Top mass dependence on kinematic variables and colour reconnection

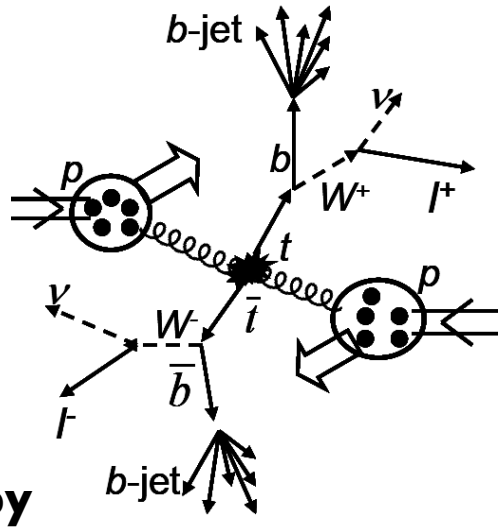
Pedro Ferreira da Silva (CERN)
on behalf of the ATLAS and CMS collaborations

TOP LHC WG meeting 21st-23rd May 2014

Introduction

- **Top quark mass from hadron colliders**
  - use final state to reconstruct top mass and its kinematics ▶
  - high precision single measurements and final combination

    $\sigma(m_t) < 0.5\%\ m_t$ (see O. Brandt's talk and arXiv:1403.4427)



- **Final uncertainty in world combination is dominated by**

Jet Energy Scale	Modelling of the signal
0.14%m_t - in-situ (scales with $\int$Ldt)	0.22%m_t – MC
0.14%m_t - b JES	0.18%m_t - colour reconnection
0.11%m_t – non-flavour specific JES	0.13%m_t - Initial/Final state radiation

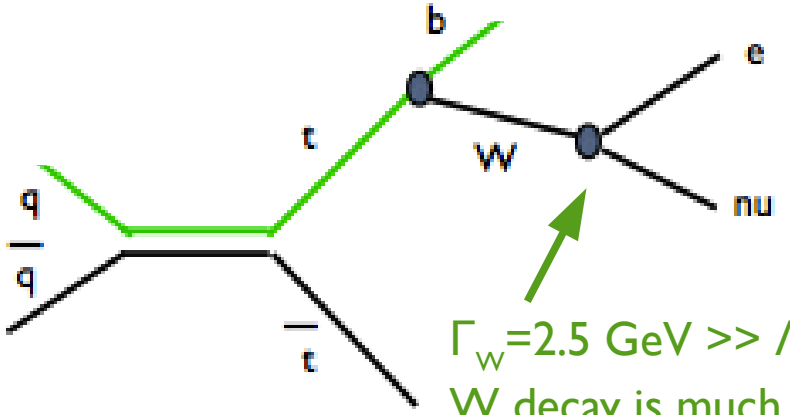
Can improve @LHC with

more data and dedicated analysis, e.g. from Z/γ+b studies or 3D fit as in ATLAS-CONF-2013-046

dedicated measurements in different phase space regions of top production+decay

Anatomy of a top quark event

adapted from M. Mangano @ TOP2013



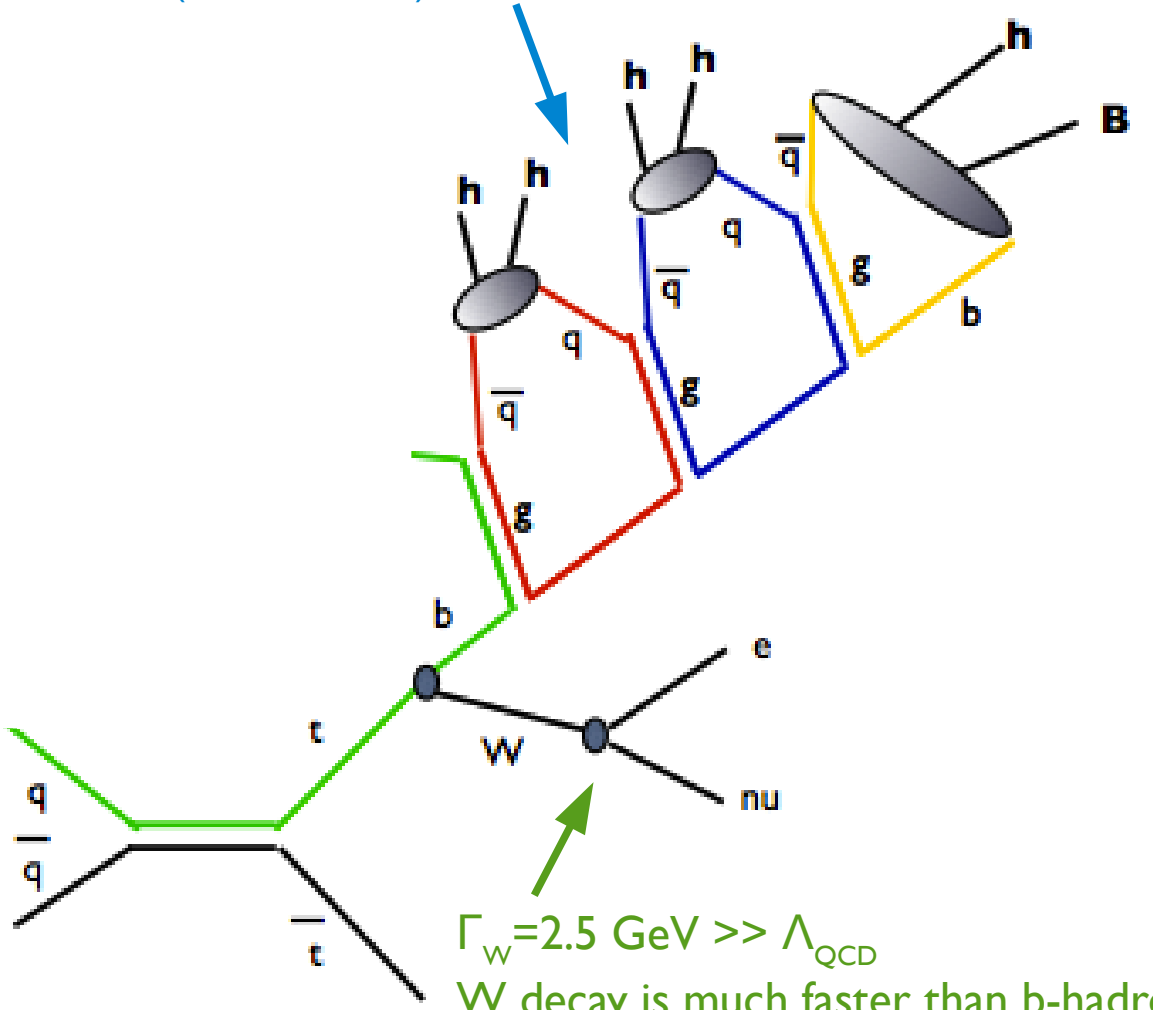
Γ_W=2.5 GeV >> Λ_{QCD}

W decay is much faster than b-hadronization time scale → **EWK dynamics "factorize"** in a top event, see S. Nauman-Emme's and A. Mitov's talks

Anatomy of a top quark event

adapted from M. Mangano @ TOP2013

Controlled by **shower evolution**, residual sensitivity to hadronization model (out-of-cone), see Tancredi's and G. Corcella's talks



Γ_W=2.5 GeV >> Λ_{QCD}

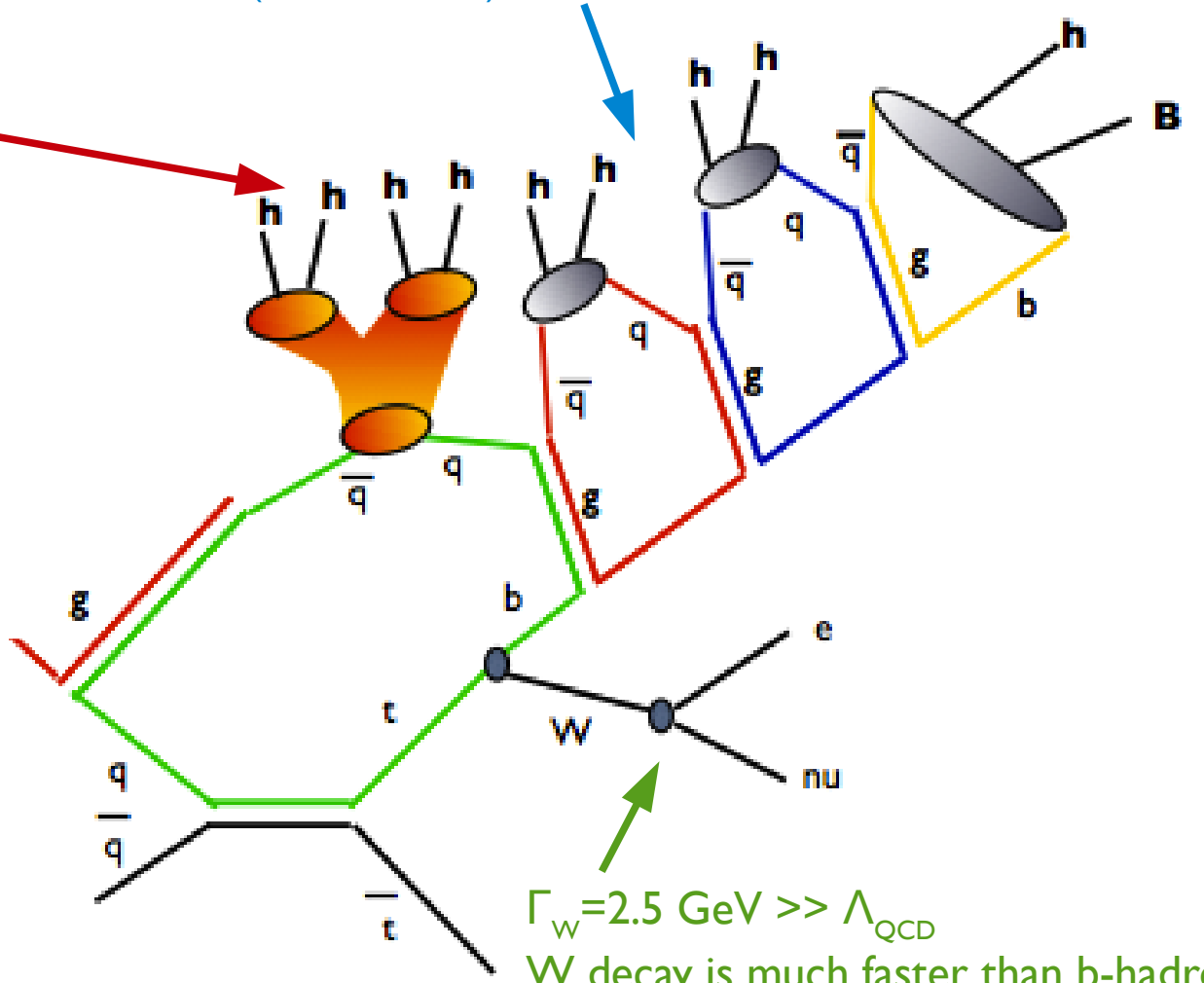
W decay is much faster than b-hadronization time scale → **EWK dynamics "factorize"** in a top event, see S. Nauman-Emme's and A. Mitov's talks

Anatomy of a top quark event

adapted from M. Mangano @ TOP2013

Controlled by **shower evolution**, residual sensitivity to hadronization model (out-of-cone), see Tancredi's and G. Corcella's talks

Controlled by **shower evolution** and **colour reconnection**: ambiguous "paternity"



Γ_W=2.5 GeV >> Λ_{QCD}

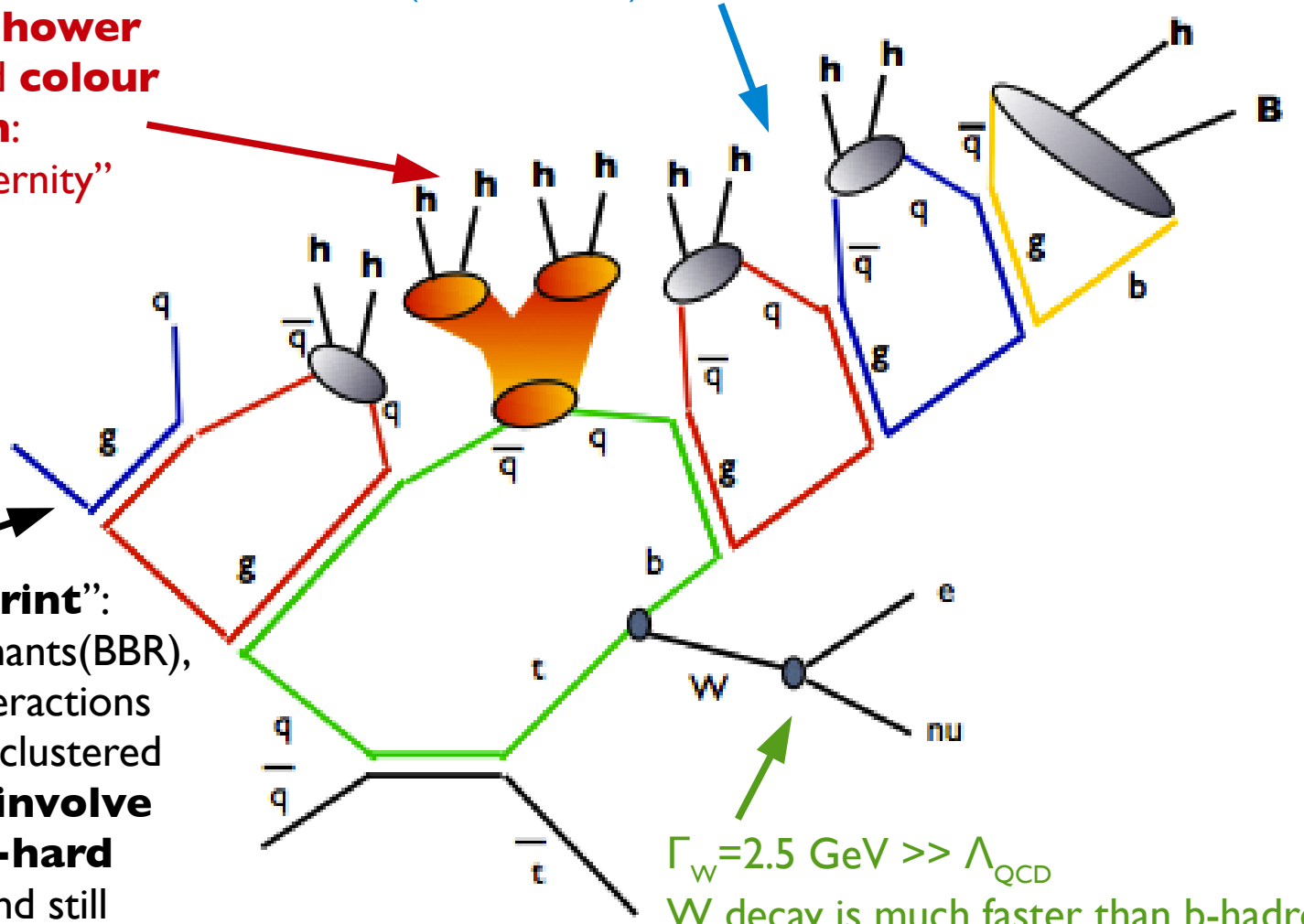
W decay is much faster than b-hadronization time scale → **EWK dynamics "factorize"** in a top event, see S. Nauman-Emme's and A. Mitov's talks

Anatomy of a top quark event

adapted from M. Mangano @ TOP2013

Controlled by **shower evolution**, residual sensitivity to hadronization model (out-of-cone), see Tancredi's and G. Corcella's talks

Controlled by **shower evolution** and **colour reconnection**: ambiguous "paternity"



"**Proton footprint**": Beam-beam remnants(BBR), Multi Particle Interactions (MPI), ISR/FSR unclustered into b-jets **may involve soft and semi-hard interactions** and still connect to the "core" of a top quark event

Γ_W=2.5 GeV >> Λ_{QCD}

W decay is much faster than b-hadronization time scale → **EWK dynamics "factorize"** in a top event, see S. Nauman-Emme's and A. Mitov's talks

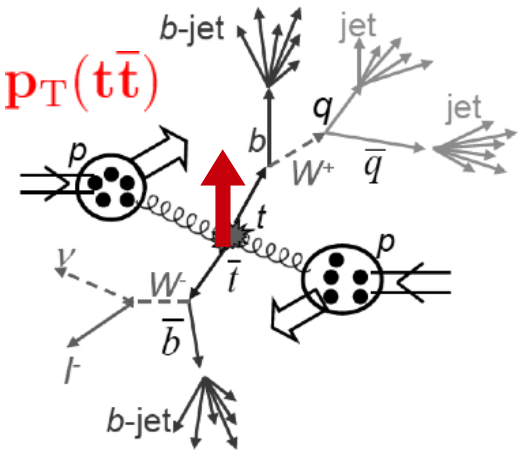
Probing the anatomy of a top quark event

We present data studies of possible kinematic biases in the measurement of the top-quark mass based on the invariant mass of its decay products.
The effects observed are well reproduced by simulations based on MadGraph, Powheg, and MC@NLO with tunes including and excluding the effects of colour reconnection.

m_t differential measurements

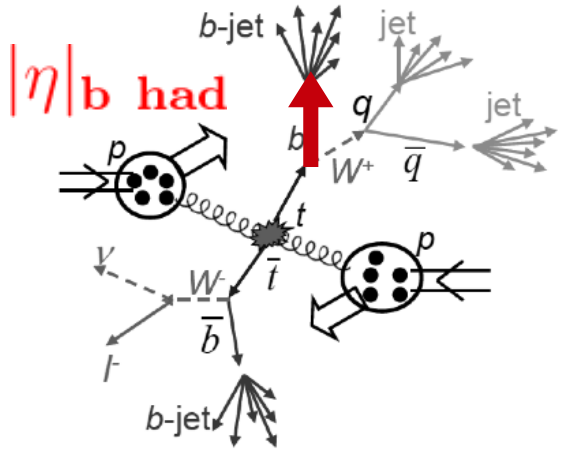
- We rely on MC-based **models of the top production and decay chain**
  - particular models for underlying event (UE), colour reconnection (CR) are taken into account
  - do these tools describe our data in the different phase space regions?
  - can we find sensitivity to different components in top quark p_T, b-quark rapidity, charge, etc. ?
- Choose **representative observables which can potentiate particular effects**

Radiation effects



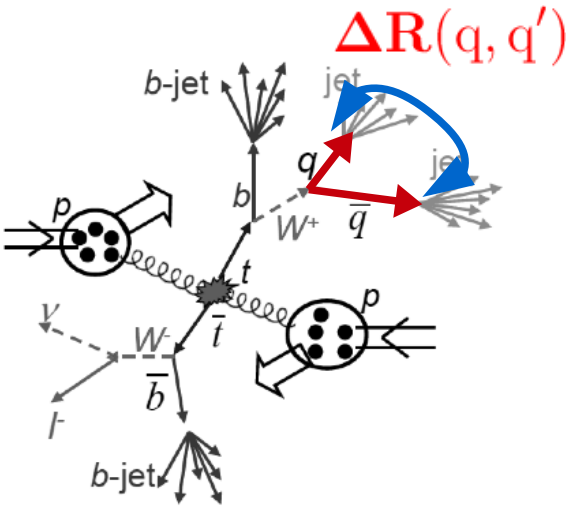
H_T $m_{t\bar{t}}$ $p_{T,t\bar{t}}$
Jet multiplicity

b-quark kinematics



$p_{T,b,had}$ $|\eta_{b,had}|$
$\Delta R_{b\bar{b}}$ $\Delta\phi_{b\bar{b}}$

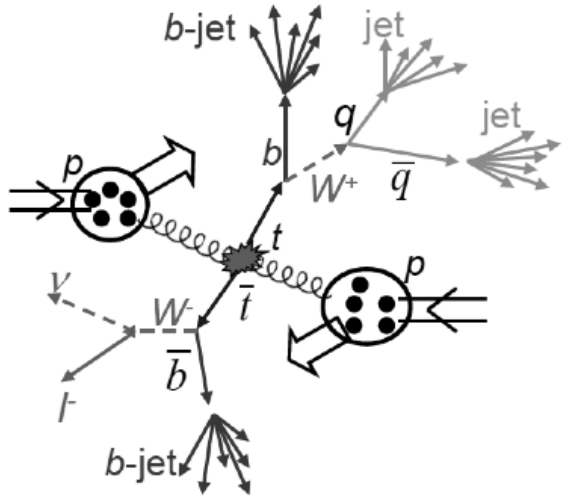
Colour reconnection



$\Delta R_{q\bar{q}}$ $\Delta\phi_{q\bar{q}}$
$p_{T,t,had}$ $|\eta_{t,had}|$

Strategy for differential measurements

- **Study performed at 7 and 8 TeV**
  - using golden l+jets channel
  - JHEP 12 (2012) 105 and CMS-PAS-TOP-14-001



