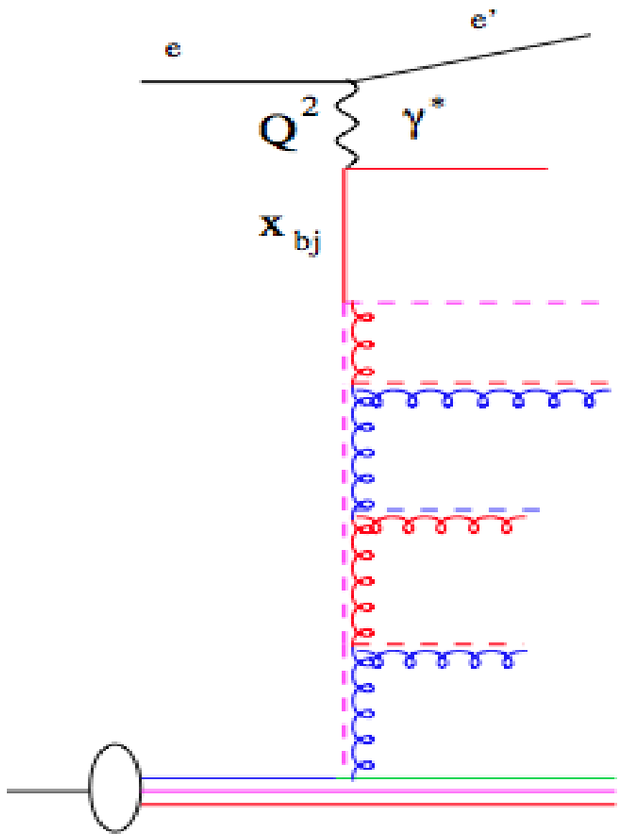
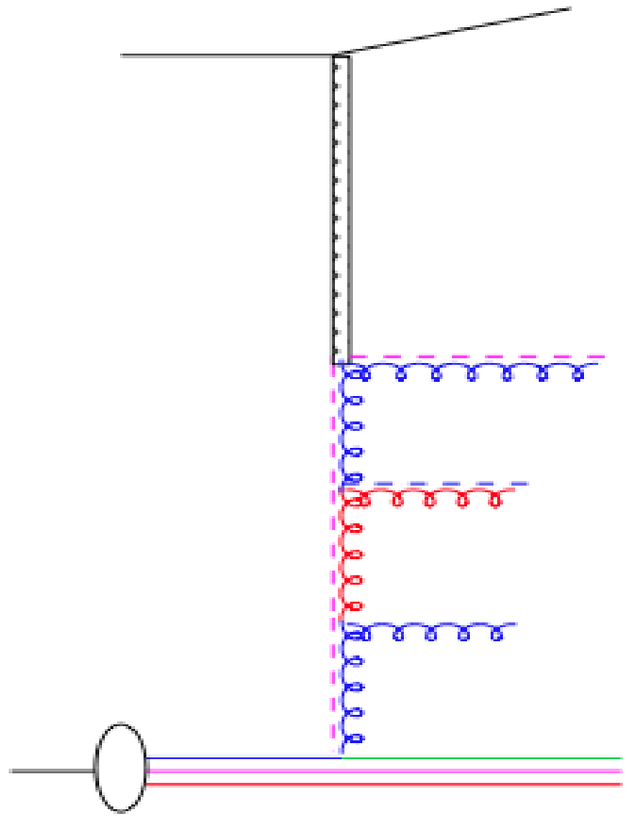
Higgs as a gluon trigger

P. Cipriano, S. Dooling, A. Grebenyuk, P. Gunnellini,
F. Hautmann, H. Jung, P. Katsas

- Imagine …
- What is so special on Higgs
- Difference to Drell-Yan at $m_{DY} = 125$ GeV
- Is it too crazy ?

Imagine, we could probe gluons directly





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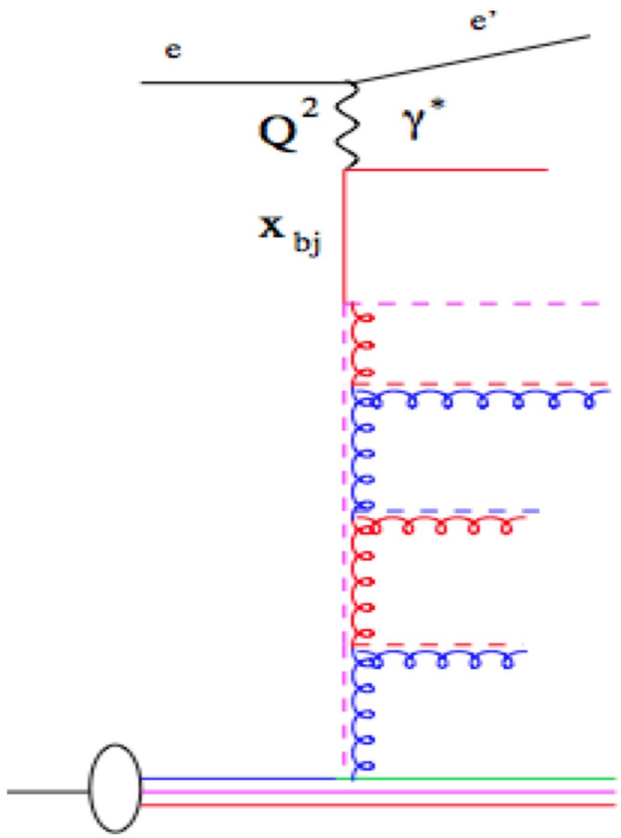
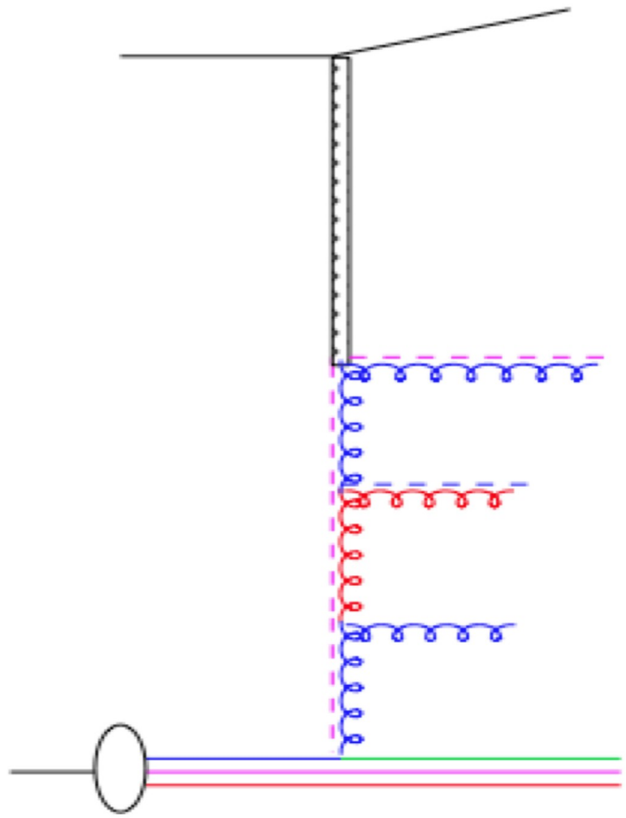


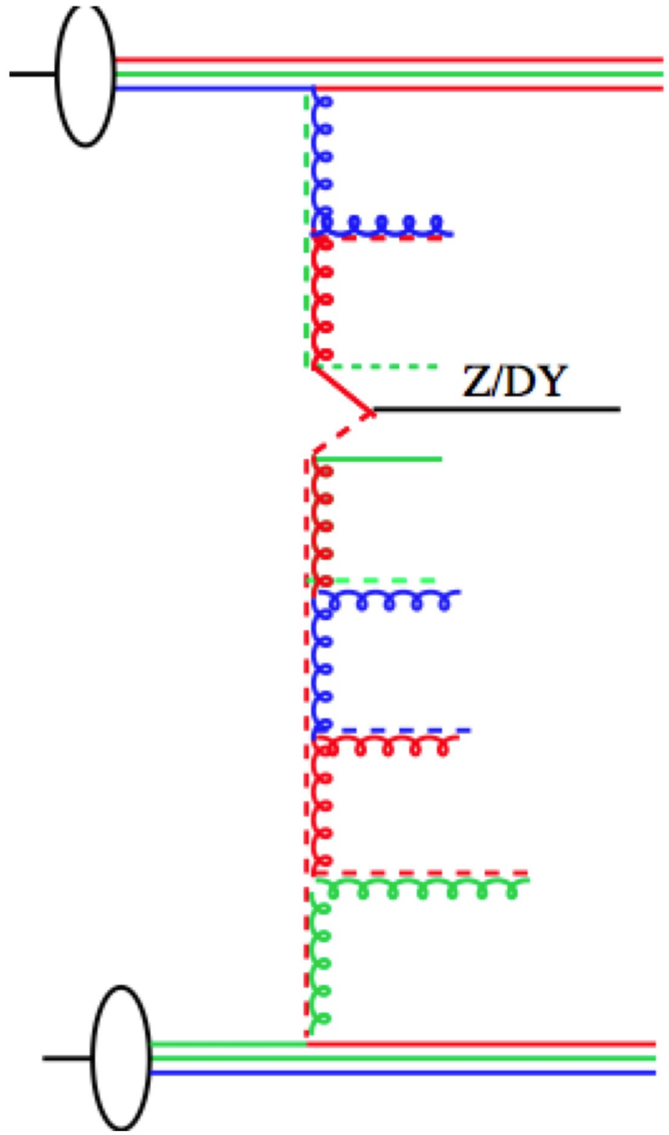


- all standard electro-weak currents couple to quarks:
  - γ, Z_0, W
  - structure function of quarks are well measured in DIS scattering, as well as in DY production
  - structure function of gluons, as well as properties of gluons are measured only indirectly via quark

