Signatures of Heavy Gauge Boson in the Littlest Higgs Model with T-parity at Future Colliders

Chuan-Ren Chen
Michigan State University

In Collaboration with Qing-Hong Cao (UC, Riverside)

Outline

- Model – Littlest Higgs Model with T-parity (LHT)
- Signatures at the LHC
- Signatures at the LC
- Conclusion

Model -- LHT

SU(5) / SO(5) non-linear sigma model:

N. Arkani-Hamed, A. G. Cohen, E. Katz and A. E. Nelson, JHEP **0207**, 034 (2002)
H. C. Cheng and I. Low, JHEP **0309**, 051 (2003)
H. C. Cheng and I. Low, JHEP **0408**, 061 (2004)
I. Low, JHEP **0410**, 067 (2004)
J. Hubsiz and P. Meade, PRD 71, 035016 (2005)

$$SU(5) \xrightarrow{f} SO(5)$$

$$[SU(2) \times U(1)]^2 \longrightarrow SU(2) \times U(1)$$

T-parity: $[SU(2) \times U(1)]_1 \longleftrightarrow [SU(2) \times U(1)]_2$

SM particles : light , T-even

T-parity partners of SM particles : heavy , T-odd

$$\Lambda \sim 4\pi f$$

Relevant mass spectrum

- Parameters: λ_2, κ (κ_l, κ_q), f , m_h
- New Particles:

  an additional copy of SM Fermion, Gauge boson (T-odd)

  $\oplus$

  6 T-odd higgs boson, 1 T-odd Top partner, 1 T-even Top partner

- Relevant particle Mass spectrum :

$$A_H \sim \frac{g'}{\sqrt{5}} f \quad W_H \sim gf \quad q_- \sim \sqrt{2}\kappa_q f \quad L_- \sim \sqrt{2}\kappa_l f$$

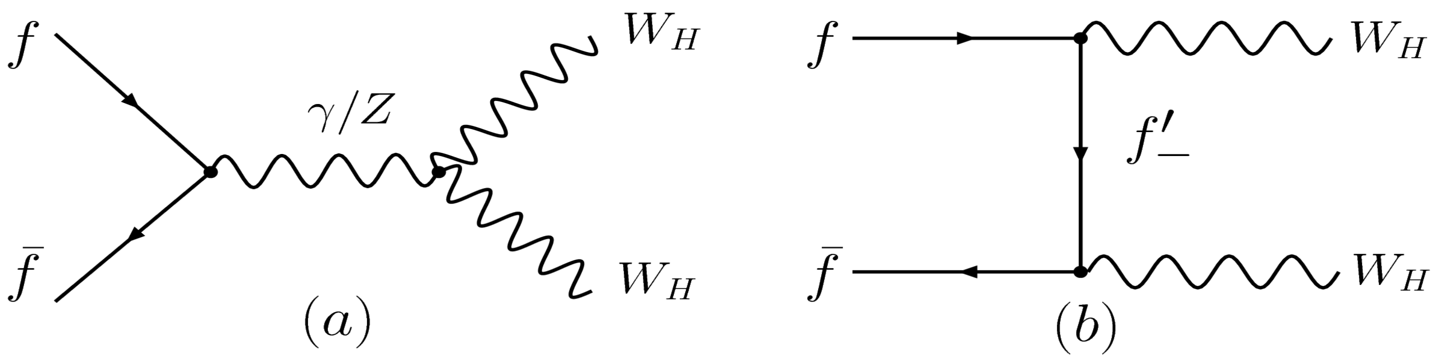
take f = 1 TeV $\kappa_q = \kappa_l = 1$ $\lambda_2 = 1$ $m_h = 120$ GeV

Dark Matter candidate → A_H

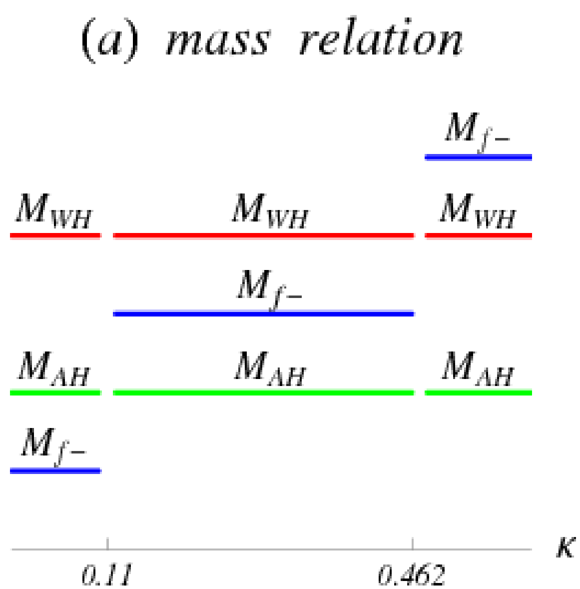
A_H	$Z(W)_H$	T	T_-	$q(L)_-$	ϕ	
0.15	0.65	1.4	1	1.4	0.69	(TeV)

Production and Decay of W_H

Production of $W_H W_H$



Decay of W_H

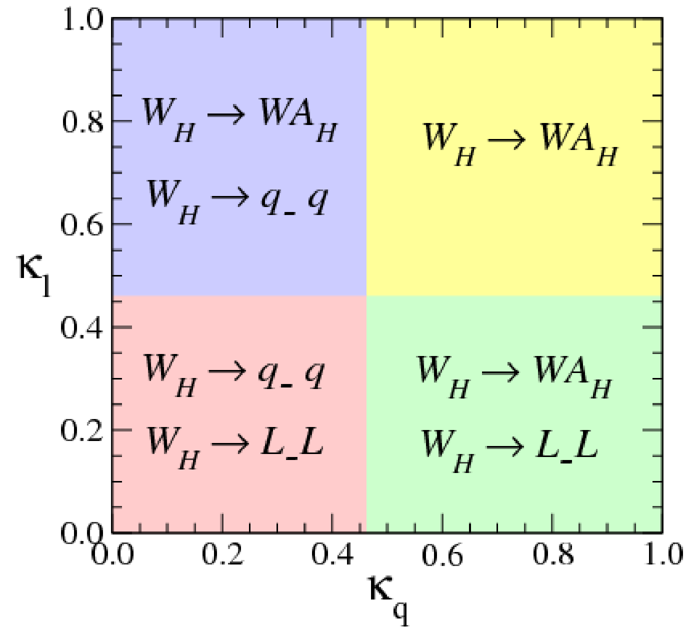


$$M_{AH} \approx 0.156 f$$

$$M_{WH} \approx 0.653 f$$

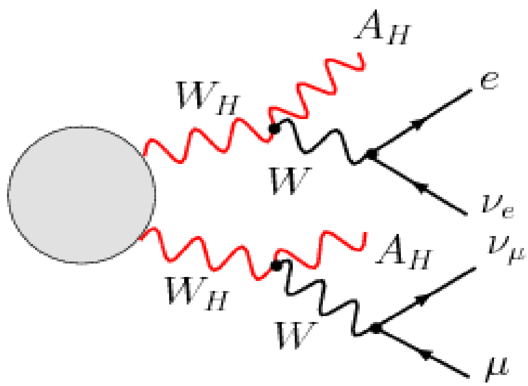
$$M_{L-} \approx 1.414 \kappa_l f$$

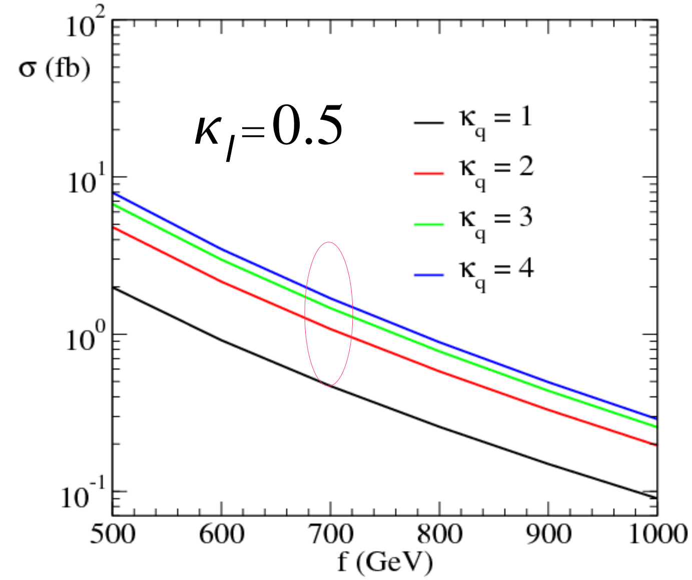
$$M_{q-} \approx 1.414 \kappa_q f$$



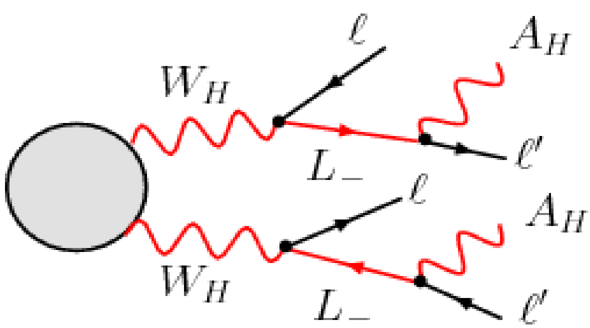
LHC signature : $e\ \mu + \not{E}_T$:

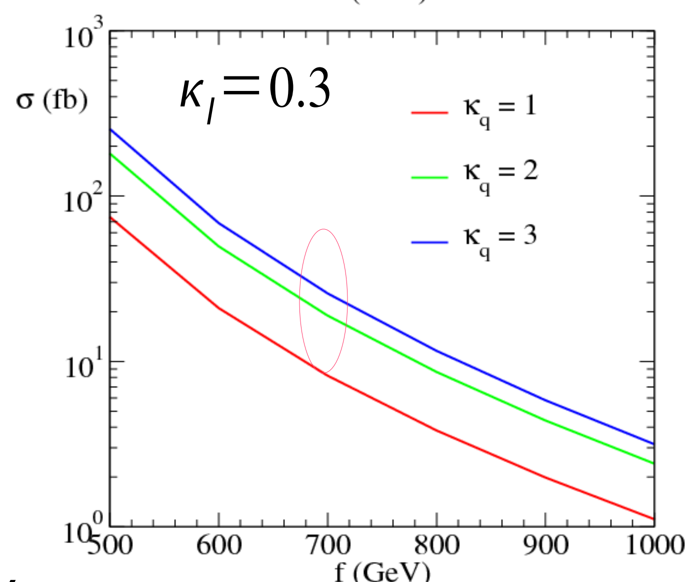
$pp \rightarrow W_H W_H \rightarrow A_H W(\rightarrow e \nu_e) A_H W(\rightarrow \mu \nu_\mu)$





$pp \rightarrow W_H W_H \rightarrow \nu_e E_-(\rightarrow e A_H) \nu_\mu M_-(\rightarrow \mu A_H)$



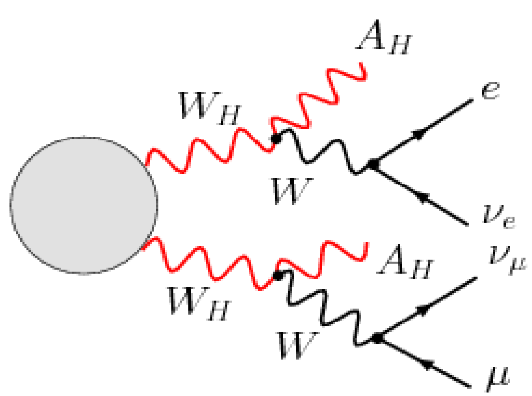


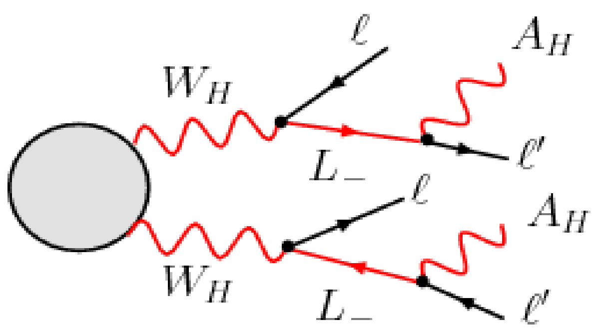
Backgrounds: $p\,p \rightarrow W\,W, W\,W\,Z, t\,\bar{t}, W\,t$

Discovery Potential at the LHC

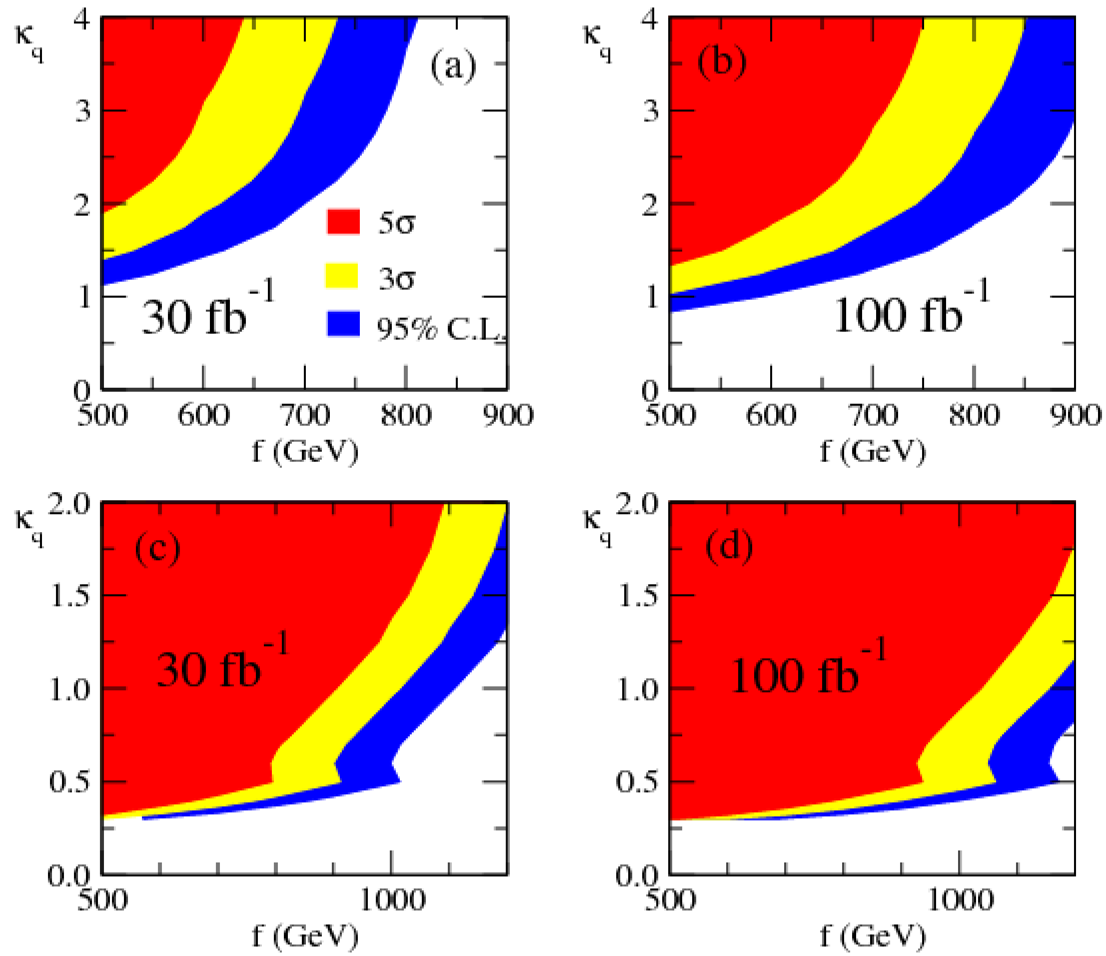
cuts : $p_T^e > 20\,GeV,\ p_T^\mu > 20\,GeV,\ |\eta^e| < 2.0,\ |\eta^\mu| < 2.0$

$$E_T > 175\,GeV,\ \cos\theta_{e\mu} < 0.6$$





$S/\sqrt{B}$ contour



From LHC to LC

LHC : di-lepton + $\not{E}_T$

→ Has a great discovery potential !!