- **Inclusive measurement**
  - High purity selection (2 b-tags)
  - choose 2 best permutations from kinematic fit

    include resolutions,m(top)=m(anti-top), m_W=80.4 GeV
  - apply ideogram method for (m_t,JES)

    event-per-event likelihood using both permutations

Permutations	Before fit	After fit, P_{gof}>0.2, and weight
Purity	94	96
Correct	13	44
Wrong	16	21
Un-matched	71	35

$$\mathcal{L}(\text{sample}|m_t,\text{JSF}) = \prod_{\text{events}} \left(\sum_{i=1}^{n} P_{\text{gof}}(i) \left(\sum_j f_j P_j(m_{t,i}^{\text{fit}}|m_t,\text{JSF}) \times P_j(m_{W,i}^{\text{reco}}|m_t,\text{JSF}) \right) \right)^{w_{\text{event}}}$$

combine all events

weight each permutation by kin. fit probability

probability of correct/wrong/un-matched permutation yielding (m_T,JSF)

pull events which have correct combinatorics

Strategy for differential measurements

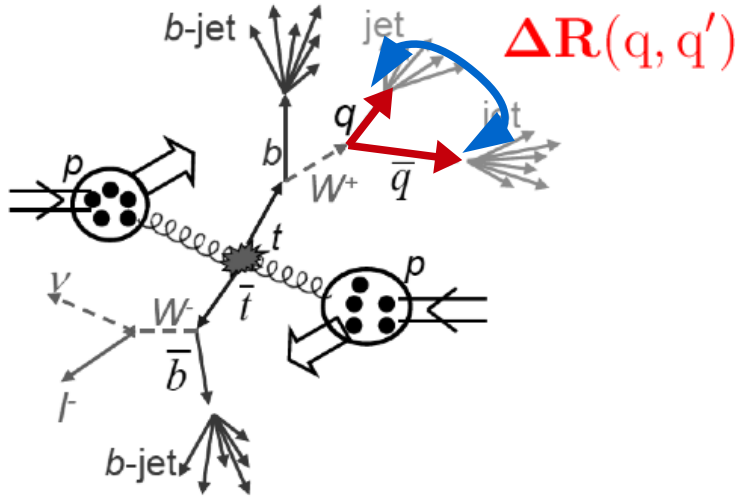
- **Study performed at 7 and 8 TeV**
  - using golden l+jets channel
  - JHEP 12 (2012) 105 and CMS-PAS-TOP-14-001

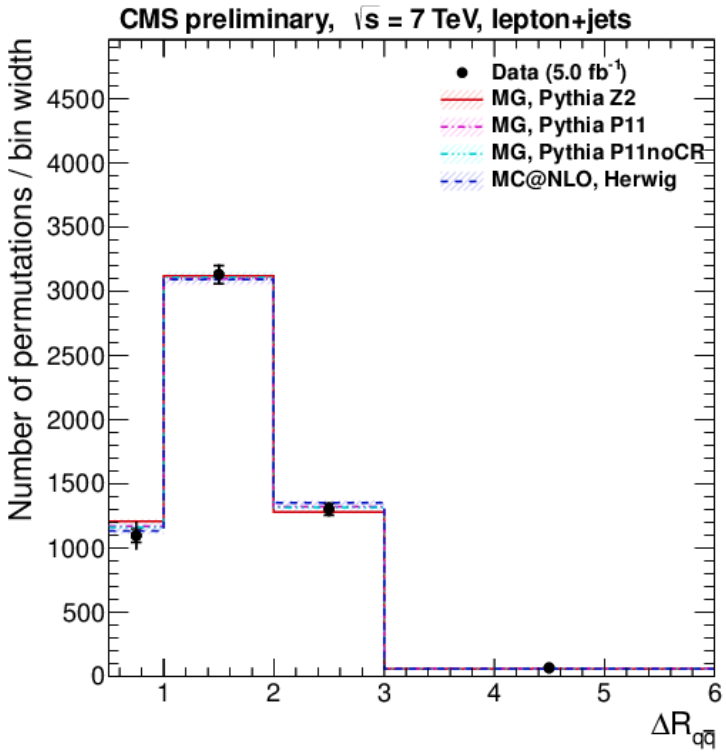
- **Inclusive measurement**
  - High purity selection (2 b-tags)
  - choose 2 best permutations from kinematic fit

    include resolutions,m(top)=m(anti-top), m_W=80.4 GeV
  - apply ideogram method for (m_t,JES)

    event-per-event likelihood using both permutations

- **Categorize** permutations according to kinematics





Strategy for differential measurements

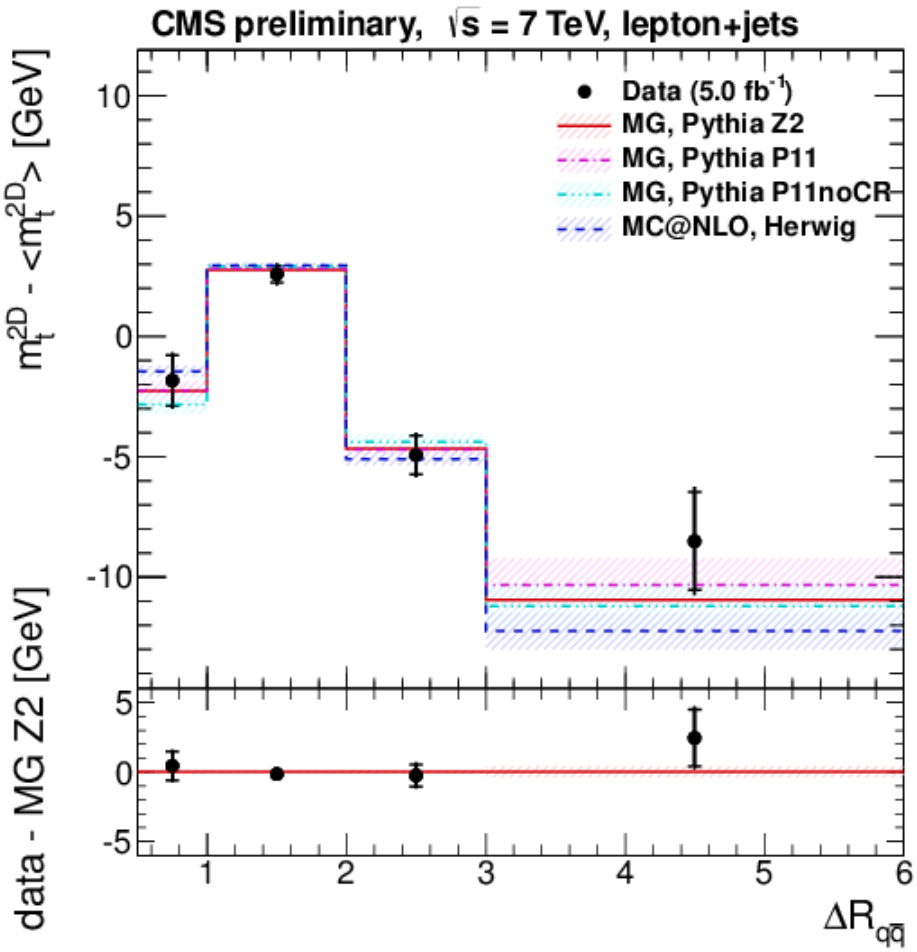
- **Study performed at 7 and 8 TeV**
  - using golden l+jets channel
  - JHEP 12 (2012) 105 and CMS-PAS-TOP-14-001

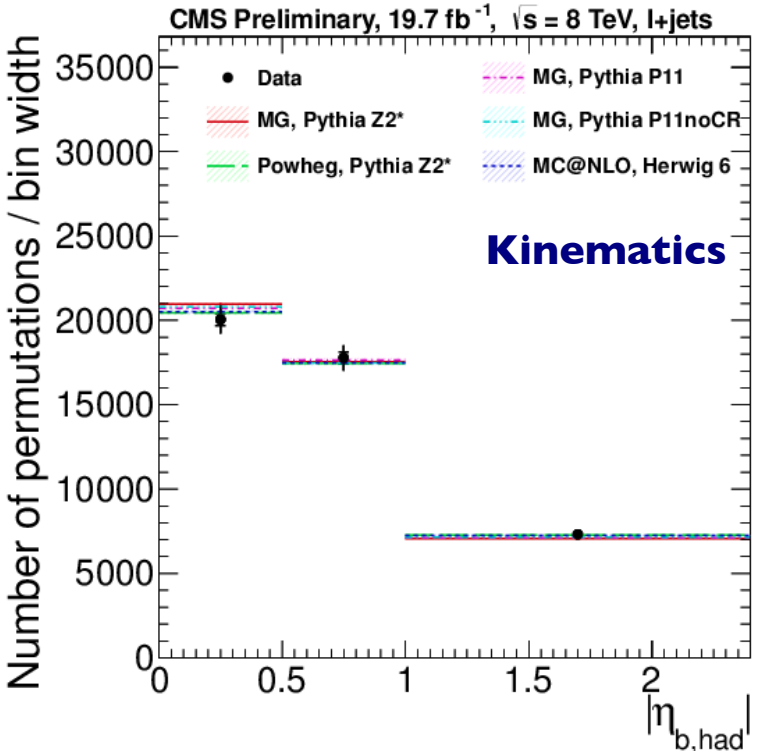
- **Inclusive measurement**
  - High purity selection (2 b-tags)
  - choose 2 best permutations from kinematic fit

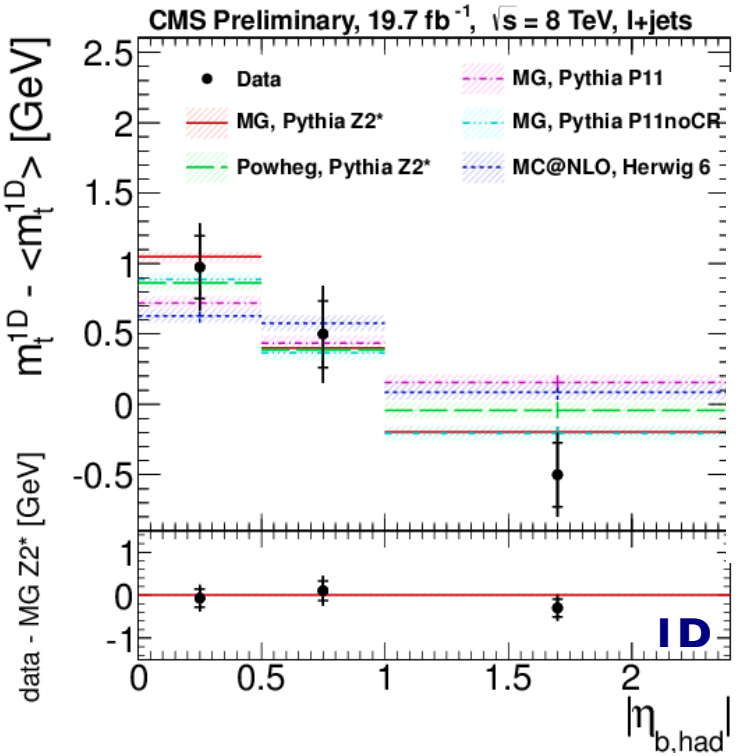
    include resolutions,m(top)=m(anti-top), m_W=80.4 GeV
  - apply ideogram method for (m_t,JES)

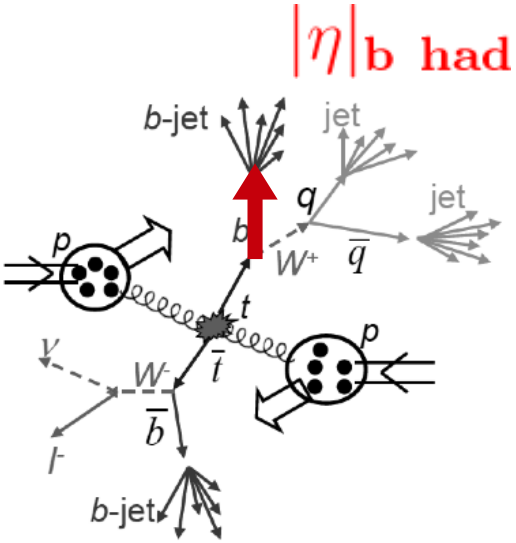
    event-per-event likelihood using both permutations

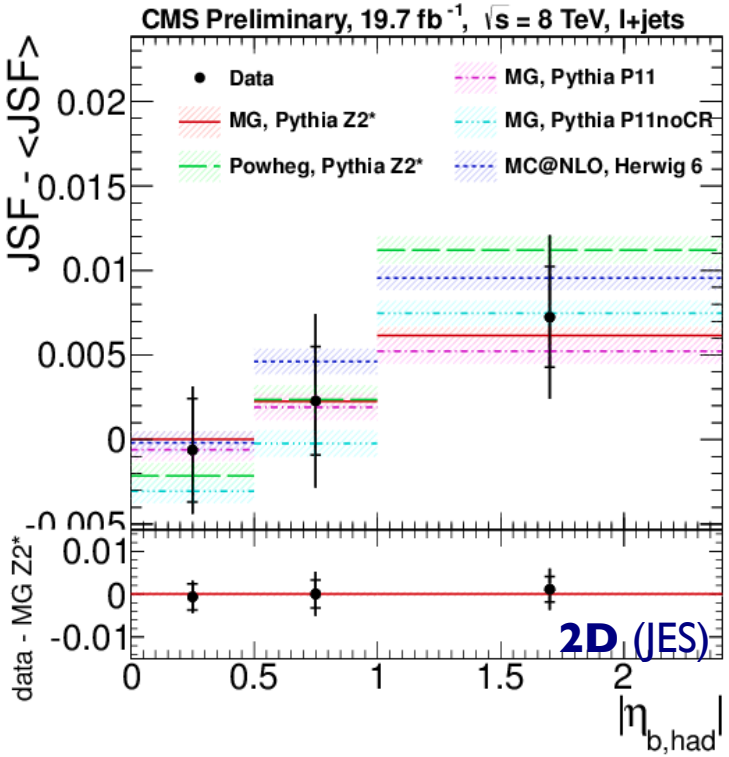
- **Categorize** permutations according to kinematics
  - fit (m_t,JES) in data and in MC
  - compare observed and expected (different models)

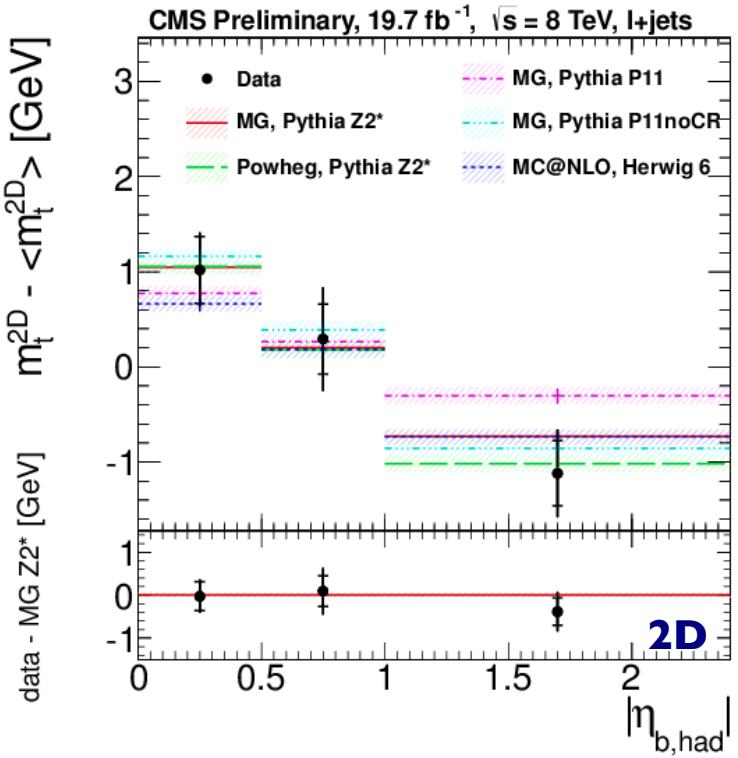


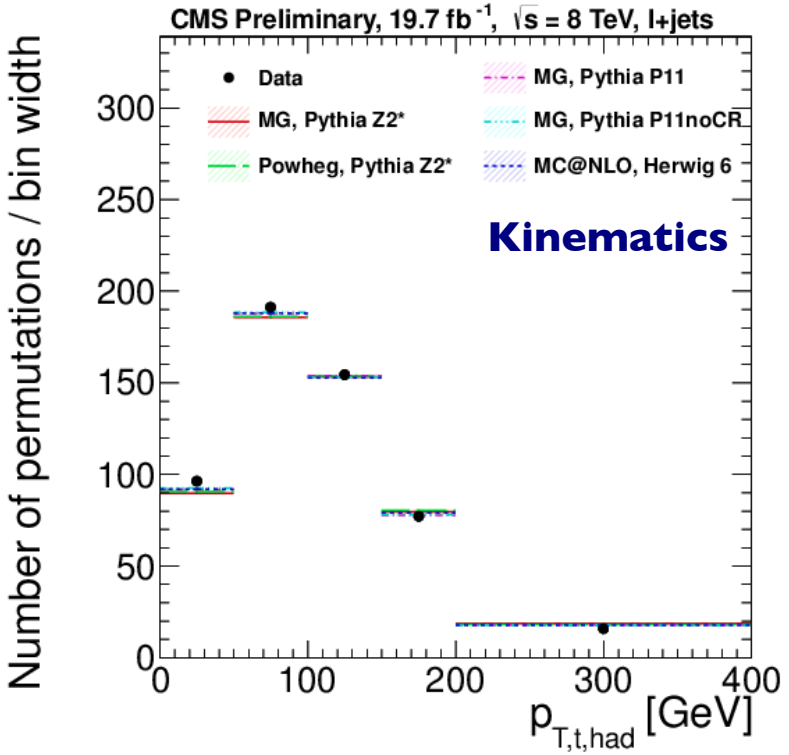

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
Kinematics
Number of permutations / bin width
$|\eta_{b,had}|$

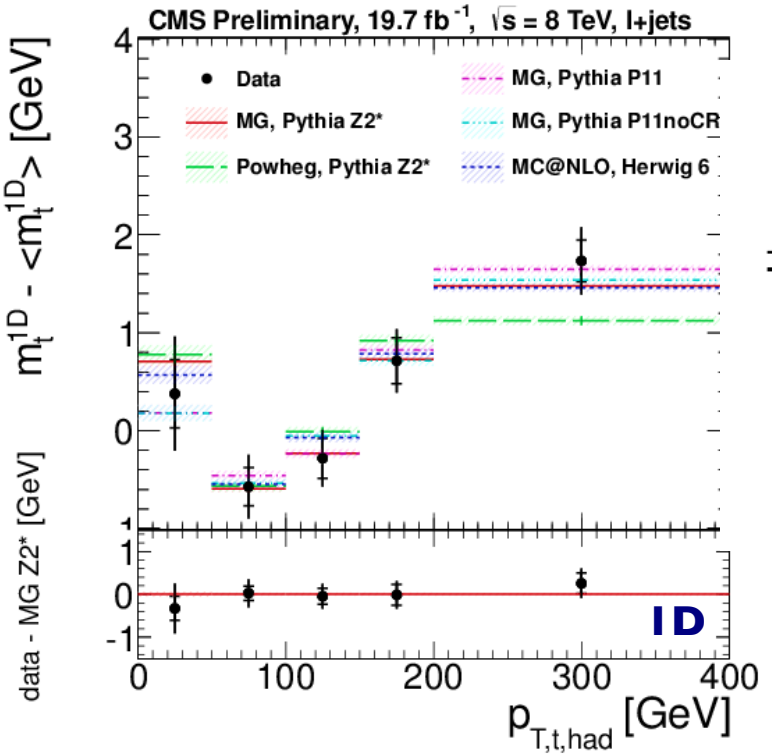

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
ID
m_t^{1D} - <m_t^{1D}> [GeV]
data - MG Z2* [GeV]
$|\eta_{b,had}|$

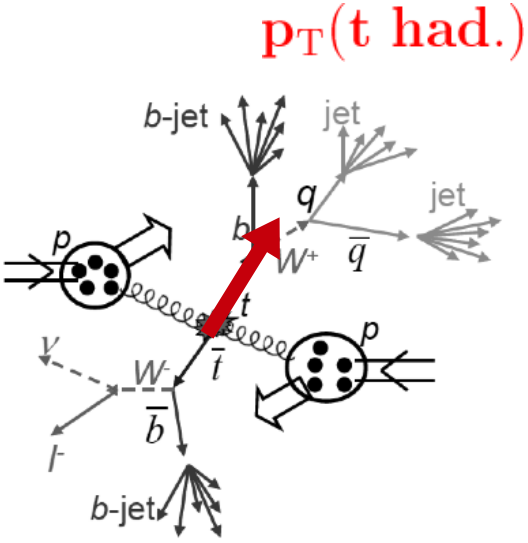

$|\eta|$b had
b-jet
jet
jet
q
b
p
W^+
$\bar{q}$
t
p
ν
W^-
$\bar{t}$
$\bar{b}$
l
b-jet

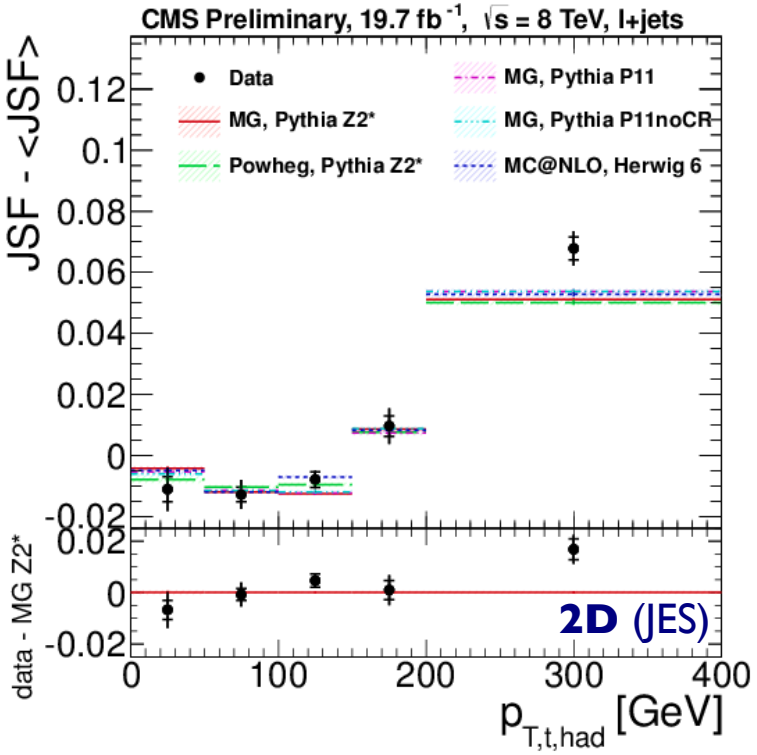

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
2D (JES)
JSF - <JSF>
data - MG Z2*
$|\eta_{b,had}|$

