MAÔS **Reconstruction** of the **SM Higgs Boson** at the **LHC**

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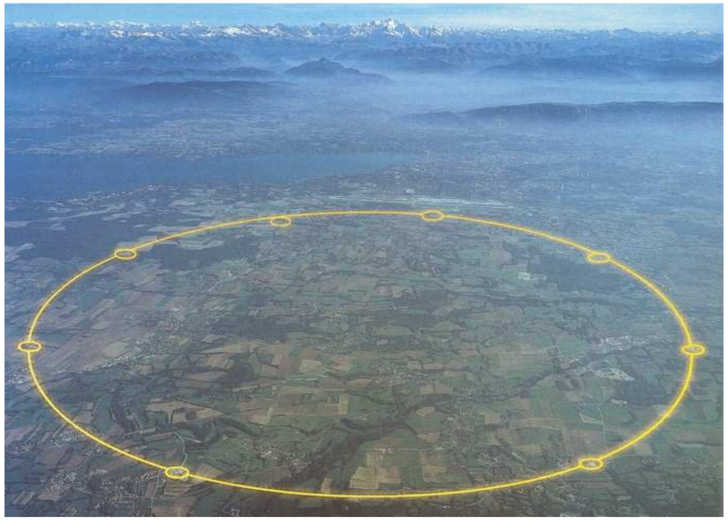
* based on PRD80(2009)073010, arXiv:0908.0079 [hep-ph], with K. Choi, S. Choi, and C. B. Park ,
and work in progress with K. Choi and C. B. Park

♠ *Preliminary: LHC*

- Brief history ...

1989 : R&D starts
1997 : Construction starts
2003 : Underground installation starts
2008 : Installation completed

11 Sep 2008 : First beam circulated
20 Sep 2008 : Magnet failures ...

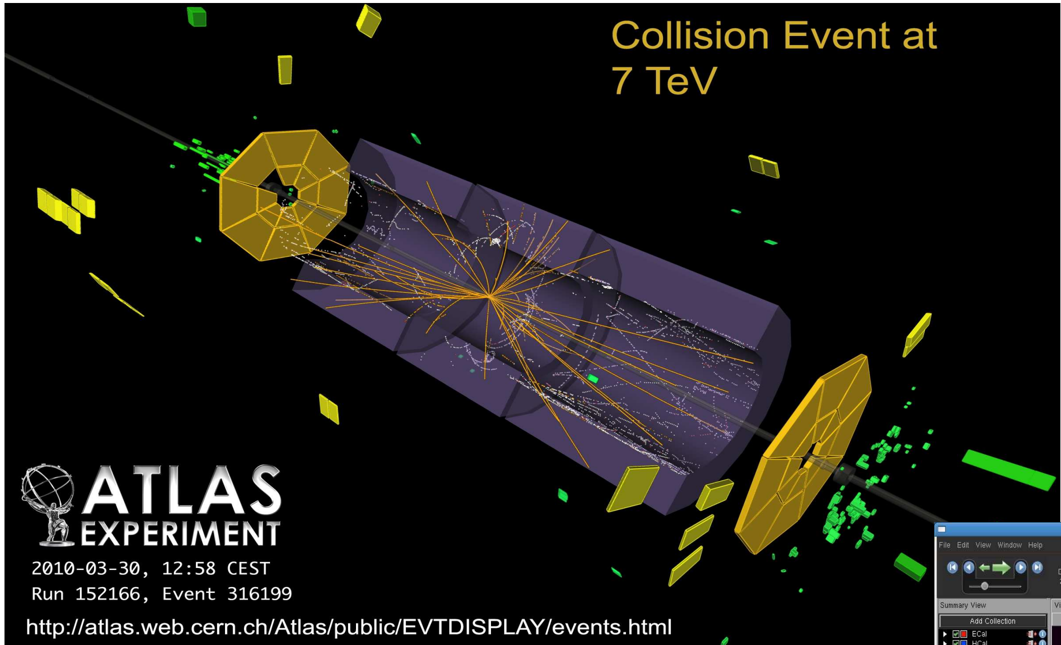


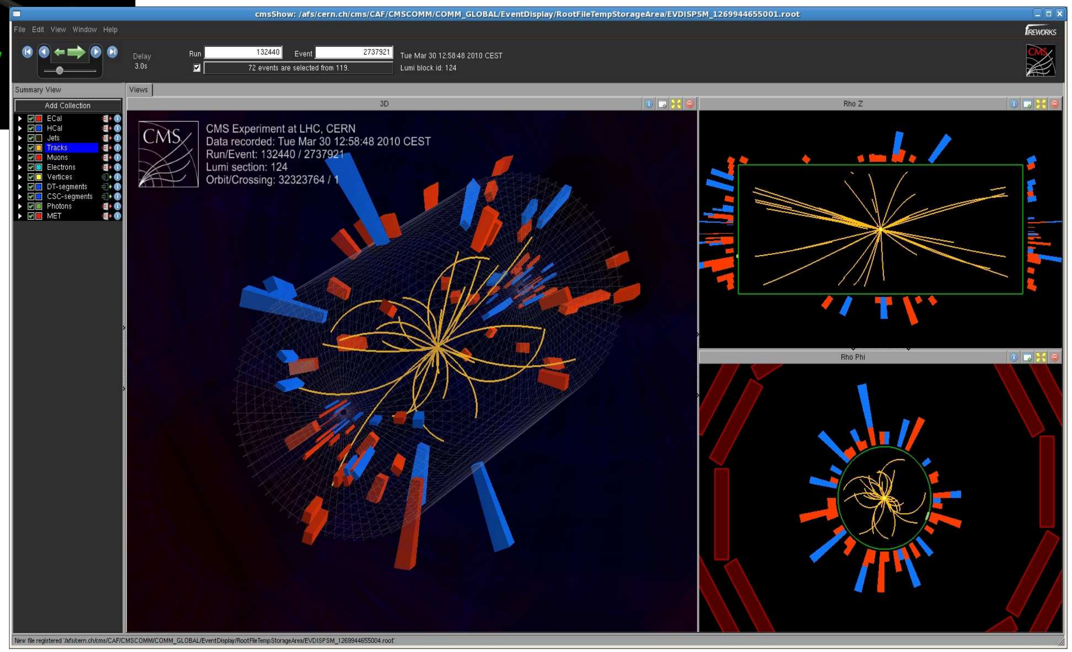
LHC.JPG

23 Nov 2009 : First collisions at $\sqrt{s} = 900$ GeV
8 Dec 2009 : First collisions at $\sqrt{s} = 2.36$ TeV
30 Mar 2010 : First collisions at $\sqrt{s} = 7$ TeV

From Junichi Kanzaki's talk @ KEKPH2010

♠ *Preliminary: LHC*





♠ *Preliminary:* *LHC*

- ... and near/far future of the LHC

2010 $\sim$ 2011 : 7 TeV (3.5+3.5 TeV) runs until 1 fb^{-1} *LHC 1/2*

2012 $\sim$ 2012 : Shutdown for repairing to achieve 7 (6.5) TeV/beam collisions

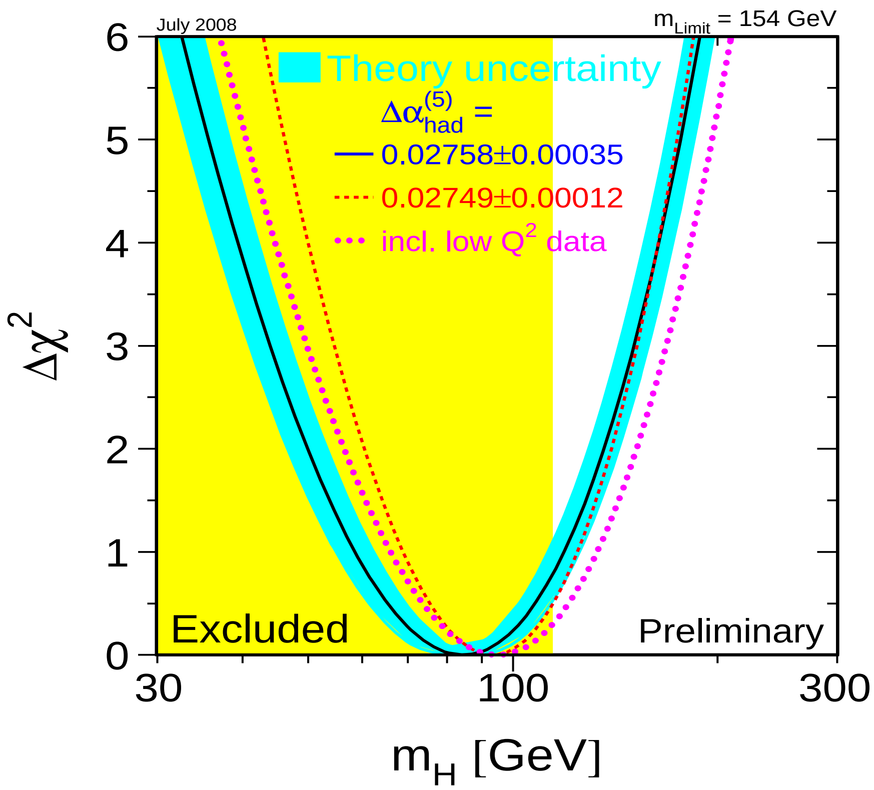
2013 $\sim$ 2014 : Go to 7 (6.5) + 7 (6.5) TeV runs to get ~ 10 fb^{-1} *LHC*

2015 $\sim$ 202? : accumulate 3000 fb^{-1} with $250 \sim 300$ fb^{-1} per year

again, from Junichi Kanzaki's talk @ KEKPH2010, or
LHC Performance Workshop - Chamonix 2010 (Jan)

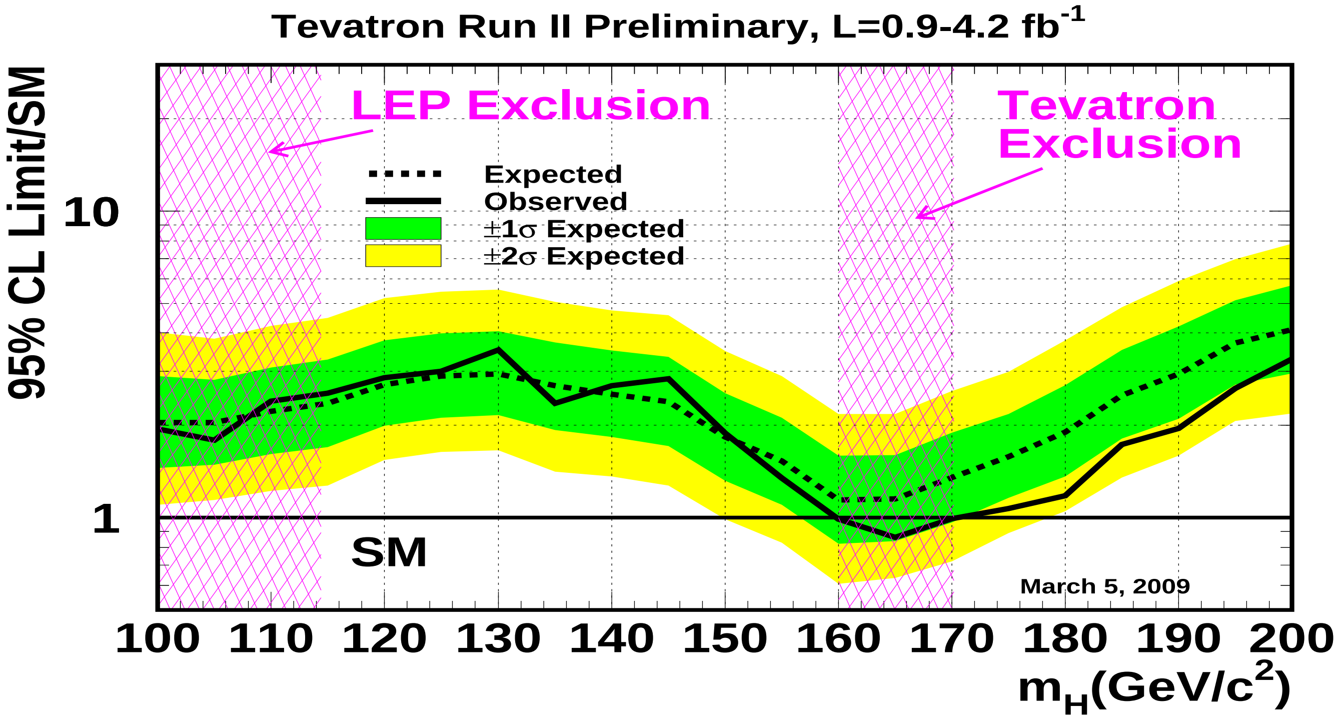
♠ *Preliminary: Standard Model Higgs Boson*

- Status of the SM Higgs:
  - LEP bound: $M_H^{\rm SM} \geq 114.4$ GeV (95 % C.L.) ADLO, arXiv:hep-ex/0306033
  - Electroweak precision data: $M_H^{\rm SM} \lesssim 185$ GeV (95 % C.L.) direct-search limit included ACDDLOS, arXiv:0811.4682[hep-ex]



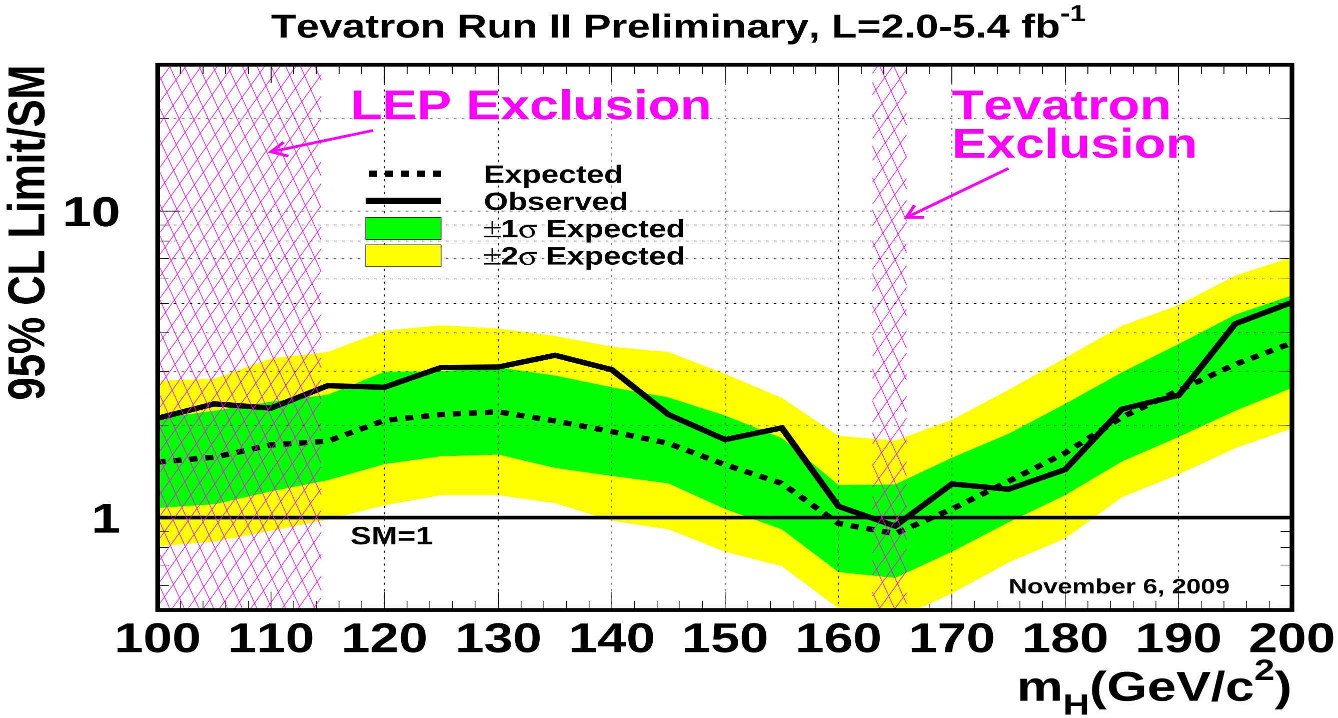
♠ *Preliminary: Standard Model Higgs Boson*

- Status of the SM Higgs: *... continued*
  - Tevatron exclusion $[\mathcal{L} = 0.9\text{-}4.2\ \text{fb}^{-1}]$: 160 GeV $\lesssim M_H^{\text{SM}} \lesssim$ 170 GeV (95 % C.L.) CDF/D0, arXiv:0903.4001[hep-ex]



