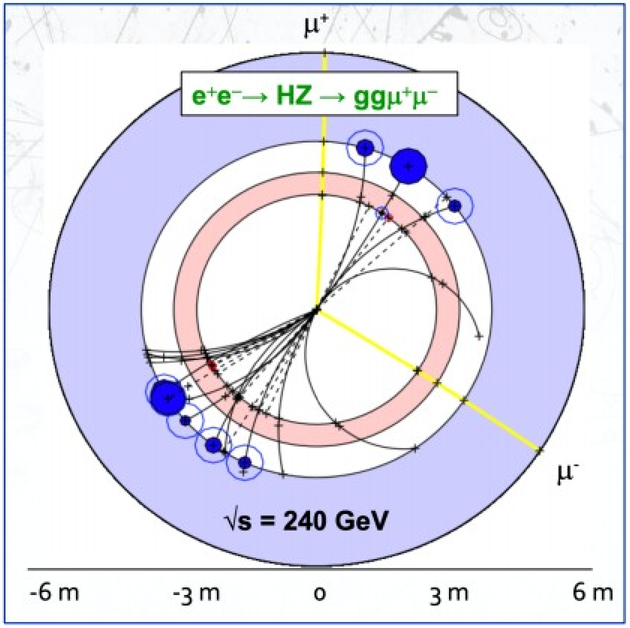
# FCC - ee @LAPP

## A few notes extracted from

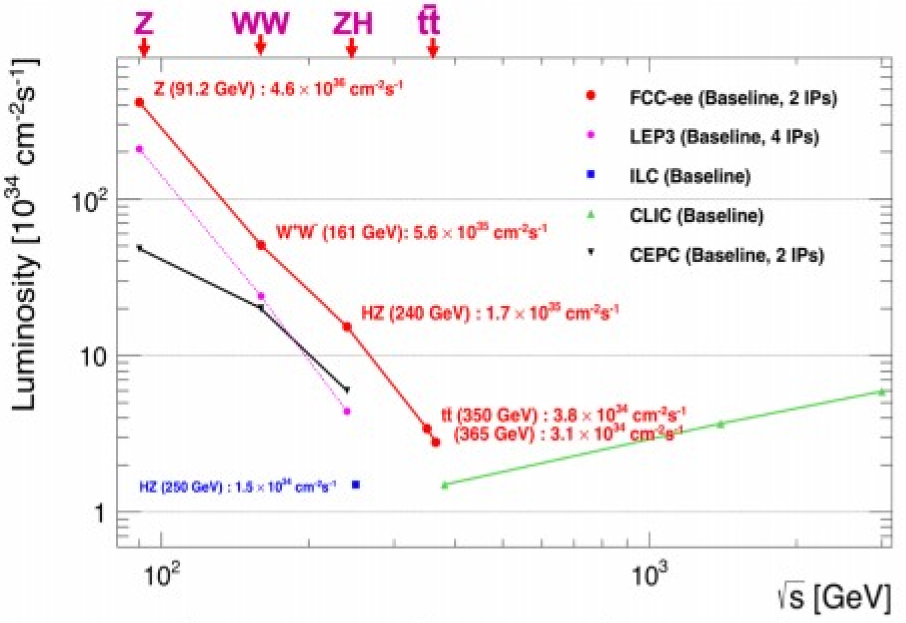
[4th FCC Physics & Experiments Workshop]




$e+e^-$: detect everything; measure precisely

# Experimental goals: precision physics

Can be seen on LEP, LHC etc…
***A common error of many 'studies' of the past was to <u>underestimate</u> how well a group of dedicated (and well prepared) physicists can deconstruct a systematic error problem to the precision level of statistics. → <u>Use statistical error as target!</u>***




| FCC-ee parameters | | Z | W⁺W⁻ | ZH | ttbar |
|---|---|---|---|---|---|
| √s | GeV | 91.2 | 160 | 240 | 350-365 |
| Luminosity / IP | $10^{34}$ cm$^{-2}$ s$^{-1}$ | **230** | 28 | 8.5 | 1.7 |
| Bunch spacing | ns | 19.6 | 163 | 994 | 3000 |
| "Physics" cross section | pb | 35,000 | 10 | 0.2 | 0.5 |
| Total cross section (Z) | pb | 40,000 | 30 | 10 | 8 |
| Event rate | Hz | **92,000** | 8.4 | 1 | 0.1 |
| "Pile up" parameter [$\mu$] | **$10^{-6}$** | 1,800 | 1 | 1 | 1 |

