Feasibility of tau g-2 measurements with ultraperipheral collisions of heavy ions

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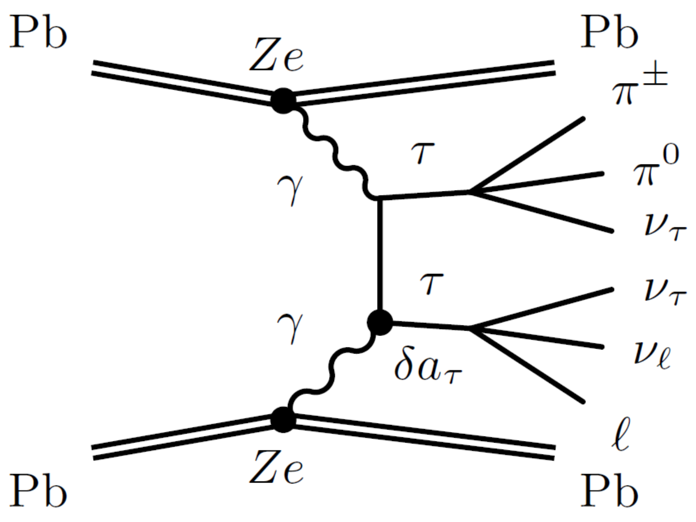
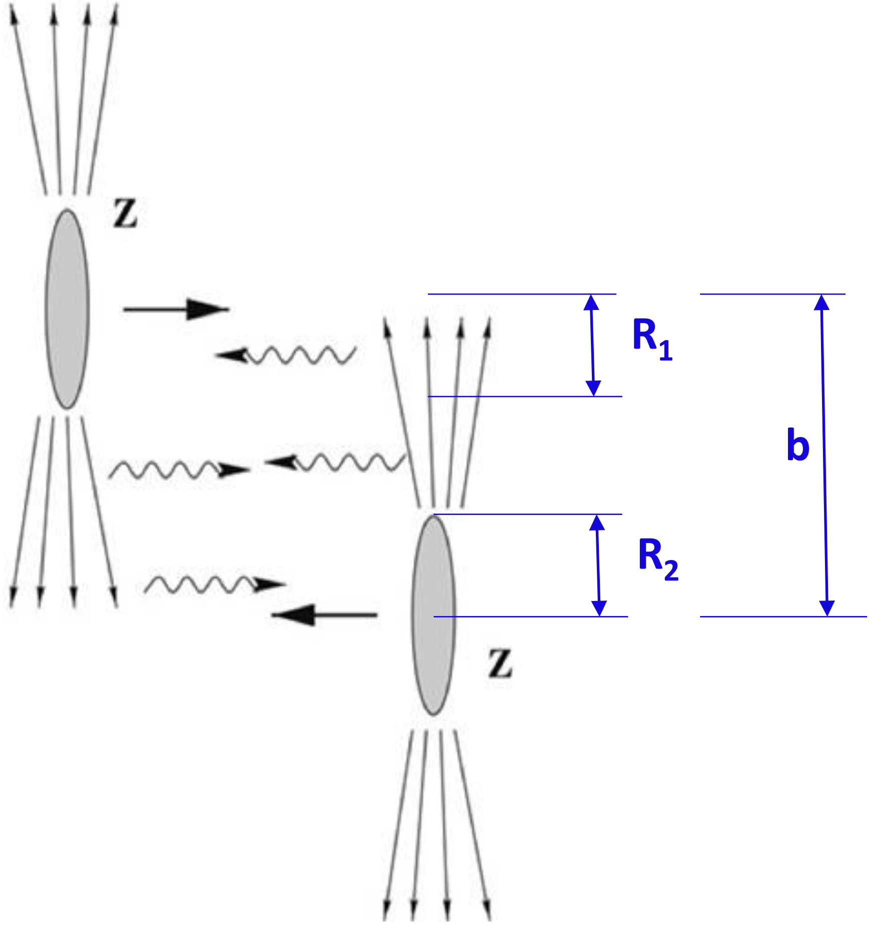


The 16th International Workshop on Tau Lepton Physics
1 October 2021

LHC as a γγ, γp and γA collider



Ultra-peripheral collisions (UPC): $b > R_1+R_2$

→ hadronic interactions strongly suppressed

High photon flux

→ well described in Weizsäcker-Williams approximation

→ flux proportional to Z^2

→ high cross section for γ-induced reactions

Pb-Pb UPC at LHC can be used to study γγ, γp, γA interactions at higher center-of-mass energies than ever before

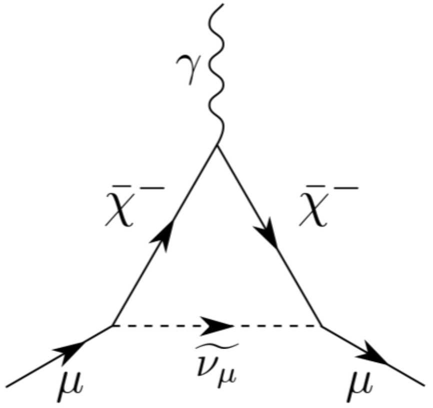
Reviews on UPC physics:
A.J. Baltz et al, Phys. Rept. 458 (2008) 1
J.G. Contreras, J.D. Tapia Takaki. Int.J.Mod.Phys. A30 (2015) 1542012

Tau anomalous magnetic moment

$$a = \frac{(g-2)}{2}$$

- Anomalous magnetic moments are sensitive to BSM physics
- Supersymmetry at a scale M_S leads to $\delta a_\ell \sim m_\ell^2/M_S^2$

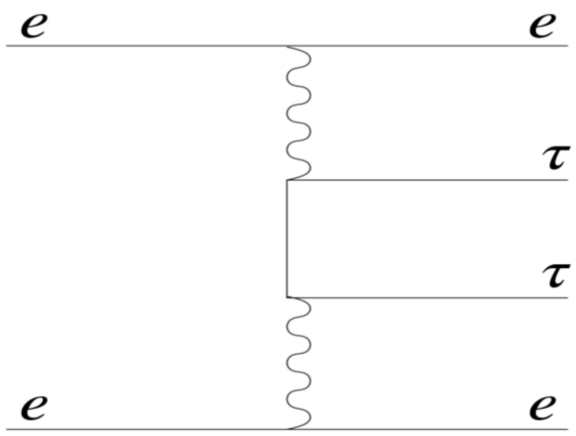
$m_\tau^2/m_\mu^2 \sim 280$ → τ is 280 times more sensitive to SUSY than μ!



- Theory:

$$a_\tau^{\mathrm{SM}} = 0.00117721(5)$$

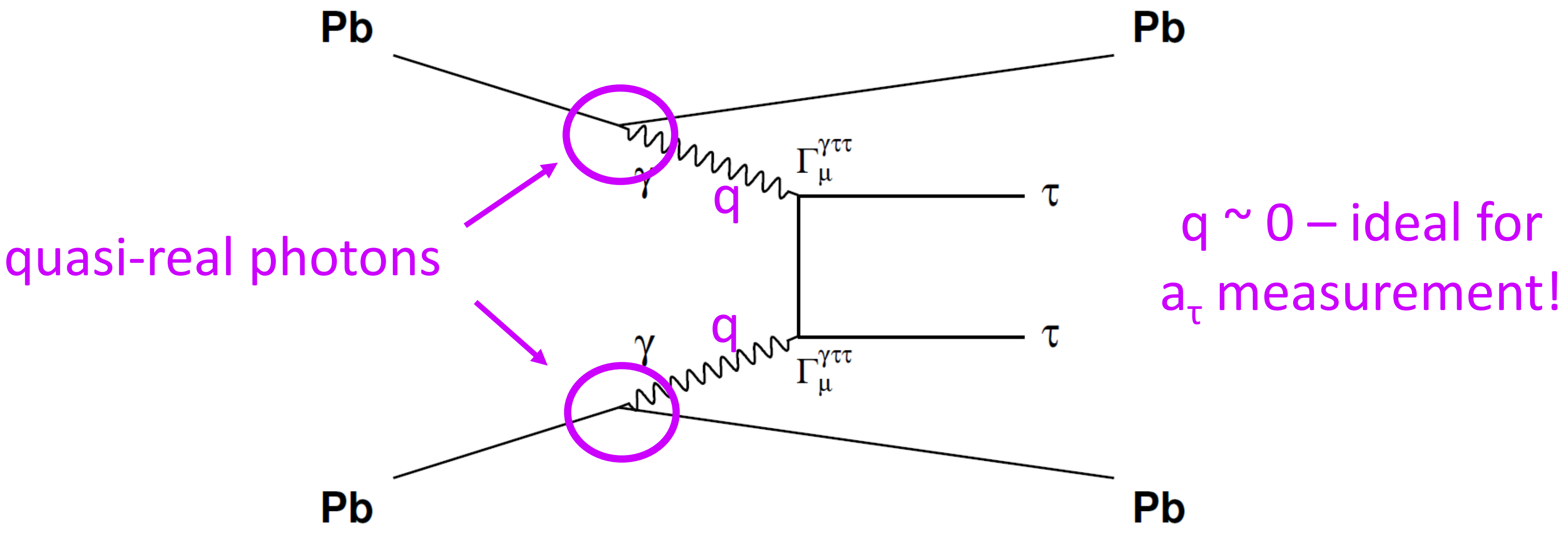
- Short tau lifetime (10^{-13} s) → standard spin precession methods used in muon g-2 experiments are not applicable
- Workaround: τ production cross sections are sensitive to a_τ
- Strongest constraints by DELPHI in $e^+e^- \rightarrow e^+e^-\tau\tau$

