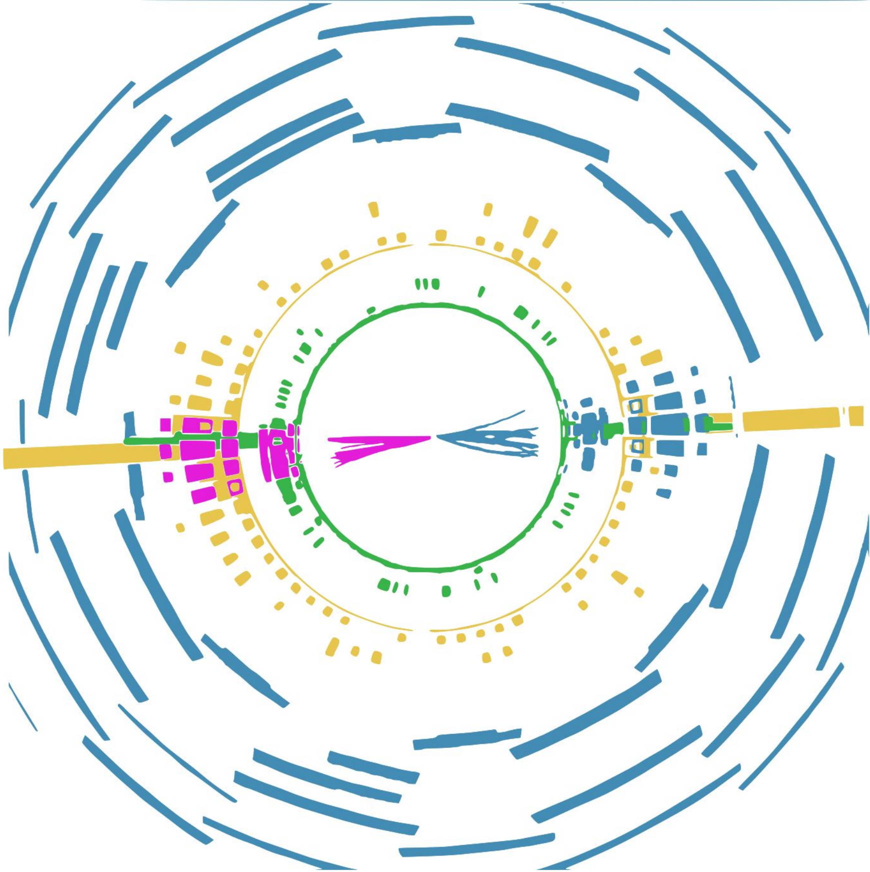
Implications of tracking-detector variations on jet flavour-tagging and Higgs coupling measurements in ZH fully hadronic final states at the FCC-ee

Iza Veliscek

Contributions from: Haider Abidi, Ketevi A. Assamagan, Diallo Boye, Elizabeth Brost, Viviana Cavaliere, Anna E. Connelly, George Iakovidis, Ang Li, Marc-André Pleier, Andrea Sciandra, Michele Selvaggi, Scott Snyder, Robert Szafron, Abraham Tishelman-Charny, Iza Veliscek

arXiv:2504.11103

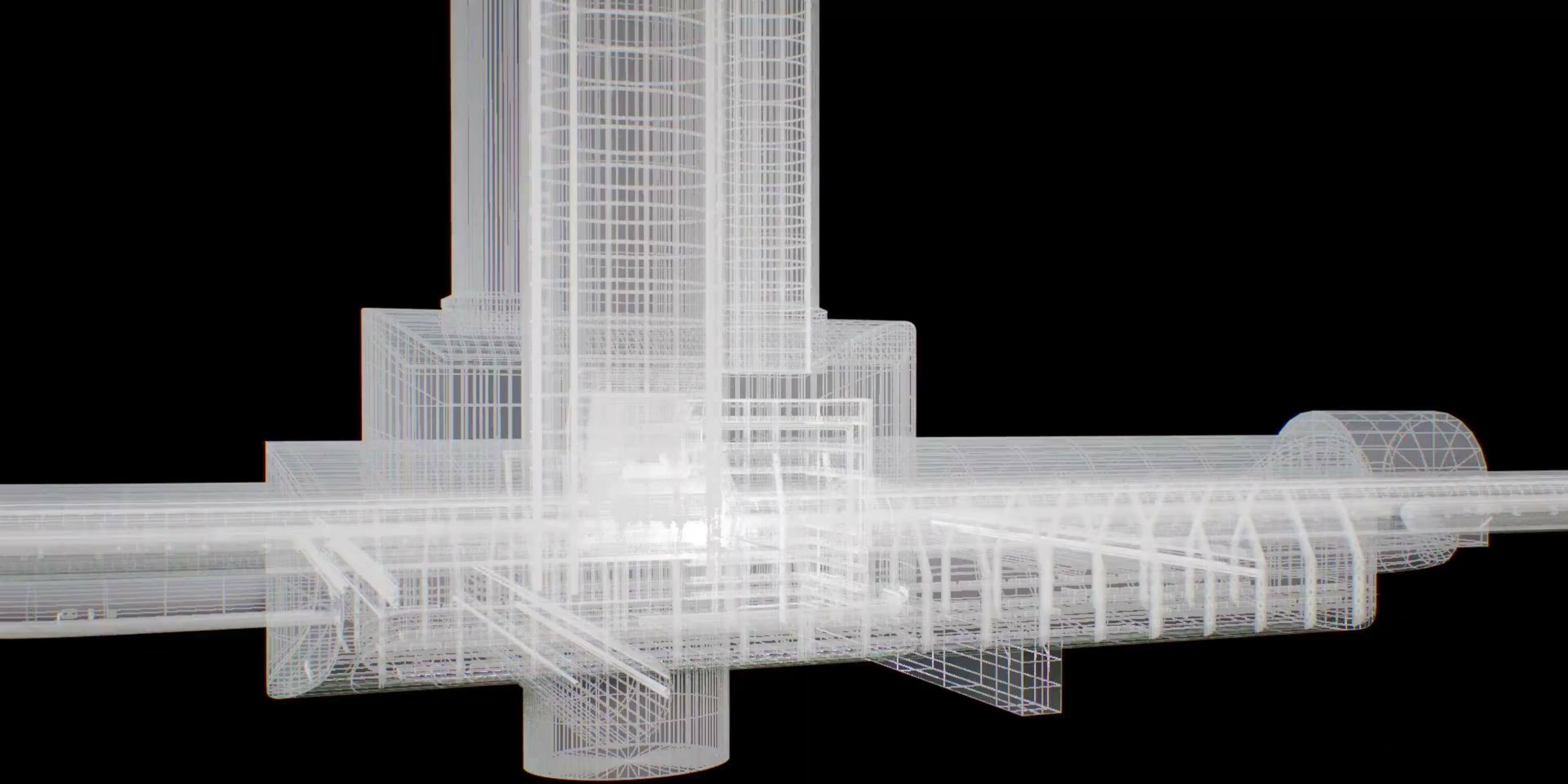


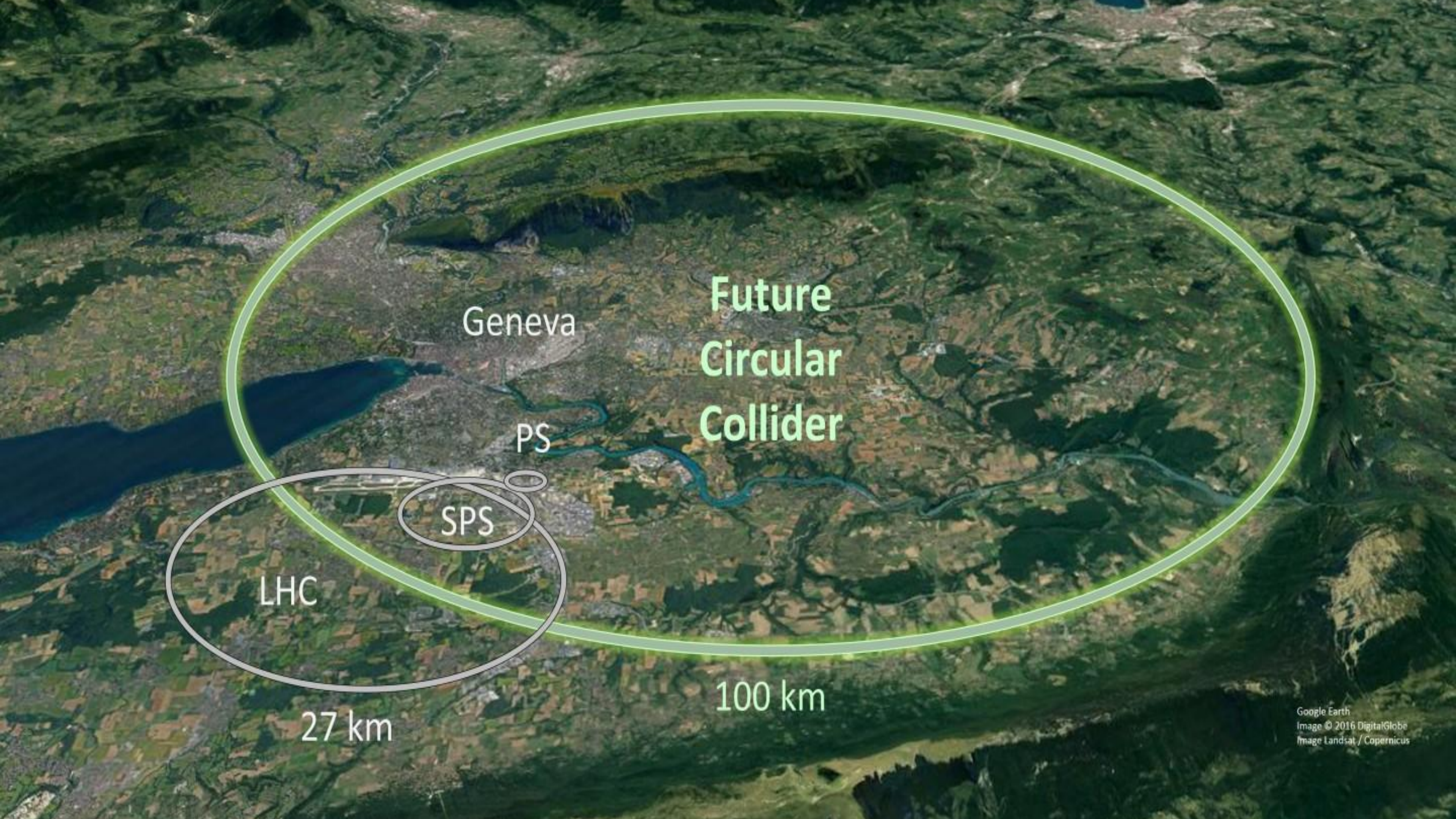
BNL Seminar

5th June 2025

Brookhaven National Laboratory

FUTURE CIRCULAR COLLIDER




Future
Circular
Collider
Geneva
PS
SPS
LHC
100 km
27 km
Google Earth
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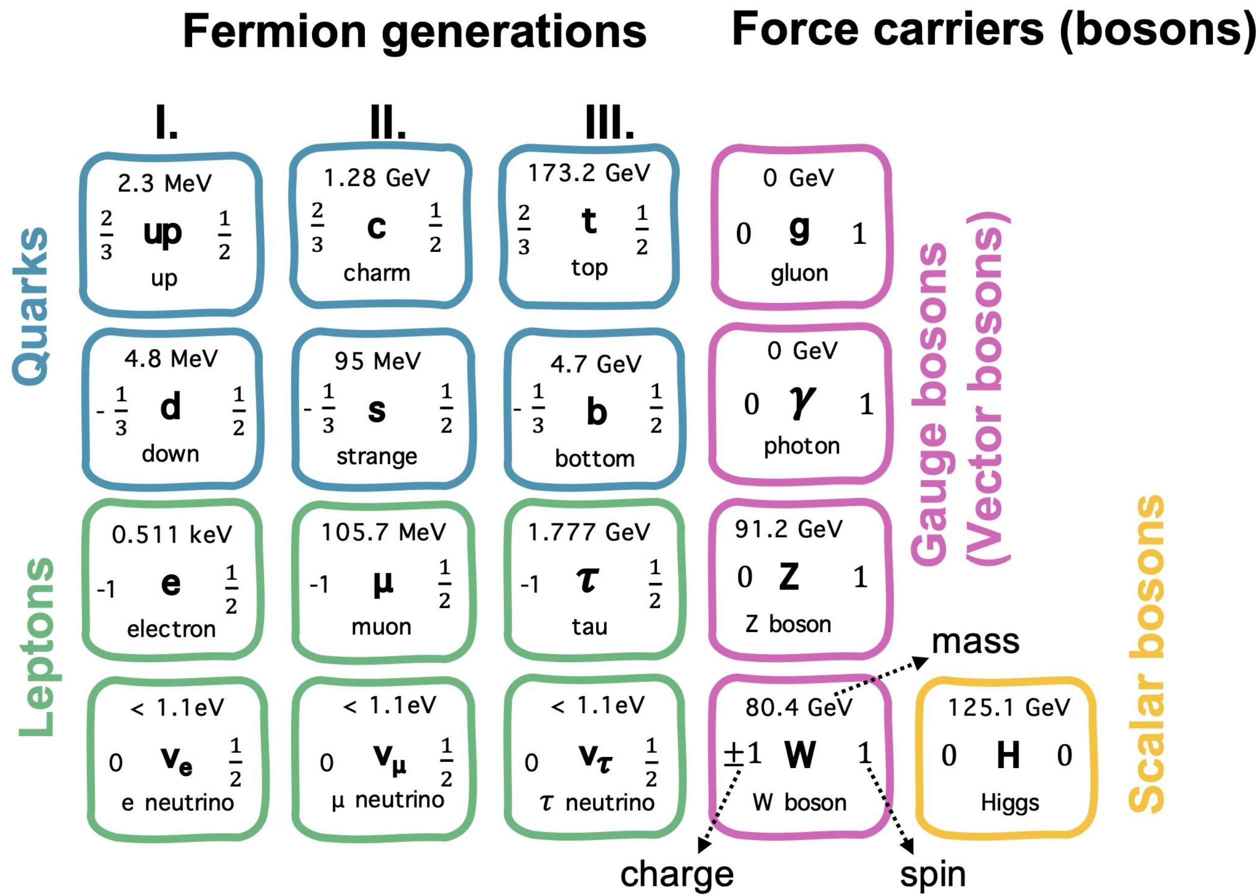
Today on the agenda

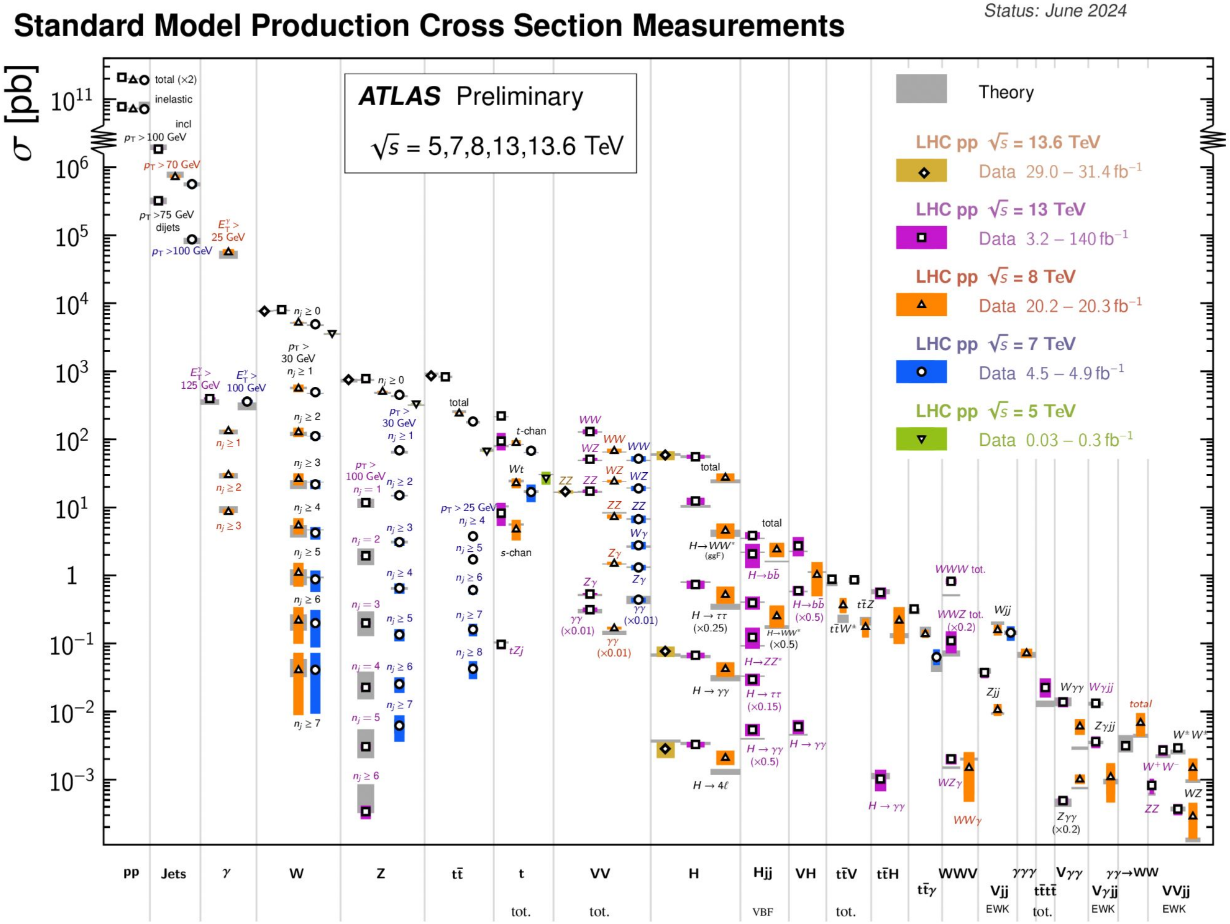
- Motivation for FCCee
- The IDEA Detector at the FCC
- Detector impact on flavour tagging at the FCC-ee [A. Sciandra]
- Impact of changes in the flavour tagger performance on the Higgs coupling measurements in ZH fully hadronic final states at the FCC-ee [I. Veliscek]

The studies shown are input for the feasibility report [CERN-FCC-PHYS-2025-0002] & a paper has been submitted [arXiv:2504.11103]

The Standard Model



So far so good



FUTURE CIRCULAR COLLIDER

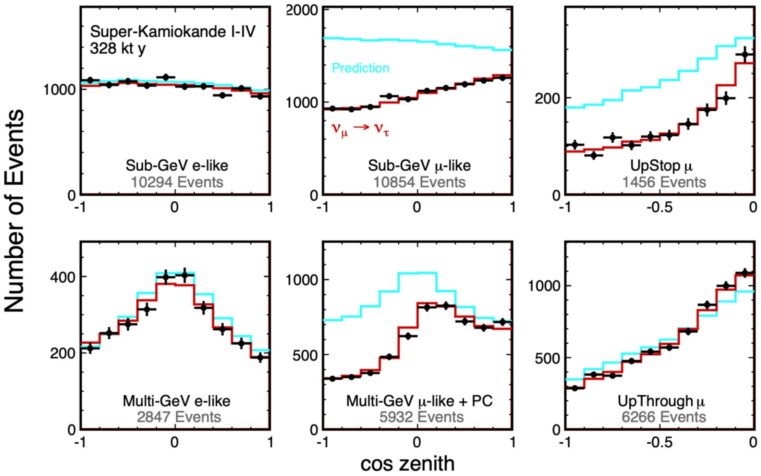
So what is missing? What are we looking for?

IS IT POSSIBLE TO HAVE A UNIFIED QUANTUM THEORY OF ELEMENTARY PARTICLES AND GRAVITY?

WHY IS THERE MORE MATTER THAN ANTIMATTER IN THE UNIVERSE?

