Direct Test of Time-Reversal Symmetry at the LHC
Feasibilities with LHCb

Z.J. Ajaltouni
Laboratoire de Physique Corpusculaire/CNRS-IN2P3
Université Blaise Pascal-CLERMONT II

with the collaboration of

E. Conte, O. Leitner, E. DiSalvo, M. Jahjah, R. Lefèvre

LPSC, GRENOBLE, September 24-25 (2009)
I— Theoretical Introduction to TIME-REVERSAL.

II— PHENOMENOLOGY of TRV, $\Lambda_b \rightarrow \Lambda V(1^{-})$

III— SIMULATIONS and PERSPECTIVES with LHCb

IV— CONCLUSION
1- Time Reversal Symmetry: Theory and Problems

- 3 Discrete Transformations which are Approximate Symmetries:

  * **PARITY P**: $\vec{r}, \vec{p} \rightarrow -\vec{r}, -\vec{p}$, $\vec{\ell}, \vec{s}$ Unchanged
  * **CHARGE CONJUGATION C**: $Q \rightarrow -Q$, $\vec{r}, \vec{p}, \vec{\ell}, \vec{s}$ Unchanged
  * **TIME REVERSAL, T**: $\vec{r} \rightarrow \vec{r}$, $\vec{p}, \vec{\ell}, \vec{s} \rightarrow$ Opposite Sign

But,

P and C are **Hermitian-Unitary** Operators, while T is an **ANTIUNITARY** Operator

\[ \downarrow \]

NO Real Eigenvalues like P and C

\[ \downarrow \]

\[ \equiv \] NO Intrinsic Quantum Numbers

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Feasibilities with LHCb (page 3)
How Testing Time-Reversal Symmetry?

- Initial State $|i\rangle = |\vec{p}_i, \vec{s}_i\rangle \rightarrow |i^T\rangle = |-\vec{p}_i, -\vec{s}_i\rangle$
- Final State $|f\rangle = |\vec{p}_f, \vec{s}_f\rangle \rightarrow |f^T\rangle = |-\vec{p}_f, -\vec{s}_f\rangle$

* If TR Exact Symmetry $\Rightarrow |<f|S|i\rangle| = |<i^T|S|f^T\rangle|$
* If Equality above Not Verified $\Rightarrow$ Sign of TR VIOLATION !?

But, Main Problem:

* Difficulties to realize experimentally the Reversed Time of any elementary process !?

So,

How to put into evidence any Violation of Time-Reversal Symmetry (TRV) ??

- (1) INDIRECT (TRADITIONAL) WAY:
  CPT Exact Symmetry because of LORENTZ Invariance of QFT.
  If CP Violated $\Rightarrow$ T Violated

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(2) DIRECT WAY:

Looking for T-Odd Observables, like

\[ C_{ijk} = \vec{v}_i \cdot (\vec{v}_j \times \vec{v}_k) \]  with \( \vec{v} = \vec{p} \) or \( \vec{s} \)

\[ C_{ijk} \rightarrow \text{TR} \rightarrow -C_{ijk} \]

Ex: POLARIZATION of Particles with Spin.

Is this last Condition Sufficient ???

\[ \implies \] Existence of the Final State Interactions (FSI) which modify the Scattering Amplitude.

\[ \downarrow \downarrow \downarrow \]

Simulation of TRV effects !?!

In order to test TR Symmetry without Reversing Initial and Final states, we must

(1) Compute with high precision the FSI (including the non-perturbative contribution !?)

(2) or, the FSI could be neglected (Wolfenstein, IJMPE, Vol.8 (1999), 501-511)

Moral of the Story: NO Special Rule for the estimation of the FSI

Direct Test of Time-Reversal Symmetry at the LHC
Feasibilities with LHCb (page 5)
II- PHENOMENOLOGY of TRV

1- Historically $\beta$ Decay

\[ ZX^A \rightarrow Z_{+1}Y^A e^- \bar{\nu}_e \]

• Looking for Correlations between Neutron Spin, $s_n$, and $\vec{p}_e$, $\vec{p}_\nu$.

★ Electromagnetic FSI taken into account (Jackson-Treiman-Wyld, 1957).

