$H \rightarrow \gamma\gamma$ Final State

5th LHC Higgs Cross section Workshop

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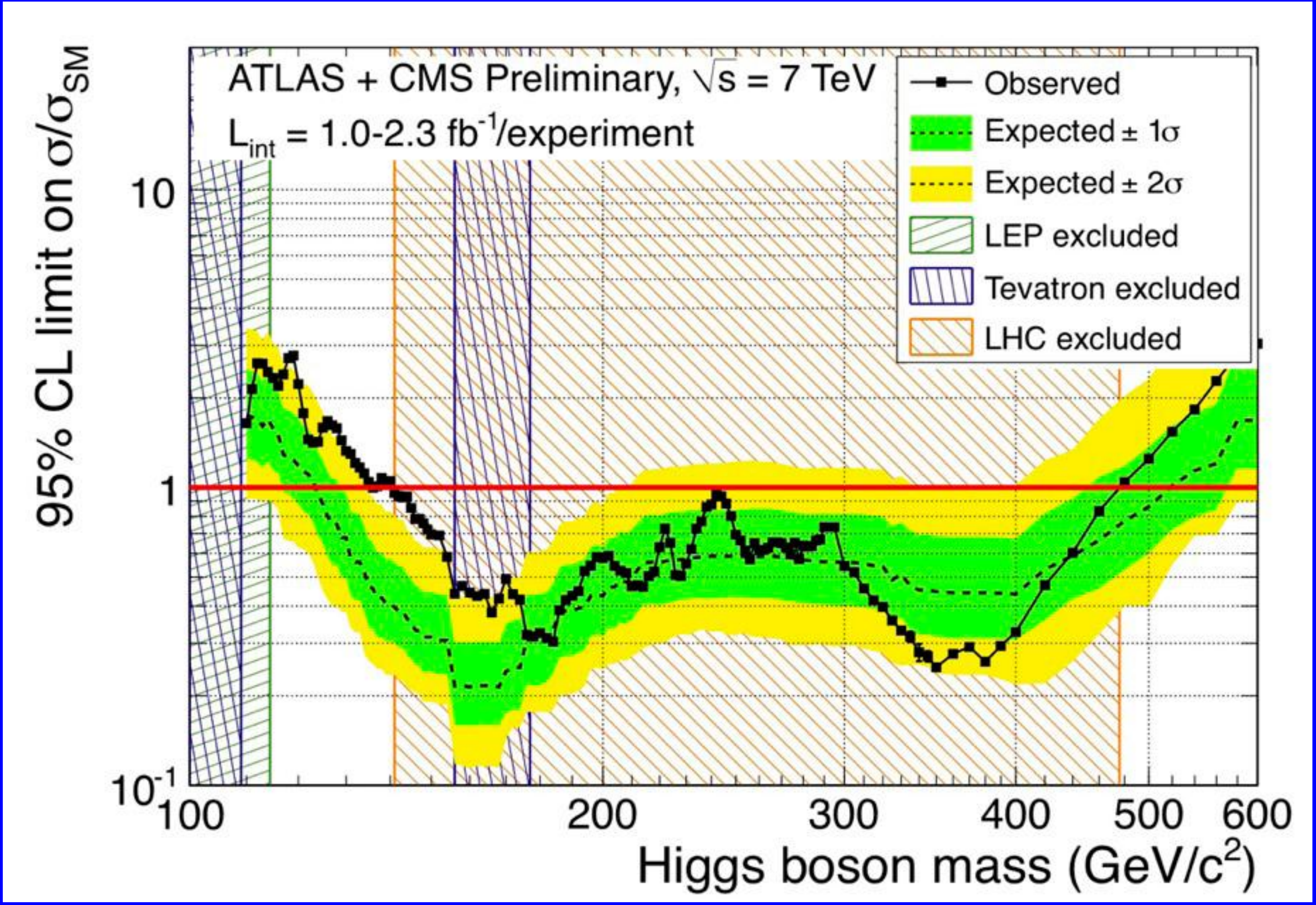
Susan GASCON-SHOTKIN (IPN Lyon/UCB Lyon 1), Marumi KADO (LAL)

Contributors:
Th: L. Dixon, D. de Florian, J-Ph. Guillet, M. Grazzini, F. Krauss, E. Pilon , F. Siegert +…
Exp: O. Bondu, N. Chanon, G. Davies, D. D'Enterria, S. Ganjour , S.Gascon-Shotkin, P.Gras, M. Kado, C.-M. Kuo, N. Lorenzo, T. Orimoto , J. Schaarschmidt, L. Sgandurra, J.Tao, M. Titov + …

- **Introduction**
- **Outline/Status of YR2 contribution**
- **List of Tools**
- **Sets of acceptance cuts**
- **Signal Modelling: Pt-reweighting**
  ggF/gg→γγ interference
- **Background extraction, calculations and Isolation considerations**
- **Wish List for theorists**

Introduction: The plot says it all… (combined HCP2011 result)



Outline/Status of YR2 contribution

- Introduction
- Sets of Acceptance Criteria used
- Signal modelling and differential k-factors
  - Differential k-factors for gluon-fusion signal
  - Gluon-fusion signal and background interference

  (Including sources of theoretical uncertainty)
- Review of Background extraction methods used
- Background calculations and differential k-factors
- Isolation criteria for background measurement
- Uncertainties
  - Impact of joint correlated systematic uncertainty related to the background model used in the context of Higgs Combination
  - Joint conventions for systematic error calculations (For signal k-factors and background determination techniques)
  - Realistic jet-bin uncertainties via the 'BNL accord'
- Resources
  - List of LO/NLO Monte Carlos/available tools

  Wish list for theorists: Most important is a consistent background treatment incorporating direct contributions and fragmentation contributions at NNLO,with higher-order box contributions

  Color code: WHITE➔Work well along, text being written in parallel

  YELLOW➔Work beginning, will profit greatly from this evening's dedicated discussion …..**SORRY WE'RE LATE!!!**

List of LO/NLO Monte Carlos used so far or shortly to be used

- **LO (+) :** Signal and Background: PYTHIA (Sjostrand et al),
  MadGraph (Stelzer, Maltoni et al) [no box diag.],
  ALPGEN (Mangano et al), [“]
  SHERPA (Gleisberg, Hoche, Krauss et al.) [“]
- **>LO:** **NLO:** Signal: Generators: MC@NLO (Frixione, Webber et al) [gluon fusion only],
  POWHEG (Nason et al)

Backgrounds: $\gamma\gamma$ + X: Calculators:
DIPHOX (Binoth, Guillet, Pilon et al) (Fixed-Order)
gamma2MC (Bern, Dixon, Schmidt) (Fixed-Order)
ResBos (Balazs, Nadolsky, Yuan) (Resummation)

γ + X: Calculators:
JETPHOX (Aurenche, Fontannaz,Guillet et al) (Fixed-Order)

NNLO: Signal: Calculators: HNNLO (Catani, Grazzini) [gluon fusion only]
FEHIP (Anastasiou, Melnikov, Petriello) [gluon fusion only]
(**NNLO+ NNLL:** HqT (Catani, de Florian, Grazzini) [gluon fusion only])

Backgrounds: gamma2MC(Bern,Dixon,Schmidt) [gg box]
ResBos (Balazs, Nadolsky, Yuan) [gg box]
2γNNLO (Catani, Cieri, de Florian, Ferrera, Grazzini) NEW!

Sets of Acceptance cuts to be used

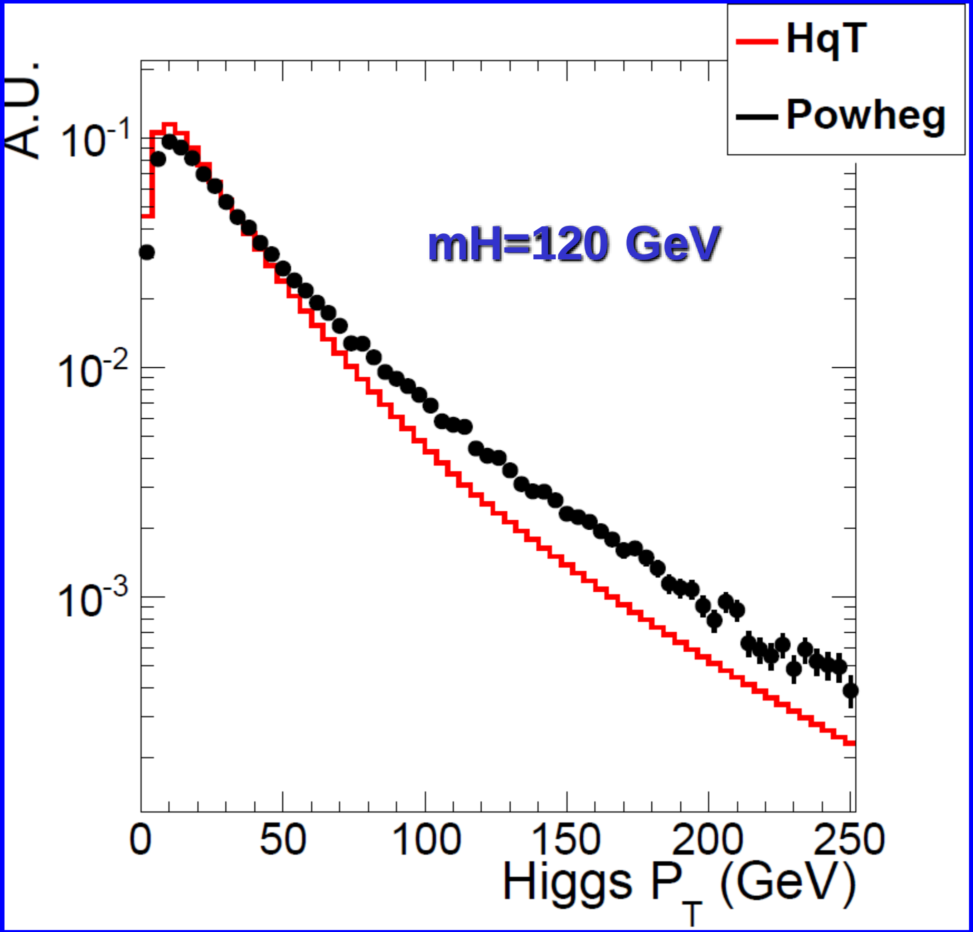
Three sets used: ‘CMS-like’, ‘ATLAS-like’, ‘Loose’:

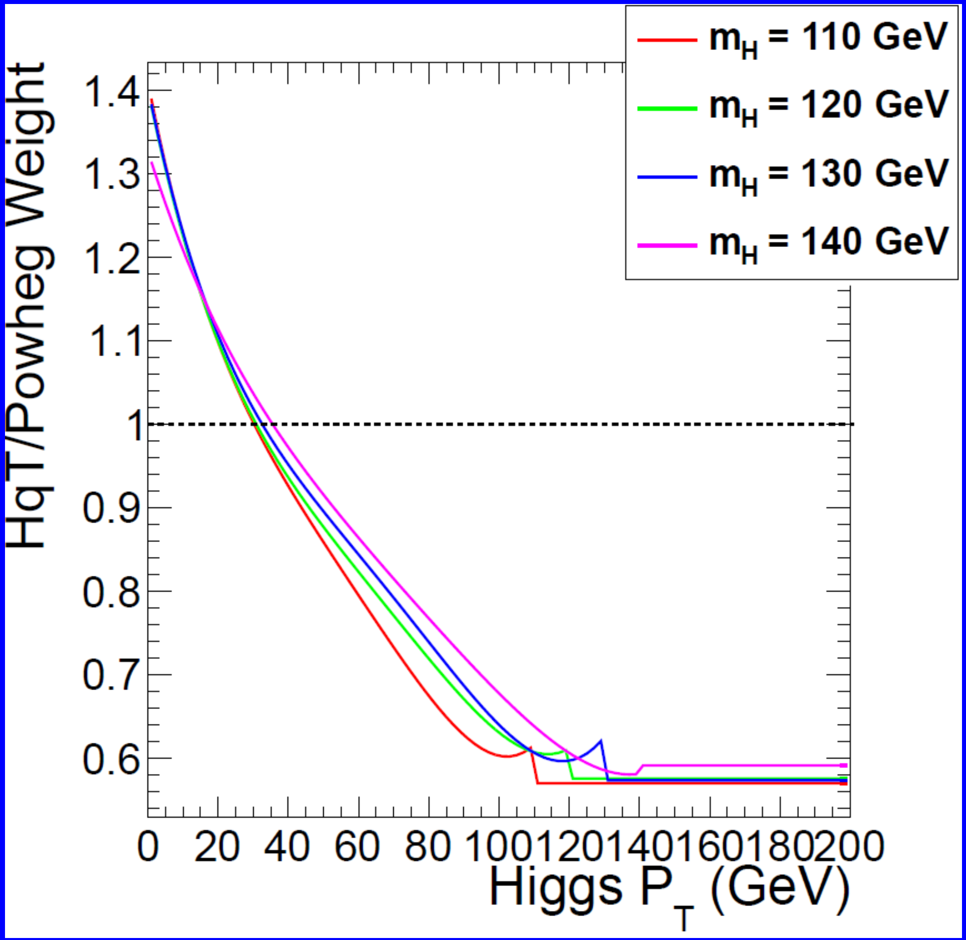
- Et_gamma1, Et_gamma2:
  CMS: 40 GeV, 30 GeV, ATLAS: 40 GeV, 25 GeV, 'Loose': 20 GeV, 23 GeV

- |eta_gamma| for both gammas: < CMS and 'Loose': 2.5, ATLAS: <2.37
- |eta_gamma| exclusions for both gammas: CMS: 1.4442 < |eta_gamma| <1.566.
  ATLAS: 1.37< |eta_gamma| <1.52
- m_gammagamma: CMS, ATLAS: 100-160 GeV 'Loose': >80 GeV

- parton-level isolation requirement for background k-factors:
  Used in our public diphoton xsec results:
  CMS: cone size 0.4 Et<5 GeV
  ATLAS:cone size 0.4 Et<4 GeV

ggF signal Pt-reweighting and effect on observable differential distributions





Done with HqT 2.0

Still to do: Evaluate impact of HqT weights on observables

Fits done with: 4deg polynomial pt<mH

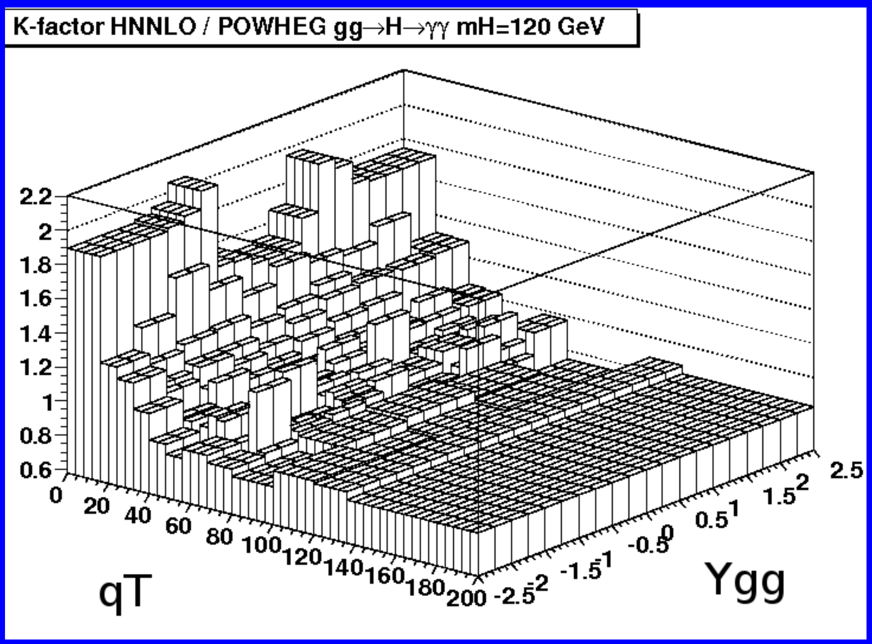
Constant pt>mH

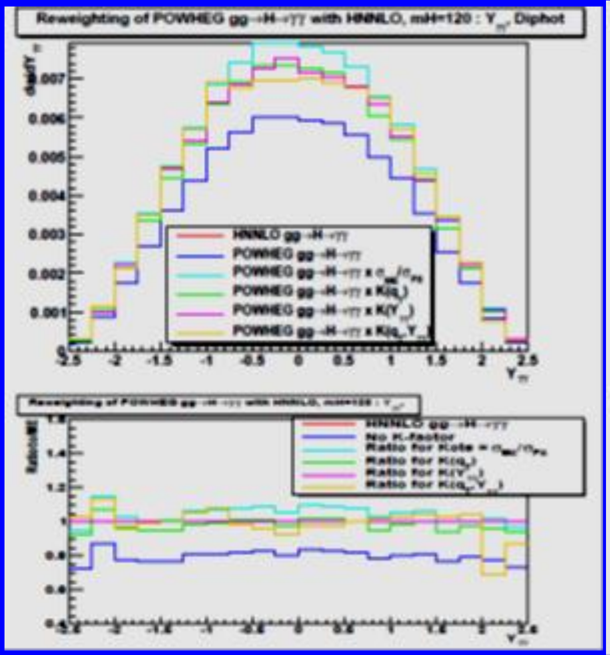
(reason for discontinuity at pt~mH)

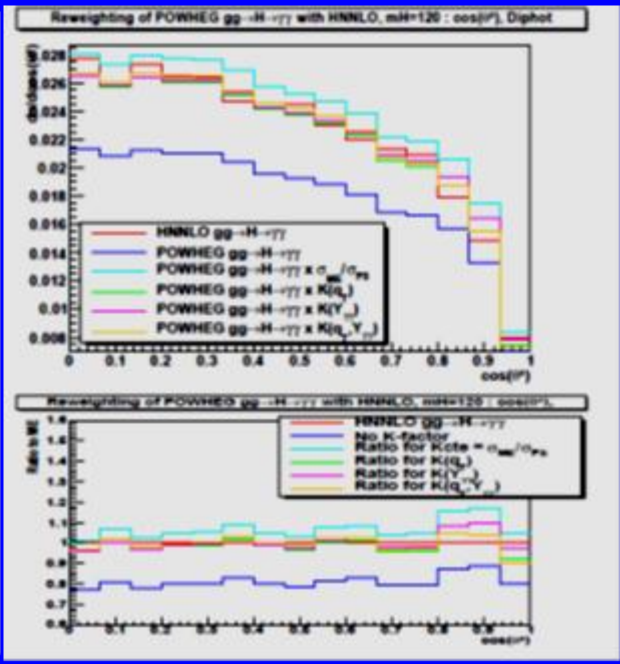
Need a group-wide decision on fitting…

ggF signal 2d k-factors to HNNLO

Doubly-differential ‘semi-smooth’ k-factors for reweighting POWHEG to HNNLO







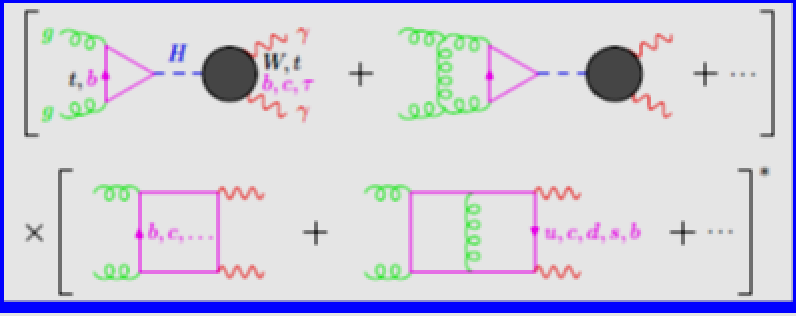
Smoothed K-factor (right plots) reproduces NNLO distribution within 5% for almost all bins in the ranges −2 < Y < 2 and 0 < cos() < 0.9