**Experimentally, Z pole most challenging**

- Extremely large statistics
- Physics event rates up to 100 kHz
- Bunch spacing at 19.6 ns
  - "Continuous" beams, no bunch trains, no power pulsing
- No pileup, no underlying event, …
  - …well, pileup of 2 x $10^{-3}$ at Z pole

# Experimental challenges – prisme LAPP

- Extremely high luminosities
  - Large statistics (high statistical precision) – control of systematics down to $10^{-5}$ level
  - Online and offline handling of $\mathcal{O}(10^{13})$ events for precision physics
    - "Big Data"
- Physics events at 100 kHz
  - Strong requirements on sub-detector front-end electronics and DAQ systems
    - Material budget: minimise mass of electronics, cables, cooling, …
  - Requirement of $10^{-5}$ level relative normalisation of physics channels
- "Continuous" beams (no bunch trains); bunch spacing at 19.6 ns
  - Power management and cooling (no power pulsing)
- 30 mrad beam crossing angle
  - Very complex MDI (Machine Detector Interface)
- More physics challenges
  - Luminosity measurement to $10^{-4}$ – luminometer acceptance to 1 μm level
  - Detector acceptance to ~$10^{-5}$ – acceptance definition to few 10s of μm, hermeticity (no cracks!)
  - Stability of momentum measurement – stability of magnetic field wrt $E_{cm}$ ($10^{-6}$)
  - b/c/g jets separation – primary importance for Higgs decays; flavour and τ physics: vertex detector precision
  - Particle identification (π/K/p) without ruining detector hermeticity – flavour and τ physics (and rare processes)

ESCAPE

Expertise ITk
+ Tracking ML

LAVISTA

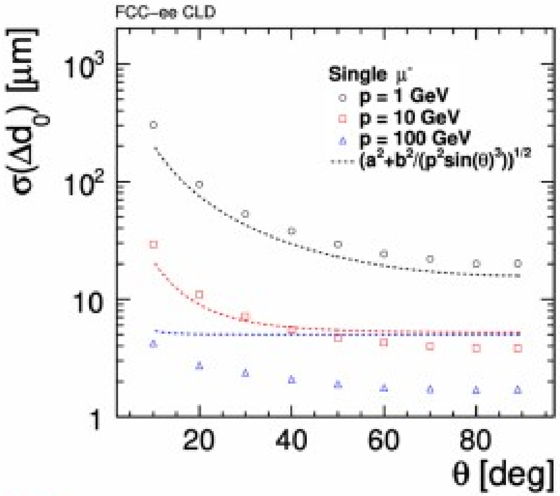
# Vertex Detector requirements for FCC - ee

