Background estimation strategies in CMS

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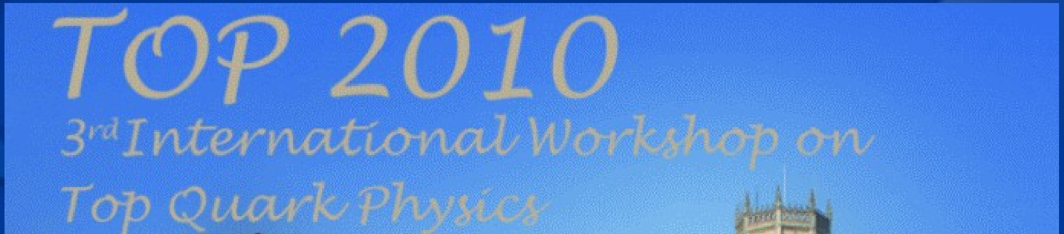
On behalf of the CMS collaboration

Presented at:

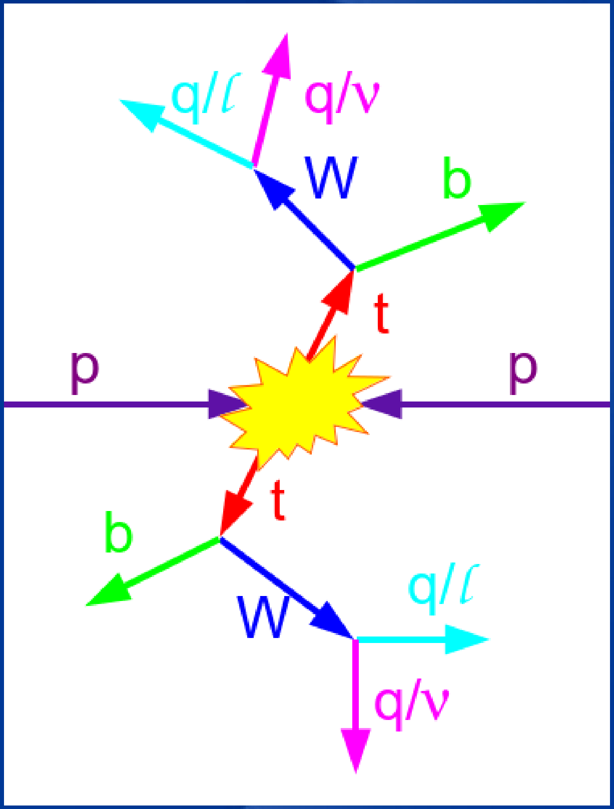


Outline

- Introduction.
- Lepton+jets mode:
  - Selecting top events and remaining backgrounds.
  - QCD background.
  - W/Z+jets background.
- Dilepton mode:
  - Selecting dileptonic top events.
  - DY+jets background, and fake leptons.
- Summary.

Introduction

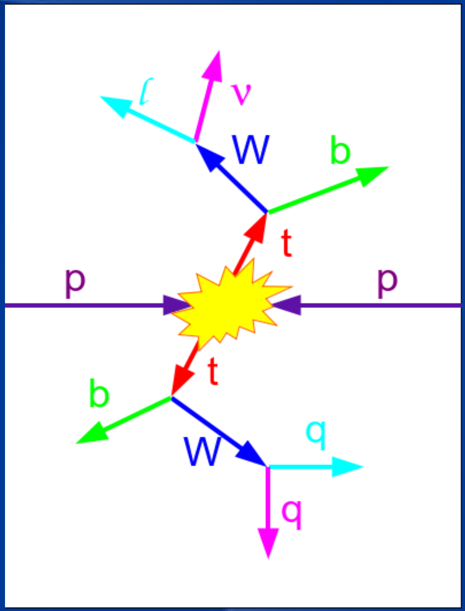
- For early data dileptonic, and lepton+jets are the top top topologies to look at.
- Methods developed with MC to study backgrounds:
  - still to be tested on data...
  - Multiple methods to cross-check.
  - robust for early data.
- Figures and tables shown are for 20pb^{-1} (lepton+jets), and 10pb^{-1} (dileptonic), except where noted.
- All studies used 10TeV MC.
- References are to CMS PAS (Physics Analysis Summary).



Lepton+jets

Selecting lepton+jets events

- Simple, robust selections for early data:
- At least 4 jets:
  - pT> 30GeV/c, $|\eta| < 2.4$, (for e+jets veto jets with $\Delta R(e, jet) < 0.3$).
- 1 lepton:
  - electron:
    single electron trigger (E_T>15GeV), E_T>30GeV,
    $|\eta|<2.5$ (exclude $1.442<|\eta|<1.560$), $d_0<200\mu m$, RelIso < 0.1
  - muon:
    single muon trigger (p_T>9GeV), p_T>20GeV/c, $|\eta|<2.1$, $d_0<200\mu m$, RelIso <0.05
- Veto events with extra isolated leptons :
  - Looser selections used (muon p_T>10GeV/c, electron E_T>15GeV, RelIso <0.2) for μ+jets.
- No MET criterion or b-tagging used.



RelIso = $(I_{Tracker}+I_{Ecal}+I_{Hcal}) / E_T$ [p_T] for electron [muon].
d_0 = transverse impact parameter (with respect to beam spot).

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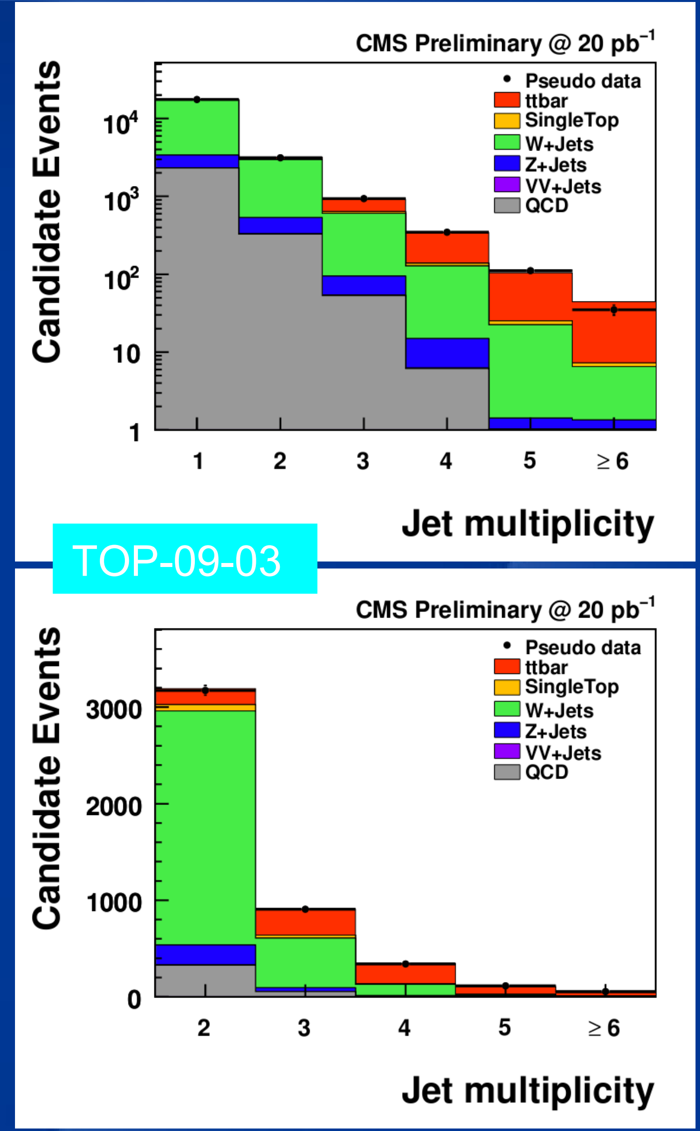
Muon+jets: Selected events

- At low jet multiplicities, dominated by W+jets.
  - Z+jets and QCD also contribute.
- ttbar events dominant for multiplicities of 4 (or higher).
- QCD contribution can be estimated from data by :
  - finding appropriate control regions
  - extrapolating from control regions to signal region.
- W(Z)+jets can be estimated by fitting discriminating variables.



