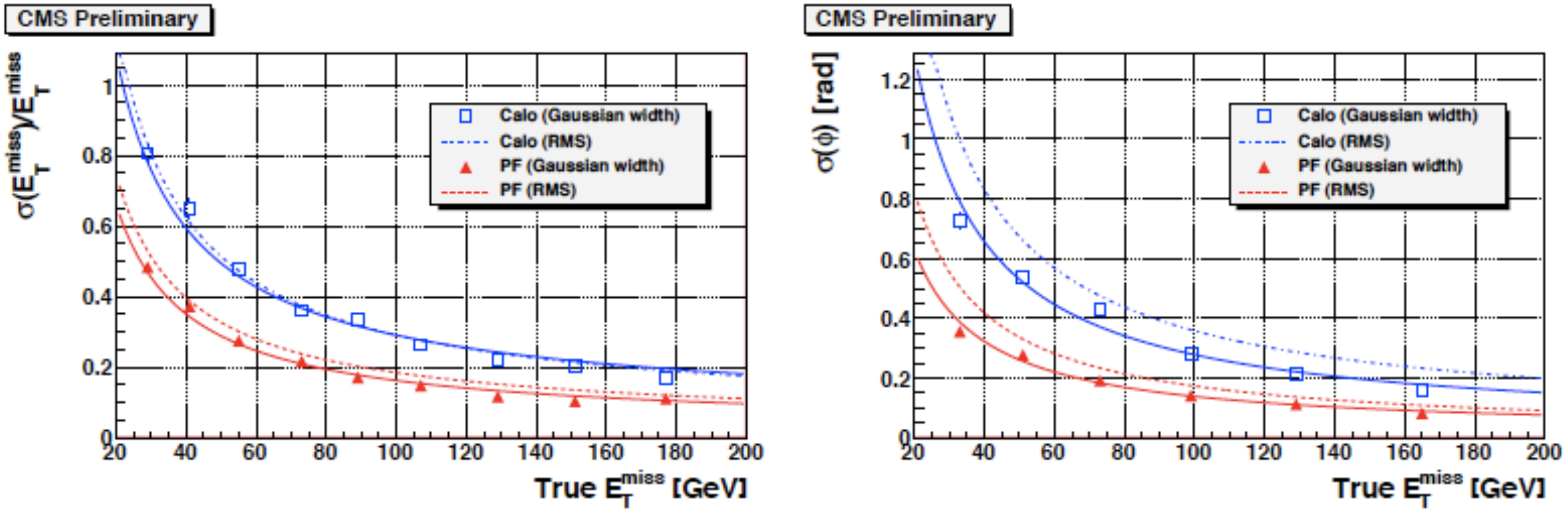




Missing ET resolution in QCD multi-jet events

CMS PAS PFT-09/001

Particle Flow

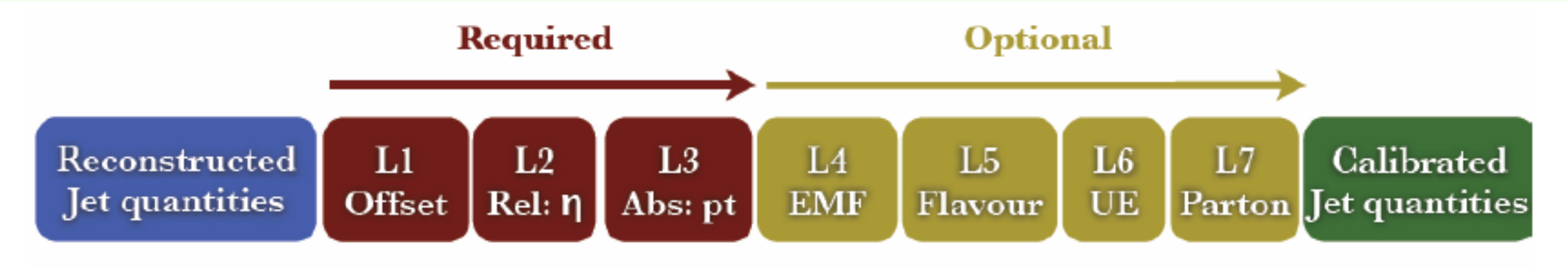


Missing ET and phi resolution in ttbar events

After we have commissioned this Particle Flow tool, this could open a new world for top quark physics in CMS…

Jet calibration strategy

Factorized approach into natural pieces with additional optional corrections:



Allows a thorough understanding of each individual part of a systematic uncertainty on the jet energy scale (factorized uncertainties).

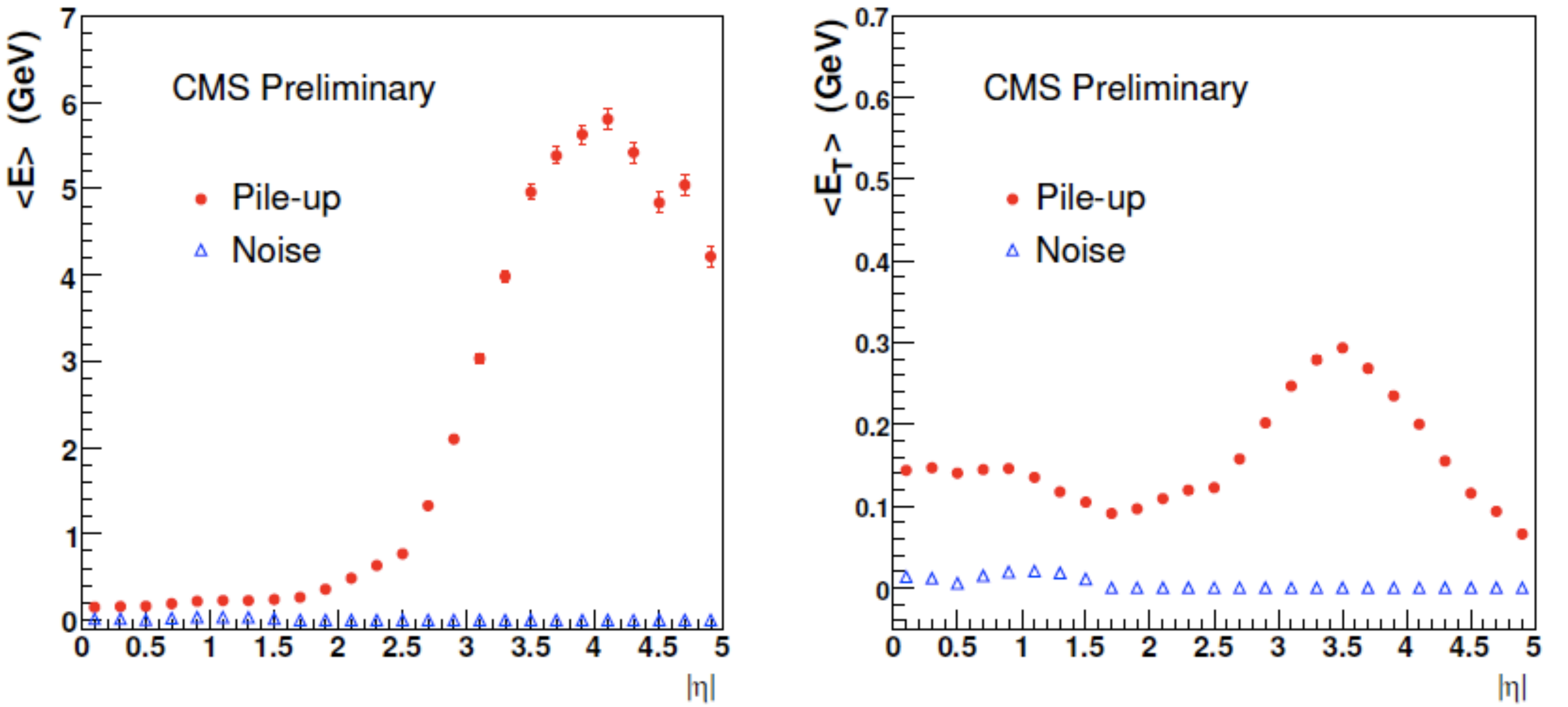
Most of the factors can be measured directly from collision data:

- **L1**: pile-up & threshold effects found in min-bias and zero-bias events.
- **L2**: jet response vs. η relative to barrel found using di-jet balance, etc.
- **L3**: jet response vs. p_T found in barrel using γ/Z + jets, top, etc.

Lots of work in progress and being put in place for first data later this year.

