Light SM Higgs at LHeC

Uta Klein

on behalf of

M. Ishitsuka, K. Kimura, M. Kuze, K. Sampei

Tokyo Institute of Technology

C. Hengler, U. Klein

University of Liverpool

UNIVERSITY OF LIVERPOOL

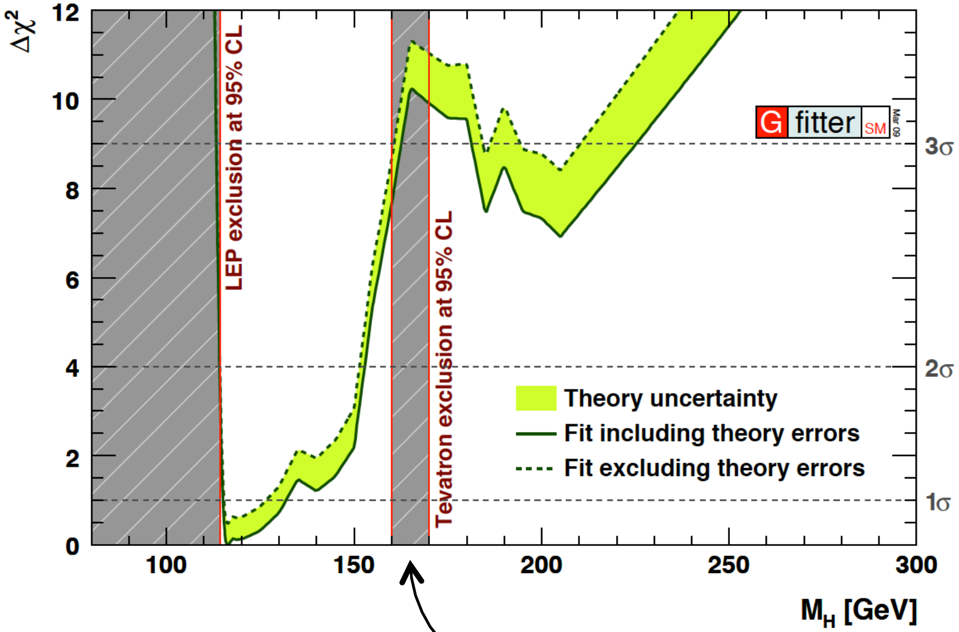
3rd LHeC Workshop, November 12th, 2010

Motivation

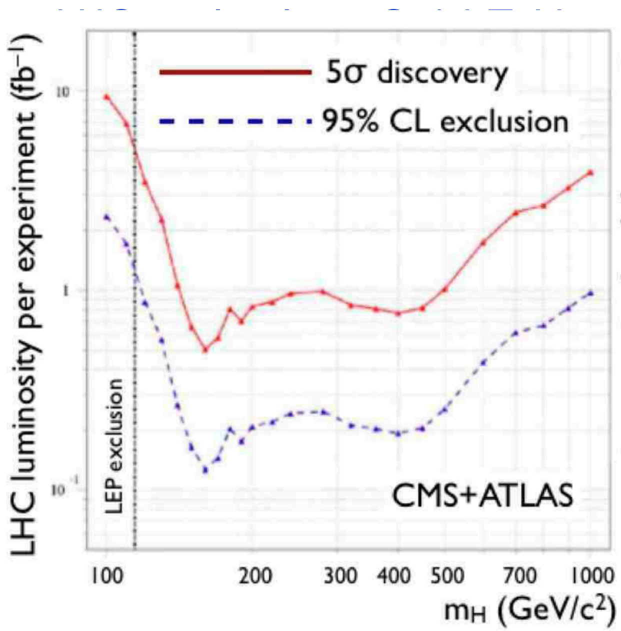
SM gauge boson and fermion mass generation mechanism needs the Higgs boson.

- LHC and Tevatron experiments will have the capability to observe or exclude the Higgs.
- EW precision data and direct searches suggest a mass range $m_H \geq 114$ GeV, see e.g. recent review by J.Ellis [arXiv:1004.0648]

$$m_h = 116.4^{+15.6}_{-1.3}\ \text{GeV}$$



$$162\ \text{GeV} < m_h < 166\ \text{GeV}$$



Higgs Boson Couplings

Higgs couplings to both gauge bosons and fermions determine the Higgs production cross sections.

→ Measurements of those provide crucial tests of the mass generation mechanism realised in nature!

→ If a Higgs with mass < 200 GeV is discovered at LHC, Higgs boson couplings and the total width may be extracted after several years of running, see e.g. M. Duhrssen et al. [hep-ph/0406323]

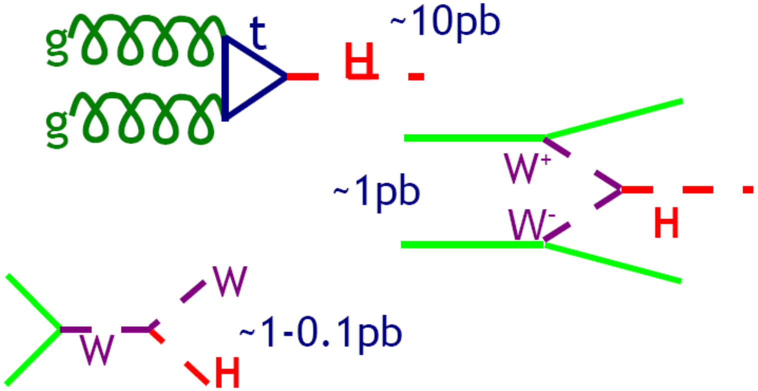
→ However, even then will be a measurement of the Higgs-bottom coupling extremely challenging since the H→bb dominant at $m_H \leq 130$ GeV is overwhelmed by QCD backgrounds for b-jets.

LHeC is an LHC upgrade proposal focusing on precision measurements of the partonic substructure of the proton and the strong coupling at √s of 1 to 2 TeV.

An ep collider can *add on valuable information w.r.t. LHC* measurements in particular if a light SM Higgs was discovered and some knowledge on the total width and some boson couplings are known.

SM Higgs Production Examples

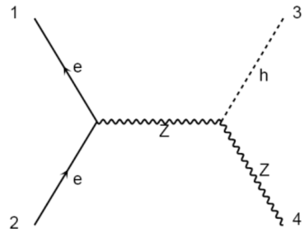
pp



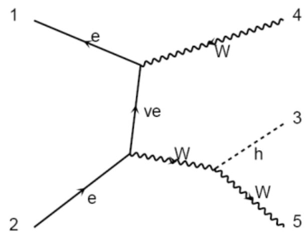
→ at LHC typically ~10^{-12} of the total cross section

