Angular distributions in top decay

A probe of new physics and top-polarization

at

Physics at TeV Colliders

23 June, 2009

Ecole de Physique, Les Houches

by

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Lehrstuhl für Theoretische Physik II, Universität Würzburg, Germany

top-quark : A looking glass

The mass of the top-quark is very large ($m_t \sim 175$ GeV)

- its decay width ($\Gamma_t \sim 1.5$ GeV) is much larger than the typical scale of hadronization, i.e. it decays before getting hadronized. The spin information of top-quark is translated to the decay distribution.

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We have a clean looking glass for new physics.

Anomalous t-decay

Anomalous tbW vertex :

$$\Gamma^{\mu} = \frac{g}{\sqrt{2}} \left[\gamma^{\mu}(f_{1L} P_L + f_{1R} P_R) - \frac{i\sigma^{\mu\nu}}{m_W} (p_t - p_b)_{\nu} (f_{2L} P_L + f_{2R} P_R) \right]$$

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$$\frac{1}{\Gamma_t}\frac{d\Gamma_t}{d\cos\theta_f} = \frac{1}{2}\Big(1 + \alpha_f\ P_t\ \cos\theta_f\Big)$$

$$\alpha_l = 1 - \mathcal{O}(f_i^2)$$

$$\alpha_b = -\left[\frac{m_t^2 - 2m_W^2}{m_t^2 + 2m_W^2}\right] + \Re(f_{2R})\left[\frac{8m_t m_W(m_t^2 - m_W^2)}{(m_t^2 + 2m_W^2)^2}\right] + \mathcal{O}\left(\frac{m_b}{m_W}, f_i^2\right)$$

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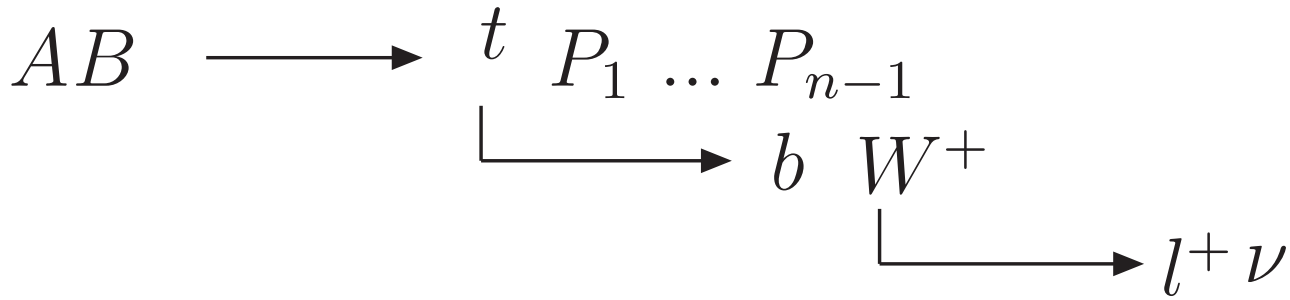
The full quadratic contribution is being calculated by:
Eduard Boos, Viacheslav Bunichev, Maxim Kiryushin

Lepton distribution

JHEP **0612**, 021 (2006), [hep-ph/0605100]



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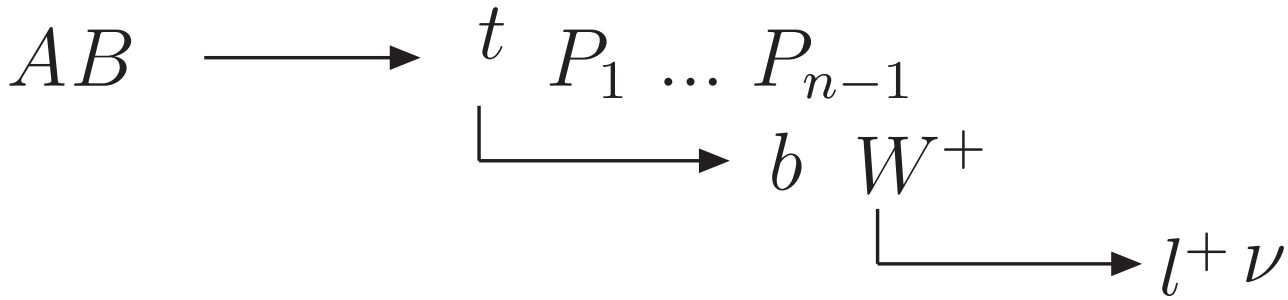

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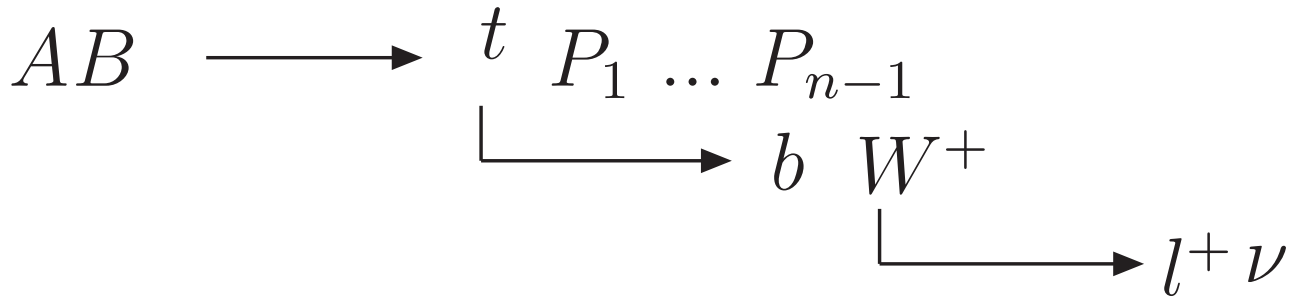

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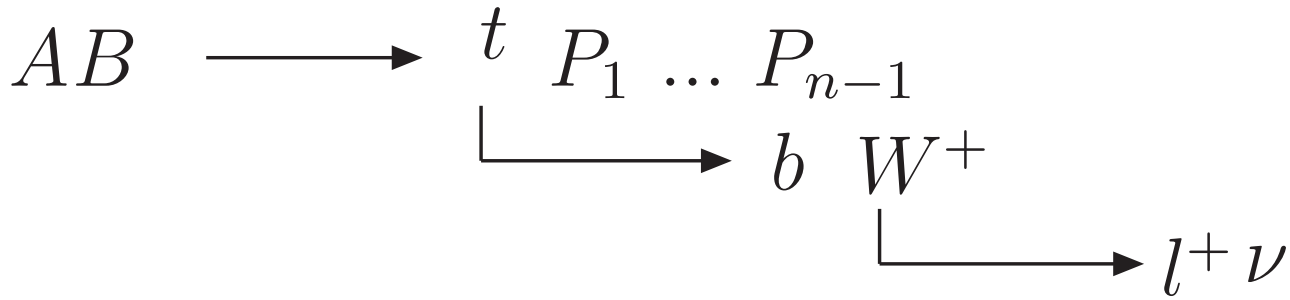

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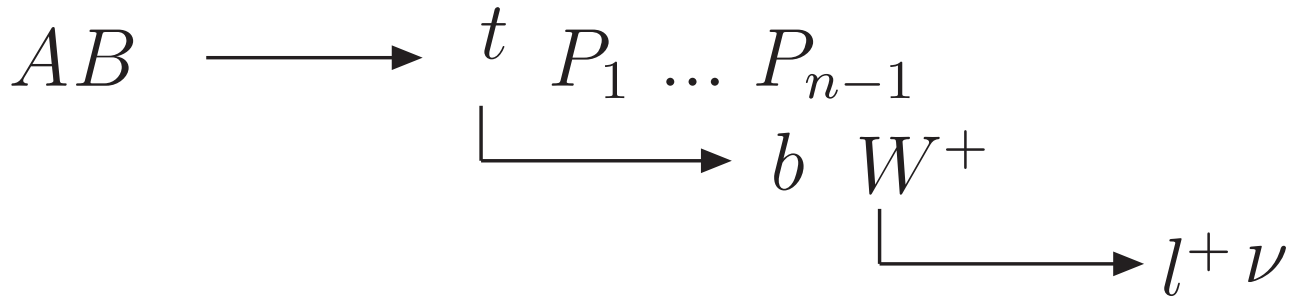

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- anomalous couplings $f_{1R},\ f_{2R}$ and f_{2L} are small,
- narrow-width approximation for W-boson,
- b-quark is mass-less,
- $t \to bW(\ell\nu_\ell)$ is the only decay channel for t-quark.

