



Targets, milestones and progress of Physics Performance

FCC Week - 28/06/2021

P. Azzi (INFN-PD/CERN), E. Perez(CERN)

- ❖ Physics Performance (Ppe) WP is the forum where the following aspects come together:
 - ❖ Prioritizing the most significant benchmark measurements
 - ❖ Developing the software tools for the simulation of detector concepts and event reconstruction
 - ❖ Extracting the detector requirements
 - ❖ Exploring the performance of innovative ideas for detector design
 - ❖ Feed back tools to the Physics Programme to explore sensitivities to new processes

All these can only happen in tight coordination with the Physics Programme, the Software and the Detector Concepts WP areas and activities

>>> **“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

The FCC Physics Performance Coordination Mandate

- ❖ **Deliver, document and maintain** a prioritised list of FCC-ee physics benchmark measurement.
 - ❖ Focusing on ultimate statistics uncertainties and limiting systematics
- ❖ For each benchmark **propose one (or more) “case studies”** aimed at delivering how to control and/or minimize the systematic uncertainties.
 - ❖ Initial focus on tool development (with input also from other lepton or hadron colliders) in collaboration with Software and Detector Concept groups
- ❖ **Gather** a growing team of developers and “case study” contacts, to build a worldwide consortium of scientific contributors to the FCC-ee science project
- ❖ **Deliver** a first complete example of a case study by Spring 2021
- ❖ **Document** in a user-friendly way the tools for other “case studies”, publish results, and present at conferences

MILESTONE

- ❖ For each “case study” we can define several clear milestones to assess its maturity:
 - ❖ Analysis Code documented and available in our central GitHub repositories
 - ❖ New software tools that might be of general use validated, document and available to work in key4hep/edm4hep
 - ❖ A few-authors publication containing:
 - ❖ Expression of the final results as function of algorithm performance, calibration or detector performance, etc...
 - ❖ Evaluation of major systematics and suggestion of methods to improve them with data
 - ❖ First results with FastSimulation, FullSim later on

Physics Performance Coordination Organization

- * Several « case studies » have already been picked up:
 - * Documentation: <https://hep-fcc.github.io/FCCeePhysicsPerformance/>
 - * Few more mature studies during **“PED Tuesday afternoon session @16:00”**
- * The work has already started, even if the overall input of detector description and software simulation and tools is in its developing phase as well.
- * Hence, more mature tools will be exploited once they become available. For instance:
 - * we'll start with Delphes Fast Simulation, developing new features (track covariance matrix, vertices, PID) that can already help out make progress on several higher level algorithms
 - * They can then be ported to FullSim
 - * the edm4hep data model used as a reference to develop reconstruction code in a coherent manner for different detector simulation inside the FCCSW framework
 - * FCCAnalysis/dataframe approach to provide common utilities to simplify analysis development

- ❖ Color coding for next slides (and some shading):

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
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- ❖ “Common tools” means :

- ❖ Delphes simulation samples within EDM4HEP centrally generated (and documented)
 - ❖ Common samples here: <https://bit.ly/35Lgft5>
- ❖ FCCAnalysis framework
 - ❖ the latter benefits from stand-alone developments (as addition to dataframe tools) or developments within Delphes (e.g. vertex fitter, PID...)
- ❖ *Note that “green/blue” does not mean “fully covered” as in general the main analyser is a student and might not be able to bring analysis to completion! Several groups on a single topic are advisable.*

