FCC-EE SUMMARY EXPERIMENTS & DETECTORS

Patrizia Azzi - INFN Padova (IT)

FCC-EE PHYS&EXP CONTRIBUTIONS TO CONFERENCE

FCC-ee experiments & detectors overview - D. D'Enterria
CLD Detector model overview - O. Viazlo
IDEA Detector model overview - F. Bedeschi
IDEA Dual-Readout Calorimeter - M. Antonello
IDEA Drift Chamber - G. F. Tassielli
A light and compact detector solenoid - H. T. Kate
Mitigation of synchrotron radiation from IR - A. M. Kolano
Beam-induced backgrounds and impact in the full-Silicon Tracker - G. G. Voutsinas
Beam-inducesdbackgrounds and impact in the IDEA drift chamber - N. A. Tehrani
LumiCal for FCC-ee and beam-background impact - M. Dam
Z pole scan strategy and beam energy spread measurement - P. Janot
FCCee as a W factory - P. Azzurri
Top threshold scan strategy - F. Simon
Update of Higgs studies with the CLD detector model - C. Bernet
New results in flavour physics - S. Monteil
Search for Heavy Right Handed Neutrinos - E. Graverini
QCD and photon-photon physics at the FCC-ee - E. D'Enterria

POSTERS

A thousand recipes to use up dimuons at the FCC-ee - P. Janot

CKM and beyond at the Z factory - S. Monteil

Detector qualification with Higgs bosons in the jets and missing energy final state - J. V Anhen, K. Peters

Direct W mass reconstruction at and above WW threshold M. Béguin

Beam Polarization and Energy calibration at FCC-ee A. Blondel

IDEA Dual-Readout calorimetry software M. Dunser

Precision calculations for FCC S. Jadach

Searching right-handed neutrinos at the FCC O. Fisher

The IDEA drift chamber (2, physics performance or software oriented) F. Grancagnolo, 2 posters

The top factory N. Foppiani, P. Azzi, F. Blekman

The W factory : anomalous W couplings P. Azzurri

TTop FCNC at FCC-ee N. Van Der Kolk

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FCC Physics talks

QCD measurements at FCC - M. Klein
Search for BSM Phenomena 1 - A. Wulzer
Search for BSM Phenomena 2 - R. Torre
Higgs Measurements - M. Klute
EW measurements at FCC - R. Tenchini
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18 FCC-ee talks

13 posters

7 complementary physics talks

DISCOVERY MACHINE AND MORE

- **EXPLORE** the 10-100 TeV energy scale region with precision measurements of the properties of the Z,W,Higss and top particles
  - 20-50fold improved precision on EWK observables
  - 10 fold more precise and model-independent Higgs coupling measurements
- **DISCOVER** that the Standard Model does not fit
  - Existence of extra-weakly-coupled and Higgs-coupled particles
  - Understanding of the underlying physics structure
- **DISCOVER** a violation of flavour conservation/universality
- **DISCOVER** very weakly coupled particles in the 5-100 GeV mass range
  - Such as right handed neutrinos, dark photons, …
- **DISCOVER** dark matter as invisible decays of the Z or Higgs

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« Leave no stone unturned »

no trigger and huge statistics,

FCC-ee is a physicist's dream

PHYSICS GOAL MINIMAL NEEDS

- 150 ab-1 at around the Z pole ($\sqrt{s}$=91.2 GeV)
- 10 ab-1 at the WW threshold ($\sqrt{s}$=161 GeV)
- 5 ab-1 at the HZ cross section maximum ($\sqrt{s}$=240 GeV)
- 0.2 ab-1 at the top threshold ($\sqrt{s}$=350 GeV)
- 1.5 ab-1 above the top threshold ($\sqrt{s}$=365 GeV)

The FCC-ee unique discovery potential is multiplied by the presence of the four heavy particles of the standard model in its energy range

Helps shape up the FCC-hh program and detectors

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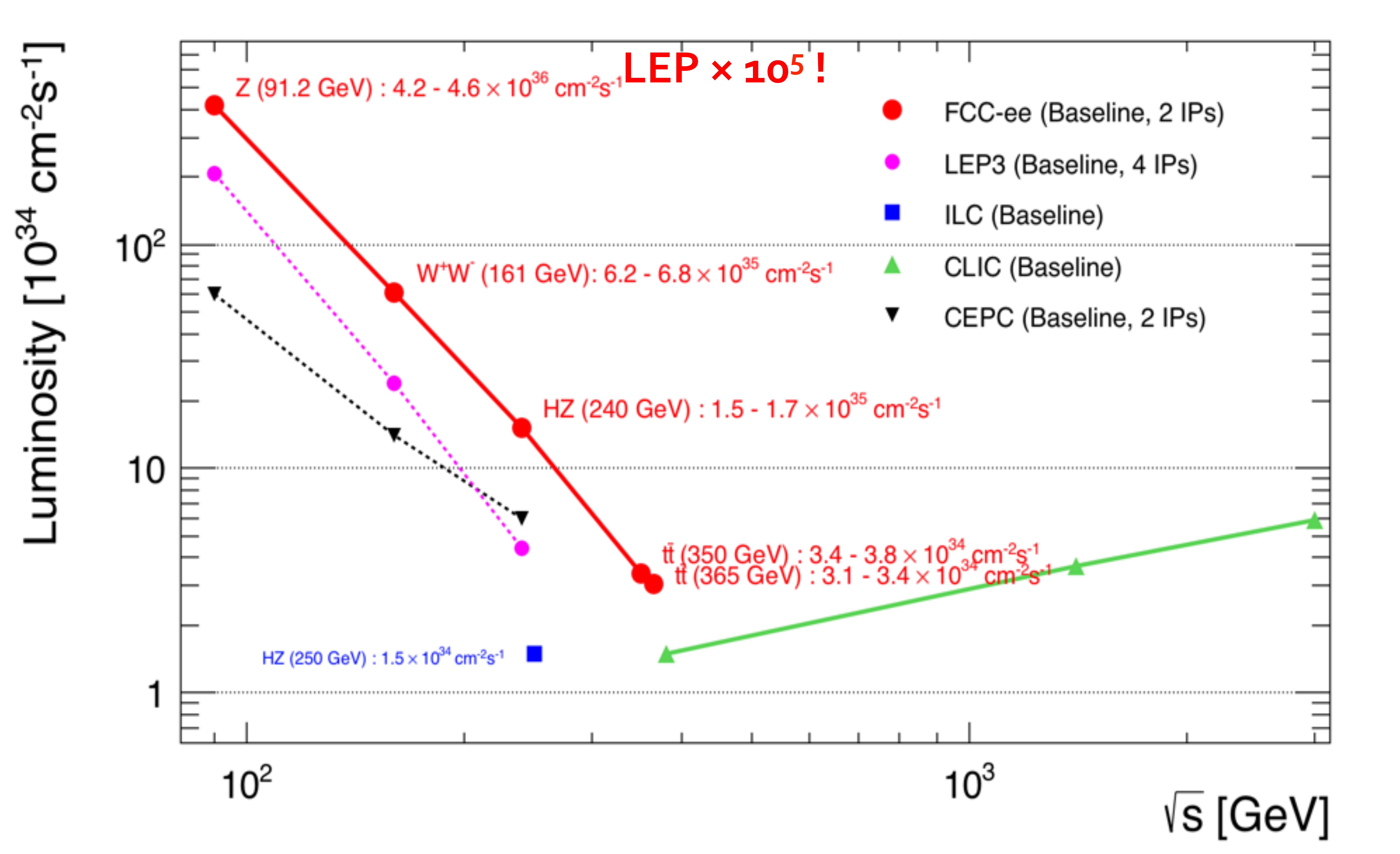
5×10^{12} Z 10^{8} W

10^{6} HZ 10^{6} tt

the more the better!

NEW LUMINOSITY PLOT



- ➤ High integrated luminosity at the needed E_{cm}
- ➤ Clean environment
- ➤ precise knowledge of the center-of-mass energy and of the luminosity
- ➤ precise detectors offering plenty of redundancy (and more than one)

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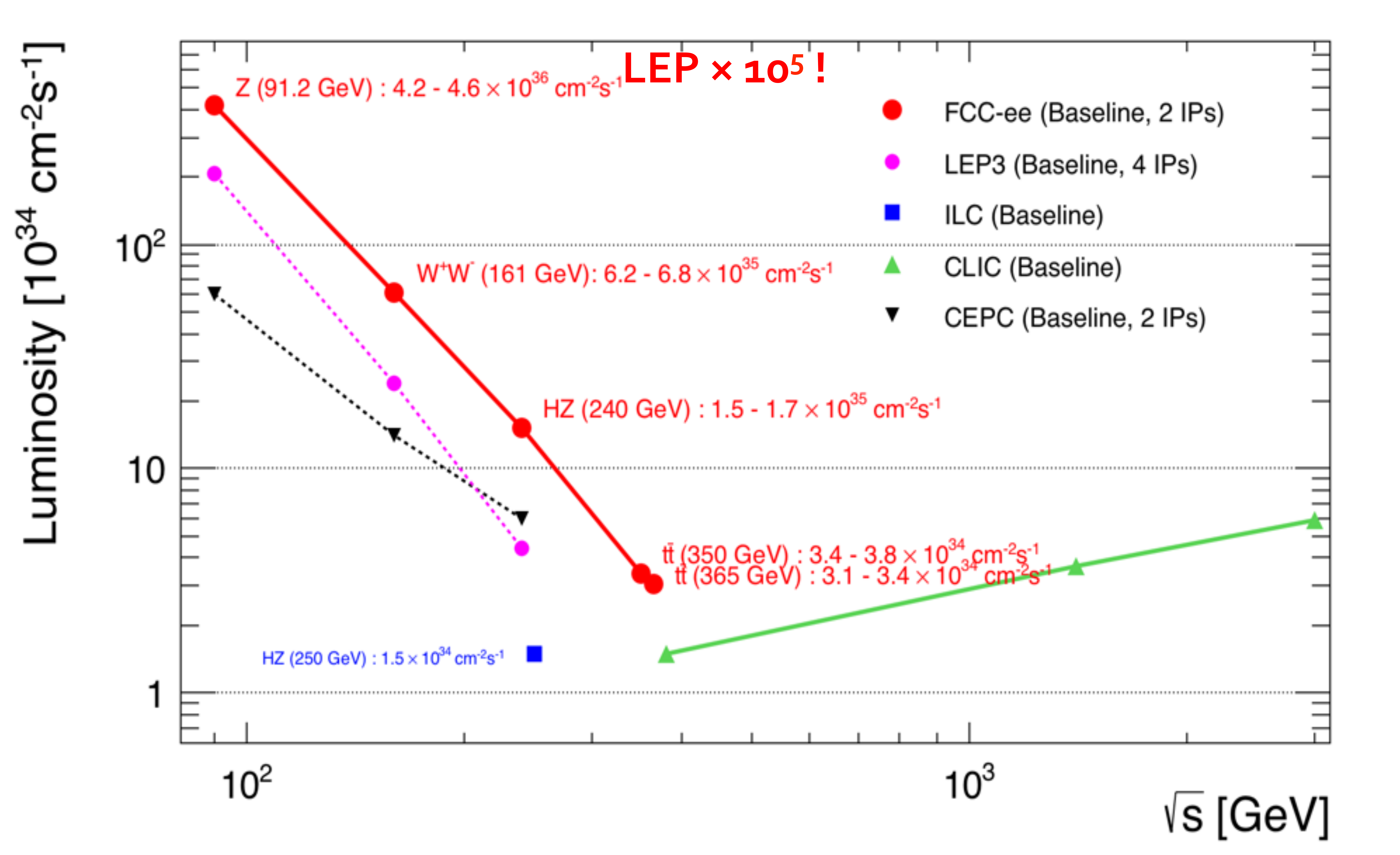

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Max E_{cm} is 365 GeV!

NEW RUN PLAN

Working point	Z, years 1-2	Z, later	WW	HZ	tt threshold	365 GeV
Lumi/IP (10^{34} $cm^{-2}s^{-1}$)	100	200	31	7.5	0.85	1.5
Lumi/year (2 IP)	26 ab^{-1}	52 ab^{-1}	8.1 ab^{-1}	1.95 ab^{-1}	0.22 ab^{-1}	0.39 ab^{-1}
Physics goal	150		10	5	0.2	1.5
Run time (year)	2	2	1	3	1	4

<u>Operation assumptions (10% safety margin)</u>

- 200 physics days/year
- Hubner factor ~0.75 (lower than KEKB top-up injection that reached >80%)
- half the design luminosity in the first year of Z and top operation
- machine upgrades during Winter shutdown (3m/y)
- Longer shutdown to install the 196 RF

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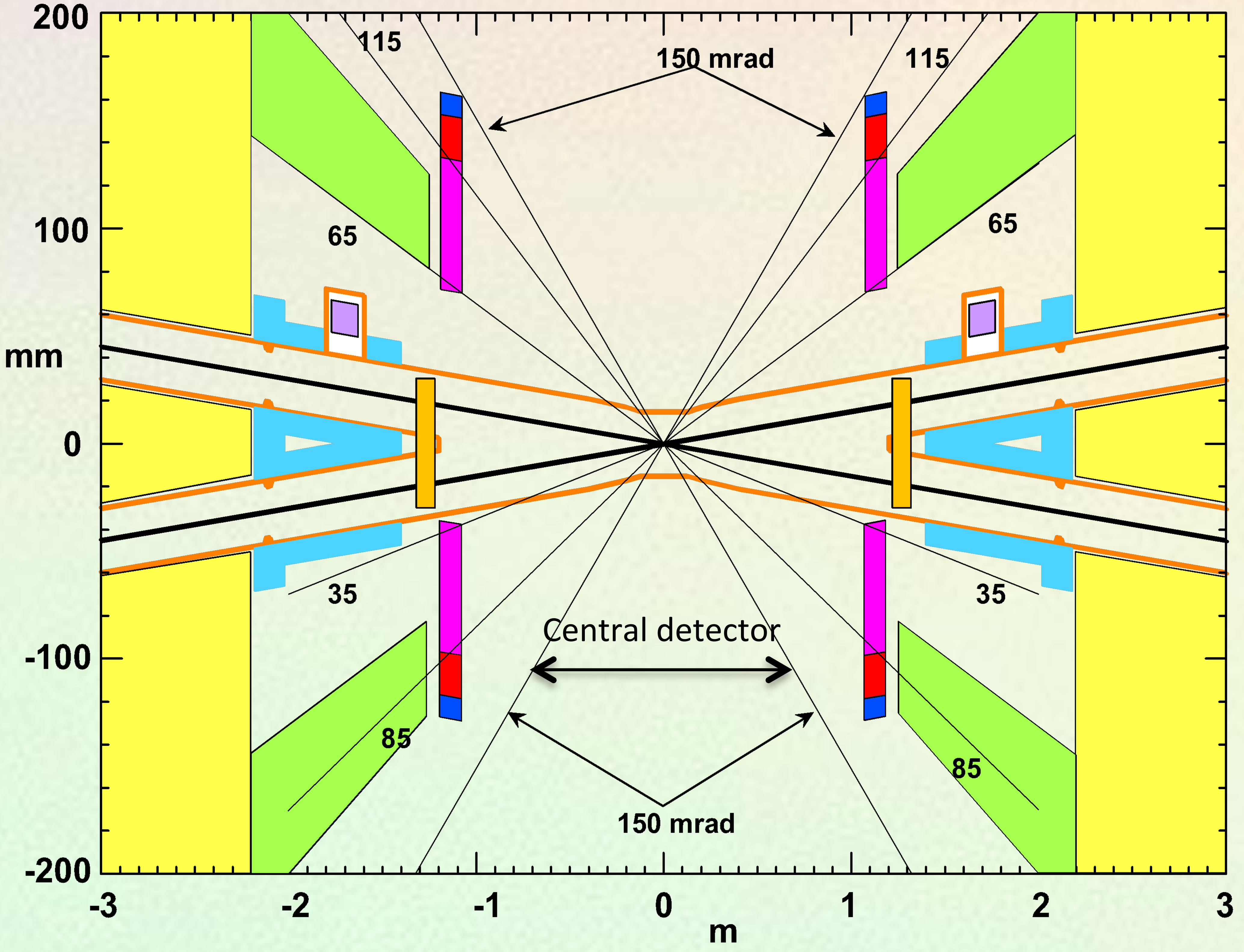
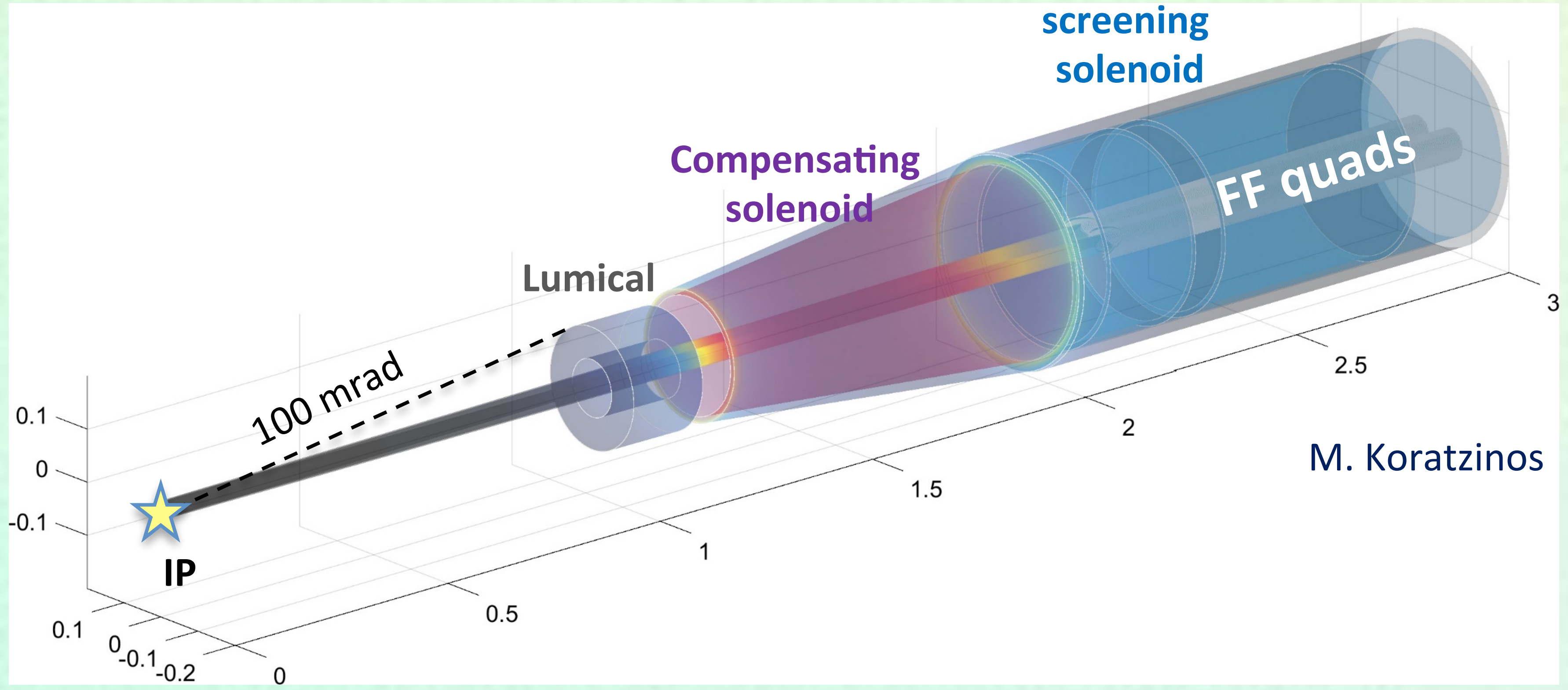
Total running time 13(+1)years (~LEP)

