Physics @FCC

PiFE Retreat - 08/09/2021

Where do we stand?

LHC and the other colliders confirmed and tested the SM up to TeV scale

SM was crowned with the discovery of the Higgs…

No evidence of new physics…

- Cosmological observations for Dark matter
- Neutrinos and leptogenesis (is L an accidental/exact symmetry?)
- Flavour puzzle

- IR simplicity and Naturalness
- “Real” SM Higgs boson or “just” one ~~of many~~ ntuplet~~s~~?
- Strong CP problem

What do we need?

An **increased sensitivity** to new physics, via more statistics and/or higher reachable center-of-mass energies for:

Higgs physics → g_{HZZ} and g_{HWW} to test SU(2) custodial symmetry, Higgs **self interaction** via double Higgs production, Yukawa electron-Higgs **coupling**, BR of decays to *invisible* or *untagged* particles

EW physic → **precise EWPO** estimation (e.g. m_Z, Γ_Z, m_W and $\alpha_s(m^2_z)$)

Top physics → m_{top}, $t\bar{t}Z$ and $t\bar{t}\gamma$ **couplings**

BSM → Both indirect (elastic eμ scattering for searching for new mediators) and **direct particles detection** (FIPs, axions, dark photons…)

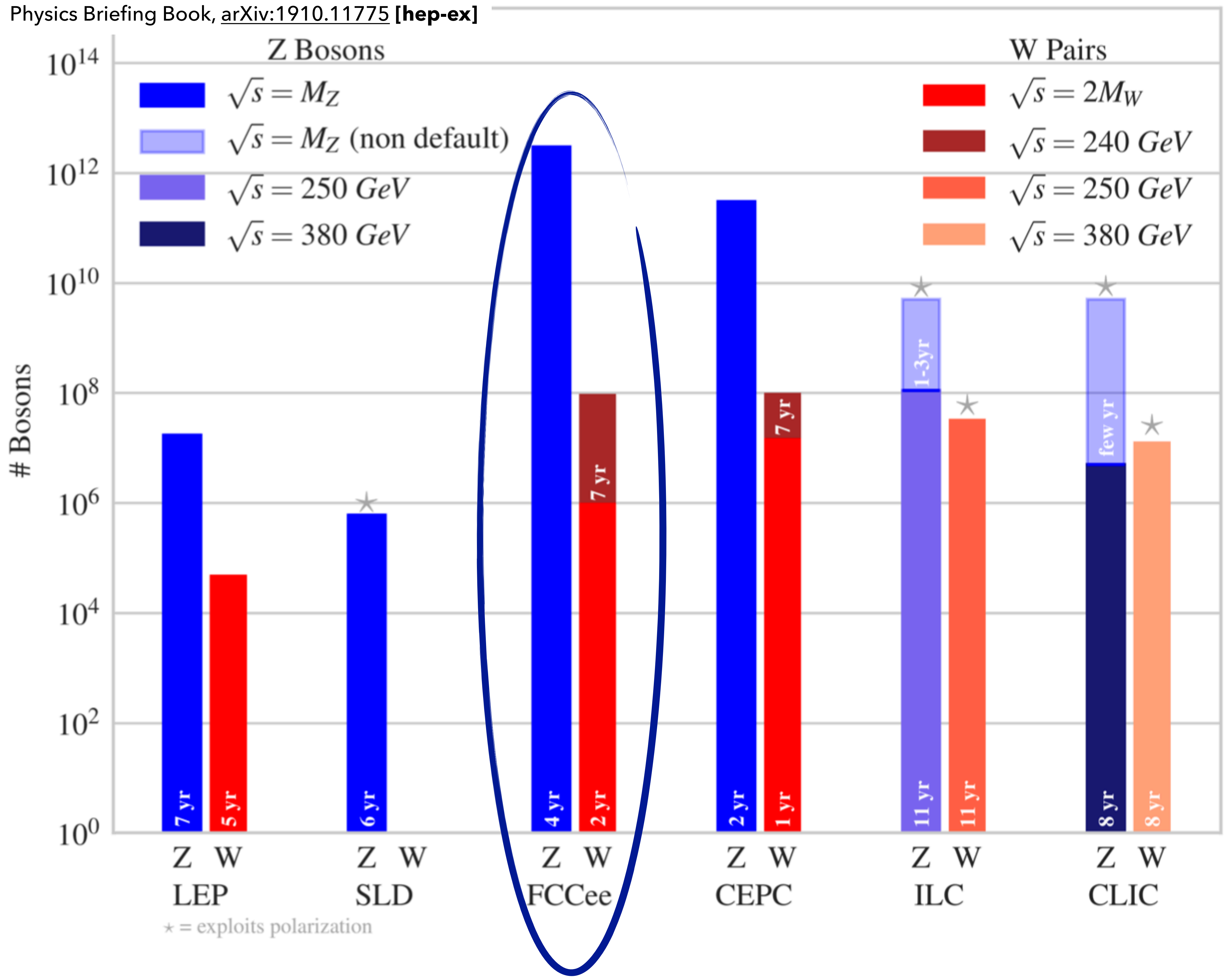
Electroweak programme

Within 6 years **FCC-ee** will reach outstanding statistics with an unparalleled precision on √s allowing to reach a **sensitivity to New Physics up to 70 TeV** (EWPO loop corrections are highly sensitive to NP and provide a powerful test of the SM)

The expected number of **10^{12} Z^0** and **10^8 WW couples** with a precision on the √s calibration of 100 keV and 300 keV, respectively, will allow FCC-ee to reach

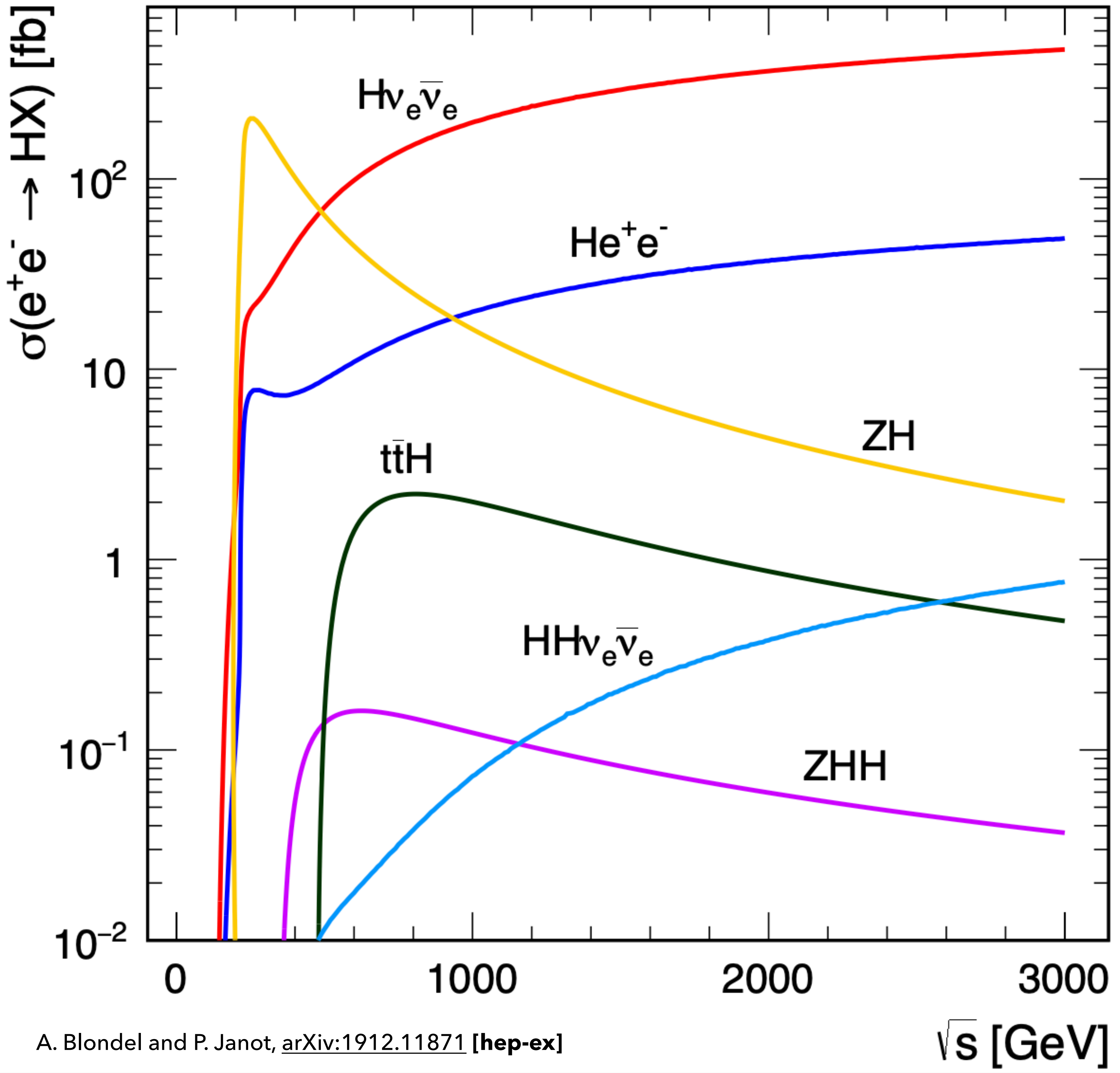
EWPO	Expected Precision
m_Z	100 KeV
Γ_Z	25 keV
m_W	< 500 keV
$\alpha_{QED}(m_Z)$	3 x 10^{-5}
$\alpha_S(m_Z)$	~ 10^{-4}