Polarization of t-quark: top-down

Polarized cross-sections :

$$\int \frac{d^3p_t}{2E_t(2\pi)^3}\left(\prod_{i=1}^{n-1}\frac{d^3p_i}{2E_i(2\pi)^3}\right)\ \frac{(2\pi)^4}{2I}\rho(\lambda,\lambda')\ \delta^4\left(k_A+k_B-p_t-\left(\sum_{i=1}^{n-1}p_i\right)\right)=\sigma(\lambda,\lambda').$$

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Polarization density matrix :

$$P_t=\frac{1}{2}\begin{pmatrix}1+\eta_3 & \eta_1-i\eta_2\\ \eta_1+i\eta_2 & 1-\eta_3\end{pmatrix},$$

$$\begin{aligned}\eta_3 &= (\sigma(+,+)-\sigma(-,-))/\sigma_{tot}\\ \eta_1 &= (\sigma(+,-)+\sigma(-,+))/\sigma_{tot}\\ i\,\eta_2 &= (\sigma(+,-)-\sigma(-,+))/\sigma_{tot}\end{aligned}$$

Polarization of t-quark: bottom-up

Polarization of t-quark through decay asymmetries:

$$\alpha_b = -0.4$$

$$\alpha_l = +1.0$$

$$\alpha_f \frac{\eta_3}{2} = \frac{\sigma(p_f.s_3 < 0) - \sigma(p_f.s_3 > 0)}{\sigma(p_f.s_3 < 0) + \sigma(p_f.s_3 > 0)}$$

$$\alpha_f \frac{\eta_2}{2} = \frac{\sigma(p_f.s_2 < 0) - \sigma(p_f.s_2 > 0)}{\sigma(p_f.s_2 < 0) + \sigma(p_f.s_2 > 0)}$$

$$\alpha_f \frac{\eta_1}{2} = \frac{\sigma(p_f.s_1 < 0) - \sigma(p_f.s_1 > 0)}{\sigma(p_f.s_1 < 0) + \sigma(p_f.s_1 > 0)}$$

$s_i.s_j = -\delta_{ij} \qquad p_t.s_i = 0$

For $p_t^\mu = E_t(1, \beta_t \sin\theta_t, 0, \beta_t \cos\theta_t)$, we have

$s_1^\mu = (0, -\cos\theta_t, 0, \sin\theta_t),\ s_2^\mu = (0, 0, 1, 0),\ s_3^\mu = E_t(\beta_t, \sin\theta_t, 0, \cos\theta_t)/m_t.$

`Ptlong` is implemented in SHERPA.

Polarization of t-quark: Reconstruction

η_2 : transverse polarization normal to the production plane.

Simplest quantity to measure;

requires reconstruction of t-production plane;

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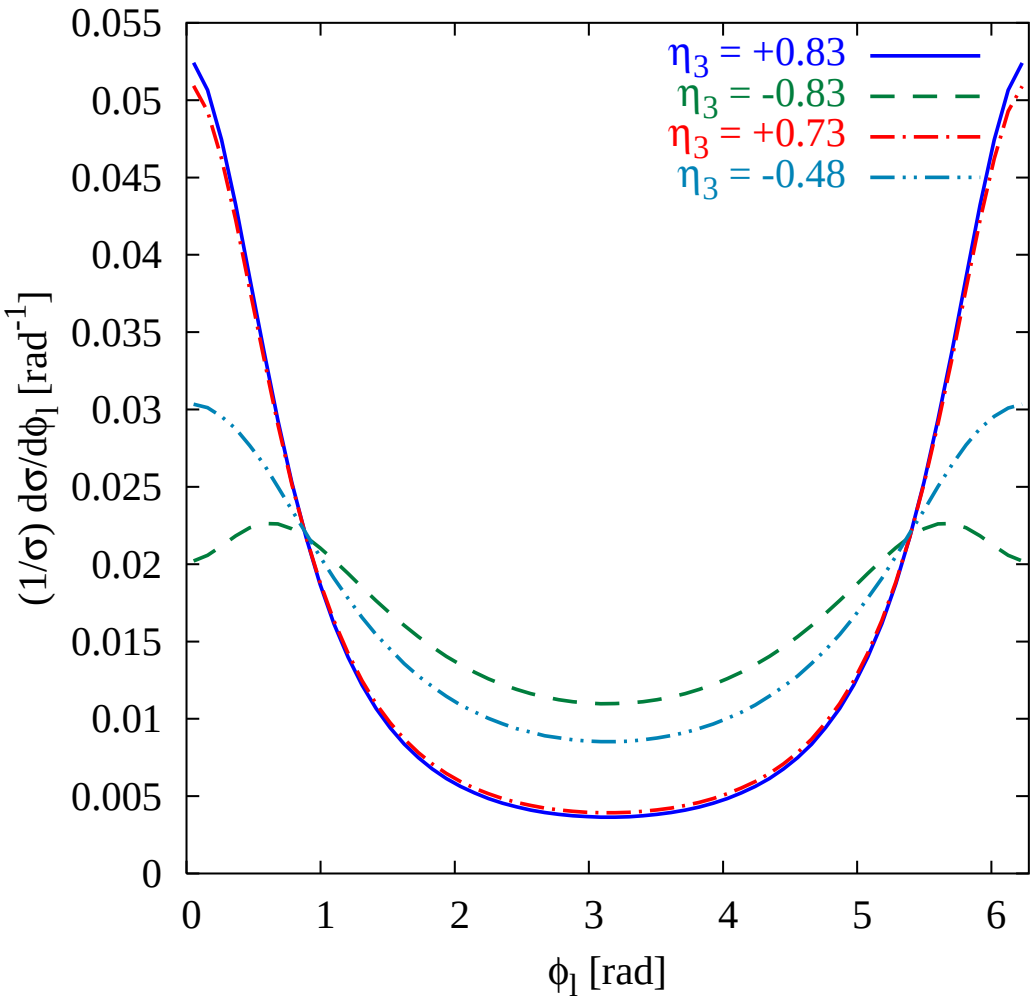
Energy and angular distribution of leptons in lab frame can be used as a measure of the t-polarization.