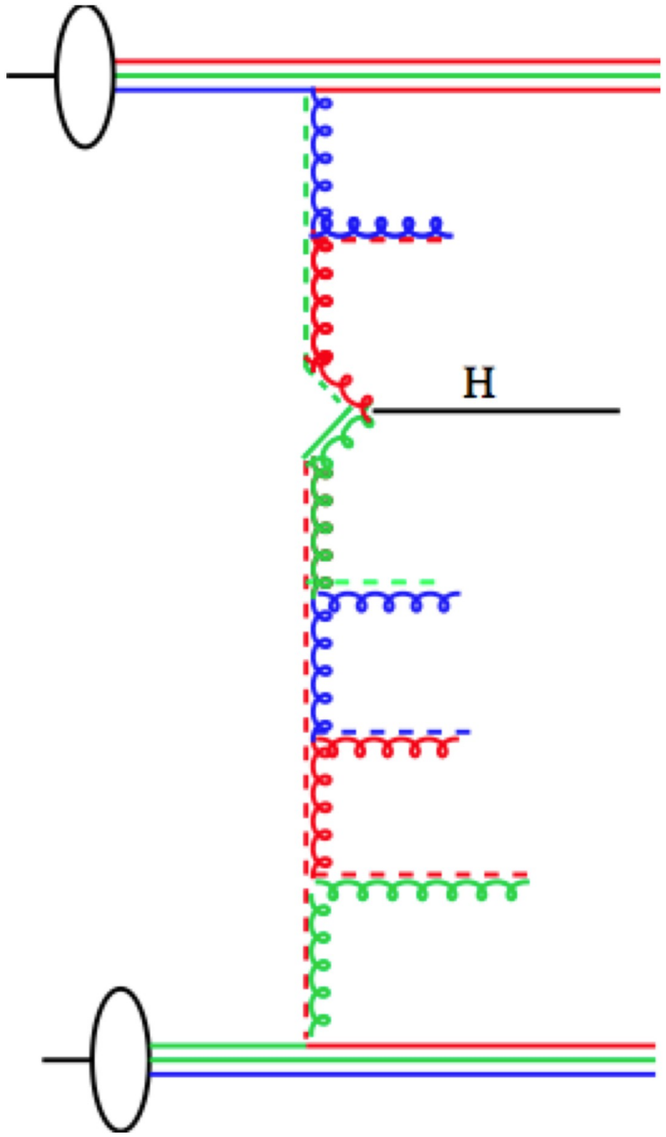
Imagine ...

- all standard electro-weak currents couple to quarks:

  $\gamma,\ Z_0,\ W$



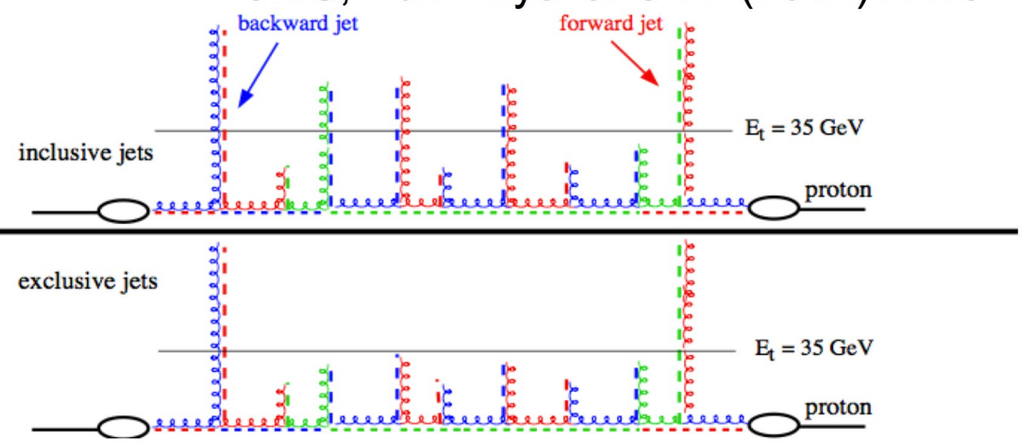
- Higgs is special:
  - in heavy top limit, couples directly to gluons



Challenge in QCD – example

- select (anti-kt) di-jets with
  $p_{t\,min} = 35\ \mathrm{GeV},\ |y| < 4.7$
- plot ratio of exclusive/inclusive xsection (many systematic cancel) as function of rapidity separation Δy between jets

CMS, Eur. Phys. J. C 72 (2012) 2216



- for large Δy expect rising xsection due to increased phase space (BFKL effects)
  - this is NOT a search channel, these effect MUST be there if QCD is correct !

Challenge in QCD – example

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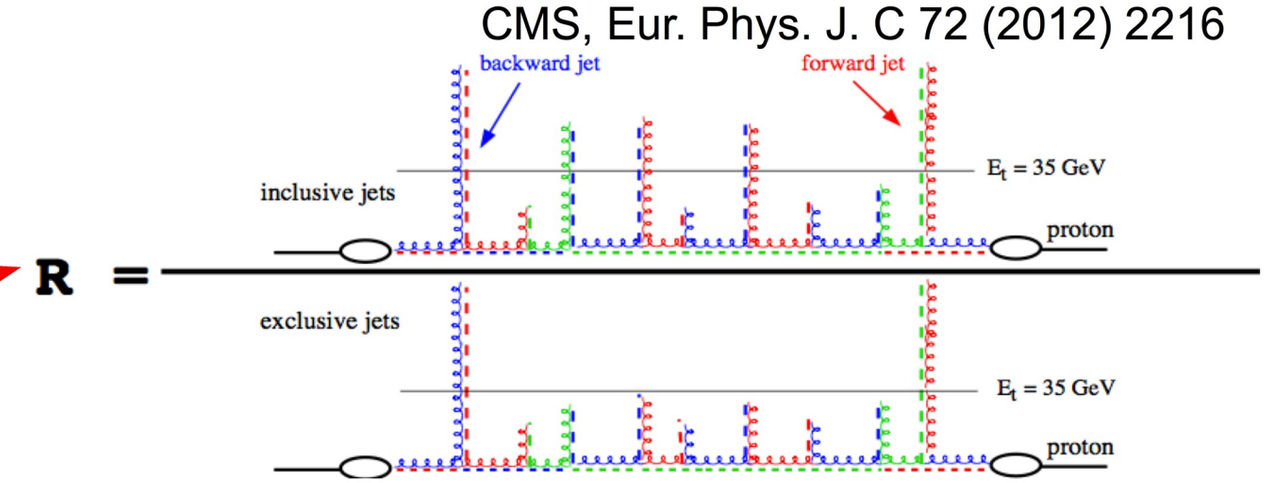
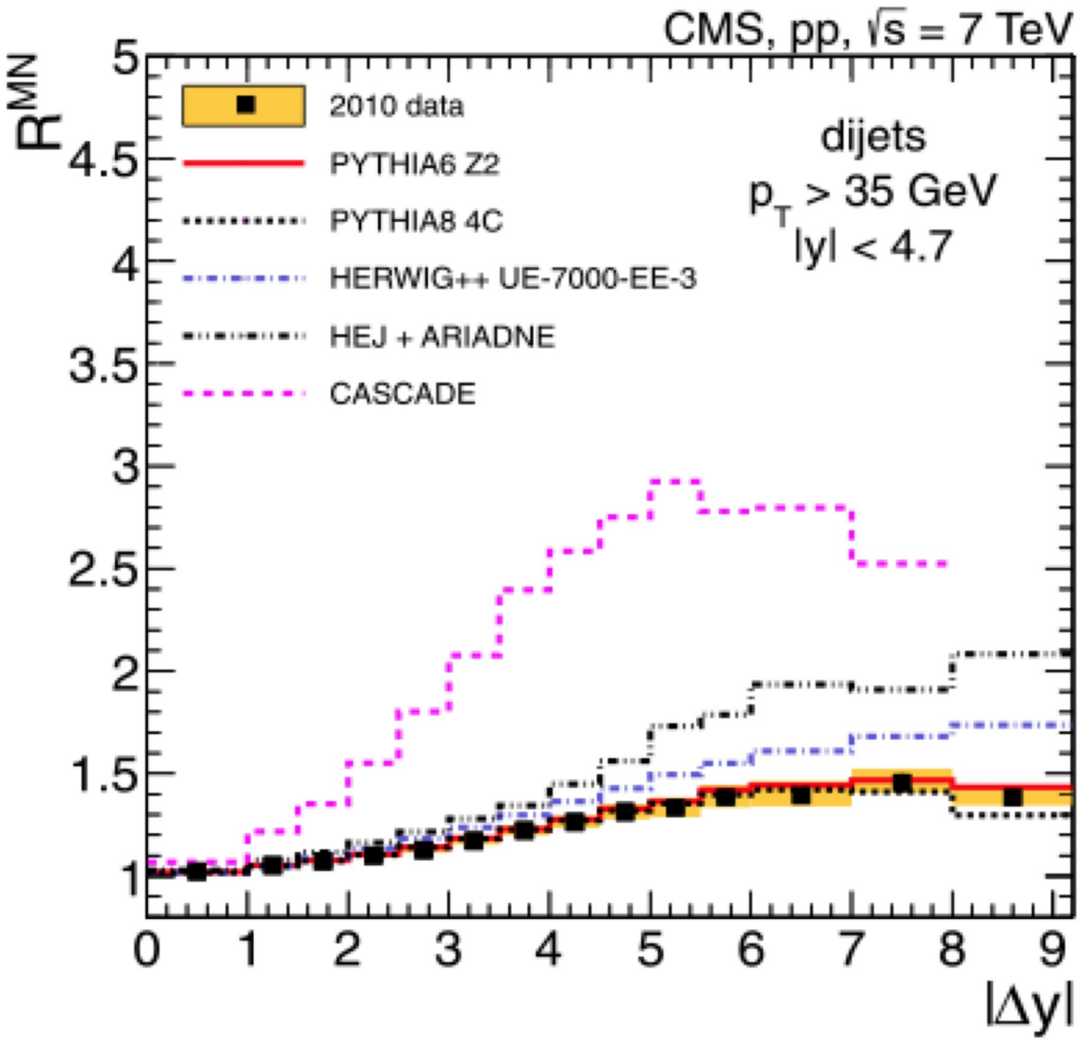




