The ep/eA study at the LHC and FCC – new impactful goals for the community

WG3

2023 | WS | 2024 | WS | 2025 | TWS | *input to ESPP*

proton and nuclear structure from EIC and HERA to LHeC and FCC-eh
novel QCD with high-energy DIS physics: what do we discover when breaking protons and nuclear matter in smaller pieces

general-purpose high-energy physics programme: precision physics and searches
enabling direct discoveries and measurements in EW, Higgs and top physics with high-energy DIS collisions

ep/eA-physics empowering pp/pA/AA-physics (LHC and FCC)
improving the ATLAS, CMS, LHCb and ALICE discovery potential with results from a high-energy DIS physics programme

developing a general-purpose ep/eA detector for LHeC and FCC-eh
critical detector R&D (DRD collaborations), integrate in the FCC framework, one detector for joint ep/pp/eA/pA/AA physics

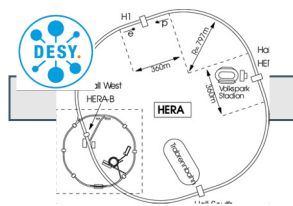
developing a sustainable LHeC and FCC-eh collider programme
design the interaction region, power and cost, coherent collider parameters & run plan, beam optimization, …

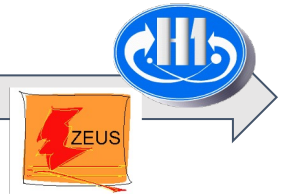
- typically 2-3 conveners per theme
- annual ep/eA workshops (WS)
- final thematic workshop with closing reports to inform the upcoming Strategy process with impactful information (TWS)
- inform the community with regular ep/eA Newsletters
- everybody is welcome to join

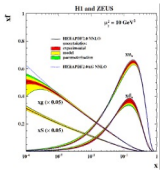
Coordination Panel: N. Armesto, M. Boonekamp, O. Brüning, D. Britzger, J. D'Hondt (spokesperson), M. D'Onofrio, C. Gwenlan, U. Klein, P. Newman, Y. Papaphilippou, C. Schwanenberger, Y. Yamazaki

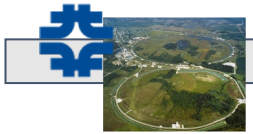
ep/eA-physics empowering pp/pA/AA-physics – HEP landscape

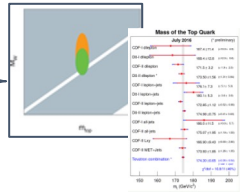
1980	1990	2000	2010	2020	2030	2040

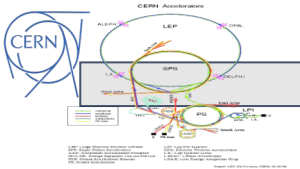












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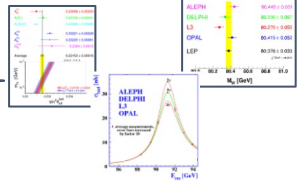
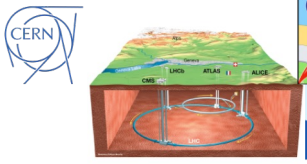
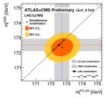
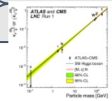








+X?

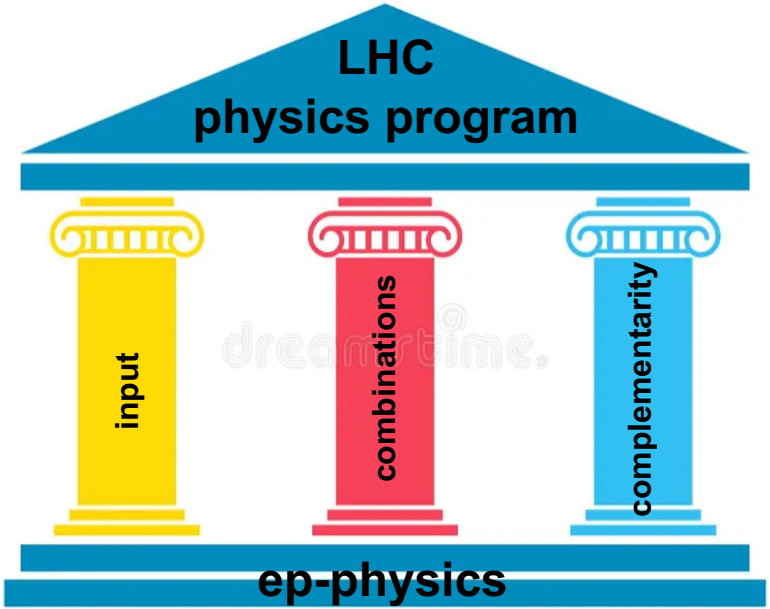
What will be the legacy of HL-LHC ? … and how to strengthen it?

?

