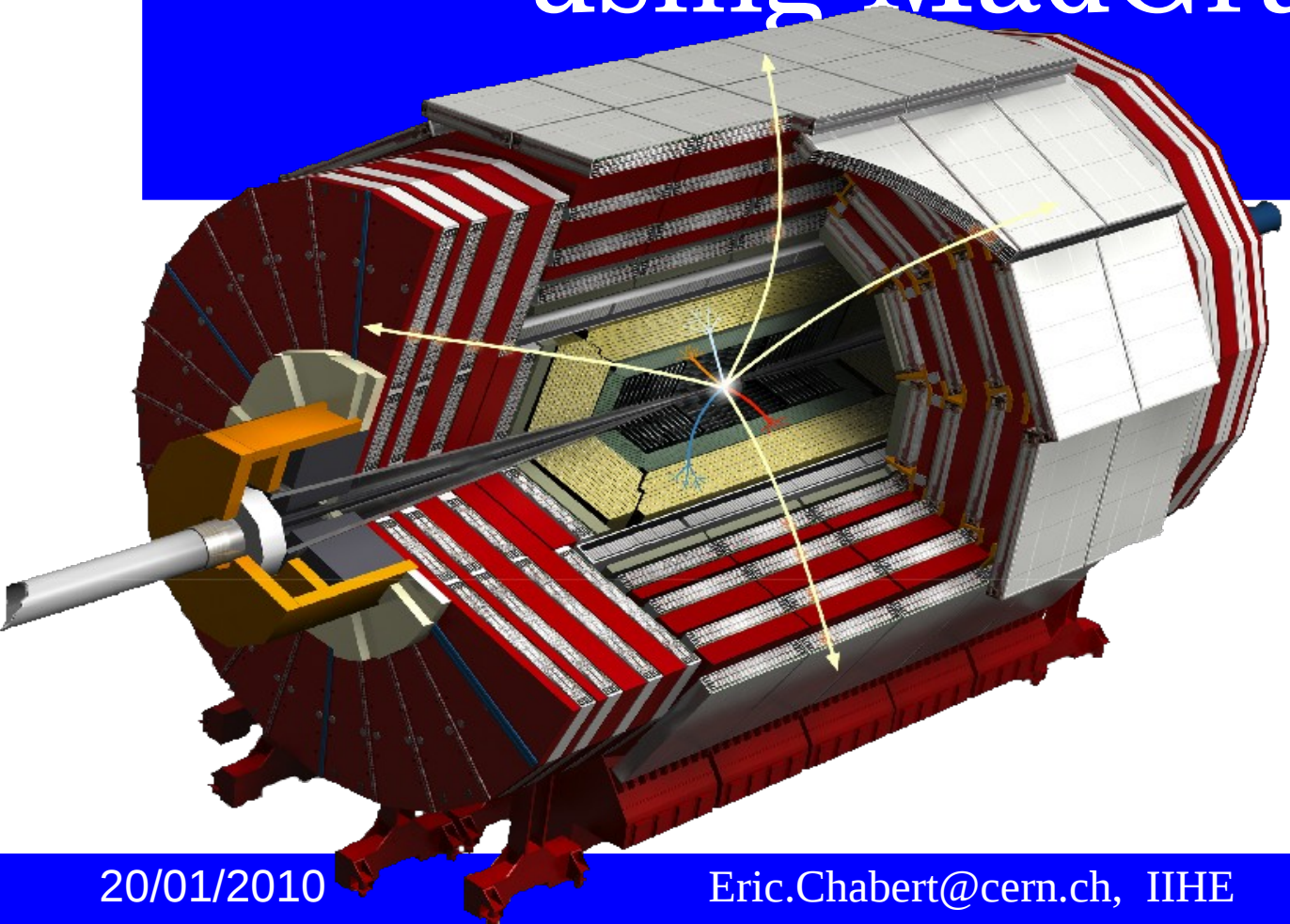
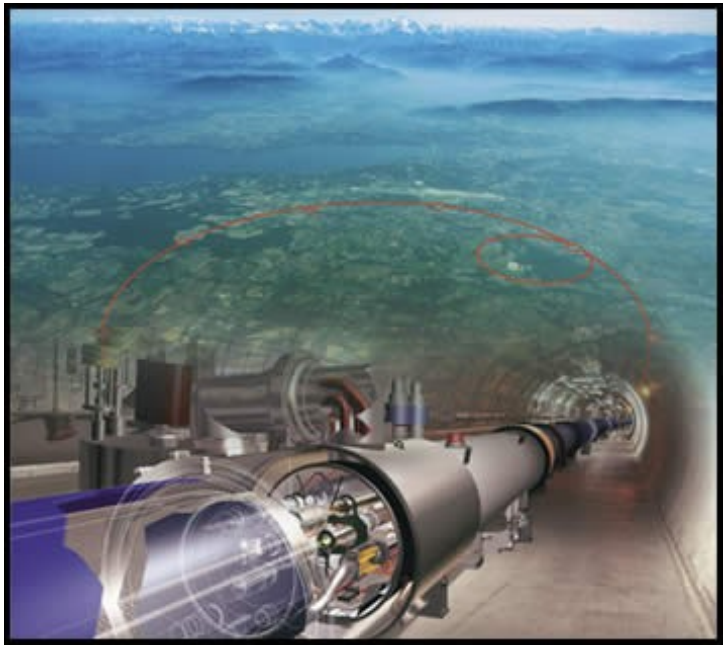
Testing the top quark topologies at the LHC using MadGraph





Outline

I. LHC

II. Monte Carlo (MadGraph) & detector simulation

III. Top quark physics

IV. Background estimations methods (l+jets)

V. Differential distributions

VI. Goodness-of-fit test

VII. Conclusions

LHC Start-up !

Long term project ...

80's: 1st ideas
1994: project approved @ CERN
2000: end of LEP
... construction ...

start-up

10/09/2008: 1st protons injection
19/09/2008: Magnetic quench (100 magnets)
05/12/2008: detailed analysis of the incident
... reparations & tests ...

re-start-up

20/11/2009 protons injection
23/11/2009: 1st collisions @ 900 GeV
30/11/2009: record: 1.18 TeV/beam
01/12/2009: 1st publication: ALICE
12/2009: collisions @ 2260 GeV
~ mars 2010: energy ramping until 3.5 TeV then ~5 TeV
End 2010: shut down - rework >5-7 TeV/beam

First results for 2010 ....

Nominaly:

$\sqrt{s}$ = 14 TeV

L = 10^{34} cm^2s^{-1}

$\int$ Ldt = 100 fb^{-1}/ an

Energy	Safe	Very Safe
450	1 e12	1 e11
1 TeV	2.5 e11	2.5 e10
3.5 TeV	3.0 e10	probe