e^+e^-

250x250 GeV^2

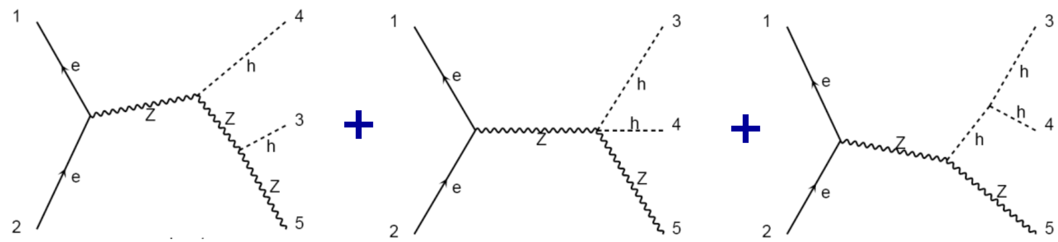


~60 fb



+ …

~6 fb

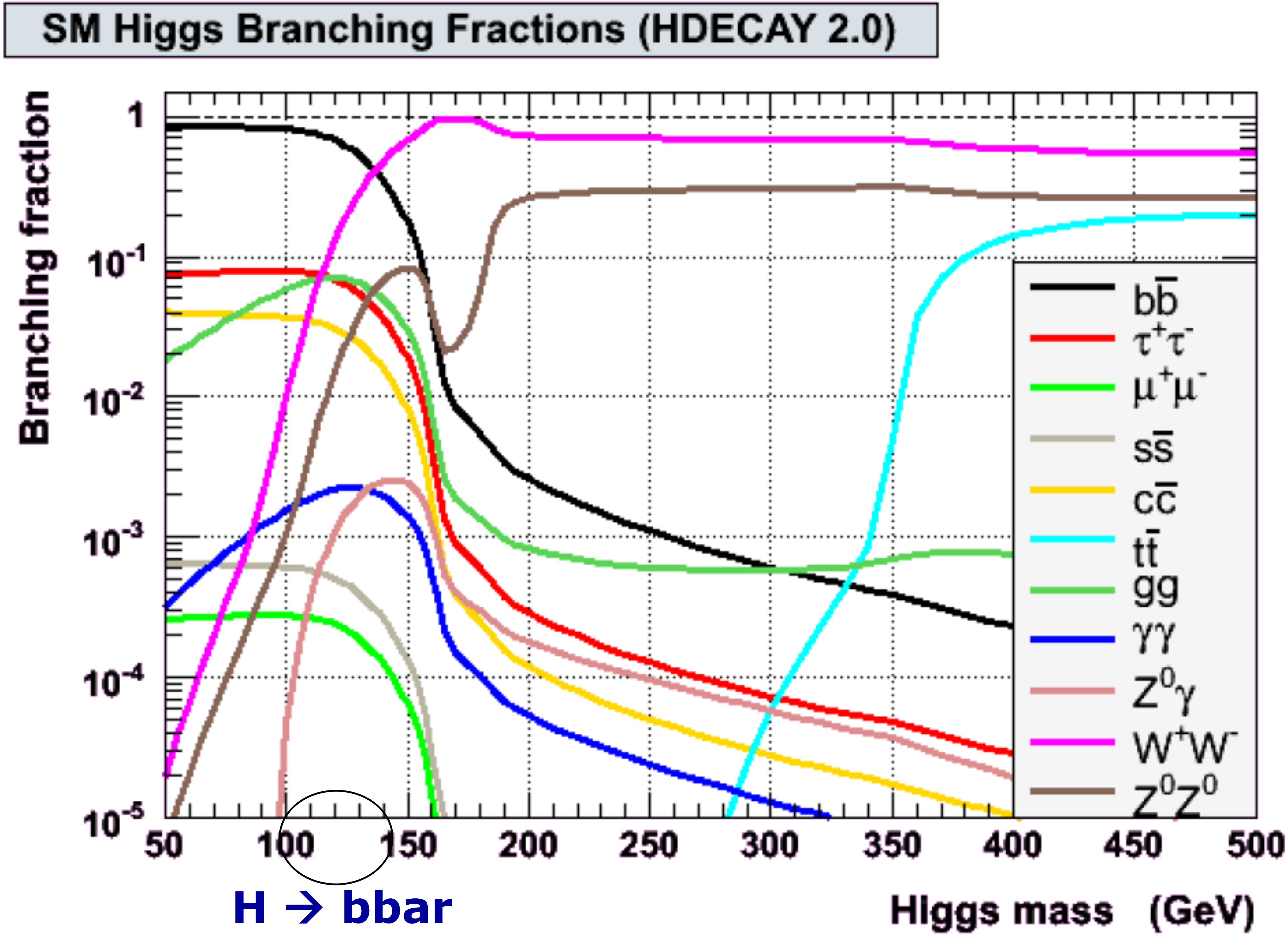


~0.2 fb

Decay depends strongly on m_H

- low masses : bbar, but also $\gamma\gamma$, $\tau+\tau-$
- high masses : WW, ZZ … ttbar

Variety of search topologies with different S/B


SM Higgs Branching Fractions (HDECAY 2.0)
Branching fraction
1
10-1
10-2
10-3
10-4
10-5
50
100
150
200
250
300
350
400
450
500
Higgs mass (GeV)
bb̄
τ+τ-
μ+μ-
ss̄
cc̄
tt̄
gg
γγ
Z0γ
W+W-
Z0Z0

H → bbar

ep

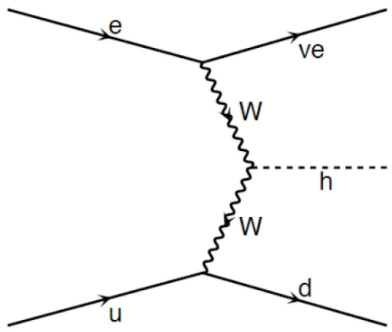
$\sqrt{s}=1 - 2$ TeV

CC : LO SM Higgs Production

~ 200 fb

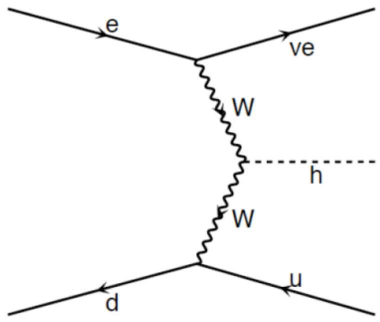
e-p (swap charges for e+p)

e- u -> ve h d



around 90-80%

e- d~ -> ve h u~



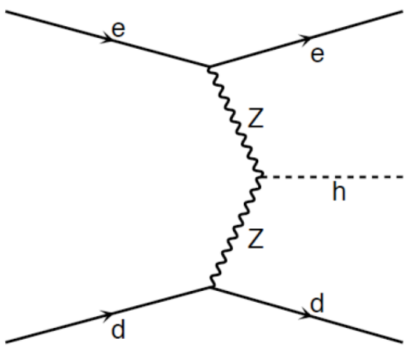
around 10-20%

NC : LO SM Higgs Production

~ 50 fb
(Z heavier
than W and
couplings to
fermions
smaller)

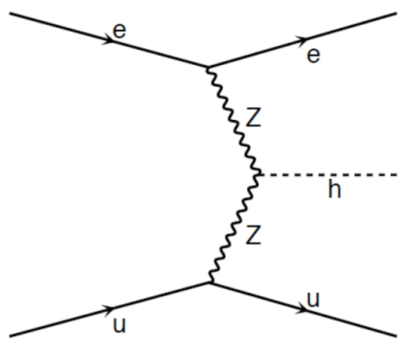
e-p (swap charges for e+p)

