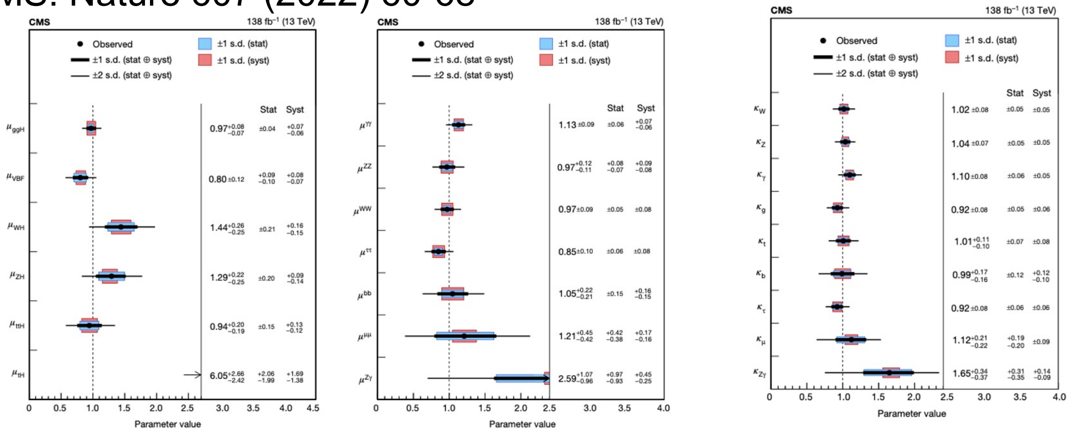
WG3 - Electroweak and BSM Physics

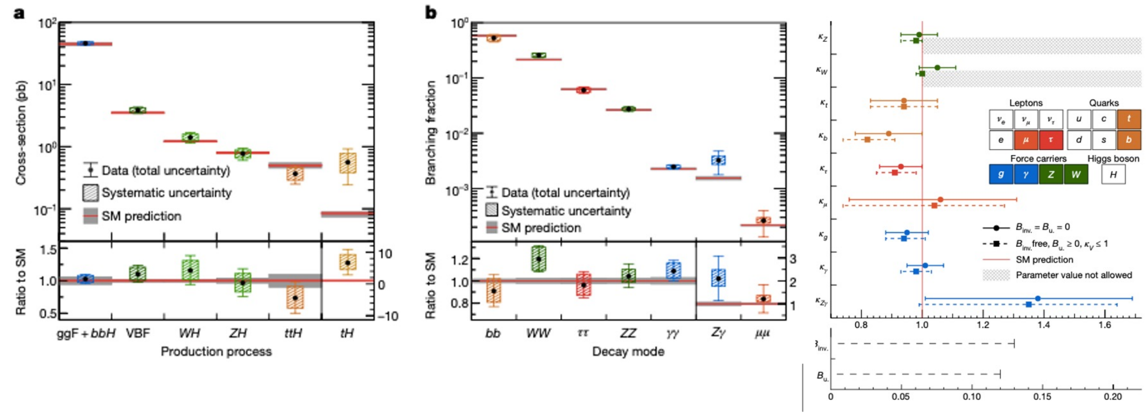
Wouter Deconinck, Niki Saoulidou, Doreen Wackeroth

Exploration of the Higgs sector at the LHC is in full swing

CMS: Nature 607 (2022) 60-68



ATLAS: Nature 607 (2022) 52-59 (see also Marc Escalier's talk)



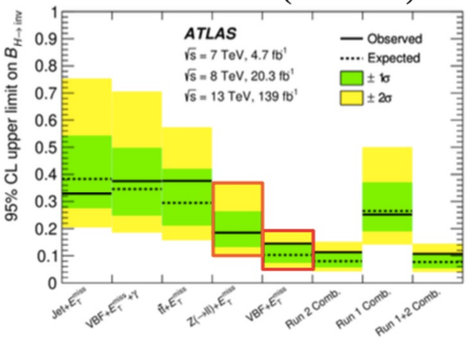
- 2nd generation couplings
- Higgs self couplings
- Kinematic properties in STXS framework
- Differential and fiducial cross sections
- Rare Higgs decays
- EFT interpretation
- CP structure of Higgs couplings
- BSM models
- …

Combined Higgs measurements and interpretations (ATLAS)

Marc Escalier (ATLAS)

	SM	BSM
H_{125}	μ_i, μ_f κ STXS	2HDM EFT invisible
$H_{125}H_{125}$	μ_{HH}, κ_λ, κ_{2V}	resonant HH
$H_{125}H_{125}+H_{125}$	κ_λ	

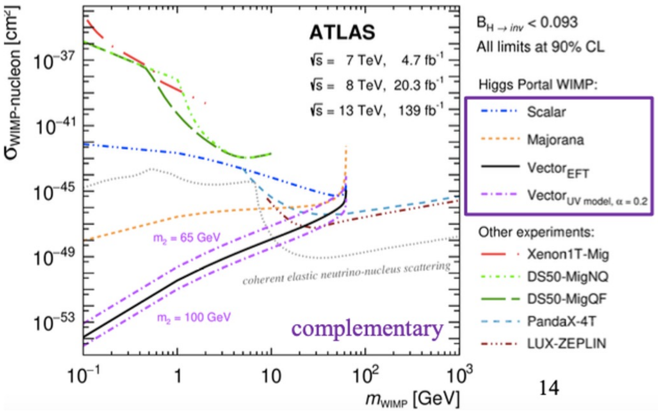
- Limit BR H→inv (95 % CL)



obs: 0.107
exp: 0.077

- EFT and UV models explored

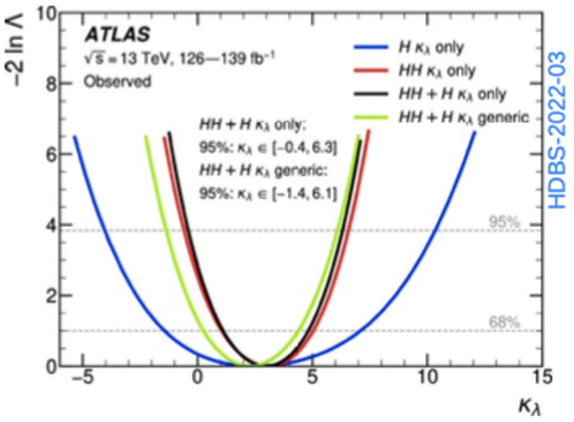
$m_H \geq 2m_{WIMP}$



Bartlomiej Zabinski (ATLAS)

Multiple diHiggs production channels:
- 4b – largest BR, huge background
- bbττ – small BR with relatively low background
- bbγγ – very small BR, but clean channel with low background.

$\sigma_{HH} < 2.4\ \sigma_{SM}$ observed
($2.9\ \sigma_{SM}$ expected)



Observed: $-0.4 < \kappa_\lambda < 6.3$
Expected: $-1.9 < \kappa_\lambda < 7.6$

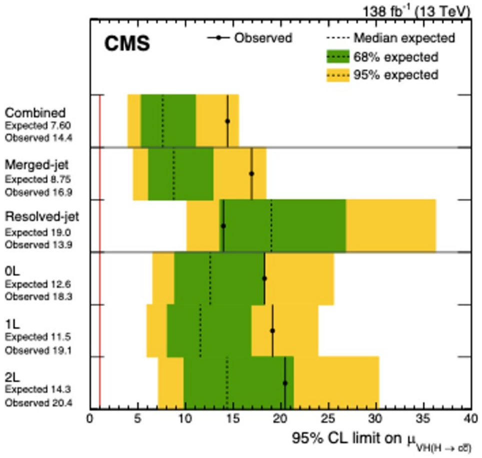
Higgs couplings to fermions

Elisabetta Gallo (CMS) [link]

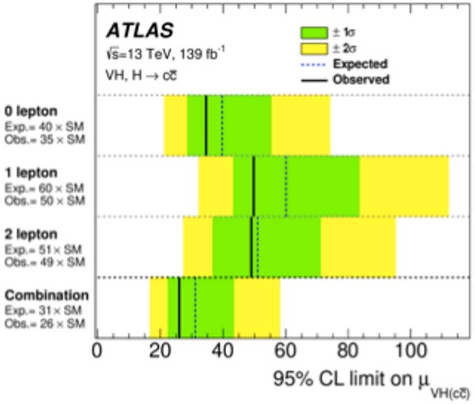
- STXS measured in H -> tau tau and VH(bb) channels and new VBF H->bb
- H->cc benefits from new c-taggers, VZ(cc) observed for the first time

Khuram Tariq (ATLAS) [link]

- VH(bb) and ttH(bb) done in resolved and boosted regime, VBF (H->bb and +photon)
- Total H->tau tau cross section and STXS measurements



Observed (expected) limit on the signal strength:
$\mu = 14$ (7.6)
$1.1 < |k_c| < 5.5(|k_c| < 3.4)$



VH ($H \to c\bar{c}$)

Observed (expected) limit: 26.0 × SM (31^{+12}_{-8} × SM)

VW(cq) and VZ(cc) are simultaneously measured as a cross-check

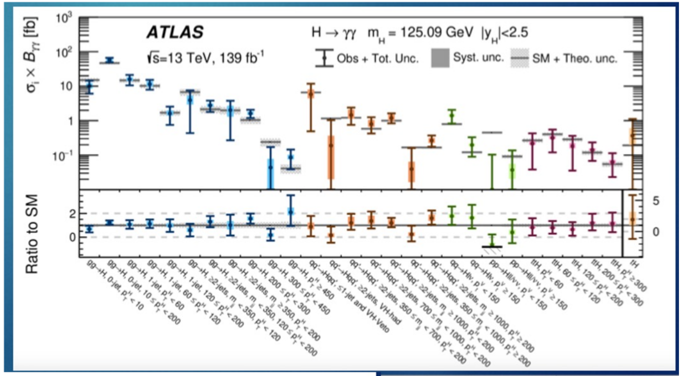
Best fit results, 95% CL:
H4l & H$\gamma\gamma$, shape & normalisation:
k_b: [-1.09, -0.86] U [0.81, 1.09]
k_c [-2.27, 2.27]
H4l & H$\gamma\gamma$ & VH(bb) & VH(cc)
BSM decays not allowed:
k_c::[-2.47, 2.53]
BSM decays allowed:
k_c :[-4.46, 4.81]

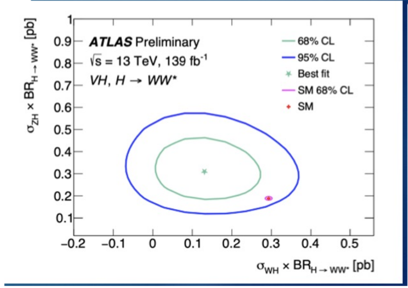
See also talks by Anamika Aggarwal (ATLAS) and Marc Escalier (ATLAS)

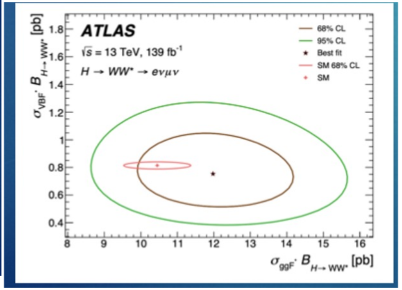
Higgs couplings to bosons, off-shell H->ZZ and Higgs width

Michela Biglietti (ATLAS) [link]

