EW physics at FCC-ee



challenges, priorities, and ongoing work

CEPC workshop 2026

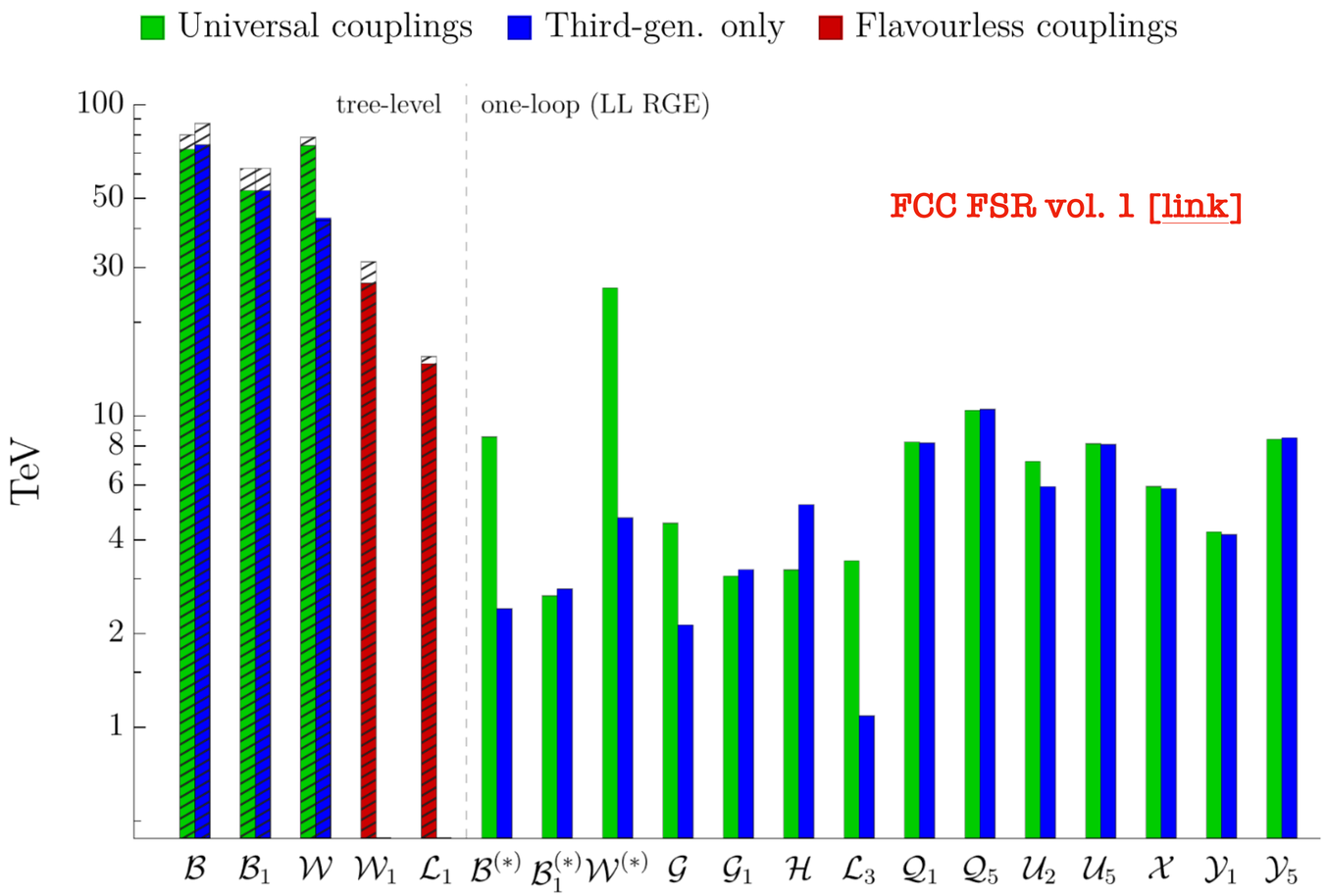
Matteo Defranchis (CERN)



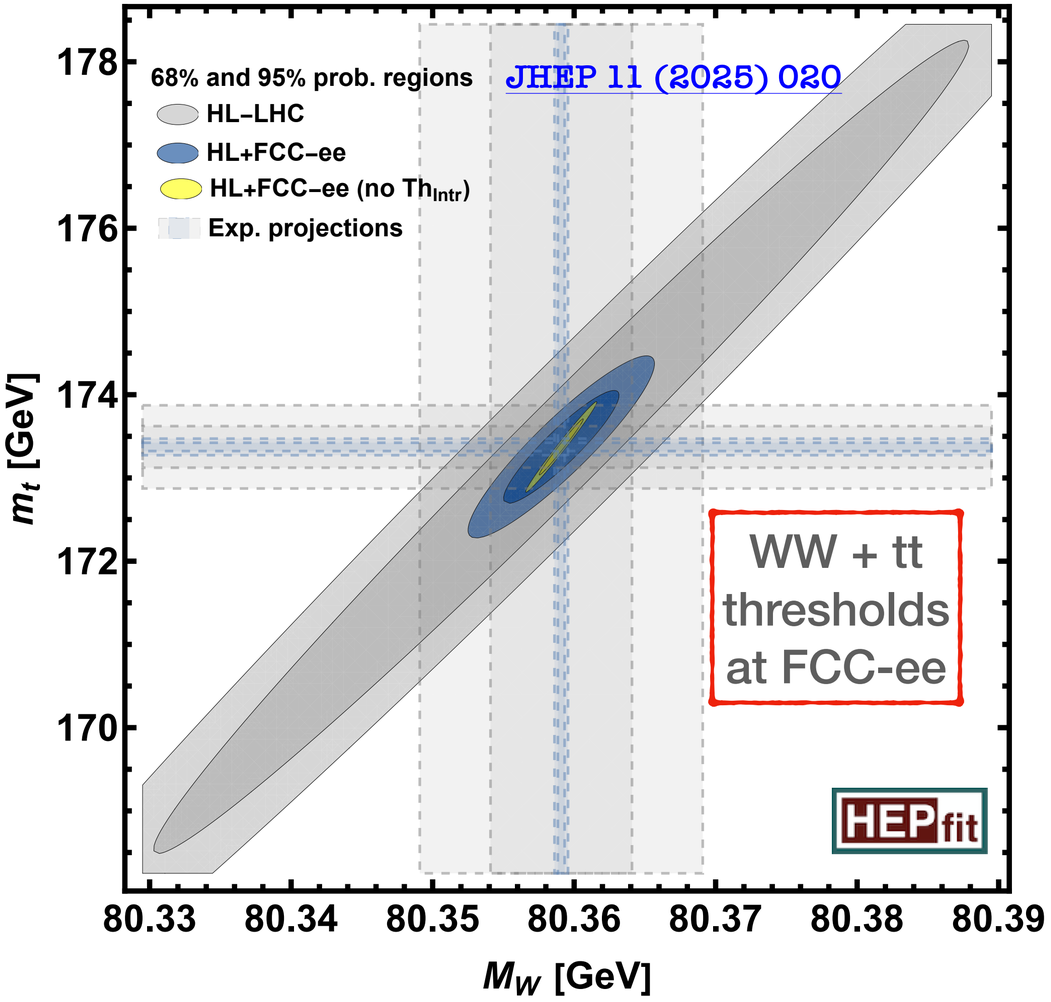
FUTURE CIRCULAR COLLIDER

for the conveners of the FCC-ee EW precision group

SM precision = BSM sensitivity



FCC FSR vol. 1 [link]

