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Topological search for like-sign top quark pairs at CMS

- motivated by FCNC and TechniColor models
- also a signal for gluino pair production
- based on a good performance of lepton isolation
- CMS analysis based on full simulation
- result: a level of 1pb visible at 30fb-1

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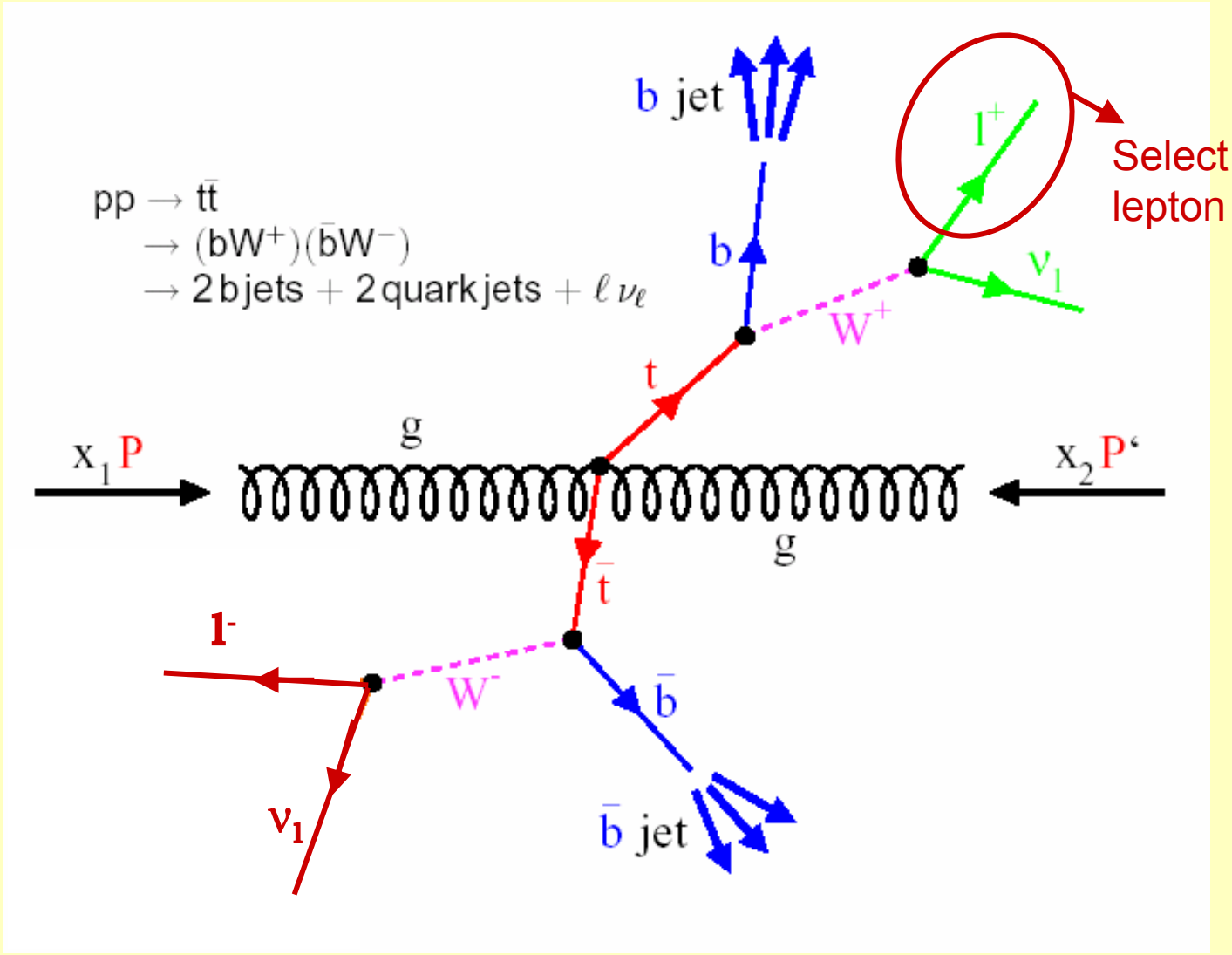
Topological search

- **Analysis strategy: search for pp✹tt excess above Standard Model pp✹ttbar**
  - *select di-leptonic top quark pairs (lepton=muon or electron) ✹ σ_{LO}~28pb*
  - *count the events with equal and opposite charge leptons*
  - *take the ratio **R = #(like-sign) / #(opposite-sign)** ✹ reduce systematics*
  - *this results in a R value for Standard Model only processes*
  - *determine the cross section of* pp✹tt *needed for a 5σ deviation*
- **Di-lepton top quark pairs have a clear topology**
  - *2 b-jet and 2 isolated leptons with a different charge*
  - *they can be selected with a large S/N*
  - *exploit the performance of the lepton isolation criteria*
- **Motivation & same topologies expected in (close to model independent):**
  - *FCNC (in SM suppressed, Z' bosons in Topcolor assisted Technicolor (TC2))*
    - → F.Larios and F.Penunuri, hep-ph/0311056
    - → Yu.P.Gouz and S.R.Slabospitsky, hep-ph/9811330
  - *from top- and techni-pion in TC2 models*
    - → C-X.Yue et al., hep-ph/0601058
  - *in MSSM from for example gluino pairs*
    - → S.Kraml and A.R.Raklev, hep-ph/0512284
    - → A.Alves, O.Eboli and T.Plehn, hep-ph/0605067

Simulated events samples used



Simulated events samples used

- **All based on full GEANT4 simulation (*discovery plots are made for 30 fb^{-1}*)**

Low lumi Pile-Up	Number of events	Int.Luminosity fb^{-1}	Cross-section pb
$t\bar{t} \to bWbW \to b\mu^{\pm}\nu_{\mu}b\mu^{\mp}\nu_{\mu}$	99.3k	14.36	6.91
$t\bar{t} \to bW\bar{b}W \to be^{\pm}\nu_{e}\bar{b}e^{\mp}\nu_{e}$	99.3k	14.36	6.91
$t\bar{t} \to bW\bar{b}W \to be^{\pm}\nu_{e}\bar{b}\mu^{\mp}\nu_{\mu}$	198.6k	14.36	13.8
$t\bar{t} \to bW\bar{b}W \to \tau + X$	492.4k	14.23	34.6
Other $t\bar{t}$ decays	1778.7k	3.66	498.8
WW	459.7k	2.42	190.0
$Z + jets$	86.7k	0.15	575.7

  - *small Z+jets and WW samples → factorized efficiency of selection cuts*
  - *Drell-Yan processes are found to be neglegible*

- **three di-lepton channel used**
  - *di-muon, di-electron, muon-electron*
  - *non-overlapping by construction of the event selection*