Higgs measurements

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

Higgs measurements

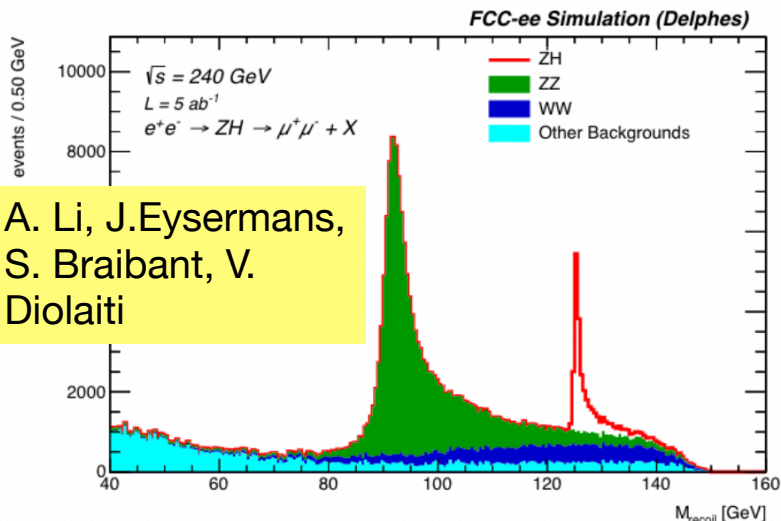
Measurement	Constraining	Person-power
H See “bcc, tagging and Hcc coupling” presentation by M. Selvaggi on Tue		
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<p>$\sigma(ZH)$ and mH, $Z \rightarrow$ leptons (Mrecoil); New scalars in $Z + S$</p>	<p>Lepton momentum & energy resolution</p>	<p>APC / Bologna / MIT (CERN) Good candidate</p>
<p>B See “HZ mass and cross section...” presentation by Jan Eysermans on Tue</p>		
<p>$\sigma(ZH)$ and mH, $Z \rightarrow$ leptons (Mrecoil); New scalars in $Z + S$</p>	<p>Lepton momentum & energy resolution; Maybe b-tagging</p>	<p>APC / Bologna / MIT (CERN) Good candidate</p>
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Measurement	Constraining	Person-power
$\Gamma(H)$ with $bb\nu\nu$ events	Visible and missing mass resolutions	
$HZ\gamma$ coupling	photon identification, energy and angular scale	
$ee \rightarrow H$ production in s-channel at Higgs pole	- q / g tagging	CERN (former analysis exists & being revamped)

- ✦ Precise mass motivation, with $O(10\text{MeV})$ already matches the statistical precision on the Higgs, BR, but to constrain or measure electron Yukawa, would need better than the Higgs width ($<4.1\text{MeV}$).
- ✦ This is an ambitious goal that poses challenges and constraints on the measurement with the ZH events:
 - ✦ accelerator operation: ZH threshold scan, control of centre-of-mass energy measurement (at different \sqrt{s})
 - ✦ detector design: lepton momentum resolution, hadronic final state reconstruction performance
 - ✦ analysis techniques: efficiency and purity optimisation with modern tools, constrained kinematic fits, categorisation of systematic uncertainties
- ✦ Preliminary recoil method determination using $Z \rightarrow \mu\mu$ decays shows $\Delta m(H) \sim \text{few MeV}$ with systematics effects from:
 - ✦ Beam energy spread, Lepton and jet angular resolution, acceptance, Momentum scale and its stability (as seen before at the Z)
- ✦ Exploring other channels with hadronic decays of the Z and H will add statistics, but challenge also the performance for reconstruction of jets and kinematical fitting



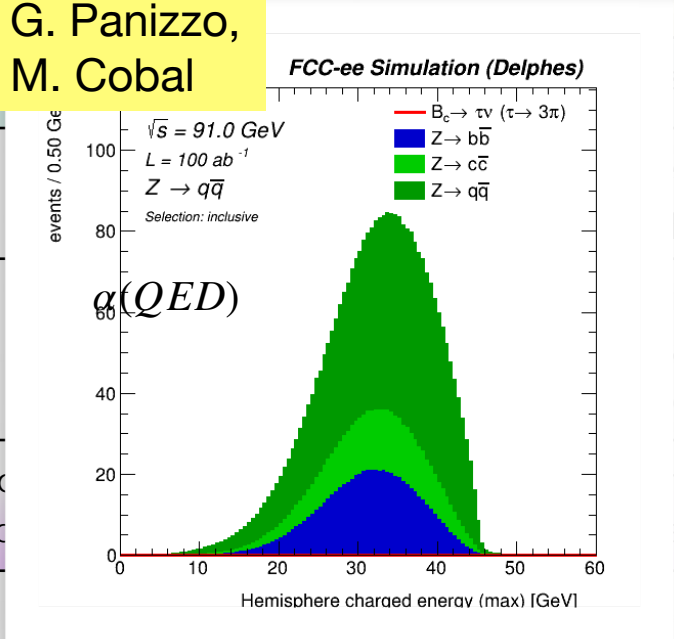
A. Li, J.Eysermans,
 S. Braibant, V.
 Diolaiti

- Analysis in progress with latest software tools
- Considering potential improvements (B field from 2T->3T)
- Extracting requirements on detector design (i.e. comparing different tracker material)
- Exploring latest generators for signal and background processes and modelling of the interaction

