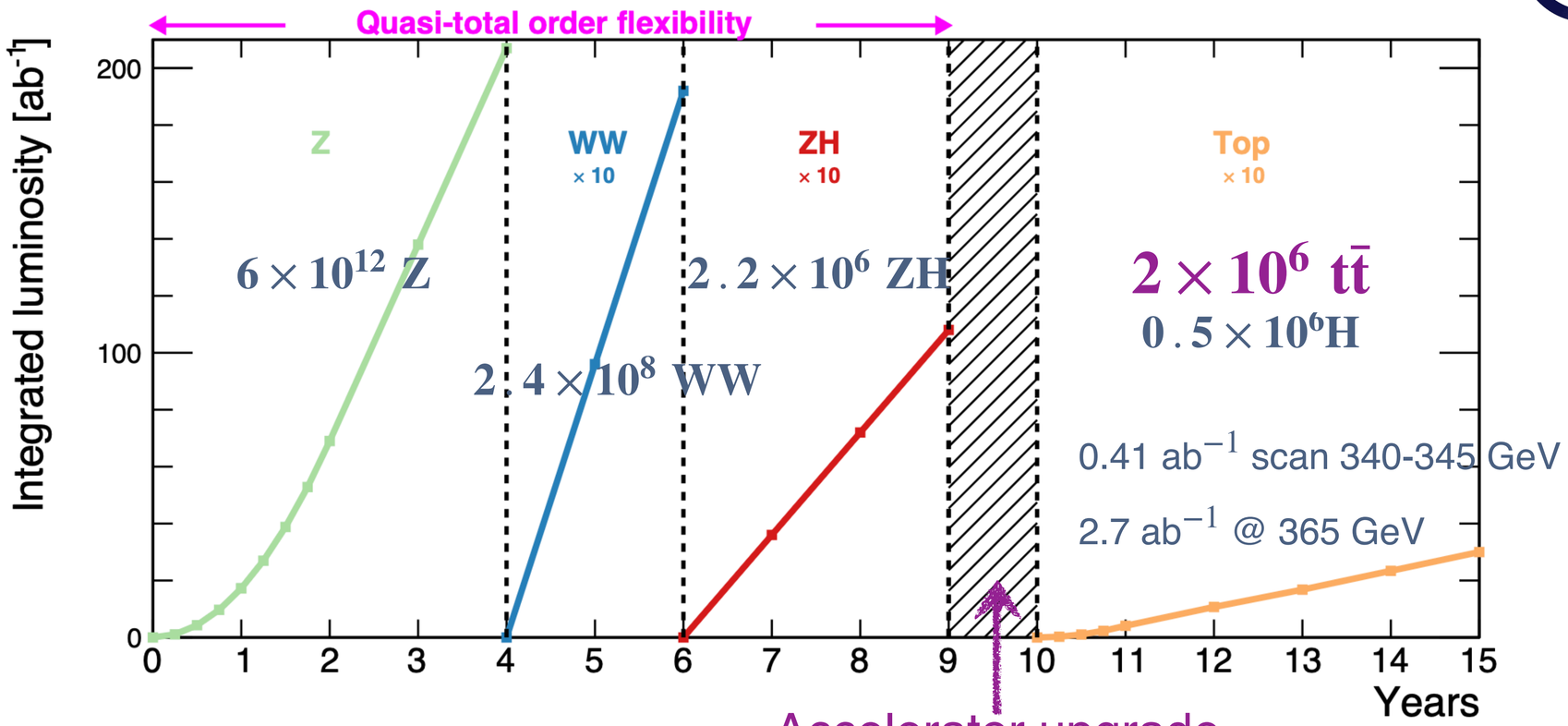
FCC-ee top overview

CEPC workshop 2026
24.10.2026



FCC top working group:
Gauthier Durieux
Juergen Reuter
Christian Schwanenberger
Xunwu Zuo

FCC luminosity and events



Running mode	Z	WW	ZH	tt̄
Luminosity/IP [10^{34} cm^{-2} s^{-1}]	144	20	7.5	1.45
Energy loss / turn [GeV]	0.039	0.369	1.86	9.94
Synchrotron Radiation Power [MW]	100	100	100	100
RF Voltage 400/800 MHz [GV]	0.09/0	1.0/0	2.1/0	2.1/9.2

Where we are at?

From 3rd European Strategy update

- **FCC-ee is the preferred** option for the next flag ship collider.
- A **descoped FCC-ee** is the **preferred alternative**

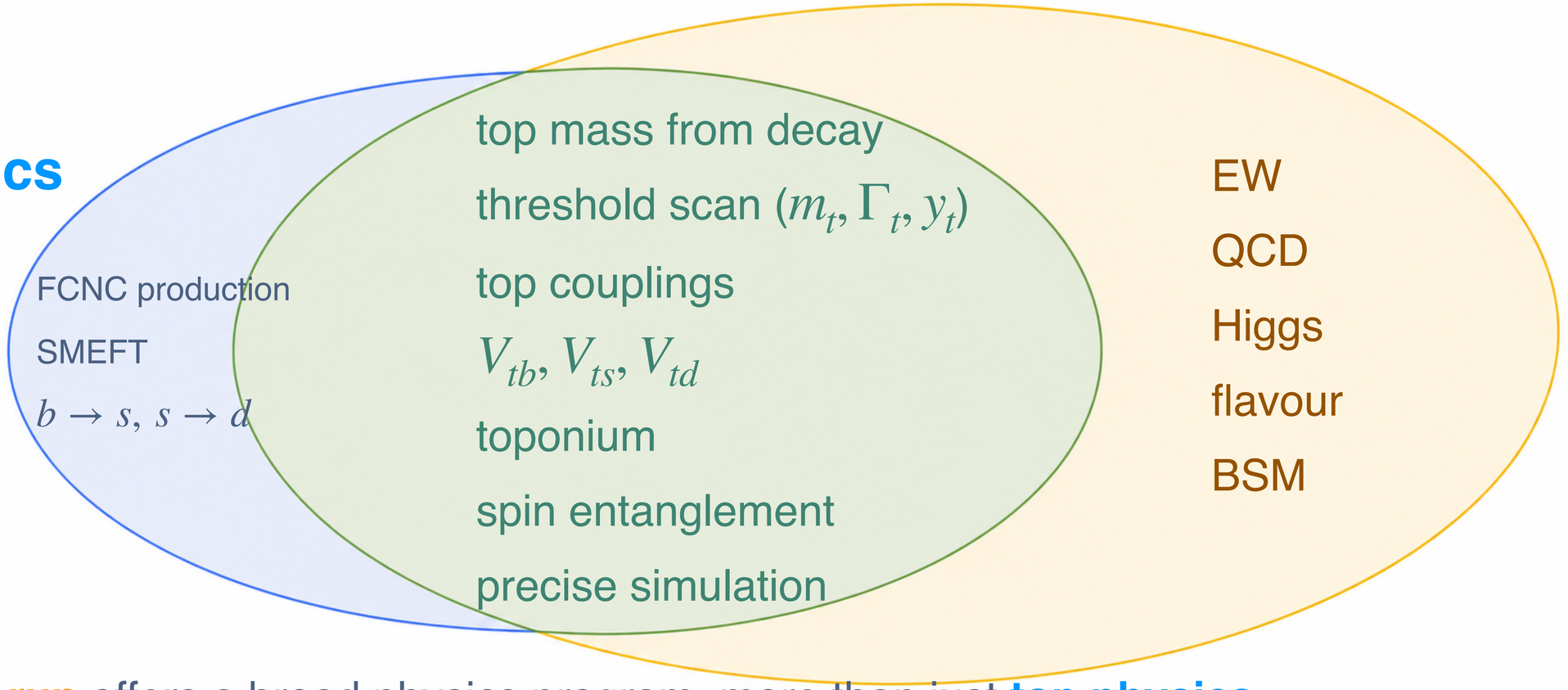
Descoped FCC-ee

- **remove tt run**
- 2 IPs instead of 4
- reduced RF power

Final decision by CERN Council in 2028

- **Critical goal of top groups: evaluate physics impact of top run**

top run, top physics



- $t\bar{t}$ **run** offers a broad physics program, more than just **top physics**
- **top physics** almost solely relies on $t\bar{t}$ **run**, besides a few corner cases
- exp studies highly connected to theory (methodology ↔ observable, theory precision)
- Interplay between observables in top and other physics (EW/Higgs/QCD/flavour)