S.Myers

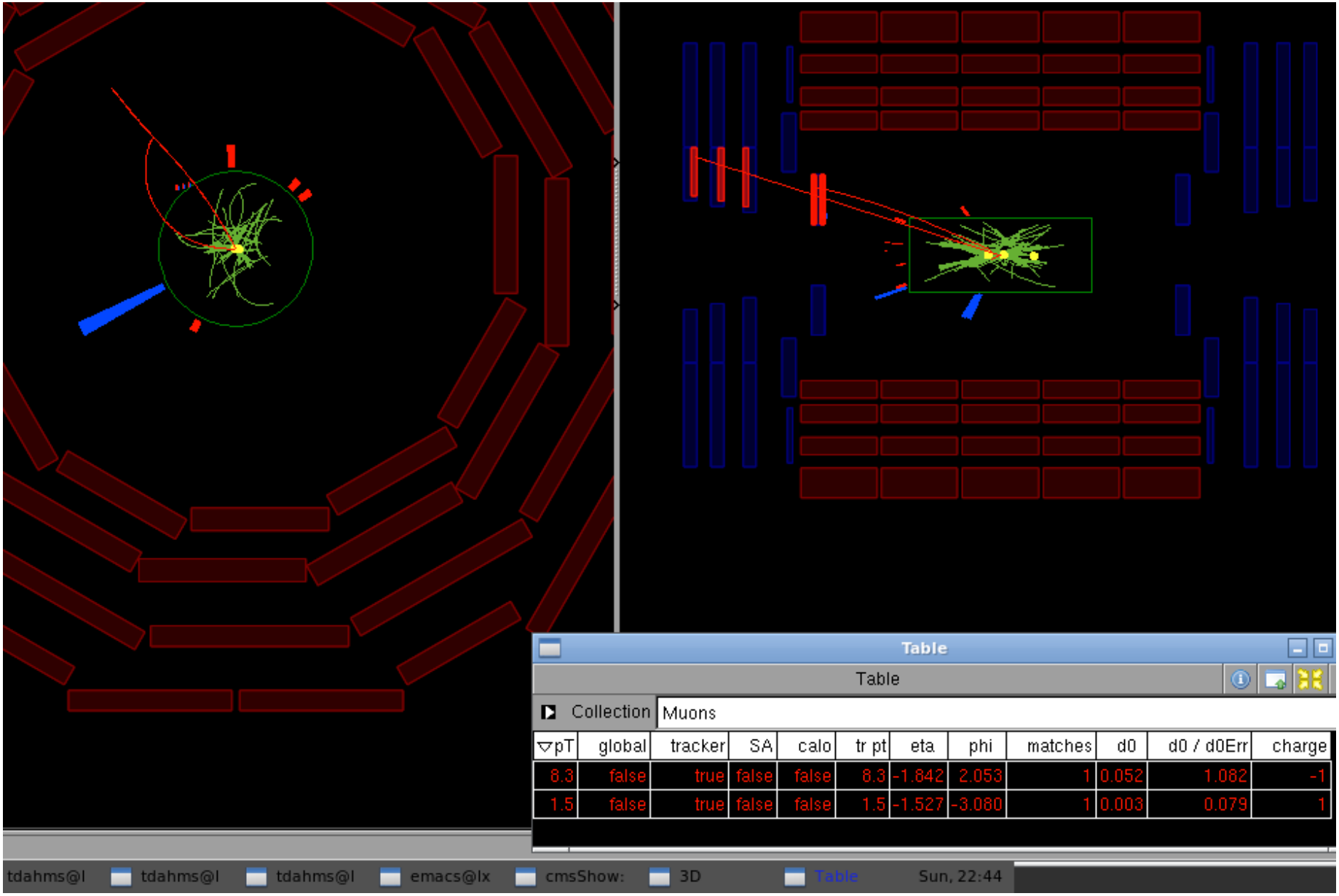
In 2010:

$\sqrt{s}$ = 7 & 10 TeV

L = 3-9 10^{10} cm^2s^{-1}

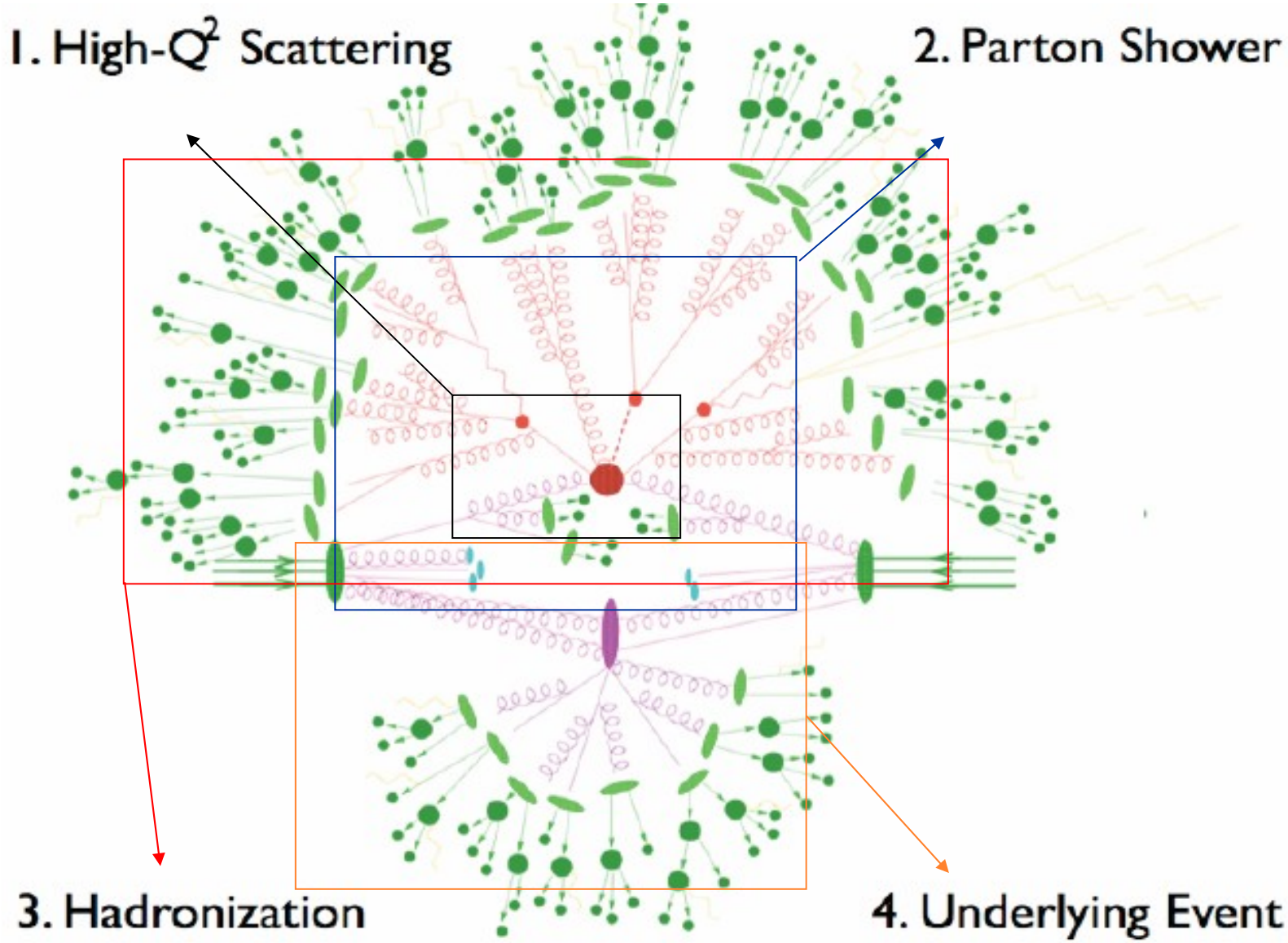
$\int$ Ldt = 70 &160 pb^{-1}

LHC collisions



▽pT	global	tracker	SA	calo	tr pt	eta	phi	matches	d0	d0 / d0Err	charge
8.3	false	true	false	false	8.3	-1.842	2.053	1	0.052	1.082	-1
1.5	false	true	false	false	1.5	-1.527	-3.080	1	0.003	0.079	1

