SUSY EW effects in single W+jet production at LHC

G.J. Gounaris, J. Layssac and F.M. Renard / arXiv:0709.1789 [hep-ph]

- If New Particles appear at LHC, **real** and **virtual** SUSY effects must be studied.

- The 1-loop EW virtual effects, enhanced by ln(s) and $\ln^2(s)$ terms, in both SM and MSSM, may easily reach the 10% level at LHC; provided $M_{SUSY} \lesssim$ few TeV,

- An example: Virtual SUSY should then be visible in **W+jet** production.
Basic subprocess: $u\, g \to d\, W^+$.
It determines all needed subprocesses: $qg \to q'W$, $\bar{q}g \to \bar{q}'W$, $q\bar{q}' \to Wg$

- **Here I describe the HC rule and apply it to the 1-loop $u\, g \to d\, W^+$ helicity amplitudes, at LHC and asymptotic energies, in SM or MSSM**

- **Then I study the p_T distribution for $W^\pm$ + jet production at LHC.**

4-dimensional SUSY at TeV-scale

•Much like Lorentz symmetry forced Dirac to associate to each particle, an anti-particle with the **same** mass,
this supersymmetric extension, associates with any given particle, another one with its spin differing by ½. The only difference is that the sparticles are **NOT** degenerate and obviously heavier than the particles.

•**In contrast to Lorenz, SUSY is softly broken.** Soft SUSY breaking eliminates mass degeneracy..

• **Usual points for SUSY**: It eliminates the UV quadratic divergences, improving mathematical consistency.
If at TeV-scale, it also softens hierarchy, and assures the gauge-coupling unification at $M_{GUT} \sim 2 \cdot 10^{16}$ GeV.

• **NEW point**: **SUSY also guaranties exact conservation of total helicity (HC), for any two-body process at asymptotic s, |t|, |u| .**

•**HC is an additional property, NOT related to the UV divergences.**

The HC rule

Renard, G., PRL 2005, PRD 2006

To all orders in perturbation theory in SUSY, and at asymptotic *(s, |t|, |u|)*-values, the only possibly non-vanishing 2-body helicity amplitudes satisfy

$$F(a_{\lambda_1} b_{\lambda_2} \to c_{\lambda_3} d_{\lambda_4}) \Leftrightarrow \lambda_1 + \lambda_2 = \lambda_3 + \lambda_4 \quad .$$

- **All amplitudes violating the HC rule, must vanish in SUSY, at (s, |t|) $\gg M^2_{SUSY}$**

- **In SM,** the theorem is also true at 1-loop leading-log approximation; i.e. only the **Ln** and **Ln²** terms respect it, provided ***(s, |t|, |u|)*** $\gg m^2_w$

- **In SM, at asymptotic *(s, |t|, |u|)*, the HC violating amplitudes go to constants. In MSSM these constants vanish.**

- In some benchmarks, the HC asymptotic region may be within the LHC range. In any case, they provide an **important simplification.**

SM or MSSM

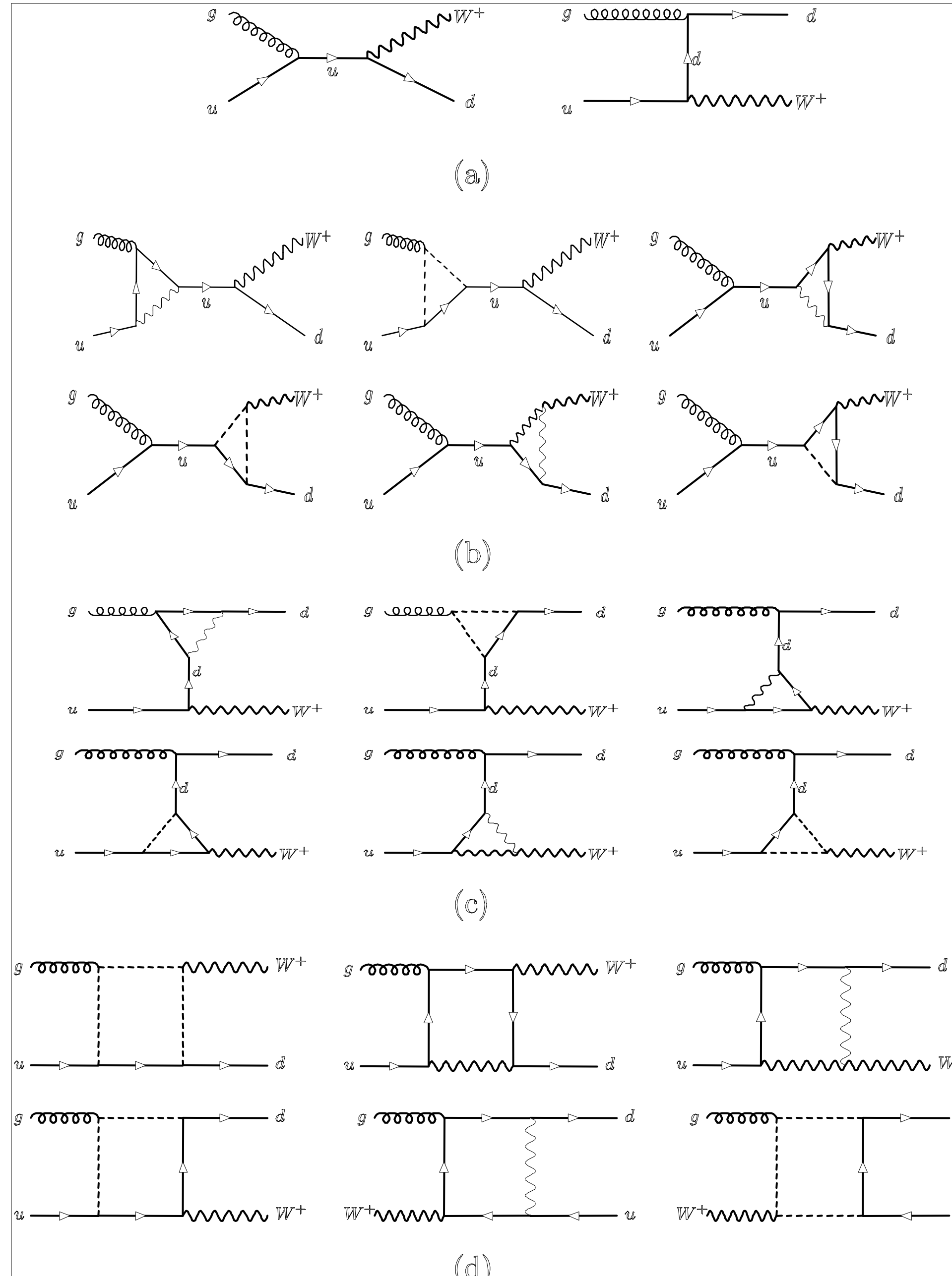
$$u(\lambda_u)+g(\lambda_g)\rightarrow d(\lambda_d)+W^{+}(\lambda_W)$$

$$F_{\lambda_u\lambda_g\lambda_d\lambda_W} \;\Rightarrow\; F_{-\lambda_g-\lambda_W} \quad ,$$

$$(\lambda_g = \pm 1) \;\; , \;\; (\lambda_W = \pm 1, 0)$$

HC $\Rightarrow \;\; \lambda_g = \lambda_W$

GBHC	**F_{----} , F_{-+-+}**	Born exists
GBHV1	**F_{---+} , F_{---0}**	No Born
GBHV2	**F_{-+--} , F_{-+-0}**	Born exists



