Light SM Higgs in ep-collisions at the TeV scale

- **Motivation**
- **Methodology**
- **Results for CC e-p**
- **Outlook**

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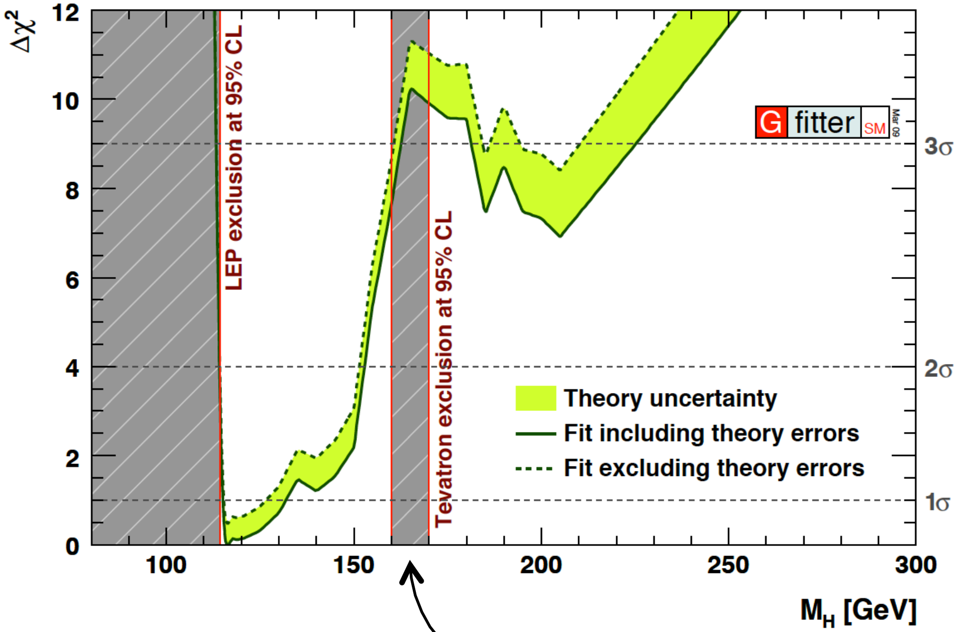
Motivation

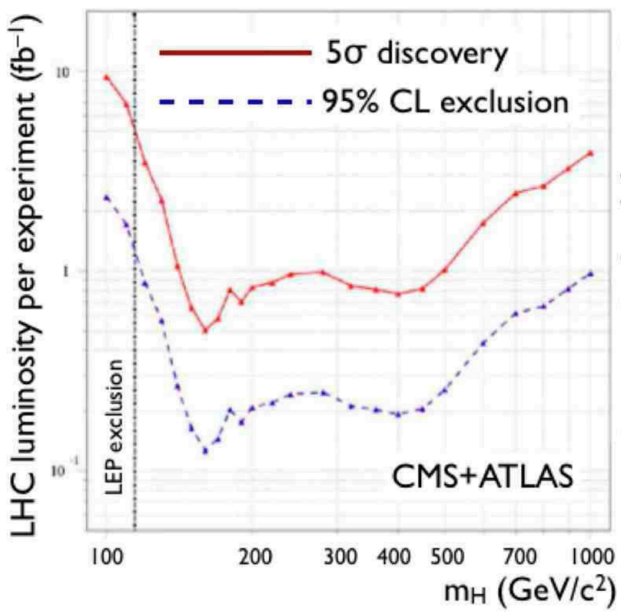
- SM mass generation mechanism needs the Higgs boson
- LHC and Tevatron experiments will have the capability to observe or exclude the Higgs
- EW precision data and direct searches suggest a mass range $m_H \geq 114$ GeV, see e.g. recent review by J.Ellis [arXiv:1004.0648]

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



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

LHC projections @ 14 TeV



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]

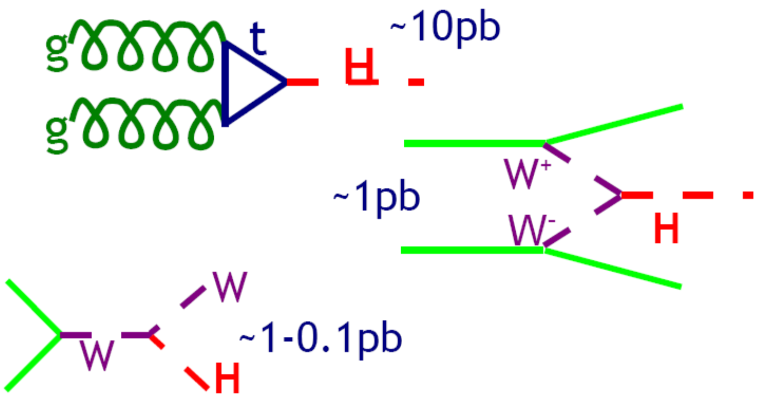
→ However, even then will be a measurement of the bottom Yukawa coupling extremely challenging since the H→bb dominant at $m_H \leq 130$ GeV is overwhelmed by QCD backgrounds for b-jets.

LHeC is an LHC upgrade proposal focusing on precision measurements of the partonic substructure of the proton and the strong coupling at $\sqrt{s}$ 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