The legacies of HEP facilities are not the results from single (competing) experiments, but are the combined results from all experiments
(plus discoveries !)

ep/eA-physics empowering pp/pA/AA-physics – Overview of Challenges

High precision *ep* measurements used as input in LHC analyses for their improvements



ep analyses with sensitivity complementary to LHC analyses to complete the overall LHC physics program

ep measurements to considerably improve LHC physics output, e.g. in final combinations

ep/eA-physics empowering pp/pA/AA-physics – Overview of Challenges

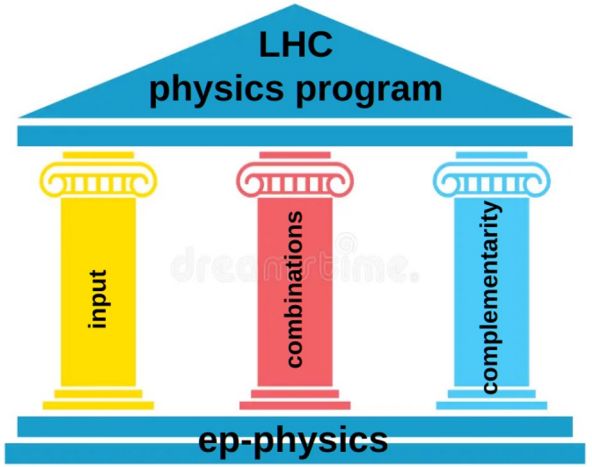
Input

→ ATLAS, CMS & LHCb members

High precision measurements in *ep* will be used as input in analyses by ATLAS, CMS and LHCb

→ Empowerment of LHC program

→ Input to pp physics analyses improving sizable uncertainties and limitations
- PDFs [transverse PDFs, TMDs, etc.] (WG1)
- input parameters to analyses,
  e.g. alpha_s, sin2(the_W),
  W mass, …
- Monte Carlo generators (constraints on parton showers, beam fragmentation, hadronization models, etc.)

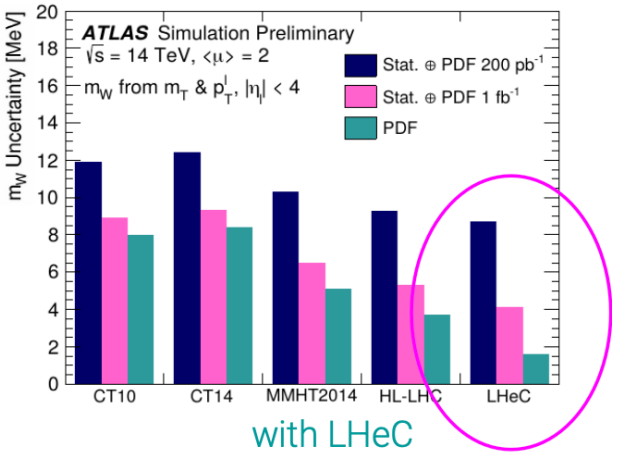


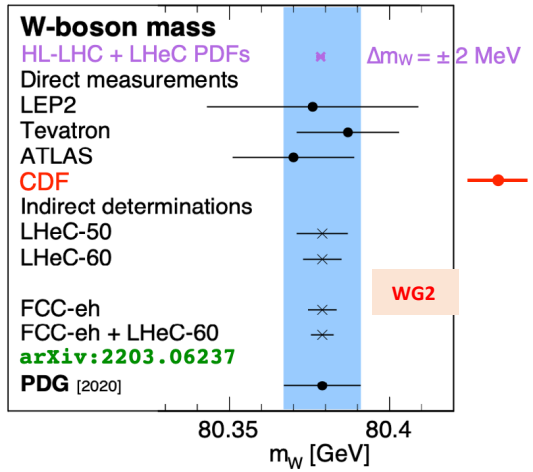
Many analyses of ATLAS, CMS or LHCb data will profit considerably

LHeC Input: Precision of W mass and effective electroweak mixing angle

W mass uncertainty prospects @ HL-LHC

ATLAS low-<μ> HL-LHC prospects





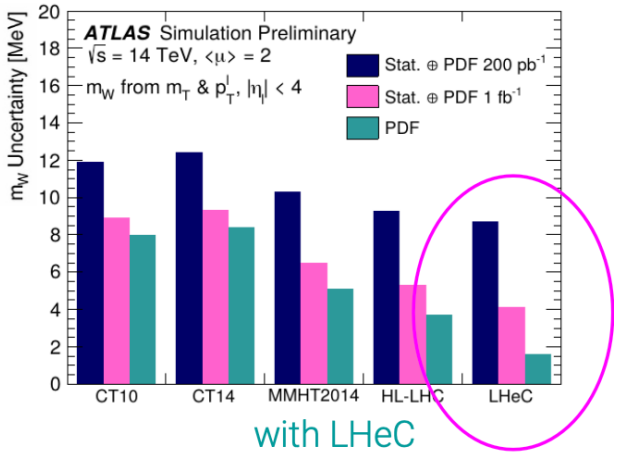
LHeC PDFs will shrink uncertainties in HL-LHC measurements of many (not only electroweak) parameters dramatically

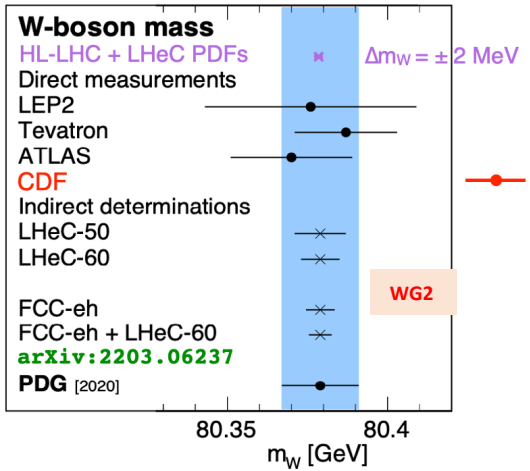
LHeC Input: Precision of W mass and effective electroweak mixing angle

