Behind the Scenes

Behind the Scenes

Non-PU backgrounds to diffractive Higgs production at the LHC

(HERA-LHC Workshop, Hamburg, 12-16.03 2007)

Durham University

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Main aims: -to quantify the mjor sources of the *Lumi-Independent* Backgrounds,
-to Exclusive Diffractive H→bb Production at the LHC

-to evaluate the role of the 'hidden' QCD backgrounds

(basec on works : A. Roeck, R. Orava and KMR, EPJC 25:391-403,2002 ;
V. Khoze, M. Ryskin and W.J. Stirling, hep-ph/0607134;
KMR , EPJC 26:229-236,2002; C34:327-334,2004
hep-ph/0702212)

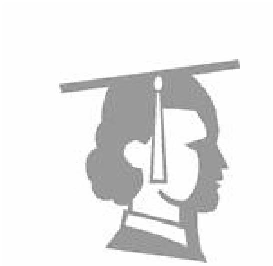
CEDP- Main Advantages:

- Measure the Higgs mass via the missing mass technique (irrespectively of the decay channel).
- H → $b\bar{b}$ *opens up* (Hbb Yukawa coupling); unque signature for the MSSM Higgs sect
- Quantum number/CP filter/analyzer.
- Cleanness of the events in the central detectors.

FP-420

Stephen Mrenna

Everybody Hates Monte Carlos



Stephen Watts

It Must be a God !

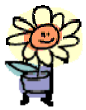
God Loves 'Forward Protons' !

$gg^{PP} \to q\bar{q}$ → unique symmetry properties

❉ In the proton tagging mode the dominant **H→** $b\bar{b}$ *in principle* can be observed *directly* .

❉certain regions of the MSSM parameter space are especially *proton tagging friendly*
(at large tan β and M ≤ 250 , S/B ≥ 20) (Marek's talk)

Myths



For the $b\bar{b}$ channel **LIB**s are well known and incorporated in the (DPE)MCs:

Exclusive LO - $b\bar{b}$ production (mass-suppressed) + *gg* misident+ soft&hard PP collisions.

Reality

(very small)

The complete background calculations are still in progress
(uncomfortably & unusually large high-order QCD and b-quark mass effects).

About a dozen various sources : known (DKMOR, Andy, Marek, CMS-Totem note) &

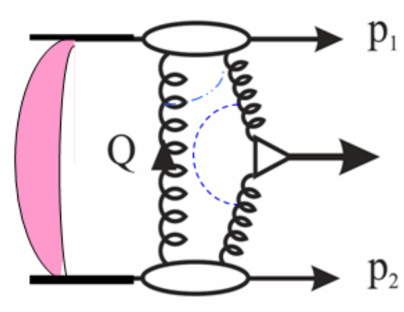
❶ admixture of |Jz|=2 production. (Not in MCs)

❷ NLO radiative contributions (hard blob and screened gluons) (Not fully in MCs) (Andy)

❸ NNLO one-loop box diagram (mass- unsuppressed, cut-nonreconstructible) (Not in MCs)

❹ b-quark mass effects in dijet events – (most troublesome theoretically) *still incomplete*
potentially, the largest source of uncertainties! (LO in Exhume)

KMR technology (implemented in ExHume)



$$\sigma_{pp}(M^2,\ldots) = L_{eff}(M^2,y) * \sigma_{hard}(M^2,\ldots)$$

$$\frac{\partial^2 L_{eff}}{\partial y \partial M^2} M^2 = S^2 * L(M^2)$$

focus on $\sigma^{bgd}{}_{hard}(M^2,\ldots)$

$L_{eff}(M^2,y)$ → the same for Signal and Bgds

$$L_{eff} \sim \frac{\hat{S}^2}{b^2} \left| N \int \frac{dQ_t^2}{Q_t^4} f_g(x_1, x_1', Q_t^2, \mu^2) f_g(x_2, x_2', Q_t^2, \mu^2) \right|^2$$

