Summary of WG3

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TÜBINGEN

9. Mai 2022

Topics

Electroweak physics

- Higgs physics
- Gauge boson production and vector boson scattering
- Photon induced processes
- Kaon physics
- Top quark physics
- Rare processes

$\longleftrightarrow$

Beyond Standard Model physics

- Dark matter
- Searches for new physics
- Specific Models with New Physics
- Effective Field Theories

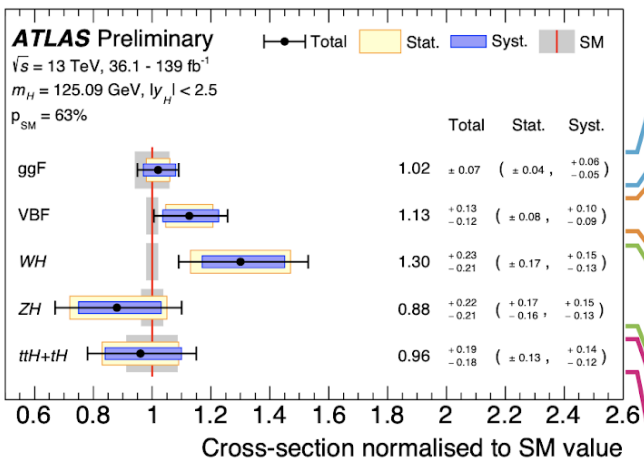
Higgs physics

- Precise measurements

Production-mode cross-sections

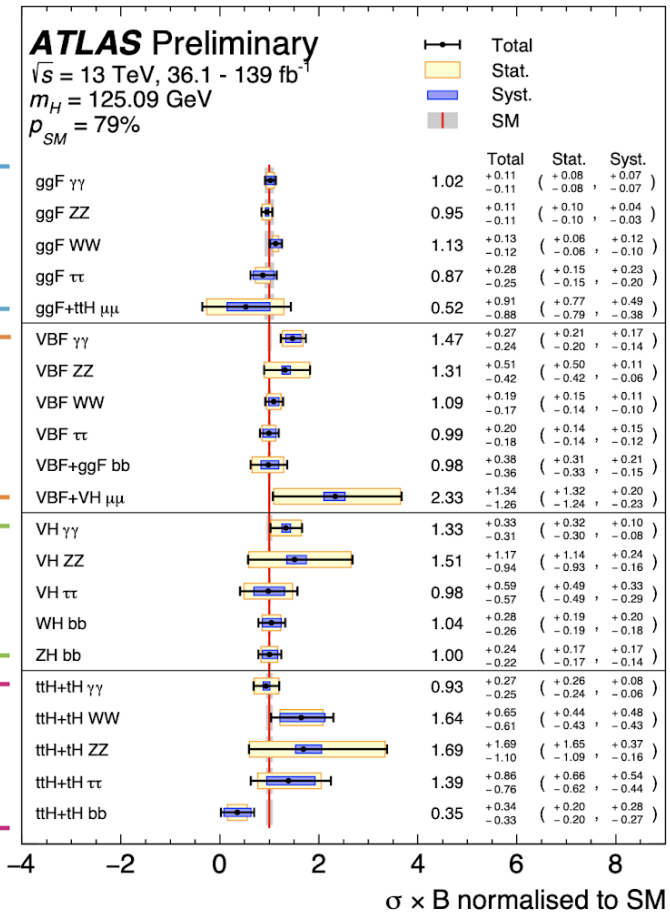
Production mode cross-sections measured to O(10-20%) precision

(ggF competitive with theo. unc.!)



(assuming Standard Model decays)

Run 2 data set also gives more "differential information"



Higgs physics

- Precise measurements
- Sophisticated interpretations in the kappa framework, SMEFT or specific models

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tH & $t\bar{t}H$ $(H \to \gamma\gamma)$

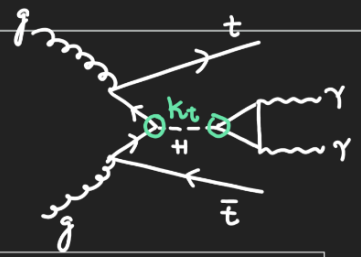
14

CP Measurement

top Yukawa coupling parameter

CP mixing angle

$$\mathscr{L} = -\frac{m_t}{v}\left\{\bar{\psi}_t \kappa_t \left[\cos(\alpha) + \mathrm{i}\sin(\alpha)\gamma_5\right]\psi_t\right\} H$$



- Analysis targets tH and $t\bar{t}H$ production modes.
- The CP-odd contribution introduces a second coupling to the top quark, which modifies the $H \to \gamma\gamma$ decay rate.

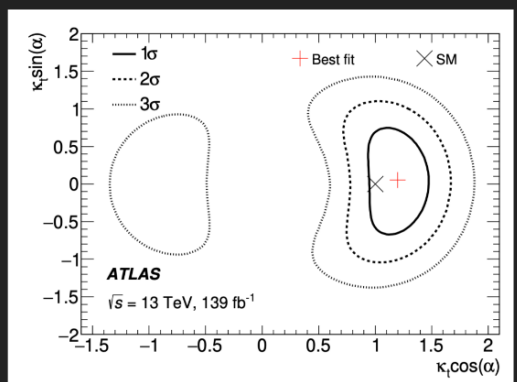
- Without prior constraints on κ_t, $|\alpha| > 43°(63°\text{expected})$ is excluded at 95% CL.
- $\alpha = 90°$ excluded at 3.9σ.
- Systematic uncertainties negligle.

"Lep" region

- Targets leptonic final state
- >= 1 isolated lepton

"Had" region

- Targets hadronic final state
- >= 2 additional jets and no leptons



arXiv:2004.04545

slide from talk by Sagar Addepalli

Higgs physics

- Precise measurements
- Sophisticated interpretations in the kappa framework, SMEFT or specific models
- Study of the CP-property of the discovered Higgs boson
- Di-Higgs production and constraints on $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{\text{SM}}$:

  λ_{HHH} = **trilinear Higgs coupling**

  ATLAS: observed: $-1.0 \leq \kappa_\lambda \leq 6.6$, expected: $-1.2 \leq \kappa_\lambda \leq 7.2$

  $\rightarrow$ talk by Jana Schaarschmidt

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- Searches for rare and exotic Higgs decays

  $\Rightarrow$ Constraints on additional scalars

  $\rightarrow$ talk by Diallo Boye

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Higgs physics

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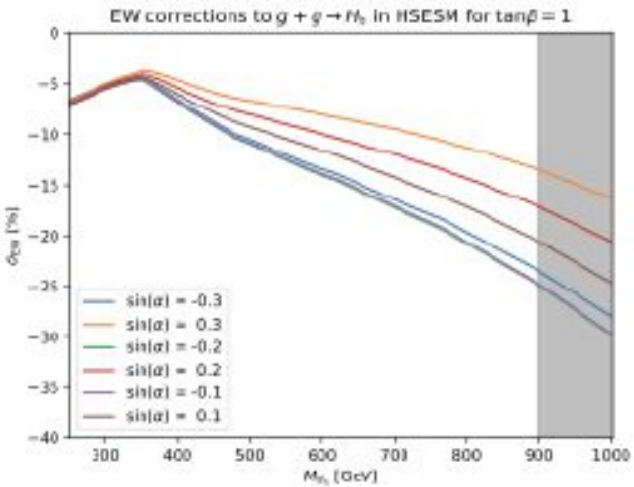

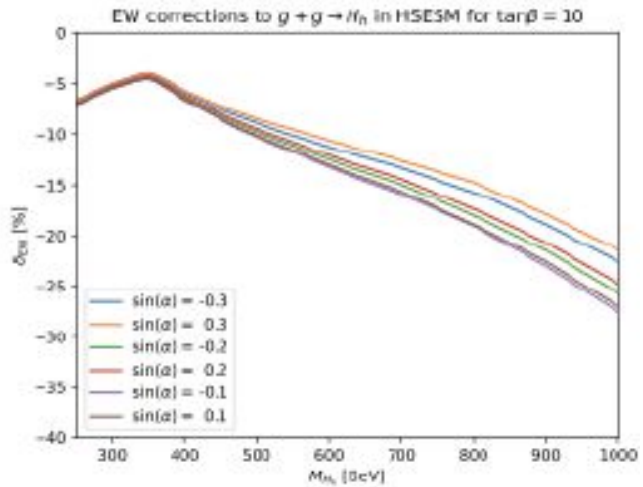

- Contributions that are sensitive to the sign of $\sin\alpha$ are $\tan\beta$-suppressed $\Longleftarrow$ true for all 4 processes!
- Corrections of -25% even in the fully perturbative regime!