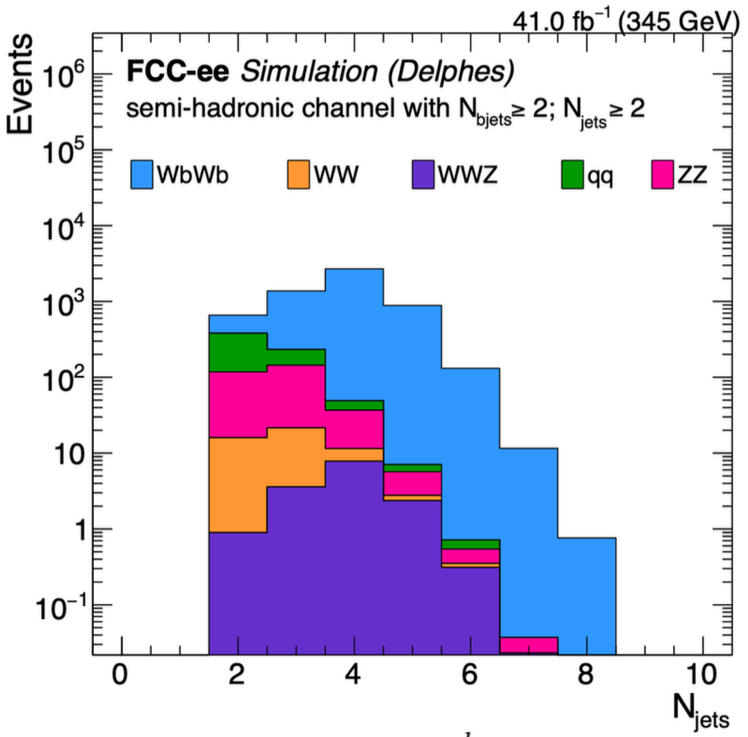
Outline

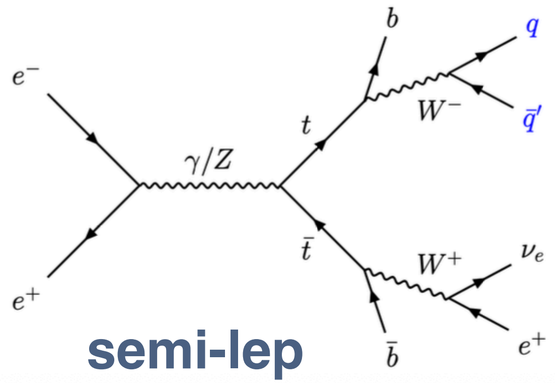
Connection between top&other physics

- top and EW parameters
- top and flavour physics
- top SMEFT and global fit

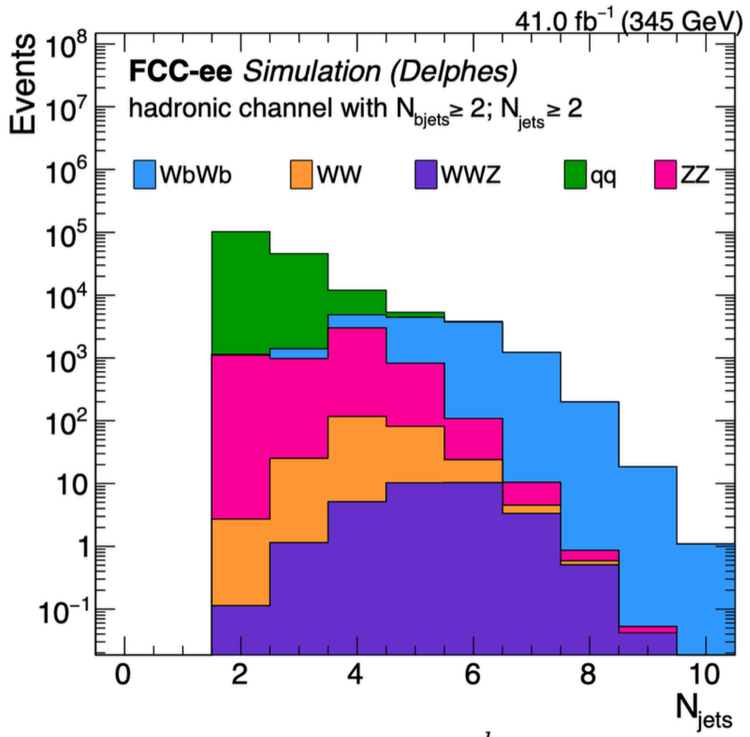
top and EW parameters

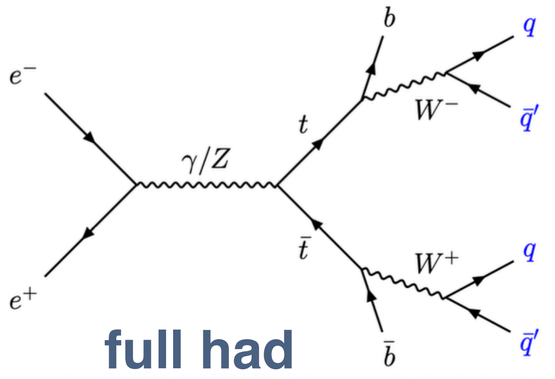
$t\bar{t}$ cross section





semi-lep





full had

counting experiment on #jets, #bjets

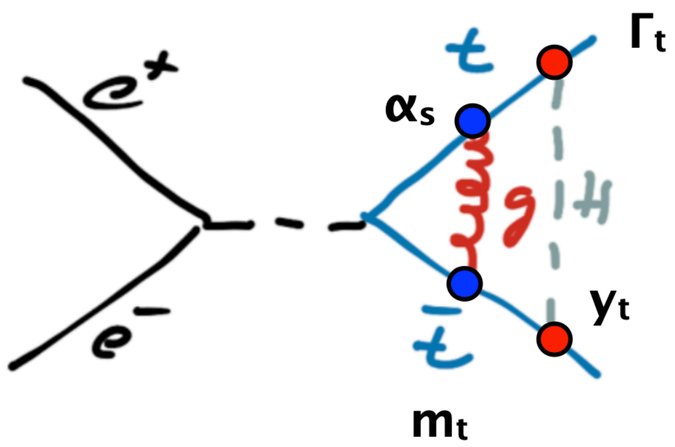
Uncertainty source	Impact on σ_{WbWb} [%]		
	340 GeV	345 GeV	365 GeV
Integrated luminosity	0.12	0.11	0.02
b tagging	0.11	0.06	0.01
ZZ had. norm.	0.46	0.19	0.04
ZZ semihad. norm.	0.23	0.07	0.03
WW had. norm.	0.17	0.09	0.02
WW semihad. norm.	0.06	0.04	0.03
$q\bar{q}$ had. norm.	0.12	0.09	0.02
$q\bar{q}$ semihad. norm.	0.18	0.06	0.01
WWZ norm.	0.03	0.01	0.01
Total (incl. stat)	2.31	0.89	0.12

0.12% precision

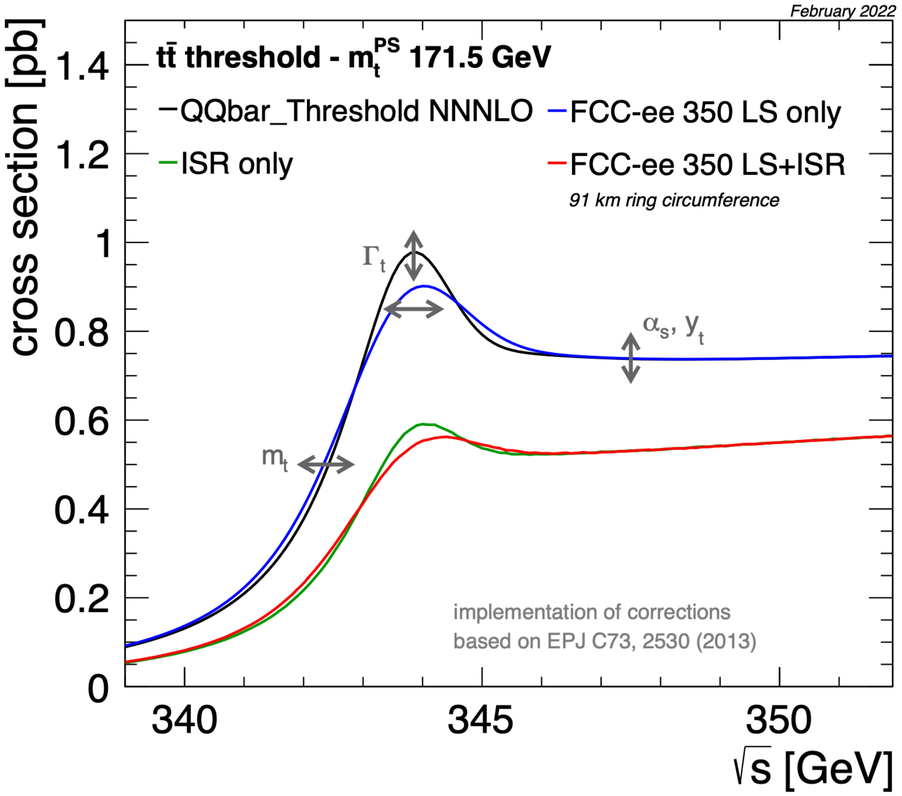
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top threshold scan

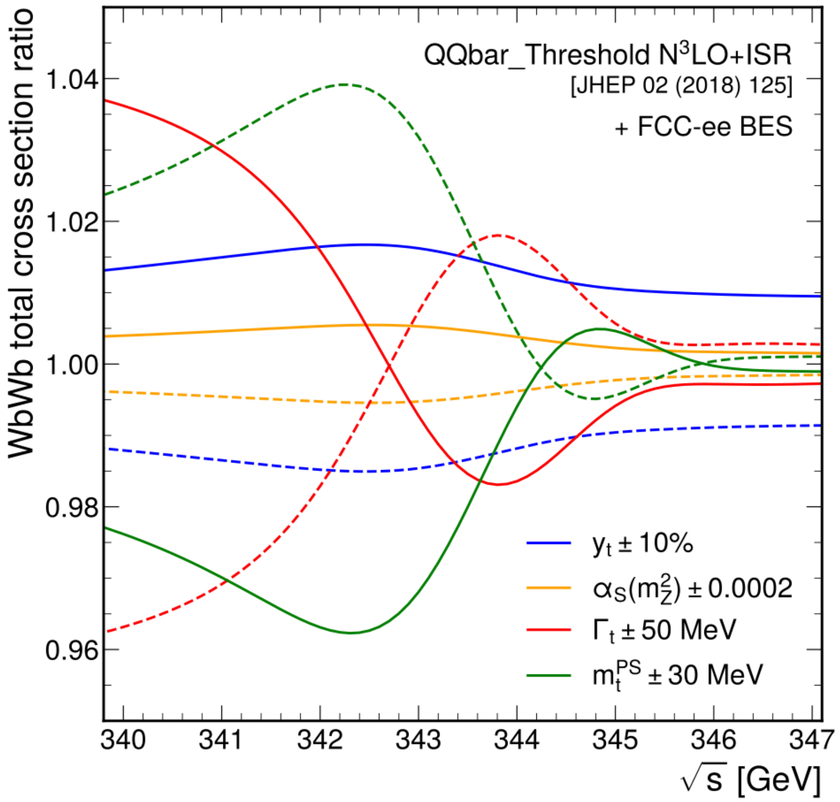
- Line shape dependence on top parameters



2203.06520

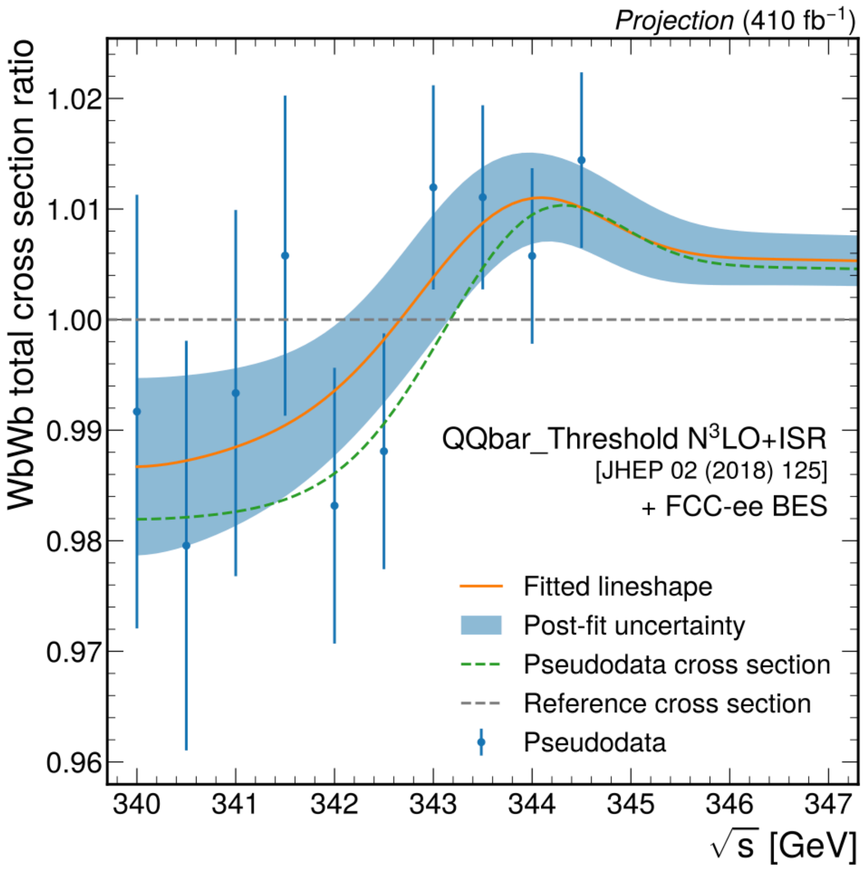


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top threshold scan

- 10 energy points with 0.5 GeV spacing
- m_t, Γ_t free params, α_s, y_t nuisances