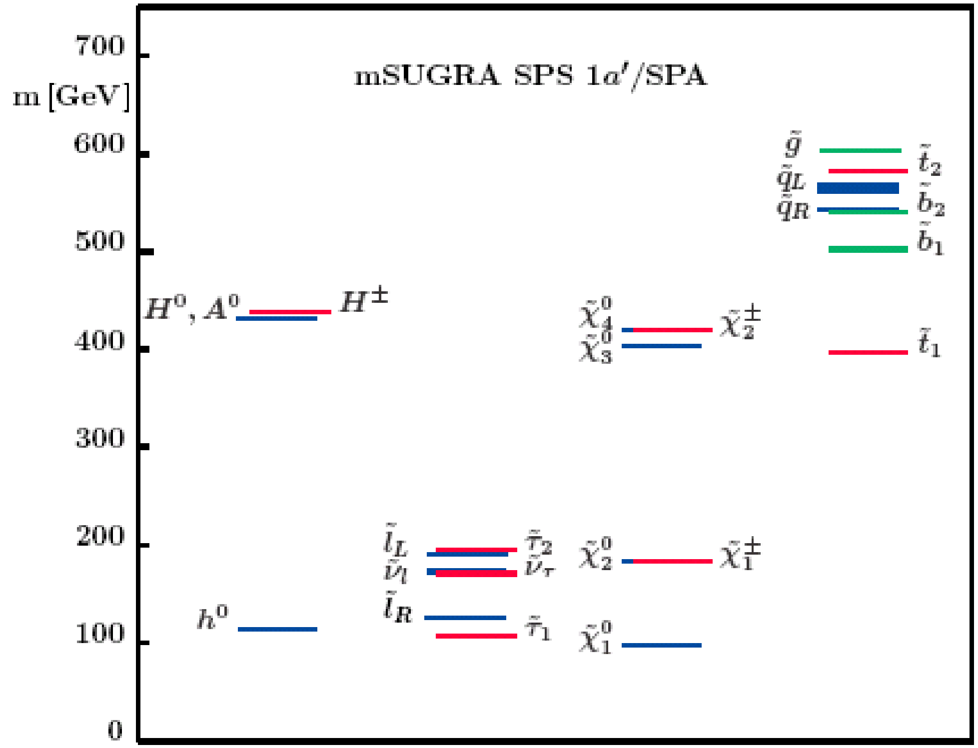
1-loop diagrams: full, broken and wavy lines describe respectively, fermion, scalar and gauge exchanges.

To describe SUSY, we use three benchmark MSSM (mSUGRA) models corresponding to heavy, medium or light SUSY breaking scales.

BBSSW and SPS1a' consistent with everything known.

(GeV)	BBSSW	SPS1a'	Light SUSY
$m_{1/2}$	900	250	50
m_0	4716	70	60
A_0	0	-300	0
$\tan\beta$	30	10	10
M_{SUSY}	3000	350	40

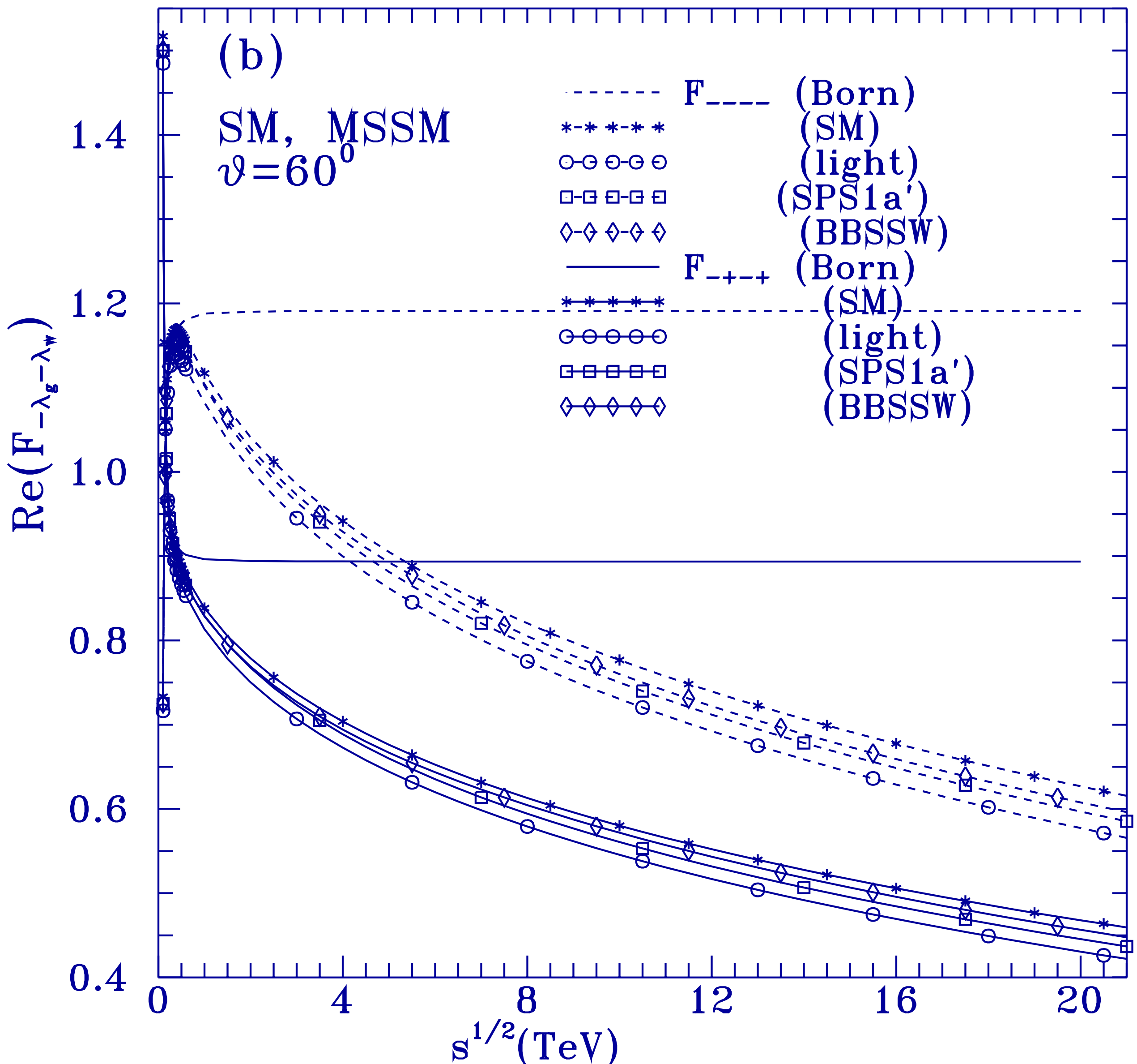
SUSY effects always reduce the important HC amplitudes.



The $u\, g \to d\, W^+$ amplitudes for any set of MSSM parameters at the EW scale, are given by the **ugdwcode.tar.gz** available at http://users.auth.gr/gounaris/FORTRANcodes

Most important GBHC $u\, g \to d\, W^+$ amplitudes in SM and MSSM

Im parts are much smaller than the Real parts..