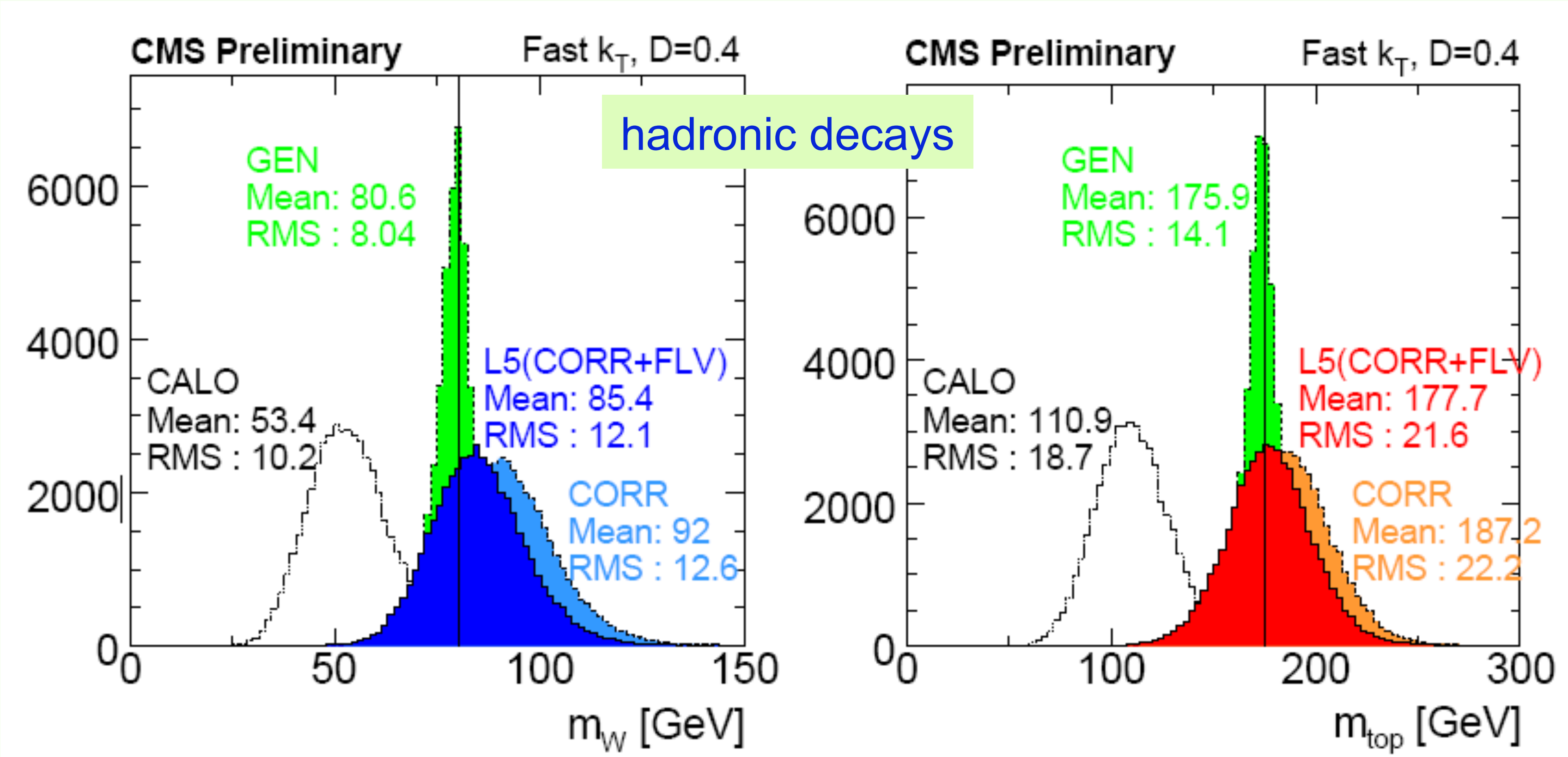
Jet calibration strategy

Average Energy or Transverse Energye in a ΔR=0.5 cone for one minimum bias event (after applying calorimeter thresholds, eg. E_T>0.5 GeV on towers)

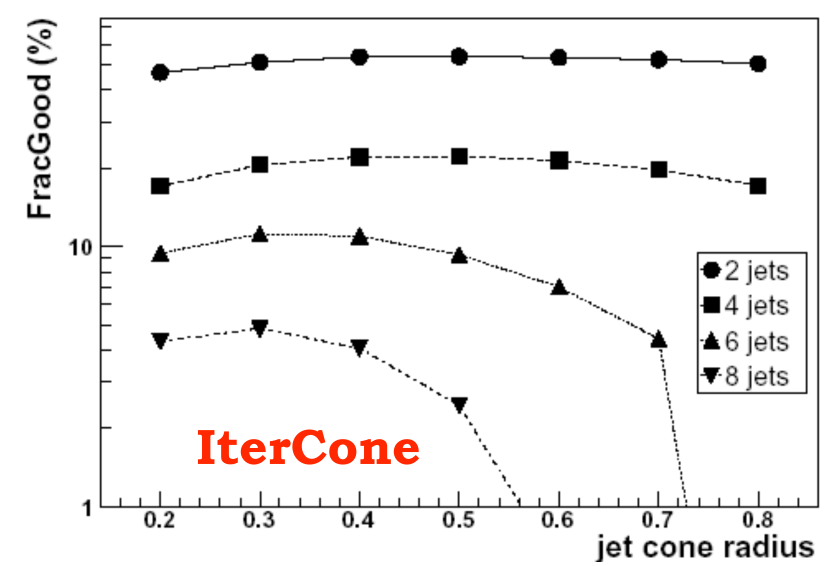


Performance of jet algorithms

The jet reconstruction performance in ttbar events is studied by selecting events with one ("lepton+jets") or zero ("alljets") electron or muon in the final state from a ttbar ALPGEN sample with no additional jets ("ttbar +0 jets"). Only events are considered for which all three decay products of one or both t(tbar) decay(s) can be uniquely matched to reconstructed calorimeter jets.

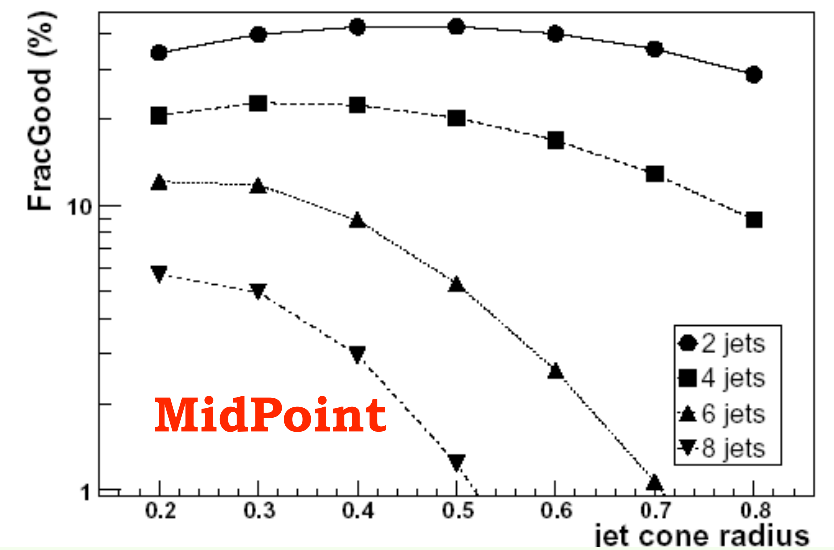


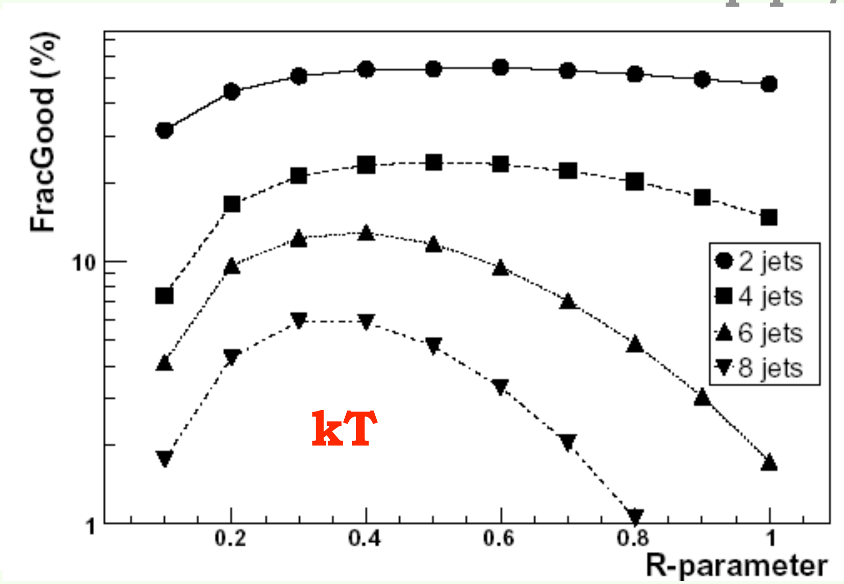
Optimization of parameters



Optimize the matching between the parton and jet kinematics for several benchmark processes (here top quark processes: single-top, top pairs and ttH). Need flexibility of the framework to allow optimization (eg. calibration for several parameters settings).

