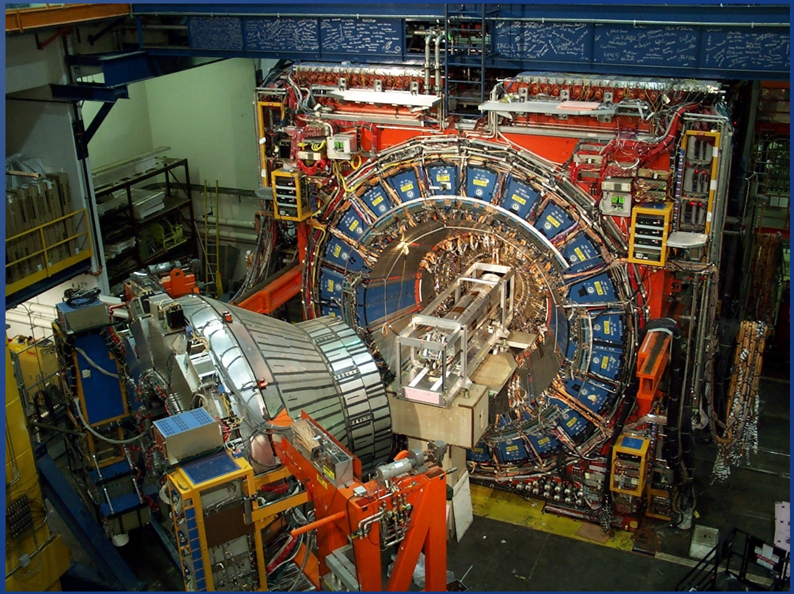
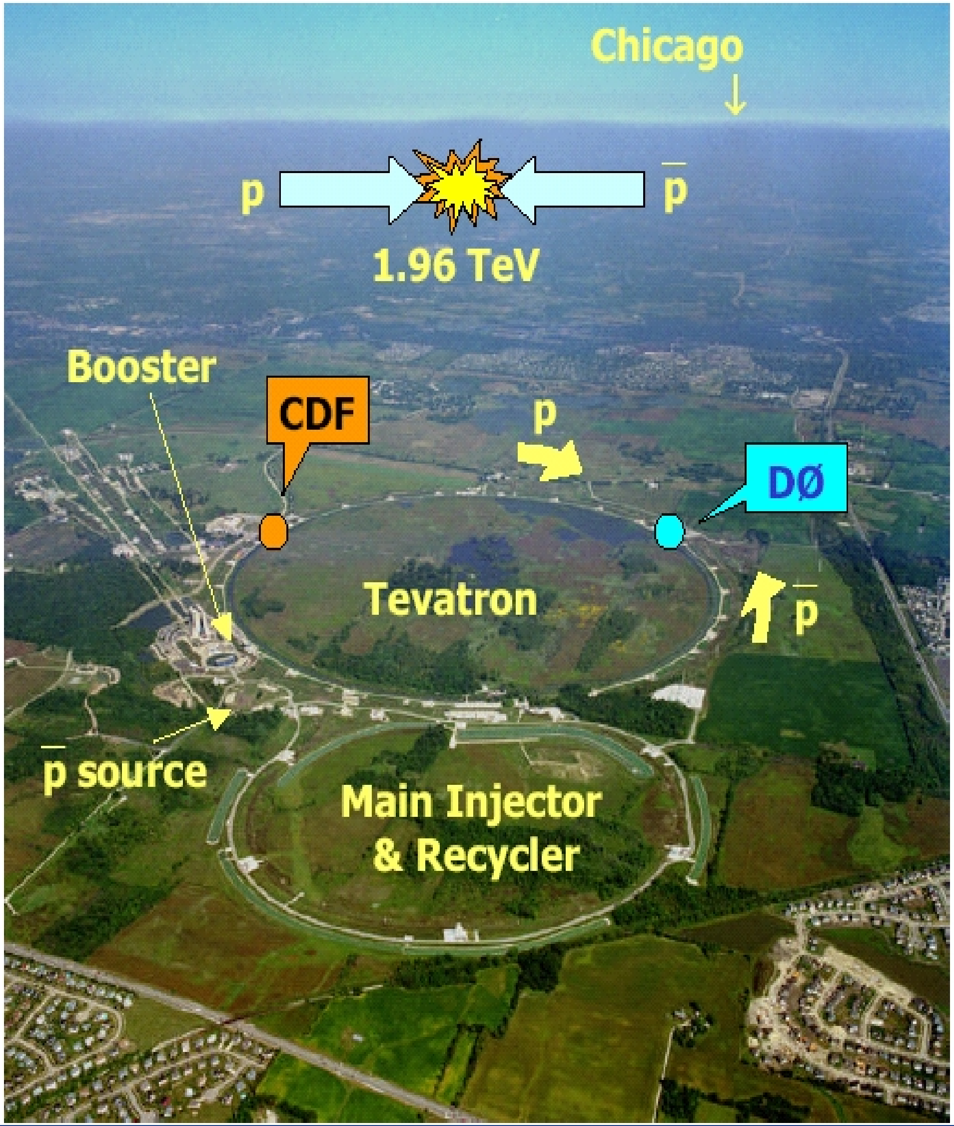
Heavy Flavours + vector bosons in CDF

Mario Campanelli (UCL)

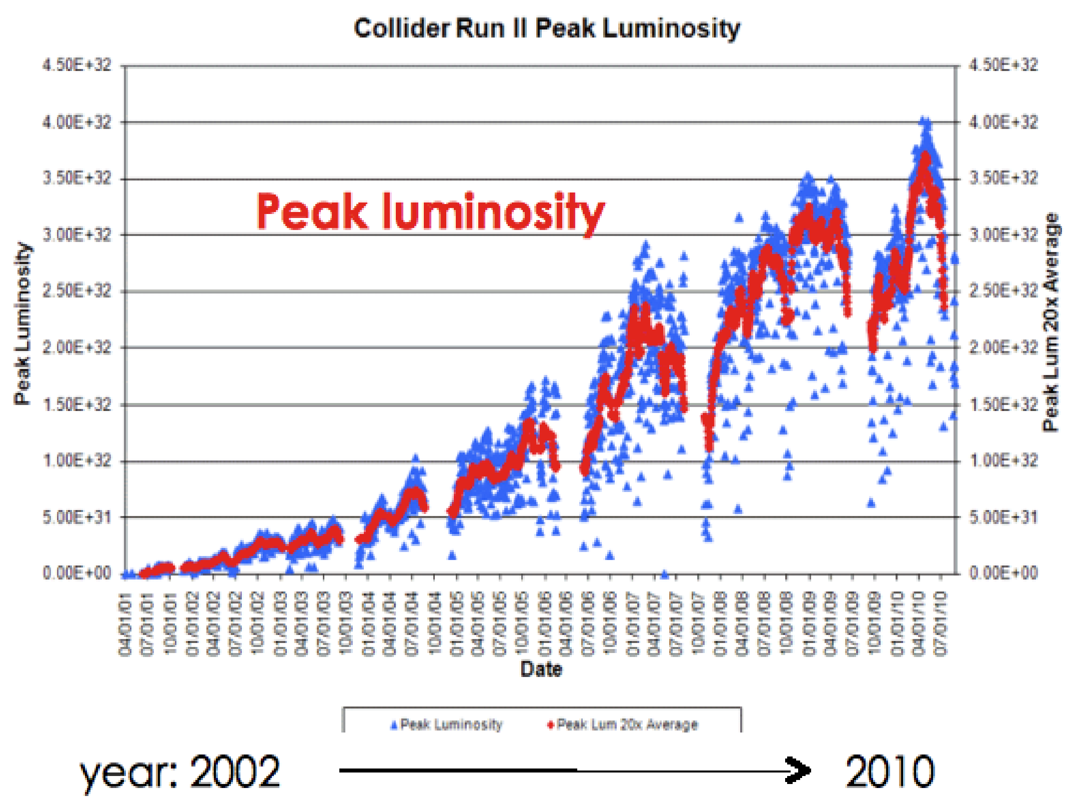
- Tevatron/CDF status
- General analysis strategy
- Z + b
- W + b
- W + c
- Photon + b