Phenomenology



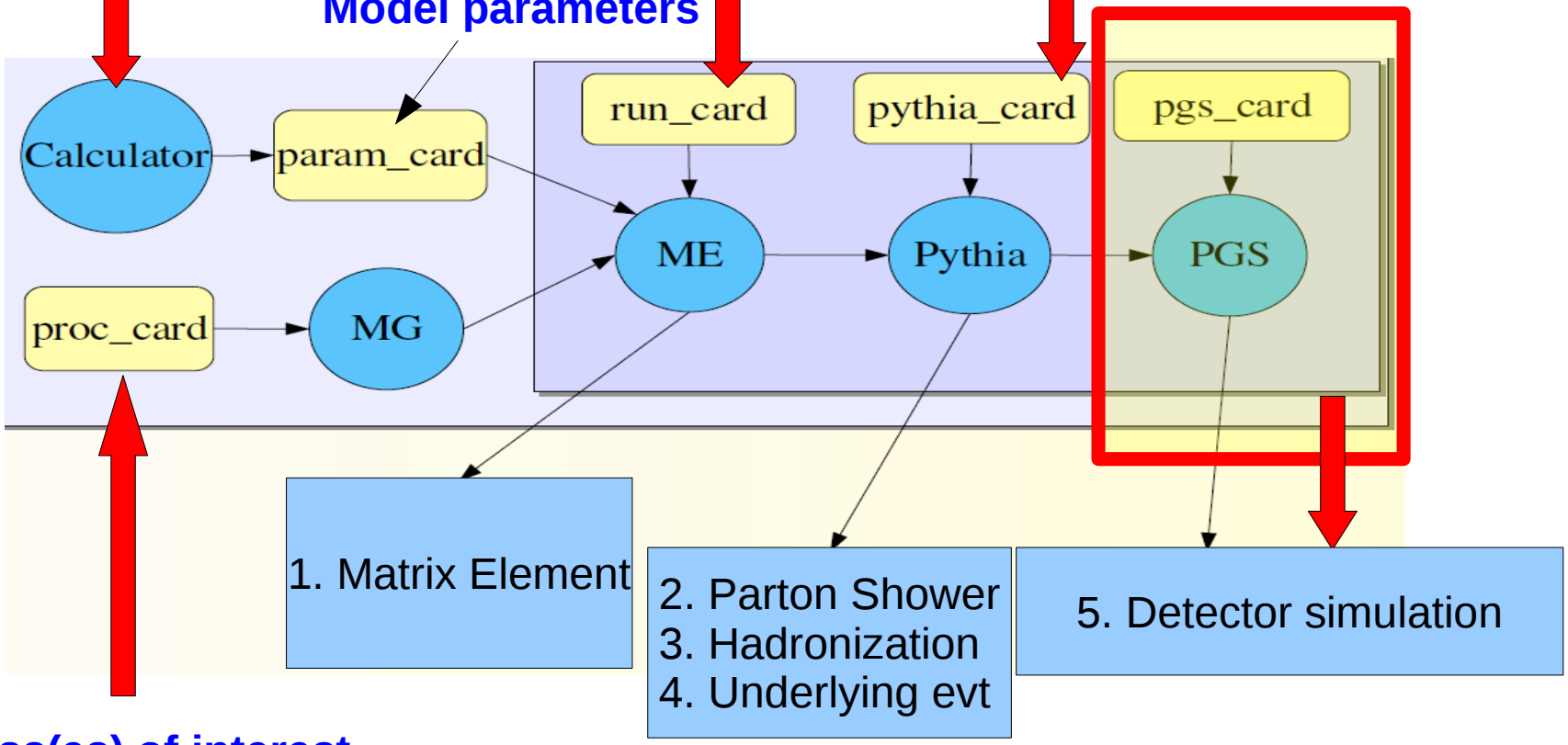
MadGraph: generation chain

Fix parameters for a given models:
- masses: top,Z/W,H ...
- coupling constant: G_F, α_{EM}, $\sin^2\theta_W$ ...
- CKM: Vud, Vtb ..

Run conditions:
- pp @ 7-10-14 TeV
- pdf
- scales
- cuts

Pythia parameters:
- Parton shower
- Fragmentation, hadronization
- ....

Model parameters



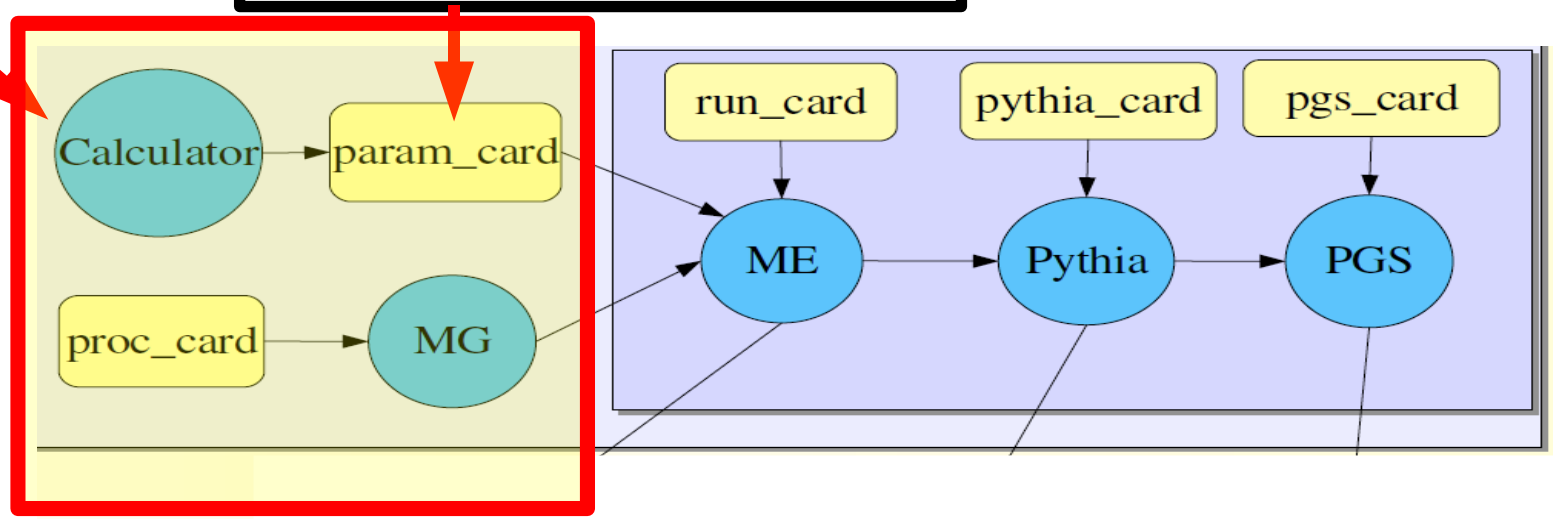
Process(es) of interest

ex: pp> tt~

Testing new ideas ...

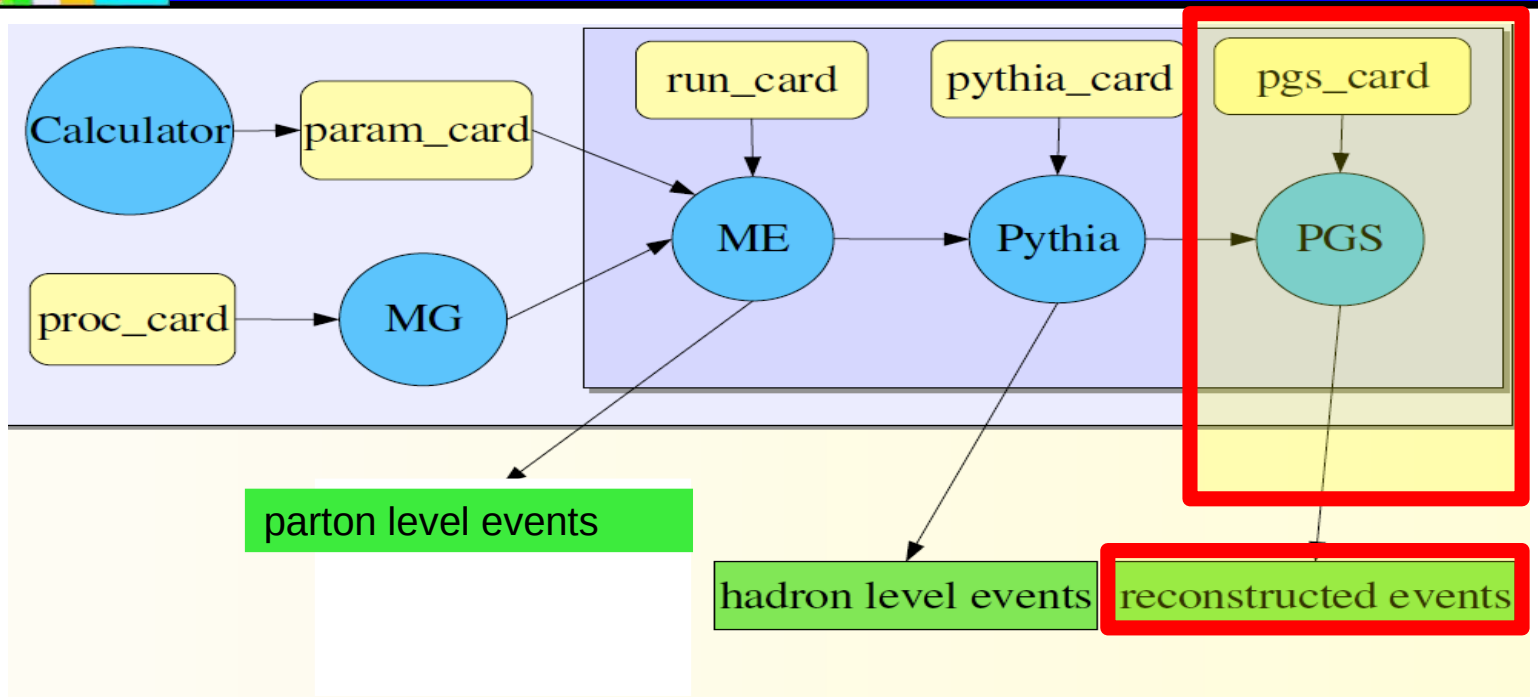
New theoretical models or constraints ...

Experimental constraints:
- cosmology & astropart
- LEP, HERA, Tevatron
- new LHC results ?