Measurement	Constraining	Person-power
Total width of the Z (<i>see next slide</i>)	Track momentum (and angular) resolution, scale (magnetic field) stability	CERN [but fellow left] Good candidate to move to FullSim "soon".
R _b , R _c , AFB of heavy quarks	Flavour tagging, acceptance, QCD corrections	QCD corr. studied at CIEMAT ; Univ. of Udine
alpha _S measurement	Z -> jets	LPNHE [report soon]
Ratio R _l	Geometrical acceptance for lepton pairs	
AFB (muons) and $\alpha(QED)$	EW corrections and control of IFI (initial-final state radiation interference)	
Luminosity from diphoton events ; NP in diphotons	e/gamma separation, gamma acceptance	CIEMAT (NP, pheno)

Measurement	Constraining	Person-power
Total width of the Z (<i>see next slide</i>)	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 ; Univ. of Udine
alphaS meas		LPNHE [report soon]
Ratio Rl	trical acceptance for pairs	
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Luminosity from NP in diphoton	na separation ance	

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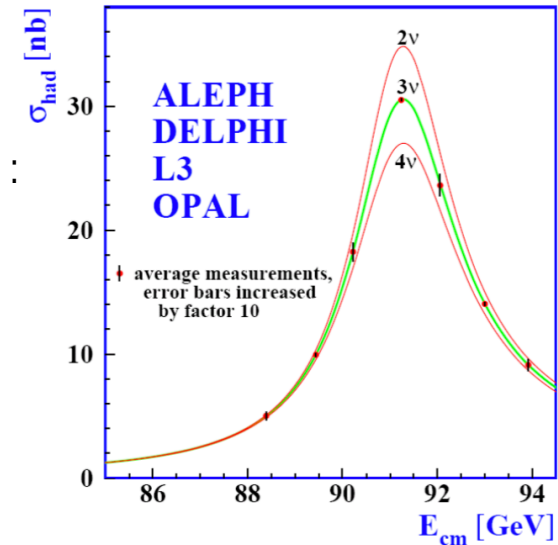
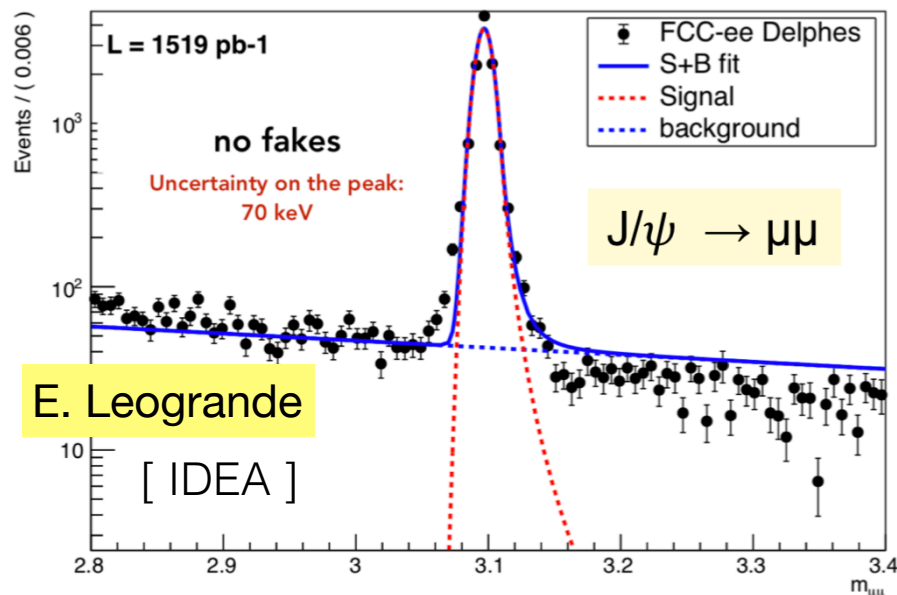
AFB(bb) analysis started on centrally produced samples.

Example : Determination of the Z width

Key = Relative uncertainty of \sqrt{s} between the different energy points of the lineshape scan.

Can be controlled via the direct measurement of $M_{\mu\mu}$ in di-muon events : compare the peak positions at the different \sqrt{s} points.