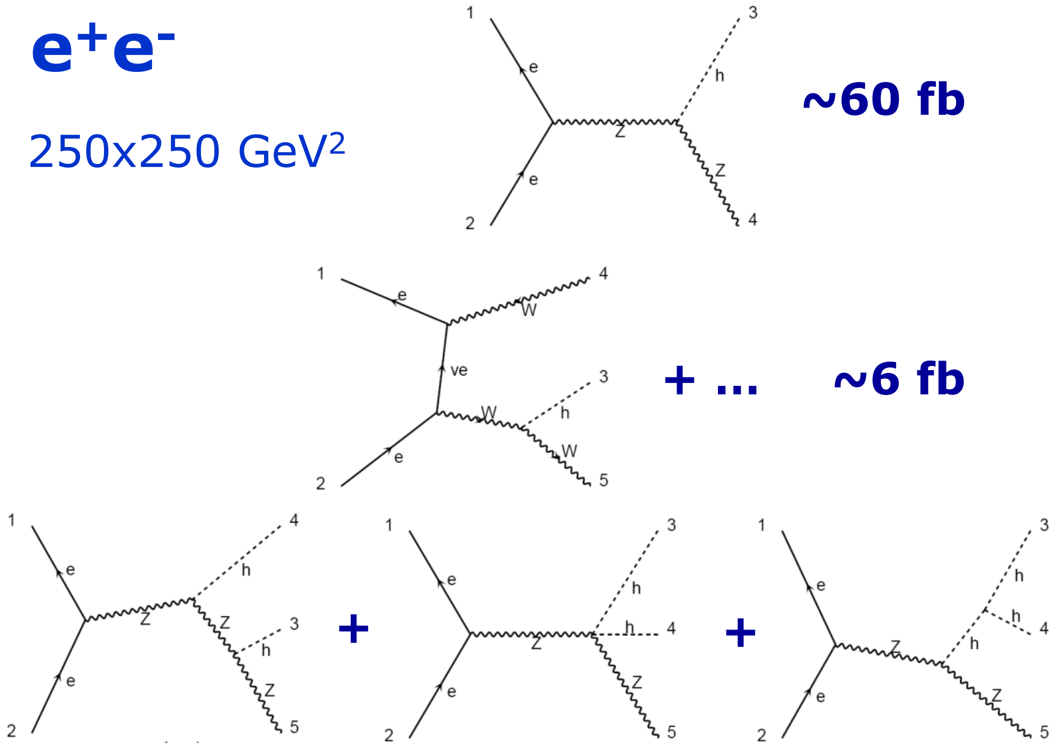
pp



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

e^+e^-

250x250 GeV^2

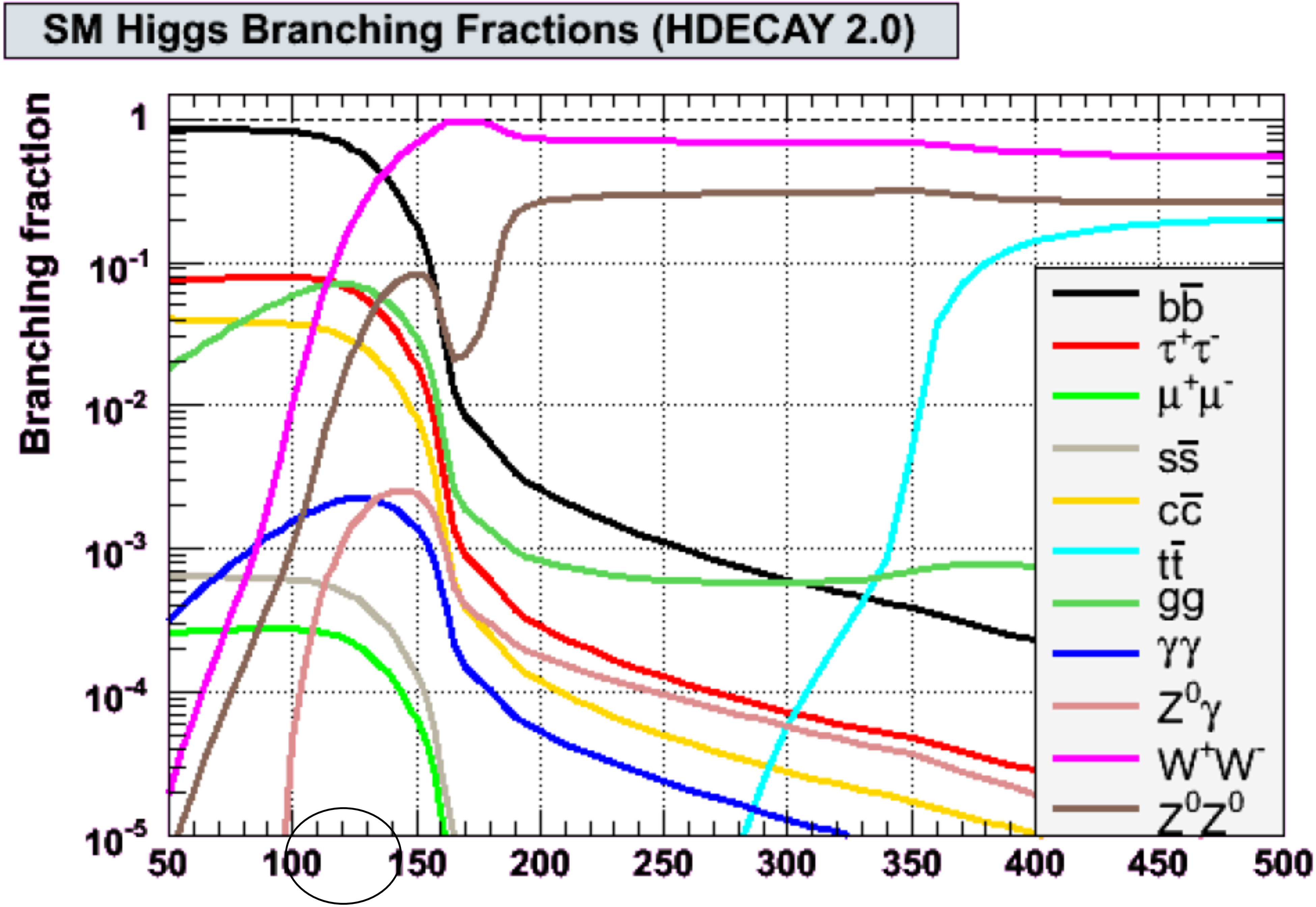


~0.2 fb

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

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

Madgraph produced all Feynman diagrams shown in this talk.

Use version 4.4.17 including pythia-pgs interface modified for DIS

→ Higgs decay is done via Pythia

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

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

→ Generator and detector-level Higgs search studies done by M.Ishitsuka, K.Kimura, M Kuze, J. Maeda [Tokyo Institute of Technology] and U.Klein, C.Hengler [University of Liverpool]

Higgs decay modes can be considered (package DECAY)**.**

→ Generator based studies using 4-vector smearing for detector by T. Han and B. Mellado [arxiv:0909.2460] using Madgraph but fixed renormalisation and factorisation scales.

→ investigated Higgs searches at LHEC assuming Higgs mass is known

ep

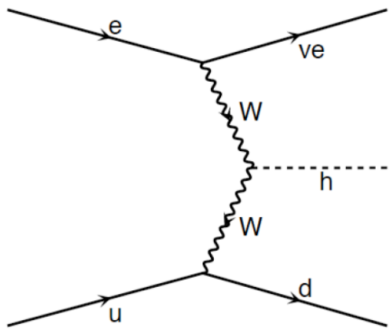
CC : LO SM Higgs Production

√s=1 – 2 TeV

~ 200 fb

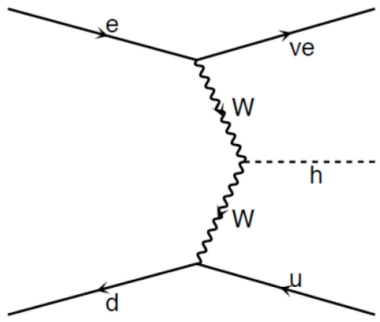
e-p (swap charges for e+p)

e- u -> ve h d



around 90-80%

e- d~ -> ve h u~



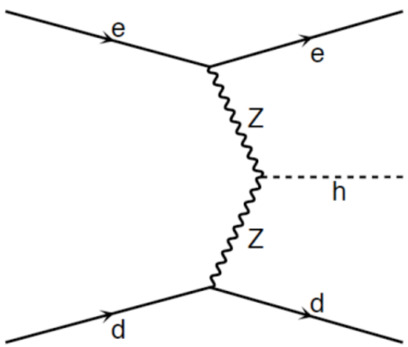
around 10-20%

NC : LO SM Higgs Production

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

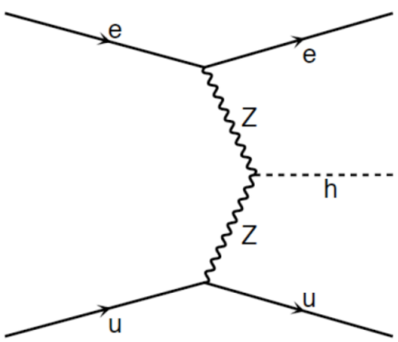
e-p (swap charges for e+p)

