The impact of ttbar cross-section measurement with the first LHC data

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Impact of Top Quark ?

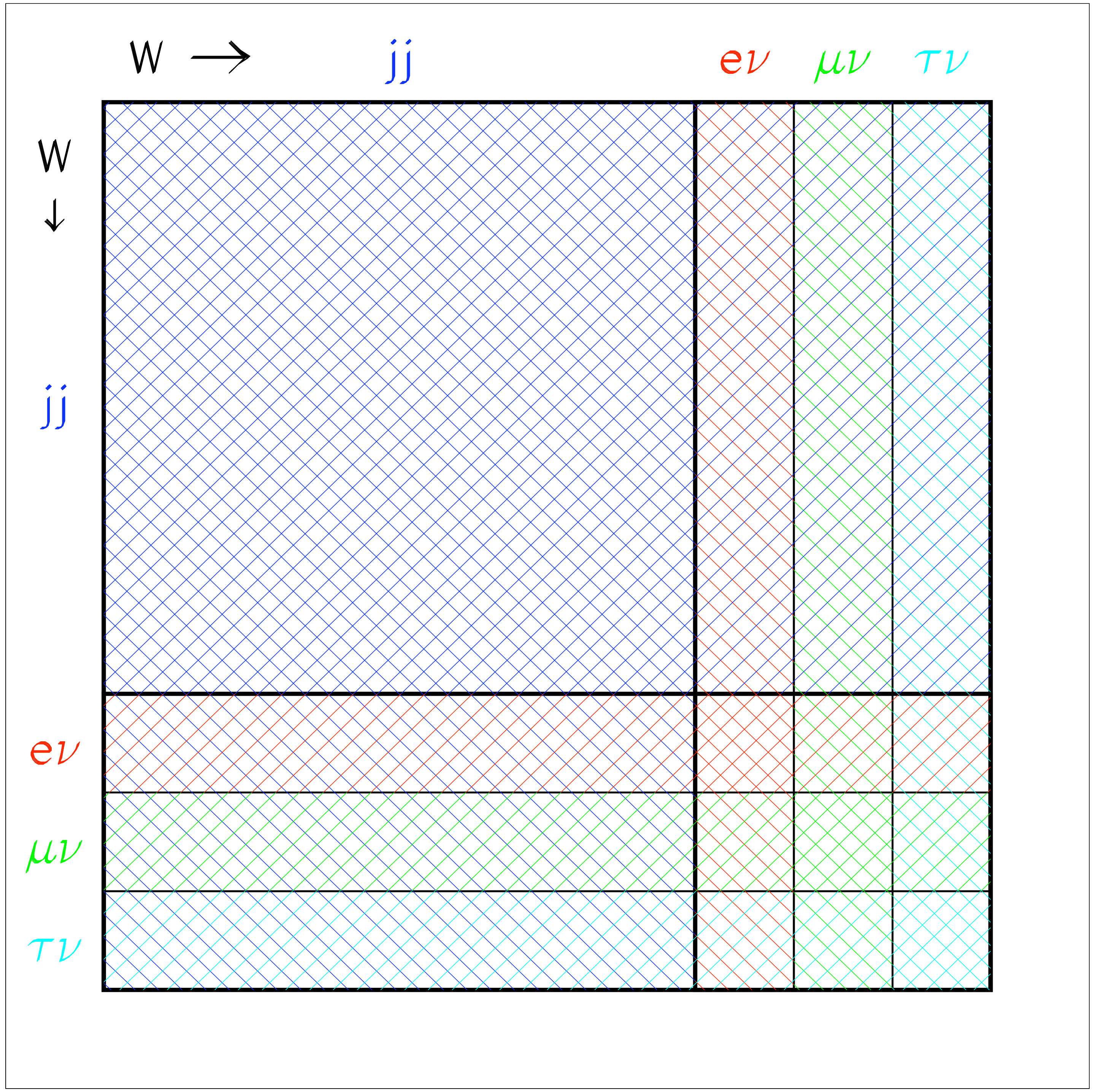
The top quark, when it was finally discovered at Fermilab in 1995, completed the three generation structure of the Standard Model (SM) and opened up the new field of top quark physics. Viewed as just another SM quark, the top quark appears to be a rather uninteresting species. Produced predominantly, in hadron-hadron collisions, through strong interactions, it decays rapidly without forming hadrons, and almost exclusively through the single mode $t \to Wb$. The relevant CKM coupling Vtb is already determined by the (three-generation) unitarity of the CKM matrix. Rare decays and CP violation are unmeasurably small in the SM. M.Beneke, I. Efthymiopoulos, M.L.Mangano, J.Womersley

What's in between?

Can Top change our perspective?

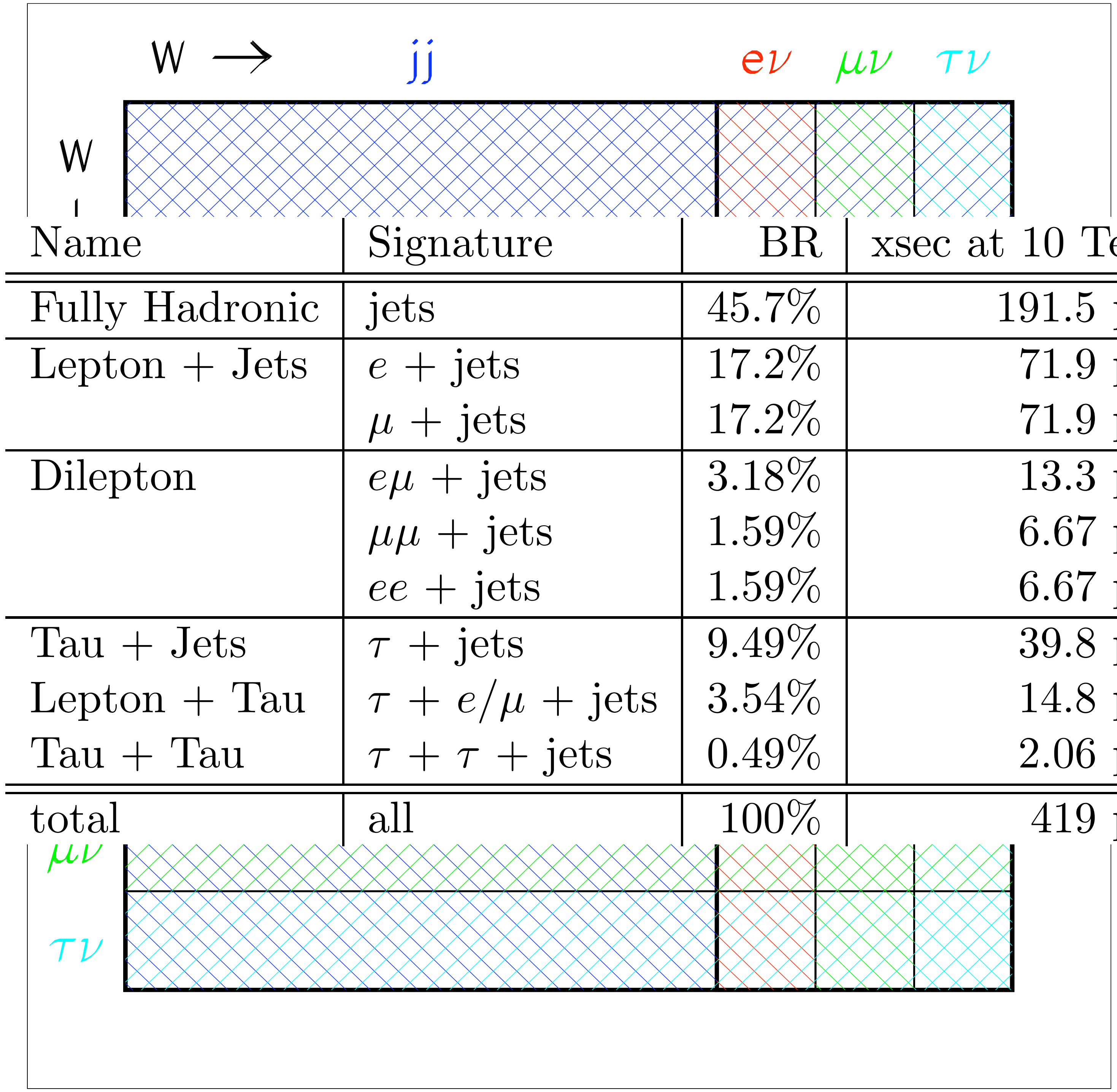
- Why is top so heavy (10 water molecules)? Any special role in EW symmetry breaking?
- Does it play even more fundamental role than Higgs mechanism + Yukawa coupling?
- If there is new physics signal lighter than top, does the top quark decay into them?
- Could non-SM physics first manifest itself in non-standard couplings of the top quark?
- Top quark can be measured at significant precision at the LHC to answer these questions.
- Top quark has been an ***extremely*** productive ground for speculation and searches at Tevatron.

New Physics via Top Decay



- Various decay modes make top physics interesting and useful
- The top interfere with a number of new physics signatures.
- Typical search modes:
  - Lepton + jets (e/mu)
  - Dileptonic
  - All hadronic
  - Tau channels
- E.g. If $m_W < m_{H+} < m_t$ and $\tan\beta >> 1$, top can decay into charged higgs, enhancing the τ lepton rate.

New Physics via Top Decay



Name	Signature	BR	xsec at 10 TeV
Fully Hadronic	jets	45.7%	191.5 pb
Lepton + Jets	e + jets	17.2%	71.9 pb
	μ + jets	17.2%	71.9 pb
Dilepton	$e\mu$ + jets	3.18%	13.3 pb
	$\mu\mu$ + jets	1.59%	6.67 pb
	ee + jets	1.59%	6.67 pb
Tau + Jets	τ + jets	9.49%	39.8 pb
Lepton + Tau	$\tau + e/\mu$ + jets	3.54%	14.8 pb
Tau + Tau	$\tau + \tau$ + jets	0.49%	2.06 pb
total	all	100%	419 pb

