Measurements of $\gamma\gamma$ and γ+b cross sections

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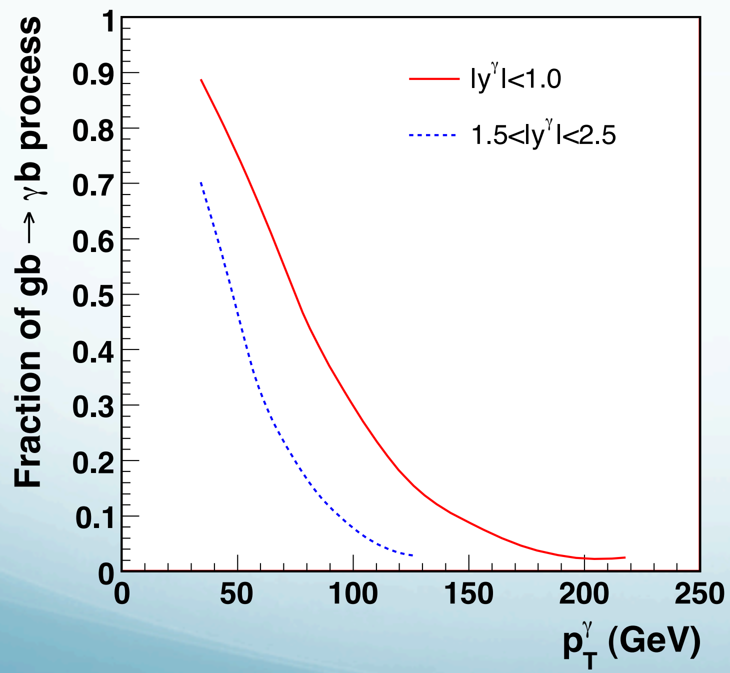
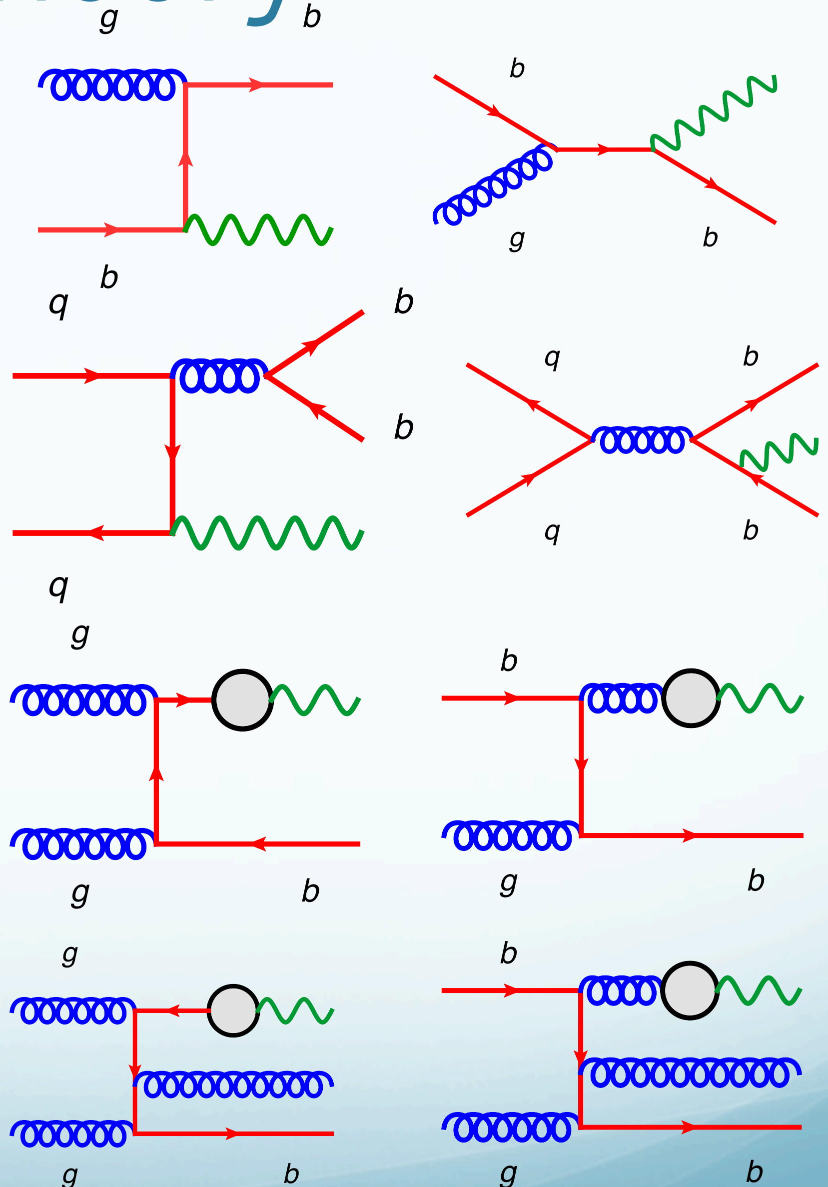
Motivation

- Both $\gamma\gamma$ and γ+b use high energy resolution of a photon
- γ+b probes a wide range of proton momentum fractions $0.007<x<0.4$
  - Excellent for tuning b-quark and gluon PDFs
  - Gluon to bb fragmentation
- $\gamma\gamma$ spectrum is an indicator of high energy states
  - One has been just announced
  - Precise cross section measurements
  - New physics still possible at even higher energies
    - Kaluza-Klein gravitons, extra dimensions, etc.

γ +b theory

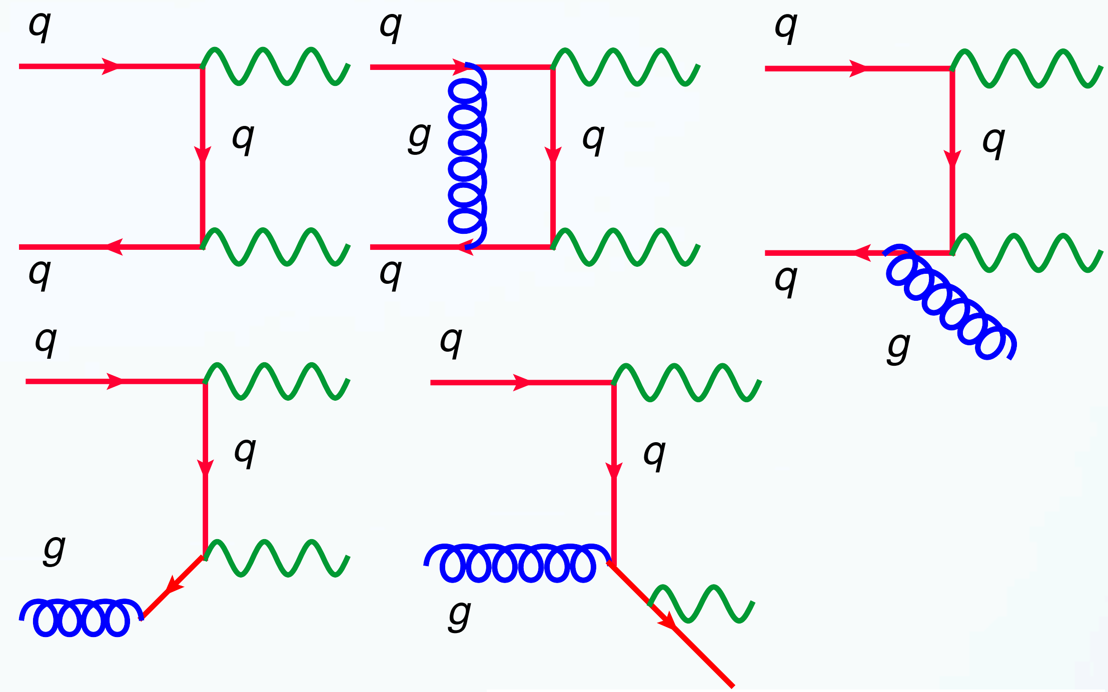
- Compton-like scattering at low $p_T{}^{\gamma}$
- Quark annihilation at high $p_T{}^{\gamma}$
- Higher order fragmentation processes
  - Gluon fusion
  - Corrections