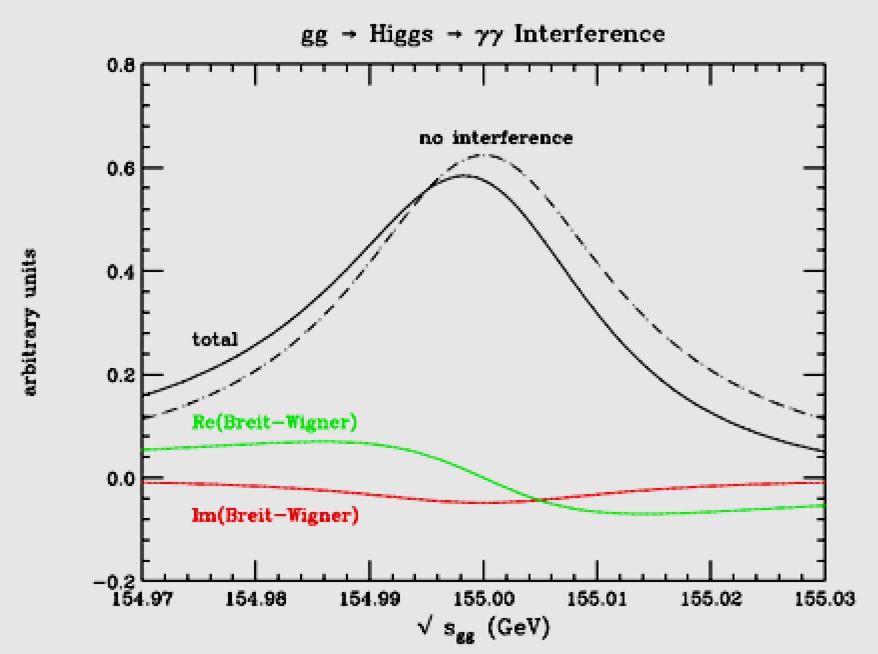
After HqT-reweighting, would there be a residual reweighting required for Ygg?

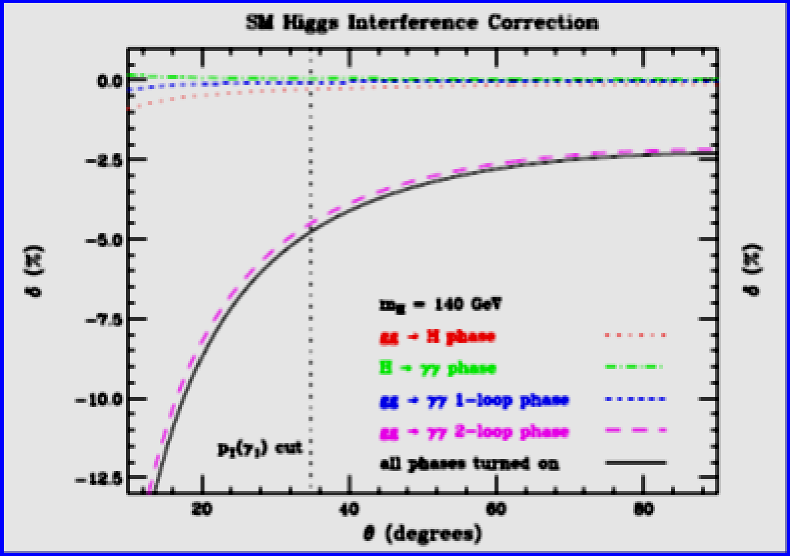
Signal-Background interference

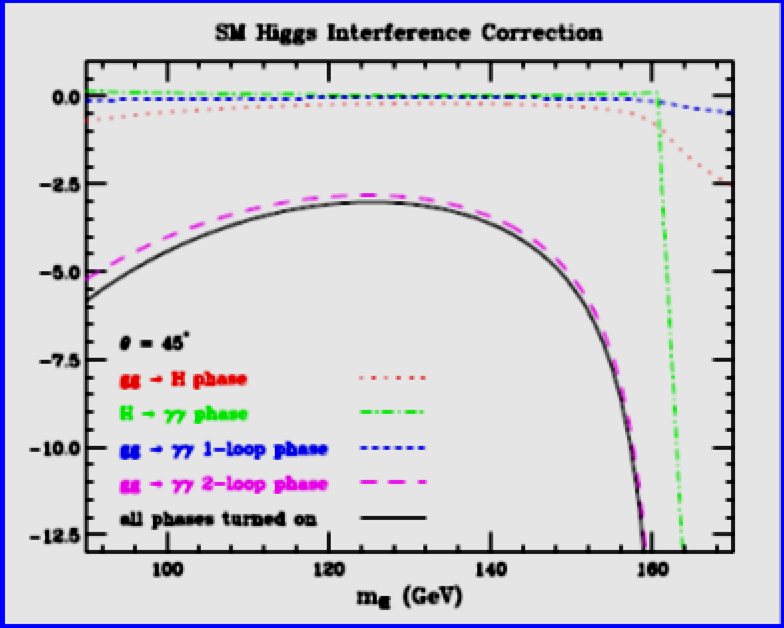
L. Dixon and S. Siu, hep-ph/0302233

- Destructive interference between ggF resonance gg→H→γγ and continuum gg→ γγ processes



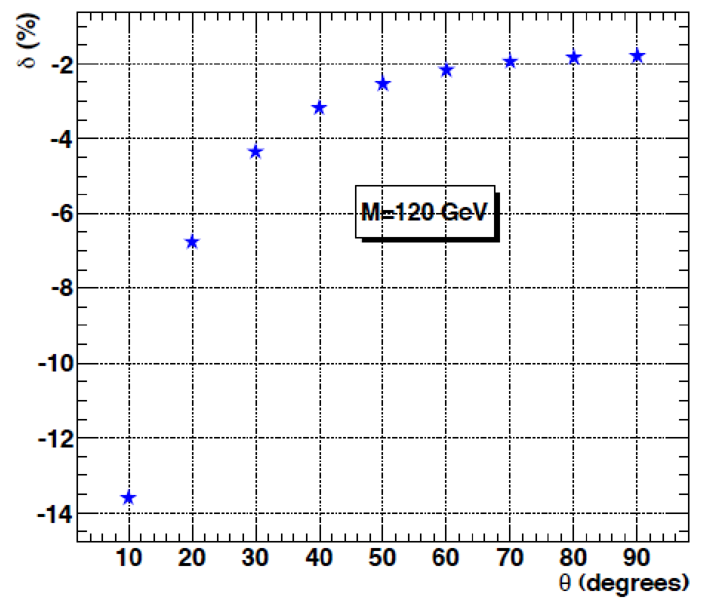


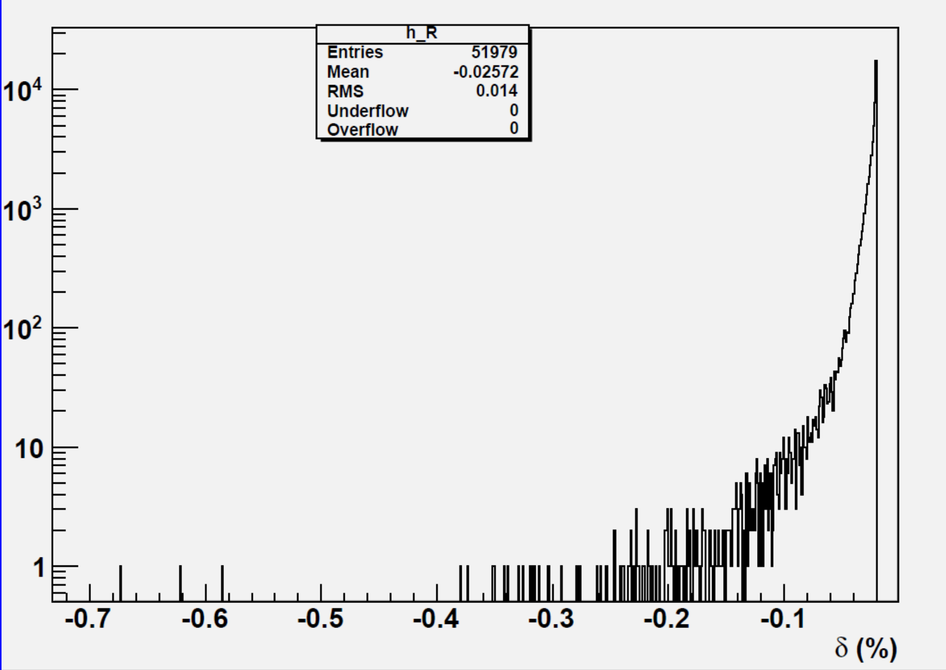




- Current calculation is at one-loop, gg -> γγ g in progress by L. Dixon et. al

Signal-Background interference





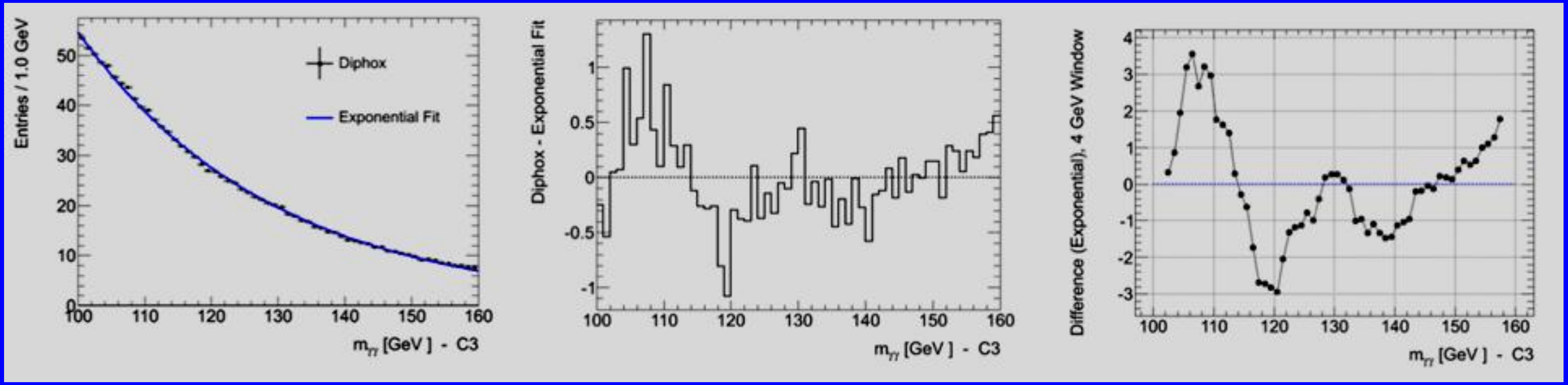
Mass (GeV)	100	105	110	115	120	125	130	135	140	145	150
δ (%)	-3.16	-2.83	-2.59	-2.42	-2.31	-2.28	-2.36	-2.54	-2.87	-3.40	-4.33

