DIS 2009

Workshop on Deep-Inelastic Scattering and Related Subjects

DIS 2009, 26-30 April 2009, Madrid

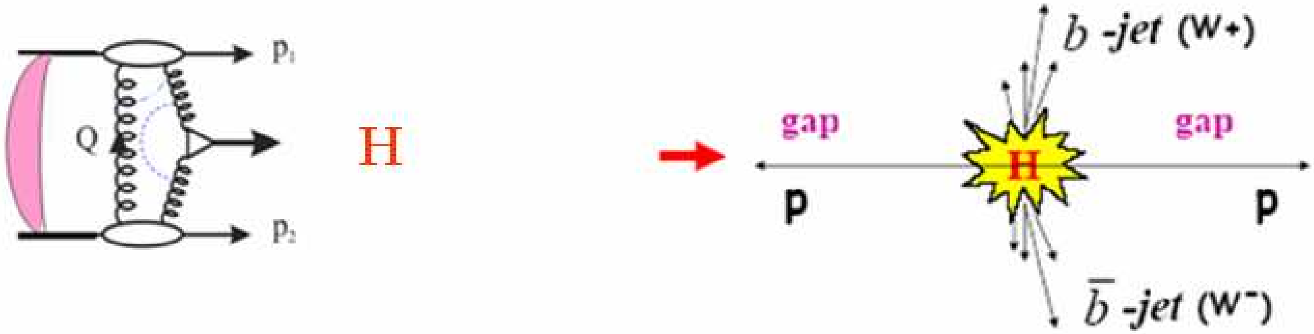
Studying the BSM Higgs sector by proton tagging at the LHC

V.A. Khoze (IPPP, Durham & PINP)

(27^{th} April)

(Based on works of extended Durham group)

main aim: to highlight recent development in the theory and phenomenology of the CED Higgs production



PLAN

1. **Introduction** (gluonic Aladdin's lamp)

2. **Central Exclusive Diffractive Production** (only a taste).

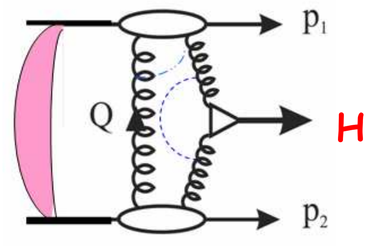
3. **Prospects for CED MSSM Higgs-boson production.**

4. ***Other BSM scenarios.***

5. **Conclusion.**

Higgs boson

The main advantages of CED Higgs production



- Prospects for high accuracy (~1%) mass measurements (irrespectively of the decay mode). (Krzystof, Jim)

- Quantum number filter/analyser.
  (0++ dominance ;C,P-even)

- H ->bb opens up (Hbb- coupl.)
  (gg)CED ⊘→ bb in LO ; NLO,NNLO, b- mass effects – controllable.

- For some areas of the MSSM param. space CEDP may become *a* **discovery channel !**
- **H →WW*, ττ** (less challenging experimentally + smaller bgds., better PU cond.)
- A handle on the overlap backgrounds- Fast Timing Detectors (10 ps timing or better). (Krzystof, Jim)
- New leverage –proton momentum correlations (probes of QCD dynamics , CP- violation effects…)

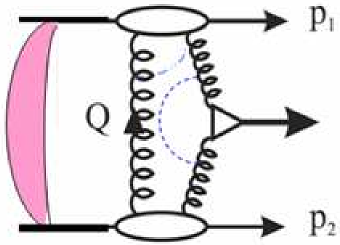
✶ LHC : 'after discovery stage', Higgs **ID**…… How do we know what we've found?

mass, spin, couplings to fermions and Gauge Bosons, invisible modes…

➔ for all these purposes the CEDP will be particularly handy !

KMR technology (implemented in ExHume MC)

(Khoze-Martin-Ryskin 1997-2009)



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

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

σ(CDPE) ~ 10^{-4} σ (incl)

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

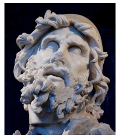
$$< Q_t >_{SP} \simeq M / 2 * \exp(-1/\bar{\alpha}_s) \approx 2 GeV \gg \Lambda_{QCD},$$

$$\bar{\alpha}_S = (N_C / \pi) * \alpha_S(M) * C_\gamma$$

Tg + anom .dim. → *IR filter*

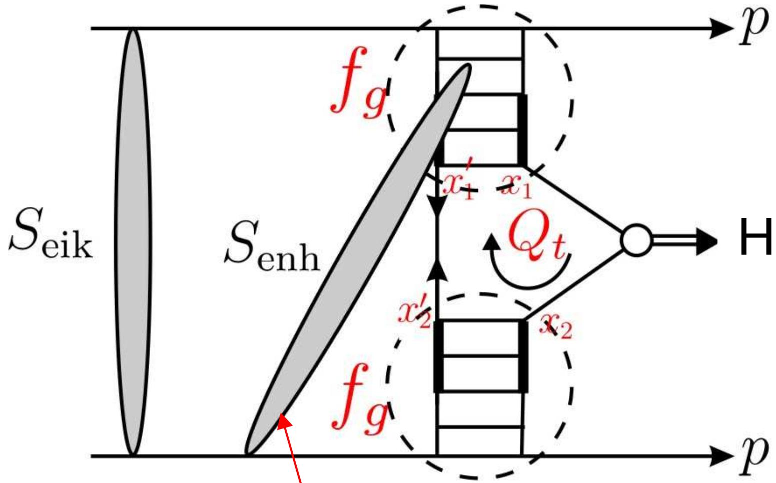
S^2 is the prob. that the rapidity gaps survive population by secondary hadrons → soft physics

New CDF results (dijets, γγ, χ_c)
(Christina, Jim)



not so long ago: between Scylla and Charibdis:
orders of magnitude differences in the theoretical predictions are now a history

“soft” scattering can easily destroy the gaps



gap

gap

S^2 → absorption effects -necessitated by unitarity

(KKMR-01; BBKM-06; RMK-07-09, ….FHSW- 07-09;GLMM-07-09..)

eikonal rescatt: between protons ← conserved

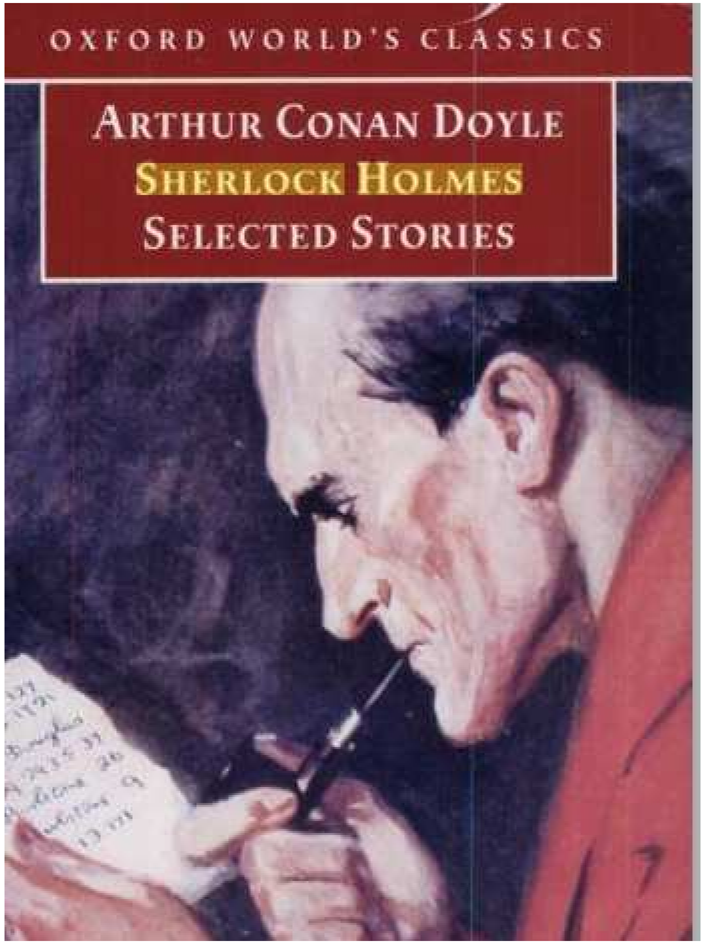
enhanced rescatt: involving intermediate partons ← broken

soft-hard factorizn

Subject of hot discussions : S^2

Far more theoretical papers than the expected number of the CED produced Higgs events

'Well, it is a possible supposition.'
'You think so, too ?'
'I did not say a probable one'



CURRENT 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.