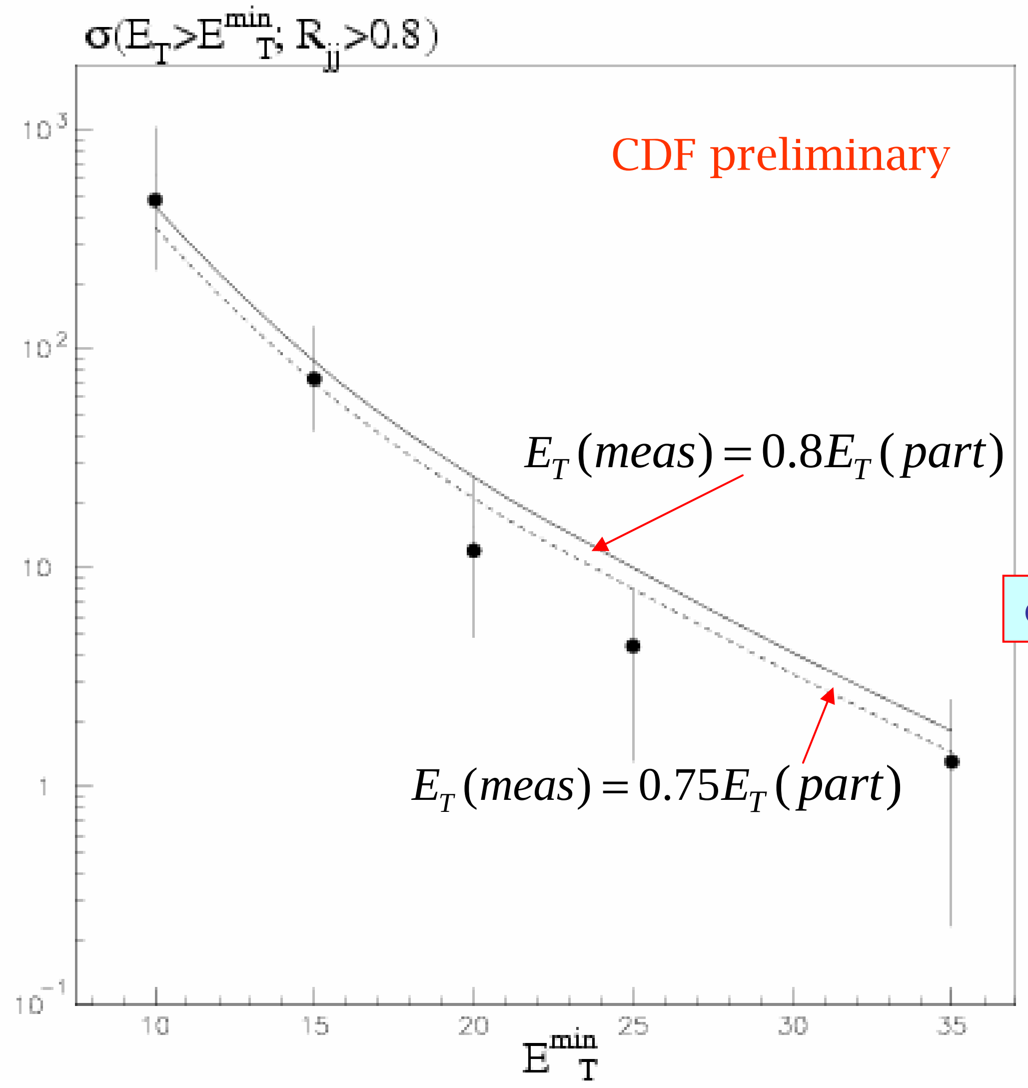
contain Sudakov factor T_g which exponentially suppresses infrared Q_t region → **pQCD**

new CDF experimental confirmation, 2006 (Dino's talk)

S^2 is the prob. that the rapidity gaps survive population KMR
by secondary hadrons → soft physics; $S^2/b^2 = 0.0015\ GeV^4$ (LHC), (Uri's talk, Mark)

S^2/b^2 -*weak dependence on* b (models)

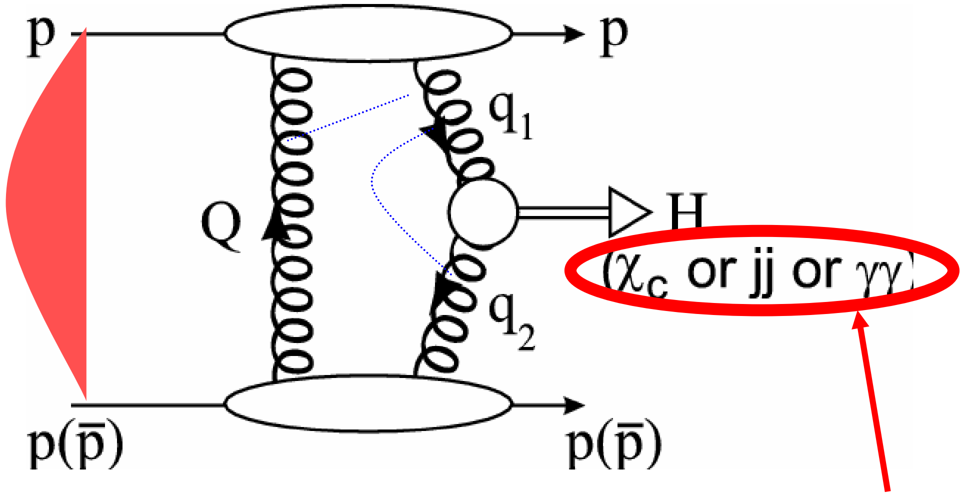
KMR analytical results



outside-cone energy (Koji)

(Rjj includes different sources : Centr. Inclus. + soft PP + (rad.) tail of Centr. Exclus. + experim. smearing) good agreement with the default ExHuME prediction up to masses in the region of the standard model Higgs mass predicted from global fits to electroweak data lends credence to the calculation of Ref. [9]. for exclusive Higgs boson production at the LHC.

[9] V. Khoze, A. Kaidalov, A. Martin, M. Ryskin, and W. Stirling, *Diffractive processes as a tool for searching for new physics*, e-Print Archive:hep-ph/0507040, and references therein.



"standard candles"

"Standard Candles"
at Tevatron to test exclusive prod. mechanism

pre-dictions, KMRS

- $pp \rightarrow p + \chi + p$ high rate, but low scale (uncertainties in the estimates)
- $pp \rightarrow p + jj + p$ rate rather high, but exclusive events should be separated
- $pp \rightarrow p + \gamma\gamma + p$ low rate, but cleaner signal

Experimental results are quite supportive

EXPERIMENTAL CHECKS

Up to now the diffractive production data are consistent with K(KMR)S results

Still more work to be done to constrain the uncertainties

- CED high-Et dijets (CDF: Run I, Run II) data up to $(E_t)_{min}$>50 GeV (Dino's talk)

- 'Factorization breaking' between the effective diffractive structure functions measured at the Tevatron and HERA.

(KKMR-01 ,a quantitative description of the results, both in normalization and the shape of the distribution)

- The ratio of high Et dijets in production with one and two rapidity gaps

- Preliminary CDF results on exclusive charmonium CEDP.