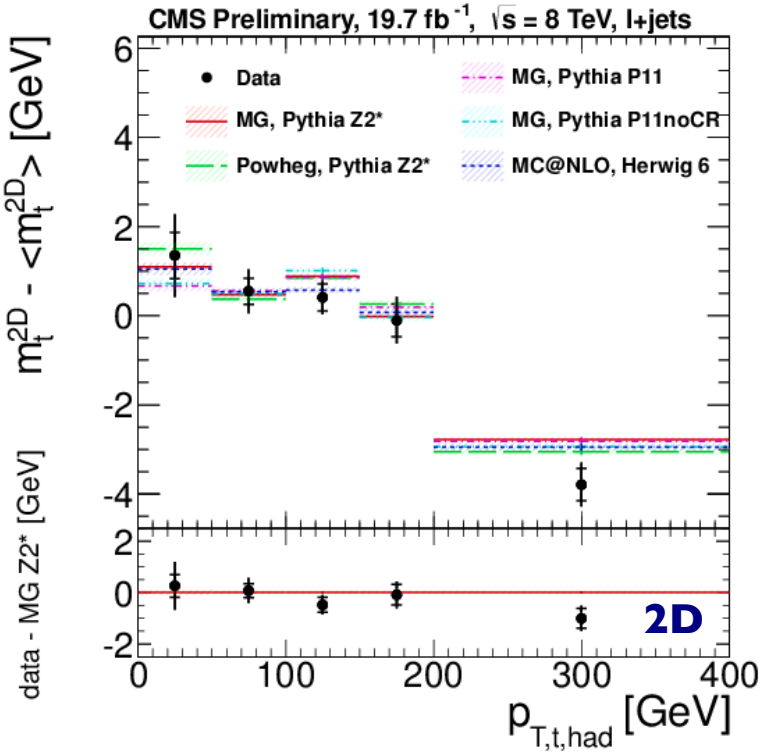

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
2D
m_t^{2D} - <m_t^{2D}> [GeV]
data - MG Z2* [GeV]
$|\eta_{b,had}|$

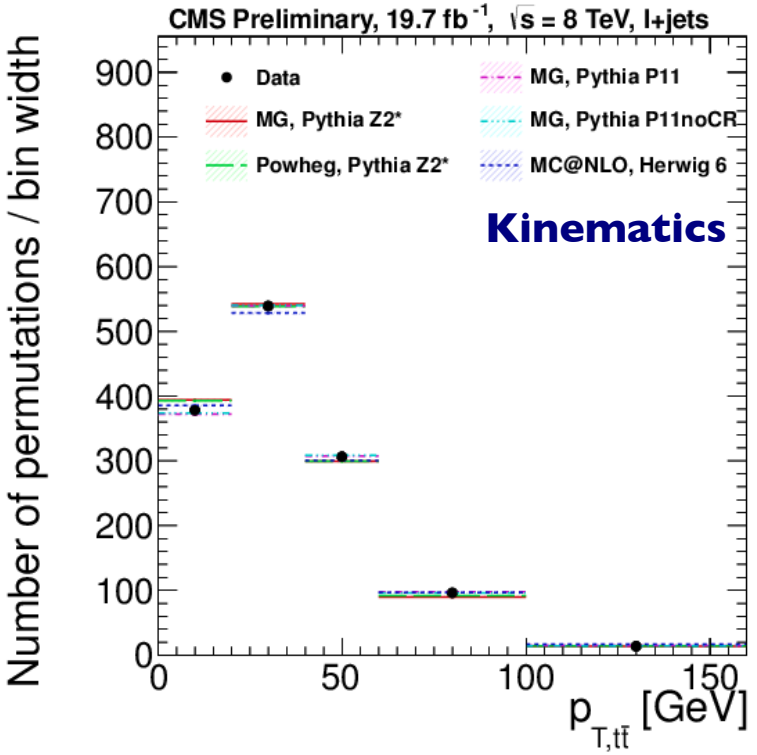

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
Kinematics
Number of permutations / bin width
$p_{T,t,had}$ [GeV]

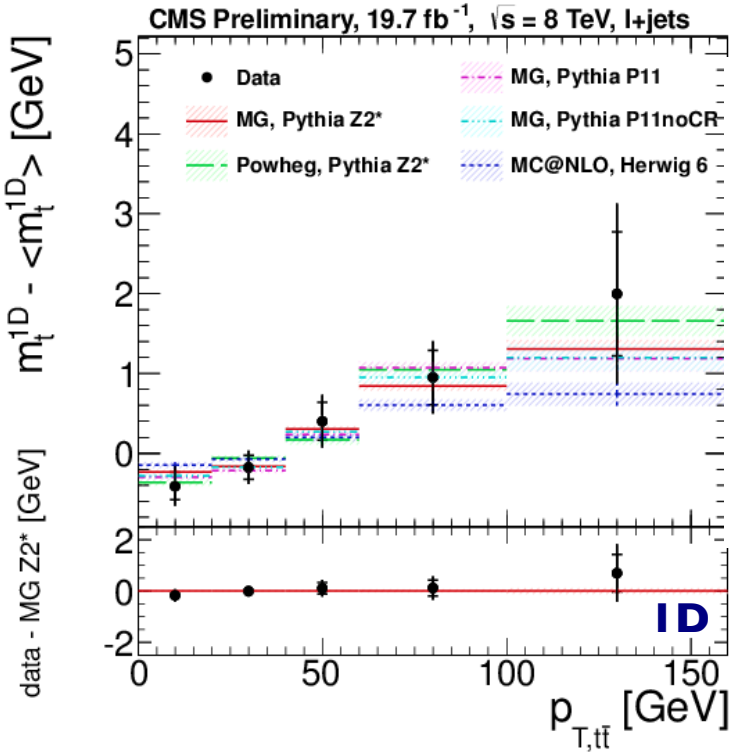

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
ID
m_t^{1D} - <m_t^{1D}> [GeV]
data - MG Z2* [GeV]
$p_{T,t,had}$ [GeV]

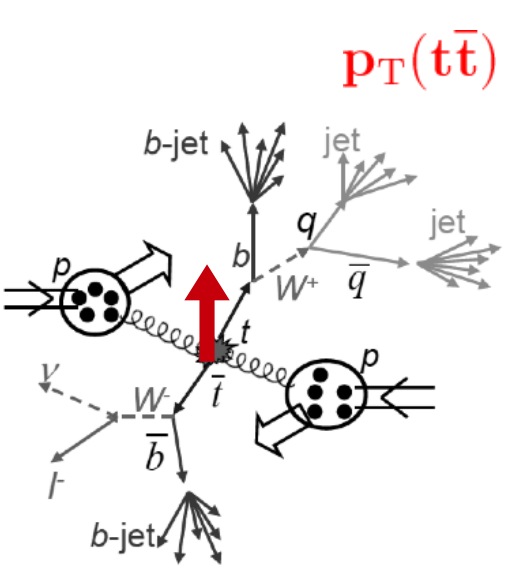

p_T(t had.)
b-jet
jet
q
jet
b
W^+
$\bar{q}$
p
t
p
ν
W^-
$\bar{t}$
$\bar{b}$
l^-
b-jet

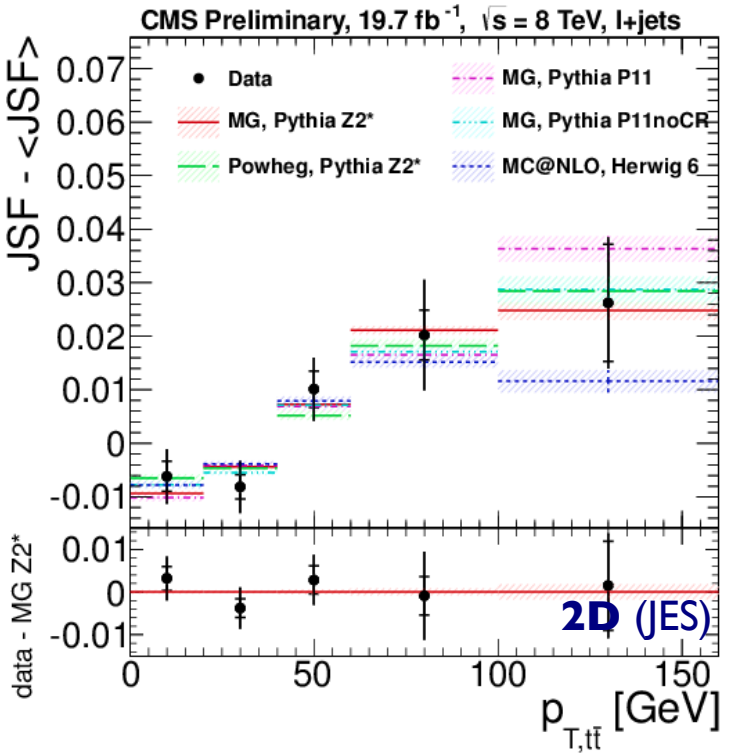

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
2D (JES)
JSF - <JSF>
data - MG Z2*
$p_{T,t,had}$ [GeV]

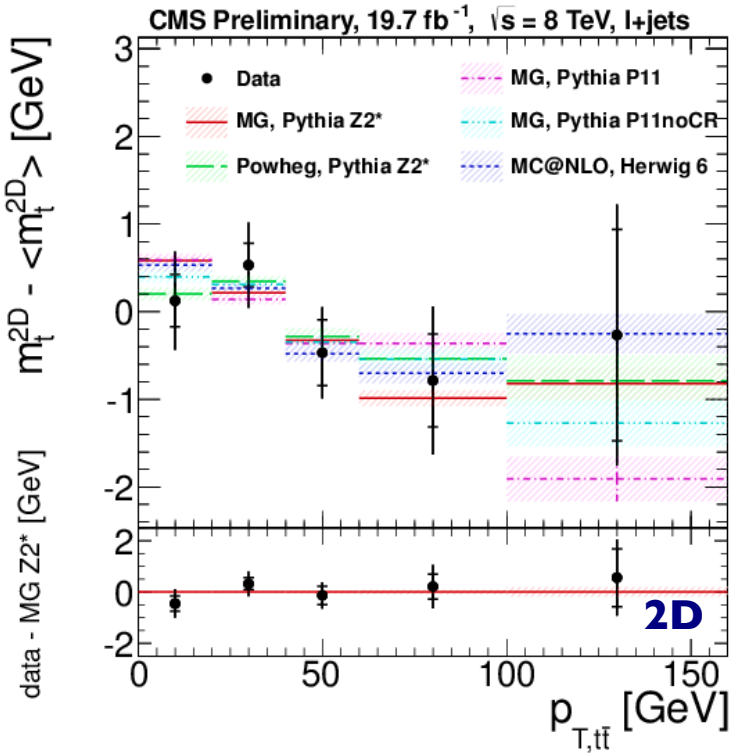

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
2D
m_t^{2D} - <m_t^{2D}> [GeV]
data - MG Z2* [GeV]
$p_{T,t,had}$ [GeV]

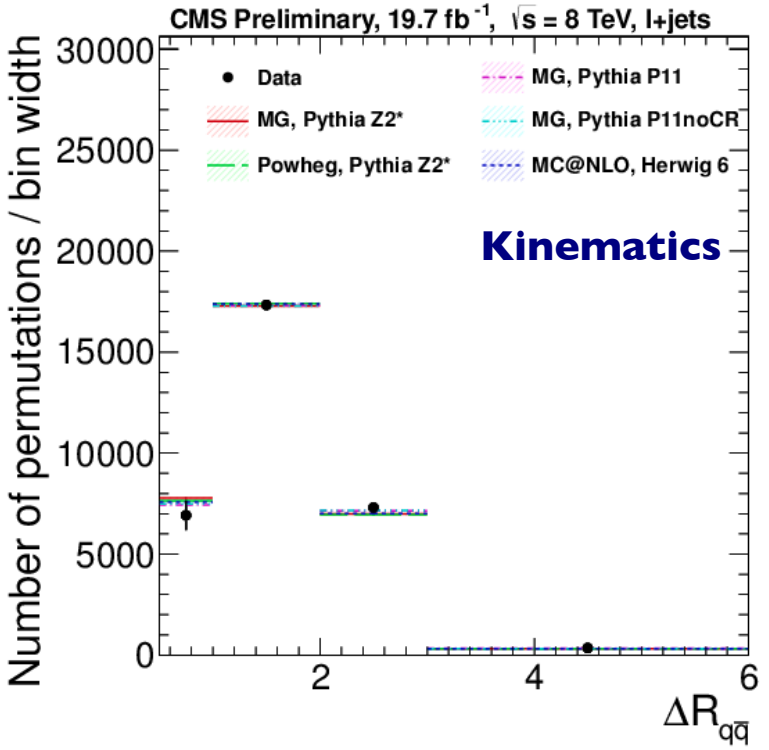

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
Kinematics
Number of permutations / bin width
$p_{T,t\bar{t}}$ [GeV]

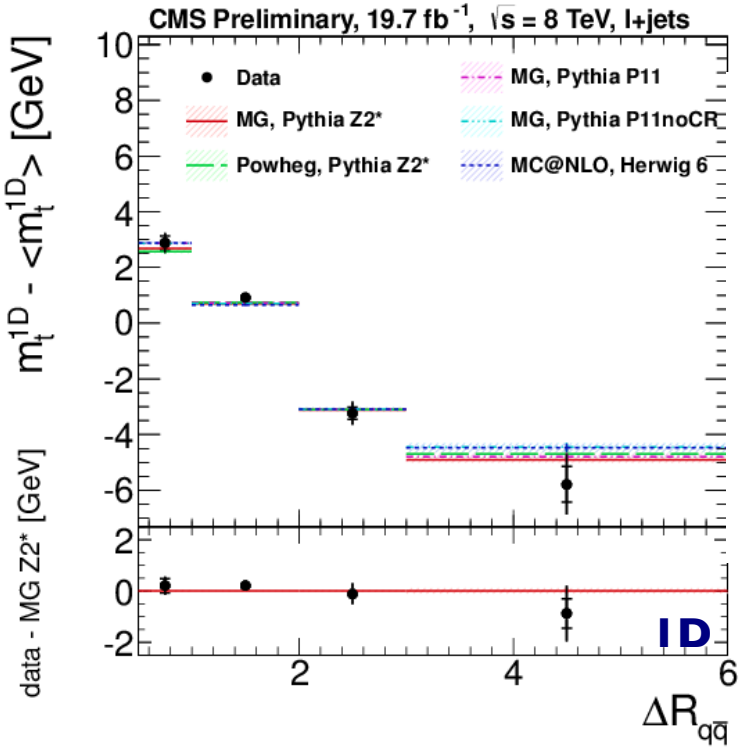

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
ID
m_t^{1D} - <m_t^{1D}> [GeV]
data - MG Z2* [GeV]
$p_{T,t\bar{t}}$ [GeV]

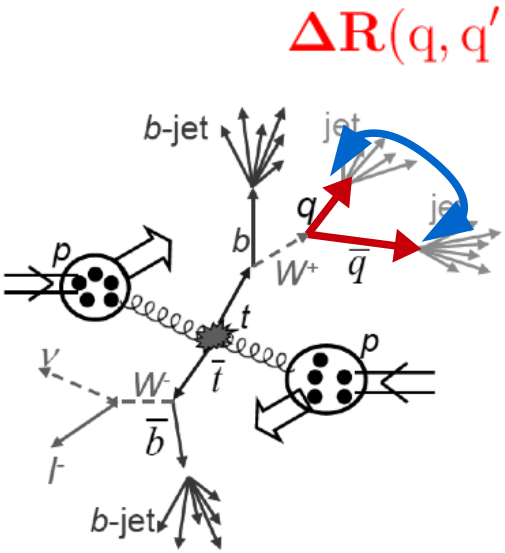

$p_T(t\bar{t})$
b-jet
jet
q
jet
b
p
W^+
$\bar{q}$
t
p
ν
W^-
$\bar{t}$
$\bar{b}$
l^-
b-jet

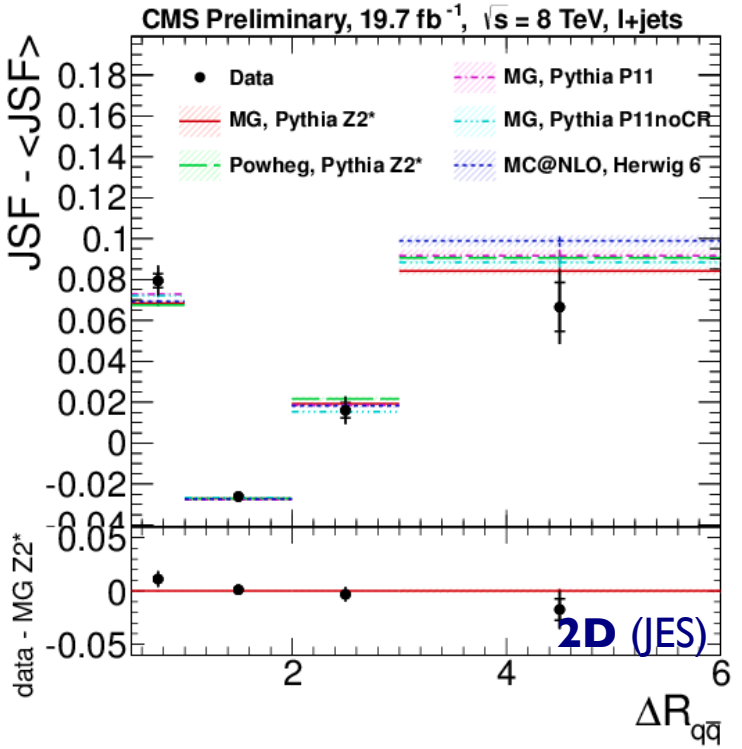

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
2D (JES)
JSF - <JSF>
data - MG Z2*
$p_{T,t\bar{t}}$ [GeV]

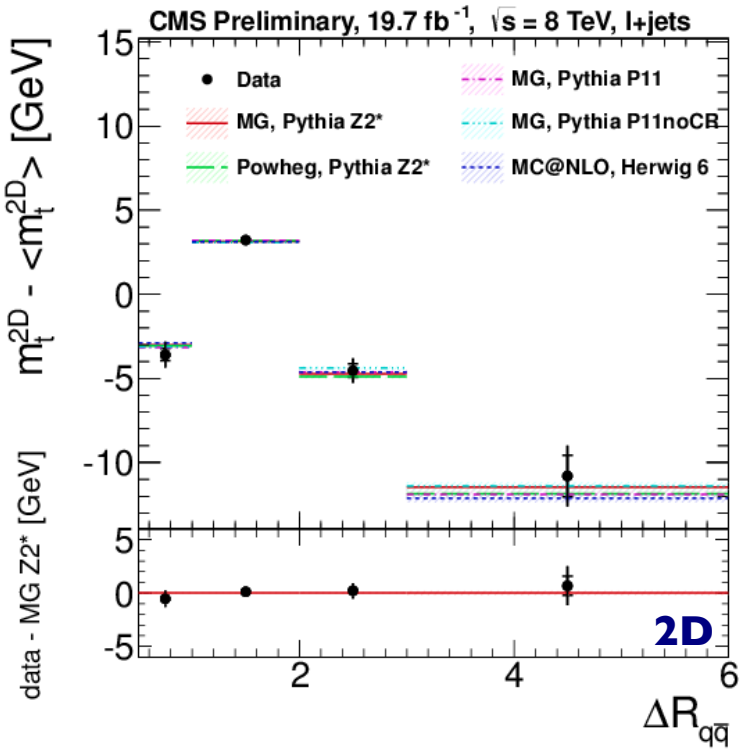

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
2D
m_t^{2D} - <m_t^{2D}> [GeV]
data - MG Z2* [GeV]
$p_{T,t\bar{t}}$ [GeV]


CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
Kinematics
Number of permutations / bin width
$\Delta R_{q\bar{q}}$


CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
ID
m_t^{1D} - <m_t^{1D}> [GeV]
data - MG Z2* [GeV]
$\Delta R_{q\bar{q}}$


$\Delta R(q, q')$
b-jet
jet
q
jet
b
p
W^+
$\bar{q}$
t
p
ν
W^-
$\bar{t}$
$\bar{b}$
l^-
b-jet


CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
2D (JES)
JSF - <JSF>
data - MG Z2*
$\Delta R_{q\bar{q}}$