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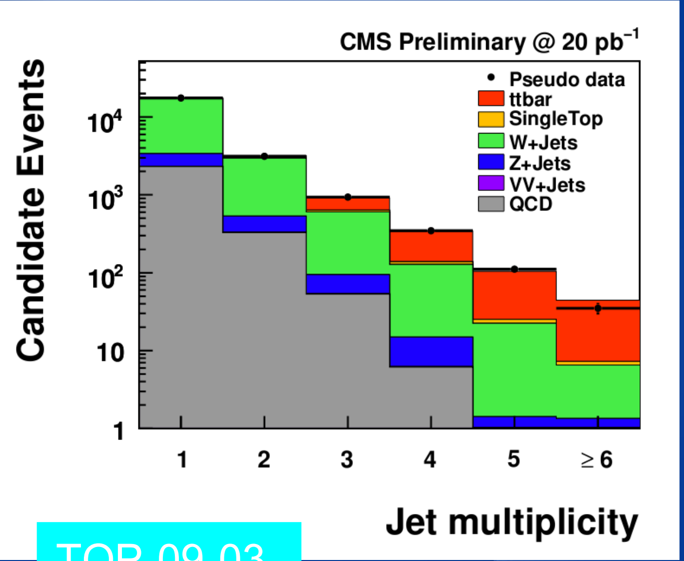

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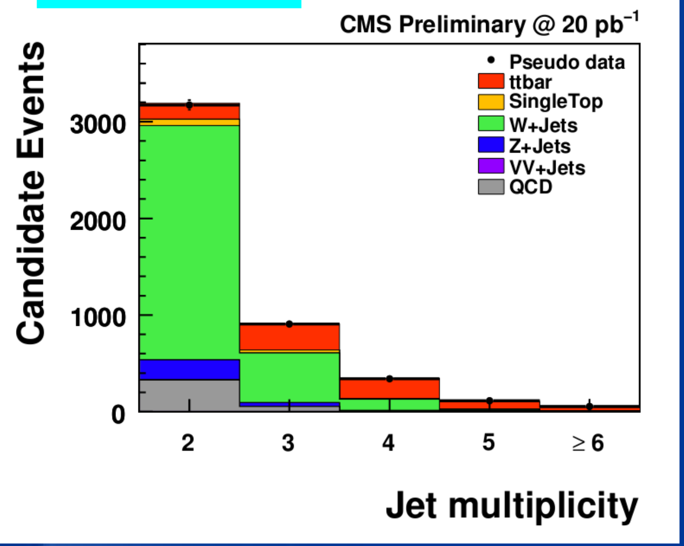
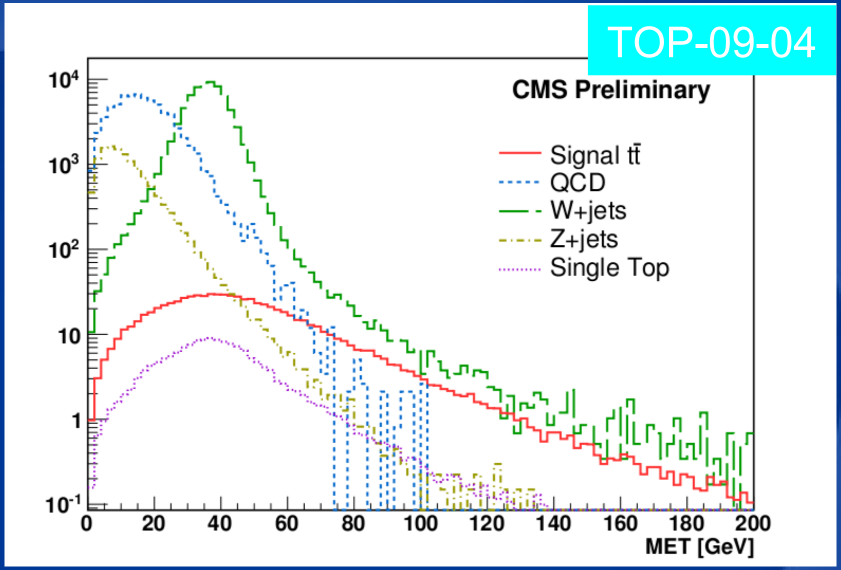
	$t\bar{t}$+jets s.l. μ	$t\bar{t}$+jets other	Single top s-Ch.	t-Ch.	tW	W+jets	Z+jets	VV+jets	QCD
AllEvents	1,220	7,060	32	832	580	912,000	76,240	236	2,546,279
Trigger	978	1,418	10	260	147	168,633	20,952	100	2,032,021
$\geq$ 1 tight μ	620	345	5	140	69	110,509	15,296	73	7,200
$<$ 2 tight μ	620	309	5	140	66	110,509	9,300	62	7,200
no tight e	620	264	5	140	62	110,508	9,292	53	7,200
veto on loose μ	618	228	5	140	60	110,503	5,492	44	7,192
veto no loose e	616	183	5	140	56	110,469	5,415	34	7,188
$\geq$ 1 jet	614	180	4	125	55	16,998	1,325	18	2,701
$\geq$ 2 jets	593	158	3	63	47	3,076	256	5	387
$\geq$ 3 jets	489	99	1	18	27	651	51	1	60
$\geq$ 4 jets	277	43	0	5	9	140	10	0	7



Electron+jets: Further selection



- W+jets and QCD are major backgrounds.
- Z+jets and QCD reduced by further selection.
- Strategies to reduce Z+jets:
  - Veto events with extra loose electrons (E_T>20GeV).
  - With events with extra electrons veto 76 < m_{ee}< 106 GeV/c^2.
- To reduce QCD backgrounds:
  - Restrict electrons to ECAL barrel only (|η| < 1.442) - most material before calorimeters in forward region.
  - Missing E_T >20 GeV.
  - Reject electrons consistent with coming from conversions.