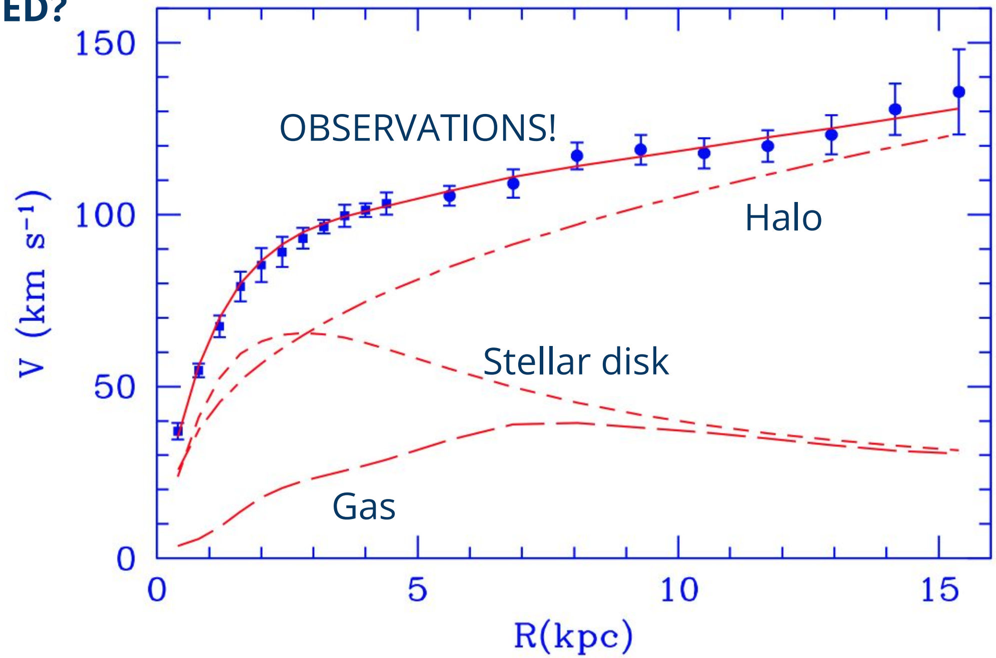
HOW ARE THE NEUTRINO MASSES GENERATED?

WHAT IS DARK MATTER?



rpp2024-rev-neutrino-mixing

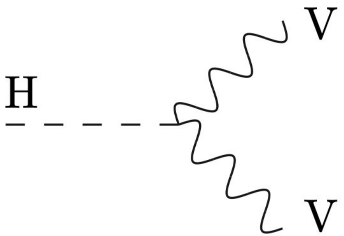
arXiv:astro-ph/9909252



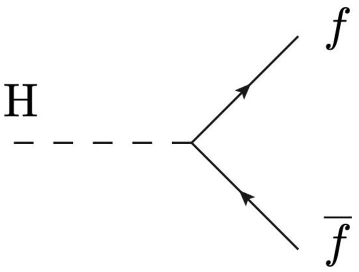
The Higgs Boson might answer some of the questions

MECHANISM THROUGH WHICH

SM PARTICLES OBTAIN MASS



$$\frac{2m_V^2}{v}$$



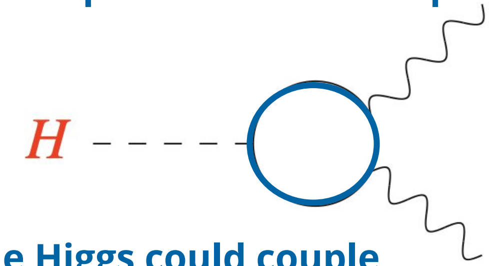
$$\frac{m_f}{v}$$

Particles mass measured

Vev known from electroweak precision measurement

The coupling strength of the Higgs to SM particles predictable!

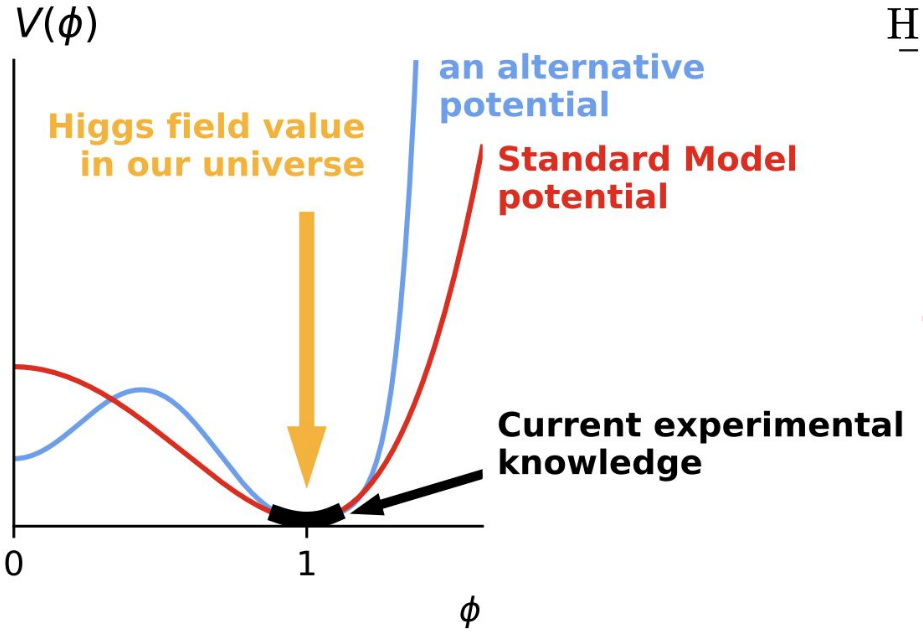
New particles in the loop?



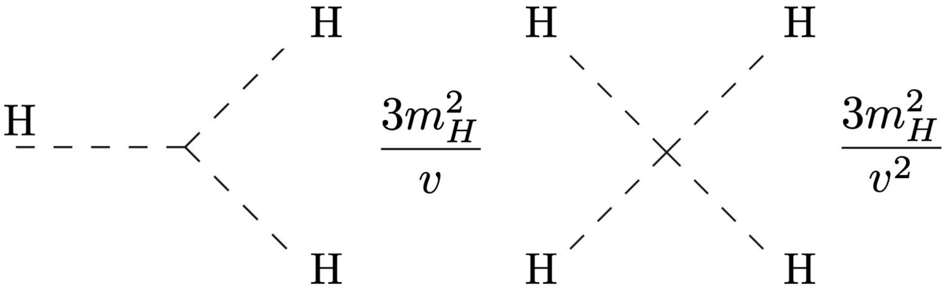
The Higgs could couple to Dark Matter

Any deviations in the couplings from the SM predictions would help of understand the Dark Sector!

Higgs self-coupling



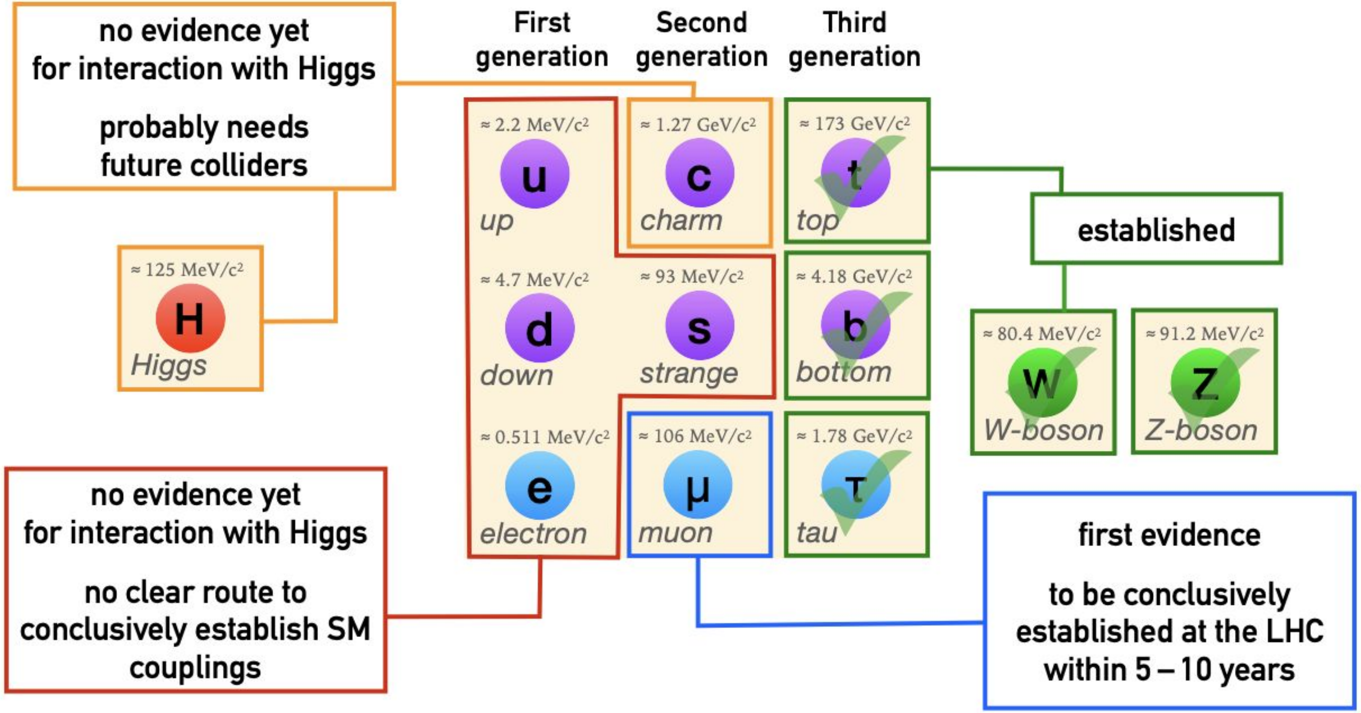
arXiv:2207.00478



The Higgs potential plays a role in the evolution of the Universe

In baryogenesis Deviations from the SM value could lead to a 1st order phase transition needed to explain matter antimatter asymmetry

The Higgs Couplings



*Run FCC-ee at
$E_{CM} = m_H = 125$ GeV
[see slide 29]

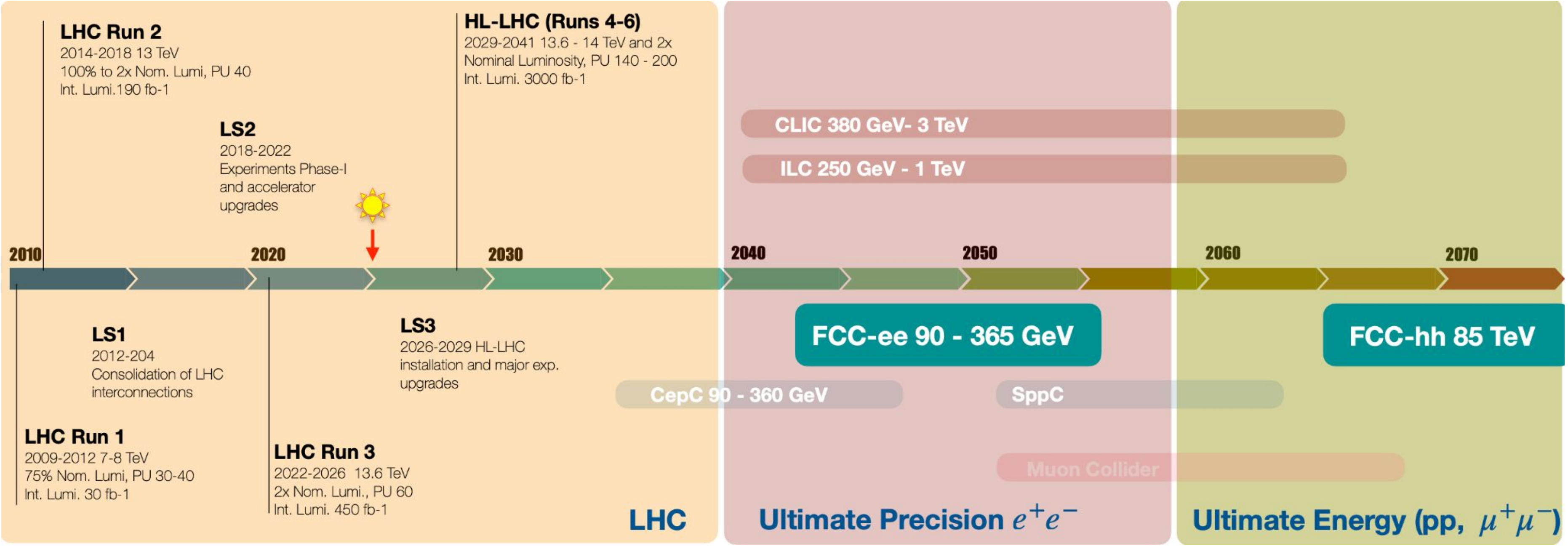
arXiv:2207.00478

CERN: LEP-> LHC -> HL-LHC -> ?

LHC produced
~ 15 million Higgs bosons
x10 statistics to come with HL-LHC

Luminosity frontier
~ 3 million Higgs bosons

Energy frontier
~ 20 billion Higgs bosons

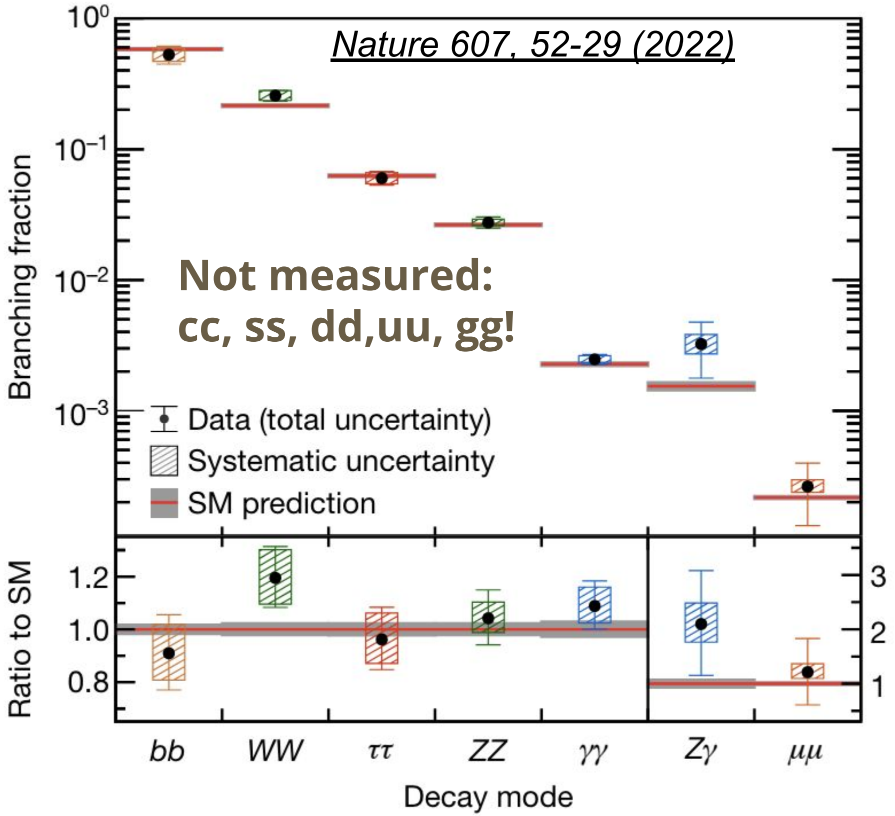


Graphics from FCC-Week-2025

Higgs couplings

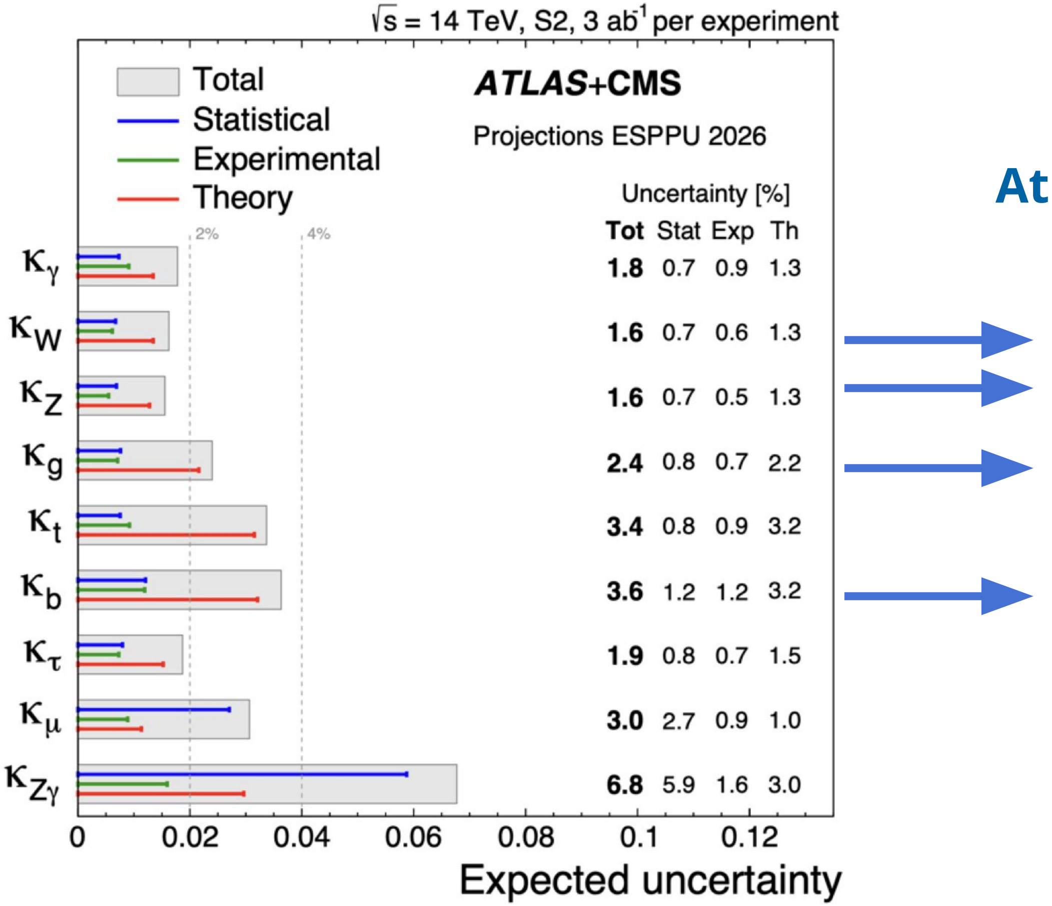
Hard to measure **Higgs properties precisely** at (HL-) LHC:

- **H->cc** challenging measurement, **H->ss/gg/dd/uu** seem impossible at the movement



FUTURE CIRCULAR COLLIDER

What to expect at HL-LHC? At FCC-ee?



At FCC

0.1%

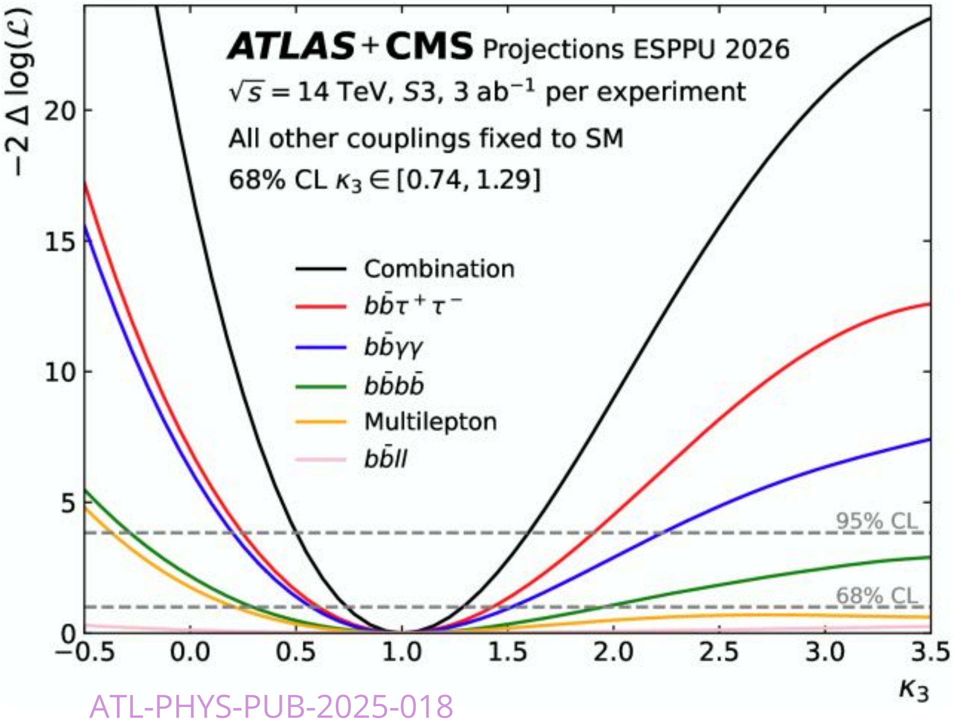
0.5%

0.5%

In addition at the FCCee

H->cc because accessible & several coupling of the Higgs can with O(0.1%) precision

Higgs self-coupling



ATL-PHYS-PUB-2025-018
CMS-HIG-25-002

HL-LHC Projections: κλ+29%−26%

FCC-ee : 27% - 18% (combined w/ HL-LHC)

- At the FCCee only indirect measurements of the self-coupling
  - Loop level

Need FCC-hh to get percentage level precision on the coupling

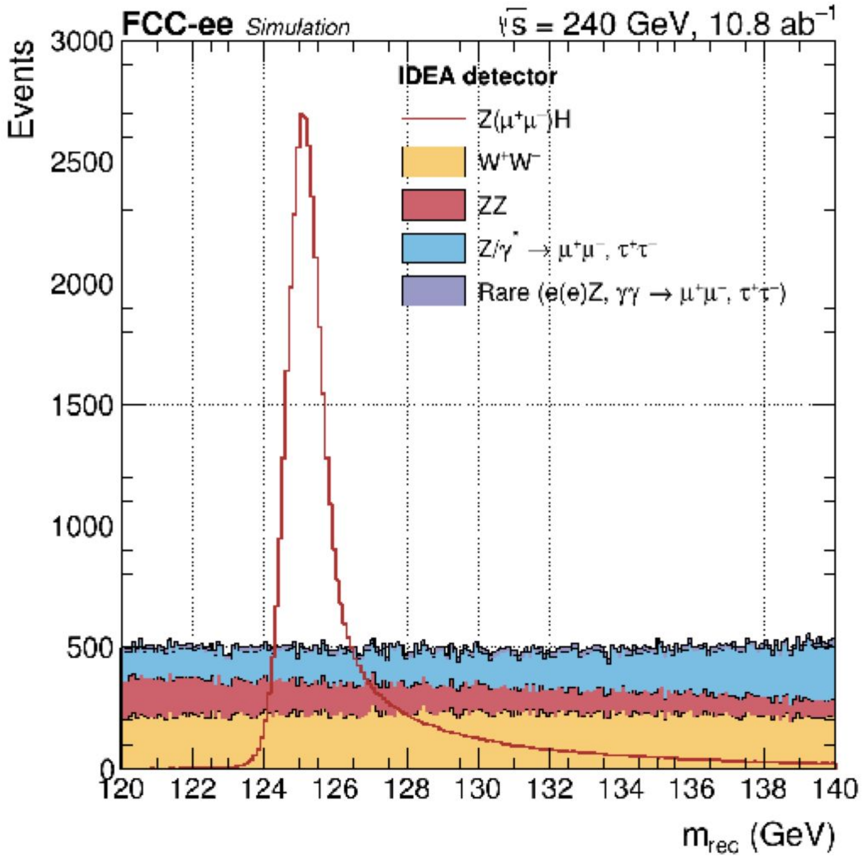
- Can be measured through the direct production of HH

What will we know (and not) by the end of (HL-) LHC?