- Energy dependence of the RG survival (D0, CDF).

- CDP of $\gamma\gamma$ (….$\pi\pi$,$\eta\eta$)

◈ (all these results in line with the KMRS calculations)

CED production processes for h, H

Signal processes: use approximate formula

$$\sigma^{\rm excl} = 3{\rm fb} * \left(\frac{136}{16+m}\right)^{3.3} \left(\frac{120}{m}\right)^{3} \cdot \frac{\Gamma(h/H \to gg)}{0.25\,{\rm MeV}} \quad {\rm BR}^{\rm MSSM}$$

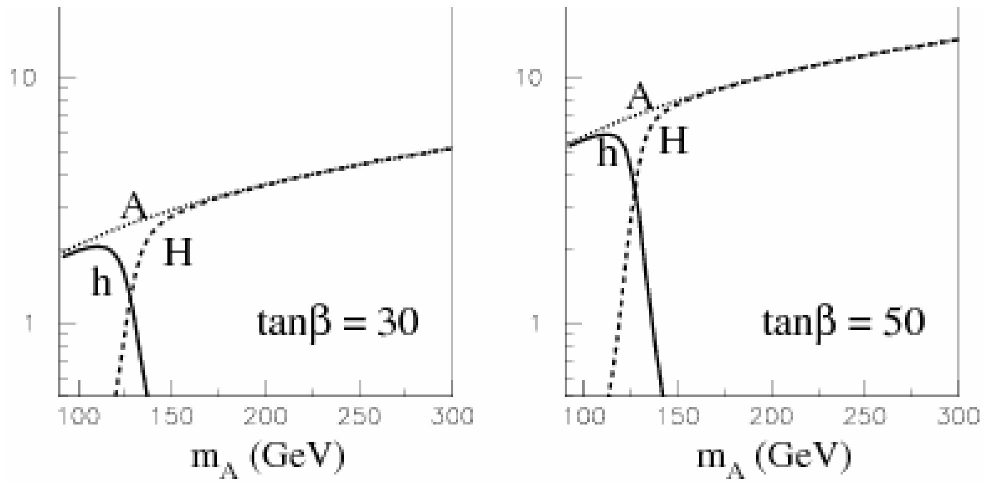
effect. PP lumi

$$\Gamma_{SM}(H \to gg) \propto M^3, \sigma_{SM} \propto 1/M^3$$

$\Gamma(h/H \to gg)$, ${\rm BR}^{\rm MSSM}$, ${\rm BR}^{\rm SM}$ evaluated with *FeynHiggs* (Marek)

(HKRSTW, work in progress).

Γ(GeV)



◈ in the MSSM at large tan β the Higgs width effects should be properly accounted for

RECALL :

- *for forward going protons* LO QCD $b\bar{b}$ bgd → suppressed by Jz=0 selection rule and by colour, spin and mass resol. (ΔM/M) –factors.

for reference purps : SM Higgs (120 GeV)

- misidentification of outgoing gluons as b –jets

the prolific LO subprocess $gg^{PP} \to gg$ may mimic $b\bar{b}$ production

SM Higgs

$$\frac{B(gg^{PP} \to gg)}{S(gg^{PP} \to H \to jj)} \simeq 600 \left(\frac{\Delta M}{1\,\mathrm{GeV}}\right)$$

for jet polar angle cut $60^\circ < \theta < 120^\circ$

$$\frac{B(gg^{PP} \to gg \to \text{“}b\bar{b}\text{”})}{S(gg^{PP} \to H \to b\bar{b})} \simeq 1/4 * (120/M)^3 * (\Delta M / 4GeV) * [P(g/b)/0.01]^2$$

(DKMOR WishList)

misidentification prob. P(g/b)=0.01 → B/S ~0.06 $\left(\frac{\Delta M}{1\,\mathrm{GeV}}\right)$

(factor of 2 …. *gluon identity* … *(AP)*)

A little bit of (theoretical) jargon

Helicity amplitudes $M^{\lambda_q,\lambda_{\bar q}}_{\lambda_1,\lambda_2}$ for the binary bgd processes

$$\mathbf{g}\ (\lambda_1, k_1) + \mathbf{g}\,(\lambda_2, k_2) \rightarrow q(\lambda_q, p) + \bar q(\lambda_{\bar q}, \bar p)$$

S – Jz=0, LO **B**- domint. Jz=2

λi – helicities of ‘active gluons’

λ_q – (double) helicities of produced quarks

❈ convenient to consider *separately*
q-helicity conserving ampt (**HCA**) and q-helicity non-conserving ampt(**HNCA**)

- do not interfere, can be treated independently,
- allows to avoid *double counting* (in particular, on the MC stage)

❈for **Jz=0** $(\lambda_1 = \lambda_2)$ the Born **HCA** *vanishes,* $M^{\lambda_q,-\lambda_q}_{\lambda,\lambda} = 0$

Symmetry argumts
(BKSO-94)

(usually, **HCA** is the *dominant* helicity configuration.)