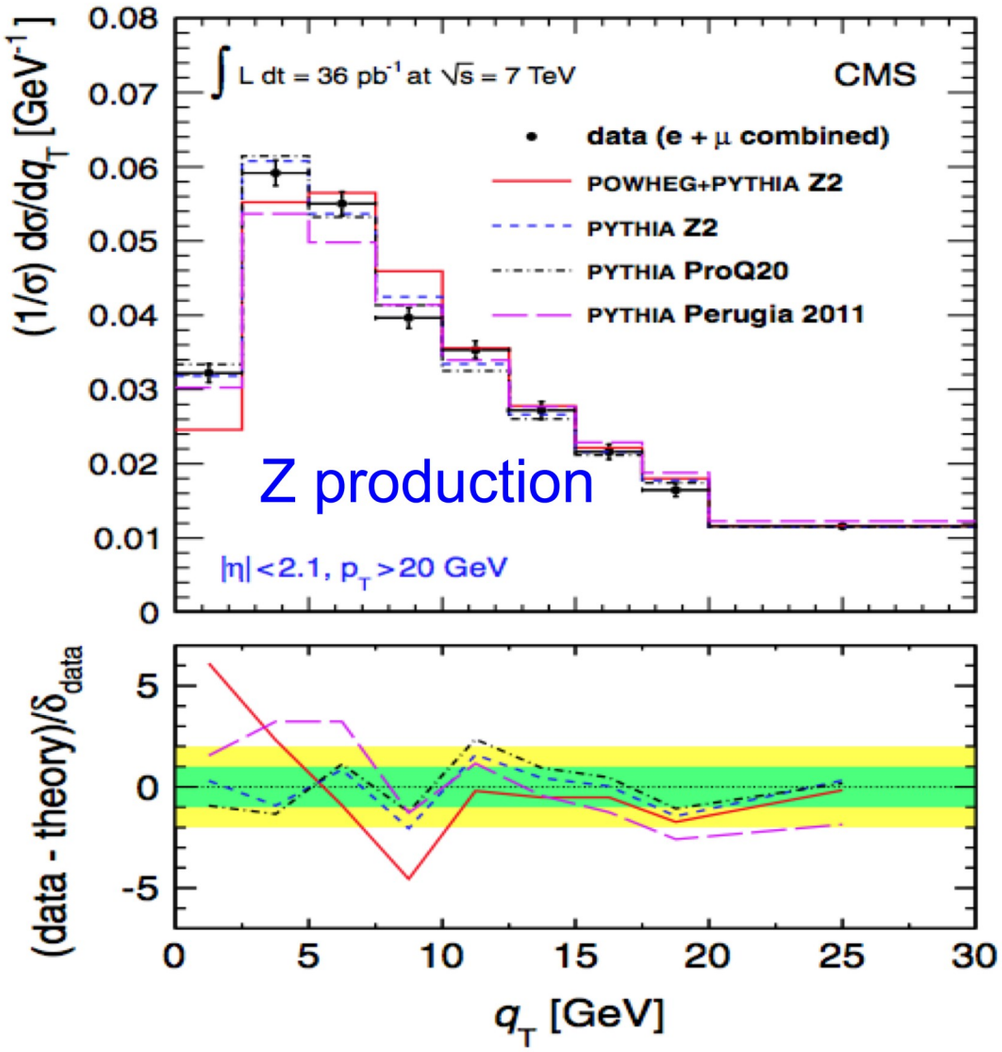
- for large Δy expect rising xsection due to increased phase space (BFKL effects)
  - this is NOT a search channel, these effect MUST be there if QCD is correct !
- BUT .....

QCD options at high luminosity LHC

Until last year, perspectives for QCD studies at HL LHC were rather bad.....

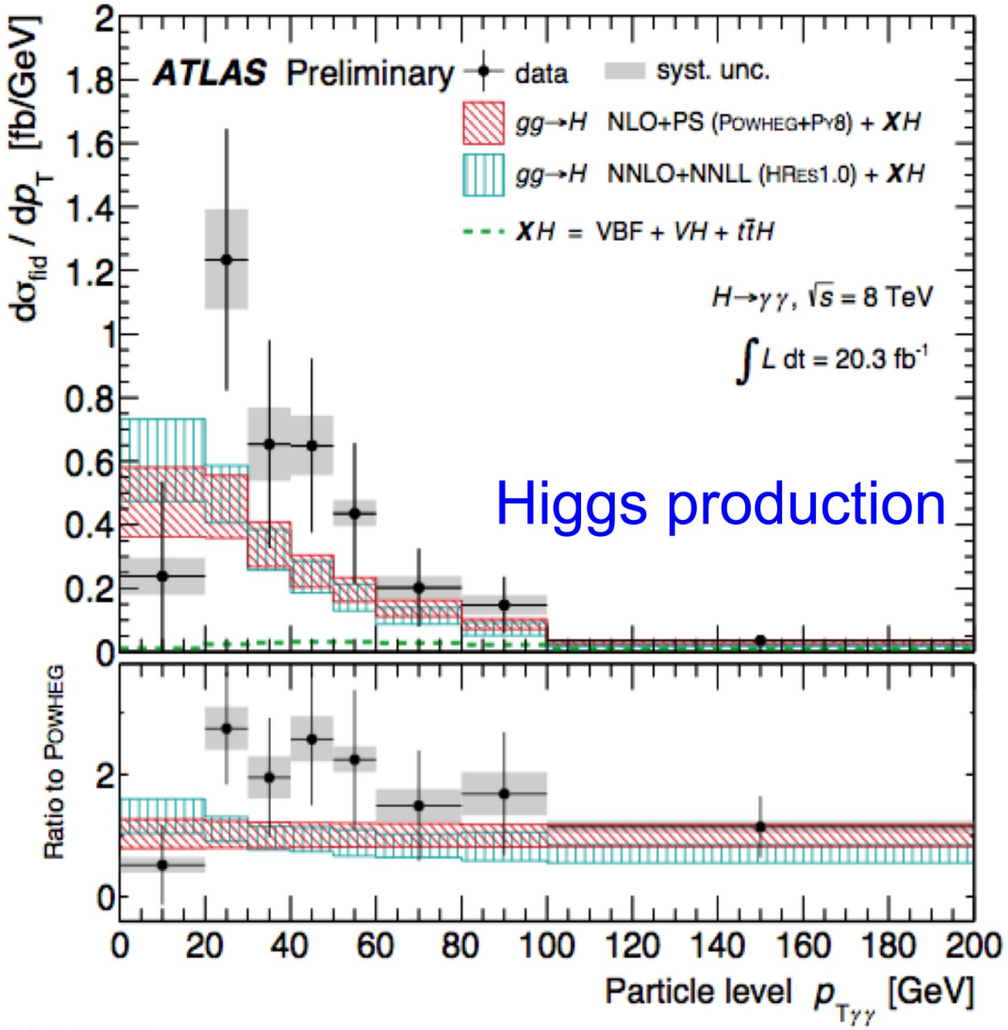
- BUT now, with Higgs, we have new and exciting options, which opens up a completely new world for QCD studies
  - gluon fusion processes with color singlet final state at large masses

CMS Coll., PRD 85, 032002 (2012)



Z production

Differential cross sections of the higgs boson measured in the diphoton decay channel using 8 TeV pp collisions. ATLAS-CONF-2013-072,