The Higgs width at **HL-LHC ~ 4.1** with a **18%** uncertainty [CMS-PAS-FTR-18-01]

At the FCCee the precision improves more than 30 times!

Delta **$\Delta\Gamma_H$~ 0.78%** using the total ZH cross section and the recoil mass



Motivation

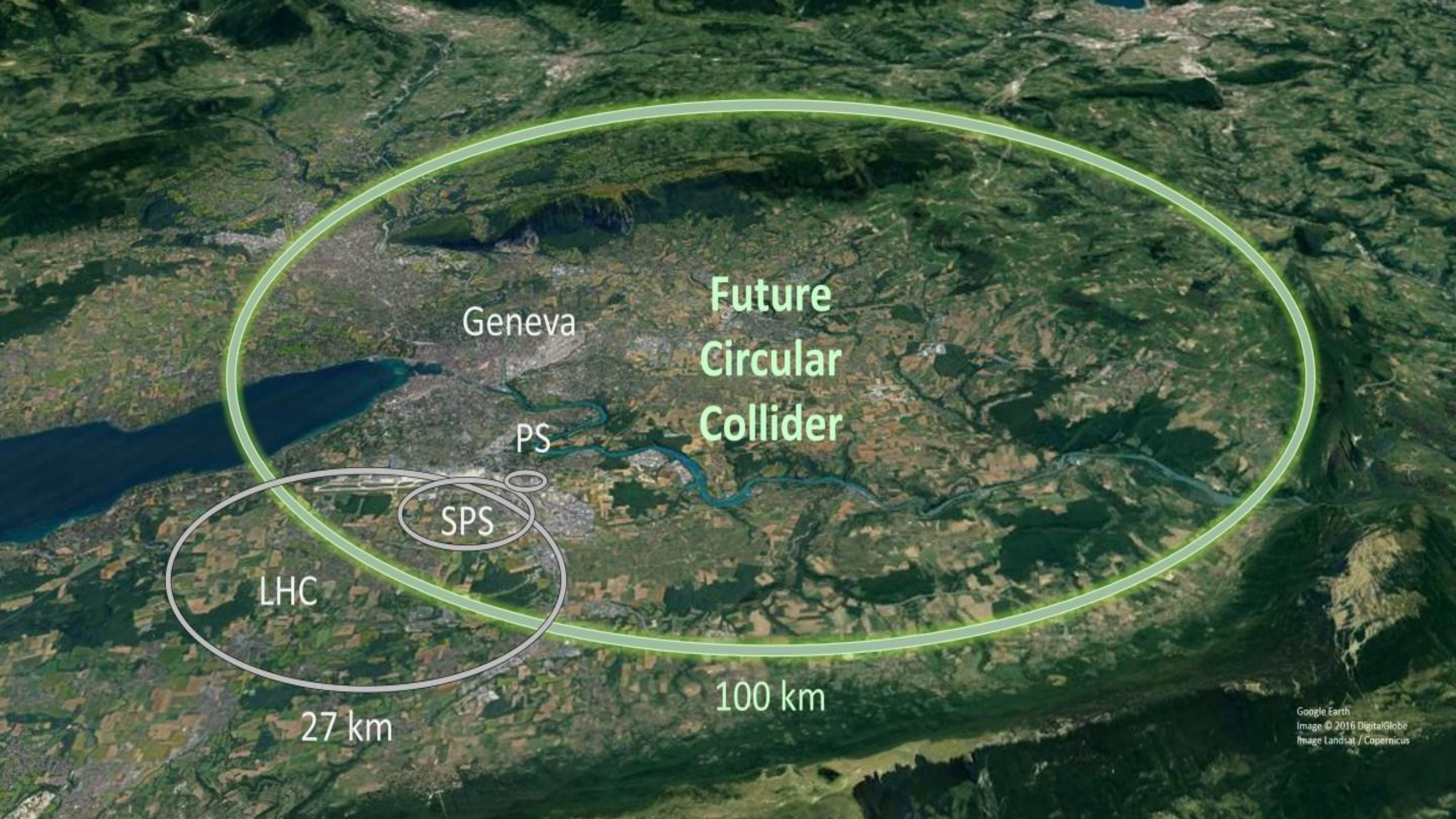
Hard to measure **Higgs properties precisely** at (HL-) LHC:

- **H->cc** challenging measurement, **H->ss/gg/dd/uu** seem impossible at the movement

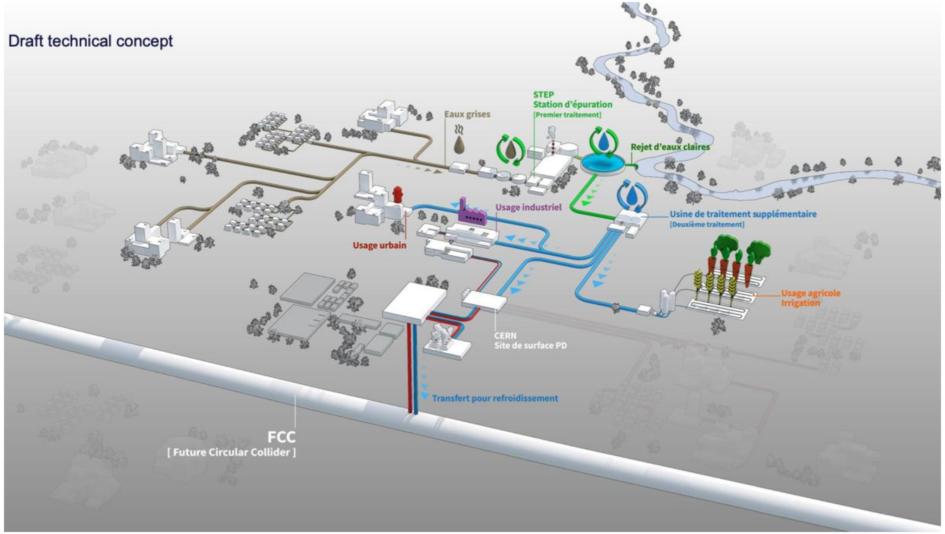
However at the **FCC-ee** we expect **millions of ZH events to be produced** in a clean environment!

- Higgs mass, width & couplings to quarks can be measured precisely!
- Need powerful **flavour tagging algorithms**

Crucial to understand how the detector design impacts the flavour tagging performance.


Future
Circular
Collider
Geneva
PS
SPS
LHC
100 km
27 km
Google Earth
Image © 2016 DigitalGlobe
Image Landsat / Copernicus

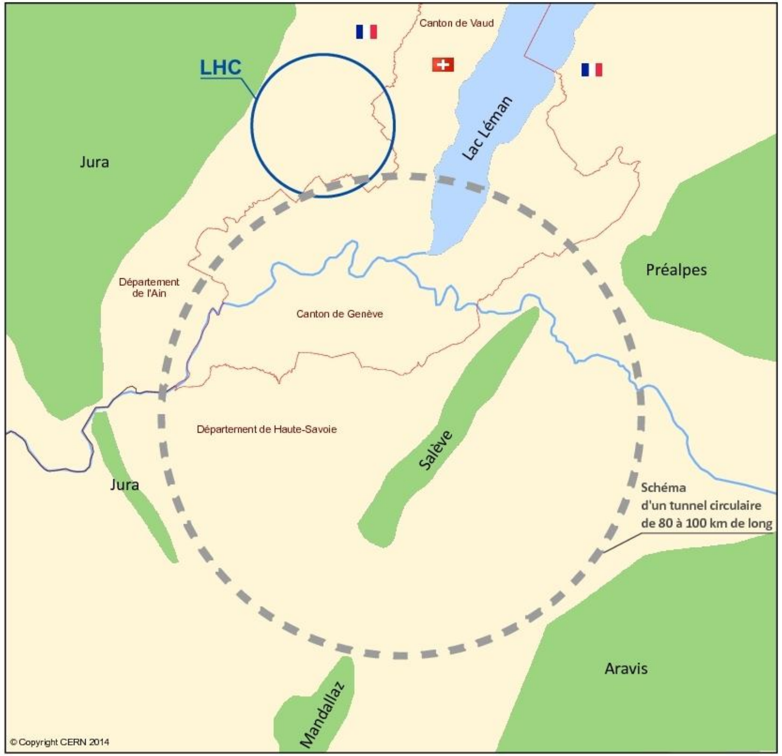
Environmental Impact

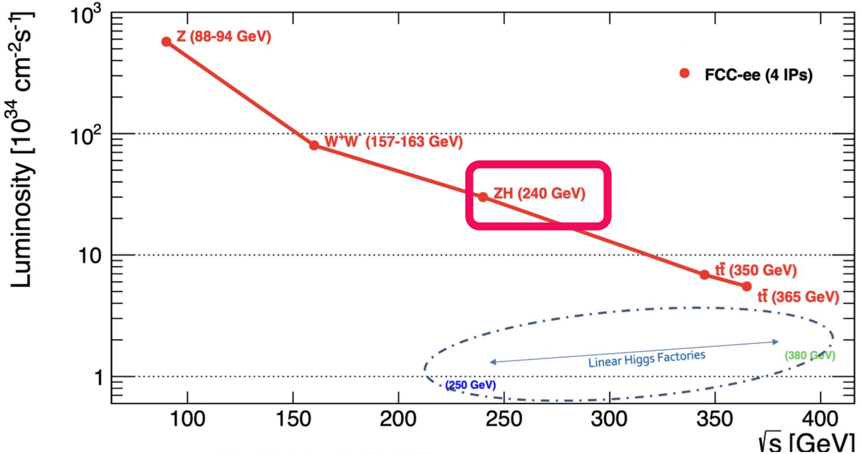


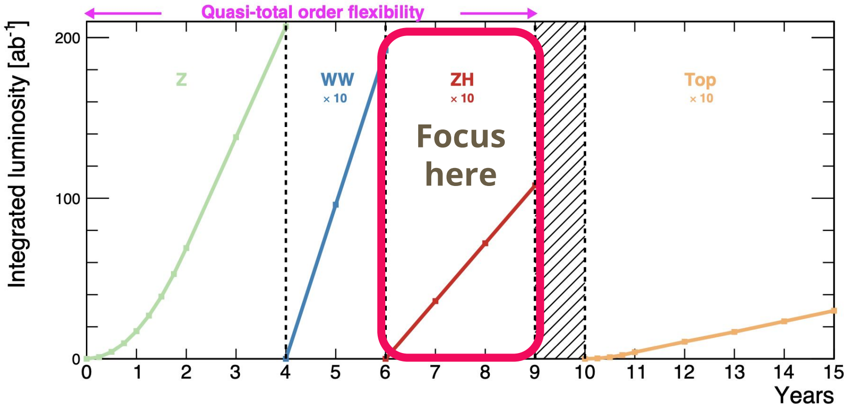
[Potential Reuse Of Wastewater For FCC And Society]

[A Platform For Developing Quality-Managed Processes For Constructing Soil From Geological Excavation Materials]

FCC-ee

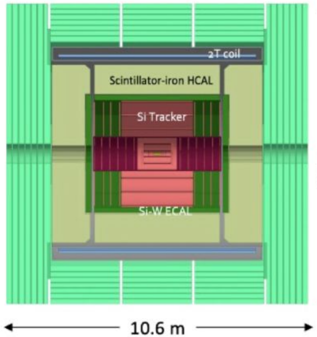

LHC
Canton de Vaud
Lac Léman
Jura
Département de l'Ain
Canton de Genève
Préalpes
Département de Haute-Savoie
Salève
Jura
Schéma d'un tunnel circulaire de 80 à 100 km de long
Aravis
Mandallaz
© Copyright CERN 2014


Luminosity [10^{34} cm^{-2}s^{-1}]
Z (88-94 GeV)
FCC-ee (4 IPs)
W$^+$W$^-$ (157-163 GeV)
ZH (240 GeV)
$t\bar{t}$ (350 GeV)
$t\bar{t}$ (365 GeV)
Linear Higgs Factories
(250 GeV)
(380 GeV)
$\sqrt{s}$ [GeV]


Quasi-total order flexibility
Integrated luminosity [ab^{-1}]
Z
WW × 10
ZH × 10
Focus here
Top × 10
Years

Current Detector Concepts

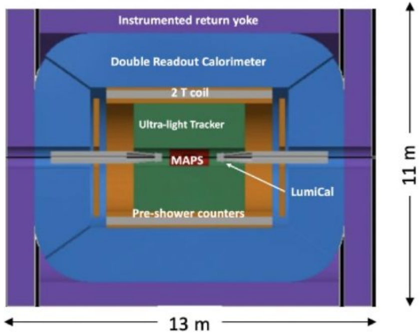
CLD



- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker
- CALICE-like calorimetry;
- Large coil, muon system
- Engineering still needed for operation with continuous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?
  - …

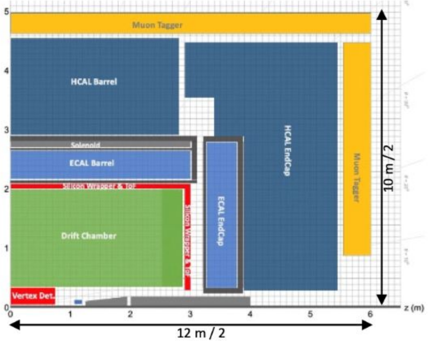
CDR

IDEA



- A bit less established design
  - But still ~15y history
- Si vtx detector; ultra light drift chamber with powerful PID; compact, light coil;
- Monolithic dual readout calorimeter;
  - Possibly augmented by crystal ECAL
- Muon system
- Very active community
  - Prototype designs, test beam campaigns, …

ALLEGRO



- The "new kid on the block"
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

FCC-ee CDR: https://link.springer.com/article/10.1140/epjst/e2019-900045-4

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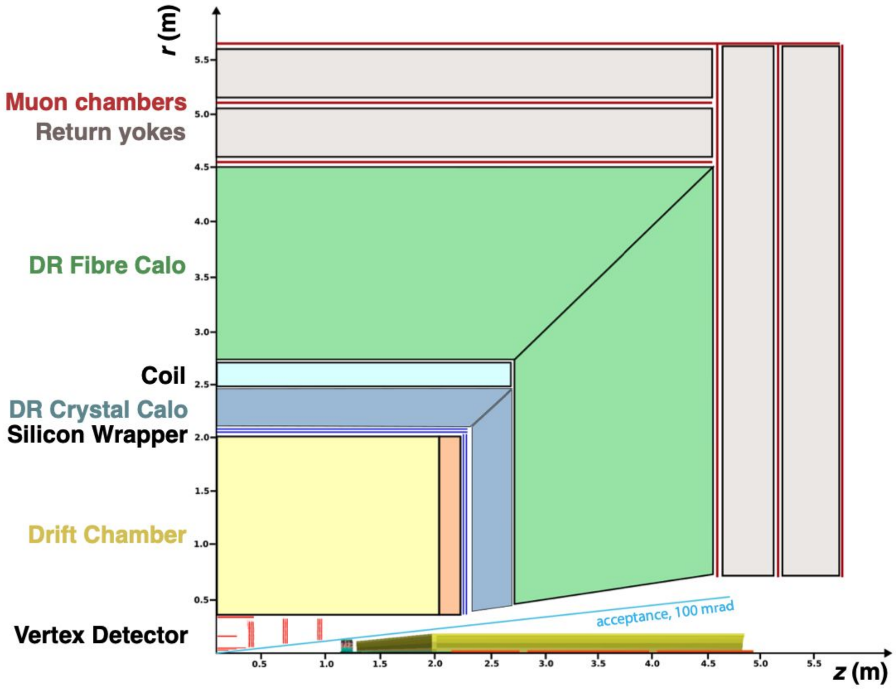
2

ATLAS EXPERIMENT

IDEA detector layout



[The IDEA detector concept for FCC-ee]

Tracking system

- Vertex Detector
- Drift chamber
- Silicon Wrapper

Dual readout calorimeters

- Crystal electromagnetic calorimeter
- Fiber-sampling calorimeter

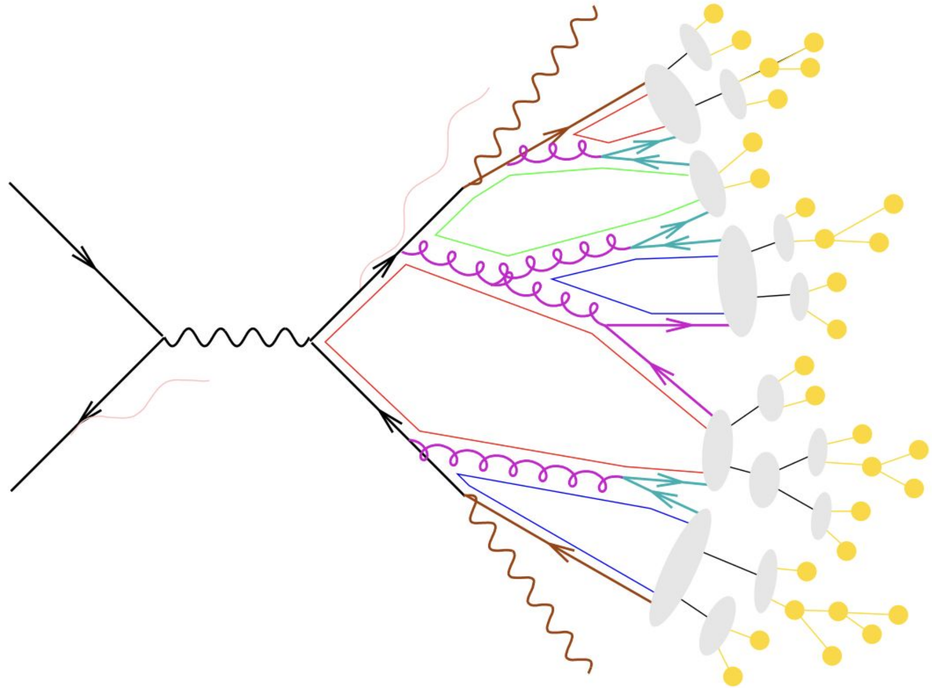
* To identify W decays to jets energy resolution of **~3% at 100 GeV** is required for **hadronic showers**

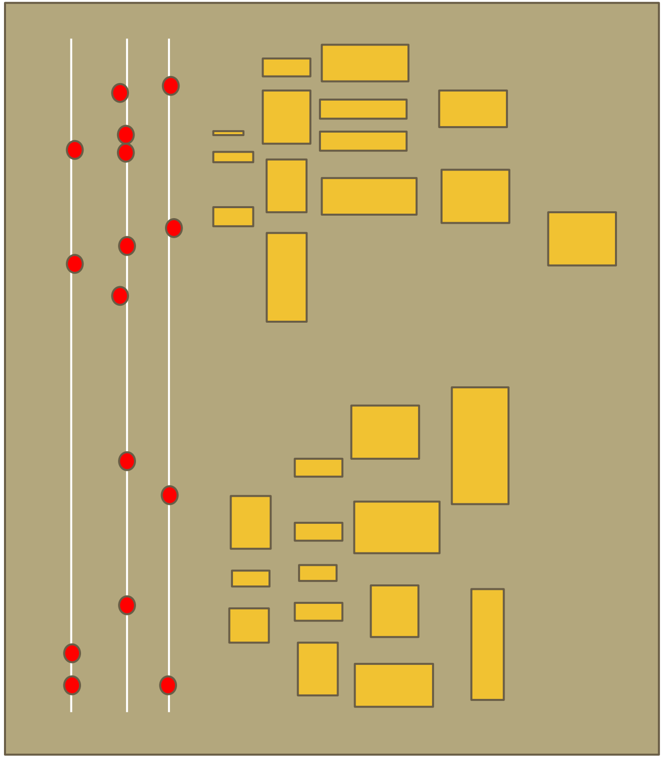
Muon Chambers

- μ-RWELL detectors
- Micro-Pattern Gaseous detectors

How does a e+e- -> ttbar ->bWbW event look?