Physics Briefing Book, arXiv:1910.11775 [hep-ex]



Higgs programme

FCC-ee will provide the **most precise** (0.17%) determination of g_{HZZ}, operating at ZH cross section maximum ($\sqrt{s}$ ~ 240 GeV) with 2 IPs



A. Blondel and P. Janot, arXiv:1912.11871 **[hep-ex]**

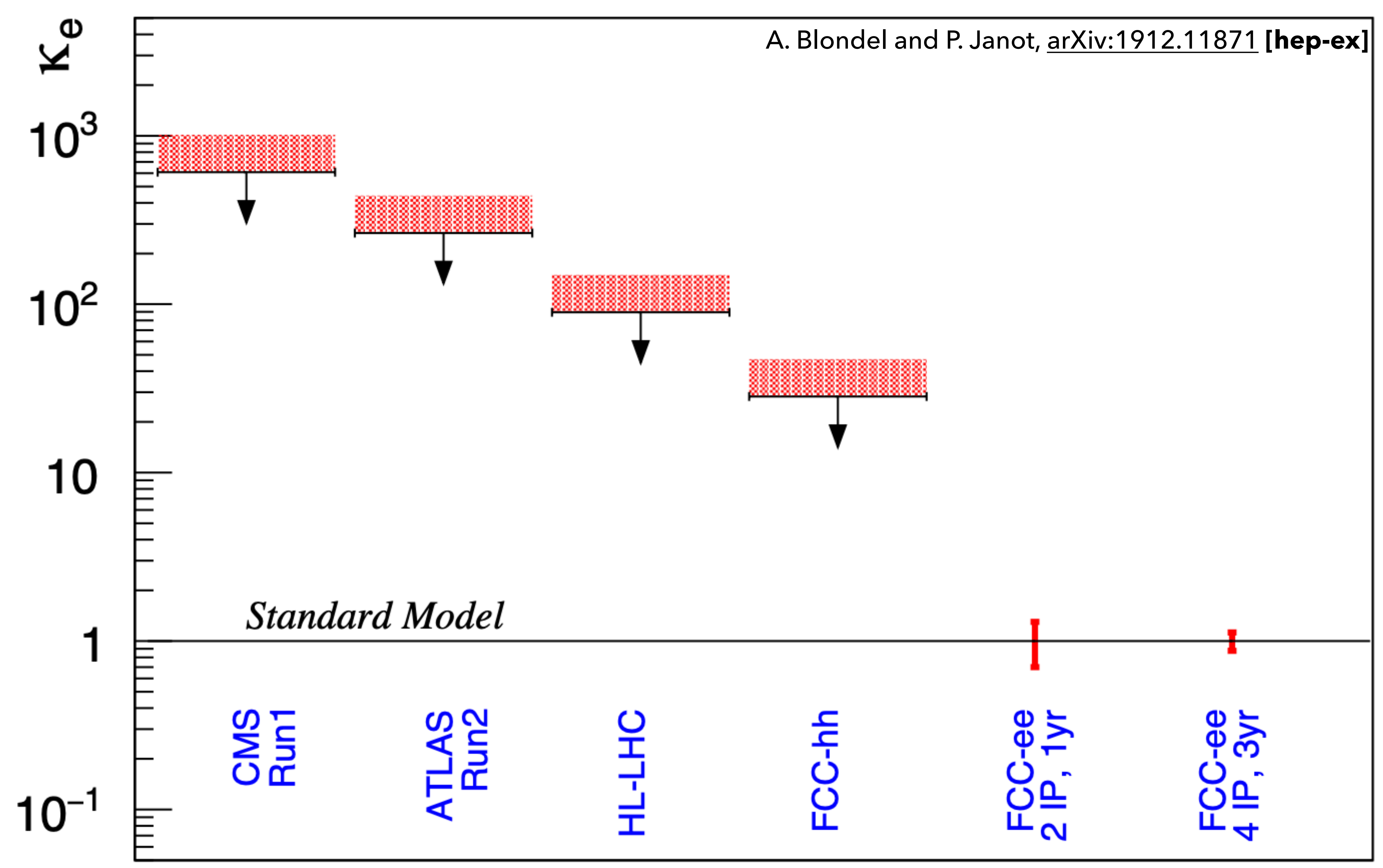
Higgs programme

FCC-ee will provide the **most precise** (0.17%) determination of **g_{HZZ}**, operating at ZH cross section maximum ($\sqrt{s}$ ~ 240 GeV) with 2 IPs

Particularly of interest for NP is the study of the **Yukawa coupling Hee**

Reachable thanks to the superb monochrome ($\sigma_{\sqrt{s}}$ < 10 MeV) FCC-ee beam @$\sqrt{s}$ = 125 GeV

After 1 year with 2 IP (20 ab^{-1}), an expected **2σ excess** will be observed



Beyond THE SM

Along with searching for NP pursuing precision measurements, **BSM** can be investigated via **direct search** and the **observation of new particles** as the still unexplained phenomena can be described by particles that resided below or around the EW scale and feebly interact

This search must be **broad and diverse** to cover many orders of magnitude of couplings and masses

Feebly interacting particles (FIPs) could be found at the **intensity frontier** (i.e. FCC-ee @Z^0 pole)
Via so-called *portal* operators FIPs interact with the SM

FCC is also a flavour factory

Many things are still expected by "HL-LHCb"…

Despite that, the **precision** reached by **FCC** will be **without comparison**

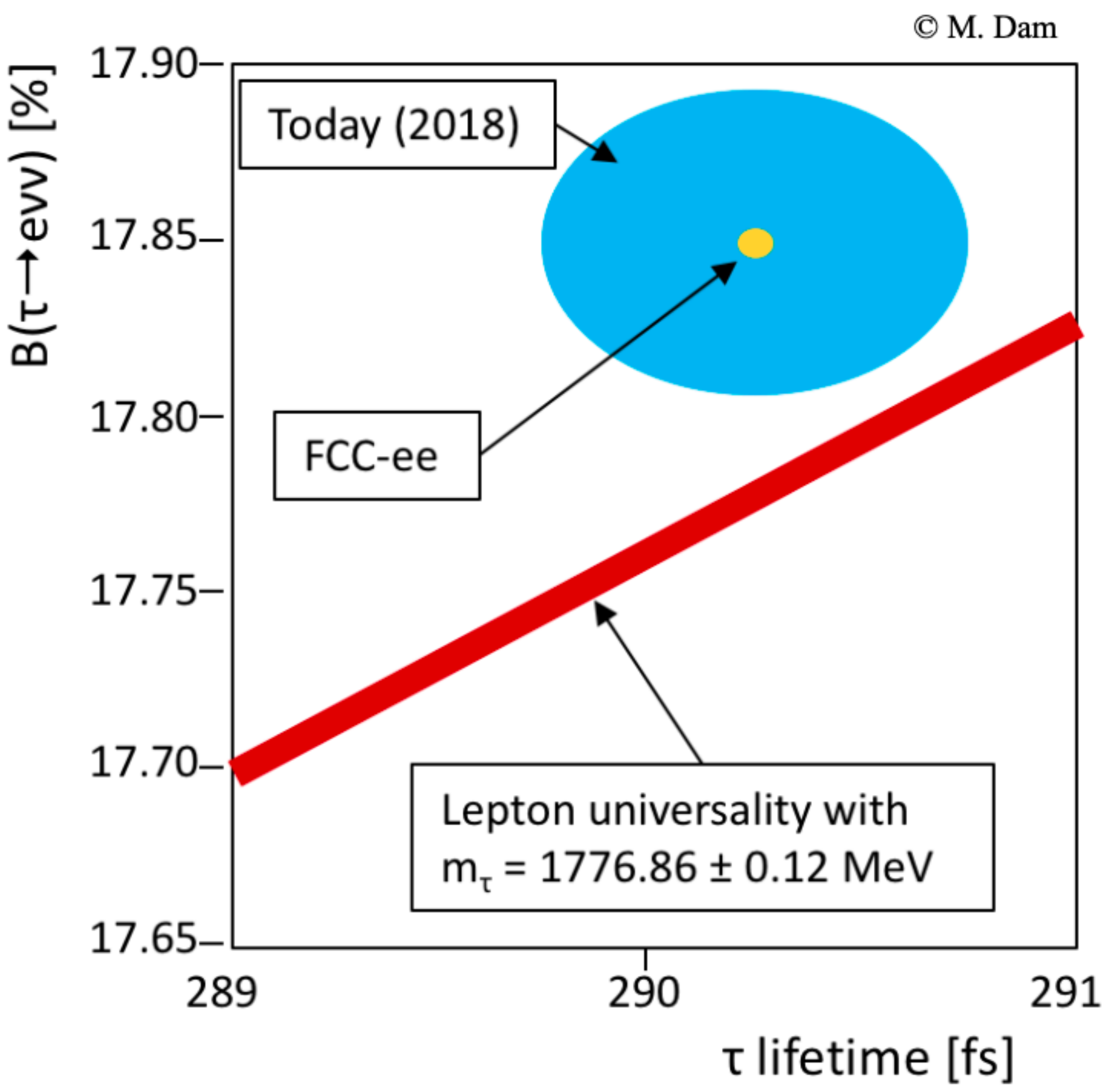
Flavour anomalies ($b \to s l^+ l^-$) will be studied with **$\sim 10^{12}\ Z^0 \to b\bar{b}$**