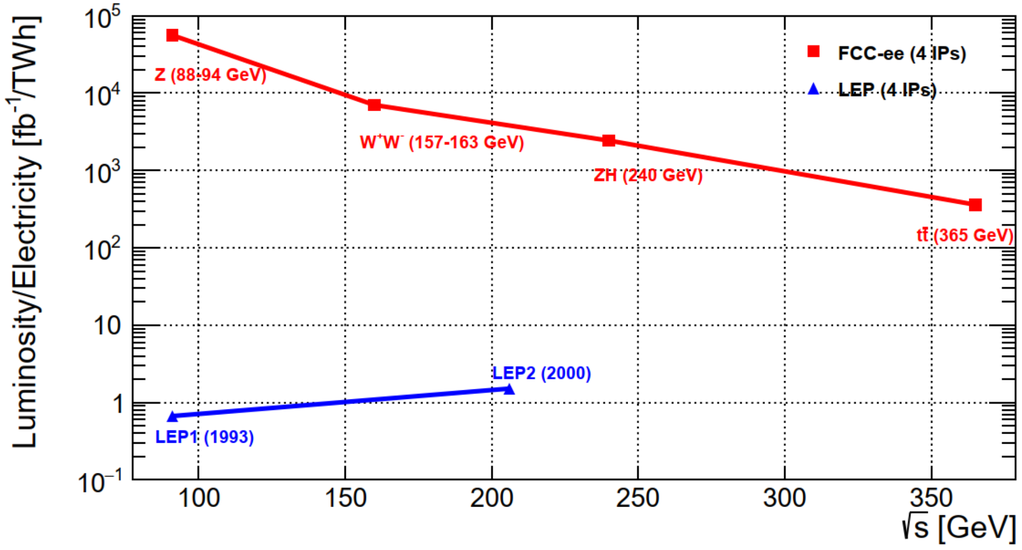


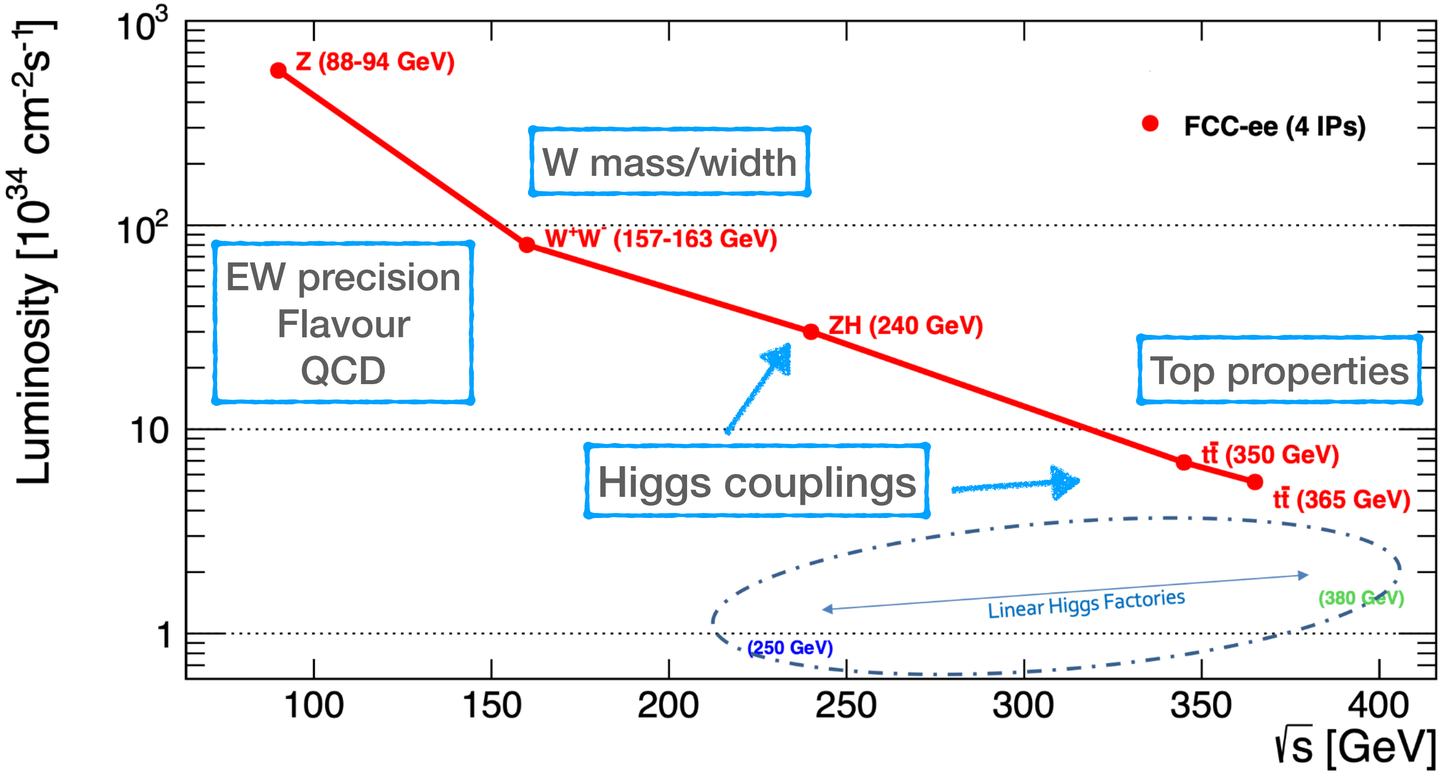
A large fraction of experimental challenges are related to estimating/controlling theoretical/modelling uncertainties (true at all colliders)

FCC-ee: an EW factory

- Enormous amount of Z and WW events
- Entire LEP program at Z pole every 30s

Main challenge: control systematics at the level of statistical precision





Working point	Z pole	WW thresh.	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94	157, 163	240	340–350	365
Lumi/IP (10^{34} cm^{-2}s^{-1})	140	20	7.5	1.8	1.4
Lumi/year (ab^{-1})	68	9.6	3.6	0.83	0.67
Run time (year)	4	2	3	1	4
Integrated lumi. (ab^{-1})	205	19.2	10.8	0.42	2.70
Number of events	6×10^{12} Z	2.4×10^8 WW	2.2×10^6 ZH + 65k WW $\to$ H	2×10^6 $t\bar{t}$ + 370k ZH + 92k WW $\to$ H	

FCC-ee EW precision challenges and priorities

Alignment / acceptance / calibration (incl. flavour tagging)

Z pole

- Z mass/width from Z line shape
- FB asymmetries, EW mixing angle
- QED coupling alpha(m_Z)

- Z hadronic decay fractions Rb/Rc/Rs…
- Z flavour violating decays

WW threshold

- W mass/width from threshold scan
- Direct m_W from decay products

- CKM elements

Improved MC tools / higher order calculations / (pseudo-)observables definition

-> detailed studies in fast/full simulation+ **reanalysis of archived LEP data!**