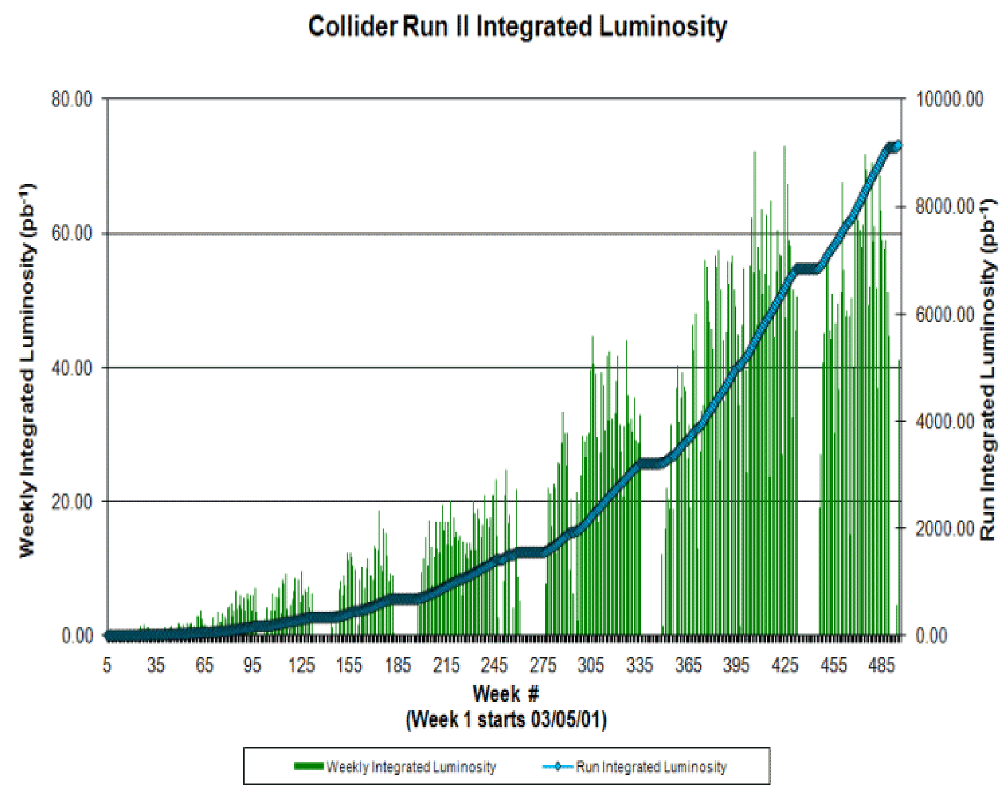


The Tevatron



- World's second largest hadron collider
- First large-scale super-conducting magnet (4.2 T) accelerator
- 6.28 Km length, theoretical maximum about 1.4 TeV per beam
- $\sqrt{s}$ = 1.96 TeV
- Started operation in 1987 (run 0), then collected about 100 pb^{-1} until 1996 (run I), then a long shutdown until 2000, and Run II between 2001 and 2011 (2014??)



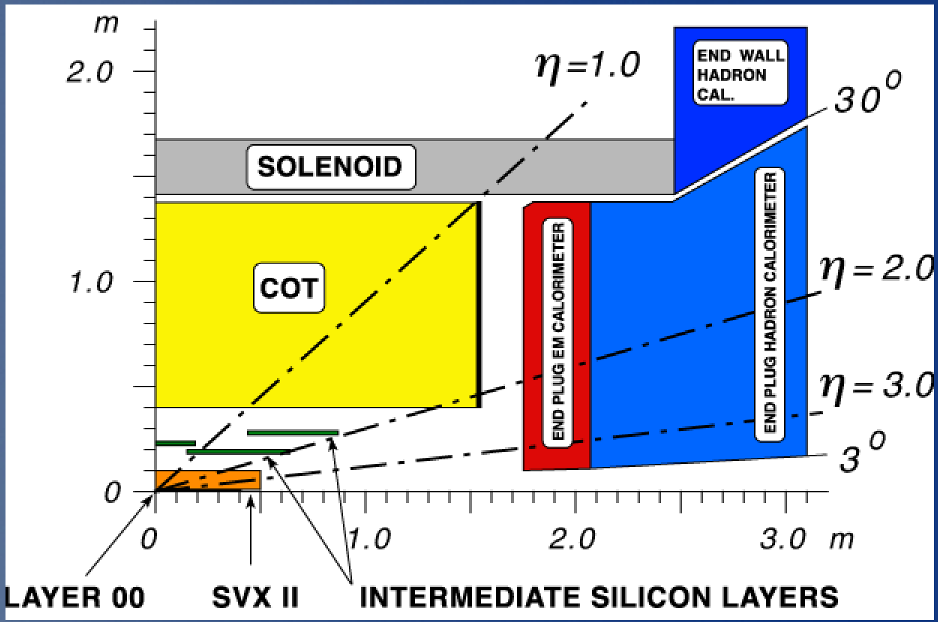


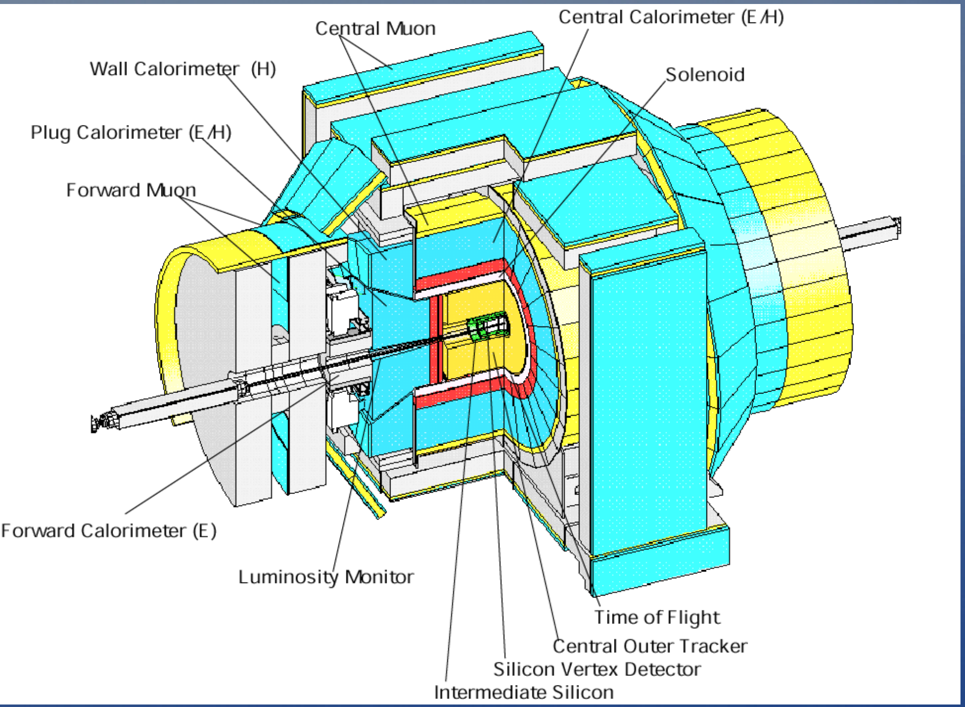
Typical initial luminosity: 3.5 E32 cm-2 s-1
Integrated in a week: 70 pb-1

Values still (slightly) improving with time

CDF II detector

- CDF fully upgraded for Run II:
  - Si & tracking
  - New endcap calorimetry
  - L2 trigger on displaced tracks
  - High rate trigger/DAQ





