New Physics with Forward Protons at the LHC

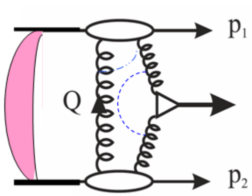
V.A. Khoze (IPPP, Durham & Rockefeller U. & PNPI)

"…The mechanic, who wishes to do his work well, must first sharpen his tools …"
—Chapter15, "The Analects" attributed to Confucius, translated by James Legge. (from X. Zu at DIS05)

(Based on works of extended Durham group)

main aims:

- to overview the (very) forward physics programme at the LHC;
- to show that the Central Exclusive Diffractive Processes may provide an exceptionally clean environment to study SM & to search for and to identify the nature of, New Physics at the LHC;
- to discuss the new Exclusive results at the Tevatron;
- to attract new members to the Exclusive Forward Club.



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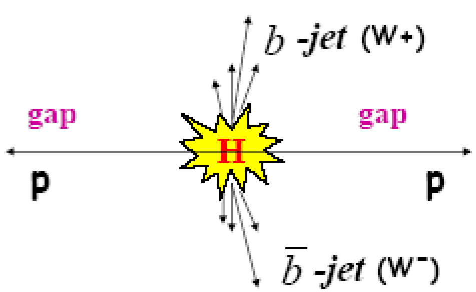

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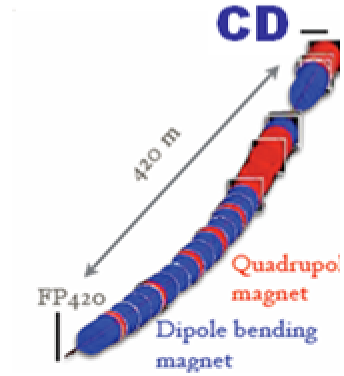


1. **Introduction** (looking forward to forward physics at the LHC).

2. **LHC** (in the forward proton mode) as a gluonic *Aladdin's* lamp.

3. **Basic elements of KMR approach** (only a taste) .

4. The 'standard candle' processes (***experimental checks at the Tevatron*****).**

5. Prospects for CED Higgs production.

6. Other BSM *scenarios, 'Exotics'.*

7. Conclusion.

CMS & ATLAS were designed and optimised to look *beyond the SM*

➔ *High -pt signatures in the central region*

The LHC is a discovery machine !

But…

• Main physics **'goes Forward'**

The LHC is a very challenging machine!

•Difficult background conditions, pattern recognition, Pile Up..

• The precision measurements are limited by systematics
(luminosity goal of $\delta L \leq 5\%$, machine ~10-15% at best, W/Z-mon.)

with a bit of personal flavour

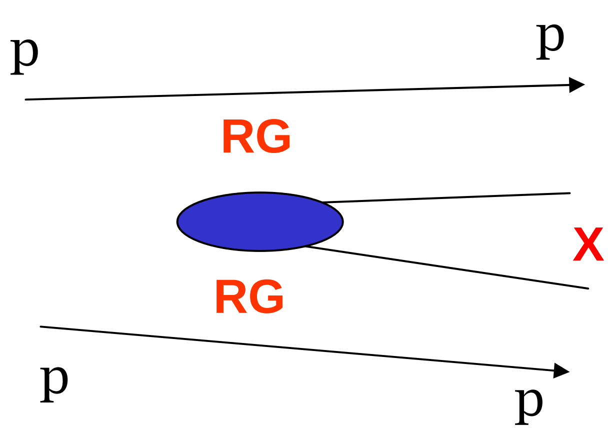
Lack of :

The LHC is not a precision machine (yet) !

•Threshold scanning , resolution of nearly degenerate states (e.g. MSSM Higgs sector)
•Quantum number analysing

•Handle on CP-violating effects in the Higgs sector
•Photon – photon reactions , …

ILC/CLIC chartered territory



Is there a way out?

YES → Forward Proton Tagging

Rapidity Gaps ⇨ Hadron Free Zones

matching Δ Mx ~ δM (Missing Mass)

Forward Proton Taggers as a gluonic Aladdin's Lamp

(Old and New Physics menu)

· **Higgs Hunting** (the LHC *'core business'*)

•Photon-Photon, Photon - Hadron Physics.

•**'Threshold Scan':** 'Light' SUSY ...

•Various aspects of Diffractive Physics (*soft & hard*).

•High intensity **Gluon Factory** (underrated gluons)
QCD test reactions, dijet P P-luminosity monitor

•Luminometry

•Searches for new heavy gluophilic states
and many other goodies...

FPT

✴Would provide a unique additional tool to complement the conventional strategies at the LHC and ILC.

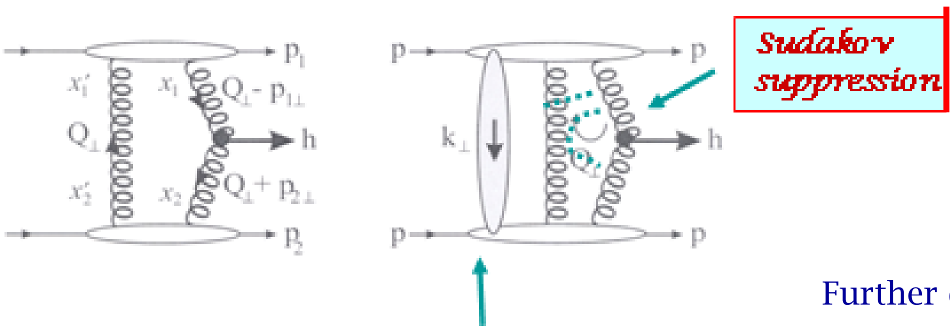
FPT ▶ will open up an additional rich physics menu ILC@LHC

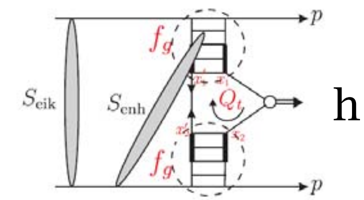
✴Higgs is only a part of the broad EW, BSM and diffractive program@LHC
wealth of QCD studies, glue-glue collider, photon-hadron, photon-photon interactions…

The basic ingredients of the Durham approach (KMR 1997-2009)

TCV- CMS-2007

- **RG** signature for Higgs hunting DKT-1987. Rescattering effects- DKS-1992.
- Developed, clearly formulated and promoted by **Bjorken** (1992-93)
- Original idea pp→pHp – **SJBrodsky** (<1990).





\+ ….

Further development (KKMR-01, **BBKM-06**, GLMM;KMR(07-09))

Bialas-Landshoff- 91
(Born-level)

rescattering/absorptive effects

(Asher's talk)

Main requirements:

•*inelastically* scattered protons remain intact

•active gluons do not radiate in the course of evolution up to the scale M

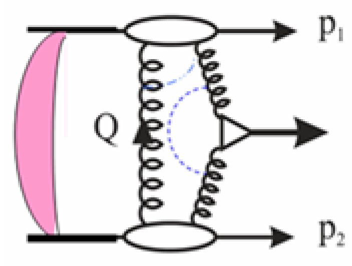
•<Qt> >>Λ_{QCD} in order to go by pQCD book

$$\sigma(CDPE) \sim 10^{-4} * \sigma \text{ (incl)}$$

KMR technology (implemented in ExHume MC)

New SuperChic 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

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

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

Tg + anom .dim. → *IR filter*

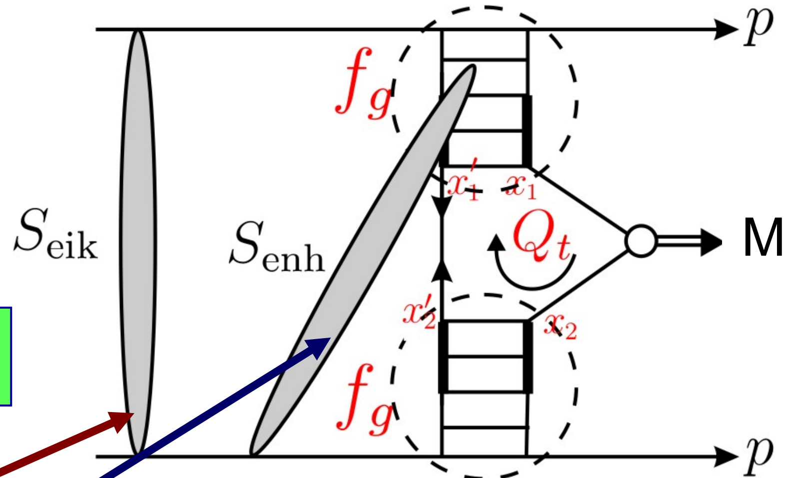
S^2 is the prob. that the rapidity gaps survive population by secondary hadrons → soft physics

