A_{FB}^{b} at FCC-ee & ALICE ITS3 Phase-II Upgrade

Activities in Trieste and Udine

Marta Urioni[1,2], *Leonardo Toffolin*[1,3,4]
[1] University of Trieste
[2] INFN Trieste & [3] INFN Trieste, Gruppo Collegato di Udine
[4] ICTP

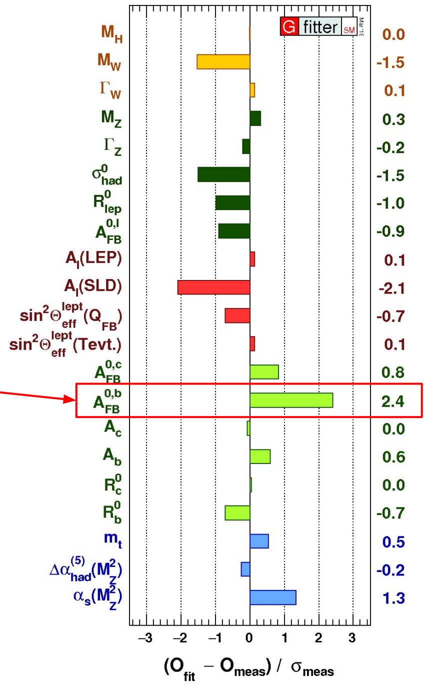
3rd July 2024
First ECFA-INFN Early Career Researchers Meeting
Laboratori Nazionali di Frascati
https://agenda.infn.it/event/42205/

A_{FB}^{b} at FCC-ee: introduction

- **A_{FB}^{b} in $e^+e^- \to Z \to b\bar{b}$ events**:

$$A_{FB}^{b} \equiv \frac{N_F - N_B}{N_F + N_B} \quad \text{with} \quad N_F = \int_0^1 \frac{d\sigma}{d\cos\theta} d\cos\theta \qquad N_B = \int_{-1}^0 \frac{d\sigma}{d\cos\theta} d\cos\theta$$

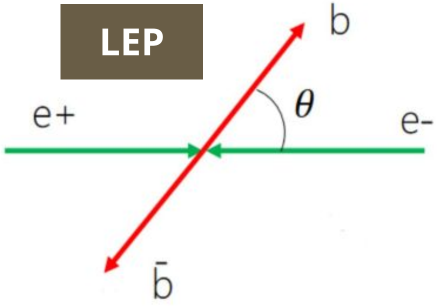
→ **>2σ deviation** with respect to global EW fits → still unsolved since ~25 years



θ_b distribution (at LO)

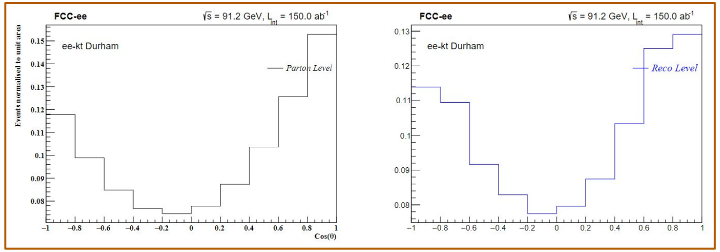
$$\frac{d\sigma_{b\bar{b}}}{d\cos\theta_b} = \sigma_{b\bar{b}} \frac{3}{8}\left(1 + \cos^2\theta_b + \frac{8}{3} A_{\rm FB}^{b} \cos\theta_b\right)$$

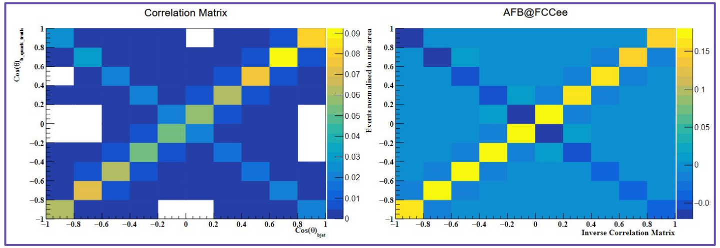
- **Measurement**:
  - A^{b}_{FB} extracted from ***cosθ(b)*** distribution
  - experimental distinction between b and $\bar{b}$ needed
    ⇒ quark **charge** determination crucial
    - via "**jet charge**" (e.g. weighted sum of charged tracks in jet, or vertex charge of MVA tagger)
    - with **soft-lepton-tagging**
    - using **machine-learning** techniques to combine all infos



