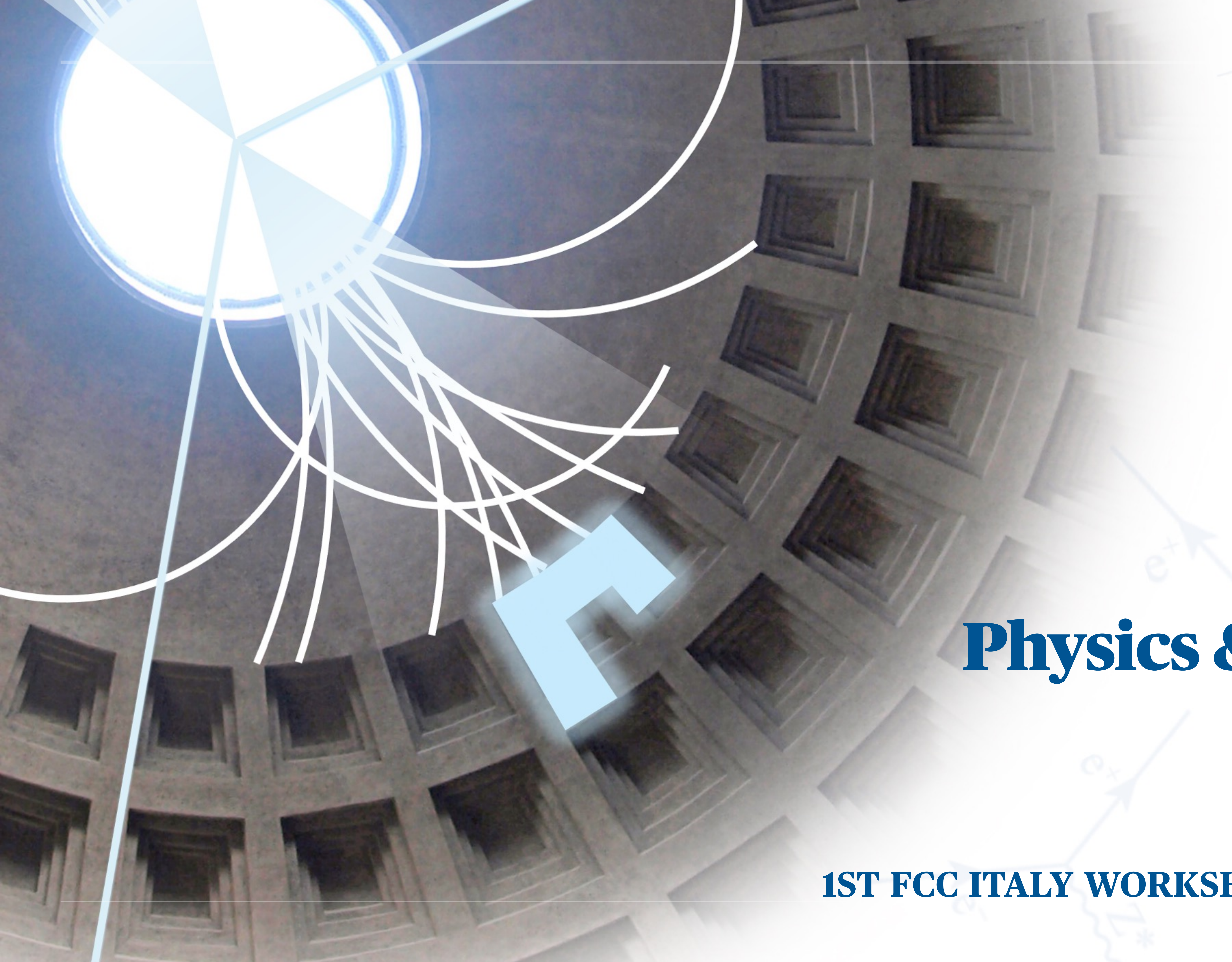


Physics & Simulation Studies

Focus on RD-FCC

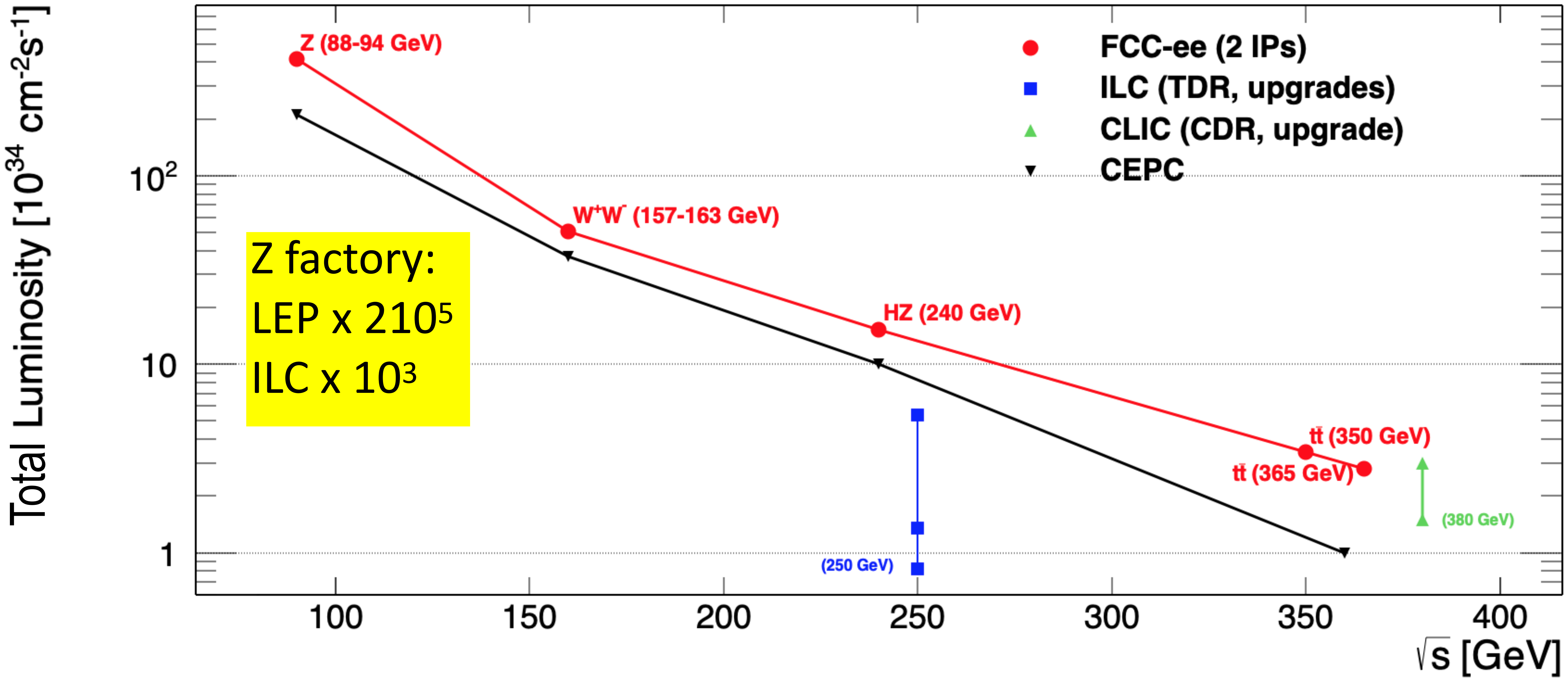
P. AZZI (INFN-PD)

1ST FCC ITALY WORKSHOP 20-21 MARCH 2022

Introduction

- The physics landscape of the FCC-ee program extends in all possible directions:
  - the difference in the physics focus at the different $\sqrt{s}$
  - the difference in the event kinematic of running from 90GeV (and possibly below) up to 365GeV
  - the challenge of being able to achieve superbe precision on SM processes but also perform unique direct searches for new physics
- The list of interesting processes and measurement is extensive, and it has not been fully explored yet, even in terms of sensitivity.
- From this richness, we need to extract concrete benchmark measurements that will be used to extract requirements on what is missing to achieve our ambitious goals: detector requirements, reconstruction tools, calibration techniques.

Can produce all the heaviest particles of the Standard Model



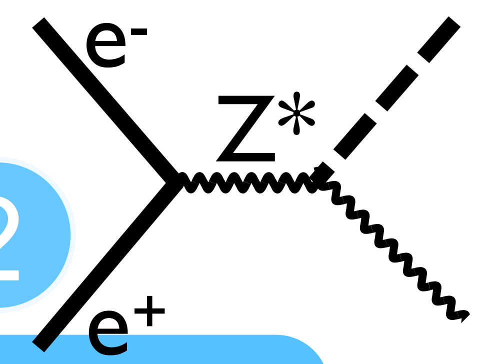
High integrated luminosity at the needed E_{cm}

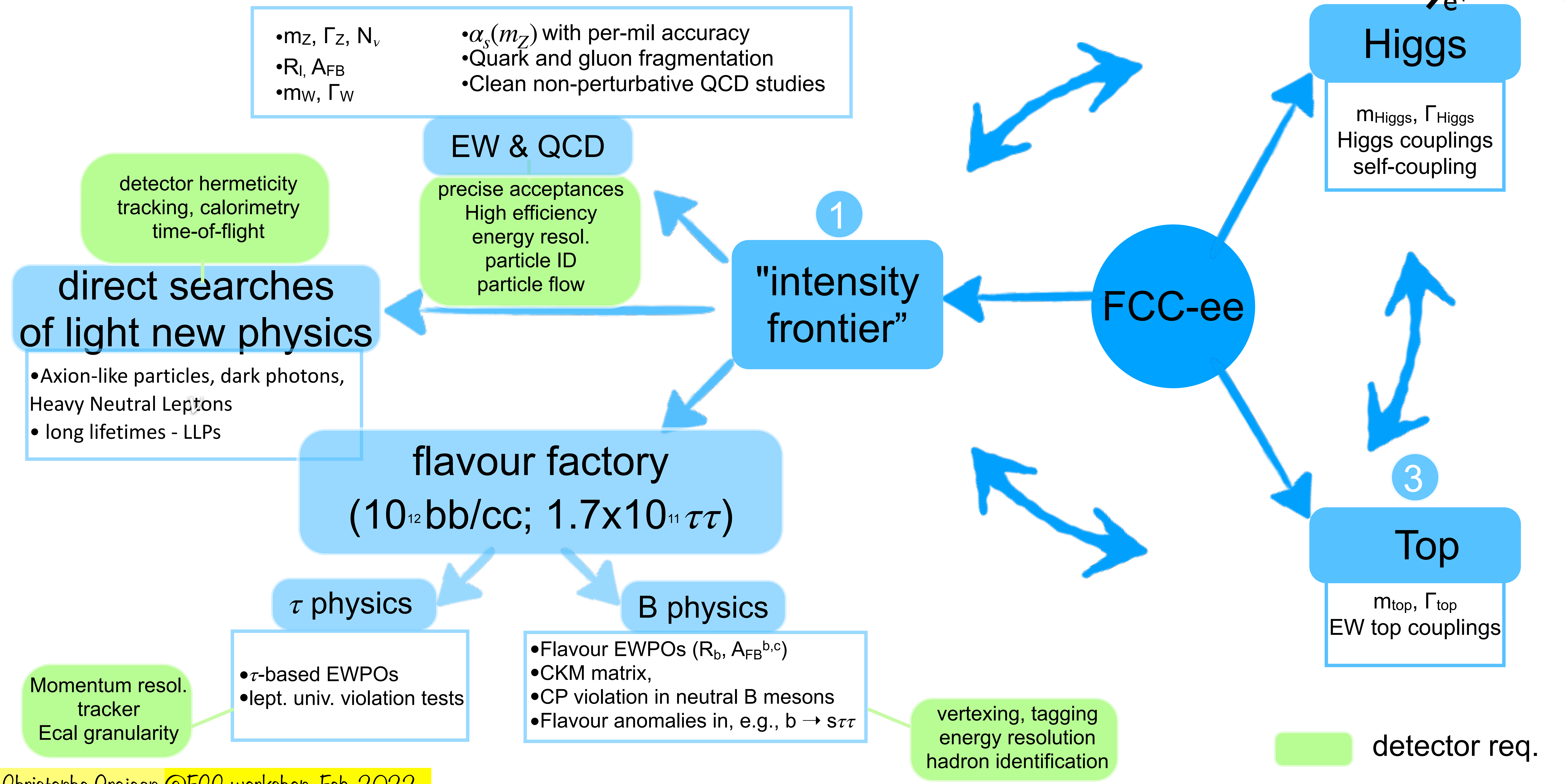
Clean environment

Precise knowledge of the center-of-mass energy and of the luminosity

						$\sqrt{s}$ errors
ZH maximum	$\sqrt{s} \sim 240$ GeV	3 years	10^6	$e^+e^- \to ZH$	Never done	2 MeV
$t\bar{t}$ threshold	$\sqrt{s} \sim 350$ GeV	5 years	10^6	$e^+e^- \to t\bar{t}$	Never done	5 MeV
Z peak	$\sqrt{s} \sim 91$ GeV	4 years	5×10^{12}	$e^+e^- \to Z$	LEP x 10^5	< 100 keV
WW threshold+	$\sqrt{s} \geq 161$ GeV	2 years	$> 10^8$	$e^+e^- \to W^+W^-$	LEP x 10^3	< 300 keV
s-channel H	$\sqrt{s} = 125$ GeV	? Years	~5000	$e^+e^- \to H$	Never done	< 200 keV

FCC-ee Physics Programme





Christophe Grojean @FCC workshop, Feb. 2022

The FCC Feasibility Study

- Design new detector concepts to realise the physics potential of the FCC-ee
  - both in term of precision and sensitivity
- Focus on benchmark studies
  - that represent the physics goals and allow to extract the detector requirements
- Need to develop simulation and analysis tools to get this done

The FCC Feasibility Study

- Design new detector concepts to realise the physics potential of the FCC-ee
  - both in term of precision and sen
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- Need to develop simulation and analysis tools to get this done

CASE STUDIES: reverse engineering of analysis

Case Studies Overview (evolving)

HIGGS

- M(H) and $\sigma(ZH)$ in HZ, Z in leptons 🇮🇹
- M(H) and $\sigma(ZH)$ in HZ, Z in hadrons
- Invisible Higgs
- $H \to b\bar{b}, c\bar{c}, s\bar{s}$ couplings 🇮🇹
- $\Gamma(H)$ in $ZH, H \to ZZ^*$
- $\Gamma(H)$ in $bb\nu\nu$ events
- $HZ\gamma$ coupling
- Higgs self-coupling
- $ee \to H$ s-channel production

EWK (Z)

- Z width
- $R_b, R_c, A_{FB}(bb, cc)$ 🇮🇹
- Ratio Rl
- $A_{FB}(muons)$
- Luminosity from di-photons/NP
- Coupling of Z to ν_e (NP)

EWK (W)

- W polarization
- M(W) from $WW \to had, semi-lep$ 🇮🇹
- $\sigma(WW)$ for M(W), TGCs
- V_{cb} from $W \to cb$
- W leptonic BRs
- √s via radiative returns

FLAVOUR

- $B_c \to \tau\nu$
- $B_s \to D_s K$ 🇮🇹
- $B^+ \to D^0 K^+$
- $B_s \to K^* \tau\tau$
- $B_s \to \phi\phi$
- $B \to K^* \nu\nu$

FLAVOUR - TAU

- Tau lifetime
- Tau mass
- Tau leptonic BR
- Tau polarisation and exclusive BR
- LFV in Z and tau decays

TOP

- EWK couplings
- FCNC 🇮🇹
- Properties at threshold

BSM

- HNL
- Axions ($\gamma\gamma$,3γ) 🇮🇹
- LLP

QCD

- Alpha_s

Initial Physics Requirements

➢ **Higgs boson sector:** Higgs sector definition imposes initial requirements on **hadronic resolution, tracking and vertexing**

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_T) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$\mathrm{BR}(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_T \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{BR}(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu\mathrm{m}$
$H \to q\bar{q},\ VV$	$\mathrm{BR}(H \to q\bar{q},\ VV)$	ECAL, HCAL	$\sigma_E^{\mathrm{jet}}/E \sim 3-4\%$
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

➢ **EWK**

- Extreme definition of detector acceptance.
- Extreme EM resolution (crystals).

➢ **Heavy Flavour:**

- PID to accurately classify final states and flavour tagging.

Physics at Tera-Z pushes the requirements to another level… don't forget BSM!

How to get there?

PHYSICS GENERATORS

See F. Piccinini's talk

DETECTOR SIMULATION (FAST & FULL)

RECONSTRUCTION & ANALYSIS TOOLS

MONTE CARLO DATASETS (STORAGE & PRODUCTION)

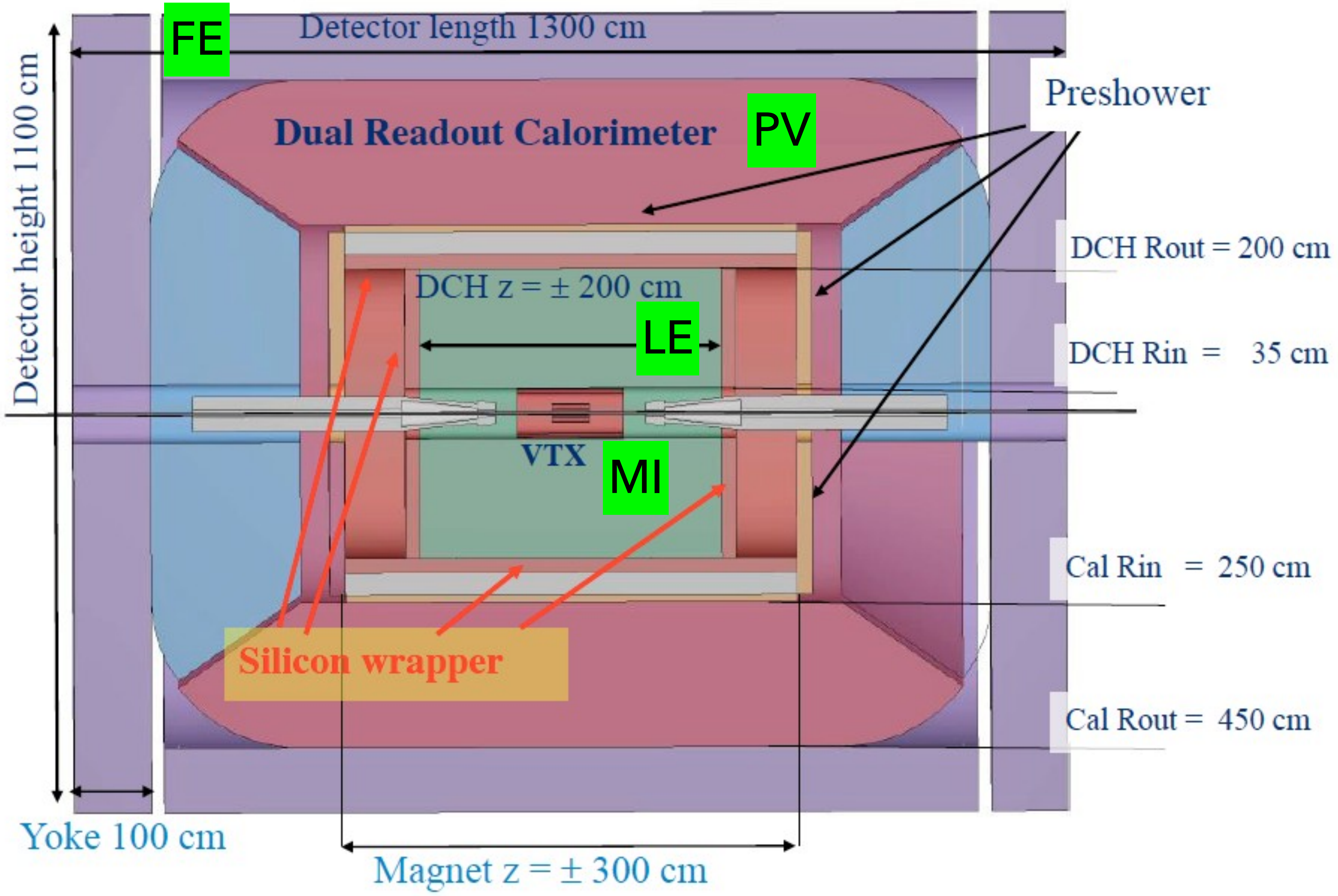
- **Key4Hep is the new software ecosystem** that holds together all the developments for future machines
- EDM4HEP a new event data model paradigm to share among projects
- Supported by HSF, CERN, DESY and European Projects such as AIDA-Innova

IDEA Detector Concept

❑ IDEA(baseline) consists of:

- ➢A silicon pixel vertex detector.
- ➢A large-volume extremely-light drift wire chamber.
- ➢A layer of silicon micro-strip detectors
- ➢A thin low-mass superconducting solenoid coil (optimized at 2 T) to maximize luminosity.
- ➢A preshower detector.
- ➢A dual read-out calorimeter.
- ➢Muon chambers inside the magnet return yoke.