❈ for large angles **HNCA**

$$M^{\lambda_q,\lambda_q}_{\lambda,\lambda} \sim \mathcal{O}\left(\frac{m_q}{\sqrt{s}}\right) M^{\lambda_q,-\lambda_q}_{\lambda,-\lambda}$$ (Jz=2, HCA)

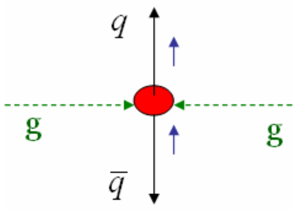
✪ in terms of the **fashionable** **MHV** rules (inspired by the behaviour in the *twistor* space)

only (+ - ; + -) $\neq 0$ J_z=2, **HCA**
(-+ ; -+ /+-)

☺ an advantageous property of the $gg^{PP} \to q\bar{q}$ large angle amplitudes

- all **HNCA** (**Jz=0, Jz=2,** all orders in α_s) are suppressed by m_q / E_T
- all **HC** gg^{PP} ampts ((**Jz=0, Jz=2,** all orders) are \propto $\cos\theta$ ➔ vanish at 90°

(z)



rotational invariance around q-direction (Jz=2, PP-case only)

➔ an additional numerical smallness (0.1-0.2)

recall: $60^\circ < \theta < 120^\circ \to |\eta_1 - \eta_2| < 1.1$ to suppress t-channel singularities in the bgds

- LO **HCA** vanishes in the Jz=0 case (*valid only for the Born amplitude*)

Jz=0 suppression is *removed* by the presence of an additional (*real/ virtual*) gluon
(BKSO-94)

because of collinear singularities angular cut is crucial (especially for the ‘hidden’ backgrounds)

Classification of the $gg^{PP} \to q\bar{q}$ backgrounds

$B/S_{SM} \sim \Delta M/M^3 * Br/Br^{SM}$

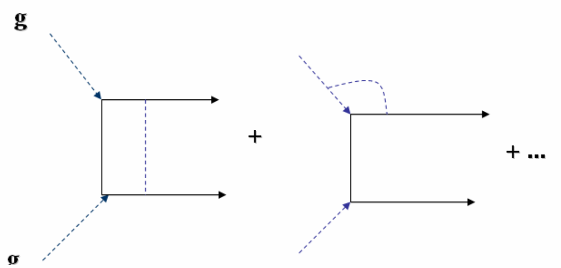
- $|J_z|=2$ **LO** production caused by *non-forward going* protons.

HC process, suppressed by $4p_{1t}^2 p_{2t}^2/Q_t^4$. and by $\cos^2\theta$

$$\frac{B_{|J_z|=2}(gg^{PP} \to b\bar{b})}{S(gg^{PP} \to H \to b\bar{b})} \approx 0.02 * (\Delta M / 1GeV)$$

NEW! *estimate*

- **NNLO** $\mathcal{O}(\alpha_S^4)$ *(cut non-reconstructible)* **HC** quark box diagrams.



NEW! *result*

$$\frac{d\sigma^{NNLO}}{d\sigma_{\mathrm{Born}}}(gg^{PP} \to q\bar{q}, J_z = 0) \approx \alpha_s^2/32 * M^2/m_q^2 * (C_F - N_C)^2 \sin^2\theta \cos^2\theta$$

- *dominant* contribution at *very* large masses M
- at M< 300 GeV still *phenomenologically* unimportant due to a combination of small factors
- appearance of the $(C_F - N_C)^2$ factor → consequence of supersymmetry

- **mass-suppressed Jz=0 contribution** $B/S_{SM} \square \Delta M / M^5 * Br/Br^{SM}$

☹ theoretically most challenging (*uncomfortably large* higher-order effects)

✷ *naively* Born formula would give $\frac{B_{m_b}(gg^{PP} \to b\bar{b})}{S(gg^{PP} \to H \to b\bar{b})}$ ~**0.06** * $\left(\frac{\Delta M}{1\,\mathrm{GeV}}\right)$

✷ however, various *higher-order* effects are essential :

- running b-quark mass - **Single Log** effects ($\overline{m}_b(M_H) < \overline{m}_b(m_b)$)

- the so-called *non-Sudakov* Double Log effects , corrections of order

3F= $(8\alpha_S/\pi) * \ln^2(M/m_b) \geq 1$

(studied in FKM-97 for the case of $\gamma\gamma \to b\bar{b}$ at Jz=0)

Guidance based on the experience with QCD effects in $\gamma\gamma \to b\bar{b}$.

- DL effects can be reliably summed up(FKM-97 , M. Melles, Stirling, Khoze 99-00).
- Complete one-loop result is known (G. Jikia et al. 96-00)

-complete calculation of SL effects (drastically affects the result)

-**bad news** :✷ *violently oscillating* leading term in the **DL** non- Sudakov form-factor:

-

Fq= $(1-\underbrace{(1+2N_C/C_F)}_{(\approx 2.5)}*F)^2+....$

✷ DL contribution exceeds the Born term; strong dependence on the NLLO, scale, running mass…. effects

✷No complete SL calculations currently available.

HNC contribution rapidly decreases with increasing M

Currently the best bet: :

$$\mathrm{Fq} \approx \left[1 - \frac{m_b(M_H m_b)}{m_b(M_H^2)}(C_F + 2N_c)\frac{\alpha_s(M_H m_b)}{\pi}\ln^2\left(\frac{c \cdot M_H}{m_b(M_H m_b)}\right)\right]^2 .$$

with c≈1/2.

Taken literally ➔ factor of two larger than the 'naïve' Born term.

