ICHEP 2022 BOLOGNA

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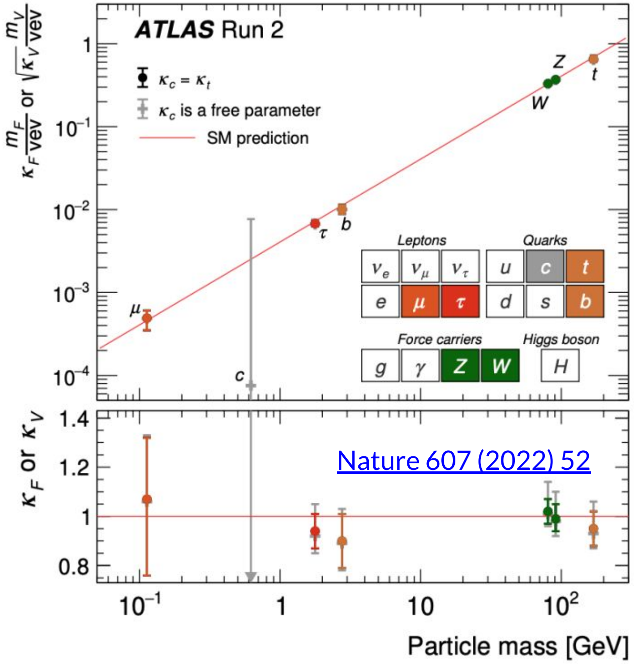
Introduction

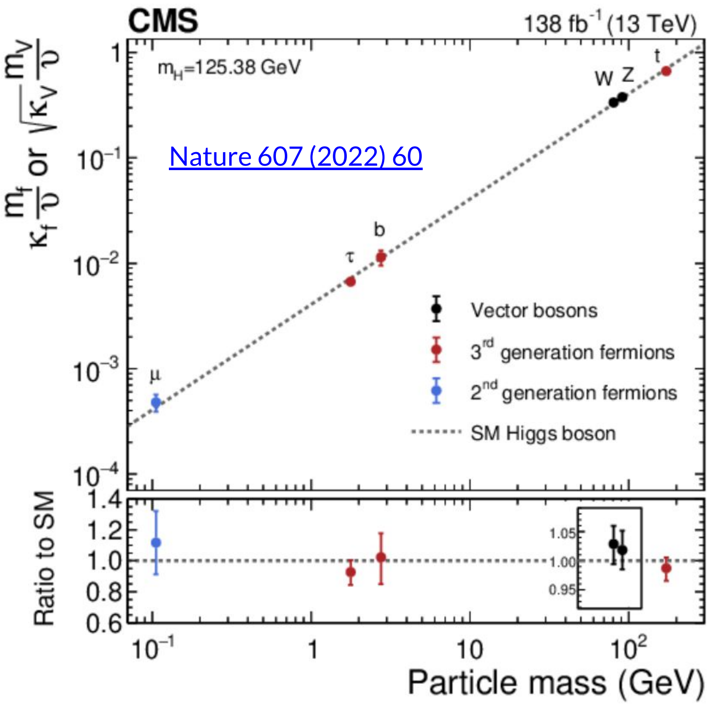
- ***Bologna:*** Capital and largest city of the Emilia-Romagna region in Italy with Significant settlements from about 9th century BCE
- ***ICHEP 2022*** conference:
  - Marks 10th anniversary of Higgs discovery
  - 1493 participants : 1215 (on-site) + 278 (on-line)
  - 17 parallel sessions with ~ 900 parallel talks + 250 posters
- We will present a few interesting (mostly new) results cherry-picked based on our taste
- For more details, please refer to this link

Higgs Couplings

Higgs couplings with full Run2 data→good agreement with SM predictions so far

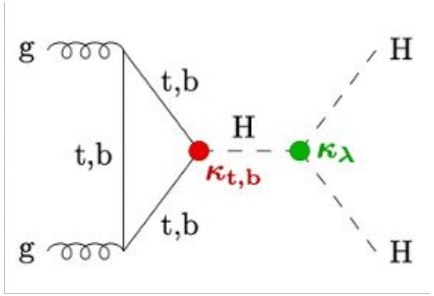


Nature 607 (2022) 52

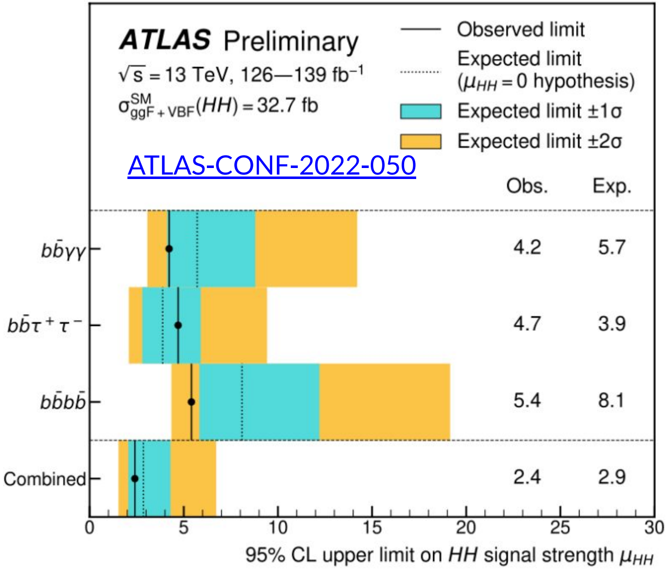


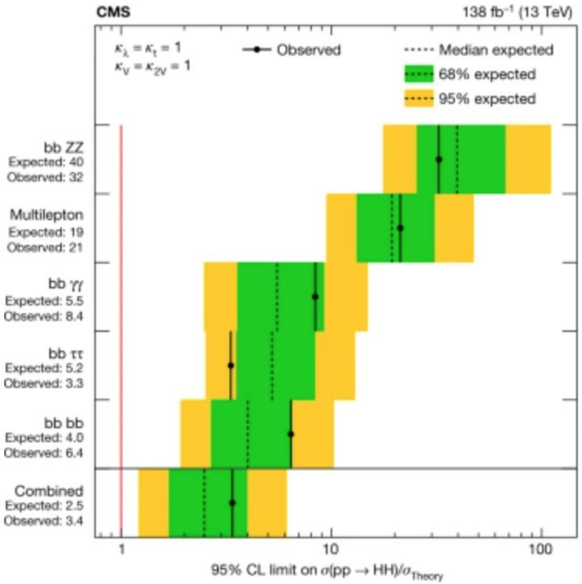
Nature 607 (2022) 60

Di-Higgs production and self-coupling



- Starting to get interesting: 95% CL limits @ 2 - 3 times SM expectations !
- Exciting prospect for Run3 and HL-LHC (Observation ??)