See F. Bedeschi's talk

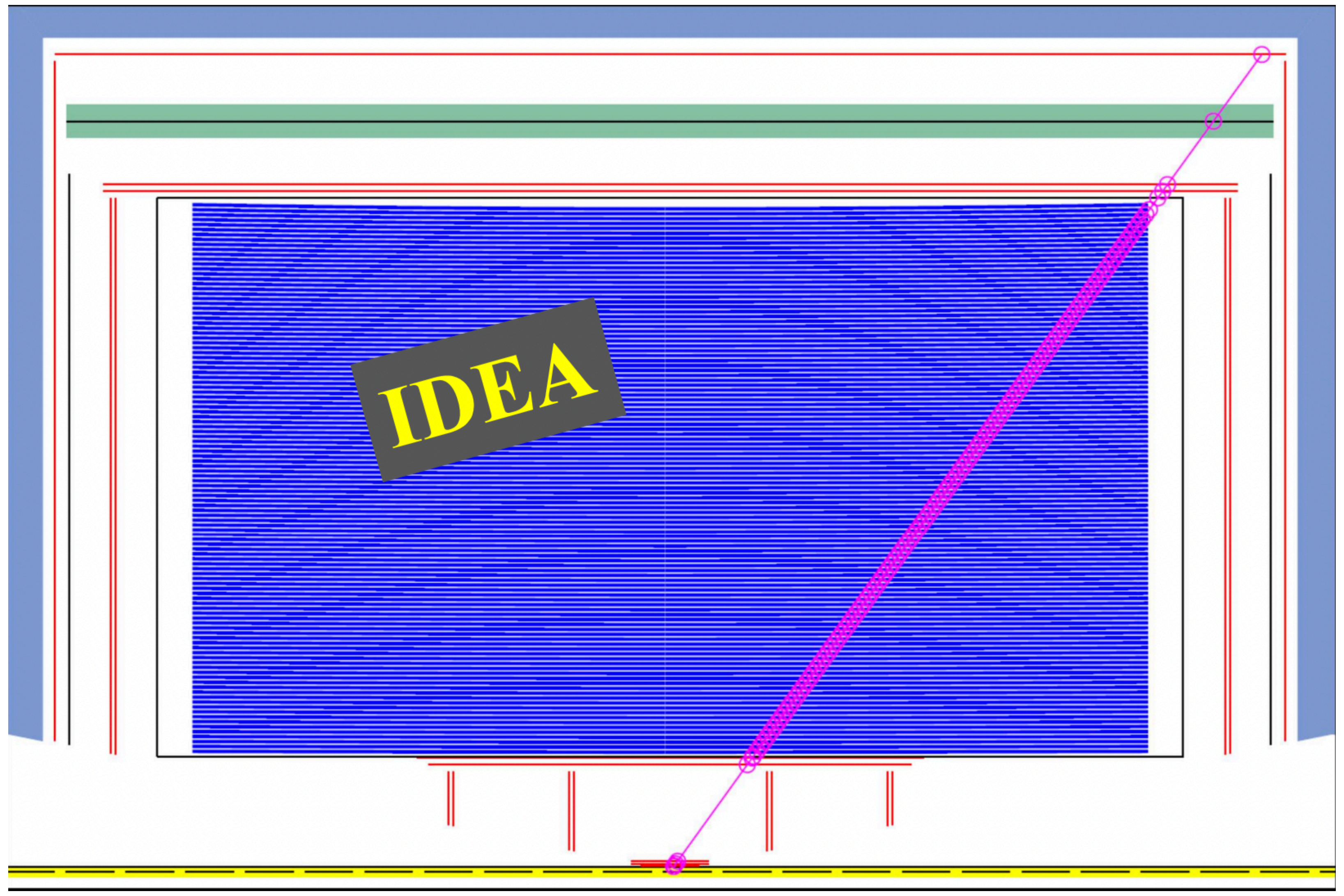


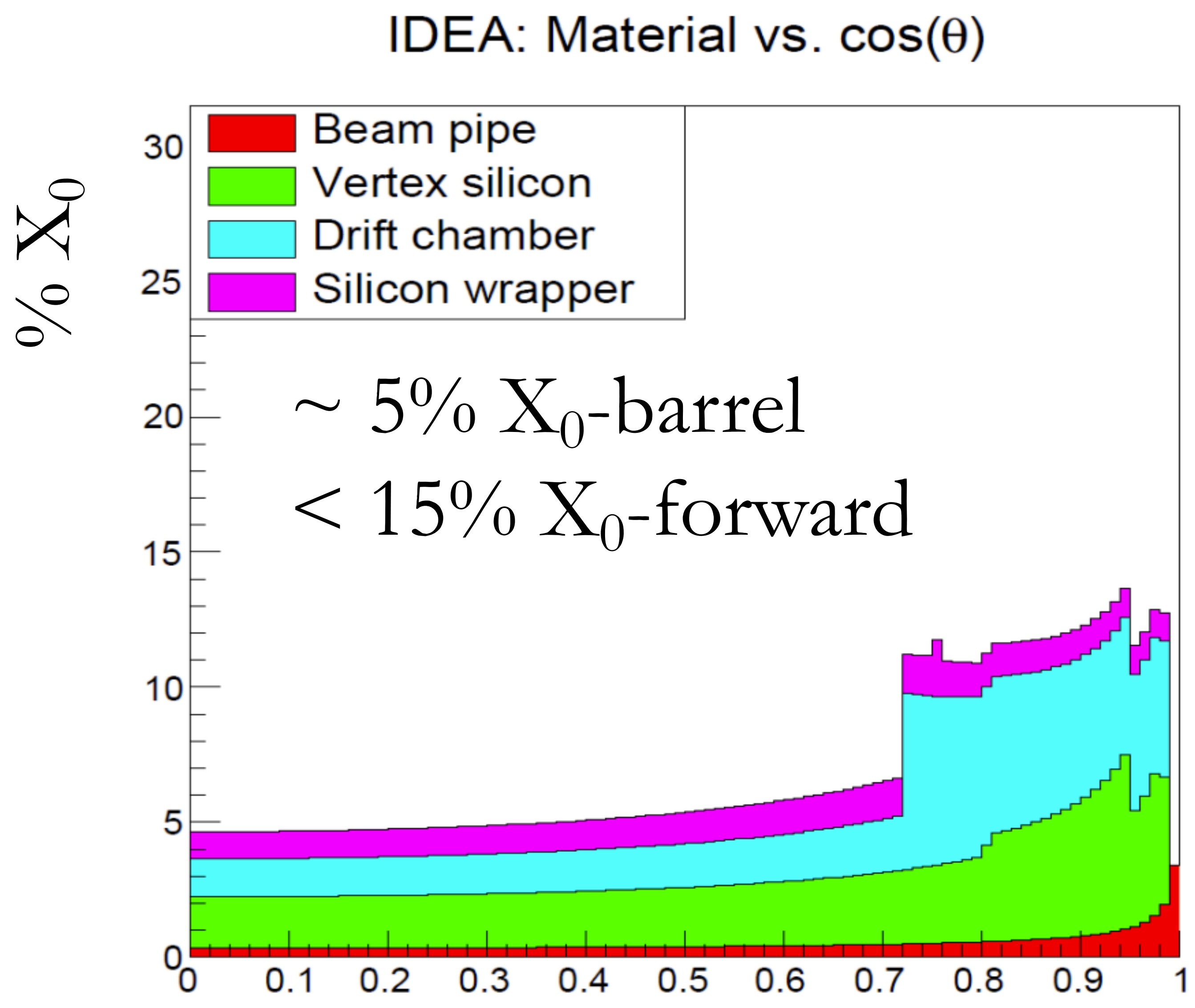
Detector Simulations

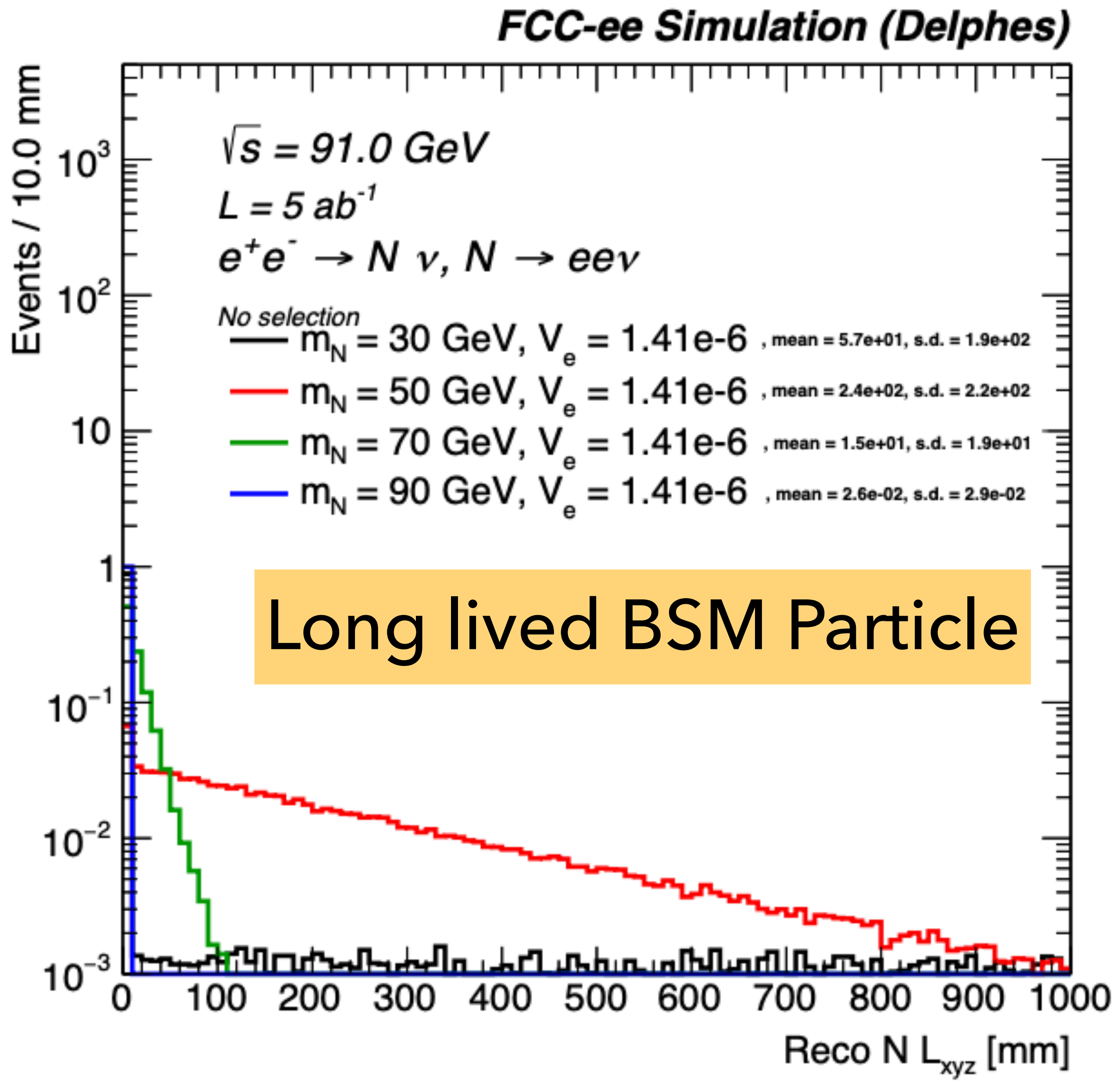
- Full simulation (GEANT): 10^2-10^3 s/ev
  - simulates all particle-detector interaction (e.m/hadron showers, nuclear interaction, brem, conversions)

- Parametric simulation (Delphes): 10^{-2}-10^{-1} s/ev
  - parameterise detector response at the particle level (efficiency, resolution on tracks, calorimeter objects)
  - reconstruct complex objects and observables(use particle-flow, jets, missing ET, pile-up ..)
  - New features can be added easily…

Improving the FastSimulation – tracking



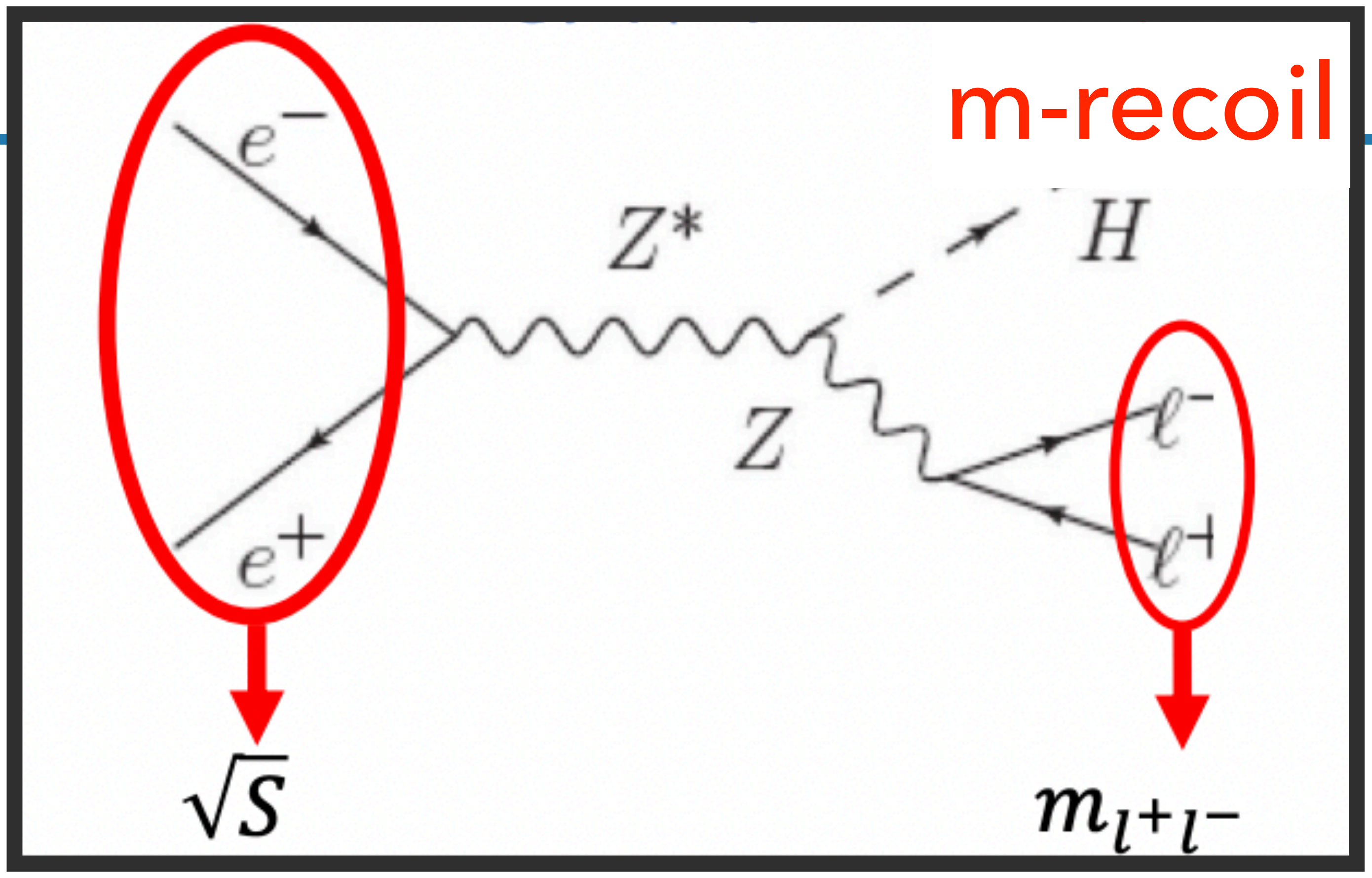


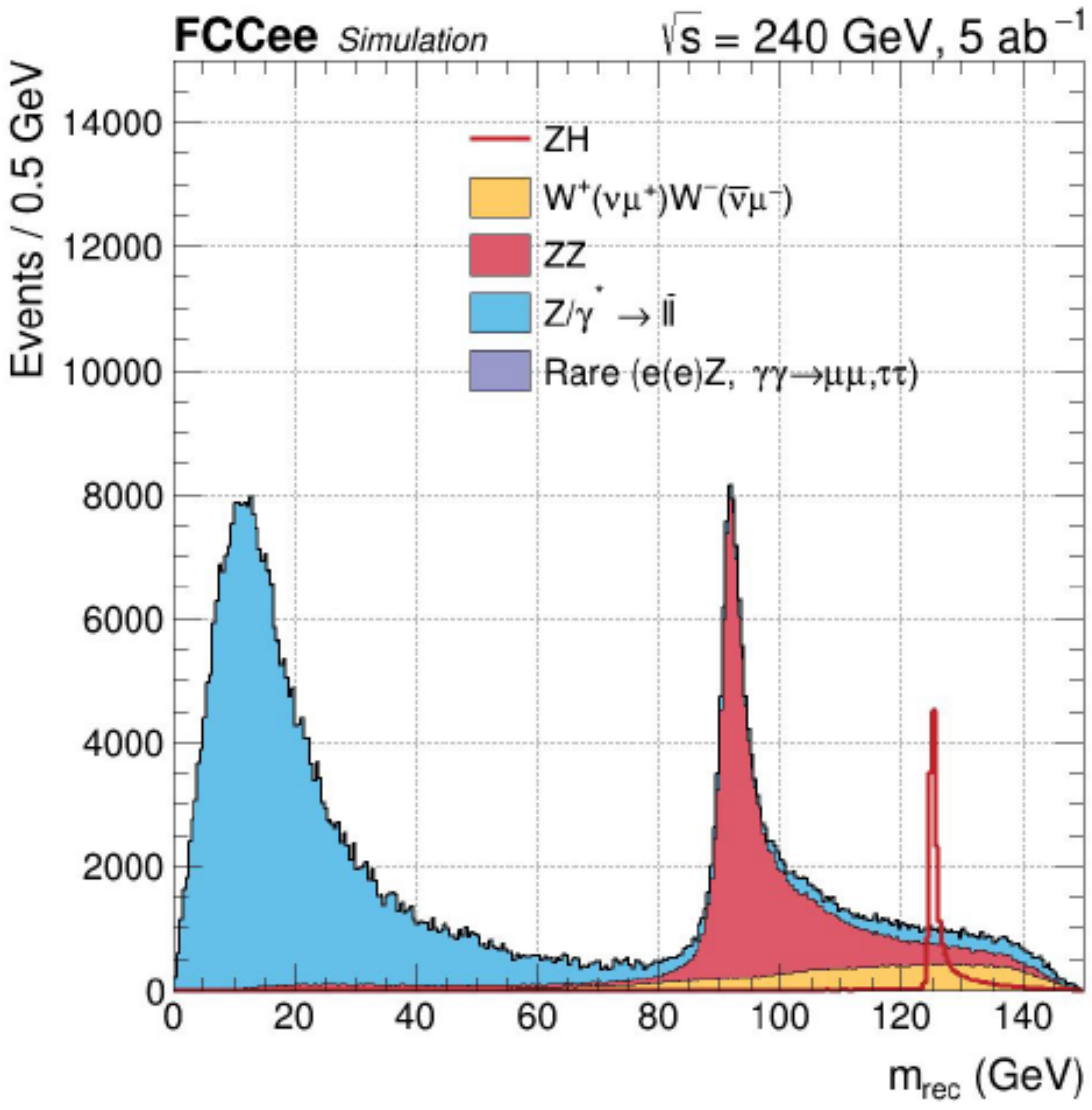


PISA, BOLOGNA+CERN

- Add a simple tracker geometry with material
- Analytical model to evaluate full covariance matrix
- Allows to study impact of material, vertexing, heavy flavour tagging and long lived particles