Z pole run

Z line shape

J. Bendavid [link]

E. Manca [link]

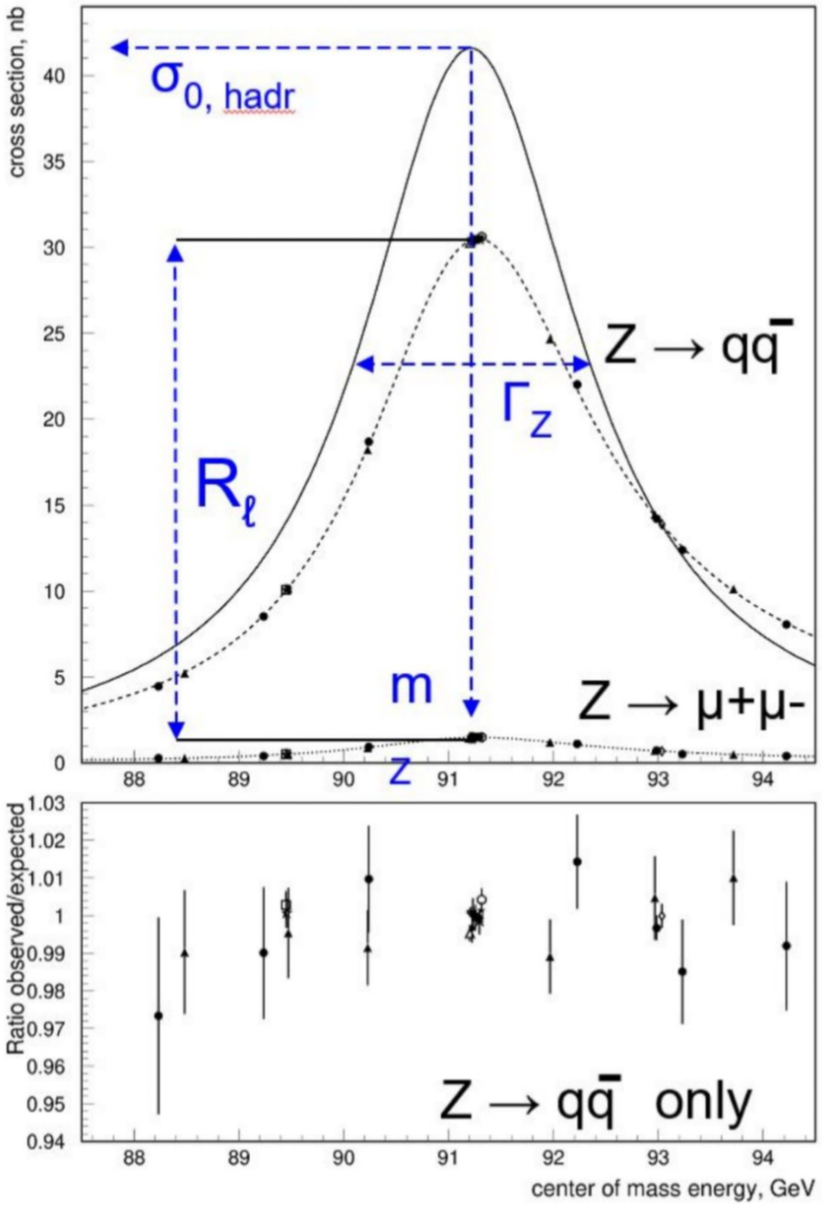
- Measure **total production cross section** as a function of √s
- Compare to standalone **theory prediction** to extract physical parameters (mass, total width...)

Stringent control over energy, luminosity, efficiency, acceptance + correlations & theoretical uncertainties

Challenge: **in-situ calibration** of relevant uncertainties + interplay between RDP, luminosity measurement, beam calibration
-> combined workflow?

Plan: start with a "commissioning run" with 1% of the total luminosity (still >10^{10} Z bosons) + incremental approach

Conceptual challenges: folding vs unfolding of detector effects, (pseudo-)observable definition, ISR (de-)convolution...

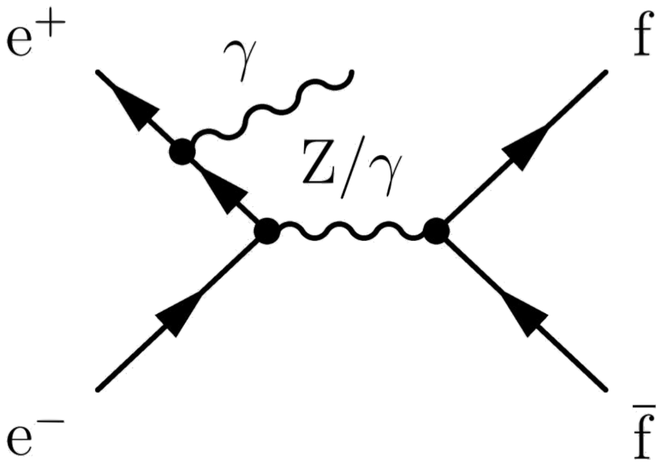


Luminosity and energy calibration

WIP

J. Eysermans [link]

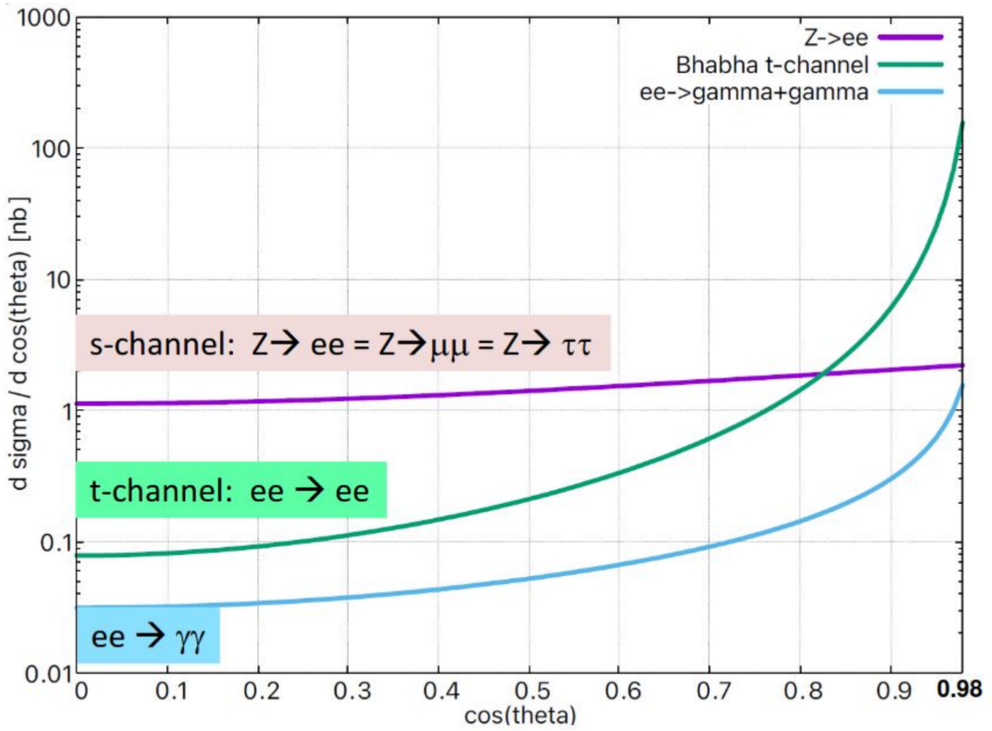
√s (GeV)	$\mathcal{L}_{int}$ (ab^{-1})	$\mu\mu$ channel	qq channel	Combined
160	19	321 keV	160 keV	143 keV
240	10.8	1.15 MeV	451 keV	420 keV
350 (total)	0.41	9.15 MeV	3.94 MeV	3.80 MeV
350 (each point)	0.041	28.9 MeV	12.5 MeV	12.0 MeV