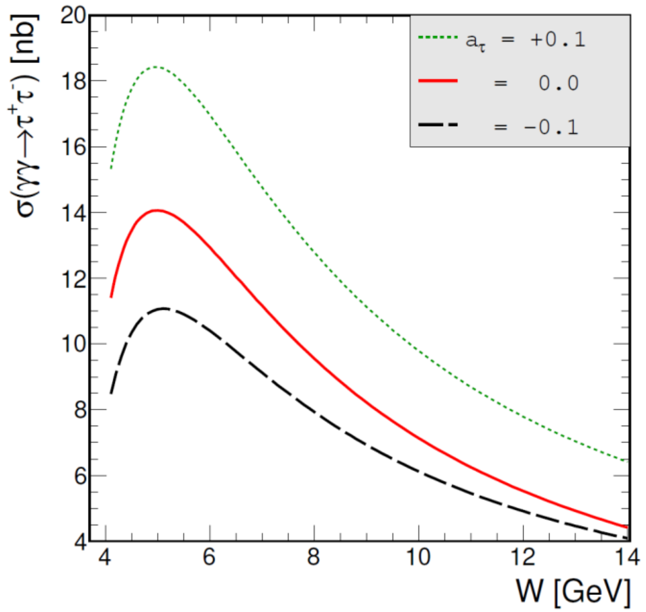


$-0.052 < a_\tau < 0.013$ (95% CL)

EPJC 35 (2004) 159

Measure tau g-2 in UPCs?





- Initial idea: F. del Aguila et al, PLB 271 (1991) 256
- SMEFT: L. Beresford, J. Liu, PRD 102 (2020) 113008
- Direct calculation: M. Dyndal et al. PLB 809 (2020) 135682

$$i\Gamma_\mu^{(\gamma\tau\tau)}(q) = -ie\left[\gamma_\mu F_1(q^2) + \frac{i}{2m_\tau}\sigma_{\mu\nu}q^\nu F_2(q^2) + \frac{1}{2m_\tau}\gamma^5\sigma_{\mu\nu}q^\nu F_3(q^2)\right] \qquad F_2(q^2 \to 0) = a_\tau$$

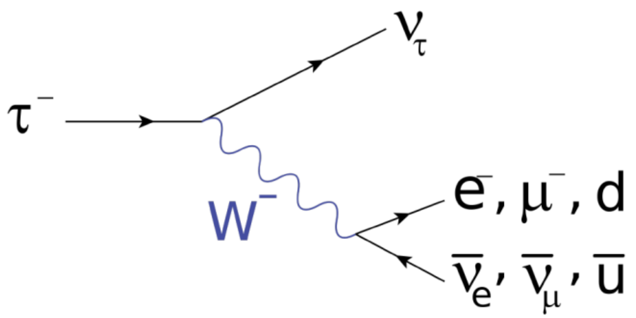
Tau decays

- 1-prong: tau decays into 1 charged particle with BR ~ 80%:

$$\mathrm{BR}(\tau^\pm \to \mathrm{e}^\pm + \nu_\mathrm{e} + \nu_\tau) = 17.8\%$$

$$\mathrm{BR}(\tau^\pm \to \mu^\pm + \nu_\mu + \nu_\tau) = 17.4\%$$

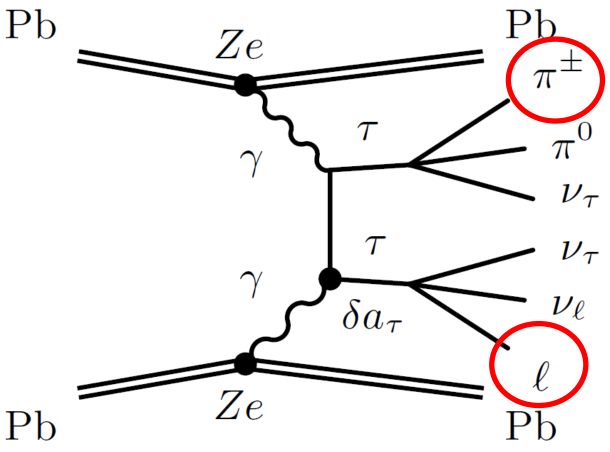
$$\mathrm{BR}(\tau^\pm \to \pi^\pm + \mathrm{n}\pi^0 + \nu_\tau) = 45.6\%$$



- 3-prong:

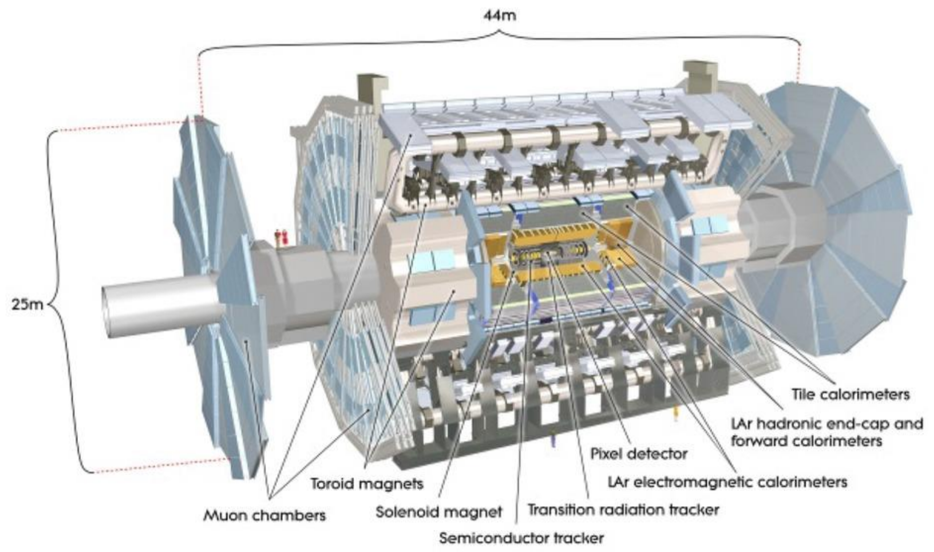
$$\mathcal{B}(\tau^\pm \to \pi^\pm\pi^\mp\pi^\pm\nu_\tau + \text{neutral pions}) = 19.4\%.$$

- Selection in UPCs:
  1 lepton + 1 charged particle
  1 lepton + 3 charged particles