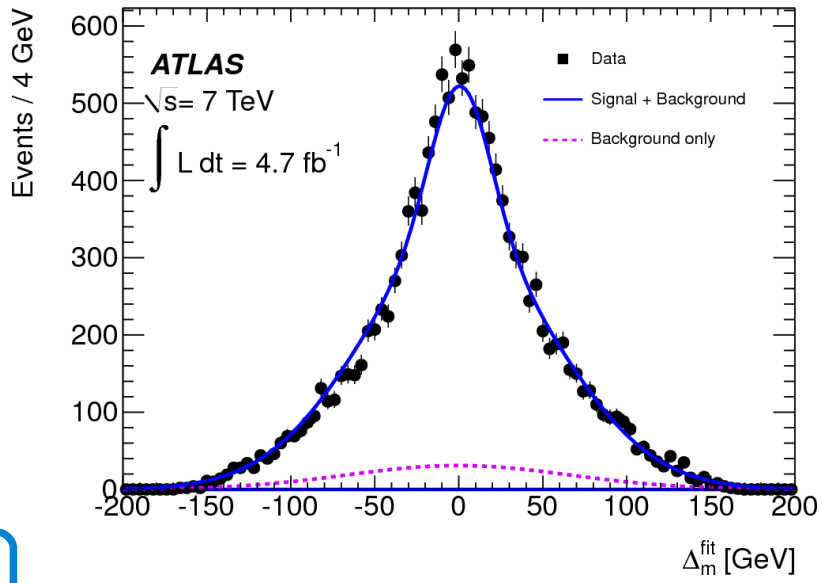

CMS Preliminary, 19.7 fb^{-1}, $\sqrt{s}$ = 8 TeV, l+jets
Data
MG, Pythia Z2*
Powheg, Pythia Z2*
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig 6
2D
m_t^{2D} - <m_t^{2D}> [GeV]
data - MG Z2* [GeV]
$\Delta R_{q\bar{q}}$

m(top)-m(anti-top) is also a differential measurement

... if CPT is conserved

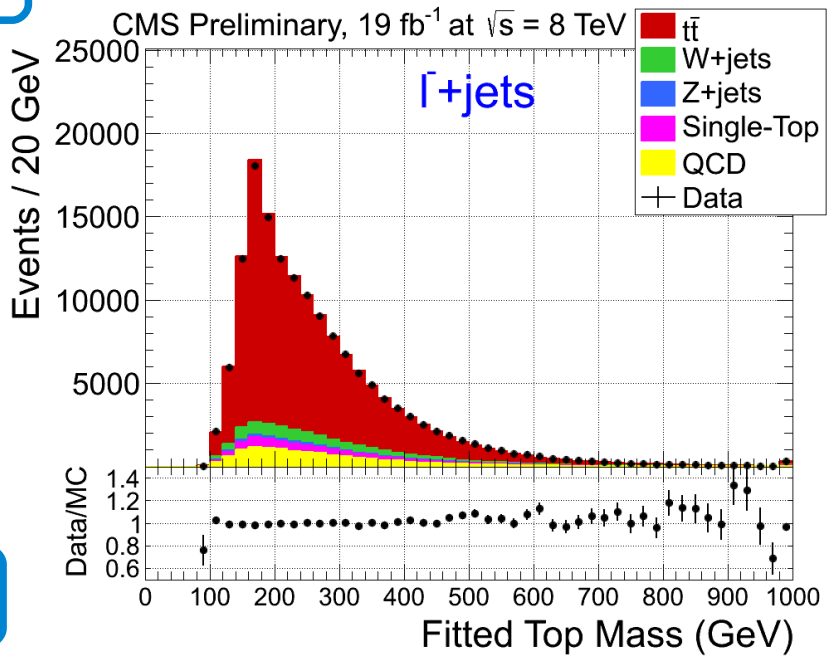
- **ATLAS** - PLB 728C (2014) 363-379
  - 1 lepton, 4 jets, 2 b-tags, ME_T
  - Δm_t is computed event-by-event
  - measure Δm_t and N_{bkg} from likelihood fit
  - dominated by uncertainty on b-hadron decays model (compare EvtGen / Pythia)

$$\Delta m \equiv m_t - m_{\bar{t}} = 0.67 \pm 0.61(\text{stat}) \pm 0.41(\text{syst})\ \text{GeV}$$



- **CMS** – CMS PAS TOP-12-031
  - 1 lepton, 4 jets, 2 b-tags
  - measure m_t inclusive in l+/l- sample with kinematic fit + ideogram method (no JES in-situ constraint)
  - uncertainty on Δm_t dominated by b / anti-b response (upper bound derived from simulation)

$$\Delta m_t = -272 \pm 196\ (\text{stat.}) \pm 122\ (\text{syst.})\ \text{MeV}$$



Summary of m_t differential distributions

- For each variable compute χ^2 variable to **quantify deviations with respect to predictions**
  - global χ^2 computed using m_T^{1D} and JES : independent measurements

Effect	Observable	m_t^{1D} χ^2 7 TeV	m_t^{1D} χ^2 8 TeV	JES χ^2 7 TeV	JES χ^2 8 TeV	m_t^{2D} χ^2 7 TeV	m_t^{2D} χ^2 8 TeV	ndof
Colour reconnection	$\Delta R_{q\bar{q}}$	1.01	2.87	3.41	3.66	1.49	0.83	3
	$\Delta\phi_{q\bar{q}}$	2.31	-	2.18	-	2.89	-	3
	$p_{T,t,had}$	9.40	0.89	7.83	12.03	2.89	5.76	4
	$\lvert\eta_{T,t,had}\rvert$	0.41	5.56	3.33	1.22	3.17	1.14	3
Radiation effects	H_T	3.18	6.19	1.19	9.18	2.24	7.54	4
	$m_{t\bar{t}}$	2.52	2.16	2.98	4.69	2.25	3.22	4/5
	$p_{T,t\bar{t}}$	3.39	1.02	1.67	1.22	2.18	1.33	4
	Jet mult.	1.47	4.24	2.00	0.10	1.56	1.16	2
b-quark kinematics	$p_{T,b,had}$	0.81	2.57	2.35	5.80	2.17	2.17	4
	$\lvert\eta_{T,b,had}\rvert$	2.64	1.15	0.30	0.08	0.48	0.72	2
	$\Delta R_{b\bar{b}}$	4.87	0.37	2.61	1.63	8.01	1.77	3
	$\Delta\phi_{b\bar{b}}$	2.87	-	3.86	-	6.86	-	3
"EWK" kinematics	$p_{T,q,had}$	-	4.04	-	8.39	-	1.28	4
	$\lvert\eta_{T,W,had}\rvert$	-	3.36	-	3.79	-	6.27	2
	$p_{T,q,had}$	-	1.59	-	8.06	-	1.60	4
	$\lvert\eta_{T,W,had}\rvert$	-	1.41	-	1.09	-	1.35	3
χ^2/ndof		**68.68/78 (p-val=0.77) at 7 TeV**						
		93.67/94 (p-val=0.49) at 8 TeV						

(Intermediate) conclusions - I

- **The top mass observable is used as a probe of the top quark event anatomy**

- **No significant deviation is found with respect to nominal calibration**
  - Baseline: Madgraph+Pythia6 Z2*
  - The extracted top mass is stable in all corners of phase space and for all models considered

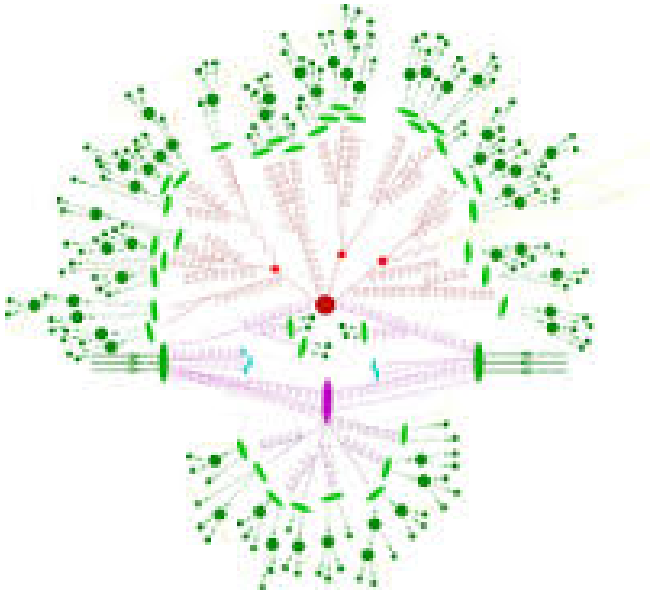
- **With more statistics (i.e. LHC Run II and beyond)**
  - establish robustness of top mass result in more detail and with better precision
  - tune models in-situ using data or simply exclude extreme models
  - use this method to compare "our" favorite MC tool to well-defined QCD calculations (cf. arXiv:1405.4781)

Mapping the proton footprint in a top quark event

Exploratory studies of the underlying event (UE) activity are performed using tt candidate events
A good agreement is found using MadGraph plus the Pythia 6 Tune Z2* simulation.

Exploring further colour reconnection effects

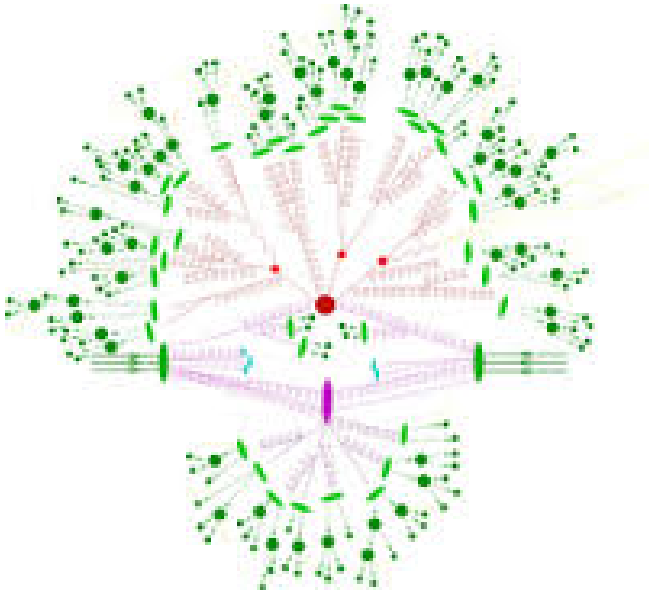
- **Particle density is large at hadron colliders ►**



- In PYTHIA this is generated with a **high string density**
  - **driven by MPI** with contributions from ISR/FSR
  - colour assignments from pQCD may be modified by npQCD
  - N_C=3 → which partons belong together in colour singlets
  - colour reconnection may potentiate non-linear dynamics

Exploring further colour reconnection effects

- **Particle density is large at hadron colliders ►**



- In PYTHIA this is generated with a **high string density**
  - **driven by MPI** with contributions from ISR/FSR
  - colour assignments from pQCD may be modified by npQCD
  - N_C=3 → which partons belong together in colour singlets?
  - colour reconnection may potentiate non-linear dynamics

Typical algorithm in PYTHIA

$$P_{\text{reconnect}} = 1 - (1 - \chi)^{N_{\text{MPI}}}$$

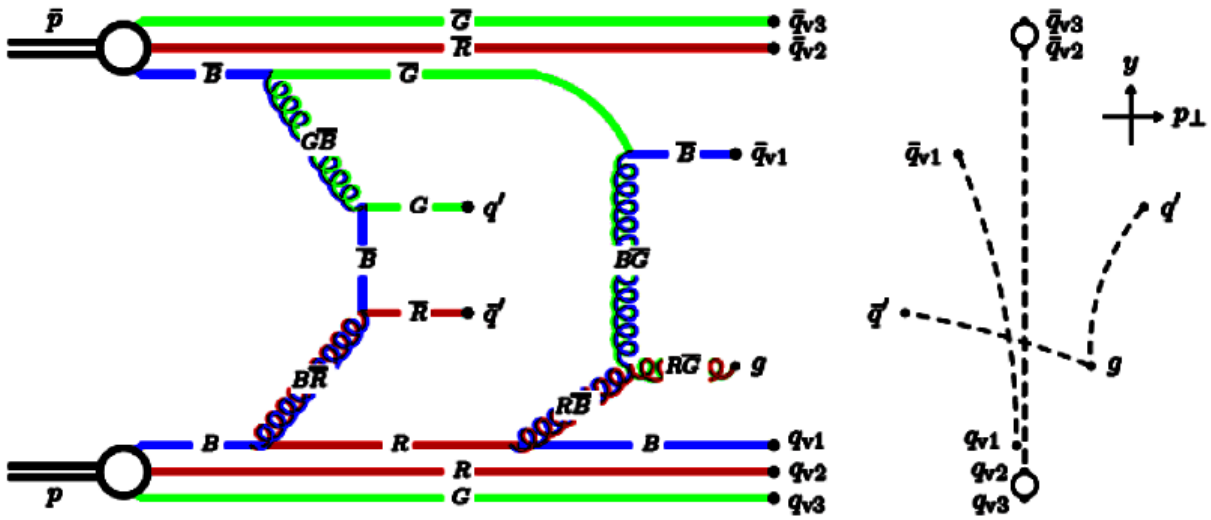
strength parameter — # MPI

- Each string candidate for reconnection
- Try possible reconnections, by minimizing

$$\lambda \sim \sum_{i,j} \ln\left(\frac{m_{ij}^2}{m_0^2}\right)$$

reference ~1 GeV

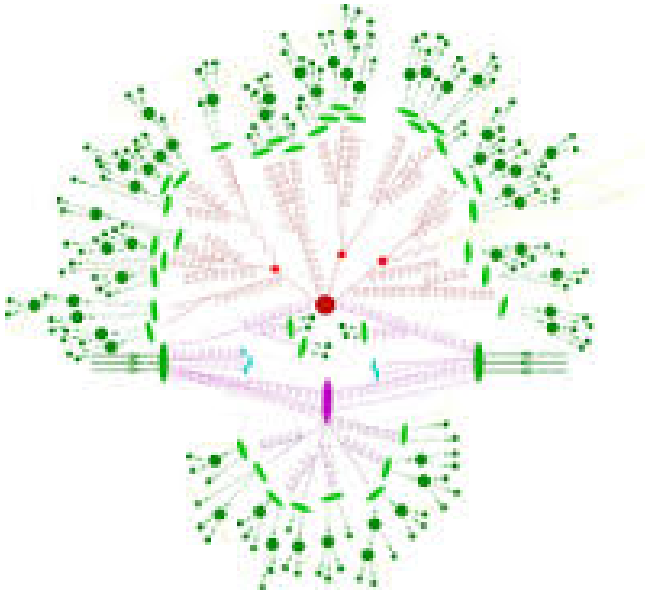
- ~12 models available...



adapted from T. Sjostrand @ ISMD 2013 and arXiv:1310.8073

Exploring further colour reconnection effects

- **Particle density is large at hadron colliders ►**



- In PYTHIA this is generated with a **high string density**
  - **driven by MPI** with contributions from ISR/FSR
  - colour assignments from pQCD may be modified by npQCD
  - N_C=3 → which partons belong together in colour singlets?
  - colour reconnection may potentiate non-linear dynamics

Typical test in m_{top} analysis

- quote the difference between two alternative UE tunes
- Perugia11 and Perugia11noCR (cf. PRD82:074018,2010)

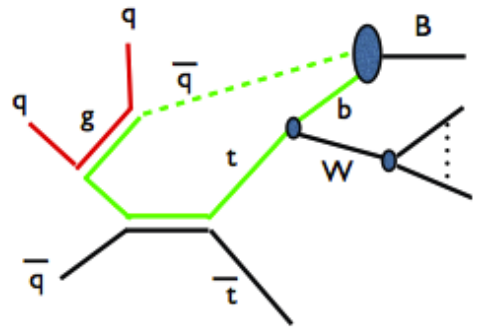
Does it tell us something useful?

Channel	$\sqrt{s}$ (TeV)	Analysis	Δm_t (GeV) 1D fit	2D fit	3D fit
$\ell\ell'$	7	EPJC 72 (2012) 2202†	0.13	-	-
		EPJC 73 (2013) 2494	0.57	-	-
		ATLAS-CONF-2012-082	1.2	-	-
		ATLAS-CONF-2013-077†	0.29	-	-
	8	CMS-PAS-TOP-13-030	0.26	-	-
ℓ+jets	7	EPJC72 (2012) 2046	0.62	0.55	-
		ATLAS-CONF-2013-046†	-	0.03	0.32
		JHEP 12 (2012) 105†	0.07	0.54	-
	8	CMS-PAS-TOP-14-001	0.08	0.07	-
		CMS-PAS-TOP-13-030	0.35	-	-
All jets	7	EPJC 74 (2014) 2758†	0.15	0.58	-

Experimental handles to test CR for top

- $\langle p_T \rangle = \langle p_T \rangle (N_{ch})$ is sensitive to CR ►

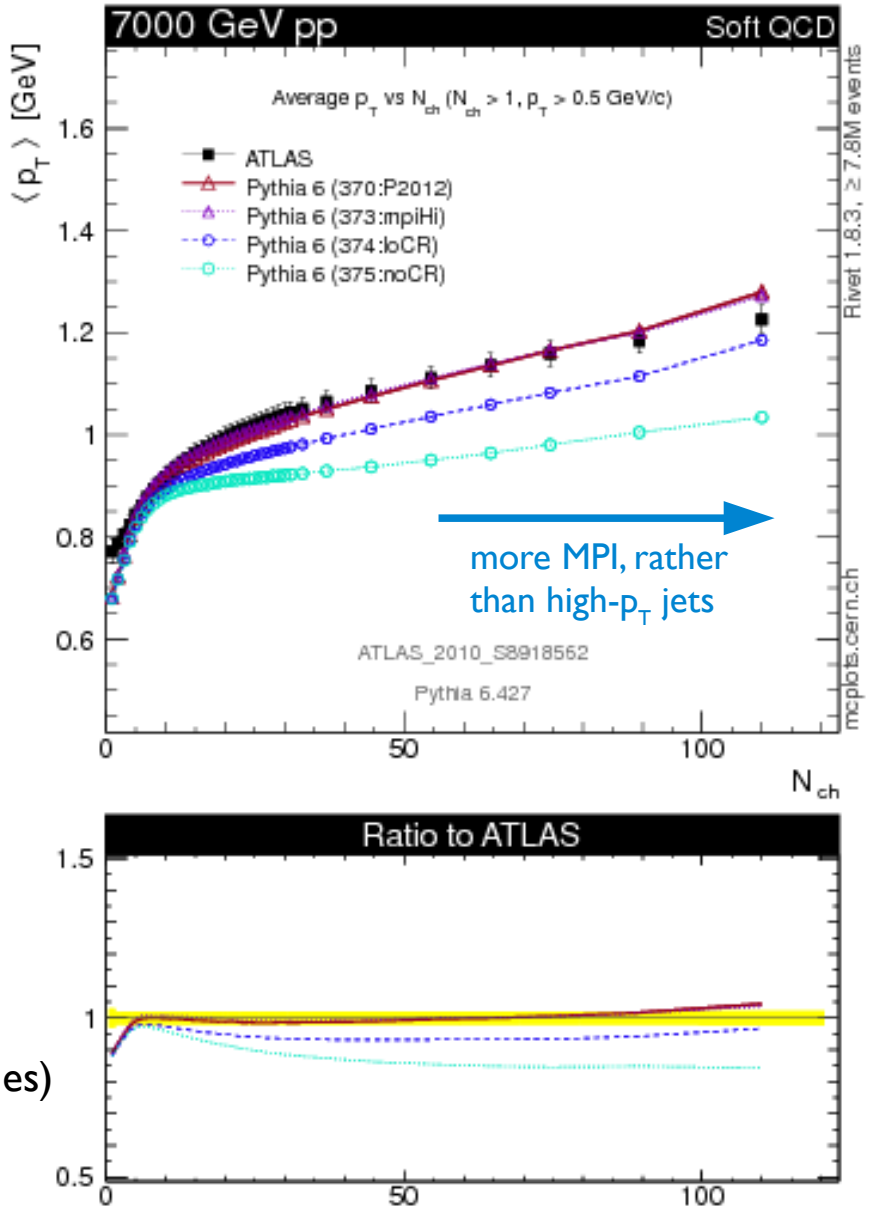
- **Top is an unstable coloured particle**: t → Wb ▼



  - b is for sure connected to somewhere else in the event
  - (W →) qq' may or may not remain as a separate singlet
  - (W →) lv is CR independent, but top kinematics dependent

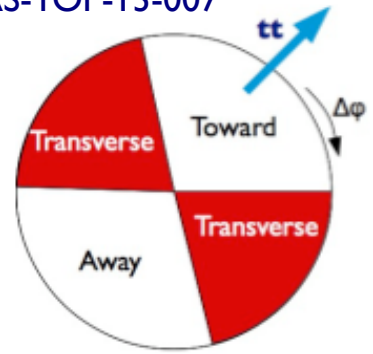
- With **LHC Run I statistics:**
  - limited sensitivity from dm_t/dx measurements (previous slides)
  - gain insight from looking to softer effects in top pair events

source: mcplots.cern.ch



Probing the Underlying Event with top quarks

CMS PAS-TOP-13-007

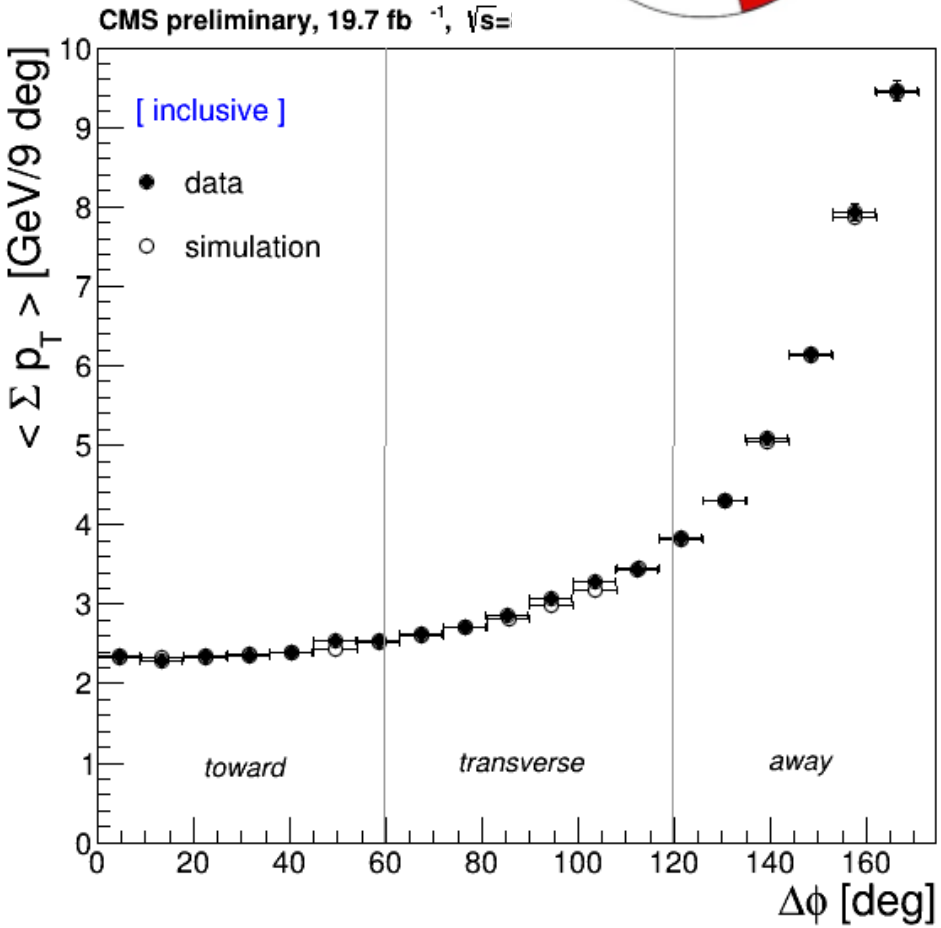


- Use **dilepton final states to probe the UE**
  - pure final state (96% pure after 2 b-tags)
  - cleaner subtraction of hard-process