- **Stringent requirements** on both luminosity and ecm calibration **at all runs** (Z, WW, ZH, tt)

- Ecm calibration using **RDP** at Z and WW
  - some new ideas using muon threshold production [J.Bendavid]
- Final state distributions in **Z radiative returns** above -> requires precise muon calibration (+stability)

- Luminosity calibration either via **forward Bhabha** (higher stats, more theory dependent) or **central di-photon** events (requires excellent photon tagging)



10^{-5} control of the electron/ photon acceptance required

$\alpha_{QED}(m_Z)$ on/off Z peak

J. Eysermans [link], M. Riembau [arXiv]

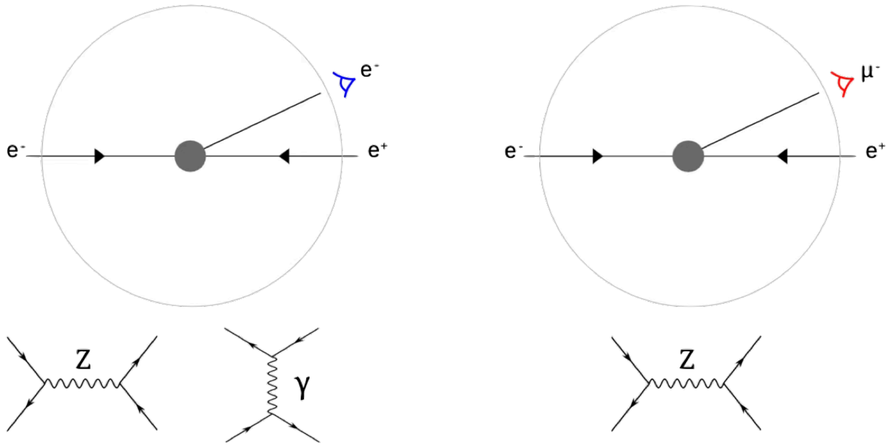
- Low-energy precision spoiled by QCD contributions in evolution to m_Z -> **needs to be measured at Z pole**
- On-off shell method can reach 3×10^{-5} precision

- Alternative method: **lepton ratios in forward region** can improve to 6×10^{-6} level (electron/muon)

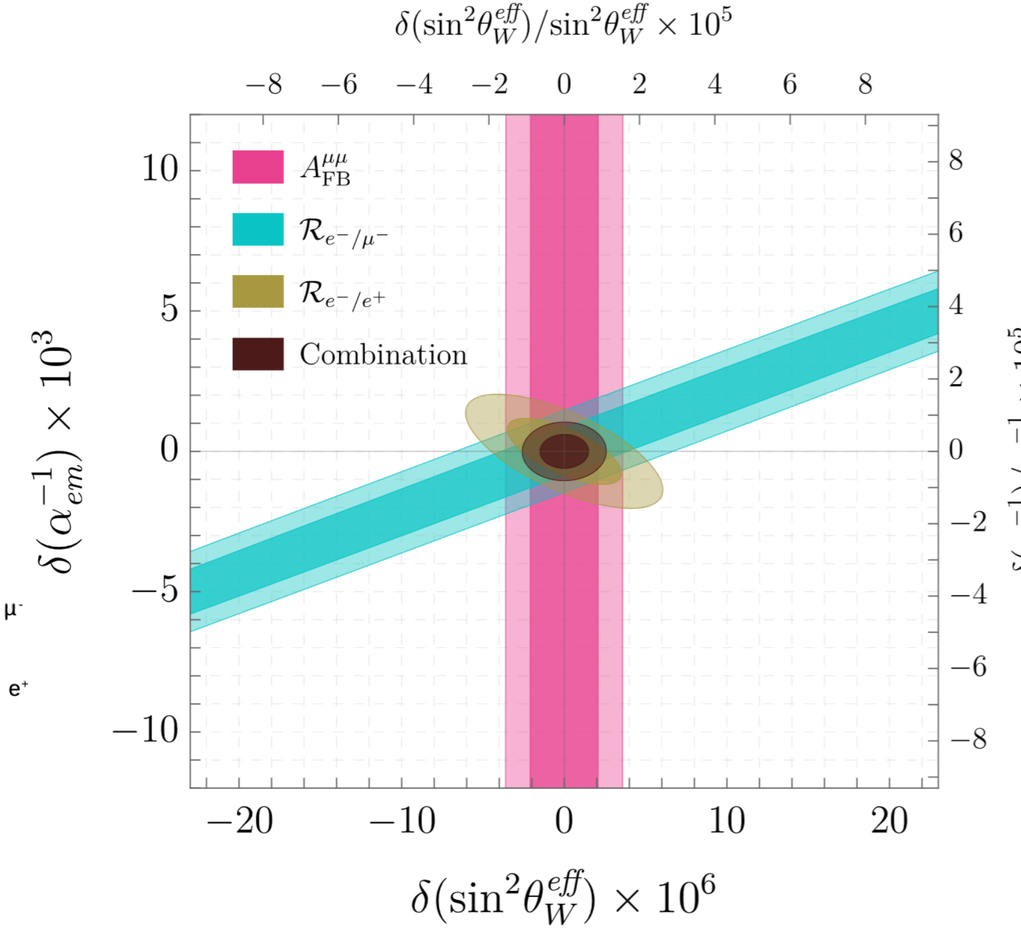
Challenge: electron/muon identification in foward region

Especially challenging for electrons (beam backgrounds, detector material) + acceptance difference between e/μ

Can also measure at different energies to probe running



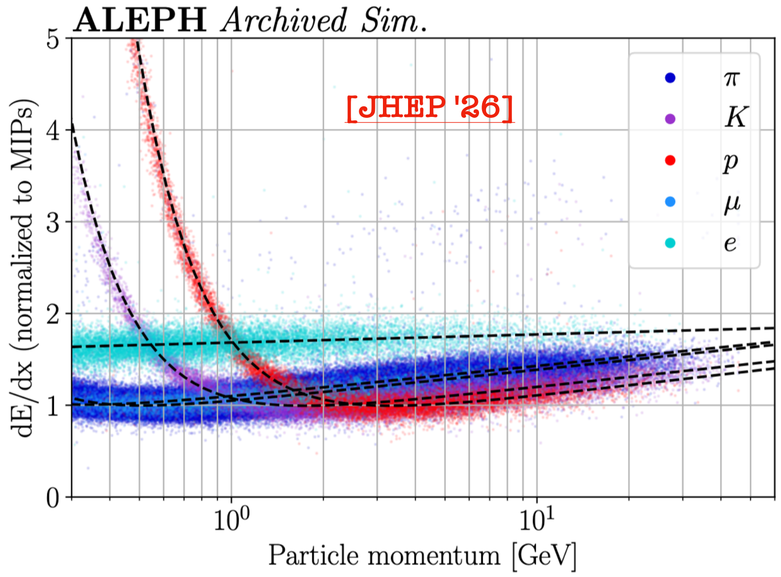
One of dominant parametric uncertainties in global EW fits