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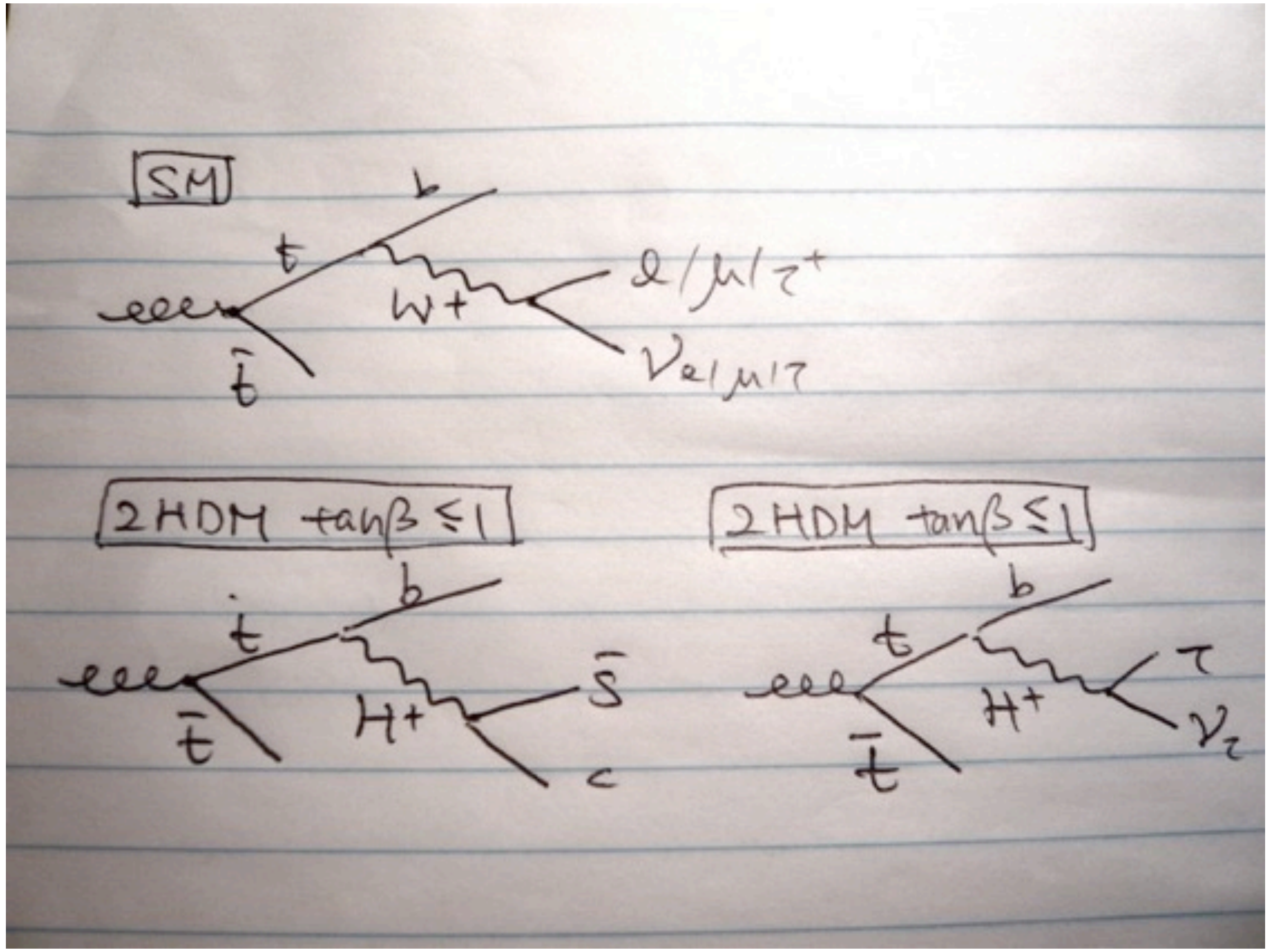
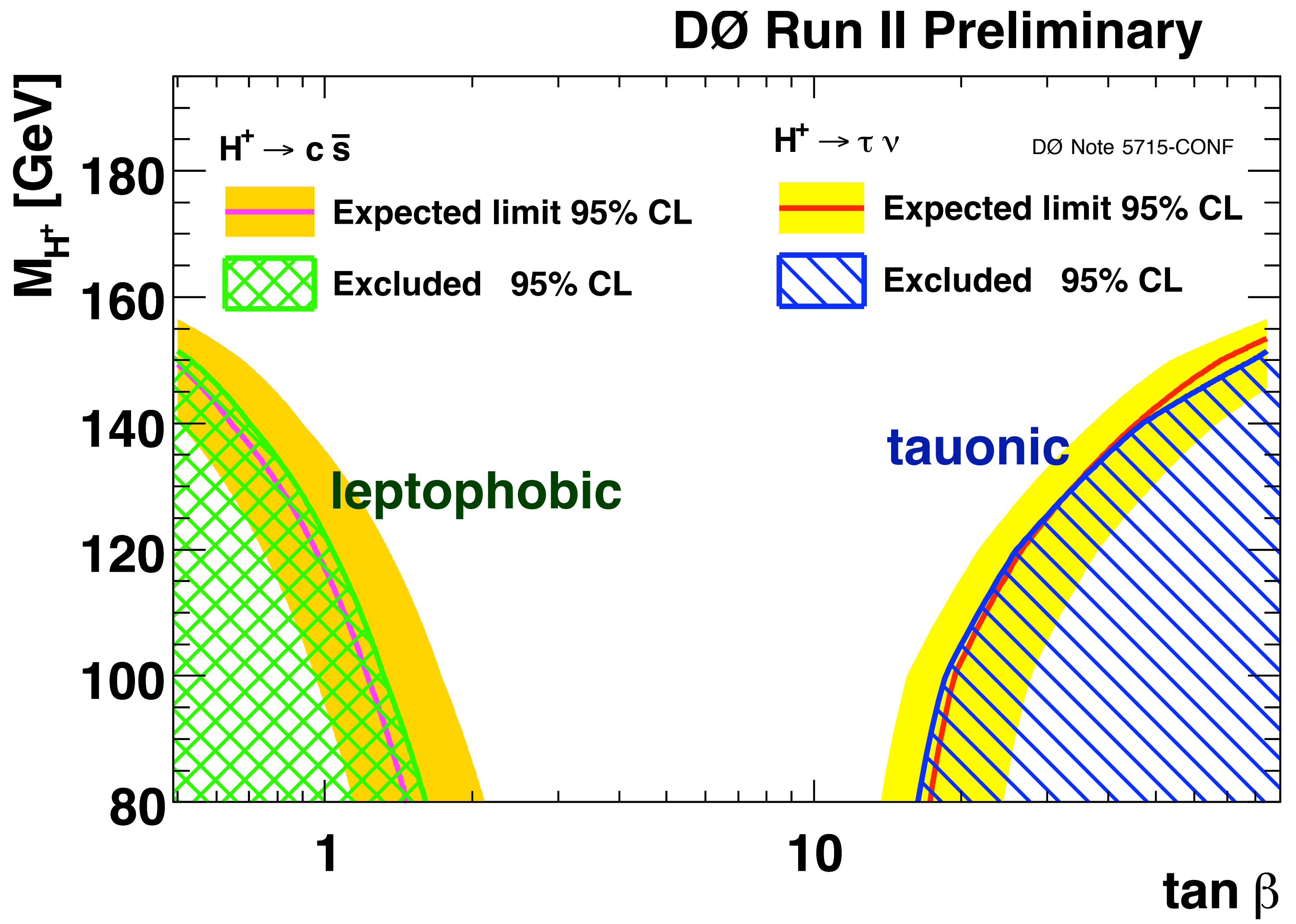
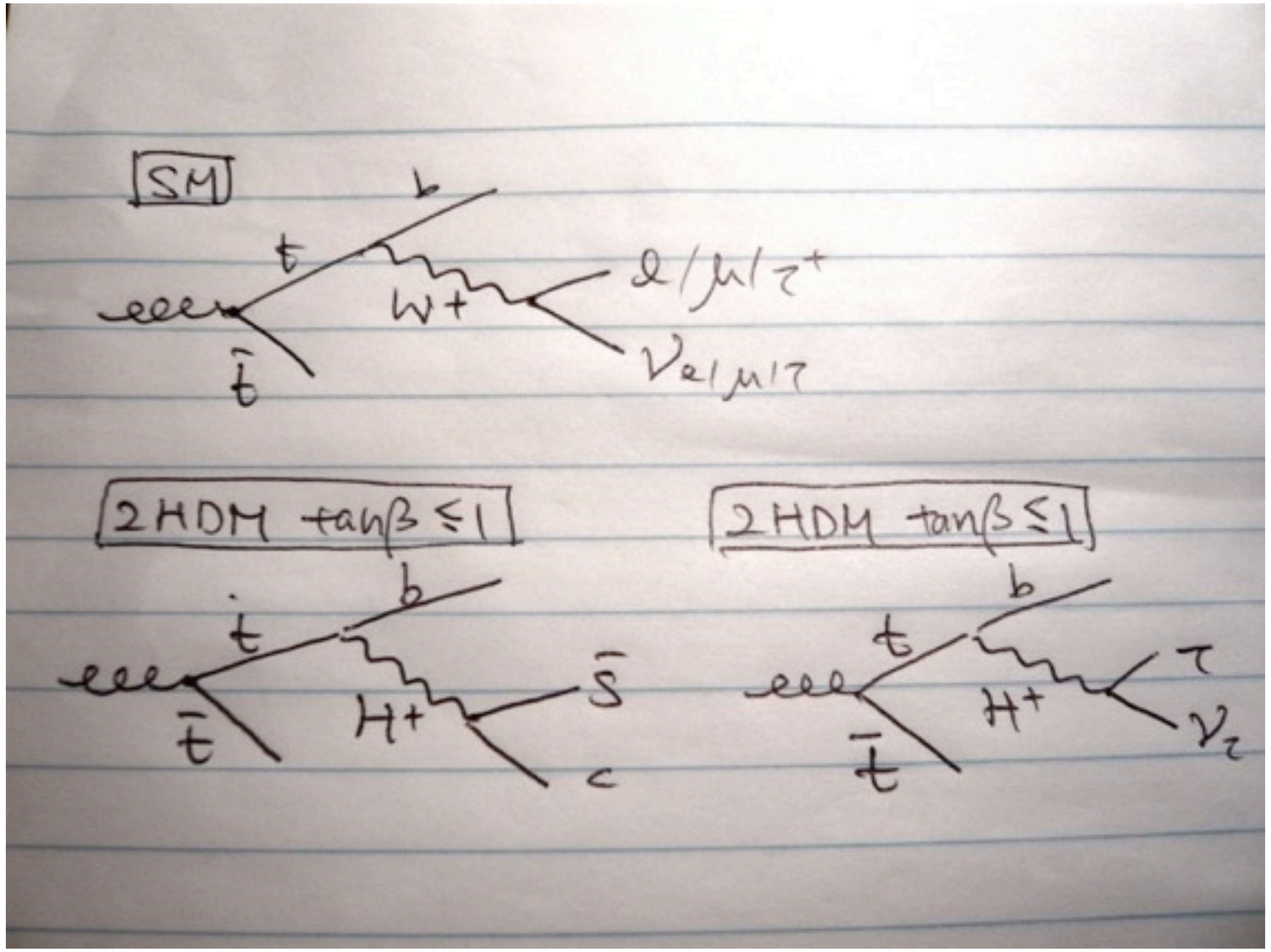
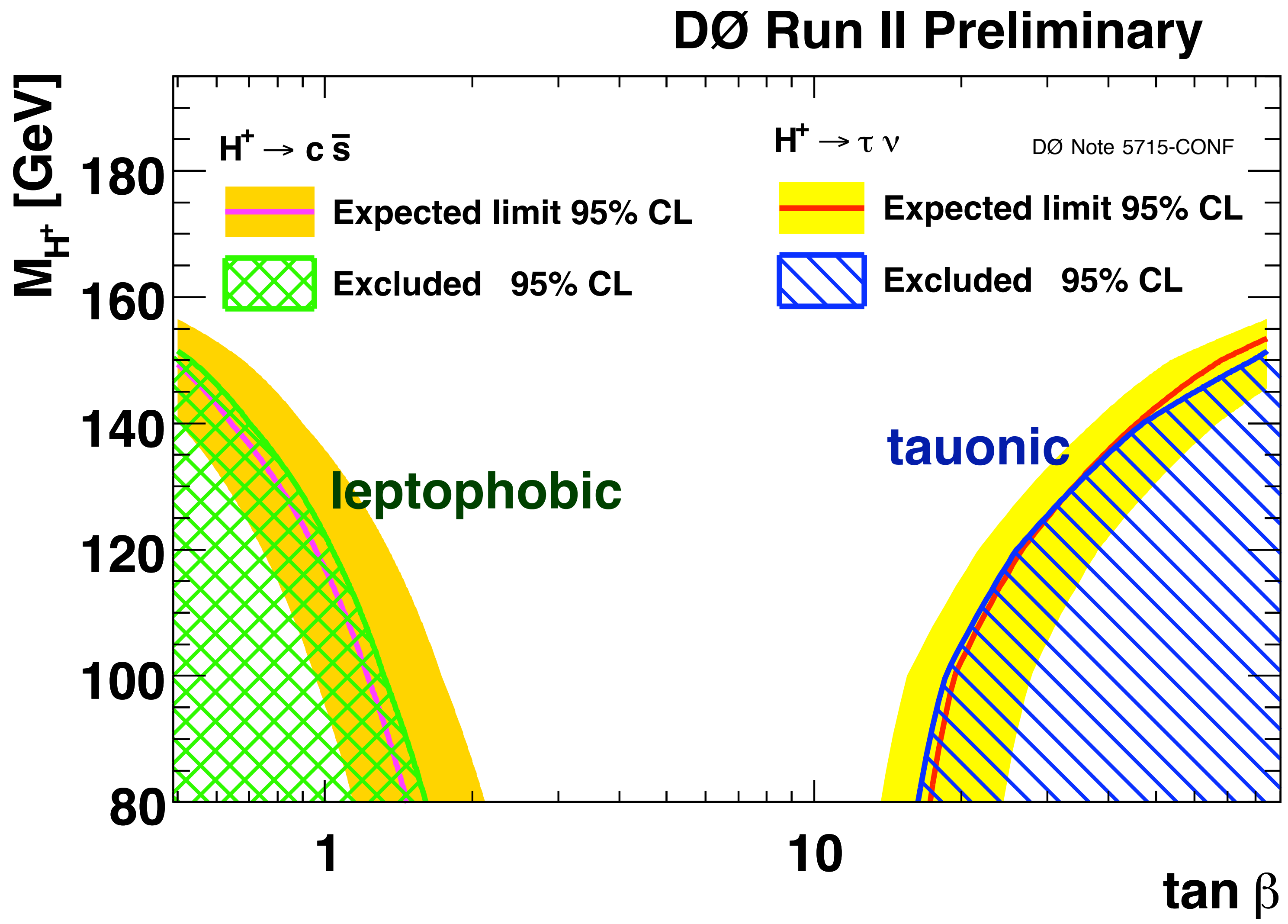
Search for Charged Higgs