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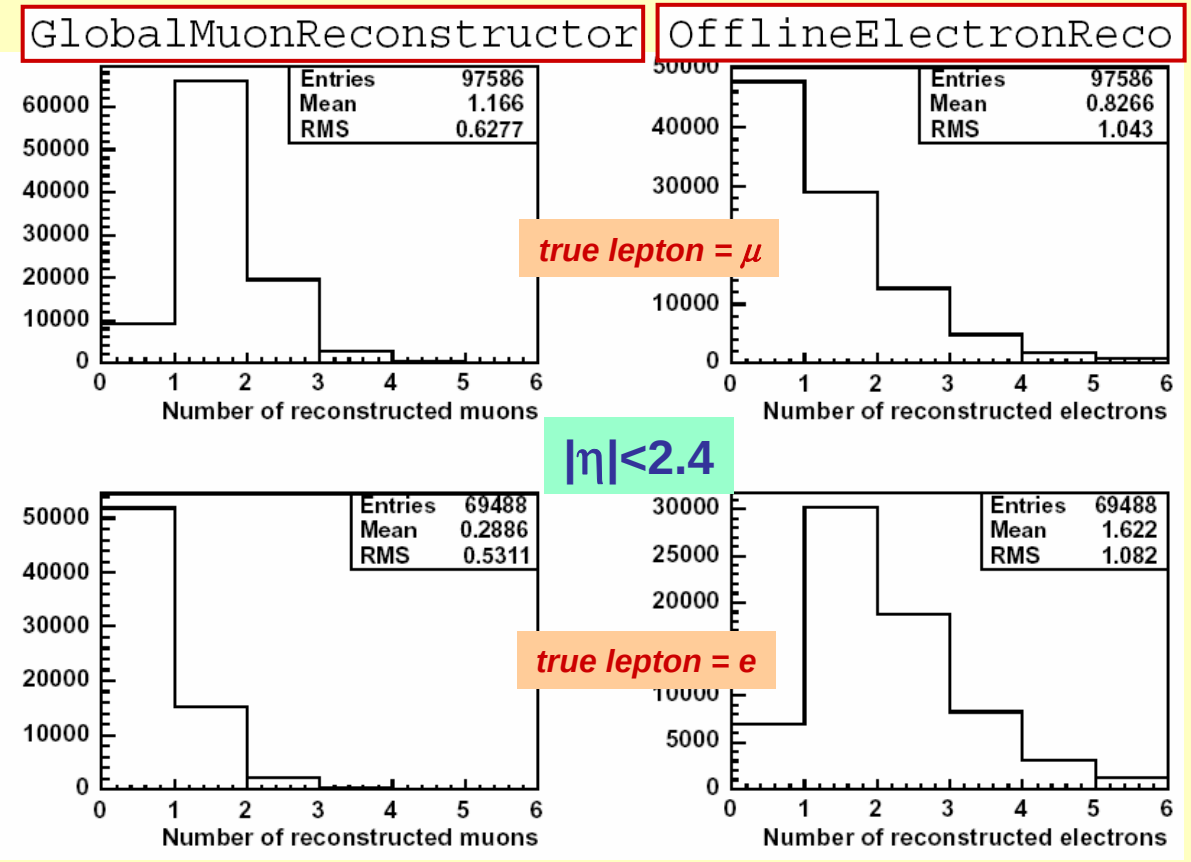
Reconstruction tools and event selection

- **Jets**
  - *reconstructed with the iterative cone algorithm (R=0.5)*
  - *calorimeter* Towers *above thresholds (excl. lepton energy deposites!)*
  - *calibrated with the Monte Carlo based tools*
  - *reject jets not associated to the primary vertex*
  - *b-tagging via a combined b-tag discriminator (secondary vertex based)*
- **Trigger (L1 + HLT)**
  - *single-muon OR single-electron OR double-muon OR double-electron*
  - *88.4% ($\mu\mu$), 77.4% (ee), 79.2% (μe)*
- **Leptons**
  - *standard* MuonReconstructor *and* ElectronReconstructor
  - *selection of correct lepton via a combined likelihood (*CMS Note 2005-024*)*
  - *tracker isolation, calorimeter isolation, vertex matching, transverse momentum, angular distance to closest jet and for electrons only a variable reflecting the reconstruction quality of the electron*
- **Select the correct leptons in the final state !!**
  - *method designed on semi-leptonic ttbar events, but valied for di-lepton events*

Lepton Reconstruction

When reconstructing the leptons (e/μ) in the final state of $t\bar{t} \rightarrow bW\bar{b}W \rightarrow bq\bar{q}\bar{b}l\nu$ events, one receives several lepton candidates. Only one originates from the true W boson decay, the other could originate from fragmentation or being mis-identified (fake).



no significant effect on mean due to Pile-Up (low luminosity)

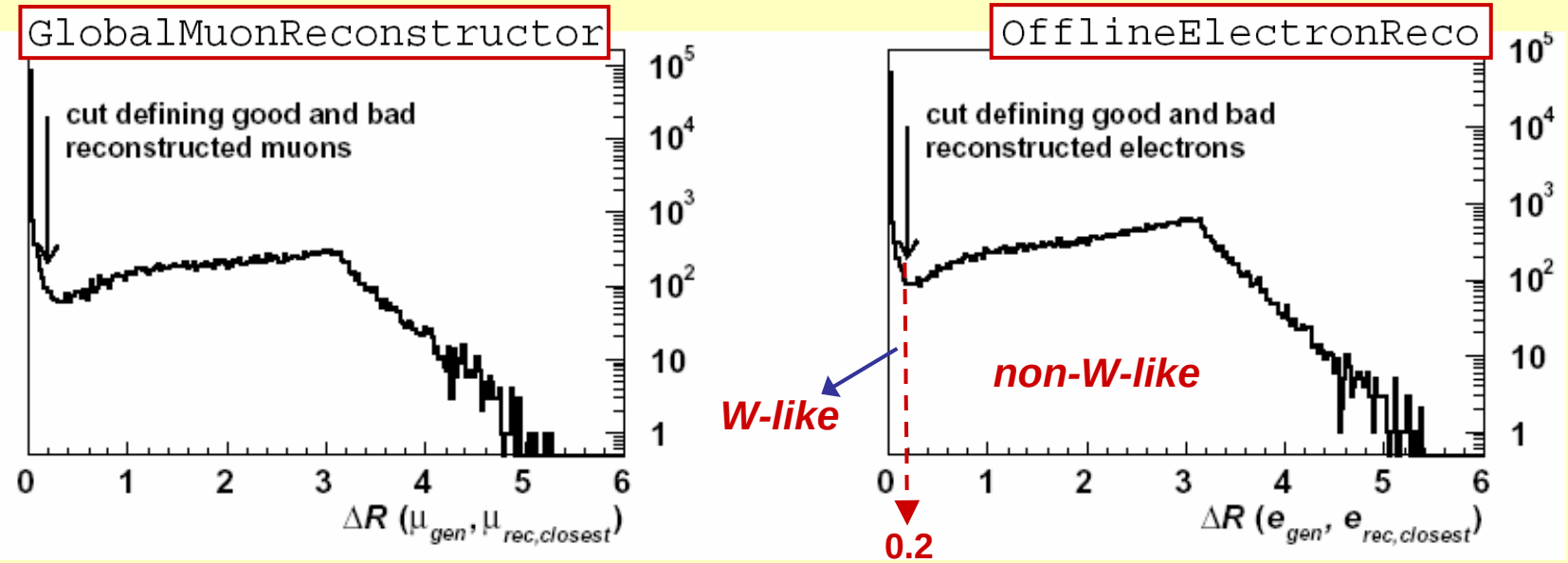
Divers aims:

1. Identify the true lepton amongst all object identified and reconstructed as leptons
2. Create an observable which differentiates between a W and QCD+fake created lepton

Lepton selection

- **Divide the reconstructed lepton candidates in the final state in two categories**
  - *correct matching with generator (W→lν)*
  - *wrong matching with generator (fakes or from b-quark fragmentation)*

Classify the reconstructed objects identified as leptons in two categories via the Monte Carlo truth information via $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$ for each lepton candidate.