BUT …

- Can NOT determine masses of W_H and A_H
- Can NOT reconstruct kinematics of A_H
- Can NOT measure the spin of W_H

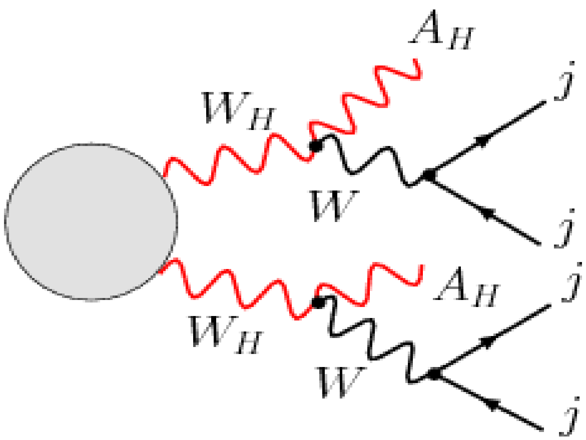
L~~H~~C :

- Can ~~NOT~~ determine masses of W_H and A_H
- Can ~~NOT~~ reconstruct kinematics of A_H
- Can ~~NOT~~ measure the spin of W_H

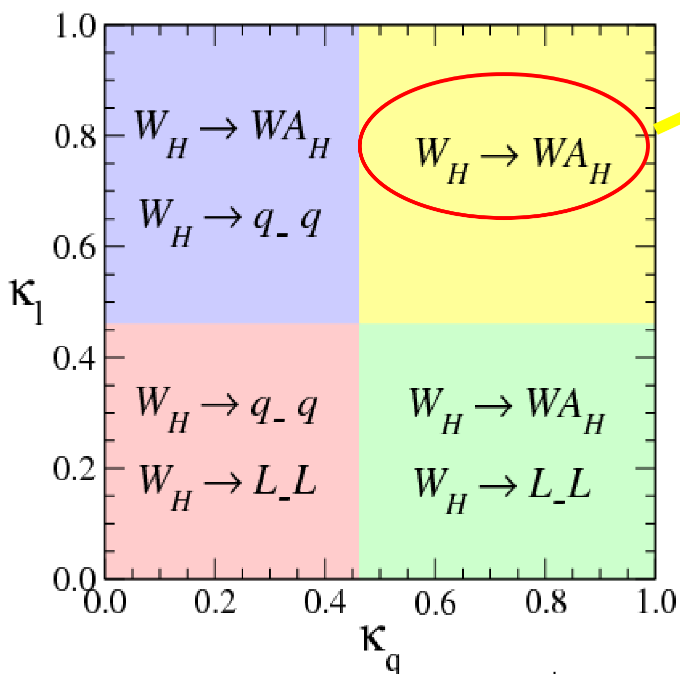
With 4 jets + $\not{E}_T$ signature

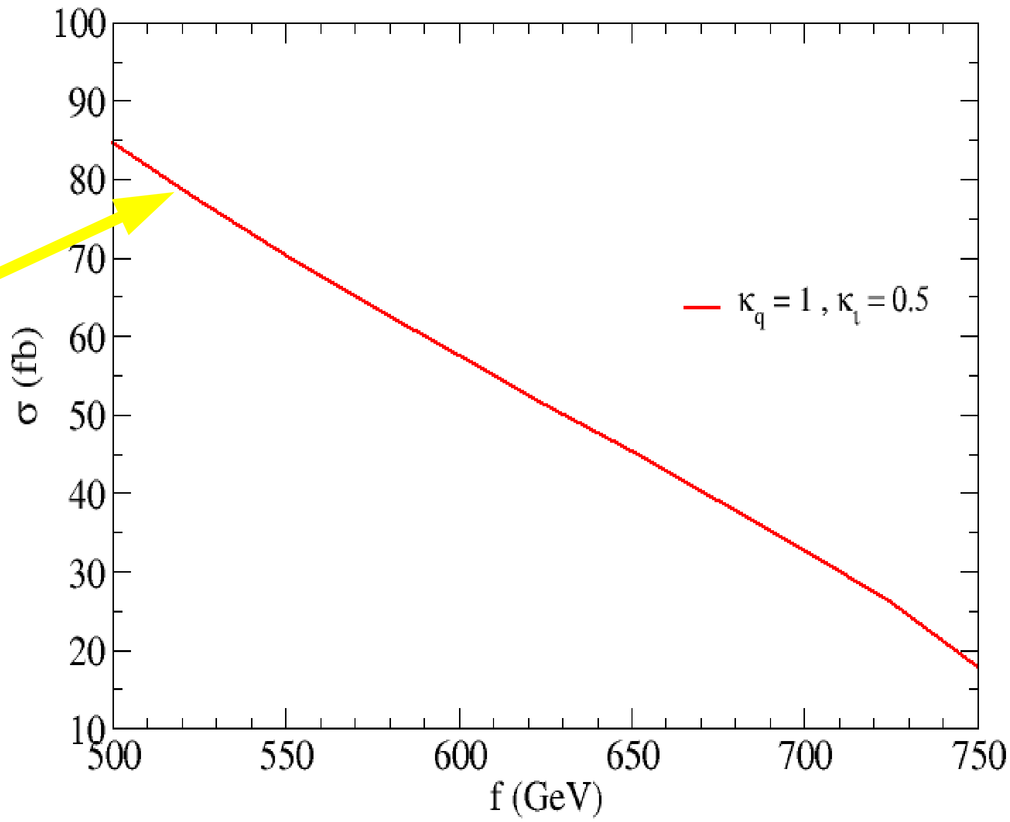
$$e^+ e^- \to W_H W_H \to A_H W(\to j\,j) A_H W(\to j\,j)$$

LC Signature: $4\, jets + \not{E}_T$



$$e^+ e^- \to W_H W_H \to A_H W(\to j\,j) A_H W(\to j\,j)$$



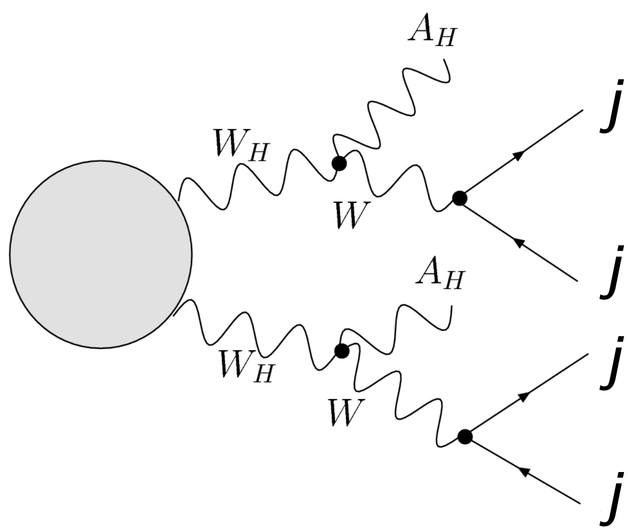


Intrinsic background : $e^+ e^- \to Z\, W\, W$

Reconstruct W bosons

Require :

$p_T^j \geq 15\,GeV,\ |\eta| \leq 3.0,\ \Delta R > 0.5$



Reconstruct W boson

* order 4 jets with respect to their transverse momentum

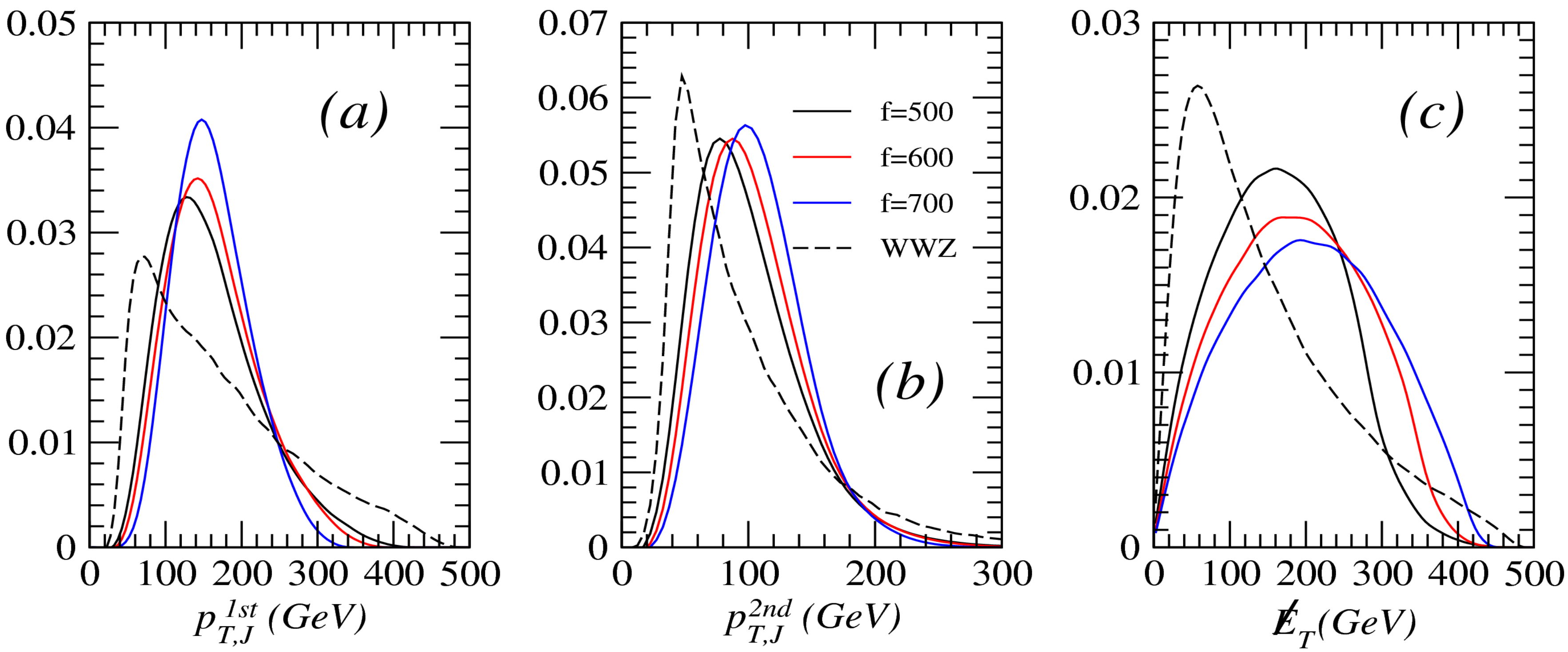
$$p_T^{j_1} > p_T^{j_2} > p_T^{j_3} > p_T^{j_4}$$