Les houches hep-ph/0604120

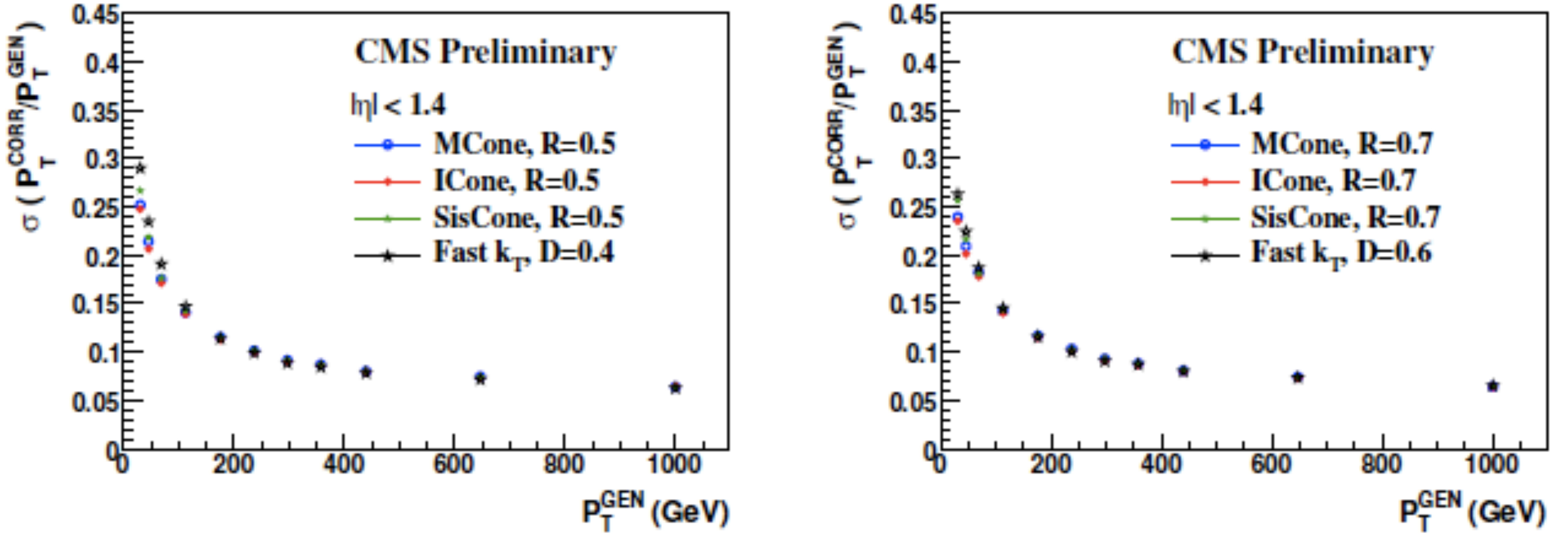




Optimization of parameters

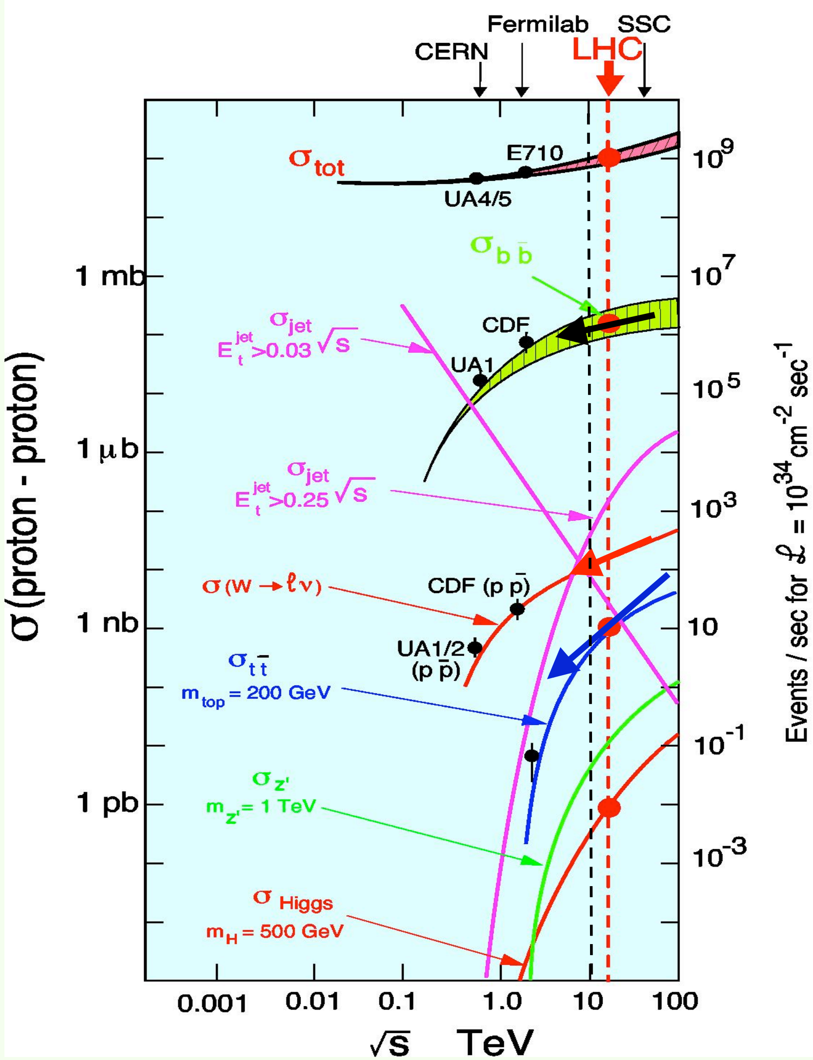
CMS PAS JME-07-003

Not that much difference between clustering algorithms observed in CMS (QCD di-jet events)



Top Quark physics at 10/14 TeV

- **Today all our analyses are performed with simulation of 14 TeV**



- **Cross section of the top signal is dropping faster from 10 to 14 TeV compared to the background processes**

	10 TeV σ_{NLO}MadGraph	14 TeV σ_{NLO}MadGraph
Top pairs	317 pb	750 pb
W+jets	40 nb	61 nb

- **Kinematics of the events is about similar (hence assumed equal)**
- **Efficiencies do not scale, S/B does!**
- **S/B scale = 1 → 0.66 & N_{signal} = 1 → 0.42**
- ***For this talk:* take a 14 TeV analysis with 10/pb to be equivalent to a 10 TeV analysis with 25/pb...**

Results from CMS

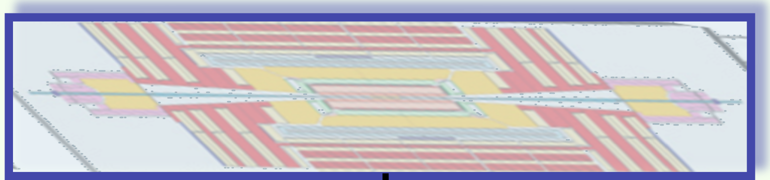
- How to find the official PUBLIC results of the CMS collaboration
- CMS website: http://cms.cern.ch/iCMS/
- Go to "physics", go to "recent physics results"
- Now you are at: https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults
- Here you find for each category so-called Physics Analysis Summary pages (PAS pages)
- Today for Top Quark physics
  - *TOP-08-001: Di-lepton ttbar cross section with 10/pb*
  - *TOP-08-002: Di-lepton ttbar cross section with 100/pb*
  - *TOP-08-004: Di-lepton ttbar tau channels (en route to)*
  - *TOP-08-005: Semi-leptonic (muon) ttbar cross section with 10/pb*
  - *TOP-07-004: Jet Energy Scale from top events*

Main aspects of the simulation being used in CMS today:

- Matrix Element generators for ttbar/W/Z: MadGraph & AlpGen.
- Single-top: didn't look enough at single-top as a background for ttbar.
- Multi-jet production: mainly biased PYTHIA samples.

Used to be 14 TeV, now we move to 10 TeV simulations.

