Physics at a Higgs factory

PASCOS 2024

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Paolo Giacomelli
INFN Bologna

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Outline

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- **The physics landscape**

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- **Why we need a new collider**

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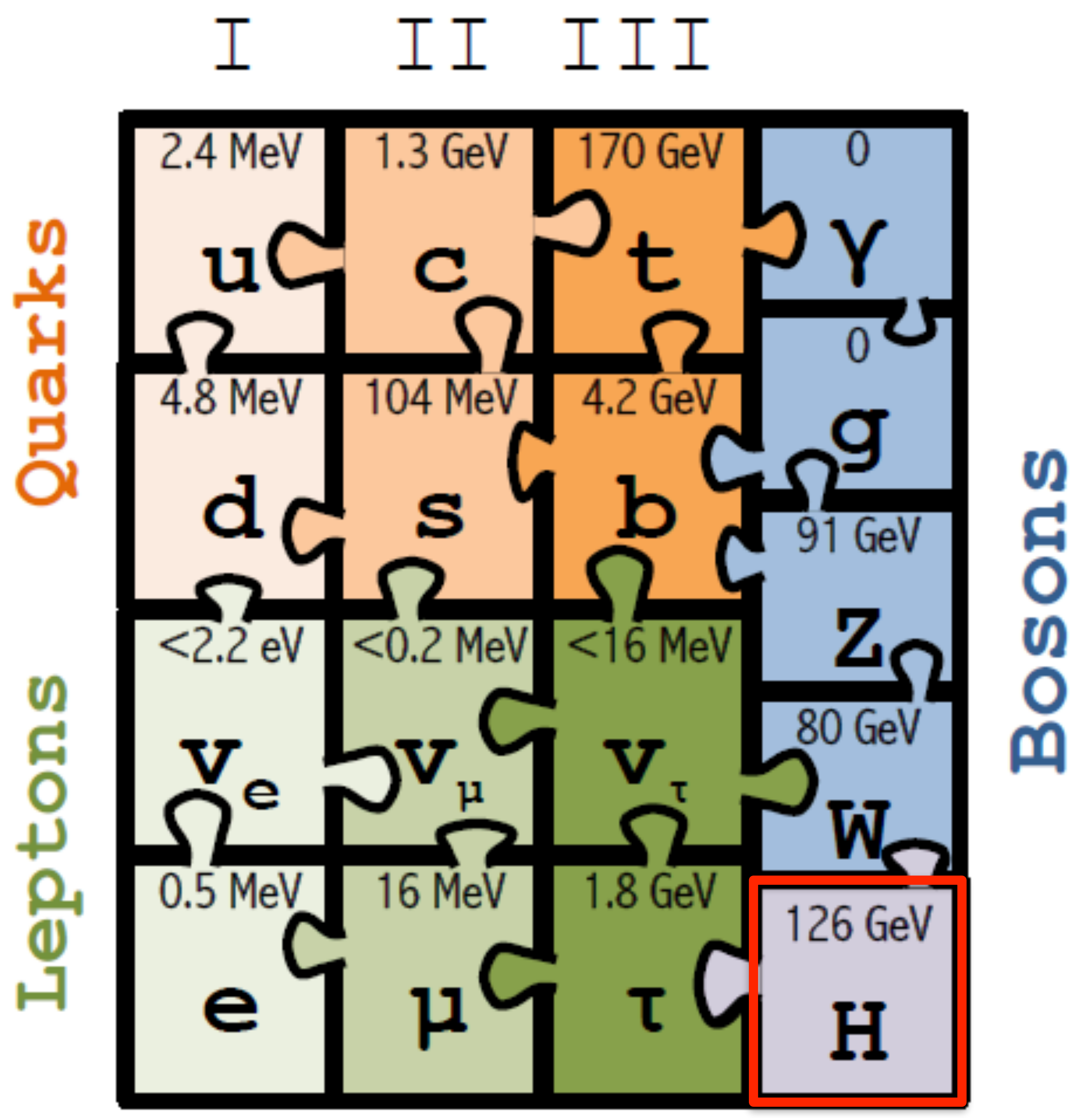
- **Conclusions**

Disclaimer

To prepare these slides I used content from many friends and colleagues, whom I wholeheartedly wish to thank. Any mistake or misinterpretation is entirely my fault!

The Physics Landscape



P. Janot

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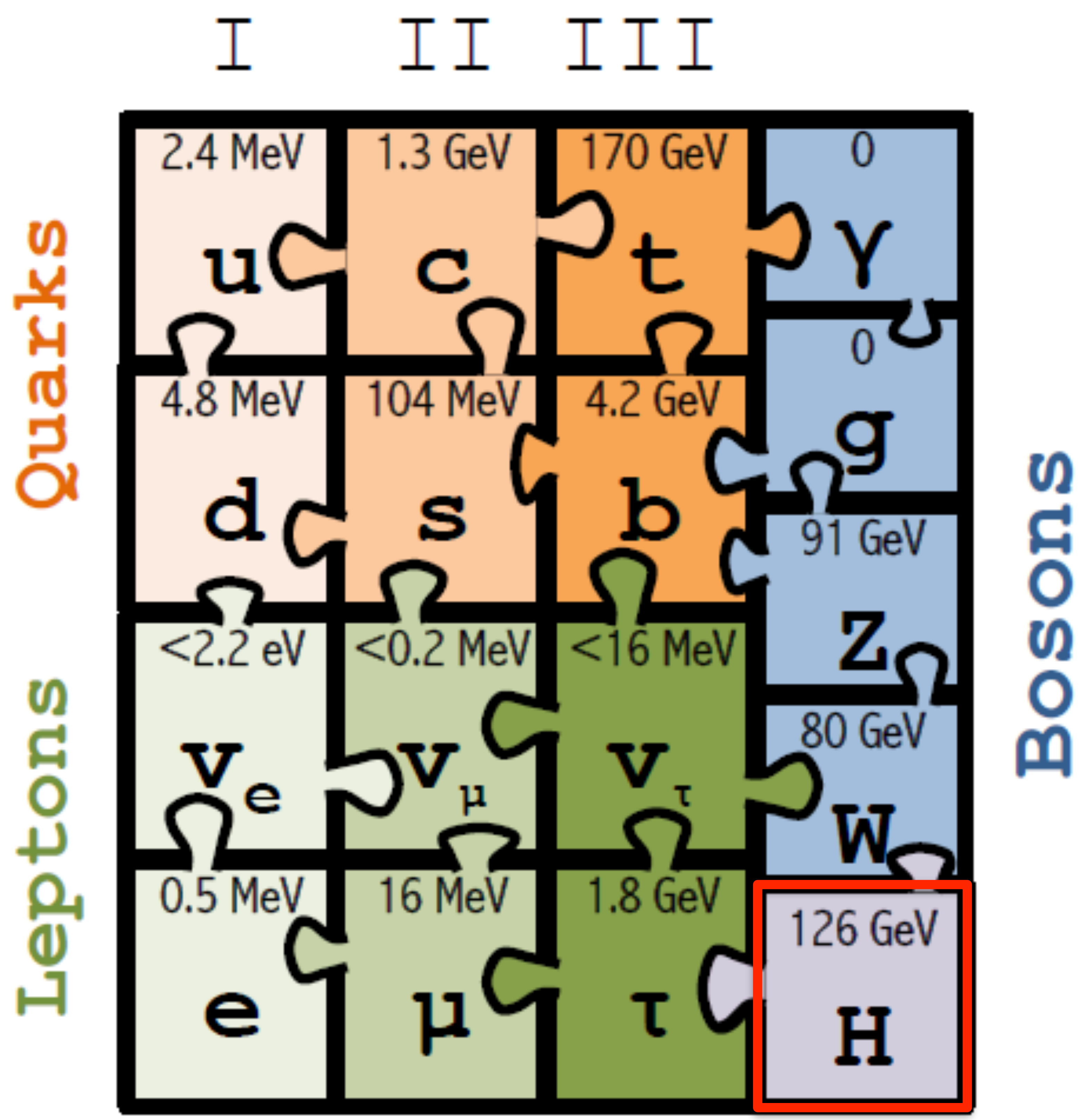

We are at an important point in Particle Physics

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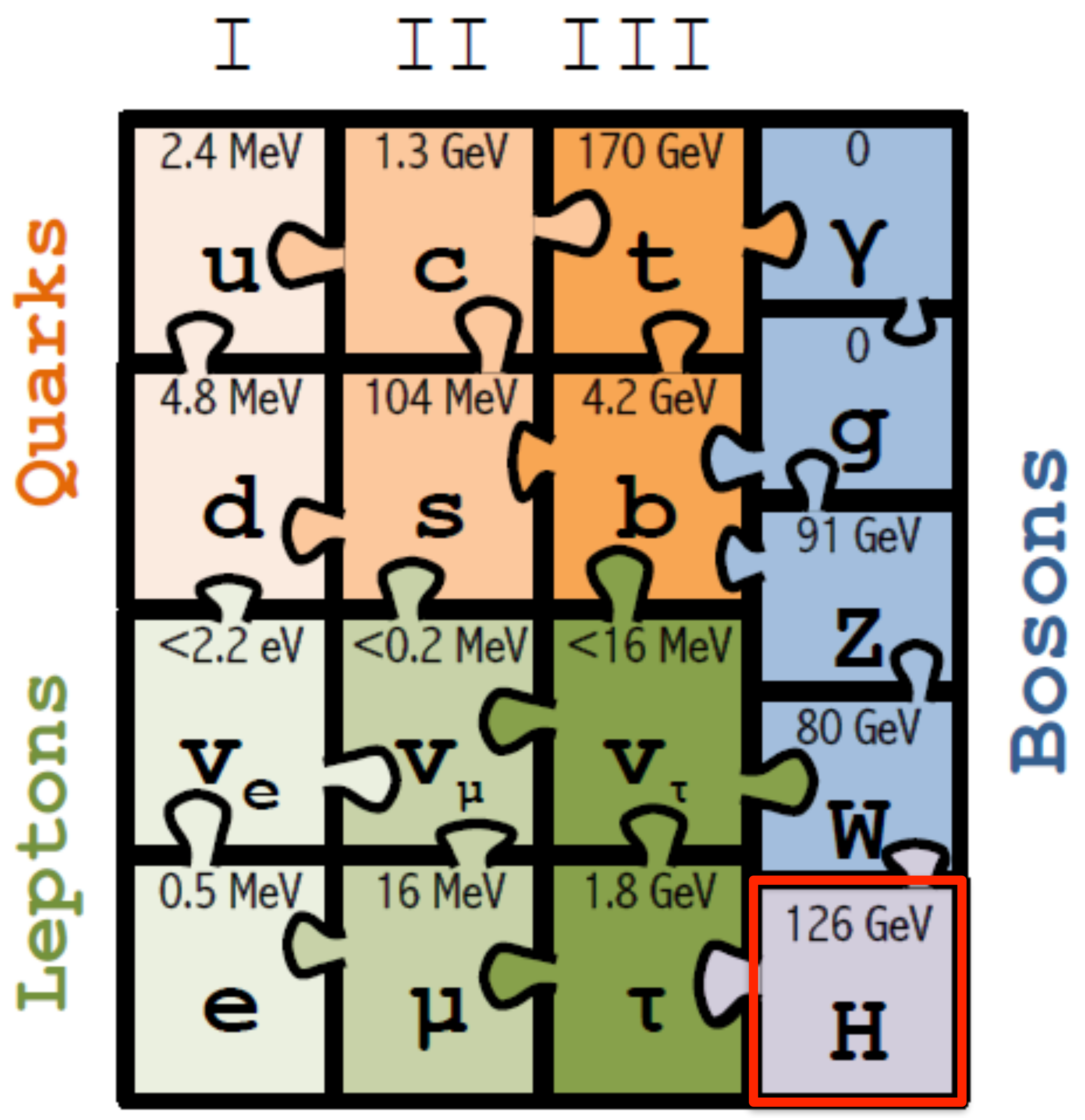

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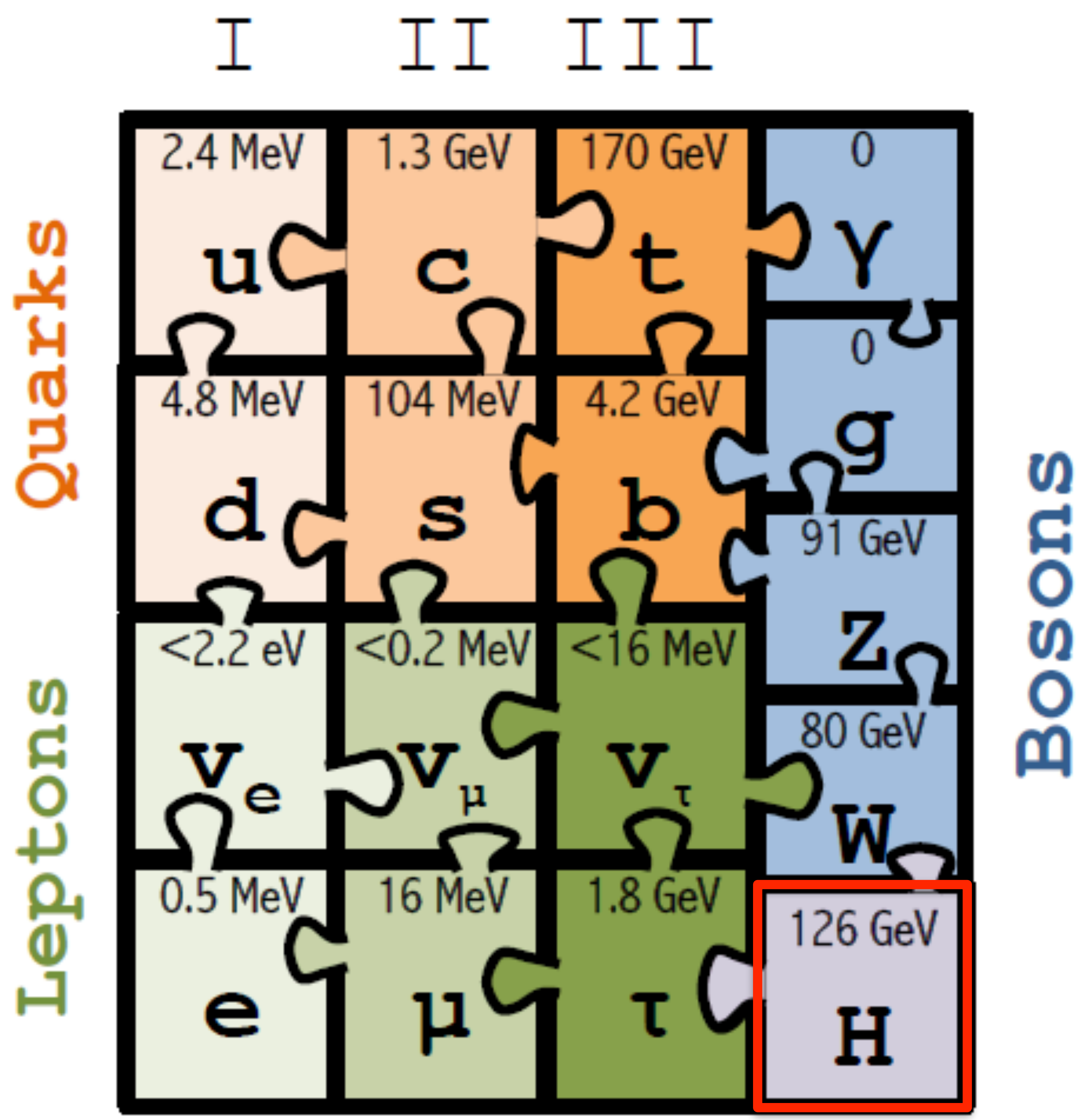

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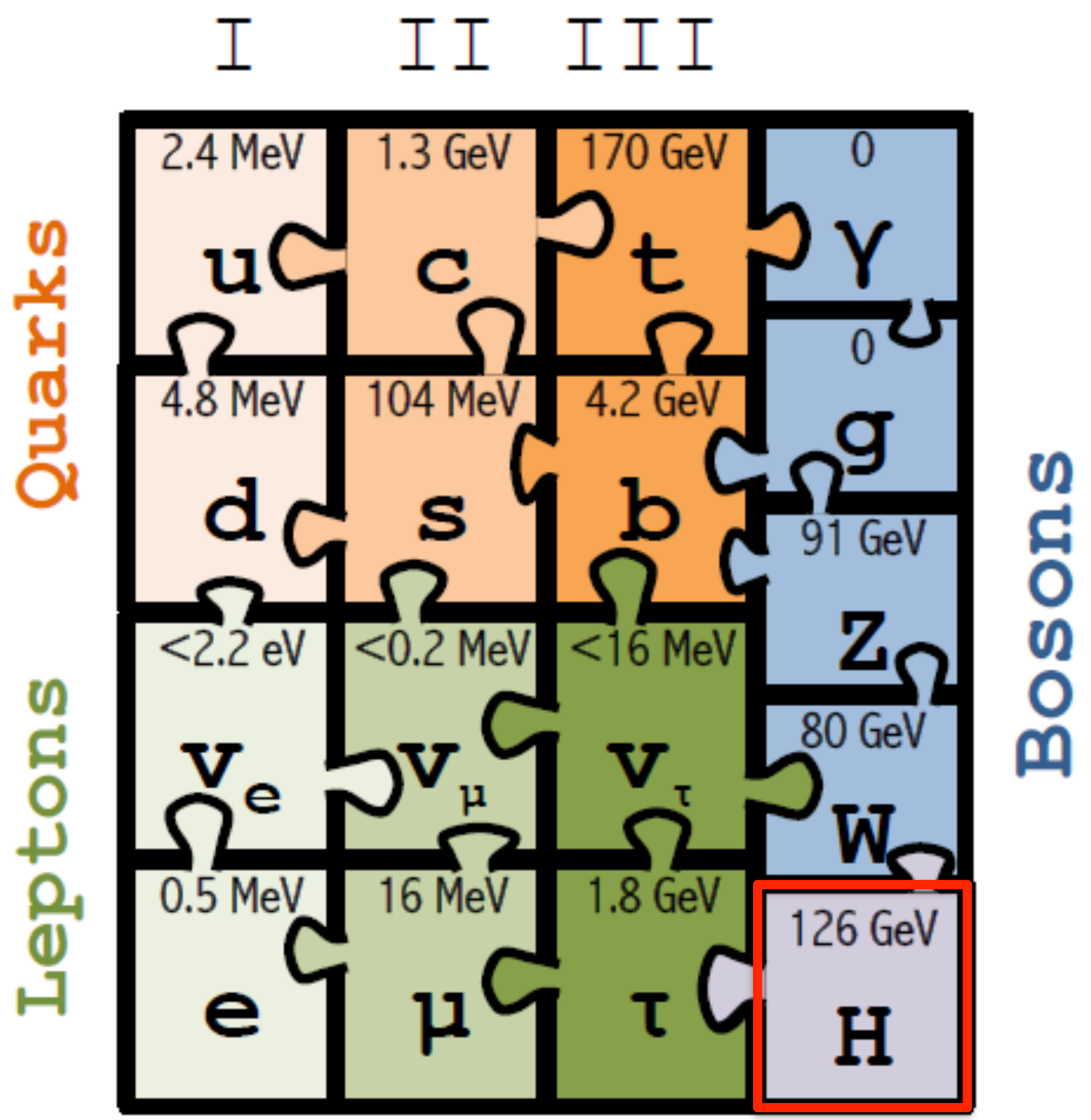

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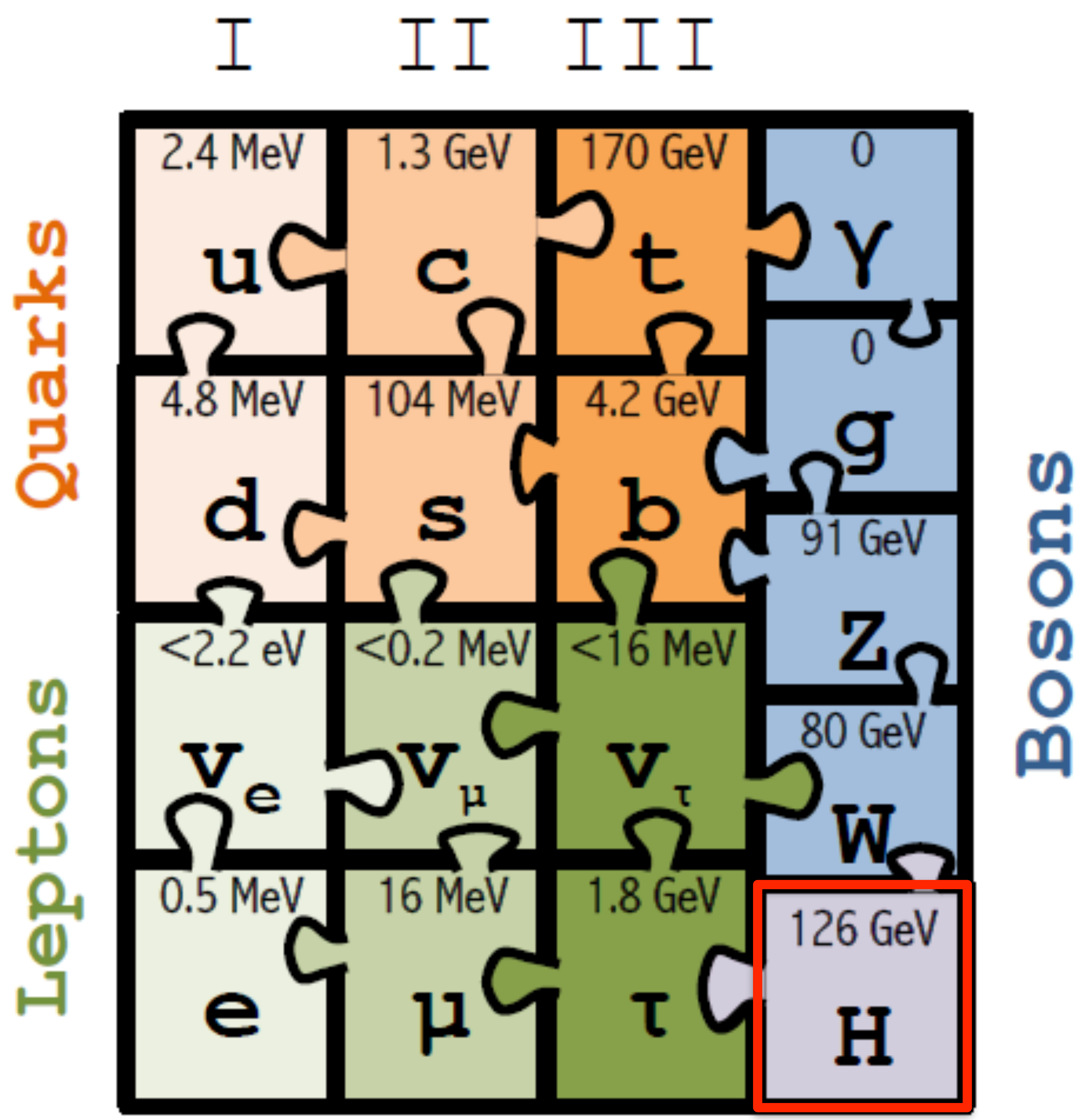

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FUTURE CIRCULAR COLLIDER

The Physics Landscape

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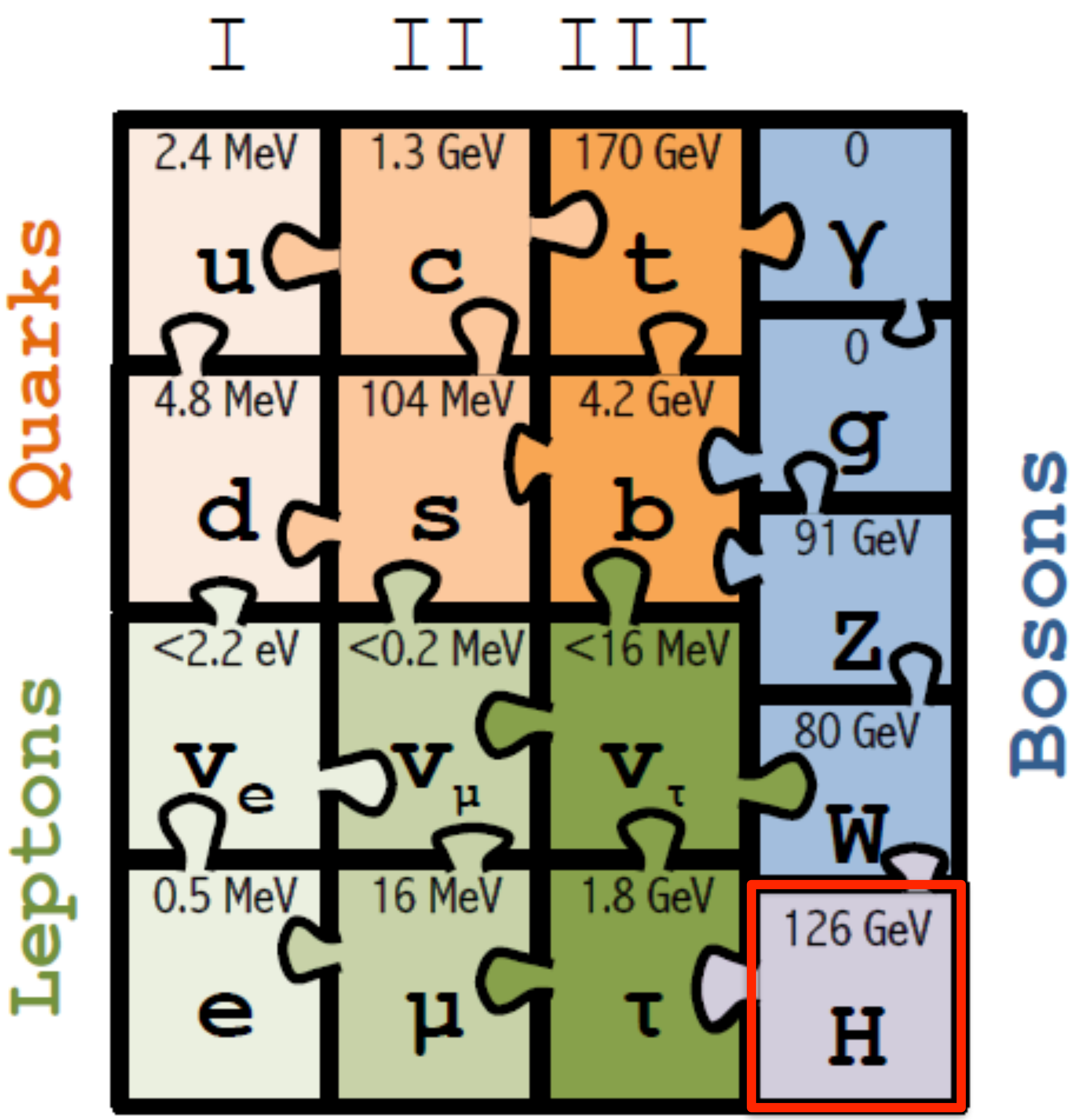

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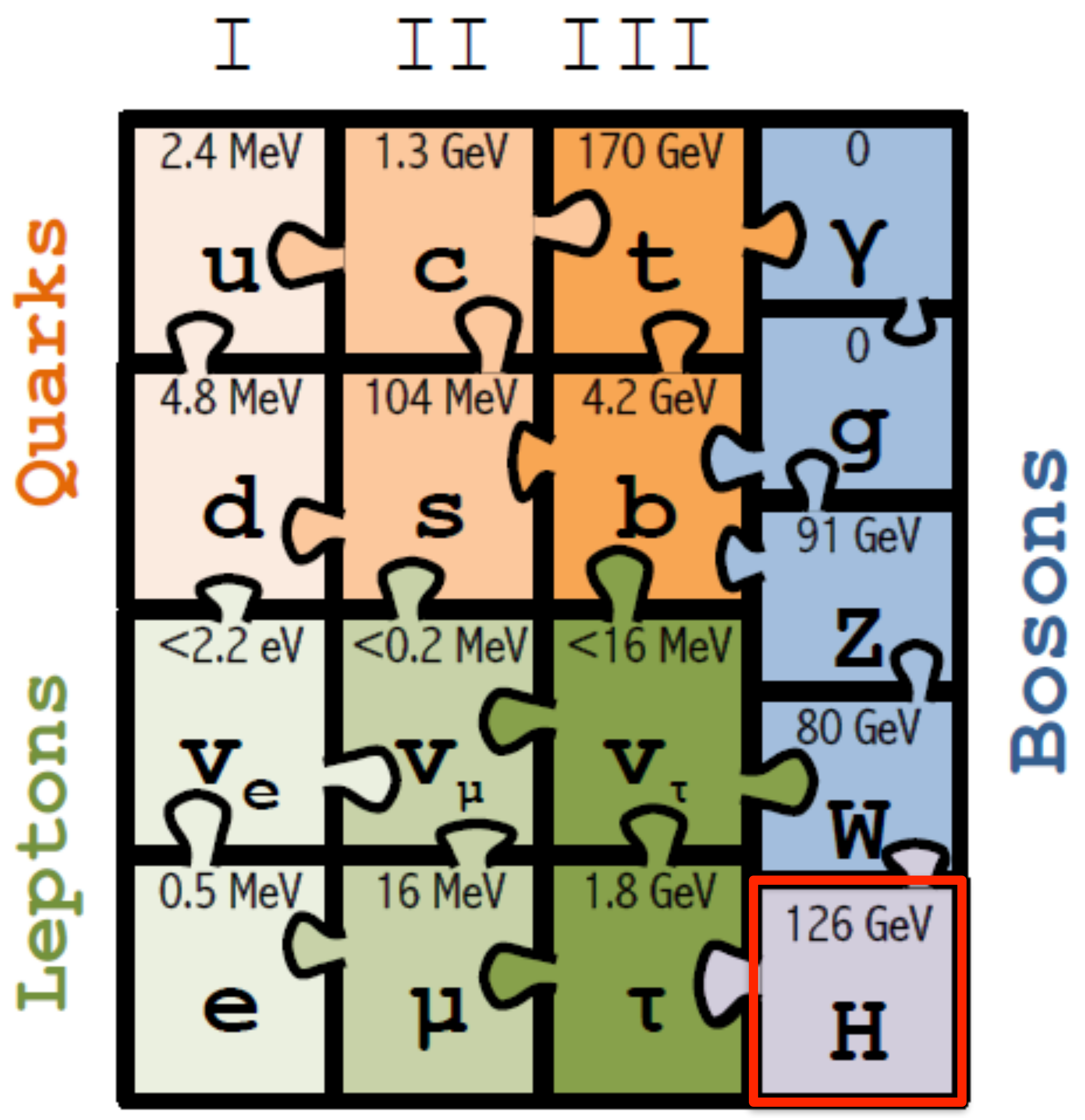

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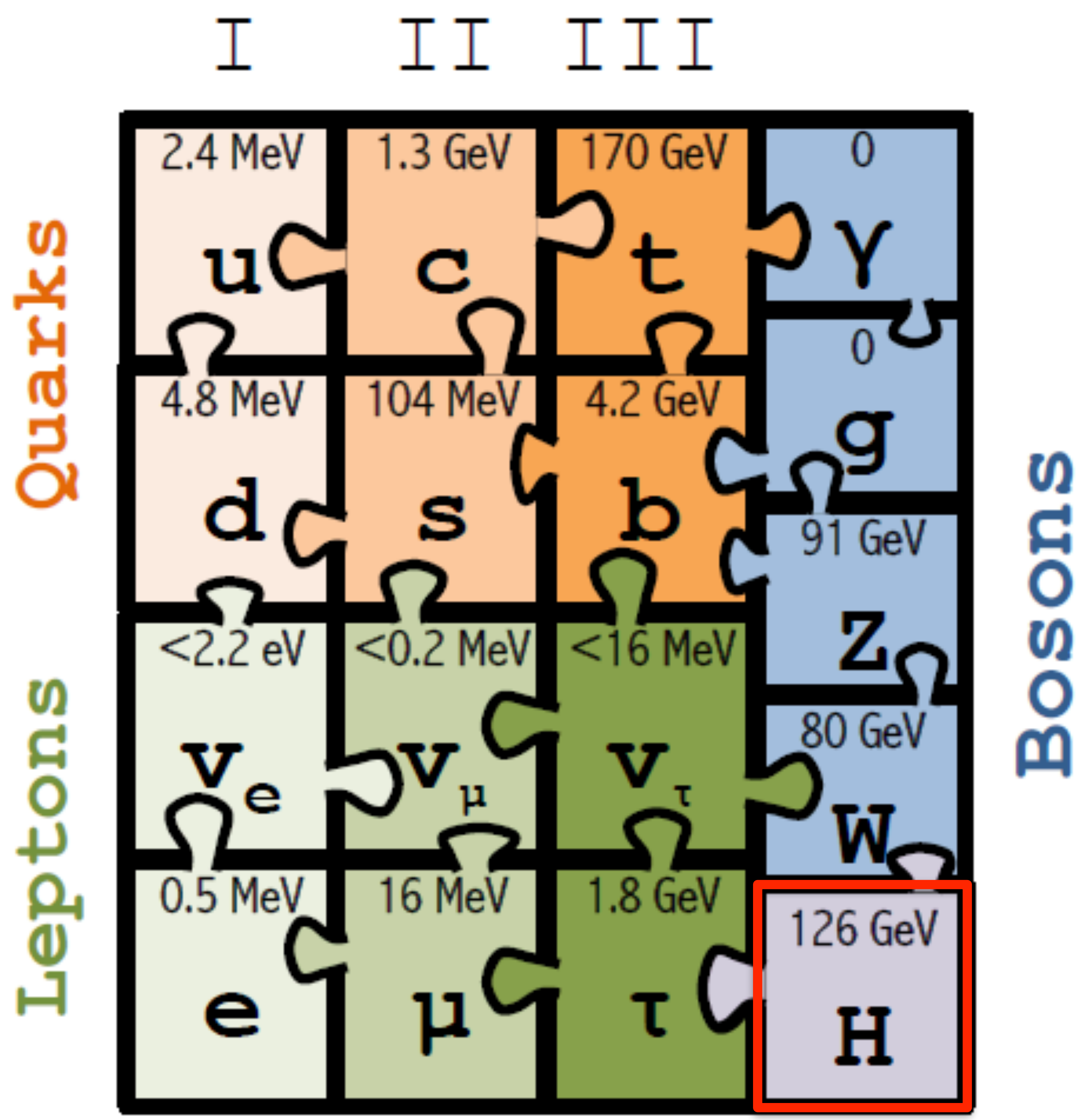

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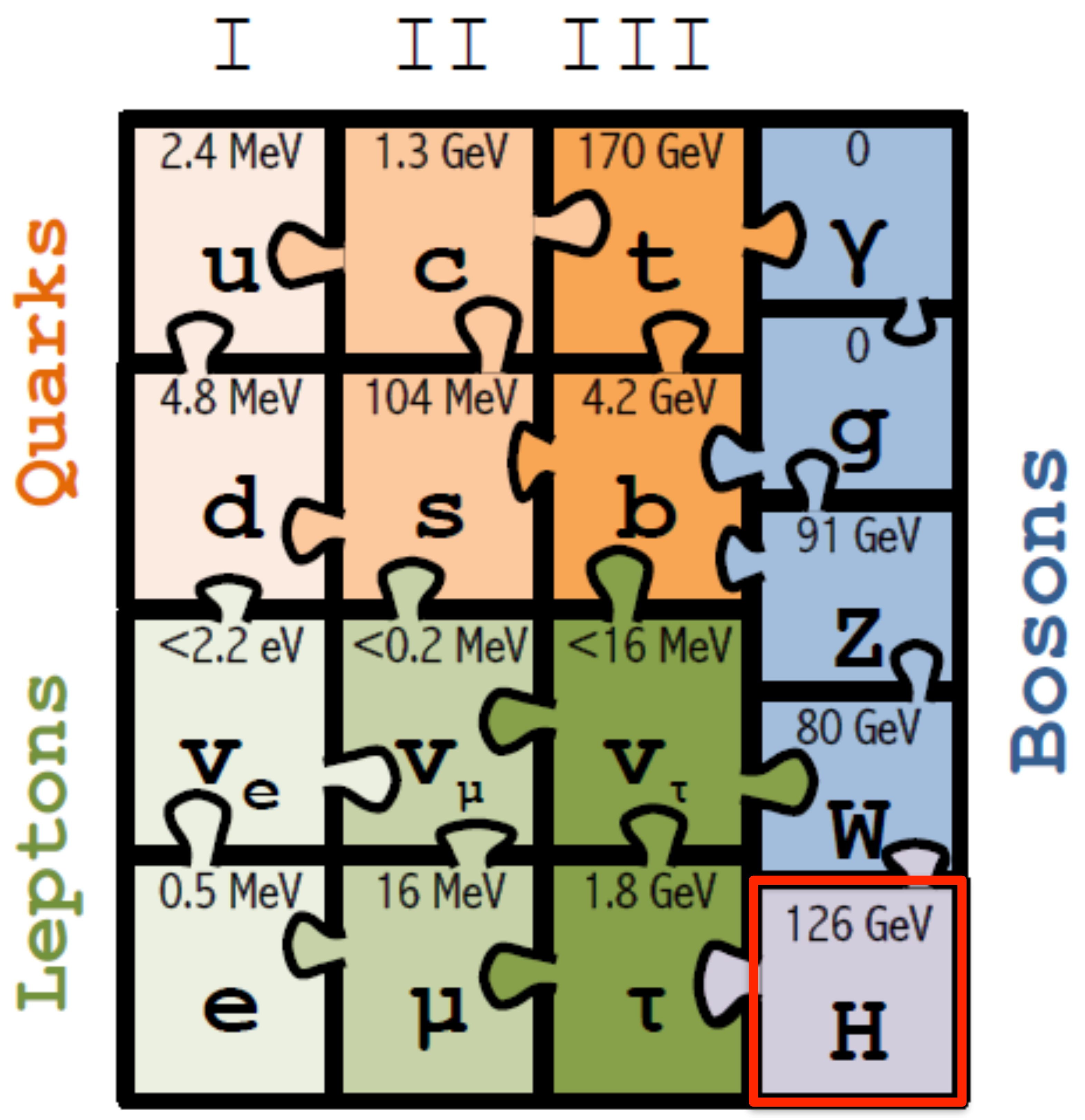

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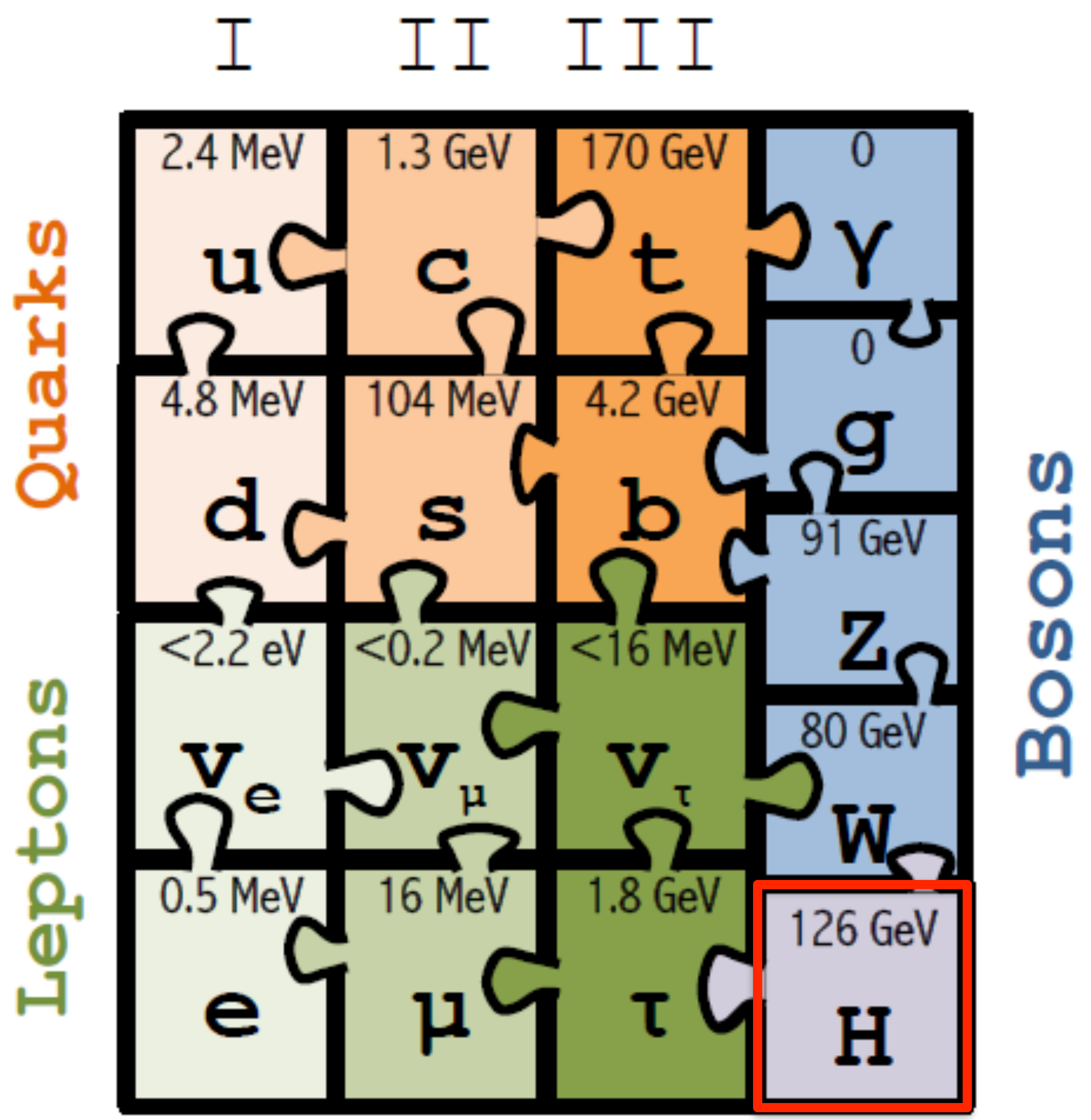