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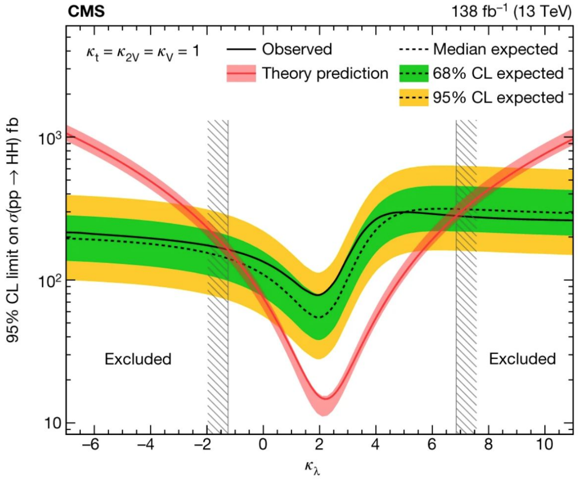
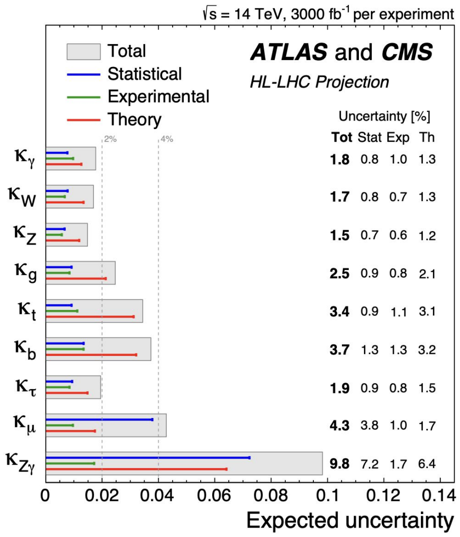
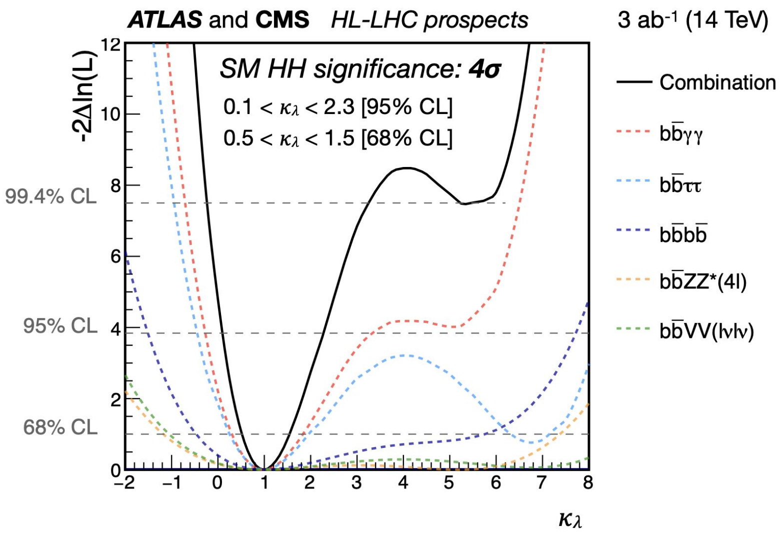


$$\kappa_\lambda \in \{-1.24, 6.49\}$$

Higgs at HL-LHC

LHC summary report: arxiv 1902.000134 based on 2016 (or 16+17) analyses





Recent updated made in individual channels in ATLAS and CMS, not combined summary yet. A. Purohit's talk

- H→4l FTR-21-007 σ(mH) = 20 (syst) ± 20 (stat) MeV, σ(ΓH) = 150 (syst) ± 94 (stat) MeV
- H→γγ FTR-21-008 σ(mH) = 70 (syst) ± 20 (stat) MeV

Complementary between ee and pp experiments

M. Selvaggi's talk

- ee experiment is more suitable for measuring main decay mode (especially hadronic modes), and Higgs mass and width

- pp experiment is more suitable for measuring rare decays, and multi-Higgs productions

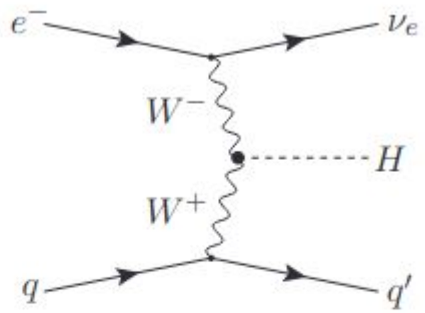
	HL-LHC	FCC-ee	FCC-hh
$\delta\Gamma_H / \Gamma_H$ (%)	SM	**1.3**	tbd
$\delta g_{HZZ} / g_{HZZ}$ (%)	1.5	**0.17**	tbd
$\delta g_{HWW} / g_{HWW}$ (%)	1.7	**0.43**	tbd
$\delta g_{Hbb} / g_{Hbb}$ (%)	3.7	**0.61**	tbd
$\delta g_{Hcc} / g_{Hcc}$ (%)	~70	**1.21**	tbd
$\delta g_{Hgg} / g_{Hgg}$ (%)	2.5 (gg->H)	**1.01**	tbd
$\delta g_{H\tau\tau} / g_{H\tau\tau}$ (%)	1.9	**0.74**	tbd
$\delta g_{H\mu\mu} / g_{H\mu\mu}$ (%)	4.3	9.0	**0.65** (*)
$\delta g_{H\gamma\gamma} / g_{H\gamma\gamma}$ (%)	1.8	3.9	**0.4** (*)
$\delta g_{Htt} / g_{Htt}$ (%)	3.4	–	**0.95** (**)
$\delta g_{HZ\gamma} / g_{HZ\gamma}$ (%)	9.8	–	**0.91** (*)
$\delta g_{HHH} / g_{HHH}$ (%)	50	~30 (indirect)	**5**
BR_{exo} (95%CL)	$BR_{inv} < 2.5\%$	**< 1%**	**$BR_{inv} < 0.025\%$**

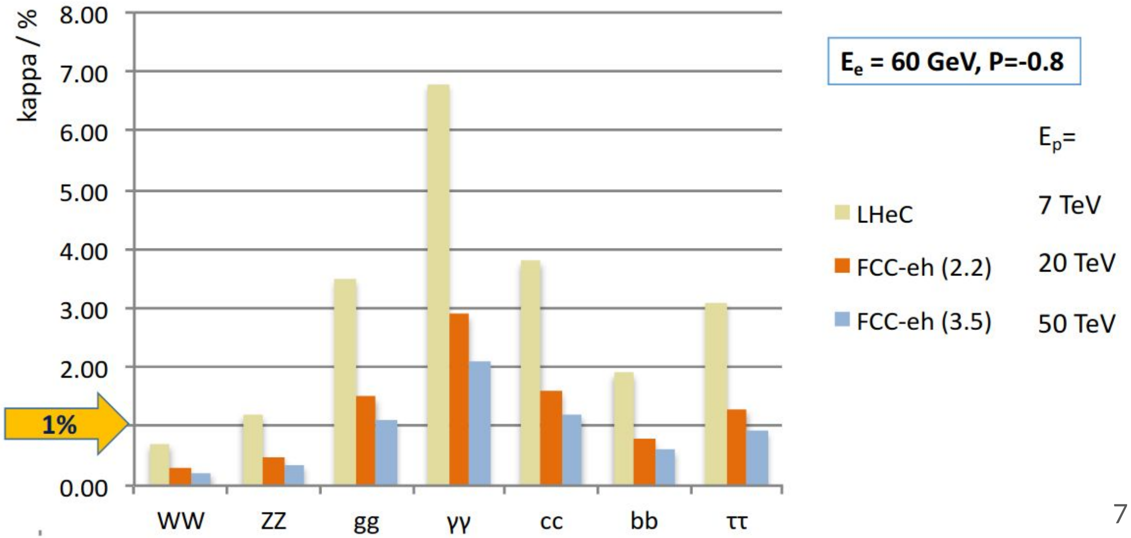
Higgs at lepton-proton colliders

arxiv: 2007:14491 and U. Klein's talk

Expect 200k Higgs events with 1 ab^-1 of data
Higgs physics is not the driving focus of lepton-proton colliders, but can be good additions

