FCC
ETH Zurich Interest

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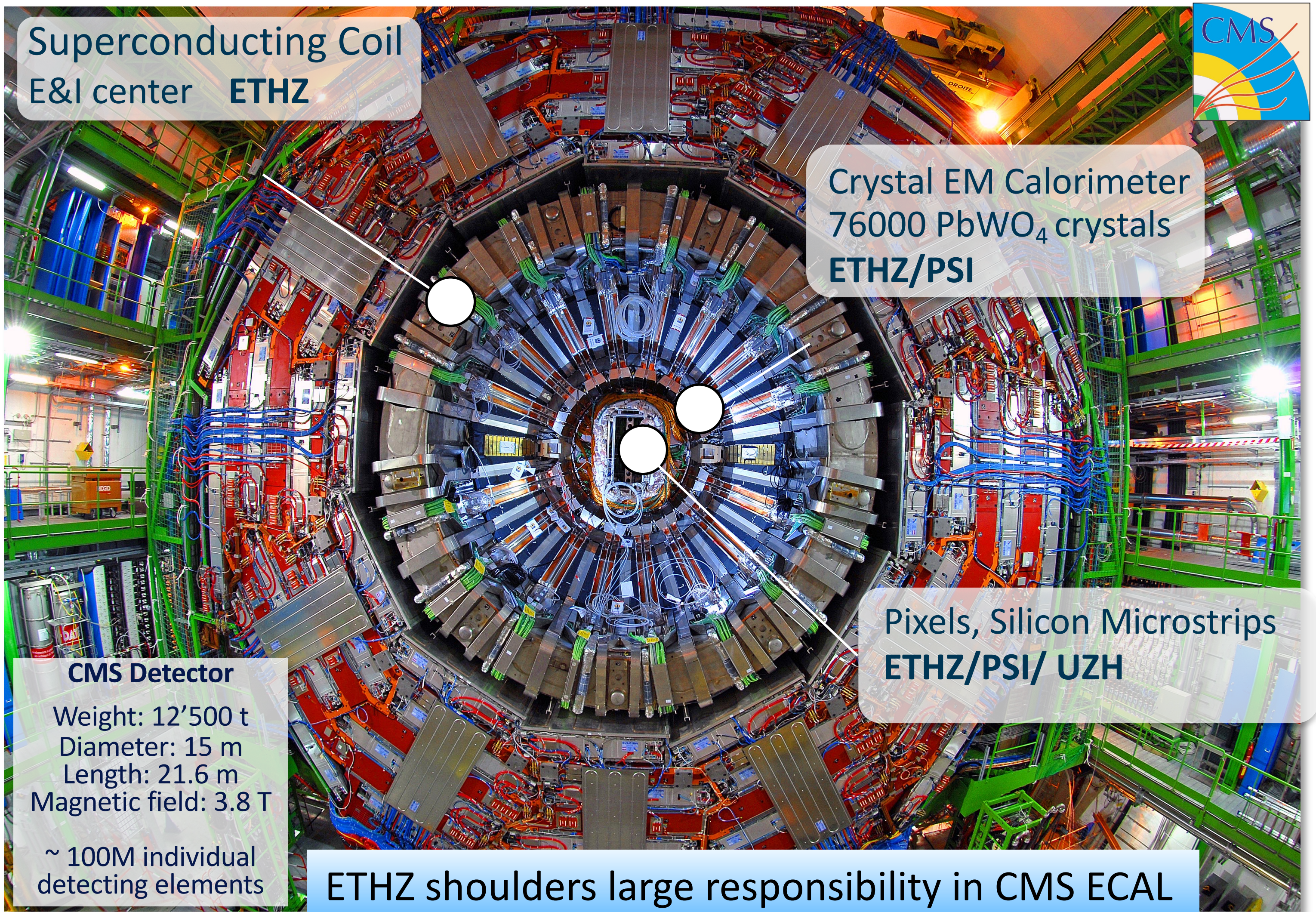
Workshop on :
Fostering Swiss collaboration towards a future circular collider
7.9.2021

Overview

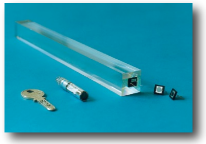
- Introduction
- Data Analysis Plans
- Hardware Activities
- Conclusions