MDI REGION



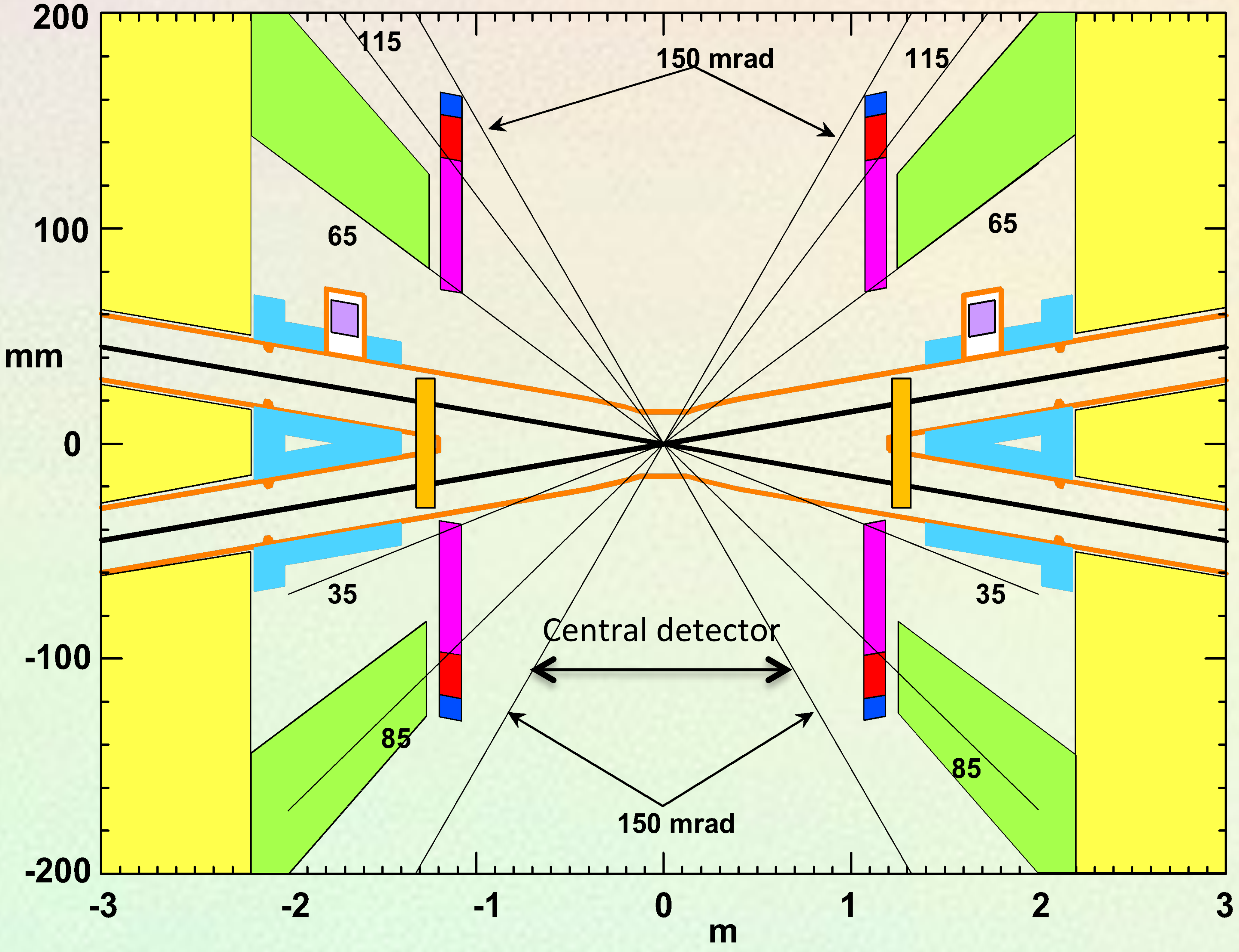
QC1
Compensating solenoid
Lumical
Lumical electronics
Lumical cables
HOM absorbers
W shielding

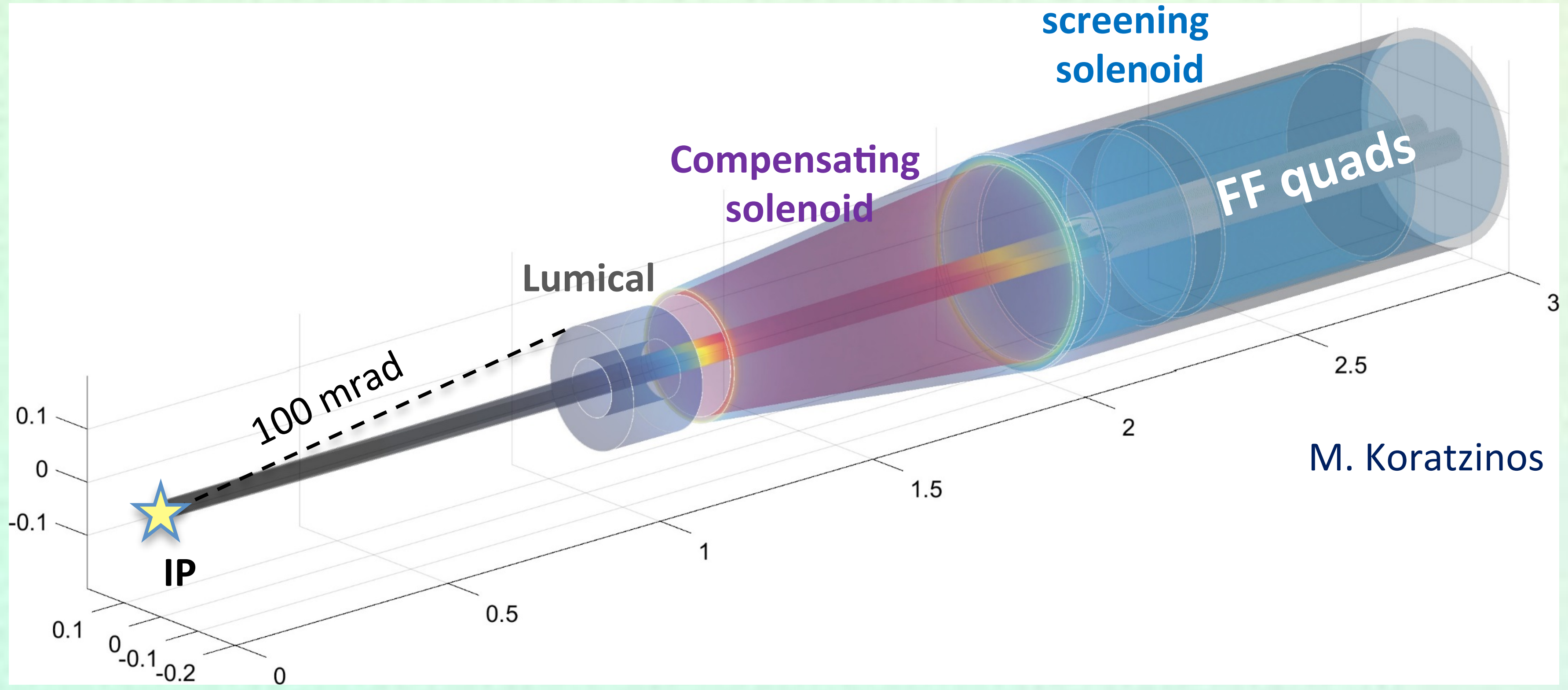


detector solenoid dimensions 3.76m × **4m** (half-length)
drift chamber at z=2m with 150 mrad opening angle (IDEA design)

- Unique and flexible design
- Crab-waist collision scheme
- Synchrotron radiation driver for IR design at high energy operations
- Asymmetric optics
- Small emittance
- Central Be beam pipe with diameter 3cm
- Solenoid compensation scheme needed for large beam crossing angle

MDI REGION





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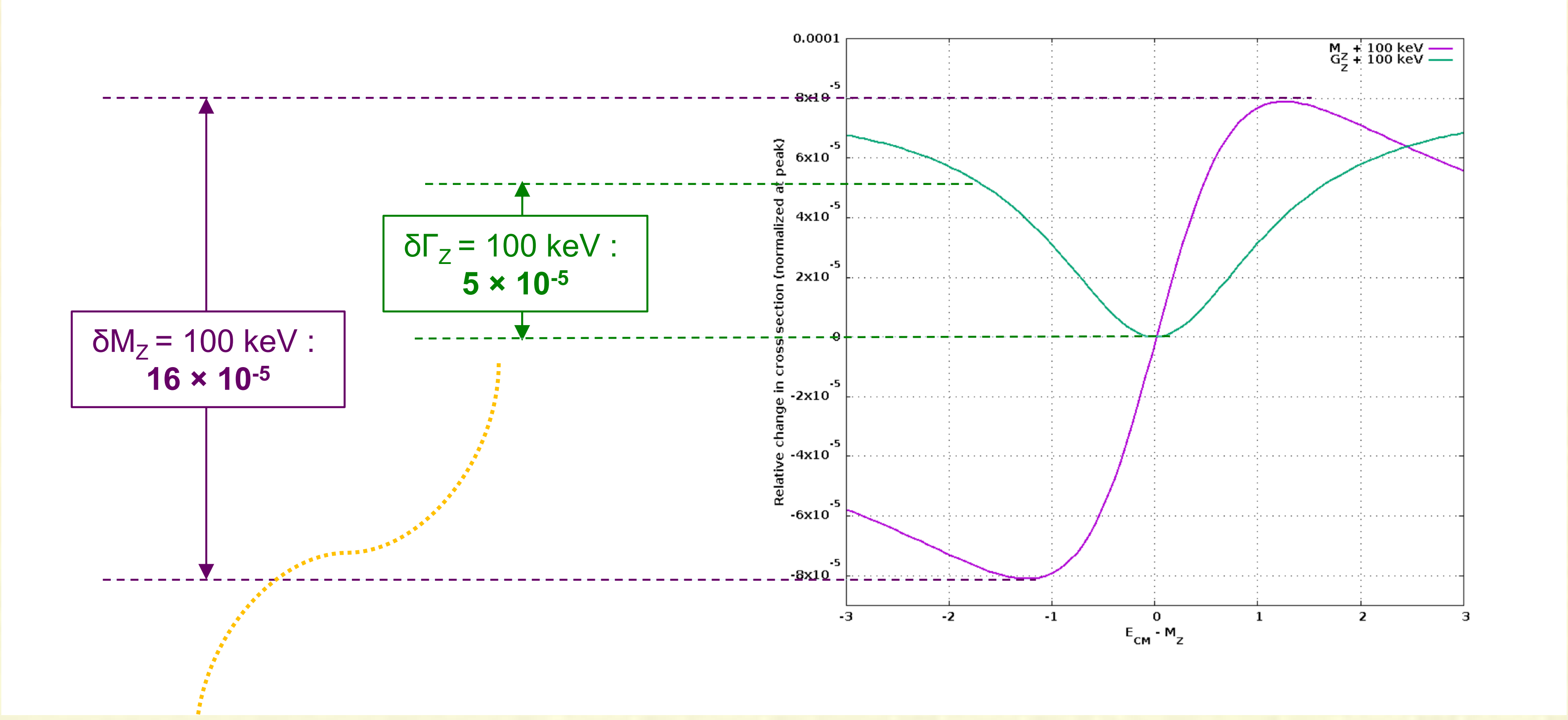
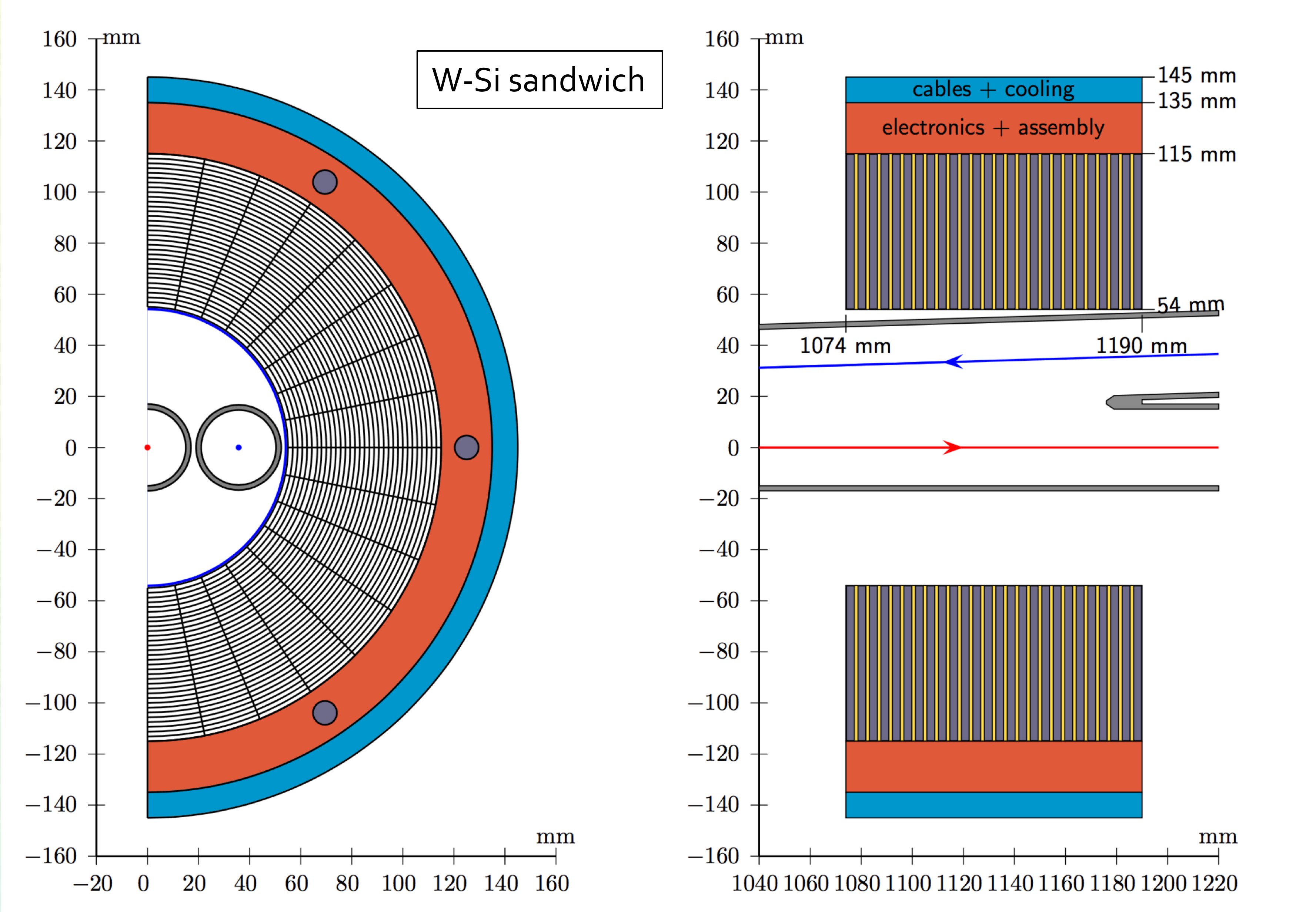
- Sole… nee…

Discussion of mechanical integration brings improvements to this scheme

LUMINOSITY MEASUREMENT

- **Using small angle Babha scattering, Very precise normalization needed: absolute normalization at 10^{-4} and relative to $5x10^{-5}$**
  - Theory now at $2x10^{-4}$!
- Can exploit also large angle Babha production of photons and/or electrons: in progress
- Basic design: Cylindrical detectors of W+Si sandwich centered around, and perpendicular to the outgoing beam line (asymmetric)
- Studied effect of:
  - synchrotron radiation: negligible with shielding
  - beam background: ee pairs soft and and close to detector boundaries. √s dependence
  - beam-gas background: negligible
- Focusing effect of opposite beam to be studied





