Commissioning della fisica con W, Z

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V Workshop italiano sulla Fisica p-p a LHC
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Outline

- Focus on W and Z production with L = 10-100 pb^{-1}
- Calibration issues: momentum scale, resolution and alignment with Z events
- W, Z inclusive cross section (electrons, muons) :
  - MC NLO predictions and acceptance studies
  - trigger and offline efficiency from data
  - events selection and backgrounds
- τ production from W, Z and τ identification
- Conclusions and outlook

LHC early data

- First physics run at very low luminosity (~10^{31} $cm^{-2}s^{-1}$)
  - detector understanding and event structure studies:10 pb^{-1} integrated luminosity
- Low luminosity "Physics run" (10^{33} $cm^{-2}s^{-1}$)
  - nominal LHC values: ~1-2 fb^{-1} integrated luminosity

Process	σ x Br [pb]	ε(estimate)	Events 10 pb^{-1}
Z → ll	2000	20%	4000
W → lν	20000	20%	40000
ttbar → lν +X	370	1.5%	< 100
Jet E_T > 25 GeV	$3 \cdot 10^9$	100%	$3 \cdot 10^{10}$ x p.f.
Minimum bias	10^{11}	100%	10^{12} x p.f.

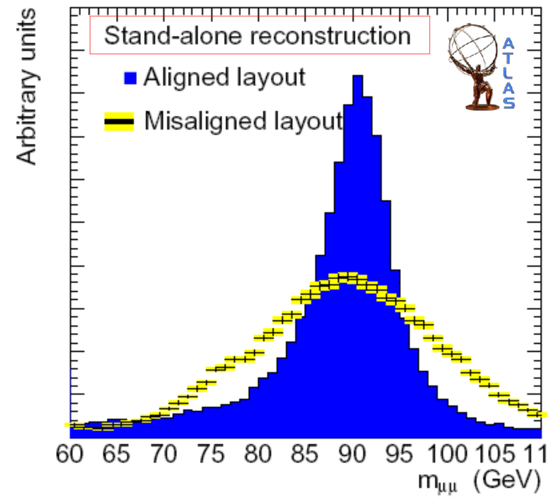
Good event rates even with modest luminosty

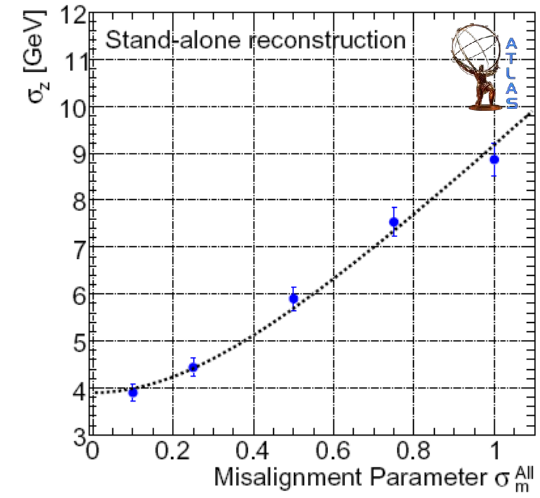
- Aim of first data (50-100 pb^{-1}): detector understanding/calibration and first physics measurements
  - Single W/Z boson production is a clean process with large cross section
    - "Standard candles" for detector calibration/understanding
    - monitor collider luminosity and constrain PDFs looking at σ_{TOT}, W rapidity,...(see talk by Diglio, Rovelli)
    - cross section measurements

Momentum scale/resolution from Z→μμ

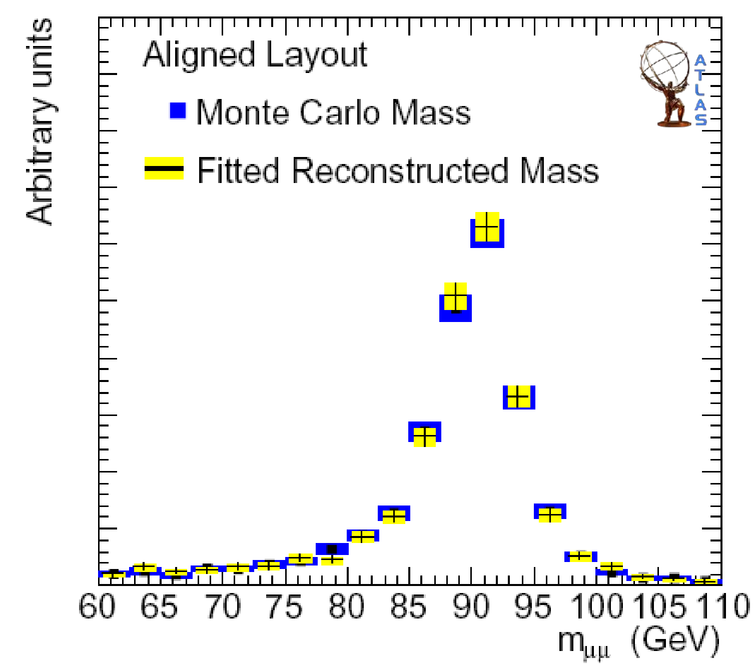
Determination of μ momentum scale/resolution from Z decay

- peak position → momentum scale
- peak width → momentum resolution
  - momentum range ~20-80GeV



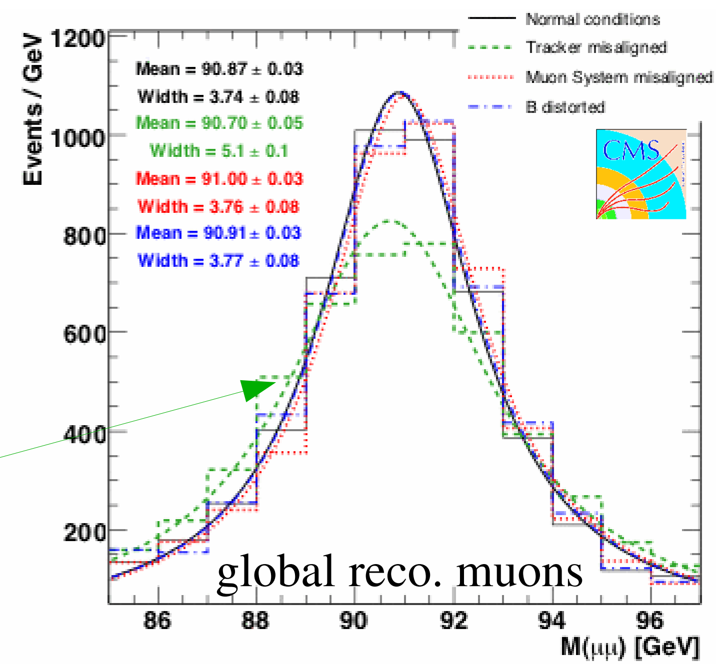


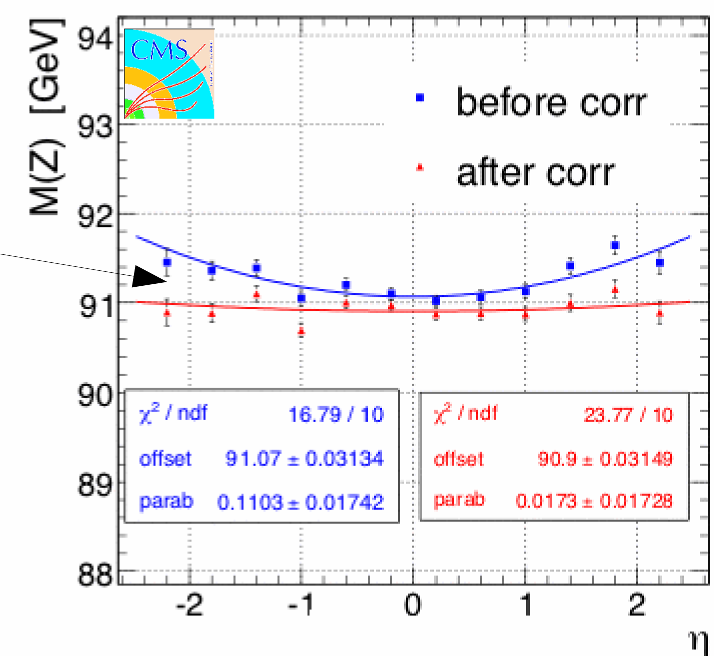
- Monte Carlo Spectra method
  - "Adjust" the MC reconstructed momentum
    - Comparison of reconstructed $M_{\mu\mu}$ in data and MC
    - Momentum scale can be estimated to roughly 0.6%, with gaussian resolution ~12% for a misaligned geometry (with 30.000 events)
- Parametrized shape method
  - As above, but resolution is parametrized as a function
    - the reconstructed momentum can be obtained on MC truth level
    - momentum Scale can be determined on 1% level for an aligned muon spectrometer layout



Momentum scale from Z→μμ

- use Z→μμ events to correct muon scale biases due to
  - effectiveness of the muon reconstruction procedure
  - imperfect knowledge of the detector conditions
- studied for 10 pb^{-1} with different scenarios
  - normal detector conditions
  - tracker misalignment
  - muon system misalignment
  - modified B-field intensity
- correct μ scale as a function of muon kinematics: $p^T = k \times p^T$ with $k = F(p^T, \eta, \phi; \alpha \ldots)$
- scale corrections improve also systematics on cross section measurements (acceptance uncertainties)

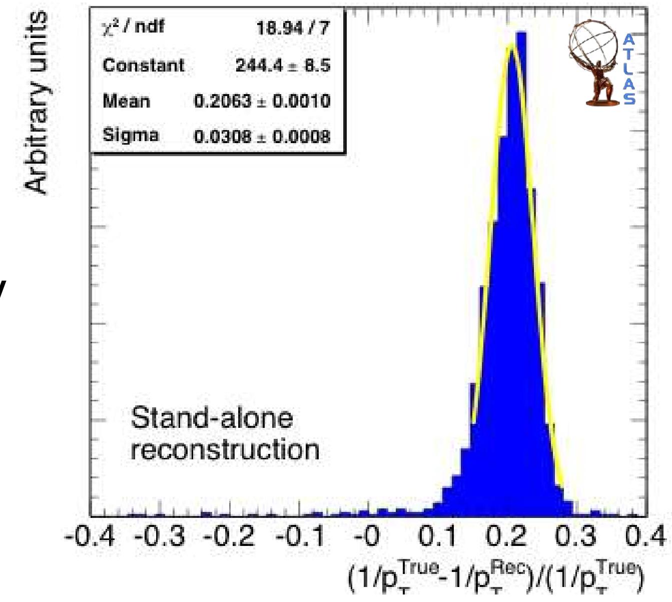


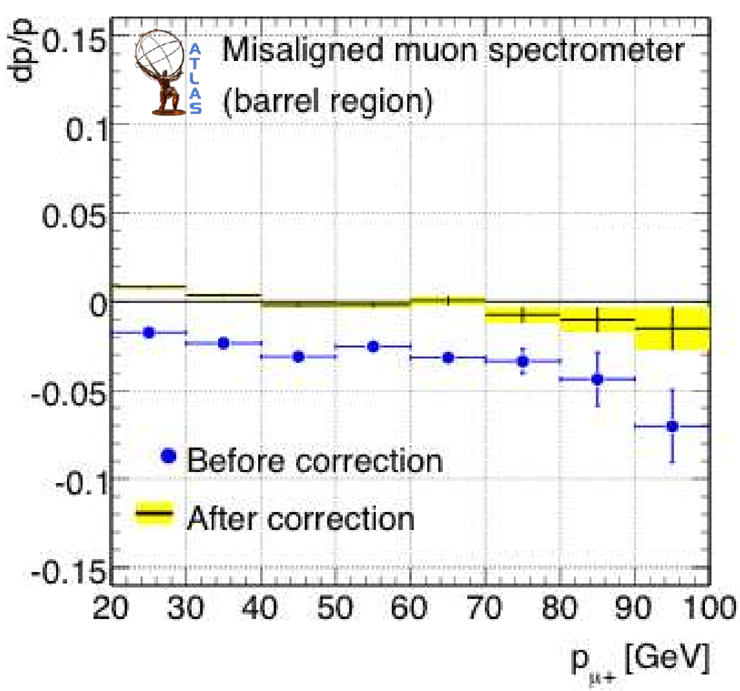


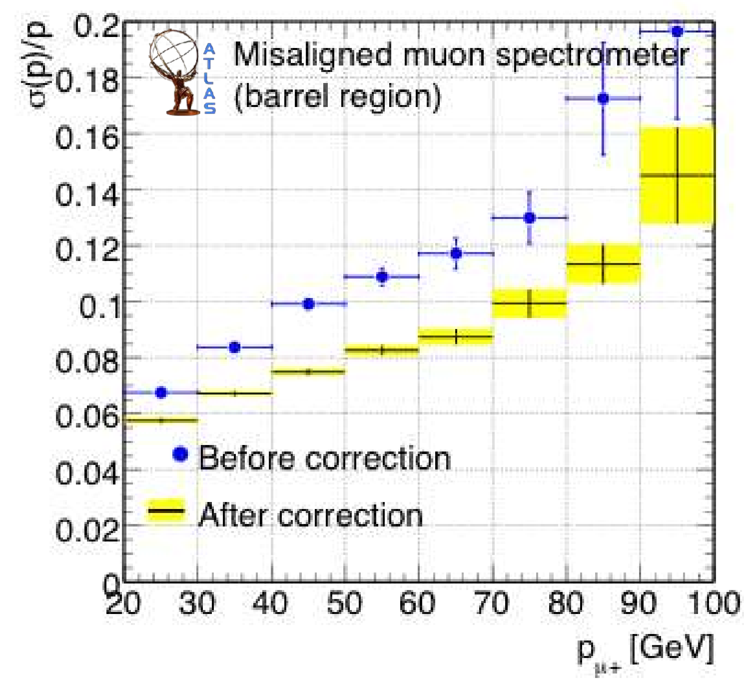
CMS AN 2007/031

Alignment with Z→μμ

- Observation: decrease of momentum resolution is first order due to sagitta-shifts in towers
  - Z boson mass constraint
  - muons from Z boson reconstructed in tower A, have other partner muons in different tower, independently misaligned
  - Results for 1 day at 10^{33} $cm^{-2}s^{-1}$
    more statistics allow for in-tower corrections with further reduction of standard deviation

