News from Wien

4. miniworkshop difrakce a ultraperiferálních srážek

September 13, 2021, Děčín, CZ

Roman Lavička*

*Guillermo Contreras Institute for Physics Graduates Production, University of Awesome Supervisors

News depends on the time scope

- Hard to define what is new...
- Capital of Austria since 1955.
- Most of the buildings since Austria-Hungary Empire rule.
- So, it looks old like Brno...

News depends on the time scope

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- Most of the buildings since Austria-Hungary Empire rule.
- So, it looks old like Brno...
- ...but people want to live here!

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- Wien beer is average, but they quite often offer Starobrno...

News depends on the time scope

- Hard to define what is new...
- Wien beer is average, but they quite often offer Starobrno...
- ...so you rather drink local beers.

News depends on the time scope

- Hard to define what is new...
- They have converted the infrastructure to be bike-friendly in the last 10 yers.
- Just like Prague is trying to do now.

News depends on the time scope

- Hard to define what is new...
- They have converted the infrastructure to be bike-friendly in the last 10 yers.
- Just like Prague is trying to do now.
- But nobody is constantly complaining about it.
- Instead, people are using it.

News depends on the time scope

- Hard to define what is new...
- Wienerschnitzel is not from Vienna.
- Originally created by arabic nations, it travels over Sicily to Milano, where you can have it in current shape (calf meat in breaded cutlet) under the name Cotoletta alla Milanese.

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- On contrary, sachertorte seems to be originally from Wien.

Tau anomalous magnetic moment measurements in ultra-peripheral collisions with ALICE at the LHC

4. miniworkshop difrakce a ultraperiferálních srážek

September 13, 2021, Děčín, CZ

Roman Lavička*

*Stefan Meyer Institute for Subatomic Physics, Austrian Academy of Sciences
†Petersburg Nuclear Physics Institute, Russian Academy of Sciences

In collaboration with Paul Bühler*, Evgeny Kryshen†, Nazar Burmasov†

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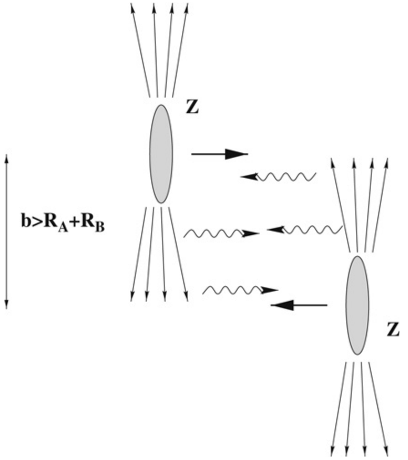
This work is supported by the Austrian Science Fund (FWF, I 5277-N) and the Russian Foundation for Basic Research (RFBR, project No. 21-52-14006).

Introduction - tools

- Ultra-peripheral collisions (UPCs).
    - Impact parameter $b > R_A + R_B$.
    - Strong interaction suppressed.
    - EM interaction remains.
- EM field of ultra-relativistic electrically charged particle $\sim$ flux of photons.
    - Interaction intensity increasing with Z^2.
- Many measurements at ALICE already.
    - Proof of usefulness of this tool.
    - Photon used as a probe to inner structure of hadrons/ions.
    - Appreciate addition to HERA/EIC.



Baltz *et al.*: Phys.Rept. 458 (2008) 1-171

Anomalous magnetic moment

- Magnetic moment μ:

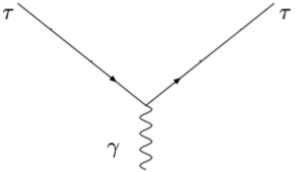
$$\boldsymbol{\mu} = g \frac{e}{2\,m} \boldsymbol{s}.$$

g - gyromagnetic factor, e - elementary charge, m - mass, $\boldsymbol{s}$ - spin

- Under Dirac assumption (point-like particle, spin 1/2) $g = 2$.

- Anomalous magnetic moment:

$$a = \frac{g-2}{2}.$$



- Standard Model prediction:

$$a = a^{\text{QED}} + a^{\text{EW}} + a^{\text{Hadron loops}}$$

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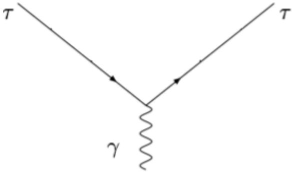

- Anomalous magnetic moment:

$$a = \frac{g-2}{2}.$$

- Standard Model prediction:

$$a = a^{\text{QED}} + a^{\text{EW}} + a^{\text{Hadron loops}} + a^{???}$$

QED contribution

- Photon and (l)epton loops (three (f)lavours).

$$a^{\mathrm{QED}} = A_1 + A_2\left(\frac{m_{l,f=1}}{m_{l,f=2}}\right) + A_2\left(\frac{m_{l,f=1}}{m_{l,f=3}}\right) + A_3\left(\frac{m_{l,f=1}}{m_{l,f=2}}, \frac{m_{l,f=1}}{m_{l,f=3}}\right)$$