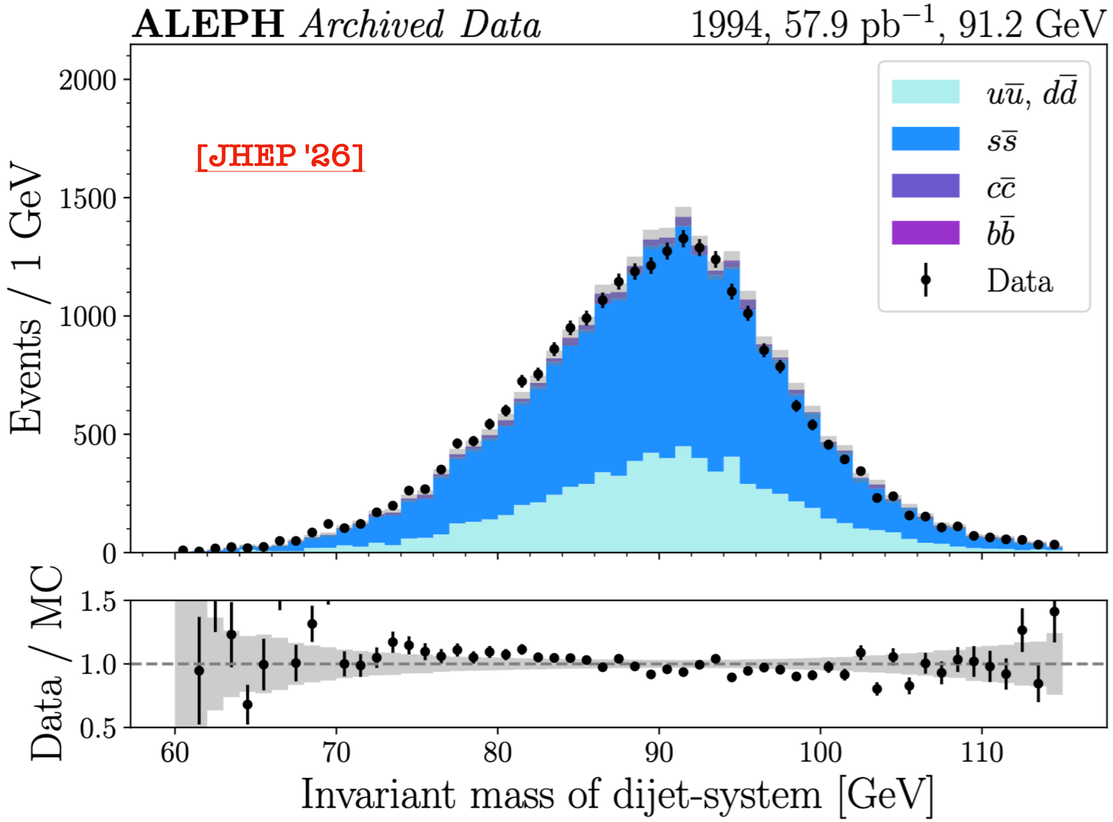


Z->qq at LEP and FCC-ee

See A. Fathei's talk + [link]

- **Archived ALEPH data** converted to edm4hep
- **Modern jet flavour tagging techniques** significantly improve heavy flavour jet identification
- First dedicated s-flavour tagger!





Effort kicked-off for FCC-ee studies [L. Toffolin, MD]

- **in-situ tagger calibration at the 10^{-6} level**
- detailed study of hemisphere correlations

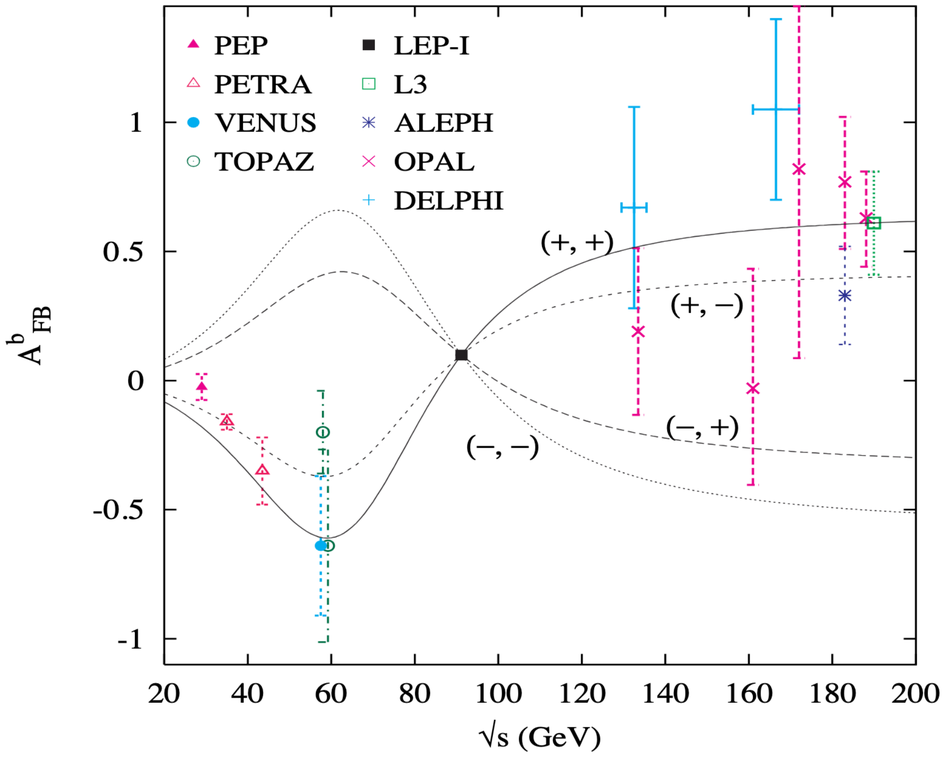
- Simultaneous measurement of **R_b and R_c** with modern taggers and in-situ calibration
- Study of strange fragmentation & **R_s** measurement
  - Relevant e.g. for H->ss projections

Re-discover main experimental challenges and obtain detector requirements for FCC-ee

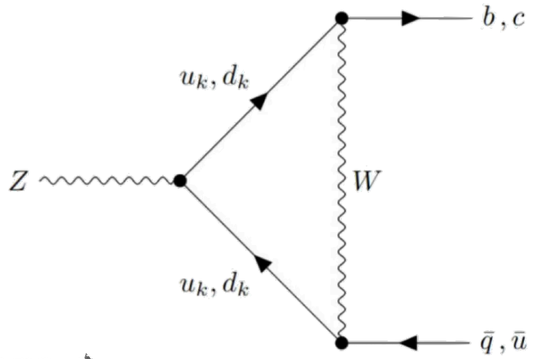
$A_{FB}(qq)$ & Z flavour violating decays