e- d -> e- h d



around 1/3

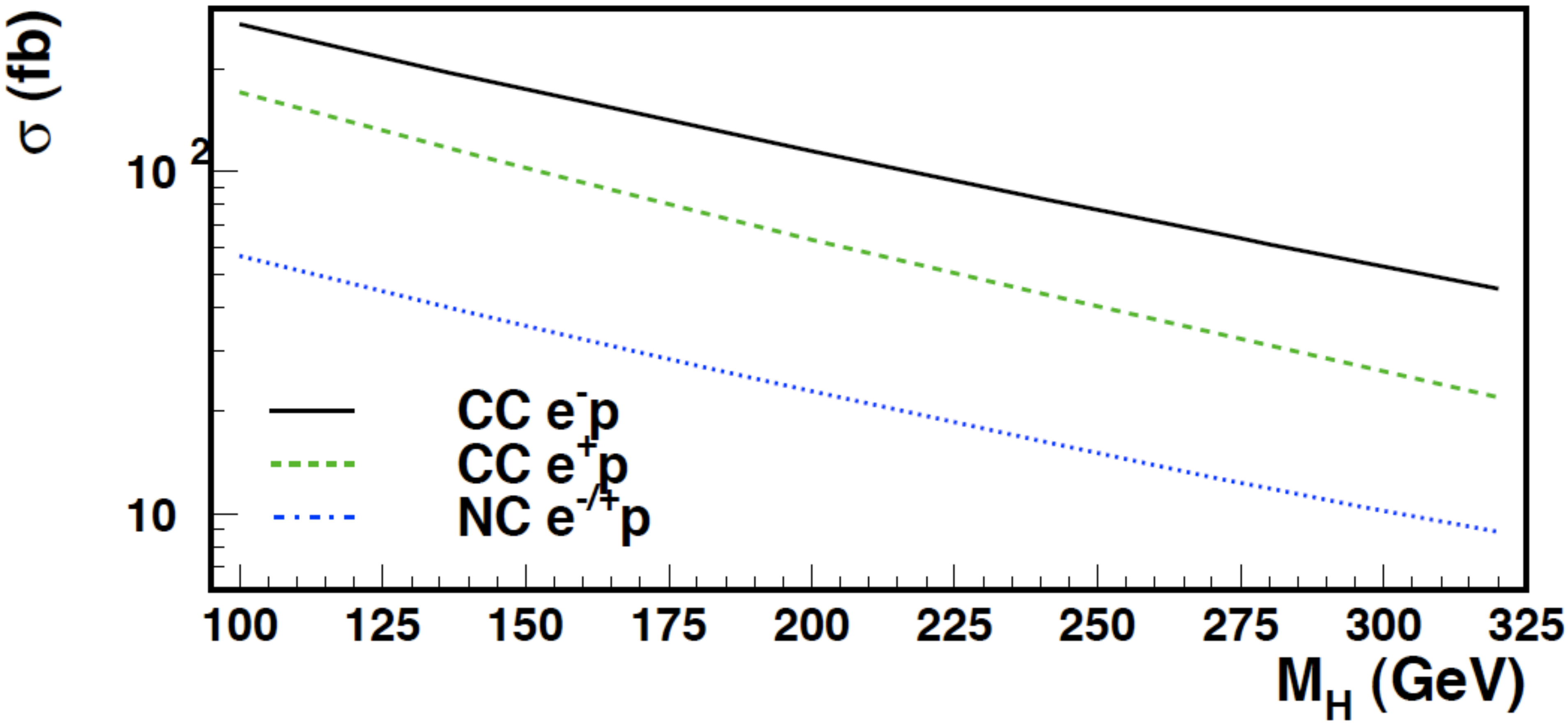
e- u -> e- h u



around 1/3

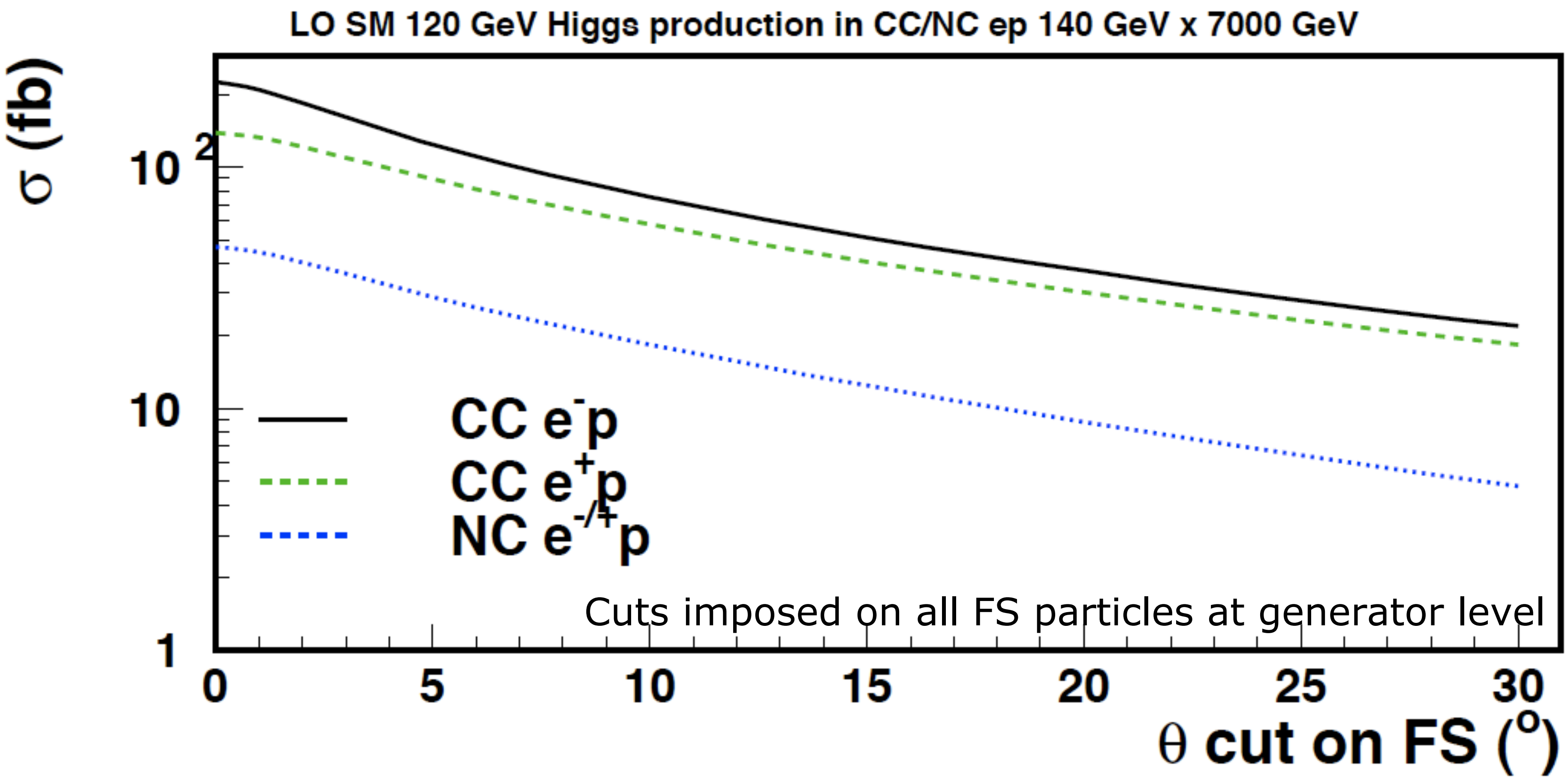
Total LO Higgs Cross Sections vs M_H

140 GeV x 7000 GeV



Effect of Detector Acceptance

M_H = 120 GeV



→ Detector design will be crucial for signal detection and background rejection efficiency.

Total CC e-p Higgs Cross Sections (fb) versus Electron Beam Energy

	100 GeV	120 GeV	160 GeV	200 GeV	240 GeV	280 GeV
50 GeV	102.4	80.6	50.3	31.6	19.9	12.5
100 GeV	201.3	165.3	113.2	78.6	55.2	39.1
150 GeV	286.3	239.5	170.4	123.3	90.5	67.1

→ Scale dependencies of the LO calculations are in the range of 5-10%.
→ QCD and QED corrections are moderate but sensitive to experimental cuts. NLO QCD corrections are small, but shape distortions of kinematic distributions up to 20%. QED corrections up to -5%.
[J. Blumlein, G.J. van Oldenborgh , R. Ruckl, Nucl.Phys.B395:35-59,1993.]
[B.Jager, arXiv:1001.3789.]

Methodology

MadGraph : tree level calculations of various processes

SM parameters can be steered via SM parameter calculator (change M_H)

Beam energy, phase space cuts, PDF, scales etc. via steering card

All Feynman diagrams shown in this talk have been produced using Madgraph.

Use Madgraph including pythia-pgs interface modified for DIS for 'detector-level' studies,

see previous studies as listed in the backup.

New : use most recent Madgraph version 4.4.44

→ Higgs decay into bbar is done in Madgraph by package DECAY

PDF : CTEQ6L1 (LO PDF and LO α_S=0.13)

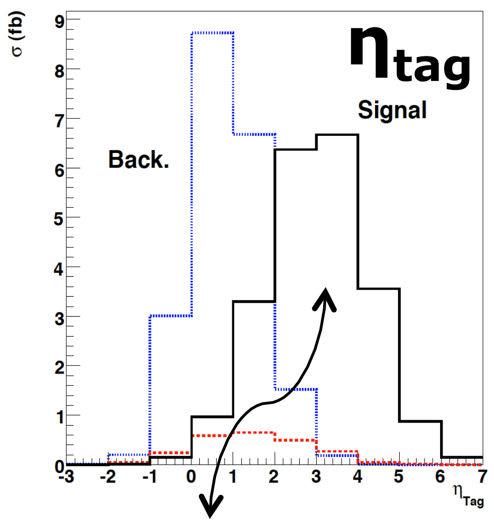
Factorisation and renormalisations scales set to partonic c.m.s.

→ Perform generator and 'detector-level' Higgs search

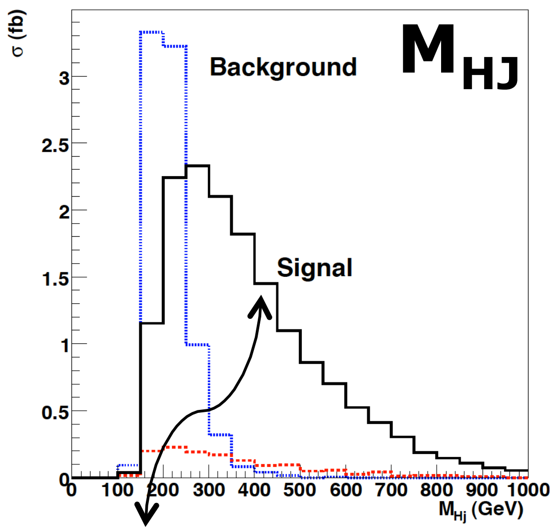
T.Han, B. Mellado
arxiv:0909.2460

Generator-level Study

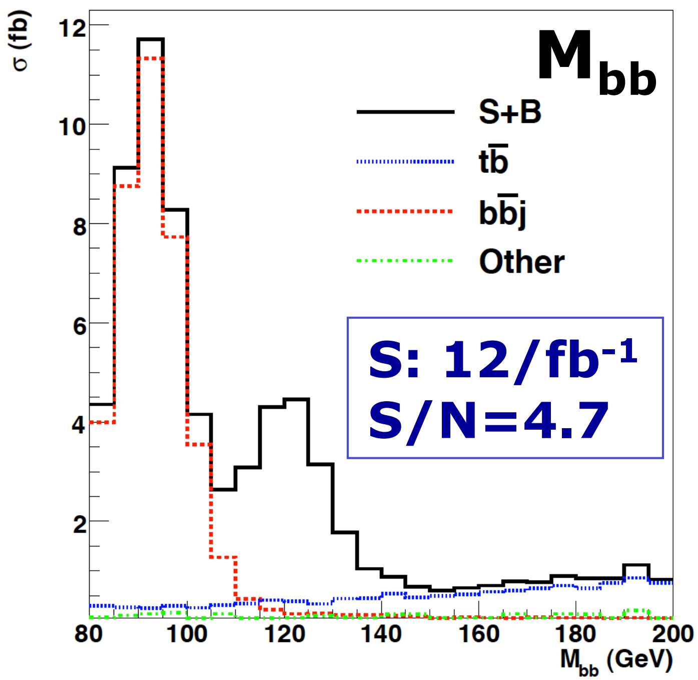
- M_H=120 GeV, ep: 140 Gev X 7000 GeV using Madgraph and DECAY
- generated parton energies and angles smeared by resolutions, e.g. δE_{had}=60% yields δm_H=7% (w/o angular smearing)
- 60% b-tagging efficiceny applied on b-quarks and rejection factors of 10 and 100 for c and light quarks, resp., for $|\eta|<2.5$
- require mass of 2 b-partons to be within 120±10 GeV (assume known M_H)
- tag the forward spectator parton within $1<\eta<5$ and $p_T>30$ GeV
- high invariant mass of H-candidate and spectator jet, $M_{HJ}>250$ GeV



forward jet tagging



inspired from VBF@LHC:
Phys. Lett. B611(2005)60



CC e-p Higgs 'Detector-level' Study

- Parameters for $\sqrt{s}$ = 2.05 TeV
  - Proton beam E_p=7 TeV
  - Electron beam E_e=150 GeV
  - Higgs mass M_H=120 GeV
  - Luminosity $L=10\ fb^{-1}$