- Exclusive high-Et dijets
  CDF: data up to (Et)min>35 GeV (PRD-2008) (Christina)

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

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

•CDF results on exclusive charmonium CEDP, (CDF, PRL) (Jim)

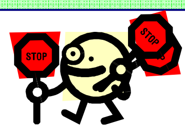
•Energy dependence of the RG survival (D0, CDF).

- Central Diffractive Production of $\gamma\gamma$ (....$\pi\pi$,$\eta\eta$) (**CDF**, PRL-07) (Jim)
  (in line with the KMRS calculations) (3 candidates & ? more candidates in the new data)

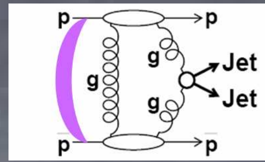
- Leading neutrons at HERA

LET THE DATA TALK !

Only a large data set would allow to impose a restriction order on the theoretical models



Comparison with KMR



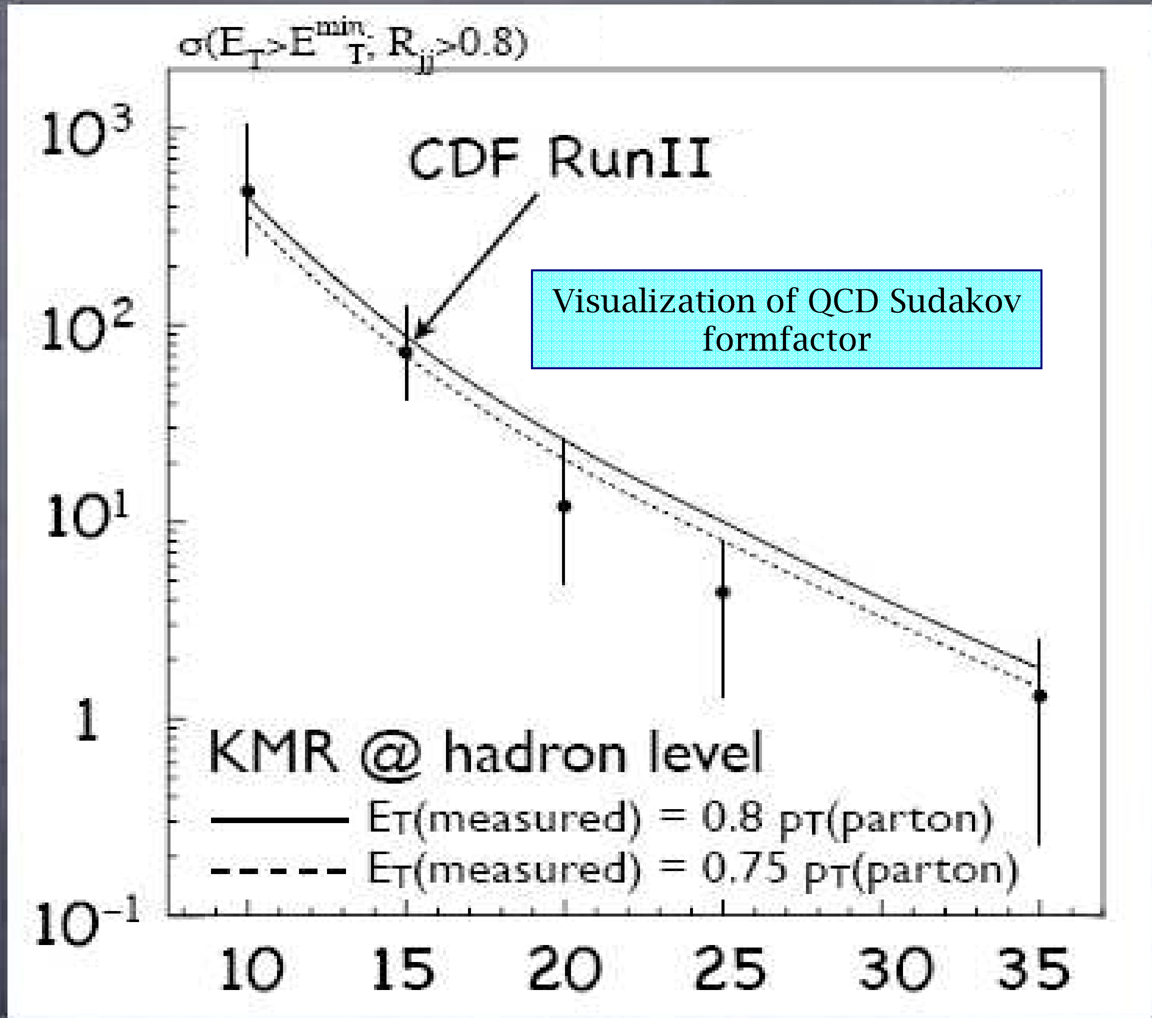
More direct comparison with KMR calculations including hadronization effects preferred

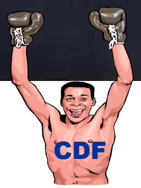
CDF out-of-cone energy measurement (cone R=0.7) :

- 20–25% at E_T^{Jet}=10–20 GeV
- 10–15% at E_T^{Jet}=25–35 GeV

Koji Terashi

Good agreement with data found by rescaling parton p_T to hadron jet E_T





A killing blow to the wide range of theoretical models.

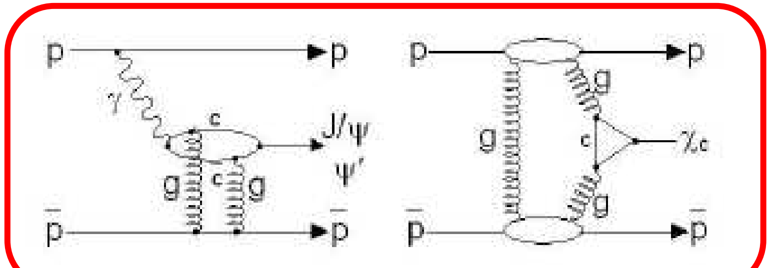
CDF
PRD-2008

(Christina)

Observation of Exclusive Charmonium Production and $\gamma\gamma \to \mu^+\mu^-$ in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

(Jim, Christina)

CDF Collaboration, arXiv:0902.1271 [hep-ex]



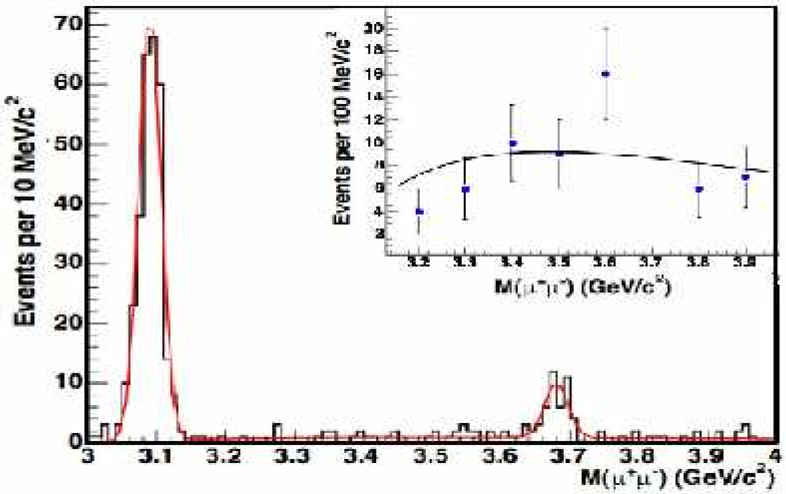


FIG. 2: Mass $M_{\mu\mu}$ distribution of 402 exclusive events, with no EM shower, (histogram) together with a fit to two Gaussians for the J/ψ and $\psi(2S)$, and a QED continuum. All three shapes are predetermined, with only the normalizations floating. Inset: Data above the J/ψ and excluding $3.65 < M_{\mu\mu} < 3.75$ GeV/c^2 ($\psi(2S)$) with the fit to the QED spectrum times acceptance (statistical uncertainties only).