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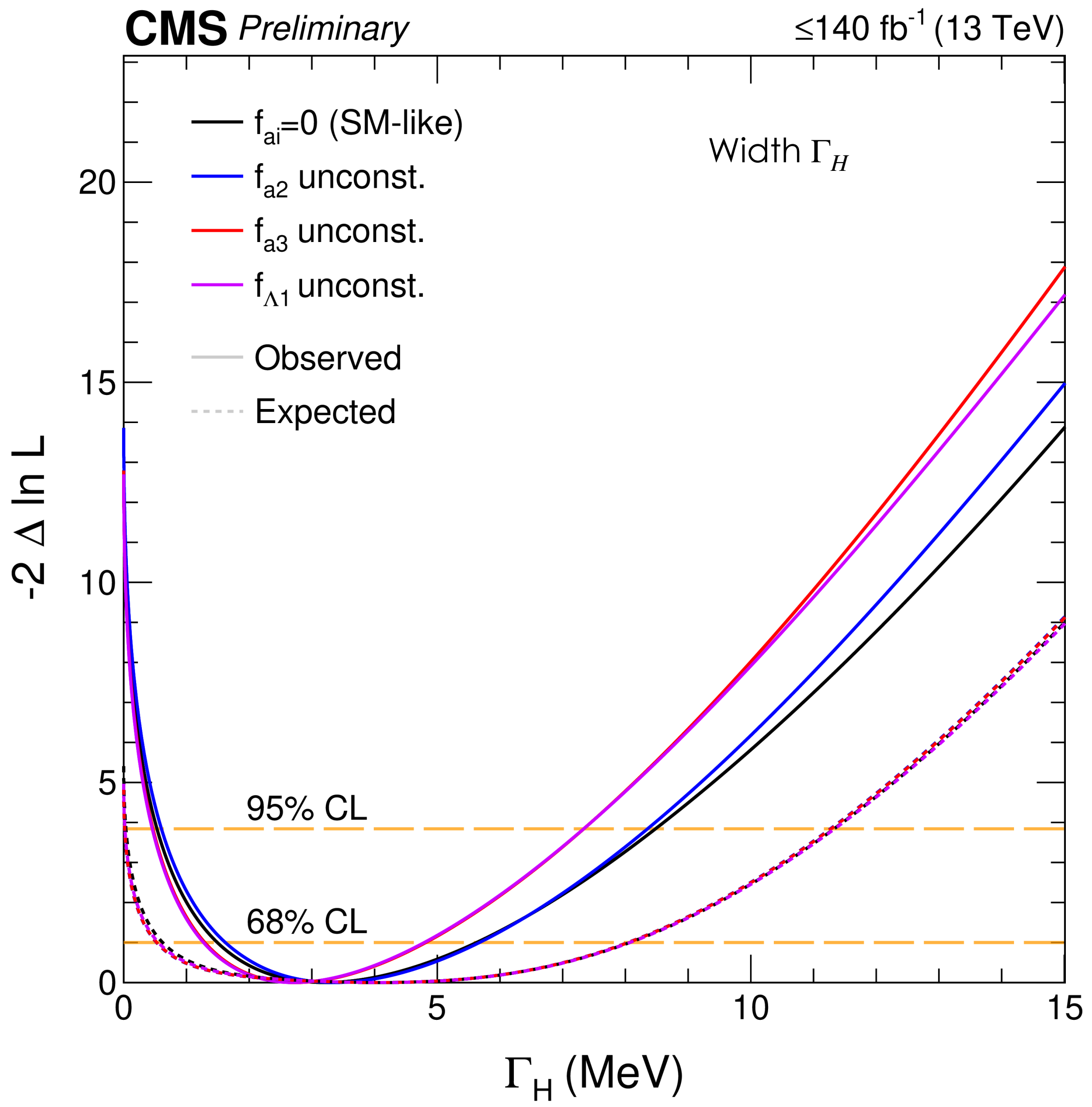
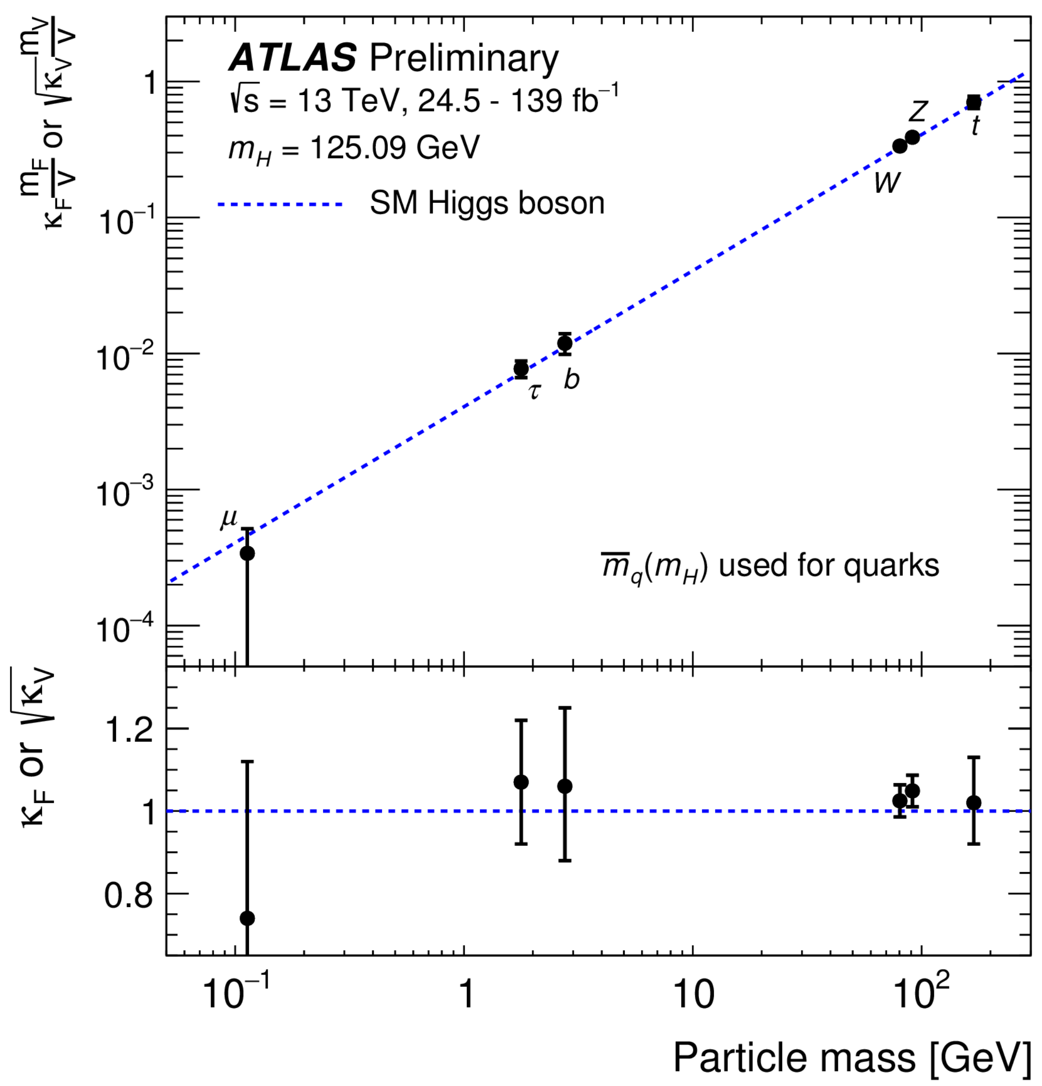
- Dark Matter
- Neutrino masses
- Matter-antimatter asymmetry
- Hierarchy problem
- etc.

P. Janot

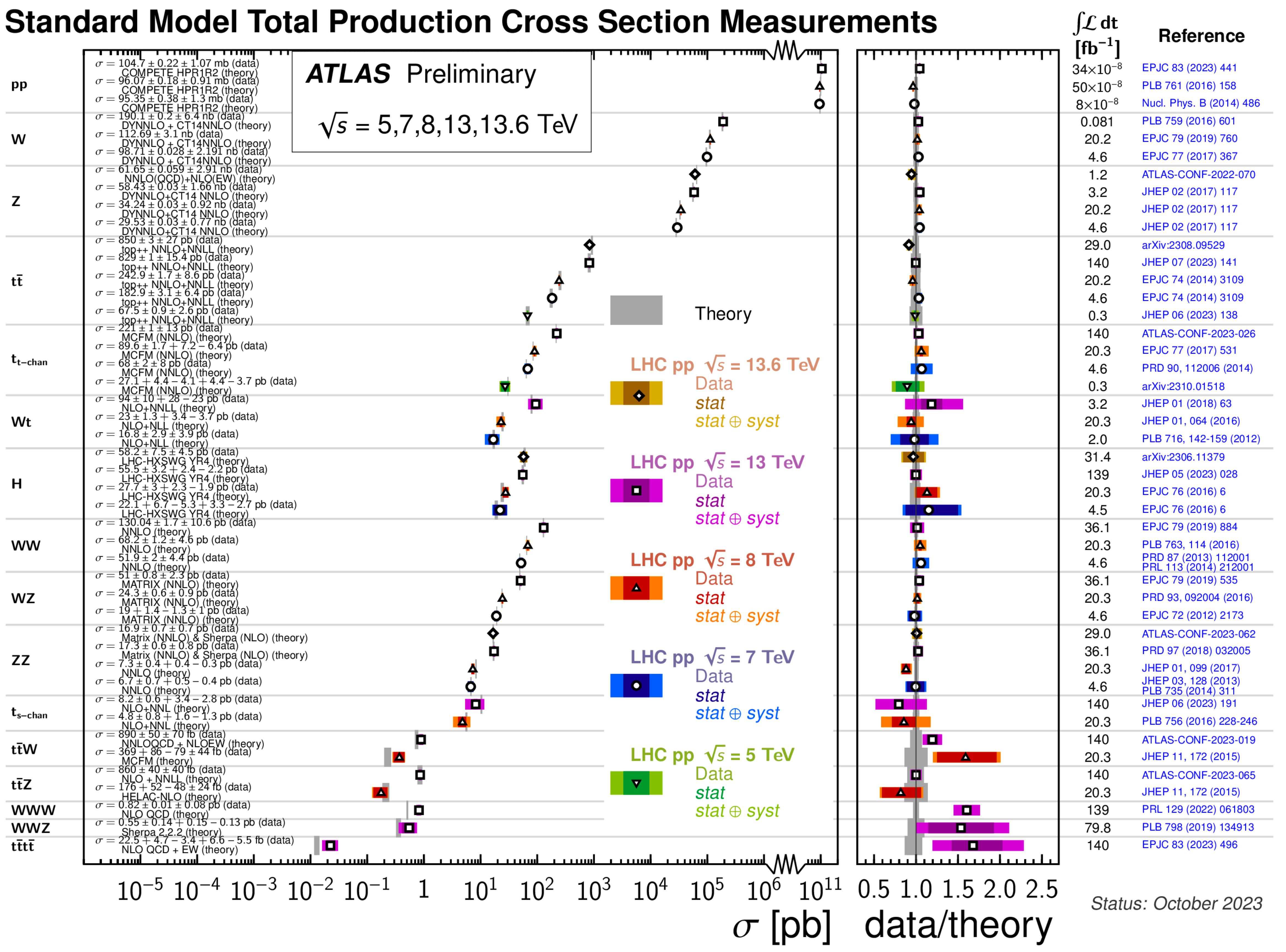
Where do we stand...

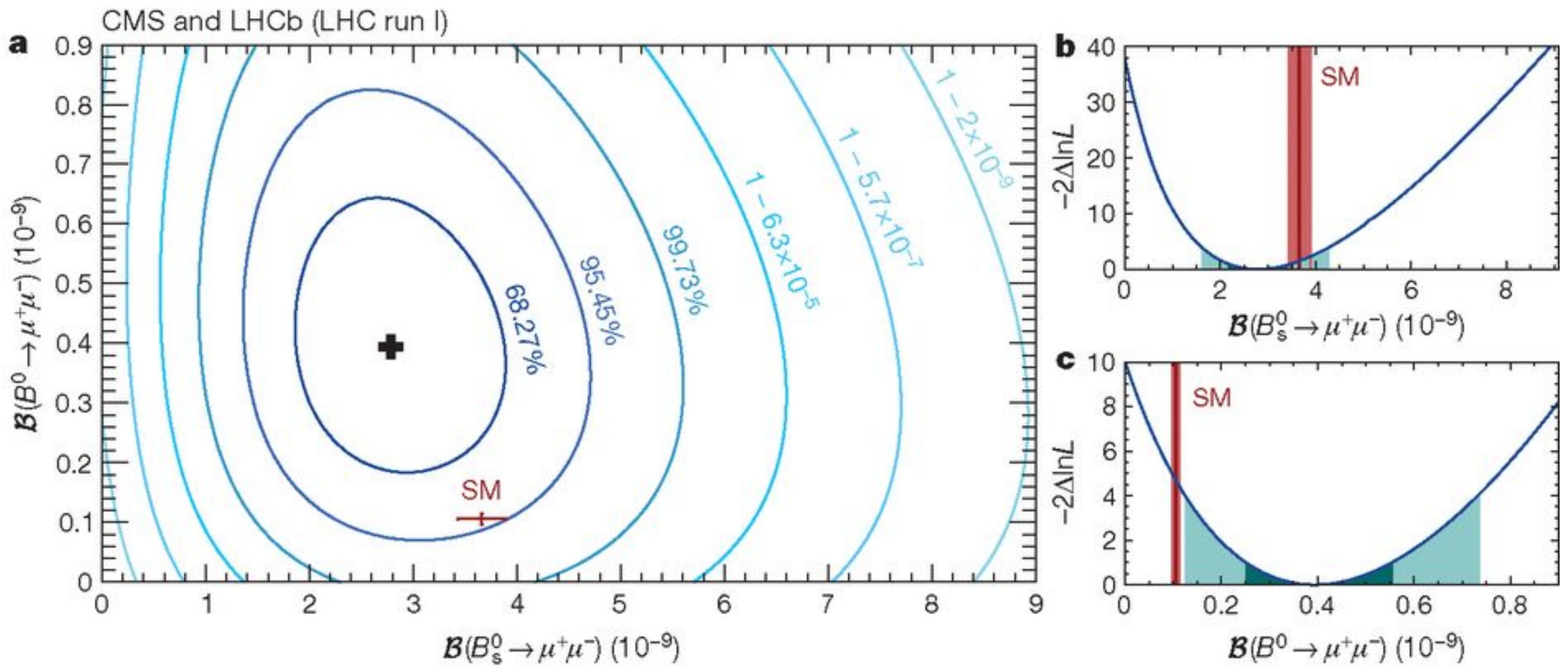
- The take-home message from the LHC so far: **this universe is very SM-like.**





No significant deviation from SM with 140 fb-1 of pp collisions (not promising for BSM at HL-LHC)





I. Vivarelli

Where do we go from here?

We are in an interesting situation

- No experimental hint to the origin of these observed phenomena
- No clear theoretical hint to indicate the best direction to go

We have no clear energy scale for new physics
We don't know its coupling strength to the SM particles

- **Next facility must be versatile**
  - With a reach as broad as possible

More Sensitivity, more Precision, more ENERGY

- A high precision, high intensity lepton collider, later followed by a high energy hadron collider offers the **best** solution

P. Janot

FUTURE CIRCULAR COLLIDER

The physics we need

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EW factory (Z,WW)

Precision SM

- $m_Z, \Gamma_Z, N_\nu, R_l, A_{FB}, m_W, \Gamma_W$
- α_s (with permille accuracy)
- Quark and gluon fragmentation
- NP QCD

BSM direct searches

Axion-like particles, dark photons, Heavy Neutral Leptons, LLPs

Flavour Physics

- 10^{11} $\tau\bar{\tau}$: tau-based EW observables, lepton universality
- 10^{12} $b\bar{b}/c\bar{c}$ pairs: flavour observables, flavour anomalies, CKM, CP, etc.

Higgs

Higgs physics

Higgs width, Higgs to invisible, couplings (including self-couplings)

Top

Top physics

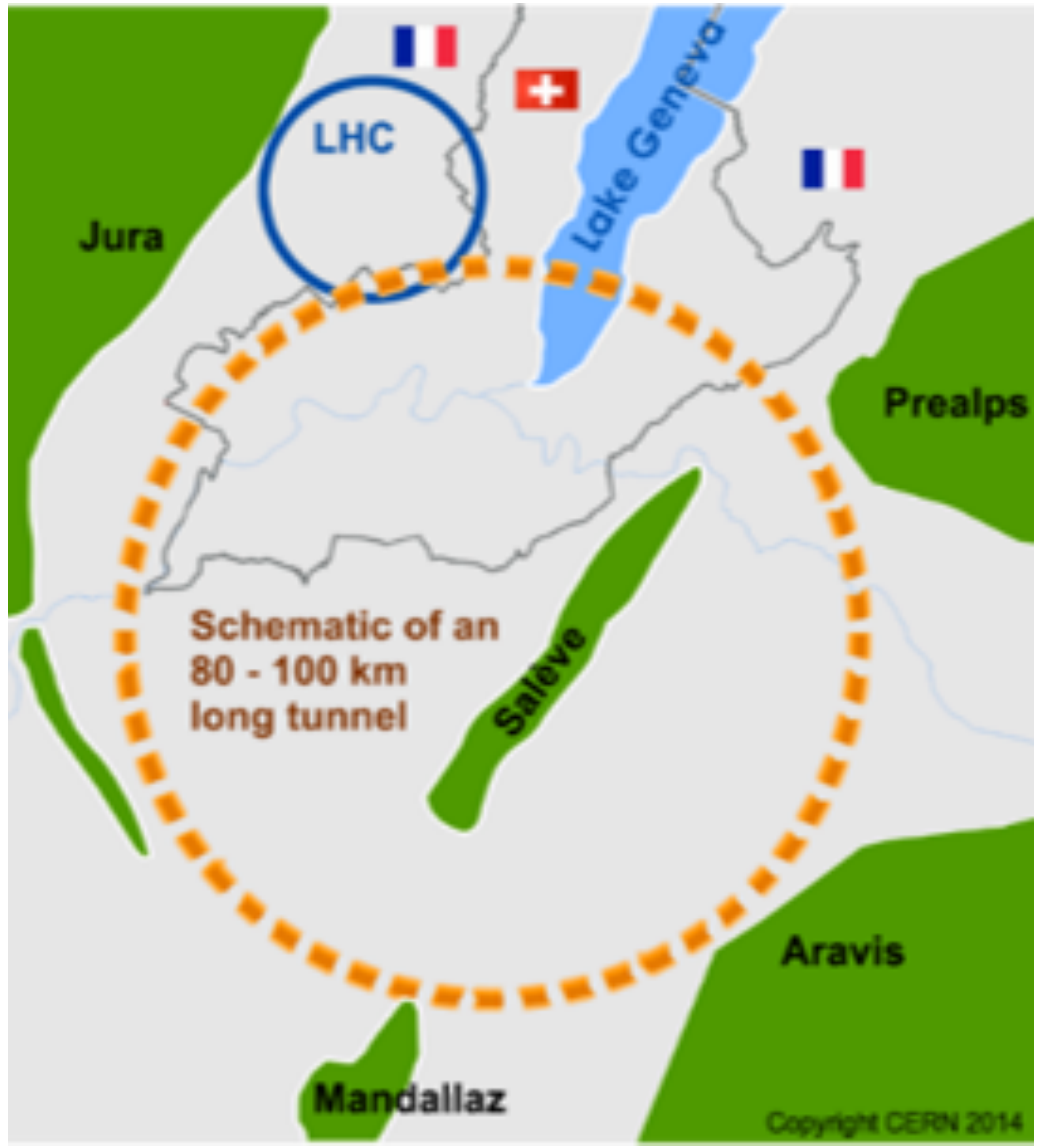
m_{top}, Γ_{top}, EW top couplings

C. Grojean

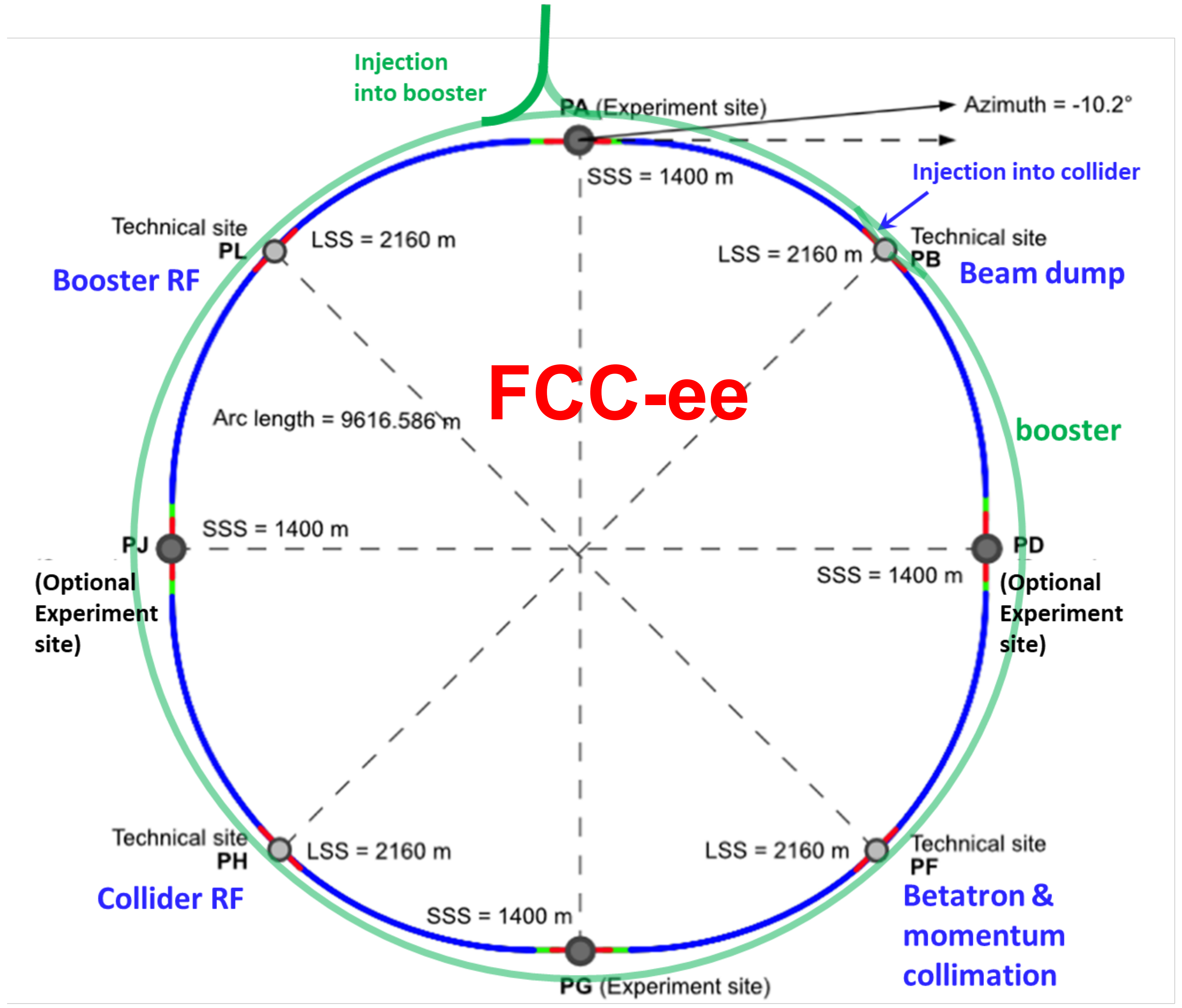
FCC integrated program

comprehensive long-term program maximizing physics opportunities

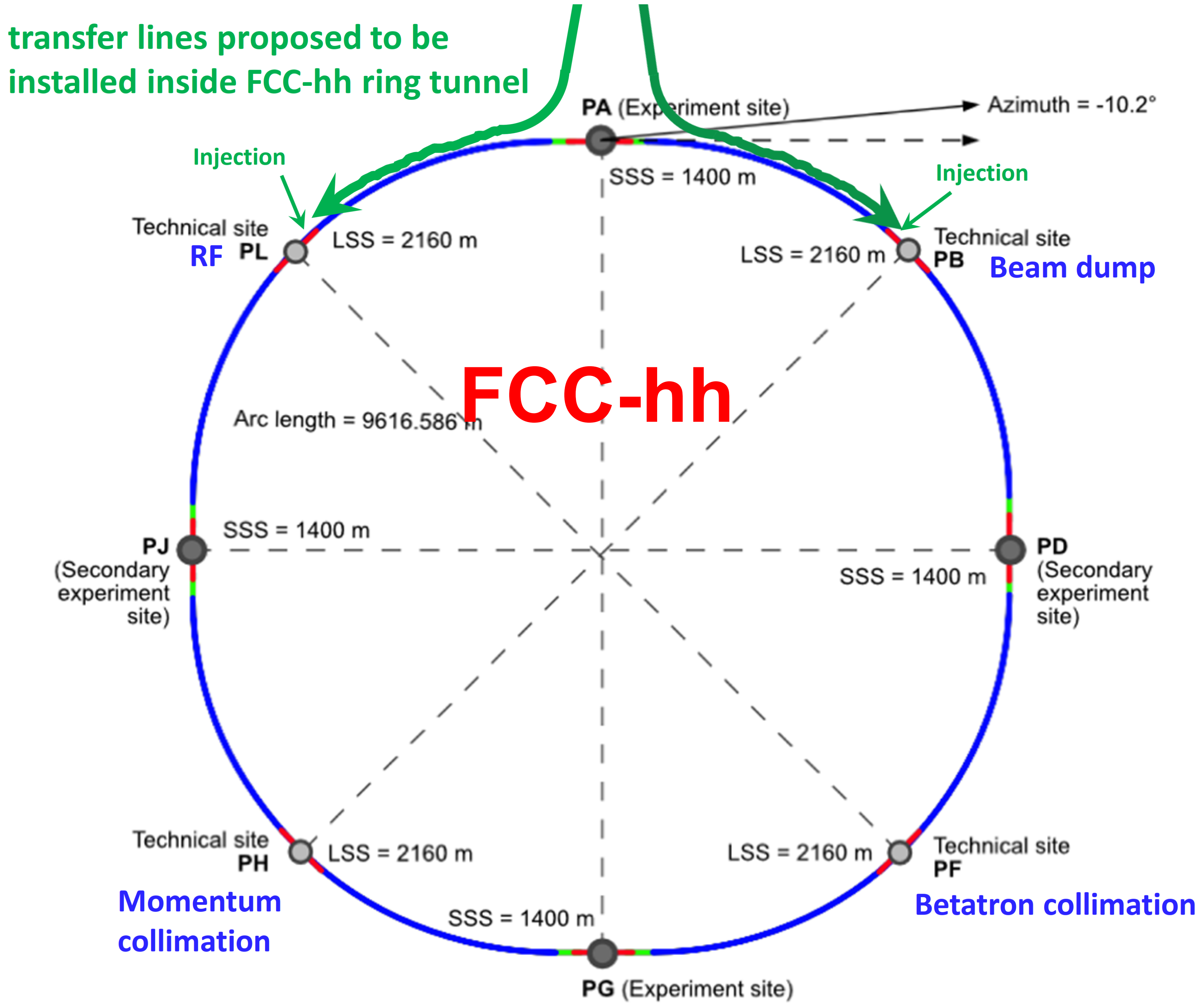
- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at the highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both colliders
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows the start of a new, major facility at CERN within a few years of the end of HL-LHC



2020 - 2040



2045 - 2063



2070 - 2095

M.Benedikt

FCC-ee main parameters

FUTURE CIRCULAR COLLIDER

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Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [mA]	1270	137	26.7	4.9
number bunches/beam	11200	1780	440	60
bunch intensity [10^{11}]	2.14	1.45	1.15	1.55
SR energy loss / turn [GeV]	0.0394	0.374	1.89	10.4
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.1/0	2.1/9.4
long. damping time [turns]	1158	215	64	18
horizontal beta* [m]	0.11	0.2	0.24	1.0
vertical beta* [mm]	0.7	1.0	1.0	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.71	1.59
vertical geom. emittance [pm]	1.9	2.2	1.4	1.6
horizontal rms IP spot size [μm]	9	21	13	40
vertical rms IP spot size [nm]	36	47	40	51
beam-beam parameter ξ_x / ξ_y	0.002/0.0973	0.013/0.128	0.010/0.088	0.073/0.134
rms bunch length with SR / BS [mm]	5.6 / 15.5	3.5 / 5.4	3.4 / 4.7	1.8 / 2.2
luminosity per IP [10^{34} cm^{-2}s^{-1}]	140	20	5.0	1.25
total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.6	0.15
beam lifetime rad Bhabha + BS [min]	15	12	12	11
	4 years 5 x 10^{12} Z LEP x 10^5	2 years > 10^8 WW LEP x 10^4	3 years 2 x 10^6 H	5 years 2 x 10^6 tt pairs

Design and parameters dominated by the choice to allow for 50 MW synchrotron radiation per beam.

- x 10-50 improvements on all EW observables
- up to x 10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
- x10 Belle II statistics for b, c, τ
- indirect discovery potential up to ~ 70 TeV
- direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

Up to 4 interaction points → robustness, statistics, possibility of specialised detectors to maximise physics output

F. Gianotti

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vertical [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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The whole LEP1 programme in 2 minutes!!

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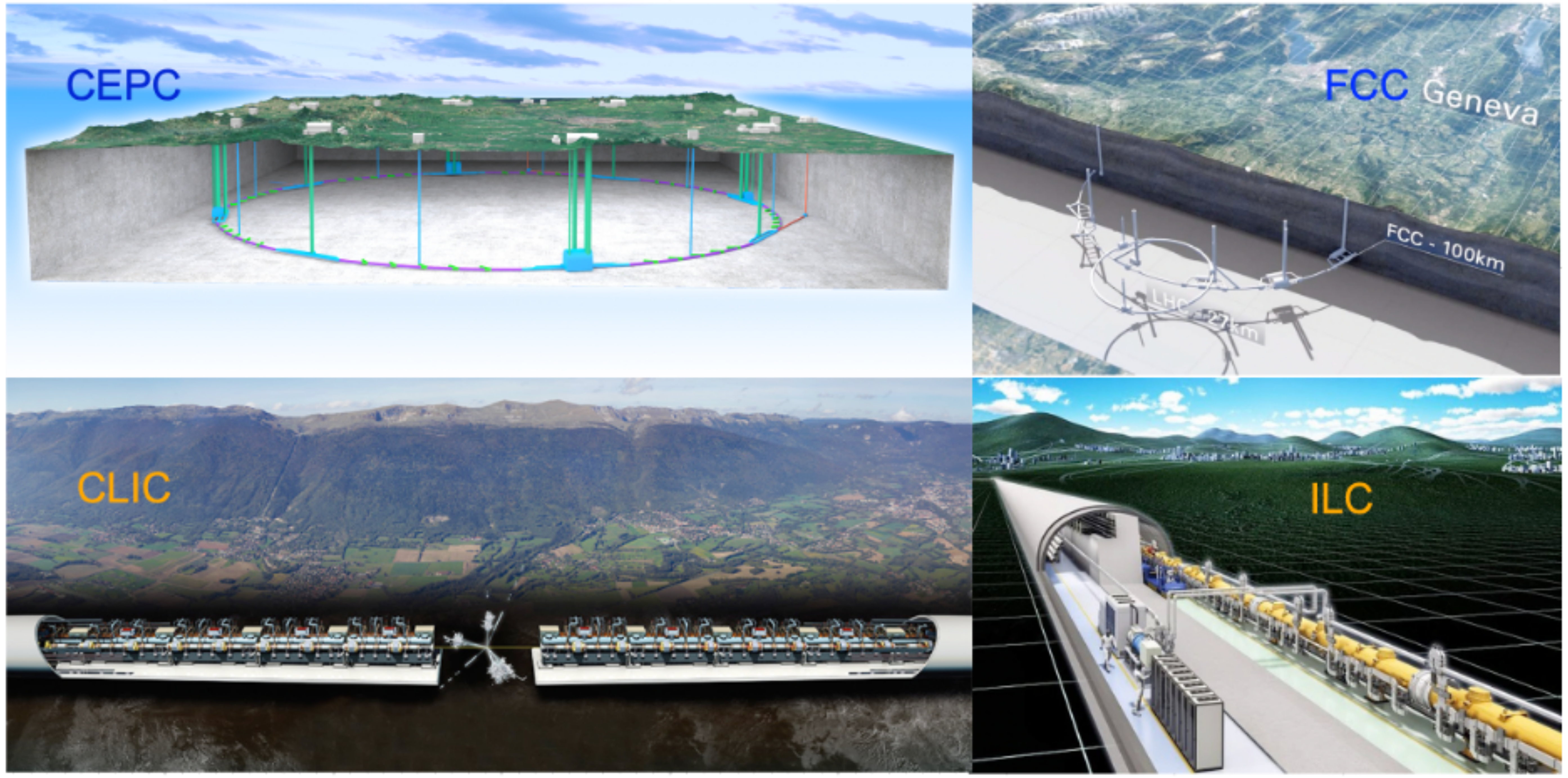
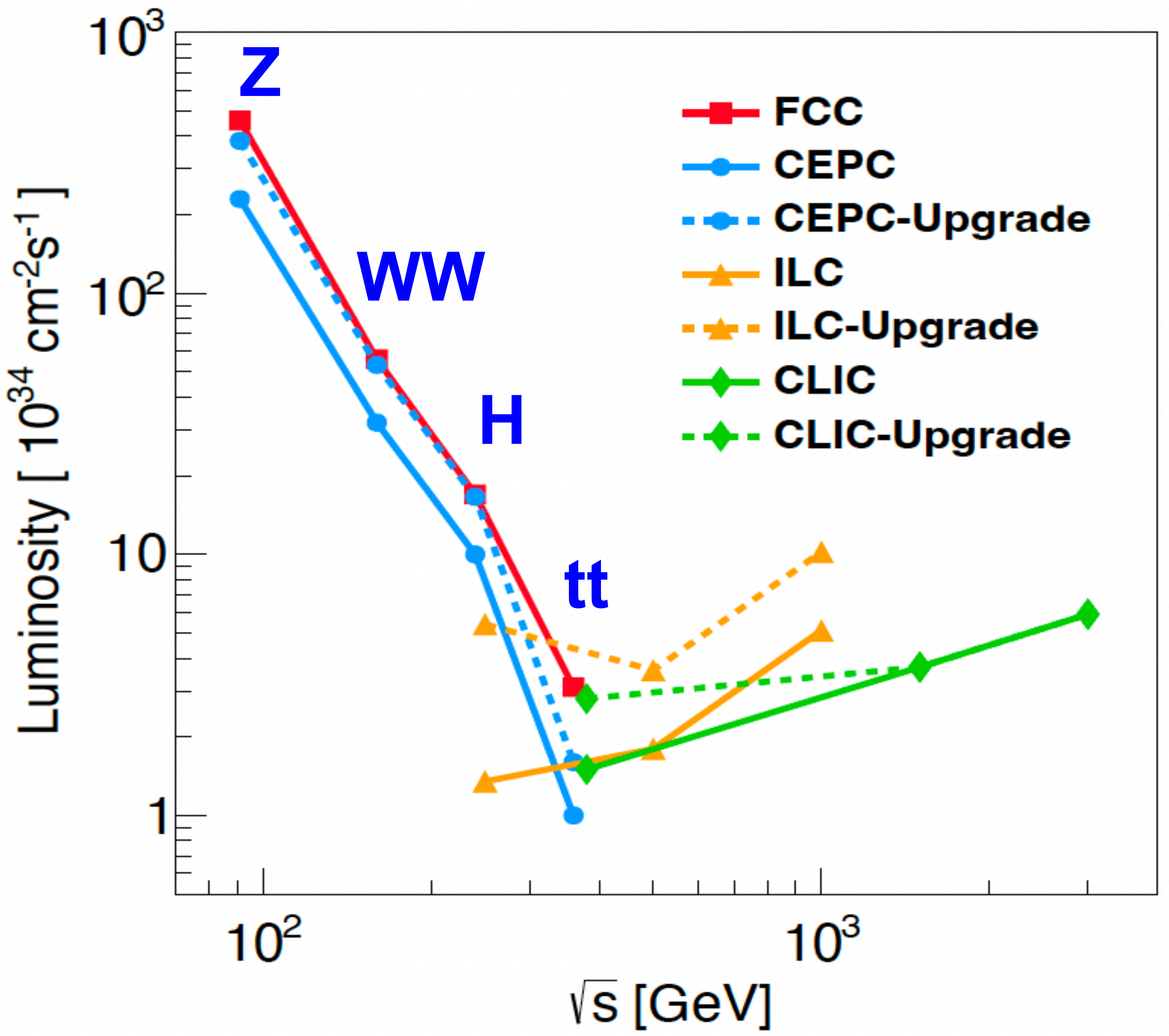
Comparison of Higgs factories: Circular vs. Linear



Circular colliders have a clear luminosity advantage up to √s ~ 400 GeV

CEPC Accelerator white paper for Snowmass21, arXiv:2203.09451



CEPC versus FCC-ee

- Earlier data: collisions expected in 2030s (vs. ~ 2040s)
- Large tunnel cross section (ee & pp coexistence)
- Lower construction cost
- Green field: Lab, complete infrastructure to be built

Circular versus Linear Colliders

- Higher luminosity / precision for Higgs & Z
- Potential upgrade for pp collider

H. Yang

Why circular is better than linear...