- Generator cuts for all samples (j: udcsg ,l:eμ, γ: photon)
  - $P_{T,j}>5$ GeV & $P_{T,lepton,photon} > 0.1$ GeV
  - $|\eta_{jet,\ b,\ lepton,\ photon}| < 5.0$
  - ΔR(between FS particles) > 0.4
  - additional cut for 3 jet NC and CC background sample of $M_{jj} > 30$ GeV

Overview of generated Samples

process	Cross-section with generator cut (pb)	# of diagrams	# of generated events
Higgs decay to bb	0.160	2	200 000
CC 3jets bgd (w/o higgs)	111	384	720 000
NC 3jets bgd (w/o higgs)	11500	1428	190 000

‘Detector’

…events passed thru PGS generic LHC detector

LHC	! parameter set name
320	! eta cells in calorimeter
200	! phi cells in calorimeter
0.0314159	! eta width of calorimeter cells |eta| < 5
0.0314159	! phi width of calorimeter cells
0.01	! electromagnetic calorimeter resolution const
0.2	! electromagnetic calorimeter resolution * sqrt(E)
0.8	! hadronic calolrimeter resolution * sqrt(E)
0.2	! MET resolution
0.01	! calorimeter cell edge crack fraction
cone	! jet finding algorithm (cone or ktjet)
5.0	! calorimeter trigger cluster finding seed threshold (GeV)
1.0	! calorimeter trigger cluster finding shoulder threshold (GeV)
0.5	! calorimeter kt cluster finder cone size (delta R)
2.0	! outer radius of tracker (m)
4.0	! magnetic field (T)
0.000013	! sagitta resolution (m)
0.98	! track finding efficiency
1.00	! minimum track pt (GeV/c)
3.0	! tracking eta coverage
3.0	! e/gamma eta coverage
2.4	! muon eta coverage
2.0	! tau eta coverage

20%→ 5%

80%→60%

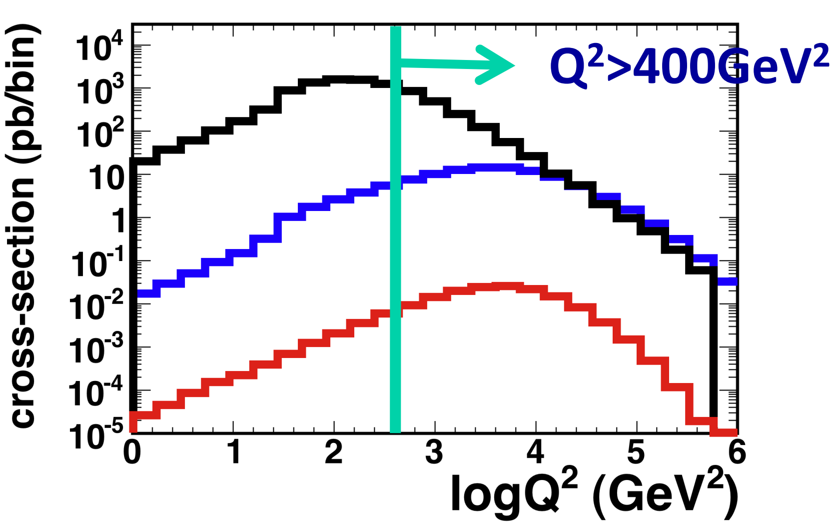
jets: cone<0.5

Disclaimer :
PGS of LHC detector
+ flat b-tagging
in the full tracking range of
$|\eta|<3.0$
b: 60%, c: 10%, udsg: 1%
CAL coverage until $|\eta|<5.0$

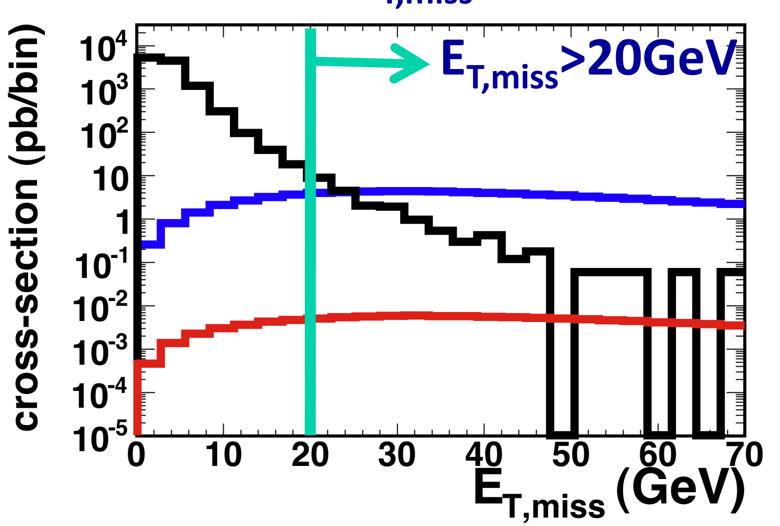
'PGS Detector' Quantities

— higgs — CC 3jets bgd — NC 3jets bgd

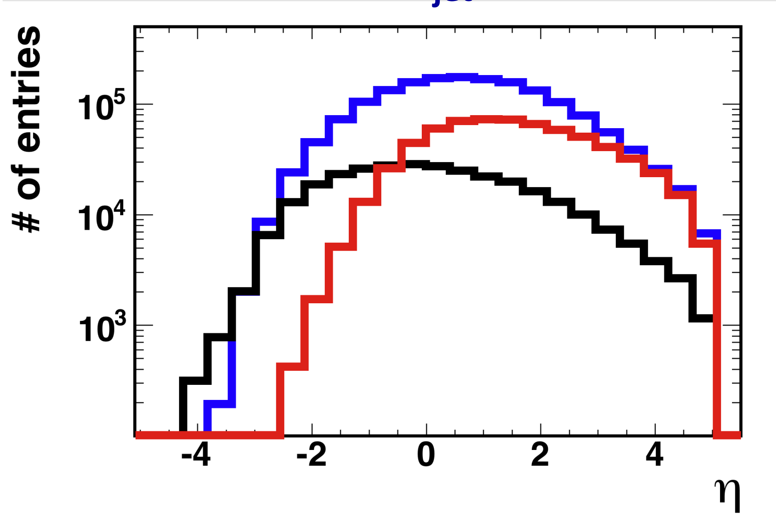
Q^2



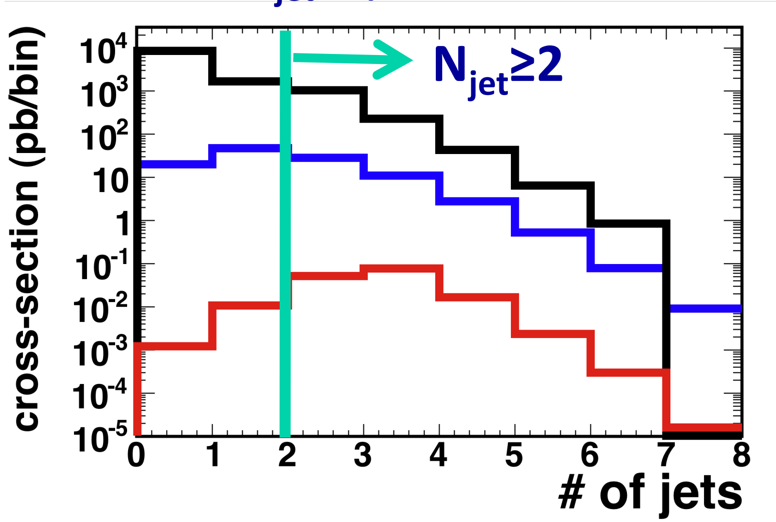
$E_{T,miss}$



η_{jet}



$N_{jet}(P_T>20GeV)$



Event Selection

Cut (1) exclude electron-tagged events.
$E_{T,miss}$>20 GeV, N_{Jet} ($P_{T,Jet}$>20 GeV) ≥2,
$E_{T,total}$ > 100 GeV, Q^2_{JB}>400 GeV², y_{JB}<0.9

Cut (2) b-tag requirement
$N_{b\text{-}Jet}$ ($P_{T,Jet}$>20GeV) ≥2
'b-Jet' is b-tagged jet

Cut (3) single top candidate veto
$N_{Jet} \geq 3$, $M_{jjj,top}$> 200 GeV, $M_{jj,W}$ > 130 GeV