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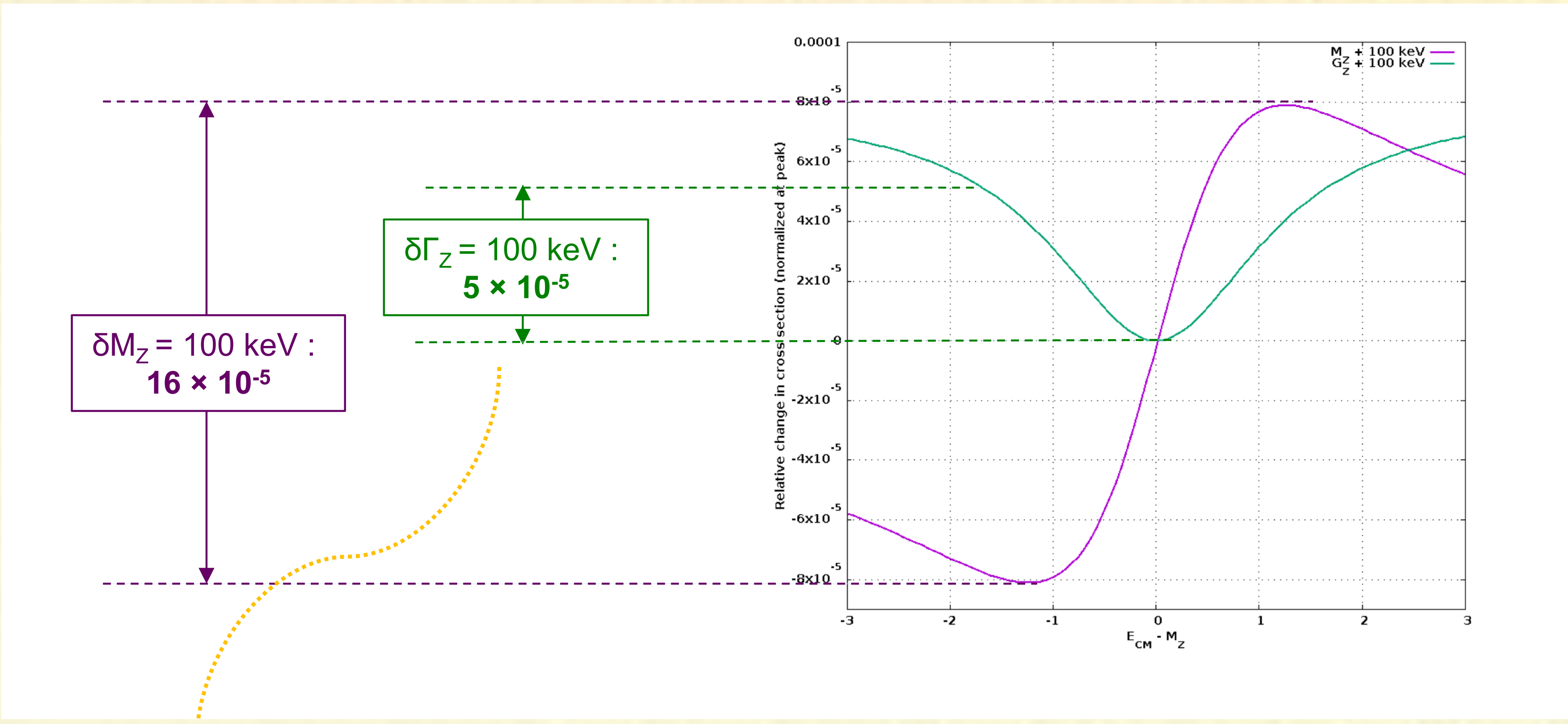
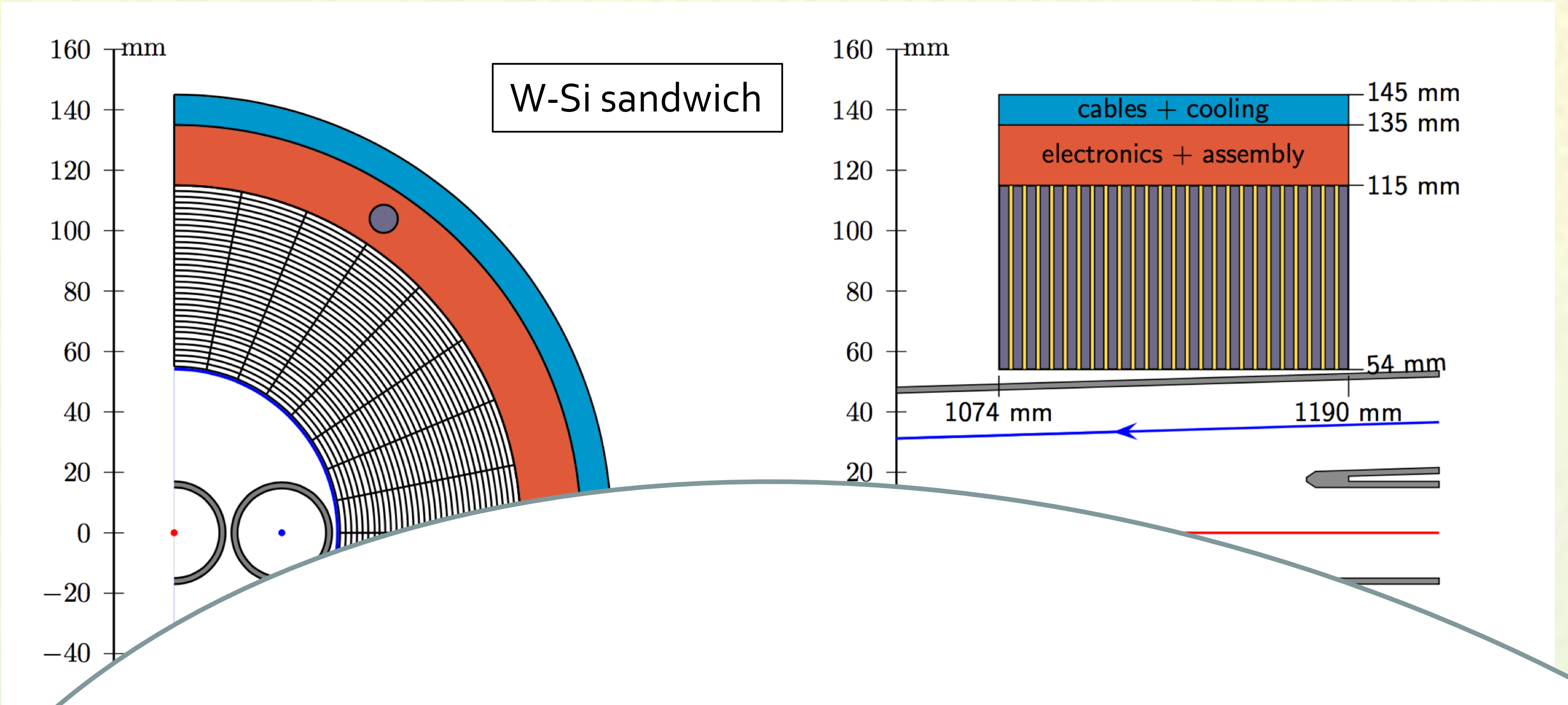


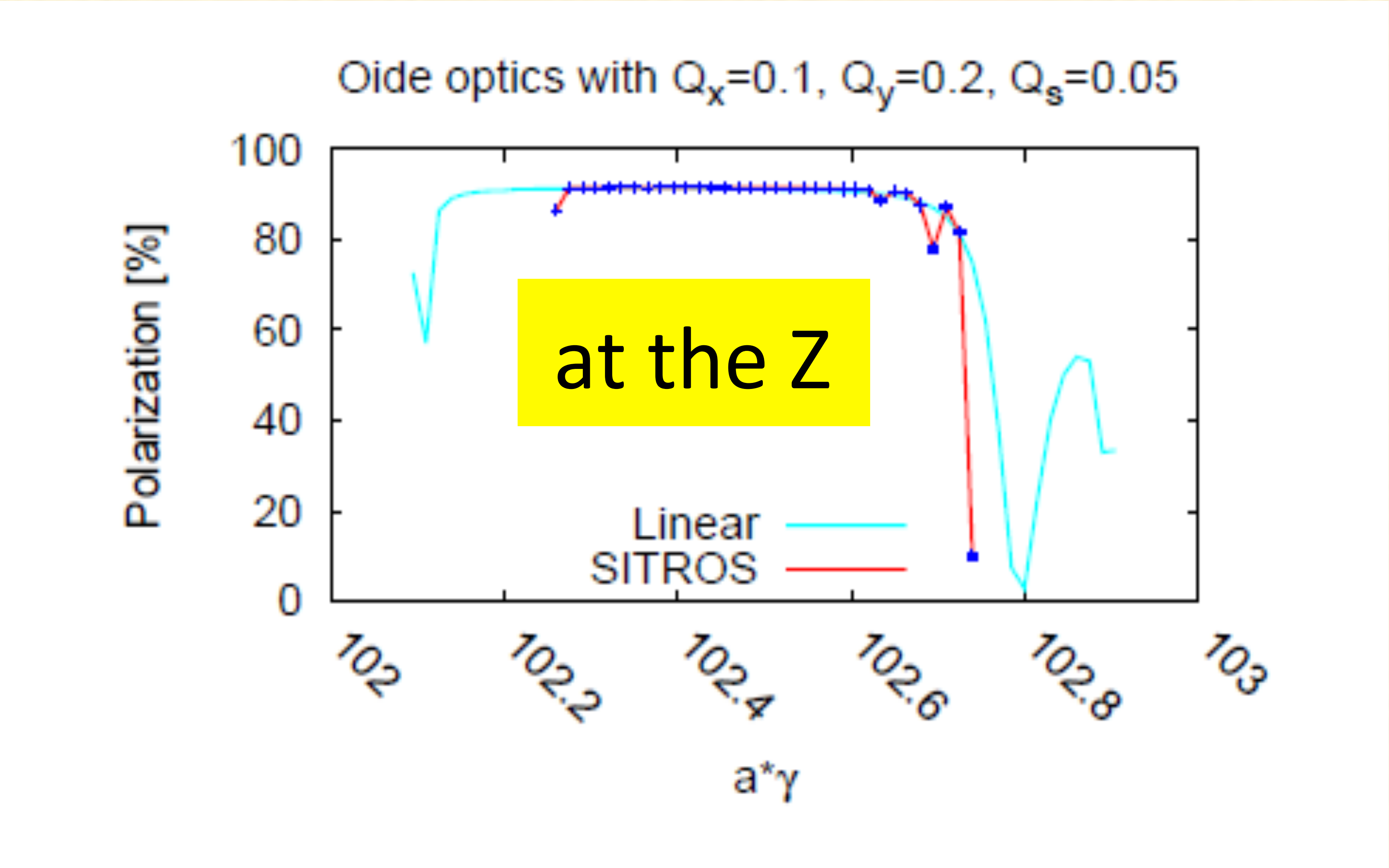


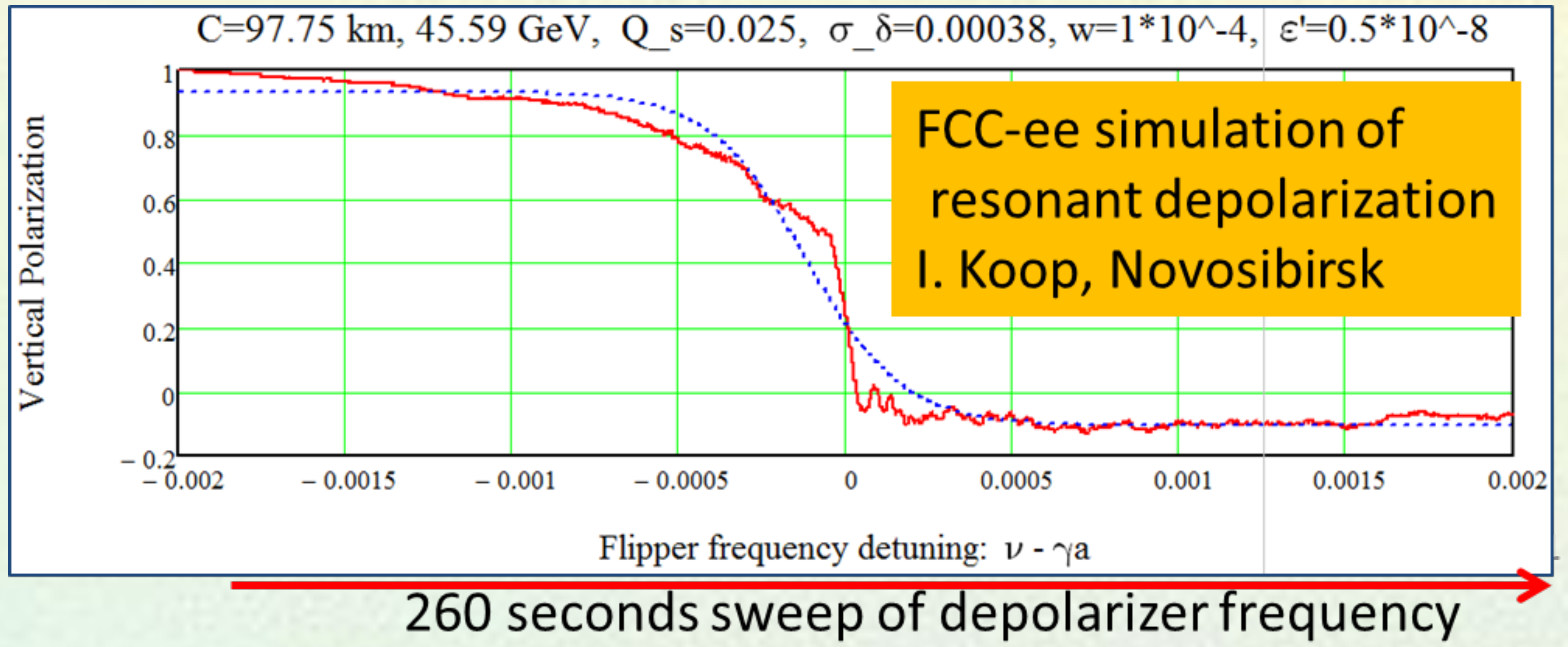
Preliminary design of LumiCal now exists!

Moving on to technical challenges

BEAM POLARIZATION AND ENERGY CALIBRATION

- **Requirement from physics**
  - **Center-of-mass energy determination with precision of ±100keV around the Z peak**
  - **Center-of-mass energy determination with precision of ±300keV at W pair threshold**
  - **For Z peak cross-section and width energy spread uncertainty: Δσ/σ=0.2%**
- Use resonant depolarization as main measurement method
- use pilot bunches to calibrate during physics data taking
- take data at points where self-polarization is expected: easy to accomodate for Z and W
- defining scan strategy to minimize loss of statistics
- Hardware requirements: wigglers (@Z), polarimeters and kickers for depolarization:
  - studies in progress to find the optimal sweep (different for Z and W)
- Systematics studies ongoing





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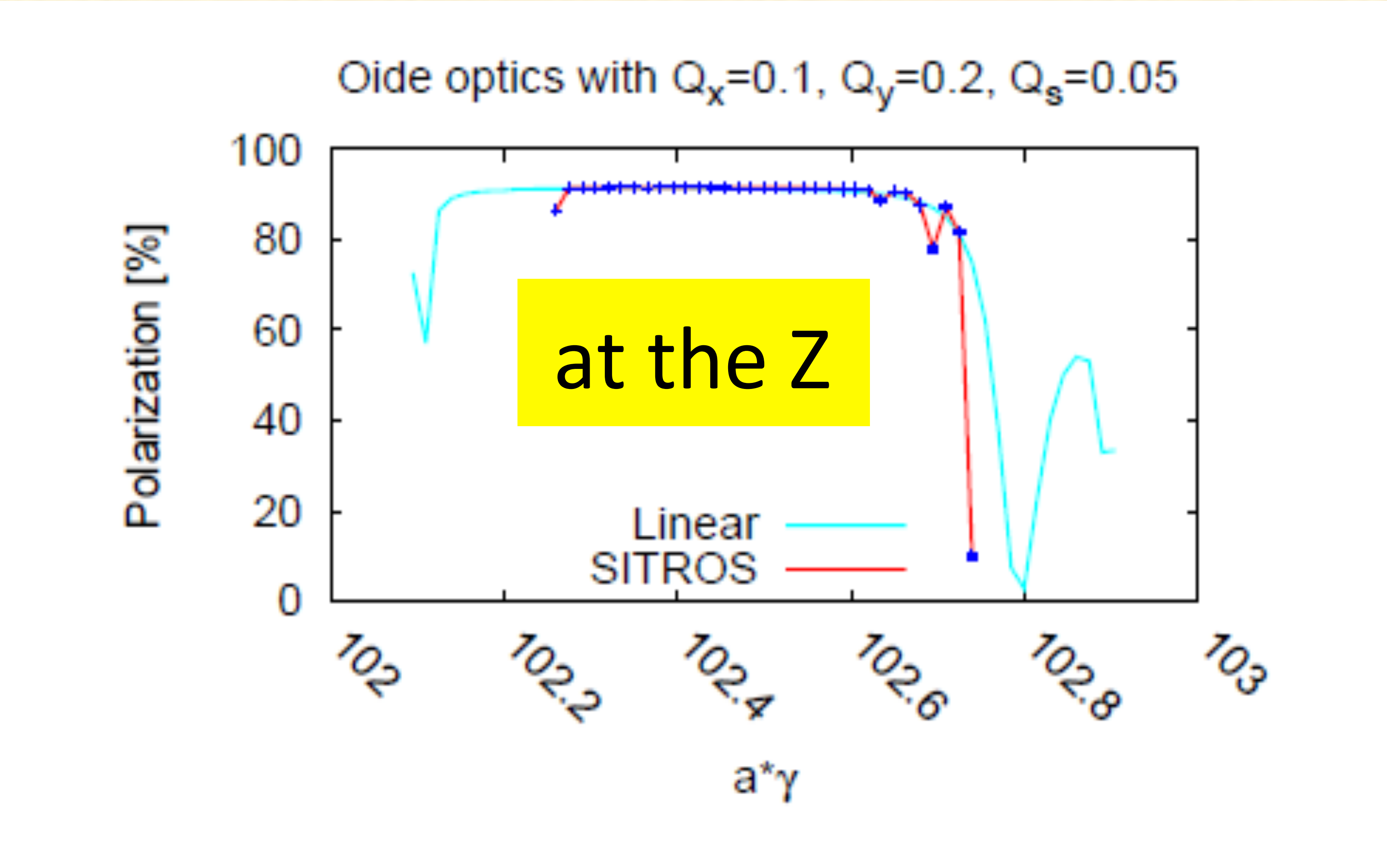
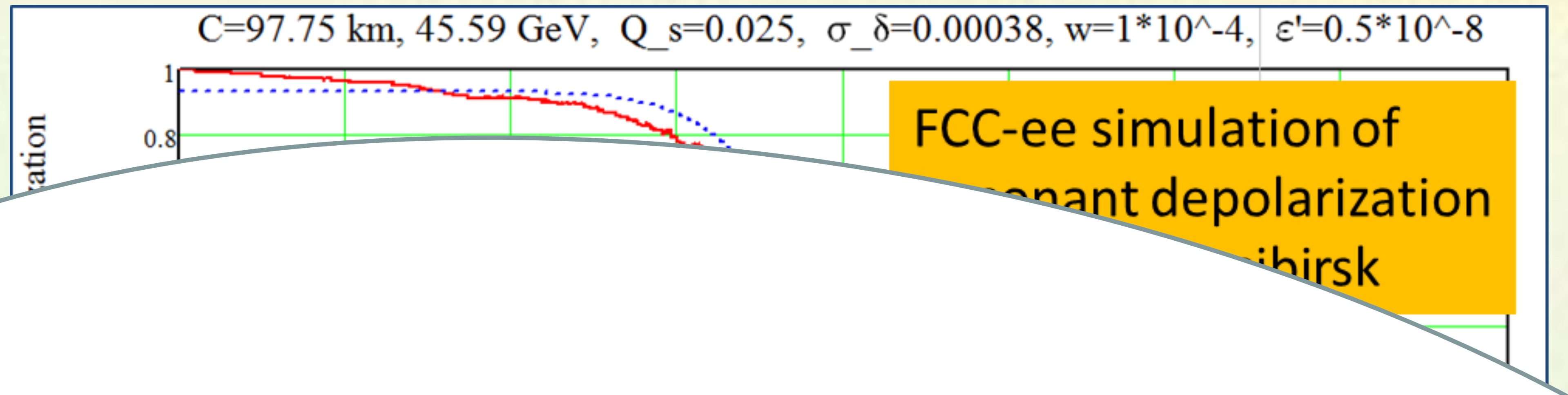