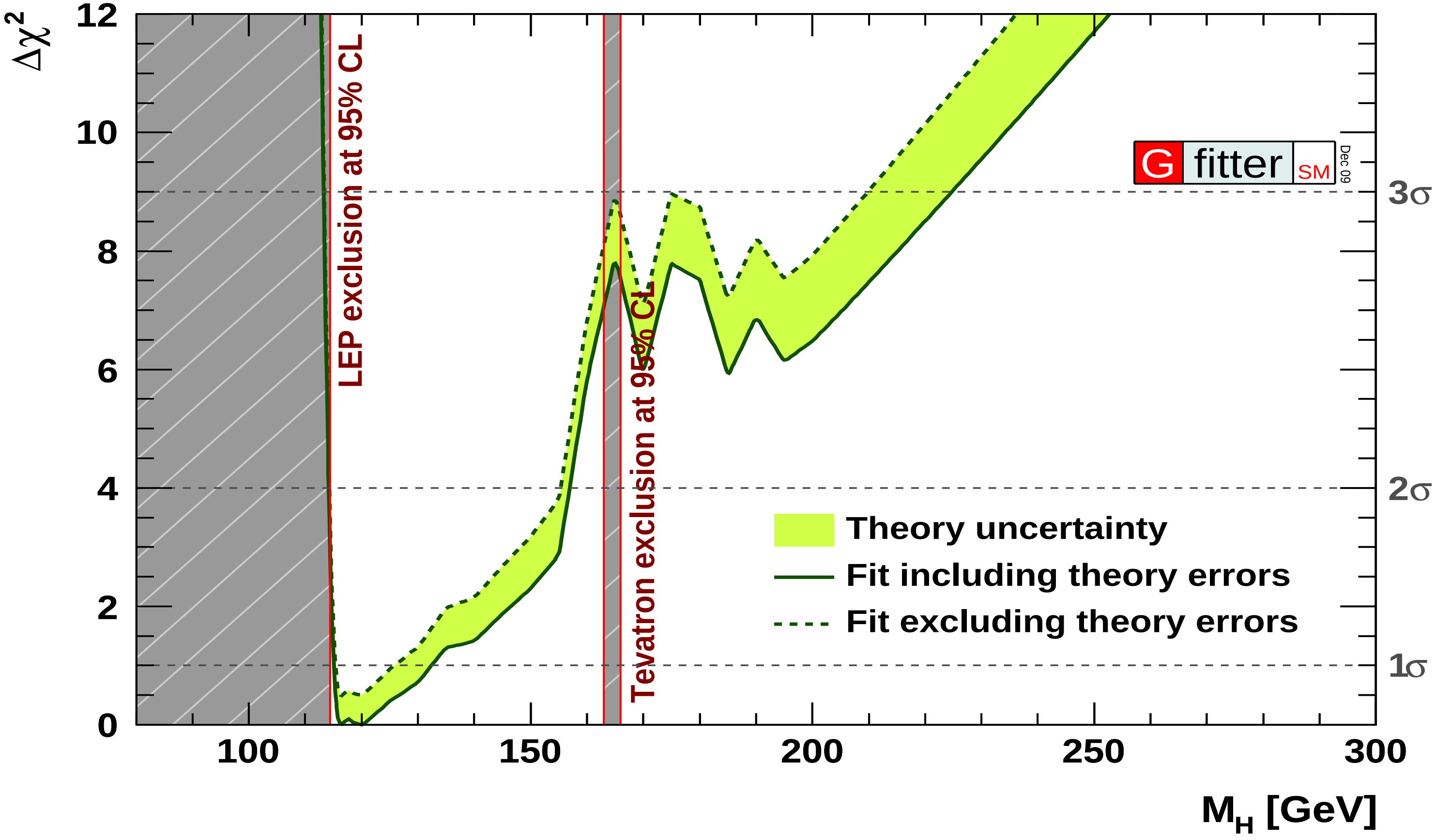
♠ *Preliminary: Standard Model Higgs Boson*

- Status of the SM Higgs: ... *continued*
  - Tevatron exclusion $[\mathcal{L} = 2.0\text{-}5.4 \text{ fb}^{-1}]$: 163 GeV $\lesssim M_H^{\rm SM} \lesssim$ 166 GeV (95 % C.L.) CDF/D0, arXiv:0911.3930[hep-ex]



♠ *Preliminary: Standard Model Higgs Boson*

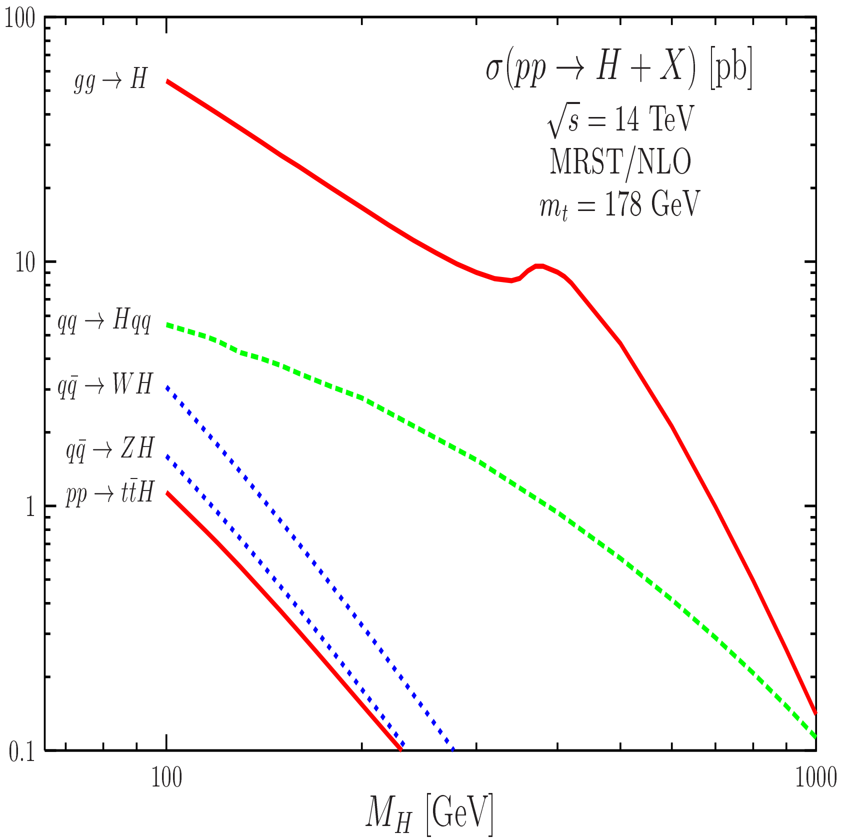
- Status of the SM Higgs: *combining all...* Gfitter, arXiv:0811.0009

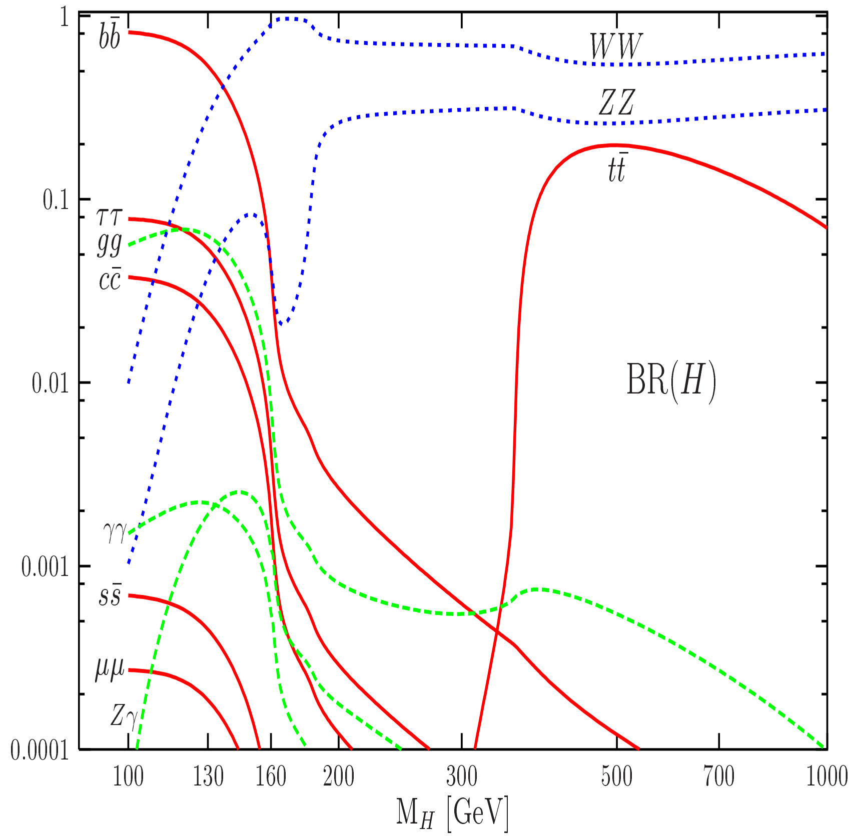


We anticipate the SM Higgs boson lighter than ∼ 200 GeV

♠ Preliminary: SM Higgs@LHC

- Production and decay of the SM Higgs boson at the LHC:

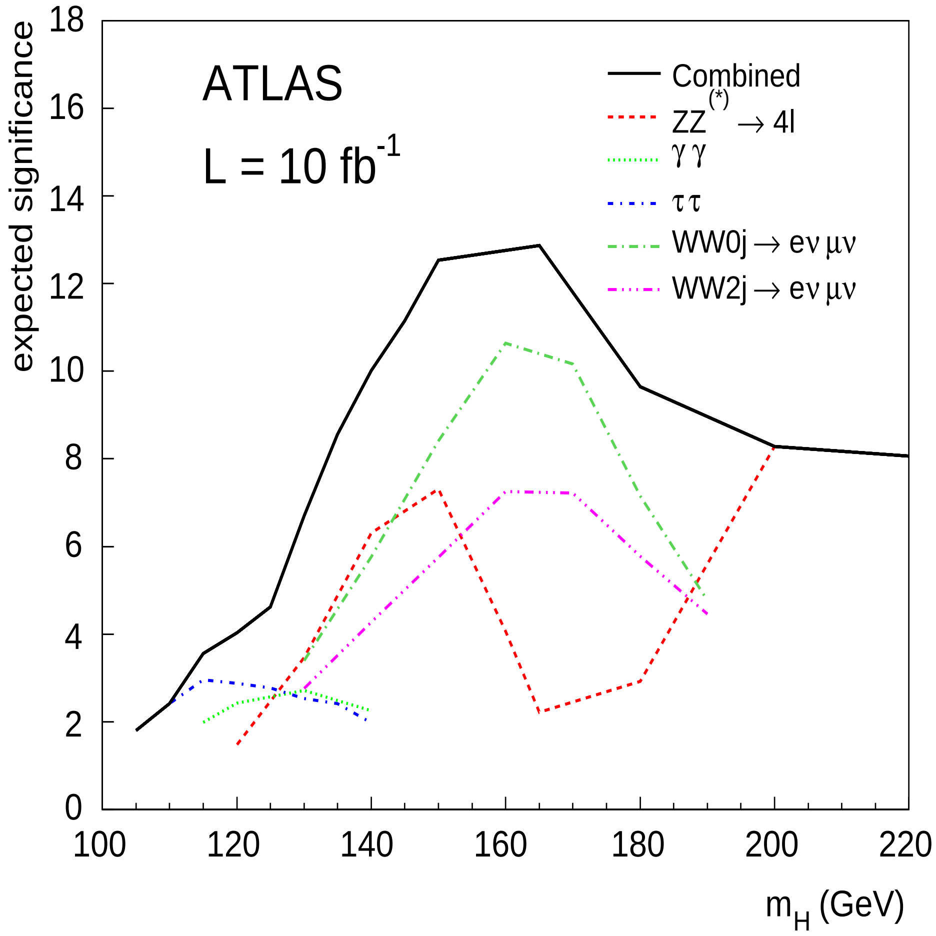




$gg \to H$; $qq \to q^{(\prime)}q^{(\prime)}(VV) \to q^{(\prime)}q^{(\prime)}H$ $\qquad$ $H \to \tau\tau\,,\gamma\gamma\,,WW\,,ZZ$

♠ Preliminary: SM Higgs@LHC

- Discovery Significance ATLAS TDR, arXiv:0901.0512[hep-ex]



- $H \to \tau\tau$
- $H \to \gamma\gamma$

▷ $H \to WW^* \to l\nu l\nu$ (GF)

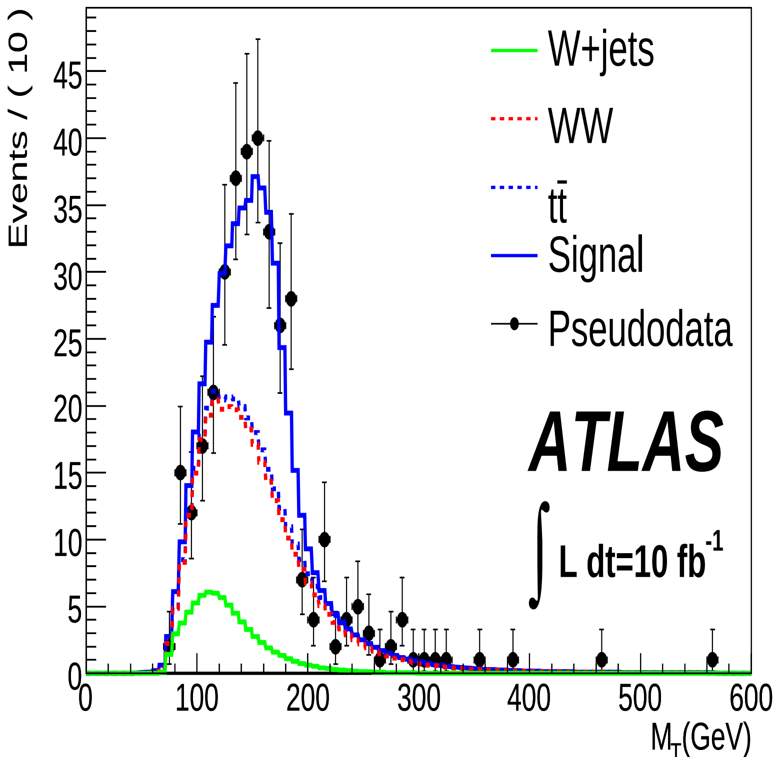
▷ $H \to WW^* \to l\nu l\nu$ (VBF)

□ $H \to ZZ^{(*)} \to 4\,l$

The WW channel plays a dominant role for 130 GeV $\lesssim M_H \lesssim$ 190 *GeV !*

♠ Preliminary: SM Higgs@LHC

- Current search strategy is to use the transverse mass as the main observable



$$M_T^2(WW \to l\nu l\nu\,;\mathbf{p}_T^{\nu\nu} = \not{\mathbf{p}}_T\,) =$$
$$m_{ll}^2 + m_{\nu\nu}{}^2 + 2\sqrt{\left|\mathbf{p}_T^{ll}\right|^2 + m_{ll}^2}\sqrt{\left|\mathbf{p}_T^{\nu\nu}\right|^2 + m_{\nu\nu}{}^2}$$
$$- 2\mathbf{p}_T^{ll} \cdot \mathbf{p}_T^{\nu\nu}$$

$$M_T^{\text{approx}} = M_T(m_{\nu\nu} = m_{ll})$$

Rainwater, Zeppenfeld, hep-ph/9906218

$$M_T^{\text{true}} = M_T(m_{\nu\nu} = 0)$$
$$\leq M_T(m_{\nu\nu} = m_{\nu\nu}^{\text{true}}) \leq M_H$$

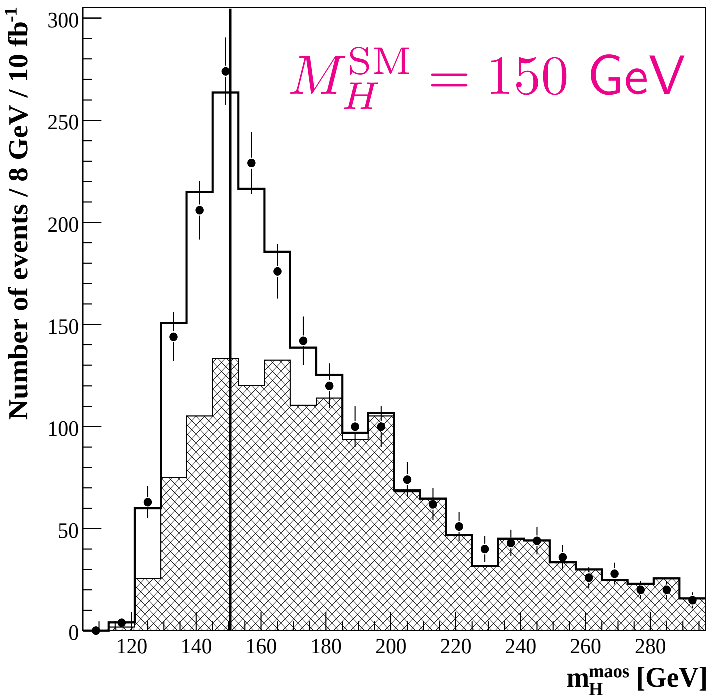
Barr, Gripaios, Lester, arXiv:0902.4864

.... excess in the M_T^{approx} distribution over the accurately estimated backgrounds

$\Rightarrow$... but, no mass peak due to missing neutrinos

♠ *Preliminary: SM Higgs@LHC*

- Our Proposal: New observable ($M_H^{\rm MAOS}$) to probe the properties of the SM Higgs boson at the LHC: its mass and characteristic features of the coupling



.... it is coming

♠ Preliminary: MAOS

- M_{T2}-Assisted On-shell Scheme

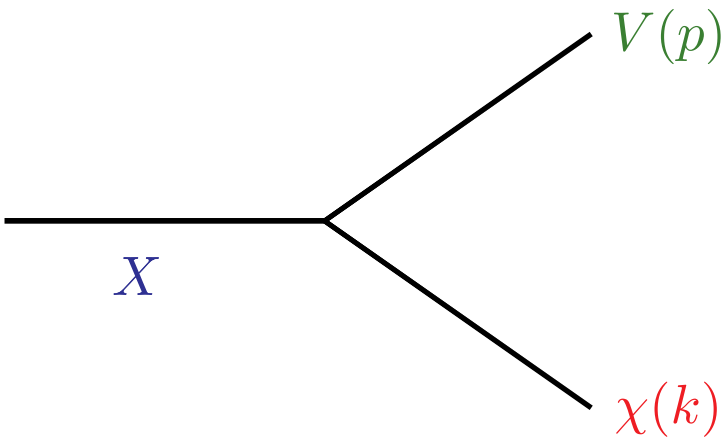
then... What is M_{T2} ?