* also require $MIN(\Delta = \sqrt{(m_1(jj) - m_W)^2 + (m_2(jj) - m_W)^2})$

* identify Ws : $W_1 \equiv m(j_1 j_x)$, the other one is W_2

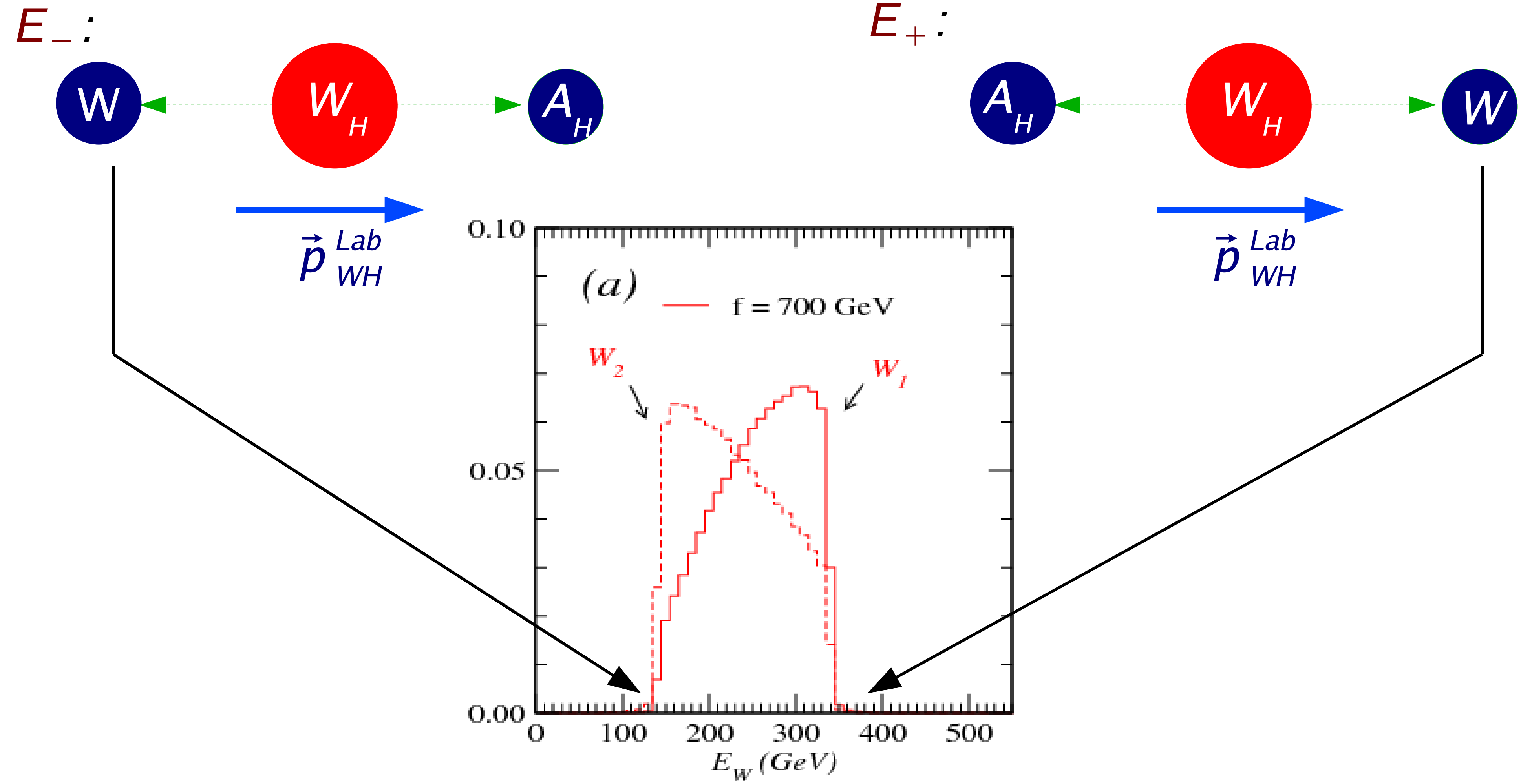
→ > 99 % accuracy

LC: kinematics distributions



normalized by total cross section

Reconstruct the mass of W_H , A_H

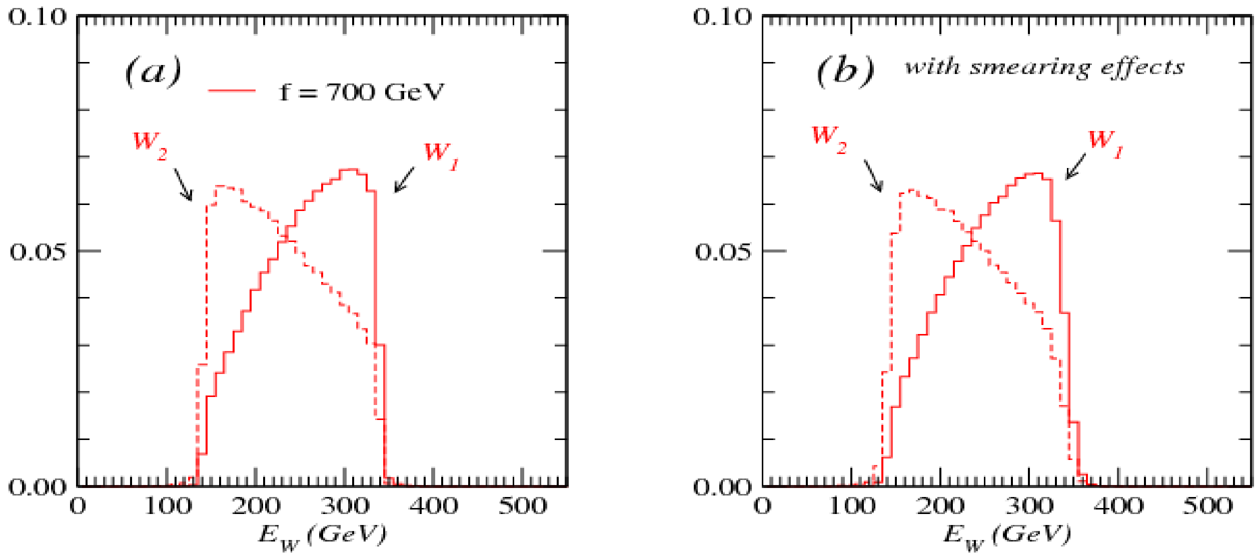


$$M_{W_H}=\sqrt{\frac{s}{2}}\frac{\sqrt{E_+E_-}}{E_++E_-}\sqrt{1+\frac{m_w^2}{E_+E_-}+\sqrt{(1-\frac{m_w^2}{E_+^2})(1-\frac{m_w^2}{E_-^2})}}$$

$$M_{A_H}=M_{W_H}\sqrt{1-2\frac{(E_++E_-)}{\sqrt{s}}+\frac{m_w^2}{M_{W_H}^2}}$$

Effect of the detector resolution

Reconstruct the mass of W_H



$$\frac{\Delta E}{E} = \frac{0.5}{\sqrt{E}}$$

$E_+ = 345\,GeV, E_- = 130\,GeV$ smeared → $E_+ = 355\,GeV, E_- = 130\,GeV$

$(M_{W_H}, M_{A_H}) \approx (435, 126)\,GeV$ $(M_{W_H}, M_{A_H}) \approx (432, 109)\,GeV$