    (remove all particle-flow candidates associated to b-tagged jets and leptons)
- **Factorize recoil effects event-by-event**
  - use transverse mass estimator

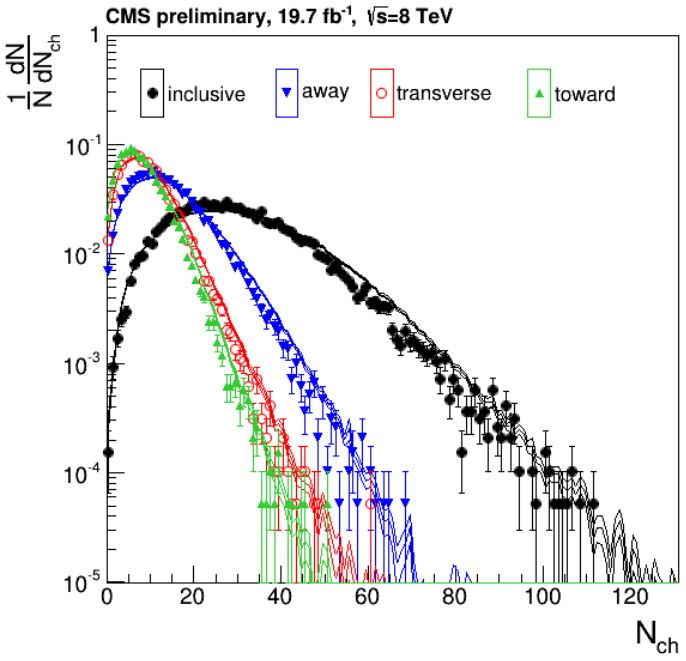
$$\vec{p}_T^{\,t\bar{t}} \approx \vec{p}_T^{\,e} + \vec{p}_T^{\,\mu} + \vec{p}_T^{\,b_1} + \vec{p}_T^{\,b_2} + \vec{\not{p}}_T$$

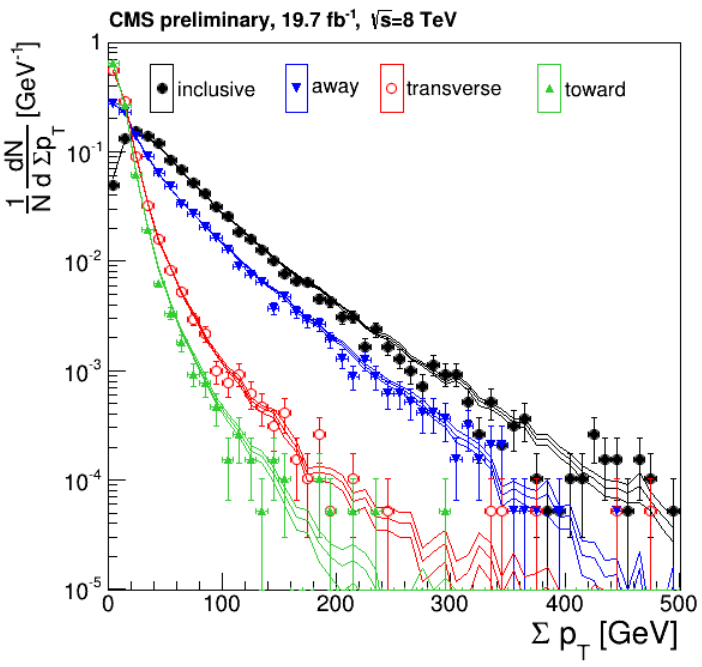
  - compute $\Delta\phi$ with respect to $p_T(tt)$
- **Characterize soft activity through:**
  - Charged multiplicity – N_{ch}
  - Flux of transverse momentum – Σp_T
  - Average p_T per charged particle - $\langle p_T \rangle$

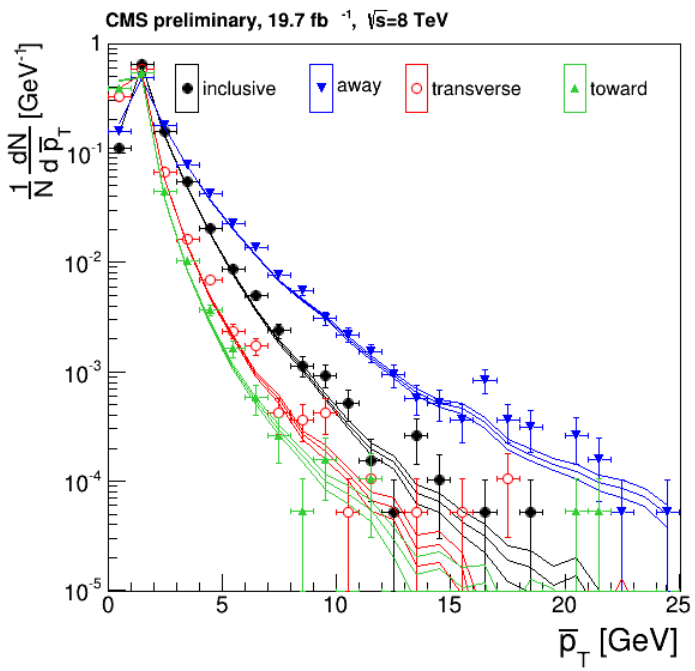


UE activity

- **Toward region** has lower multiplicities and softer p_T spectrum
- **Away region** dominated by recoil increase of particle multiplicity correlated with ISR
- Comparison with the **Madgraph+Pythia6 Z2*** default used in CMS
  - slightly smaller multiplicities observed in data but well reproduced p_T flux

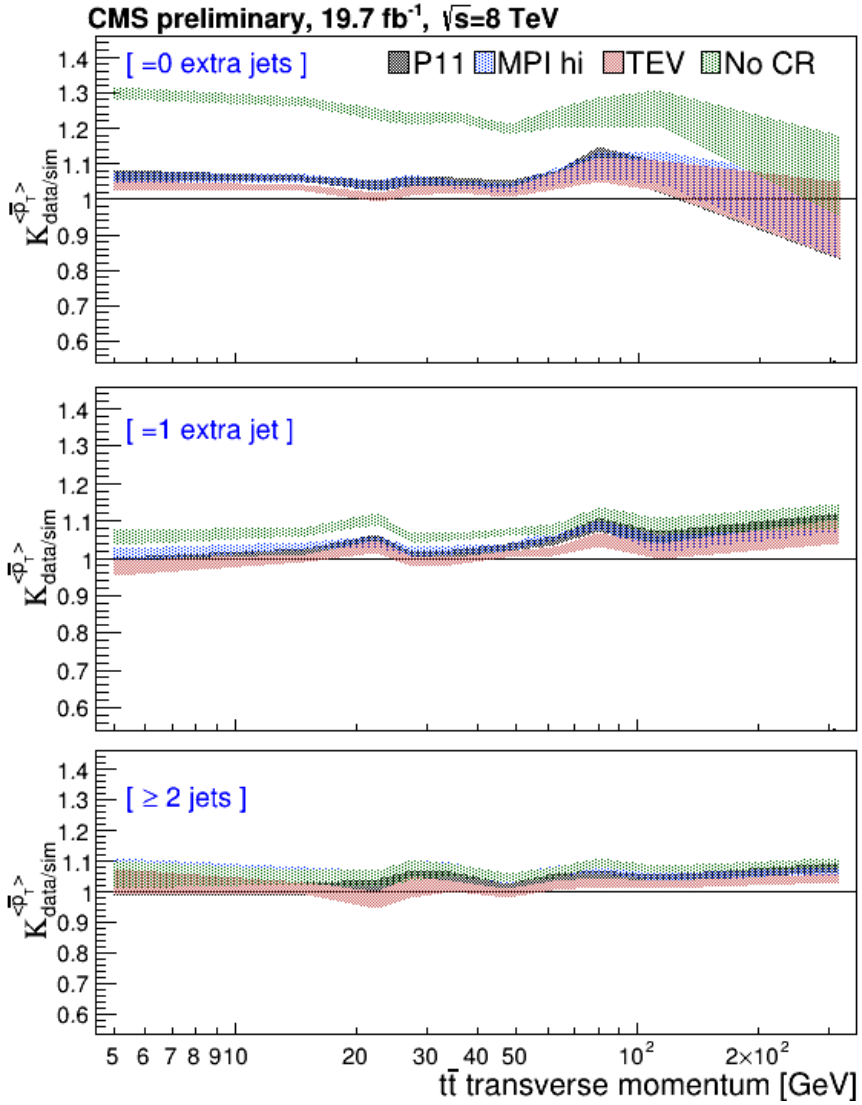






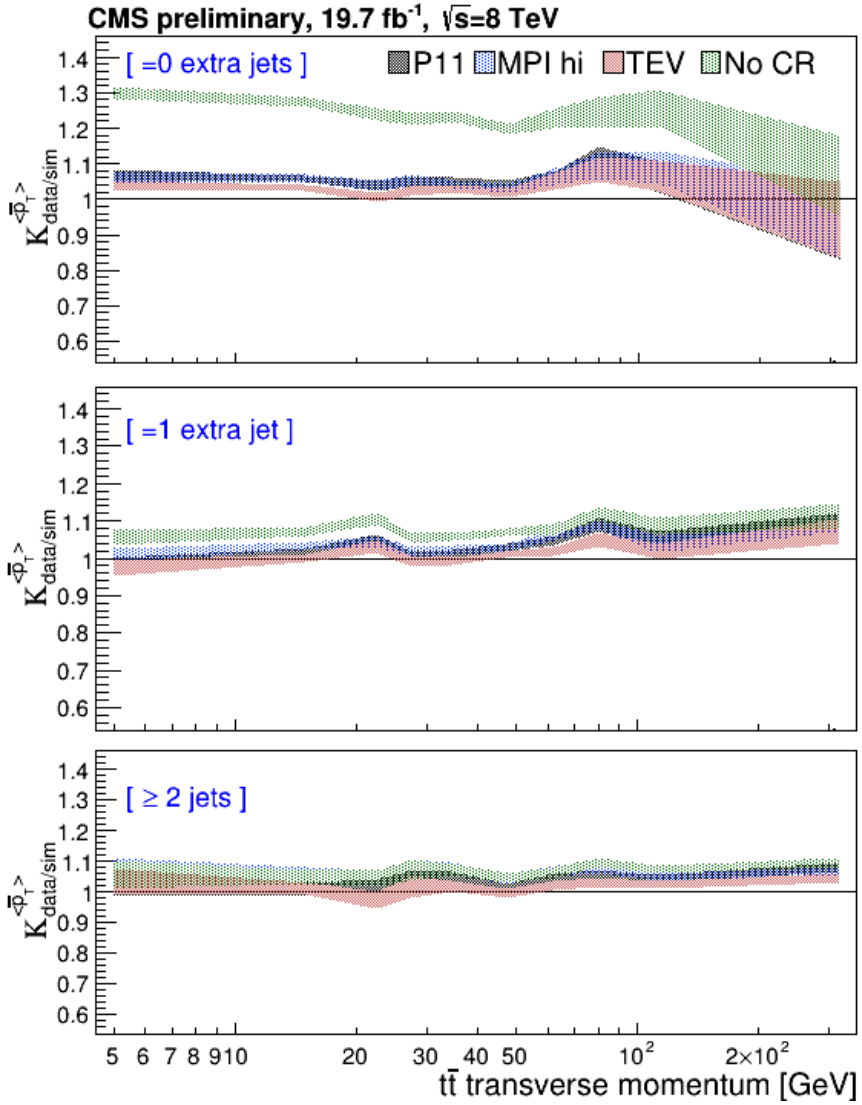
CR effects in top pair events

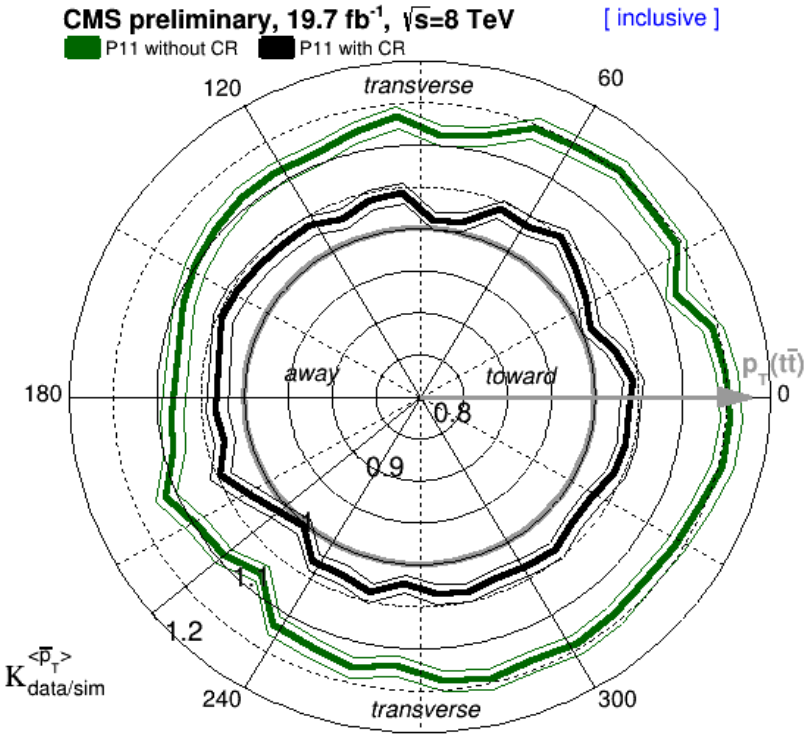
- For the **average p_T per particle** consider the **data/simulation ratio**
- Characterize as function of $p_T(t\bar{t})$



CR effects in top pair events

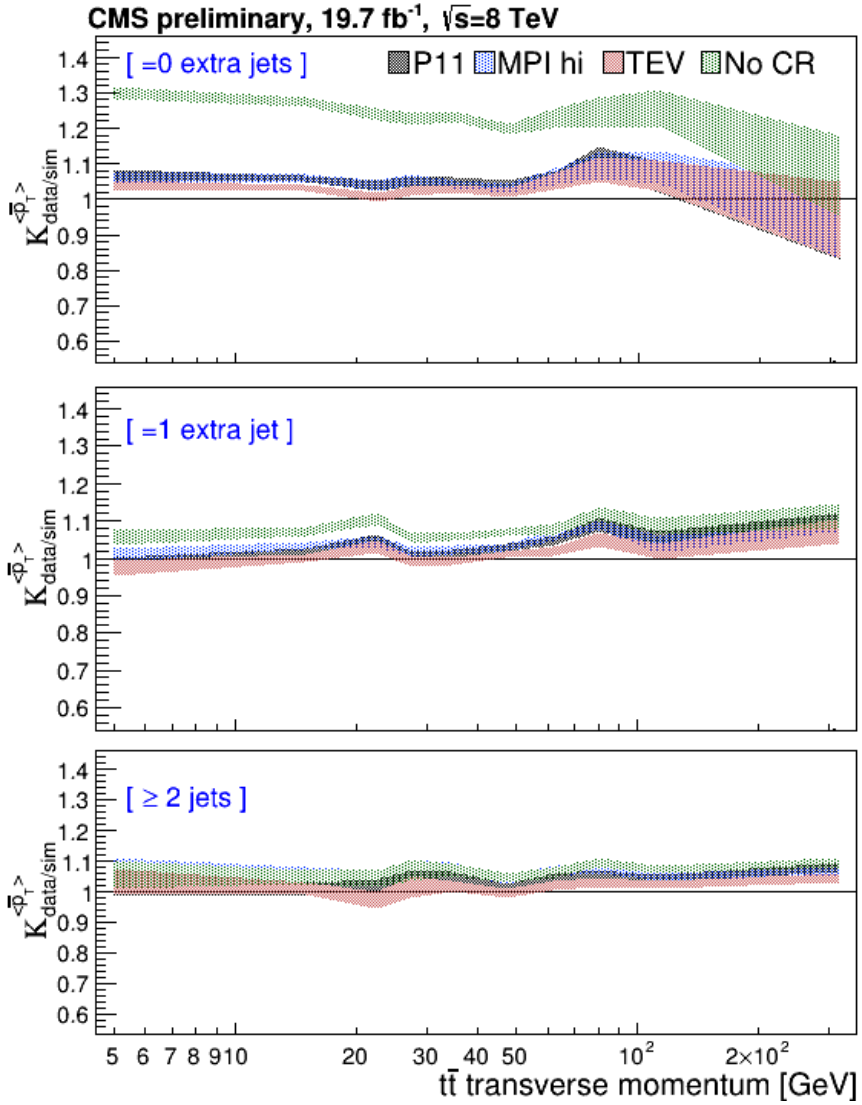
- For the **average p_T per particle** consider the **data/simulation ratio**
- Characterize as function of $p_T(tt)$ or as function of the event-by-event angle $\Delta\phi$

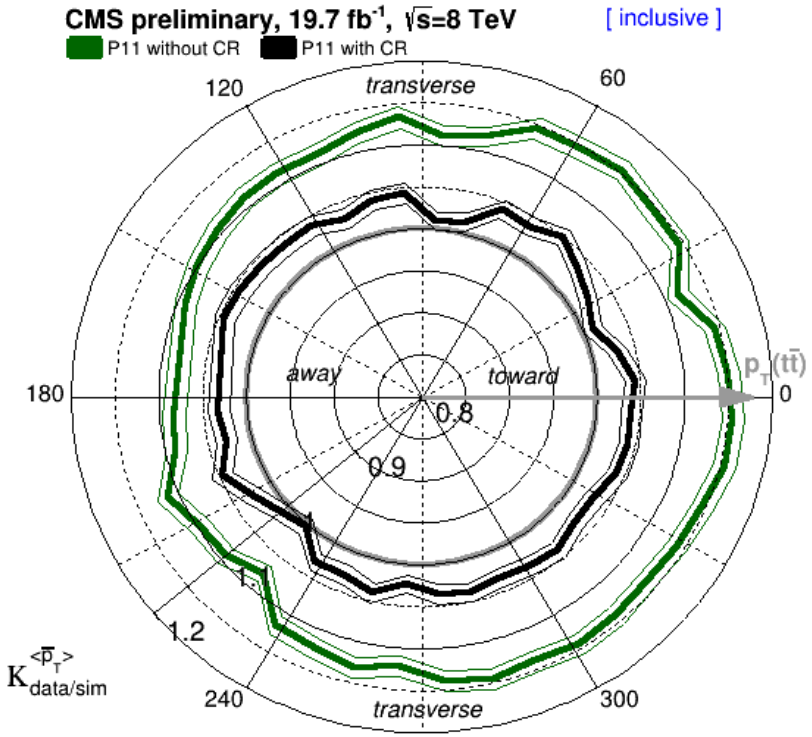




CR effects in top pair events

- For the **average p_T per particle** consider the **data/simulation ratio**
- Characterize as function of $p_T(tt)$ or as function of the event-by-event angle $\Delta\phi$