2503.18713

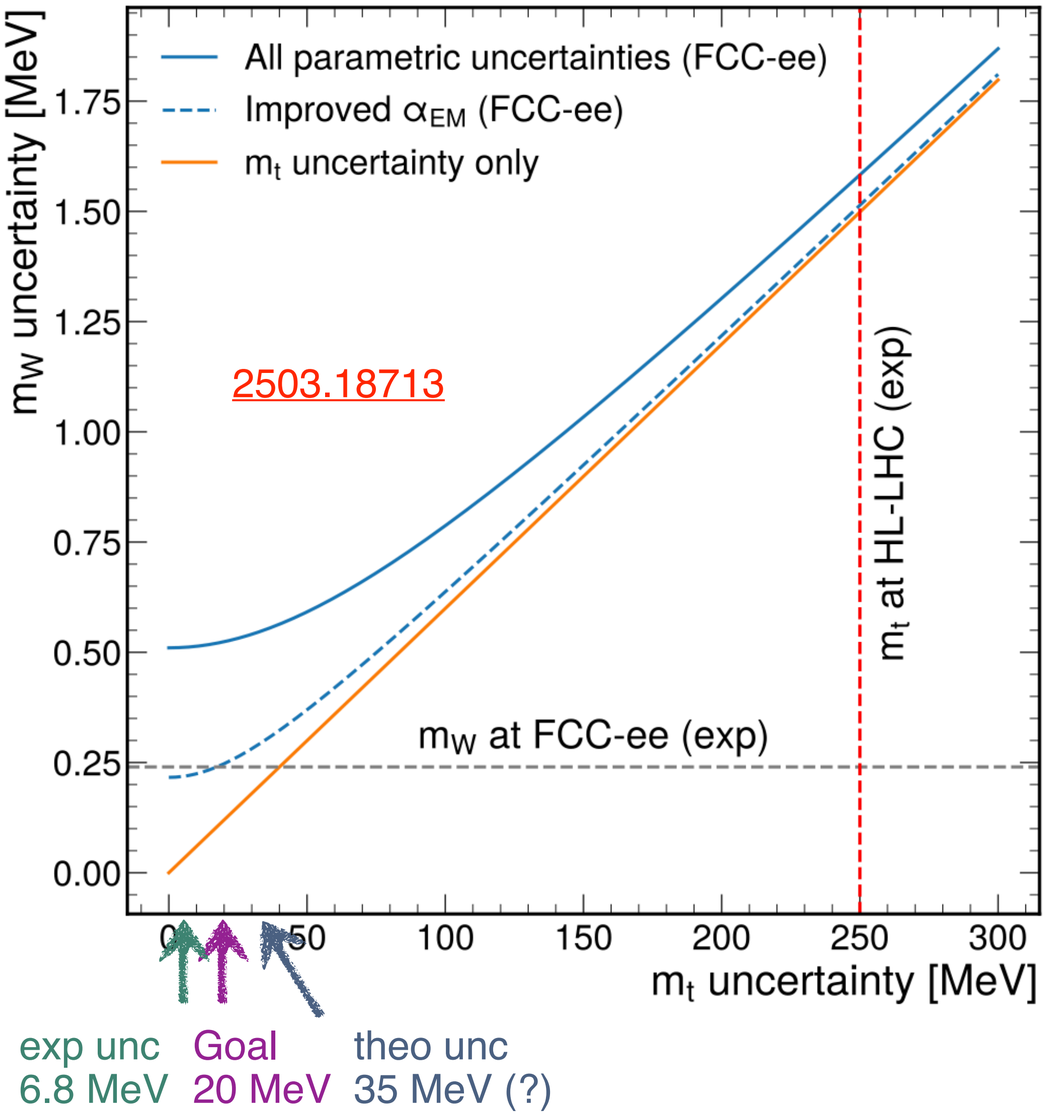
Uncertainty source	m_t^{PS} [MeV]	Γ_t [MeV]	Input values
Experimental (stat. $\times 1.2$)	4.3	10.4	$L = 410\,\text{fb}^{-1}$ (FCC-ee)
Parametric y_t	4.2	3.6	$\delta y_t = 3\%$
Parametric α_S	2.2	1.7	$\delta\alpha_S(m_Z^2) = 10^{-4}$
Luminosity calibration (uncorr.)	0.5	1.0	$\delta L/L = 0.1\%$
Luminosity calibration (corr.)	0.4	0.4	$\delta L/L = 0.05\%$
Beam energy calibration (uncorr.)	1.2	1.8	$\delta\sqrt{s} = 5\,\text{MeV}$ [41, 42]
Beam energy calibration (corr.)	1.2	0.1	$\delta\sqrt{s} = 2.5\,\text{MeV}$
Beam energy spread (uncorr.)	0.3	0.8	$\delta\Delta E = 1\%$ [41]
Beam energy spread (corr.)	0.1	1.1	$\delta\Delta E = 0.5\%$
Total profiled	6.8	11.5	
Theory, unprofiled (scale)	35	25	N^{3}LO NR-QCD [11]

total exp unc

proxy for theo unc
if vary renormalization
scale by factor of 2

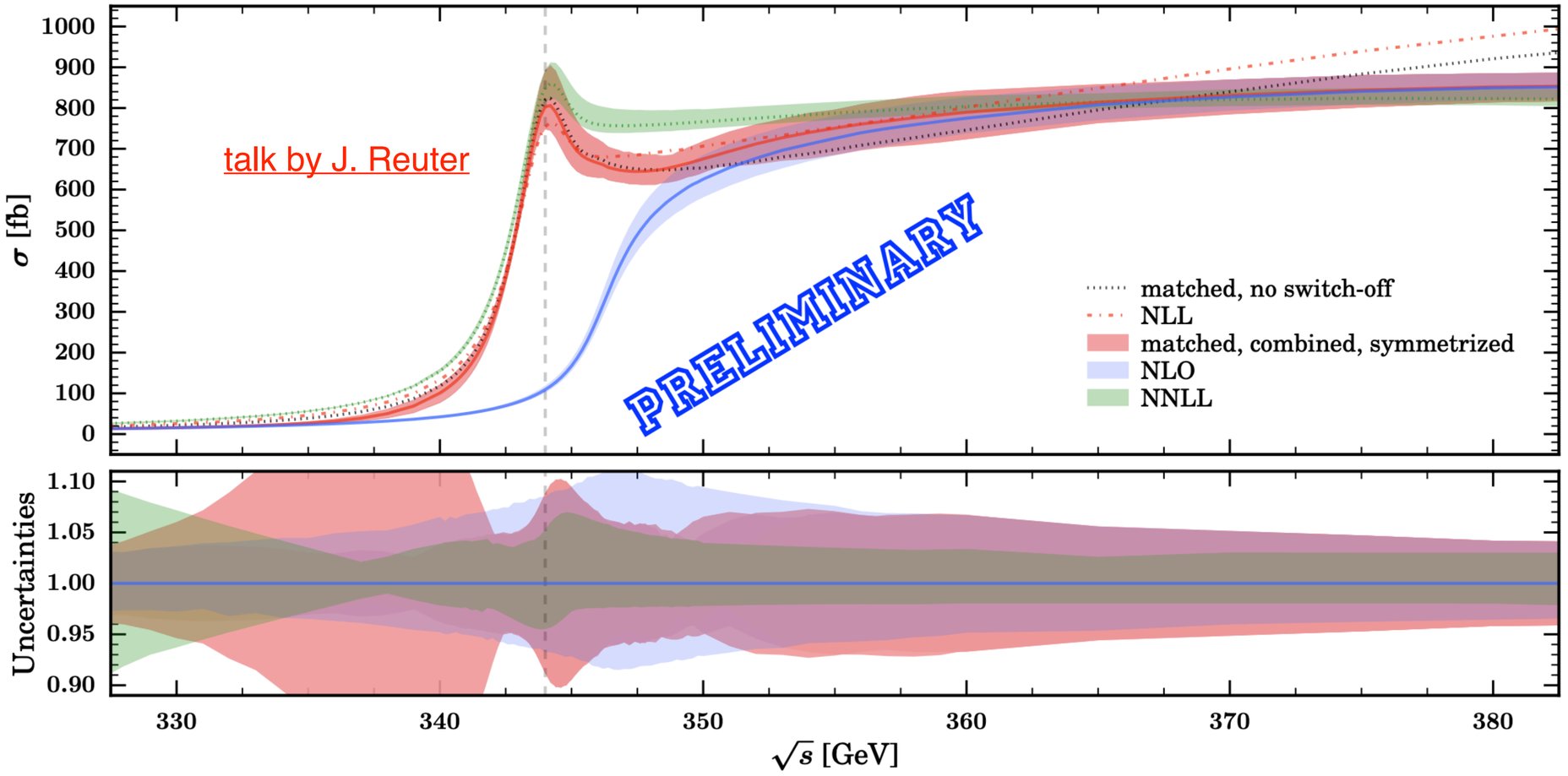
Interplay with m_W

- HL-LHC expect, optimistically, measure m_t at 250 MeV precision
- FCC-ee expect to measure m_W with exp precision of 0.24 MeV
- Considering other EW parameters with precision expected at FCC-ee, **need to know m_t better than 20 MeV precision to provide an SM prediction of m_W with comparable to exp precision**