$true\,(450, 101)\,GeV$ $\delta \approx 4\,\%, 8\,\%$

Reconstruct momentum of A_H

Probing the Weak Boson Sector in e+ e- ---> W+ W-

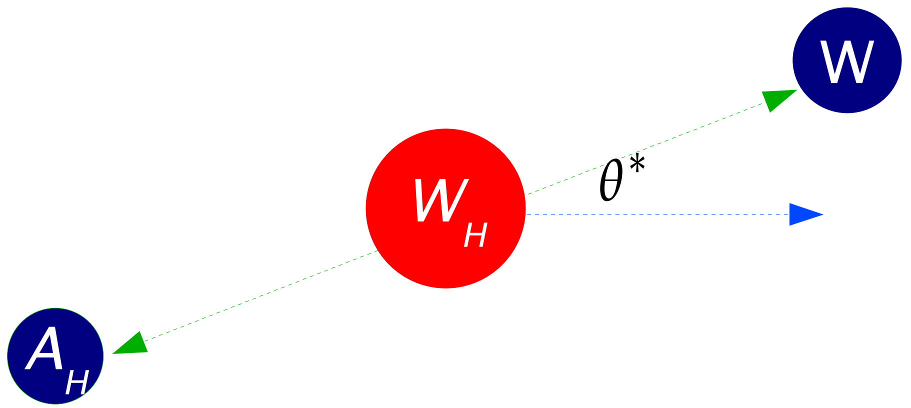
K. Hagiwara, R. D. Peccei and D. Zeppenfeld, Nucl.Phys.B282:253,1987.