e- d -> e- h d



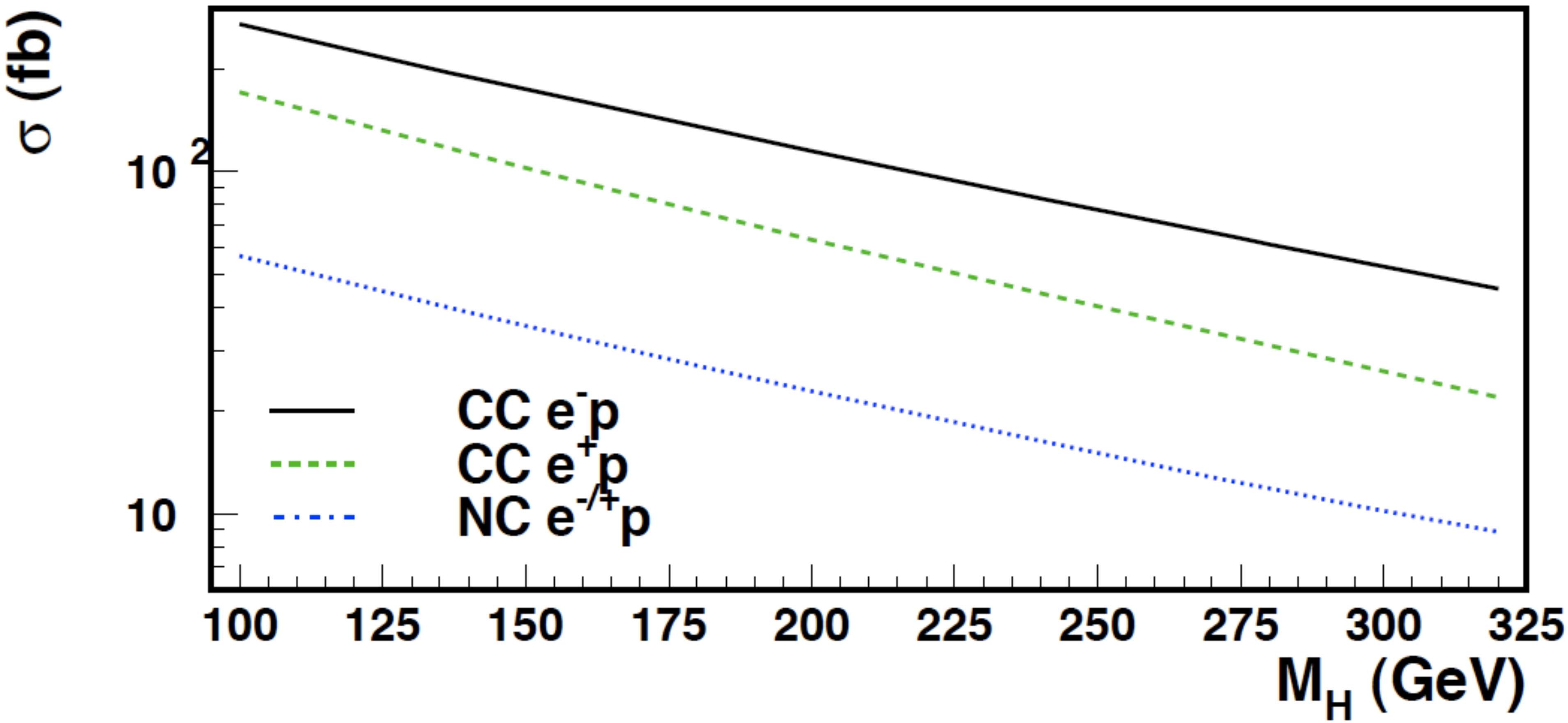
around 1/3

e- u -> e- h u

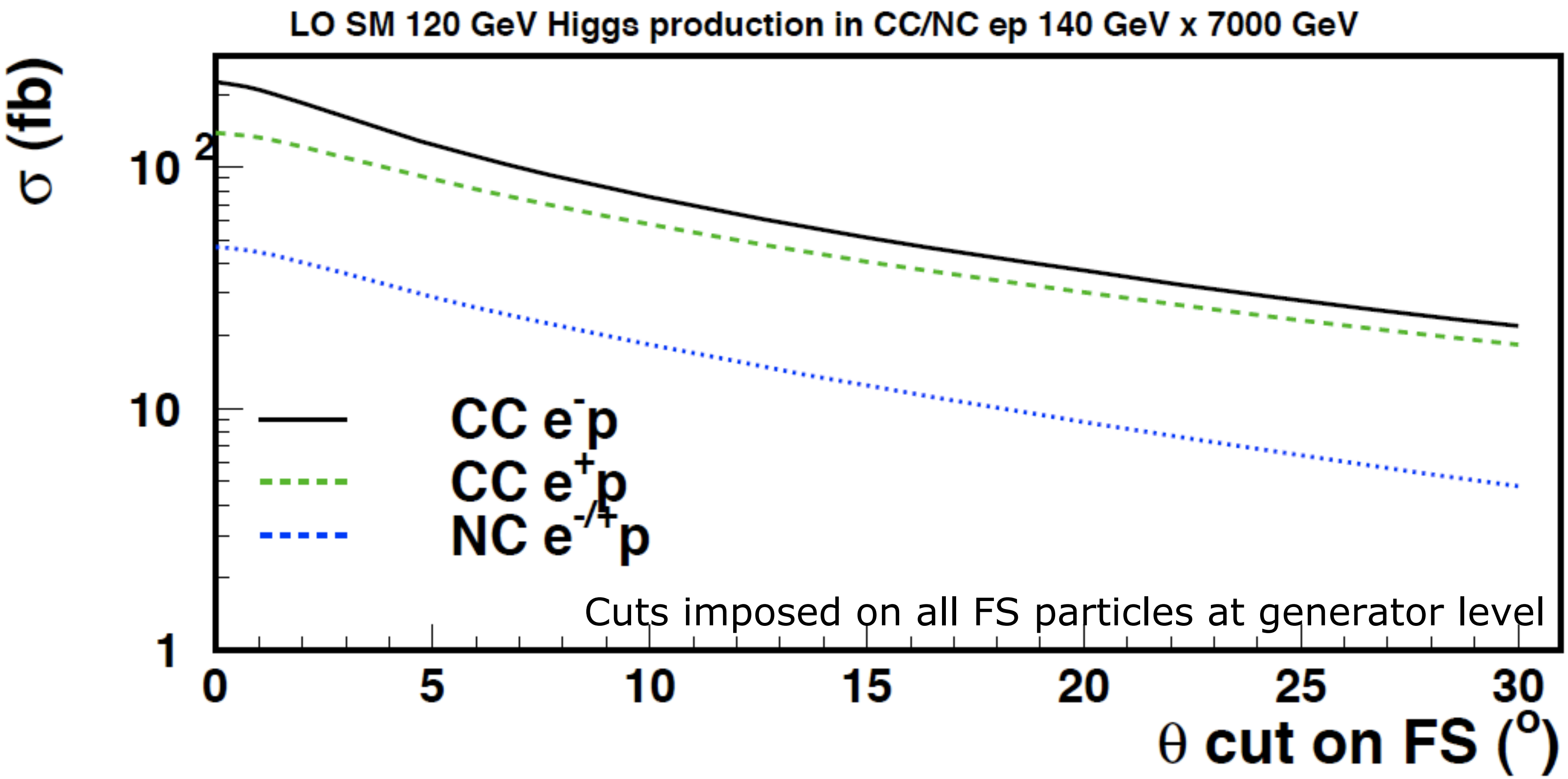


around 1/3

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

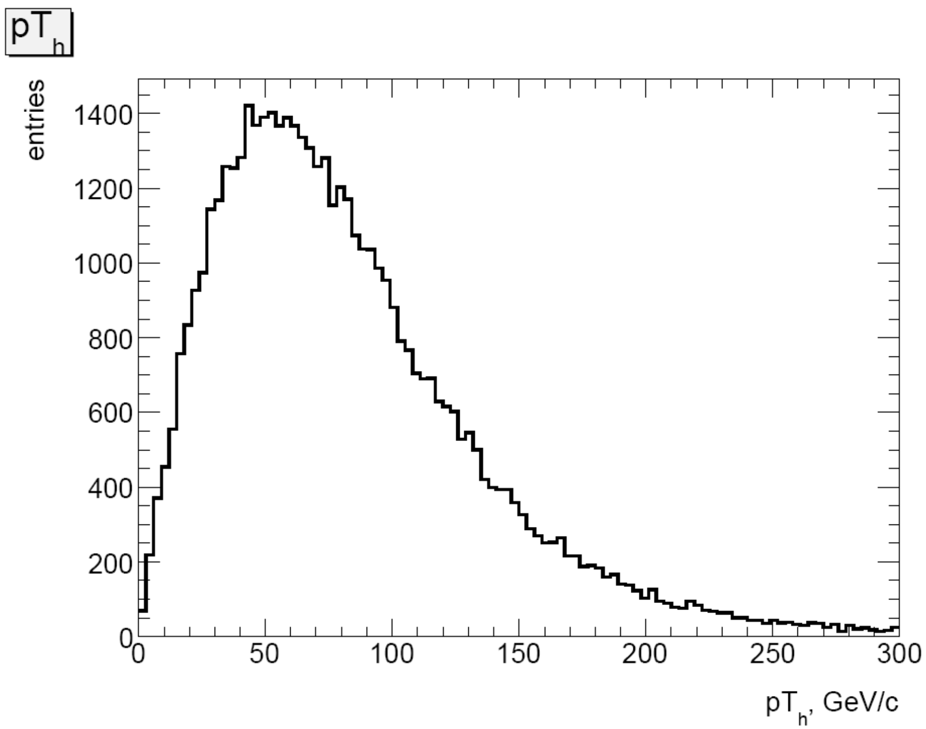
→ Scale dependencies of the LO calculations are in the range of 5-10%.
→ QCD and QED corrections are moderate but sensitive to experimental cuts. NLO QCD corrections are small, but shape distortions of kinematic distributions up to 20%. QED corrections up to -5%.
[J. Blumlein, G.J. van Oldenborgh , R.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