- A_1 - only photon loops (no mass and flavour dependency).
- Expansion as power series in α/π:

$$A_i = A_i^{(2)}\left(\frac{\alpha}{\pi}\right) + A_i^{(4)}\left(\frac{\alpha}{\pi}\right)^2 + \dots$$

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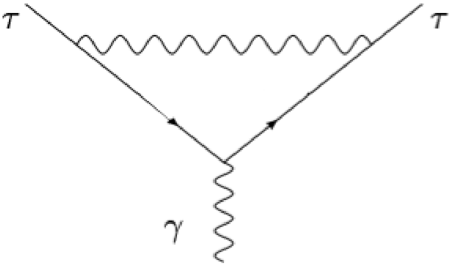

- Only one diagram in the lowest order.
- $A_1^{(2)} = 1/2$.
- Schwinger, Phys. Rev. 73, 416 (1948).

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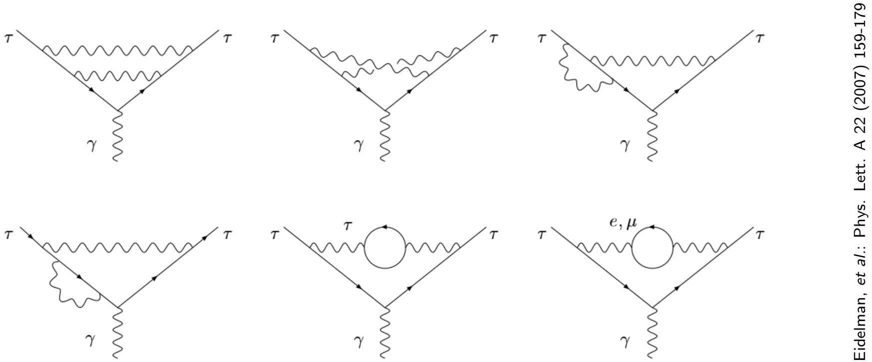
- Only one diagram in the lowest order.
- $A_1^{(2)} = 1/2$.
- Schwinger, Phys. Rev. 73, 416 (1948).
- Very apprehensive wife.

QED contribution

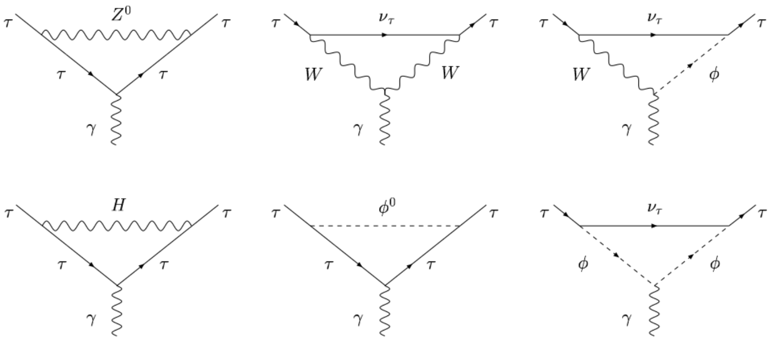
- The two-loop order example (8 diagrams in total):



- The three-loop order:
  - More than one hundred diagrams.
  - Analytic computations required three decades...

Elektroweak contribution

- Loops with $W^{\pm}, Z, H$, goldstone bosones...

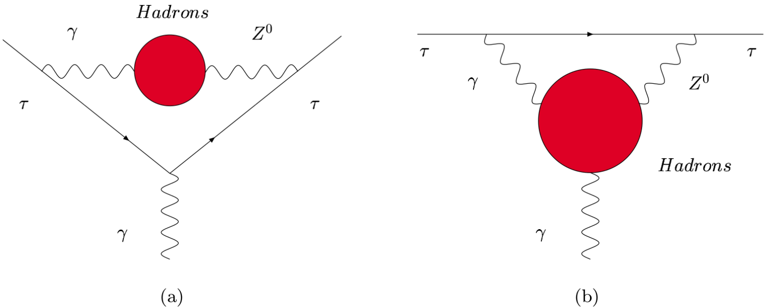


Eidelman, *et al.*: Phys. Lett. A 22 (2007) 159-179

- Wrt. QED, EW contribution is proportional to $\sim (m_l/m_W)^2$.
- For electron, this contribution is strongly suppressed!
- For tauon, on the level of the three-loop order.

Hadron contribution

- Hadronic vacuum polarization, light-by-light, higher orders loops...



Eidelman, *et al.*: Phys. Lett. A 22 (2007) 159-179

- Calculations based on experimental results.
- For electron, again, this contribution is strongly suppressed!