TABLE I: Numbers of events fitted to classes $J/\psi, \psi(2S)$, QED and χ_{c0}. Backgrounds are given as percentages of the fit events, and efficiencies are to be applied to the events without background. The stated branching fraction $\mathcal{B}$ for the χ_{c0} is the product of the $\chi_{c0} \to J/\psi + \gamma$ and $J/\psi \to \mu^+\mu^-$ branching fractions [11]. The cross sections include a 6% luminosity uncertainty.

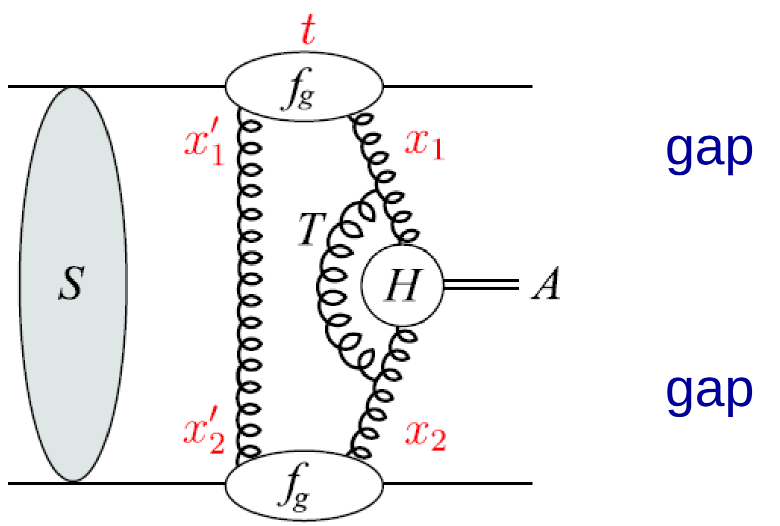
Class	J/ψ	$\psi(2S)$	$\gamma\gamma \to \mu^+\mu^-$	$\chi_{c0}(1P)$
Acceptances:				
Detector(%)	18.8±2.0	54±3	41.8±1.5	19±2
Efficiencies:				
μ-quality(%)	33.4±1.7	45±6	41.8±2.3	33±2
Photon(%)	-	-	-	83±4
Events(fit)	286±17	39±7	77±10	65±8
Backgrounds:				
Dissoc.(%)	9±2	9±2	8±2	11±2
Non-excl.(%)	3±3	3±3	9±5	3±3
χ_{c0}(%)	4.0±1.6	-	-	-
Events(corr.)	243±21	34±7	65±10	56±8
$\mathcal{B}.\sigma_{FKR}$(pb)	28.4±4.5	1.02±0.26	2.7±0.5	8.0±1.3
$\mathcal{B} \to \mu^+\mu^-$(%)	5.93±0.06	0.75±0.08	-	0.076 ±0.007
$\frac{d\sigma}{dy}\vert_{y=0}$(nb)	3.92±0.62	0.53±0.14	-	76±14

KMRS -2004: **130 nb** →90 nb (PDG-2008)

(role of higher spin states, NLO-effects, DD…. need further detailed studies)

ππ/KK mode as a spin-parity analyzer

Are the early LHC runs,
without proton taggers,
able to check estimates
for pp → p+A+p ?



KMR: 0802.0177

Possible checks of:

Divide et Impera

(i) survival factor S^2: W+gaps, Z+gaps

(ii) generalised gluon f_g : $\gamma p \to \Upsilon p$

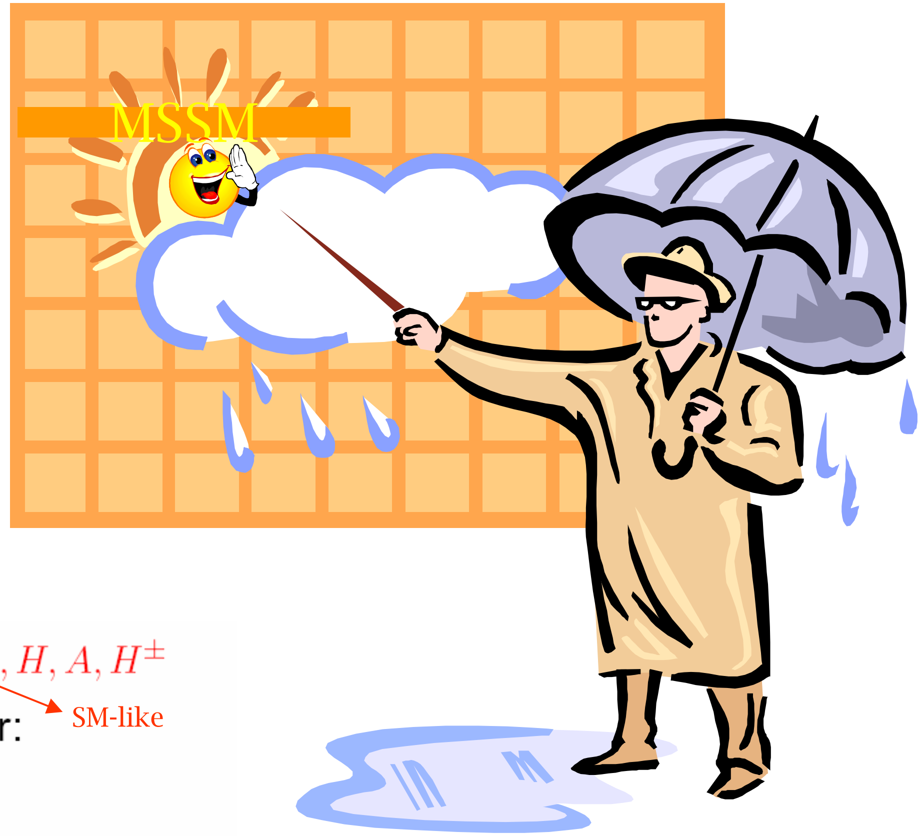
(iii) Sudakov factor T : 3 central jets

(iv) **soft-hard factorisation (enhanced absorptive corr^n)** $\frac{\#(\text{A+gap})\ \text{evts}}{\#(\text{inclusive A})\ \text{evts}}$

with A = W, dijet, Υ…

without 'clever hardware':
for H(SM)→bb at 60fb-1 only
a handful of events due to
severe exp. cuts and low efficiencies,
though **S/B~1** .
H->WW mode at M>135 GeV. (B.Cox et al-06)

enhanced trigger strategy & improved
timing detectors (FP420, TDR)



situation in the MSSM is **very different**
from the SM

- Higgs sector of the MSSM: physical states $h, H, A, H^{\pm}$ (SM-like)

  Described by two parameters at lowest order:
  M_A, $\tan\beta \equiv v_2/v_1$

- Search for heavy MSSM Higgs bosons ($M_A, M_H > M_Z$):
  Decouple from gauge bosons
  $\Rightarrow$ no HVV coupling
  $\Rightarrow$ no Higgs production in weak boson fusion
  $\Rightarrow$ no decay $H \to ZZ \to 4\mu$

  Large enhancement of coupling to $b\bar{b}$ (and $\tau^+\tau^-$) in region of high $\tan\beta$

Conventionally due to overwhelming QCD backgrounds, the direct measurement of Hbb is hopeless

The backgrounds to the diffractive H bb mode are manageable!