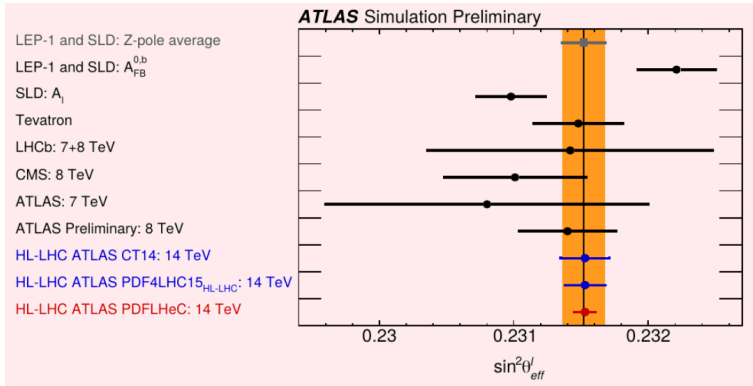
W mass uncertainty prospects @ HL-LHC

$\sin^2\theta_W$ prospects @ HL-LHC

ATLAS low-<μ> HL-LHC prospects







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ep/eA-physics empowering pp/pA/AA-physics – Overview of Challenges

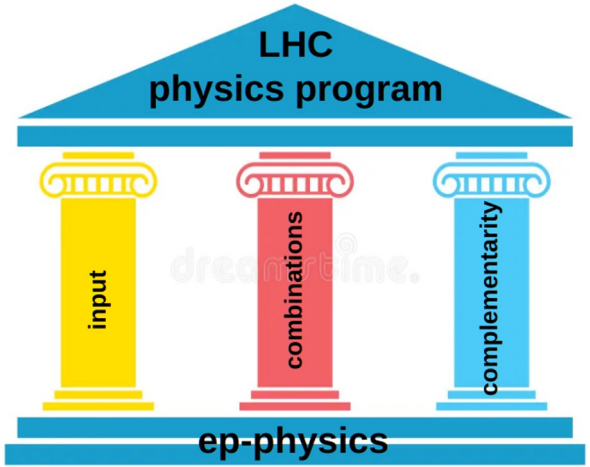
Combinations

→ LHC combination WGs, global fitters, etc.

***ep* measurements will significantly improve the final LHC physics output**

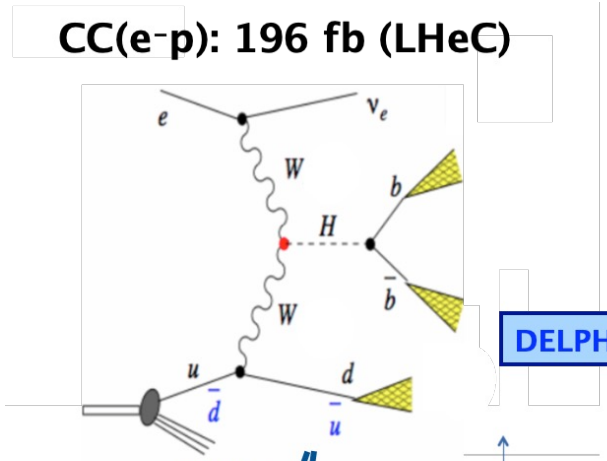
→ Competitive precision of measurements and combination of results
- alpha_s, sin2(theW), W mass, EWK quark couplings, top mass,Vtb, Vts, Vtd, anomalous Wtb, Higgs couplings (HWW, Hcc, Hbb, HZZ, CPV Htt, …), SMEFT Fit Higgs couplings, …

→ uncorrelated uncertainties
→ resolve correlations in parameters of interest
→ resolve common/correlated uncertainties between ATLAS&CMS
→ empowers global fits

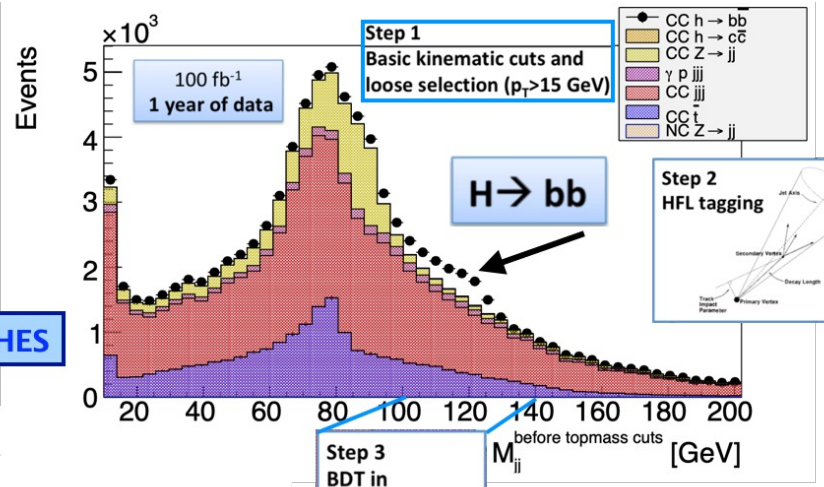


Final combinations of LHC results will considerably improve!