Hard Scatter | **Parton Shower** $<10^{-18}$m | **Hadronization** 10^{-15}m | **Detection** 10m





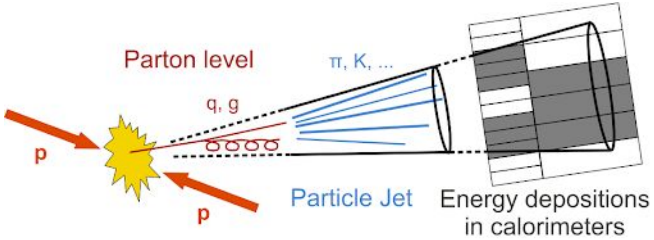
*it is a sketch, do not rea

to much into it

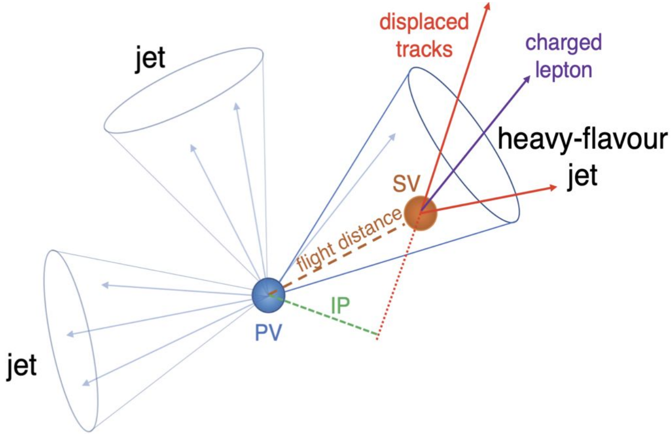
Hits   Energy deposition

Adapted from D. Zeppenfeld lectures

Identifying the flavour of the jets



CMSDAS CERN 2020



Bottom & charm tagging

- Large lifetime (~1-0.1 ps) ⇒ decay length (~50-500 μm)
- Displaced vertices/tracks
- Relatively large invariant mass
- Characteristic track multiplicity ~5 charged particles
- Non-isolated leptons from semileptonic decays
  - → 20(10)% in B(C)-hadrons decays

Tracker needs: Good spatial resolution, small material budget

Strange tagging

- Large Kaon content ⇒ **K/π separation, neutral K_S->ππ**

Tracker needs: Good particle identification (PID) -> timing detectors, Cherenkov detectors, charged energy loss

Pixel Vector Detector

How much can we gain or loss by changing the resolution?

3 μm nominal single-point resolution

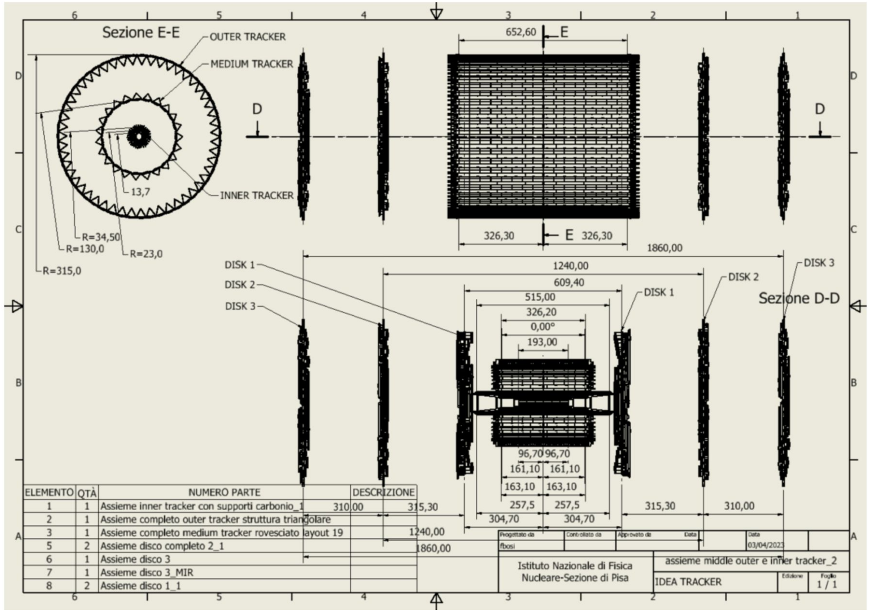
- 25 × 25 μm^2 pitch vertex detector

What happens if we remove a layer?

4 innermost silicon barrel layers

- 1.2cm, 2cm, 3.15cm and 15cm from the beam axis of 1 cm diameter

Latest IDEA tracker layout from F. Palla's talk

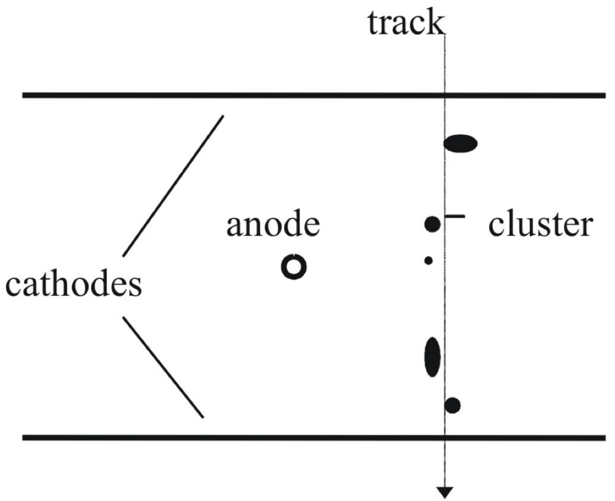


Ultralight Drift Chamber

- **2 T solenoidal field**
- Gas mixture **90% He–10% C_4H_{10}**
  - Light, easily produced, affordable & low global warming potential

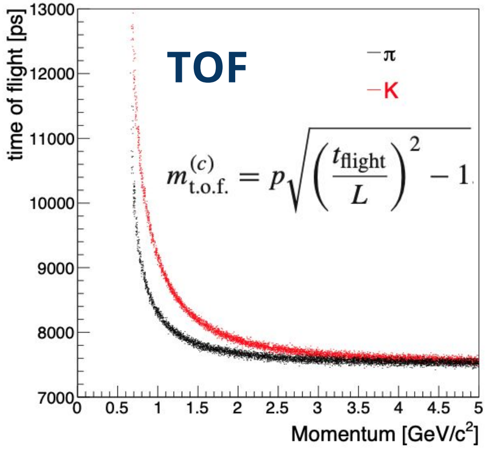
Excellent particle identification (PID)!

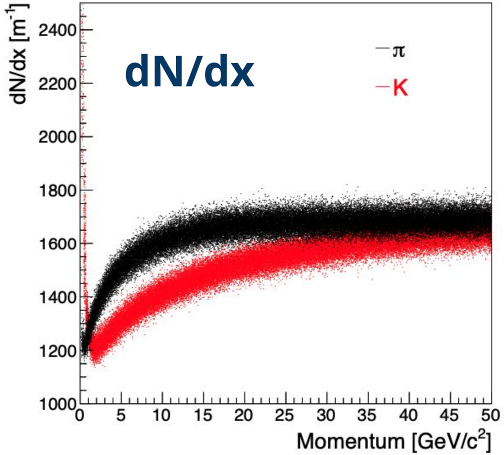
- K/π separation



J.Phys.Conf.Ser. 18 (2005) 346-361

[Eur. Phys. J. C 82, 646 (2022).]





What happens if we remove Time of flight (TOF) or cluster-counting (dN/dx) information?

FUTURE CIRCULAR COLLIDER

Study the impact of detector configurations and properties on physics performance

The ParticleNet Tagger

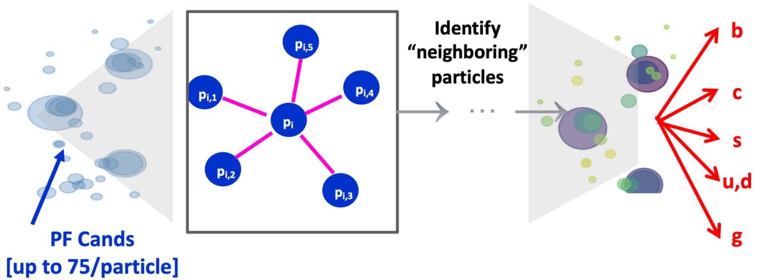
Graph-based tagger, where each jet is treated as a “**cone**” of reconstructed particles traversing the detector

Particle-flow (PF) principle: particle candidates are mutually exclusive and have lots of info associated with: **E/p, position, Impact parameters, particle type, Timing**

kT jet-reconstruction algorithms to reco jets: unordered sets of particles with correlations & relationships.

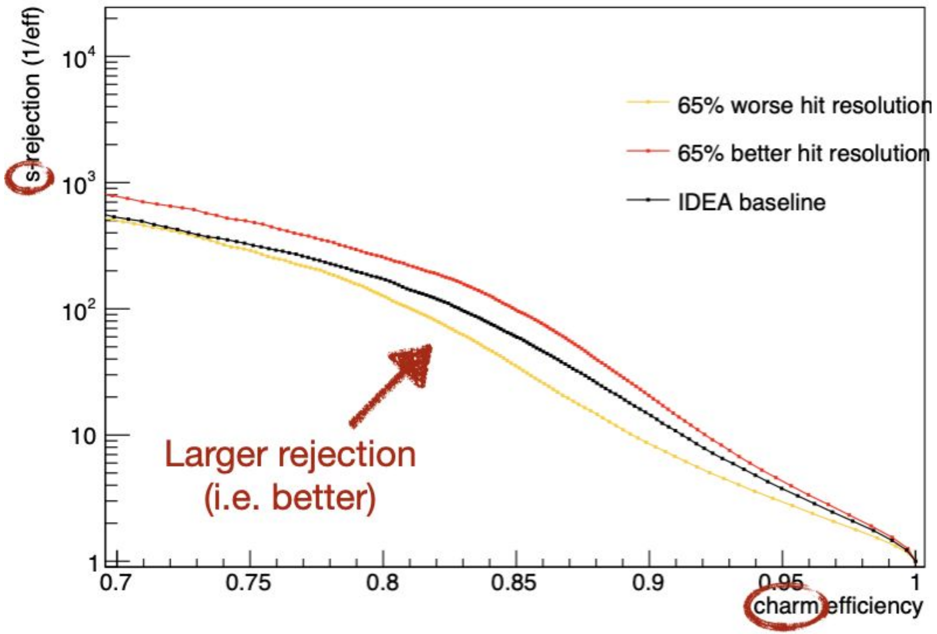
Graph-Neural-Network architecture for ParticleNet: Identify properties of “particle cloud”, represented as a graph
Each particle: **node** of the graph; connections between particles: **the edges**
Learn local structures -> move to more global ones

Inputs
~O(50) properties/particle x
~50-100 particles/jet
=
~O(1000) inputs/jet



FUTURE CIRCULAR COLLIDER

Tracker impact on flavour tagging



±65% variation on the single-point resolution

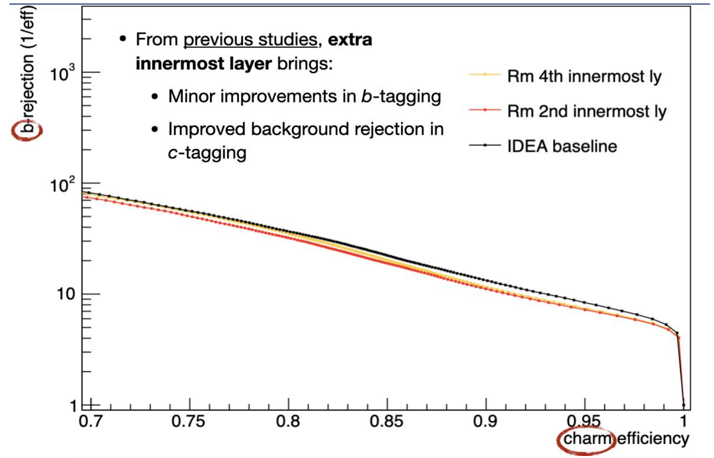
Reminder: nominal resolution of 3μm with 25x25μm2 inner

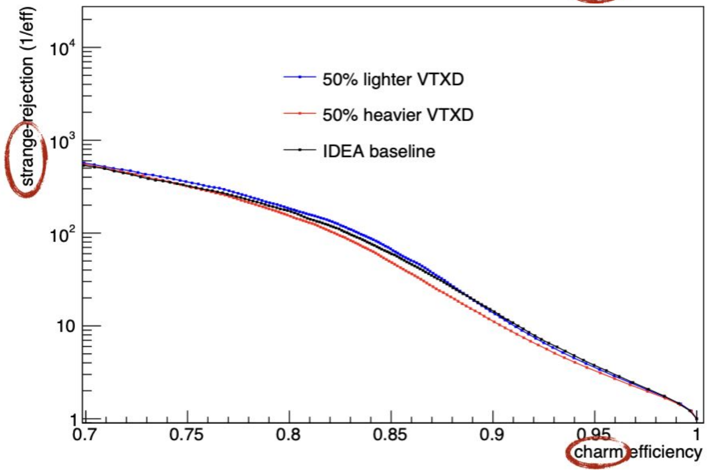
Most significant effects on **c-tagging** rejecting **s-jets**

- **Factor of 2 improvement/degeneration**

But minimal improvement in **b-jet** rejection

Tracker impact on flavour tagging





Assuming innermost layer at 1.2cm, **removal of intermediate layers (2cm and 15cm)***

Minor effects on **b-tagging** - picture may change at high momentum

Visible effects on **c-tagging with at most 15%** improvements in rejection across flavours

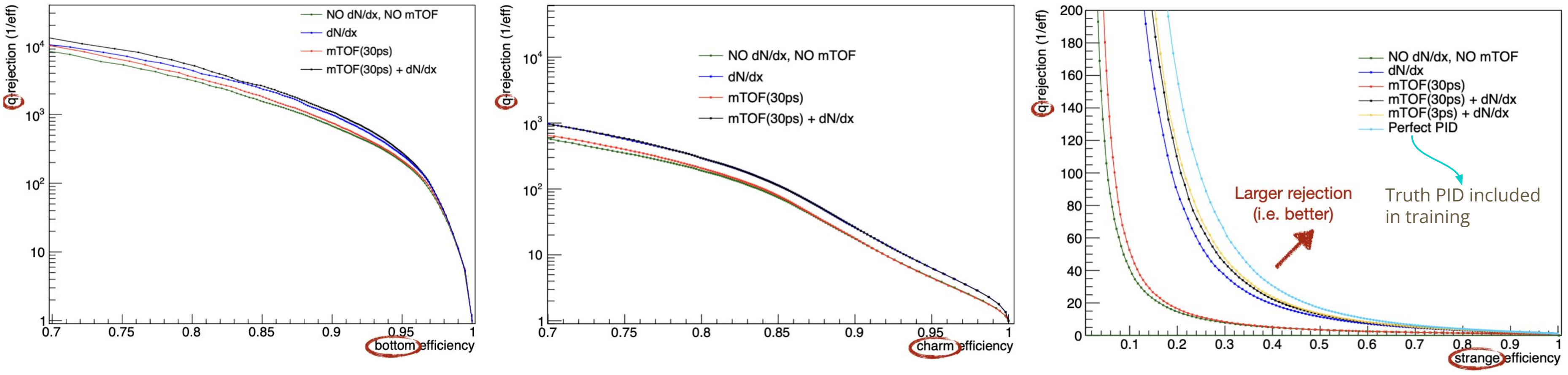
* 2nd & 4th layer removed

±50% relative variations in the radiation length for all of the vertex layers

Asymmetric impact observed for **c-tagging**

Little gain much from lighter vertex detector but can lose in performance with more/heavier material!

Impact of PID on flavour tagging



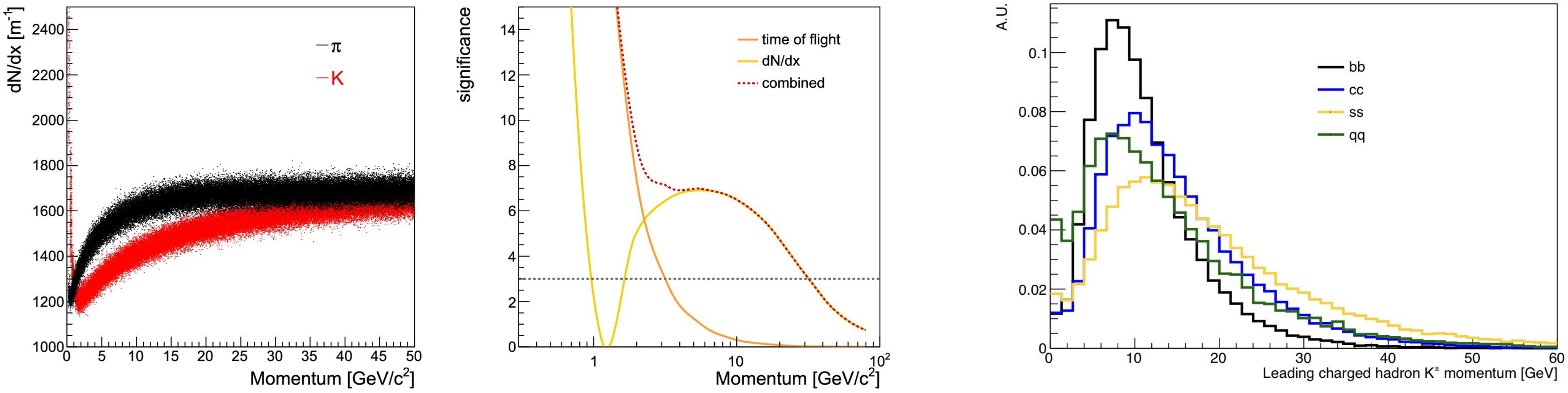
Count number of primary ionization clusters along track path (dN/dx)

Time of Flight (ToF) results in good K/π separation at low-momenta

- Most of achievable gain from PID confirmed to come from **dN/dx**
- Very limited impact of **TOF** mass measurement (even with dream resolution) on strange tagging
  - Benchmark: 60% efficiency -> light rejection 2.5 (mTOF) vs. 7.5 (dN/dx) vs. 8 (dN/dx+mTOF)

Identifying Kaons

[Eur. Phys. J. C 82, 646 (2022).]

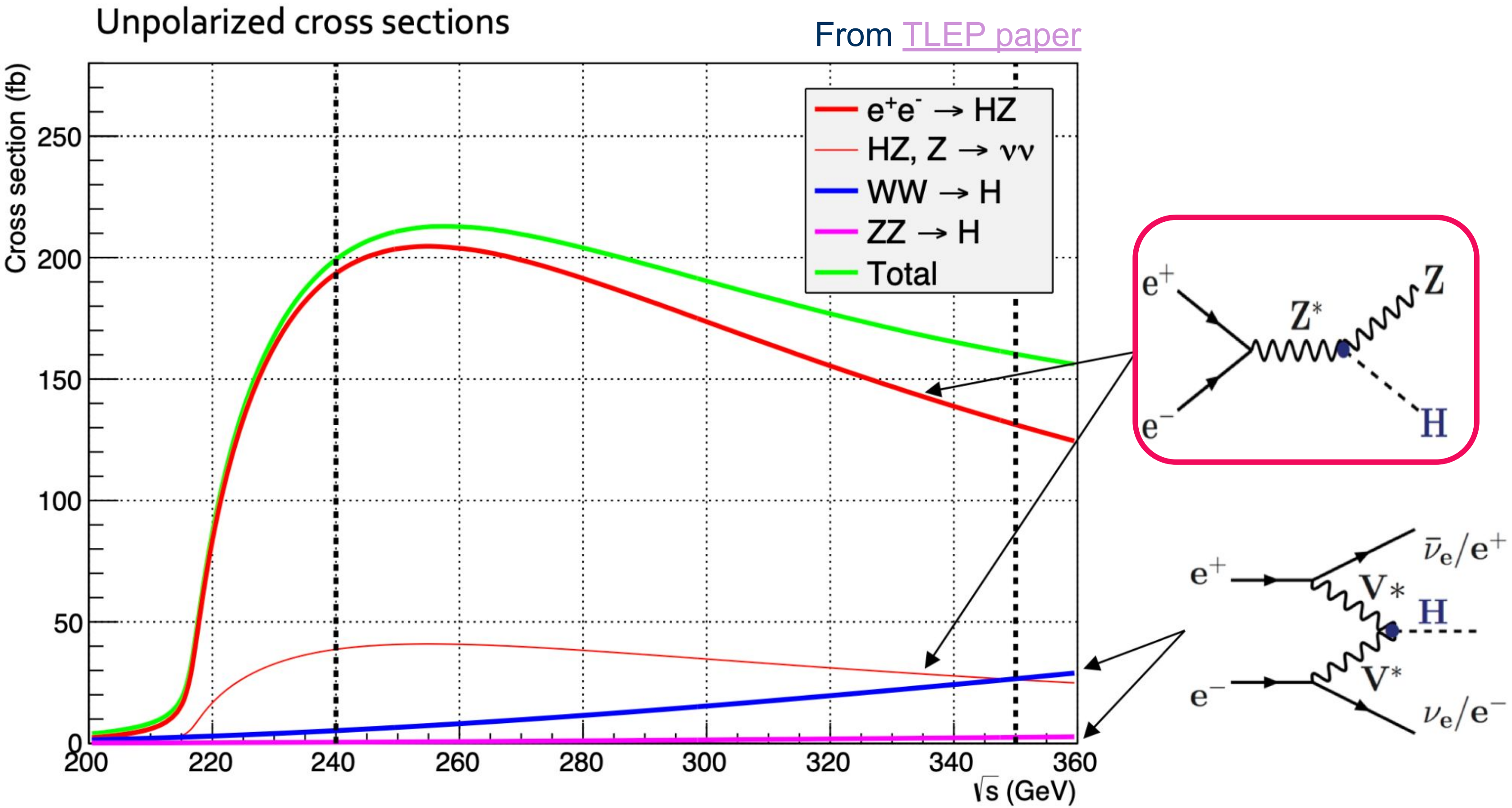


- Hierarchy of TOF impact on light rejection for b, c & s-tagging reflected by spectra of leading K± in jet
- Generally, **harder spectrum in strange jets**, more evident for leading charged hadrons

What is the impact on the Higgs coupling measurements in the ZH fully hadronic analysis?