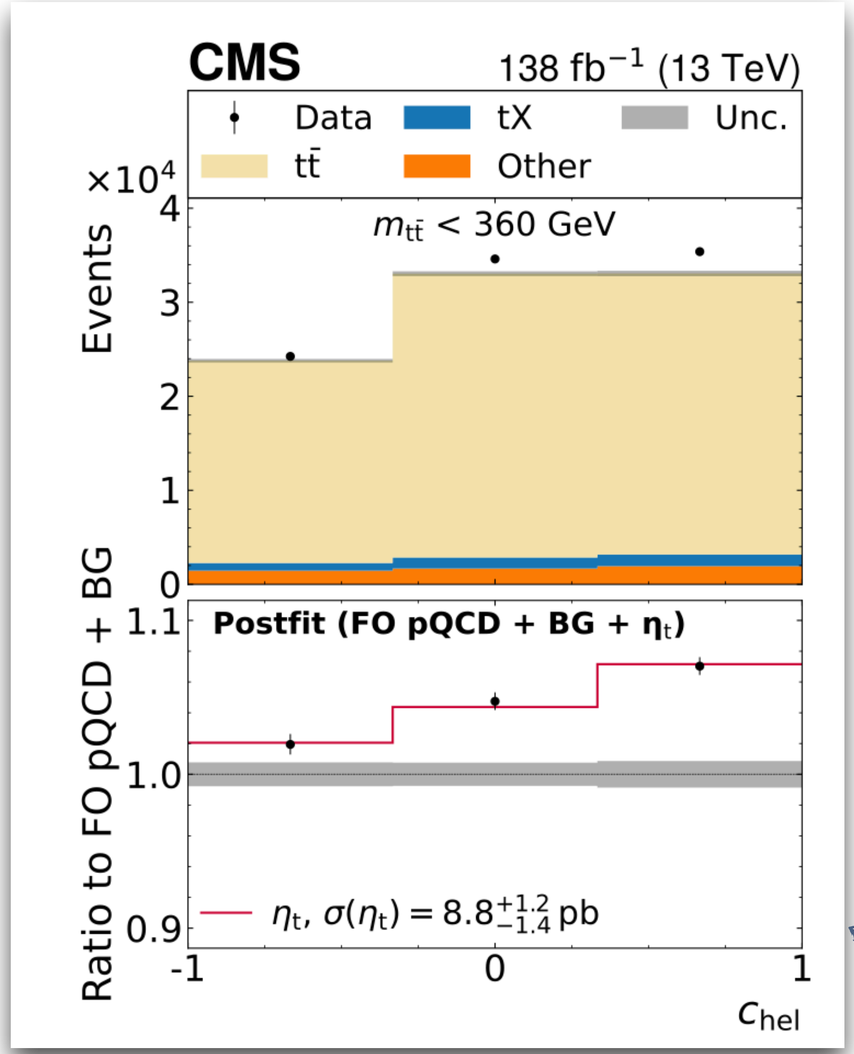


Theory modeling

- Need high order calculation (fixed order and resummation) for precise modeling

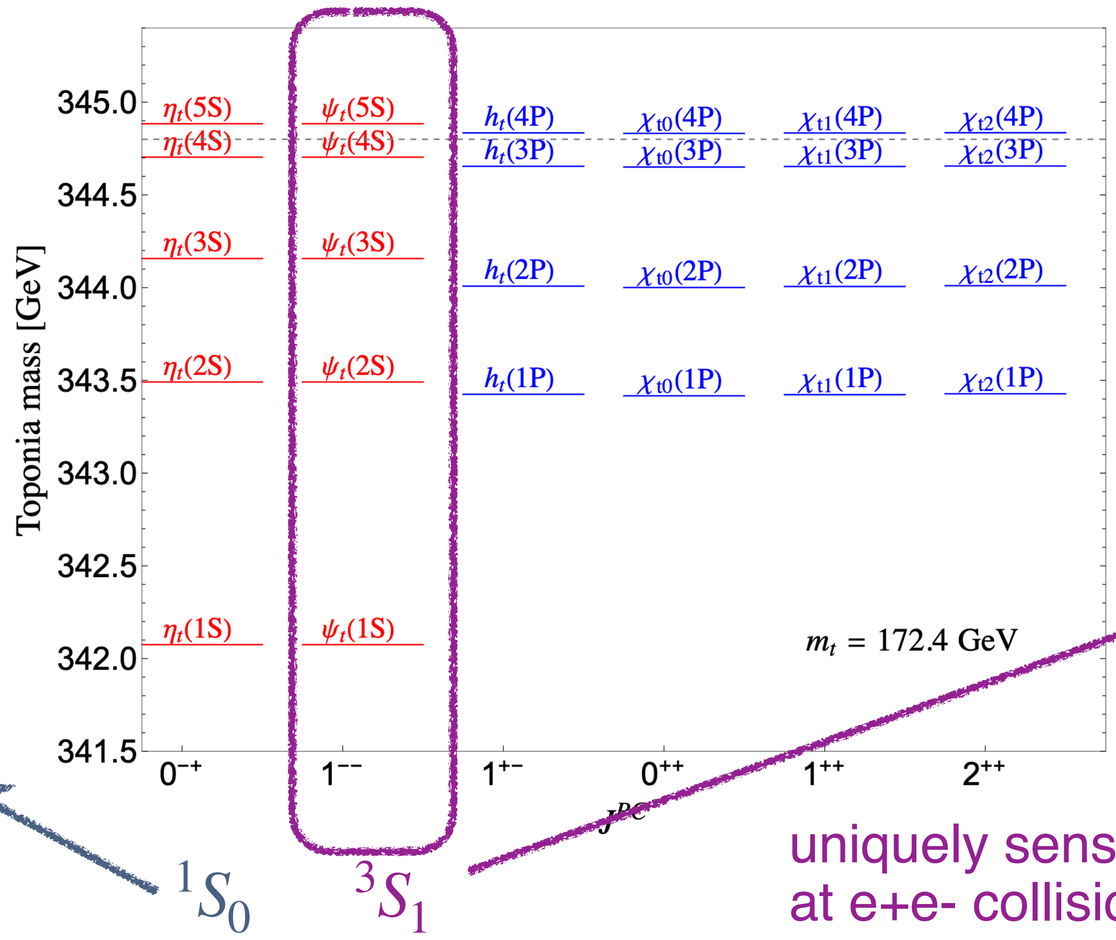


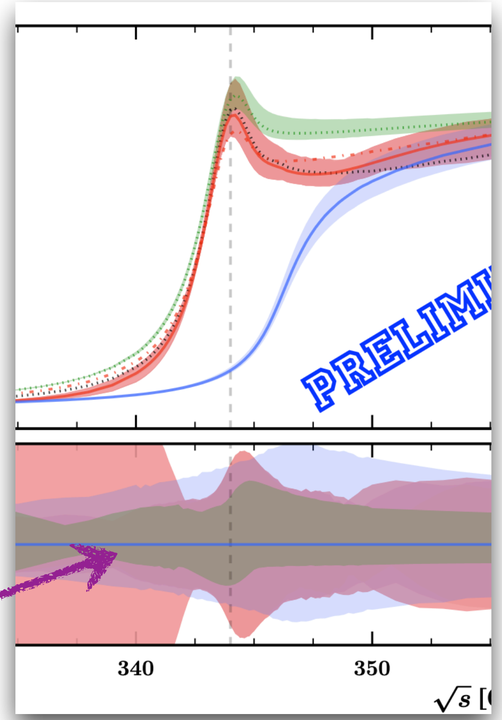
Toponium



CMS-TOP-24-007

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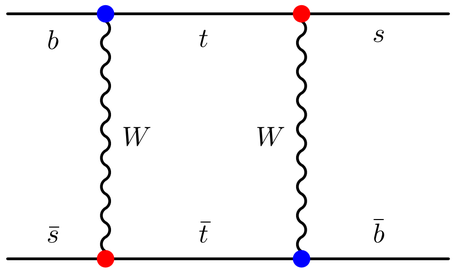


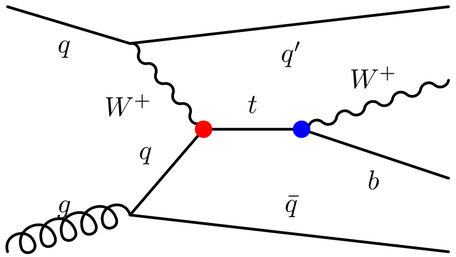


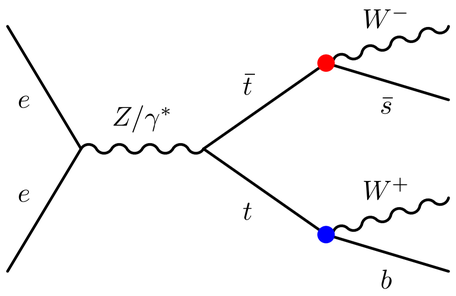
uniquely sensitive
at e+e- collisions

top and flavour physics

Direct CKM measurements — $|V_{ts}|$



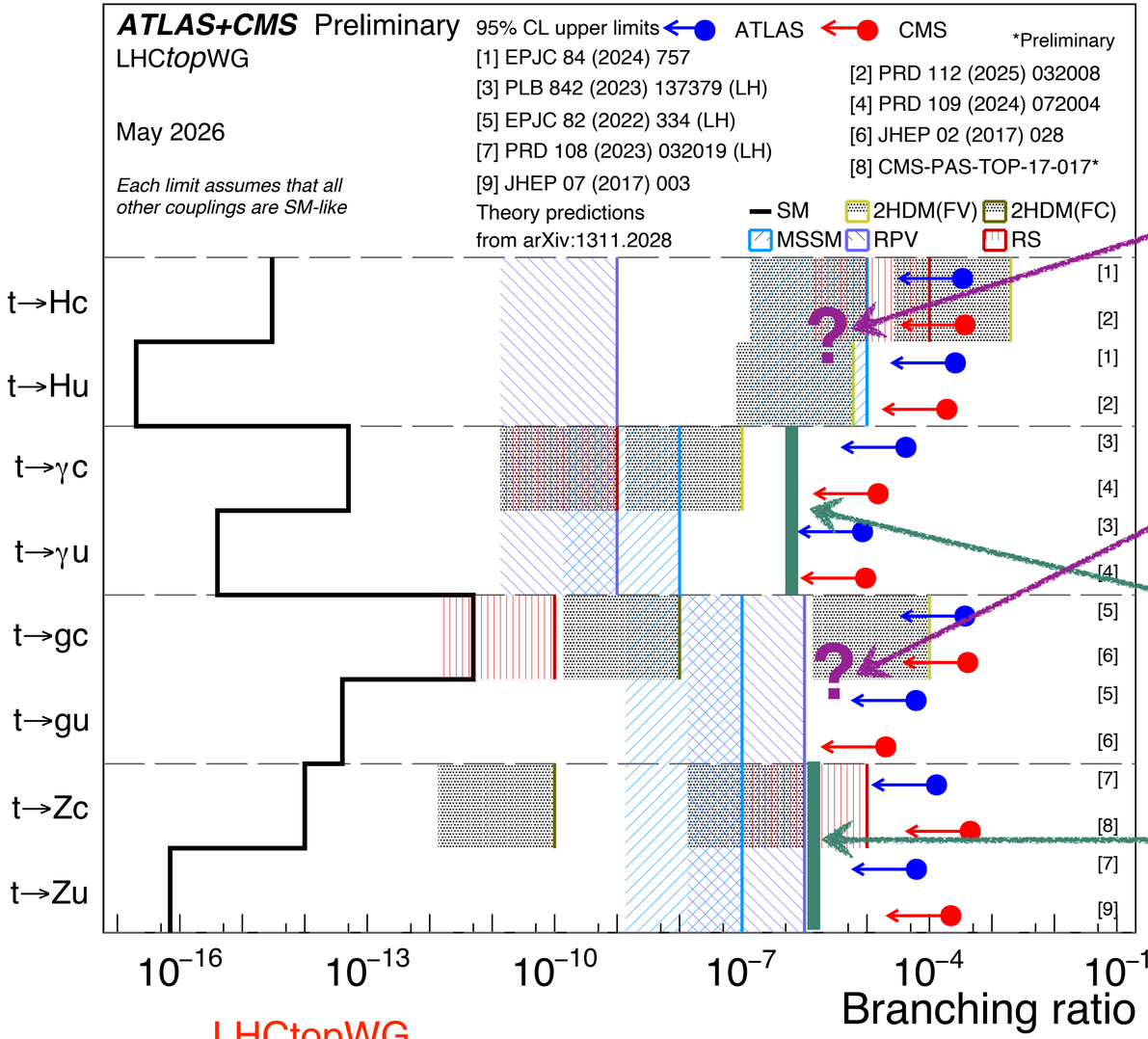




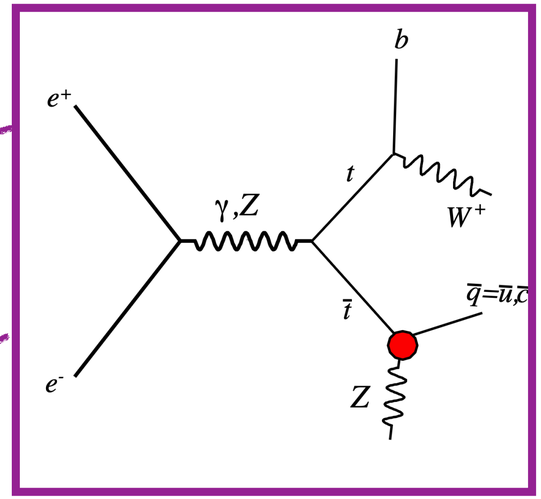
- $|V_{tb}|$
- $|V_{ts}|$

- Current (PDG): from $B_s^0 - \bar{B}_s^0$ mixing at LHCb
  - $|V_{ts}| = (41.5 \pm 0.9) \times 10^{-3}$ (**2.2%** precision)
  - Assume no NP in the loop, dominated by LQCD uncertainty
- Direct measurement at LHC: single top production
  - $|V_{ts}|^2 + |V_{td}|^2 = 0.06 \pm 0.06$, far from SM precision
- Potential at e^+e^- colliders
  - Model-independent direct measurement
  - FCC-ee expects $2 \times 10^6 \times 2 \times |V_{ts}|^2 \sim$ 6600 cases of $t \to Ws$ → **hard stats limit: 0.6%**
  - Expect precision on $|V_{ts}|$ at **3.1% or better** FCC note: Vts
  - Similar measurement for $|V_{tb}|$, expect O(0.1%) precision