Lepton family overview

	a_e	a_μ	a_τ
SM pred.	0.00115965218164(77)	0.00116591804(51)	0.00117721(5)
Exp. val.	0.00115965218073(28)	0.00116592061(41)	[-0.052, 0.013] (95%CL)

- Difference of Standard Model and observations:
  - Compositness of leptons?
  - New physics Behind Standard Model (BSM)?
- BSM scales with $(m^2_{\text{lepton}}/m^2_\Lambda)$, where m_Λ is the mass scale of BSM particles.
  - $e : \mu = 1 : 42750$
  - $\mu : \tau = 1 : 280$
- Higher mass of lepton $\rightarrow$ reaching lower scale $\rightarrow$ better sensitivity to BSM.

a_e experimental value: Hanneke *et al.*: Phys. Rev. A 83, 052122 (2011)

a_μ experimental value: Muon g-2: Phys. Rev. Let. 126, 141801 (2021)

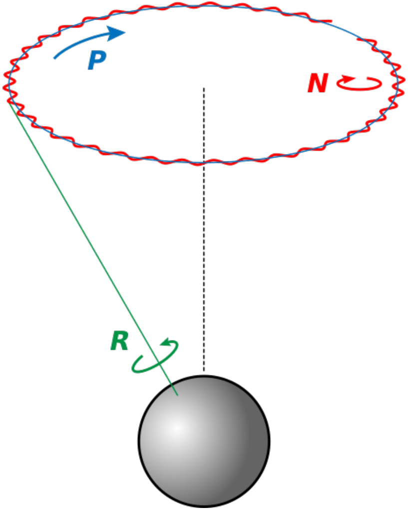
a_τ experimental value: DELPHI: Eur. Phys. J. C 35, 159-170 (2004)

Measurement method: Precession

- Three possible movements around Euler angles.
- Rotation R, precession P and nutation N.
- A magnetic dipole (particle with spin and momentum) in an external magnetic field $\vec{B} \rightarrow$ precession.

$$\vec{\omega}_a = -a_\mu \frac{q\,\vec{B}}{m}.$$

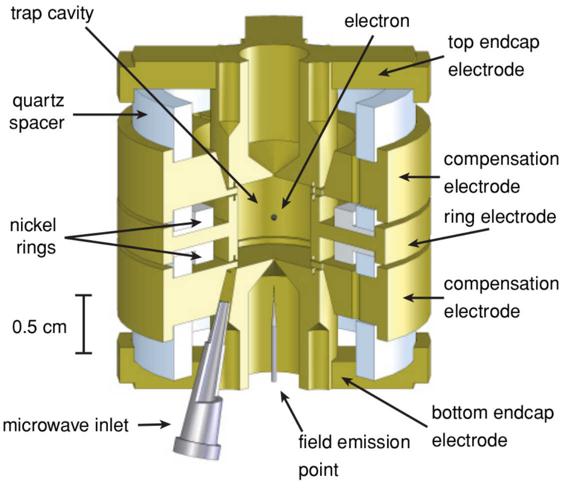
- Through precession frequency $\vec{\omega}_a$ you measure anomalous magnetic moment a_μ.
- Highly uniform magnetic field $\vec{B}$ needed!
- Possible for electrons and muons (2×10^{-6}s), tauons have too short lifetime (3×10^{-13}s).



Wikimedia Commons

Electron and fine-structure constant α

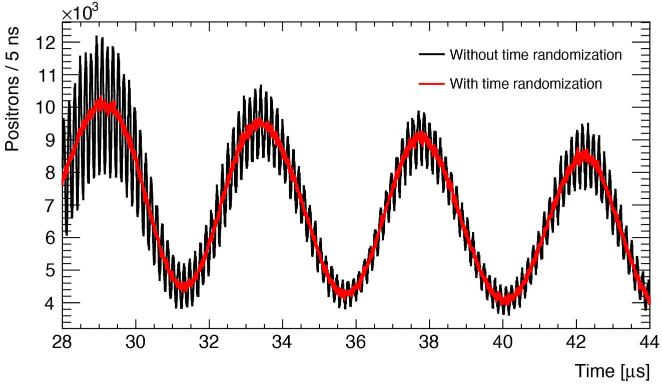
- Electron trapped in cyclotron.
- You only need to measure the spin and cyclotron frequency.
- QED contribution dominates.
- a^{QED} proportional to α.
- Measurement of electron anomalous magnetic moment allows us a direct access to fine-structure constant!
- Measured with an accuracy to 12 digits.
- The most precise measurement of a constant in the history of physics.
- $\alpha^{-1} = 137.035999084(51)$



Hanneke *et al.*: Phys. Rev. A 83, 052122 (2011)

Muon and the latest evidence of BSM

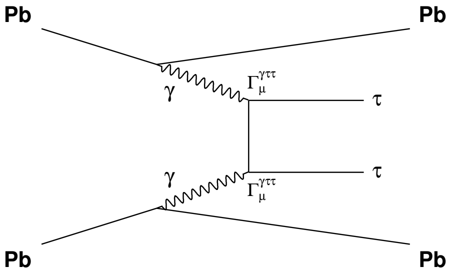
- Example: Fermilab Muon $g-2$ Collaboration, details: Phys. Rev. D 103, 072002 (2021).
- (Almost) exclusively $\mu^{\pm} \rightarrow \mathrm{e}^{\pm} + \bar{\nu}_{\mathrm{e}/\mu} + \nu_{\mu/\mathrm{e}}$, $\gamma \approx 30 \rightarrow \bar{\tau}_{\tau} = 60 \times 10^{-6}\mathrm{s}$.
- Measurement of the positron energy spectrum.
- Muon spin and momentum aligned = spectrum easiest.
- Muon spin and momentum anti-aligned = spectrum steepest.
- N events in certain energy interval is changing with time.
- Modulation frequency = $\vec{\omega}_a$.
- 4.2σ strong evidence!
- Other explanation within QCD: arXiv:2002.12347