Higgs mass with ZH events



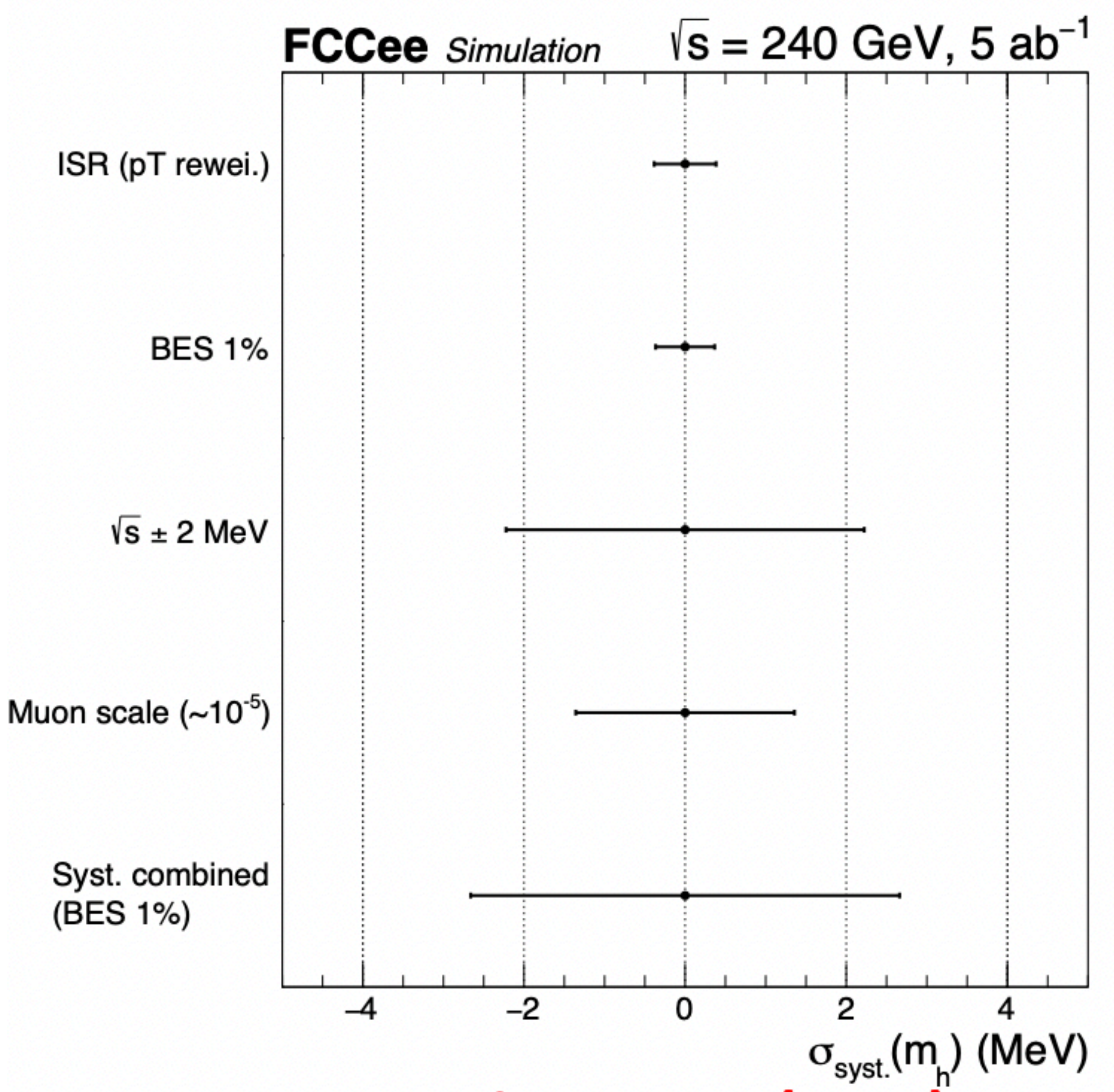


- Precise mass motivation, with O(10MeV) already matches the statistical precision on the Higgs, BR, but to constrain or measure electron Yukawa, would need better than the Higgs width (<4.1MeV).
  - This is an ambitious goal that poses challenges and constraints on the measurement with the ZH events
  - Recoil method unique at FCC-ee
  - IDEA (FastSim) used as baseline

Statistics Only

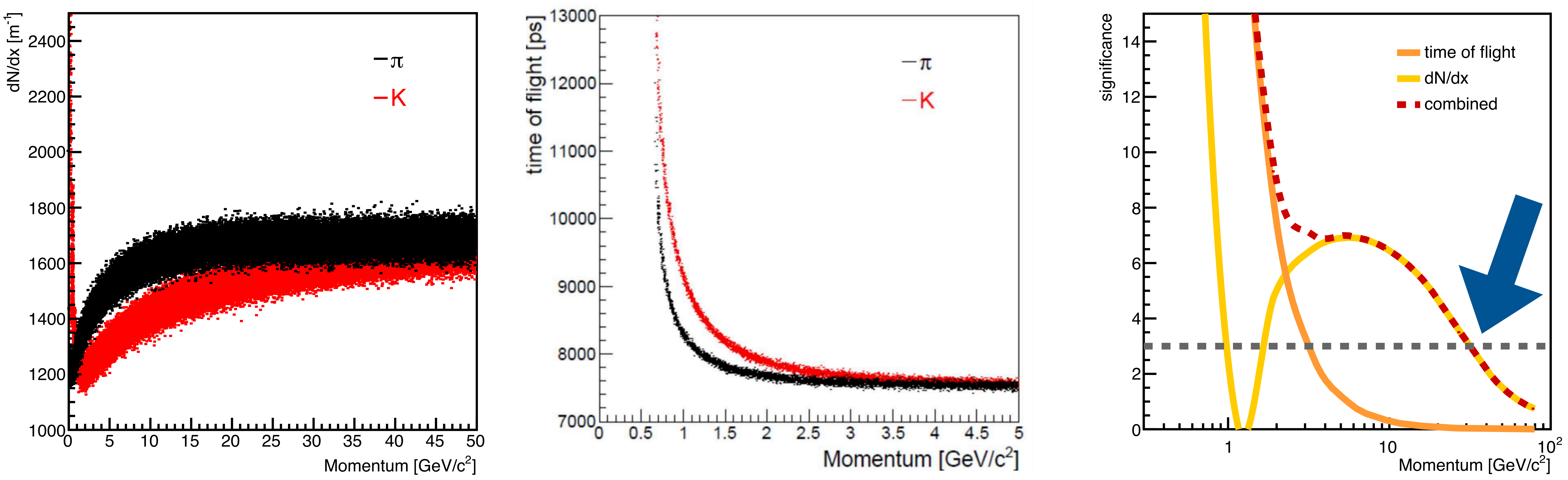
IDEA	Δm_H (MeV)	$\Delta\sigma$ (%)
IDEA	6.7	1.07
FullSilicon	9.0	1.12
3T	5.8	1.06

Systematics



Higgs Mass (MeV)

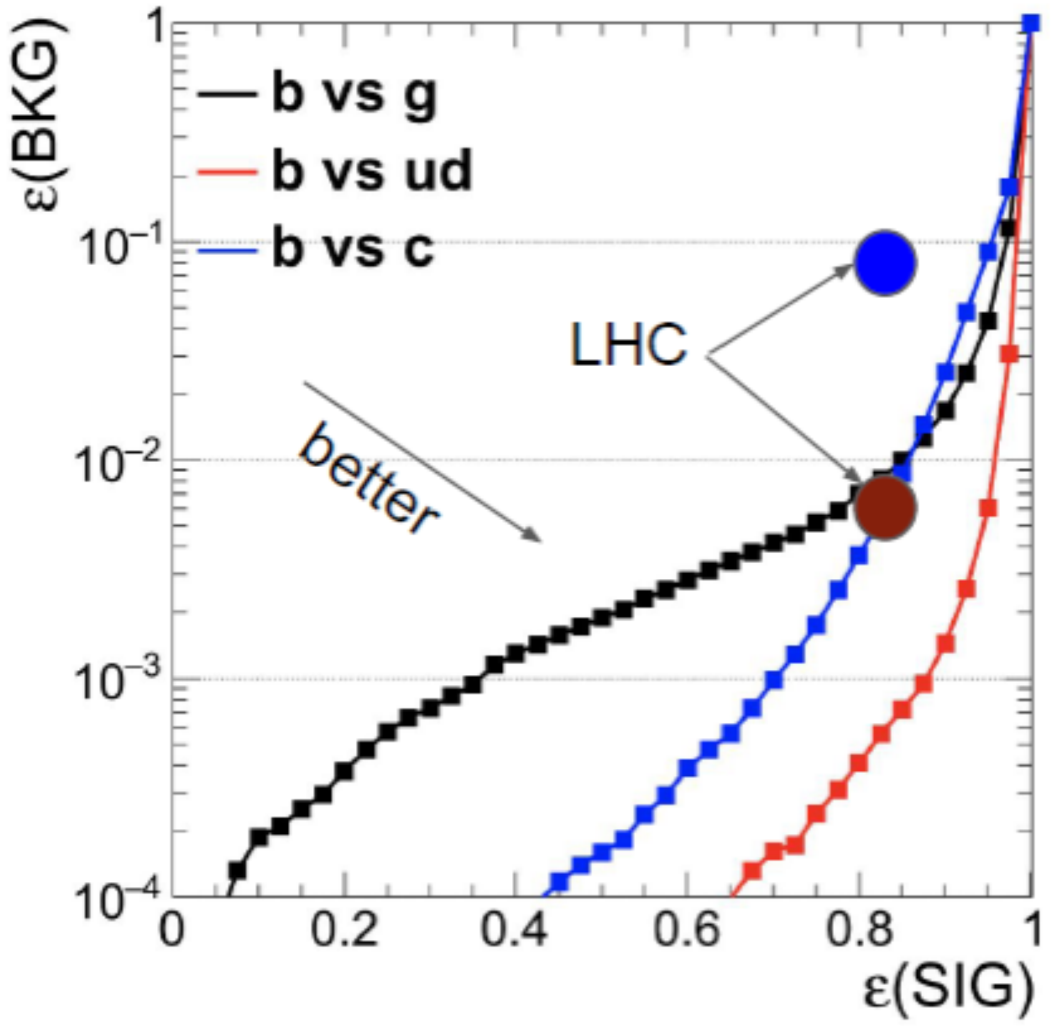
Improving the FastSimulation – Particle ID

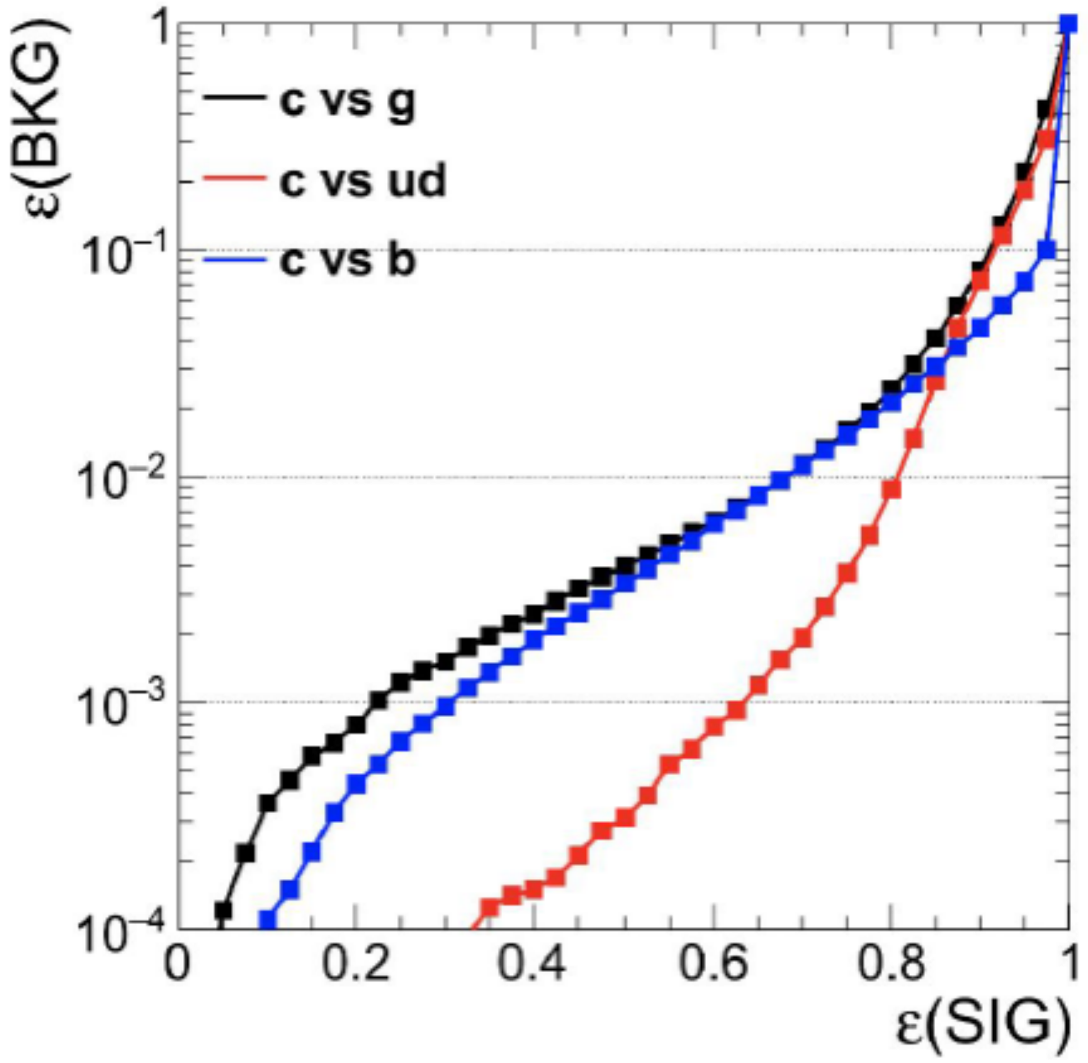


- dN/dx: The cluster information (given a volume crossed) is computed and saved in the track output for further use in the analysis.
- Timing information is available as well: can be tuned for performance studies with TOF.

Example: Jet-flavor tagging

- New tagging algorithm developed based on DNN approach (ParticleNet)
  - [arXiv:1801.07829, [arXiv:1902.08570]
- c-tagging efficiency is 80-90%, improves when beam pipe radius decreases
  - Crucial for A_{FB}(bb,cc)
- $H \to c\bar{c}$ coupling performance: promising!



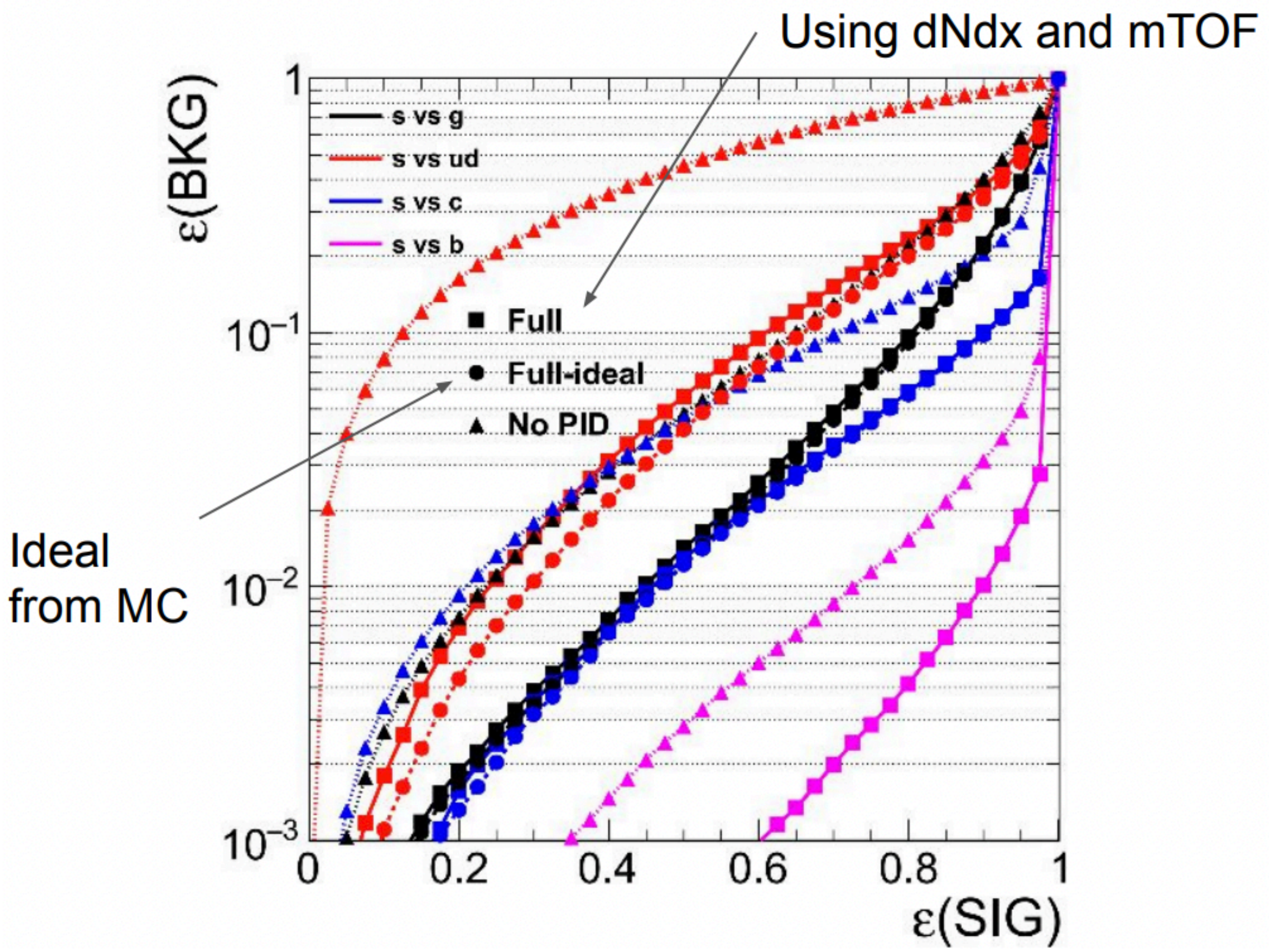


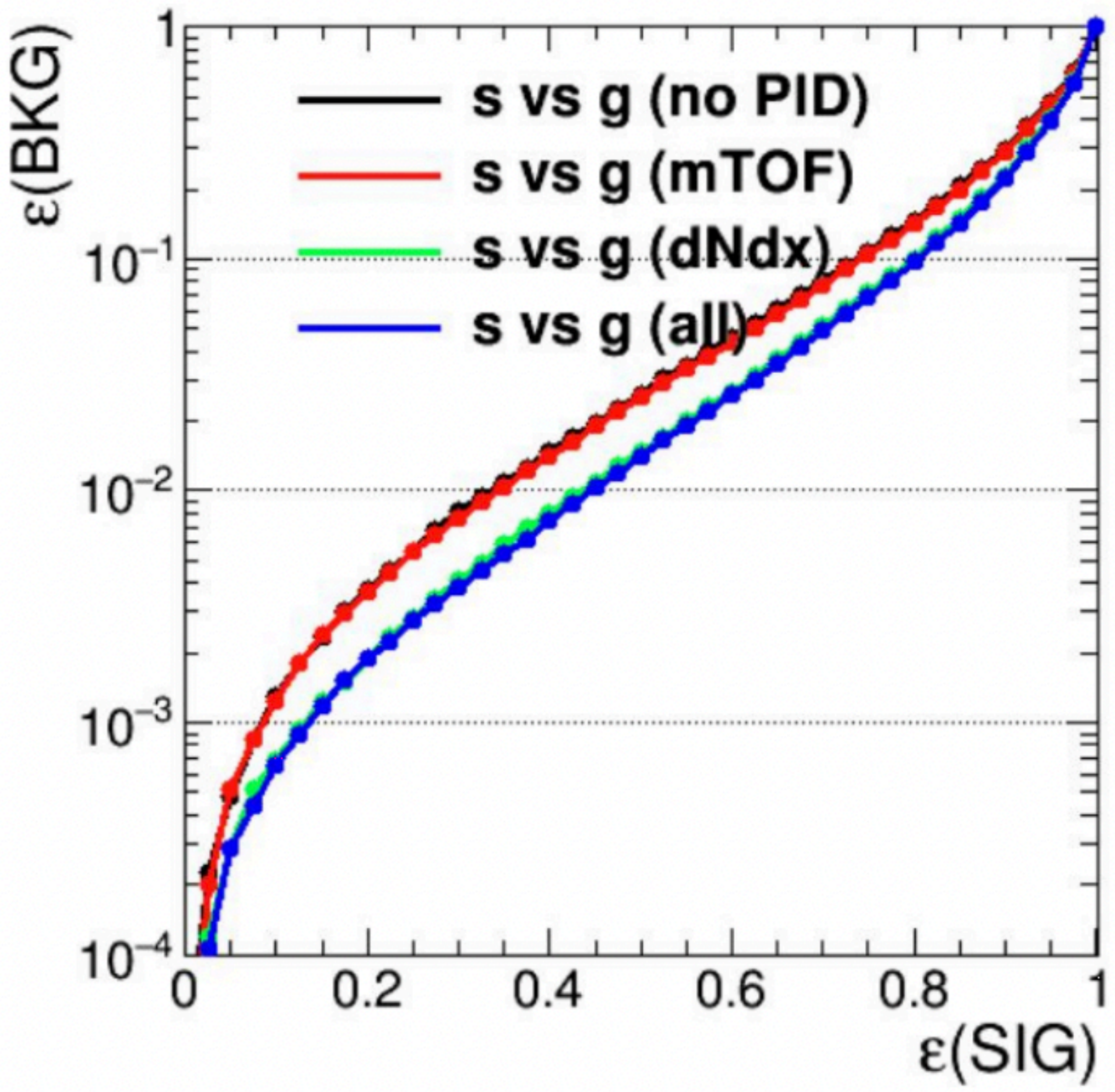
WP	Eff (b)	Mistag (g)	Mistag (ud)	Mistag (c)
Loose	90%	2%	0.2%	3%
Medium	80%	0.7%	<0.1%	0.4%

WP	Eff (c)	Mistag (g)	Mistag (ud)	Mistag (b)
Loose	90%	8%	7.5%	5%
Medium	80%	3%	0.9%	2.5%

$$\delta(\sigma \times BR)/(\sigma \times BR)\,\% \approx 0.6(\text{stat . only}) \text{ or } 2.9(\text{no Bkg rej})$$

…and Strange tagging?