- H->ZZ,WW,gamma gamma
- Signal strengths STXS
- kappa-framework and SMEFT



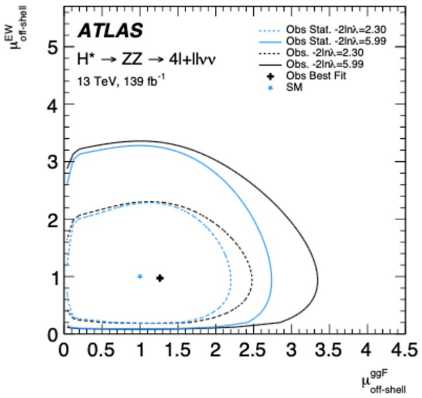




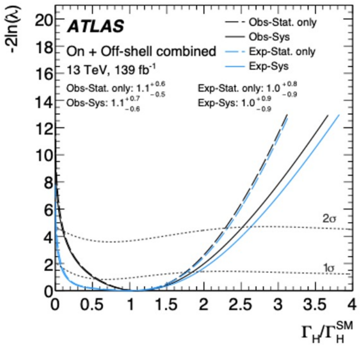
Will Leight (ATLAS)

- Evidence for off-shell H->ZZ production (EW and ggF)
- Higgs width measurement

Measured value of $\mu_{\text{off-shell}}$=1.1, 95% CL upper limit of 2.4→3.3σ evidence for off-shell production



- $\Gamma_H = 4.5^{+3.3}_{-2.5}$ MeV, with 95% CL limits of $0.5 < \Gamma_H < 10.5$ MeV



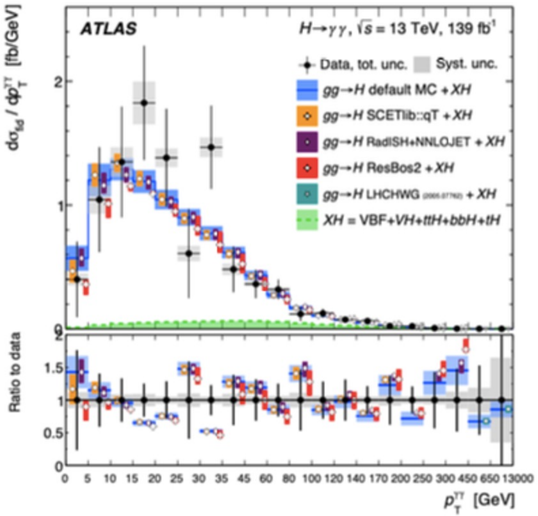
Differential and fiducial Higgs cross sections

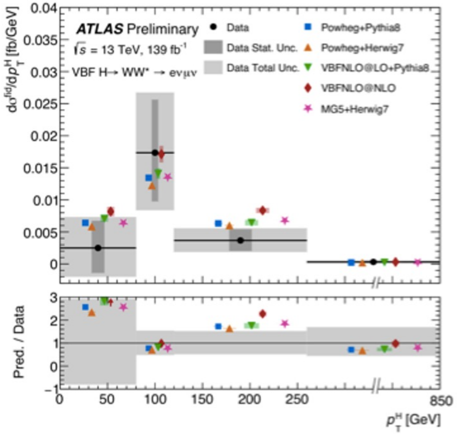
$$\sigma_{\text{fid}} = 67 \pm 5\,(\text{stat.}) \pm 4\,(\text{sys.})\ \text{fb}$$

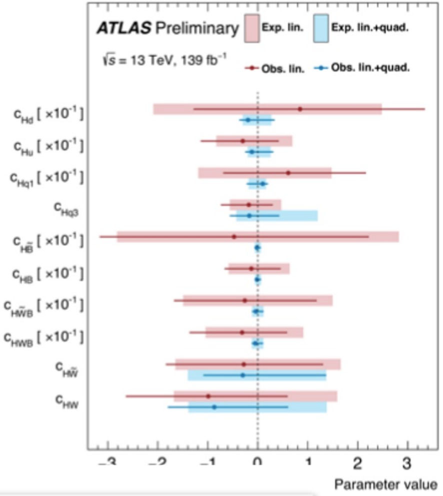
Anamika Aggarwal (ATLAS)

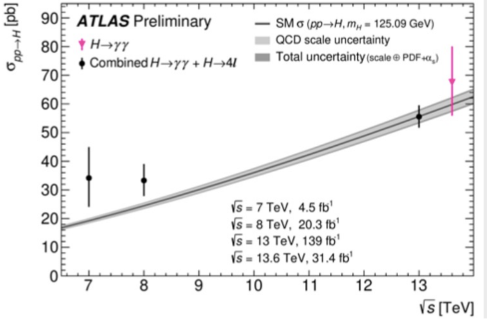
$$\sigma_{\text{fid,SM}} = 64 \pm 4\ \text{fb}$$

- H->ZZ,WW,gamma gamma, H(bb)+E_Tmiss
- Interpretation in SMEFT
- Constraints on c,b coupling modifiers









$$\sigma^{\text{fid}} = 1.68 \pm 0.40\ \text{fb} = 1.68 \pm 0.33\,(\text{stat}) \pm 0.23\,(\text{syst})\ \text{fb}$$

Testing for CP violation in Higgs couplings

Marcos Miralles (ATLAS) [link]

Bosonic couplings

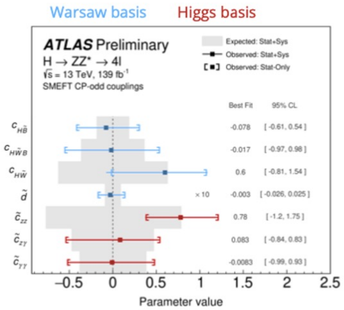
- Modelled by higher-order-mass dimension terms in **EFT**
- Suppressed by powers in expansion scale Λ
- Explored in VBF prod., $H \to WW$ and $H \to ZZ$ decay channels

$$\mathcal{L}_{VVH} = \mathcal{L}_{SM} + \frac{c_i}{\Lambda^2}\phi \tilde{V}_{\mu\nu}V^{\mu\nu} + \ldots$$

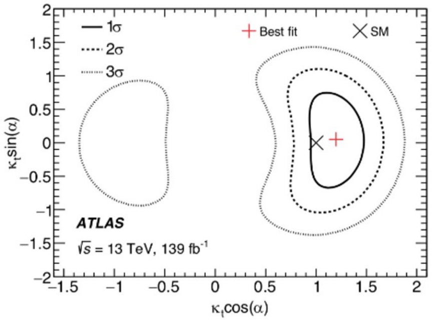
Fermionic couplings

- CP-odd terms enter at the **same order** as CP-even terms
- Explored in $t\bar{t}H/tH$ production and $H \to \tau\tau$ decay channel
- Parameterised with a CP-mixing angle

$$\mathcal{L}_{ffH} = \kappa_f' y_f \phi \bar{\psi}_f(\cos\alpha + i\gamma_5 \sin\alpha)\psi_f$$

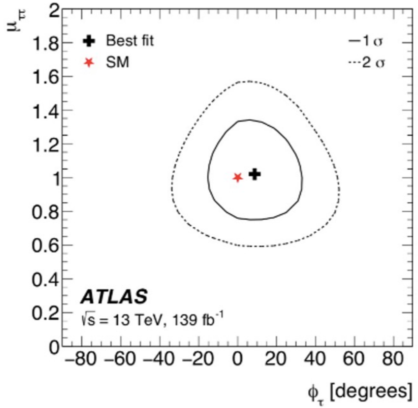


$t\bar{t}H/tH$ **production with** $H \to \gamma\gamma$ **[Ref.]**



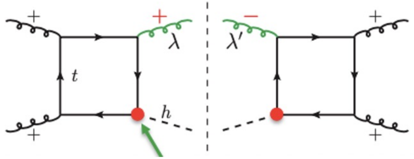
$\alpha < |43|°$ at 95%CL and pure CP-odd coupling is excluded at 3.9σ

H-> tau tau



Zhite Yu

- New observable to probe CP structure of Higgs-top coupling: gluon jet anisotropy
- Example: Polarized gg->gh production



$$\sum_{\lambda_1,\lambda_2} \mathcal{M}_{\lambda_1\lambda_2\lambda}\mathcal{M}^*_{\lambda_1\lambda_2\lambda'} = \rho_{\lambda\lambda'}(\xi)\,\overline{|\mathcal{M}|^2}$$

$$\xi_1 = 2\,\mathrm{Re}(\rho_{+-}) \sim \kappa^2 - \tilde{\kappa}^2 \propto \cos 2\alpha$$ **CP-even**

$$\xi_2 = -2\,\mathrm{Im}(\rho_{+-}) \propto \kappa \cdot \tilde{\kappa} \propto \sin 2\alpha$$ **CP-odd**

$$\xi_1 = \frac{\omega + \beta_1 \cos 2\alpha}{1 + \Delta \cos 2\alpha}, \quad \xi_2 = \frac{\beta_2 \sin 2\alpha}{1 + \Delta \cos 2\alpha}$$

Searches for rare and LFV Higgs decays

Pawel Brueckman (ATLAS) [link]

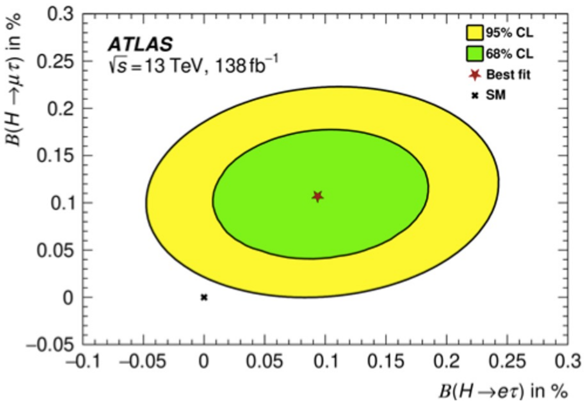
Rare loop-induced or Yukawa-suppressed radiative decays
- $H \to Z\gamma$, $H \to \gamma\gamma^*$ ☆ $(Z, \gamma^* \to ll)$
- $H \to J/\psi\gamma$, $\psi\gamma$ or $\Upsilon\gamma$ $(J/\psi, \psi, \Upsilon \to \mu\mu)$
- NEW $H \to \omega\gamma$, $K^*\gamma$

Is the Higgs sector responsible for LFV?
- NEW $H \to e\tau$, $H \to \mu\tau$ ☆
- $H \to e\mu$,

Can we observe Higgs decays to 1st and 2nd generation?
- $H \to ee$
- $H \to \mu\mu$ ☆

Full Run 2 ATLAS data (~140 fb^{-1})

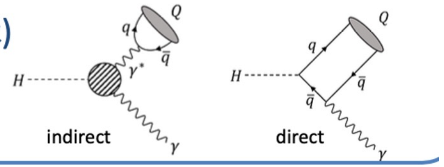
2 PoI combined fit

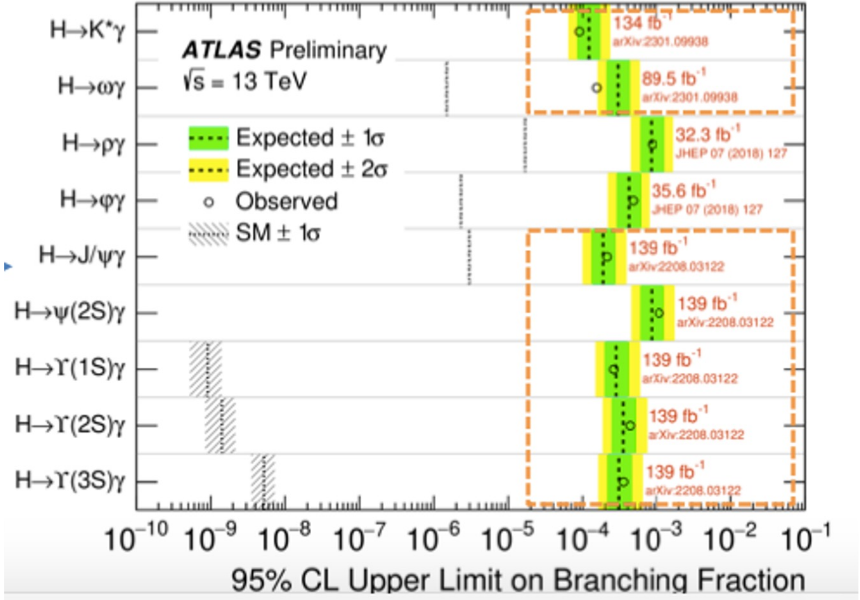


2.1σ ☆

$H \to J/\psi\gamma$, $\psi(2S)\gamma$ or $\Upsilon\gamma$ $(Q \to \mu\mu)$

$H \to \omega\gamma$, $K^*\gamma$ (exclusive!)