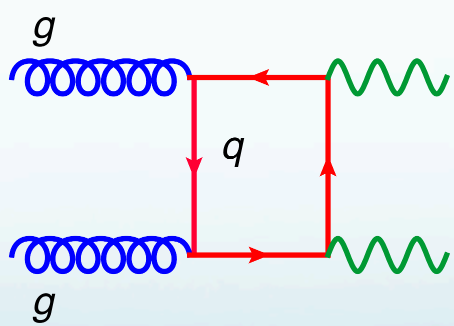


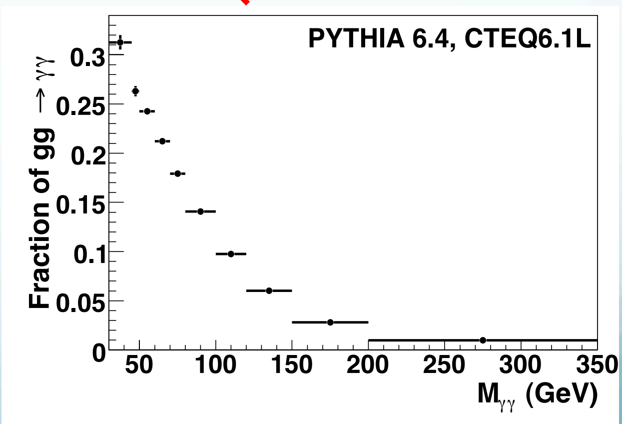


Direct QCD $\gamma\gamma$

- Leading process at Tevatron is Born ($qq \rightarrow \gamma\gamma$)
  - At NLO real emissions and virtual corrections
  - DIPHOX uses fixed order NLO for initial state radiation and fragmentation functions
  - Initial state corrections resummed to all orders of α_s in RESBOS to NNLL accuracy
- $qg \rightarrow \gamma\gamma$ (NLO)
  - Up to 50% at LHC energies
- Box diagrams (with corrections) NNLO but important at low mass (large gluon PDFs)





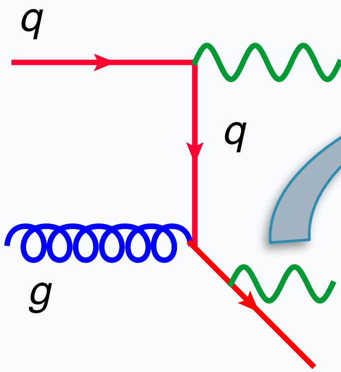


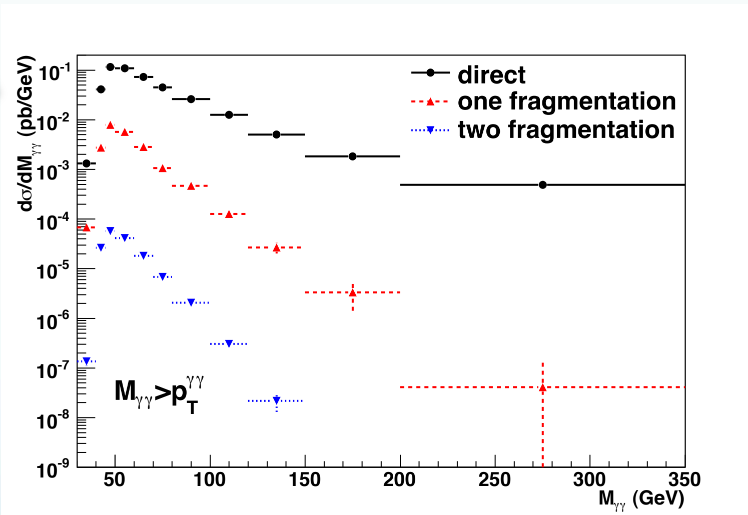
Fragmentation QCD $\gamma\ \gamma$

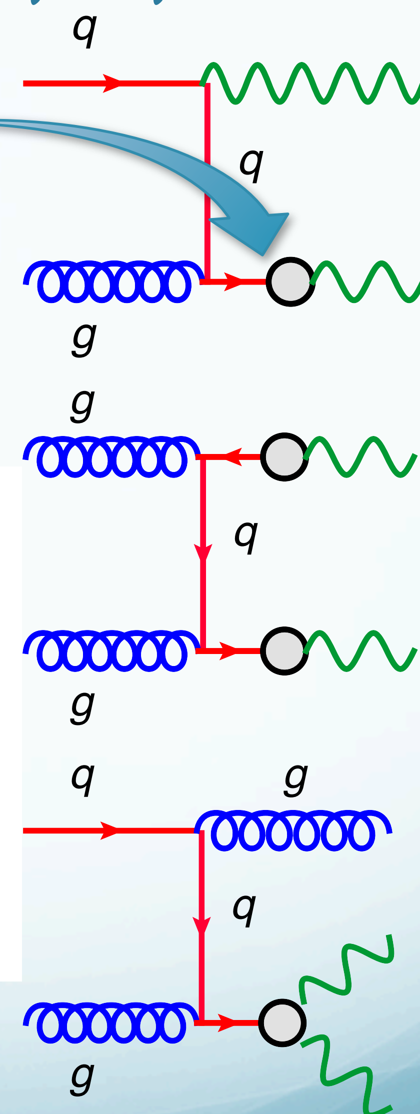
- Single or double fragmentation
  - Needs isolation to separate

$$E_T^{iso} = \sum_{i,R<0.4} (p_{T,i} - p_{T,\gamma})$$

  - $M_{\gamma\gamma} > p_T^{\gamma\gamma}$ removes a lot of fragmentation (low at Tevatron energies)
- Collinear singularities (final state)
  - Factorized into FF D (Z, μ) in DIPHOX
  - Auxiliary regulator in RESBOS $Q_T < E_t^{iso}$, single fragmentation is included via parametrization approximating NLO FF rates
  - Parton showers replaced by ME at scale Q SHERPA