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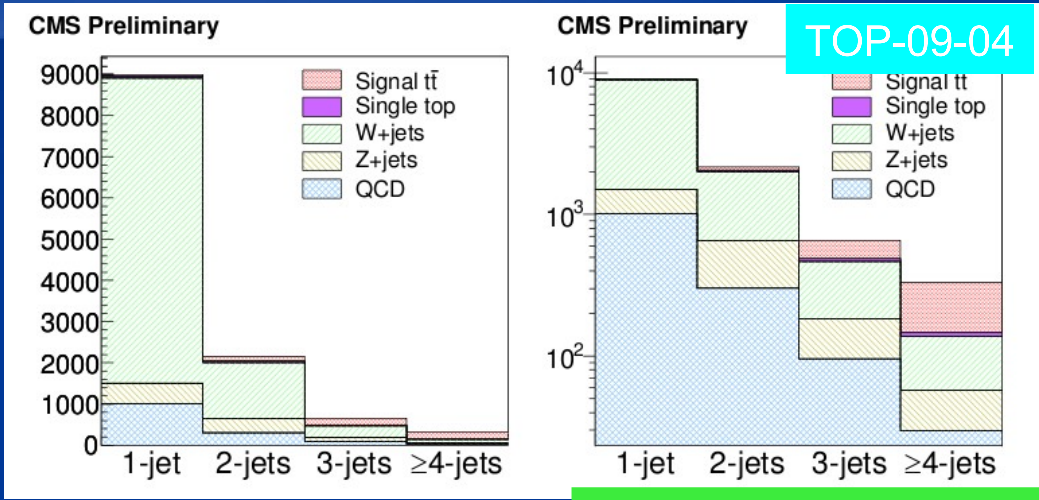
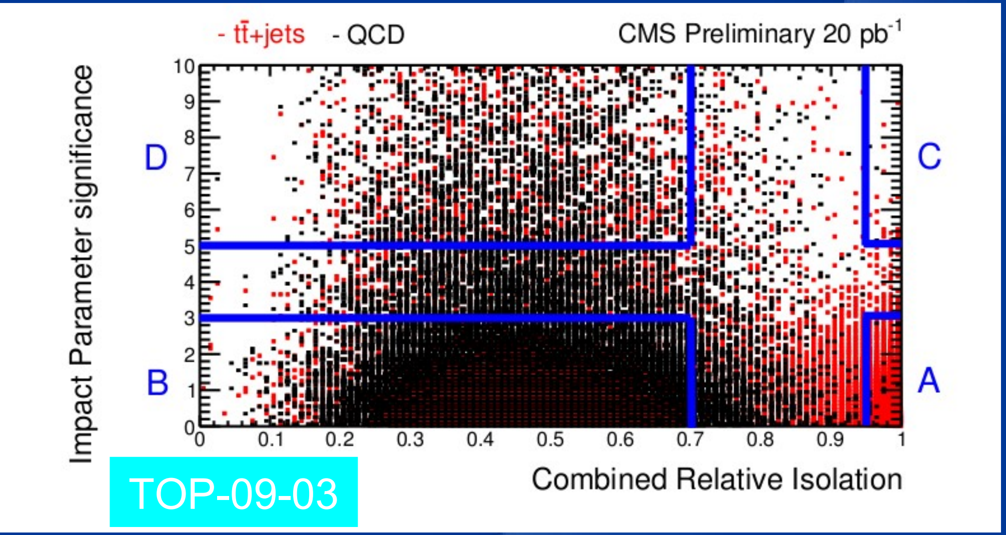


Events after baseline + m_{ee} veto, MET cut and conversion rejection.

	Cuts	$t\bar{t}$	W+jets	Z+jets	QCD	Single Top
	-	8280 ± 6	$9.1E5 \pm 265$	$8.4E{+}04 \pm 60$	$1.7E8 \pm 3.4E4$	1455 ± 2
	Trigger	4727 ± 5	$2.0E5 \pm 175$	$2.7E{+}04 \pm 42$	$3.4E7 \pm 1.9E4$	669 ± 2
	$\geq$1 Iso e	654 ± 2	$6.4E4 \pm 102$	$1.2E{+}04 \pm 29$	9030 ± 318	148 ± 1
	=1 Iso e	640 ± 2	$6.4E4 \pm 102$	8672 ± 25	9030 ± 318	146 ± 1
	Muon Veto	590 ± 2	$6.4E4 \pm 102$	8664 ± 25	9030 ± 318	143 ± 1
	$\geq$ 4 jet	215 ± 1	95 ± 4	46 ± 2	76 ± 20	10 ± 0
Option 1	Loose e Veto	208 ± 1	95 ± 3	20 ± 1	76 ± 13	10 ± 0
	$\|\eta\| < 1.442$	172 ± 1	57 ± 2	12 ± 1	31 ± 10	8 ± 0
Option 2	$\not{E}_T > 20$ GeV	188 ± 1	83 ± 4	34 ± 2	48 ± 15	9 ± 0
	Z Veto	186 ± 1	83 ± 4	29 ± 2	48 ± 15	9 ± 0
	Conv. Veto	183 ± 1	80 ± 4	28 ± 1	30 ± 14	9 ± 0

QCD - ABCD method

- Used in muons+jets analysis.
- Assign a phase space with two (uncorrelated) variables.
- Define four regions (A, B, C, D):
  - Each dominated by signal or (QCD) background.
  - Region A is the signal region.
  - Assume ratio of number of events in regions is: $N_A/N_B = N_C/N_D$
- Therefore $N_A = N_B \times N_C / N_D$



QCD - ABCD method

- Variables used:
  - Combined relative isolation of muon:
    RelIso' = 1/(1+RelIso)
  - muon impact parameter significance:
    significance(d_0) = $d_0/\sigma(d_0)$
    with respect to beam spot
- Produces results in good agreement.
- Boundary changes used to test stability and estimate uncertainty:
- Estimated conservatively as 50%.

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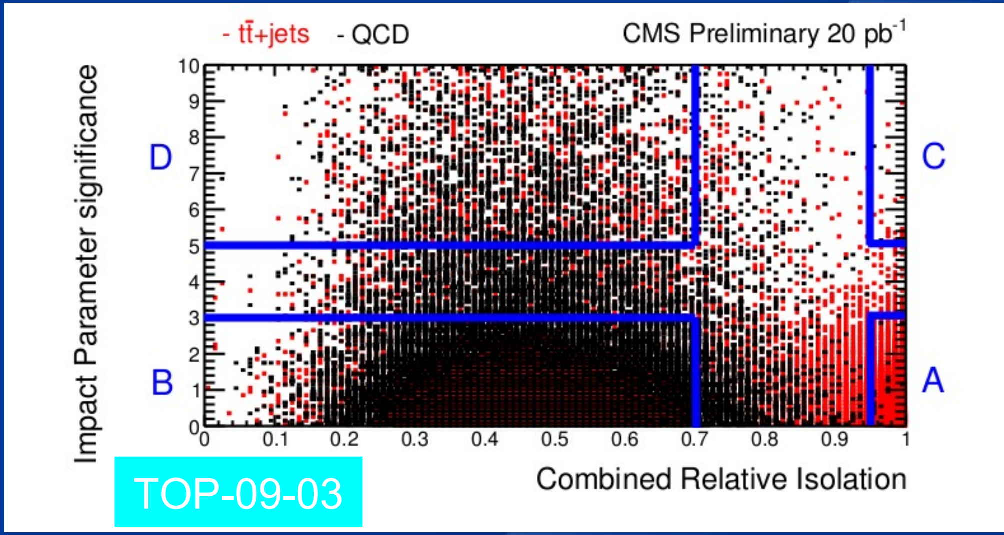
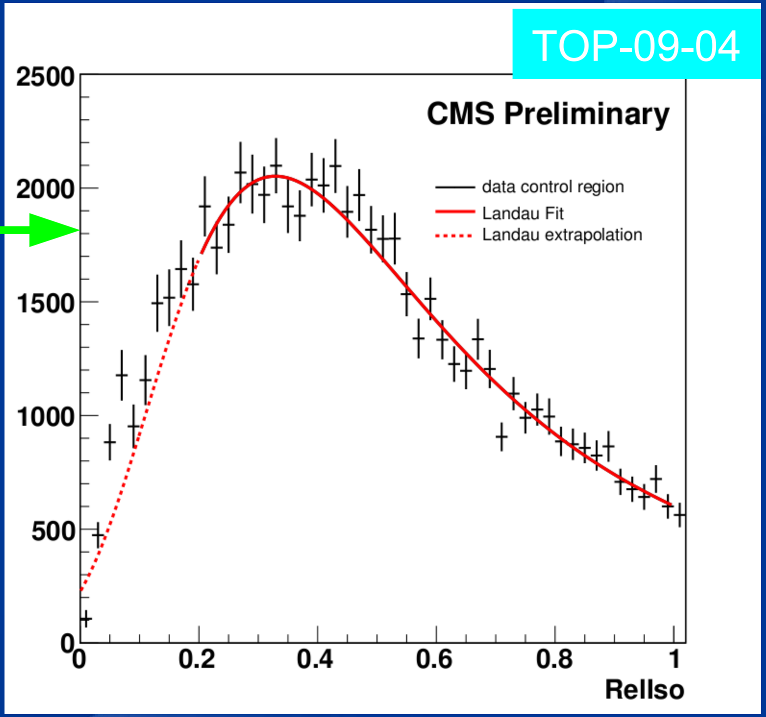
N_A → N(QCD) Estimated