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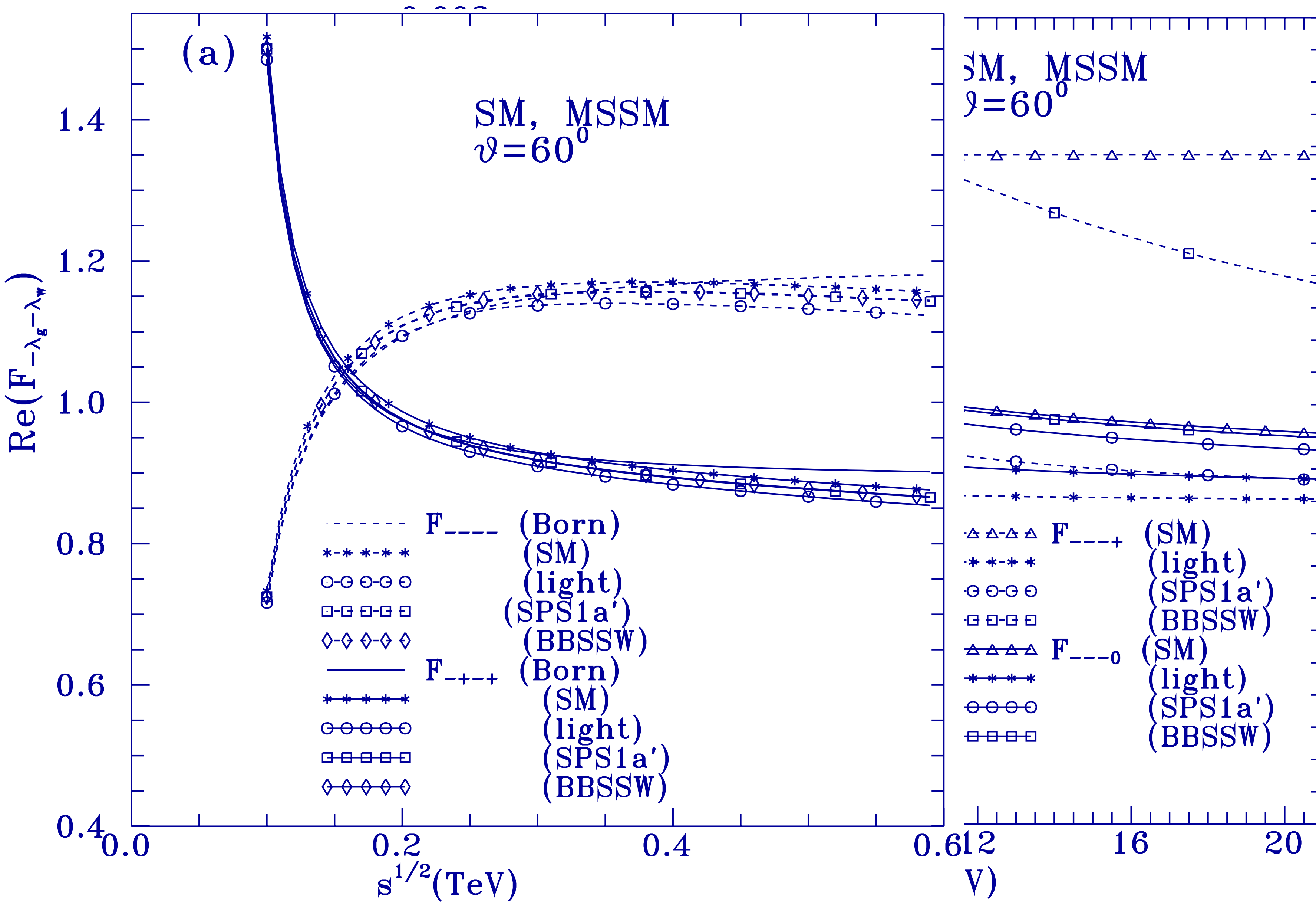
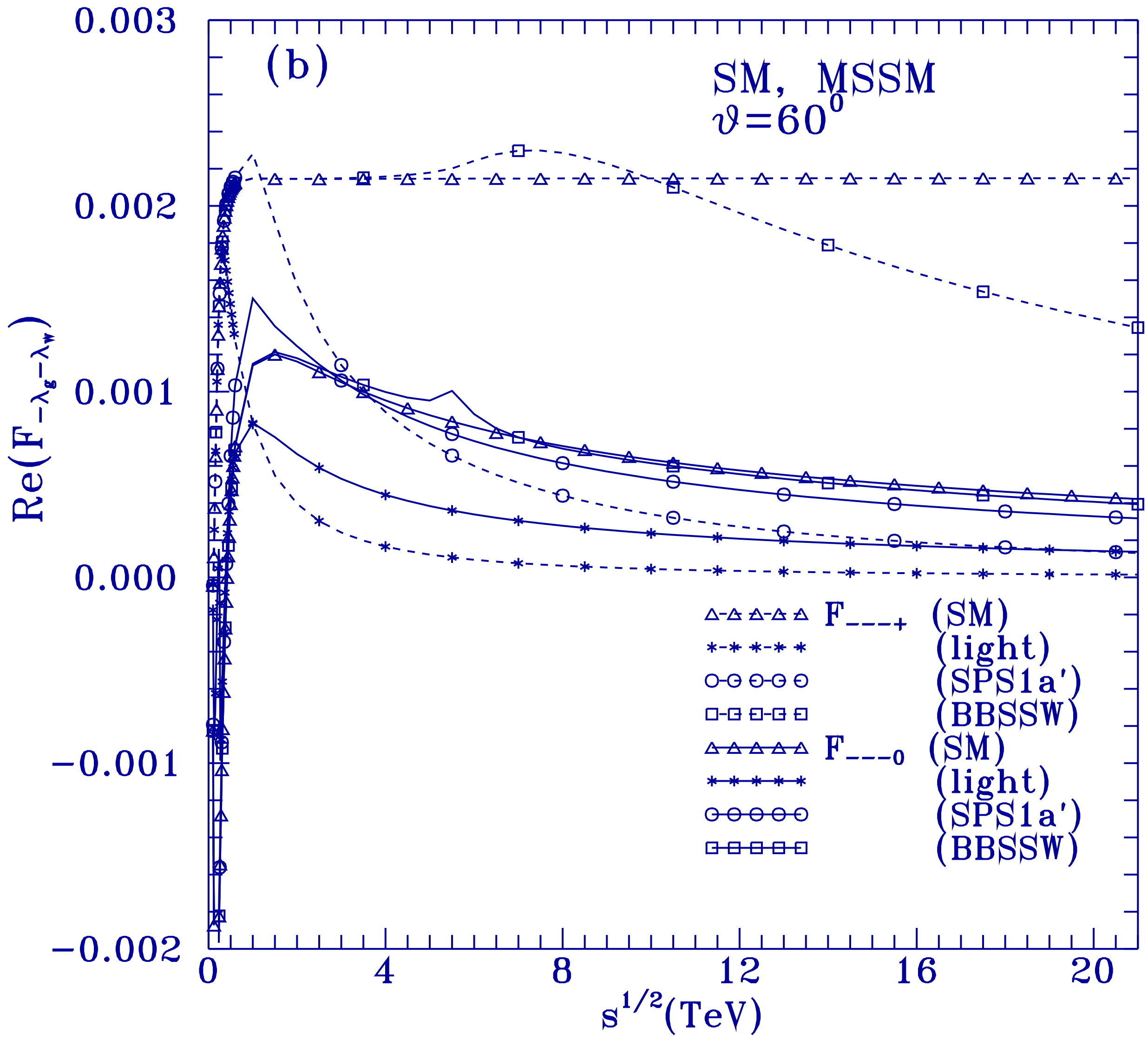


Very small GBHV1 $u\,g \to d\,W^{+}$ amplitudes in SM and MSSM
There exist is no Born contributions to them.

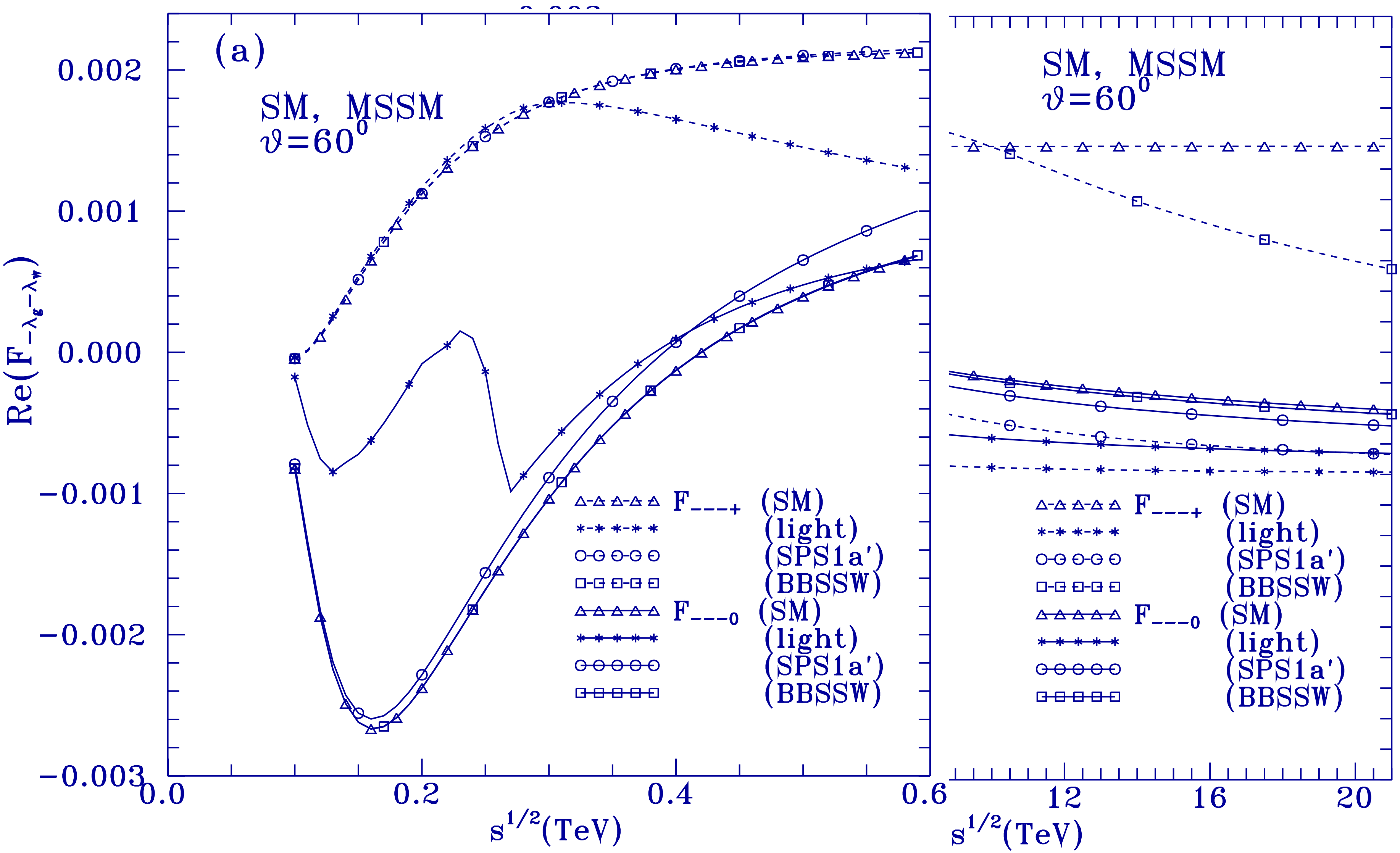
Im and Real parts may be comparable at low energies, where threshold singularities appear.