Getting ready to learn something



offline

data format

Physics Object Groups

reconstruction

generators

Detector Performance Groups

detector & machine performance

selection → **we have developed some benchmark selections**

feedback

online

controlling bck & trigger → **analysis are being setup for bck estimates**

time

2009

2010

testing the SM
σ, ratios, decay, mass, ...

testing generators
diff.distr.

top as a calibration tool
JES & ε_b

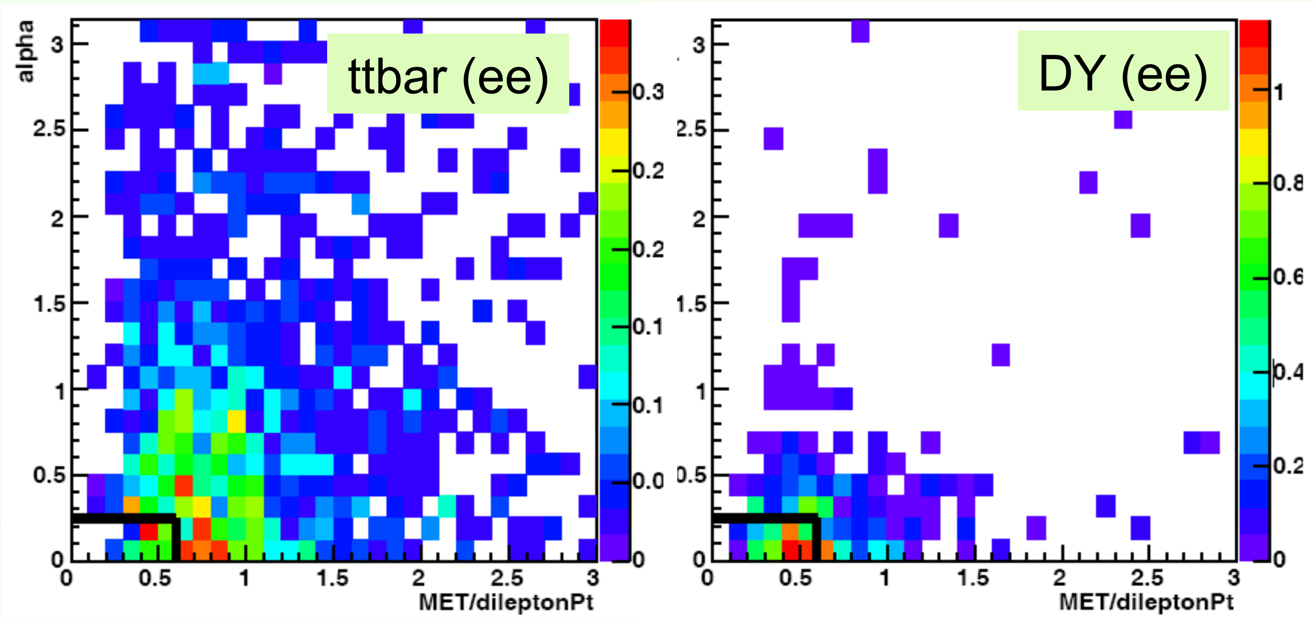
preparing the path for searches
diff.distr.

Selection: di-leptons

- Small branching ratio but can obtain a pure event sample
- Trigger based on single lepton triggers as cuts in the analyses are higher than the HLT single-lepton thresholds

ee mode	$\mu\mu$ mode	$e\mu$ mode
HLT1ElectronRelaxed 17	HLT1MuonNonIso 16	HLT1ElectronRelaxed 17 OR HLT1MuonNonIso 16

- Muons (+isolation) :
  - $|d_0^{X,Y}|<2.5$mm,
  - #hits≥7,
  - χ^2/ndf<5
- Electrons (+isolation) :
  - e/γ "tight" eID,
  - $|d_0^{X,Y}|<400\mu$m,
  - no μ in ΔR=0.1
- $ME_T>30$ GeV & $\phi(ME_T,\ell\ell)$ or $ME_T>0.6\,p_T(\ell\ell)$

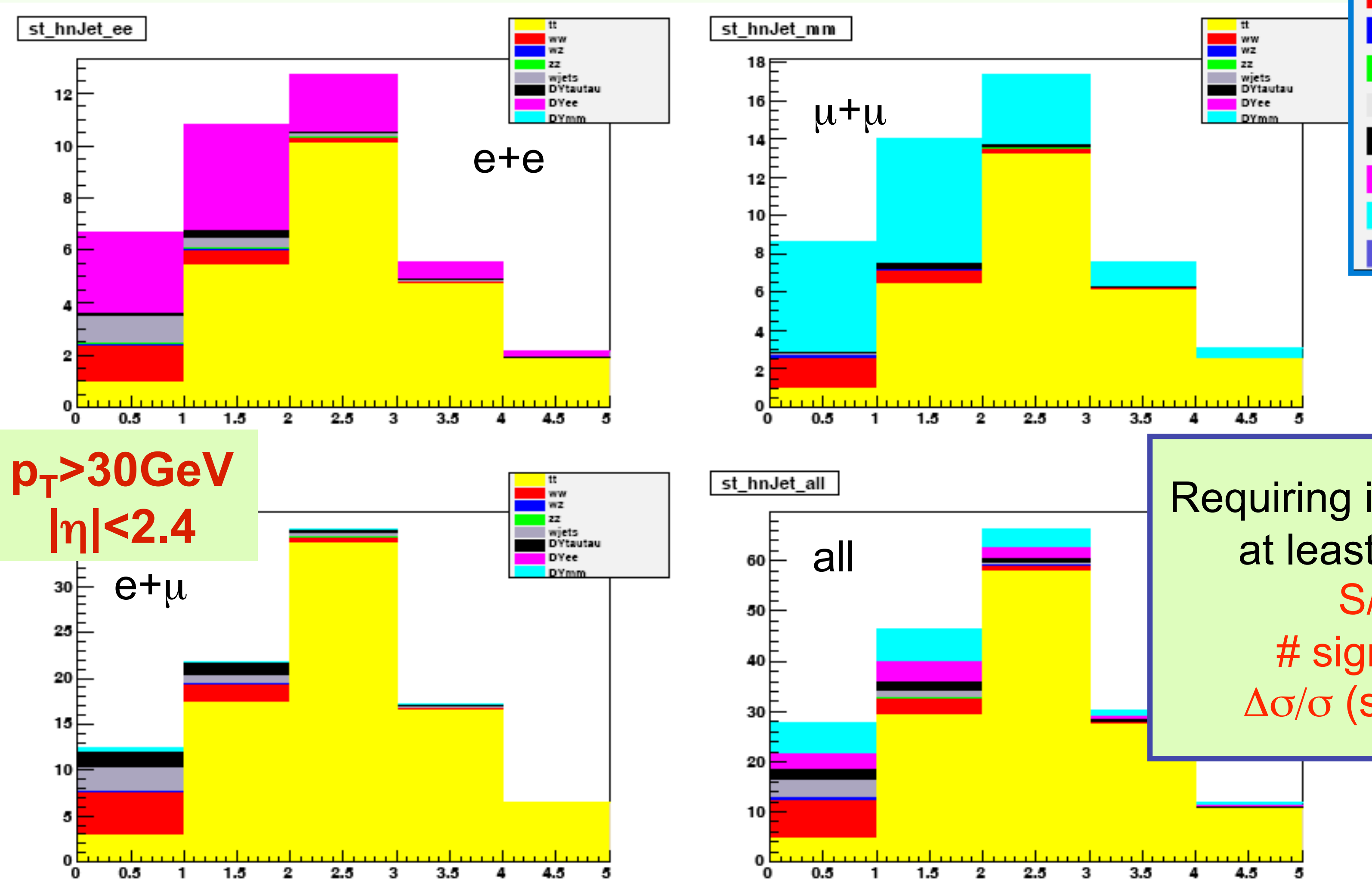


CMS PAS TOP-08-001

10/pb at 14 TeV

Results: di-leptons

- **After Z veto [76,106] GeV, the resulting jet multiplicities**



p_T>30GeV
|η|<2.4

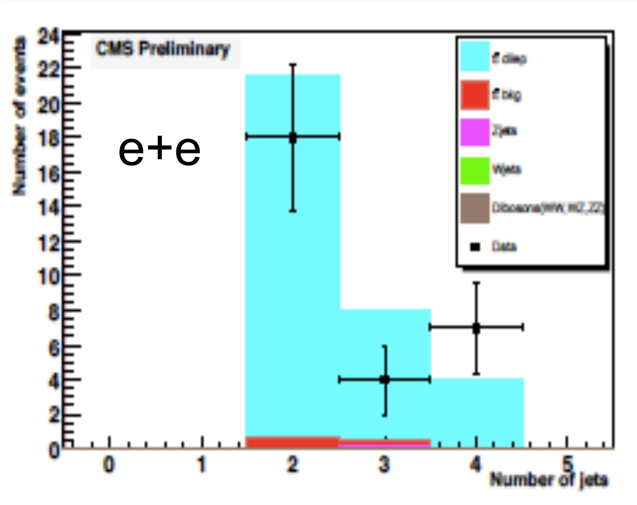
Requiring in the selection at least 2 jets give:
S/N ~ 8
signal ~ 100
$\Delta\sigma/\sigma$ (stat) ~ 10%