ZH Production at FCCee

From TLEP paper



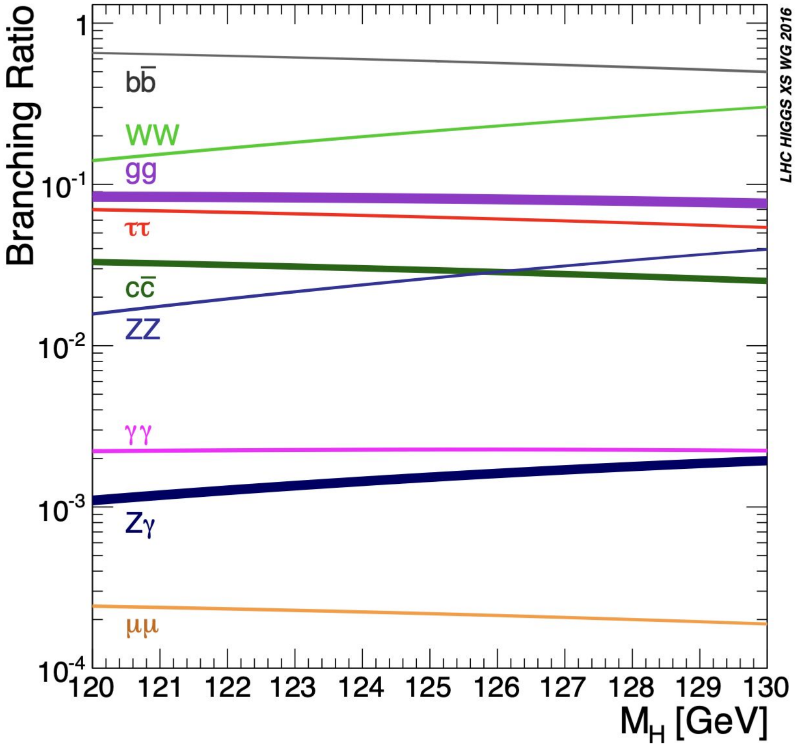
ZH Production at FCC-ee

- **ZH leading Higgs production mode**
  - \+ All hadronic decay has the largest branching fraction
  - \- Jet combinatorics, flavour identification
- Abundance of Higgs produced @ √s = 240 GeV
  - ~2 000 000 ZH events

Performance of the flavour tagging algorithms depends on the detector properties.

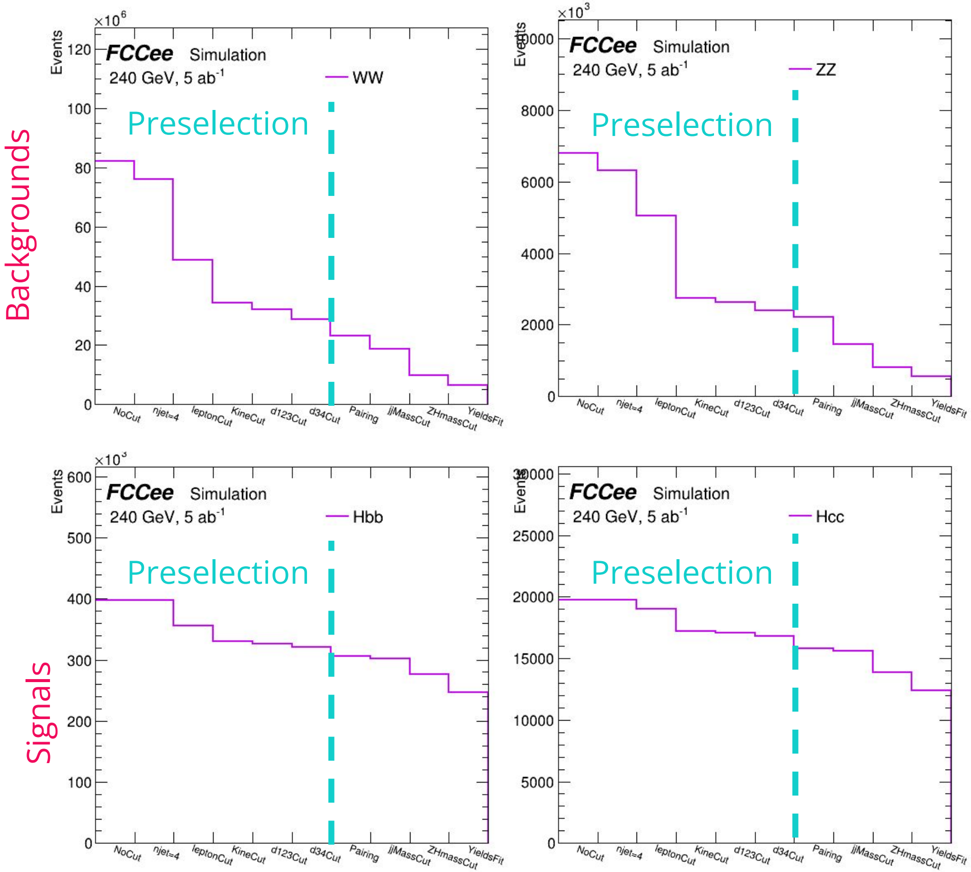
The goal is to determine the impact of flavor tagging performance on the Higgs coupling measurements!

Handbook of LHC Higgs cross sections



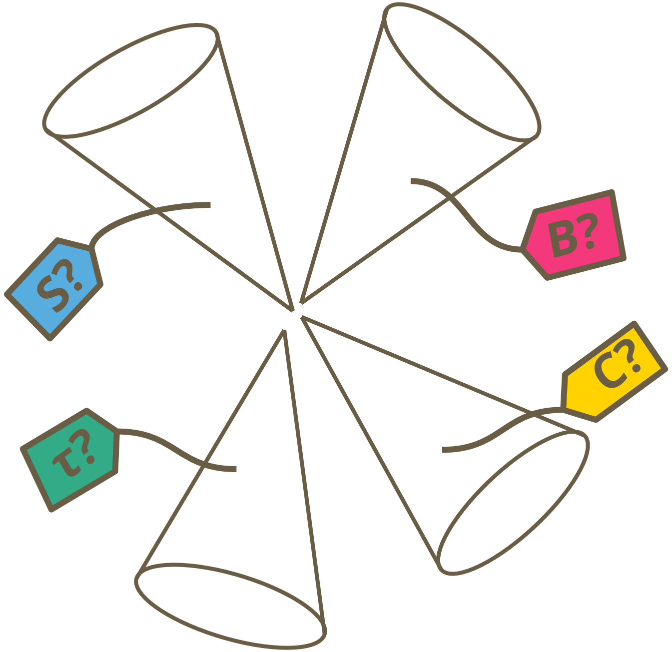
Some technicalities

- **IDEA Detector**
  - Delphes fast sim
- **Jet Clustering**
  - N = 4 Durham k_T exclusive algorithm
- **ParticleNet jet tagger** [trained by A. Sciandra]
  - See 2202.03285 for details on the flavor tagger
- Build on ZH(fully hadronic) analysis presented in Annecy by **G. Iakovidis** [slides]



FUTURE CIRCULAR COLLIDER

Jet "tagging"

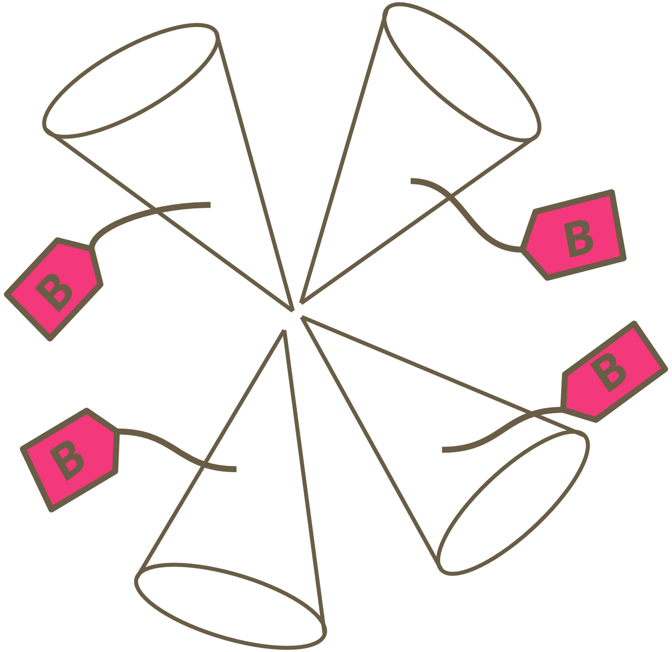


ParticleNet jet tagger

- Scores provided for the "flavours":
  - B, C, S, g, τ, U, D
    - q: U,D
- Scores ~ probability jet is of flavour X
- Flavour tagging
  - Maximum flavour score ~ flavor of jet
  - Sums of same flavour scores for jet pairs ~ flavour of jet pair

  * Note - no fixed working point used, different than in ATLAS or CMS

Jet pairing



CASE 1: All jets have the maximum score from the same flavour

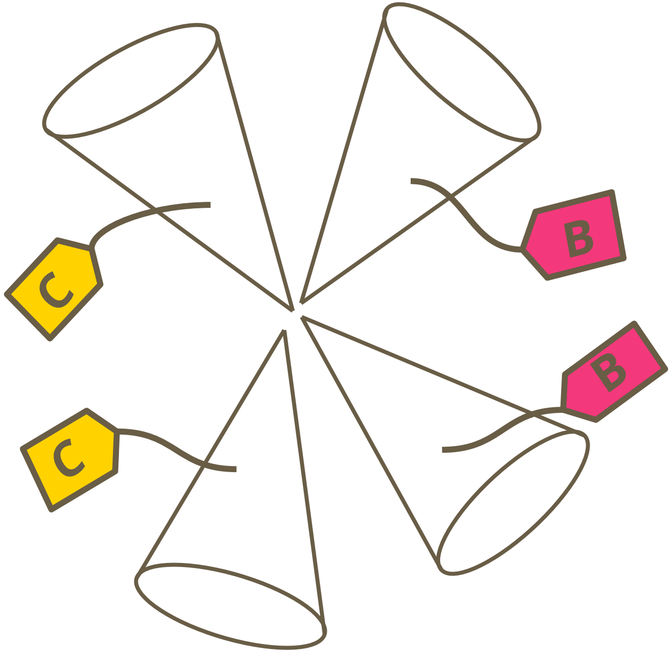
Finding the H&Z candidates

Consider all possible jet pairs

- $\chi_H = (m_{ij} - m_{H,true})^2$
- $\chi_Z = (m_{lk} - m_{Z,\ true})^2$
- $\chi_{comb} = \chi_H + \chi_Z$

The jet paring that gives the **minimum** $\boldsymbol{\chi_{comb}}$ is chosen!

Jet pairing



CASE 2: Two jet pairs with same maximum score from the same flavour, but different flavour of the pairs

Finding the H&Z candidates

- Jet paired, if they have the same flavour maximum score
- Z candidate: Pair with minimum $\chi_Z=(m_{lk} - m_{Z,\, true})^2$

A few more cuts

WW & ZZ rejection

$$\sqrt{(m_{Z_{jj}} - m_W)^2 + (m_{H_{jj}} - m_W)^2} > 10$$

$$\sqrt{(m_{Z_{jj}} - m_Z)^2 + (m_{H_{jj}} - m_Z)^2} > 10$$

Mass window

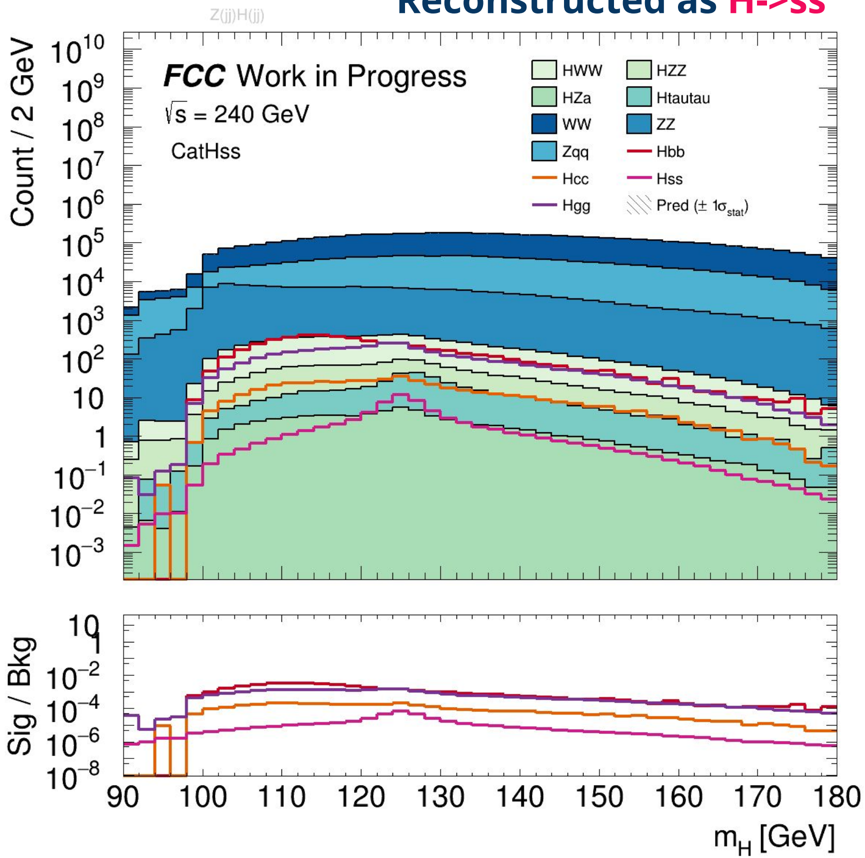
$$50 < m_{Z_{jj}} < 125\,\mathrm{GeV}, m_{H_{jj}} > 90\,\mathrm{GeV}$$

After flavour tagging and Z&H identification reject events reconstructed as:

- H->ττ
- H->qq, q=u,d
- Z->ττ
- Z->gg

*Jet energies are recomputed from jet directions & energy-momentum conservation

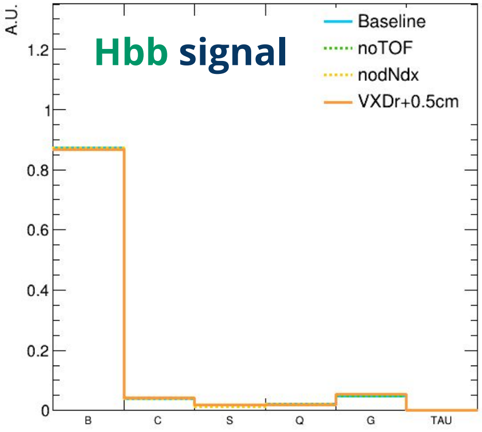
Reconstructed as H->ss



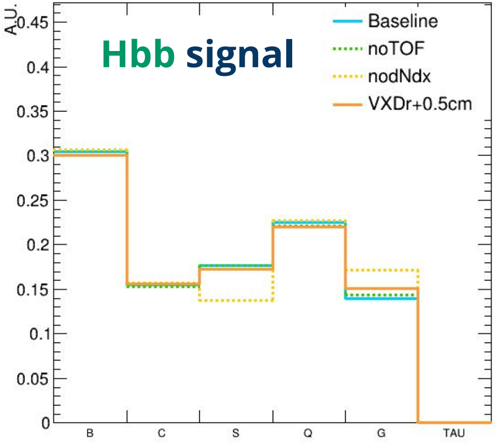
FUTURE CIRCULAR COLLIDER

Categorization

H candidate



Z candidate

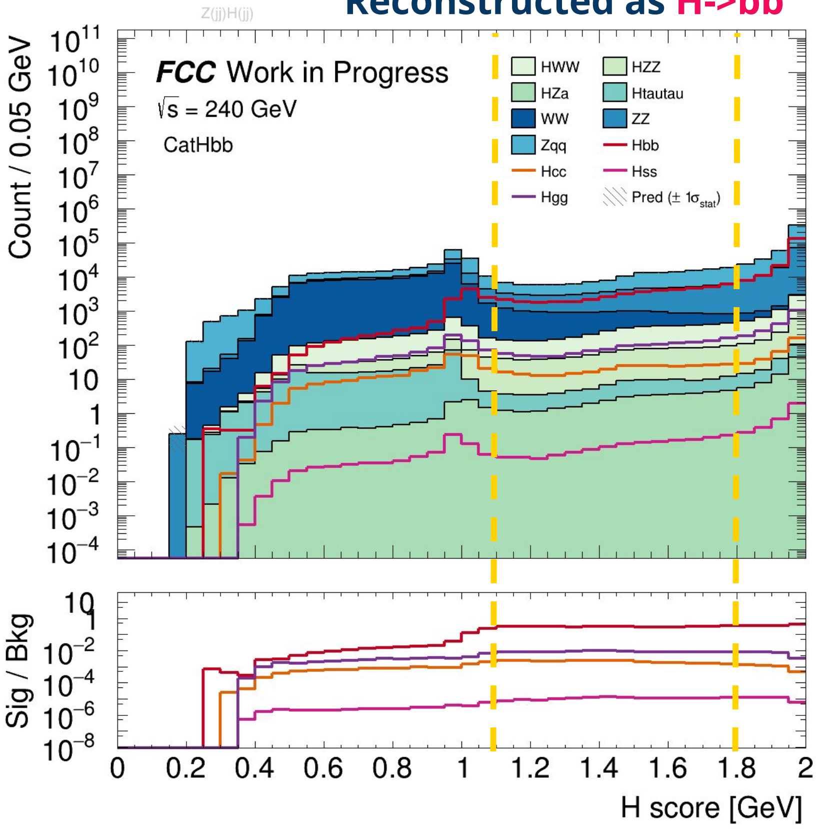


Hbb signal categorized according to the flavour tagged. Additional split according to H flavour score in fit (purity)