In any case GBHV1 are very small.



Very small GBHV1 ***u g → d W⁺*** amplitudes in SM and MSSM

There exist is no Born contributions to them.



For $\sqrt{s} \gtrsim 0.5$TeV, the GBHV2 $u\, g \to d\, W^+$ amplitudes are also very small, both in SM and MSSM. Born contributions now exist

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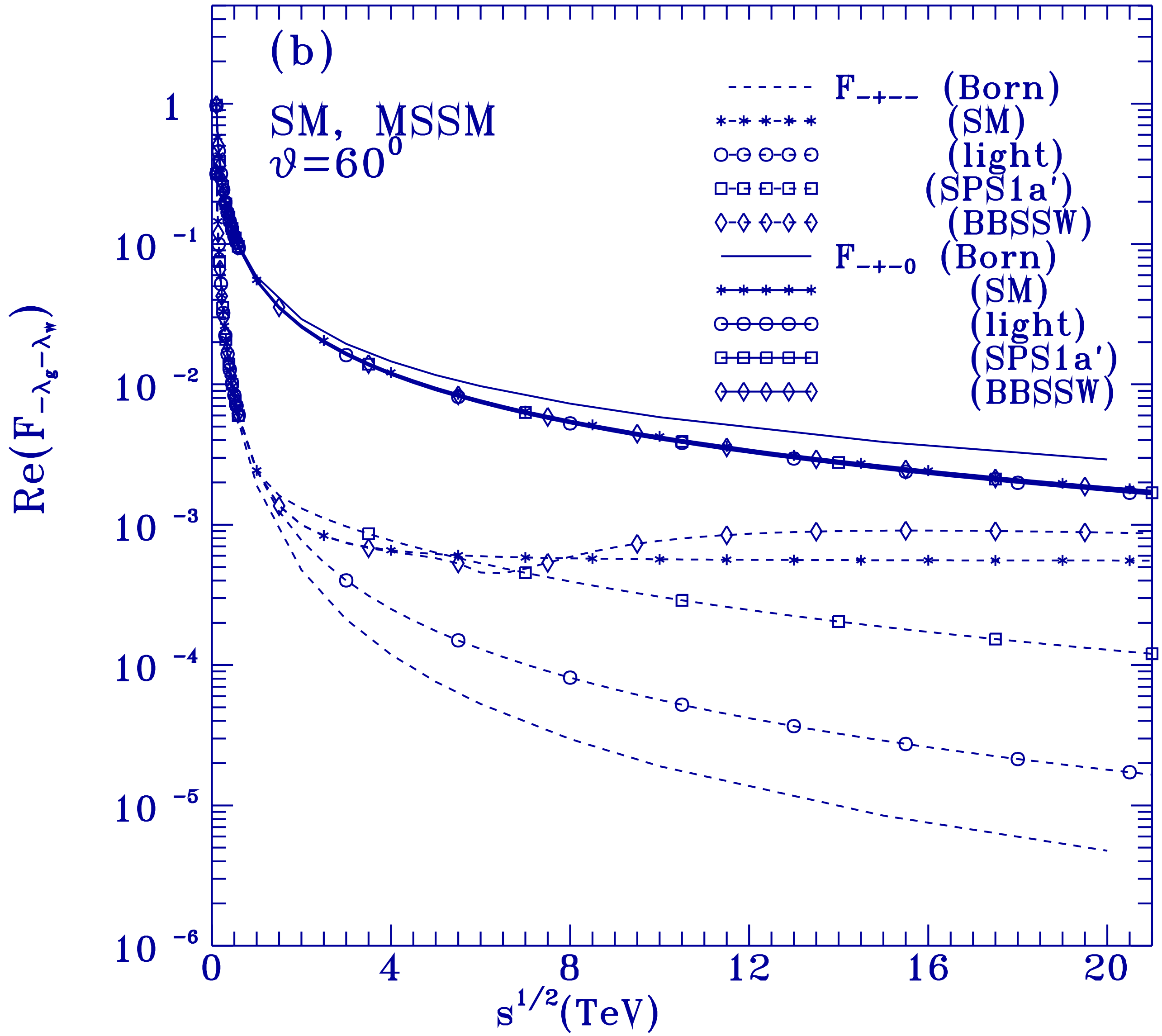