Lepton-flavour-violating decays

$BR(Z \to e\tau, \mu\tau) \sim 10^{-9}$

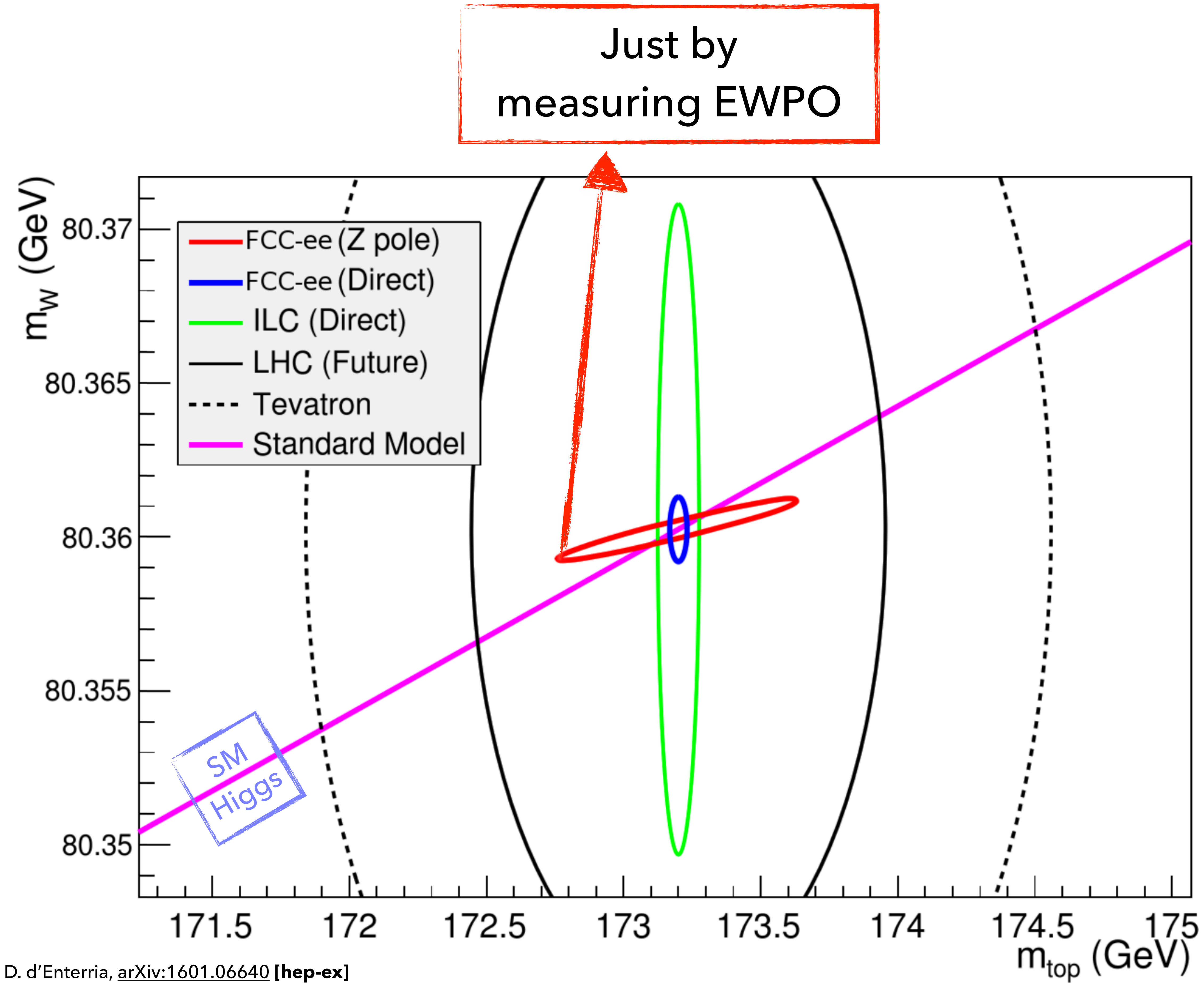
$BR(\tau \to \mu\gamma, \mu\mu\mu) \sim 10^{-10}$

τ lifetime vs $BR(\tau \to e\nu_e\nu_\tau, \mu\nu_\mu\nu_\tau)$: lepton universality tests



Top Physics

Along with the other EWPO, **FCC-ee** can, at the top-pair threshold, **precisely** (50 MeV) **assess m_{top}** guaranteeing another probe of the SM

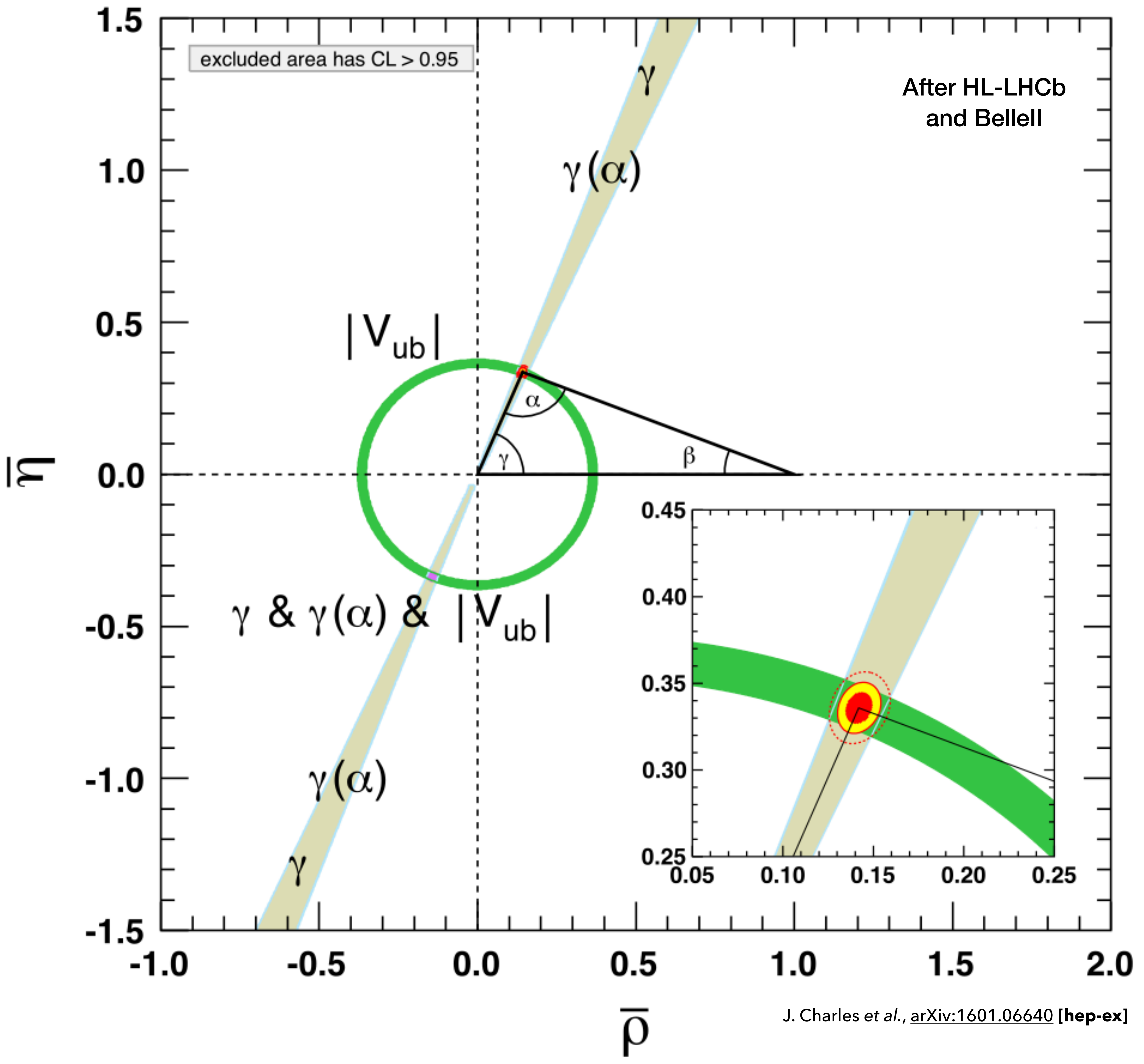


D. d'Enterria, arXiv:1601.06640 [hep-ex]

CKM Matrix

Another way to indirectly probe BSM, especially with $\Delta F = 2$ (i.e., where FCC can really shine)

Also CP violation in the mixing can be measured
(via asymmetries in the semi-leptonic B decays)