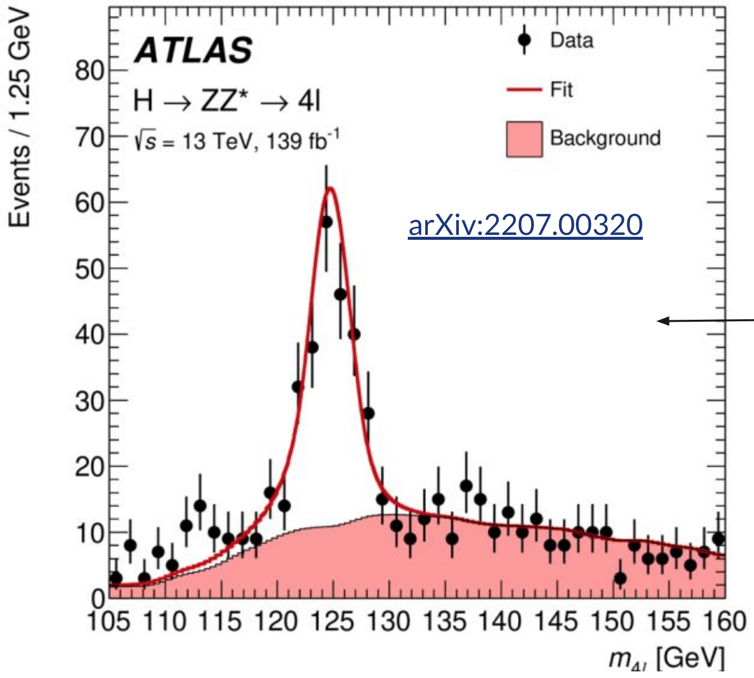
- High sensitivity in HWW coupling measurement
- Contributed to the cross-experiment combination in all major decay channels





Higgs mass

$$m_H = 124.94 \pm 0.17(\text{stat.}) \pm 0.03(\text{syst.})\ \text{GeV}$$



arXiv:2207.00320

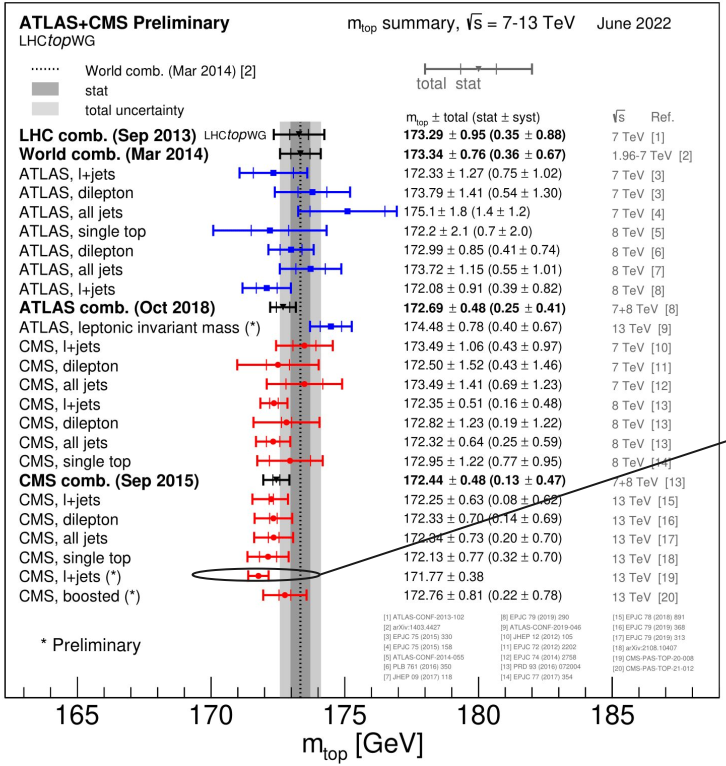
- ***New*** ATLAS measurement with ***full Run2 data***
- Precision ***better than 1.5 per mil*** in individual channels

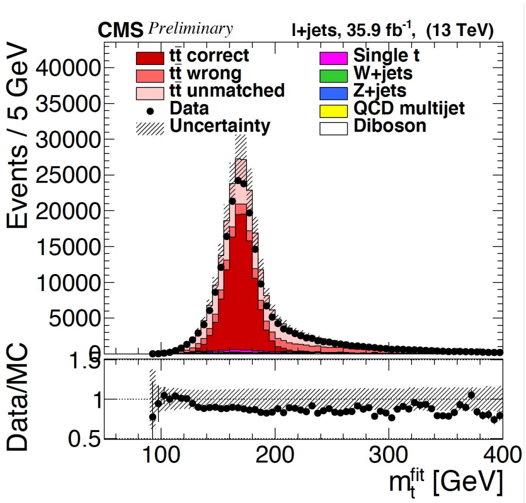
Systematic Uncertainty	Contribution (MeV)
Muon momentum scale	±20
Electron energy scale	±16
Signal Theory	±13

CMS Combination (γγ + 4l) with ***Run1 + partial Run2 (2016) data:***

$$m_H = 125.38 \pm 0.14\ \text{GeV}$$

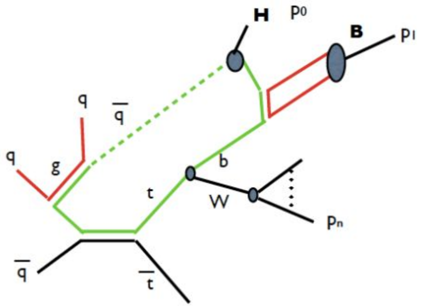
Top quark mass





$$m_t = 171.77 \pm 0.38(\text{stat.} + \text{syst.})\ \text{GeV}$$

CMS-PAS-TOP-20-008



- Top quark decays before hadronizing, but the daughter(s) hadronize(s)
- Impossible to assign final state particles only to the parent top quark → effect $O(\lambda_{QCD}) \approx 0.2$ GeV
- Important to measure mass with different methods to reduce uncertainties
- Reached ~ 2 permil precision with individual measurements