Muon g-2: Phys. Rev. Let. 126, 141801 (2021)

Measurement method: Differential cross section of τ production

- $\gamma\tau\tau$ vertex is sensitive to a_τ.
- Two vertices = enhanced sensitivity.
- Different options like $e^+e^- \to \tau\tau(e^+e^-)$ and $Z \to \tau\tau\gamma$...
- ...or employ UPCs!
- Great source of photons at hadron colliders.
- $q^2 \to 0$ is ideal.

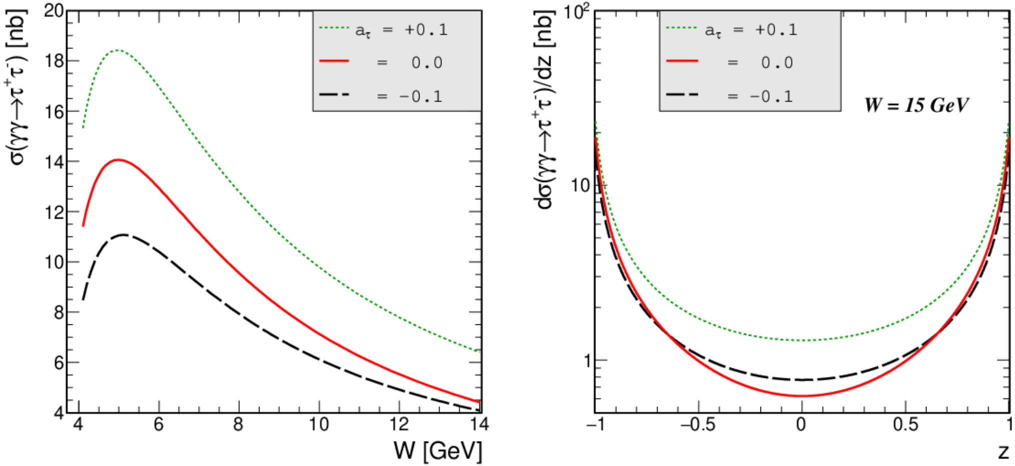


- Proposed for LHC (and SSC) in 1991, del Aguilla *et al.*: Phys. Lett. B 271 (1991) 256.
- SM effective field theory (SMEFT), Bereford *et al.*: Phys. Rev. D 102, (2020) 113008.
- Direct calculation, Dyndal *et al.*: Phys. Lett. B 809, (2020) 135682.

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

a_τ connection to cross section

- Non-trivial, but observable dependency on W, $z = \cos\theta$ (in $\gamma\gamma$ CM frame).



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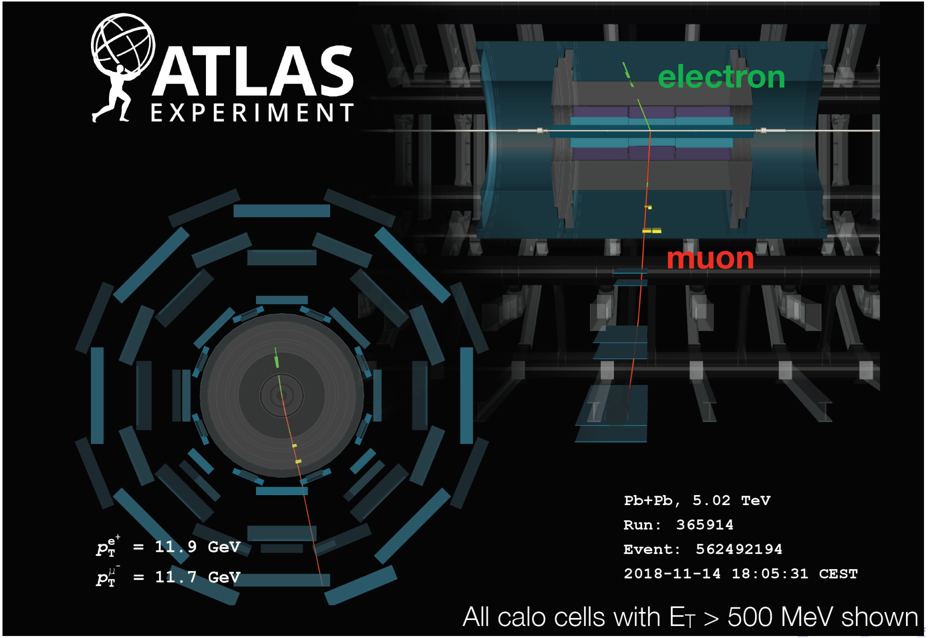
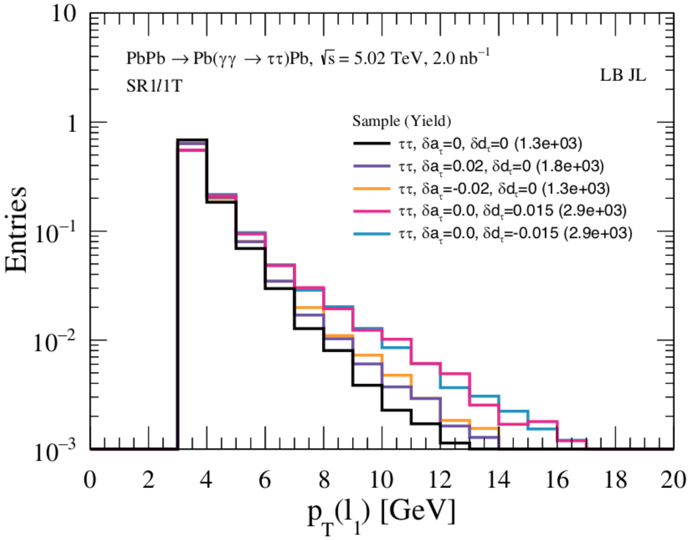