- *distribution of the ΔR of all reconstructed lepton candidates (e/μ) in the final state*
- *robustness against the used metric was checked: (η,φ) versus (θ,φ)*

- **Matching with generator lepton : ΔR(η,φ) < 0.2**

Lepton selection

- **Several lepton related observables can differentiate both categories**
  - *transverse momentum of the reconstructed lepton candidate*
  - *isolation with respect to tracks*
  - *isolation with respect to calorimeter deposites*
  - *isolation with respect to jets*
  - *vertex matching*
  - *reconstruction quality variable for electrons (ECal versus HCal)*

- **Combine the information of the observables via a likelihood ratio method**
  Here we consider the PDF of the signal (s) and the background (b) for observable i

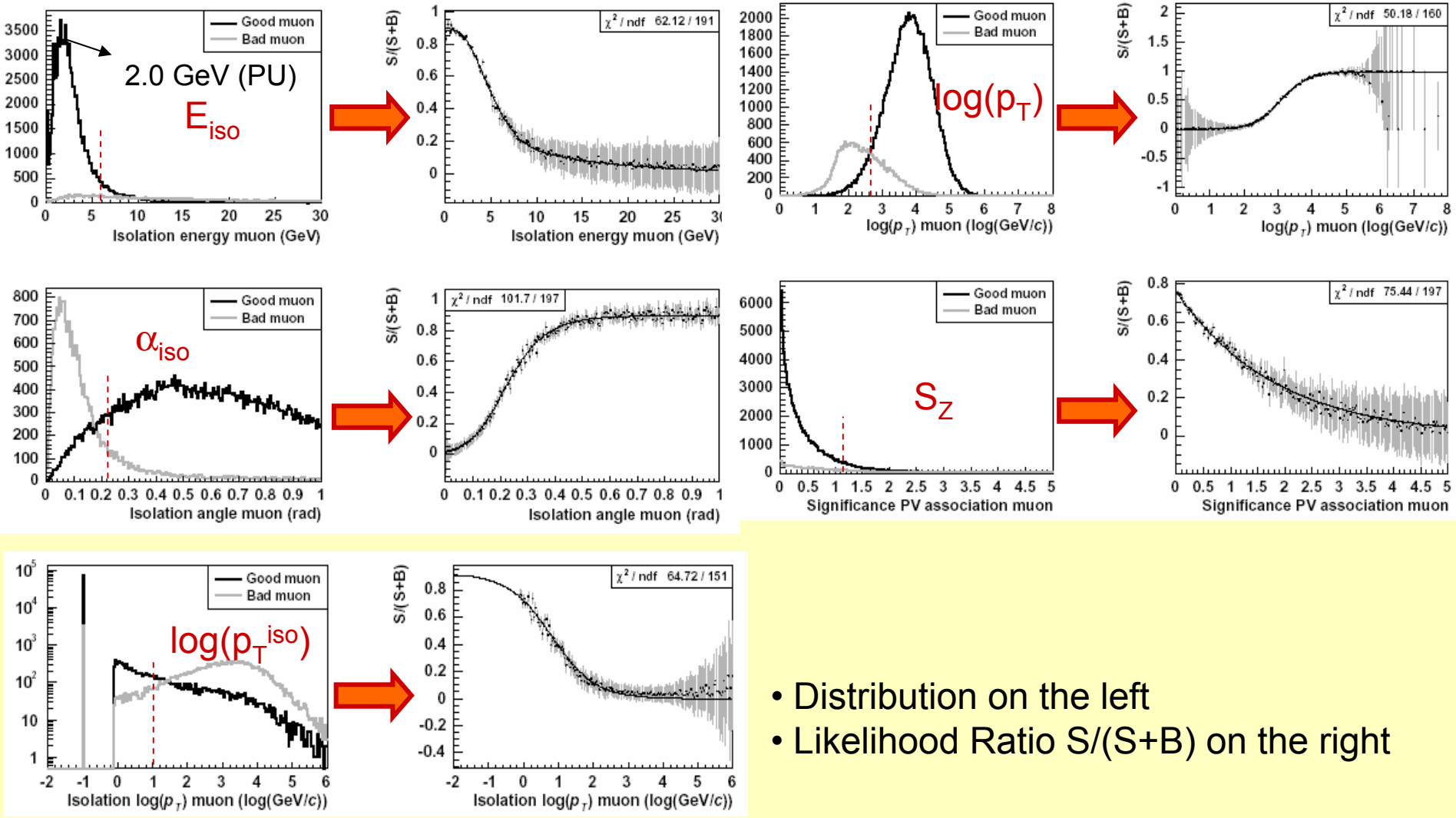
$$\mathcal{L}_i(x_i) = \frac{P_i^s(x_i)}{P_i^s(x_i) + P_i^b(x_i)}$$

These $\mathcal{L}_i$ function are fitted with a single or double sigmoid function. The information is combined with an ad-hoc formula to take into account the small correlations between the observables:

$$\mathcal{L}' = \prod_{i=1}^{5 \text{ or } 6} \mathcal{L}_i(x_i)^{\frac{1}{\sum_j |c_{ij}|}}$$

correlation between observable i and j

Lepton observables (muon)



- Distribution on the left
- Likelihood Ratio S/(S+B) on the right

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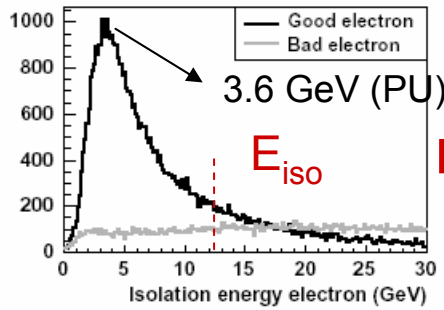
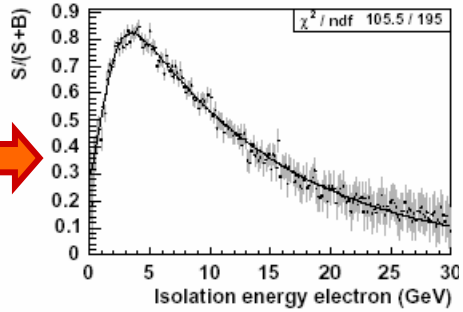
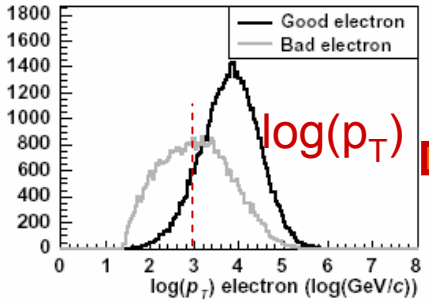
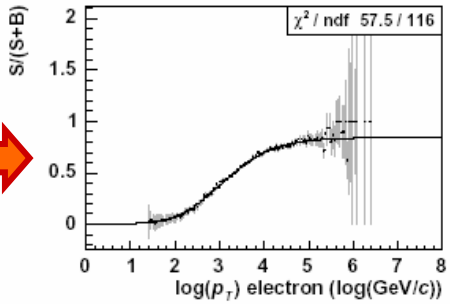
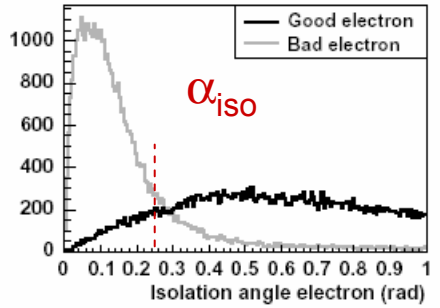
Lepton observables (electron)