Available models in MadGraph:
- **SM**
- **HEFT**: Higgs Effective Field Theory
- **MSSM**: Minimal Supersymmetric Standard Model with no R-parity violation
- **2HDM**: Two Higgs Doublet Model with CP violation and FCNCs
- **TOPBSM**: Model to study new physics (heavy resonances) with the top quark

Detector simulation



Generic detector simulation:

- PGS: Pretty Good Simulation [98-today]
- DELPHES (@ UCL)
  ex: LHC-like, CMS-like detector geometry

We developed 3 interfaces to our analysis program in Brussels

N-tuple format

- object-oriented
- analysis dedicated

CMS detector simulation: (for CMS collaborators)

- Full simulation (GEANT 4)
- Fast simulation (with smearing)
  exact CMS detector geometry

Analysis is independent of the detector simulation tool used

Top Quark

Discovery: top/anti-top 1995 @ Tevatron (CDF/D0)

⇒ completes quarks sector

single top : 03/2009

Life time: ~ 5 10^{-25}s << λ^{-1}_{QCD}

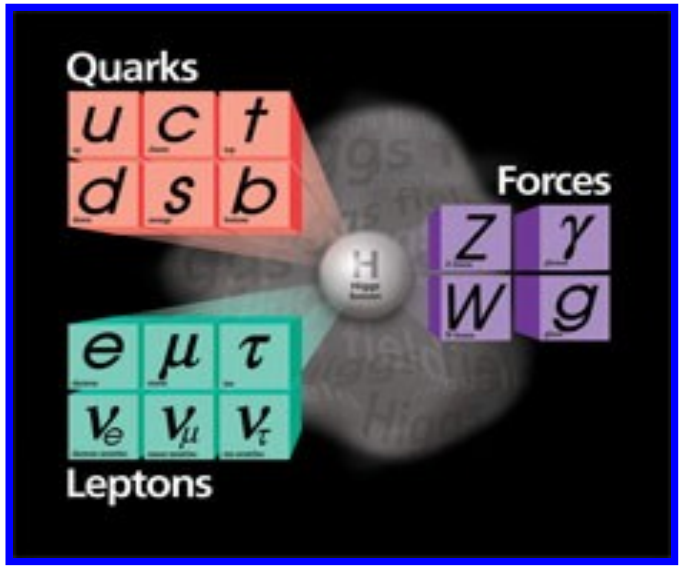
⇒ decay before hadronisation

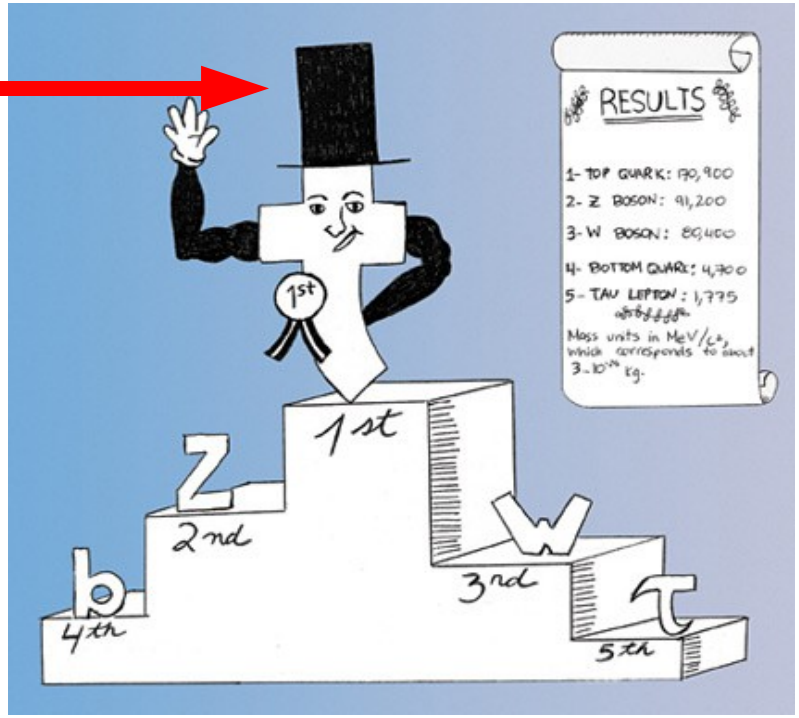
Mass: 173.1 ± 0.6 (stat.) ± 1.1 (syst.) GeV/c^2
[Tevatron 03/09]

⇒ Strong coupling to Higgs boson ($\lambda_t \approx 1$)

⇒ Important role in EWSB

⇒ **Sensitive to New Physics …**





Top Quark physics

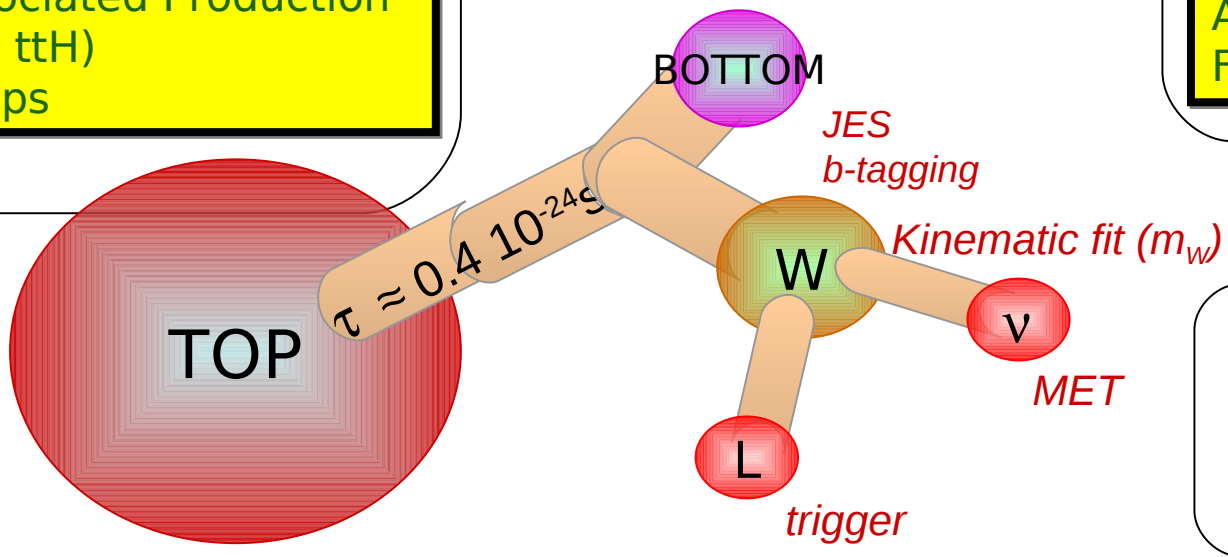
PRODUCTION
- Cross section
- Spin correlation

Resonances X→tt
4th generation t'
SUSY (stops ...)
Associated Production (ex: ttH)
4 tops

PROPRERTIES
- Mass
- Charge
- Life time & width
- Spin

DECAY
- W helicity
- Measurement V_{tb} (CKM)

Charged Higgs
Anomalous coupling
FCNC



CALIBRATION

Jet energy scale

B-tag efficiency

1. Calibration of detector & tools
2. Electroweak precision measurement
3. **Direct search for New Physics**

Testing the top quark topologies opens a windows towards New Physics

Top quarks production @ LHC

Standard Model

Observed at Tevatron

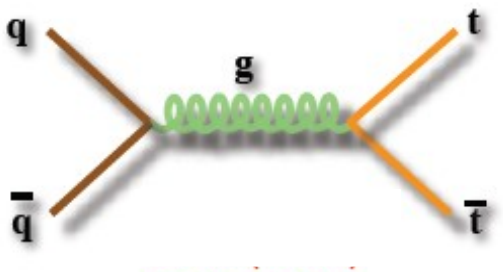
top pairs [σ=908-414pb (@14-10TeV)]
single top (3 channels) [σ=333-164 pb]

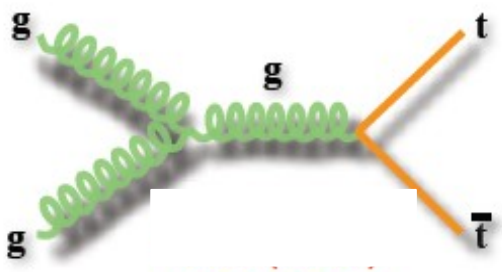
Associated production (ttZ,ttW) [σ ~ 1 pb]
3 tops [σ ~ 2 fb]
4 tops [σ ~3 fb]