Results on the A_{FB}^{b} feasibility study

- Event generation and selection:
  - beam energy: 45.5348 GeV (*Z*-pole) from **"Spring2021"**
  - signal: **2 *b*-tagged jets**
    - 1 jet with charge > 0
    - 1 jet with charge < 0
- Building **truth-level and reco-level *cosθ* distributions** for *b*-quarks and *b*-quark-jets
- **Response matrix** and efficiency correction vector built from $1 \cdot 10^6$ events
  - re-scaling the event number to match expected luminosity at *Z*-pole: $L_{Z\text{-pole}} = 140\ \text{ab}^{-1}$
- **Unfolding with simple matrix inversion**, 10x10 matrix used
- **Statistical uncertainty** extracted from pseudo-experiments
- Different sources of systematic uncertainty investigated:
  - modelling of **heavy-quark fragmentation**
  - emission of **final-state QCD radiation**
  - **Pythia** versus **Dire** parton shower
  - *b*-tagging and *c*-mistagging rates





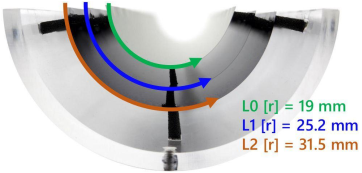
more details in the technical note (also on INSPIRE)

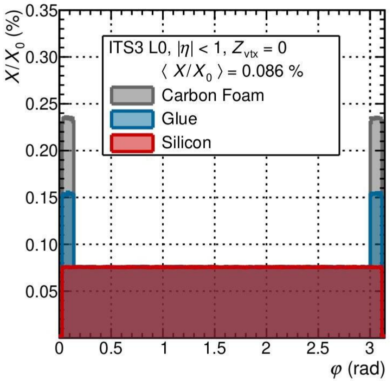
systematic uncertainty strongly dominating

$$A_{FB}^{b} = 0.091170 \pm 0.004907\,(syst) \pm 0.00001\,(stat)$$

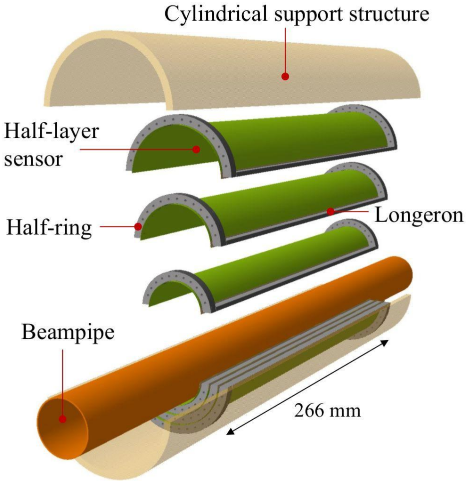
Trieste: R&D for ALICE ITS3 (& ALICE 3 Tracker)

- **ITS3: 3 layers of curved, ≤ 50 μm thick, wafer-scale MAPS in TPSCo 65 nm CMOS process**
  - Replacing ITS2 Inner Barrel (innermost radius reduced from 24 mm to **19 mm**)
  - Each half-layer made of one wafer-size **flexible sensor**
  - **In-silicon** data transmission and power distribution
  - Minimal **carbon foam** support structures
  - **Air cooling**





Minimal material budget: ~0.09% X_0 on average
- **Uniform ~0.07% X_0** on most of the acceptance