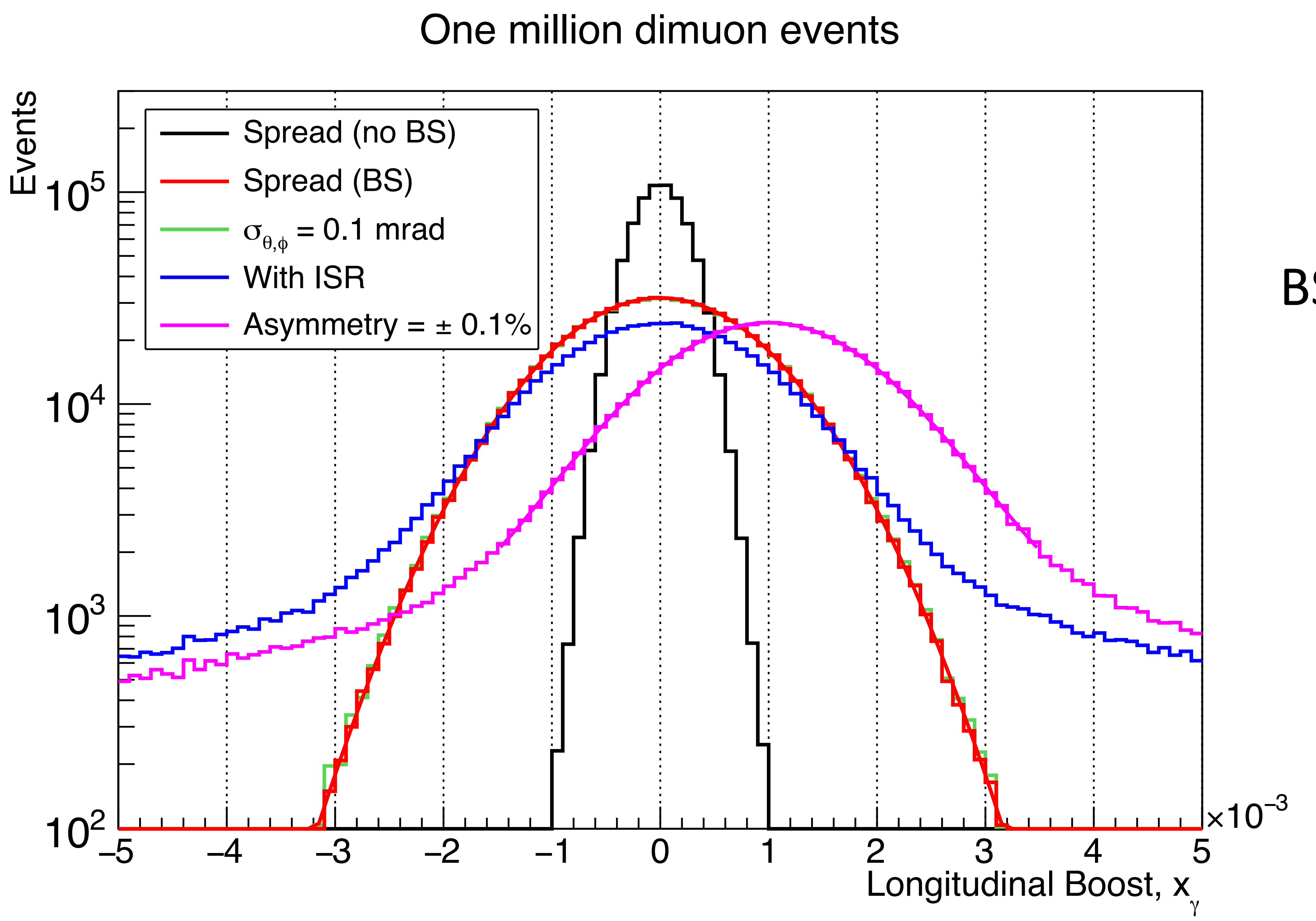


Preliminary estimate of systematics range from $\Delta E/E=10^{-14}$ to 10^{-6}

Precision needed requires to take into account all effects specific to the machine

MEASUREMENT OF ENERGY SPREAD

- The beam energy spread affects the lineshape changing the cross section
- The size of the energy spread and its impact on Γ_Z is similar to LEP but sytematic shave to be controlled in a different way
- FCC-ee asymmetric optics with a beam crossing angle α of 30 mrad
- **Using 10^6 dimuon events (4 min @FCC-ee) can measure the energy spread at 0.1% of its value**
- Detector requirement on muon angular resolution of 0.1mrad



BS=beamstrahlung

$$x_\gamma = -\frac{x_+ \cos\theta^+ + x_- \cos\theta^-}{\cos(\alpha/2) + |x_+ \cos\theta^+ + x_- \cos\theta^-|}$$

Can keep related systematic uncertainty on Γ_Z at less than 30 keV

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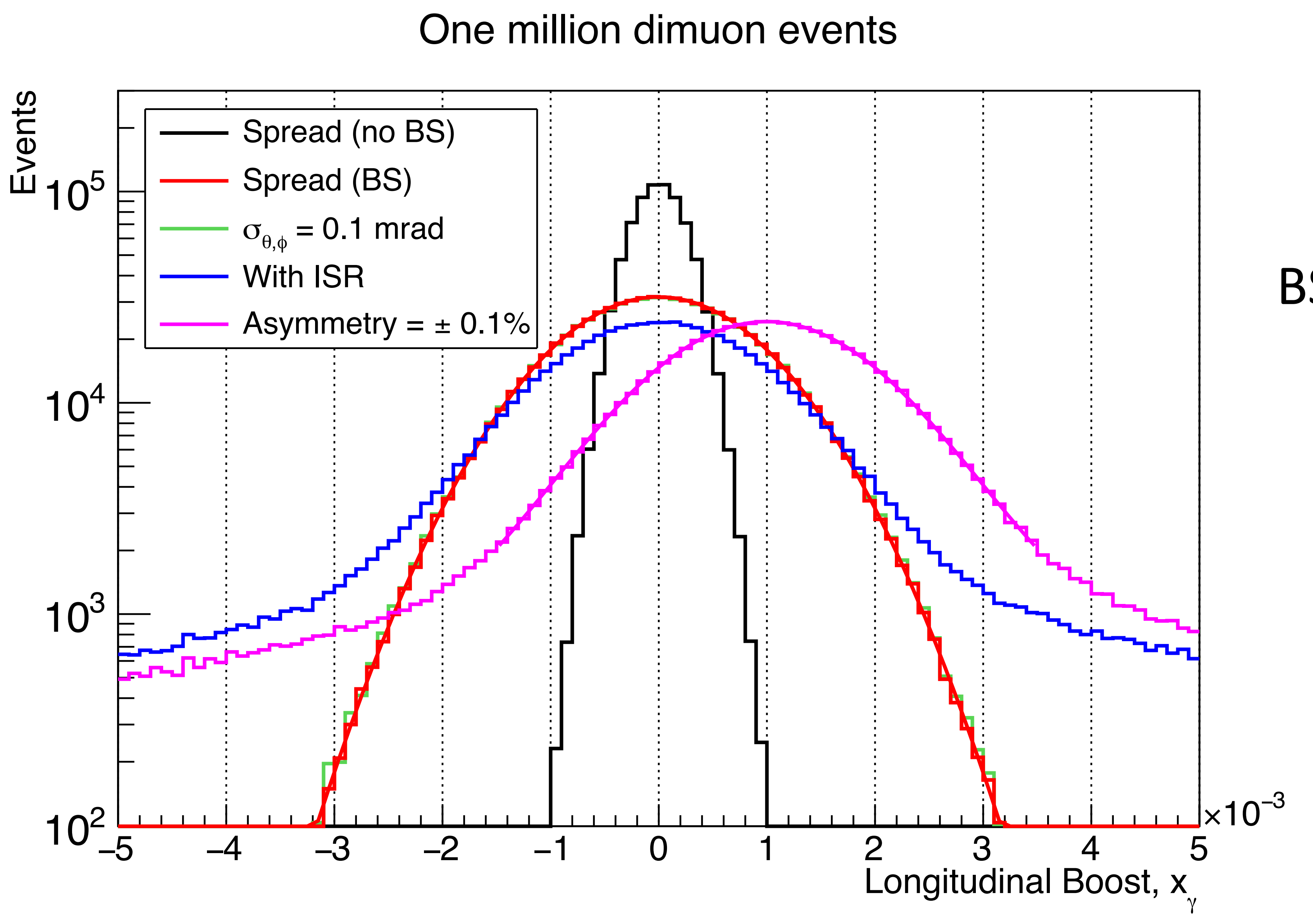

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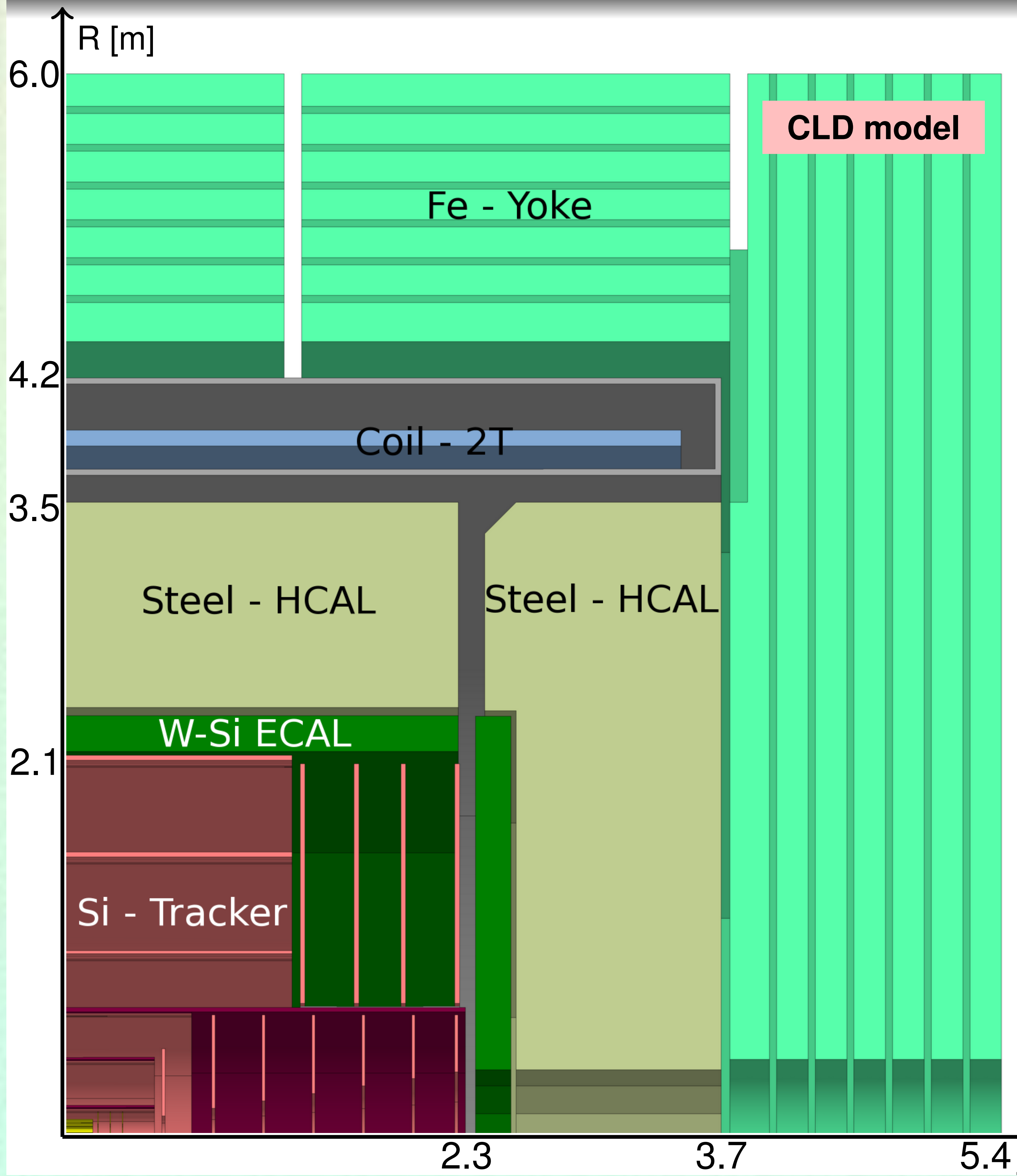
Can keep related ... on Γ_Z at less th...

New technique using dimuons events does the job!

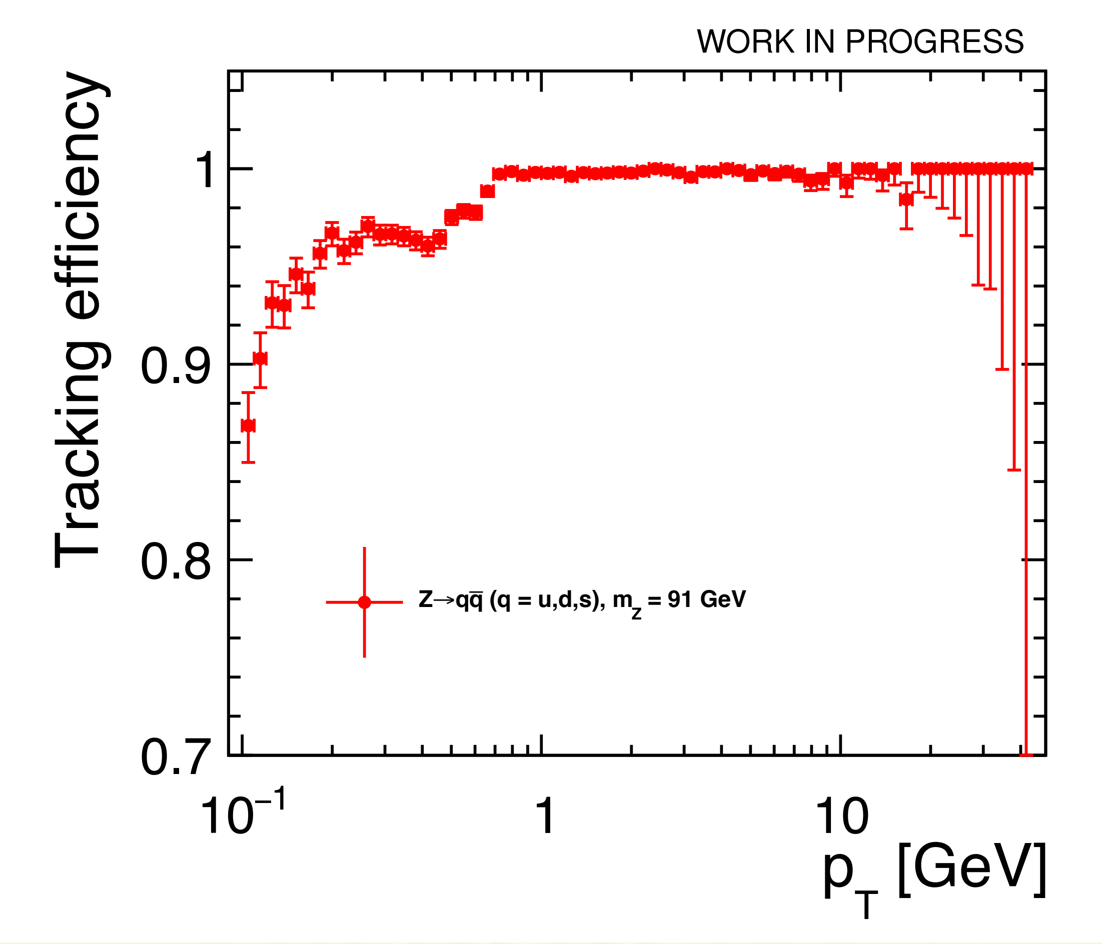
CLD DETECTOR PERFORMANCE

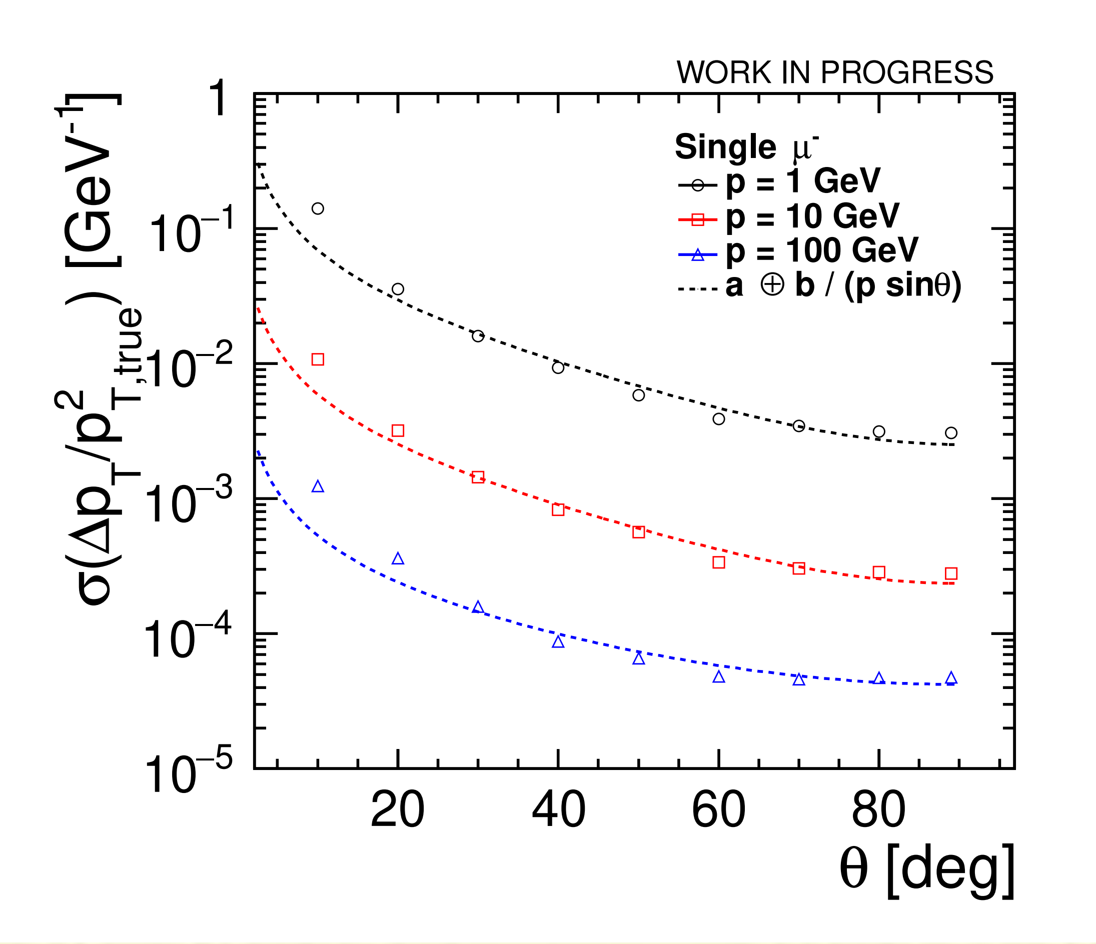
- Inspired by the CLIC detector model and adapted for the FCC-ee running conditions