$\rightarrow$ talk by Benjamin Summ

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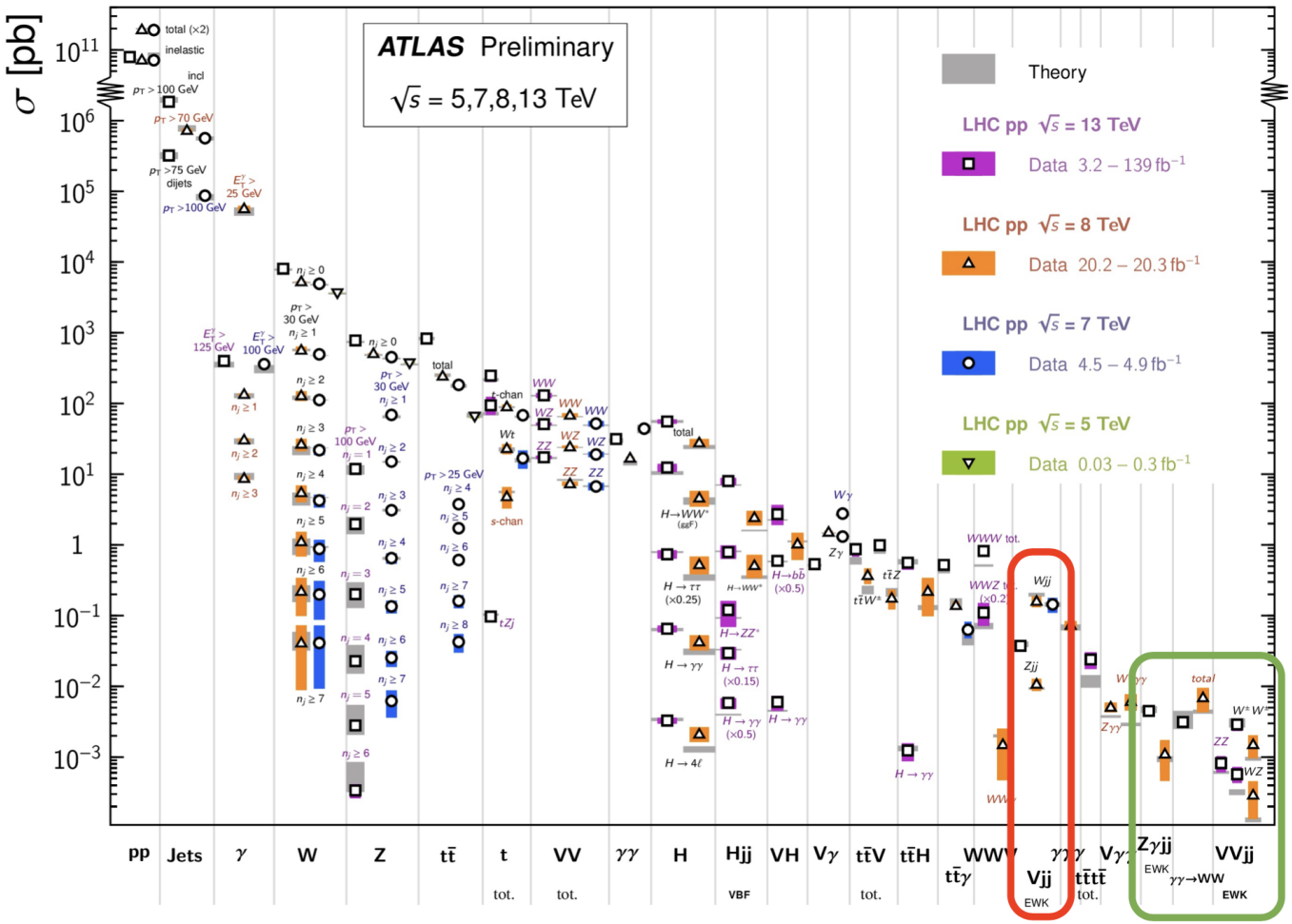
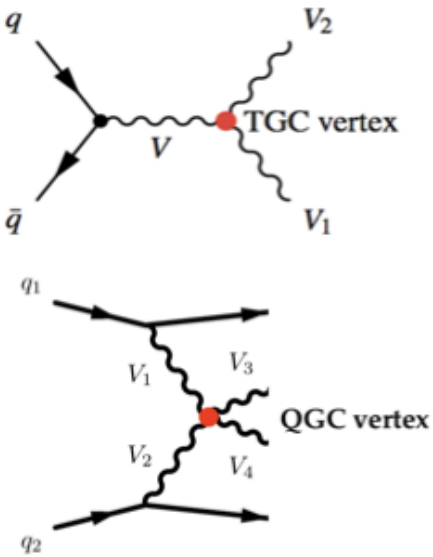
- Searches for rare and exotic Higgs decays
- Electroweak corrections to gluon fusion and Higgs decay to two photons in an singlet extension of the Standard Model
- ILC: Sensitivity study:
  Higgs coupling to strange quarks: $\kappa_s < 6.74$
  $\rightarrow$ Matthew Basso's talk

Gauge-boson production



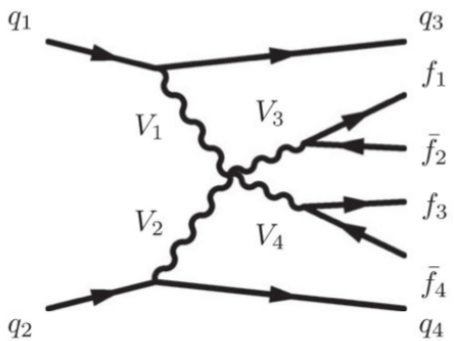
- Diboson prod.: Precision
- Diboson + jets, triboson prod.: Discovery

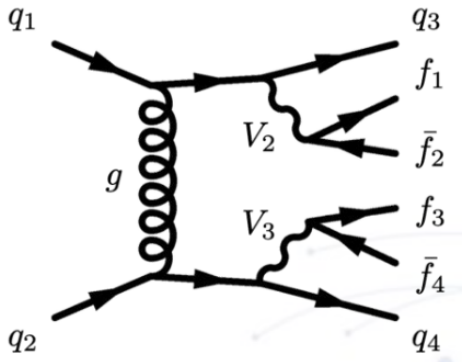


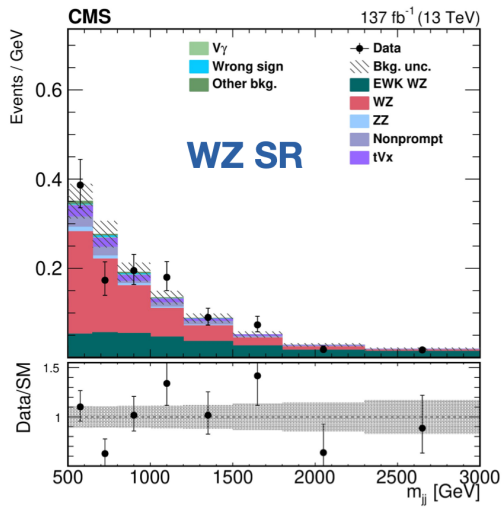
Test of SM multiboson coupling

Diboson production in Vector Boson Scattering (VBS)

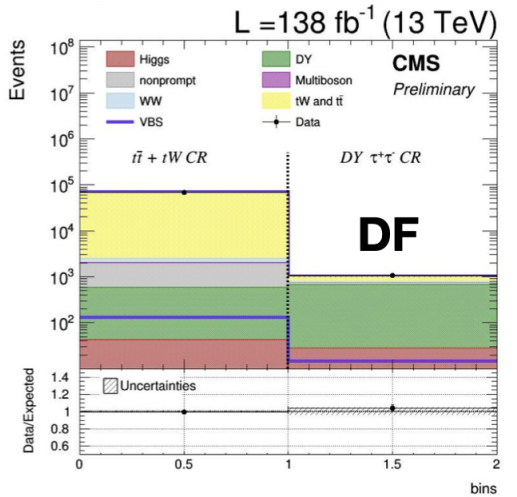
Separating electroweak from QCD contributions:



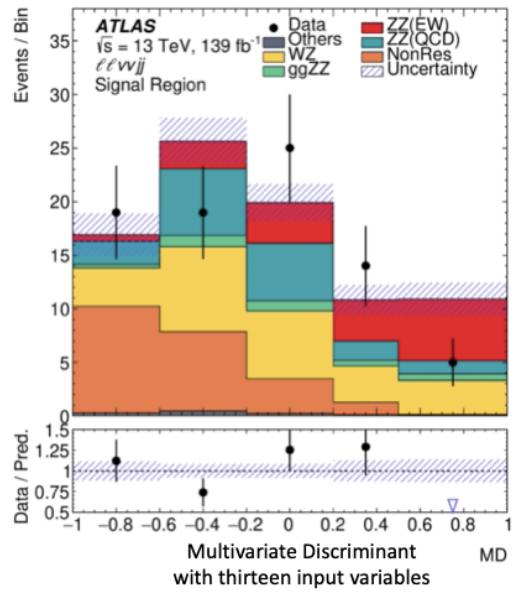




→ A. Piccinelli's talk



First observation in WW leptonic VBS



→ talk by A. Bellerive

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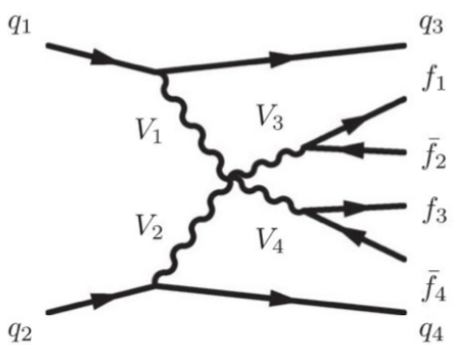
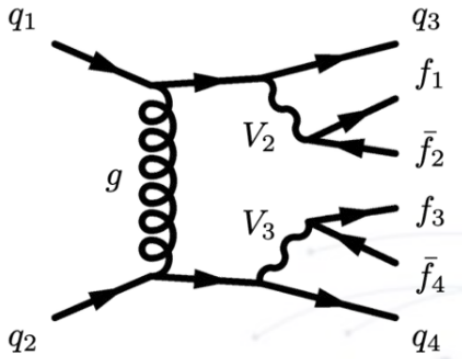
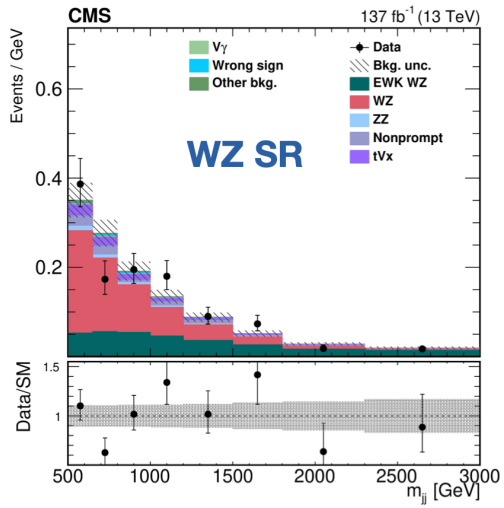




- see also the results by CMS-Totem Precision Proton Spectrometer
  → Enrico Robutti's talk



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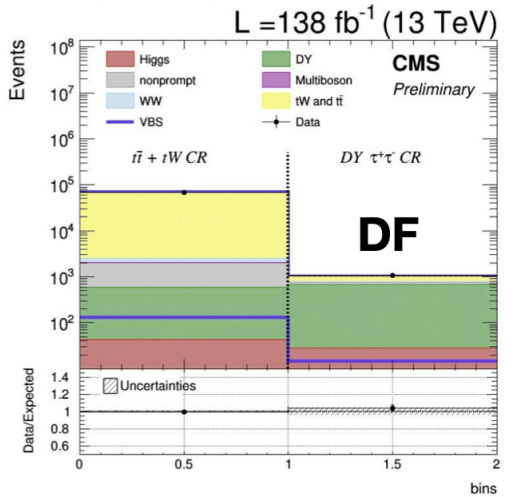

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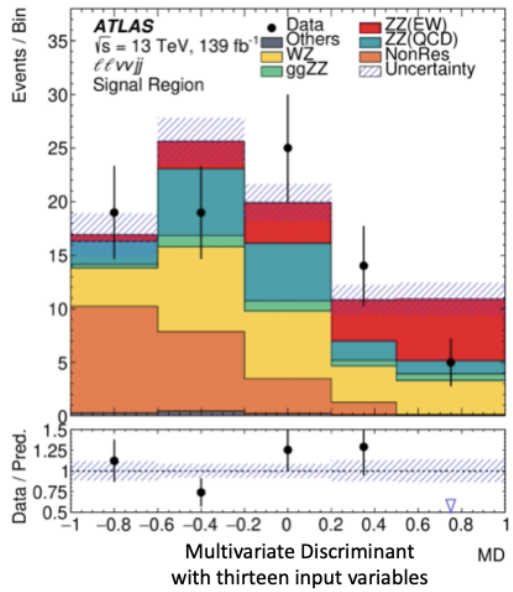

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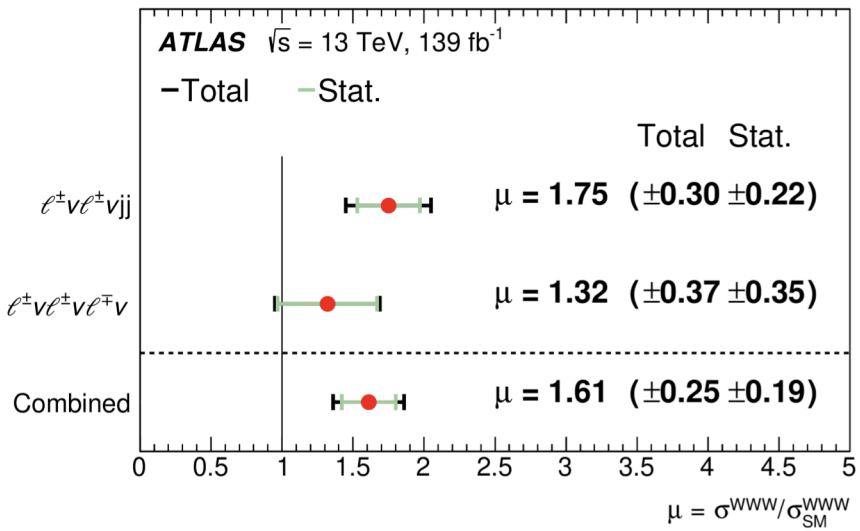
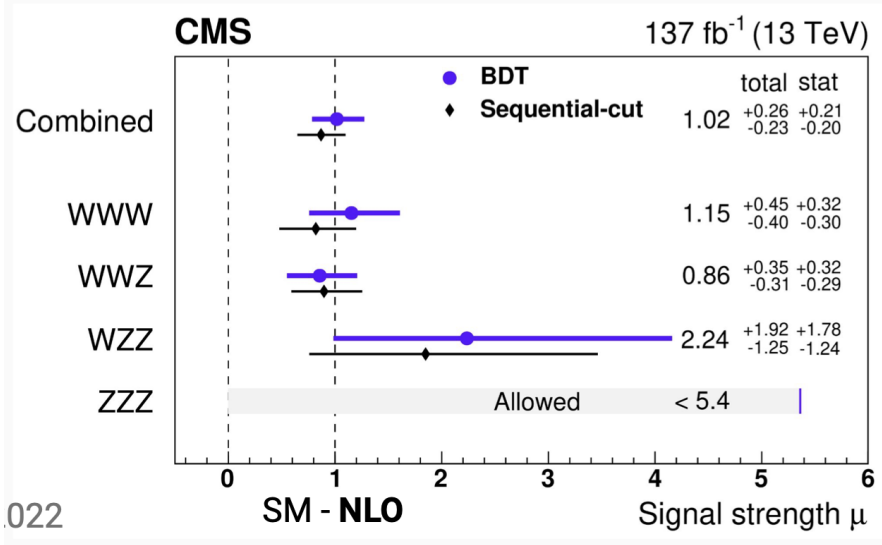
Triboson discovery by ATLAS and CMS





→ Ruchi Gupta's talk

→ Alberto Mecca's talk

Interpreted in an EFT framework

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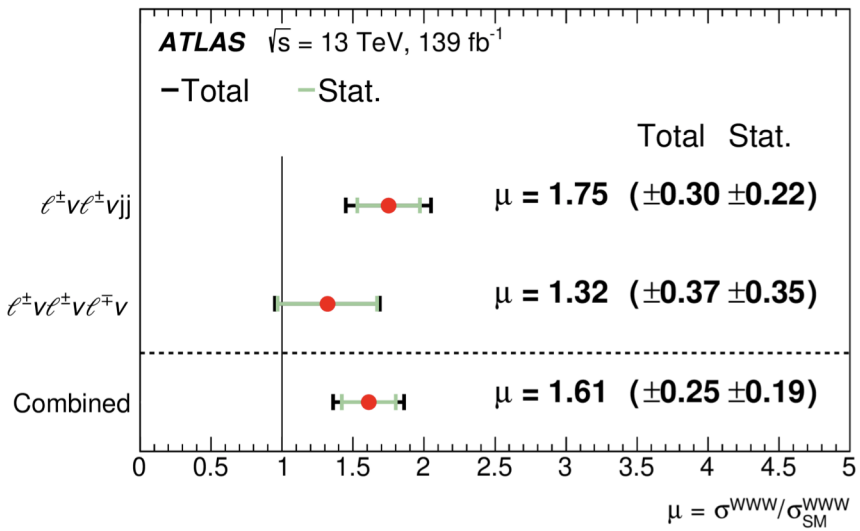