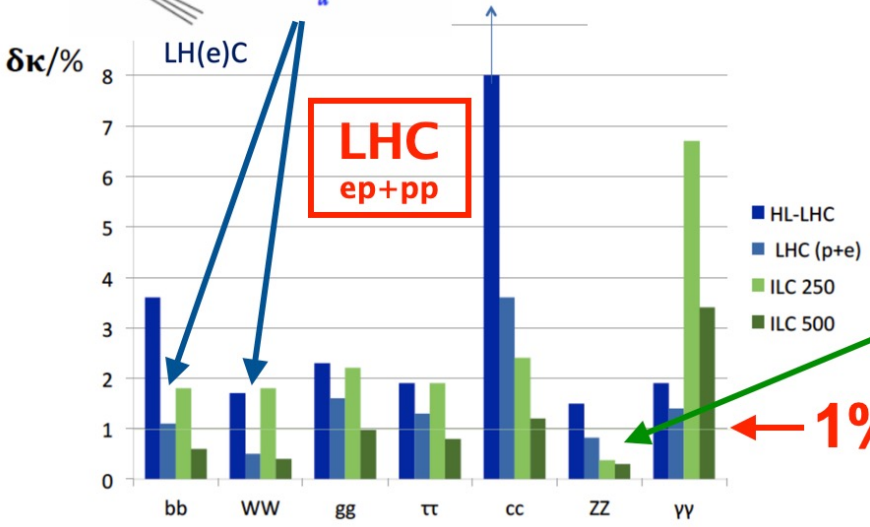
Higgs Coupling combinations (κ-framework)



DELPHES



WG2



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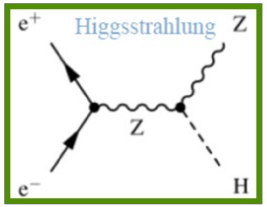
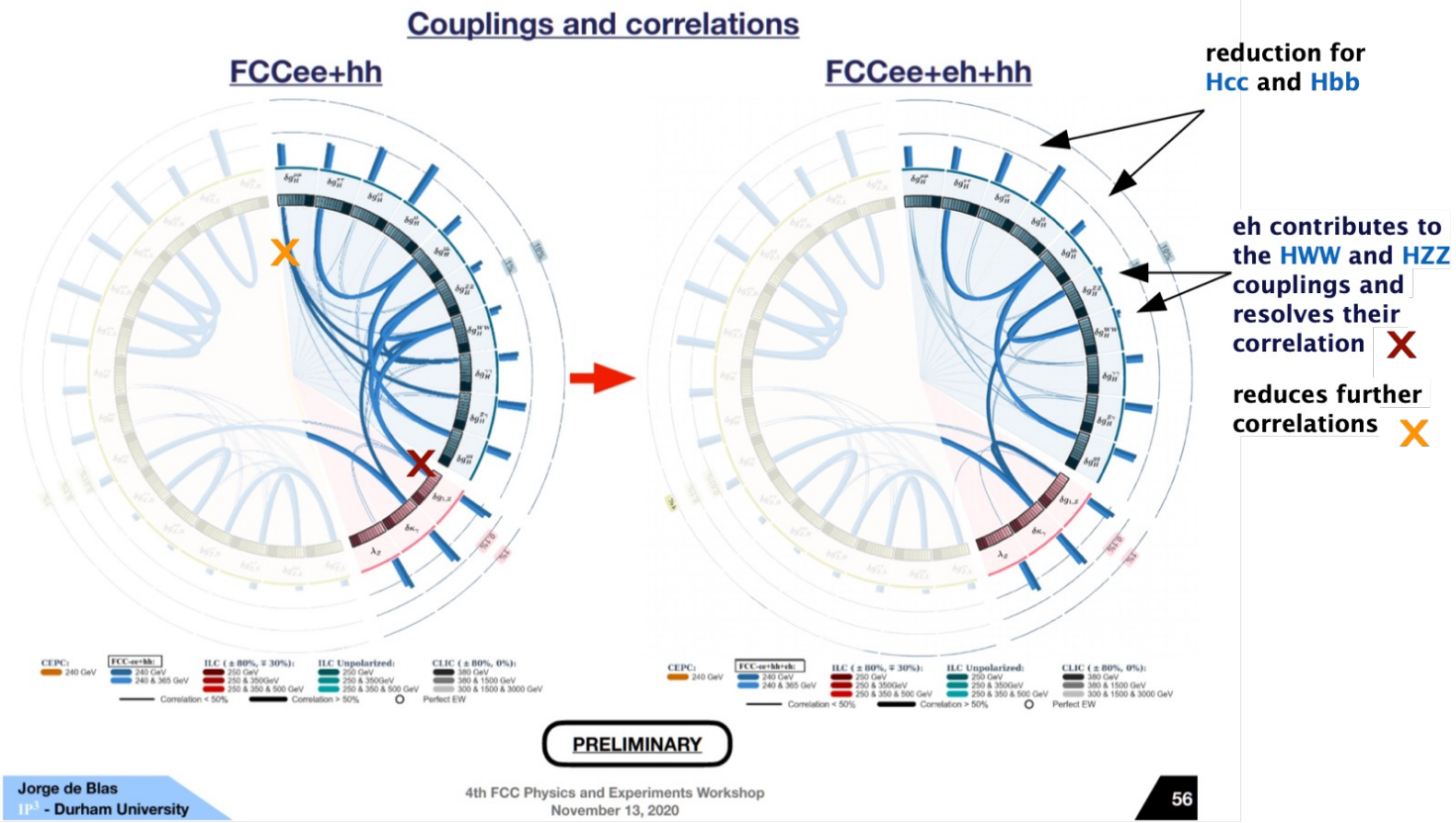


we profit from diversity through complementarity

→ adding electrons makes the LHC a Higgs precision facility

SMEFT fit results after FCC era



Higgs SMEFT coupling combinations profit from diversity: ee, ep, and pp

ep/eA-physics empowering pp/pA/AA-physics – Overview of Challenges

Complementarity

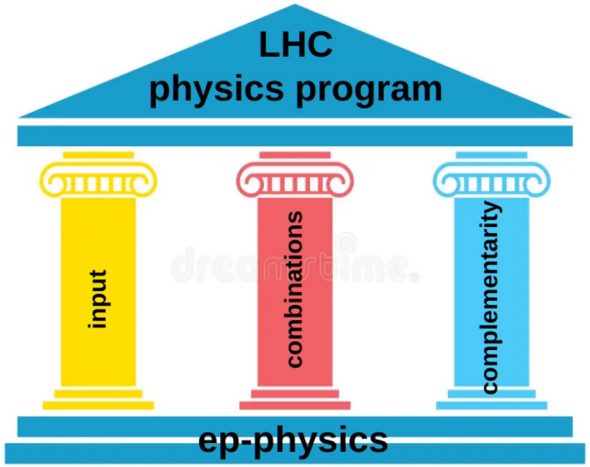
→ HEP community, PDG, adjacent fields (astro, nucl., etc.)