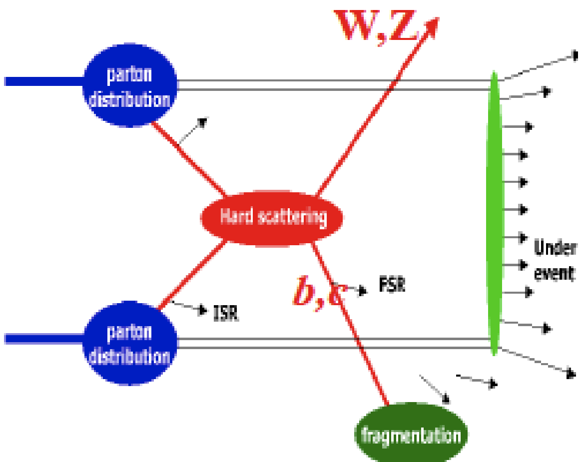
Calorimeter

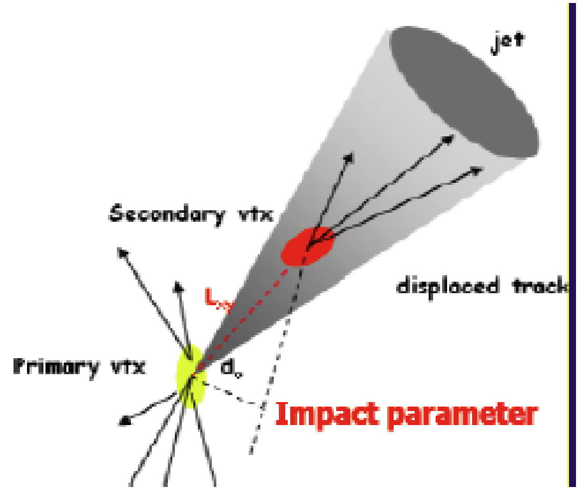
- CEM lead + scint $13.4\%/\sqrt{E_t} \oplus 2\%$
- CHA steel + scint $75\%/\sqrt{E_t} \oplus 3\%$

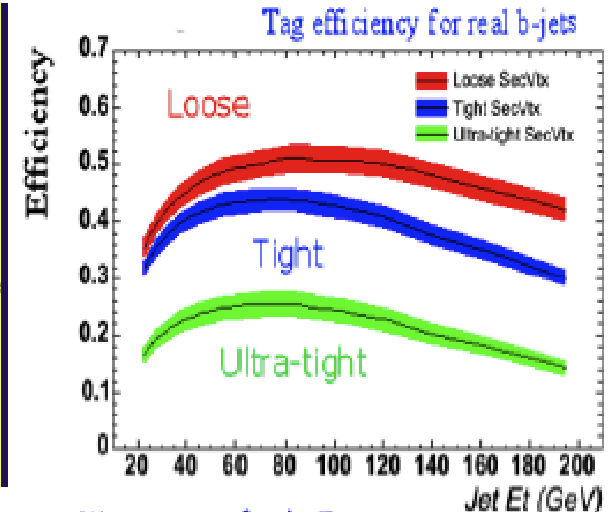
Tracking

- $\sigma(d0)$ = 40μm (incl. 30μm beam)
- $\sigma(pt)/pt$ = 0.15 % pt

Strtegy for heavy flavour + vector boson measurements

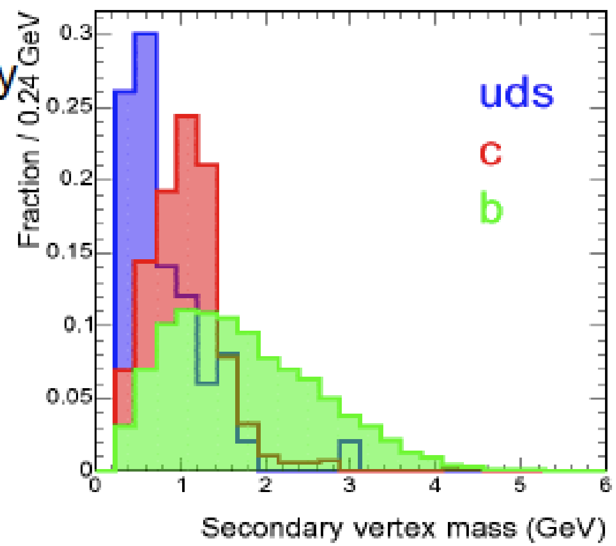


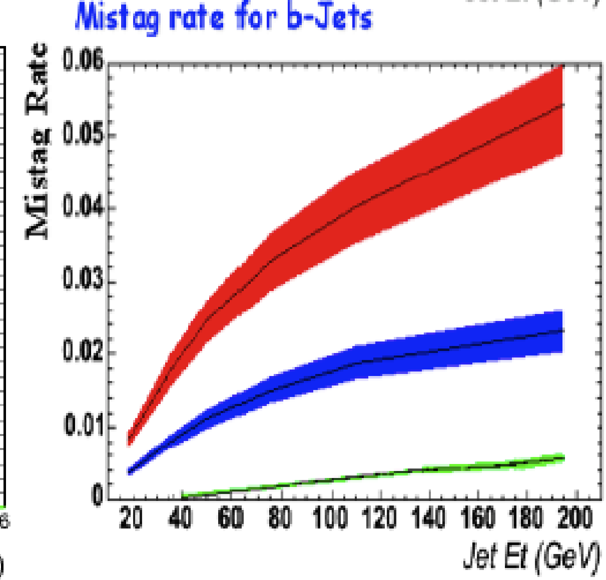




Secondary vertex tag (based on large B lifetime)

- 3 operating points in efficiency and purity (loose/tight/ultra-tight)
- Secondary vertex mass used to separate light from c and b quarks





Soft Lepton Tag (20% Branching ratio…)

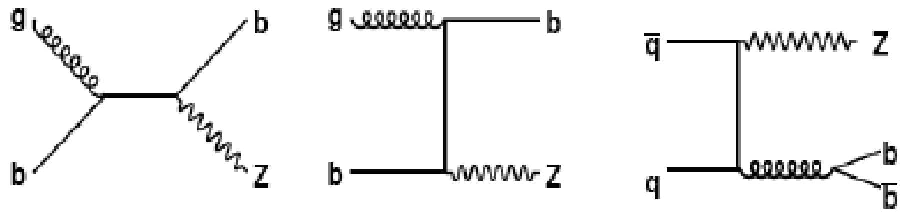
Main uncertainties from templates definition, b- tag efficiencies and mistag rates

M.Martinez, HCP'10

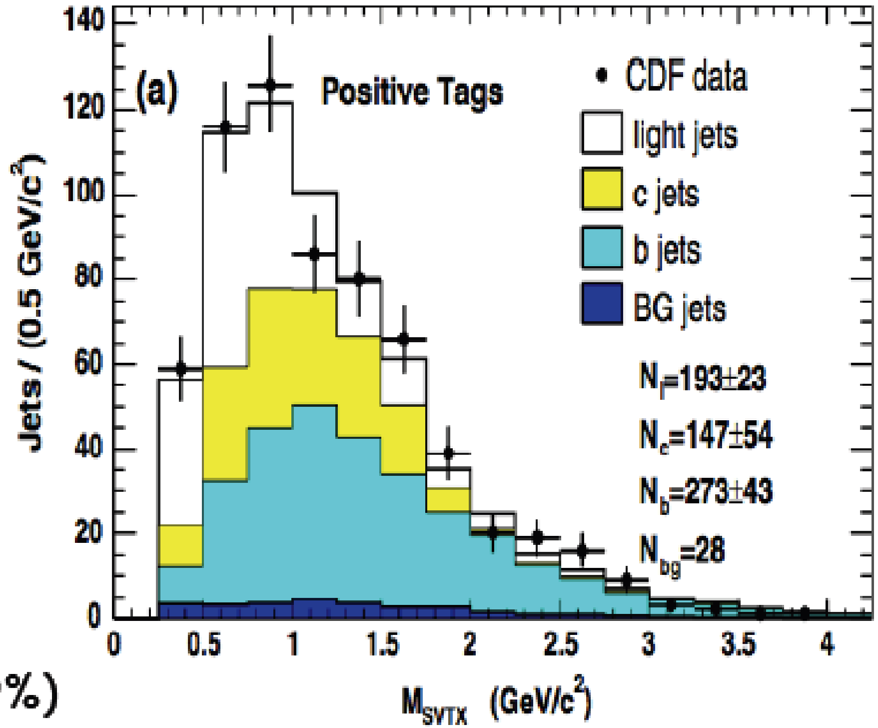
Phys.Rev.D79:052008,2009

2 fb^{-1}

Inclusive Z+b



$$\frac{\sigma^{\text{jet}}(Z + b\,\text{jet})}{\sigma(Z)} = \frac{N^{\text{jet}}(Z + b\,\text{jet})/N(Z)}{\epsilon^{\text{jet}}(Z + b\,\text{jet})/\epsilon(Z)}$$