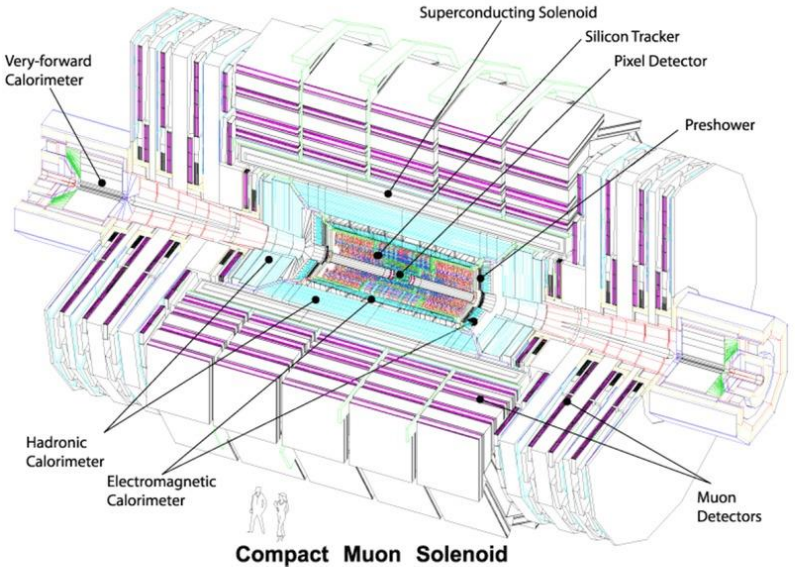


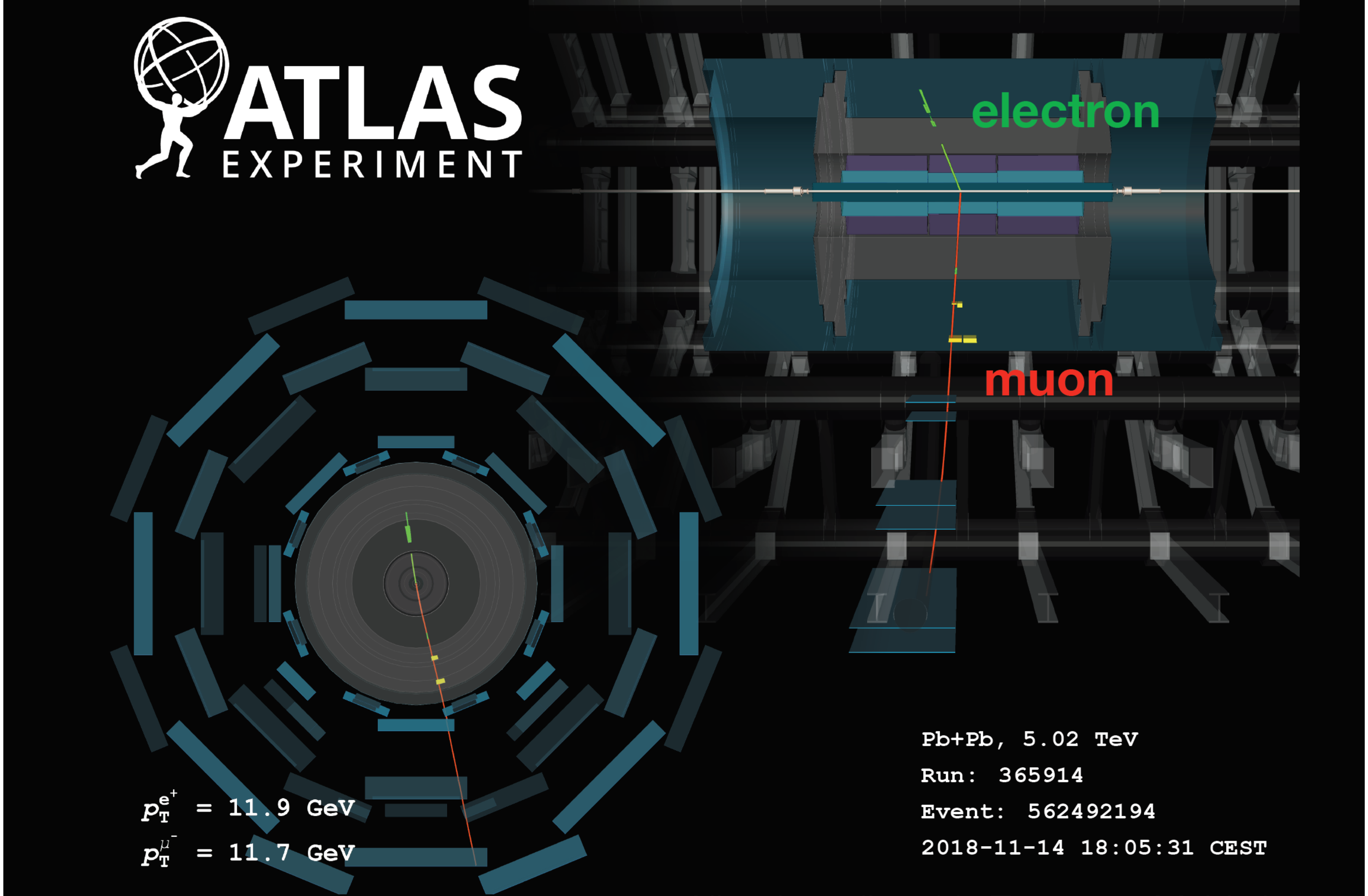
ATLAS and CMS potential

- ATLAS:
  - Tracking: $|\eta|<2.5$, $p_T > 0.5$ GeV
  - Electron selection: $p_T > 4.5$ GeV
  - Muon selection: $p_T > 4$ GeV



- CMS:
  - Tracking: $|\eta|<2.5$, $p_T > 0.5$ GeV
  - Muon selection: $p_T > 3$ GeV



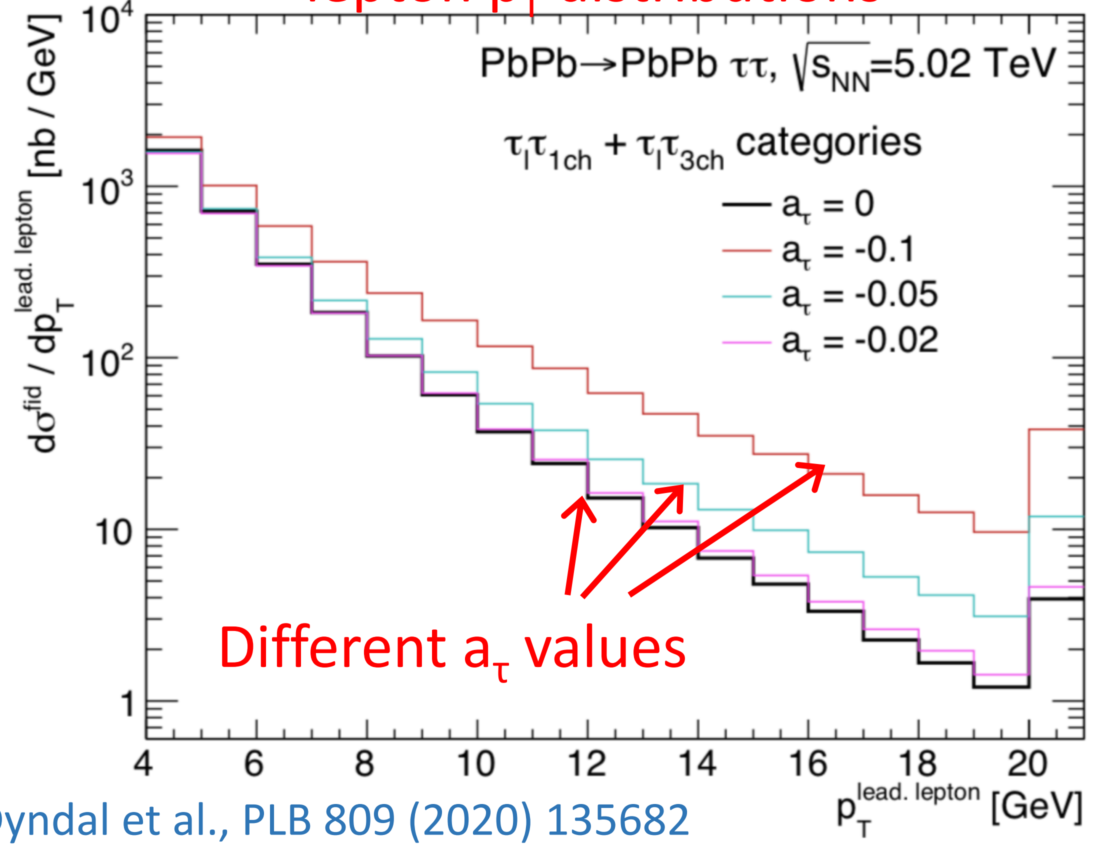


All calo cells with E_T > 500 MeV shown

L. Beresford, ICHEP 2020

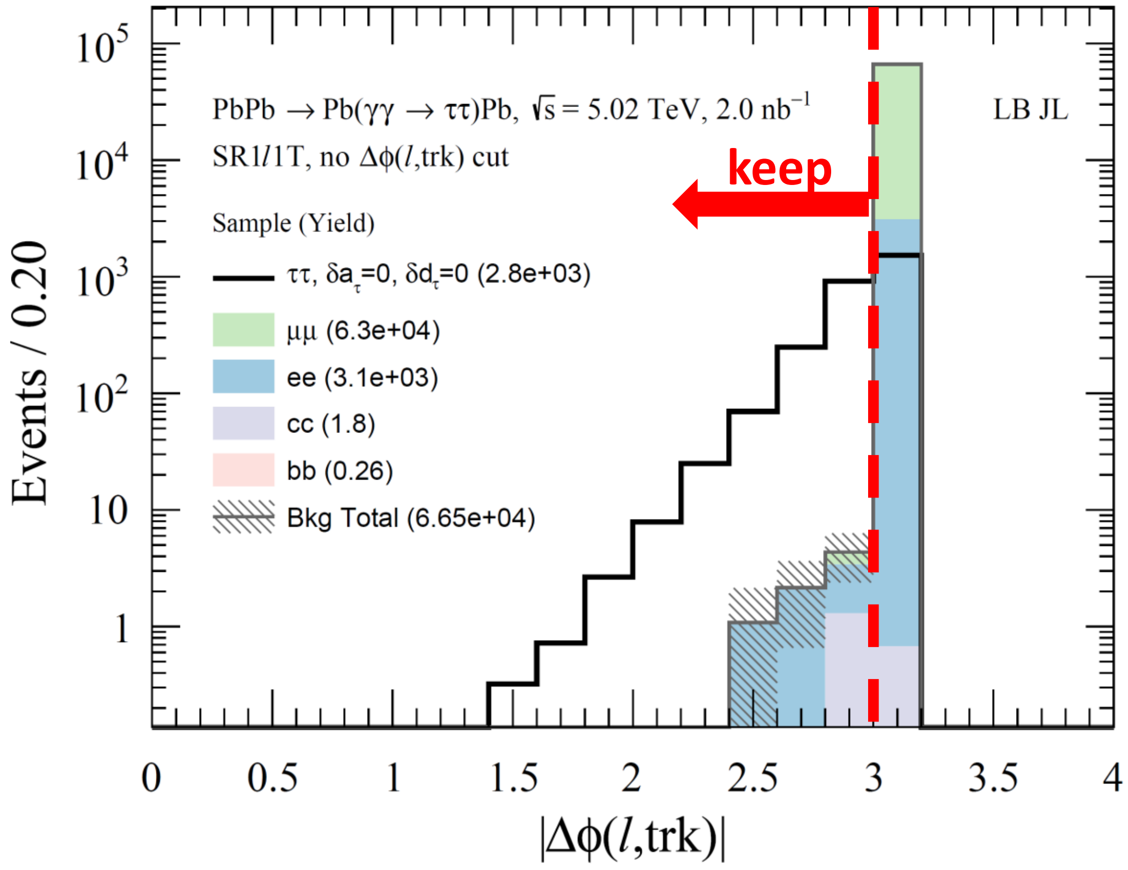
Lepton p_T spectra and background mitigation