Design goal…

$$\sigma_{d_0} = a \oplus \frac{b}{p \sin^{3/2}\theta}$$

$$a \simeq 5\,\mu\text{m}; \quad b \simeq 15\,\mu\text{m}\,\text{GeV}$$

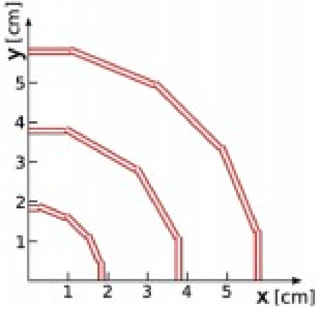
…satisfied in CLD full simulation study



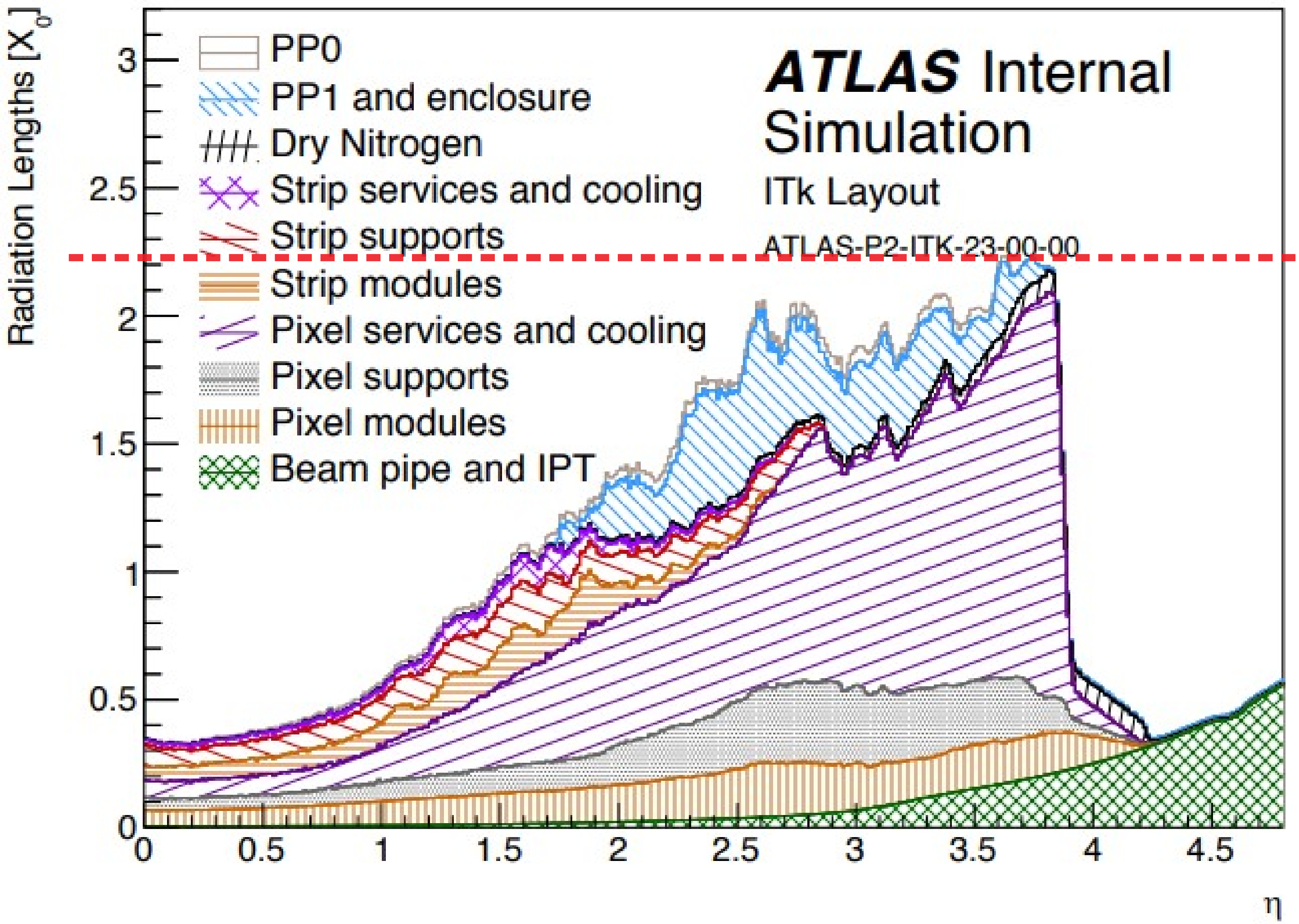

arXiv:1911.12230

- Single point accuracy of 3 µm
- Three very thin double sensor layers (50 µm Si) at radii 18, 37, 57 mm
  - 0.6% of $X_0$ for each double layer
- Beryllium, water cooled beam pipe at r=15 mm
  - 0.5% of $X_0$