Considering electron and muon channels

76 < M_{ll} < 106 GeV
(eff. 41% for Z→ ee, 23% for Z→ μμ)

Jets with Et > 20 GeV and |η| < 1.5
(JETCLU R=0.7)

At least one jet b-tagged (eff. Z+b-jet : 9%)

(b-jet fraction from fit to vertex mass)

$$\frac{\sigma^{\text{jet}}(Z + b\,\text{jet})}{\sigma(Z)} = (3.32 \pm 0.53(\text{stat}) \pm 0.42(\text{syst})) \times 10^{-3}.$$

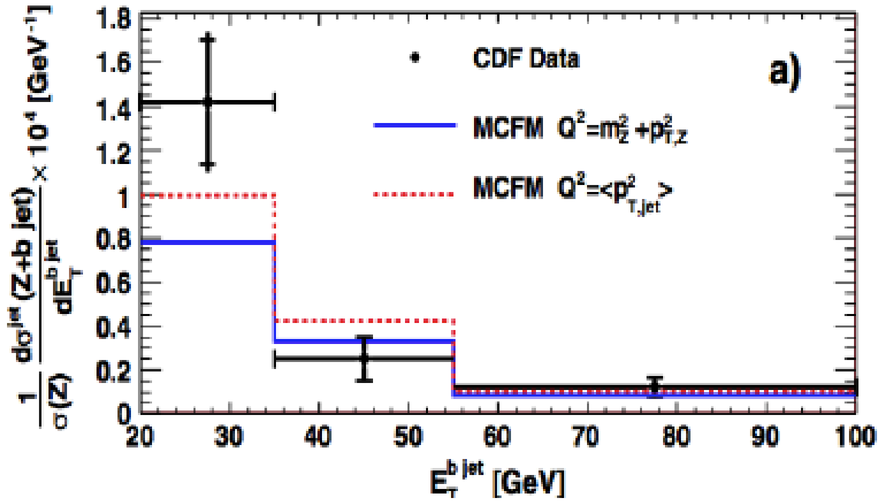
Background from other
physics processes taken from MC

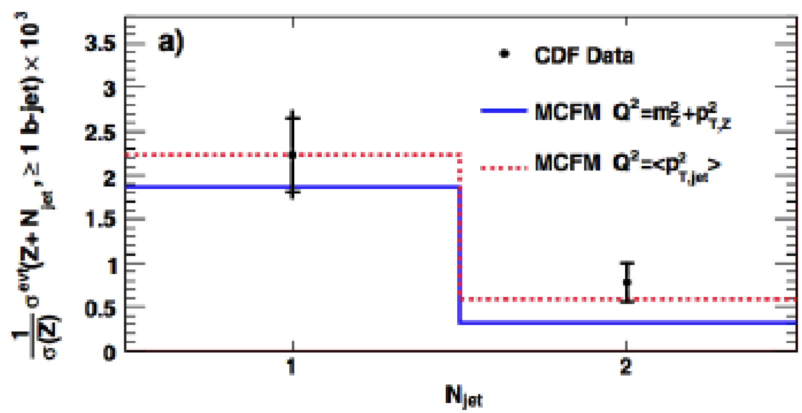
$$MCFM : 2.3 \times 10^{-3}\ (Q^2 = M_Z^2 + P_{T,Z}^2)$$

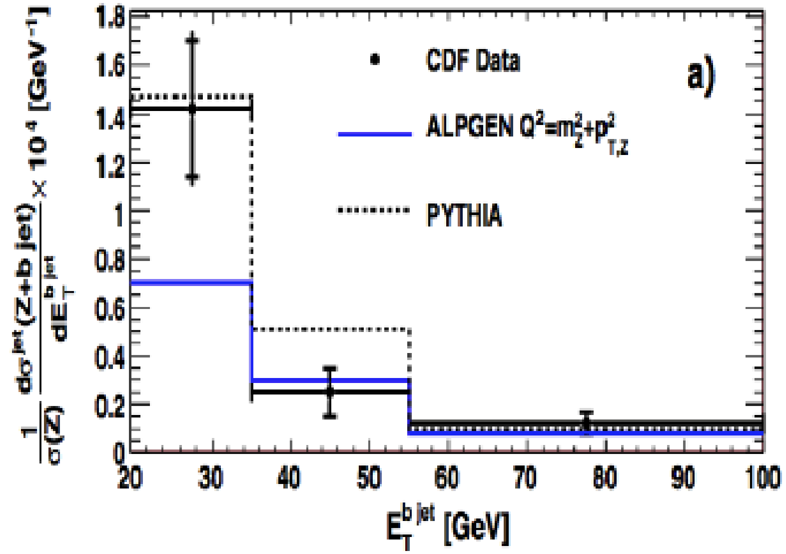
$$: 2.8\ \times 10^{-3}\ (Q^2 = \ <P_{T,Jet}^2>)$$

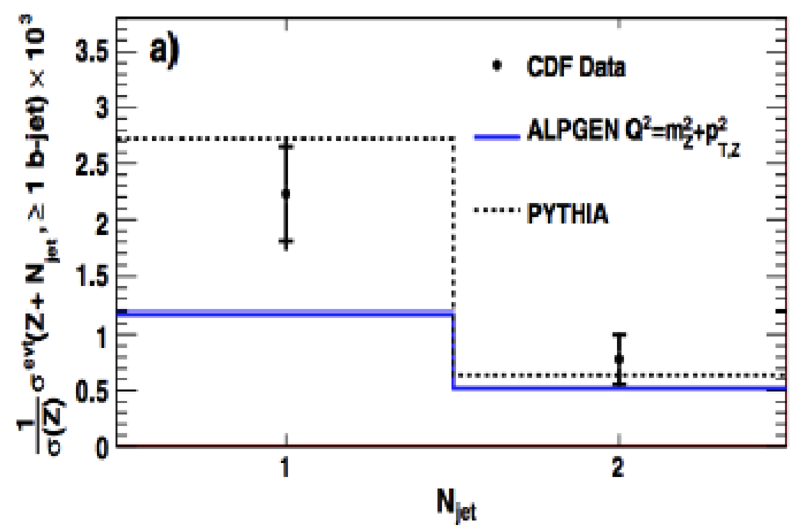
non-pQCD corrections applied to MCFM : +8%

Z+b









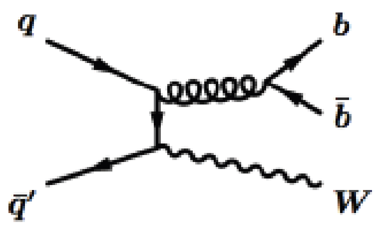
$$\frac{\sigma(Z+b)}{\sigma(Z+jets)} = 2.08 \pm 0.33 \pm 0.34(\%)$$

$$MCFM : 1.8\%\ (\mathrm{Q}^2 = M_Z^2 + \mathrm{P}_{\mathrm{T,Z}}^2)\ ;\ 2.2\%\ (\mathrm{Q}^2 = \ <\mathrm{P}_{\mathrm{T,Jet}}^2>)$$

Measurements in agreement with predictions (large uncertainties in both data and theory)

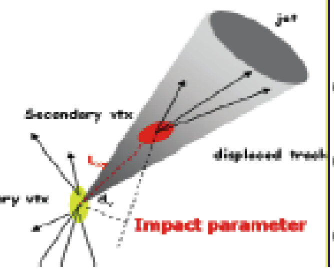
Also large variations between PYTHIA and ALPGEN

W +b-jet(s)