★ Differential cross-section :

\[ d\sigma \approx \bar{s}_n \cdot (A\vec{p}_e + B\vec{p}_\nu + D\vec{p}_e \times \vec{p}_\nu) \]

(i) $A$ and $B$ violates Parity .
(ii) $D$, related to Neutron Transverse Polarization, violates TR.

★ Experimental Results ( KEK, 2007 ) : $D \sim 0$ with a high confidence level.

2- $K^0 - \bar{K}^0$ Oscillations ( CP-LEAR, KTEV (1999) )

\[ P(K^0 \rightarrow \bar{K}^0) \neq P(\bar{K}^0 \rightarrow K^0) \]

• First Observation of Direct TRV in Particle Physics

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3- Electric Dipole Moments (EDM)
• \( d_e \neq 0 \) or \( d_n \neq 0 \) \( \implies \) Sign of TRV
• ILL (Grenoble) best placed to provide the most recent results.....

Why \( \Lambda_b \) Decay?

• Search for TRV in Hyperon Weak Decays like \( \Lambda \rightarrow p\pi^- \) where Parity is Violated (R. Gatto, 1958).

If

\[ \implies \text{s-quark is replaced by b-quark} \]

\[ \Lambda \equiv (uds) \iff \Lambda_b \equiv (u db) \]

(1) Important Increase of the Phase Space : \( m_{\Lambda_b}/m_{\Lambda} \approx 5 \)
(2) Both CP and TR could be Tested.
(3) Possible Tests of some specific models beyond the SM : SuperSymmetry, FCNC, LR Symmetric Models, ...

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• "Best Channel": \( \Lambda_b \rightarrow \Lambda J/\psi \) (LEP, CDF) where both \( \Lambda(1/2^+) \) and \( J/\psi(1^-) \) are POLARIZED because of \( \Lambda_b \) Weak Decay.

• What is expected at \( \text{LHCb} \)?

\[ BR(\Lambda_b \rightarrow \Lambda J/\psi) = (4.7 \pm 2.1_{\text{stat}} \pm 1.9_{\text{sys}}) \times 10^{-4} \]

\[ \text{With a mean luminosity } \mathcal{L} \simeq 10^{32} cm^{-2} s^{-1} \text{ for 1 year data taking (} \approx 10^7 \text{ sec }, \text{ we expect:} \]

\[ 10^{12} \ (b\bar{b}) \text{ pairs} \]
\[ \downarrow \]
\[ \approx 9.2\% \text{ of } b-\text{quark hadronize into } \Lambda_b \]
\[ \downarrow \]
\[ \approx 2 \times 10^6 \ \Lambda_b(\bar{\Lambda}_b) \]
• Performing $\Lambda_b \oplus \text{TRV}$ Physics in two Steps:

(1) Constructing **T-Odd** Observables from the Kinematics of the Final Particles: $p, \pi^-, \mu^+, \mu^-$ (O.Leitner, E.Conte, Z.J.A.)

(2) Looking for Polarization-Vectors of the Intermediate Resonances which Transverse Components are T-Odd observables (E.DiSalvo, M.Jahjah, R.Lefèvre, Z.J.A.)

**Kinematics and Dynamics of** $\Lambda_b \rightarrow \Lambda J/\psi$

1- DYNAMICS

• Hadronic Matrix Element (**HME**) computed by the techniques of the Operator Product Expansion, **OPE**.

$$H_{\text{eff}} = \frac{G_F}{\sqrt{2}} V_{qb} V_{qs} \sum_{i=1}^{10} c_i(m_b) O_i(m_b)$$

★ $c_i =$ Wilson Coefficients = Hard Perturbative Contributions
★ $O_i =$ Soft Non-Perturbative Contributions.
• **Factorization Hypothesis** ⇒ \( \text{HME} = \text{Sum of Products of Currents} \)

\[
A(\lambda_1, \lambda_2) = \frac{G_F}{\sqrt{2}} f_{J/\psi} E_{J/\psi} \times \langle \Lambda^0 | \bar{s} \gamma_\mu (1 - \gamma_5) b | \Lambda^0_b \rangle
\]

\[
\times \left\{ V_{cb} V_{cs}^* \left[ C_1 + \frac{C_2}{N_{c,\text{eff}}} \right] - V_{tb} V_{ts}^* \left[ C_3 + C_5 + C_7 + C_9 + \frac{C_4 + C_6 + C_8 + C_{10}}{N_{c,\text{eff}}} \right] \right\}
\]

• **Form-Factors** estimated in the framework of the **HQET** by performing perturbative calculations of order \( O(1/m_b) \).