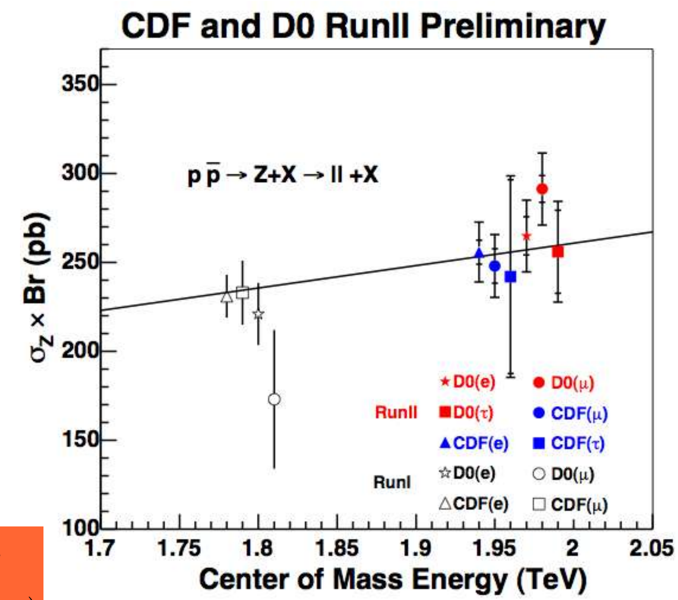






Inclusive cross section measurements

- Cross section measurements used in the past as a test for perturbative QCD
- With large Tevatron and LHC datasets main uncertainties are non-statistical:
  - luminosity (5-7%) and systematics (2-3%) [D0 Note 4750; arXiv:hep-ex/0508029]

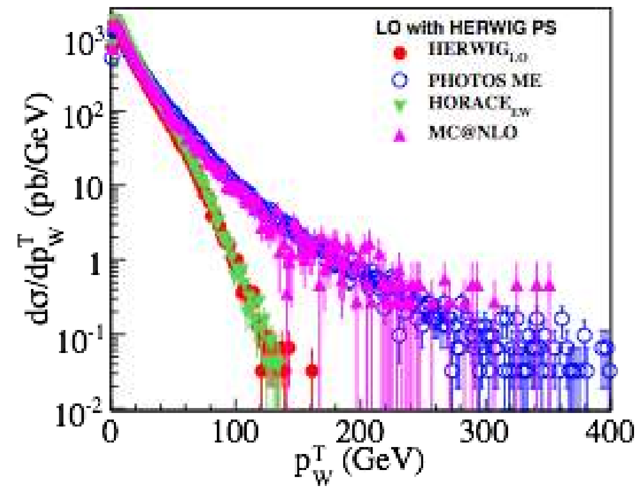


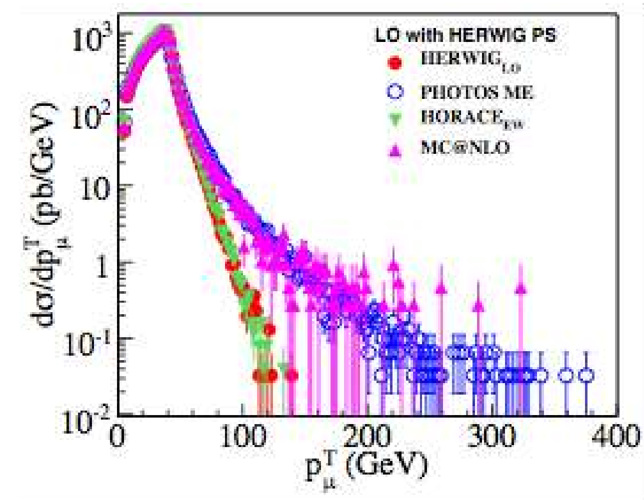
$$\sigma_{W(Z)} \times BR(W(Z) \to leptons) = \frac{N^{obs}_{W(Z)} - N^{bkg}_{W(Z)}}{\epsilon_{W(Z)} A_{W(Z)} \int \mathscr{L}\, dt}$$

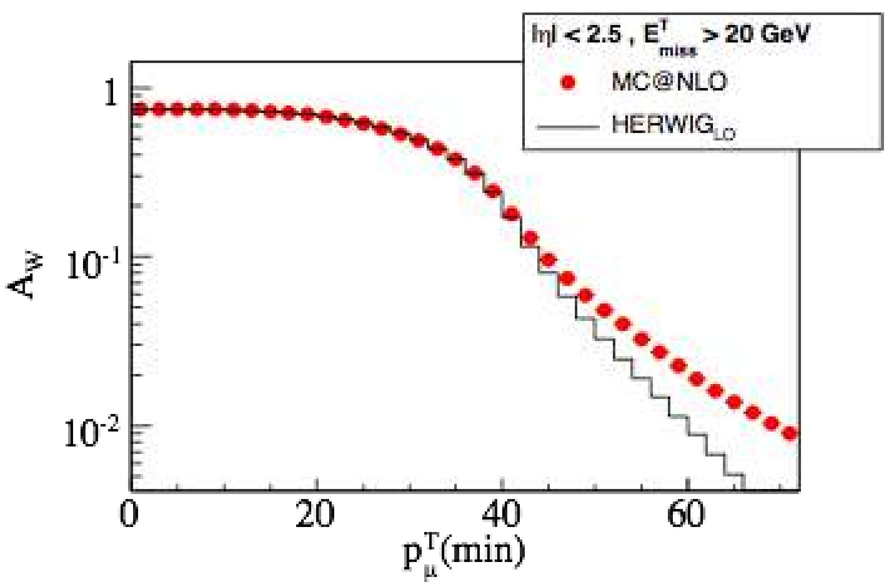
- *<u>Cross section measurement related issues :</u>*
  - Acceptance studies with best NLO QCD and EW theoretical predictions
  - Efficiencies measurement <u>from data</u> to not rely on MC simulations
  - Event selections and background estimation
  - Detailed systematics studies (impact of alignment, calibration...)

Acceptance studies in $W \to \mu\nu$

- Study the acceptance corrections due to geometrical coverage of detector and trigger system
  - Theoretical description with NLO QCD and EW corrections
  - MC@NLO, Photos and Horace generators with Herwig parton shower





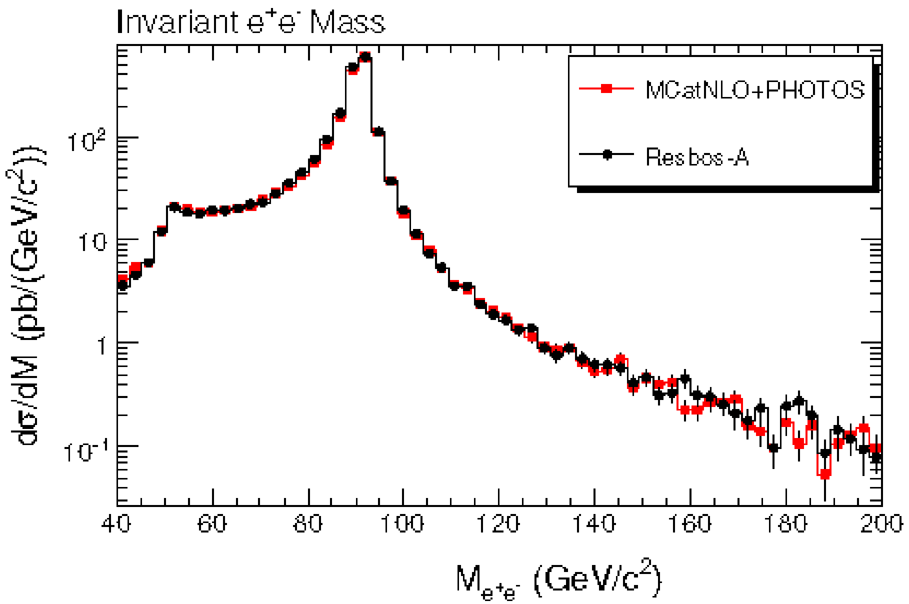


- Transverse momentum and pseudorapidity curves
  - LO and NLO comparison
  - QCD corrections up to 2%
  - lower impact from EW corrections (<1%)

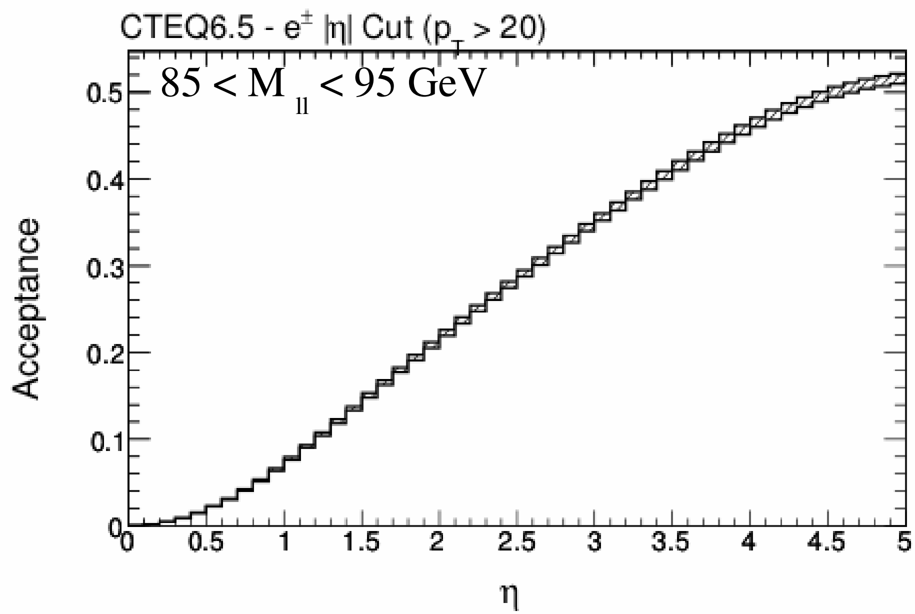
Acceptance studies in Z→ll events

CMS AN 2007/031,CMS AN 2007/026

- NLO EW and QCD corrections
  - comparison MC@NLO+PHOTOS vs RESBOS-A
  - comparison HORACE vs LO MC+PHOTOS
  - MC@NLO + PHOTOS → overall theoretical uncertainties on Z acceptance at the percent level



- PDF uncertainties ~ O(1%)
  - with CTEQ6.5 and comparison with other PDF sets



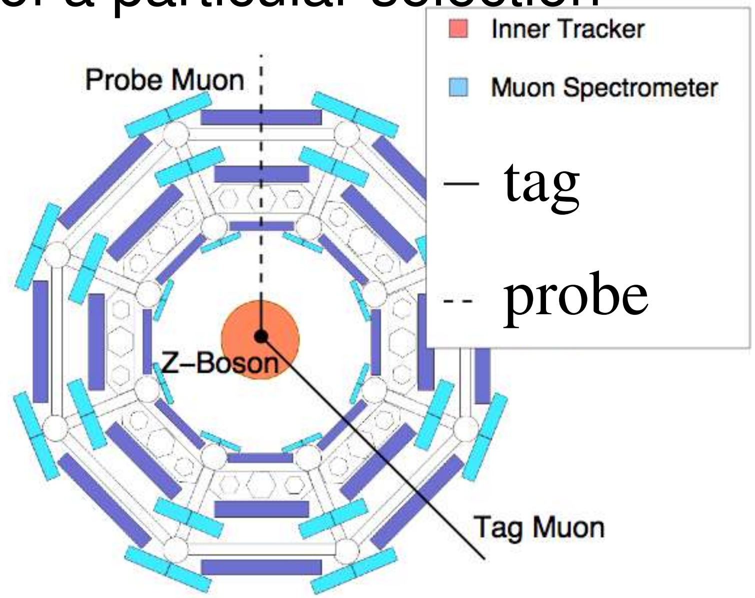
Efficiency measurements

- **The "Tag&Probe" method**

  Use of $Z \rightarrow ee$ ($\mu\mu$) events to provide an unbiased, high purity electron (muon) sample to measure the efficiency of a particular selection

TAG electron (muon) selected with tight criteria

PROBE electron(muon) candidate with loose selections depending on the efficiencies under study