Polarization estimation: Φ_ℓ

Lab frame azimuthal distribution of leptons: (JHEP **0612**, 021 (2006))



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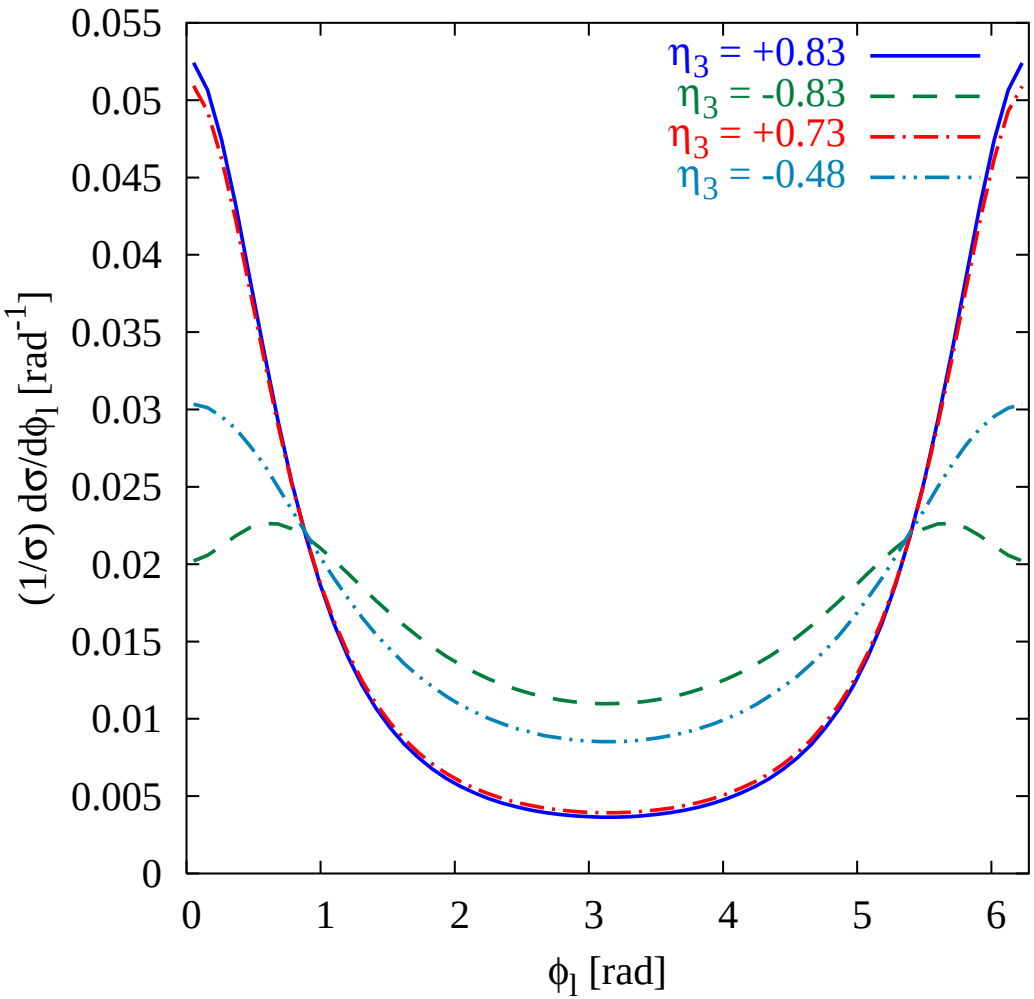

$$A_\ell = \frac{\sigma(\cos\phi_l > 0) - \sigma(\cos\phi_l < 0)}{\sigma(\cos\phi_l > 0) + \sigma(\cos\phi_l < 0)}$$

Used for:

- Z' at LHC (Les Houches 05)
- $g^{(1)}$ in RS model at LHC (Nucl. Phys. **B797**, 1, (2008))

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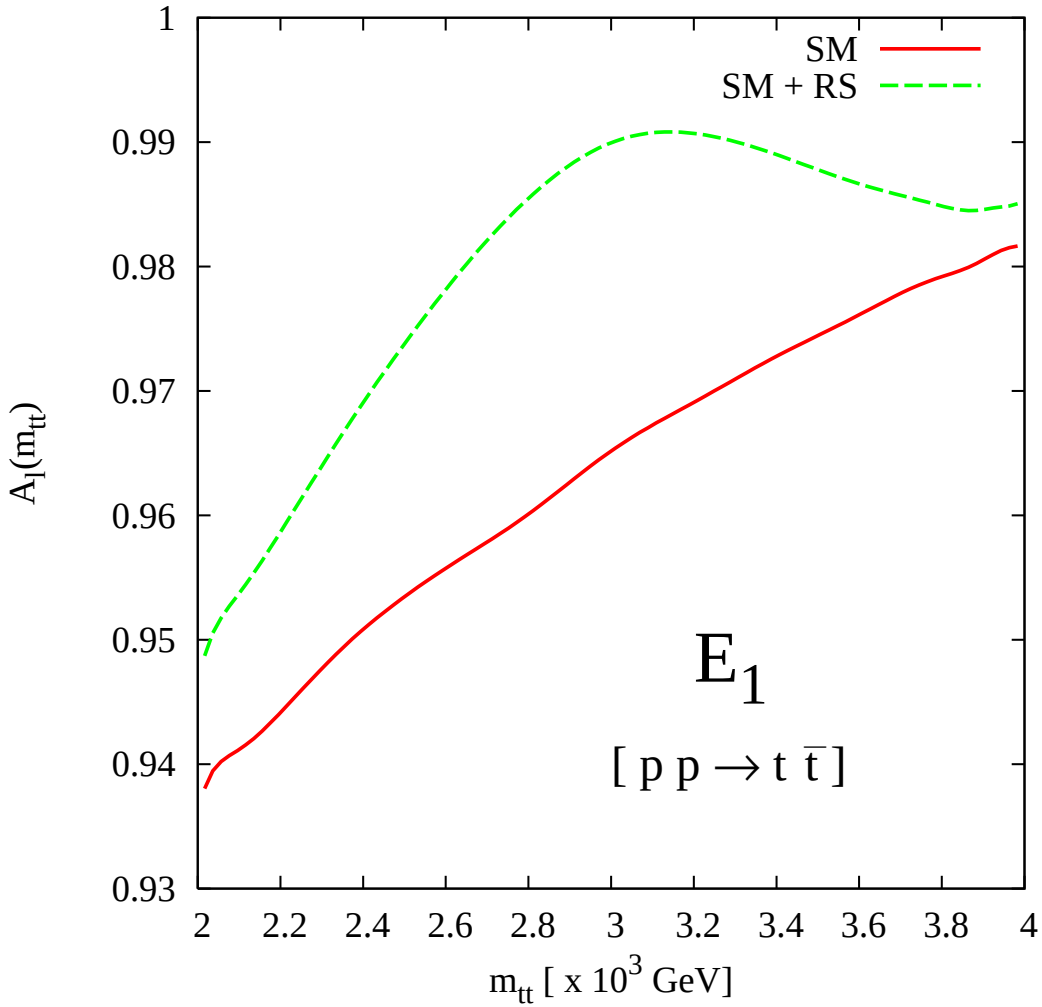