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

KKMR-04 ; HKRSTW-07; B. Cox, F.Loebinger, A.Pilkington-07 , C. Royon et al

Myths

For the $b\bar{b}$ channel bgds are well known and incorporated in the MCs:

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

Reality

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

About a dozen various sources (studied by Durham group)

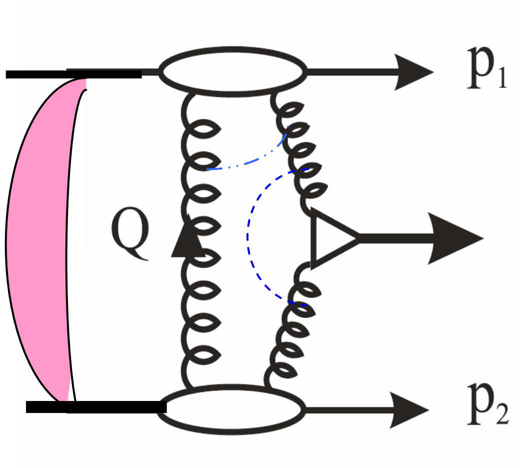
❶ admixture of |Jz|=2 production.
❷ NLO radiative contributions (hard blob and screened gluons)

❸ NNLO one-loop box diagram (mass- unsuppressed, cut-non-reconstructible)
❹ 'Central inelastic' backgrounds (soft and hard Pomerons)
❺ b-quark mass effects in dijet events

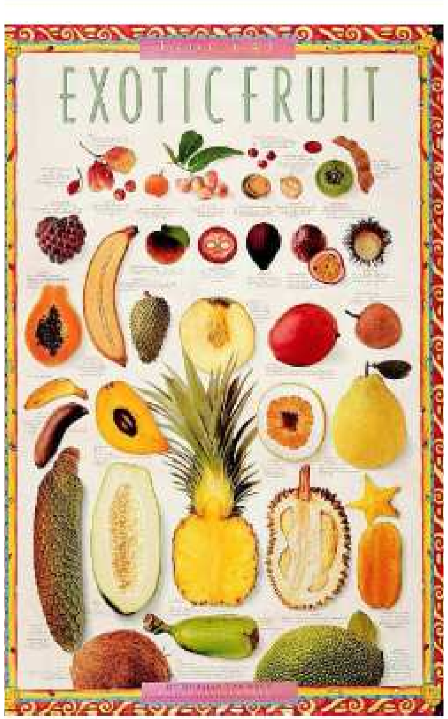
………..

The MSSM and more '*exotic*' scenarios

$$pp \rightarrow p + \phi + p$$



If the coupling of the Higgs-like object to gluons is large, double proton tagging becomes very attractive



- *The intense coupling regime of the MSSM* (E.Boos et al, 02-03)

- CP-violating MSSM Higgs physics (B.Cox et al . 03, KMR-03, J. Ellis et al. -05)

Potentially of great importance for electroweak baryogenesis

- Triplet Higgs bosons (CHHKP-2009)
- Fourth Generation Higgs
- NMSSM (J. Gunion, et al.)
- *Invisible' Higgs* (BKMR-04)

There is NO experimental preference for a SM Higgs. Any Higgs-like boson is very welcome !

Extended Higgs sectors: "typical" features

Search for heavy MSSM Higgs bosons ($M_A, M_H \gg M_Z$):

Decouple from gauge bosons

$\Rightarrow$ no HVV coupling

$\Rightarrow$ no Higgs production in weak boson fusion

$\Rightarrow$ no decay $H \to ZZ \to 4\mu$

Large enhancement of coupling to $b\bar{b}$, $\tau^+\tau^-$ for high $\tan\beta$

$\Rightarrow$ Decays into $b\bar{b}$ and $\tau^+\tau^-$ play a crucial role

"Typical" features of models with an extended Higgs sector:

- A light Higgs with SM-like properties, couples with about SM-strength to gauge bosons
- Heavy Higgs states that decouple from the gauge bosons

Four integrated luminosity scenarios

(S.Heinemeyer, VAK, M.Ryskin, W.J.Stirling, M.Tasevsky and G.Weiglein- 07,08)

(**bb**, WW, $\tau\tau$- modes studied)

1. L = 60fb^{-1}: 30 (ATLAS) + 30 (CMS): 3 yrs with L=10^{33}cm^{-2}s^{-1}

2. L = 60fb^{-1}, effx2: as 1, but assuming doubled exper.(theor.) eff.

3. L = 600fb^{-1}: 300 (ATLAS) + 300 (CMS) : 3 yrs with L=10^{34}cm^{-2}s^{-1}

4. L = 600fb^{-1},effx2: as 3, but assuming doubled exper.(theor.) eff.

upmost !

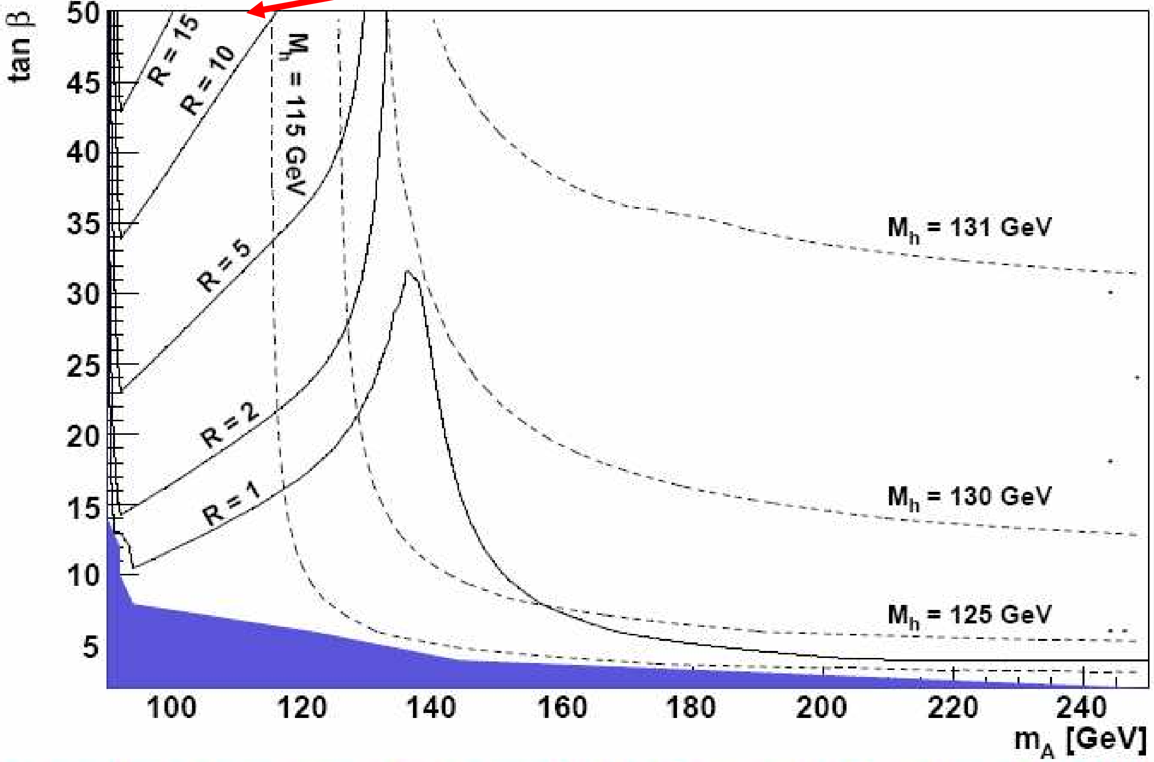
We have to be open-minded about the theoretical uncertainties.

