τ Leptons: a Gateway to New Physics?

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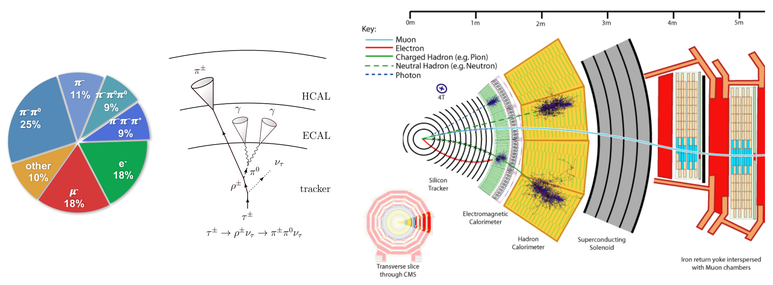
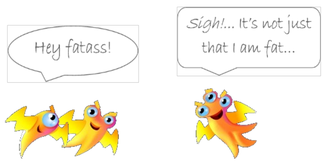
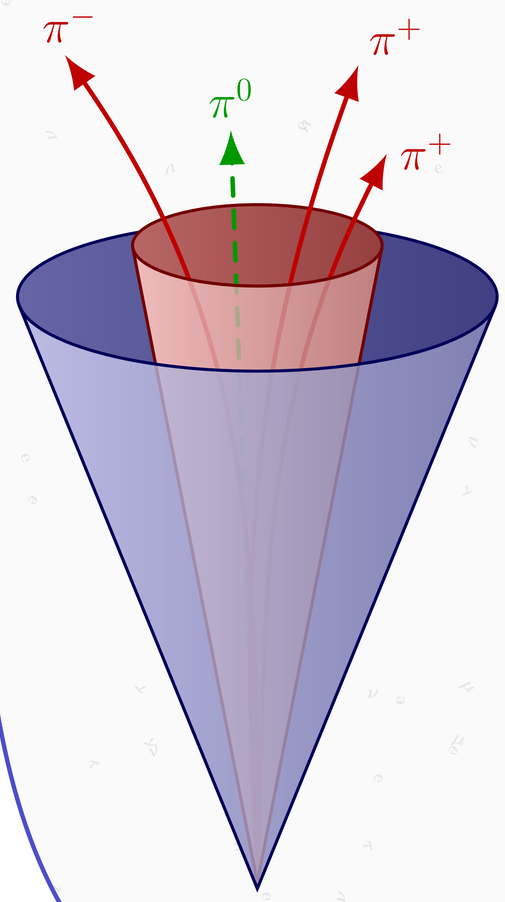
τ lepton

- Third generation of leptons
  - Heaviest lepton ⇒ decays promptly
  - Only lepton that can decay to quarks
- Mostly decays to different numbers of pions
  - Difficult to reconstruct in a detector
  - Large backgrounds from quark/gluon jets



- Pathway to new forces via stronger couplings?
  - The **Standard Model** (SM) has apparent **Lepton Flavor Universality** (LFU): the charged leptons' ($e^{\pm}$, $\mu^{\pm}$, $\tau^{\pm}$) couplings through the weak interaction have the same strength
  - **New Physics** models predict stronger couplings to higher generations: τ lepton, t and b quark



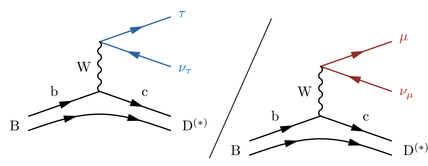


Lepton Flavour Universality tests

- **B anomalies**: the BaBar, BELLE, and LHCb collaborations report deviations between observation and SM prediction
  → if confirmed, evidence for New Physics
- CMS can also test LFU in b → c$\ell\nu$ decays
- Compare decay rates of rare semileptonic B-hadron decays