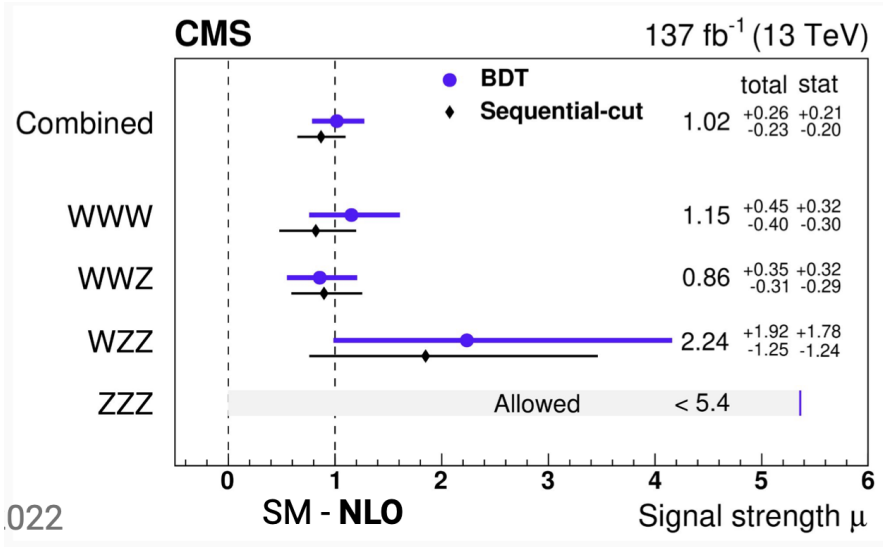

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For further results, e.g. $V\gamma$ production

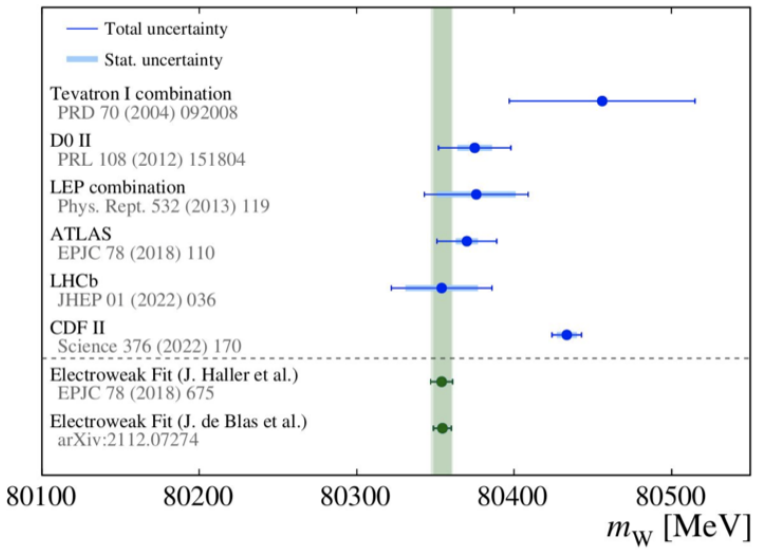
→ talk by Santiago Folgueras, CMS

W mass measurement from LHCb

The current picture of the measurement

- Striking result from the CDF II collaboration in early April [Science, 376, 6589, (136-136), (2022)], with unprecedented precision
- 7σ away from the electroweak fits, and in tension with other experimental results
- Open questions now being raised:
  - Resolution, efficiency and detector response
  - Physics modelling (proton-proton, proton-antiproton, PDFs, ...)
- Encouraging the full LHC combination

[LHCB-FIGURE-2022-003]



Uncertainty budget

[JHEP 01 (2022) 036], [LHCB-PAPER-2021-024]

Source	Size (MeV)
Parton distribution functions	**9.0**
Total theoretical syst. uncertainty (excluding PDFs)	**17.4**
Transverse momentum model	12.0
Angular coefficients	9.0
QED FSR model	7.2
Additional electroweak corrections	5.0
Total experimental syst. uncertainty	**9.7**
Momentum scale and resolution modelling	7.5
Muon ID, tracking and trigger efficiencies	4.3
Isolation efficiency	3.9
QCD background	2.3
Statistical	**22.7**

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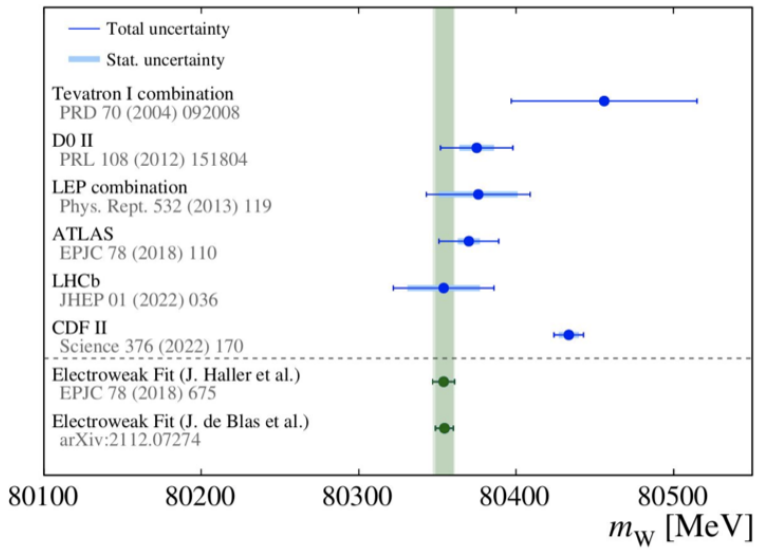

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- Third-order predictions for Z and $W^{\pm}$ q_T spectra at the LHC

→ Johannes Michel's talk

SMEFT and beyond

- Sensitivity study to dim. 6 EFT operators at the LHC:
  EW VBS phenomenology richer than diboson
  $\rightarrow$ sensitive to many operators
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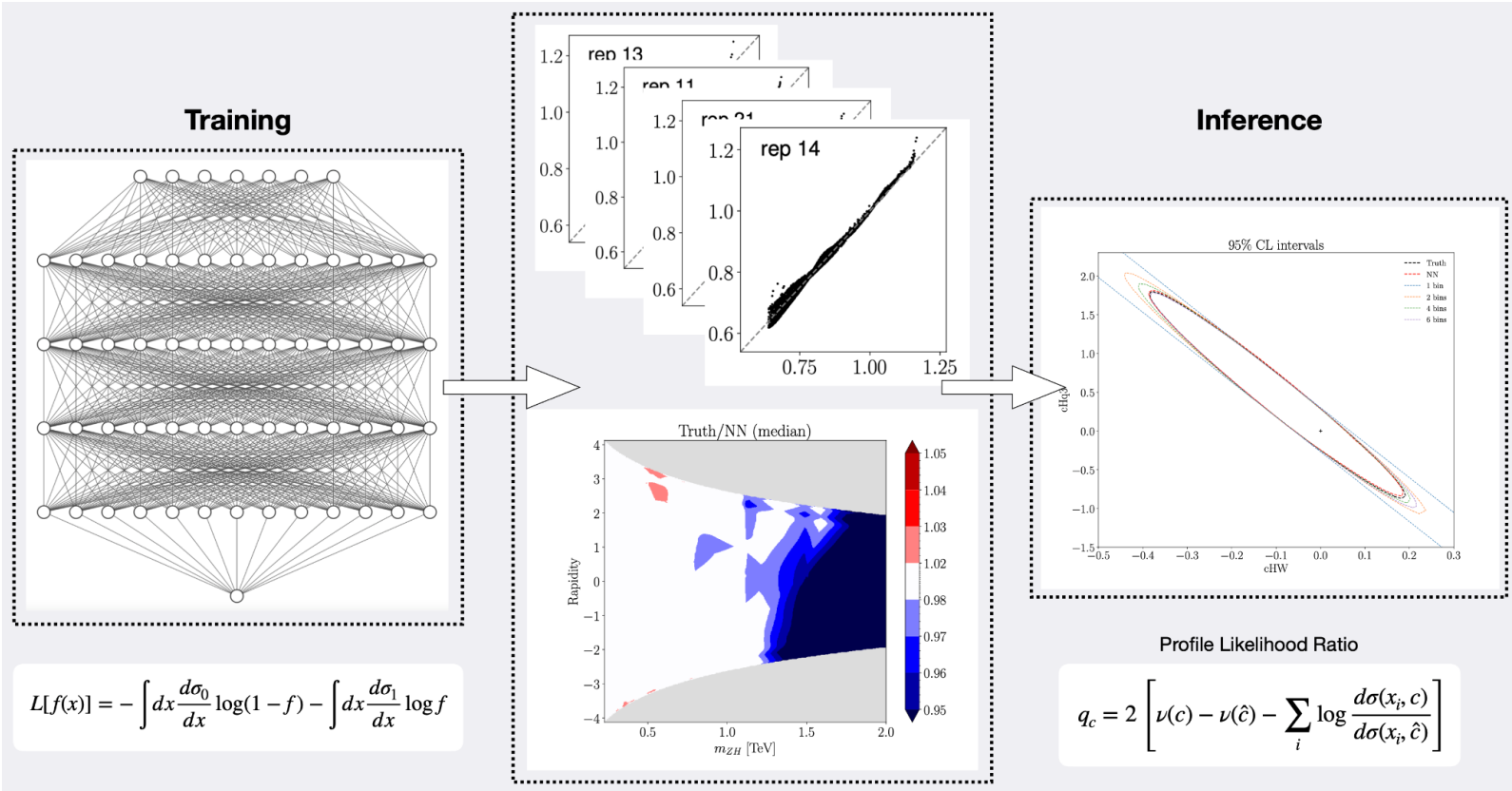