***ep* analyses with sensitivity complementary to LHC analyses**

→ high precision QCD analyses (WG1)

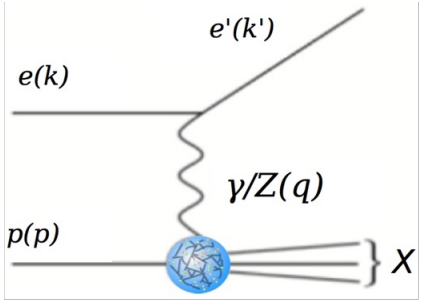
→ high precision measurements of specific parameters (WG2)

→ searches in complementary phase space regions (WG2)



Physics results from WG1 and WG2 will substantially enlarge the LHC physics program with additional results on specific EWK+top+Higgs parameters and high precision QCD measurements

Electroweak Fermion Couplings and SMEFT couplings



Britzger, Klein, Spiesberger,
Eur.Phys.J.C 80 (2020) 831

$$g_A^f = \sqrt{\rho_{\mathrm{NC},f}\rho'_{\mathrm{NC},f}}\, I^3_{\mathrm{L},f}\,,$$

$$g_V^f = \sqrt{\rho_{\mathrm{NC},f}\rho'_{\mathrm{NC},f}}\left(I^3_{\mathrm{L},f} - 2Q_f\kappa_{\mathrm{NC},f}\kappa'_{\mathrm{NC},f}\sin^2\theta_W\right)$$

→ **precision on per mille level**

(largely unaccessible in e^+e^-)

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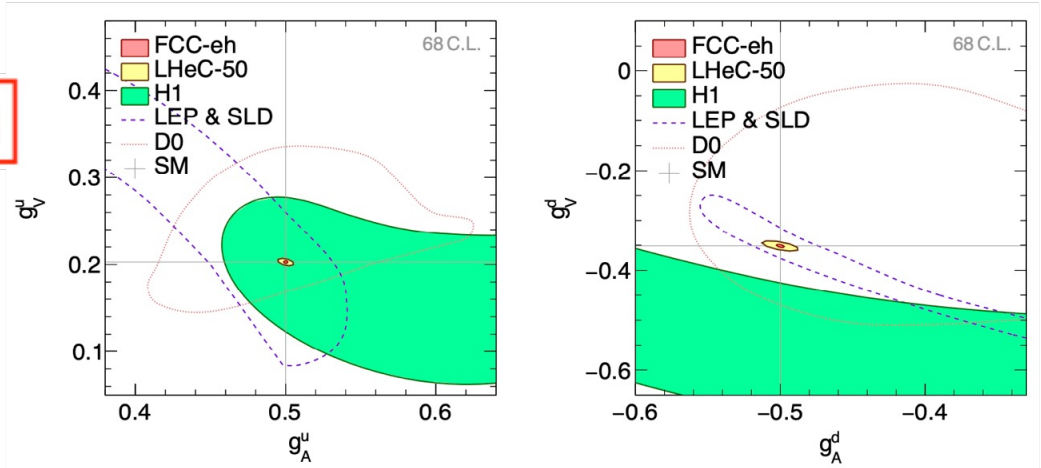

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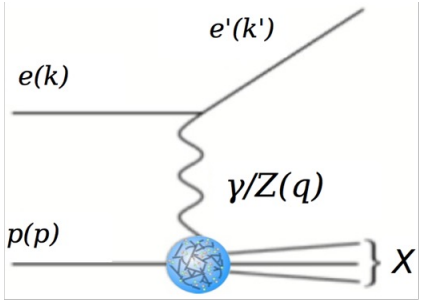
Electroweak Fermion Couplings and SMEFT couplings



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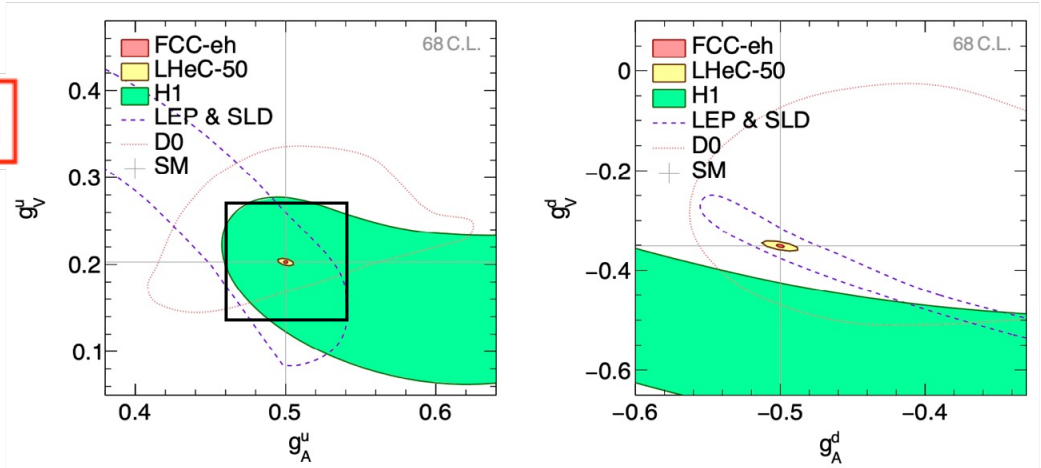

