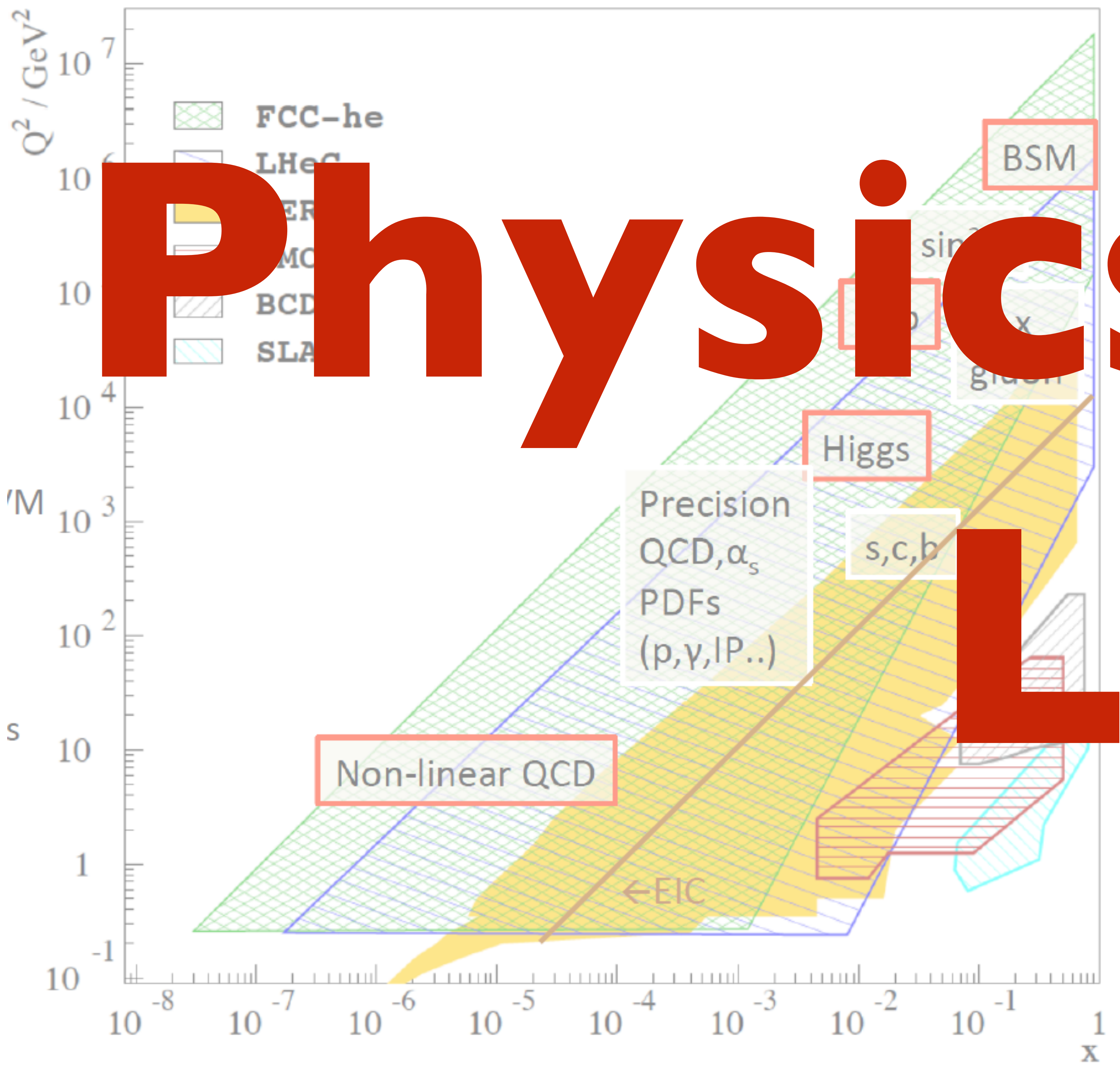
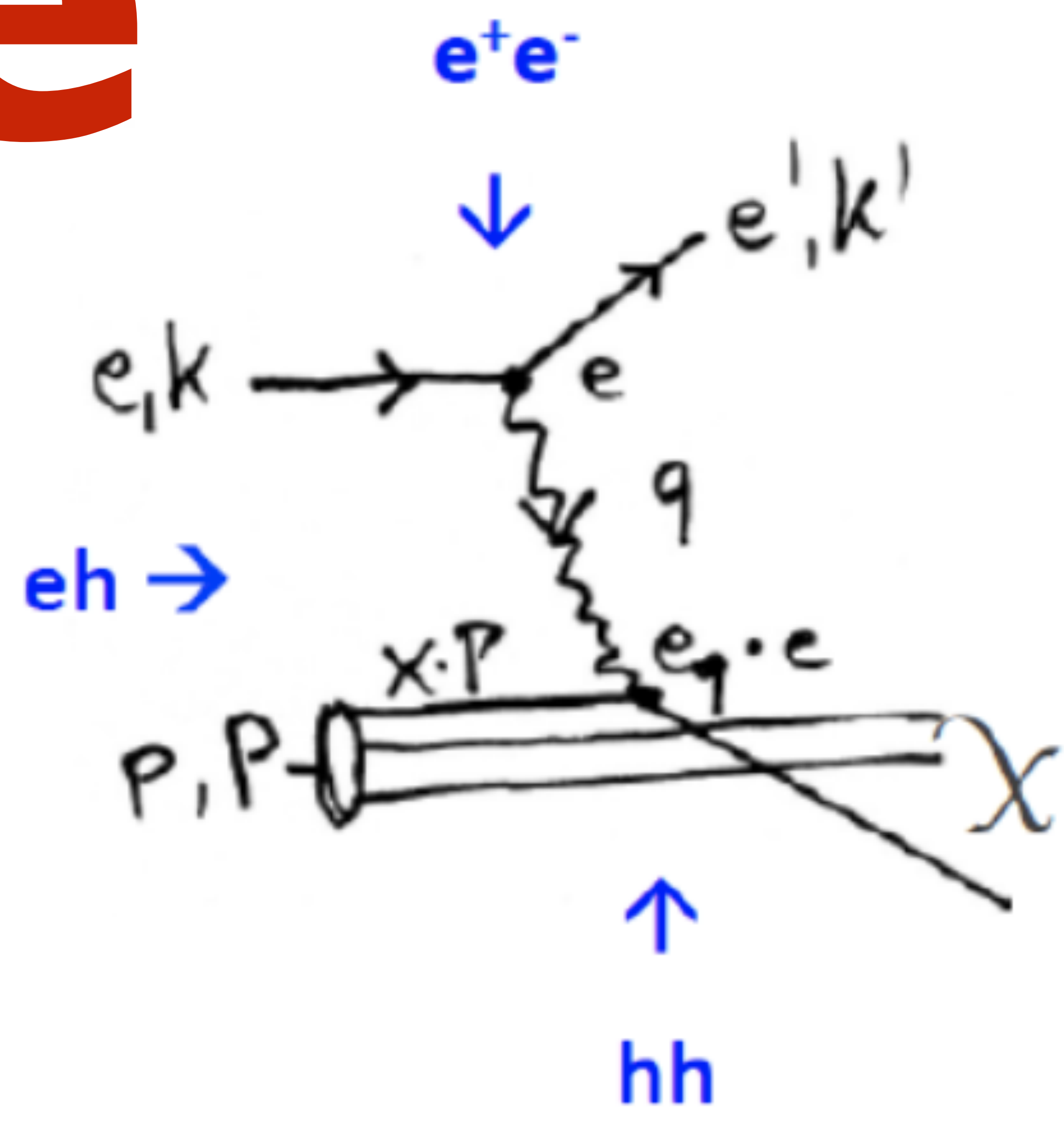
2025 European Edition of the International Workshop on the Circular Electron-Positron Collider
Universitat Pompeu Fabra, Barcelona, June 18th 2025

Physics with the LHeC





Néstor Armesto
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for the LHeC/FCC-eh Study Group, https://indico.cern.ch/event/lhecfcceh.

Contents:

1. Introduction.

2. Physics (some examples):
   - ➜ QCD.
   - ➜ Higgs.
   - ➜ EW.
   - ➜ Top.
   - ➜ BSM.

3. Summary.

References:

- *Future Circular Collider CDR: Vol. 1 Physics opportunities (Eur. Phys. J. C79 (2019) no.6, 474) and Vol. 3 FCC-hh: The Hadron Collider (Eur. Phys. J. ST 228 (2019) no.4, 755-1107);*
- *LHeC CDR, 1206.2913;*
- *European Strategy Update: Briefing Book, 1910.11775;*
- *Update of the 2012 LHeC CDR, 2007.14491;*
- *2201.02436;*
- *LHeC/FCC-eh talks at ICHEP2024, https://indico.cern.ch/event/1291157/, and DIS2025, https://indico.cern.ch/event/1436959/.*
- *Talks at the Synergy workshop between ep/eA and pp/pA/AA physics experiments, February 29th-March1st 2024, https://indico.cern.ch/event/1367865/.*
- ***White paper: 2503.17727**, annex to the EPPS submission.*

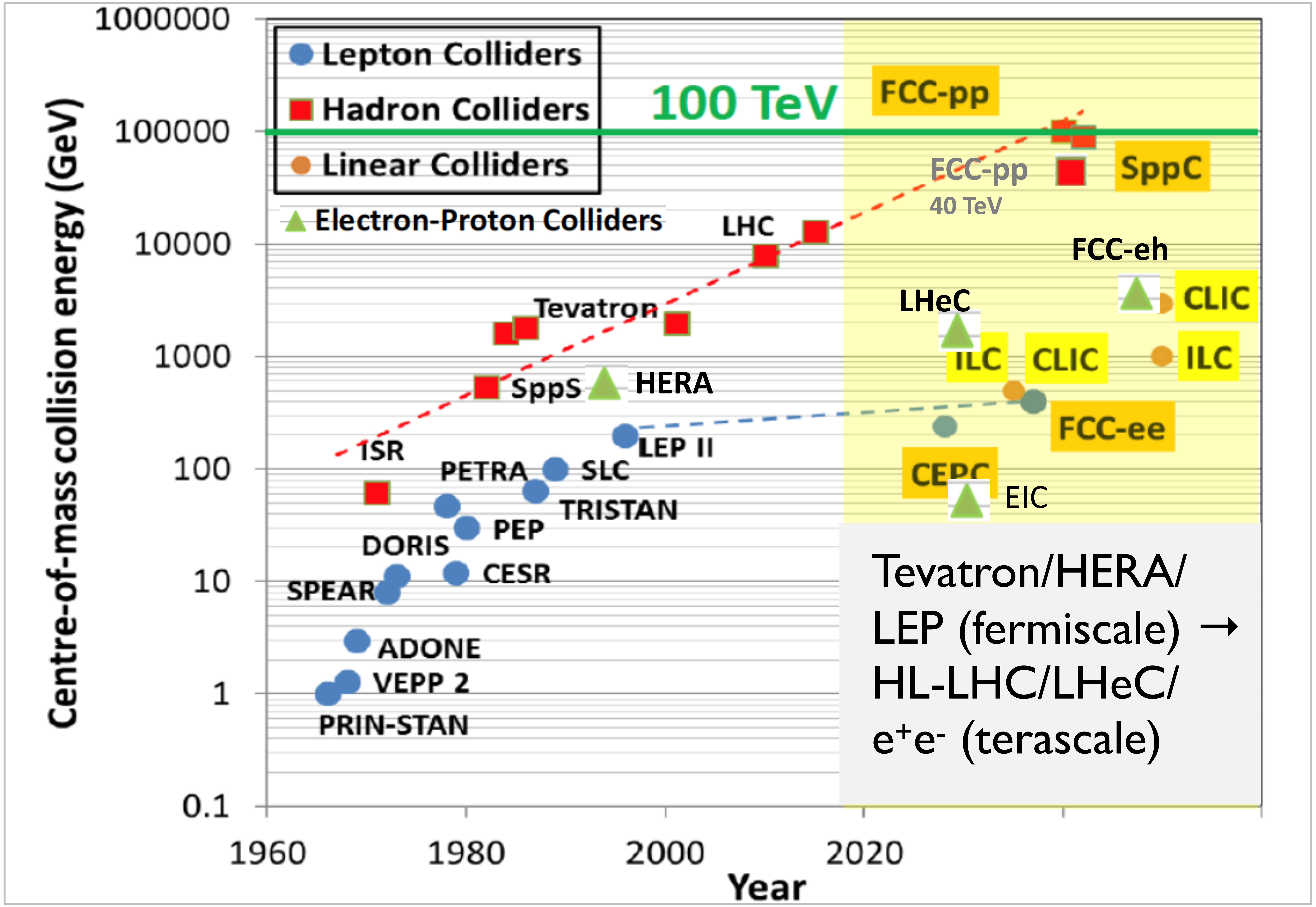
https://indico.cern.ch/event/lhecfcceh

Accelerators:

- Thoughts of combining LEP with LHC came from the start (1990's).

- LHeC idea born in 2005: upgrade of the HL-LHC to study DIS at the terascale.

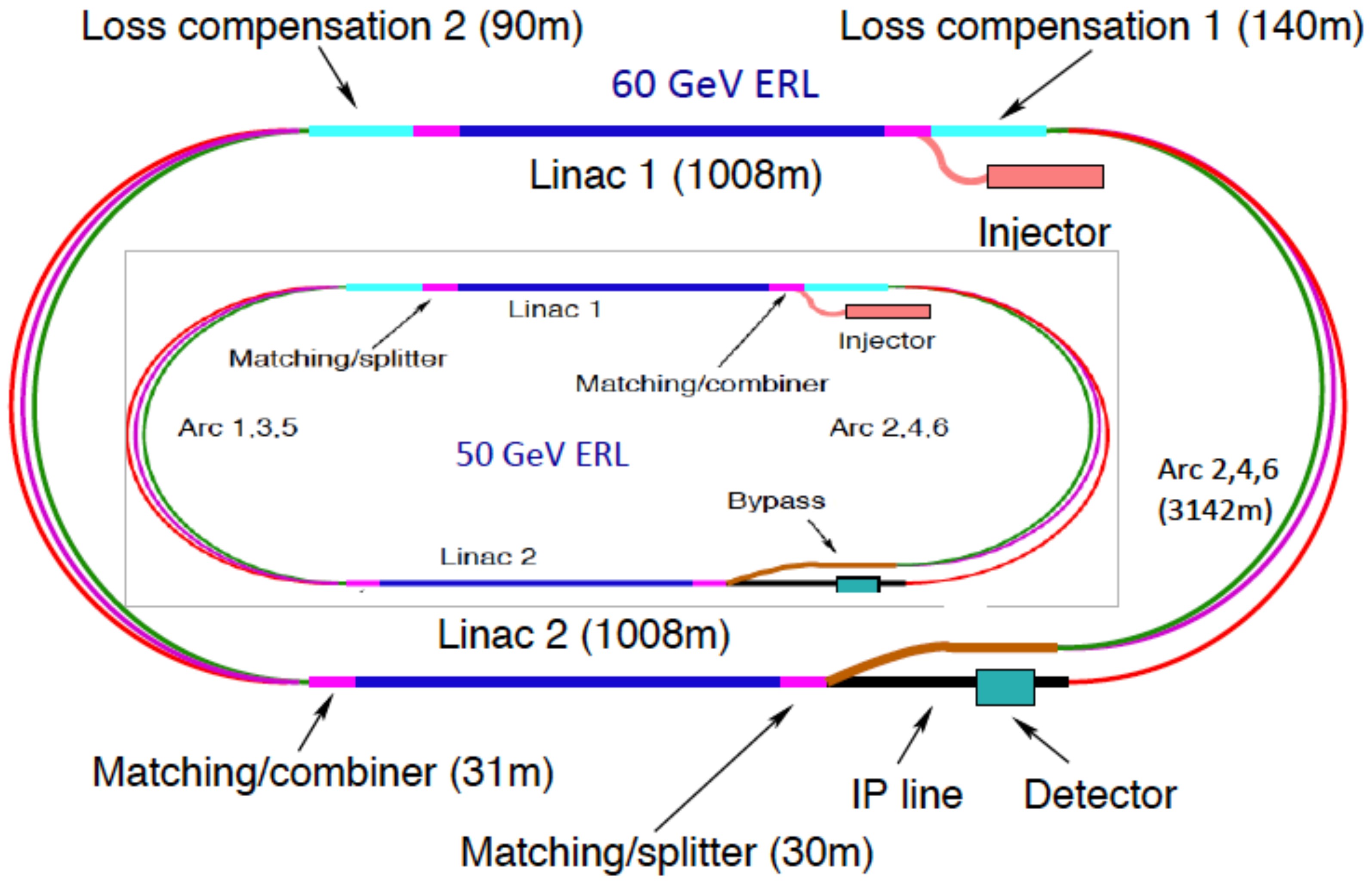
- **It should be able to run concurrently with pp** (also FCC-eh), plus limitations on power consumption, high luminosity for Higgs studies,… ⇒ energy recovery linac as baseline.



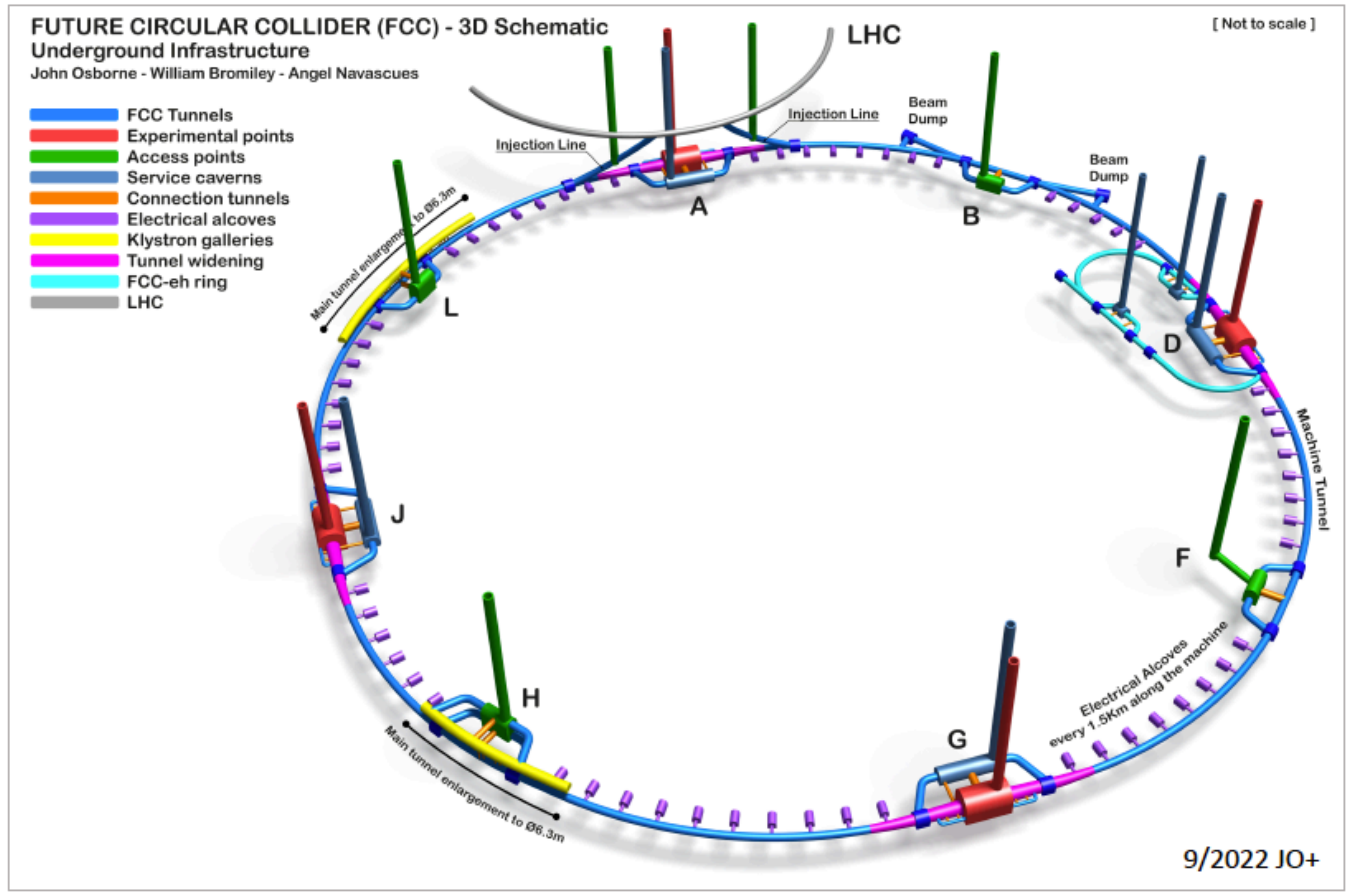
Tevatron/HERA/LEP (fermiscale) → HL-LHC/LHeC/e^+e^- (terascale)

Accelerators:

LHeC



FCC-eh



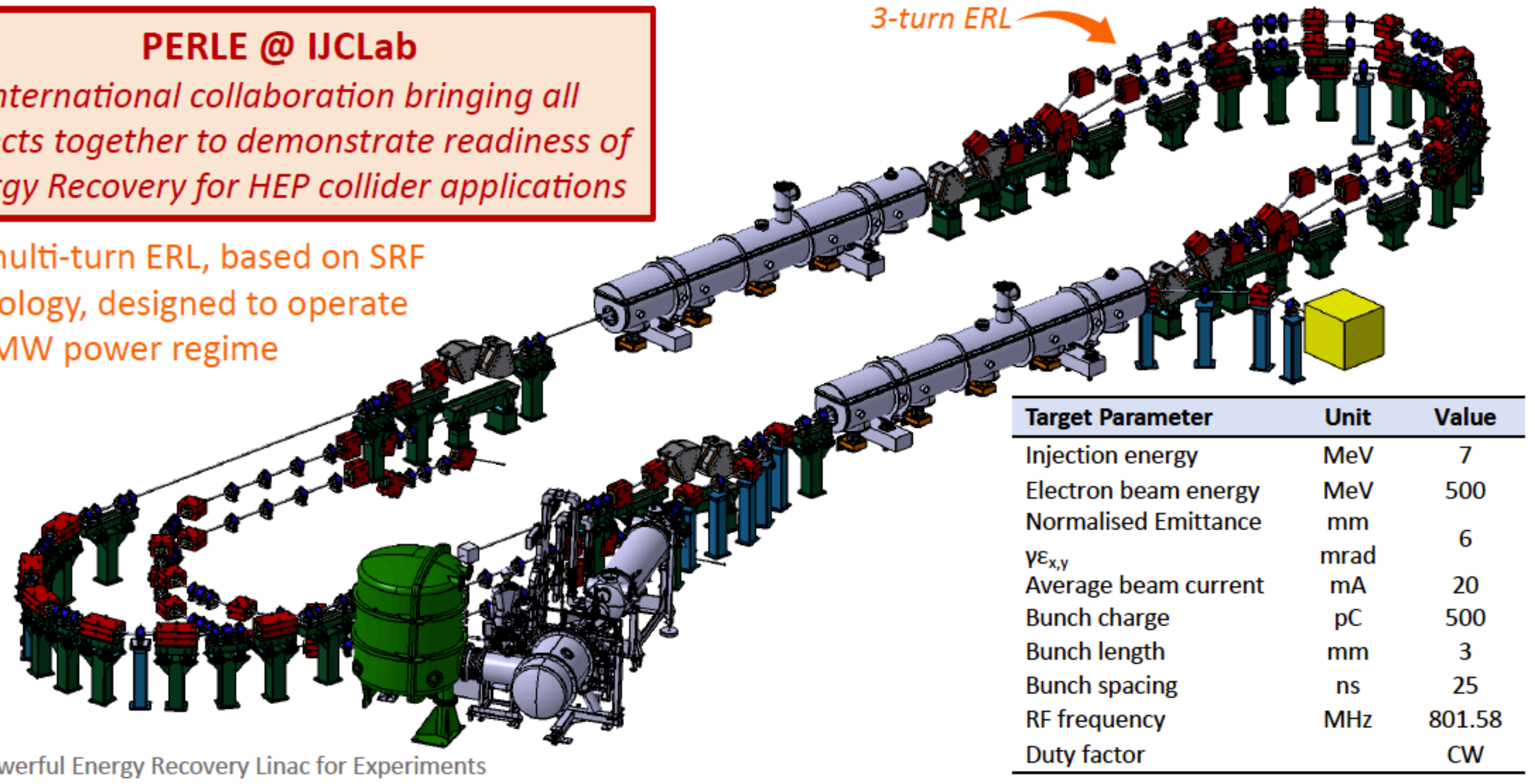
FCC-eh

$$\text{DIS at } \sqrt{s} \simeq 1.2/2.2/3.5 \quad \text{TeV}, \qquad \int \mathscr{L} dt \sim 1-2 \quad \text{ab}^{-1} \sim 1000 \times \text{HERA}$$

PERLE @ IJCLab
international collaboration bringing all aspects together to demonstrate readiness of Energy Recovery for HEP collider applications

first multi-turn ERL, based on SRF technology, designed to operate at 10MW power regime

PERLE



Target Parameter	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	500
Normalised Emittance $\gamma\varepsilon_{x,y}$	mm mrad	6
Average beam current	mA	20
Bunch charge	pC	500
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor		CW

PERLE – Powerful Energy Recovery Linac for Experiments

Parameter	Unit	LHeC				FCC-eh	
ep	P=±0.8 (e^-)	CDR	Run 5	Run 6	Dedicated	E_p=20 TeV	E_p=50 TeV
E_e	GeV	60	30	50	50	60	60
N_p	10^{11}	1.7	2.2	2.2	2.2	1	1
ϵ_p	μm	3.7	2.5	2.5	2.5	2.2	2.2
I_e	mA	6.4	15	20	50	20	20
N_e	10^9	1	2.3	3.1	7.8	3.1	3.1
β^*	cm	10	10	7	7	12	15
Luminosity	10^{33} cm^{-2}s^{-1}	1	5	9	23	8	15

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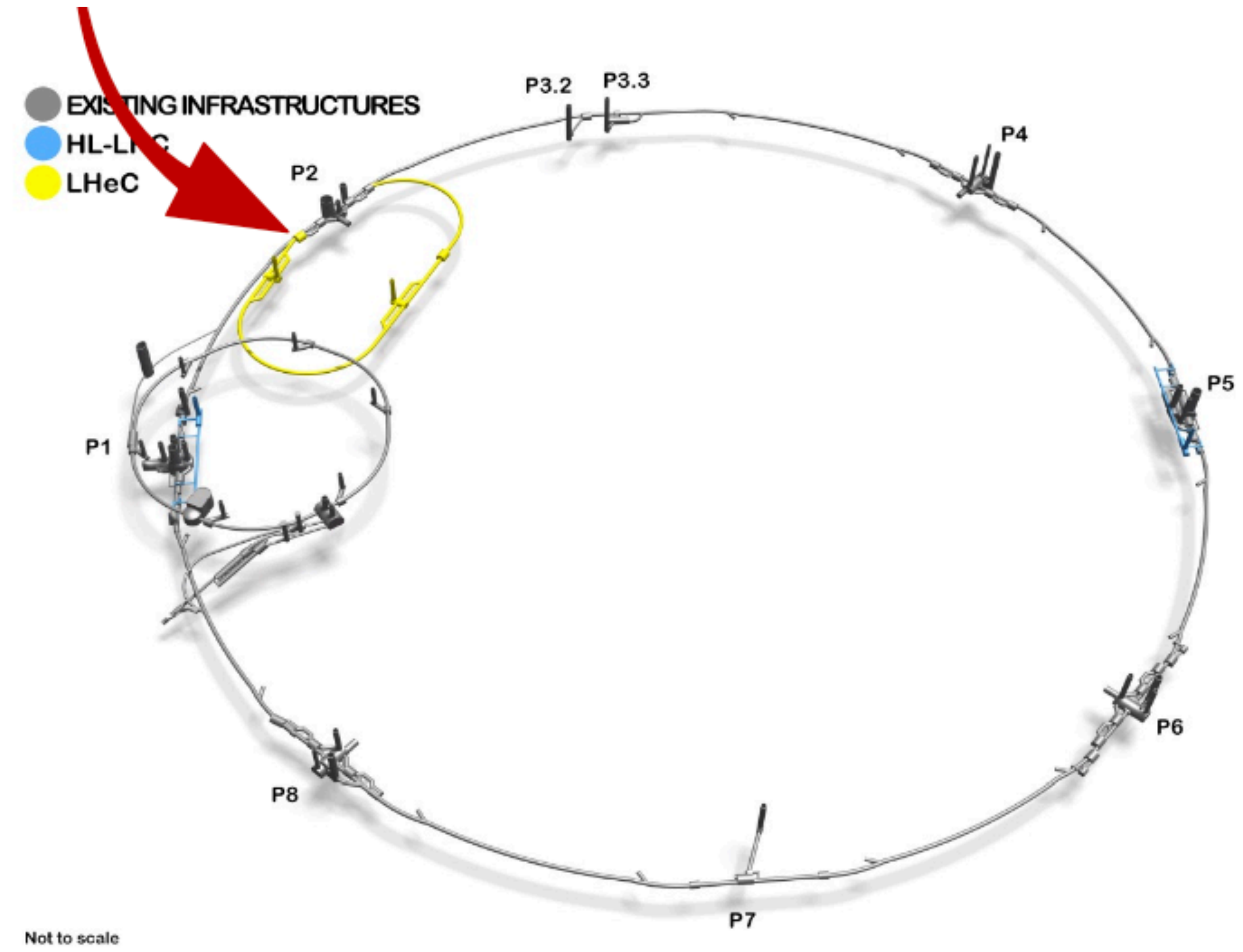
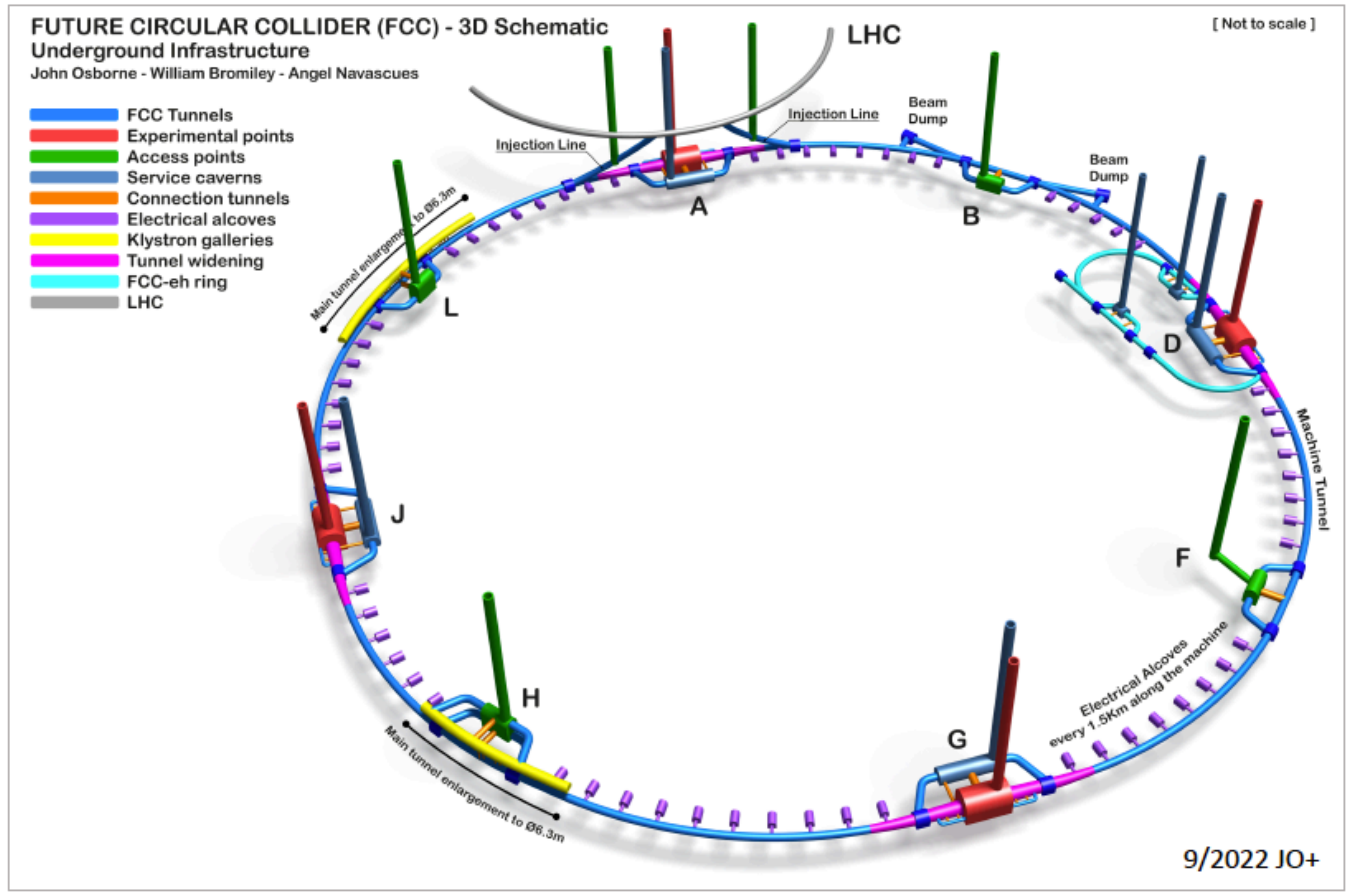
Accelerators:

LHeC



FCC-eh



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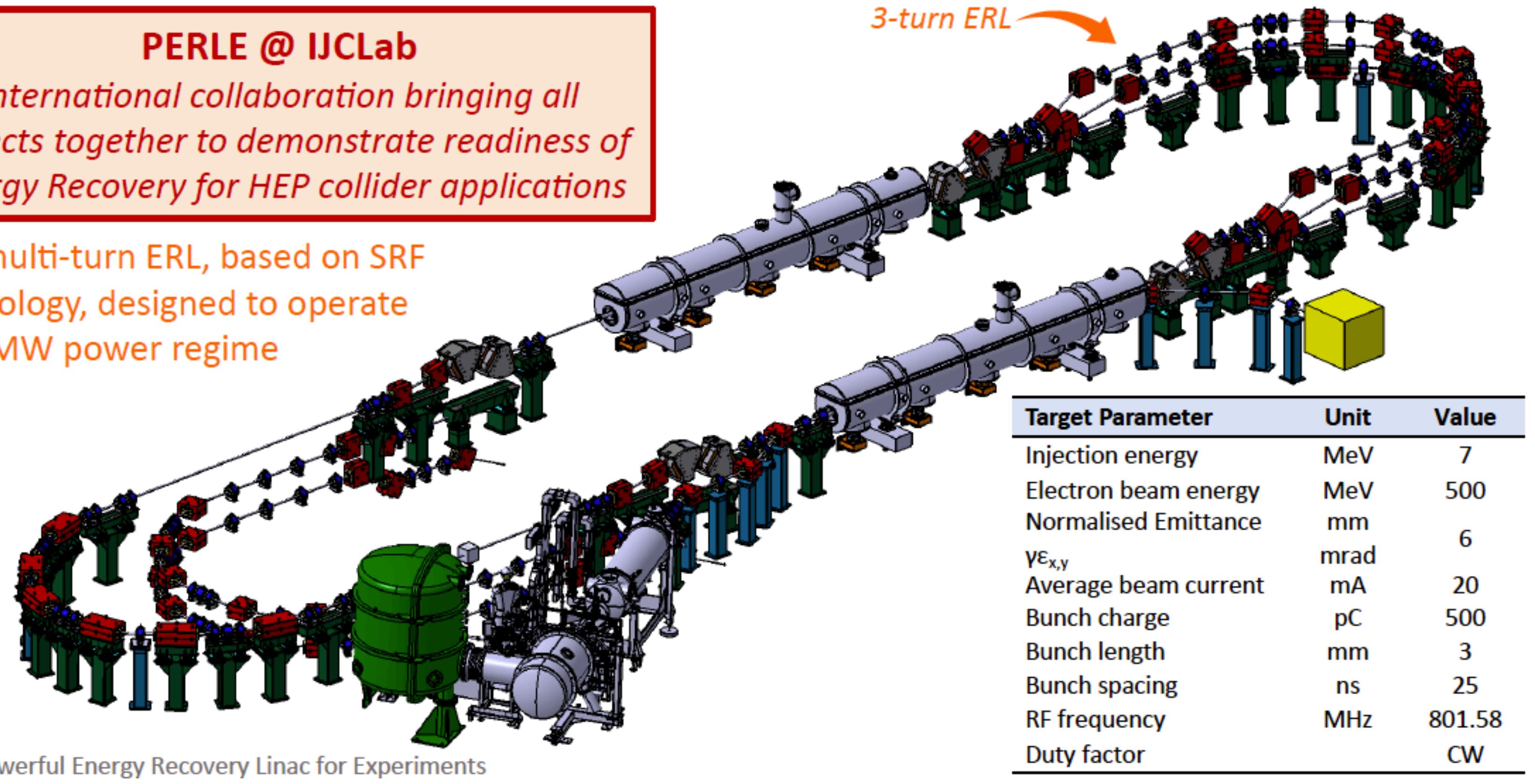

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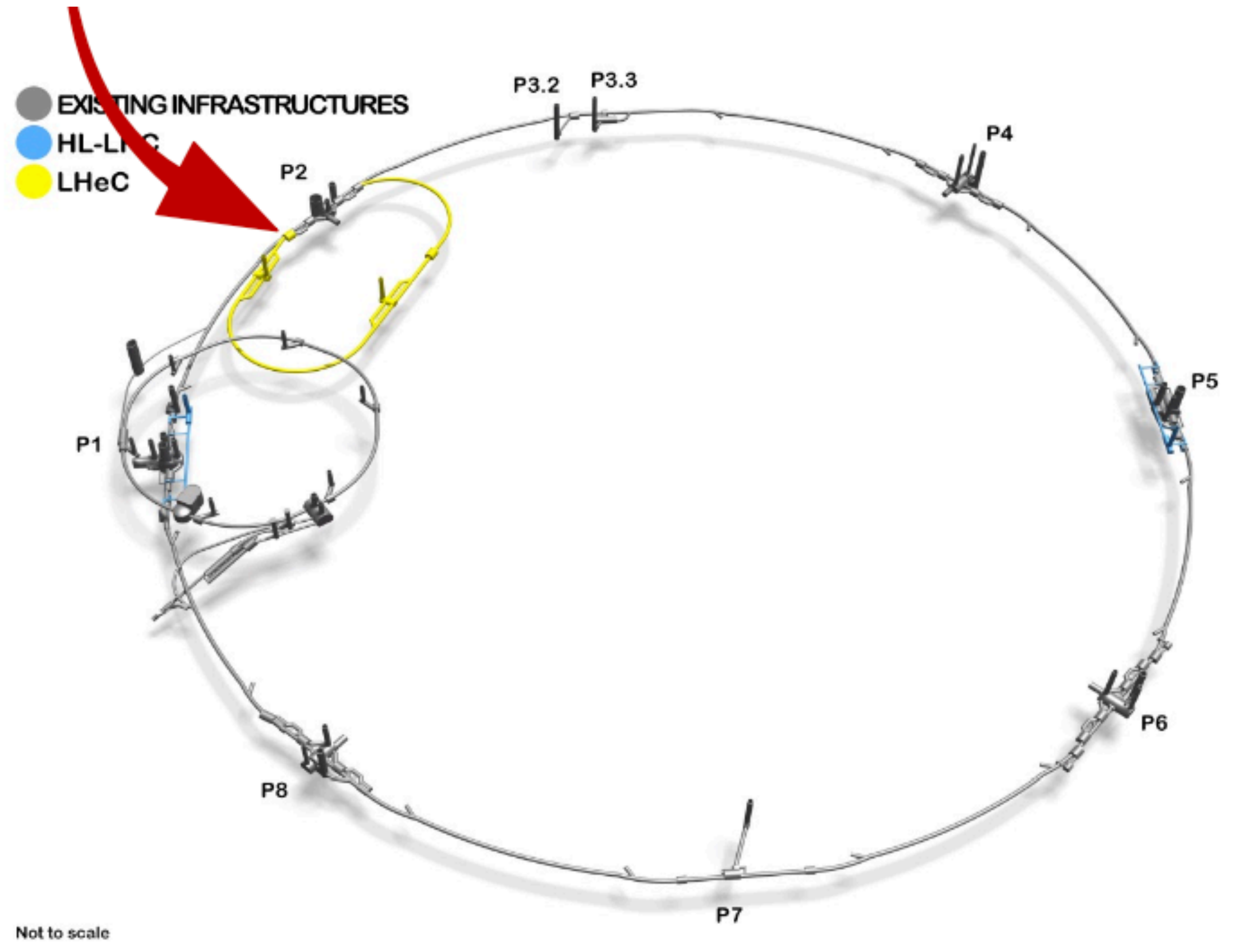
Accelerators:

LHeC



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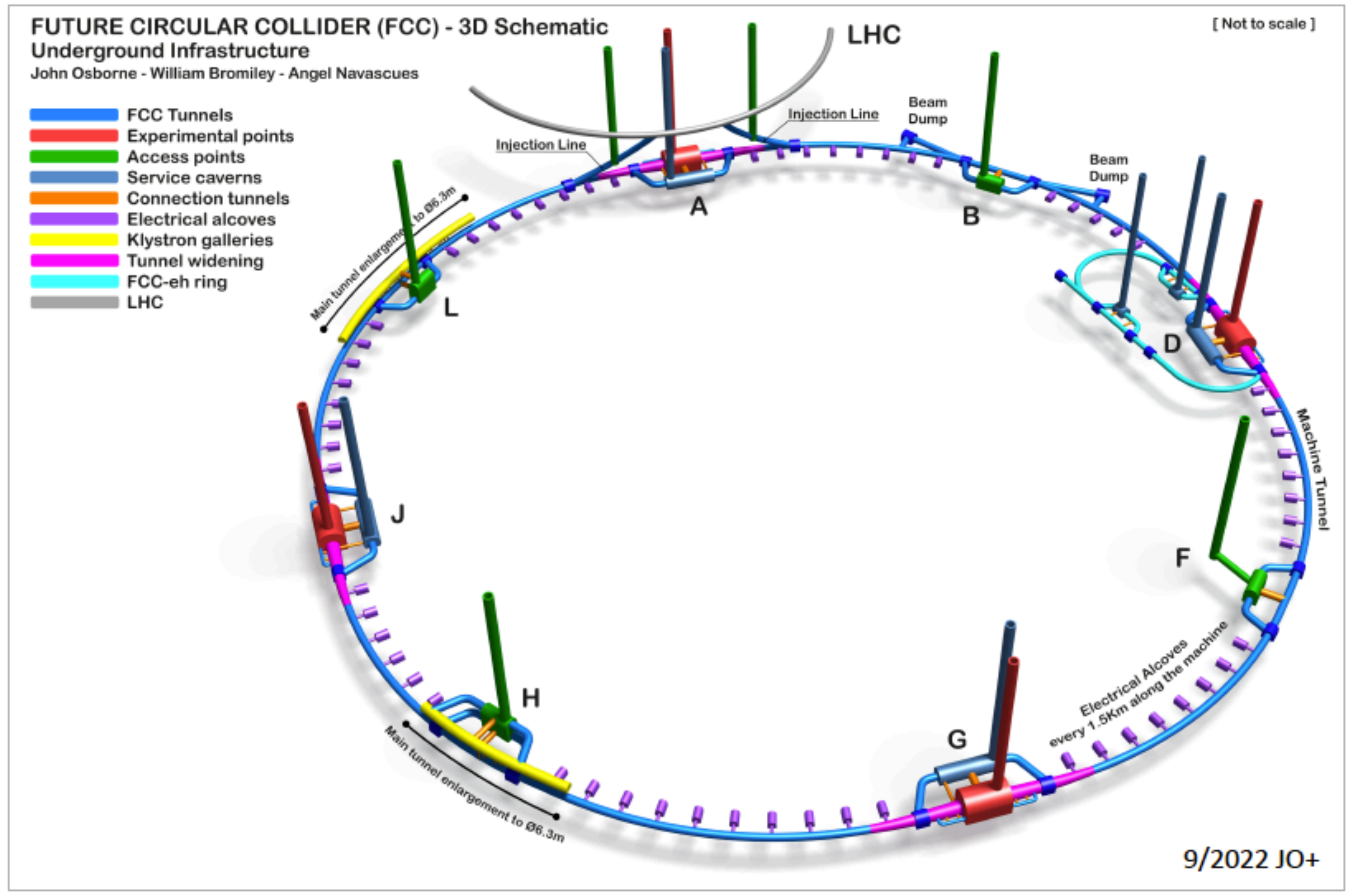

FCC-eh

ePb

Parameter	Unit	LHeC	FCC-eh (E_p=20 TeV)	FCC-eh (E_p=50 TeV)
Ion energy E_{Pb}	PeV	0.574	1.64	4.1
Ion energy/nucleon E_{Pb}/A	TeV	2.76	7.88	19.7
Electron beam energy E_e	GeV	50	60	60
Electron-nucleon CMS $\sqrt{s_{eN}}$	TeV	0.74	1.4	2.2
Bunch spacing	ns	50	100	100
Number of bunches		1200	2072	2072
Ions per bunch	10^8	1.8	1.8	1.8
Normalised emittance ϵ_n	μm	1.5	1.5	1.5
Electrons per bunch	10^9	6.2	6.2	6.2
Electron current	mA	20	20	20
IP beta function β^*_A	cm	10	10	15
e-N Luminosity	$10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	7	14	35