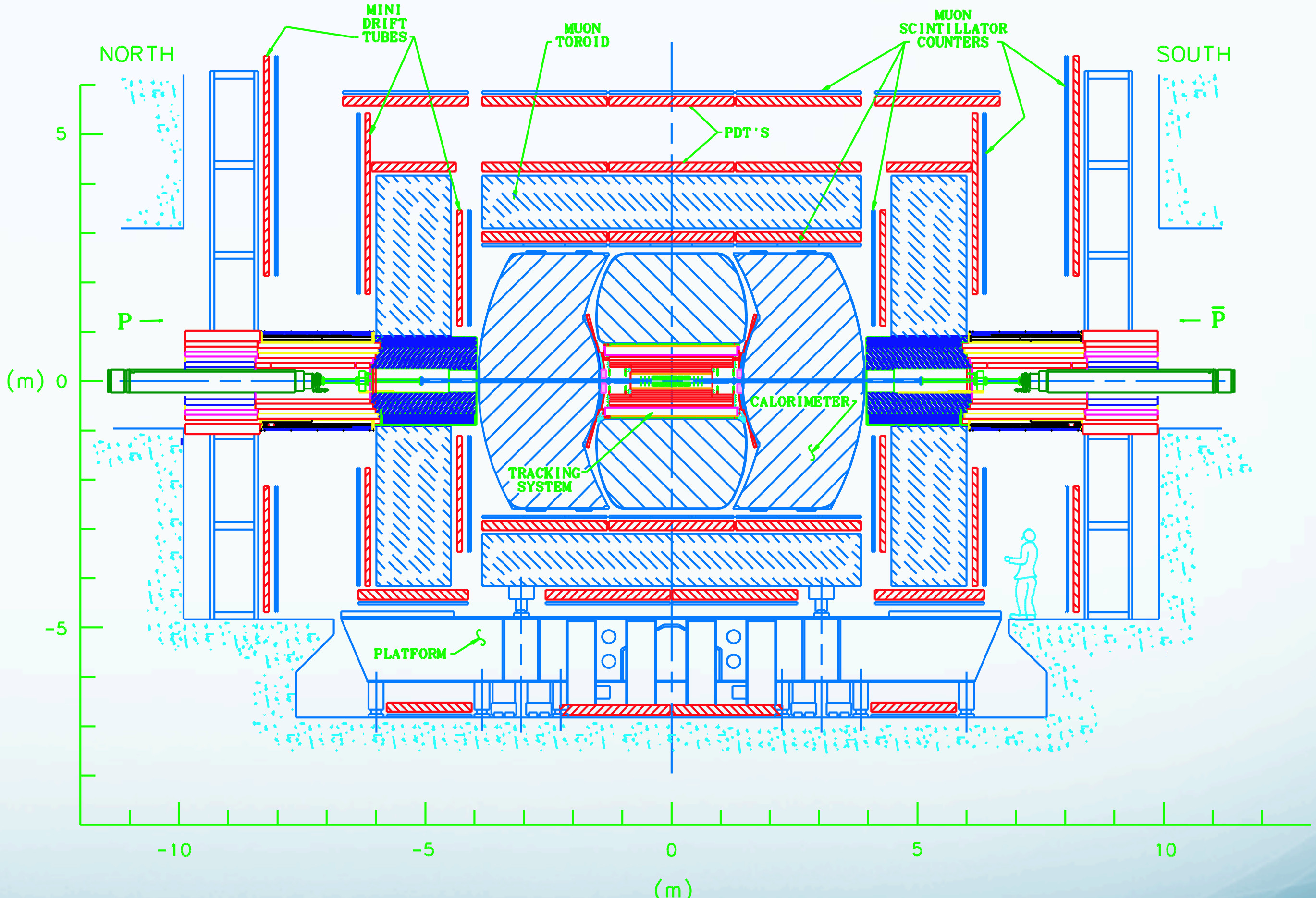






D0 detector

- Liquid Ar calorimeter
- Silicon micro-strip tracker
- Central fiber tracker
- Muon system
- Central preshower



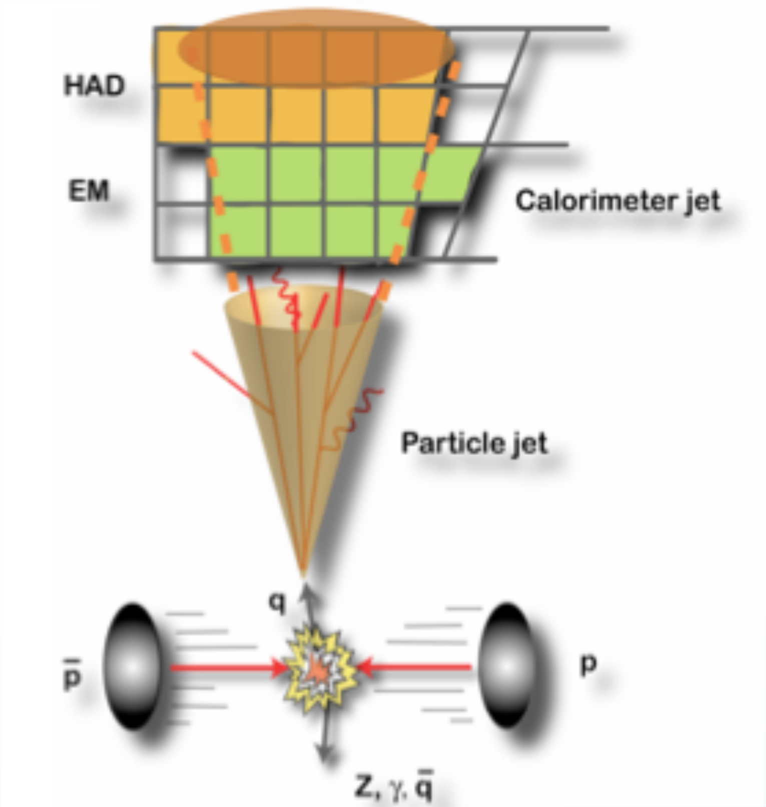
Analyses

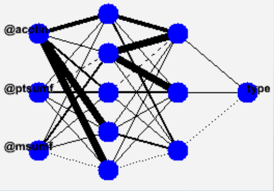
- γ+b measuring $d\sigma/dp_T^{\gamma}$
  - $|\eta_{\gamma}|<1.0$ or $1.5<|\eta_{\gamma}|<2.5$
  - $|\eta_{b\text{-}jet}|<1.5$, $p_T^{b\text{-}jet}>15$ GeV
  - $L=8.7\pm0.5$ fb^{-1}

- $\gamma\gamma$ measuring $d\sigma/dM_{\gamma\gamma}$, $d\sigma/dp_T^{\gamma\gamma}$, $d\sigma/d\Delta\phi_{\gamma\gamma}$, $d\sigma/d|\cos\theta^*|$
  - $|\eta_{\gamma}|<0.9$, $p_T^1>21$ GeV, $p_T^2>20$ GeV, $\Delta\phi_{\gamma\gamma}>\pi/2$
  - $M_{\gamma\gamma}>p_T^{\gamma\gamma}$, $30<M_{\gamma\gamma}<350$ GeV, $p_T^{\gamma\gamma}<100$ GeV
  - $L=4.2\pm0.3$ fb^{-1}
  - Also $d^2\sigma/dp_T^{\gamma\gamma}dM_{\gamma\gamma}$, $d^2\sigma/d\Delta\phi_{\gamma\gamma}dM_{\gamma\gamma}$, $d^2\sigma/d|\cos\theta^*|dM_{\gamma\gamma}$ in 3 $M_{\gamma\gamma}$ bins

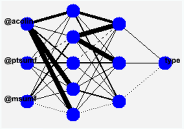
γ identification

- Iso=[E_{tot}(0.4)-E_{EM}(0.2)]/E_{EM}(0.2) <0.07 (calorimeter cone isolation)
- EMF>0.97 (electro-magnetic fraction)
- p_{Ttrk}^{iso}=p_{Ttrk}(0.4)-p_{Ttrk}(0.2)<1.5 GeV (track cone isolation)
- SigPhi<18 (cell energy-weighted shower shape)
- TrkProb<0 and HOR<0.9 (anti-track match)
  - Track-match probability
  - Tracker hits along the projection from the calorimeter (hits on the road)
- ANN>0.3 (Neural Net output)