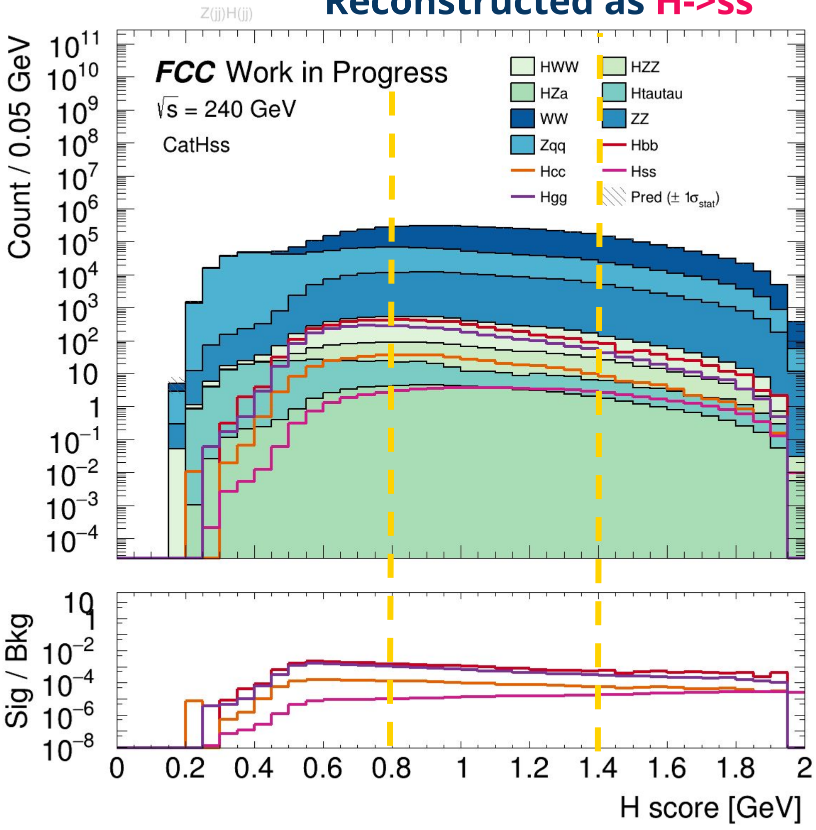
- **Categorize by H->j_1j_2 decay**
  - **Categorize by Z->j_3j_4 decay**
  - Additionally by H flavour score
    - **Purity category :**
      - High (>1.8 (1.4 for Hss))
      - Mid(1.1 (0.8) < score < 1.6 (1.4) (Hss cut in ())
      - Low (<1.1 (0.8 for Hss))
- 48 Categorised in total!
- + 1 GeV binning in $m_{jj,H}$
- + 5 GeV binning in $m_{jj,Z}$

H score determining the purity categories

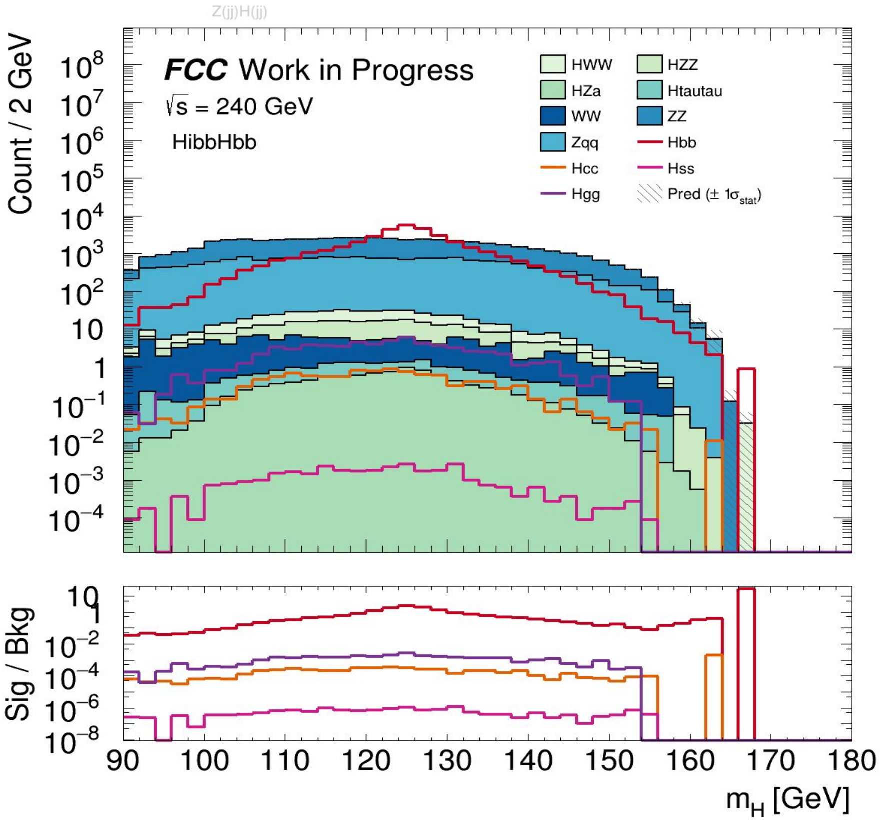
Reconstructed as H->bb

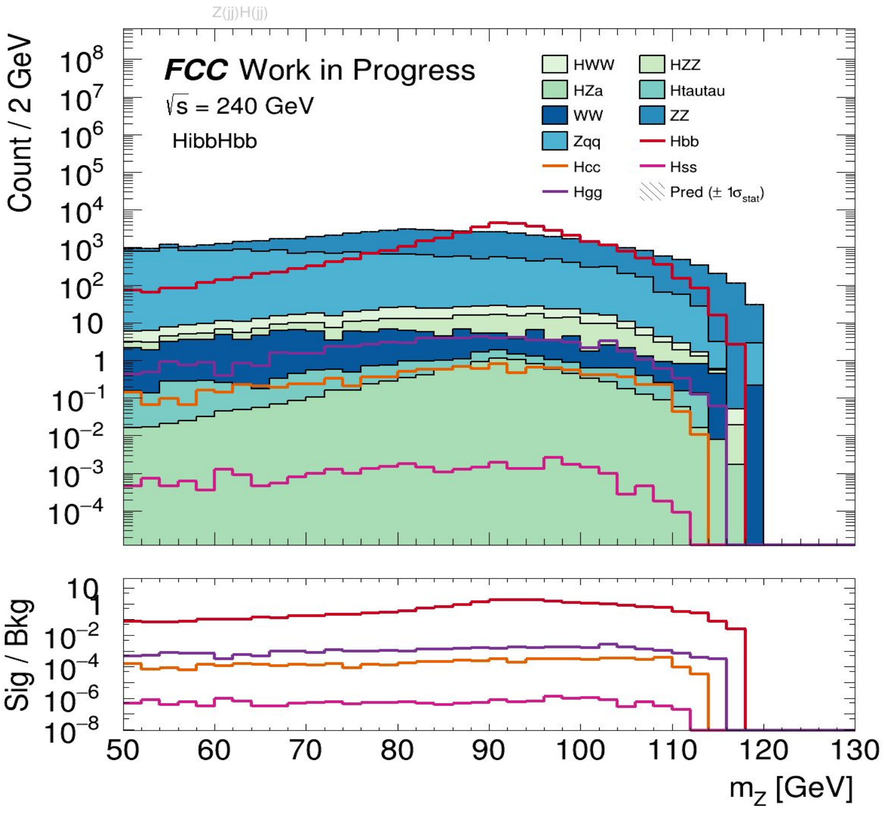


Reconstructed as H->ss



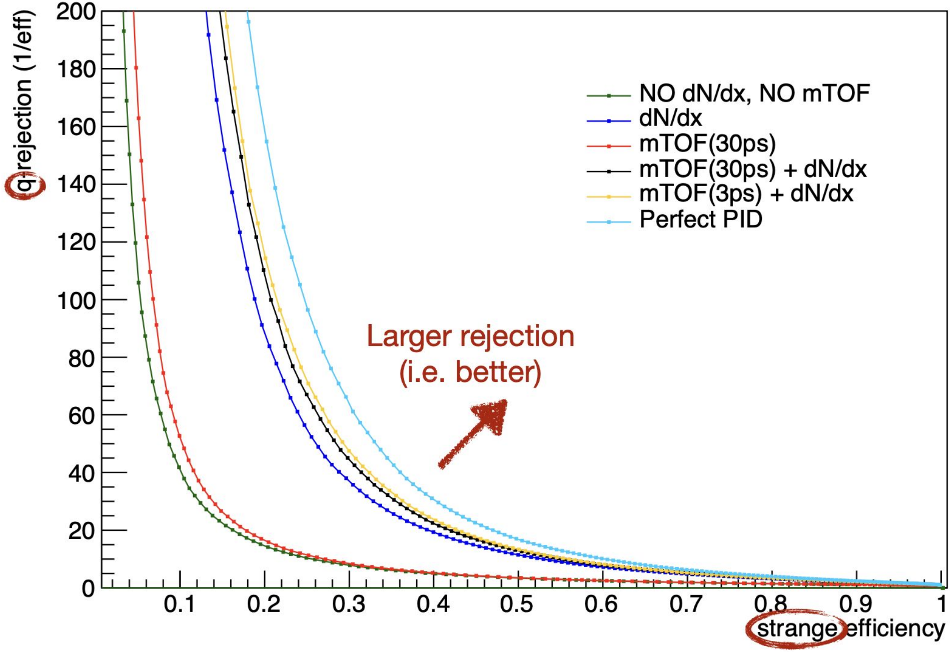
Categorization - High purity ZbbHbb category





Reminder - Flavour Tagging & PID

by Andrea Sciandra

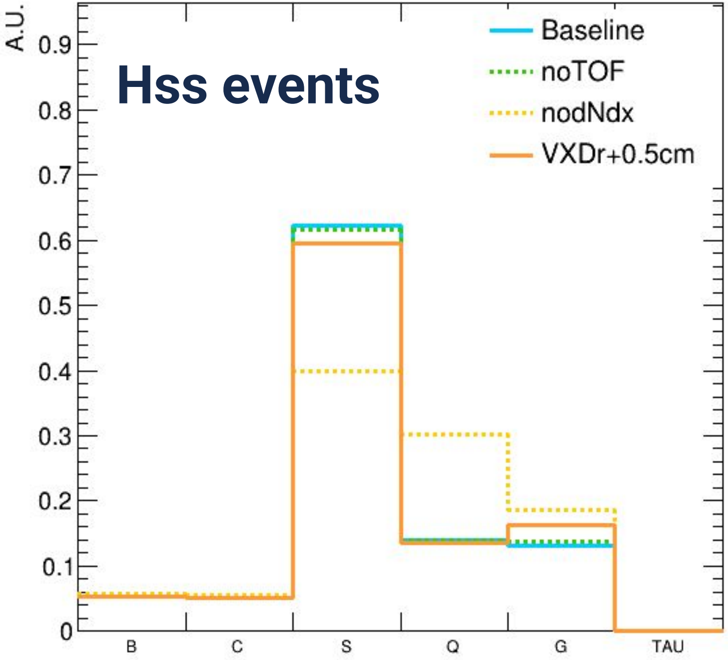


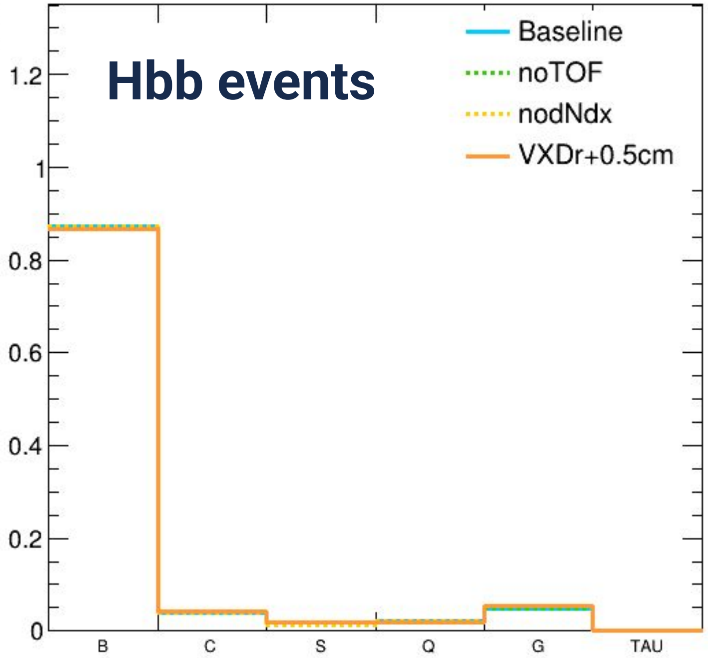
Will only show biggest changes in tagger's performance

- **Baseline** = baseline IDEA detector concept
- **No TOF** (time of flight, dNdX on the plot)
- **No dNdx** (cluster counting)
- **Prefect PID** (accessing the truth information)

*Initial studies shown that number of pixel layers and pixel-detector material budget have a negligible impact on the analysis

Robustness of flavour tagging strategy





Very little migration between the flavour categories

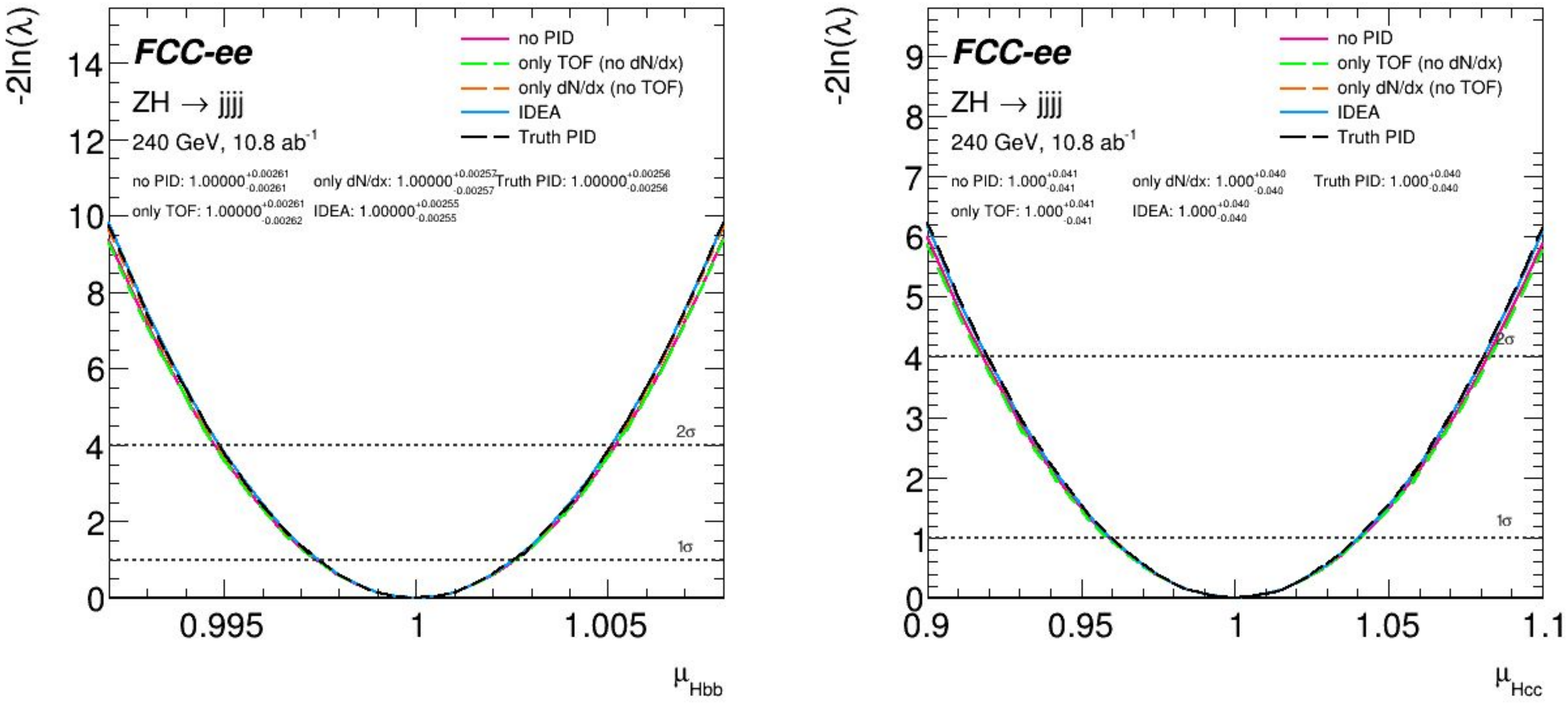
Summing the flavour scores and not rejecting events with low flavour scores guarantees the robustness of flavour tagging

Missing dNdx information notably impacts flavour categorization

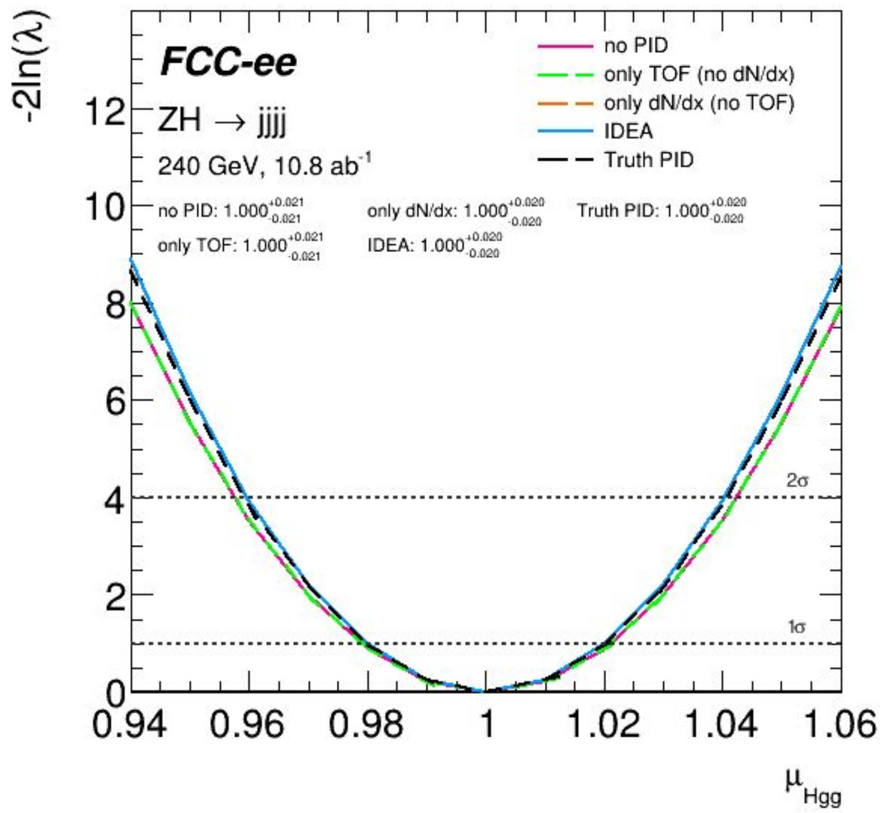
- **Strange** tagging impacted the most
- Expected from ROC curves

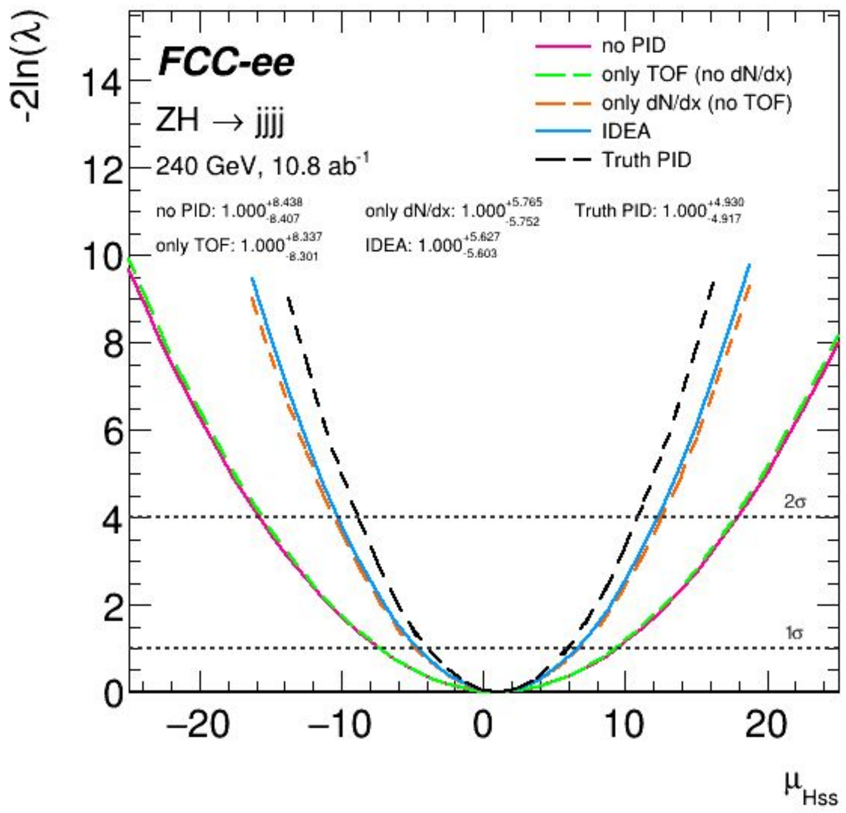
*True also for the backgrounds

Impact on the Higgs couplings; H->bb(cc)