Should be constrained by the early LHC measurements (KMR-08)

Ratio of signal rate for the light MSSM Higgs boson over the SM rate in the $h \to b\bar{b}$ channel

$m_h^{\max}$ benchmark scenario:

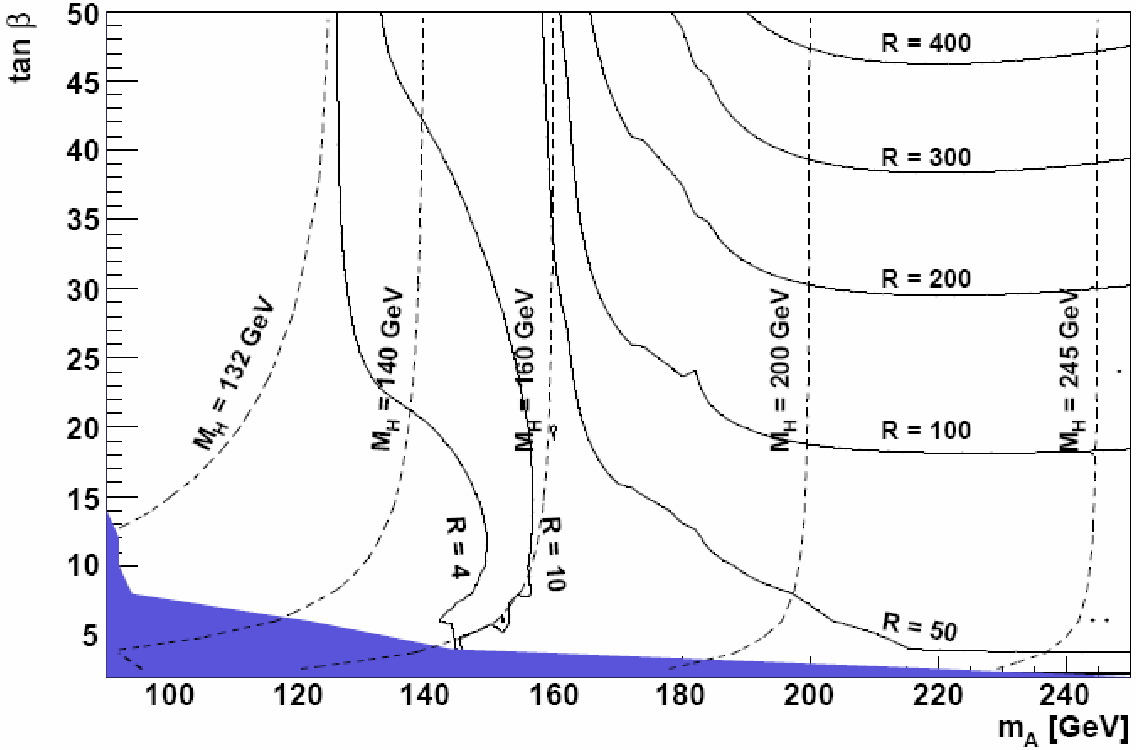
New Tevatron data still pouring



⇒ Large enhancement possible for relatively small M_A and large $\tan\beta$

Ratio of signal rate for the heavy $\mathcal{CP}$-even MSSM Higgs boson over the SM rate, $H \to b\bar{b}$ channel

m_h^{max} benchmark scenario:



⇒ Huge enhancement compared to SM case, up to factor 400

NEW DEVELOPMENT

- Current Tevatron limits implemented. 

- CDM scenarios analysed

  Compliant with the **C**old **D**ark **M**atter and **EW** bounds

- 4 Generation scenarios

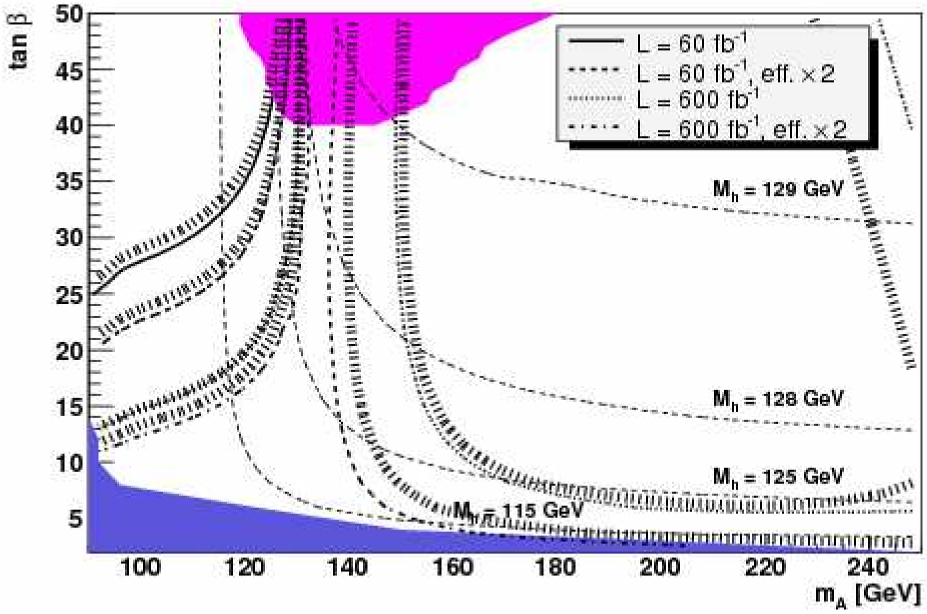
(S.Heinemeyer, VAK, M.Ryskin, W.J.Stirling, M.Tasevsky and G.Weiglein 07-08)

- bb backgrounds revisited (Shuvaev +KMR)
- Neutral Higgs in the triplet model (CHHKP-09)

Still to come

- $\tau\tau$ -mode, in particular, trigger strategy
- Charged Higgs bosons in MSSM and triplet models

HKRTW-08



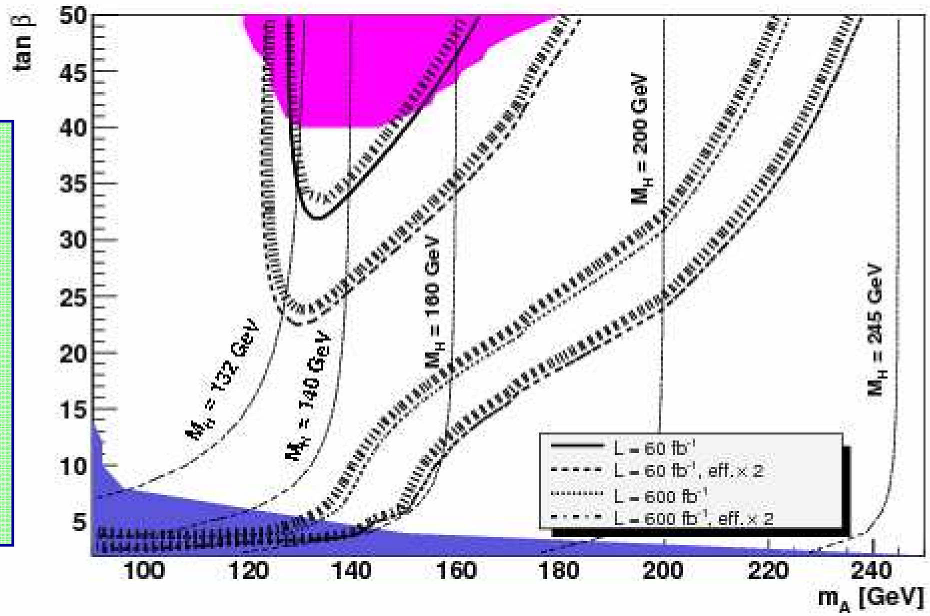
- Tevatron limits shown.
- Updated theory calculations
- New bb-backgrounds

Mhmax benchmark scenario
Improved theory & background
3σ contours

- "600x 2" scenario covers nearly the whole allowed region for the light Higgs.

For large tan β heavy Higgs reach goes beyond 235 GeV.

- For the H-boson the area reachable in the "60"-scenario is to large extent ruled out by the Tevatron data.