Higgs production

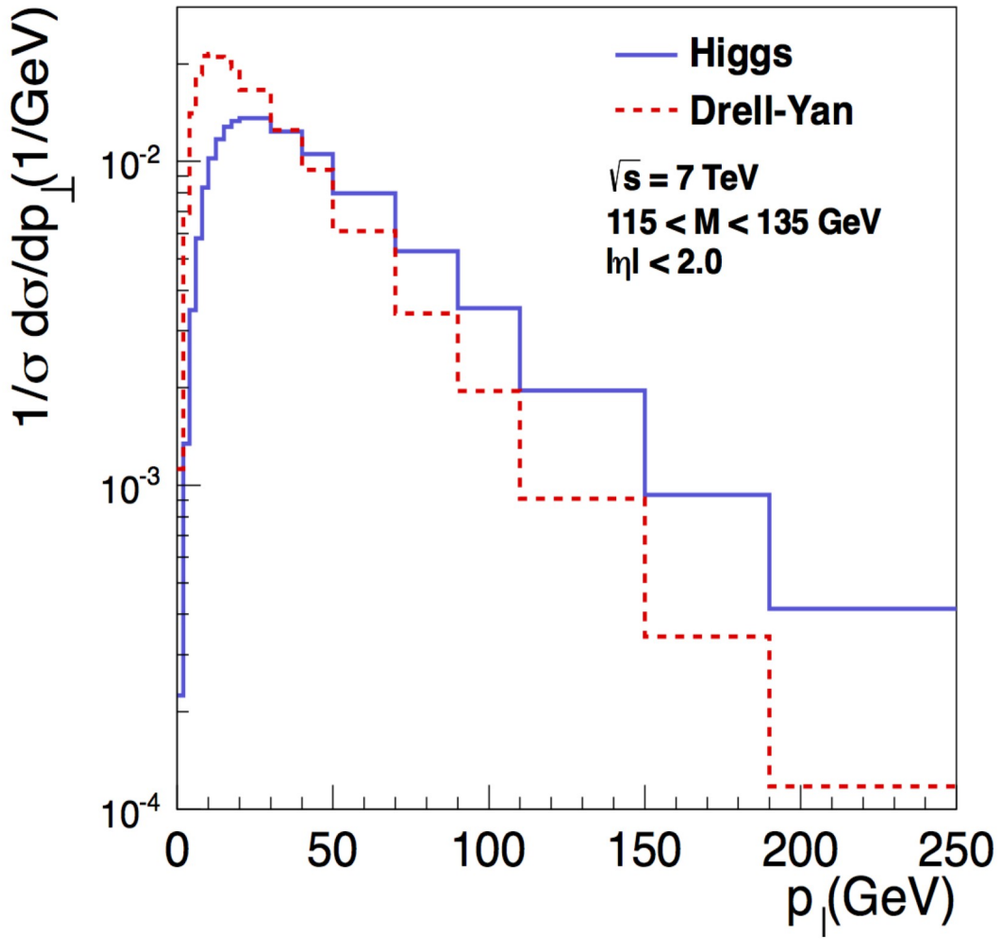
Higgs as a gluon trigger

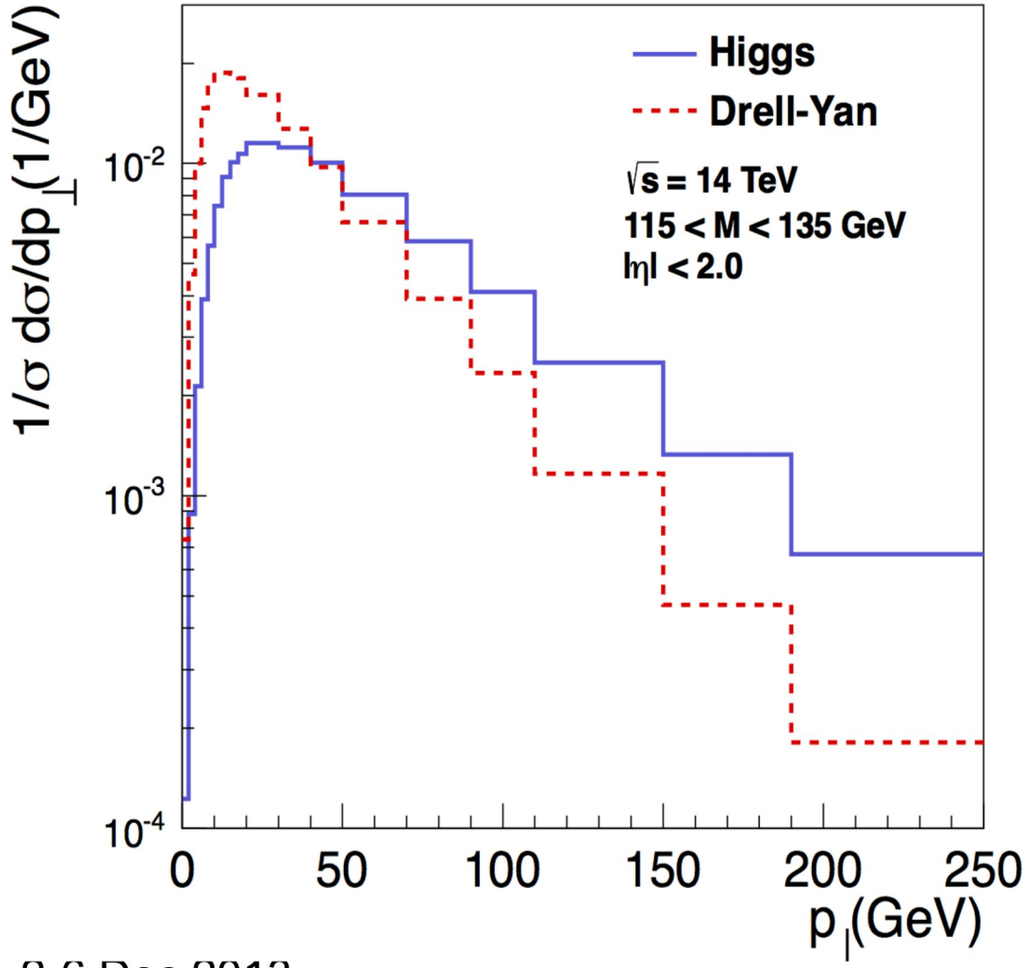
- Start new QCD program with Higgs as gluon trigger

  P. Cipriano, S. Dooling, A. Grebenyuk, P. Gunnellini, F. Hautmann, H. Jung, P. Katsas
  (arXiv:1308.1655 and Phys. Rev. D 88, 097501 (2013)

  - comparison with DY production at same mass range
  - p_T spectrum of DY and Higgs:

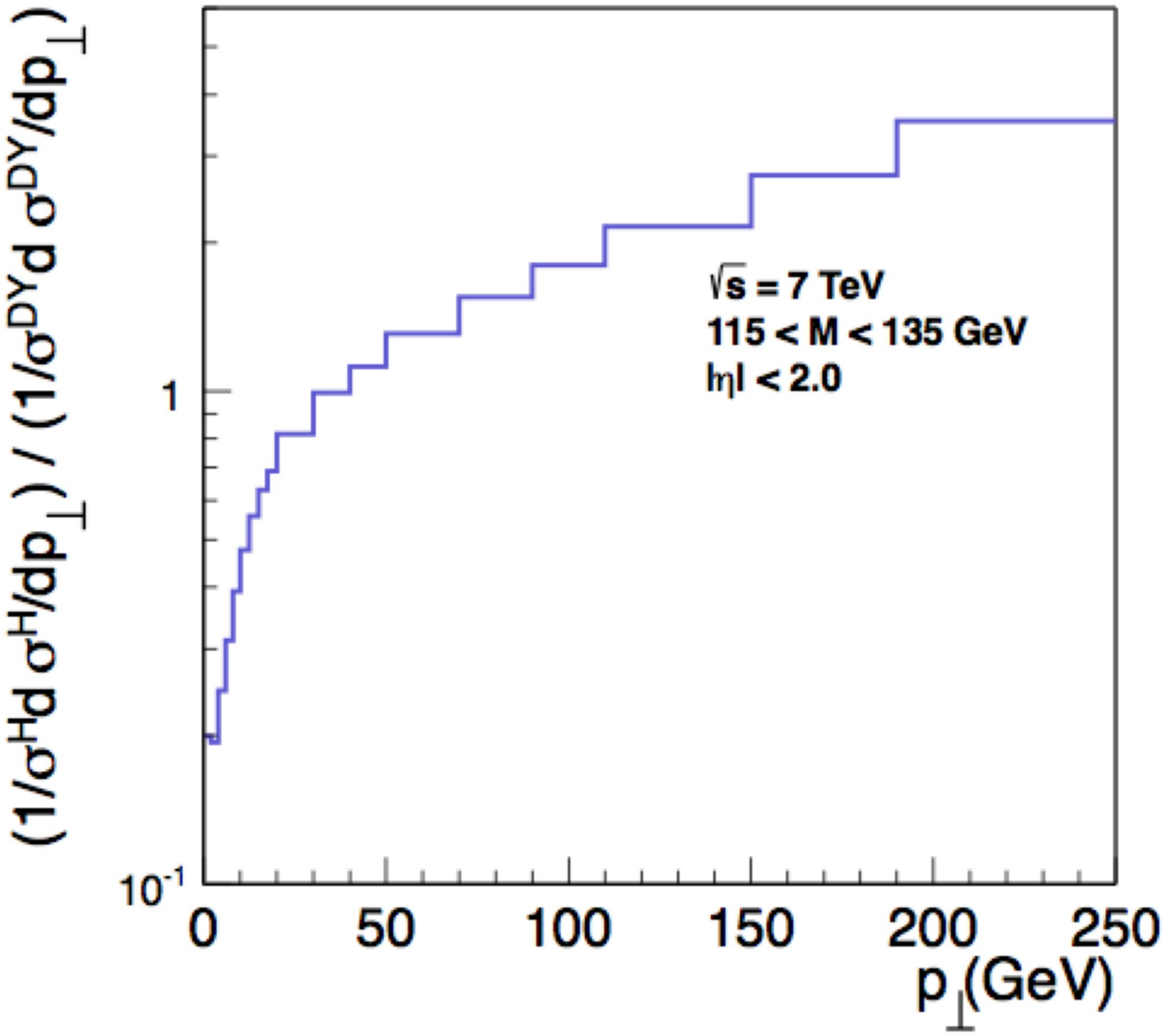
    difference in soft gluon resummation

