LPCC

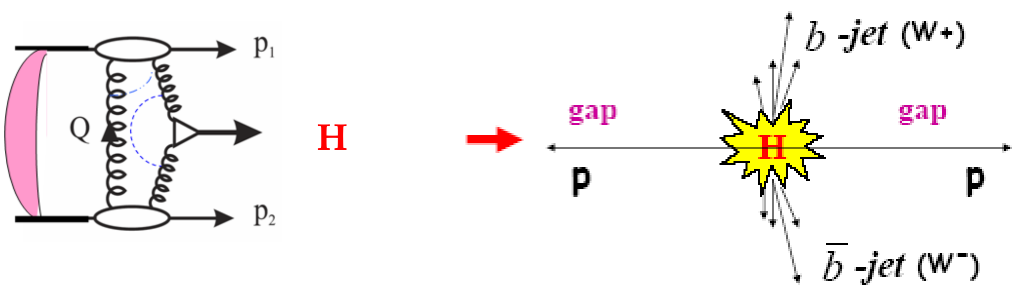
LHC Physics Centre at CERN

LHC WG on Forward Physics and diffraction

Higgs Production in the Forward Proton Mode Revisited

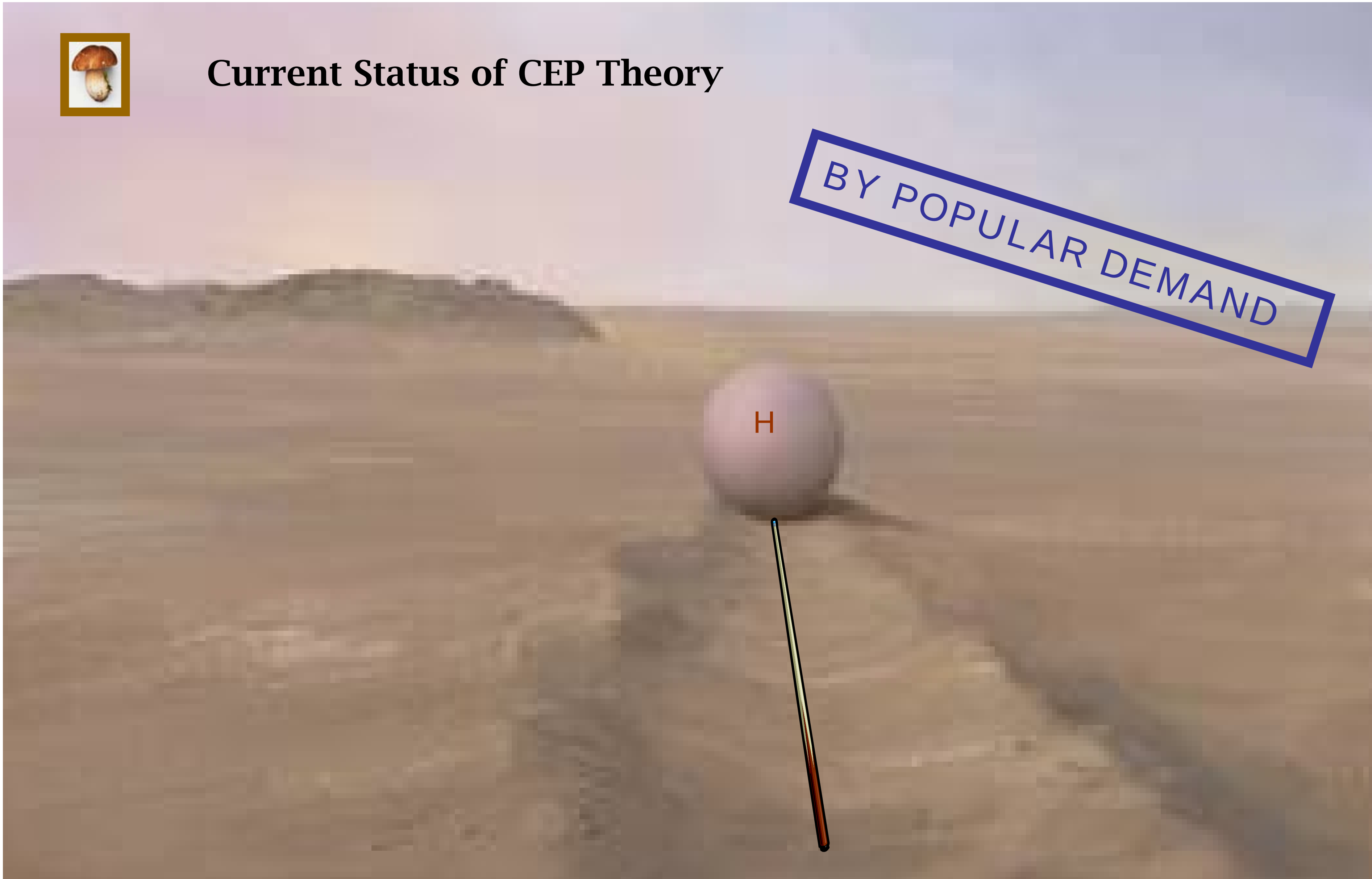
V.A. Khoze (IPPP, Durham)

(in collaboration with Lucian Harland-Lang , Misha Ryskin and Marek Tasevsky)



Main Goal: **KEEP THE BALL ROLLING**

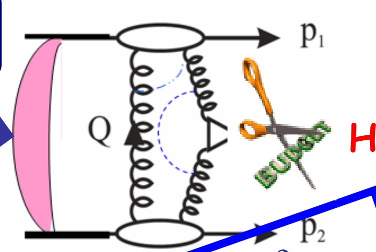
Current Status of CEP Theory



Current situation
with ‘diffractive Higgs’
(post- LHC discovery)

We have to be open-eyed

The main advantages of CEP Higgs production



PRIOR TO THE LHC START-UP

currently ATLAS FP-420 (STFC cutting rule)
CMS-HPS, Totem
ATLAS-AFP

- Prospects for high accuracy (~1%) mass measurement

  (irrespectively of the decay mode). ☹

- Quantum number filter/analyser. 😐

  (0++ dominance ;C,P-even)

- H ->bb opens up (Hbb Yukawa coupl.) ☺

  $(gg)_{CED}$ ↛ bb in LO ; NLO,NNLO, b- mass effects – controllable.

- For some BSM scenarios CEP may become *a* **discovery channel** 😐

  - 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…)

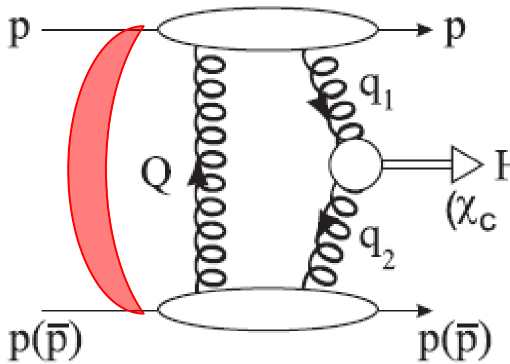
Triple product correlation: $\vec{n}_0 \cdot (\vec{p}_{1\perp} \times \vec{p}_{2\perp}) \sim \sin\varphi$,

Integrated counting asymmetry (~10%)

$$\boxed{A = \frac{\sigma(\varphi < \pi) - \sigma(\varphi > \pi)}{\sigma(\varphi < \pi) + \sigma(\varphi > \pi)} \,,}$$

CEP through the eyes of the KRYSTHAL (2008-2013)

- Colliding protons interact via a colour singlet exchange and remain intact: can be measured by adding detectors far down the beam-pipe. **(or LRGs)**
- A system X of mass M_X is produced at the collision point, and *only* its decay products are present in the central detector.



(Lucian's talk)

$\boxed{M\overline{M}}$

- The generic process $pp \to p + X + p$ is modeled perturbatively by the exchange of two t-channel gluons, with the use of pQCD justified by the presence of a hard scale $\sim M_X$.
- '$J_z = 0$ selection rule': production of states with non-$J_Z^P = 0^+$ quantum numbers is strongly suppressed by $\sim$ 2 orders of magnitude.

- χ_c, $\gamma\gamma$ CEP already observed by CDF and *jj* CEP observed by CDF & D0.
- χ_{cJ} CEP is reported by LHCb (DIS-11)
- new CDF $\gamma\gamma$CEP results (PRL-2012)
- All measurements in agreement with Durham group (pre)dictions.