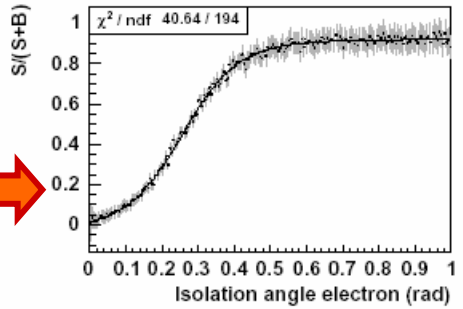


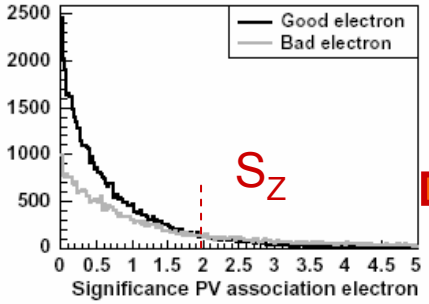


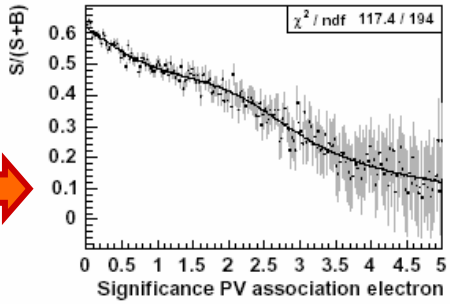


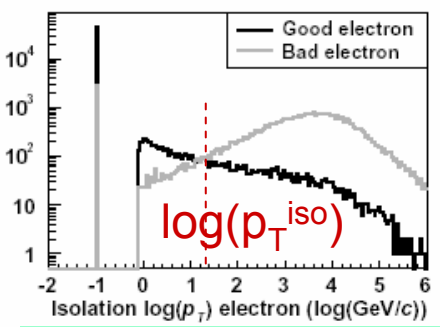


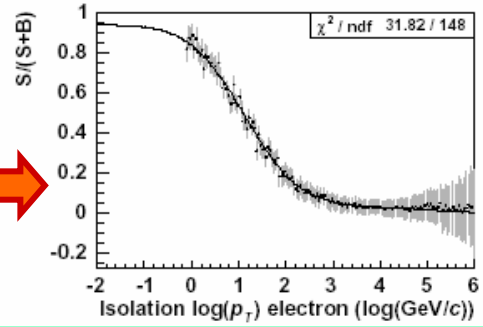








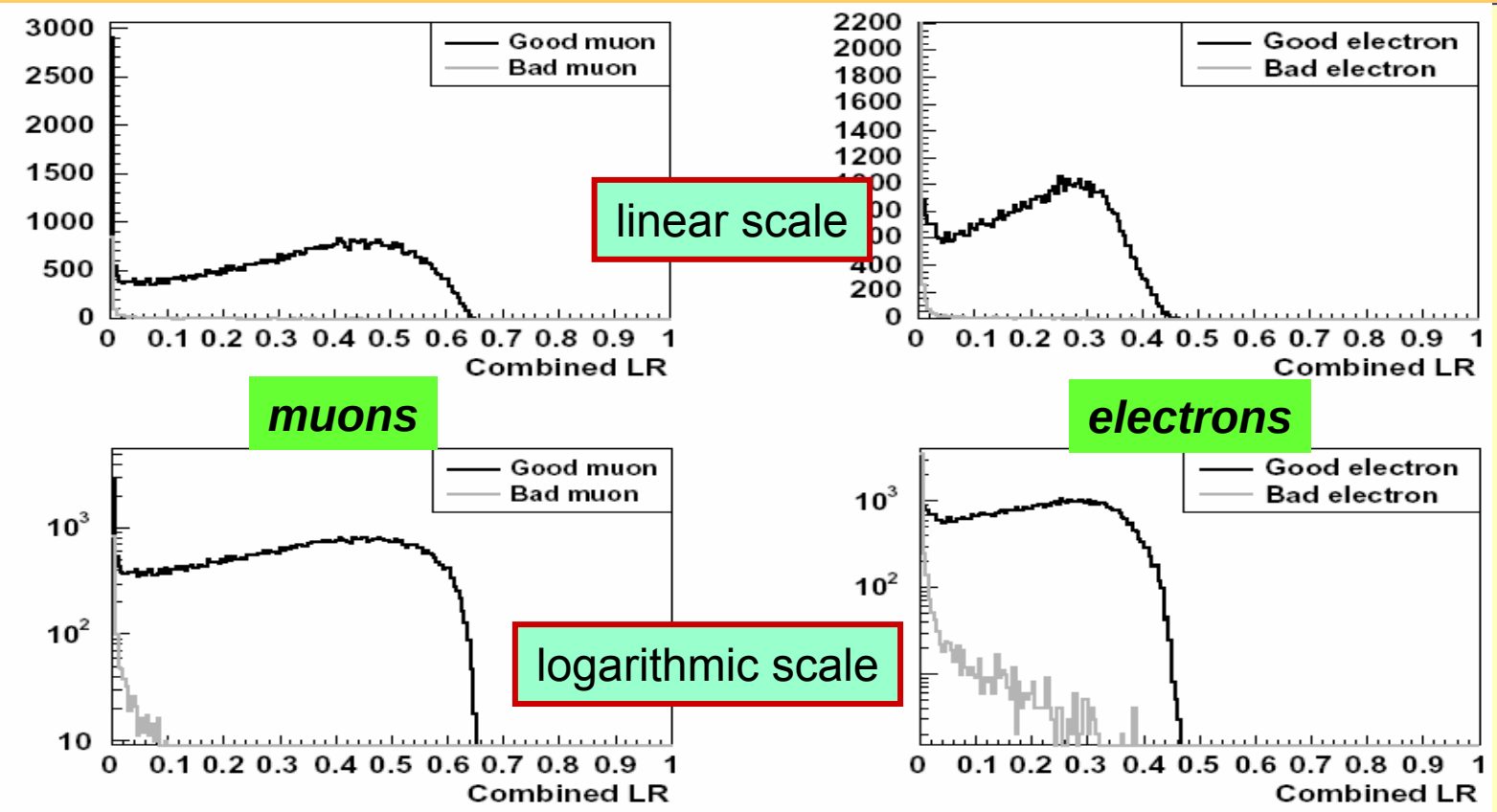




- Distribution on the left
- Likelihood Ratio S/(S+B) on the right

Same tendencies for electrons and muons, as expected

Combined likelihood



Correct lepton is the one with the highest Combined LR value

	without HLT				with HLT			
	no pile-up		with pile-up		no pile-up		with pile-up	
	e	μ	e	μ	e	μ	e	μ
correct electron selected	93.7	-	93.3	-	99.2	-	99.0	-
correct muon selected	-	97.3	-	97.9	-	98.4	-	98.9

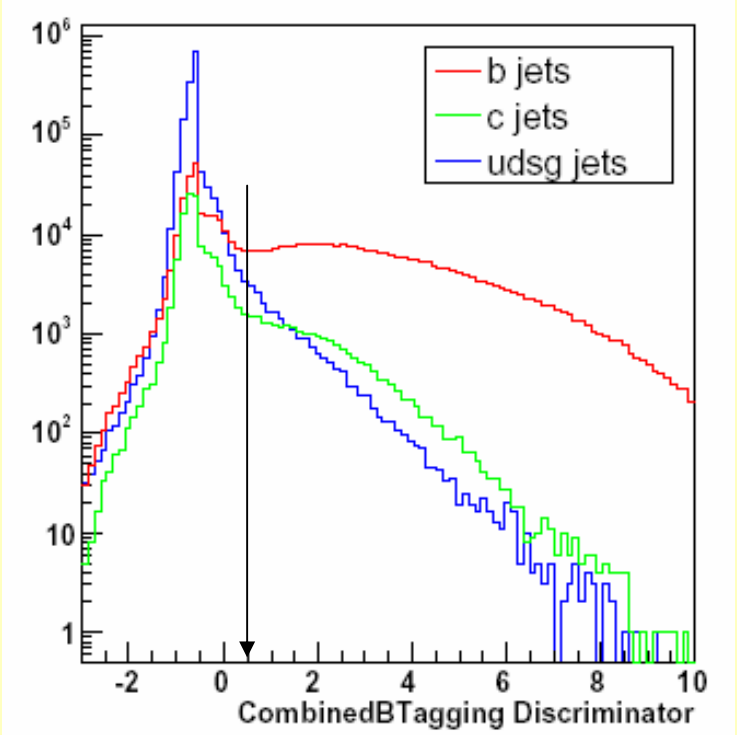
Event selection

- **Trigger (L1 + HLT)**
  - *single-muon OR single-electron OR double-muon OR double-electron*
  - *88.4% ($\mu\mu$), 77.4% (ee), 79.2% (μe)*

- **Event selection (1st part)**
  - *2 Iterative Cone jets :*
    E_T > 25 GeV and $|\eta|$<2.4 and b-tag >0.5

    (combined b-tag discriminant)
    (CMS Note 2006-014)