- $\sigma(M_{\mu\mu})$: statistical potential to control relative $\delta(\sqrt{s})$ to $O(40 \text{ keV})$
- Requires the stability of the momentum scale, esp. of B, to that level, i.e. $40 \text{ keV} / 90 \text{ GeV} < 10^{-6}$



In-situ, using the large statistics of well-known resonances, e.g. $J/\psi \rightarrow \mu\mu$

First studies: Target seems within reach with an IDEA-like resolution.

- post-doc left, but code available!
- **candidate analysis to move asap to FullSim tracks !**

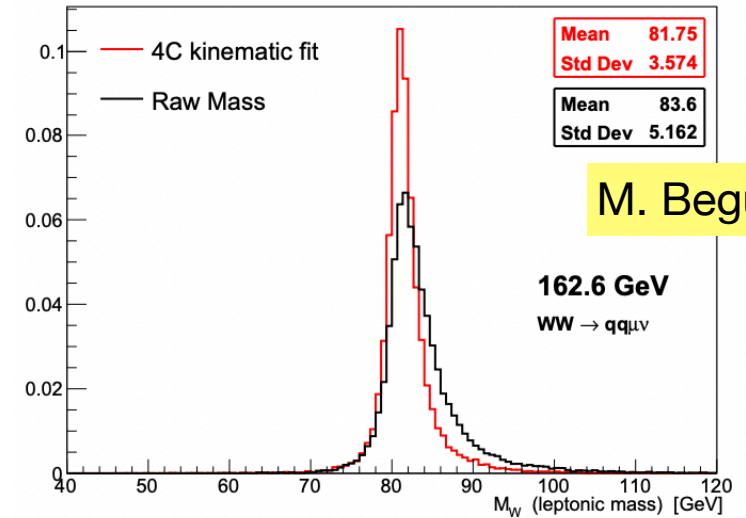
Measurement	Constraining	Person-power
Coupling of Z to ν_e (also, at the Z peak: invisible ALP, dark γ)	Photon energy resolution, acceptance, track efficiency	Saclay Udine [2020]
M_W from WW \rightarrow had, semi-lep	Lepton and jet angles, Kinem fits	Saclay [2019]
$(d)\sigma(WW)$ for M_W, TGCs	Lepton ID, angular resolutions	LAPP, Pisa
Vcb via W \rightarrow 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	

- ❖ Precise $M(W)$ from threshold run $\sim 400\text{keV}$ (stat)
- ❖ $M(W)$ direct reconstruction from decay products useful at other \sqrt{s} .
- ❖ Competitive as statistical uncertainty but different challenges to be considered:
 - ❖ Event reconstruction, choice of jet algorithms
 - ❖ Lepton momentum scale and resolution
 - ❖ Kinematical fitting

Definition of W mass estimators and study and optimisation of:

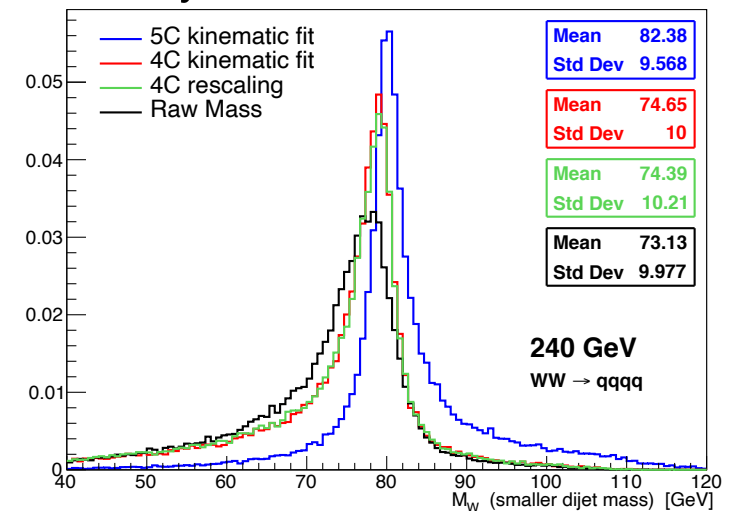
- ❖ Statistical and systematic uncertainties with templates fit
- ❖ W hadronic decay modelling systematics
- ❖ Exploiting also ZZ and $Z\gamma$ events for constraints and calibration
- ❖ Thesis of M. Beguin available as starting point