• **Conservation of the Angular Momentum** :

\[
\downarrow
\]

**FOUR** Helicity Amplitudes :

\[
(\lambda_1, \lambda_2) = \left( \frac{1}{2}, 1 \right), \left( \frac{1}{2}, 0 \right), \left( -\frac{1}{2}, 0 \right), \left( -\frac{1}{2}, -1 \right)
\]

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Feasibilities with LHCb (page 10)
Analytical Expressions of the corresponding four amplitudes given by:

\[
\langle \Lambda^0 | \bar{s} \gamma_\mu (1 - \gamma_5) b | \Lambda^0_b \rangle = \begin{cases} 
- \frac{P_{J/\psi}}{E_{J/\psi}} \left( \frac{m_{\Lambda^0_b} + m_{\Lambda^0}}{E_{\Lambda^0} + m_{\Lambda^0}} \zeta^- + \zeta^+ - \zeta^- \right); & (\lambda_{\Lambda^0}, \lambda_{J/\psi}) = (1) \\
\frac{1}{\sqrt{2}} \left( \frac{P_{J/\psi}}{E_{\Lambda^0} + m_{\Lambda^0}} \zeta^- + \zeta^+ \right); & (\lambda_{\Lambda^0}, \lambda_{J/\psi}) = (2) \\
\frac{1}{\sqrt{2}} \left( \frac{P_{J/\psi}}{E_{\Lambda^0} + m_{\Lambda^0}} \zeta^- - \zeta^+ \right); & (\lambda_{\Lambda^0}, \lambda_{J/\psi}) = (3) \\
\left( \zeta^+ + \frac{P_{J/\psi}^2}{E_{J/\psi} (E_{J/\psi} + m_{\Lambda^0})} \zeta^- \right); & (\lambda_{\Lambda^0}, \lambda_{J/\psi}) = (4)
\end{cases}
\]

\[\star \zeta^+ \text{ and } \zeta^- \text{ are the corresponding Form-Factors.}\]

\[
\text{• } N_C \text{ can vary in the range } [2, 3] \text{ in order to take account of the Non-Perturbative effects.}
\]
At $90\%$ CL $\Rightarrow 2.1 \leq N_C^{eff} \leq 2.7$
2- KINEMATICS

- Use of the Helicity Formalism of Jacob-Wick-Jackson.

\* TRANSVERSE Frame for the Decay $\Lambda_b \rightarrow \Lambda J/\psi$

→ Quantization Axis being Normal to the $\Lambda_b$ Decay Plane.

\[
\begin{align*}
OX \parallel \vec{p}_{\text{proton}}, \\
OZ = \frac{\vec{p}_{\text{proton}} \times \vec{p}_{\Lambda_b^0}}{|\vec{p}_{\text{proton}} \times \vec{p}_{\Lambda_b^0}|}, \\
OY = OZ \times OX \quad (2)
\end{align*}
\]

\* HELICITY Frame for each Resonance Decay.

→ Quantization Axis being parallel to the Resonance momentum, $p_{\Lambda}$, $p_{J/\psi}$, in the $\Lambda_b$ rest-frame.

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Feasibilities with LHCb (page 13)
Figure 1: $\Lambda_b$ in the Standard LHCb Frame
Figure 2: $\Lambda_b$ Transversity Rest-Frame

Direct Test of Time-Reversal Symmetry at the LHC

Feasibilities with LHCb (page 15)
Figure 3: From $\Lambda_b$ rest-frame to $\Lambda$ Helicity rest-frame
Figure 4: Λ Helicity Rest-Frame
Figure 5: $J/\psi$ Helicity Rest-Frame
According to our Phenomenological Model, all the parameters entering into the 3 Decays:

\[ \Lambda_b \rightarrow \Lambda J/\psi \ , \ \Lambda \rightarrow p\pi^- \ , \ J/\psi \rightarrow \mu^+ \mu^- \]

can be determined, like:

- Asymmetry Parameter, \( \alpha_{\Lambda b}^{\Lambda s} \)
- Spin Density Matrices: \( \rho^\Lambda , \rho^V \)
- Polarizations: \( \mathcal{P}^\Lambda , \mathcal{P}^V \)
Main Results:

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>$\alpha_{AS}^{\Lambda_b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda J/\psi$</td>
<td>49.0%</td>
</tr>
<tr>
<td>$\Lambda \rho^0$</td>
<td>19.4%</td>
</tr>
</tbody>
</table>

Table 1: Asymmetry Parameter of the $\Lambda_b$

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>$P^\Lambda$</th>
<th>$\rho_{+-}^\Lambda$</th>
<th>$\rho_0^V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda J/\psi$</td>
<td>-0.17</td>
<td>0.25</td>
<td>0.66</td>
</tr>
<tr>
<td>$\Lambda \rho^0$</td>
<td>-0.21</td>
<td>0.31</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Table 2: Long. Polarizations and SDM main elements

$\rho_0^V = \text{Probability of the Vector-Meson to be Longitudinally Polarized}$

$\implies$ All the Angular Distributions in the different frames can be computed.
\[ \Lambda_b \rightarrow \Lambda V(1^-) \]

\[
\frac{d\sigma}{d\Omega} \propto 1 + \alpha_{AS}^\Lambda b \mathcal{P}^\Lambda b \cos \theta + 2\alpha_{AS}^\Lambda b \Re(\rho_{+}^\Lambda b \exp i\phi) \sin \theta .
\] (3)

\[ \Lambda \rightarrow p\pi^- \]

\[
\frac{d\sigma}{d\Omega_1} \propto \left\{ 1 + \alpha_{AS}^\Lambda \mathcal{P}^\Lambda \cos \theta_1 - \frac{\pi}{2} \mathcal{P}^\Lambda b \alpha_{AS}^\Lambda \Re\left[ \rho_{+}^\Lambda \exp (i\phi_1) \right] \sin \theta_1 \right\} ,
\] (4)

\[ J/\psi \rightarrow \mu^+\mu^- , \ \rho^0 \rightarrow \pi^+\pi^- \]

\[
\frac{d\sigma}{d\cos \theta_2} \propto (1 - 3\rho_0^V)\cos^2 \theta_2 + (1 + \rho_0^V) ,
\] (5)

\[
\frac{d\sigma}{d\cos \theta_2} \propto (3\rho_0^V - 1)\cos^2 \theta_2 + (1 - \rho_0^V) ,
\] (6)

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Feasibilities with LHCb  (page 21)
III- SIMULATIONS and PERSPECTIVES with LHCb

- Calculations implemented in the Generator Code of LHCb, EvtGen
- Full Simulations of the LHCb Detector.

- Main Systematic Effects: $\Lambda$, $\bar{\Lambda}$ Absorption by the detector material

$$ S = \mathcal{L}_{\text{int}}^{\text{year}} \times \sigma(pp \rightarrow b\bar{b}) \times 2 \, \mathcal{P}(b \rightarrow \Lambda^0) \times BR(\Lambda^0 \rightarrow \Lambda^0 J/\psi) \times BR(\Lambda^0 \rightarrow p\pi^-) \times BR(J/\psi \rightarrow \mu^+ \mu^-) $$

(7)

with $BR(\Lambda^0 \rightarrow p\pi^-) = 63.9\%$, $BR(J/\psi \rightarrow \mu^+ \mu^-) = 6.76\%$, $\mathcal{L}_{\text{int}}^{\text{year}} = 2 \text{ fb}^{-1}$

$$ \Rightarrow \text{Expected Signal (including errors on the branching ratio measurements):} $$

$$ S = (3.4 \pm 2.2) \times 10^6 $$

III-1 CP Asymmetry

- Standard Model predictions: \( 1.7 \times 10^{-4} \leq AS_{CP} \leq 2.8 \times 10^{-4} \)

- Limits on CP-Asymmetry Beyond the Standard Model could be set, provided total error is estimated.