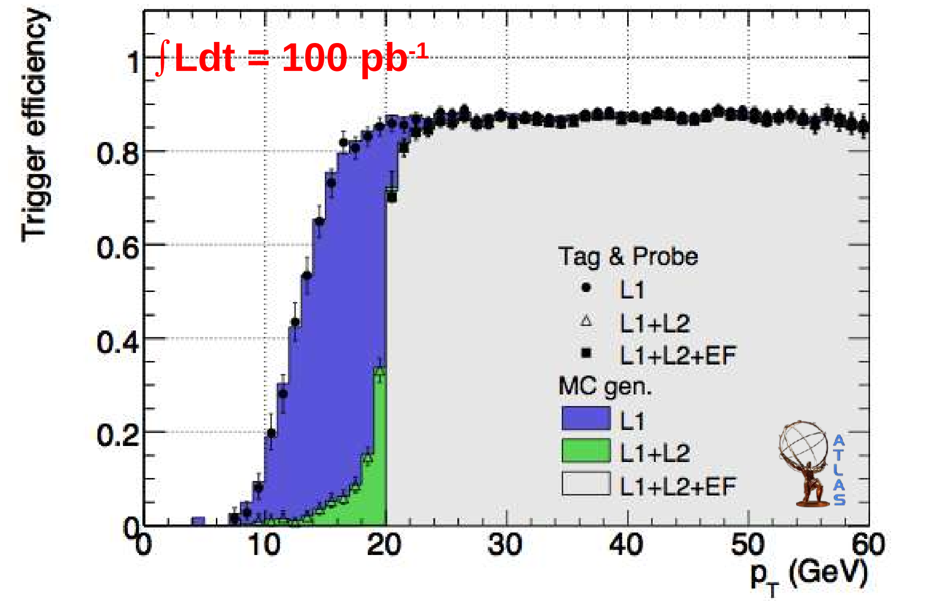


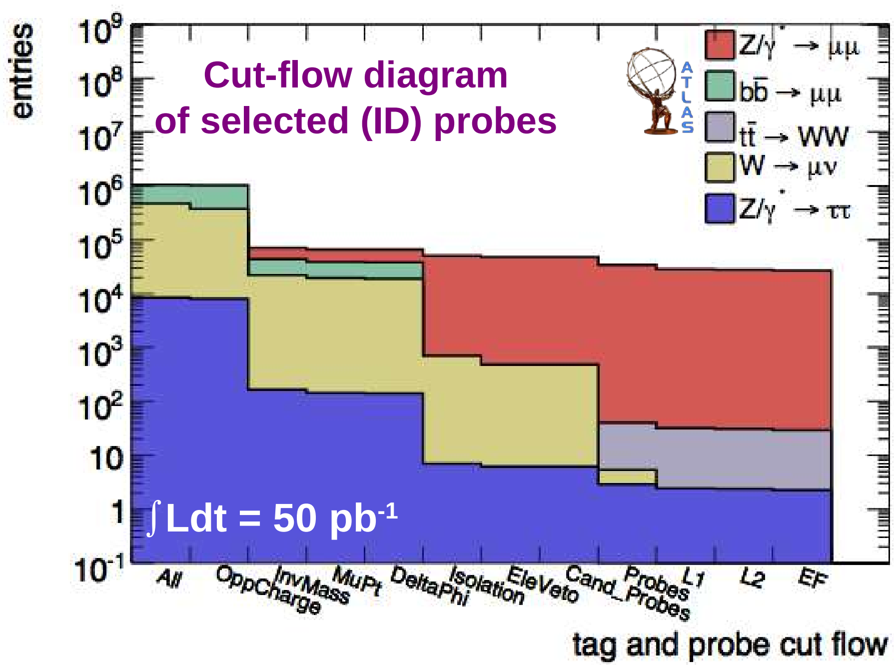
- tag-probe invariant mass within a narrow window around M(Z) + possible additional requirement on $\Delta\Phi$(tag-probe)
- tight selections + kinematic cuts to ensure a high purity sample

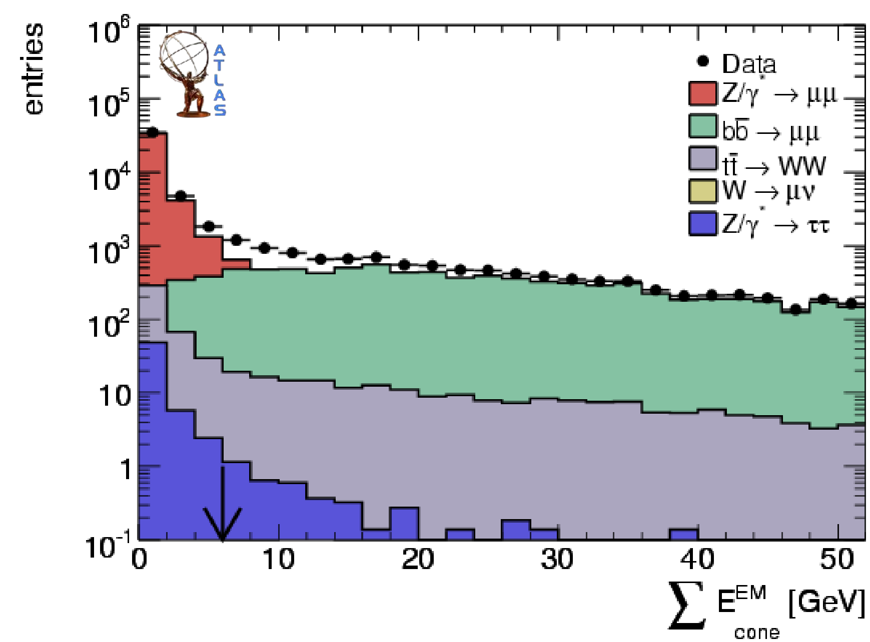
- map efficiencies as a function of p_T, η, Φ for phyisics analysis
- critical issues of the method
  - residual background contamination (QCD, W+jets) to be subtracted
  - check correlations and dependencies on the selections applied

Trigger efficiency from Z→μ+μ-

- Measurements wrt ID or offline muon reconstruction:
  - $c_1 * c_2 < 0, 81 < M_{\mu\mu} < 101$ GeV, $p^T > 20$ GeV
- Background rejection with kinematical and tight isolation cuts:
  - **ID** ⇒ $\Sigma N^{ID} < 4$, $\Sigma p_T^{ID} < 8$GeV,
    Calo ⇒ $E_{jet} < 15$GeV, $\Sigma E_T^{EM} < 6$ GeV





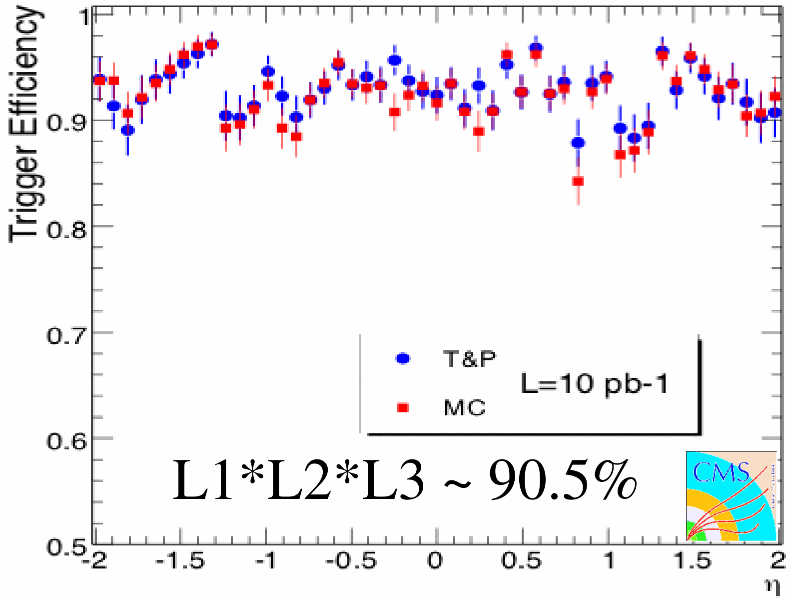


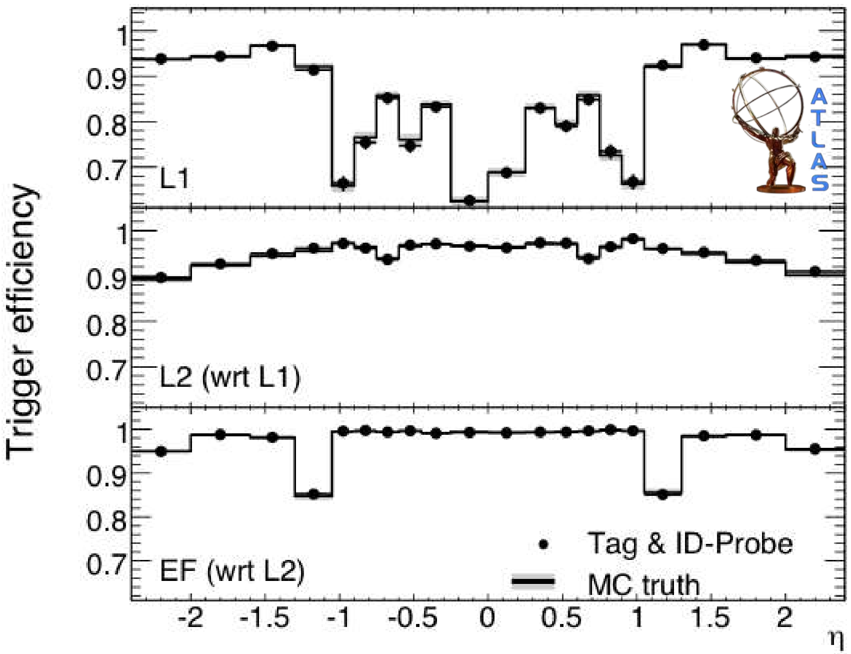
Trigger efficiency from Z→$\mu^+\mu^-$

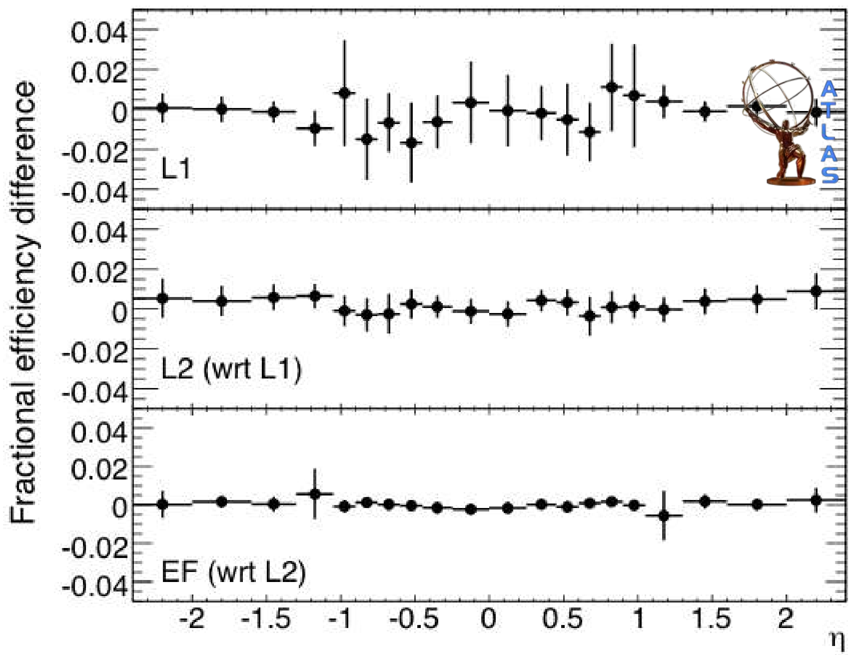
Use standalone and combined reconstructions to cope with early data requirements

- e.g. ID-MS alignment

Statistical uncertainty for 50 pb^{-1} ≈ 0.3%
Systematic uncertainty ≈ 0.5%
Background contribution <0.5%







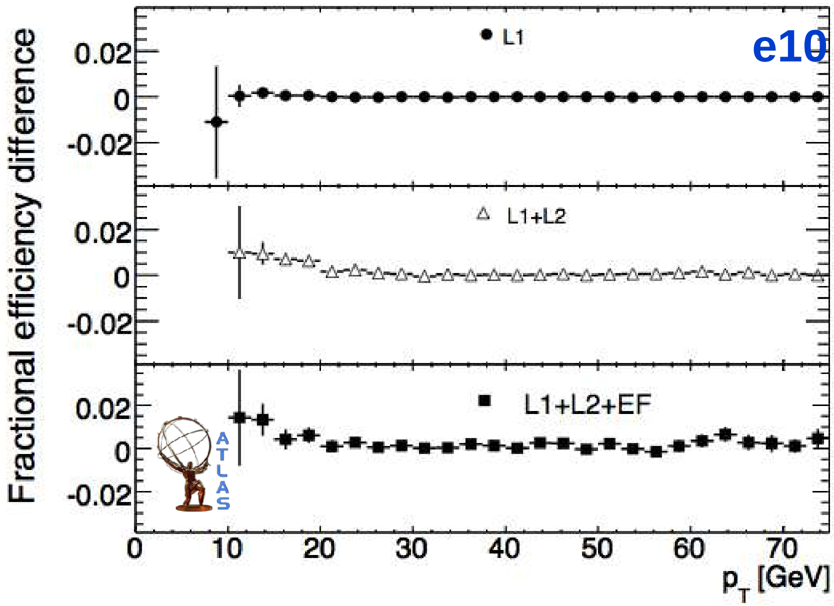
Trigger efficiency from Z→e⁺e⁻

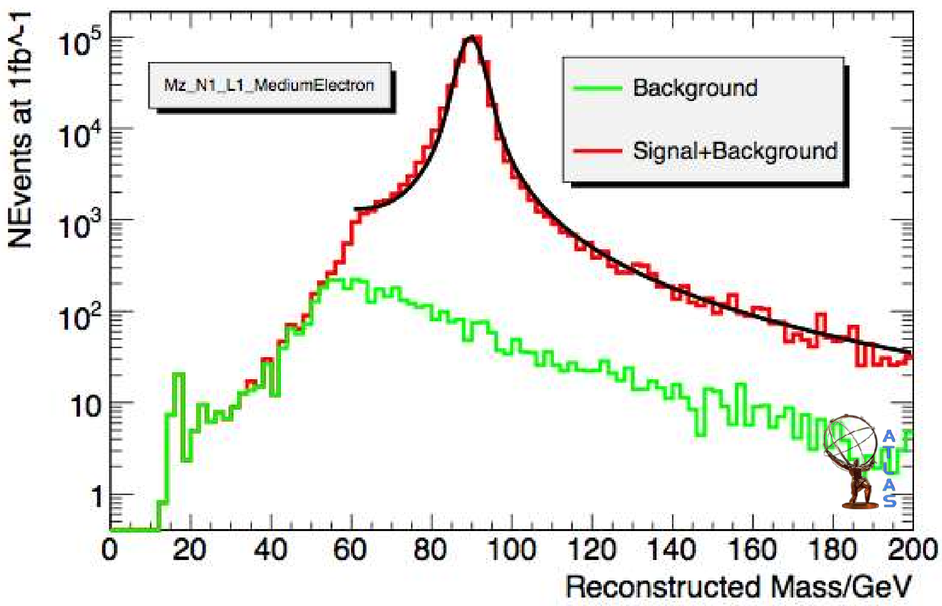
Trigger items e10, e22

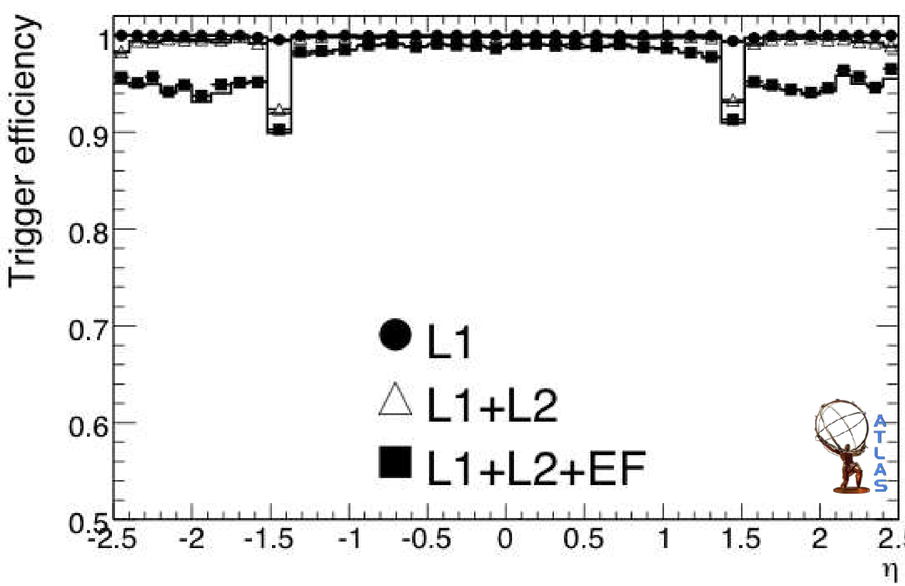
Cut on	Requirement
Invariant Mass Requirement	$70 < M_{ee}^{rec} < 100\ GeV$
Transverse Momentum	$p_T > 25\ GeV$ or $15\ GeV$
Pseudorapidity	$0 < \|\eta\| < 1.37$ or $1.52 < \|\eta\| < 2.4$