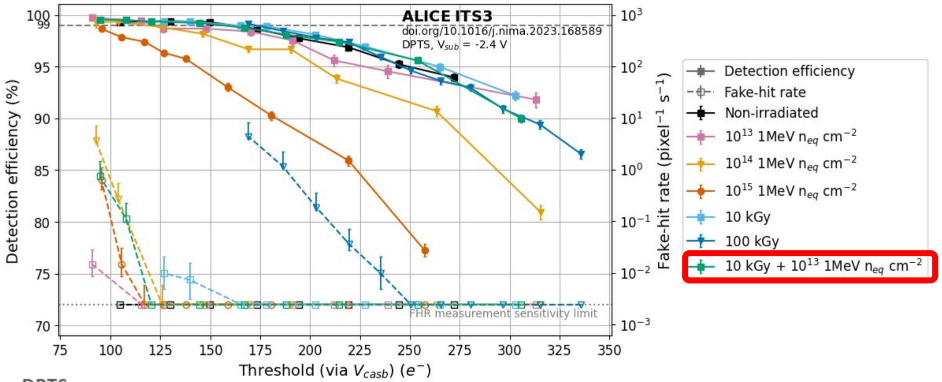
Lab and in-beam characterization of CMOS sensors

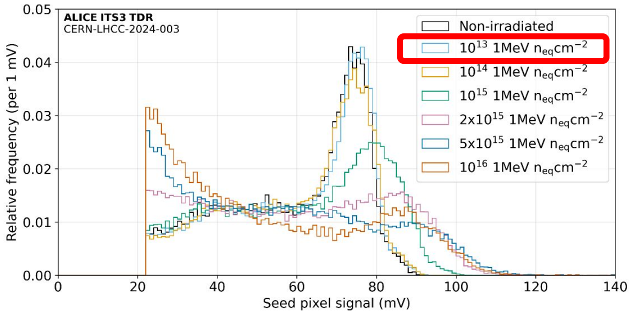
65 nm CMOS process validated on test structures with laboratory tests (also in Trieste):

- Efficiency > 99%
- Fake-hit rate < $2 \cdot 10^{-3}$ pix^{-1} s^{-1}

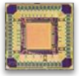
} over a wide operating range, even after irradiation at **ITS3 required level**

- **Sensor characterization @ Trieste:**
  - In-lab parameter scan, noise minimization, energy response of digital prototypes
  - Participation in test beams for efficiency and spatial resolution measurement



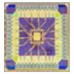


DPTS



Detection efficiency and fake-hit rate Vs threshold and irradiation levels, as measured on 15 μm pitch **Digital Pixel Test Structures (DPTS)**

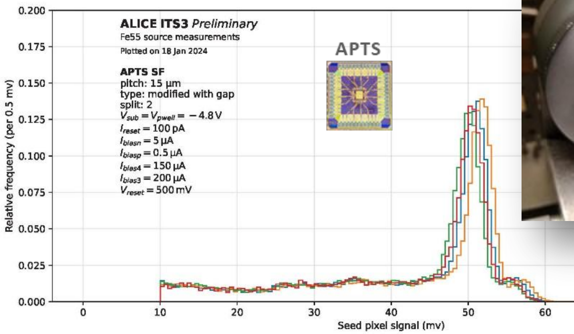
APTS

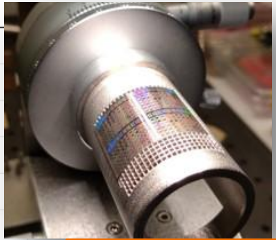


Seed **pixel signal response to ^{55}Fe** Vs irradiation levels, as measured on 15 μm pitch **Analog Pixel Test Structures (APTS)**

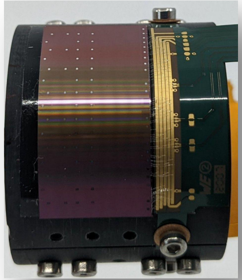
Mechanical bending of sensors and effects on performance