lepton p_T distributions



Dyndal et al., PLB 809 (2020) 135682

L. Beresford, J. Liu, PRD 102 (2020) 113008

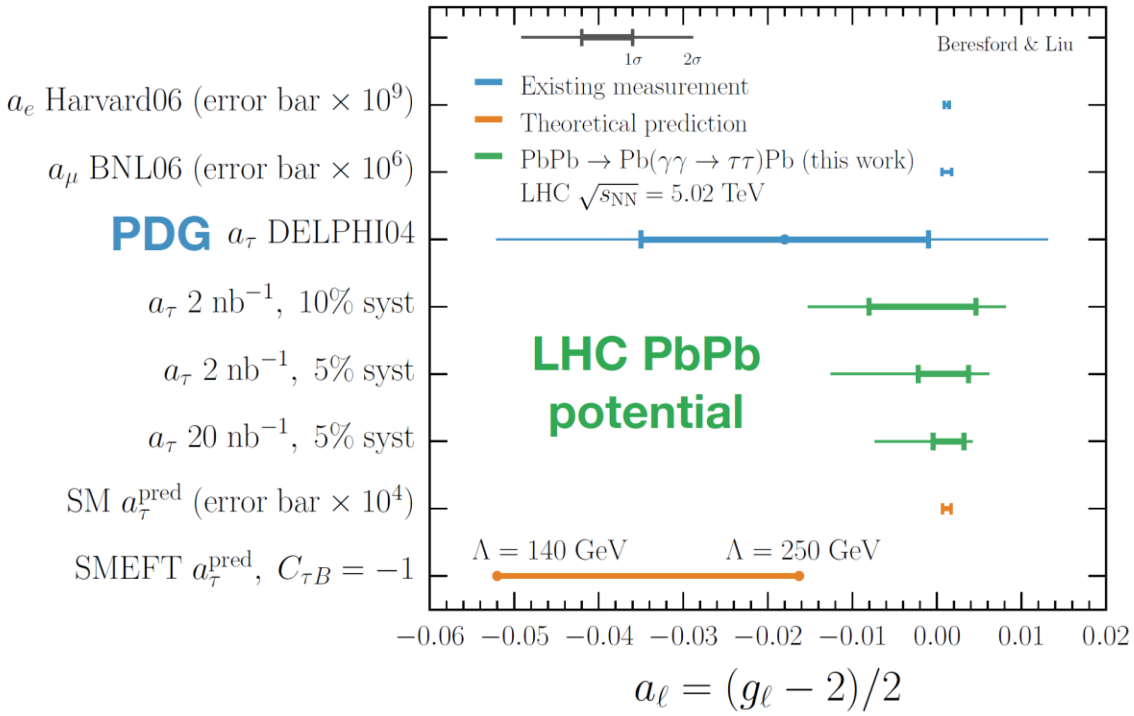


p_T differential measurements provide better sensitivity

Acoplanarity cuts can be used to suppress continuum dilepton background

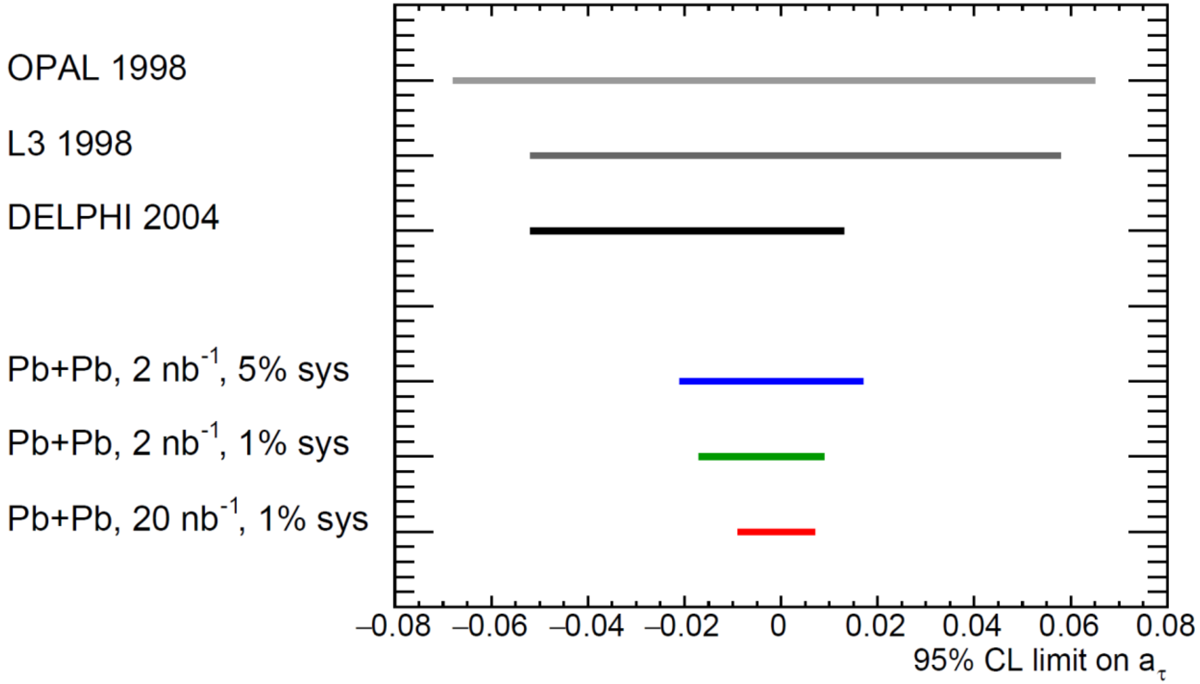
Possible constraints on a_τ with ATLAS/CMS

Beresford et al. (SMEFT)



$$\chi^2 = \frac{(S_{\mathrm{SM+BSM}} - S_{\mathrm{SM}})^2}{B + S_{\mathrm{SM+BSM}} + (\zeta_s S_{\mathrm{SM+BSM}})^2 + (\zeta_b B)^2}$$

Dyndal et al. PLB 809 (2020) 135682

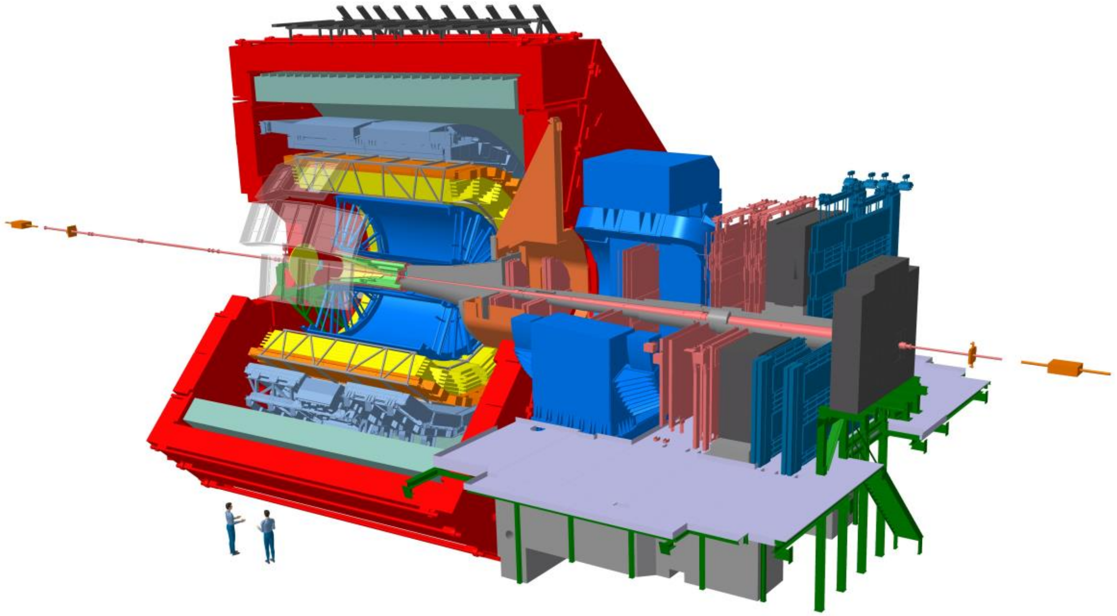


- Run 2 (2/nb) statistics estimates for ATLAS/CMS: 1280 events with 1-prong selection
- Looser limits predicted by Dyndal et al. Issue with SMEFT calculations?
- Measurements might be limited by systematics

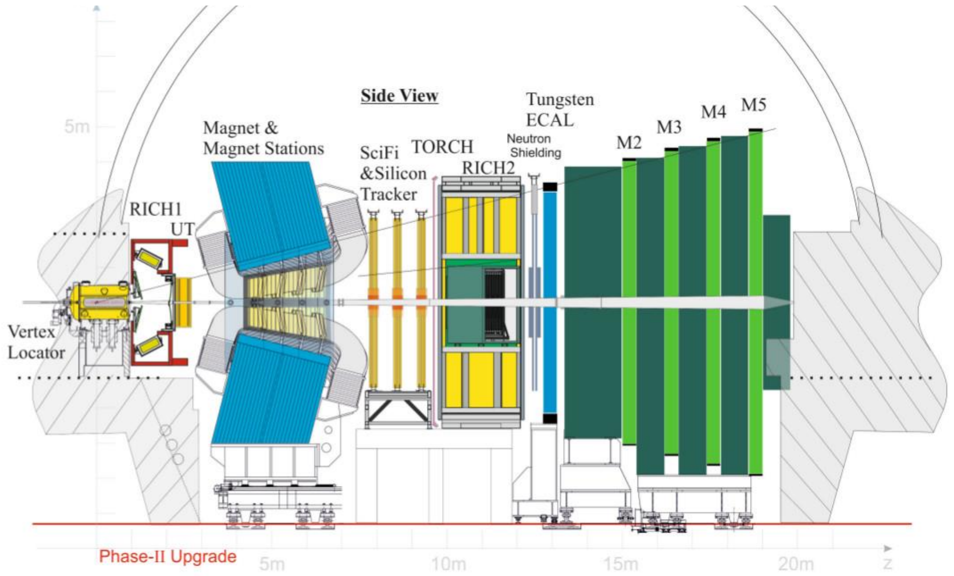
Can we measure a_τ with ALICE and LHCb detectors?