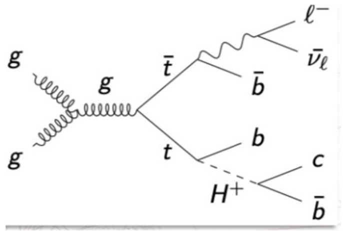


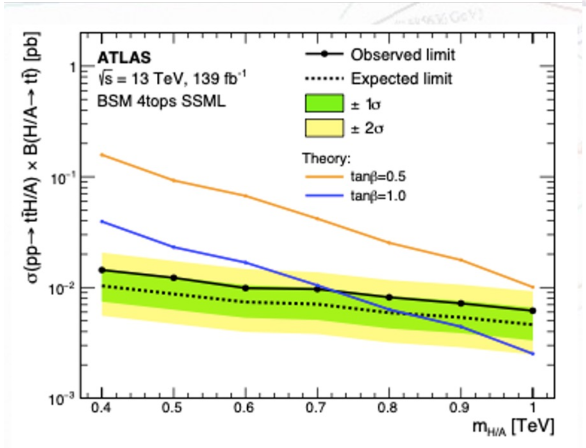
Searches for additional Higgs bosons

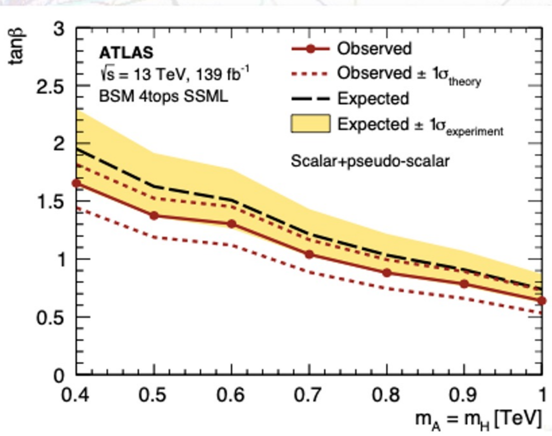
Anna Karvzmarska (ATLAS) [link]

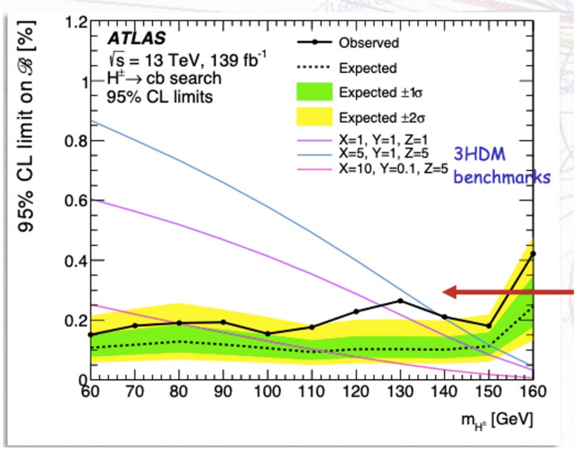
Sensitivity has improved significantly with respect to the latest results due to the enlar
dataset and new analysis techniques e.g.

- $t\bar{t}\,H/A \to t\bar{t}t\bar{t}$ => 4x improvement wrt previous ATLAS result
- FCNC $t \to qX$ (q=u,c) $\to$ qbb => 3x improvement wrt previous ATLAS result
- $t \to H^{\pm}b$ decays, with $H^{\pm} \to cb$ => 5x improvement wrt previous CMS result
- $H^{\pm\pm} \to l^{\pm}l^{\pm}$ => 2x improvement wrt previous ATLAS result
- ZH production with dark photons => 2x improvement wrt CMS result









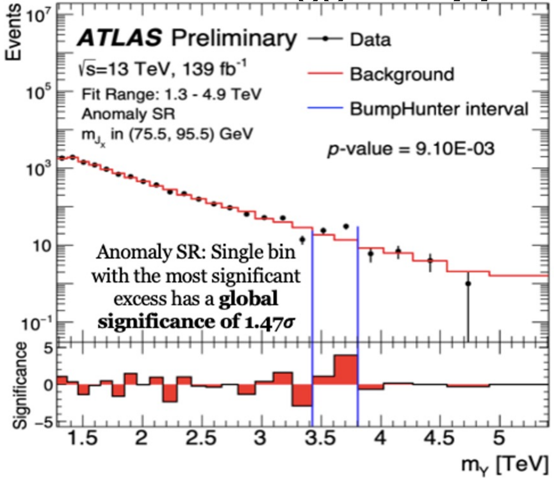
Small excess corresponds to a local (global) significance
3 σ (2.5 σ) at m(H±)= 130 GeV

Searches for resonances decaying into pairs of heavy bosons

Jem Guhit (ATLAS) [link]

- Summary of jet reconstruction and W/Z/H tagging techniques used to probe hadronically decaying final states
- Searches for Y->XH, XZ, VV, VH, HH, VHH

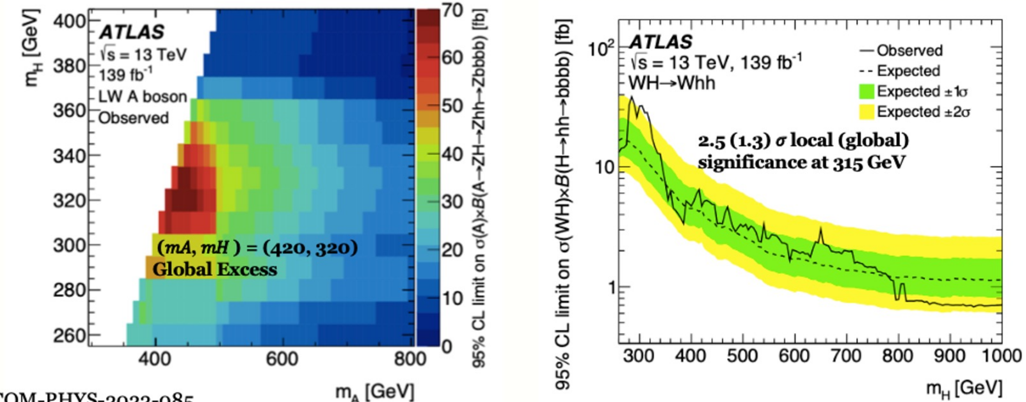
Search for Y→X + Higgs → $qqbb$



$W/Zhh \rightarrow (W/Z \rightarrow \ell\nu/\ell\ell/\nu\nu) + (hh \rightarrow bbbb)$

Resonant:

Global excess observed in LW $A \rightarrow ZH \rightarrow Zhh$, where local (global) sig is 3.8σ (2.8σ)



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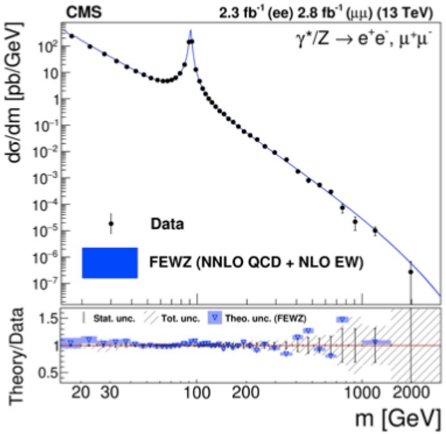
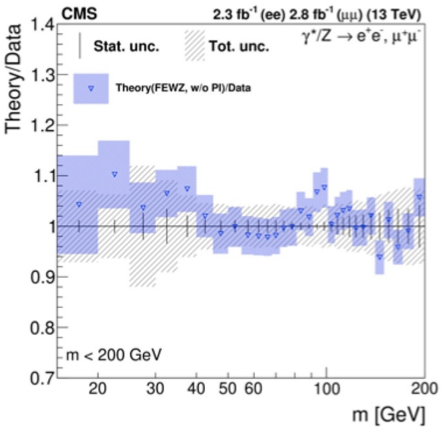
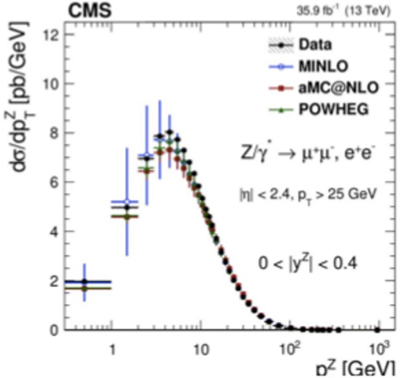
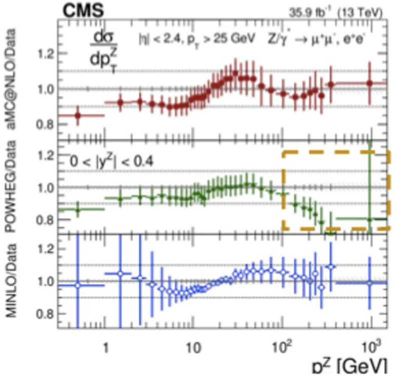
Drell-Yan measurements and higher-order predictions

Duong Nguyen (CMS)









Tobias Neumann

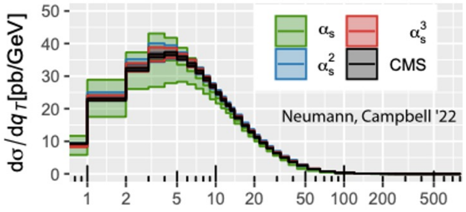
- N3LO+N4LL predictions for Z production (CuTe-MCFM) and jet-veo resummation at alphas^2 for WW production

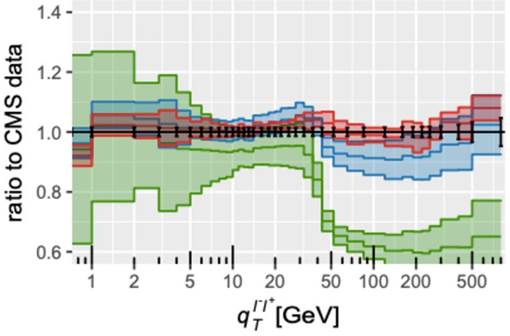
› via small-q_T factorization

$$d\sigma_{ij} \sim \int d\xi_1 d\xi_2\, d\sigma^0_{ij} \cdot H(\xi_1 p_1, \xi_2 p_2, \mu) \cdot$$

$$\cdot \int d^2 x_\perp\, e^{-iq_\perp x_\perp} (x_T^2 Q^2)^{-F(x_\perp,\mu)} \cdot B_i(\xi_1, x_\perp, \mu) \cdot B_j(\xi_2, x_\perp, \mu)$$

based on formalism of Becher, Neubert '10; Becher, Neubert, Wilhelm '11; Becher, Hager '19
implemented in CuTe-MCFM (Becher, Neumann '19)