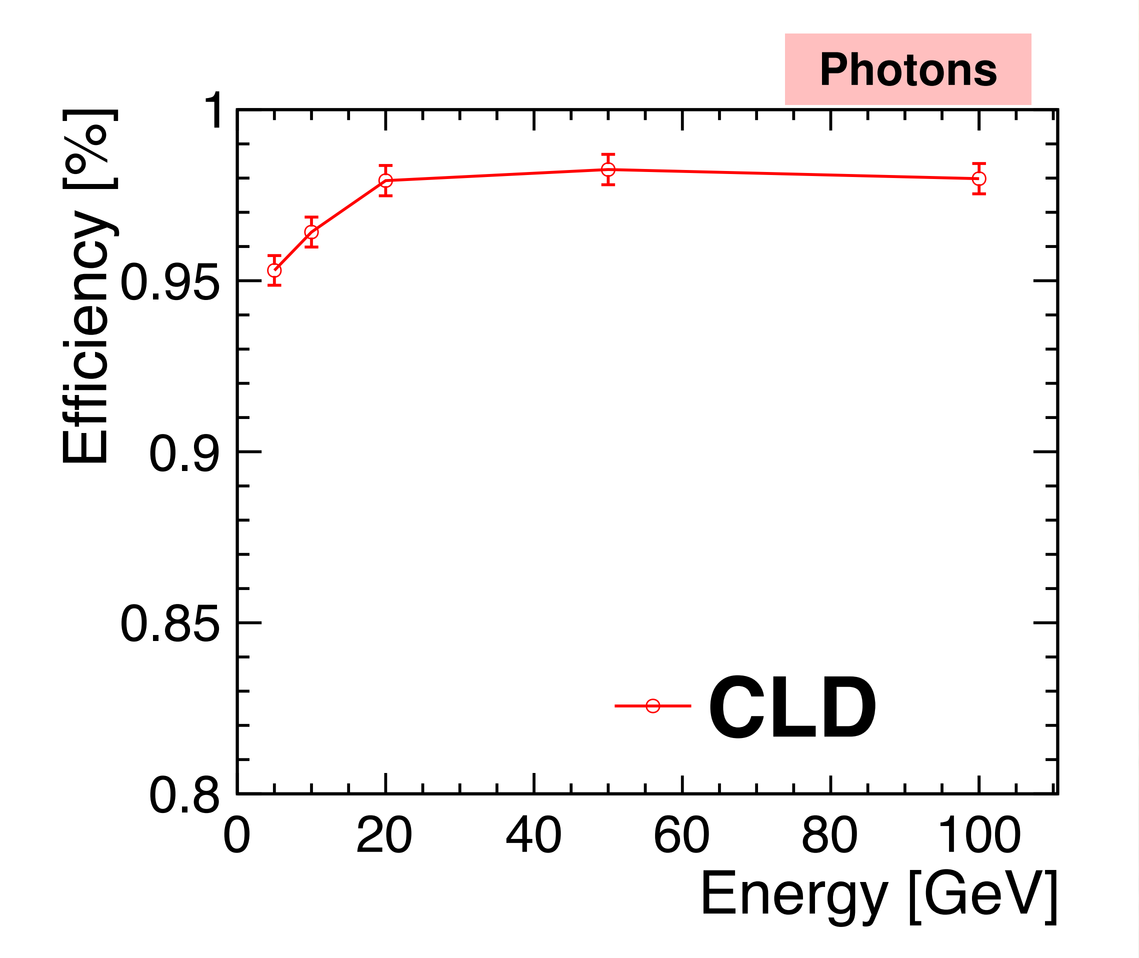
CLD detector layout

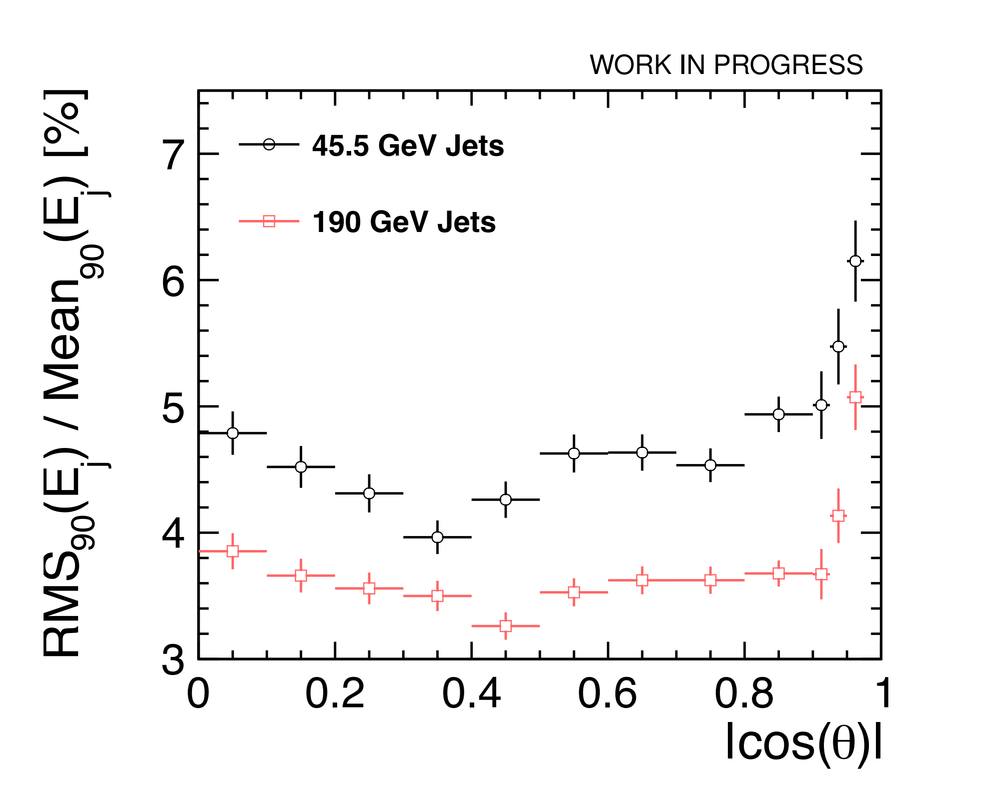


- Full silicon tracking system - provides $\geqslant$12 hits per track
- Fine-grained ECAL and HCAL optimised for particle flow reconstruction
- Superconducting solenoid is outside of the calorimeter
- Steel return yoke with muon chambers
- Forward detector region ($<$ 150 mrad) is reserved for Machine-Detector Interface (accommodates LumiCal)
- Support structures, cables and services are included in the model









- Jet energy resolution in barrel region:
  - 45.5 GeV jets: 4-5 %
  - 190 GeV jets: 3-4 %

CLD DETECTOR PERFORMANCE

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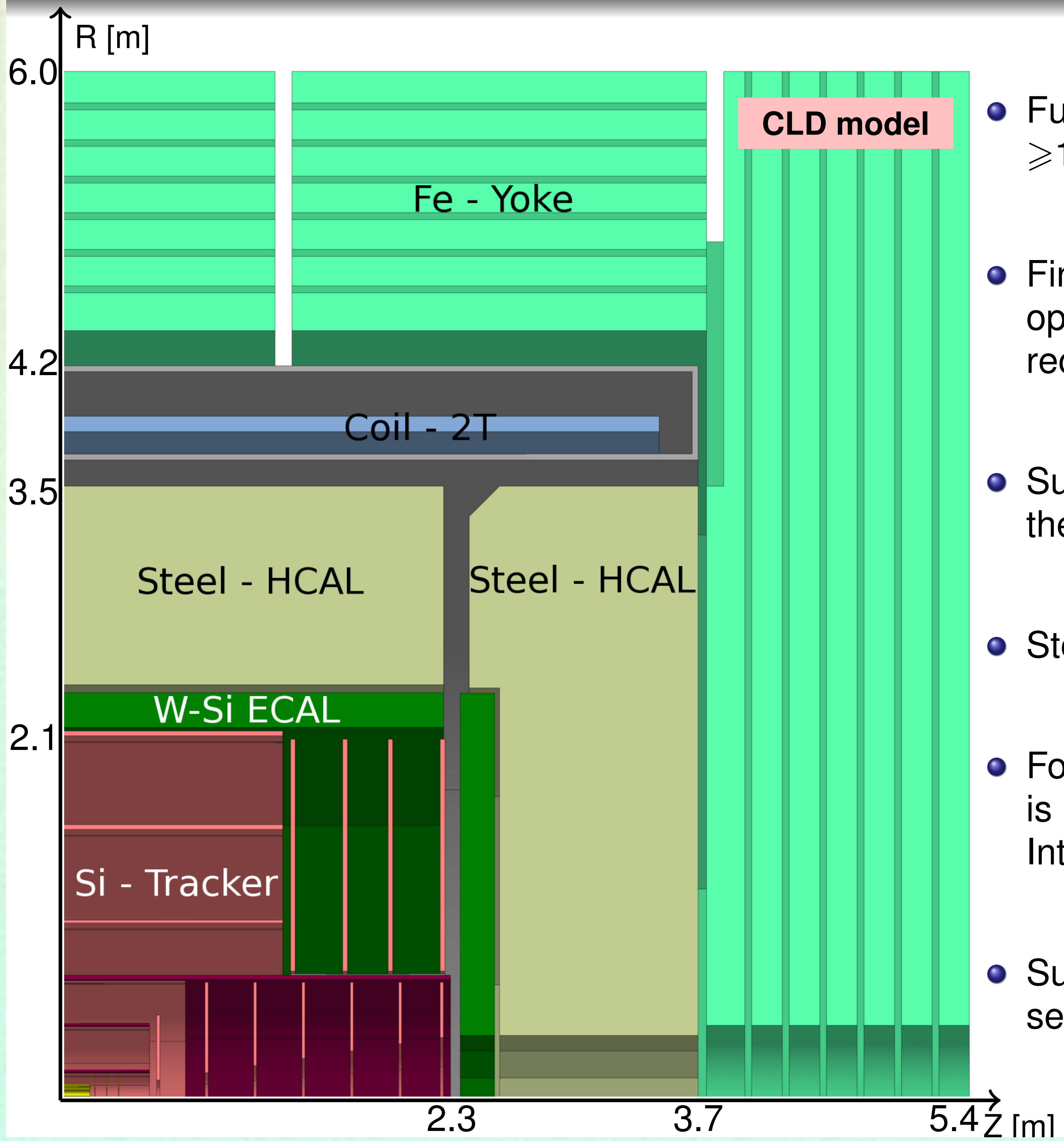
CLD detector layout



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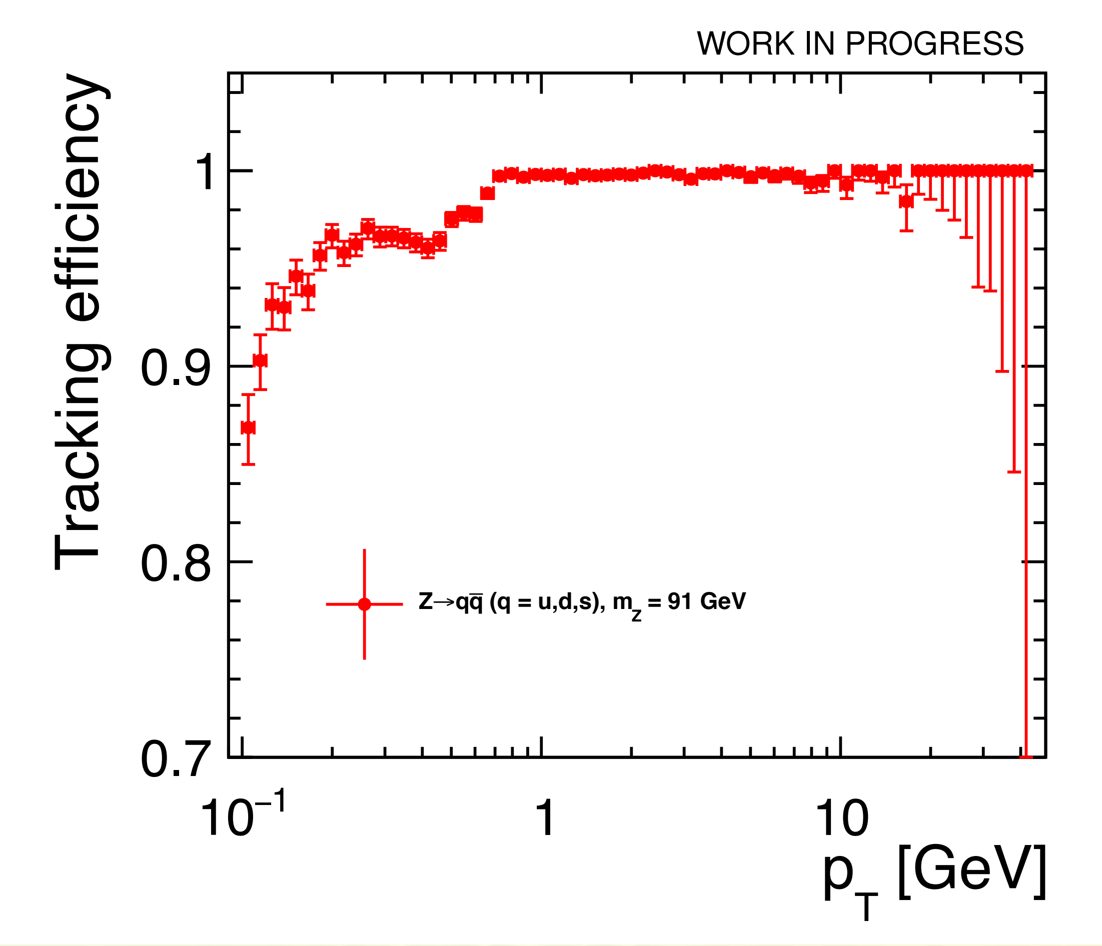
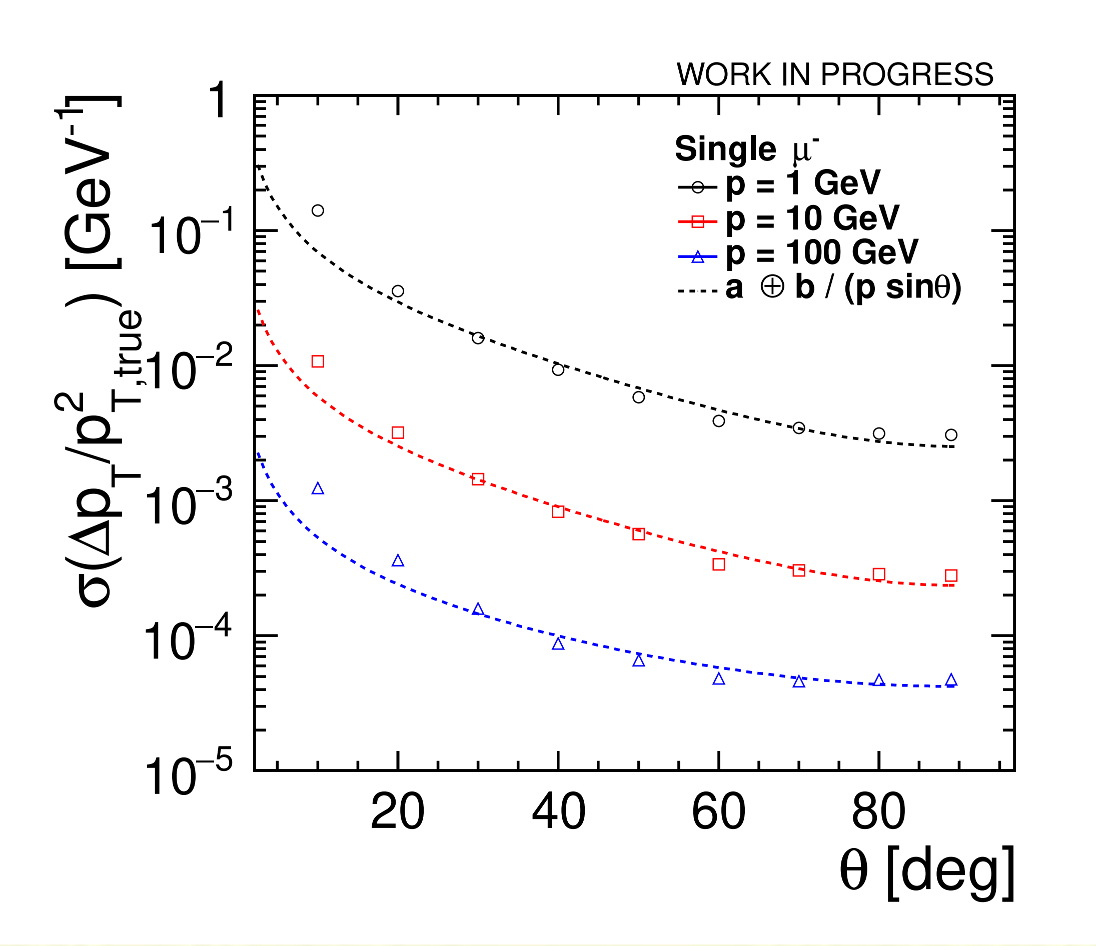