... we'd better start from the Transverse Mass M_T

N.B. nothing(?) to do with ...

♠ *Preliminary: MAOS*

- Transverse Mass M_T :



$$p^\mu = \left(\sqrt{m_V{}^2 + |\mathbf{p}_T|^2 + p_L^2}\,, \mathbf{p}_T\,, p_L\right)$$

$$k^\mu = \left(\sqrt{m_\chi{}^2 + |\mathbf{k}_T|^2 + k_L^2}\,, \mathbf{k}_T\,, k_L\right)$$

$$\mathbf{k}_T = \not{\mathbf{p}}_T\,(\textit{fully determined})$$

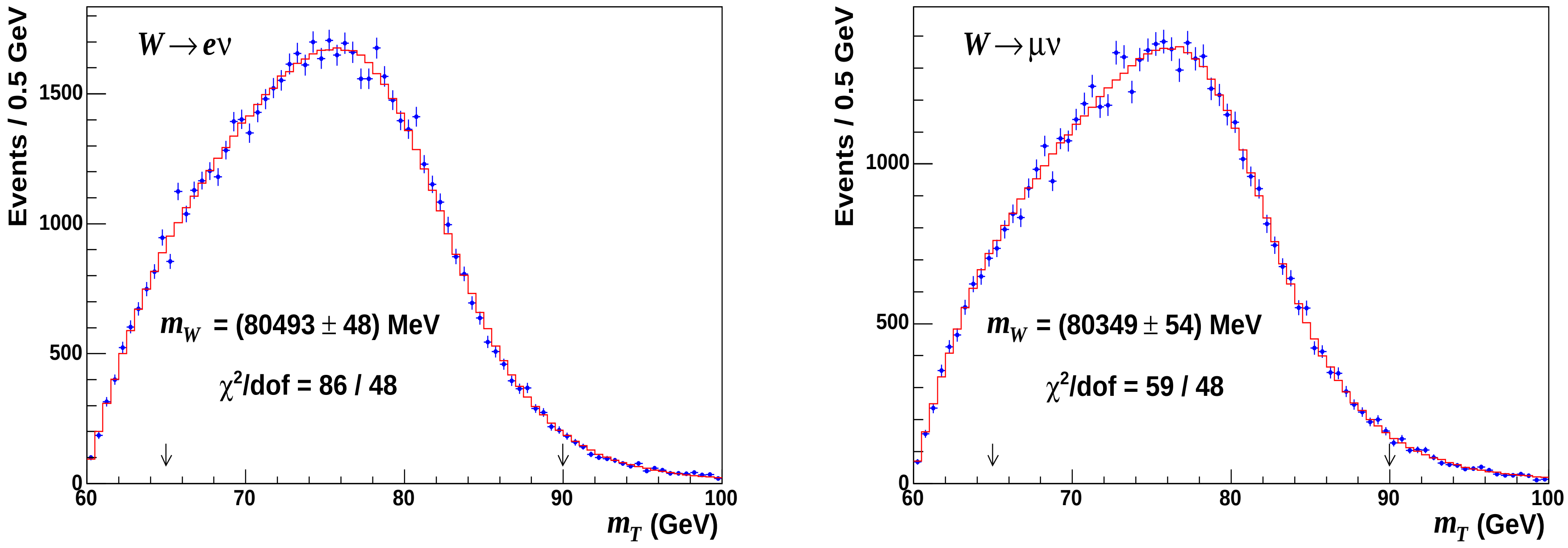
$$M_X{}^2 = m_V{}^2 + m_\chi{}^2 + 2\left(\sqrt{m_V{}^2 + |\mathbf{p}_T|^2 + p_L^2}\sqrt{m_\chi{}^2 + |\mathbf{k}_T|^2 + k_L^2} - \mathbf{p}_T \cdot \mathbf{k}_T - p_L k_L\right)$$

$$M_T{}^2 = m_V{}^2 + m_\chi{}^2 + 2\left(\sqrt{m_V{}^2 + |\mathbf{p}_T|^2}\sqrt{m_\chi{}^2 + |\mathbf{k}_T|^2} - \mathbf{p}_T \cdot \mathbf{k}_T\right)$$

$$M_T \leq M_X$$

♠ Preliminary: MAOS

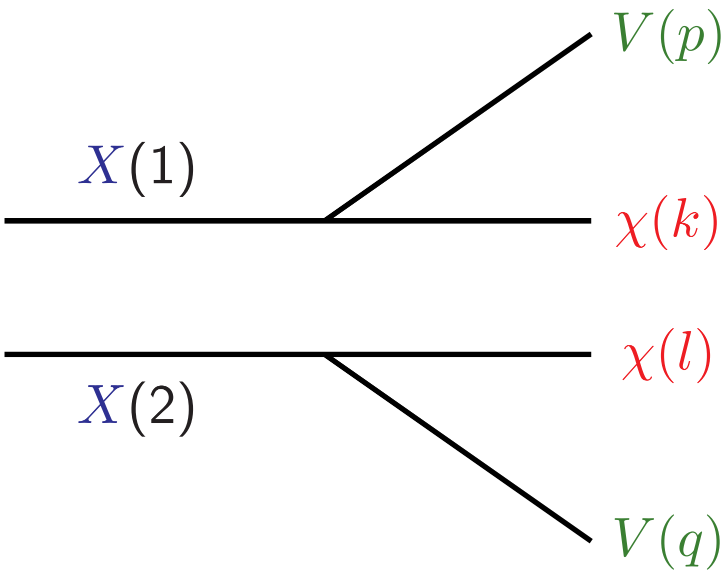
- Fit to the bkg. $\oplus$ sig. $M_T(W \to l\nu)$ distribution: CDF, arXiv:0708.3642 [hep-ex]



$$M_W = 80.417 \pm 0.048 \text{ GeV}$$

♠ Preliminary: MAOS

- ... then M_{T2} ?: Generalization of M_T when there are 2 missing particles



$$\mathbf{k}_T + \mathbf{l}_T = \not{\mathbf{p}}_T$$

Only determined are ...

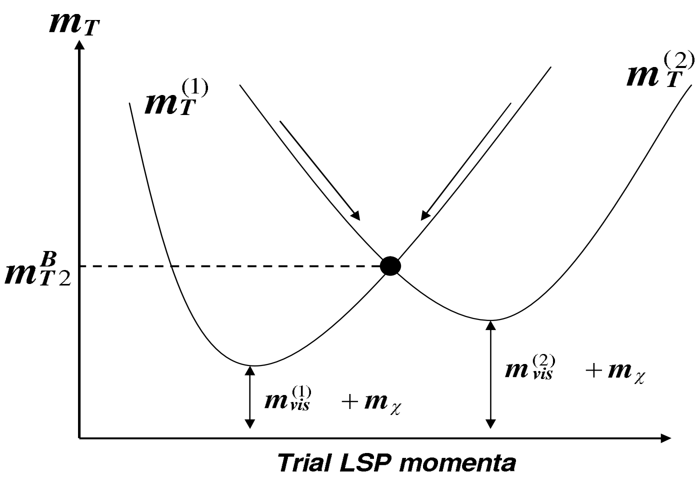
the 2 among the 4 unknown degrees of freedom !

... but we know:

$$\max\{M_T^{(1)}, M_T^{(2)}\}(\mathbf{k}_T^{\rm true}, \mathbf{l}_T^{\rm true}) \leq M_X$$

♠ Preliminary: MAOS

- ... then M_{T2} ?: Generalization of M_T when there are 2 missing particles



$$\mathbf{k}_T + \mathbf{l}_T = \not{\mathbf{p}}_T$$

Only determined are ...

the 2 among the 4 unknown degrees of freedom !

... but we know:

$$\max\{M_T^{(1)}, M_T^{(2)}\}(\mathbf{k}_T^{\rm true}, \mathbf{l}_T^{\rm true}) \le M_X$$

$$\max\{M_T^{(1)}, M_T^{(2)}\}(\mathbf{k}_T^{\rm min}, \mathbf{l}_T^{\rm min}) \le \max\{M_T^{(1)}, M_T^{(2)}\}(\mathbf{k}_T^{\rm true}, \mathbf{l}_T^{\rm true}) \le M_X$$

$$M_{T2} \equiv \min_{\mathbf{k}_T + \mathbf{l}_T = \not{\mathbf{p}}_T}\left[\max\left\{M_T^{(1)}, M_T^{(2)}\right\}\right] \le M_X$$

♠ *Preliminary: MAOS*

- So, M_{T2} somehow determines the transverse momenta of the missing particles:

$\Rightarrow$ Nothing can be done for the *longitudinal momenta* ? W.S.Cho, K.Choi, Y.G.Kim, C.B.Park, PRD79(2009)031701,arXiv:0810.4853 [hep-ph]

$$X \to V(p)\,\chi(k)$$

Once M_X is known, using the M_{T2}-determined $\widetilde{\mathbf{k}}_T$, the longitudinal momenta can be fixed requiring the **on-shell** condition $(p+\widetilde{k})^2 = {M_X}^2$:

$$\widetilde{k}_L^{\pm} = \frac{1}{{m_V}^2 + |\mathbf{p}_T|^2}\left[p_L\,A \pm \sqrt{{m_V}^2 + |\mathbf{p}_T|^2 + p_L^2}\right.$$
$$\left.\times\sqrt{A^2 - ({m_V}^2 + |\mathbf{p}_T|^2)({m_\chi}^2 + |\widetilde{\mathbf{k}}_T|^2)}\right] ,$$

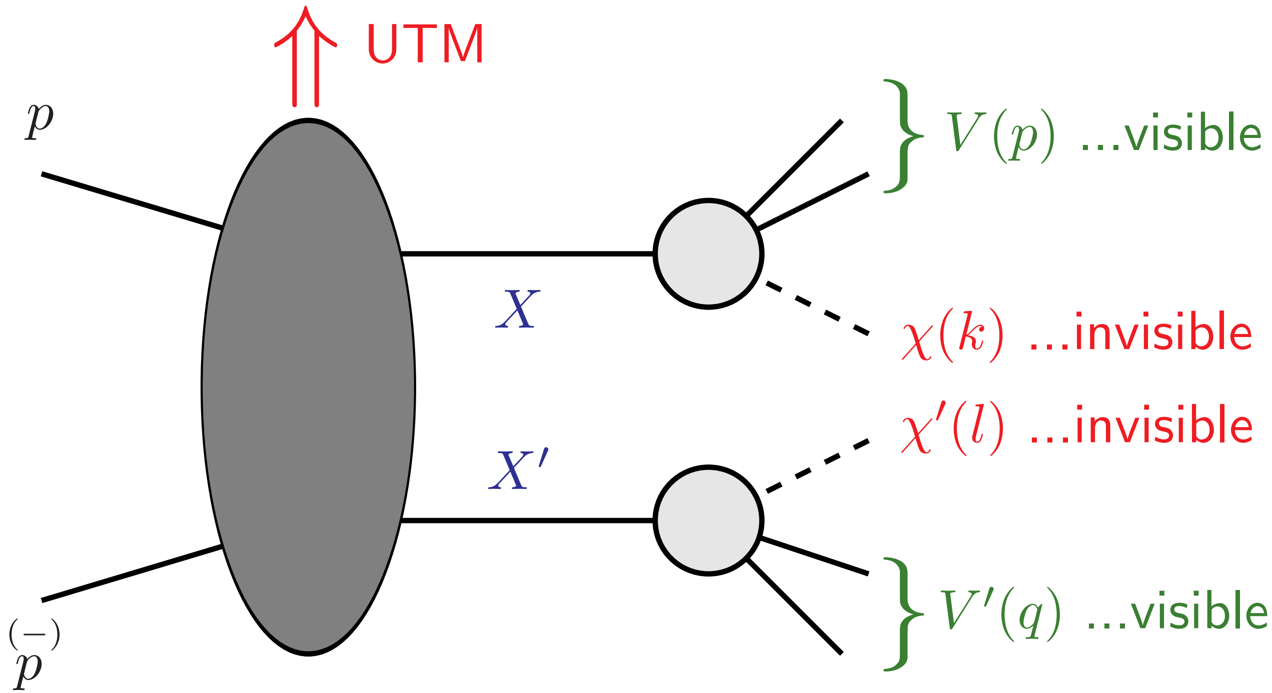
where $A \equiv ({M_X}^2 - {m_V}^2 - {m_\chi}^2)/2 + \mathbf{p}_T \cdot \widetilde{\mathbf{k}}_T$

M_{T2}-Assisted On-shell Scheme $\Rightarrow$ MAOS

♠ *Contents*

♠ *The process and* M_{T2} (1/7)

- LHC Signature of a New Physics Model with a Z_2 symmetry:



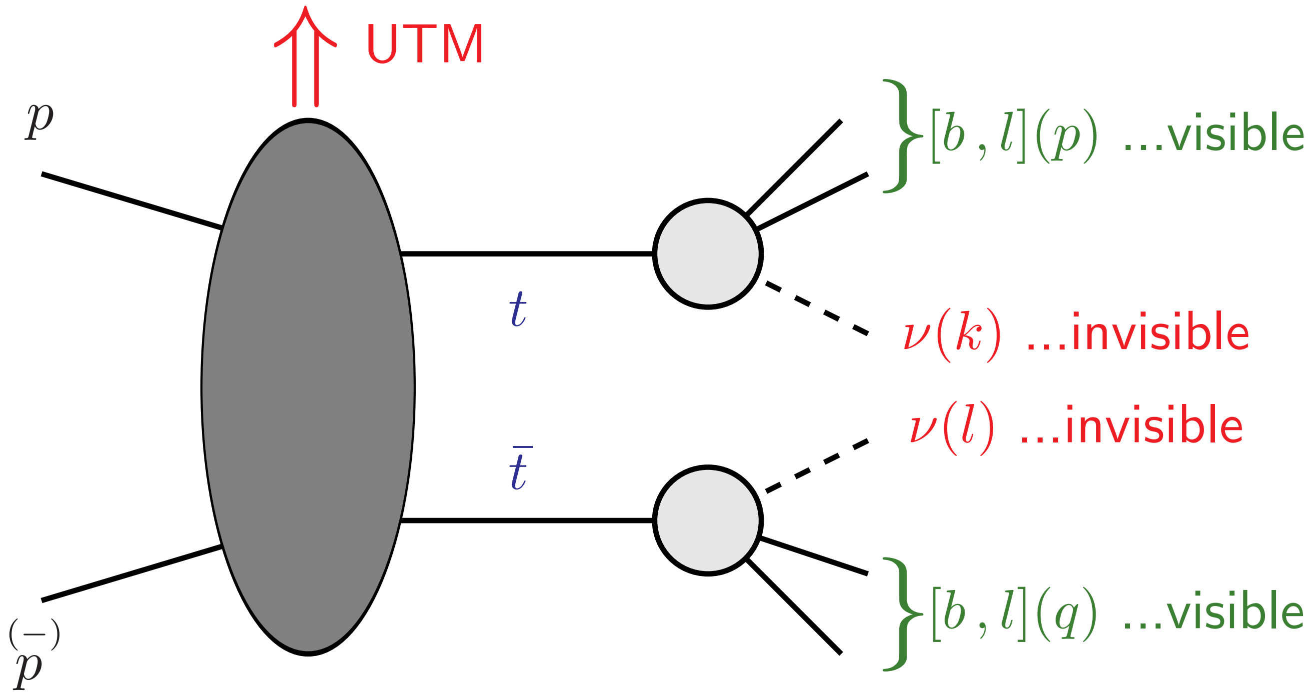
$$M_{T2}(\text{event}, m_\chi) \equiv \min_{\mathbf{k}_T+\mathbf{l}_T=\not{p}_T}\left[\max\left\{M_T(p^2, \mathbf{p}_T, m_\chi, \mathbf{k}_T), M_T(q^2, \mathbf{q}_T, m_\chi, \mathbf{l}_T)\right\}\right]$$

a systematic scheme for determinging transverse momenta of the two invisible particles

C.G.Lester and D.J.Summers, PLB463(1999)99; A.J.Barr, C.G.Lester and P.Stephenes, JPhysG29(2003)2343

♠ *The process and* M_{T2} $(2/7)$

- Why not Standard Model with two missing neutrinos ?:

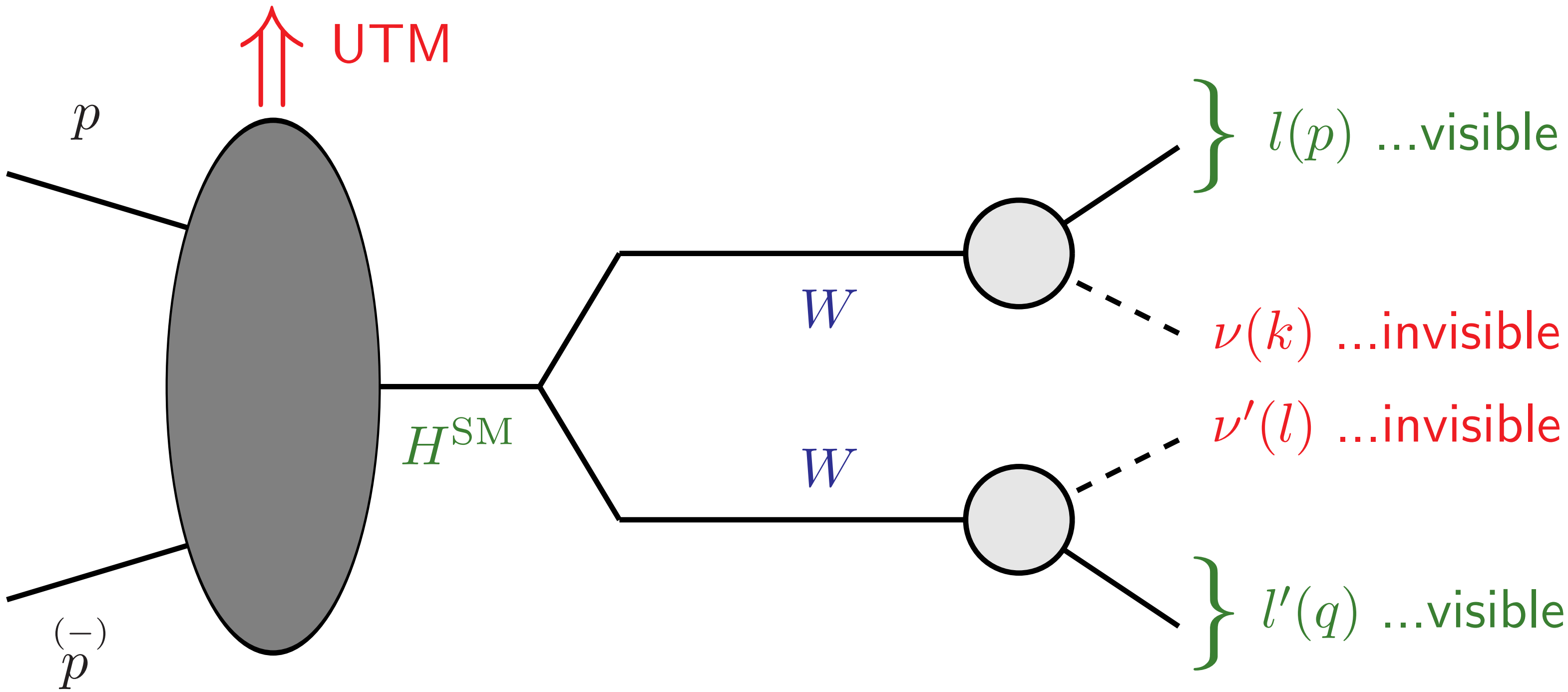


$M_{T2}(\text{event}, m_\nu = 0) \leq m_t$ in the zero-width limit

W.S.Cho, K.Choi, Y.G.Kim, C.B.Park, PRD78(2008)034019; CDF Note 9769 (2009)

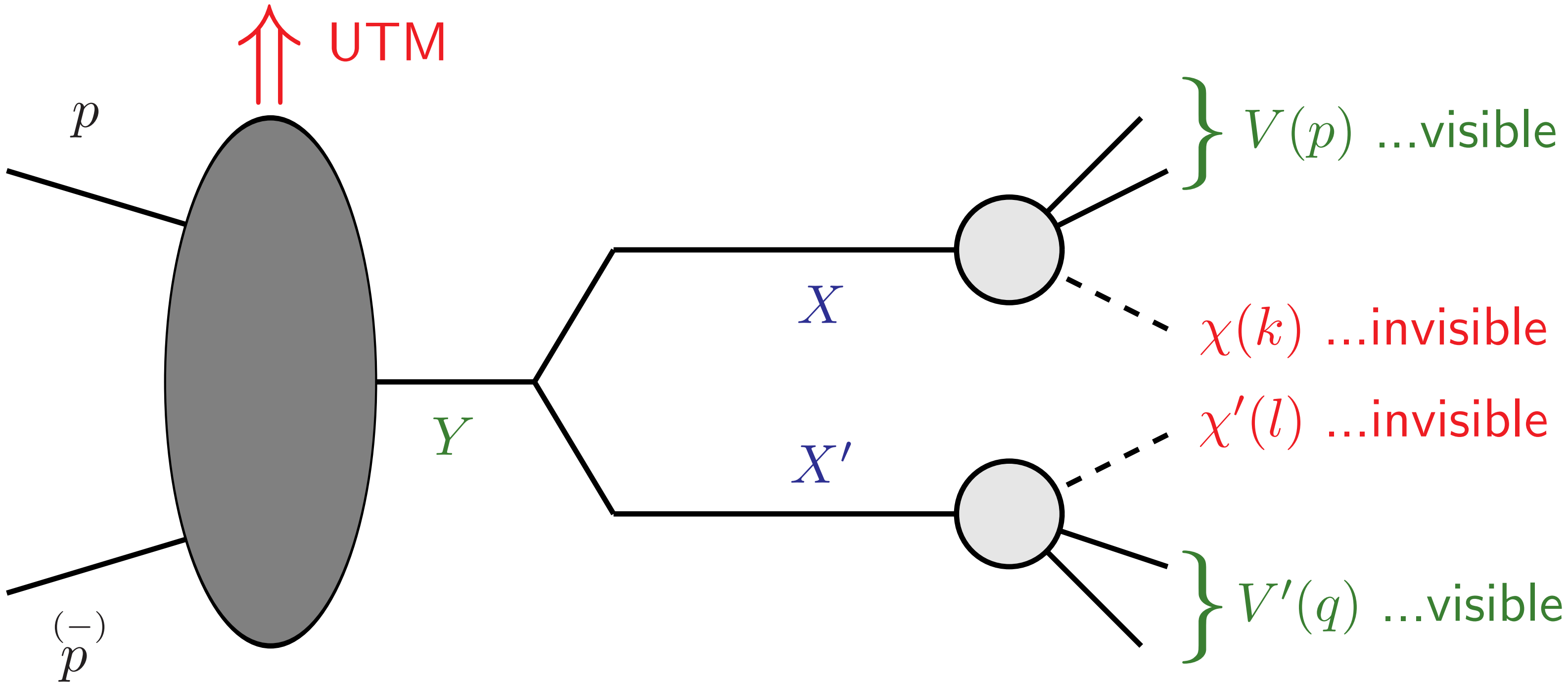
♠ *The process and* M_{T2} $(3/7)$

- The SM process we want to consider ...:

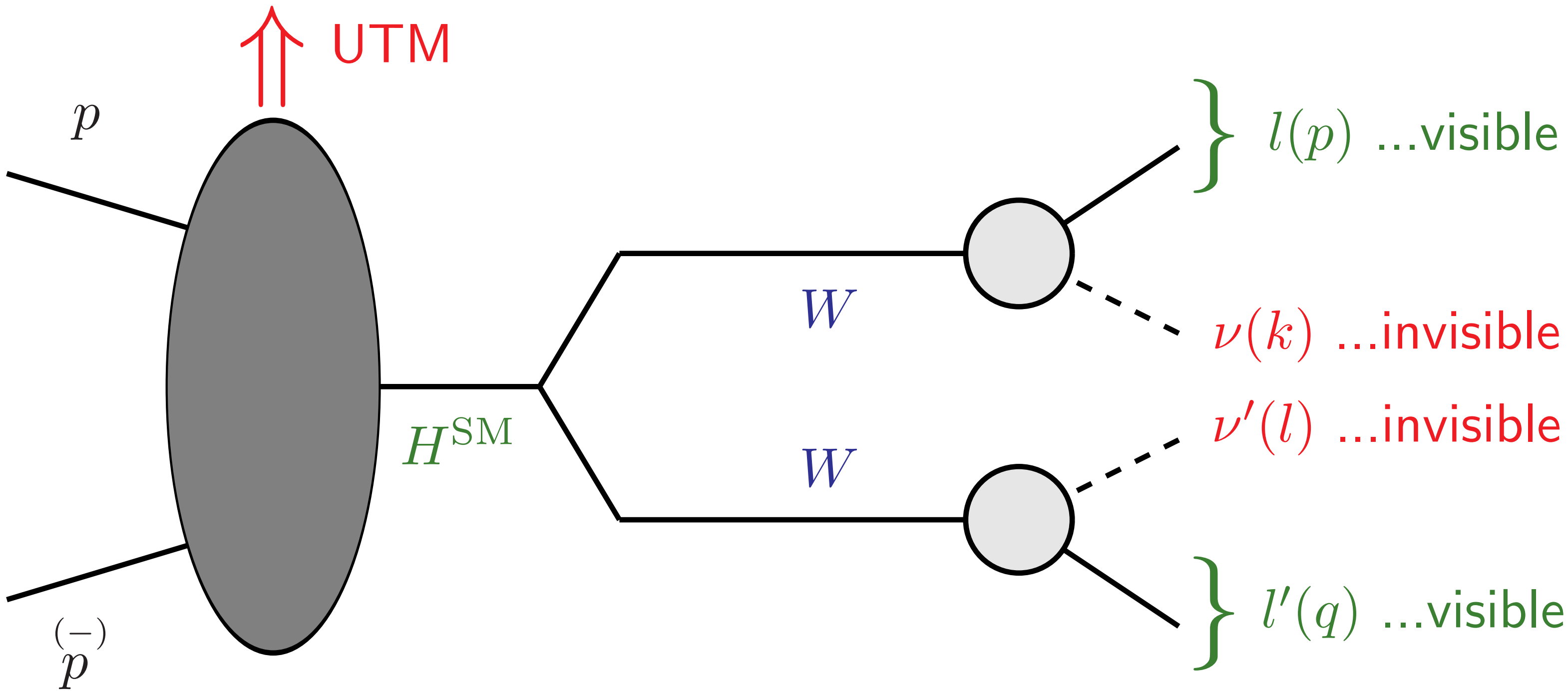


♠ *The process and* M_{T2} $(4/7)$

- Of course ...: T.Han, I.W.Kim, J.Song, arXiv:0906.5009 [hep-ph]



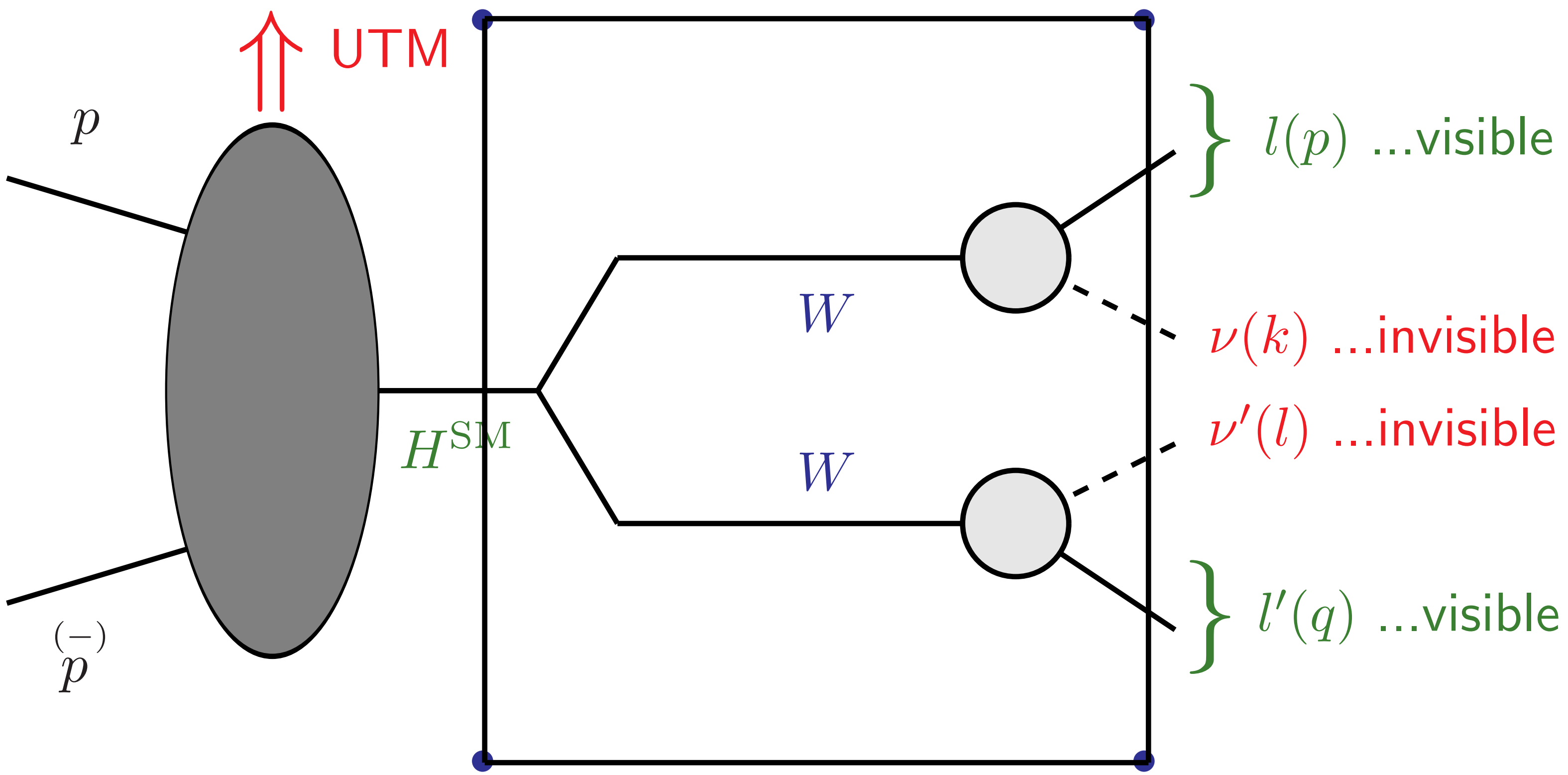
- Returning to the process:



How does it look like?

♠ *The process and* M_{T2} (6/7)

- If you see this process from the viewpoint:

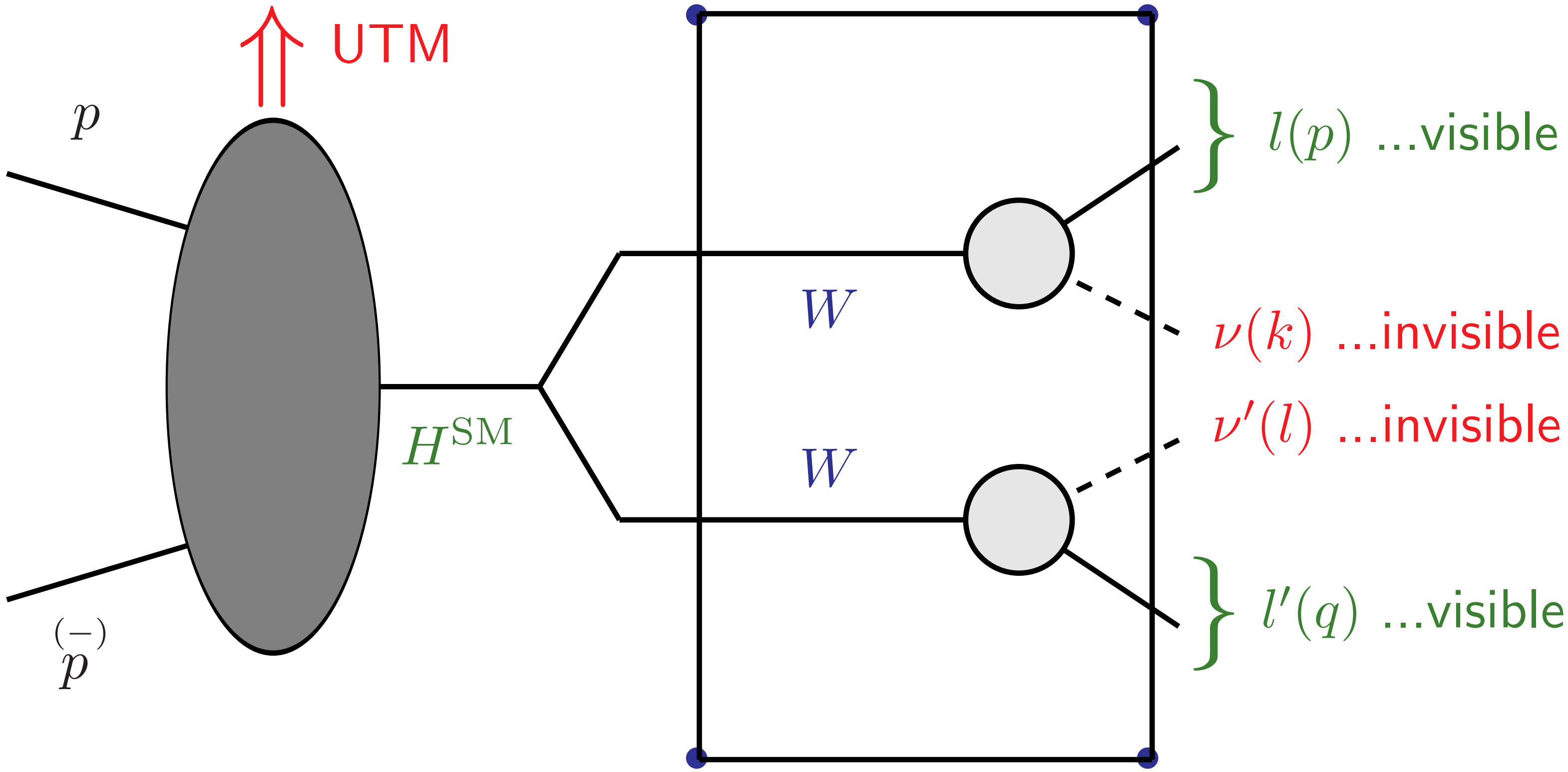


$$M_T[(p+q)^2\,,(\mathbf{p}+\mathbf{q})_T\,,(k+l)^2\,,(\mathbf{k}+\mathbf{l})_T\,] \le M_{H^{\rm SM}}$$