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- Non-dim.-6 SMEFT operators in LEFT
  e.g. $(\bar{\nu}_\ell \gamma_\mu P_L \ell)(\bar{c}\gamma^\mu P_R b) \Rightarrow$ need at least dim.-8 SMEFT operators
  $\rightarrow$ Jacky Kumar's talk

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- Exotic charges under SU(3): Operators with exotic fields
  $\rightarrow$ Linda Carpenter's talk

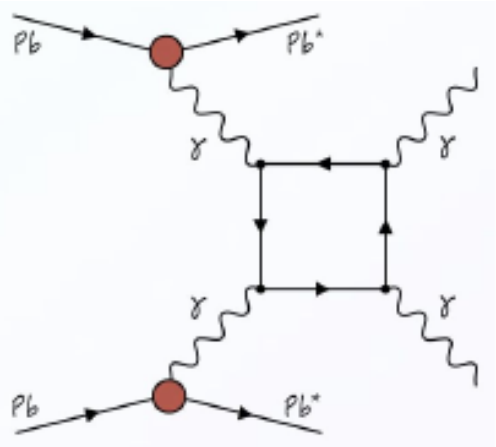
Light-by-light scattering

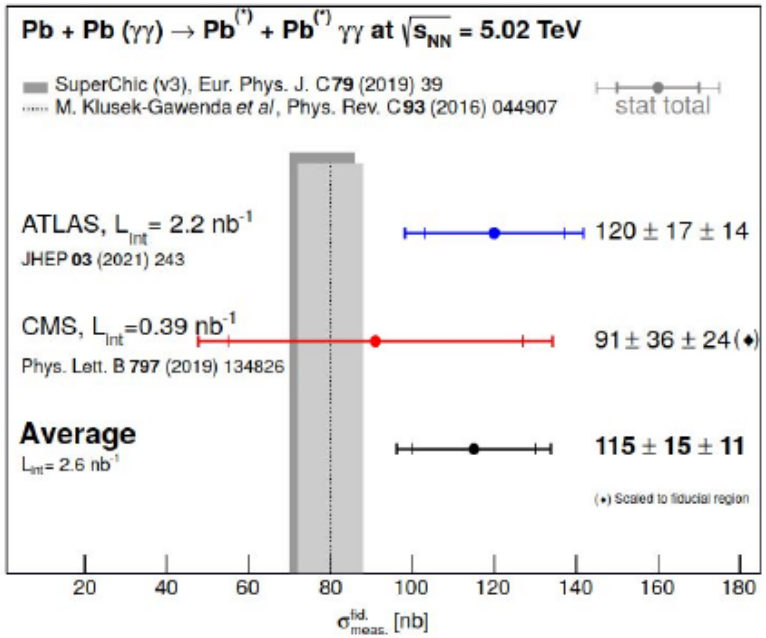
in ultra-peripheral collisions (UPCs)

- Used Best Linear Unbiased Estimator (BLUE v2.4.0) to average the cross-sections.

$$\sigma^{\text{fid.}}_{\text{meas.}} = 115 \pm 15\,(\text{stat.}) \pm 11\,(\text{syst.}) \pm 3\,(\text{lumi.}) \pm 3\,(\text{theo.})\ \text{nb}$$
$$= 115 \pm 19\ \text{nb},$$

- The averaged cross-section is consistent within ~2σ with standard model predictions.
- It is currently limited by the statistical uncertainty.





arXiv:2204.02845

→ talk by Ruchi Chudasama, CMS
see also talk by Iwona Grabowska-Bold, ATLAS

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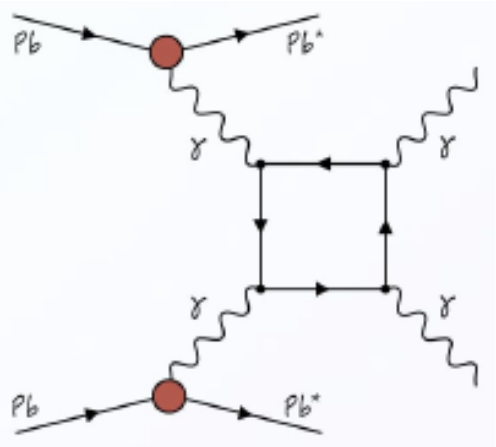
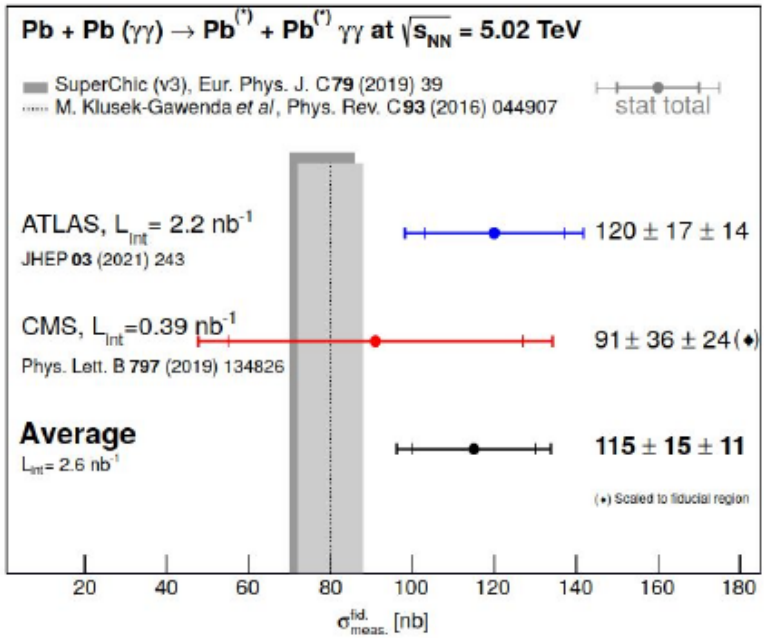




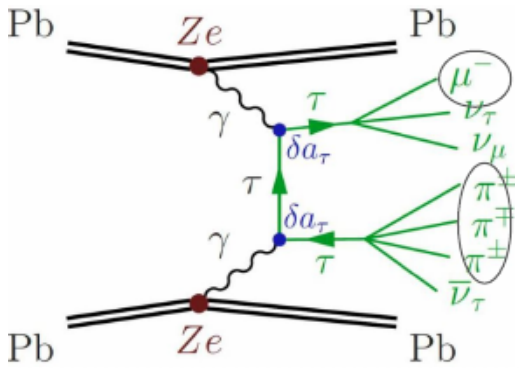
arXiv:2204.02845

⇒ Constraints on ALP mass

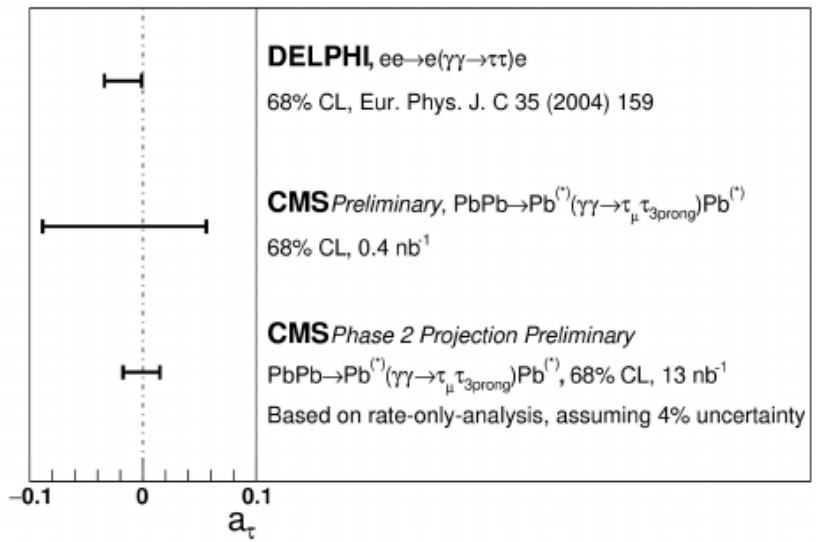
5 GeV $\leq m_a \leq$ 90 GeV (CMS)