<table>
<thead>
<tr>
<th>( \int \mathcal{L} dt ) (fb(^{-1}))</th>
<th>( \sigma(A_{CP}) ) for BR = ( 7.5 \times 10^{-4} )</th>
<th>( \sigma(A_{CP}) ) for BR = ( 4.8 \times 10^{-4} )</th>
<th>( \sigma(A_{CP}) ) for BR = ( 1.9 \times 10^{-4} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.84%</td>
<td>0.95%</td>
<td>1.36%</td>
</tr>
<tr>
<td>4</td>
<td>0.74%</td>
<td>0.81%</td>
<td>1.06%</td>
</tr>
<tr>
<td>6</td>
<td>0.70%</td>
<td>0.75%</td>
<td>0.94%</td>
</tr>
<tr>
<td>8</td>
<td>0.69%</td>
<td>0.72%</td>
<td>0.87%</td>
</tr>
<tr>
<td>10</td>
<td>0.67%</td>
<td>0.70%</td>
<td>0.83%</td>
</tr>
</tbody>
</table>

Table 3: Total Error on the CP Asymmetry

- CP Asymmetry of 2.8% (90% CL) can be put into evidence after one year of data taking.

- Limit of 1.6% can been reached (90% CL) for 10fb\(^{-1}\) (5 data taking years).
III-2 **T-Odd Observables and their Asymmetries**

\[
\vec{n}_{\Lambda^0} = \frac{\vec{p}_p \times \vec{p}_\pi}{|\vec{p}_p \times \vec{p}_\pi|} \quad \vec{n}_{J/\psi} = \frac{\vec{p}_{\mu^+} \times \vec{p}_{\mu^-}}{|\vec{p}_{\mu^+} \times \vec{p}_{\mu^-}|}
\]  

- T-Odd Observables: **Cosine and Sine of** \( \phi \vec{n}_{\Lambda^0} \)

\[
\cos \phi_{(n_{\Lambda^0})} = \frac{\vec{e}_Y \cdot (\vec{e}_Z \times \vec{n}_{\Lambda^0})}{|\vec{e}_Z \times \vec{n}_{\Lambda^0}|}, \quad \sin \phi_{(n_{\Lambda^0})} = \frac{\vec{e}_Z \cdot (\vec{e}_X \times \vec{n}_{\Lambda^0})}{|\vec{e}_X \times \vec{n}_{\Lambda^0}|}
\]

<table>
<thead>
<tr>
<th>( \mathcal{P}_{\Lambda_b} )</th>
<th>( AS(\cos \phi_{(n_{\Lambda^0})}) )</th>
<th>( AS(\sin \phi_{(n_{\Lambda^0})}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>5.2%</td>
<td>-5.0%</td>
</tr>
<tr>
<td>75%</td>
<td>3.3%</td>
<td>-3.6%</td>
</tr>
<tr>
<td>50%</td>
<td>2.2%</td>
<td>-2.9%</td>
</tr>
<tr>
<td>25%</td>
<td>0.6%</td>
<td>-1.8%</td>
</tr>
<tr>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

**Table 4: Asymmetry Variations of the C-S Observables**

*Direct Test of Time-Reversal Symmetry at the LHC*  
*Feasibilities with LHCb* (page 24)
Potentialities of LHCb to put into evidence TRV

\[ \int \mathcal{L} dt \ (\text{fb}^{-1}) \quad \sigma(AS') \text{ for BR} = 7.5 \times 10^{-4} \quad \sigma(AS') \text{ for BR} = 4.8 \times 10^{-4} \quad \sigma(AS') \text{ for BR} = 1.9 \times 10^{-4} \]

<table>
<thead>
<tr>
<th>( \int \mathcal{L} dt \ (\text{fb}^{-1}) )</th>
<th>( \sigma(AS') ) for BR = 7.5 \times 10^{-4}</th>
<th>( \sigma(AS') ) for BR = 4.8 \times 10^{-4}</th>
<th>( \sigma(AS') ) for BR = 1.9 \times 10^{-4}</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.56%</td>
<td>0.72%</td>
<td>1.21%</td>
</tr>
<tr>
<td>4</td>
<td>0.40%</td>
<td>0.51%</td>
<td>0.85%</td>
</tr>
<tr>
<td>6</td>
<td>0.32%</td>
<td>0.41%</td>
<td>0.70%</td>
</tr>
<tr>
<td>8</td>
<td>0.28%</td>
<td>0.36%</td>
<td>0.60%</td>
</tr>
<tr>
<td>10</td>
<td>0.25%</td>
<td>0.32%</td>
<td>0.54%</td>
</tr>
</tbody>
</table>