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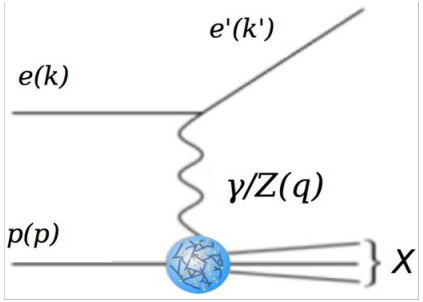

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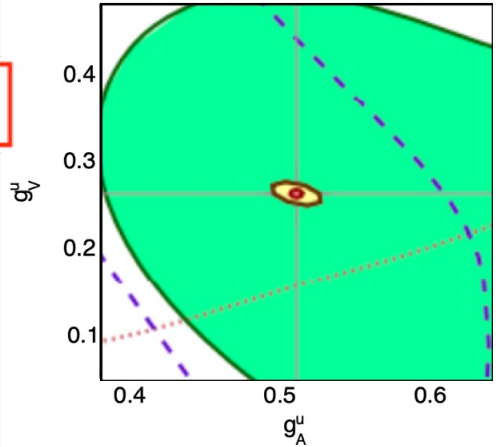

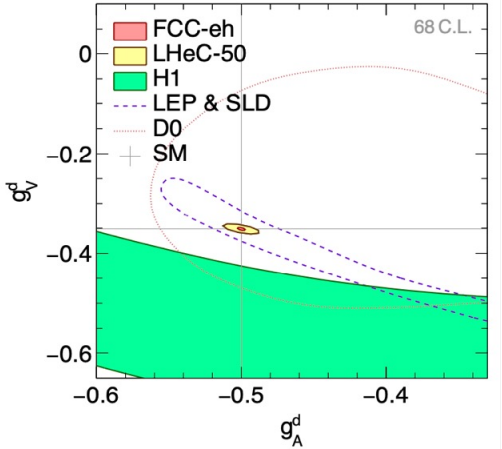

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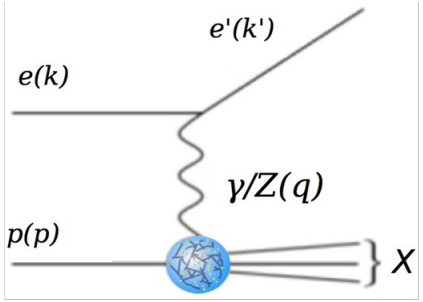
Electroweak physics of 1st generation quarks are largely inaccessible at other colliders

Electroweak Fermion Couplings and SMEFT couplings



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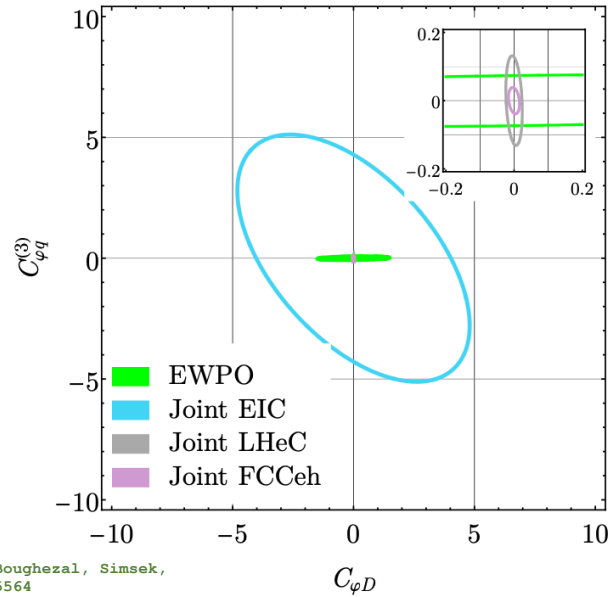
→ **precision on per mille level**

(largely unaccessible in e⁺e⁻)

$$O^{(3)}_{\varphi q} = (\varphi^\dagger i \overleftrightarrow{D}_\mu \tau^I \varphi)(\bar{q}\gamma^\mu \tau^I q)$$

$$O_{\varphi D} = (\varphi^\dagger D_\mu \varphi)^*(\varphi^\dagger D^\mu \varphi)$$

95% CL, Λ = 1 TeV, 17 *d* fit



Bissolotti, Boughezal, Simsek, arXiv:2306.05564

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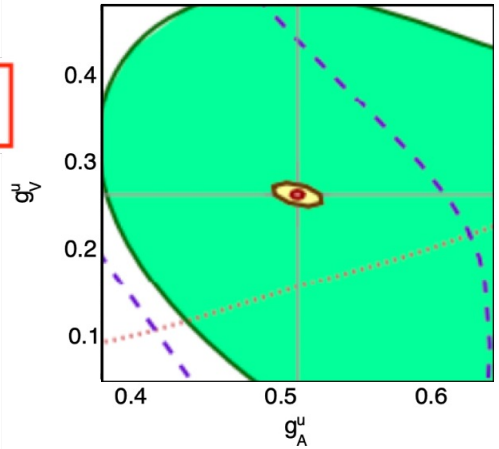