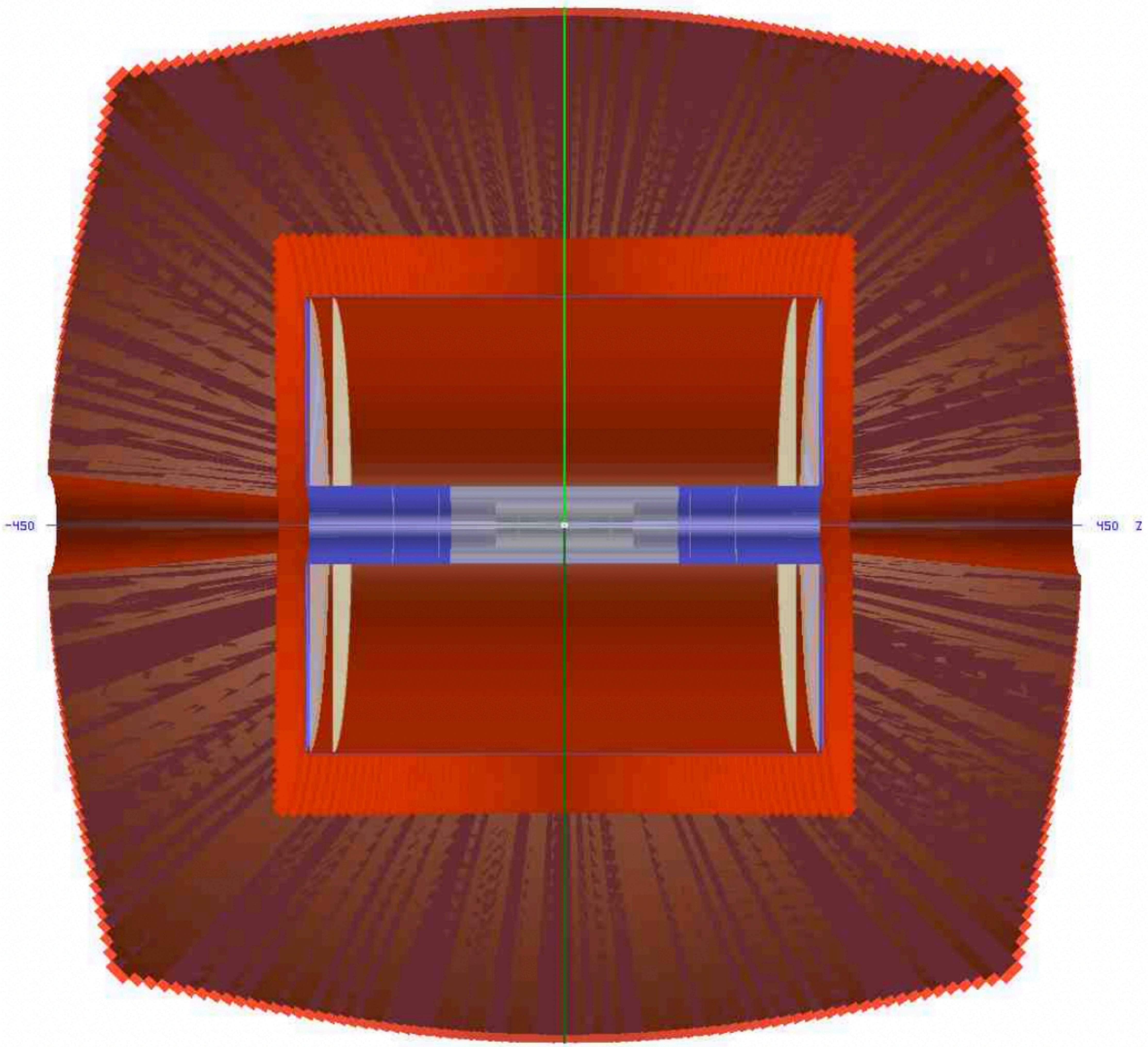




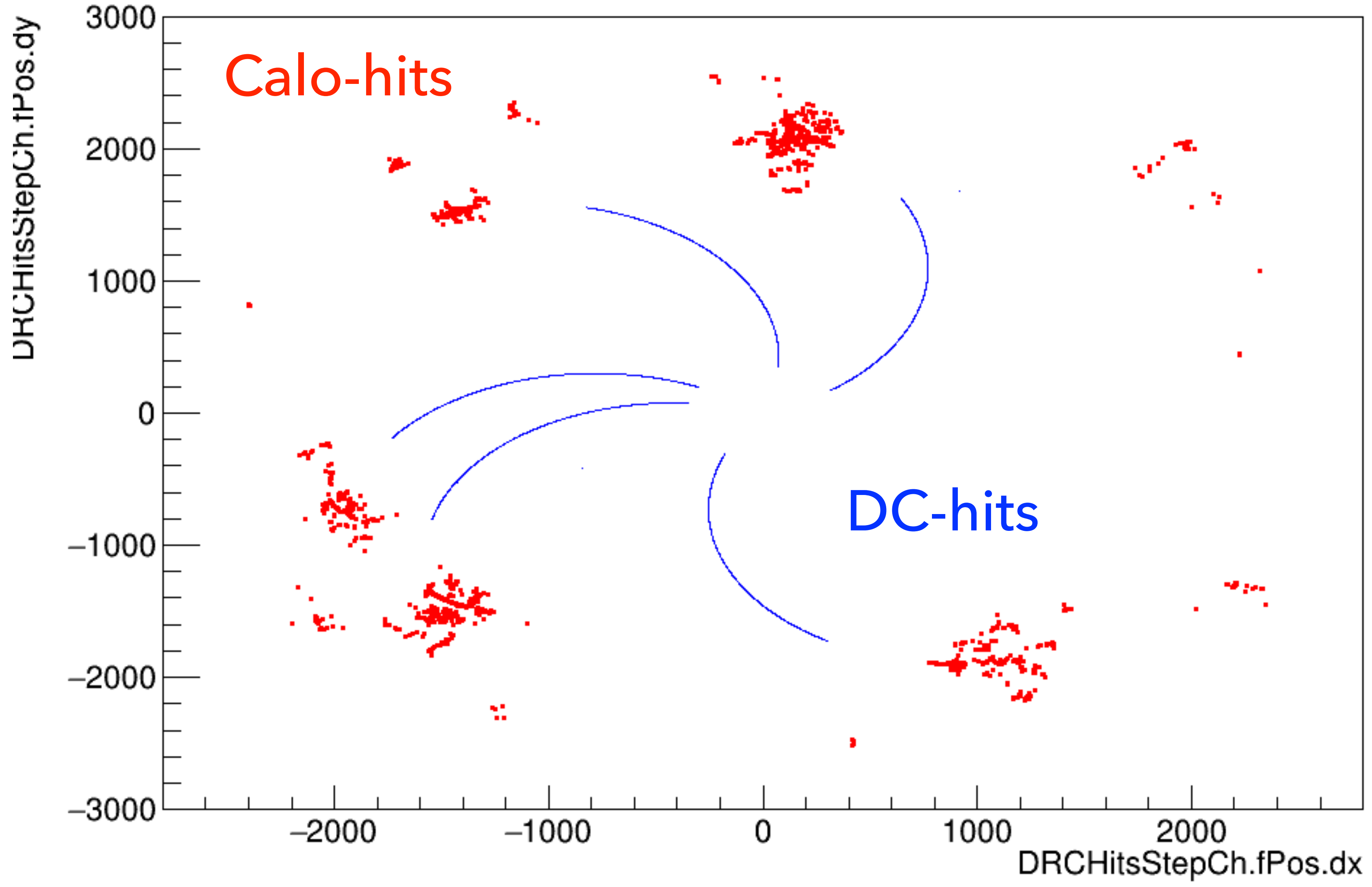
WP	Eff (s)	Mistag (g)	Mistag (ud)	Mistag (c)	Mistag (b)
Loose	90%	20%	40%	10%	1%
Medium	80%	10%	20%	6%	0.4%

- Strange tagging is the new "hot topic", can it be done?
  - Combined PID with dN/dx and TOF(30ps): $3\sigma\ K/\pi$ separation for p<30GeV
- Starting blocks for more exploration of new detector options

Full Simulation of IDEA



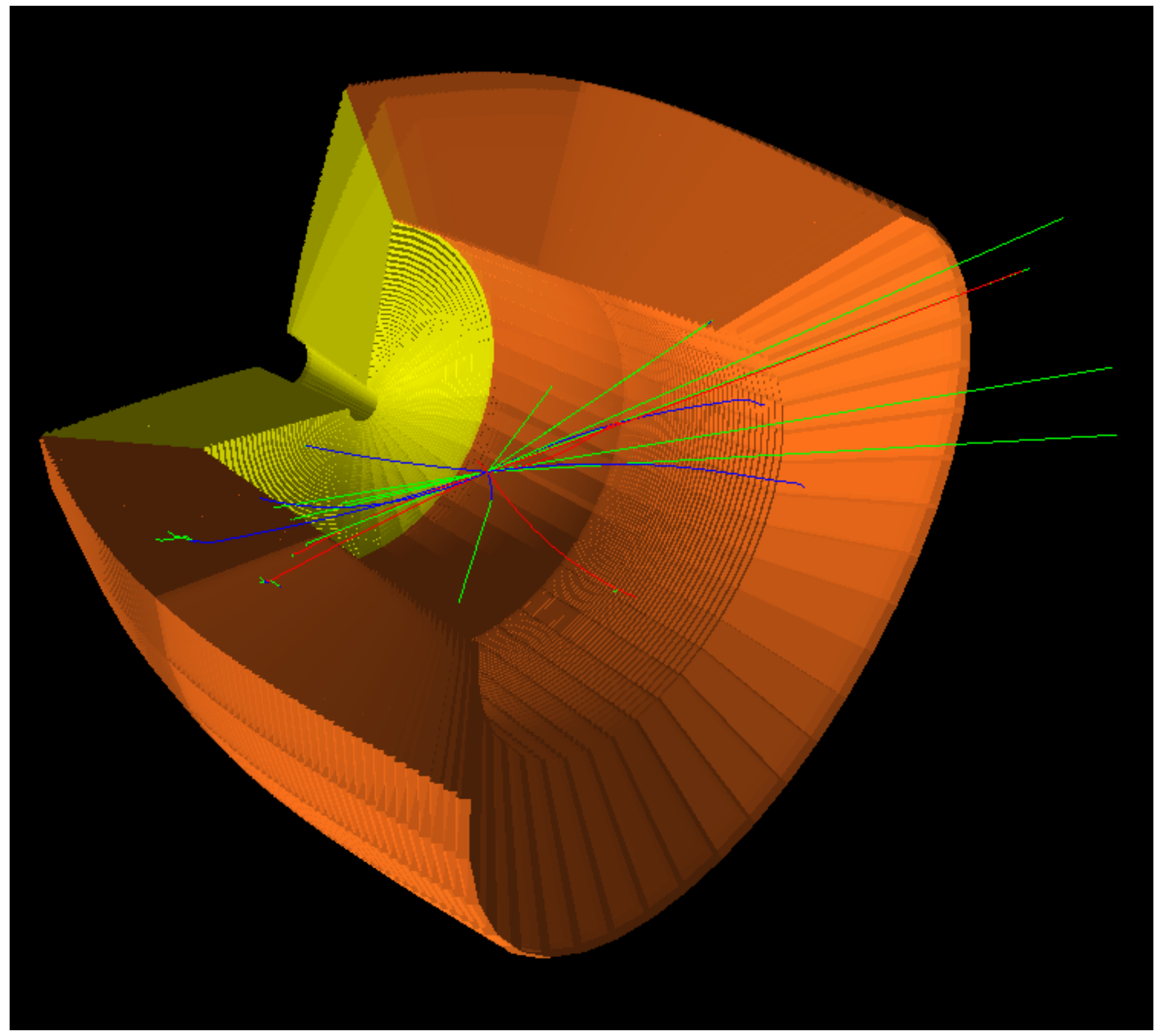
Visualization of IDEA geometry in GEANT
Vertex, Drift Chamber and DR Calorimeter



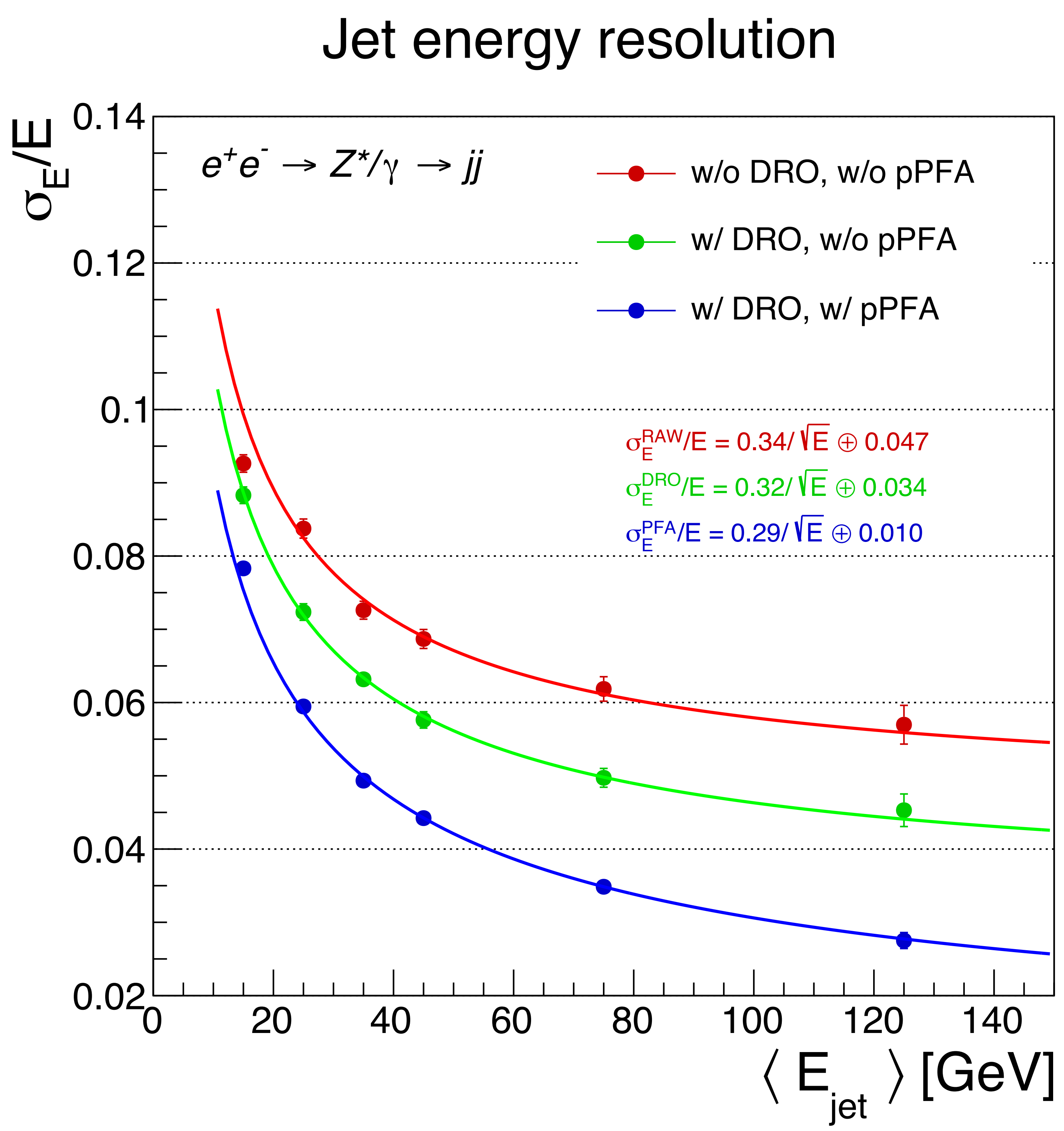
- Description of the full detector response at the hit level for:
  - Reconstruction algorithms development
  - physics performance studies
  - TestBeam data comparison for validation

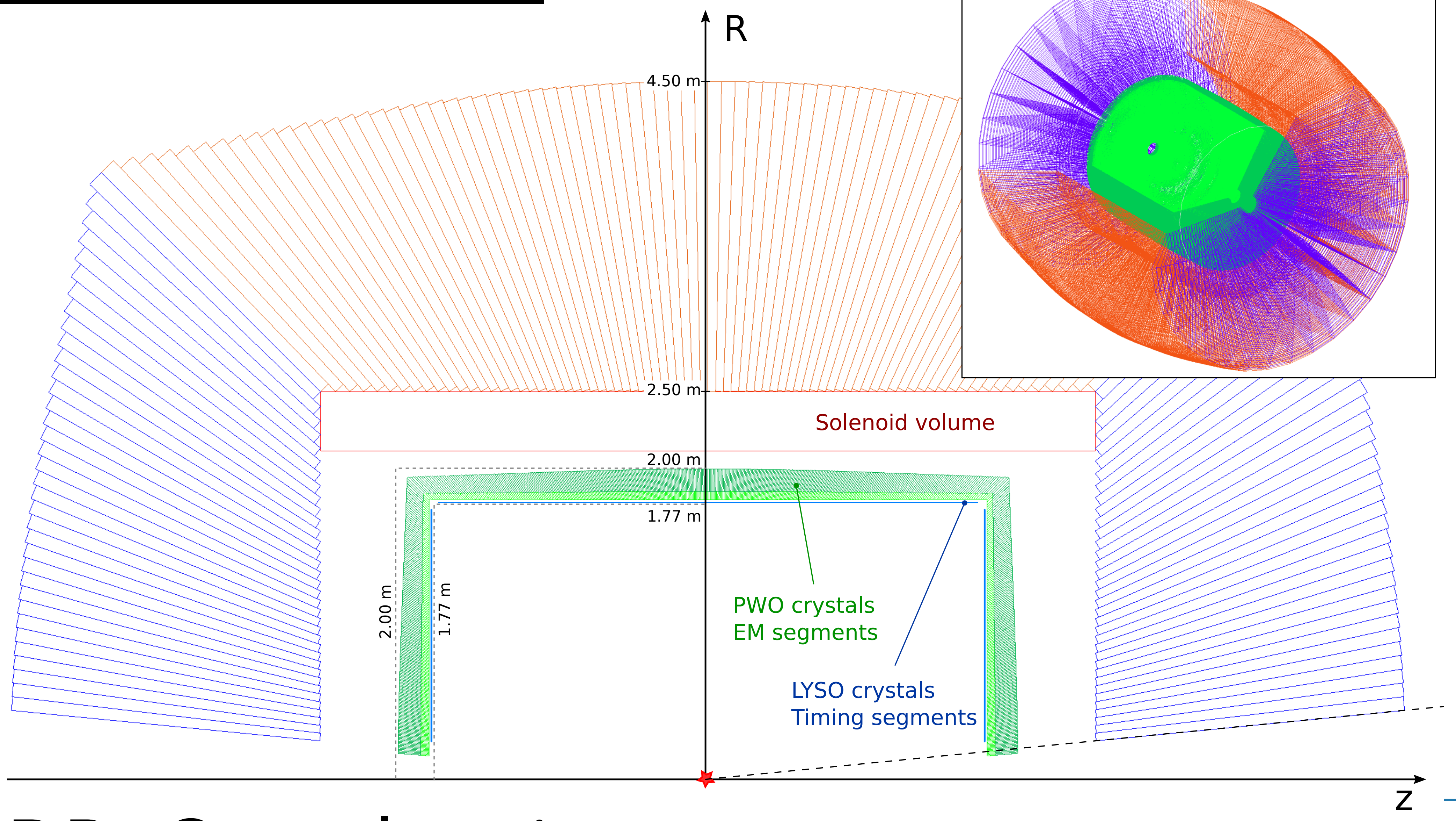
Exploring calorimetry options

GEANT4 - Qt visualizer - IDEA / $e^+e^- \to jj$



- Full simulations describing different configurations including response of the electronic
- Develop and test new reco algorithms