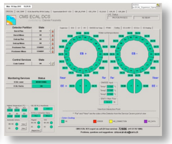
Hardware Contributions to CMS

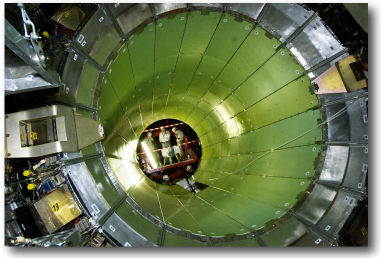


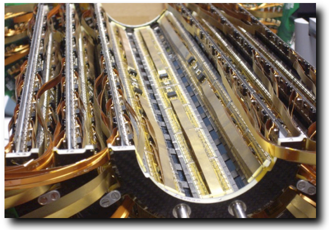
ETHZ shoulders large responsibility in CMS ECAL and pixel detector operations and upgrade

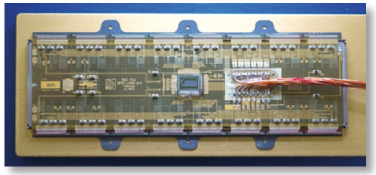
Important management roles since the 1990s











Past and Current Data Analysis efforts of the ETH Zurich Group

- Higgs Physics [27*] (cross section, STXS, differential, global fits)
  - VH(→bb), ttH(→bb)
  - H→γγ
  - HH→γγbb
- BSM Physics [39*]
  - SUSY (di-lepton, multilepton / EWK, all-hadronic / MT2)
  - HNL
  - Dark Sectors
  - $B_S \rightarrow \mu\mu$, R(J/psi)
- SM Physics [17*]
  - W,Z cross sections / Luminosity
  - b-hadron production, angular correlation
  - Substructure Analysis
  - Event shapes
- Top Physics [3*]
  - tt cross section
  - ttV production
- Physics Objects [10*]
  - Jet / MET
  - b-tagging
  - Tracking

[*] papers with significant ETH Zurich contribution 2011-2021

Data Analysis Plans

General remarks

- FCCee will provide huge statistics i.e. “high precision”, which means that the game will be on the understanding of the systematics:
  - Detector calibration: alignment, material, etc… +luminosity measurements
  - Reconstruction techniques/algorithms
  - Theory predictions
  - “new” being an ee: center of mass energy measurements (machine and experiments)
- Simulations:
  - Detector design: what will it look like ?
  - Now work on “Delphes”
  - Will there be a distinction between full and fast sim ?
- Computing:
  - What will be the requirements (evt-size x #evts)
  - What is the role of AI ?

FCC-ee

FCC-ee

FCC-ee run	Z pole	WW threshold	HZ	$t\bar{t}$ threshold	Above $t\bar{t}$ threshold
$\sqrt{s}$ [GeV]	90	160	240	350	> 350
$\mathcal{L}$ [ab^{-1}/year]	88	15	3.5	1.0	1.0
Years of operation	0.3 / 2.5	1	3	0.5	3
Events	$10^{12}/10^{13}$	10^8	2×10^6	2.1×10^5	7.5×10^4

plus possible runs at the Z peak (125 GeV) and around the Z pole
(extraction of α_{QED} at M_Z)

https://indico.cern.ch/event/517784/contributions/2550640/attachments/1462710/2259814/Mangano-FCC-landscape.pdf

Higgs couplings @ FCC-ee

	240 GeV	350 GeV
Total Integrated Luminosity (ab^{-1})	10	2.6
Number of Higgs bosons from $e^+e^- \to HZ$	2,000,000	340,000
Number of Higgs bosons from boson fusion	50,000	70,000

the value of tt runs goes beyond top physics….

sub-% precision

g_{HXY}	240	240+350 (4IP)	240+350 (2IP)
ZZ	0.16%	0.15%	0.18%
WW	0.85%	0.19%	0.23%
bb	0.88%	0.42%	0.52%
cc	1.0%	0.71%	0.87%
gg	1.1%	0.80%	0.98%
ττ	0.94%	0.54%	0.66%
μμ	6.4%	6.2%	7.6%
γγ	1.7%	1.5%	1.8%
Zγ			
tt		~13% from loop effects at tt threshold	
HH	~30% from loop effects at ZH production		
uu,dd	H->ργ, under study		
ss	H->φγ, under study		
BR_{inv}	< 0.48%	< 0.45%	< 0.55%
Γ_{tot}		1%	