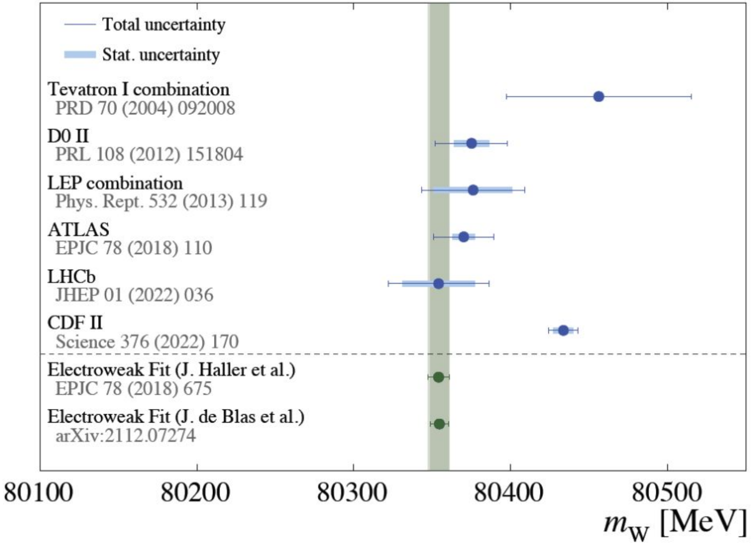
The W mass conundrum

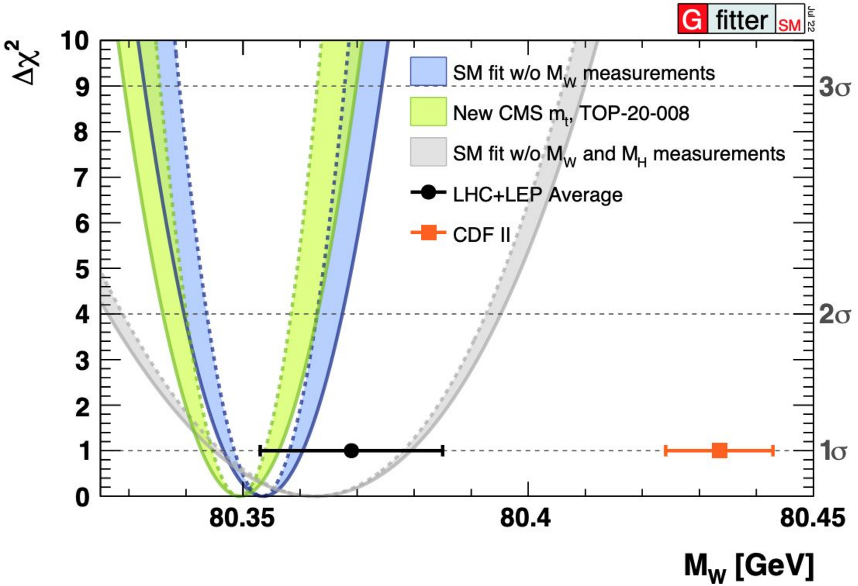
See this talk

- Life becoming difficult at EW fits with the new CDF measurement

  →6.8σ deviation from prediction (Blue Band)

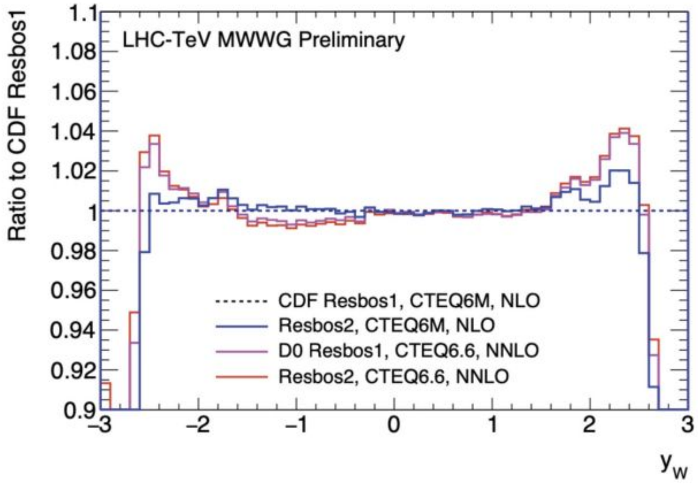
- Using m_t from CMS-PAS-TOP-20-008 the deviation is even larger (Green Band)

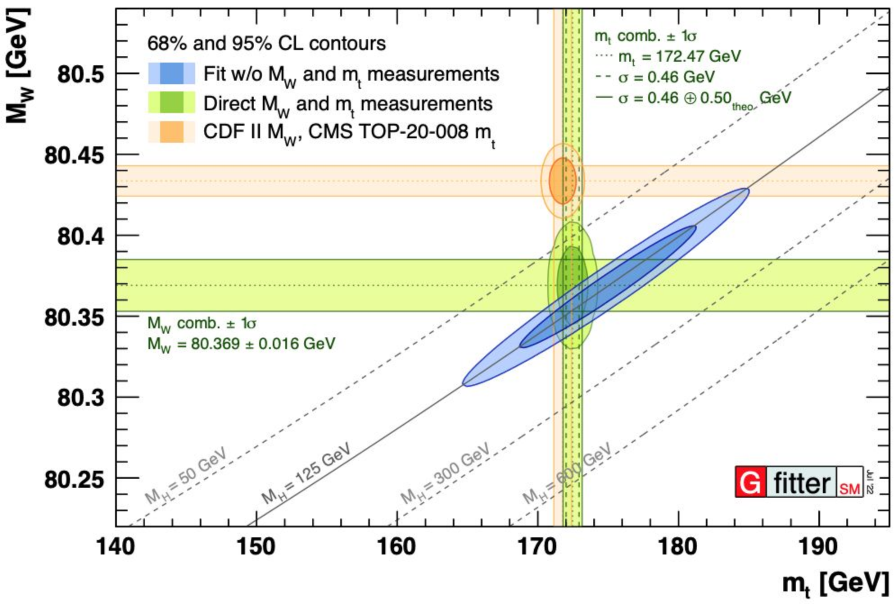




The W mass conundrum

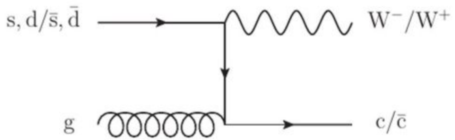
- SM predictions consistent with LEP + LHC measurements
- Need to resolve tension with new W mass result from CDF
- PDFs are key inputs → need to understand the differences and harmonize PDF+generators before combining measurements

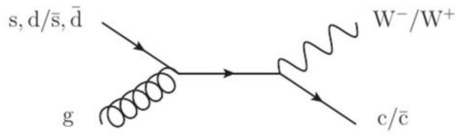


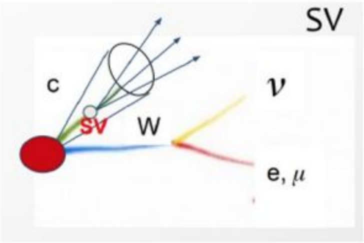


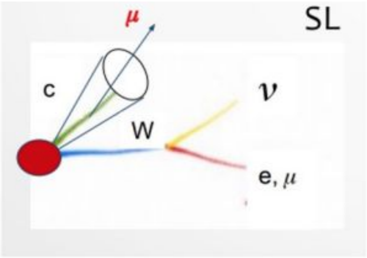
W + c production

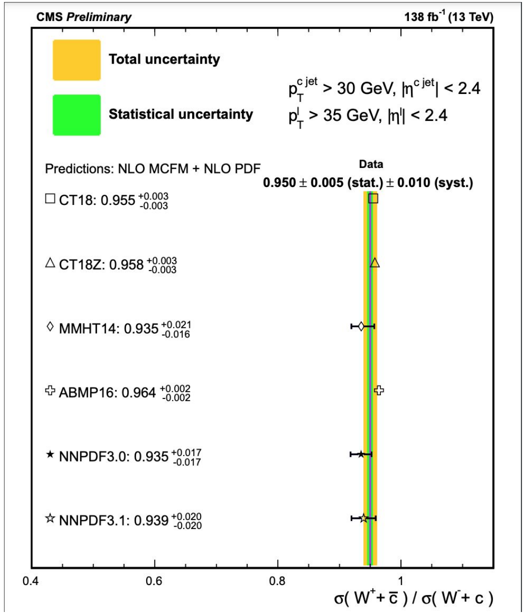
- Measurement sensitive to s-quark PDF
- c- tagging employed to identify charm jets