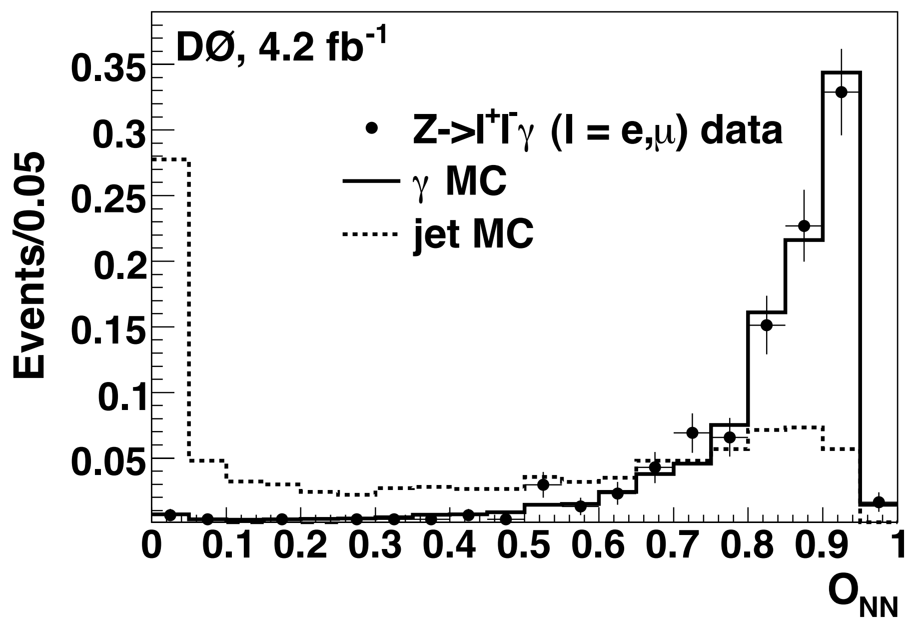


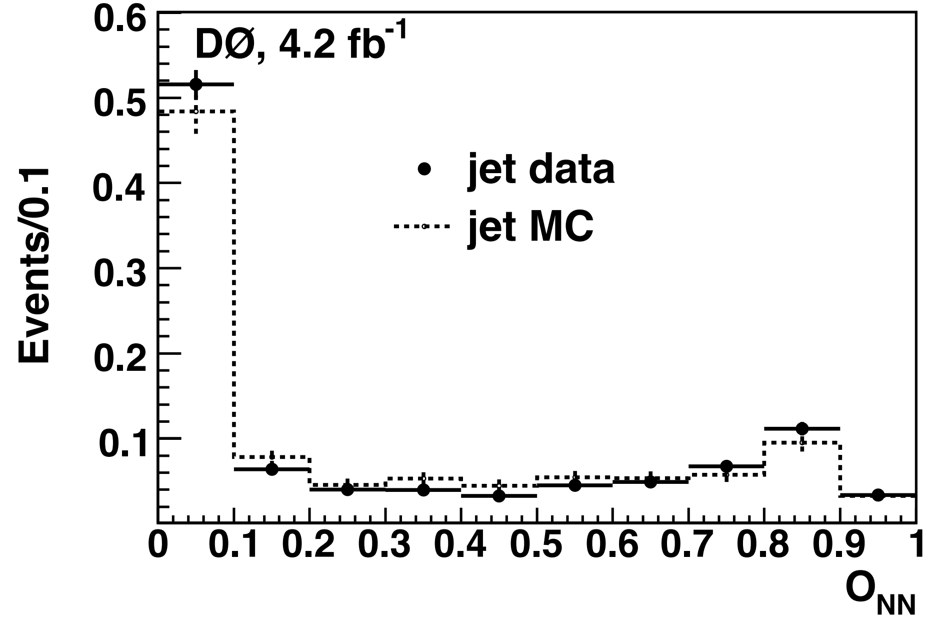


γ ANN



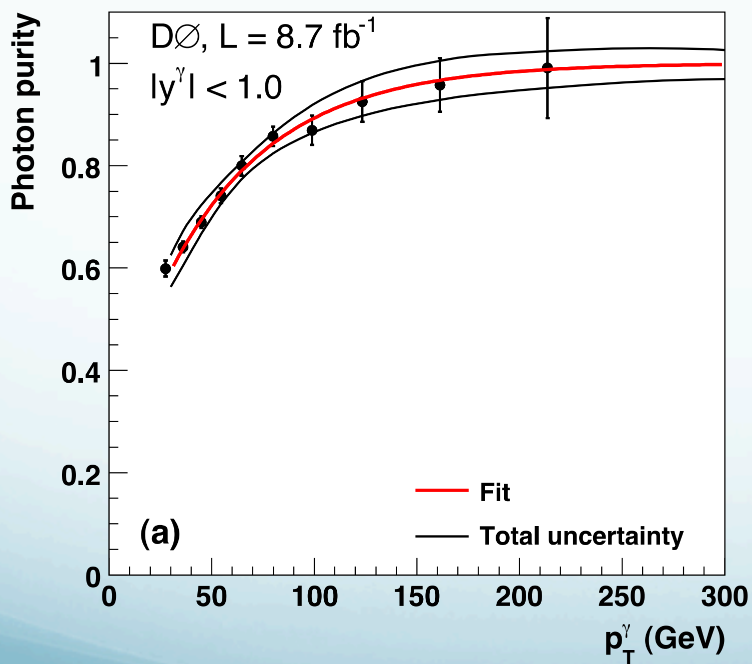
- Exploits differences in tracker, EM calorimeter and CPS activity between photons and jets, trained on MC
- Compared between γ and jets, describes data well
- ANN>0.3 is 98% efficient for photons

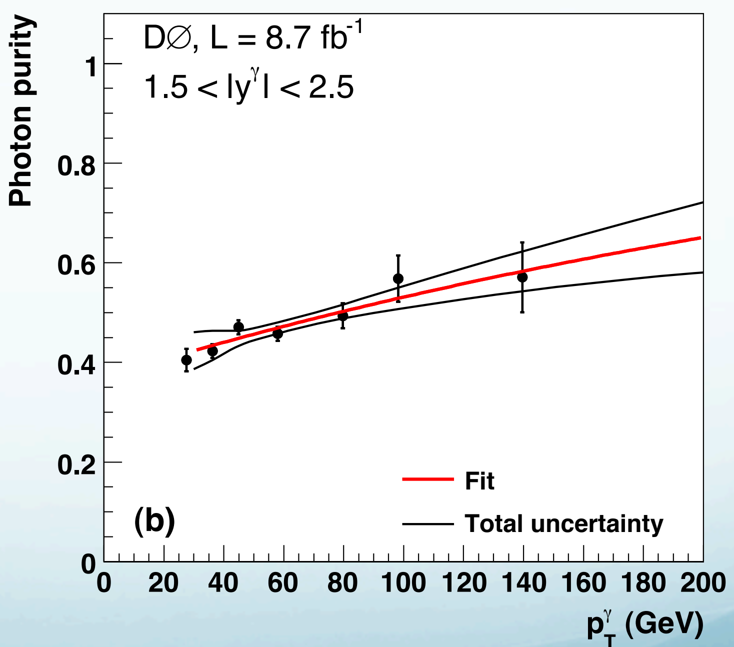




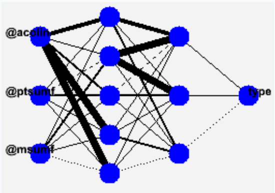
γ purities

- $\gamma\gamma$ uses 4x4 matrix method (solving for $\gamma\gamma$, γ+jet,jet+γ,jet+jet fractions, particles p_T ordered)
- γ+b uses bin-by-bin ANN template fit to data