1810.13022

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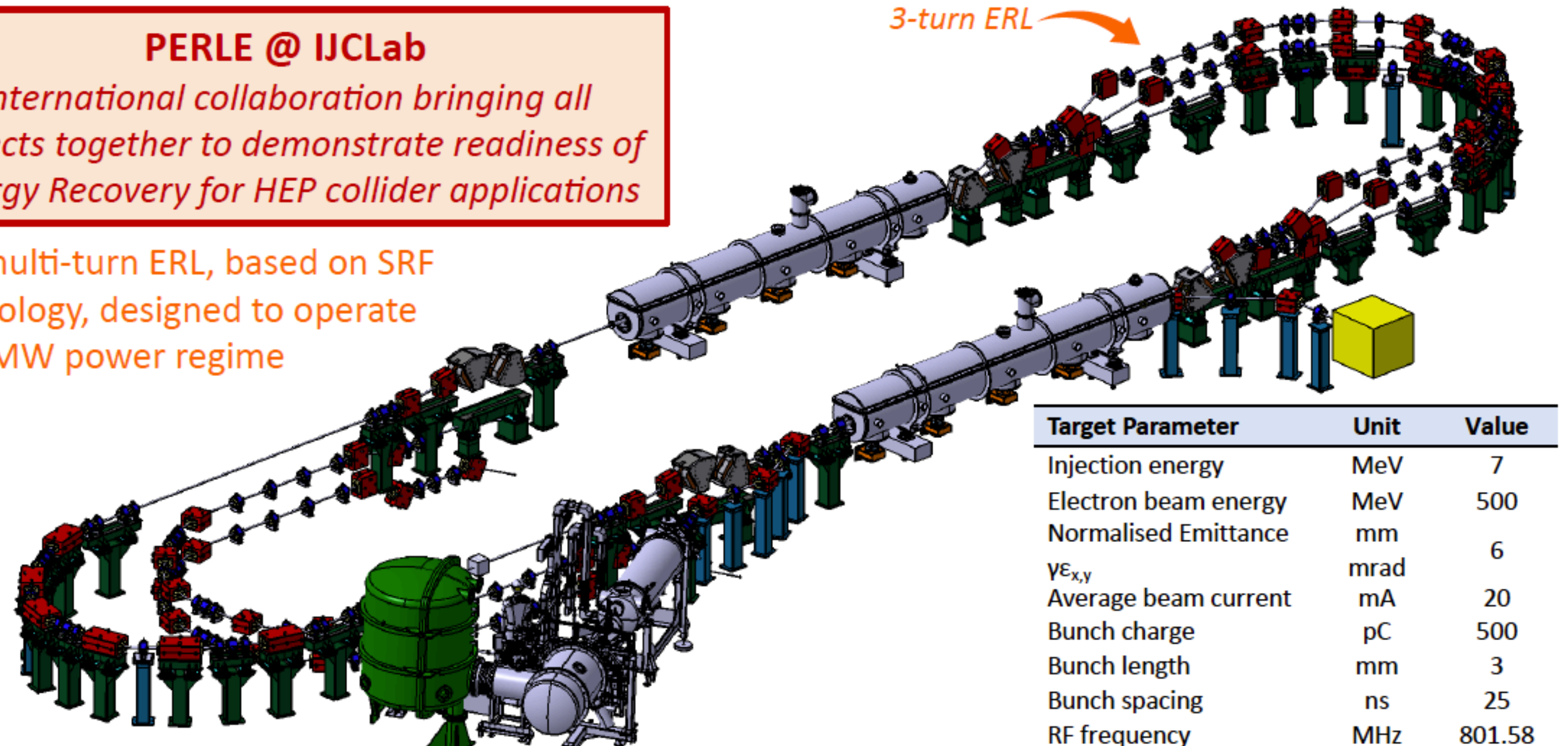
3-turn ERL



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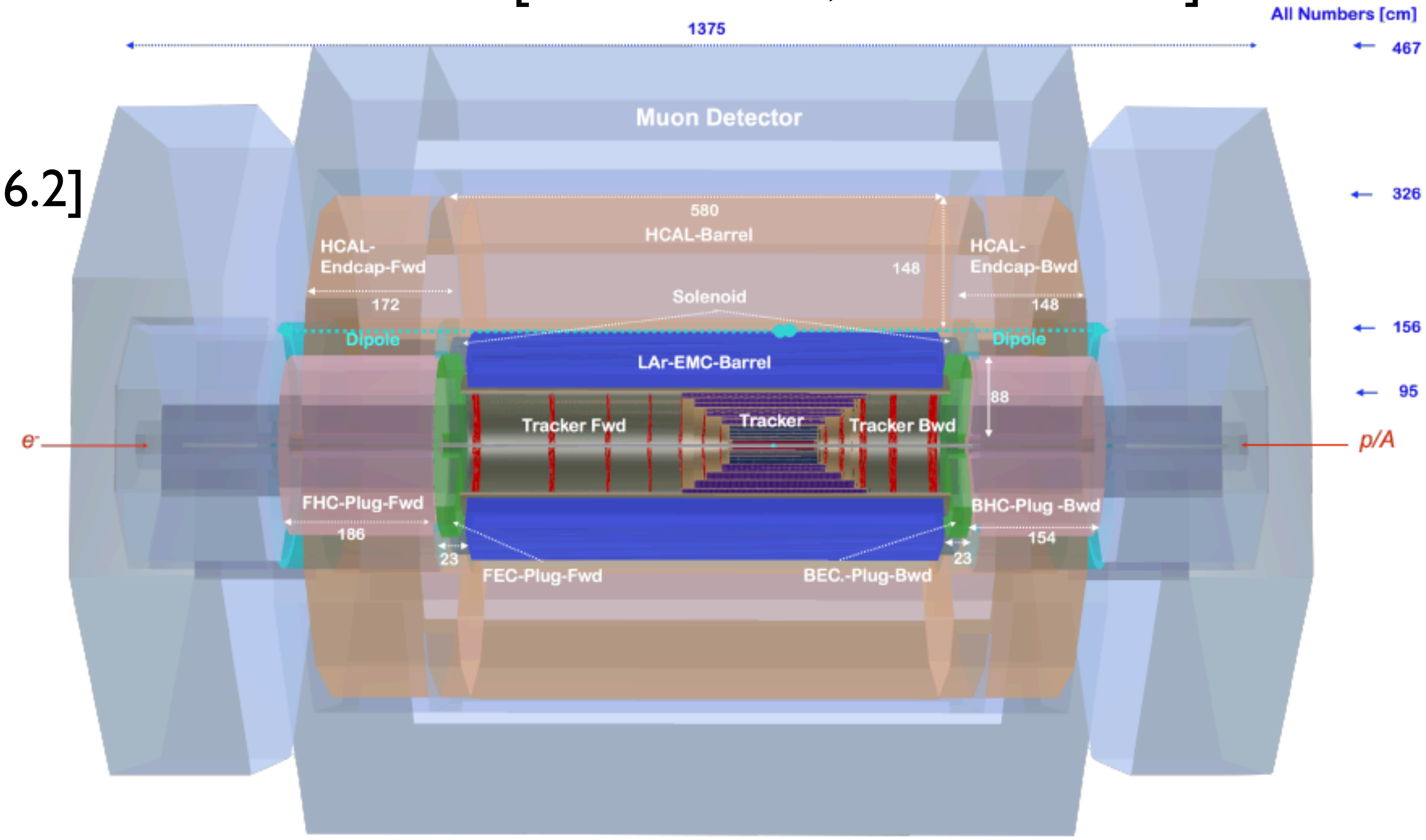
PERLE – Powerful Energy Recovery Linac for Experiments

Detectors:

L=13.2 m [FCC-eh: 19.3, about CMS size]

R=4.8 m
[FCC-eh: 6.2]



➜ Large acceptance, precision device: design determined by kinematics and high precision ($H \to b\bar{b}$ in CC).

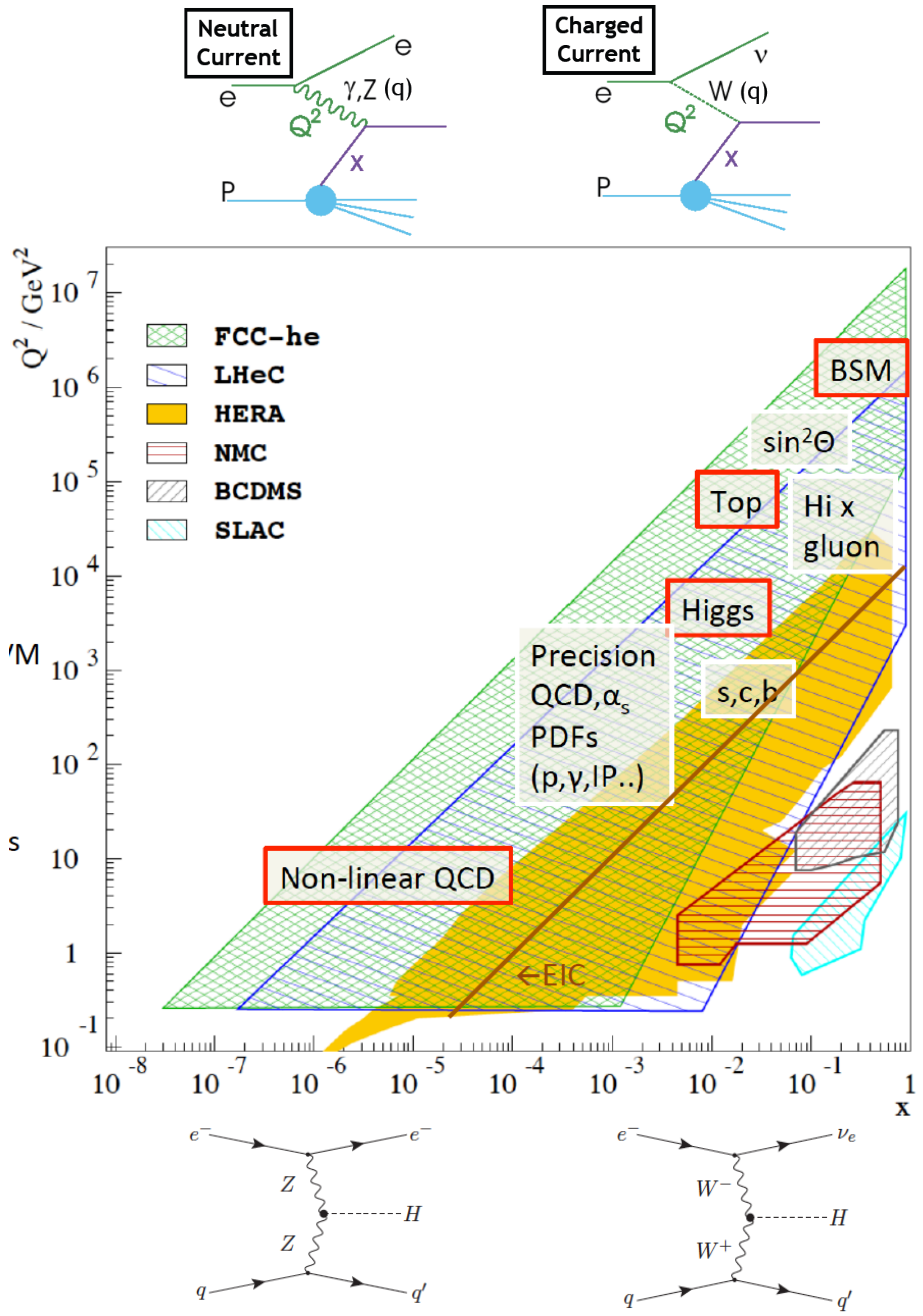
➜ Low radiation (1/100 that of pp) enables sensitive technology such as HV CMOS to be used.

➜ Low field dipole inserted before the HCAL to ensure head-on ep collision; conventional solenoid.

➜ Modular structure for fast installation, fitting inside the L3 magnet in IP2.
➜ Forward-backward symmetrised version would allow eh and hh collisions in the same IP (2201.02436).

➜ Forward (p,n) and backward (e, γ) tagging detectors.

Summary of physics:



- ep/eA colliders are the cleanest High Resolution Microscope:
  - ➜ Precision and discovery in QCD;
  - ➜ Study of EW / VBF production, LQ, multi-jet final states, forward objects,…

- Empower the LHC Search Programme (e.g. PDF, EW measurements).
- Transform the LHC into a precision Higgs facility.
- Has unique and complementary discovery potential of BSM particles (prompt and long-lived).

- It is also a $\gamma\gamma$ facility.

- **Overall: a unique Particle and Nuclear Physics Facility.**

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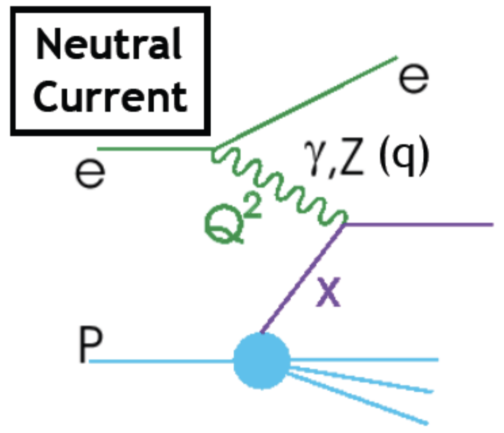

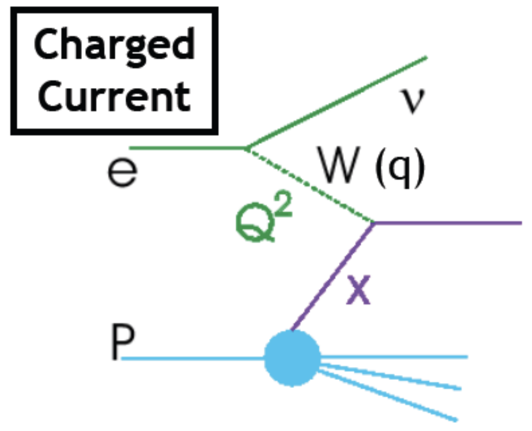

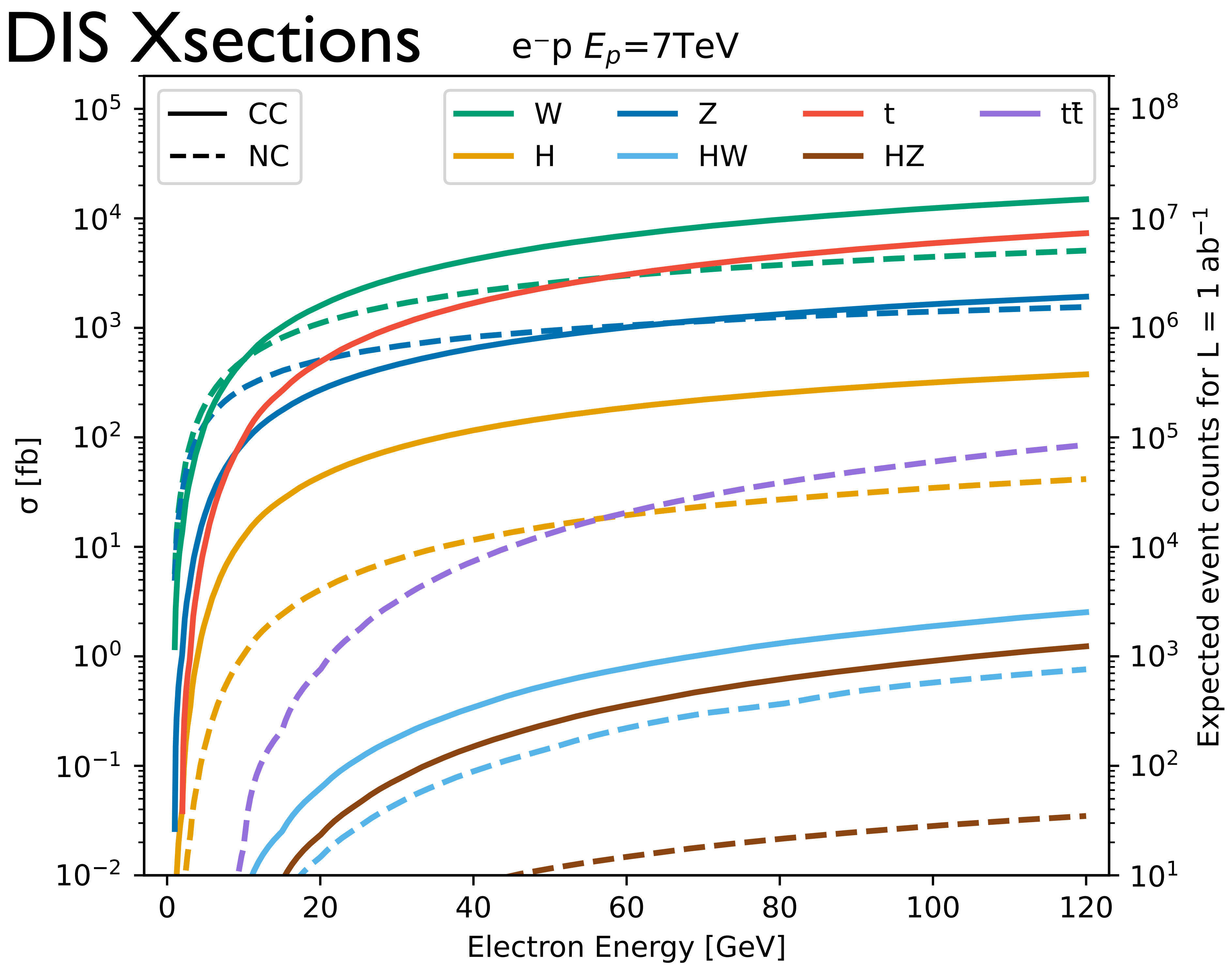

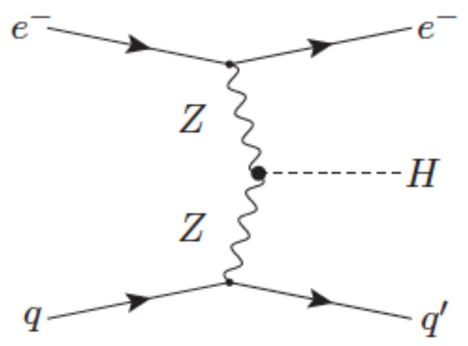

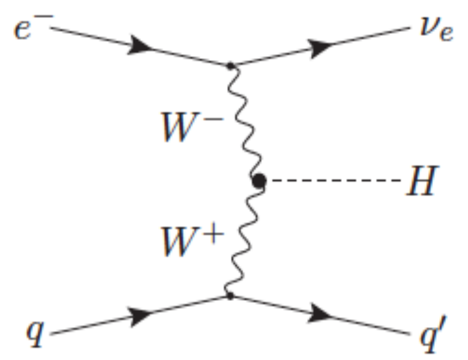

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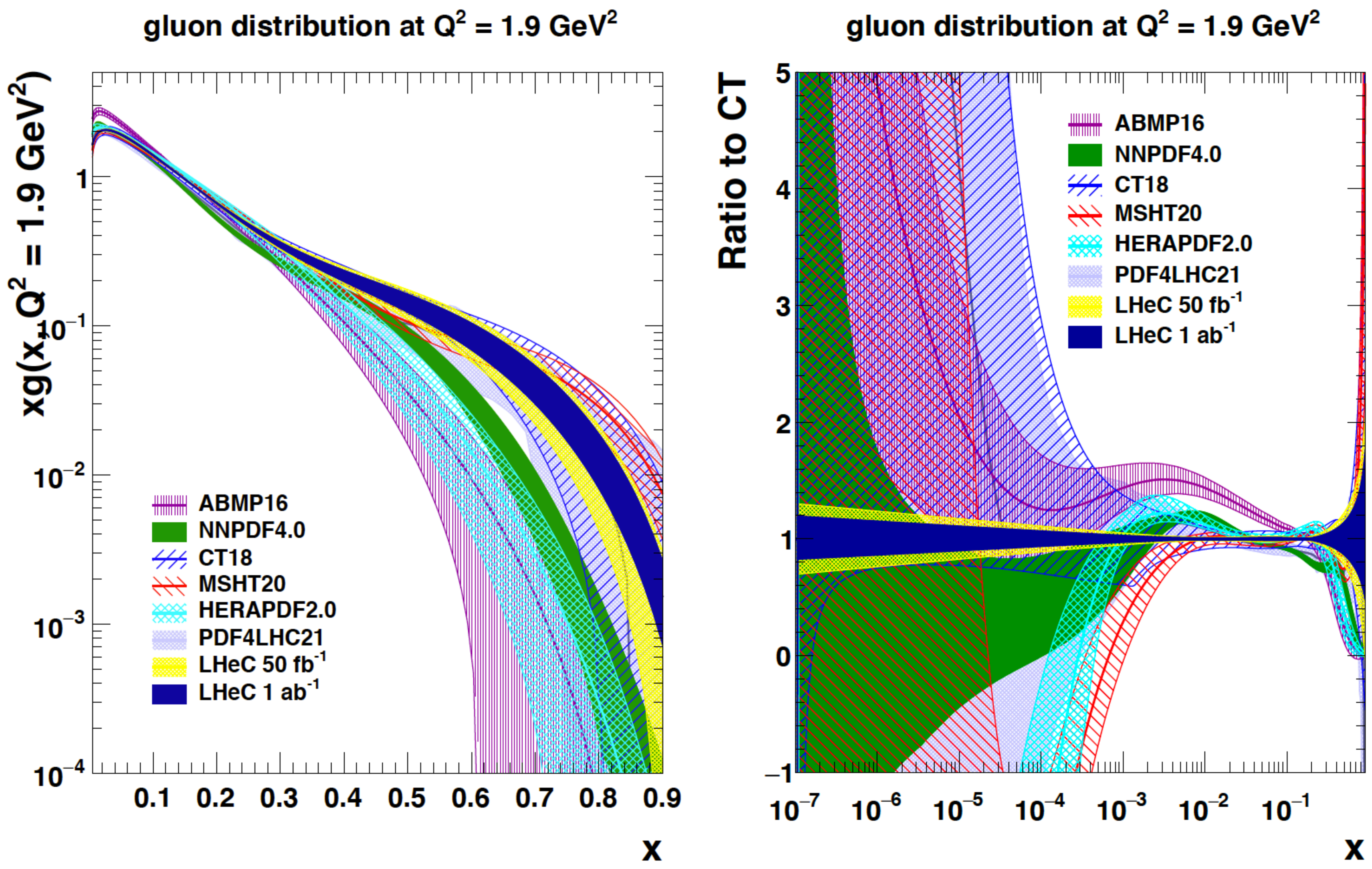
Parton luminosities:

• PDFs and α_s crucial for HL-LHC: high precision electro-weak, Higgs measurements (e.g., remove essential part of QCD uncertainties of gg→H), extension of high mass search range, non-linear parton evolution at low x: saturation.

• LHeC provides a complete resolution of flavour and gluon substructure in single system/ experiment, in unprecedented kinematic range (no higher twists, no nuclear corrections,…): implications for hadron colliders.



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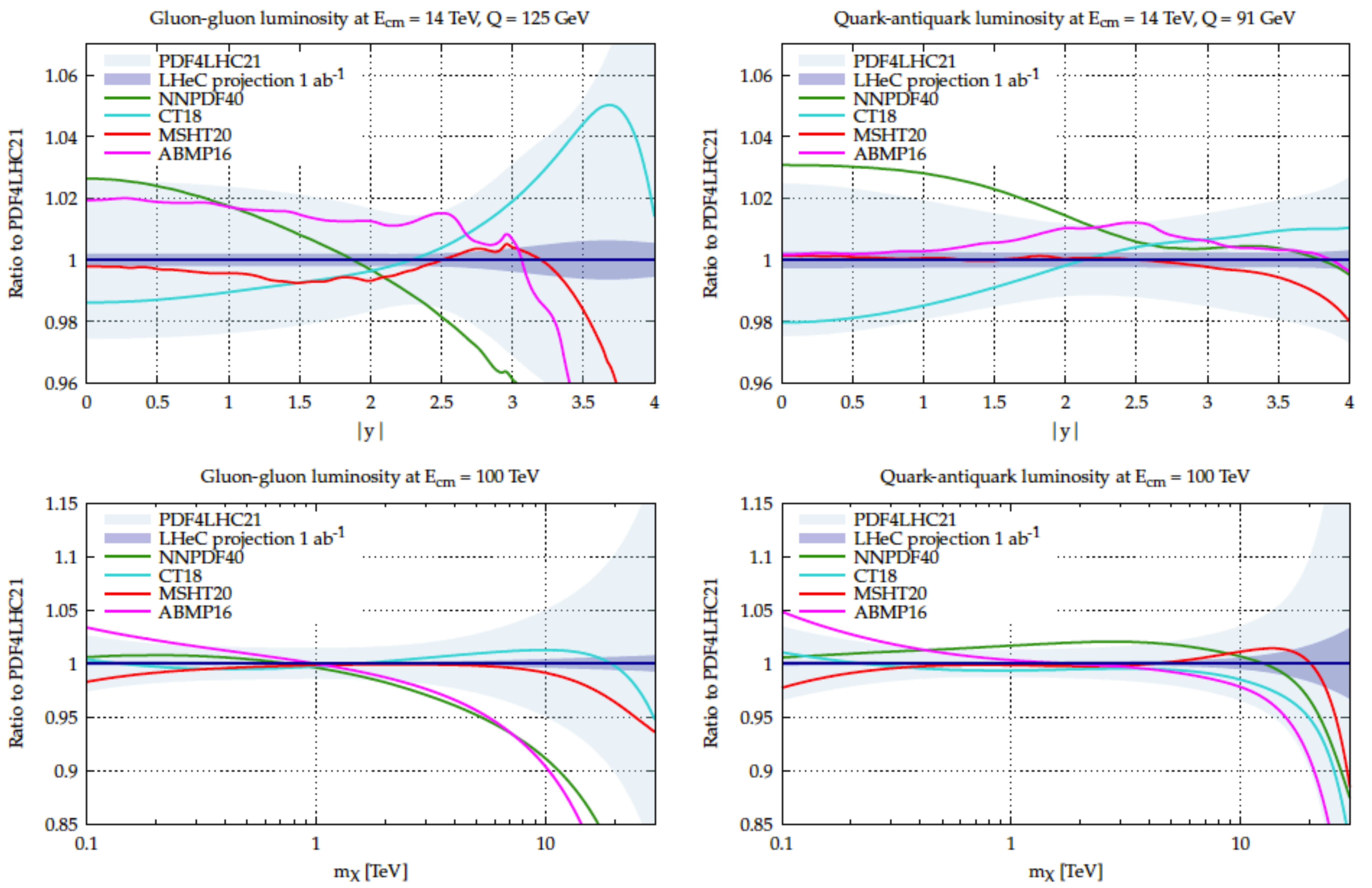
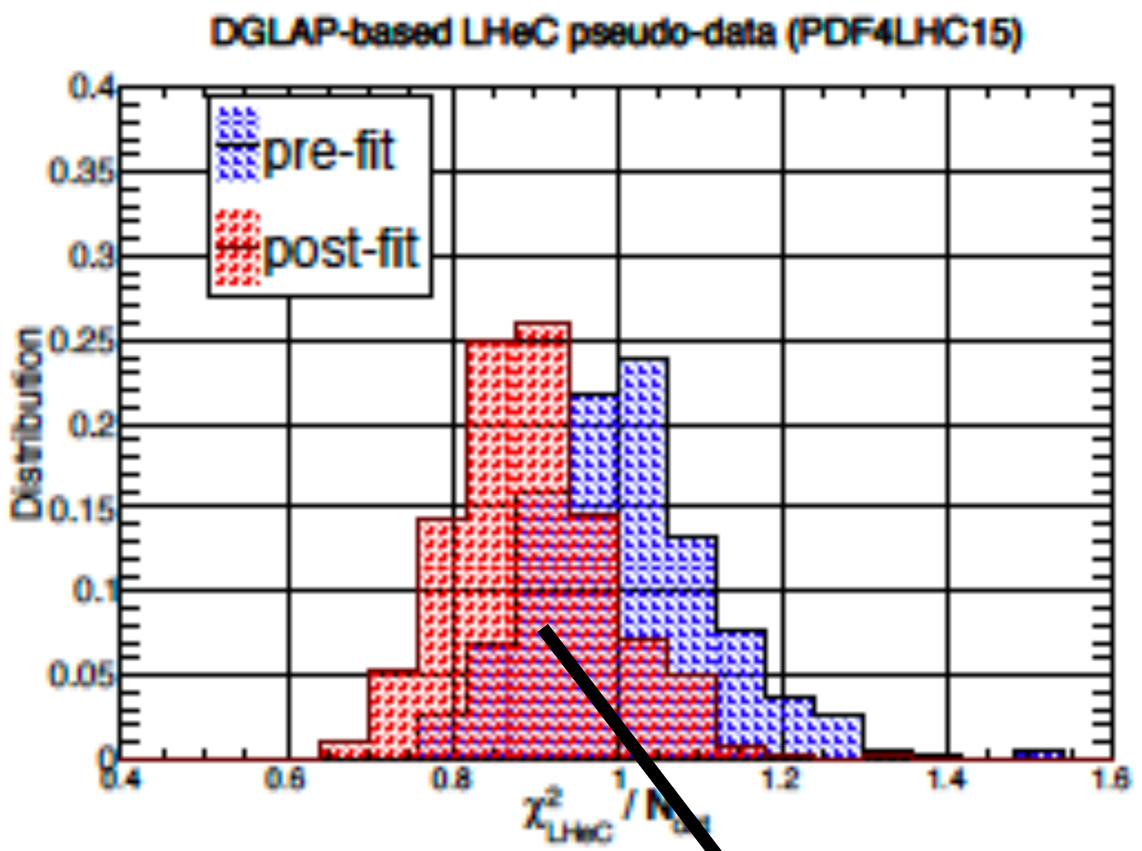
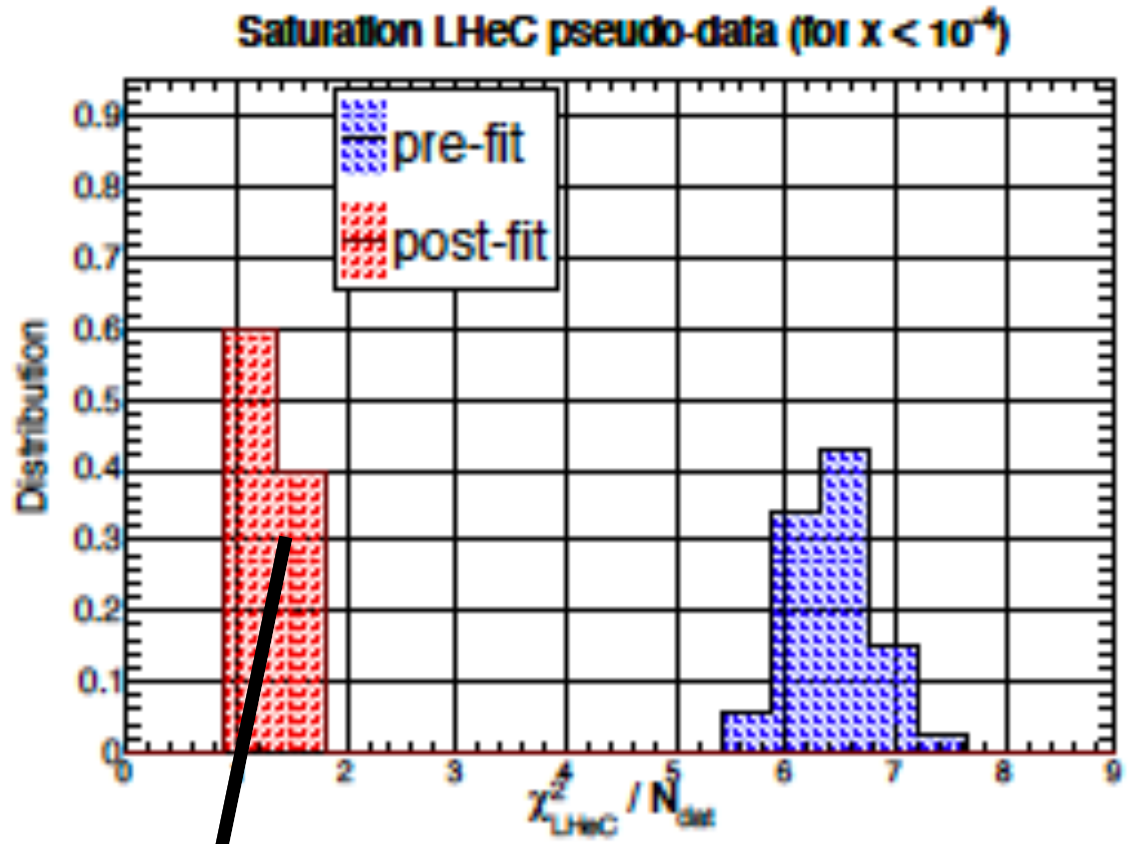


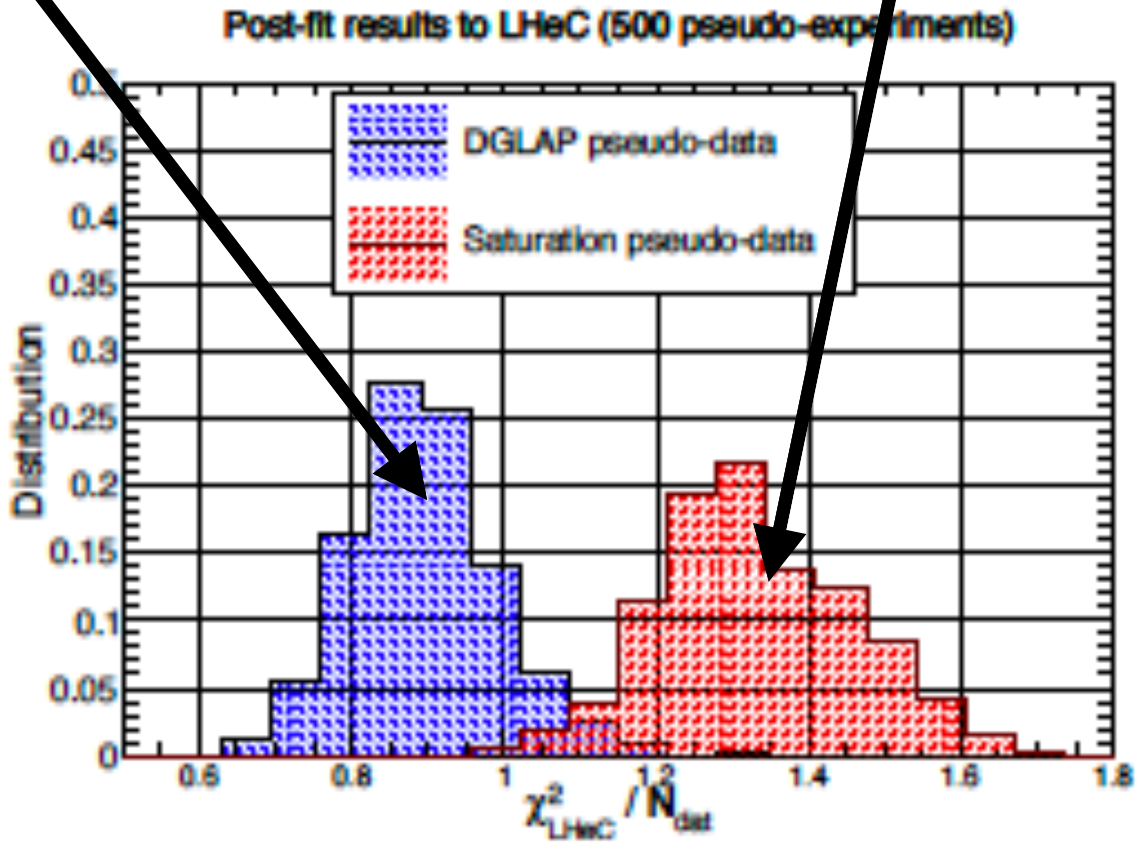
QCD: small x and α_s

- Breaking of *standard* factorisation: resummation and new non-linear regime of QCD, implications for FCC (e.g., gg→H).





DGLAP fit to DGLAP pseudodata

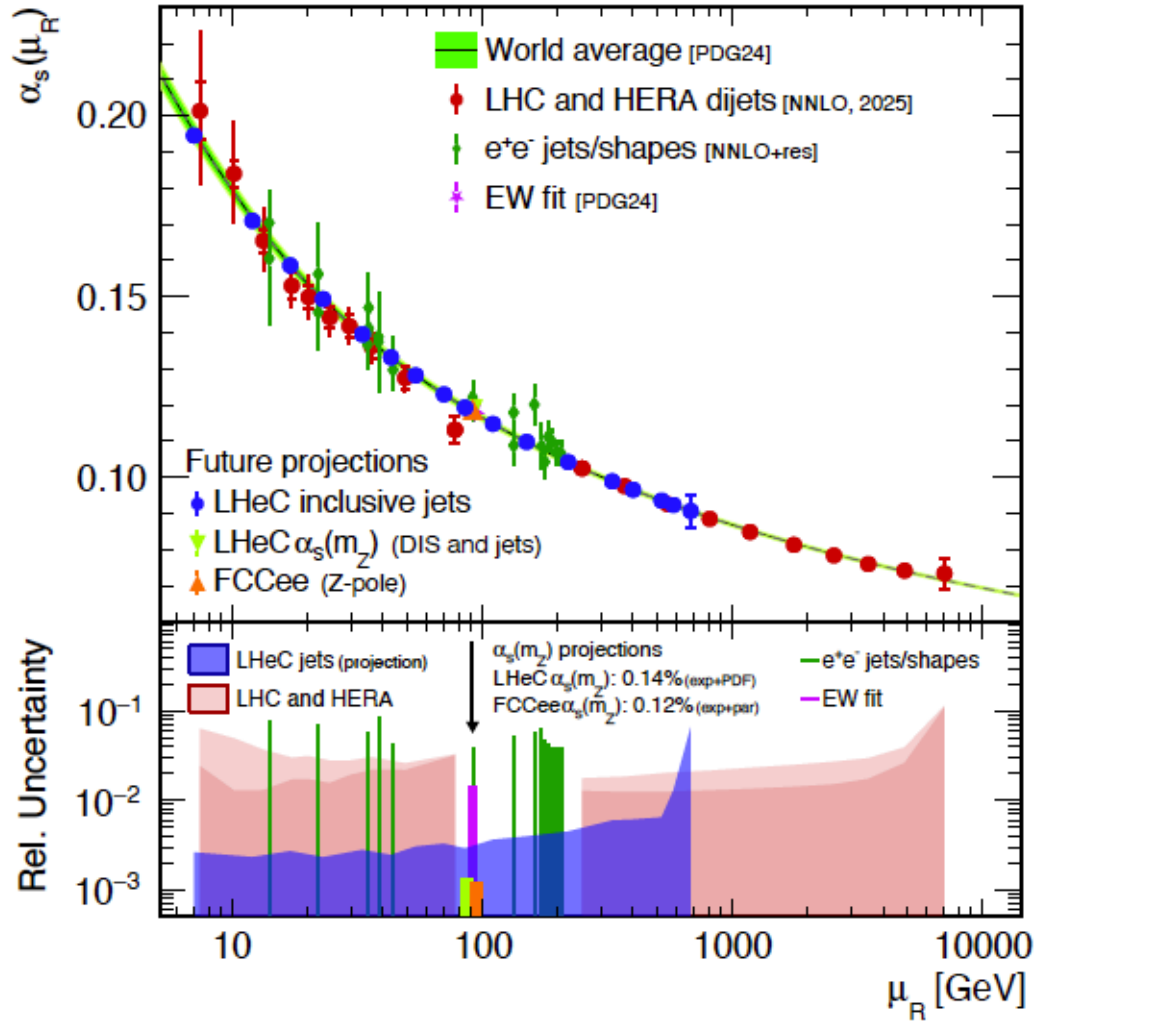


DGLAP fit to saturation pseudodata

- α_s to per mille accuracy (incl.+jets):

$$\Delta\alpha_s(M_Z)\ (\text{incl. DIS}) = \pm\, 0.00022_{(\text{exp+PDF})}$$

$$\Delta\alpha_s(M_Z)\ (\text{incl. DIS \& jets}) = \pm\, 0.00016_{(\text{exp+PDF})}$$



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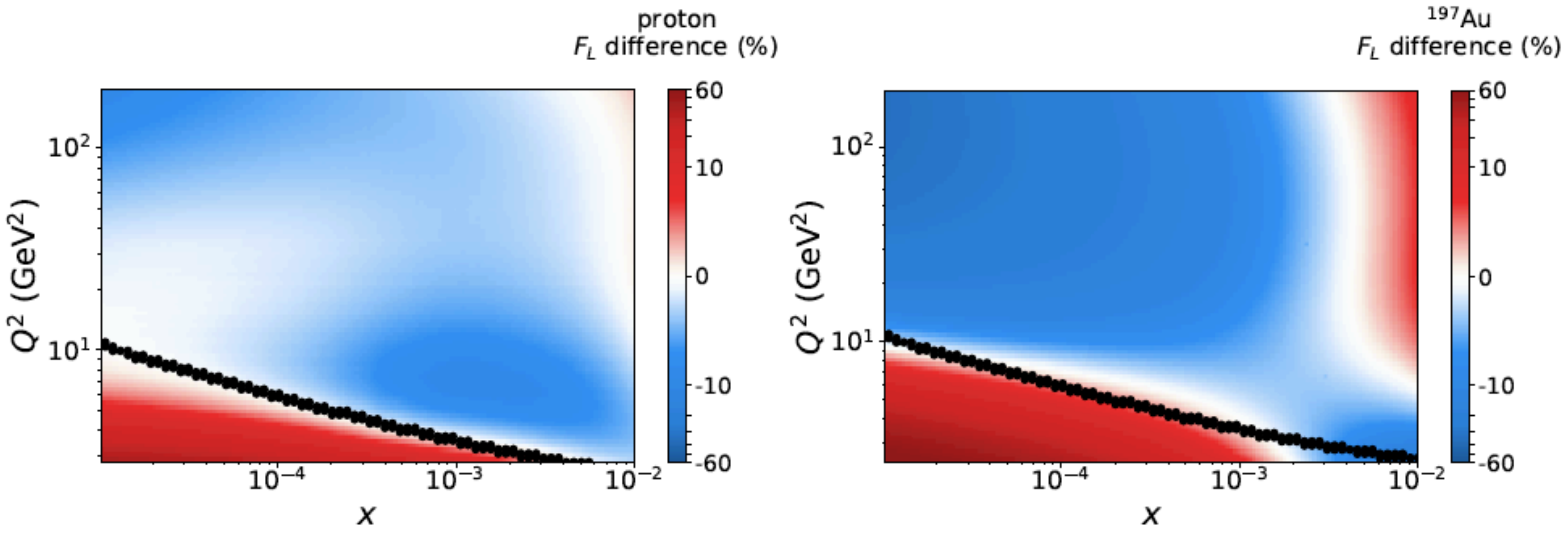
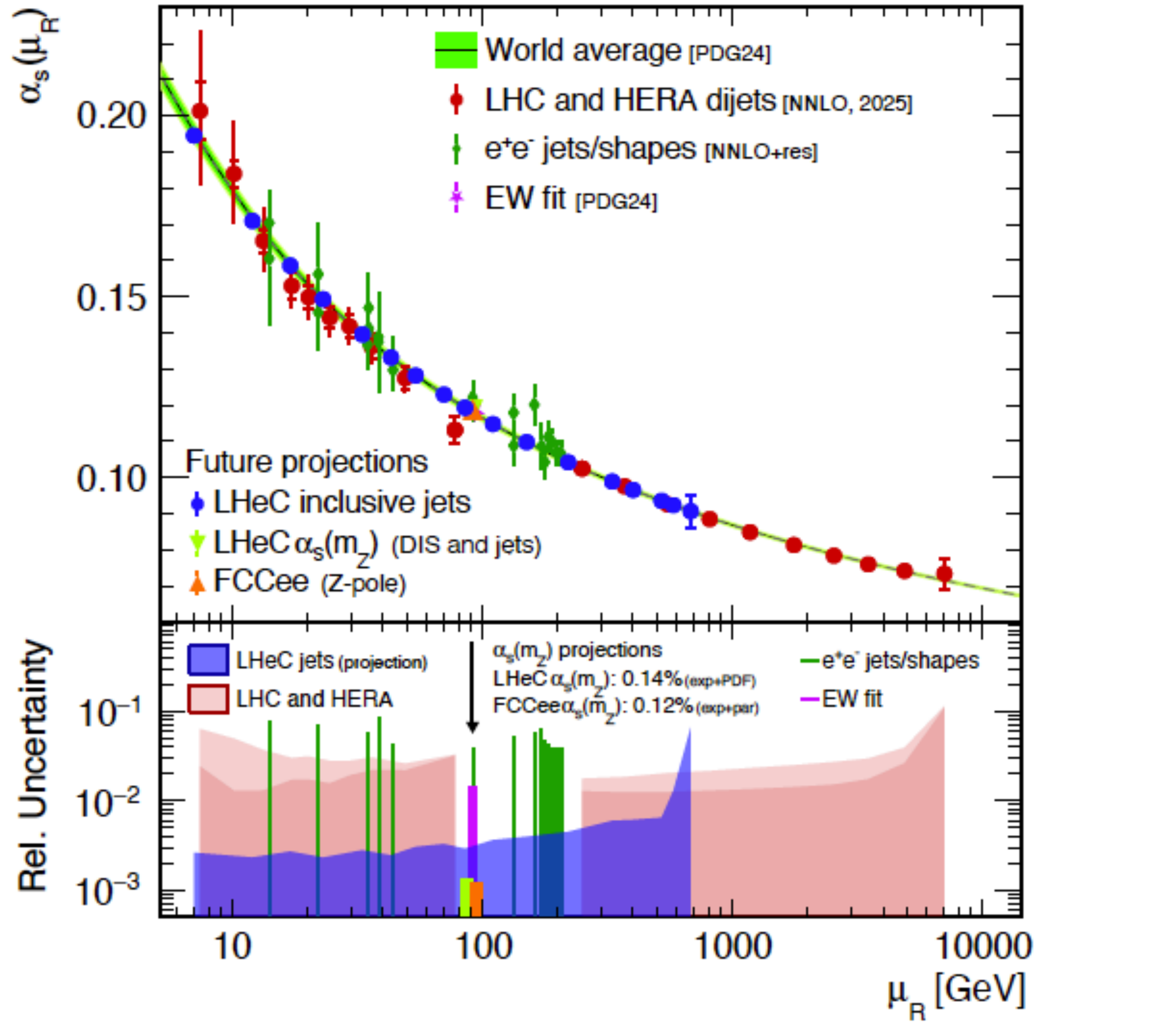
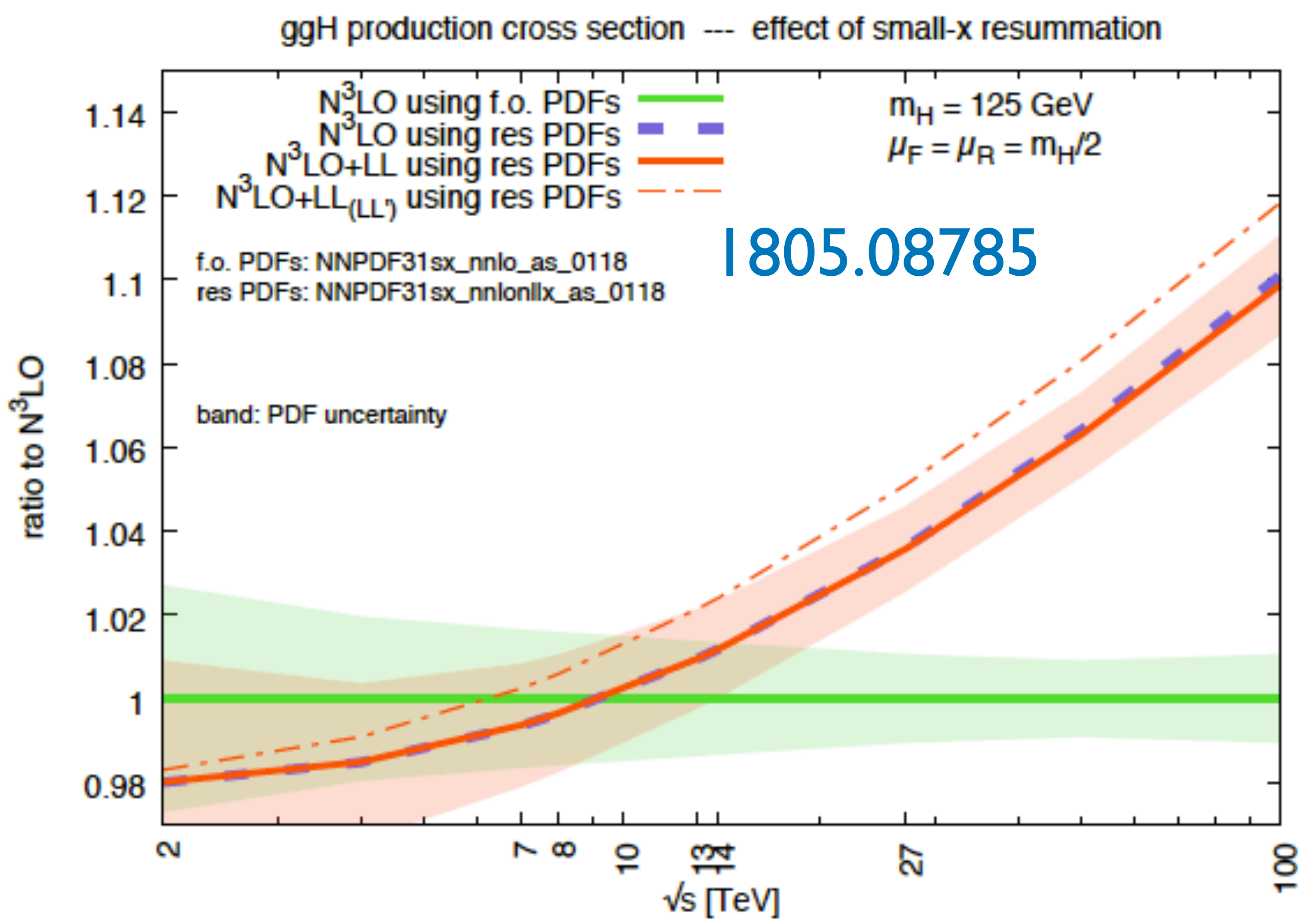




Higgs:

- PDFs+α_s measurements at the LHeC reduce very strongly the corresponding uncertainties in the Higgs cross section.