CMS--first results, more to come

SuperCHIC MC

A MC event generator including[8]:

- Simulation of different CEP processes, including all spin correlations:
  - $\chi_{c(0,1,2)}$ CEP via the $\chi_c \to J/\psi\gamma \to \mu^+\mu^-\gamma$ decay chain.
  - $\chi_{b(0,1,2)}$ CEP via the equivalent $\chi_b \to \Upsilon\gamma \to \mu^+\mu^-\gamma$ decay chain.
  - $\chi_{(b,c)J}$ and $\eta_{(b,c)}$ CEP via general two body decay channels
  - Physical proton kinematics + survival effects for quarkonium CEP at RHIC.
  - Exclusive J/ψ and Υ photoproduction.
  - $\gamma\gamma$ CEP.
  - Meson pair ($\pi\pi$, KK, $\eta\eta$...) CEP.
- More to come (dijets, open heavy quark, Higgs).

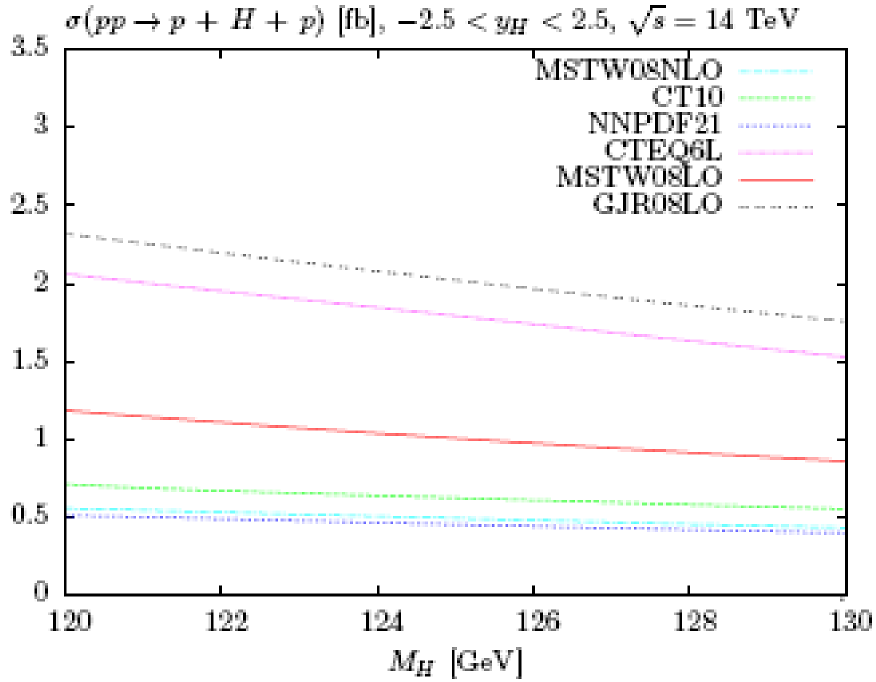
subprogram to evaluate S^2

→ Via close collaboration with CDF, STAR and LHC collaborations, in both proposals for new measurements and applications of SuperCHIC, it is becoming an important tool for current and future CEP studies.

KRYSTHAL Col

[8]The SuperCHIC code and documentation are available at http://projects.hepforge.org/superchic/

Higgs Boson: cross section predictions



SuperCHIC

- Cross section $\sim$ fbs, i.e. roughly 4 orders of mag. lower than inclusive case (price paid for exclusivity).
- Uncertainties (Survival factors, higher–order corrections, PDFs) exist in theoretical calculation. But $\gamma\gamma$ CEP cross section tends to lie a little above theory estimates $\to$ favours the higher predictions shown.

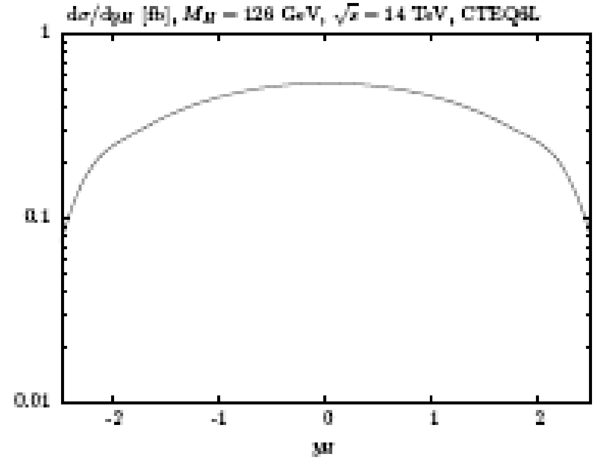


Figure 5: Rapidity distribution $d\sigma/dy_H$ for a $M_H = 126$ GeV SM Higgs boson, using CTEQ6L PDFs.

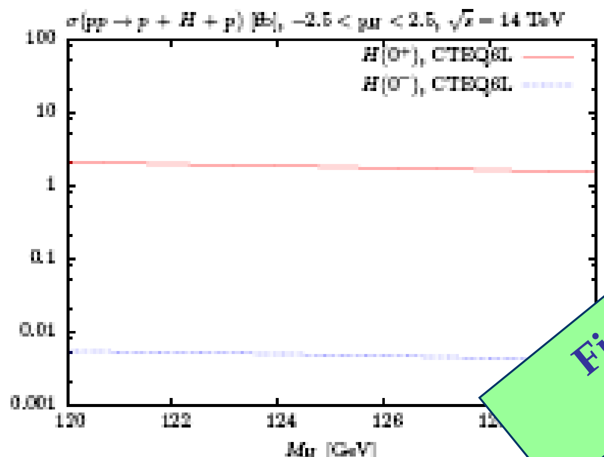


Figure 6: Cross sections for the CEP of scalar $J^P = 0^+$ and pseudoscalar $J^P = 0^-$ particles of the Higgs sector as a function of the Higgs mass, M_H, integrated over the rapidity interval $-2.5 < y_H < 2.5$.

Find a CEP resonance and you have confirmed its quantum numbers!

THINGS TO DO !

(known unknowns)

- Account for the b-dependence of the survival factors $S^2_{\rm enh}$, $S^2_{\rm eik}$ (GLM-new results)

- NLO effects in the unintegrated parton densities
  (N)NLO-effects in hard ME.

- A systematic account of self–energy insertions in the propagator of the screening gluon

- The dependence on the gluon PDF is amplified by the fact that the CEP cross section is essentially proportional to $(xg(x))^4$.

CDF $\gamma\gamma$ data *may* suggest more 'LO–type' PDFs ($\rightarrow$ more optimistic Higgs cross sections) are appropriate.

Improvements of models for soft diffraction: remove tensions with Totem data on $\sigma_{\rm el}$ and $\sigma_{\rm tot}$,

(Durham- work in progress)

agreement with the LHC results on low mass SD,

agreement with the Tevatron/LHC data on CEP processes

Subprogram for SuperCHIC

SM Higgs, 125 GeV

Signal-to-Background Ratio (a brief reminder)

$H \to b\bar{b}$

- The largest signal, but large background and (most) difficult trigger

  (other channels –too low rate).

- Major theor. uncertainties cancel in the ratio, in particular survival factors, PDFs,..
- Experimental efficiencies (trigger, b-tagging..) cancel.

Dominant non-PU backgrounds:

[DeRoeck, Orava+KMR, EPJC 25 (2002) 392, EPJC 53 (2008) 231]

1) Admixture of |Jz|=2 production

2) NLO gg→bbg, large-angle hard gluon emission

3) LO gg→gg, g can be misidentified as b

4) b-quark mass effects in dijet processes, HO radiative corrections

Main characteristics:
2007 (HKRTSW) values

- Mass window ΔM ~4 GeV.
- g-b misID $P(g/b)$ ~ 1.3%
- cone size ΔR ~0.5.

S/B ≈1 (420+420)

Could be improved by a factor of 2 or so.

Dijet-monitor for the Higgs yield, high-ET diphotons @CMS

$b\bar{b}$ non-PU backgrounds

$$\sigma_B \simeq 2\,fb*(\Delta M/4GeV)[A*(120GeV/M)^6 + 1/2C_{NLO}*(120GeV/M)^8],$$
$$A \simeq 1/4+1/4+1/4(P(g/b)^2,$$
$$C_{NLO} \simeq 0.48-0.12*\ln(M/120GeV).$$

- $P(g/b)$ 1.3%→1% (CMS)
- ΔM new detailed (post-2007) studies needed
- $\sigma_{bbg}/S \sim 20*(\alpha_s C_F/2\pi)*(\Delta R)^2(\Delta M/4GeV)$ (ccg-similar)

  (requires detailed MC studies)

The problem with pile-up
How to trigger on low-p_T jets?