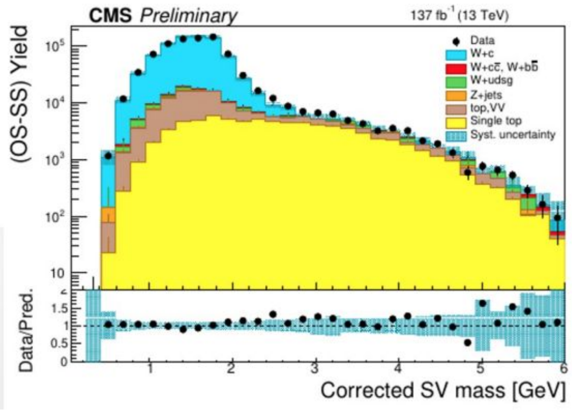


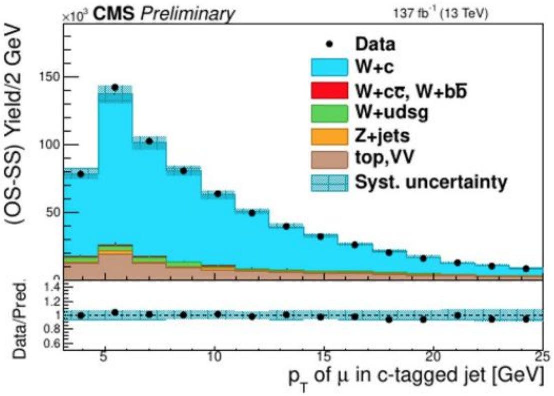








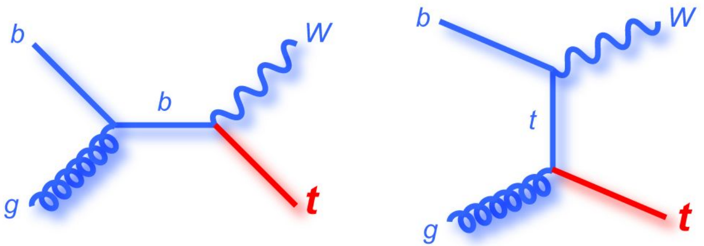


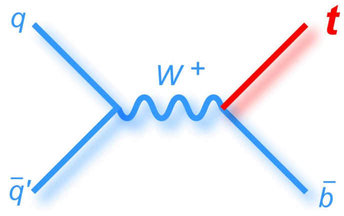


CMS-PAS-SMP-21-005

Single top (tW and *s*-channel production)

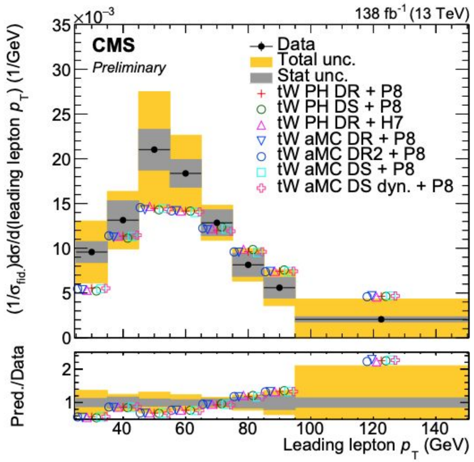
ATLAS-CONF-2022-030



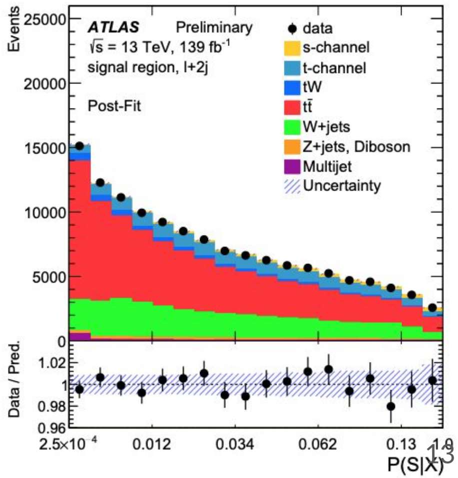


$$\sigma_{meas.} = 79.2 \pm 0.8(\text{stat.})^{+7.0}_{-7.2}(\text{syst.}) \pm 1.1(\text{lumi})\ \text{pb}$$

$$\sigma_{meas.} = 8.2^{+3.5}_{-2.9}\ \text{pb},\ \sigma_{SM} = 10.32^{+0.40}_{-0.36}\ \text{pb}$$



Evidence with 3.3(3.9)σ observed (expected) significance

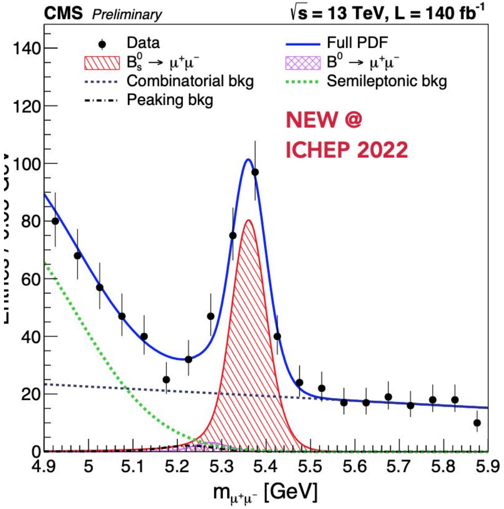


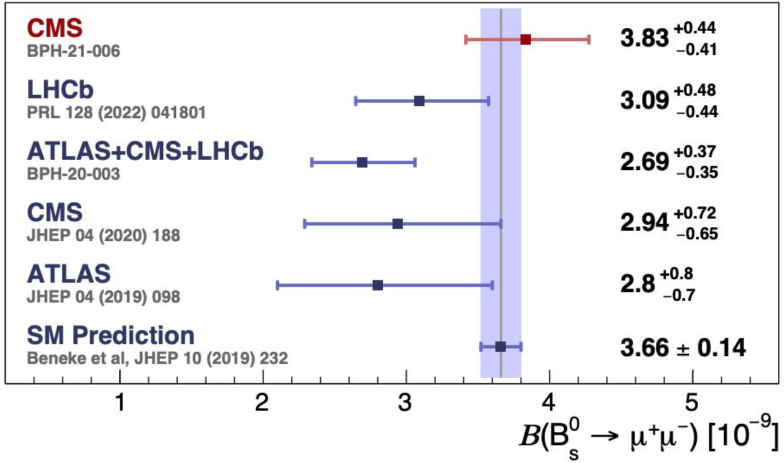
$B_s \to \mu\mu$

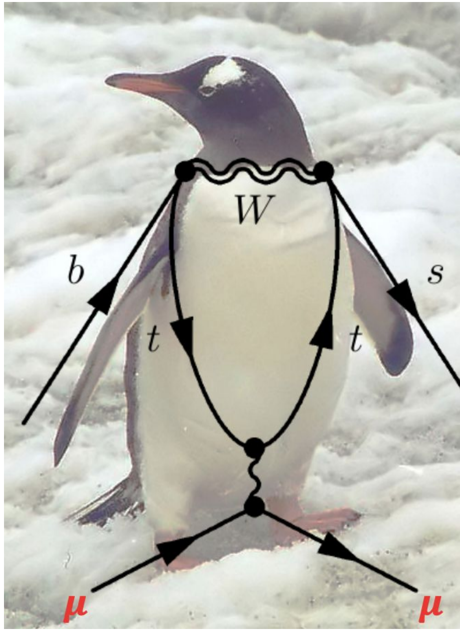
[CMS-BPH-21-006]