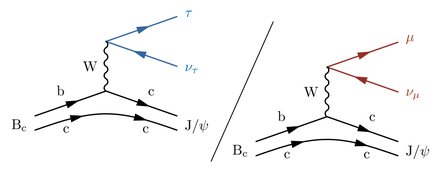
$R(\mathrm{D}^*)$ analysis

$$R_{\mathrm{D}^*} = \frac{\Gamma(\mathrm{B} \to \mathrm{D}^* \tau \bar{\nu})}{\Gamma(\mathrm{B} \to \mathrm{D}^* \mu \bar{\nu})}$$

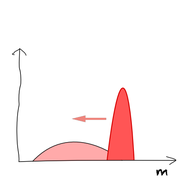


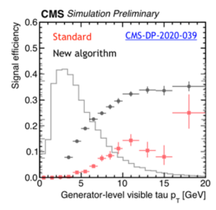
$R(\mathrm{J}/\psi)$ analysis

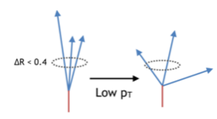
$$R_{\mathrm{J}/\psi} = \frac{\Gamma(\mathrm{B_c} \to \mathrm{J}/\psi \tau \bar{\nu})}{\Gamma(\mathrm{B_c} \to \mathrm{J}/\psi \mu \bar{\nu})}$$



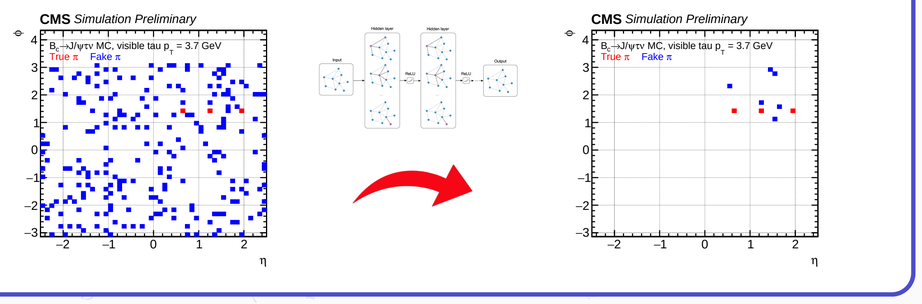
- **Challenges**:
  - Large backgrounds from (partially reconstructed) $\mathrm{D}^{(*)}_{(s)}$ mesons
  - Poor reconstruction efficiency of low-momentum τ leptons





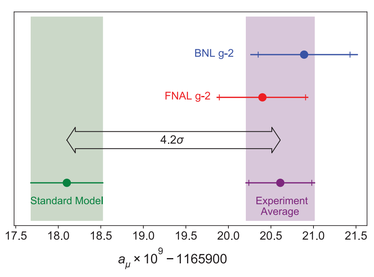


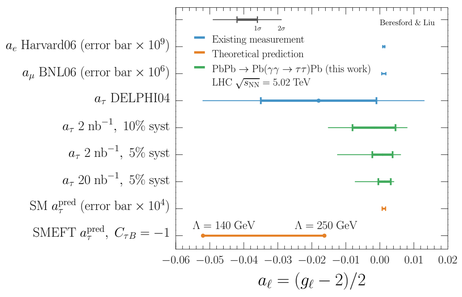
- Use **machine learning** for selecting the τ decay products



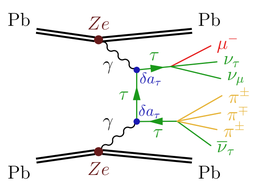
Anomalous magnetic moment $g-2$

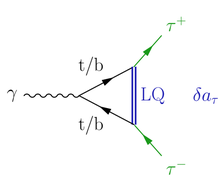
- Magnetic moment $\mu = g\frac{q}{2m}S$, with $g \approx 2.002$
- **Anomalous magnetic moment** of leptons: $a_\ell = \frac{(g-2)_\ell}{2} \approx 0.001$
- Precision measurement of Standard Model
- Sensitivity to New Physics increases with lepton mass → τ !
- Current best measurement of a_τ from DELPHI, using 1997-2000 data.