Cut (4) tag of forward jet
$1 < \eta_{fowardjet} < 5$, M_{Hj}> 250 GeV

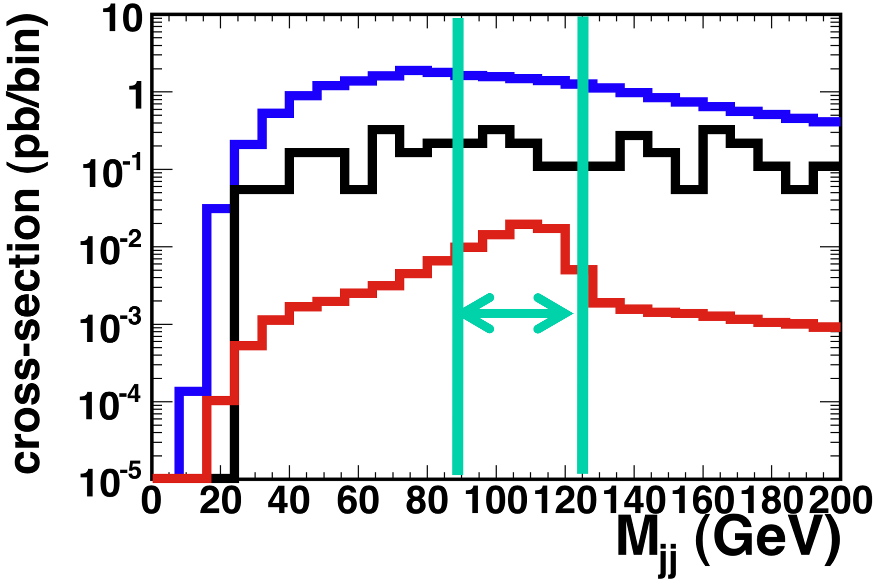
Cut M_H 90 GeV < M_H< 125 GeV

Invariant Dijet Mass Distribution

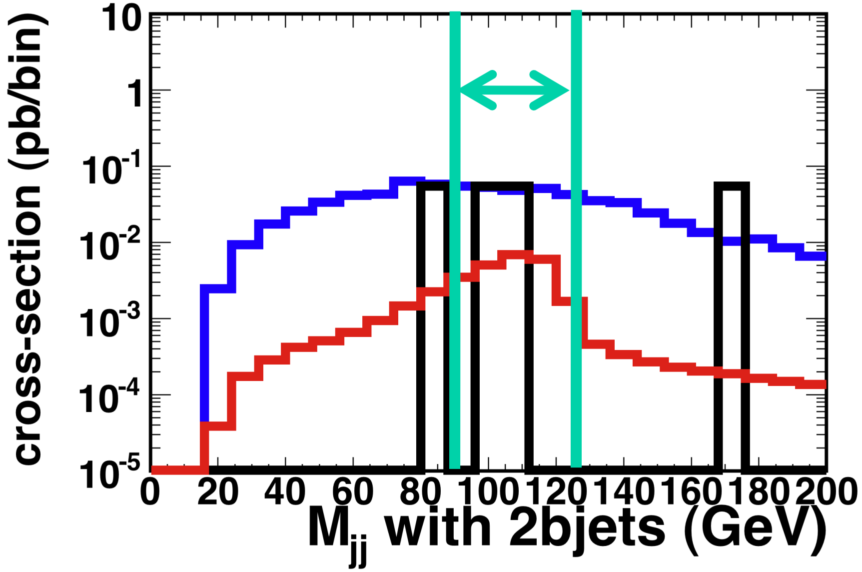
with and w/o b-tag requirement

— higgs — CC 3jets bgd — NC 3jets bgd

Cut (1)



Cut (1) +(2) b-tag requirement



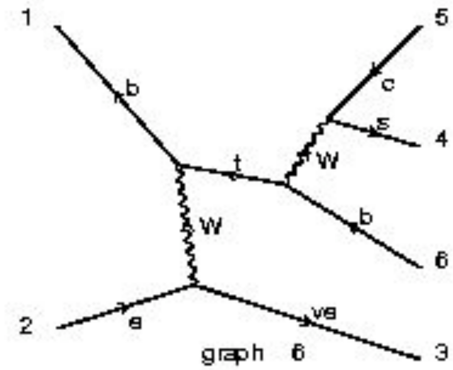
Number of events（10 fb^{-1}）

Applied cut	H→bb	CC 3jets bg	NC 3jets bg
No cut (All events)	1600	1.11×10^{6}	1.15×10^{8}
Cut (1) + M_H	629	6.47×10^{4}	8210
Cut (1) + (2) + M_H	222	2220	1090

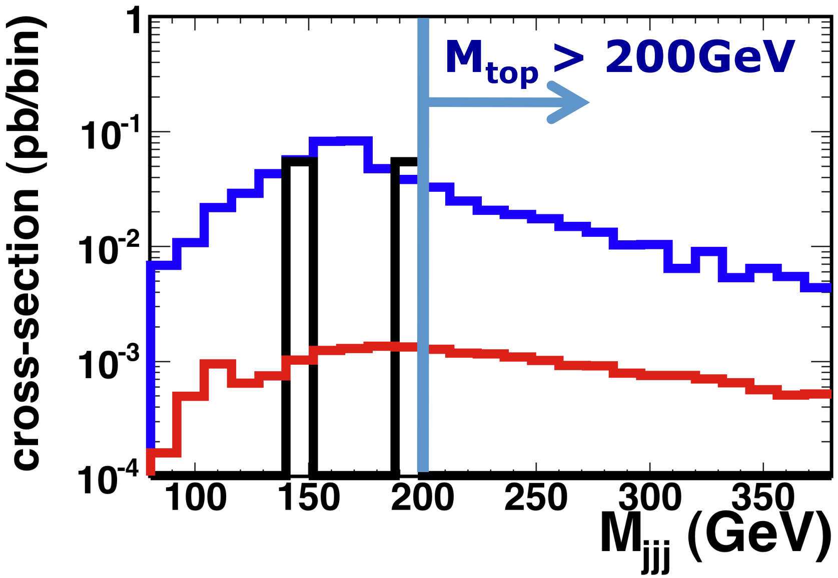
Trijet and Dijet Masses

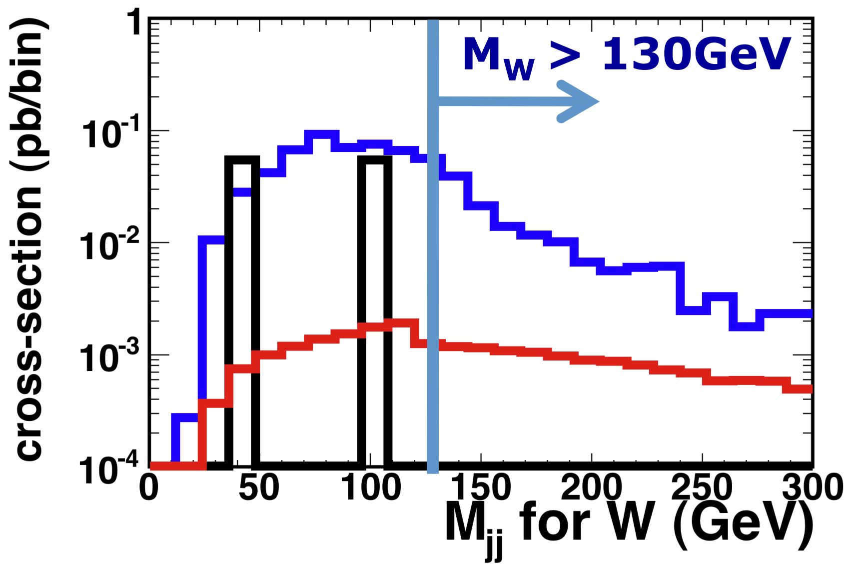
Veto single top candidates

Cut (1) +(2) b-tag requirement applied



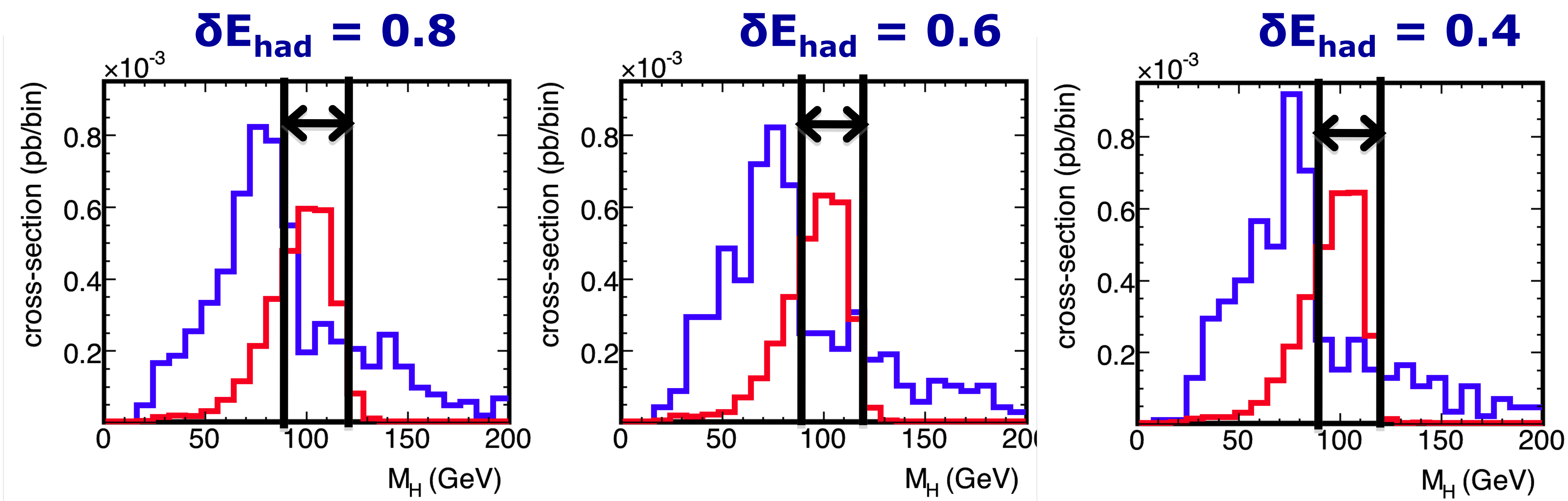
— higgs — CC 3jets bgd — NC 3jets bgd





- ➢$M_{jjj,top}$ was reconstructed from two b-tagged jets with lowest η + any 3rd jet with lowest η (regardless of b-tag).
- ➢$M_{jj,W}$ was reconstructed from lowest η b-tagged jet + lowest η jet (regardless of b-tag but excluding 2nd lowest η b-jet).