(SM: 0.12%)

10

https://indico.cern.ch/event/517784/contributions/2550640/attachments/1462710/2259814/Mangano-FCC-landscape.pdf

Preliminary benchmark studies

1. Towards an ultimate measurement of $R_\ell = \frac{\sigma(\mathrm{Z}\to\mathrm{hadrons})}{\sigma(\mathrm{Z}\to\mathrm{leptons})}$
2. Towards an ultimate measurement of the Z total width Γ_Z
3. Towards an ultimate measurement of the Z peak cross section
4. Direct determination of $\sin^2\theta_\mathrm{eff}^\ell$ and of $\alpha_\mathrm{QED}(m_\mathrm{Z}^2)$ from muon pair asymmetries
5. Determination of the QCD coupling constant $\alpha_\mathrm{S}(m_\mathrm{Z}^2)$
6. Tau Physics, Lepton Universality, and Lepton Flavour Violation
7. Tau exclusive branching ratios and polarization observables
8. Z-pole Electroweak observables with heavy quarks
9. Long lived particle searches
10. Measurement of the W mass
11. Measurement of the Higgs boson coupling to the c quark
12. Measurement of the ZH production cross section
13. Measurement of the Higgs boson mass - Part I
14. Measurement of the Higgs boson mass - Part II
15. Inferring the total Higgs boson decay width - Part I
16. Inferring the total Higgs boson decay width - Part II
17. Determination of the HZγ effective coupling
18. Electron Yukawa via s-channel $\mathrm{e^+e^-} \to \mathrm{H}$ production at the Higgs pole
19. Measurement of top properties at threshold and above
20. Search for FCNC in the top sector
21. Theory Needs for FCC-ee
22. Beyond MFV: constraints on RH charged currents and on dipole operators
23. Construction of CP-odd observables to probe CP-violating Higgs couplings
24. Combined fit of Higgs and top data

$$m_\mathrm{recoil}^2 = s + m_{\ell\ell}^2 - 2\sqrt{s}\,(E_{\ell^+} + E_{\ell^-})$$

$$\mathrm{e^+e^-} \to \mathrm{ZH} \to \mathrm{q\bar{q}b\bar{b}}.$$

$$\sigma_\mathrm{ZH} \times \mathcal{B}(\mathrm{H}\to\mathrm{X\overline{X}}) \propto \frac{g_\mathrm{HZZ}^2 \times g_\mathrm{HXX}^2}{\Gamma_\mathrm{H}}$$