New Physics

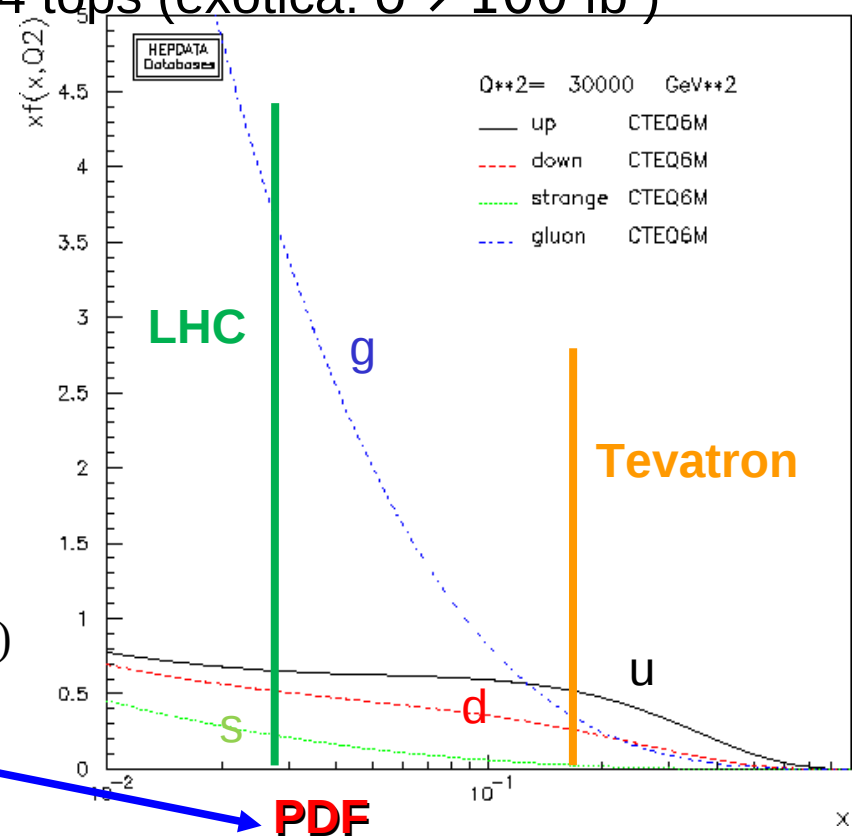
- Ttbar resonances (ex: H, Z' ...)
- "X→top+Y" (ex: stop, $H^{\pm -}$)
- ttH etc ...
- 3 tops (σ~28-41 fb) [Z',MSSM]
- 4 tops (exotica: σ ↗100 fb)

- top pairs production by strong interaction
  gg (87%) & qq (13%)

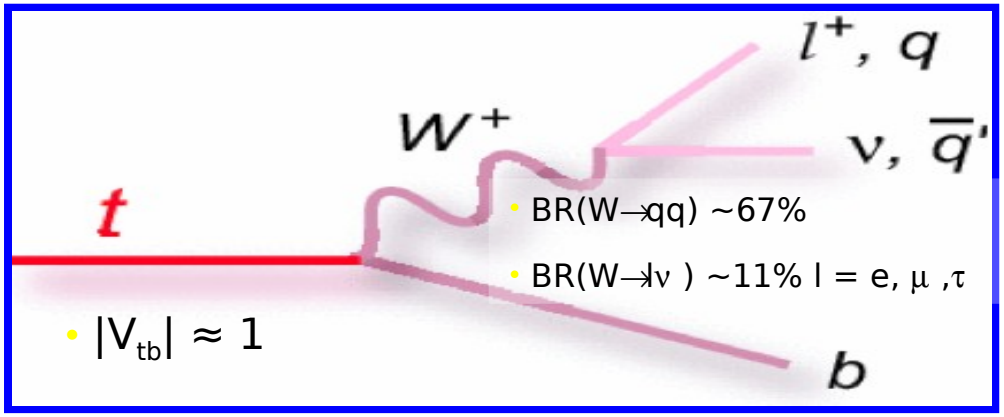




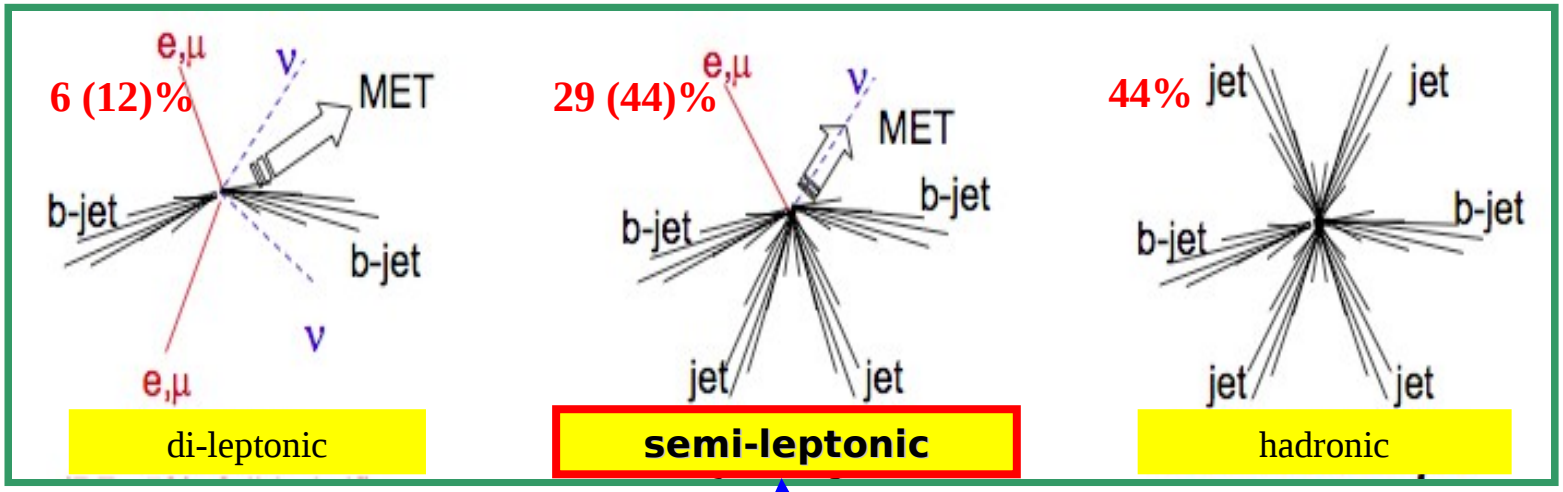
$$\sigma(\hat{s}, m_t^2) = \sum_{i,j} \int dx_i dx_j \, f_i(x_i, \mu_f^2) f_j(x_j, \mu_f^2) \cdot \sigma_{ij}(ij \to t\bar{t}; \hat{s}, \mu_R^2, \mu_f^2)$$



lepton+jets channel



- BR(W→qq) ~67%
- BR(W→lν) ~11% l = e, μ ,τ
- $|V_{tb}| \approx 1$



lepton+jets channel:

- Multi-jets: 4 jets
- = 1 lepton: focus on 1 muon

Signature:

- 4 jets , 2 coming from b
- 1 isolated lepton from W
- MET from neutrino

Event selection

Jets:

SisCone CaloJet calibrated
- At least 4 jets
- P_T> 30 GeV
- |η|<2.4
- Jet-ID
- *"B-tagging"*

Muons:

@ 10 TeV

Global muon :tracker + μ-chambers
- P_T>30 GeV
- |η|<2.1 (trigger)
- Quality cut (χ^2 ,# hits, d0 ...)
- Isolation: (ΔR= 0.3)
- RelIso = (TrackIso+EcalIso+HcalIso)/P_T(μ)

signal

	multijets	ttjets	wjets	zjets	single top
Number of events for 100/pb with :					
- at least a muon :	2.10984e+06	9574	26904	4639	819
- muon ID selection :	2.00747e+06	8304	24723	4352	711
- kinematic selection :	495399	5410	18683	3568	466
- exactly one muon :	494521	5193	18677	2061	466
- isolation selection :					
– $d_0/\sigma < 3$:	373567	4945	18565	2031	461
– $RelIso < 0.1$:	4803	3899	15584	1742	441
- jet selection :	84	2048	849	104	87
- 4 jets :	71	1300	686	85	67
- 5 jets :	11	509	134	15	16
- ≥ 6 jets :	2	239	28	4	4

SUSY mSUGRA-LM1
σ = 16.06 pb
m_0=60,$m_{1/2}$=250,A_0=0, tan β=10

203 evts selected

Events selected
= Signal Region (SR)

~ #events expected for end of 2010

Strategy

Control Region
- Bkg enriched
- ttbar/NP free
- "unbiased"