A.J.Barr, B.Gripaios, C.G. Lester,JHEP0907(2009)072, arXiv:0902.4864 [hep-ph]

♠ *The process and* M_{T2} $(7/7)$

- We see this process from the WW subsystem:



$M^2_{H^{\rm SM}} = (p + k + q + l)^2$ with $\mathbf{k}$ and $\mathbf{l}$ determined by the $\rm MA\hat{O}S$

♠ MAÔS *momenta of the missing neutrinos* (1/10)

- MAÔS transverse momenta:

$$H \to \; W(p+k)\,W(q+l) \to \; l(p)\;\nu(k)\;\; l'(q)\;\nu'(l)$$

$$\begin{aligned} p^\mu &= (\sqrt{|\mathbf{p}_T|^2 + p_L^2}\,, \mathbf{p}_T\,, p_L)\,, \quad k^\mu = (\sqrt{|\mathbf{k}_T|^2 + k_L^2}\,, \mathbf{k}_T\,, k_L)\,, \\ q^\mu &= (\sqrt{|\mathbf{q}_T|^2 + q_L^2}\,, \mathbf{q}_T\,, q_L)\,, \quad l^\mu = (\sqrt{|\mathbf{l}_T|^2 + l_L^2}\,, \mathbf{l}_T\,, l_L) \end{aligned}$$

$$\left(M_T^{(1)}\right)^2 = 2\,(|\mathbf{p}_T||\mathbf{k}_T| - \mathbf{p}_T\cdot\mathbf{k}_T), \quad \left(M_T^{(2)}\right)^2 = 2\,(|\mathbf{q}_T||\mathbf{l}_T| - \mathbf{q}_T\cdot\mathbf{l}_T)$$

♠ MAÔS *momenta of the missing neutrinos* (2/10)

- <u>MAÔS transverse momenta</u>: *... continued*

  For the transverse momenta of the two neutrinos, we assign the usual M_{T2} momenta which minimize

$$\max\left\{M_T^{(1)}, M_T^{(2)}\right\}$$

In our case, assuming vanishing UTM or $\not{\mathbf{p}}_T = -(\mathbf{p}_T + \mathbf{q}_T)$, the solution of the minimization is simply given when $M_T^{(1)} = M_T^{(2)}$ or

$$2(|\mathbf{p}_T||\mathbf{k}_T^{\text{maos}}| - \mathbf{p}_T \cdot \mathbf{k}_T^{\text{maos}}) = 2(|\mathbf{q}_T||\mathbf{l}_T^{\text{maos}}| - \mathbf{q}_T \cdot \mathbf{l}_T^{\text{maos}})$$

which results in

$$\boxed{\mathbf{k}_T^{\text{maos}} = -\mathbf{q}_T \quad \text{and} \quad \mathbf{l}_T^{\text{maos}} = -\mathbf{p}_T}$$

♠ MAÔS *momenta of the missing neutrinos* (3/10)

- ... then M_{T2} is given by:

$$(M_{T2})^2 = 2(|\mathbf{p}_T||\mathbf{q}_T| + \mathbf{p}_T \cdot \mathbf{q}_T) \leq 4|\mathbf{p}_T||\mathbf{q}_T| \leq (|\mathbf{p}_T| + |\mathbf{q}_T|)^2 \leq \frac{M_H^2}{4}$$

Note $(M_T^H)^2 = 4(|\mathbf{p}_T| + |\mathbf{q}_T|)^2$

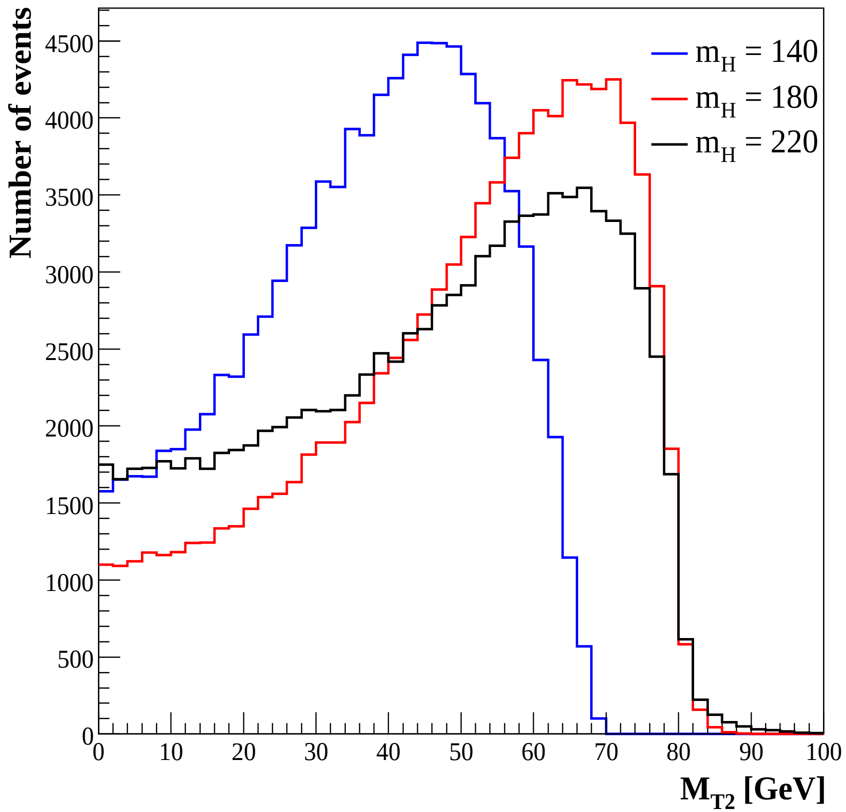
$$\boxed{M_{T2} \leq \min\left(M_W\,, \frac{M_H}{2}\right)}$$

♠ MAÔS *momenta of the missing neutrinos* (4/10)

- ... then M_{T2} is given by:

$$(M_{T2})^2 = 2(|\mathbf{p}_T||\mathbf{q}_T| + \mathbf{p}_T \cdot \mathbf{q}_T) \leq 4|\mathbf{p}_T||\mathbf{q}_T| \leq (|\mathbf{p}_T| + |\mathbf{q}_T|)^2 \leq \frac{M_H^2}{4}$$

$$M_{T2} \leq \min\left(M_W\,,\frac{M_H}{2}\right)$$



$| + |\mathbf{q}_T|)^2$

♠ MAÔS *momenta of the missing neutrinos* (5/10)

- MAÔS longitudinal momenta:

$$H \to W(p+k)\,W(q+l) \to l(p)\,\nu(k)\;\; l'(q)\,\nu'(l)$$

Using the M_{T2}-determined $\mathbf{k}_T^{\rm maos}$ and $\mathbf{l}_T^{\rm maos}$, the longitudinal momenta $k_L^{\rm maos}$ and $l_L^{\rm maos}$ can be chosen to satisfy the *on-shell* conditions $(p+k_{\rm maos})^2 = (q+l_{\rm maos})^2 = M_W^2$: W.S.Cho, K.Choi, Y.G.Kim, C.B.Park, PRD79(2009)031701,arXiv:0810.4853 [hep-ph]

$$k_L^{\rm maos}(\pm) = \frac{1}{|\mathbf{p}_T|^2}\left[p_L\,A \pm \sqrt{|\mathbf{p}_T|^2 + p_L^2}\,\sqrt{A^2 - |\mathbf{p}_T|^2|\mathbf{k}_T^{\rm maos}|^2}\right],$$

$$l_L^{\rm maos}(\pm) = \frac{1}{|\mathbf{q}_T|^2}\left[q_L\,B \pm \sqrt{|\mathbf{q}_T|^2 + q_L^2}\,\sqrt{B^2 - |\mathbf{q}_T|^2|\mathbf{l}_T^{\rm maos}|^2}\right],$$

where $A \equiv M_W^2/2 + \mathbf{p}_T \cdot \mathbf{k}_T^{\rm maos}$ and $B \equiv M_W^2/2 + \mathbf{q}_T \cdot \mathbf{l}_T^{\rm maos}$

♠ MAÔS *momenta of the missing neutrinos* (6/10)

- MAÔS longitudinal momenta: *... continued*

... complication : what about off-shell W boson?

$\Rightarrow$ the *modified* MAÔS *scheme* using M_{T2} instead of M_W:

$$(p + k_{\rm maos})^2 = (q + l_{\rm maos})^2 = (M_{T2})^2$$

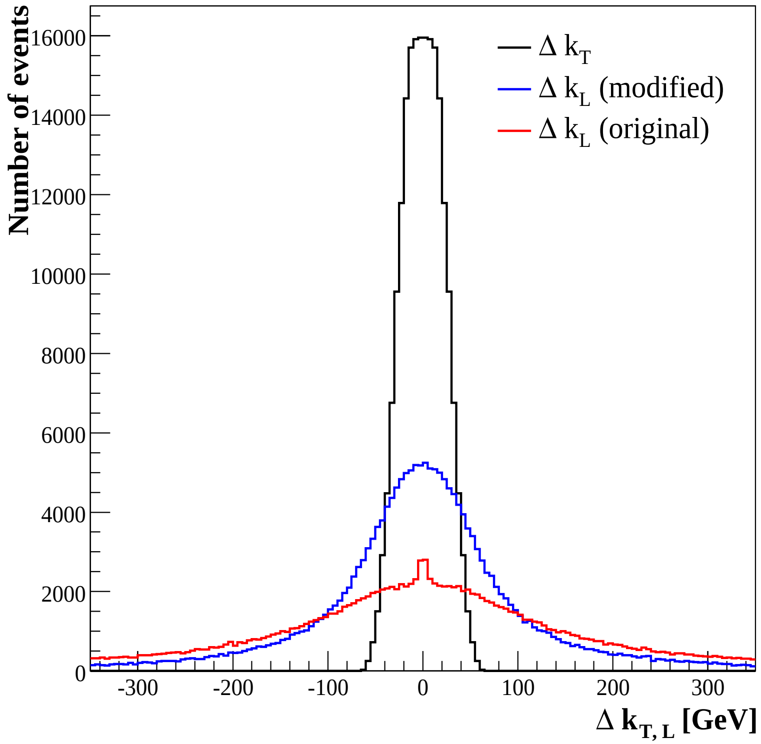
Then we arrive at, with no ambiguity,

$$k_L^{\rm maos} = \frac{|\mathbf{k}_T^{\rm maos}|}{|\mathbf{p}_T|} p_L, \quad l_L^{\rm maos} = \frac{|\mathbf{l}_T^{\rm maos}|}{|\mathbf{q}_T|} q_L$$

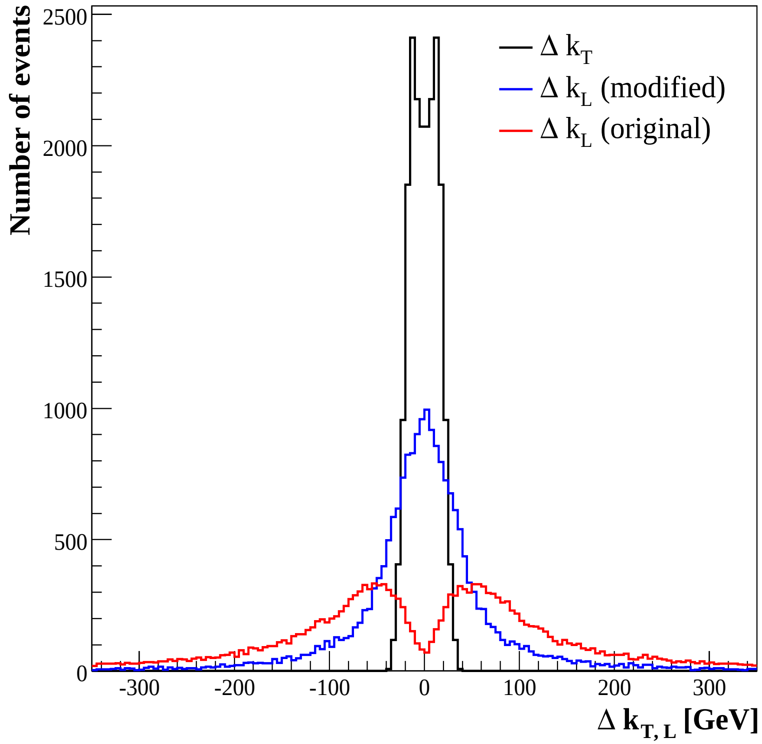
♠ MAÔS *momenta of the missing neutrinos* (7/10)

- Is the modified MAÔS scheme working well?: $M_H = 140$ GeV $< 2M_W$

Full events



Upper 10% near M_{T2} end point



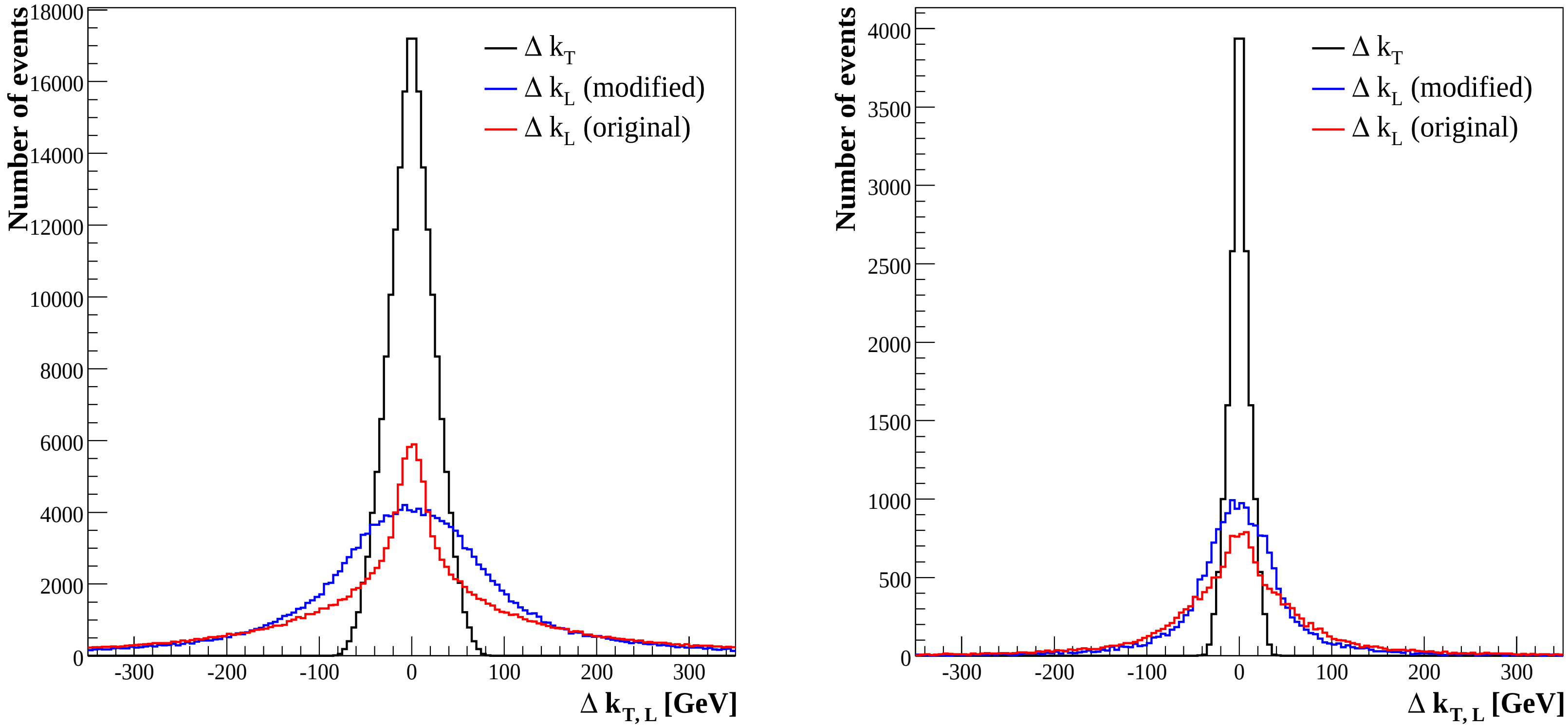
the original scheme fails (!) especially when the M_{T2} cut has been introduced

... the modified scheme works better

♠ MAÔS *momenta of the missing neutrinos* (8/10)

- Is the modified MAÔS scheme working well?: $M_H = 180$ GeV $> 2M_W$

Full events — Upper 10% near M_{T2} end point



the modified scheme is working well (!) especially together with the M_{T2} cut

♠ MAÔS *momenta of the missing neutrinos* (9/10)