Search for Charged Higgs





Good tau/jet calibration and background control is essential for this search.

Not a “Day-1 physics”

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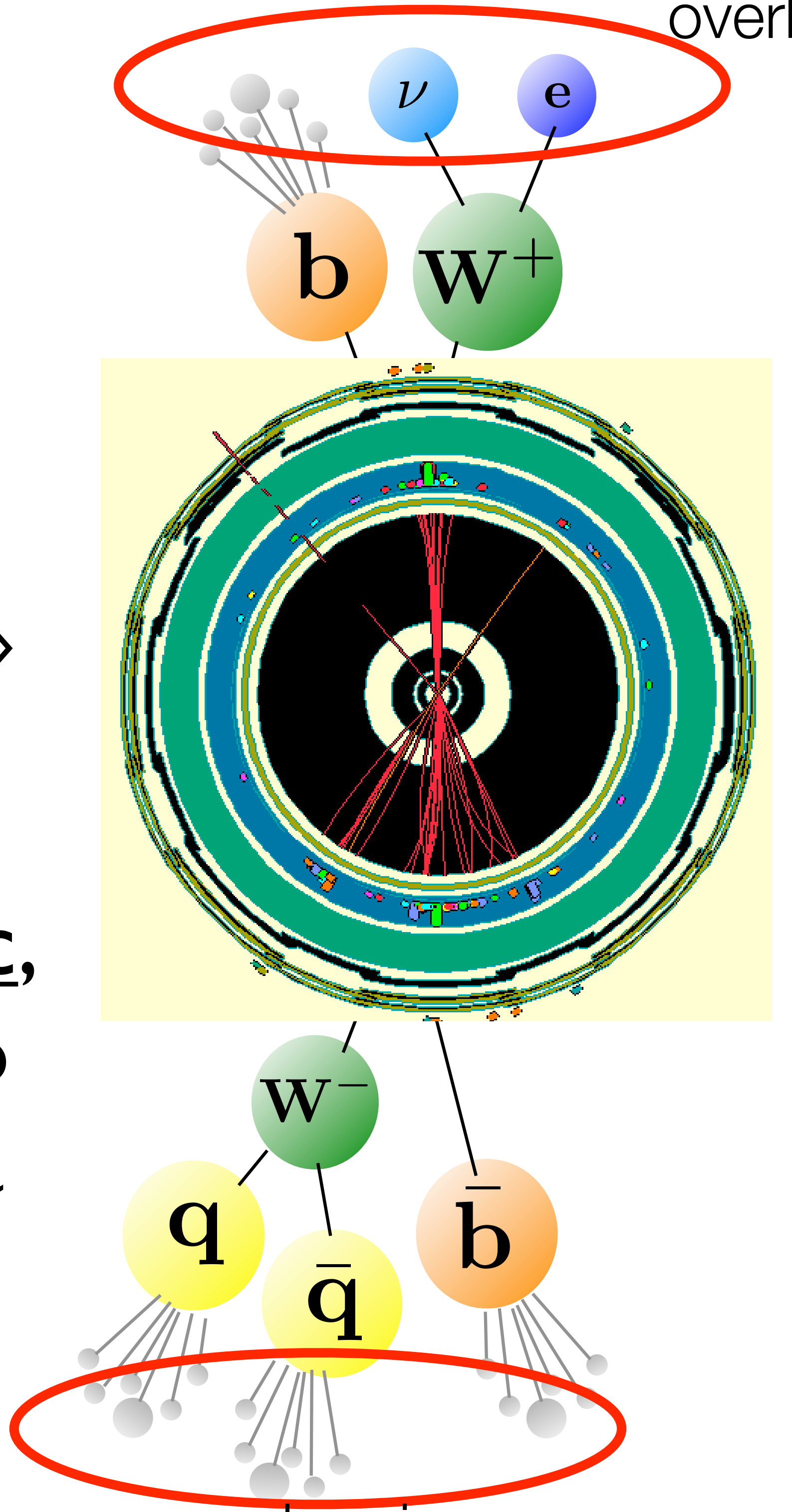
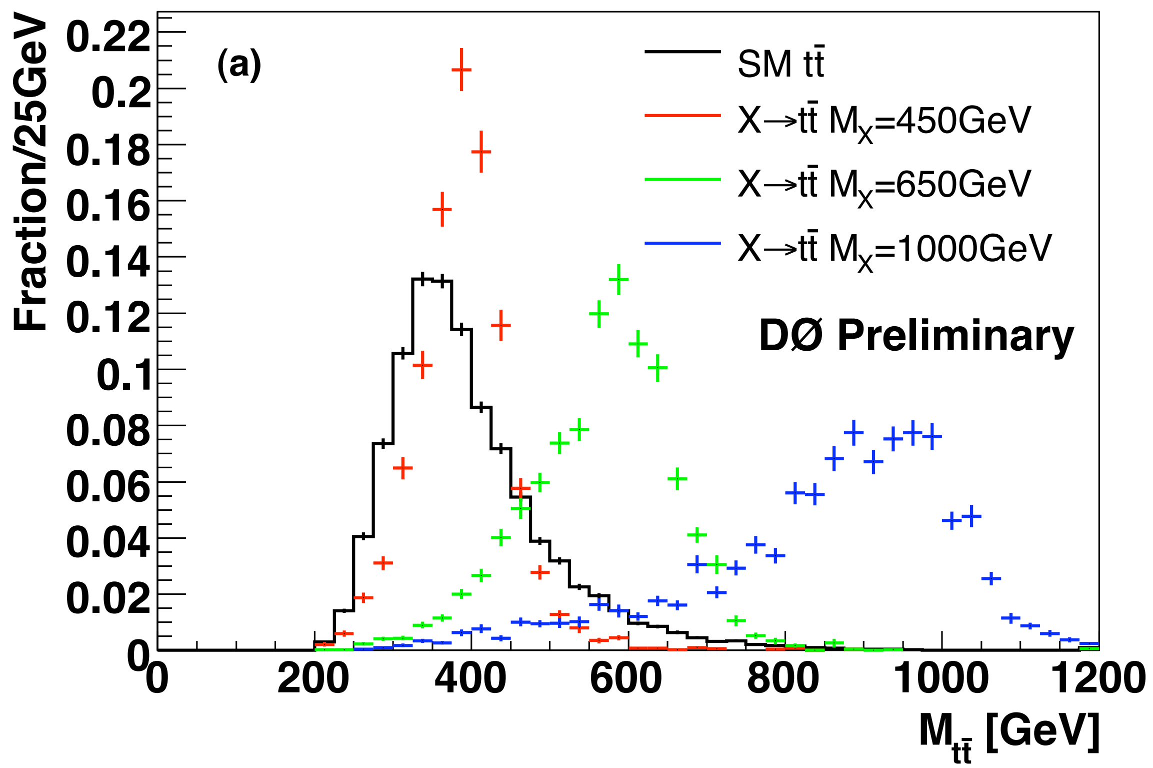
New Physics into Top