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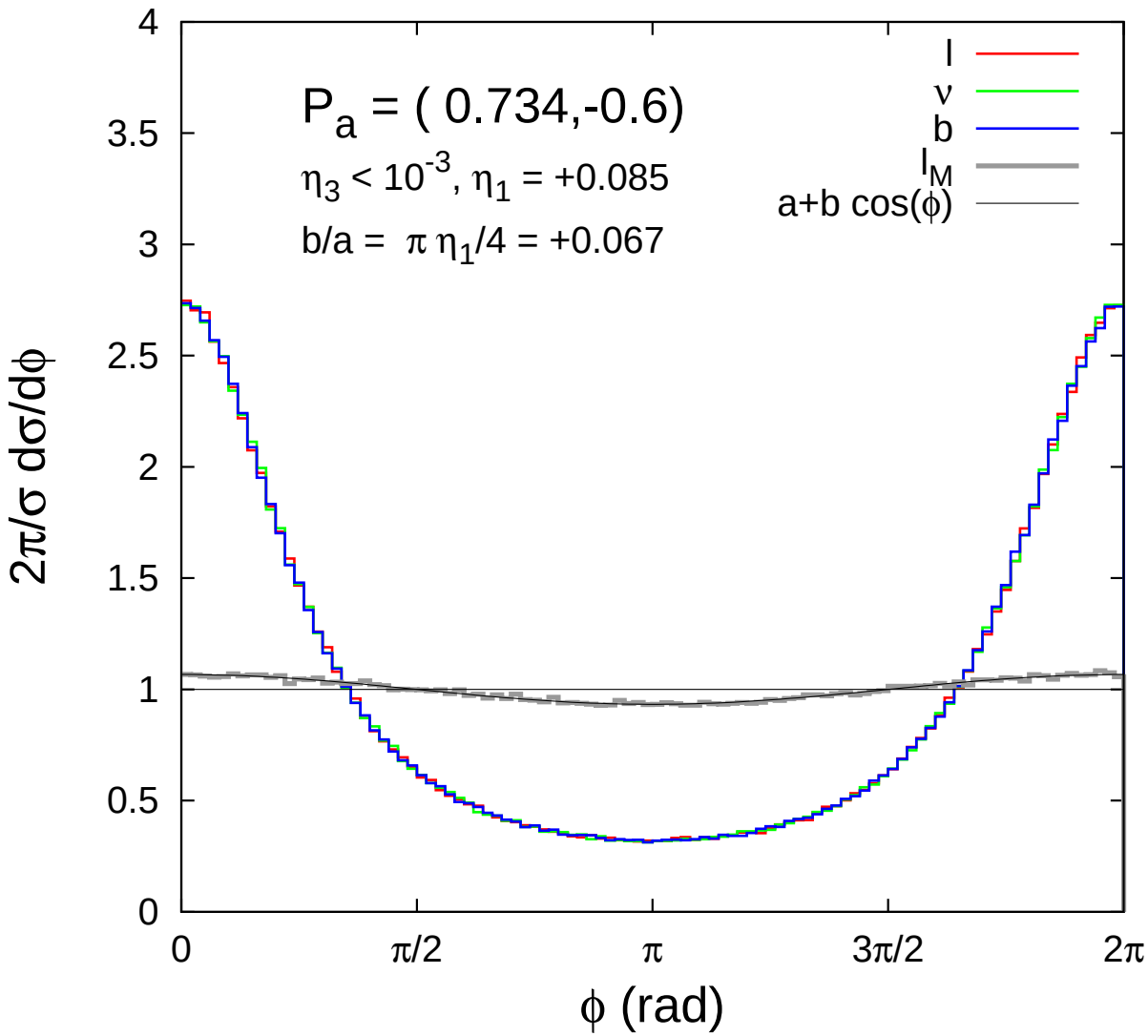

$$\Delta = \left| \frac{d\sigma}{d\phi_l} - \frac{d\sigma}{d\phi_b} \right|$$

Depends upon:

- Top polarization
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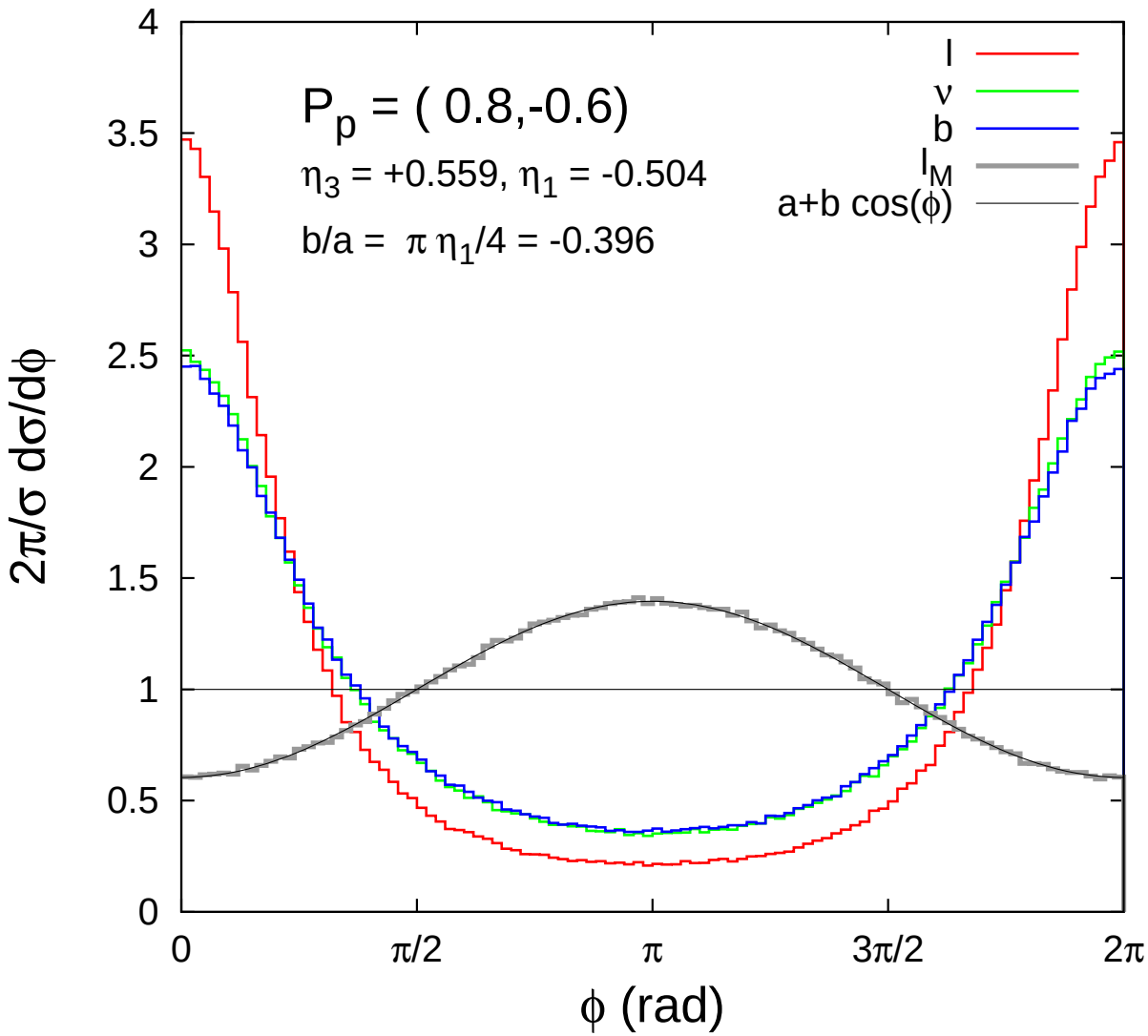