$\sqrt{s}$ [TeV]	$\sigma_{gg\to H}$ [pb]	TH uncertainty		PDF+α_S uncertainty			Total		
		Ref.	S2	Ref.	S2	S2+LHeC	Ref.	S2	S2+LHeC
14	54.7	3.9%	2.0%	3.2%	1.6%	0.5%	5.1%	2.6%	2.0%
27	146.6	4.0%	2.0%	3.3%	1.7%	0.6%	5.2%	2.6%	2.1%
100	804.4	4.2%	2.1%	3.7%	1.9%	0.7%	5.6%	2.8%	2.2%



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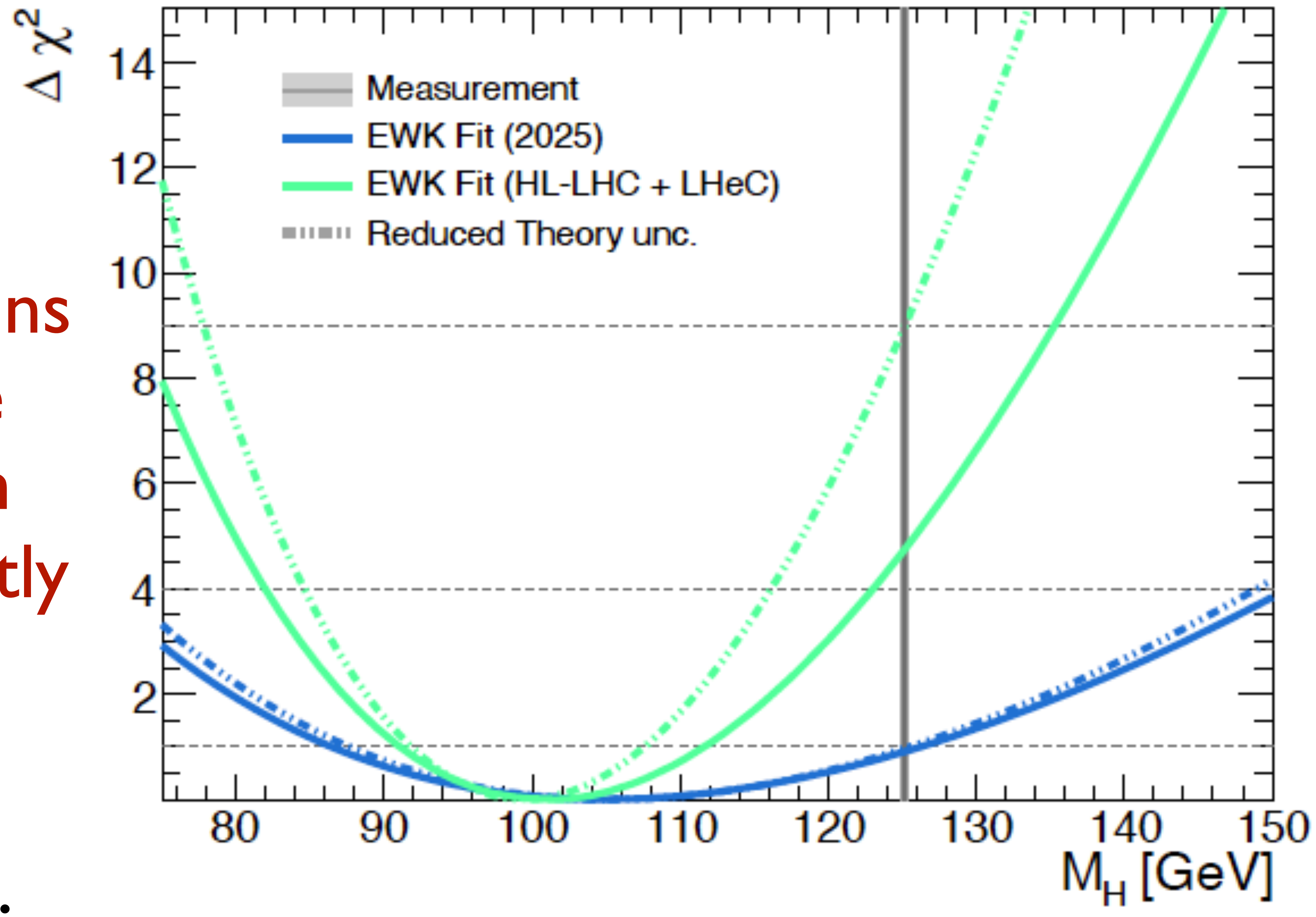
- Also constrains the mass in the SM indirectly in EWK fits (mostly effect of m_W):



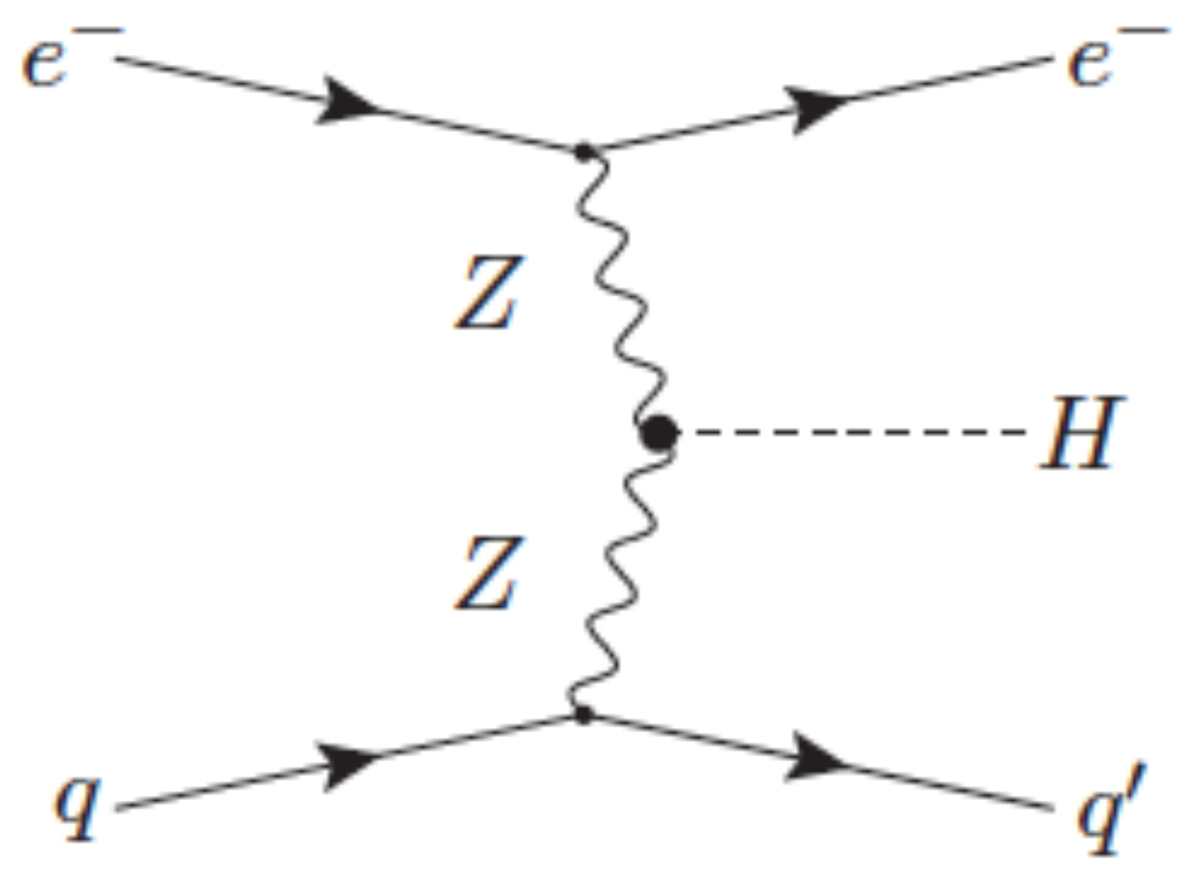
- Sizeable effect of the type of factorisation at small x.

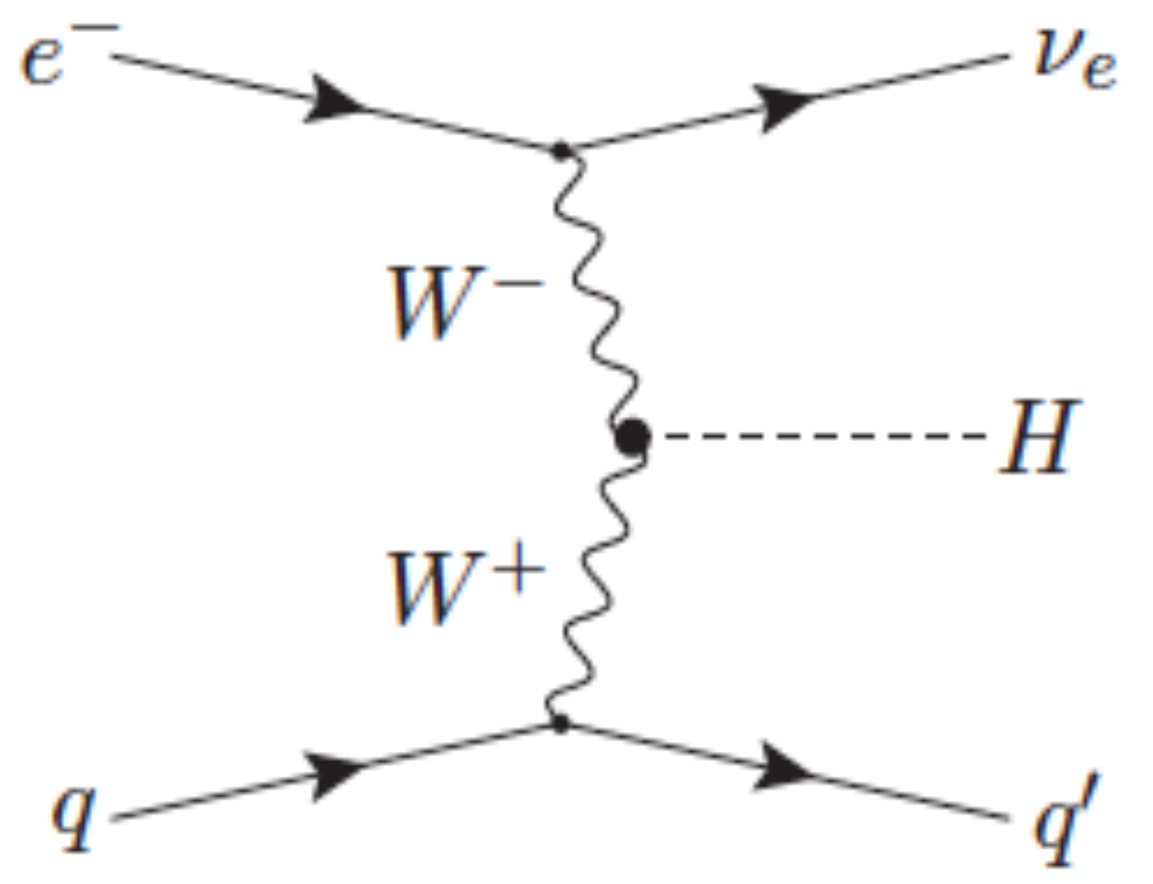
Higgs physics: κ-framework

- κ_i : coupling strength modified parameters, powerful method to parameterise possible deviations from SM couplings.

$$\sigma^i_{CC} = \sigma_{CC}\, br_i \cdot \kappa_W^2 \kappa_i^2 \frac{1}{\sum_j \kappa_j^2 br_j}$$

$$\sigma^i_{NC} = \sigma_{NC}\, br_i \cdot \kappa_Z^2 \kappa_i^2 \frac{1}{\sum_j \kappa_j^2 br_j}$$





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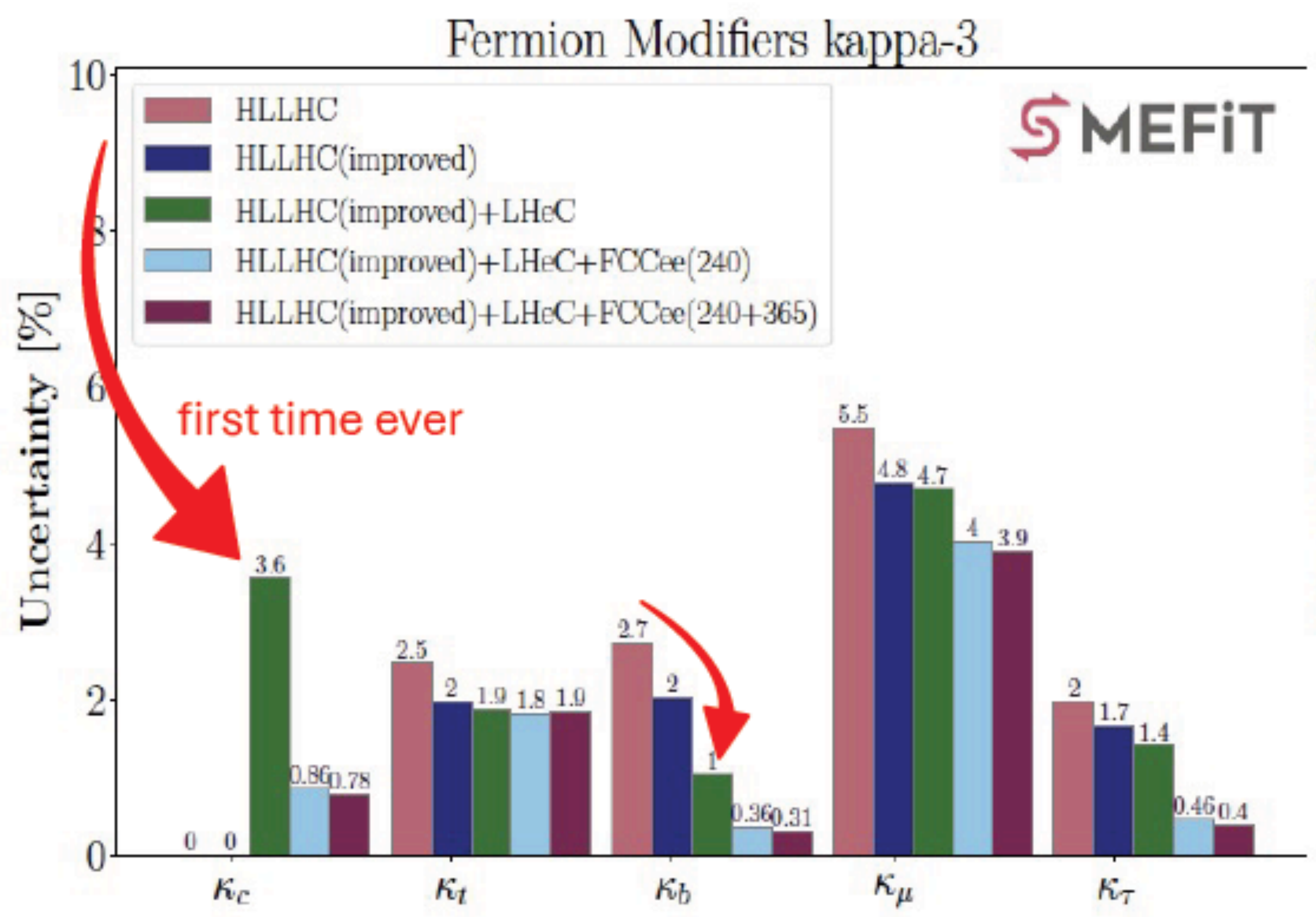
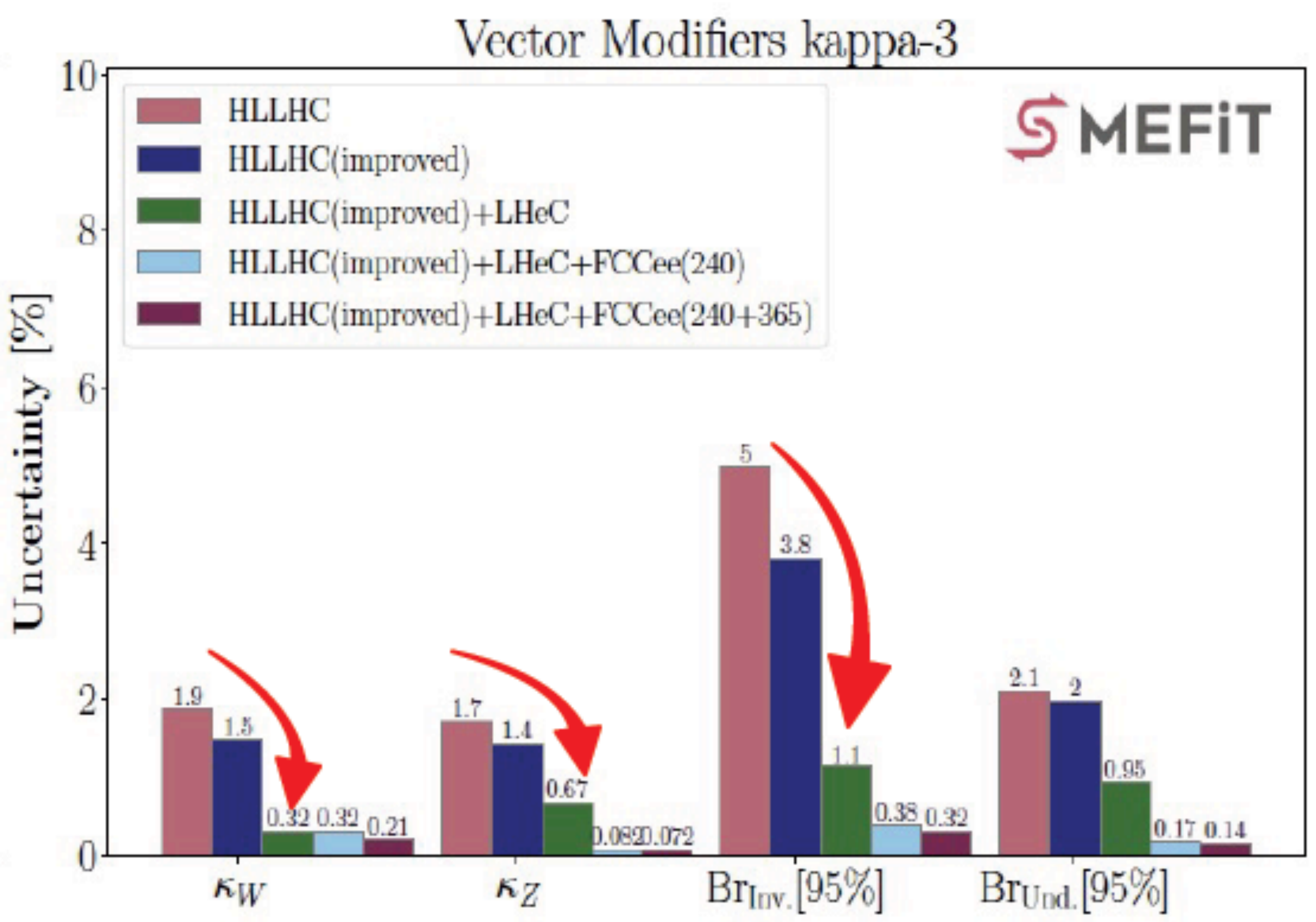
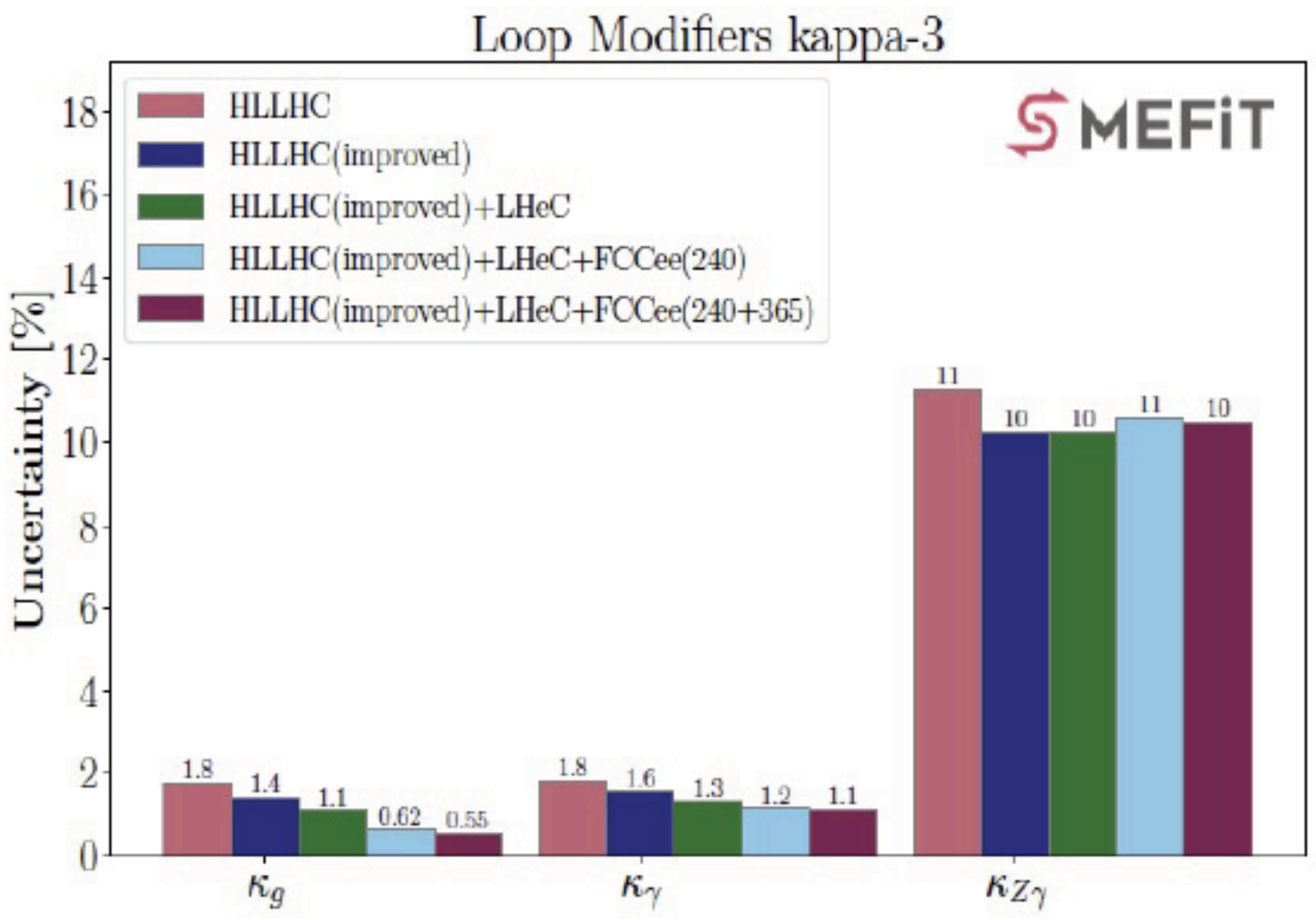
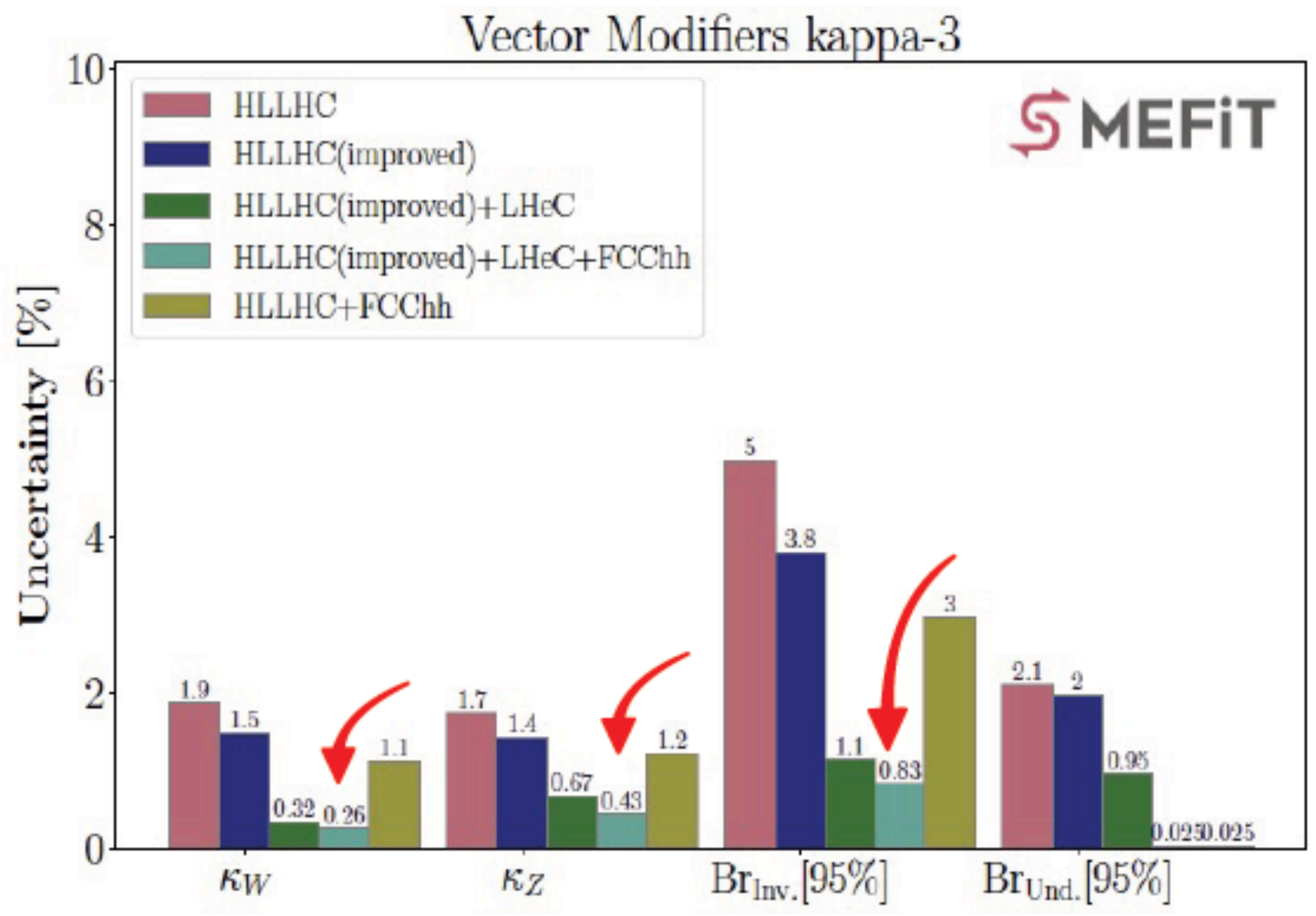




- LHeC PDFs+α_s improve all HL-LHC results:
  - ➜ Significantly κ_t, κ_τ, κ_g.
  - ➜ Greatly κ_b, κ_W, κ_Z.
  - ➜ First time κ_c.

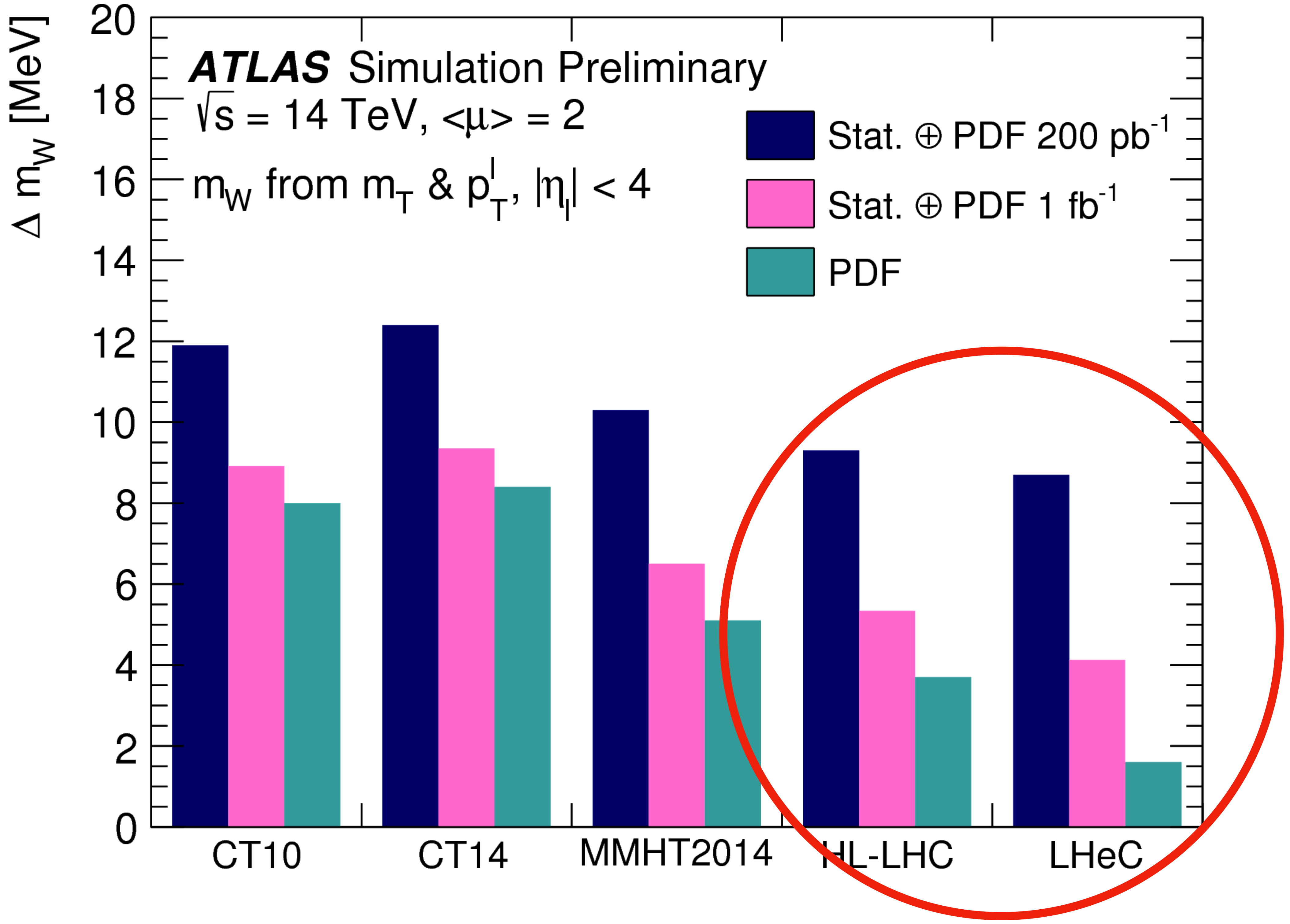




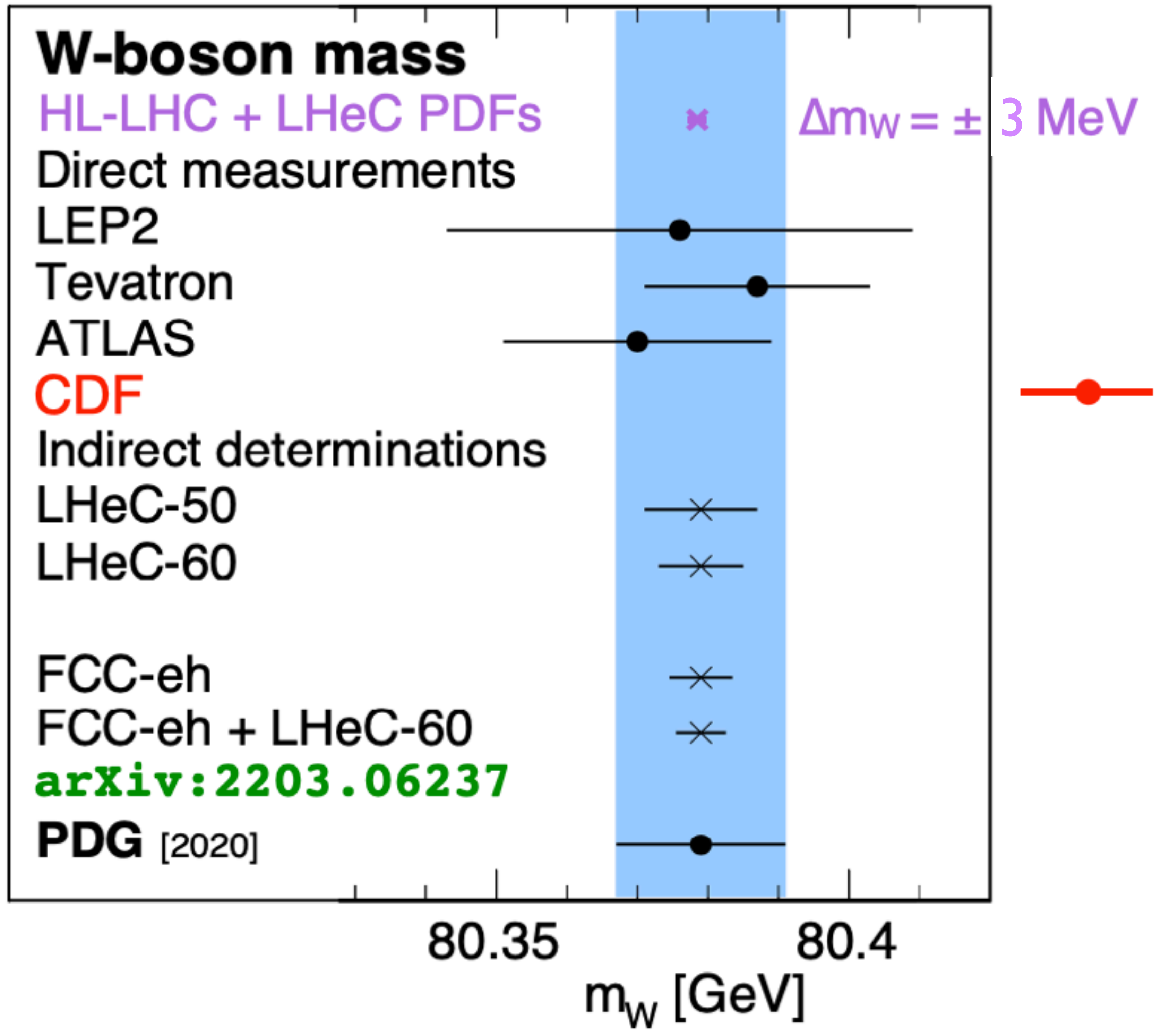
W mass:

- PDFs+α_s measurements at the LHeC reduce the corresponding uncertainties in the EWK parameters at the HL-LHC.