Table 5: Statistical Error on the Asymmetry of the C-S observables

•• Consequences:

(1) For 1 year of data taking, an Asymmetry of 2.4% can be put into evidence at 90% CL, \( \Rightarrow \Lambda_b \) Polarization, \( \mathcal{P}^{\Lambda_b} \geq 50\% \)

(2) With an Integrated Luminosity of 10 fb\(^{-1}\), an Asymmetry \( \geq 1\% \) could be detected at 90% CL, \( \Rightarrow \Lambda_b \) Polarization, \( \mathcal{P}^{\Lambda_b} \geq 20\% \)

Direct Test of Time-Reversal Symmetry at the LHC
Feasibilities with LHCb (page 25)
III-3  Polarizations of the Resonances Λ and \( J/\psi \)

- New Method to put into evidence TRV

- Intermediate Resonances, \( \Lambda \) and \( J/\psi \), are still POLARIZED even if \( \Lambda_b \) is not polarized, \( \mathcal{P}^{\Lambda_b} = 0 \)  

- How Polarization could be related to TRV ??
  
  ⋆ Measurement of the Polarization according to a direction \( \vec{n} \) Invariant by TR.

\[
P_n = \vec{P} \cdot \vec{n} = \langle \vec{s} \rangle \cdot \vec{n} \rightarrow TR \rightarrow - \langle \vec{s} \rangle \cdot \vec{n} = -P_n
\]

⋆ If TR is an EXACT SYMMETRY \( \implies P_n = 0 \)

⋆ But, if \( (P_n)_{\text{measured}} \neq 0 \) \( \Rightarrow \) TR Violated !!!

\[\downarrow \downarrow \downarrow \]

VIOLATION of TR, if and only if

FSI are NEGLIGIBLE

Direct Test of Time-Reversal Symmetry at the LHC
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• In some Specific Frames related to the Resonances :

(1) Transverse Component, $P_T$, is T-Odd

(2) Correlations $P_{TN}$ and $P_{NT}$ between Vector-Polarizations of the Resonances $\Lambda$ and $J/\psi$ are T-Odd.

\[\downarrow \downarrow \downarrow\]

SIGN of TRViation !?

*** Only DATA could help to answer this fundamental question....
IV - CONCLUSION

• Possibility to measure the $\Lambda_b$ Polarization, which is a challenge for QCD, similarly to the Hyperon Polarizations in Hadron-Hadron Collisions.

• Putting into evidence T-Odd Observables like the C-S Parameters is possible, provided $\Lambda_b$ is Polarized; but need to handle the Systematic Effects.

• (Very) Promising Method :
  $\implies$ Measuring Transverse Polarization of the Resonances $\Lambda, J/\psi$ and their Correlations independently of any value of the $\Lambda_b$ polarization.

• If TRVViolation process not predicted by the Standard Model
  $\downarrow$
  Evidence for a new process beyond the SM
  $\downarrow$
  New Physics ?
If *Saint-Augustin* was hearing us, He would say:

... Finally, what is Time (Reversal)??

"If nobody asks me, I know the answer. But, if somebody does ask me and I must explain it, thus I would be unable to do it”

**Publications**

"**Analysis of the channel** $\Lambda_b^0 \rightarrow \Lambda^0 J/\psi$”


"**Angular Analysis of** $\Lambda_b$ decays into $\Lambda V(1^-)$”

hep-ph/0409262, PCCF RI 0409.

"**Testing Fundamental Symmetries with** $\Lambda_b \rightarrow \Lambda - Vector$ Decays”


"$\Lambda_b$ Decays into $\Lambda - Vector$”

Eric Conte,
"Recherche de la violation des symétries CP et T dans les réactions
Λ_b → Λ + meson − vecteur "
Thèse de Doctorat d’Université, Université Blaise Pascal; DU1785, EDSF546, PCCF T0710 (Novembre 2007).

"Testing CP and Time Reversal Symmetries with Λ_b → Λ V(1−) Decays"

E.DiSalvo, Z.J.Ajaltouni
"Model independent tests for Time Reversal and CP violations and for CPT theorem in Λ_b, Λ̄_b two body decays"