ATLAS
EXPERIMENT
electron
muon
$p_T^{e^+}$ = 11.9 GeV
$p_T^{\mu^-}$ = 11.7 GeV
Pb+Pb, 5.02 TeV
Run: 365914
Event: 562492194
2018-11-14 18:05:31 CEST
All calo cells with E_T > 500 MeV shown

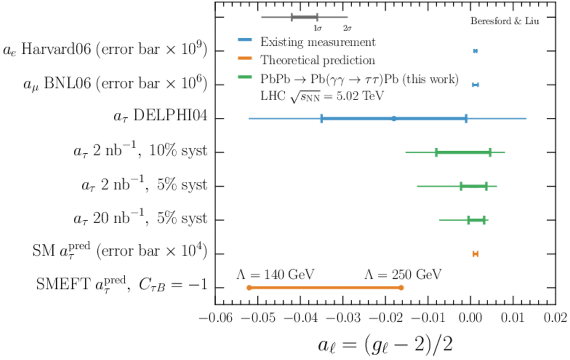
p_T-spectrum sensitivity to a_τ

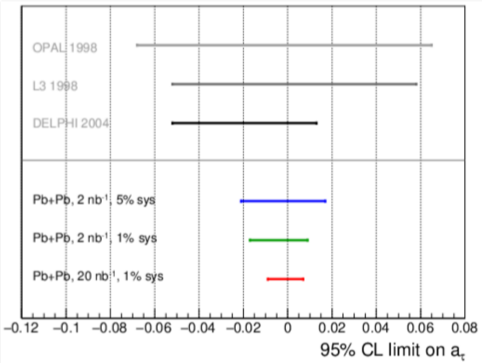
Bereford *et al.*: Phys. Rev. D 102, (2020) 113008.



New possible limits by ATLAS/CMS and its comparison to current values

Bereford *et al.*: Phys. Rev. D 102, (2020) 113008.

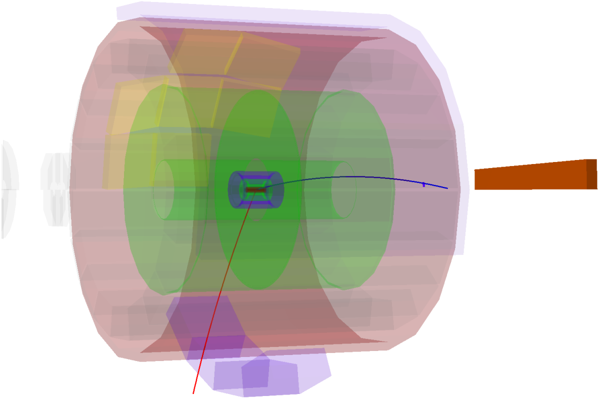


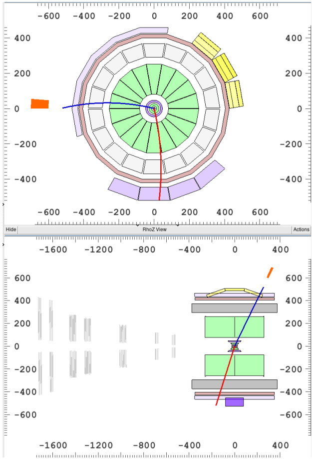


Dyndal *et al.*: Phys. Lett. B 809, (2020) 135682.

- ATLAS/CMS Run 2 statistics estimates: 1280 events (2 nb^{-1}).
- Systematics can strongly limits this measurement.