J. Charles *et al.*, arXiv:1601.06640 **[hep-ex]**

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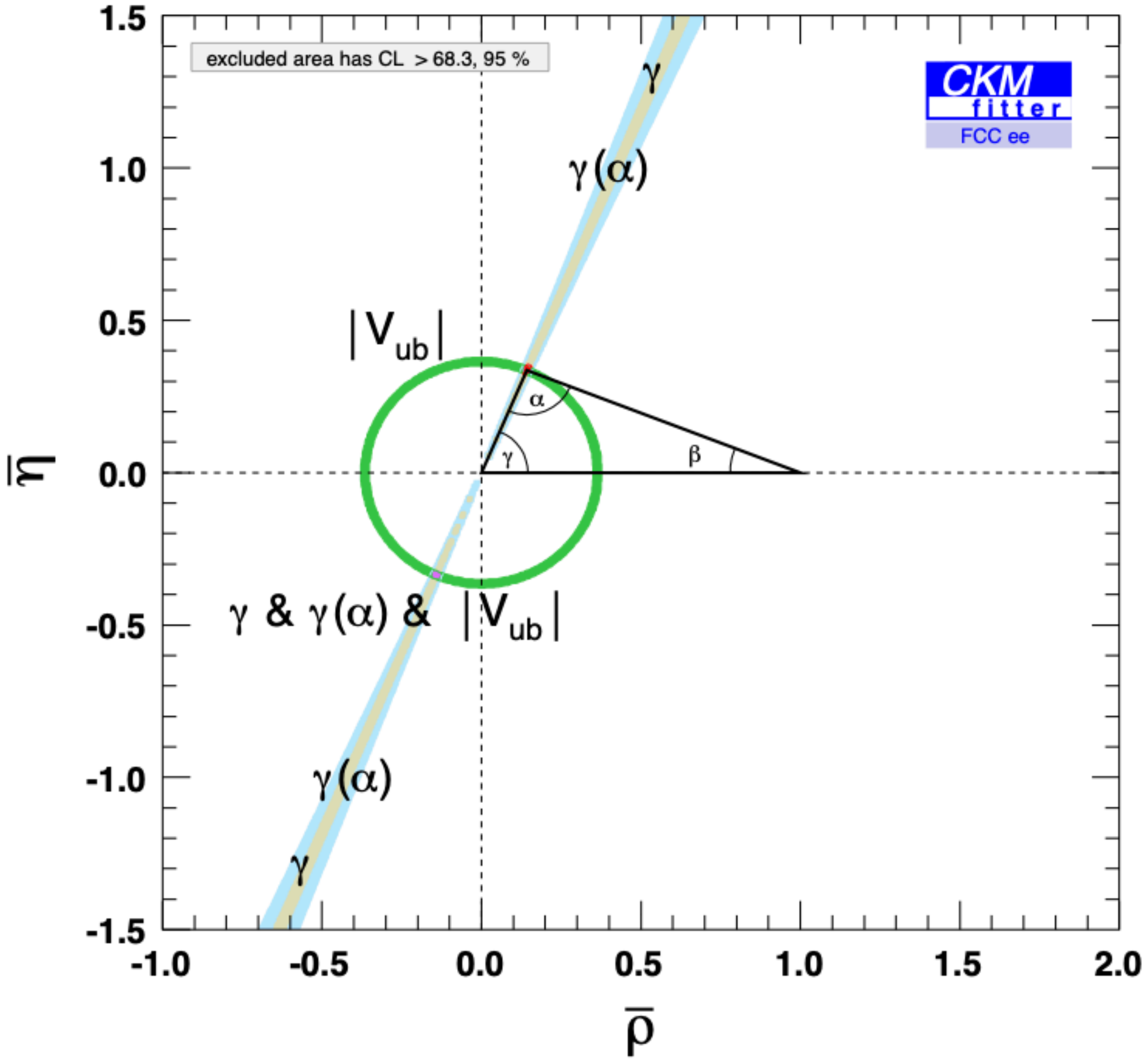
Observable / Experiments	Current W/A	Belle II (50 /ab)	LHCb-U1 (23/fb)	FCC-*ee*
CKM inputs				
γ (uncert., rad)	$1.296^{+0.087}_{-0.101}$	1.136 ± 0.026	1.136 ± 0.025	1.136 ± 0.004
$\|V_{ub}\|$ (precision)	5.9%	2.5%	6%	1%
Mixing-related inputs				
$\sin(2\beta)$	0.691 ± 0.017	0.691 ± 0.008	0.691 ± 0.009	0.691 ± 0.005
ϕ_s (uncert. rad 10^{-2})	-1.5 ± 3.5	n/a	-3.65 ± 0.05	-3.65 ± 0.01
Δm_d (ps^{-1})	0.5065 ± 0.0020	same	same	same
Δm_s (ps^{-1})	17.757 ± 0.021	same	same	same
a^d_{fs} (10^{-4}, precision)	23 ± 26	-7 ± 15	-7 ± 15	-7 ± 2
a^s_{fs} (10^{-4}, precision)	-48 ± 48	n/a	0.3 ± 15	0.3 ± 2



Flavour Physics

@Z^0
5×10^{12} eventi Z^0

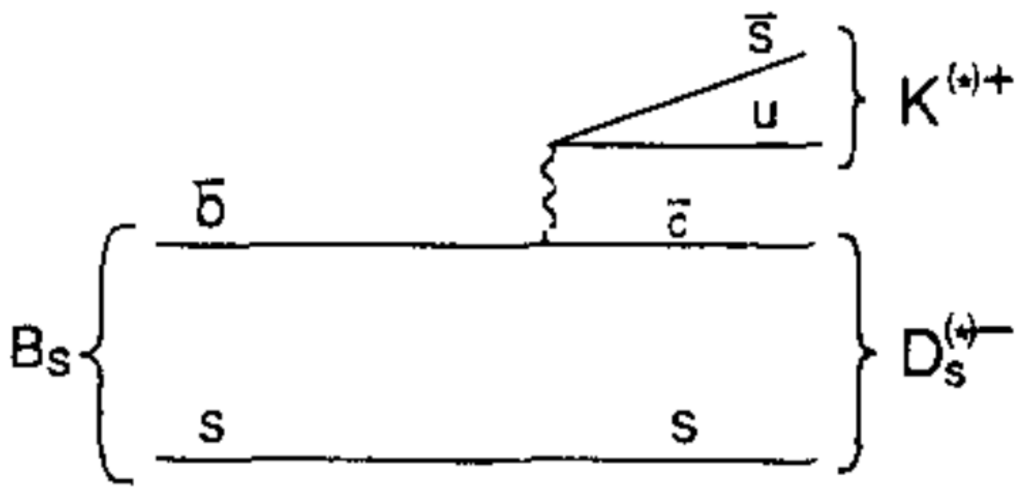
@Z^0
7.5×10^{11} coppie $b\bar{b}$

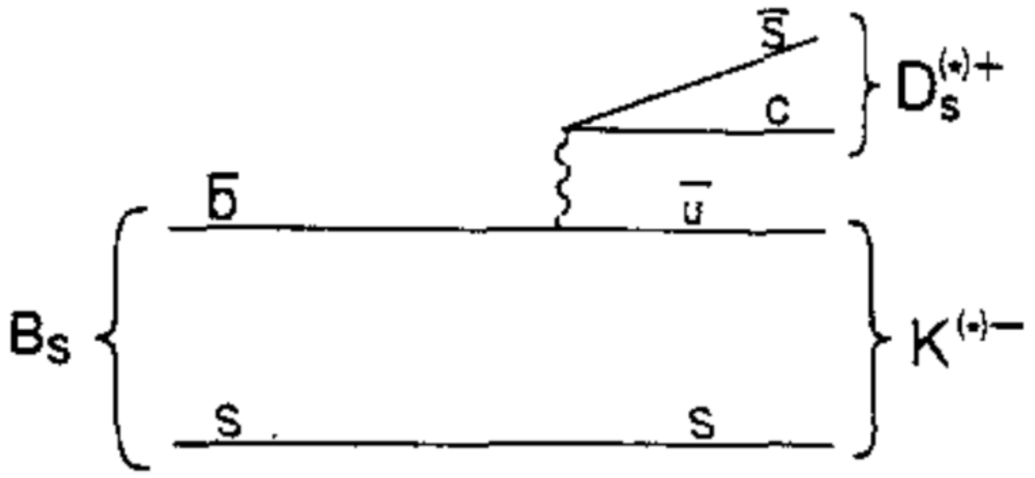
B PHYSICS

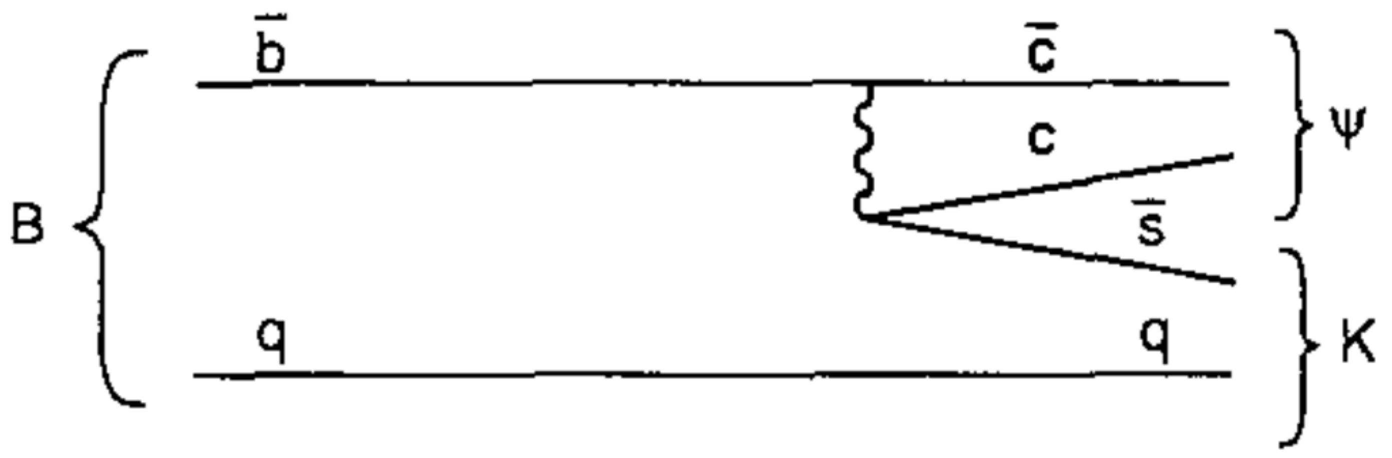
1. Studio di decadimenti rari del *b* (per studiare anomalie di sapore)
2. Decadimenti bi-leptonici (essenzialmente FCNC → Diagramma Pingu)
3. **Decadimenti (semi-)leptonici ($B_c \to l\nu$, per test della LFU e misure CKM)**
4. **Violazione di CP e misure delle entrate della matrice CKM (e.g. $B^- \to (D^0 \to K^- \pi^+)\, \pi^-$)**
5. (Spettroscopia)
6. Studi di cLFV con Z^0 o con quark *b* (focalizzandosi sul τ)

WHERE DO WE STAND?