Jets	N(QCD) Predicted	N_B	N_C	N_D	N(QCD) Estimated
2	327	86625	61	16240	325 ± 26
3	53	24216	10	5058	48 ± 9
≥ 4	7	5345	3	1148	12 ± 5



QCD - RelIso extrapolation

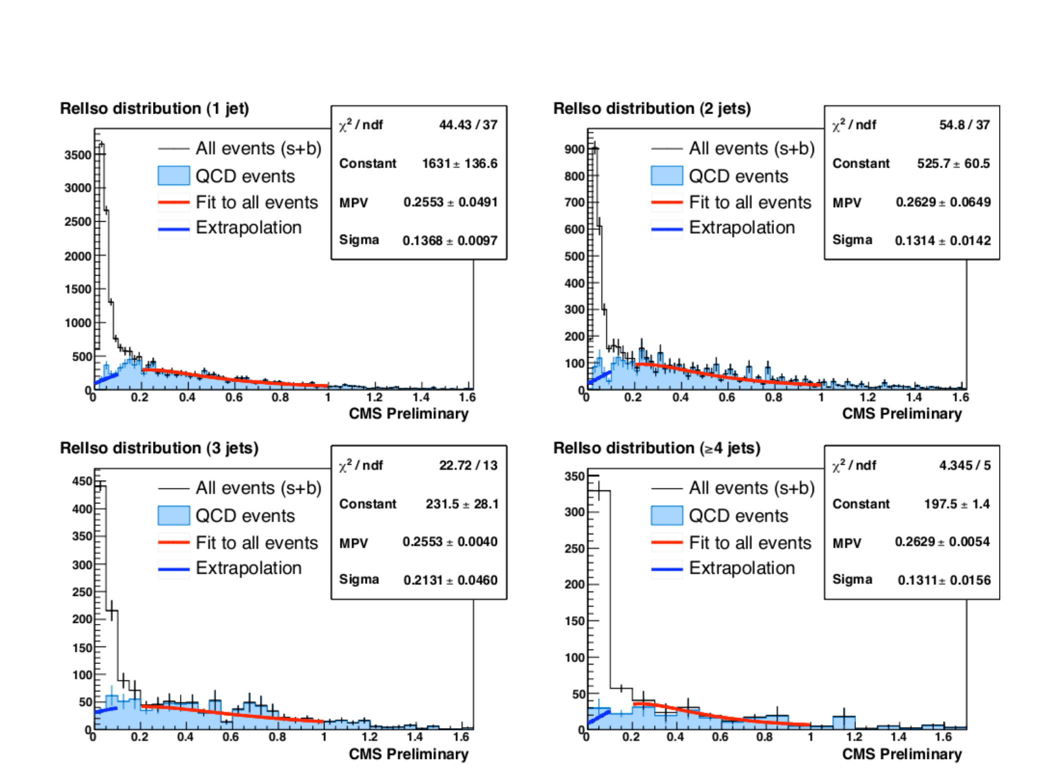
- Used by both electron+jets and muon+jets channels.
- For electron+jets channel:
  - RelIso = $(I_{tracker} + I_{ecal} + I_{hcal})/E_T$
- Signal (and non-QCD backgrounds) region: RelIso < 0.1
- Use higher values as a control region.
  - Extrapolate from background control region into signal region.
- Test various functional forms on pure QCD sample:
  - invert Missing E_T selection.
  - loosen electron selection.
  - tighten Z veto.
  - Apply H_T selection



H_T = scalar sum jet E_T, electron E_T, missing E_T.

QCD - RelIso extrapolation

- Landau function gave best fit.
  - This is used to fit main RelIso dist^n.
  - No physical motivation.
- Very few events with 3 or 4 selected jets:
  - Fix mean peak value from 1 and 2 jet fits.
  - Improves stability.
- A 50% total uncertainty is applied to result.
- Results are systematically slightly low:
  - remaining conversions are the major factor.



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	Signal region	
	True QCD $20\ pb^{-1}$	Estimate $20\ pb^{-1}$
1j	1007 ± 102	815
2j	301 ± 47	227
3j	96 ± 28	71
$\geq$4j	30 ± 14	17

QCD - RelIso extrapolation

- RelIso extrapolation in mu+jets channel:
- Similar to e+jets channel:
  - Narrower signal region (RelIso <0.05).
  - Wider control region.
  - Landau again gives best fit.
- RelIso' also studied using a Gaussian fit.
- Stability studied by varying signal and region ranges.
- From studies a conservative uncertainty of 50% is placed on the extrapolation.

Jets	N(QCD) Predicted	N(QCD) Estimated
2	327	378 ± 82
3	53	47 ± 24
≥ 4	7	13 ± 7

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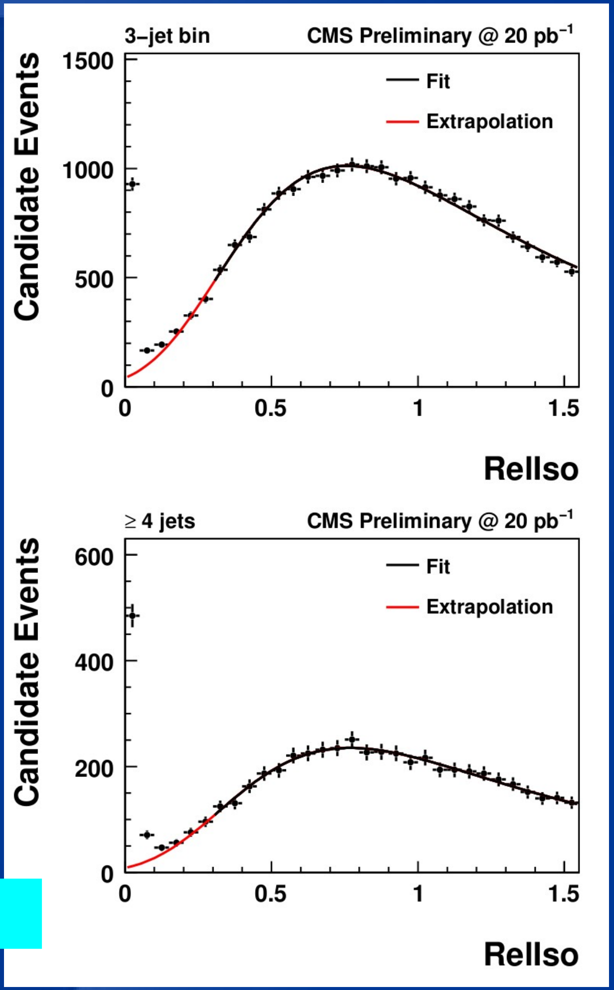
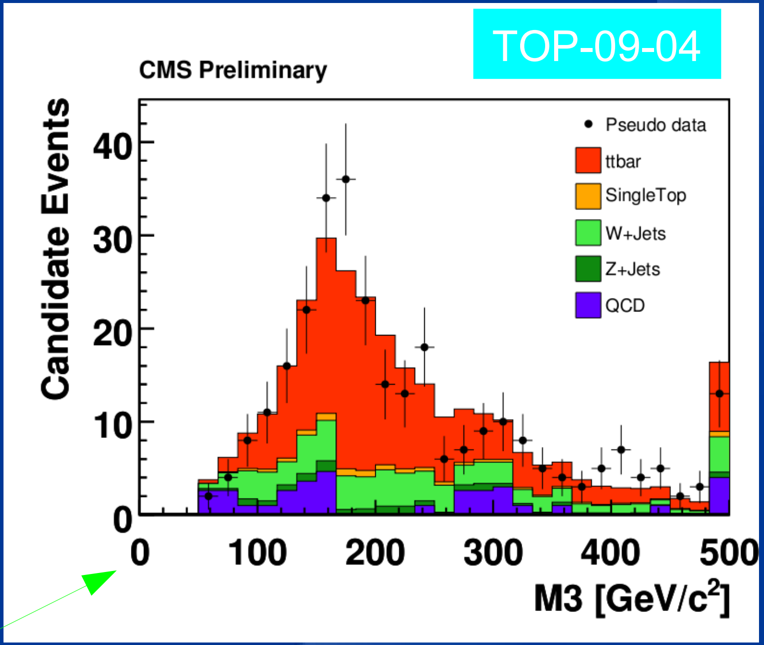