Systematics of the method < 0.5 %

Background systematics ≈ 0.5 %

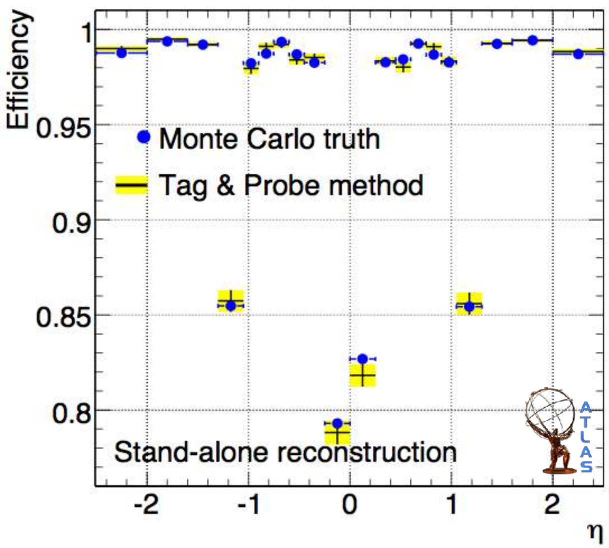


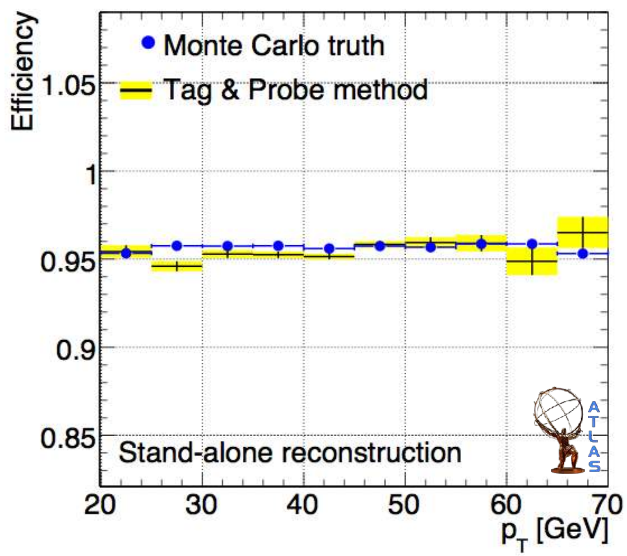


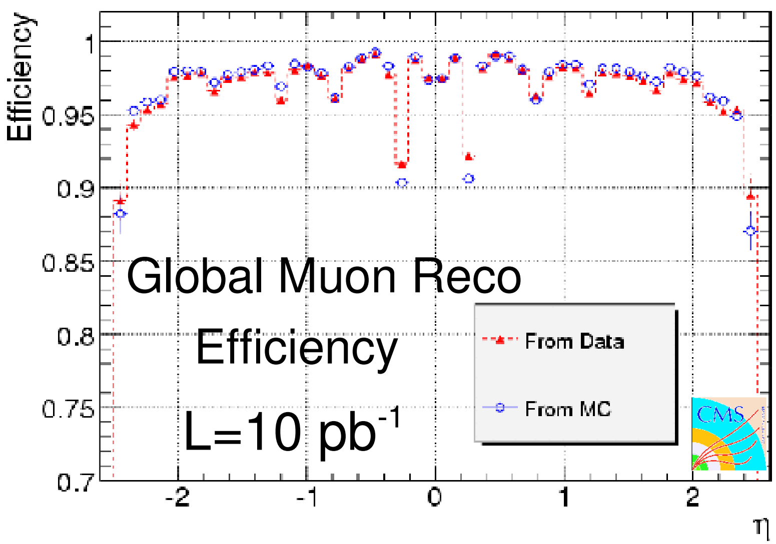


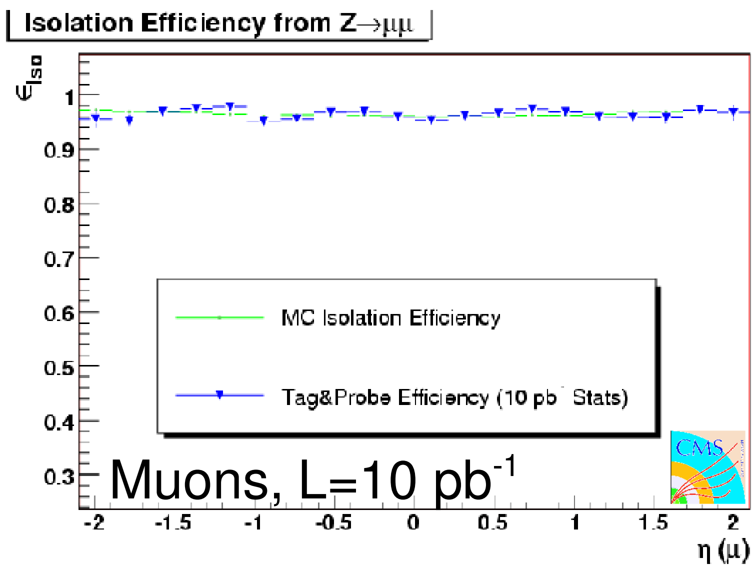
Offline efficiency

- in a similar way, use “Tag&Probe” to measure offline efficiencies



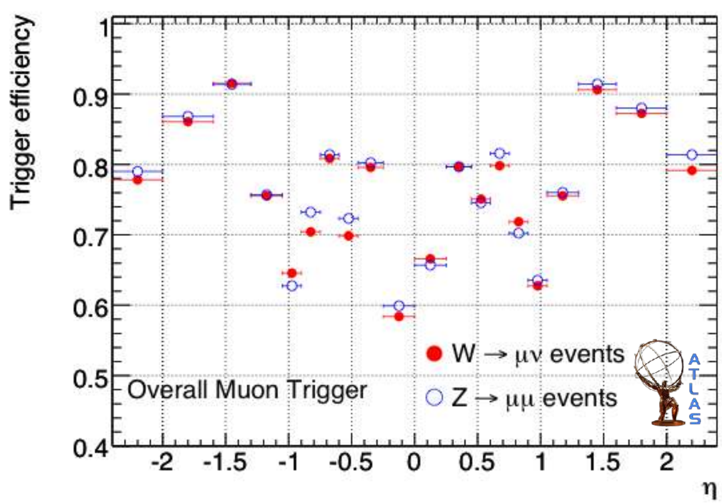






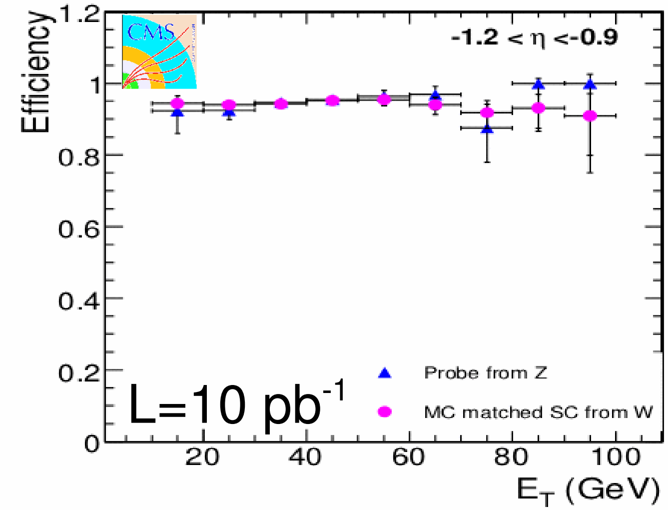
Efficiency: Tag&Probe vs $W \to l\nu$

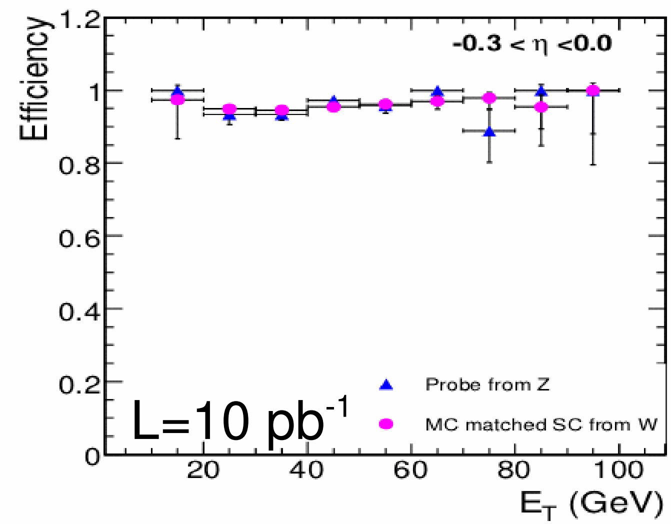
- to apply efficiency measured with $Z \to ll$ to $W \to l\nu$, **$\varepsilon(p^T, \eta)$** is needed to account for different kinematic distributions of leptons from Z and W
- comparison between "Tag&Probe" and MC efficiency in $W \to e\nu$ events performed as a function of E^T and slices in η
  - good agreement between Tag&Probe and MC truth



High luminosity ($\int \mathcal{L}dt = 1000\ pb-1$)			
Detector region	Barrel ($\lvert\eta < 1.05\rvert$)	Endcap ($1.05 < \lvert\eta\rvert < 2.4$)	Overall ($0 < \lvert\eta\rvert < 2.4$)
$\lvert\epsilon^{W\to\mu\nu}_{mu20i} - \epsilon^{Z\to\mu\mu}_{mu20i}\rvert$	0.005 ± 0.001	0.004 ± 0.001	0.008 ± 0.001

electron tracking efficiency





Tag: HLT electron, E^T>15GeV,track isol.
Probe: ECAL SC, E^T>20 GeV
85 GeV < M(tag-probe) < 95 GeV

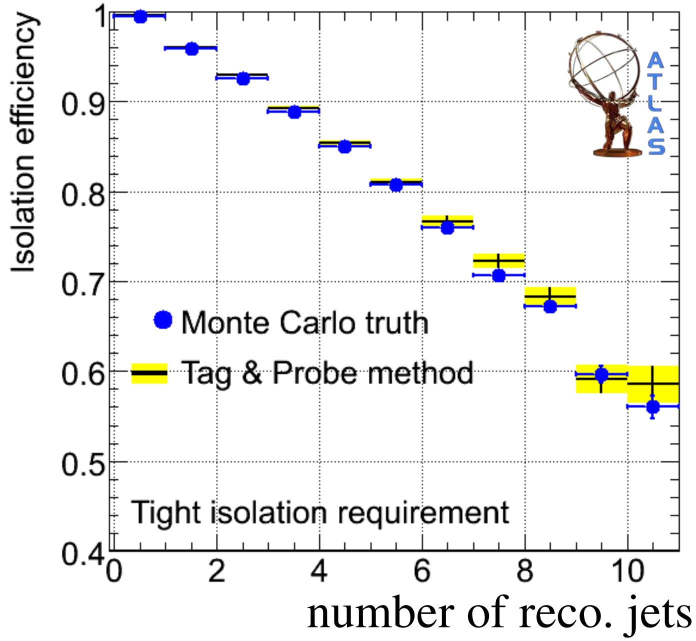
Systematic uncertainties

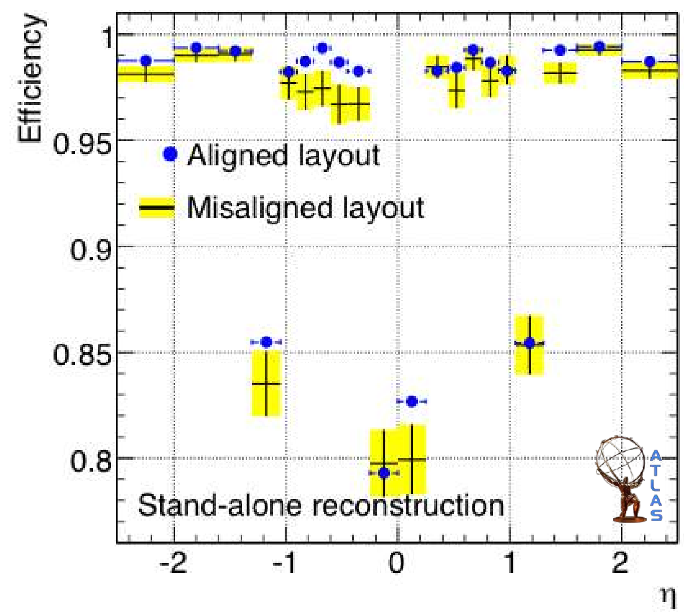
- Efficiency of isolation requirement also determined via Tag&Probe
  - Avoid correlations by determination versus number of reconstructed jets