$$pp \to X \to t\ \bar{t}$$
$$pp \to b'\ \bar{b}' \to W^- t\ W^+ \bar{t}$$



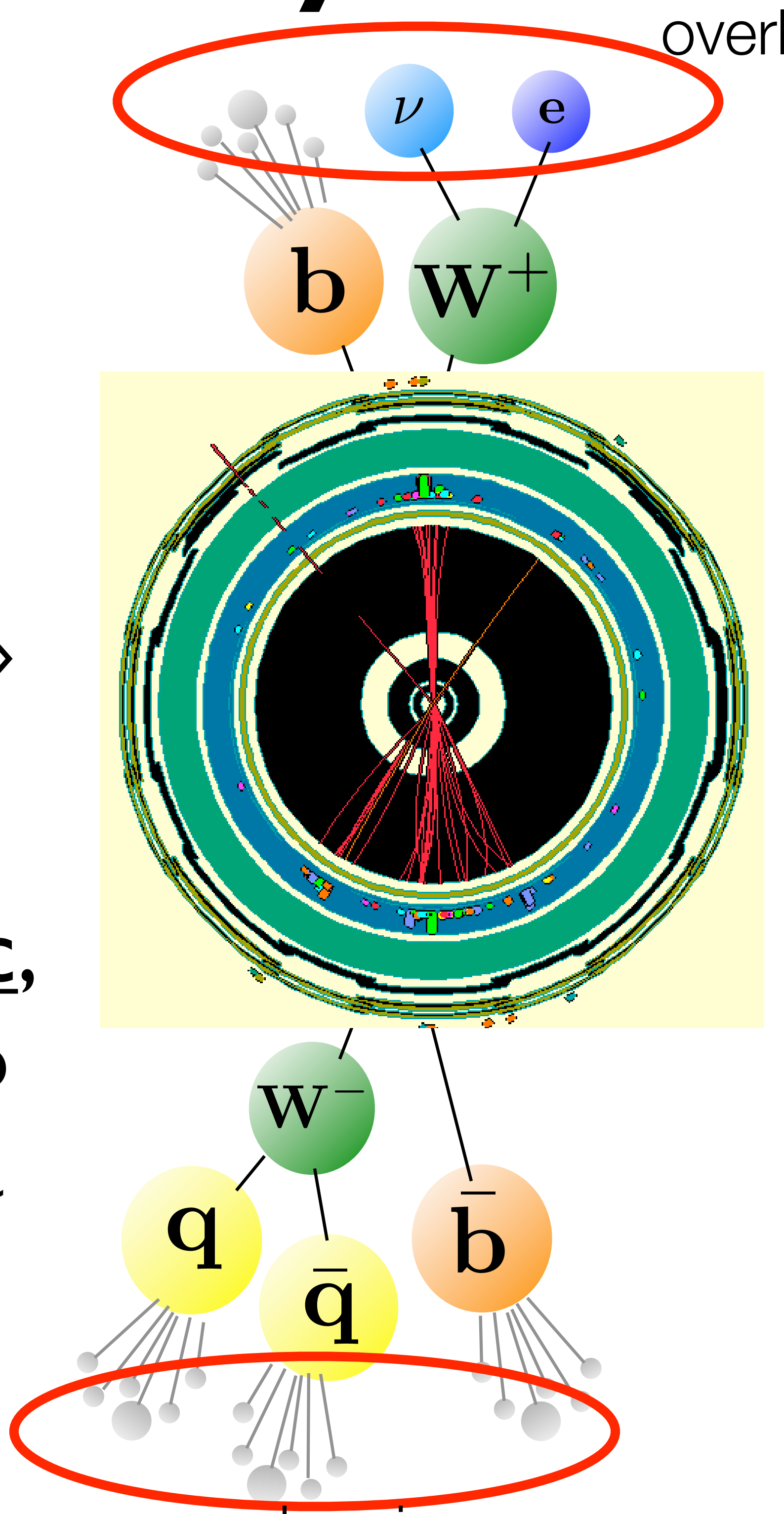


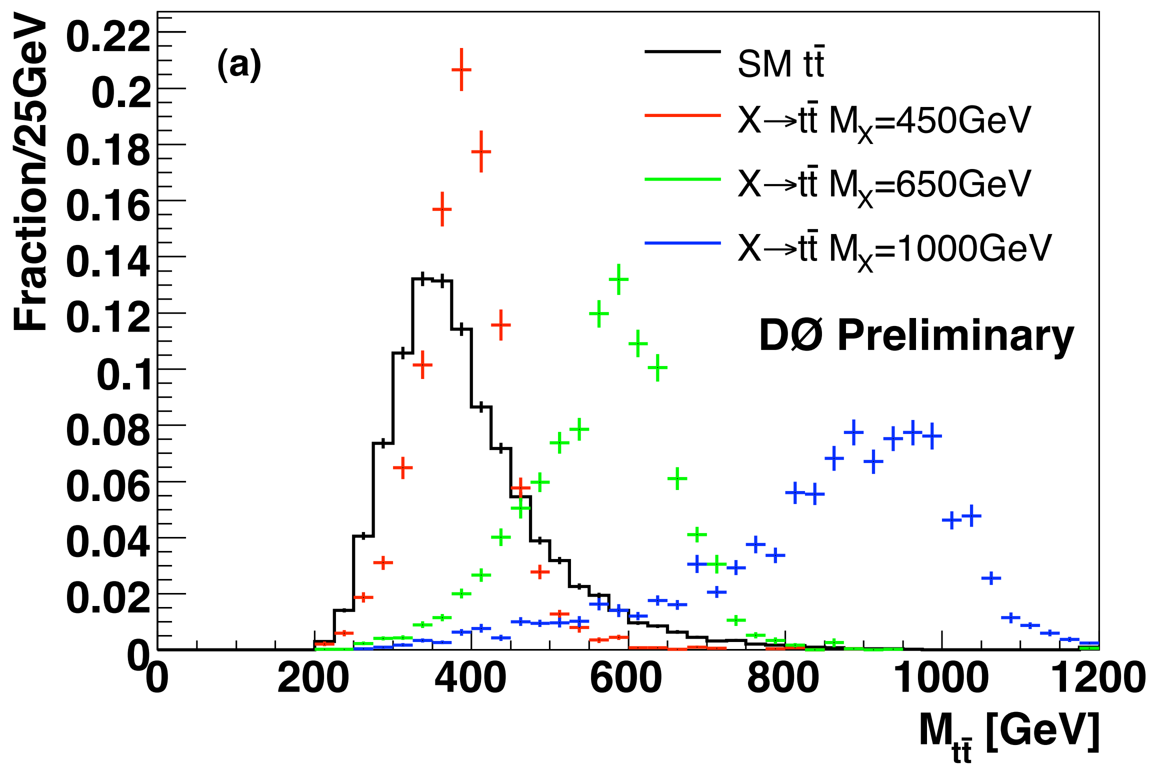
Topcolor Z' excluded < 800 GeV.
Kaluza-Klein gluon excluded < 1TeV

<u>If new physics is leptophobic</u>, they may couple strongly to top. Otherwise, dimuon is a clearer signature.

New Physics into Top

$$pp \rightarrow X \rightarrow t\ \bar{t}$$
$$pp \rightarrow b'\ \bar{b}' \rightarrow W^- t\ W^+ \bar{t}$$





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<u>If new physics is leptophobic</u>, they may couple strongly to top. Otherwise, dimuon is a clearer signature.

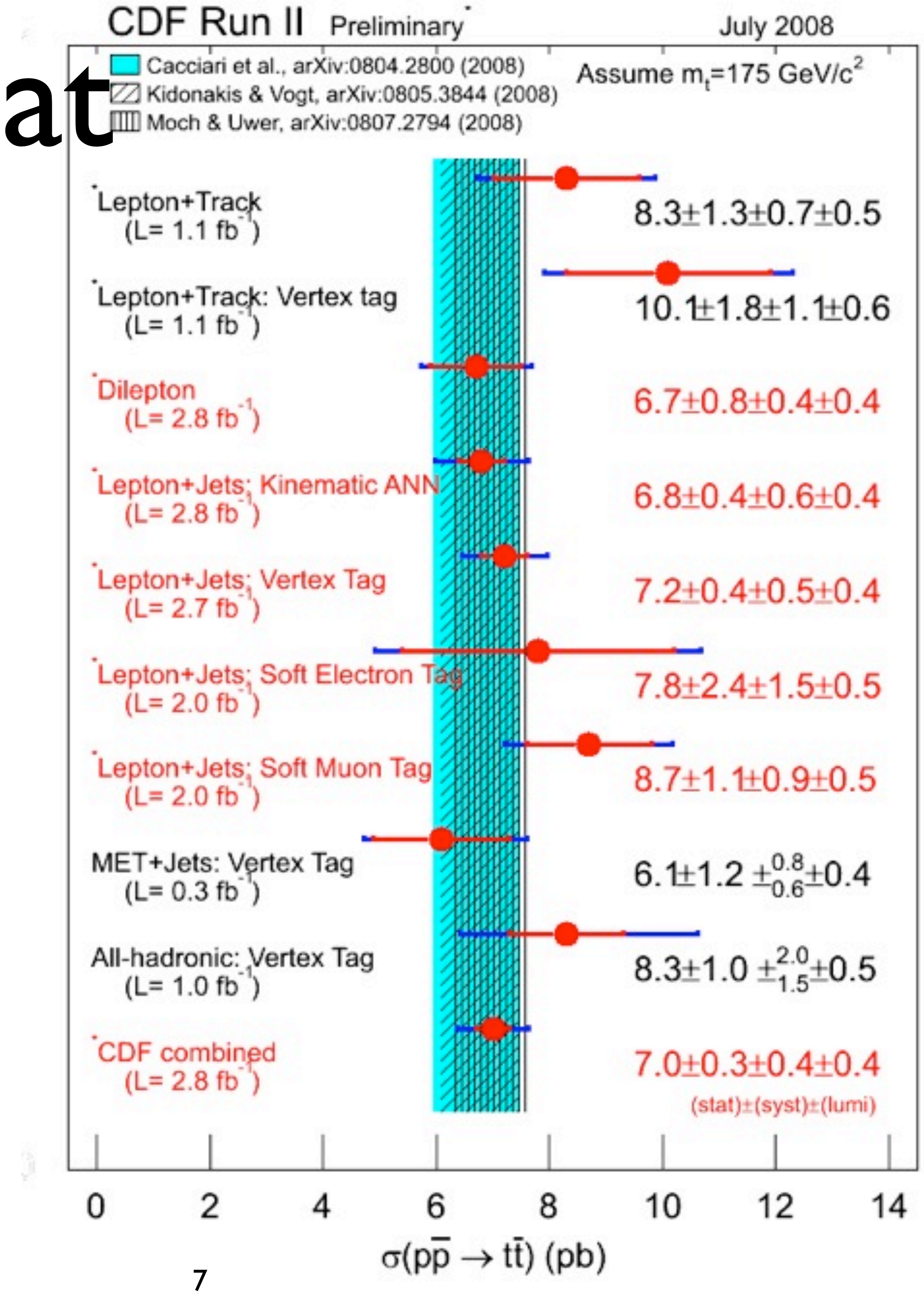
Good control of SM top and jet resolution & jet substructure.

Not a "Day-1 physics"

State of the Art at Tevatron

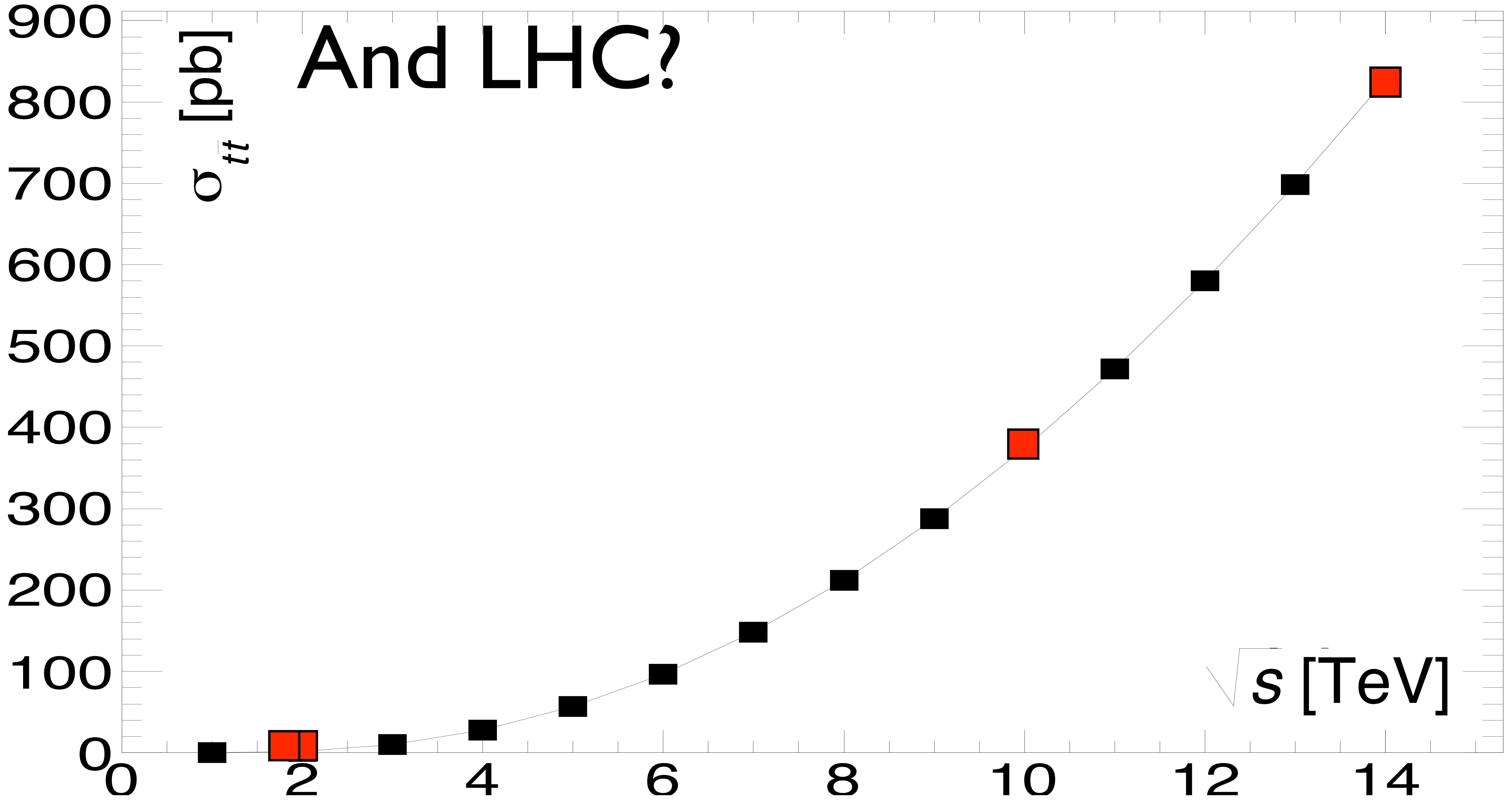
Cross-Section Measurement

- Semileptonic channel
  - High branching ratio (~36/81)
  - Event over-constrained
  - Manageable background
- Dileptonic channel
  - Low background
  - Low branching ratio (~9/81)
  - Event under-constrained
- Fully hadronic channel
  - Event fully constrained
  - Huge QCD and comb. background
- Lepton + Track
  - Highly inclusive
  - Different systematics for track performance.