Semi-leptonic channel



M. Beguin

Fully hadronic channel



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	

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Bs to Ds K	Many things.. Vertexing, PID, EM resolution	Saclay / Ferrara (CERN)
Bc -> tau nu	<div style="border: 2px solid black; background-color: #00aaff; color: black; padding: 5px; display: inline-block;"> See Donal Hill's talk on Tue@16:00 </div>	
B -> K* tau tau	Flight distance resolution (vertexing)	Former work at Clermont
Modes with pi0's	EM resolution	

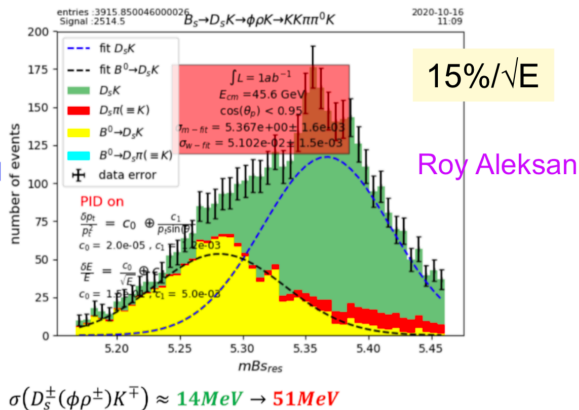
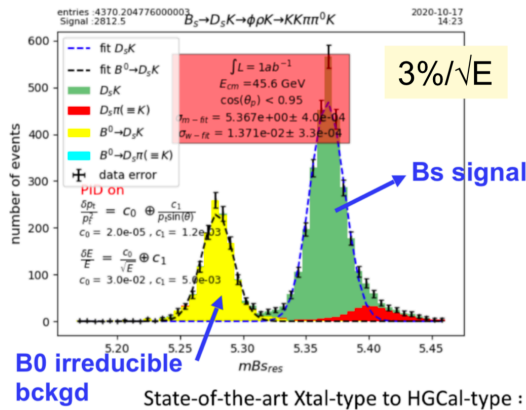
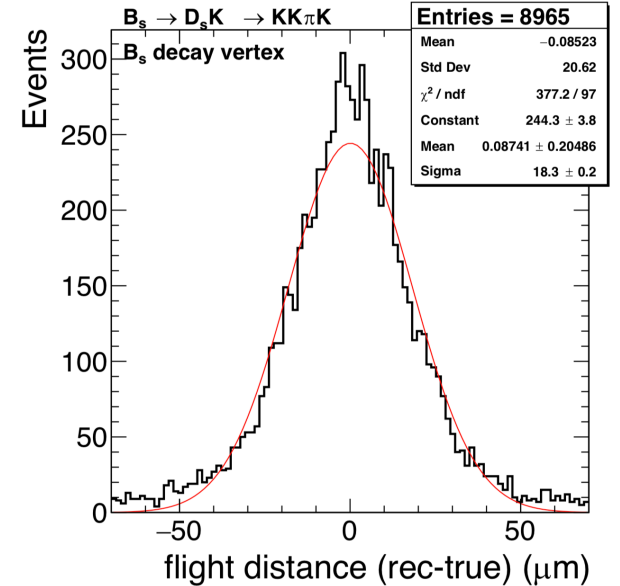
Excellent benchmark for several detector requirements !

- **Precise reconstruction of displaced vertices**

- Esp. for CP violation measurements
- Vertexing tools implemented within FCCAnalyses

- **Excellent EM resolution**

- Mandatory to see the signal in modes with neutrals !



State-of-the-art Xtal-type to HGCal-type : $\sigma(D_s^\pm(\phi\rho^\pm)K^\mp) \approx 14\text{MeV} \rightarrow 51\text{MeV}$

Good starting points exist. Need to put all bricks together in the common framework.

- **Good π / K separation**

- PID tools recently implemented in Delphes - see talk M. Selvaggi tomorrow

Measurement	Constraining	Person-power
Tau Lifetime	Construction and alignment of vertex detector	
Tau mass	Track momentum scale (in multi-track collimated environment)	
Tau leptonic BR	Electron and muon ID	
Tau polarisation and exclusive BR	Photon, Pi^0 , neutrals, K/pi separation	Milano/Rome
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 developments in FCCSW with the LAr [NBI]
 - ✦ NN-based tau-ID in the IDEA calo [Roma]