On shell condition
momentum conservation
known C.M. energy

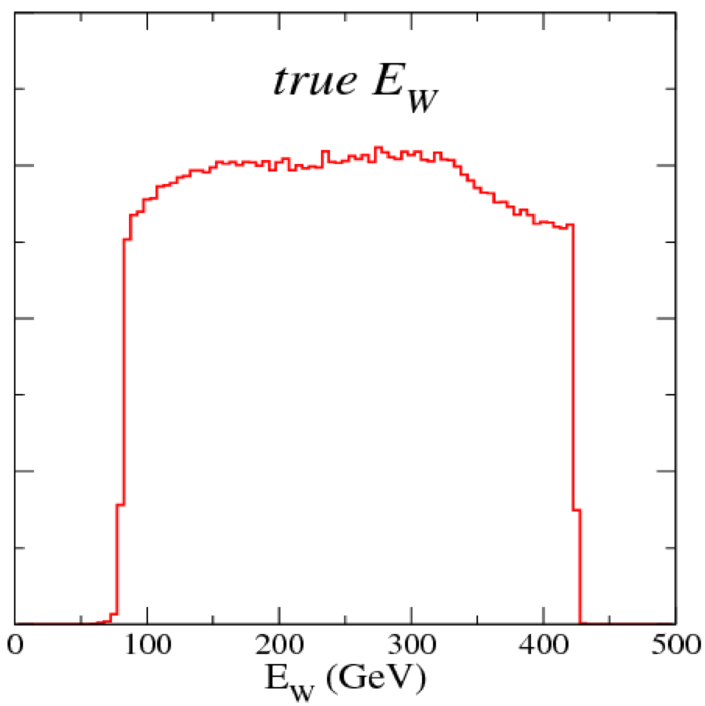
→ reconstruct the kinematics of A_H

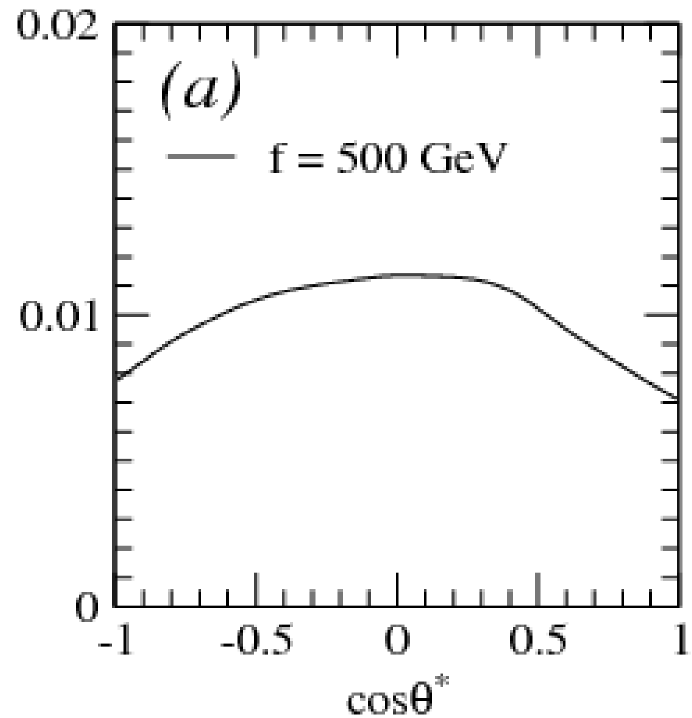
Spin of W_H

rest frame of W_H



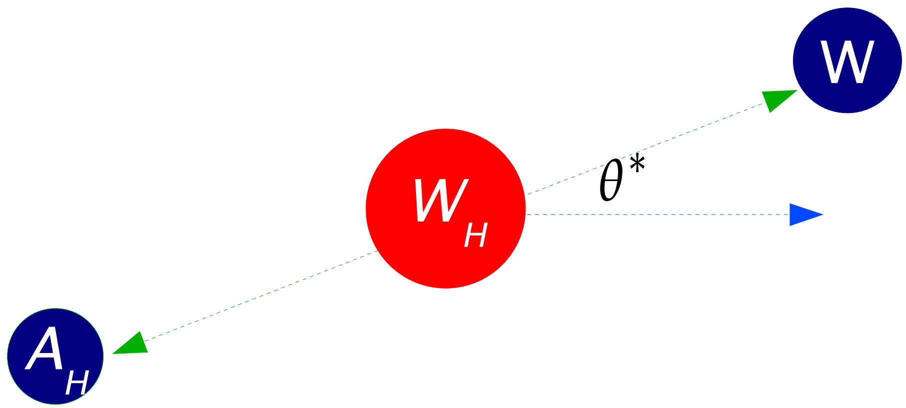
P-wave dominates

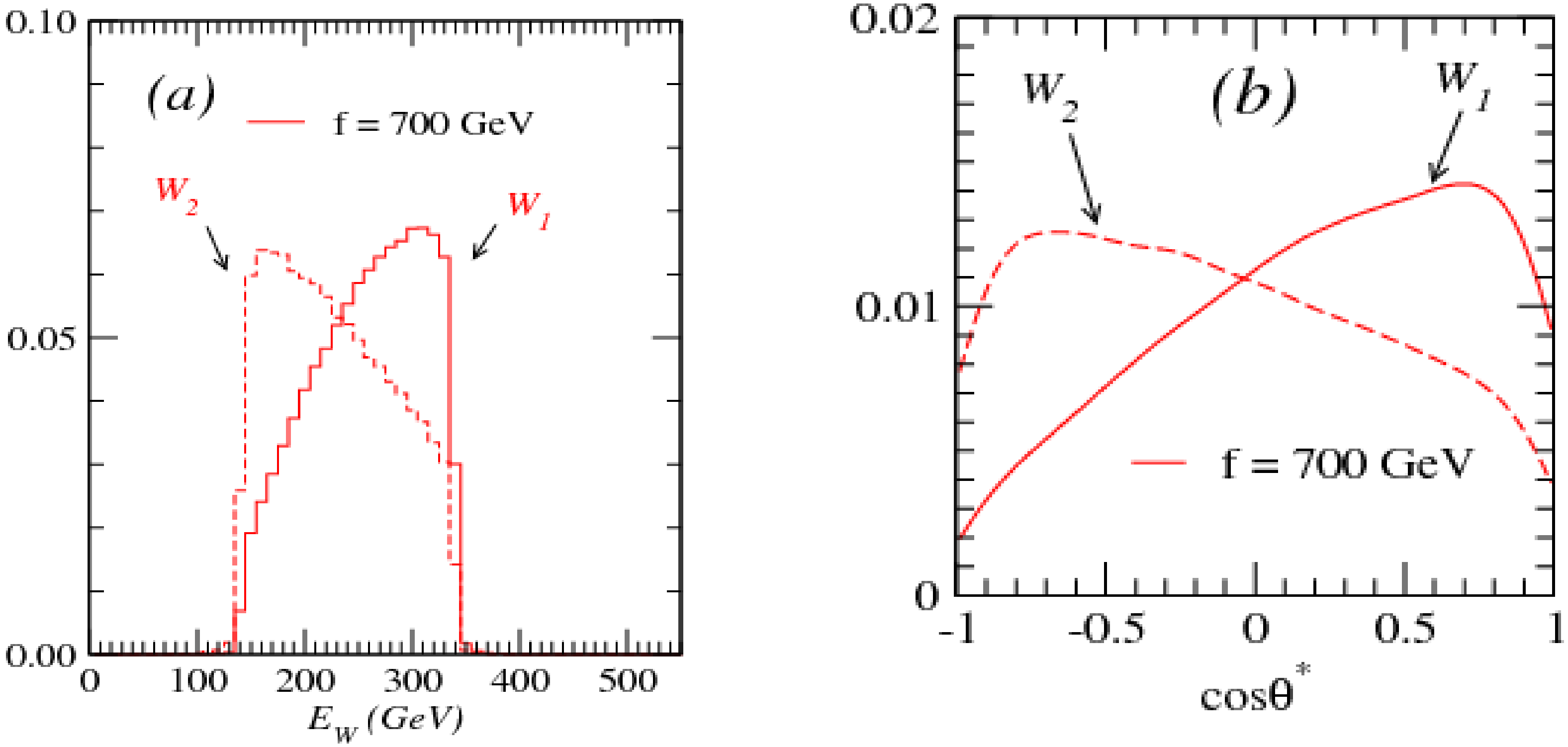




Spin of W_H after W-boson reconstruction

rest frame of W_H





Conclusion

* LHC: di-lepton + $\not{E}_T$

-- has a great potential to discover the signatures of W_H

-- can NOT reconstruct the masses of W_H and A_H

-- can NOT measure the spin of W_H

* LC: 4 jets + $\not{E}_T$

-- can reconstruct the mass of W_H A_H

-- can reconstruct the momentum of missing particle A_H

-- can measure the spin of W_H

⬇

distinguishing alternative models with dark matter candidates with different spin.

Backup slides

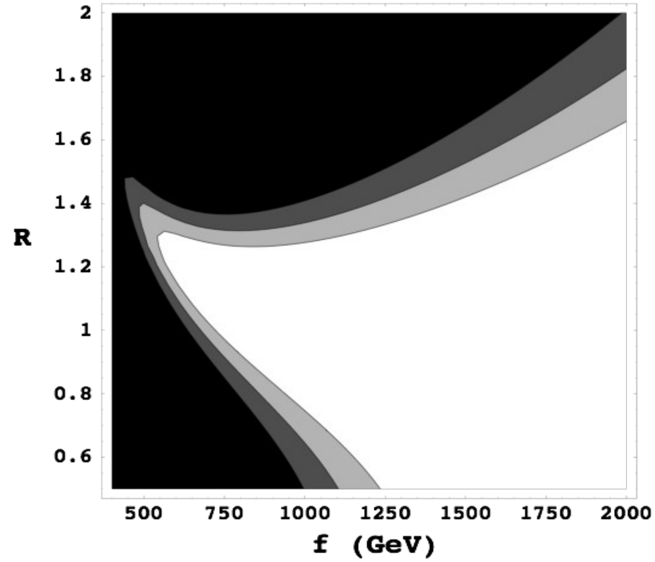
Constraints on Parameters

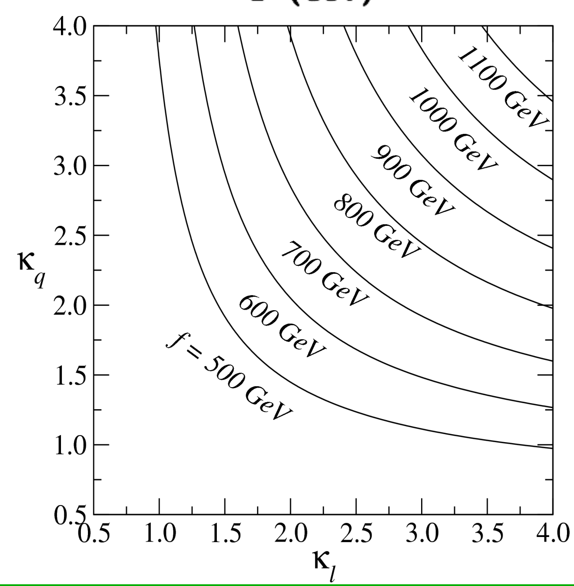
Constraints on Parameters:

Heavy particles contribute to EW observables at one-loop level

Exclusion contours:

From lightest to darkest, the contours correspond to the 95, 99, and 99.9 confidence level exclusion. Hubisz et al, hep-ph/0506042



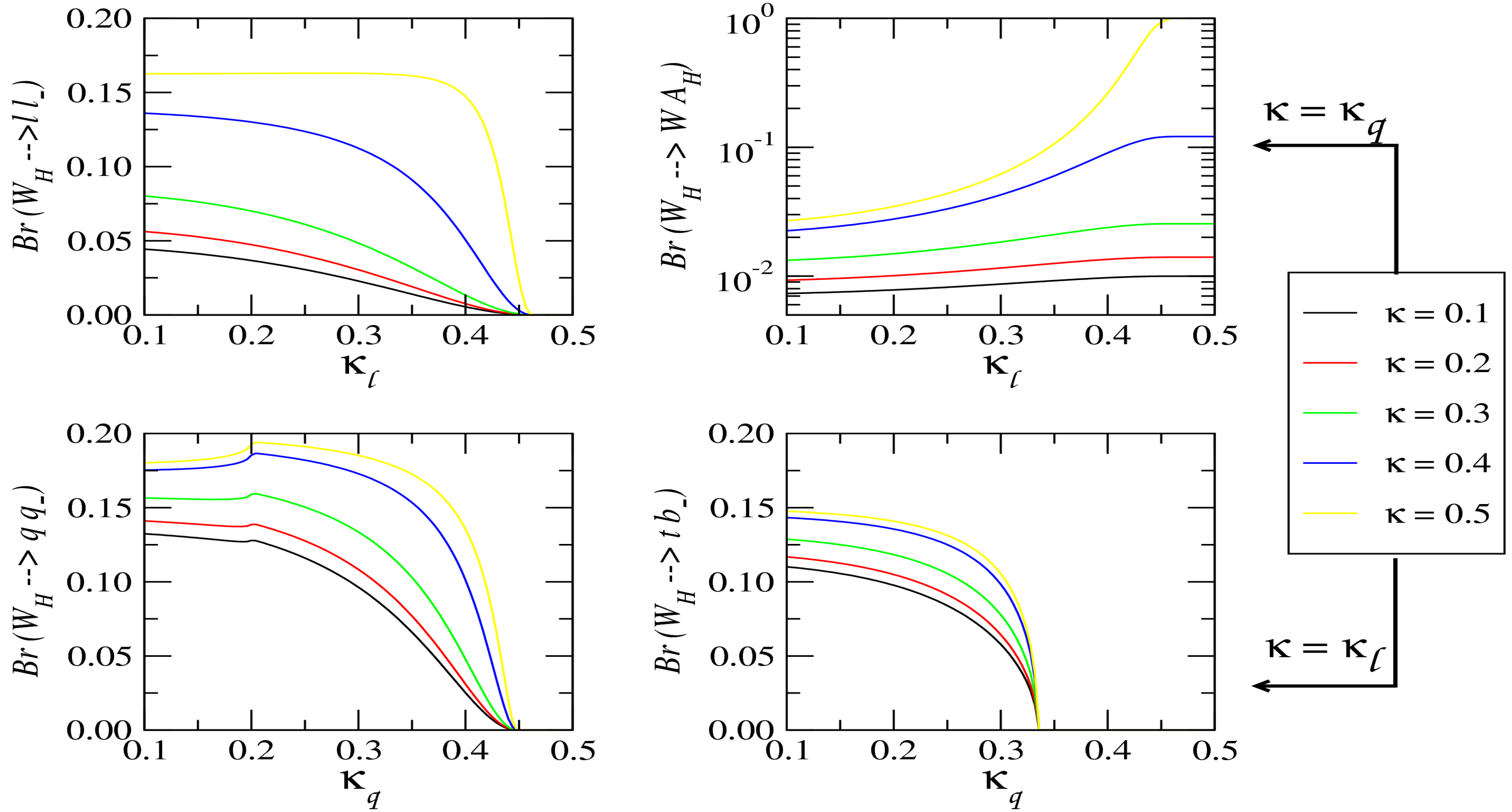


4-fermion operators (eeee, uudd, eedd)

