A new CP violating observable for the LHC

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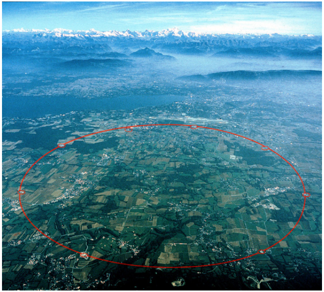
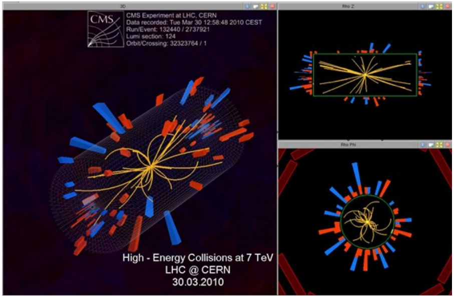
arXiv:1105.0672

August 11, 2011

The LHC era has begun!





1. Identify new states
2. Measure masses and spins
3. Measure couplings, flavor structure, CP-violation

The Upshot

Goal: Find calculable & measurable $\not{C}\not{P}$ observables

- Requires interference & different strong phases
- So far: strong rescattering $(B \to K\pi)$ and oscillation (meson mixing)
- Our result: new type of strong phase in 3-body decays with different orderings

Seeing CP-violation

- Looking for asymmetry:

$$\mathcal{A}_{\rm CP} = \frac{\Gamma(i \to f) - \Gamma(\bar{i} \to \bar{f})}{\Gamma(i \to f) + \Gamma(\bar{i} \to \bar{f})} \neq 0$$

- Requirements:
  1. Two interfering amplitudes a_1, a_2
  2. Different weak (CP-odd) phases φ_1, φ_2
  3. Different strong (CP-even) phases δ_1, δ_2

$$\mathcal{A}_{\rm CP} \propto |a_1||a_2| \sin(\varphi_1 - \varphi_2) \sin(\delta_1 - \delta_2)$$

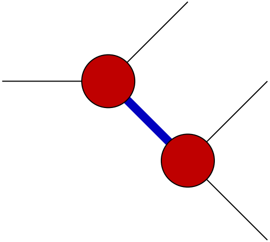
Strong phase?

- In general, comes from time evolution: e^{iEt}
- Basic case: oscillation of intermediate states - requires states with same quantum #'s
- More complicated: strong interaction rescattering - hard to calculate

Another way to get a calculable strong phase?

The Breit-Wigner Formula

- Process with narrow-width virtual state:



$$= \mathcal{M}_1 \frac{1}{q^2 - m^2 + i\Gamma m} \mathcal{M}_2$$

- Breit-Wigner propagator contributes phase
- Momentum-space equivalent of e^{iEt}

Strong phase from the propagator

Strong phase from intermediate particle:

1. Different particles $\leftrightarrow$ Time-integrated oscillation
2. Different virtuality $\rightarrow$ New!

$$\delta = \arg\left(\frac{1}{q^2 - m^2 + im\Gamma}\right)$$

A new calculable strong phase

Requirements:

1. Three body decay
2. Two different orderings
3. On-shell resonance

Result:

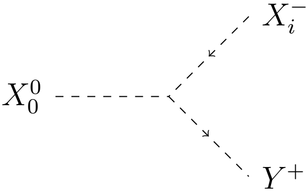
CP-asymmetry in Dalitz plot

Toy model content

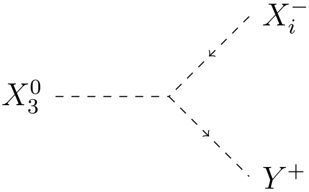
- All particles are scalars
- Heavy neutral particle: X_0^0
- Charged resonance: Y^+
- Lighter particles: $X_{1,2}^+$, X_3^0
- Phase space $\implies$ scale hierarchy:

$$m_{X_0^0} > m_{Y^\pm} > m_{X_3^0} + m_{X_{1,2}^\pm}$$

Feynman rules



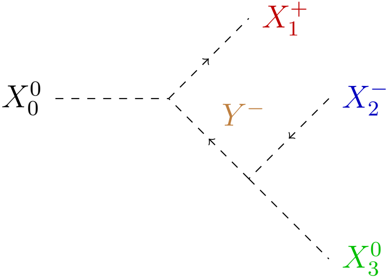
$$= -iae^{i\varphi_a}$$



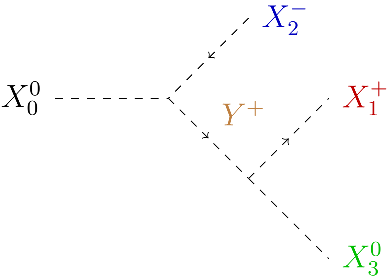
$$= -ibe^{i\varphi_b}$$

- One weak phase: $\varphi = \varphi_b - \varphi_a$

Toy model decays



$$= \frac{|a||b|e^{i\varphi}}{q_{23}^2 - m_Y^2 + i m_Y \Gamma_Y}$$

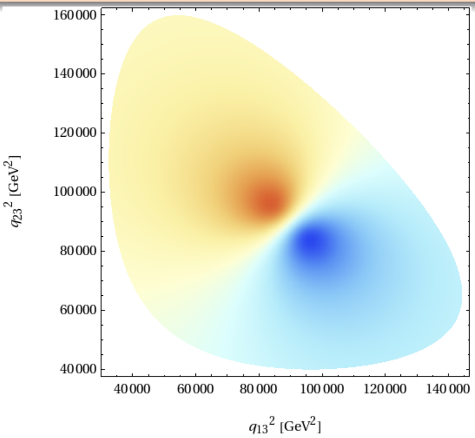


$$= \frac{|a||b|e^{-i\varphi}}{q_{13}^2 - m_Y^2 + i m_Y \Gamma_Y}$$

Different weak phase, different strong phase

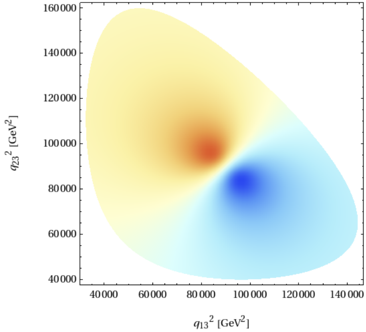
Asymmetry in the Dalitz plot

$$\mathcal{A}_{\mathrm{CP}}^{\mathrm{diff}} \propto \sin 2\varphi (q_{13}^2 - q_{23}^2) \Gamma_Y m_Y$$



Integrated asymmetries

$$X_0^0 \to X_1^+ X_2^- X_3^0$$



- Integrated rate suppressed:

$$\mathcal{A}_{\rm CP}^{\rm int} \propto \frac{\Delta m_{12}^2}{m_0^2}$$

- Eliminate suppression by phase space weighting:

$$\mathcal{A}_{\rm CP}^{\rm wgt} \equiv \frac{1}{\Gamma + \bar{\Gamma}} \int dq_{13}^2 dq_{23}^2 \; {\rm sgn}(q_{23}^2 - q_{13}^2) \left(\frac{d\Gamma}{dq_{13}^2 dq_{23}^2} - \frac{d\bar{\Gamma}}{dq_{13}^2 dq_{23}^2} \right)$$

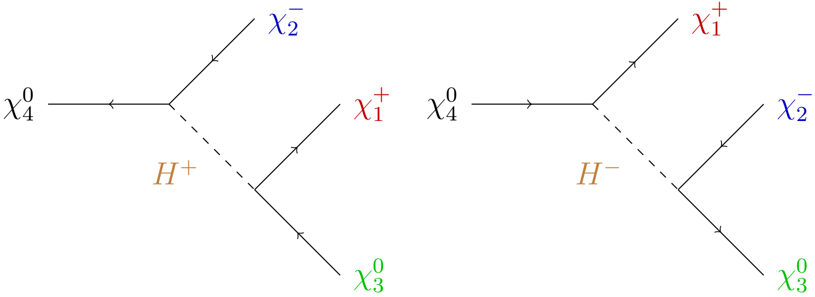
The relevant model

Electroweak sector of MSSM

- Heavy neutral particle: $\sim \tilde{B}$
- Intermediate charged resonace: $H^{\pm}$
- "Light" final states: lighter charginos and neutralinos
- Hierarchy of scales for maximal signal:

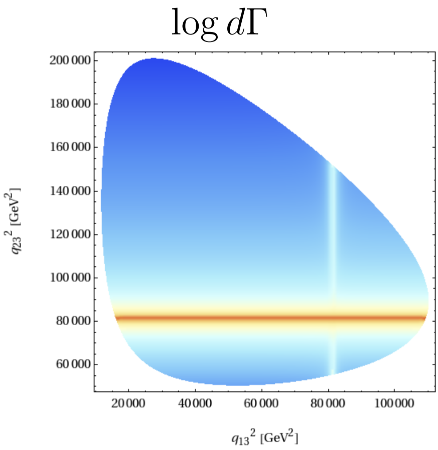
$$m_{\chi_4^0} \sim M_1 \gg m_{H^+} \gg m_{\chi_i^0}, m_{\chi_j^\pm} \sim \sqrt{|\mu M_2|} > m_Z$$

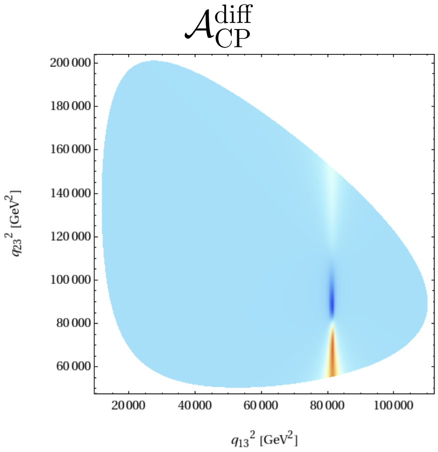
The Feynman diagrams



- One weak phase: $\arg(\mu b^* M_2)$

Dalitz plot observables





MSSM results

- Suppressed integrated asymmetry:

$$\mathcal{A}_{\mathrm{CP}}^{\mathrm{int}} = -3.5 \times 10^{-5}$$

- Using phase space weighting:

$$\mathcal{A}_{\mathrm{CP}}^{\mathrm{wgt}} = -6.5 \times 10^{-4}$$

Electroweak MSSM is challenging

The ingredients

Recipe for Dalitz plot asymmetry:

- Three body decay
- Two different orderings
- On-shell resonance