Parameter	Unit	Value	Uncertainty		
			Present	HL-LHC	HL-LHC+LHeC
m_Z	MeV	91187.6	2.1	< 2	< 2
m_W	MeV	80369.2	13.3	5–6	3
$\sin^2\theta^\ell_{\rm eff}$		0.23152	0.00016	0.00016	0.00008
$m_{\rm top}$	GeV	172.57	0.29	< 0.2	< 0.2
α_S		0.1179	0.0010	0.0008	0.00016

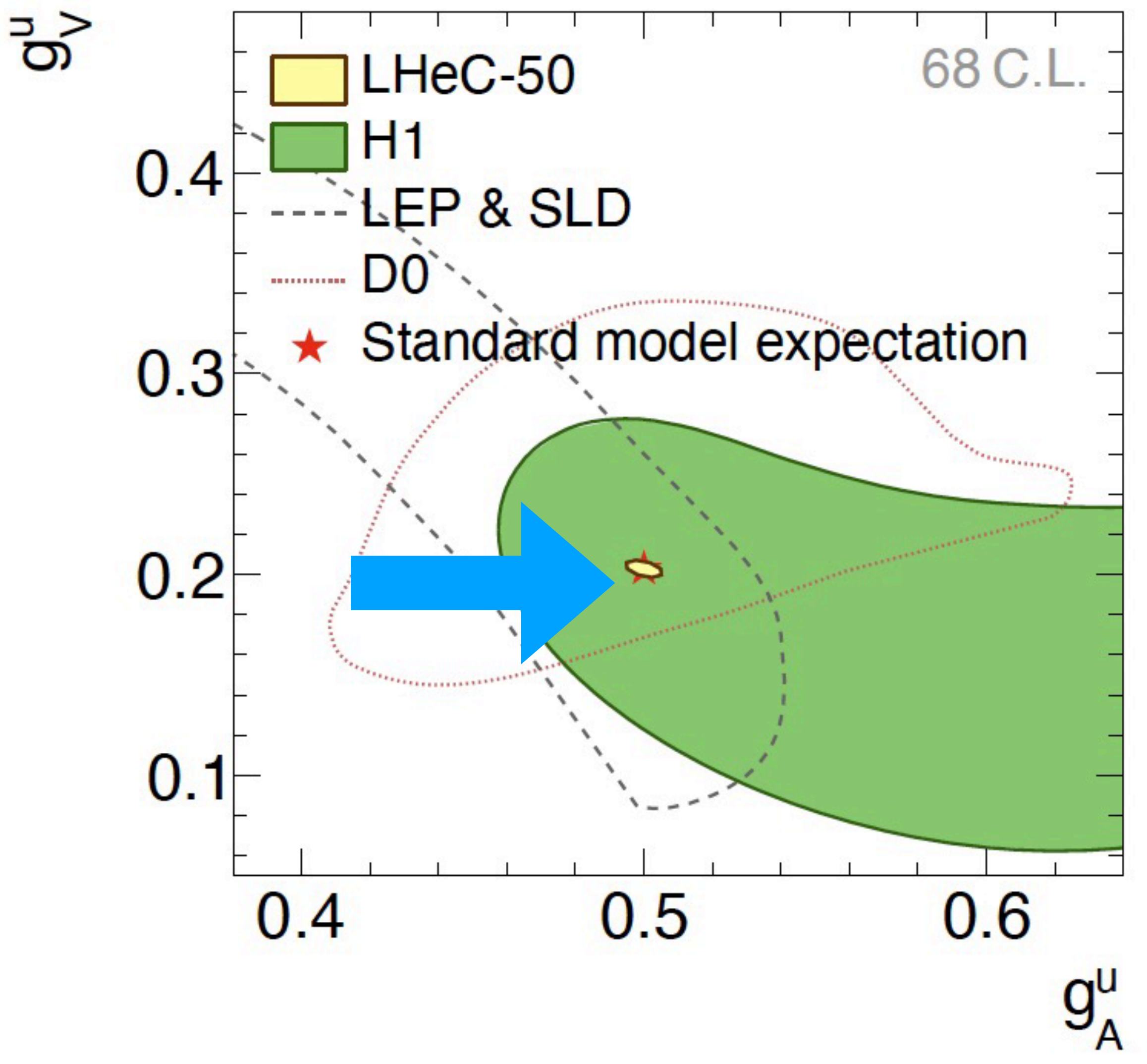


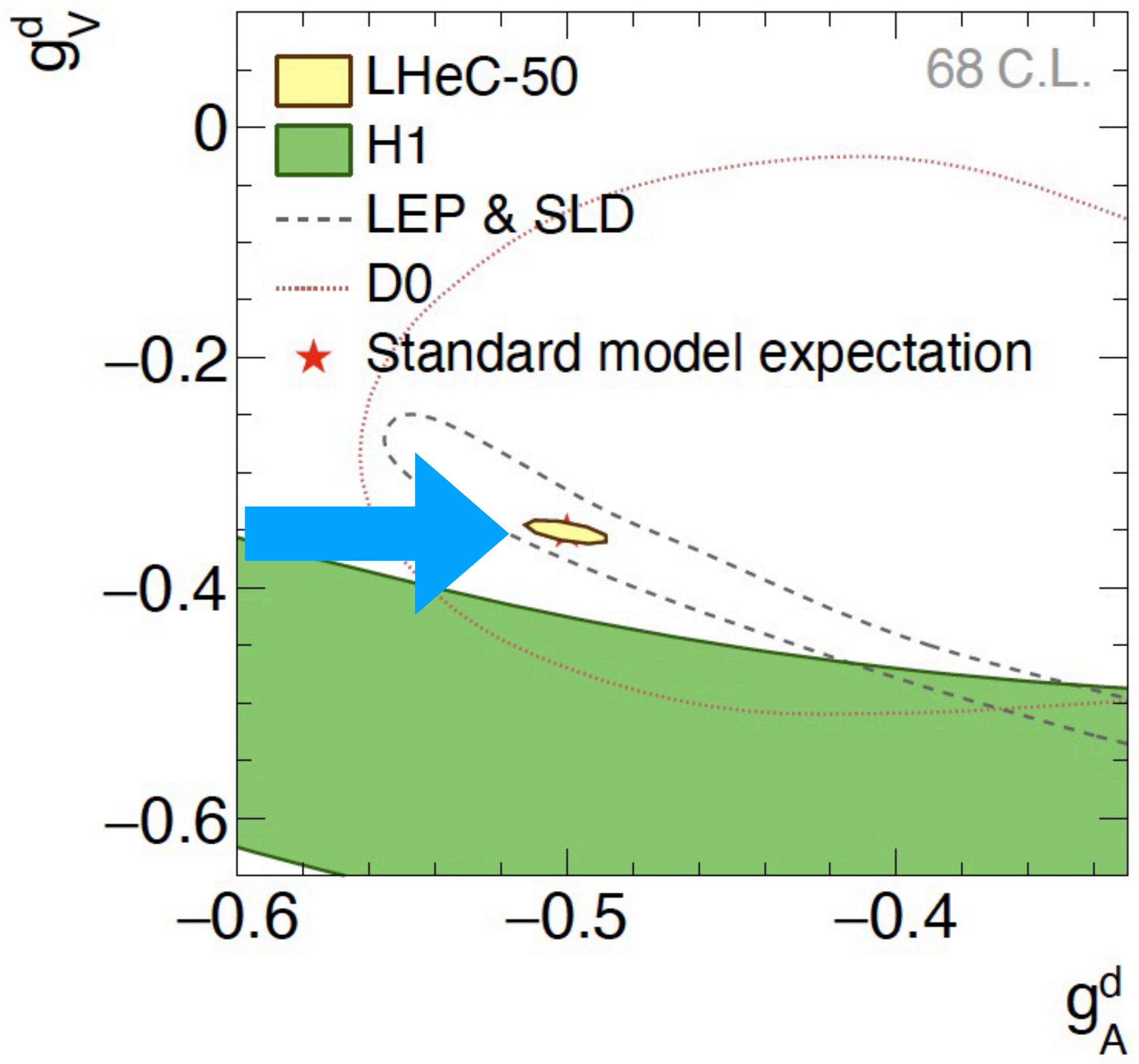
$\Delta M_W = \pm 5$-6 MeV (HL-LHC)
→ ±3 MeV (HL-LHC + LHeC PDFs)

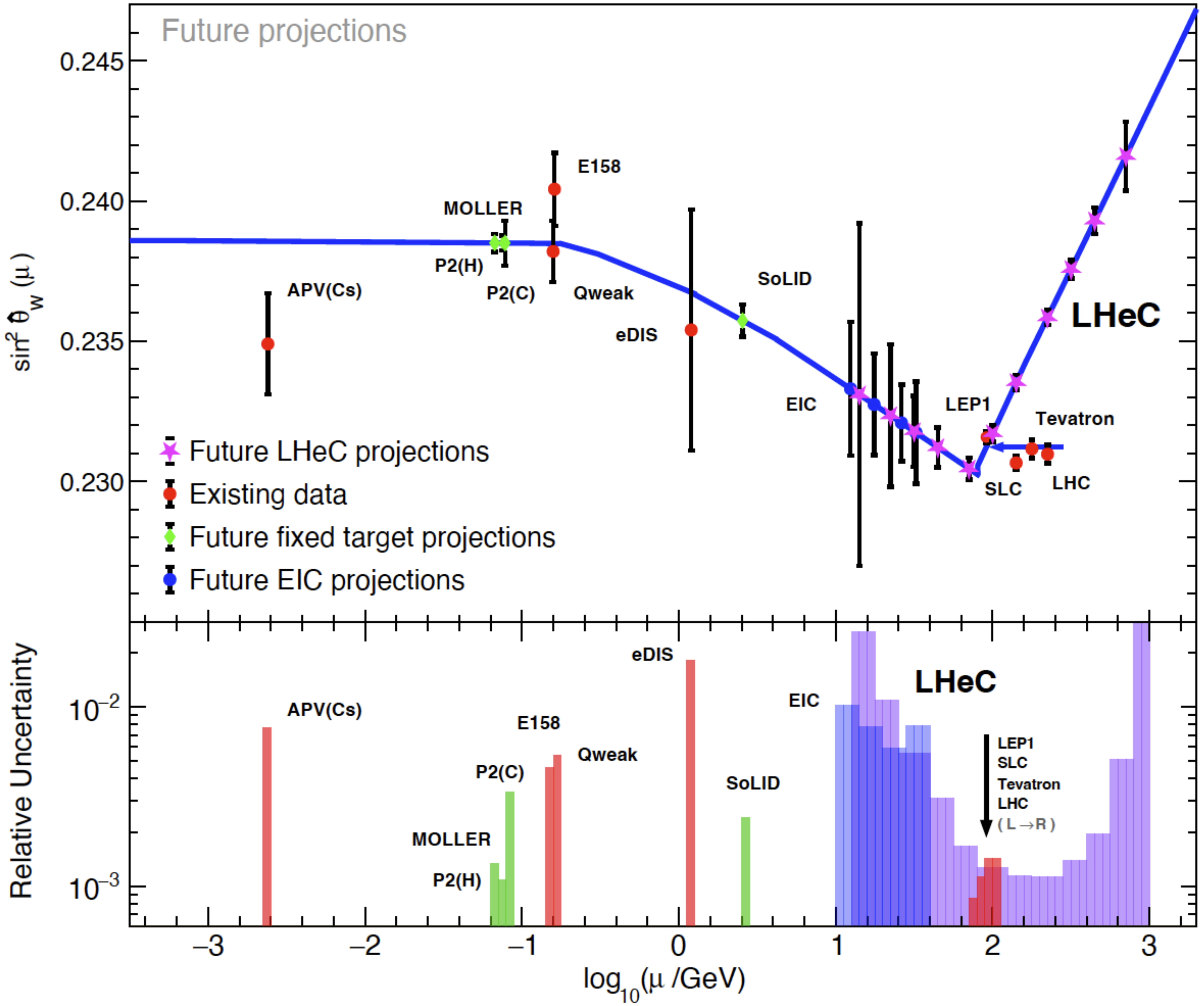


EW mixing angle and couplings to light quarks:

- At the LHeC, many EW physics opportunities (spacelike vs. timelike in e^+e^- /pp) through PDF+EW fits: W&Z mass, $\sin^2\theta_W^{eff,l}$ and its running, V and A NC/CC couplings to light quarks, triple and quartic couplings,…

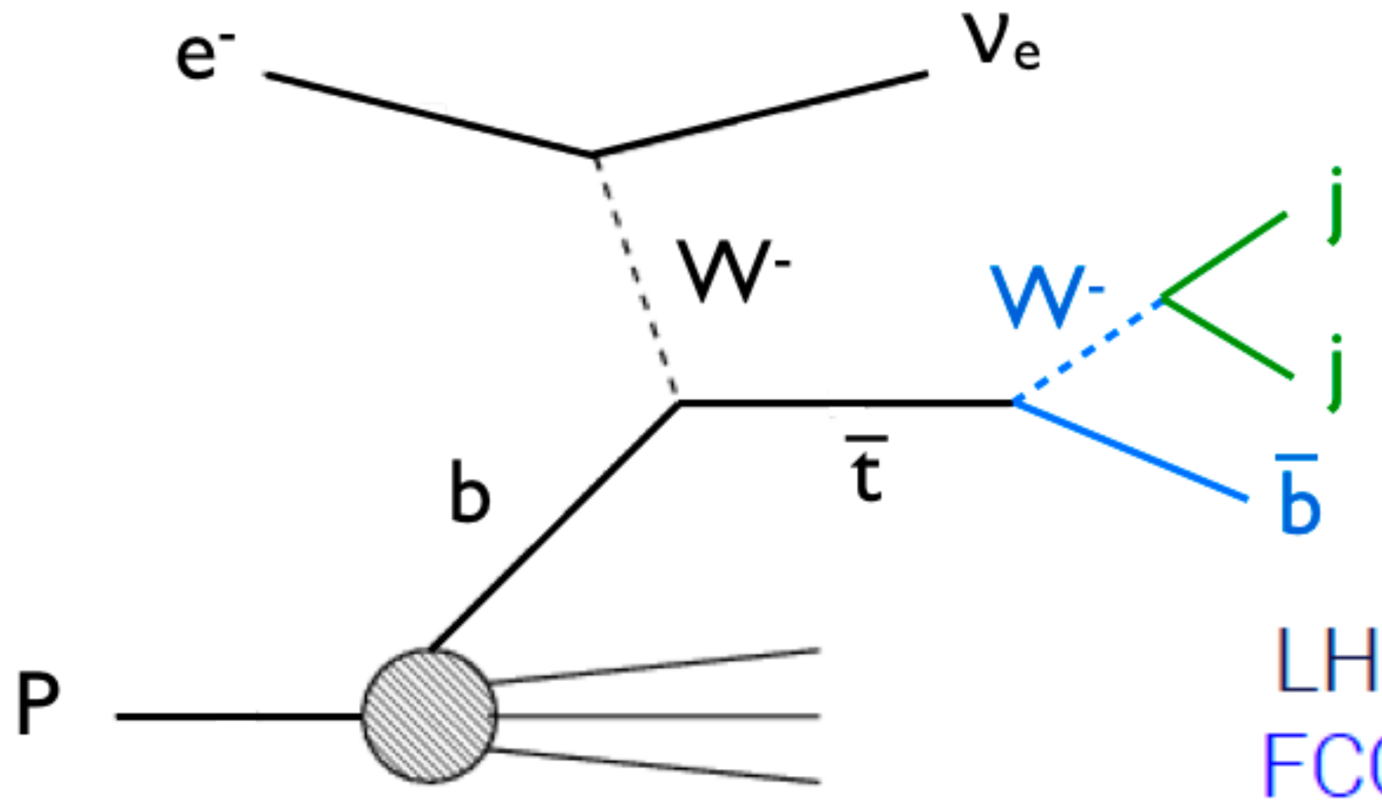






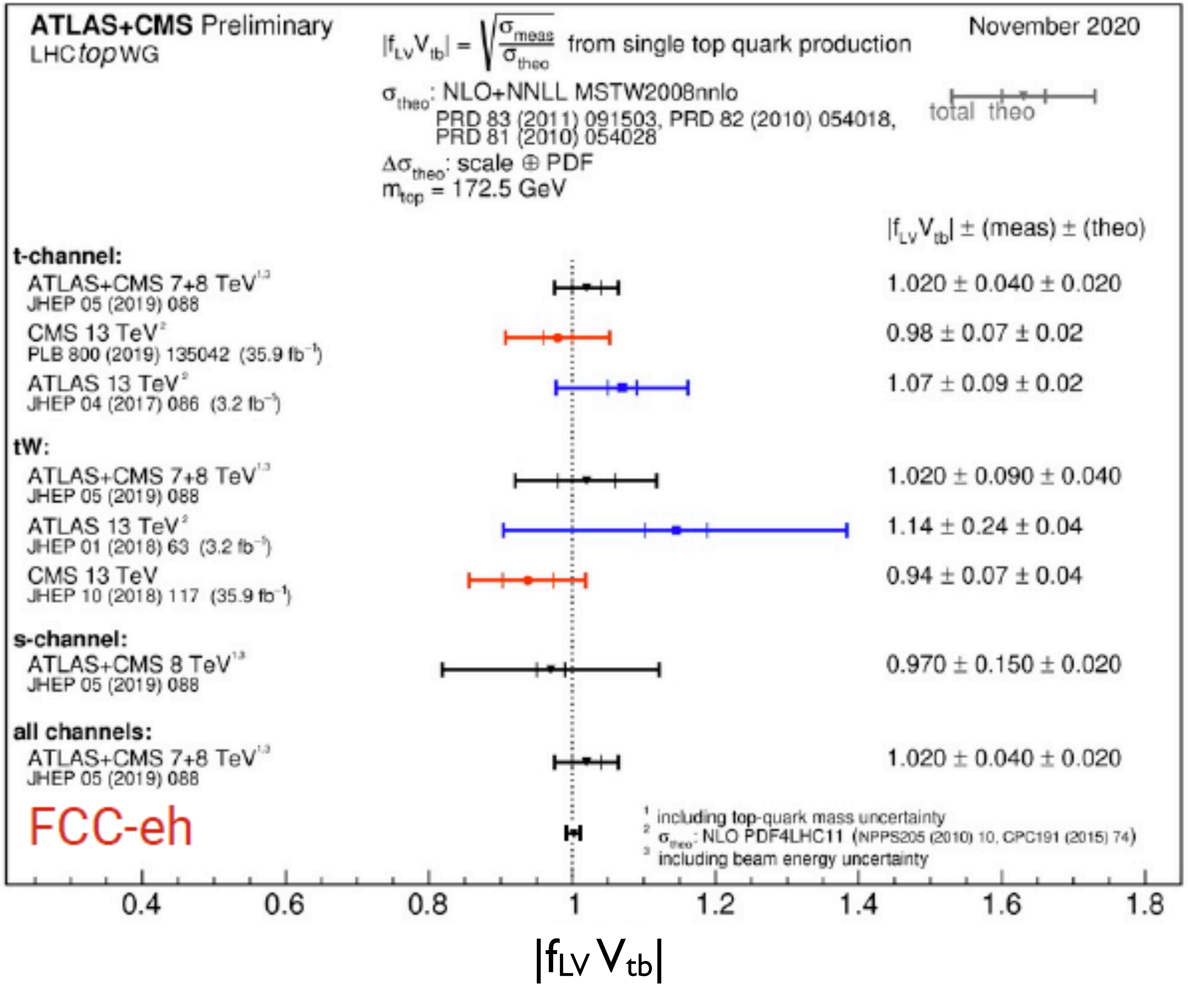
Top physics: CKM

- At the LHeC, limits on several CKM matrix elements can be set using single top production (V_{tb} to 1% at the LHeC): polarisation essential.



LHeC	σ~ 1.9pb
FCC-eh	σ~15.3pb

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

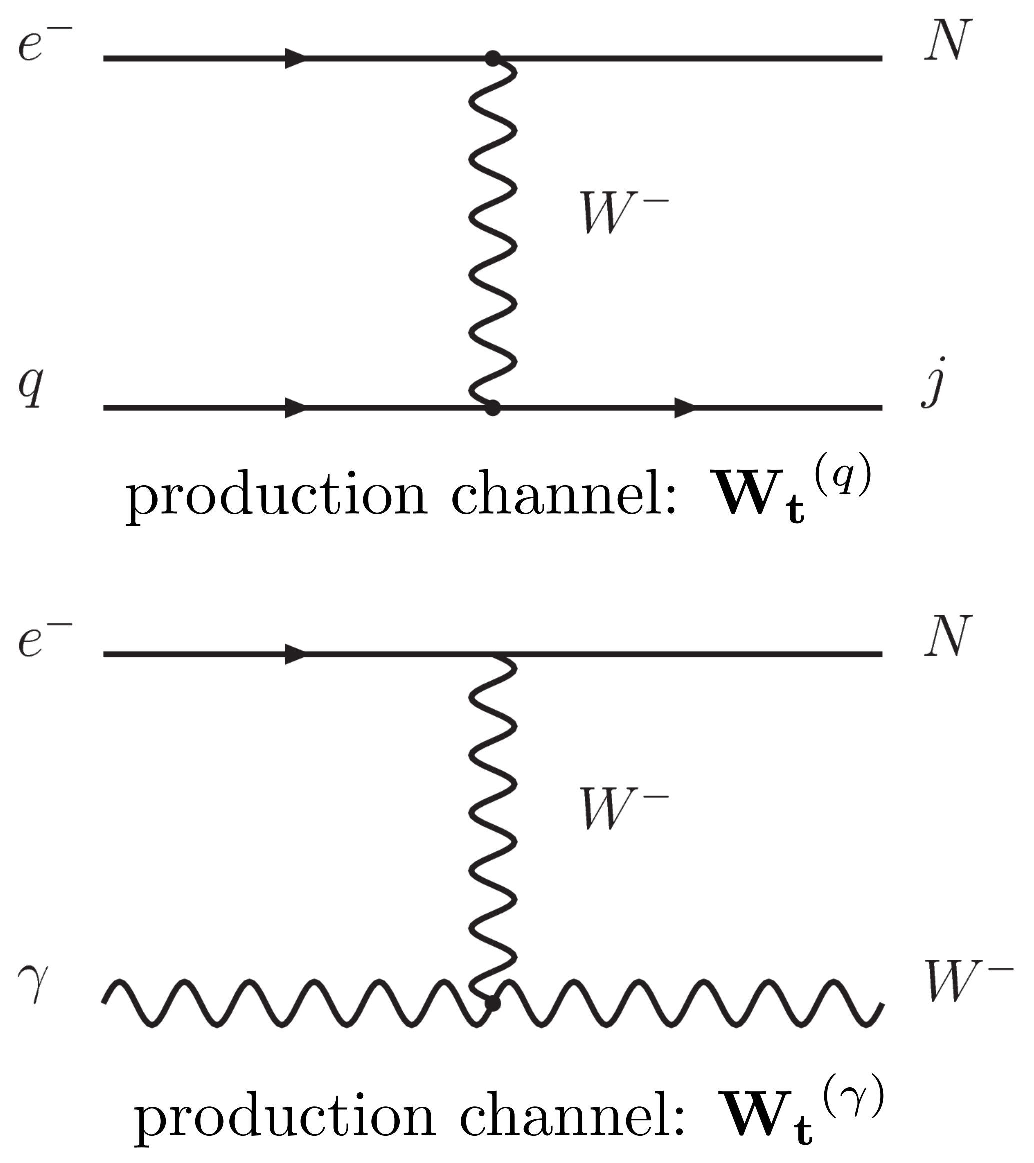


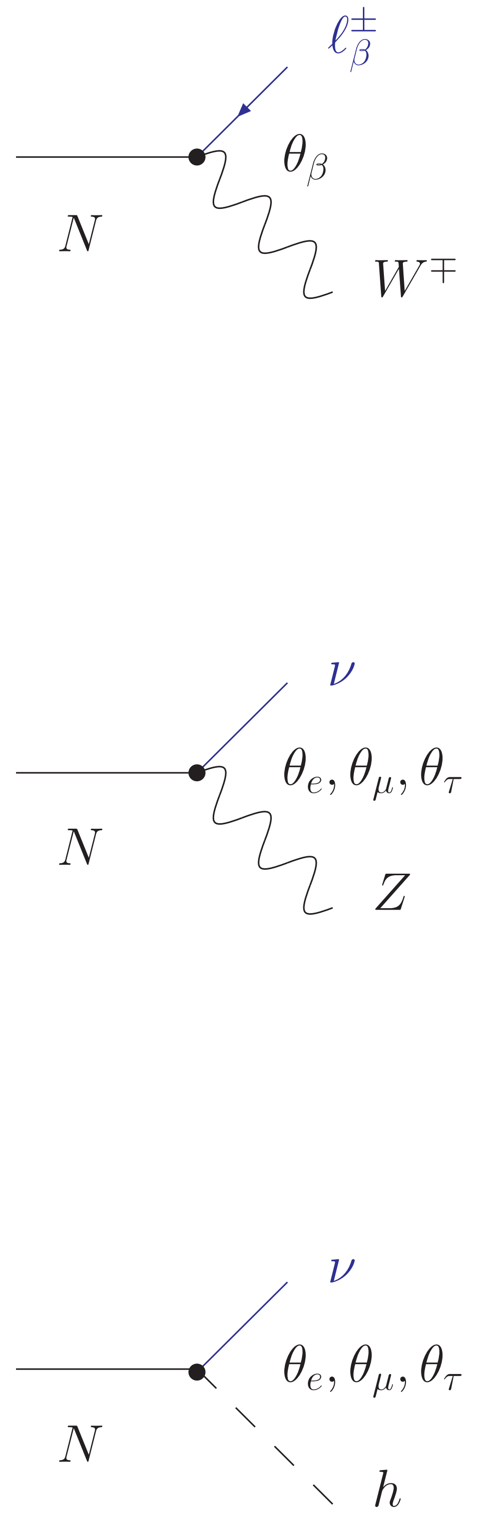
- Also sensitivity to anomalous top couplings and top FCNC.

BSM physics: heavy neutrinos

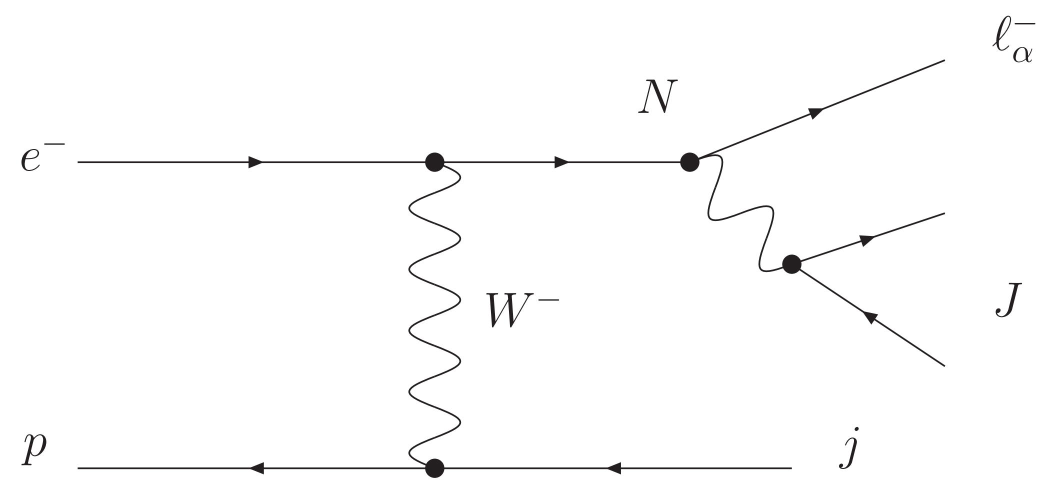
- In general, weakly produced and/or non-promptly decaying particles very challenging at pp and e^+e^- colliders: good complementarity with ep colliders, similarly to the case of the Higgs exotics decays, sterile neutrinos.

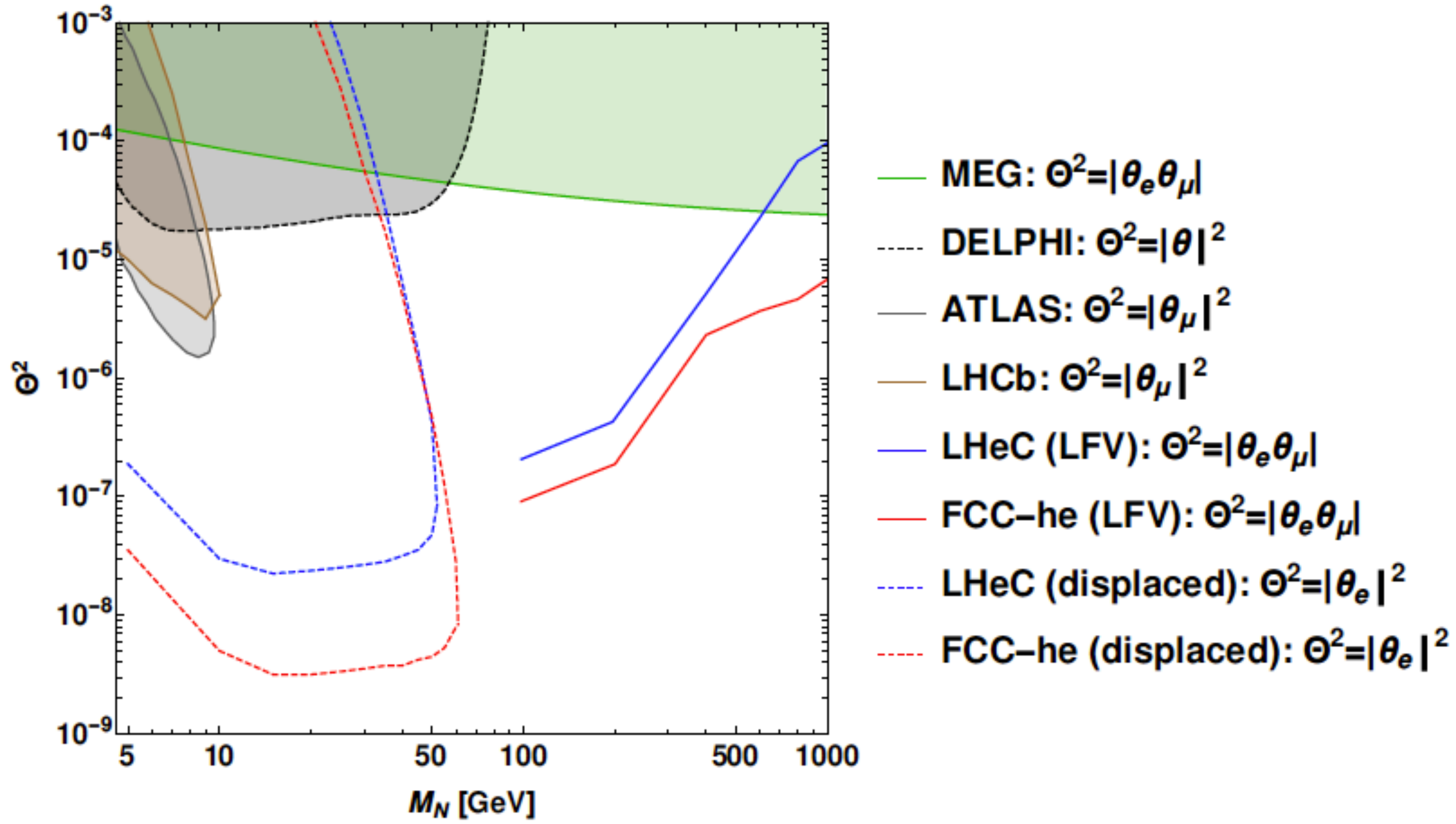
active-sterile neutrino mixing with the electron flavour → $|\theta_e|^2$





Sensitivity of the LFV lepton-trijet searches (at 95 % C.L.) and of the DV one





- Dark photons with masses < 1 GeV can be tested via displaced decays into e^+e^-, covering regions between ee/pp and low energy experiments.

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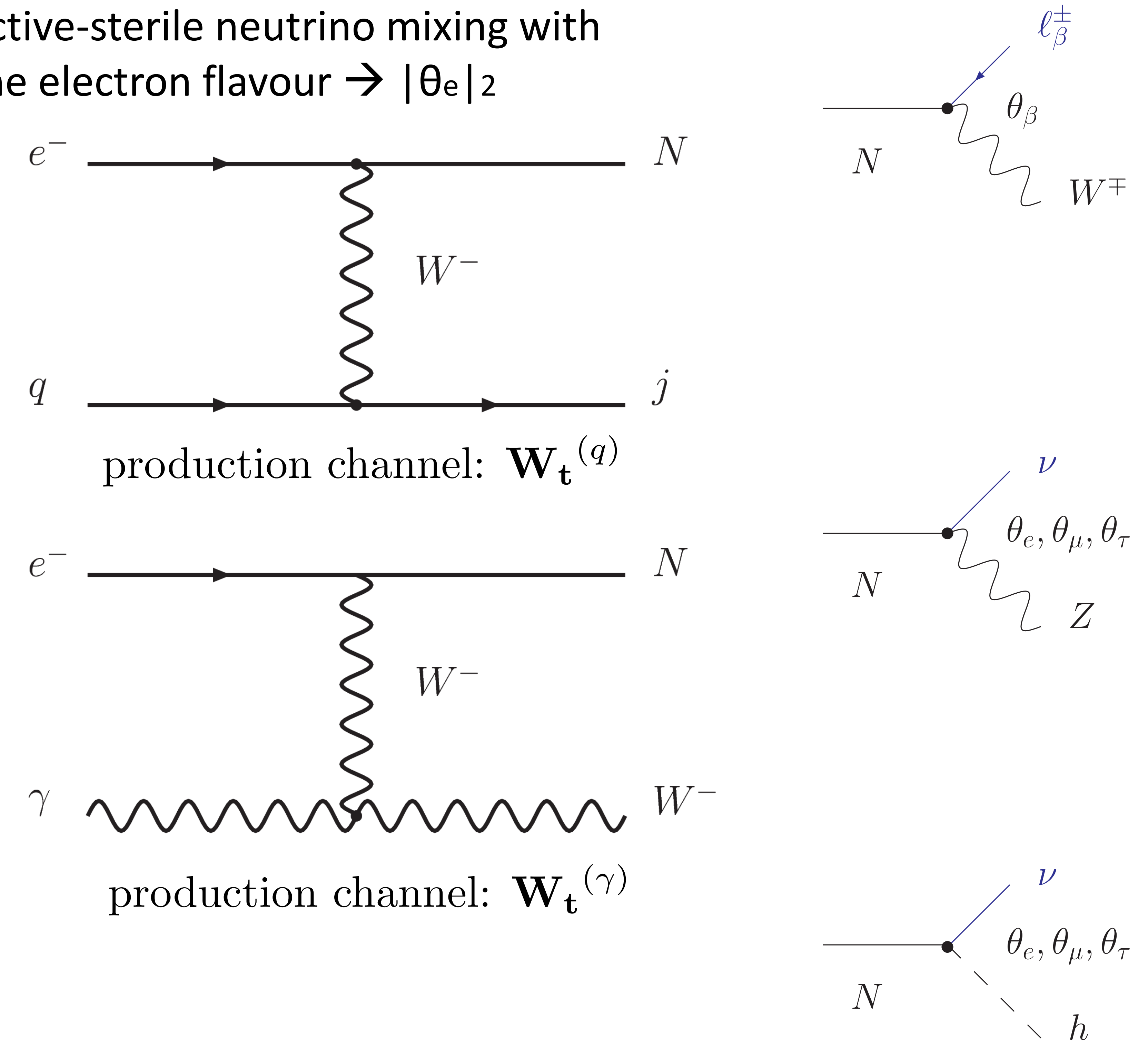

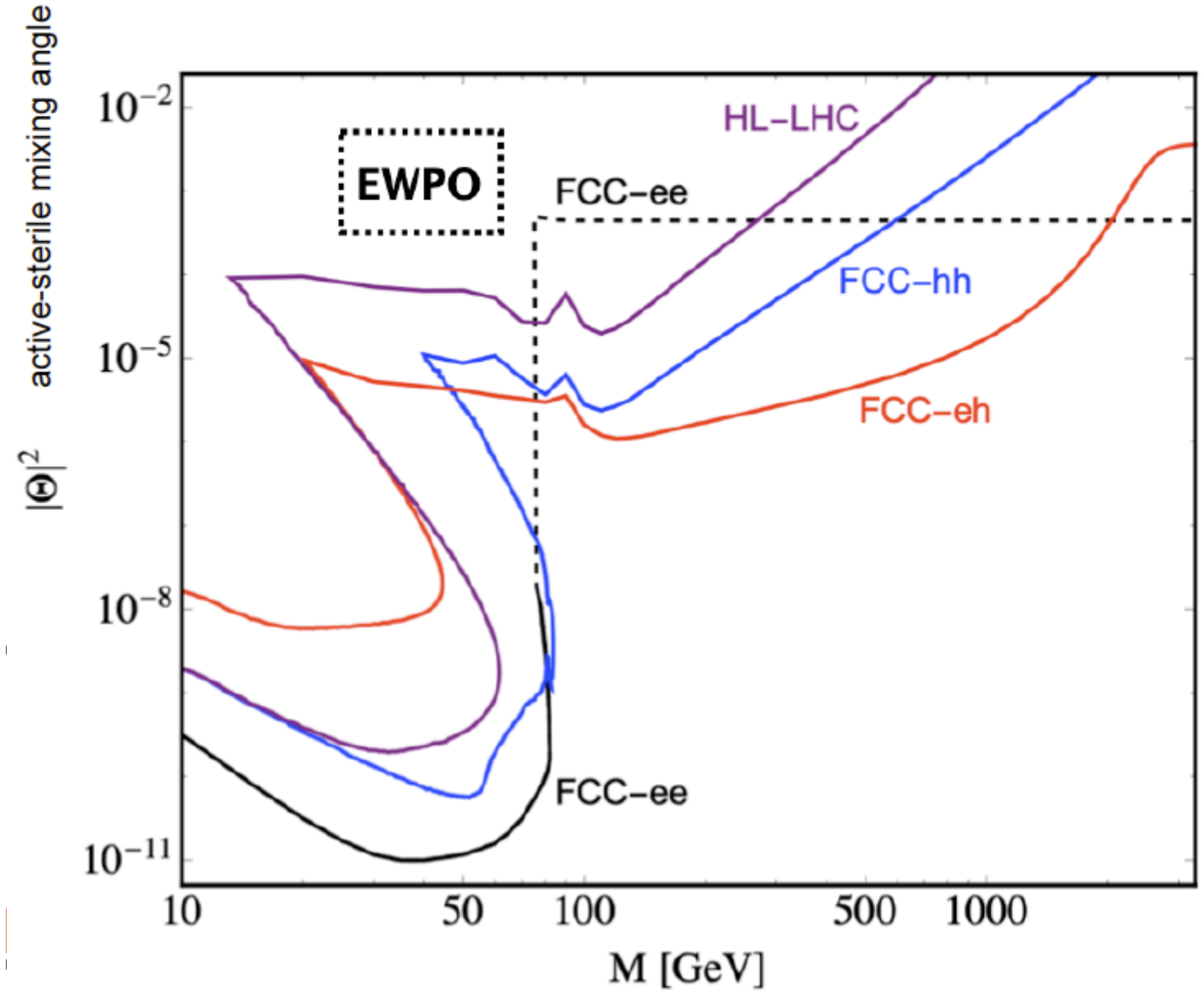

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LHeC as a bridge:

● In standalone mode (ep/eA only), LHeC may be a bridge between major colliders at CERN, between the end of the HL-LHC (2041) and the next flagship CERN collider.

Slide by J. D’Hondt

LHC

FCC (ee or hh)

LHeC as a bridge:

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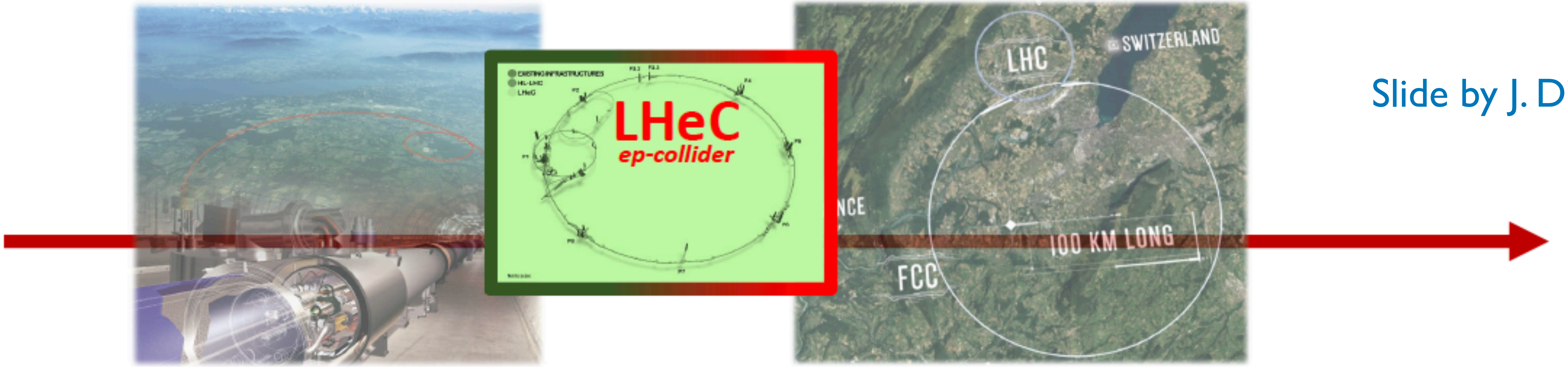
ep-option with HL-LHC: LHeC

updated CDR: J.Phys.G 48 (2021) 11, 110501
10y @ 1.2 TeV (1ab^{-1}) = Run-6 + 5y ep-only@LHC
6y ep-only@LHC > 1 ab^{-1}



Slide by J. D'Hondt

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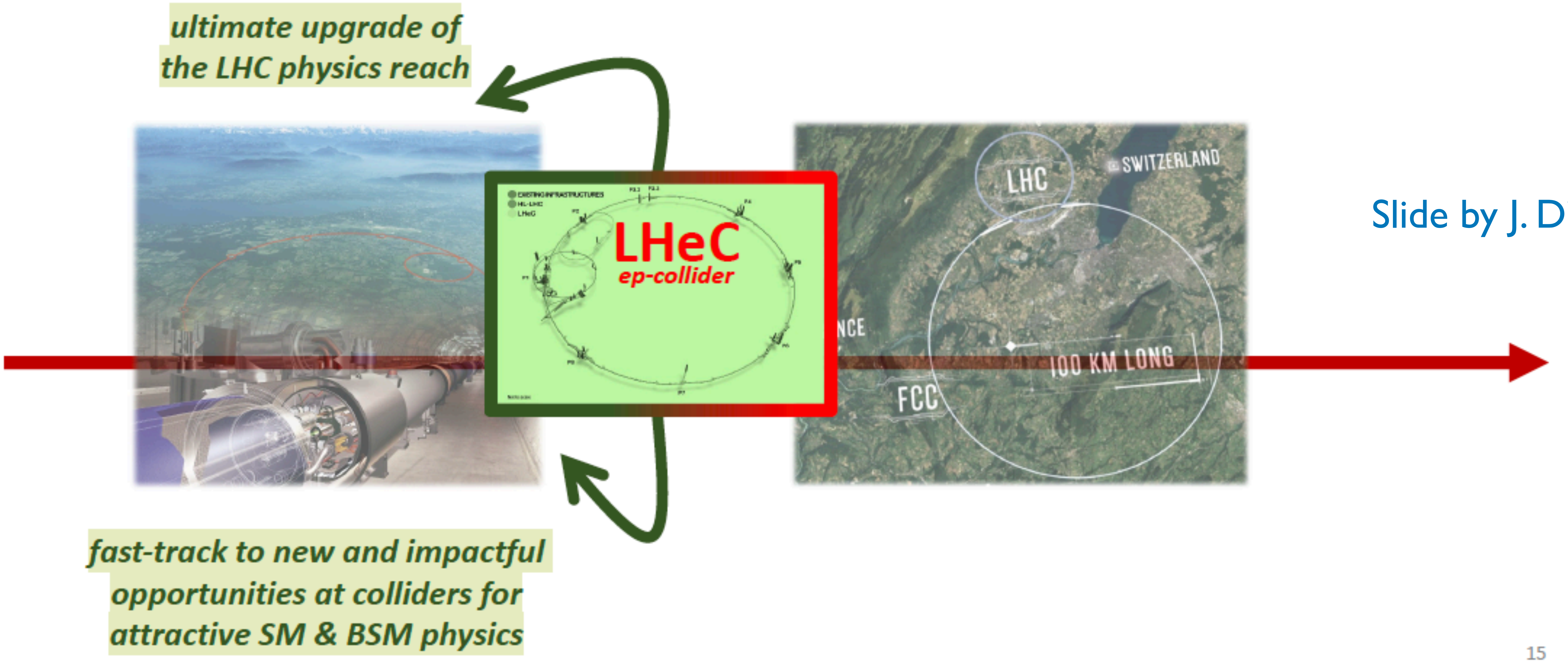

Slide by J. D’Hondt

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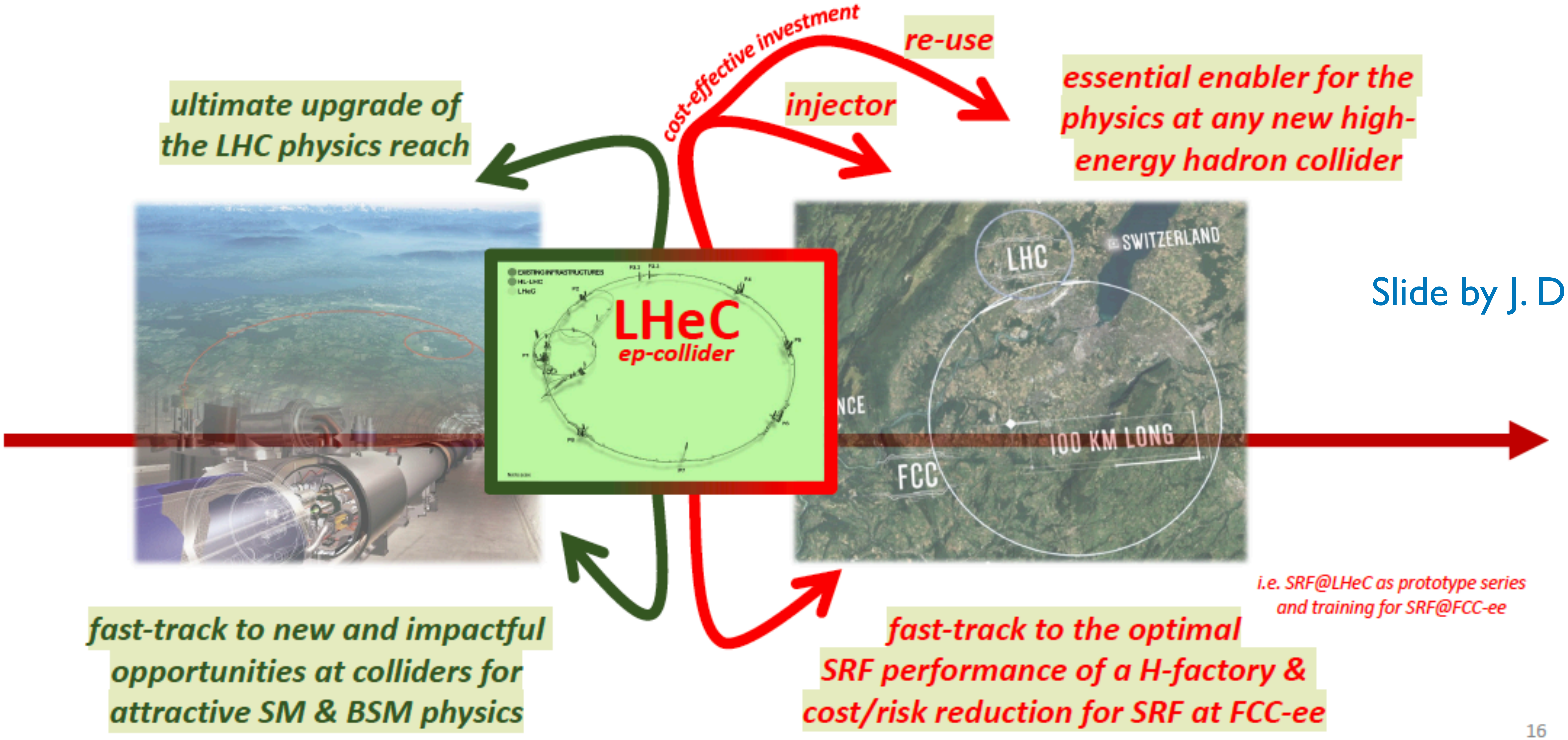