W+jets - M3

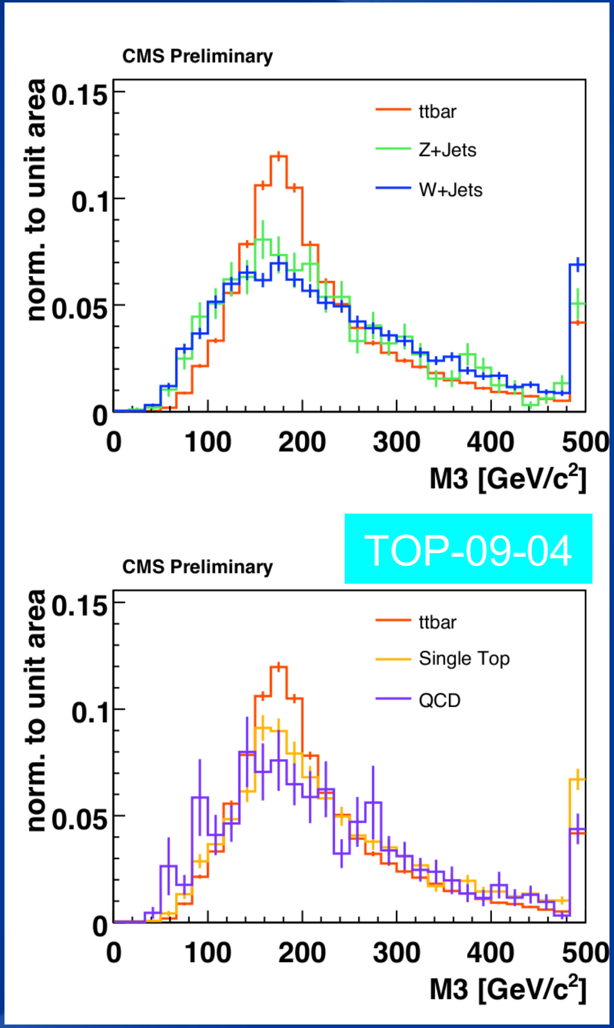
- W+jets is the dominant remaining background.
  - It can be separated from ttbar by performing a fit to a discriminating variable distribution.
  - Remaining Z+jets background may be included with W+jets.
- One discriminating variable is “M3”:
  - invariant mass of the 3 jet combination, with highest p_T (vector sum).
- Approximates top mass
  - should peak near m_{top} for $t\bar{t}$.



e+jets M3 distribution

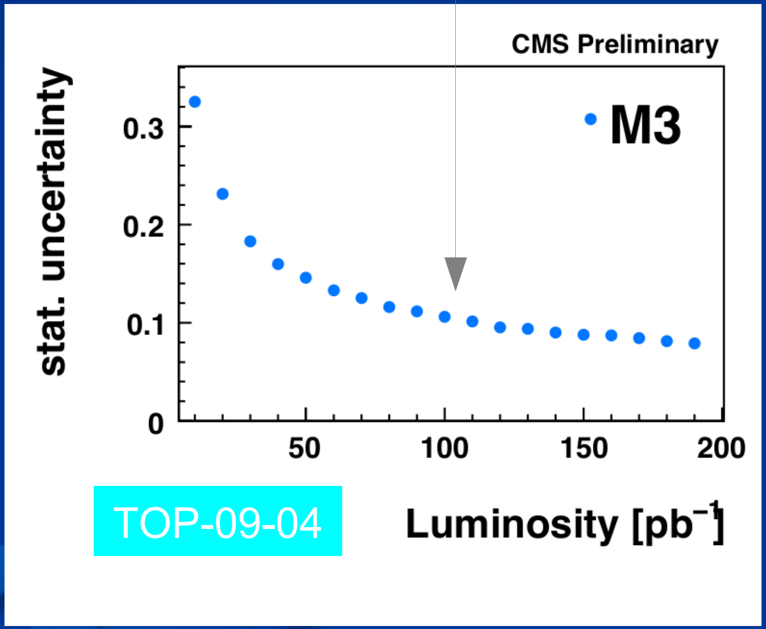
W+jets - M3 fit - electron channel

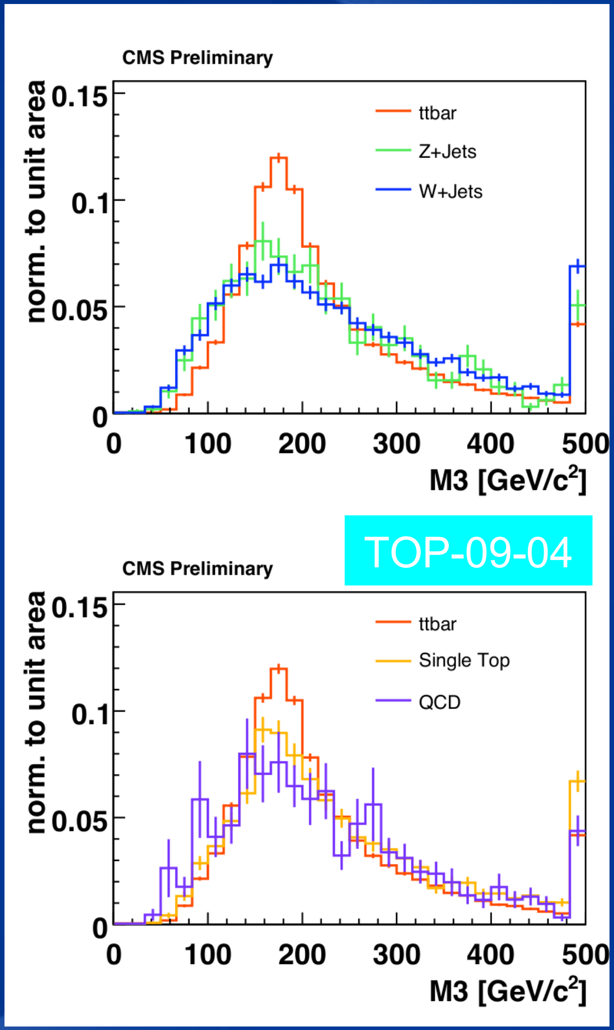
- Perform a fit to 4 components:
  - ttbar, W(Z)+jets, QCD, and single top.
  - QCD template can be taken from data (control region).
  - Others taken from simulation.
  - W(Z)+jets shape could be taken from Z+jets data, but not enough early on.
- QCD and single top contributions are constrained in the fit.
- N_{ttbar} and $N_{W/Z+jets}$ are extracted.
- pseudo-experiments are preformed to check for bias and estimate error.
  - Error estimated at 23% for $20pb^{-1}$.



W+jets - M3 fit - electron channel

~10% for $100pb^{-1}$

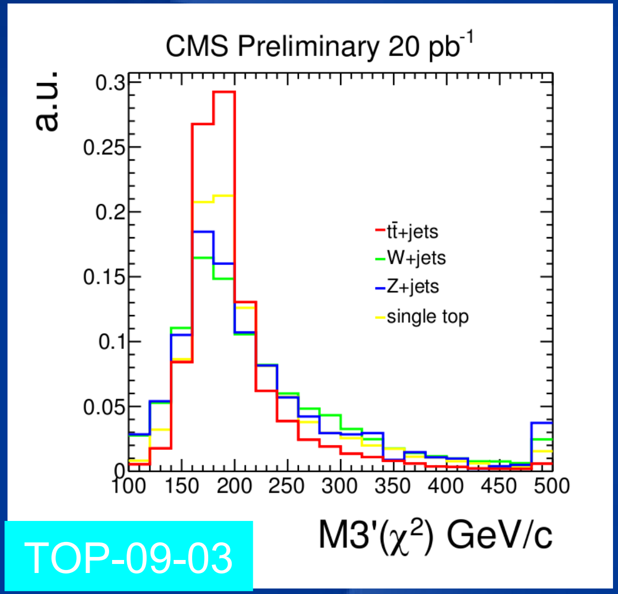




- pseudo-experiments are preformed to check for bias and estimate error.
  - Error estimated at 23% for $20pb^{-1}$.