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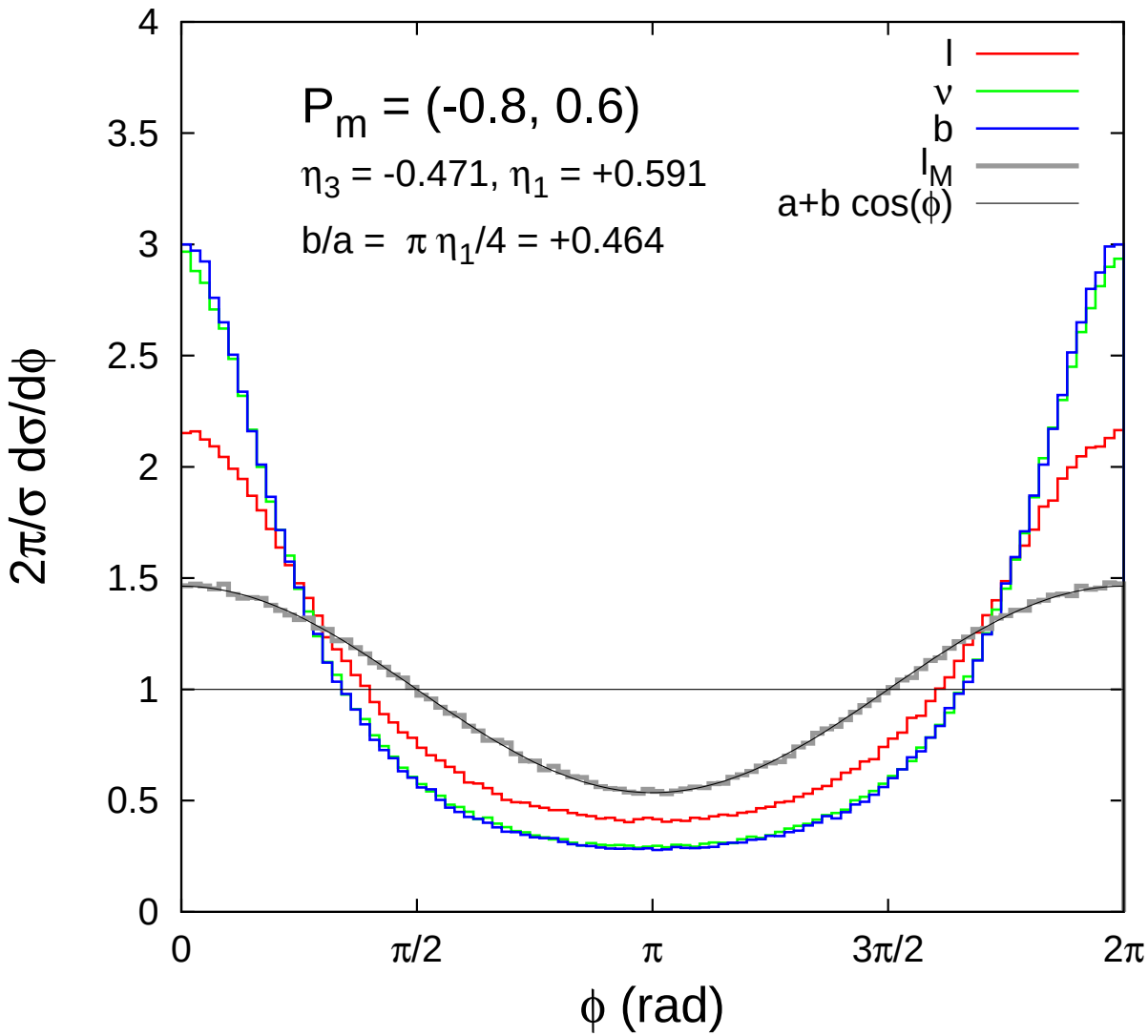

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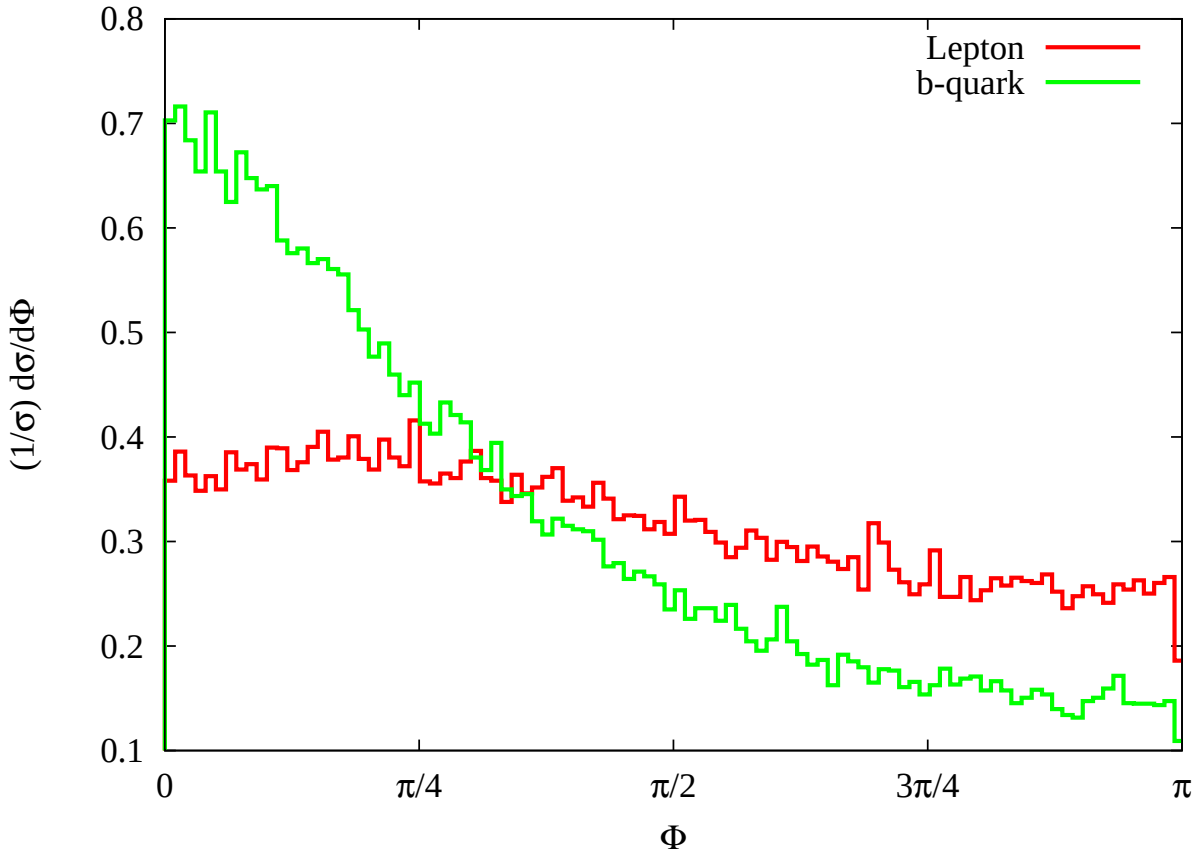
Next we look at LHC examples.

LHC: $pp \to tj \to bl^+\nu_l\, j$



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$\sigma = 14.6$ pb

$\eta_3 = -0.196$

Model: SM

Cuts: No cuts

"Partial" analysis with anomalous tbW coupling at D0

Phys. Rev. Lett. **102**, 092002 (2009)