Slide by J. D'Hondt

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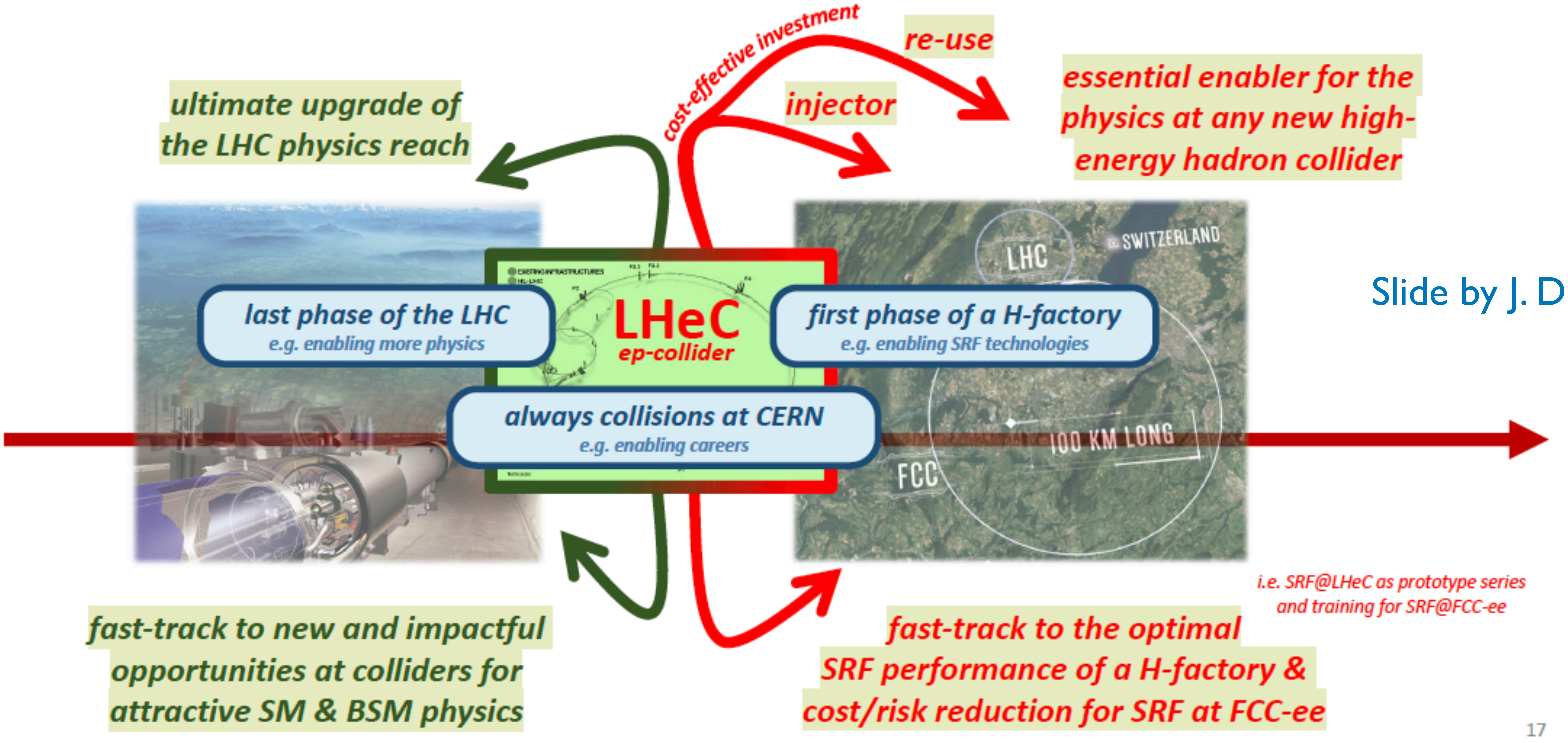
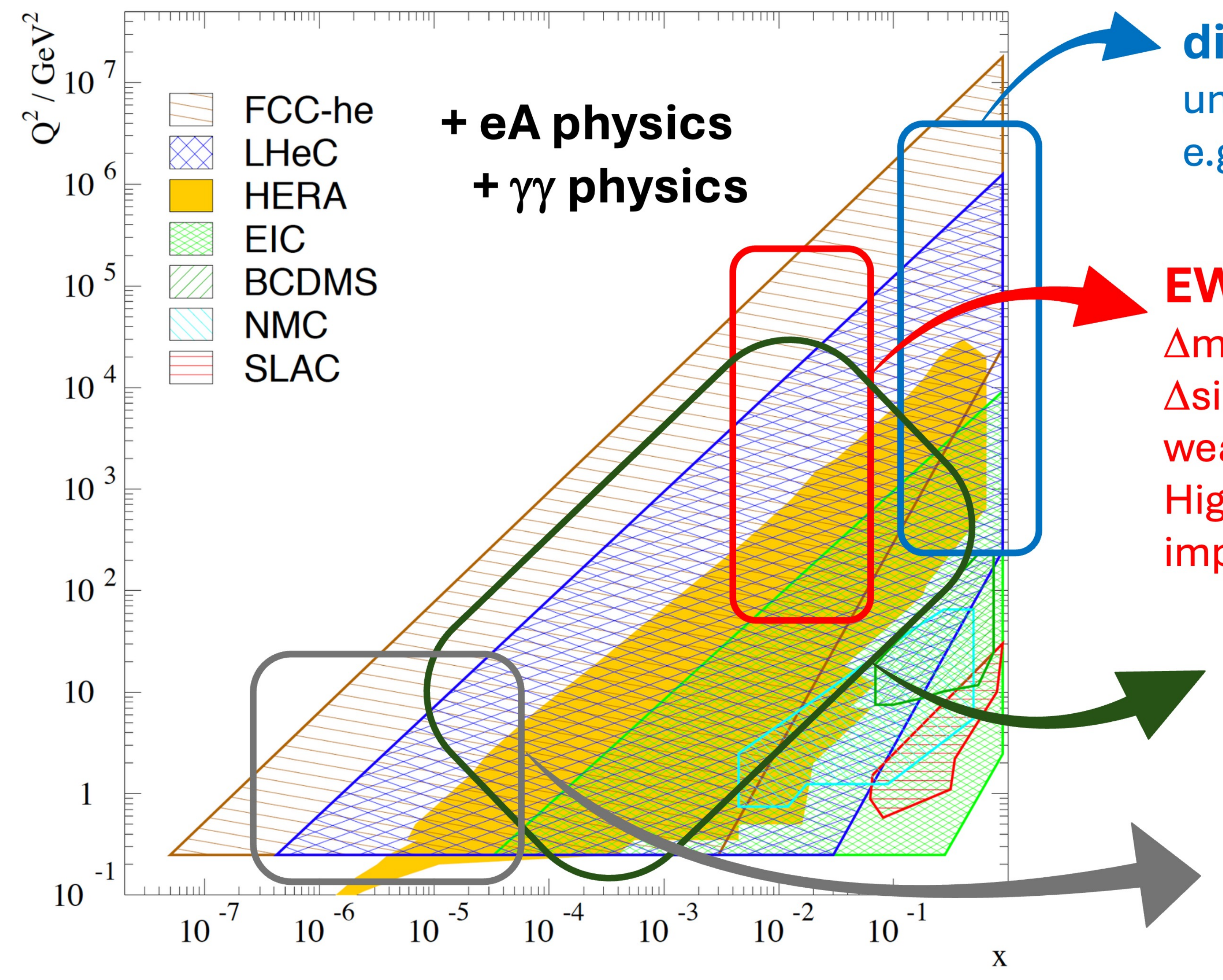


Slide by J. D'Hondt

Summary:

1.2 TeV ep collisions cover the (Q^2,x) plane → ***General Purpose Experiment***



direct searches for new physics
unique environment: eq only EW interactions
e.g. heavy ν, dark γ, axion-like particles

EW, Higgs and top quark physics
$\Delta m_W \sim 3$ MeV, $\Delta|V_{tb}| \sim 1\%$, top-quark FCNC
$\Delta \sin^2\theta_W^{eff} \sim 0.0002$ (full scale-dependency)
weak neutral couplings to light quarks ~ 1%
Higgs couplings largely improved wrt HL-LHC
improved SMEFT fits (accuracy & degeneracy)

precision QCD physics
$\Delta\alpha_s \sim 0.14\%$ & running of α_s
PDFs covering a vast kinematic range

non-linear QCD physics
a new discovery frontier

- **LHeC in the landscape of particle physics colliders:**
  ➜ Physics case on their own: QCD (precision and discovery in ep & eA), EW, top, Higgs, BSM.
  ➜ Enlarge the reach of hadronic colliders into (higher) precision, both for pp and for AA.
  ➜ Complementarities/synergies with hh & e^+e^-.

- **LHeC is not the next flagship project at CERN but it may serve as bridge between HL-LHC and a new major project at CERN (2503.17727):**
  ➜ Ultimate exploitation of the results of the LHC (e.g., m_W, Higgs couplings).
  ➜ Physics program on its own: proton/nuclear structure and dynamics, EW, top , Higgs, BSM.
  ➜ It facilitates technology (SRF, ERL, detector) and physics (e.g., PDFs for pp and AA, combinations of Higgs couplings, complementary regions on searches) for future projects.

The end:

Rohini Godbole, 1952-2024
IAC

Max Klein, 1951-2024
Spokesperson 2005-2022

Thanks to the organisers for the talk and to you for your attention!!!

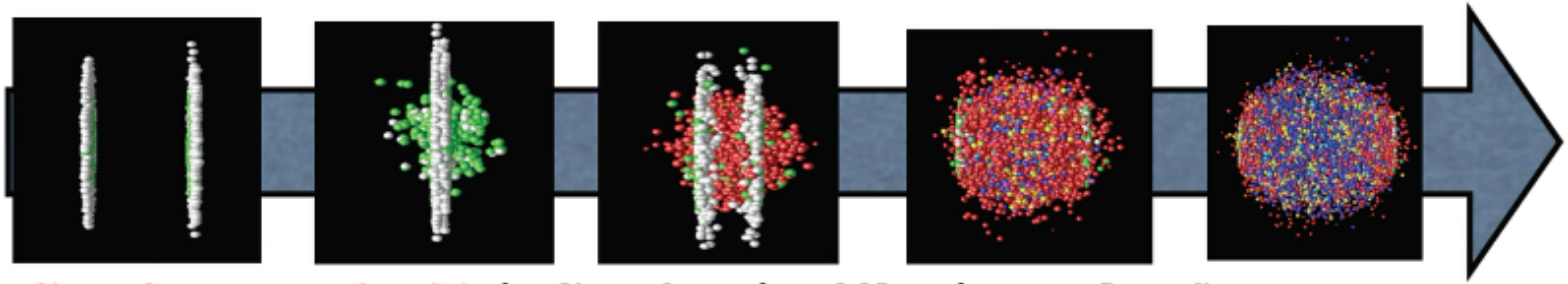
https://indico.cern.ch/event/lhecfcceh

Backup:

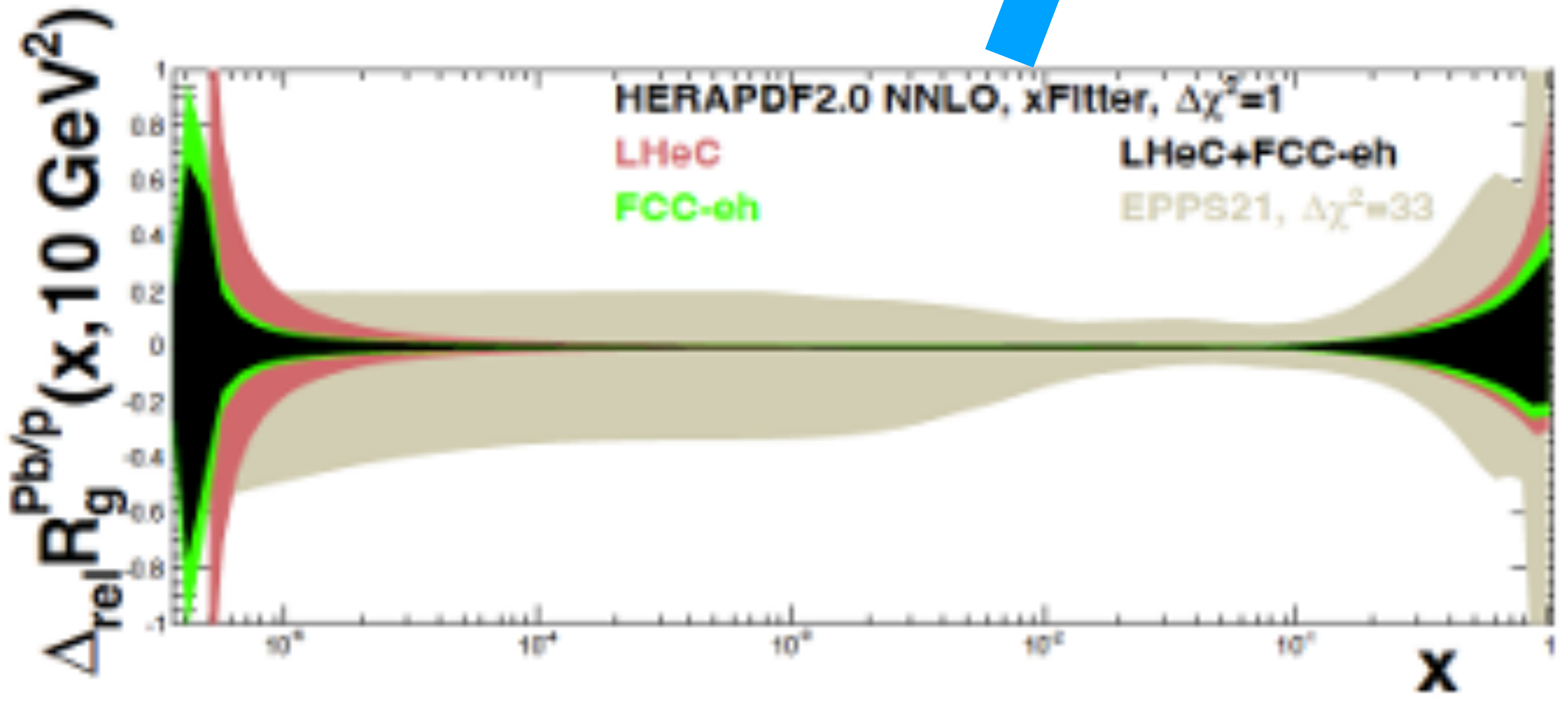
Implications of eA on pA/AA:

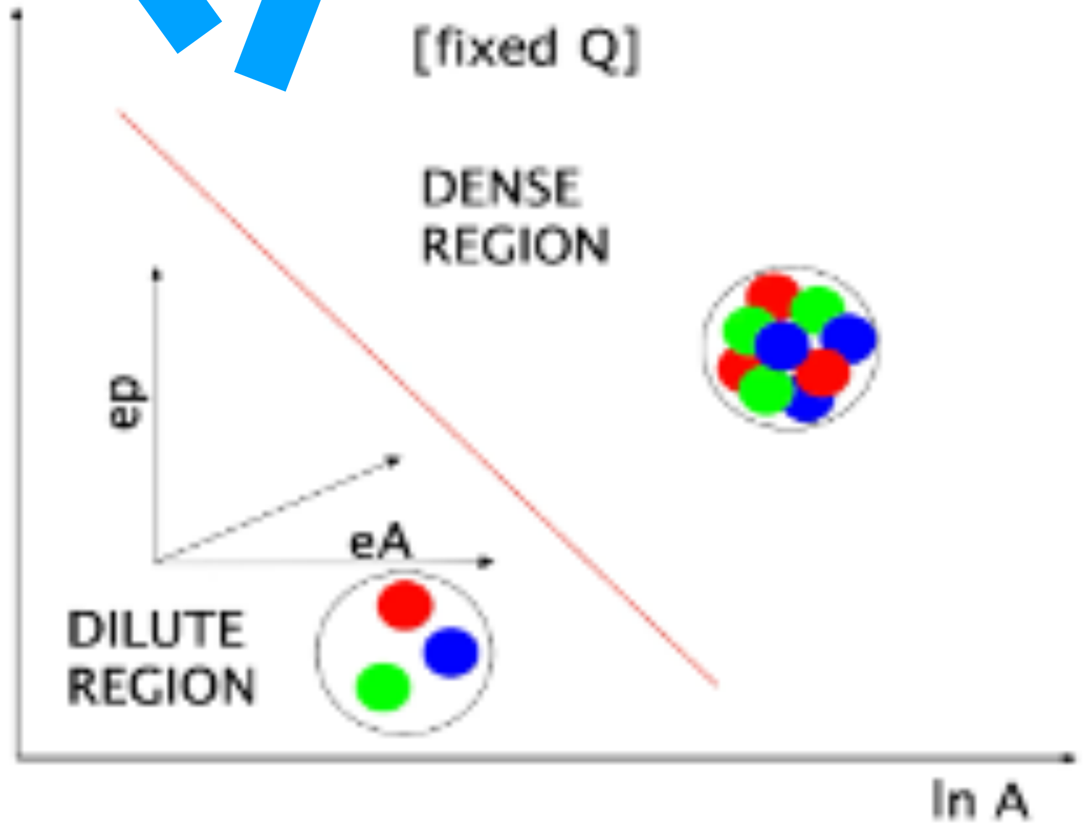
- eA collisions at the LHeC will provide precise information on the partonic structure of nuclei and the dynamics of dense partonic systems (a new non-linear regime of QCD which requires ep and eA), relevant for all stages of HICs.

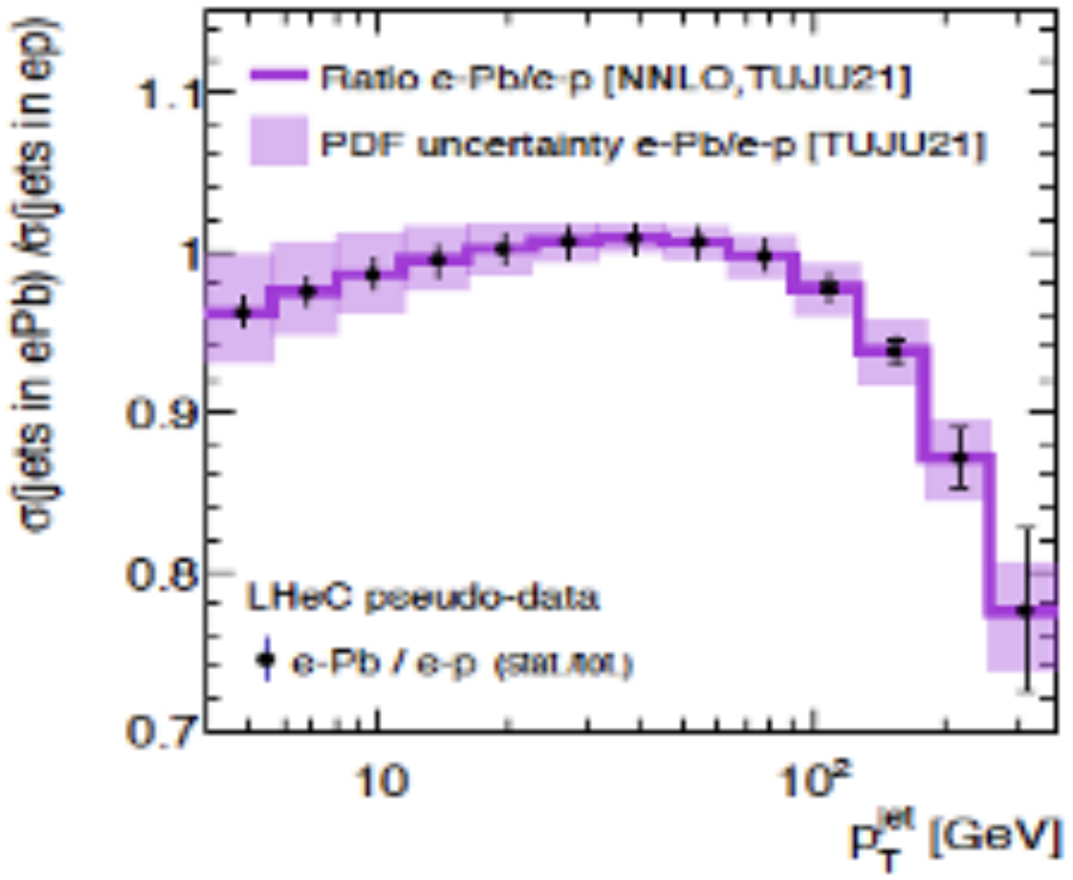
[B. Cole]



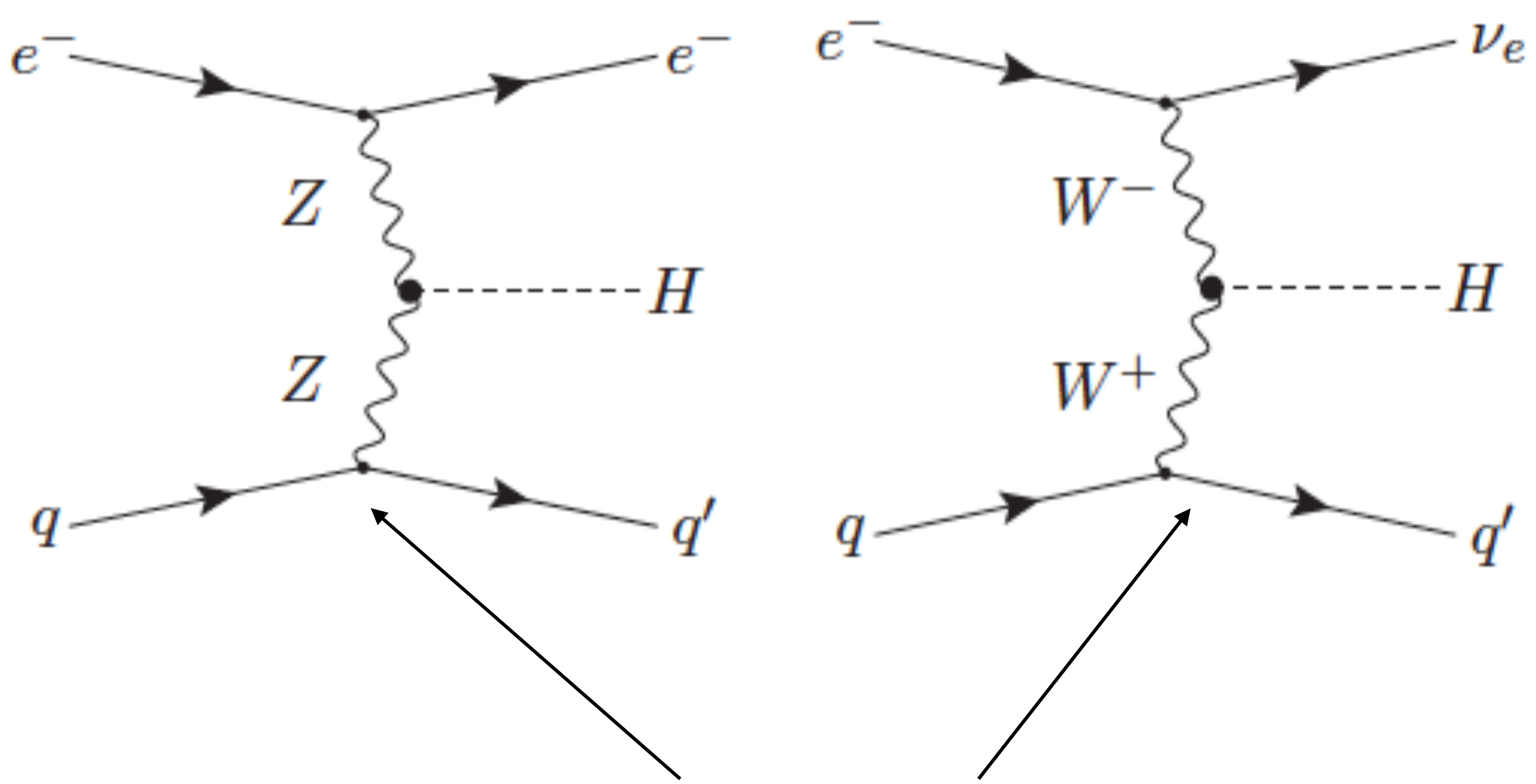
Gluons from saturated nuclei → Glasma? → QGP → Reconfinement







Higgs physics: cross sections



Parameter	Unit	LHeC	HE-LHeC	FCC-eh	FCC-eh
E_p	TeV	7	13.5	20	50
$\sqrt{s}$	TeV	1.30	1.77	2.2	3.46
$\sigma_{CC}\ (P=-0.8)$	fb	197	372	516	1038
$\sigma_{NC}\ (P=-0.8)$	fb	24	48	70	149
$\sigma_{CC}\ (P=0)$	fb	110	206	289	577
$\sigma_{NC}\ (P=0)$	fb	20	41	64	127
HH in CC	fb	0.02	0.07	0.13	0.46

		Number of Events			
		Charged Current		Neutral Current	
Channel	Fraction	LHeC	FCC-eh	LHeC	FCC-eh
$b\bar{b}$	0.581	114 500	1 208 000	14 000	175 000
W^+W^-	0.215	42 300	447 000	5 160	64 000
gg	0.082	16 150	171 000	2000	25 000
$\tau^+\tau^-$	0.063	12 400	131 000	1 500	20 000
$c\bar{c}$	0.029	5700	60 000	700	9 000
ZZ	0.026	5 100	54 000	620	7 900
$\gamma\gamma$	0.0023	450	5 000	55	700
$Z\gamma$	0.0015	300	3 100	35	450
$\mu^+\mu^-$	0.0002	40	410	5	70
σ [pb]		0.197	1.04	0.024	0.15

- Cross section for NC and CC Higgs production through VBF makes study possible with foreseen luminosities; initial estimate of g_{HHH} to 20 % accuracy at the FCC-eh.
- NLO contributions ~20% with shape distortions.
- Large Higgs dataset for precision measurements.

EW physics: couplings to light quarks

- Coupling of γ,Z,W to light flavours not accessible in other processes; also BSM contributions (e.g., in the SMEFT framework) and running are measurable.

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

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

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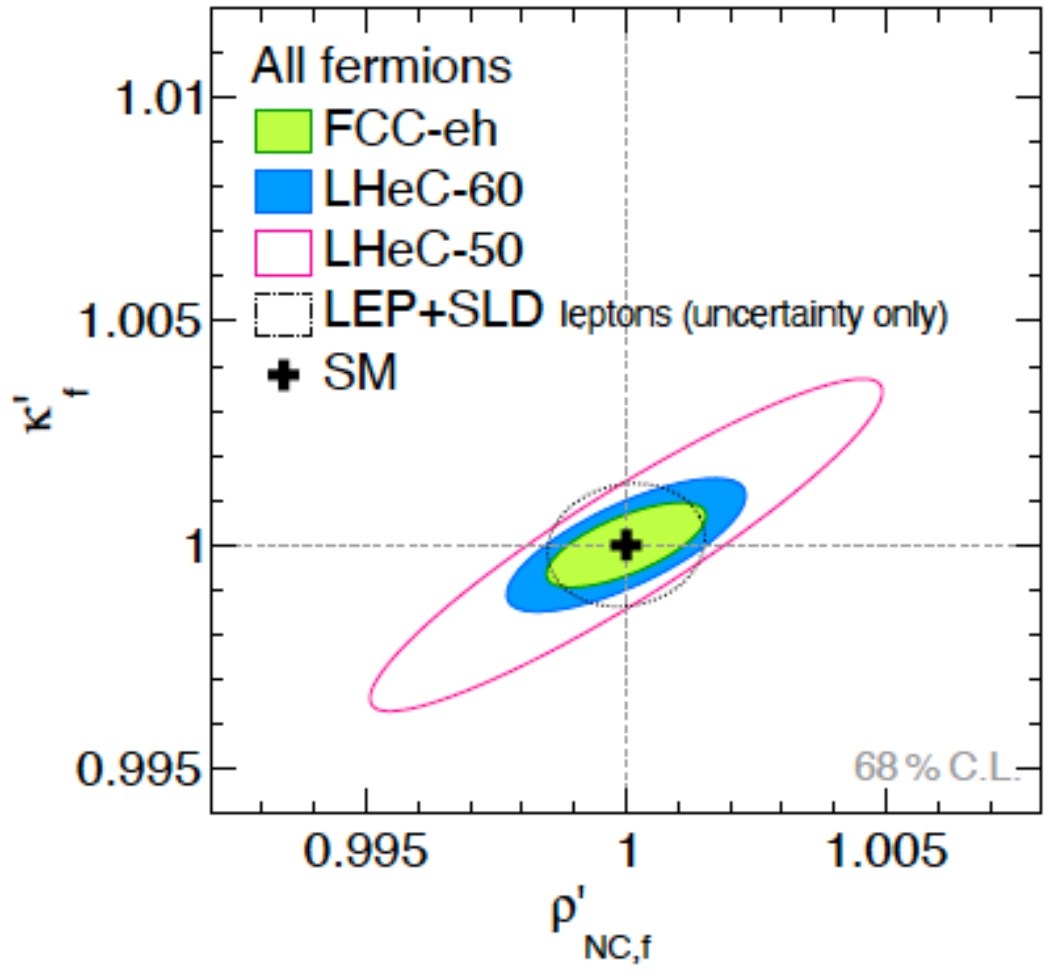

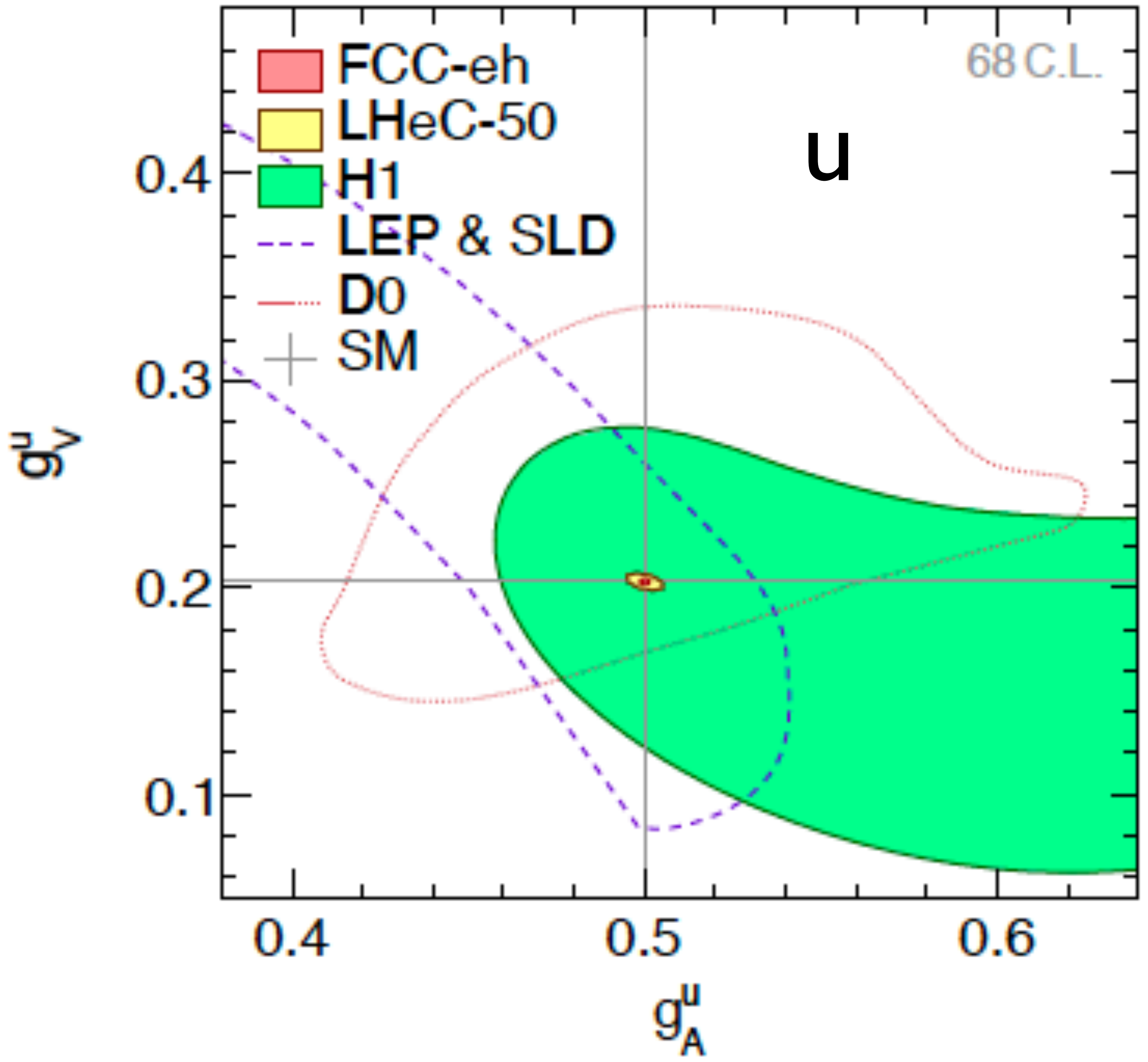

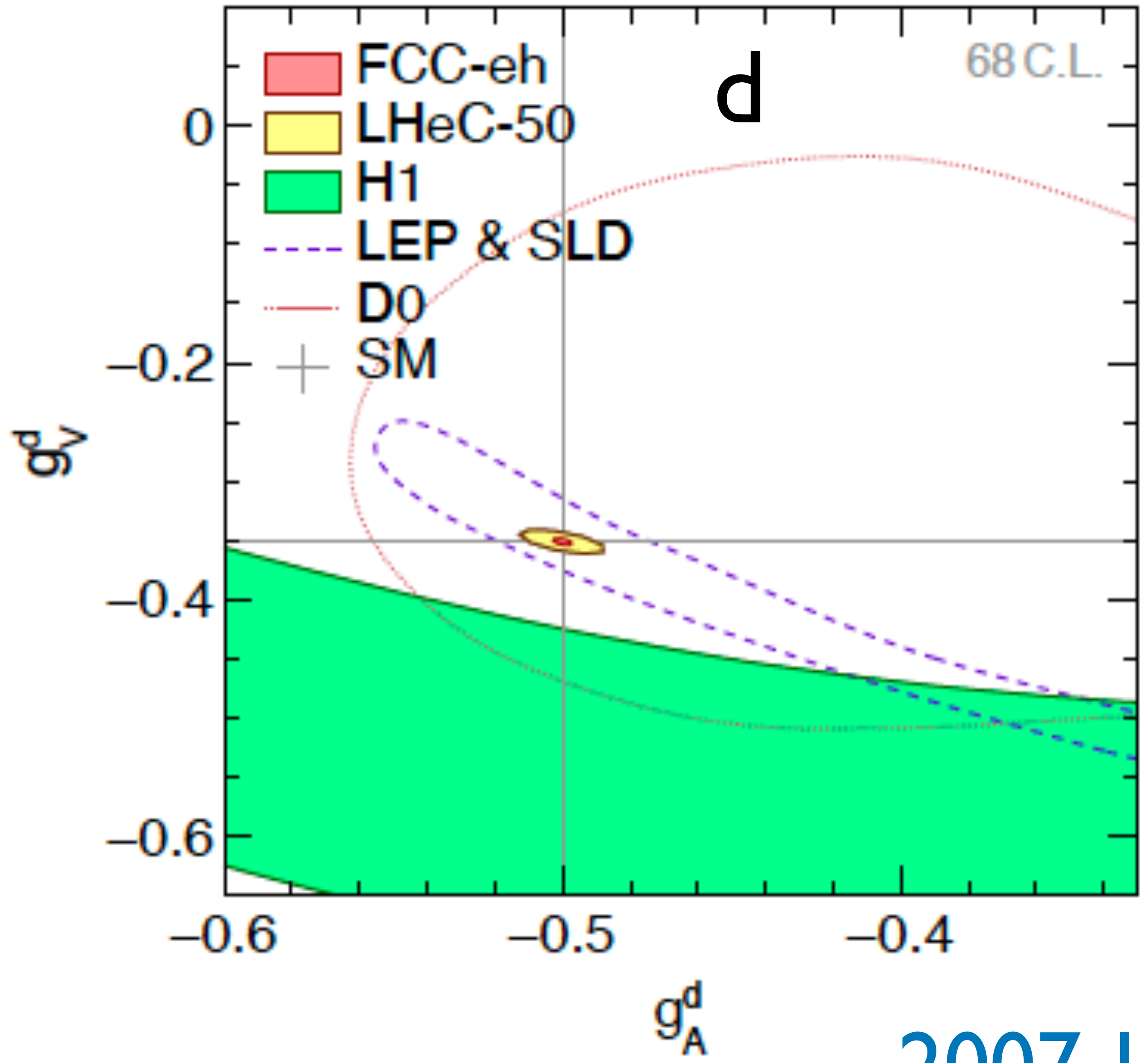

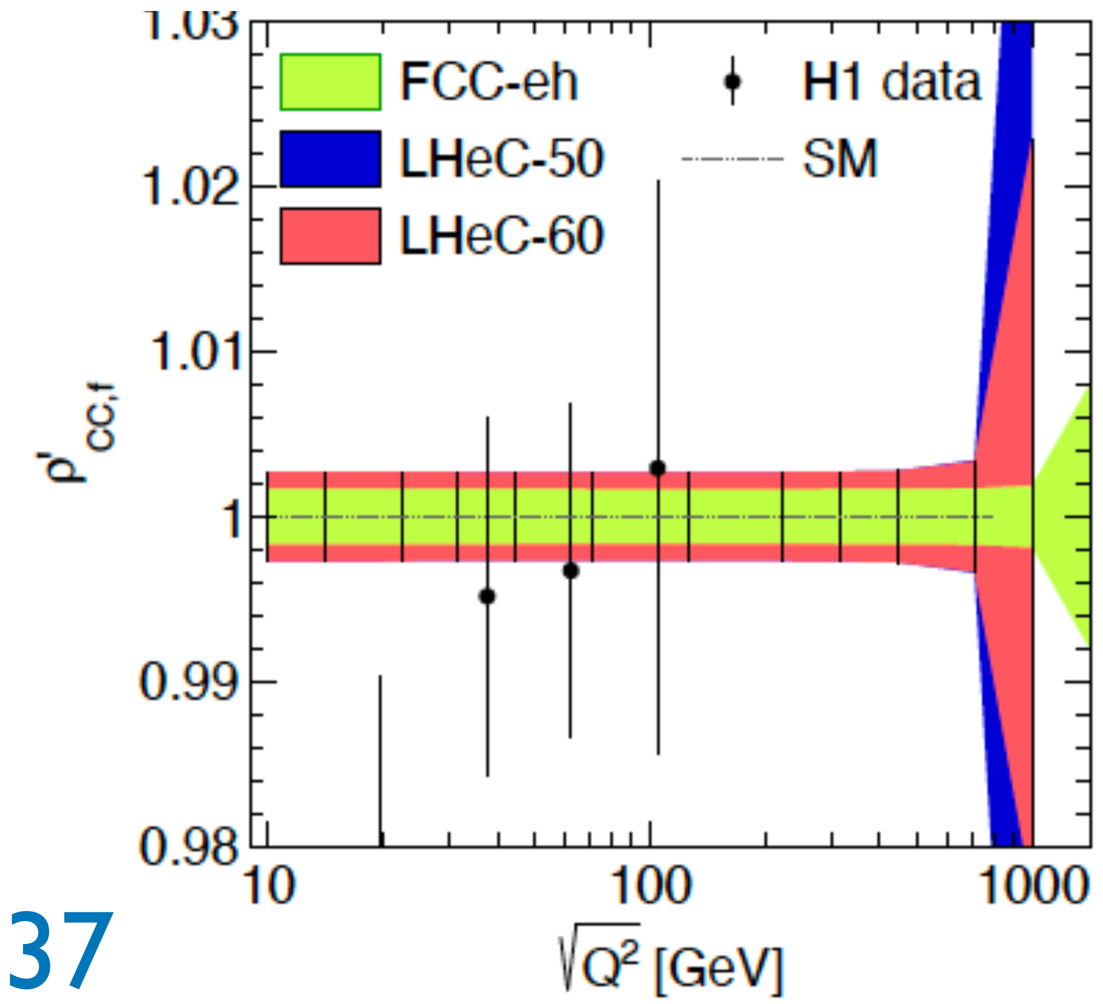

2007.11799, 2203.06237

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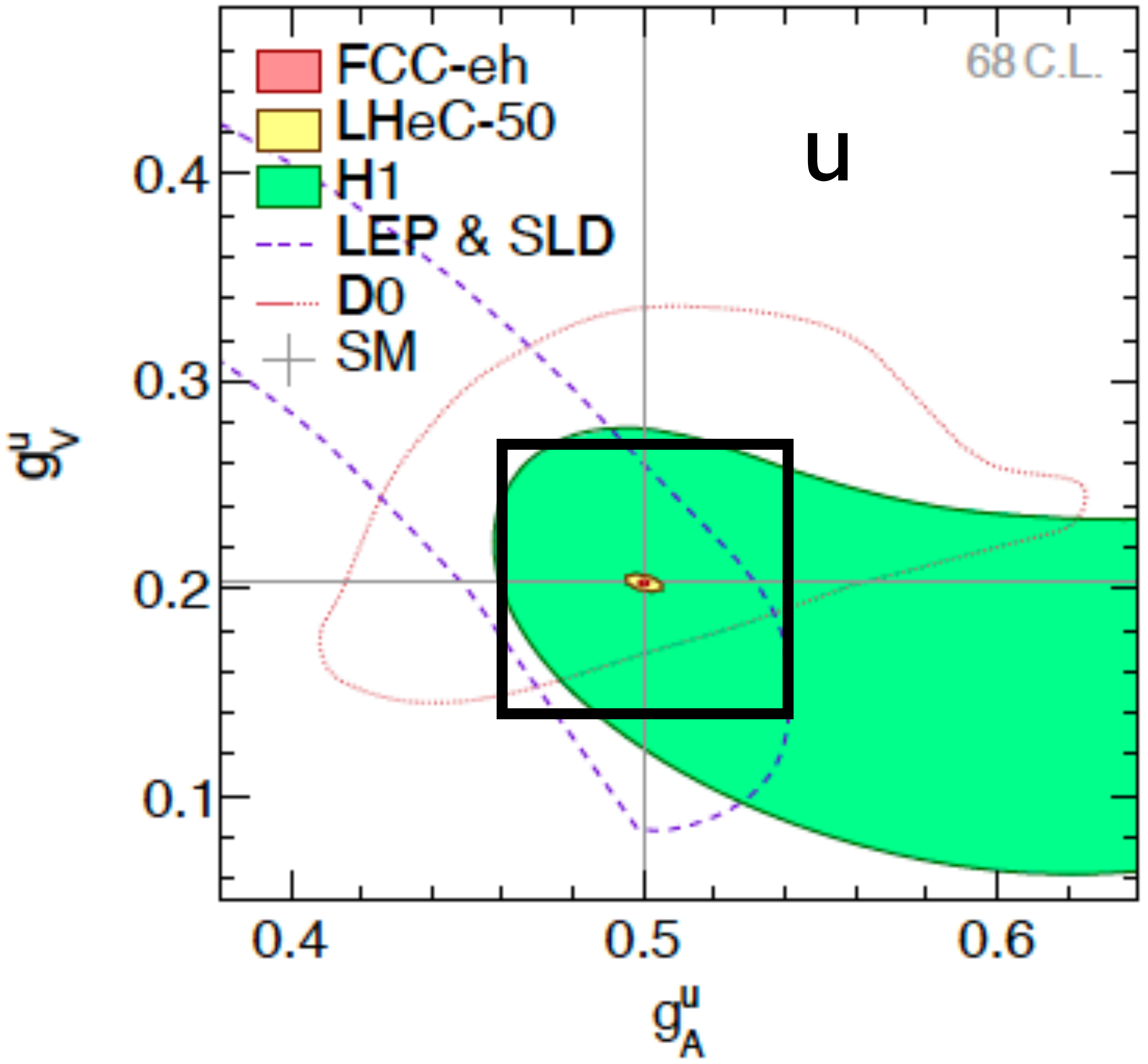