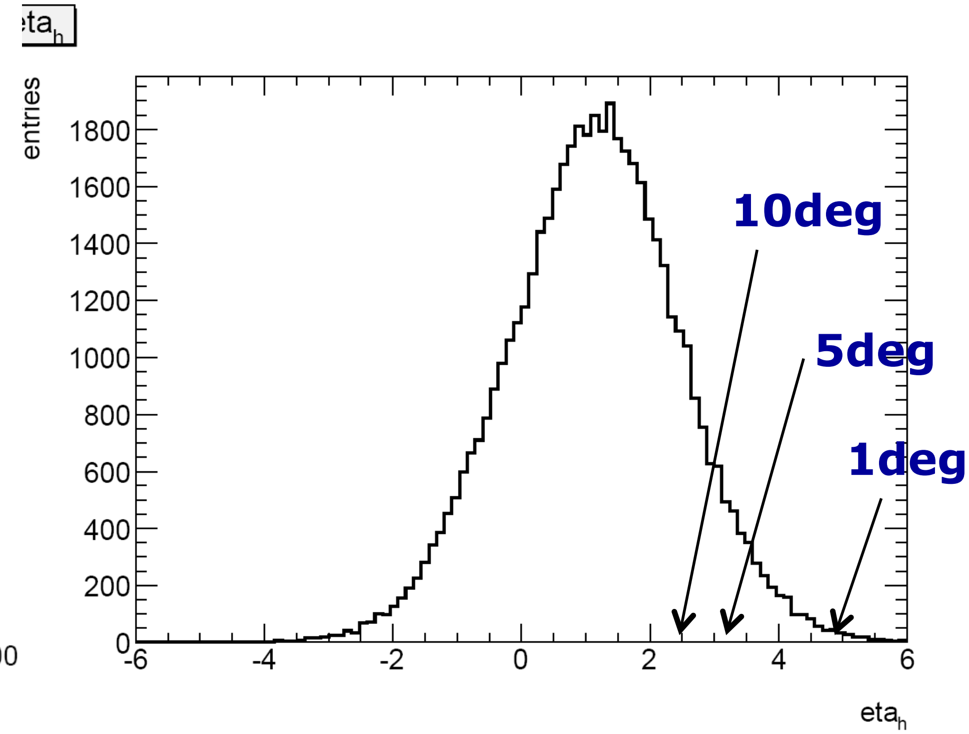
Higgs Kinematics in e⁻p CC

- 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

'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

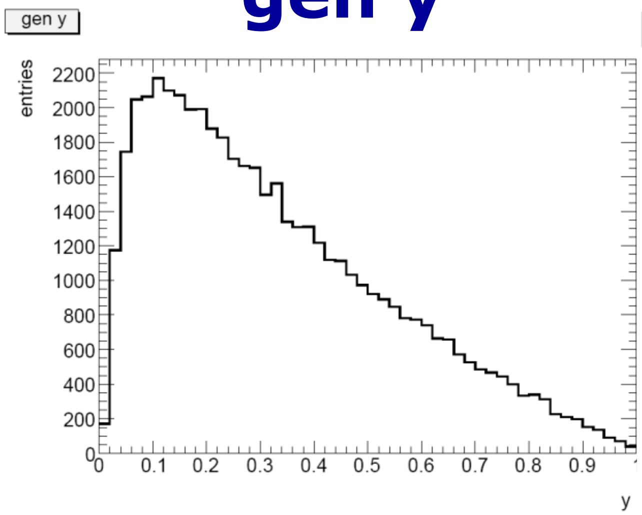
E_{ele} 20%→ 10%
E_{had} 80%→40%

jets: cone<0.5
→ Use kT

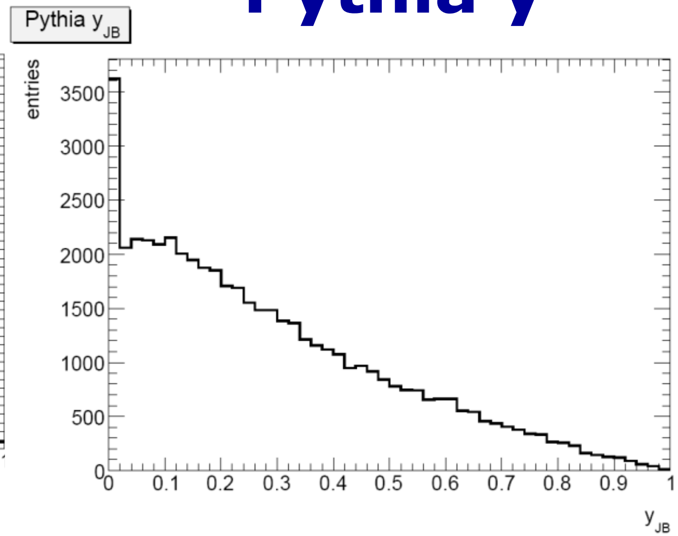
Disclaimer :
PGS of LHC detector
+ CDF type b-tagging
will be replaced
by LHeC detector!
(work is ongoing, possible values given in green)