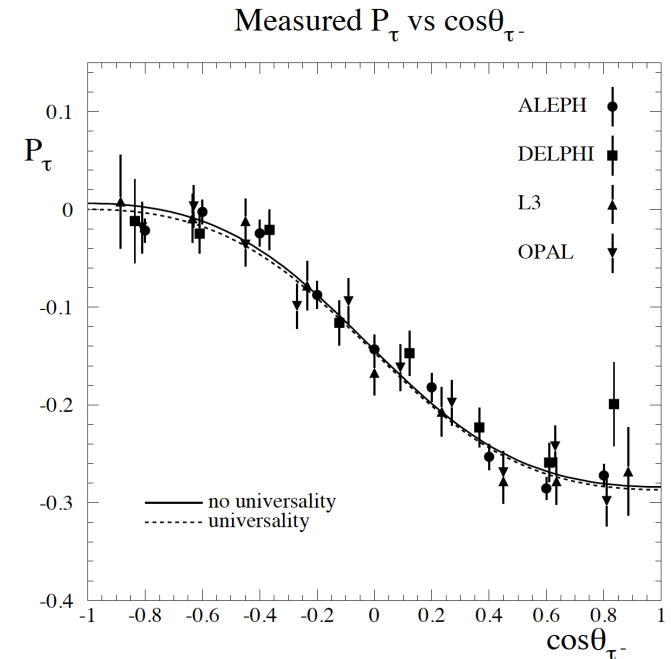
* Tau polarisation has a central role at the FCC-ee: crucial ingredient for $A_e, \sin^2\theta_{eff}$ at a circular collider

* Desired precision of few $\times 10^{-6}$ on $\sin^2\theta_{eff}$, similar to that from $A_{FB}^{\mu\mu}$ but model independent

* Very large tau statistics ($\approx 1.5 \times 10^{11}$): not only use leptonic decays, but extend to hadronic decays!

* For instance use best decay channels such as $\tau \rightarrow \rho\nu_\tau$

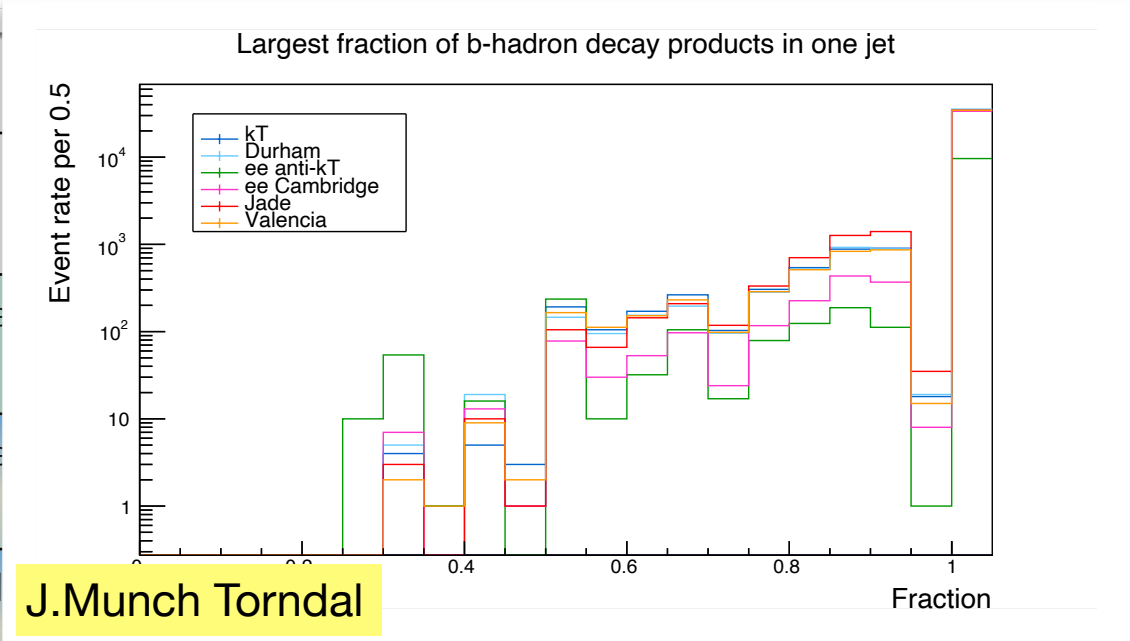
$$P_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau(1 + \cos^2\theta) + \mathcal{A}_e(2\cos\theta)}{(1 + \cos^2\theta) + \frac{4}{3}\mathcal{A}_{fb}(2\cos\theta)}$$