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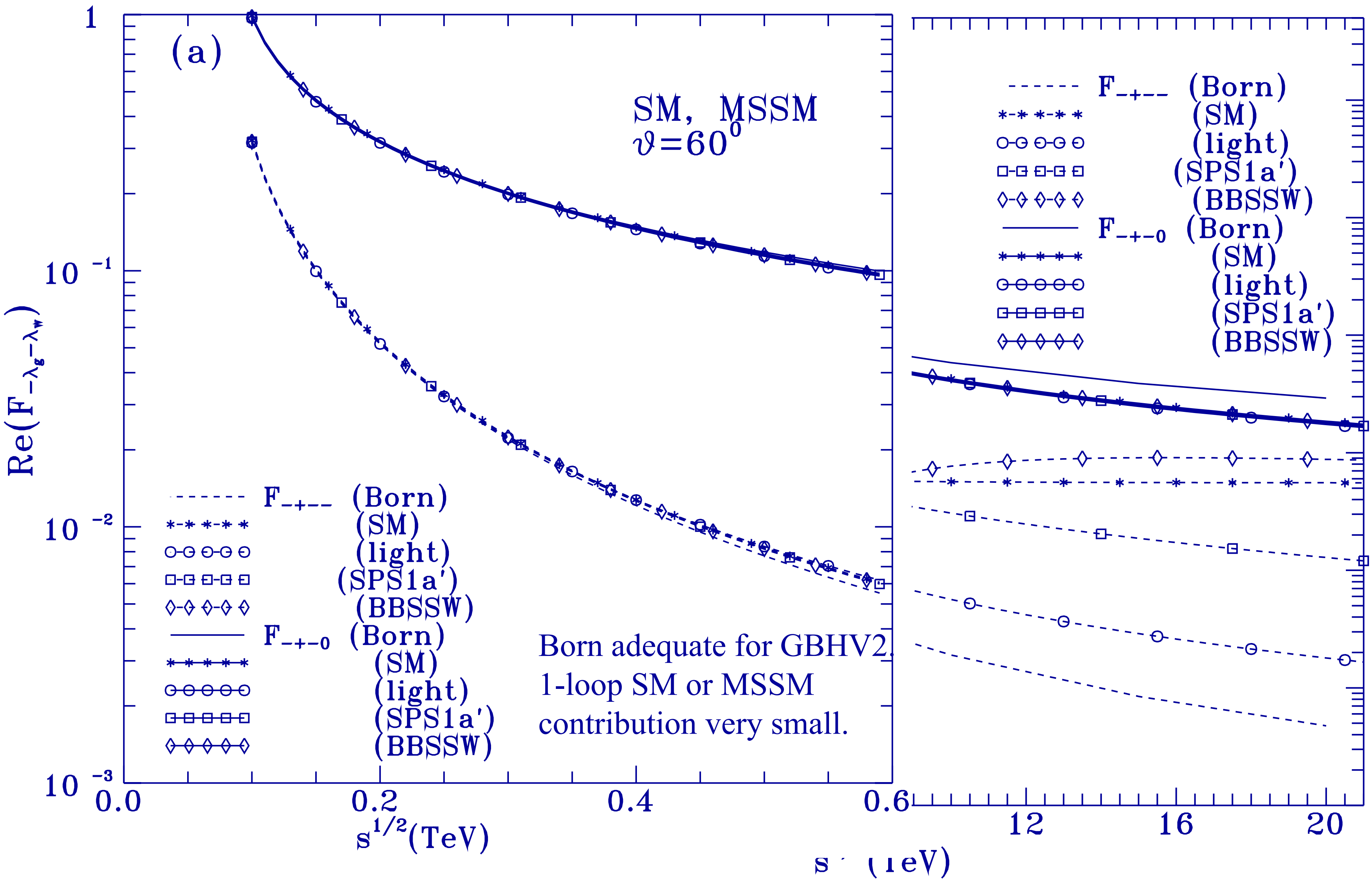
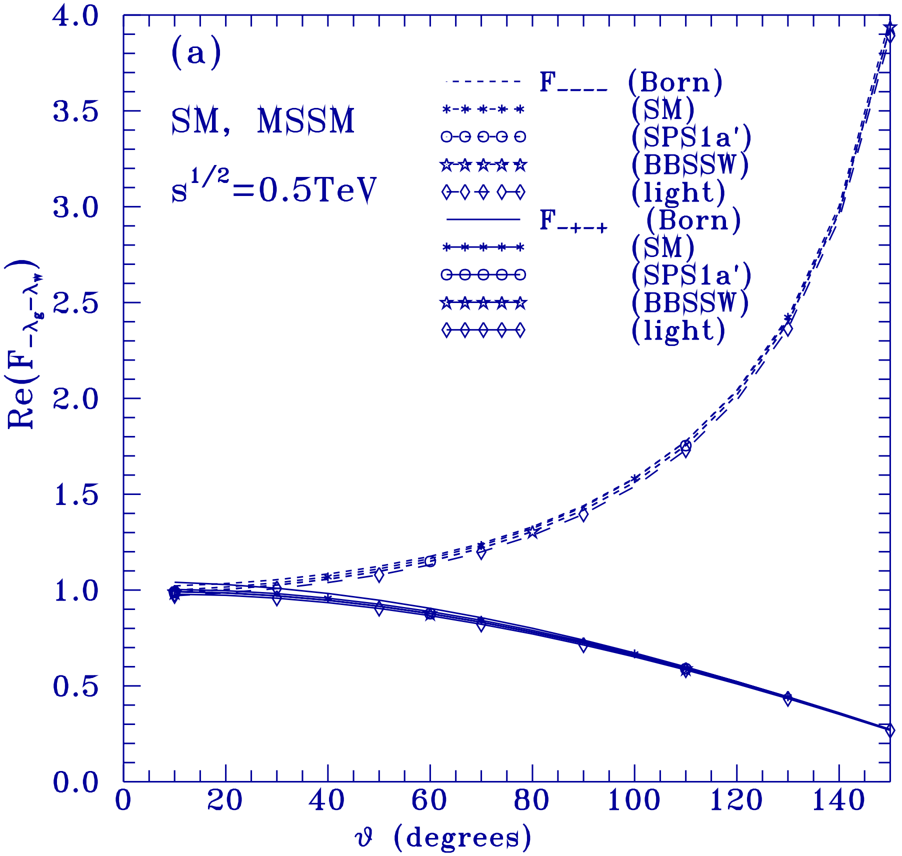
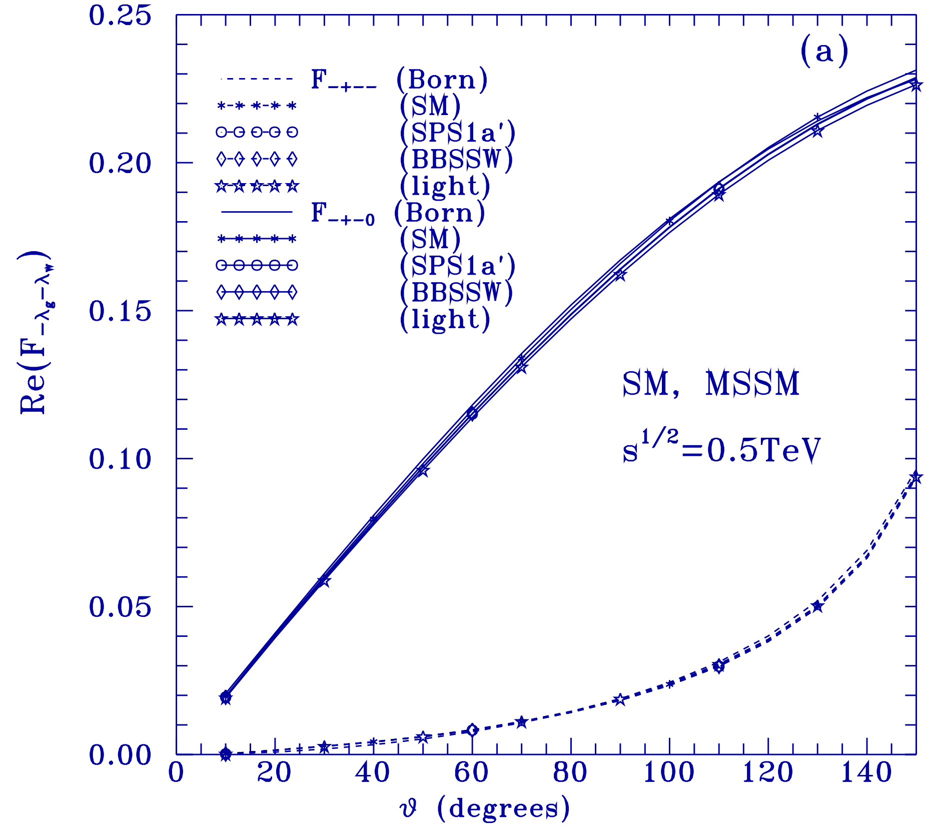


ATLAS-Thessaloniki 2007

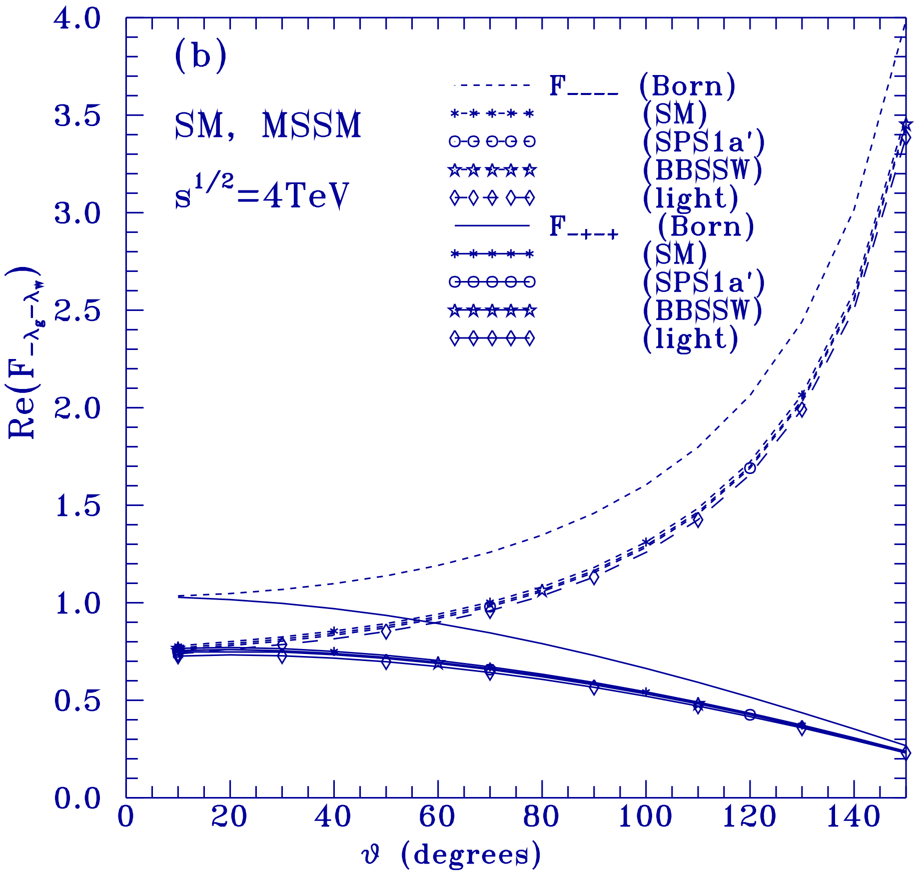
Angular dependence for the GBHC and GBHV2 $u\, g \to d\, W^+$ amplitudes at $\sqrt{s}$=0.5TeV