New CDF results (dijets, γγ, χ_c)

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

S² ➔ absorption effects -necessitated by unitarity



gap

gap

Everybody's ~ happy (KMR, GLMM, FHSW, Petrov et al, BH, GGPS, Luna...MCs)

soft-hard factoriz^{n}

eikonal rescatt: between protons ← conserved

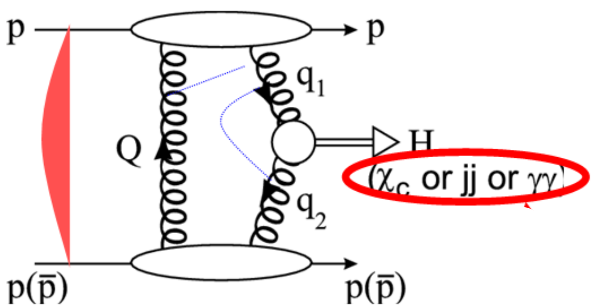
enhanced rescatt: involving intermediate partons ← broken

Subject of hot discussions nowadays : $S^2_{\rm enh}$

Standard Candle Processes

'BETTER TO LIGHT A CANDLE THAN TO RANT AGAINST DARKNESS'

(Confucius)



The process p-p →γγ/χc/ χb/ j-j are standard candles for the exclusive Higgs

孔夫子

孔丘 *Kong Qiu*

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 (PRD-2008)
  CDF: data up to $(Et)_{min}>35$ GeV

- 'Factorization breaking' between the effective diffractive structure functions measured at the Tevatron and HERA. CDF (PRD-00)

- The ratio of high Et dijets in production with one and two rapidity gaps. CDF (PRL-00)

- CDF results on exclusive charmonium CEP, (CDF, PRL-09)

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

- Central Diffractive Production of $\gamma\gamma$ (….$\pi\pi$,$\eta\eta$) (CDF, PRL-07)

  (in line with the KMRS calculations) (3 candidates & ? more candidates in the new data)

- Leading neutrons at HERA

(Cannot detect p/pbar, down beam pipe, but BSC → $\eta = 7.4$ empty)

* $p+\bar{p} \rightarrow p+\gamma\gamma+\bar{p}$ ← Cleanest (no S.I.) but smallest σ. KMR: 38 pb in our box). 2+1 candidates

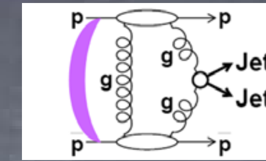
* $p+\bar{p} \rightarrow p+\chi_c+\bar{p}$ ← Clean, big σ: $\frac{d\sigma}{dy}(y=0) \sim 100\ \text{nb (KMRS)}$ but M(c) small (non-pert) & hadron

$p+\bar{p} \rightarrow p+\chi_b+\bar{p}$ ← More perturbative, smaller theory uncertainty. But σ ~ 1/500th χc. Also BR's not known! See next slide.

* $p+\bar{p} \rightarrow p+JJ+\bar{p}$ ← Big cross section, but least well defined (jets!) and largest background. ~ 100 pb for M(JJ) > 30 GeV

Our 3 measurements are all in good agreement (factor "few") with the Durham group predictions.

Comparison with KMR



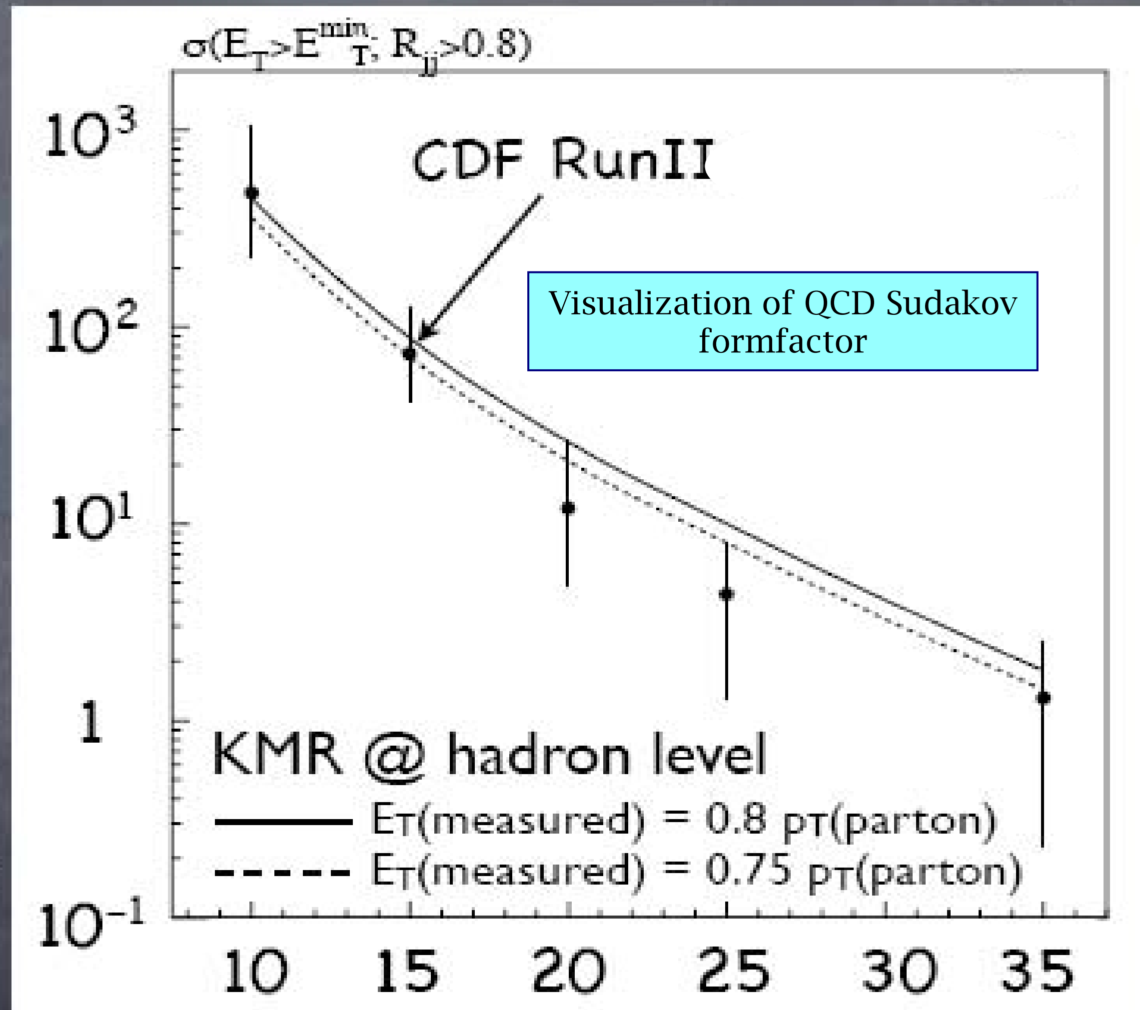
More direct comparison with KMR calculations including hadronization effects preferred

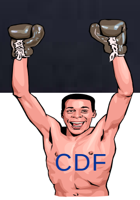
CDF out-of-cone energy measurement (cone R=0.7) :

- 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





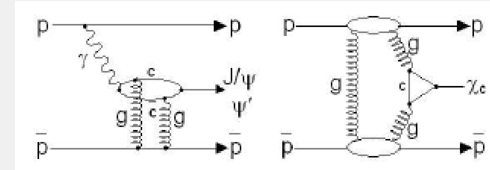
A killing blow to the wide range of theoretical models.