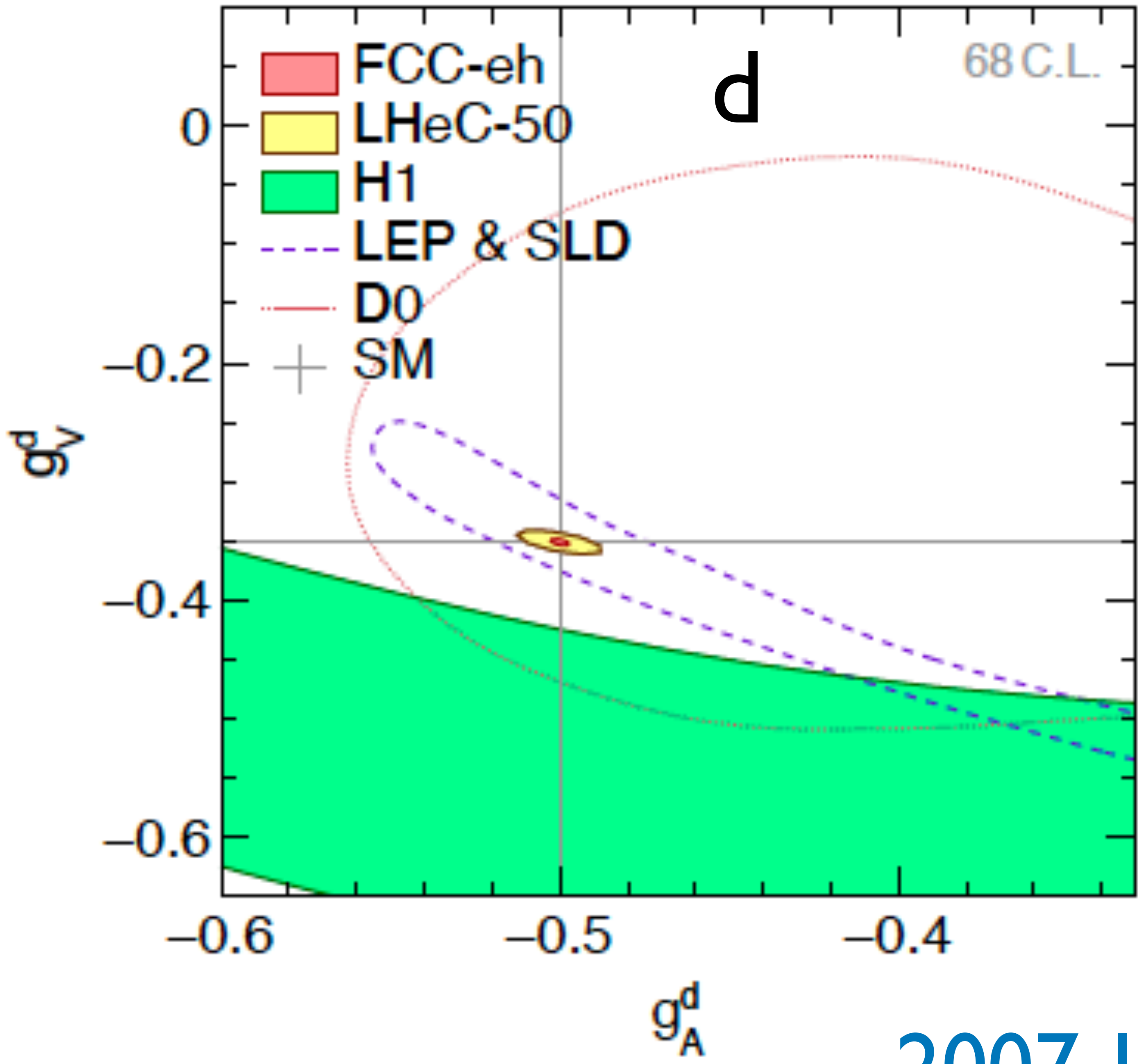

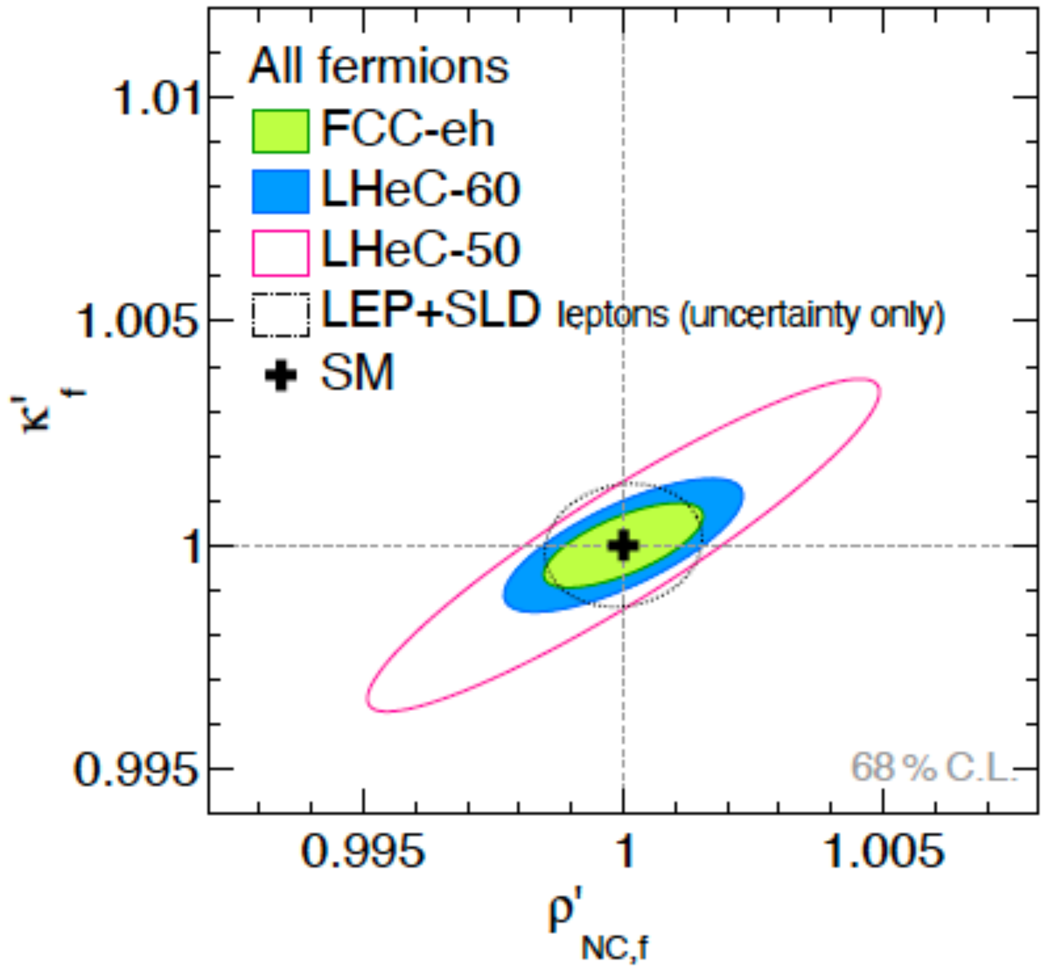

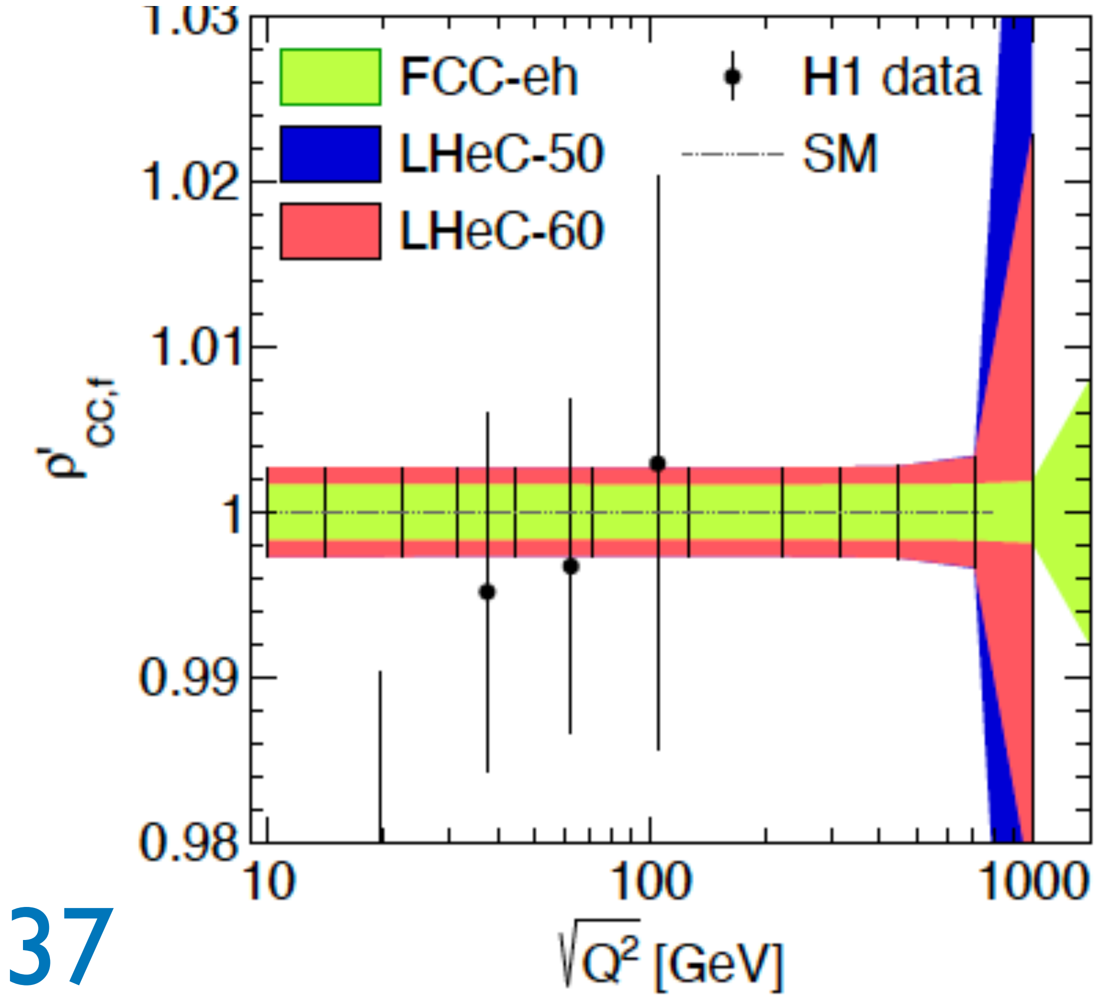

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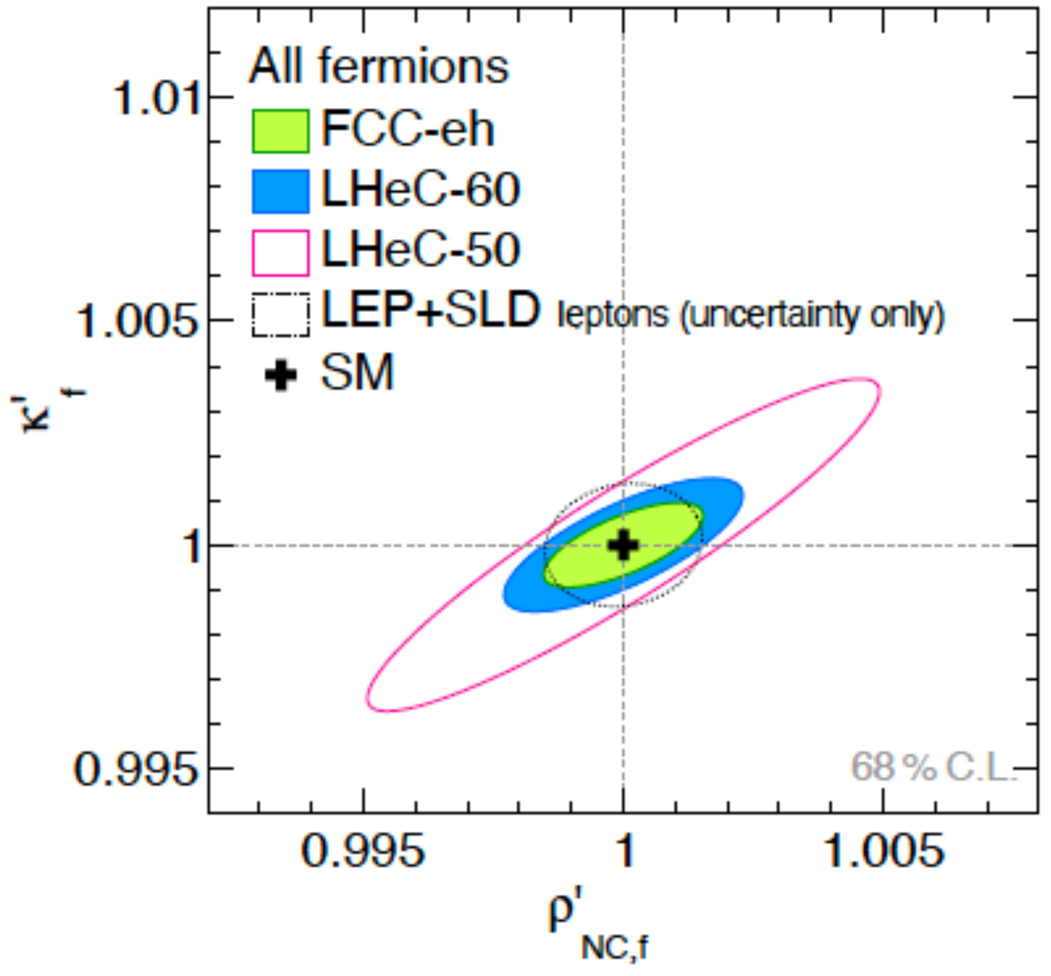

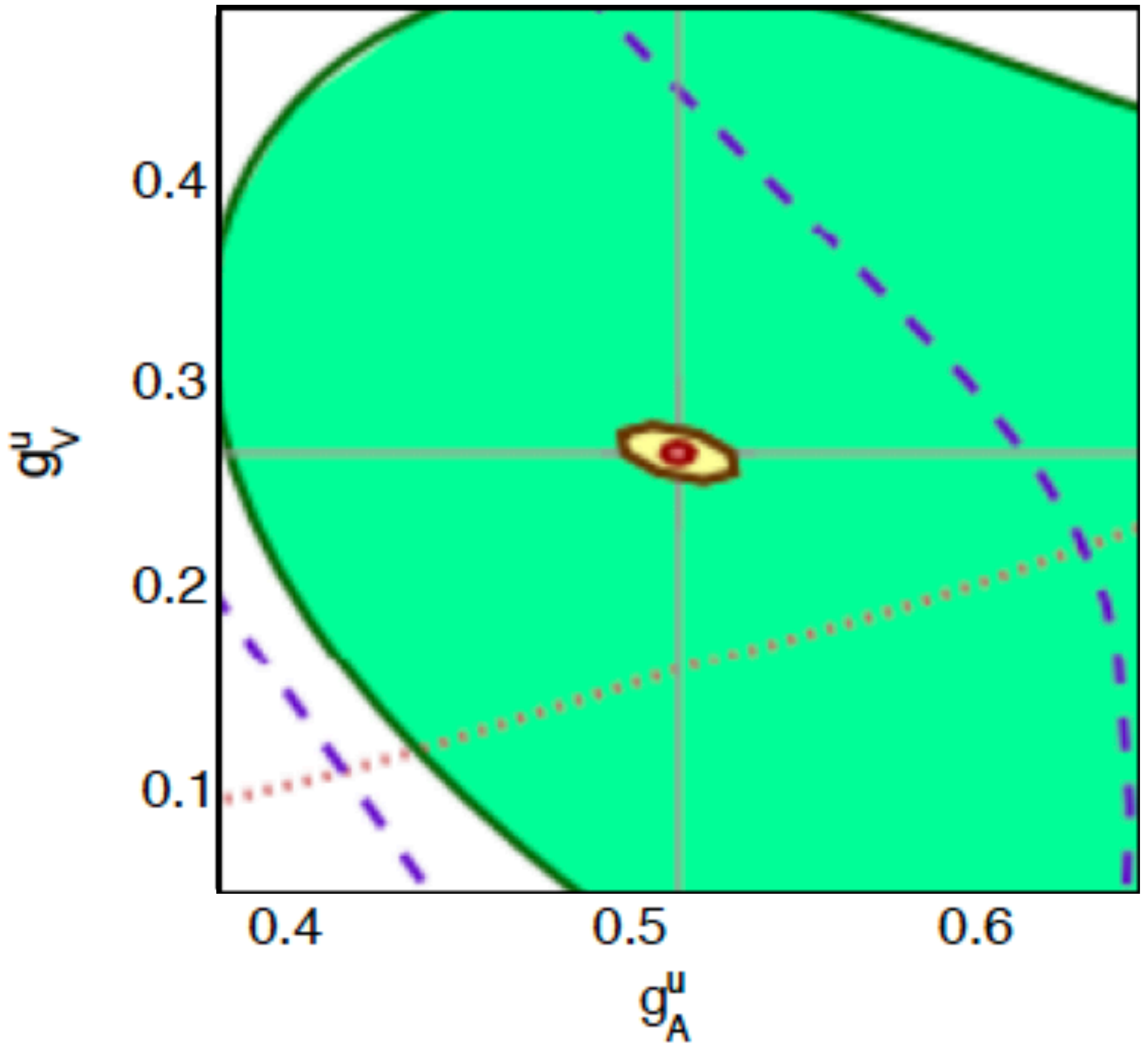

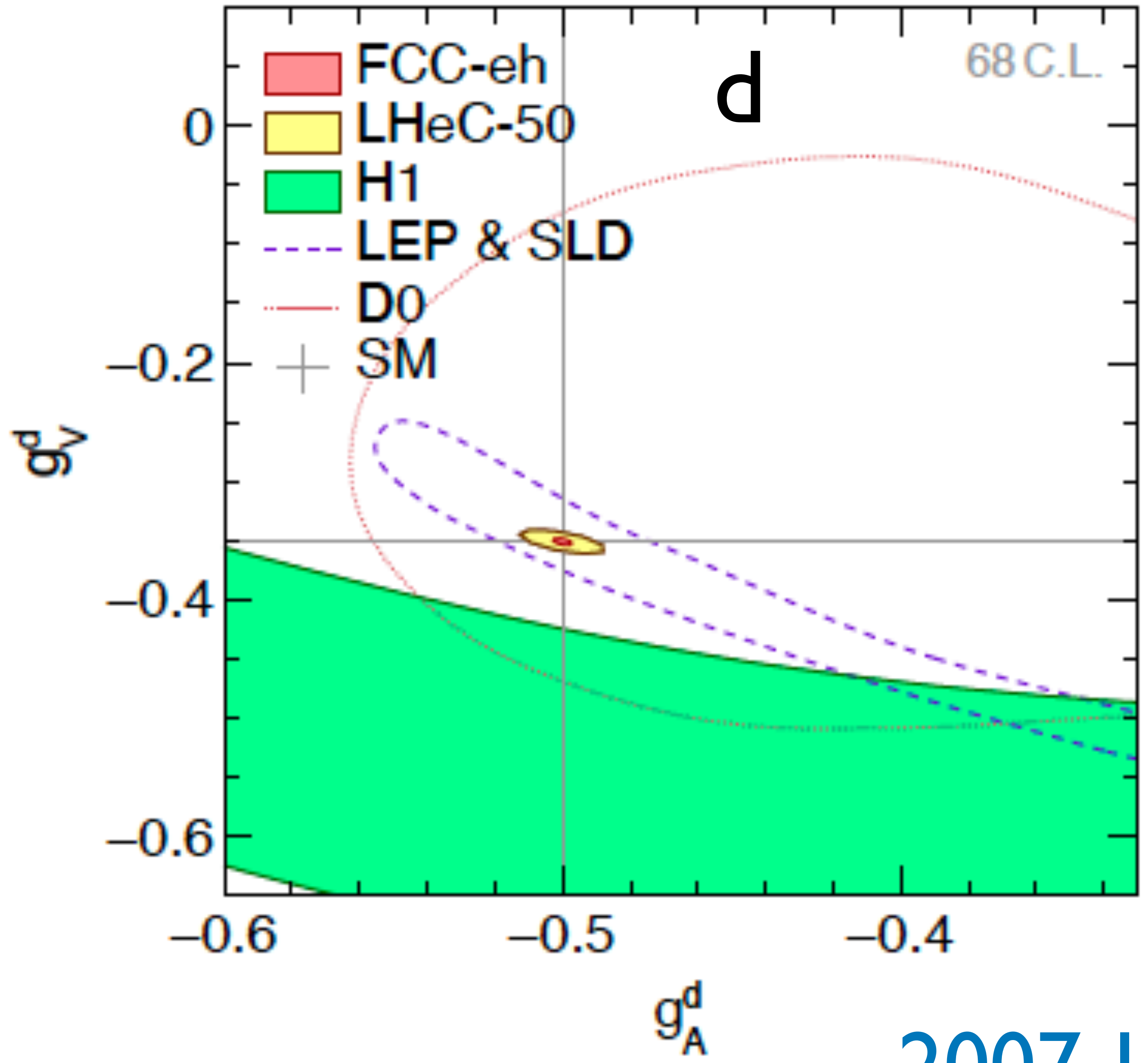

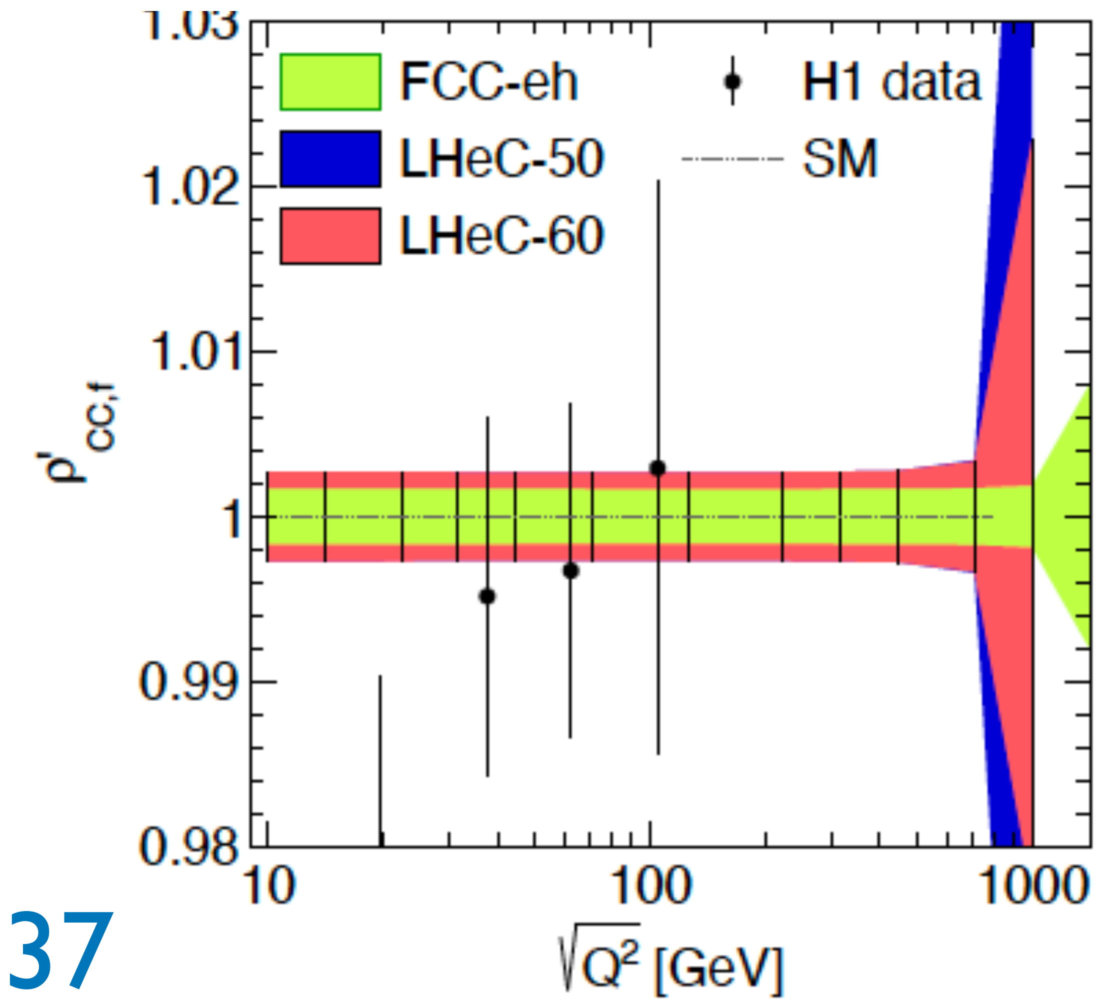

2007.11799, 2203.06237

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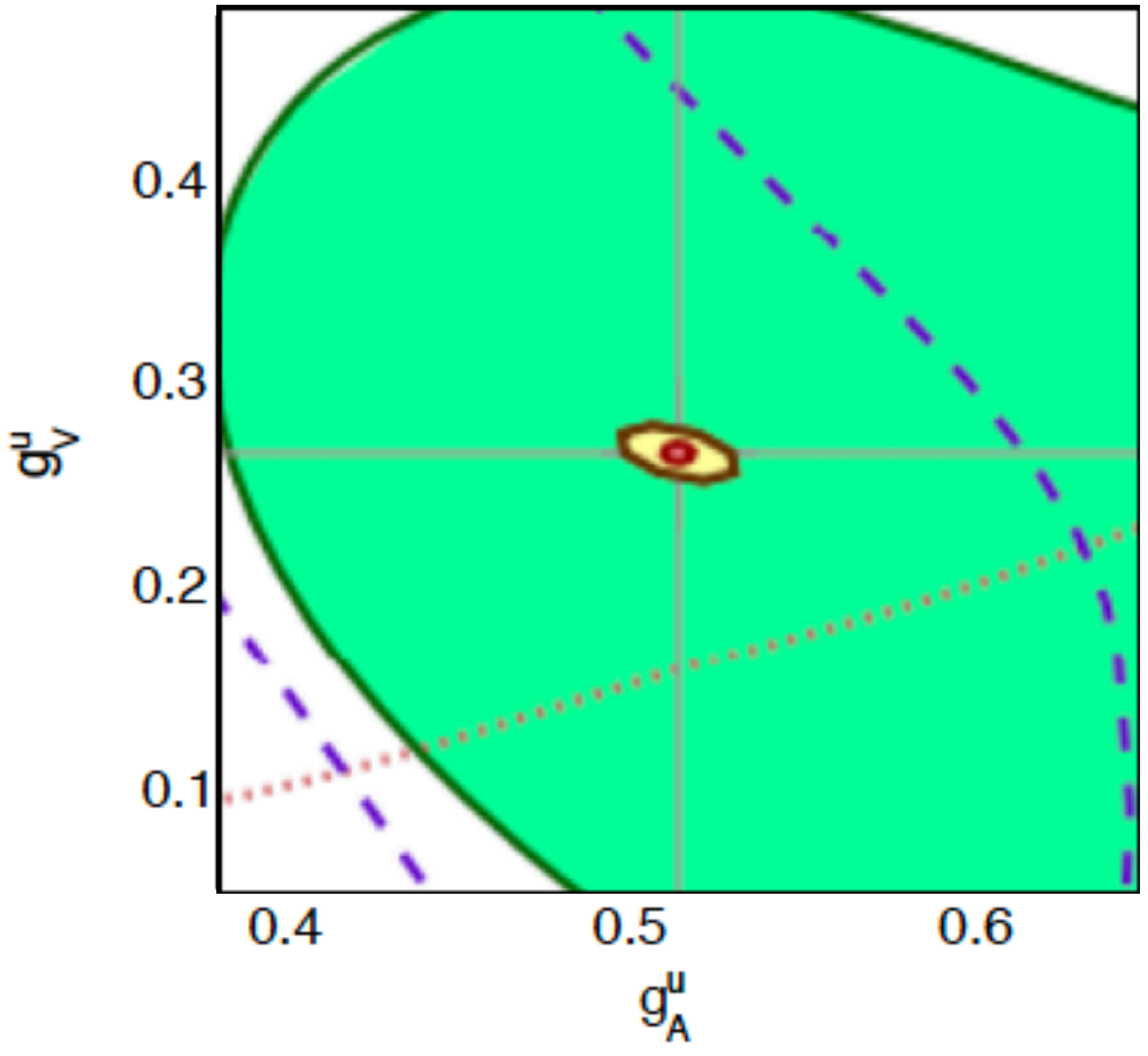
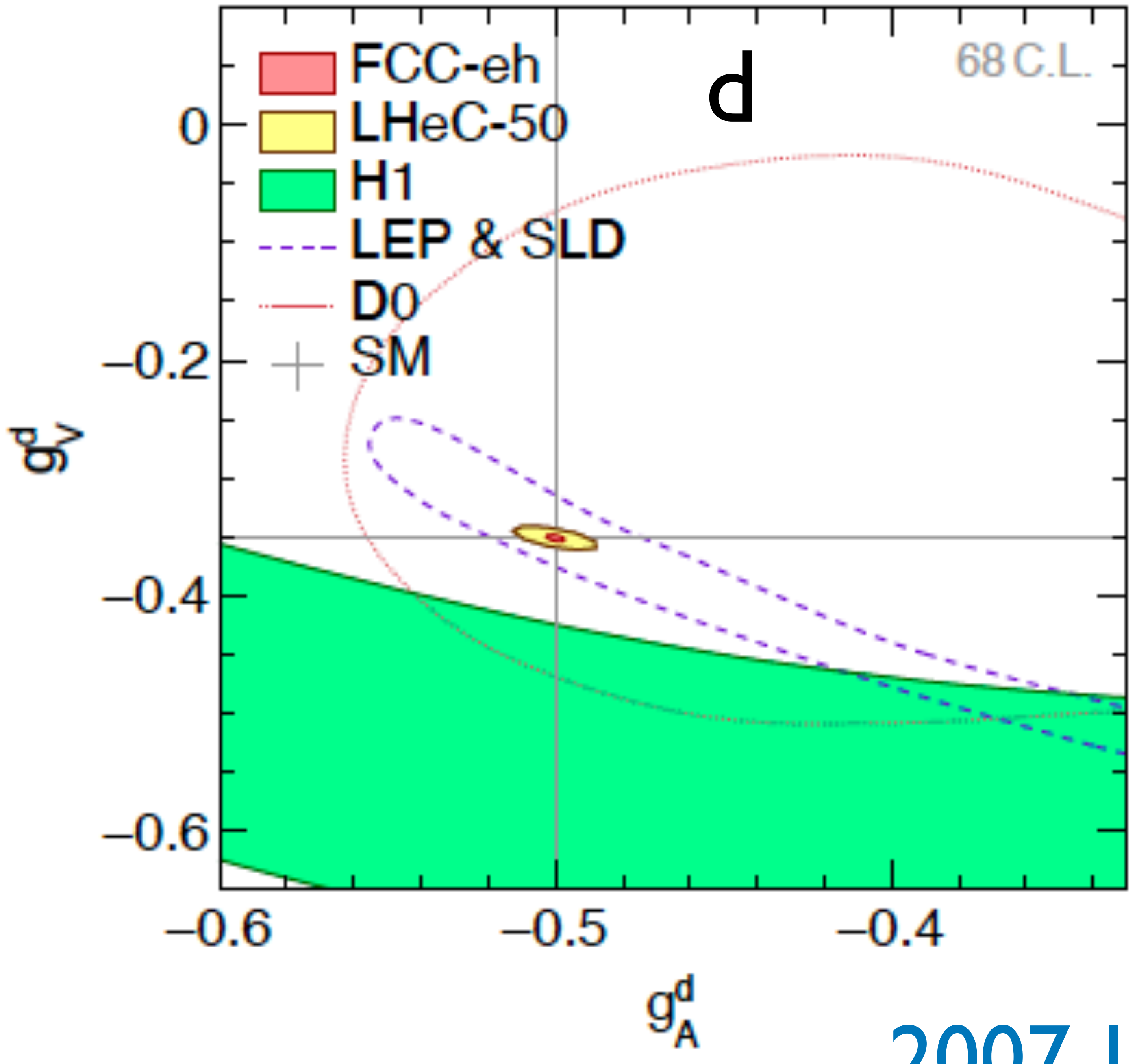
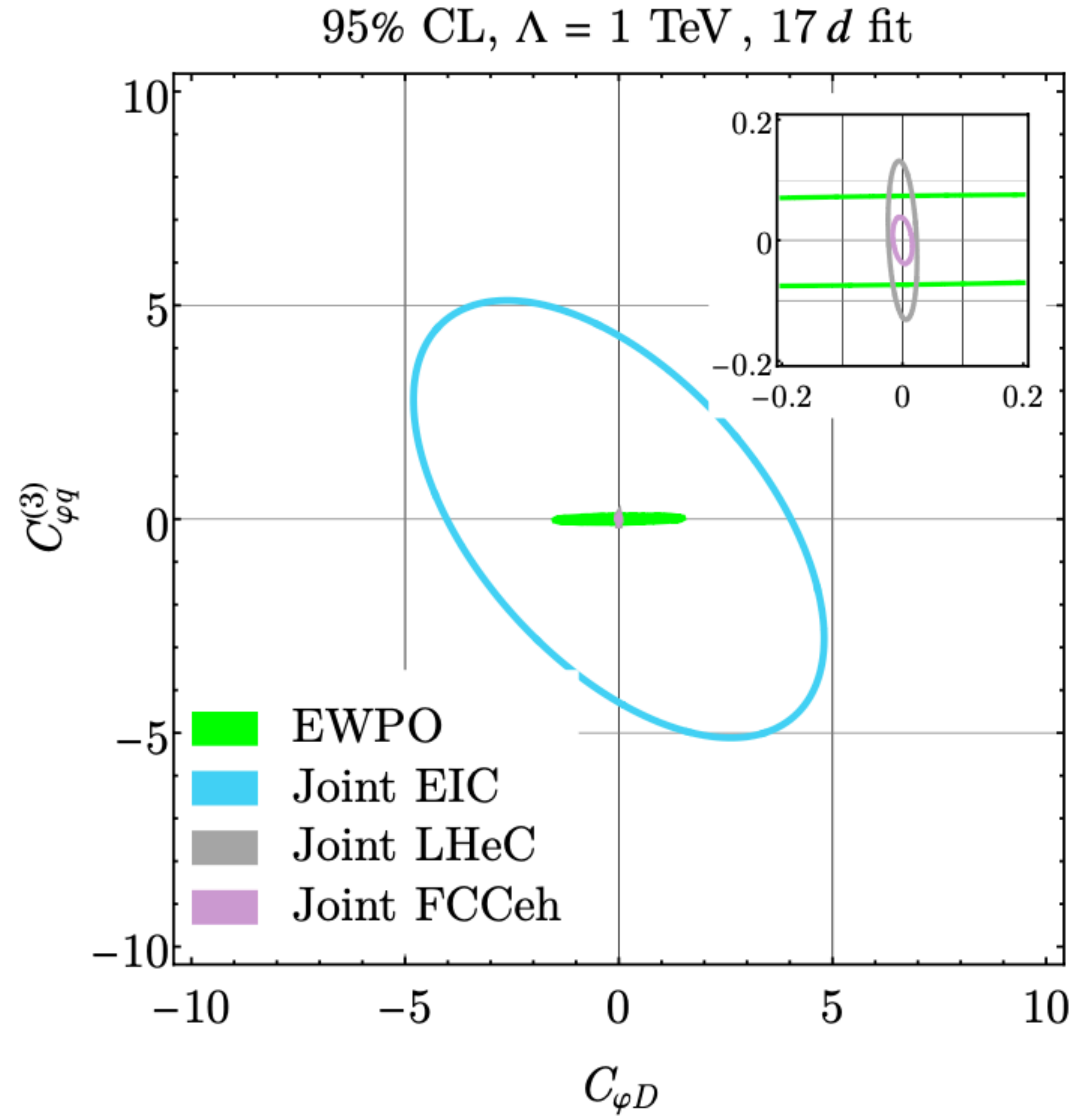
2306.05564

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







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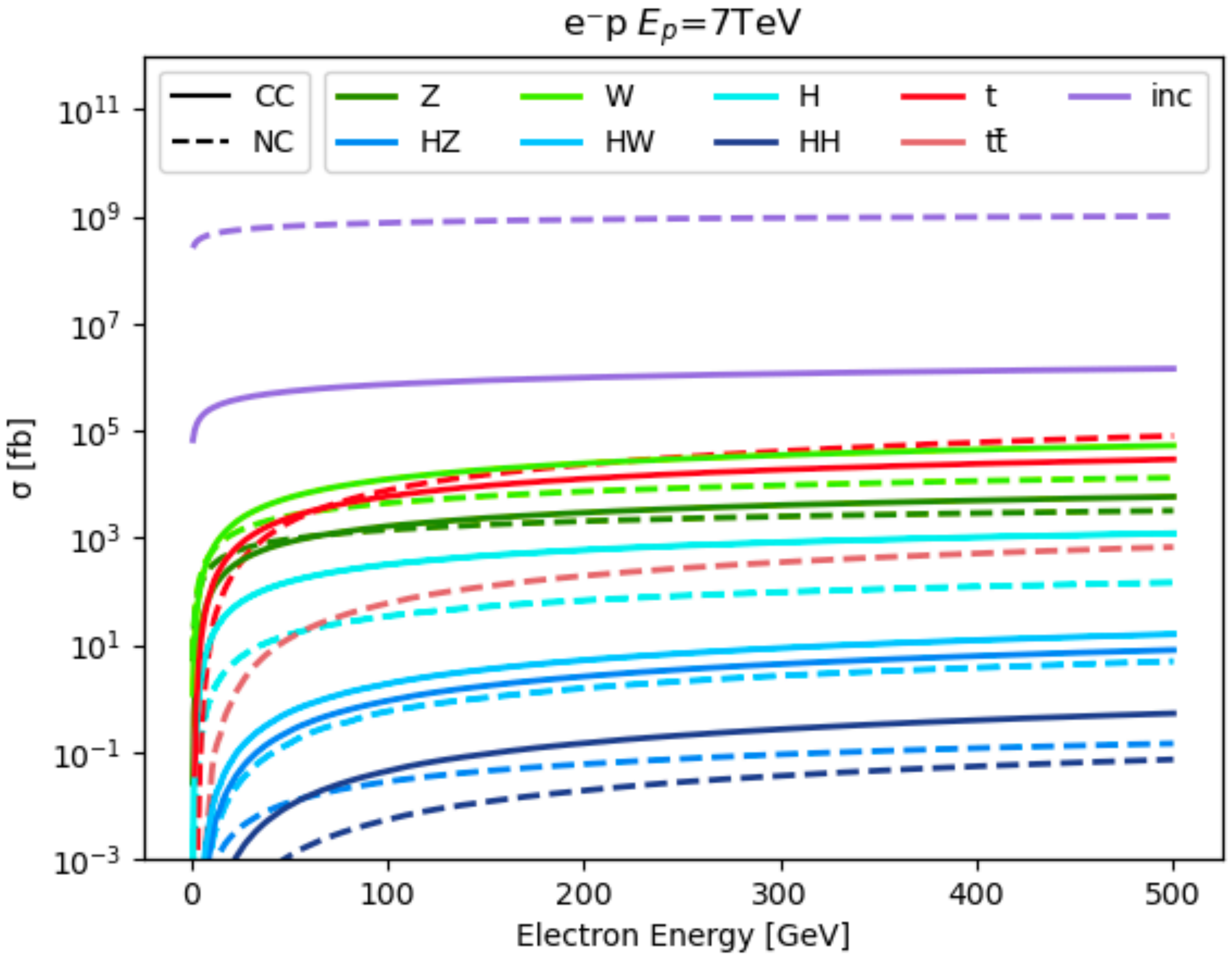
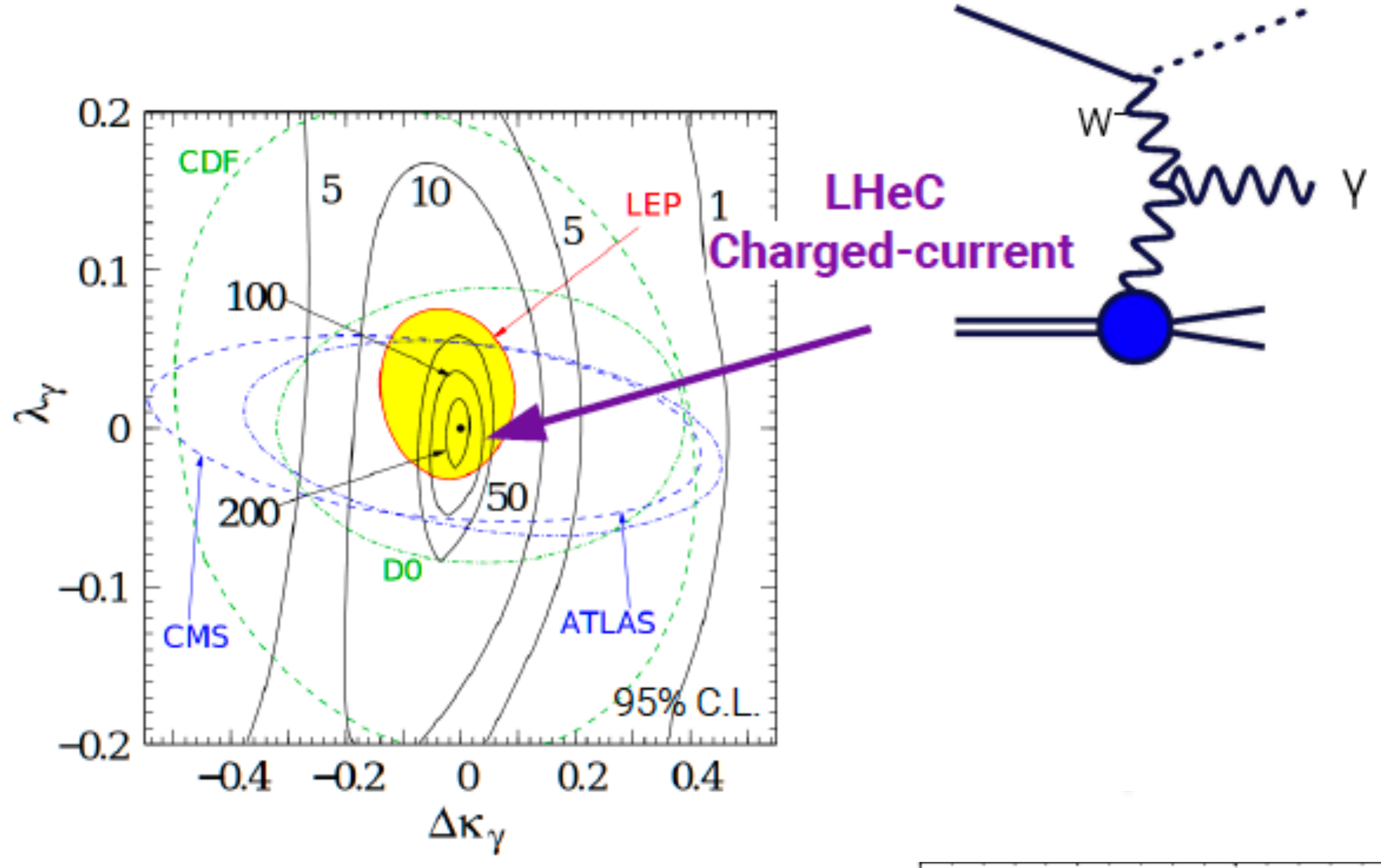
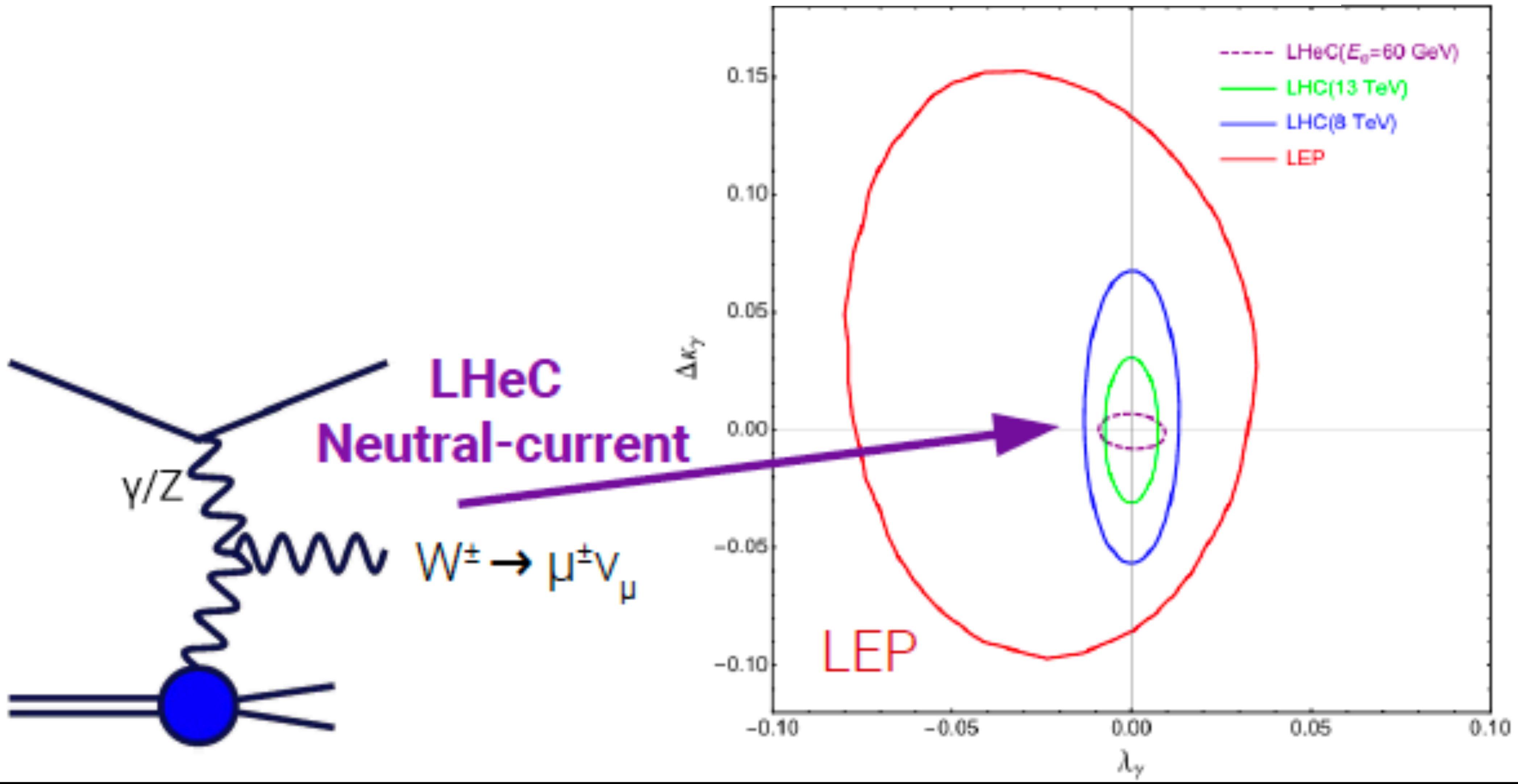
EW physics: triple and quartic gauge couplings

- Triple and quartic gauge couplings can be probed (D. Britzger, EPS-HEP2023) (also in $\gamma\gamma$ mode).