The analysis



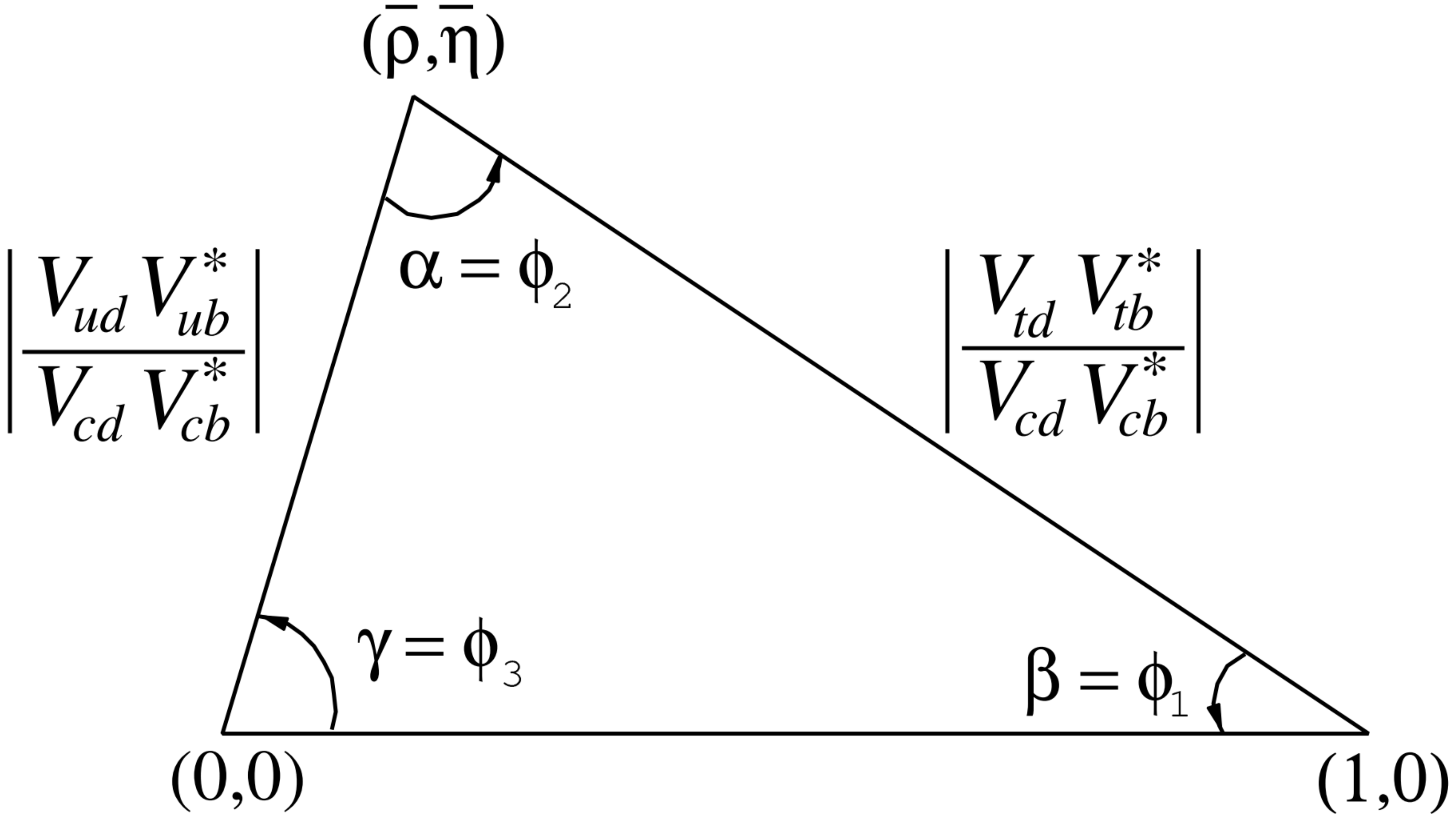




As already mentioned the studied decays are:

1. $B^0_s \rightarrow D^{\pm}_s K^{\mp}$
2. $B_s \rightarrow J/\psi\ \varphi$

The analysis



$$\beta = \phi_1 = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right),$$
$$\alpha = \phi_2 = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right),$$
$$\gamma = \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right).$$

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1. $B^0_s \to D^{\pm}_s K^{\mp}$
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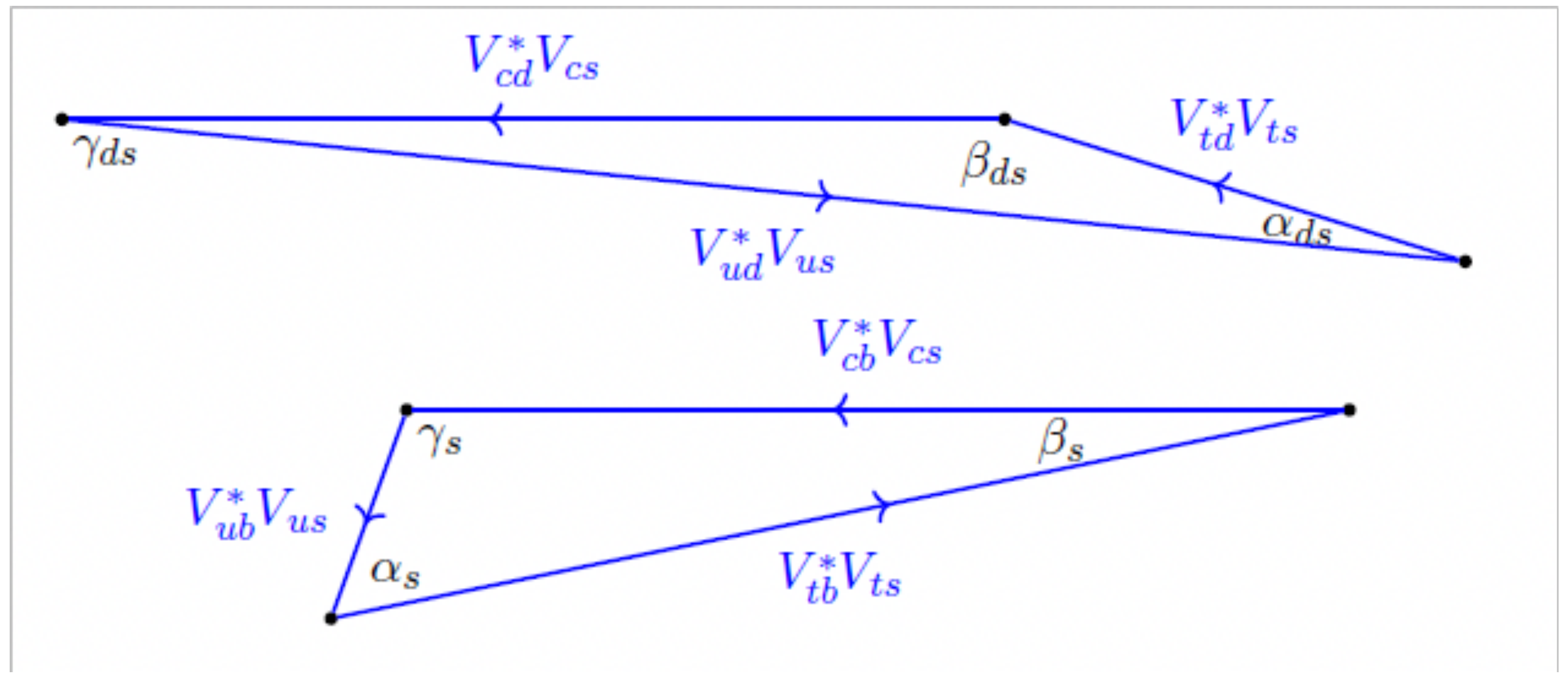
with the final objective (for the *fast-sim*) to estimate $\varphi = \gamma_{CKM} + \gamma_{ds} - 2\beta_s$ and $2\beta_s$