WIP

G. Panizzo et al [link]



K. Cormier [link]



A_{FB} can be measured for b/c/s at FCC-ee

- Requires development and calibration of **jet charge tagger**
- Cancellation of systematics -> stat limited
  -> large improvement wrt LEP can be expected

Z flavour violating decays

- **Extremely rare**, accessible thanks to tera-Z sample
- Crucially relies on tagging performance and calibration

Challenge: **calibrate tagger without assuming flavour universal decays** -> extended ABCD for all flavours simultaneously

Decay	SM prediction	exp. bound	indir. constr.
$\mathcal{B}(h \to bs)$	$(8.9 \pm 1.5) \cdot 10^{-8}$	0.16	2×10^{-3}
$\mathcal{B}(h \to bd)$	$(3.8 \pm 0.6) \cdot 10^{-9}$	0.16	10^{-3}
$\mathcal{B}(h \to cu)$	$(2.7 \pm 0.5) \cdot 10^{-20}$	0.16	2×10^{-2}
$\mathcal{B}(Z \to bs)$	$(4.2 \pm 0.7) \cdot 10^{-8}$	2.9×10^{-3}	6×10^{-8}
$\mathcal{B}(Z \to bd)$	$(1.8 \pm 0.3) \cdot 10^{-9}$	2.9×10^{-3}	6×10^{-8}
$\mathcal{B}(Z \to cu)$	$(1.4 \pm 0.2) \cdot 10^{-18}$	2.9×10^{-3}	4×10^{-7}

WW threshold

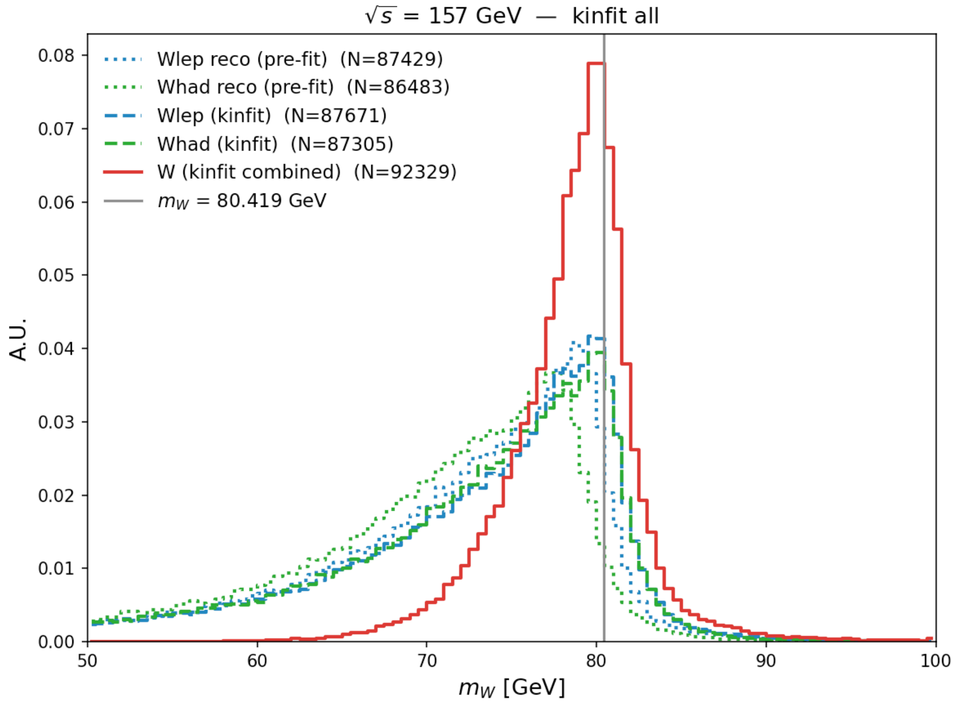
m_W: threshold scan & kinematic reco

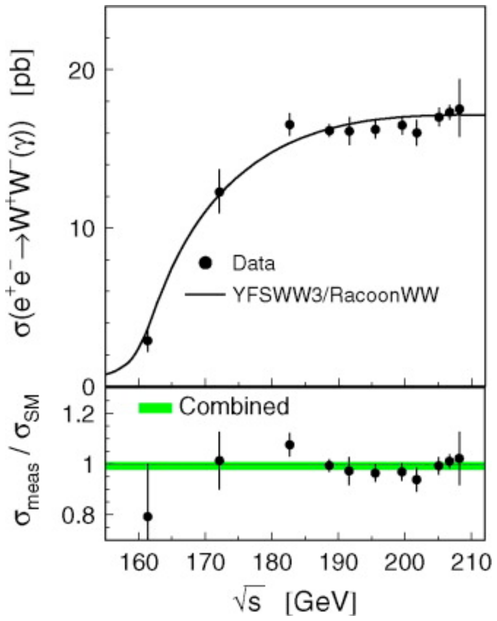
MD [link], Ankita Mehta,
A. Singh, D. D'Enterria
+ U. Tehran group [link]

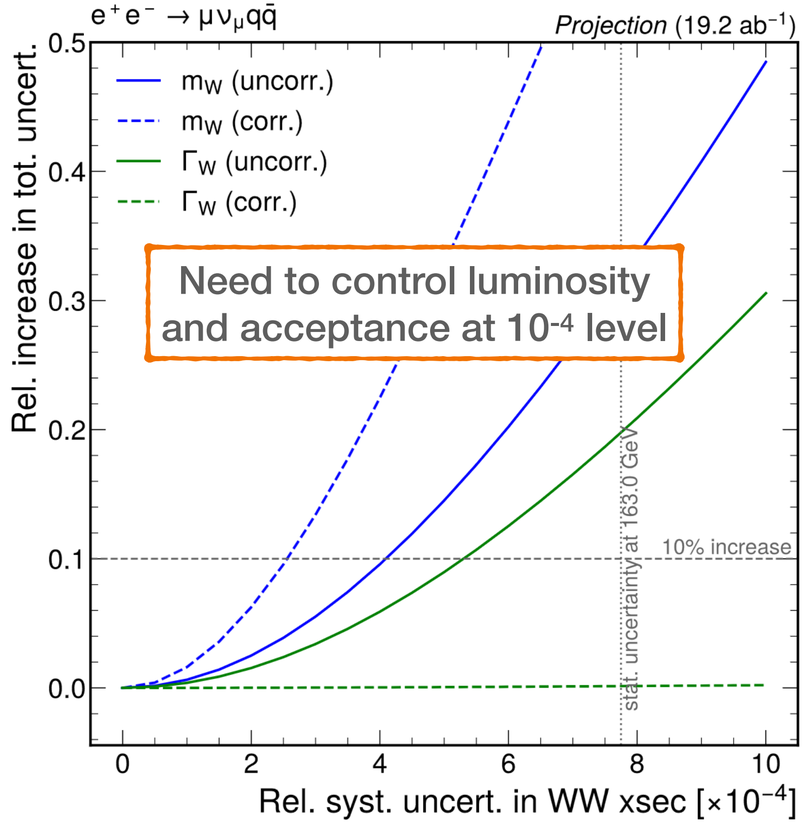
- Refine and optimise WW threshold scan using state-of-the art calculations
- Include detailed studies of **systematic, beam-related, and theoretical uncertainties**