Inclusive Kinematics *(rec=Jaquet-Blondel)*

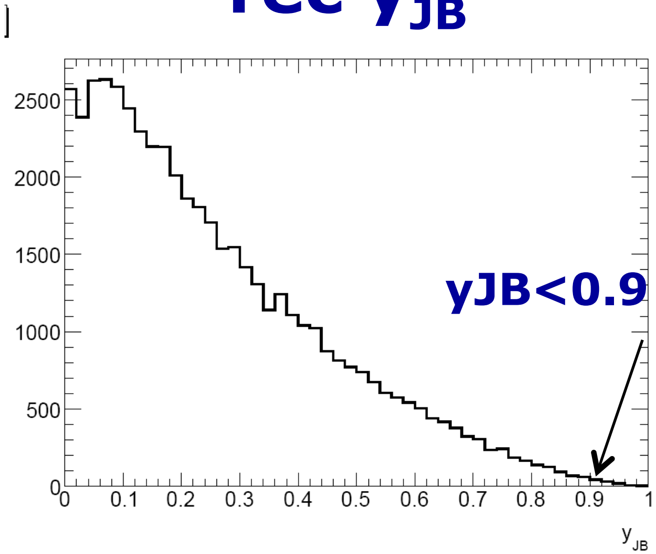
gen y



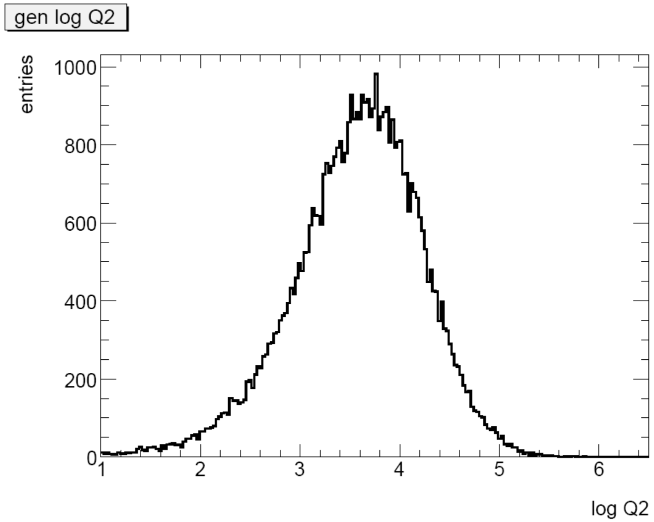
Pythia y



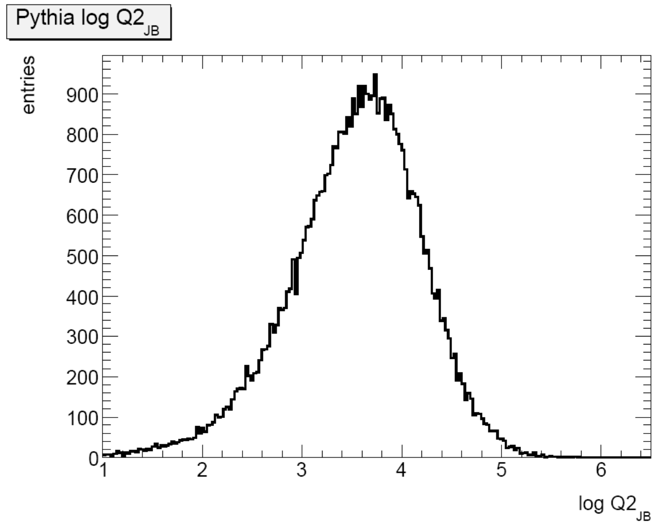
rec y_{JB}



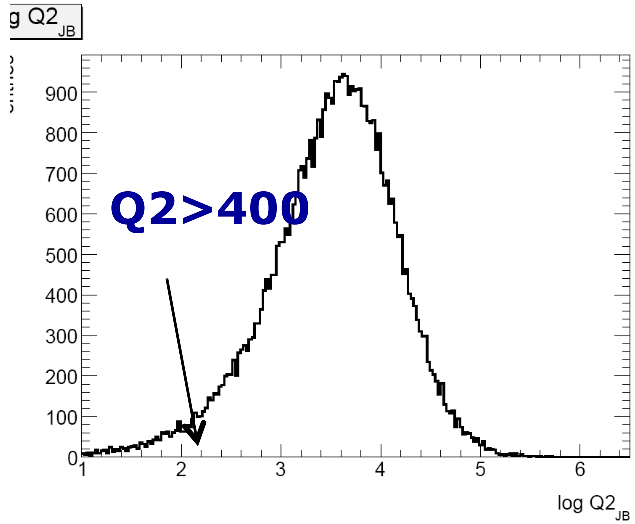
gen Q^2



Pythia Q^2



rec Q^2_{JB}

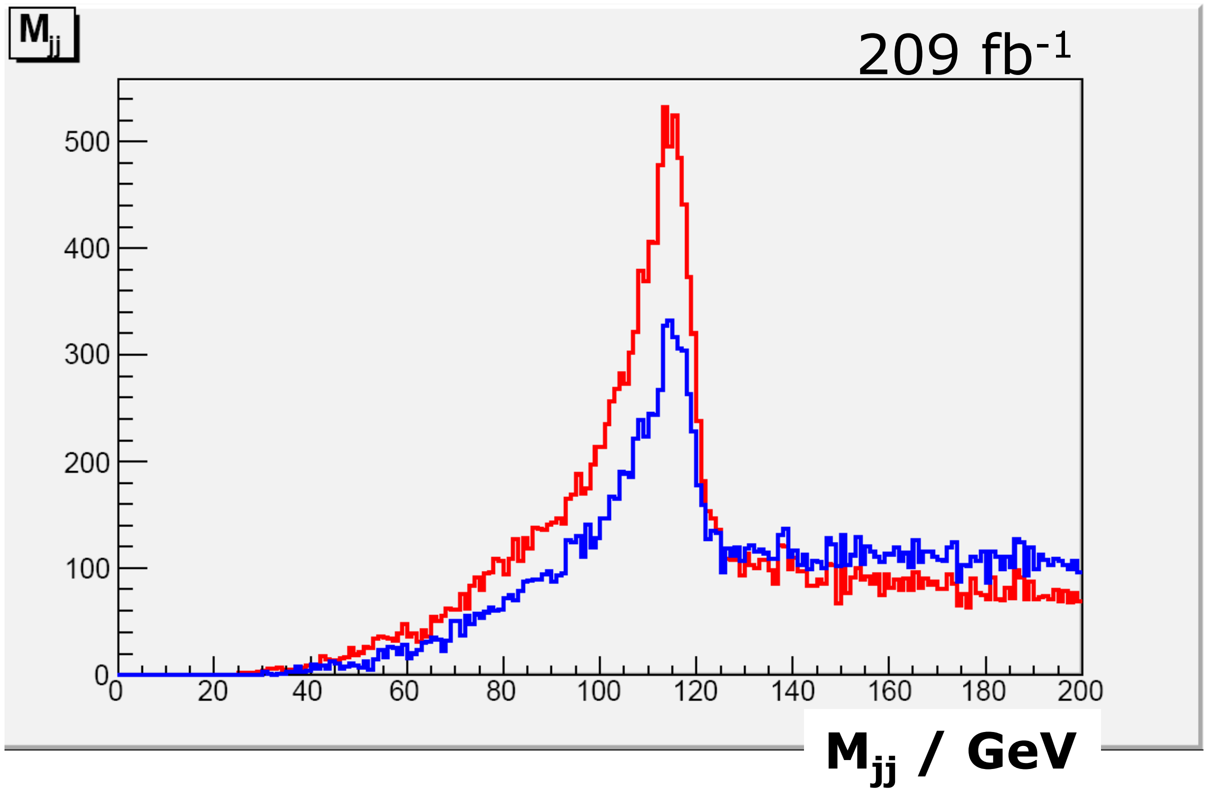


Search for Higgs: Invariant Dijet Mass

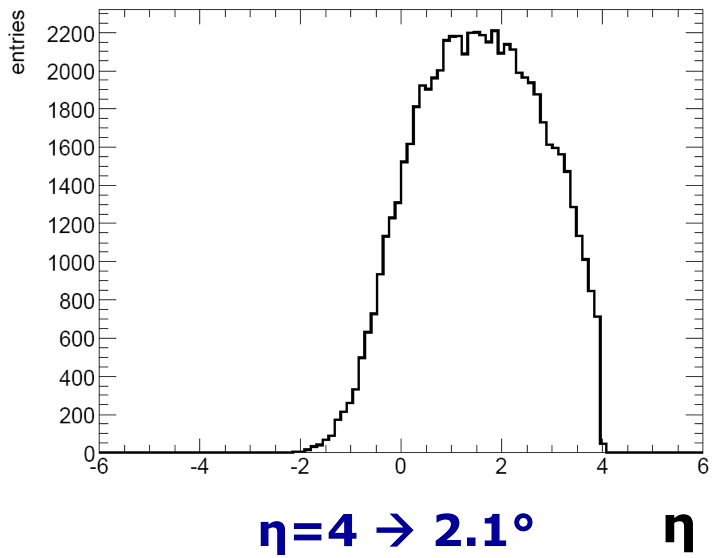
Q^2>400 GeV^2, y_{JB}<0.9, E^T_{jet}>20 GeV, E^T_{miss}>20 GeV, θ_{jet}>1° (CAL), NO b-tagging (!), no Higgs mass constraint (!)