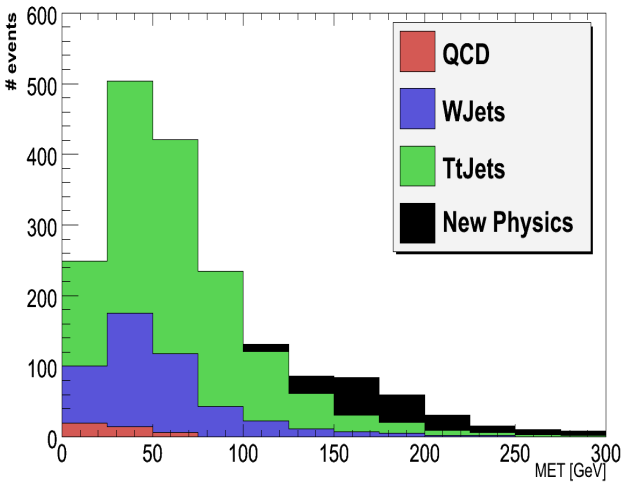
New physics
- Products: muon+jets
- σxBR important

Signal Region:
- Trigger
- muon+jets selection

Bkg estimation

Reconstruction

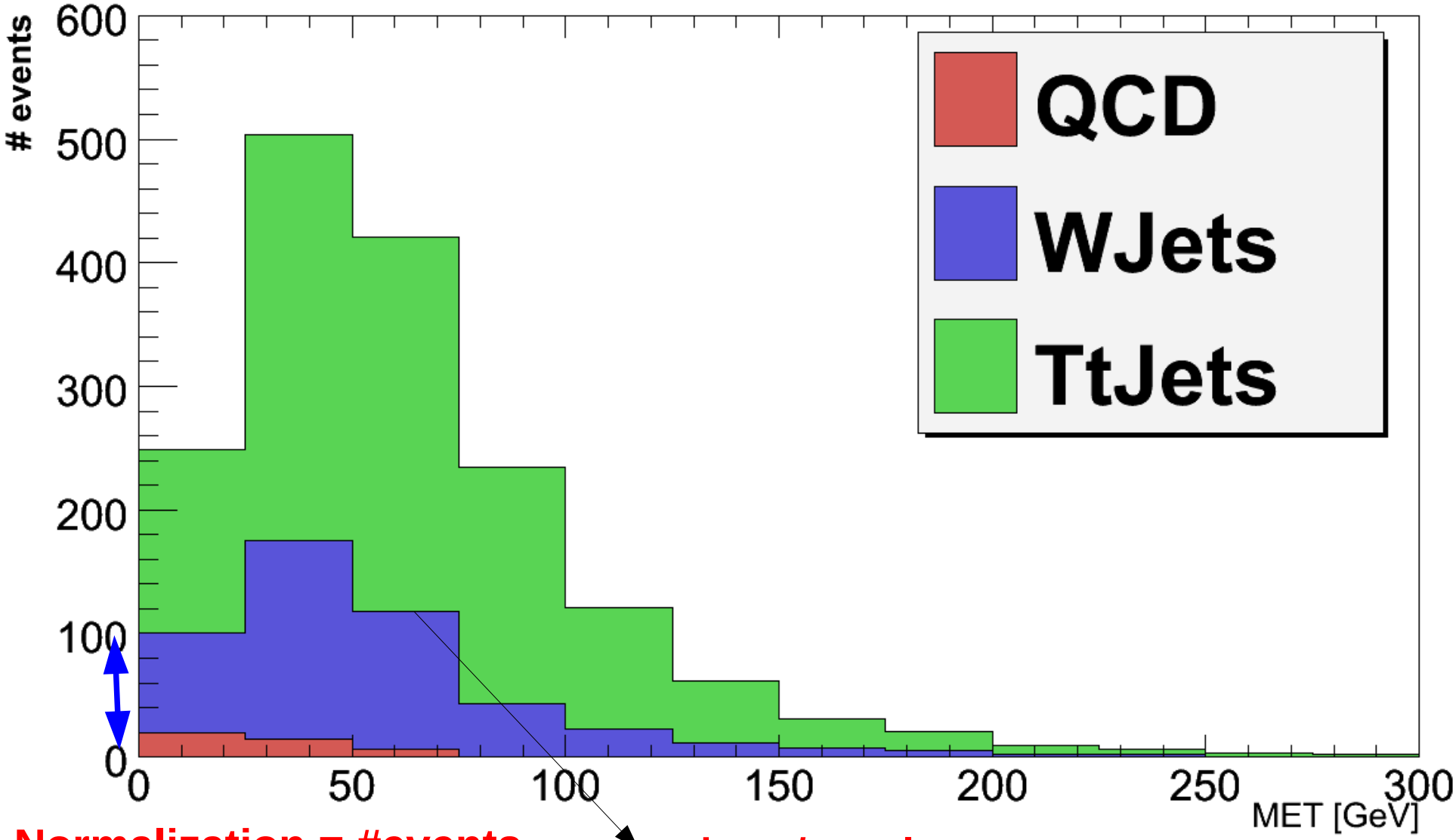
Differential distribution
- List to be defined
- Properties



Sensitivity estimation

Results:
- "Goodness-of-fit" test
- Search for New Physics
- Model Identification

Background estimation



Normalization = #events

shape/template

QCD multi-jets estimation

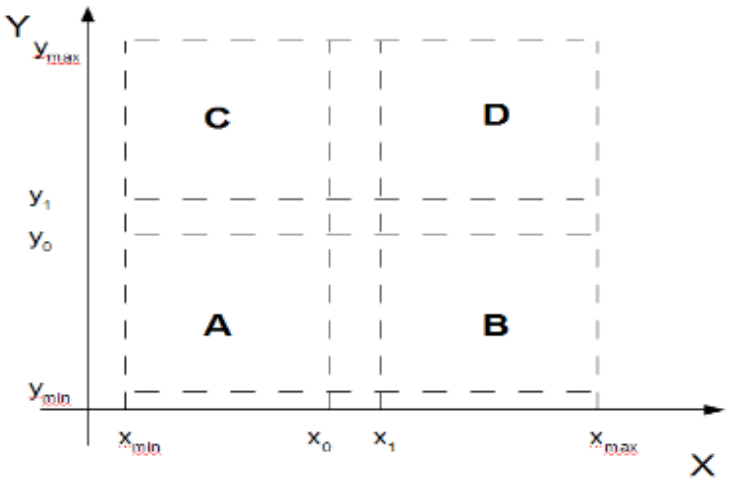
Production:

- Jets: hard process, radiations, PU, UE ...
- Muons:
  - fake & decay-in-flight: 30 % (rejected by quality cuts)
  - Leptonic decay of b/c-hadrons: 70%: non isolated, displaced vertex
- With 1 muon P_t>15 GeV/c: σ = 121675 pb (@10 TeV) – 300 x σ_{ttbar} !

normalization **"ABCD" method**

- 2 variables uncorrelated:
  - RelIso = (TrackIso+EcalIso+HcalIso)/P_T(μ)
  - D0Sign = d0/σ(d0)
- 4 regions:
  - A: signal region (ttbar+W+jets ...)
  - B–C–D: QCD is dominant
- QCD contribution in A is :

N(A) = N(C)/N(D)*N(B)



Statistical errors: 20 % @ 100 pb^{-1}

template/shape

QCD Template from data:

- Muon isolation criterion inverted
- Other criteria remain the same

W+jets estimation

Production:

- Muons: leptonic W decay as in ttbar
- Jets: mainly radiations
- Cross section ($W \to \mu\nu$) : = 13900 pb (NLO @ 10 TeV) - 100 x σ_{ttbar} !
- Main background: >1/4 of selected evts
- Main differences:
  - Invariant masses (jj) → W & (jjj) → top
  - B content is not the same

Principle

W+jets normalization from data

- Event categorization as function of #jets & **#b-jets**
- System of 4 non linear equations for #b-jets [0,1,2,3] per #jets [4,5,>=6] with 4 unknowns

Ex: For N=4 jets, evts with 1 b-tagged jet

data **$f(\varepsilon_b, \varepsilon_{udsc}, N_{ttbar}, N_W)$**

b quark b-tagged

light quark b-tagged

$$N^{1\ bjet} = \left(C_2^1 \times \epsilon_b(1-\epsilon_b) \times (1-\epsilon_{udsc})^2 + C_2^1 \times (1-\epsilon_b)^2 \times \epsilon_{udsc}(1-\epsilon_{udsc})\right) \times N^{ttbar-like} + C_4^1 \epsilon_{udsc}(1-\epsilon_{udsc})^3 \times N^{W-like}$$