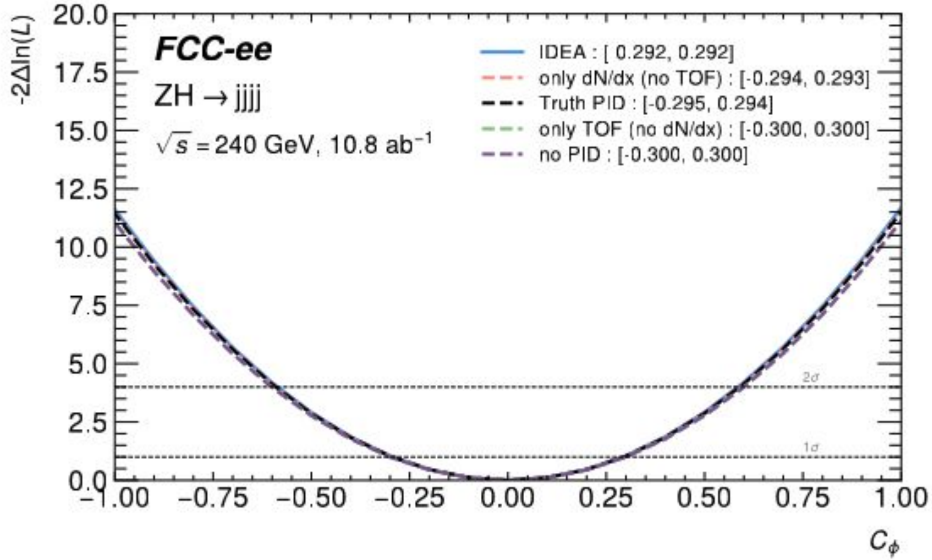


Impact on the Higgs couplings; H->gg(ss)

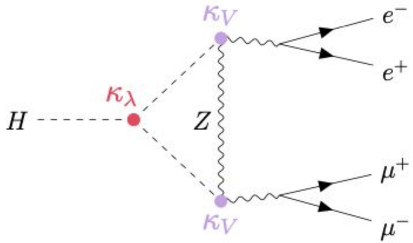




Impact on the Higgs Self-Coupling



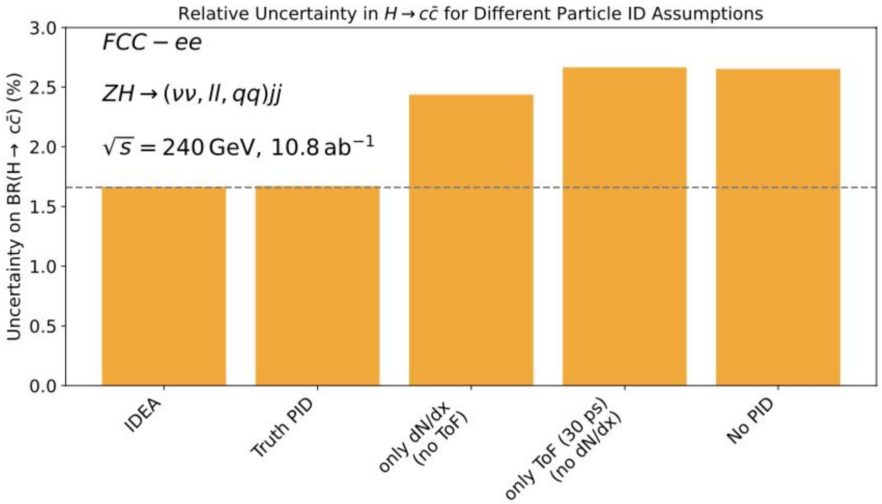
Indirectly measured through loop corrections in single Higgs production



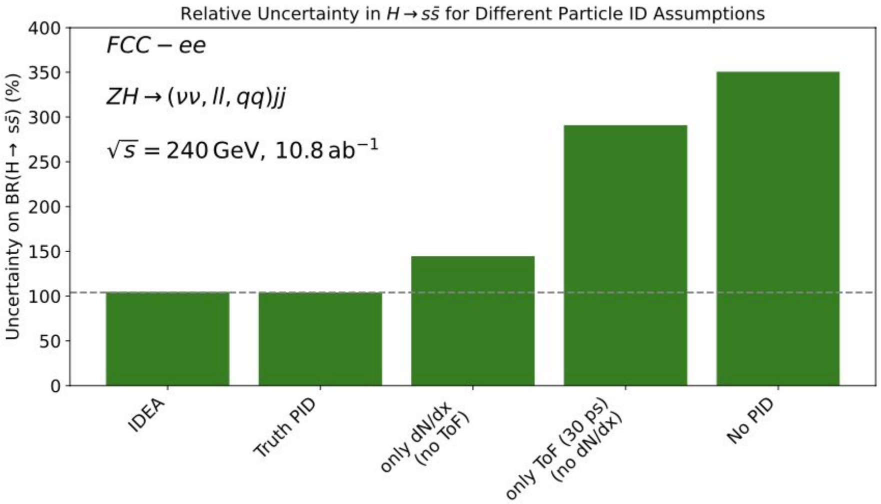
Not impacted by the considered detector variations

Analysis description: 2504.11103
SMEFT description: 2406.03557, 2409.11466

What about Z(νν)H(hadrons)?



H->cc



H->ss

Conclusions

Significant effects observed in efficiency (rejection) at fixed rejection(efficiency) for different silicon and particle-identification detector properties.

However

Changing the tracker configuration does not impact the fully hadronic ZH analysis significantly

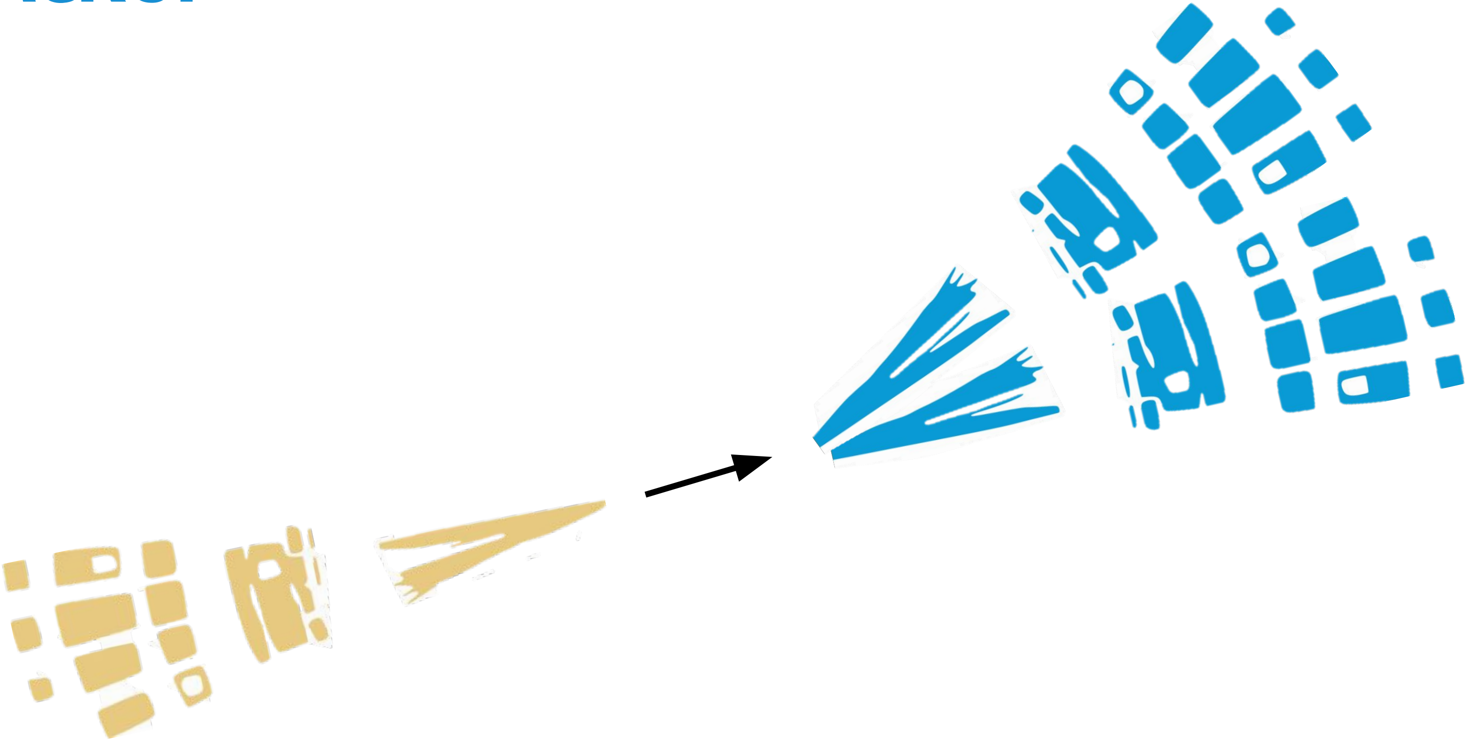
- Could be an underestimation as flavour tagging strategy might be too robust
- Caveat - Only change the flavour tagging training not IDEA simulation

- Cluster information (**dNdx**) is crucial and has a significant impact on the sensitivity of the measurements
  - Without the number of cluster information **x1.5** worse precision on **Hss coupling**!

Bigger impact on Z(**vv**)H(hadrons) analysis

- Largest loss in precision remains on the **Hss coupling measurement** without **dNdx information**

BACKUP



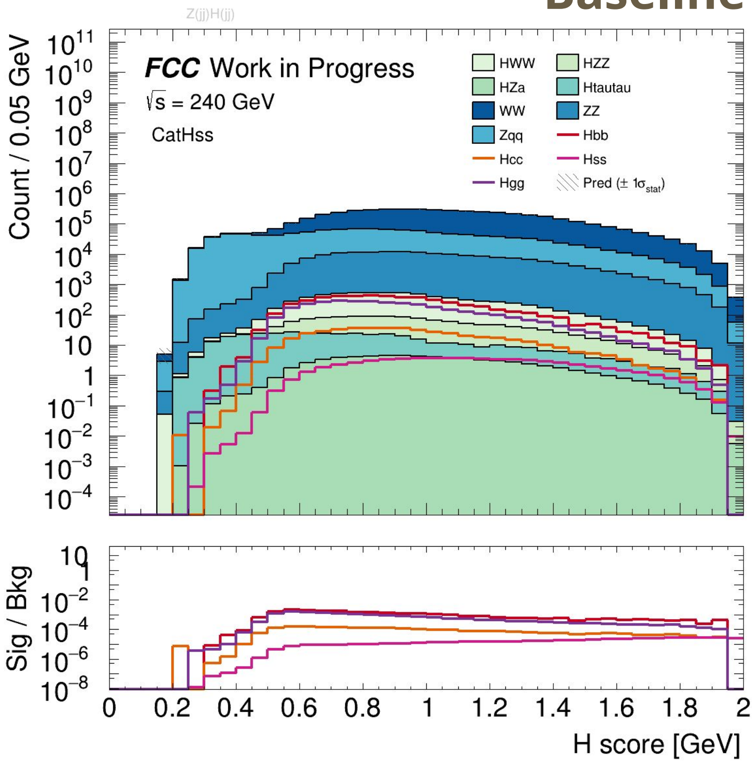
ParticleNet - flavour tagging

Full List of Input Variables

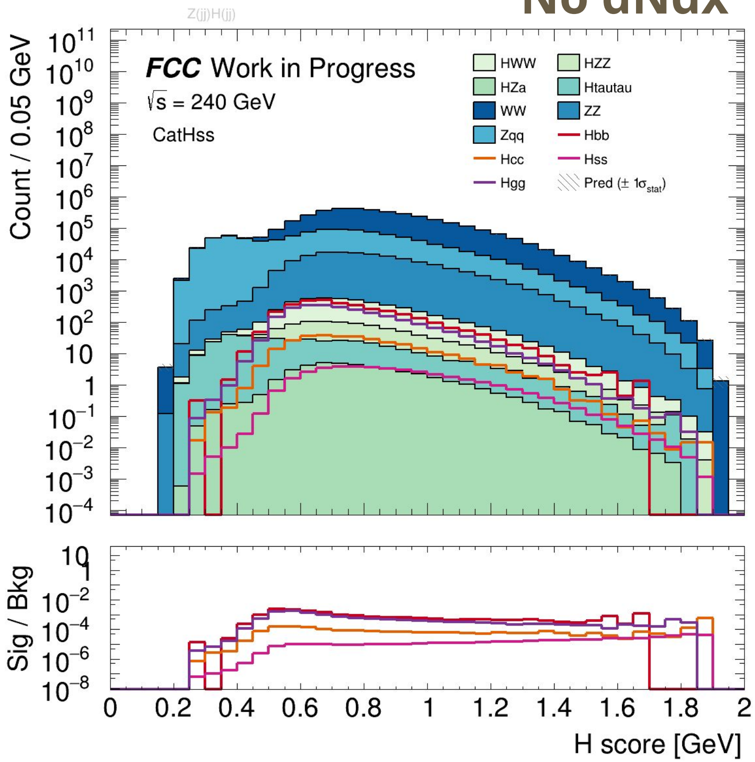
Variable	Description
	Kinematics
$E_{\text{const}}/E_{\text{jet}}$	energy of the jet constituent divided by the jet energy
θ_{rel}	polar angle of the constituent with respect to the jet momentum
ϕ_{rel}	azimuthal angle of the constituent with respect to the jet momentum
	Displacement
d_{xy}	transverse impact parameter of the track
d_z	longitudinal impact parameter of the track
SIP_{2D}	signed 2D impact parameter of the track
$\text{SIP}_{\text{2D}}/\sigma_{\text{2D}}$	signed 2D impact parameter significance of the track
SIP_{3D}	signed 3D impact parameter of the track
$\text{SIP}_{\text{3D}}/\sigma_{\text{3D}}$	signed 3D impact parameter significance of the track
d_{3D}	jet track distance at their point of closest approach
$d_{\text{3D}}/\sigma_{d_{\text{3D}}}$	jet track distance significance at their point of closest approach
C_{ij}	covariance matrix of the track parameters
	Identification
q	electric charge of the particle
$m_{\text{t.o.f.}}$	mass calculated from time-of-flight
dN/dx	number of primary ionisation clusters along track
isMuon	if the particle is identified as a muon
isElectron	if the particle is identified as an electron
isPhoton	if the particle is identified as a photon
isChargedHadron	if the particle is identified as a charged hadron
isNeutralHadron	if the particle is identified as a neutral hadron

H score in the H->ss categorise

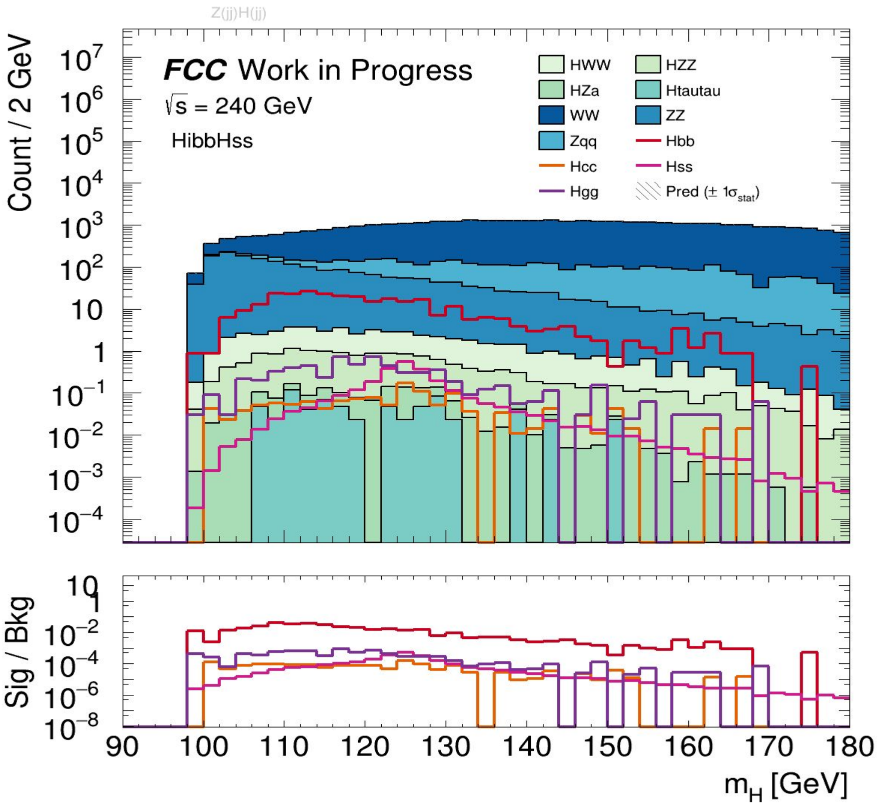
Baseline

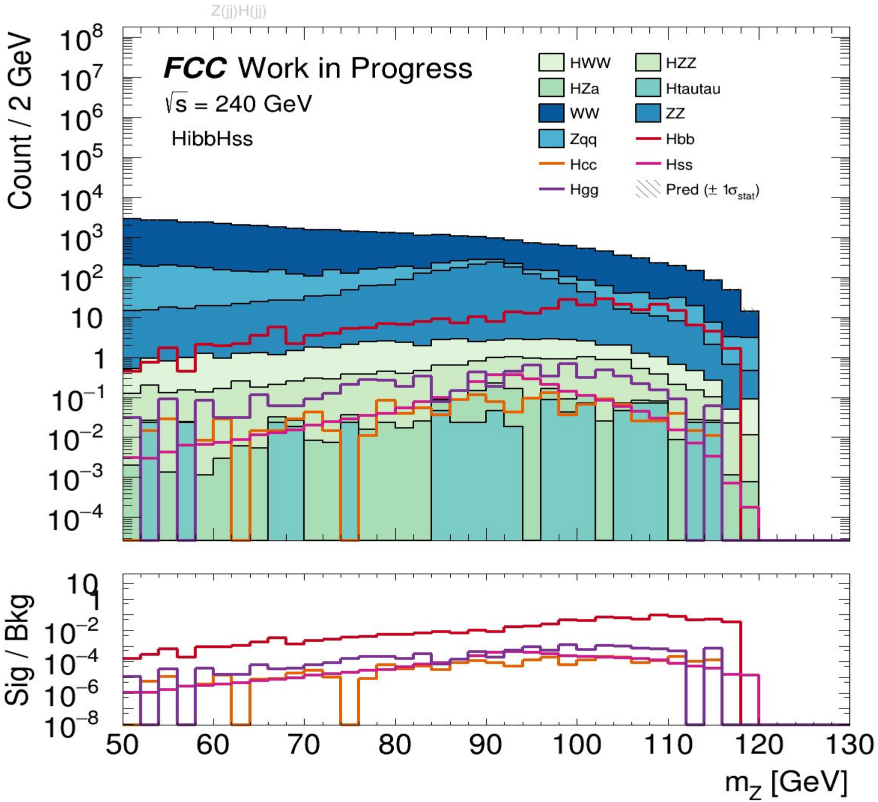


No dNdx

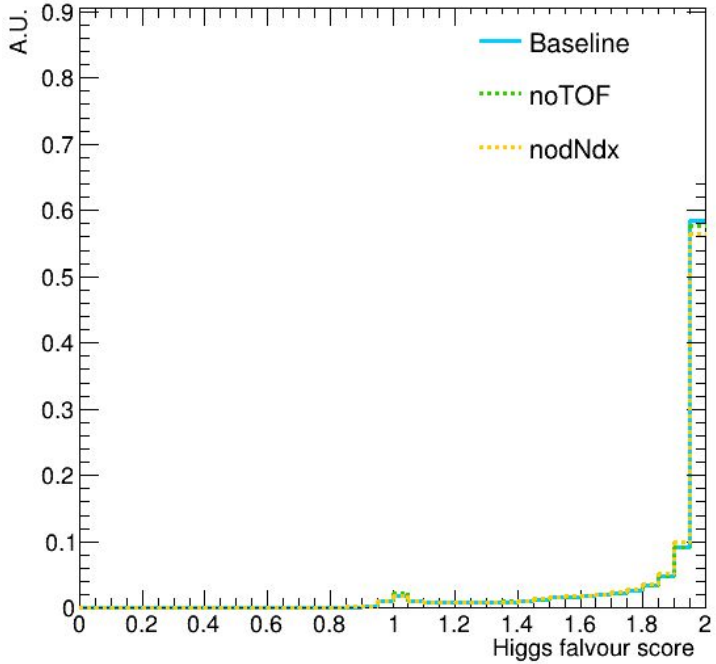


Categorization- High purity ZbbHss category





Reconstructed H->bb decays

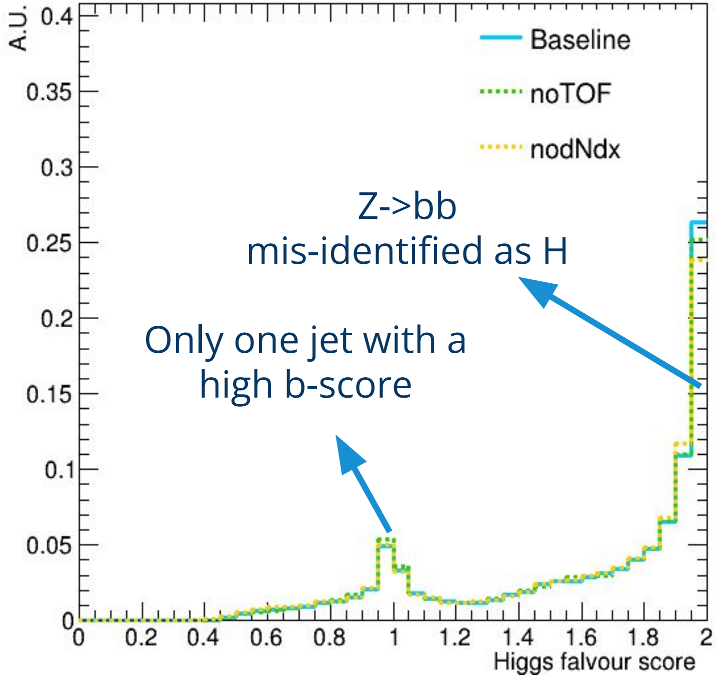


Hbb signal events identified as H->bb

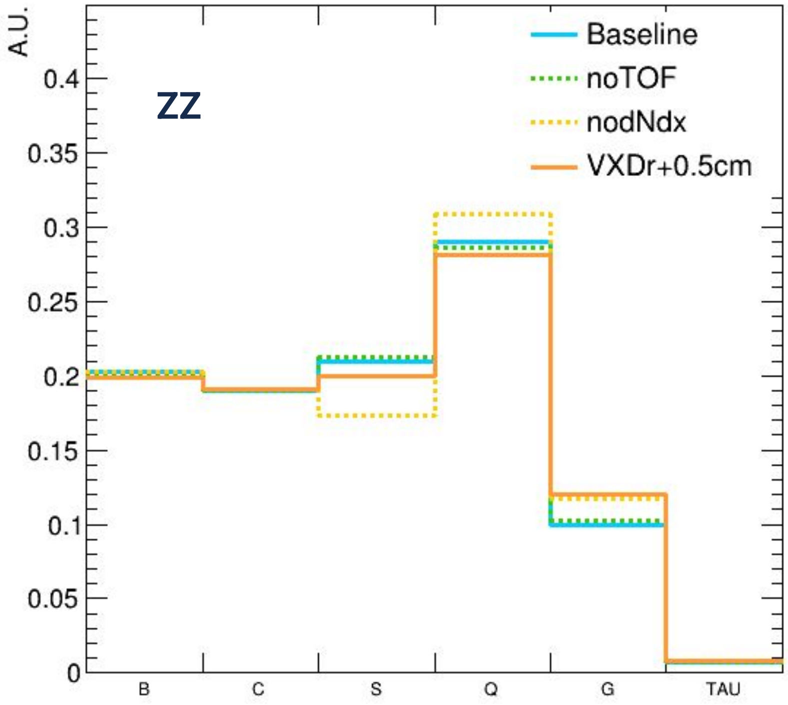
- Very high b-score
- Negligible change between different taggerc