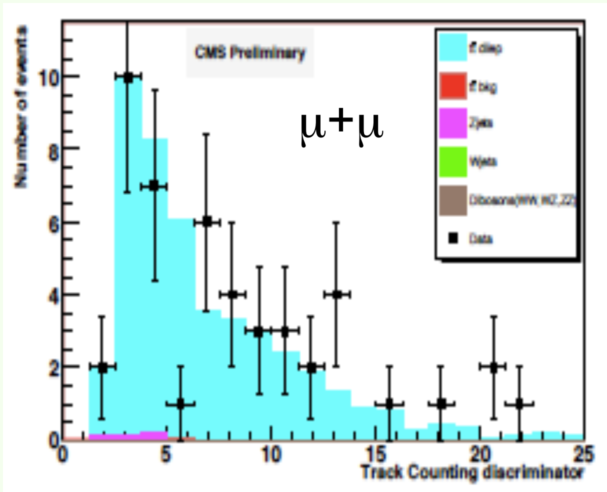
back of the envelop

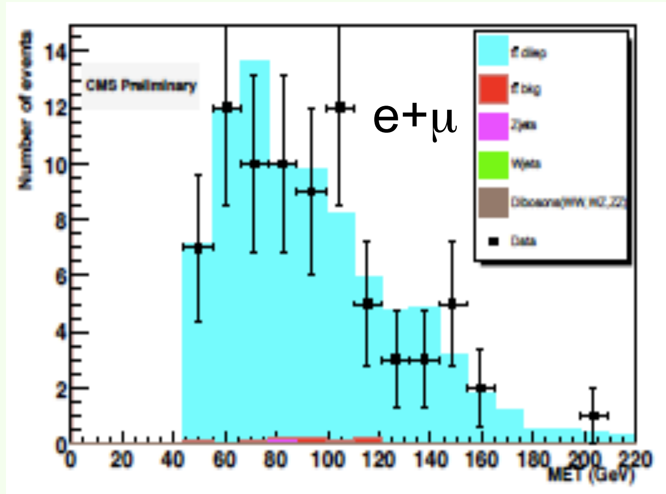
100/pb at 14 TeV

Results: di-leptons

- Similar selection (but not exactly the same) as for 10/pb analysis
- But also applies b-tagging (loose working point, track counting)
- Very pure sample of di-lepton ttbar events (trade off MET vs b-tagging)







- About 160 signal events expected for a total background of ~3 events (incl Z+jets, W+jets, di-bosons)
- Efficiencies: ee - 2.5%, μμ - 3.5%, eμ - 3.2%

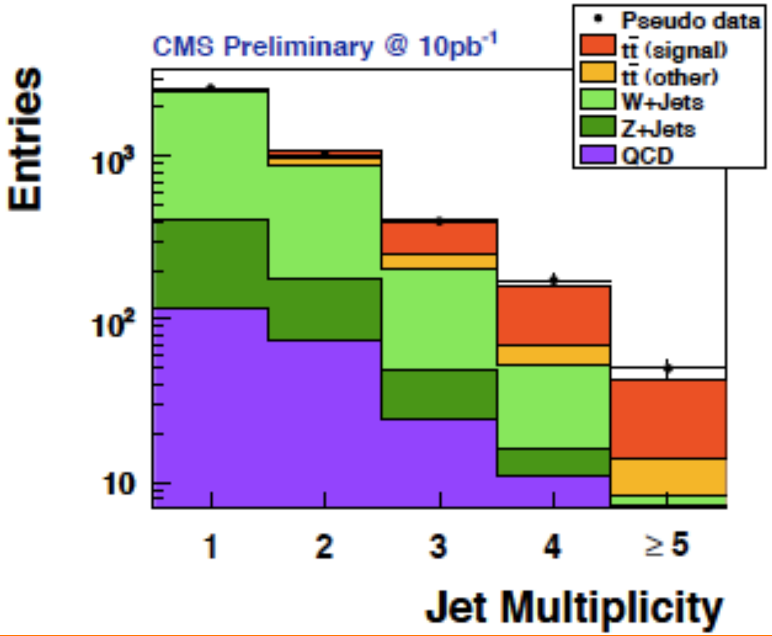
- Total di-lepton cross section can be measured to 8% stat. precision

10/pb at 14 TeV

Selection: lepton+jets

- **Larger branching ratio but only one isolated lepton (here muon channel)**
- **Apply the HLT1MuonNonIso (p_T>30GeV → 91% efficiency plateau)**
  - **Exacly 1 muon with p_T>30GeV & $|\eta|$<2.1 + isolation**
  - **At least 4 jets with E_T>65-40GeV & $|\eta|$<2.4**

	$t\bar{t}$ (signal)	$t\bar{t}$ (other)	W+jets	Z+jets	QCD	S/B(QCD)	S/B
Preselection	749	527	7474	1430	–	–	–
4 Jets $p_T > 65/40/40/40$ GeV	236	135	83	16	–	–	–
1 Muon $p_T > 30$ GeV	163	32	57	8	110	1.48	0.79



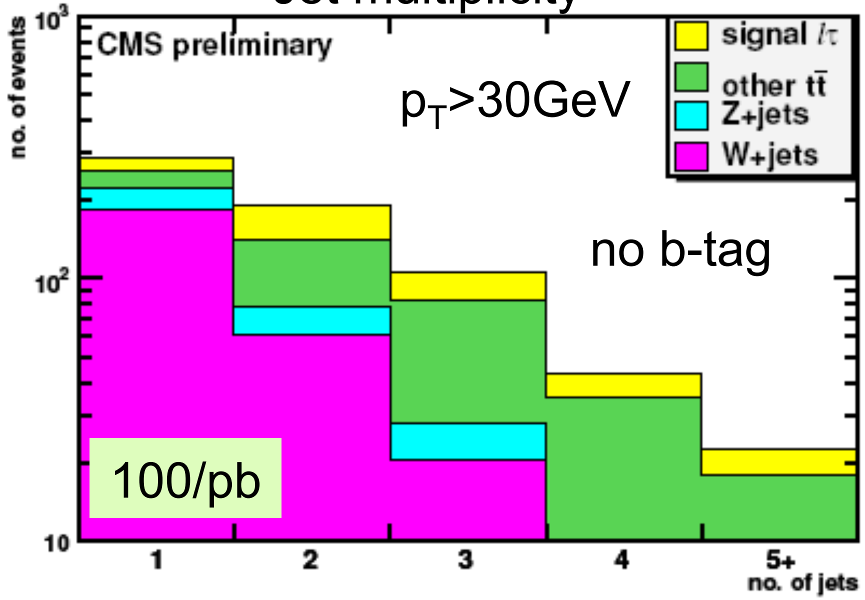
Requiring in the selection at least 4 jets and tight isolation give :
S/N ~ 1.5
S/N (m_t window) ~ 3
S/QCD ~11.6
\# signal ~ 128
$\Delta\sigma/\sigma$ (stat) ~ 15-20%

back of the envelop

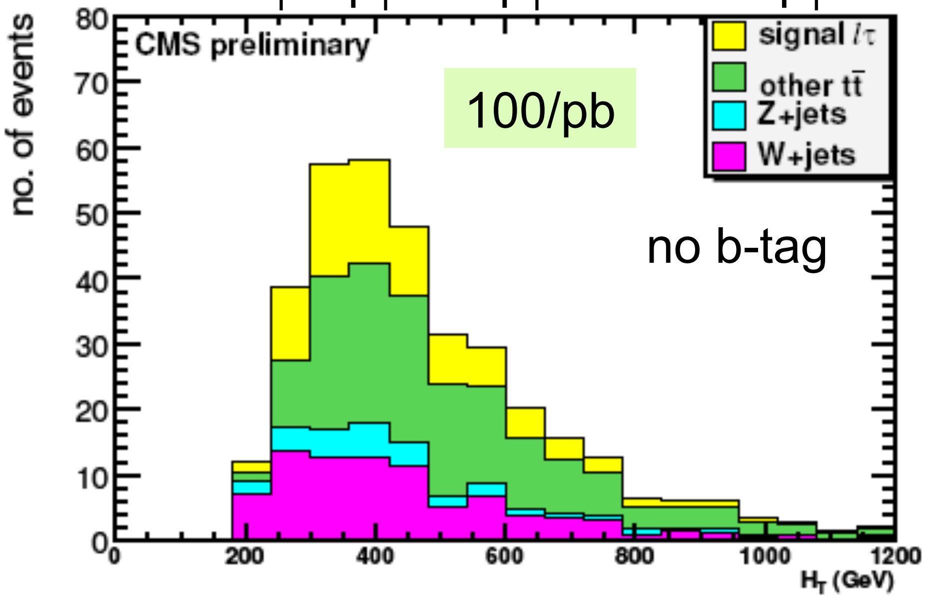
Tau's visible this year?