Current theoretical uncertainty order 2 MeV (exp. target 350 keV)

Ongoing work on higher order calculations (A. Vicini, M. Beneke)





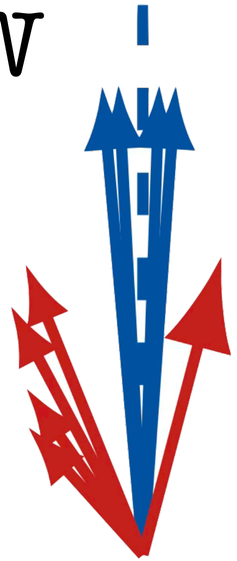


- Full kinematic reconstruction including det. resolution, momentum conservation, ISR + off-shell effects
- Detailed study of systematics, including **jet calibration, ISR + color reconnection** in hadronic decay channel

Colour reconnection in WW

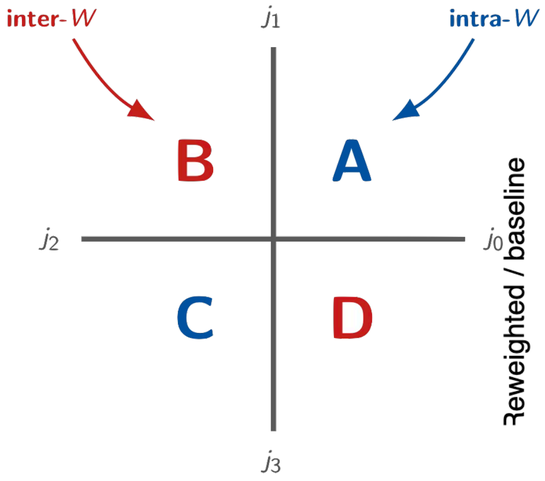
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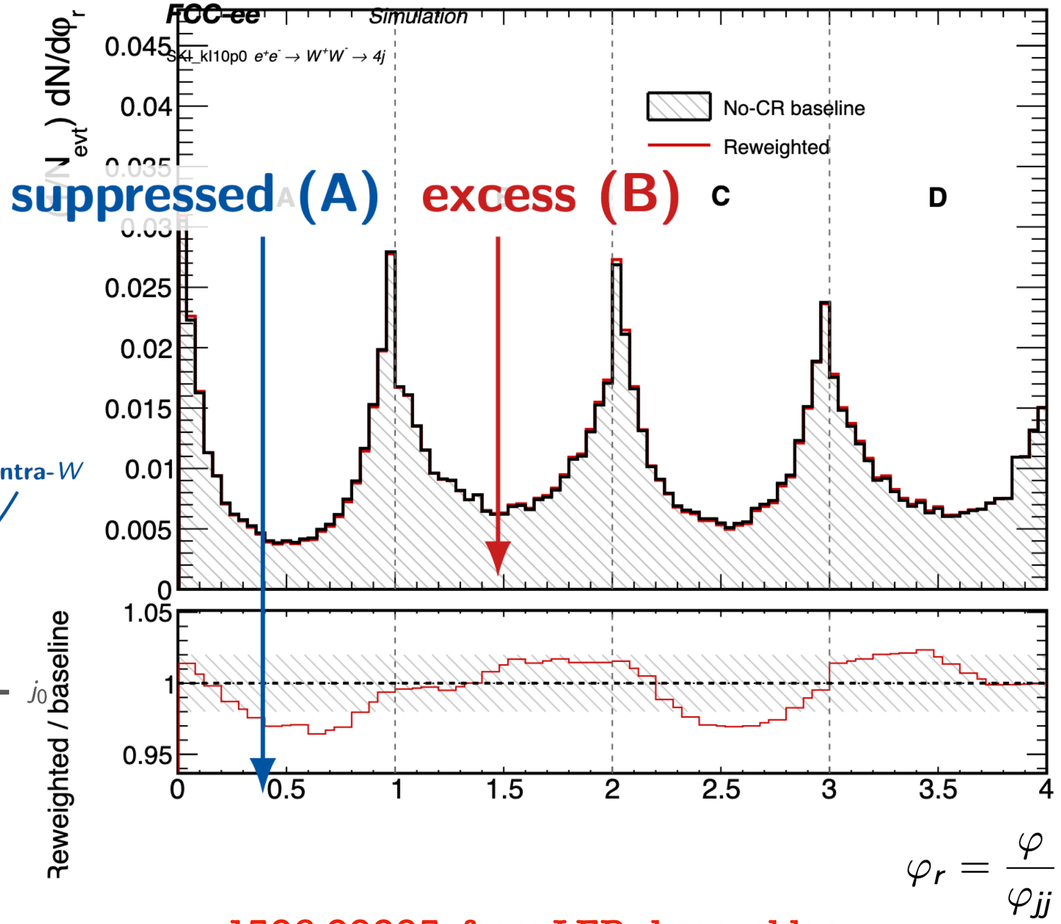
Apoorva Singh, MD, D. d'Enterria



Order **10-20 MeV** shift in reconstructed m_W
-> would make hadronic channel unusable

- use **soft particles** in the the event to constrain CR and hard particles to construct m_W-sensitive observables (in progress)
- use **m_Z constraint** from Z-pole run to constrain CR using ZZ hadronic events
  - challenge: pure ZZ selection over WW





Most CR models don't have tunable parameters (except single-parameter SK-I)

=> statistical interpretation of CR constraint remains unclear

True also for modelling of other non-perturbative QCD effects

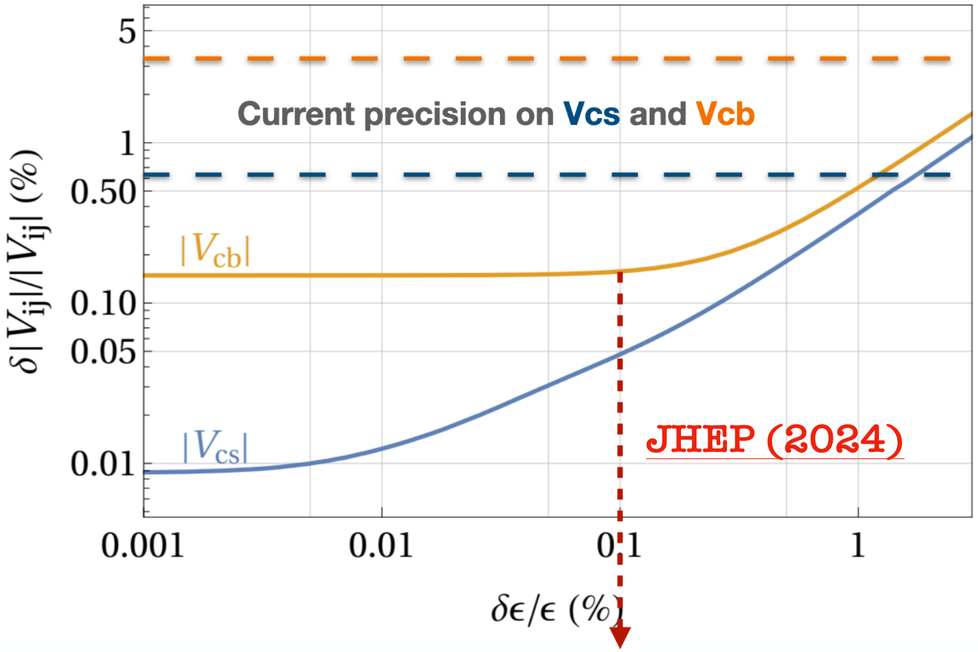
1506.09085, from LEP observables

	no CR	I	II	II′	GM-I	GM-II	GM-III	CS	I max	CS max
n_σ	2.0	0.7	1.5	1.6	3.9	1.6	1.5	1.4	2.1	0.6

Deviations from the measured result shown in number of standard deviations ($n_\sigma = (r_{\rm exp} - r_{\rm th})/(\delta r)_{\rm exp}$).