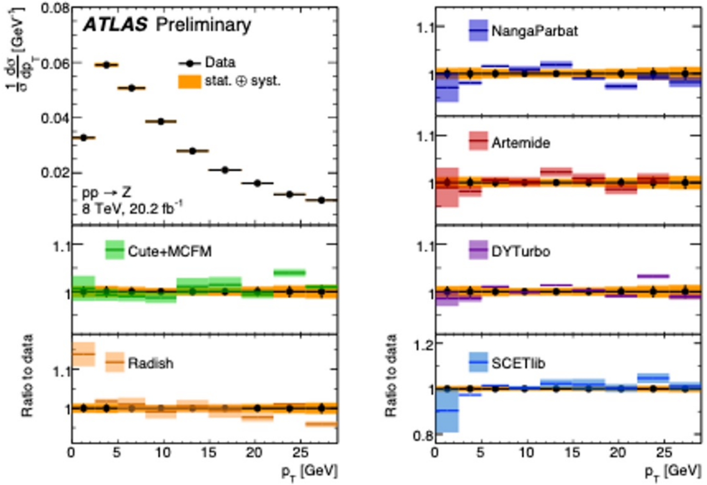


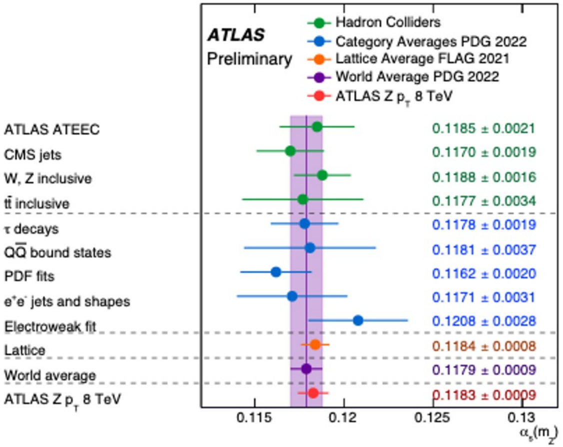


W and Z boson measurements with ATLAS

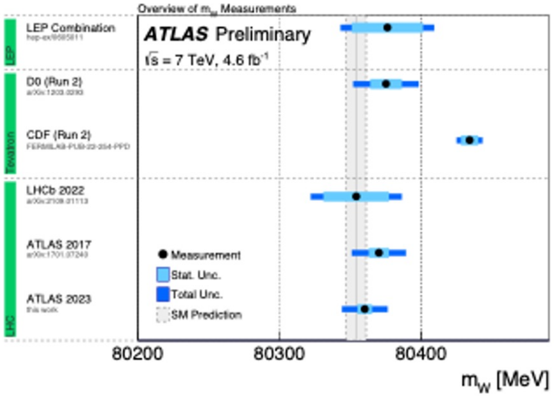
Hugo Beauchemin (ATLAS)

- Z(p_T,y) distribution: compared to N3LO+N4LL predictions and different PDF sets (first aN3LO)
- alpha_s from Z p_T
- W mass update





$\alpha_s(M_Z)$= 0.11828 ± 0.0009



Improvements: PDFs, multi-jet background estimate, fitting procedure

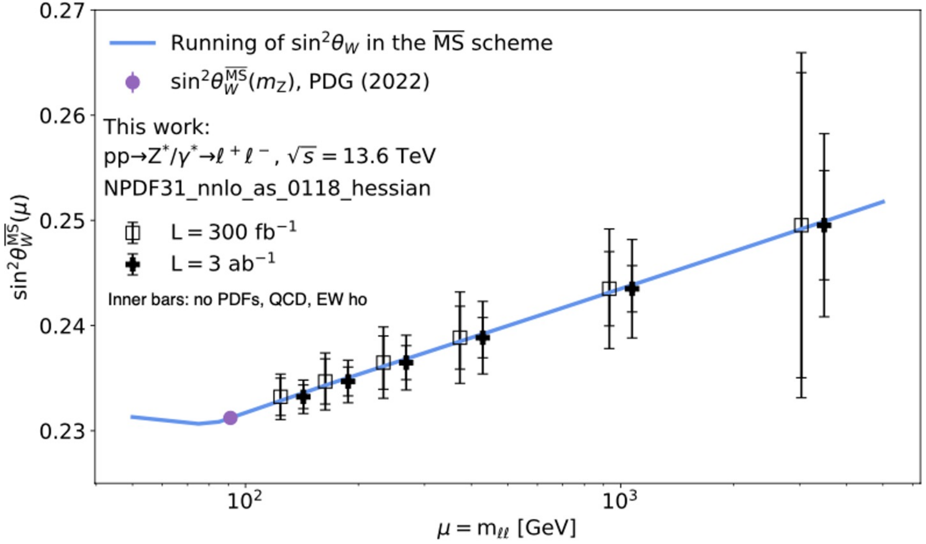
Probing the weak mixing angle at high energies

Clara Lavinina del Pio

Monte Carlo code with $\sin^2\theta_w^{\overline{MS}}(\mu)$ **as input** that allows its direct determination consistently at NLO at hadronic colliders

$$\sin\theta_w^{\overline{MS}}(\mu) = \frac{e^{\overline{MS}}(\mu)}{g_2^{\overline{MS}}(\mu)}$$

$$\left.\frac{\delta A_{FB}}{A_{FB}}\right|_{\mu=1\,\text{TeV}} \sim 0.3\,\frac{\delta\sin^2\theta_w^{\overline{MS}}(\mu)}{\sin^2\theta_w^{\overline{MS}}(\mu)}$$

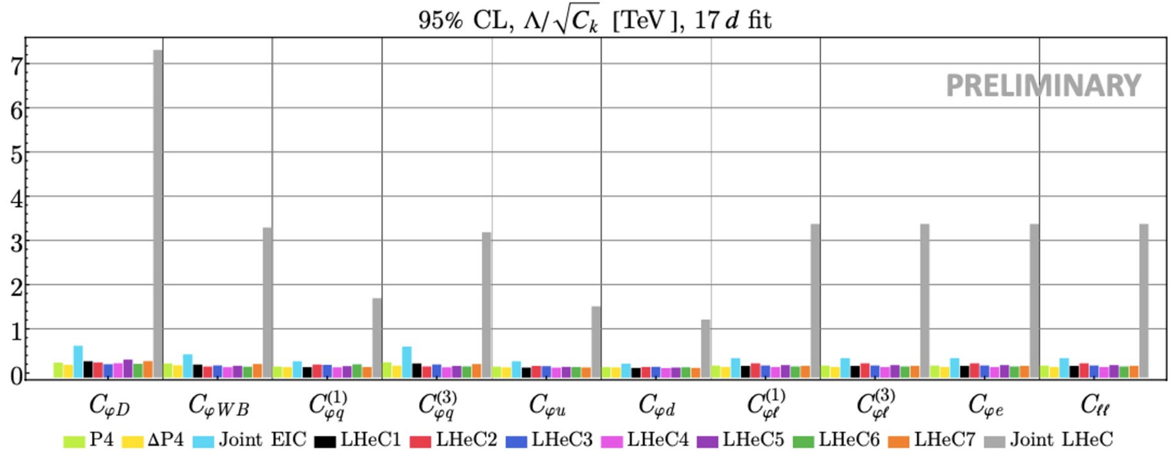


EW precision fits and contact interactions with LHeC and EIC pseudo data

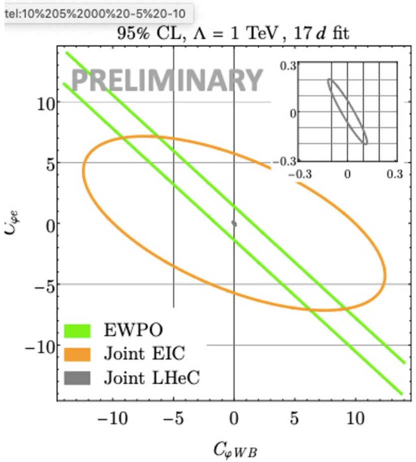
Chiara Bissolotti

- Multi-dimensional fits of NC DIS cross sections and asymmetries in SMEFT including uncertainties and correlations

LHeC can probe scales up to 7 TeV



(Some of) the blind spots and flat directions observed by Ellis et al.
are found to be resolved by EIC and LHeC



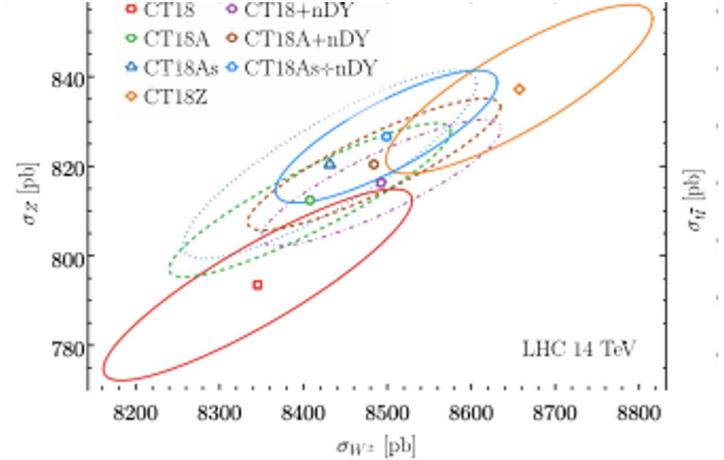
34D EWPO fits

J. Ellis, M. Madigan, K. Mimasu
V. Sanz, T. You
JHEP04 (2021) 279

CTEQ-TEA global analyses: Impact of new DY data on CT18 and of simultaneous fit of SMEFT parameters and PDFs

Keping Xie

- Included new DY data from ATLAS, CMS and LHCb: error ellipses decrease, increase single W,Z boson cross sections, pull towards CT18Z direction



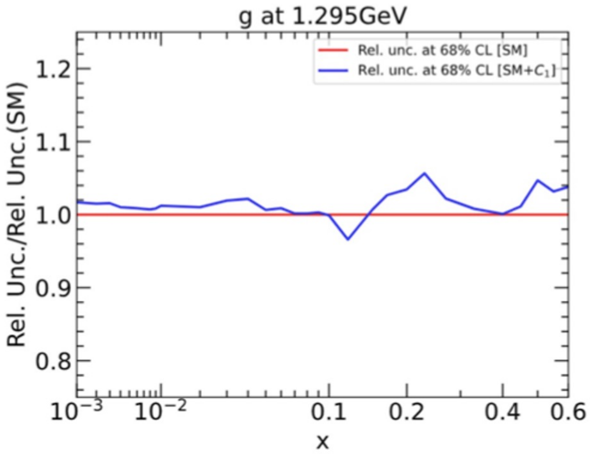
Tim Hobbs

→ PDFs not actively fitted alongside SMEFT parameters

→ could potentially bias resulting SMEFT analysis

→ demonstration study focusing on select data: jet, $t\bar{t}$ production

→ relatively weak PDF-SMEFT correlations

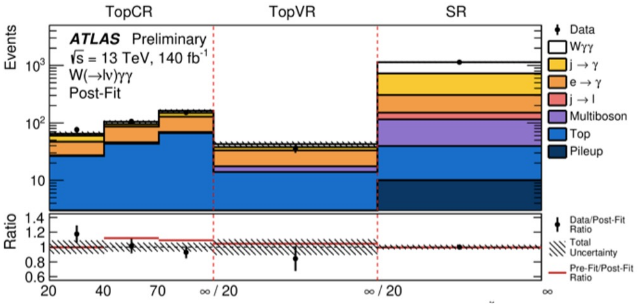


Jointly fitting contact interaction to jet prod. shifts gluon PDF

Multi-V boson production in ATLAS

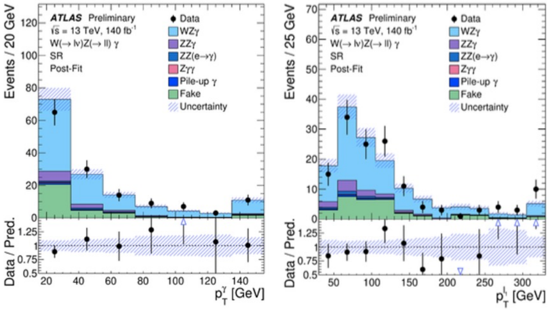
Marc-Andre Pleier (ATLAS)