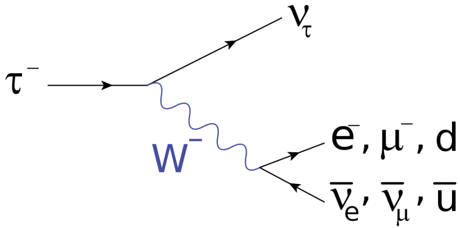
ALICE possibilities





Event selection strategy

- 1-prong decay ($\sim 80\%$):
  - $\tau^{\pm} \rightarrow e^{\pm} + \bar{\nu}_{e/\tau} + \nu_{\tau/e}$ (17.8%)
  - $\tau^{\pm} \rightarrow \mu^{\pm} + \bar{\nu}_{\mu/\tau} + \nu_{\tau/\mu}$ (17.4%)
  - $\tau^{\pm} \rightarrow \pi^{\pm} + n\pi^{0} + \nu_{\tau}$ (45.6%)
- 3-prongs decay ($\sim 20\%$):
  - $\tau^{\pm} \rightarrow 3\pi^{\pm} + n\pi^{0} + \nu_{\tau}$

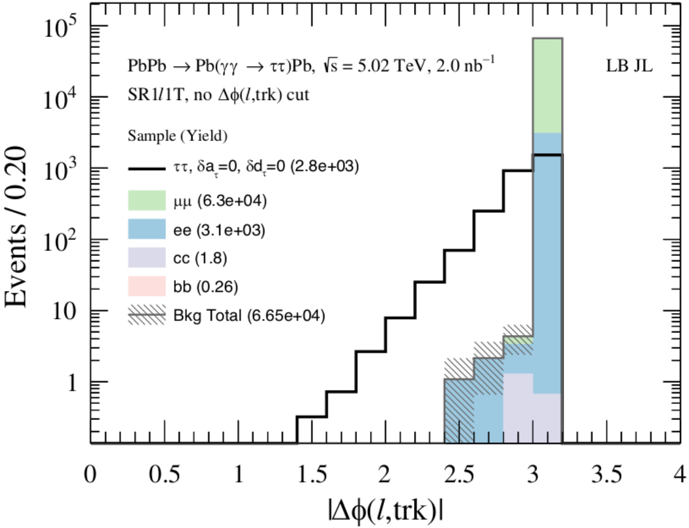


- ALICE strategy:
  - Exclusivity requirement: to avoid $\gamma\gamma \rightarrow q\bar{q}$ (or UPCs dipion), one decay is leptonic.
  - Midrapidity: Separation of μ and π with central barrel impossible $\rightarrow$ looking for electron(positron) + charged track (muon/pion).
  - Semi-forward rapidity: Forward muon + charged track in central barrel.
  - Forward rapidity: Only muon channel $\rightarrow$ suppressed to other cases.

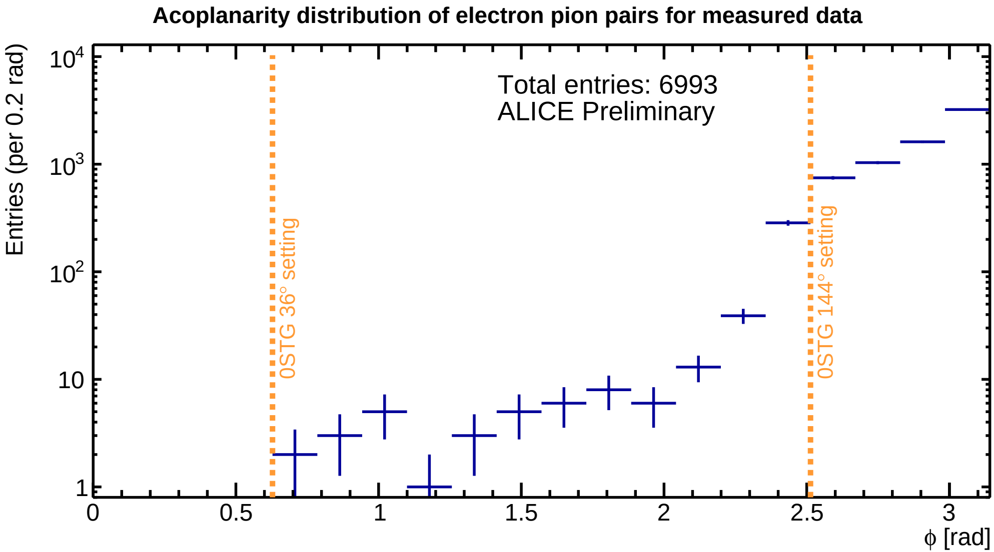
Suppressing background - acoplanarity cut

- Background from continuum.
- Avoiding back-to-back tracks.
- Run 2 trigger strategy did not favor such events.

Bereford *et al.*: Phys. Rev. D 102, (2020) 113008.