CDF PRD-2008

Summary of Results

$$p + \bar{p} \rightarrow p + \mu^+\mu^- + \bar{p}$$
$$p + \bar{p} \rightarrow p + \mu^+\mu^-\gamma + \bar{p}$$

M = 3-4 GeV/c2

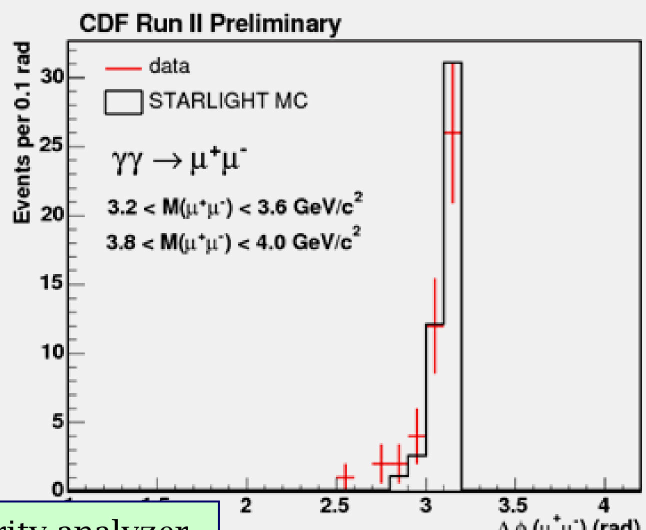


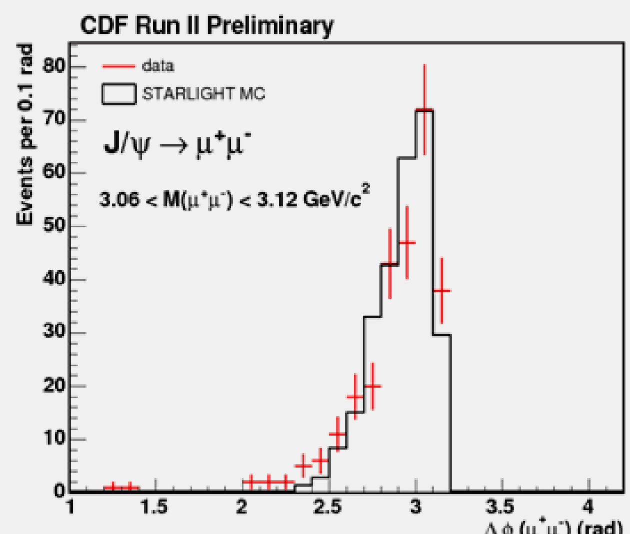
Quantity	This analysis	Theory
$\frac{d\sigma}{dy}(y=0)J/\psi$ (nb)	3.92±0.62	3.0±0.3
$\frac{d\sigma}{dy}(y=0)\psi(2S)$ (nb)	0.53±0.14	$0.46^{+0.11}_{-0.04}$
$\frac{d\sigma}{dy}(y=0)\chi_c^\circ$ (nb)	76±14	130± ≈50
$\sigma(box, QED, pb)$	2.7±0.5	2.18 ± 0.02
$\frac{d\sigma}{dy}(y=0)O\mathbb{P} \rightarrow J/\psi$	<2.3 nb (95% C.L.)	
$\frac{J/\psi}{\chi_c}$	0.052±0.015	No Prediction

90 nb
(χ width)
Durham

No **strong** evidence for odderon

$$\langle p_T(\gamma\gamma)\rangle < \langle p_T(IP)\rangle$$





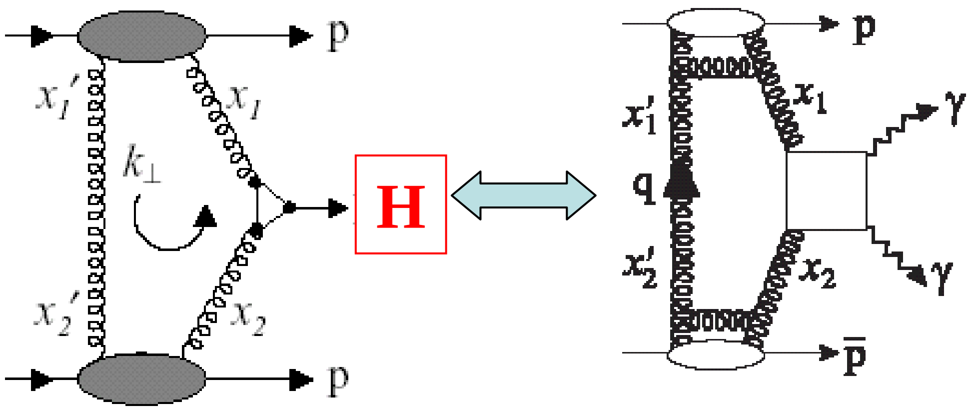
ππ/KK mode as a spin-parity analyzer

PRL 99, 242002 (2007) PHYSICAL REVIEW LETTERS week ending 14 DECEMBER 2007

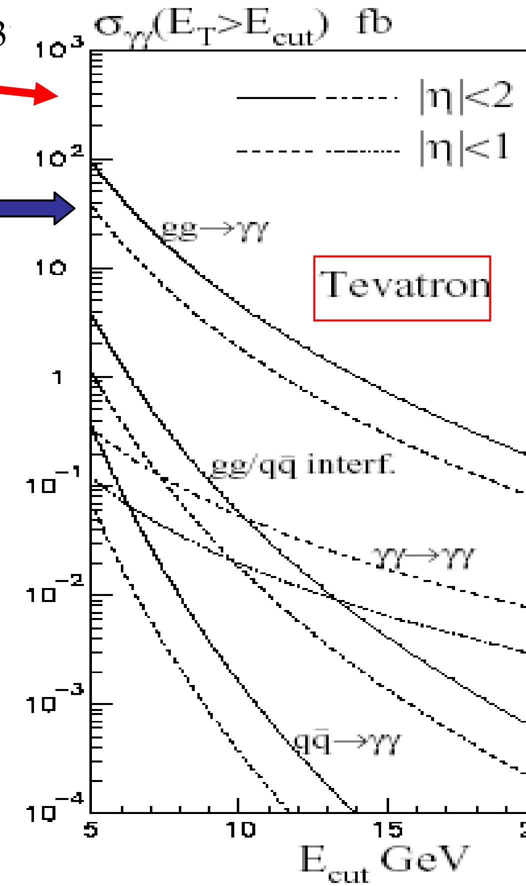
Search for Exclusive $\gamma\gamma$ Production in Hadron-Hadron Collisions

Khoze, Martin and Ryskin, Eur.Phys.J. C23: 311 (2002) ; KMR+Stirling hep-ph/040903

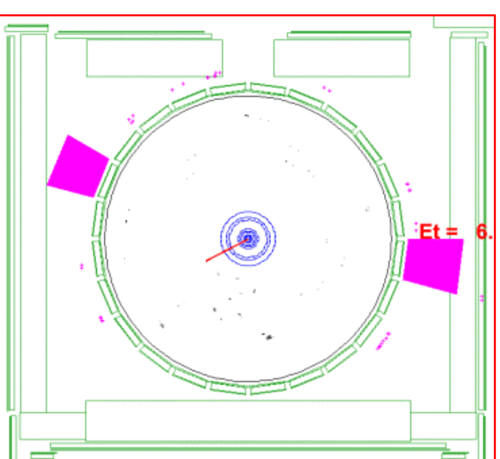
Claim factor ~ 3 uncertainty ; Correlated to p+H+p



36 fb



$\gamma\gamma \to \gamma\gamma$ & $q\bar{q} \to \gamma\gamma$ much smaller



$E_T(\gamma) > 5$ GeV; $|\eta(\gamma)| < 1.0$

3 candidates, 2 golden, 1 ? $\pi^0\pi^0$?

36 fb → 0.8 events

$$\text{Note}: \sigma_{MEAS} \approx 2\times10^{-12}\sigma_{INEL} \,!$$

New data, Lower threshold, possible "observation" to come(?)

& SuperCHIC ! (HKRS-09)

Current consensus on the LHC Higgs search prospects

•SM Higgs : detection is in principle guaranteed for any mass.

mH (SM) <157 GeV @95% CL

Recall, 14 TeV,L=10^{34} - anticipated only in ~2013-14

•In the MSSM h-boson most probably cannot escape detection, and in large areas of parameter space other Higgses can be found.

(Marcela's talk)

•But there are still troublesome areas of the parameter space:
intense coupling regime of MSSM, MSSM with CP-violation…

•More surprises may arise in other SUSY
non-minimal extensions: NMSSM, charming Higgs, hidden Higgs,…

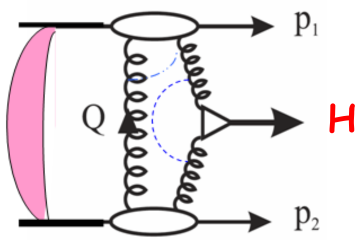
'Just' a discovery will not be sufficient!

• After discovery stage (Higgs Identification):

SPIN-PARITY

✶ The ambitious program of precise measurements of the Higgs mass, width, couplings, and, especially of the quantum numbers and CP properties would require an interplay with a *ILC* .