Experimental road-map: Andy Pilkington (CERN, Febr. 2013)

(4) New cuts to reject the pile-up backgrounds will be necessary in order to extract a SM Higgs boson in the H->bb channel

(5) Extensive work is needed to define the most appropriate trigger strategy for H->bb

Jeff Forshaw's Conclusion on Higgs CEP Theory (CERN, 11. 04.2013, CERN)

Most recent predictions

Harland-Lang, Khoze, Ryskin & Stirling: 0.5 to 2 fb

arXiv:1301.2552

Depending on parton distribution functions. CTEQ6L gives upper value and provides best agreement with CDF di-photon data. $S^2 = 1\%$ and $|y| < 2.5$

Cudell, Dechambre, Hernández: 0.3 to 2 fb

arXiv:1011.3653

'Our predictions are significantly lower than those of KMR'. $S^2 = 5\%$ (?). Gluon constrained by CDF dijet data.

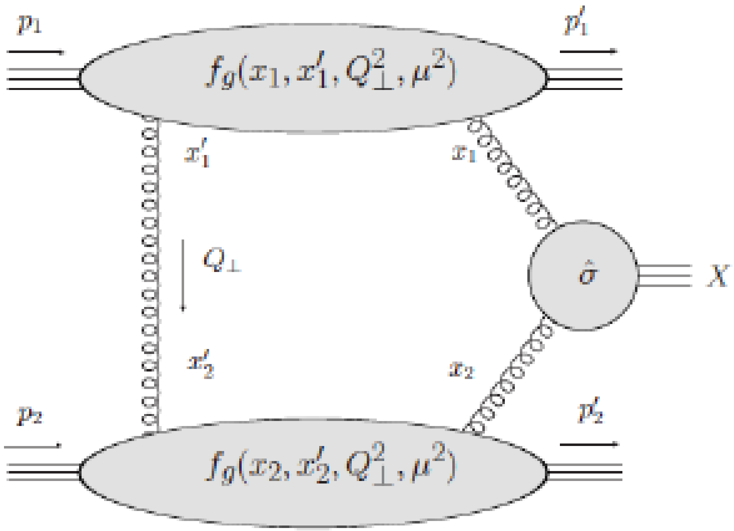
No Sudakov derivative

Ryutin: 0.55 fb

arXiv:1211.2105

$S^2 = 3\%$.

No Sudakov derivative



Maciula, Pasechnik & Szczurek: $0.2 \sim 0.4$ fb

$S^2 = 3\%$.

Higher scale in Sudakov

arXiv:1011.5842

Rg outside

Agreed uncertainty of a factor 3

KMR-2000

$$\mathcal{M}(pp \to p + H + p) = A\pi^3 \int \frac{dQ_T^2}{Q_T^4} f_g(x_1, x_1', Q_T^2, M_H^2/4)\, f_g(x_2, x_2', Q_T^2, M_H^2/4) \qquad (7)$$

where $f_g(x, x', Q_T^2, M_H^2/4)$ denotes the skewed or off-diagonal unintegrated gluon density in the initial proton. The diagonal density is defined such that the probability to find a gluon (with transverse momentum Q_T and momentum fraction x in the interval $dQ_T^2 dx$) is $f_g(dQ_T^2/Q_T^2)(dx/x)$. These unintegrated distributions are the quantities which enter when we apply the Q_T-factorization theorem [13] to the evaluation of the Feynman diagram of Fig. 1a. The procedure of how to calculate $f_g(x, x, Q_T^2, \mu^2)$ from the conventional integrated gluon $g(x, Q_T^2)$ is described in Ref. [14]. Here we will use the form proposed by DDT [15]

$$f_g(x, x, Q_T^2, \mu^2) = \frac{\partial}{\partial \ln Q_T^2} \left[T(Q_T, \mu)\, xg(x, Q_T^2) \right], \qquad (8)$$

where $T(Q_T, \mu)$ is the survival probability that the gluon with $x, x' = x$ and transverse momentum Q_T remains untouched in the evolution up to the hard scale $\mu (= M_H/2)$. T is the result of resumming the virtual ($\propto \delta(1-z)$) contributions in the DGLAP evolution equation and is given by [14]

$$T(Q_T, \mu) = \exp\left(- \int_{Q_T^2}^{\mu^2} \frac{\alpha_S(k_t^2)}{2\pi} \frac{dk_t^2}{k_t^2} \int \left[zP_{gg}(z) + \sum_q P_{qg} \right] dz \right). \qquad (9)$$

The derivative $\partial T/\partial \ln Q_T^2$ in (8) cancels the virtual DGLAP term in $\partial(xg)/\partial \ln Q_T^2$. To be precise the equation for f_g is a little more complicated than (8) (see eq. (3) of [14]). However in the relevant small x and $Q_T \ll M_H$ region, (8) is sufficiently accurate for our purposes. Note that after integrating (8) up to scale μ we do indeed get back the integrated gluon distribution

$$\int^{\mu^2} f_g(x, x, Q_T^2, \mu^2) \frac{dQ_T^2}{Q_T^2} = T(\mu, \mu)\, xg(x, \mu^2) = xg(x, \mu^2). \qquad (10)$$

Jeff Forshaw's Conclusion on Higgs CEP Theory (CERN, 11. 04.2013, CERN)

1. The pQCD part of the calculation is under "reasonable" control (off-diagonal gluon uncertainty dominates).

2. Need a good model of factorization breaking exchanges (a.k.a. gap survival). Central production of other high-mass systems (di-photons & dijets) will really help us to understand it.

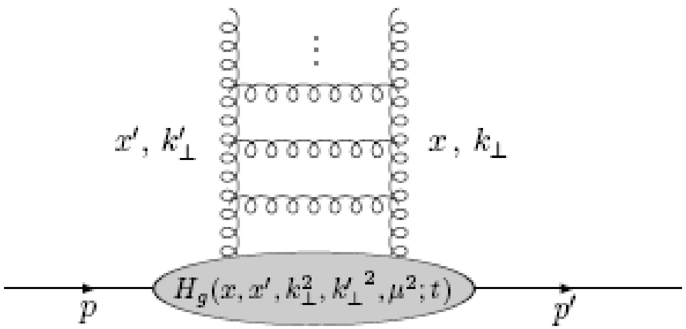
3. Correct treatment of Sudakov and TOTEM data pull cross section down. (taken into account in SuperCHIC)

4. Higher order corrections and CDF data push cross section up. (in progress)

5. Nobody is claiming a cross section above 2 fb.

Off–diagonal partons (1)

- The CEP cross section is given in terms of 'off–diagonal' PDF, unintegrated over the gluon $k_\perp$: corresponds to extraction of 2–gluon state from proton. For CEP have



$$f_g(x, x', Q^2, \mu^2) = \frac{\partial}{\partial \ln(Q_\perp^2)} \left[R_g \left(x g(x, Q^2) \right) \sqrt{T(Q_\perp, m_H)} \right] .$$

KMR(2000)- an extension of the results by DDT(1980) (ignored by some authors of the recent papers)

- $R_g = H_g(x, x'; \mu^2)/xg(x, \mu^2)$: ratio of off–diagonal to conventional integrated gluon PDF. Can be calculated from Shuavev transform, which relates conventional to off–diagonal PDFs at small x. Valid up to corrections of $O(x^2, x'^2)$.
- In CEP kinematics momentum fraction of screening gluon $x' \ll x$ and $x \sim M_X/\sqrt{s} \ll 1$.

$\rightarrow$ Off–diagonal gluon density can be calculated to very good $\lesssim 1$ % accuracy from conventional gluon, and does not represent an important source of theoretical uncertainty.

Recent analysis by Lucian Harland-Lung (in press)

Off–diagonal partons (2)

- Often the approximation is made

$$f_g(x, x', Q^2, \mu^2) \approx R_g \frac{\partial}{\partial \ln(Q_\perp^2)} \left[xg(x, Q^2) \sqrt{T(Q_\perp, m_H)} \right] , \qquad (1)$$

  ignoring the scale dependence of R_g, i.e. assuming the off–diagonal and conventional PDFs have the same evolution with scale μ.
- However only approximately true, and as $\sigma_{\rm CEP} \sim (f_g)^4$, care is needed.
- A more careful treatment, including R_g inside the differential, shows that for Higgs CEP at the LHC ($M_h = 126$ GeV, $\sqrt{s} = 14$ TeV), this can underestimate the cross section by up to a factor of ~ 2. Table: cross sections in fb, with R_g inside and outside differential (1).
- Latest Durham predictions (arXiv:1301.2552) are consistent with this correct treatment.