Tracking fully efficient from 700 MeV

Pt Resolution of $4x10^{-5}GeV^{-1}$ for 100 GeV muons

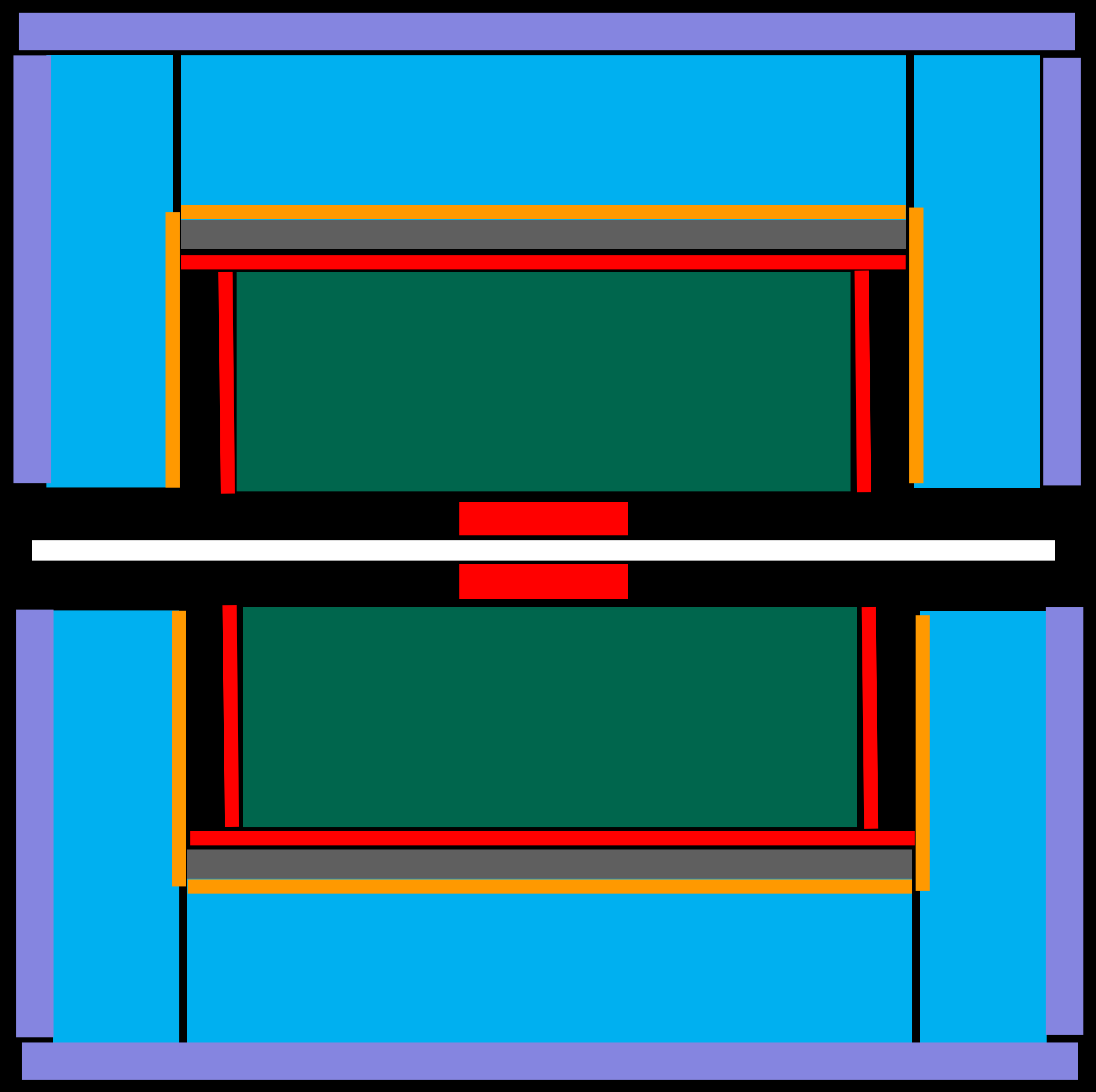
>95% Photon and electron efficiency

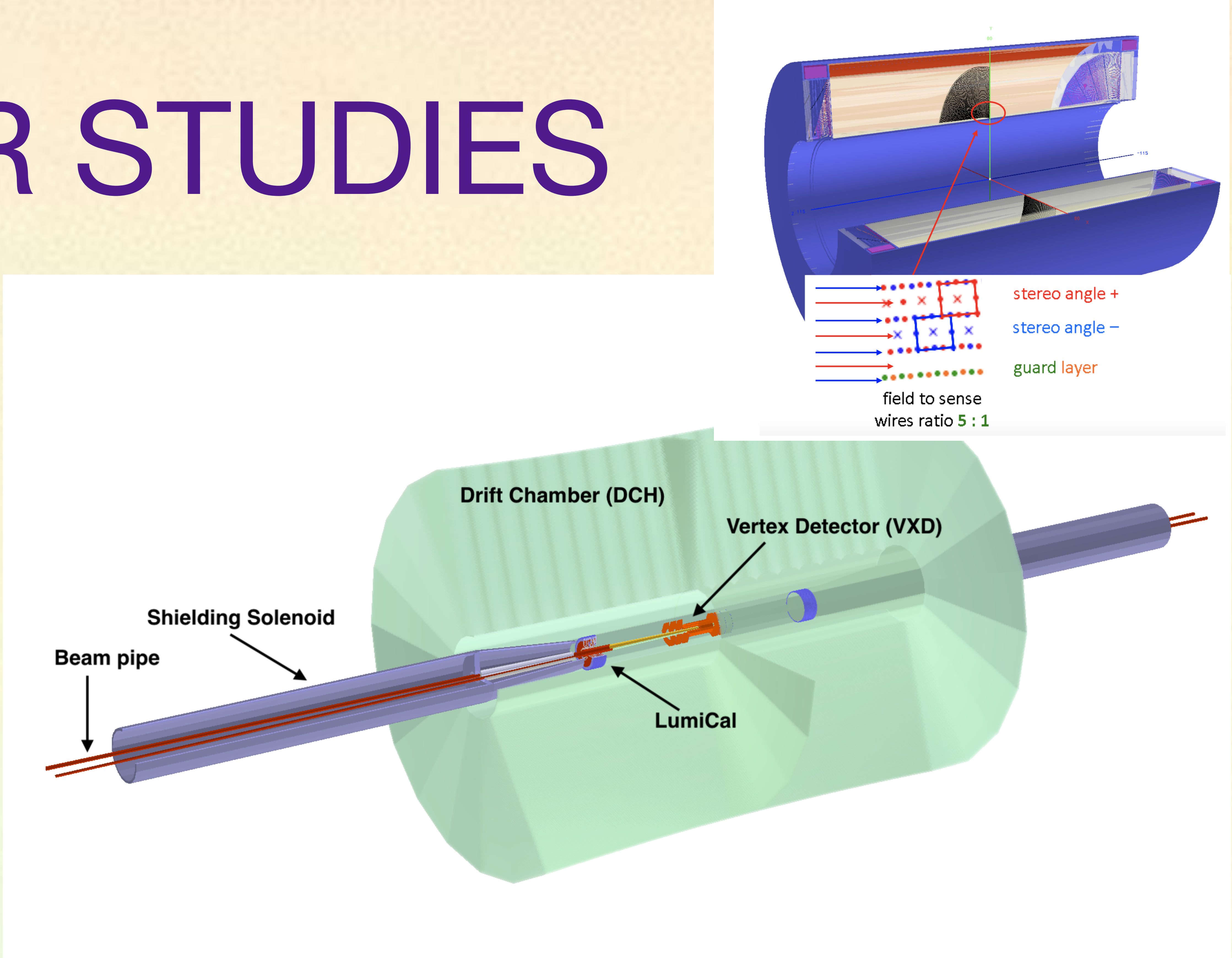
Energy resolution in barrel region 3-5%

Very similar to original CLIC detector

IDEA DETECTOR STUDIES

- Beam pipe (R~1.5 cm)
- VTX: 4-7 MAPS layers
- DCH: 4 m long, R 30-200 cm
- Outer Silicon Layer
- SC Coil : 2 T, R~2.1 m
- Preshower: ~ 1-2 X_0
- DR calorimeter: 2 m/7 λ_{int}
- Yoke + muon chamber





- Significant steps in the simulation of the subdetectors in the FCC-SW. Validation in progress with standalone software
- More detector R&D in progress in all sub-components
- Study of the background effects in the drift chamber ongoing
- Next completing simulation of the overall detector

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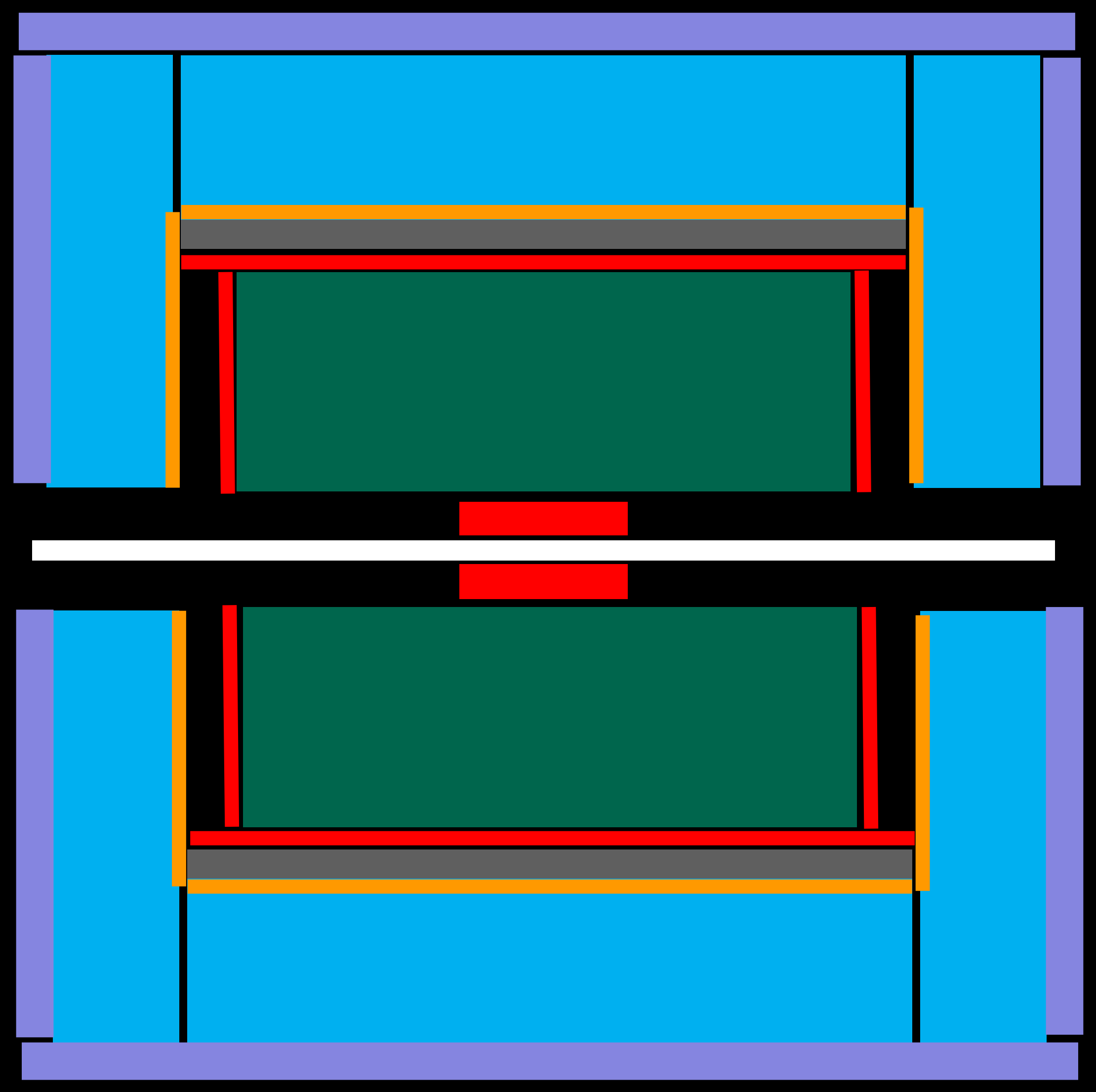
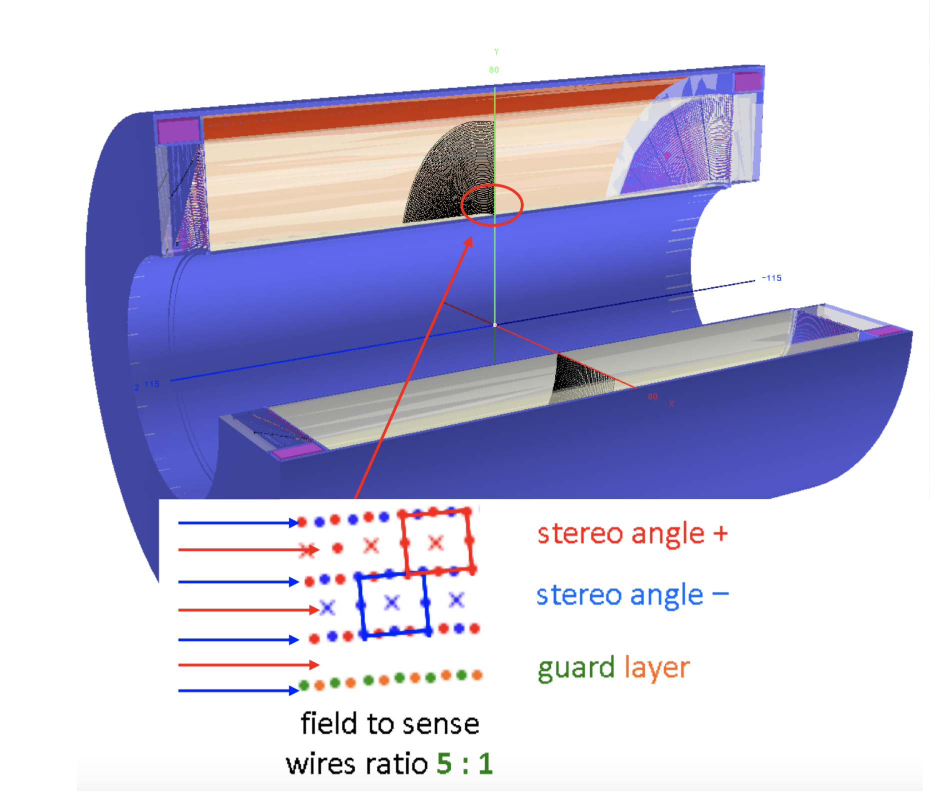
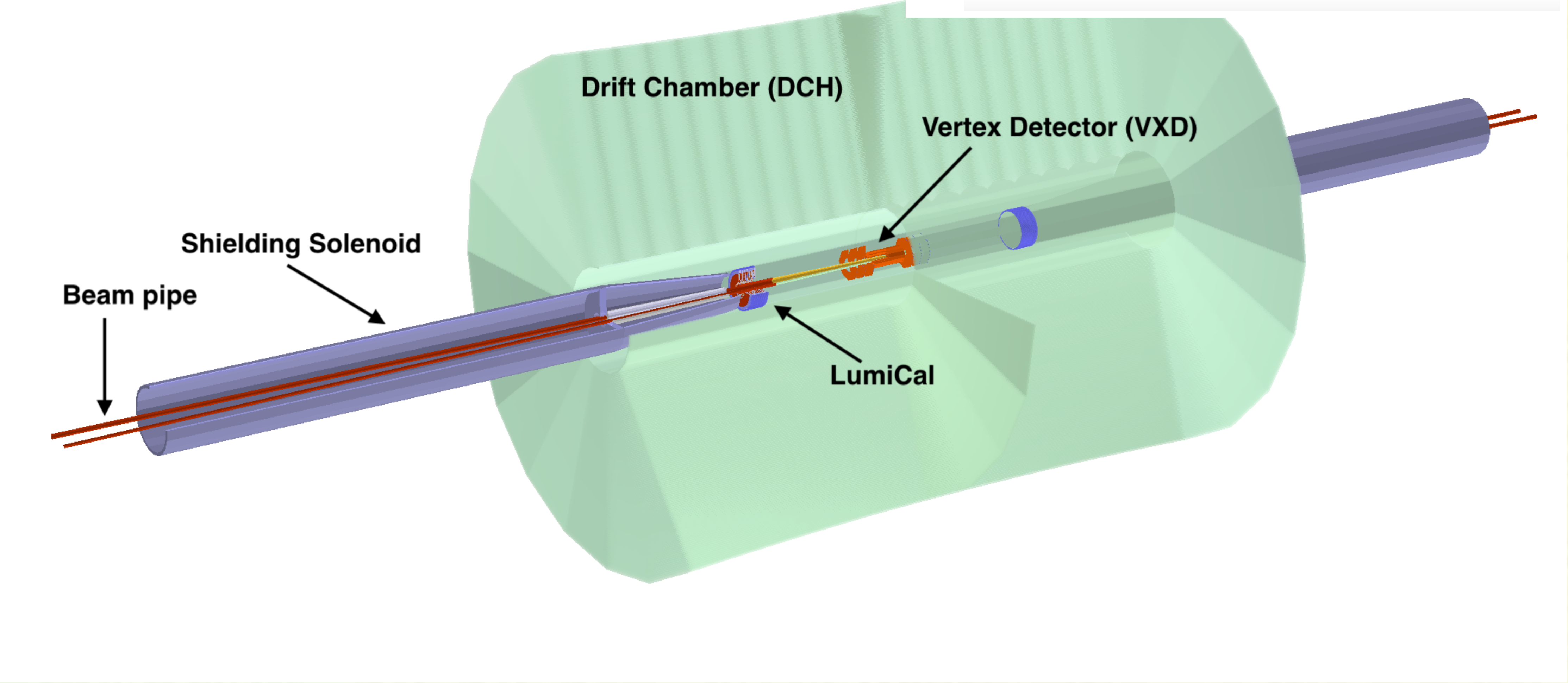