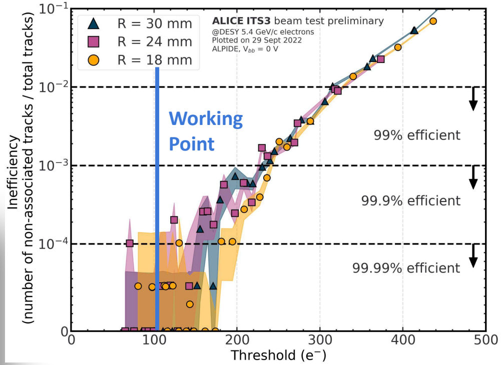
- MAPS performance in **curved geometry** has been validated
  - Efficiency preserved on bent ALPIDE (180 nm CMOS sensors)
  - Charge collection properties preserved on bent APTS (65 nm CMOS)





Seed pixel signal response to ^{55}Fe as measured by flat and bent **APTS**





Detection inefficiency Vs threshold for curved 180 nm CMOS sensors (**ALPIDE**), bent beyond the ITS3 radii

- @ Trieste:
  - Development of the first tools and procedure to mechanically bend the silicon
  - First in-lab electrical and functional characterization of bent sensors

THANK YOU FOR YOUR KIND ATTENTION

BACKUP

b-quark charge determination

- Two classes of **methods**:

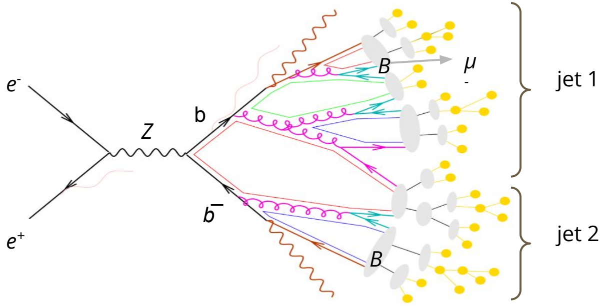
  1. **Jet charge**:

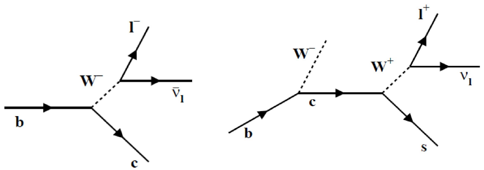
     - charge of jet obtained as weighted **sum** of charges of constituent **tracks**
     - can be applied to all jets ⇒ maximal efficiency
     - relatively low purity
     - strong dependence on jet shape and hadronization

  2. **Soft lepton tagging**:

     - charge of *b* inferred from charge of *e* or *μ* in ***B*-hadron semileptonic decay**
       - crucial to minimize ***b*** **→** ***c*** **→** ***μ*** contribution that "fakes" charge
     - relatively low efficiency (restricted to semileptonic decays)
     - better purity
     - highly sensitive to *B*-hadron decay modelling

many possible variations exist, e.g. based on exclusive final states from B-hadron decays, secondary vertex reconstruction…



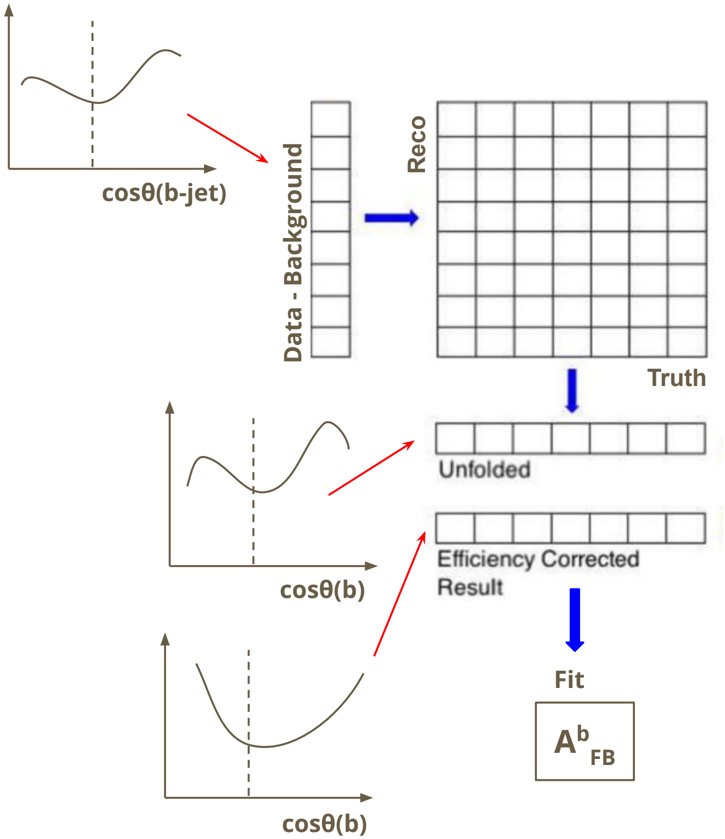


Branching ratios (in %)