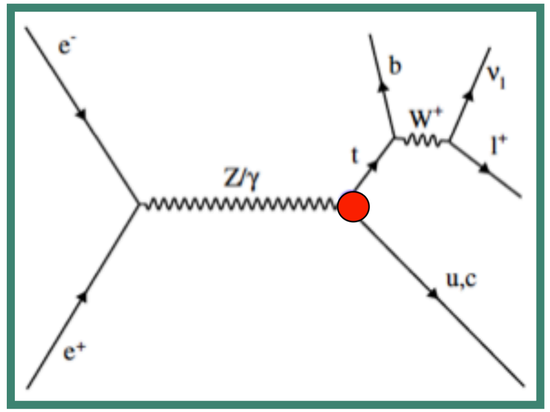
FCNC processes



LHCtopWG



only with $t\bar{t}$ run



achievable with 240 GeV run

top SMEFT and global fit

top quark SMEFT coupling

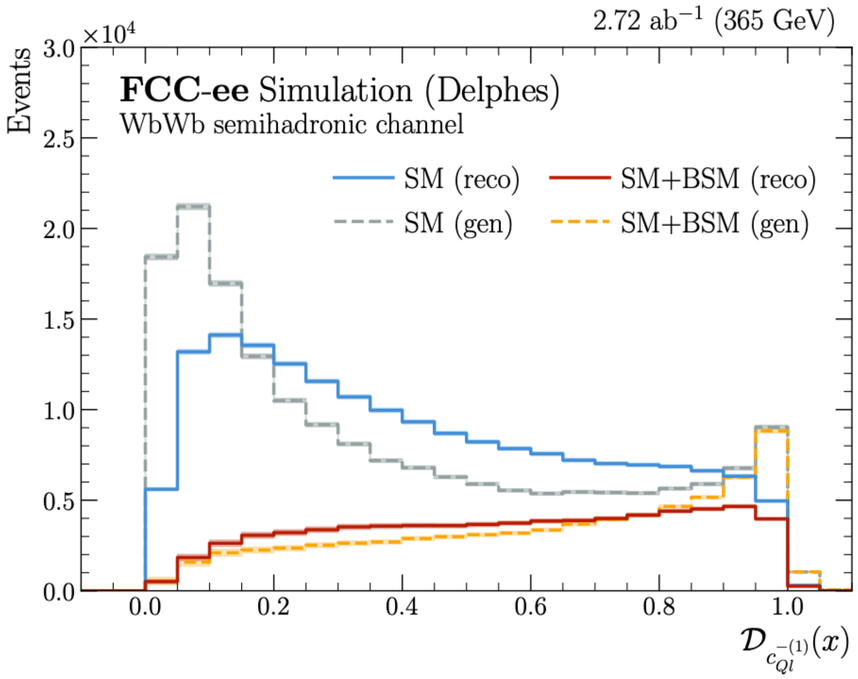
- Consider 2- and 4-fermion operators
- Optimal discriminants directly related to matrix elements

Operator	Definition	Coefficient
$O_{\varphi q}^{1(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{q}_i \gamma^\mu q_j)$	$c_{\varphi Q}^- + c_{\varphi Q}^3$
$O_{\varphi q}^{3(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar{q}_i \gamma^\mu \tau^I q_j)$	$c_{\varphi Q}^3$
$O_{\varphi u}^{(ij)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{u}_i \gamma^\mu u_j)$	$c_{\varphi t}$
$^\ddagger O_{uW}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} \tau^I u_j)\, \tilde{\varphi}\, W^I_{\mu\nu}$	$c_{tW} + i c_{tW}^I$
$^\ddagger O_{uB}^{(ij)}$	$(\bar{q}_i \sigma^{\mu\nu} u_j)\, \tilde{\varphi}\, B_{\mu\nu}$	$\frac{c_W c_{tW} - c_{tZ}}{s_W} + i \frac{c_W c_{tW}^I - c_{tZ}^I}{s_W}$
$O_{lq}^{1(ijkm)}$	$(\bar{l}_i \gamma^\mu l_j)(\bar{q}_k \gamma^\mu q_m)$	$c_{Ql}^{-(\ell)} + c_{Ql}^{3(\ell)}$
$O_{lq}^{3(ijkm)}$	$(\bar{l}_i \gamma^\mu \tau^I l_j)(\bar{q}_k \gamma^\mu \tau^I q_m)$	$c_{Ql}^{3(\ell)}$
$O_{lu}^{(ijkm)}$	$(\bar{l}_i \gamma^\mu l_j)(\bar{u}_k \gamma^\mu u_m)$	$c_{tl}^{(\ell)}$
$O_{e\bar{q}}^{(ijkm)}$	$(\bar{e}_i \gamma^\mu e_j)(\bar{q}_k \gamma^\mu q_m)$	$c_{Qe}^{(\ell)}$
$O_{eu}^{(ijkm)}$	$(\bar{e}_i \gamma^\mu e_j)(\bar{u}_k \gamma^\mu u_m)$	$c_{te}^{(\ell)}$
$^\ddagger O_{lequ}^{1(ijkm)}$	$(\bar{l}_i e_j)\, \varepsilon\, (\bar{q}_k u_m)$	$c_t^{S(\ell)} + i c_t^{SI(\ell)}$
$^\ddagger O_{lequ}^{3(ijkm)}$	$(\bar{l}_i \sigma^{\mu\nu} e_j)\, \varepsilon\, (\bar{q}_k \sigma_{\mu\nu} u_m)$	$c_t^{T(\ell)} + i c_t^{TI(\ell)}$

2609.16342

$$D(x_{reco}, \{c_i^{opt}\}) = \frac{\mathscr{L}_{SM+BSM}(x_{reco}, \{c_i^{opt}\})}{\mathscr{L}_{SM}(x_{reco})}$$

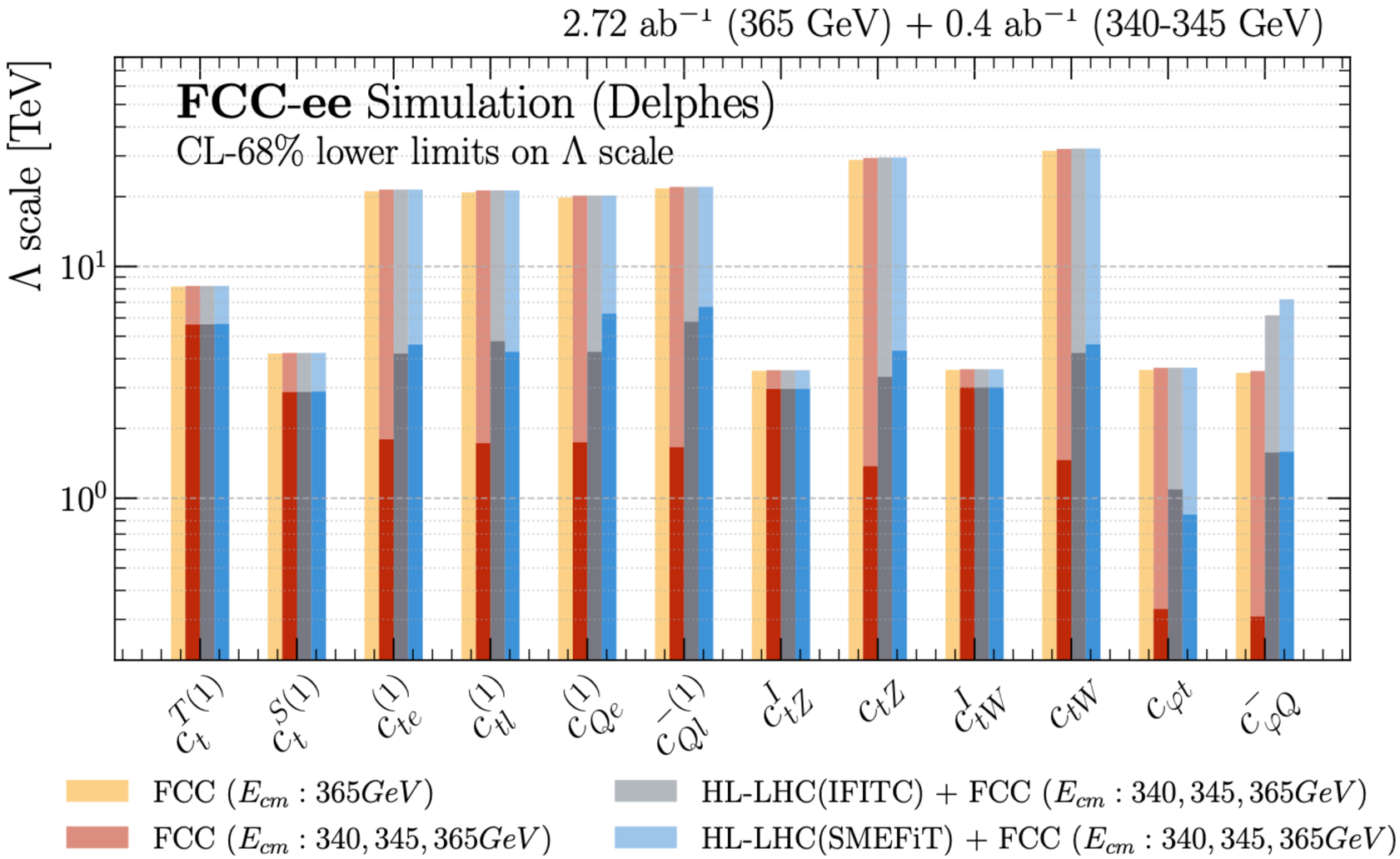
$$= \frac{|A_{SM}(x_{reco}) + \sum_i c_i^{opt} A_{EFT,i}(x_{reco})|^2}{|A_{SM}(x_{reco})|^2}$$



top SMEFT - limits

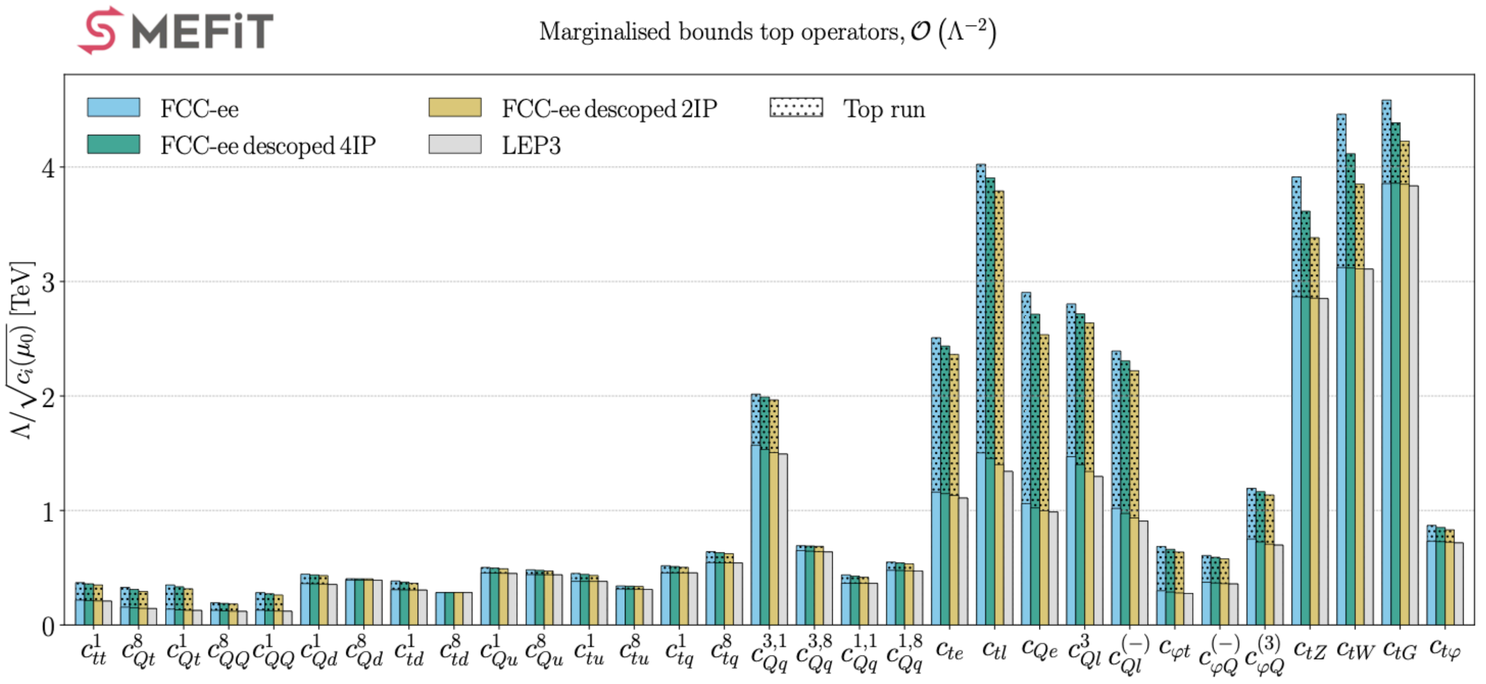
- Constrain EFT scale to O(10) TeV
- For a few operators, constrain comes purely from FCC-ee