    Early Data:
    - $\Delta\varepsilon_{iso}/\varepsilon_{iso}$=0.002(stat)±0.003(sys)

    High Luminosity
    - $\Delta\varepsilon_{iso}/\varepsilon_{iso}$=0.000(stat)±0.001(sys)
- Main systematics from background
- Uncertainty on **impact-parameter** and **misalignments** should be negligible
- **Efficiency of kinematic cuts**
  Uncertainty arises from uncertainty on momentum scale measurement

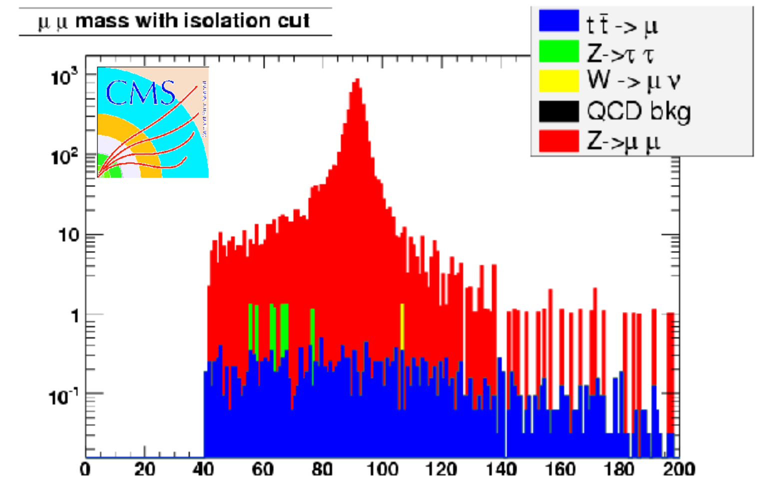
  $\varepsilon_{kinematic}$=0.906±0.003(sys)

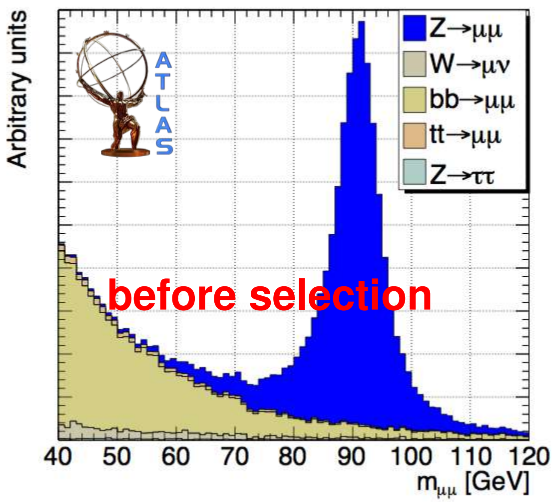


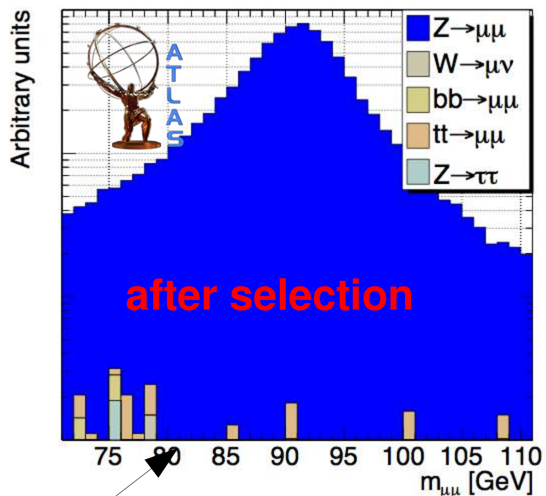


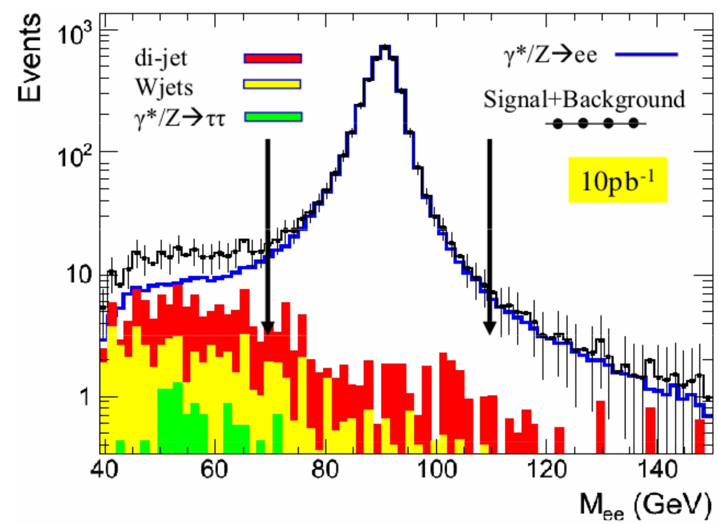
Events selections and backgrounds in Z→ll

- Selections:
  - two isolated leptons with opposite charge within detector acceptance
    - lepton ID based on simple but robust cuts
  - high p^T (well above trigger thresholds)
  - invariant mass in a window around M(Z)
- final background contamination almost negligible [~ few ‰]









Muon Spectrometer reconstruction for muon tracks in |η|< 2.5 + isolation

Uncertainty from bkg. expected ≈ 0.2%

Main backgrounds

- EW: Z→ττ, ttbar
- di-jets, W+jets → can be estimated from data

Background estimation in $Z \rightarrow ll$ events

- QCD and W+jets residual contamination can be estimated from data
  - background subtraction needed for a correct estimation of efficiencies with T&P and cross section

- Different techniques under investigation

(1) "Charge Correlation" Method:

look at "same-sign"(SS) and "opposite-sign"(OS) events

(2) "Side Bands" Method:

count the number of events in the upper and lower mass side band regions and extrapolate to the signal region

(3) fit with background (or signal+background) templates of a discriminating variable

- more sophisticated
- may require higher luminosities (i.e. with enough data to model background shapes)

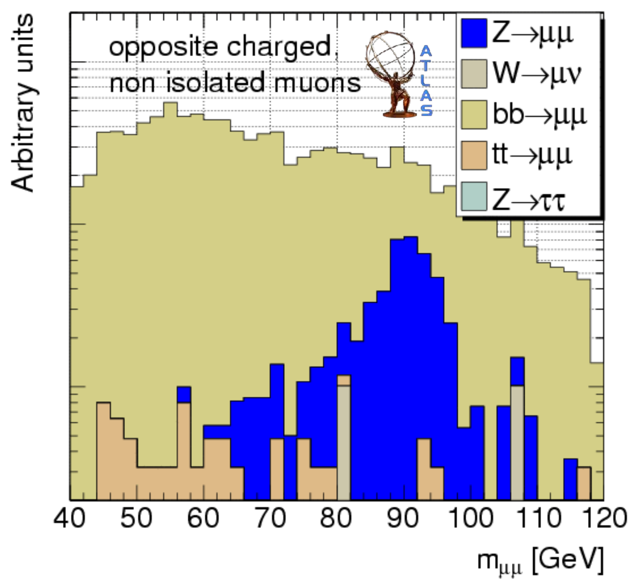
(1) and (2) are simple but robust methods:

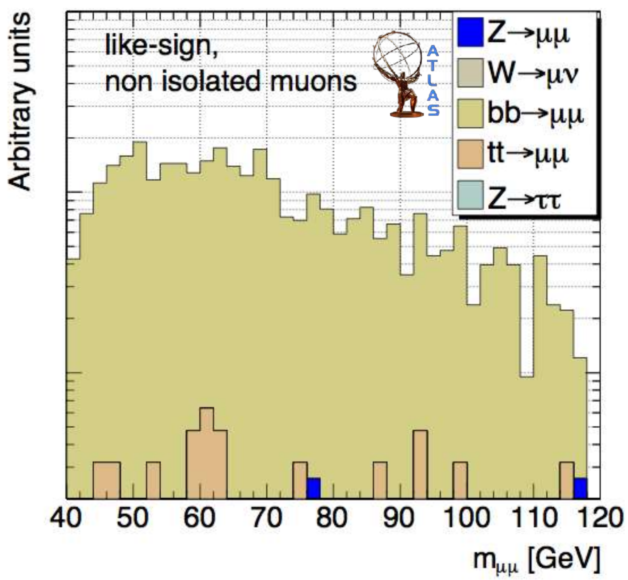
- desirable for a start-up scenario
- adequate for the level of background expected in ~10 pb^{-1}

"Charge correlation" method

- General assumption: no charge correlation in lepton pairs from hadronic events
  - under this assumption: N(SS) = N(OS)
  - correction for charge mismeasurement probability in the signal needed (from MC)
  - *need to verify that the charge correlation is negligible*

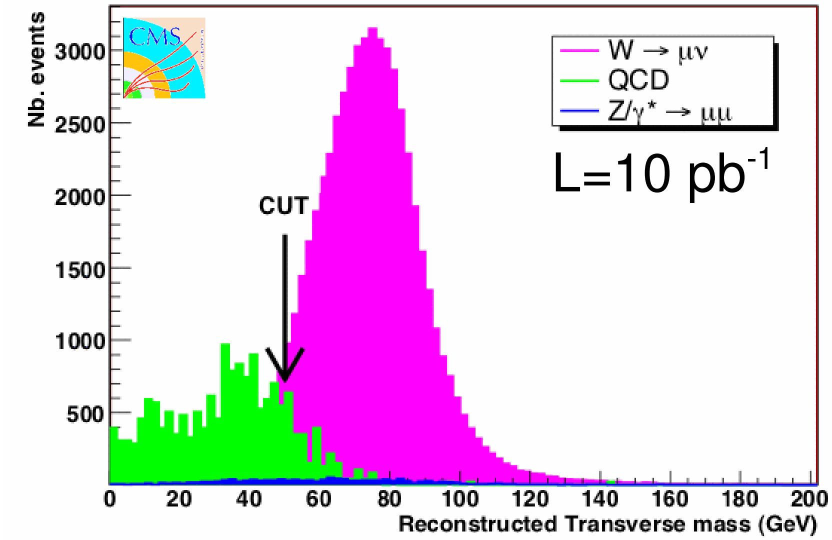
- QCD enriched sample from data (like-sign) and normalization to signal selection from MC (ratio OS/SS) or with side-bands techniques from data



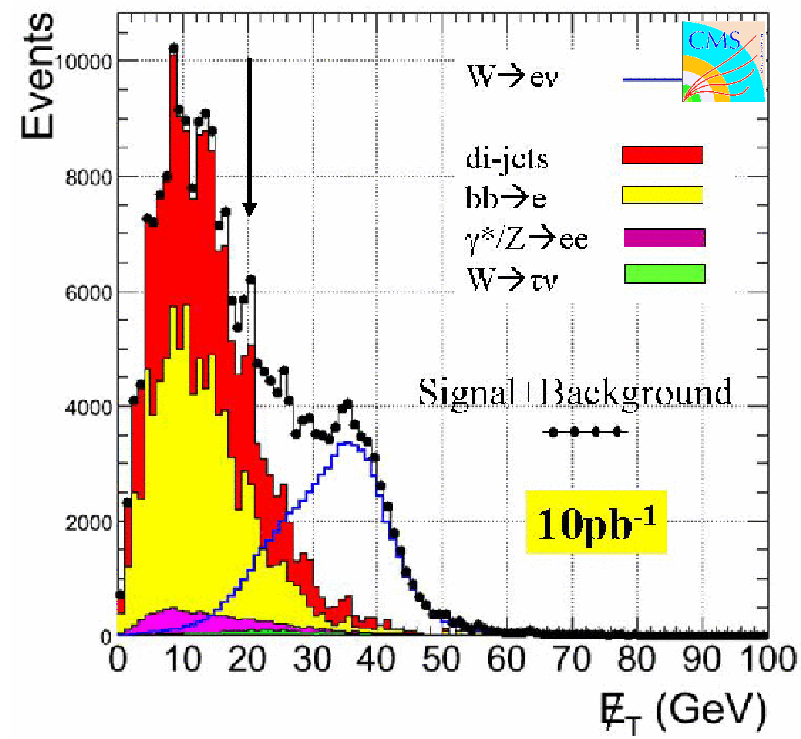


Events selections and backgrounds in W→lν

- Selections
  - one well reconstructed lepton within detector acceptance and passing HLT requirements
  - lepton isolation
  - lepton p^T > 20-25 GeV
  - transverse mass or MET cut + possible jet veto to reduce hadronic backgrounds



- <u>Electroweak backgrounds</u>
  - W→τν, Z/γ*→ll, Z→ττ, ttbar (~ few %)
  - WW,WZ,ZZ,tW: ~ negligible
  - can be reliably estimated from MC simulation