- Demonstration above with ATLAS acceptance cuts (but no HqT-reweighting) using gHinterference code from L. Dixon, calculates δ as function of costheta*
- Average effect is -2.5% for mH=120 GeV but can go as high as ~15% or more for very low values of costheta*. Effect minimal for mH=125 GeV
- Goal is to provide procedure to calculate $k_{pt} \times k_{\delta}$
- Still to be done (~1-2 weeks): Evaulate sources of theoretical systematic error:
  - Commutativity of Pt- and δ-reweighting
  - Limit minimal value of costheta* where interference calculation applicable

Background Extraction: How to estimate possible biases from the model

- Use our best knowledge of the background
  - Intensively looking at parton level MC (DiPhox, ResBos, ggNNLO, JetPhox, etc…)
  - Simulated MC (Pythia, Alpgen, Sherpa, etc…)
- Estimate the possible bias
- Account for the bias as a spurious signal term in the overall fit model

$$Ns = \mu \times \varepsilon \, \sigma \, L + \delta \times n_{spurious}$$

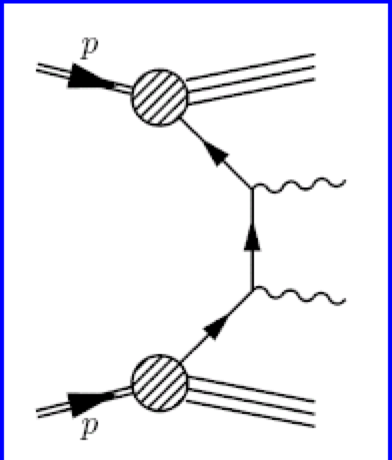


CMS : 2nd order Bernstein ATLAS (shown): Exponential

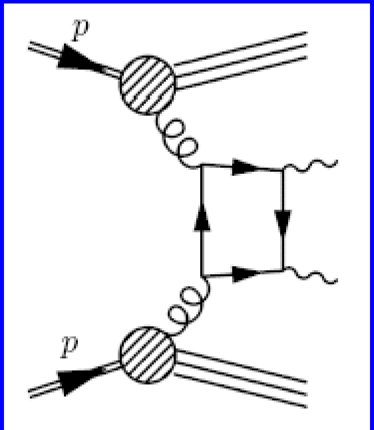
- Spurious signal is large O(20%) signal (a benchmark to estimate possible biases)
- Very conservative approach should be kept at a more reasonable size (smaller mass range or additional constrained parameters)

Generators/calculators of SM $\gamma\gamma$+X processes

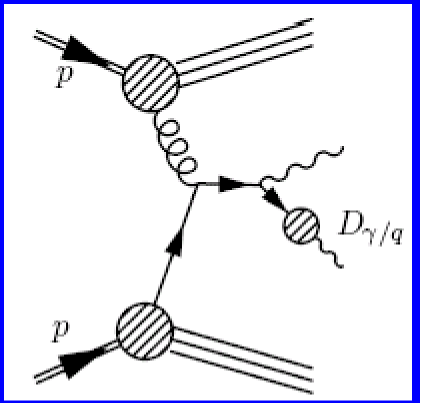
BORN



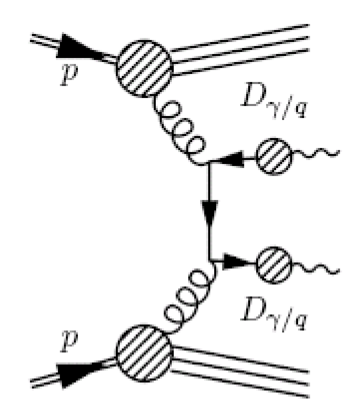
BOX



ONE FRAG



TWO FRAG



DIRECT

FRAGMENTATION

Generator	ME/PS	Resum accuracy	Born	1-frag	2-frag	Box
DIPHOX	ME	-¶	NLO	NLO	NLO	LO
GAMMA2MC	ME	-	-	-	-	NLO
RESBOS	ME	NNLL	NLO	LO§	-	NLO‡
PYTHIA	PS	LL+†	LO	-	-	LO
MADGRAPH + PYTHIA frag/had	ME+PS	LL+†	LO + up to 2 jets	-	-	-

¶ : Soft gluon resummation for final state fragmentation contributions only (BLL)

§ : 1-frag LO included effectively (no fragmentation function)

† : LL formulae, plus momentum conservation and angular ordering.

‡ : One more diagram than with Gamma2MC.

Currently DIPHOX contains the most complete treatment of fragmentation

Generators/calculators of SM γγ+X processes

Université Claude Bernard Lyon 1

DIPHOX
Binoth, Guillet, Pilon, Werlen, hep-ph/9911340, 2000

RESBOS
Balazs, Berger, Mrenna, Yuan, hep-ph/9712471, 1997

gamma2MC, NLO
Bern, Dixon, Schmidt, hep-ph/0211216, 2002

2gammaNNLO
Catani et al, hep-ph/11102375, 2011

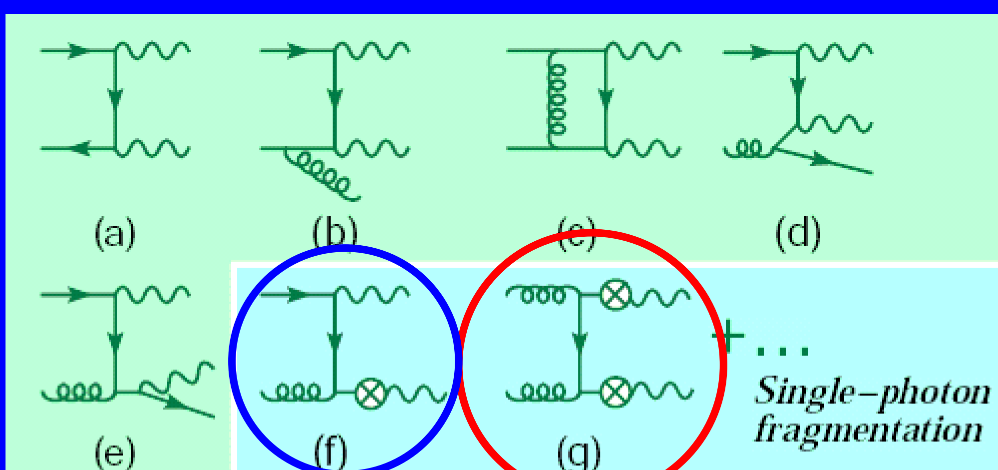
qT SUB : NNLO

FIXED ORDER : NLO

NLO with NNLL Resummation

FIXED ORDER : NLO

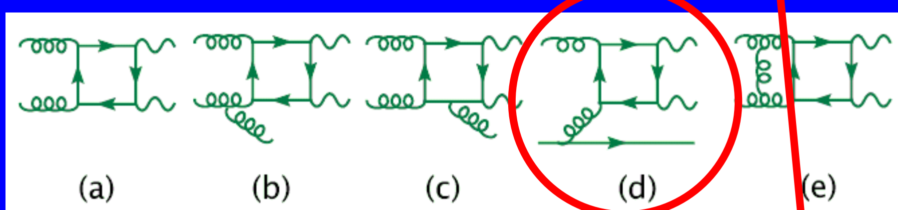
BORN + FRAG (and NLO corrections)



1-frag :
- LO, effectively in Resbos
- NLO in Diphox

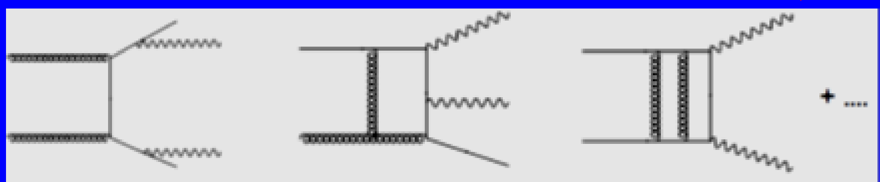
2-frag :
DIPHOX only (NLO)

BOX (and NLO corrections)



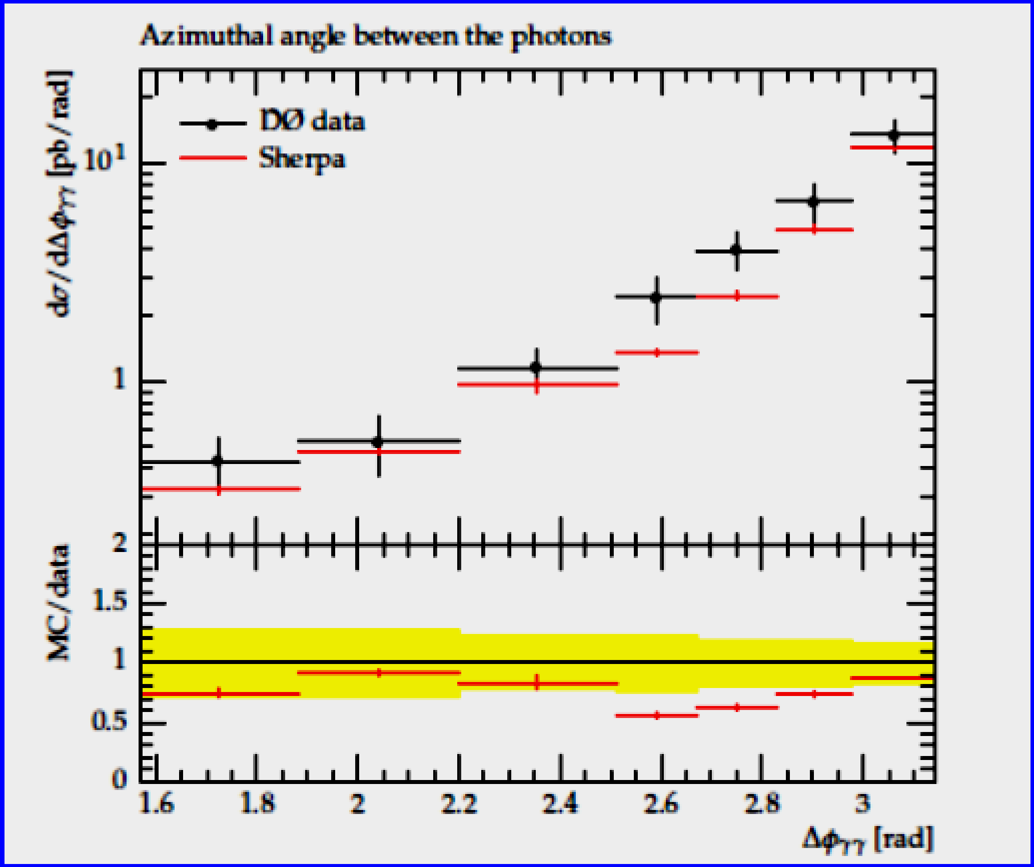
Resbos only

BORN (up to NNLO corrections)