The main advantages of CED Higgs production



- Prospects for high accuracy (~1%) mass measurements (irrespectively of the decay mode).
- Quantum number filter/analyser.
  (0++ dominance ;C,P-even)
- H ->bb opens up (Hbb Yukawa coupl.)

conventionally- the needle in the haystack!

(gg)CED ⊘→ bb in LO ; NLO,NNLO, b- mass effects – controllable.

- For some BSM scenarios CEP may become a discovery channel !

(SM Higgs (if exists) will be discovered by the standard methods.)

- A handle on the overlap backgrounds- Fast Timing Detectors (10 ps timing or better).
- 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?

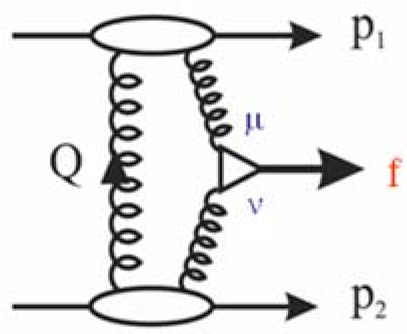
mass, spin, couplings to fermions and Gauge Bosons, invisible modes…
→ for all these purposes the CEP will be particularly useful !

for Higgs searches in the forward proton mode the QCD bb backgrounds are suppressed by Jz=0 selection rule and by colour, spin and mass resolution ($\Delta M/M$) –factors.

There must be a god !

The origin of Jz=0 selection rule

KMR-2000



$$M_{\mu\nu}(gg^{PP}) \sim (p_{t,1} - Q_t)_\mu (p_{t,2} + Q_t)_\nu$$

after $(\bar{Q}_t)$ angular integration at $p_{t,i} = 0$ → $-\delta^{(2)}_{\mu\nu} Q_t^2 / 2$

in terms of helicity amplitudes . $1/2\{(++;f) + (--;f)\}$ → Jz=0, P-even state

at non-zero $p_{t,i}$ - an admixture of Jz=2 → $\frac{(2p_{1,t}p_{2,t})^2}{Q_t^4}$

in terms of the MHV rules the only nonzero amplitudes gg→qq

(S .Parke, T.Taylor (1986))

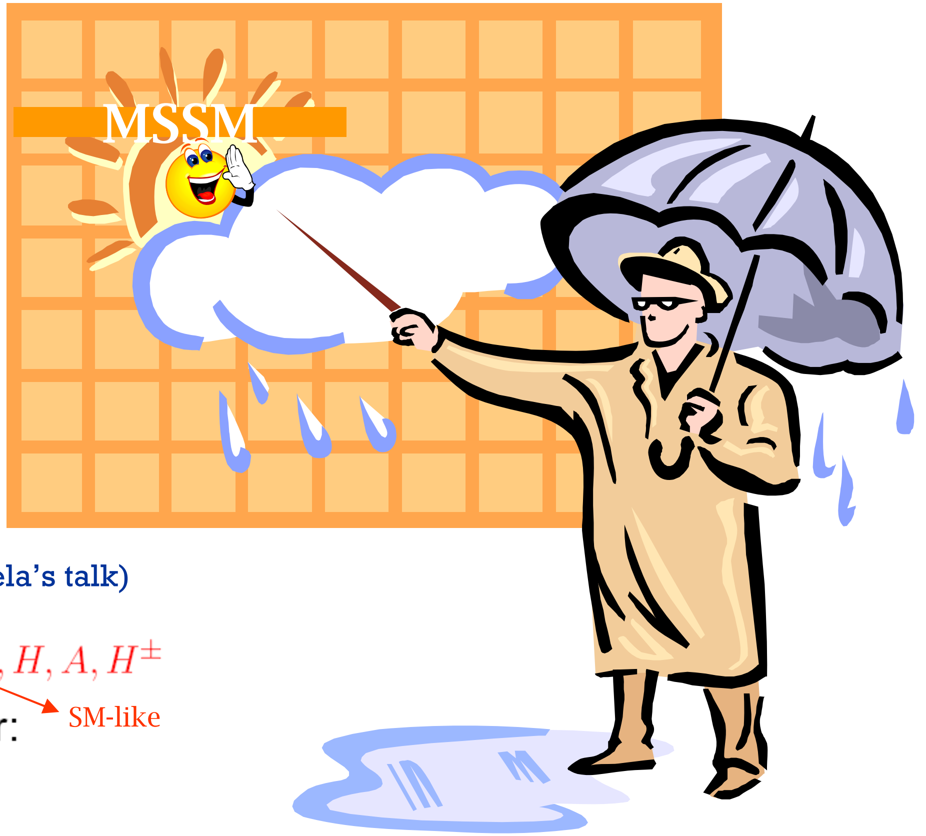
(+ - ; + -) J_z=2, HCA

(-+ : -+ /+-)

(very fashionable nowadays)

without 'clever hardware':
for H(SM) at 60 fb-1
only a handful of events due to
severe exp. cuts and low efficiencies,
(factor ~50), though **S/B~1** .

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



Situation in the MSSM is very different from the SM

(Marcela's talk)

- Higgs sector of the MSSM: physical states $h, H, A, H^{\pm}$ (h → 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 $H \to ZZ \to 4\mu$

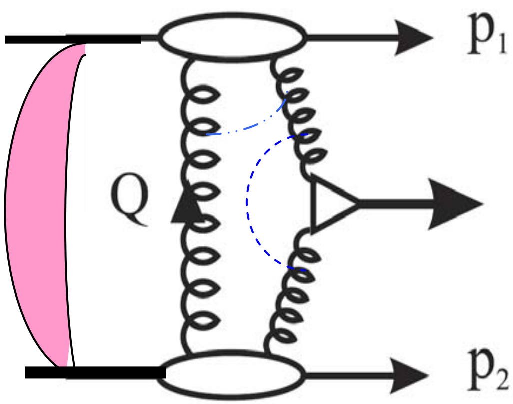
  Large enhancement of coupling to $b\bar{b}$ (and $\tau^+\tau^-$) in region of high $\tan\beta$

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

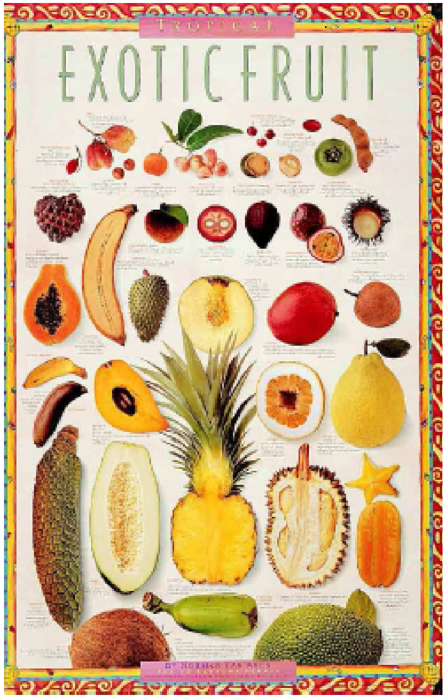
The backgrounds to the diffractive H bb mode are manageable!

The MSSM and more '*exotic*' scenarios

$$pp \longrightarrow p + \phi + p$$



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 (HKRTW-08,09)
- NMSSM (J. Gunion, et al.),
- Hidden/Charming Higgs (C.Csaki et al)
- *Invisible' Higgs* (BKMR-04)

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

Higgs spin-parity determination

HKRTW-09

Standard analyses for the LHC:

rely largely on the coupling of the Higgs to heavy gauge bosons:

$$
\begin{aligned}
H &\to ZZ \to 4\ell \\
H &\to WW \to \ell\nu\,\ell\nu \\
WW \to H &\to \tau^+\tau^-
\end{aligned}
$$

Needed for this analysis: a Higgs with

– a sufficiently large $HV_\mu V^\mu$ coupling
  i.e. no large suppression with respect to the SM value

– a sufficiently large BR($H \to VV$)
  $\Rightarrow M_H \gtrsim 140$ GeV to suppress $H \to b\bar{b}$

– possibly a large BR($H \to \tau^+\tau^-$)

Situation in MSSM: *

Light Higgs: $M_h \lesssim 135$ GeV

$\Rightarrow$ light Higgs h has too small BR($h \to VV^{(*)}$)

Heavy Higges:

$$g_{hVV} = g_{HVV}^{\text{SM}} \times \sin(\beta - \alpha)$$
$$g_{HVV} = g_{HVV}^{\text{SM}} \times \cos(\beta - \alpha)$$
$$g_{AVV} = 0 \qquad \text{at tree-level}$$

$M_H \approx M_A \gtrsim 150$ GeV:

$\Rightarrow \beta - \alpha \to \pi/2$

$\Rightarrow$ h has substantial VV coupling

$\Rightarrow$ H and A have negligible VV coupling

$\Rightarrow$ no heavy Higgs with substantial coupling to VV in the MSSM

$\Rightarrow$ method relying on $H \to VV$ cannot be applied

* α diagonalizes the neutral $\mathcal{CP}$-even Higgs sector

Situation in other models beyond the SM:

If:

– Higgs sector consists of doublets and singlets
– one has one light SM-like Higgs, $M_H^{\text{SM-like}} \lesssim 140$ GeV

then:

– $\text{BR}(H^{\text{SM-like}} \to VV^{(*)})$ is too small
– the following sum rule for the New Physics (NP) Higgs couplings holds:

$$\sum_i (g_{H_iVV})^2 = (g_{HVV}^{\text{SM}})^2$$

Since the light Higgs is SM like all other Higgses have small H_iVV coupling

$H \to VV^{(*)}$: method cannot be applied

$H \to \tau^+\tau^-$: large enhancement of $\Gamma(H \to \tau^+\tau^-)$ needed ...