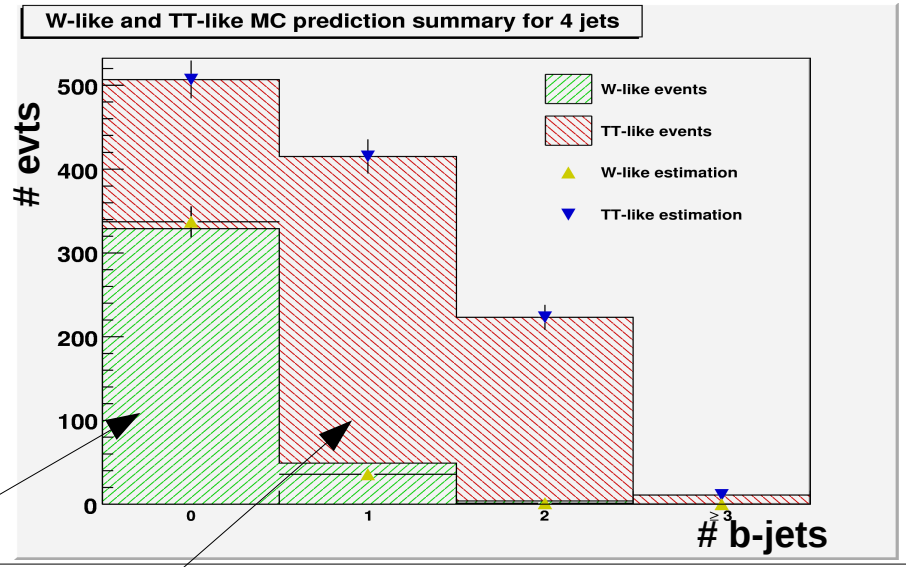
light quark b-tagged

- Main hypothesis = 2 categories of processes
  - "W-like" : processes with 0 intrinsic b-quarks
  - "Ttbar-like" : processes with 2 intrinsic b-quarks
- 2 other parameters: $\varepsilon_b, \varepsilon_{udsc}$

W+jets estimation

W+jets normalization from data

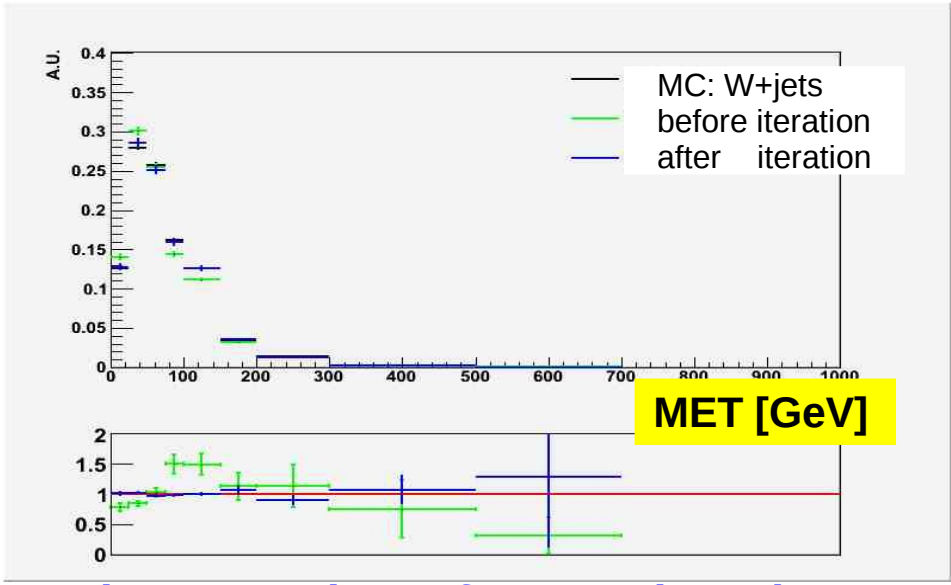
- #(W/Z+jets) estimated per #jets
- Statistical errors for L = 100 pb^{-1}
  $\sigma(N_W)/N(_W)$ = 8%



W+jets template/shape from data

Principle:

- 2 "templates" from **data**:
  - Tw^{init} : N(b-jet = 0) (W-like enriched)
  - $Ttop^{init}$: N(b-jet = 1) (tt-like enriched)
- Aim: obtaining 2 "templates":
  - W-like contribution: Tw
  - Tt-like contribution: Ttop



Equations:

$N^{j=0} = x_0\ Tw + y_0\ Ttop$

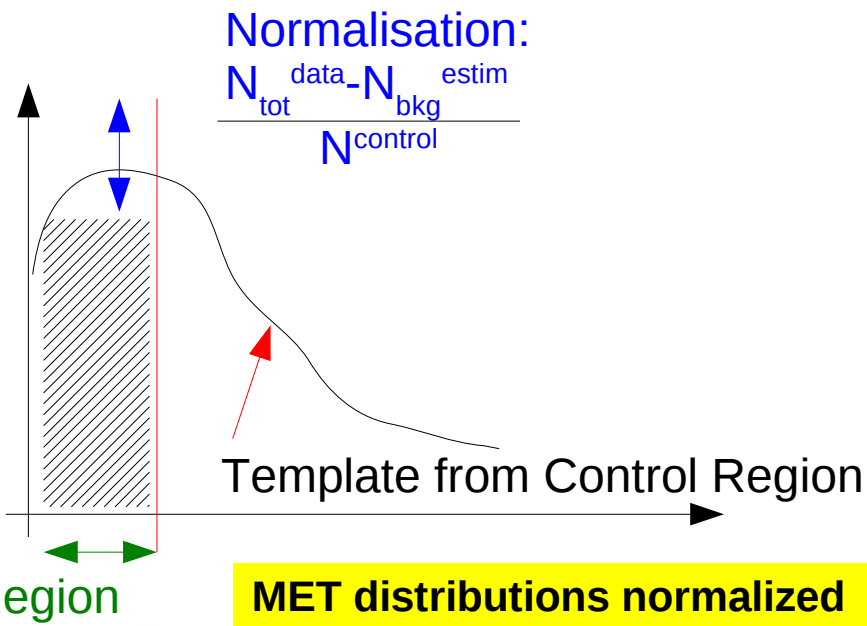
$N^{j=1} = x_1\ Tw + y_1\ Ttop$

Template obtained with a iterative procedure after < 10 iterations

Ttbar estimation

Principle

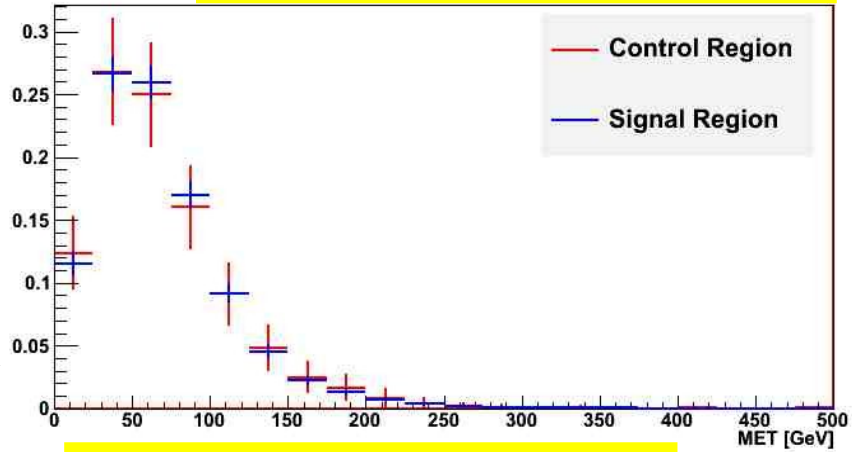
- Defining a control region (CR)
  - ttbar enriched
  - "unbiased": → shape invariance CR/SR
  - As New Physics free as possible
- Obtain a "template" per observable X (ex: MET)
- Normalize it to data (NR)



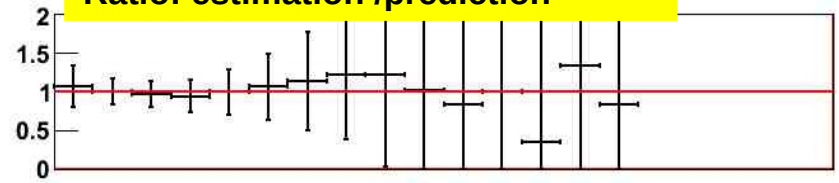
Control Region

- Require 2 b-jets
- Cuts on ttbar oriented observables (b,b,l)
  - **M(b,l)< 160 GeV** reflect leptonic top decay
  - $\Delta R(b,b)>2.3$ reflect top/anti-top ~ back to back
  - $H_T(b,b)<500$ GeV search for High P_T objects
- Same distributions for ttbar leptonic/di-leptonic