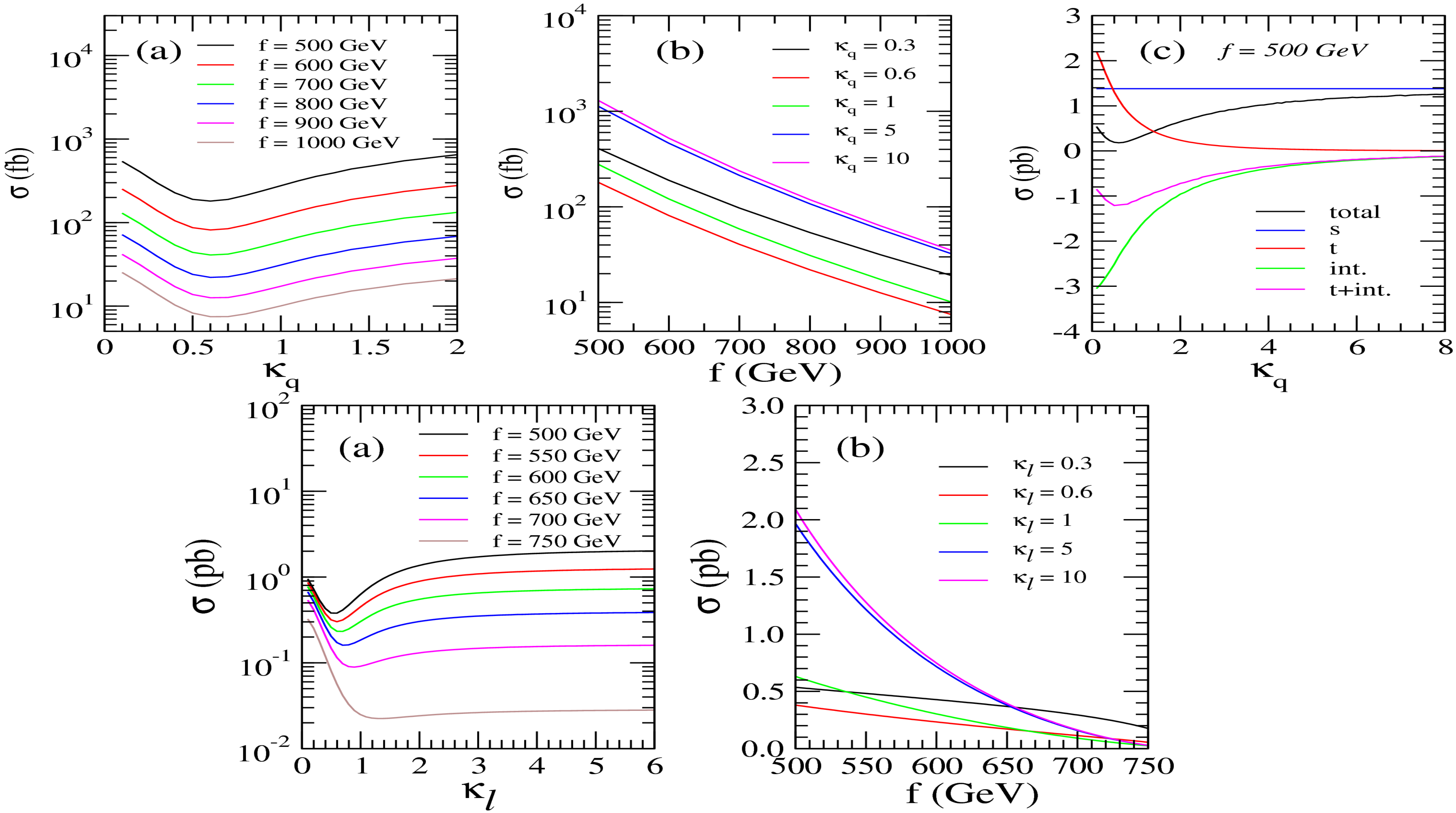
$$\kappa_l \leq 8.6 f/TeV \qquad \kappa_q \leq 37.1 f/TeV$$

$$\frac{\kappa_l^2 \kappa_q^2}{\kappa_l^2 - \kappa_q^2} \ln\left(\frac{\kappa_l}{\kappa_q}\right) \leq \frac{128\pi^3 f^2}{(26.4\,TeV)^2}$$

Decay BR of WH



Xsection



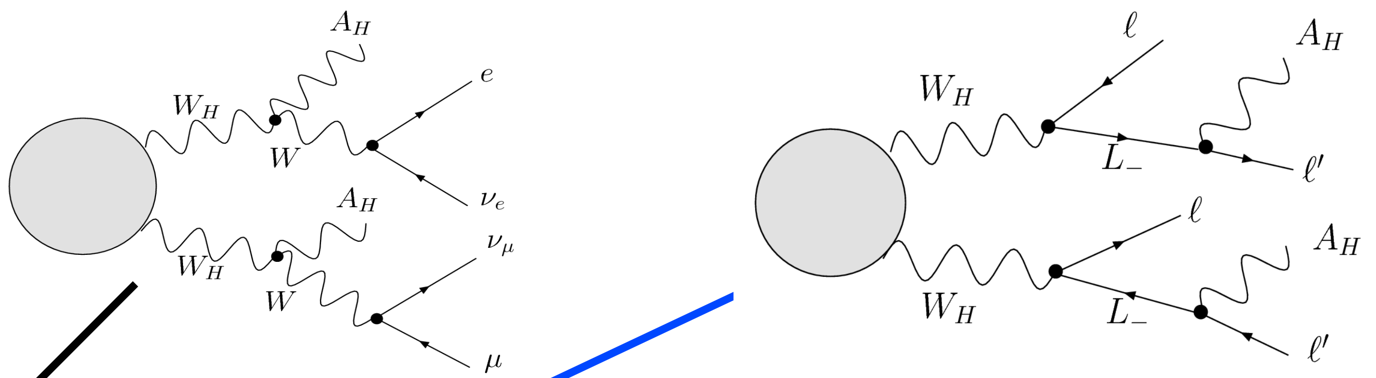
(a)
f = 500 GeV
f = 600 GeV
f = 700 GeV
f = 800 GeV
f = 900 GeV
f = 1000 GeV
σ (fb)
κq
(b)
κq = 0.3
κq = 0.6
κq = 1
κq = 5
κq = 10
σ (fb)
f (GeV)
(c) f = 500 GeV
total
s
t
int.
t+int.
σ (pb)
κq
(a)
f = 500 GeV
f = 550 GeV
f = 600 GeV
f = 650 GeV
f = 700 GeV
f = 750 GeV
σ (pb)
κl
(b)
κl = 0.3
κl = 0.6
κl = 1
κl = 5
κl = 10
σ (pb)
f (GeV)