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

Some details ($\phi = h^{\mathrm{MSSM}}, H^{\mathrm{MSSM}}, H^{\mathrm{4th\ gen}}$):

1. Proton detection: in Forward Proton Taggers at 220 m, 420 m
2. Higgs decay: (here only) $\phi \to b\bar{b}$
   two high p_T b jets, measured in ATLAS or CMS
3. Trigger to keep signal (2):
   "cocktail" of triggers: FP @ 220m, high p_T jets, high p_T leptons, ...
4. Identification of signal: (1) and (2) have to match in mass
5. Cross section calculation: $\sigma_{\mathrm{SM}} \times \frac{\Gamma(gg\to\phi)_{\mathrm{NP}}}{\Gamma(gg\to H)_{\mathrm{SM}}}$
6. Decay calculation: $\mathrm{BR}_{\mathrm{NP}}(\phi \to b\bar{b})$ $\Rightarrow$ FeynHiggs (MSSM: incl. Δ_b dep.)
   advantage over SM: possibly enhanced decay rates
7. Backgrounds:
   taken into account according to recent analyses/
   best available estimates

$\Rightarrow$ 5 σ discovery contours, 3 σ significance sensitivities

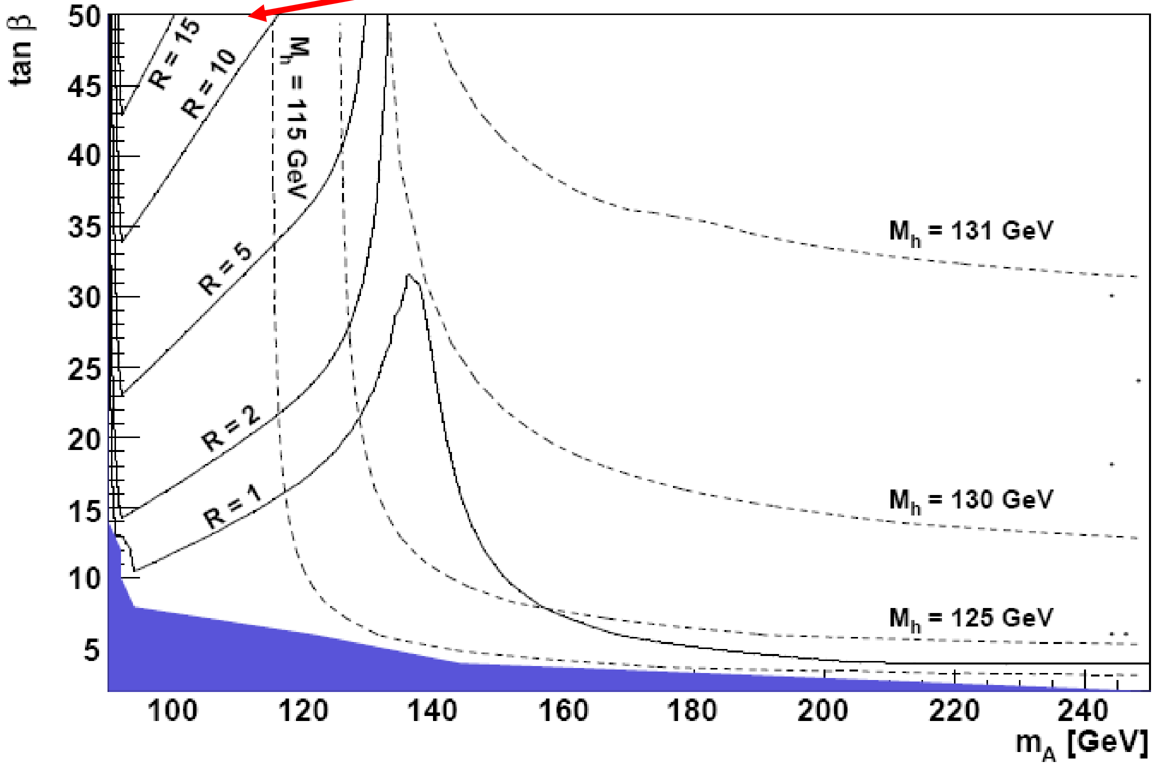
Sven Heinemeyer/Georg Weiglein, FP420 workshop (Manchester), 13.12.2009

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

HKRSTW-07

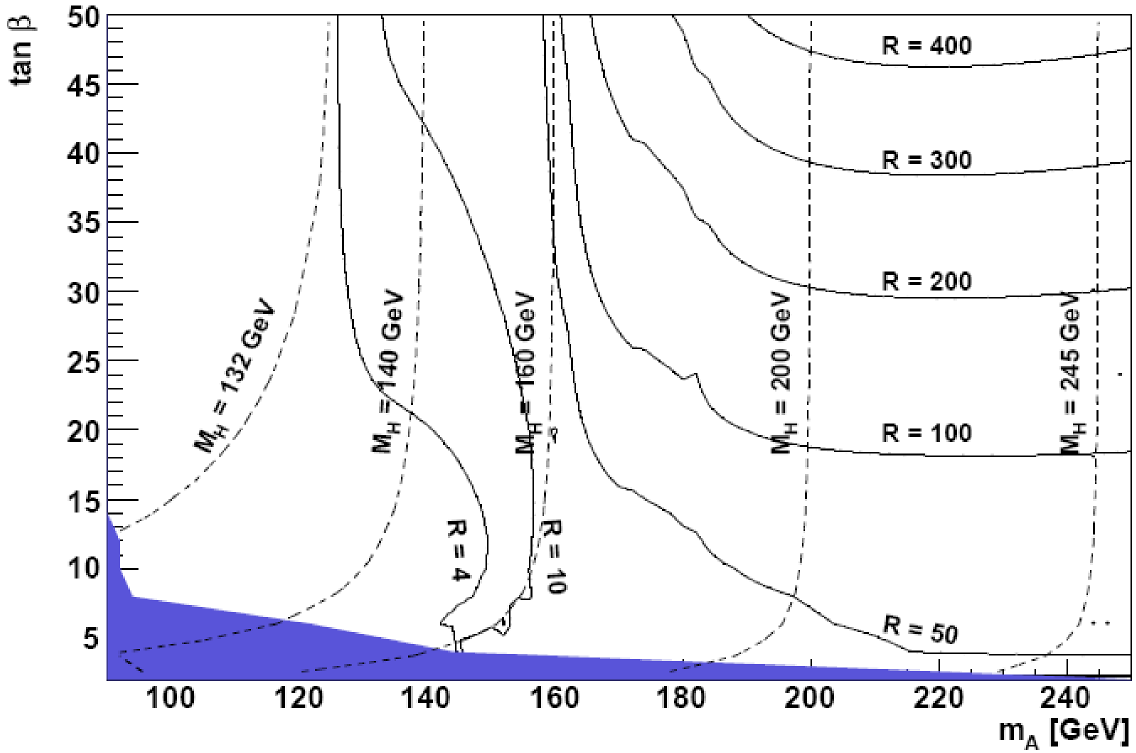


⇒ Large enhancement possible for relatively small M_A and large $\tan\beta$

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:

HKRSTW-07



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

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

Four luminosity assumptions:

60 fb^{-1}:

$\mathcal{L} = 2 \times 30 \ \ \text{fb}^{-1}$: three years of low-luminosity running