- Highly suppressed in SM, however enhancement predicted in several BSM scenario
- Theoretically pristine as well as experimentally accessible → ultimate tool to test new physics

$$\mathcal{B}(\mathrm{B}^0_\mathrm{s} \to \mu^+\mu^-) = \left[3.83^{+0.38}_{-0.36}\ (\mathrm{stat})\ ^{+0.19}_{-0.16}\ (\mathrm{syst})\ ^{+0.14}_{-0.13}\ (f_\mathrm{s}/f_\mathrm{u})\right] \times 10^{-9}$$

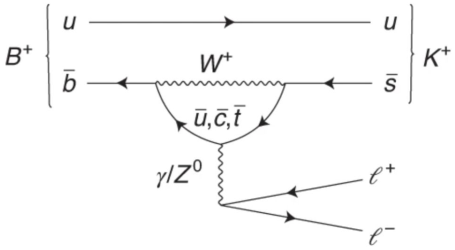


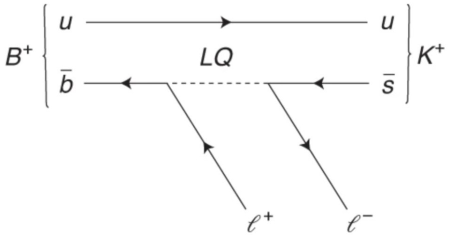


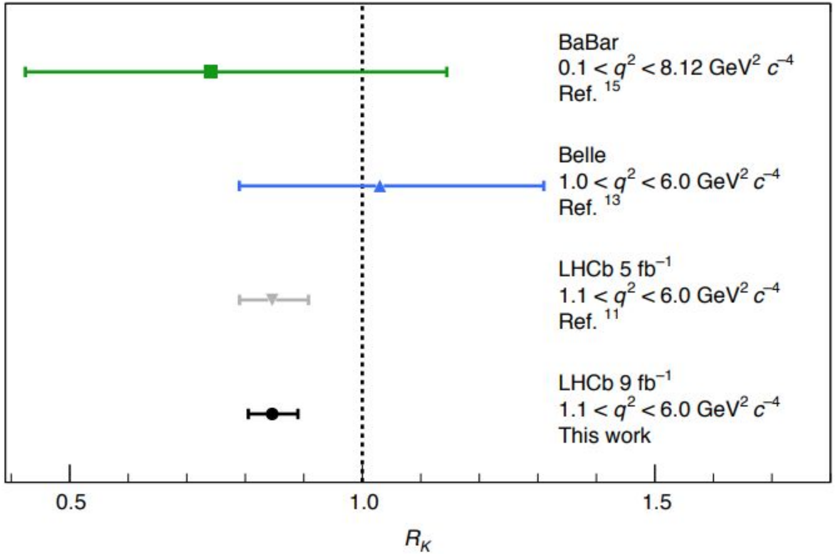


LFU using B-decays

$$R_K = \frac{\mathcal{B}\ (B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}\ (B^+ \to J/\psi(\to \mu^+\mu^-)K^+)} \Big/ \frac{\mathcal{B}\ (B^+ \to K^+e^+e^-)}{\mathcal{B}\ (B^+ \to J/\psi(\to e^+e^-)K^+)}$$







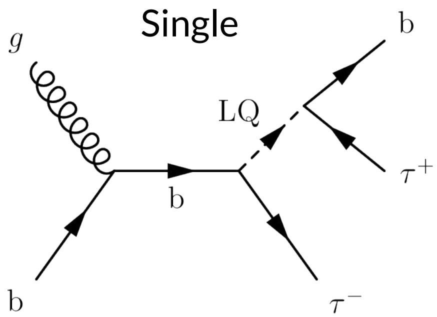
[Nature Physics, 18, 277-282 (2022)](https://example.com)

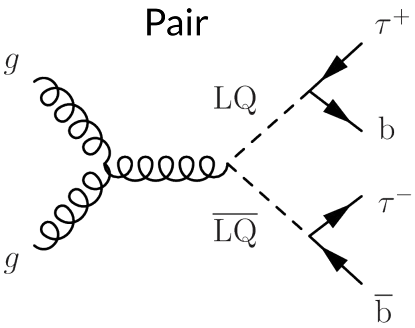
- Measurement deviates from SM by 3.1σ
- New Belle2 results for control channels , preparing for R_K

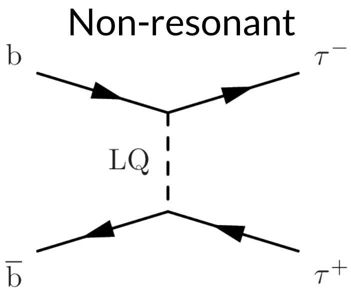
Observable	Belle II	Belle (2021)
$R_{K^+}(J/\psi)$	$1.009 \pm 0.022 \pm 0.008$	$0.994 \pm 0.011 \pm 0.010$
$R_{K^0_S}(J/\psi)$	$1.042 \pm 0.042 \pm 0.008$	$0.993 \pm 0.015 \pm 0.010$

LQ searches at LHC

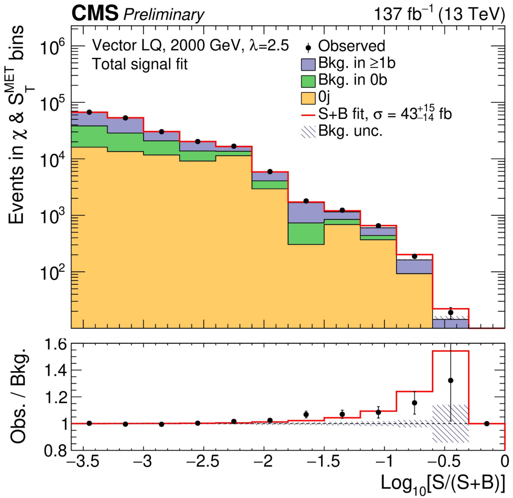
[CMS-PAS-EXO-19-016](CMS-PAS-EXO-19-016)