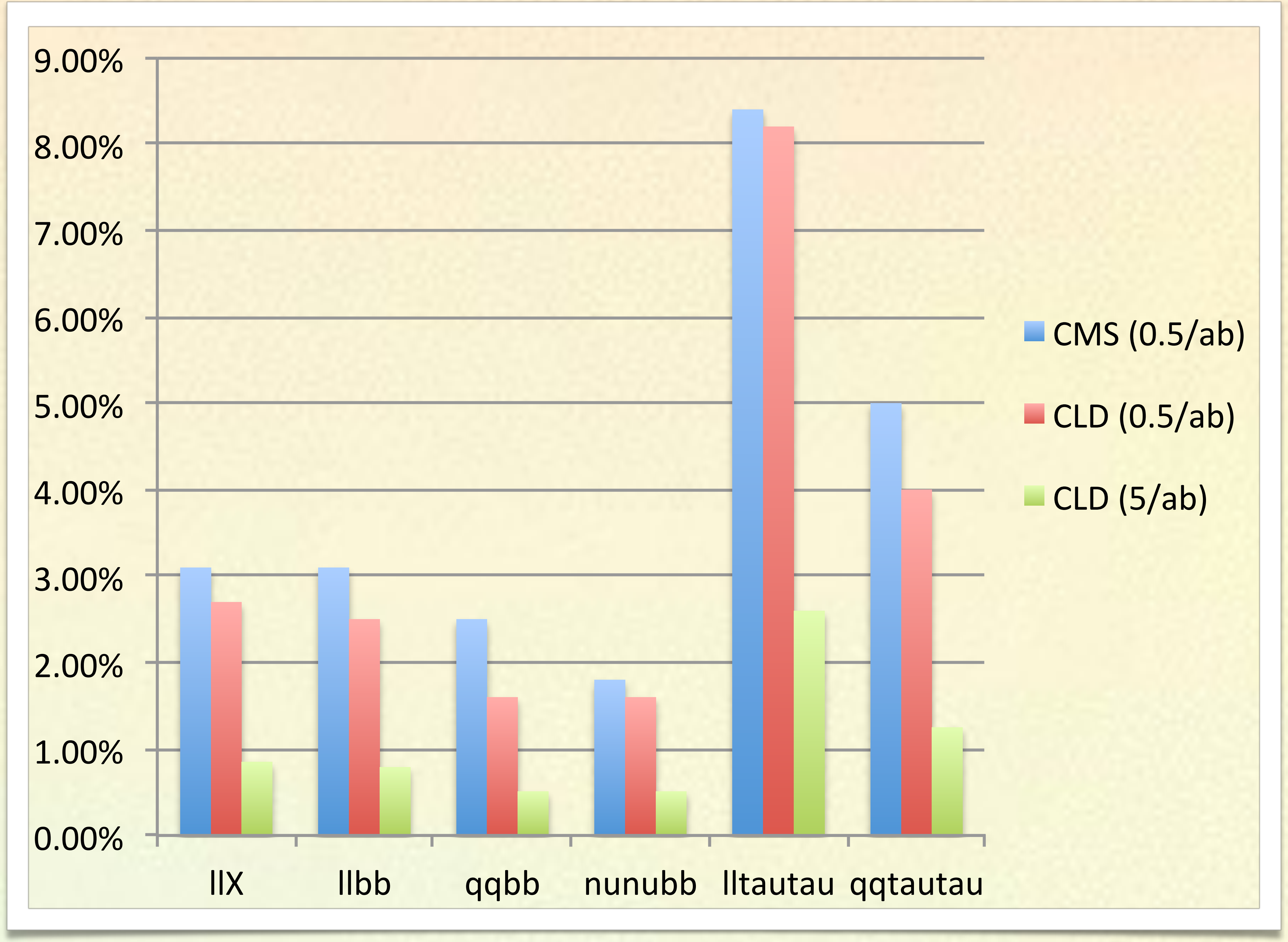
- Significant steps in the simulation of the subdetectors in the FCC-SW. Validation in progress with standalone software
- More detector R&D in progress in all sub-components
- Study of the background effects in the drift chamb
- Next completing simulation of the overall detect

IDEA detector concept becoming a reality in FCC-SW

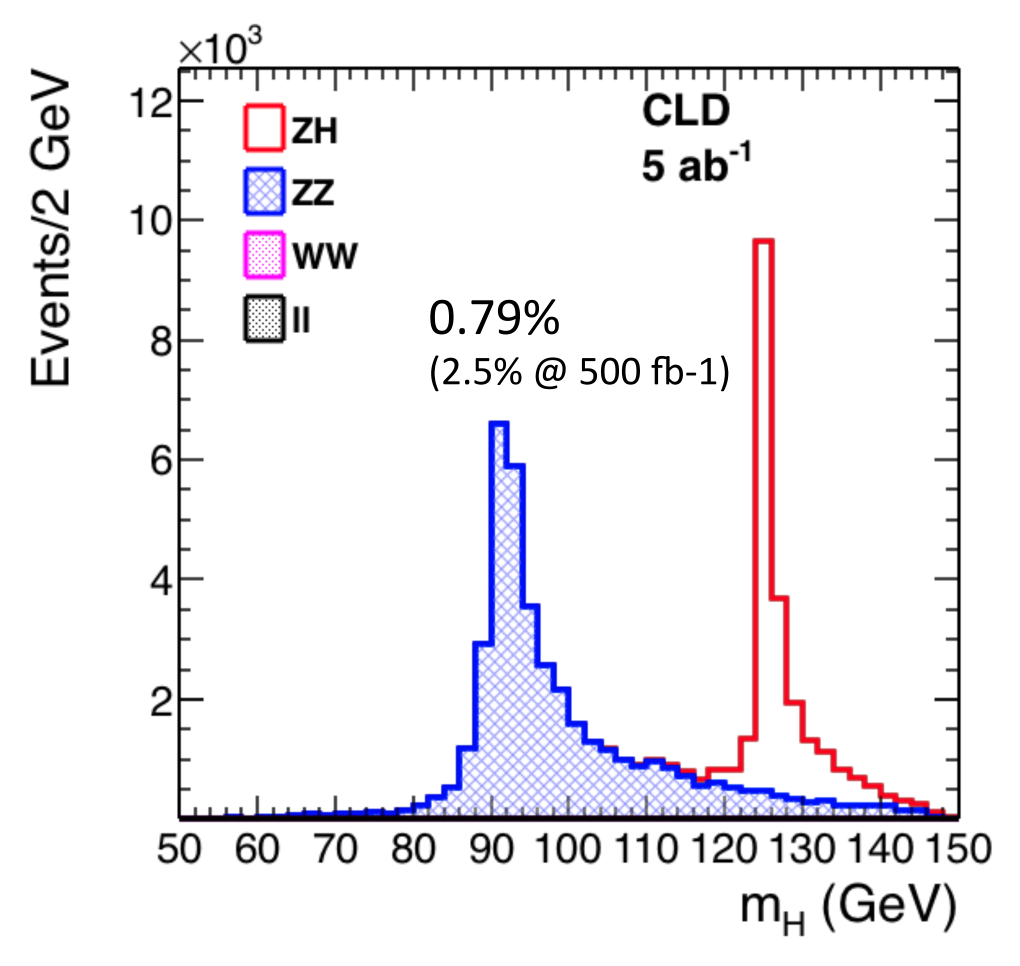
Test beam planned in Fall 2018!

HIGGS

- **Ultimate precision on Higgs couplings below 1% (and measurement of the total width) a milestone of the FCC physics program.**
- **Model independent determination of the total Higgs decay width**
- New estimates of Higgs coupling precision made with custom simulation (PAPAS)
  - CLD performs 10-35% better compared to results with CMS simulation
  - now ready to study variation in detector design cost/performance



$ZH \to \ell\ell bb$



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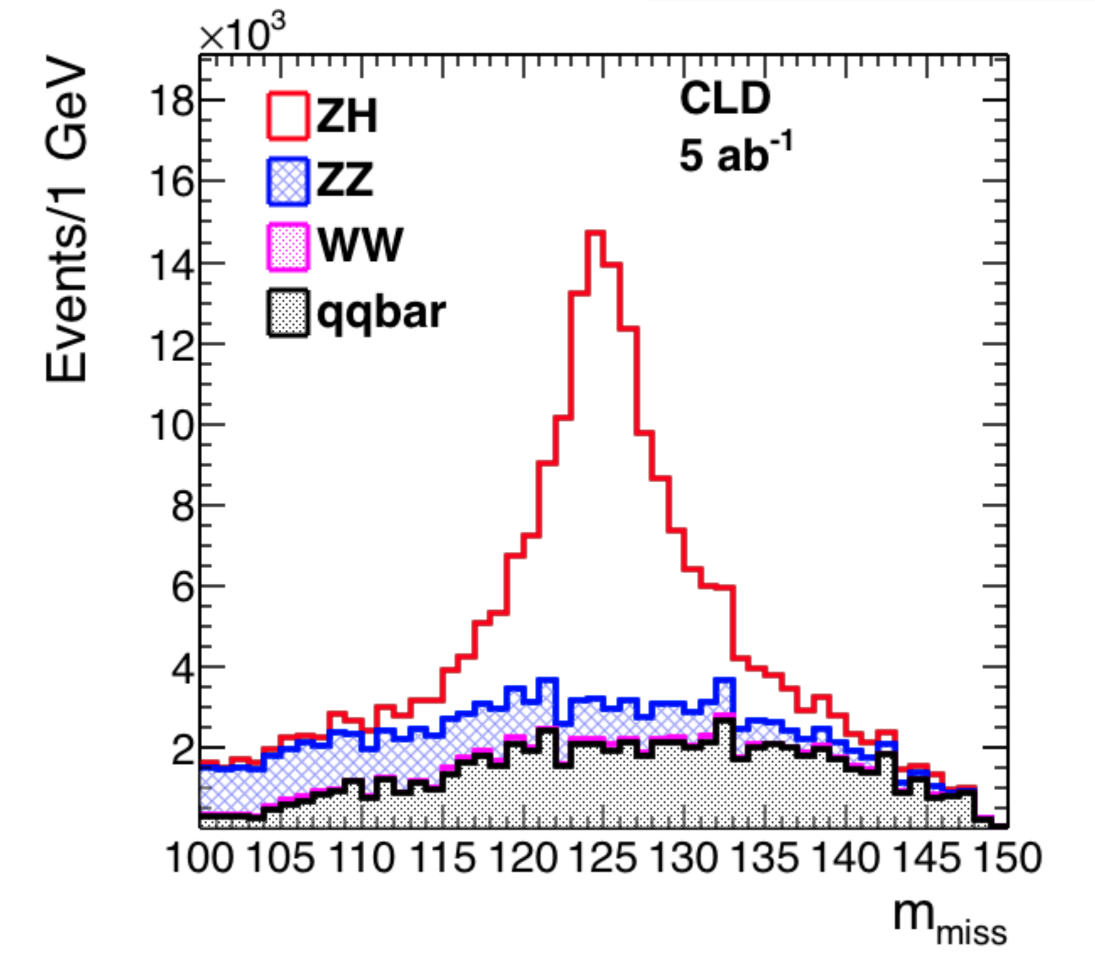

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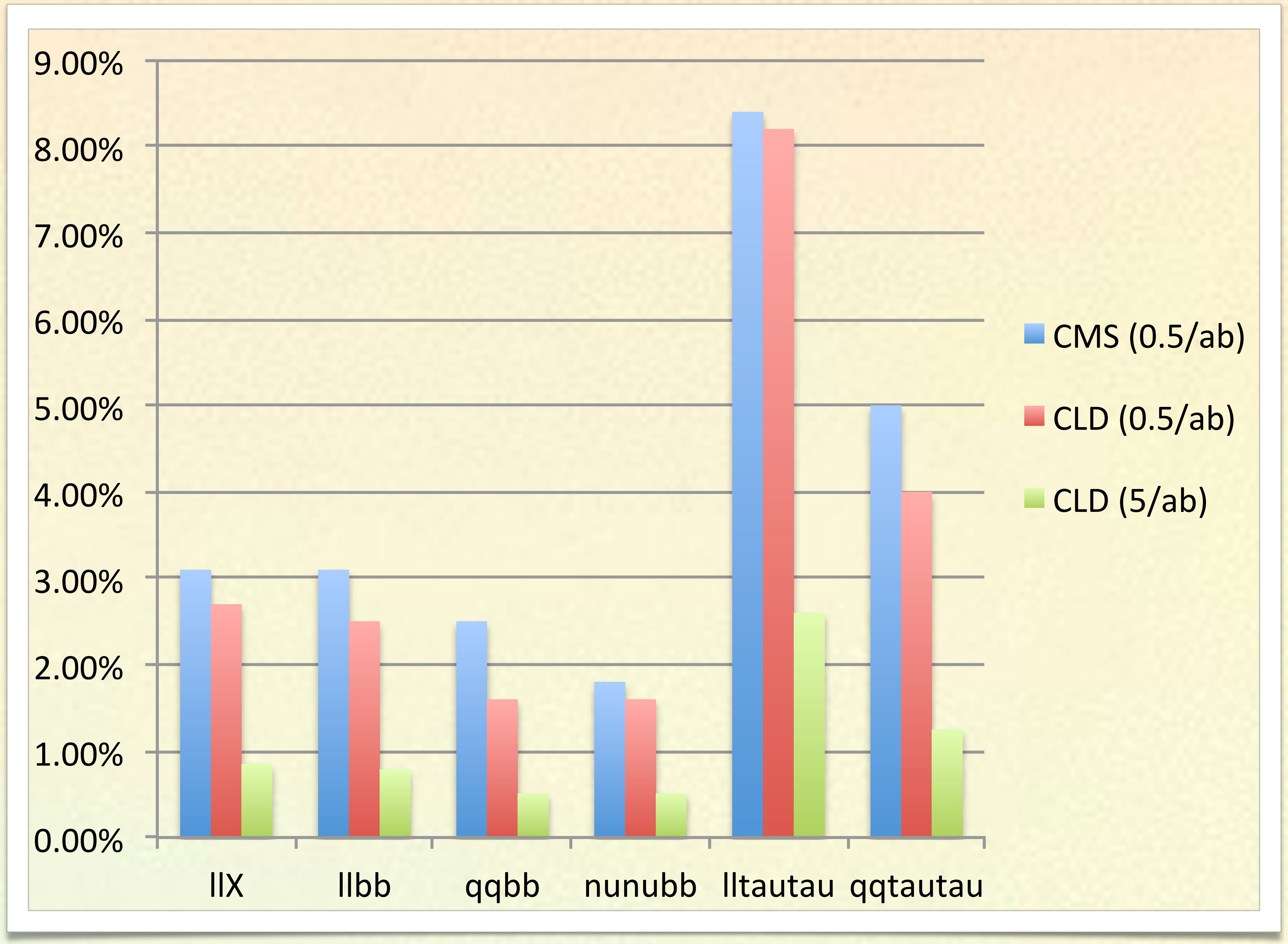

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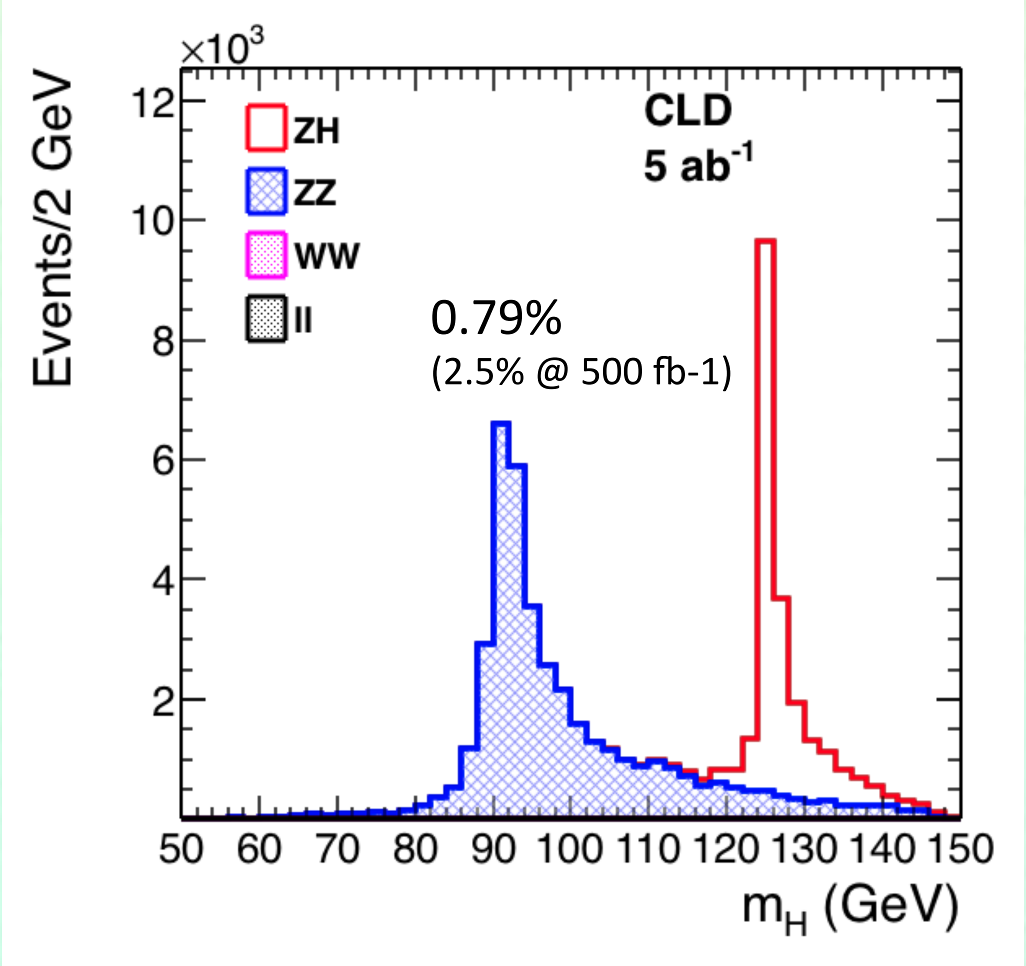