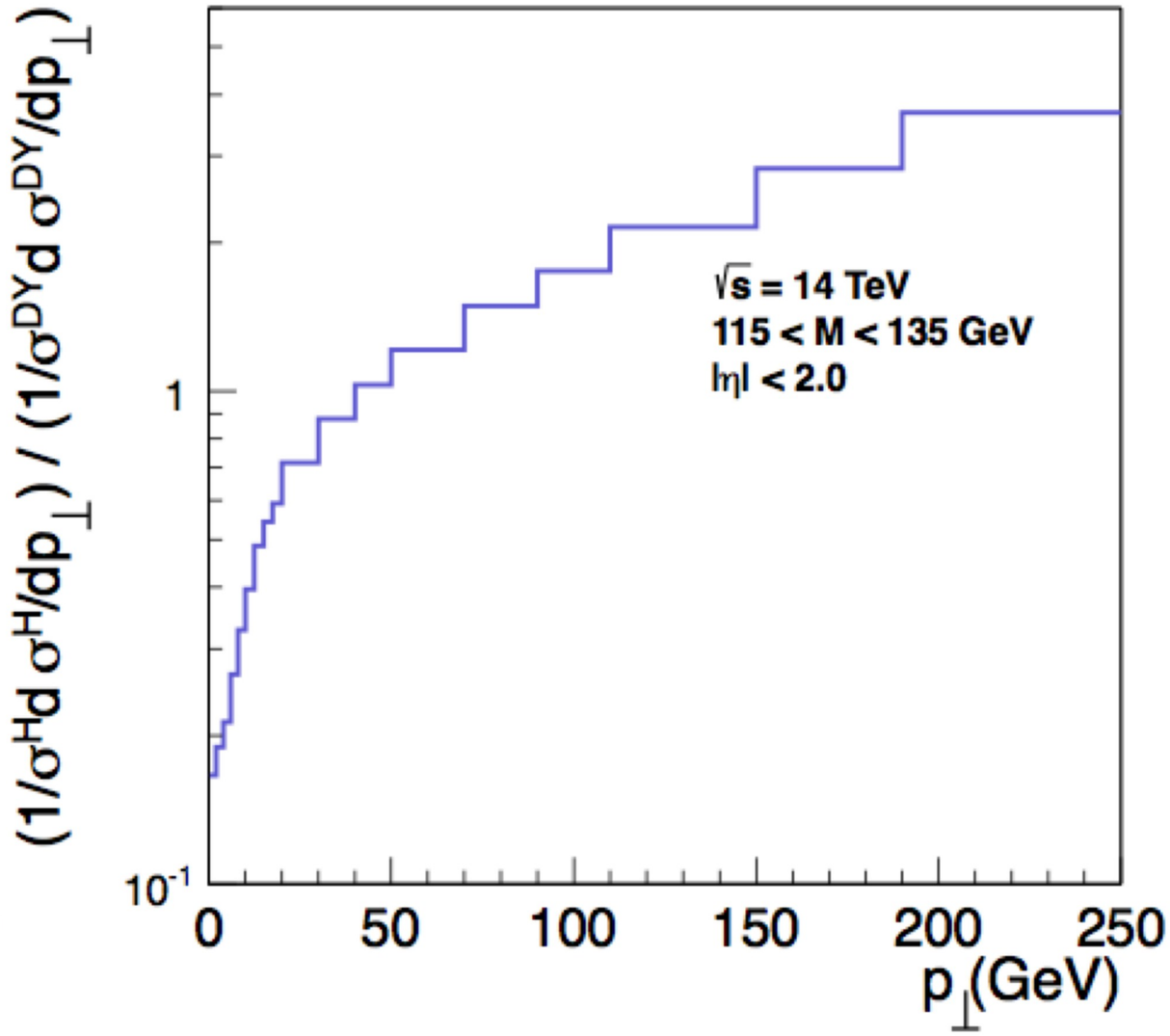




Higgs as a gluon trigger

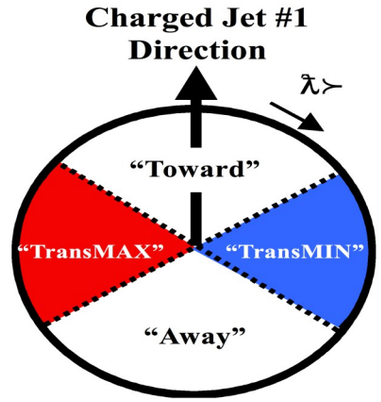
- Start new QCD program with Higgs as gluon trigger
  (P. Cipriano et al Phys. Rev. D 88, 097501 (2013))
  - plot ratio of Higgs/DY xsections at m=125 GeV at fixed rapidity
    → pdf shape dependence drops out
  - observe directly difference in soft gluon resummation