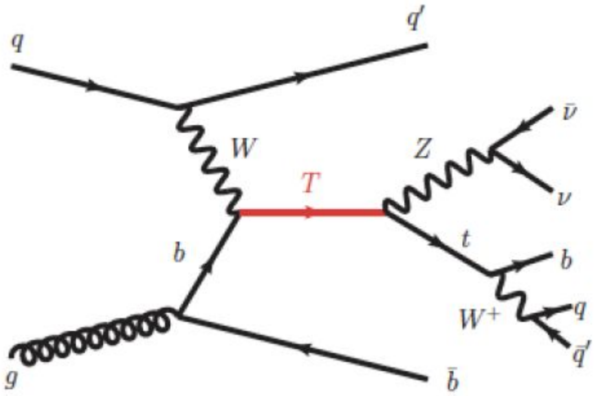


- Limits obtained for Scalar and Vector LQs with varied couplings in the bτ-LQ search
- ***3.4σ excess above SM expectation for LQ mass of 2 TeV and coupling strength (λ) = 2.5 observed by CMS !***
- Mostly compatible with H→ττ result driven by non-resonant categories

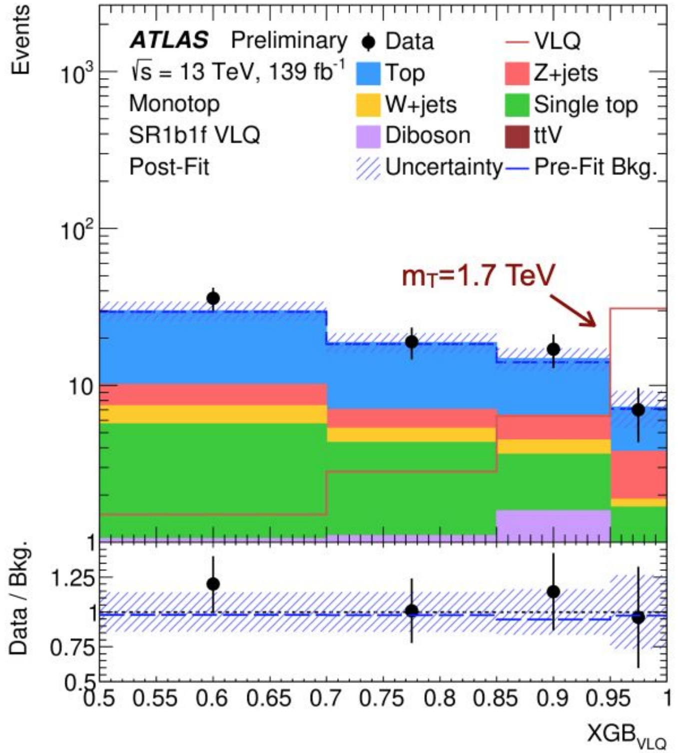


Search for Vector Like Quarks (VLQ)

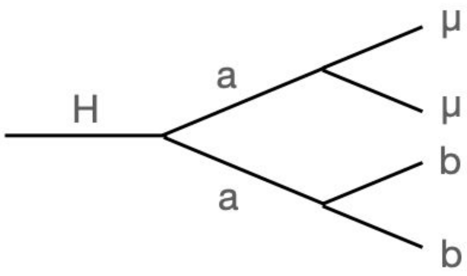
ATLAS-CONF-2022-036

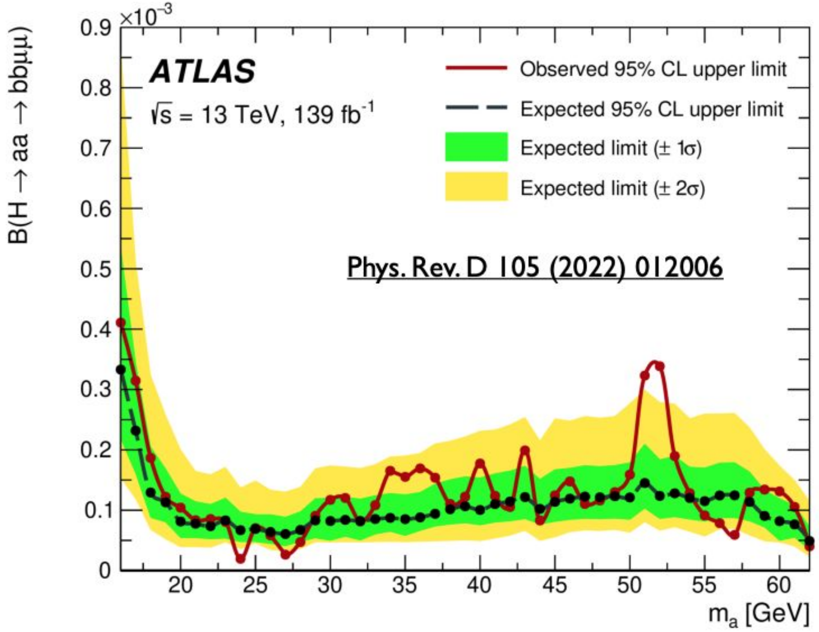


- New search from ATLAS in the monotop final state
- Benchmark scenario: k_T = 0.5 and BR (T→tZ)= 25%
- **m_T > 2.2 TeV @ 95% CL** (Gain by 500 GeV !)



H→aa





- SM Higgs decays to light pseudoscalar particles predicted by nMSSM models
- **ATLAS reports intriguing 3.1σ(1.7σ) local (global) excess at $m_a \approx 52$ GeV (a→μμ) in the bbμμ final state**

Conclusion

- The first large scale HEP conference post pandemic
- Significant excesses and deviations from SM reported by various experiments →Exciting times ahead
- Precision measurements could indicate the nature of new physics
- ICHEP 2024 to be held in Prague. Check out the video invitation

Thank You

Backup

Future collider possibility - muon collider

D. Calzolari's talk

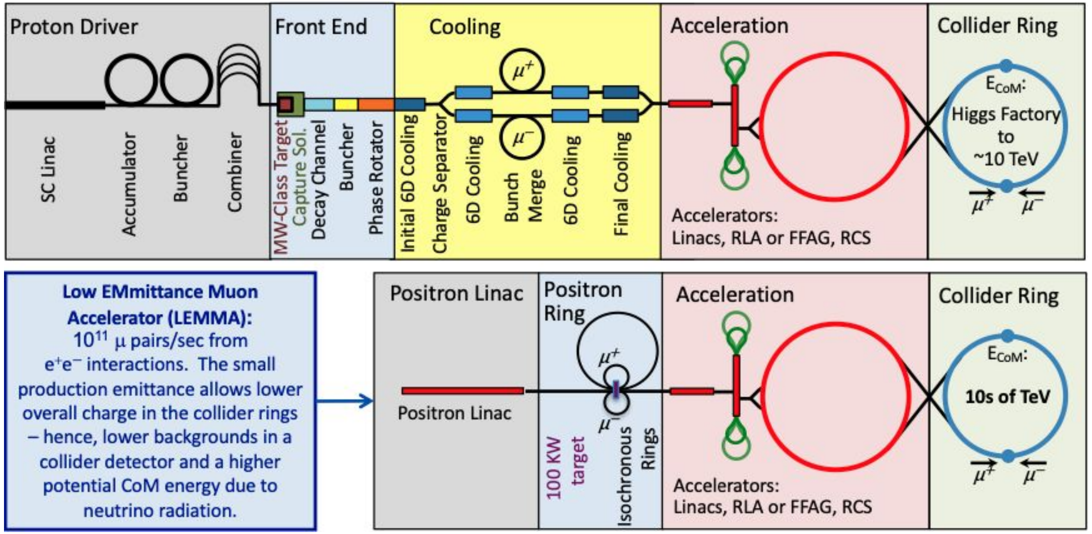
Clean and kinematically-constrained collisions at O(10 TeV).