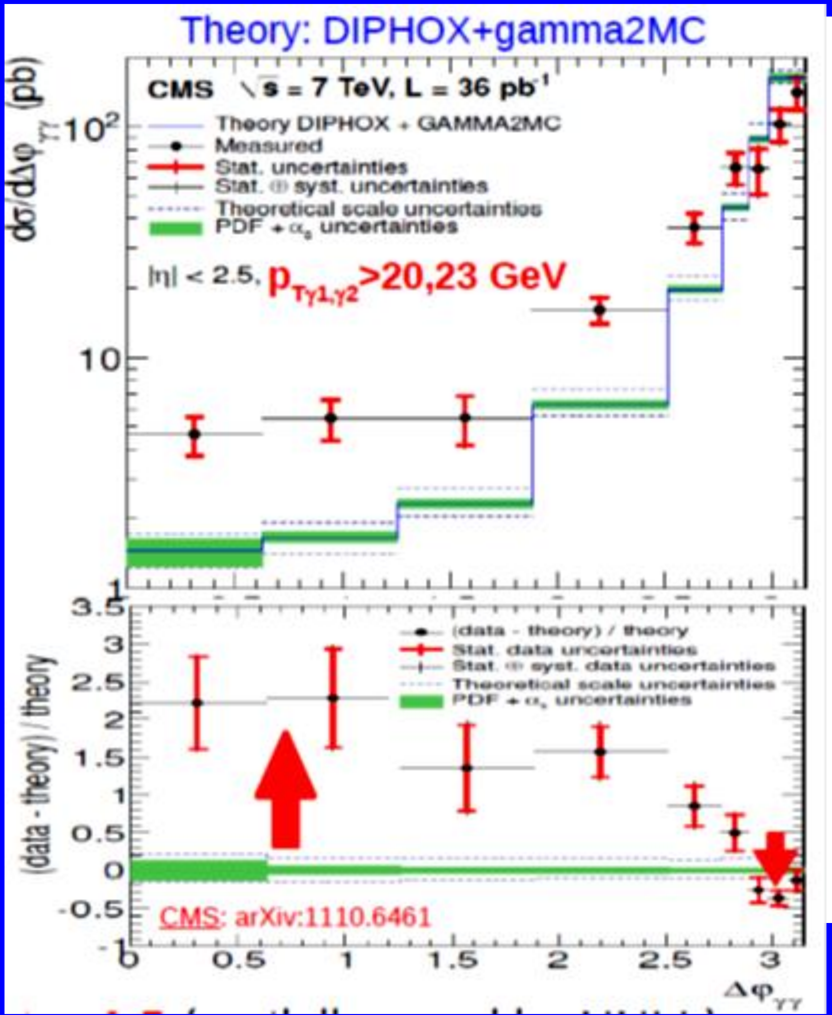
SHERPA

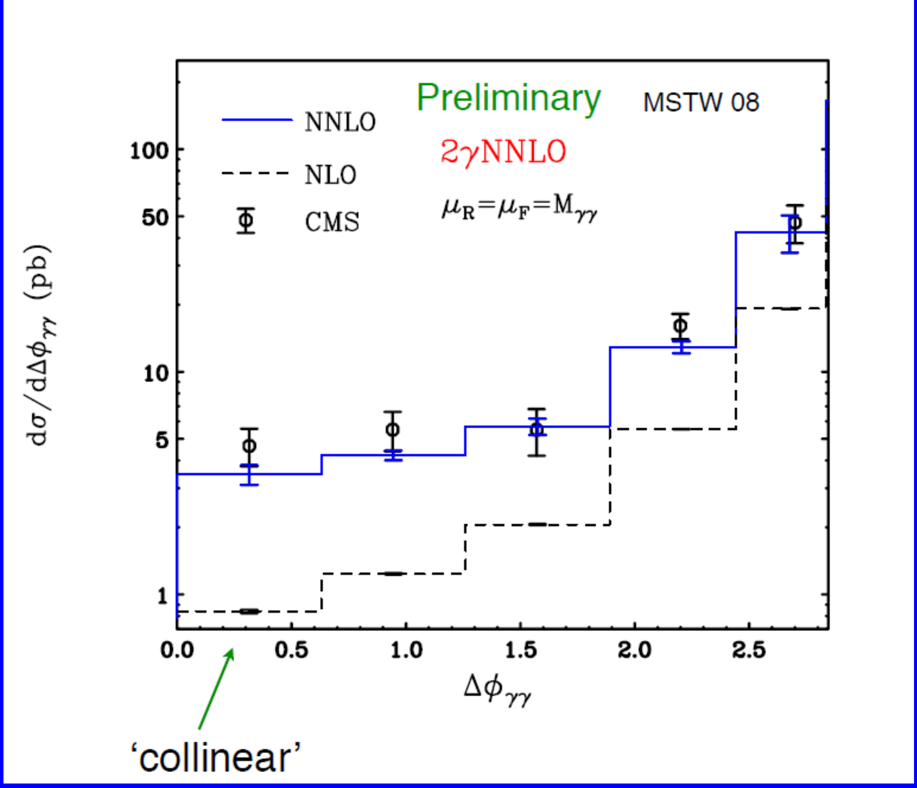
Includes matching between Matrix Element and Parton shower photons, to be validated by direct photon measurements (Gleisberg, Hoche, Krauss, Schonherr, Schumann, Siegert , Winter, JHEP 02 (2009) 007 , Phys.Rev.D81:034026,2010)



Diphoton production at Tevatron
D Phys.Lett.B690:108-117,2010
Isolated hard photons with:
E1> 21 GeV E2> 20 GeV
|eta |< 0.9
Isolation: Et(R = 0.4) –E < 2.5 GeV
Here: Azimuthal angle between the diphoton pair
ME/PS simulation using Sherpa 1.2.2 with
QCD+QED interleaved shower and merging

2γNNLO



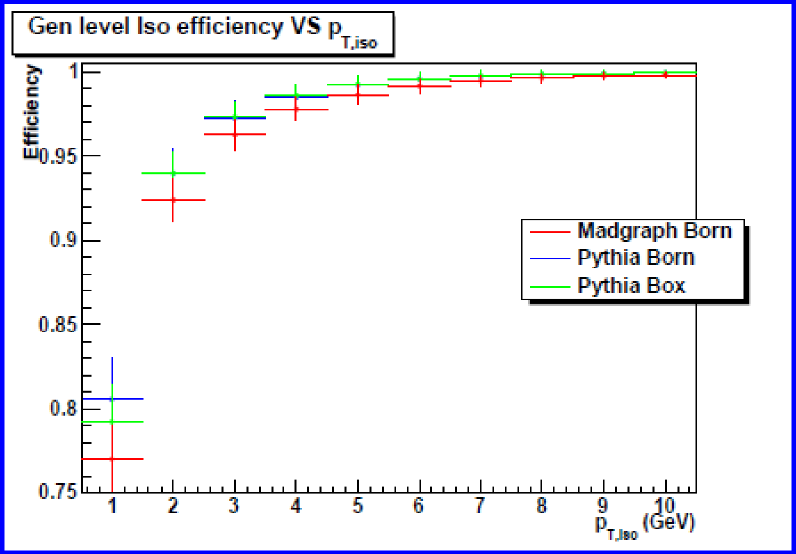


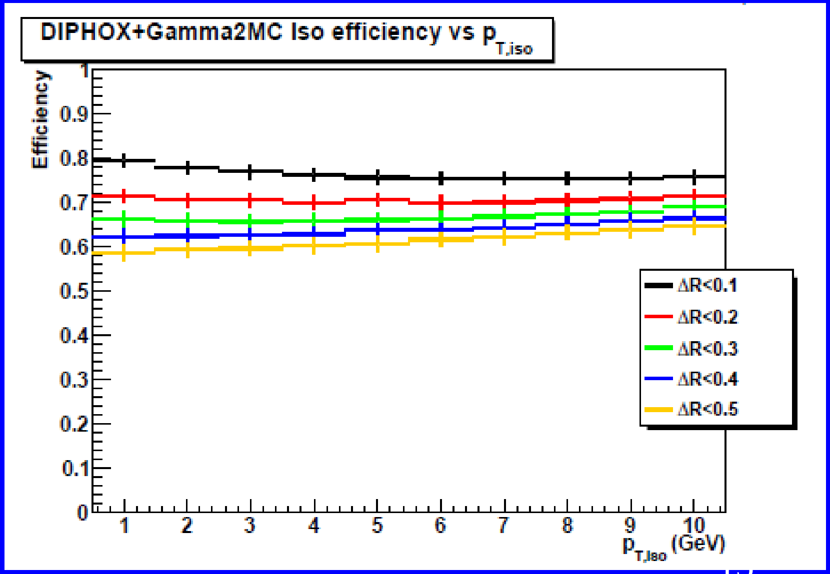
- Greatly improves data-theory agreement in the 'collinear' regime
- But uses 'Smooth' Frixione Cone Isolation to reduce fragmentation to ~<5%
- Need to do for Higgs acceptance selection, in progress

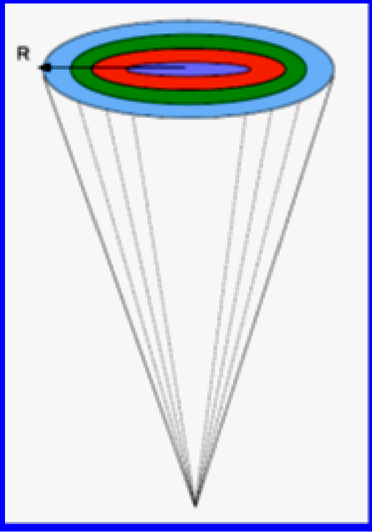
Isolation Considerations

What are the particle- and partonic-level isolations corresponding to reconstructed-level isolation?