	MSTW08LO	CTEQ6L	GJR08LO
σ/fb, R_g Outside	0.83	1.15	1.94
σ/fb, R_g Inside	1.39	1.91	2.66

One proton measured, still some physics at high PU?:

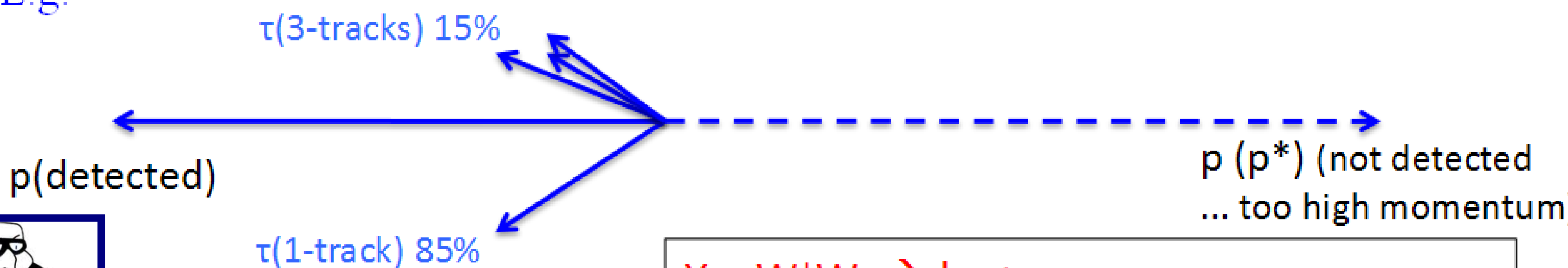
also Totem

High mass diffraction well explored in ~ 1 week of μ = <n/x> ~ 1 running ~100/pb.

M(min) ~ 100 GeV.

No M(X) from p's, no PH rejection by timing, but very clean central states may be accessible.

E.g.



X = W^+W^- → leptons
X = e^+e^- , $\mu^+\mu^-$, $\tau^+\tau^-$ from γγ (or H !?)
X = Z photoproduction → e^+e^- , $\mu^+\mu^-$, $\tau^+\tau^-$

No additional tracks on X vertex (already very selective)

In e^+e^- , $\mu^+\mu^-$, **$\tau^+\tau^-$ cases $\Delta\phi = \pi$ and $p_T(X) \sim 0$.**

Can we see p + [H125 → $\tau^+\tau^-$] + p(*)(undetected) in Stage 1 ??

(Study with Harland-Lang, Khoze, Ryskin)

3-momentum of X (~ p_z) determines both proton momenta

e^+e^- , $\mu^+\mu^-$ already calibrates HPS spectrometers (don't need both p's)

Can we see H(125) in Stage 1 with one proton?

Exclusive p + τ+τ- + p (clean) :

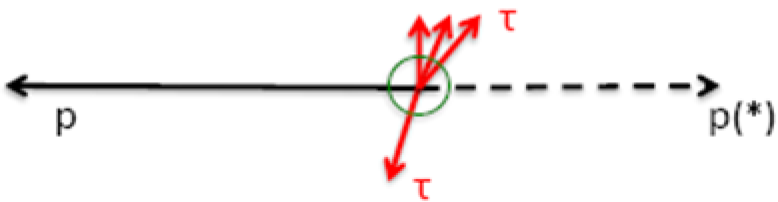
Only 3 sources:

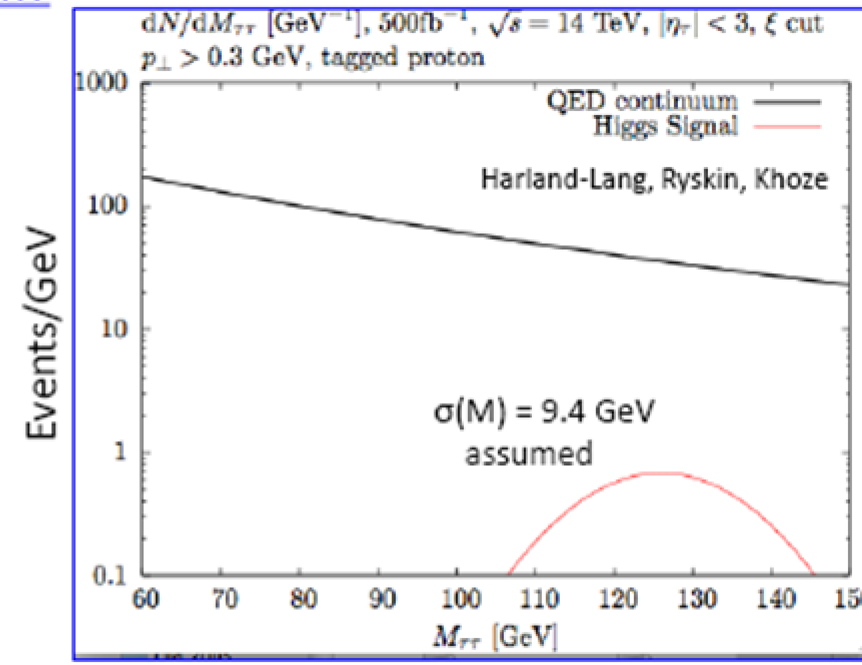
1) QED: γγ → τ+τ-

2) Photoproduction: γ+IP → Z (BR = 3.7%)

3) Gluon fusion IP + IP → H (BR = 6%)

1^{st} two same in e+e-and μ+μ- (control)





Two neutrinos missing, but 4-momentum constraints & two M(τ) constraints.

a) If fully optimised, how good can M(τ+τ-) be?

Factor x2 better σ(M) → factor x2 peak height and in S:B. (possible??)

b) QED continuum, γγ → τ+τ- , p_T(p) < p_T(p) in H → τ+τ- (gluons, or IP)

pT > 0.3 GeV cut (as in plot) reduces QED by factor ~ 5, only 10% reduction in H.

c) Unseen low mass p-dissociation on other side increases σ, factor ~ 2(?) without spoiling kinematics. σ(H) also uncertain by a factor ~ 2-3 each way.

Still, SMH(125) → p + τ+τ- + p(*) probably too small to see in Stage 1.

>> at Stage 2 with 420+240 have other p, better mass resolution, & timing for z(vtx) constraint. :-)

News on Exclusive Production of [illegible]SM Higgs bosons

Courtesy of Marek Tasevsky

Marek Taševský

[illegible]itute of Physics, Academy of Sciences, Prague

(i[illegible]ollaboration with S. Heinemeyer, V. Khoze and G. Weiglein)

LHC Higgs observation and MSSM exclusion bounds from all LHC data

New MSSM benchmark scenarios

New MSSM benchmark scenarios

- M. Carena, S. Heinemeyer, O. Stal, C. Wagner, G. Weiglein: 1302.7033

New low-energy MSSM scenarios that are compatible with the mass and production rates of the observed Higgs boson signal at ~ 125.5 GeV:

1. Mhmax: mass of the light CP-even Higgs boson is maximized for fixed $\tan\beta$ and large M_A
2. Mhmod+: modified Mhmax: reduces the mixing in the stop sector compared to the value that maximizes M_h
3. Mhmod-: similar to Mhmod+
4. Lightstop: suppression of the lightest CP-even Higgs gluon fusion rate
5. Lightstau: enhanced decay rate of $h \to \gamma\gamma$ at large $\tan\beta$
6. Tauphobic: the lightest Higgs has suppressed couplings to down-type fermions
7. LowMh: fixes the value of M_A (=110 GeV) and varies μ

light Higgs~SM-like

1-6: the discovered Higgs is the CP-even lightest Higgs; look for the heavy partner
7: the discovered Higgs is the CP-even heavy Higgs; look for the lighter partner

The LHC exclusion regions inferred from analyses searching for MSSM Higgs bosons:
[φ=h,H,A]: 1) $pp \to \varphi \to \tau^+\tau^-$ (inclusive); $bb^-\varphi$, $\varphi \to \tau^+\tau^-$ (with b-tag); 2) $bb^-\varphi$, $\varphi \to bb^-$(with b-tag),
$pp \to tt^- \to H^{+-}W^{\mp}bb^-$, $H^{+-} \to \tau\nu_\tau$, $gb \to H^-t$ or $gb^- \to H^+t^-$, $H^{+-} \to \tau\nu_\tau$

Strategy

1) Try out all scenarios. Look only at $H \to b\bar{b}$

2) Look at MSSM CED cross sections: Take the KMR formula for production of SM Higgs in Central exclusive processes and use MSSM partial widths and branching fractions for $H \to b\bar{b}$.