Background and Hadronic Energy Resolution *after kinematic, b-tagging & single top cuts*



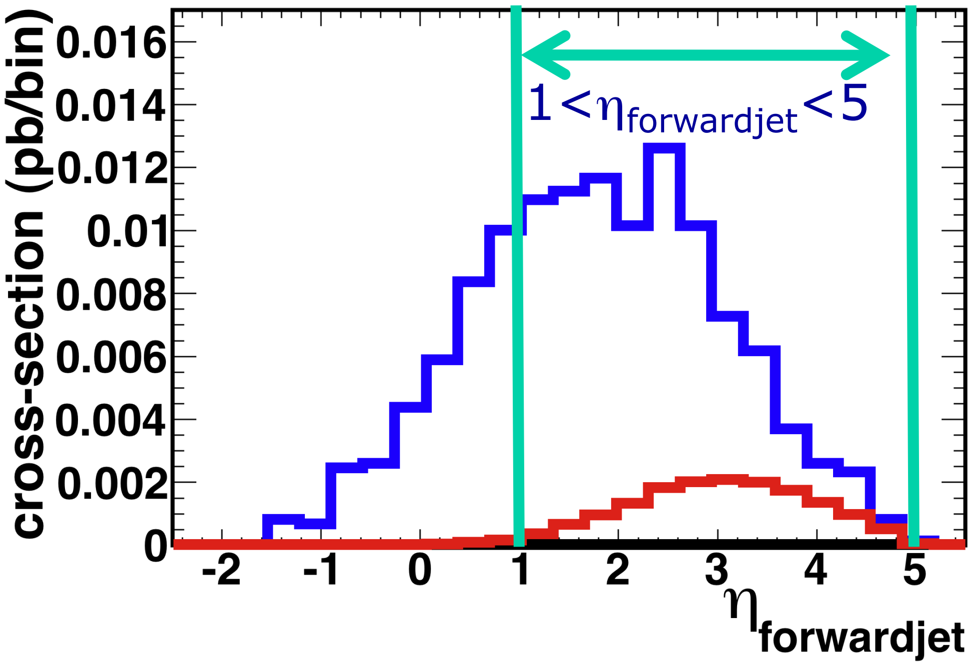
— Higgs events **— CC 3jet BG** (Z→bb!)

→ plots (result of previous study) illustrate that an excellent hadronic energy resolution is crucial for background suppression

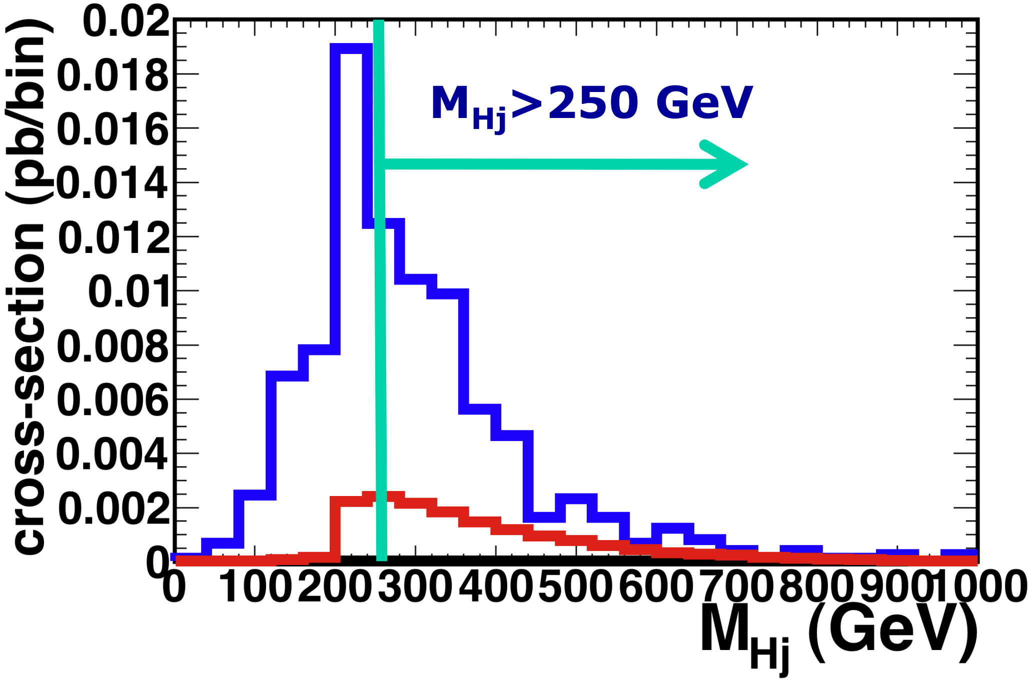
Forward Jet Tag

after kinematic, b-tagging & single top cuts

— higgs
— CC 3jets bgd
— NC 3jets bgd



Add cut 1<$\eta_{forwardjet}$<5



- Reconstruct M_{Hj} with forward tagged jet and 2b-jets.

- Final requirement: Select the events with M_{Hj} >250 GeV.

Number of Events *($L=10\ fb^{-1}$)*

90 GeV < M_{jj} < 125 GeV &

Number of events after cut (1) & (2) & (3) & M_H

	Higgs event	CC 3jets bg	NC 3jets bg	S/N	S/√N
# of events after	129	310	0*	0.42	7.3

*statistics for NC 3jets bgd is not enough.

Number of events after ALL cuts.

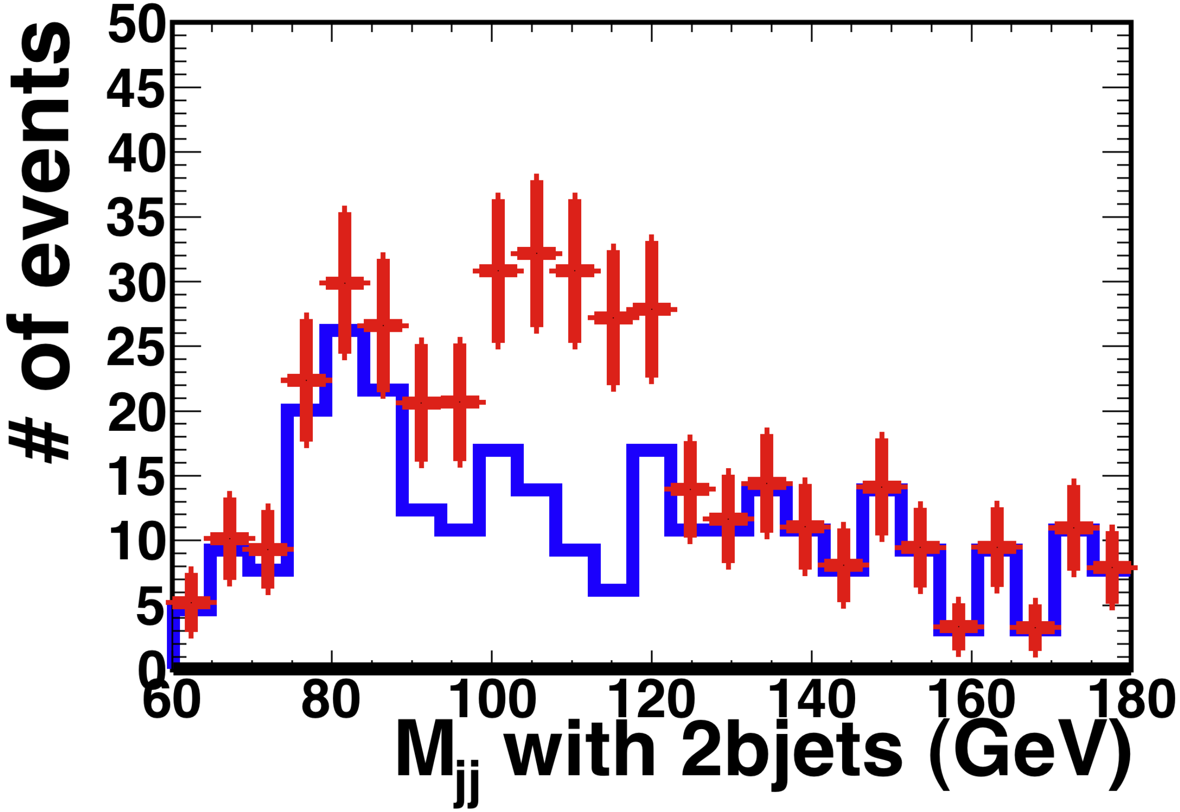
	Higgs event	CC 3jets bg	NC 3jets bg	S/N	S/√N
# of events	104	86.4	0	1.2	11

- **Efficiency of Higgs event selection is 6.5%** (104/1600)
- **We could identify H→bb events within 11σ.**

Invariant Dijet Mass after ALL Cuts

Cut: (1) + (2) + (3) + (4) forward tagged jet cut

— higgs — CC 3jets bgd — NC 3jets bgd



Error bars show statistical errors only.