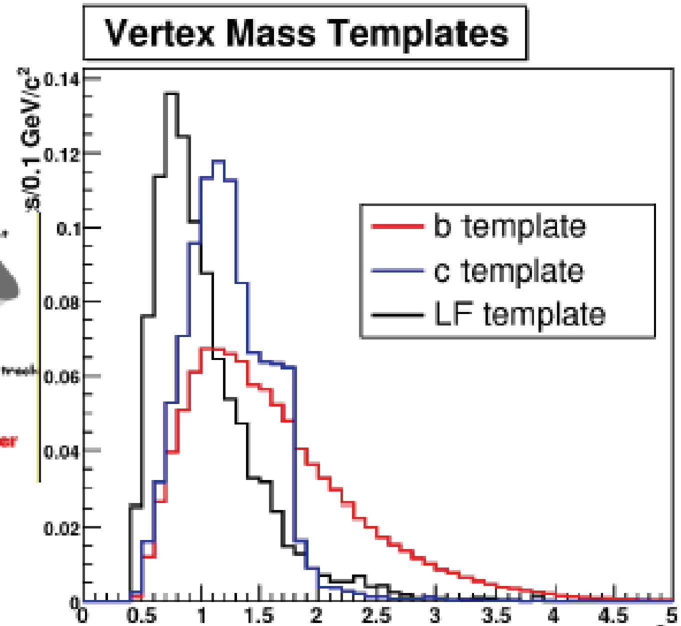


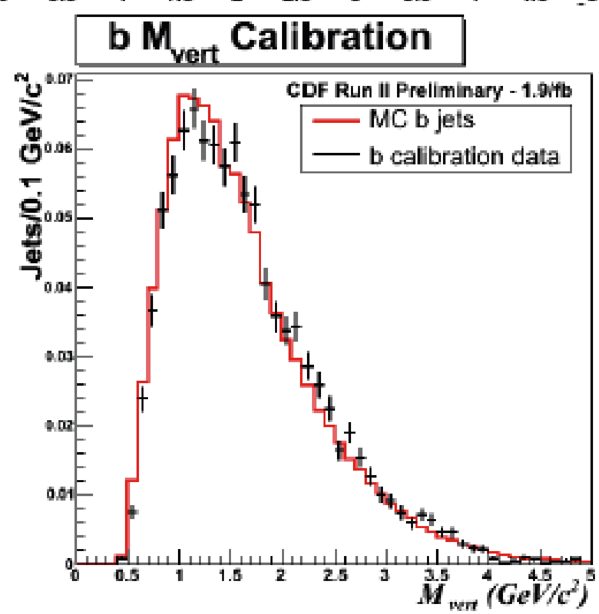
PRL 104, 131801 (2010)

- Both electron and (muon) channels
  - P_T>20 GeV/c
  - $|\eta|$<1.1
  - MET > 25 GeV
- Exactly one or two jets JetClu (R=0.4)
  - E_T^{jet}>20 GeV/c
  - $|\eta^{jet}|$ < 2.0
  - One b-tagged jet (SVTX ultra-tight)

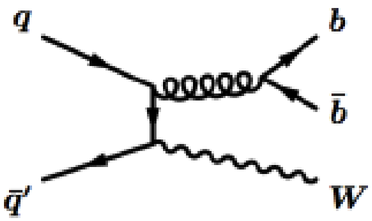


- B-quark composition extracted from fit to secondary vertex mass
  - Templates for light, charm and bottom taken from MC
  - Validated in control samples in data
- Physics Processes that contribute:
  - W+b/c production (taken from ALPGEN)
  - Top and dibosons (taken from PYTHIA)
  - Single top production (taken from MADEVENT)
  - QCD multijets (from DATA)
- Comparison with theory in the restricted phase space (no extrapolation is made)





W+b-jet(s)



Fraction of b-jets : 0.71 +- 0.05

In 1.9 fb^{-1}

TOTAL : 670 +- 44 (stat.) b-tagged jets

BACKG.: 177 +- 22 (stat.) "

18% uncertainty on the measurement

vertex modeling (8%)

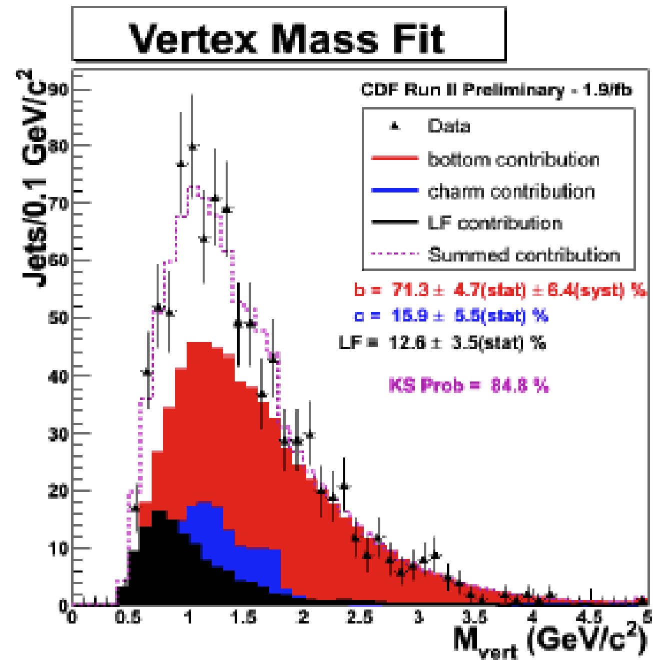
b-tag effi. (6%), lumi. (6%)

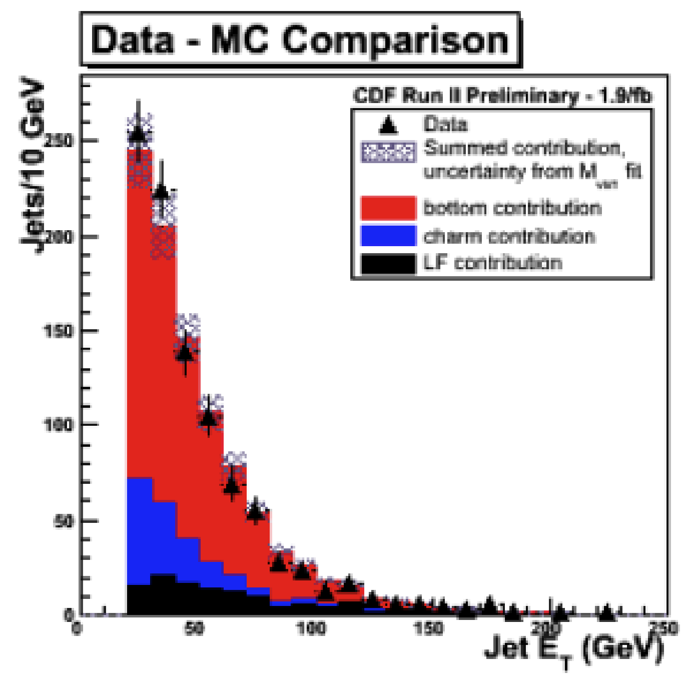
$$\sigma_{bjets}\,(W + b\ \text{jets}) \times BR(W\rightarrow l\nu) = 2.74 \pm 0.27 \pm 0.42\ \text{pb}$$

ALPGENv2 +PYTHIA 6.3

$(Q^2 = M_W^2+P_{T,W}^2) = 0.78$ pb

NLO pQCD = 1.22 +- 0.14 pb

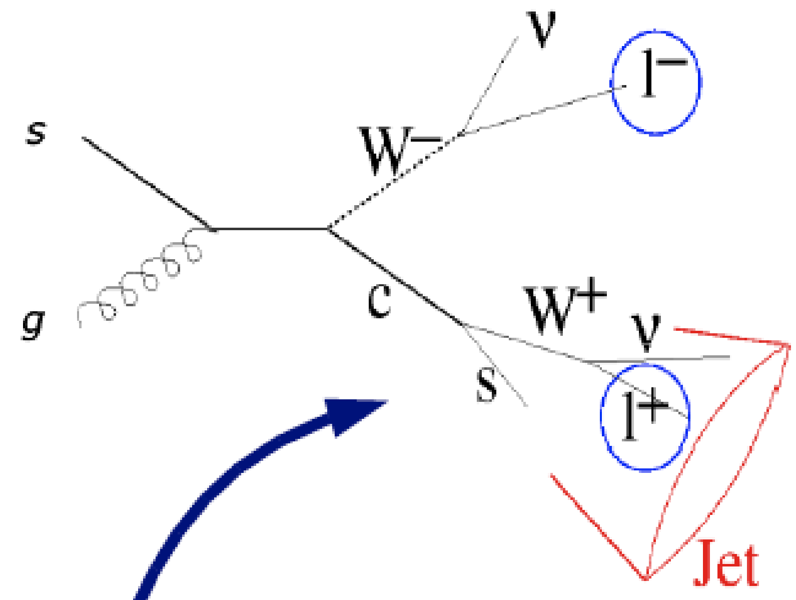




W + single c Production

New results based on 4.3 fb^{-1}

- Probe s-content of proton at high Q^2
  g+s ~ 90% g+d ~ 10%
- Background for single-top, W + H