Excellent benchmark for detector performance in π^0/γ separation

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

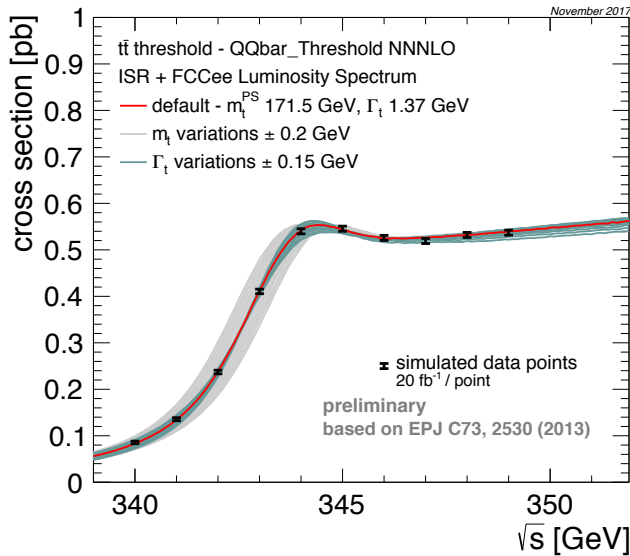
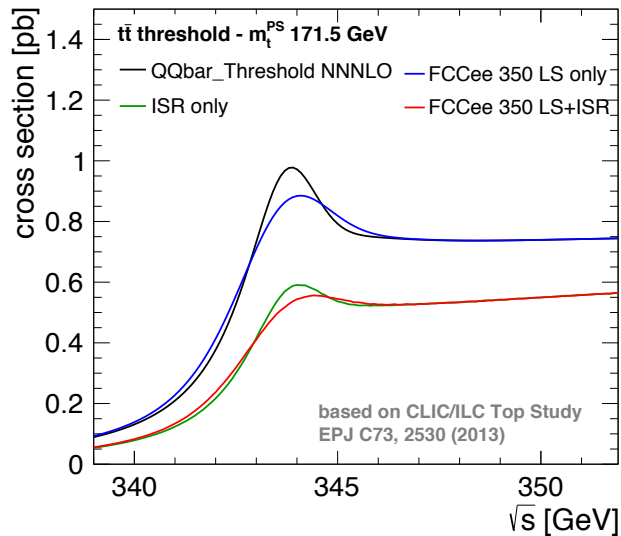
Measurement	
EW couplings of the top	Je
Top properties from threshold scan	Je
FCNC couplings	Id



EWK Coupling of the top:

- Study of different jet clustering algorithm in top l+jets events
- Development of code to rerun jet clustering after Delphes
- Addition of parameterised B-tagging in FCCAnalysis
- Reoptimization of event selection
- Development of fitting code in progress

- ❖ **Most precise top mass measurement method with specific threshold scan of 100fb^{-1}**
- ❖ Theory available at NNNLO/NNLO+NNLL: $\Delta m/m \approx 40\text{MeV}$ from scale. Generators description of the threshold region important
- ❖ No need for kinematic fit, counting experiment: optimisation of threshold scan strategy important
- ❖ **Needs excellent control of beam energy, beam energy spread, luminosity spectrum ($\Delta m/m \approx 3\text{MeV}$) and ISR** : generator description to study effects
- ❖ **Needs excellent b-tagging, jet algorithm reconstruction**: systematics effects from selection to be studied
 - ❖ If α_S from TeraZ $\Delta m/m \approx 5\text{MeV}$ (30MeV for parametric uncertainty if current value)



For differential studies at threshold will need direct top reconstruction and fitting: control combinatorial effects, association, etc...