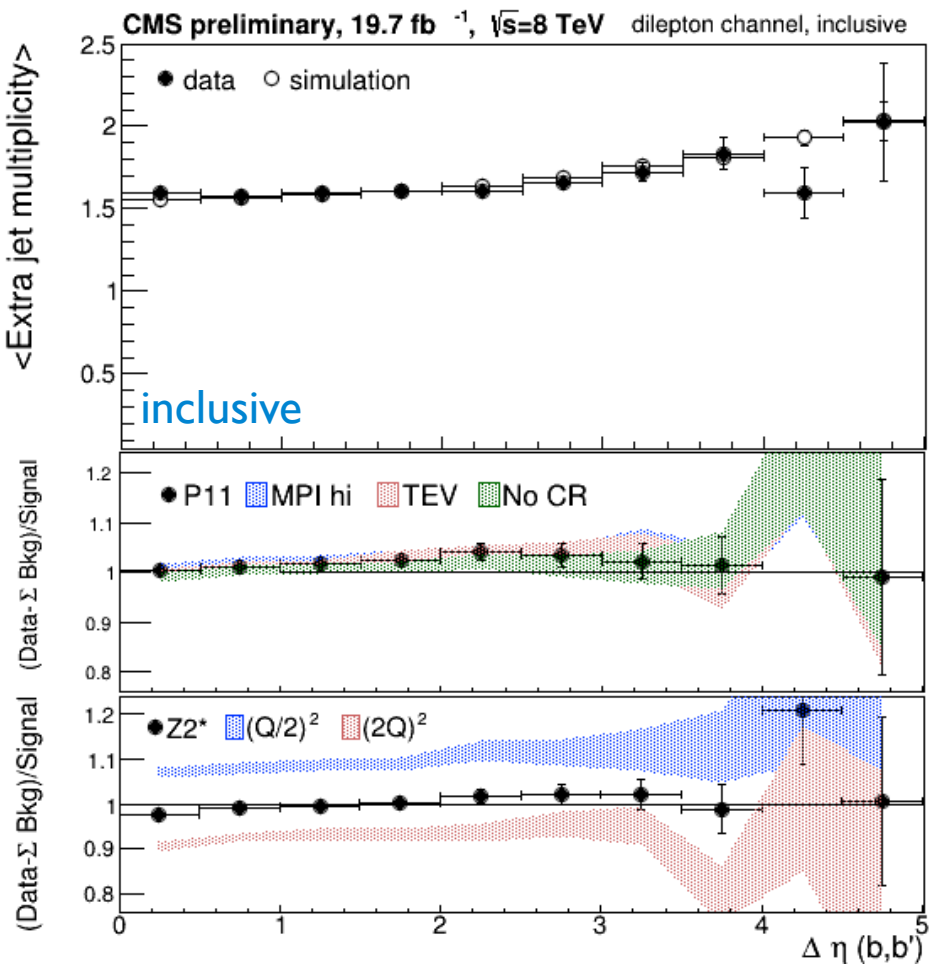


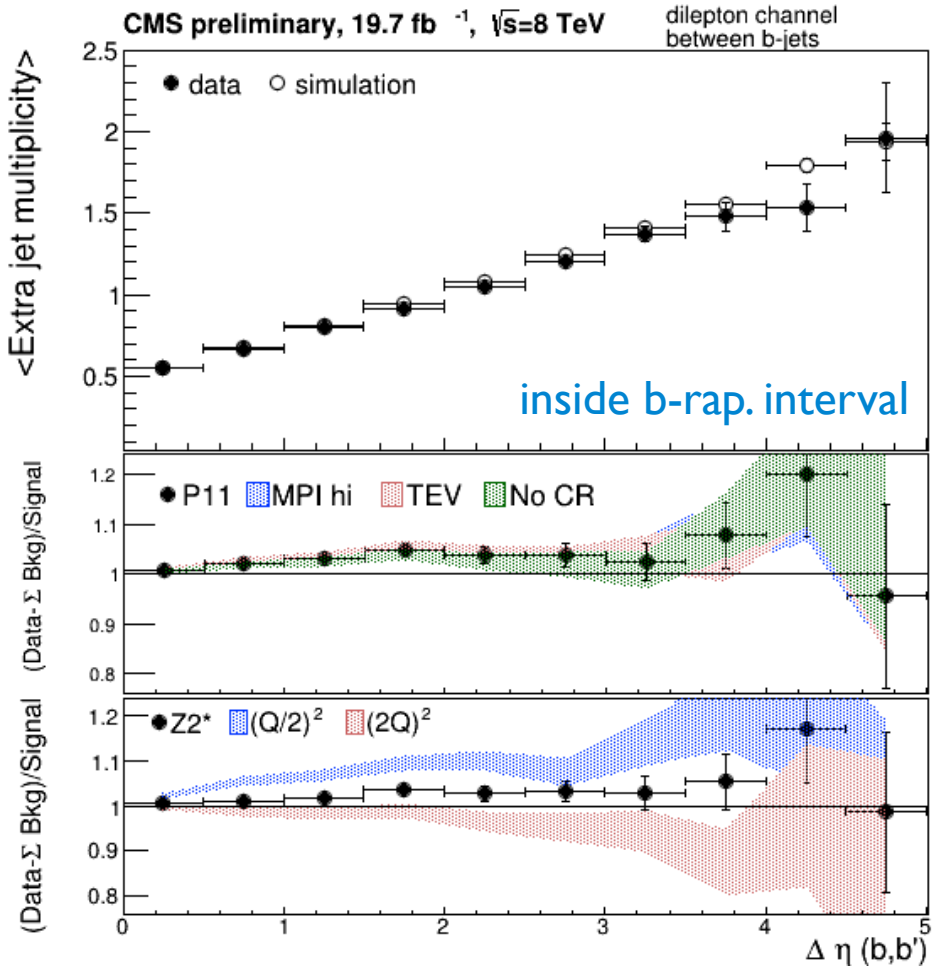


- **CR model is crucial**
  - when system is close to rest
  - along the tt direction
- <u>What is being tested with noCR?</u>

b-rapidity-interval related effects

- **Counting extra jets** (p_T>20 GeV) inclusively or inside the b-rapidity interval
  - **no sensitivity to CR** : mostly dependent on QCD scale choice
  - good agreement with the default choice in Madgraph+Pythia6





(Intermediate) conclusions - II

- **We have mapped the "proton footprint" in top quark events**

- **Fair agreement is found with MinBias-derived tune**
  - Madgraph+Pythia6 Z2* based
  - Extreme models do not describe the data and offer conservative envelopes

- **Colour reconnection effects (Pythia model)**
  - "CR on" confirmed in top pair events: pronounced for systems at rest and along tt direction
  - "CR off" is excluded by the data
  - Observed effect CR on/off for top mass generally small (<0.1 GeV in the latest measurements)
  - is CR on/off, with a single tune, ending its days in m_{top} analysis ?
  - shouldn't we look at other models? attempt to trace an emerging pattern from comparison?

Summary

Trying to understand our m_{top} measurements we have probed top quark events as Pollock would:

"*the strangeness will wear off and I think we will discover the deeper meanings...*".

We aim to have a better understanding of the fine details in a near future.

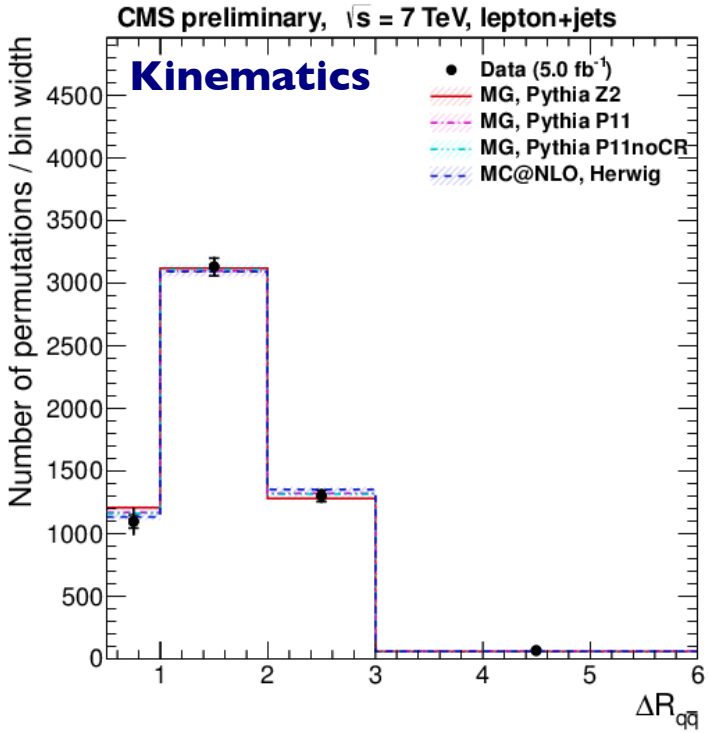
Summary

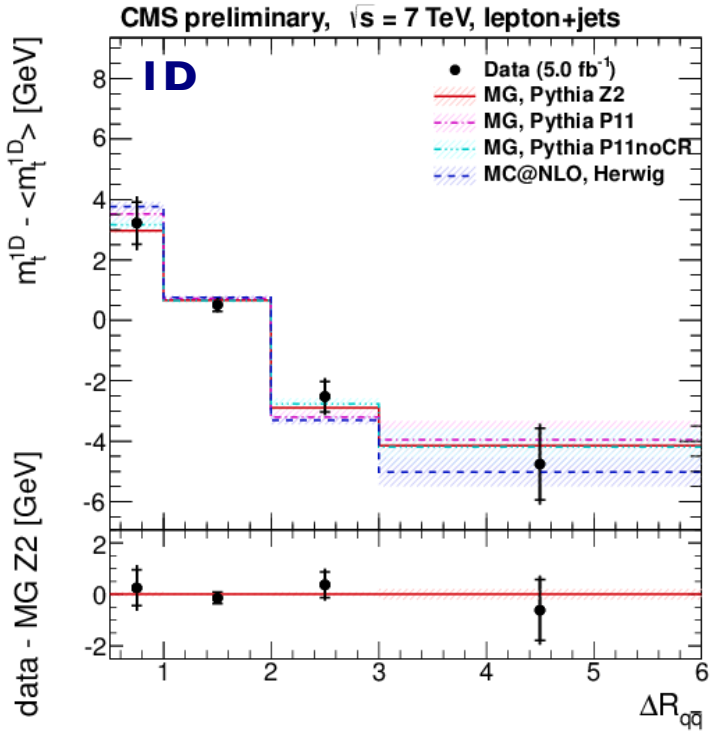
- **"Standard" mass measurements adopt the MC definition of m_{top}**
  - 0.73 GeV uncertainty (0.43% m_{top}) ~ 4 Λ_{QCD} !
  - inclusive phase-space calibration is performed
  - robustness tested against different theory models and experimental uncertainties

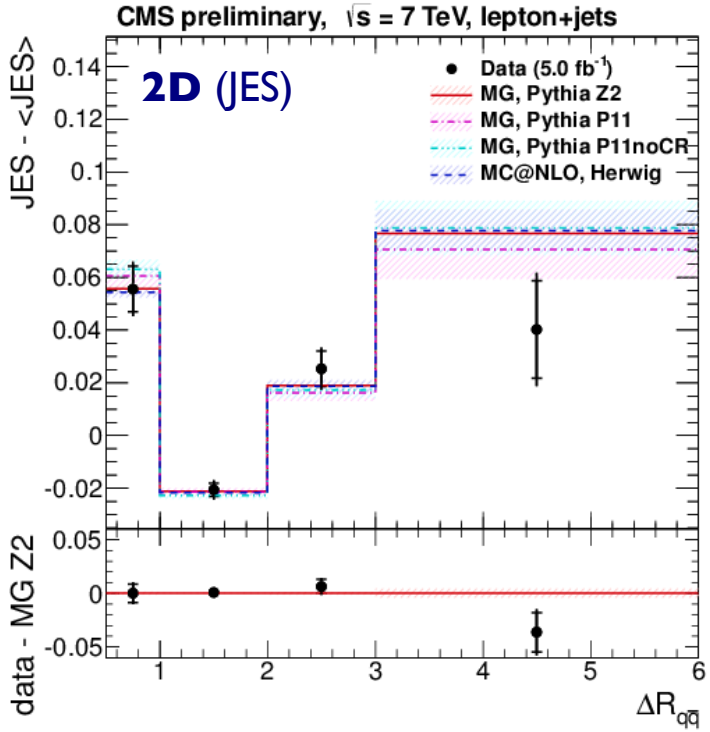
- **Data can be used to image in finer detail a top quark event**
  - differential measurements do not reveal significant biases for different variables
  - UE studies show evidence for colour reconnection effects in top pairs

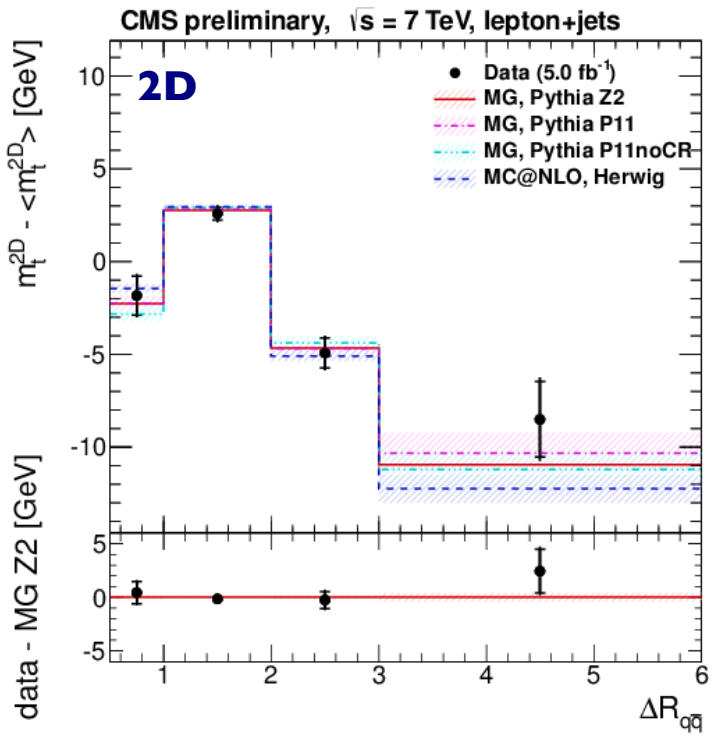
- Strategy for **future m_{top} measurements should consider these approaches**
  - show consistency of top mass definition with your favorite MC
  - constrain/exclude in-situ some of the uncertainties

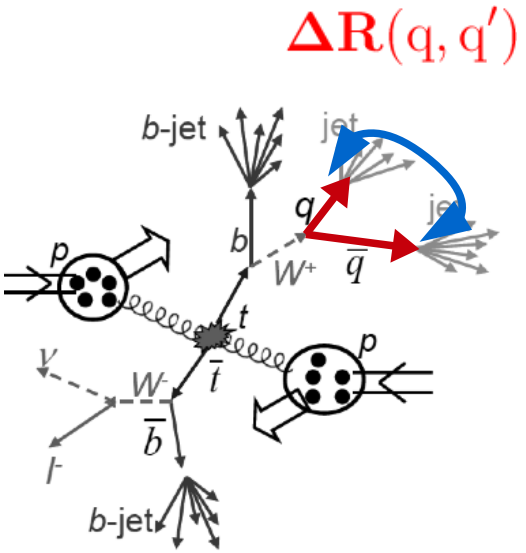
Backup

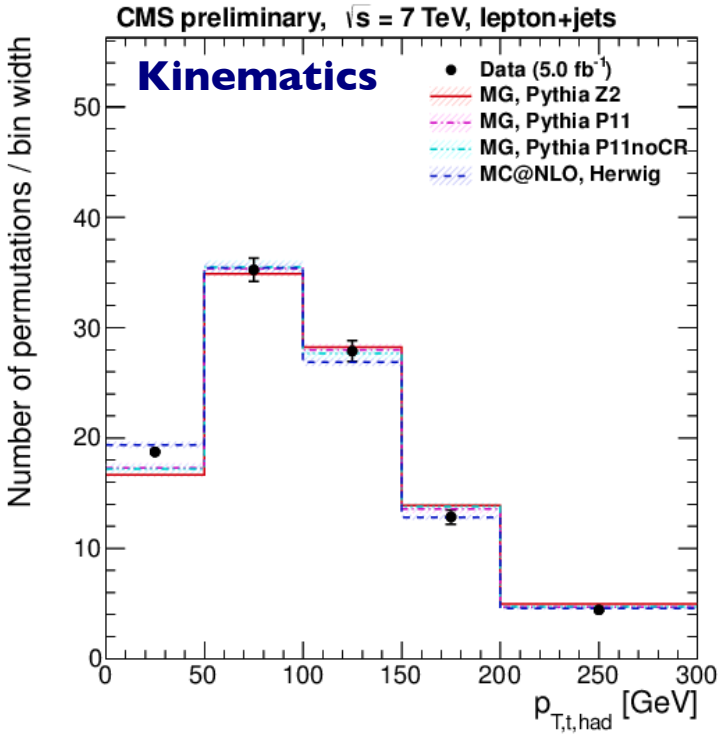

CMS preliminary, √s = 7 TeV, lepton+jets
Kinematics
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig
Number of permutations / bin width
ΔRqq̄

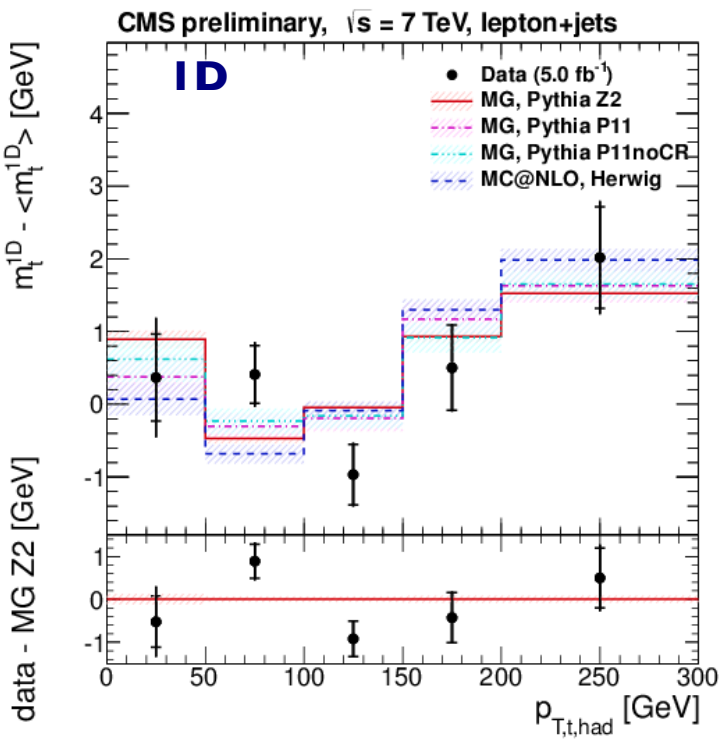

CMS preliminary, √s = 7 TeV, lepton+jets
1D
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig
m1D - <m1D> [GeV]
data - MG Z2 [GeV]
ΔRqq̄

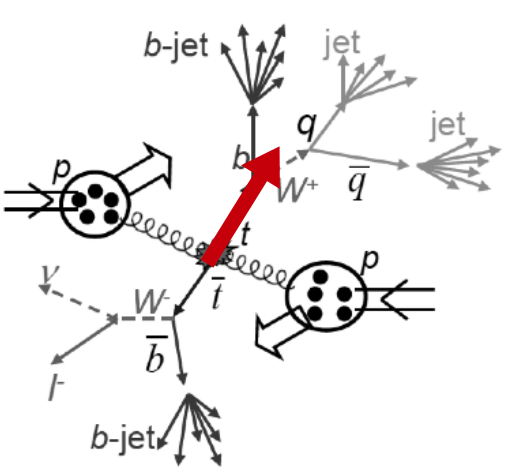

CMS preliminary, √s = 7 TeV, lepton+jets
2D (JES)
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig
JES - <JES>
data - MG Z2
ΔRqq̄

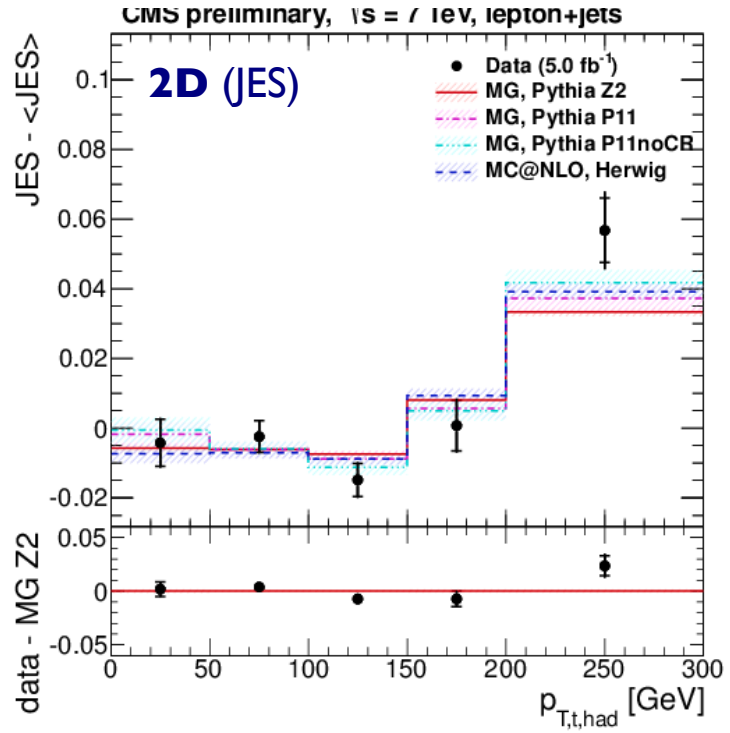

CMS preliminary, √s = 7 TeV, lepton+jets
2D
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig
m2D - <m2D> [GeV]
data - MG Z2 [GeV]
ΔRqq̄

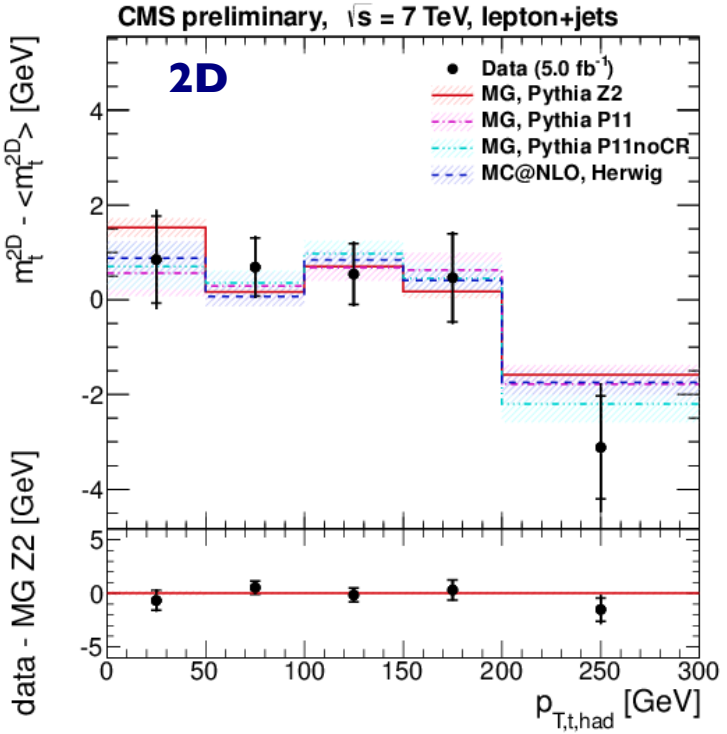

ΔR(q, q′)
b-jet
jet
q
jet
b
W+
q̄
p
t
p
ν
W-
t̄
b̄
l-
b-jet

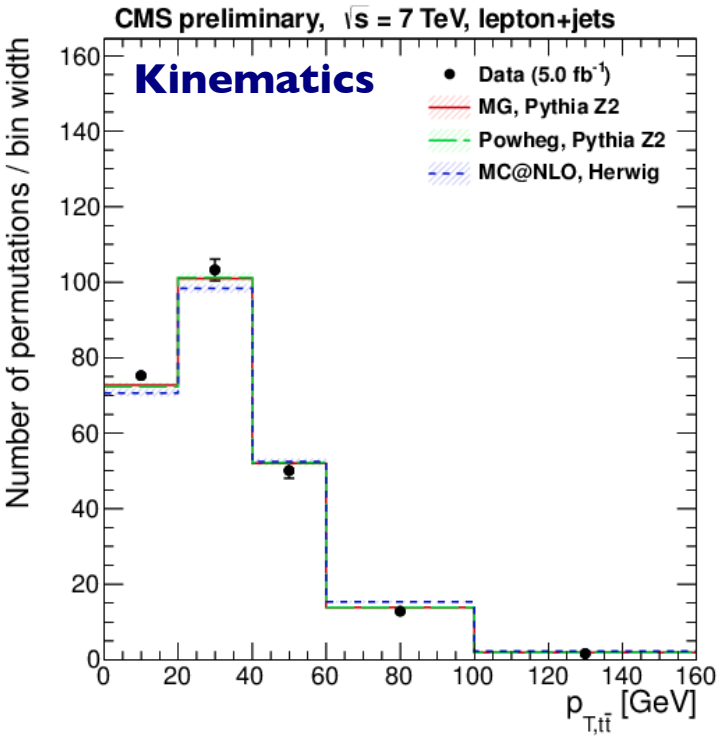

CMS preliminary, √s = 7 TeV, lepton+jets
Kinematics
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig
Number of permutations / bin width
pT,t,had [GeV]