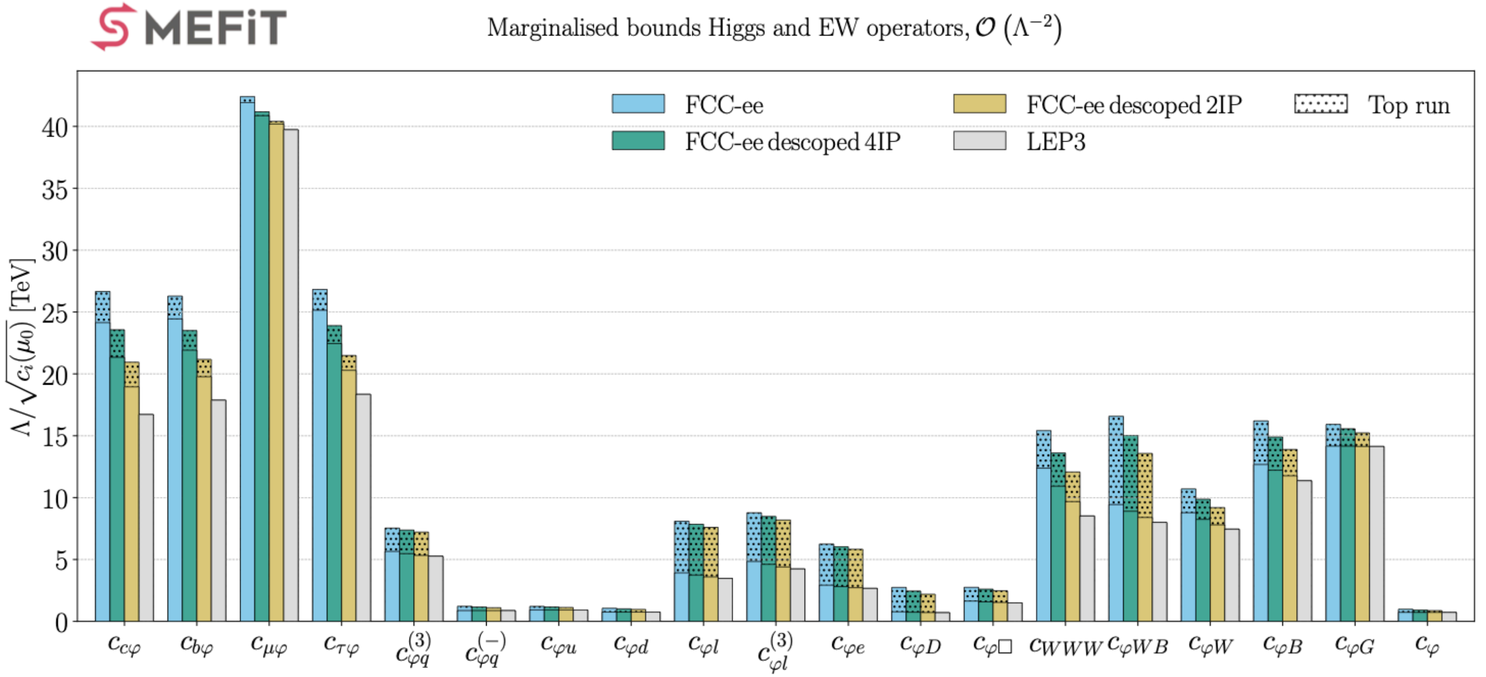
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SMEFT global fit

Constraining power much reduced without $t\bar{t}$ run

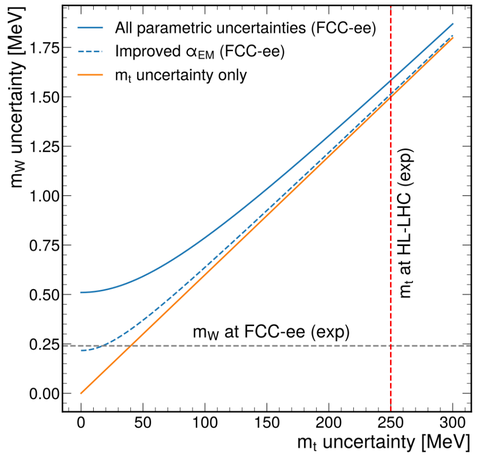




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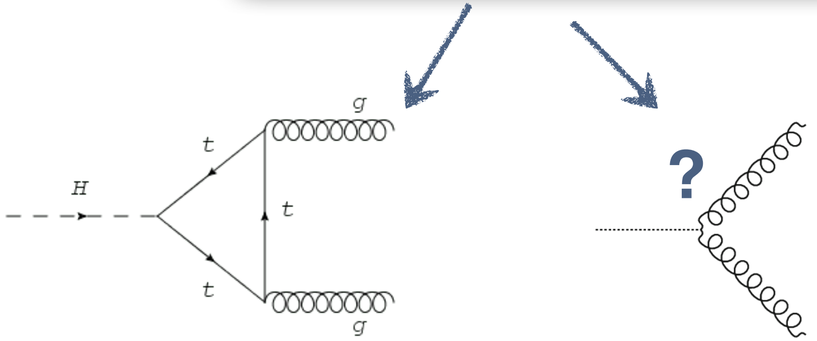
Interplay: top&others

top & EW

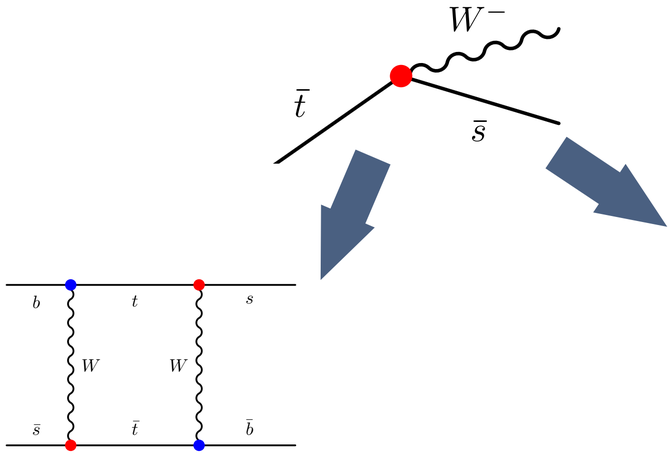


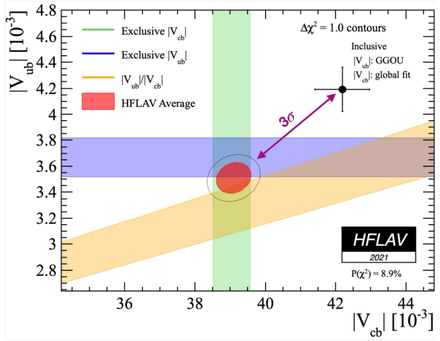
top & Higgs

$$H \to gg \qquad \pm 0.80\%$$

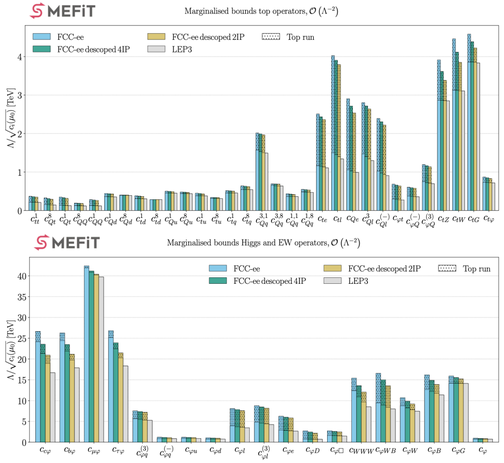


top & flavour





global SMEFT fit



2608.05874

Get in touch with us

subscribe to e-group: FCC-PED-PhysicsGroup-Top@cern.ch

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Juergen Reuter (juergen.reuter@desy.de),

Xunwu Zuo (xunwu.zuo@cern.ch)

Activity summary: https://github.com/HEP-FCC/FCCeePhysicsStudies/tree/master/phys-groups/top