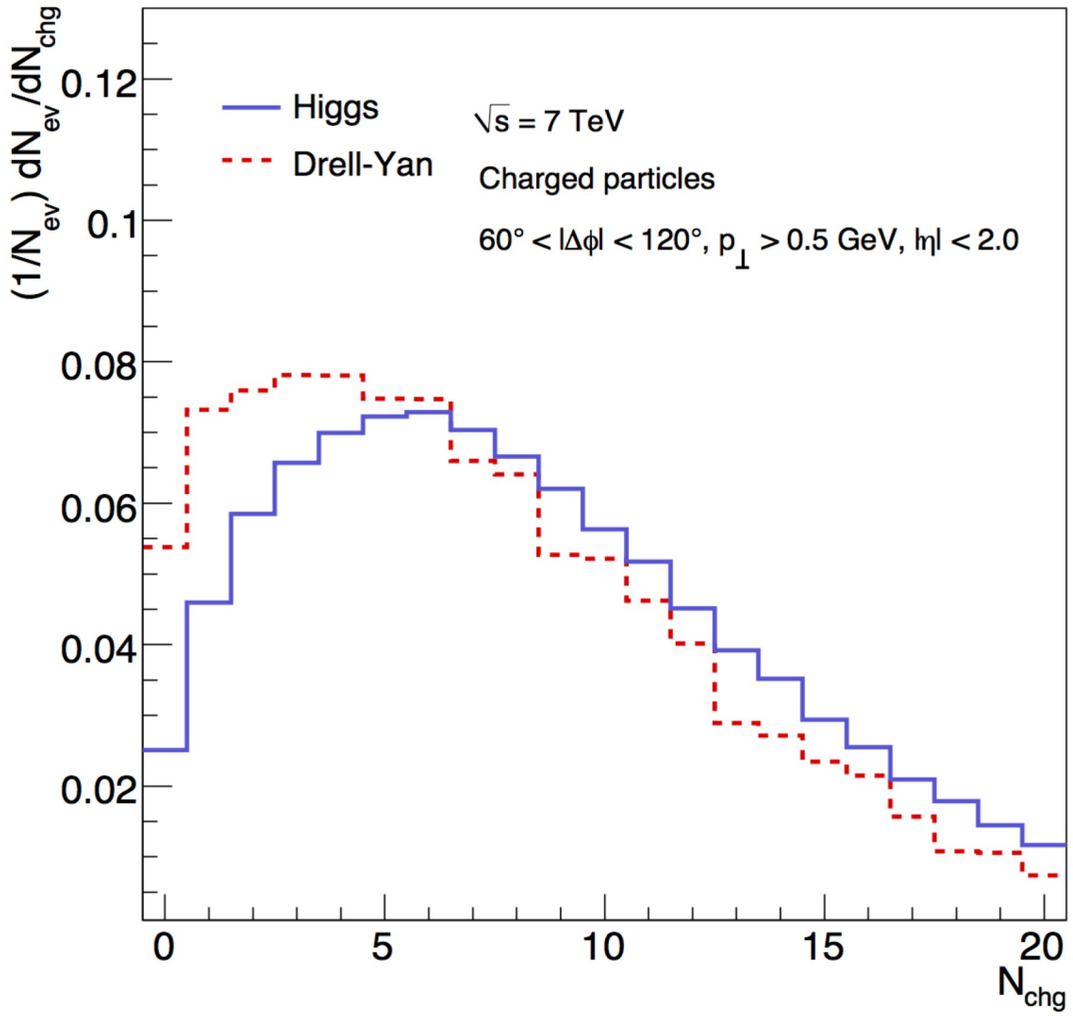


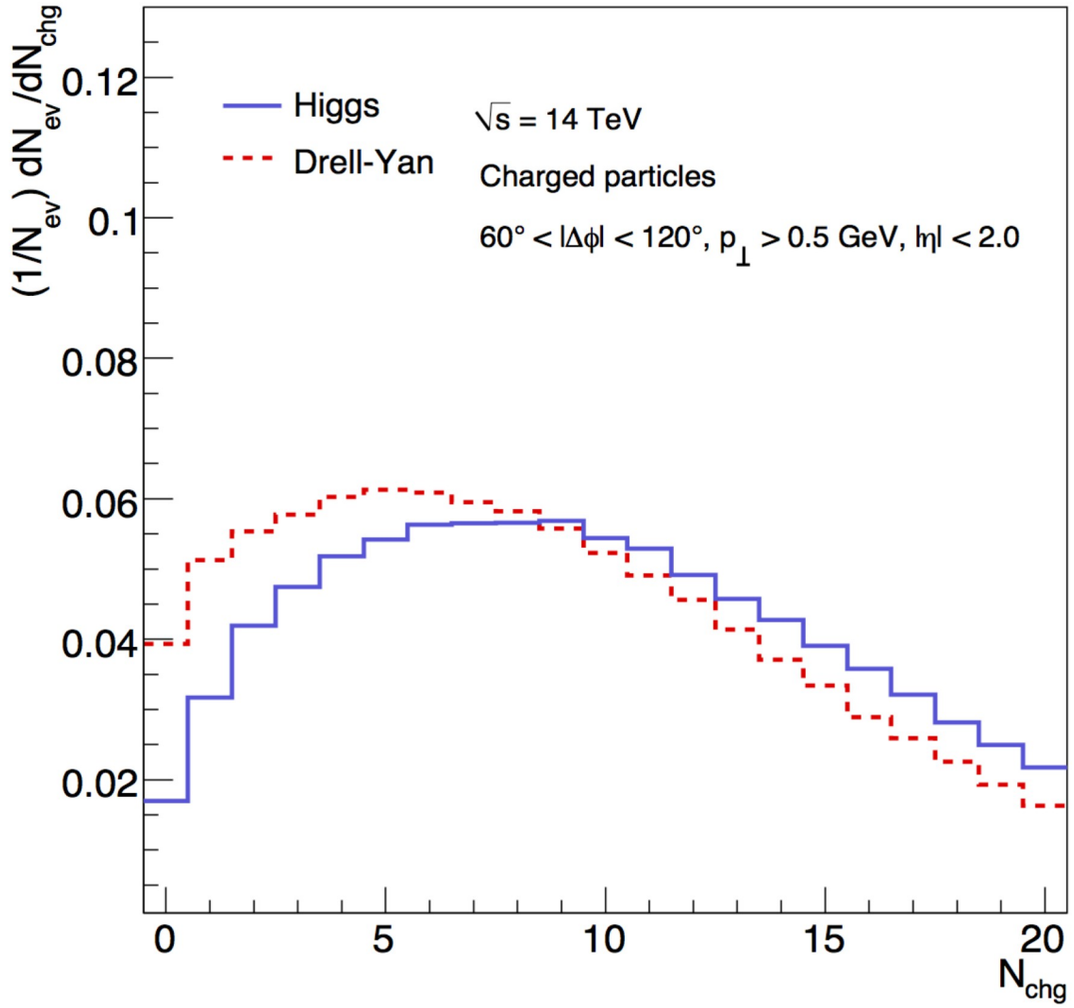


Higgs as a gluon trigger – UE studies

- Start new QCD program with Higgs as gluon trigger
  (P. Cipriano et al Phys. Rev. D 88, 097501 (2013))
  - comparison with DY production at the same mass range
  - underlying events in DY and Higgs:
    difference in quark vrs gluon induced process



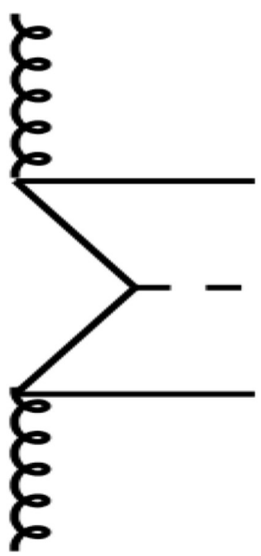




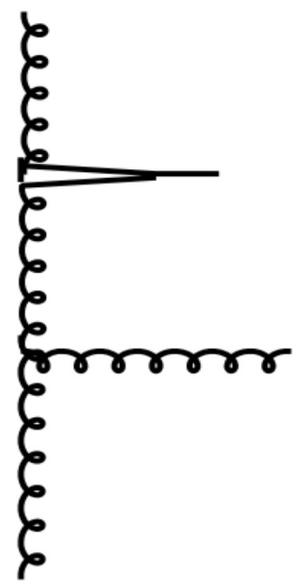
Higgs as a gluon trigger

- Start new QCD program with Higgs as gluon trigger
  (P. Cipriano et al Phys. Rev. D 88, 097501 (2013))
  - comparison with DY production at the same mass range
  - jet + DY / Higgs: in rest-frame see effect of quark vrs gluon propagator → angular distribution