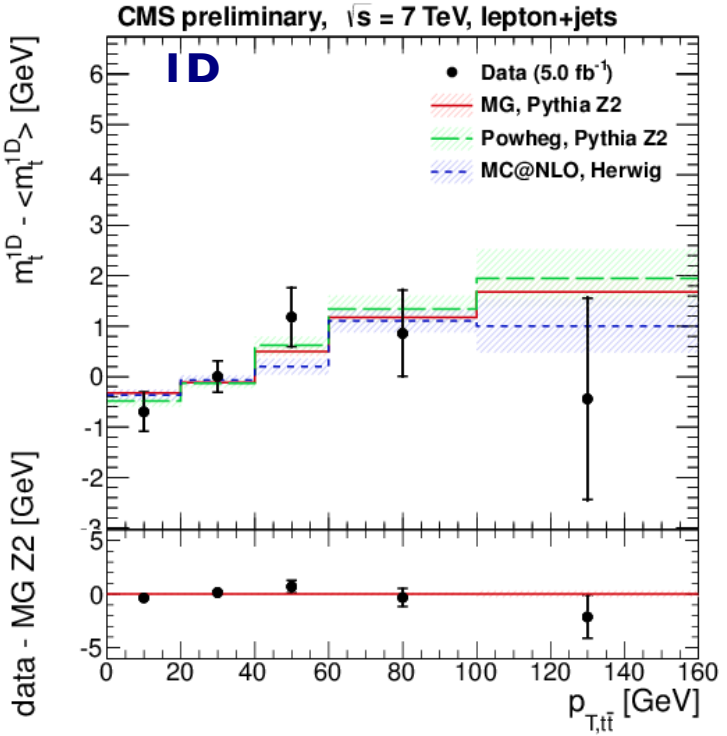

CMS preliminary, √s = 7 TeV, lepton+jets
1D
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig
m1D t - <m1D t> [GeV]
data - MG Z2 [GeV]
pT,t,had [GeV]

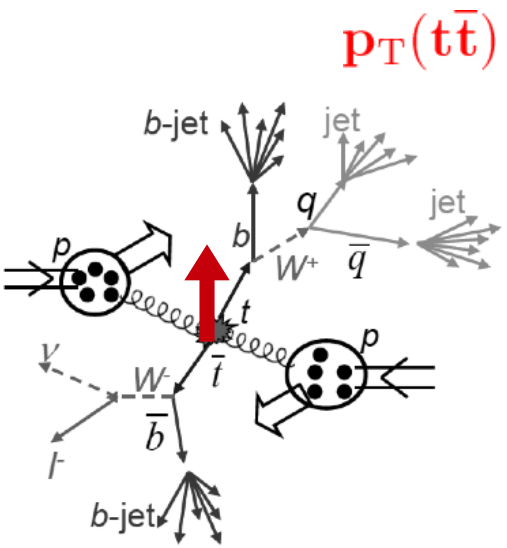

pT(t had.)
b-jet
jet
q
jet
p
b
W+
q̄
t
p
ν
W-
t̄
b̄
l-
b-jet

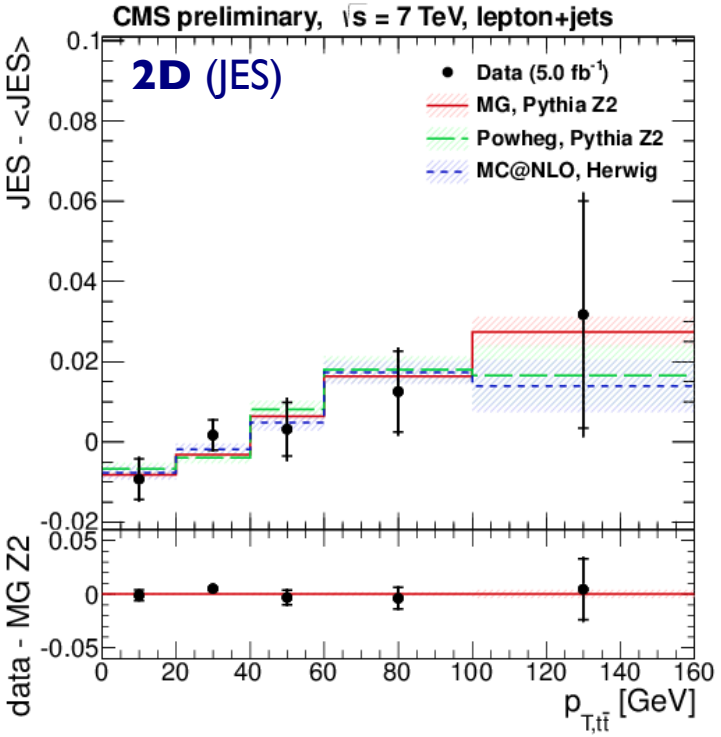

CMS preliminary, √s = 7 TeV, lepton+jets
2D (JES)
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig
JES - <JES>
data - MG Z2
pT,t,had [GeV]

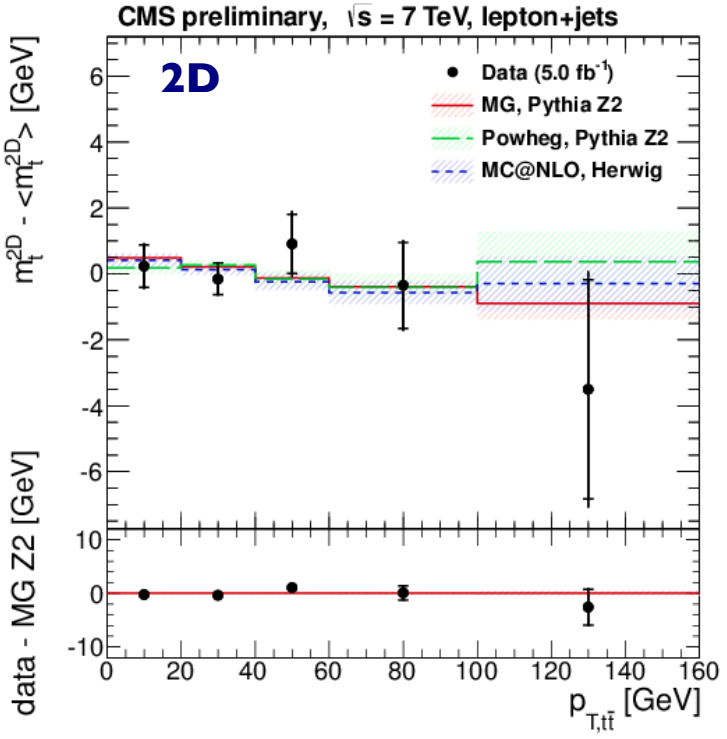

CMS preliminary, √s = 7 TeV, lepton+jets
2D
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
MC@NLO, Herwig
m2D t - <m2D t> [GeV]
data - MG Z2 [GeV]
pT,t,had [GeV]

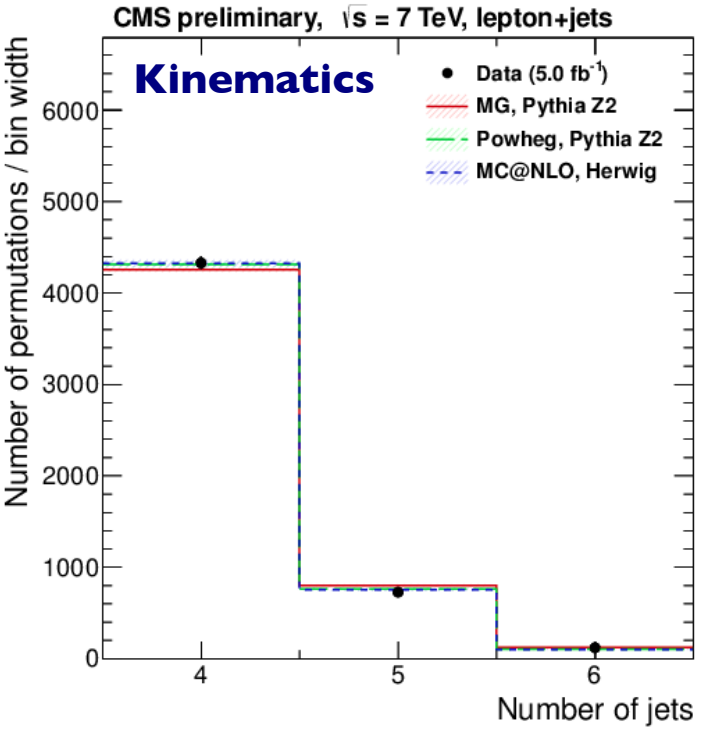

CMS preliminary, √s = 7 TeV, lepton+jets
Kinematics
Data (5.0 fb-1)
MG, Pythia Z2
Powheg, Pythia Z2
MC@NLO, Herwig
Number of permutations / bin width
p T,tt̄ [GeV]

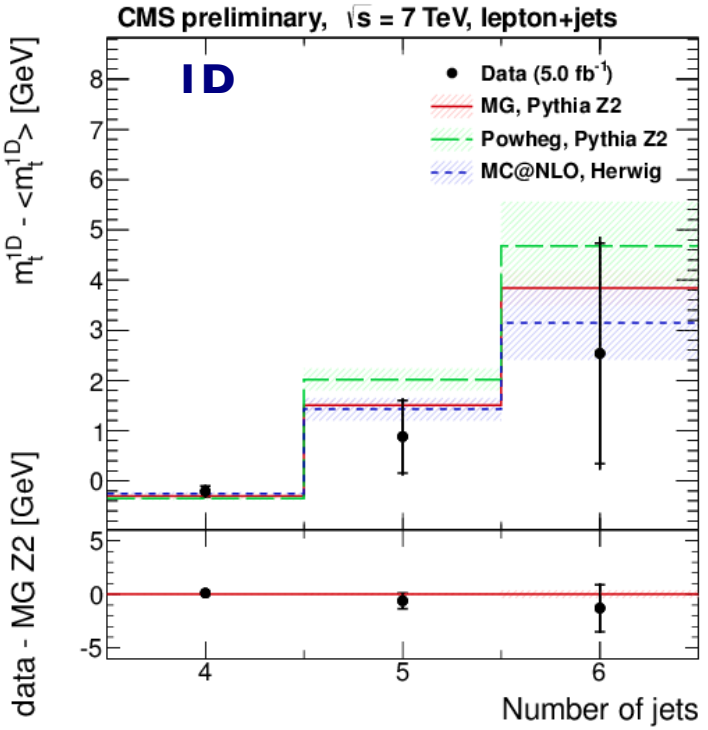

CMS preliminary, √s = 7 TeV, lepton+jets
1D
Data (5.0 fb-1)
MG, Pythia Z2
Powheg, Pythia Z2
MC@NLO, Herwig
m t 1D - <m t 1D> [GeV]
data - MG Z2 [GeV]
p T,tt̄ [GeV]

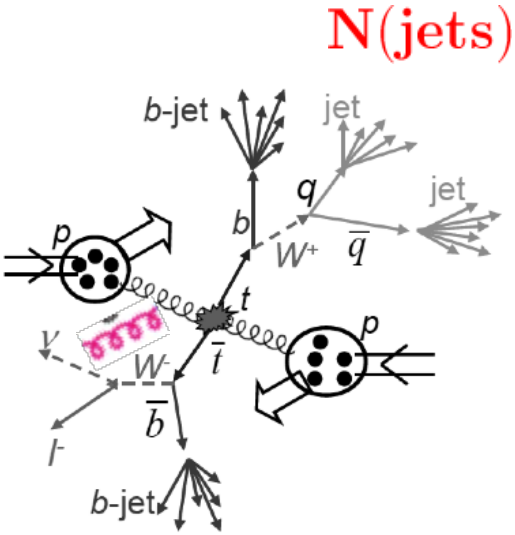

pT(tt̄)
b-jet
jet
q
jet
b
p
W+
q̄
t
p
ν
W-
t̄
b̄
l-
b-jet

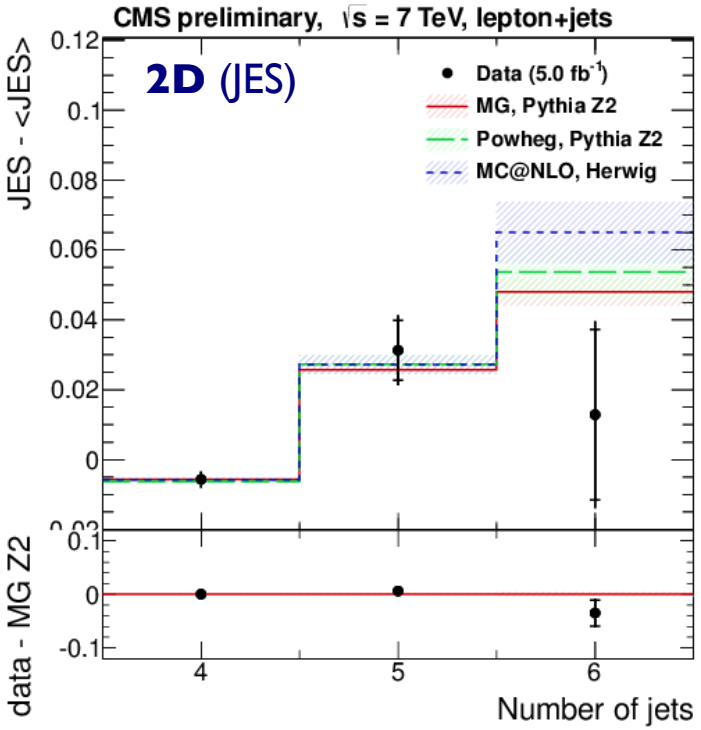

CMS preliminary, √s = 7 TeV, lepton+jets
2D (JES)
Data (5.0 fb-1)
MG, Pythia Z2
Powheg, Pythia Z2
MC@NLO, Herwig
JES - <JES>
data - MG Z2
p T,tt̄ [GeV]

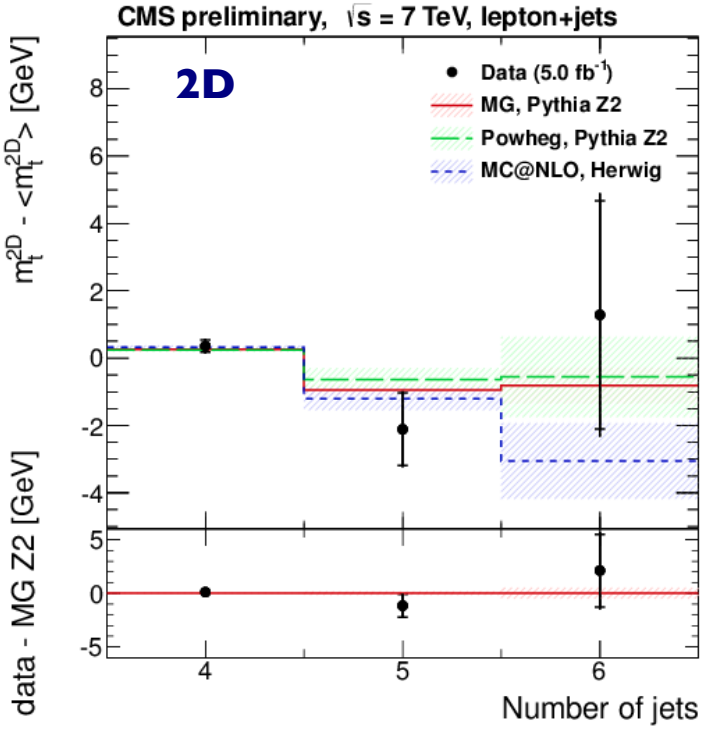

CMS preliminary, √s = 7 TeV, lepton+jets
2D
Data (5.0 fb-1)
MG, Pythia Z2
Powheg, Pythia Z2
MC@NLO, Herwig
m t 2D - <m t 2D> [GeV]
data - MG Z2 [GeV]
p T,tt̄ [GeV]

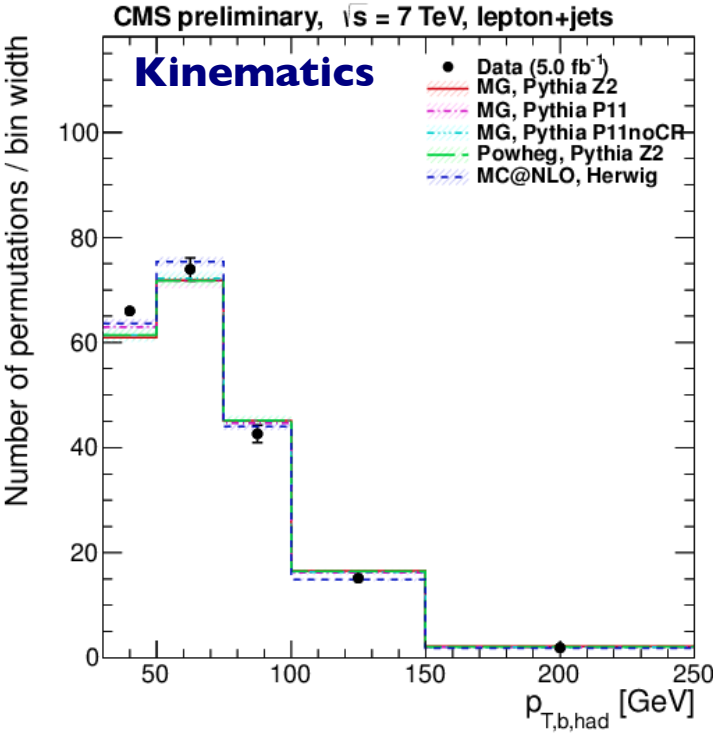

CMS preliminary, √s = 7 TeV, lepton+jets
Kinematics
Data (5.0 fb-1)
MG, Pythia Z2
Powheg, Pythia Z2
MC@NLO, Herwig
Number of permutations / bin width
Number of jets

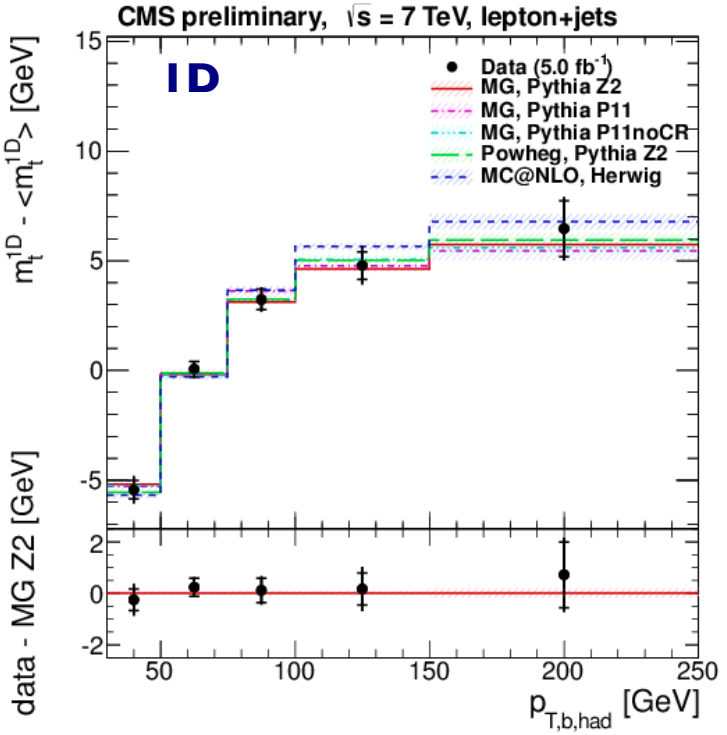

CMS preliminary, √s = 7 TeV, lepton+jets
1D
Data (5.0 fb-1)
MG, Pythia Z2
Powheg, Pythia Z2
MC@NLO, Herwig
m_t^1D - <m_t^1D> [GeV]
data - MG Z2 [GeV]
Number of jets