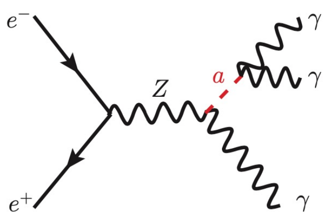
Combined fit of EW and Higgs

Long-Lived Particles

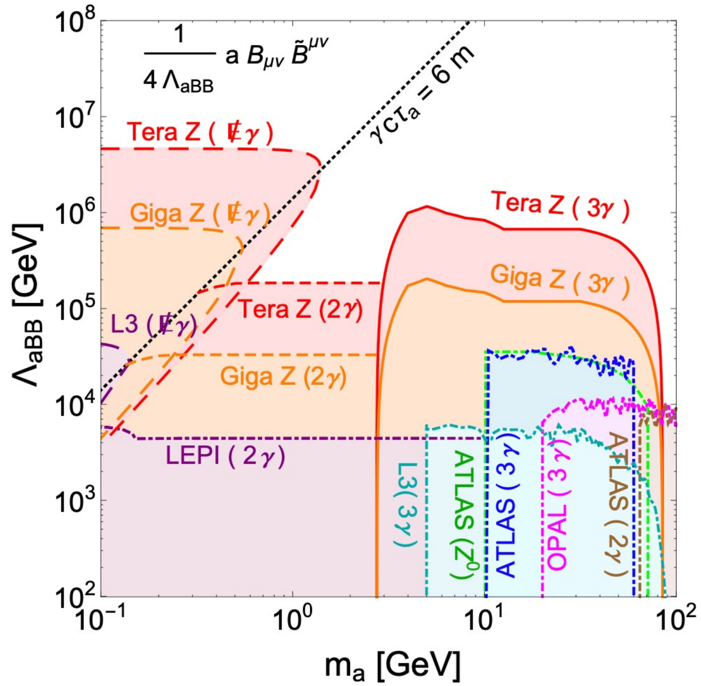
- Long-lived particles (LLPs): new physics particles with lifetimes long enough to decay within the detector volume
  - Lead to distinct experimental signatures
  - Appear in a multitude of BSM scenarios (e.g. SUSY, Hidden Sectors, Exotic H/Z decays, …) trying to address SM open questions (DM, neutrino masses, baryogenesis etc.)
- Possible interesting physics cases:
  - Hidden Sectors
  - Exotic H/Z decays

Long-lived Particles
Hidden Sectors

- New physics hiding in a secluded sector consisting of new particles and forces, very feebly interacting with SM particles
  - Hidden Dark Sectors often introduced to explain DM
- A class of HSs models predict Axion-Like Particles (ALPs) providing a connection between dark and visible sectors via their very-weak coupling to SM particles
  - Light ALPs with small coupling can lead to quite displaced signatures
  - Experiments at FCC-ee can probe a large portion of ALPs parameter space already at the Z pole