**1.8% of X0 in total**



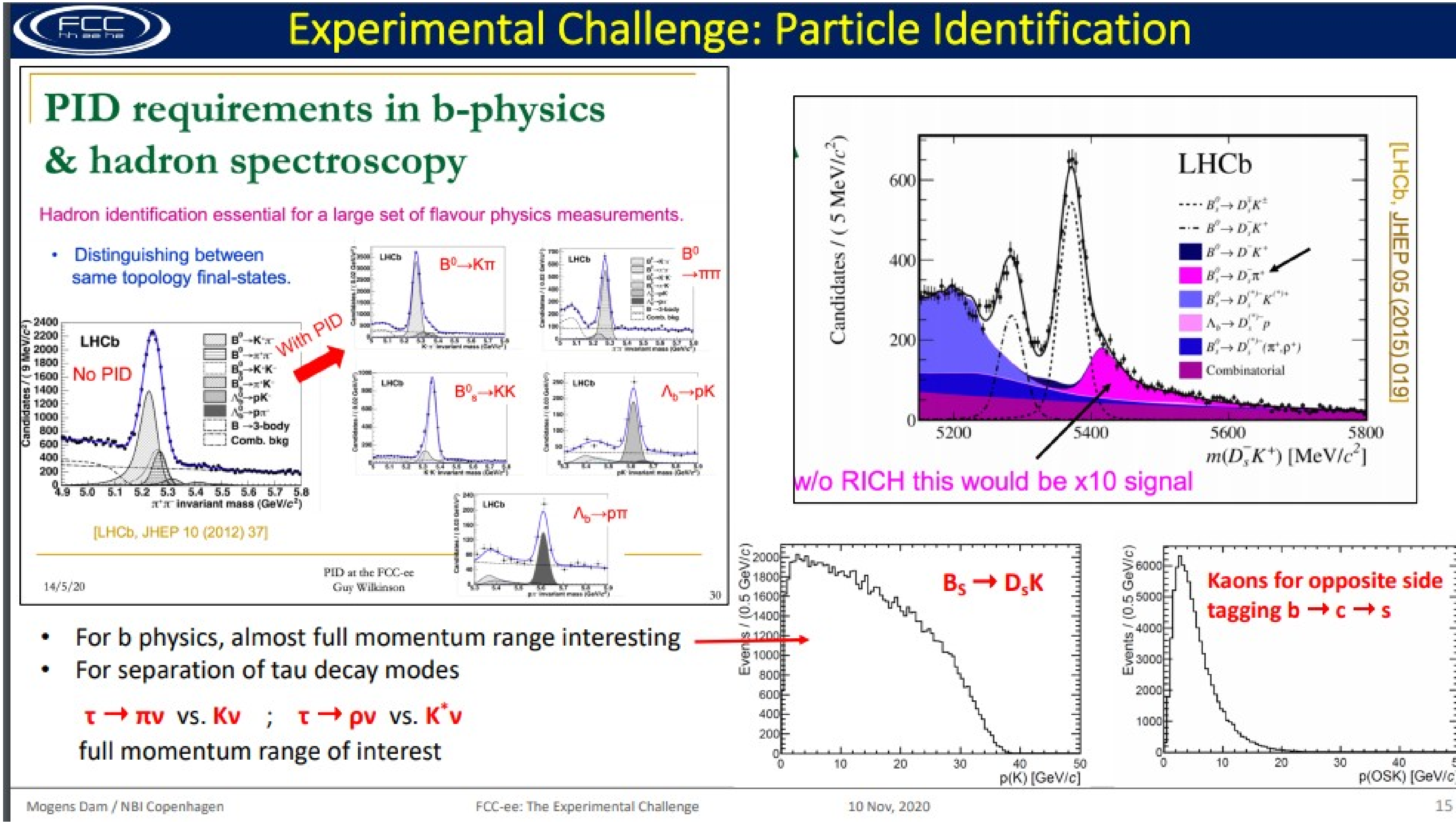
# State of the Art…



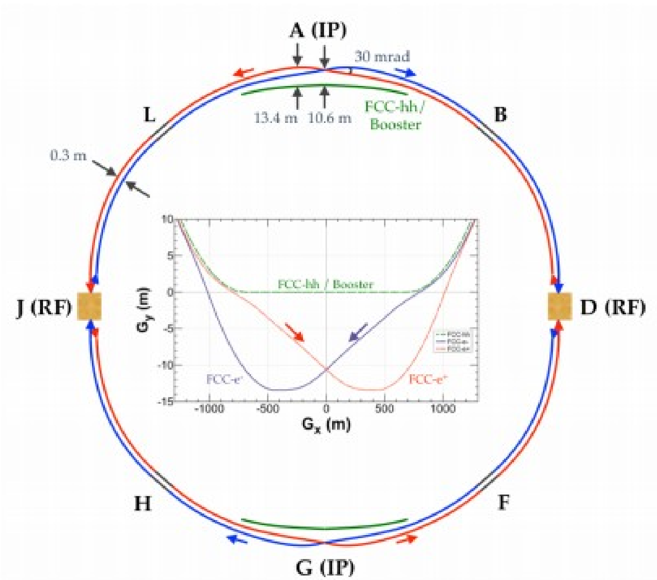

**2.3% of X0**

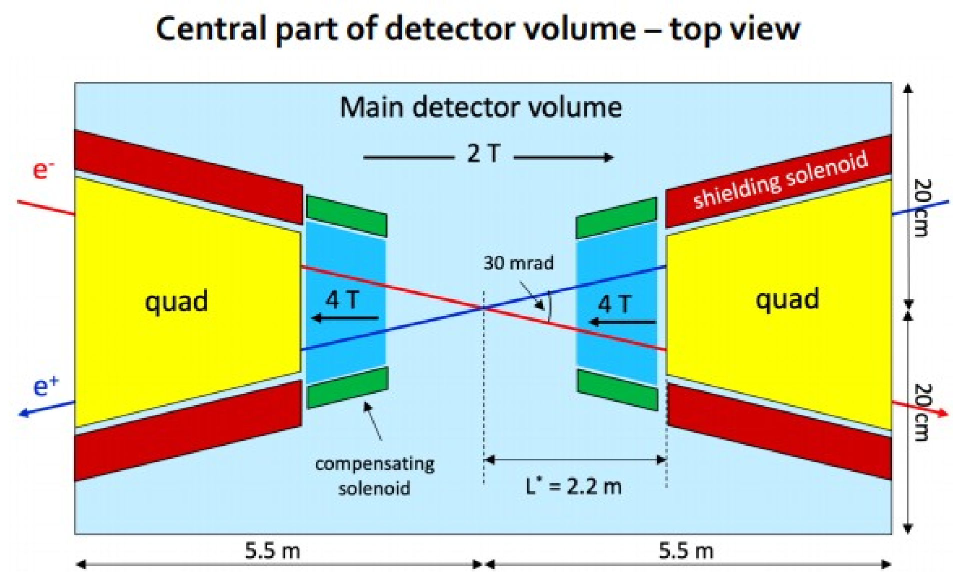
1.28Gb.s$^{-1}$
Power: 2 W

# Lien avec la physique du B au LAPP ?



# Machine Detector Interface

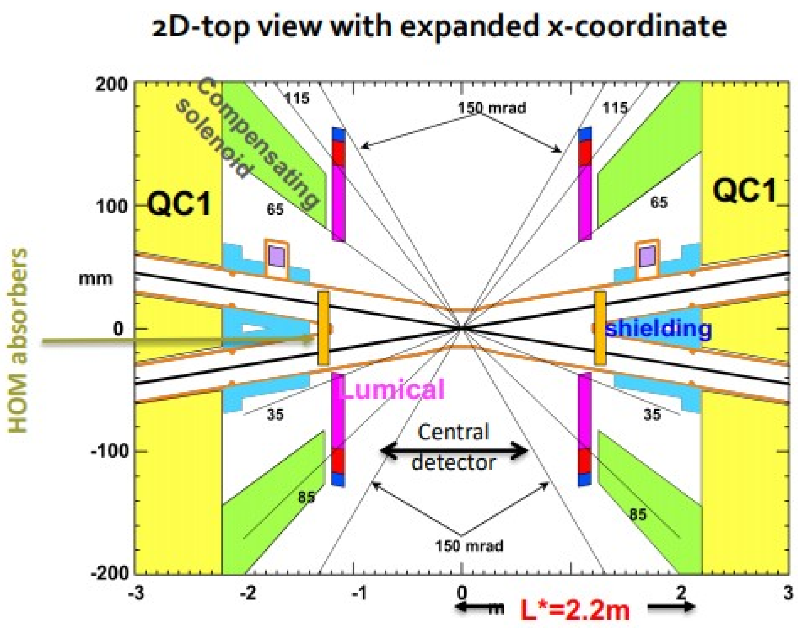


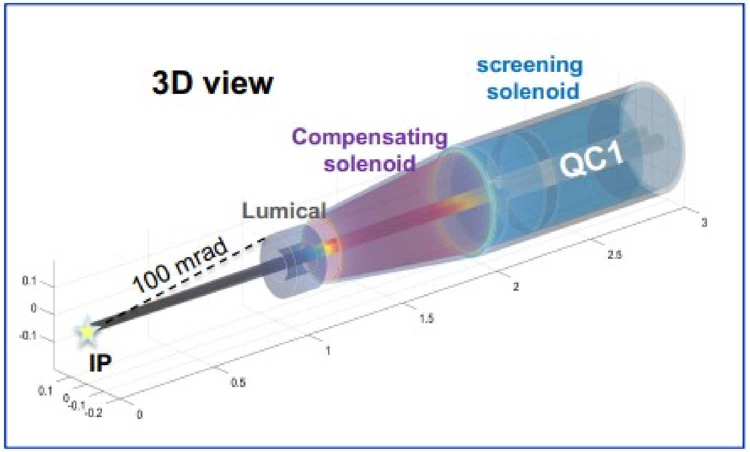

- Large horizontal crossing angle 30 mrad
- Beams only mildly bent before IP to minimize synchrotron radiation into detector volumes
  - Beams bent mainly after IP

- Focussing quadrupoles protrude into detector volume
  - QC1 down to distance $L^* = 2.2$ m
  - Necessary to shield quads from detector field
- Beams cross detector field at a 15 mrad crossing angle