Summary & Outlook

- Studies on CC e-p higgs production confirms the early LEP+LHC studies on dominant dijet+spectator jet background and the importance of the b-tagging, hadronic energy resolution and forward jet tagging.

  → **Our results are very encouraging and**

  We could identify H→bb events within 11σ.

  ...It is all work in progress!

- Full MadGraph + Pythia + PGS chain is working for DIS and Pythia-Madevent files can be read in into detector simulation tools

  → Higgs channel has been used to optimise LHeC detector!

- More detailed background sources for CC e-p higgs has to be studied in particular beauty in photoproduction, but *we need our own detector simulation* for more sophisticated estimates of rejection factors or tagging possibilities.

Outlook

Tools:

- Thanks to H. Jung, we got a Rapgap (for PHP) and Djangoh (for CC multijet but w/o top, W, Z, H) stand alone versions which delivers also hepmc files.
- Thanks to S. Hoeche, we got a brand-new pre-release DIS version of Sherpa (v1.2.3).
- We started working with the Delphes detector simulation which is (in principle) more flexible than PGS and allows various file formats (hepmc, stdhep, lhe).

Physics:

- Study also NC Higgs searches which is an important benchmark process for understanding the HZZ coupling.
- Study the extraction of Hbb coupling using LHeC Higgs cross sections in NC and CC in combination with LHC Higgs signal projections…

Special thanks to

E.Perez, G.Azuelos, G.Grindhammer,
B.Kniehl, G.Kramer, H.Spiesberger,
G.Weiglein, W.Khater, B.Mellado,
O.Behnke, F.Krauss, S.Hoeche,
H.Jung, P.Kostka, M.Klein

… and others

for contributions

and fruitful discussions.

Material

1st LHeC workshop, 1st - 3rd September 2008, Divonne.

http://indico.cern.ch/conferenceDisplay.py?confId=31463

Talks by E.Perez and G.Weiglein; M.Kuze et al.; U.Klein

LHeC pre Meeting at DIS 2009, 25th April 2009, Madrid.

http://indico.cern.ch/conferenceOtherViews.py?view=cdsagenda&confId=55684

Talks by M.Ishitsuka et al.; U.Klein

2nd LHeC workshop, 1st - 3rd September 2009, Divonne.

http://indico.cern.ch/conferenceDisplay.py?confId=59304

Talks by M.Kuze et al.; B.Mellado and T.Han; U.Klein

LHeC Mini_workshop, 8th April 2010, Hamburg.

http://indico.cern.ch/conferenceDisplay.py?confId=83882

Talk by K.Kimura et al.

More material on the LHeC project can be found here:

http://www.ep.ph.bham.ac.uk/exp/LHeC/

Some inspiring previous studies

Searching for the Higgs in e p collisions at LEP / LHC.
G.Grindhammer, D. Haidt, J. Ohnemus, (Florida State U.) , J. Vermaseren, D. Zeppenfeld. MAD-PH-618, Nov 1990.
Contribution to Proc. of Large Hadron Collider Workshop, Aachen, Germany, Oct 4-9, 1990. Published in Aachen ECFA Workshop 1990:0967-985.

***Standard-model Higgs boson production at HERA*.**
Bernd A. Kniehl
Prepared for Workshop on Future Physics at HERA (Preceded by meetings 25-26 Sep 1995 and 7-9 Feb 1996 at DESY), Hamburg, Germany, 30-31 May 1996.
In *Hamburg 1995/96, Future physics at HERA, vol. 1* 219-221.

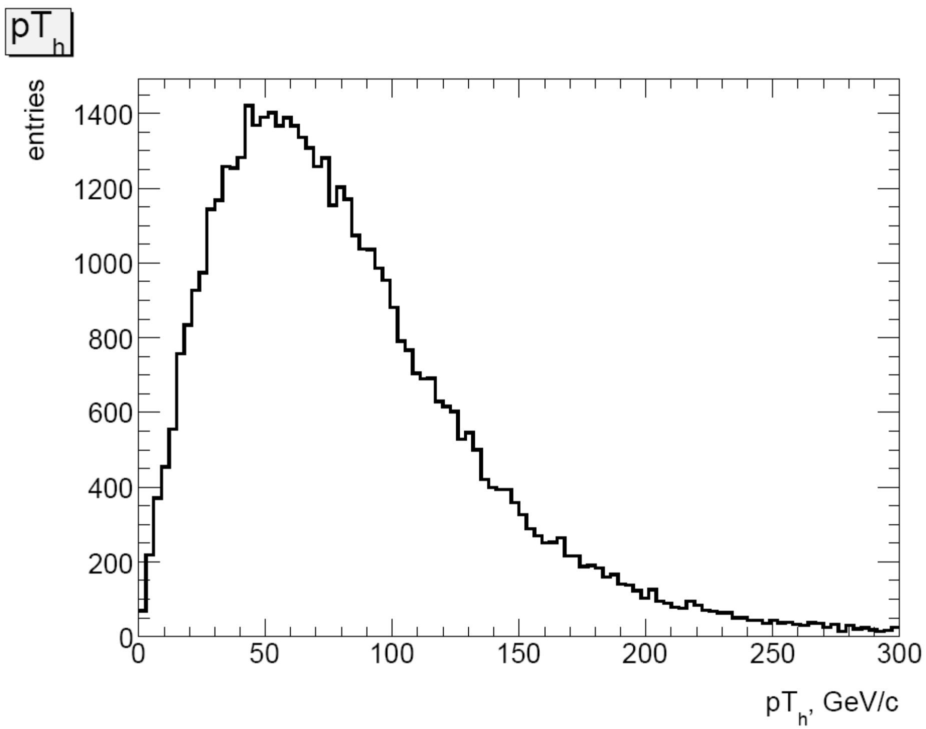
Additional Slides

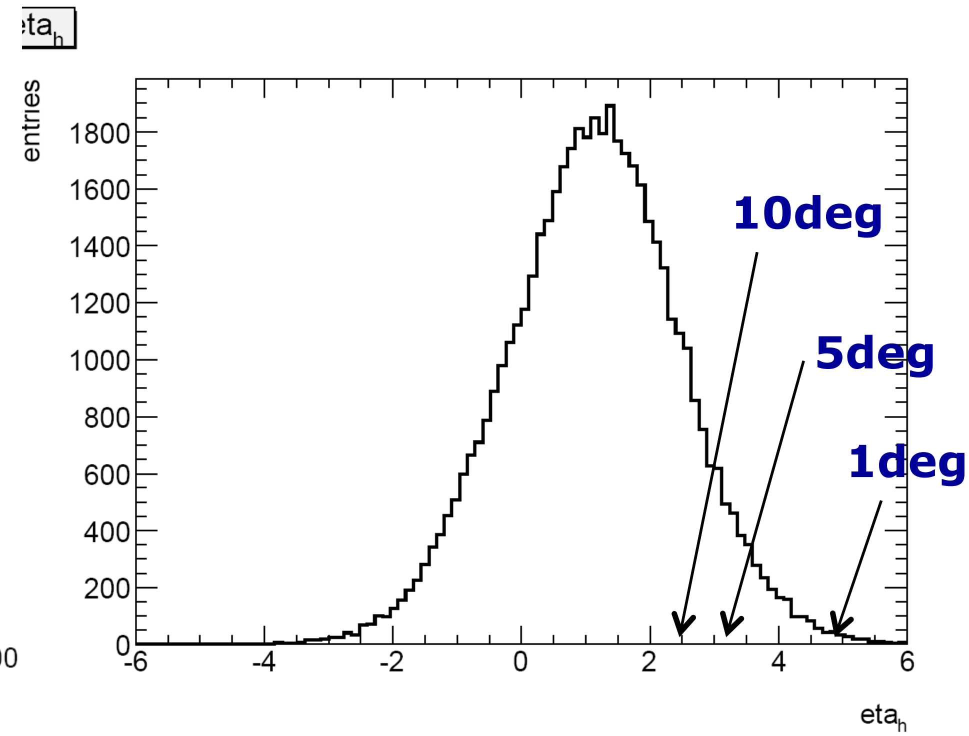
Higgs Kinematics in e^-p CC

- 50 k Higgs events, m_H=120 GeV, 150 GeV x 7000 GeV
- Higgs decay via Pythia :