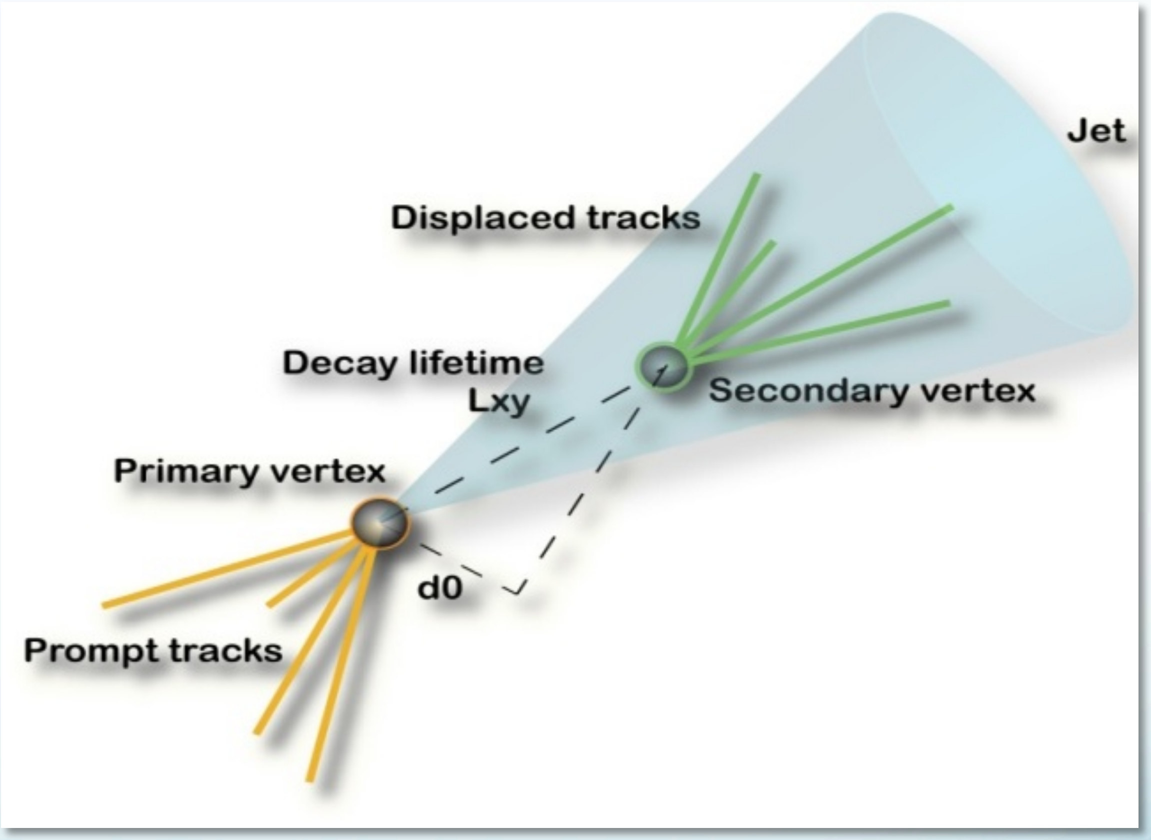




B-jet ANN

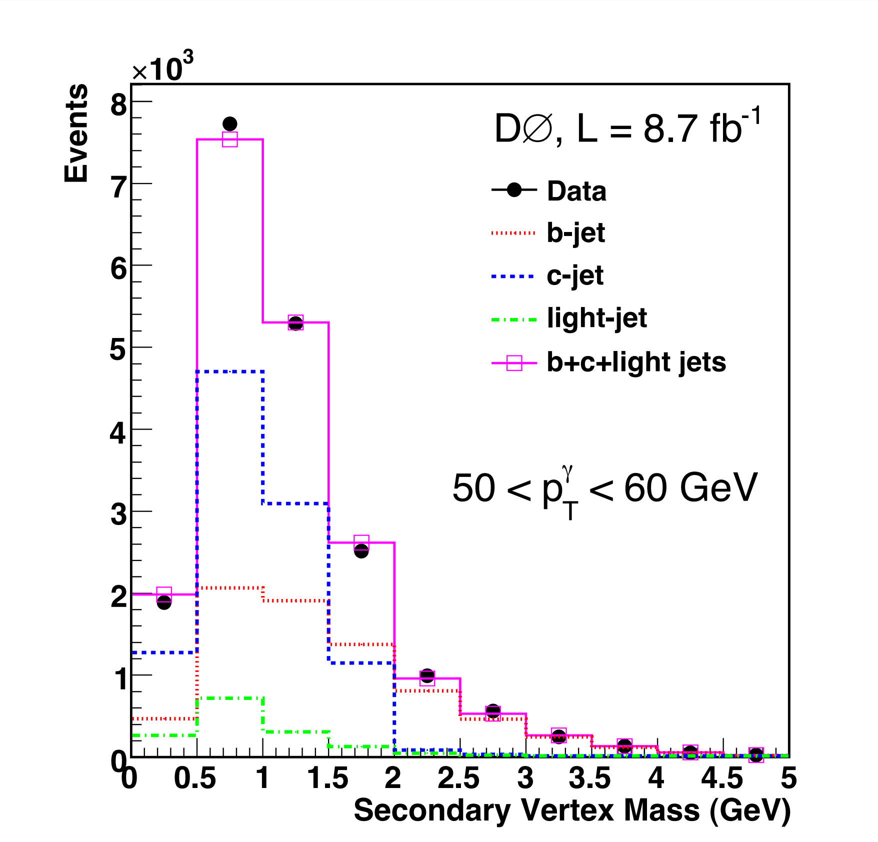


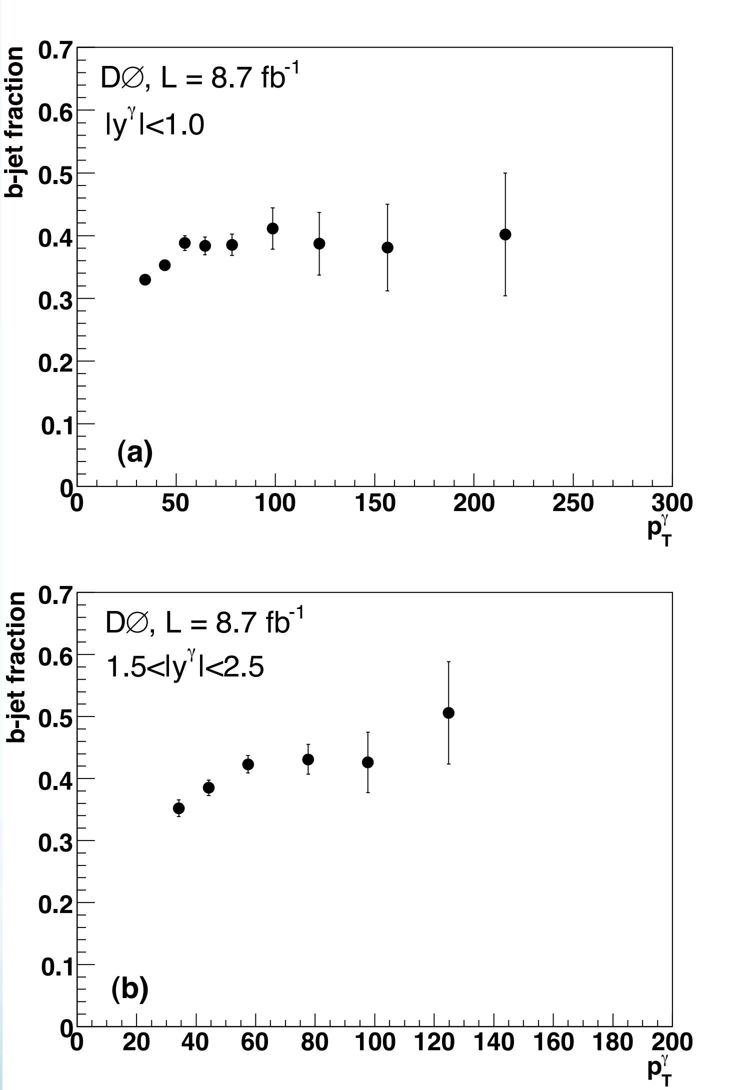
- Variables
  - Number of SV
  - Invariant mass of tracks, associated with SV (M_{SVT})
  - Number of tracks used to reconstruct SV
  - 2D decay length significance of the SV
  - Weighted combination of transverse IP significances
  - Probability of jet tracks to originate from PV



γ+b b-jet fractions

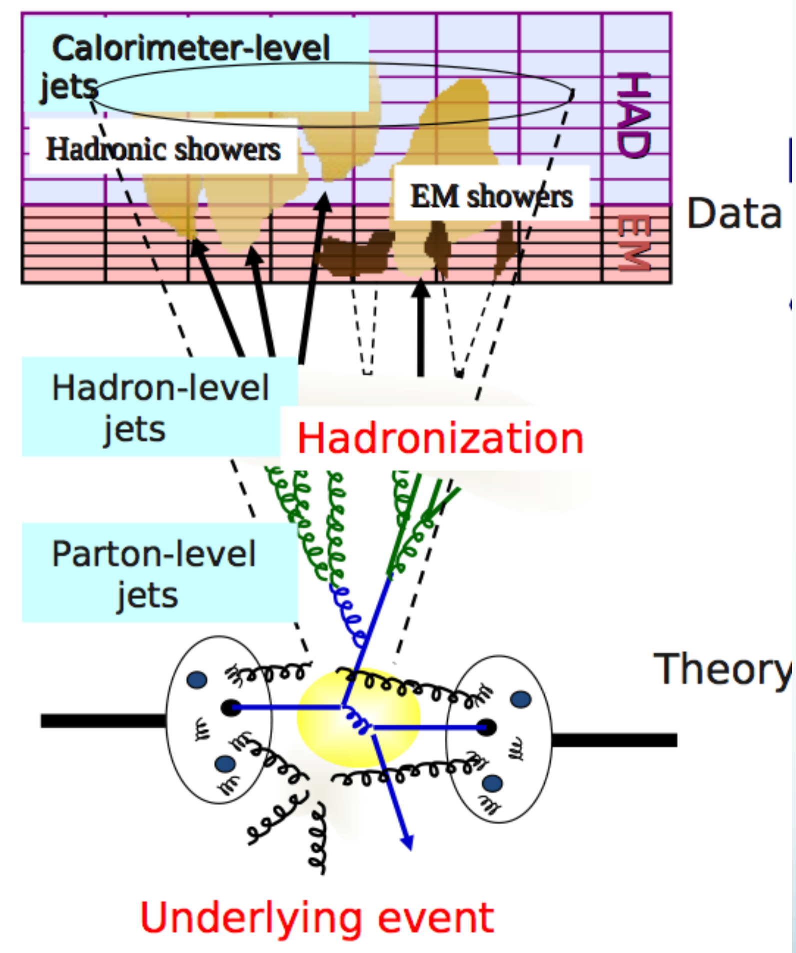
- Bin-by-bin M_{SVT} template fit to data