- Is the modified MAÔS scheme working well?:

$\Rightarrow$ *Yes!*, it seems working well independently whether the intermediate W bosons are on-shell or not, especially when it's combined with the M_{T2} cut

$$H \to W(p+k)\,W(q+l) \to l(p)\,\nu(k)\;\; l'(q)\,\nu'(l)$$

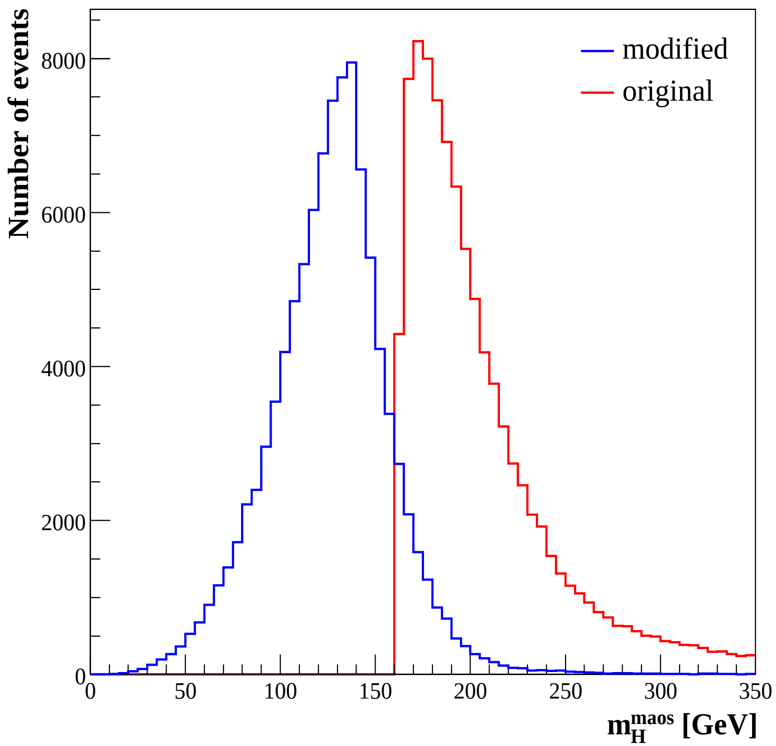
$$(M_H^2)^{\text{MAÔS}} = (p + k^{\text{MAÔS}} + q + l^{\text{MAÔS}})^2$$

$$\mathbf{k}_T^{\text{MAÔS}} = -\mathbf{q}_T \quad \text{and} \quad \mathbf{l}_T^{\text{MAÔS}} = -\mathbf{p}_T$$

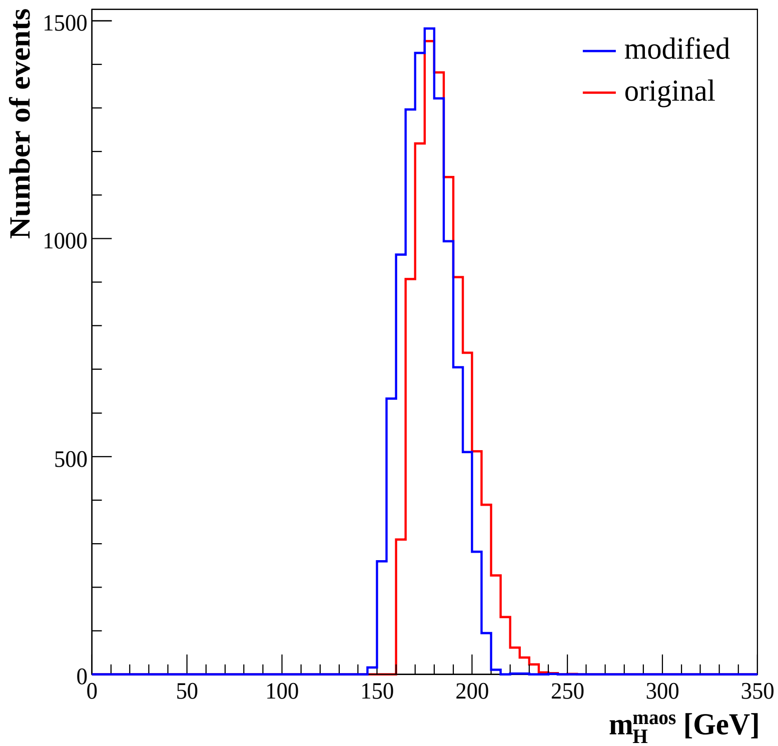
$$k_L^{\text{MAÔS}} = \frac{|\mathbf{k}_T^{\text{MAÔS}}|}{|\mathbf{p}_T|} p_L, \qquad l_L^{\text{MAÔS}} = \frac{|\mathbf{l}_T^{\text{MAÔS}}|}{|\mathbf{q}_T|} q_L$$

♠ MAÔS *momenta of the missing neutrinos* (10/10)

- <u>The modified MAÔS scheme does work well</u>: *... with the upper-10% M_{T2} cut*



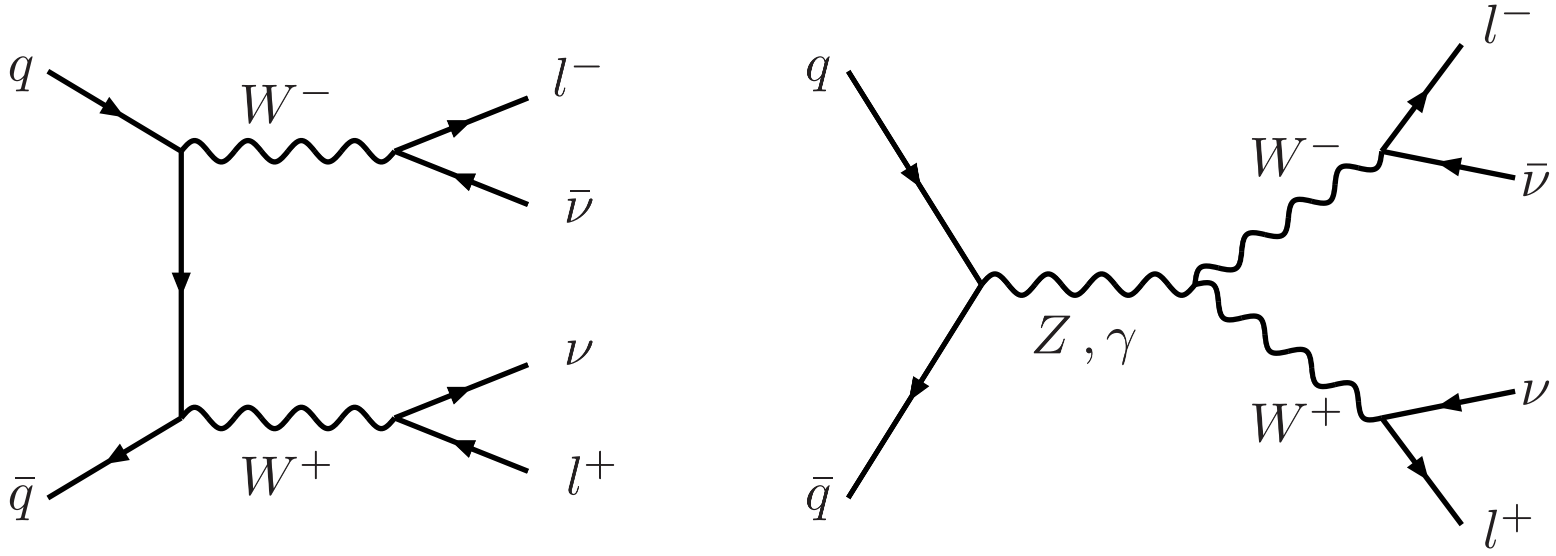
$M_H = 140$ GeV



$M_H = 180$ GeV

ISR yes but no hadronization, no detector smearing, no backgrounds ... yet

- The main SM background: $pp \to qq/qg/gg \to WW$

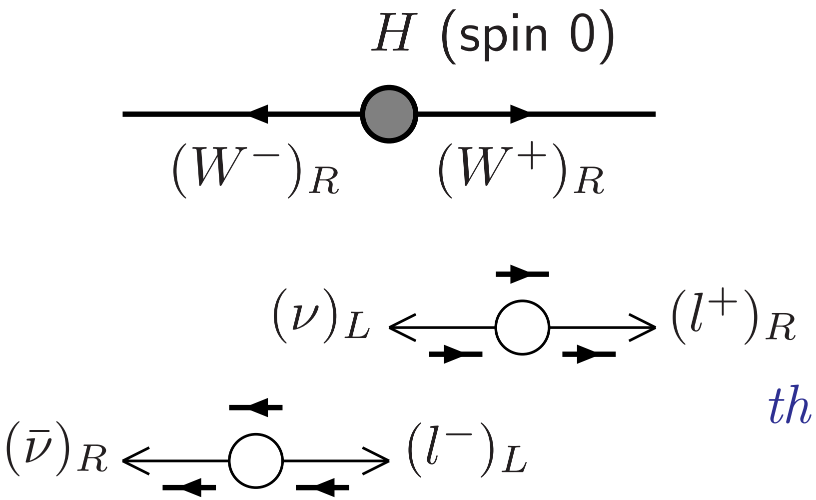


$\sigma_{\rm bkg}^{pp\to WW} \sim 120$ pb while $\sigma_{\rm signal}^{gg\to H\to WW} \sim 20$ pb ($M_H = 170$ GeV)

ATLAS TDR, arXiv:0901.0512[hep-ex]

- The spin-spin correlation in the signal:

  $\Delta\Phi_{ll}$: the transverse opening angle between l^- and l^+



the two leptons tend to be aligned !

$\Rightarrow$ small $\Delta\Phi_{ll}$

- Also included is the $t\bar{t}$ background: *Cut flows for* $m_H = 170\ GeV$ *with* $\Delta\Phi_{ll}^{\rm cut} = 1.6$ *and* $M_{T2}^{\rm cut} = 67\ GeV$ *at 10* fb^{-1}.

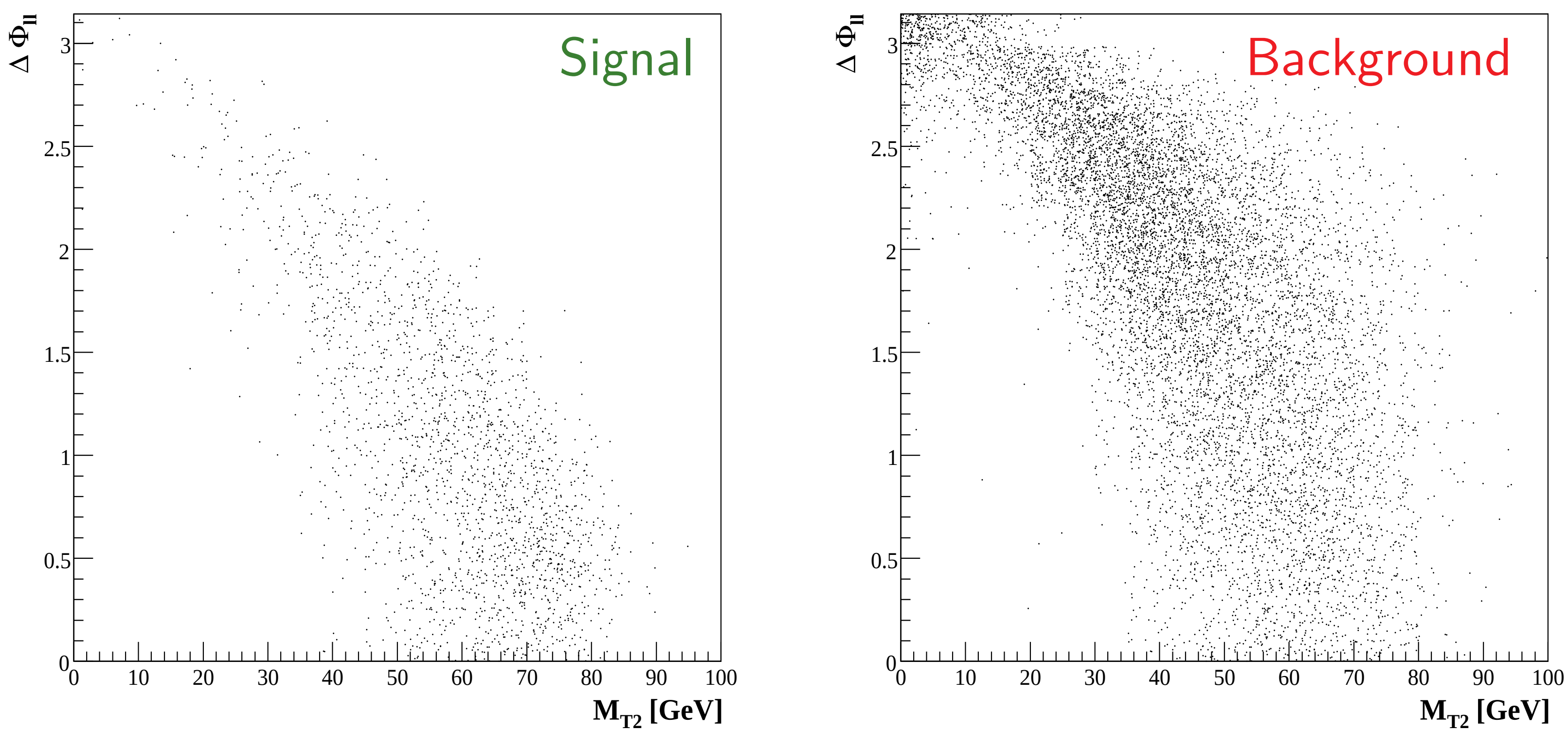
Selection	Selection cuts	$gg \to H$	WW	$t\bar{t}$
Basic Selection	Lepton selection $+m_{ll}$	$4,445$	$18,501$	$139,256$
	$\lvert \not{p}_T \rvert > 30$ GeV	$4,012$	$12,801$	$120,597$
	b-veto	$3,956$	$12,656$	$60,438$
	Jet veto	$2,039$	$8,096$	$1,287$
Tuned Selection	$\Delta\Phi_{ll} < \Delta\Phi_{ll}^{\rm cut}$	$1,621$	$2,939$	332
	$M_{T2} > M_{T2}^{\rm cut}$	619	585	107

ISR, hadronization, detector smearing, ALL simulated : `PYTHIA6.4` and `PGS4`

♠ MAÔS *reconstruction of the Higgs boson mass* (4/11)

- So, we have two important cuts: $\Delta\Phi_{ll} < \Delta\Phi_{ll}^{\rm cut}$ and $M_{T2} > M_{T2}^{\rm cut}$

Actually, they are correlated: $(M_{T2})^2 = 2(|\mathbf{p}_T||\mathbf{q}_T| + \mathbf{p}_T \cdot \mathbf{q}_T)$



♠ MAÔS *reconstruction of the Higgs boson mass* (5/11)

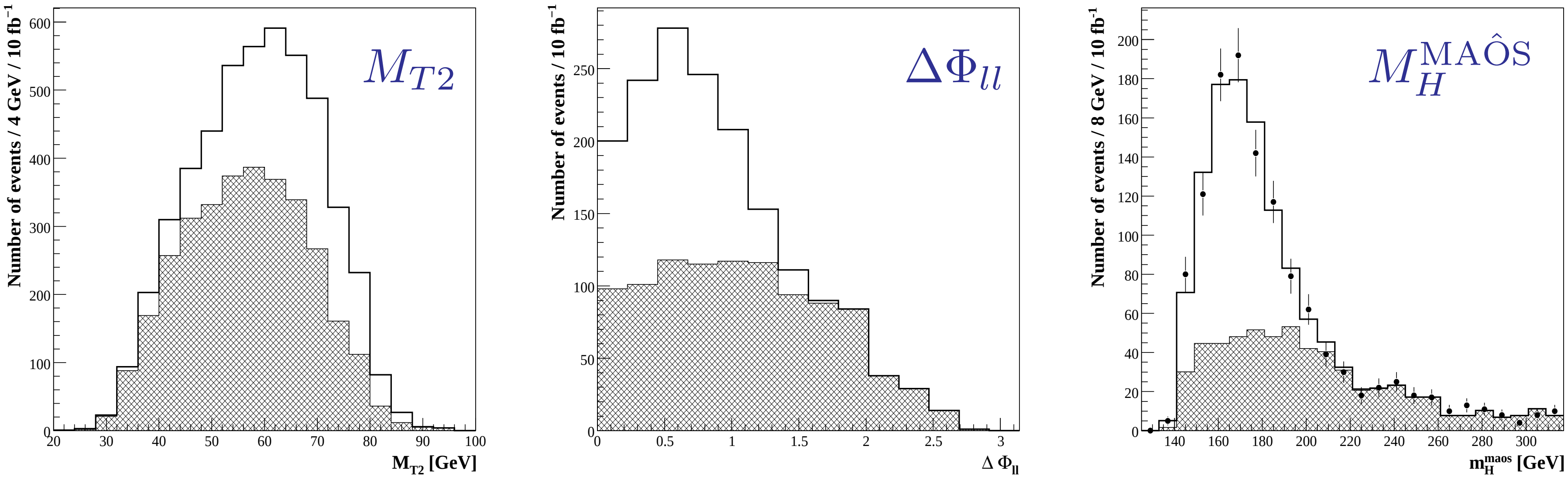
- Optimization of the cuts: $\Delta\Phi_{ll} < \Delta\Phi_{ll}^{\rm cut}$ and $M_{T2} > M_{T2}^{\rm cut}$