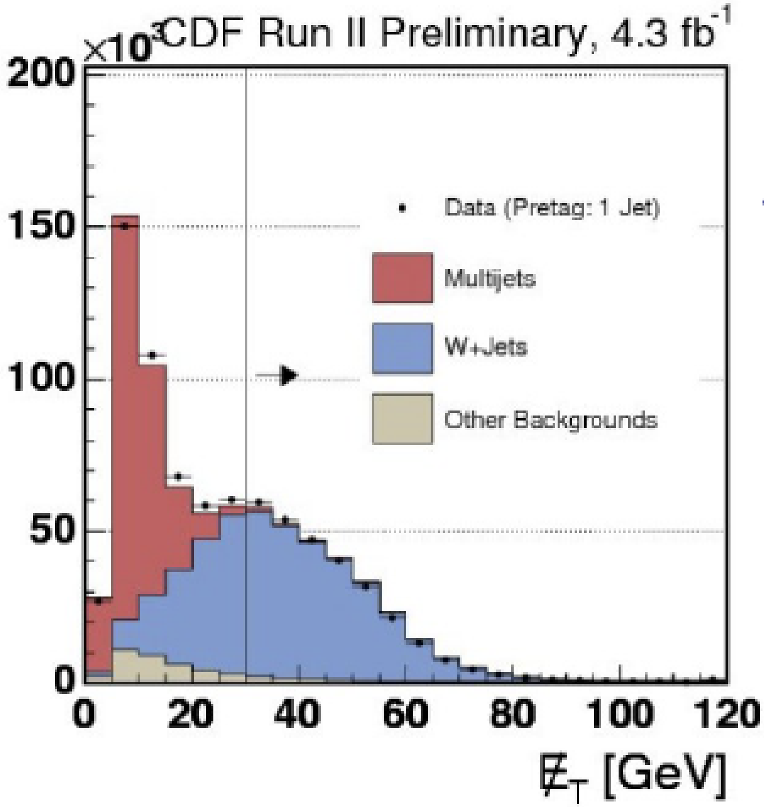


Event Selection

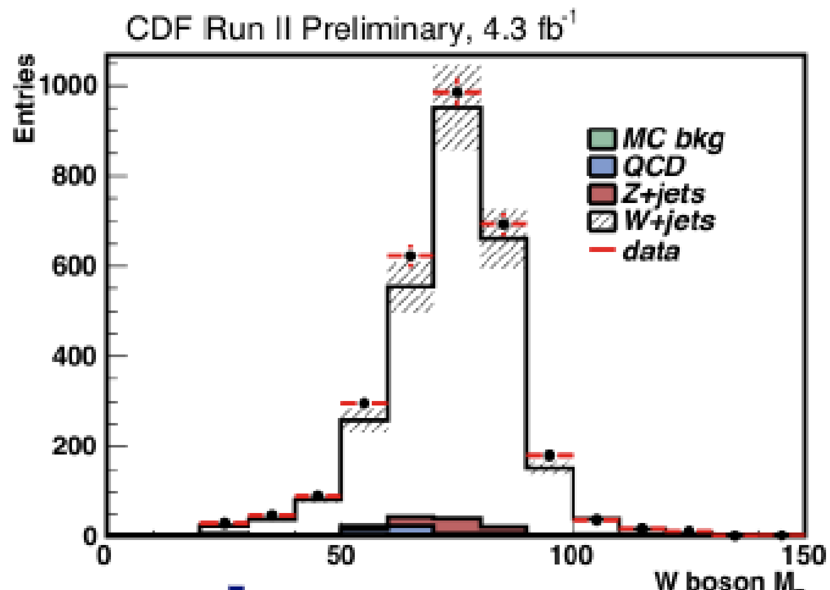
- $W \rightarrow l\nu$ selected by high p_T e,μ + MET
- JETCLU R = 0.4 jet with E_T > 20 GeV/c and $|\eta| < 2.0$
- Charm-jet identified by soft electron tagging (SLT_e) algorithm
- Exploit opposite charge correlation between W lepton and SLT electron

$$\sigma_{W+c} \times Br(W \rightarrow l\,\nu) = \frac{N_{data}^{OS-SS} - N_{bkg}^{OS-SS}}{\epsilon \cdot A \cdot L}$$

W + charm background



QCD background is estimated by a fit to the MET spectrum



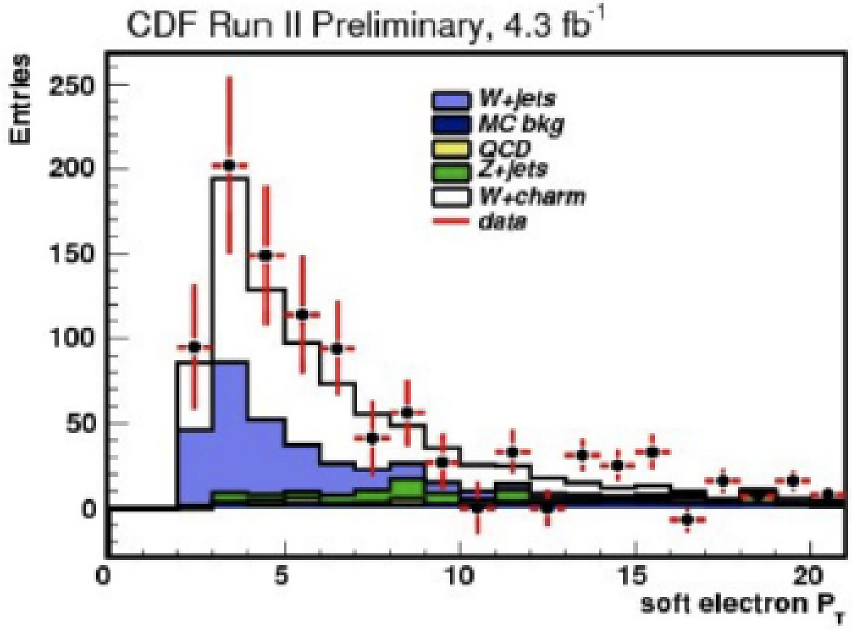
Background validation in OS+SS control region

Main backgrounds:

- Fake W (QCD)
- W + light jets
- Drell-Yan

W + charm result

Soft electron tagger validation



Main systematic uncertainties:

- Q^2 10%
- SLT tagging efficiency 8.8%
- Luminosity 8.3%
- PDF 8%
- ISR/FSR 7%
- Jet Energy Scale 6%

Charm $p_T > 20$ GeV/c and $|\eta| < 1.5$

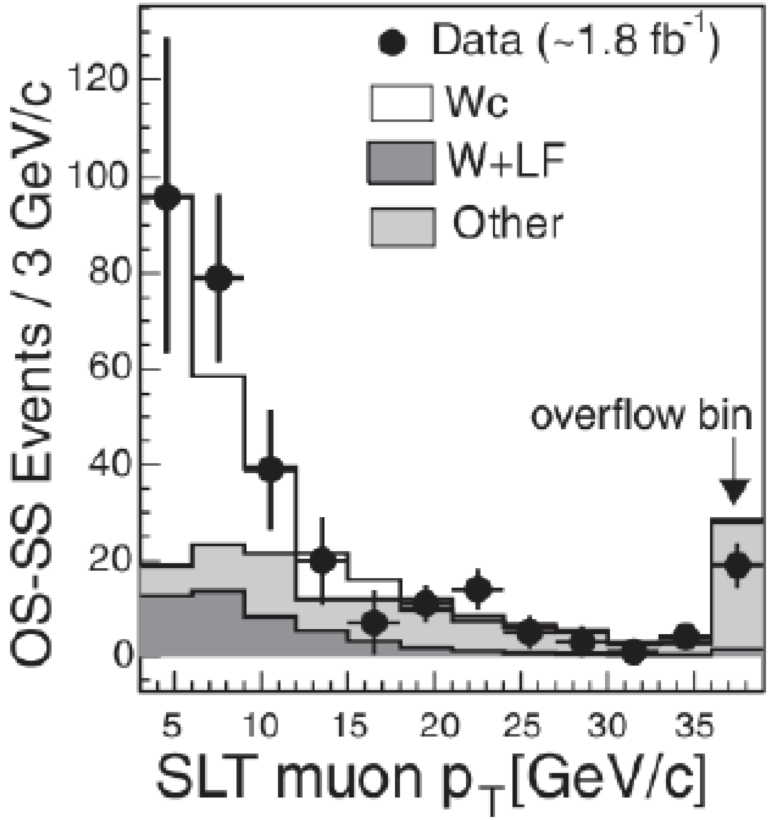
$$\sigma_{W+c} \times Br(W \rightarrow l\nu) = 21.1 \pm 7.1(stat) \pm 4.6(syst)\ pb$$