Optimal energy range for SM particles

Sharpen and challenge our knowledge of already existing physics

LEP1 statistics in a few minutes

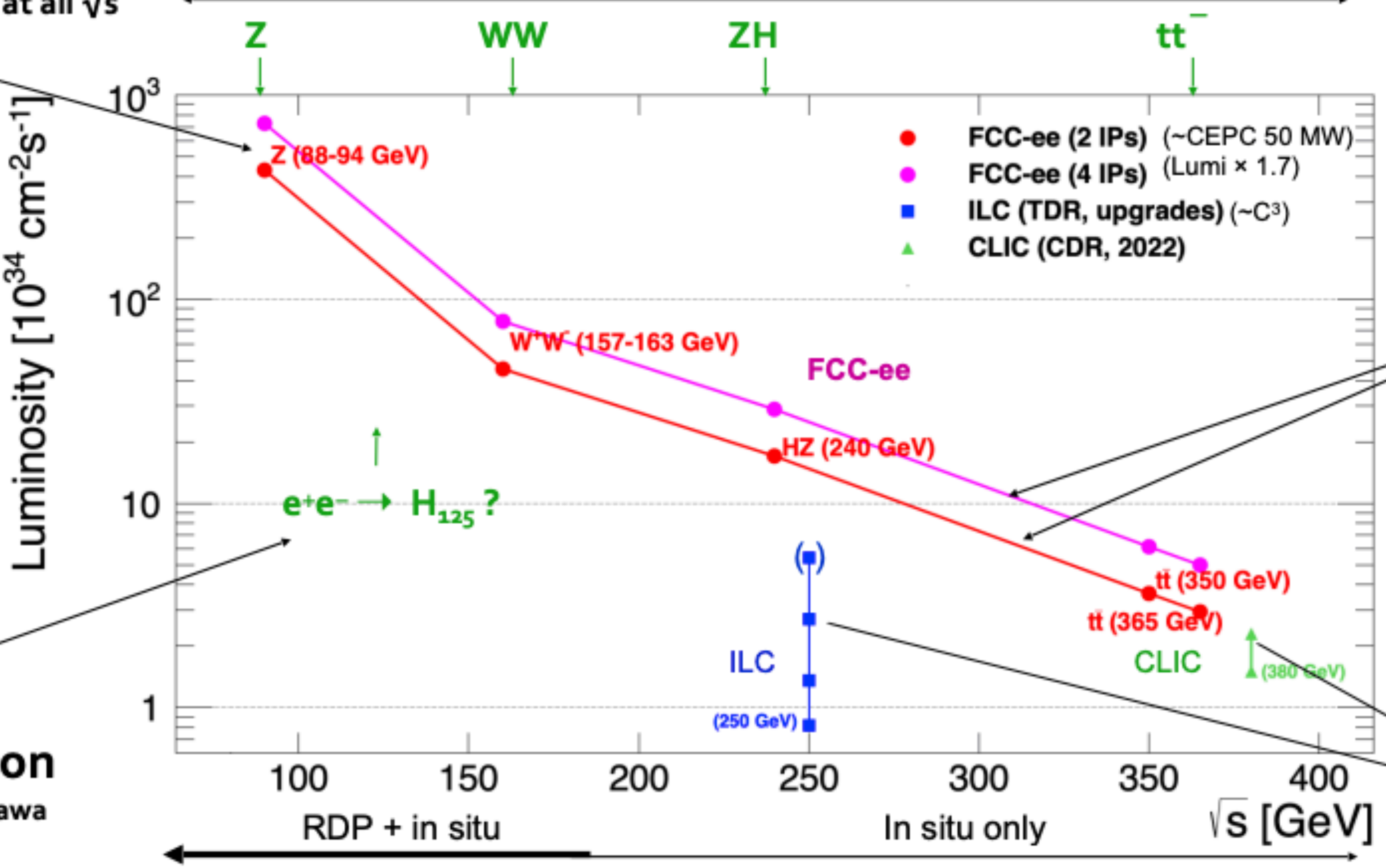
Detector calibration/alignment at all √s

Highest luminosities

Less running time for a given physics outcome
Better physics outcome for a given running time
Increase discovery potential

Serve up to 4 interaction points

Net overall gain in MW/ab⁻¹ or CO2-eq/ab⁻¹
Essential redundancy for precision measurements
May satisfy all detector requirements
Increase discovery potential
Enhance the community (FCC/CERN clients)



√s Monochromatisation

Unique opportunity for electron Yukawa

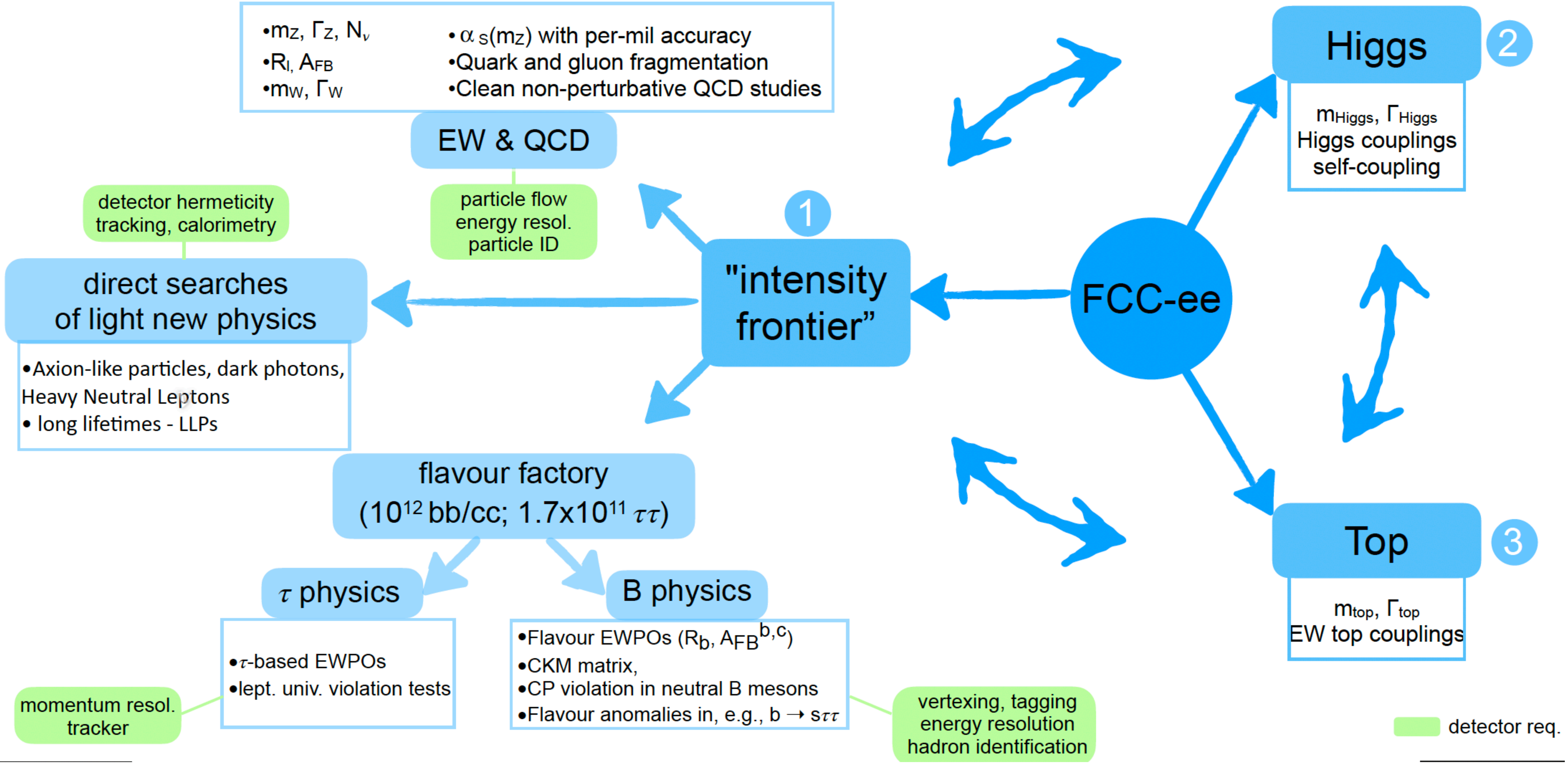
Motivates the competition

Luminosity is the name of the game

Precise and continuous √s, √s spread, boost determination

Both with resonant depolarisation (RDP) and with collision events in up to four detectors
Essential for precision measurements

FCC-ee Physics programme



C. Grojean

FCC-ee explore and discover

- **EXPLORE INDIRECTLY the 10-100 TeV energy scale with precision measurements**
  - From the correlated properties of the Z , b, c, τ, W, Higgs, and top particles
  - Up to 20-50-fold improved precision on ALL electroweak observables (EWPO)
  - Up to 10 × more precise and model-independent Higgs couplings (width, mass) measurements
- **DISCOVER that the Standard Model does not fit**
- **DISCOVER a violation of flavour conservation/universality**
- **DISCOVER dark matter, e.g., as invisible decays of Higgs or Z**
- **DISCOVER DIRECTLY elusive (aka feebly-coupled) particles**
  - in the 5-100 GeV mass range, such as right-handed neutrino

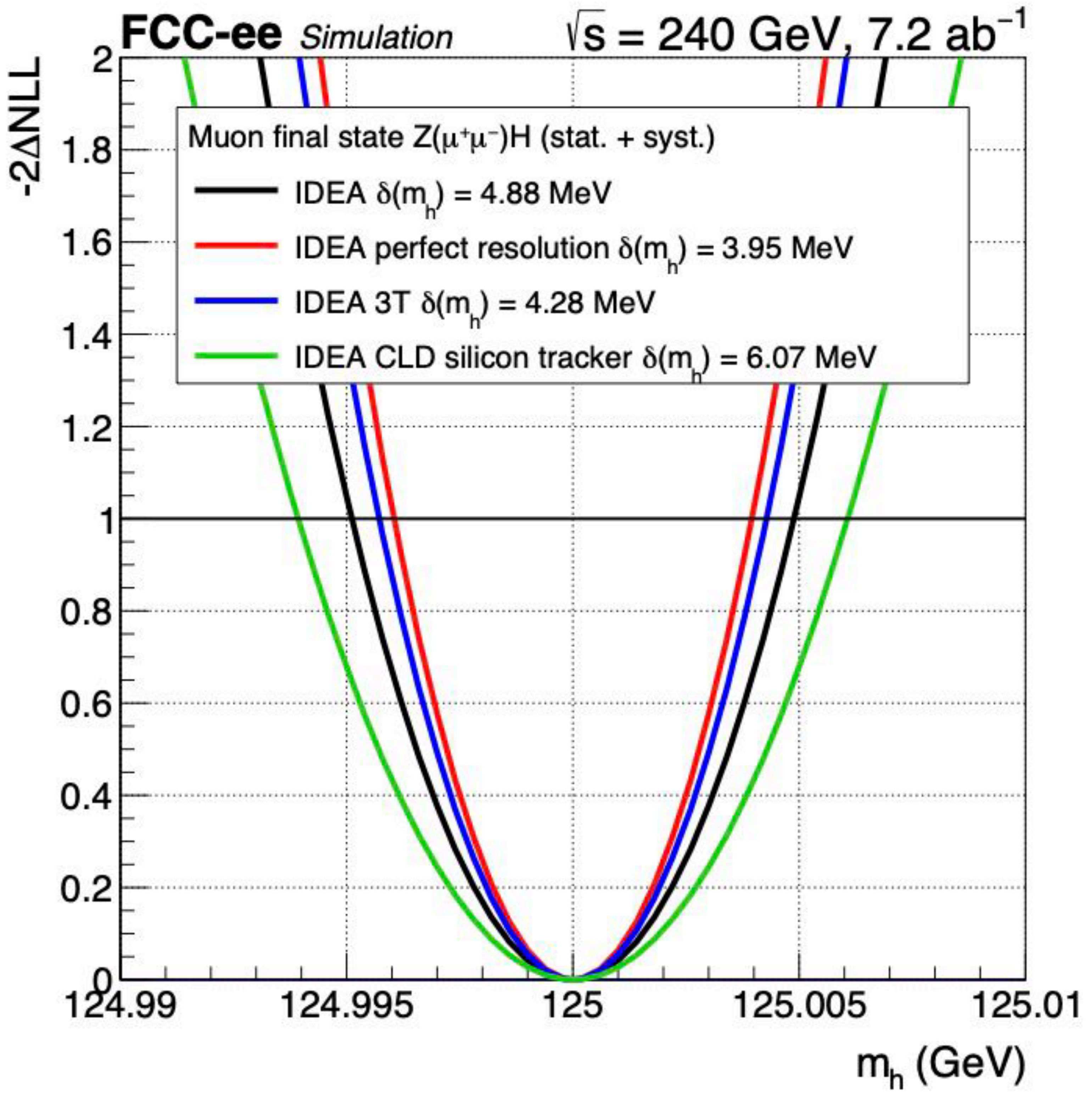
P. Azzi

EW observables at the Z

5×10^{12} $e^+e^- \rightarrow Z$

From data collected in a lineshape energy scan:

- **Z mass** (key for jump in precision for ewk fits)
- **Z width** (jump in sensitivity to ewk rad corr)
- **R_l** = hadronic/leptonic width ($\alpha_s(m_Z^2)$, lepton couplings)
- **peak cross section** (invisible width, N_ν)
- **$A_{FB}(\mu\mu)$** ($\sin^2\theta_{eff}$, $\alpha_{QED}(m_Z^2)$, lepton couplings)

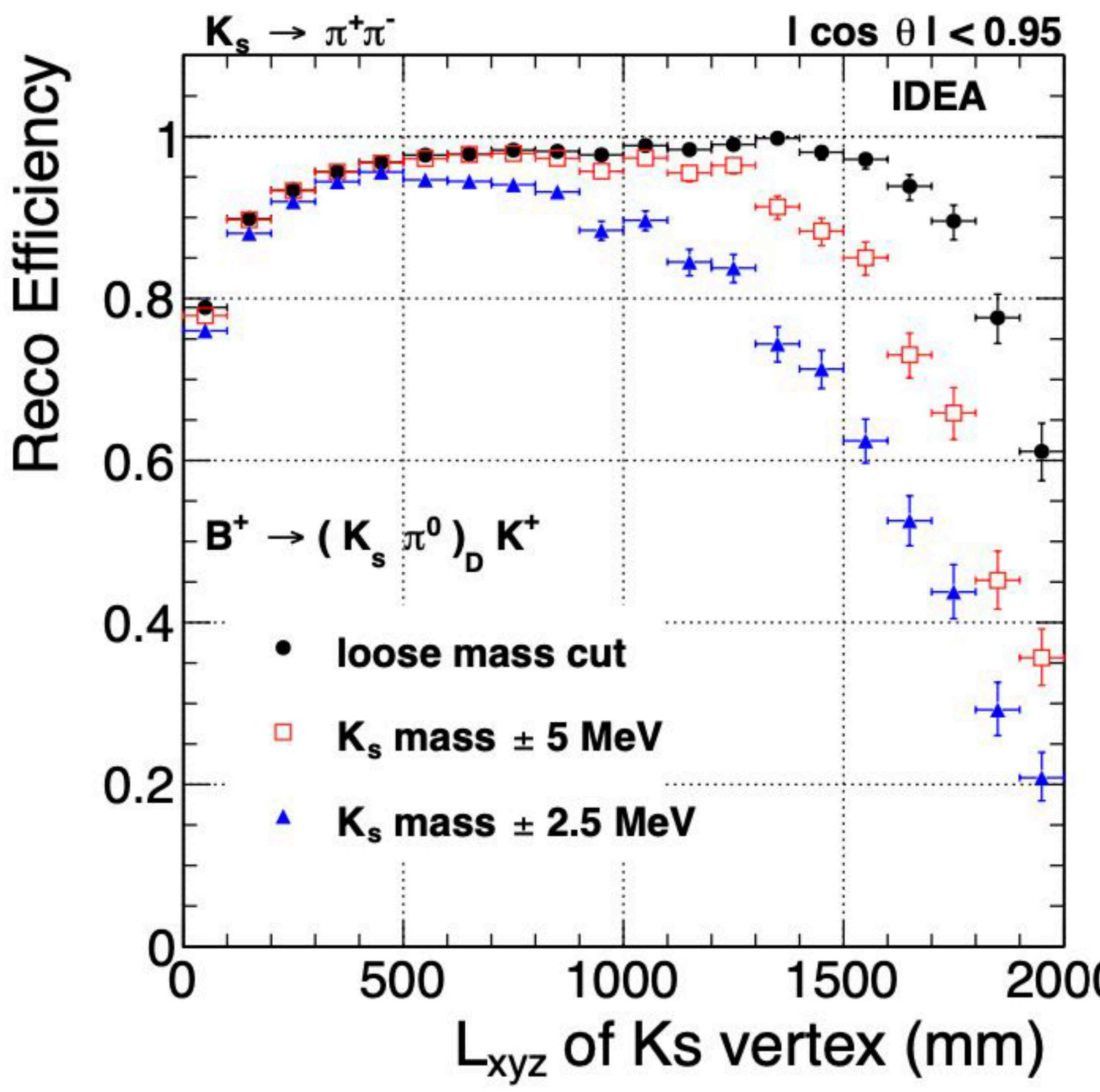


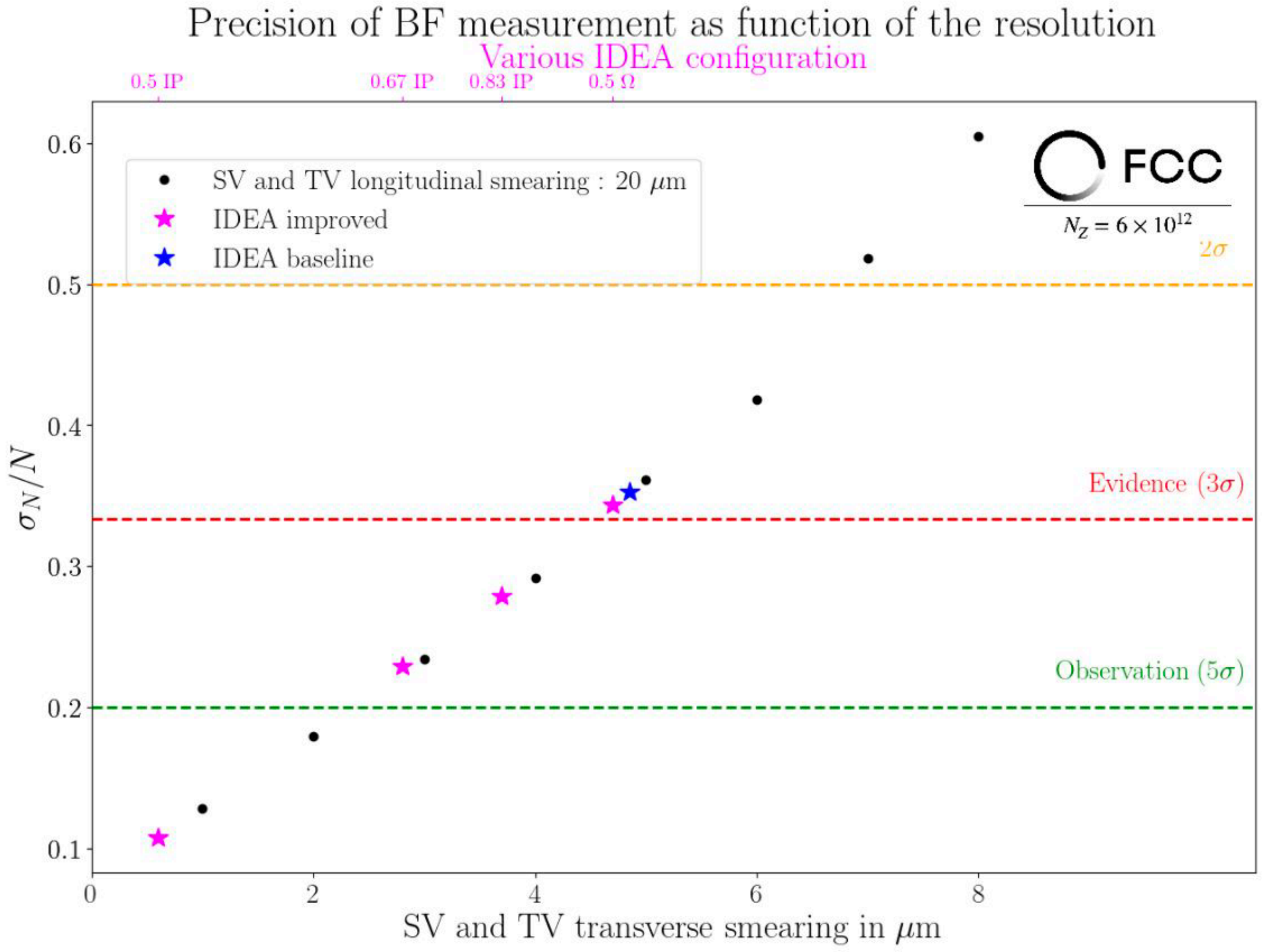
R. Tenchini, P. Azzi

Flavour potential

10^{12} bb/cc, 1.7x10^{11} ττ

- **R_b, R_c, A_{FB}(bb), A_{FB}(cc)** (quark couplings)
- **CKM matrix**
- **CP violation in neutral B mesons**
- **Flavour anomalies**
- **Tau polarization** ($\sin^2\theta_{eff}$, lepton couplings, $\alpha_{QED}(m_Z^2)$)
- much more...





R. Tenchini, P. Azzi

Flavour physics with Tera-Z run

Particle production (10^9)	B^0	B^-	B^0_s	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	600	170

FCC-ee = 10 x BelleII

Decay mode/Experiment	Belle II (50/ab)	LHCb Run I	LHCb Upgr. (50/fb)	FCC-*ee*
EW/H penguins				
$B^0 \to K^*(892)e^+e^-$	~ 2000	~ 150	~ 5000	~ 200000
$\mathcal{B}(B^0 \to K^*(892)\tau^+\tau^-)$	~ 10	–	–	~ 1000
$B_s \to \mu^+\mu^-$	n/a	~ 15	~ 500	~ 800
$B^0 \to \mu^+\mu^-$	~ 5	–	~ 50	~ 100
$\mathcal{B}(B_s \to \tau^+\tau^-)$				
Leptonic decays				
$B^+ \to \mu^+\nu_{mu}$	5%	–	–	3%
$B^+ \to \tau^+\nu_{tau}$	7%	–	–	2%
$B_c^+ \to \tau^+\nu_{tau}$	n/a	–	–	5%
CP / hadronic decays				
$B^0 \to J/\Psi K_S$ ($\sigma_{\sin(2\phi_d)}$)	$\sim 2. * 10^6$ (0.008)	41500 (0.04)	$\sim 0.8 \cdot 10^6$ (0.01)	$\sim 35 \cdot 10^6$ (0.006)
$B_s \to D_s^\pm K^\mp$	n/a	6000	~ 200000	$\sim 30 \cdot 10^6$
$B_s(B^0) \to J/\Psi\phi$ (σ_{ϕ_s} rad)	n/a	96000 (0.049)	$\sim 2.10^6$ (0.008)	$16 \cdot 10^6$ (0.003)

boosted b's/τ's at FCC-ee

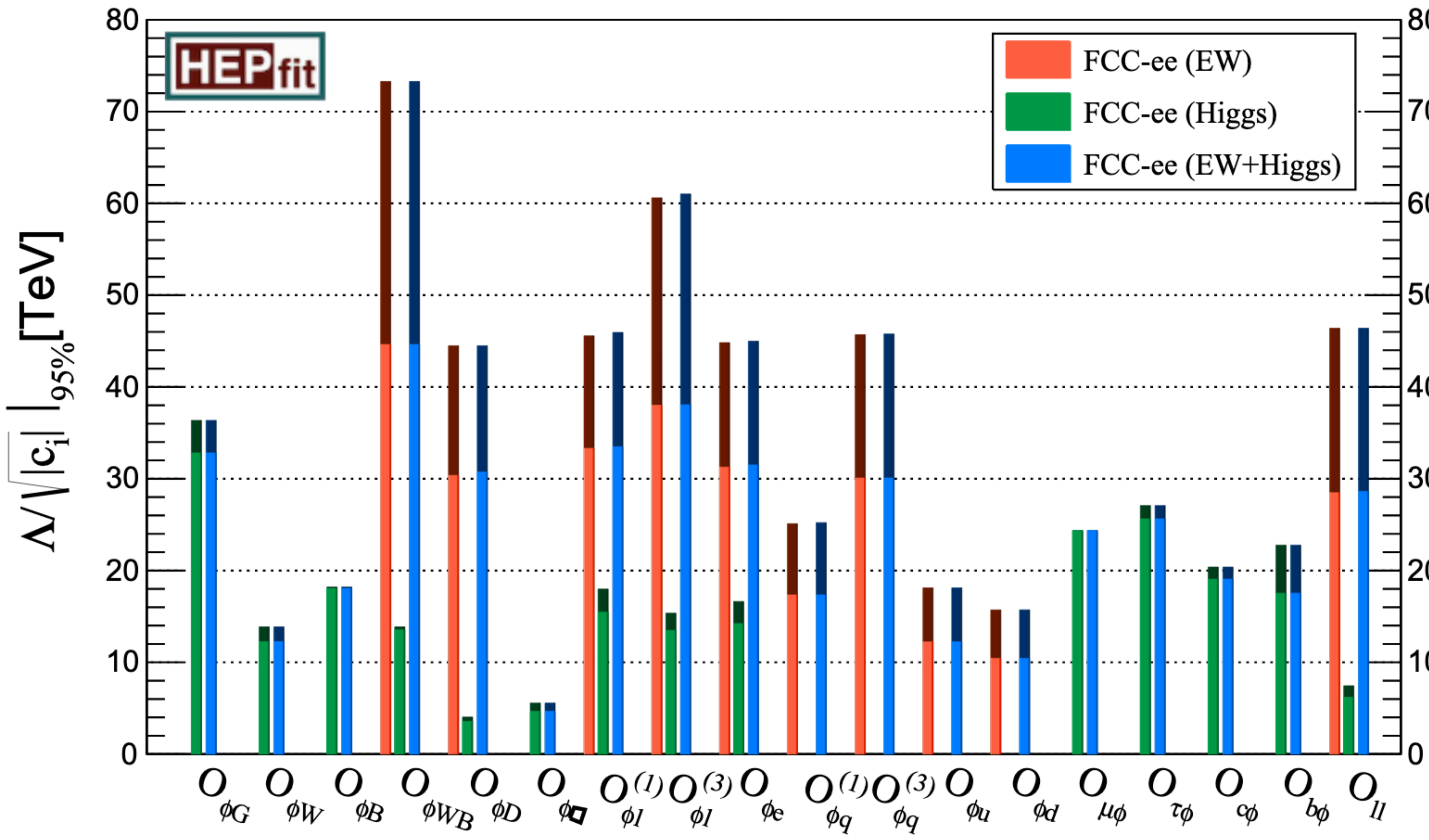
Makes possible
a topological rec.
of the decays
w/ miss. energy

Out of reach at LHCb/Belle

P. Azzi

Indirect BSM sensitivity from EWPO

- Target: reduce systematic uncertainties to the level of statistical ones
- Exquisite √s precision (100keV@Z, 300keV@WW)
- ~50 times better precision than LEP on EW precision observables



Need TH results to fully exploit Tera-Z

Quantity	Current precision	FCC-ee stat. (syst.) precision	Required theory input	Available calc. in 2019	Needed theory improvement†
m_Z Γ_Z $\sin^2\theta^{\ell}_{\rm eff}$	2.1 MeV 2.3 MeV 1.6×10^{-4}	0.004 (0.1) MeV 0.004 (0.025) MeV $2(2.4)\times10^{-6}$	non-resonant $e^+e^-\to f\bar{f}$, initial-state radiation (ISR)	NLO, ISR logarithms up to 6th order	NNLO for $e^+e^-\to f\bar{f}$
m_W	12 MeV	0.25 (0.3) MeV	lineshape of $e^+e^-\to WW$ near threshold	NLO ($ee\to 4f$ or EFT framework)	NNLO for $ee\to WW$, $W\to f\bar{f}$ in EFT setup
HZZ coupling	—	0.2%	cross-sect. for $e^+e^-\to ZH$	NLO + NNLO QCD	NNLO electroweak
$m_{\rm top}$	100 MeV	17 MeV	threshold scan $e^+e^-\to t\bar{t}$	N^{3}LO QCD, NNLO EW, resummations up to NNLL	Matching fixed orders with resummations, merging with MC, α_s (input)

†The listed needed theory calculations constitute a minimum baseline; additional partial higher-order contributions may also be required.

Indirect sensitivity to 70TeV-scale sector connected to EW/Higgs

P. Azzi

EW observables at W^+W^-

10^8 $e^+e^- \rightarrow$ WW

From data collected around and above the WW threshold:

- **W mass** (key for jump in precision for ewk fits)
- **W width** (first precise direct measurement)
- **$R^W = \Gamma_{had}/\Gamma_{lept}$** ($\alpha_s(m_Z^2)$)
- Γ_e , Γ_μ , Γ_τ (precise universality test)
- direct **CKM** measurements (with jet-flavor tagging)
- **Triple** and **Quartic Gauge couplings** (jump in precision, especially for charged couplings)

R. Tenchini

EW precision measurements at FCC-ee

Observable	present value	±	error	FCC-ee Stat.	FCC-ee Syst.	Comment and leading error
m_Z (keV)	91186700	±	2200	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200	±	2300	**4**	25	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{eff}(\times 10^6)$	231480	±	160	**2**	2.4	From $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z^2)(\times 10^3)$	128952	±	14	**3**	small	From $A_{FB}^{\mu\mu}$ off peak QED&EW errors dominate
R_ℓ^Z $(\times 10^3)$	20767	±	25	**0.06**	0.2-1	Ratio of hadrons to leptons Acceptance for leptons
$\alpha_s(m_Z^2)$ $(\times 10^4)$	1196	±	30	**0.1**	0.4-1.6	From R_ℓ^Z
σ_{had}^0 $(\times 10^3)$ (nb)	41541	±	37	**0.1**	4	Peak hadronic cross-section Luminosity measurement
$N_\nu(\times 10^3)$	2996	±	7	**0.005**	1	Z peak cross-sections Luminosity measurement
R_b $(\times 10^6)$	216290	±	660	**0.3**	$<$ 60	Ratio of $b\bar{b}$ to hadrons Stat. extrapol. from SLD
$A_{FB}^b, 0$ $(\times 10^4)$	992	±	16	**0.02**	1-3	b-quark asymmetry at Z pole From jet charge
$A_{FB}^{pol,\tau}$ $(\times 10^4)$	1498	±	49	**0.15**	<2	τ polarisation asymmetry τ decay physics
τ lifetime (fs)	290.3	±	0.5	**0.001**	0.04	Radial alignment
τ mass (MeV)	1776.86	±	0.12	**0.004**	0.04	Momentum scale
τ leptonic $(\mu\nu_\mu\nu_\tau)$ B.R. (%)	17.38	±	0.04	**0.0001**	0.003	e/μ/hadron separation
m_W (MeV)	80350	±	15	**0.25**	0.3	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2085	±	42	**1.2**	0.3	From WW threshold scan Beam energy calibration
$\alpha_s(m_W^2)(\times 10^4)$	1010	±	270	**3**	small	From R_ℓ^W
$N_\nu(\times 10^3)$	2920	±	50	**0.8**	small	Ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV)	172740	±	500	**17**	small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV)	1410	±	190	**45**	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2	±	0.3	**0.10**	small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings		±	30%	**0.5 – 1.5 %**	small	From $\sqrt{s} = 365$ GeV run

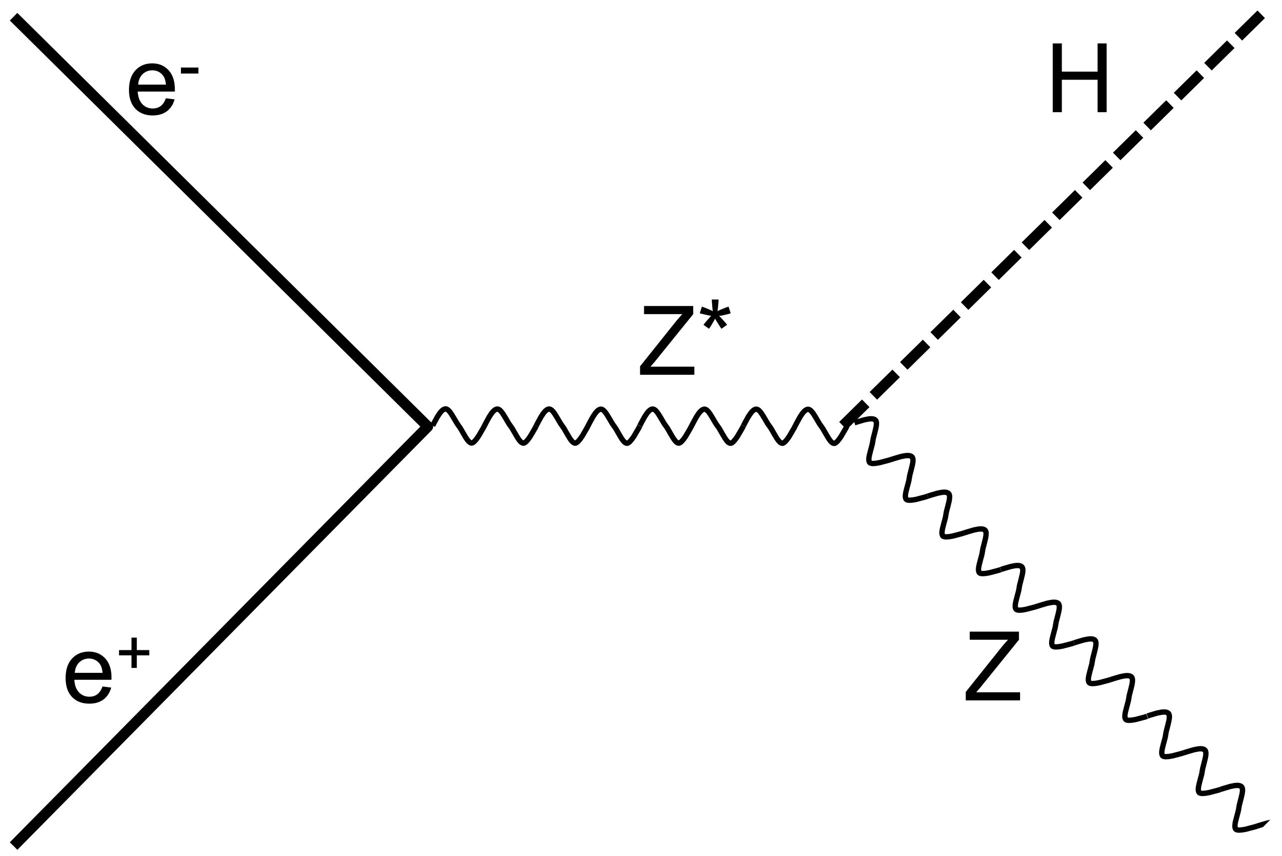
Improvement of **10-50** times compared to LEP

Higgs production at an e^+e^- collider

"Higgsstrahlung" process close to threshold

Production cross section has a maximum at near threshold ~200 fb

$10^{34}/cm^2/s$ ➔ 20’000 HZ events per year

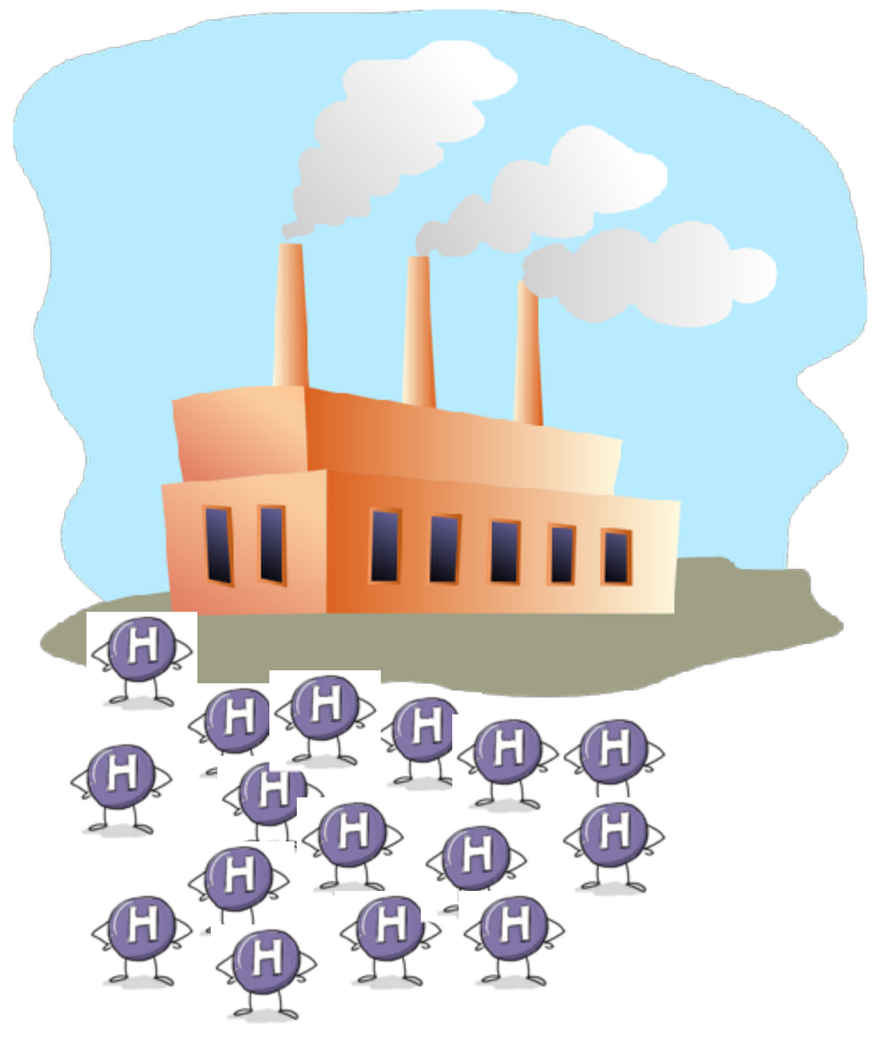


Z – tagging
of Higgs events

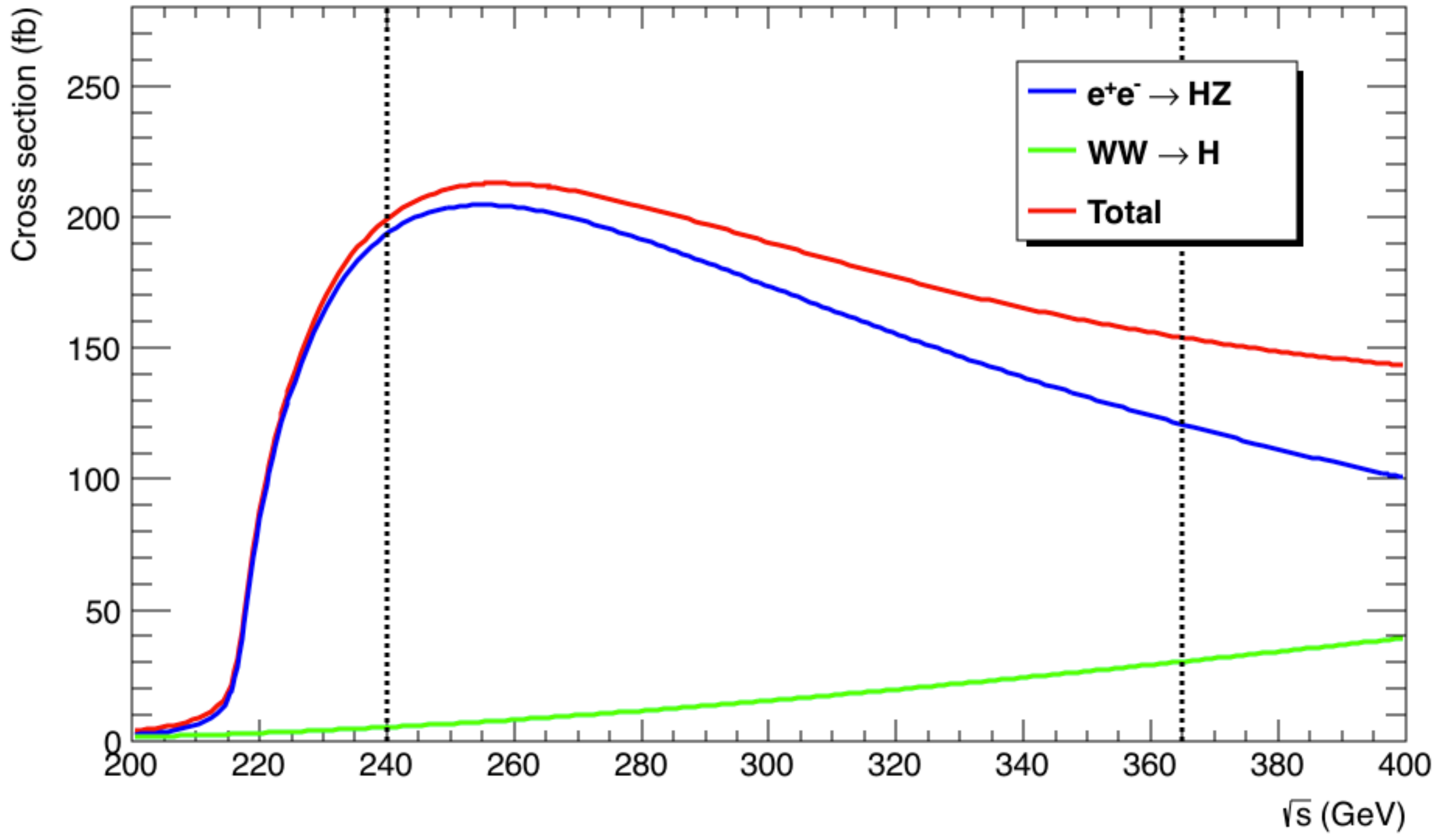
For a Higgs of 125 GeV, a centre of mass energy of 240-250 GeV is optimal
➔ kinematical constraint near threshold for high precision in mass, width, selection purity

Higgs production at FCC-ee

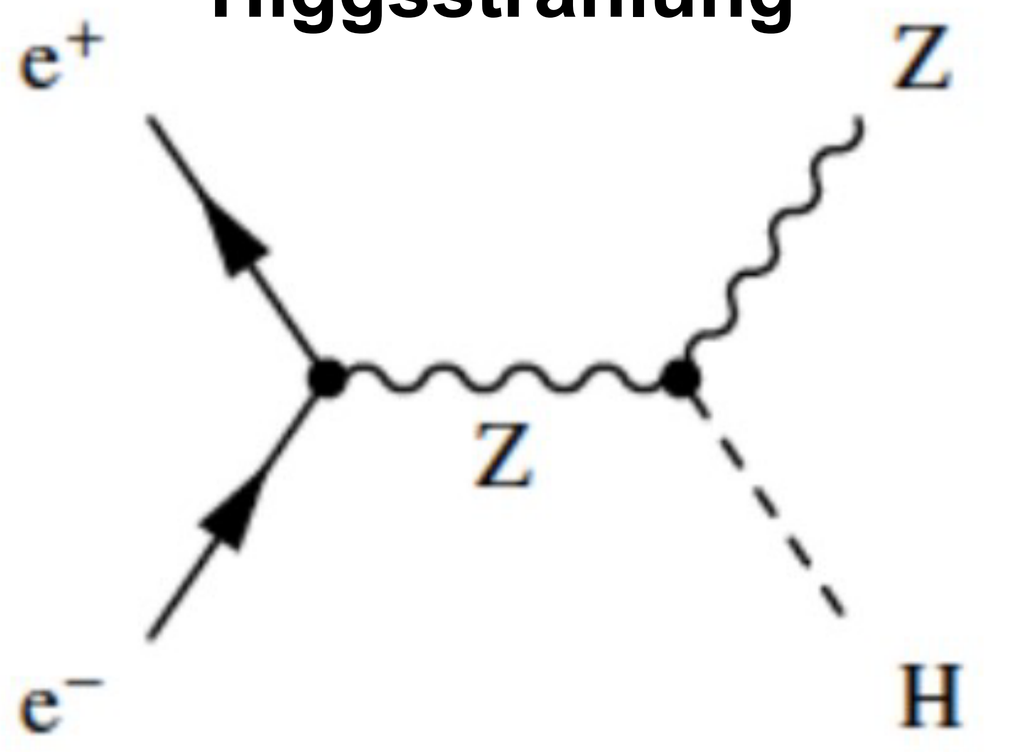
FCC-ee
7.2 ab^{-1}@240 GeV
~2.7 ab^{-1}@365 GeV

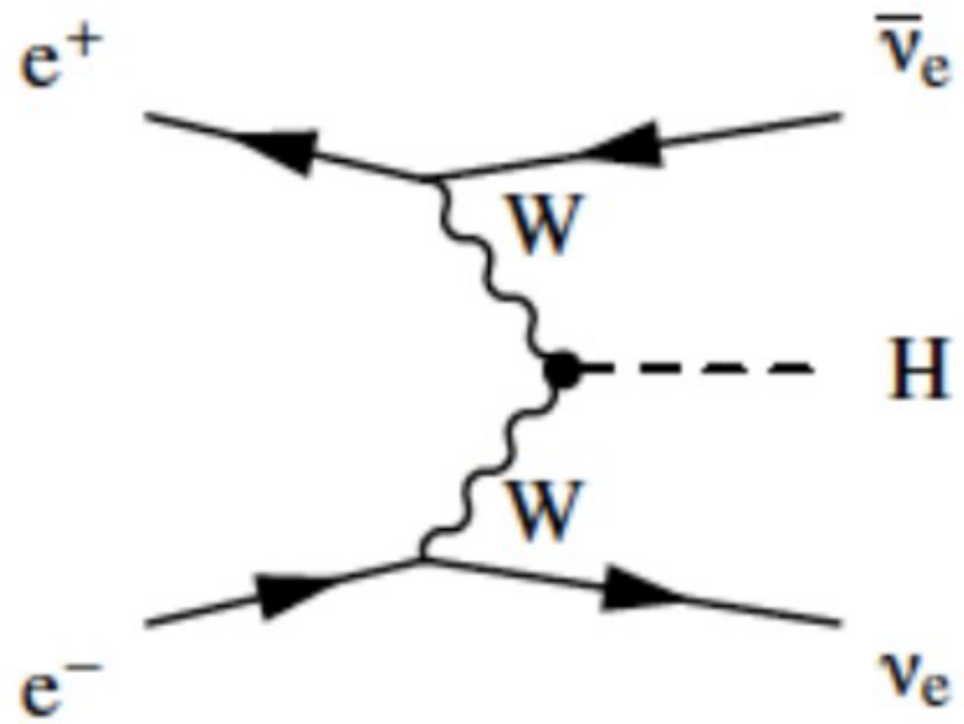


Higgs Factory!