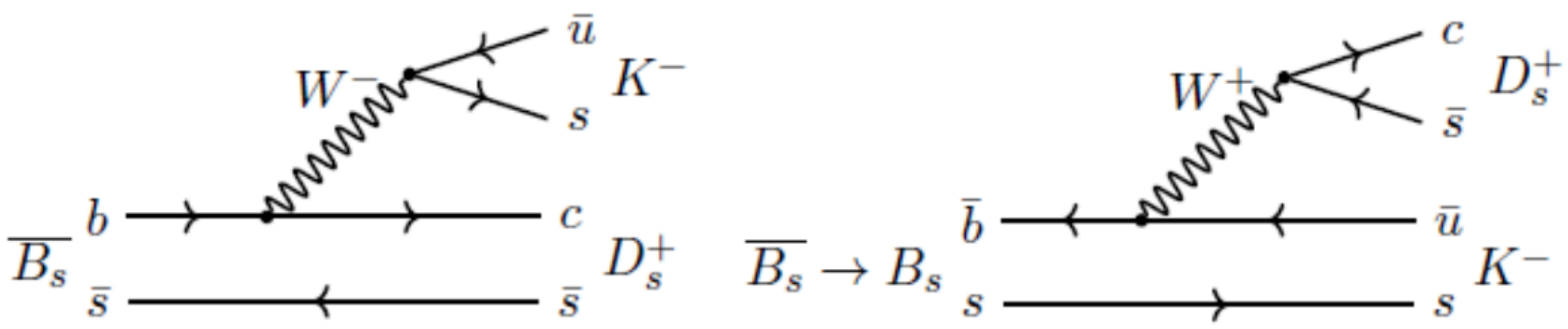




DR+Crystal option

Reach desired 3-4% resolution for jets >50 GeV with crystal+PF

Flavour physics case study

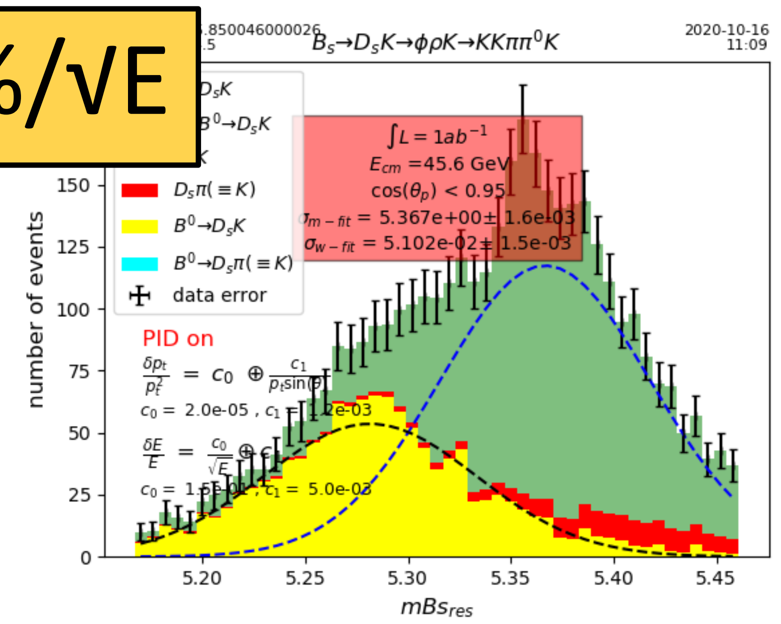


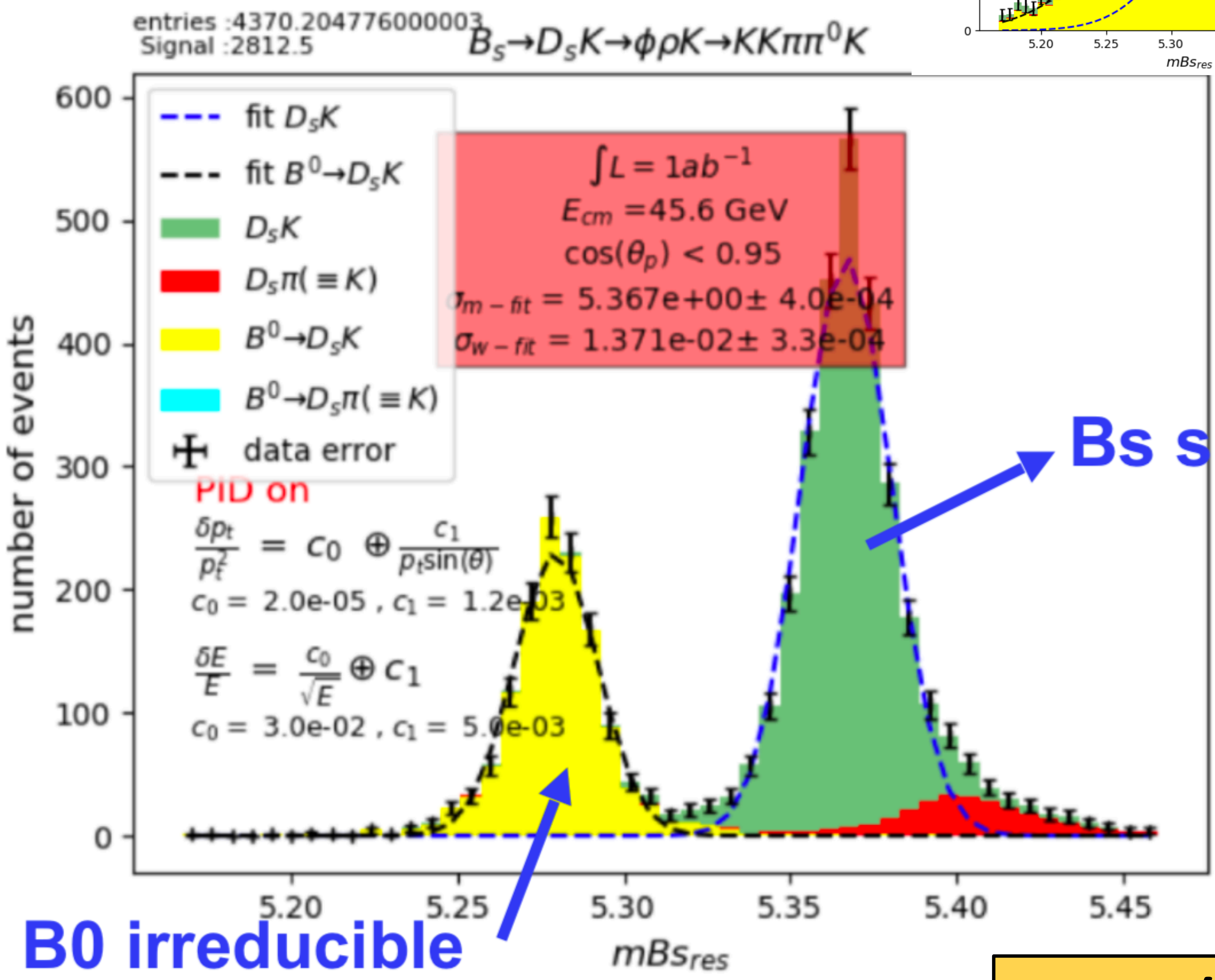
$$\phi_{CKM} = \gamma + \gamma_{ds} - 2\beta_s$$

UT tiny small

- $B_s \to D_s K$ is an excellent showcase for:
  - Studying sensitivity on CP violation (measurement of CKM angle γ)
  - Determining constraints on detector (in particular for vertexing and calorimeter)
  - Preliminary studies show $\delta(\gamma) \lesssim 0.4^\circ\ (stat.)$ achievable
  - FullSim studies in progress

15%/√E





State-of-the-art Xtal-type 3%/√E

On the way to ParticleFlow reconstruction…

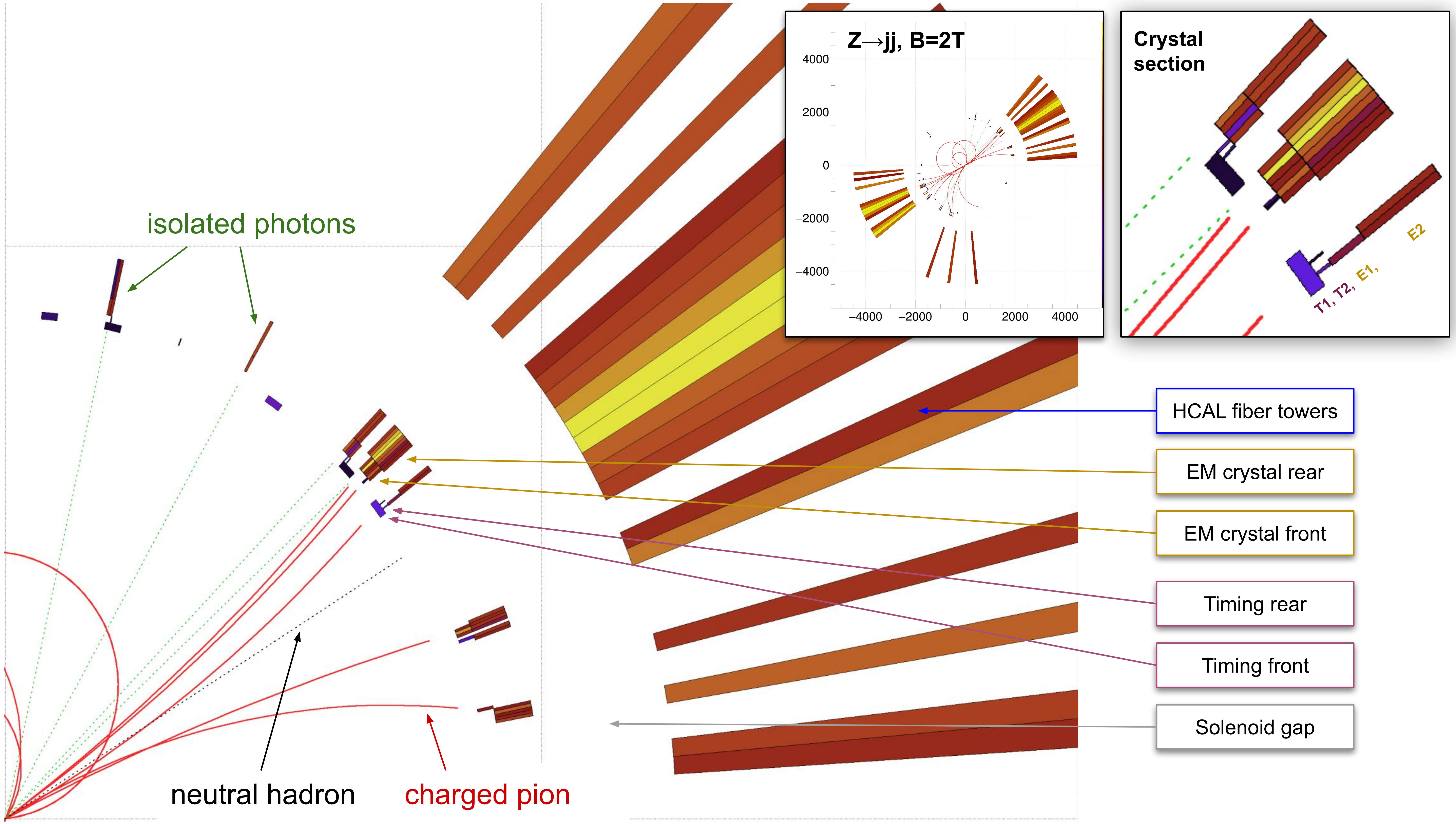
- 1) Hits around *crystal neutral seeds* are clustered as *photon hits* and are not associated to tracks.

Crystal section is crucial in 1) ↑

- *2) Calorimeter hits* are associated to tracks based on their track-distance.

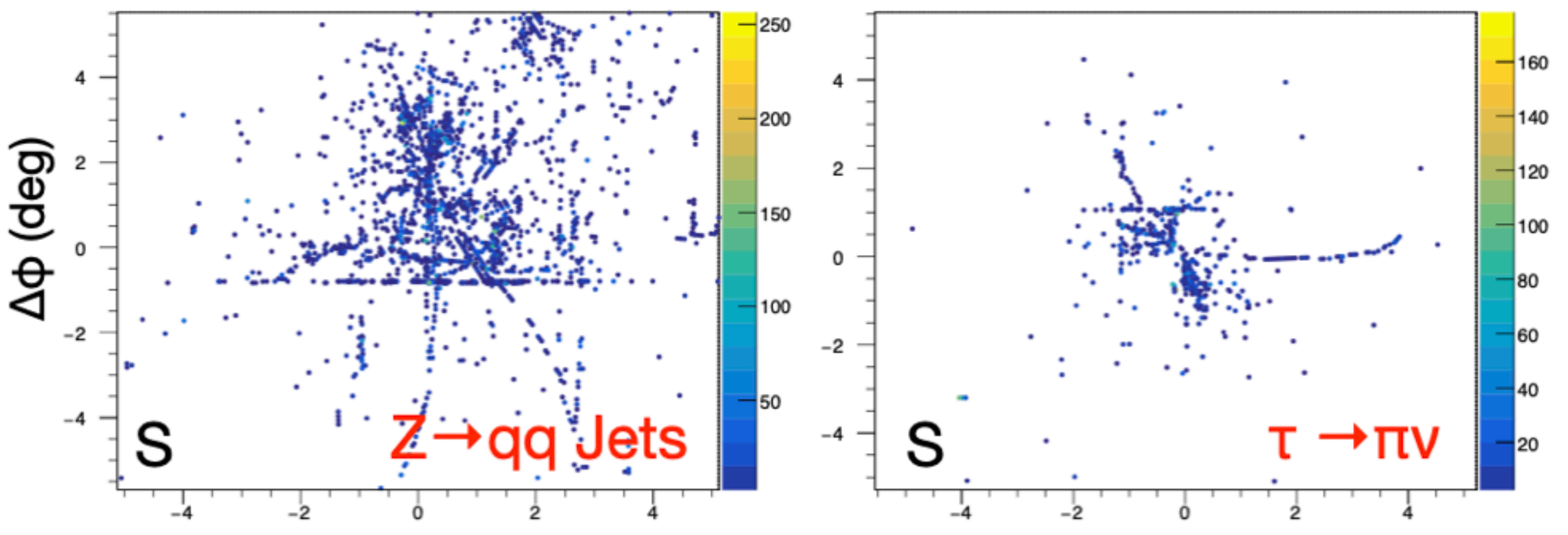
↓

If the sum of the energy associated to a track is within 1σ from the expected energy the calorimeter hits are replaced with the track momentum.

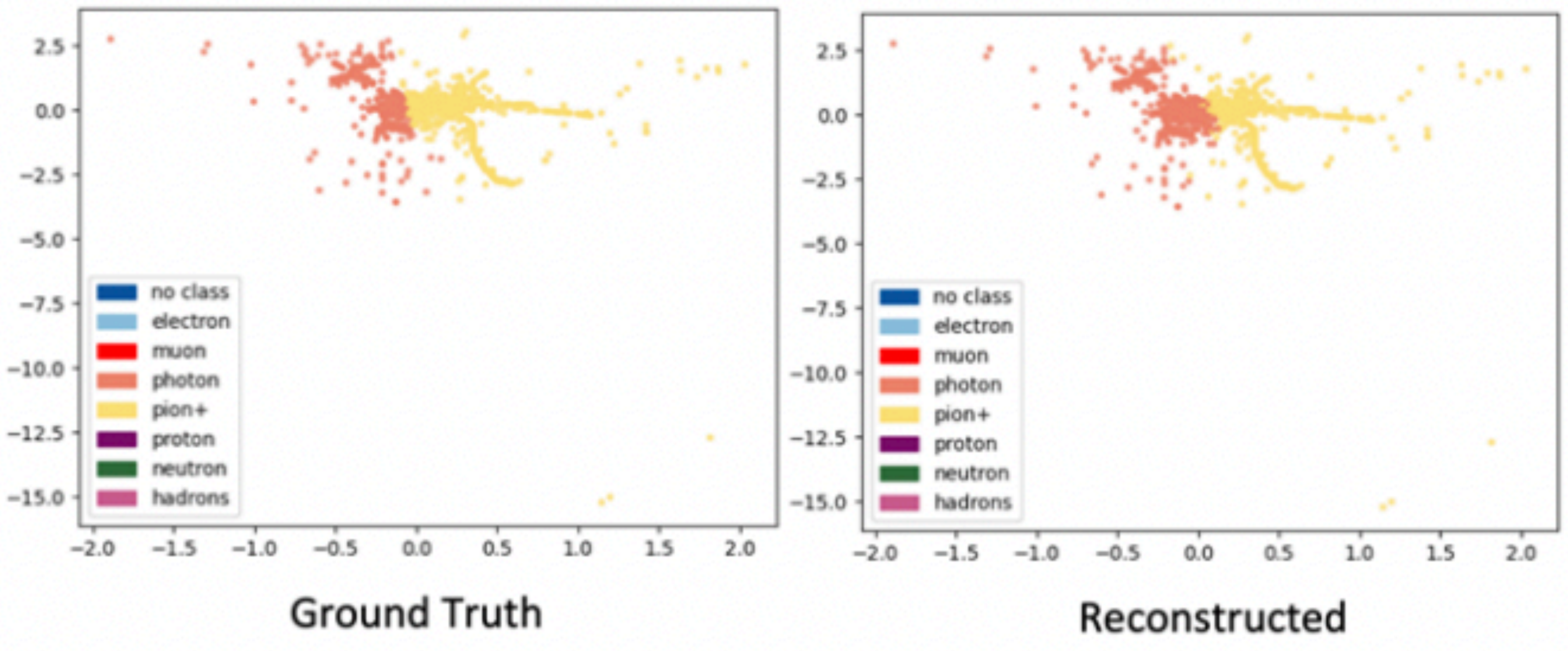


Example: NN for τ–ID in DR Calo

- Exploiting a DGCNN for:
  - separation of hadronic τ decays from QCD jets using only DR information.
  - Identification of objects inside Identification of objects inside τ decay (γ and n)
- Up to 91% average identification accuracy of classification of QCD and τ decays *only with DR calo hit information.*
  - Straightforward application to ParticleFlow algorithm