6 GeV $\leq m_a \leq$ 100 GeV (ATLAS)

Anomalous magnetic moment of the tauon a_τ



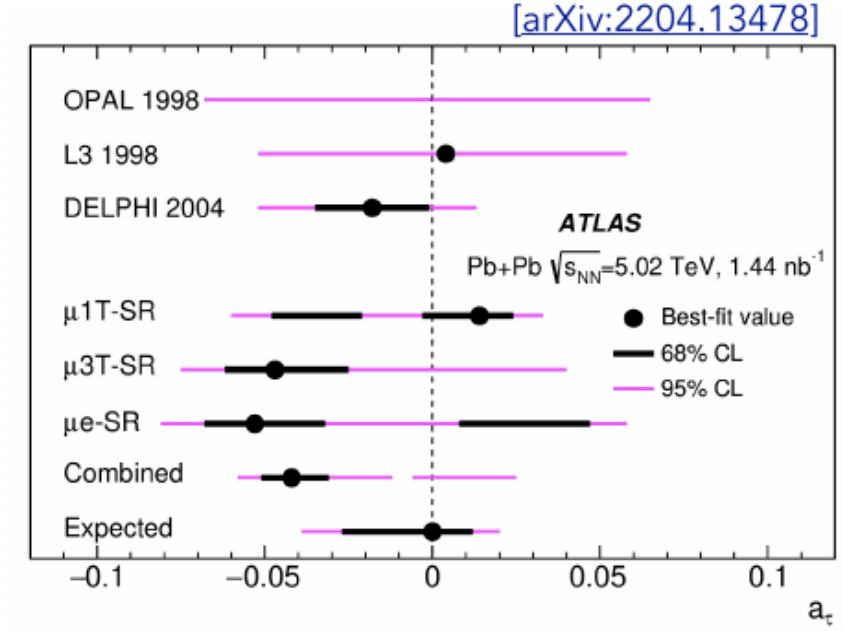
$\Rightarrow a_\tau$



First limits by CMS

→ Georgios Krintiras' talk

[arXiv:2204.13478]



First final measurement:

$a_\tau \in (-0.058, -0.012) \cup (-0.006, 0.025)$

→ Iwona Grabowska-Bold's talk

Parton distribution functions with photons and more

- NNLO QCD is standard for inclusive processes:

  since $\alpha_{\mathrm{QED}}(M_Z) = \alpha_s^2(M_Z)$: QED effects need to be included:

  $\Rightarrow$ photon pdf

Two groups and several pdf sets:

- $\star$ MSHT20qed: Update of MMHT14qed $\rightarrow$ Lucian Harland-Lang's talk
- $\star$ CT18lux and CT18qed $\rightarrow$ Keping Xie's talk

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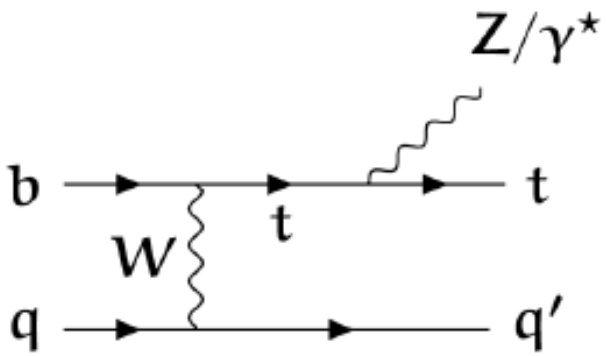
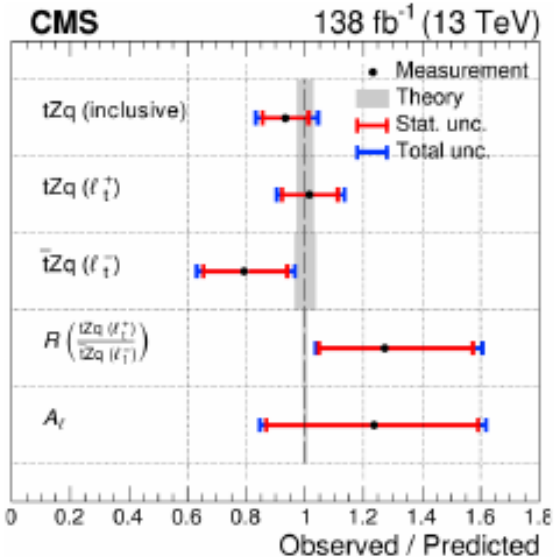
Two further studies:

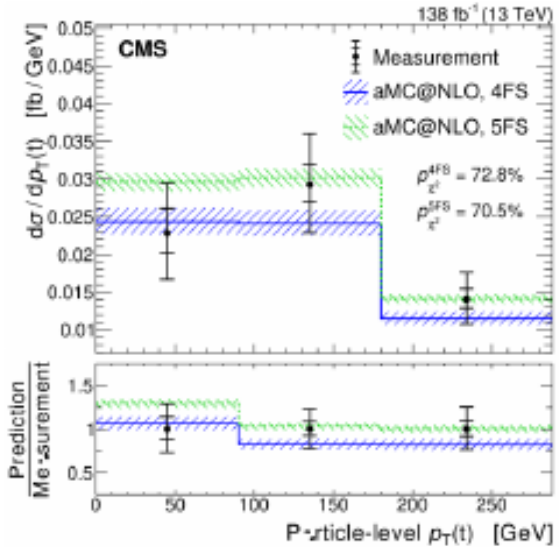
- ⋆ *WW* with rapidty gaps at the LHC
  interplay of (non)-photon-initated diagrams and multi-parton interactions
  $\rightarrow$ Lucian Harland-Lang's talk
- ⋆ Extension of general-mass heavy quark scheme to
  charged current DIS at (N)NNLO
  νDIS scale uncertainties reduced to $\sim 1-3$ %
  $\rightarrow$ Tim Hobbs' talk

Single Top Differential (tZq)

- Inclusive & first differential xsec measurements for tZq (pure EW production).





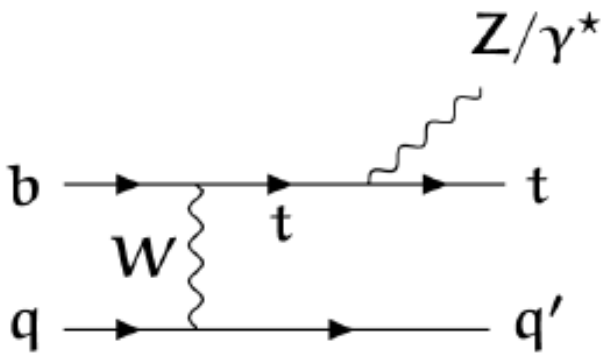


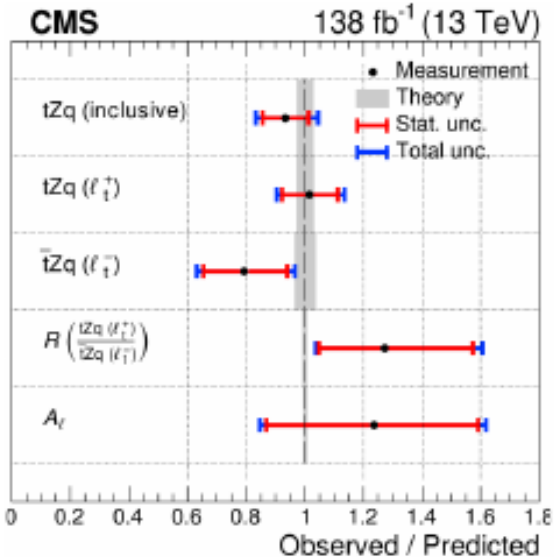
- Binned fit to multivariate classifier in 3-lepton events categorized w/ n_{jets} & $n_{b\text{-}jets}$.
- **Most precise tZq inclusive xsec so far.** Differential xsec compatible w/ SM & top spin asymmetry also consistent w/ SM.

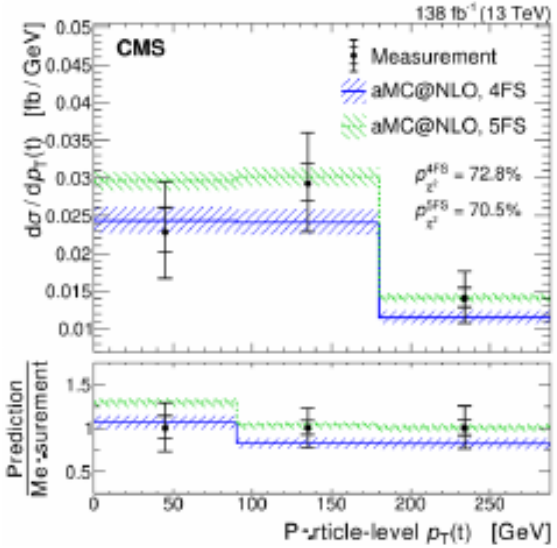
→ Hideki Okawa's talk

Single Top Differential (tZq)

- Inclusive & first differential xsec measurements for tZq (pure EW production).