3) Calculate cross sections of background processes.

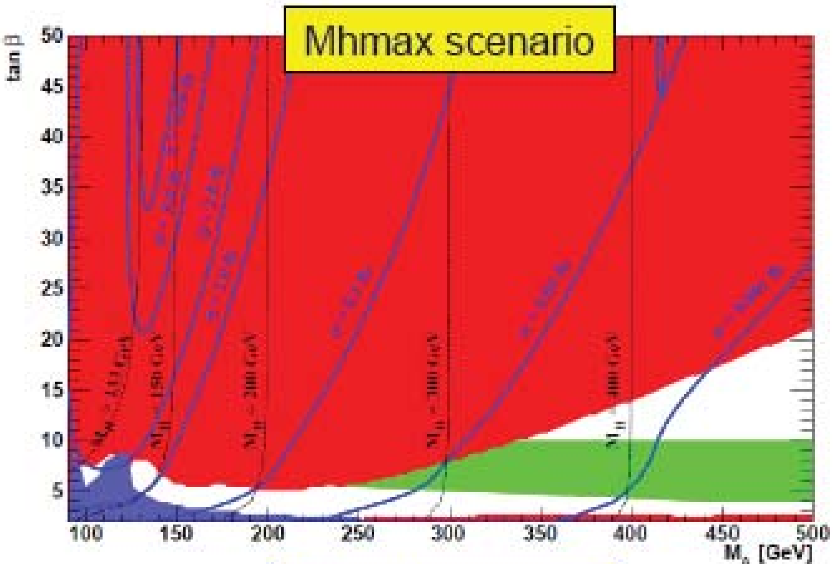
4) Plot signal cross sections and signal/background ratios in tables $M_A - \tan\beta$

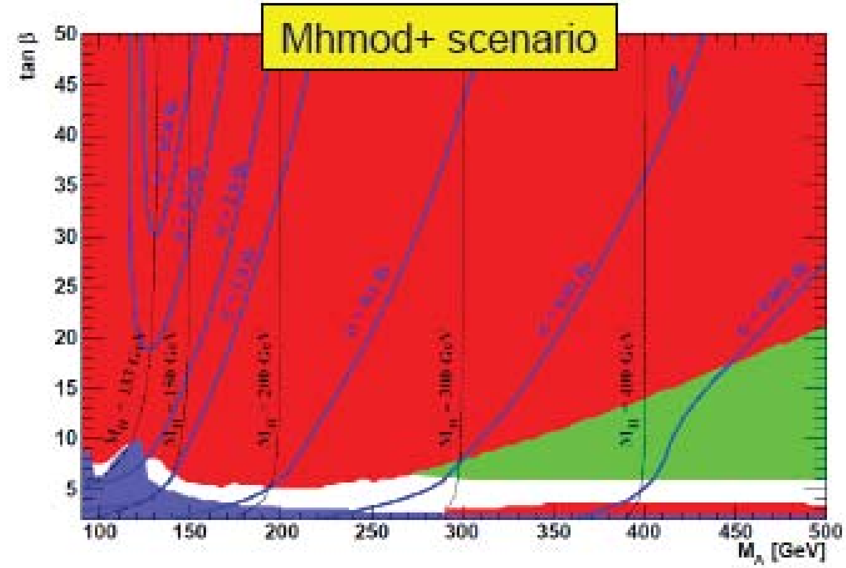
5) Where not hopeless, look also at statistical significances. For that we need experimental acceptances and efficiences.

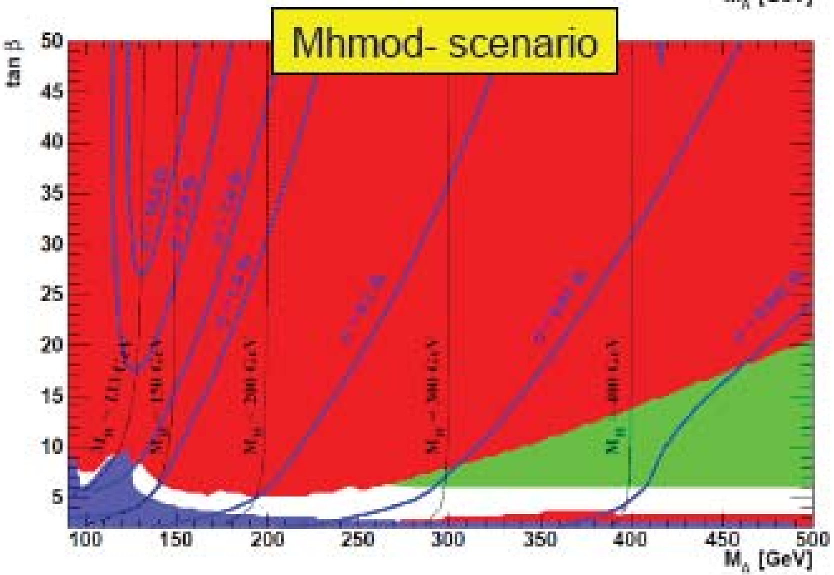
6) Compare with the region of the observed Higgs signal (125.5 GeV +- 3 GeV) and with the LHC exclusion regions.

The whole procedure described in more detail in EPJ C53 (2008) 231 and EPJ C71 (2011) 1649.

CED H→bb signal x-sections







$122.5 < M_h < 128.5$ GeV

LHC exclusion regions

LEP exclusion regions

X-sections come from KMR calculations. They still need to be multiplied by experim. efficiencies (~10%) to get significances. **Signal yields in the allowed region are tiny.**

similar unpromising situation with the CEP rates for heavier H- boson in other MSSM scenarios

Low M_H MSSM scenario

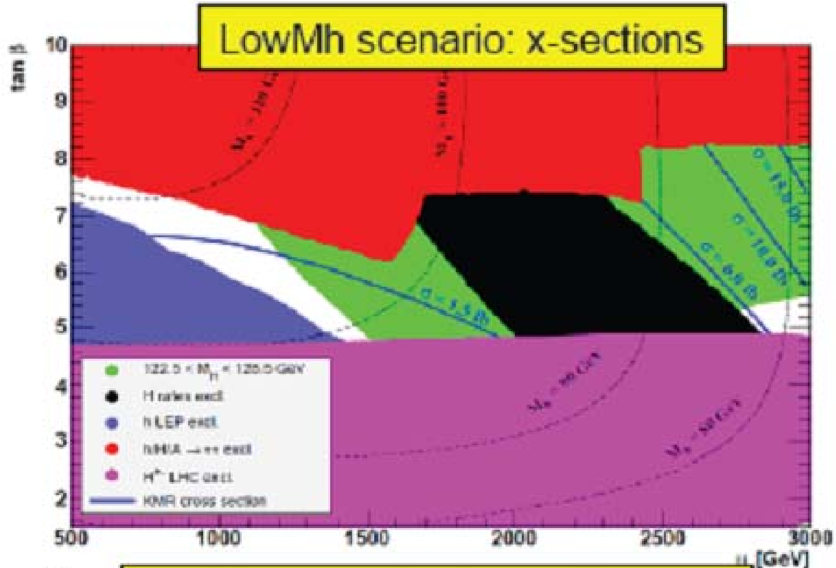
(see for instance arXiv: 1302.7033, also NMSSM)