Stay tuned: FCC Higgs/top/EW workshop, Jan 25-29, 2027

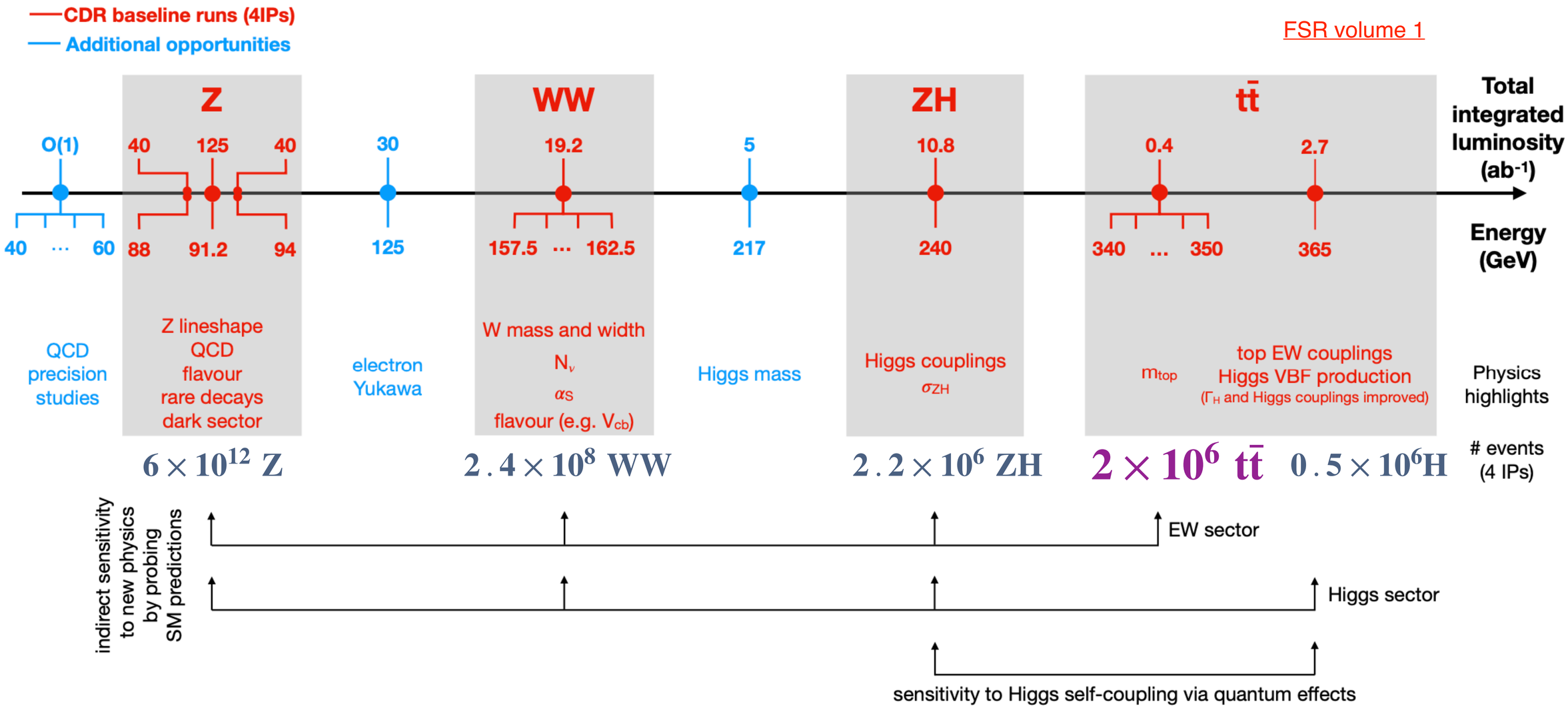
backup

A descoped FCC-ee

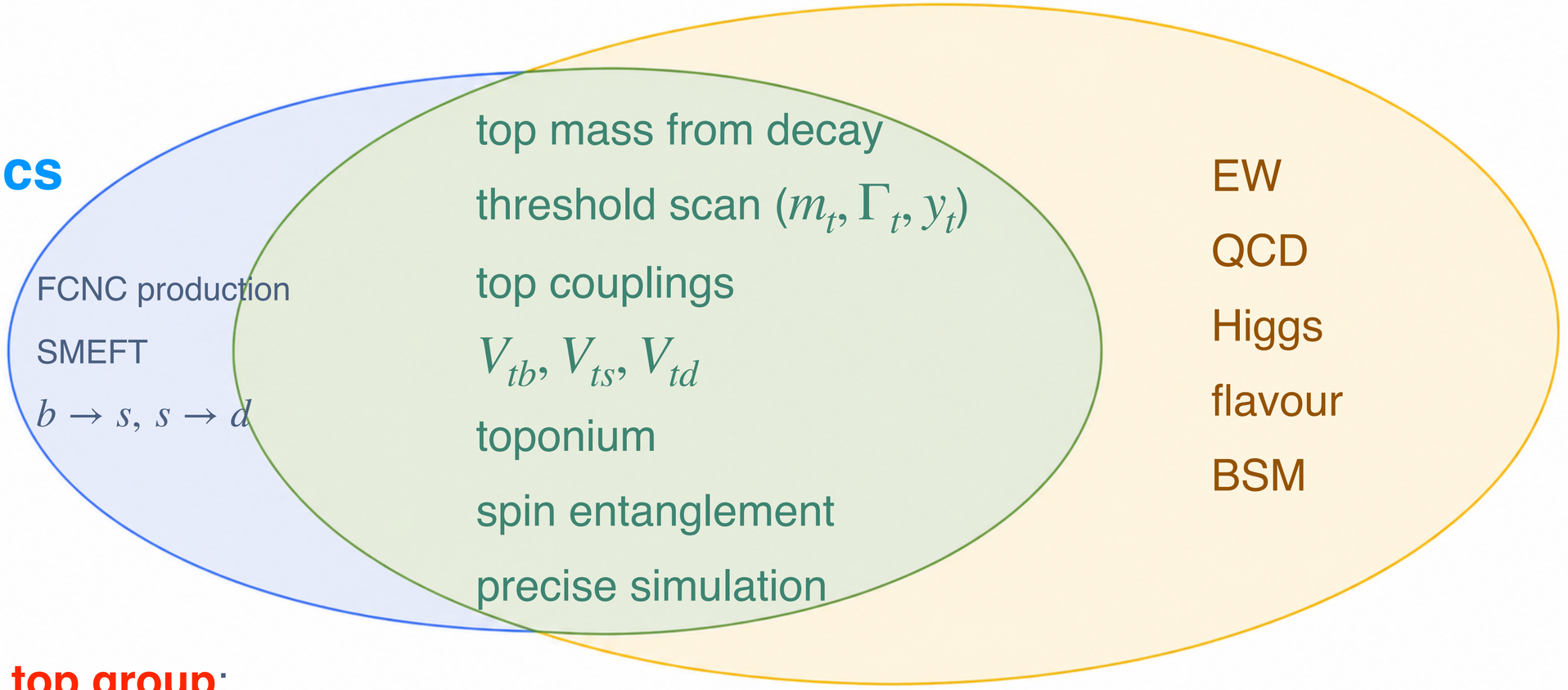
- **To improve financial feasibility**
  - Descoping scenarios include:
    - removing the top-quark run – 1.26 BCHF
    - constructing two rather than four
    - interaction regions and experiments – 0.80 BCHF
    - decreasing RF system power
    - (50 MW → 30 MW) – 0.35 BCHF
  - These measures would reduce construction cost by approximately 15%.
  - The luminosity would be lower by a factor 3/5 x 1/2 x 1.2 (reoptimization) = 0.36

- **Although this would have a significant impact on the breadth of the physics programme (top) and the precision achieved (luminosity), compared to the alternative collider options, the descoped FCC-ee would still provide**
  - A very strong physics programme and
  - A viable path towards high energies
  - Very importantly: Should additional resources become available, these descoping scenarios would be reversible.

FCC-ee physics runs



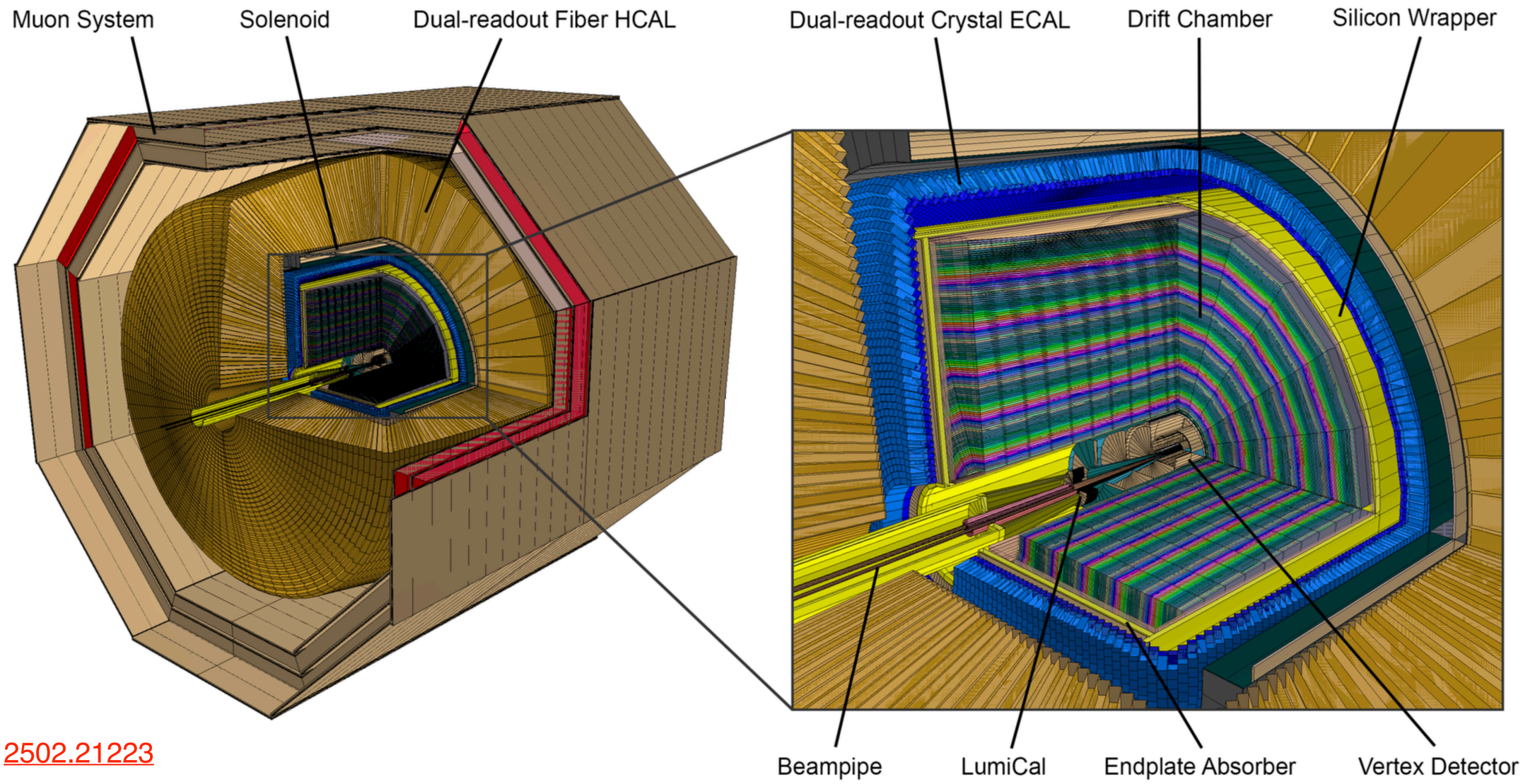
top run, top physics, top group



Goal of **top group**:

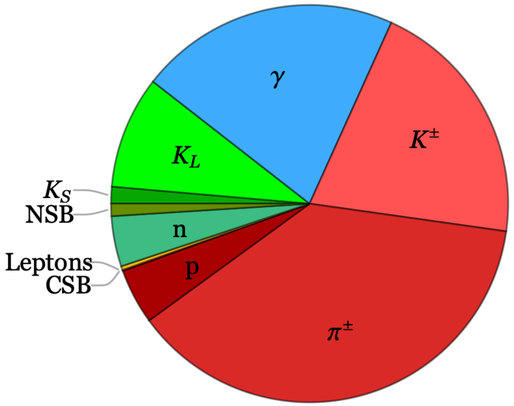
- Concrete and complete **top physics** results
- Together with theorist community, develop precise calculation/simulation
- Together with other physics groups, work out clear understanding of $t\bar{t}$ **run** impact

IDEA detector

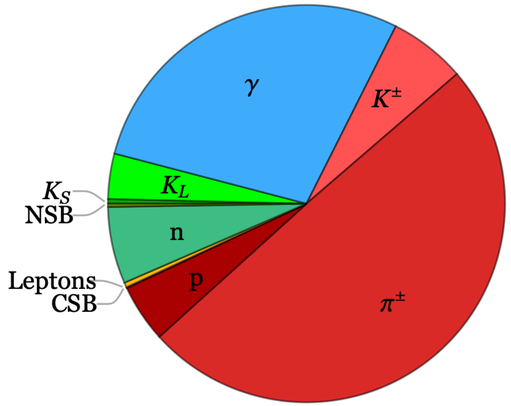


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$|V_{ts}|$ - Strange tagging