W+jets - muon channel

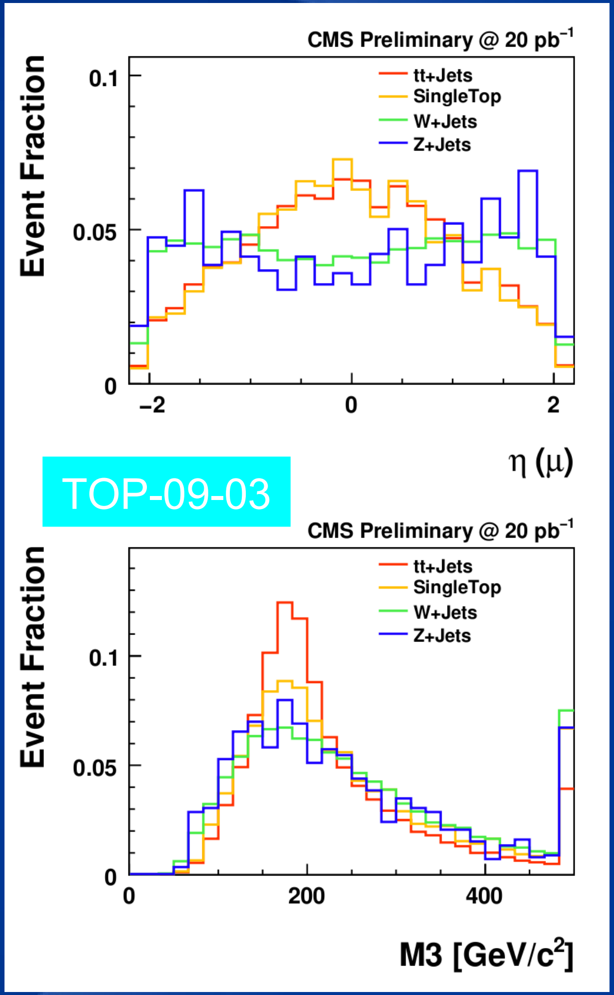
- Three discriminating variables tested:
  - $\eta(\mu)$, M3, and M3'.
- M3' is calculated using a χ^2 distribution:
- $\chi^2 = (m_{j1j2} - m_W)^2/\sigma^2_{jj} + (m_{j1j2j3} - m_t)^2/\sigma^2_{jjj} + (m_{\mu\nu j4} - m_t)^2/\sigma^2_{\mu\nu j}$
- σ_x are resolutions of each jet combination.
- Requires MET to calculate $m_{\mu\nu j4}$.



- χ^2 for Combinations of up to 7 jets calculated.
- M3' is the invariant mass of the three jets forming the hadronic component of the χ^2 for the lowest calculated χ^2.
- Fit carried out using M3' distributions as templates.
- Pseudo experiments used to evaluate an uncertainty of ±12%.

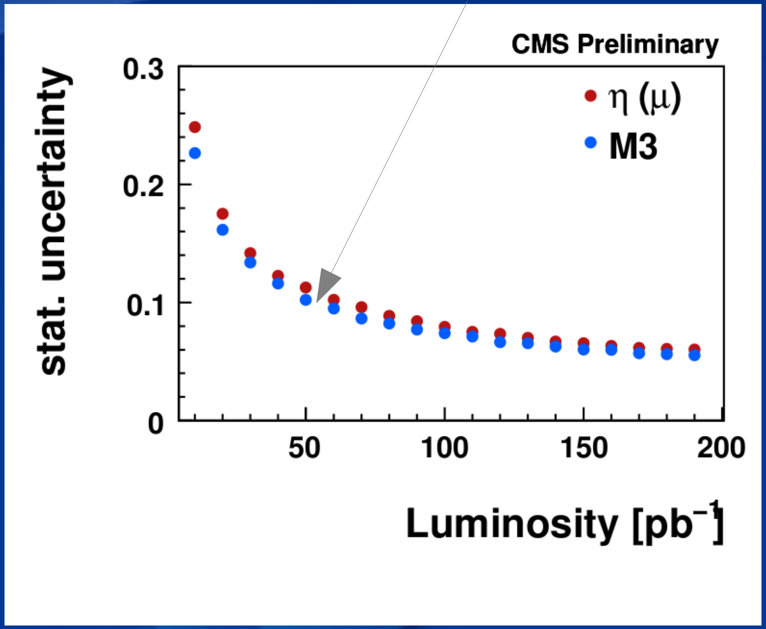
W+jets - muon channel

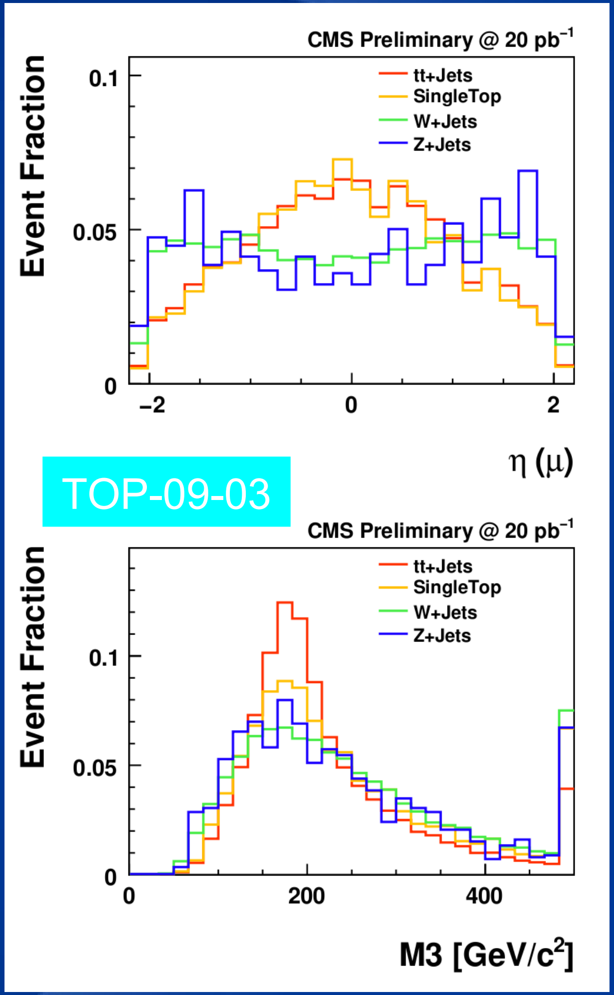
- Three discriminating variables tested:
  - $\eta(\mu)$, M3, and M3'.
- Three components fitted:
  - ttbar, single top, and W+jets (including Z+jets and QCD).
  - Taken from simulation.
  - Could be taken from lower jet multiplicities with enough data.
  - Single top constrained.
- Pseudo experiments used to check method, and estimate uncertainty.
  - Uncertainty estimated to be ±16% for M3, and ±18% for $\eta(\mu)$.