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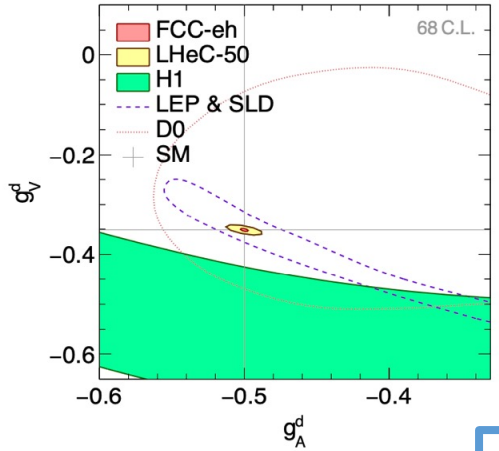


Electroweak physics of 1st generation quarks are largely inaccessible in other colliders

FCC-eh and LHeC will improve upon existing precision electroweak bounds in SMEFT parameter space in many cases, also for correlations

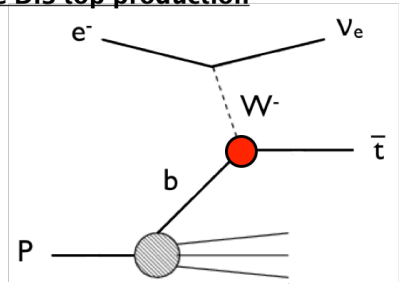
Expected measurements of Wtb couplings

= 1 in SM

$$L = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}\left(f_V^L P_L + f_V^R P_R\right)tW_{\mu}^{-}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(f_T^L P_L + f_T^R P_R\right)tW_{\mu}^{-} + h.c.$$

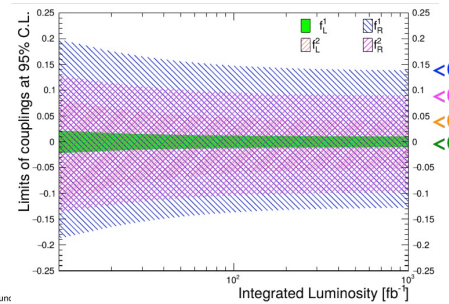
Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688
Kumar, Ruan, to be publ.

CC DIS top production

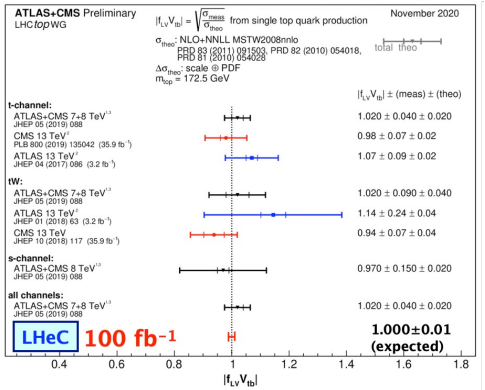


hadronic channel:

LHeC



WG2



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Unprecedented precision < 1%

Expected measurements of Wtb couplings

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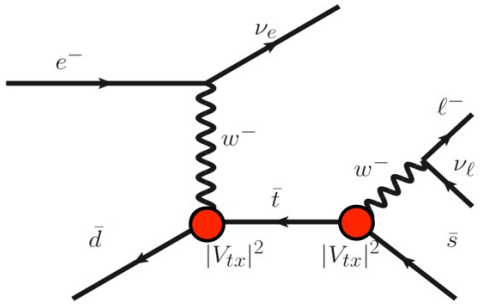
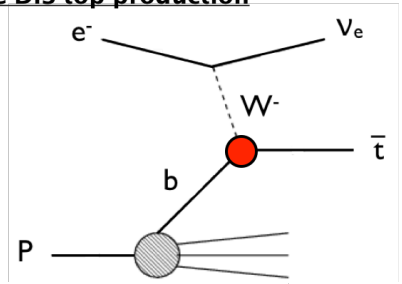
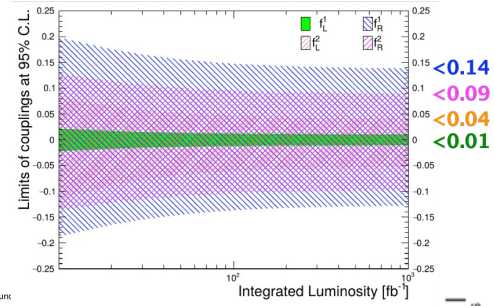


CC DIS top production

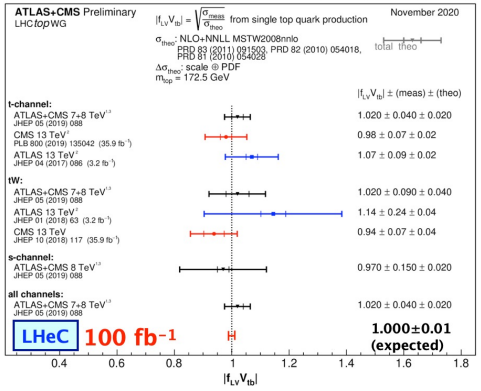


hadronic channel:

LHeC

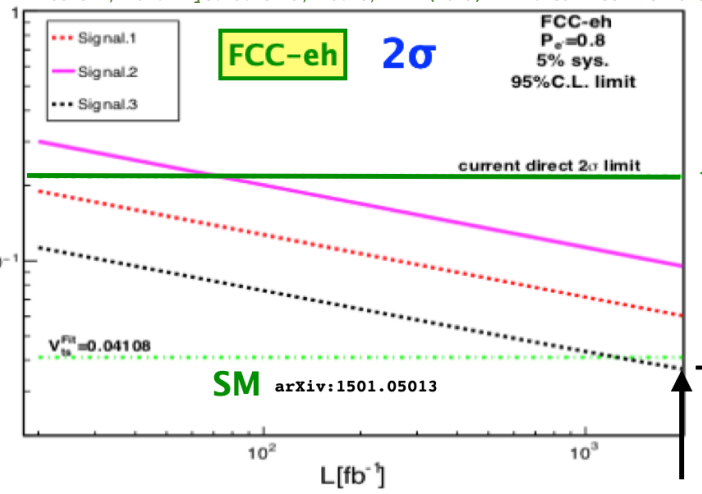


WG2



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

FCC CDR, Eur. Phys. J. C 79, no. 6, 474 (2019) H. Sun PoS DIS 2018, 167 (2018)



arXiv:1709.07887

LHC

→ $|V_{ts}|<0.037$

Unprecedented precision < 1%

Probing SM prediction directly for the first time

ep/eA-physics empowering pp/pA/AA-physics – Methodology

Path forward

Regular working group meetings

Input
Contributions from core analyzers (ATLAS,CMS,LHCb) on future pp analysis strategies and assess LHeC's impact on flagship pp measurements

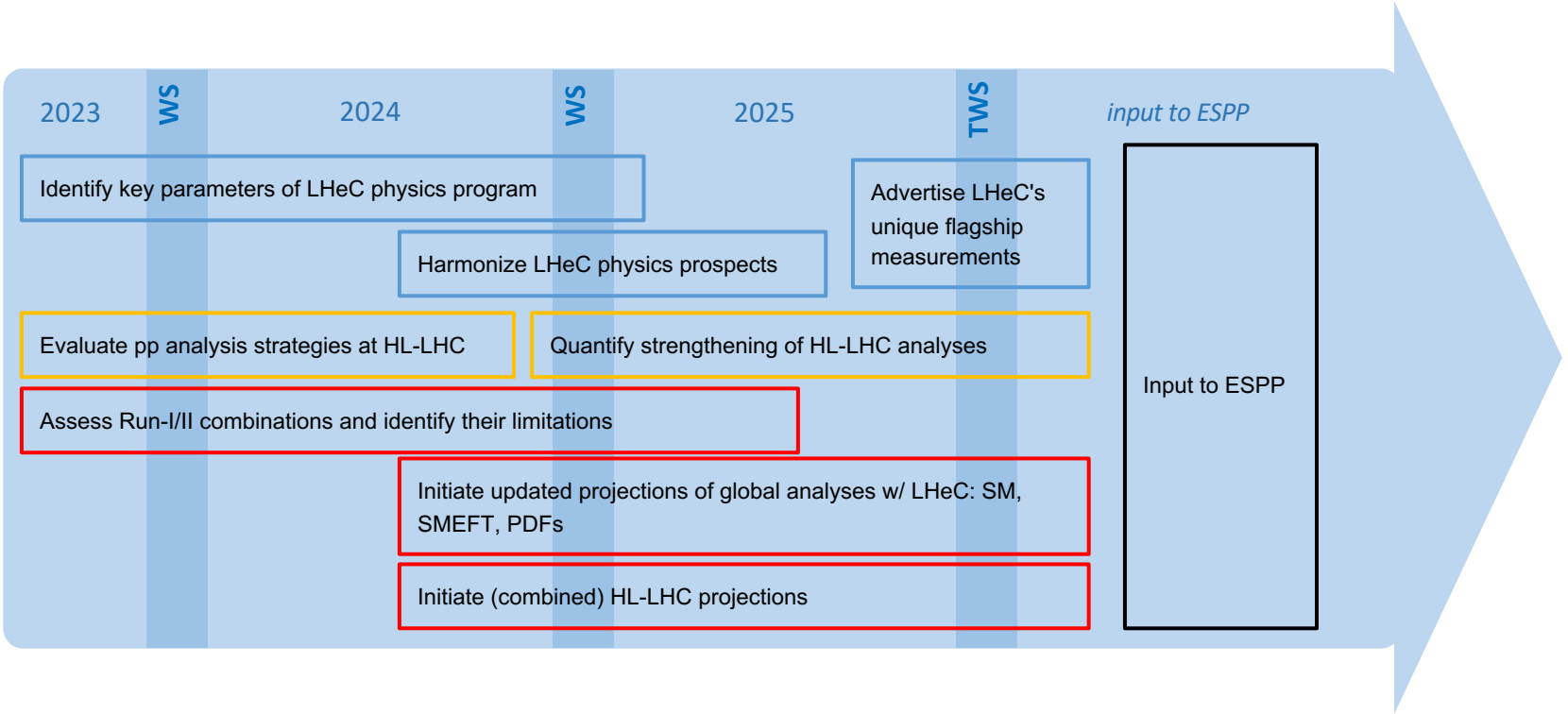
Combinations
Collaborate with LHC combination WGs, theorists, and 'global fitters' and identify: dominant LHC uncertainties, dominant parameter correlations, limited sensitivities, and assess LHeC's ep/eA/pp/AA impact on 'final' LHC results

Complementarity
Joint meetings with WG1 & WG2 on core topics in ep/eA/pp/AA physics program

WG convenors: Maarten Boonekamp, Daniel Britzger, Christian Schwanenberger
WG indico page: https://indico.cern.ch/category/17309/
Self-subscribe to the WG mailing list: ep-eA-WG3-ep-for-pp @cern.ch

Backup

ep/eA-physics empowering pp/pA/AA-physics – timescale and deliverables



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