arXiv:1712.07237

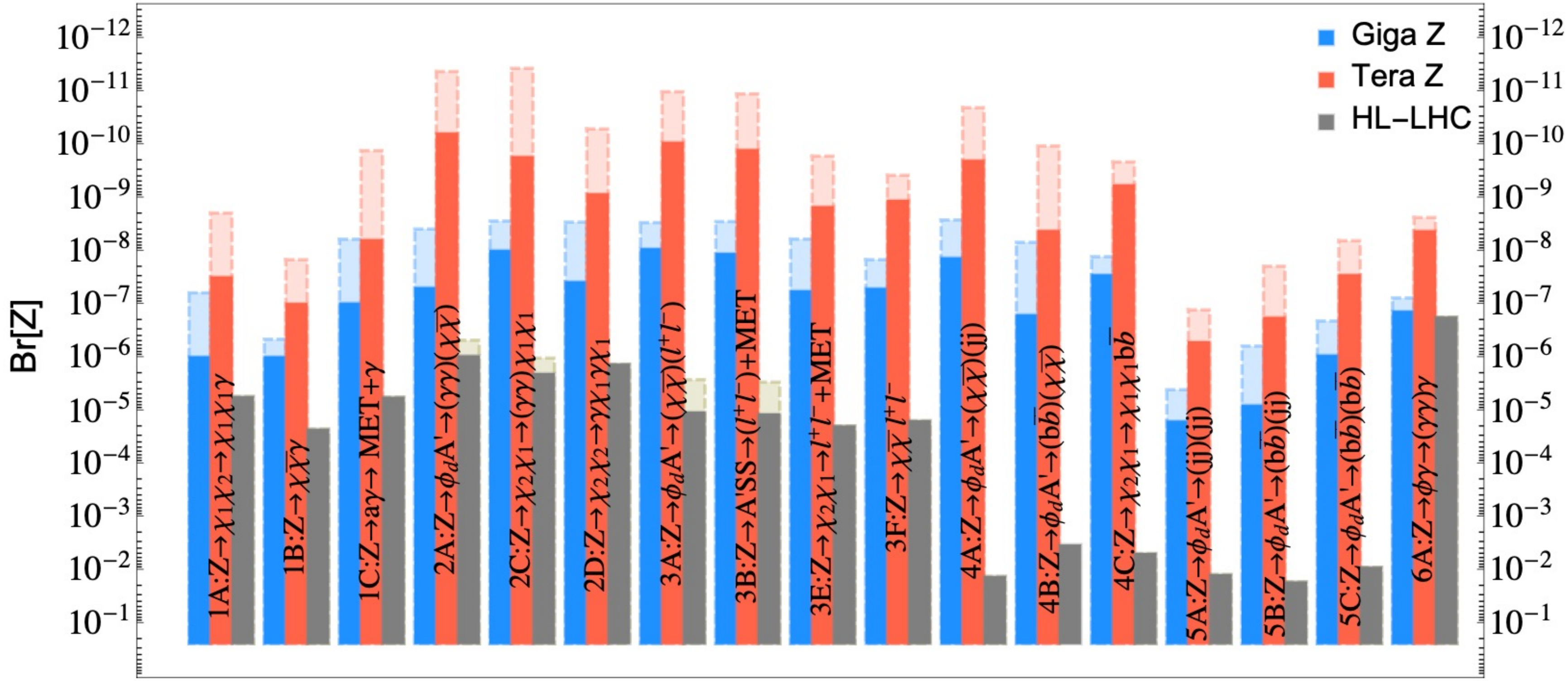


ALP coupling to hypercharge field

Long-lived Particles
Exotic Z decays

- Exotic Z decays can arise from many dark sector models
  - FCC-ee provides a very clean environment, suitable to probe such decays (including full reconstruction of missing momentum)

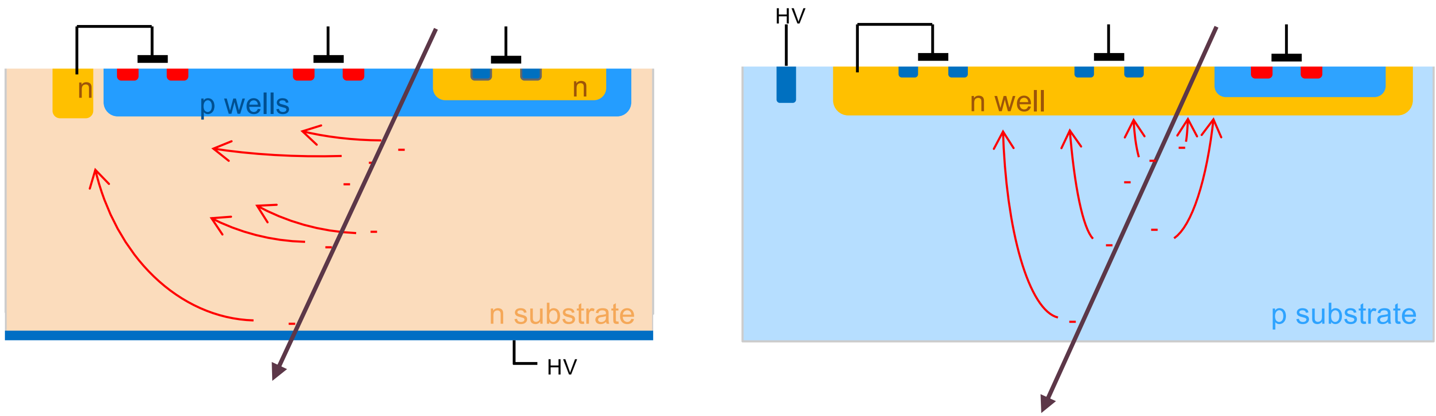
arXiv:1712.07237



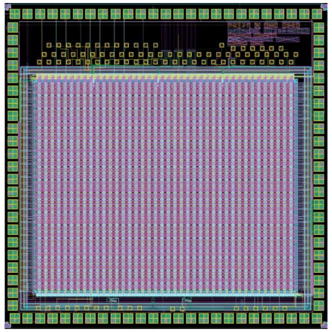
Hardware Activities

Depleted Monolithic Active Pixel Sensors

Collaboration with PSI



- Chip silicon bulk as sensor material → low mass and high precision (time + spatial)
- Large parameter space of options vs. requirements → careful optimization needed
- We investigate two complementary technologies → radiation hardness vs. time resolution
- Submitted test structures and two large scale prototype structures to two fabs
  → Prototypes received and characterization started