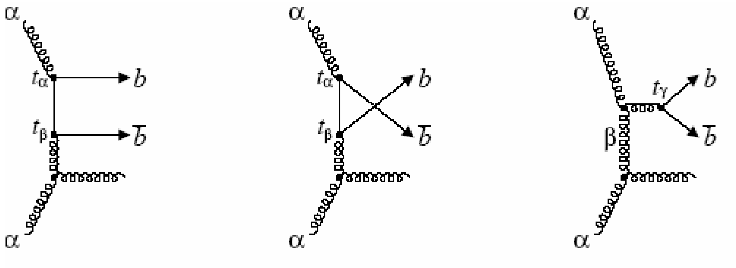
Cautiously : accuracy, not better than a factor of 4

A lot of further theoretical efforts is needed

A.Shuvaev et al.,
E.W.N. Glover et al.

NLO radiation accompanying hard $gg^{PP} \rightarrow q\bar{q}$ subprocess

Large-angle, hard-gluon radiation does not obey the selection rules



+ radiation off b-quarks

* potentially a *dominant* bgd :($\alpha_S / \pi >> (m_b / M)^2$) strongly exceeding the LO expectation.

$$B_{qqg} / S_{SM} \sim \alpha_S * \Delta M / M^3 * Br / Br^{SM}$$

* only gluons with $p_t \geq Q_t$ could be radiated, otherwise cancel. with screening gluon ($\lambda_g > d_t \sim 1/Q_t$).

* KRS-06 → complete LO analytical calculation of the HC , Jz=0 NEW!

$$|M_{gg \rightarrow q\bar{q}g}|^2$$ in the massless limit, using MHV tecnique.

Hopefully, these results can be (*one day*) incorporated into MC programmes to investigate radiative bgd in the presence of realistic expt. cuts.

How hard should be radiation in order to *override* Jz=0 selection rule ?

as well known $$\frac{d\sigma_{\mathrm{unpol}}}{dE_g} \sim \frac{1}{E_g}$$ (*classical* infrared behaviour)

(BKSO-94)

neglecting quark mass $$\frac{d\sigma(J_z=0)}{dE_g} \sim E_g^3$$

(a consequence of Low-Barnett-Kroll theorem, generalized to QCD)

➔ the relative probability of the *Mercedes -like* qqg configuration for Jz=0 radiative bgd process becomes unusually large

✪ marked contrast to the Higgs-> bb (quasi-two-jet- like) events.

✪ charged multiplicity difference between the H->bb signal and the Mercedes like bbg – bgd:

for M ~120, $\Delta N \approx 7$, ΔN rises with increasing M.

- *hopefully*, clearly pronounced 3-jet events can be eliminated by the CD,
- can be useful for bgd calibration purposes.

Exceptions:
- radiation in the beam direction;
- radiation in the b- directions.

DKMOR-02, KMR-07

Production by hard and soft *Pomeron-Pomeron* collisions

(KMR hep-ph/0702213)

Requirement: $M_{PP} = M_{missing}$ lies with mass interval $M_{bb} \pm \Delta M_{bb}$

Suppression: $\frac{1}{2}(\Delta M_{bb} / M_{PP})^2 * g^2{}_P (1 - \Delta M_{bb} / M_{PP})$ (soft PP and qualitatively for hard PP)

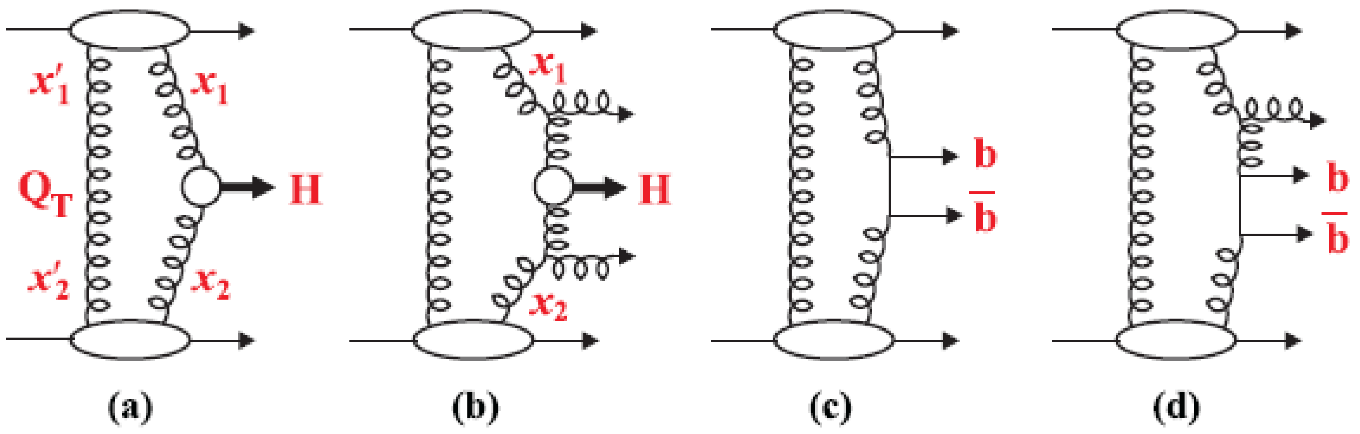


Figure 1: (a) Exclusive Higgs production by the fusion of two hard Pomerons; (b) Higgs production, via hard Pomerons, but accompanied by the emission of two undetected gluons; (c,d) background QCD $b\bar{b}$ production processes. For (b,c,d) we account for the full set of Feynman diagrams at this order and, moreover, for (b,d) allow for additional soft gluon emission.