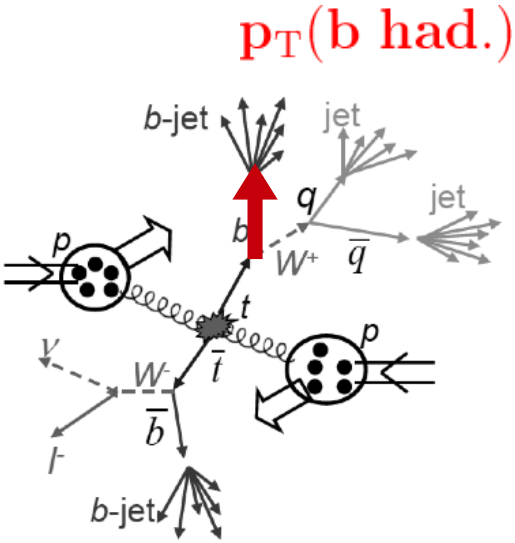

N(jets)
b-jet
jet
q
jet
b
p
W+
q̄
t
ν
W-
t̄
p
b̄
l-
b-jet

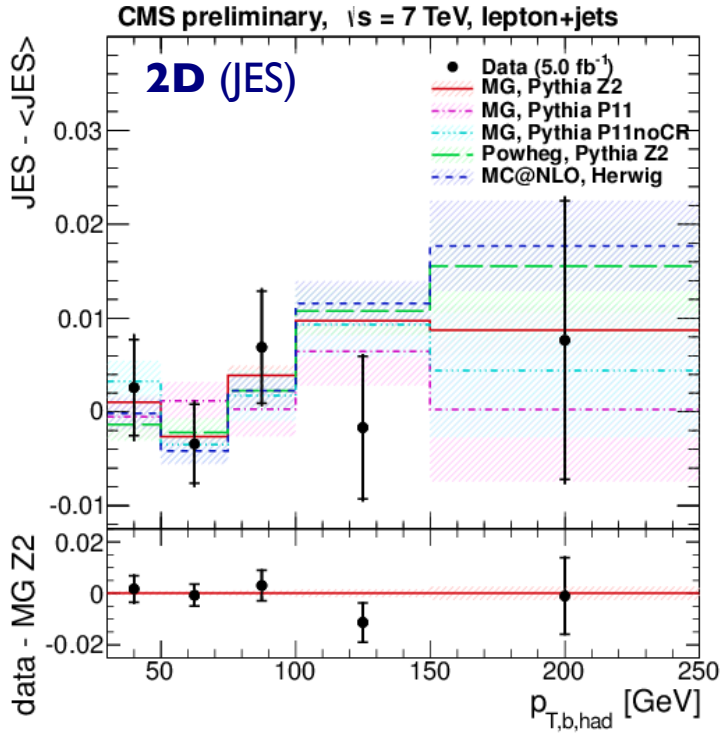

CMS preliminary, √s = 7 TeV, lepton+jets
2D (JES)
Data (5.0 fb-1)
MG, Pythia Z2
Powheg, Pythia Z2
MC@NLO, Herwig
JES - <JES>
data - MG Z2
Number of jets

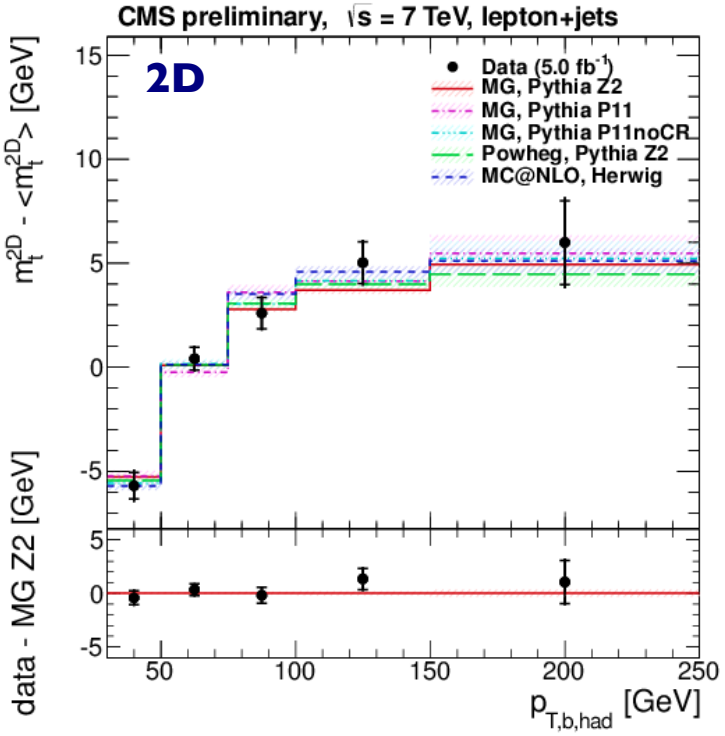

CMS preliminary, √s = 7 TeV, lepton+jets
2D
Data (5.0 fb-1)
MG, Pythia Z2
Powheg, Pythia Z2
MC@NLO, Herwig
m_t^2D - <m_t^2D> [GeV]
data - MG Z2 [GeV]
Number of jets

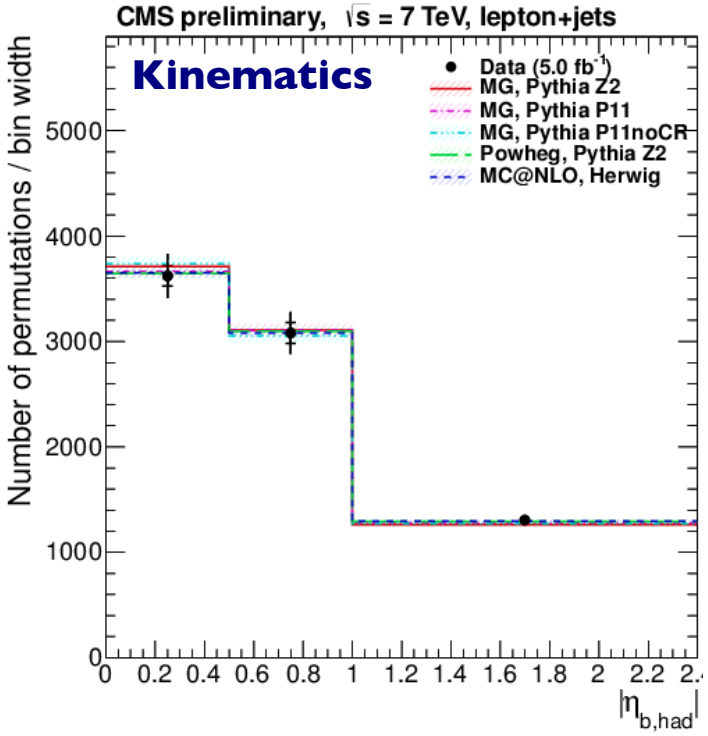

CMS preliminary, √s = 7 TeV, lepton+jets
Kinematics
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
Number of permutations / bin width
p_T,b,had [GeV]

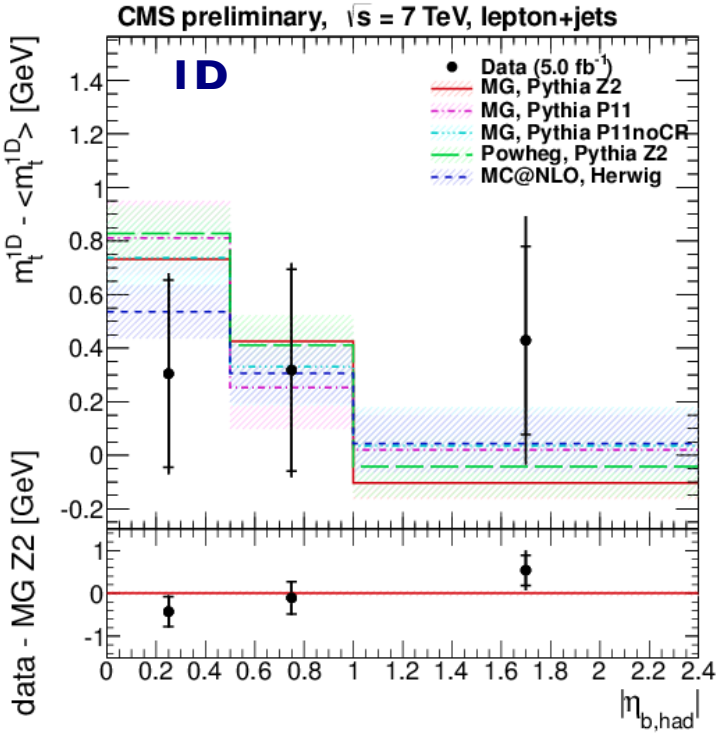

CMS preliminary, √s = 7 TeV, lepton+jets
1D
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
m_t^1D - <m_t^1D> [GeV]
data - MG Z2 [GeV]
p_T,b,had [GeV]

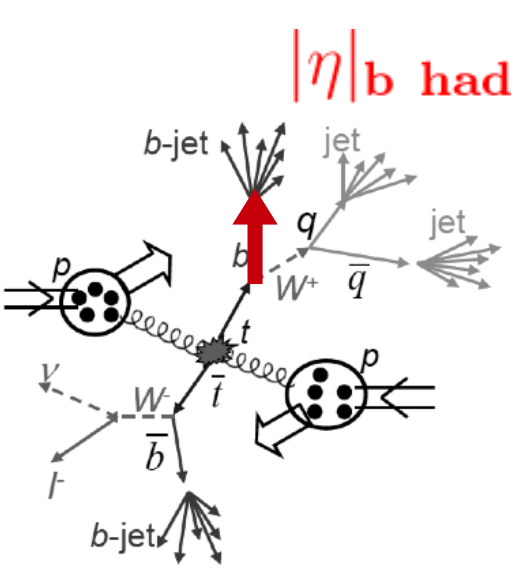

p_T(b had.)
b-jet
jet
q
jet
b
W+
q̄
p
t
p
ν
W-
t̄
b̄
l-
b-jet

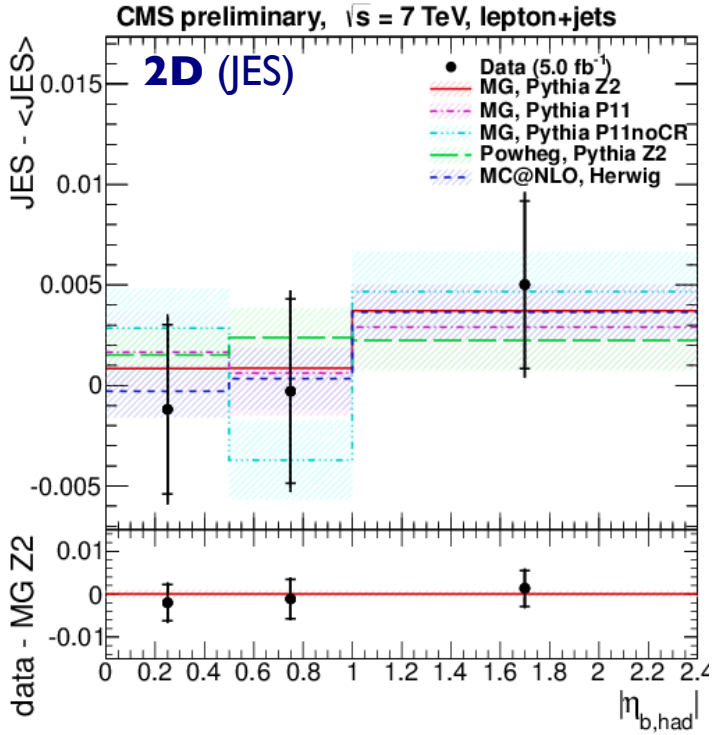

CMS preliminary, √s = 7 TeV, lepton+jets
2D (JES)
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
JES - <JES>
data - MG Z2
p_T,b,had [GeV]

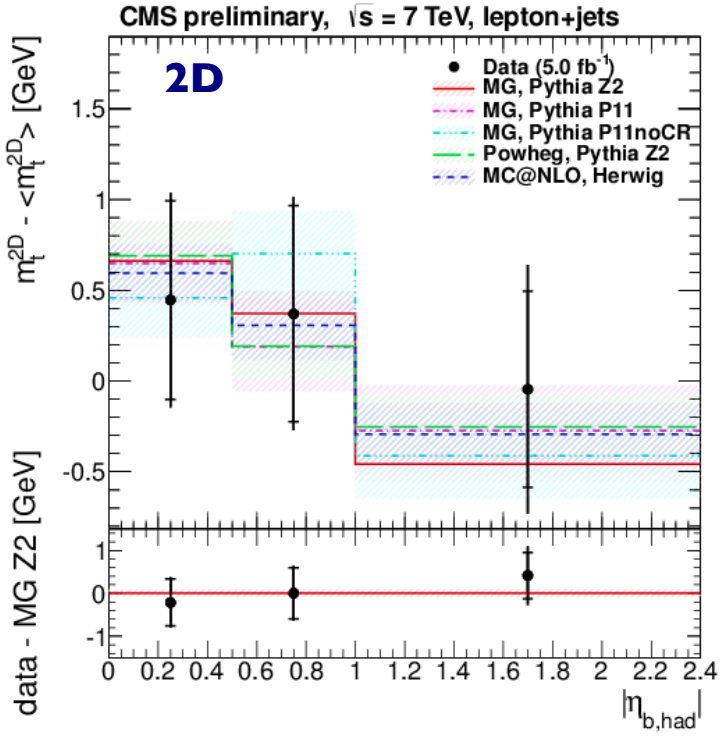

CMS preliminary, √s = 7 TeV, lepton+jets
2D
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
m_t^2D - <m_t^2D> [GeV]
data - MG Z2 [GeV]
p_T,b,had [GeV]

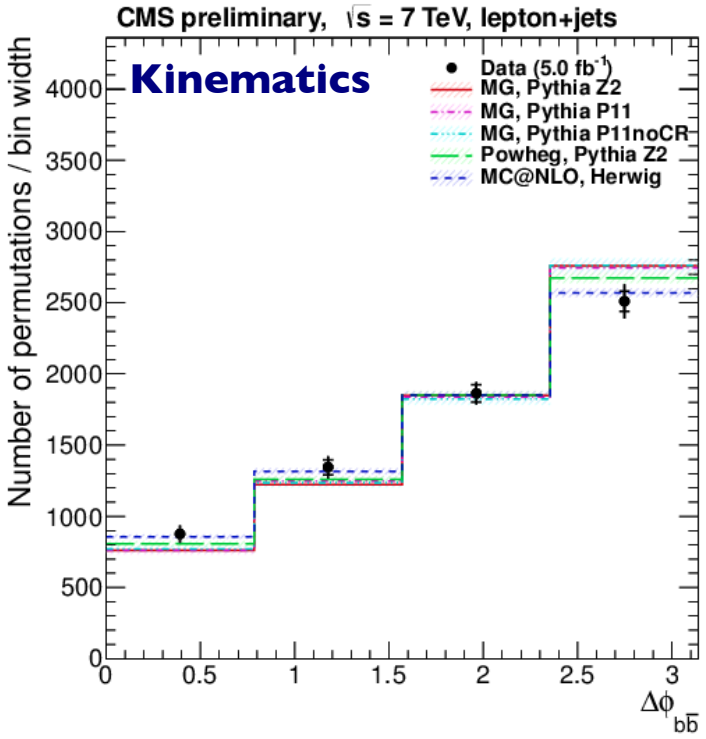

CMS preliminary, √s = 7 TeV, lepton+jets
Kinematics
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
Number of permutations / bin width
|η b,had|

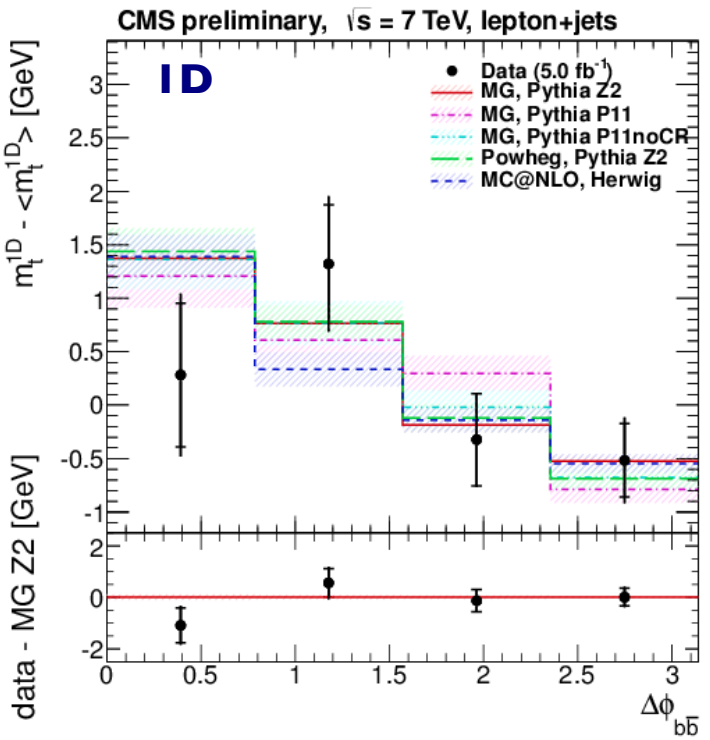

CMS preliminary, √s = 7 TeV, lepton+jets
1D
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
m1D t - <m1D t> [GeV]
data - MG Z2 [GeV]
|η b,had|

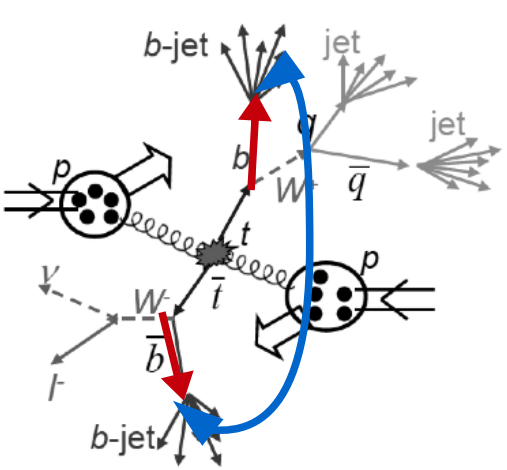

|η| b had
b-jet
jet
jet
q
b
W+
q̄
p
t
p
ν
W-
t̄
b̄
l-
b-jet

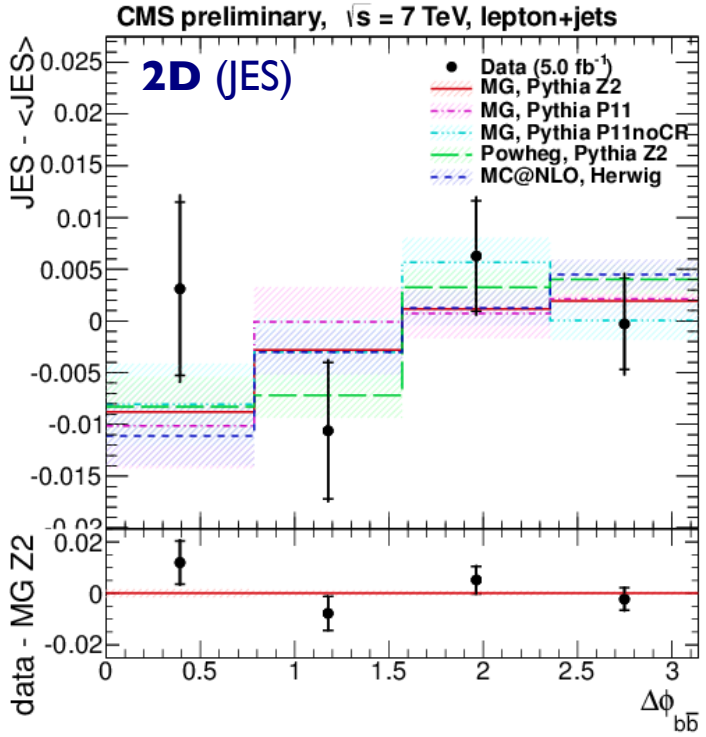

CMS preliminary, √s = 7 TeV, lepton+jets
2D (JES)
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
JES - <JES>
data - MG Z2
|η b,had|

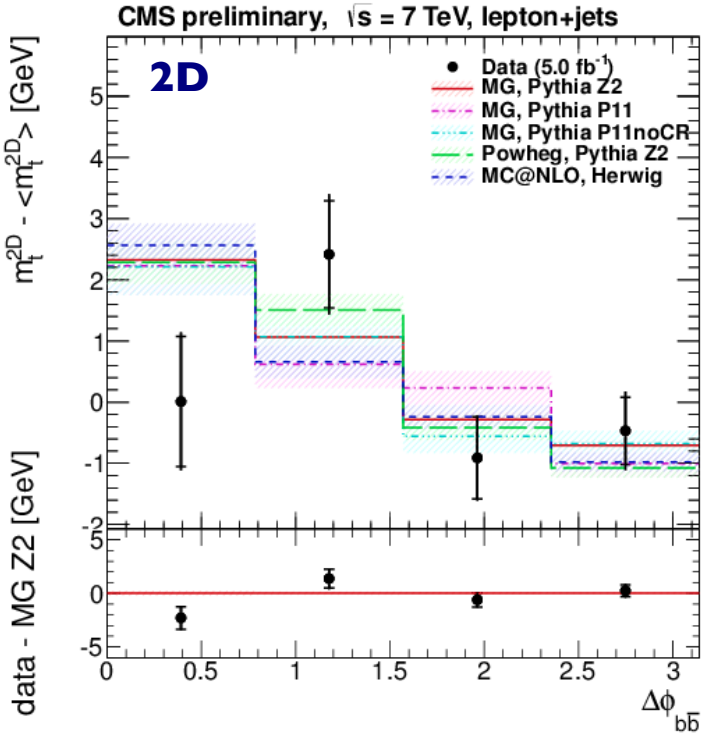

CMS preliminary, √s = 7 TeV, lepton+jets
2D
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
m2D t - <m2D t> [GeV]
data - MG Z2 [GeV]
|η b,had|


CMS preliminary, √s = 7 TeV, lepton+jets
Kinematics
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
Number of permutations / bin width
Δφ bb̄


CMS preliminary, √s = 7 TeV, lepton+jets
1D
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
m_t^1D - <m_t^1D> [GeV]
data - MG Z2 [GeV]
Δφ bb̄


Δφ(bb̄)
b-jet
jet
jet
p
b
q
W+
q̄
t
p
ν
W-
t̄
b̄
l-
b-jet


CMS preliminary, √s = 7 TeV, lepton+jets
2D (JES)
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
JES - <JES>
data - MG Z2
Δφ bb̄


CMS preliminary, √s = 7 TeV, lepton+jets
2D
Data (5.0 fb-1)
MG, Pythia Z2
MG, Pythia P11
MG, Pythia P11noCR
Powheg, Pythia Z2
MC@NLO, Herwig
m_t^2D - <m_t^2D> [GeV]
data - MG Z2 [GeV]
Δφ bb̄

Average p_T per particle