Higgsstrahlung





WW fusion

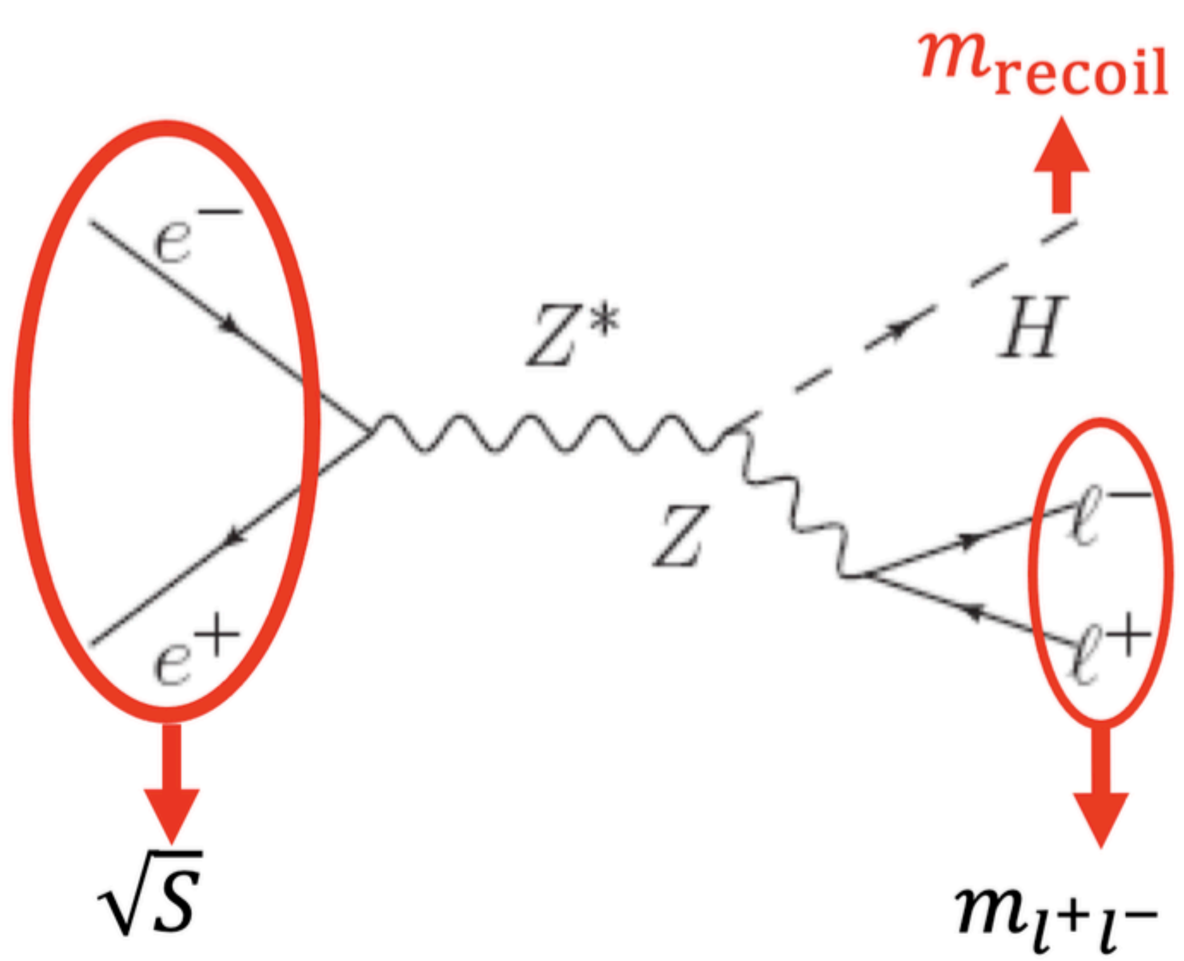
	FCC-ee 240 GeV	FCC-ee 365 GeV
Total Integrated Luminosity (ab^{-1})	7.2	2.7
# Higgs bosons from $e^+e^- \to HZ$	1500000	330000
# Higgs bosons from fusion process	45000	80000

Higgs couplings to Z

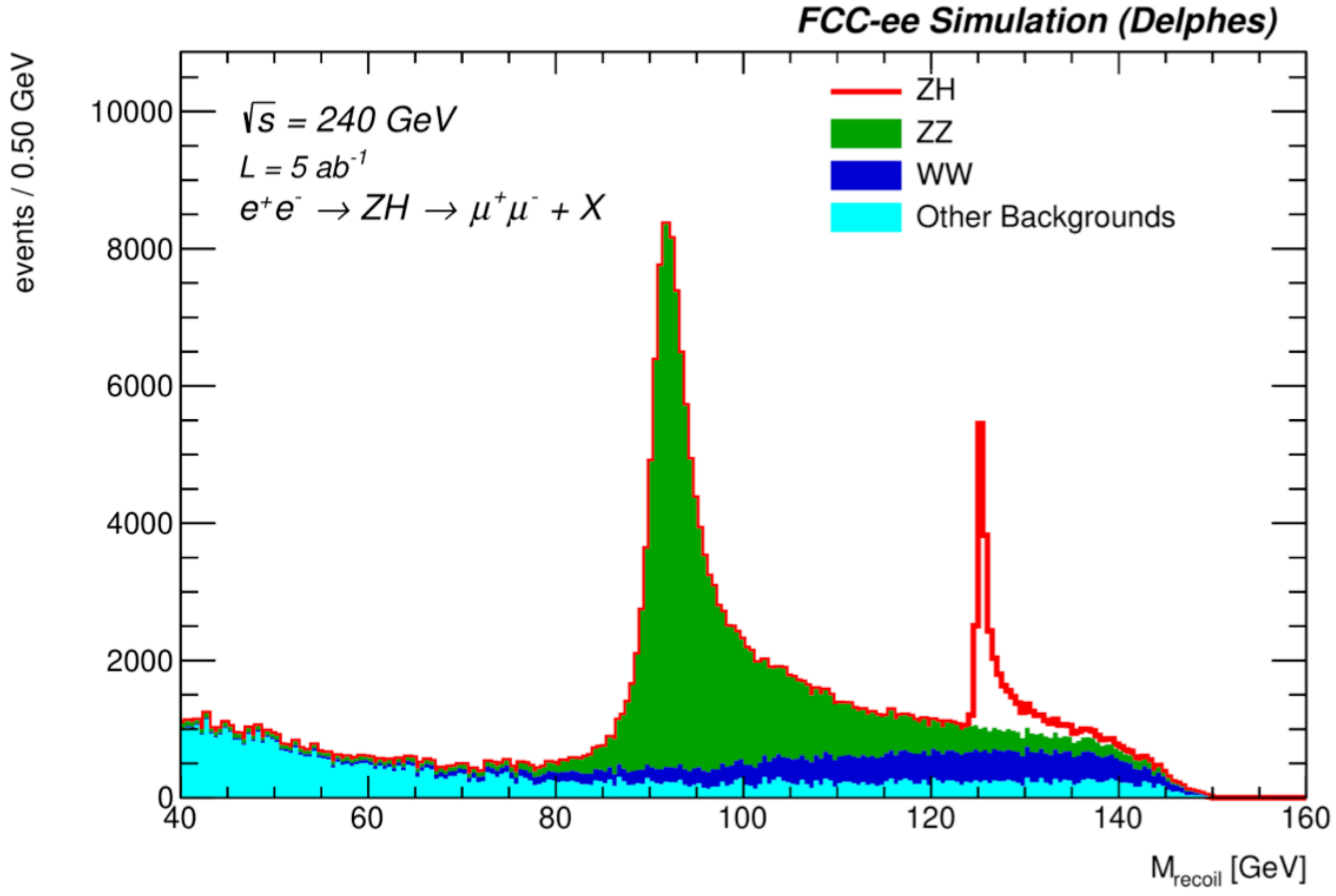
➡ **Recoil method provides a unique opportunity for a decay-mode independent measurement of the HZ coupling**

- Higgs events are tagged with the Z boson decays, independently of Higgs decay mode, $m_{recoil} = m_H$
- Expected precision **0.7%** on the ZH cross section
- Using only leptonic Z decays and only a measurement at 240 GeV so far

$$\sigma(ee \to ZH) \propto g^2_{HZ}$$



$$m^2_{recoil} = (\sqrt{s} - E_{\ell\ell})^2 - |\vec{p}_{\ell\ell}|^2$$



Higgs @ FCC-ee

- Absolute normalisation of couplings (by recoil method)
- Measurement of width (from ZH>ZZZ* and WW>H)
- $\delta\Gamma_H \sim 1\%, \delta m_H \sim 3\,\mathrm{MeV}$ (resp. 25%, 30 MeV @ HL-LHC)
- Model-independent coupling determination and improvement factor up to 10 compared to LHC
- (Indirect) sensitivity to new physics up to 70 TeV (for maximally strongly coupled models)

$$(\delta\kappa_X = v^2/f^2 \quad \& \quad m_{\mathrm{NP}} = g_{\mathrm{NP}} f)$$

— Higgs programme needs Z-pole —

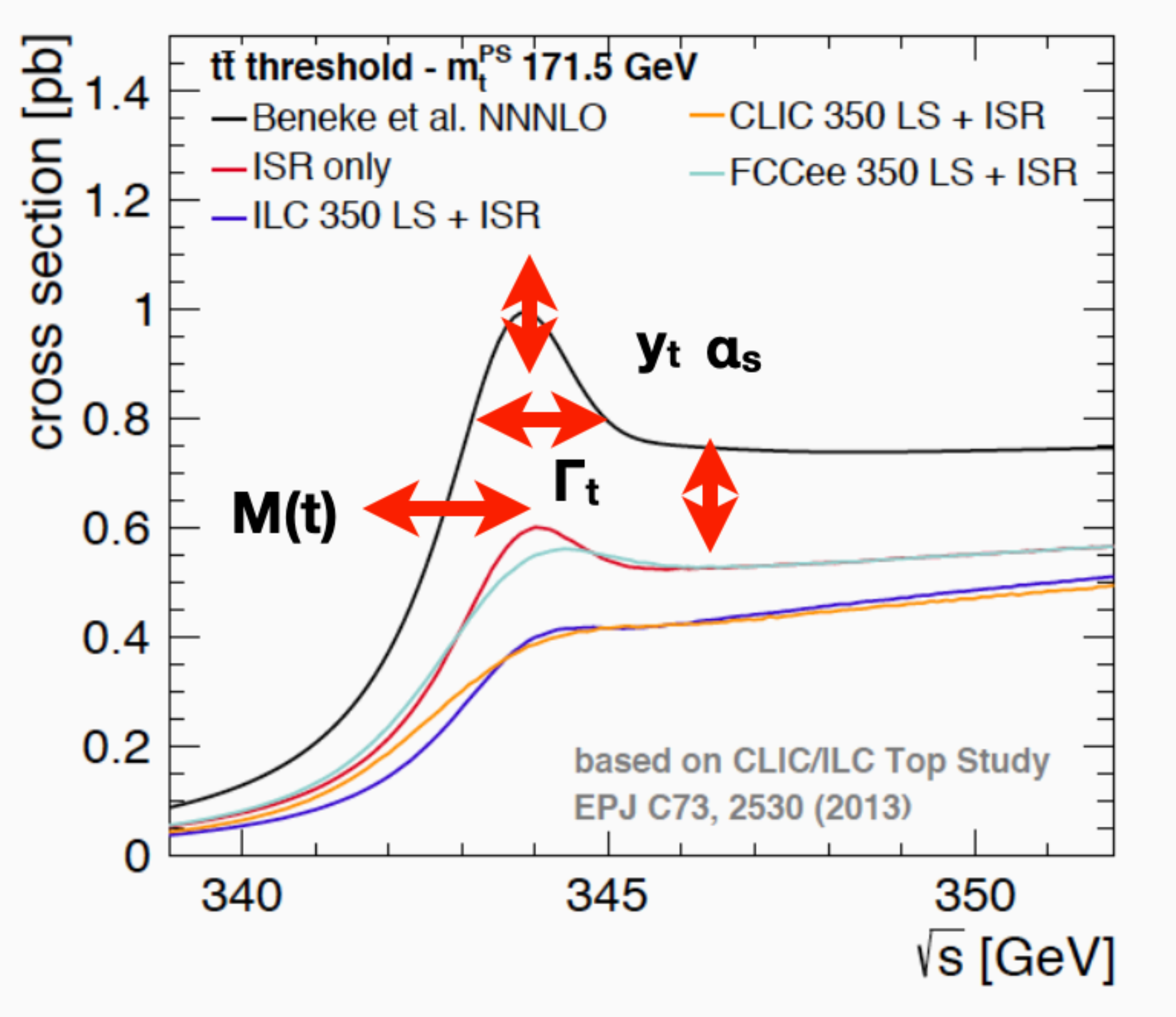
Higgs coupling sensitivity

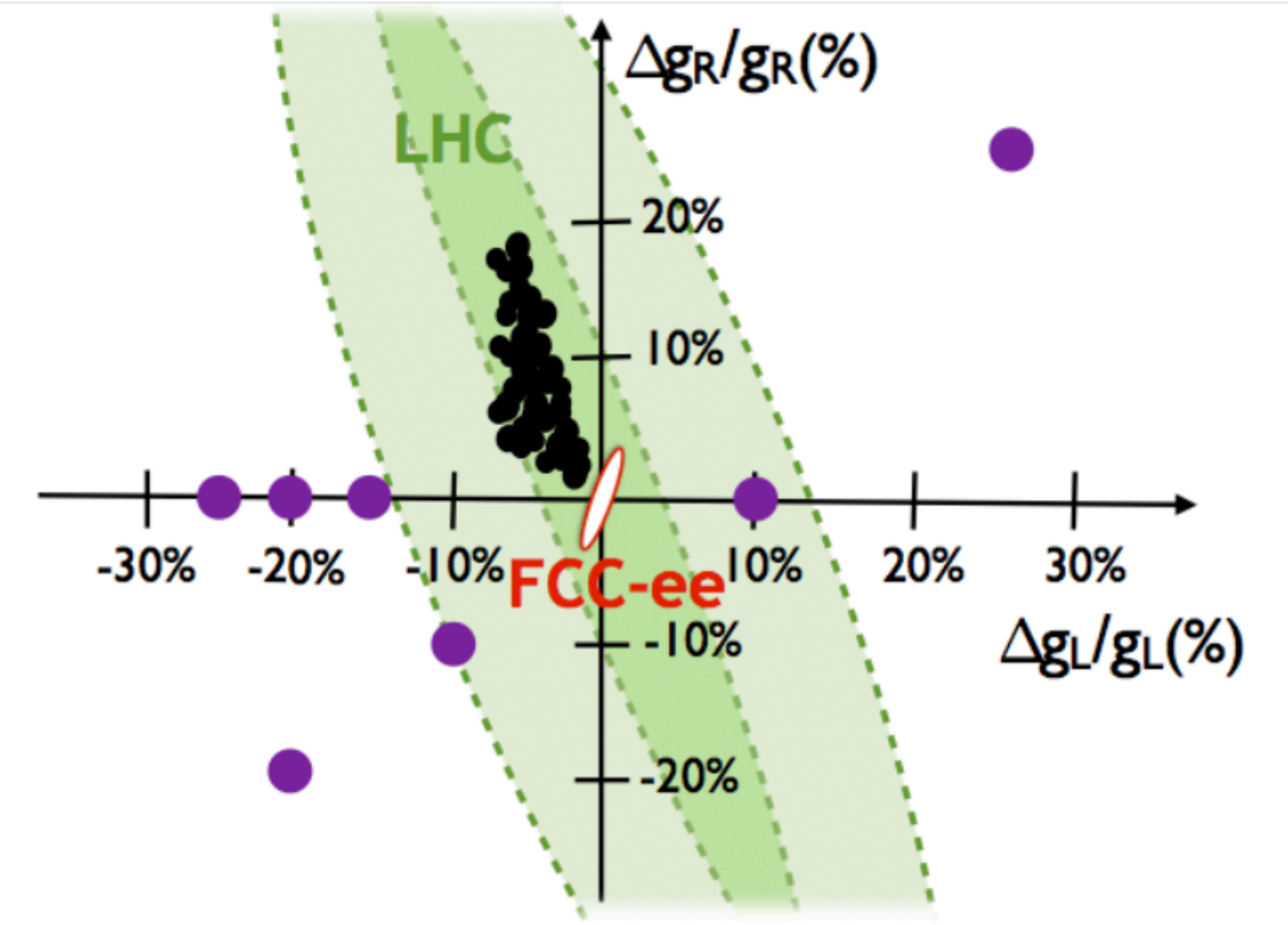
Coupling	HL-LHC	FCC-ee (240–365 GeV) 2 IPs / 4 IPs
κ_W [%]	1.5*	0.43 / 0.33
κ_Z [%]	1.3*	0.17 / 0.14
κ_g [%]	2*	0.90 / 0.77
κ_γ [%]	1.6*	1.3 / 1.2
$\kappa_{Z\gamma}$ [%]	10*	10 / 10
κ_c [%]	–	1.3 / 1.1
κ_t [%]	3.2*	3.1 / 3.1
κ_b [%]	2.5*	0.64 / 0.56
κ_μ [%]	4.4*	3.9 / 3.7
κ_τ [%]	1.6*	0.66 / 0.55
$\mathrm{BR_{inv}}$ (<%, 95% CL)	1.9*	0.20 / 0.15
$\mathrm{BR_{unt}}$ (<%, 95% CL)	4*	1.0 / 0.88

C. Grojean

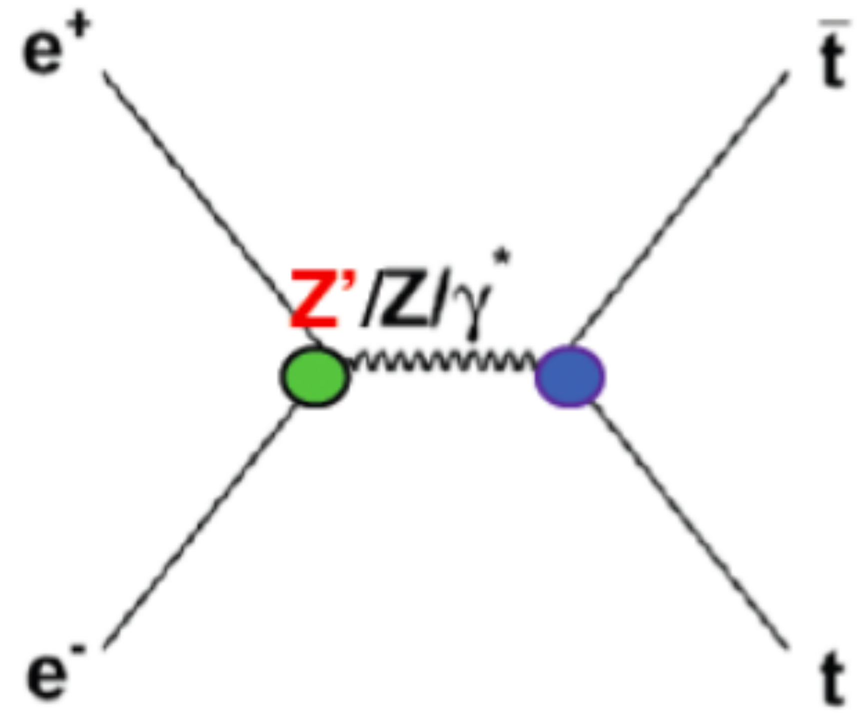
Top physics

Threshold scan allows most precise measurements of top mass





From top EWK coupling precision sensitivity up to 4TeV Z' mass



- **Measurements at threshold:** top mass (< 20 MeV stat), width, and estimate of Yukawa coupling
- **Run at 365 GeV:** precision measurements of top EWK couplings at ~10^{-2},10^{-3} and search for FCNC in the top sector.

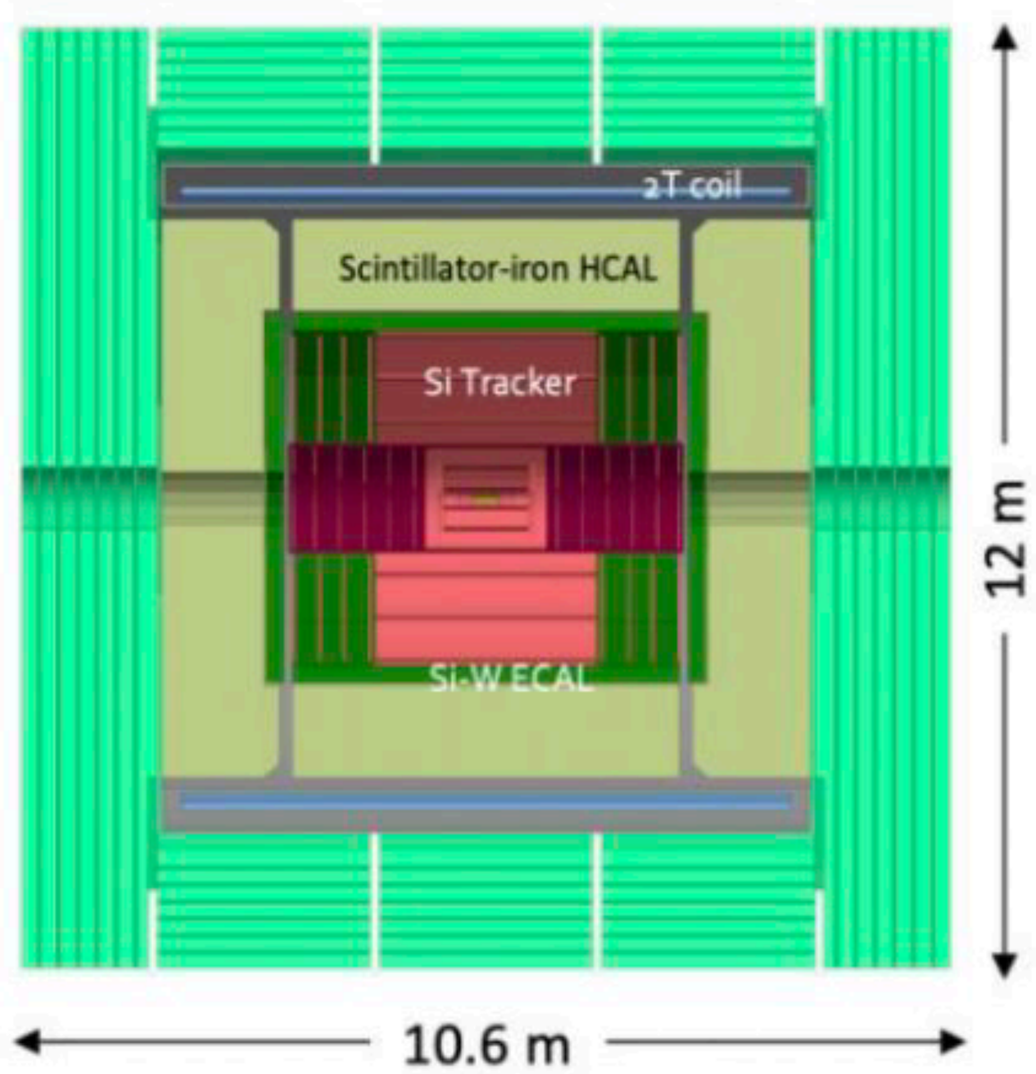
P. Azzi

Detector requirements

C. Grojean, I. Vivarelli

Detector concepts fast overview

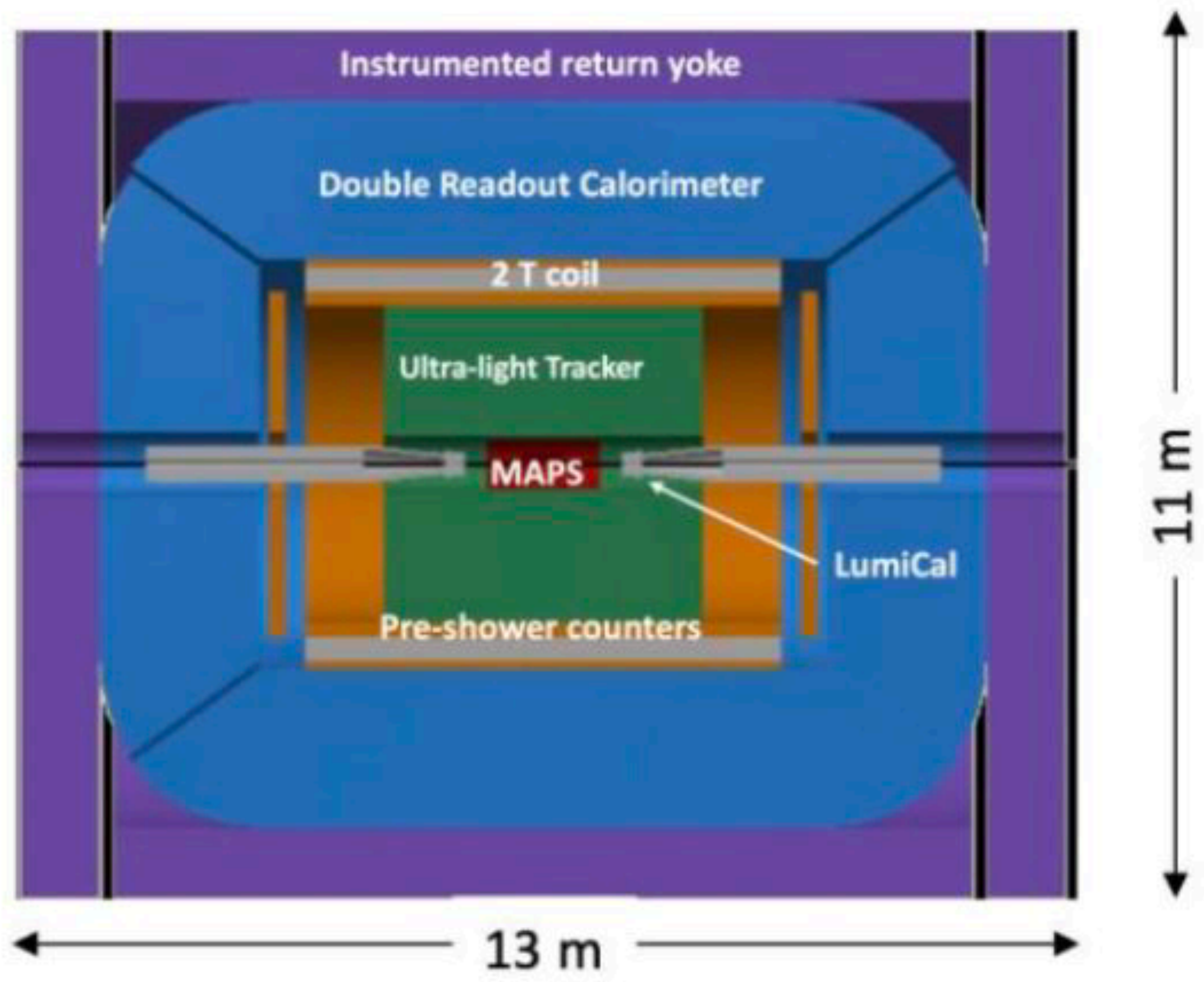
CLD



- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker;
- CALICE-like calorimetry;
- Large coil, muon system
- Engineering still needed for operation with continuous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?
  - …

CDR

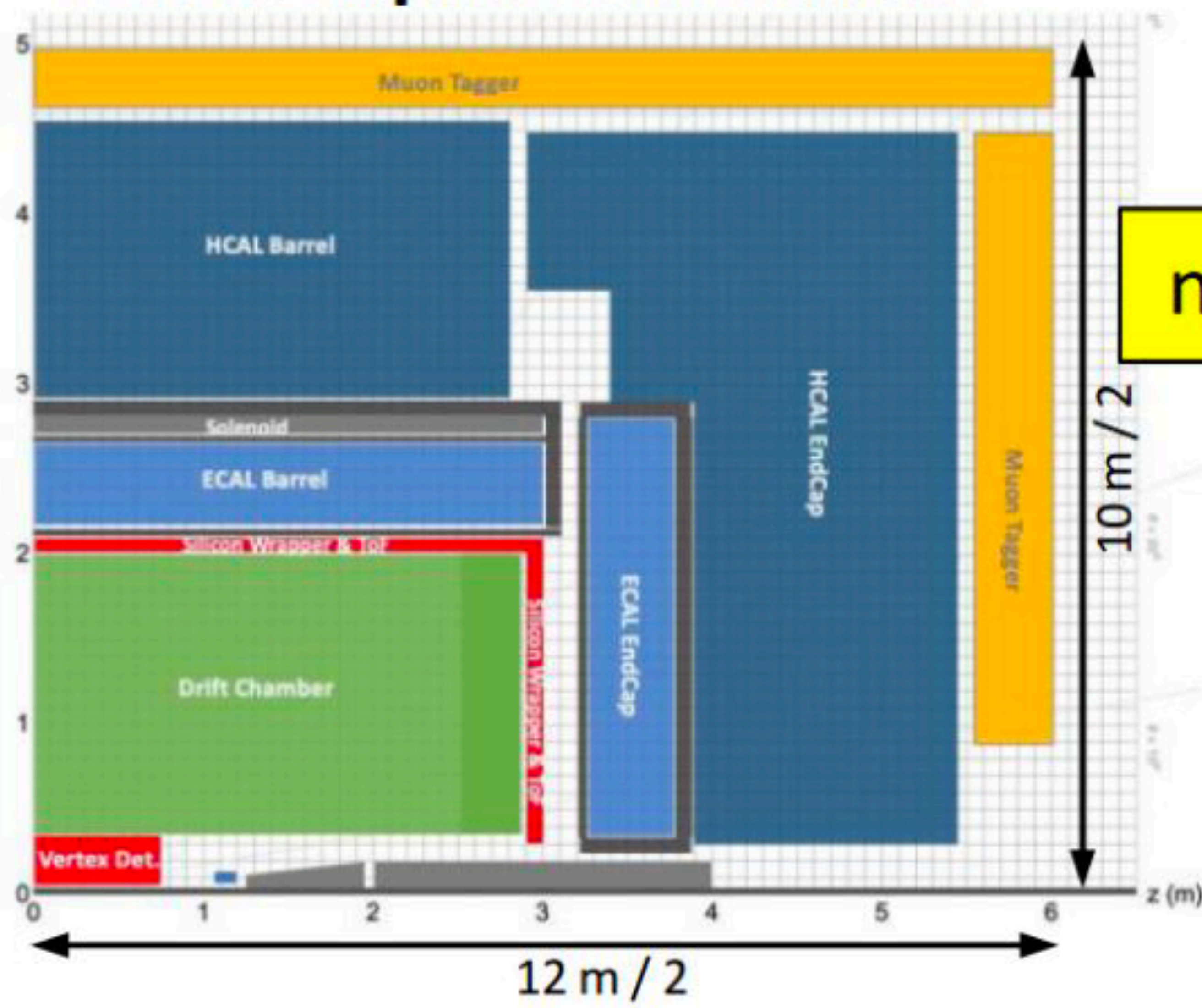
IDEA



- A bit less established design
  - But still ~15y history
- Si vtx detector; ultra light drift chamber w powerful PID; compact, light coil;
- Monolithic dual readout calorimeter;
  - Possibly augmented by crystal ECAL
- Muon system
- Very active community
  - Prototype designs, test beam campaigns, …

Noble Liquid ECAL based

new



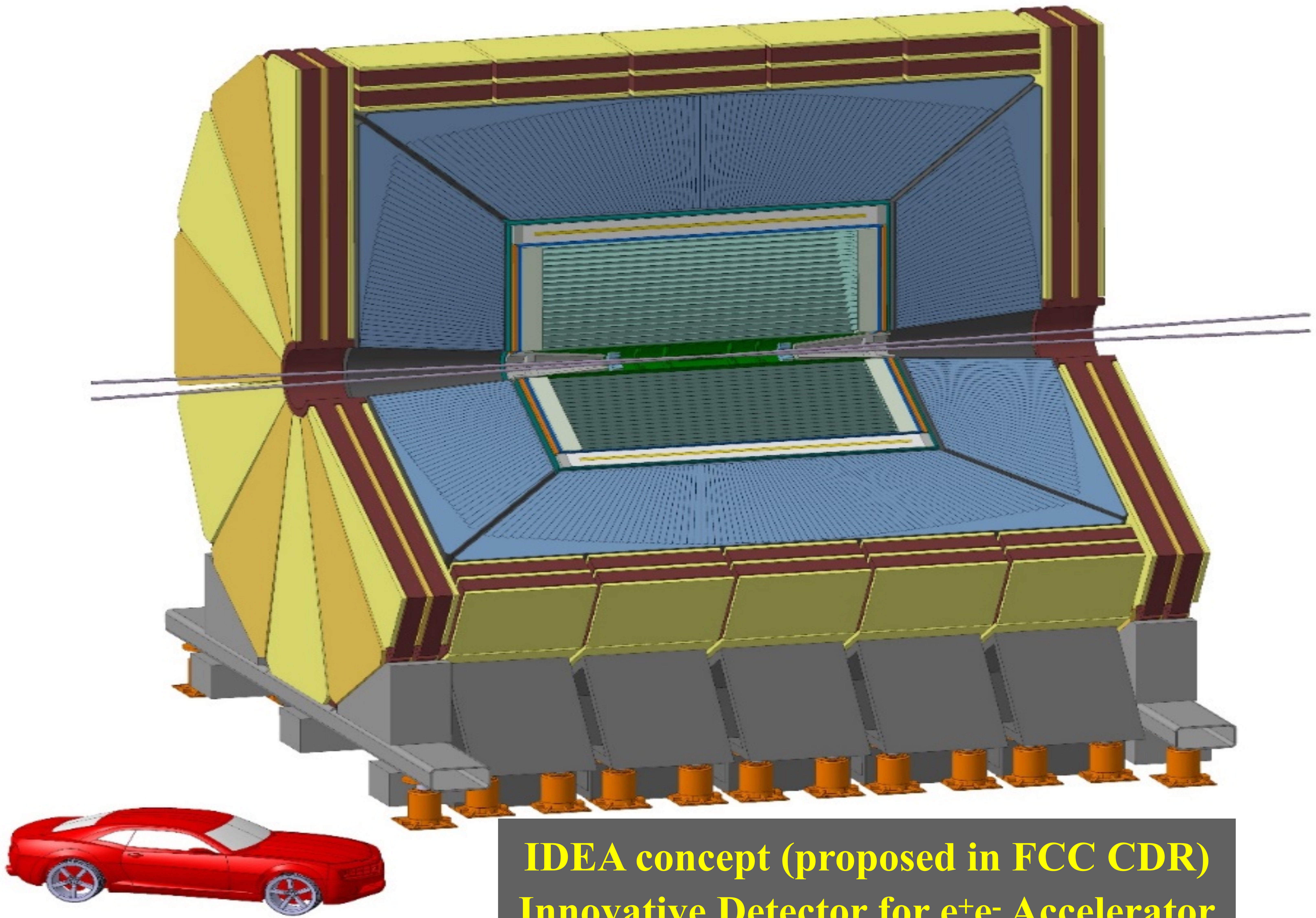
- A design in its infancy
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

FCC-ee CDR: https://link.springer.com/article/10.1140/epjst/e2019-900045-4

https://arxiv.org/abs/1911.12230, https://arxiv.org/abs/1905.02520 https://pos.sissa.it/390/