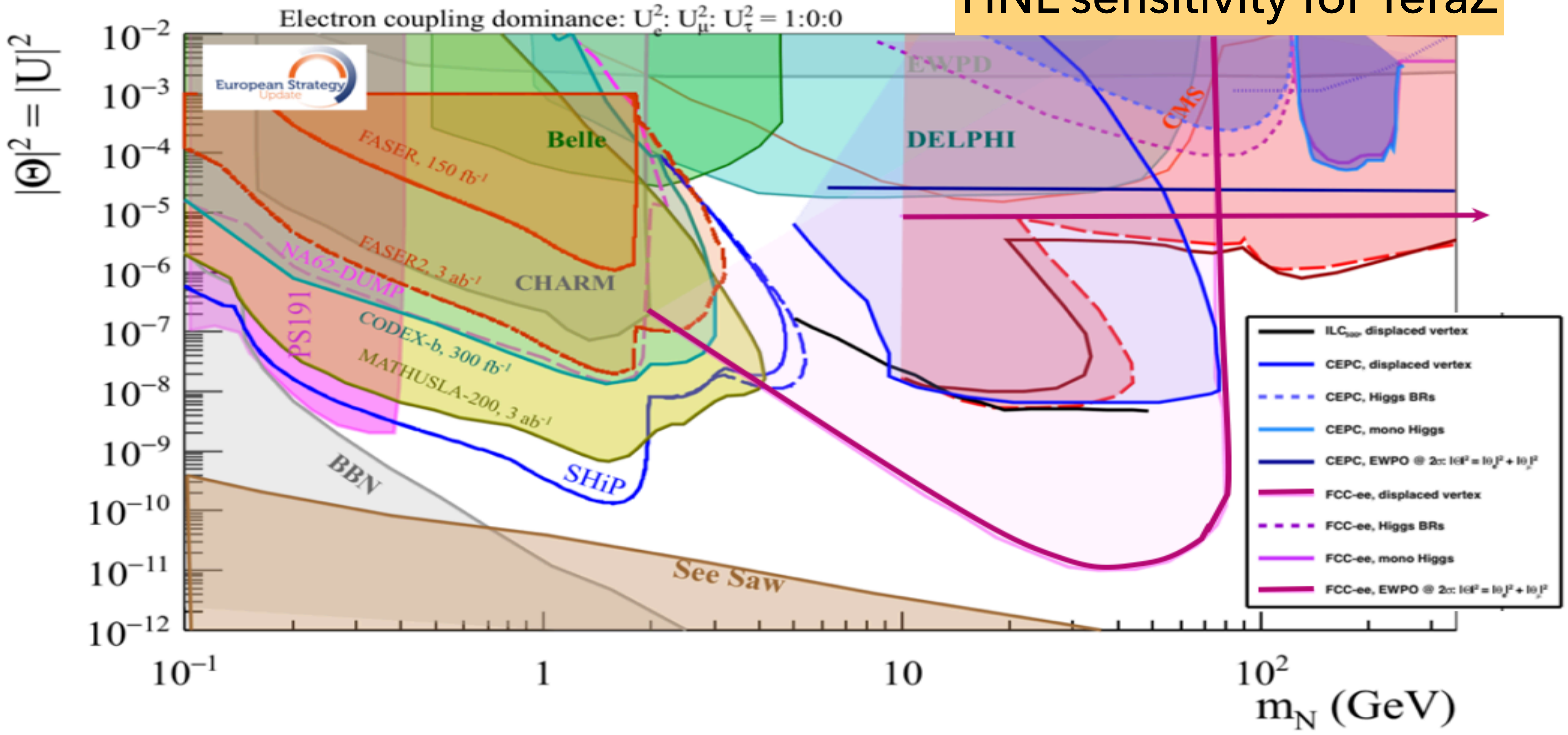
Example: segmentation of two $\tau \rightarrow \pi\pi^0\nu_\tau$ events



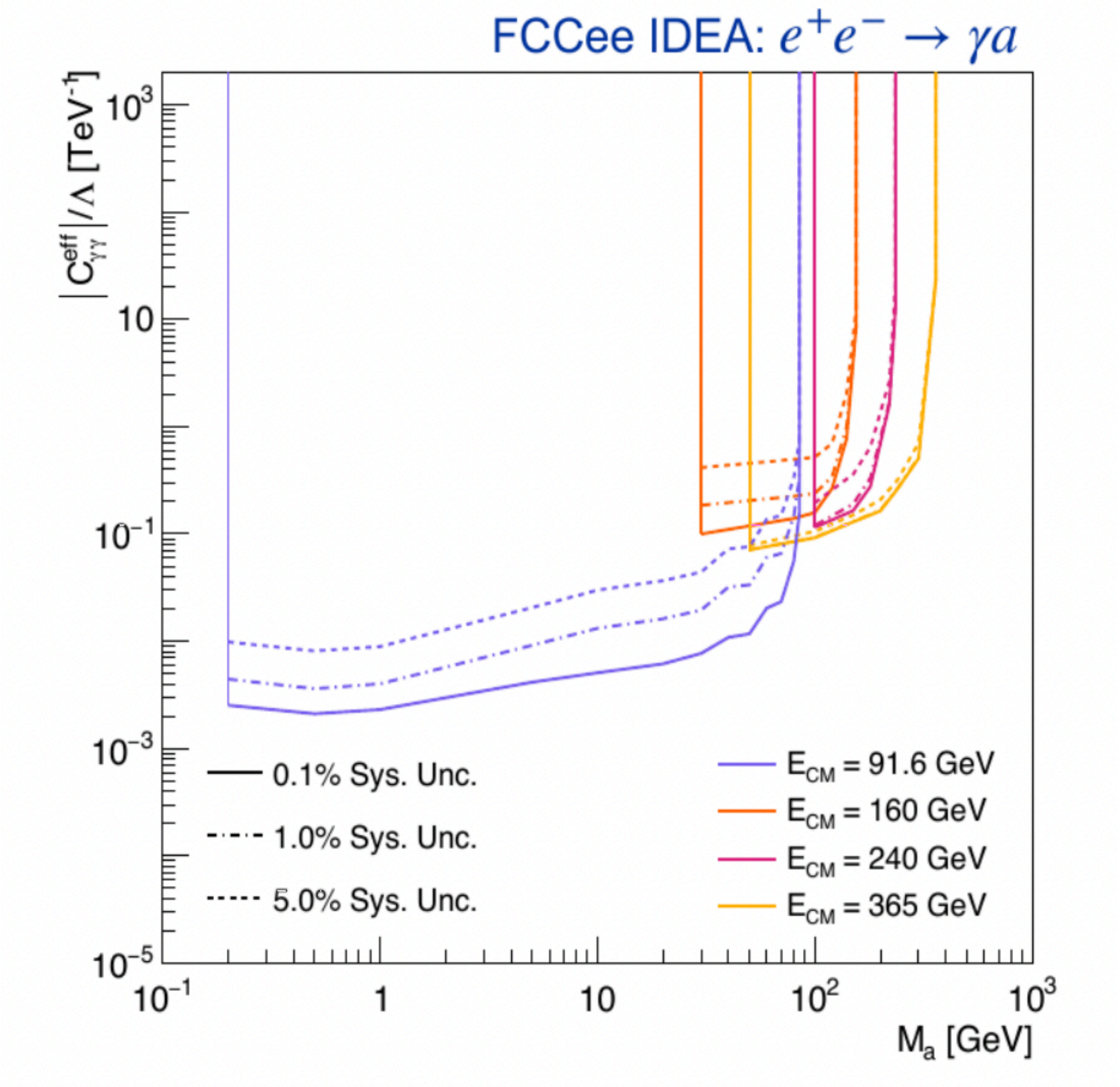
BSM Physics opportunities

- Intensity frontier offers the opportunity to directly observe new feebly interacting particles below m(Z) (even with long lifetimes): ALPS, HNL, Dark photons

HNL sensitivity for TeraZ



Preliminary study for ALPS in 3γ final state



PAVIA

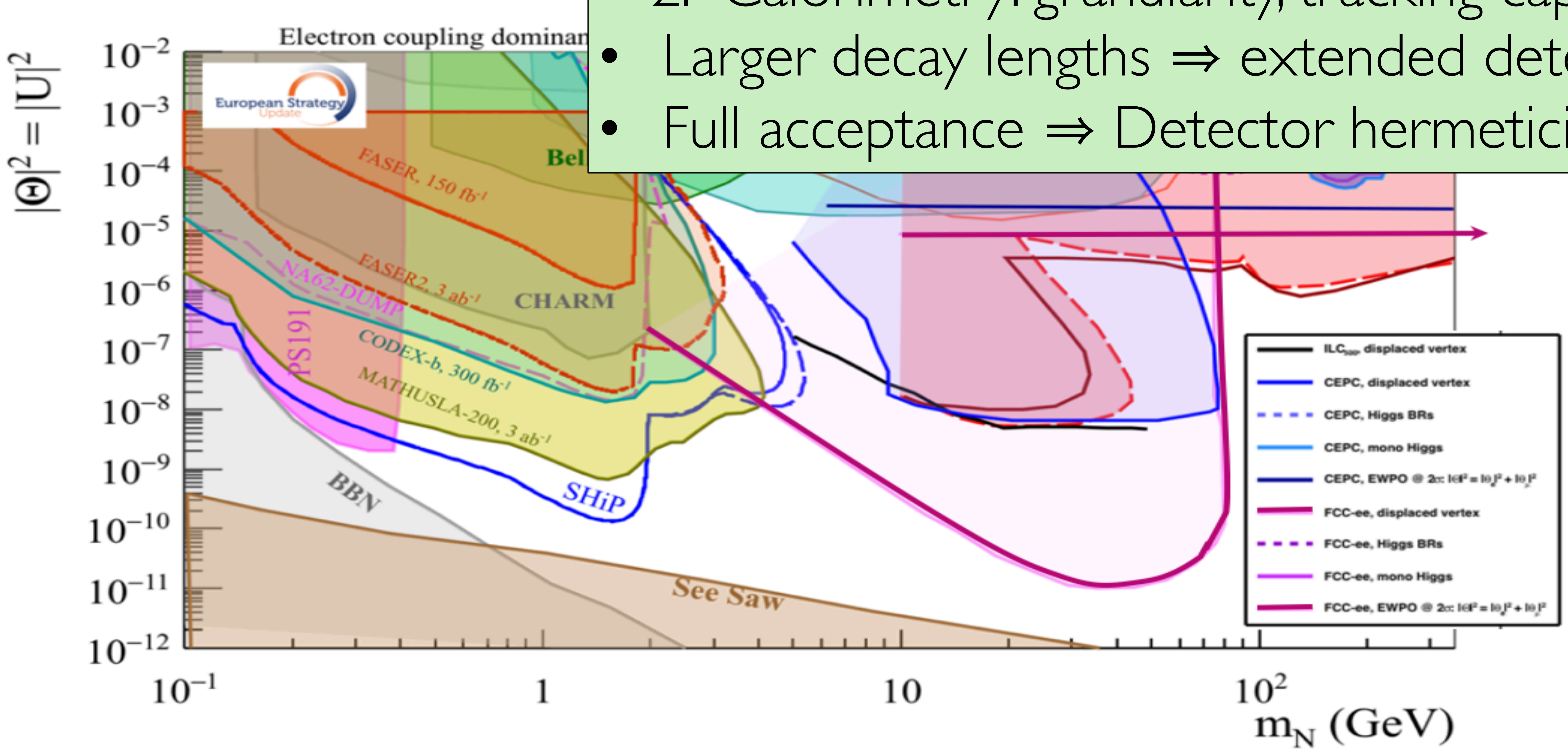
BSM Physics opportunities

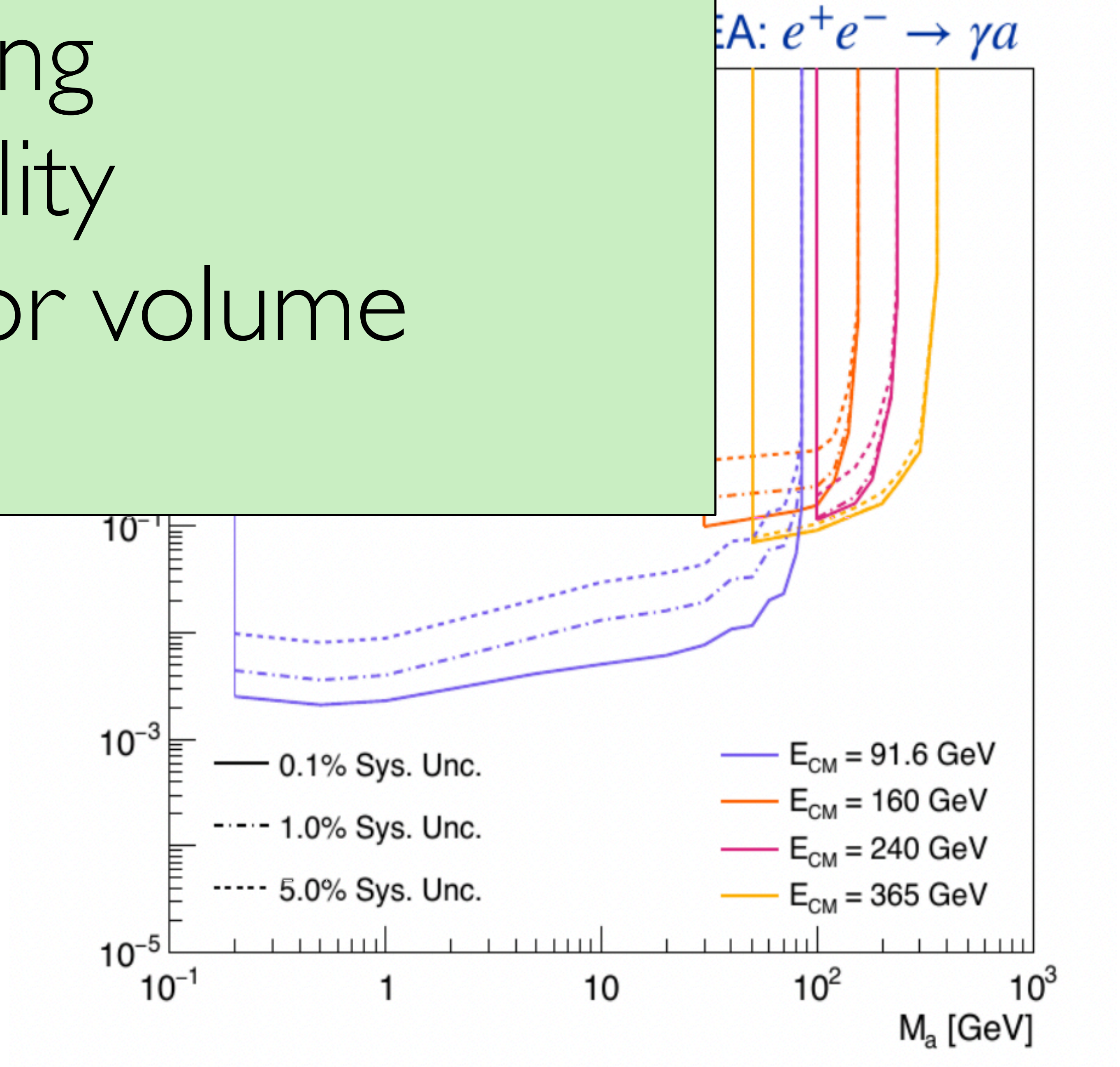
- Intensity frontier offe
new feebly interactin
lifetimes): ALPS, HNL,

tudy for
nal state

Detector Requirements

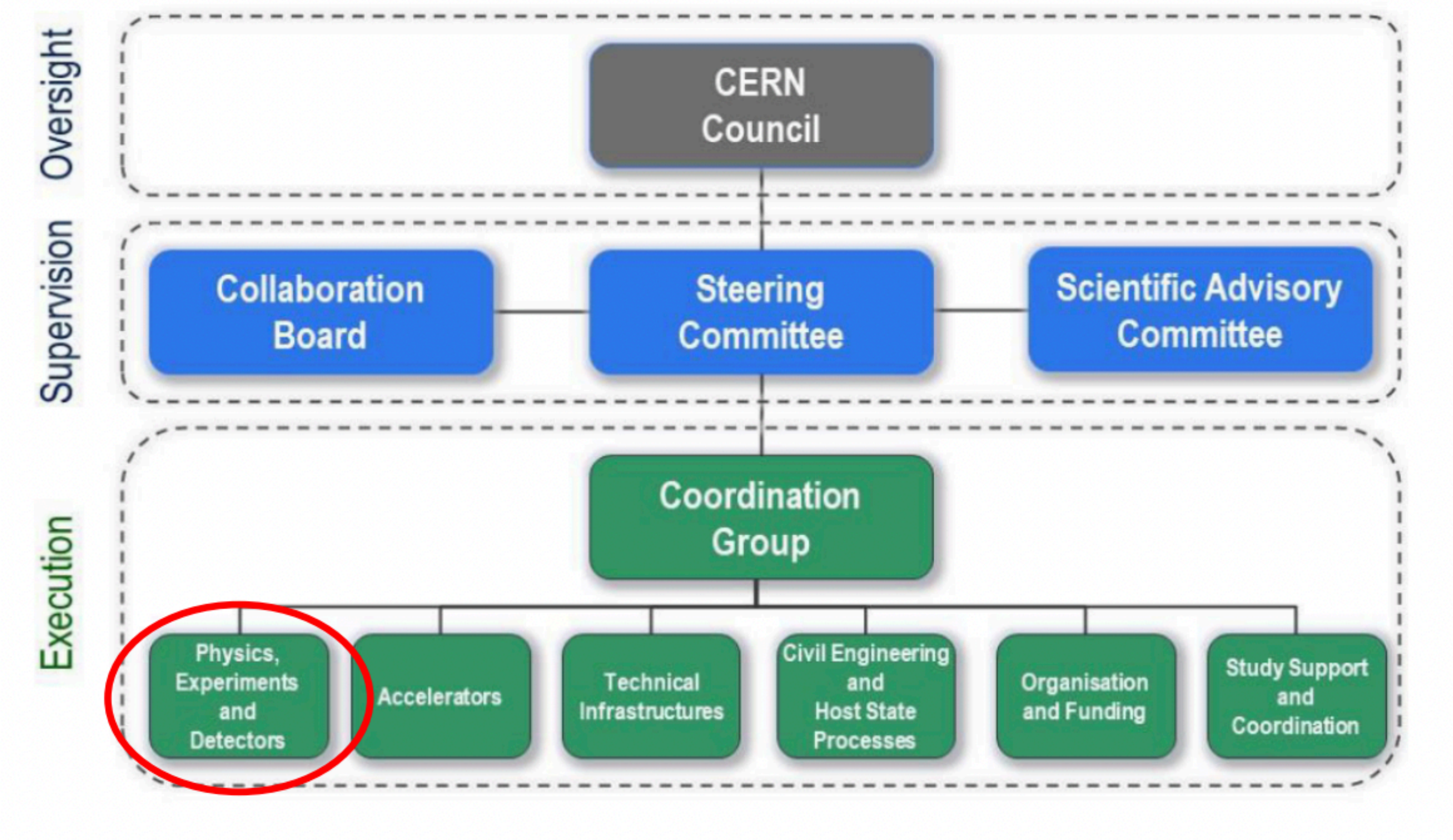
- Sensitivity to far-detached vertices (mm → m)
  1. Tracking: more layers, continuous tracking
  2. Calorimetry: granularity, tracking capability
- Larger decay lengths ⇒ extended detector volume
- Full acceptance ⇒ Detector hermeticity





PAVIA

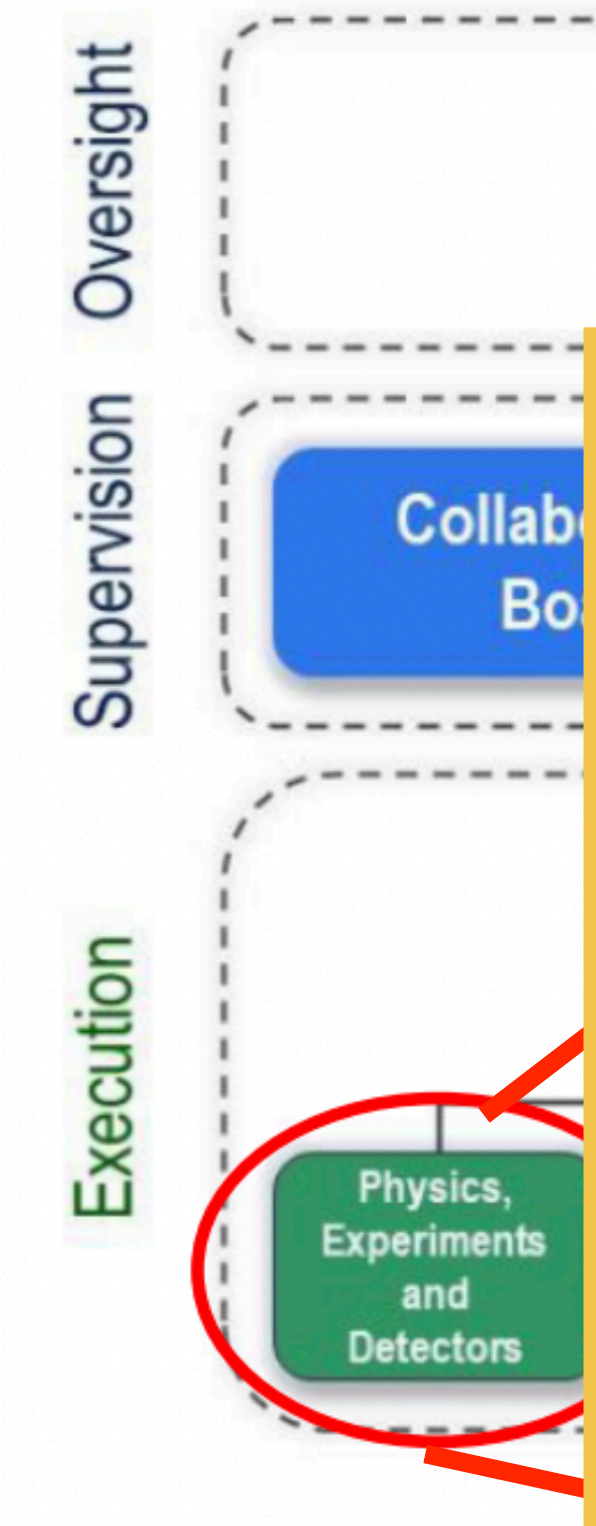
Organization



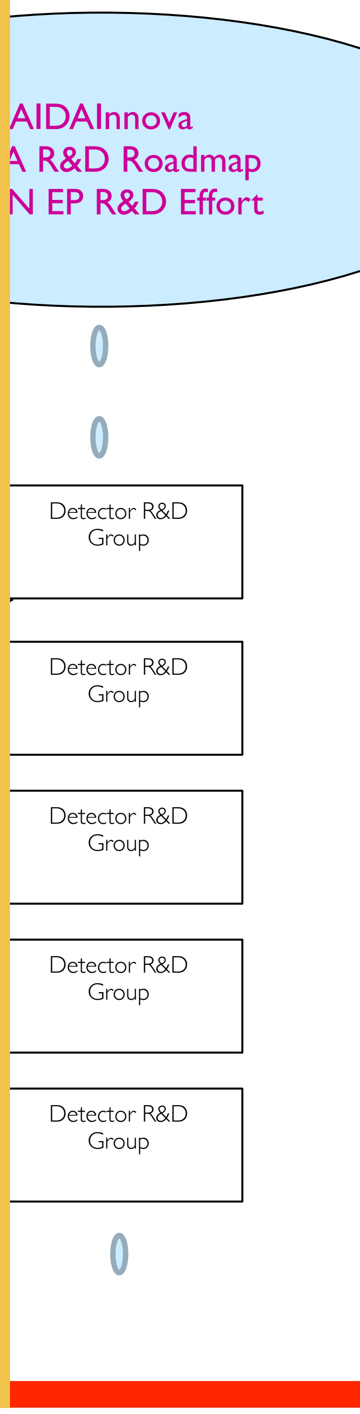
Organization

Organization

Organization



- **Physics Programme:** proposes physics benchmarks
- **Detector Concepts:** explores new technologies
- **Physics Performance:** connects the two by means of "case studies"
  - To optimise the ultimate statistical sensitivity
  - To identify and evaluate the limiting systematic uncertainties
  - To establish detector requirements and pass them on to the Detector Concept