W+jets - muon channel

~10% at $50pb^{-1}$





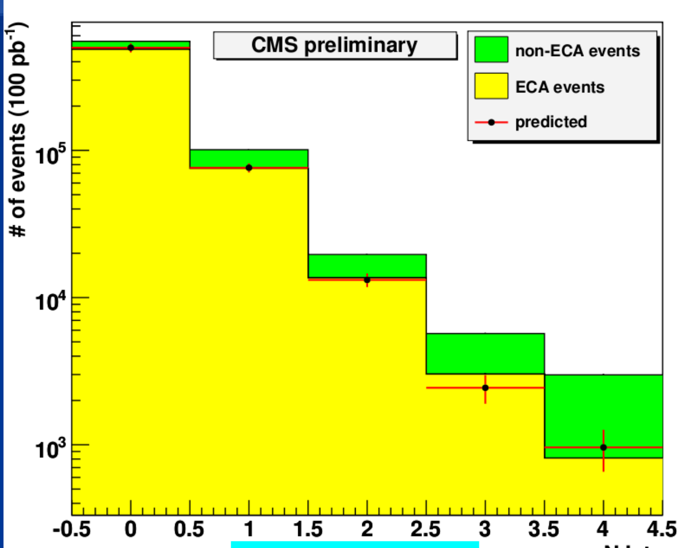
- Pseudo experiments used to check method, and estimate uncertainty.
  - Uncertainty estimated to be ±16% for M3, and ±18% for η(μ).

W+jets - Charge Asymmetry

- Signal $t\bar{t}$ is charge symmetric:
  - Consider W+jets with other asymmetric backgrounds (Vbb, single top (s and t-channels) as “Events leading to Charge Asymmetry”.
- Total ECAs:
  - $(N_+ + N_-)_{data} = R_\pm(W) \times (N_+ - N_-)_{data}$
  - $R_\pm(W)$ corresponds to inverse of W charge asymmetry:
    - $$R_\pm(W) = \frac{N_{W+} + N_{W-}}{N_{W+} + N_{W-}} = \frac{A_+\sigma_{W+} + A_-\sigma_{W-}}{A_+\sigma_{W+} + A_-\sigma_{W-}}$$
  - $\sigma_{+(-)}$: $W^{+(-)}$ cross section, $A_{+(-)}$: geometrical acceptance.
- Assume ECAs dominated by W+jets, and $R_\pm$ is same for all ECAs and W+jets.

W+jets - Charge Asymmetry

- $(N_+ - N_-)_{data}$ will have a large statistical uncertainty.
  - Method studied for $100pb^{-1}$.
- $(N_+ - N_-)_{data}$ estimated from pseudo data, counting muon and anti-muon events.
- $R_\pm$ estimated from statistically independent W+jets sample.
- In data an independent sample may be found (low jet multiplicities).
- Statistically dominated:
  - systematic (PDF and ECA components) ~11%.
- Total uncertainty ~30% for $100pb^{-1}$.



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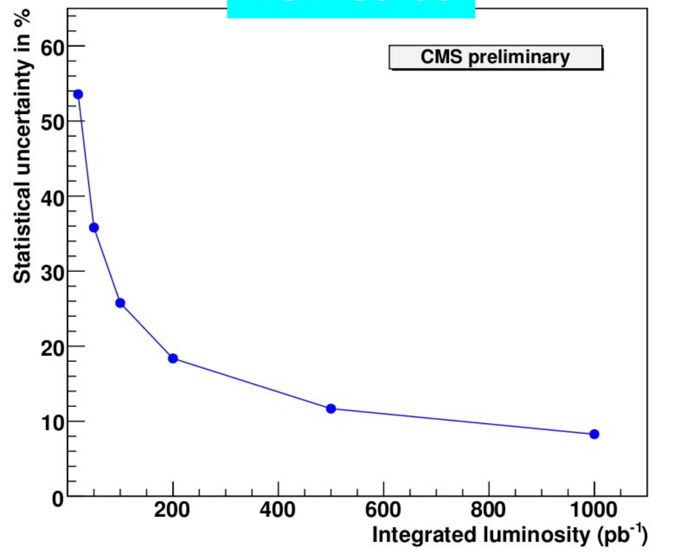
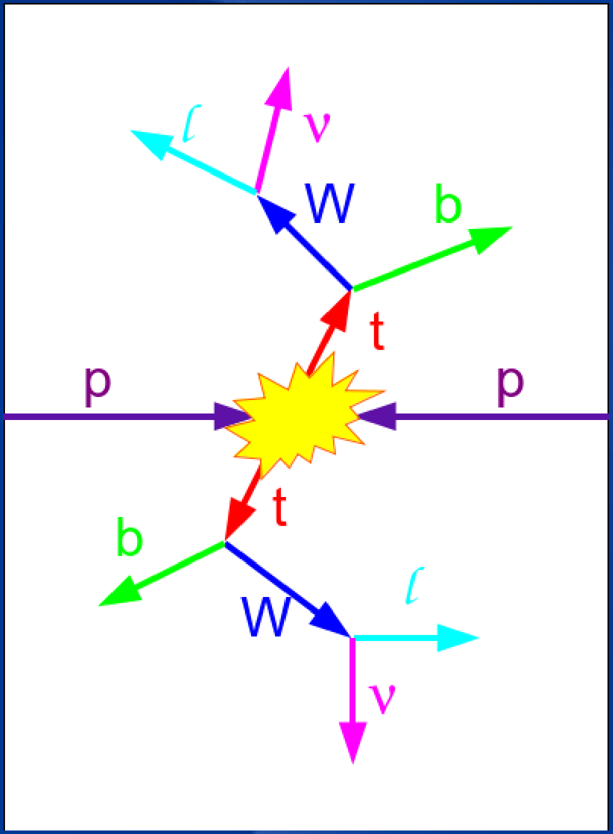


Dileptonic

Selecting Di-leptonic events

- 2 leptons (μ or e):
  - single electron (E_T>15GeV) or single muon (p_T>9GeV/c) trigger,
  - p_T >20GeV, $|\eta|$<2.4, opposite signs.
  - Individual relative isolations*: I_{trk} > 0.9, I_{cal} > 0.9 (0.8) for μ (e).
- 2 (or more) jets:
  - p_T>30, $|\eta|$<2.4
  - no b-jet identification.
- Missing E_T:
  - ME_T > 20/30 GeV (decay channel dependent).

* Individual relative isolation
  = $p_T/(p_T$ + absolute_isolation)



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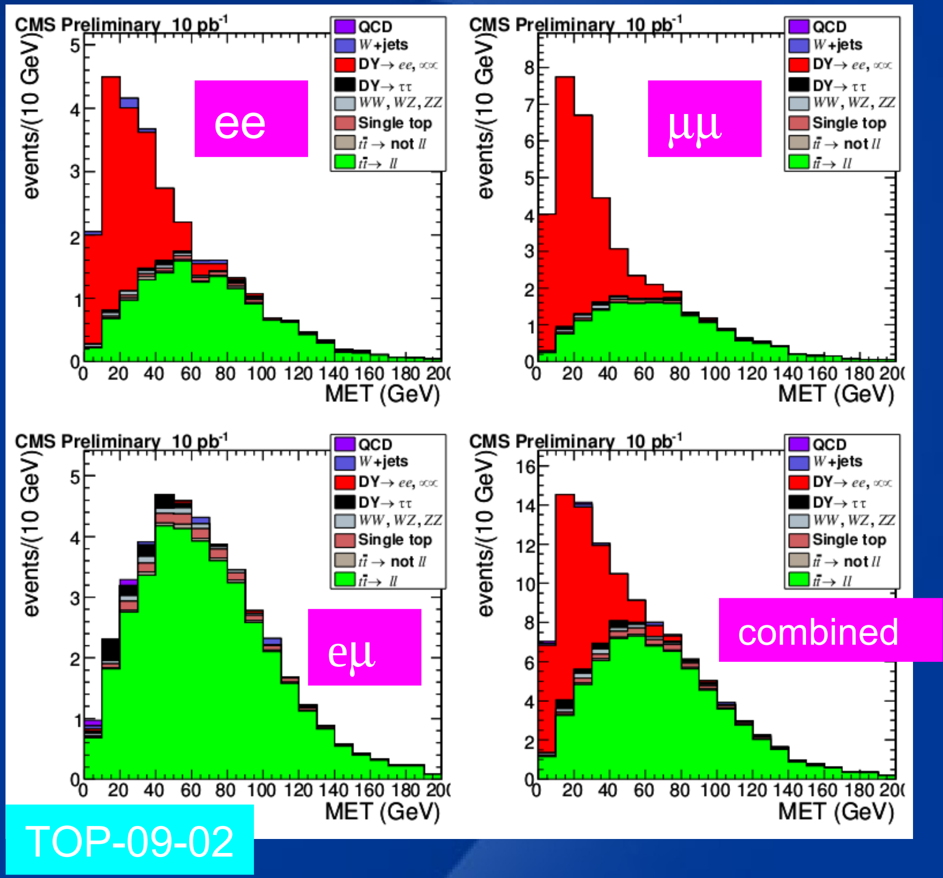
Selecting Di-leptonic events