The IDEA detector concept

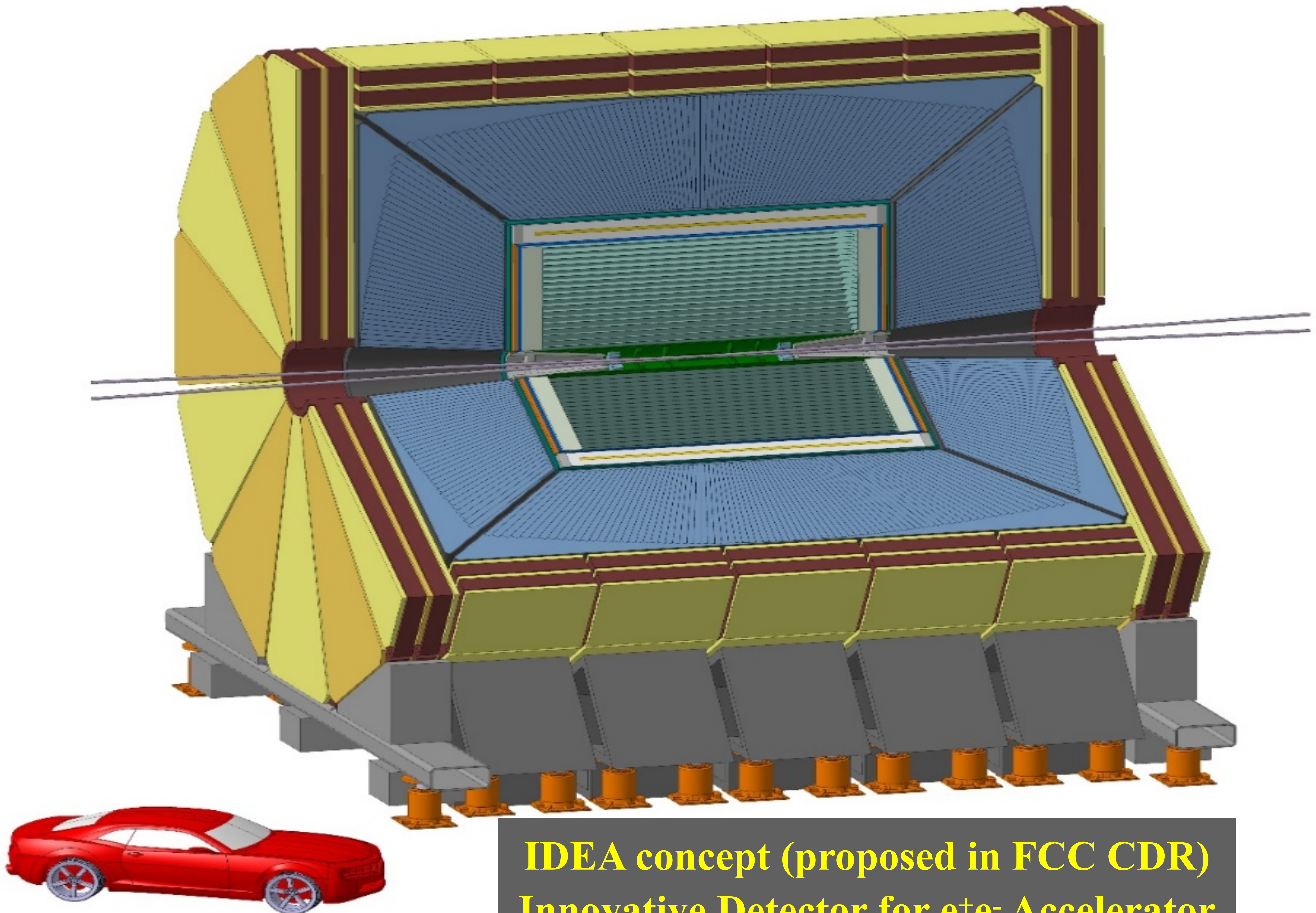
The IDEA detector concept



IDEA concept (proposed in FCC CDR)
Innovative Detector for e^+e^- Accelerator

The IDEA detector concept

- New, innovative, possibly more cost-effective concept



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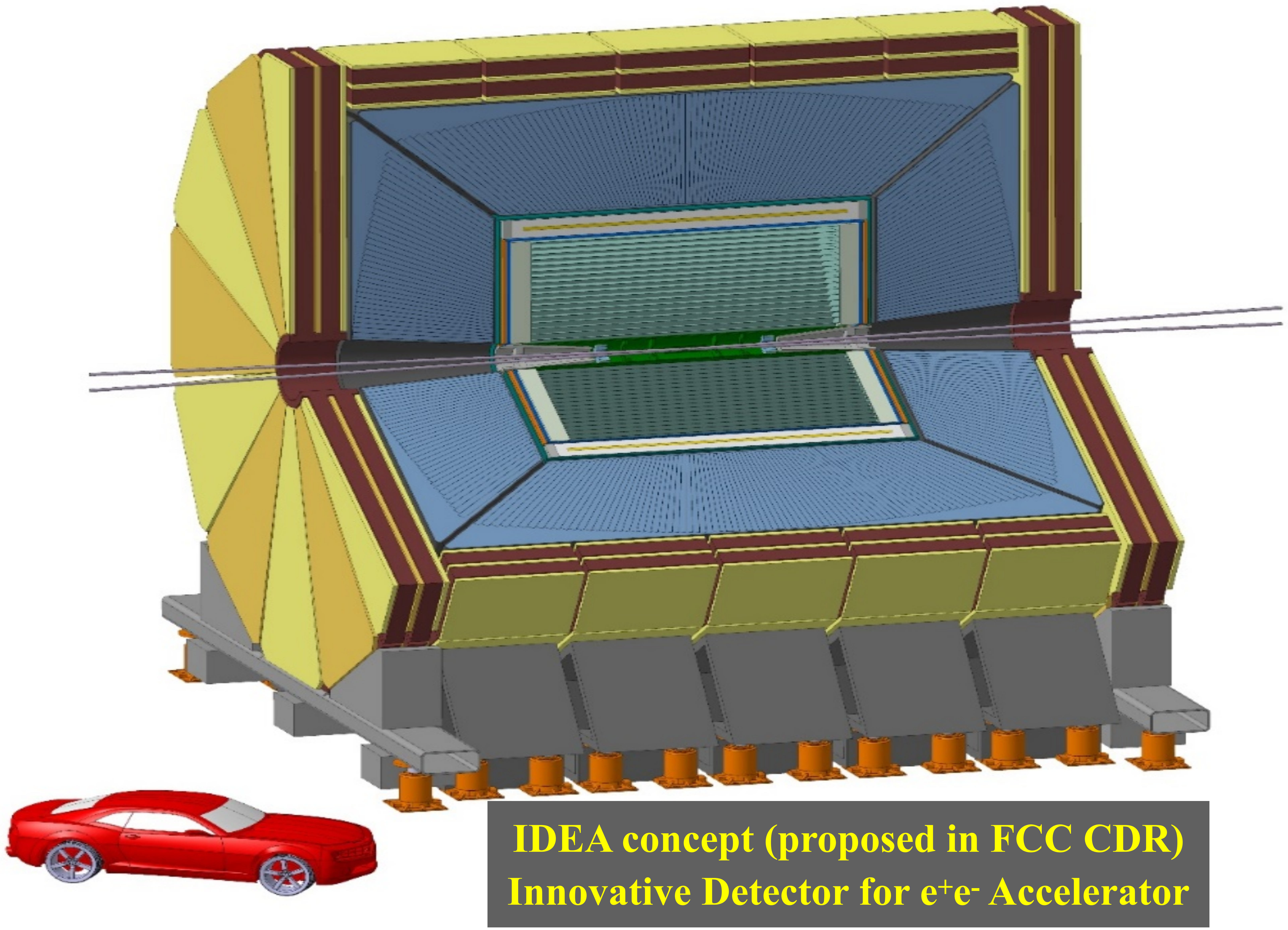
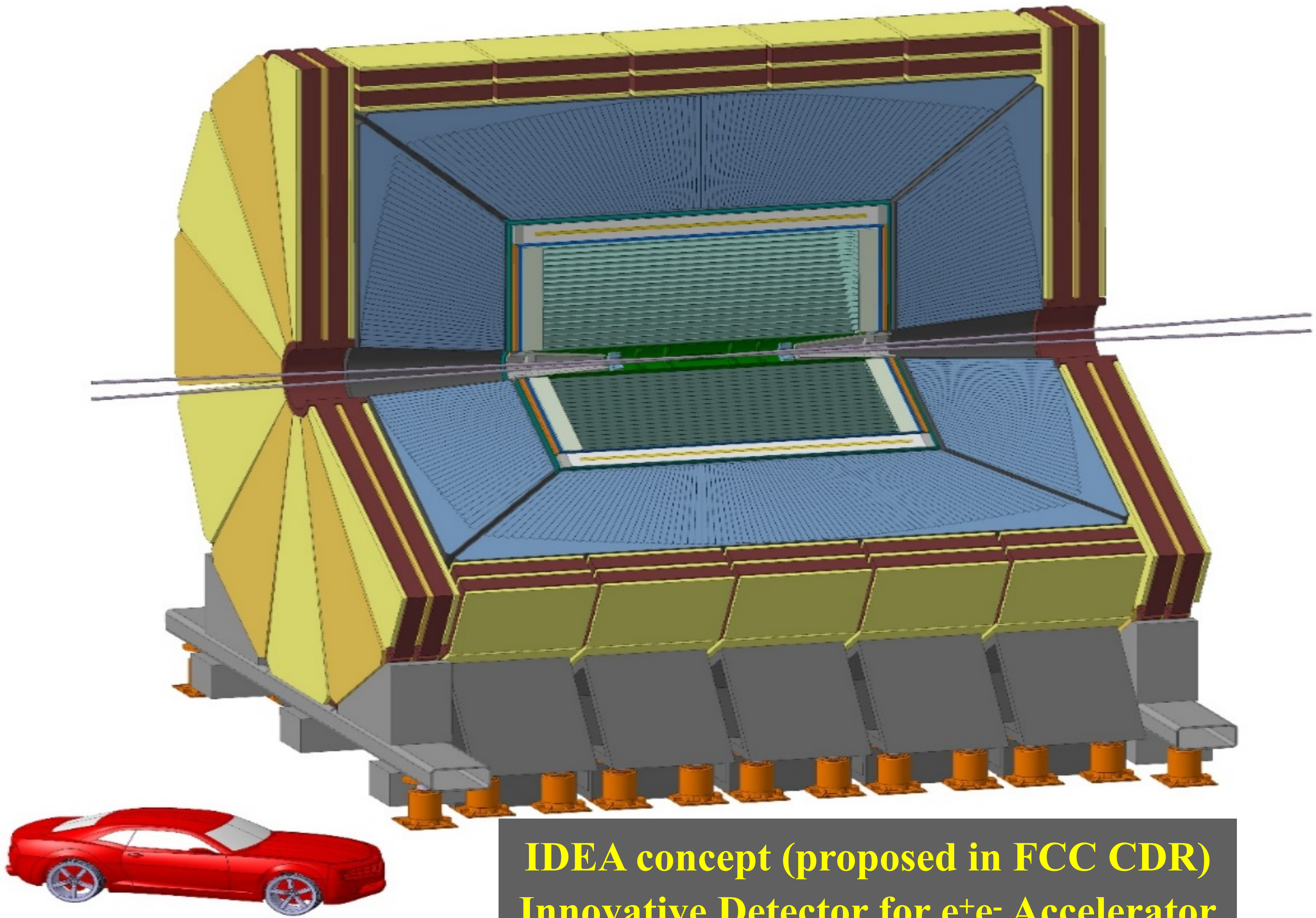


- **New, innovative, possibly more cost-effective concept**
  - Silicon vertex detector

The IDEA detector concept



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Innovative Detector for e^+e^- Accelerator

- **New, innovative, possibly more cost-effective concept**
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  - Short-drift, ultra-light wire chamber

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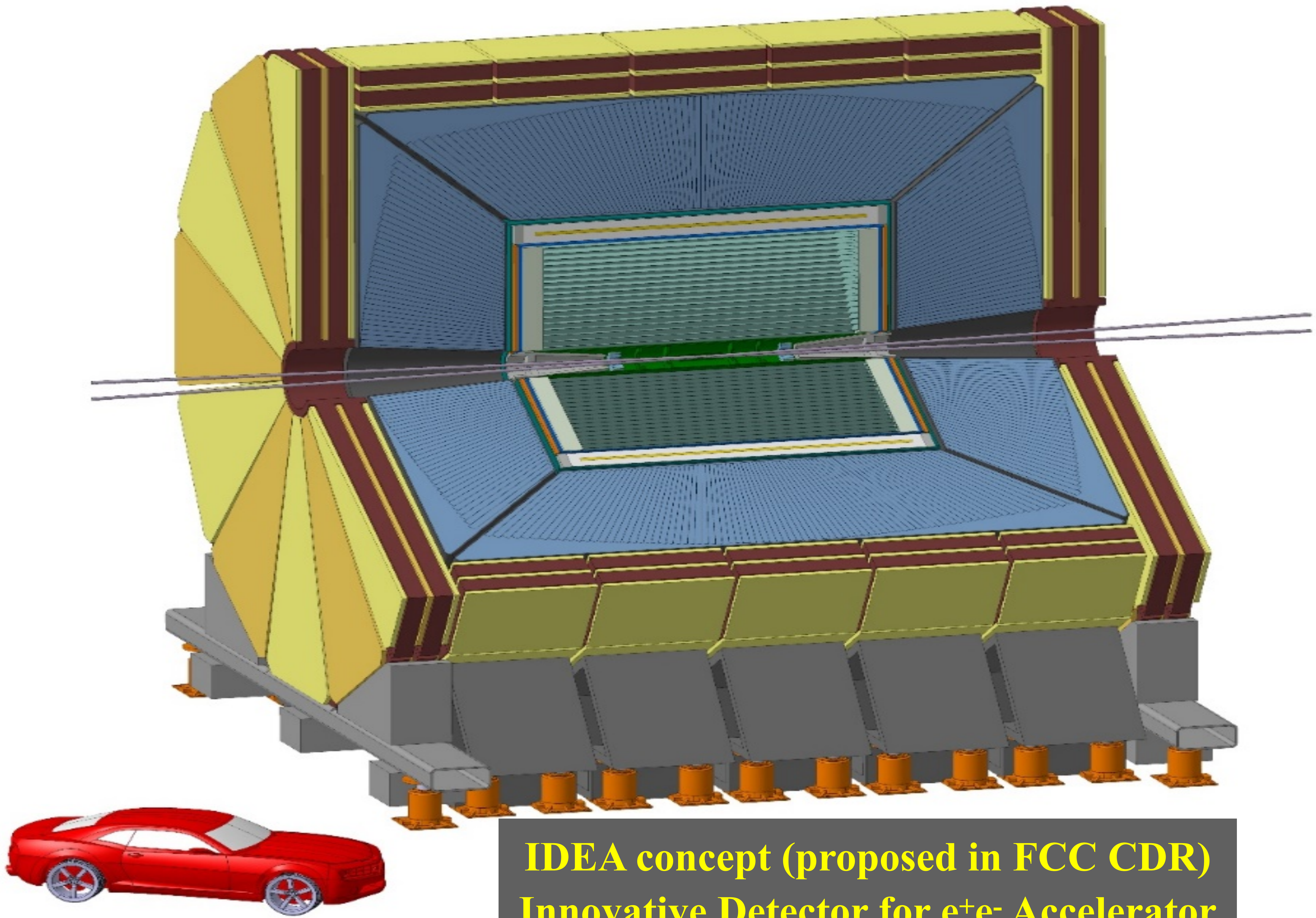

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  - Dual-readout calorimeter

FUTURE CIRCULAR COLLIDER

The IDEA detector concept

INFN
Istituto Nazionale di Fisica Nucleare

- **New, innovative, possibly more cost-effective concept**
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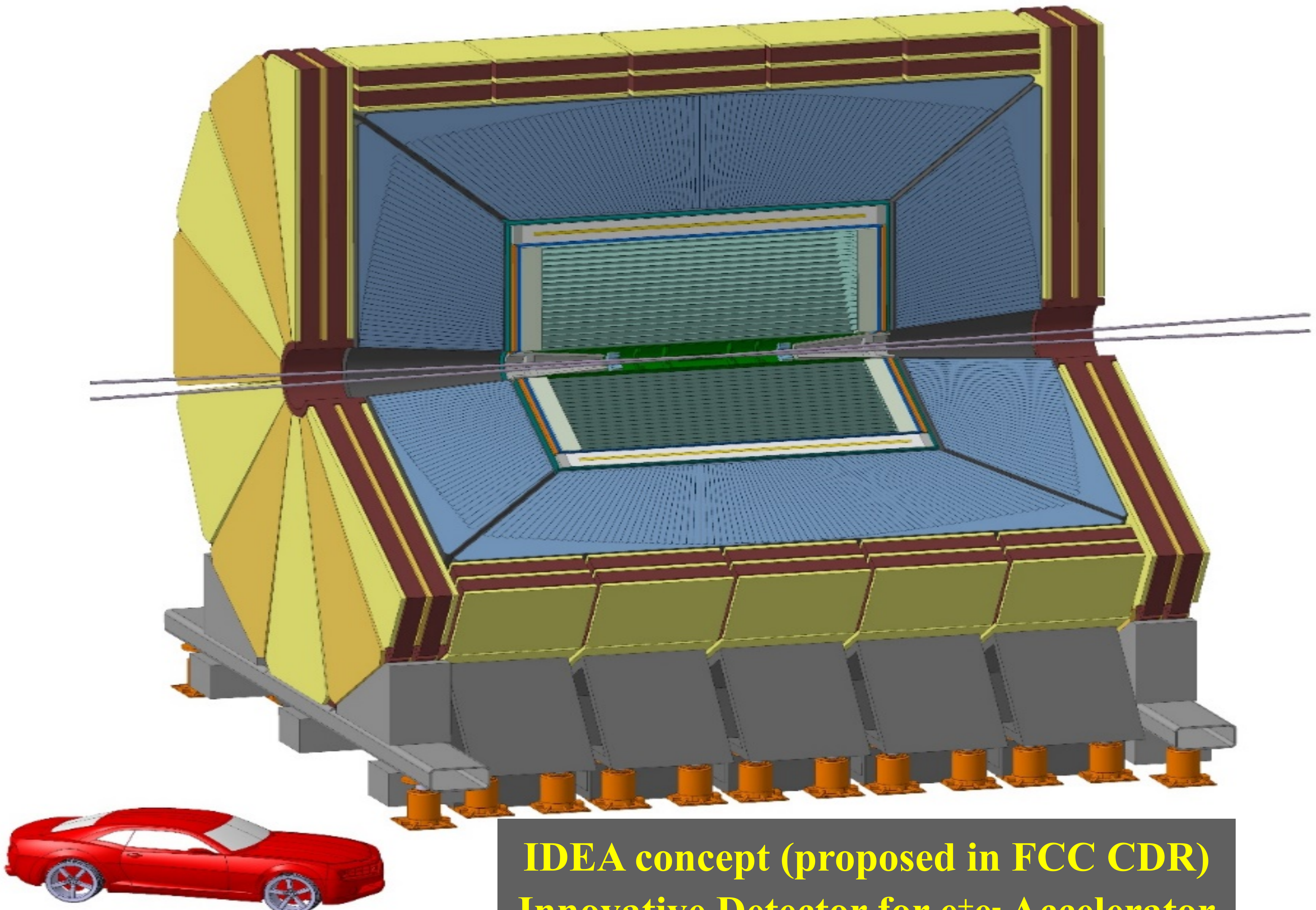
  - Thin and light solenoid coil *inside* calorimeter system



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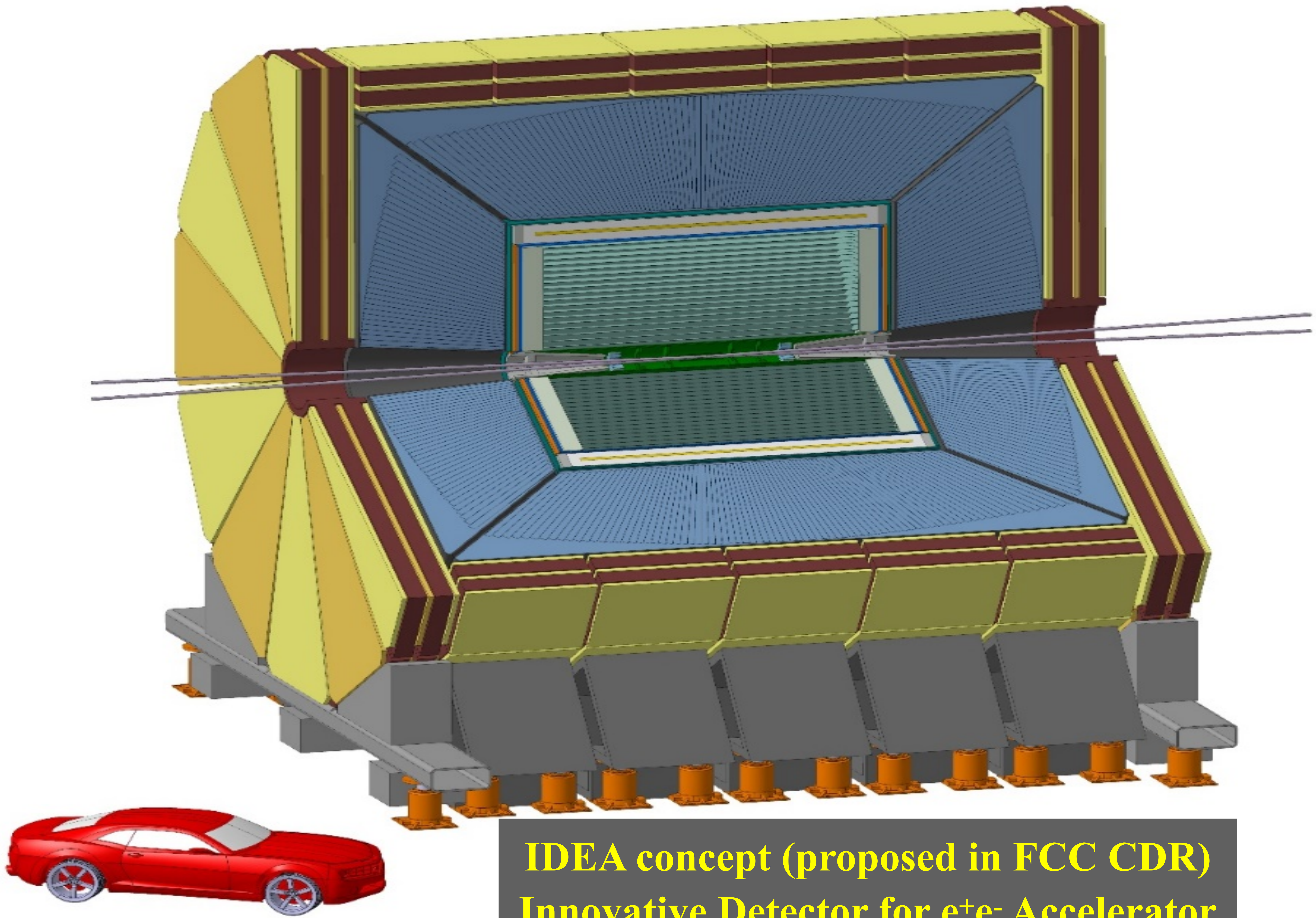

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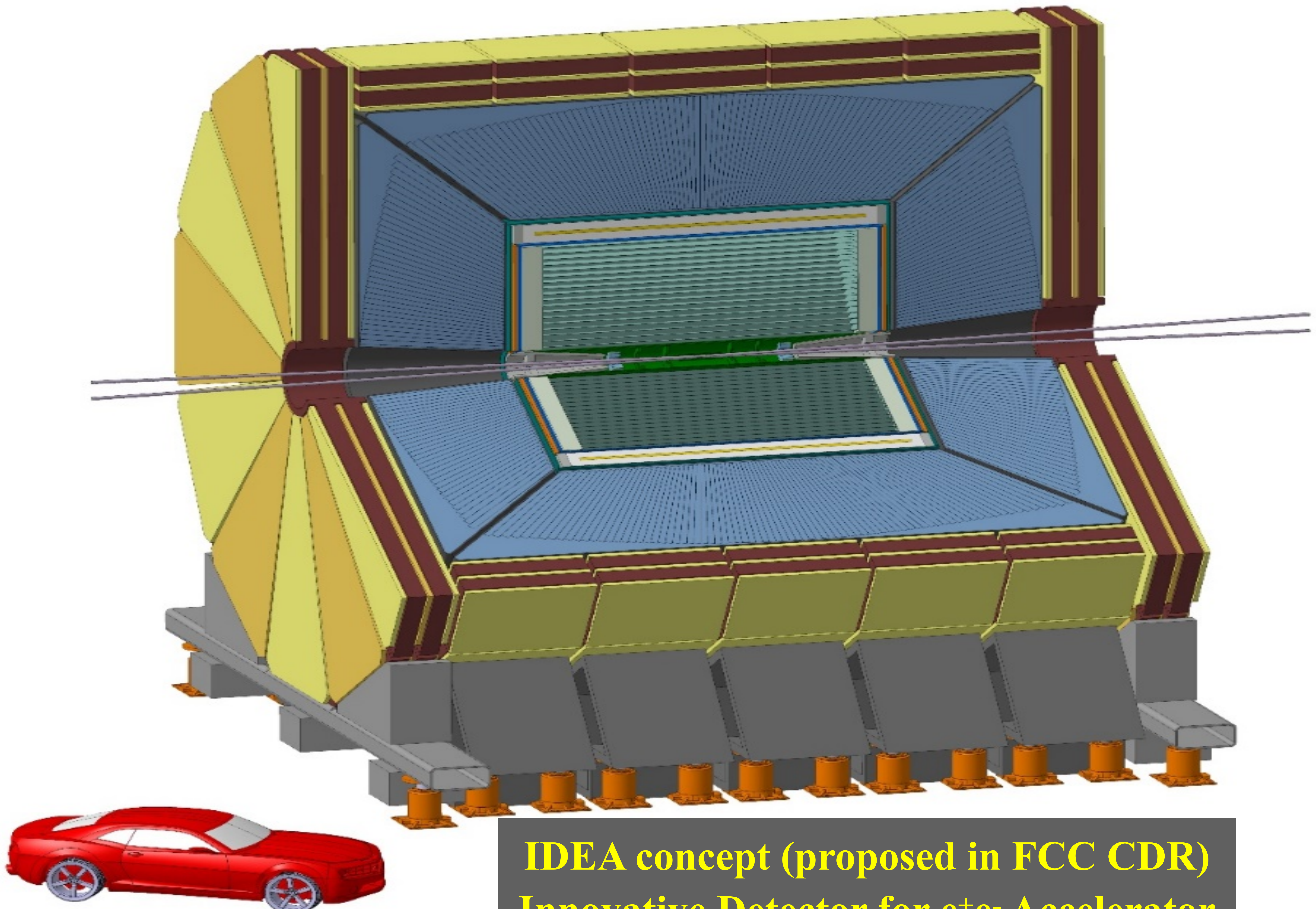

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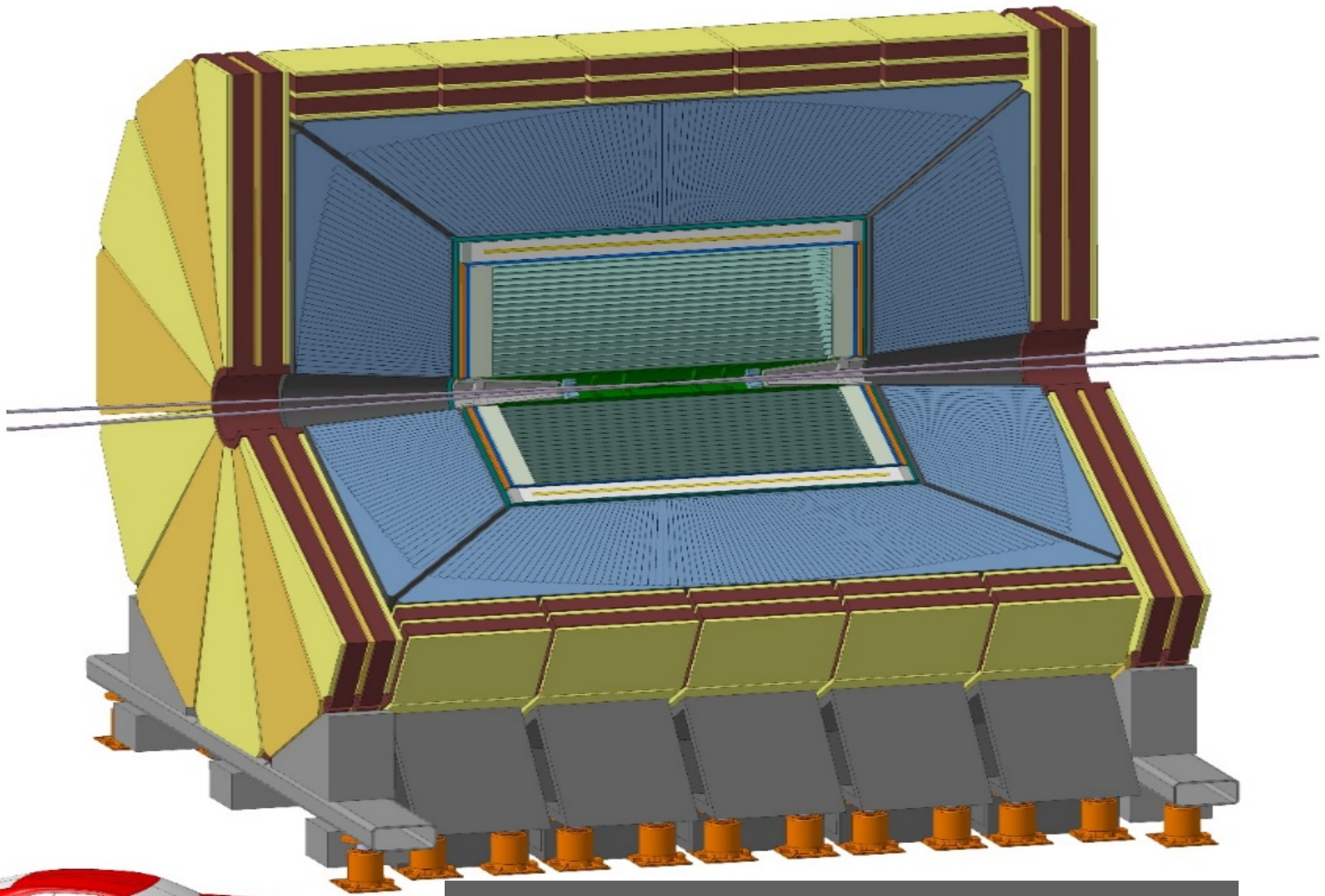

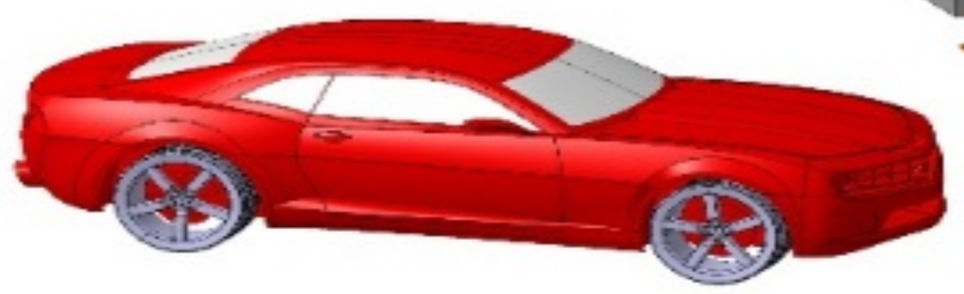

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https://pos.sissa.it/390/

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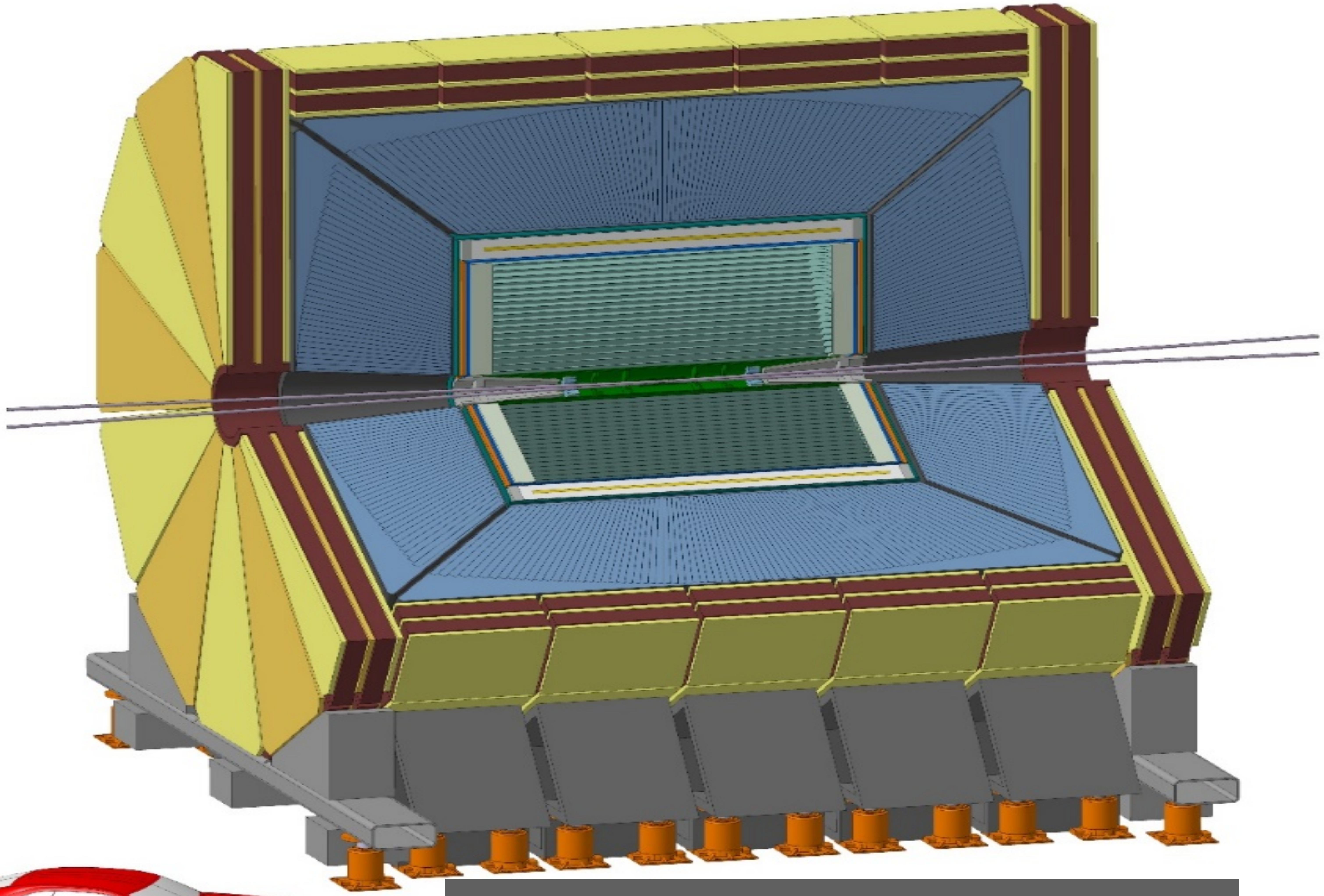

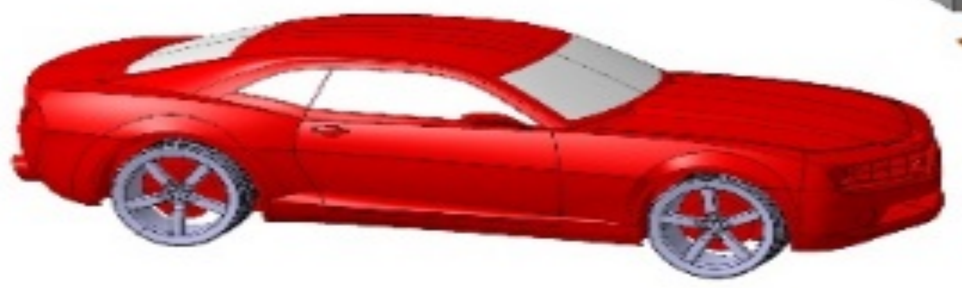

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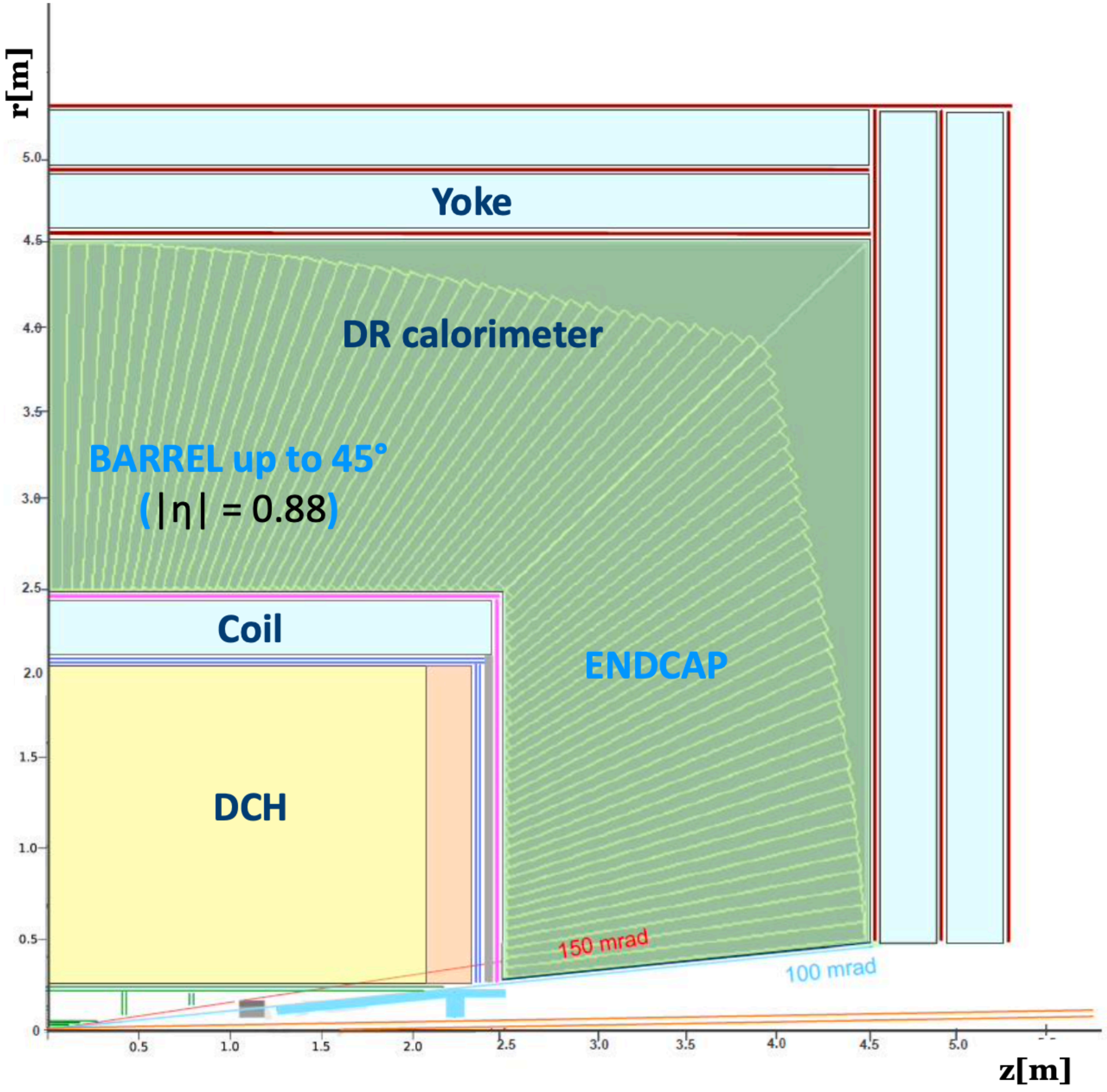
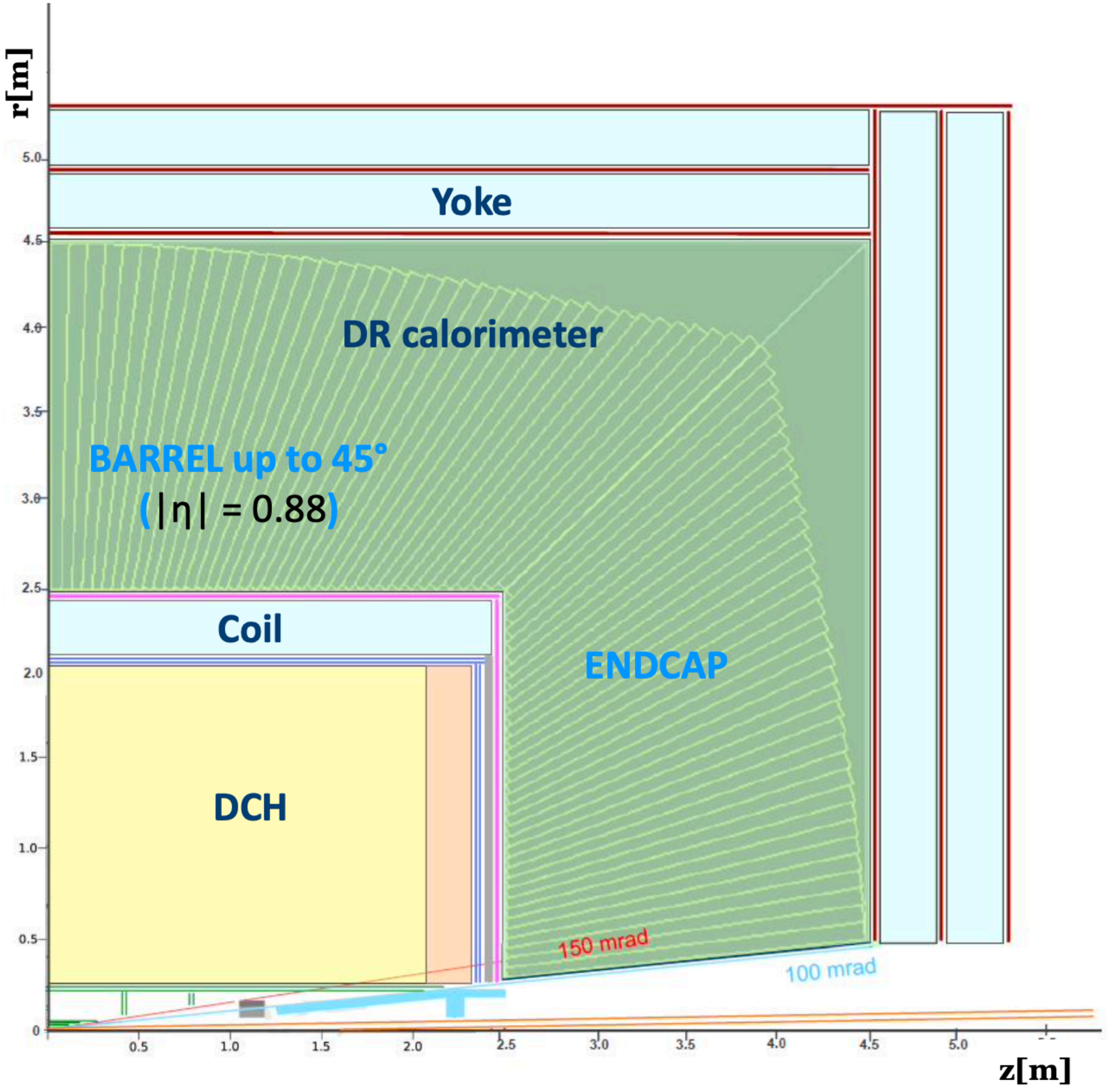
Acknowledgments
I need to thank many colleagues, in particular:
F. Bedeschi