~68% into bbar + other decay modes

…somewhat lower than expected, similar number via DECAY in Madgraph (~72%)





Higgs rapidity in central to forward region

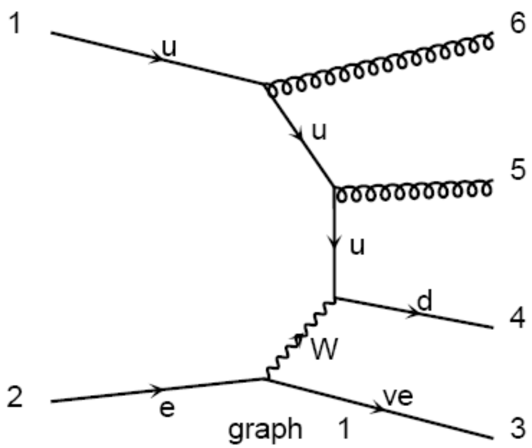
Background

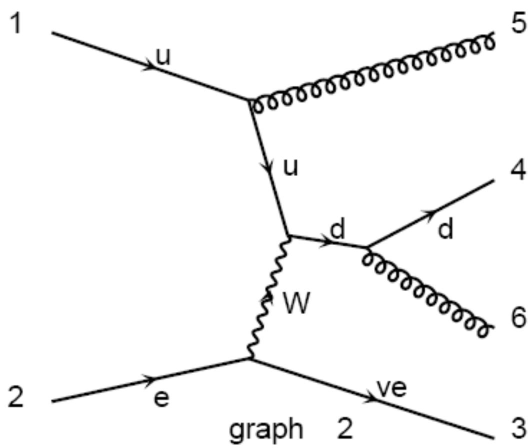
~100 k CC dijet+spectator events, E_{jet}>5 GeV, θ_{jet}>0.5 deg, M_{jj}>30 GeV

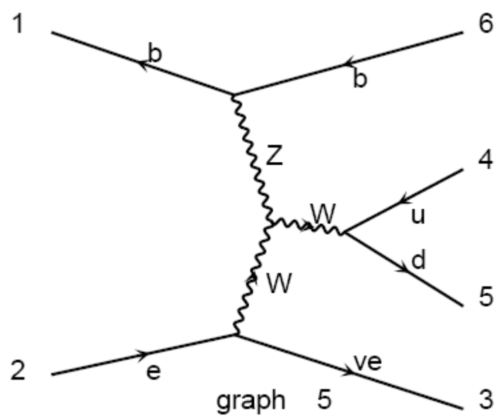
58.8 pb (LO cross section, scale uncertainty expected to be 50-100%)

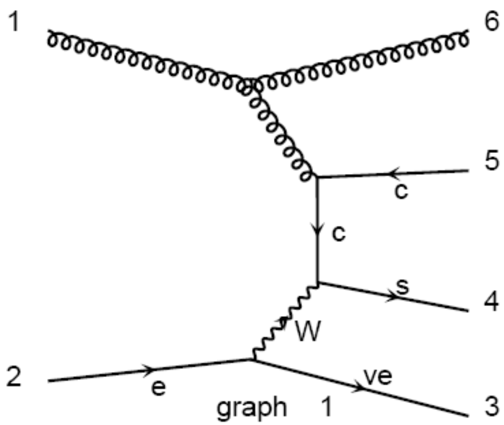
MadGraph generated 542 diagrams including higgs, single top, single W

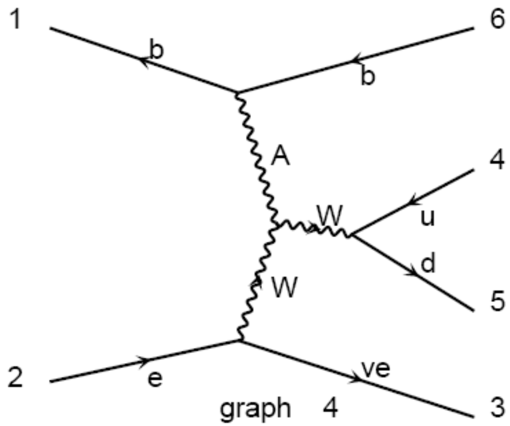
→ After 'simple' dijet-selection: BG ~100 times larger than Higgs signal!

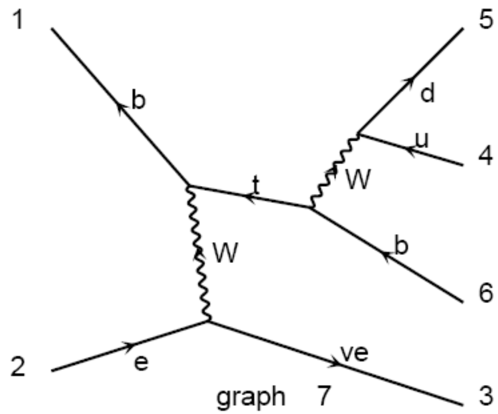




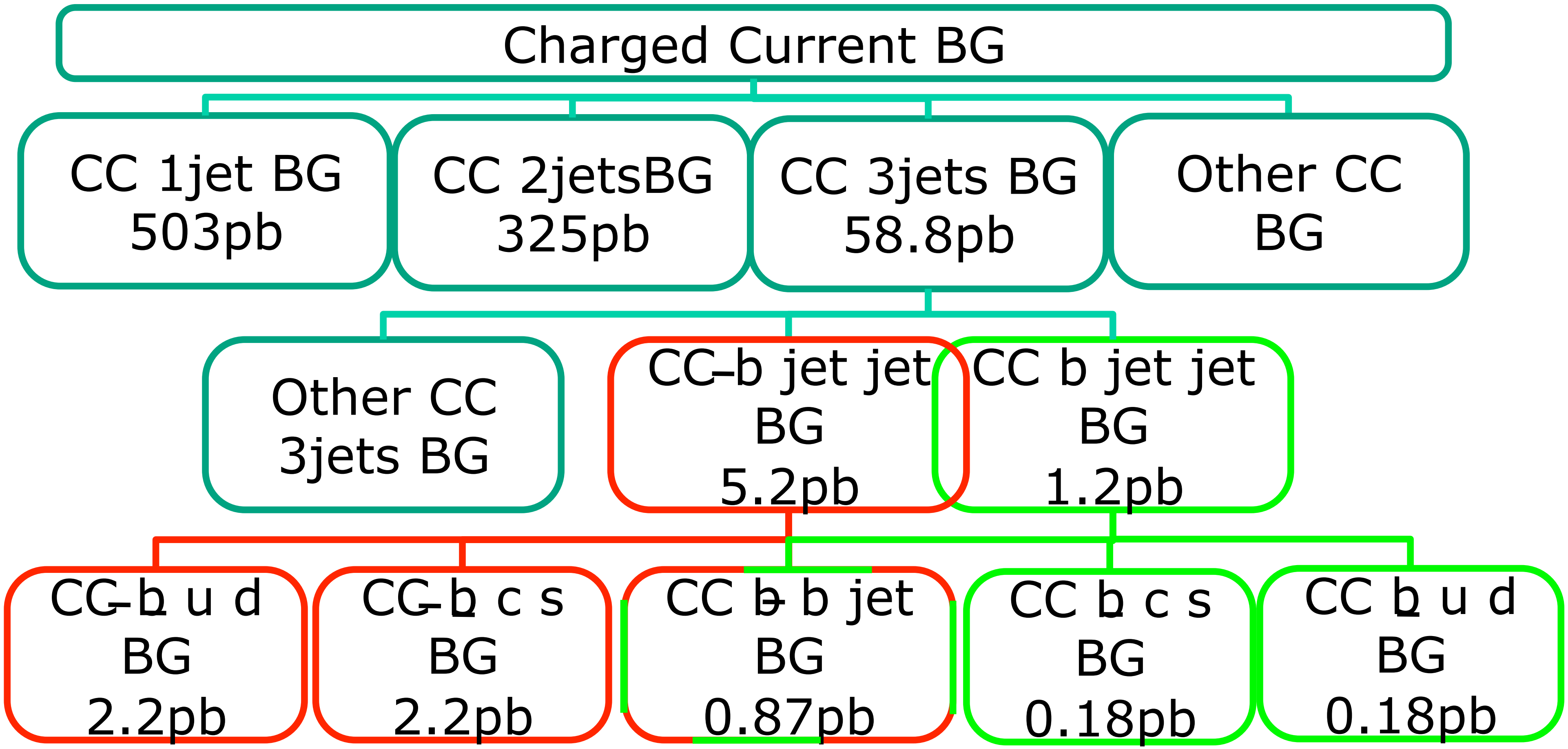








CC Dijet Subprocess Cross Sections



Large cross-sction of $\bar{b}\bar{c}s$ or $\bar{b}\bar{u}d$ 3 Jets events.

95% of these processes was single-top production $\bar{t} \rightarrow W\bar{b} \rightarrow (\bar{c}s$ or $\bar{u}d)\ \bar{b}$

They were suspected 3Jets background for Higgs discovery.