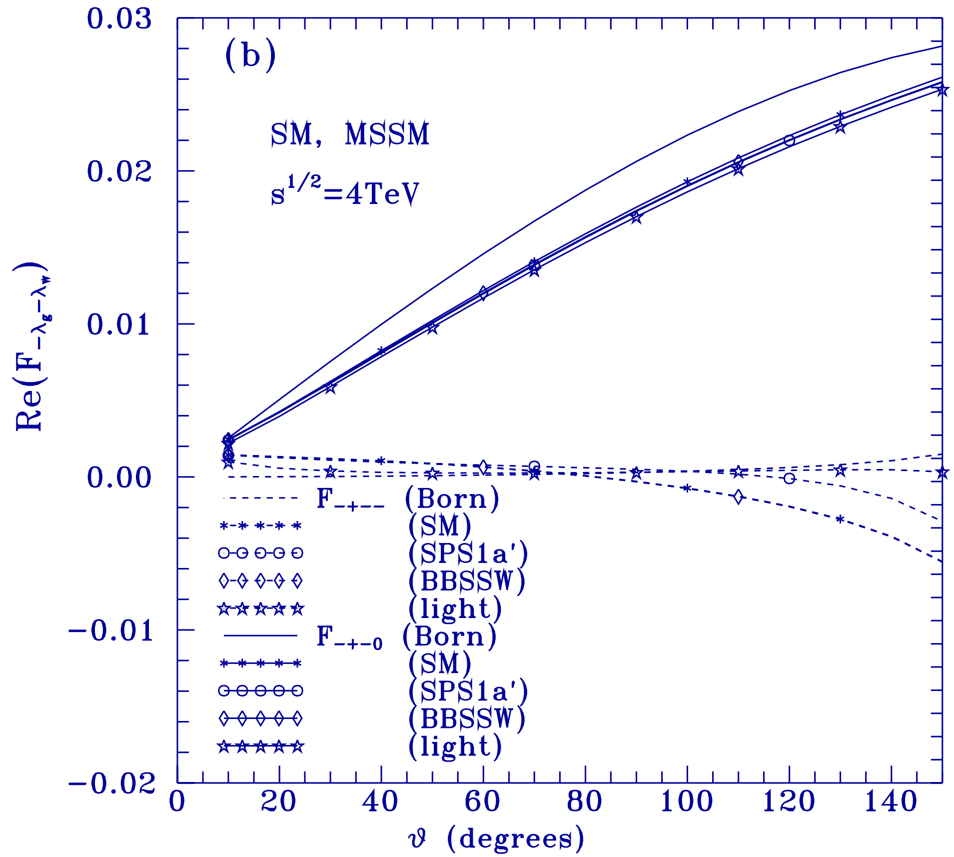




At such energies, the 1-loop SM and MSSSM effects are barely visible.
GBHC ≳ GBHV1, GBHV2 , in the complete angular region.

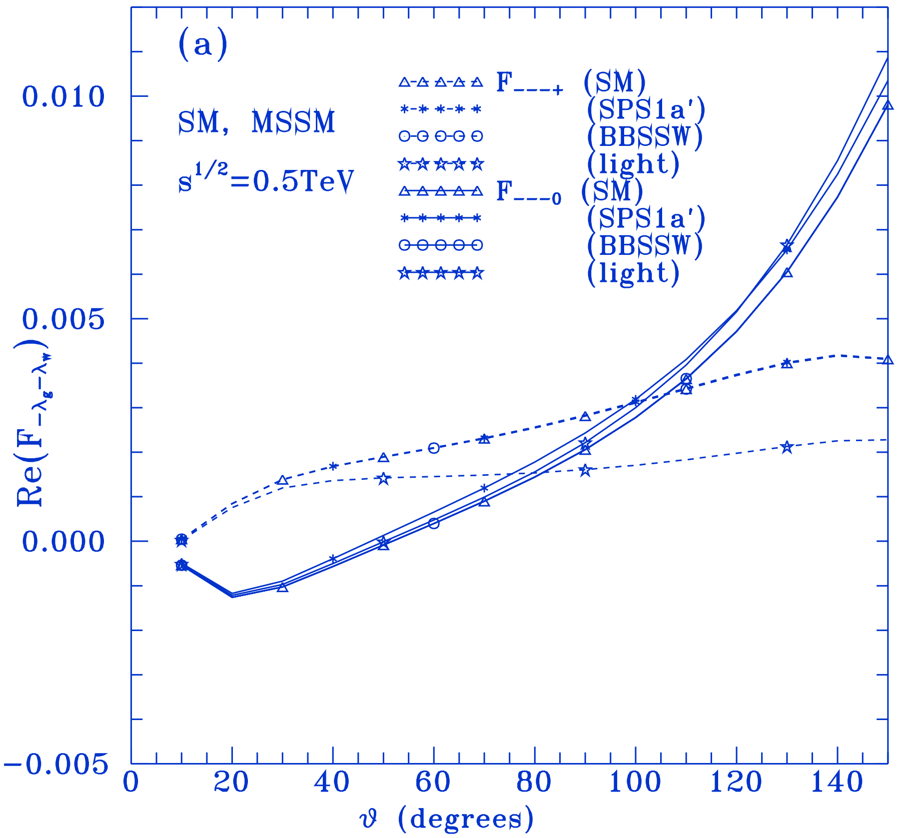
Angular dependence for the GBHC and GBHV2 $u\, g \rightarrow d\, W^{+}$ amplitudes at $\sqrt{s}$=4 TeV

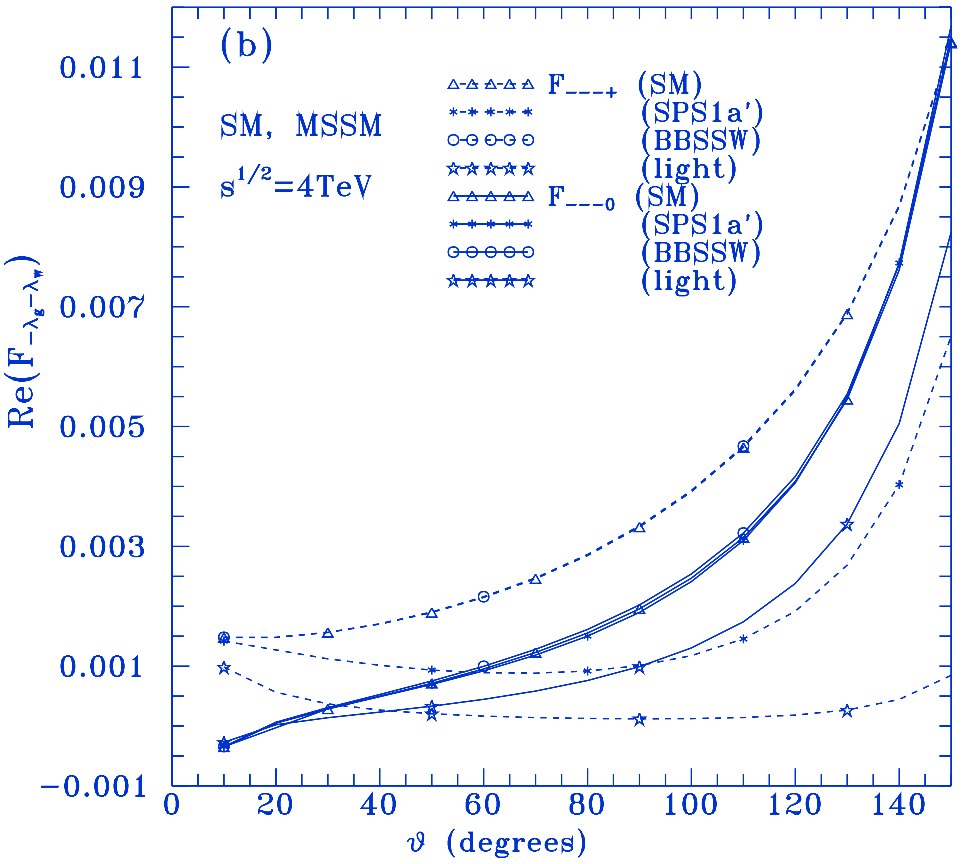




The 1-loop SM and MSSSM effects are enhanced with energy, and the **GBHC dominance is increasing: GBHC ≫ GBHV1, GBHV2** now