- Not limited by synchrotron radiation, O(10 TeV) with 10 km rings.
- If high luminosity can be achieved, ideal for precision measurement of physics at TeV level.

$\sqrt{s}$	$\int \mathcal{L}dt$
3 TeV	1 ab^{-1}
10 TeV	10 ab^{-1}
14 TeV	20 ab^{-1}

Challenge: Muon lifetime ~ 2.2 μs

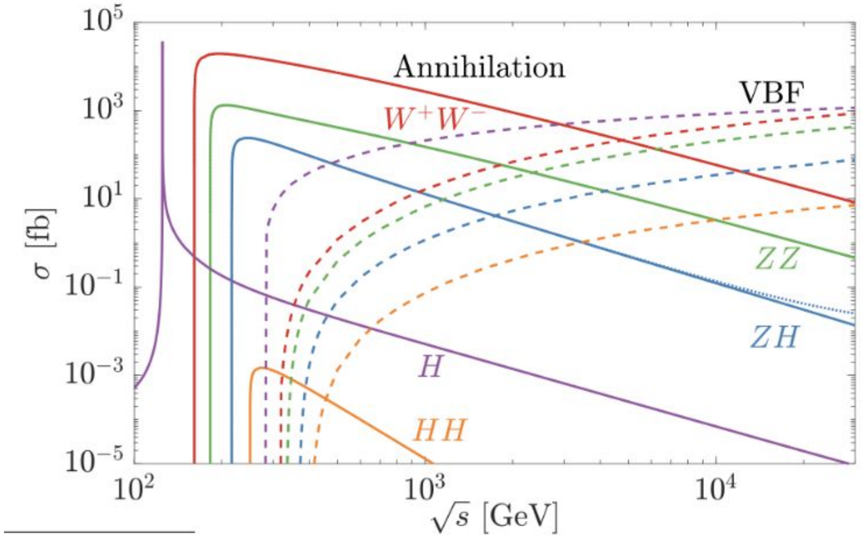
- Electrons heat up accelerator magnets
- Intense neutrino flux around beam rings



Higgs at muon colliders

L. Sestini's talk and J. Reuter's talk

With 1 ab^-1 data at 3 TeV, expect 500k Higgs events
With 10 ab^-1 data at 10 TeV, expect > 5M Higgs events
(Compared to 1M~2M Higgs at FCC-ee)



(Why not 125 GeV collision?)

Channel	$\Delta\sigma/\sigma$ (%)	
	3 TeV	10 TeV
bb	0.76	0.21
cc	13	4.0
gg	3.3	0.89
$\tau^+\tau^-$	4.0	1.1
$WW^*(jj\ell\nu)$	1.7	0.45
$WW^*(4j)$	5.7	1.3
$ZZ^*(4\ell)$	45	12
$ZZ^*(jj\ell\ell)$	11	3.2
$ZZ^*(4j)$	65	14
$\gamma\gamma$	6.1	1.6
$Z(jj)\gamma$	47	13
$\mu^+\mu^-$	40	9.8
$ttH(bb)$	61	53

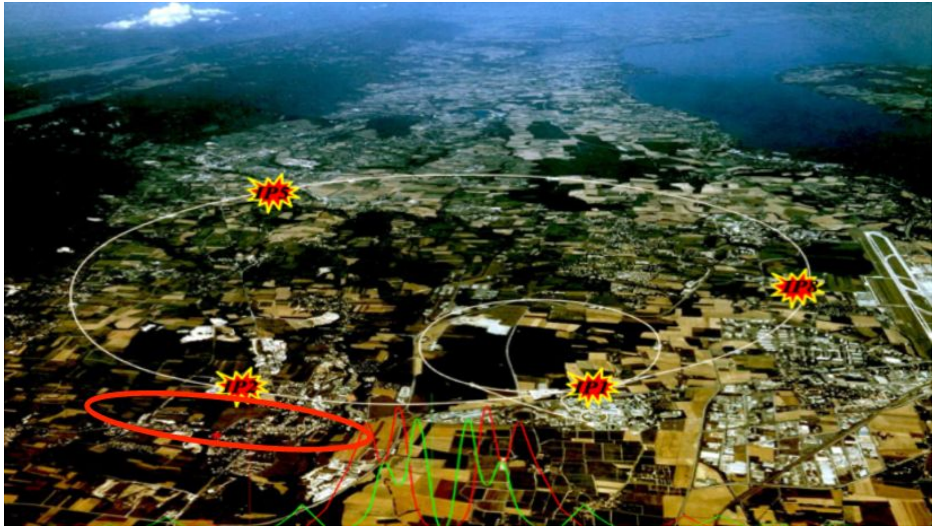
Future collider possibility - LHeC

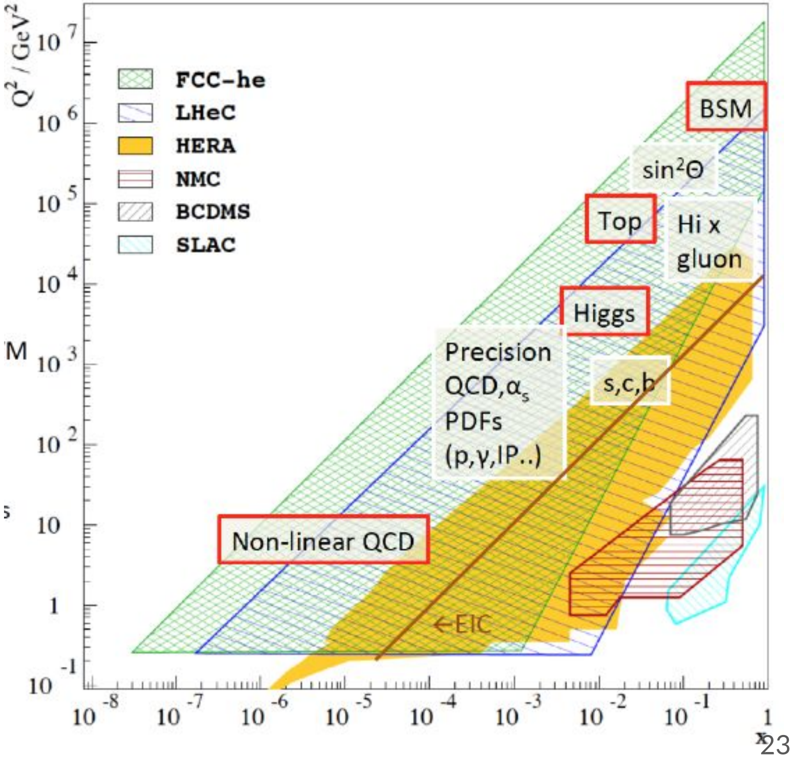
B.J. Holzer's talk

With an extra electron ring, the LHeC can operate at concurrently with HL-LHC (replacing ALICE)

- DIS experiments with rich physics cases

Similarly, an FCC-eh program is also planned.





Ichep dinner

florence