IDEA detector layout



IDEA detector layout

Beam pipe: R~1.2 cm



FUTURE CIRCULAR COLLIDER

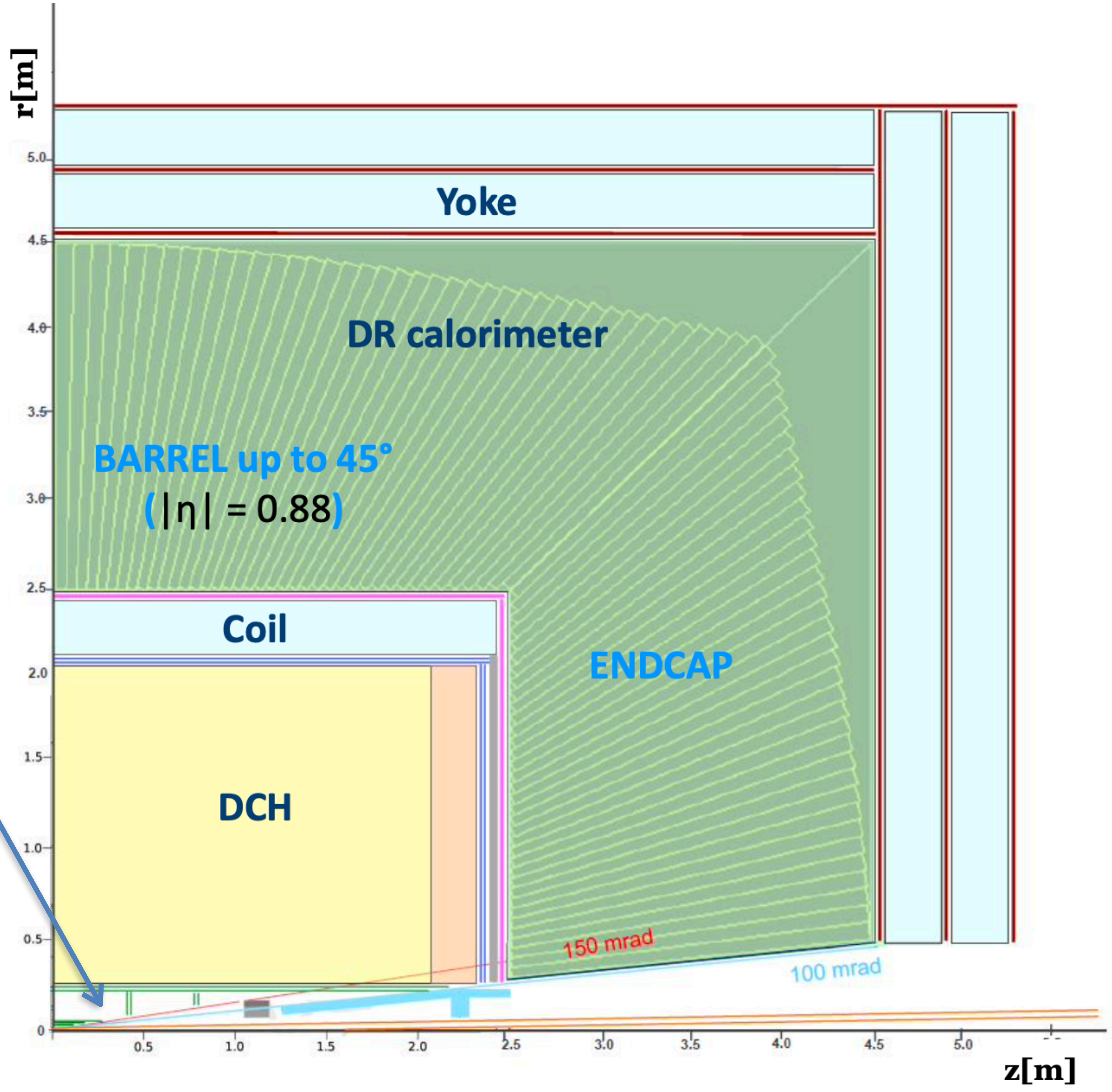
IDEA detector layout

Beam pipe: R~1.2 cm

Vertex:

5 MAPS layers

R = 1.37-31.5 cm



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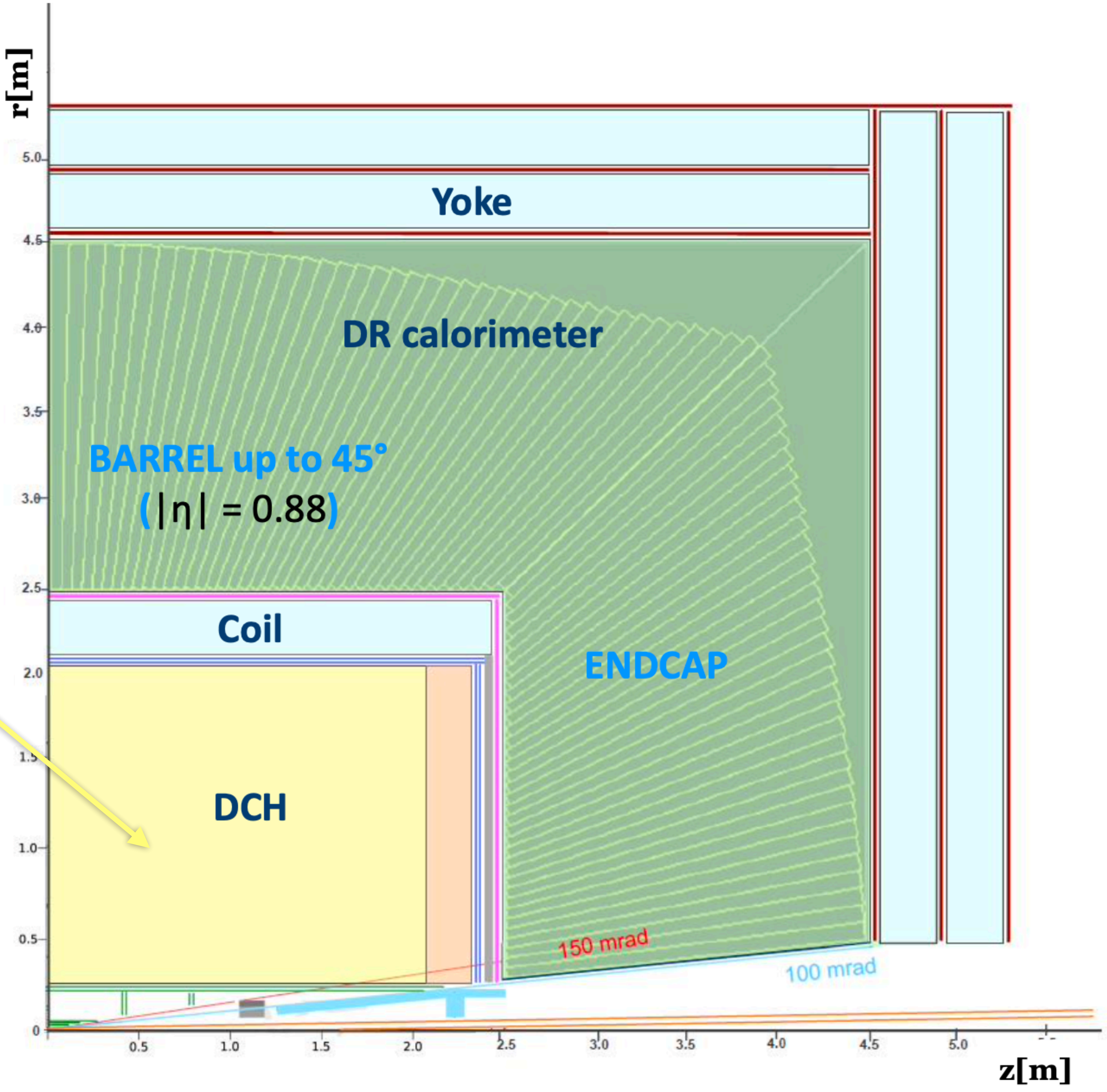
Drift Chamber: 112 layers

4 m long, R = 35-200 cm



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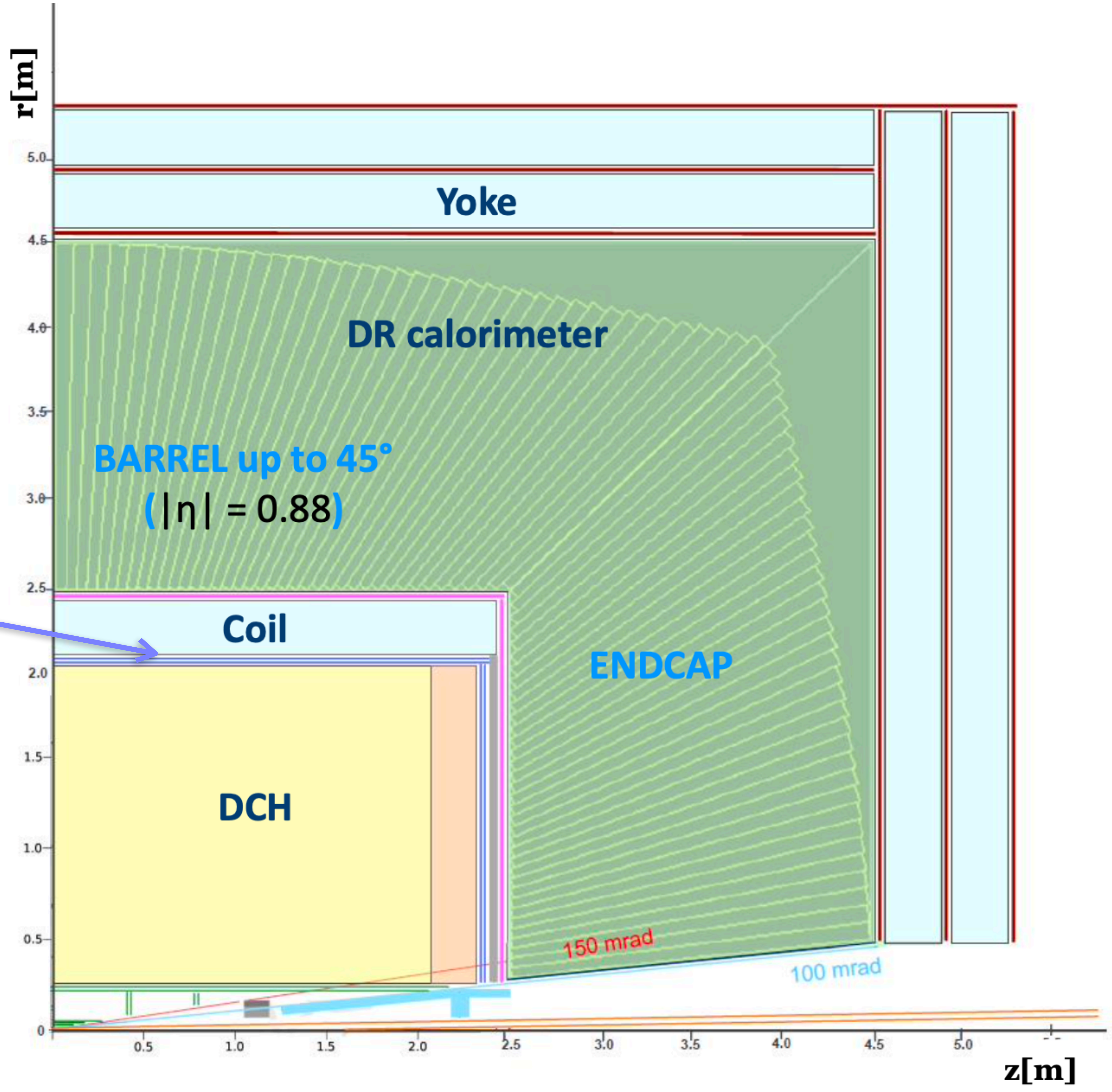
Si strips



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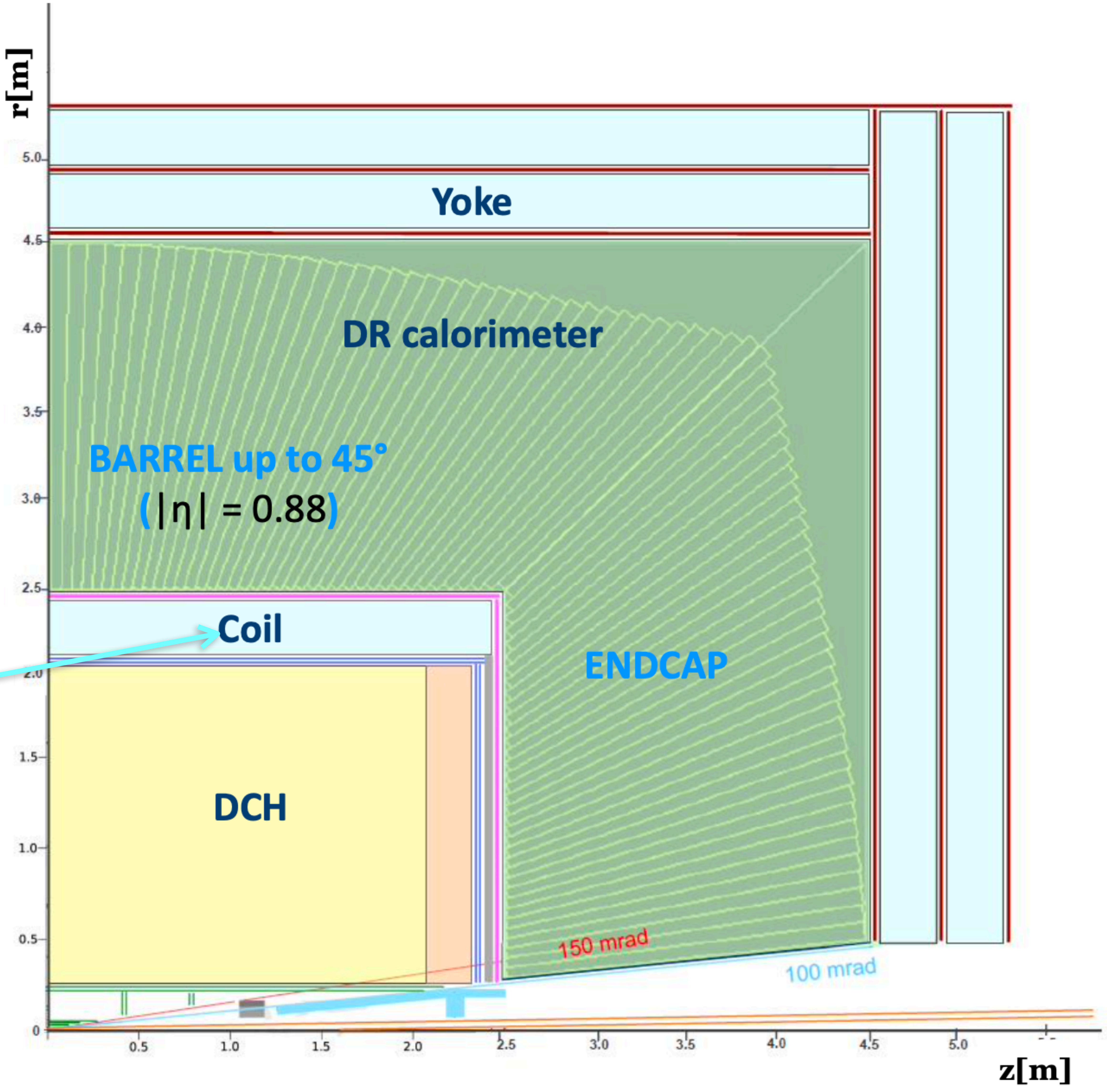
Superconducting solenoid coil:

2 T, R ~ 2.1-2.4 m

0.74 X_0, 0.16 λ @ 90°



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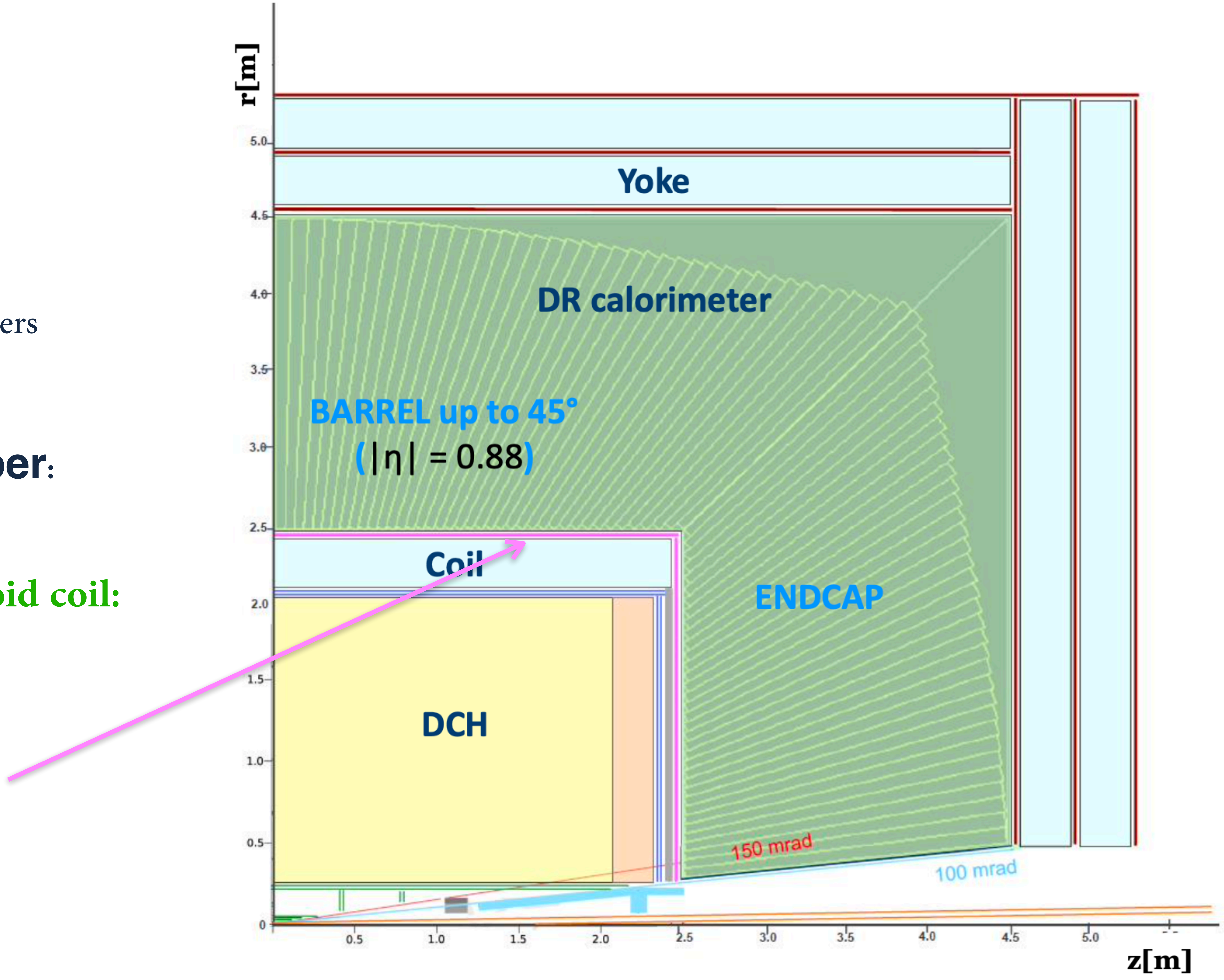

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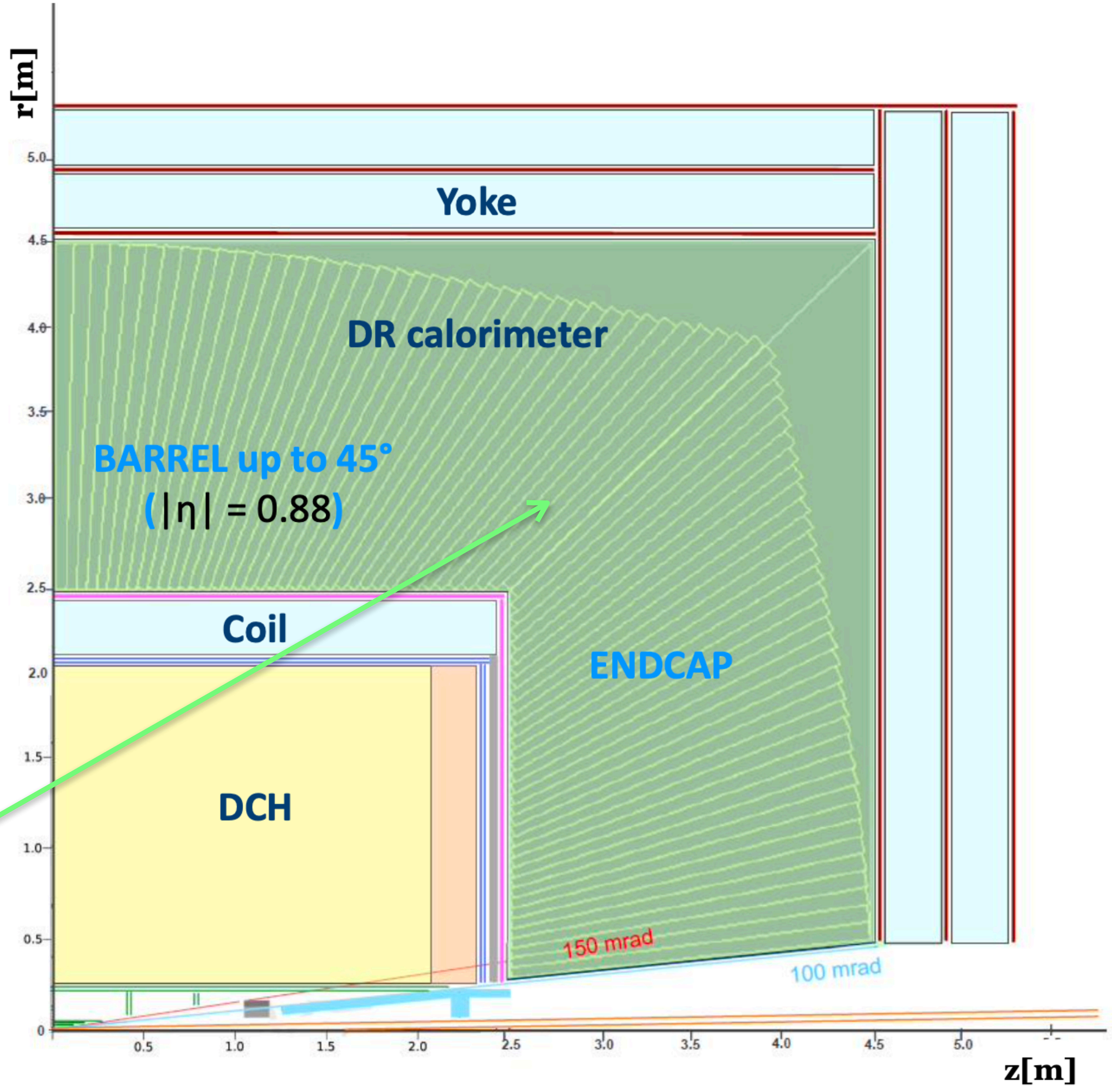
Dual-Readout Calorimeter:

2m / 7 λ_{int}



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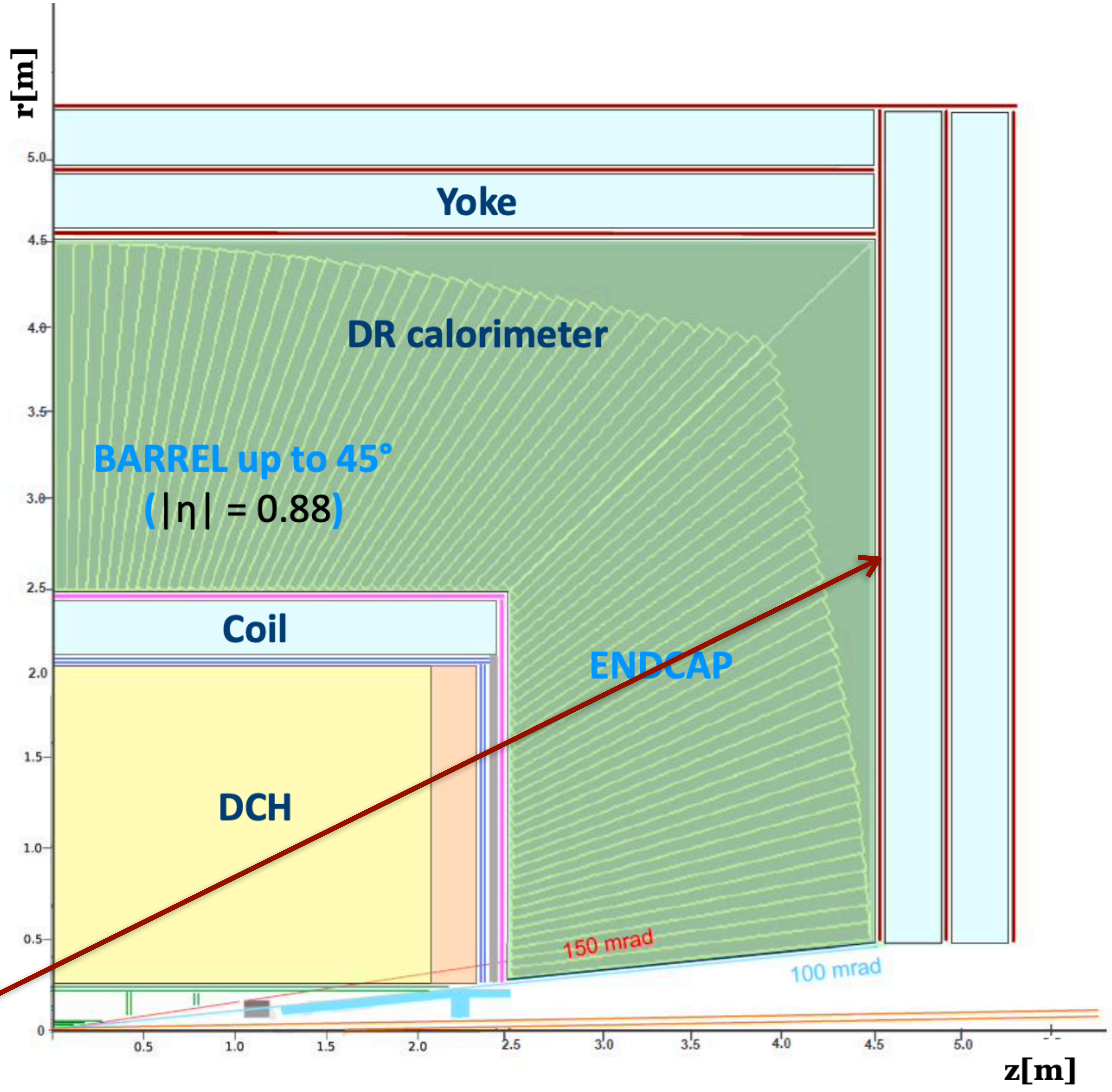
Yoke + Muon chambers



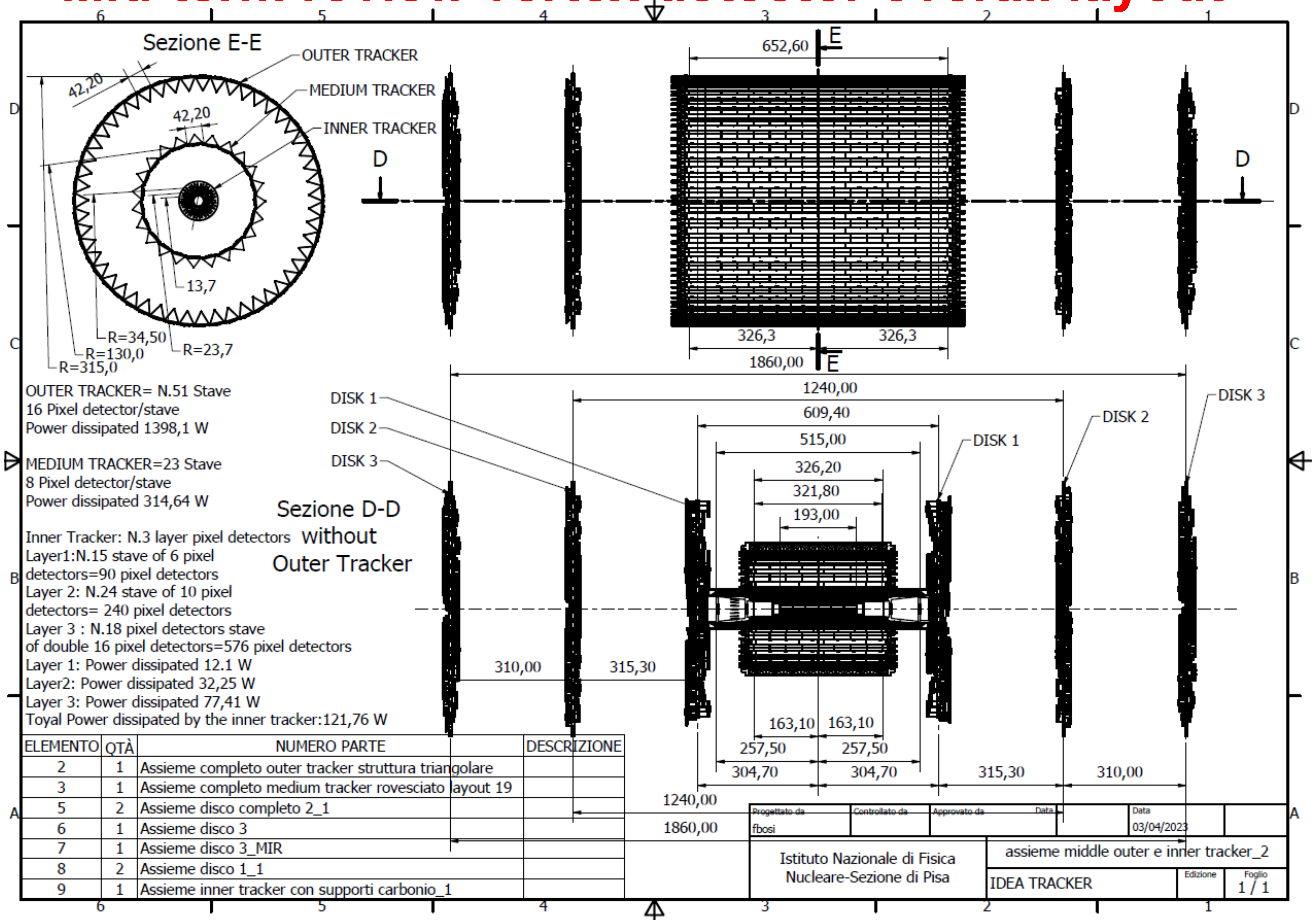
Vertex detector: IDEA

Mid-term review vertex detector overall layout

F. Palla

Vertex detector: IDEA

Mid-term review vertex detector overall layout



F. Palla

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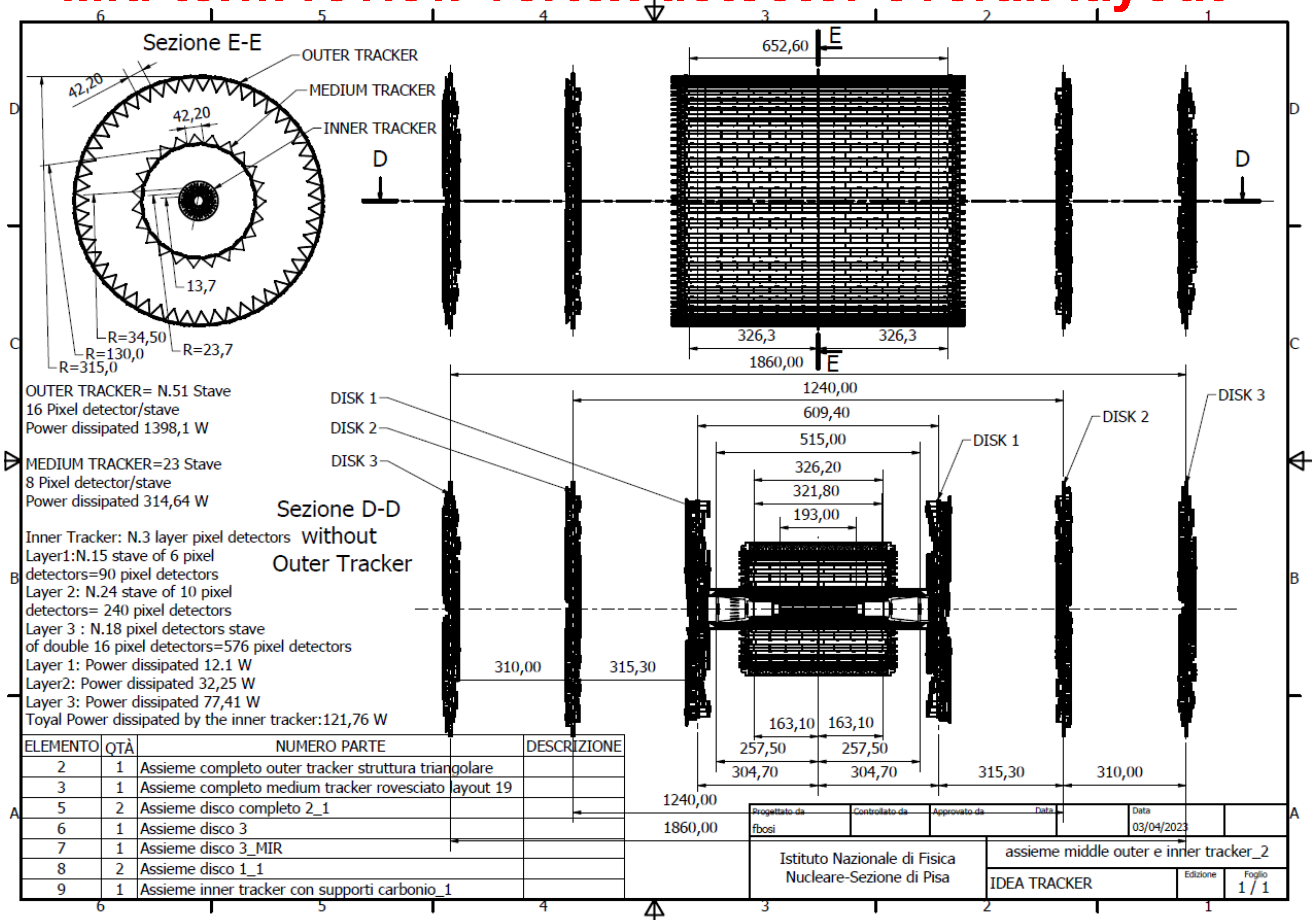
Mid-term review vertex detector overall layout



Inner Vertex detector:

Modules of $25 \times 25\ \mu m^2$ pixel size

3 barrel layers at
- 13.7, 22.7 and 34.8 mm radius

F. Palla

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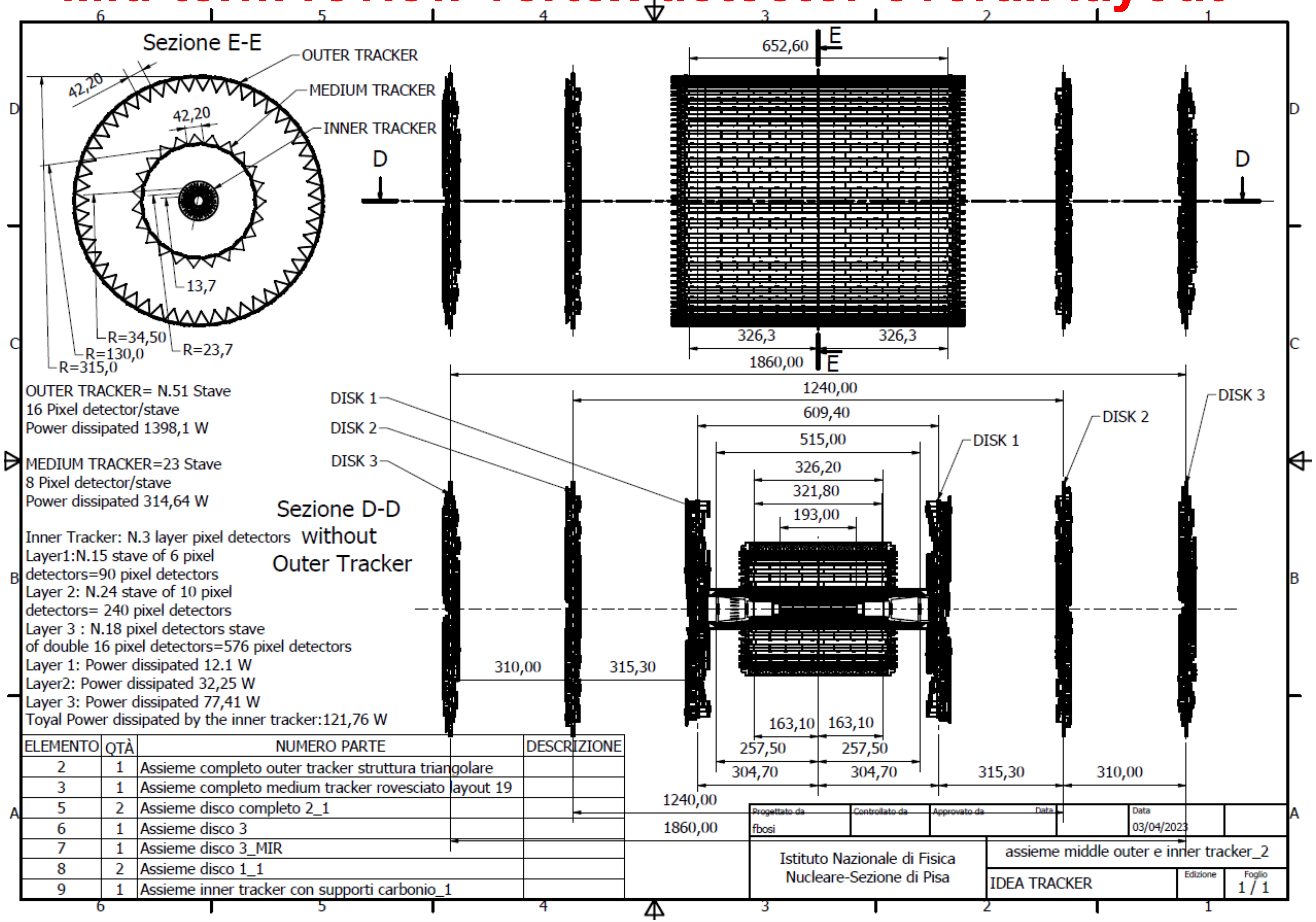
Mid-term review vertex detector overall layout



Outer vertex tracker:

Modules of $50 \times 150\ \mu m^2$ pixel size

- Intermediate barrel at 13 cm radius (improved reconstruction for $p_T > 40$ MeV tracks)
- Outer barrel at 31.5 cm radius
- 3 disks per side

Inner Vertex detector:

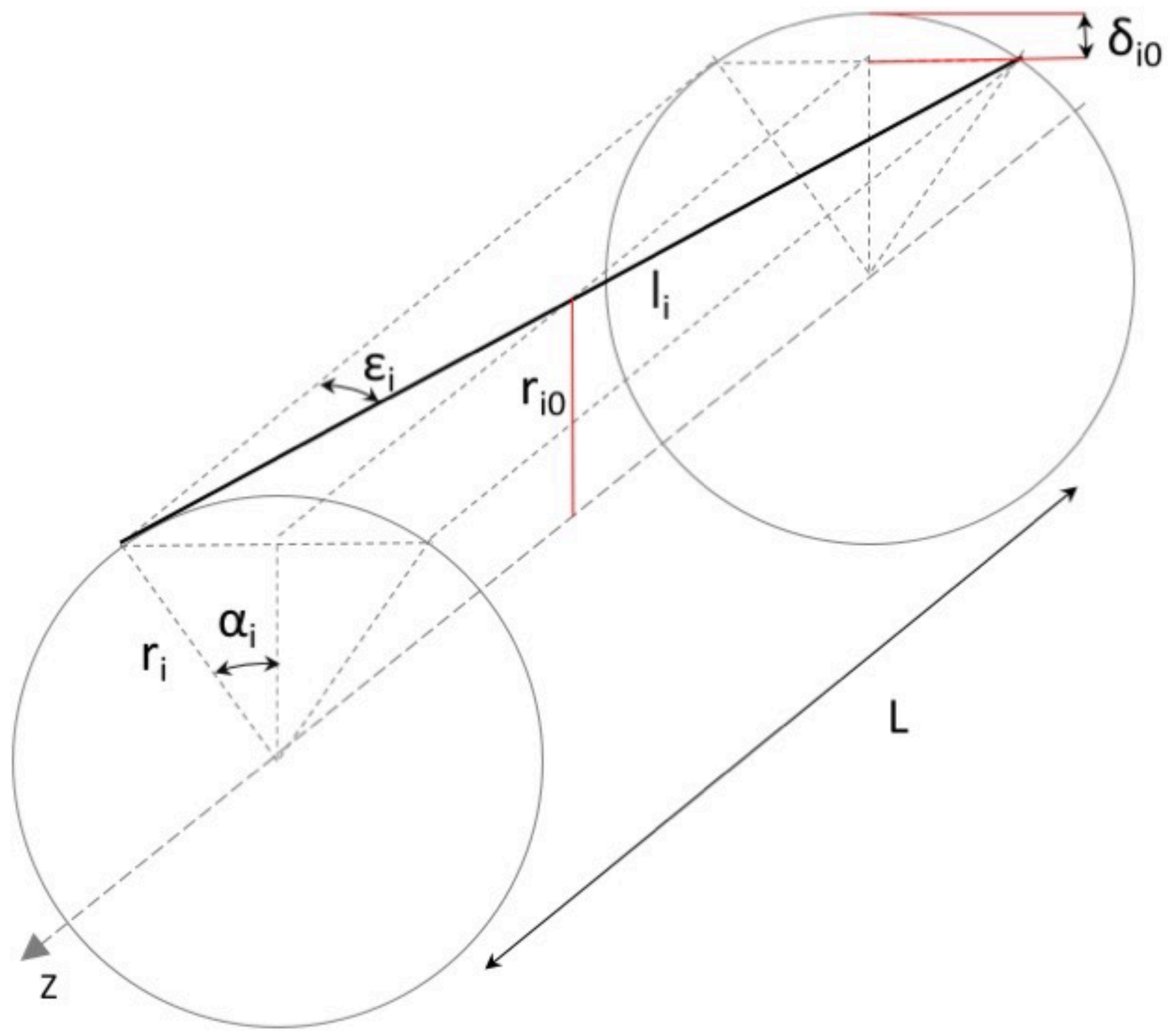
Modules of $25 \times 25\ \mu m^2$ pixel size