Compatibility of theoretical pseudo-isolation and experimental isolation constraints from a theoretical point of view. DIPHOX/RESBOS/gamma2MC/2gammaNNLO have discretized version of isolation cone proposed by S. Frixione to avoid problem of Large Logs when *Rexp* → 0 and *ET max* → 0





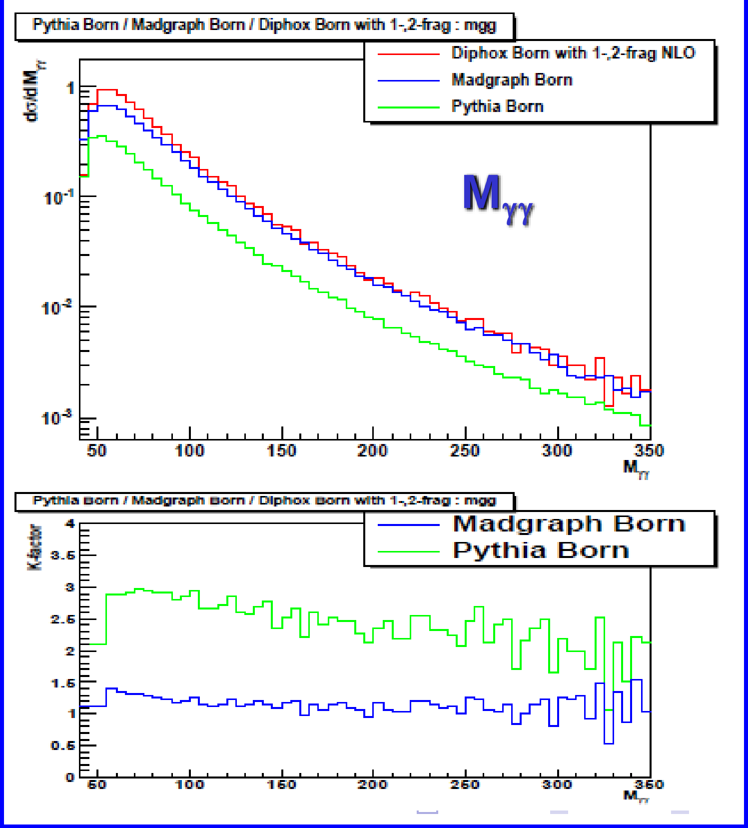


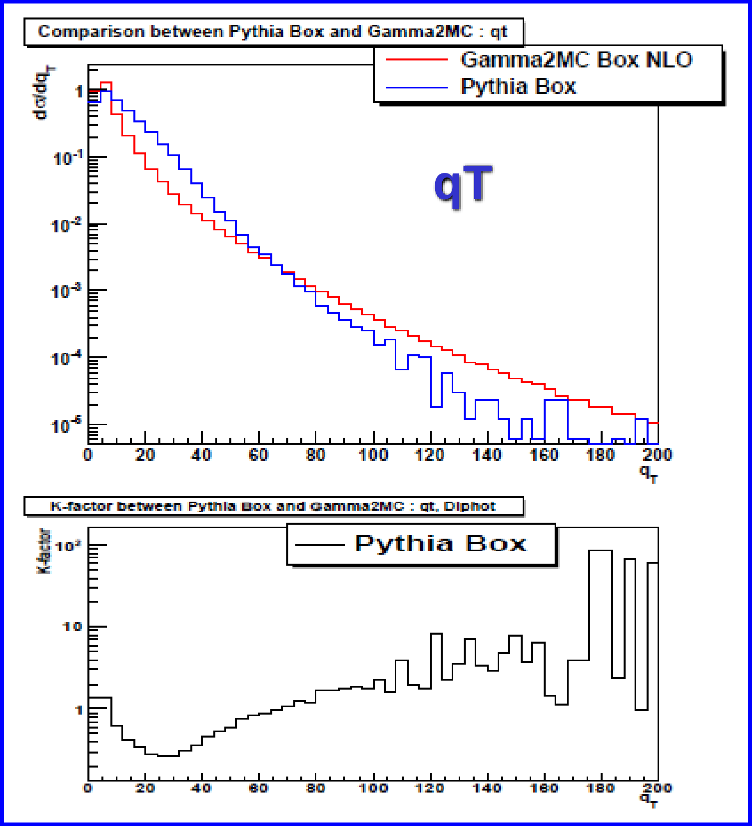
$$\epsilon_{GenIso|RecoIso} = \frac{N_{GenIso|RecoIso}}{N_{RecoIso}}$$

$$E^{j}_{T\,max} = \epsilon P_{T\,\gamma} \left(\frac{1-\cos(r_j)}{1-cos(R)}\right)^{n}$$

Doubly-differential Reweighting of $\gamma\gamma$ + x and gg → H → $\gamma\gamma$

Inspired by Dissertori et al, JHEP0607:037,2006. Done for H→$\gamma\gamma$ signal and $\gamma\gamma$ SM backgrounds (for the first time) with CMS acceptance cuts (similarly with 1D in ATLAS)

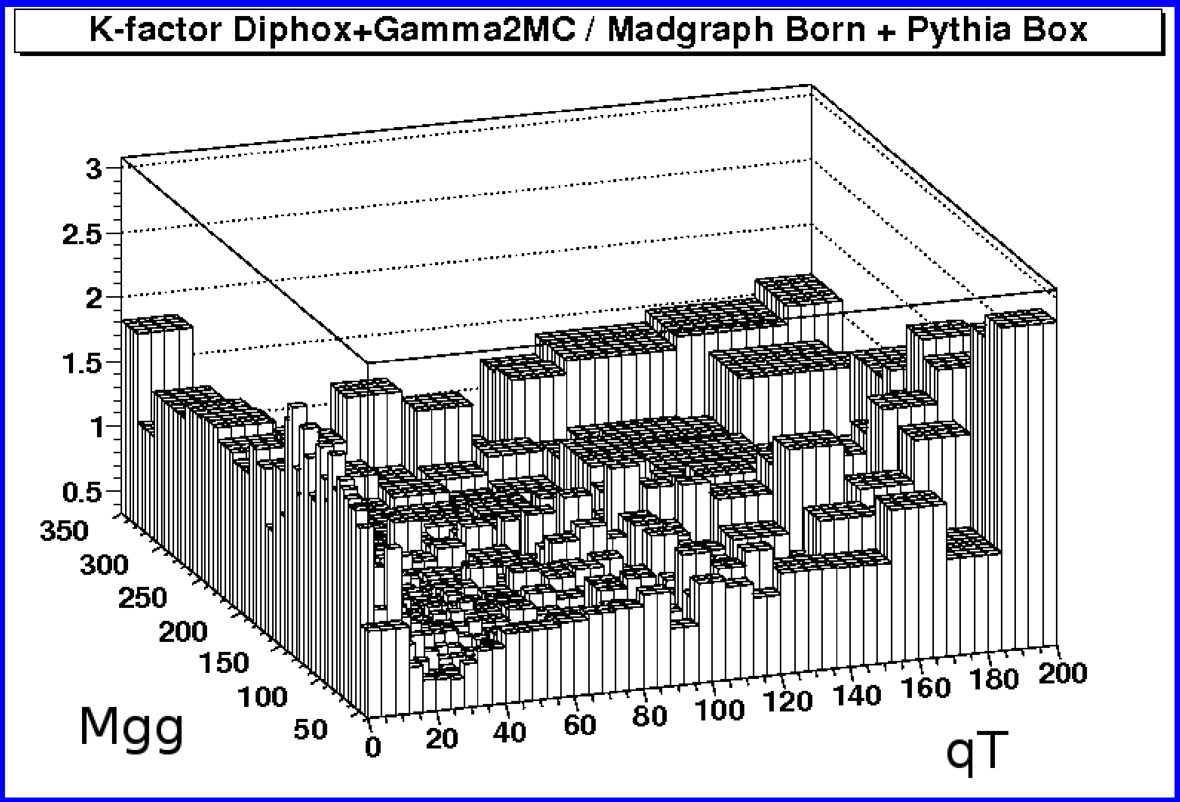


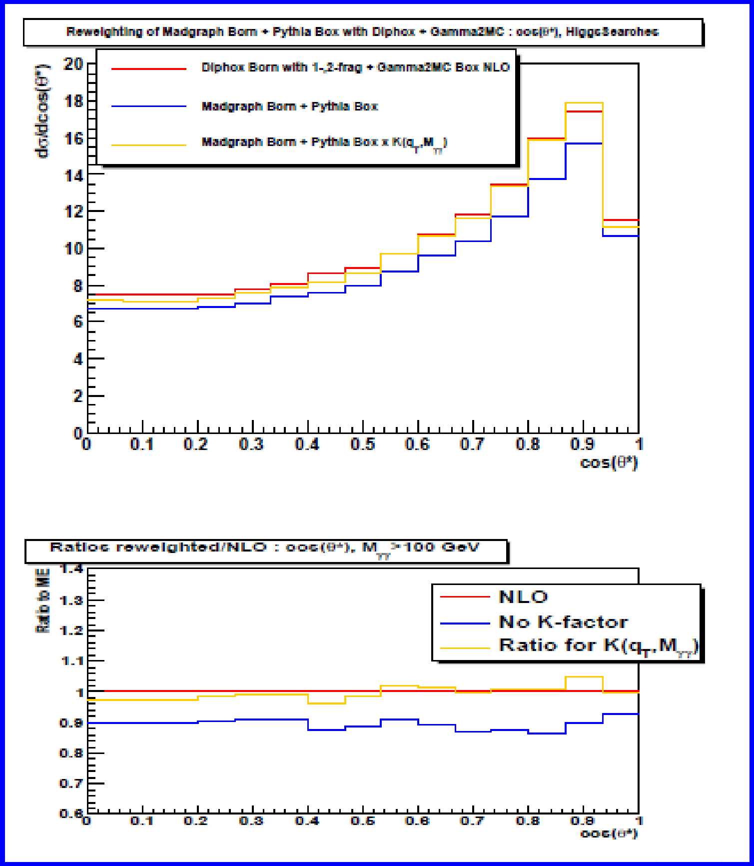


Simultaneous reweighting of Madgraph Born and PYTHIA Box gg → H → $\gamma\gamma$ with K(qT , $M_{\gamma\gamma}$) to DIPHOX and gamma2MC