RED : 2 jets with lowest rapidity & E^T_{total}>100 GeV

BLUE : 2 jets with highest p_T



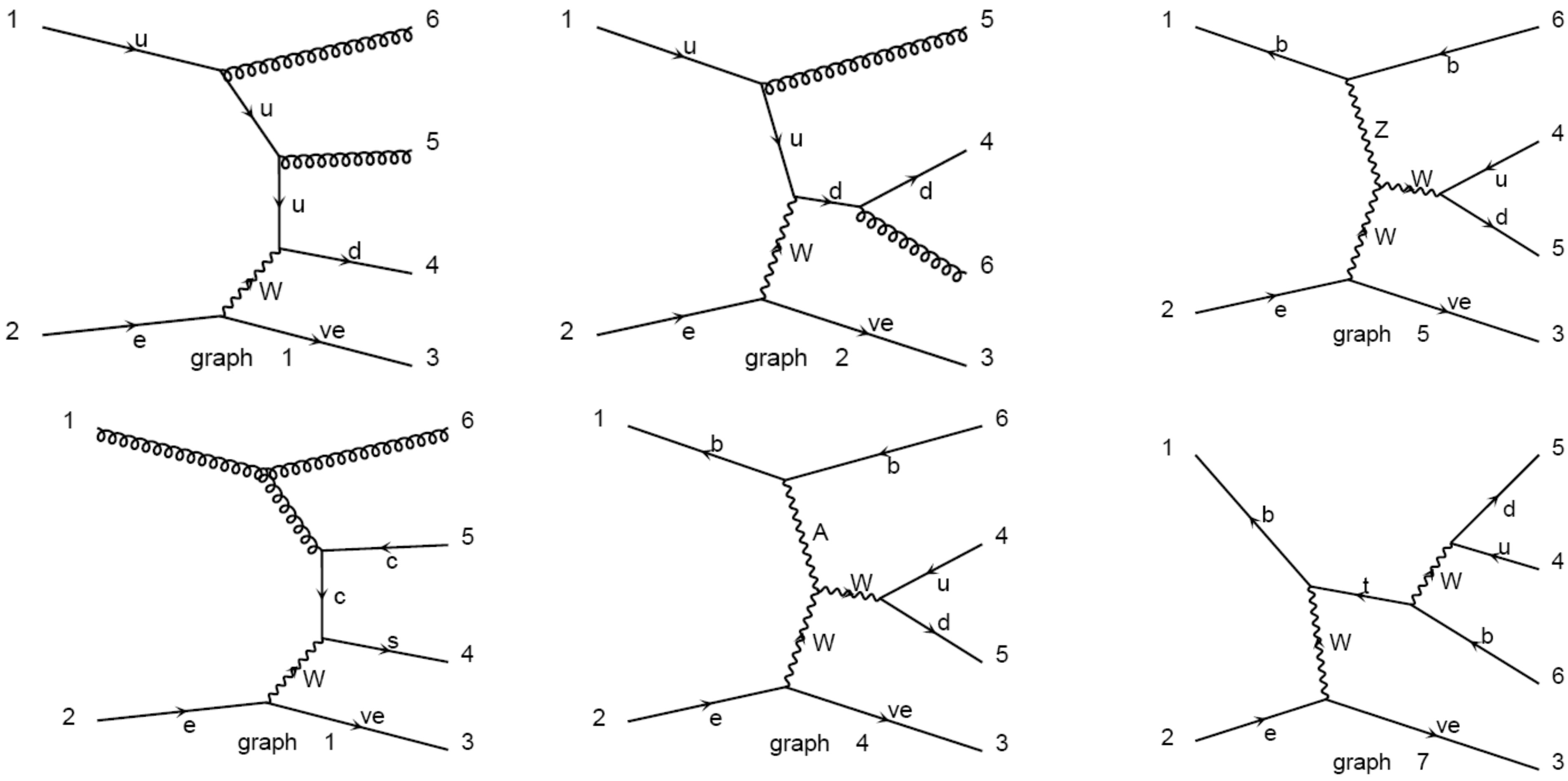
Jets with lowest rapidity
(red selection)



η=4 → 2.1°

Background

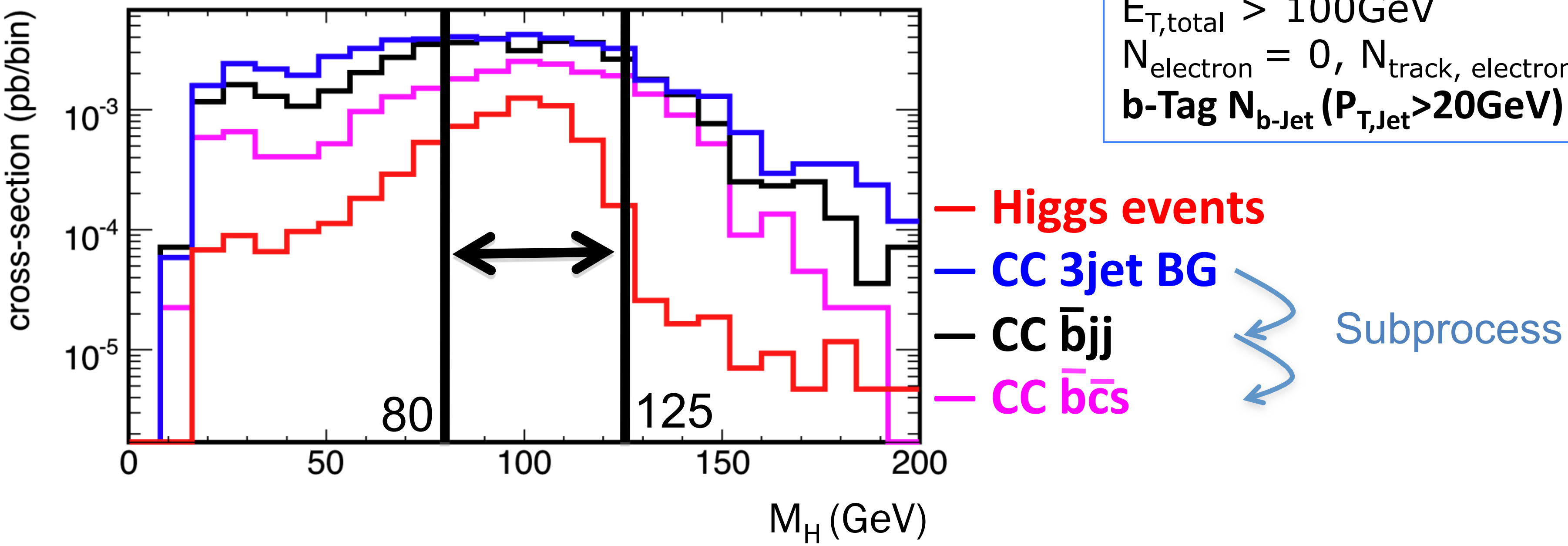
~100 k CC dijet+spectator events, E_{jet}>5 GeV, θ_{jet}>0.5 deg, M_{jj}>30 GeV
58.8 pb (LO cross section, scale uncertainty expected to be 50-100%)
MadGraph generated 542 diagrams including higgs, single top, single W
→ After 'simple' dijet-selection: BG ~100 times larger than Higgs signal!



Remaining Background

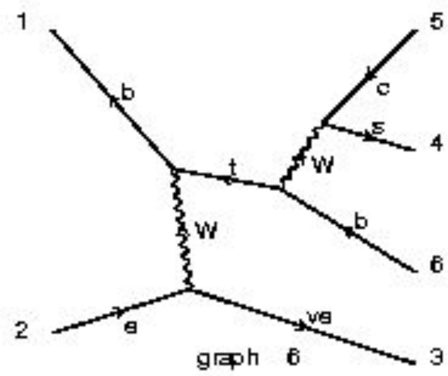
after kinematic and b-tagging cuts

Q^2_{JB}>400GeV², y_{JB}<0.9,
E_{Tmiss}>20GeV
N_{Jet} ($P_{T,Jet}$>20GeV) ≥2,
$E_{T,total}$ > 100GeV
$N_{electron}$ = 0, $N_{track, electron}$= 0
b-Tag $N_{b\text{-}Jet}$ ($P_{T,Jet}$>20GeV) ≥2