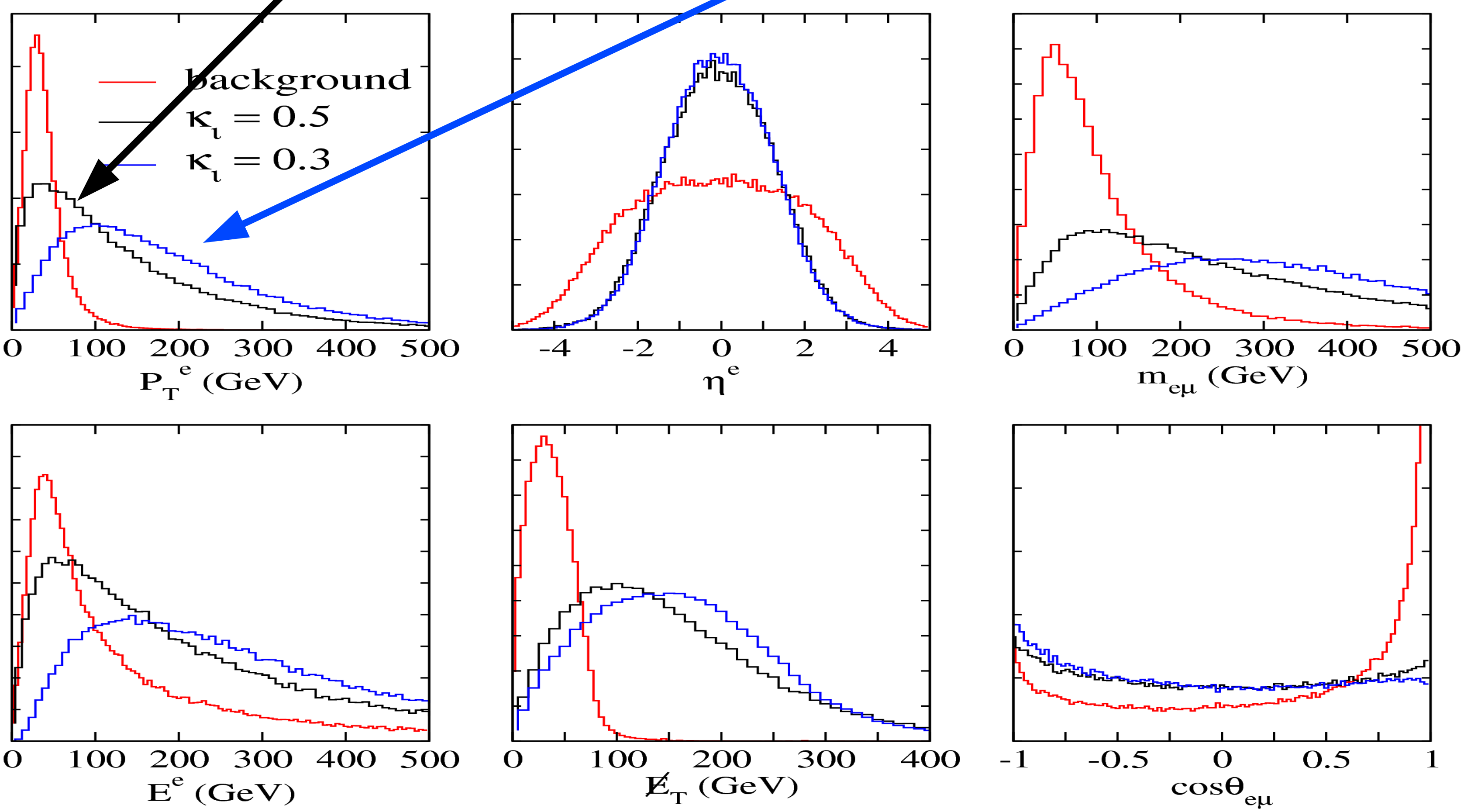
Kinematics before cuts (LHC)

Kinematics

$f = 700\ GeV$

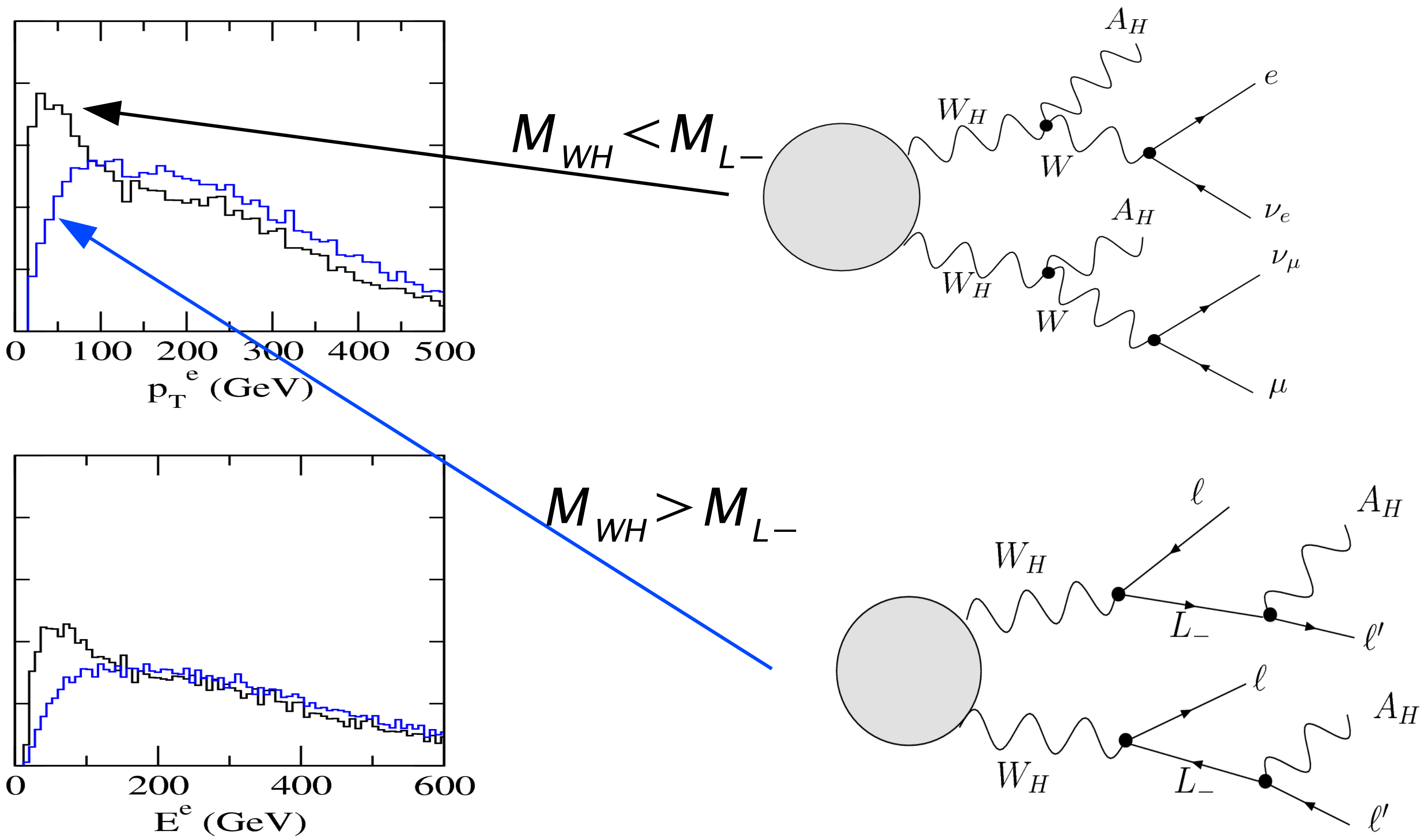
$\kappa_q = 1$





Kinematics after cuts -- LHC

Kinematics distributions after imputing cuts :



Reconstruction of M_wh

At the rest frame of W_h

$$E_w^{res} = \frac{m_{WH}^2 - m_{AH}^2 + m_w^2}{2\mathrm{m}_{WH}} \qquad p_w^{res} = \frac{\sqrt{[m_{WH}^2 - (m_{AH} + m_w)^2][m_{WH}^2 - (m_{AH} - m_w)^2]}}{2\mathrm{m}_{WH}}$$

$$E_{\pm} = \gamma (E_w^{res} \pm \beta p_w^{res}) \qquad \beta = \sqrt{1 - \frac{m_{WH}^2}{s}}$$

$$\Rightarrow \quad M_{W_H} = \sqrt{\frac{s}{2} \frac{\sqrt{E_+ E_-}}{E_+ + E_-} \sqrt{1 + \frac{m_w^2}{E_+ E_-} + \sqrt{(1 - \frac{m_w^2}{E_+^2})(1 - \frac{m_w^2}{E_-^2})}}}$$

$$M_{A_H} = M_{W_H} \sqrt{1 - 2\frac{(E_+ + E_-)}{\sqrt{s}} + \frac{m_w^2}{M_{W_H}^2}}$$

Further discriminate the signal from BG

$$\cos\theta_{wA_H} = \frac{-2\left(E_w - \frac{\sqrt{s}}{4}\right)^2 + \left(\frac{\sqrt{s}}{4}\right)^2 + m_{A_H}^2 + m_w^2 - M_{W_H}^2}{2\sqrt{\left(\frac{\sqrt{s}}{2} - E_W\right)^2 - m_{A_H}^2}\ \sqrt{E_w^2 - m_w^2}}$$