ALICE and LHCb detectors

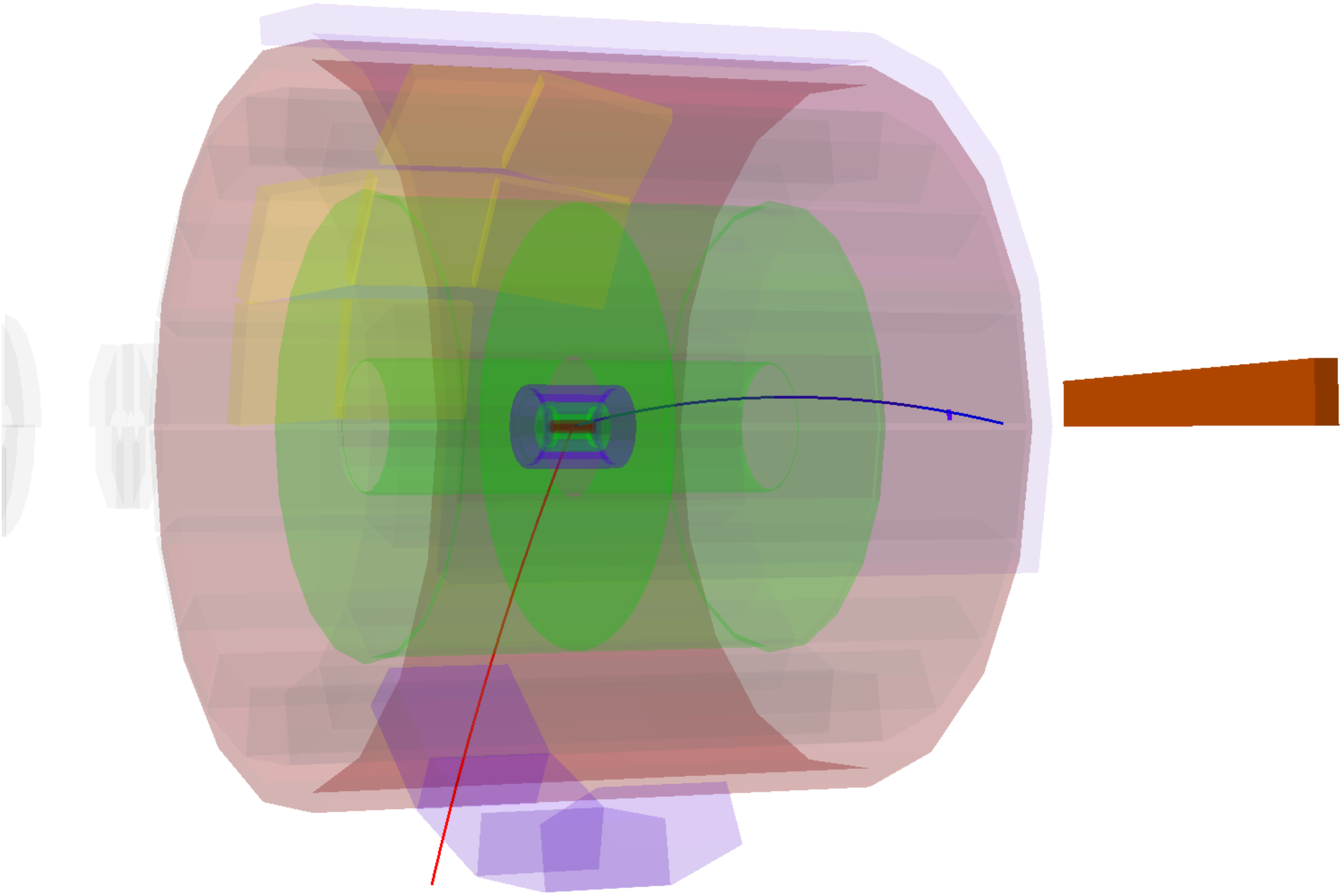
- ALICE:
  - Dedicated heavy ion experiment
  - $|\eta|<0.9$, $p_T > 0.3$ GeV
  - Continuous readout in Run3+Run4
    - no trigger losses
  - Expected Pb-Pb lumi: 2.7 nb^{-1} per year

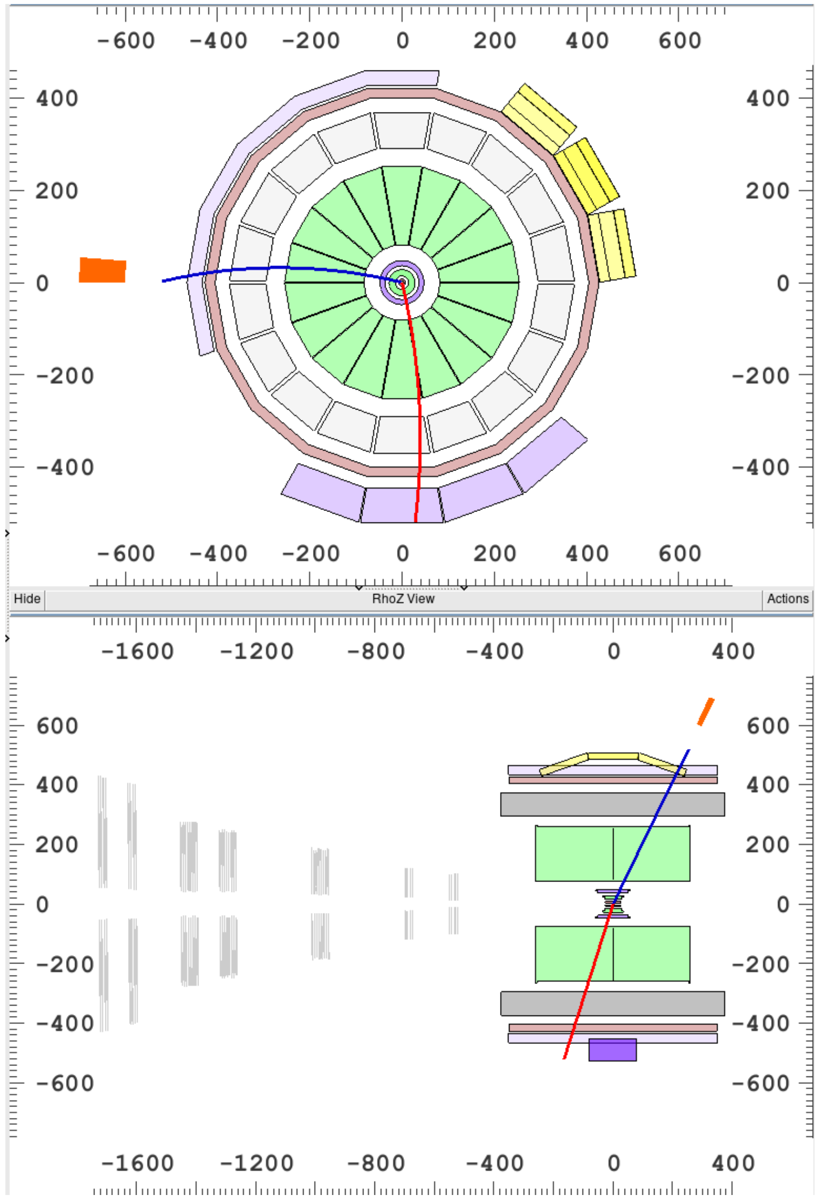


- LHCb:
  - $2 < \eta < 4.5$
  - Electron reconstruction: p > 2 GeV
  - Muon reconstruction: p > 6 GeV
  - Muon triggers: $p_T > 0.9$ GeV



Ditau event candidate from Run2 in ALICE

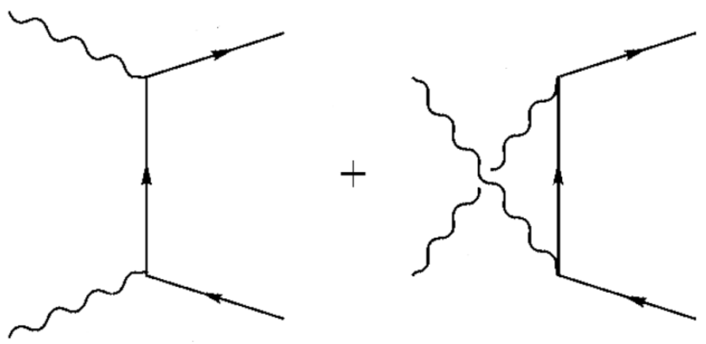




1 electron + 1 muon/pion UPC event with large acoplanarity

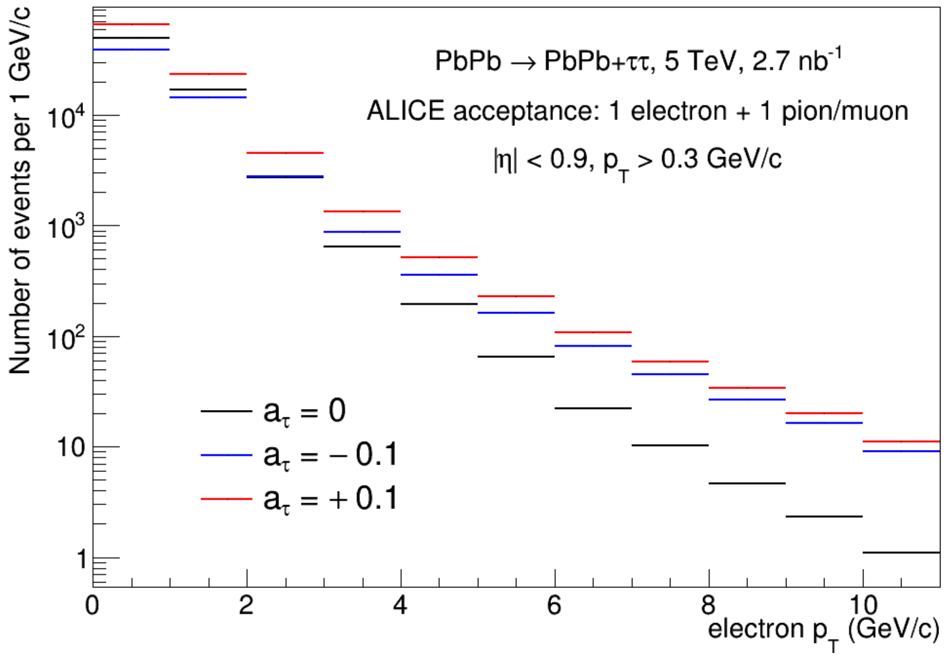
ALICE: p_T-differential electron yields for arbitrary a_τ