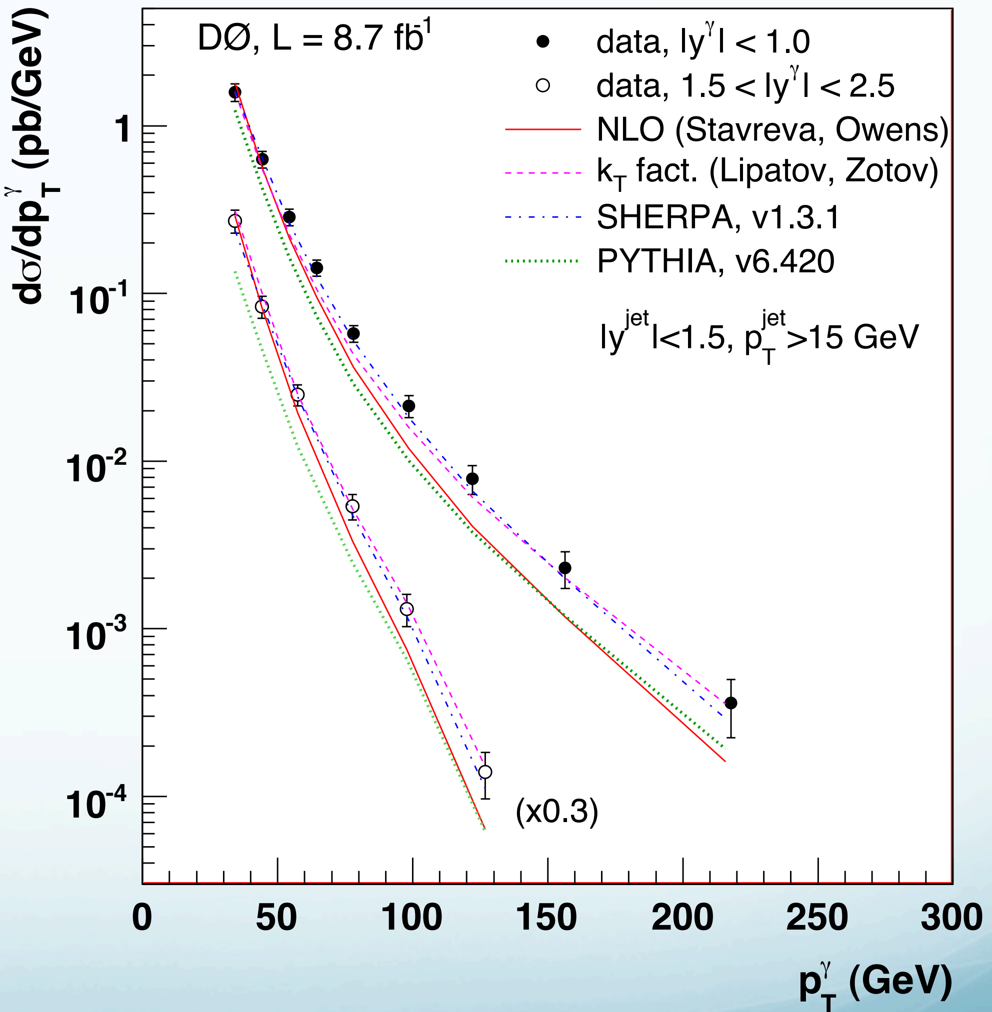
Compatibility corrections

- Theory (fixed order NLO) corrected to hadronization and multiple parton interactions
  - γ+b 5-10%(2% uncert)
  - $\gamma\gamma$ 4-5.5% (0.5% uncert)
  - Calculated from Pythia tune A and SO ($\gamma\gamma$)
  - Pythia tune A and Sherpa (γ+b)
  - Sherpa already has
- Data are corrected for detector effects, migrations and pileup, and presented at particle level



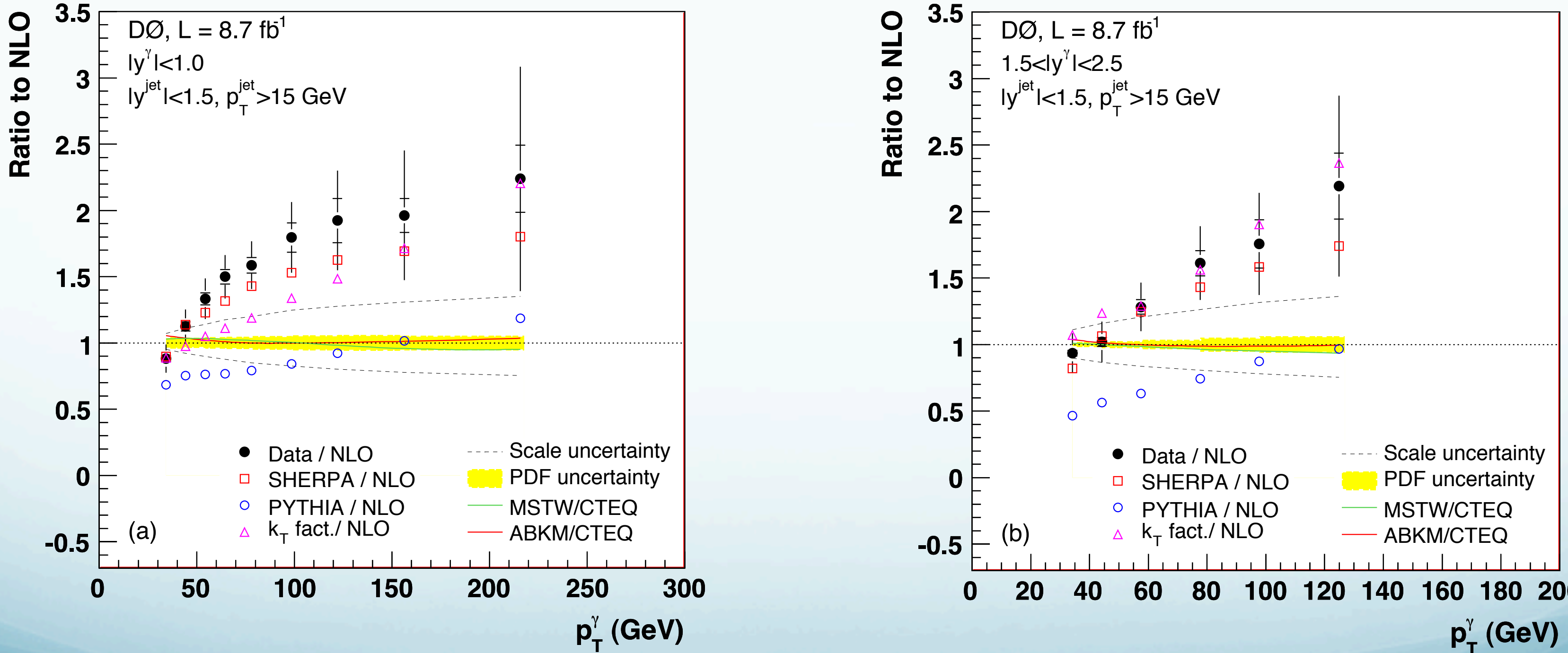
γ+b cross sections

- Theory isolation PYTHIA and SHERPA particle level, NLO parton level
  - $E_T^{iso}(0.4)<2.5$ GeV
- NLO at factorization μ_F, fragmentation μ_f, renormalization scales $\mu_R = p_T^{\gamma}$
  - CTEQ6.6M
- k_T
  - Additional contributions due to integration over k_T^2 above scale μ^2 (additional gluon radiation)
- PYTHIA 2→2 ME (g→bb in PS), CTEQ6.1L
- SHERPA ME γ + up to 3 jets, at least 1 b-jet, 2nd hard jet in g→bb
  - Resummation of further emissions