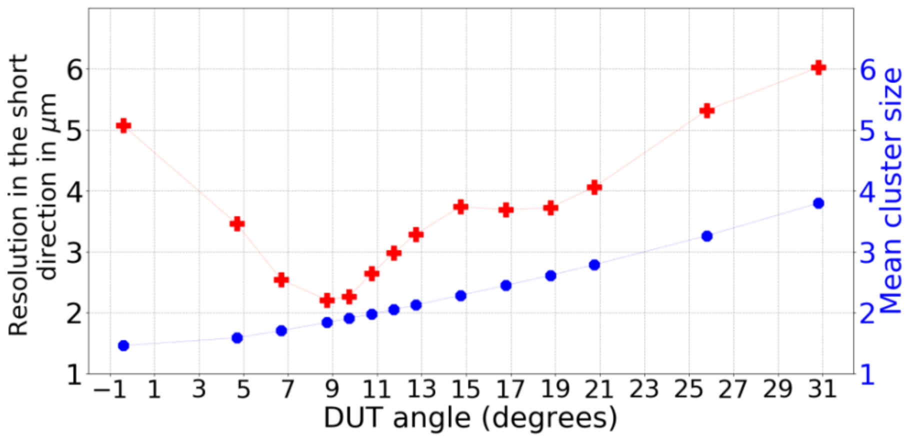
MoTiC chips (S. Burkhalter + PSI/ETH design team)

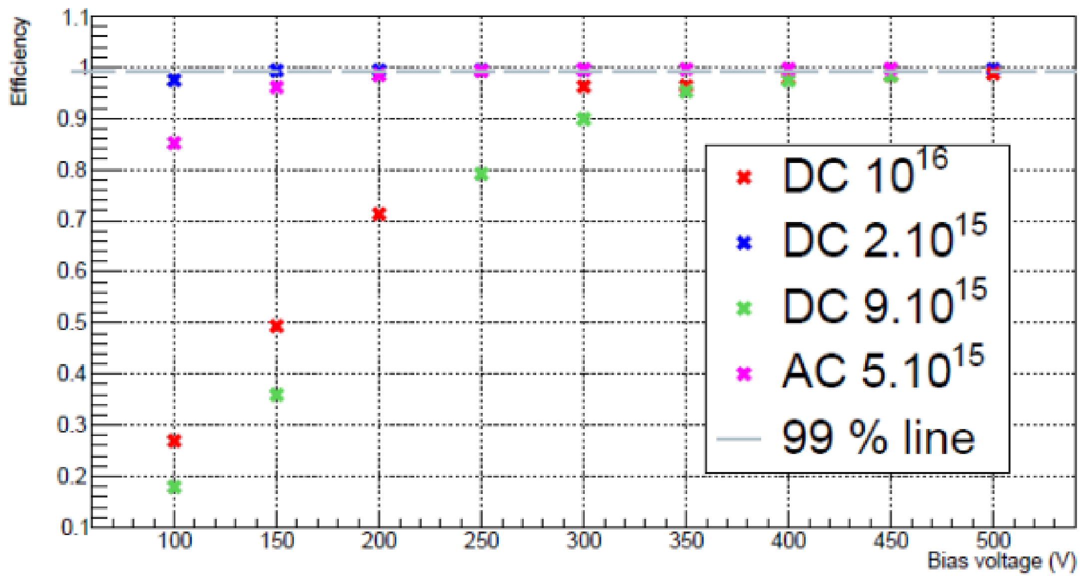
- 5x5 mm^2 dimensions
- Flavor A: different preamplifier designs
- Flavor B: sensing diode variations
- Several test structures for charge collection measurements
- Time to Digital Converter circuit

Passive CMOS Pixel Sensors

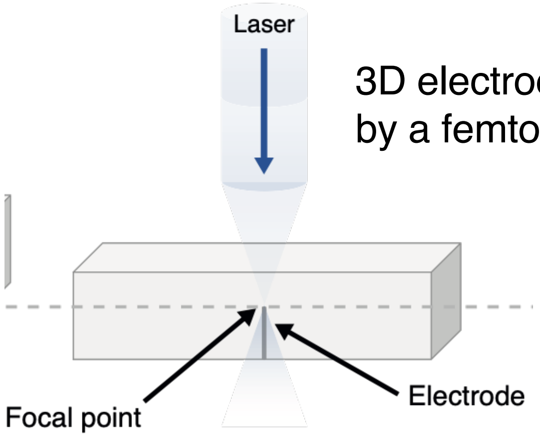
Collaboration with UZH + University of Bonn