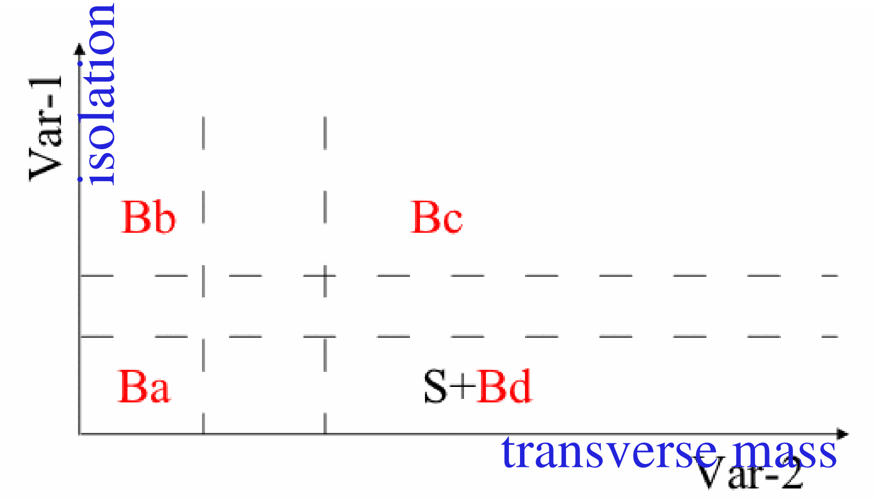


- <u>Hadronic backgrounds</u>
  - highest uncertainty
  - can be estimated **from data**

Background from data: "Matrix method"

General technique used by CDF and D0

- consider two variables with signal/background discrimination power
  - main assumption: the two variables are largely uncorrelated
  - e.g. lepton isolation and MET (M^T)
  - look at Var1%Var2



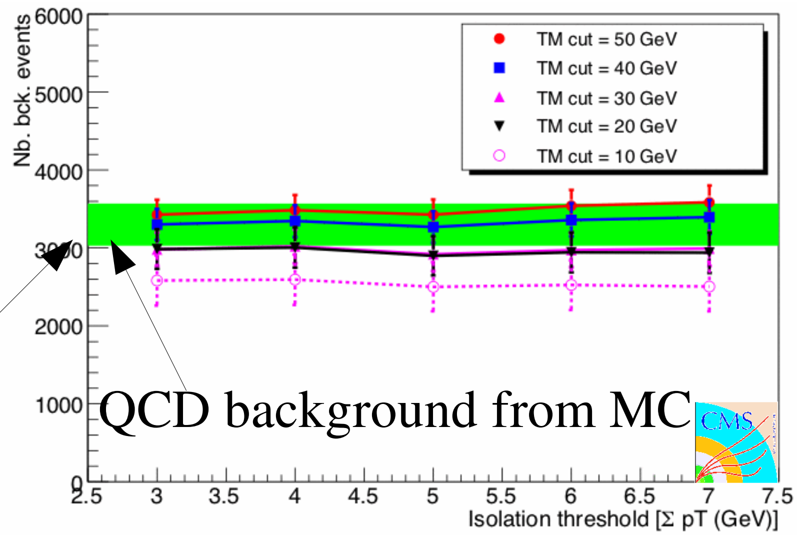
- Simplest approach: assuming that Ba, Bb, Bc are *only QCD* events, the number of bkg events Bd in the signal region is

$$R = \frac{Bb}{Ba} = \frac{Bc}{Bd} \rightarrow Bd = \frac{Bc}{R}$$

- may require "non-QCD" contamination correction in regions a, b, c

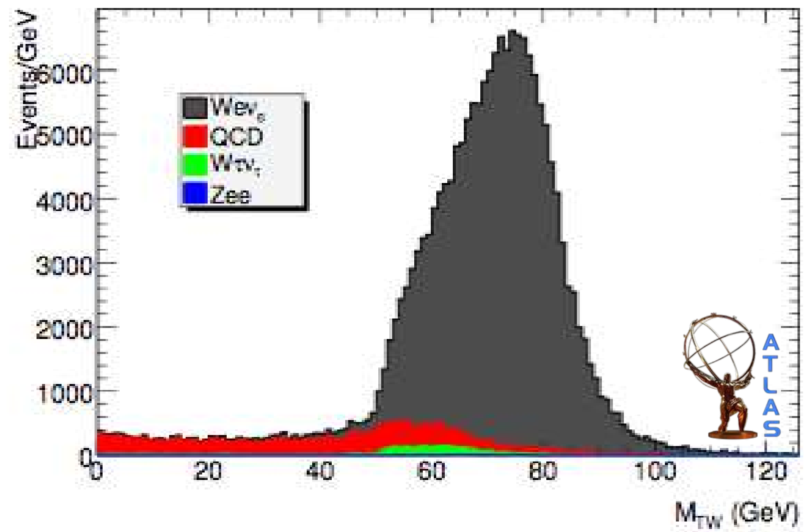
Example of QCD bkg estimation in $W \rightarrow \mu\nu$

- results after "non-QCD" events subtraction in control regions and using 0.5 pb^{-1} (for different control region choices)

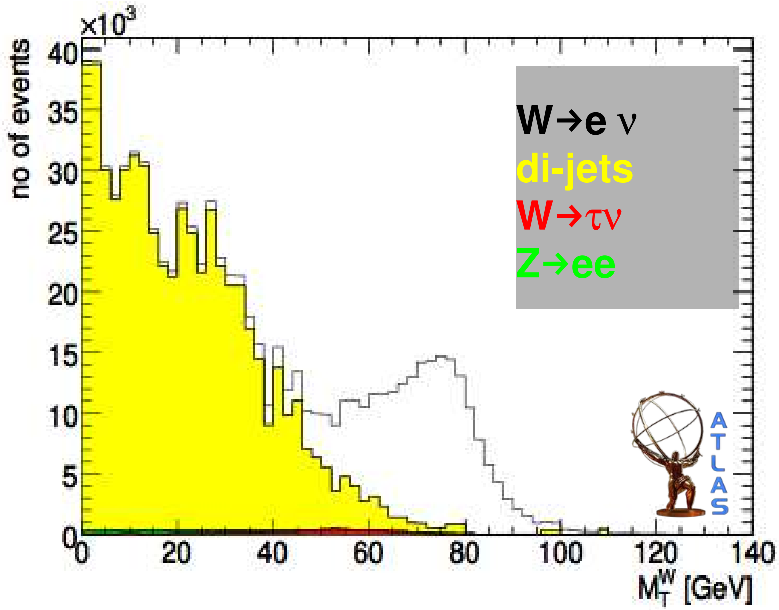


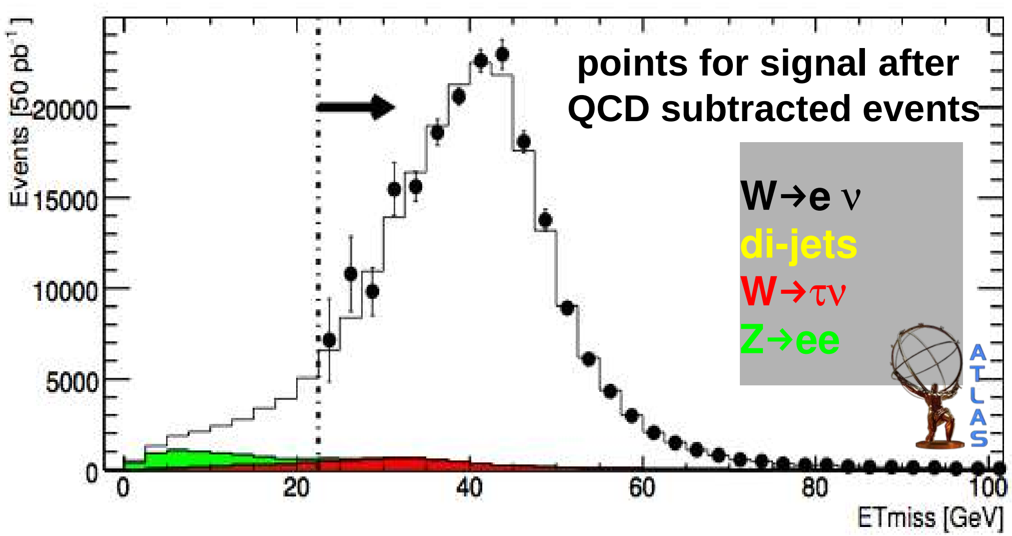
W→ eν

- Event selections:
  - triggered electron with E_T > 25 GeV, |η| < 1.37 or 1.52 < |η| < 2.4
  - E_T^{miss} > 25 GeV
  - Jet veto: E_{jet} < 30 GeV
- Highest uncertainty on QCD bkg.
- Z→ee removed via calculation of invariant mass with e-e, e-γ and e-EMjet pairs

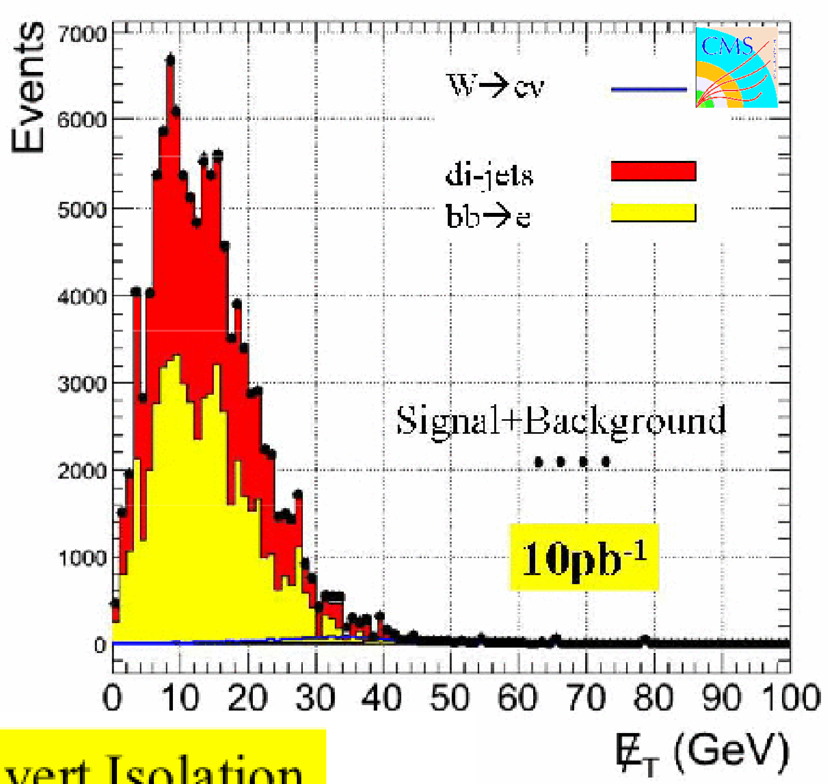


QCD shape parametrized from pure QCD sample (99.8%) from photon selection and normalized using sidebands



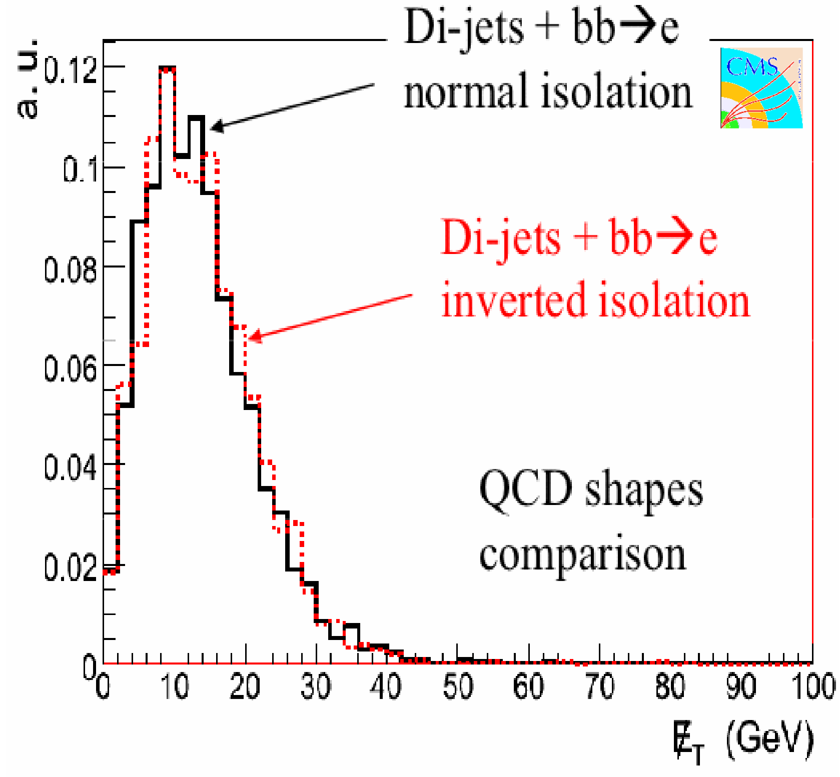


W→ eν



Invert Isolation

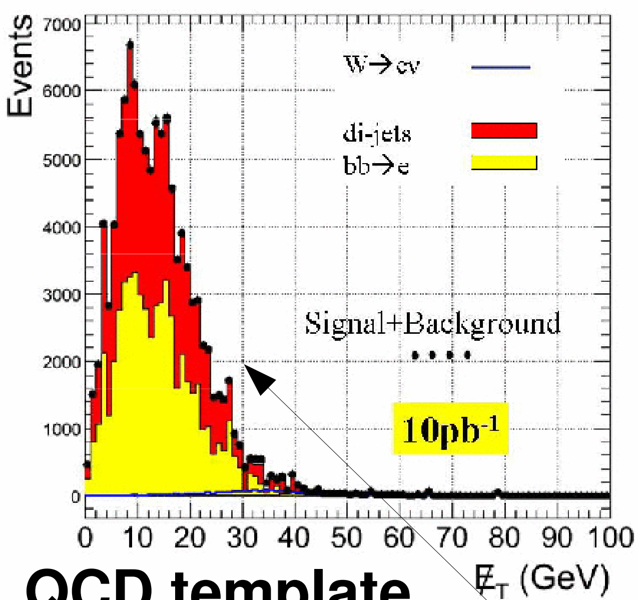
$$\sum_{track} \left(\frac{p_T^{track}}{p_T^{ele}} \right)^2 > 0.02$$