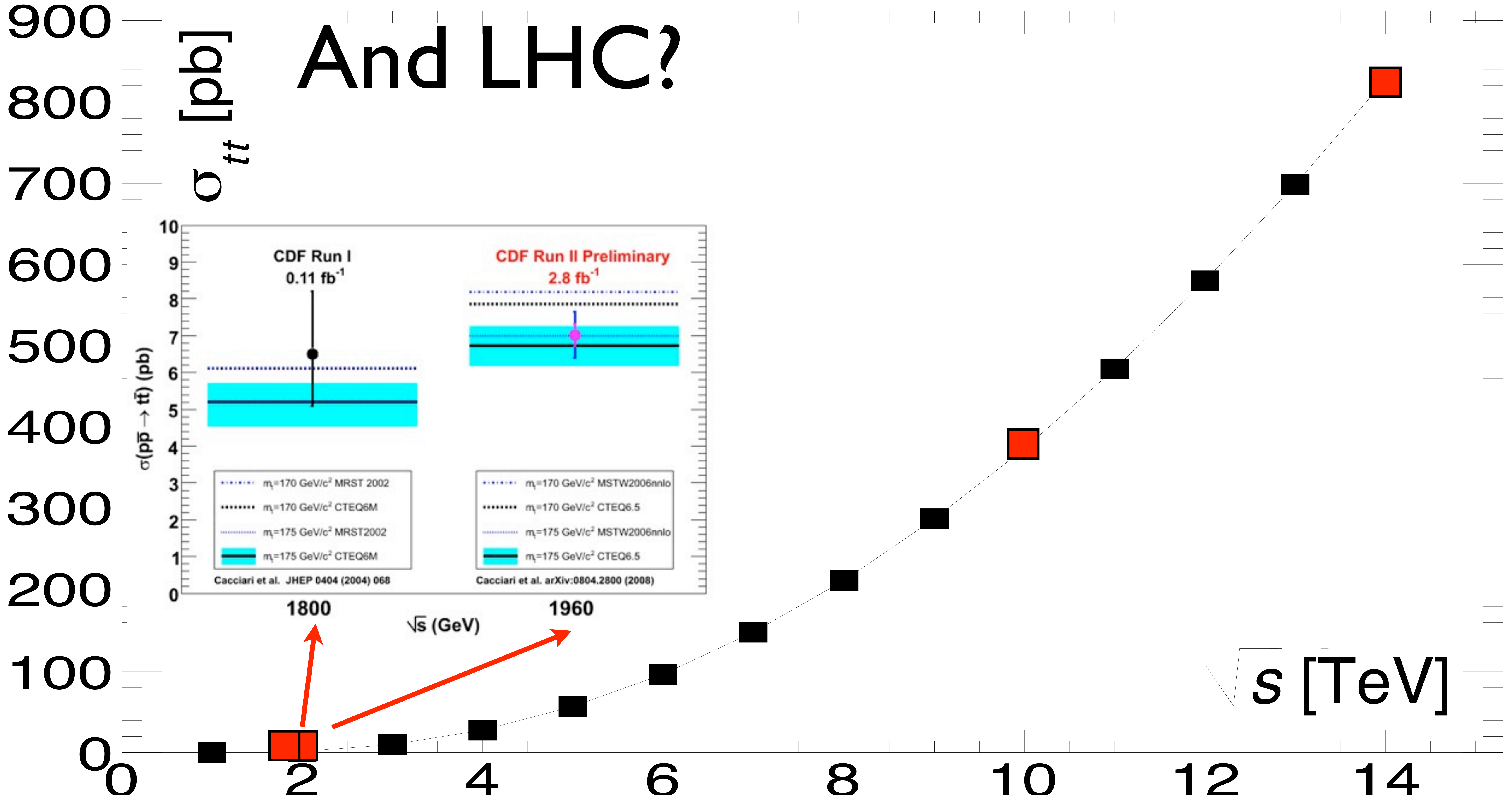
8% precision all combined (summer 2008)

And LHC?



900
800
700
600
500
400
300
200
100
0
$\sigma_{t\bar{t}}$ [pb]
0
2
4
6
8
10
12
14
$\sqrt{s}$ [TeV]

And LHC?



900
800
700
600
500
400
300
200
100
0
σ_tt̄ [pb]
0
2
4
6
8
10
12
14
√s [TeV]
CDF Run I
0.11 fb-1
CDF Run II Preliminary
2.8 fb-1
σ(pp̄ → tt̄) (pb)
m_t=170 GeV/c² MRST 2002
m_t=170 GeV/c² CTEQ6M
m_t=175 GeV/c² MRST2002
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Cacciari et al. JHEP 0404 (2004) 068
m_t=170 GeV/c² MSTW2006nnlo
m_t=170 GeV/c² CTEQ6.5
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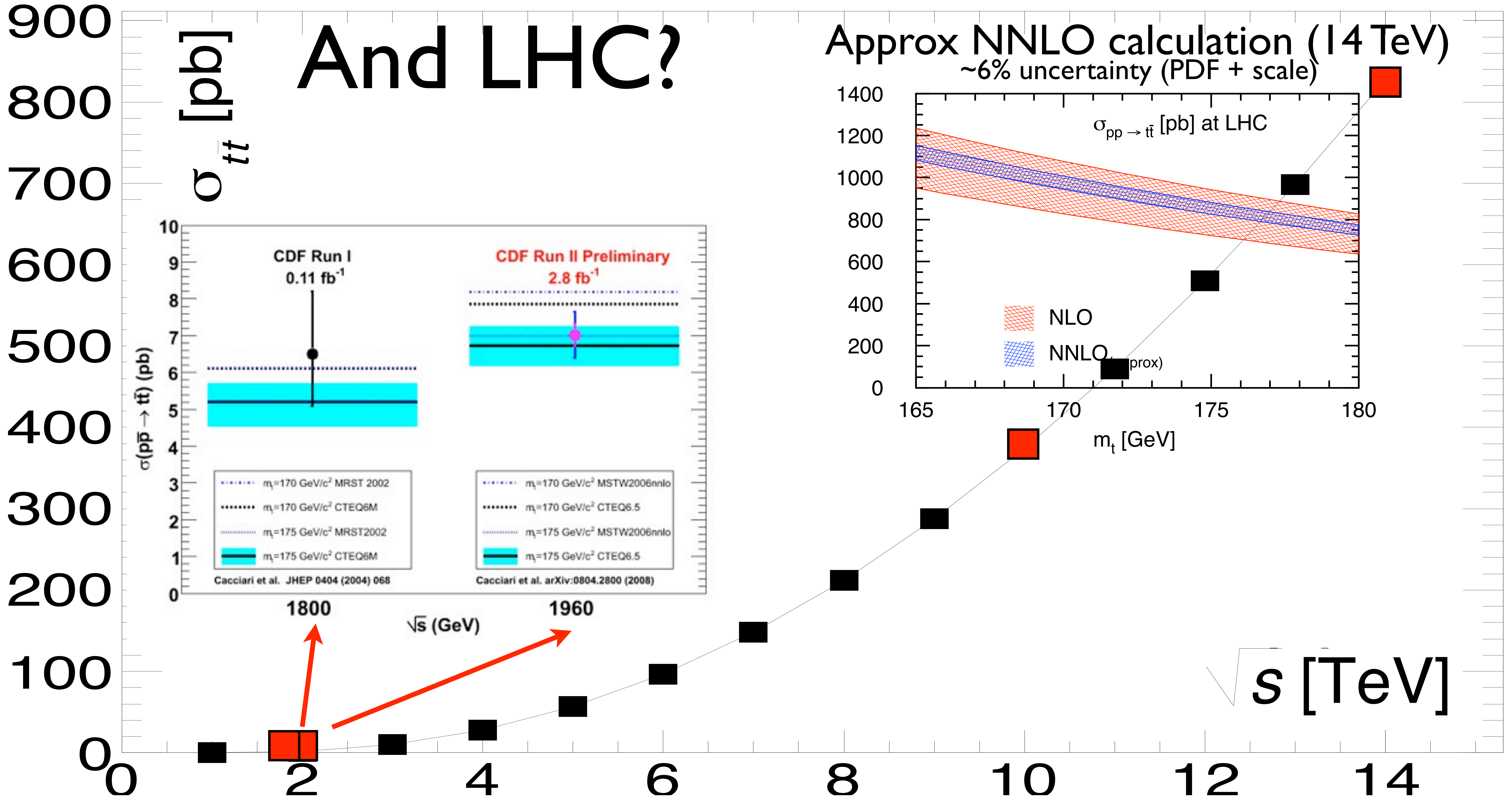
Cacciari et al. arXiv:0804.2800 (2008)
1800
1960
√s (GeV)

And LHC?