The GBHV1 $u\,g \rightarrow d\,W^+$ amplitudes are the smallest



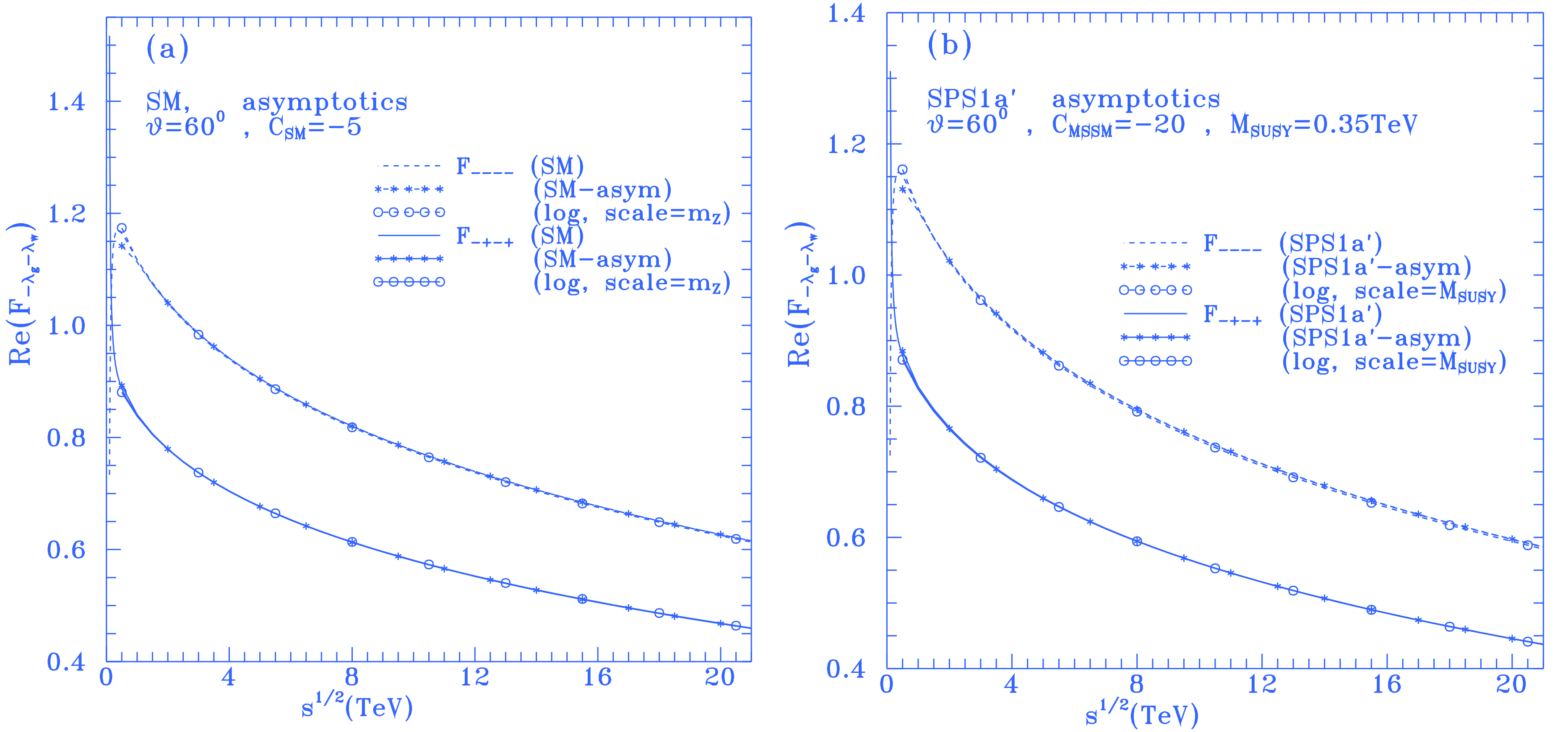


The GBHC amplitudes in the LL+ constant approximation: SM and SUSY contributions

- **SM:** $\eta=0$, $C_{SM} \simeq -5$
- **MSSM:** $\eta=1$, $C_{SM}+C_{SUSY}=C_{MSSM}$
- $C_{MSSM} \simeq -20$
- **SUSY** dependence is fully contained in C_{SUSY} and C_{MSUSY}
- Imaginary parts develop, increasing like **ln(s)**. They are always much smaller than the corresponding Real parts.

$$
\begin{aligned}
F_{----} \simeq & \frac{eg_s}{\sqrt{2}s_W}\left(\frac{\lambda^a}{2}\right)\frac{2}{\cos\frac{\theta}{2}}\Big\{1 \\
+ & \frac{\alpha}{4\pi}\frac{(1+26c_W^2)}{36s_W^2c_W^2}\left[3\ln\frac{s}{m_Z^2} - \eta\ln\frac{s}{M_{SUSY}^2} - \ln^2\frac{-s-i\epsilon}{m_Z^2}\right] \\
- & \frac{\alpha}{4\pi s_W^2}\ln^2\frac{-s-i\epsilon}{m_W^2} - \frac{\alpha}{4\pi}\Big[\frac{(1-10c_W^2)}{36s_W^2c_W^2}\Big(\ln^2\frac{-t}{m_Z^2} - \ln^2\frac{-s-i\epsilon}{m_Z^2}\Big) \\
+ & \frac{1}{2s_W^2}\Big(\ln^2\frac{-u}{m_Z^2} + \ln^2\frac{-u}{m_W^2} - \ln^2\frac{-s-i\epsilon}{m_Z^2} - \ln^2\frac{-s-i\epsilon}{m_W^2}\Big)\Big] \\
+ & \frac{\alpha}{4\pi}[C_{SM} + \eta C_{SUSY}]\Big\},
\end{aligned}
$$

$$
\begin{aligned}
F_{-+-+} \simeq & \frac{eg_s}{\sqrt{2}s_W}\left(\frac{\lambda^a}{2}\right)2\cos\frac{\theta}{2}\Big\{1 \\
+ & \frac{\alpha}{4\pi}\frac{(1+26c_W^2)}{36s_W^2c_W^2}\left[3\ln\frac{s}{m_Z^2} - \eta\ln\frac{s}{M_{SUSY}^2} - \ln^2\frac{-s-i\epsilon}{m_Z^2}\right] \\
- & \frac{\alpha}{4\pi s_W^2}\ln^2\frac{-s-i\epsilon}{m_W^2} - \frac{\alpha}{4\pi}\Big[\frac{(1-10c_W^2)}{36s_W^2c_W^2}\Big(\ln^2\frac{-t}{m_Z^2} - \ln^2\frac{-s-i\epsilon}{m_Z^2}\Big) \\
+ & \frac{1}{2s_W^2}\Big(\ln^2\frac{-u}{m_Z^2} + \ln^2\frac{-u}{m_W^2} - \ln^2\frac{-s-i\epsilon}{m_Z^2} - \ln^2\frac{-s-i\epsilon}{m_W^2}\Big)\Big] \\
+ & \frac{\alpha}{4\pi}[C_{SM} + \eta C_{SUSY}]\Big\},
\end{aligned}
$$



C_{SM} and C_{MSSM} are roughly model independent; (at least in the considered benchmarks). The full SUSY effect is described by M_{SUSY} very accurately.

Helicity Conservation seems approximately correct at the LHC range, strongly reducing the number of independent helicity amplitudes.

Universality arguments allows the calculation of the 1-loop leading log amplitudes, in terms of the very few helicity conserving Born ones.

The relevant subprocesses for W$^{\pm}$+jet distribution at LHC

$$W^{+} \Rightarrow \quad ug \to dW^{+} \;,\; \bar{d}g \to \bar{u}W^{+} \;,\; \bar{d}u \to gW^{+} \frac{\partial^2 \Omega}{\partial u^2}$$

$$W^{-} \Rightarrow \quad \bar{u}g \to \bar{d}W^{-} \;,\; dg \to uW^{-} \;,\; d\bar{u} \to gW^{-}$$

They are calculated by applying crossing and CP to the ug→dW^{+} squared amplitudes

$$R_I(s,t,u) = \sum_{\lambda_g \lambda_W \lambda_u \lambda_d} |F_{\lambda_u \lambda_g \lambda_d \lambda_W}|^2 \quad ,$$

$$\frac{d\hat{\sigma}(ug \to dW^{+})}{dp_T} = \frac{p_T}{768\pi s\,|t-u|}\left[R_I|_{\theta} + R_I|_{\pi-\theta}\right]$$