RD-FCC WG1: PHYSICS & SIMULATION

- LOIs to Snowmass, **challenges**: https://indico.cern.ch/event/951830/

EPJ+ special issue "A future Higgs and EW Factory: Challenges towards discovery"

All 34 references in this Overleaf document: https://www.overleaf.com/read/xcssxqyhtrgt

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MDI, $\sqrt{s}$

Challenges to match statistical precision

Detector requirements & possible solutions

Theory challenges

Software and computing challenges

Now is a good time to join the FCC feasibility study

Registration open: https://indico.cern.ch/event/1064327/

BACKUP

FCC-ee as a Higgs factory and beyond

Higgs provides a very good reason why we need both e^+e^- AND pp colliders

- FCC-ee measures g_{HZZ} to 0.2% (absolute, model-independent, standard candle) from σ_{ZH}
  - Γ_H, g_{Hbb}, g_{Hcc}, $g_{H\tau\tau}$, g_{HWW} follow
  - Standard candle fixes all HL-LHC couplings
- FCC-hh produces over 10^{10} Higgs bosons
  - (1st standard candle →) $g_{H\mu\mu}$, $g_{H\gamma\gamma}$, $g_{HZ\gamma}$, Br_{inv}
- FCC-ee measures top EW couplings ($e^+e^- \to t\bar{t}$)
  - Another standard candle
- FCC-hh produces 10^8 ttH and 2. 10^7 HH pairs
  - (2nd standard candle →) g_{Htt} and g_{HHH}

Collider	HL-LHC	FCC-ee$_{240\to365}$	FCC-INT	
Lumi (ab^{-1})	3	5 + 0.2 + 1.5	30	
Years	10	3 + 1 + 4	25	
g_{HZZ} (%)	1.5	0.18 / 0.17	0.17/0.16	ee
g_{HWW} (%)	1.7	0.44 / 0.41	0.20/0.19	ee
g_{Hbb} (%)	5.1	0.69 / 0.64	0.48/0.48	ee
g_{Hcc} (%)	SM	1.3 / 1.3	0.96/0.96	ee
g_{Hgg} (%)	2.5	1.0 / 0.89	0.52/0.5	ee
$g_{H\tau\tau}$ (%)	1.9	0.74 / 0.66	0.49/0.46	ee
$g_{H\mu\mu}$ (%)	4.4	8.9 / 3.9	0.43/0.43	pp
$g_{H\gamma\gamma}$ (%)	1.8	3.9 / 1.2	0.32/0.32	pp
$g_{HZ\gamma}$ (%)	11.	– / 10.	0.71/0.7	pp
g_{Htt} (%)	3.4	10. / 3.1	1.0/0.95	pp
g_{HHH} (%)	50.	44./33. 27./24.	2-3	pp
Γ_H (%)	SM	1.1	0.91	ee
BR_{inv} (%)	1.9	0.19	0.024	pp
BR_{EXO} (%)	SM (0.0)	1.1	1	ee

- **FCC-ee + FCC-hh is outstanding**
  - All accessible couplings with per-mil precision; self-coupling with per-cent precision

FCC-ee is also the most effective way toward FCC-hh

FCC-ee AS AN ELECTROWEAK FACTORY

- With highest luminosities at 91, 160 and 350 GeV
  - Complete set of EW observables can be measured
    - Precision (10^{-3} today) down to few 10^{-6}

e.g., m_Z (100 keV), Γ_Z (25 keV), $\alpha_{QED}(m_Z)$ (3.10^{-5}), $\sin^2\theta_W$ ($3.\ 10^{-6}$), m_W (<500 keV), m_{top} (20 MeV)

Benefiting from √s calibration with resonant depolarisation at 91 and 160 GeV

- Precision unique to FCC-ee, with smallest parametric errors
  - Challenge: match syst. uncertainties to the stat. precision
    - A lot more potential to exploit with good detector design than the present treatment suggests
    - Theory work is critical and initiated
- Precision = discovery potential (e.g., NP in Z/W propagators)
  - Generic discovery potential: Show that SM does not suffice
  - Challenge: test specific models with ALL information
    - Clarify the need for precision from a theoretical perspective
    - Explain how FCC-ee go towards answering big questions in fundamental physics

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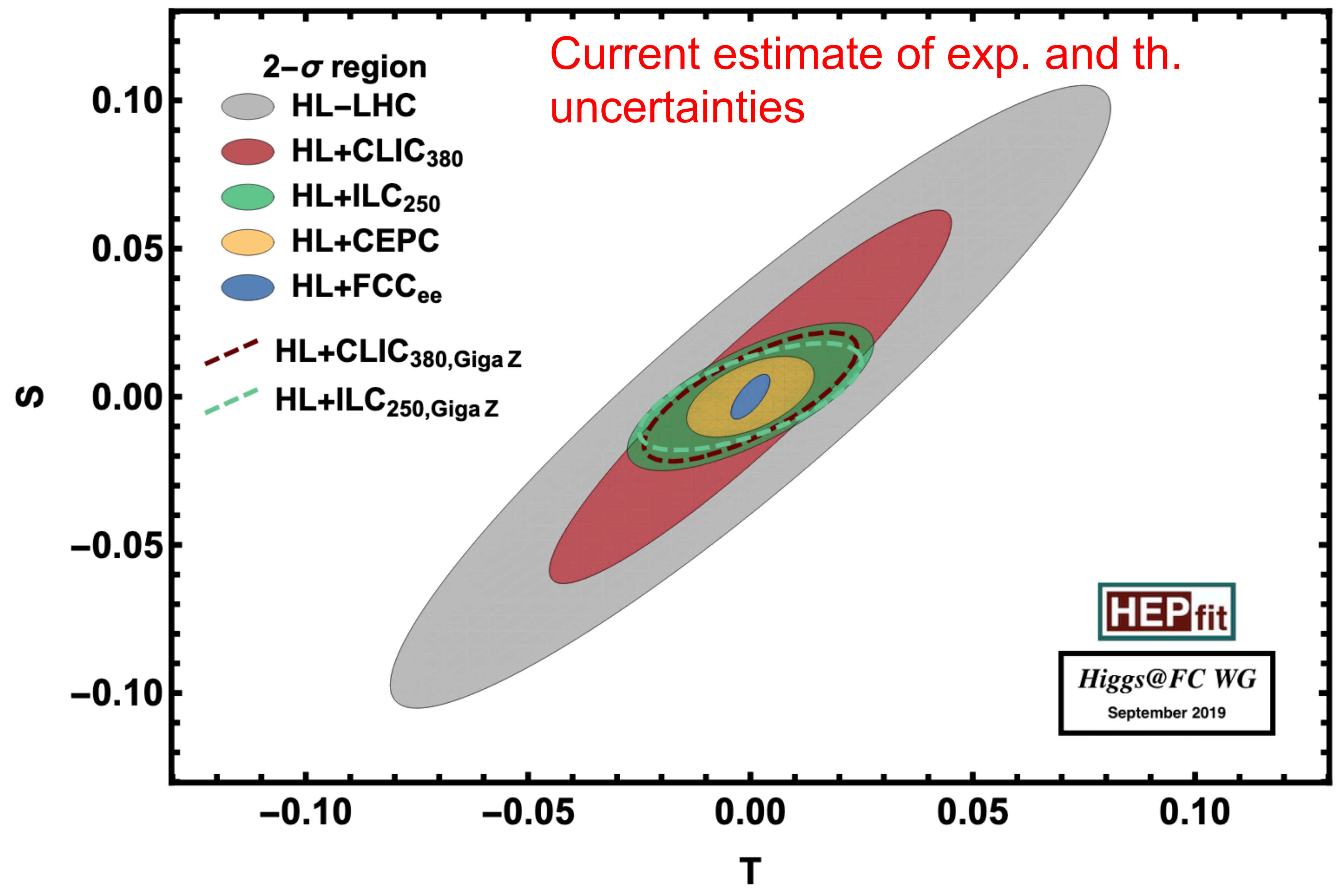
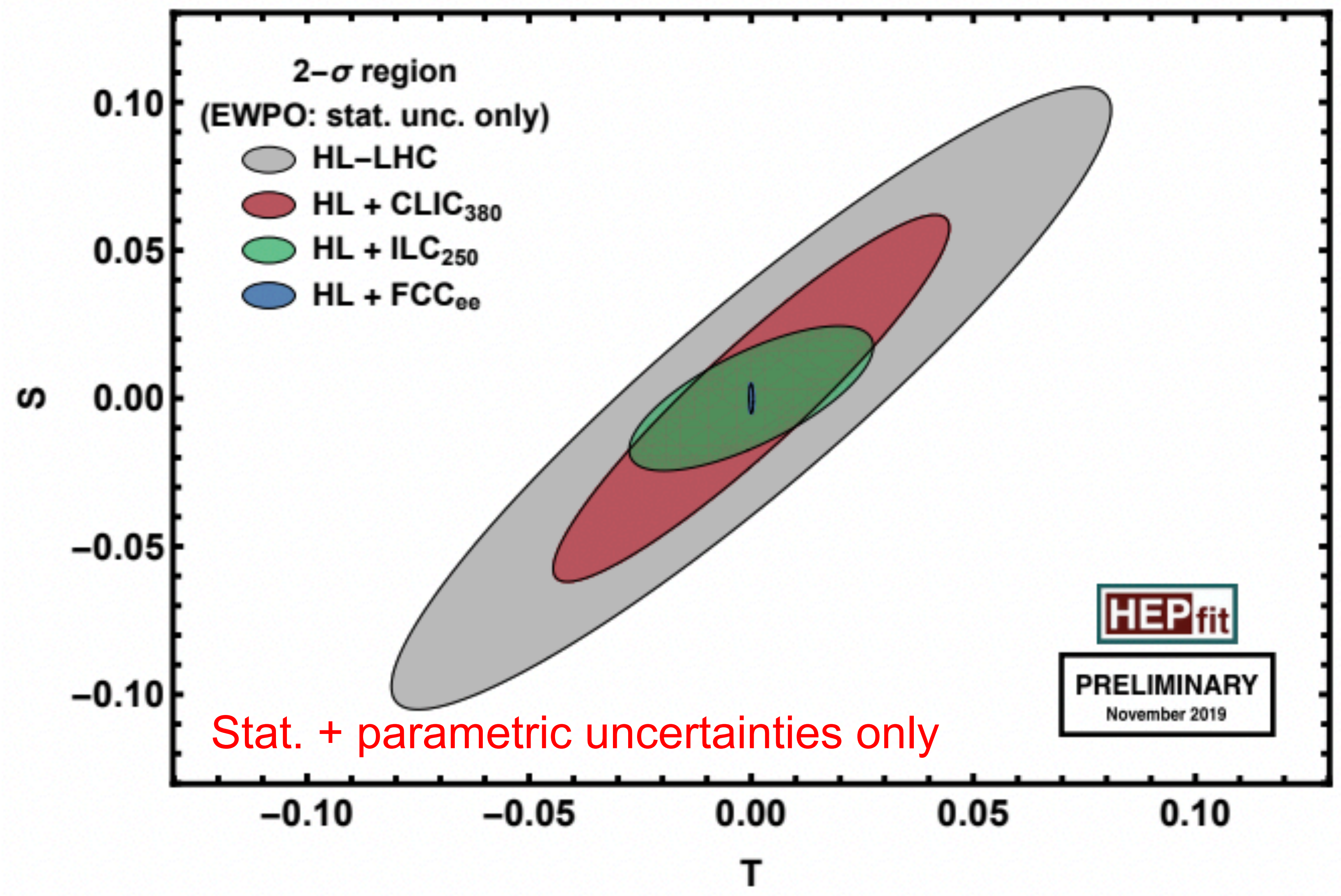
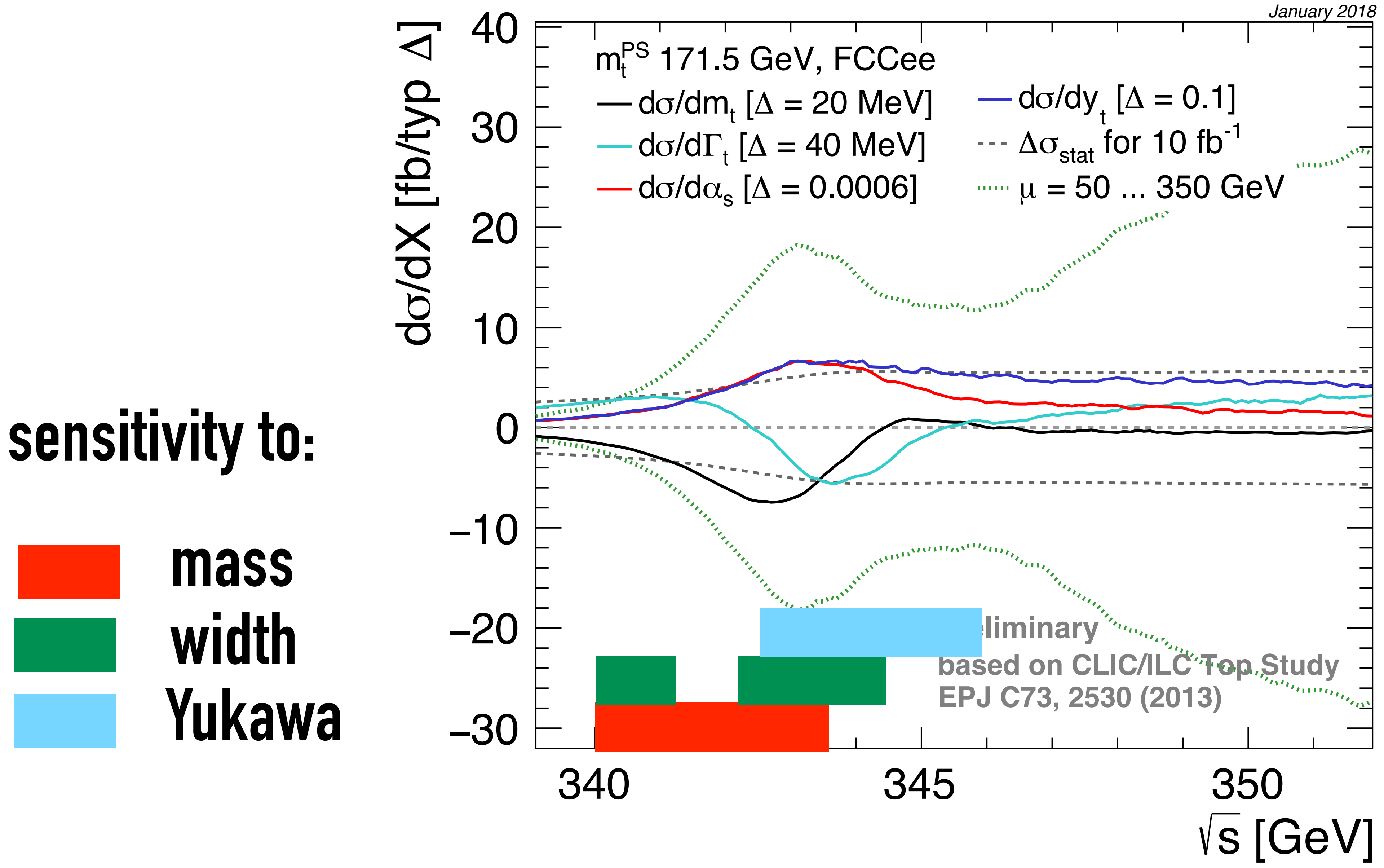
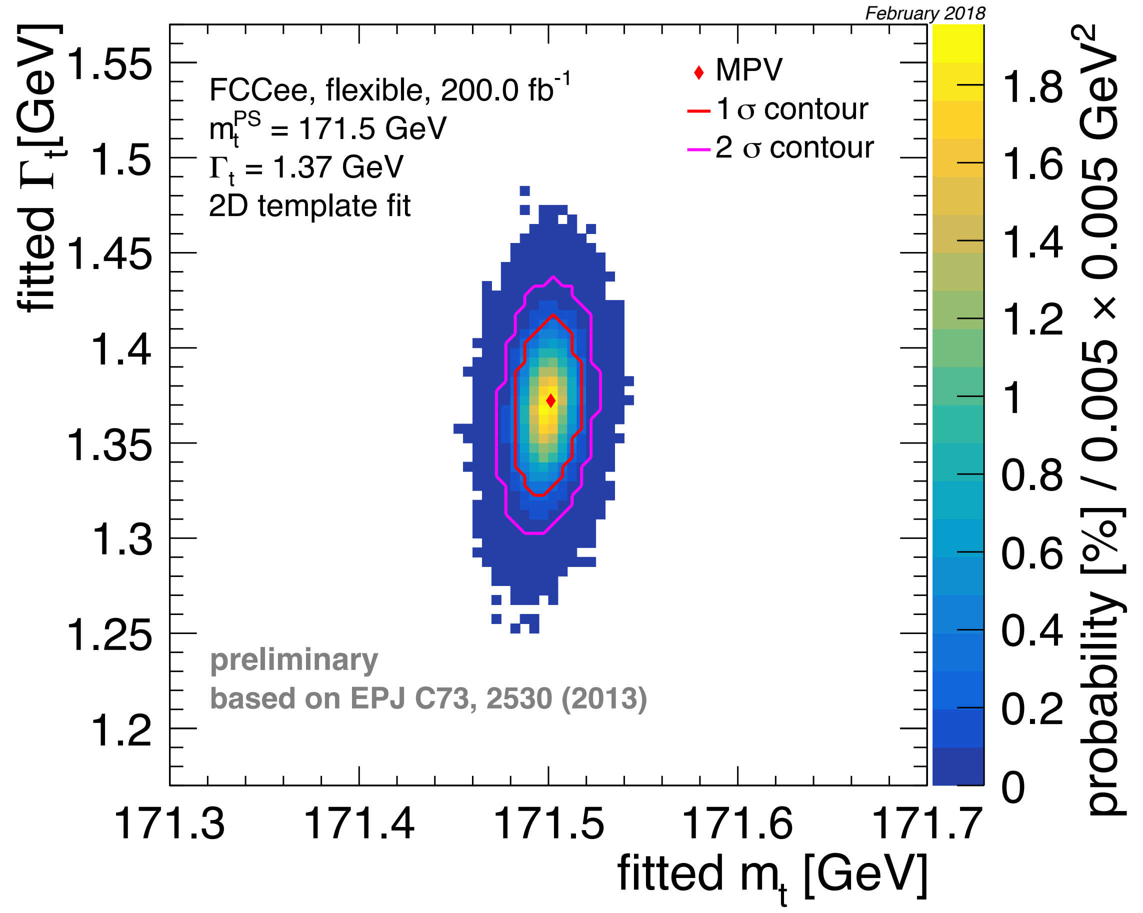