- Three channels:
  - e^+e^-, $e^\pm\mu^\mp$, $\mu^+\mu^-$
- In ee and μμ,
  - Z veto: $|m_{\ell\ell} - m_Z| < 15\text{GeV}/c^2$
  - Missing E^T > 30GeV.
- eμ is far cleaner:
  - looser missing E_T cut.
- Dominant background is from Drell-Yan(DY) + jets.



Selecting Di-leptonic events

- Three channels:
  - e^+e^-, $e^{\pm}\mu^{\mp}$, $\mu^+\mu^-$

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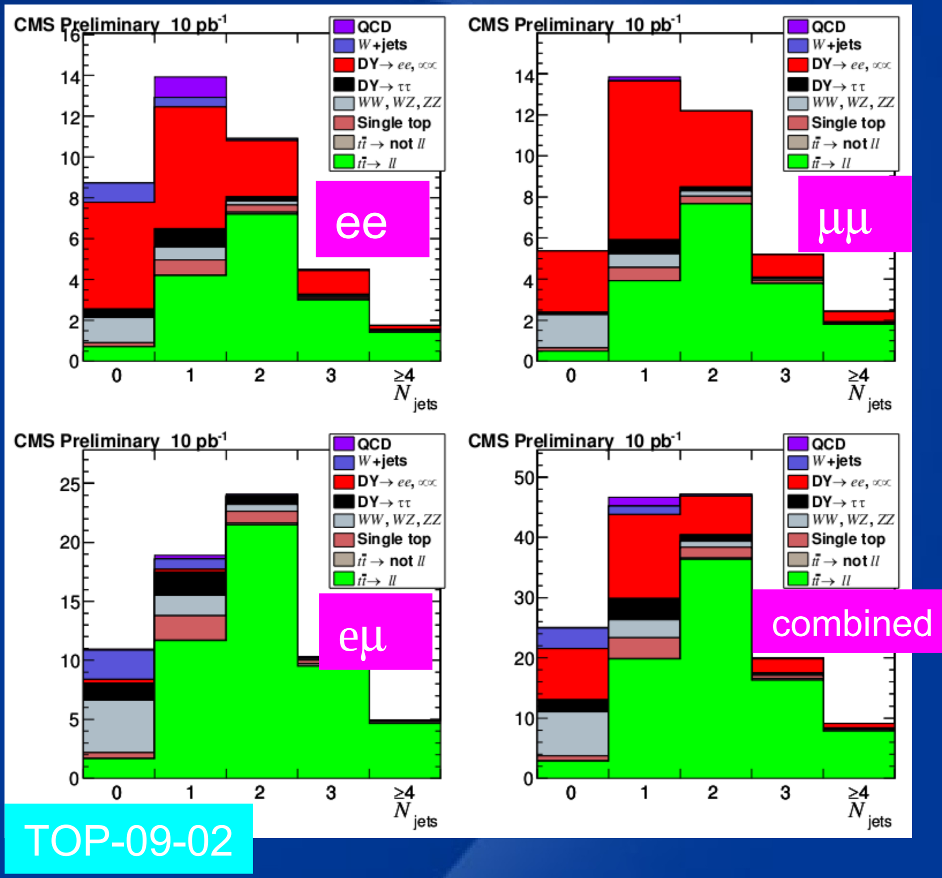
	Main selection		
	e^+e^-	$\mu^+\mu^-$	$e^{\pm}\mu^{\mp}$
$t\bar{t} \to \ell\ell$	11.6 ± 0.2	13.2 ± 0.2	35.6 ± 0.4
other $t\bar{t}$	0.21 ± 0.03	0.04 ± 0.01	0.46 ± 0.04
Single top	0.46 ± 0.03	0.56 ± 0.03	1.40 ± 0.06
$WW/WZ/ZZ$	0.26 ± 0.02	0.33 ± 0.03	0.71 ± 0.05
DY$\to \tau\tau$ + jets	0.3 ± 0.1	0.3 ± 0.1	0.7 ± 0.2
DY$\to ee/\mu\mu$ + jets	4.1 ± 0.4	5.3 ± 0.4	0.08 ± 0.05
W + jets	0.2 ± 0.1	< 0.1	0.3 ± 0.1
QCD	< 1	< 0.4	< 0.4
Total backgrounds	5.5 ± 0.4	6.6 ± 0.4	3.7 ± 0.2
Data driven fakes	1.1 ± 0.6	0.8 ± 0.4	2.5 ± 1.2
Data driven DY	4.0 ± 1.3	5.1 ± 1.6	

- Dominant background is from Drell-Yan(DY) + jets.



Drell-Yan + jets

- DY events selected due to mis-measurement of missing E_T.
- To estimate contribution, use dileptonic events $76 < m_{\ell\ell} < 106$ GeV/c^2.
  - Estimate $R_{out/in} = N^{in}_{DY\ MC}/N^{out}_{DY\ MC}$ fraction of DY events inside the range, relative to outside, directly from simulation.
  - $N^{out}_{DY}{}^{(est)} = R_{out/in} \times N^{in}_{DYdata}$ then estimates the number of DY expected.
    - Non-DY contribution inside corrected for with eμ events.
    - Relies on simulated events, but not jet and MET properties.
- Modified selection, and different simulated samples used to estimate systematic uncertainty of 30%

Fake leptons

- Use events that pass a looser selection:
  - loosen lepton isolation (calorimeter and tracker) requirements.
- Fake Ratio (FR) is number of these events that pass main selection.
- Scale number of events passing loose selection, and failing main selection by FR/(1 – FR):
  - obtain estimate of number of fake leptons.
  - Small biases due to double counting and trigger differences.
- Uncertainty estimated from statistics of samples used, and variation in different jet multiplicities:
  - gives overall systematic uncertainty estimate of ±50%.
  - From 0.8±0.4 events in mm, to 2.5±1.2 events in em.

Summary

- Early measurements of $t\bar{t}$ cross-section are possible using some data driven methods to estimate backgrounds.
- e+jets and μ+jets decay channels, dominant backgrounds:
  – QCD - estimated from data driven methods, uncertainty ~50%.
  – W+jets - estimated from template fits, uncertainty 15-25%.
- For dilepton decay channel:
  – Drell-Yan major background for ee and μμ; estimated uncertainty ~30%.
  – Fake lepton background, uncertainty ~50%.
- Work is ongoing - these methods will soon meet data for the first time...

Backup

Conversion Algorithm

- When a photon converts the electron (positron) will bend in opposite directions in the magnetic field, in the ϕ plane.
  - Algorithm looks for pairs of tracks with opposite charges:
  - Calculate closest 2D distance between them in ϕ plane.
  - Veto events where distance < 0.04 cm and $|\Delta \cot \theta| < 0.03$
- Efficiency is ~50%, with a signal loss of 1.7% from ttbar and QCD MC samples.