$$NLO\ prediction\ (MCFM): 11.0^{+1.4}_{-3.0}\ pb$$

Data and NLO in reasonable agreement

W + charm – μ channel

Previous result with 1.8 fb^{-1} in the charm → μ channel



Soft muon tagger validation

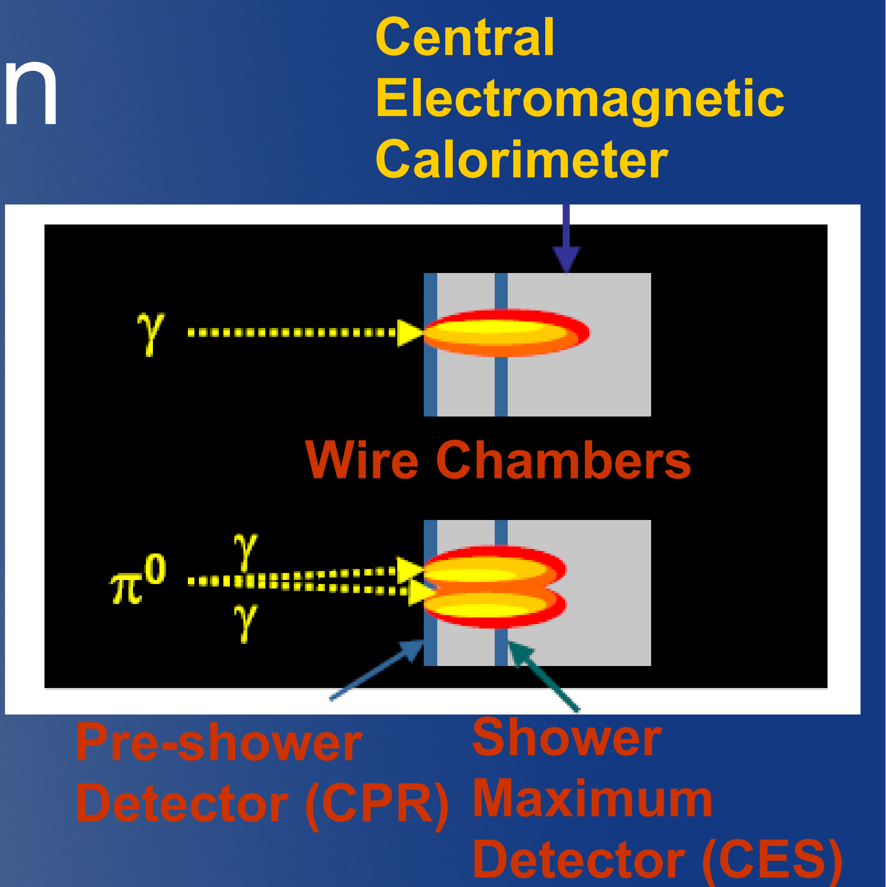
Charm $p_T > 20$ GeV/c and $|\eta| < 1.5$

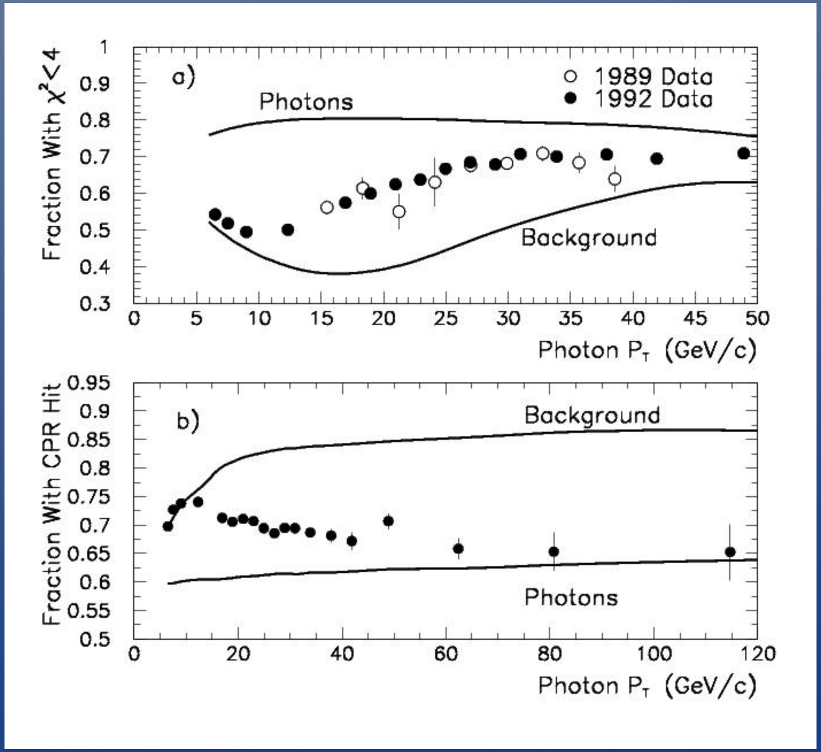
$$\sigma_{W+c} \times Br(W \to l\nu) = 9.8 \pm 2.8(stat)^{+1.4}_{-1.6}(syst) \pm 0.6(lum)\ pb$$

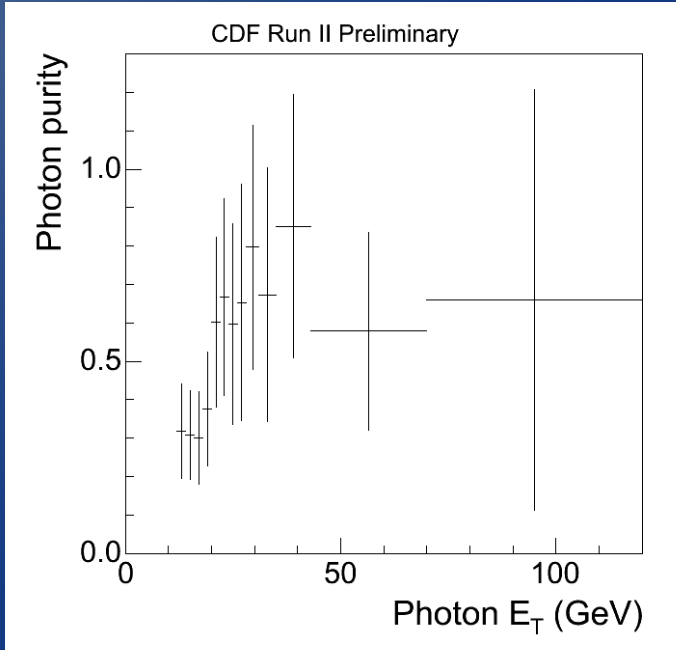
$$NLO\ prediction\ (MCFM): 11.0^{+1.4}_{-3.0}\ pb$$