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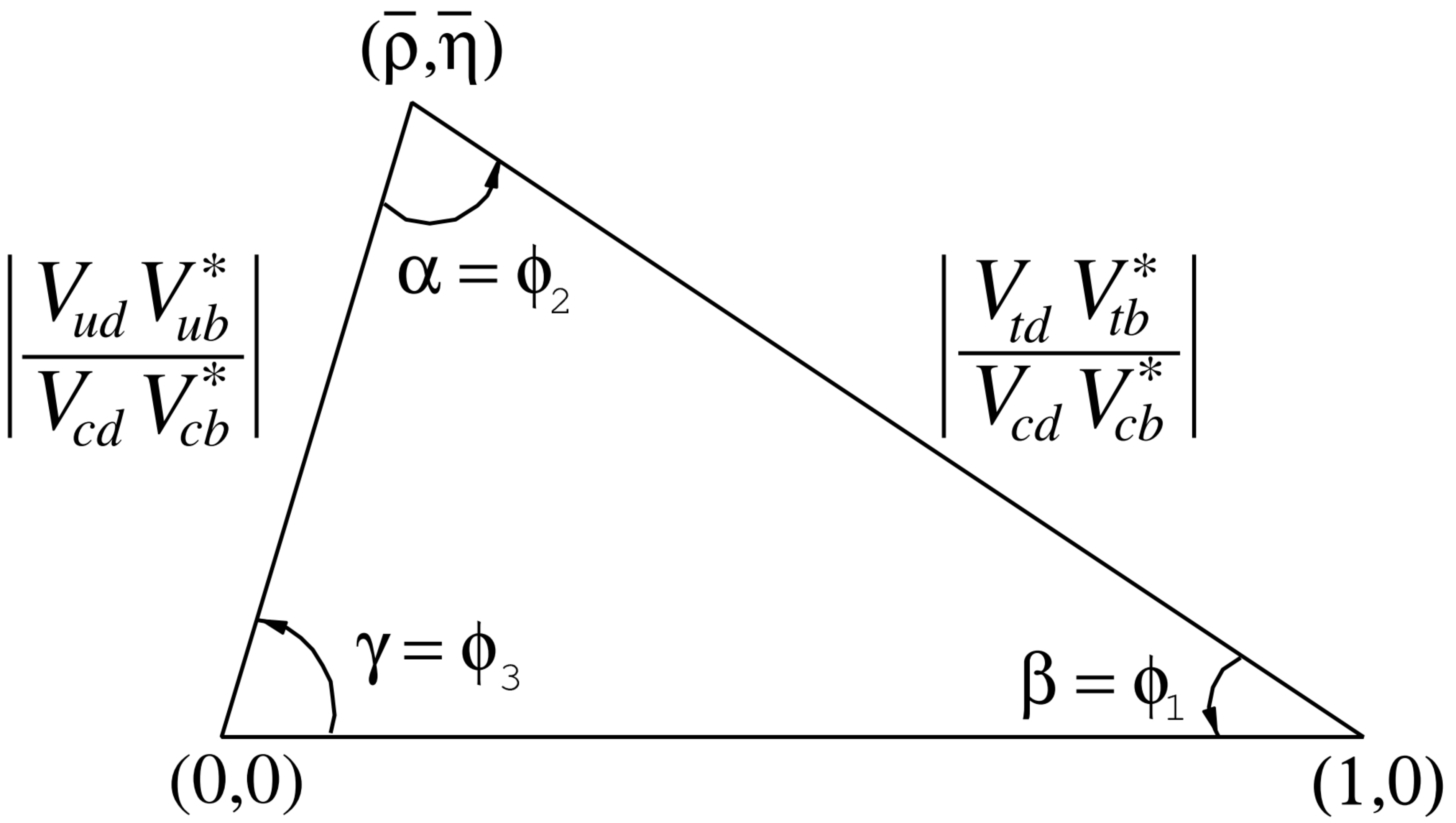

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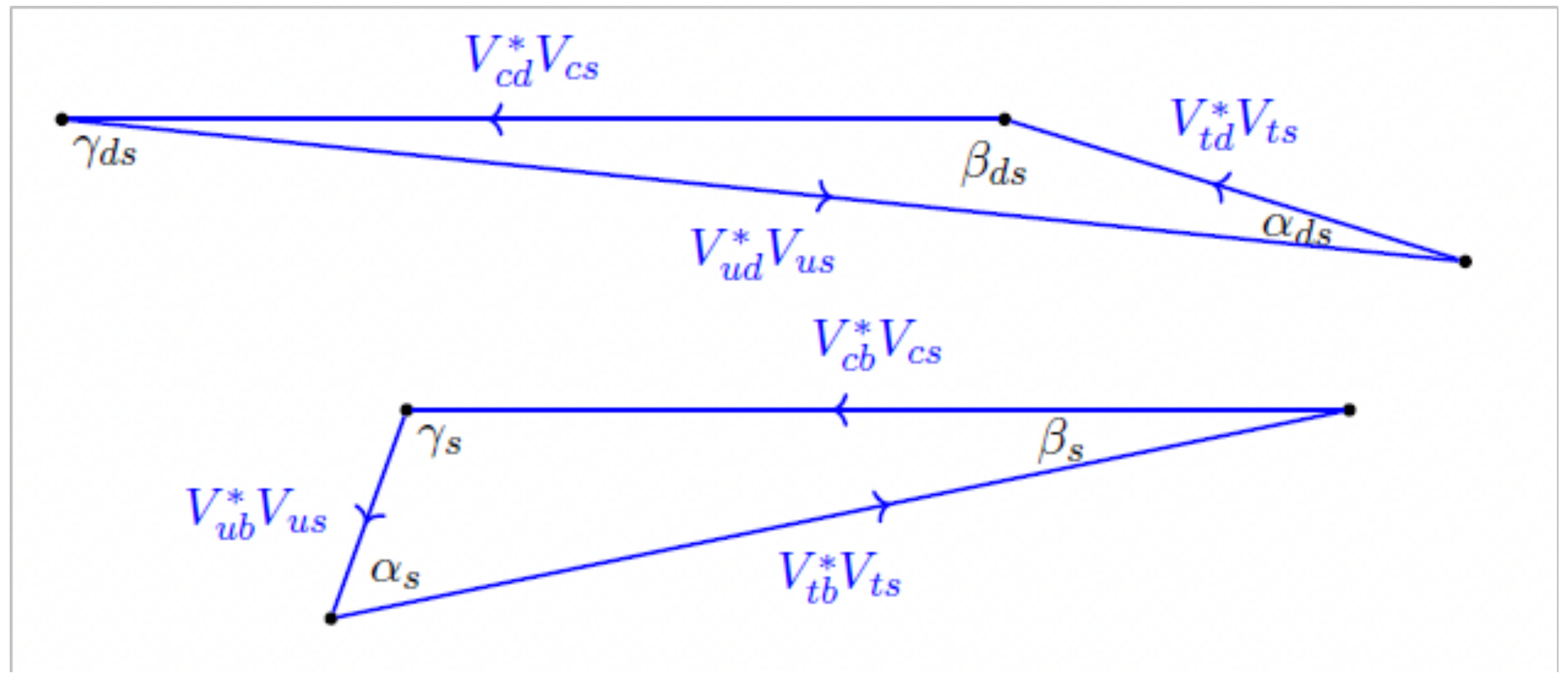
With 75 (310) billions of B^0_s (B^0) a statistical precision of 0.4° on γ (3.4° x 10^{-2} on β_s) is expected and can be compared with the present measurements…

$$\gamma = (72.1^{+4.1}_{-4.5})^\circ \qquad 2\beta_s = 0.051 \pm 0.023$$



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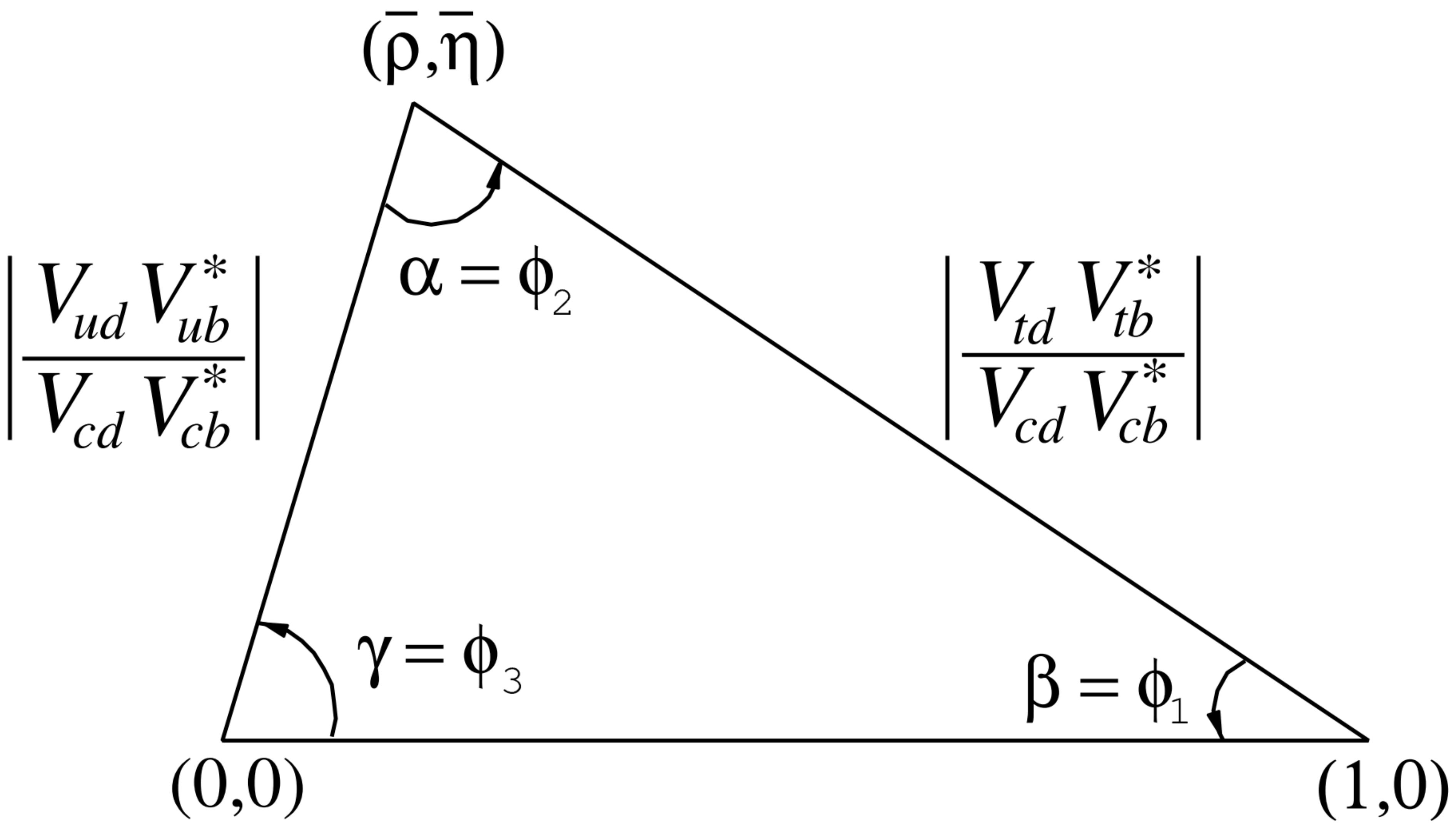