60 fb^{-1} eff $\times$ 2:

as "60", but assuming an improvement in signal efficiency etc.

effectively: signal rates doubled

600 fb^{-1}:

$\mathcal{L} = 2 \times 300 \ \ \text{fb}^{-1}$: three years of high-luminosity running

600 fb^{-1} eff $\times$ 2:

as "600", but assuming an improvement in signal efficiency etc.

effectively: signal rates doubled

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

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

NEW DEVELOPMENT

Update with respect to 2007 analysis:

– Update of background estimates: NLO for $gg \to b\bar{b}$

– Update of LEP and Tevatron exclusion bounds
  $\Rightarrow$ HiggsBounds [B. Bechtle, O. Brein, S.H., G. Weiglein, K. Williams '08]

– Update of σ and BR calculation
  $\Rightarrow$ FeynHiggs [T. Hahn, S.H., W. Hollik, H. Rzehak, G. Weiglein '98 - '09]
  (small changes in Δ_b, $gg \to h$ improved)

MSSM scenarios:

– "normal" benchmarks: m_h^{max}, no-mixing ($\mu = +200$ GeV)

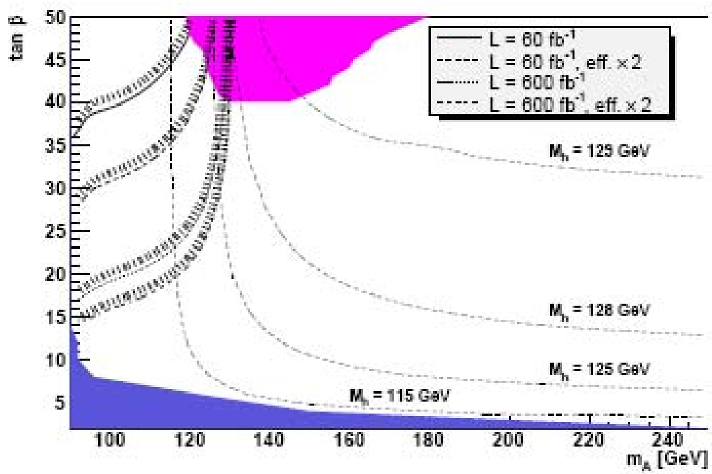
– CDM benchmarks: M_A-$\tan\beta$ planes in agreement with CDM
  [J. Ellis, T. Hahn, S.H., K. Olive, G. Weiglein '07]

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

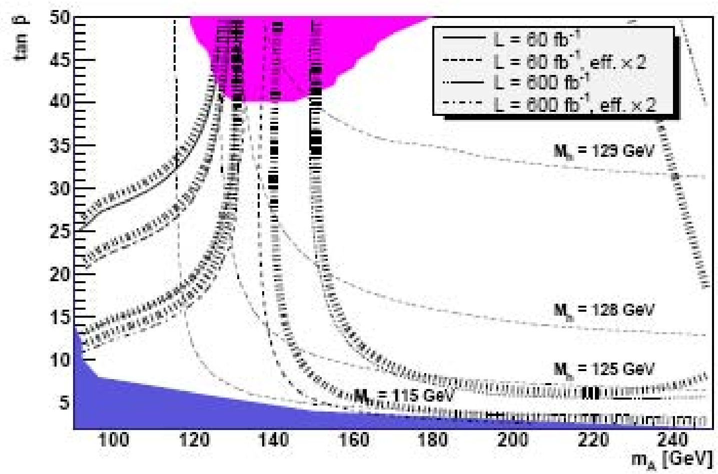
$H \to b\bar{b}$

Results for h in the $m_h^{\max}$ scenario:

5 σ discovery



3 σ evidence



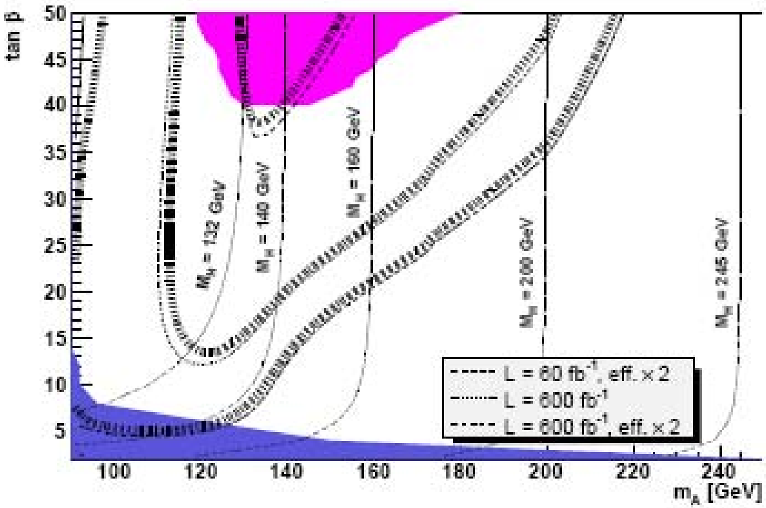
pink: Tevatron exclusion bounds
blue: LEP exclusion bounds

$\Rightarrow$ large parts can be covered at 3 σ!

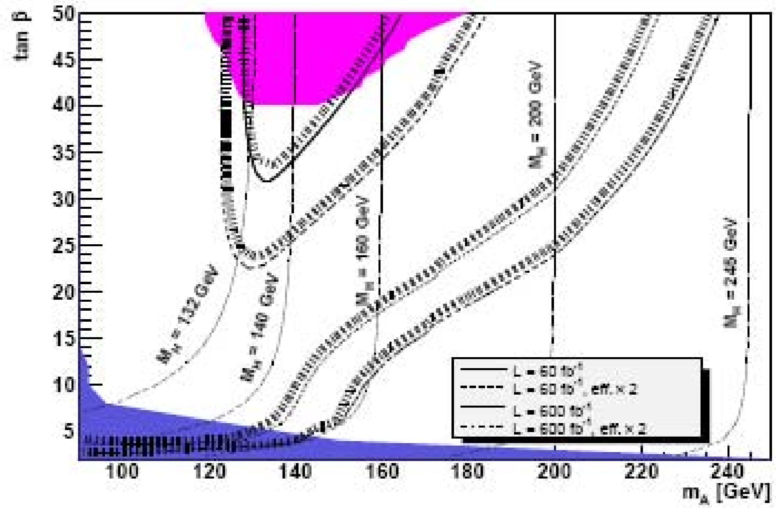
$H \to b\bar{b}$

Results for H in the m_h^{max} scenario:

5 σ discovery



3 σ evidence



pink: Tevatron exclusion bounds
blue: LEP exclusion bounds

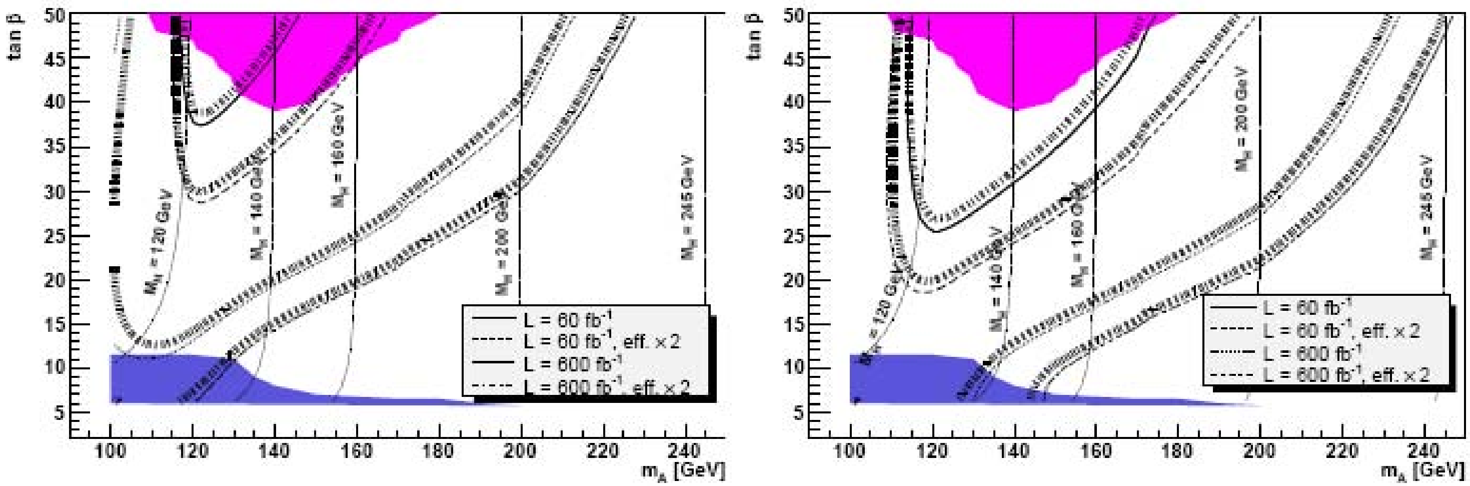
$\Rightarrow$ large discovery regions, but no "LHC wedge" coverage