M_H (GeV)	130	140	150	160	170	180	190	200
$\Delta\Phi_{ll}^{\rm cut}$	1.85	1.70	1.65	1.50	1.60	1.70	1.90	2.05
$M_{T2}^{\rm cut}$ (GeV)	38.0	51.0	57.0	66.0	67.0	68.0	69.5	70.0

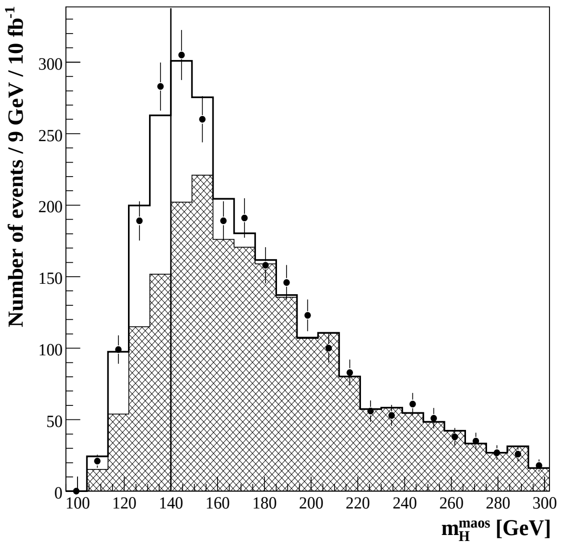
♠ MAÔS *reconstruction of the Higgs boson mass* (6/11)

- Optimization of the cuts: $\Delta\Phi_{ll} < \Delta\Phi_{ll}^{\rm cut}$ and $M_{T2} > M_{T2}^{\rm cut}$

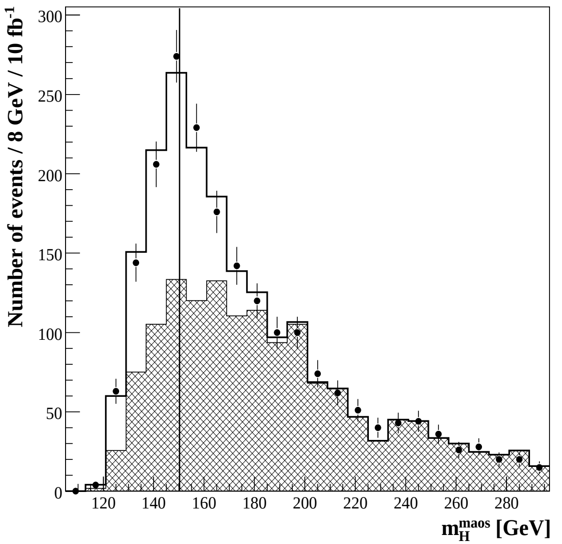
M_H (GeV)	130	140	150	160	170	180	190	200
$\Delta\Phi_{ll}^{\rm cut}$	1.85	1.70	1.65	1.50	1.60	1.70	1.90	2.05
$M_{T2}^{\rm cut}$ (GeV)	38.0	51.0	57.0	66.0	67.0	68.0	69.5	70.0



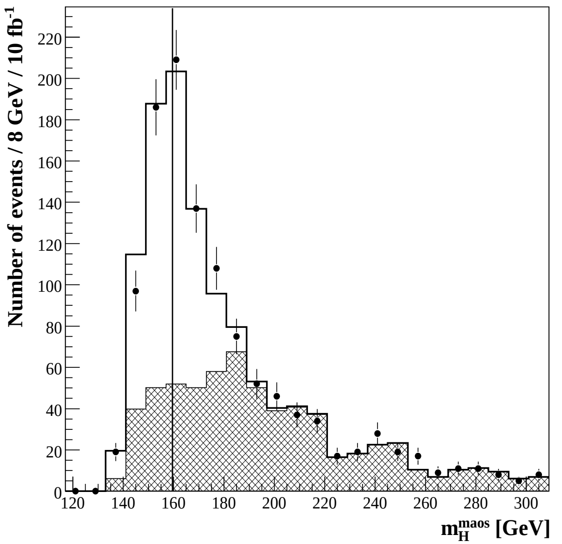
- MAÔS Higgs mass distribution:



$M_H = 140$ GeV



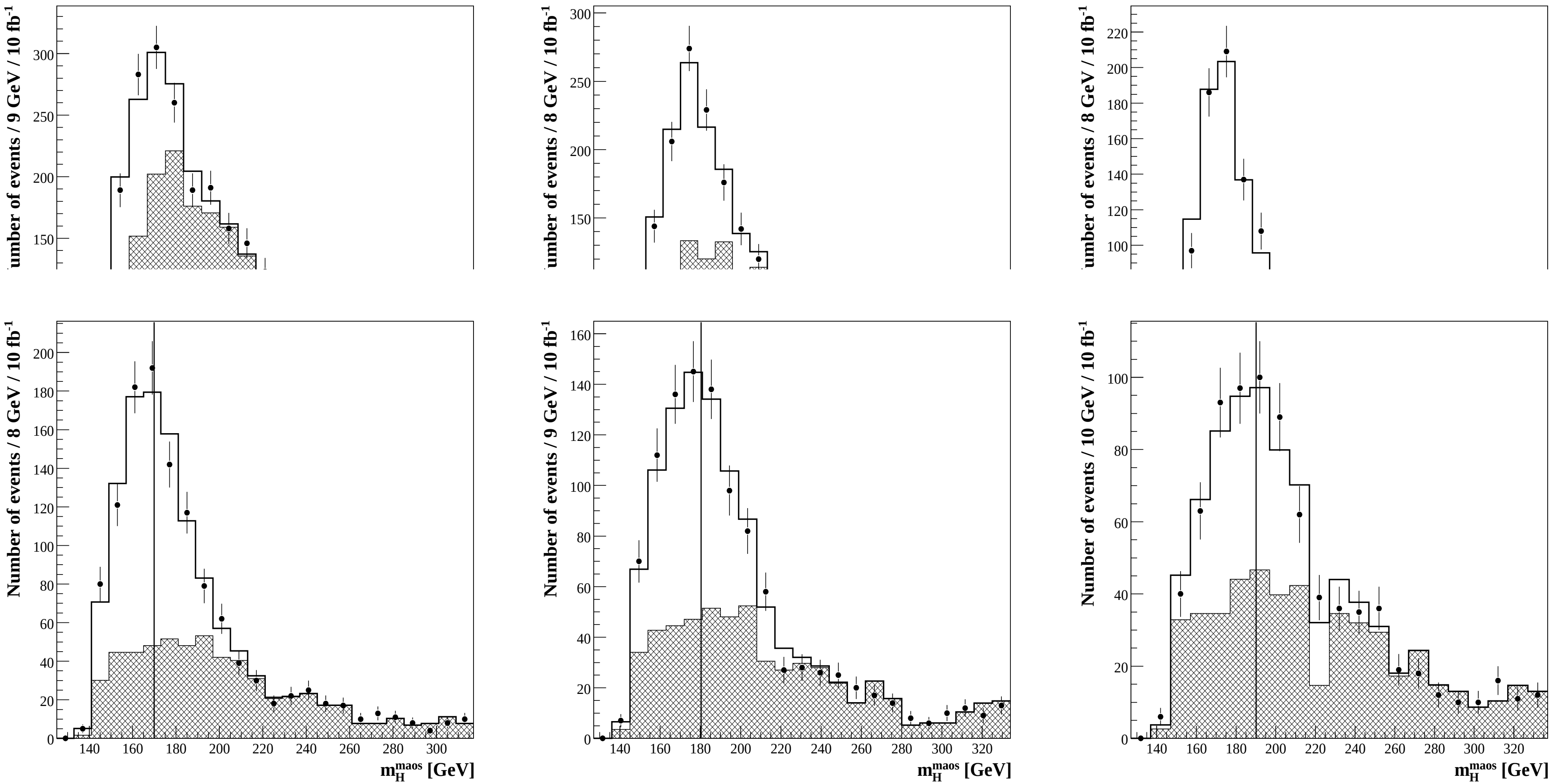
$M_H = 150$ GeV



$M_H = 160$ GeV

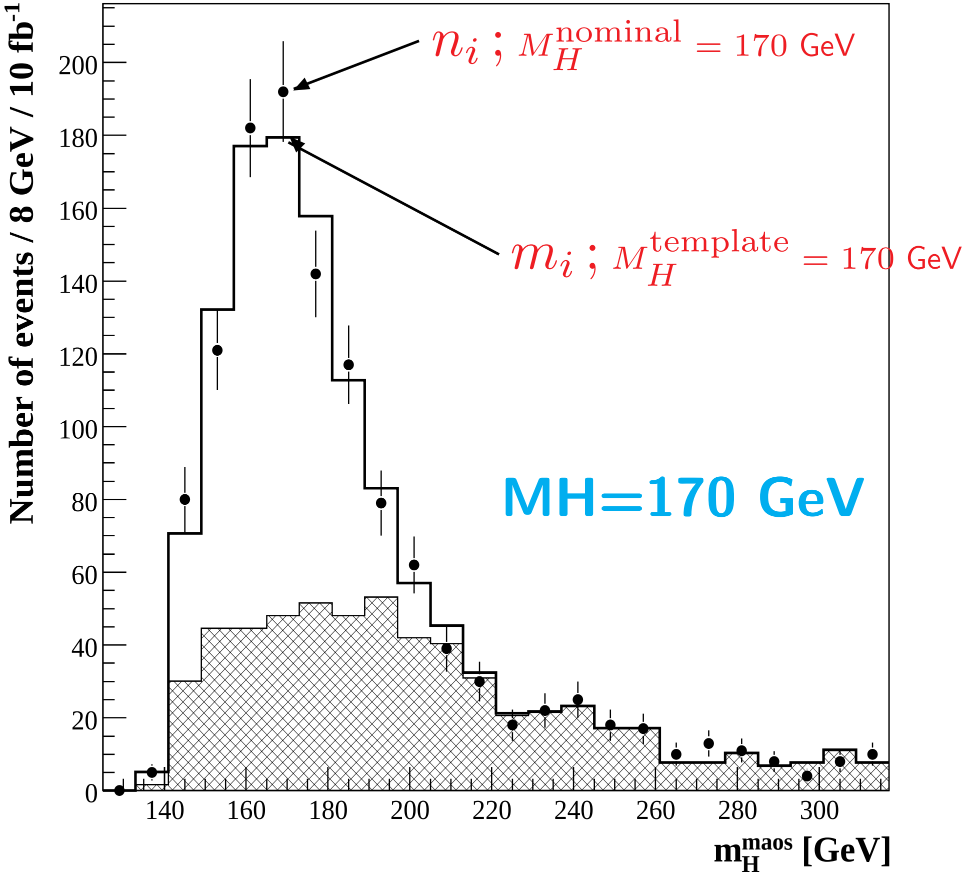
♠ MAÔS *reconstruction of the Higgs boson mass* (8/11)

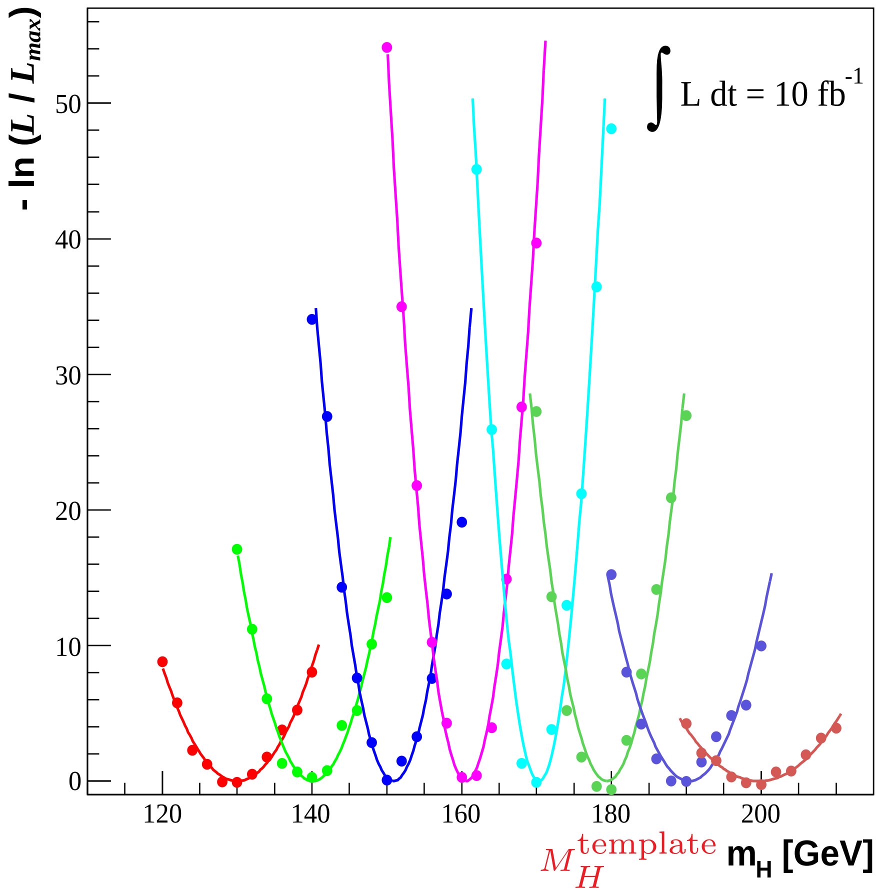
- MAÔS Higgs mass distribution:



$M_H = 170$ GeV $\quad$ $M_H = 180$ GeV $\quad$ $M_H = 190$ GeV

- Likelihood analysis: $\mathcal{L} \equiv \prod_i^{\mathcal{N}} \frac{e^{-m_i} m_i^{n_i}}{n_i!}$ with n_i/m_i the number of events in the i-th bin of the nominal/template $M_H^{\mathrm{MAÔS}}$ distribution





♠ MAÔS *reconstruction of the Higgs boson mass* (10/11)

- Likelihood analysis: *... continued*

M_H (GeV)	130	140	150	160	170	180	190	200
Fitted value (GeV)	130.0	140.1	150.9	160.6	170.3	179.4	190.4	199.7
1-σ error (GeV)	2.4	1.7	1.2	1.0	0.9	1.4	2.0	3.5

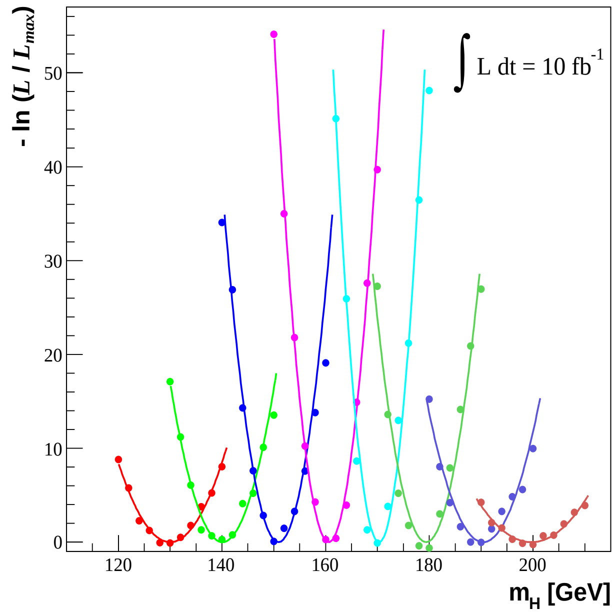
$$1\text{-}\sigma \Rightarrow \Delta(-\ln\mathcal{L}) = 1/2$$

Note, if there is only 1 bin:

$-\ln\mathcal{L} = m - n\ln(m) + \ln(n!) \simeq (m-n) + n\ln\left(\frac{n}{m}\right)$