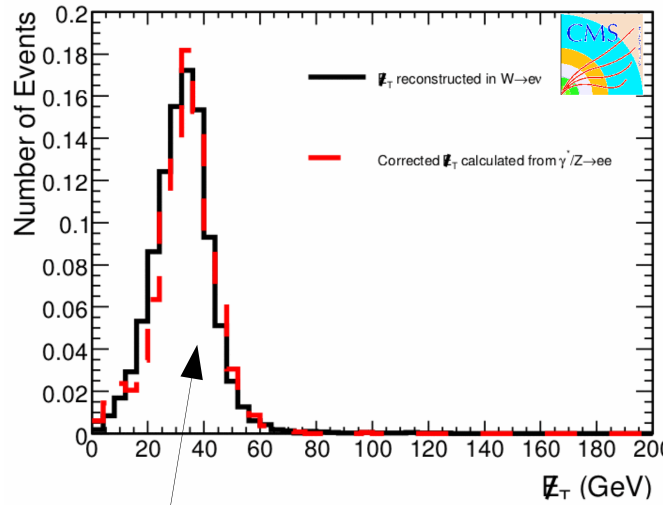
- MET distribution in QCD events almost independent of whether the candidates pass or fail the isolation requirement
- MET in QCD events can then be modeled on ANTI-ISOLATED electrons

W→ eν

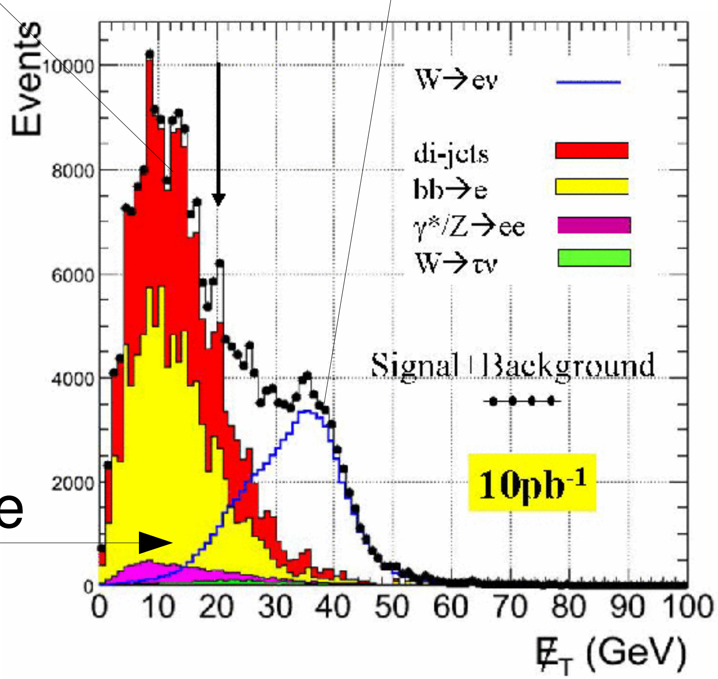
CMS AN-2007-026



QCD template from anti-isolated electrons



W→eν MET template: Z→eX̸ + corrections for different W/Z kinematics



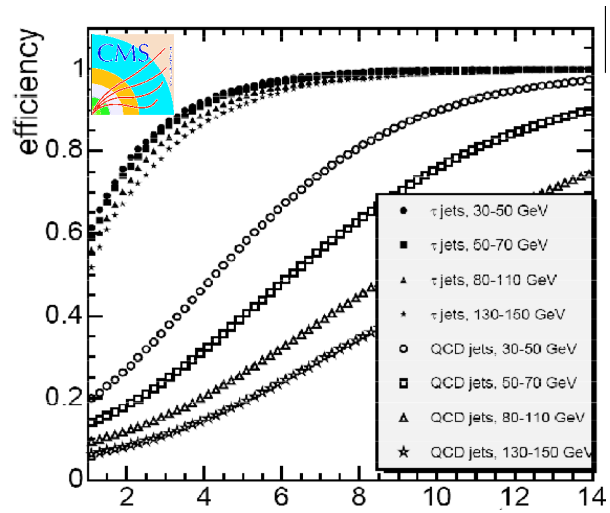
Other backgrounds: use full simulation

Possible systematic uncertainties
- bias in modelling QCD and signal templates
- bias from W and EW events in the non-isolated electron sample
- accuracy in the MC prediction of EW backgrounds

τ production from W, Z

Z→ττ , W→τν

- useful for validation, tuning algorithms, calibration, measurement of τ-ID efficiency
- cross section analysis

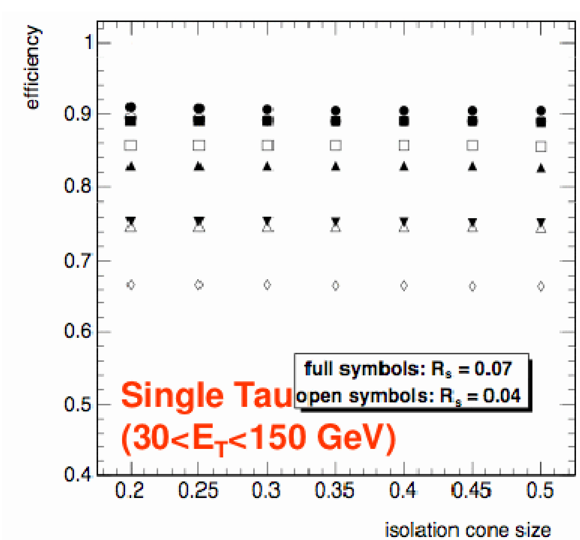


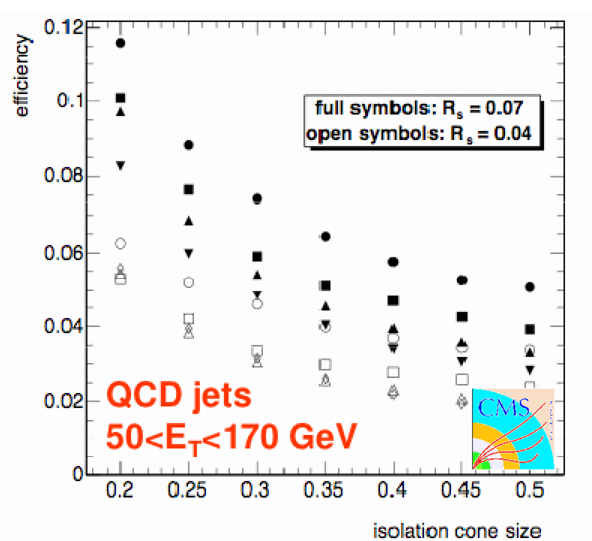
$$P_{isol} = \sum_{\Delta R<0.40} E_T - \sum_{\Delta R<0.13} E_T$$

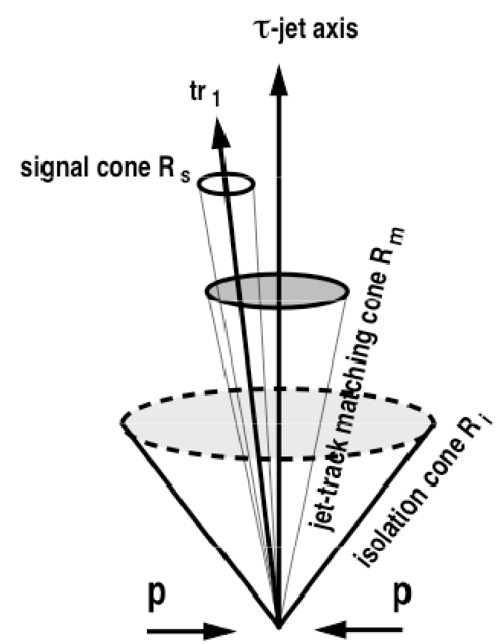
Identification of hadronic τ decays

- selection based on calorimetric isolation
  + tracker isolation

good background rejection (ε(QCD)~4-6%) with ~70% efficiency for τ jets







τ trigger

HLT efficiency: W→τν→τ–jet+MET

Table 5.3: Efficiencies of the TauWithMET HLT path.

	W $\rightarrow \tau\nu$	QCD $\hat{p}_T$ 120-170
Level-2 $\not{E}_T$ cut	53%	35%
Level-2 Jet Reconstruction and Ecal Isolation	78%	57%
Level-2.5 SiStrip Isolation in the small rectangle	37%	30%
Level-3 SiStrip Isolation in the final rectangle	61%	20%
HLT	10%	1.2%
L1 * HLT	1.8%	-

- Study of Trigger performance under start-up conditions (L = 10^{32}cm^{-2}s^{-1})
- HLT algorithms based on isolation

HLT efficiency: Z→ττ→τ–jet + τ–jet

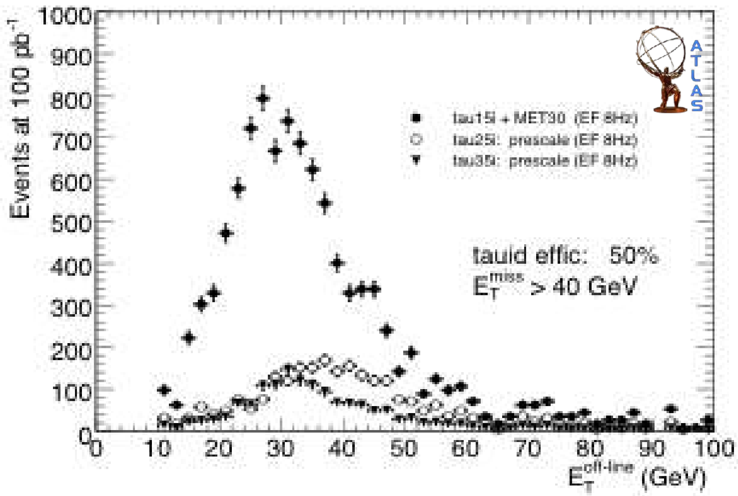
Table 5.4: Efficiencies and rates of the DoubleTau HLT path.

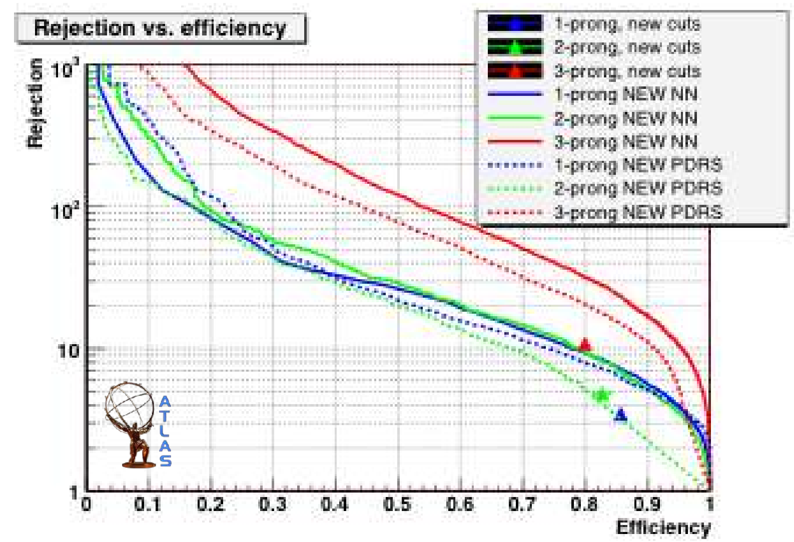
	Z $\rightarrow \tau\tau$	QCD $\hat{p}_T$ 120-170
Level-2 jet reconstruction	91%	58%
Level-2 Ecal Isolation	86%	37%
Level-2.5 Pixel Isolation	28%	0.77%
HLT	22%	0.17%
L1 * HLT	8.6%	-

Also combined trigger studies on signals Z→ττ→e+τ–jet or Z→ττ→ +τ–jet with overall L1*HLT efficiency ~20-25%

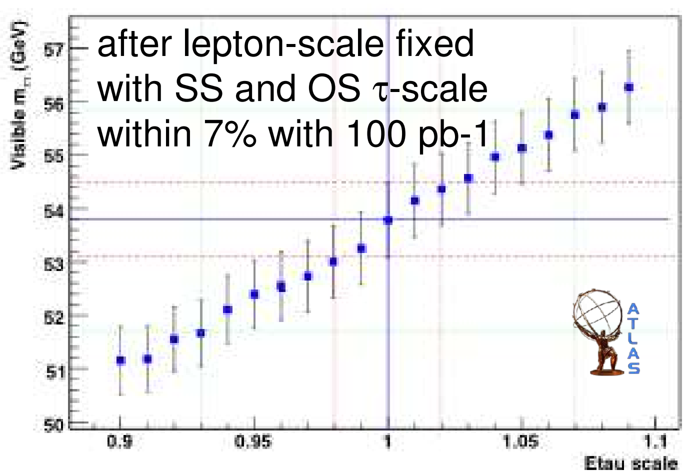
W, Z τ physics

- W→τν with hadronic τ decays: τ trigger optimization (Z→ττ unbiased sample) and offline selection tuning (e,μ vetoes, rejection of QCD jets)



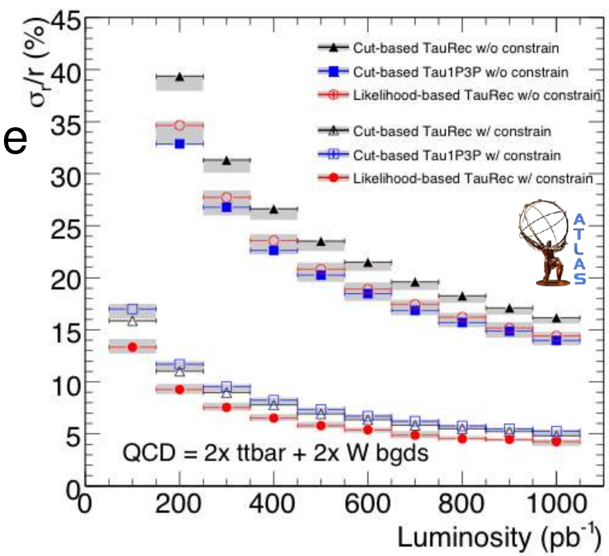


- Z→ττ : lower rate but more robust selection and background control (SS and OS)



•**QCD background rejection:**
e.g. looking at isolation outside τ-id cone and re-calculating multiplicity

• fraction of τ events for cross section measurement by likelihood fit (red points)