HKRTW-08

CDM benchmarks

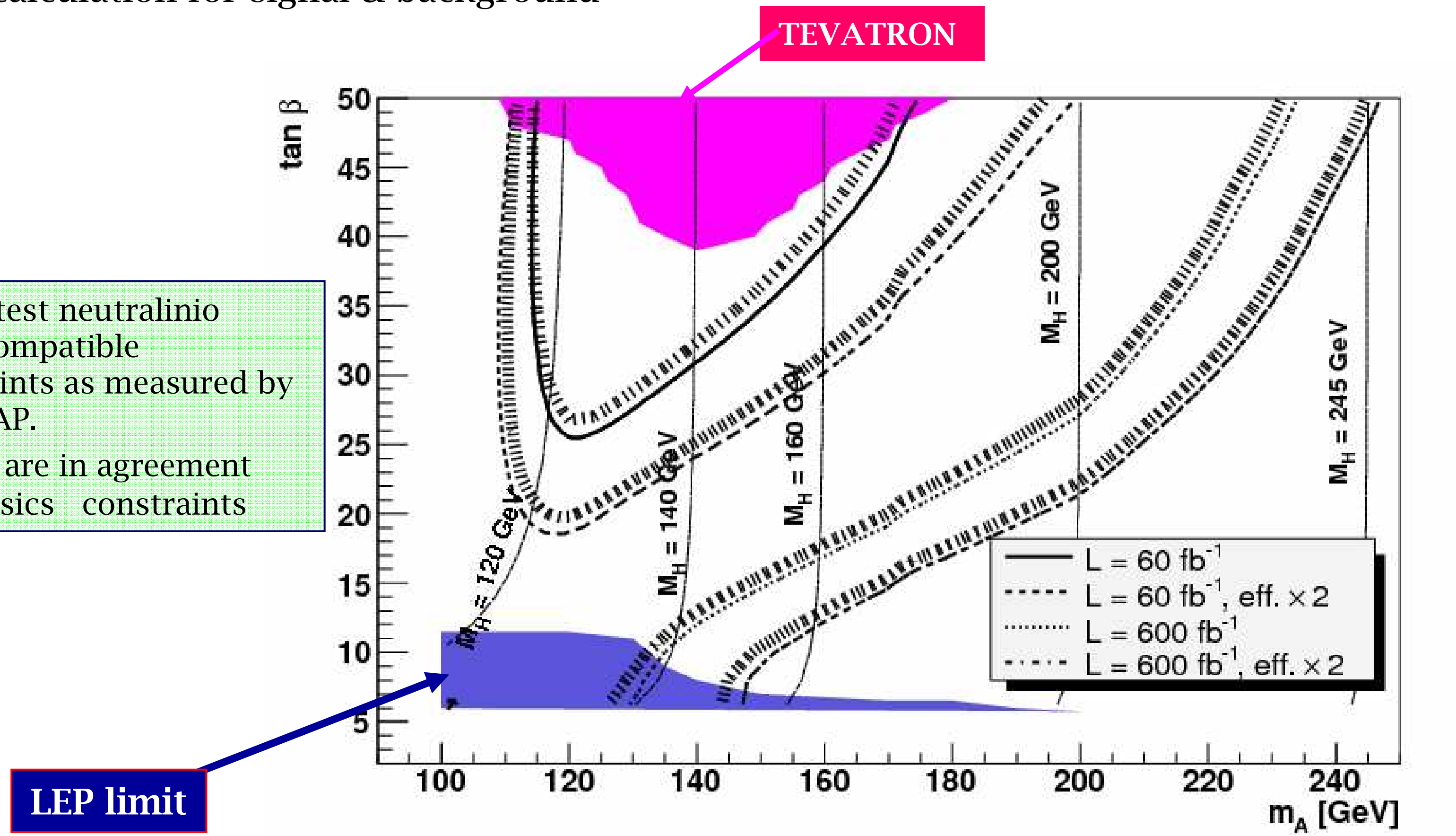
3σ contours
P3- NUHM scenario

•Updated theory calculation for signal & background

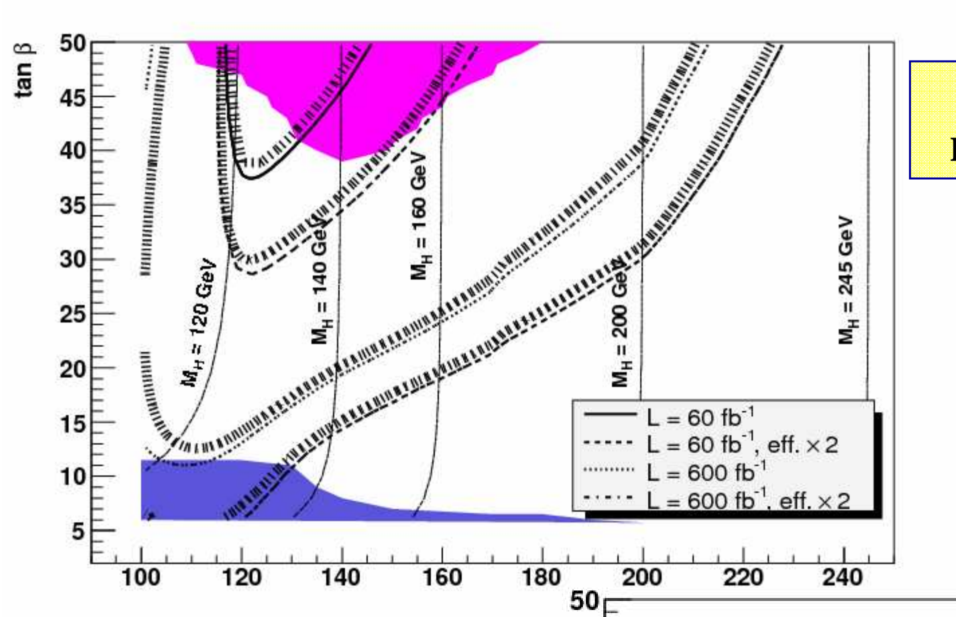
$H \rightarrow b\bar{b}$

Abundance of the lightest neutralinio in the early universe compatible with the CDM constraints as measured by WMAP.

The **M_A − tanβ** planes are in agreement with the EW and B-physics constraints

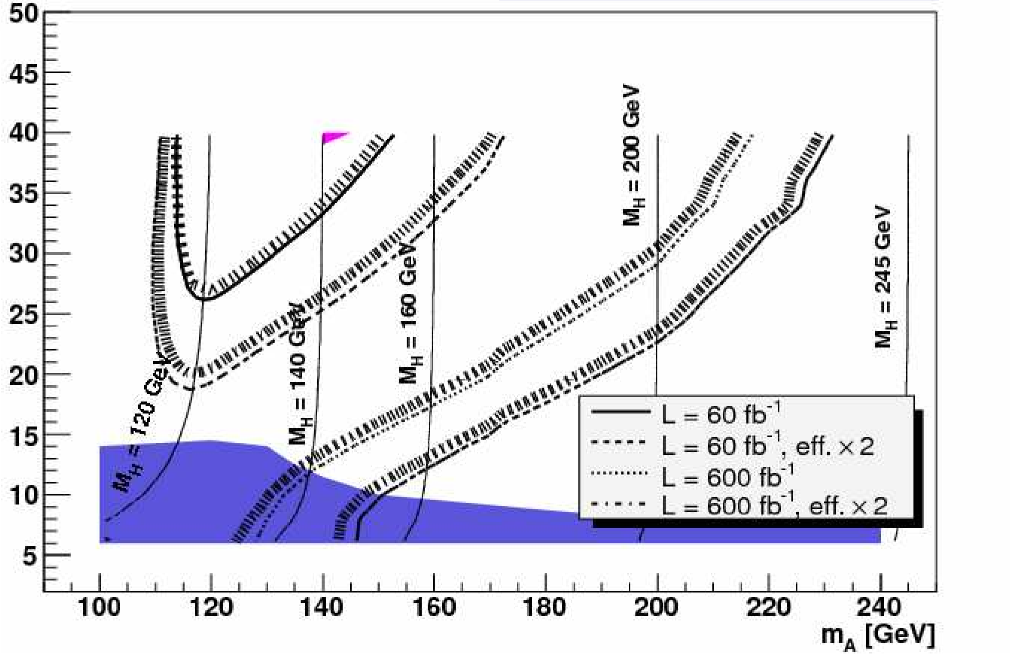


$H \to b\bar{b}$



5σ -discovery,
P3- NUHM scenario

3σ -contours,
P4- NUHM scenario



MSSM SUMMARY

- Detailed analysis of prospects for CED production of $\mathcal{CP}$-even MSSM Higgs bosons, $pp \to p \oplus h, H \oplus p$
- Light MSSM Higgs boson, $h \to b\bar{b}$ channel: almost complete coverage of M_A–$\tan\beta$ plane (and case of light SM Higgs) at the 3σ level with $600\ \mathrm{fb}^{-1} \times 2$