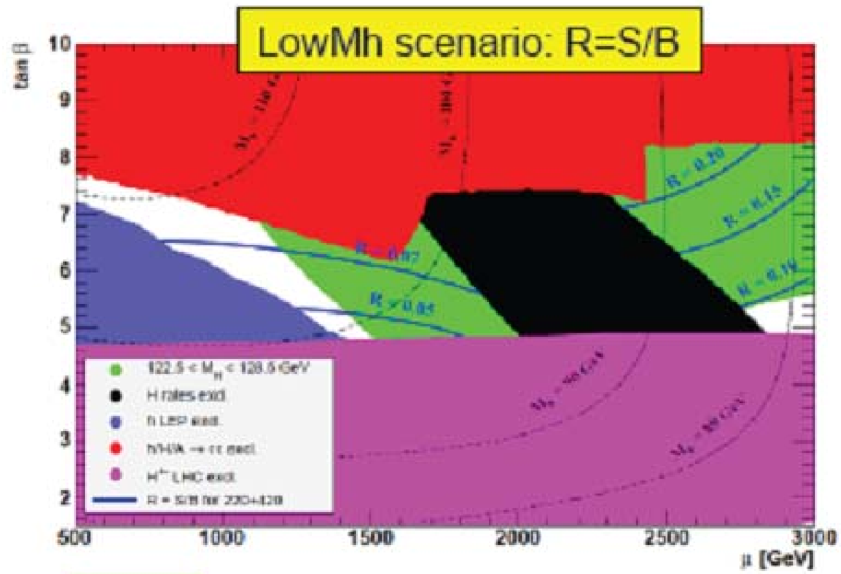
- The LHC signal corresponds to the heavy CP-even Higgs boson.- SM like.
- Light CP-even Higgs – heavily suppressed couplings to the gauge bosons.
- The available parameter space is already affected by the current limits.
- All 5 Higgs states have masses have masses of order 100 GeV
- Rich phenomenology- but might be excluded by the standard search channels at the LHC comparatively soon. 
- Recall also that the background is increasing with mass decreasing 

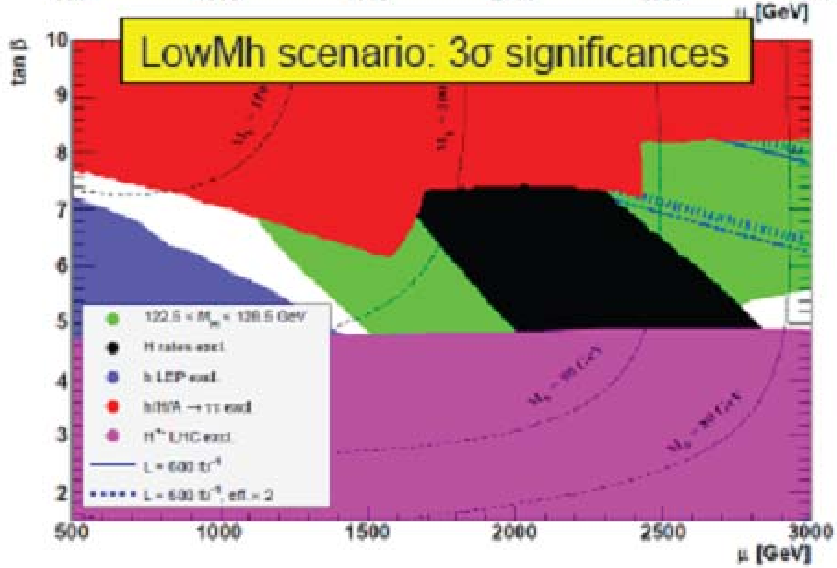
$$\boxed{S / B \sim \Delta M / M^3}$$

(New studies in progress by M.Tasevsky, S.Heinemeyer, G.Weiglein and VAK)

CED H→bb at LowMh scenario







- $122.5 < M_h < 128.5$ GeV
- H → ZZ,WW rates exclusion
- h LEP exclusion
- h/H/A → ττ exclusion
- H^{+-} LHC exclusion

Ratios and significances include the experim. efficiencies

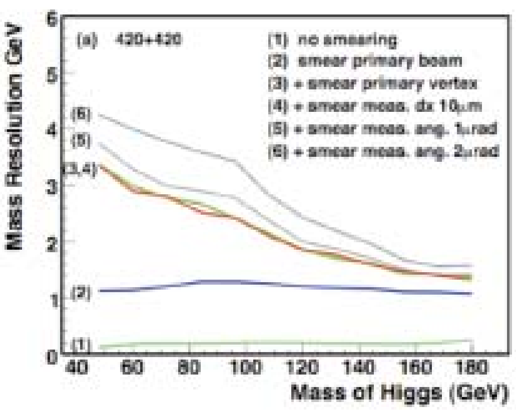
LowMh considerations

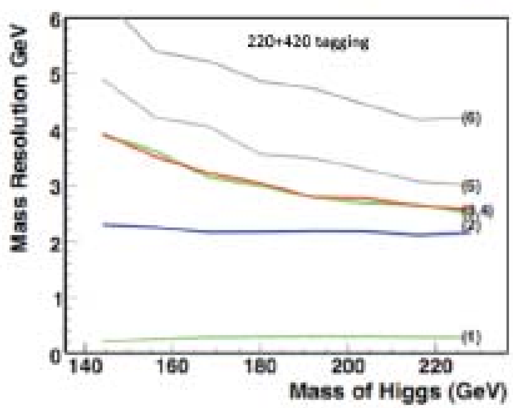
- Ratios S/B and 3σ-significances include the experimental efficiencies.

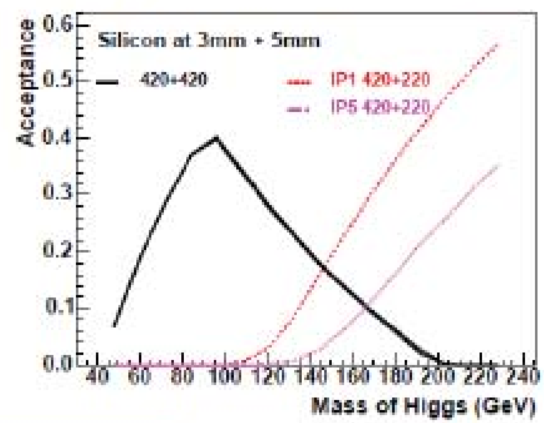
- 3σ is reachable only for large integrated luminosity (~1000 fb^{-1}). This means we need to combine data from both CMS and ATLAS.

- In this scenario, the Higgs boson found at M_H ~ 125.5 GeV is the heavy one; we need to search for the lighter one → picture shows the region of interest M_h ~ 80-90 GeV.

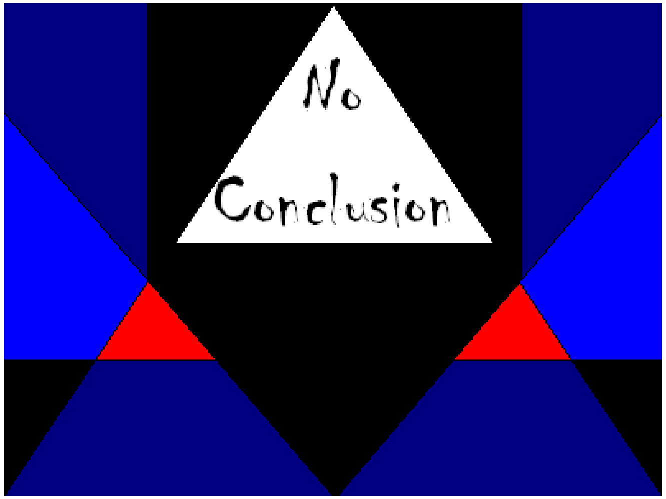
- The region of interest M_h ~ 80-90 GeV is experimentally difficult:
  1. Only 420+420 configuration relevant
  2. 420m station can hardly be put into L1 trigger (at least in ATLAS)
  3. Slightly worse missing mass resolution than for higher masses
  4. Worse situation also in the central detector (L1 triggers highly prescaled, Pile-up issue)