Summary for discussion

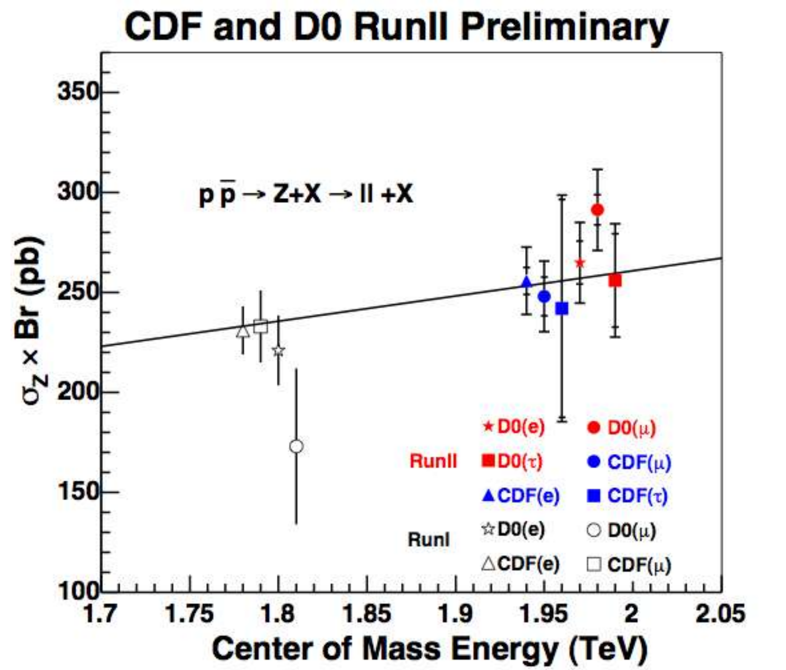
- **NLO QCD and EW tools available**
- **Detector calibration & understanding**
  - "Standard candles" are fundamental tools with many different approaches (tag and probe, independent signatures, mass constraints, energy scales)
  - tau identification, hadronic scales
- **Estimation of important analysis parameters from data** minimizing dependence from Monte Carlo simulations
  - Trigger/Offline selections with detailed analysis of systematic effects
  - QCD shape and normalization for background estimation

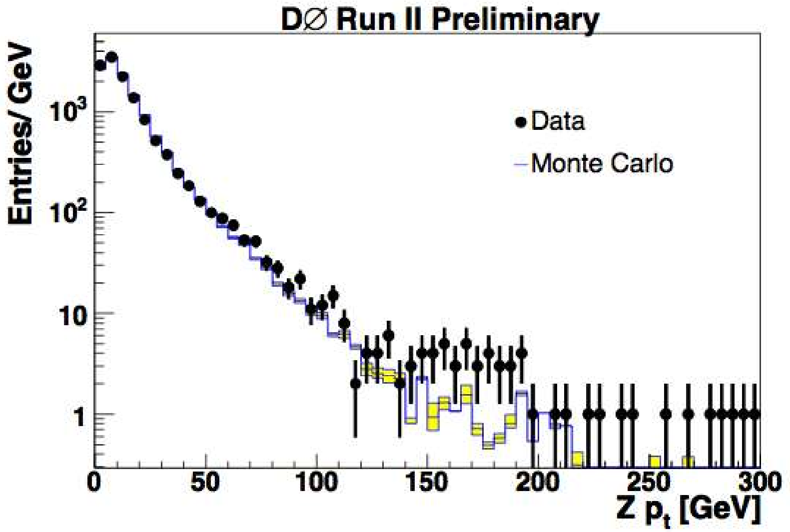
- **Precise PDFs determination as input for the LHC experiments**
  - improvements in the PDF fits: higher order effects, heavy quarks treatment
  - inclusion of low x effects
  - rigorous approach for uncertainties determination.
- **Z and W productions are good candidates to constrain PDFs at the LHC**
  - LHC data can be sensitive to gluon and quark distributions at low x
  - control of the experimental systematic errors needed

Backup slides

W, Z physics

- Measurements of Electroweak observables
  - W mass and width, $\sin^2 \Theta_{eff}$, A_{FB}
  - W, Z cross sections and their ratio $R_{W/Z}$
  - W charge asymmetry $A(\eta_l)$ and differential cross sections
  - Di-Boson productions
- Single W/Z boson production is a clean processes with large cross section useful also for :
  - monitor collider luminosity and constrain PDFs looking at σ_{TOT}, W rapidity, ...
  - to search for new physics looking at invariant mass high tail, ...
  - "Standard candles" for detector calibration/understanding



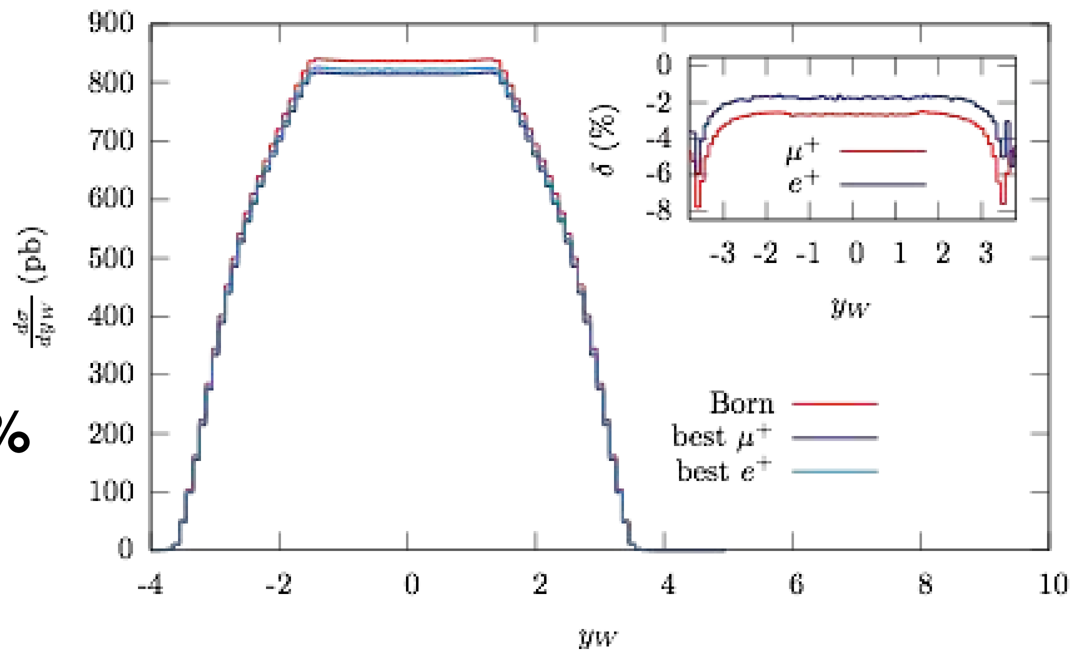


NLO MC Generators for W, Z

- The best theoretical description from NLO QCD and EW generators, as:
  - MC@NLO S. Frixione, P. Nason and B.R. Webber [hep-ph/0204244] [hep-ph/0305252]
  - HORACE C.M. Carloni Calame, G. Montagna, O. Nicrosini and A. Vicini [JHEP 0612:016,2006] [JHEP 0710:109,2007]

- EW corrections with lepton $|\eta|<2.5$ $p_T>25$ GeV @ **5-10 %**

- EW corrections for high invariant mass regions (>1 TeV) @ **20-30%**



Trigger efficiency from Z→e⁺e⁻

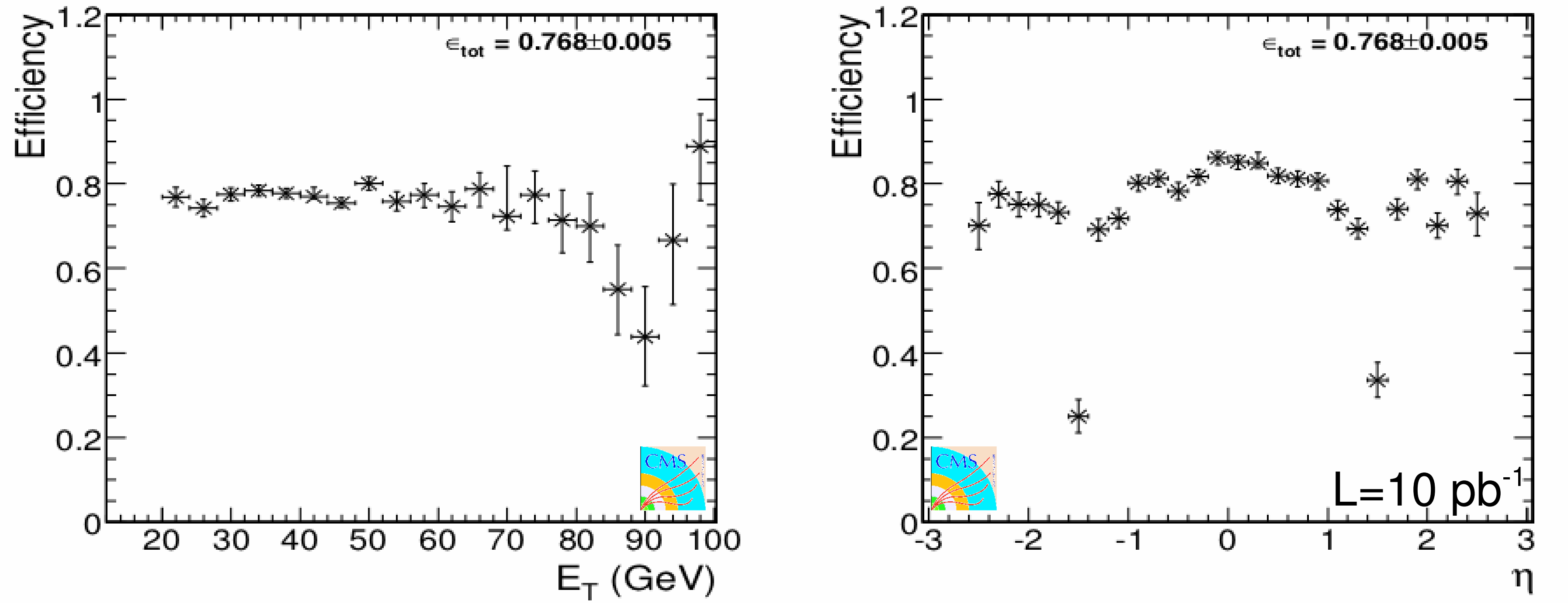
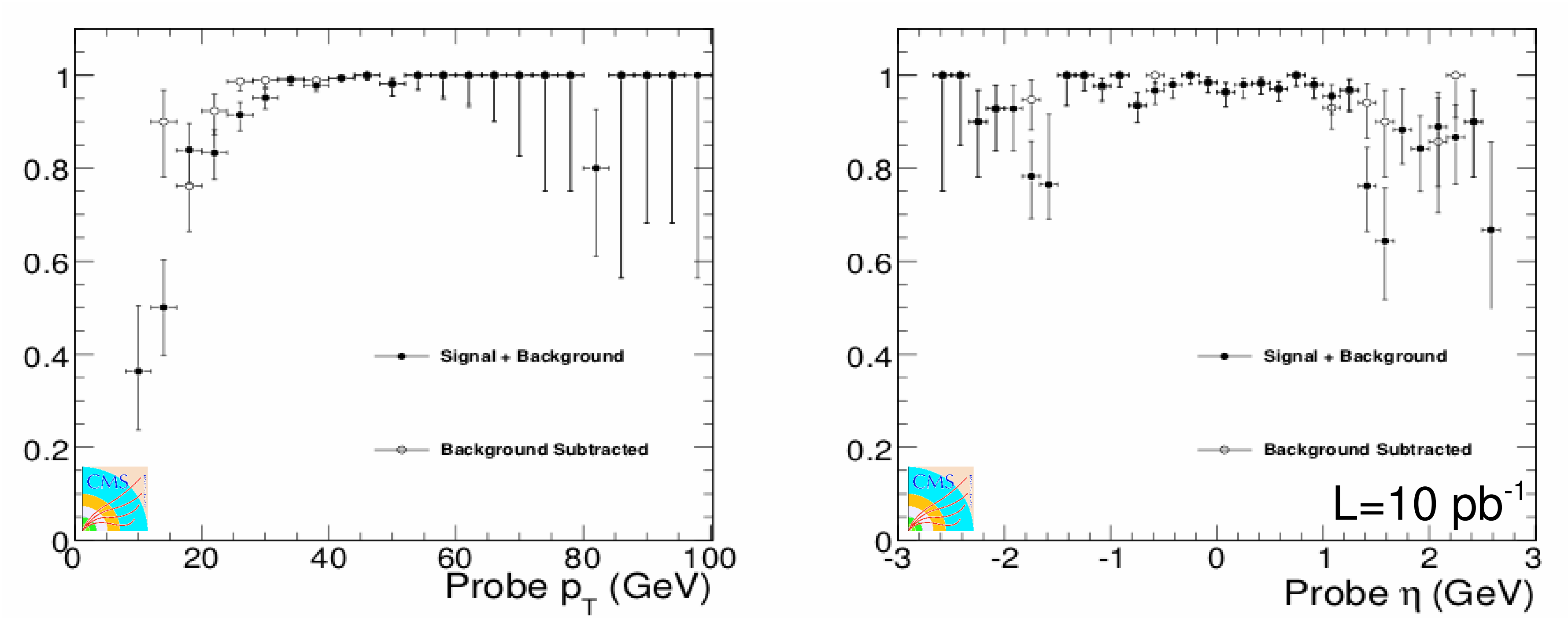


Figure 3: L1+HLT efficiency versus supercluster E_T.   Figure 4: L1+HLT efficiency versus supercluster η.

Efficiency from Z→e^+e^-

Electromagnetic calorimeter reconstruction efficiency as a function of probe track p^T



- ϕ symmetry exploited for initial ECAL intercalibration with inclusive jets
- use $Z \rightarrow ee$ for intercalibration between rings
  - 0.6 % precision with 2 fb^{-1}