    $|\eta|$<2.4 = Central Tracker range

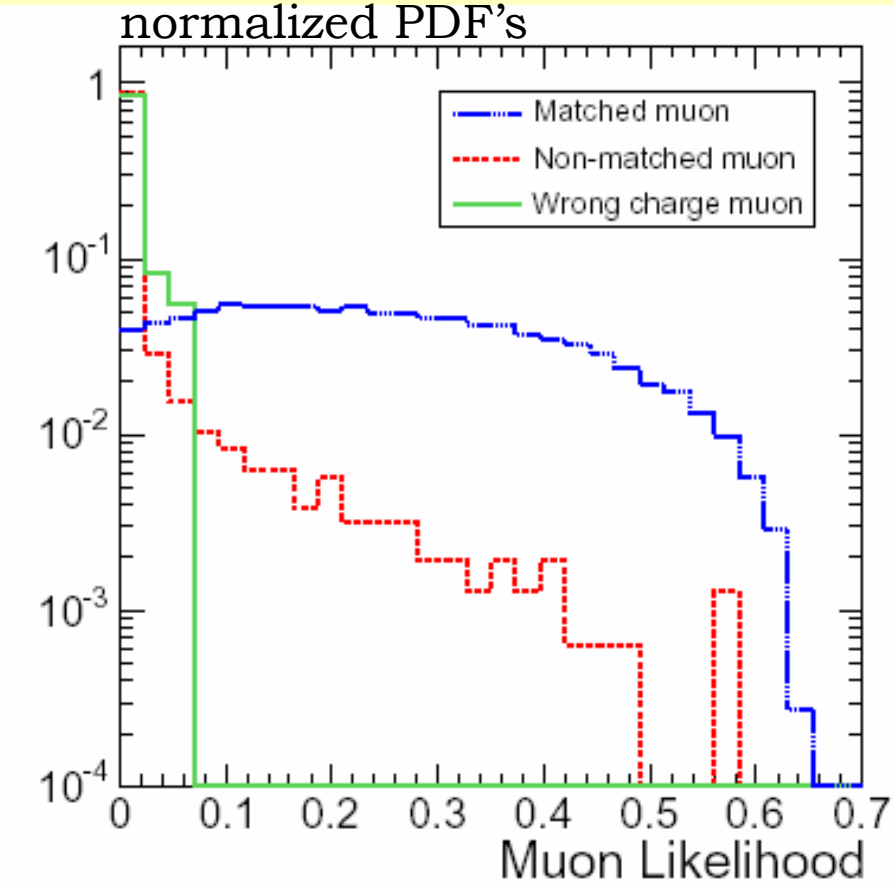


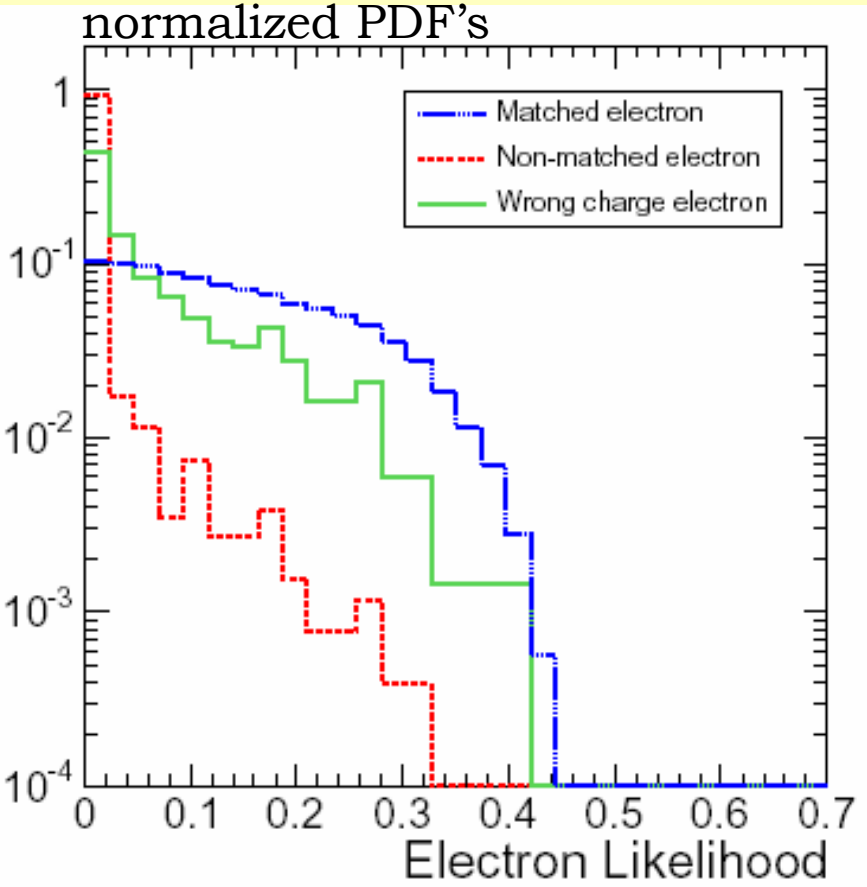
  - *2 selected leptons : p_T > 25 GeV and $|\eta|$<2.4*

- **Extra selection cuts on the quality of the selected leptons**
  - *this to purify the identification performance (same versus opposite sign !!)*
  - *not only the correct lepton has to be found, but also the correct charge*

Reconstruction tools and event selection

- **Event selection (2nd part) : cut on the likelihood observable L>0.05**





scaled to 1fb^{-1}

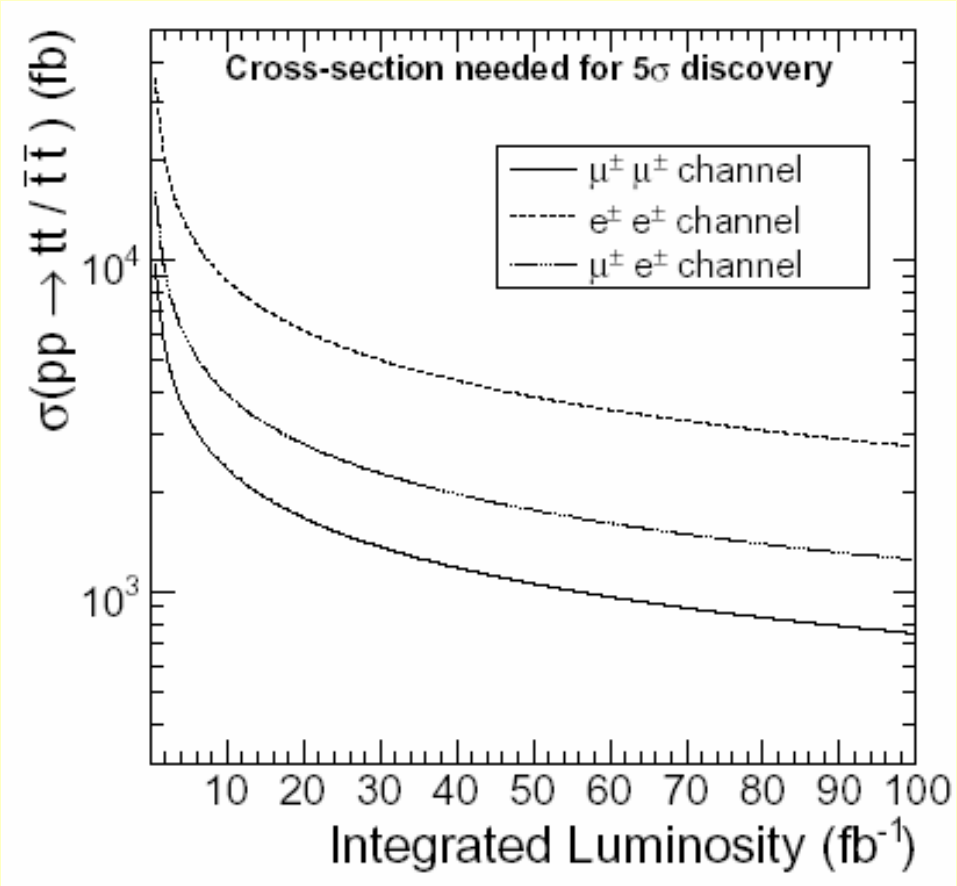
	$\mu\mu$	μe and ee	$t\bar{t} \to \tau + X$	Other $t\bar{t}$	$W^{\pm}W^{\mp}$	$Z + jets$	S/N
Before selection	6915.0	20745.0	34606.2	485973.2	189951.7	578033.3	0.0078
Trigger	6114.7	16314.8	17415.6	100137.2	41288.4	266366.7	0.017
Two jets E_T >25 GeV	4398.2	11982.7	13560.9	93858.2	20593.8	66146.7	0.032
b-tag criteria	989.8	2485.4	2289.6	8784.7	133.5	240.0	0.13
Two leptons identified	888.2	30.1	375.8	801.6	1.7	73.3	1.30
Two leptons selected (LR and p_T)	481.5	0.07	48.4	3.01	0.4	53.3	4.7
Efficiency (in %)	6.96	0.0003	0.14	0.0006	0.00022	0.0092	
Opposite-sign	481.3	0	48.3	2.19	0	53.3	
Same-sign	0.2	0.07	0.1	0.82	0.4	0	