$H \to b\bar{b}$

CDM benchmarks

Results for H in the CDM scenario (#3):

5 σ discovery | 3 σ evidence



pink: Tevatron exclusion bounds

blue: LEP exclusion bounds

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

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

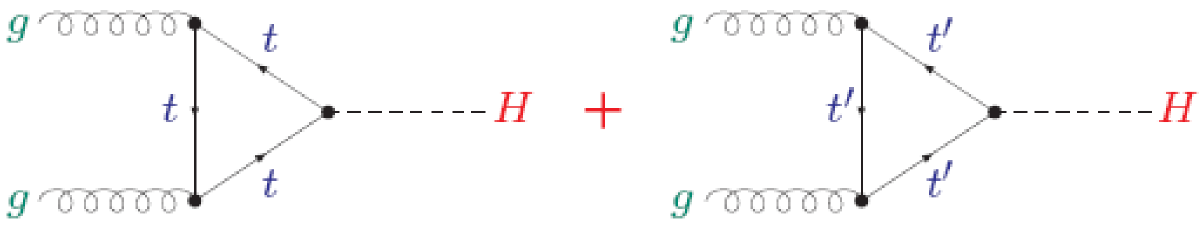
⇒ large discovery regions, but no "LHC wedge" coverage (slightly better than in $m_h^{\max}$)

3. 4th generation model

Assume the SM with a 4th generation of heavy fermions

Relevant changes:

1. additional contribution to $gg \to H$:



$\Rightarrow$ factor of ~ 9 in Higgs production cross section

2. $\Rightarrow$ factor of ~ 9 in $\Gamma(H \to gg)$

   $\Rightarrow$ reduced $\mathrm{BR}(H \to b\bar{b})$, $\mathrm{BR}(H \to \tau^+\tau^-)$

B(H→γγ) is suppressed

Evaluation of SM quantities with FeynHiggs

subsequent application of reduction and enhancement factors

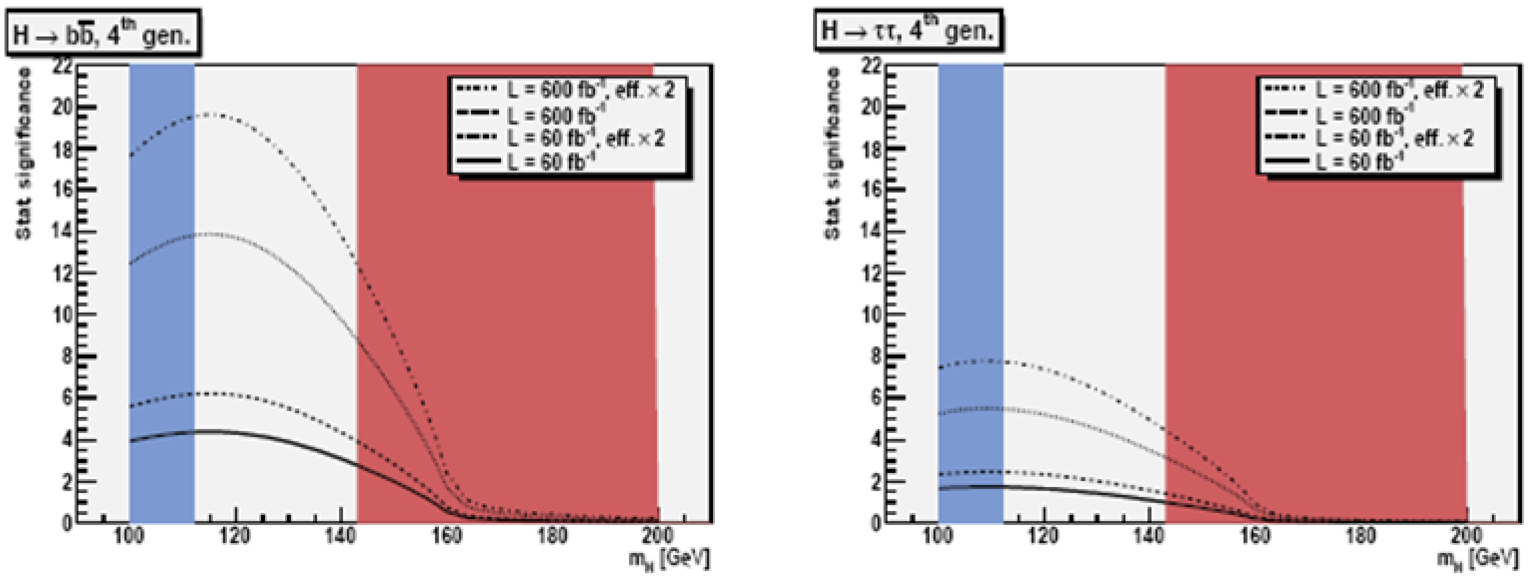


Figure 4: Significances reachable in the SM4 in the $H \rightarrow b\bar{b}$ (left) and $H \rightarrow \tau^+\tau^-$ (right) channel for effective luminosities of "60 fb^{-1}", "60 fb^{-1} eff×2", "600 fb^{-1}" and "600 fb^{-1} eff×2". The regions excluded by LEP appear as blue/light grey for low values of $M_{H^{\mathrm{SM4}}}$ and excluded by the Tevatron as red/dark grey for larger values of $M_{H^{\mathrm{SM4}}}$.

⇒ good prospects even with relatively low luminosity

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

New approach to study heavy quarkonia and new charmonium-like states

(work together with L. Harland-Lang, M.Ryskin and W.J. Stirling)

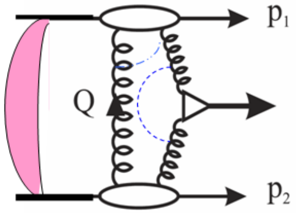
of interest for ALICE & LHCb

Issues addressed:

- New **SUPERCHIC** MC for all $c\bar{c}$ **P** -states.
- Absorption effects for **CEP** of the $0^+, 1^+, 2^+, 0^-$ $c\bar{c}$ - states revisited
- Proton angular correlations for different $0^+, 1^+, 2^+, 0^-$ $c\bar{c}$ -states.
- Expectations for the CEP of the $0^+, 1^+, 2^+, 0^-$ $b\bar{b}$ -states.

As compared to the previous K(KMR)S studies:

- More comprehensive calculation of the absorption effects using the new KMR-07/08 model for soft diffraction (including the enhanced screening).
- New calculational routine for implementing polarization structure in the b-space.
- New experimental/theoretical results for the parameters of heavy quarkonia, in particular $\Gamma(\chi \to gg)$.



χ_c, χ_b

Why an interest to the CEP of χ_c, χ_b ?

- Testing ground for the formalism of CEP used to evaluate the New Physics signals (e.g. 'Diffractive Higgs')
- Open issues in Quarkonium Spectroscopy, such as χ_b quantum numbers. New way to address Quarkonium Physics (numerous new exotic charmonium like states).
- New Encouraging CDF results on CEP of the χ_c .

Heavy Quarkonia

Traditional testing ground for various aspects of QCD

- NRQCD, QCDME, Lattice QCD, QCD sum rules, potential models
- Large NLO….. PT corrections.
- P-states- sensitivity to the derivatives of the wave function, relativistic effects….
- Nature of the new states around 4 GeV; X, Y, Z, other applications of the CEP…

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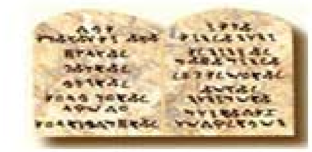
CONCLUSION



God Loves Forward Protons

- Forward Proton Tagging would significantly extend the physics reach of the **LHC** 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 sometimes challenging even at a **ILC**.

- For certain BSM scenarios the **FPT** may be the Higgs discovery channel.