80 GeV < M_H < 125 GeV (10 fb⁻¹)

Higgs / CC 3jets BG S/(S+N) = 46.9 / 229 = 0.20

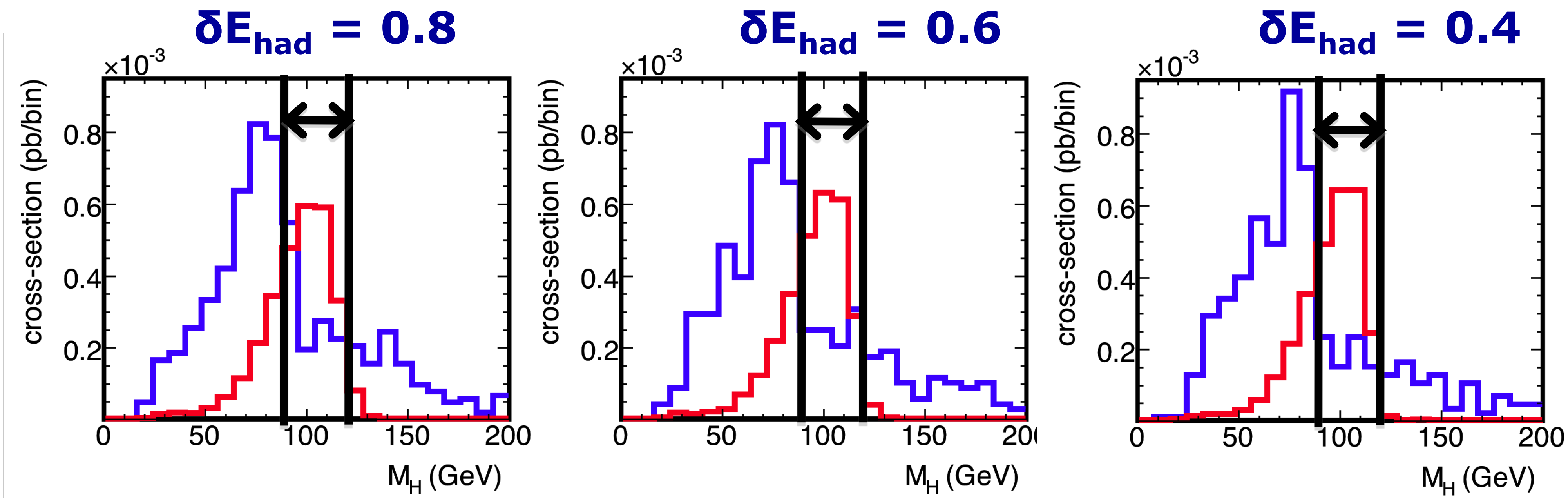


- dominant CC 3-jets bgd due bcs processes (c-jet had high b-tag efficiency)
- 95% of bcs processes from *single-top events*

→ reject single top events using

N_{Jet} ≥ 3, M_{top}> 200 GeV, M_W > 130 GeV

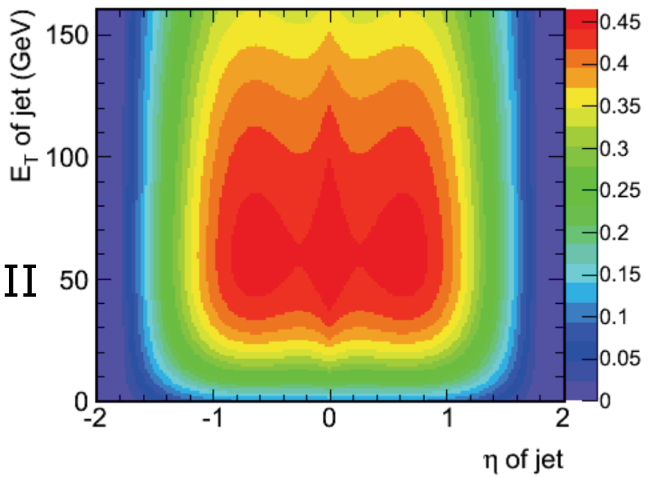
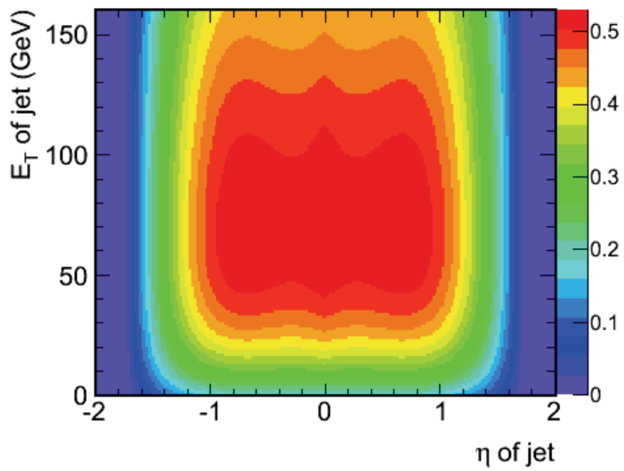
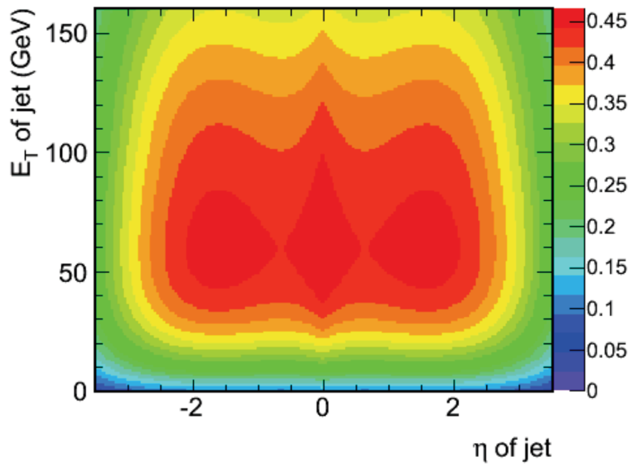
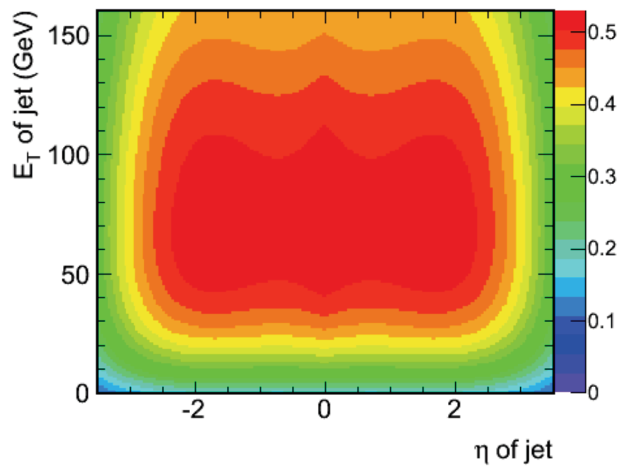
Background and Hadronic Energy Resolution *after kinematic, b-tagging & single top cuts*



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

Resolution	Higgs event	CC 3jet BG	S/(S+N)	S/√(S+N)
80 %	20.0	12.5	1.60	5.67
60 %	20.5	10.1	2.02	6.43
40 %	20.2	7.64	2.62	7.24

B-Tagging in PGS $f_b(E_T, \eta)$

	Tight btag	Loose btag
original based on CDF Run II →stops mainly at eta ~ 1		
change η scale (× 2.5) →more LHeC-like b-tagging up to eta ~2.5		

Higgs Search at LHeC for 10 fb^{-1}

150 GeV X 7000 GeV
CDF-type b-tagging
extended in η
& $\varepsilon(\eta_{max}) = 60\%$

Cut	$b\bar{b}$ decays	
		$90<M_H<120$
no cut	1690	
$Q^2>400GeV^2$ & $y<0.9$	1520	
$E_{T,miss} > 20$ GeV	1390	
$N_{trk,electron} = 0$	1370	
$E_{T,total} > 100GeV$	1060	
$N_{jet} \geq 2$	1030	443
$N_{bjet} \geq 2$	328	160
$N_{jet} \geq 3$	256	121
$M_W > 130GeV$ & $M_{top} > 200GeV$	111	67.3

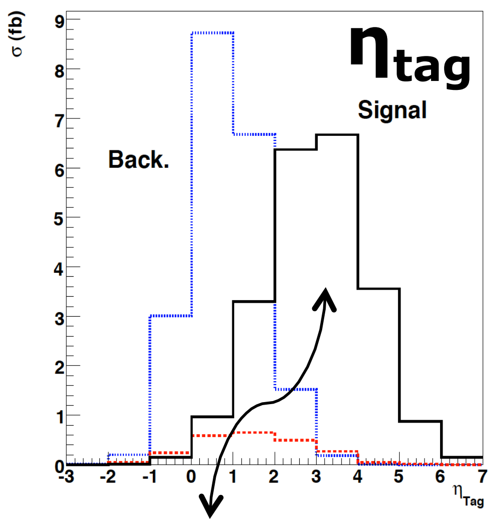
→extended b-tagging improves signal extraction by more than factor 3.
→work is ongoing!