HNL	<ul style="list-style-type: none"> - displaced vertices - specific tracking 	Uppsala/Graz/Geneva
ALPS: $ee \rightarrow a\gamma \rightarrow 3\gamma$	<ul style="list-style-type: none"> - Photon resolution - separation of close-by photons - displaced γ vertices 	Pavia FullSim needed...
ALPS: $\gamma\gamma \rightarrow \gamma \rightarrow \gamma\gamma$	Photon resolution	CERN / Rio
Dark Photons $ee \rightarrow \gamma\bar{\gamma}$	Photon resolution	Udine [2020] https://arxiv.org/abs/2006.15945

HNL

Area with documentation & initial code in the PhysicsPerformance Github:
<https://hep-fcc.github.io/FCCeePhysicsPerformance/case-studies/BSM/LLP/>

ALPS: ee

>> **Talk by Rebeca on Wednesday @11.00**

R. Sengupta, R. Gonzalez-Suarez, S. Kulkarni

ALPS: $\gamma\gamma \rightarrow \gamma \rightarrow \gamma\gamma$

Photon resolution

CERN / Rio

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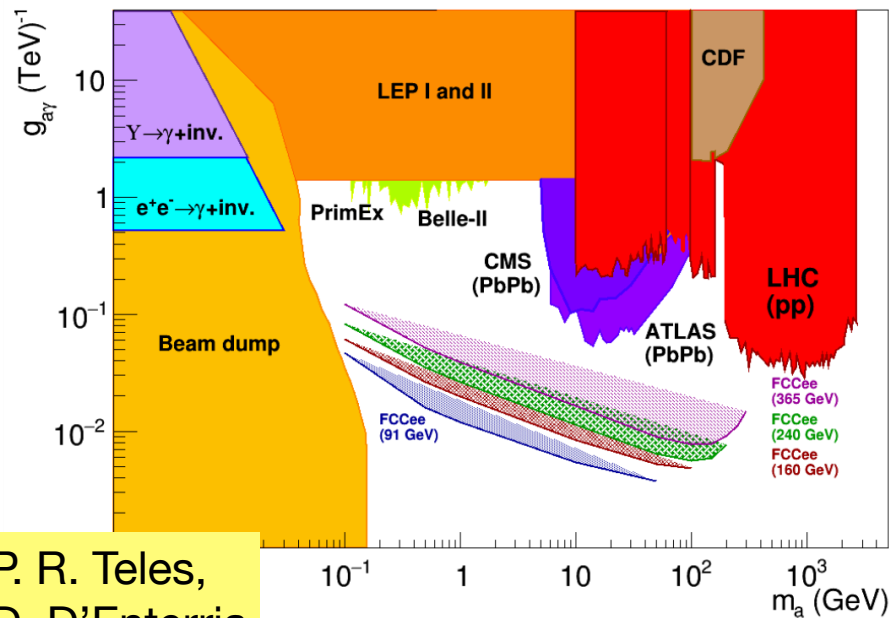
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Photon resolution

CERN / Rio

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P. R. Teles,
D. D'Enterria

Parton level sensitivities extracted on light-by-light production of ALPS. Results with IDEA Delphes card in progress

- ❖ Because it is a forum where all the different aspects come together:
 - ❖ your group is interested in a specific detector technology and your student can have a physics study connected to it
 - ❖ you have/are a student that wants to explore some future physics studies while working at an LHC experiment
 - ❖ you are interested in taking the challenge of pushing the limits of detector and analysis performance, trying new technologies & new algorithms
 - ❖ you just have a new idea!
- ❖ Follow reports of the ongoing work in PPC during:
 - ❖ *Session Physics, Experiment&Detector Tuesday at 16:00*

- A. **PID:** implement the PID algorithms now in Delphes (from F. Bedeschi) into FCCAnalyses
- B. **Vertexing:** starting with the vertex fitter that is implemented, write a vertex finder, that determines the primary vertex as well as detached ones
- C. **b-tagging:** implement simple algorithms - not as powerful as the ParticleNet (or other ML ones) but several algorithms are useful to cross-calibrate the efficiencies.
 - Also useful to be employed in simpler selections or sensitivity studies while the more complex algorithms need specific training and tuning

All these small projects can be easily integrated as part of an analysis of course, while producing a results that can be useful for many!

- ❖ « case studies » have generated a very nice momentum!
 - ❖ the FCCAnalysis model has proven to be easy to use and it allows a collaborative modus operandi that speeds up work
- ❖ The start of the Physics Programme activities will nicely merge and complement ongoing work
 - ❖ through the proposal of new benchmarks to extend the physics potential exploration using the tools developed within PPC
- ❖ The start of the Detector Concept Coordination area will help speed up the development of FullSimulation response to explore new design and technologies
 - ❖ A nice feedback from “case studies” result will inform and guide detector designs

**This year has been quite intense and has brought much progress in the development of the first “case studies”.
This is just the beginning!**