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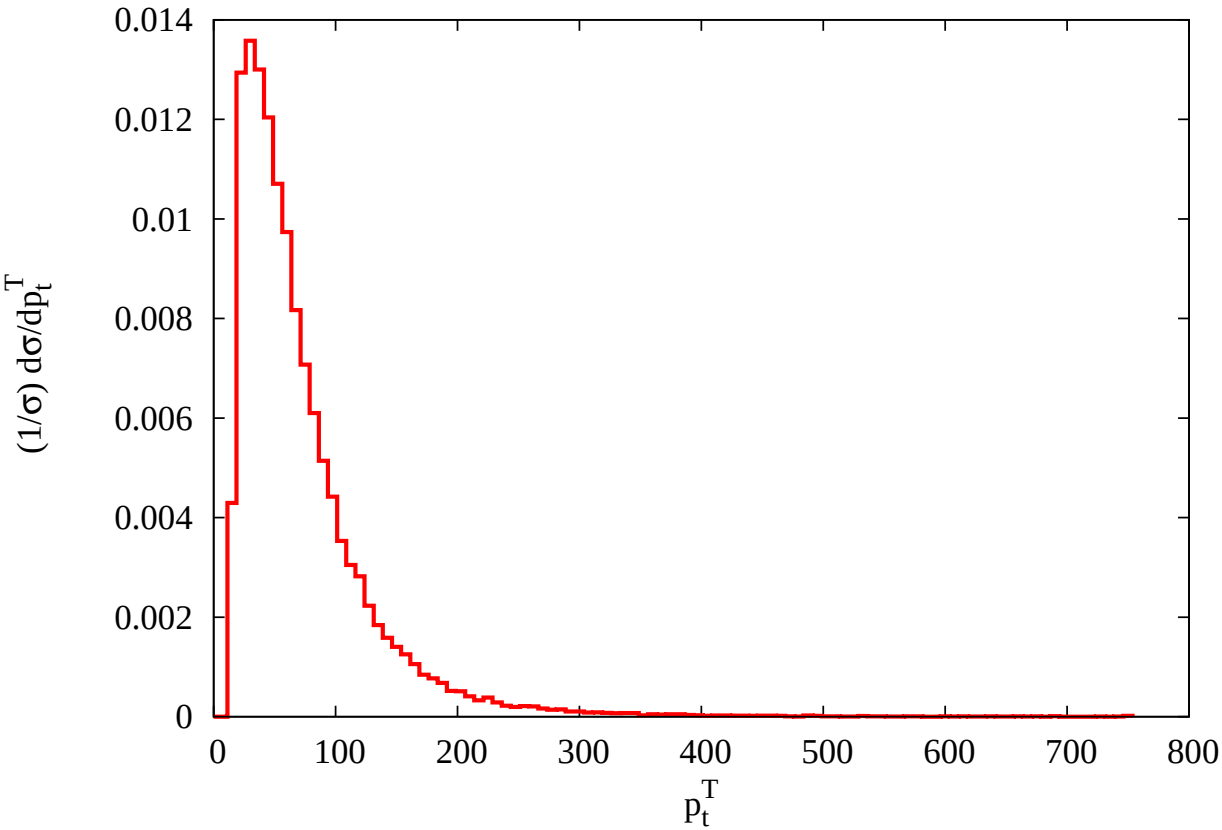

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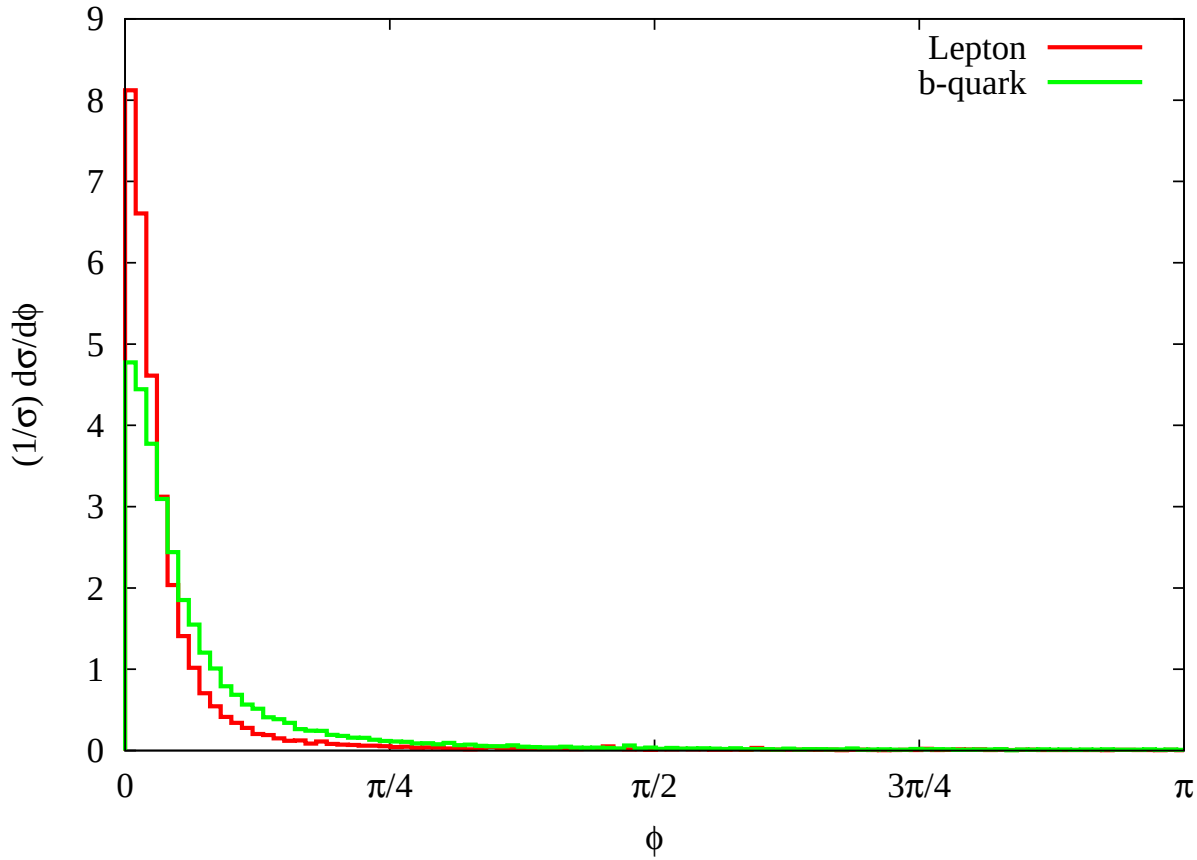

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$M_g = 3000$ GeV, $\Gamma_g = 500$ GeV

$C_L^t = 1.118$, $C_R^t = 5.201$

Cuts: $m_{t\bar{t}} := [2500, 3500]$ GeV

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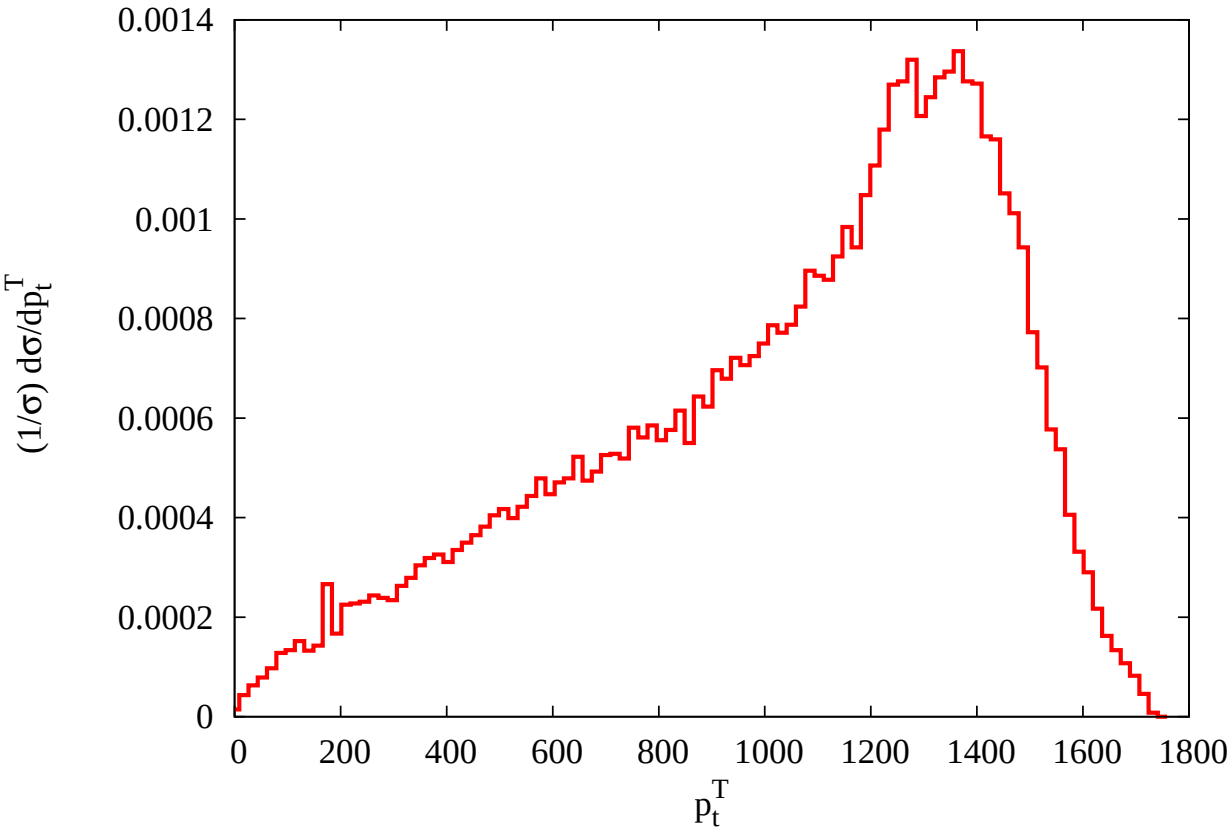