- First observation of Wgamma gamma and WZgamma
- Testing aQGCs in VBS and VVV



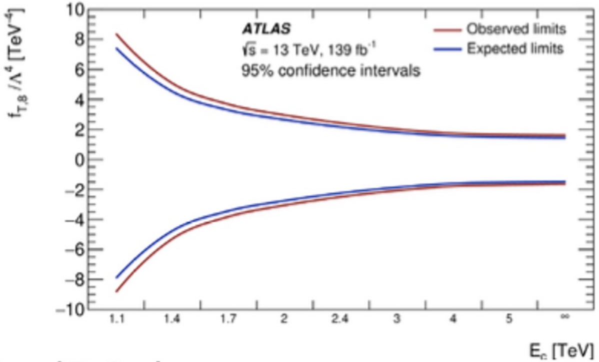
Exp. significance:

5.6σ (5.6σ)



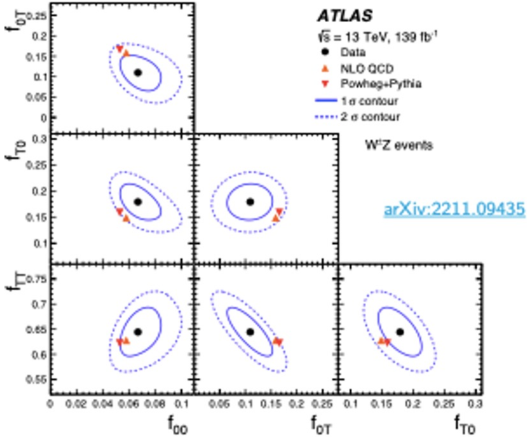
6.3σ (5.0σ)

Impact of unitarization (clipping) on aQGC limits:



Man Yuan (ATLAS)

- First observation of W_L Z_L production with 7.1 (6.2) sigma significance
- New measurements of Zgamma+jets and WW jet inclusive



Multi-V boson production in CMS

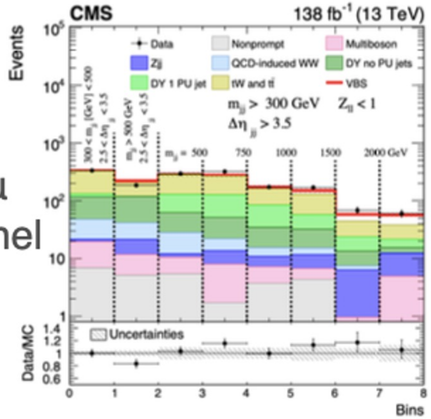
Irene Zoi (CMS)

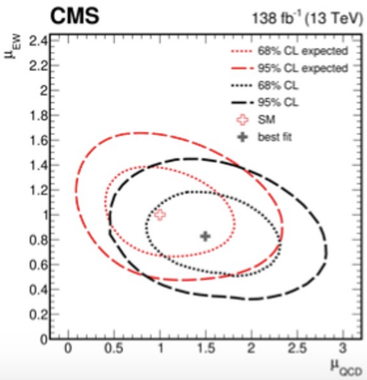
- New VBS results: observation of osWW and evidence for WV
- New opportunities for Run 3 (ML taggers, boosted W/Z tagging, q/g discrimination)

▷ Obs. (exp.) significance 5.6 (5.2)
▷ Fiducial cross-sections:
10.2 ± 2.0 fb (theory: 9.1 ± 0.6 pb

▷ Evidence obs. (exp.) significance 4.4 (5.1
▷ $\mathrm{EW_{WV}}$ xsec obs. (exp.) $1.90^{+0.53}_{-0.46}$ pb (2.23
▷ μ_{EW}=0.85±0.12(stat) $^{+0.19}_{-0.17}$(syst)

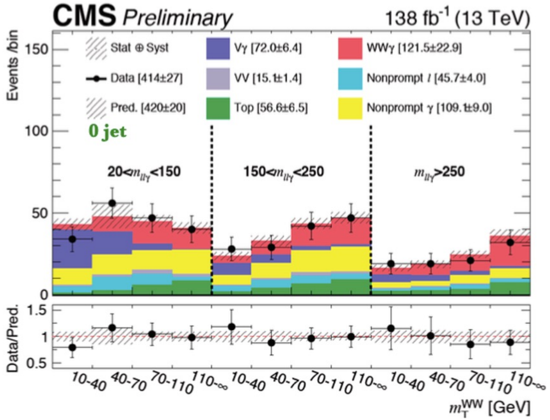
e-μμ
hannel





Monika Mittal (CMS)

- New: observation of WWgamma
- Observation of Wgamma jj (EWK-only and QCD), limits on Dim-8 aQGCs
- gamma gamma -> WW/ZZ (PPS)



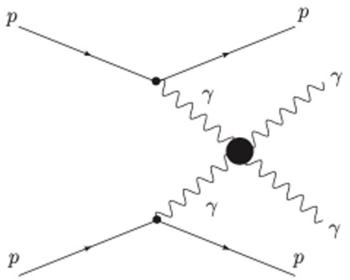
Signal significance is 5.6 σ (expected 4.7 σ)

$$\sigma = 6.04 \pm 1.69\,\mathrm{fb} = 6.04 \pm 1.03\,(\mathrm{stat}) \pm 0.97\,(\mathrm{syst}) \pm 0.85\,(\mathrm{theo})\,\mathrm{fb}$$

Results from CMS Precision Proton Spectrometer (PPS)

Christophe Royon (CMS)

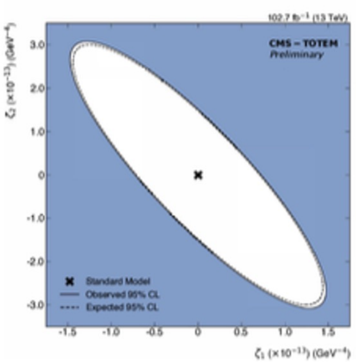
- LHC can be seen as a γγ collider! Lead to extremely clean events where all particles in the final state are measured, like at LEP



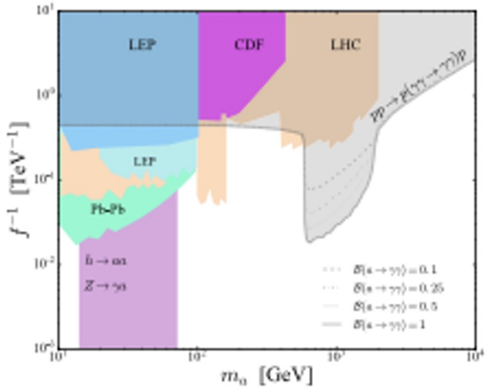
Search for production of two photons and two intact protons in the final state: $pp \to p\gamma\gamma p$

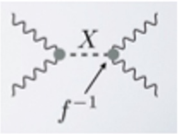
Additional channels: WW, ZZ, γZ, $t\bar{t}$

Limits on anomalous quartic photon couplings:



Search for axion-like particles:





Exclusive WW,ZZ production: see also M. Mittal's talk

- Limits on SM cross section $\sigma_{WW} < 67$fb, $\sigma_{ZZ} < 43$fb for $0.04 < \xi < 0.2$ (CMS-PAS-EXO-21-014)
- New limits on quartic anomalous couplings (events violating unitarity removed) : $a_0^W/\Lambda^2 < 4.3\ 10^{-6}$ GeV^{-2}, $a_C^W/\Lambda^2 < 1.6\ 10^{-5}$ GeV^{-2}, $a_0^Z/\Lambda^2 < 0.9\ 10^{-5}$ GeV^{-2}, $a_C^Z/\Lambda^2 < 4.\ 10^{-5}$ GeV^{-2} with 52.9 fb^{-1}

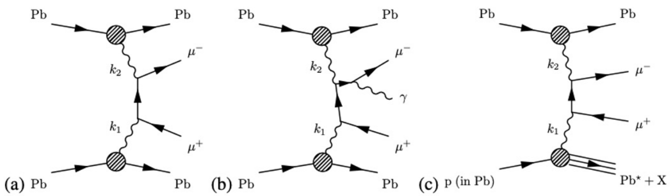
Photon-photon fusion in Pb-Pb collisions with ATLAS

Peter Steinberg (ATLAS)

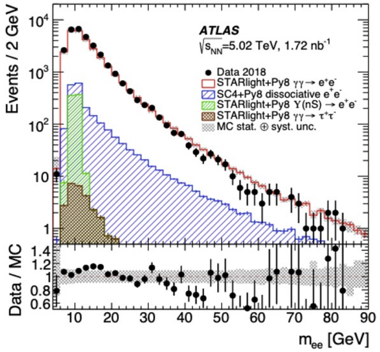
Ultraperipheral collisions are a unique opportunity to study photon-photon and photon-nucleus (& nucleon) physics in a clean environment, synergistic w/ EIC

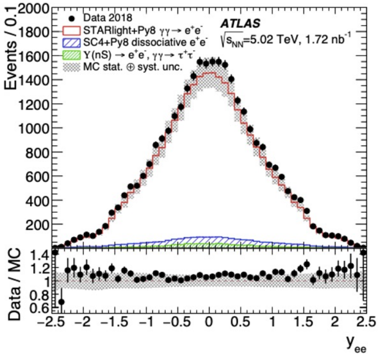
Dileptons provide the most direct & precise way to check the assumed photon fluxes

- Important for precise calculations of LbyL and tau g-2!



2 generators: SuperChic and STARlight

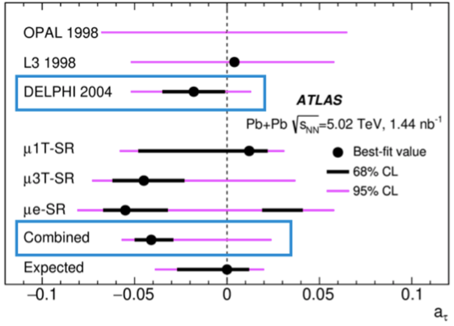


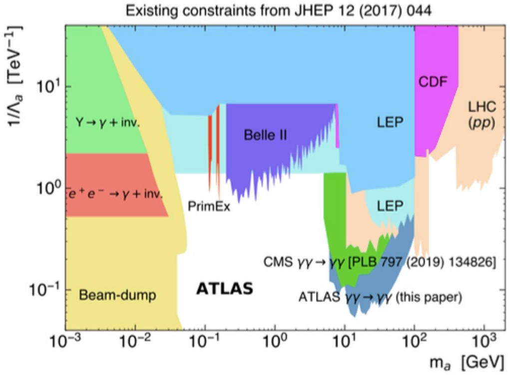


Klaudia Maj (ATLAS)

- Search for BSM physics in UPCs
- Measurement of tau anom. magnetic moment in $\gamma\gamma \to \tau^+\tau^-$
- Search for axion-like particles in light-by-light scattering

[arXiv:2204.13478]

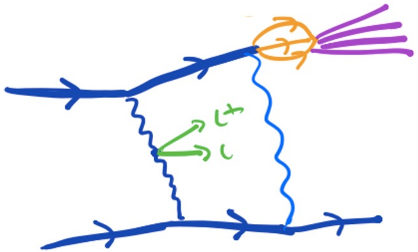




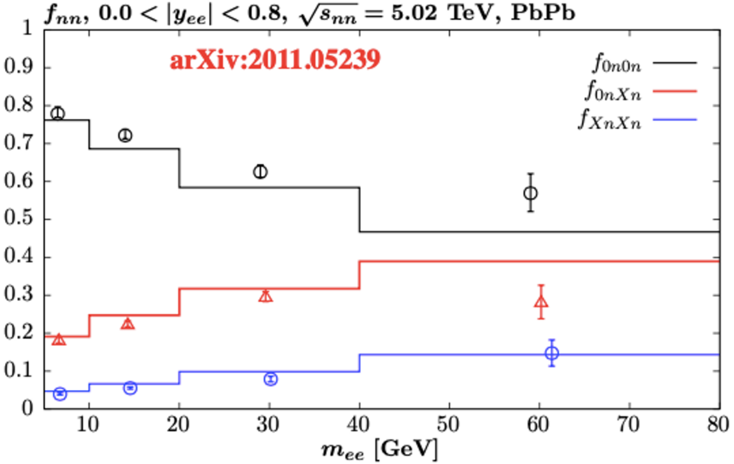
Ultrapheripheral Heavy Ion collisions with nuclear breakup