- Dedicated event selection (isolated lepton + MET>60GeV + 2 b jets)
- One tau lepton (CaloTau) with general tau tagging algorithms
- An opposite charge is required from lepton and leading track in tau

Jet multiplicity

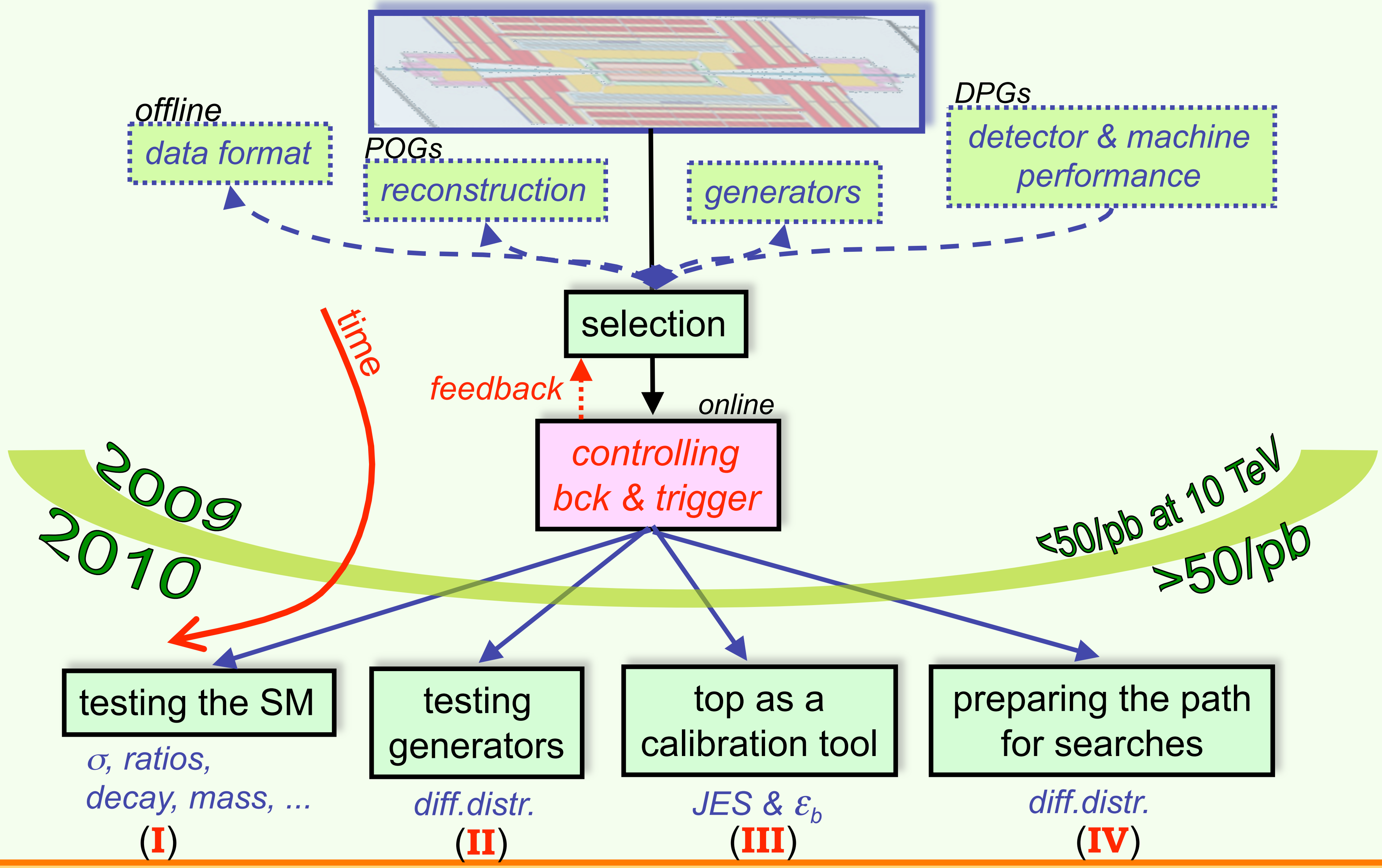


$H_T = p_T^{e,m} + p_T^{\tau} + MET + p_T^{jets}$



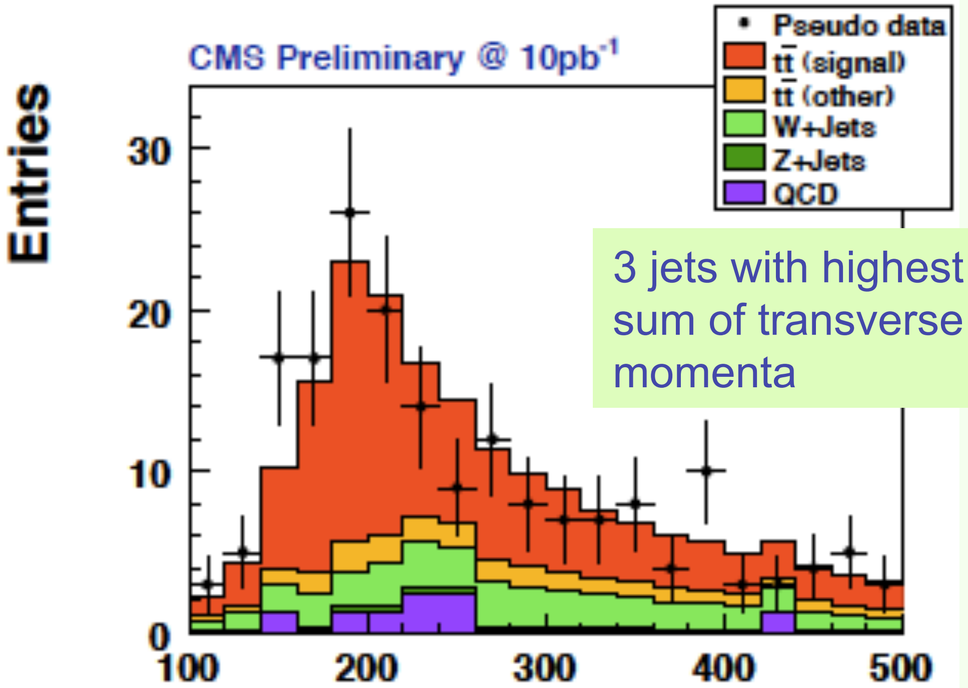
- After this selection
  - 1 prong : S/N ~ 0.40 (S~7.3 events for 10/pb at 14 TeV → S/sqrt(B)~2)
  - 3 prong : S/N ~ 0.14 (S~1.3 events for 10/pb at 14 TeV → S/sqrt(B)<1)

Getting ready to learn something



(I) Testing the Standard Model

- After the event selection we have to convience ourselves that we see the Standard Model top quark, hence measure its properties



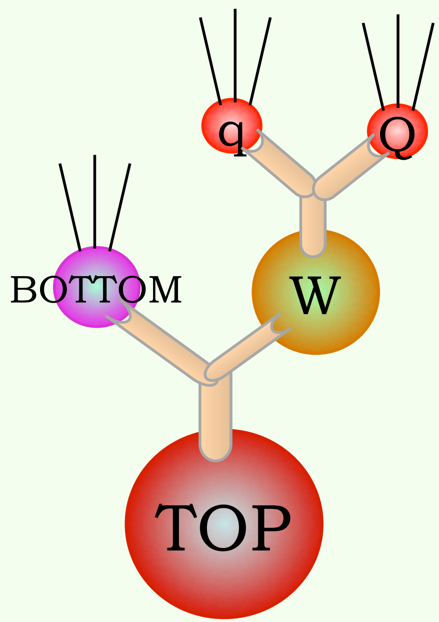
3 jets with highest sum of transverse momenta

- Usually this requires to combine the jets into a t→bW→bjj tree
- Several methods explored from simple choices to multi-variable Likelihood Ratios
- We reach jet combination efficiencies of ~30% from simple to ~70% of advanced methods and looking in a window around m_{top}

- Ongoing activity to estimate QCD & W+jet background from data itself
- Trivial but important remark
  - If you select the 4 highest E_T jets in the event, it happens only in ~20-30% of the events that you find that these jets match the 4 primary quarks