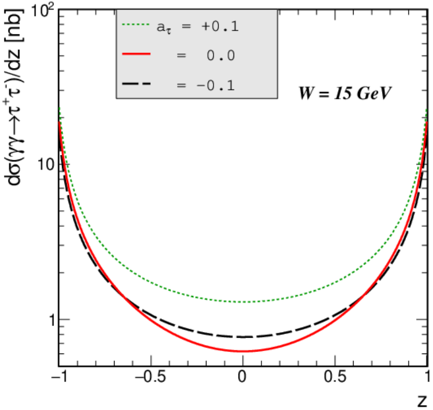


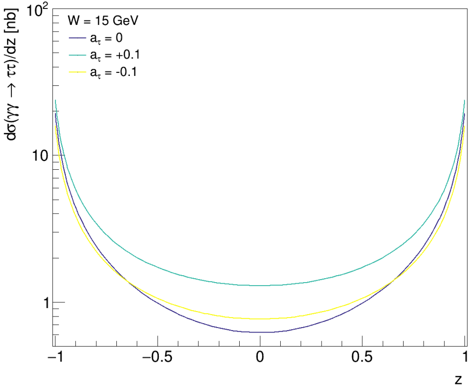
Example: Run 2 2018 Pb–Pb collisions, 0.23nb^{-1}



Simulations: Run 3 2022 Pb–Pb collisions, 2.3nb^{-1}

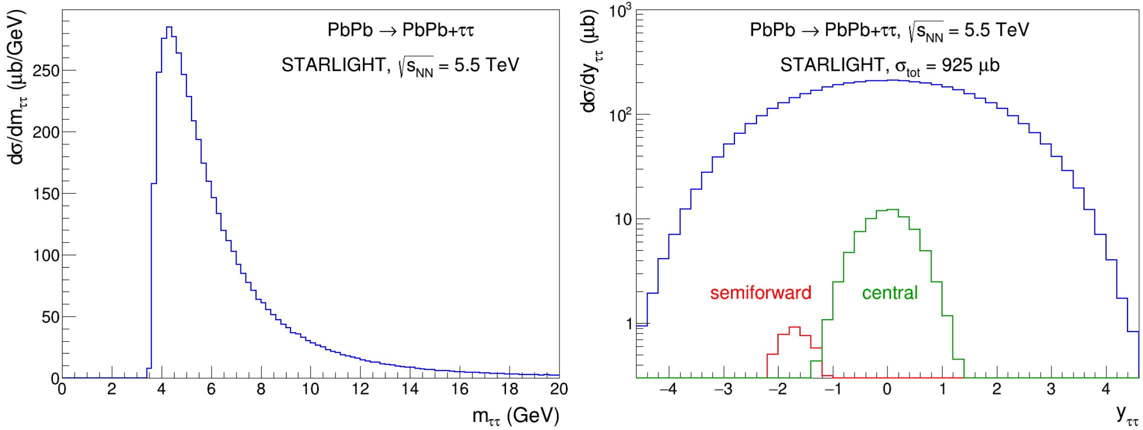
Dyndal *et al.*: Phys. Lett. B 809, (2020) 135682.





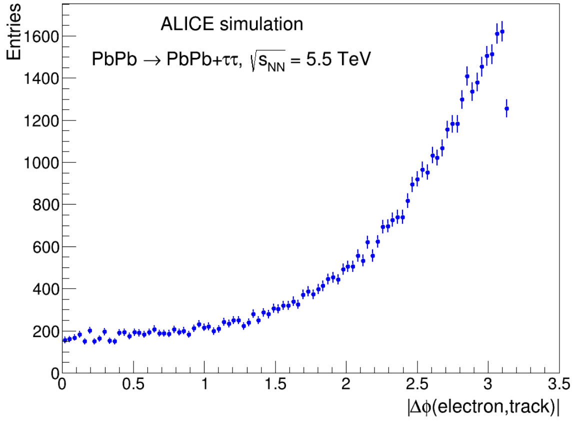
- Our simulations reproduce well those used for ATLAS/CMS.

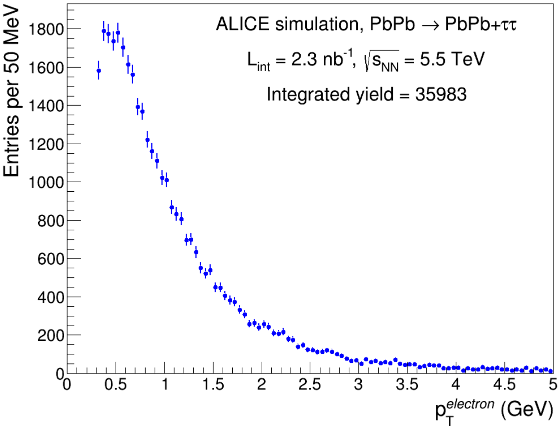
Simulations: Run 3 2022 Pb–Pb collisions, 2.3nb^{-1}



- 36 000 events in central barrel (electron + muon/pion).
- 2 000 events in semi-forward rapidity (two muons).