Doubly-differential Reweighting of γγ + x and gg → H →γγ

Inspired by Dissertori et al, JHEP0607:037,2006. Done for H→γγ signal and γγ SM backgrounds (for the first time) with CMS acceptance cuts (1d for ATLAS)





Simultaneous reweighting of Madgraph Born and PYTHIA Box gg → H → $\gamma\gamma$ with K(qT , $M_{\gamma\gamma}$) to DIPHOX and gamma2MC

Doubly-differential Reweighting of $\gamma\gamma$ + x and gg → H →$\gamma\gamma$: 'Integrated' K-factors

K-factors after cuts (Kcut) : calculated integrating over the differential cross-section phase space used for 2D K-factors

Process	No K-factor	$K_{inclusive}$	K_{cut}	Differential K-factor
Madgraph $\gamma\gamma$+jets (born)	1.0	1.0	1.126	$K_{\gamma\gamma}(q_T, M_{\gamma\gamma})$
Pythia $\gamma\gamma$ box	1.0	1.2	1.126	$K_{\gamma\gamma}(q_T, M_{\gamma\gamma})$
m_H = 110 GeV, POWHEG $gg \to H \to \gamma\gamma$	1.0	1.56	1.247	$K_{110}(q_T, Y_{\gamma\gamma})$
m_H = 120 GeV, POWHEG $gg \to H \to \gamma\gamma$	1.0	1.56	1.261	$K_{120}(q_T, Y_{\gamma\gamma})$
m_H = 130 GeV, POWHEG $gg \to H \to \gamma\gamma$	1.0	1.56	1.248	$K_{130}(q_T, Y_{\gamma\gamma})$
m_H = 140 GeV, POWHEG $gg \to H \to \gamma\gamma$	1.0	1.56	1.250	$K_{140}(q_T, Y_{\gamma\gamma})$

Wish List for theorists

1.- A robust procedure for the estimation of systematic errors on differential cross-section predictions (in particular on qT)

2.- A procedure for the estimation of error on fragmentation

4.- Definition of parton-level pseudo-isolation cuts and the best scales to use

5.- Higher-order treatment of GF signal/gg-->gamma gamma interference

6.- An entire consistent background treatment incorporating direct contributions and fragmentation contributions at NNLO,with higher-order box contributions

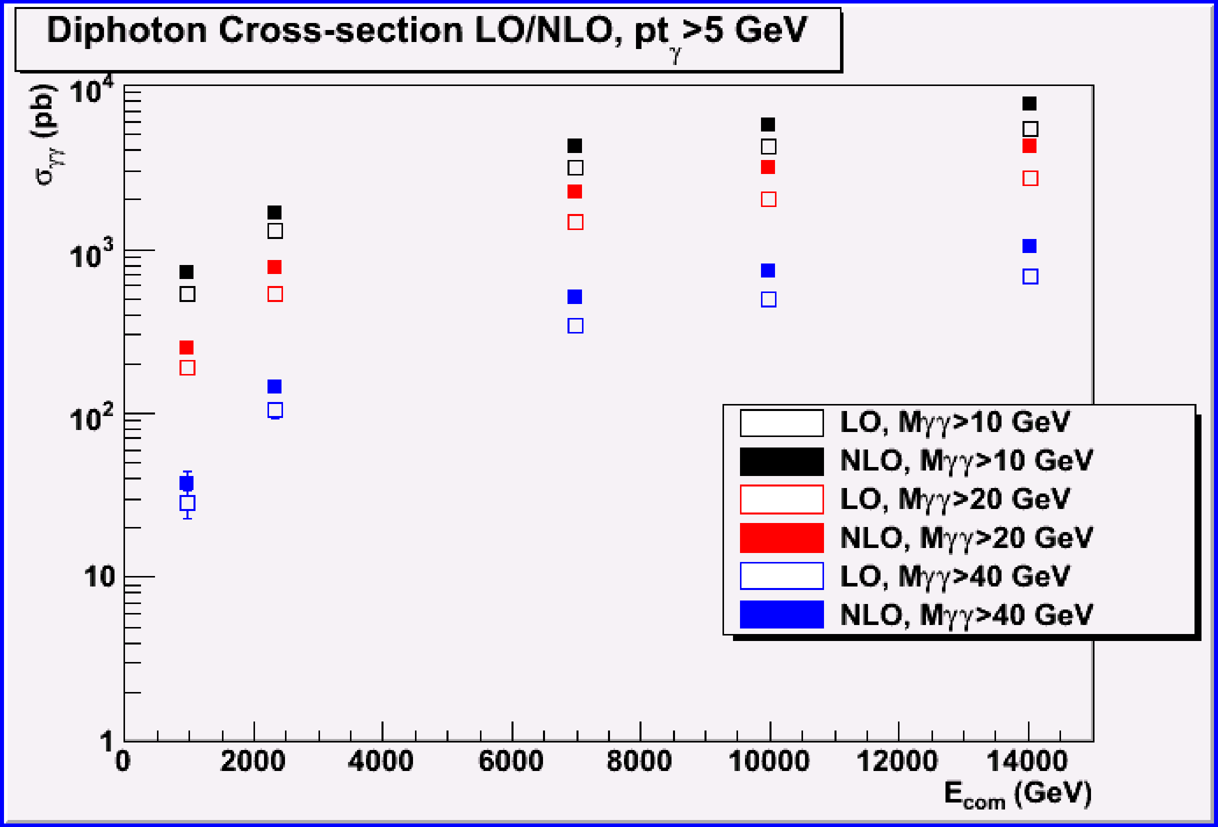
Acknowledgements

G. Dissertori, F. Stoeckli, M. Fontannaz
The local organizers, LAL and convenors
(C. Mariotti, R. Tanaka, S. Dittmaier, G. Passarino, M. Felcini, J. Yu)

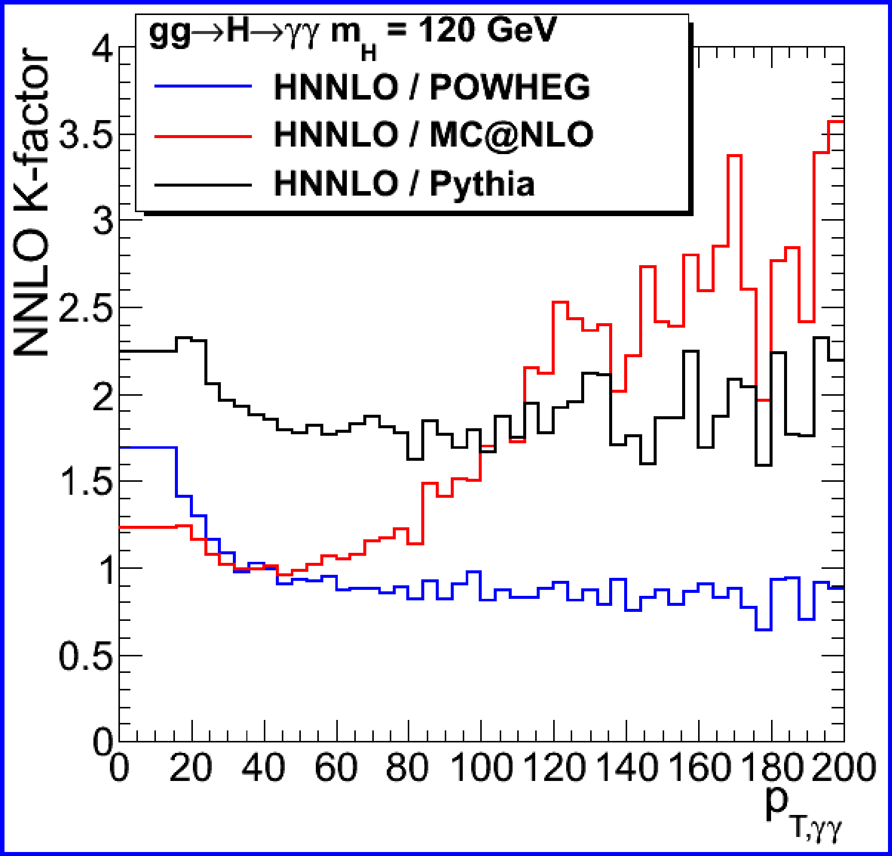
Backup

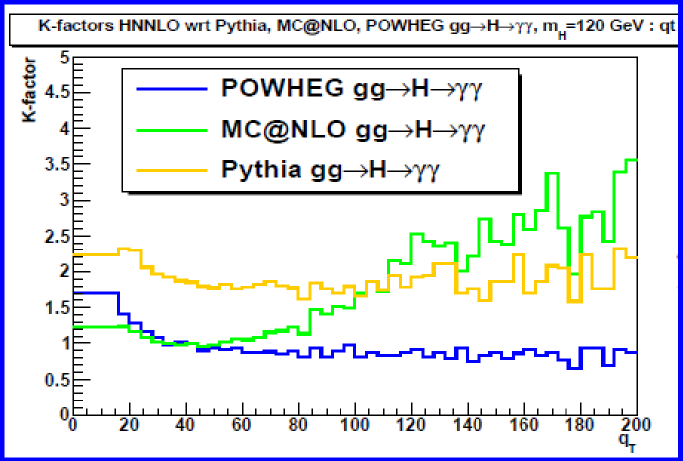
Diphoton cross-sections at different luminosities