  $\Rightarrow$ CED channel may yield crucial information on bottom Yukawa coupling and $\mathcal{CP}$ properties
- Heavy $\mathcal{CP}$-even Higgs boson, $H \to b\bar{b}$ channel: discovery of a $140\ \mathrm{GeV}$ Higgs for all values of $\tan\beta$ with $600\ \mathrm{fb}^{-1} \times 2$

  In high $\tan\beta$ region: discovery reach beyond $M_H \approx 200\ \mathrm{GeV}$ also for lower luminosities
- 'Semi-exclusive' production of A looks challenging

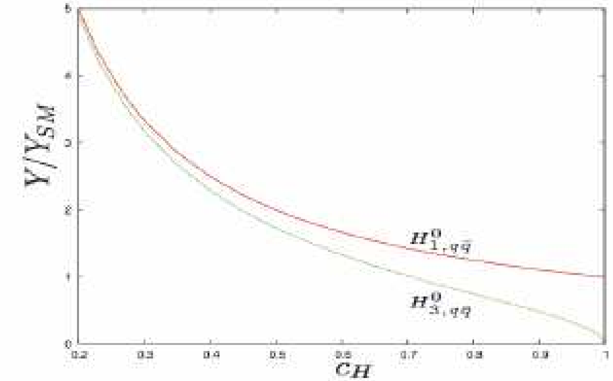
$\Rightarrow$ Interesting physics potential for probing MSSM Higgs sector; further experimental + theoretical efforts desirable

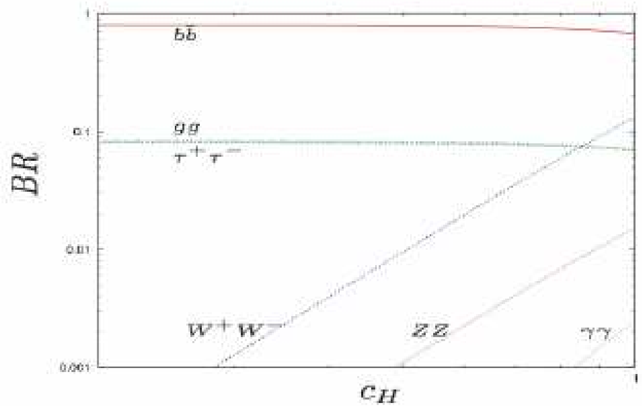
M. Chaichian, P.Hoyer, K.Huitu, VAK, A.Pilkington, JHEP (in print)

Higgs bosons in a triplet model

- Extend SM by addition of higher representations of Higgs sector in addition to the doublet.
  - One real and one complex triplet chosen ala Georgi and Machacek.

- 4 neutral scalar Higgs' bosons, charged and doubly charged Higgs also.
- Enhancement of Higgs-fermion-antifermion coupling by $1/c_H^2$ where c_H is a doublet-triplet mixing parameter.
- Large enhancement in CEP production cross section for $c_H < 1$ (top-loop).
- LEP constraints on Higgs mass weaker as coupling to weak bosons reduced by c_H^2.
- Tevatron will be able to access c_H=0.2 in tau-tau decay channel in near future.

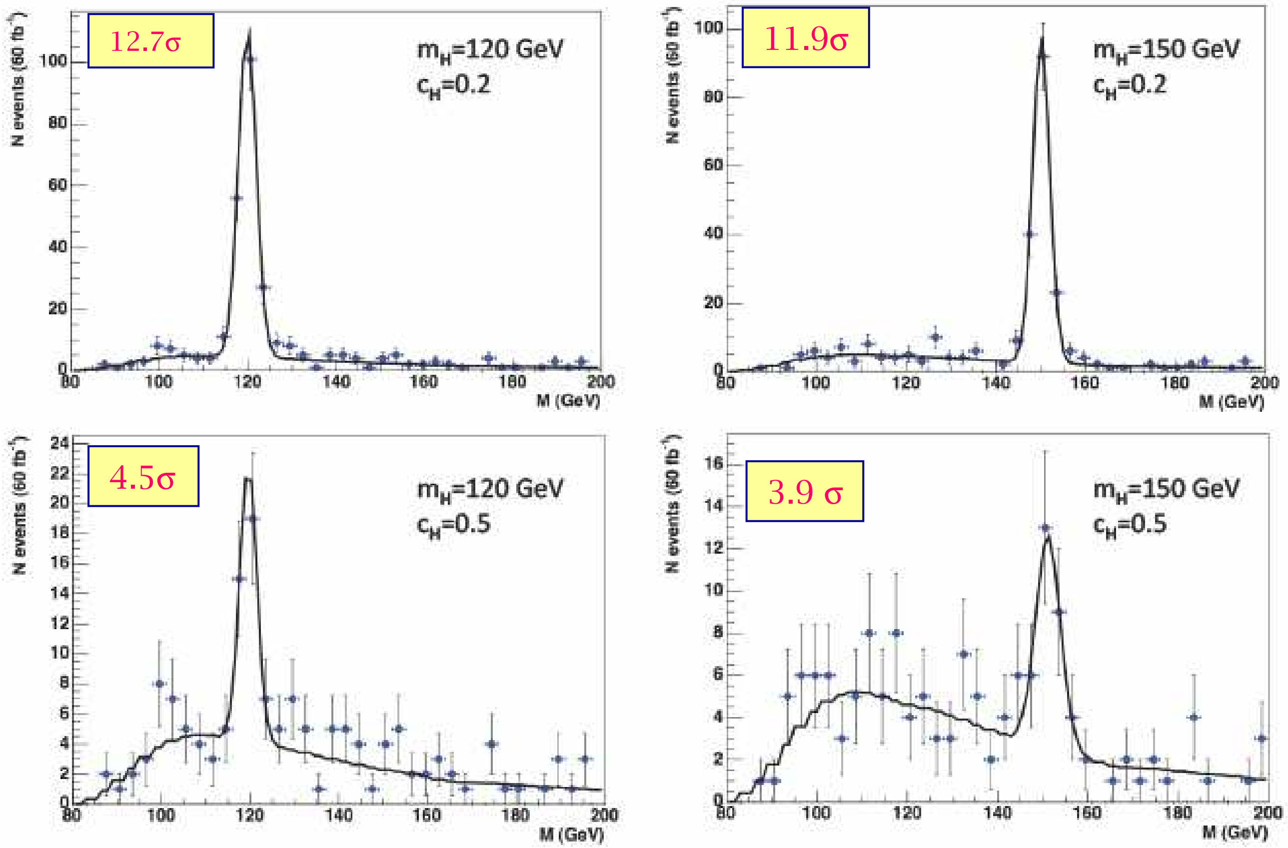




An additional bonus: doubly charged Higgs in photon-photon collisions → factor of 16 enhancement