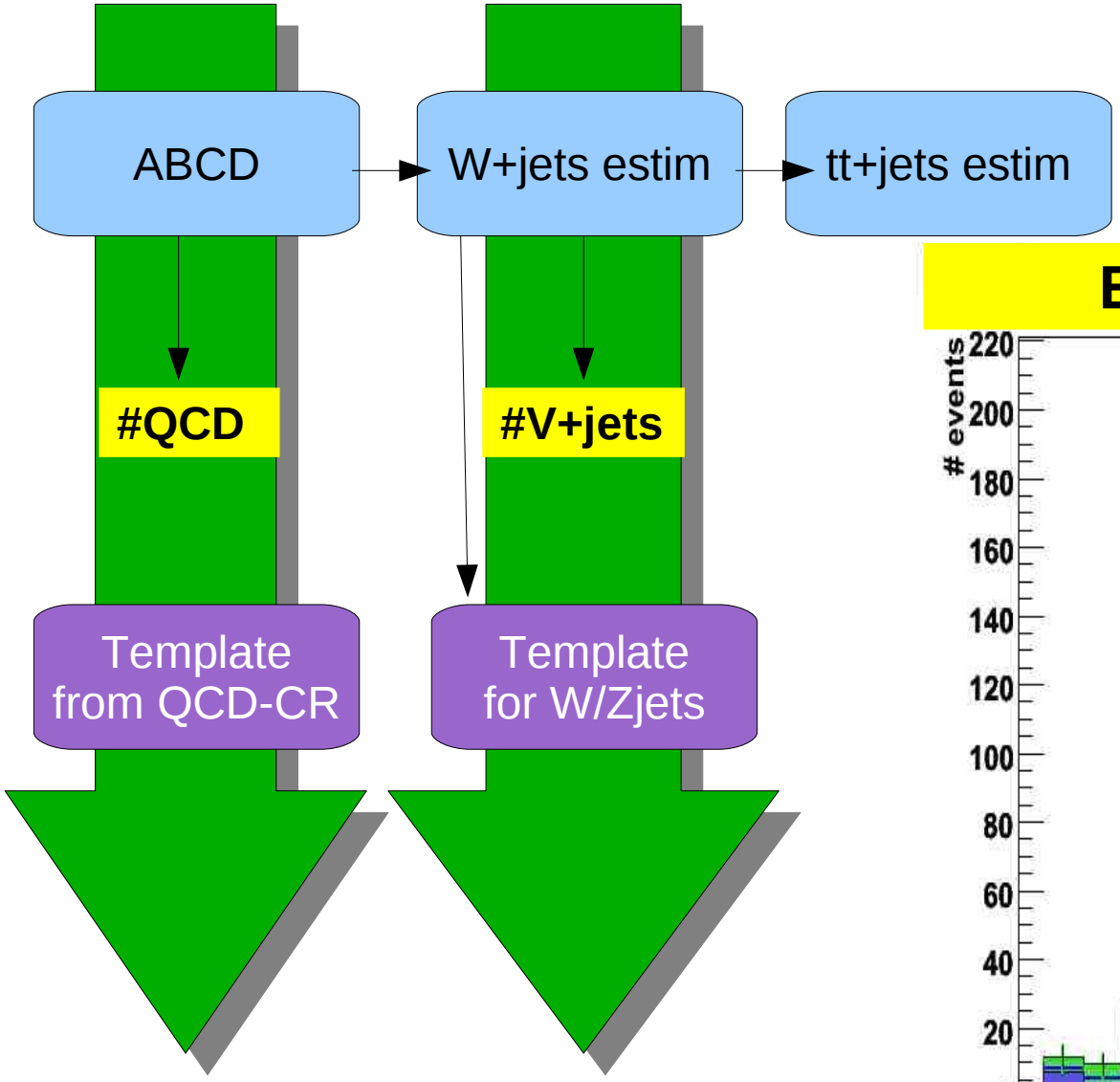
MET distributions normalized



Ratio: estimation /prediction



Differential distributions



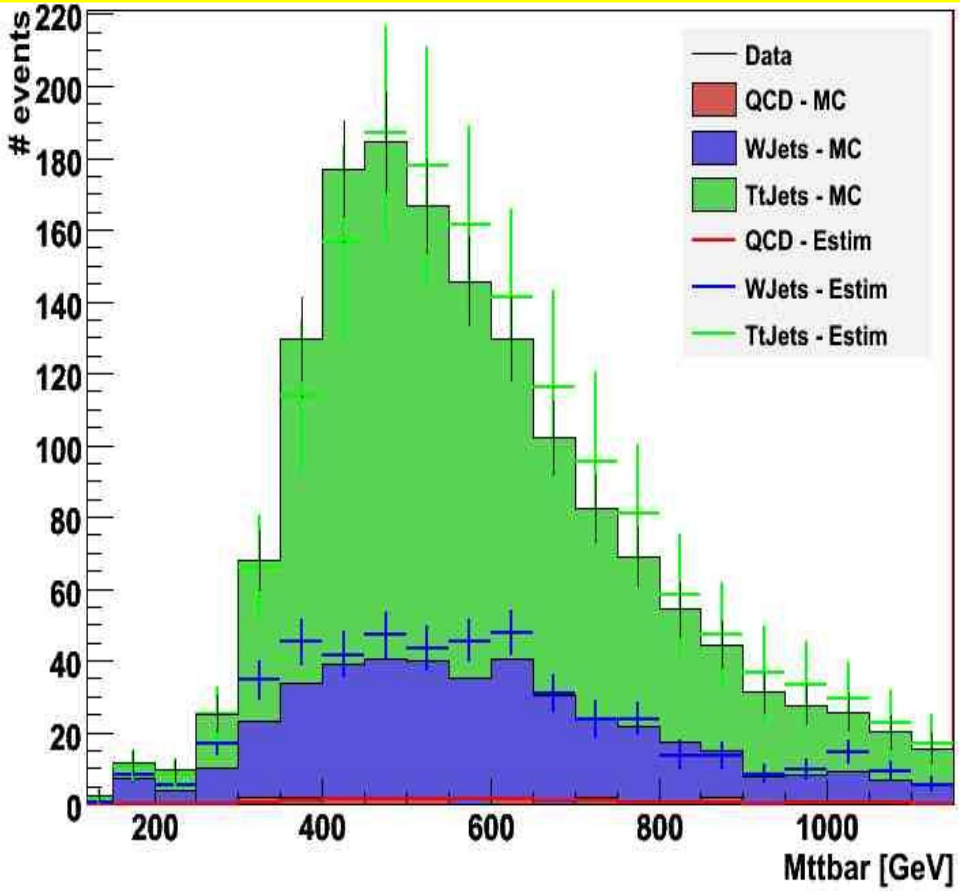
QCD estimated

V+jets estimated

Single top: MC prediction

For L = 100 pb-1 @ 10 TeV

Ex: Mttbar distribution



Goodness-of-fit test

Building a g-o-f test variable V

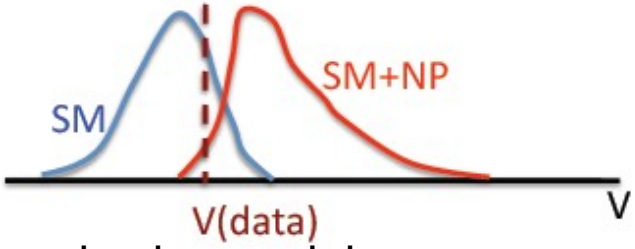
- Consider N observables:
  - related to top quark topologies
  - sensitive to New Physics
- For each observable, performed the background estimation methods
- For each observable & each event compute a significance
- Significance per observables combined to gives a weight per event S
- Rank the events according to their weight
- Combine weights for a fraction of events (least SM-like) gives a estimator $V = \sum_{10\%\ highest} S_i$

$$s_{k,j} = \frac{\left(x_{k,j} - y^{est}_{k,j}\right)^2}{Var[X] + Var[Y]}$$

Building a P-value

- Obtain a V-distribution with MC pseudo-experiments for different hypothesis
  - SM
  - SM + New Physics (ex: SM+SUSY(LM1), ...)
- On data: V value converted in probability for an hypothesis to be true

$$p = \left(\int_{V_{data}}^{+\infty} V_{distr}\right) / \int_{-\infty}^{+\infty} V_{distr}$$



Estimation of our experimental sensitivity to a given new physics models.
Scanning the parameters with MadGraph production → exclusion contours

Conclusion

- **A chain for testing top quark topologies (and new physics) with MadGraph is ready**
- **A full background estimation chain from data in lepton+jets channel is ready**
- **Goodness-of-fit test in place & under testing**
- **Ready for testing new models & estimate their observability**
- **Interaction between theorists & experimentalists will be fruitful**

Team: T.Caebergs, E.Chabert, J.D'Hondt, G.Hammad, A.Kalogeropoulos, C. Vander Velde, G. Van Onsem