	ee	μe and $\mu\mu$	$t\bar{t} \to \tau + X$	Other $t\bar{t}$	$W^{\pm}W^{\mp}$	$Z + jets$	S/N
Before selection	6915.0	20745.0	34606.2	485973.2	189951.7	578033.3	0.0078
Trigger	5354.8	17074.7	17415.6	100137.2	41288.4	266366.7	0.015
Two jets E_T >25 GeV	3960.9	12420.0	13560.9	93858.2	20593.8	66146.7	0.029
b-tag criteria	802.7	2672.4	2289.6	8784.7	133.5	240.0	0.11
Two leptons identified	724.5	34.6	453.8	2283.6	73.1	126.7	0.57
Two leptons selected (LR and p_T)	285.0	0.3	37.5	5.2	0.8	53.3	3.1
Efficiency (in %)	4.12	0.0013	0.11	0.0011	0.00044	0.0092	
Opposite-sign	279.6	0.3	36.8	4.1	0.4	46.7	
Same-sign	5.4	0	0.7	1.1	0.4	6.7	

	$e\mu$	$\mu\mu$ and ee	$t\bar{t} \to \tau + X$	Other $t\bar{t}$	$W^{\pm}W^{\mp}$	$Z + jets$	S/N
Before selection	13830.0	13830.0	34606.2	485973.2	189951.73	578033.3	0.016
Trigger	10960.0	11469.5	17415.6	100137.2	41288.4	266366.7	0.030
Two jets E_T >25 GeV	8021.8	8359.1	13560.9	93858.2	20593.8	66146.7	0.061
b-tag criteria	1682.7	1792.5	2289.6	8784.7	133.5	240.0	0.25
Two leptons identified	1500.6	66.4	822.1	3001.6	30.2	20.0	0.88
Two leptons selected (LR and p_T)	722.7	0.9	85.2	6.3	0.4	0	8.3
Efficiency (in %)	5.23	0.0065	0.25	0.0013	0.00022	0	
Opposite-sign	715.5	0.9	83.8	4.9	0	0	
Same-sign	7.2	0	1.3	1.4	0.4	0	

Discovery potential for same-sign events

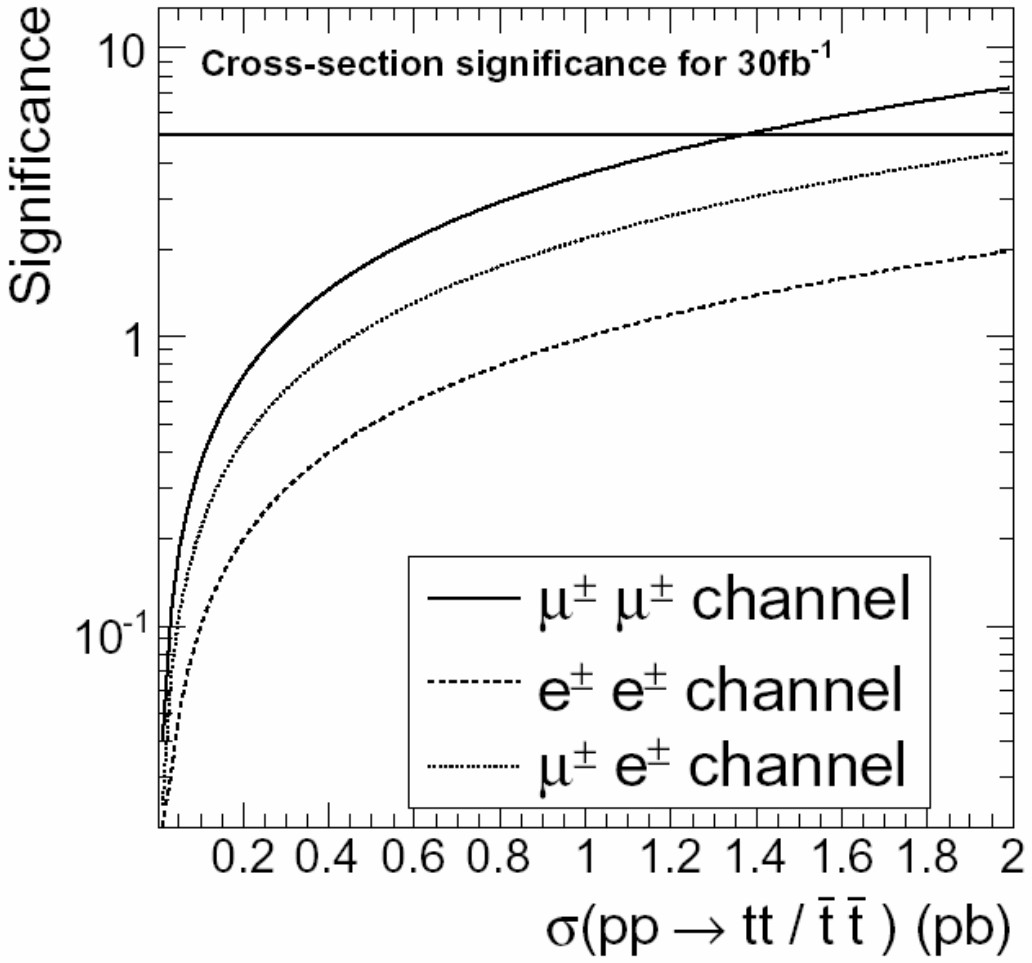
- **From the ratio and its expected uncertainty (depending on int.lumi)**
  - *compute a 5σ deviation from the expected R^{SM} value*
  - *calculate which cross section is needed of* pp->tt *for this excess*



- *muon channel performs better compared to the electron channel*
- *the electron+muon channel is in the middle of the electron and muon significance*
- *combination foreseen in future*

Systematics

- **In the ratio almost all experimental and theoretical uncertainties cancel**
  - *difference in significance when taking these 'rescaled' numbers is small*

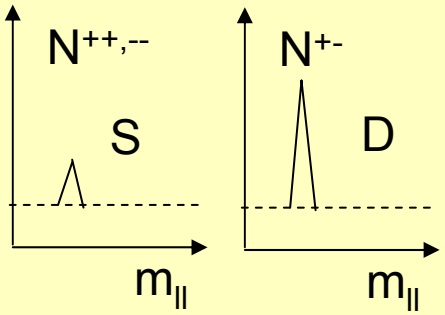


- *changing the tau selection efficiency by 20% does not change the significance plots*
- *including or not the Z+jets events does not make a significant change in the significance plots*