(III) Top as a calibration tool

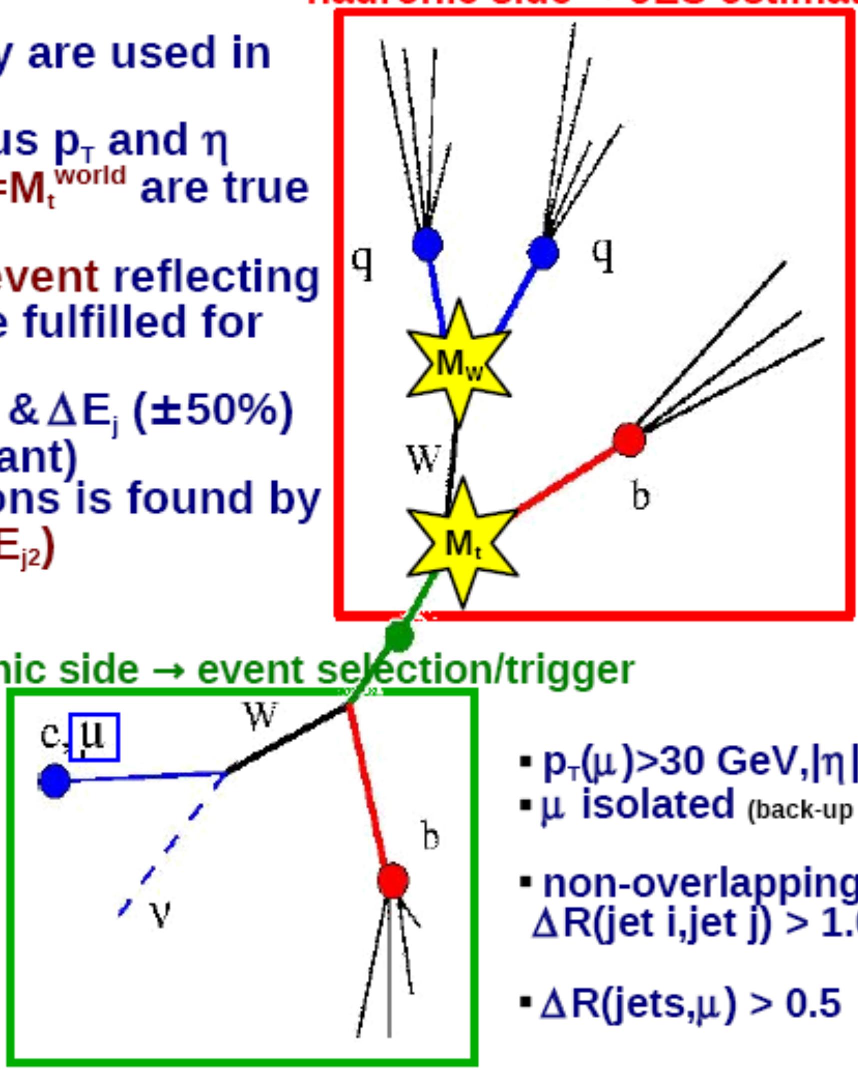
- In the top decay we have two mass constraints and one flavour constraint if we assume the Standard Model
  - m_W has been measured with a precision of 0.03 %
  - m_t has been measured with a precision of 0.8 %
  - flavour constraint $BR(t \rightarrow bW) = 1$



- Methods are put in place to use 100/pb of data at 10/14 TeV to estimate the b-tagging efficiency and the Jet Energy Corrections

Top as a calibration tool: JEC

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

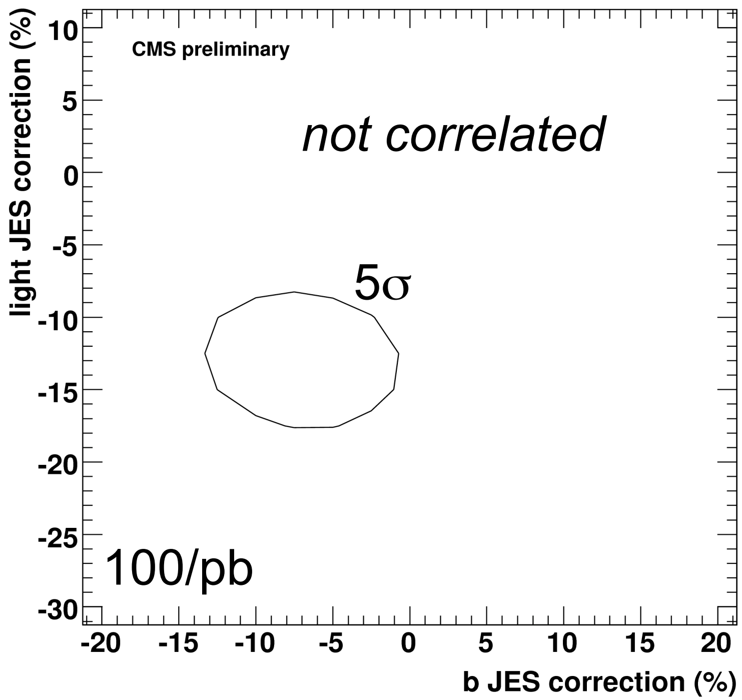


- To reduce the process background a tight event selection is applied
- A likelihood ratio is constructed to identify the correct jet combination
- A cut on this likelihood ratio is made to reduce combinatorial background
- To reduce contributions from mis-reconstructed events cuts are made on the probability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

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

Top as a calibration tool: JEC

- Hence for each event a $\chi^2 = \chi^2(\Delta E_b, \Delta E_{q1}, \Delta E_{q2})$
- When estimating an inclusive correction we can put $\Delta E_{q1} = \Delta E_{q2}$
- Hence we obtain a confidence interval in 2 dimensions: ΔE_b & ΔE_{q1},

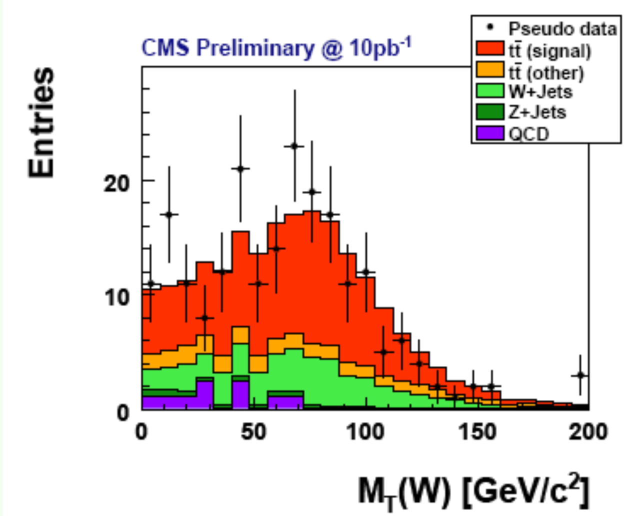


- The residual jet energy correction is
  - $\Delta E_b = -7.0 \pm 0.9$ %
  - $\Delta E_q = -12.9 \pm 0.9$ %
- These uncertainties are corrected to have a unity width of the pull distribution
- These data-driven numbers agree well with the MC expectation and the method can therefore serve as a measure and a closure test for JEC's.

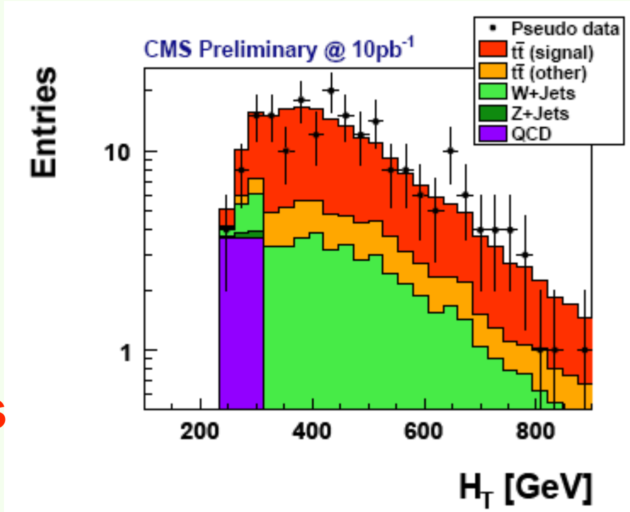
- with 100/pb we could have a precision of about 1% on the JEC
- effort to project vs (p_T,η)-jet to profit optimal from this data, and going towards a combine JEC/m_{top} measurement

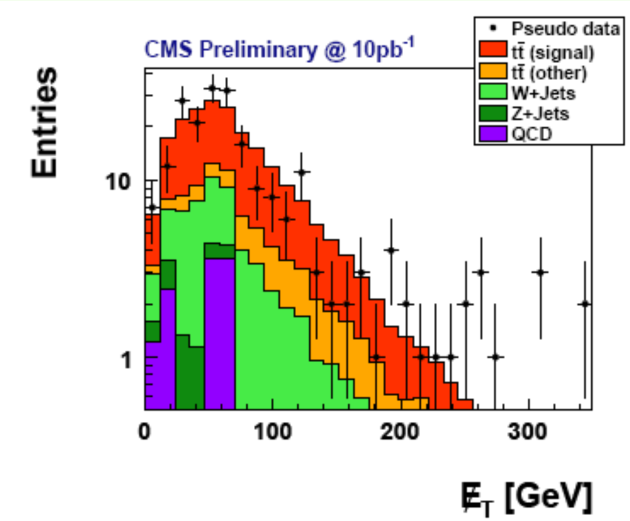
(IV) Preparing the path for searches

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



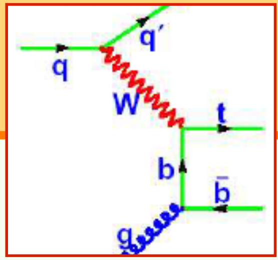
- Examples:
  H_T, MET, p_T^{top}, p_T^{ttbar}, p_T^{lept}, m_{ll}, m_T(l+MET), topo. variables, ...