(not in MCs)

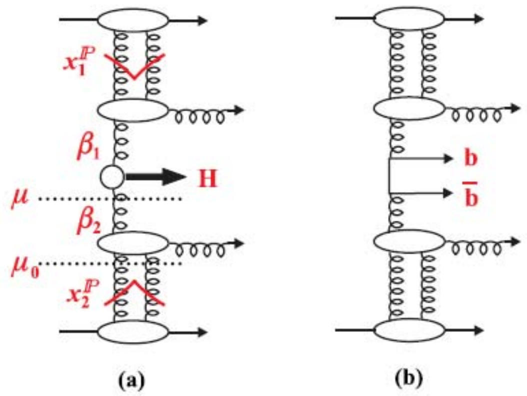


Figure 2: (a) Higgs production by the fusion of two soft Pomerons; (b) background $b\bar{b}$ production via soft Pomerons.

process	diagram	cross section	
$\sigma_{\rm excl}(H \to b\bar{b})$	Fig. 1(a)	150	exclusive signal
$\sigma(gHg)$	Fig. 1(b)	20	
$\sigma^{\rm QHNC}(b\bar{b} : {\rm LO})$	Fig. 1(c)	70	irreducible background
$\sigma^{\rm QHNC}(b\bar{b}g)$	Fig. 1(d)	5.2	λ not conserved
$\sigma^{\rm QHC}(b\bar{b}g)$	Fig. 1(d)	0.6	negligible; λ conserved
$\sigma^{\rm DPE}(gHg)$	Fig. 2(a)	0.14	negligible
$\sigma^{\rm DPE}(gb\bar{b}g)$	Fig. 2(b)	9	small

Table 1: The cross sections $d\sigma/dy|_{y=0}$ (in units of 10^{-3} fb) of the hard Pomeron processes shown in Fig. 1 and the soft Pomeron processes of Fig. 2. In each case the $H \to b\bar{b}$ branching ratio has been included and a polar-angle cut $60^\circ < \theta(b) < 120^\circ$ in the Higgs rest frame has been applied to the b jet, that is the jet rapidity separation $|\eta_1 - \eta_2| < 1.1$. We have taken $M_H = 120$ GeV, and assumed that the mass resolutions of the central detector and roman pots are such that they correspond to mass windows $\Delta M_{\rm dijet}/M_{b\bar{b}} = 20\%$ and $\Delta M_{\rm missing} = 4$ GeV, respectively. λ is the helicity along the b quark line. For the processes of Fig. 1(b,d), we allow for the emission of any number of gluons with transverse momentum $k_T < k_{T,{\rm max}} = 5$ GeV.

beam direction case

if a gluon jet is to go unobserved outside the CD or FD ($M \gg p_t > Q_t$)

➔Violation of the equality : $M_{missing} \approx M_{bb}$ (limited by the ΔM_{bb})

contribution is smaller than the admixture of Jz=2. KRS-06

b-direction case (**HCA**)

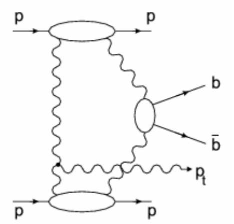
$$\frac{B(gg^{PP} \to b\bar{b}g)}{S(gg^{PP} \to H \to b\bar{b})} \sim 0.2 * (\Delta R/0.5)^2$$

(ΔR -separation cone size)

Note : ✷ soft radiation factorizes ➔ strongly suppressed ➔ *is not a problem,*
✷ NLLO *bbgg* bgd ➔ numerically small

✷ radiation from the screening gluon with pt~Qt :

KMR-02



HC (Jz=2) LO ampt. ~ $\cos\theta$ ➔*numerically* very small

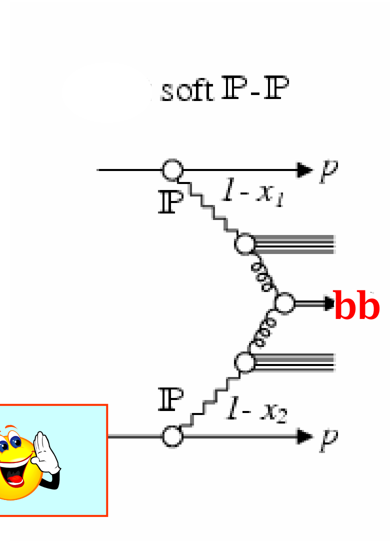
✷ hard radiation - *power suppressed* $\sim (Q_t / p_t)^2$

Production by soft *Pomeron-Pomeron* collisions

main suppression : $M_{PP} = M_{missing}$ lies within

$M_{bb} \pm \Delta M_{bb}$ mass interval

suppr. factor $\frac{1}{2}(\Delta M_{bb} / M_{PP})^2 * g^2{}_P (1 - \Delta M_{bb} / M_{PP}) \longrightarrow B_{PP} < B(J_z = 2)$



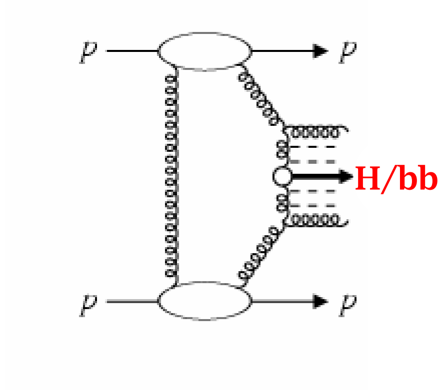
(HI 2006 Fit B and http://www.hep.ucl.ac.uk/~watt/DDIS/
additional factor of ~100 suppression as compared to the 'old DPDFs'

Background due to *central inelastic* production

mass balance, again

subprocess $gg^{PP} \to Hgg$ is strongly *suppressed*

produces a *small tail* on the high side of the missing mass



NEW!