- Looking into 1 electron + 1 pion/muon events
- Following Dyndal et al., developed a dedicated UPC generator of tau pairs with arbitrary a_τ using generalized vertex:

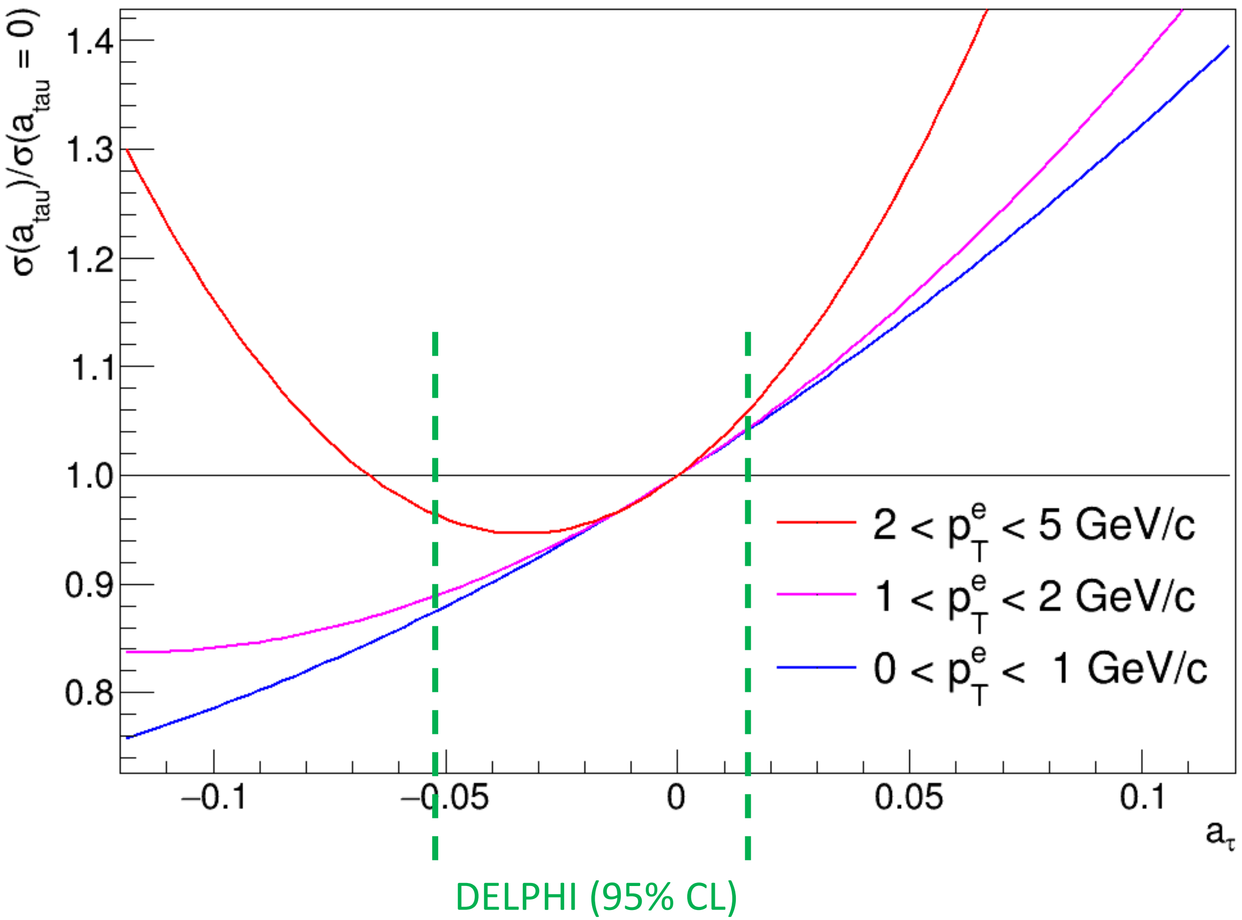


$$i\Gamma^{\mu}(q) = -ie\left(\gamma^{\mu}F_1(q^2) + \frac{i}{2m}\sigma_{\mu\nu}q^{\nu}F_2(q^2)\right) \rightarrow -ie\left(\gamma^{\mu} + \frac{i}{2m}\sigma_{\mu\nu}q^{\nu}a_{\tau}\right)$$

- Using Pythia8 for tau decays
- Looking into 1 electron + 1 pion/muon events
- Fiducial cuts:
  - $|\eta|<0.9$
  - $p_T > 0.3$ GeV/c
- ~ 70k events expected in the first year of Run3
- p_T differential measurements provide better sensitivity