Lucian Harland-Lang

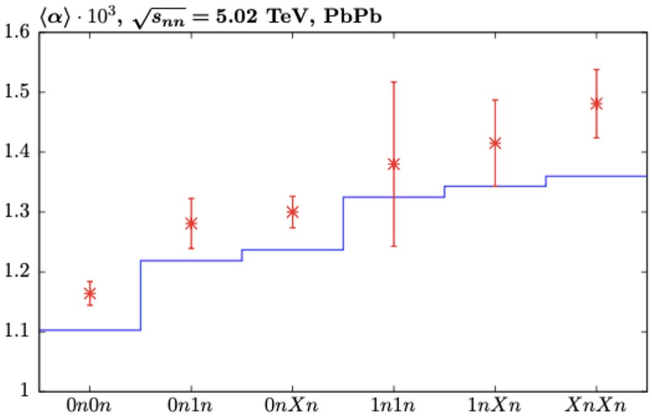
- SuperChic 4.2: MC event generator for central exclusive and photon-initiated processes
- First complete MC treatment of UPCs with mutual ion dissociation -> additional boosted neutrons
- Future work: including FSR and further higher order QED effects essential for precision programme



ATLAS di-electron data:



CMS di-muon data:

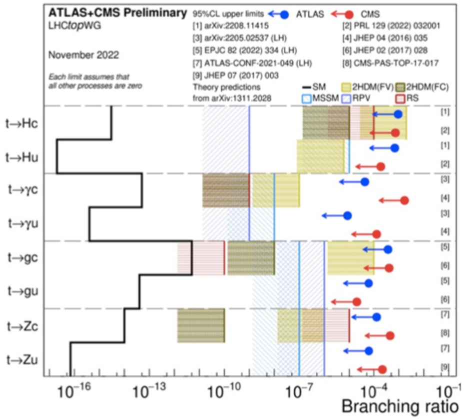


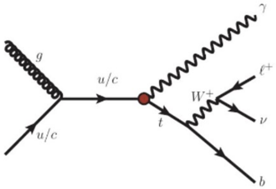
$$\alpha = 1 - \frac{\Delta\phi_{\mu\mu}}{\pi}$$

Searches for rare top quark production and decay processes with ATLAS

Will George (ATLAS)

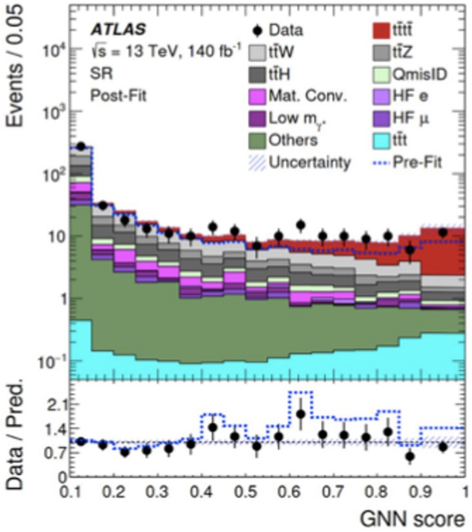
- **Observation** of 4 top quark production!
- Searches for FCNC couplings of the top quark: $tq\gamma$, tqg, tqH, tqZ
- Search for charged lepton flavour violating couplings of the top quark





Observable	Vertex	Coupling	Observed	Expected
SRs+CRs				
$\mathcal{B}(t \to Zq)$	tZu	LH	6.2×10^{-5}	$4.9\,^{+2.1}_{-1.4}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZu	RH	6.6×10^{-5}	$5.1\,^{+2.1}_{-1.4}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZc	LH	13×10^{-5}	$11\,^{+5}_{-3}\times10^{-5}$
$\mathcal{B}(t \to Zq)$	tZc	RH	12×10^{-5}	$10\,^{+4}_{-3}\times10^{-5}$
$\lvert C_{uW}^{(13)*}\rvert$ and $\lvert C_{uB}^{(13)*}\rvert$	tZu	LH	0.15	$0.13\,^{+0.03}_{-0.02}$
$\lvert C_{uW}^{(31)}\rvert$ and $\lvert C_{uB}^{(31)}\rvert$	tZu	RH	0.16	$0.14\,^{+0.03}_{-0.02}$
$\lvert C_{uW}^{(23)*}\rvert$ and $\lvert C_{uB}^{(23)*}\rvert$	tZc	LH	0.22	$0.20\,^{+0.04}_{-0.03}$
$\lvert C_{uW}^{(32)}\rvert$ and $\lvert C_{uB}^{(32)}\rvert$	tZc	RH	0.21	$0.19\,^{+0.04}_{-0.03}$

Observation of 4 tops production!



Observed (expected) significance: 6.1σ (4.3σ)

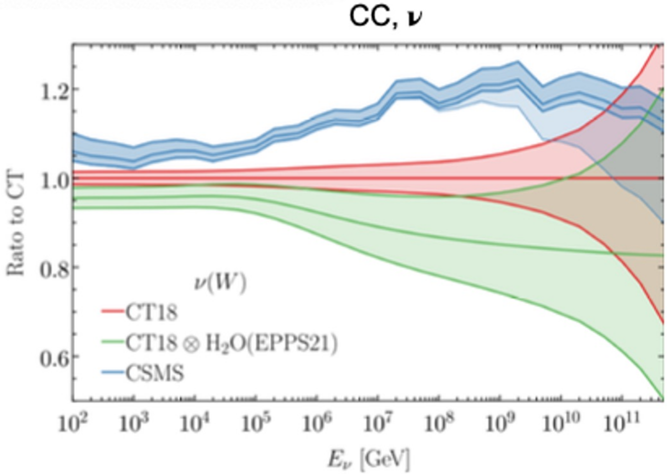
$$\mu = 1.89^{+0.37}_{-0.35}(\text{stat})\,^{+0.62}_{-0.37}(\text{syst}) = 1.89\,^{+0.73}_{-0.51}.$$

$$\sigma_{t\bar{t}t\bar{t}} = 22.7^{+4.7}_{-4.4}(\text{stat})\,^{+4.6}_{-3.4}(\text{syst})\text{ fb} = 22.7\,^{+6.6}_{-5.5}\text{ fb}.$$

Improvements in predictions for neutrino cross sections

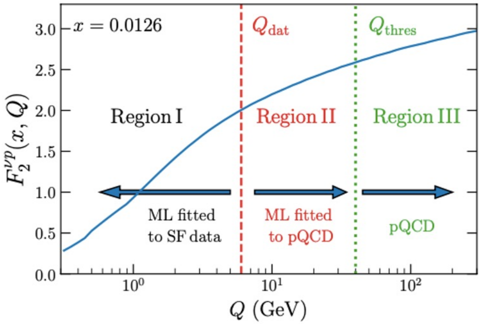
Daniel Stump

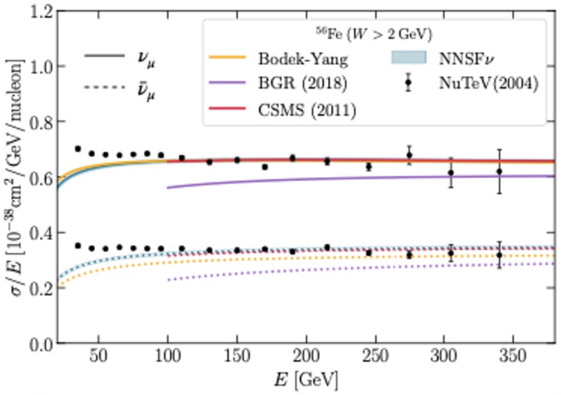
- High-energy neutrino-nucleon cross sections from 100 GeV to 1000 EeV with CT18
- IceCube used the CSMS model (NLO PDF); comparison with CT18 (NNLO, LHC data nuclear effects):



Tanjona Rabemananjara

- Inclusive neutrino cross-section receives sizeable contributions from Q < 2 GeV where QCD calculations cannot be evaluated in pQCD
- **NNSFν**: Use available data on neutrino-nucleus scattering to parametrise and determine the inelastic structure functions using a NN

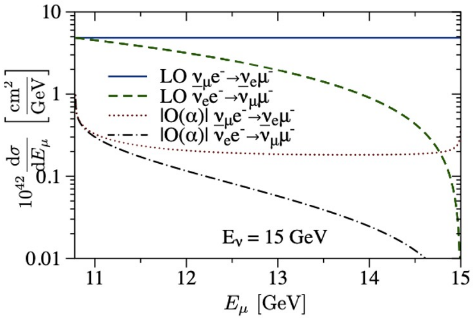


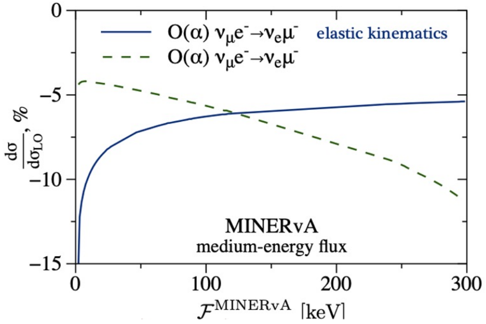


Improvements in predictions for neutrino flux constraints and polarized lepton-hadron colliders

Oleksandr Tomalak

- Radiative corrections to (anti)neutrino energy spectra from muon, pion, and kaon decays and to inverse muon decay
- Calculation done in EFT framework





$$\mathcal{F}^{\mathrm{MINERvA}} = \frac{E_\mu \theta_\mu^2}{1 - \frac{E_\mu}{35\ \mathrm{GeV}}}$$

Paul Anderson

- Predictions for DIS cross sections need to be updated for simulation studies for the EIC
- Full nucleon polarization, lepton and proton masses

$$\begin{aligned}
L^{(Z)}_{\mu\nu} W^{\mu\nu(Z)} = & -4\left[\left(g_V^2+g_A^2\right)\left(2m^2-Q^2\right)-8g_A^2m^2+4mg_Vg_A(k'\cdot s)\right]F_1^Z \\
& + \frac{4Q^2}{xy^2}\Bigg\{\left(g_V^2+g_A^2\right)\left(1-y-\frac{M^2x^2y^2}{Q^2}\right)-\frac{4g_A^2x^2y^2m^2M^2}{Q^4} \\
& + \frac{4mg_Vg_Axy}{Q^2}\left[\frac{M^2xy(k'\cdot s)}{Q^2}-(1-y)(P\cdot s)\right]\Bigg\}F_2^Z \\
& - \frac{4}{y}\left\{my\left(g_V^2+g_A^2\right)\left[2x(P\cdot s)-(k'\cdot s)\right]+2g_A^2m[(k'\cdot s)-xy(P\cdot s)]+Q^2g_Vg_A(y-2)\right\}F_3^Z \\
& + \frac{16Mx}{Q^2}\Bigg\{m\left(g_V^2+g_A^2\right)\left[Q^2(s\cdot S)-(q\cdot S)(k'\cdot s)\right]+mg_A^2\left[2(k\cdot S)(k'\cdot s)-Q^2(s\cdot S)\right] \\
& - Q^2g_Vg_A[(k\cdot S)+(k'\cdot S)]\Bigg\}g_1^Z \\
& + \frac{16Mx}{Q^2y}\Bigg\{my\left(g_V^2+g_A^2\right)\left[Q^2(s\cdot S)-2x(q\cdot S)(P\cdot s)\right]-2g_A^2m\left[Q^2(s\cdot S)-2xy(k\cdot S)(P\cdot s)\right] \\
& + 2Q^2g_Vg_A[(1-y)(k\cdot S)-(k'\cdot S)]\Bigg\}g_2^Z \\
& - \frac{4M}{yQ^2}\Bigg\{Q^2\left(g_V^2+g_A^2\right)\left[(S\cdot k')+(1-y)(k\cdot S)\right] \\
& - 2mg_Vg_A\left[Q^2(1-y)(S\cdot s)+2xy(P\cdot s)(k'\cdot S)\right]\Bigg\}g_3^Z \\
& + \frac{8M(S\cdot q)}{y^2}\Bigg\{\left(g_V^2+g_A^2\right)\left(1-y-\frac{M^2x^2y^2}{Q^2}\right)-\frac{4g_A^2m^2M^2x^2y^2}{Q^4} \\
& + \frac{4mxyg_Vg_A}{Q^2}\left[\frac{M^2xy(k'\cdot s)}{Q^2}-(1-y)(P\cdot s)\right]\Bigg\}g_4^Z \\
& + \frac{8Mx(S\cdot q)}{Q^2}\left[\left(g_V^2+g_A^2\right)\left(2m^2-Q^2\right)-8g_A^2m^2+4mg_Vg_A(k'\cdot s)\right]g_5^Z
\end{aligned}$$