- Need to increase the activity and ideas in this direction

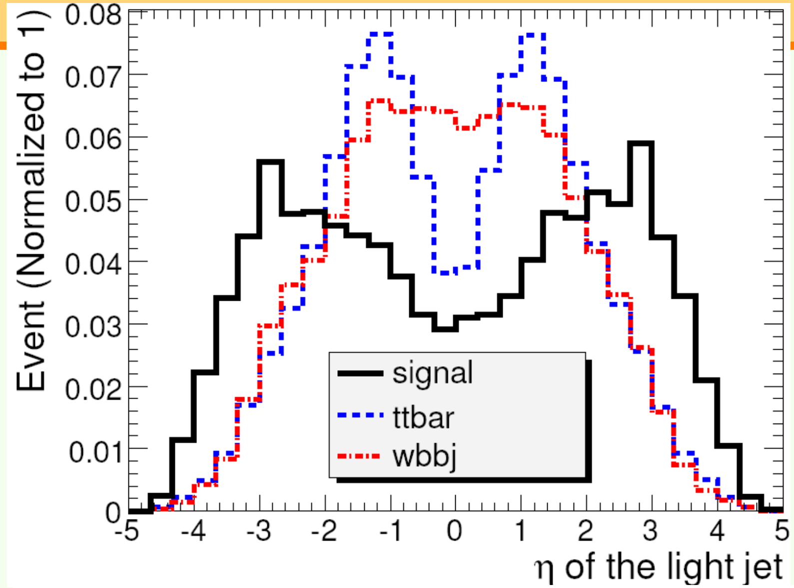
Extra: single-top (t-channel)

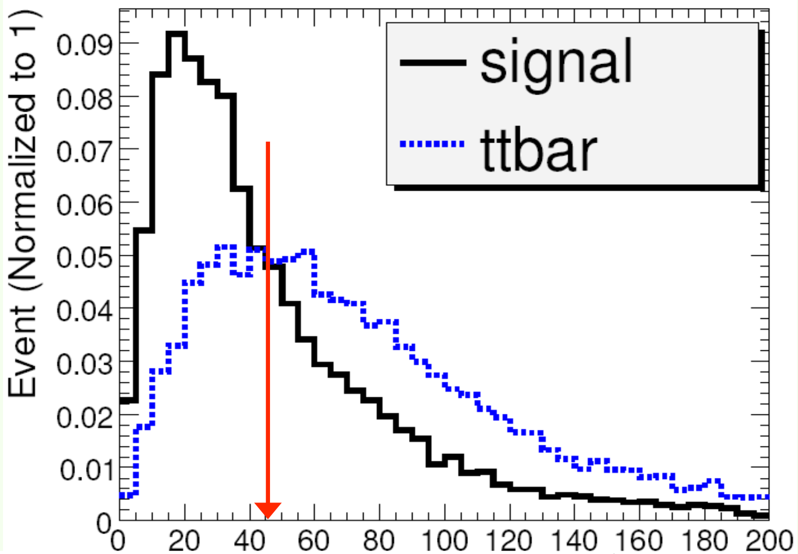


- Production channel with largest cross section
- Optimized event selection (σ_{NLO} ~ 243pb)
  - MET > 40 GeV
  - b-jet: p_T>35GeV, $|\eta|$<2.5
  - light-jet: p_T>40GeV, $|\eta|$>2.5 (forward)
  - topological cuts: m_{rec}(top), m_T(W)
- Expected number of events ($10fb^{-1}$)
  - signal = 2389
  - tt = 1188
  - W+jets = 597 (CompHEP, TopReX, MadGraph)
  - QCD = negligible (using factorisation of ε)
- Resulting S/B~1.34
- Estimate of cross section ($10fb^{-1}$)

$$\frac{\Delta\sigma_t}{\sigma_t} = 2.7\%(stat) \oplus 8.1\%(syst) \oplus 3\%(lumi) = 9.0\%$$

theory, JES, b-tagging

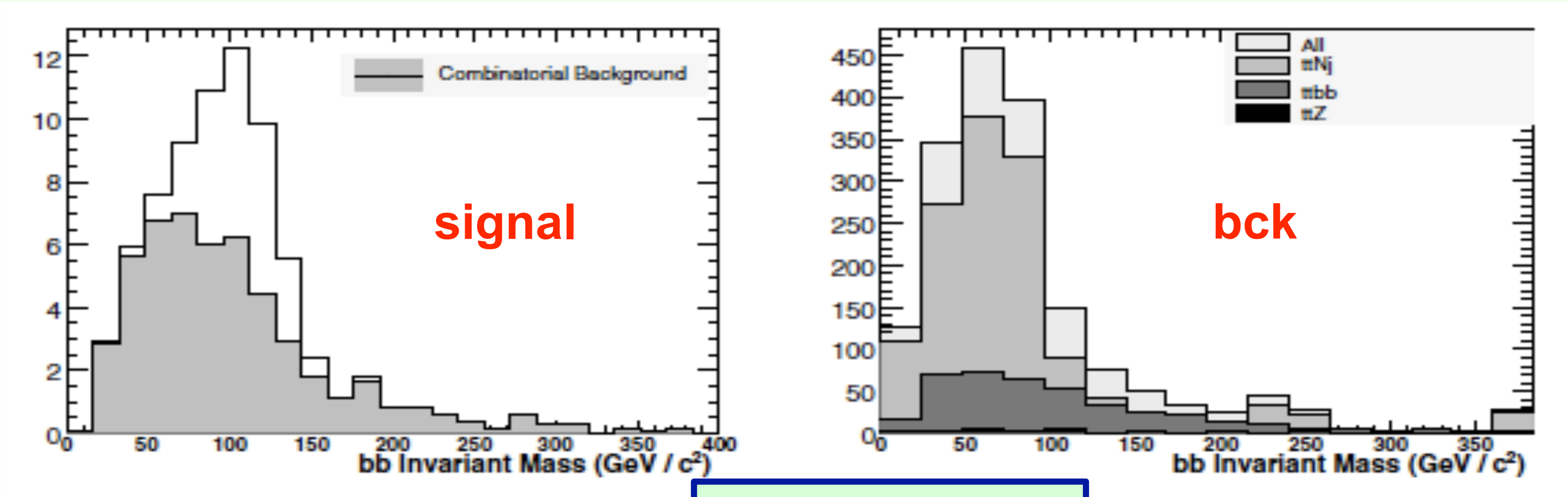




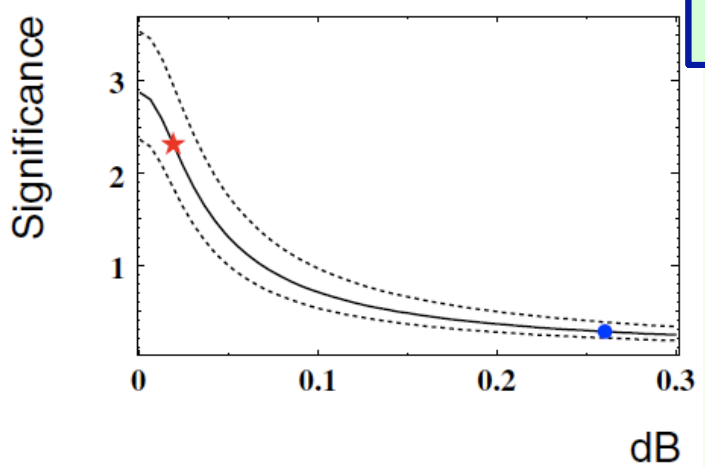
$\vec\Sigma_T \equiv \vec P_T(W) + \vec E_T(b\,\text{jet}) + \vec E_T(\text{light jet})\ [+\vec E_T(\text{second } b\text{ jet})]$

Extra: ttH (H→bb)

- **Strong effort to make visible the ttH channel with traditional techniques**
- **Combining all decay channels (di-lepton,semi-lepton,fully hadron)**



60/fb at 14 TeV



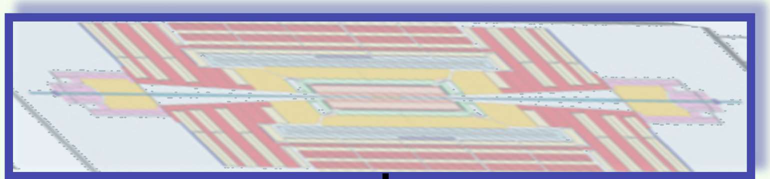
Total significance as a function of the relative background uncertainty

Dot → current knowledge

Star → 1% on ttNj and 4% on ttbb)

→ not a priority today

En route to data…



offline

data format

Physics Object Groups

reconstruction

generators

Detector Performance Groups

detector & machine performance

we have settled on unified formats for Physics Analyses

selection

finalizing, now effort to equalize them

online

controlling bck & trigger

- **main effort and good progress**
- **ideas for bck estimates are being implemented and tested**
- **settling on control triggers**

2009

2010

testing the SM

good progress

testing generators

need more effort for data driven validation

top as a calibration tool

good progress

preparing the path for searches

need some kick-off

Some important publicity…

TOP2010 Conference

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

CP3 - IIHE

Website: http://www.top2010.be/