- Produce radiation hard passive planar pixel sensors using an industrial CMOS technology
  → benefit from CMOS process options: multiple metal layers, 150nm feature size, MIM capacitors, …
  → challenge: stitching of structures with high electric field
- Status: currently in qualification for CMS Phase 2 Upgrade. Interesting option for LHC - Phase 3 and FCC (very small pixel sizes and AC coupled pixel sensors possible)
- Excellent results from RD53A sensors with 25x100 μm^2 and 50x50 μm^2 DC- and AC-coupled sensors:
  - Crosstalk below measurement efficiency of ~3% (~10% in traditional sensor with 25x100 μm^2)
    → improved spatial resolution
  - DC coupled sensor: >99% efficient after 1 x $10^{16} n_{eq}$ NIEL fluence at 400V (work in progress)
  - AC coupled sensor: >99% efficient after 5 x $10^{15} n_{eq}$ NIEL fluence at 250V (work in progress)



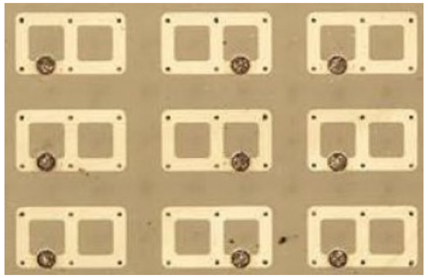


3D diamond research

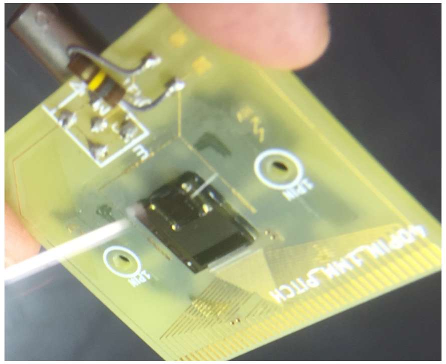


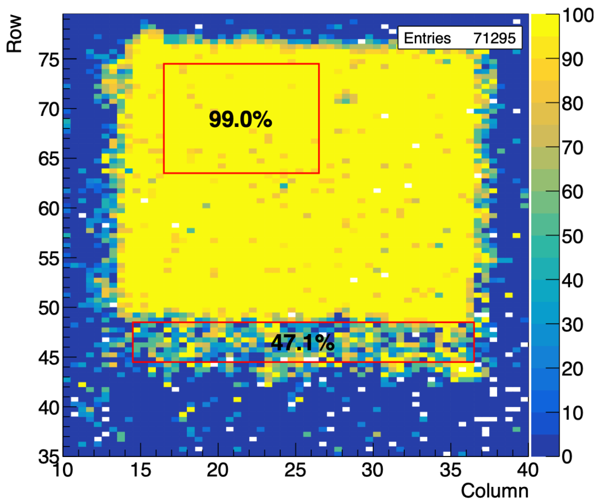
3D electrodes produced
by a femtosecond laser

6 50μmx50μm cell
ganged together
to match readout chip
geometry



3D sensor with
PSI46digv2.1respin
readout





> 99% efficiency in 3D area
< 50% efficiency in 2D area
Sensor bias is -55 V

- Motivation:
  - 3D diamond promises the highest radiation hardness
- Current status:
  - tested both pixel and strip 3D detector prototypes
- Future plans:
  - radiation hardness tests with the current readout chips
- Testing methods:
  - CCD, 4-photon edge-TCT, test beam tests at CERN and PSI

Conclusions

- The CMS group of ETH Zurich is committed to the FCC program
  - Large commitments to the LHC and HL-LHC program still binds most of the resources
- Continue our interest in Higgs physics, BSM and SM measurements at FCC-ee and -hh
  - Our current skillsets put us in a good position to contribute both to the data analysis efforts as well as hardware development
- Most concrete next steps:
  - High precision tracking detector R&D
  - Simulation studies
- Collaboration most welcome!