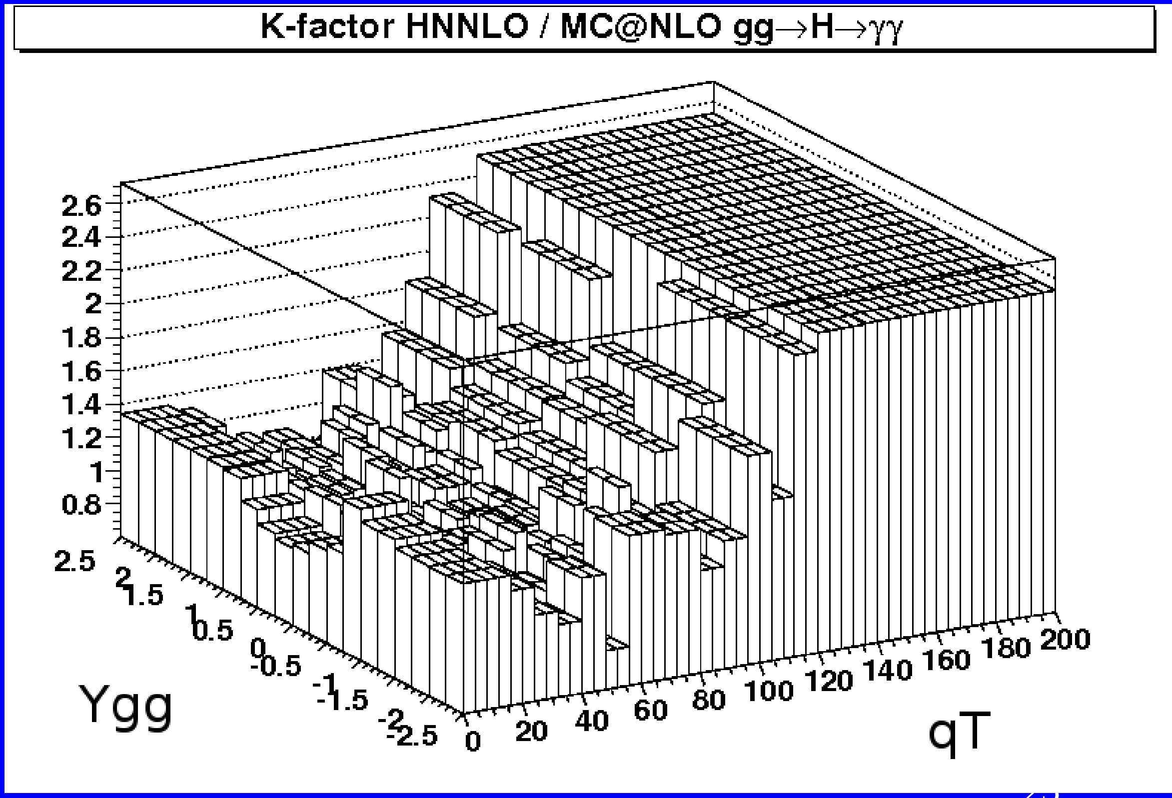
Diphox [J.P. Guillet, E. Pilon, T. Binoth]
Gamma2MC [Z. Bern, L. Dixon, and C. Schmidt]

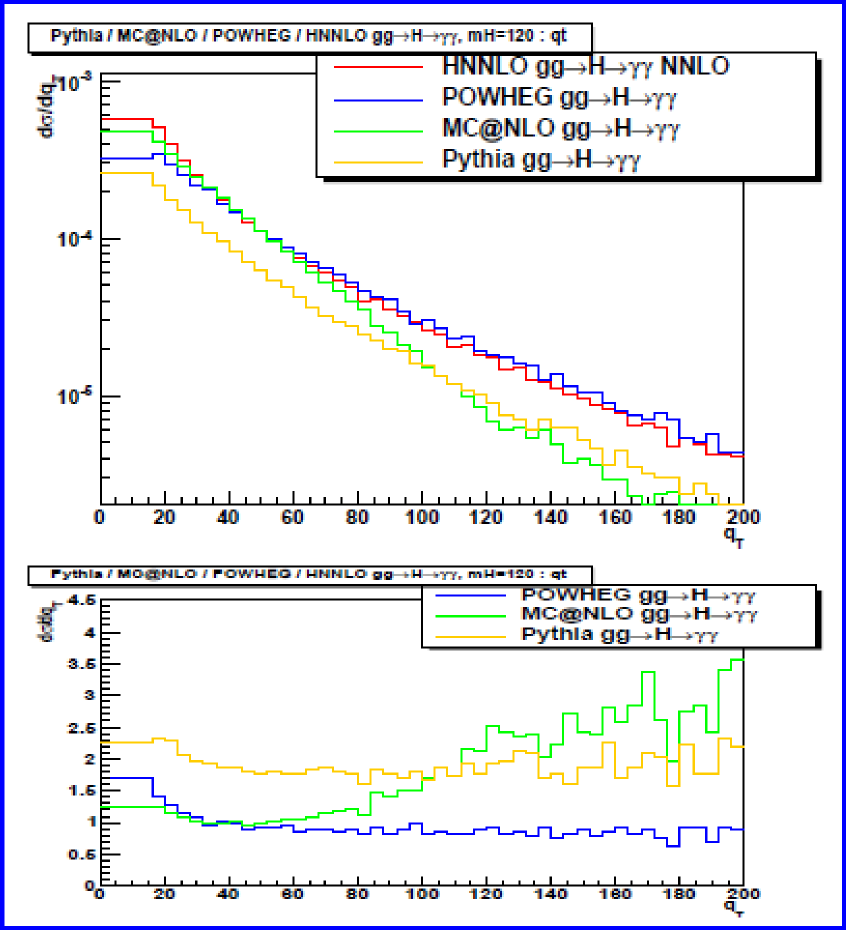


- For all the cross sections, pt_gamma > 5 GeV is required - Born, one frag and two frag contributions at LO and NLO are calculated with DIPHOX
- Box contributions are calculated with GAMMA2MC at LO and NLO, except at Ecom = 900 GeV, where it is calculated with Diphox (only at LO, because Diphox does not compute Box contribution at NLO

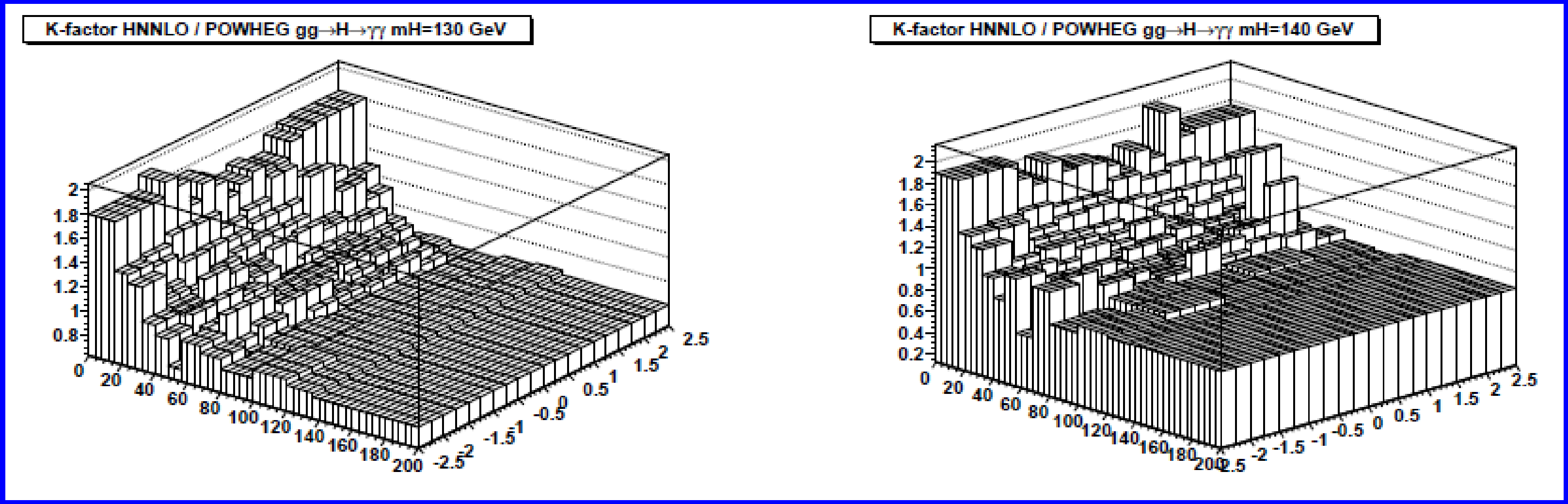

gg→H→γγ m_H = 120 GeV
HNNLO / POWHEG
HNNLO / MC@NLO
HNNLO / Pythia
NNLO K-factor
p_T,γγ


K-factors HNNLO wrt Pythia, MC@NLO, POWHEG gg→H→γγ, m_H=120 GeV : qt
POWHEG gg→H→γγ
MC@NLO gg→H→γγ
Pythia gg→H→γγ
K-factor
q_T


K-factor HNNLO / MC@NLO gg→H→γγ
Ygg
qT



Pythia / MC@NLO / POWHEG / HNNLO gg→H→γγ, mH=120 : qt
HNNLO gg→H→γγ NNLO
POWHEG gg→H→γγ
MC@NLO gg→H→γγ
Pythia gg→H→γγ
dσ/dq_T
q_T
POWHEG gg→H→γγ
MC@NLO gg→H→γγ
Pythia gg→H→γγ


K-factor HNNLO / POWHEG gg→H→γγ mH=130 GeV
K-factor HNNLO / POWHEG gg→H→γγ mH=140 GeV

```
50                  #nbinsx
0                    #xmin
200                    #xmax
62                  #nbinsy
40                    #ymin
350                    #ymax
##########################
0 0 0.0424977
0 1 0.0424977
0 2 0.0956266
0 3 0.0825195
0 4 0.0639126
0 5 0.0501463
0 6 0.040691
0 7 0.0326094
0 8 0.0251993
0 9 0.0220482
0 10 0.0148402
0 11 0.0131009
0 12 0.011838
0 13 0.00817432
0 14 0.00688524
0 15 0.00645668
0 16 0.00610477
0 17 0.00405877
0 18 0.00353558
0 19 0.00371579
0 20 0.00302585
```

Structure of the K-factors ASCII files (inspired by H ! WW W.G. K-factors)
Header : number of bins, initial and final values
Each line corresponds to the bin numbers and the associated weight K(M