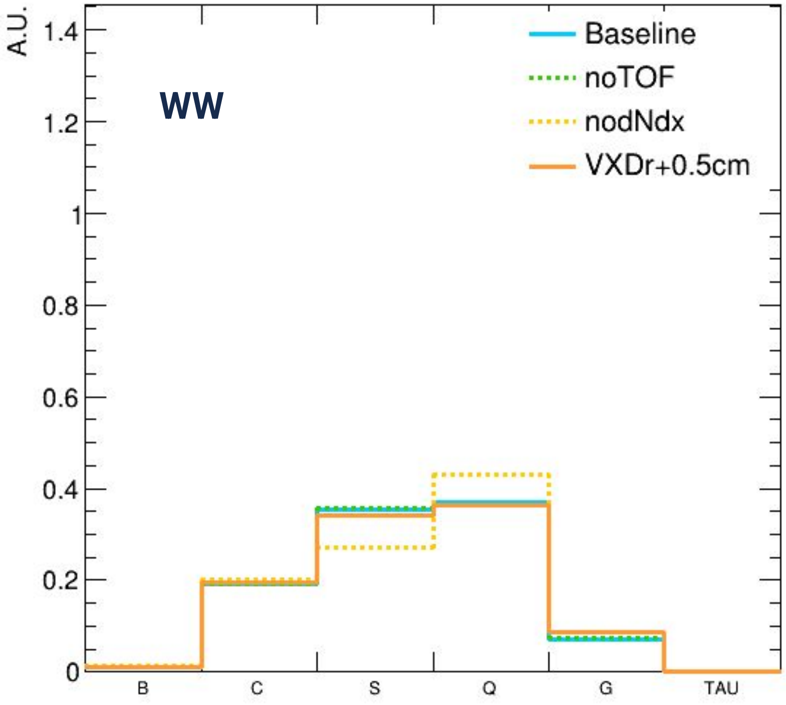
- No significant change in H score distributions of background event

Hgg events identified as H->bb



Robustness of flavour tagging strategy





Likelihood scan

- **Asimov** (expected) **data = SM = background estimation + SM signal**
  - How compatible are different μ_{xx} to the asimov data set, i.e. how sensitive are we?
  - Compare the **test statistic (λ)** of the different μ_{xx} on this dataset.

$$\lambda(\mu_{xx}) = -2\,ln\left(\frac{L(\mu_{xx},\hat{\hat{\theta}})}{L(\bar{\mu}_{xx},\hat{\theta})}\right)$$

Maximize $L(\kappa_\lambda, \theta)$ by holding μ_{xx} fixed and fitting the model.

Nuisance parameters

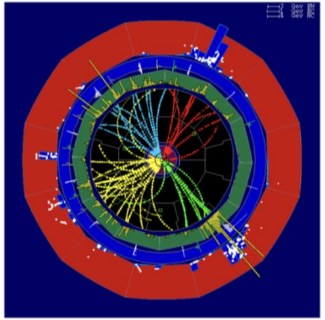
Best-fit coupling

Find μ_{xx} that maximizes ***L*** for the data, i.e. let μ_{xx} vary in a global fit.

Jet energy correction

Precision with e⁺e⁻ colliders (4)

- Why are e^+e^- colliders the tool of choice for precision anyway ? (cont'd)
  - Electrons are leptons, i.e., elementary particles: no underlying event
    - Corollary: Final state has known energy and momentum: ($\sqrt{s}$, 0, 0, 0)
  - Example: an $e^+e^- \to W^+W^- \to q\bar{q}q\bar{q}$ candidate
    - Four jets in the event and nothing else
    - Total energy and momentum are conserved
      - $E_1 + E_2 + E_3 + E_4 = \sqrt{s}$
      - $P_1^{x,y,z} + p_2^{x,y,z} + p_3^{x,y,z} + p_4^{x,y,z} = 0$
    - Jet directions ($\beta_i = p_i/E_i$) are very well measured



$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ \beta_1^x & \beta_2^x & \beta_3^x & \beta_4^x \\ \beta_1^y & \beta_2^y & \beta_3^y & \beta_4^y \\ \beta_1^z & \beta_2^z & \beta_3^z & \beta_4^z \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \end{bmatrix} = \begin{bmatrix} \sqrt{s} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

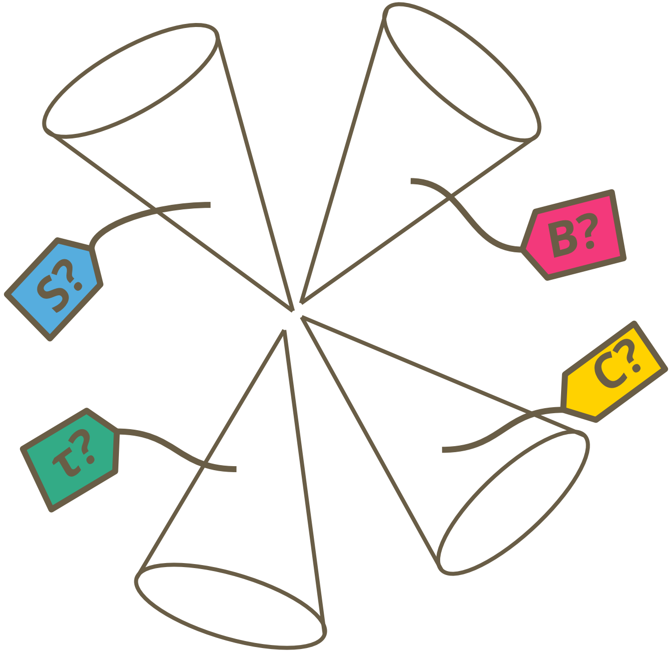
    - Jet energies (or di-jet masses: m_W) determined analytically by inverting the matrix
      - No systematic uncertainty related to jet energy calibration

A lot of Z are available anyway to calibrate and align everything

Patrick Janot — Physics at Future Colliders 28-29 July 2016 — 7

- If any jet in event **E<0** OR **E>240** GeV [only a few percent of events] keep uncorrected value

Jet “tagging”



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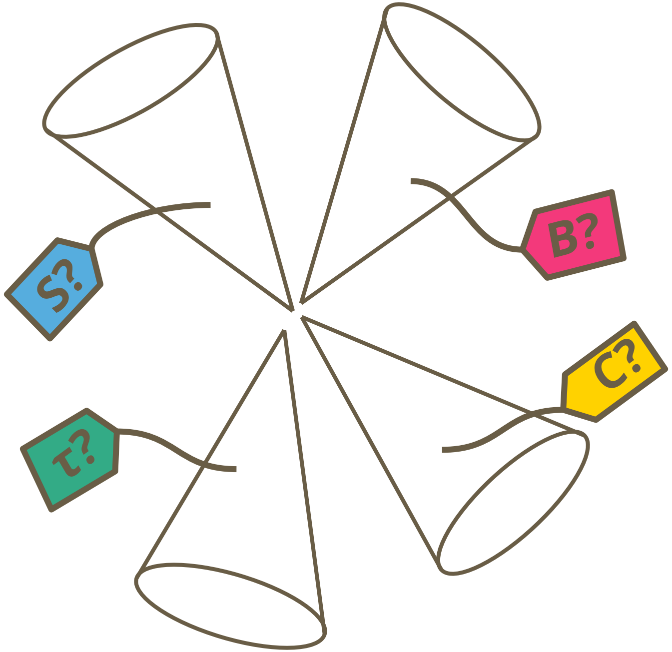
Jet pairing

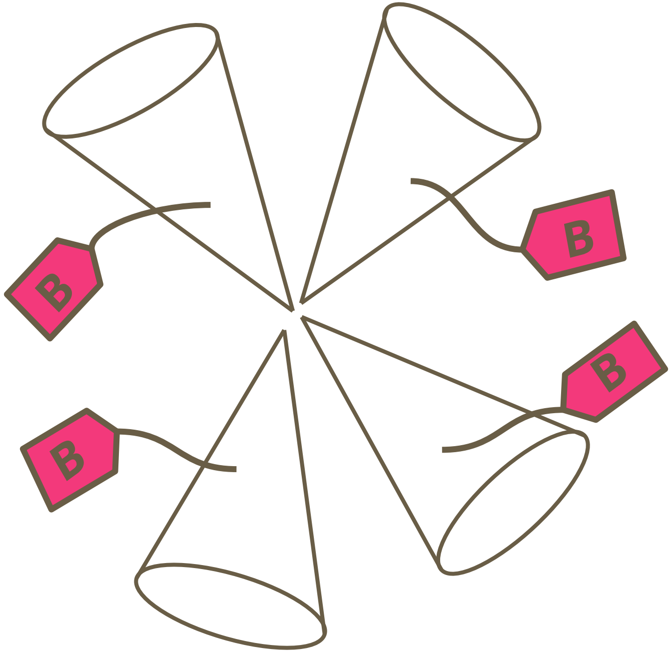


Each jet has a maximum tagger score from a different flavour

-

TOSS EVENT

Jet pairing



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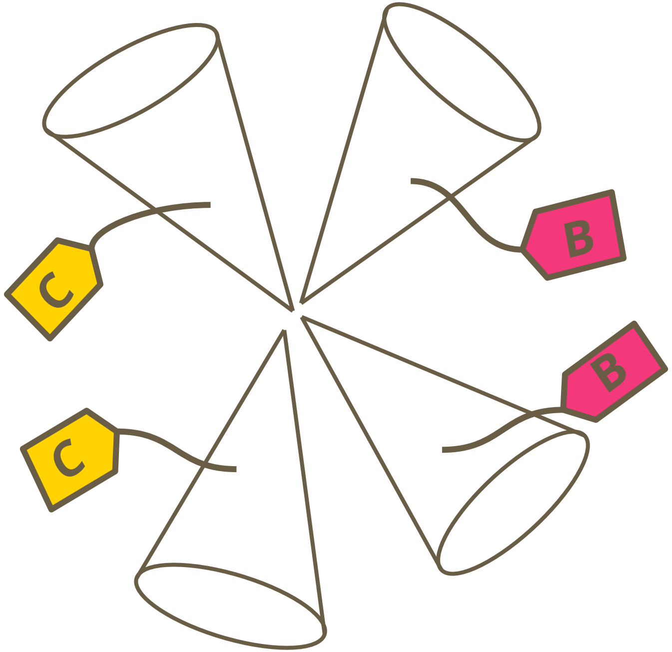
The jet paring that gives the **minimum** χ_{comb} is chosen!

FUTURE CIRCULAR COLLIDER

Jet pairing

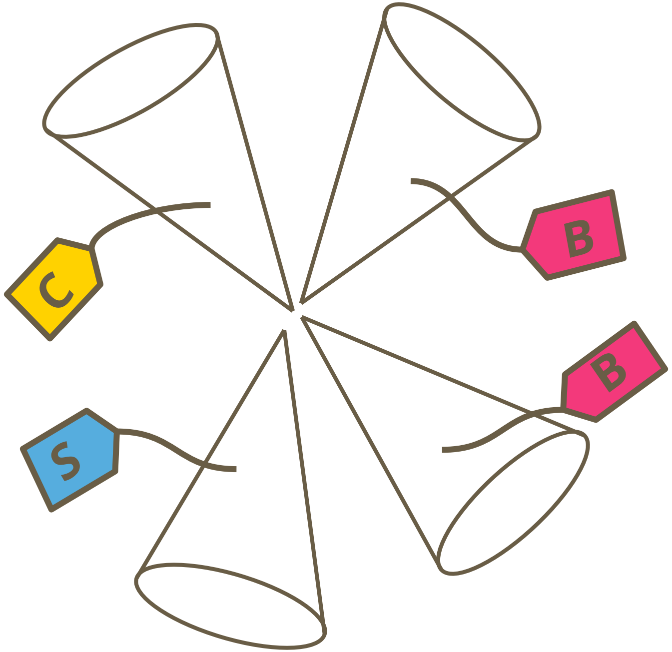


CASE 2: Two jet pairs with same maximum score from the same flavour, but different flavour of the pairs

Finding the H&Z candidates

- Jet paired, if they have the same flavour maximum score
- Z candidate: Pair with minimum $\chi_Z=(m_{lk} - m_{Z,\ true})^2$

Jet pairing



CASE 3: Two jets with maximum score from the same flavour form a pair

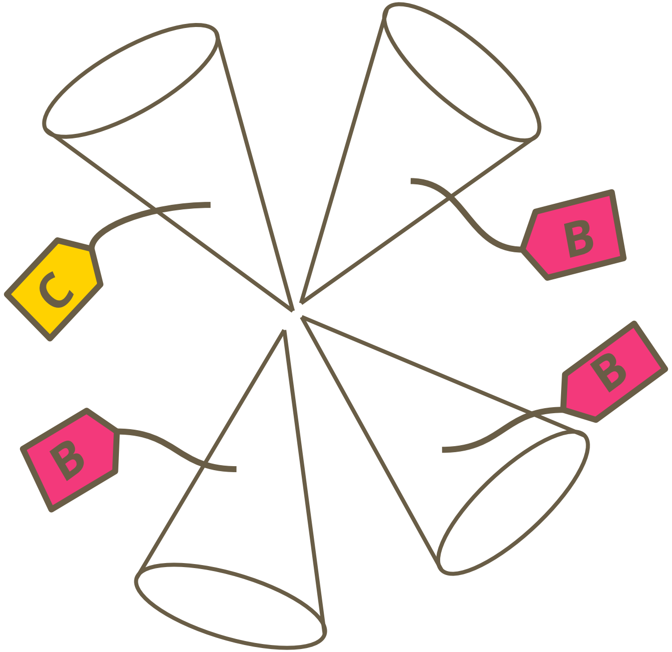
Recover second pair:

- Consider all sums of tagger scores
    - **Max**($\sum_{ij}$Bscore, $\sum_{ij}$Cscore, $\sum_{ij}$Sscore, …)
        - Determines the flavour of the pair

Finding the H&Z candidates

- Same flavour pairs (Case 1)
    - Min($\chi_{comb}=\chi_H+\chi_Z$)
- Different flavour pairs (Case 2)
    - Min($\chi_Z=(m_{lk} - m_{Z,\ true})^2$

Jet pairing



CASE 4: Three jets with maximum score from the same flavour

Recover first pair:

- Maximum tagger score sum
  - **Max**($\sum_{ij}$Bscore, $\sum_{ik}$Bscore, $\sum_{jk}$Bscore, …)
    - Determines the flavour of the 1st pair

Recover second pair:

- Consider all sums of tagger scores
  - **Max**($\sum_{ij}$Bscore, $\sum_{ij}$Cscore, $\sum_{ij}$Sscore, …)
    - Determines the flavour of the pair

Finding the H&Z candidates

- Same as for Case 3

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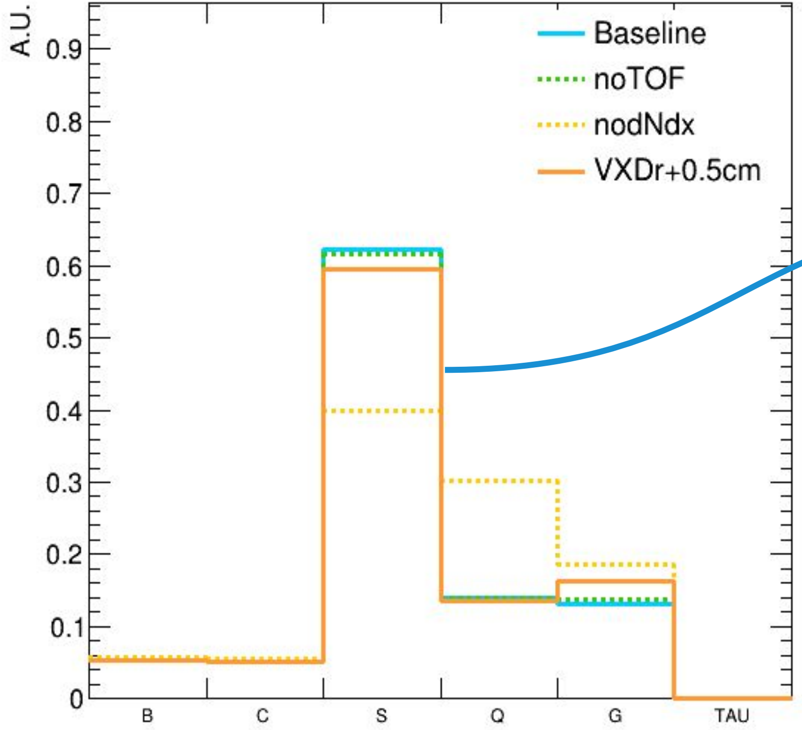
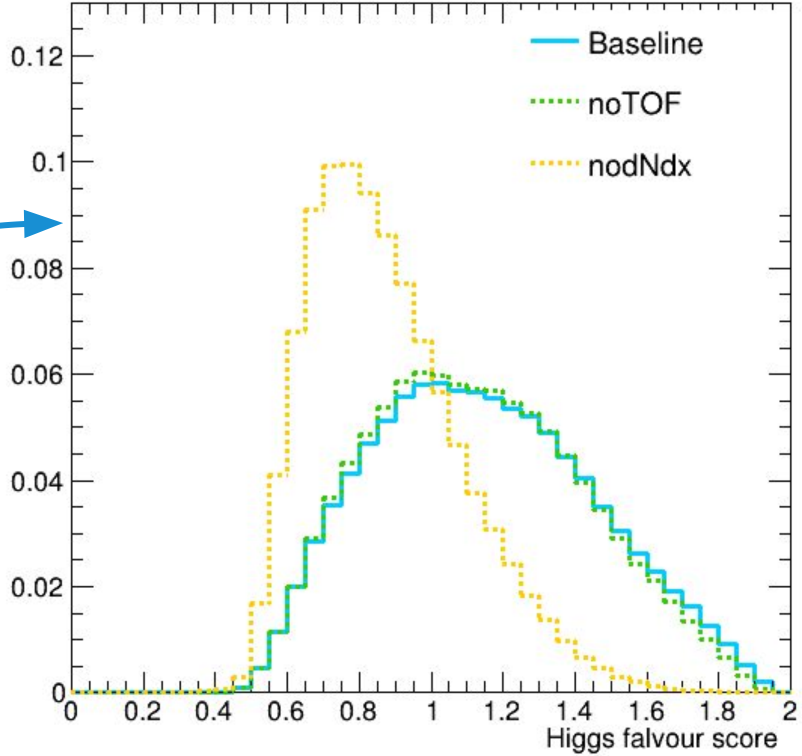
Impact on strange tagging

Categorization of Hss events



Hss events identified as H->ss



* Re-optimized Hss category definition for no dNdx case