FP420 R&D Report JINST 4 (2009) T10001

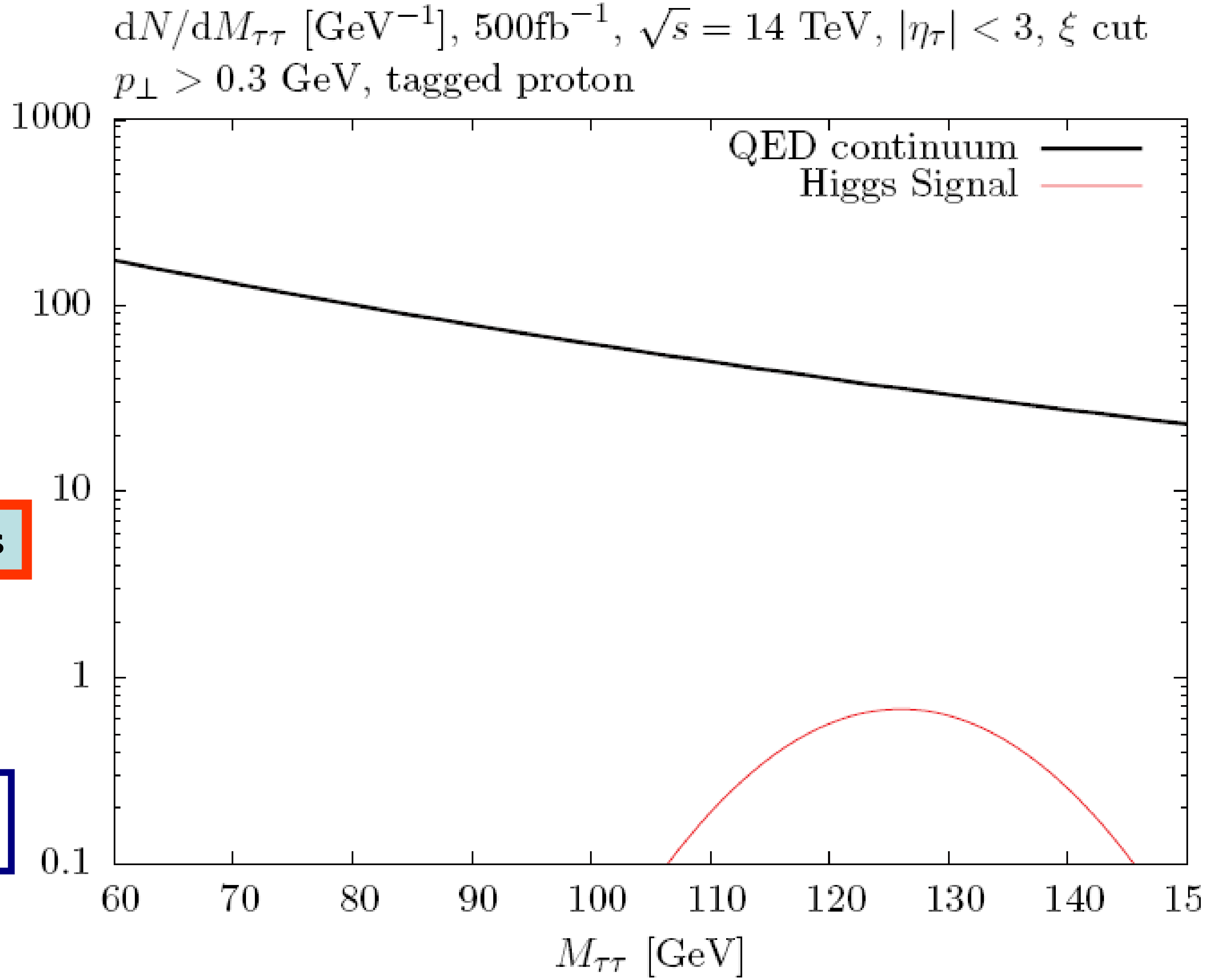


Jury is still out


THANK YOU


QUESTIONS?

BACKUP



~20 signal events

S/B may improve by a factor of ~2

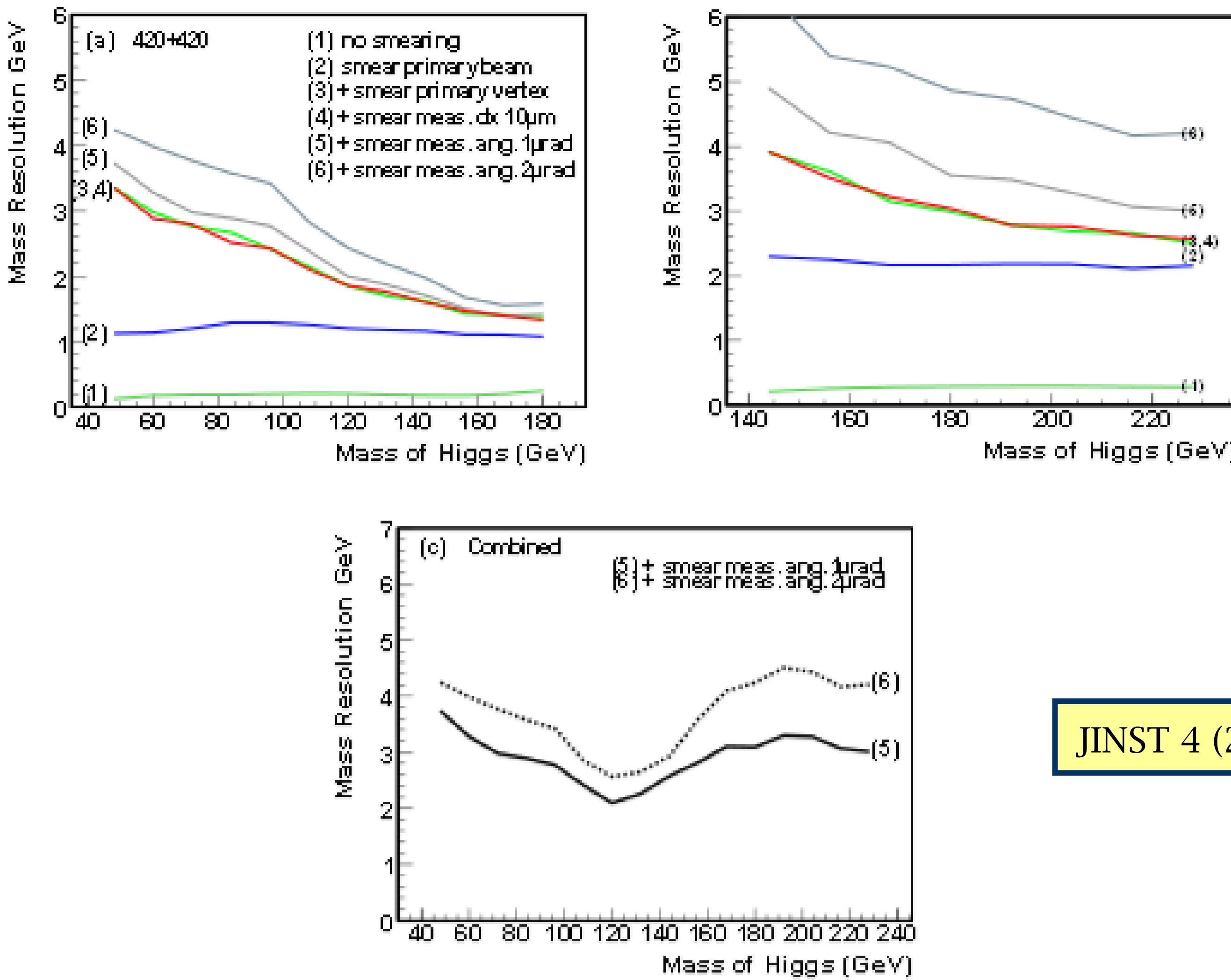
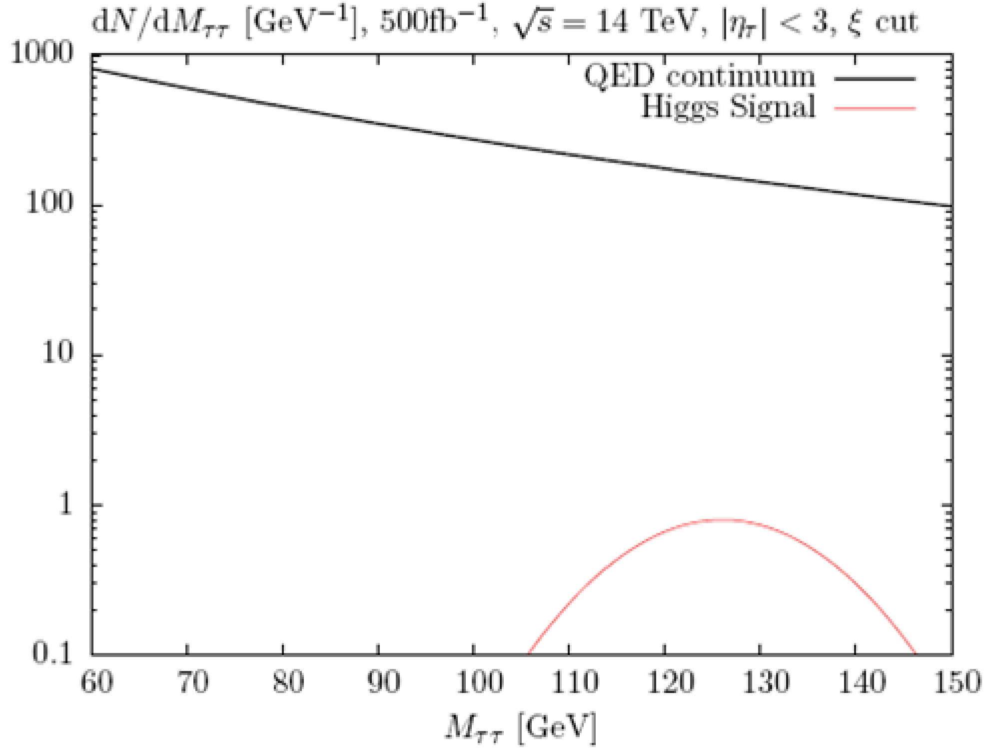


Fig. 32: Mass resolutions obtainable in ATLAS (a) for 420 + 420 m measurements, (b) for 420 + 220 m measurements, (c) combined. The curves have different amounts of smearing applied as explained in the text.