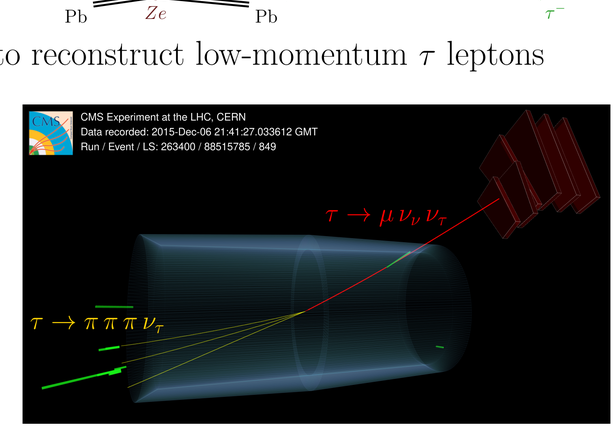


- Use "ultraperipheral" collisions of lead nuclei to find di-τ photo production
  - Cross section and τ kinematics sensitive to a_τ
  - Cross section $\propto Z^4$, where $Z = 82$ for lead



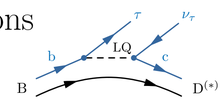


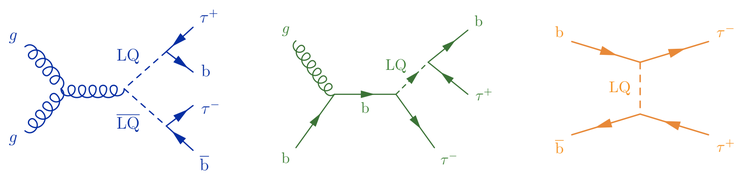
- Challenging to reconstruct low-momentum τ leptons

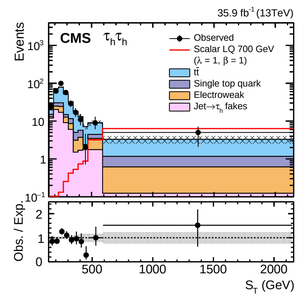


Leptoquarks

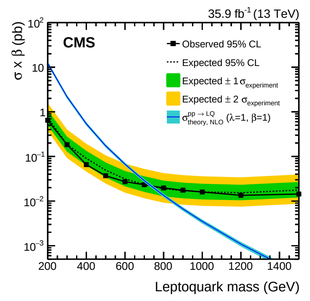
- **Leptoquarks** (LQs) are hypothetical particles that interact with quarks & leptons
- Bosons with spin 0 (scalar) or 1 (vector), but have fractional charge and carry color like quarks
- Coupling strengths λ vary between the generations of quarks and leptons
- Can explain the B anomalies through LFU violation
- Created in high-energy proton collisions recorded by the CMS detector
- Look for excess of data over SM expectation in order to search for LQs

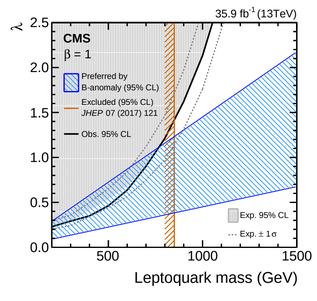






- In case of no observation, constrain mass, cross section, and couplings





- Some models also include interaction with **dark matter** to explain cosmological observations

Interested ?

Contribute, and acquire new skills & experiences:

- Study the Standard Model of Particle Physics, and New Physics models
- Programming in python, C++, ROOT, ...
- Advanced analysis tools like multivariate analysis techniques using neural networks, deep learning, ...
- Simulate and analyze proton & lead collision data from the CMS detector
- Interact with physicists around the world via CERN
- Discuss, present, document & publish results
- Help to find New Physics, and advance our understanding of the Universe

Contact Prof. Ben Kilminster at
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