900
800
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σ_tt̄ [pb]
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4
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12
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√s [TeV]
Approx NNLO calculation (14 TeV)
~6% uncertainty (PDF + scale)
σ_pp → tt̄ [pb] at LHC
NLO
NNLO (approx)
m_t [GeV]
165
170
175
180
1400
1200
1000
800
600
400
200
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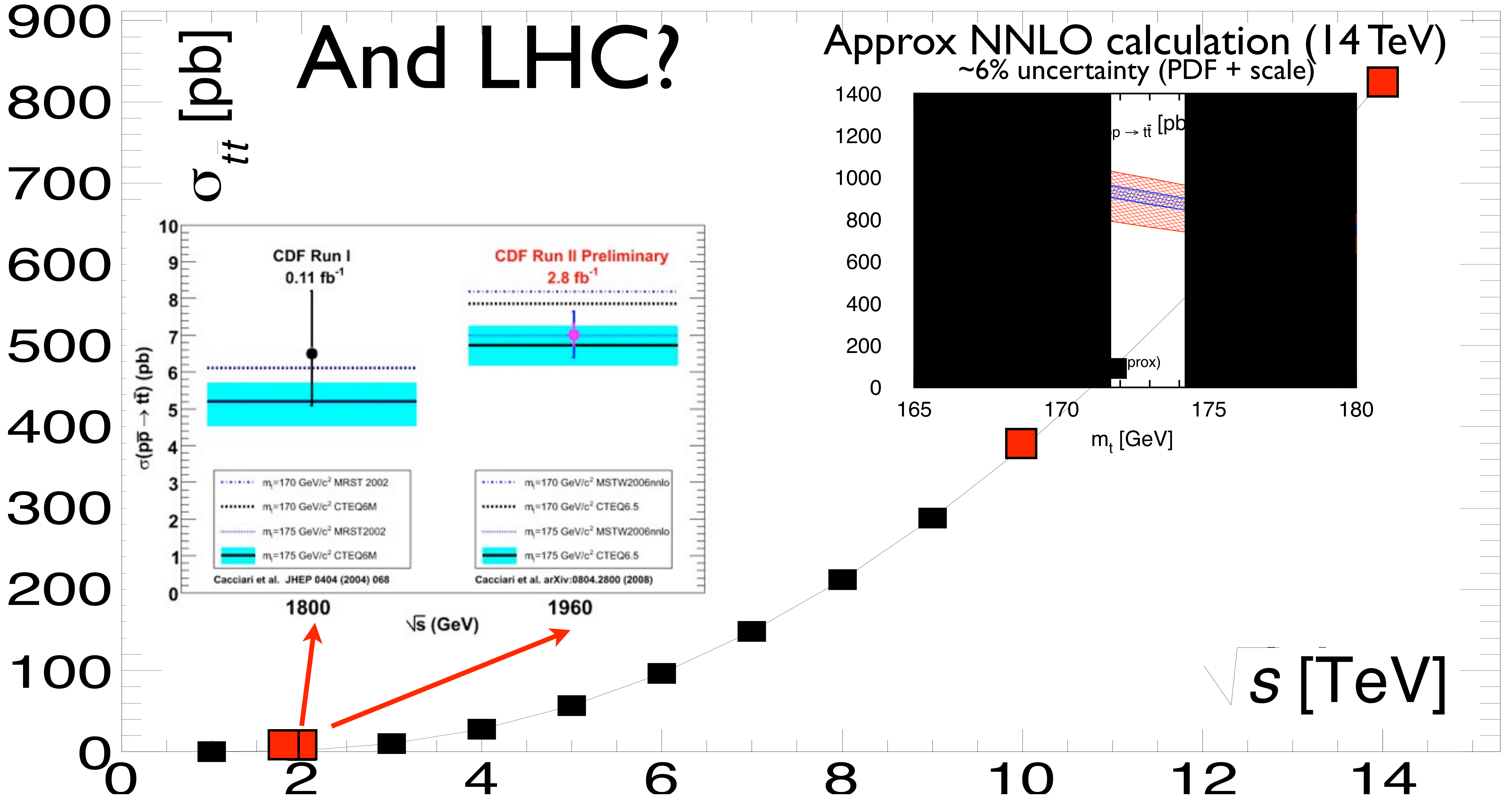
And LHC?
Approx NNLO calculation (14 TeV)
~6% uncertainty (PDF + scale)
$\sigma_{t\bar{t}}$ [pb]
$\sqrt{s}$ [TeV]
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Strategy with the First Data

Do the simplest thing we can do, count the number of events

$$N = L\, \sigma_{t\bar{t}}\, BR\, \epsilon_{trig} \epsilon_{lep}\, A + B$$

- L: pray for a large number but expect large uncertainty may not be available quickly
- BR: well known in SM
- ϵ_{trig}, ϵ_{lep}: to be estimated from data
- A: sensitive to theoretical uncertainty
- B: part data driven, part MC driven

Realistically, e and mu single lepton and dilepton channels only. Taus, too difficult to calibrate. Fully hadronic too difficult to trigger.

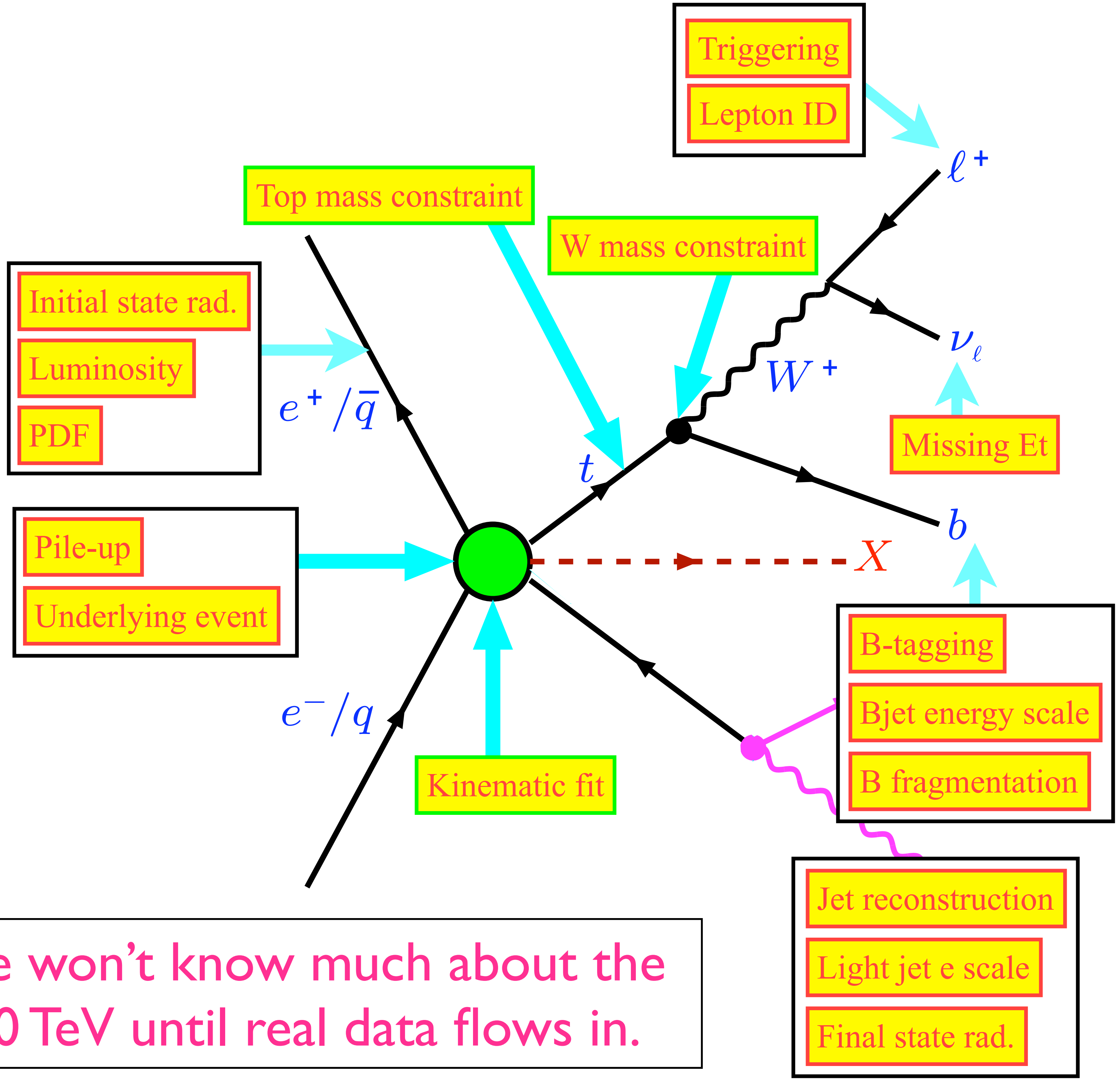
Methods based on likelihood fit also studied. Different or superior systematic uncertainties.

Will show (14 TeV) studies from "Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics." (a.k.a. CERN-OPEN-2008-20, "CSC")

Obstacles with First Data

Numerous uncertainties that affect measurements with the early data:

- Trigger efficiency
- Non-uniform detector
- Lepton identification
- Missing Et calibration and tails
- Light/b jet energy scale
- QCD activity (MI, ISR/FSR)
- Beam related issues (Pile-up, Luminosity)
- PDF
- Background normalization
- other unknown unknowns



We have performance estimates but we won't know much about the real detector and the real physics at 10 TeV until real data flows in.

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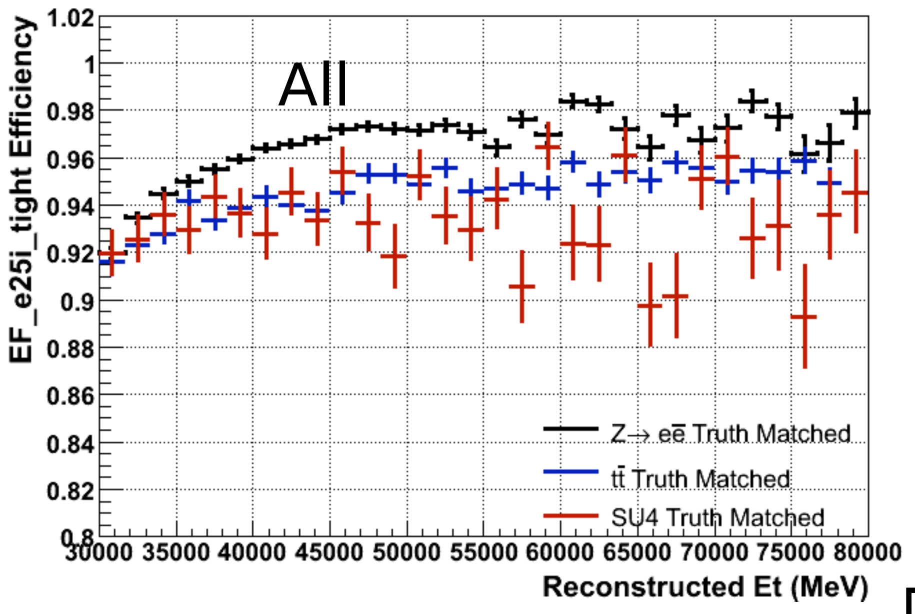
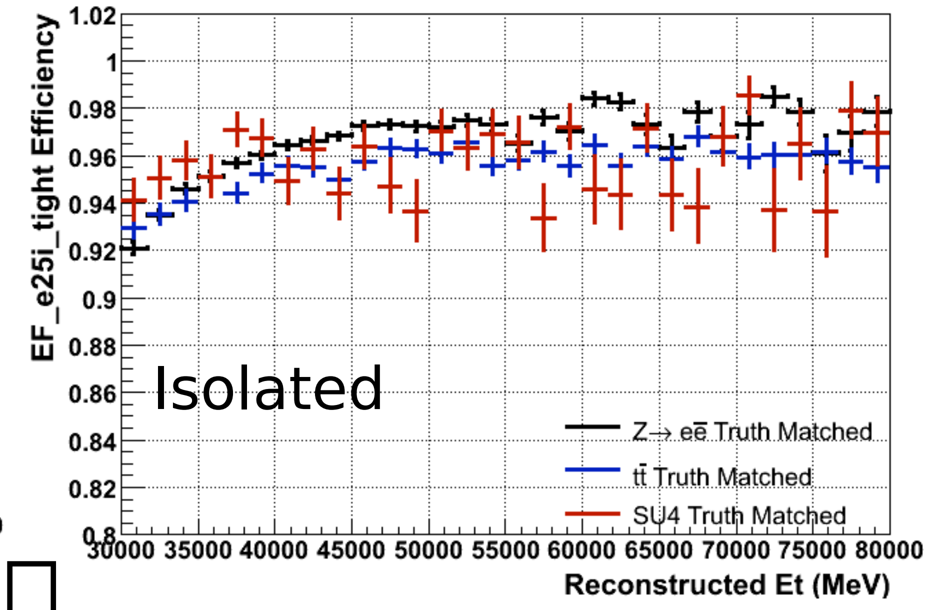
Measuring Efficiency from Z