  - Compensate for detector field to avoid $\varepsilon_y$ blow-up
  - Limits detector field to B = 2 Tesla

# Interaction Region Layout




- Unique and flexible design at all energies
  - Acceptance: 100 (150) mrad
  - Solenoid compensation scheme
  - Quadrupole shielding
  - Beam pipe
    - Warm, liquid cooled
    - Be in central region, then Cu
    - R = 15 mm in central region (investigating 10 mm)
    - SR masks, W shielding
  - Mechanical design and assembly concept under study



# Case Studies 1 : B physics

## « case studies » for flavor physics

| Measurement | Goal | Need to | Constraining |
|---|---|---|---|
| | CKM angle gamma | $B_s \to D_s^{\pm} K^{\pm}$ | PID and K/pi separation |
| CP violation in HF<br><br>(see talk on Flavor #117 S.Mor | Modes with $\pi^0$ in the final state | $B^0 \to \pi^+ \pi^- \pi^0 \pi^0$ | Ecal with excellent energy resolution also at low energies |
| | CP violation in the B(Bs) meson mixing | charge particle detection asymmetry limiting systematic | overall detector design and reconstruction methods |
| | FCNC modes | $B^0 \to K^{*0} \tau^+ \tau^-$<br>$B_c^+ \to \tau^- \nu_\tau$ | precise vertex detection for partial-reconstruction cases |

- Initial list in term of « case studies ». More coming.
- Ongoing studies already for exclusive decays, *see talk #122 D. Hill*
- Obvious need of a high performance of the vertexing for all the time-dependent measurement as well