BR($b \to \ell^-$)	10.90 ± 0.32 (∓ 0.21)
BR($b \to c \to \ell^+$)	8.30 ± 0.47 (± 0.19)
BR($b \to c \to \ell^-$)	1.30 ± 0.50
BR($b \to \tau \to \ell^-$)	0.70 ± 0.20
BR($c \to \ell^+$)	9.80 ± 0.50

Analysis strategy

- **Analysis framework**:
  1. **feasibility study** with **Key4hep-FCCAnalyses** framework and **standalone Madgraph private** simulation
     - **EDM4hep** for event generation
     - **Pythia8** for parton shower simulation
     - **Delphes** for detector fast-simulation
  2. Software features:
     - **IDEA detector** concept
     - **Durham ee-kT** jet algorithm used, **R=0.4**
     - simplified Delphes ***b*-tagging** (flat 80% efficiency, 10%/1% *c*/light-mistagging)
- **Investigated workflow**:
  1. build **reco-level observable** using:
     - jet direction
     - charge determined with one of the two methods (studies in parallel)
  2. perform **unfolding** from reco-level to parton-level
  3. extract A_{FB}^{b} from **fit** to unfolded distribution

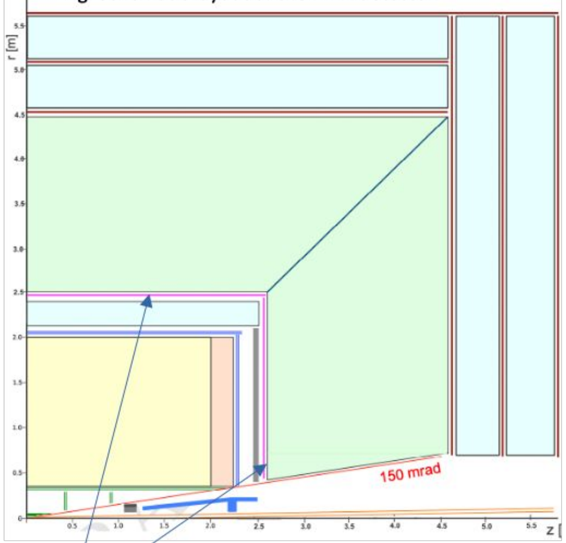


Alternative workflow:
starting to consider also template fit at reco-level (with templates obtained via "folding" or reweighting)

Other activities: IDEA pre-shower simulation in Key4hep

Nitika Nitika
Postdoc (ATLAS)

Fig. Schematic layout of the IDEA detector.



➔**Pre-shower geometry implementation** Initially establishing the detector geometry in terms of simple cylinders with sensitive layers and then advancing towards intricate and descriptive geometry based on complex tiling of µRWELL technology.

➔**Digitization of the Pre-shower**

➔**Integration of the Pre-shower** with the ECAL for the calorimeter reconstruction process.

➔**Photon identification algorithm implementation** to reject the false signals (π^0) as it is important to differentiate the photons from the Higgs decay channel to π^0.

XML file corresponding to the simple sensitive cylindrical geometry has been formally created and will be publicly available in the near future (probably by next week).

Table. The configuration of the barrel and endcap Pre-shower detector.

Pre-Shower	Layer	R or R_{in} (mm)	L(mm) or R_{out}	Thickness (mm)	Pixels size (mm^2)
Barrel	µRWELL	2450	±2550	20	0.4×500
Endcap	µRWELL	390	2430	20	0.4×500

https://fcc-ee-detector-full-sim.docs.cern.ch/IDEA/