H1 2006 data show that diffractive gluon densities at $\beta \rightarrow 1$ are (much) much lower than in the previous analyses.

The new MRW2006 fits (which are close to H1 fit B) dpdf are readily availiable at Durham HEPDATA,

(P.Newman)

http://www-spires.dur.ac.uk/

With the MRW2006 partons and $\Delta M \approx 20$ GeV in the Central Detector the soft DPE bb cross section is less then 0.05 of the Higgs signal (for M_H=120 GeV)

The overall suppression of the soft/hard Central Inelastic contributions ~ $(\Delta M / M)^N$ with N>4.

(HI 2006 Fit B and http://www.hep.ucl.ac.uk/~watt/DDIS/

additional factor of ~100 suppression as compared to 'old DPDF'- based results (CMS-Totem note)

Approximate formula for the $b\bar{b}$ background

$$\sigma_B \approx 2\,\text{fb}\left[0.92\frac{\Delta M}{(4\ \text{GeV})}\left(\frac{120}{M}\right)^6 + \frac{1}{2}\frac{\Delta M}{(4\ \text{GeV})}\left(\frac{120}{M}\right)^8\right]$$

main uncertn. at low masses

ΔM- mass window over which we collect the signal

- b-jet angular cut : ($60^\circ < \theta < 120^\circ \rightarrow |\eta_1 - \eta_2| < 1.1$)
- both S and B should be multiplied by the overall 'efficiency' factor ε (combined effects of triggers, acceptances, exp. cuts, tagging efficienc., ….),

ε ~4% (120 GeV) (Marek)

- g/b- misident. prob. P(g/b)=1.3% (ATLAS)

Four major bgd sources ~ $(1/4 + 1/4 + (1.3)^2/4 + 1/2)$ at $M \approx 120$ GeV, $\Delta M = 4$GeV

Five years on

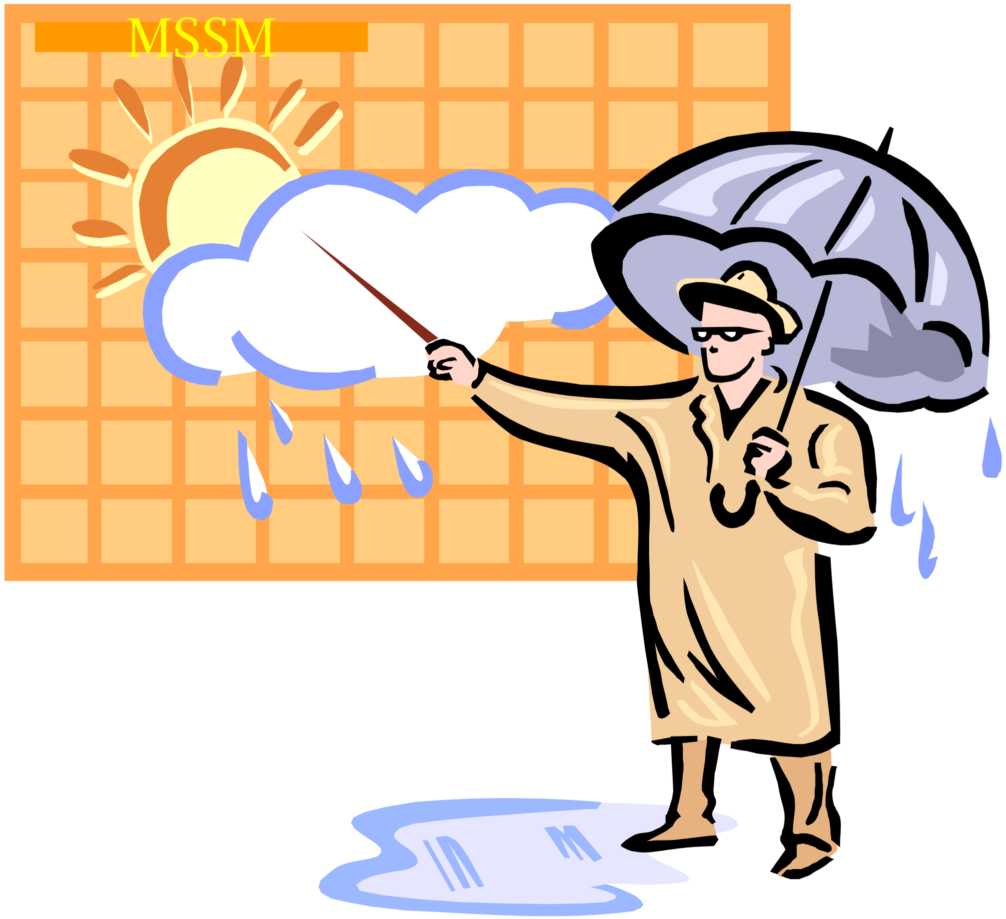
M=120 GeV

DKMOR (2002)

currently

- $\Delta M \approx 3\sigma \approx 1 GeV$ (87% signal catch) — 5.76 GeV (or worse –PB)
- ΔM_{CD} □ $10 GeV$ — 30-40 GeV
- misidentification prob. P(g/b)=1% — 1.3% (ATLAS) (Andy) (A. Rozanov)

  (b-tag efficiency) $(\varepsilon_b)^2$ □ 0.6 — $(\varepsilon_b)^2$ □ 0.36
- no **Pile-Up** studies — PU (Marek, Andy, Andrew, Monika, Michele…)
- narrow width approximation — Width effects - (HKRSTW) studies (Marek’s talk)



Recall : large M situation in the MSSM is *very different* from the SM.