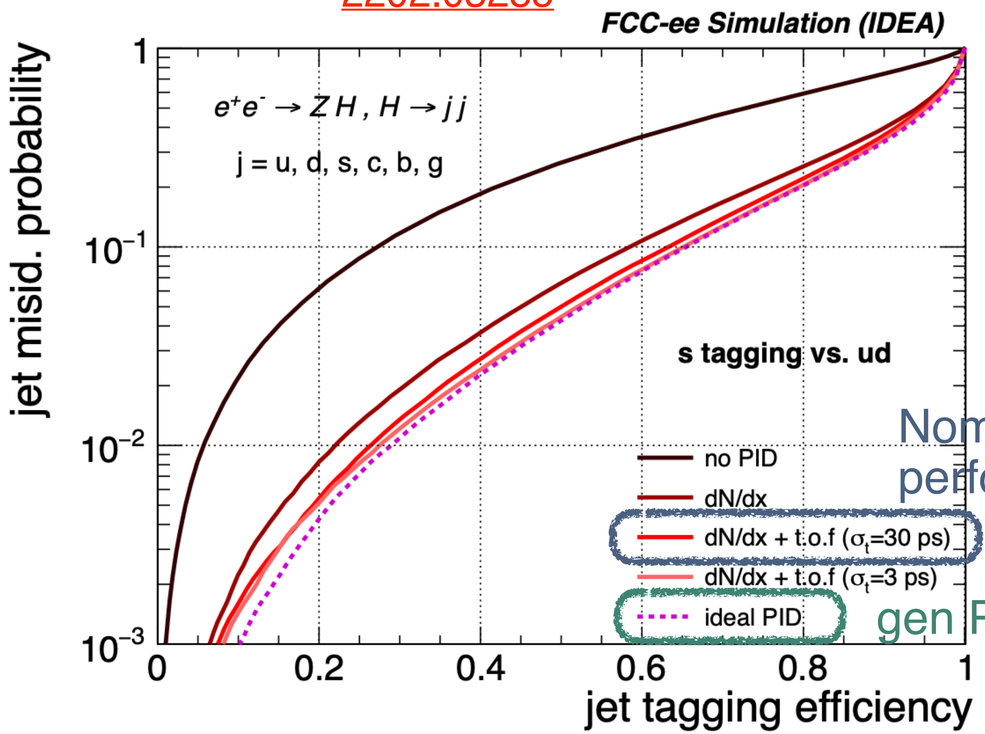


Strange $p_T = 45\,\text{GeV}$



Down $p_T = 45\,\text{GeV}$

2202.03285



Nominal performance

gen PID info

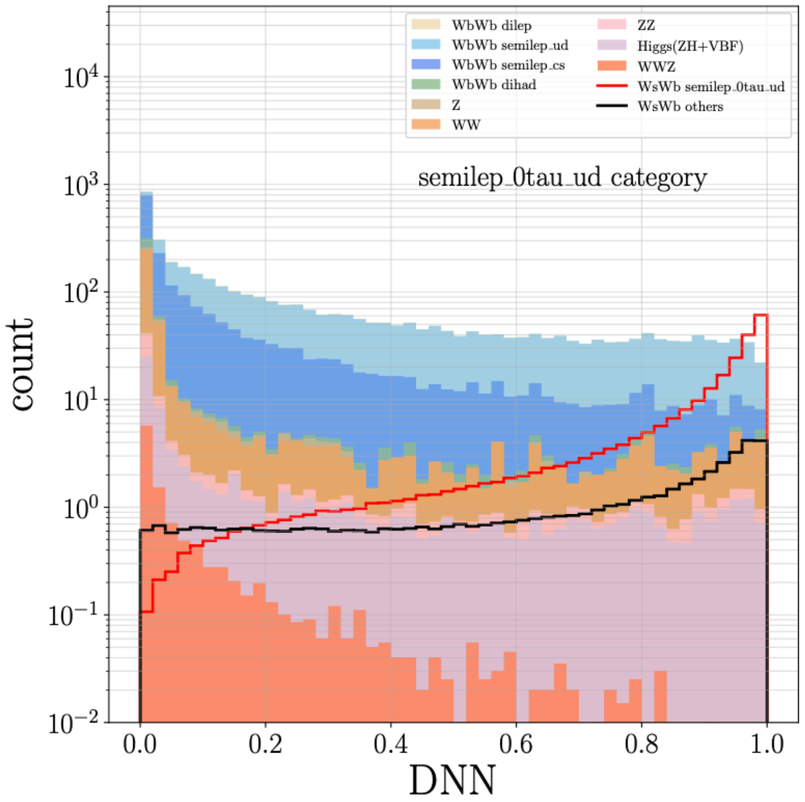
Limited natural separation between s and ud

- Main difference: high fraction of momentum carried by kaons
- Nominal PID (dN/dx, $\sigma(\text{TOF}) = 30$ ps) performance close to perfect PID

	Eff (**s**)	Mistag (**g**)	Mistag (**ud**)	Mistag (**c**)	Mistag (**b**)
Loose	90%	20%	40%	10%	1%
Medium	80%	9%	20%	6%	0.4%

$|V_{ts}|$, maybe $|V_{tb}|$, $|V_{td}|$

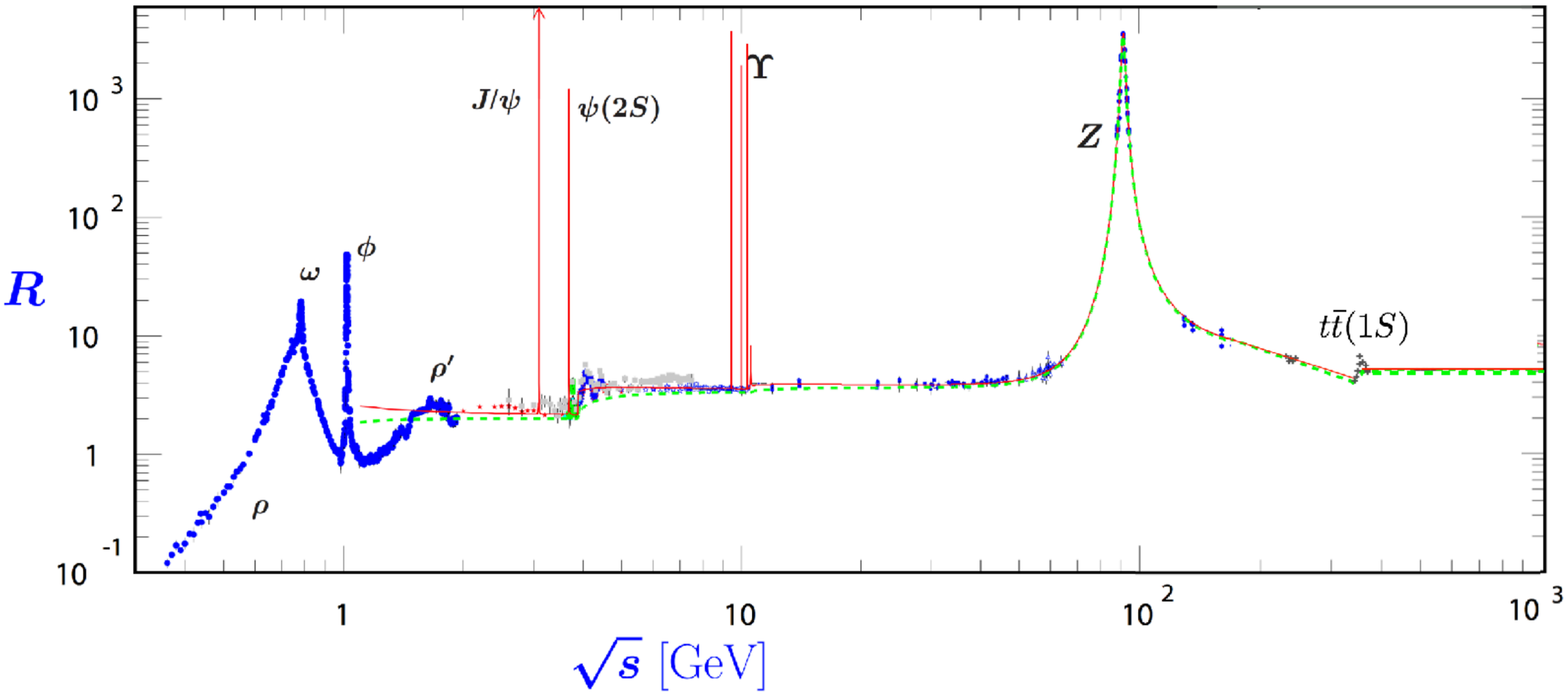
- 6.3% precision on $\mathcal{B}(t \to Ws)$ –> 3.1% on $|V_{ts}|$ (stats limited)
- $|V_{tb}|$ will depend on tagging uncertainty
- $|V_{td}|$ will have large uncertainty (total 300 events)



FCC note: Vts

Fit config	Free bkg	bkg ±20%	bkg ±5%	bkg ±2%	bkg ±1%
category					
dilep_0tau	14.5%	12.4%	12.0%	11.9%	11.8%
semilep_0tau_ud	13.2%	10.8%	10.2%	9.9%	9.7%
semilep_0tau_cs	30.3%	18.9%	18.3%	17.8%	17.7%
dihad_ud_only	25.4%	20.2%	19.8%	19.1%	18.6%
dihad_udcs	32.4%	26.0%	25.6%	24.7%	24.1%
dihad_cs_only	108%	83.1%	78.4%	76.5%	76.2%
combined	6.8%	6.6%	6.5%	6.4%	6.3%

$|V_{ts}|$ stats limited

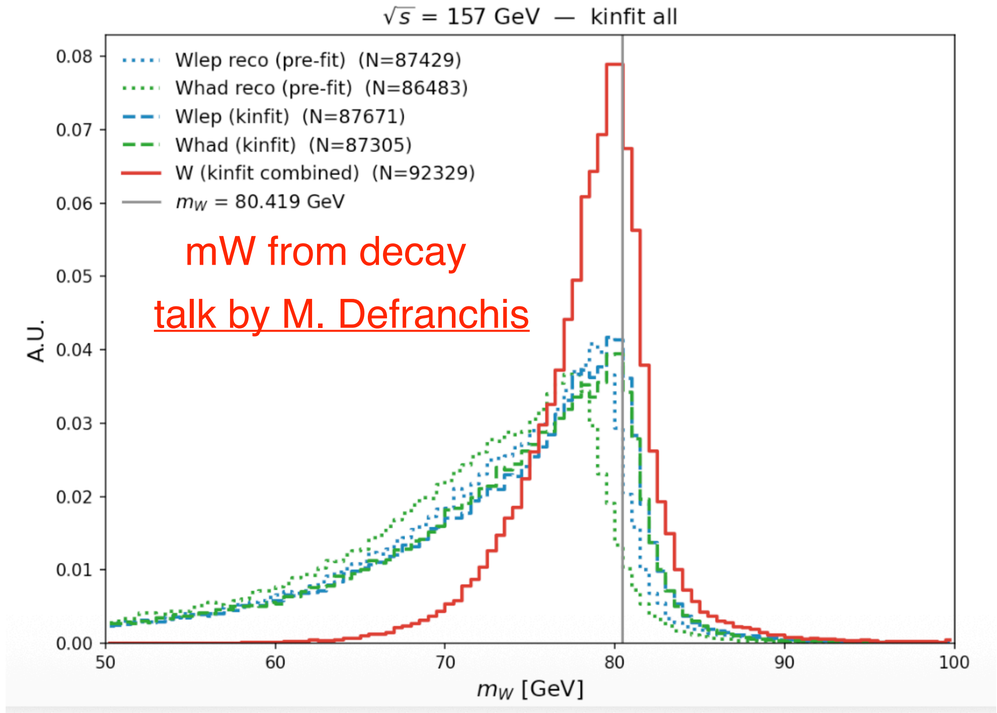

R
10^3
10^2
10
1
10^{-1}
J/ψ
$\psi(2S)$
Υ
Z
$t\bar{t}(1S)$
ω
ϕ
ρ'
ρ
1
10
10^2
10^3
$\sqrt{s}$ [GeV]

More about top masses

- On-shell mass M: inverse quark propagator has zero at on-shell mass talk by J. Reuter
- $\overline{\mathrm{MS}}$ mass m: just divergent part is subtracted to achieve a finite quark propagator
- Short-distance masses: PS [potential subtr.], 1S, RS [renormalon subtr.] masses
- 1S mass is half the (pert.) mass of the 1^3S_1 bound state

MC template from threshold scan - PS/1S mass

mass from decay reco - pole mass



conversion uncertainty

$\Delta M_{PS} = 23\,\mathrm{MeV}$ $\Delta M_{1S} = 7\,\mathrm{MeV}$ $\Delta M_{RS} = 11\,\mathrm{MeV}$