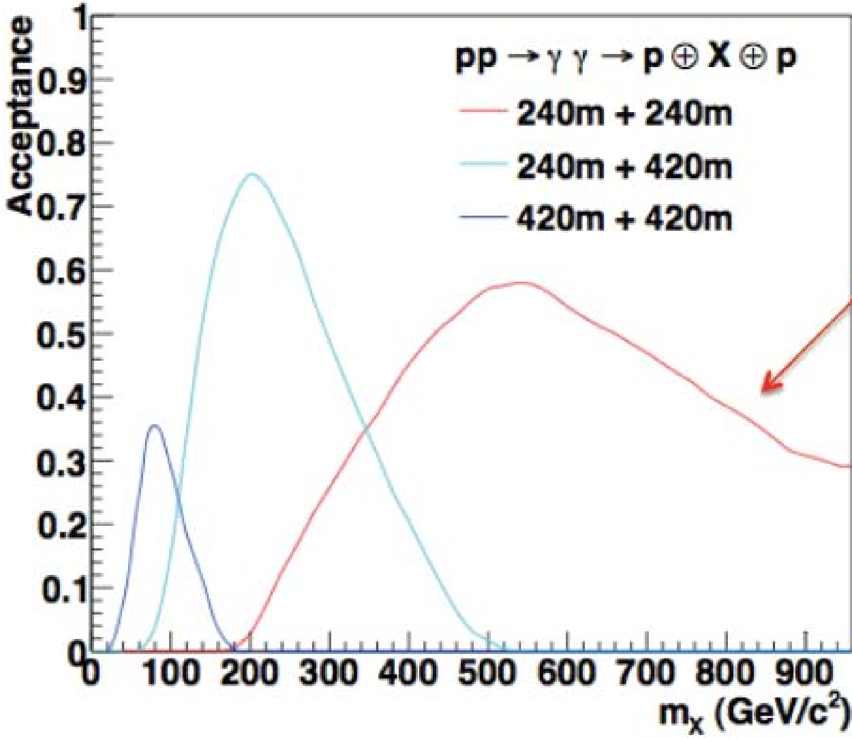
JINST 4 (2009) T10001


Maurice
TOOLS


$dN/dM_{\tau\tau}$ [GeV^{-1}], 500fb^{-1}, $\sqrt{s}$ = 14 TeV, $|\eta_\tau| < 3$, ξ cut
QED continuum
Higgs Signal
1000
100
10
1
0.1
60
70
80
90
100
110
120
130
140
150
$M_{\tau\tau}$ [GeV]

Mass acceptance for two arms for small |t| at Stations 1 & 2

(Assumes Δx(min) from beam = 3 mm at 240m)



Stage 1: very good for W+W- and Jet+Jet and BSMH(400-800)

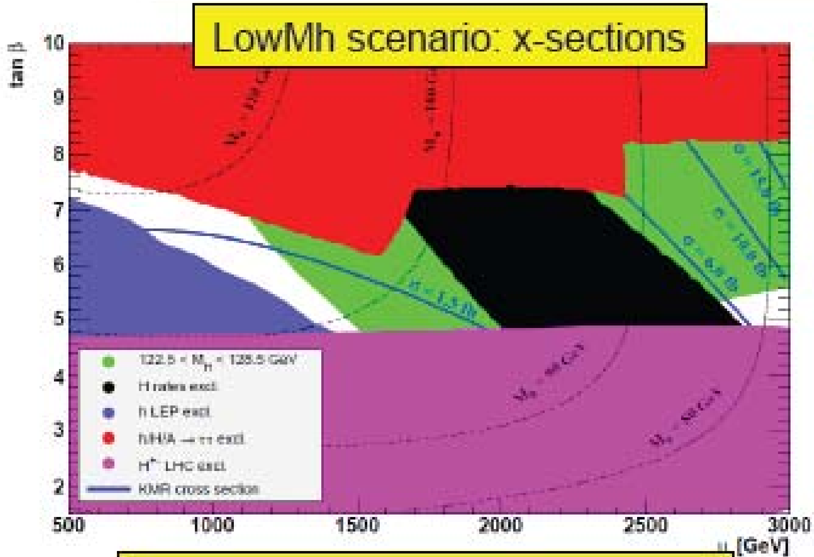
Each arm at 240m by itself has ~ superimposed light blue and red.

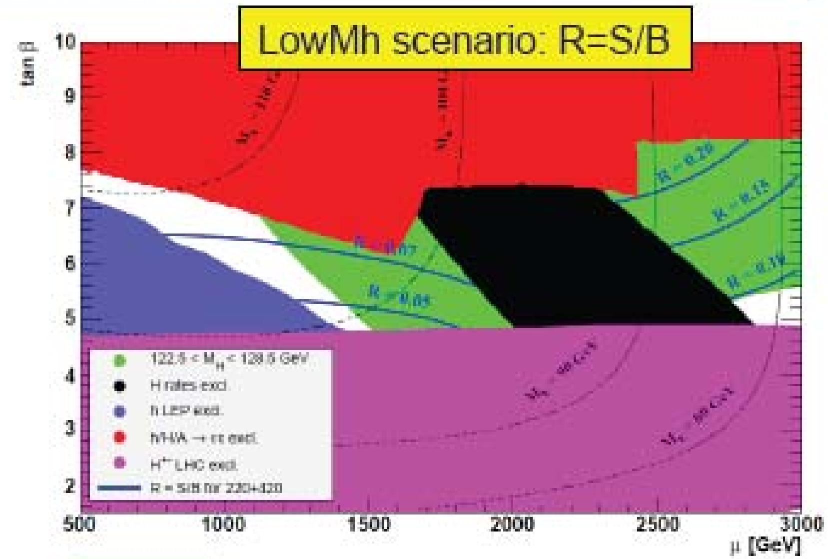
Stage 2 has ~ all 3 superimposed, and light blue x 2.

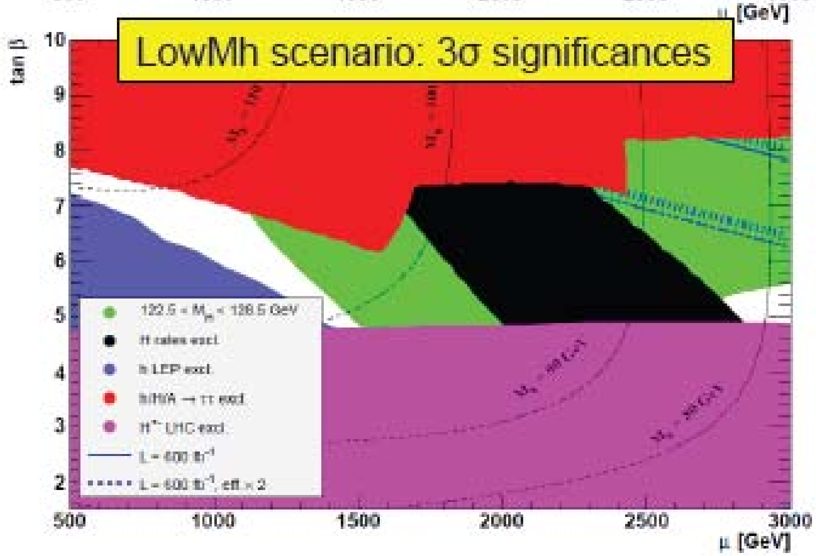
For IP + IP |t| is larger and acceptance shifts.

For H(125) best is [240 + 420] & [420 + 240]

CED H→bb at LowMh scenario







- $122.5 < M_h < 128.5$ GeV
- H → ZZ,WW rates exclusion
- h LEP exclusion
- h/H/A → ττ exclusion
- H^{+-} LHC exclusion

Ratios and significances include the experim. efficiencies