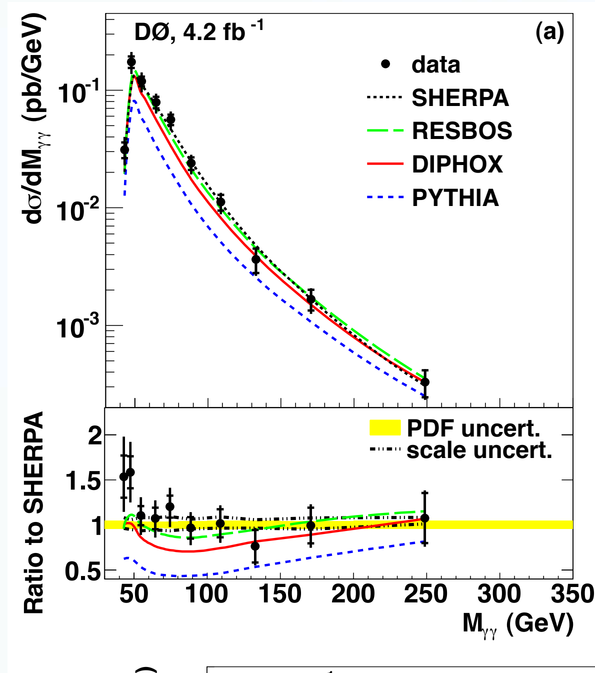
γ +b ratios to NLO

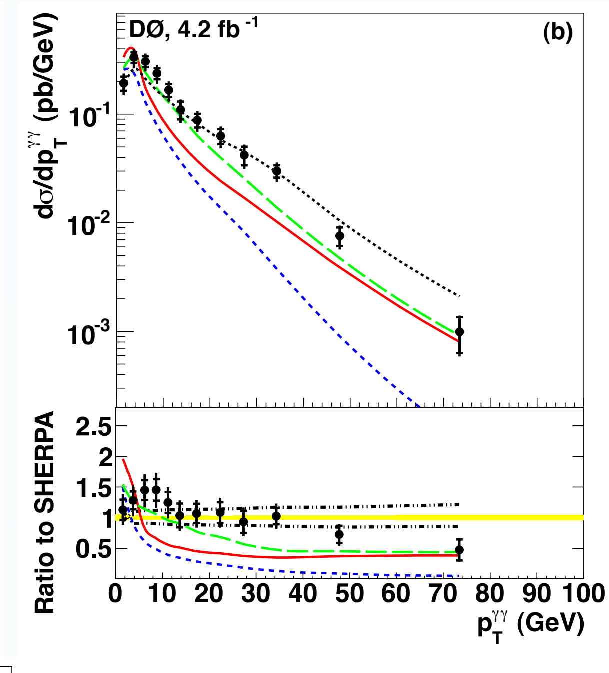
- NLO agrees $30<p_T^{\gamma}<70$ GeV (within scale, PDF and experimental uncertainties), differs above
  - Needs higher order corrections for qq→γg (g→bb)
- Best with SHERPA (allows 2 additional jets)

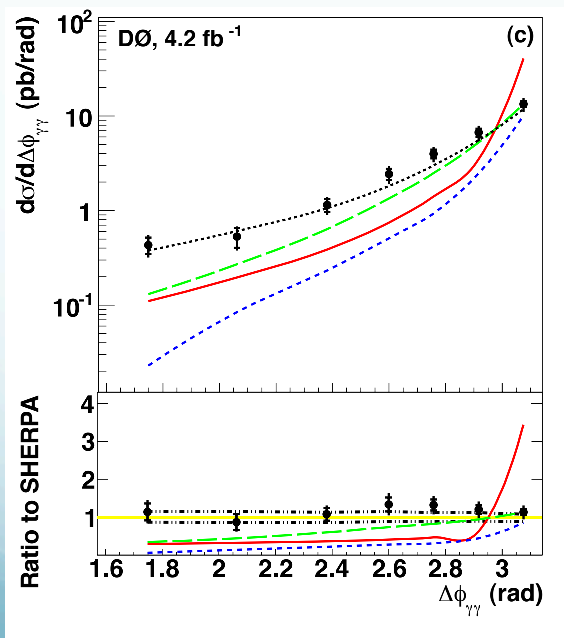


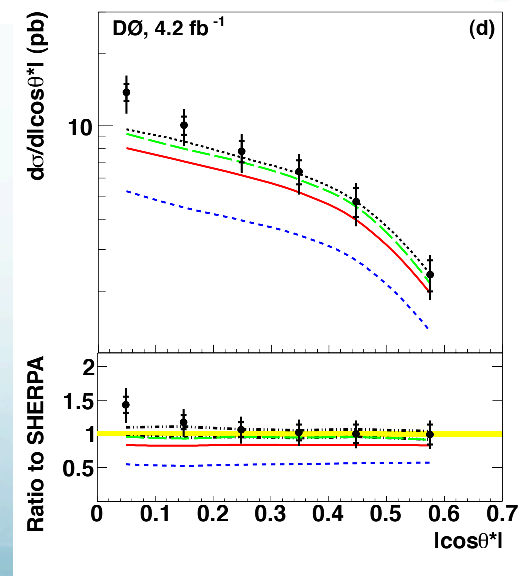
$\gamma\,\gamma$ single differential X-sections

- $E_t^{iso}(0.4)<2.5$ GeV
  - Particle SHERPA, PYTHIA
  - Parton RESBOS, DIPHOX





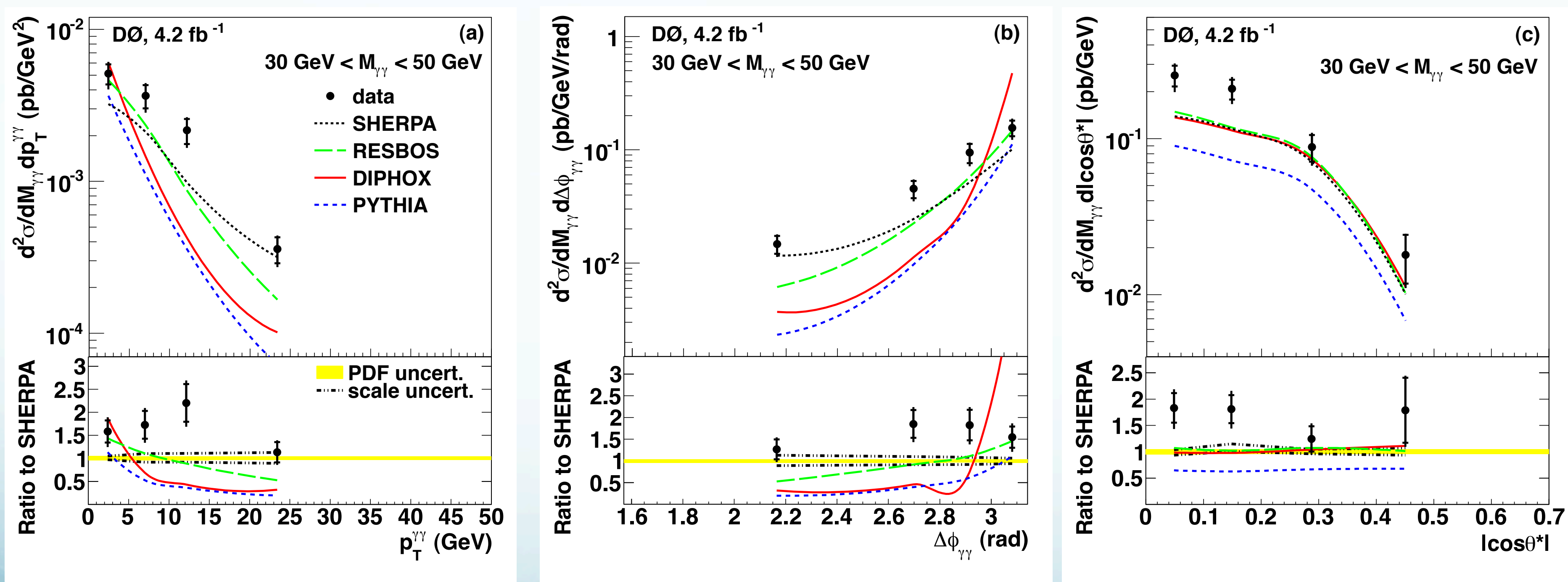




- RESBOS, DIPHOX, SHERPA CTEQ6.6M
- PYTHIA CTEQ5.1L
- $\mu_F = \mu_f = \mu_R = M_{\gamma\gamma}$
- PDF, scale uncertainty from DIPHOX