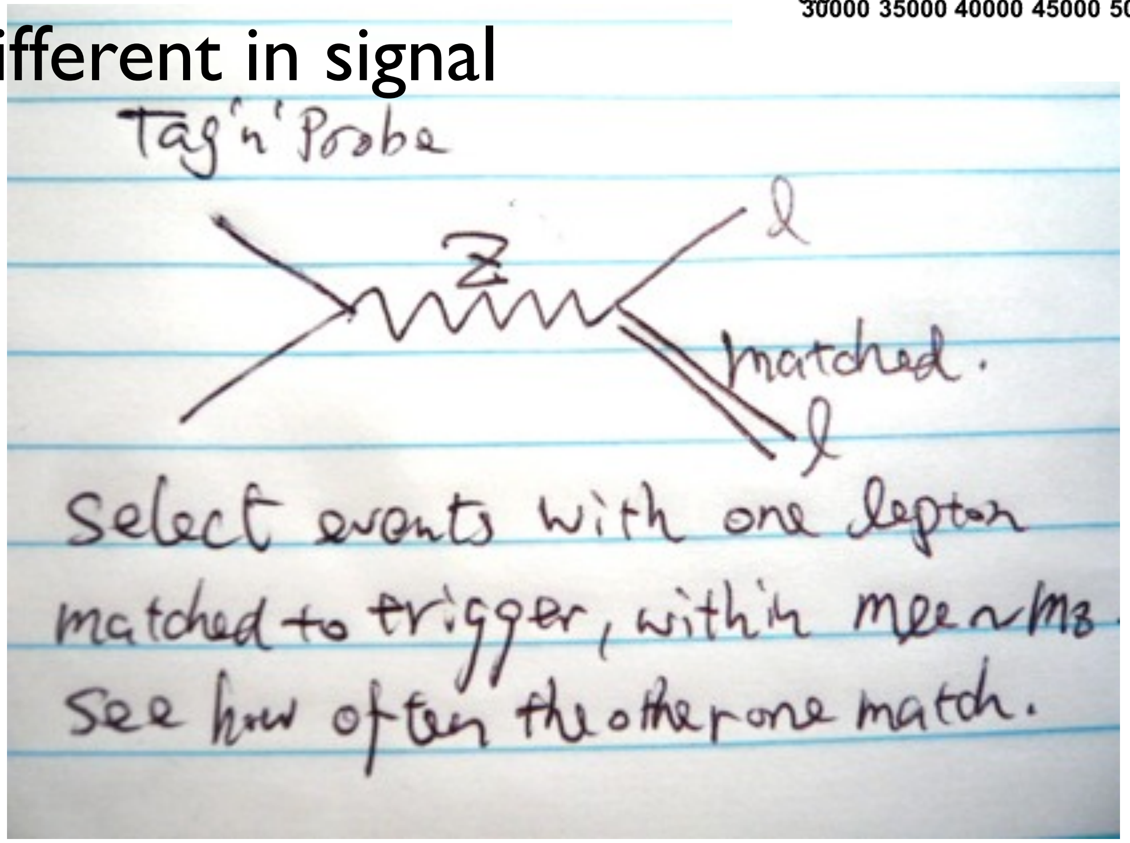
Why we won't know until real data comes

Low Pt single lepton triggers at low lumi is highly efficient (>90%) for tT. Their performance of the <u>real detector</u> need to be estimated from data.

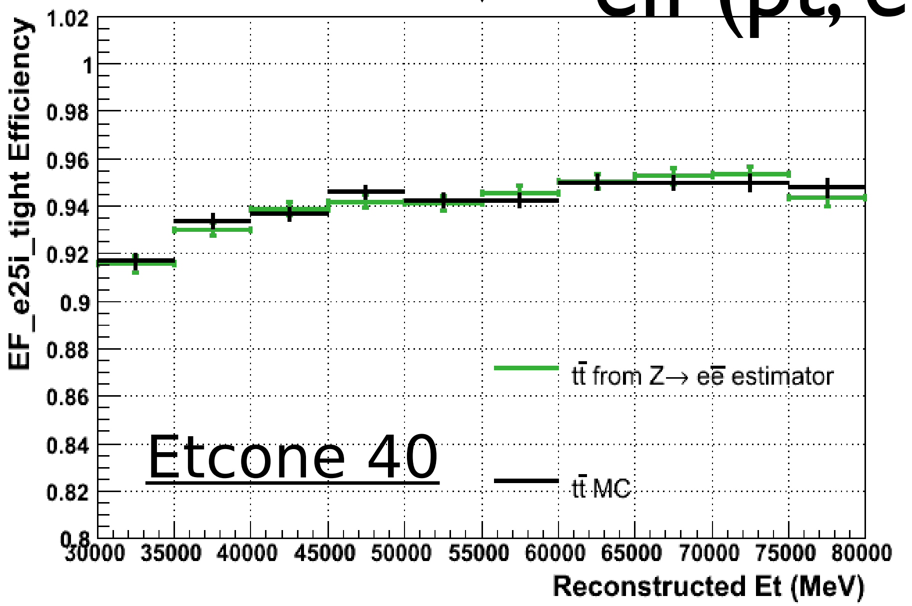
Z events are the most useful control sample for performance extraction but condition can be different in signal events.





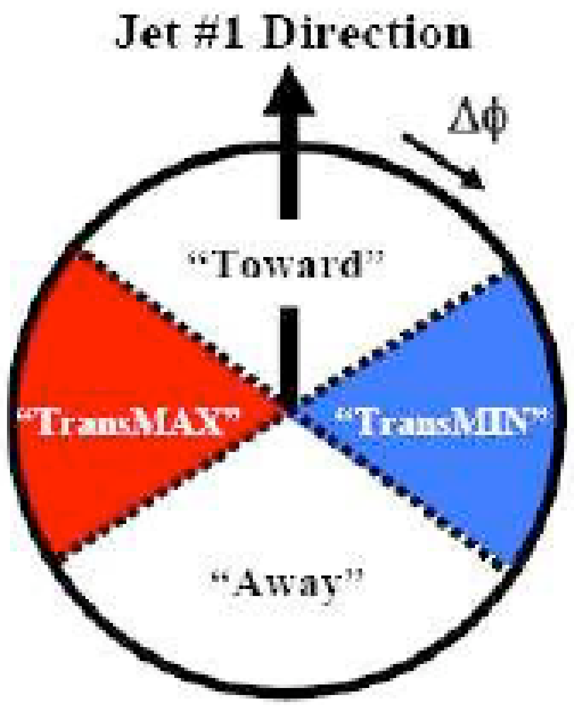


eff (pt, eta & isolation)

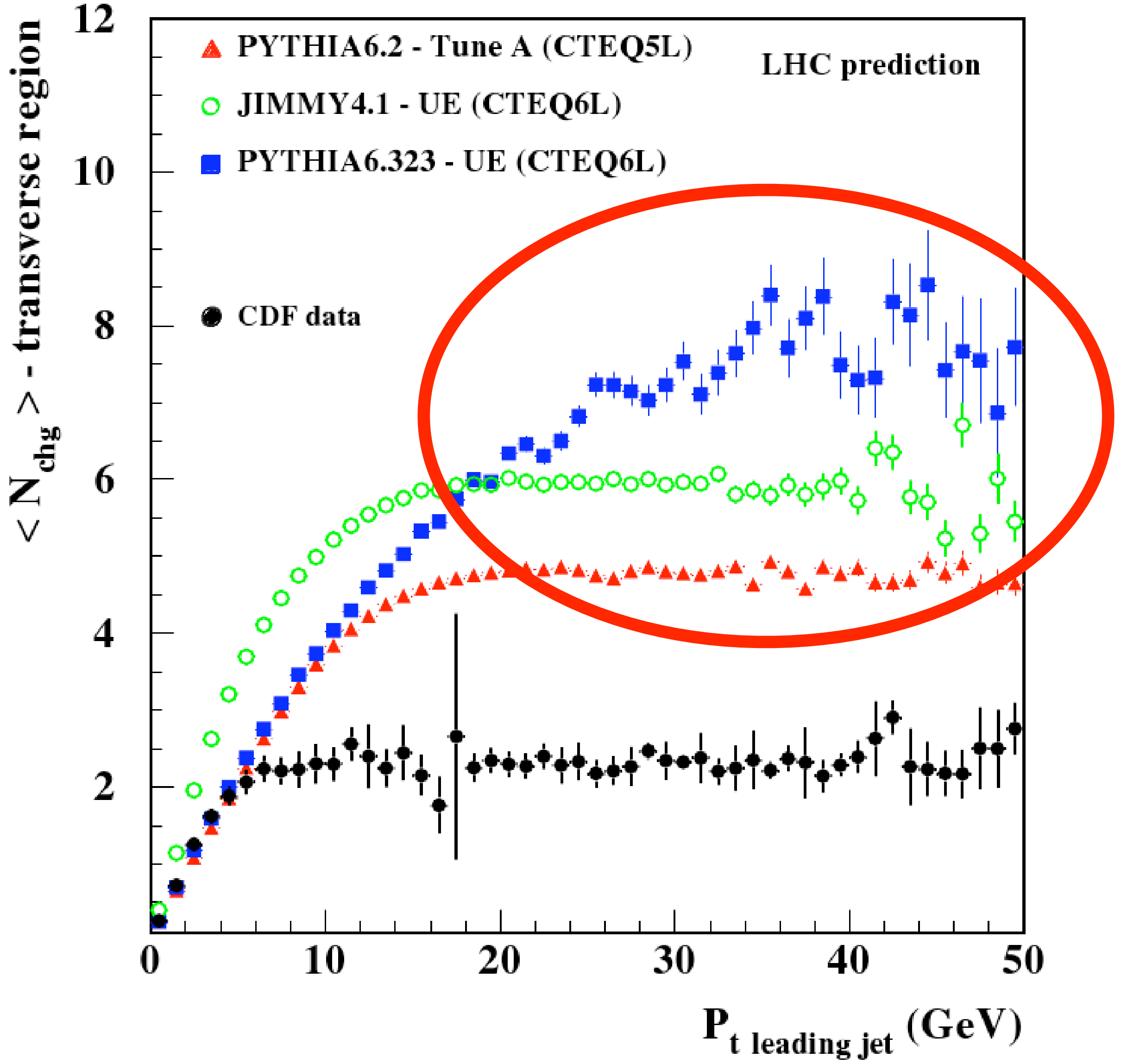


Underlying Event and ISR/FSR

Why we won't know until real data comes



QCD 2 → 2 process
TransMAX region: hardest ISR/FSR
TransMIN: beam-beam UE component
TransMAX - TransMIN: ISR/FSR probe