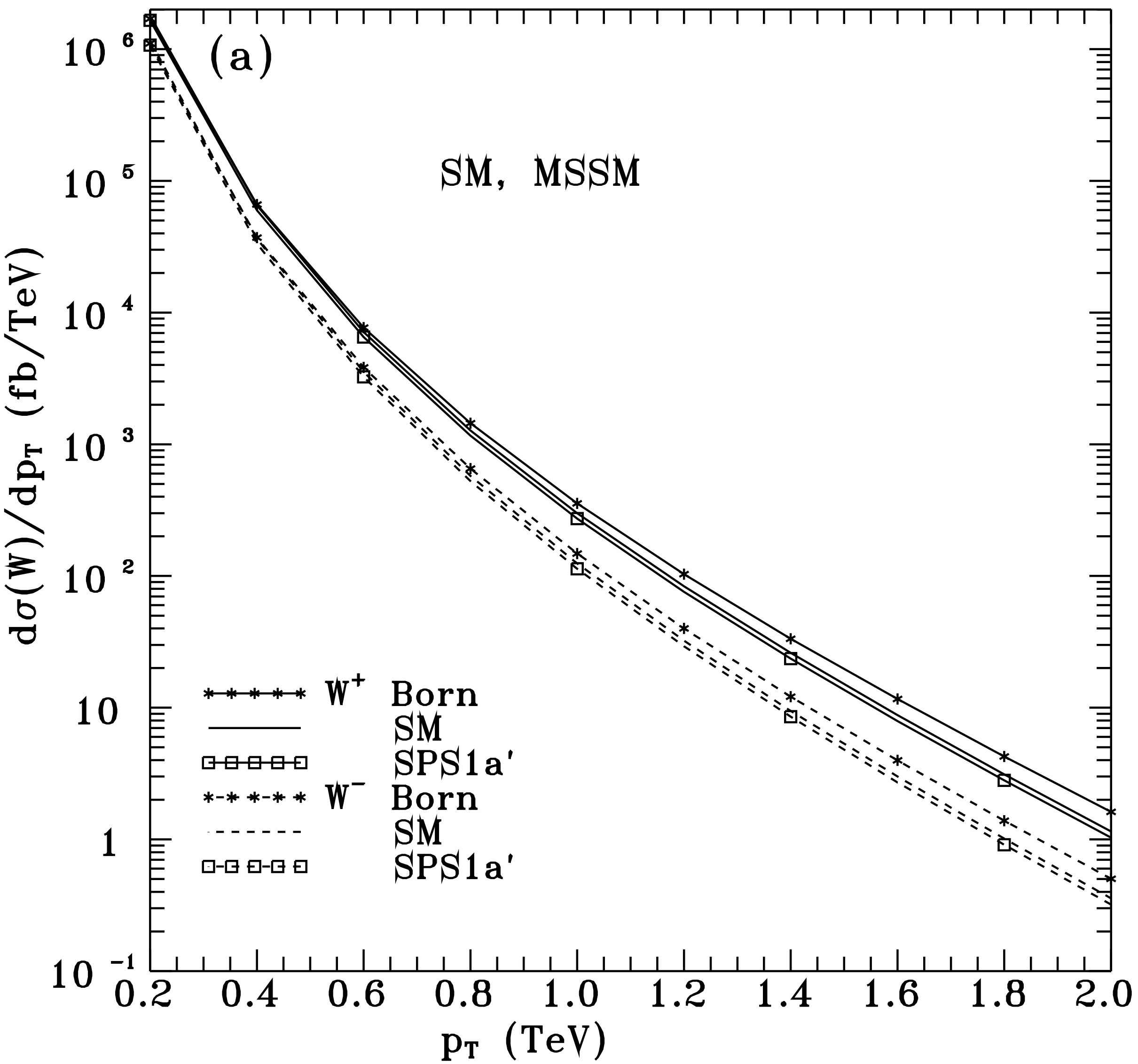
The remaining subprocesses are then given by

$$\frac{d\hat{\sigma}(\bar{d}g \to \bar{u}W^{+})}{dp_T} = \frac{p_T}{768\pi s\,|t-u|}\left[R_{II}\,|_{\theta} + R_{II}\,|_{\pi-\theta}\right],$$

$$R_{II} = R_I(u,t,s) \quad ,$$

$$\frac{d\hat{\sigma}(\bar{d}u \to gW^{+})}{dp_T} = \frac{p_T}{288\pi s\,|t-u|}\left[R_{III}\,|_{\theta} + R_{III}\,|_{\pi-\theta}\right],$$

$$R_{III} = R_I(t,s,u) \quad ,$$



EW SM and MSSM 1-loop corrections to the W+jet production at LHC.

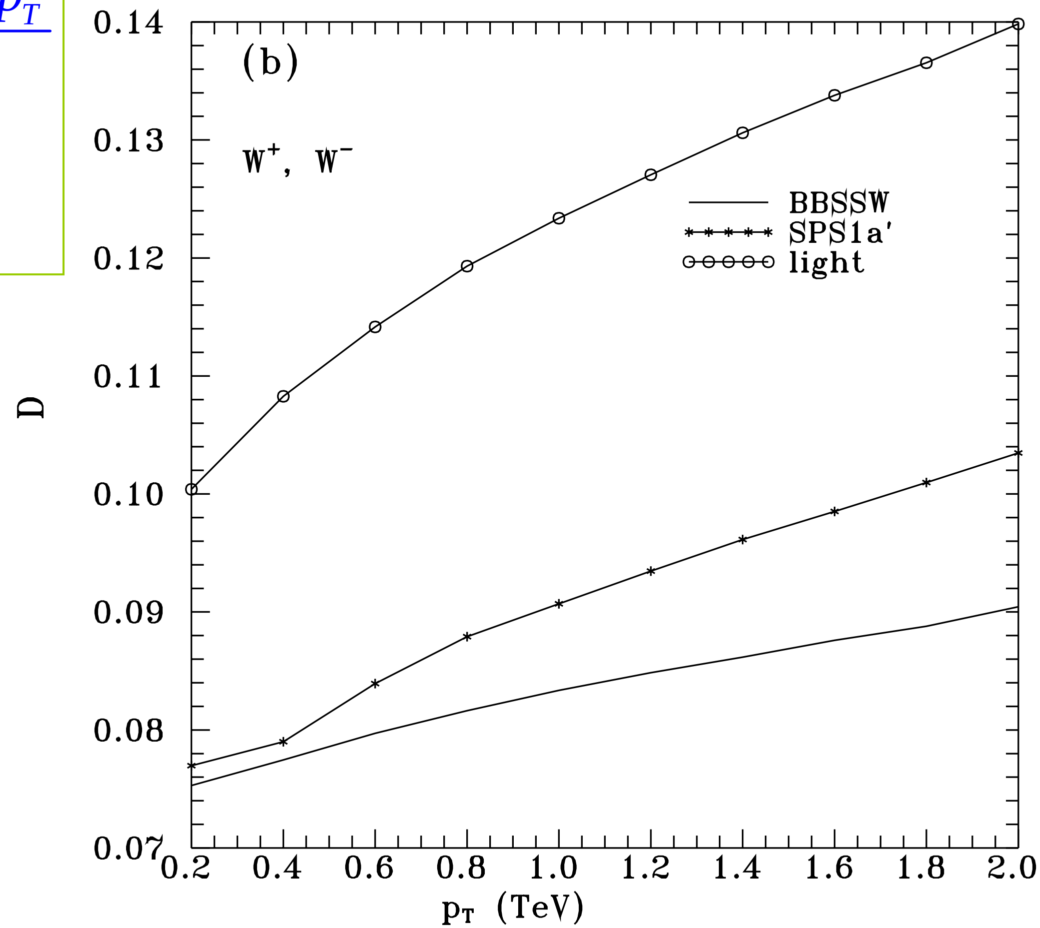
Infrared divergences are regularized by imposing $m_\gamma = m_Z$

Infrared and QCD corrections must be included in a real measurement.

$$D = \frac{d\sigma^{SM}(W^+)/dp_T - d\sigma^{MSSM}(W^+)/dp_T}{d\sigma^{SM}(W^+)/dp_T} = \frac{d\sigma^{SM}(W^-)/dp_T - d\sigma^{MSSM}(W^-)/dp_T}{d\sigma^{SM}(W^-)/dp_T}$$

The SUSY reduction, compared to the SM contributions, is of the order of 10%.

Similar effects may be expected also in models involving extra gauge bosons or extra large dimensions…



Conclusions on identifying SUSY at LHC

- **Helicity Conservation is a striking SUSY property which strongly reduces the number of independent amplitudes.**
- **If present benchmarks are not far off, HC may be acting already at LHC energies.**
- **W+jet production offers a way to study virtual SUSY effects. Virtual and real SUSY effects should be considered together.**