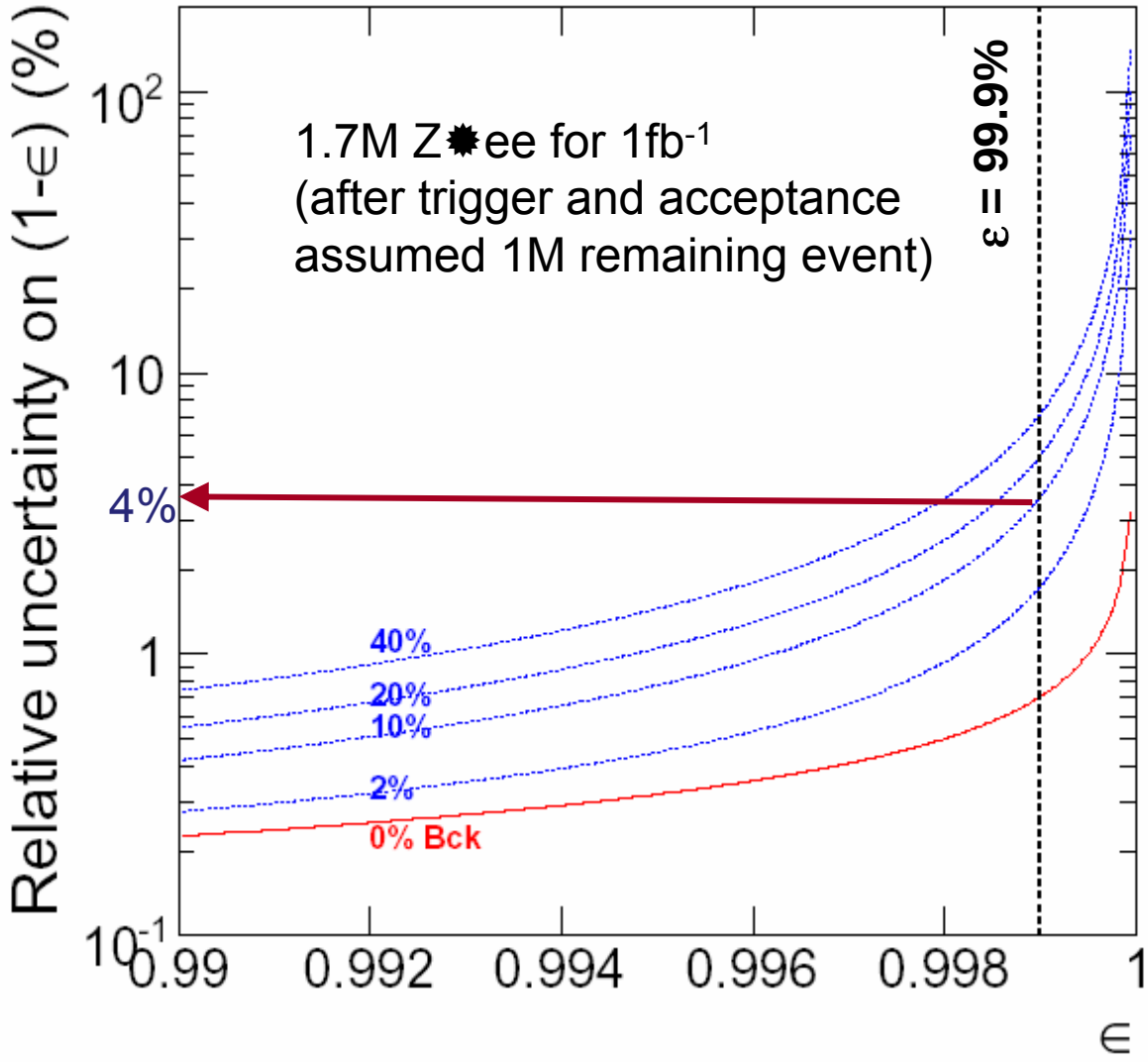
at 30fb^{-1} a pp✹tt cross section of 1pb becomes visible as a 5σ effect on the ratio R

Systematics due to knowledge of charge Id eff

- **Feasibility study**
  - *using Z decays*
  - *select 2 leptons and veto jets*



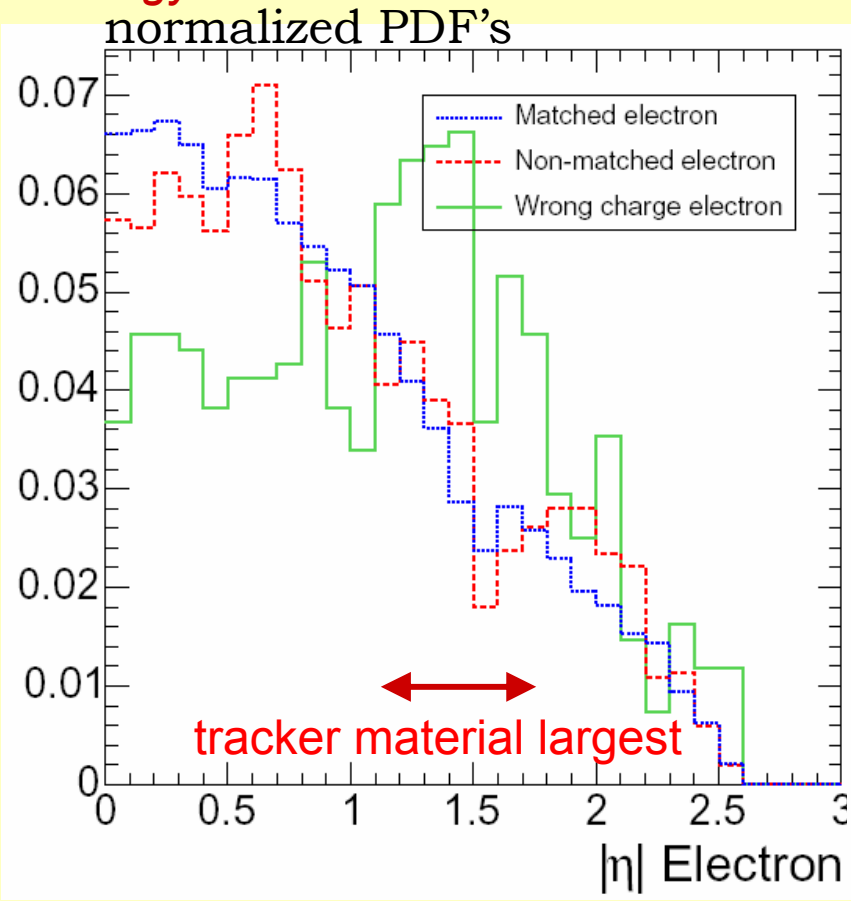
  - *make di-lepton mass (S and D)*
  - *mass window count : N_S & N_D*
  - *assume equal bck in both plots*
  - *$\varepsilon = (N_S+2N_D) / (2N_S+2N_D)$*
  - *estimate uncertainty one can obtain on the charge mis-ID eff or (1-ε)*
  - *$10fb^{-1}$ ✹ $\Delta(1-\varepsilon) \sim 4\% (1-\varepsilon)$ (Bck~10% and ε~99.9%)*
  - ***effect neglegible on R***