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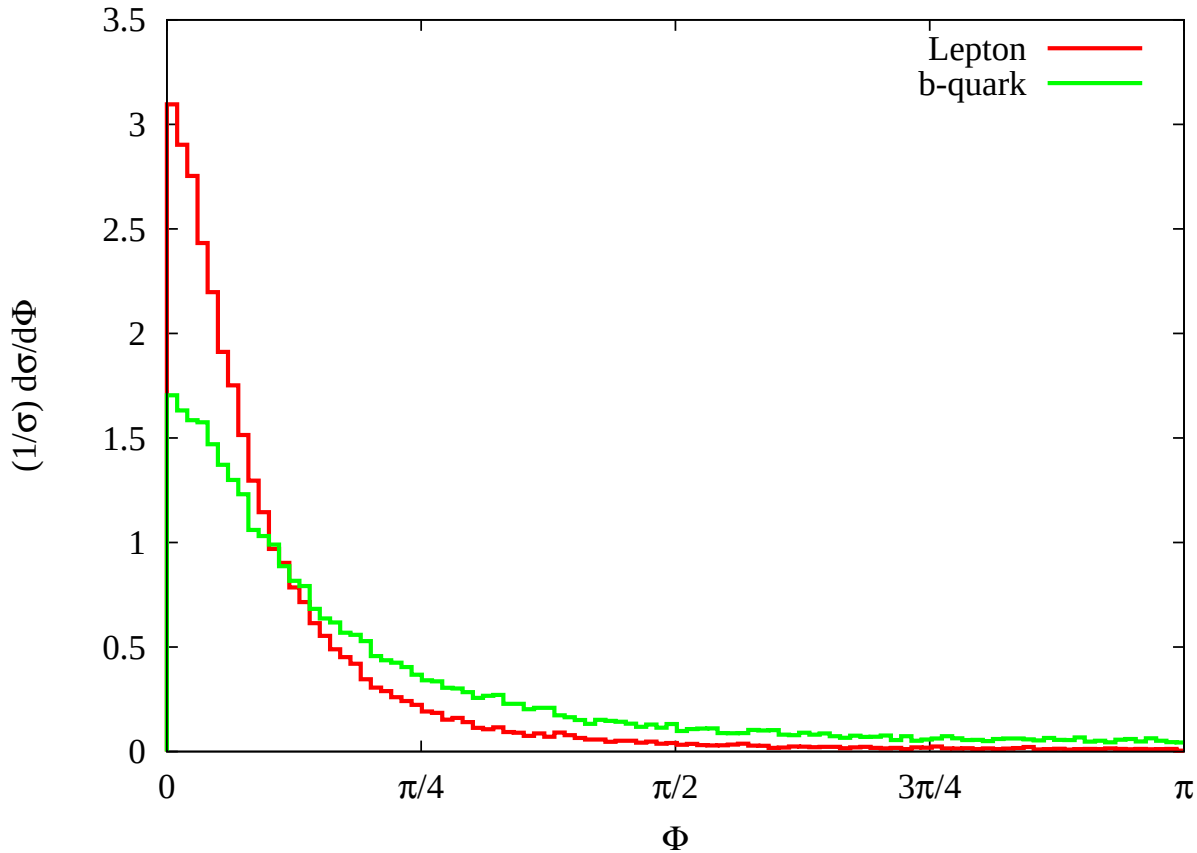

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Cuts: No cuts.

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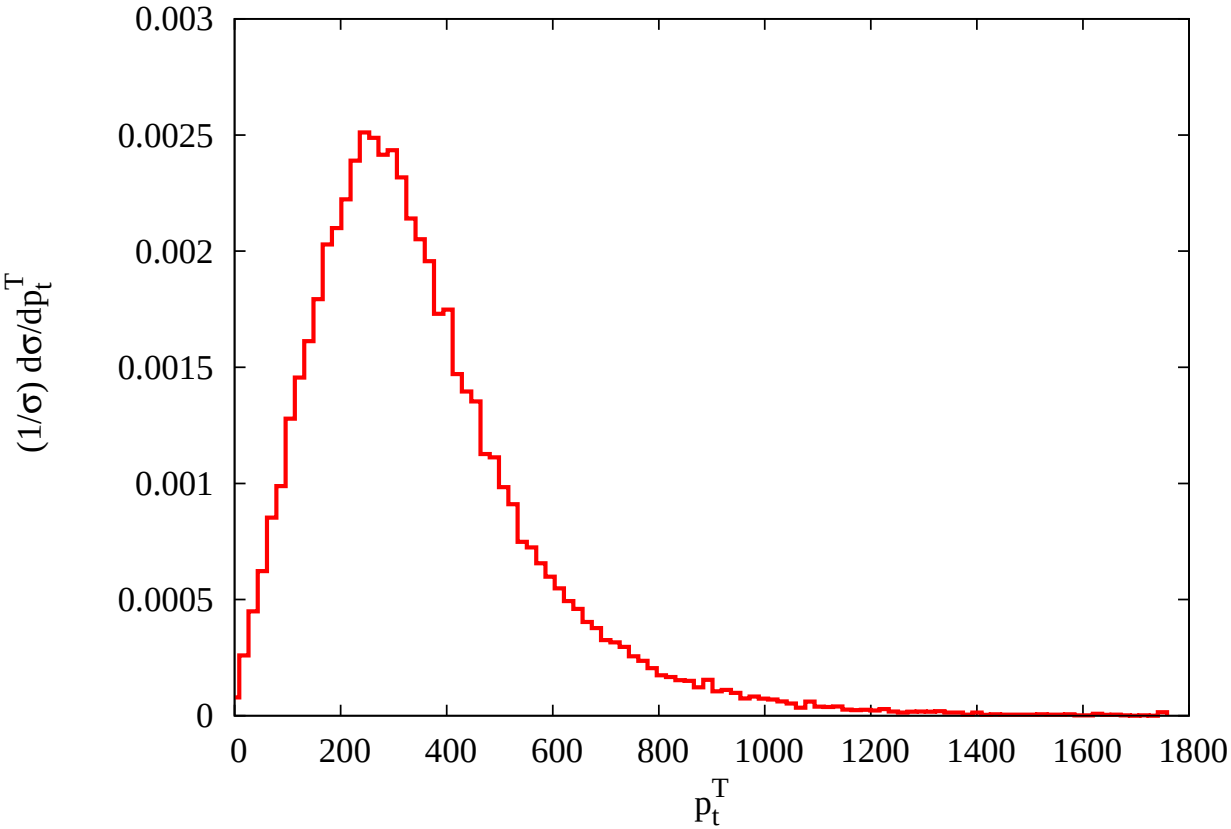