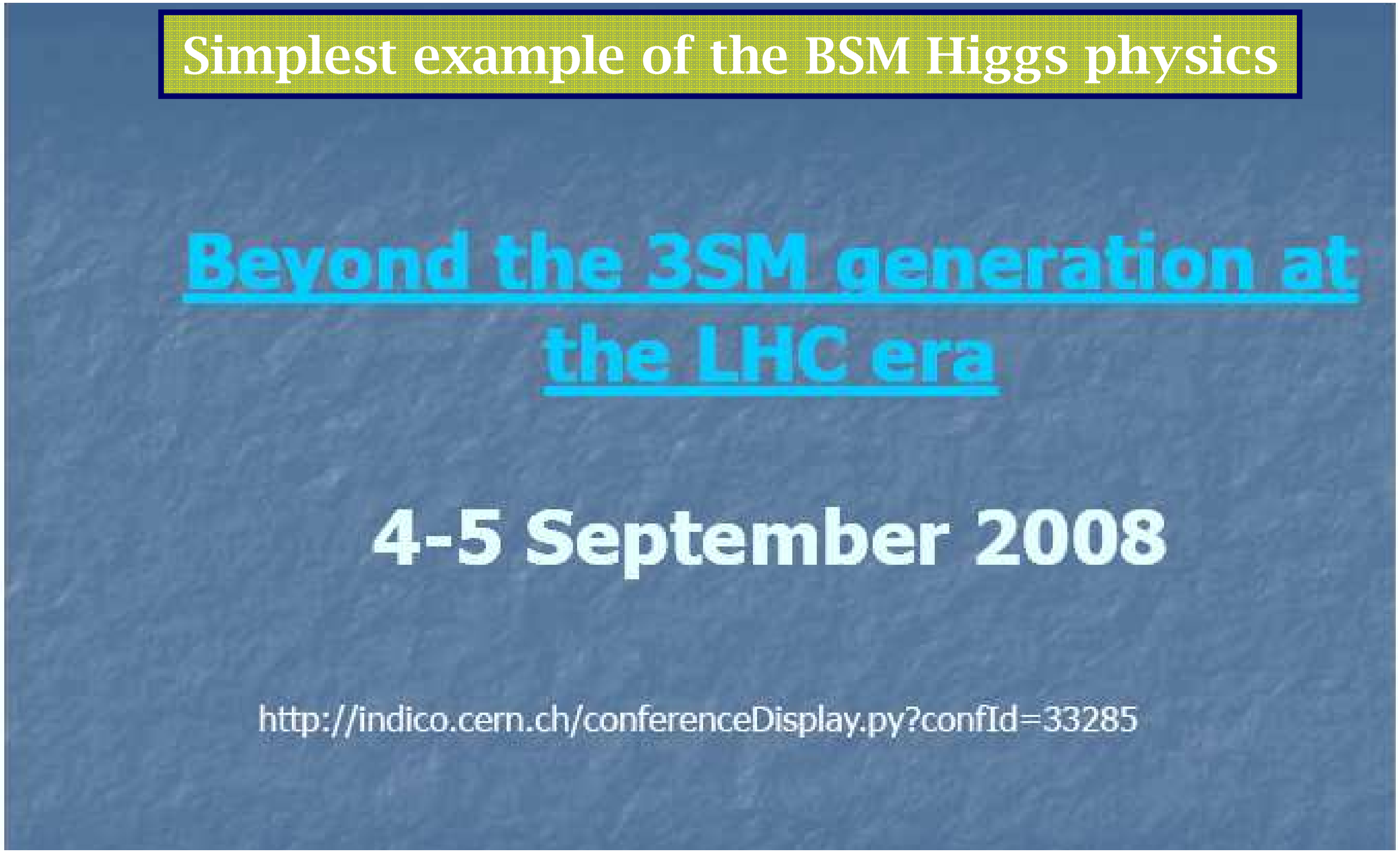
Simulation by A. Pilkington

Results: Triplet Higgs production



Expected mass distributions given 60 fb-1 of data.

Simplest example of the BSM Higgs physics



Enhancement of $\Gamma(H\to gg)$ ➔

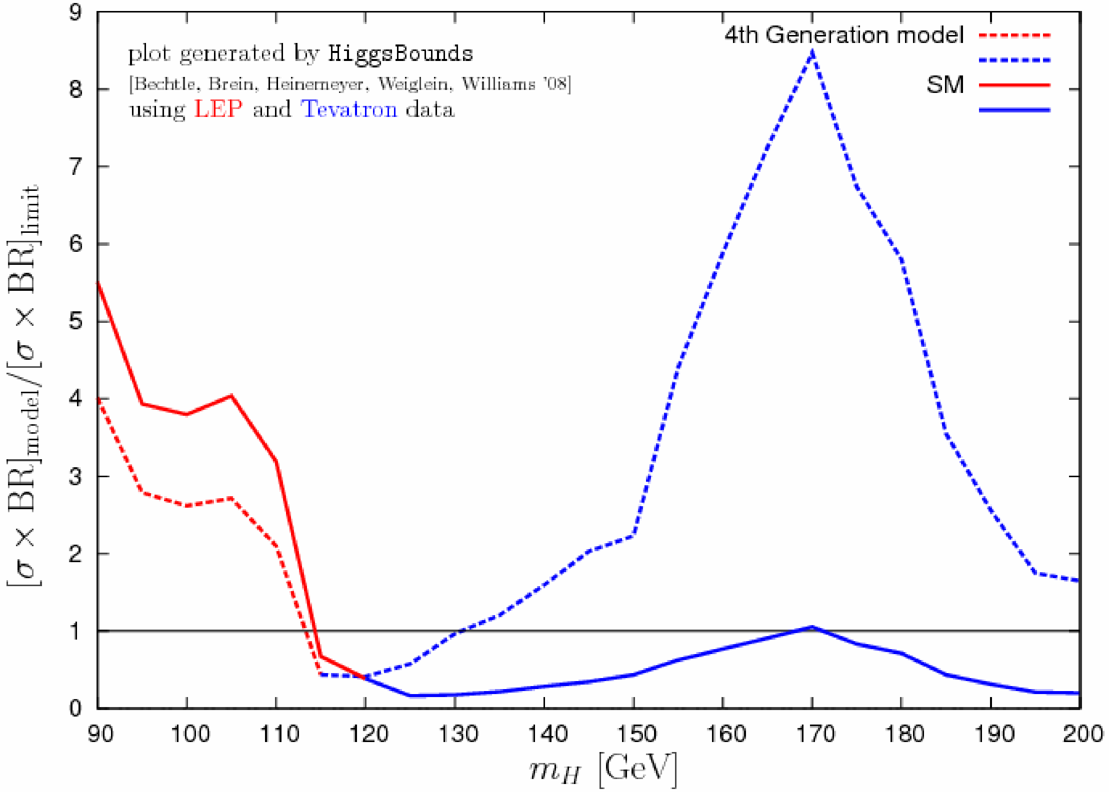
at 220 GeV:
CED ($H\to WW/ZZ$) rate – factor of **~9;**
at 120 GeV
CED ($H\to bb$) rate – factor of **~5.**

$B(H\to\gamma\gamma)$ is suppressed

$H\to ZZ$ – especially beneficial at M= 200-250 GeV

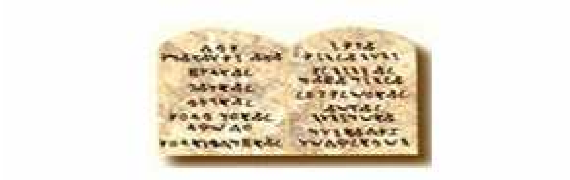
CDF & D0

L (fb^{-1})	Stat. Sign.
60	3.7
60*2	5.2
600	11.1
600*2	15.7



At 60 fb-1 : for M=120 GeV , ~25 bb ev; for M=220 GeV, ~ 50 WW ev; favourable bgs

CONCLUSION



God Loves Forward Protons

- Strongly suppressed QCD backgrounds in the forward proton mode provide a potential for direct determination of the Hbb Yukawa coupling, for probing CP properties and for measuring Higgs mass and width.
- Forward Proton Tagging would significantly extend the physics reach of the ATLAS and CMS detectors by giving access to a wide range of exciting new physics channels.
- FPT has the potential to make measurements which are unique at LHC and challenging even at a ILC.
- For certain BSM scenarios the FPT may be the Higgs **discovery channel.**

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