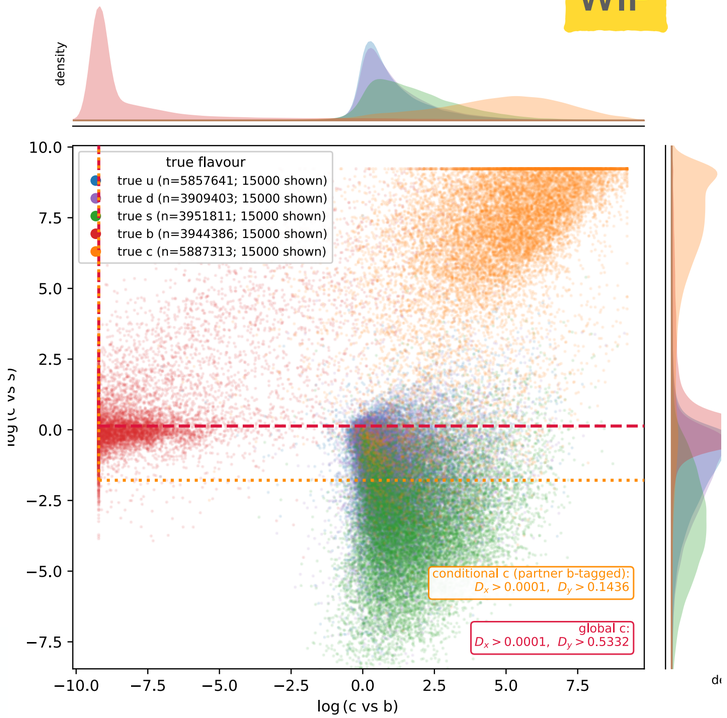
CKM elements from WW production

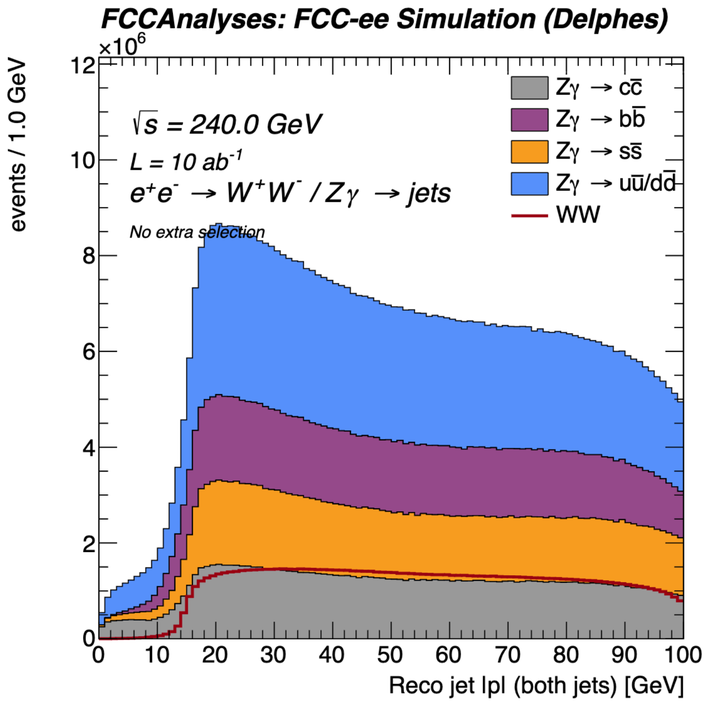
Louise Beriet, Gino Daniels,
Mason Levere, MD,
K. Cormier M. Selvaggi,
A. Sciandra, J. Andrea, A. Jung



0.1% precision on the tagger leads to an order of magnitude improvement in Vcb and Vcs

WIP



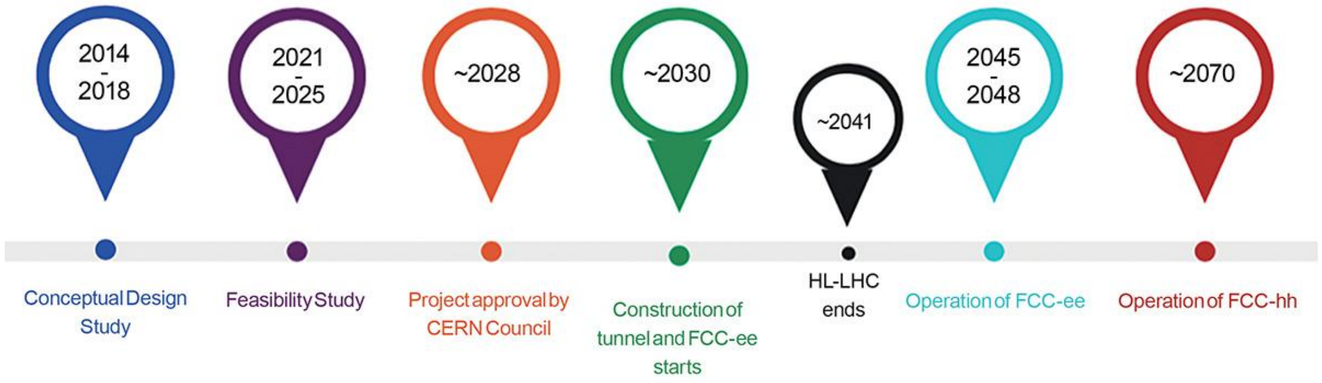


- Developing optimized tagger for WW event topology
- **Multi-dimensional working points** to define the jet flavour tag of each jet
- Profile likelihood fit to event jet tags -> simultaneously measure **all CKM elements**
- Developing in-situ tagger calibration using Z radiative events

Unique opportunity to precisely probe CKM *directly*

Take home messages and the work ahead

- FCC-ee EW precision: numerous **high-priority deliverables** for Council approval in 2028
- Common denominator: demonstrate that all systematic effects are controlled at the level of the statistical precision (both experimental and theoretical)
- Active work ongoing on several key aspects, both at the Z pole and at the WW threshold



Challenges at FCC-ee and CEPC are expected to be very similar

Don't hesitate to get in touch to collaborate!

email: fcc-ped-physicsgroup-ewprecision-admin@cern.ch
egroup: fcc-ped-physicsgroup-ewprecision
indico: link

Thank you