# Case Physics 2 : EW

## « case studies » for EWK

| Measurement | Goal | Need to | Constraining |
|---|---|---|---|
| Z pole EWK observables with heavy-quark | $O(10^{-6})$ precision on Z decays to h.f. ewk properties | reduce systematics to match with statistics unc. | - detector design in general<br>- vertexing/tracking<br>- b/c-tagging algorithms |
| W mass | ~500keV maybe less (measure at threshold and above) | - beam energy calibration at 300keV<br>- competitive measurement of final state reco | - event reconstruction<br>- lepton mom scale & resolution<br>- kinematical fitting |

- The Z & W studies here might seem similar to a repeat of the LEP program, but this is a wrong assumption!
- The Tera-Z luminosity brings the overall approach to measurements at a totally different scale. The statistical precision achievable and the large statistics of events allows to shrink and control the systematics to the desired level.

# Case Physics 3 : Higgs

| Measurement | Goal | Need to | Constraining |
|---|---|---|---|
| total Higgs width (part 1) | Higgs width from H->ZZ* multilepton or H->WW* | increase efficiency, reduce the background | jet clustering and kinematic fits and jet angolar resolution vs jet energy resolution |
| Total Higgs width (part 2) | using WW fusion process with H->bb | separation of signal and bkg | visible and missing mass resolution. profit of √s=365 kinematic before going to √240 |
| HZgamma coupling | better than HL-LHC | measure of ZH->ZZγ, H->γγ and ee->Hγ | photon identification, photon energy/angular resolutions, in p |
| ee->H production in s-channel at Higgs pole (talk #82 D. D'Enterria) | assess the ultimate reach on the H->ee coupling | resonant production & monochromatization ee->H | - machine challenges<br>- ML tools needed to beat the huge background |

# Lectures sélectionnées

Detector requirements:
https://indico.cern.ch/event/932973/contributions/4076717/attachments/2139667/3604876/2020_11_10_detector_requirements.pdf

Software status:
https://indico.cern.ch/event/932973/contributions/4076723/attachments/2139959/3605481/FCC-Software-PDS-FCCIS-Nov2020.pdf

Mechanical Design of interaction region:
https://indico.cern.ch/event/932973/contributions/4075873/attachments/2141011/3607517/Interaction%20Region%20MECHANICAL%20DESIGN%20final.pdf

Physics Driver for Tracker:
https://indico.cern.ch/event/932973/contributions/4073513/attachments/2141522/3608554/paula_collins_physics_drivers_1.pdf

Tracker Performance:
https://indico.cern.ch/event/932973/contributions/4041312/attachments/2141444/3608344/AllSiTrackers_Leogrande_4thFCCWSNov2020.pdf

Tracker Cooling, Mechanics and readout:
https://indico.cern.ch/event/932973/contributions/4102407/attachments/2142143/3609779/CoolingTalkFCCworkshop10nov20.pdf

https://indico.cern.ch/event/932973/contributions/4073514/attachments/2141373/3608219/2020-11-12_FCC_ALICE_MAPS.pdf

https://indico.cern.ch/event/932973/contributions/4041338/attachments/2141369/3609392/sculpting_silicon.pdf

https://indico.cern.ch/event/932973/contributions/4099071/attachments/2141945/3609429/20201112-Aglieri-Readout-Ultra-Light-Vertex.pdf

# Remarque de conclusion (A. Blondel)

**How do we attract the young generation of experimenters for FCC-ee studies?**

understanding of how to collaborate with the big LHC experiments to somehow find a way that youngsters can do e.g. R&D on FCC and operations+analysis on CMS or ATLAS is important.

Probably difficult until HL-LHC upgrade is done but it is important to think about it for the experimentalists.

Guenther: need to discuss with LHC experiments ..

**-- chat room:**

Future accelerator studies are a great opportunity to explore uncharted territory, discover/invent new things and to publish 'few authors' original material.

Also an opportunity to broaden one's vision of the physics, contact theorists and acc. physicists, etc...

Alain Blondel 4th physics workshop concluding remarks