Drell Yan

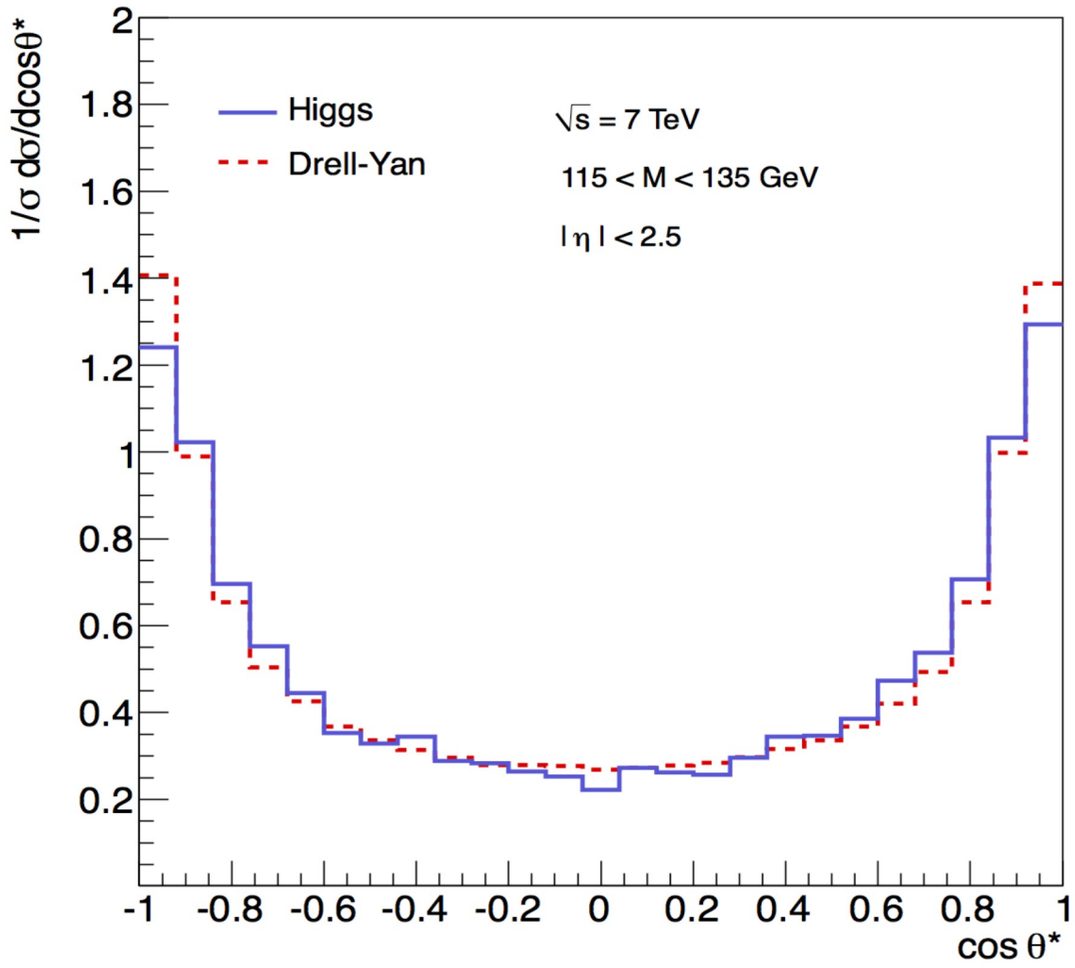


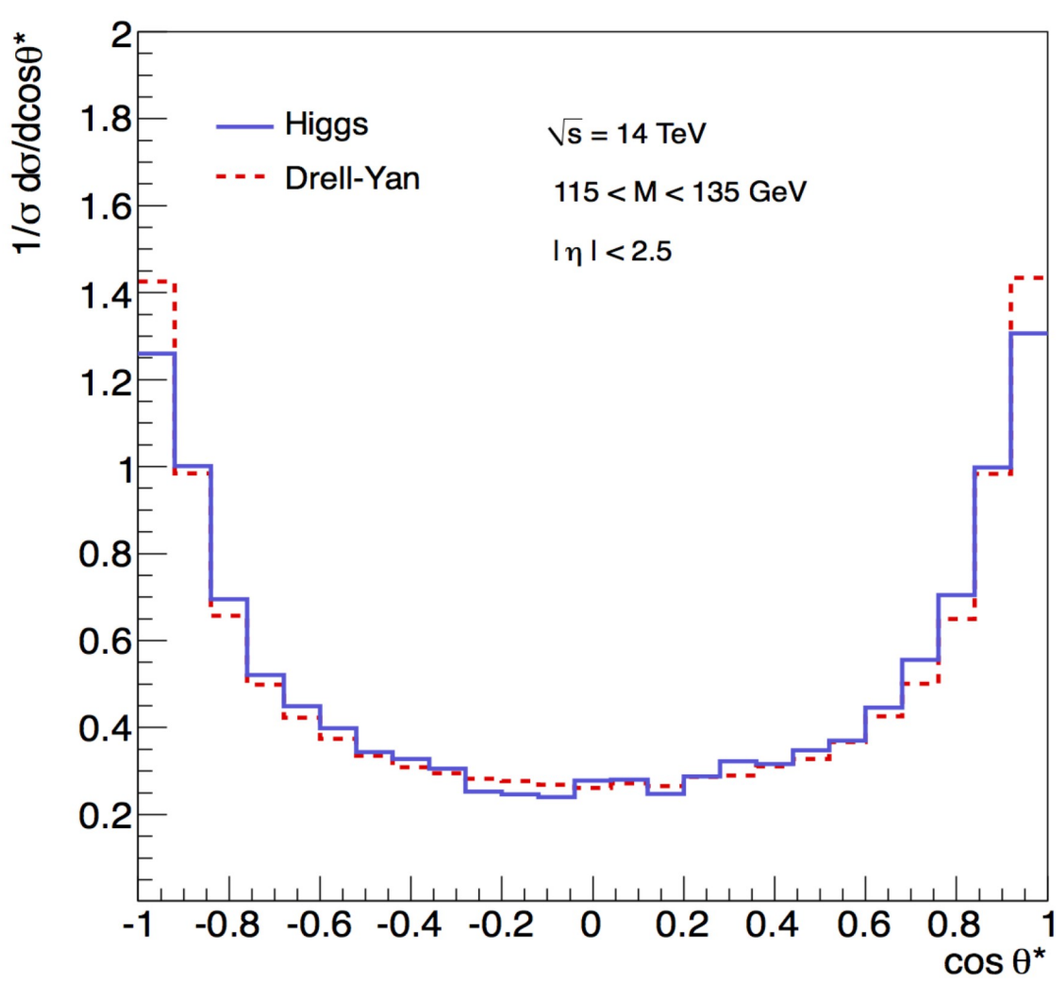
Higgs



Higgs as a gluon trigger

- Start new QCD program with Higgs as gluon trigger
  (P. Cipriano et al Phys. Rev. D 88, 097501 (2013))
  - comparison with DY production at the same mass range
  - jet + DY / Higgs: in rest-frame sensitivity to spin-zero coupling to gluons - vanishing effect of quark vrs gluon propagator





What is new ?

- NEW: comparison of DY with Higgs
- DY and Higgs allows direct comparison of quark vrs gluon induced process
  - with DY we can go to the same mass as with Higgs
    - comparing DY and Higgs at fixed y: pdf dependence cancels
  - advantage is: color singlet final state
    - high energy factorization applicable (!!!!)
    - no issue with color flow from initial to final state as in ttbar, bbar or jet processes
  - pile-up is no issue: by comparing DY and Higgs, pile-up drops out (too large extend):

$$\frac{dn}{dp_t}(H-DY) = \frac{dn}{dp_t}_{H} + \frac{dn}{dp_t}_{pileup} - \left(\frac{dn}{dp_t}_{DY} + \frac{dn}{dp_t}_{pileup}\right)$$

  - ditto for UE contribution: isolate directly initial state effects
  - can even measure jet at low transverse momenta

    (how low depends on resolution...)

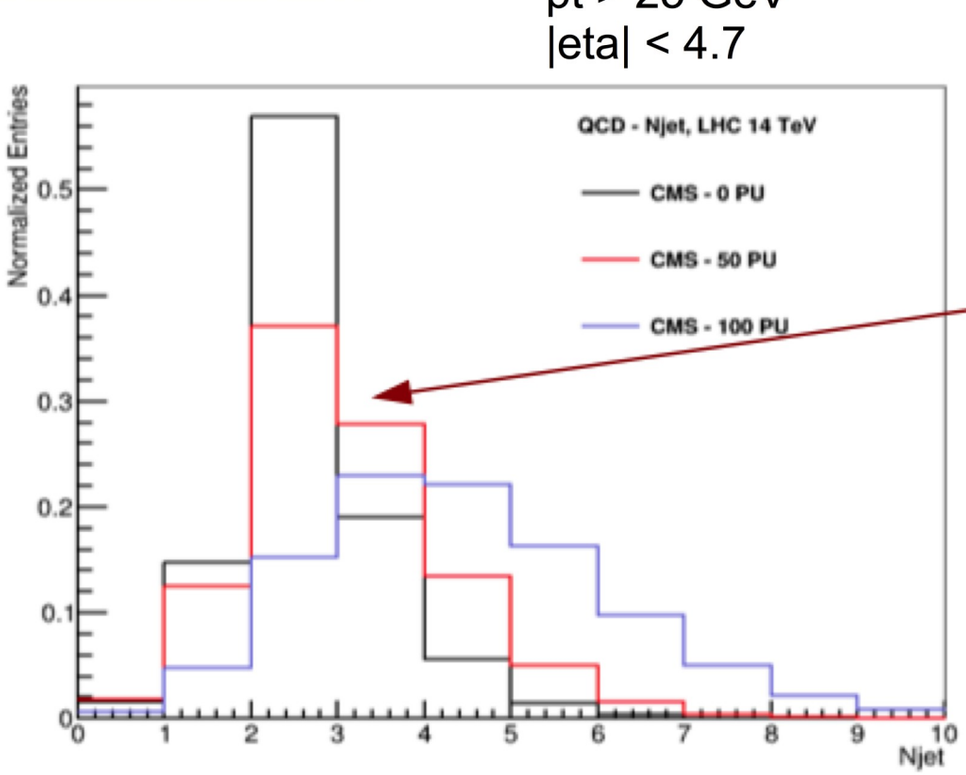
PU issues (I)

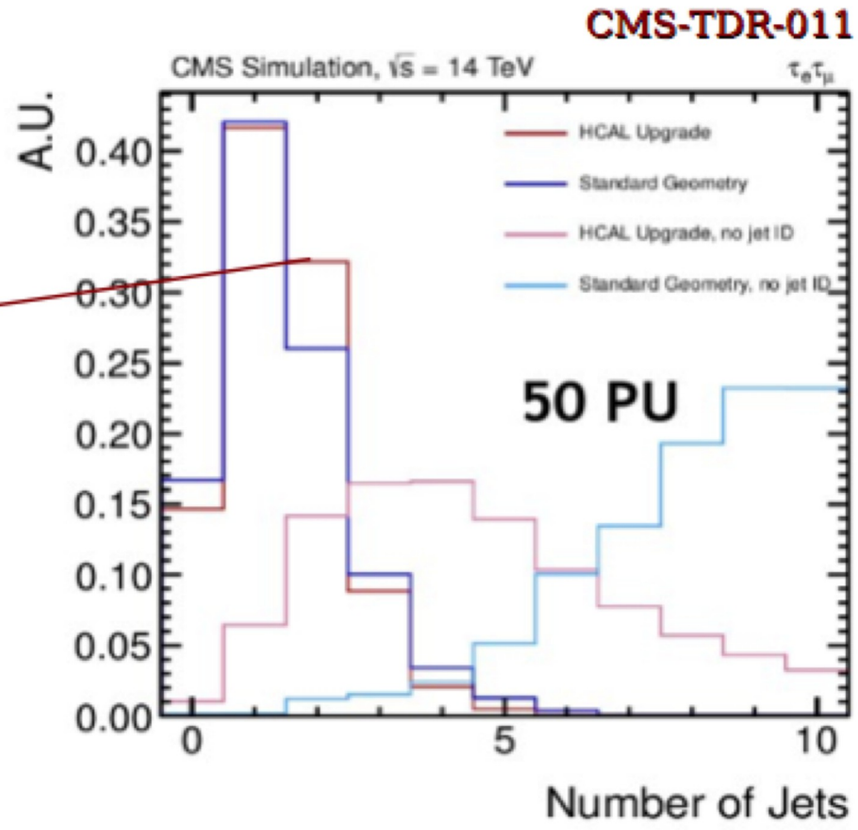
Jets

S. Padhi, Snowmass WS, 2013:
https://indico.bnl.gov/conferenceDisplay.py?confId=571

QCD MC events

antikt 0.5
pt > 25 GeV
|eta| < 4.7





Jet multiplicities increases with increase in PU conditions

- Jet smearing alone cannot produce "new Jets"

Area subtraction method is even more important for high PU environment

April 3rd, 2013. Snowmass Energy Frontier Workshop, BNL. 37 Sanjay Padhi

- Additional jets are produced by PU → drop out when taking difference DY-Higgs

H. Jung et al, Higgs as a gluon trigger, MPI workshop, Antwerp, 2-6 Dec 2013

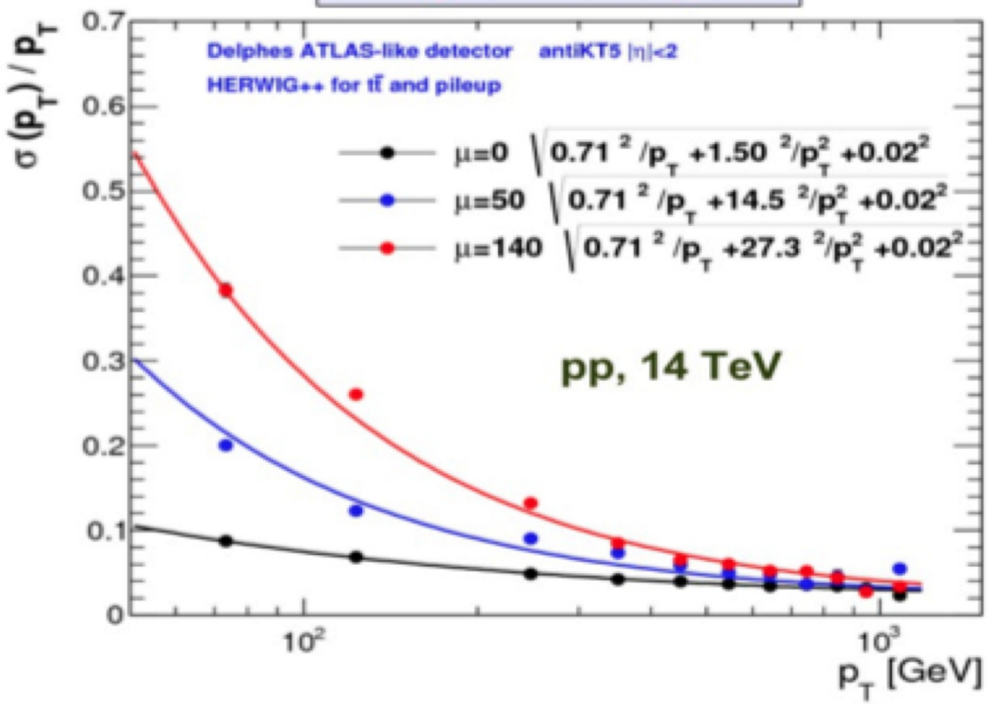
Pileup issues (II)