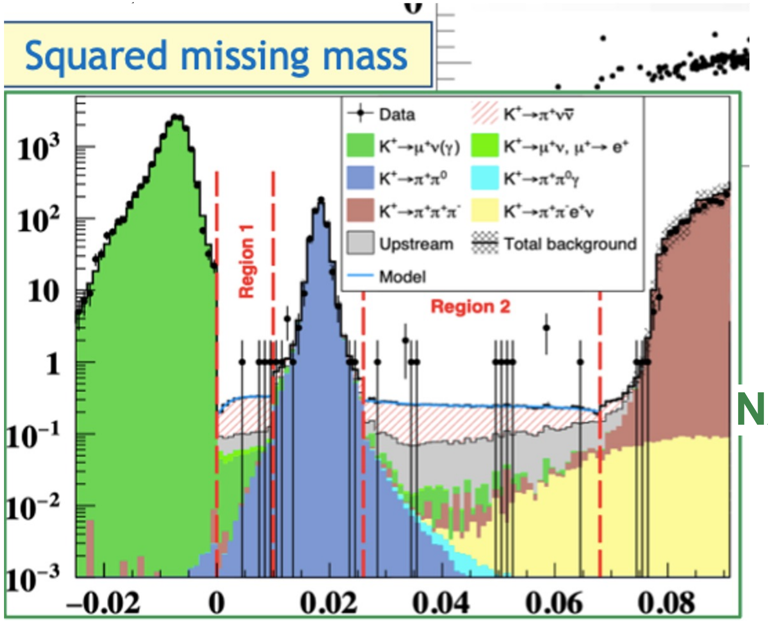
Future plans:
- More cross checks
- Estimates for EIC kinematics

Recent results from NA62: rare Kaon decays

Peter Cooper (NA62)

- Rare kaon decays (**K→πνν**, ...): unique probes for heavy new physics at the **O(100 TeV)** mass scale, and for light hidden

K+ decays in FV: $(1.33\pm0.02)\times10^{12}$
Expected background: 1.07 ± 0.20 evt
Candidates observed: 0
$BR(K^+\to\pi^-\mu^+e^+)<4.2\times10^{-11}$ at 90% CL



Full Run 1 data set:

Candidates observed: **20** (**17** in 2018)

Expected background: $7.03^{+1.05}_{-0.82}$

Expected SM events:

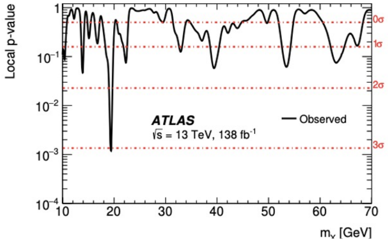
$10.01\pm0.42_{syst}\pm1.19_{ext}$

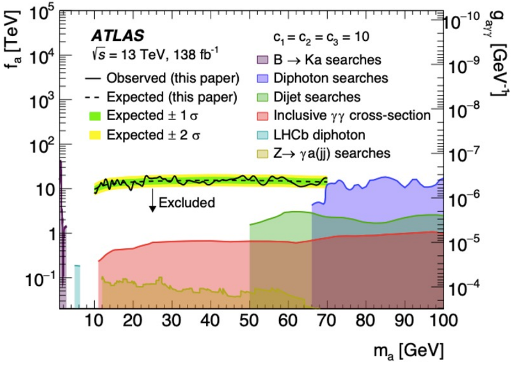
NA62 is improving on **BR(K+→π+νν)**, aiming at **O(10%)** precision by **2025**

Resonance and DM searches with ATLAS

Chris Meyer (ATLAS)

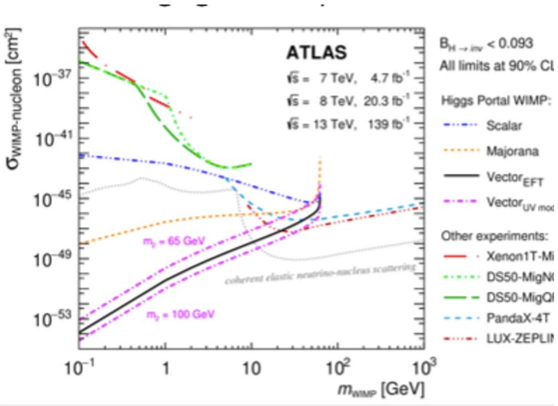
- Search for resonances in low-mass di-photon mass spectrum
- Limits on axion mass/coupling



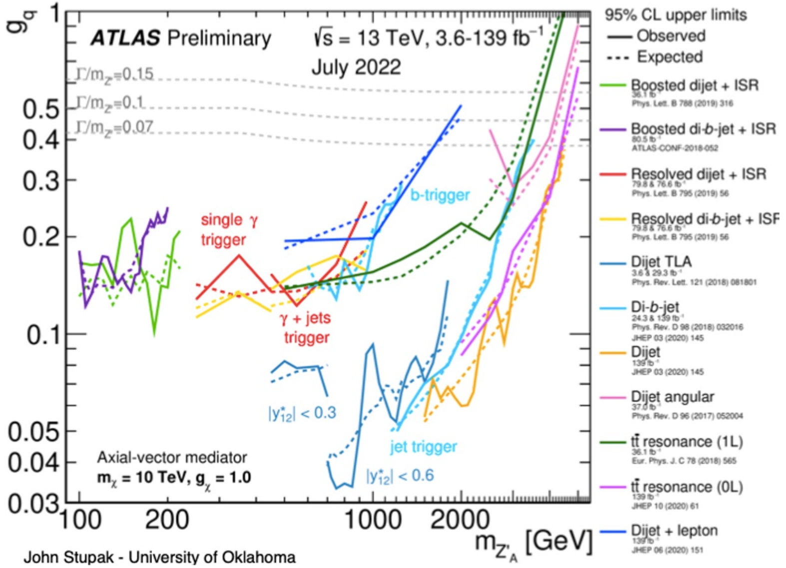


John Stupak (ATLAS)

- Higgs portal, simplifies models, resonance searches, dark QCD



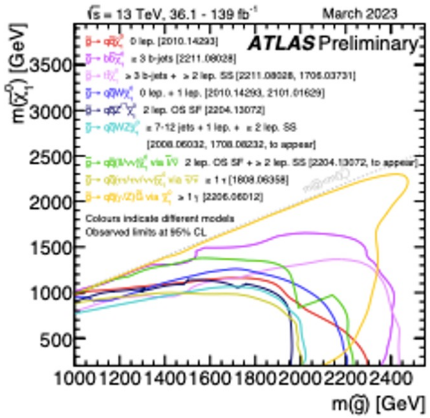
Resonance searches can be interpreted in DM simplified models

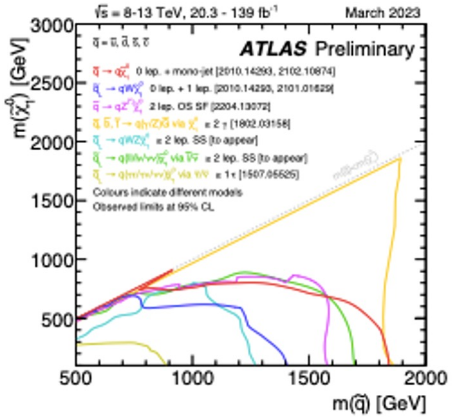


SUSY searches with ATLAS

Shiyi Liang (ATLAS)

$\tilde{q}/\tilde{g}$ search in SS/3L final states

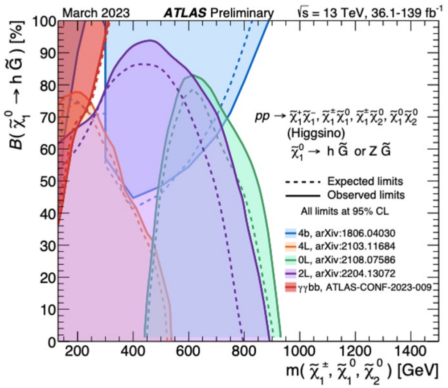


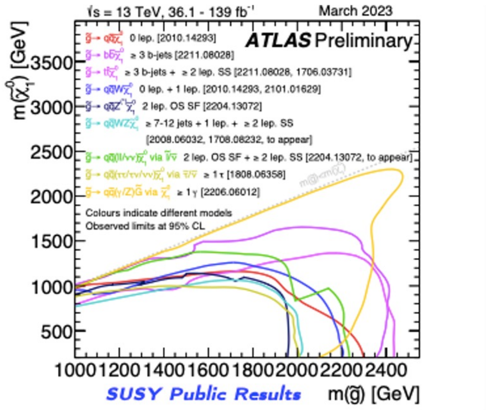


Francesco Gravili (ATLAS)

- *R-parity conserving* (RPC) scenarios with large E_T^{miss}:
  - Strong processes
  - Squarks and LeptoQuarks
  - Electroweak
- *R-parity violating* (RPV) scenarios with large lepton/jet multiplicities

$\tilde{g}$ excluded up to $\sim$ 2.4 TeV for massless $\tilde{\chi}_1^0$





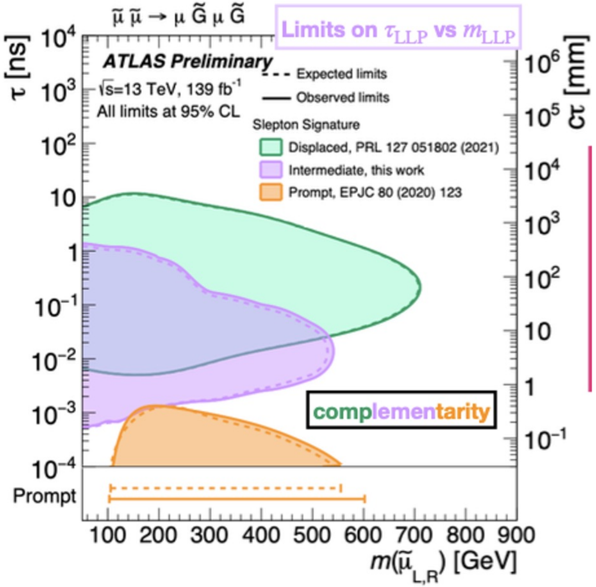
$\tilde{g}$ excluded up to $\sim$ 2.4 TeV for massless $\tilde{\chi}_1^0$

LLP and LeptoQuark searches with ATLAS

Elena Pompa Pacchi (ATLAS)

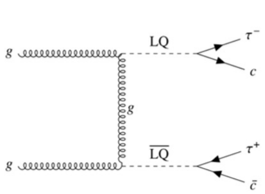
- Multi-charged particles; SUSY: Displace vertices with jets, displaced photons, slightly displaced muons

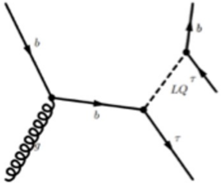
Unconventional reconstruction, novel trigger algorithm, very good knowledge of detectors are needed...