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Further CMS top quark measurments:

Top quark production in *pp*, *pPb*, *PbPb*

→ Luis F. Alcerro's talk

Top quark energy asymmetry

- Select boosted $t\bar{t}$ + j events in the semi-leptonic decay channel
- measure energy asymmetry for the first time

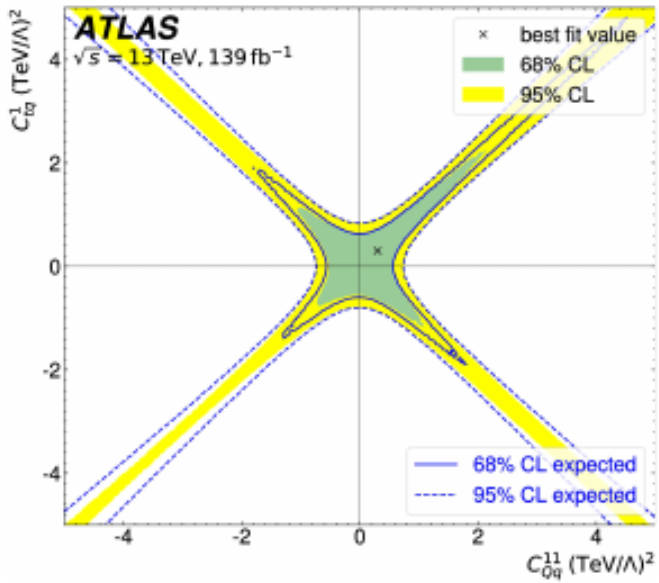
$$A_E(\theta_j) \equiv \frac{\sigma^{\text{opt}}(\theta_j|\Delta E > 0) - \sigma^{\text{opt}}(\theta_j|\Delta E < 0)}{\sigma^{\text{opt}}(\theta_j|\Delta E > 0) + \sigma^{\text{opt}}(\theta_j|\Delta E < 0)}$$

  - $\Delta E = E_t - E_{\bar{t}}$
  - θ_j the jet scattering angle w.r.t the beam axis

$$\sigma^{\text{opt}}(\theta_j) = \sigma(\theta_j|y_{t\bar{t}j} > 0) + \sigma(\pi - \theta_j|y_{t\bar{t}j} < 0)$$

- Set EFT limits on this asymmetry measurement

2D constraints

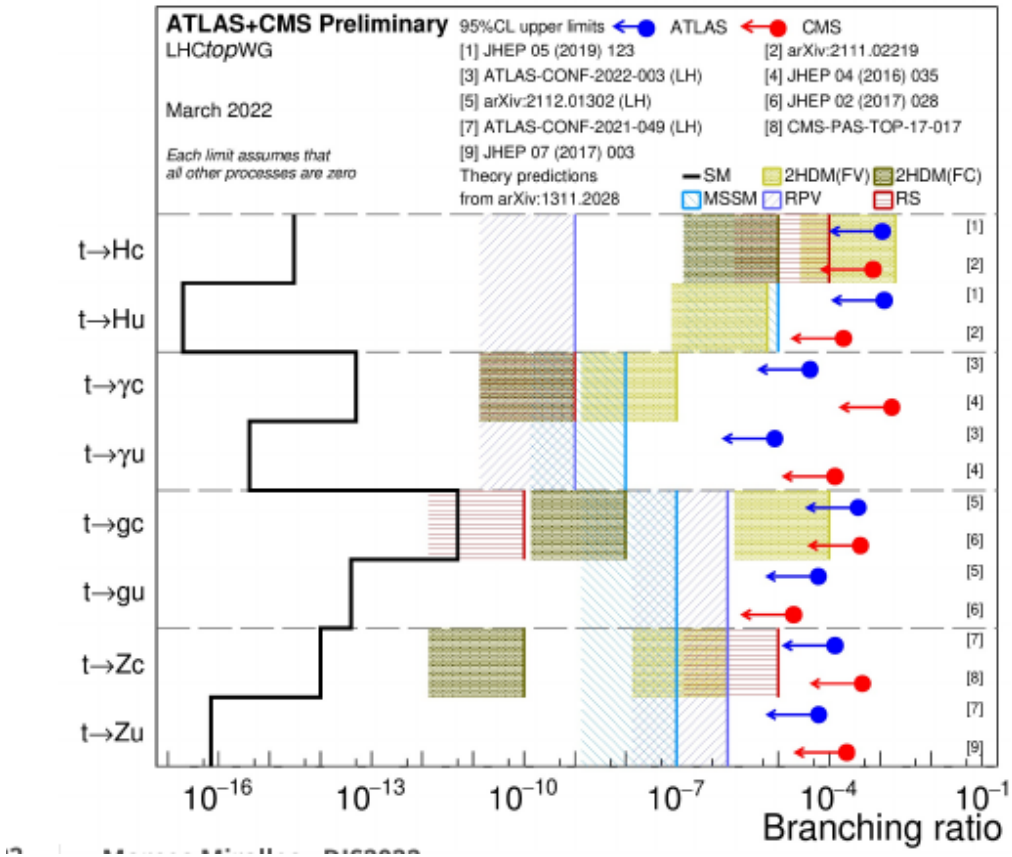


- A_E probes new directions in the parameter space of Wilson coefficients, complementing other observables the rapidity asymmetry

→ Shayma Wahdan's talk

Flavour changing neutral currents & off-shell effects

- FCNC constraints from top quark production:



→ Marcos Miralles' talk
→ Hideki Okawa's talk

- W decays in off-shell $t\bar{t}$ production at NLO+PS → tool `bb4l`
  → Tomáš Ježo's talk

Precision Kaon Physics

NA62 Lepton number/flavour violation summary:

→ Artur Shaikhiev's talk

	Previous UL @ 90% CL	NA62 UL @ 90%CL		
$K^+ \to \pi^-\mu^+\mu^+$	8.6×10^{-11}	4.2×10^{-11}	2017 data → improved by factor 2	Phys. Lett. B 797 (2019) 134794
$K^+ \to \pi^-e^+e^+$	6.4×10^{-10}	5.3×10^{-11}	Run1 data → improved by factor 12	NEW ! arXiv:2202.00331
$K^+ \to \pi^-\pi^0e^+e^+$	no limit	8.5×10^{-10}	Run1 data	
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10}	4.2×10^{-11}	2017+2018 data → improved by factor 12	PRL 127 131802 (2021)
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}	6.6×10^{-11}	2017+2018 data → improved by factor 8	
$\pi^0 \to \mu^-e^+$	3.4×10^{-9}	3.2×10^{-10}	2017+2018 data → improved by factor 13	
$K^+ \to \pi^+\mu^+e^-$	1.3×10^{-11}	-	sensitivity similar to previous search	
$\pi^0 \to \mu^+e^-$	3.8×10^{-10}	-	sensitivity similar to previous search	
$K^+ \to \mu^-\nu e^+e^+$	2.1×10^{-8}	-	Ongoing analysis on 2017 data: SES ~ 1×10^{-10}	
$K^+ \to e^-\nu\mu^+\mu^+$	no limit		Ongoing analysis on 2017 data: SES ~ 5×10^{-11}	

→ also Marco Mirra's talk

- The 2016-2017-2018 NA62 combined result for $K^+ \to \pi^+ \nu\nu$ has been presented
  - 20 events found

$$BR(K^+ \to \pi^+\nu\bar{\nu}) = (10.6^{+4.0}_{-3.4}\big|_{stat} \pm 0.9_{syst}) \times 10^{-11} (68\%\ CL)$$

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First measurement of $K^\pm \to \pi^0\pi^0\mu^\pm\nu$ with NA48/2 experiment:

Preliminary: $BR(K^\pm \to \pi^0\pi^0\mu^\pm\nu) = (3.4 \pm 0.2) \times 10^{-6}$

→ Riccardo Fantechi's talk

Anomalies, Lepton flavour violation and νs

Belle II:

- B meson anomalies: Belle II will provide important tests:
  First results for $B \to K^+ \nu\bar{\nu} \to$ Martin Angelsmark's talk

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MEG II:

- Measurement of $\mu \to e\gamma$ and $X17$ search
  $X17 \hat{=}$ anomaly in $^7Li(p, e^+, e^-)^8Be$
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FASERν:

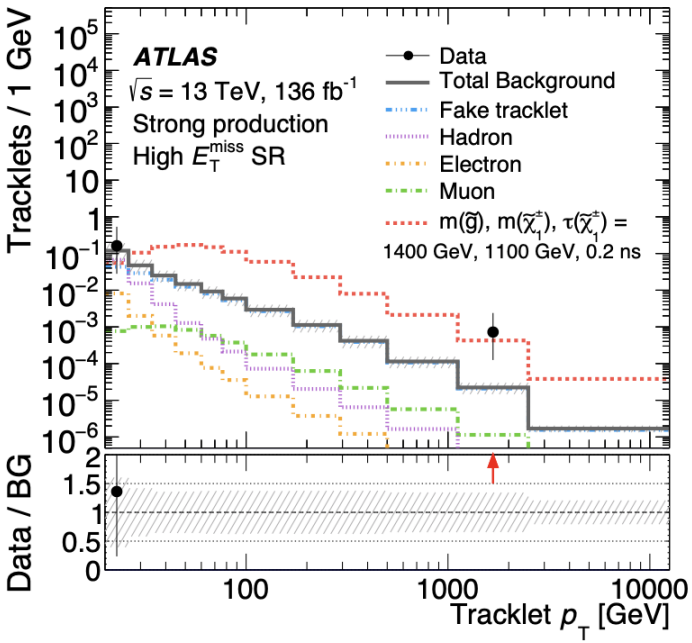
- Lepton universality checks with in particular ν_τ interactions
  $\to$ Osamu Sato's talk