3 barrel layers at
- 13.7, 22.7 and 34.8 mm radius

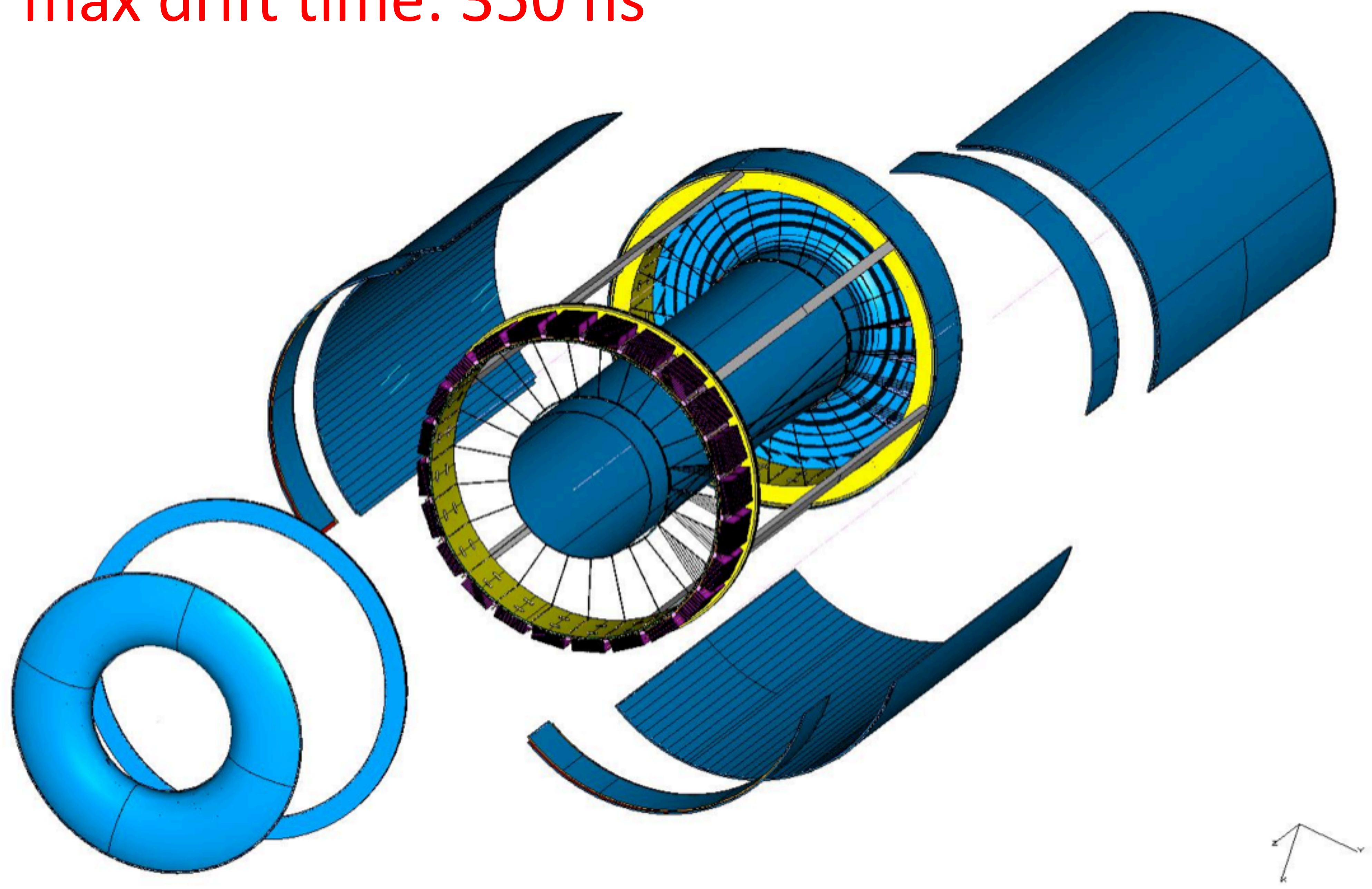
F. Palla

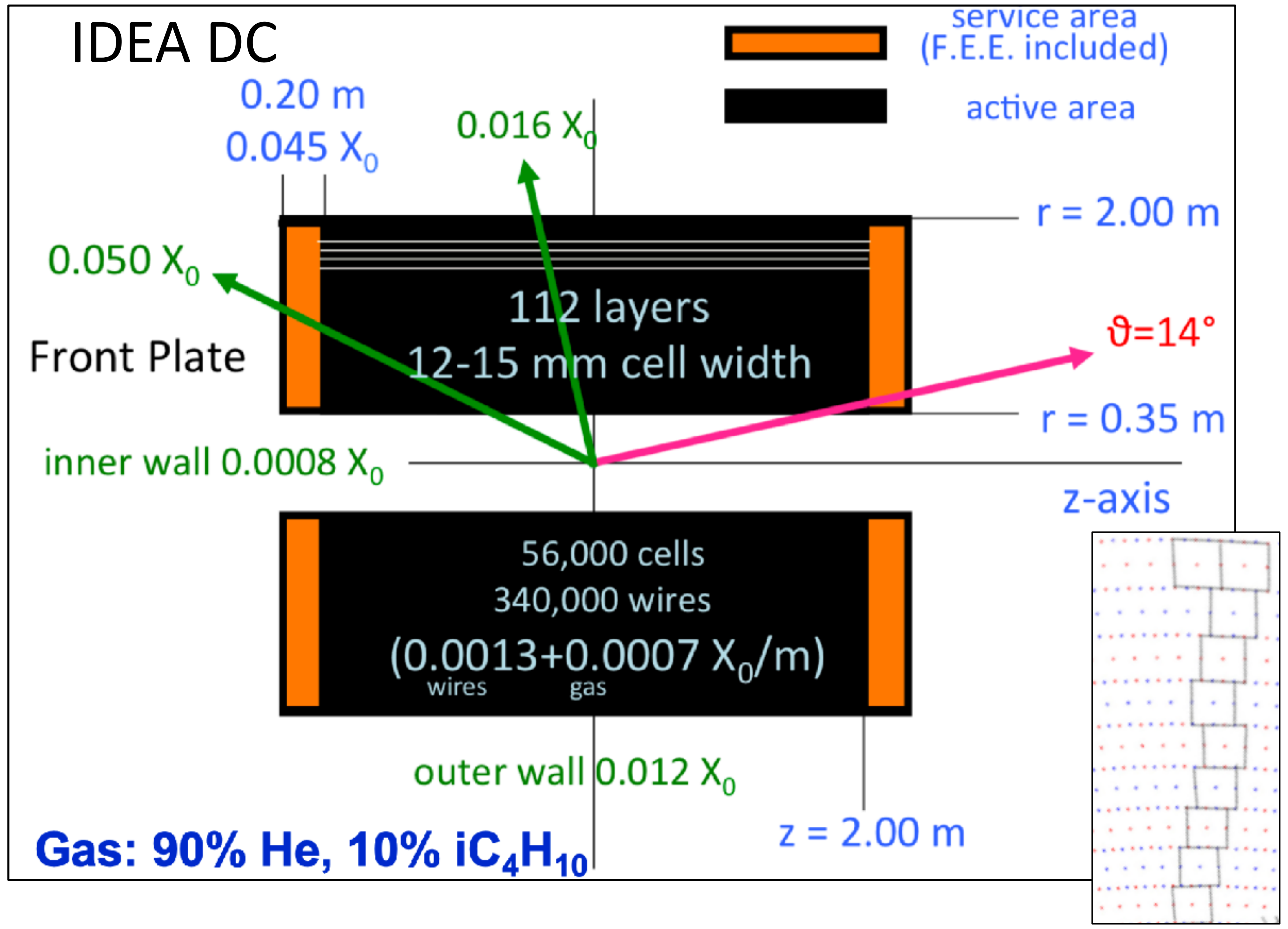
Drift chamber

- IDEA: Extremely transparent Drift Chamber
  - Gas: 90% He – 10% iC_4H_{10}
  - Radius 0.35 – 2.00 m
  - Total thickness: 1.6% of X_0 at 90°
  - All stereo wires (56448 cells, 343968 wires)
    - Tungsten wires dominant contribution
  - 112 layers for each 15° azimuthal sector
  - max drift time: 350 ns



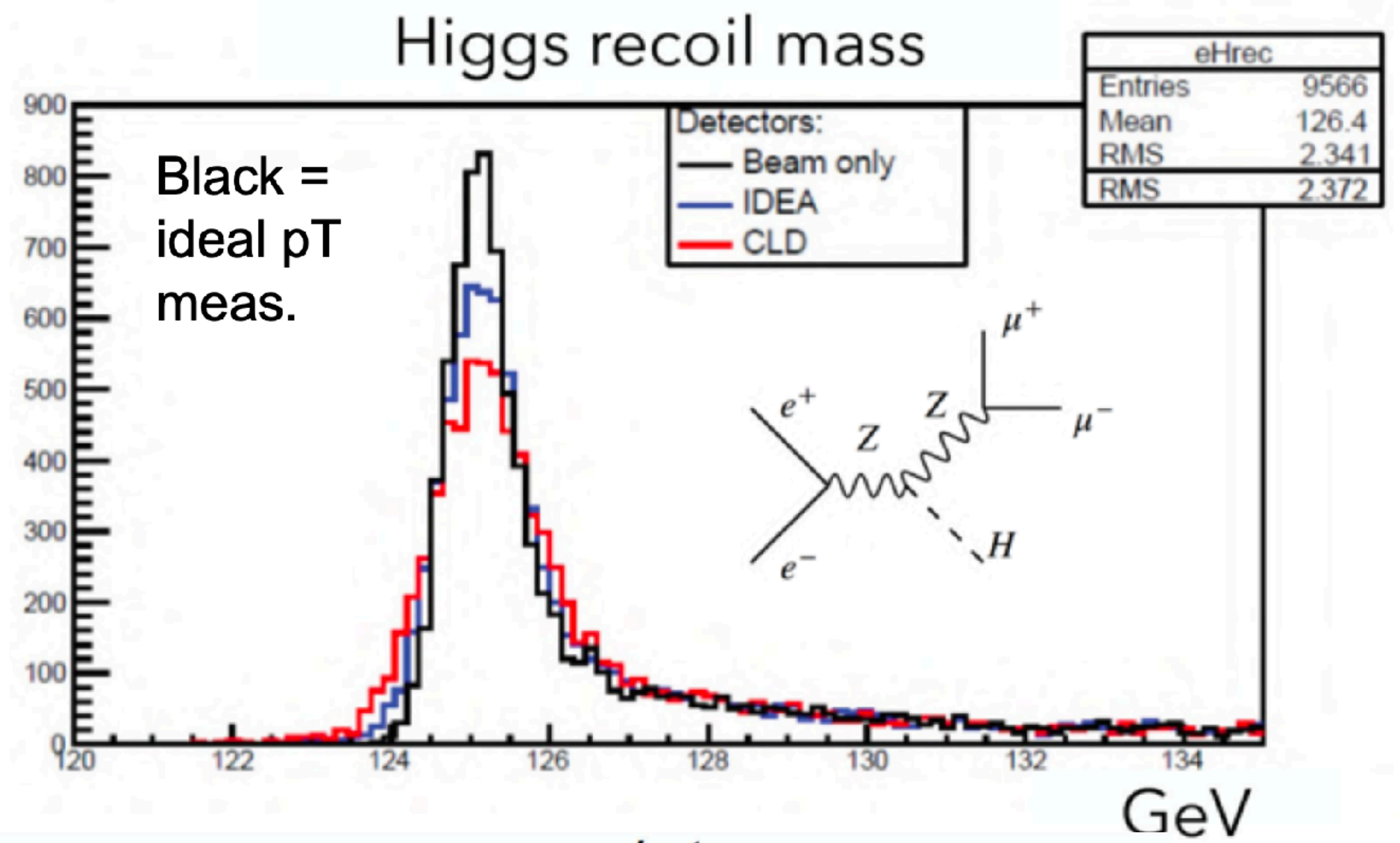
L = 4m

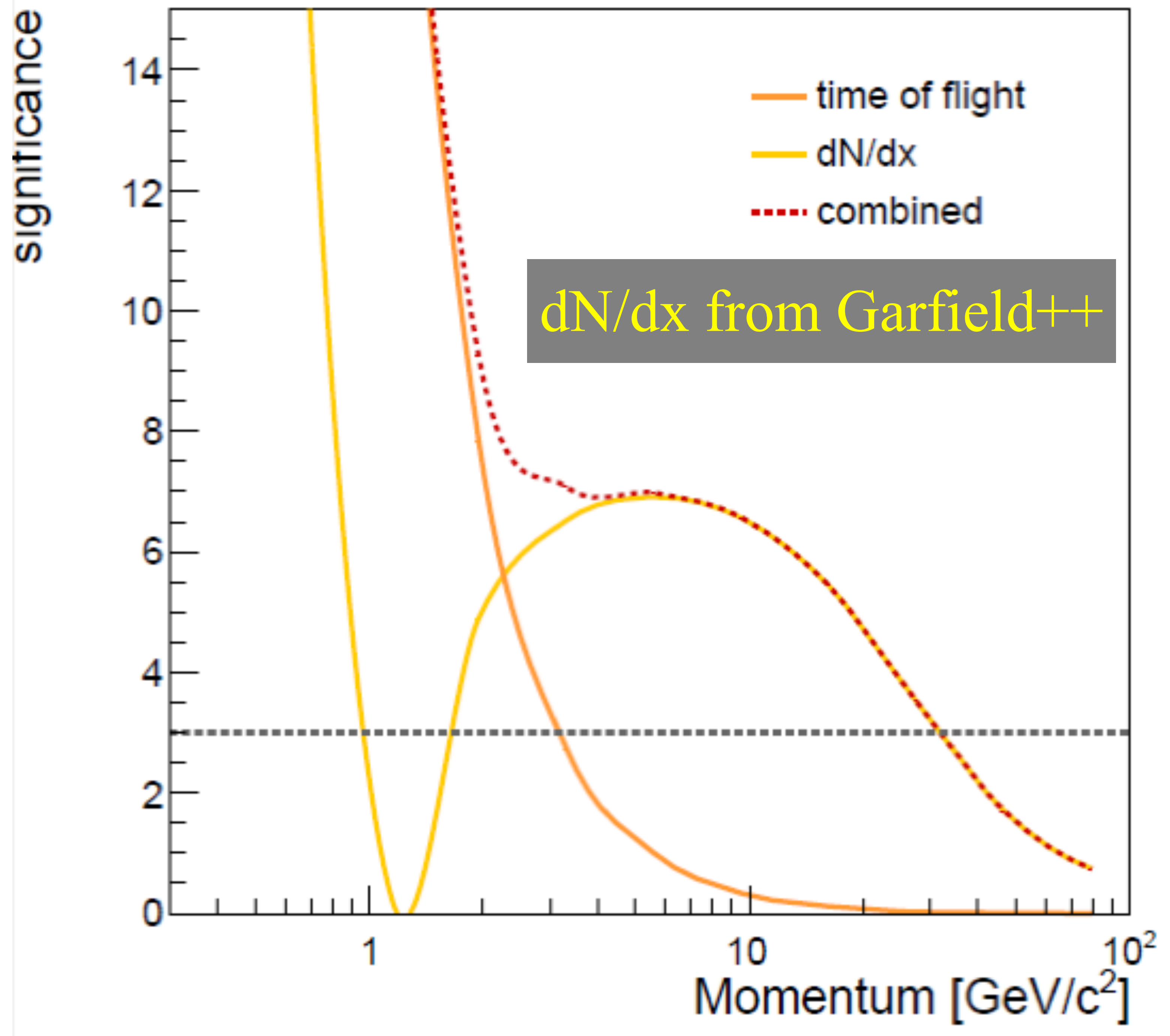


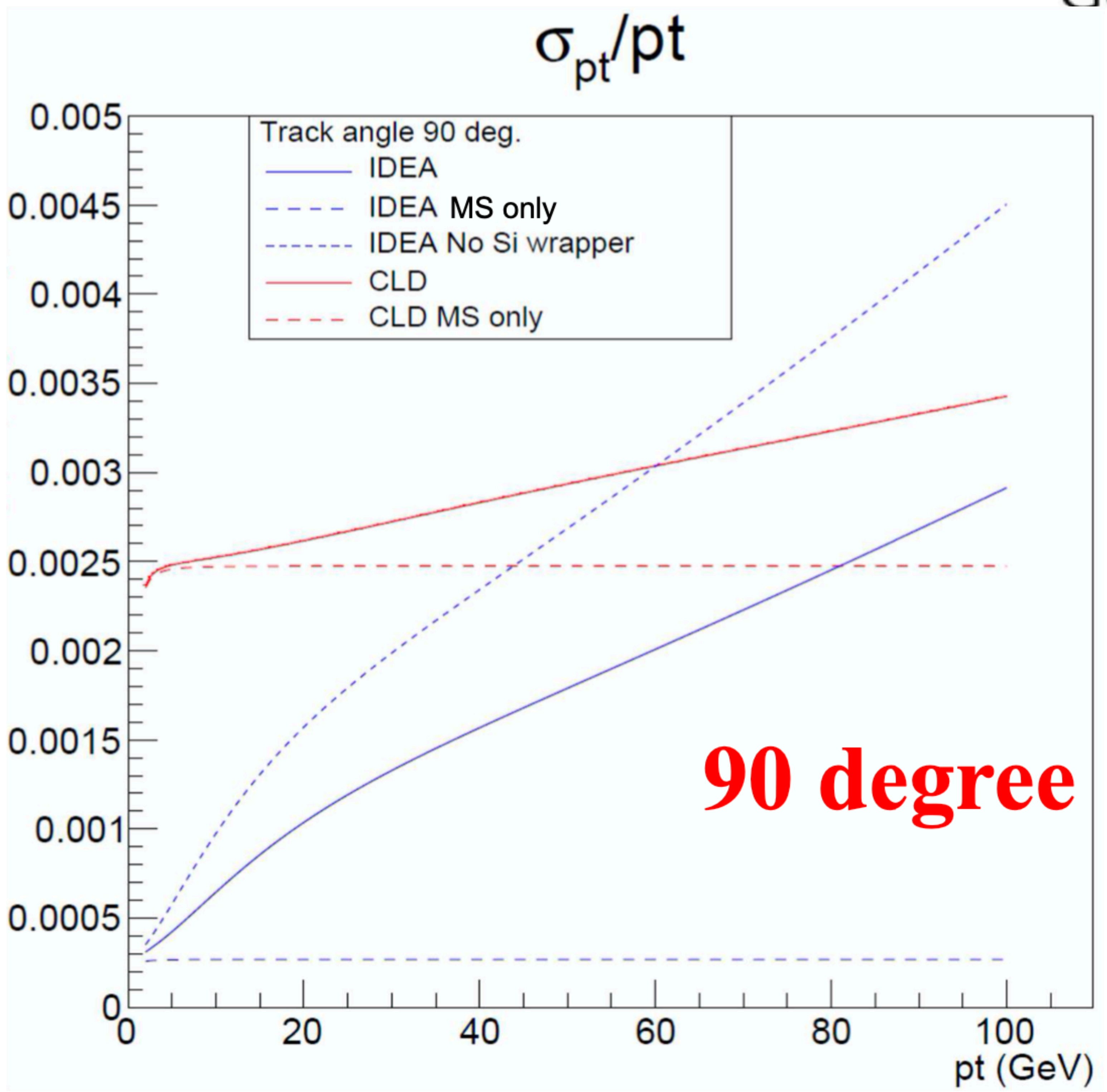


Drift chamber

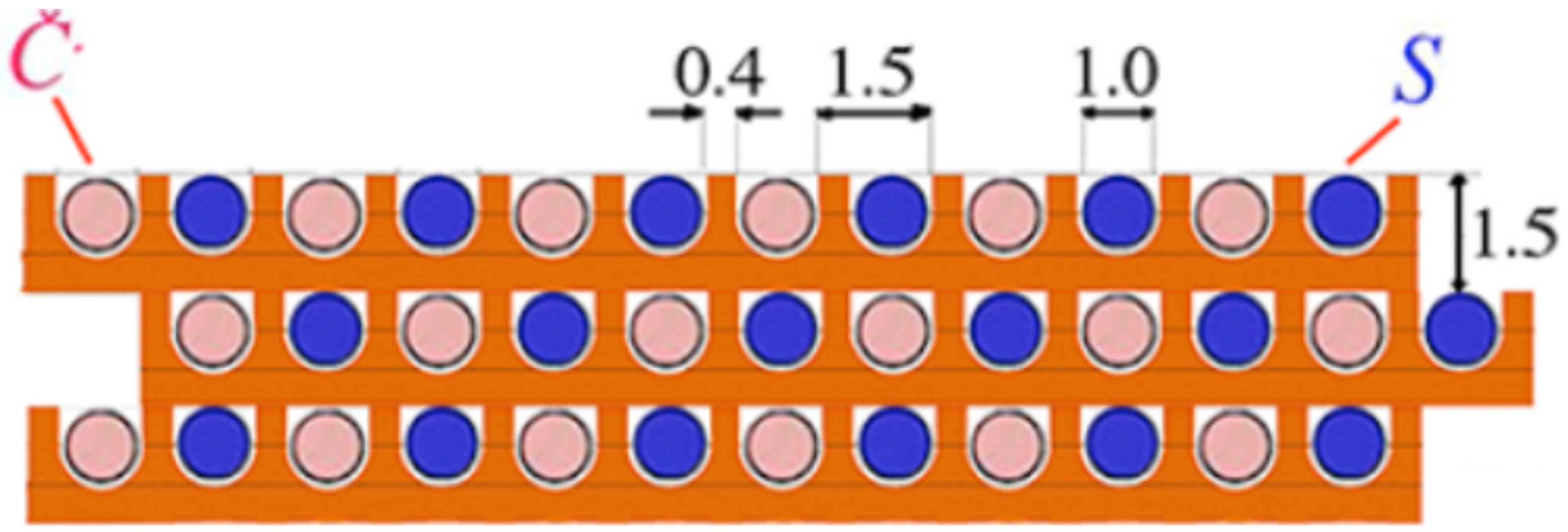
- In general, tracks have rather low momenta ($p_T \lesssim 50$ GeV)
  - Transparency more relevant than asymptotic resolution
- Drift chamber (gaseous tracker) advantages
  - Extremely transparent: minimal multiple scattering and secondary interactions
  - Continuous tracking: reconstruction of far-detached vertices (K^0_S, Λ, BSM, LLPs)
  - Outstanding Particle separation via dE/dx or cluster counting (dN/dx)
    - >3σ K/π separation up to ~35 GeV





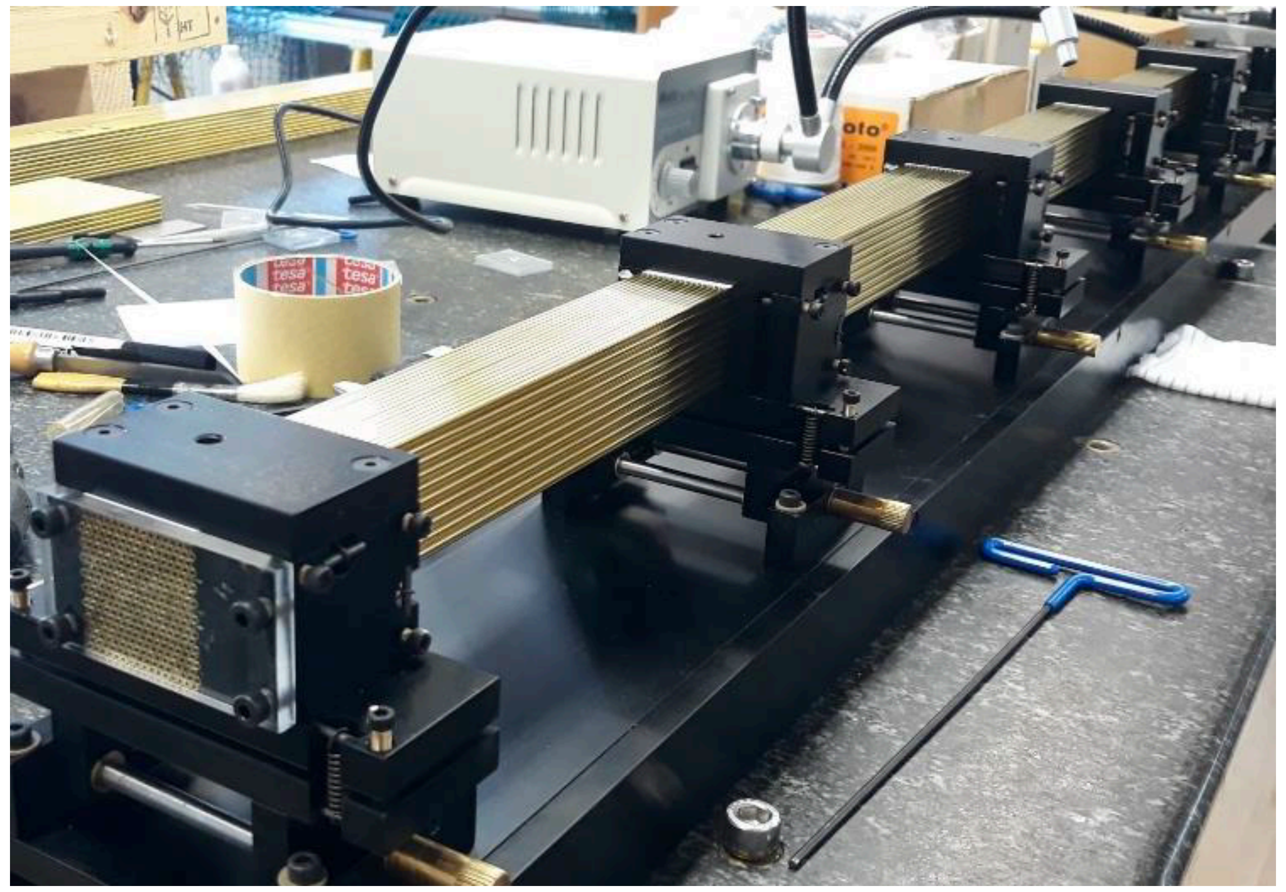


Dual Readout Calorimetry

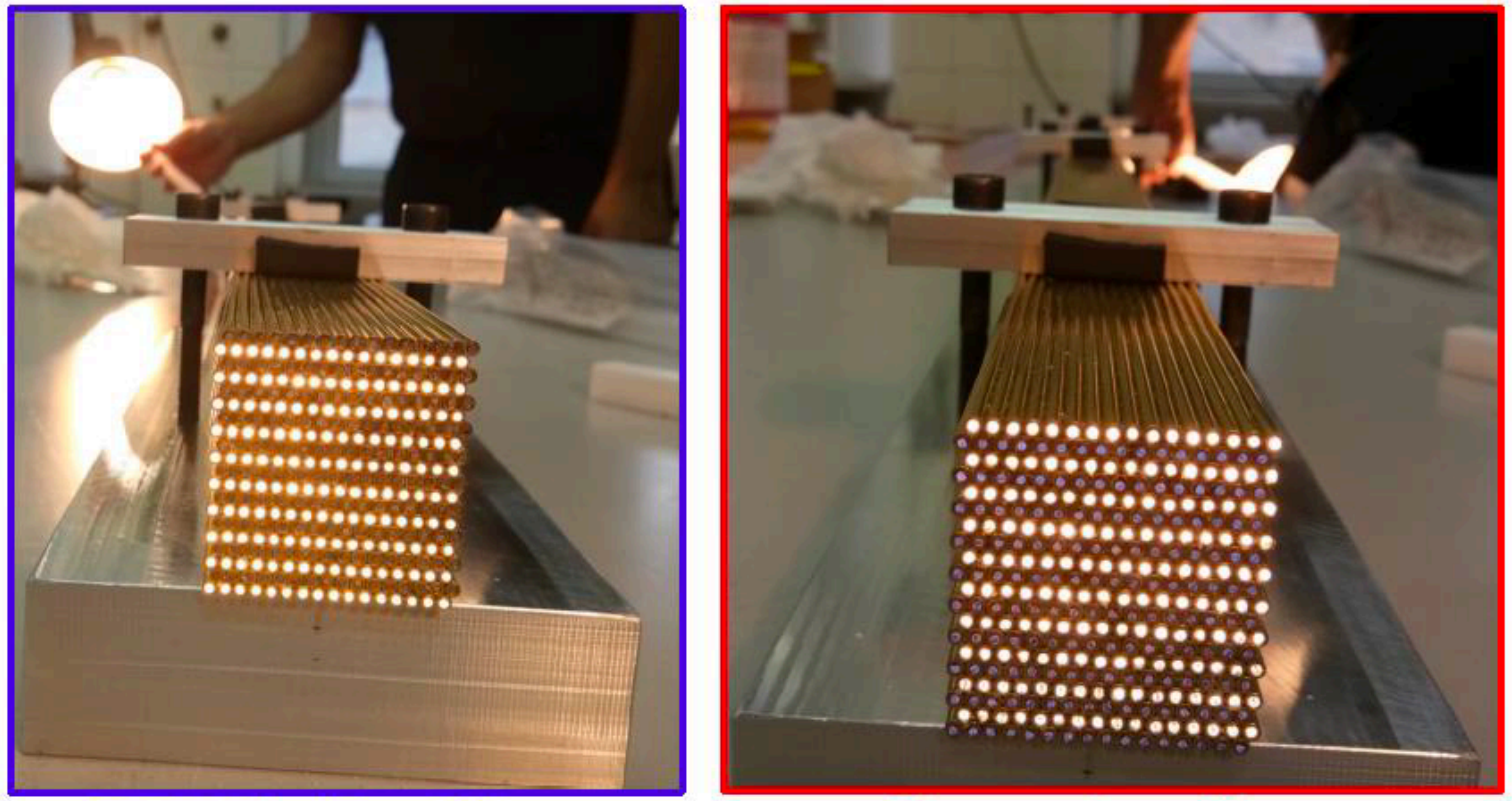


Alternate
Cherenkov fibers
Scintillating fibers

~2m long capillaries



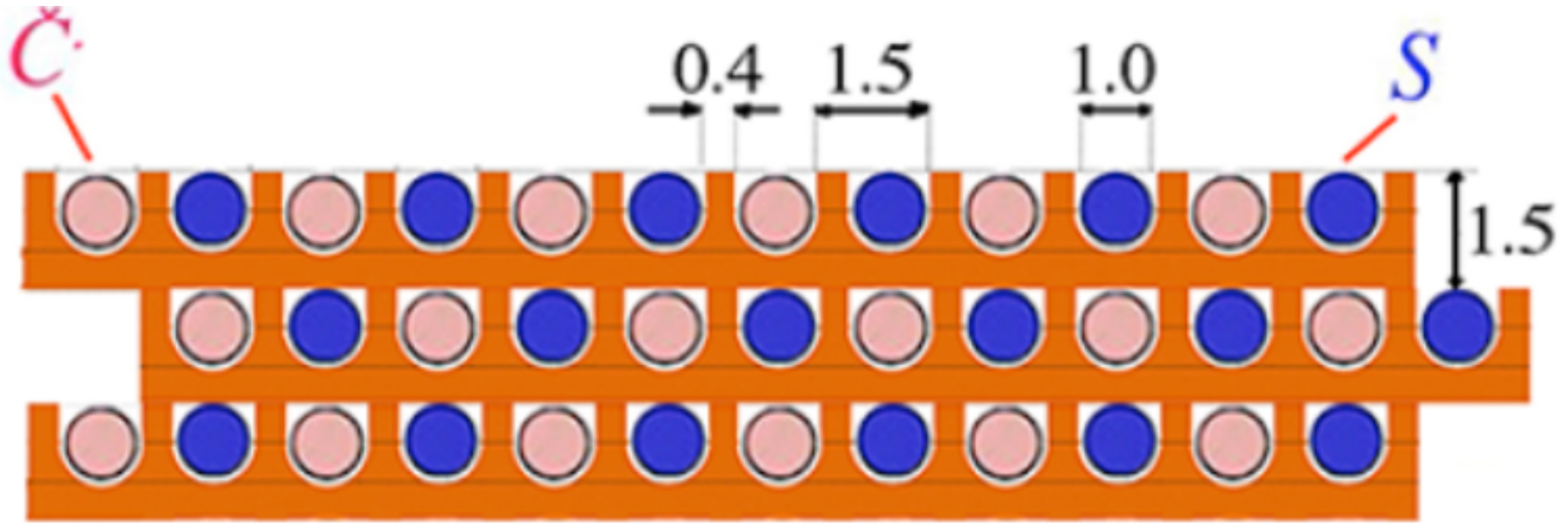
Newer DR calorimeter
(bucatini calorimeter)



Scintillation fibers

Cherenkov fibers

Dual Readout Calorimetry



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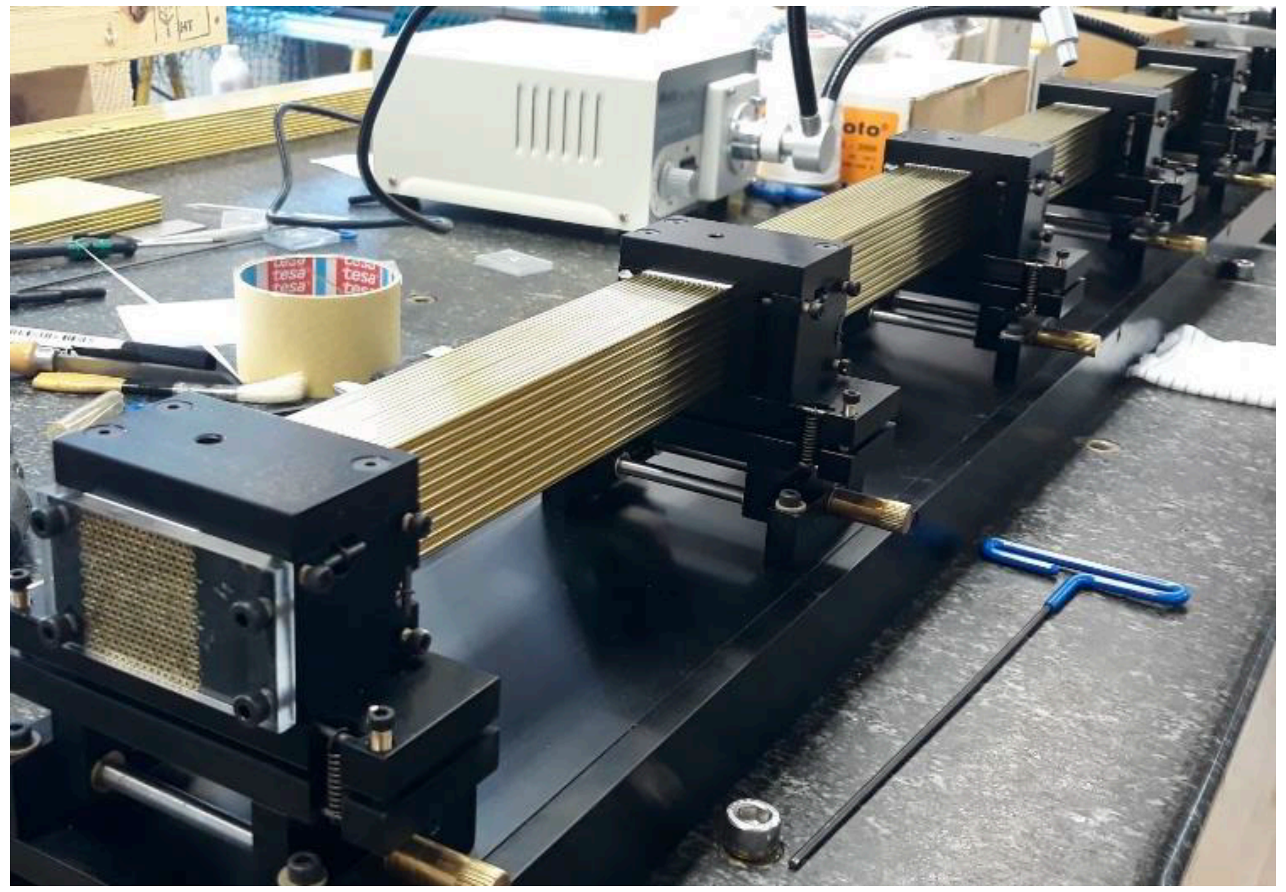
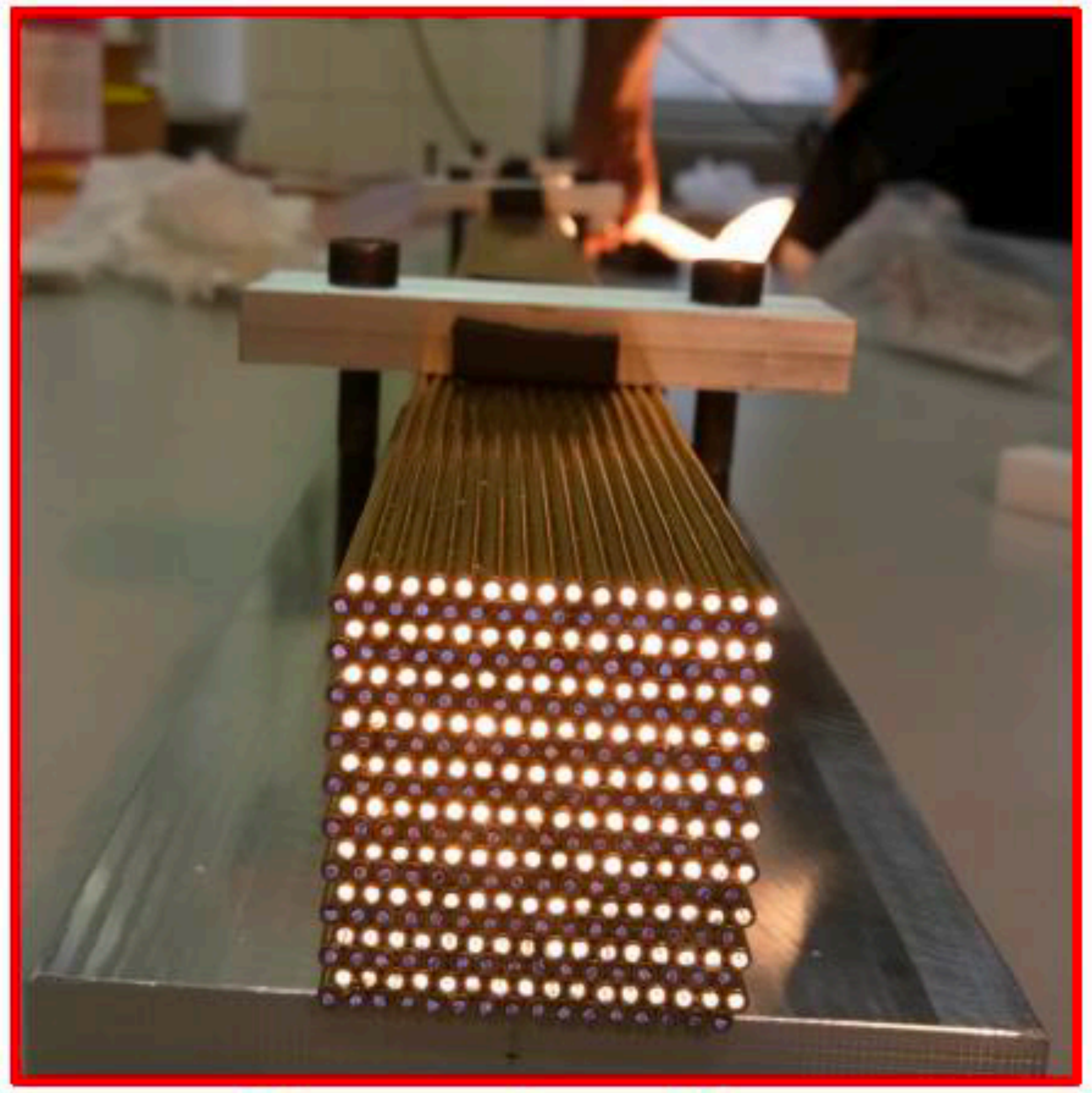


- ❖ Measure simultaneously:
  - ➢ Scintillation signal (S)
  - ➢ Cherenkov signal (Q)

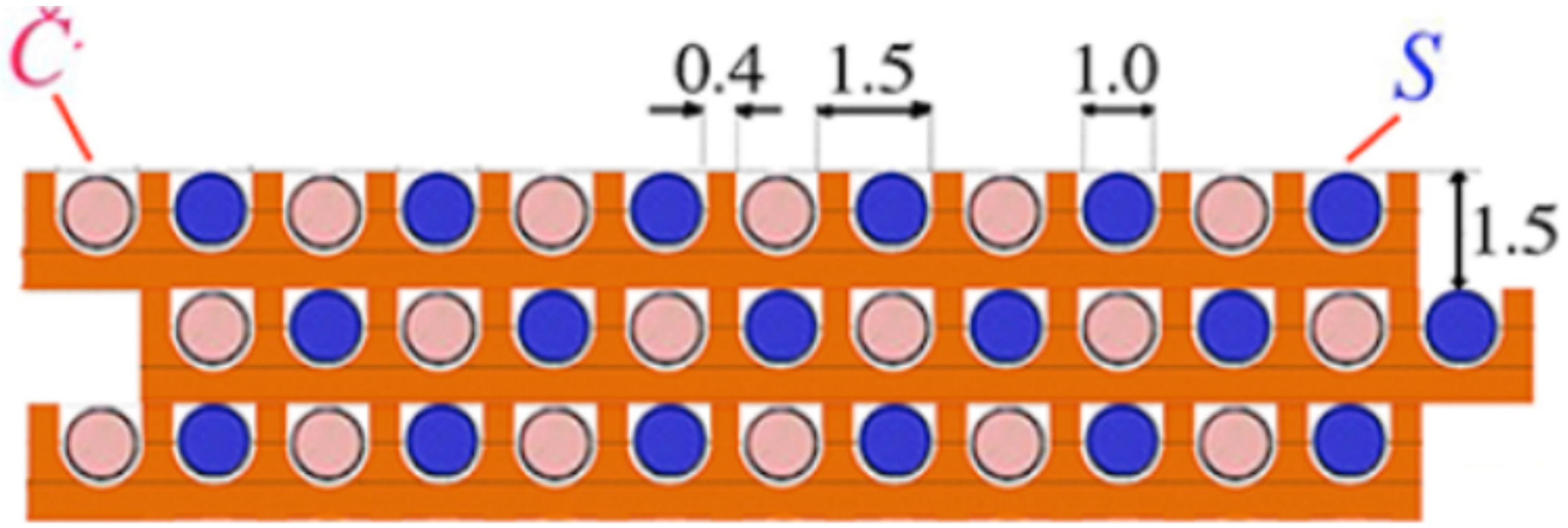
Newer DR calorimeter
(bucatini calorimeter)