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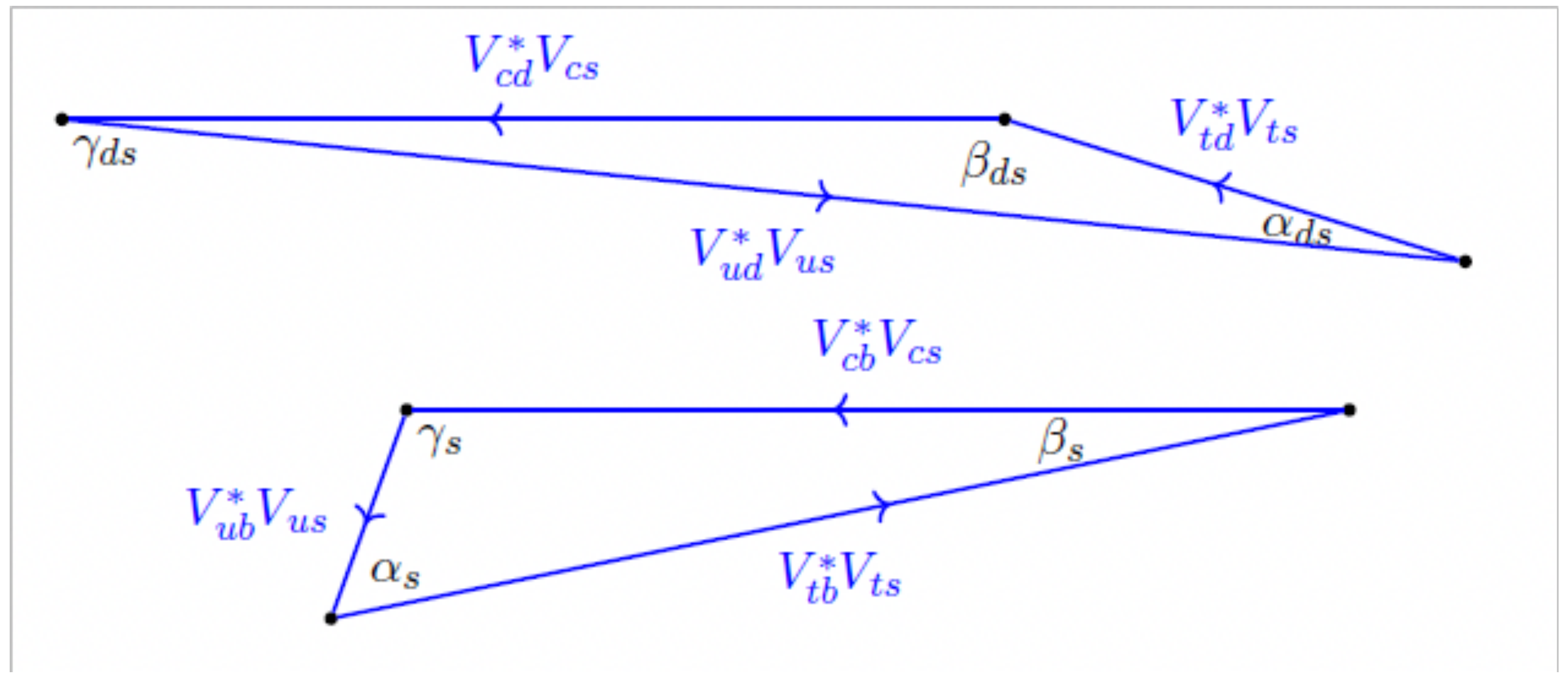
With 75 (310) billions of B^0_s (B^0) a statistical precision of 0.4° on γ (3.4° *x* 10^{-2} on β_s) is expected and can be compared with the present measurements…