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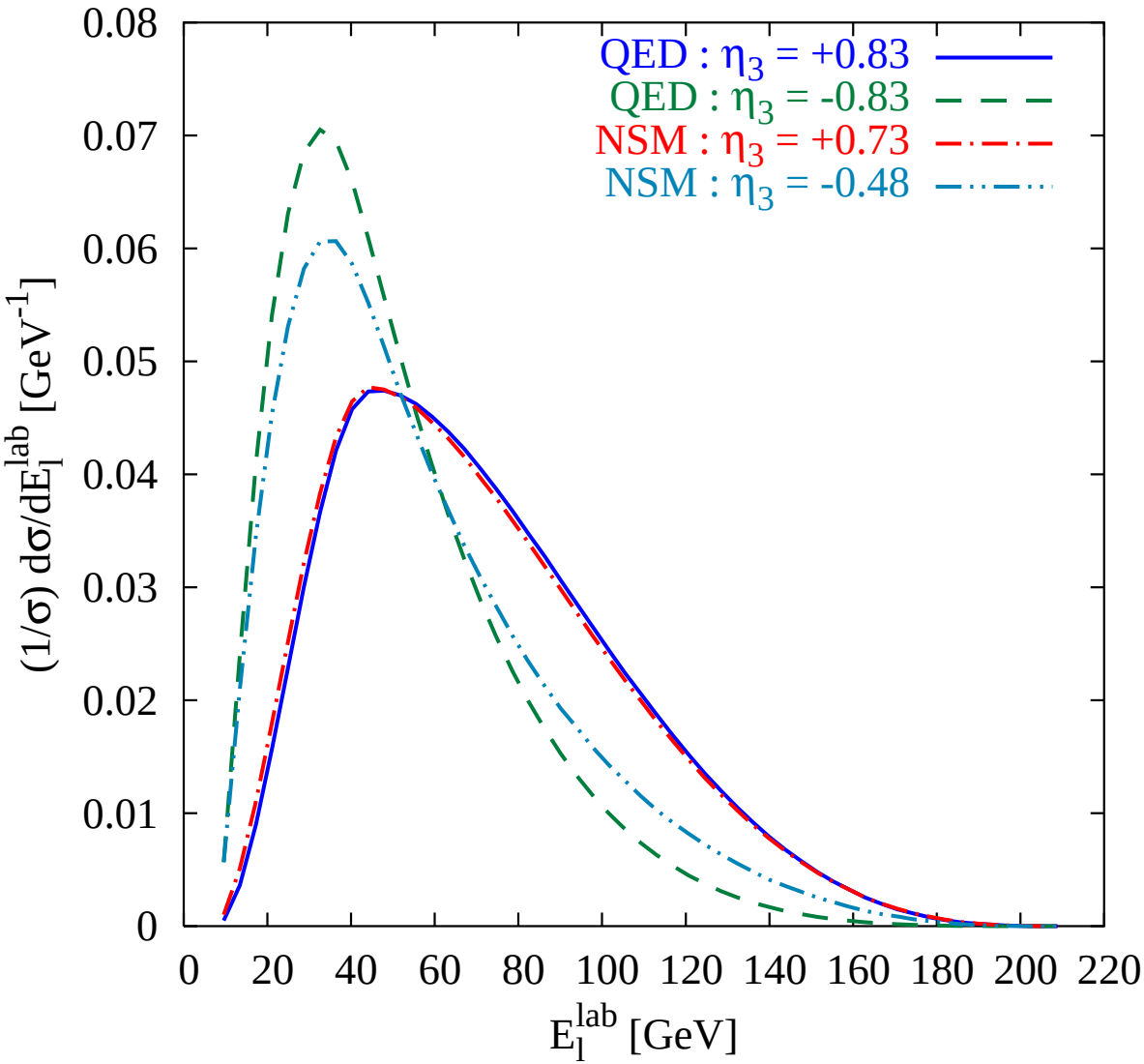
Lab frame energy distribution of leptons:



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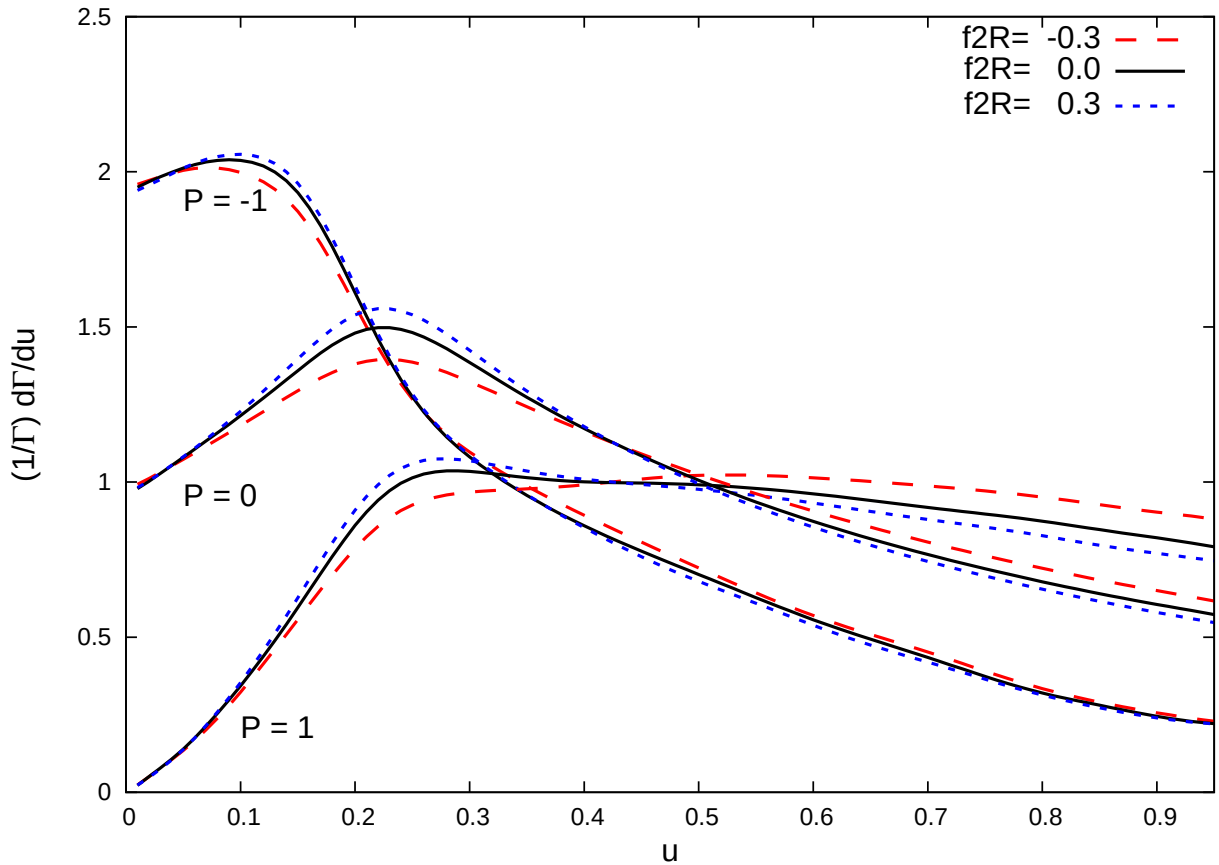
Lepton energy fraction in lab frame $u = E_l/(E_l + E_b)$
Shelton Phys. Rev. D **79**, 014032 (2009)
(Plots from Rohini's talk @TOP09)



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