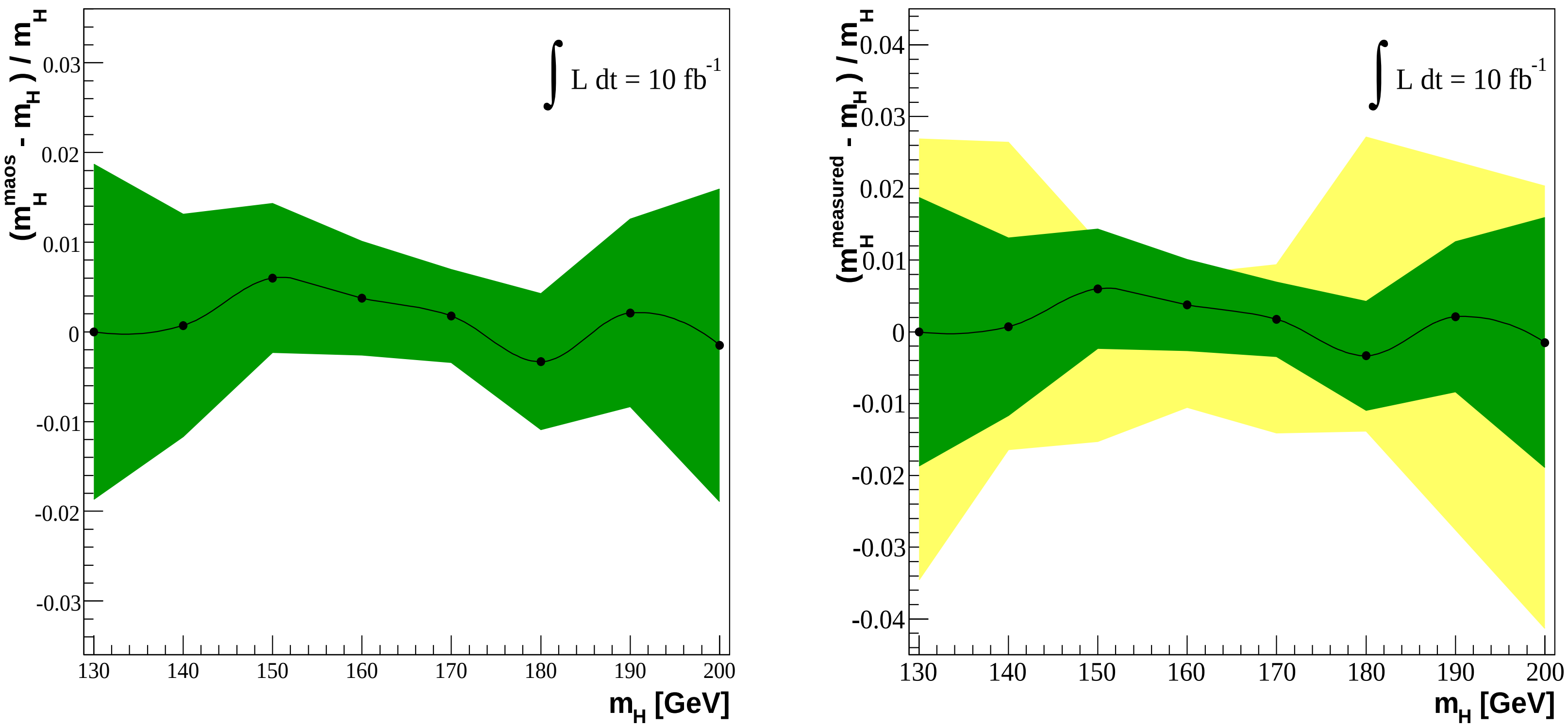
leading to

$-\ln\mathcal{L}[n=m] \simeq 0\,; \quad -\ln\mathcal{L}[n = m \pm \sqrt{m}] \simeq 1/2$



♠ MAÔS *reconstruction of the Higgs boson mass* (11/11)

- Comparison: ... $M_H^{\text{MAÔS}}$ *works better!*

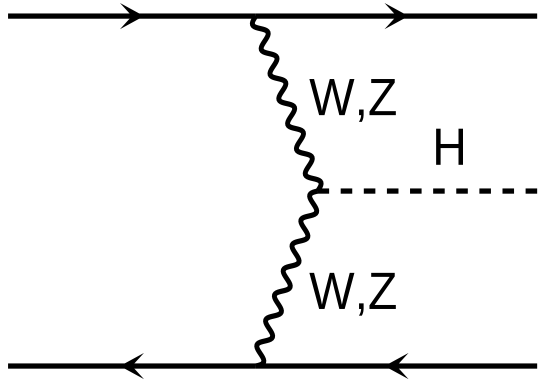


Ours

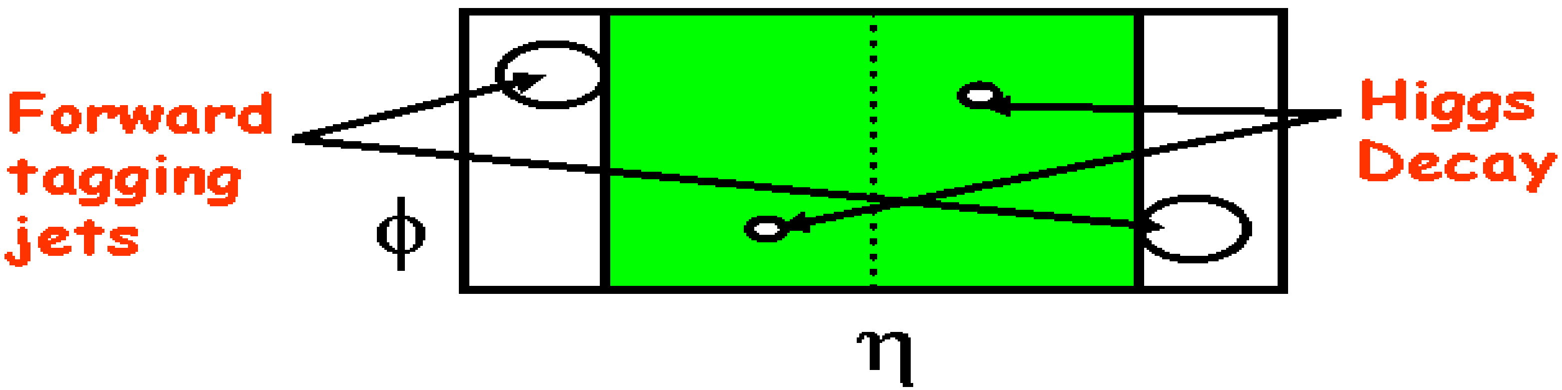
BGL,arXiv:0902.4864

♠ *Vector boson fusion* (1/4)

- Why VBF? See, for example, D. Rainwater, hep-ph/0702124
  - The 2nd largest source of Higgs at LHC
  - Two forward tagging jets
  - Large rapidity gap
  - Central Higgs decay



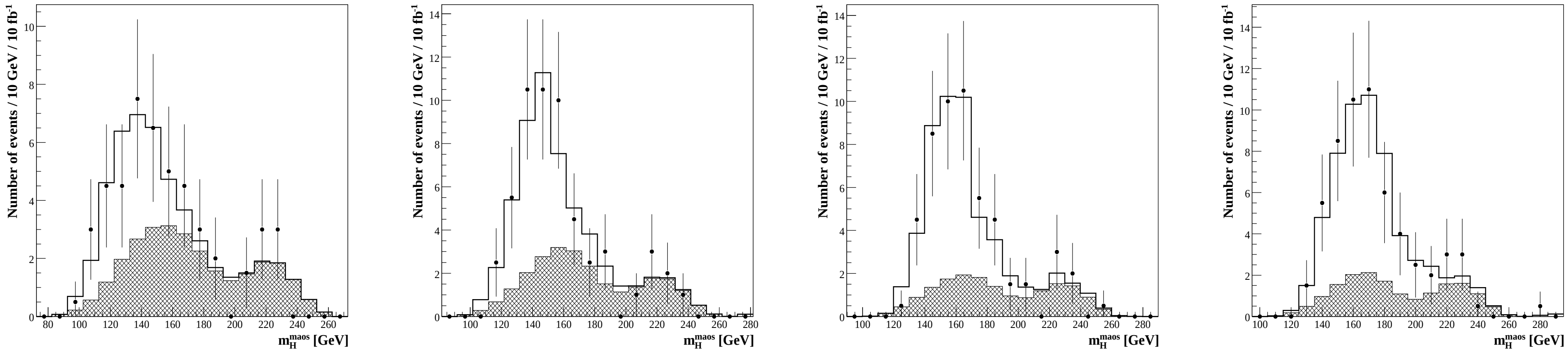
⇒ *Clean environment with low background !*



⇒ *Useful to measure properties of the Higgs boson !*

♠ Vector boson fusion (2/4)

- MAÔS reconstruction of the Higgs boson mass with 10 fb^{-1}:
  (*Preliminary:* `PYTHIA6.4`, `MadGraph/MadEvent`, `VBFNLO`, `PGS4`)



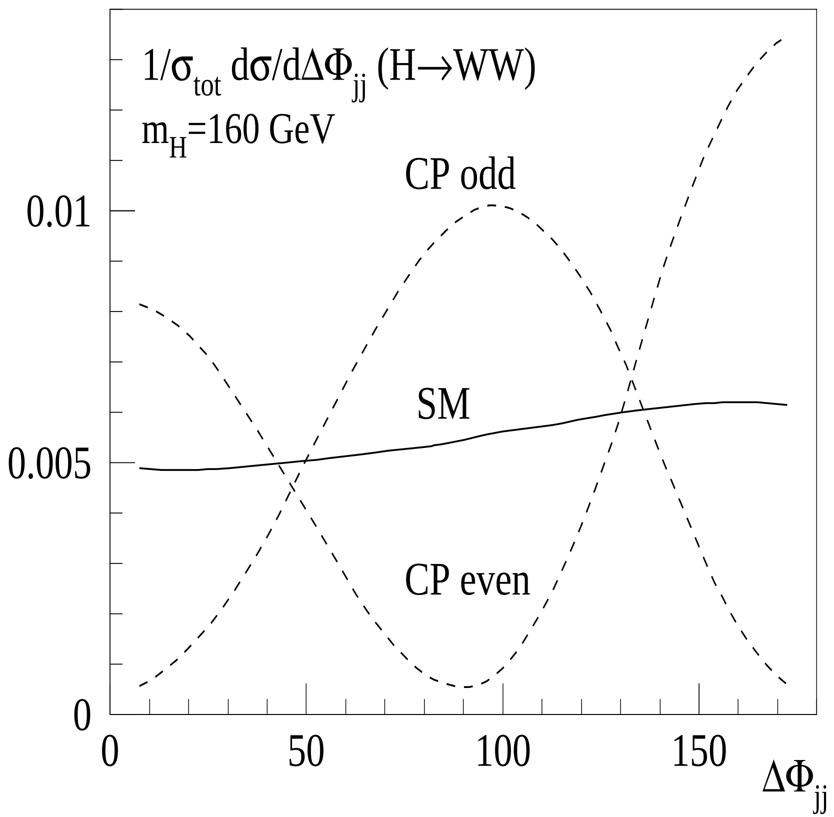
M_H : 140 GeV 150 GeV 160 GeV 170 GeV

m_H (GeV)	130	140	150	160	170
Fitted value (GeV)	131.8	140.1	150.9	160.6	170.3
$1-\sigma$ error (GeV)	7.840	5.415	4.711	3.532	4.339

♠ *Vector boson fusion* (3/4)

- Azimuthal angle distribution: Plehn, Rainwater, Zeppenfeld, PRL88(2002)051801, hep-ph/0105325

  The distribution of the azimuthal angle between the two tagging jets $\Delta\Phi_{jj}$ probes the tensor structure of the H-W-W coupling



SM : $T^{\mu\nu} \propto g^{\mu\nu}$

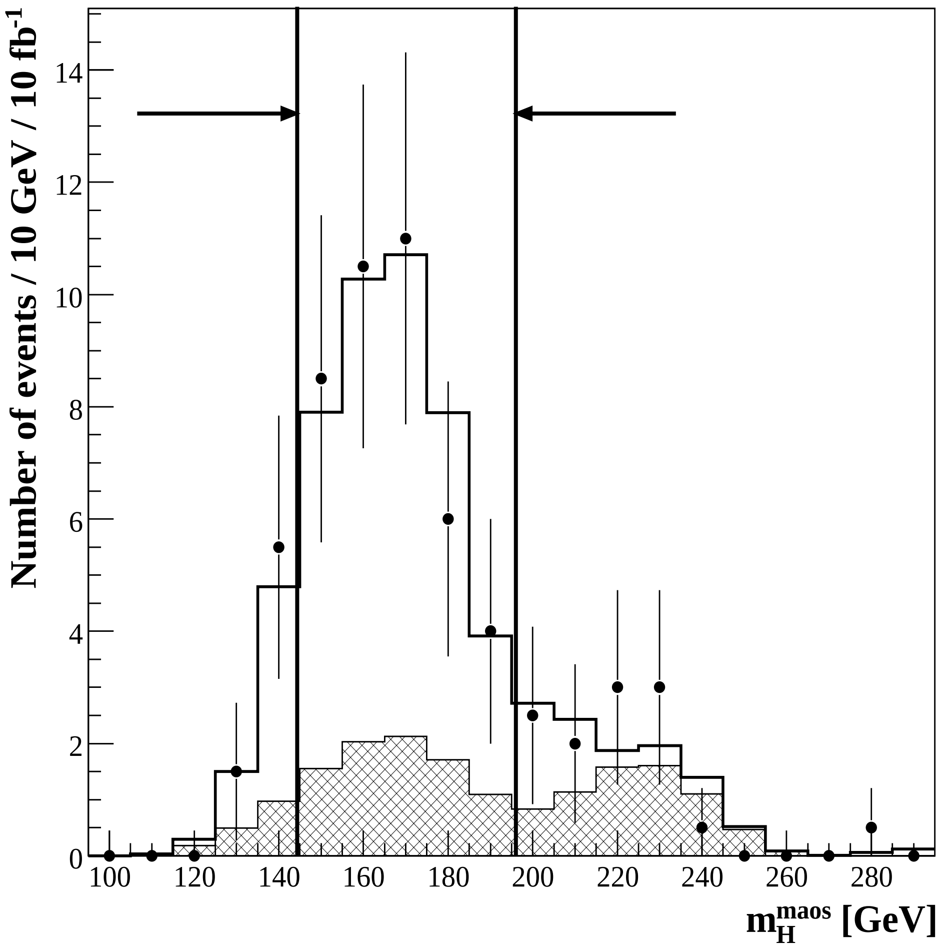
CP even : $T^{\mu\nu} \propto [q_1 \cdot q_2 g^{\mu\nu} - q_2^\mu q_1^\nu]$

CP odd : $T^{\mu\nu} \propto \epsilon^{\mu\nu\rho\sigma} q_{1\rho} q_{2\sigma}$

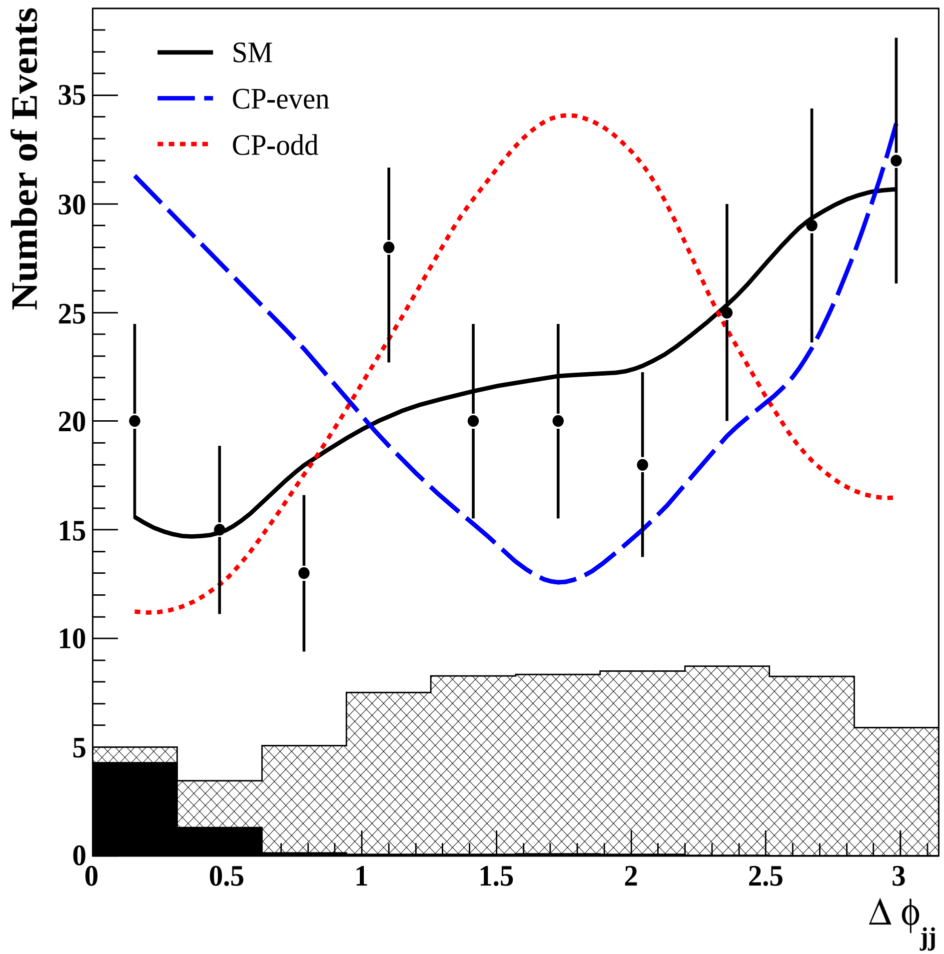
♠ Vector boson fusion (4/4)

- Azimuthal angle distribution with 30 fb^{-1} (*Preliminary*)

$M_H = 170$ GeV



no M_{T2} cut, $145 < m_H^{maos} < 195$



♠ *Summary and future prospects*

- Dileptonically decaying W bosons play a crucial role in the Higgs boson searches at the LHC when 130 GeV $\lesssim M_H \lesssim$ 190 GeV.

- We propose to use new observable $M_H^{\rm MAOS}$ to probe the properties of the SM Higgs boson at the LHC

- The modified $\rm MA\hat{O}S$ is powerful in the reconstruction of the SM Higgs boson ! : useful to measure the mass and characteristic features of the coupling of the SM Higgs boson

- You may have more ideas on how to apply the $\rm MA\hat{O}S$ to other SM/NP processes

♠ Backup: What can we do with 1 fb^{-1} at LHC 1/2

- *ATLAS sensitivity*: arXiv:0901.0512