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The University of Manchester

IP3 University of Durham

The FP420 R&D project (2004-2009)

- FP420 was a joint R&D collaboration between CMS and ATLAS to develop a forward proton detector system to tag outgoing protons.
- Key questions:
  - Can suitable forward detectors be placed close to the LHC beam
  - What is the physics potential of these detectors?
  - Will they cover an interesting region of Higgs mass?
- Final report is available at JINST 4:T10001,2009 [arXiv:0806.0302]

The ATLAS Forward Proton upgrade (2008+)

- AFP is the proposed forward proton detector upgrade to ATLAS:
  - Detectors would be installed at 220m and 420m either side of the interaction point
  - Already reviewed as Letter-of-intent by ATLAS. Encouraged by Executive Board to produce a Technical Proposal by end of 2010.
  - If approved, will be installed in 2013/2014 shutdown, take data at the LHC design luminosity.

January 4, 2009

JINST-09

The FP420 R&D Project: Higgs and New Physics with forward protons at the LHC

M. G. Albrow[1], R. B. Appleby[2], M. Arneodo[3], G. Atoian[4], I.L. Azhgirey[5], R. Barlow[2], I.S. Bayshev[5], W. Beaumont[6], L. Bonnet[7], A. Brandt[8], P. Bussey[9], C. Buttar[9], J. M. Butterworth[10], M. Carter[11], B.E. Cox[2,], D. Dattola[12], C. Da Via[13], J. de Favereau[7], D. d'Enterria[14], P. De Remigis[12], A. De Roeck[14,6,*], E.A. De Wolf[6], P. Duarte[8,†], J. R. Ellis[14], B. Florins[7], J. R. Forshaw[13], J. Freestone[13], K. Goulianos[15], J. Gronberg[16], M. Grothe[17], J. F. Gunion[18], J. Hasi[13], S. Heinemeyer[19], J. J. Hollar[16], S. Houston[9], V. Issakov[4], R. M. Jones[2], M. Kelly[13], C. Kenney[20], V.A. Khoze[21], S. Kolya[13], N. Konstantinidis[10], H. Kowalski[22], H.E. Larsen[23], V. Lemaitre[7], S.-L. Liu[24], A. Lyapine[10], F.K. Loebinger[13], R. Marshall[13], A. D. Martin[21], J. Monk[10], I. Nasteva[13], P. Nemegeer[7], M. M. Obertino[3], R. Orava[25], V. O'Shea[9], S. Ovyn[7], A. Pal[8], S. Parker[20], J. Pater[13], A.-L. Perrot[26], T. Pierzchala[7], A. D. Pilkington[13], J. Pinfold[24], K. Piotrzkowski[7], W. Plano[13], A. Poblaguev[4], V. Popov[27], K. M. Potter[2], S. Rescia[28], F. Roncarolo[2], A. Rostovtsev[27], X. Rouby[7], M. Ruspa[3], M.G. Ryskin[21], A. Santoro[29], N. Schul[7], G. Sellers[2], A. Solano[23], S. Spivey[8], W.J. Stirling[21], D. Swoboda[26], M. Tasevsky[30], R. Thompson[13], T. Tsang[28], P. Van Mechelen[6], A. Vilela Pereira[23], S.J. Watts[13], M. R. M. Warren[10], G. Weiglein[21], T. Wengler[13], S.N. White[28], B. Winter[11], Y. Yao[24], D. Zaborov[27], A. Zampieri[12], M. Zeller[4], A. Zhokin[6,27]*

FP420 R&D Collaboration

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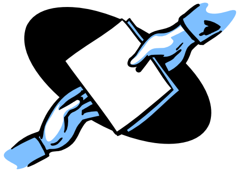
*Contact persons: Brian.Cox@manchester.ac.uk, Albert.de.Roeck@cern.ch
†Now at Rice University

There has been huge progress over the past few years...

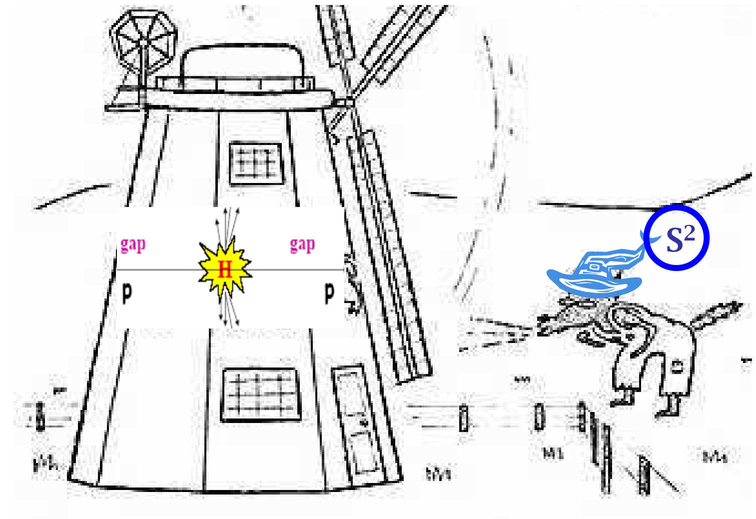


- 175 page report
- 96 authors
- 29 institutions

Thank You

BACKUP

Who's Afraid of the Big, Bad S^2 -Wolf?



- S^2 does not affect the signal-to-background ratio- for all irreducible backgrounds (signal evidence is much less affected).

  Overlap background ☛ psec (not lifetime of theor. pred^{ns}, but **FTD** resol^{n})

- Main reduction of the signal (factor of ~50) comes from the experimental requirements (cuts and efficiencies...) which are currently known mainly for the inclusive environment. Further progress with hard/soft -ware for the **CEP** processes can be expected.
  More experimental work needed.

But we have to be open-eyed

- Experimentally we have not seen (at least so far) any evidence in favour of large enhanced absorption (KKMR-01 KMR-09).

- Current selection of the UPDF is quite conservative.
  Due to the $(f_g)^4$ behaviour- rise up to a factor of 3 (Cox et al, KMR).
  New studies (including NLO effects) are underway (MRW-09,KMR).

.

Up to two orders of magnitude rise in the popular BSM Higgs models.

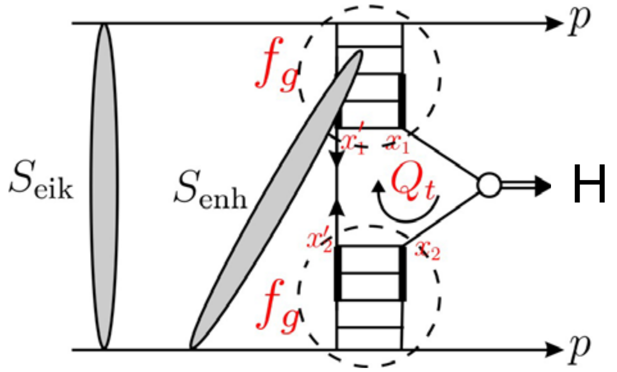
Far more theoretical papers than the expected number of the CED produced (**SM**) Higgs events

pp → p+H+p

Base value: σ = 2.5 fb

{ SM M_H=120 GeV
LHC=14 TeV
eikonal screening }

A. Martin, 12.12.09, Manchester



-45% adjust c in upper limit $1 - k_t/(cM_H+k_t)$ of z integration of Sudakov factor to reproduce one-loop result.

EML

Find c=1 (Forshaw-Coughlin, KMR09), and not 0.62 (KKMR04)

-25% if enhanced screening included (KMR-0812.2413)

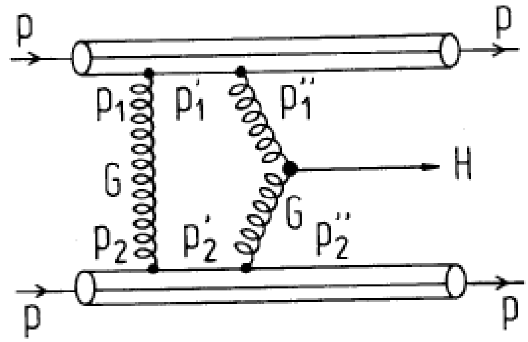
+20% due to NLO unintegrated gluon (MRWatt-0909.5529)

+20% connected with self-energy insertions in propagator of screening gluon (Ryskin et al.)

PS Recall factor 3 uncertainty

PPS Remember SUSY Higgs can be greatly enhanced

Production of Higgs particles in diffractive hadron hadron collisions.
A.Schafer, O.Nachtmann and R..Schopf
Phys.Lett.B249:331-335,1990.



S.J. Brodsky observed that as the experimental isolation of these very special collisions might be very difficult, it could be more sensible to study the corresponding strong interaction process, namely coherent higgs production due to pomeron exchange. In this contribution we present some estimates for this process.