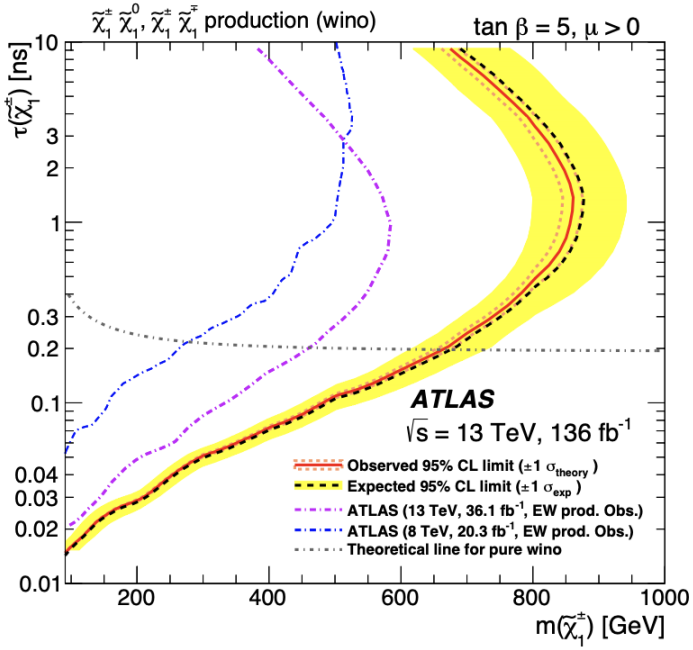
New ideas for 'old' dark matter scenarios

Missing track search for compressed electroweakinos:

After selection: look for an excess of candidate events in the p_T distribution of pixel tracklets

→ (Left-plot) No excess observed in the SRs: (Right-plot) place exclusion limits at 95% CL





- Electroweak production: LL $\tilde{\chi}^{\pm}$ (0.2 ns life-time) are excluded up to 660 GeV

→ Pure wino LSP model; mass-splitting between the charged and neutral wino of 160 MeV

→ Results can be interpreted also using other SUSY-EW simplified models, e.g. pure-higgsino

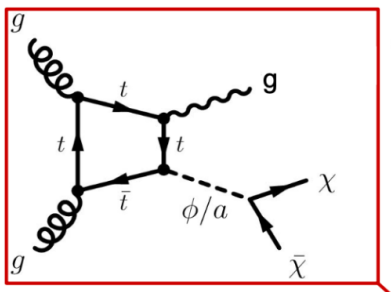
→ Otilia Ducu's talk

More exotic Dark Matter: Top-philic scalar

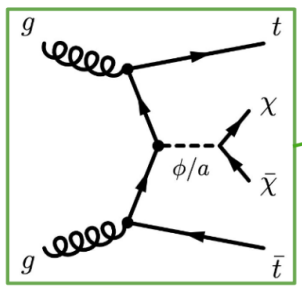
X+E_T^{miss} Bounds on New Spin-0 Mediators

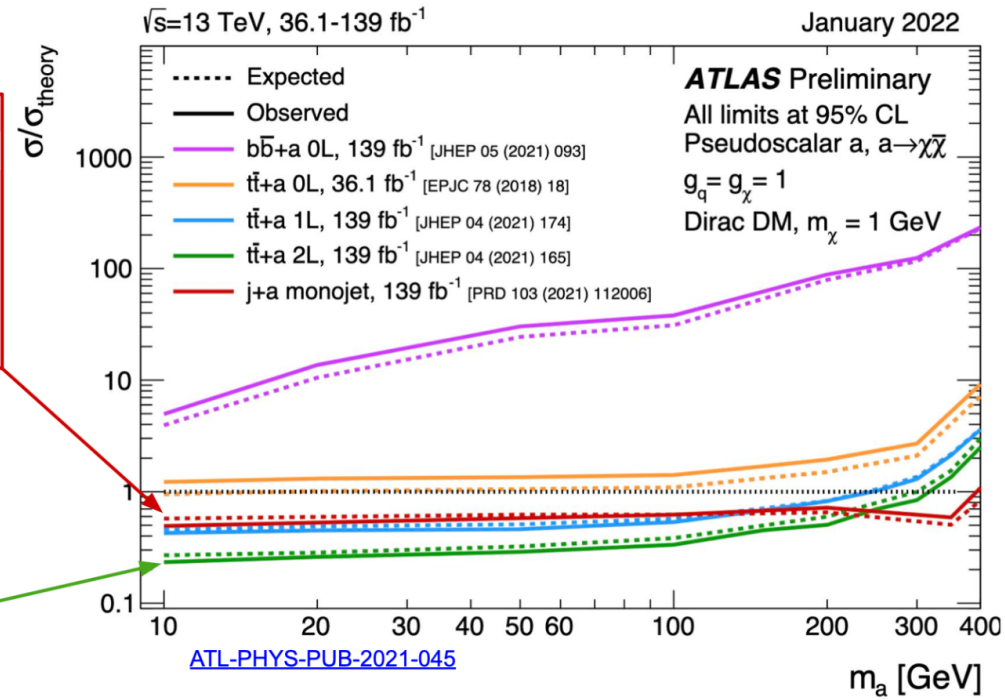
Tightest bounds(*) on simplified spin-0 mediator model come from searches in the tt+E_T^{miss} and jet+E_T^{miss} (PRD 103, 112006 (2021)) final states.

jet+E_T^{miss} signature



tt+E_T^{miss} signature





(*)Comparison of bounds depends on choice of couplings.

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→ Danika MacDonnell's talk

Further Dark Matter studies

- Competitive dark sector searches at LHCb:

  In particular for low masses and lifetimes

  Excellent vertexing, tracking and soft trigger

  $\rightarrow$ Carlos Vásquez Sierra's talk

Further Dark Matter studies

- Competitive dark sector searches at LHCb:

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- Are there new dark constituents of the proton?

  If yes, dark pdf sets needed

  → James Moore's talk

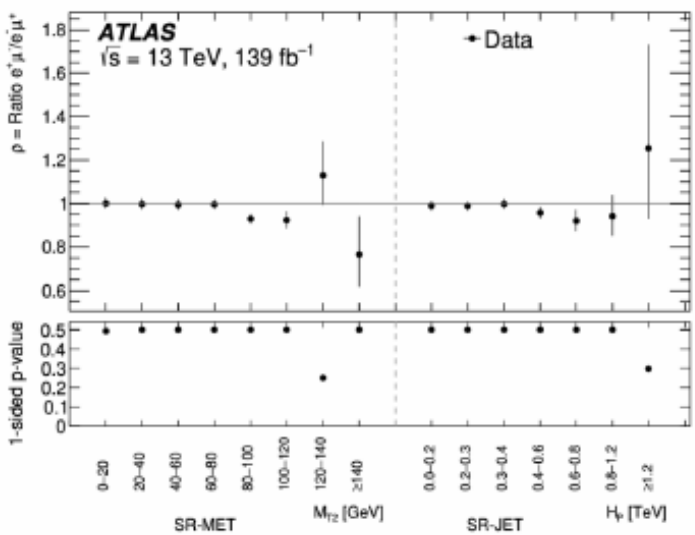
New type of searches

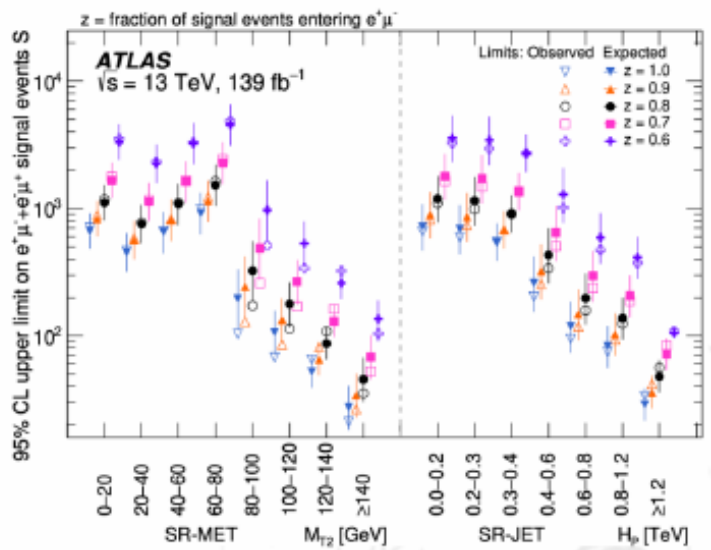
Example: e/μ charge flavour conspiracy $\rightarrow$ Will Fawcett's talk

$\rho = \frac{\sigma(pp \rightarrow e^+\mu^- + X)}{\sigma(pp \rightarrow e^-\mu^+ + X)} = 1$ in SM, $\rho < 1$ at LHC experiment due to pp collision biasing fakes.

$\rho > 1$ possible for BSM. $\Rightarrow$ Look for $\rho > 1$.

- ρ measured in data, consistent with the SM of $\rho = 1$
- Able to set model independent limits on the number of eμ events that could be in the signal regions





- No background estimate needed for data self-consistency test

Conclusion

- A variety of topics covering all sorts of aspects of WG3
- Thank you for all the contributions.
- Thank you to Pier Paolo Giardino and Luigi Bellafronte for the support during the sessions.
- And of course, thank you to Nestor Armesto Perez!