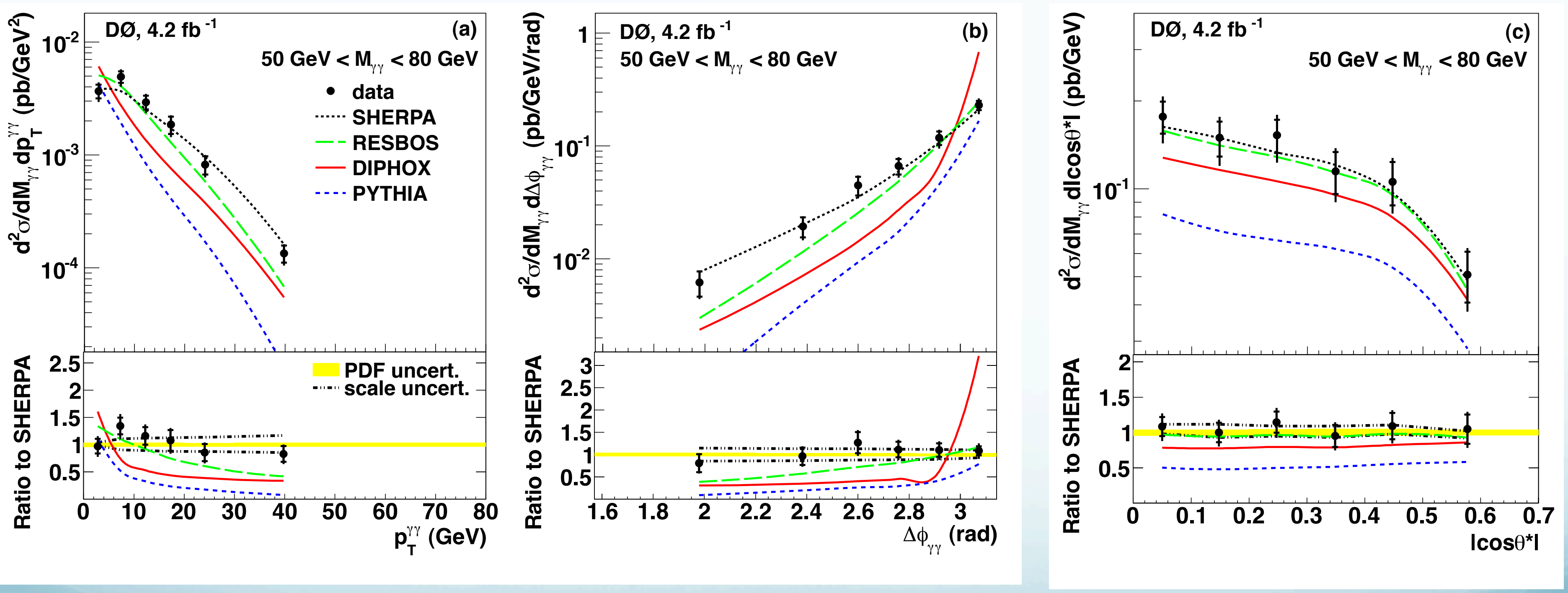
$\gamma\gamma$ double differential X-sections $30<M_{\gamma\gamma}<50$ GeV

- Large discrepancies with RESBOS (used to correct for experimental effects, with acceptance reweightings to eliminate model dependence), SHERPA better



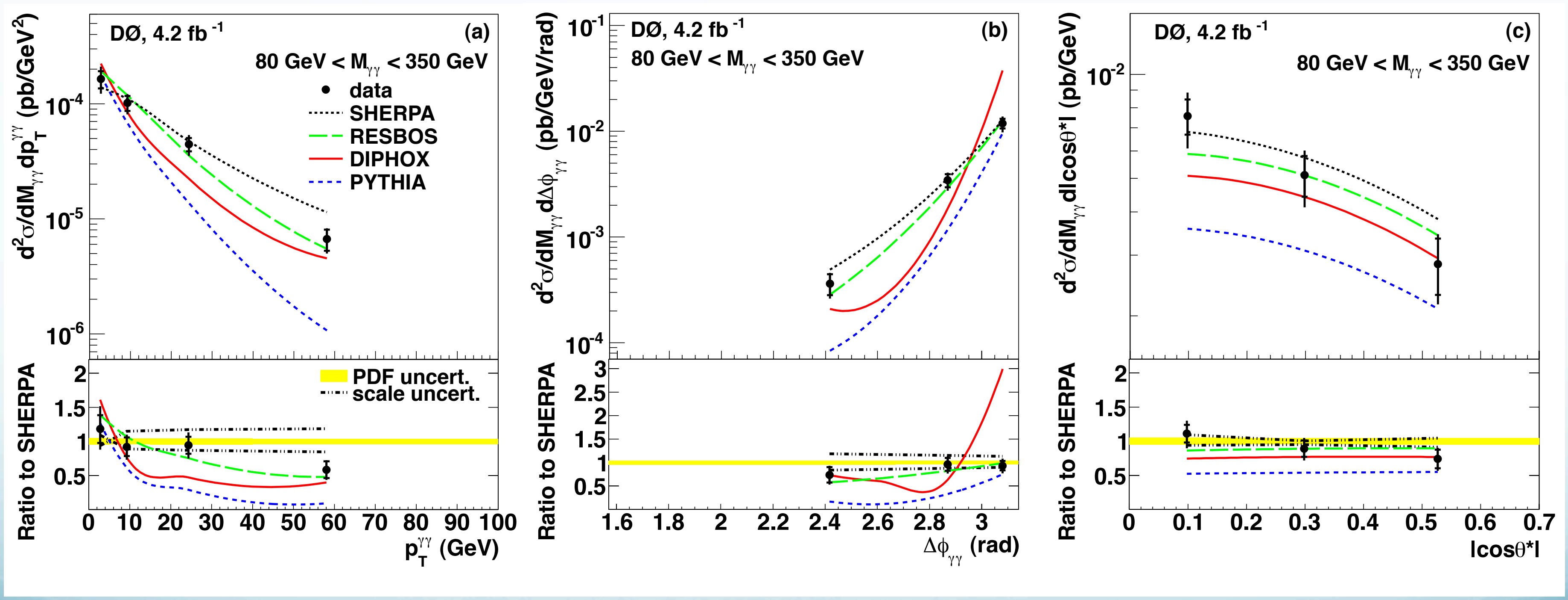
$\gamma\gamma$ double differential X-sections $50<M_{\gamma\gamma}<80$ GeV

- Predictions agree better
- DIPHOX divergent at $\Delta\phi_{\gamma\gamma}\approx\pi$ (no resummation)



$\gamma\gamma$ double differential X-sections 80<$M_{\gamma\gamma}$<350 GeV

- High mass SHERPA overshoots data at high $p_T^{\gamma\gamma}$



Summary

- Measured γ+b differential x-sections vs p_T^{γ}
- Single differential $\gamma\gamma$ x-sections vs $M_{\gamma\gamma}$, $p_T^{\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$, $|\cos\theta^*|$
- Double differential $d^2\sigma/dp_T^{\gamma\gamma}dM_{\gamma\gamma}$, $d^2\sigma/d\Delta\phi_{\gamma\gamma}dM_{\gamma\gamma}$,

  $d^2\sigma/d|\cos\theta^*|dM_{\gamma\gamma}$ in 3 $M_{\gamma\gamma}$ bins
- Used high photon energy resolution to probe wide range of x (0.007<x<0.4) in γ+b
- Details of $\gamma\gamma$ shapes for fragmentation, new phenomena precision background x-section measurements, PDF effects
- NLO calculations miss higher order terms to describe effects in qq→γg (g→bb) at high p_T^{γ}, SHERPA describes those better by using extra jets in ME.
- RESBOS does not describe well the fragmentation effects at low $\Delta\phi_{\gamma\gamma}$, SHERPA again does a better job in describing higher order effects because of the match of PS and ME.