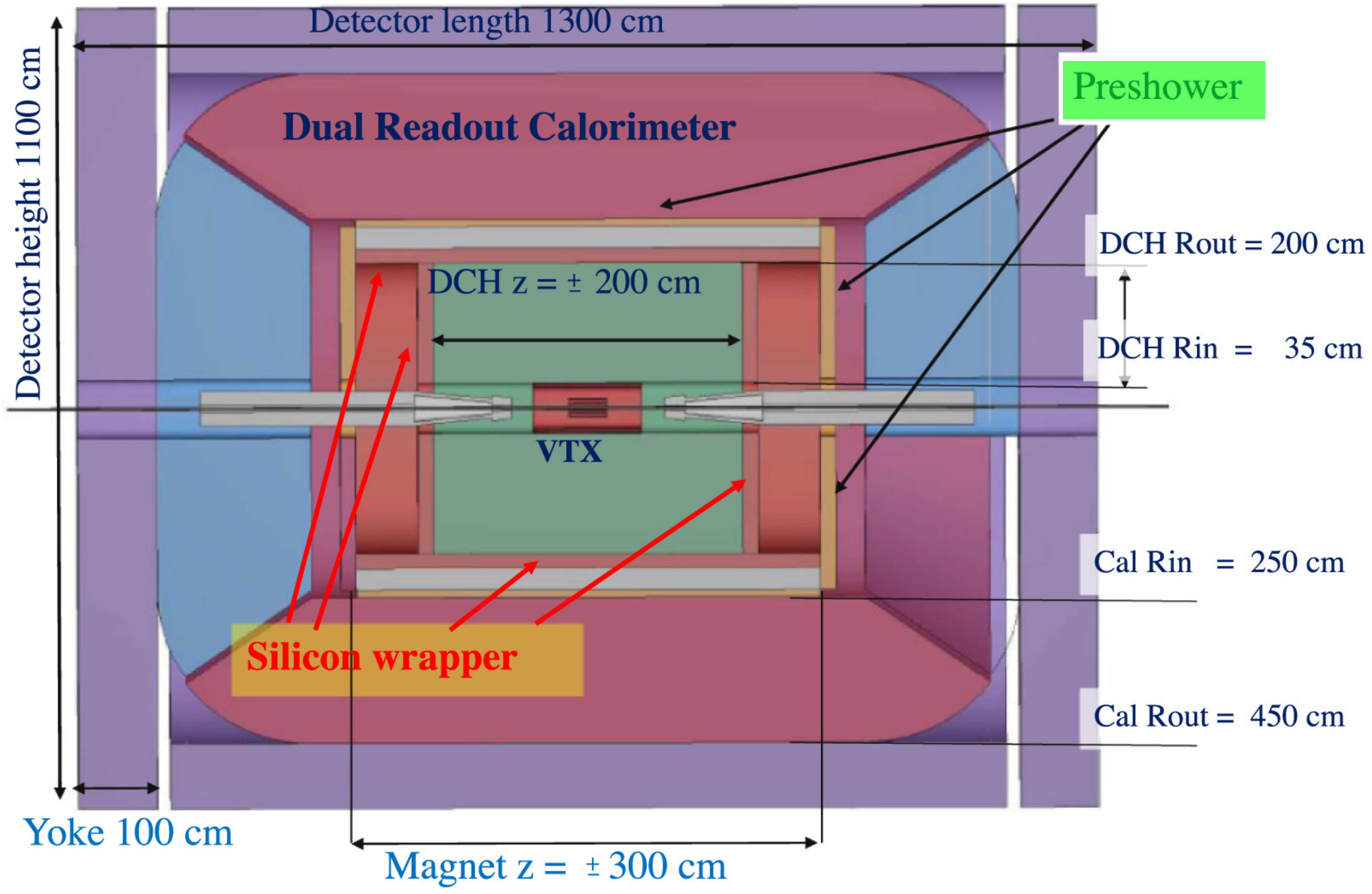
$$2\beta_s = 0.051 \pm 0.023$$

$$2\beta_s = 0.0383^{+0.0012}_{-0.0011}$$

To be tested against a very precise SM prediction



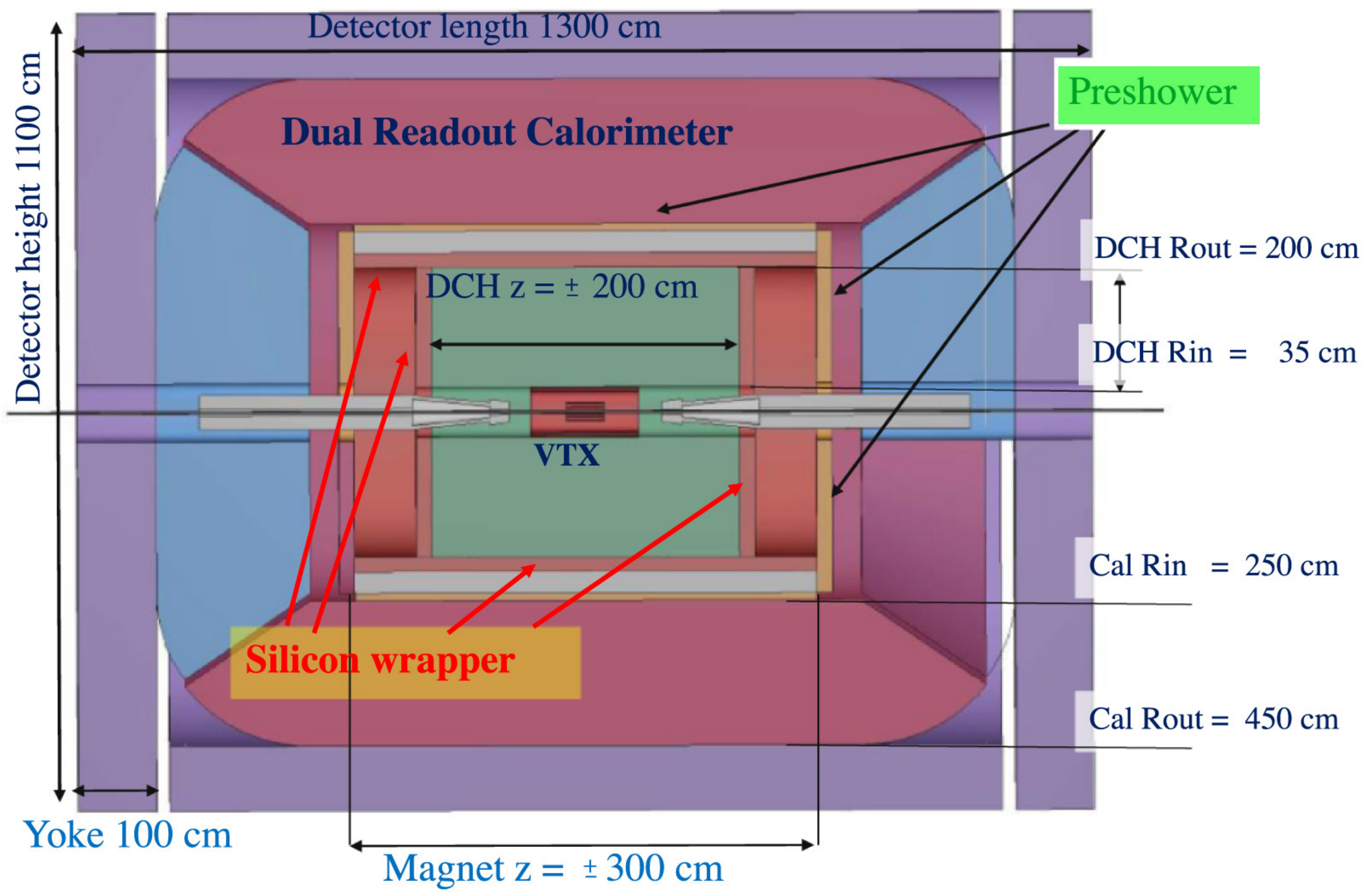
Why though?



Simulate and analyse a physics benchmark channel

Starting with *fast-sim*
(to mostly test and understand the physics) making use of the FCC tools, and then move to *full-sim*
(to really test the IDEA sub-detectors)

Why though?



The *channels*

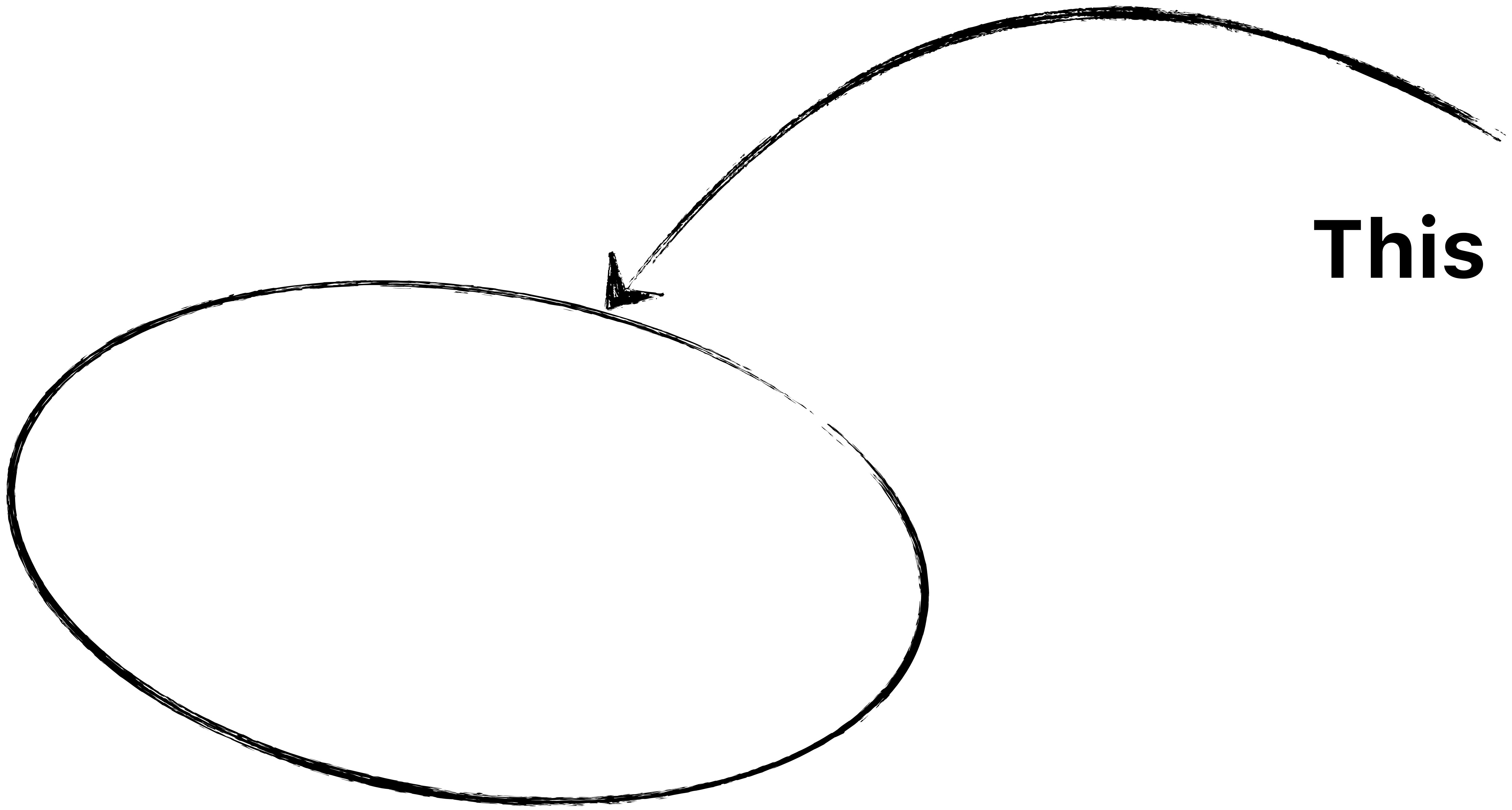
$B^0_s \rightarrow D^{\pm}_s K^{\mp}$

$B_s \rightarrow J/\psi\ \varphi$

will allow to test the IDEA tracking system and have the potential to investigate the calorimeter

What have I done?

What have I done?



This much!

Why?

Well, a combination of different reasons which I'll try to summarise:

I. Despite my interest on this subject, I feel my priorities rest somewhere else

II. Some projects took more than expected (or better I took more than I initially though)

III. There is not much literature to read to be ready to start on my own

IV. Most of the code has been developed by people inside CERN so they already know what they are handling, as such the GitHub is not that informative as I'd have hoped

V. There are 2 SW which are being used F. Bedeschi uses Delphes, while P. Azzi pushed for key4Hep

Honestly, though, probably a week of head bashing and a re-prioritisation could do the trick… it is a matter of revving up the engine

AND SO?

What Next?

It is not easy to say “What Next”… answering it is the problem, not asking the question, that comes spontaneously

The wishful thinking is to have the *fast sim* done by some time in the future, I would like to give a reasonable time scale, but I proved top be unreliable on this

The *full sim* will come next…

Inserire frase cringe motivazionale su fatica e salita...