→light SM Higgs could be (re)discovered in Hbb-channel at LHeC …

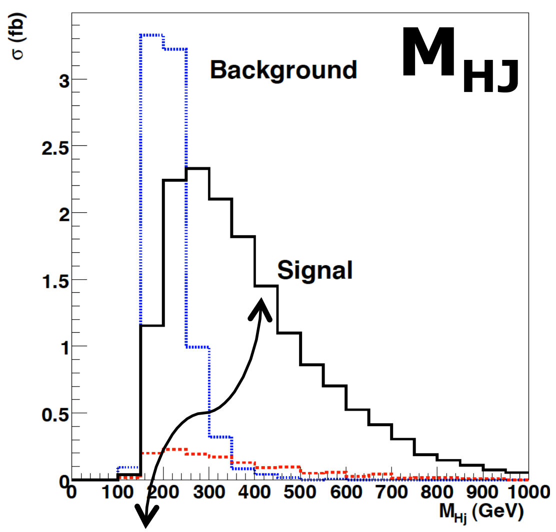
[arxiv:0909.2460]

Another Promising Study

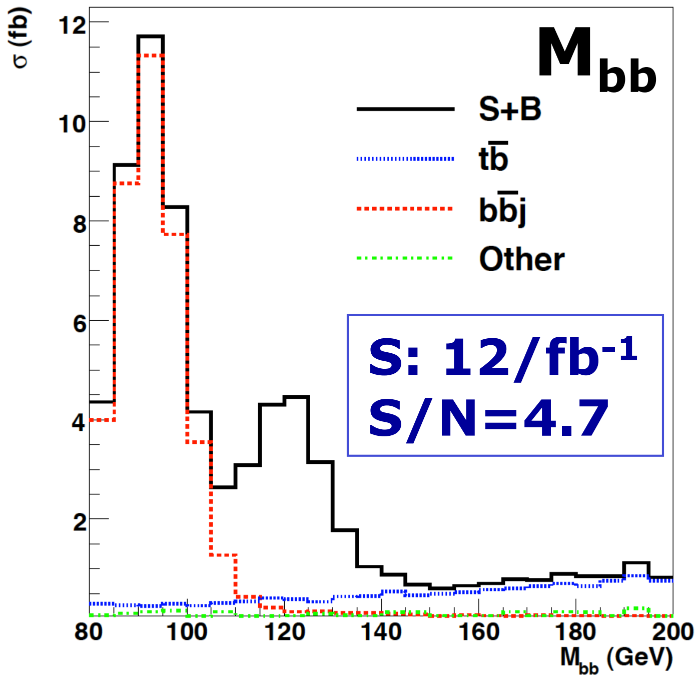
- m_H=120 GeV, ep: 140 Gev X 7000 GeV using Madgraph and DECAY
- generated parton energies and angles smeared by resolutions, e.g. δE_{had}=60% yields δm_H=7% (w/o angular smearing)
- 60% b-tagging efficiceny applied on b-quarks and rejection factors of 10 and 100 for c and light quarks, resp., for $|\eta|<2.5$
- 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



Outlook

- A first look to 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.

  → first results are very encouraging! 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 can be 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 realistic estimates of rejection factors or tagging possibilities.

- 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, M.Kuze, M.Ishitsuka,
K.Kimura, J.Maeda, C.Hengler,
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/

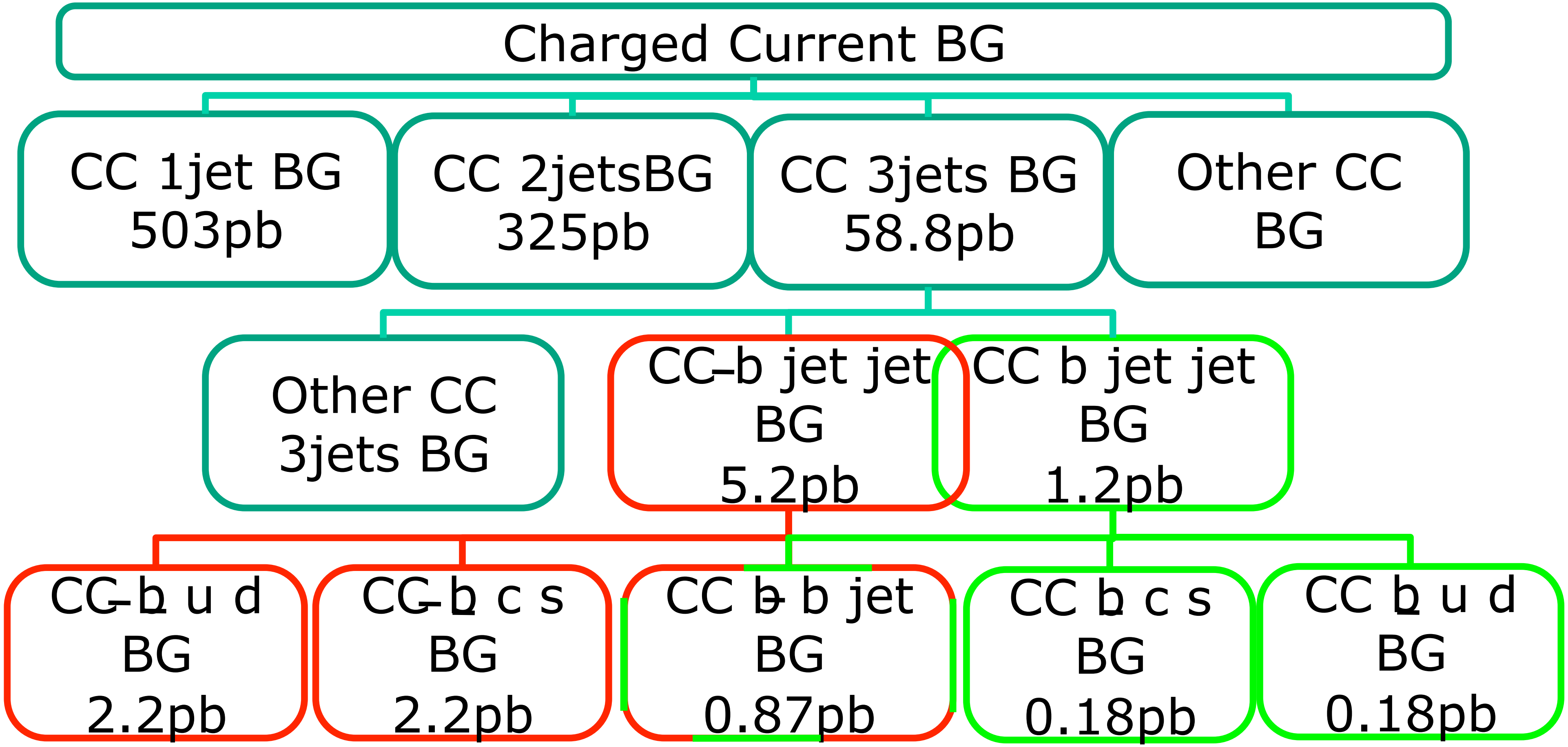
Some inspiring previous studies

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

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.