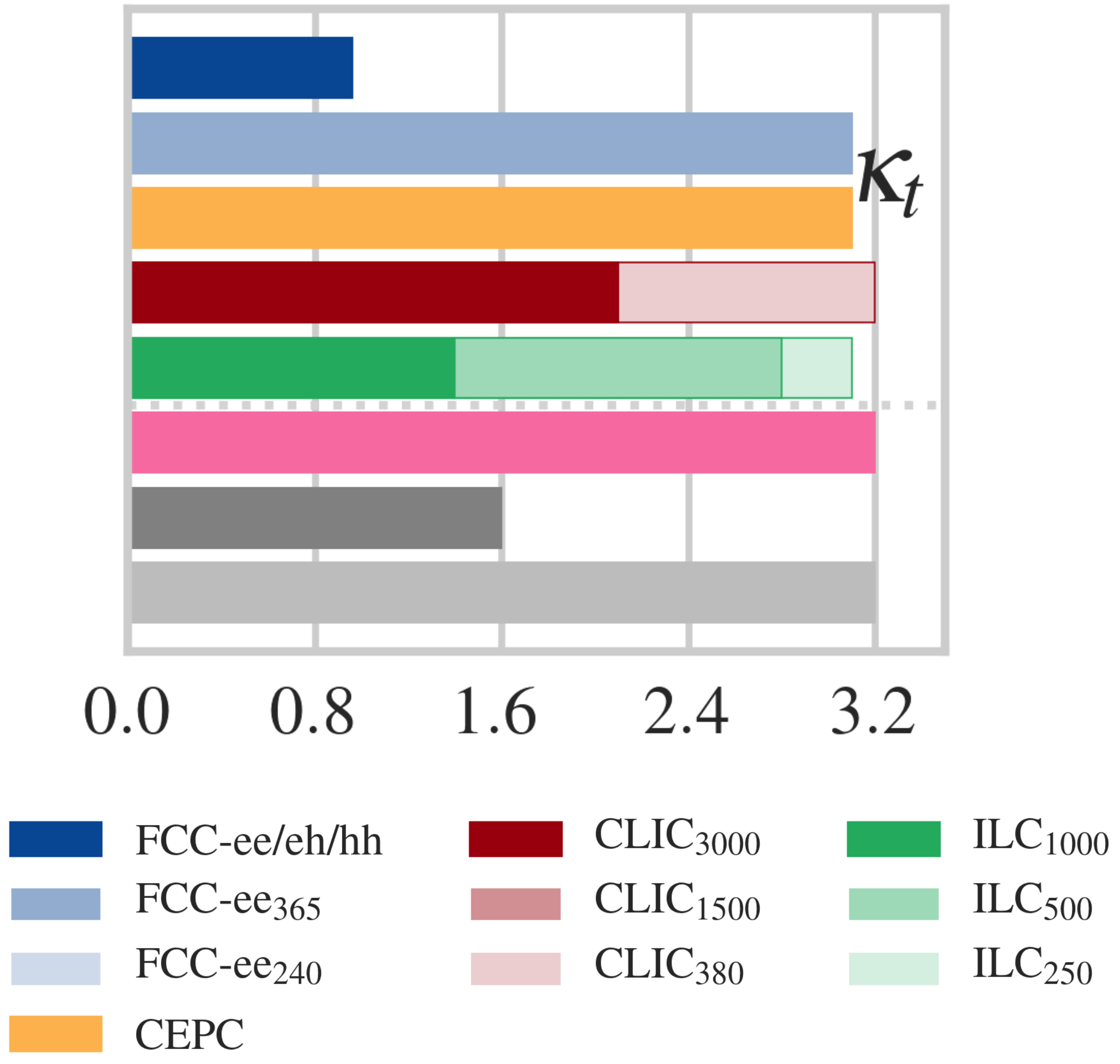
TOP PHYSICS AT FCC-ee

- Threshold region allows most precise measurements of top mass, width, and estimate of Yukawa coupling. Scan strategy can be optimized
  - FCC-ee has some standalone sensitivity to the top Yukawa coupling from the measurements at thresholds for a 10% precision (profiting of the better αS).
    - But, HL-LHC result of about 3.1% already better (with FCC-ee Higgs measurements removing the model dependence)





Mass only: 8.8 MeV (stat), 5.4 MeV (αs [2 x 10-4]),   44 MeV (theo)



- **Run at 365 GeV used also for measurements of top EWK couplings (at the level of 10^{-2}-10^{-3}) and FCNC in the top sector.**

Flavor physics potential

- Enormous statistics 10^{12} bb, cc
- Clean environment, favourable kinematics (boost)
- Small beam pipe radius (vertexing)

1. Flavour EWPOs (R_b, $A_{FB}^{b,c}$) : large improvements wrt LEP
2. CKM matrix, CP violation in neutral B mesons
3. Flavour anomalies in, e.g., b → sττ

Working point	Lumi. / IP [10^{34} cm^{-2}.s^{-1}]	Total lumi. (2 IPs)	Run time	Physics goal
Z first phase	100	26 ab^{-1} /year	2	
Z second phase	200	52 ab^{-1} /year	2	150 ab^{-1}

Particle production (10^9)	B^0	B^-	B_s^0	Λ_b	$c\bar{c}$	$\tau^-\tau^+$
Belle II	27.5	27.5	n/a	n/a	65	45
FCC-*ee*	400	400	100	100	800	220

~15 times Belle's stat

Boost at the Z!

Decay mode	$B^0 \to K^*(892)e^+e^-$	$B^0 \to K^*(892)\tau^+\tau^-$	$B_s(B^0) \to \mu^+\mu^-$
Belle II	~ 2 000	~ 10	n/a (5)
LHCb Run I	150	-	~ 15 (–)
LHCb Upgrade	~ 5000	-	~ 500 (50)
FCC-ee	~ 200000	~ 1000	~1000 (100)

Yelds for flavor anomalies studies:

b→sll yelds and $B^0 \to K^{*0}\tau^+\tau^-$ 👍

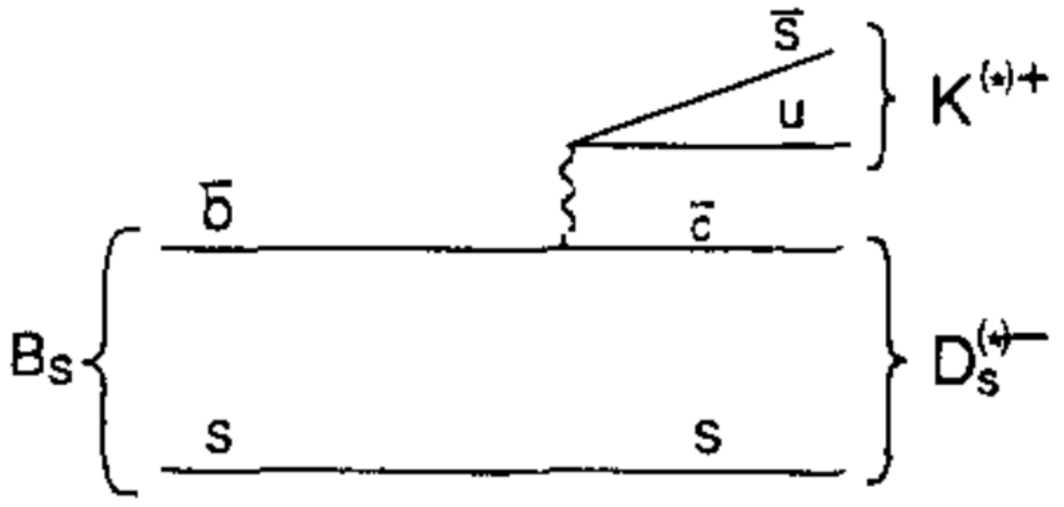
Full reconstruction possible

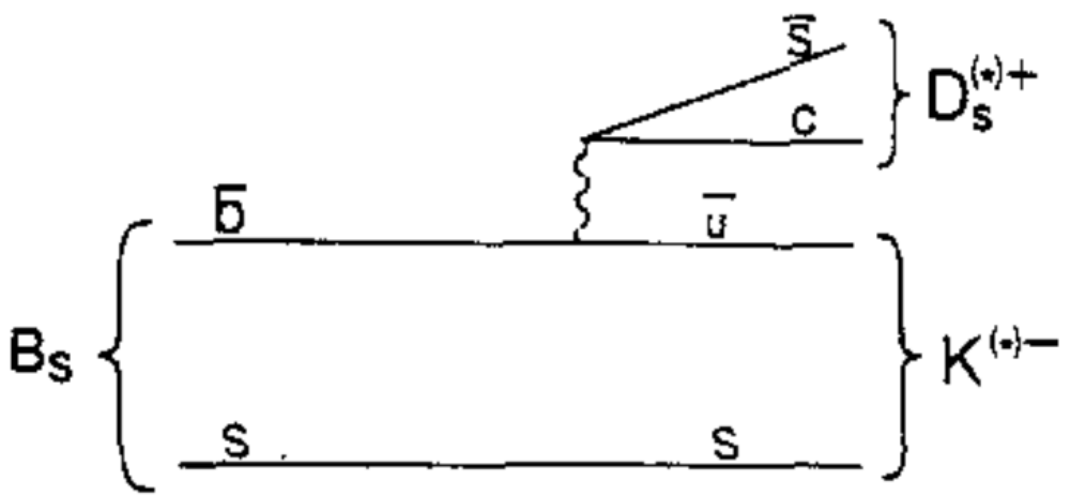
THE ANALYSIS

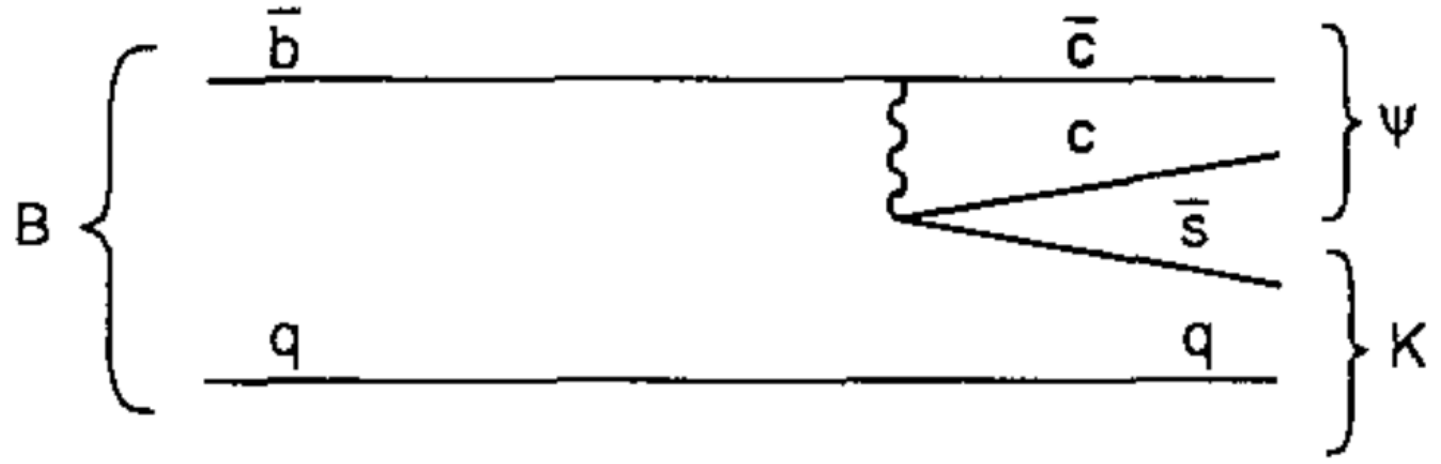
Study the decays:

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

with the final objective (for the *fast-sim*) to estimate $\varphi = \gamma_{CKM} + \gamma_{ds} - 2\beta_s$ and $2\beta_s$







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…

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

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

To be tested against a very precise SM prediction

2021 PLAN

Familiarise with the software k4SimDelphes

Reproduce and develop the many results already presented in the meetings

Simulate the signal decay chain and produce the necessary datasets

Perform a preliminary analysis on the *fast-sim* to understand the behaviour of the two channels

FCC-ee at the intensity frontier

- TeraZ offers four additional pillars to the FCC-ee physics programme

Flavour physics programme

- Enormous statistics 10^{12} bb, cc
- Clean environment, favourable kinematics (boost)
- Small beam pipe radius (vertexing)

1. Flavour EWPOs (R_b, $A_{FB}^{b,c}$) : large improvements wrt LEP
2. CKM matrix, CP violation in neutral B mesons
3. Flavour anomalies in, e.g., $b \to s\tau\tau$

QCD programme

- Enormous statistics with $Z \to \ell\ell$, qq(g)
- Complemented by 100,000 $H \to gg$

1. $\alpha_S(m_Z)$ with per-mil accuracy
2. Quark and gluon fragmentation studies
3. Clean non-perturbative QCD studies

Often statistics-limited
$5. 10^{12}$ Z is a minimum

Tau physics programme

- Enormous statistics: 1.7 10^{11} $\tau\tau$ events
- Clean environment, boost, vertexing
- Much improved measurement of mass, lifetime, BR's

1. τ-based EWPOs (R_τ, A_{FB}^{pol}, P_τ)
2. Lepton universality violation tests
3. PMNS matrix unitarity
4. Light-heavy neutrino mixing

Rare/BSM processes, e.g. Feebly Coupled Particles

Intensity frontier offers the opportunity to directly observe new feebly interacting particles below m_Z

- Signature: long lifetimes (LLP's)
- Other ultra-rare Z (and W) decays

1. Axion-like particles
2. Dark photons
3. Heavy Neutral Leptons

FCC-ee at the intensity frontier

- … which in turn provide specific detector requirements

Flavour physics programme

- Formidable vertexing ability; b, c, s tagging
- Superb electromagnetic energy resolution
- Hadron identification covering the momentum range expected at the Z resonance

QCD + EW programme

- Particle-Flow reconstruction
- Lepton and jet angular and energy resolution ; Lepton ID

More case studies will lead to more detector requirements

Tau physics programme

- Momentum resolution
  Mass measurement, LFV search
- Precise knowledge of vertex detector dimensions
  Lifetime measurement
- Tracker and ECAL granularity and e/μ/π separation
  BR measurements, EWPOs, spectral functions

Rare/BSM processes, e.g. Feebly Coupled Particles

- Sensitivity to far-detached vertices (mm → m)
  1. Tracking: more layers, continuous tracking
  2. Calorimetry: granularity, tracking capability
- Larger decay lengths ⇒ extended detector volume
- Full acceptance ⇒ Detector hermeticity

If all these constraints are met, Higgs and top programme probably OK (tbc)

Case Studies

- >>>"Case Studies": reverse engineering of a chosen benchmark process. The elements contributing to the final results are "unpacked" to allow maximal optimisation on all aspects.

- extract detector requirements to achieve desired performance
- develop a detector simulation that allows this performance to be merged in the full analysis
- develop reconstruction algorithms that fully exploit the detector information
- develop calibration strategies and analysis techniques to shrink the uncertainties as needed
- Extract requirements on event generation and simulation of machine effects to ensure realistic predictions

Status of analysis efforts that were reported to PP meetings

Summarized in the next slides, color-coding :

Work on-going with the common tools	Work on-going with private tools or stand-alone Delphes	Recent pheno work	Not started, but people expressed interest	

with some "shading" too

"Common tools" means :

- Delphes simulation samples within EDM4HEP,
- FCCAnalysis framework
  - the latter benefits from stand-alone developments or devels within Delphes (e.g. vertex fitter, soon PID modules)

In most cases, 1 group = 1-2 people, part-time.

Higgs measurements

Measurement	Constraining	Person-power
Higgs boson coupling to c quark	Flavour tagging, vertexing	CERN Also interest from APC
σ(ZH) and mH, Z →leptons (Mrecoil); New scalars in Z + S	Lepton momentum & energy resolution	APC / Bologna / MIT (CERN); Good candidate to move to FullSim "soon".
σ(ZH) and mH, Z → hadrons ; BR(Higgs invisible)	hadronic mass and hadronic recoil-mass resolution ; Maybe b-tagging	MPI Munich
Γ(H) in ZH, H → ZZ*	Lepton ID efficiencies; jet clustering algorithms, jet directions, kinematic fits	CERN fellow expressed interest
Higgs boson mass in hadronic final states	b-tagging eff and purity, jet angular resolution, jet reco, kin fits	

Higgs measurements (2)

Measurement	Constraining	Person-power
Γ(H) with bbnunu events	Visible and missing mass resolutions	
HZγ coupling	photon identification, energy and angular scale	
ee->H production in s-channel at Higgs pole	- q / g tagging	CERN (former analysis exists)

EW measurements at the Z peak

Measurement	Constraining	Person-power
Total width of the Z	Track momentum (and angular) resolution, scale (magnetic field) stability	CERN [but fellow left] Good candidate to move to FullSim "soon".
Rb, Rc, AFB of heavy quarks	Flavour tagging, acceptance, QCD corrections	QCD corr. studied at CIEMAT ; Udine
alphaS measurement	Z -> jets	LPNHE [report soon]
Ratio Rl	Geometrical acceptance for lepton pairs	
AFB (muons)	QED corrections	
Luminosity from diphoton events ; NP in diphotons	e/gamma separation, gamma acceptance	CIEMAT (NP, pheno)

EW measurements at WW

Measurement	Constraining	Person-power
Coupling of Z to nu_e (also, at the Z peak: invisible ALP, dark γ)	Photon energy resolution, acceptance, track efficiency	Saclay Udine
MW from WW -> had, semi-lep	Lepton and jet angles, Kinem fits	Saclay [2019]
(d)σ(WW) for MW, TGCs	Lepton ID, angular resolutions	LAPP
Vcb via W -> cb	Flavour tagging	Pisa + interest from postdoc?
W leptonic BRs	Lepton ID, acceptance	
Meas of $\sqrt{s}$ via radiative return	lepton and jet angular resolutions, acceptance	

Tau physics

Case studies

- The measurement of the tau lifetime: accuracy of the construction and the alignment of the vertex detector
- The measurement of the tau mass: track momentum scale (in a multi-track collimated environment)
- The measurement of the tau leptonic branching fractions: electron and muon identification
- Tau polarisation and exclusive branching fractions: reconstruction of photons, π0s and other neutral particles, K/π separation
- Lepton Flavor violation in Z and tau decays: lepton momentum scale

- Delphes samples of limited use for (several of) these studies
- Goal of separation of tau decay modes has triggered FullSim studies:
  - Clustering devels in FCCSW with the LAr [NBI]
  - NN-based tauID in the IDEA calo [Roma]

Flavour physics

Measurement	Constraining	Person-power
Bs to Ds K	Many things.. Vertexing, PID, EM resolution	Saclay / Ferrara (CERN)
Bc -> tau nu	Flight distance resolution (vertexing)	EPFL / CERN / Orsay
B -> K* tau tau	Flight distance resolution (vertexing)	Former work at Clermont
Modes with pi0's	EM resolution	

Top physics

Measurement	Needs good:	Person-power
EW couplings of the top	Jet reco, b-tagging, kine fits	NBI
Top properties from threshold scan	Jet reco, b-tagging, kine fits	Strasbourg/Padova
FCNC couplings	Idem + photon reco	Tehran/Behshahr

ALPs / LLPs / Heavy Neutrinos

- “Informal group” regular meetings involving both theorists and experimentalists. Focus:
  - defining model benchmarks
  - better defining case studies to perform: they include both characterization of signals and detector requirements
  - first pass at having analysis code in place for validation of MC signals in Delphes
  - need to develop specific tools to use Delphes in this context. Will profit largely of FullSim tracking in EDM4Hep
- Informal group mailing list ~50 names (including Uppsala, Graz, Geneva, Bologna, PD, CERN...)

Area with documentation in the Physics Performance Github collecting documentation and other info
https://hep-fcc.github.io/FCCeePhysicsPerformance/case-studies/BSM/LLP/

HNLs	- displaced vertices - specific tracking	Uppsala/Graz/Geneva
ee → $a\gamma \rightarrow 3\gamma$	- Photon resolution - separation of close-by photons - displaced γ vertices	Pavia FullSim needed…
$\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$	Photon resolution	CERN / Rio