S. Padhi, Snowmass WS, 2013:
https://indico.bnl.gov/conferenceDisplay.py?confId=571

Hadronic Jets

Delphes fast simulation. Jet resolution vs <μ>

Delphes tower jets



$$\frac{\sigma(E)}{E} = \sqrt{\frac{a^2}{E} + \frac{b^2}{E^2} + c^2}$$

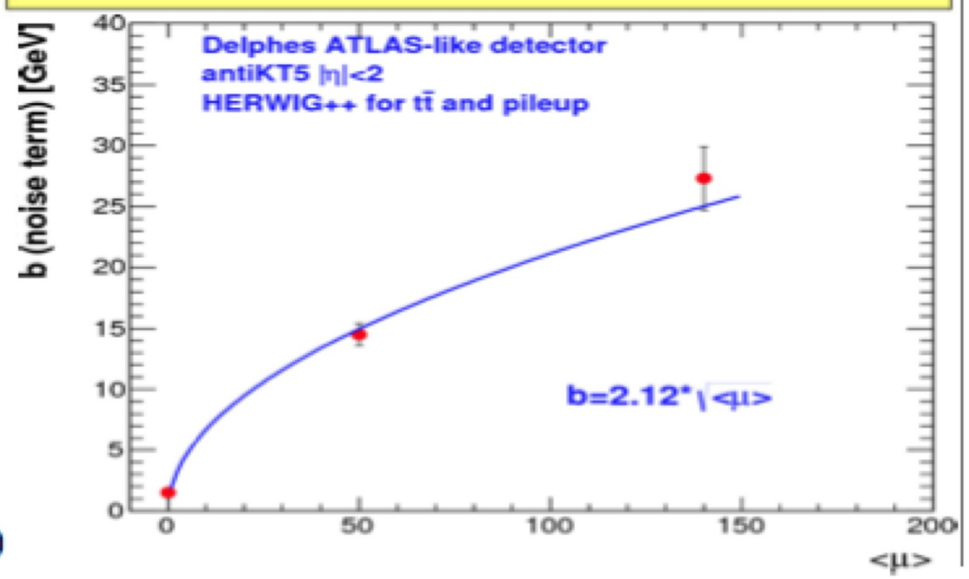
The noise term follow sqrt(μ)

Delphes result agrees with the assumption that pileup mainly changes the noise term ("b")

Noise term ("b") for high-pileup scenario:

Delphes: b ~ 27 GeV for <μ>~140 for 14 TeV

ATLAS full simulation (extrapolation):
b ~14 GeV for <μ>~150 for 7 TeV



- PU adds noise term → makes resolution worse, but can be treated to some extend by area subtraction

H. Jung et al, Higgs as a gluon trigger, MPI workshop, Antwerp, 2-6 Dec 2013

A word on x-sections

- need a clean channel:
  - $h \to \gamma\gamma$ is difficult since fit to signal and background needed in each bin
  - but $h \to ZZ \to 4l$ is clean but has small x-section: ca 20 evts in 20 fb^{-1}
  - use also other channels: $h \to WW$
- really high luminosity is needed, but then one can measure to low p_t

- can one use instead χ_c and J/ψ or χ_b and Υ **?**
  - in principle yes,
    - but difficulties in description of production mechanism
    - mass is low, evolution is less important
    - not really in weak coupling limit

Challenge in QCD – another example

- Higgs + jet production
  - as function of Δ y jet multiplicity must increase
  - similar to dijet case
- Measure at fixed $m = 125\,GeV$:

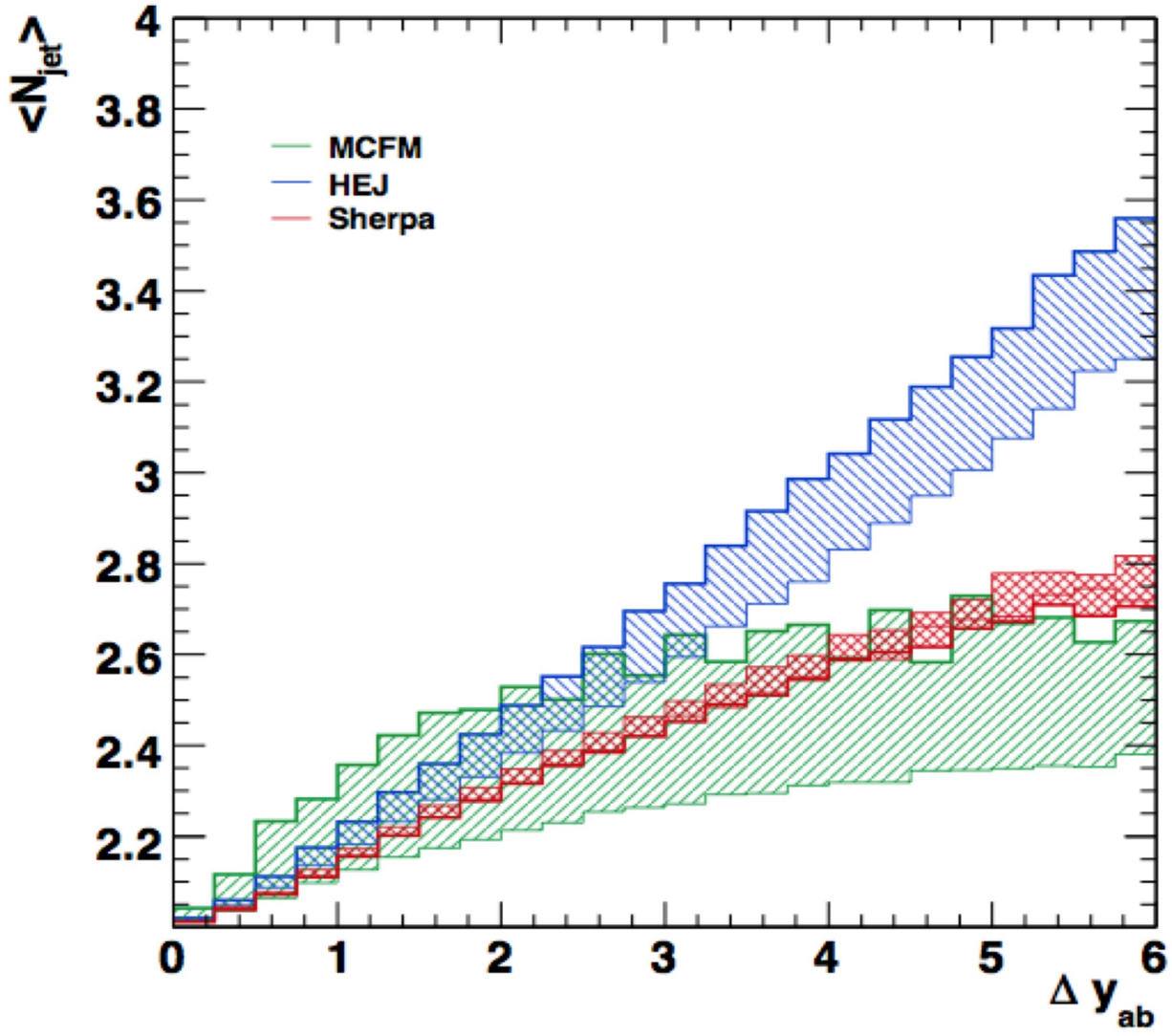
$$\frac{dn}{d\Delta y}_{Higgs} - \frac{dn}{d\Delta y}_{DY}$$

- pileup and UE effects cancel
- isolate gluon contribution

High Energy Description of Processes with Multiple Hard Jets
Jeppe R. Andersen. Jennifer M. Smillie.
Nucl.Phys.Proc.Suppl. 205-206 (2010) 205-210, 1007.4449

$$pp \to h + 2 \text{ jets } (+ \text{ n jets})$$

$$\sqrt{s} = 10 \text{ TeV}, \; p_T > 40 \text{ GeV}$$



Conclusion

- Higgs measurement offers new perspectives for challenging QCD measurements
- Higgs is the only electroweak current which couples to gluons
- advantage since color singlet state has no complications from final state effects
- Higgs – DY comparison at $m = 125\,GeV$ removes most of background:
  - pdf shape dependence drops at fixed y
  - UE and pileup background cancels largely in difference or ratios
- Higgs allows interesting and challenging QCD measurements at high luminosity