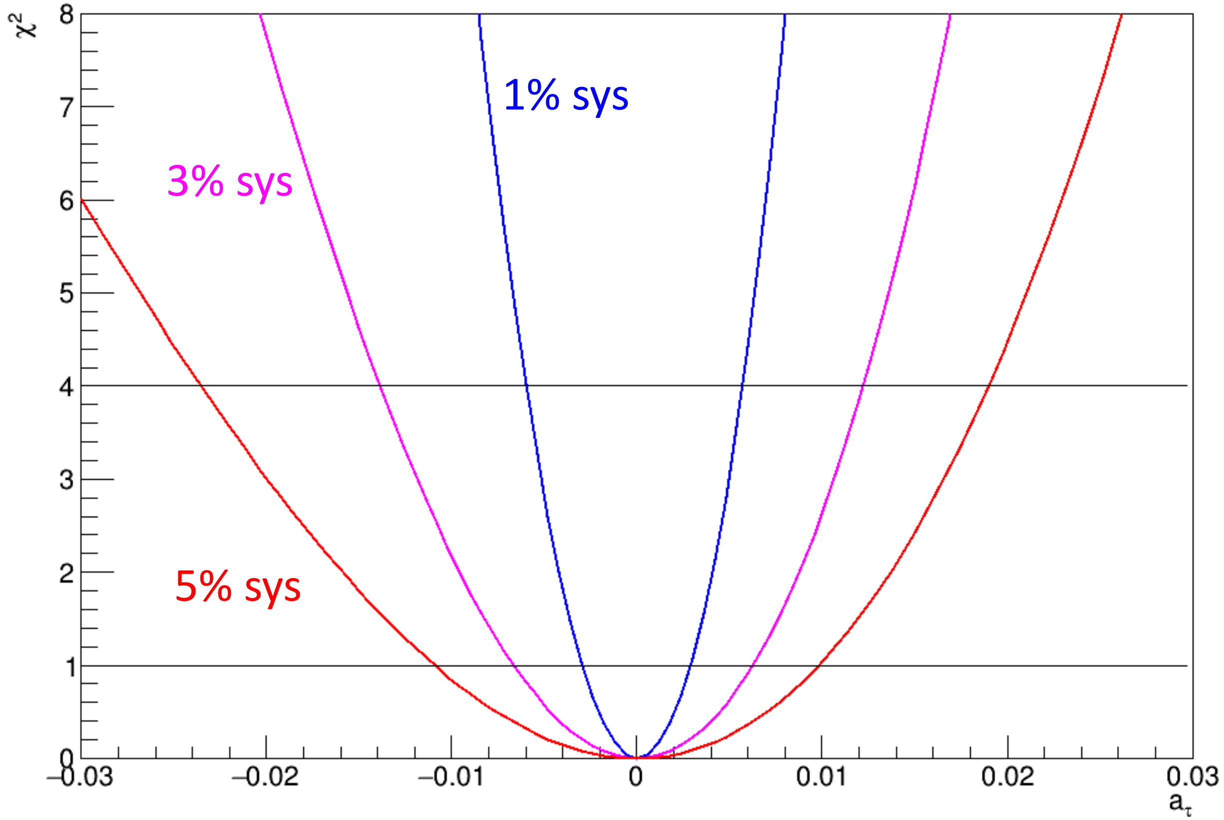


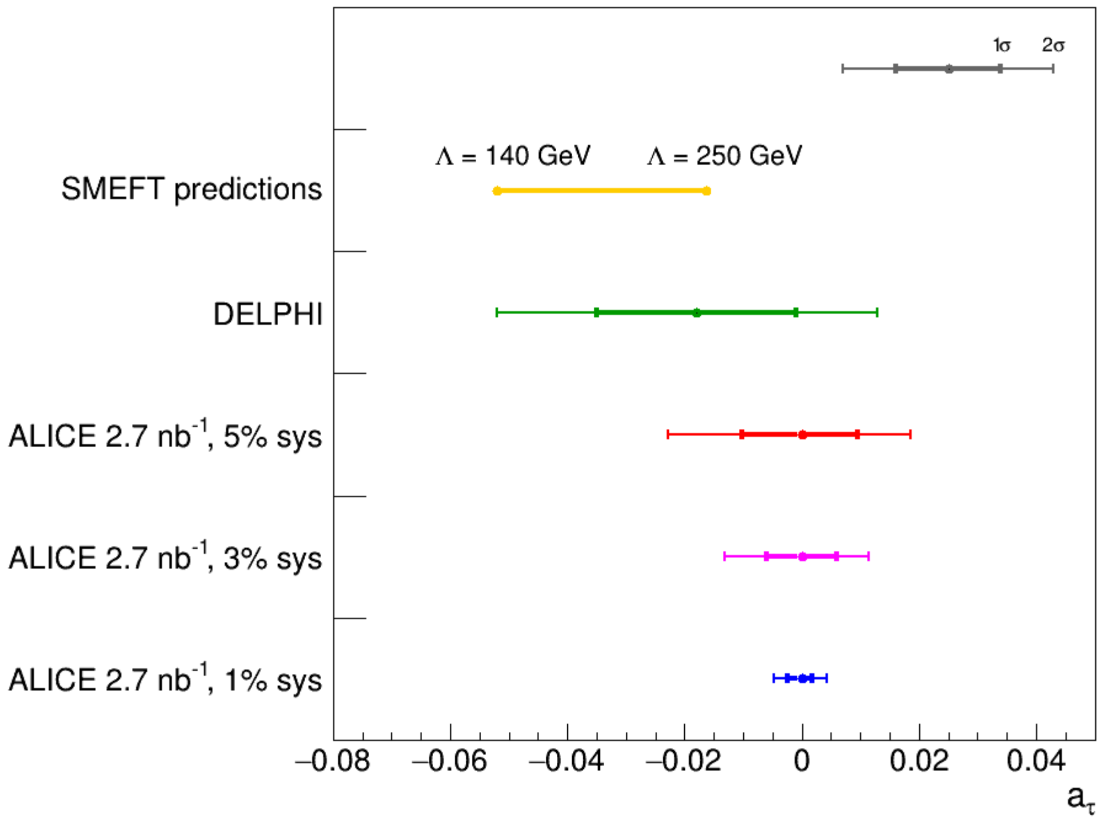
Closer look: sensitivity to a_τ in p_T bins



- Consider 3 bins in p_T providing 1%-tish statistical uncertainty
- Ratio of electron p_T differential cross sections has a parabolic shape in the vicinity of $a_\tau = 0$
- Up to 15% variations of the yields within the range restricted by DELPHI limits

a_τ limits with ALICE





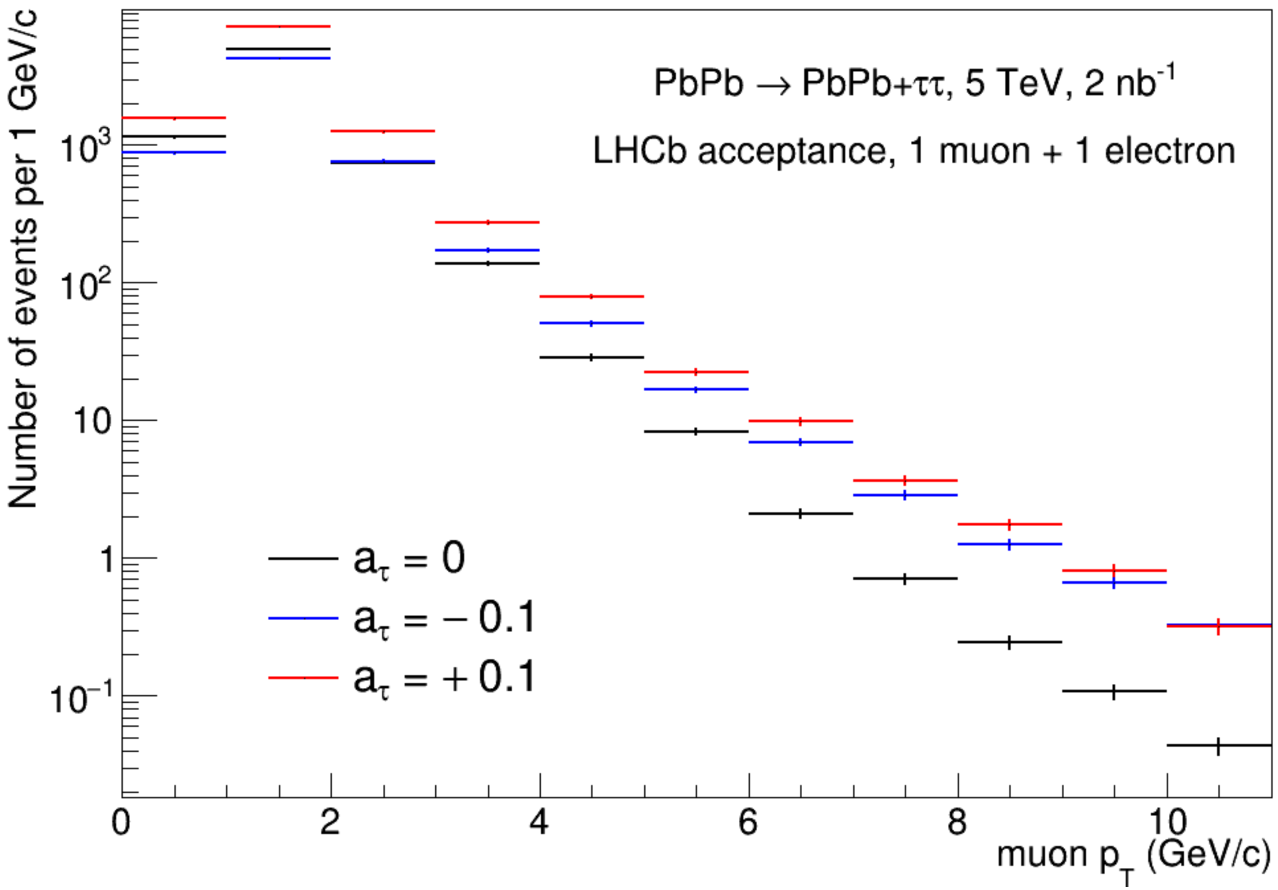
Deviation from SM

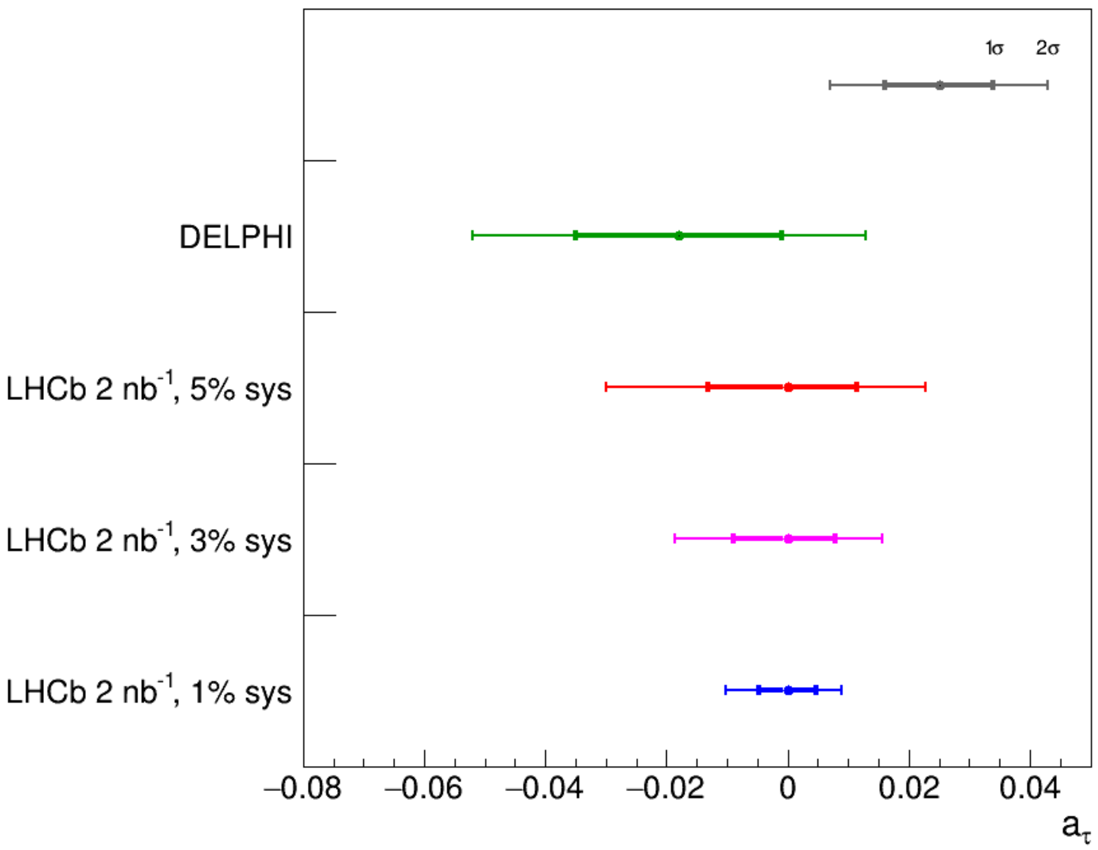
$$\chi^2 = \sum_{i=1}^{N_{\rm bins}} \frac{[S_i(0) - S_i(a_\tau)]^2}{\sigma_{\rm stat}^2 + (\sigma_{\rm syst}^{\rm uncorr})^2}$$