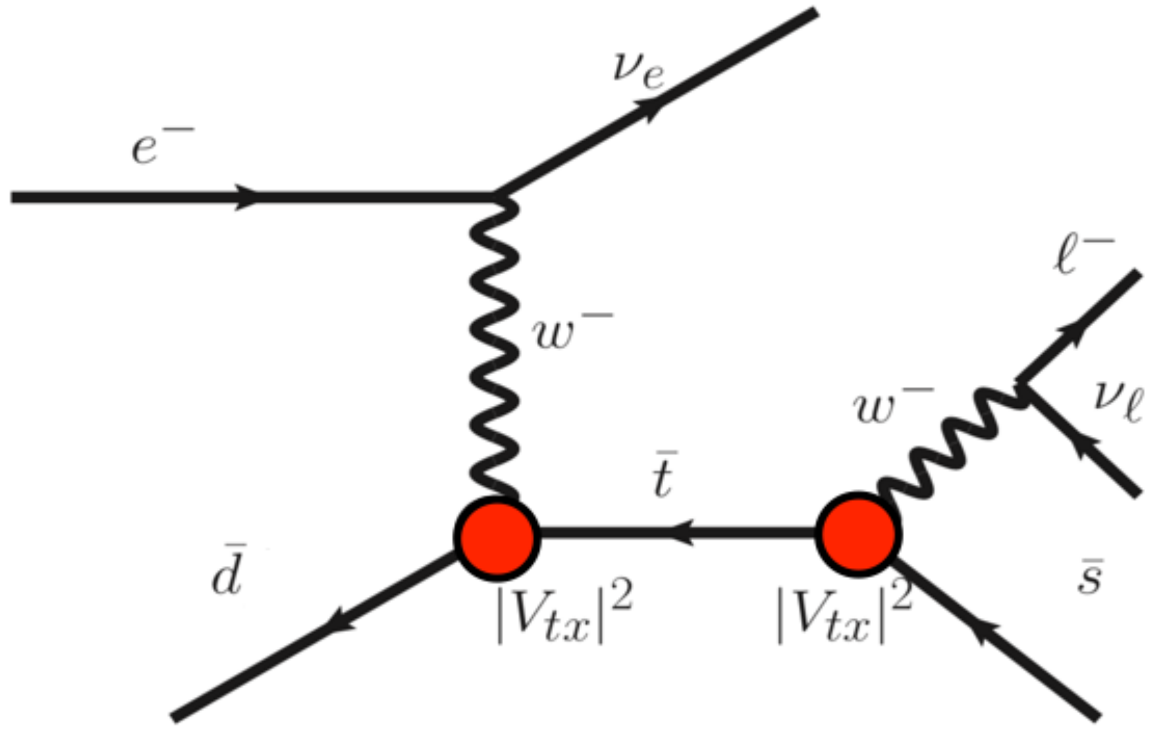




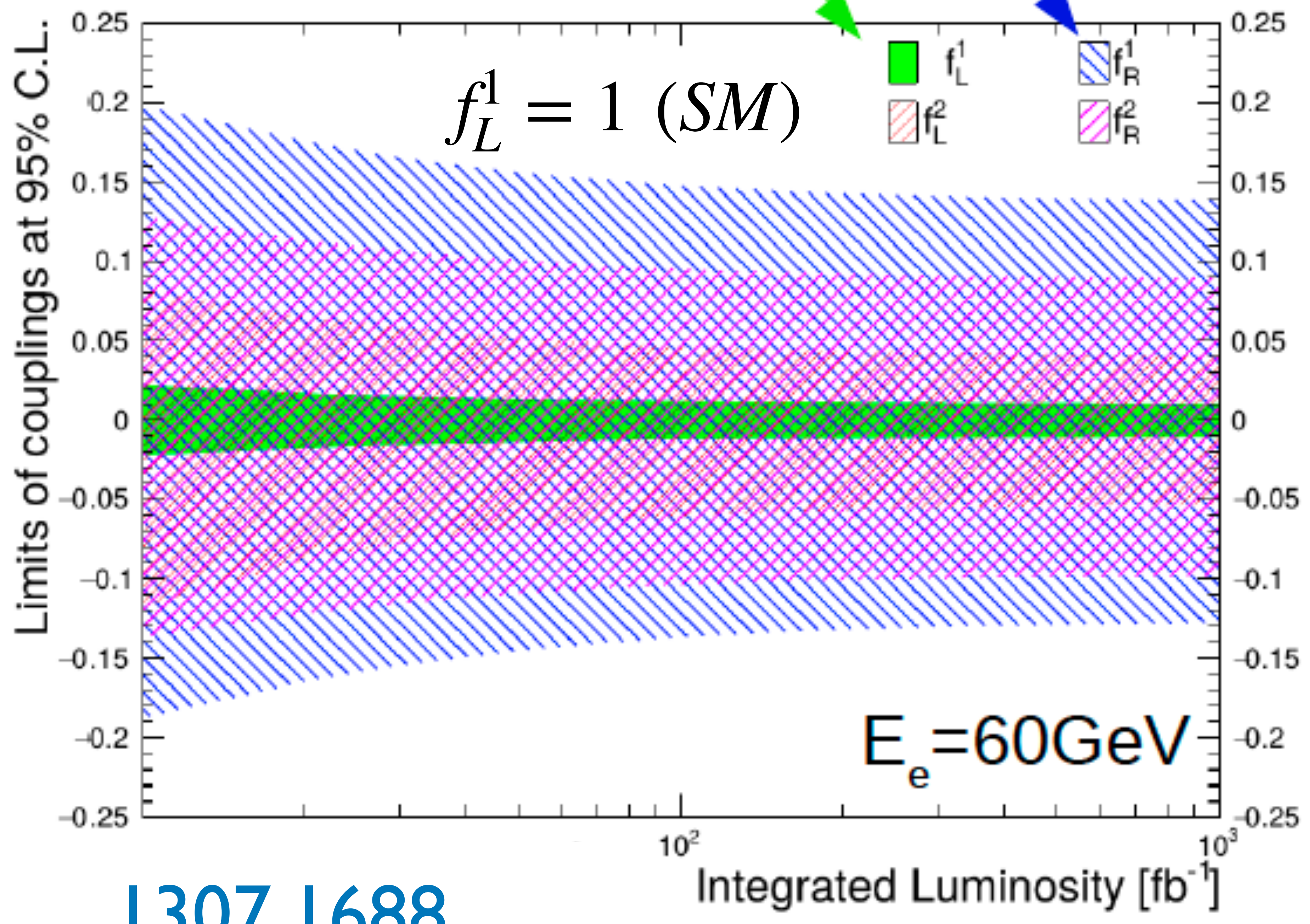


Top physics: anomalous couplings

- Anomalous couplings can be probed, limits competitive with HL-LHC, plus FCNC and CP violation.
- Checks of SM predictions.



$$\mathscr{L}_{Wtb} = \frac{g}{\sqrt{2}}\Big[W_\mu \bar{t}\gamma^\mu (V_{tb}\, f_1^L P_L + f_1^R P_R) b - \frac{1}{2\,m_W} W_{\mu\nu}\bar{t}\sigma^{\mu\nu}(f_2^L P_L + f_2^R P_R) b\Big] + h.c.$$



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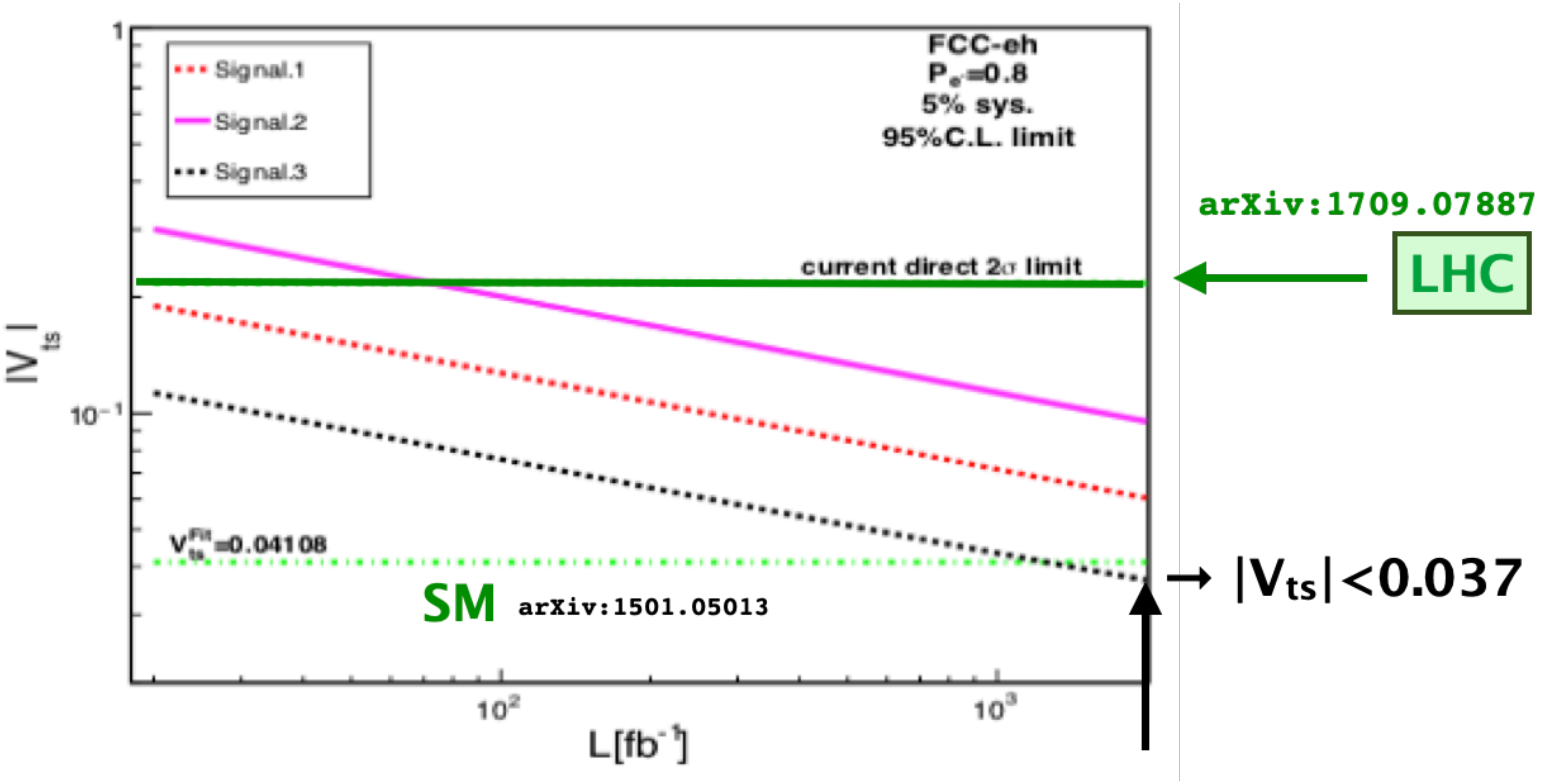
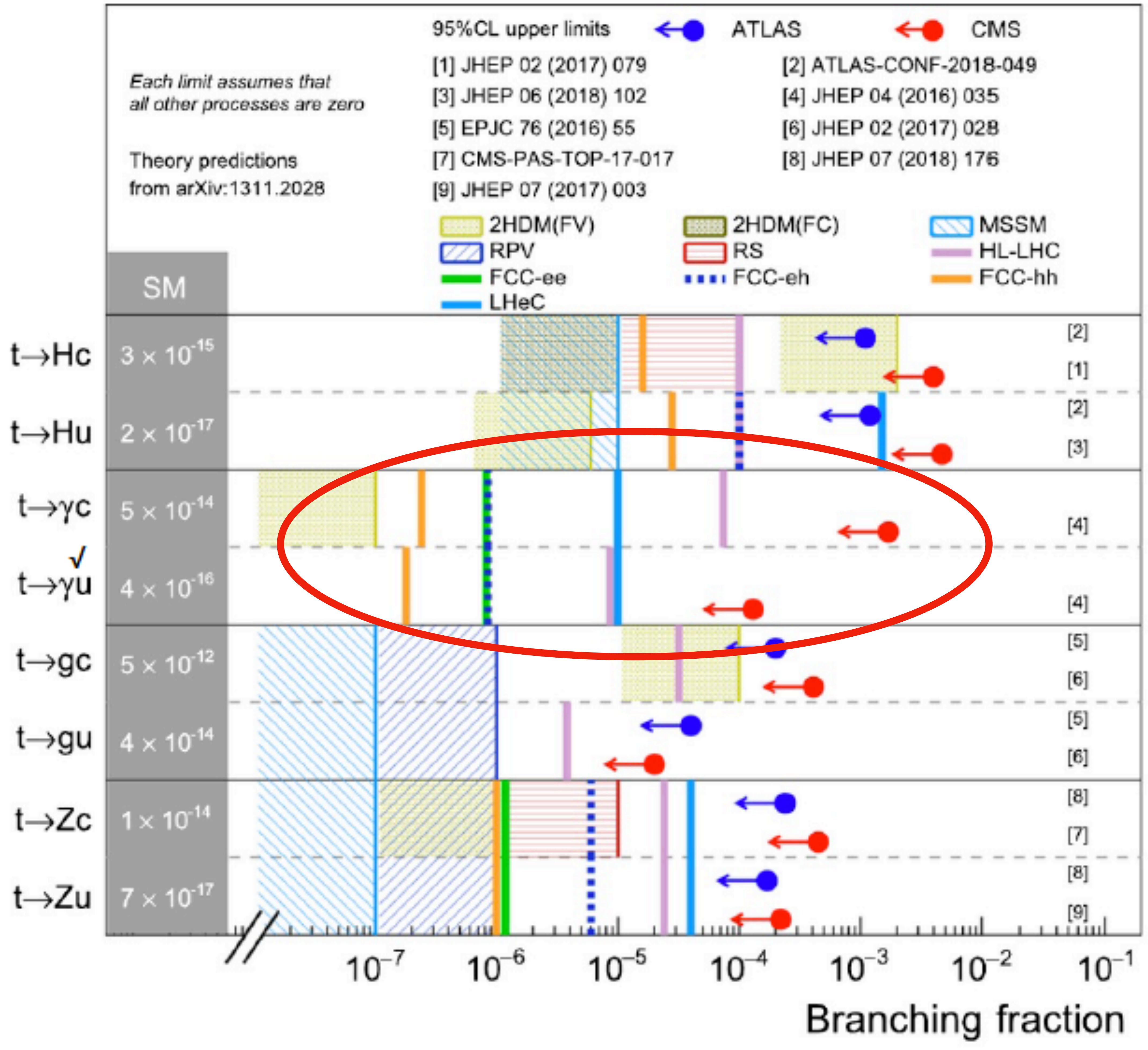
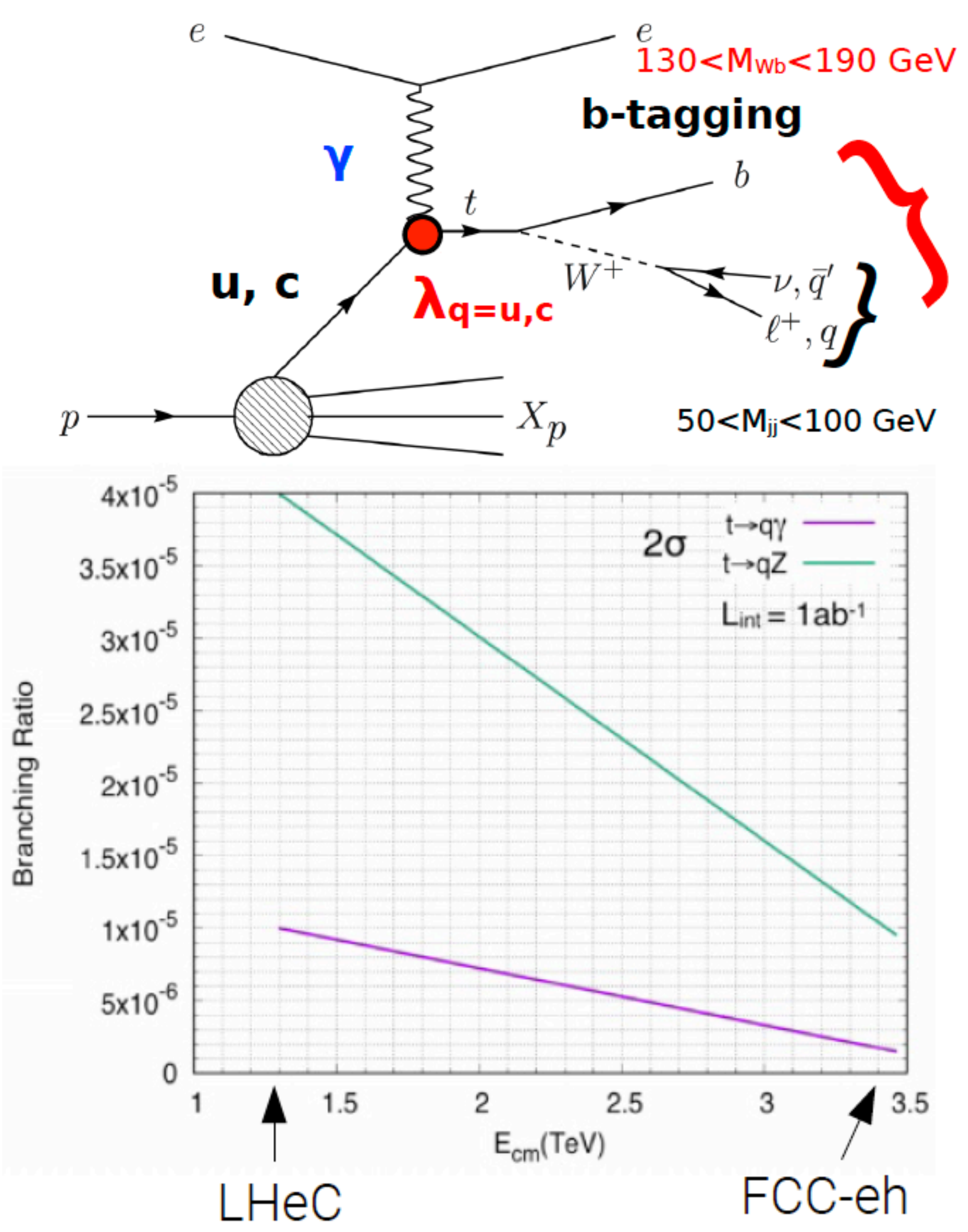


Top physics: FCNC

- Also top FCNC (suppressed in the SM and enhanced through BSM) or CP violation in top Yukawa couplings: competitive/complementary with other machines.



I. Cakir, Yilmaz, Denizli, Senol, Karadeniz, O. Cakir, Adv. High Energy Phys. 2017, 1572053 (2017)



BSM physics:

• ep collider is ideal to study common features of electrons and quarks with EW / VBF production, LQ, forward objects, long-lived particles.

• BSM programme at ep aims to:
➜ Explore new and/or challenging scenarios.
➜ Characterize hints for new physics if some excess or deviations from the SM are found at pp colliders.

• Differences and complementarities with pp colliders.

• Some promising aspects:
➜ small background due to absence of QCD interaction between e and p;
➜ very low pileup.

• Some difficult aspects: low production rate for NP processes due to small E_{cm}.

BSM physics: invisible Higgs

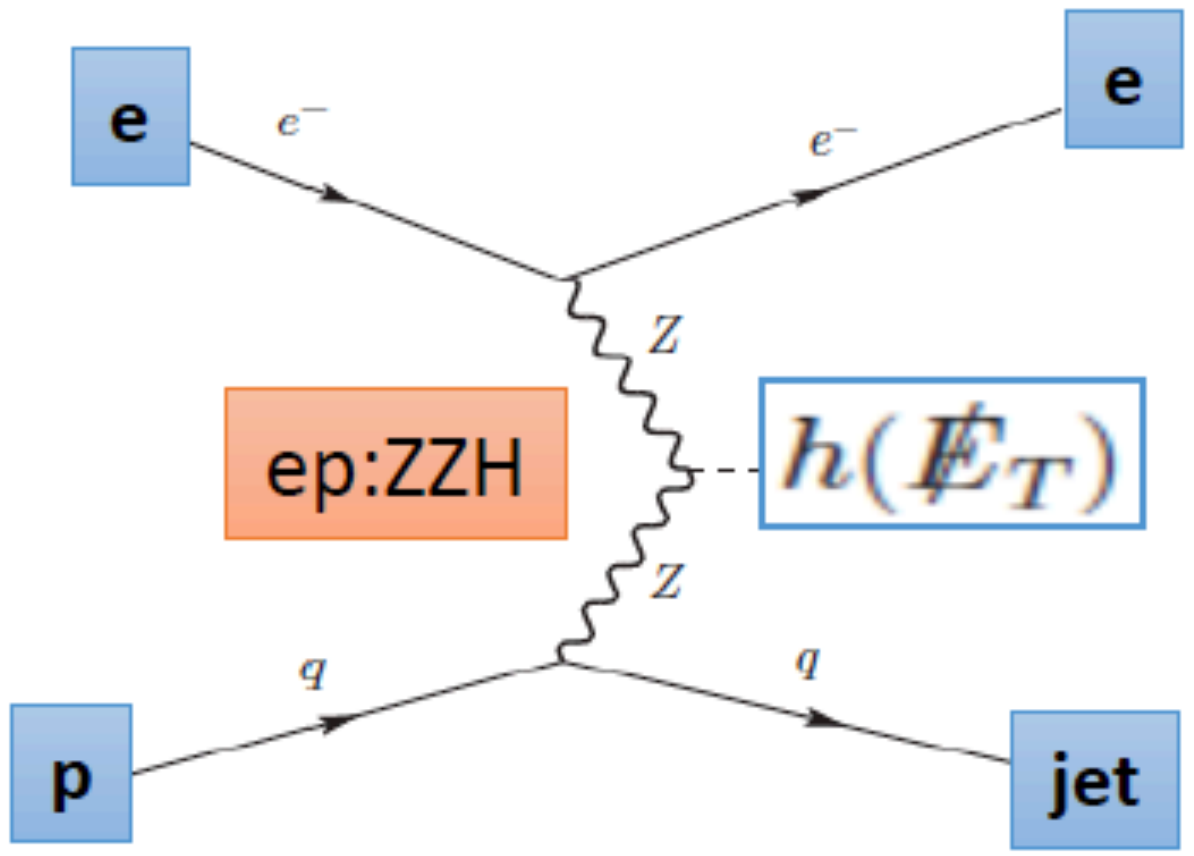
Stand alone Branching for invisible Higgs

Satoshi Kawaguchi,
Masahiro Kuze
Tokyo Tech

Values given in case of 2σ and L=1 ab^{-1}

Delphes detectors	LHeC [HE-LHeC] 1.3 [1.8 TeV]	FCC-eh 3.5 TeV
LHC-style	4.7% [3.2%]	1.9%
First 'ep-style'	5.7%	2.6%
+BDT Optimisation	5.5% (4.5%*)	1.7% (2.1%*)

LHeC parton-level, cut based <6% [Y.-L.Tang et al. arXiv: 1508.01095]



PORTAL to Dark Matter ?

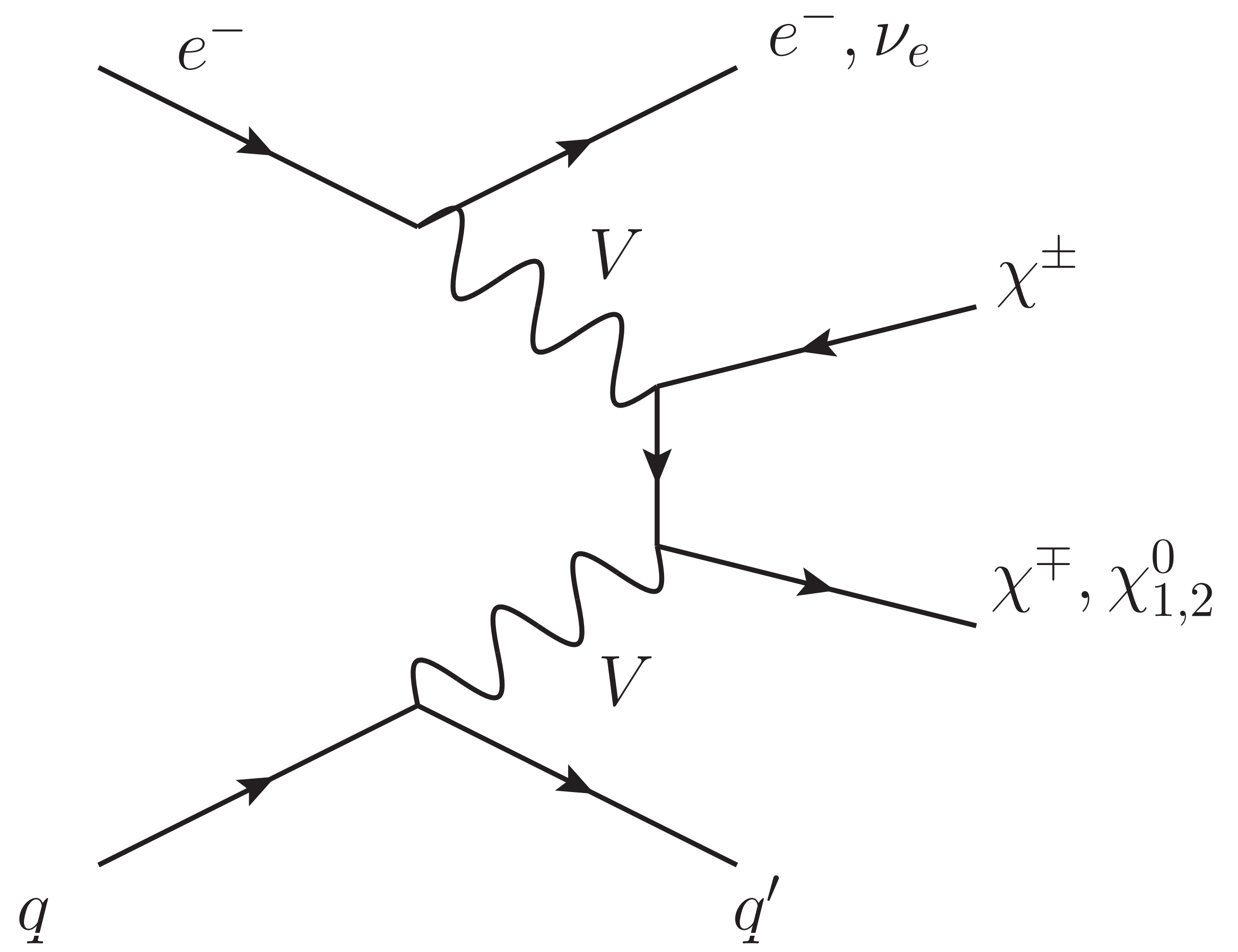
Uta Klein at LHeC/FCC-eh/PERLE workshop 2022

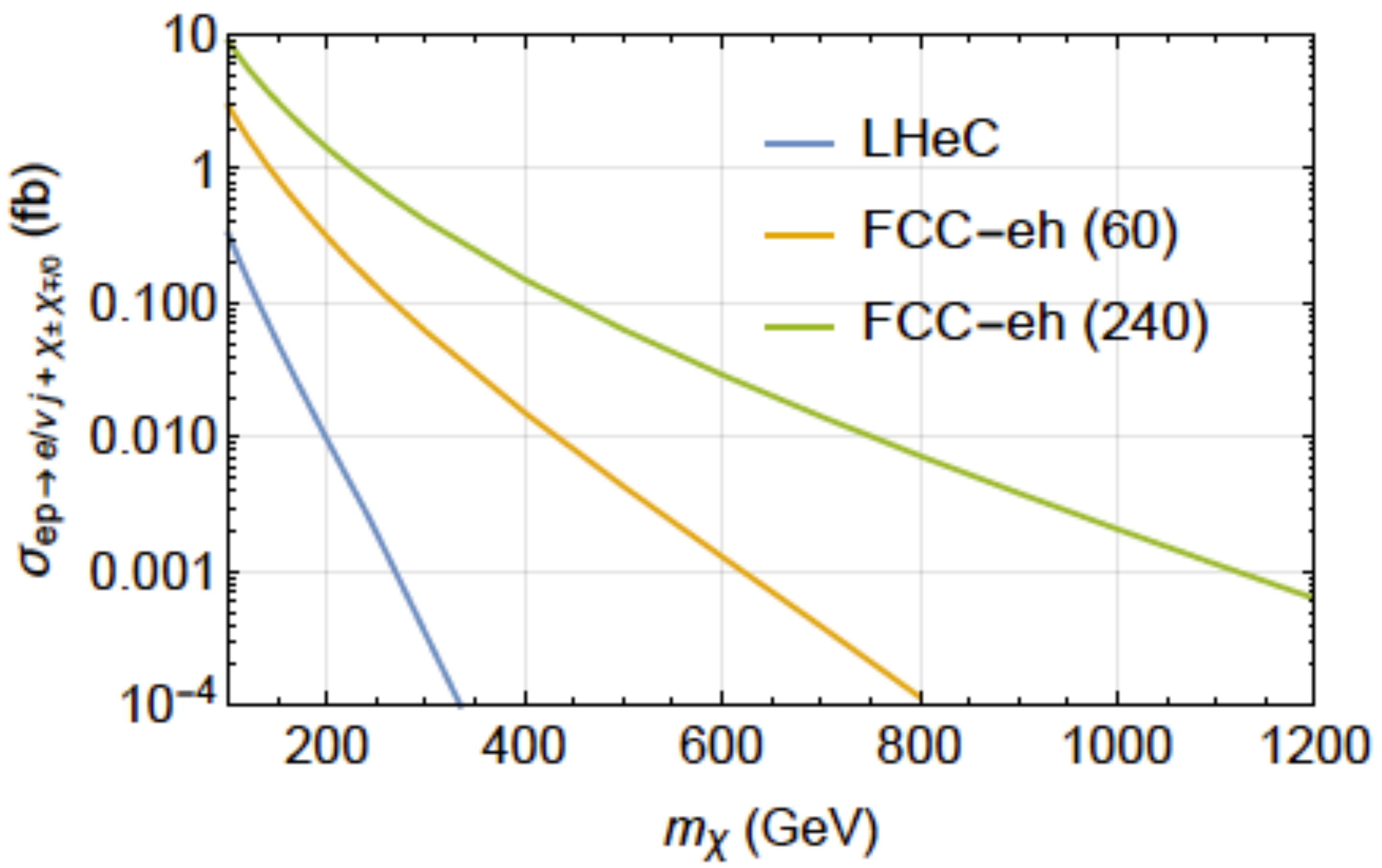
- ✓ **Uses ZZH fusion process to estimate prospects of Higgs to invisible decay using *standard cut/BDT analysis techniques focused on a stand alone determination***
- ✓ **Full MG5+Delphes analyses, done for 3 c.m.s. energies → very encouraging for a measurement of the branching of Higgs to invisible in ep down to 5%** [1.2%] **for 1** [2] **ab^{-1} for LHeC** [FCC-eh]

- Sub-percent branching ratios H → 2 scalar LLP can be tested (2008.09614).

BSM physics: disappearing tracks

- Searches for Higgsinos with masses $\mathcal{O}(100)$ GeV appearing in natural SUSY theories, through disappearing tracks.





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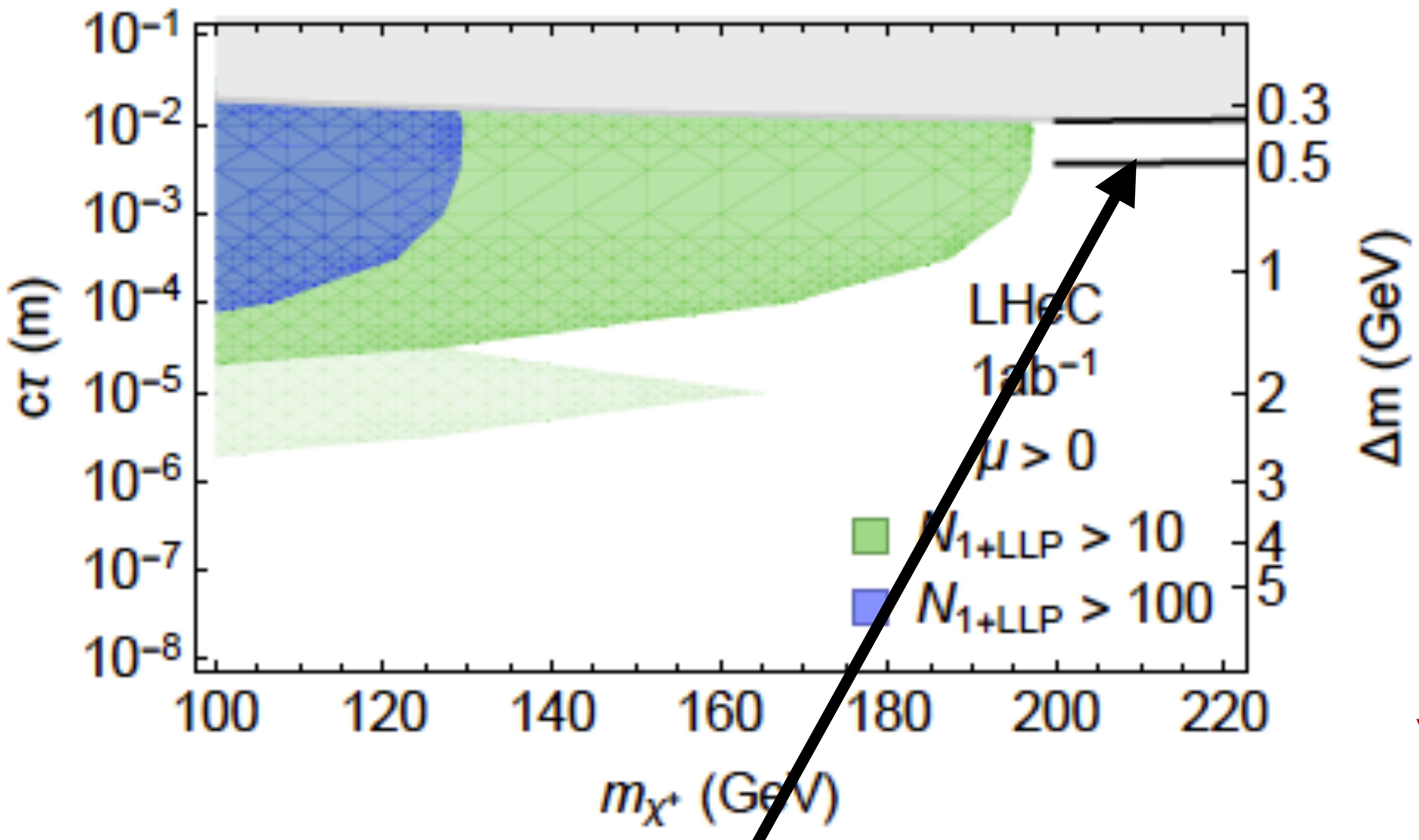
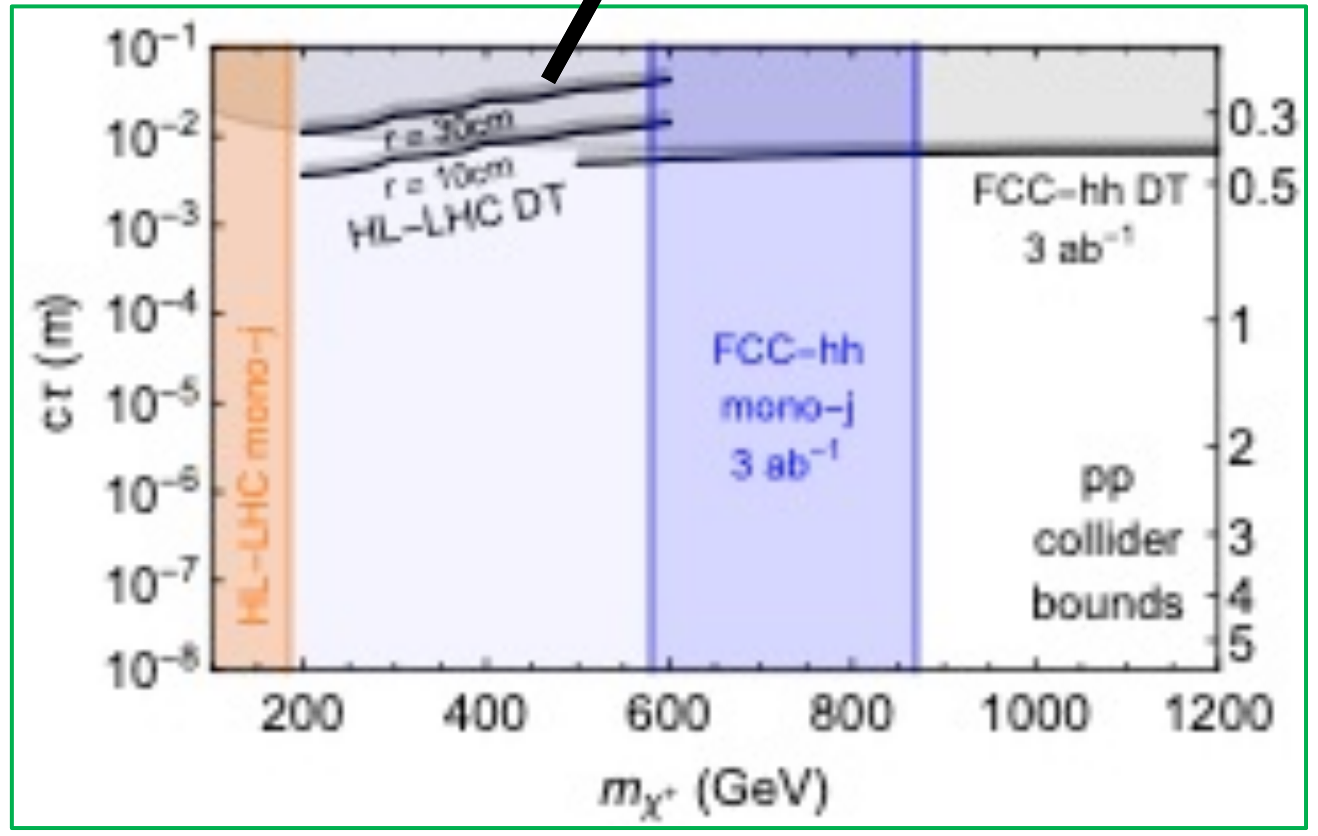




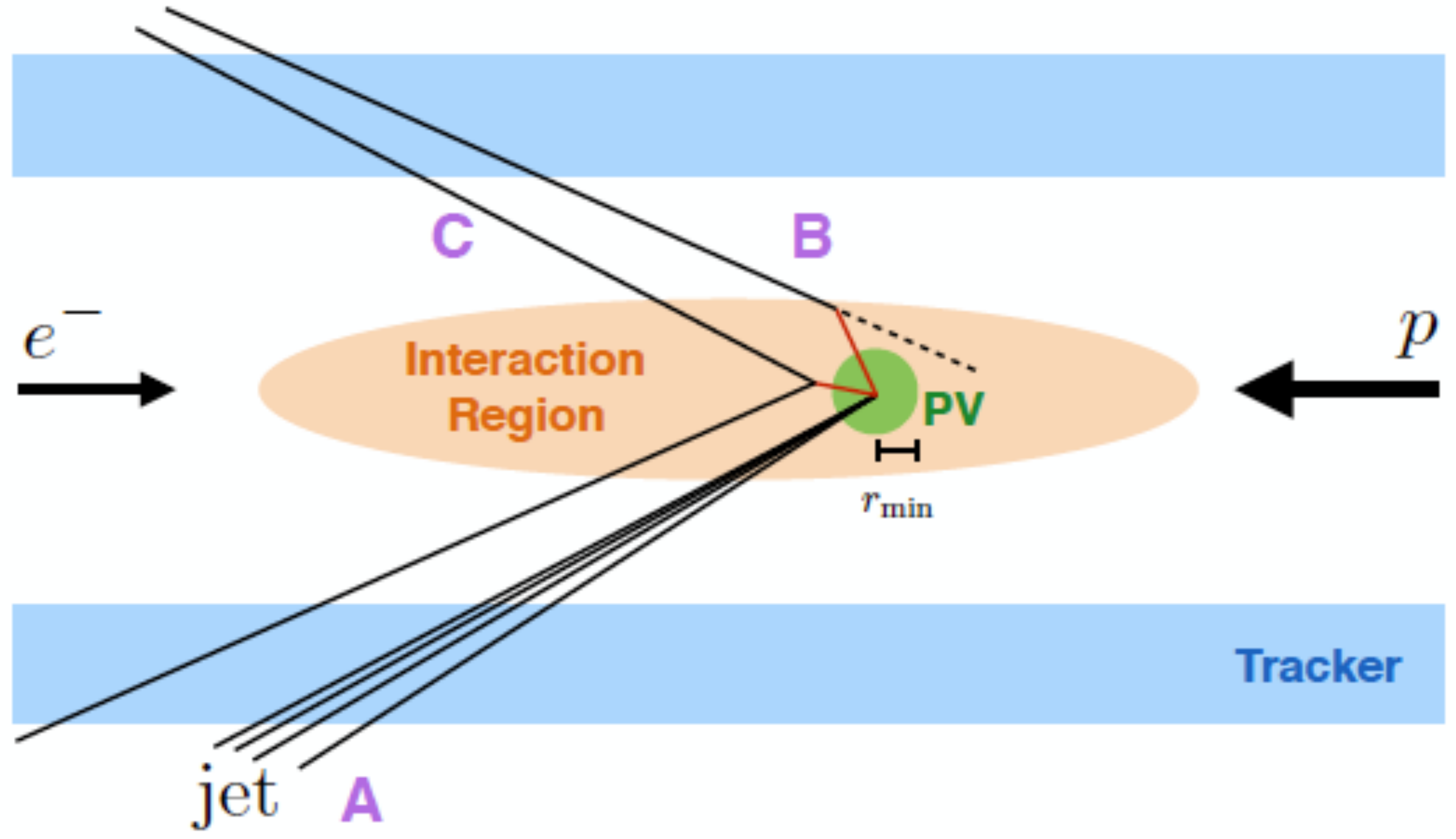
green (blue) region: 2σ sensitivity estimate in the presence of τ backgrounds; 10 (100) events with LLP observed.

- Larger sensitivity to very short lifetimes than pp colliders.