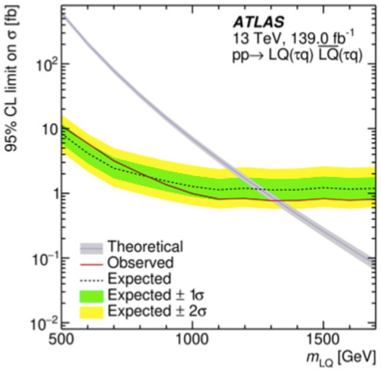


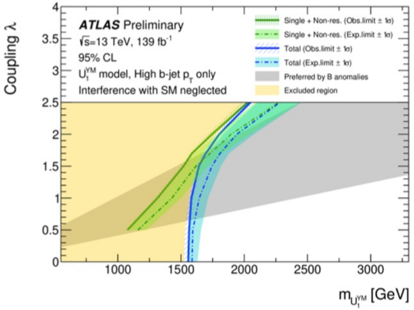
Allison Deiana (ATLAS)

- Mixed generation or third generation









Study of LFV and FVU at Belle and BSM searches at Belle II

Shun Watanuki (Belle)

➢ **LFU tests at Belle**

- $B \to D^{(*)}\tau\nu/D^{(*)}\ell\nu$ using semi-leptonic (SL) tag
- $B \to K^*\ell^+\ell^-$
- $B \to K\ell^+\ell^-$

– $R_{K^{(*)}} \equiv \frac{\mathcal{B}(B\to K^{(*)}\mu\mu)}{\mathcal{B}(B\to K^{(*)}ee)}$ (1-loop) *Cross-check is still needed!!*

– $\boldsymbol{R_{D^{(*)}} \equiv \frac{\mathcal{B}(B\to D^{(*)}\tau\nu)}{\mathcal{B}(B\to D^{(*)}\ell\nu)}}$ **(tree)**

➢ **LFV searches at Belle**

- $B^0_{(s/d)} \to \tau\ell\ (\ell = \mu, e)$
- $B^+ \to K^+\tau\ell\ (\ell = \mu, e)$ using hadronic tag ← New result!

BR U.L. (90% CL)	$\mathcal{B}(K^+\tau^+\mu^-)\times10^5$	$\mathcal{B}(K^+\tau^-\mu^+)\times10^5$	$\mathcal{B}(K^+\tau^+e^-)\times10^5$	$\mathcal{B}(K^+\tau^-e^+)\times10^5$
Babar	<2.8	<4.5	<1.5	<4.3
LHCb	<3.9	-	-	-
Belle (Preliminary)	**<0.59**	**<2.45**	**<1.51**	**<1.53**

– $R_{D^{(*)}}$ (tree) shows more than 3σ anomaly from SM

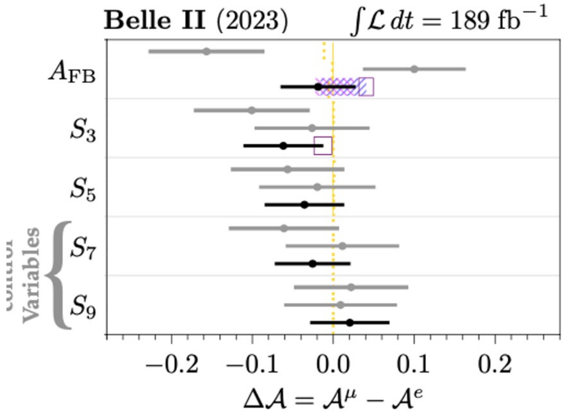
– $R_{K^{(*)}}$ (loop) is all consistent with SM

Roberta Volpe (Belle II)

$$R(D^{(*)}) = \frac{B(B\to D^{(*)}\tau\nu)}{B(B\to D^{(*)}l\nu)}$$

$l = e, \mu$

- **Tests of light-lepton universality:**
  - Measurement of $R(X_{e/\mu}) = 1.033 \pm 0.010\ (\text{stat}) \pm 0.019\ (\text{syst})$
  - First dedicated light-LU test using a set of angular observables with the $B^0 \to D^{*-}l^+\nu$ decay NEW
- **Search for a long-lived scalar in b → s transitions** NEW



Consistent with SM

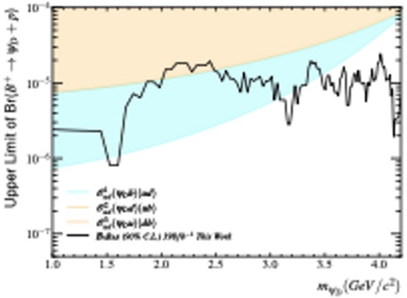
Search for low-mass BSM at Babar

Michael Sokoloff (Babar)

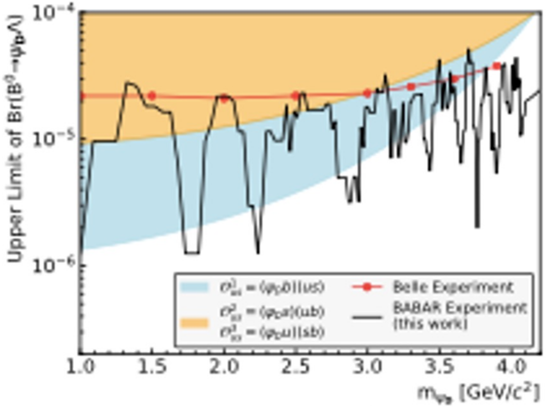
Search for evidence of dark sector physics in two analyses:

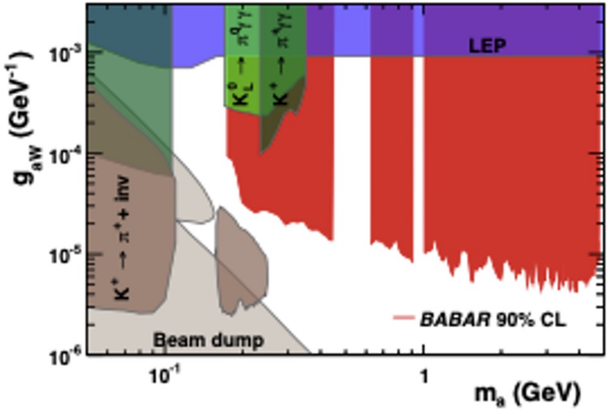
- $B^+ \to K^+ a$; $a \to \gamma\gamma$ where a is an **axion-like particle** (ALP);
- $B \to \Lambda \psi_D$ where ψ_D is a **dark anti-baryon**.

$$\mathcal{L} = -\frac{g_{aW}}{4} a W_{\mu\nu} \tilde{W}^{\mu\nu}$$



Upper limits on the $B^0 \to \psi_D p$ branching fraction at the 90% CL, along with $B^0 \to \psi_D p$ branching fractions allow to generated B-Mesogenesis for the indicated operators.





90% CL upper limits on the coupling g_{aW} as a function of the ALP mass (red), together with existing constraints (blue, green, brown, and grey).

The existing constraints are taken from PRL **118**, 111802 (2017)

Search for effective Lorentz and CPT violation with ZEUS data

Enrico Lunghi

- Effective description: Standard Model extension (SME)
- LV in the quark sector (DIS and DY) : factorization still works

Interactions that we consider are ($q = u, d, s$):

$$\mathscr{L}_{\mathrm{SM}} \ni \frac{1}{2}\bar{q}\gamma^{\mu} iD_{\mu} q + \mathrm{h.c.}$$

$$\mathscr{L}_{\mathrm{SME}} \ni \frac{1}{2}c_q^{\mu\nu}\, \bar{q}\gamma_{\mu} iD_{\nu} q$$

$$-\frac{1}{2}a_q^{(5)\mu\alpha\beta}\, \bar{q}\gamma_{\mu} iD_{(\alpha} iD_{\beta)} q + \mathrm{h.c.}$$

- Estimated sensitivity of **DIS at HERA/EIC** and **Drell-Yan**

	HERA	EIC	LHC
$\lvert a_{Su}^{(5)TXX} - a_{Su}^{(5)TYY}\rvert$	7.0×10^{-6}	2.3×10^{-6}	1.5×10^{-8}
$\lvert a_{Su}^{(5)XXZ} - a_{Su}^{(5)YYZ}\rvert$	1.8×10^{-5}	5.2×10^{-6}	-
$\lvert a_{Su}^{(5)TXY}\rvert$	2.3×10^{-6}	3.4×10^{-7}	2.7×10^{-9}
$\lvert a_{Su}^{(5)TXZ}\rvert$	4.7×10^{-6}	1.3×10^{-7}	7.2×10^{-9}
$\lvert a_{Su}^{(5)TYZ}\rvert$	4.6×10^{-6}	1.3×10^{-7}	7.0×10^{-9}
$\lvert a_{Su}^{(5)XXX}\rvert$	1.7×10^{-6}	1.4×10^{-7}	-
$\lvert a_{Su}^{(5)XXY}\rvert$	1.6×10^{-6}	1.4×10^{-7}	-
$\lvert a_{Su}^{(5)XYY}\rvert$	1.6×10^{-6}	1.4×10^{-7}	-
$\lvert a_{Su}^{(5)XYZ}\rvert$	1.0×10^{-5}	4.3×10^{-7}	-
$\lvert a_{Su}^{(5)XZZ}\rvert$	2.1×10^{-6}	1.2×10^{-7}	-
$\lvert a_{Su}^{(5)YYY}\rvert$	1.7×10^{-6}	1.4×10^{-7}	-
$\lvert a_{Su}^{(5)YZZ}\rvert$	2.1×10^{-6}	1.2×10^{-7}	-

[units of GeV^{-1}]

CONSTRAINTS ON $a_q^{(5)\mu\nu\alpha}$ COEFFICIENTS

Coefficient	Lower (GeV^{-1})	Upper (GeV^{-1})
$a_{Su}^{(5)TXX} - a_{Su}^{(5)TYY}$	-5.1×10^{-7}	4.3×10^{-7}
$a_{Su}^{(5)XXZ} - a_{Su}^{(5)YYZ}$	-1.7×10^{-6}	2.0×10^{-6}
$a_{Su}^{(5)TXY}$	-8.3×10^{-8}	6.5×10^{-7}
$a_{Su}^{(5)TXZ}$	-2.9×10^{-7}	1.1×10^{-6}
$a_{Su}^{(5)TYZ}$	-4.3×10^{-7}	7.4×10^{-7}
$a_{Su}^{(5)XXX}$	-3.9×10^{-7}	1.2×10^{-7}
$a_{Su}^{(5)XXY}$	-2.3×10^{-7}	1.8×10^{-7}
$a_{Su}^{(5)XYY}$	-4.6×10^{-7}	9.2×10^{-8}
$a_{Su}^{(5)XYZ}$	-2.6×10^{-6}	3.3×10^{-7}
$a_{Su}^{(5)XZZ}$	-5.4×10^{-7}	1.4×10^{-7}
$a_{Su}^{(5)YYY}$	-2.9×10^{-7}	1.5×10^{-7}
$a_{Su}^{(5)YZZ}$	-3.6×10^{-7}	2.1×10^{-7}

From ZEUS data;
CPT violating coefficients

Thank you!

And special thanks to all speakers and Chairs!