Scintillation fibers



Cherenkov fibers

Dual Readout Calorimetry



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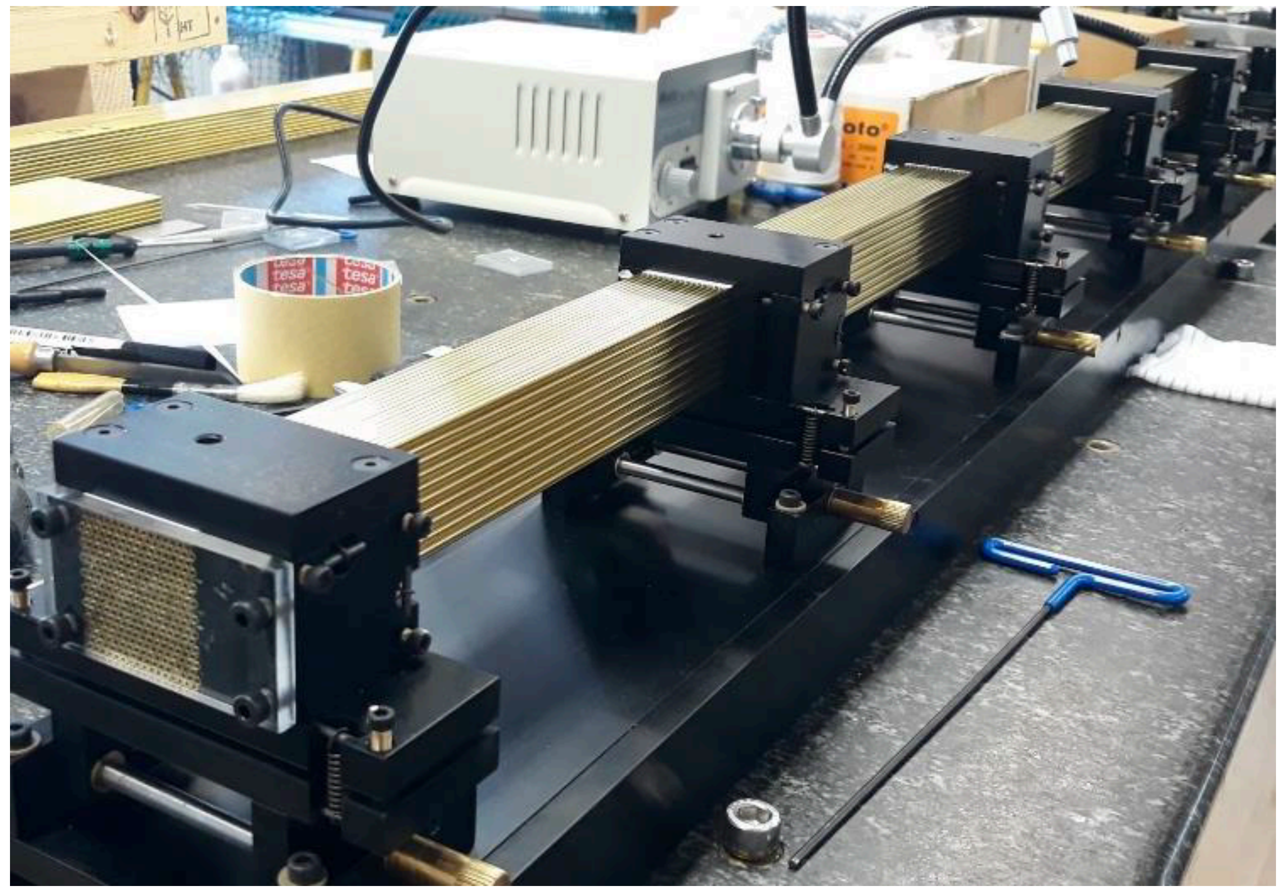

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- Calibrate both signals with e-

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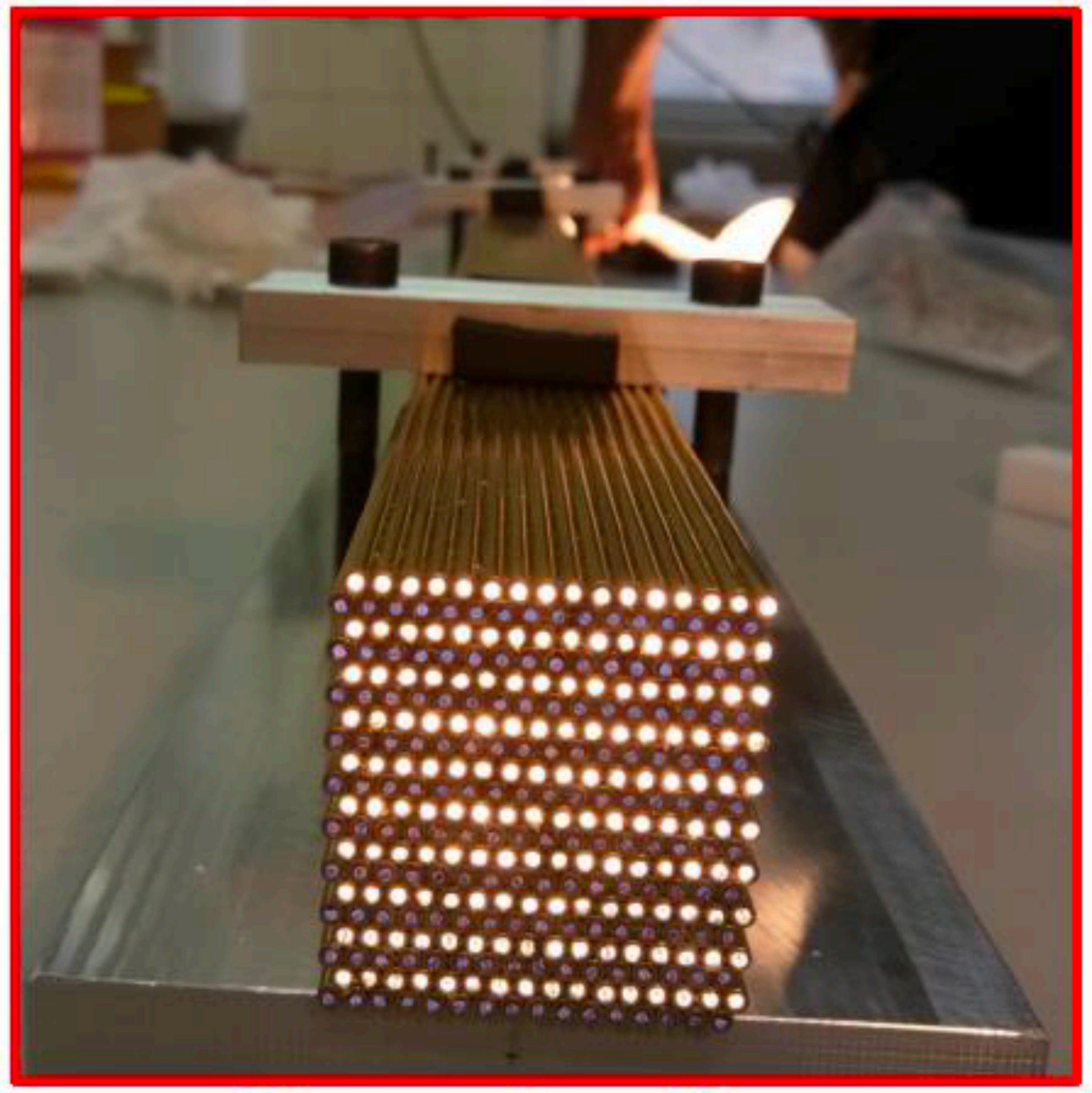

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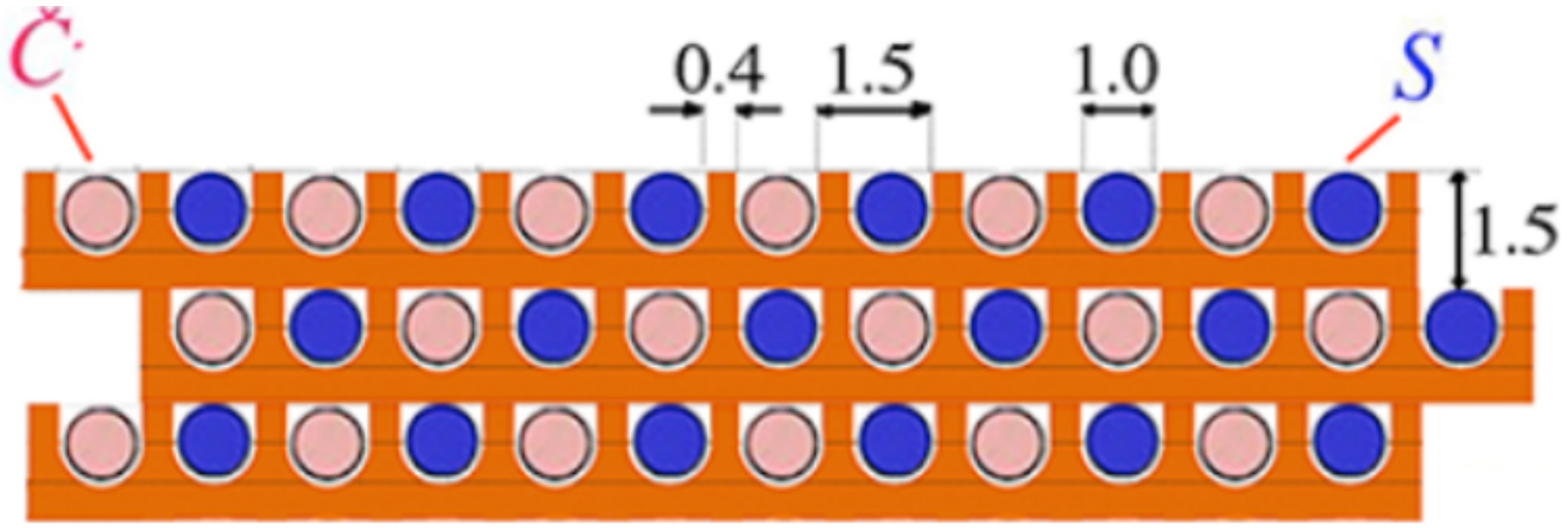

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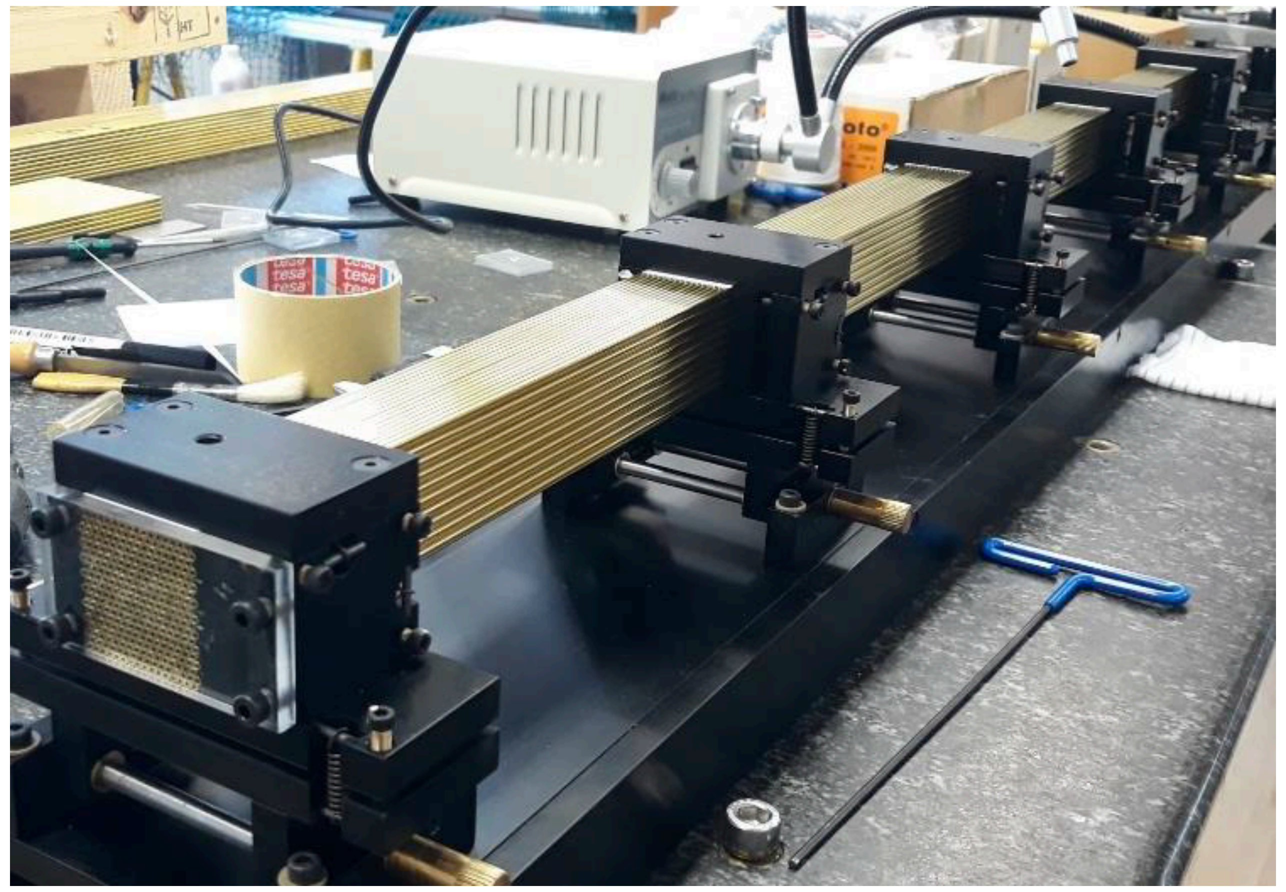

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Newer DR calorimeter
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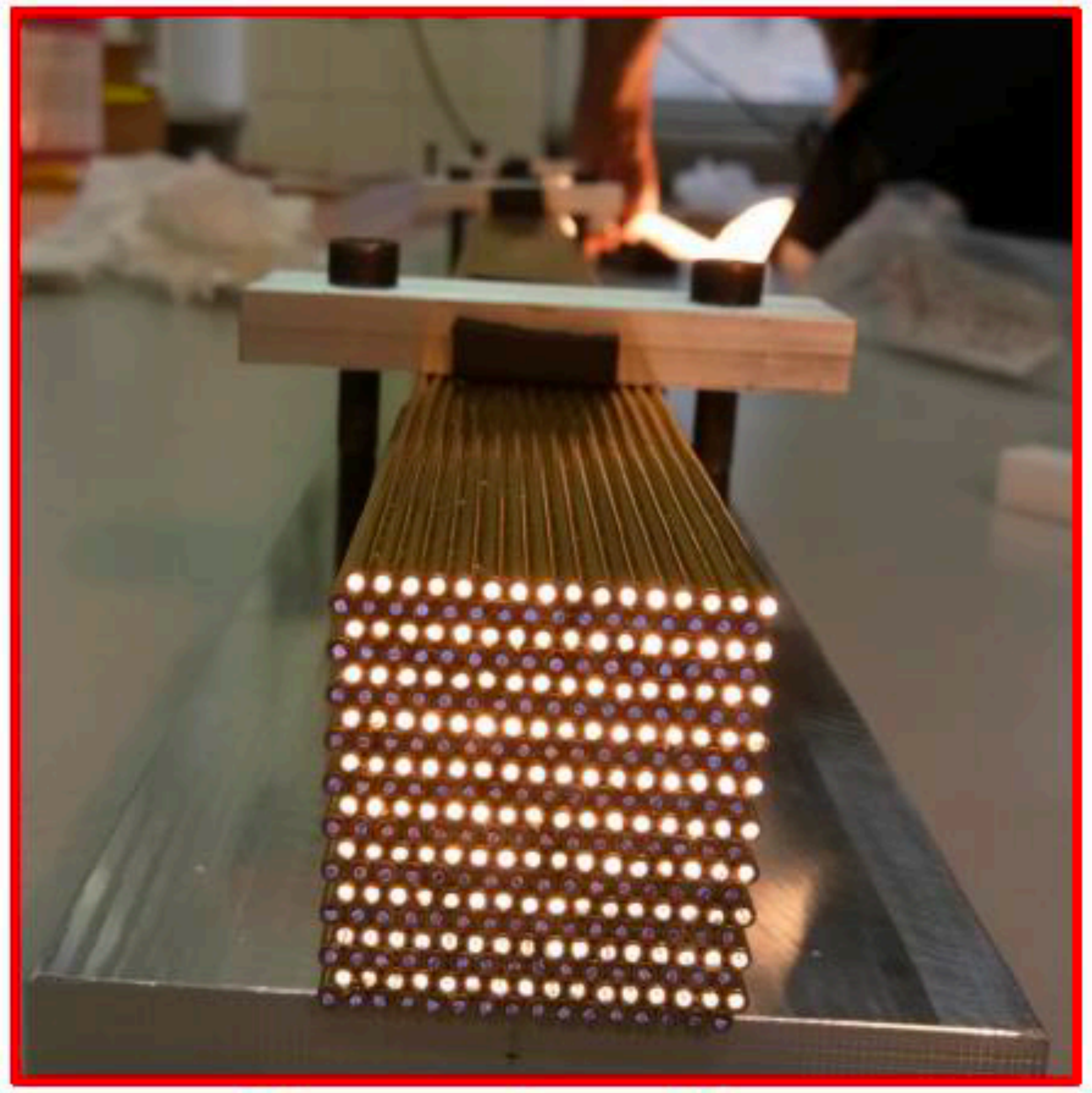

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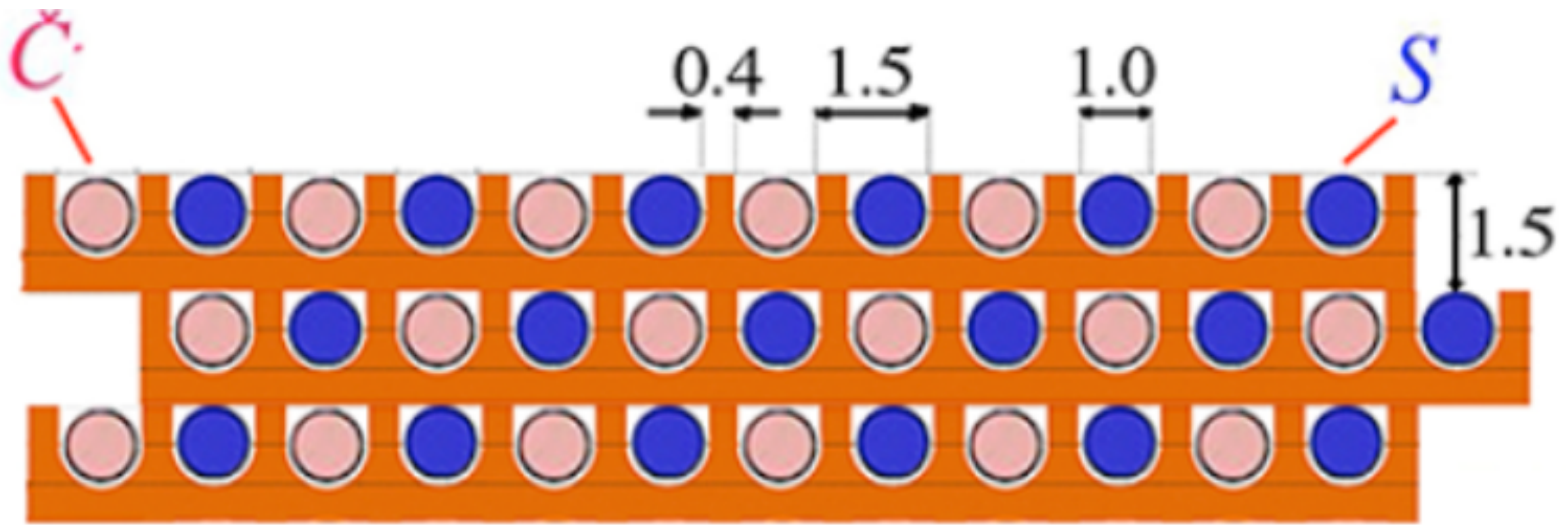

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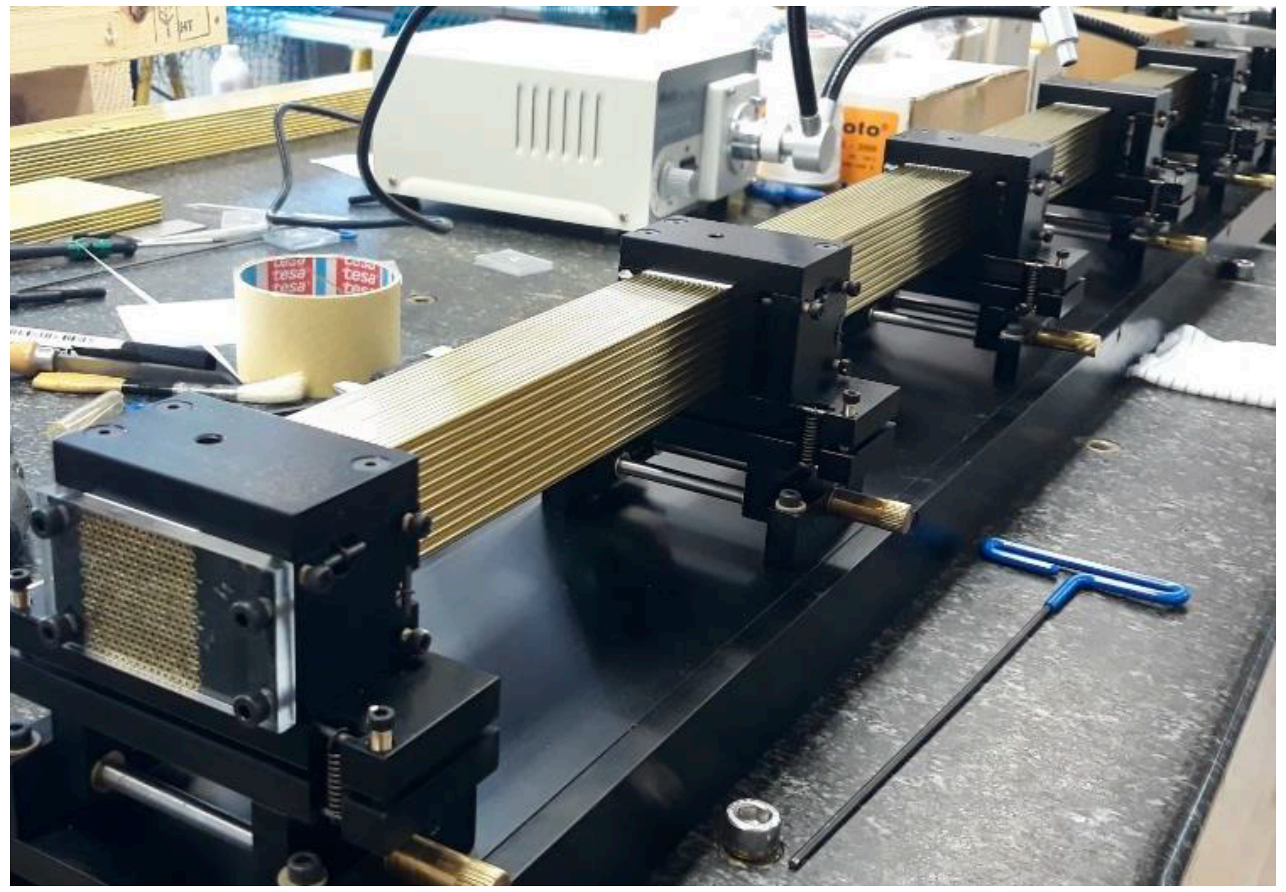

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$$S = E\left[f_{em} + (h/e)_S(1 - f_{em})\right]$$

$$C = E\left[f_{em} + (h/e)_C(1 - f_{em})\right]$$

$$E = \frac{S - \chi C}{1 - \chi} \quad \text{with:} \quad \chi = \frac{1 - (h/e)_S}{1 - (h/e)_C}$$

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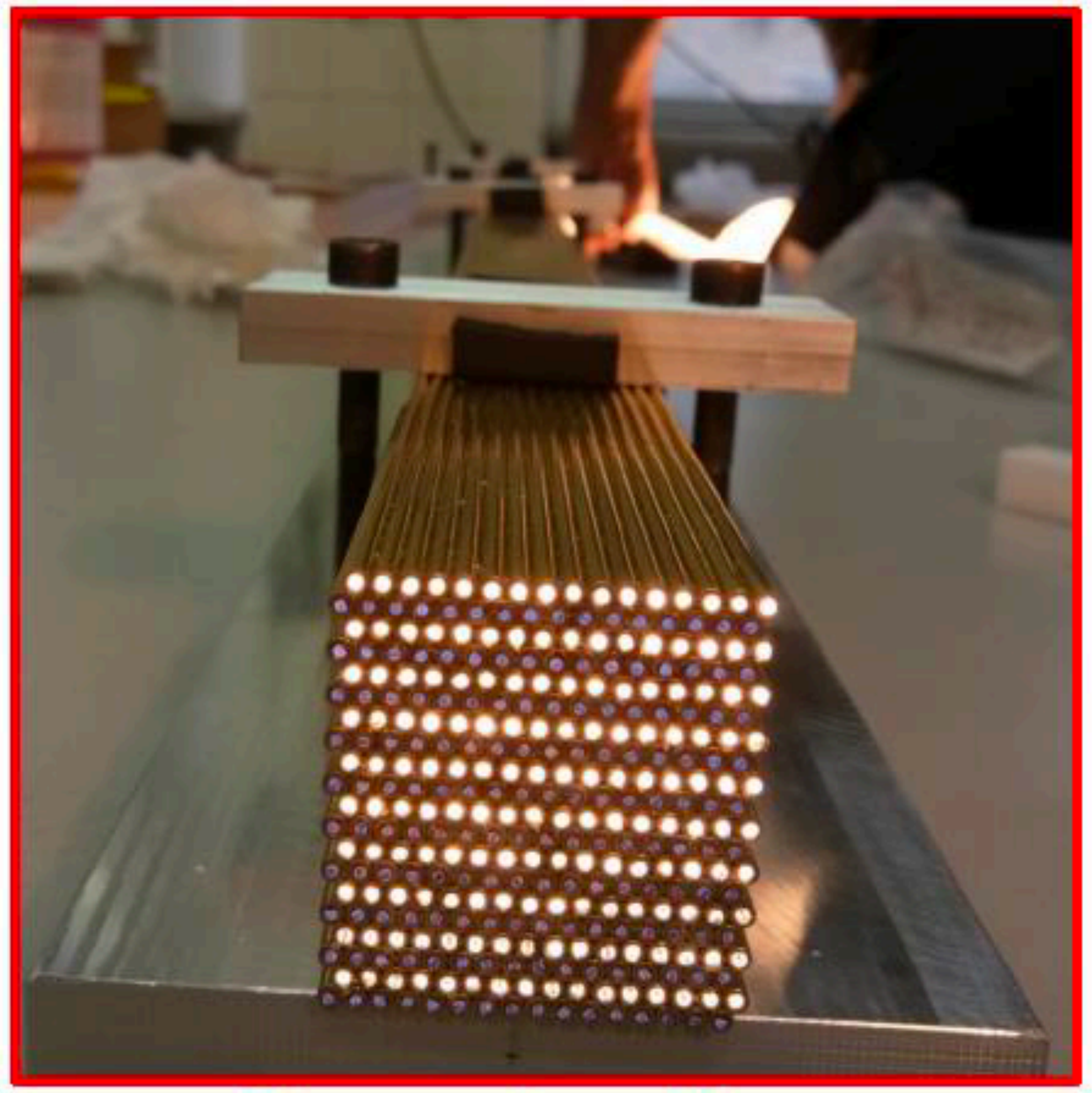
Scintillation fibers



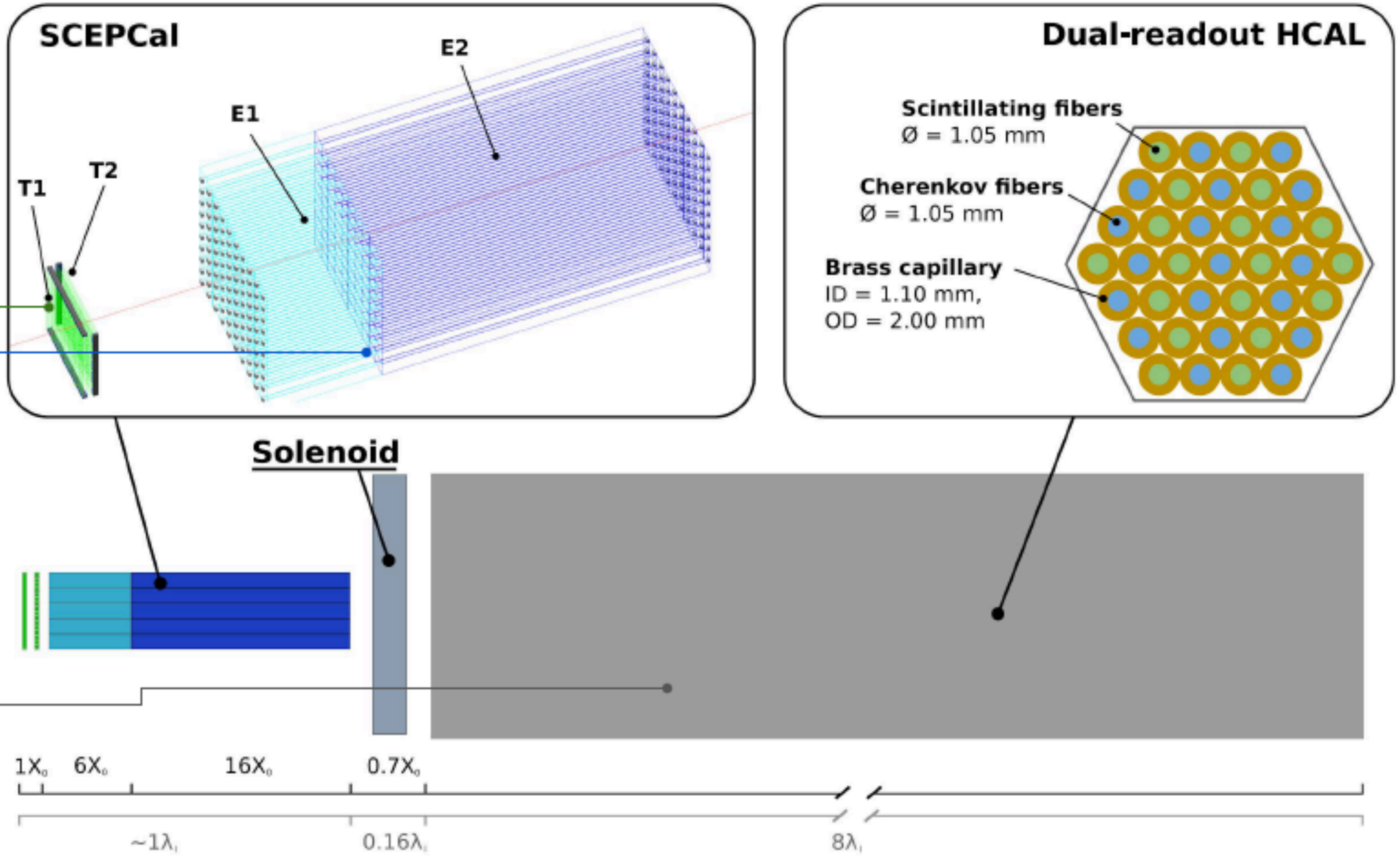
Cherenkov fibers

Crystal ECAL with DR calorimeter

Layout overview

- **Transverse and longitudinal segmentations** optimized for particle identification and particle flow algorithms
- Exploiting **SiPM readout** for contained cost and power budget

- **Timing layers** — $\sigma_t \sim 20$ ps
  - LYSO:Ce crystals ($\sim 1X_0$)
  - 3x3x60 mm³ active cell
  - 3x3 mm² SiPMs (15-20 um)
- **ECAL layers** — $\sigma^{EM}_E/E \sim 3\%/\sqrt{E}$
  - PWO crystals
  - Front segment ($\sim 6X_0$)
  - Rear segment ($\sim 16X_0$)
  - 10x10x200 mm³ crystal
  - 5x5 mm² SiPMs (10-15 um)
- **Ultra-thin IDEA solenoid**
  - $\sim 0.7X_0$
- **HCAL layer** — $\sigma^{HAD}_E/E \sim 26\%/\sqrt{E}$
  - Scintillating and "clear" PMMA fibers (for Cherenkov signal) inserted inside brass capillaries



M. Lucchini

Preshower and muon detector

Preshower Detector

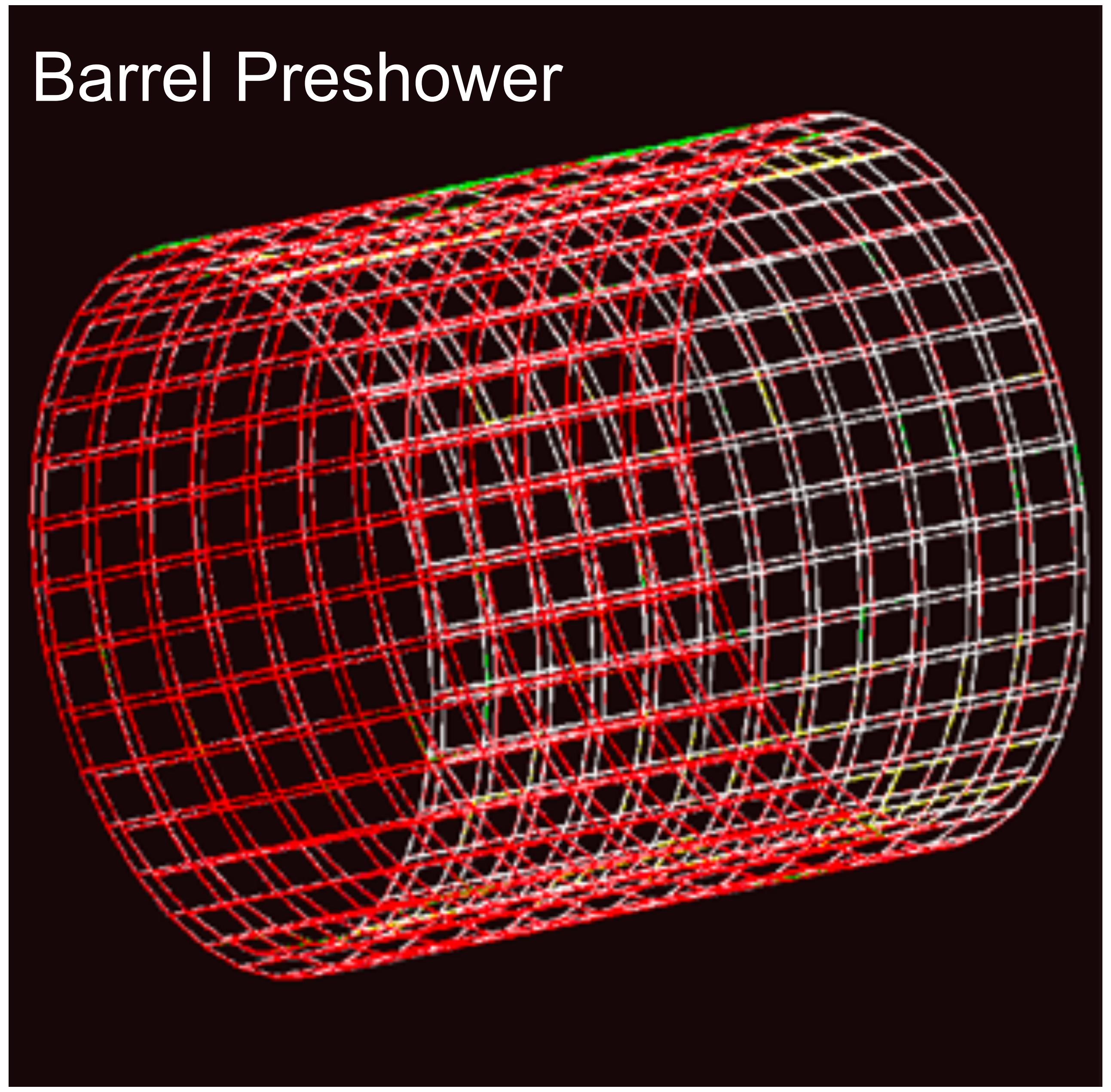
High resolution after the magnet
to improve $\pi^{\pm}/e^{\pm}$ and 2γ separation

Efficiency > 98%
Space Resolution < 100 μm
Mass production
Optimization of FEE channels/cost

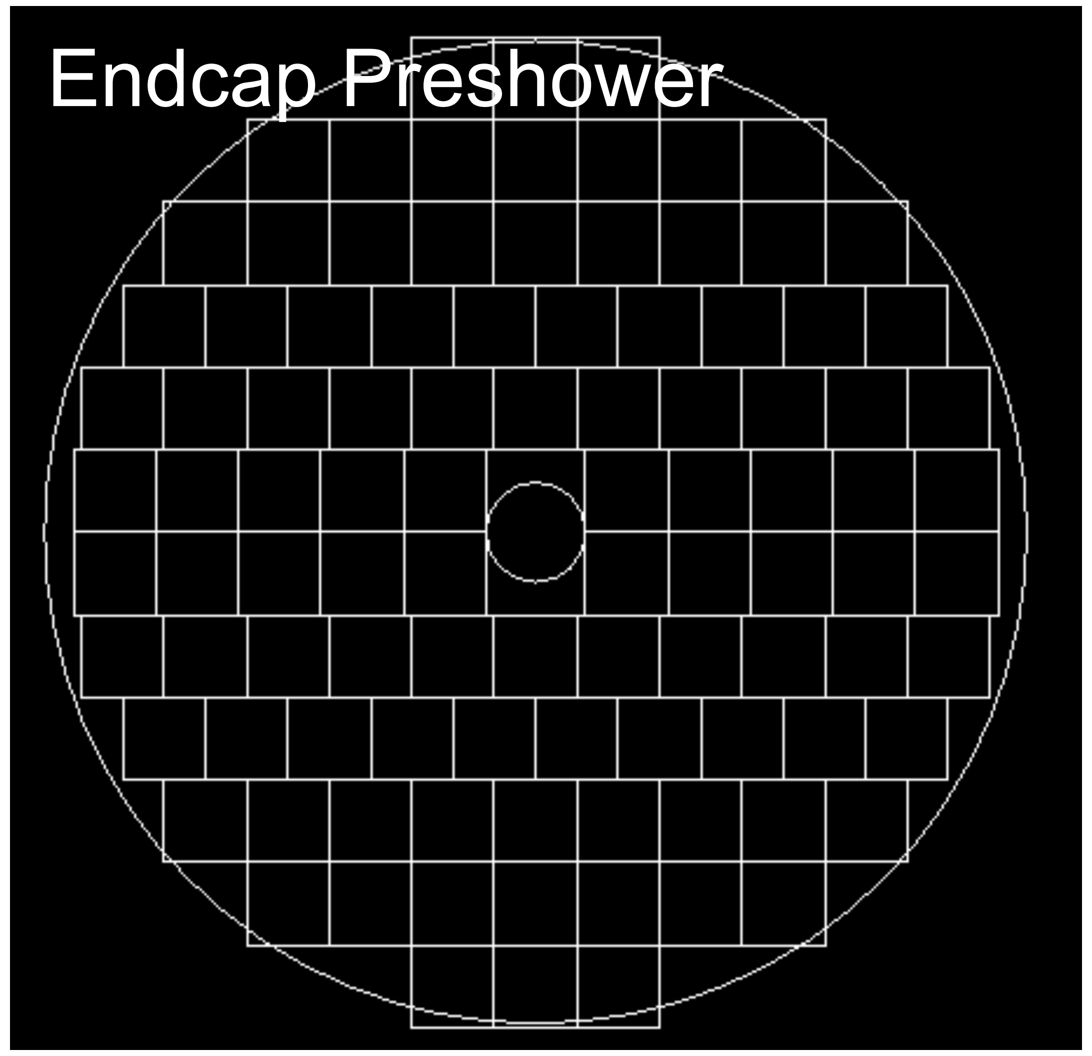
Muon Detector

Identify muons and search for LLPs

Efficiency > 98%
Space Resolution < 400 μm
Mass production
Optimization of FEE channels/cost



Similar design for
the Muon detector



Similar design for
the Muon detector

Detector technology: μ-RWELL

50x50 cm^2 2D tiles to
cover more than 1650 m^2

Preshower
pitch = 0.4 mm
FEE capacitance = 70 pF
1.3 million channels

Muon
pitch = 1.2 mm
FEE capacitance = 220 pF
5 million channels

Conclusions

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- **Lots of possibilities for many colleagues, from all over the world, to participate and contribute to all these developments!!**