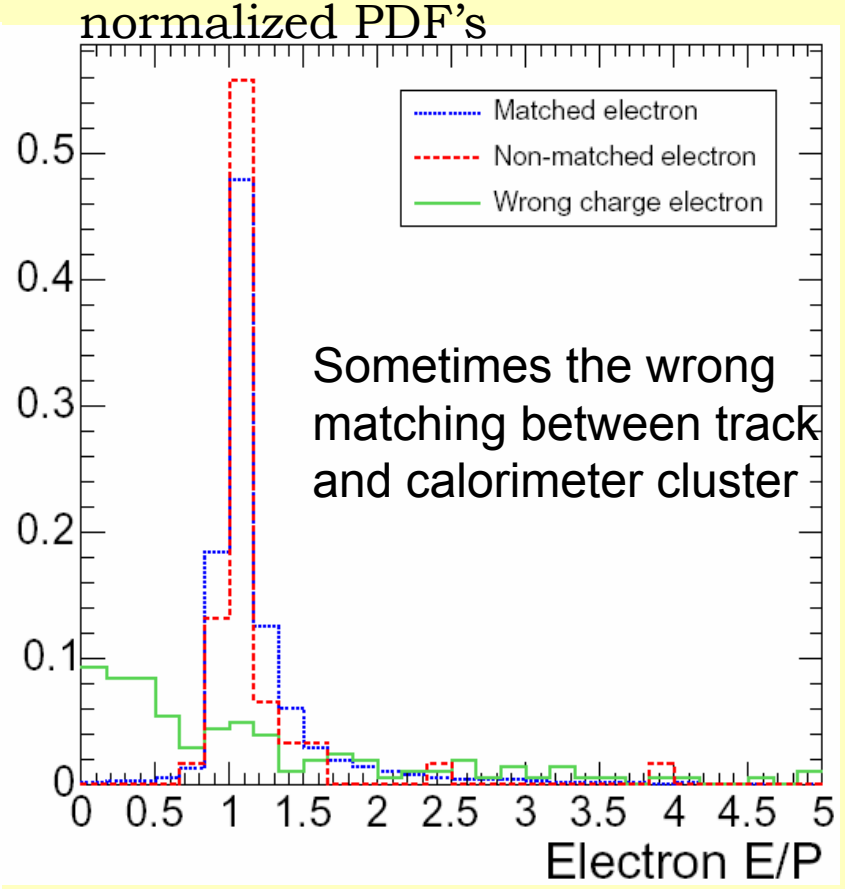


This is just a back-of-the-envelope calculation !

Observations

- **Purify the sample of same-sign lepton pair events**
  - *material budget is important for electrons*
  - *in the electron reconstruction sometimes a wrong track is matched with the energy cluster in the calorimeter*

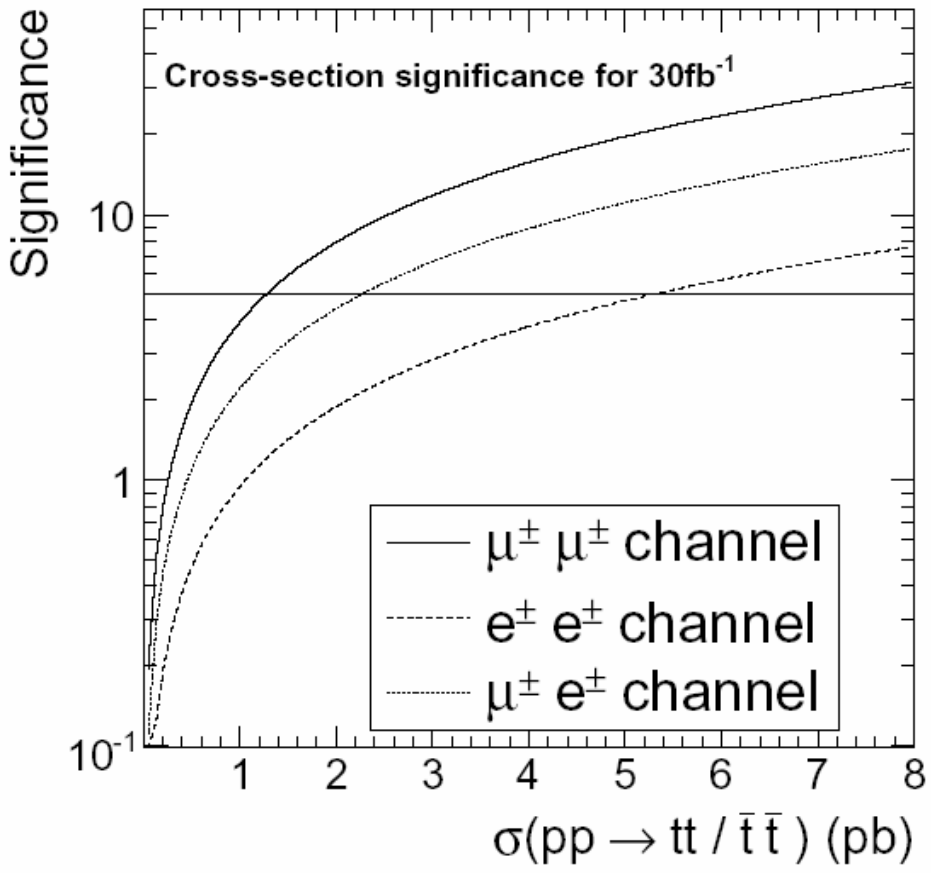


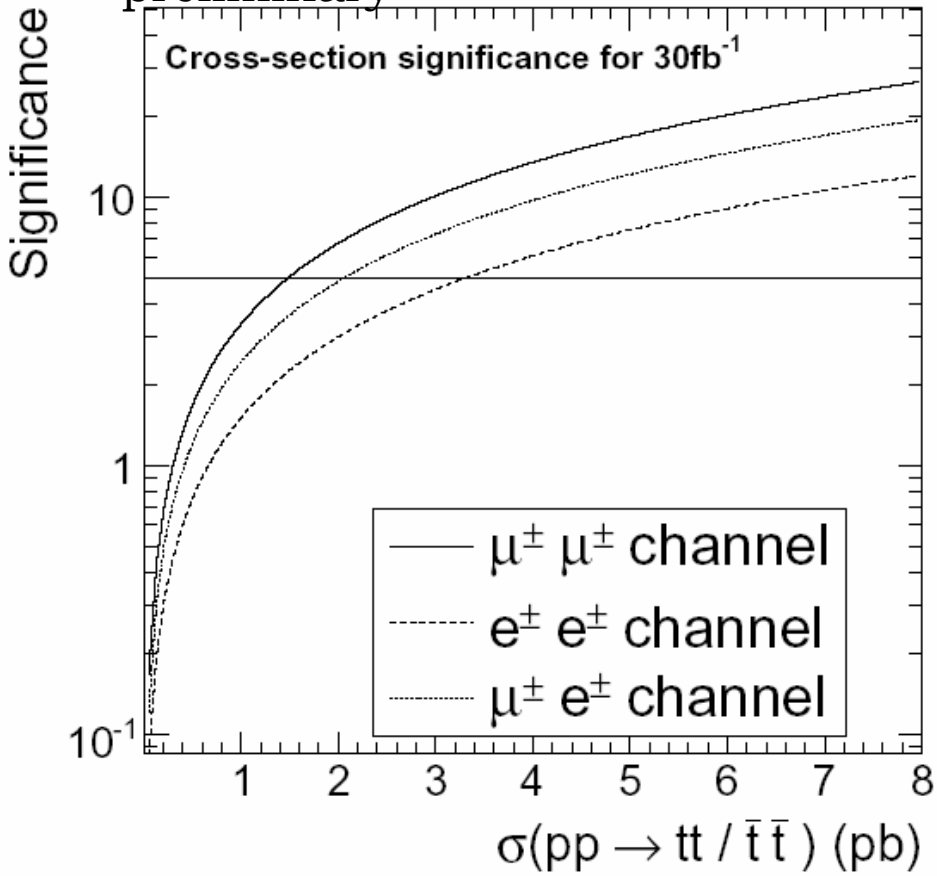


Observations

- **Preliminary improvement when cutting on E/p for the electrons**
  - *cut 0.7 < E/p < 1.7*

preliminary





without E/p cut **with E/p cut**

Conclusion

Event selection of di-lepton top quark pairs:

- ☑ simple and providing a large S/N ... all relevant background taken into account
- ☑ L1+HLT trigger applied
- ☑ very good performance of **lepton likelihood** (rejects QCD+fake leptons)

Construction of the ratio R:

- ☑ checked robustness versus background events
- ☑ indicated where muons are different from electrons (track-cluster matching)

Systematic uncertainties:

- ☑ most of the experimental and theoretical uncertainties cancel in the ratio
- ☑ feasibility study with Z decays to estimate the influence of the uncertainty on the charge identification efficiency (neglegible!)

Result : at 30fb^{-1} a $pp \to t\bar{t}$ cross section of 1pb becomes visible

Useful results for theoreticians as it provides an almost model independent potential (if new physics has about the same kinematic topology of ttbar) !