Photon identification

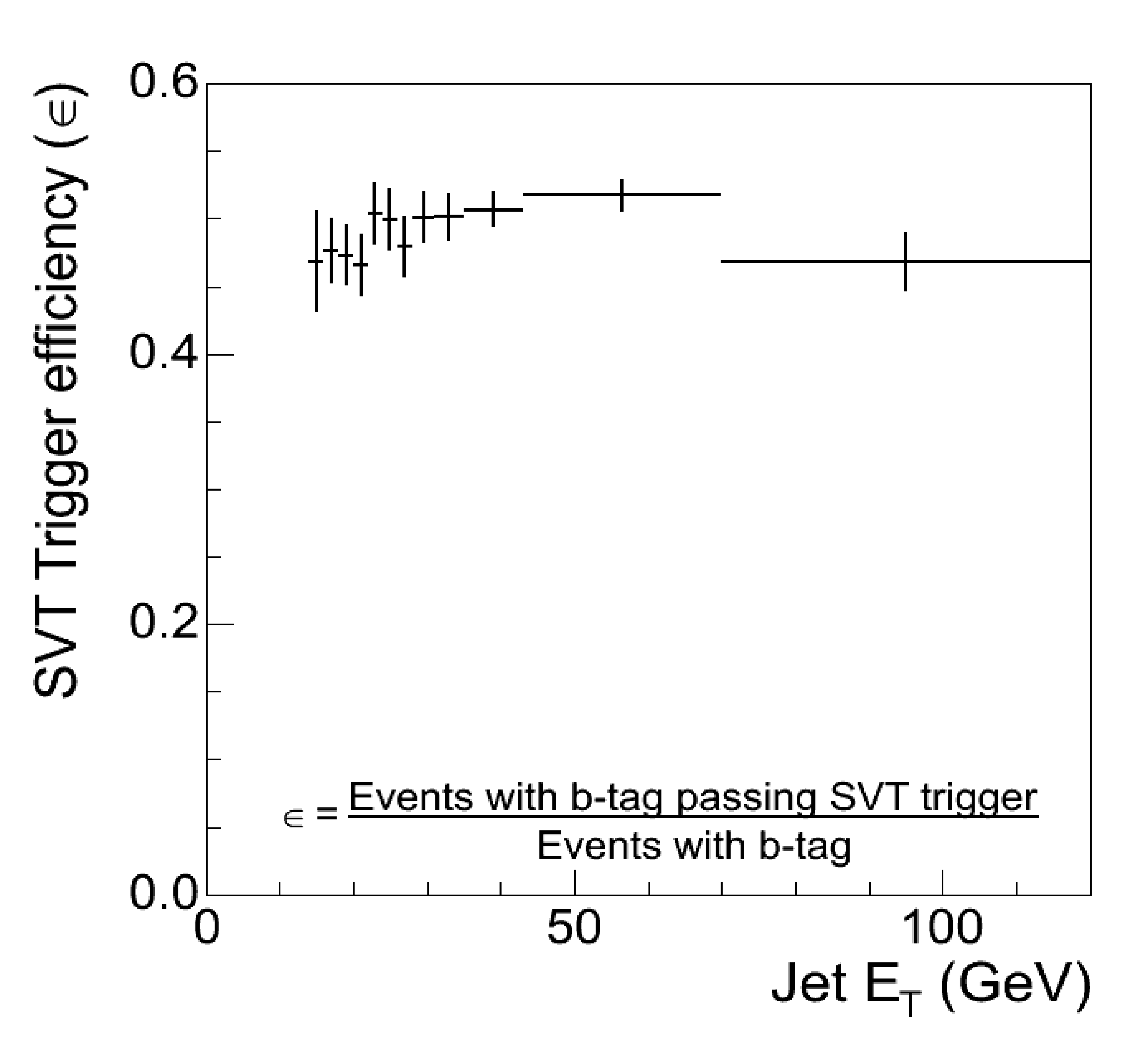
No event-by-event photon identification possible: only statistical separation based on shower shape measured by tracking devices inside the calorimeter





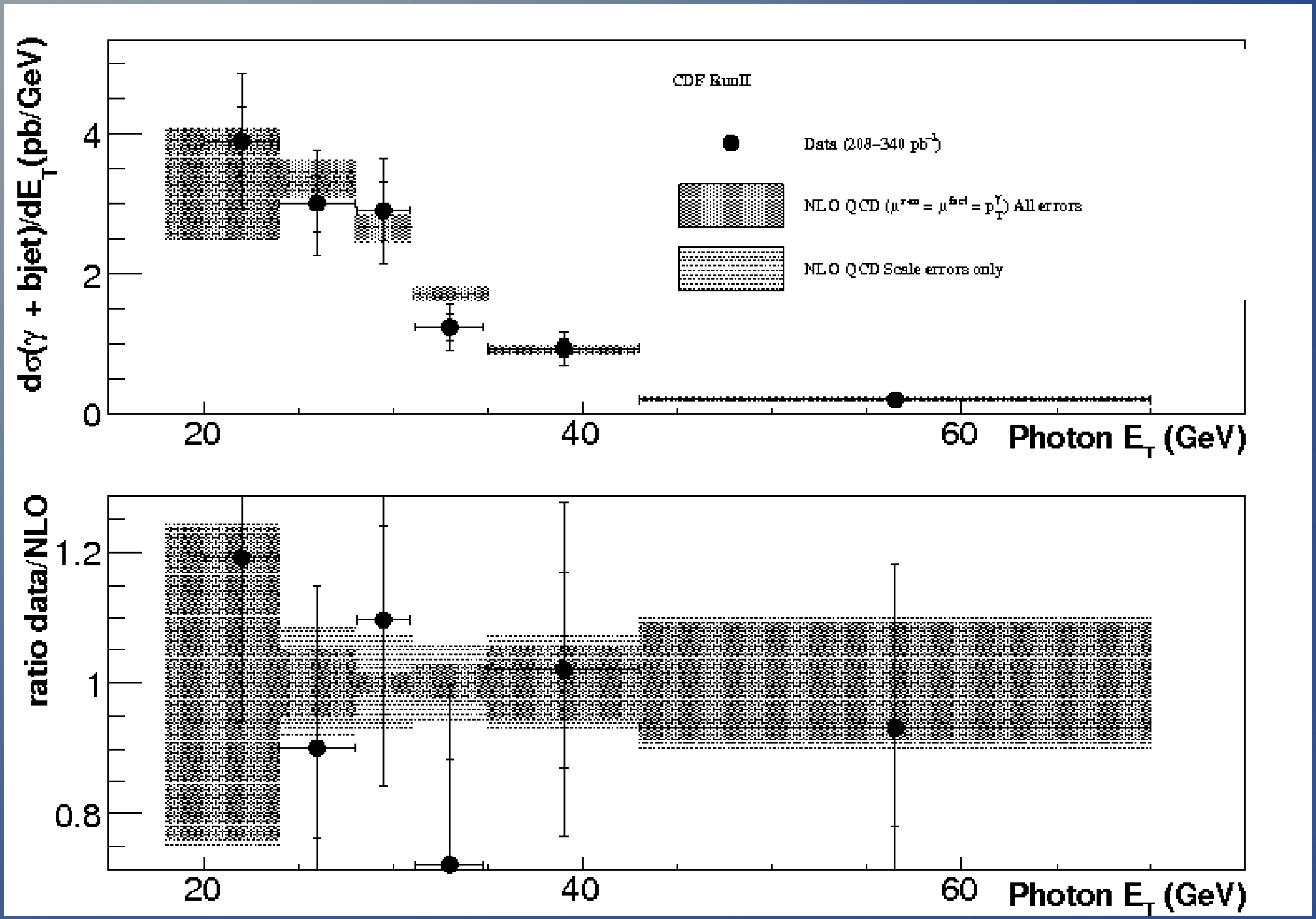


Analysis strategy



- Events were taken from two datasets:
  - Those with photon Et > 26 GeV came from a photon trigger (25 GeV threshold)
  - Those with photon Et in the range between 20 and 26 GeV were taken by a dedicated gamma + displaced track trigger, whose efficiency (around 50%) was measured in the overlap region

Results (340 pb-1)



- Syst. errors:
- Luminosity: 6%
- Trigger efficiency extrapolation (from statistics):10%
- Jet energy scale: 4% (from JES group methods)
- B purity templates: +20% -10%

Data: 54.2 ± 3.3 (stat.) ± 5.1 (syst) pb

NLO (T.Stavreva, J.Owens) : 55.6 ± 3.9 pb

Conclusions

- Vector boson plus heavy flavour production measured in most of the relevant channels
- Pioneering experimental techniques have been established
- Mainly seen now as background to top or new physics, where most of the manpower is presently concentrated