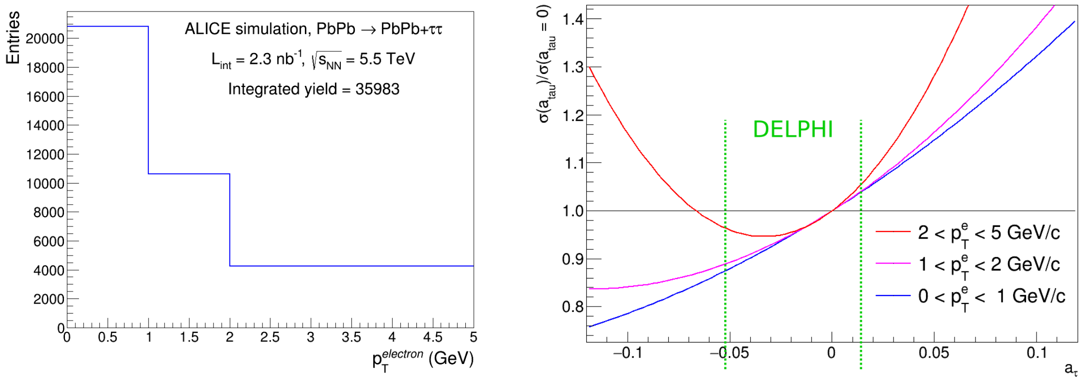
Simulations: Run 3 acoplanarity cut





- Still many events available after acoplanarity cut.

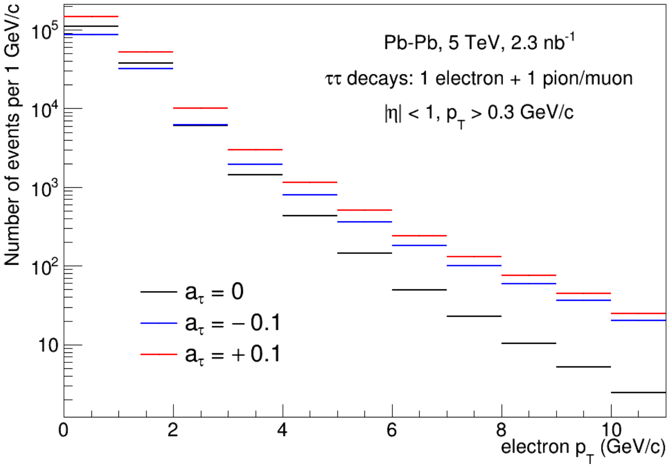
Simulations: Run 3 a_τ and cross section ratio p_T dependency



- Parabolic shape of ratio of electron p_T-differential cross sections in the vicinity of $a_\tau = 0$.
- Up to 15% variations of the yields within the range restricted by DELPHI limits.

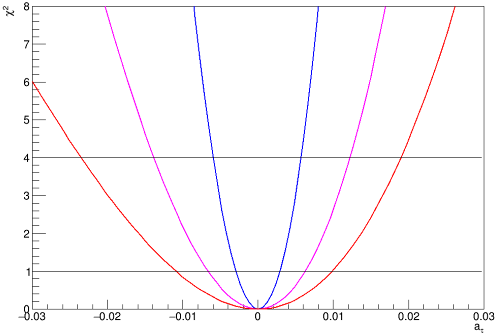
Simulations: Run 3 differential p_T-spectrum

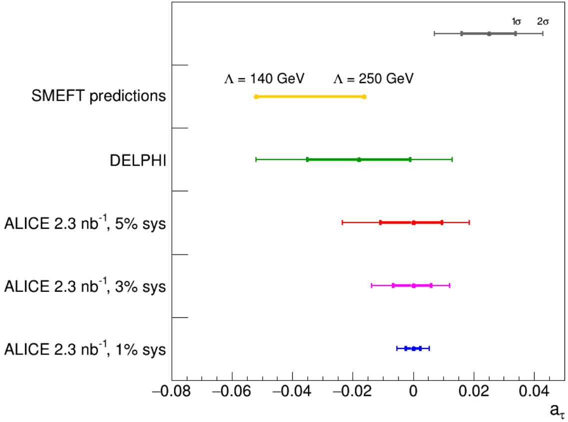
- We can also try to perform p_T-differential measurement.
- A lot of low-p_T events, where ALICE has a good sensitivity.
- Positive a_τ cross sections above Standard Model.
- Negative a_τ p_T-differential cross section distribution steeper than Standard Model.



Simulations: Run 3 a_τ limits from p_T-differential measurement

- Combining the cross section ratios of different p_T intervals.
- Using χ^2 sum of 10 p_T intervals.
- Uncorrelated systematics.
- Limits improvement looks feasible.





Summary

- Determination of anomalous magnetic moment is a powerful check of Standard Model.
- Heavy weight of tau-lepton provides the best sensitivity.
- LHC beams together with the ALICE detector with good low-momentum resolution provides us a unique opportunity for a competitive measurement.
- Pb–Pb collisions in upcoming Run 3 will deliver enough luminosity to try to improve the current experimental limits 2-8$\times$.
- There is still some work to do before 2022 data-taking:
  - Fine-tune our simulations to have a great control on possible systematic effects.
  - Understanding the background in detail.
  - Identifying the best selection criteria.
- Other news:
  - Austrian representative in ALICE computing resource board.

Time for your questions, please

back up