H→WW/ZZ - negligible;

H→ bb/ττ- *orders of magnitude* higher than in the SM

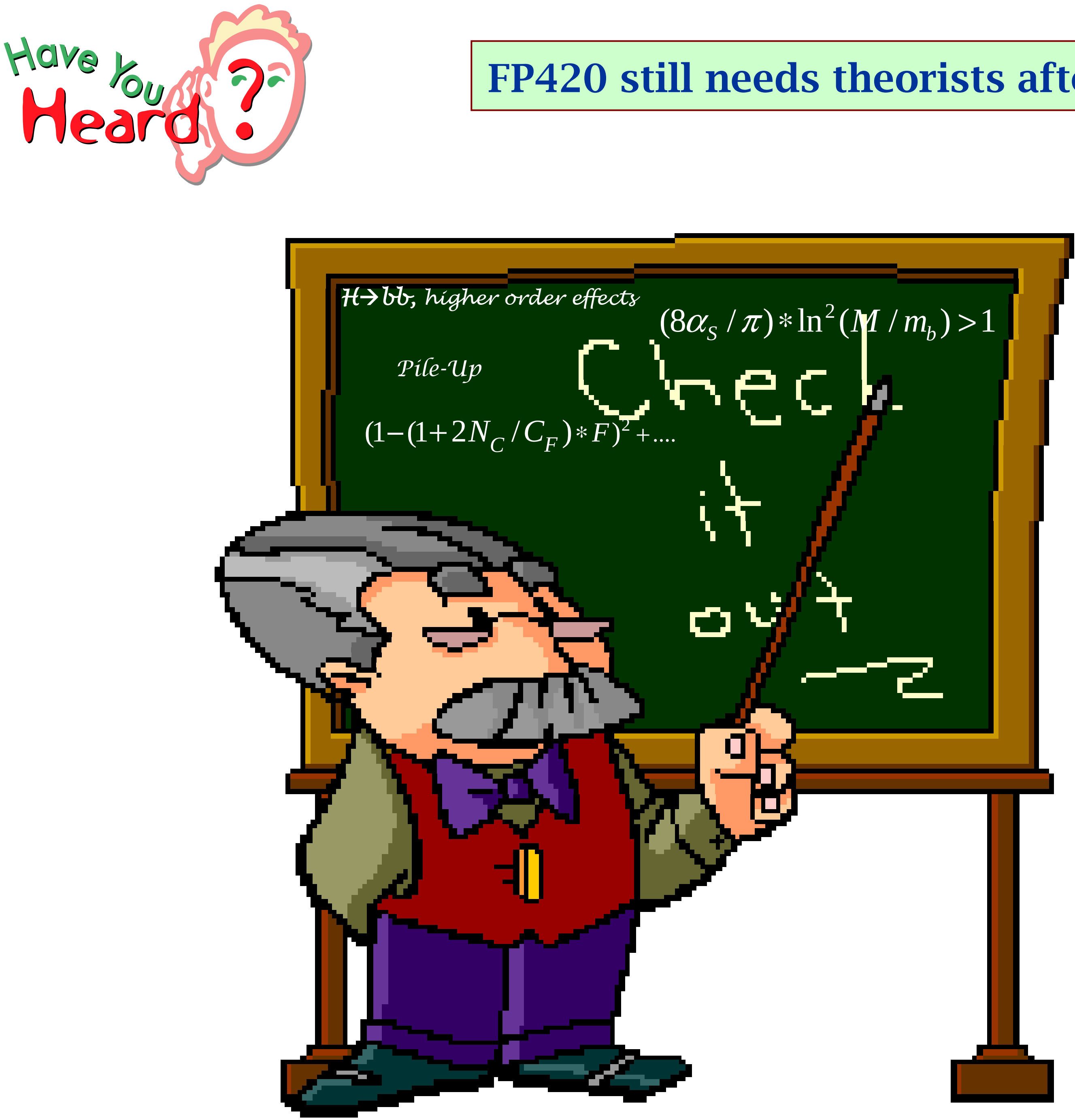
✵ detailed studies of statistical significance for the MSSM Higgs signal discovery , still in progress (HKRSTW) (Marek's talk)

Conclusion

- Luminosity Independent Backgrounds to CEDP of $H \rightarrow bb$ do not overwhelm the signal and can be put under full control especially at M> 120 GeV.
- The complete background calculation is still in progress (*unusually & uncomfortably* large high-order QCD effects).
- Further reduction can be achieved by experimental improvements, better accounting for the kinematical constraints, correlations…..
- Optimization, complete MC simulation- still to be done

Further theoretical & experimental studies are needed

FP420 still needs theorists after all



Known (un)knowns

❶ The probability to misidentify a gluon as a b-jet P(g/b) and the efficiency of $b, \bar{b}$ tagging, ε_b.

(At the Tevatron P(g/b) =0.33%, lower effic.)

The CEDP environment may help then…

❷ RP -mass resolution σ (M), further improvement ?
(*Risto*- conservative estimates)

❸ Correlations, optimisation -to be studied

❹ S^2 (S^2/b^2), further improvements, experimental checks.

❺ Triggering issues:

Electrons in the bb –trigger ?
Triggering on the bb/ττ without RP condition at M≥ 180 GeV ?

❻ Mass window ΔM_{CD} from the Central Detector only (bb, ττ modes) in the Rap Gap environment?
Can we do better than ΔM_{CD} ~20-30 GeV? Mass dependence of ΔM_{CD} ?

(*special cases: inclusive bgds, hunting for CP-odd Higgs*)

Backup