S_i $(\zeta\, S_i)^2$

- Considering uncorrelated systematic uncertainties: ζ = 1%, 3%, 5%
- Precision limited by systematics

LHCb potential

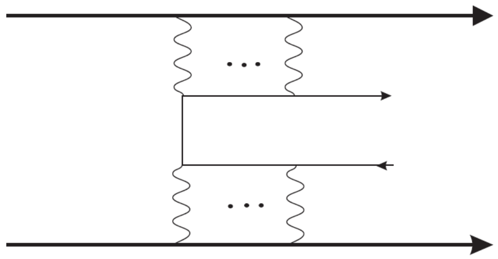




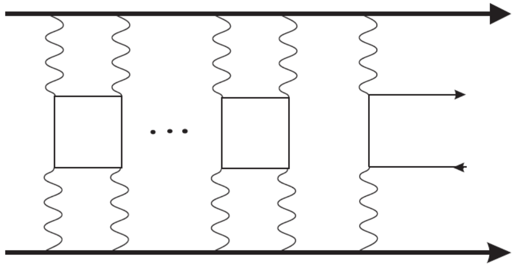
- Considering 1 muon + 1 electron events in $2 < \eta < 4.5$
- ~ 7k events expected with 2 /nb
- Complementary pseudorapidity coverage but limited statistics

Caveats and future steps

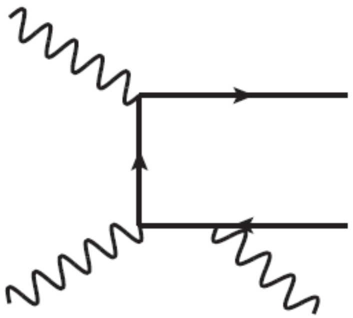
- Higher-order corrections
  - Multiple interactions due to high Zα, e.g. Hencken et al. PRC 75 (2007) 034903
  - Radiation from final state particles, e.g. S. Klein et al. PRD 102 (2020) 094013
- Precision of the equivalent photon approximation
  - Need to study flux uncertainties due to variation of Pb shape parameters
- Try ratios to electron/muon spectra to reduce systematics, proposed by M. Dyndal et al. PLB 809 (2020) 135682



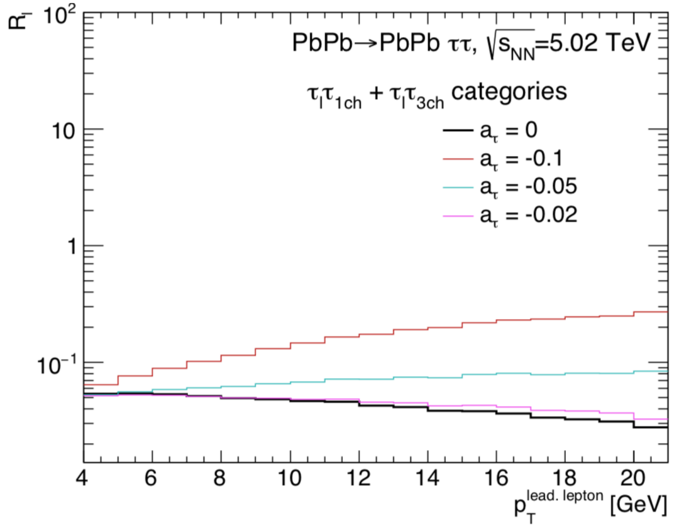
Coulomb corrections



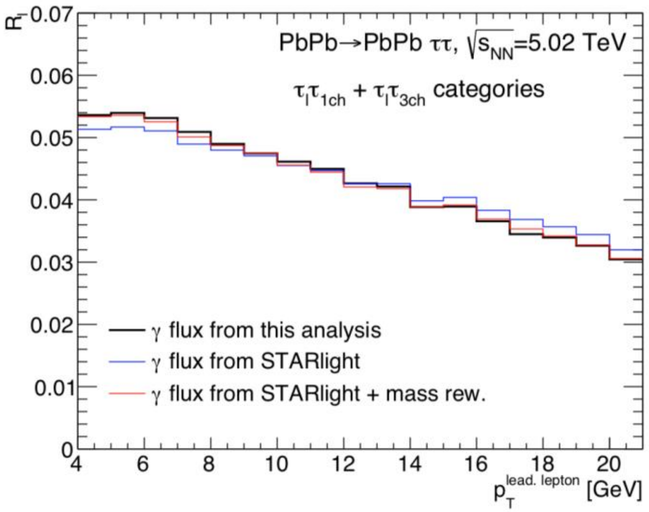
Unitarity corrections



Final state radiation



Ratio to electron/muon spectra

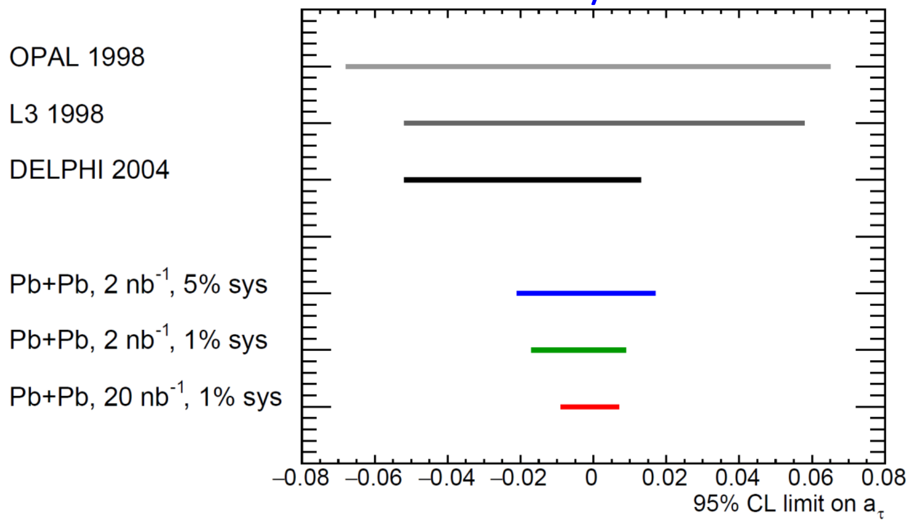


Flux differences in Starlight/Dyndal

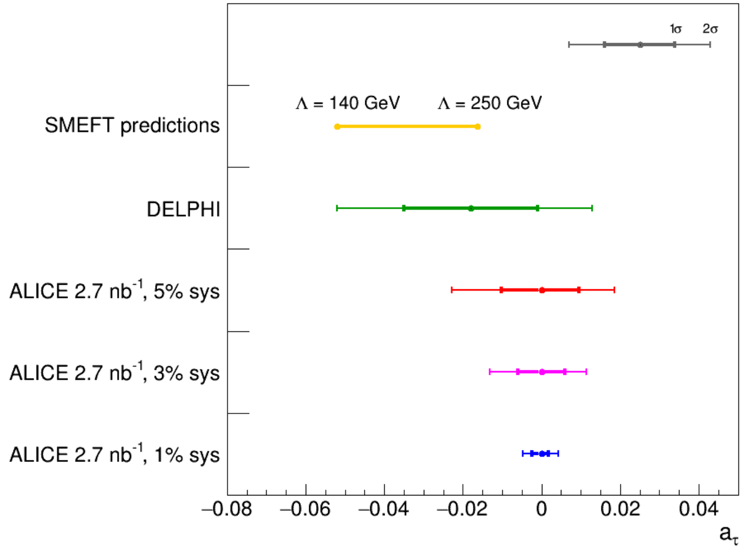
Conclusions

- ATLAS/CMS statistics from Run2 can be used to improve a_τ limits
- ALICE can help to extend a_τ measurements down to low p_T
- precision is limited by systematic uncertainties
- Expected limits on a_τ at least x2 better compared to DELPHI results

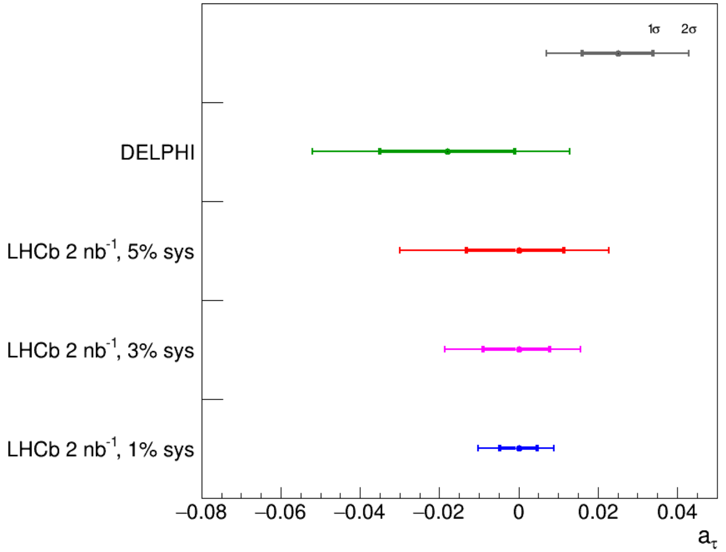
ATLAS/CMS



ALICE



LHCb



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