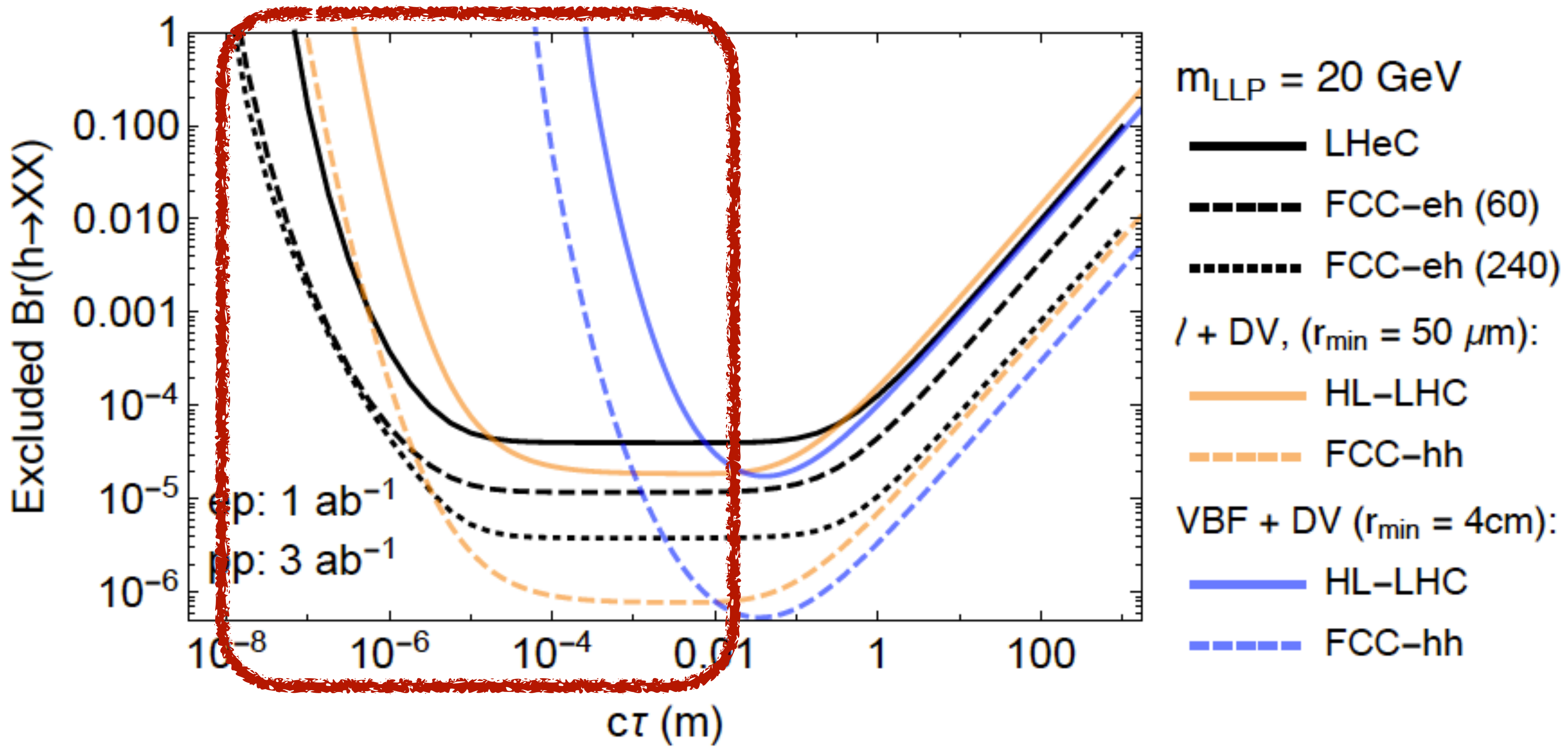
black curves: projected bounds from disappearing track searches for HL-LHC (optimistic and pessimistic)

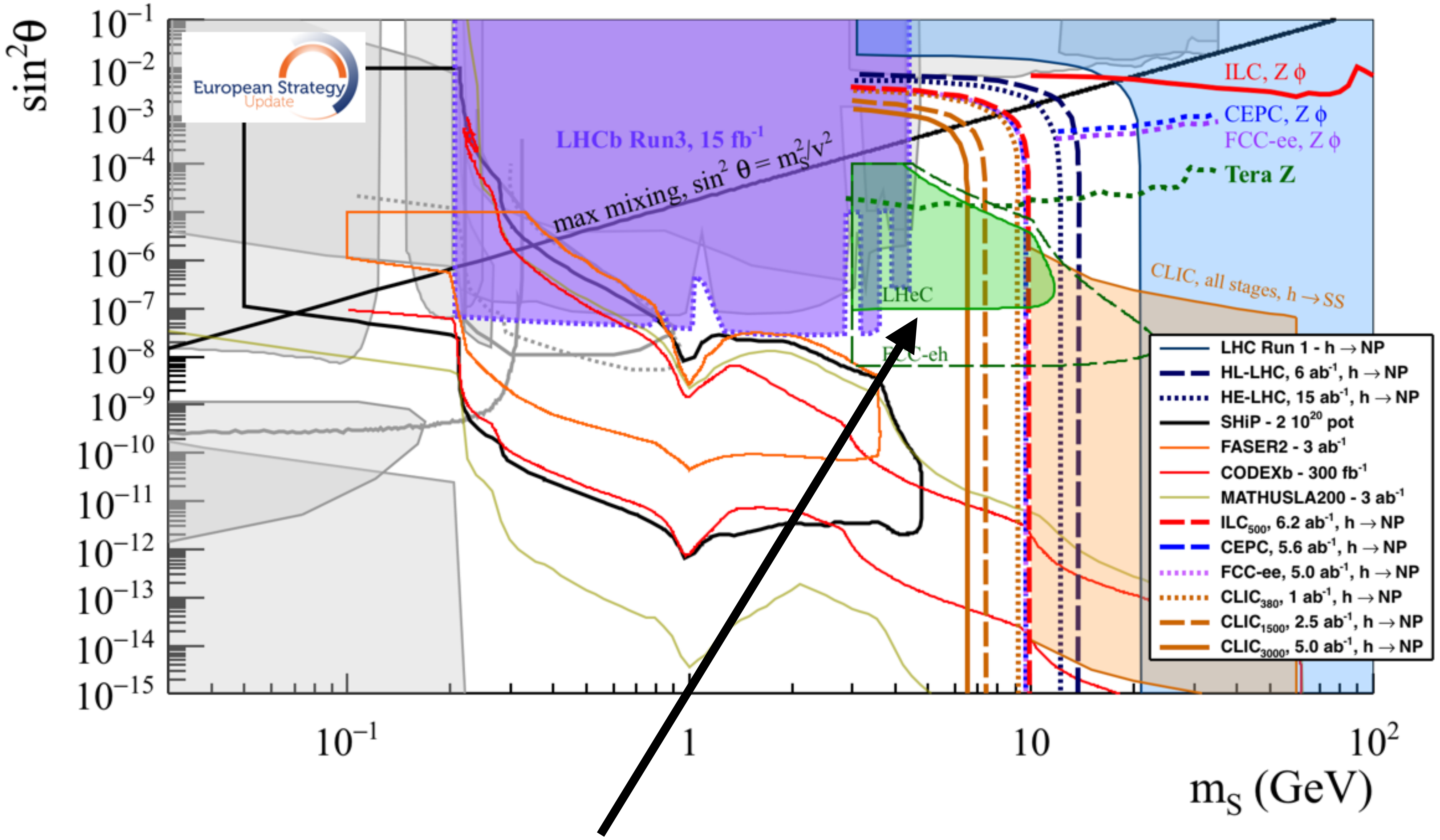
BSM physics: new scalars from Higgs

- New exotic scalars (X) from Higgs decay: displaced signatures if long-lived.
- X → 2+ charged particles above p_T threshold to identify DV and $r>r_{min}$ from PV: LLP.



Improvements wrt HL-LHC

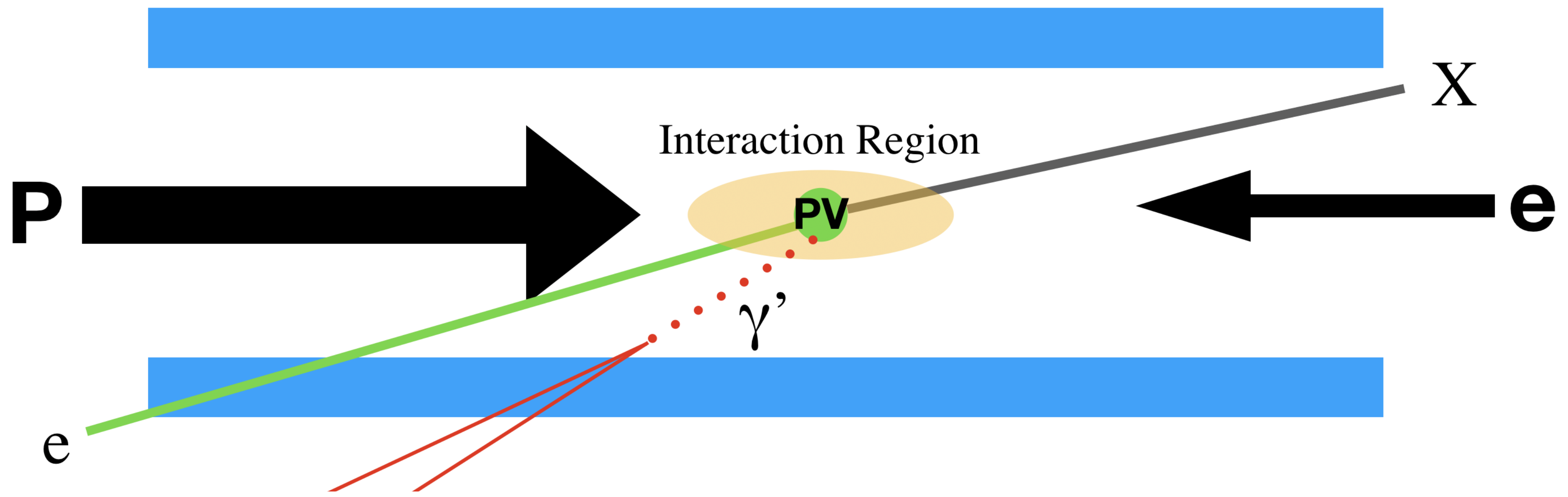


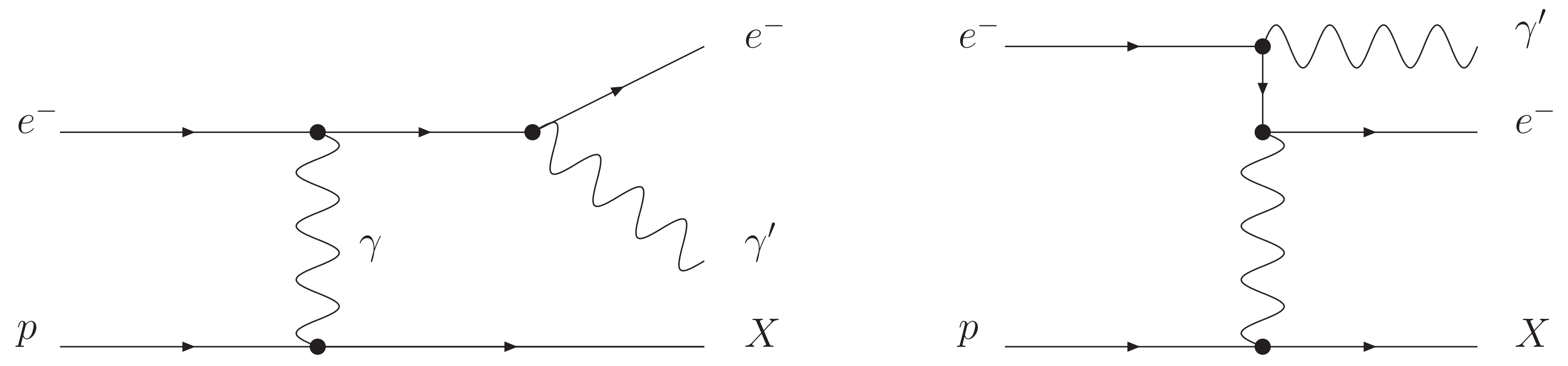


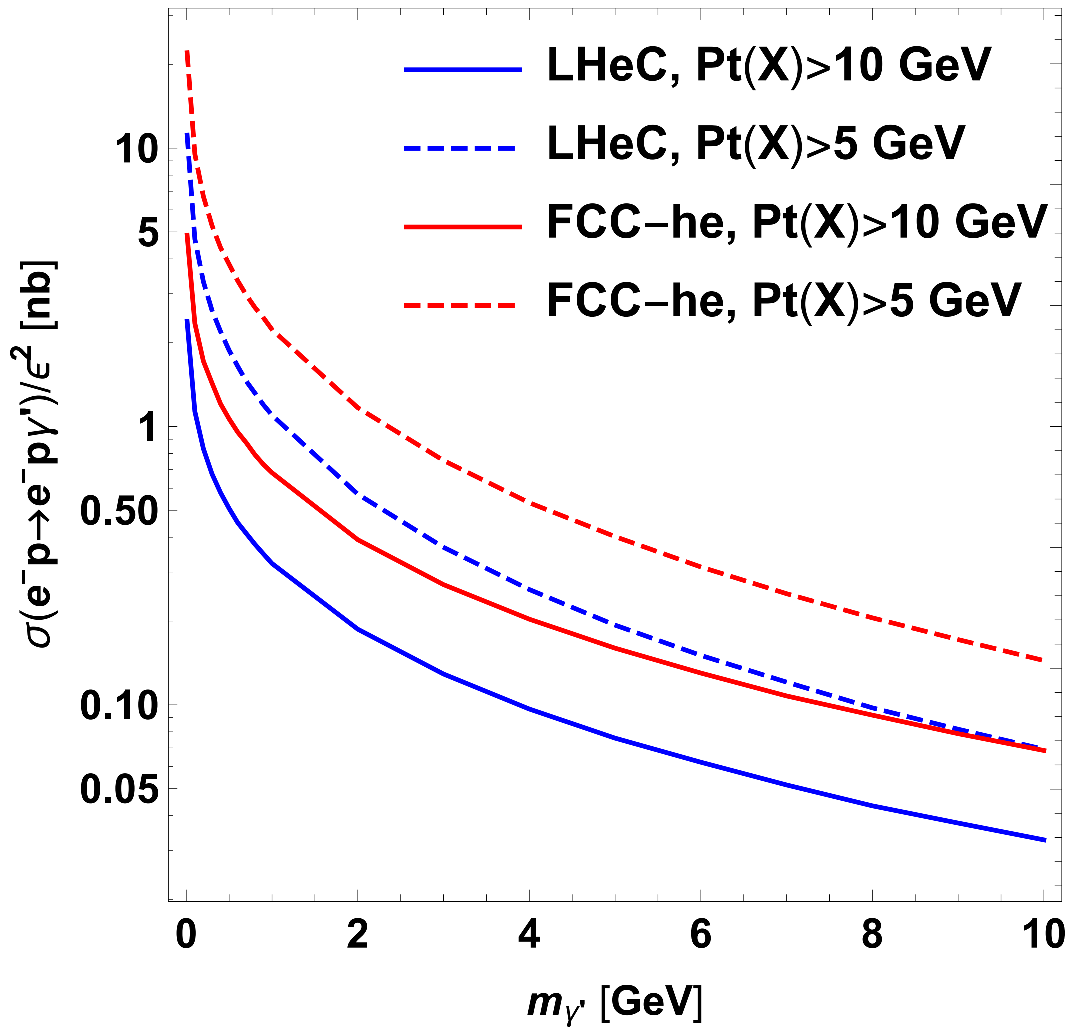
Covering regions between pp and e^+e^- / low energy experiments

BSM physics: dark photons

- Additional gauge boson mixed with the $U(1)_Y$ SM factor kinetically.
- Masses $\mathcal{O}(1)$ GeV, QED-like interactions, small mixing ε.
- Decay to pairs of leptons, hadrons, or quarks, which can give rise to a displaced vertex.

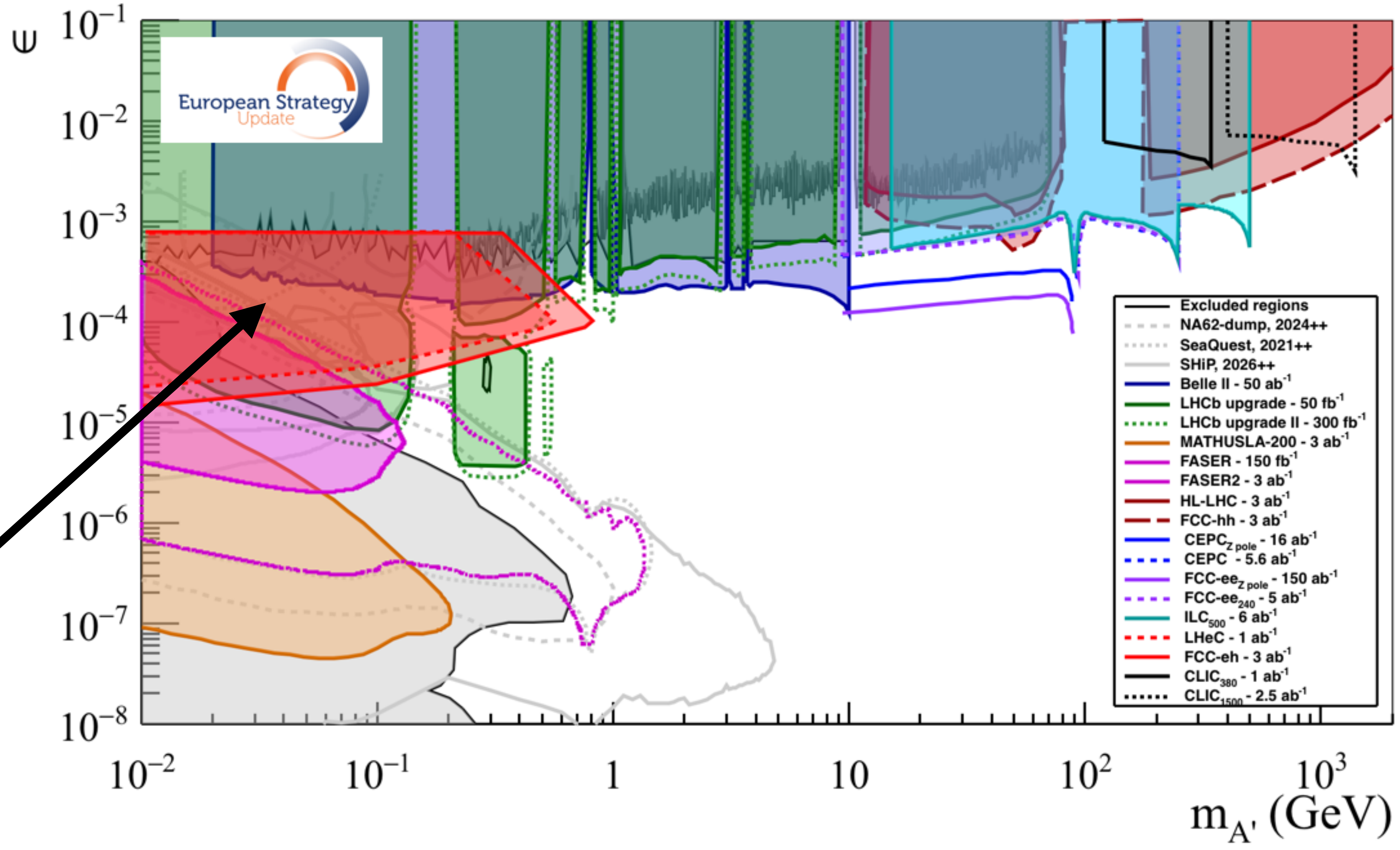






$$-\frac{\varepsilon}{2\cos\theta_W}F'_{\mu\nu}B^{\mu\nu}$$

Covering regions between pp and e^+e^- / low energy experiments



Components, cost, sustainability:

Section	Horizontal Dipoles			Vertical Dipoles			Quadrupoles			RF Cavities		
	Number	*Field*	*Mag. Length*	*Number*	*Field*	*Mag. Length*	*Number*	*Gradient*	*Mag. Length*	*Number*	*Frequency/Cell*	*RF Gradient*
LINAC 1							29	1.9	1.0	448	802/5	20.0
LINAC 2							29	1.9	1.0	448	802/5	20.0
Arc 1	344	0.039	4.0	8	0.51	4.0	158	9.3	1.0			
Arc 2	294	0.077	4.0	6	0.74	4.0	138	17.7	1.0			
Arc 3	344	0.123	4.0	6	0.92	4.0	158	24.3	1.0	6	1604/9	30.0
Arc 4	294	0.181	4.0	6	1.23	4.0	138	27.2	1.0	6	1604/9	30.0
Arc 5	344	0.189	4.0	4	0.77	4.0	156	33.9	1.0	18	1604/9	30.0
Arc 6	344	0.226	4.0	4	1.49	4.0	156	40.8	1.0	30	1604/9	30.0
Total	**1964**			**34**			**962**			**956**		

Units: meter (m), Tesla (T), T/m, MHz, MV/m

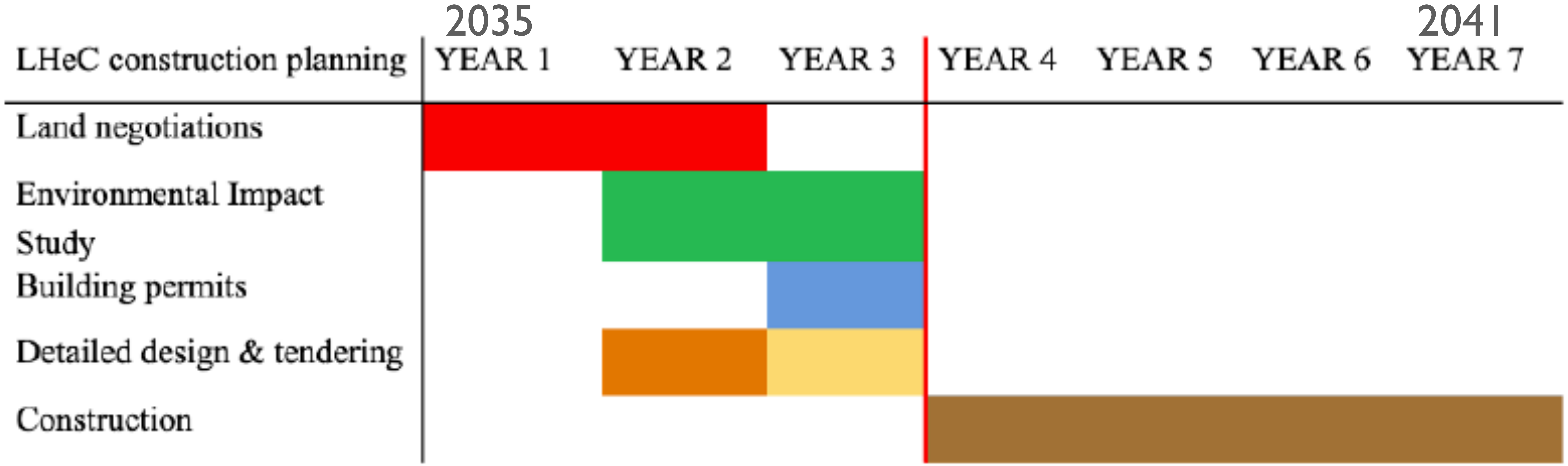
A. Bogacz, full lattice simulation for ERL at 50 GeV

Budget Item	**Cost**
SRF System	671 MCHF
SRF R&D and Proto Typing	31MCHF
Injector	40MCHF
Magnet and Vacuum System	215MCHF
SC IR magnets	105MCHF
Dump System and Source	5MCHF
Cryogenic Infrastructure	100MCHF
General Infrastructure and installation	69MCHF
Civil Engineering	386MCHF
Total	1622 MCHF

- Cost estimate for 1/3rd of the LHC, 50 GeV racetrack: 1.6 BCHF (2018 cost, CERN-ACC-2018-0061), 46% corresponding to the SRF ERL accelerator and 24% to civil engineering; detector: 360 MCHF (75% calorimetry).

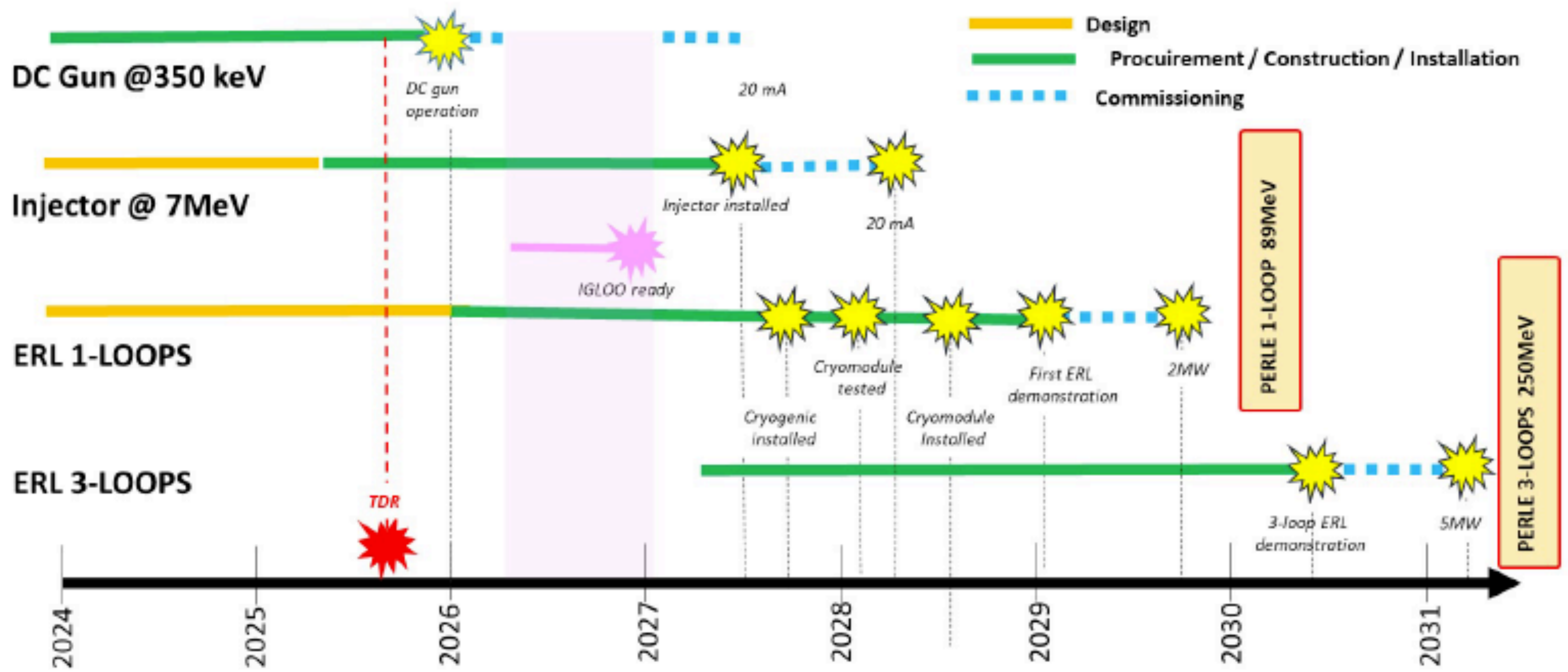
- Power consumption for this option: 220 MW including the ERL, the single-beam HL-LHC and the detector ⟶ +60 MW w.r.t. HL-LHC and +75 MW w.r.t. nominal LHC operation.

Feasibility:



- Target ep luminosity of $1\ \mathrm{ab}^{-1}$ can be achieved in 6 years: two years for installation and commissioning plus one year LS leads to completion in 2050.

- Demonstration of multi-turn high-current ERL in PERLE in 2029/2030:



Challenges:

- Accelerator (ERL in the ECFA Accelerator Roadmap and in the 2020 strategy):
  ➜ High quality SRF cavities integrated in the cryomodule: PERLE (iSAS).
  ➜ High-current, multi-pass ERL → PERLE as demonstrator (2029 1-turn, 2030 3-turn).
- Detector (in the ECFA Detector Roadmap):
  ➜ Keep material budget in the forward direction low (MAPS) → synergies with ALICE(3) and ePIC.
  ➜ Choose between more conservative or more aggressive proposal: particle ID, EMCAL? → synergies with EIC.
  ➜ Further develop an ep/pp option and the possibility of reusing existing detectors.
- Machine-detector interface:
  ➜ Synchrotron radiation protection: beam pipe and inner tracking.
  ➜ 3-beam IR: high aperture, field-free region Q1 (HL-LHC complexity). 2-beam configuration simpler.

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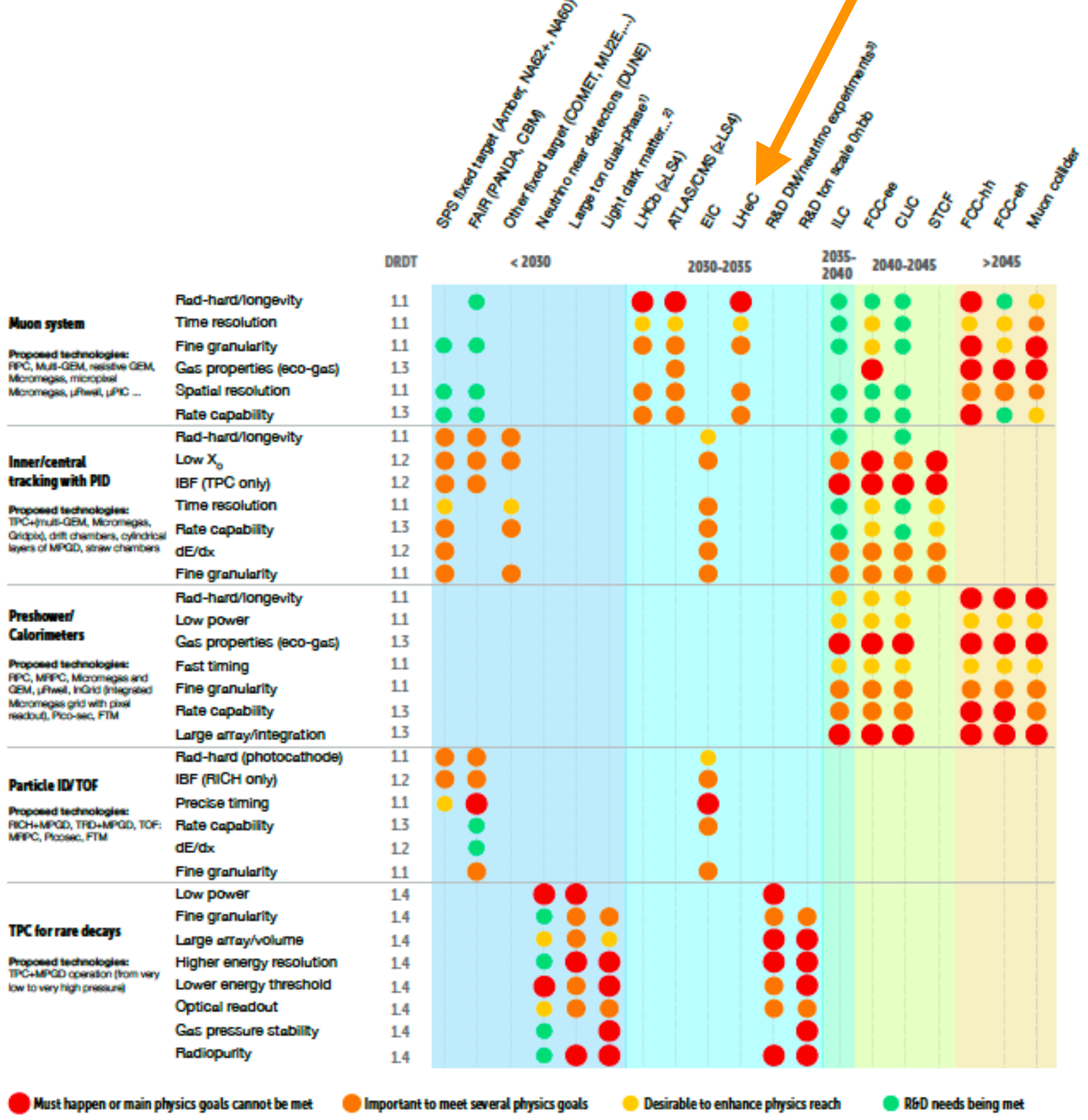
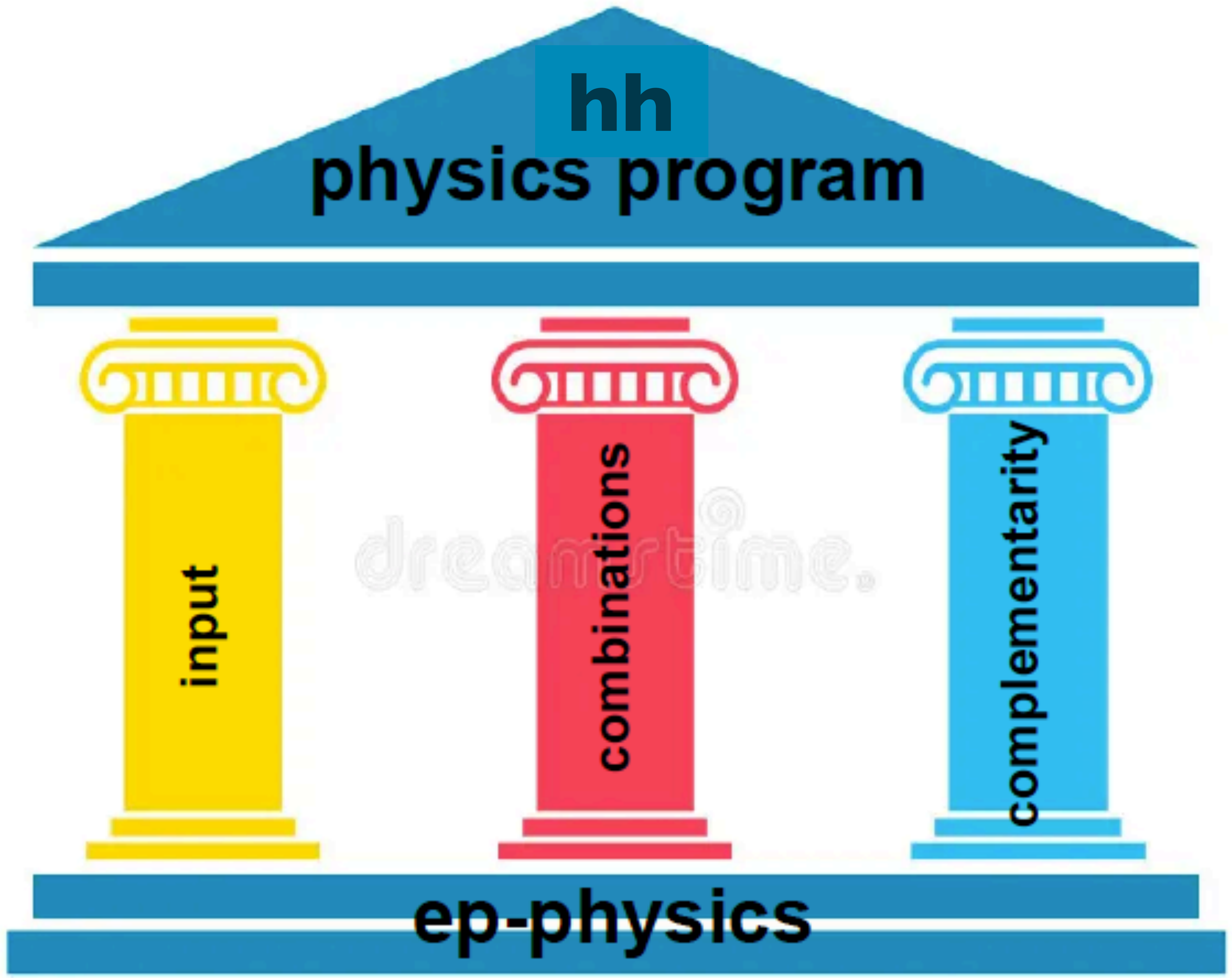


Synergies between eh and hh programes:

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



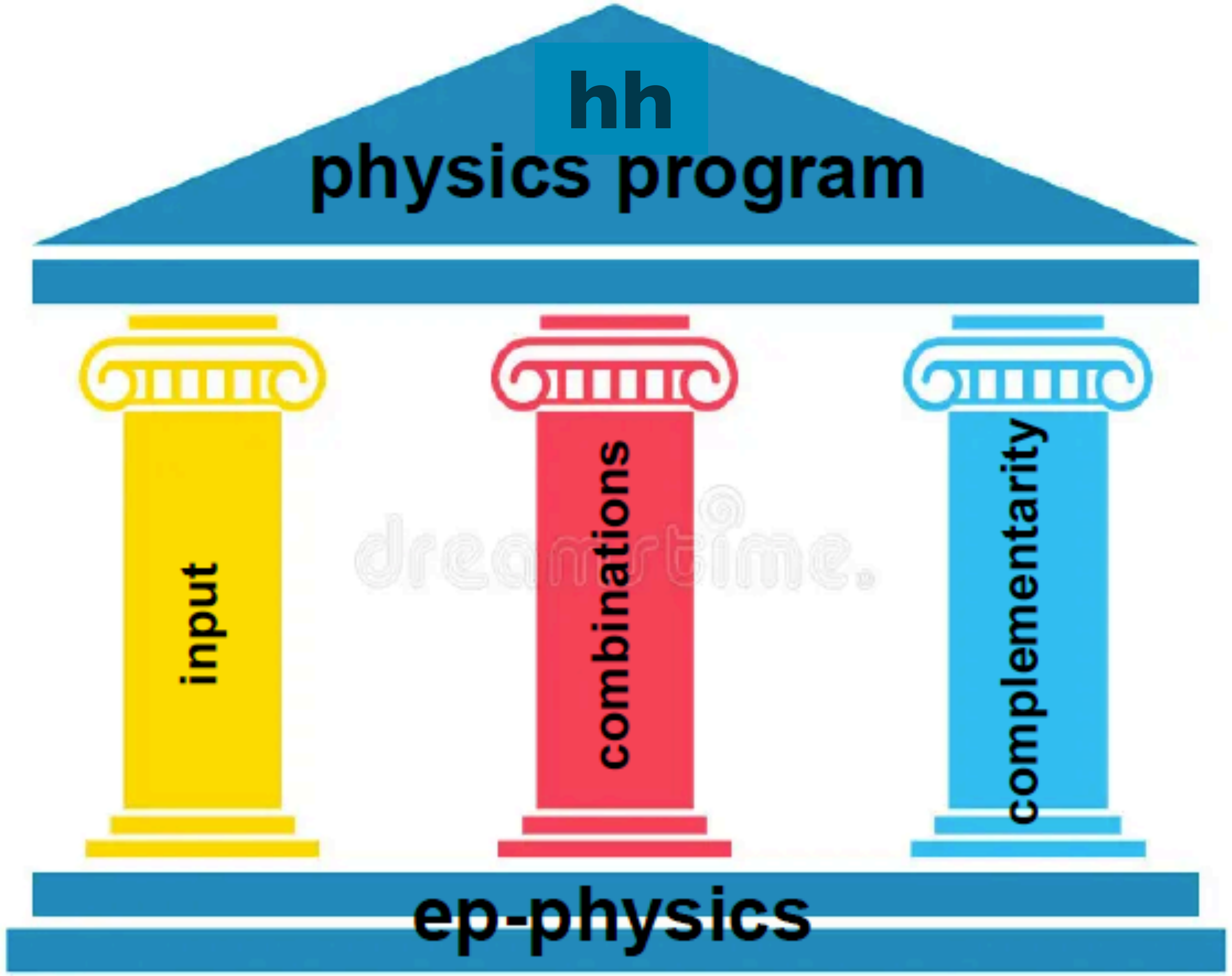
ep analyses with sensitivity complementary to hh analyses to complete the overall hh physics program

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

Synergies between eh and hh programes:

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

→ Empowerment of hh program.
→ Input to pp physics analyses improving sizable uncertainties and limitations.



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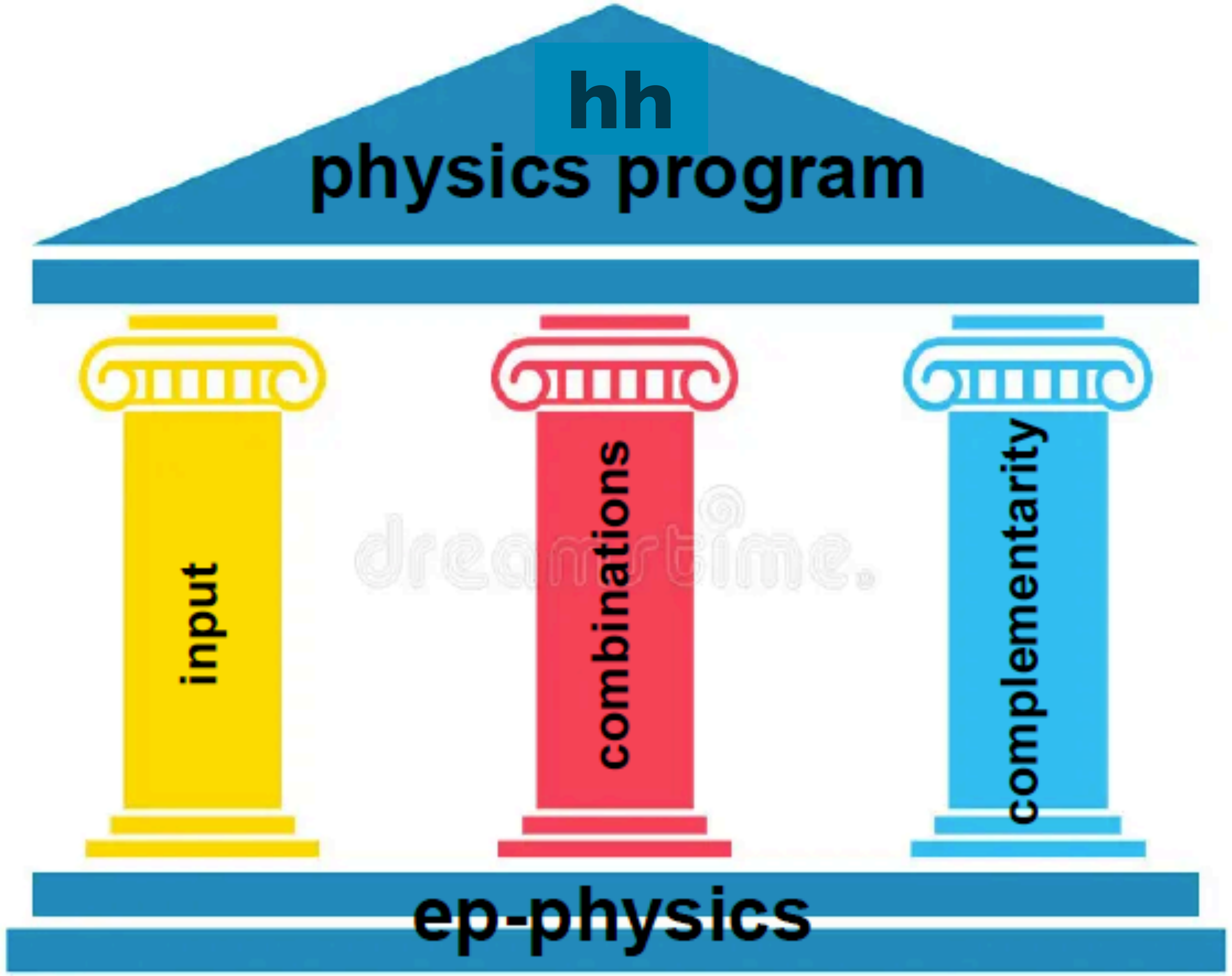

ep analyses with sensitivity complementary to hh analyses to complete the overall hh physics program

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

→ Competitive measurements and combination of results.
→ Uncorrelated uncertainties.
→ Resolve common/correlated expt. uncertainties.
→ Resolve correlations in parameters of interest.
→ Empowers global fits.

Synergies between eh and hh programes:

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

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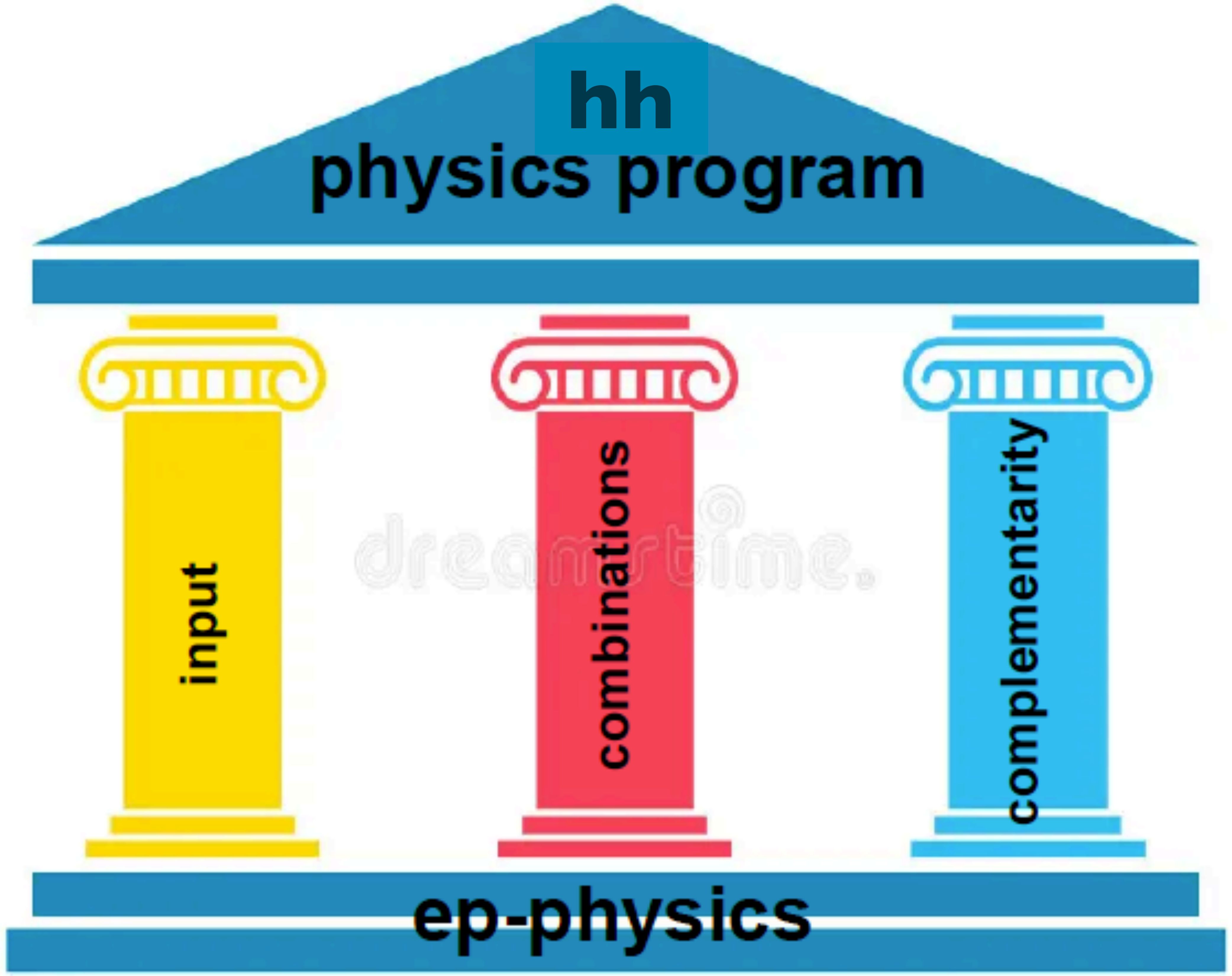

ep analyses with sensitivity complementary to hh analyses to complete the overall hh physics program

→ High precision QCD analyses.
→ High precision measurements of specific parameters.
→ Searches in complementary phase space regions.

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

→ Competitive measurements and combination of results.
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