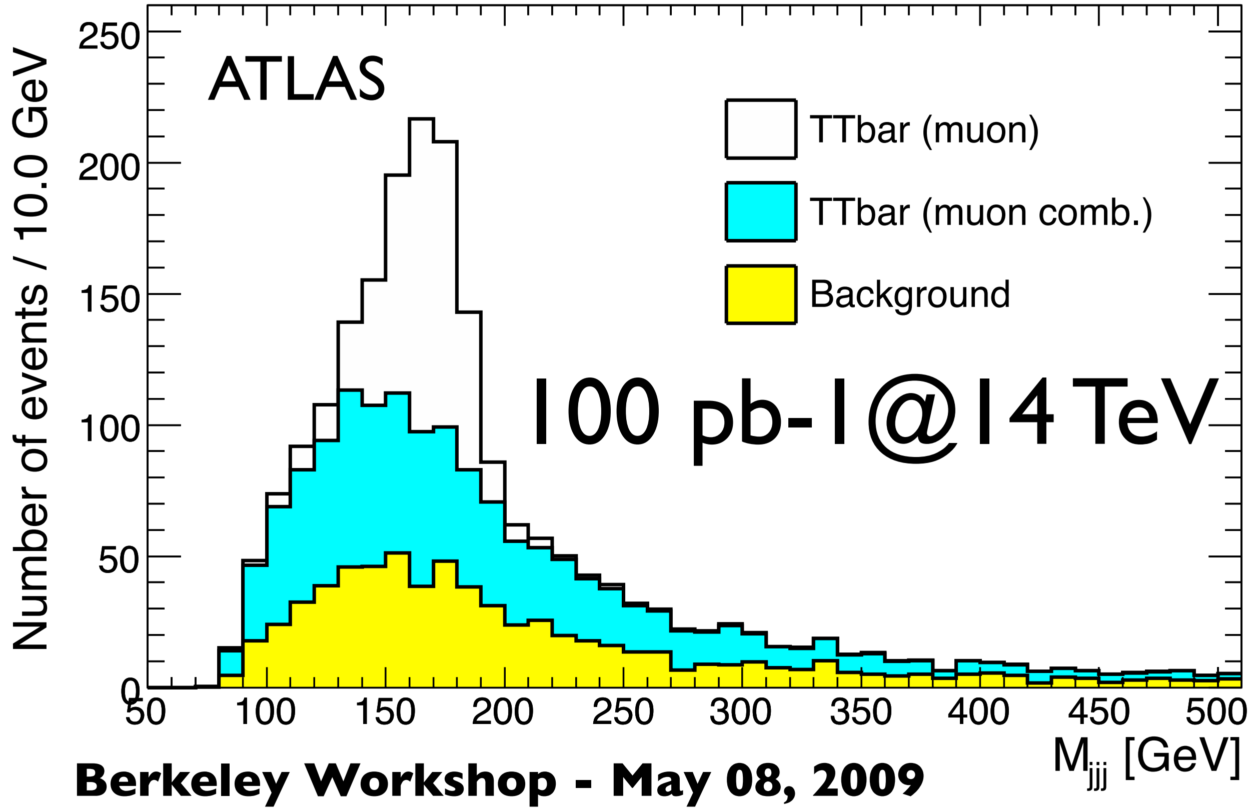
UE tunings applied to LHC MC shows divergence with high pt jets. Need to constrain model parameters, need to know handles to evaluate uncertainties.

Single Lepton Channels

18% precision

One lepton with pT>20 GeV,
Missing Transverse Energy > 20 GeV,
at least 4 jets with pT>20 GeV
of which 3 have pT > 40 GeV
- "default" - 18% eff for muon channel
Look for trijet combination with highest pT and select those with dijet mass ~ Mw.
Lose half using Mw cut

Source of Unc.	Detail	Count Elec
Statistical	1262 sig evts	3.5%
Lepton ID	1% variation	1.0%
Trigger eff	1% variation	1.0%
W+Jet norm.	50% more	9.5%
JES	5%	9.7%
PDF	CTEQ error	2.5%
ISR/FSR	Λ_{QCD} / cutoff	8.9%



Likelihood method: $\Delta\sigma/\sigma = (7(\mathrm{stat}) \pm 15(\mathrm{syst}) \pm 3(\mathrm{pdf}) \pm 5(\mathrm{lumi}))\%$

Counting method: $\Delta\sigma/\sigma = (3(\mathrm{stat}) \pm 16(\mathrm{syst}) \pm 3(\mathrm{pdf}) \pm 5(\mathrm{lumi}))\%$

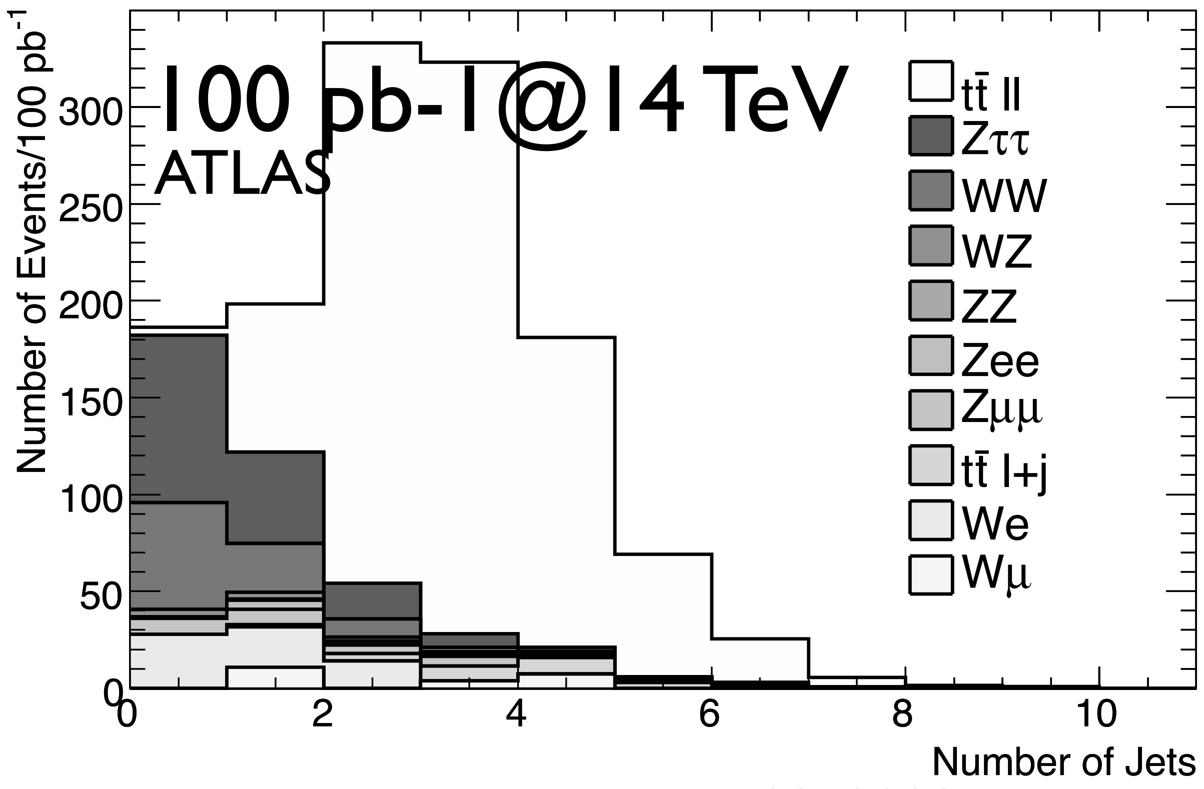
Likelihood fit on top mass stable against background fluctuation but relies on good understanding of Mjjj shape. Counting method is sensitive to background normalization and jet energy scale.

Dileptonic Channels

9% precision

Two lepton with pT>20 GeV,
Missing Transverse Energy > 25 GeV
(30 GeV for ee/mumu)
at least 2 jets with pT>20 GeV
remove mll ~ 90 GeV (ee/mumu)
21% (emu) , 15% (ee), 19% (mumu)
~1010 events in combined with
100pb^{-1} at 10TeV

Source of Unc.	Detail	Avg All Chan
Statistical	1010 sig evts	3.5%
Lepton ID	1% variation	1.0%
Trigger eff	1% variation	1.0%
W+Jet	50%	2.9%
Bkg Model	10%	1.4%
JES	5%	+4.6/-2.1%
PDF	CTEQ error	2.4%
ISR/FSR	Λ_{QCD} / cutoff	2.3%



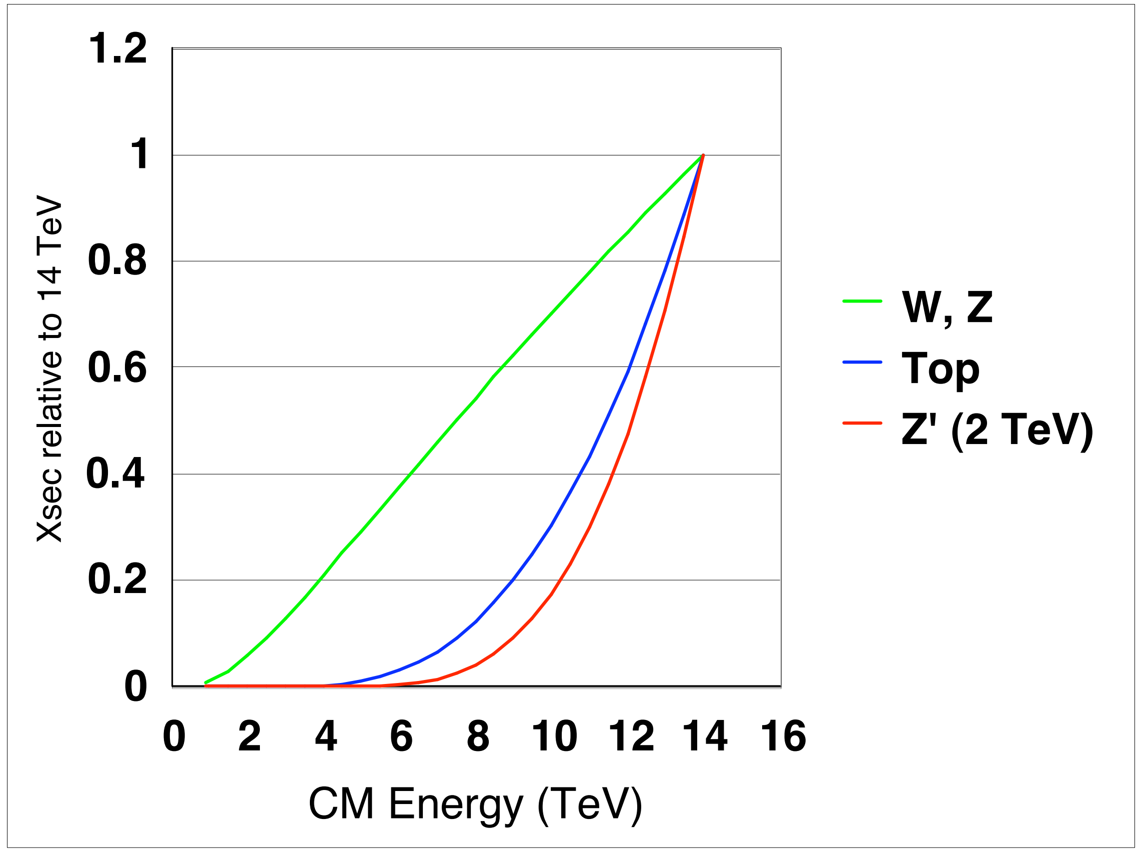
$$\text{Cut and Count method:} \quad \Delta\sigma/\sigma = \quad (4(\text{stat})^{+5}_{-2}(\text{syst}) \pm 2(\text{pdf}) \pm 5(\text{lumi}))\%$$

$$\text{Template method:} \quad \Delta\sigma/\sigma = \quad (4(\text{stat}) \pm 4(\text{syst}) \pm 2.(\text{pdf}) \pm 5(\text{lumi}))\%$$

Treatment of systematic is symmetric to single lepton analysis. Significantly higher precision in dilepton analysis.

14 TeV > 10 TeV

10 TeV analysis ongoing. Analyses being re-evaluated / re-optimised for 10 TeV but nothing public yet. Look out for the summer conferences!



Conclusions

- There is no easy win with Top!
  - Cross section is large but first data is limited.
  - Very many uncertainties to be constrained from the data itself.
  - First top observation at LHC will be a huge step.
- Sensitivities to new physics exist in many places around top
  - Tevatron results are impressive and updated with increasing luminosity.
  - Estimated sensitivity of 9-18% (systematics dominate) is a good start for cross-section measurements. Dilepton analysis may have a kick start.
- Measurements in 10 TeV is interesting
  - Comparison with Tevatron and 14 TeV is very important.
  - Who knows what kind of surprise is waiting at 10 TeV?
- **Impact of first top observation at the LHC ? Incalculable.**