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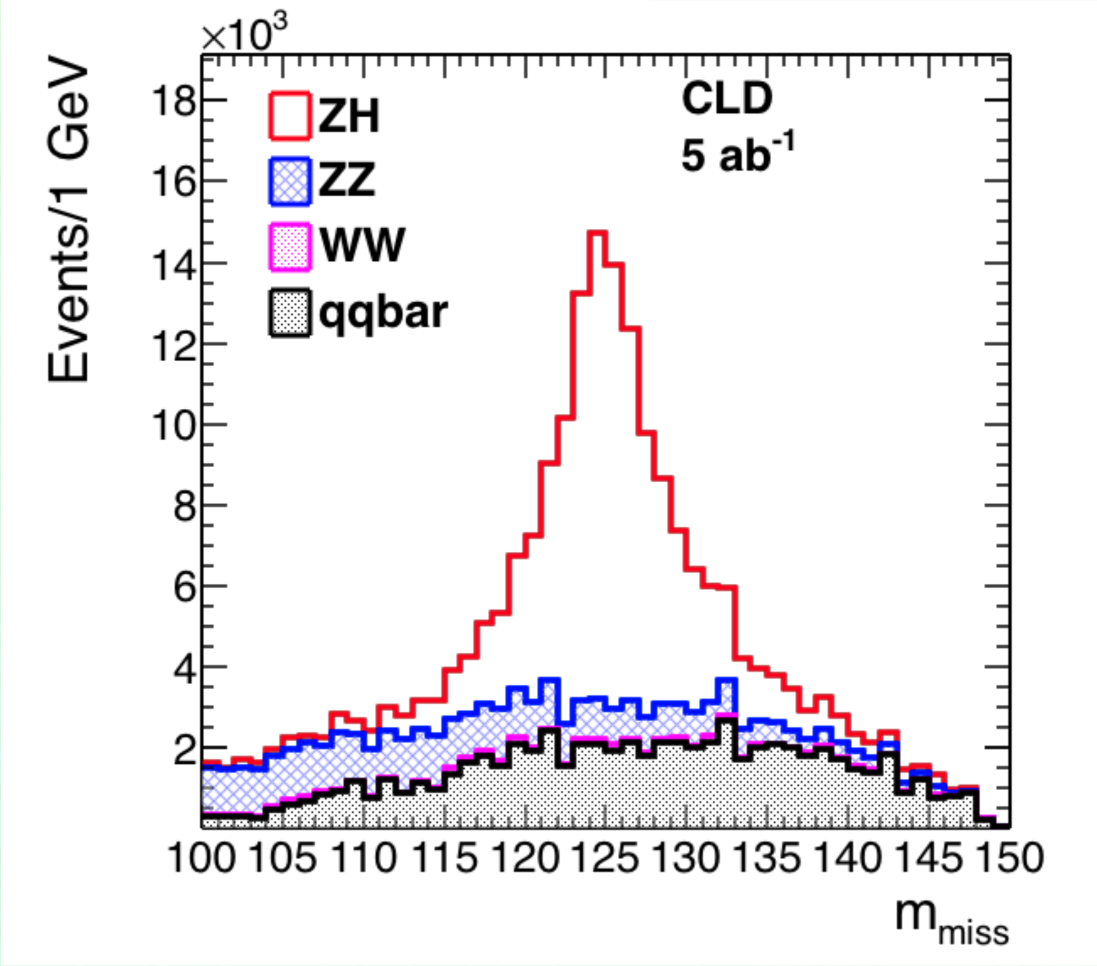
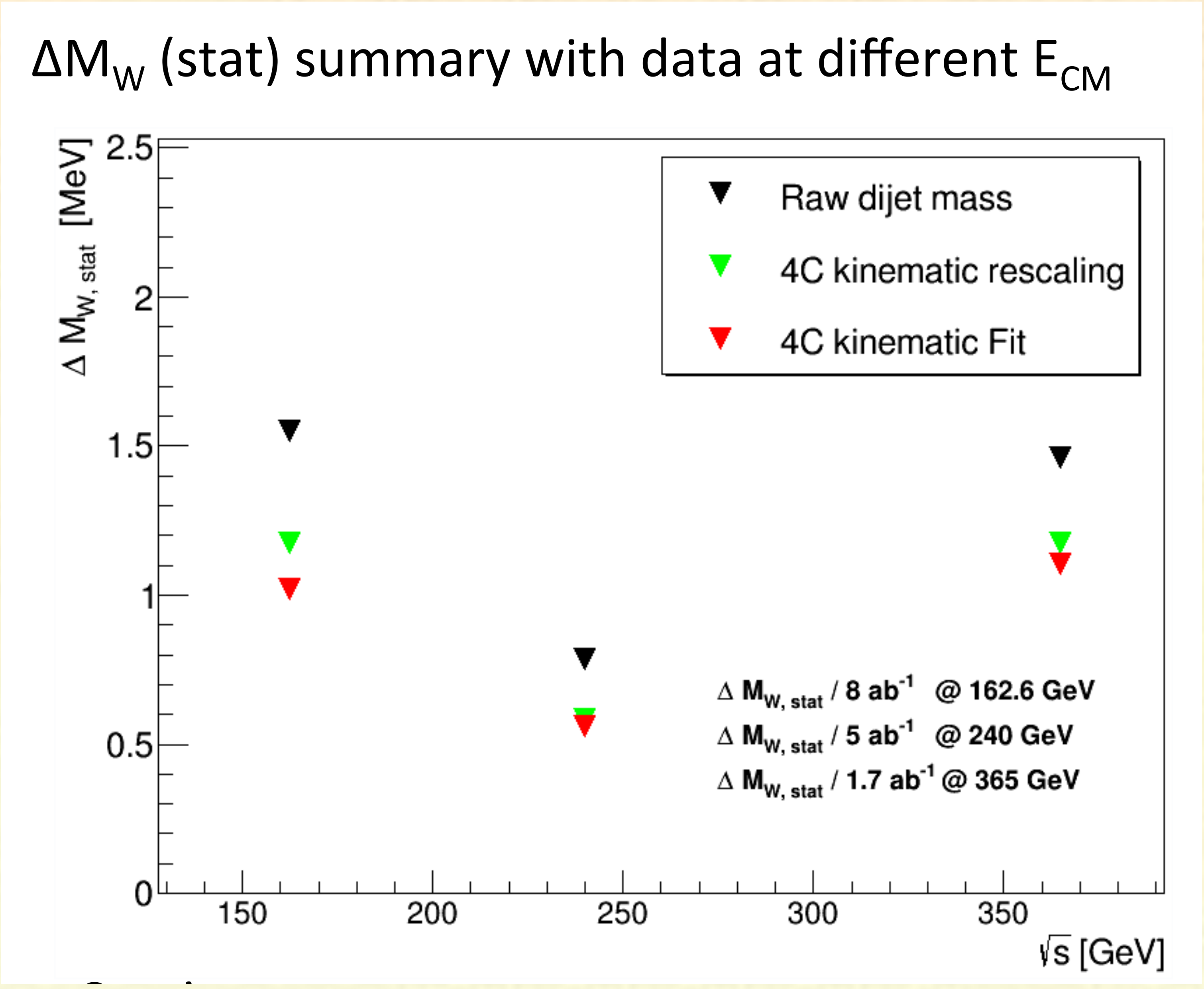
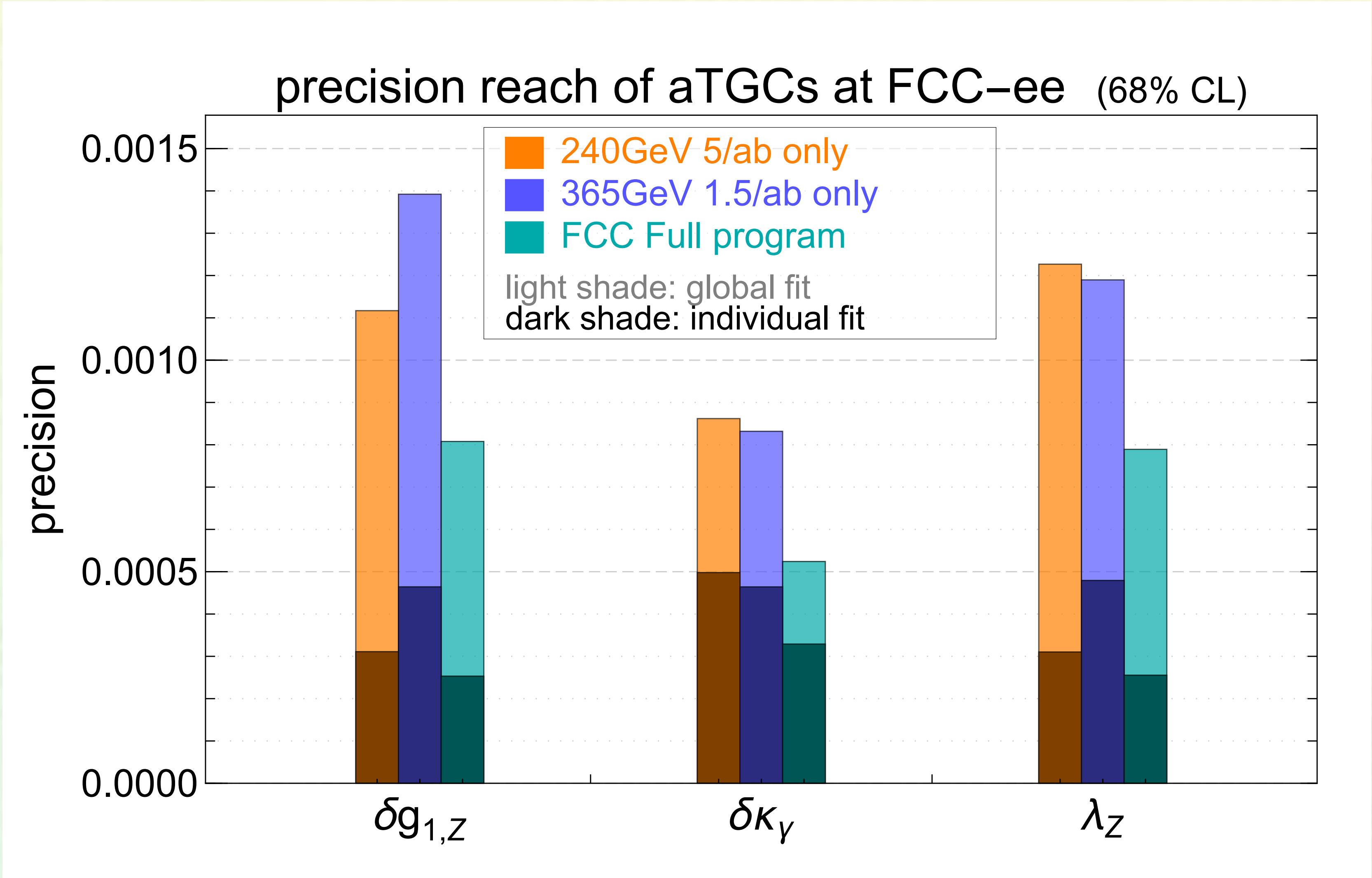


Precision estimates on Higgs couplings confirmed AND improved by 10-35%

EWK

- Integrated luminosity goals for Z and W physics
  - 150 ab^{-1} around the Z pole (~ 25 ab–1 at 88 and 94 GeV, 100 ab–1 at 91 GeV)
  - 10 ab^{-1} around the WW threshold (161 GeV with ±few GeV scan)
  - runs at 240 and at 350-365 GeV very important for WW physics as well
- **FCC-ee program will bring improvement of 1 to 2 orders of magnitude in precision of EWPO**
- New at this collaboration meeting:
  - Direct M(W) reconstruction in the 4-jet channel to be used above the WW threshold region. ΔM(W)=0.5MeV (stat) with 5ab^{-1} at $\sqrt{s}$=240 GeV
  - Study of TGC (leptonic mode only) shows a precision achievable of $O(10^{-3})$!





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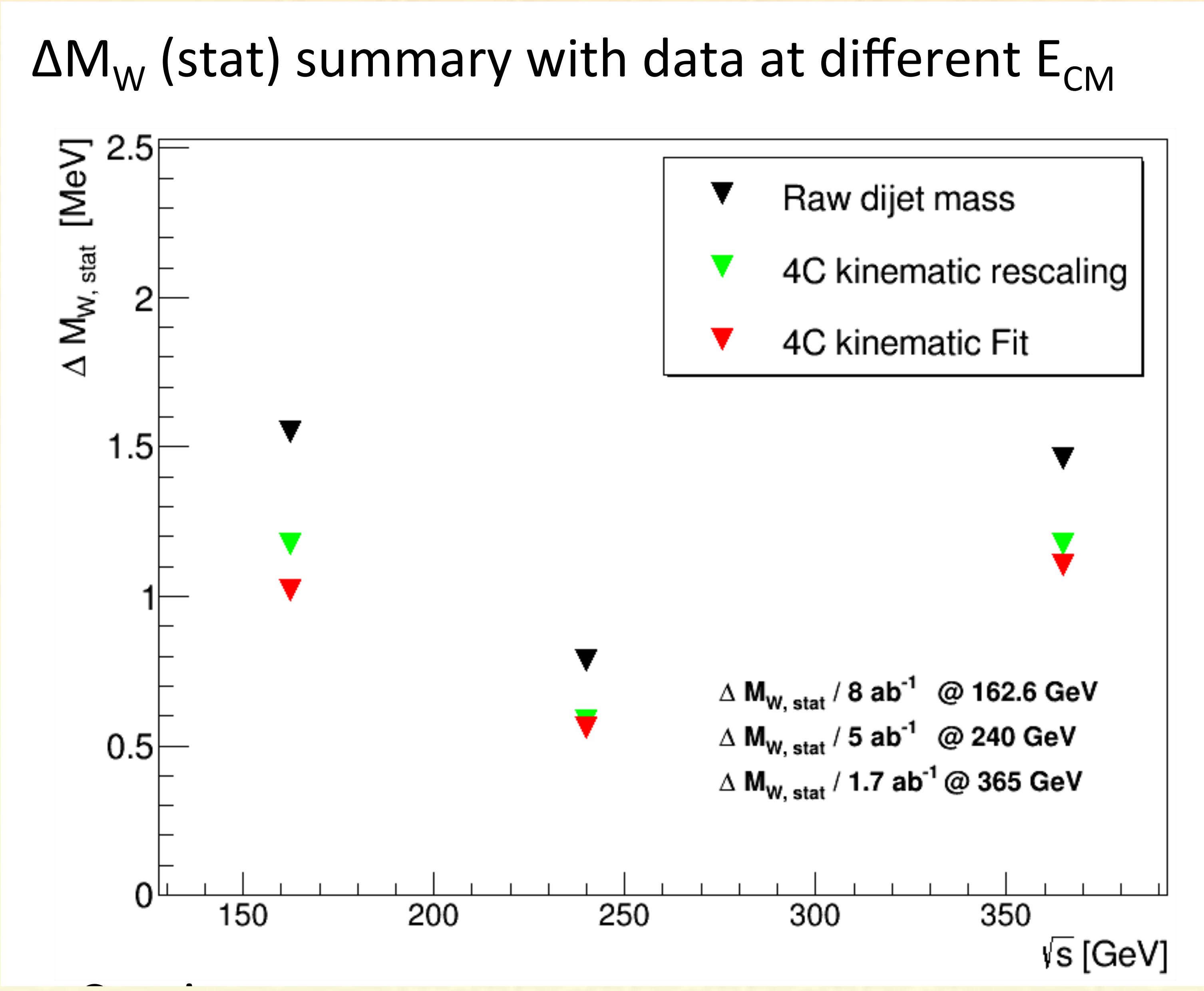
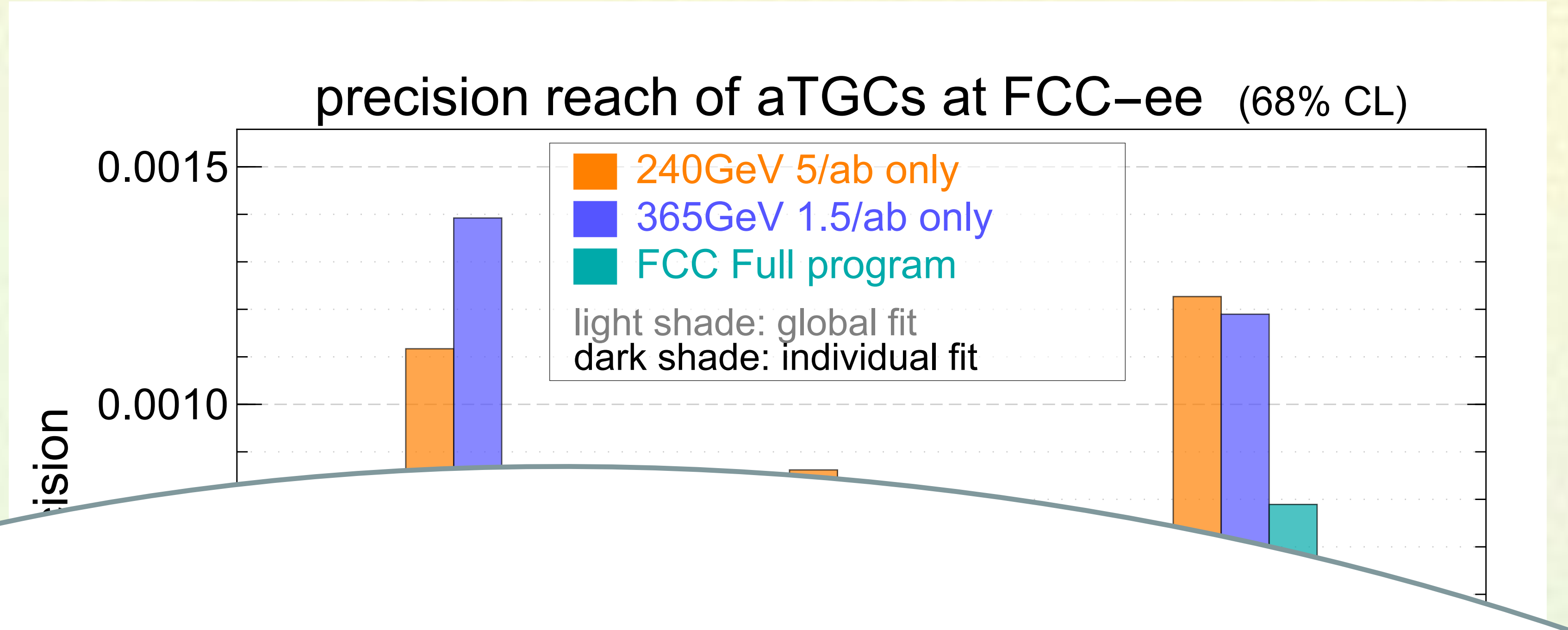
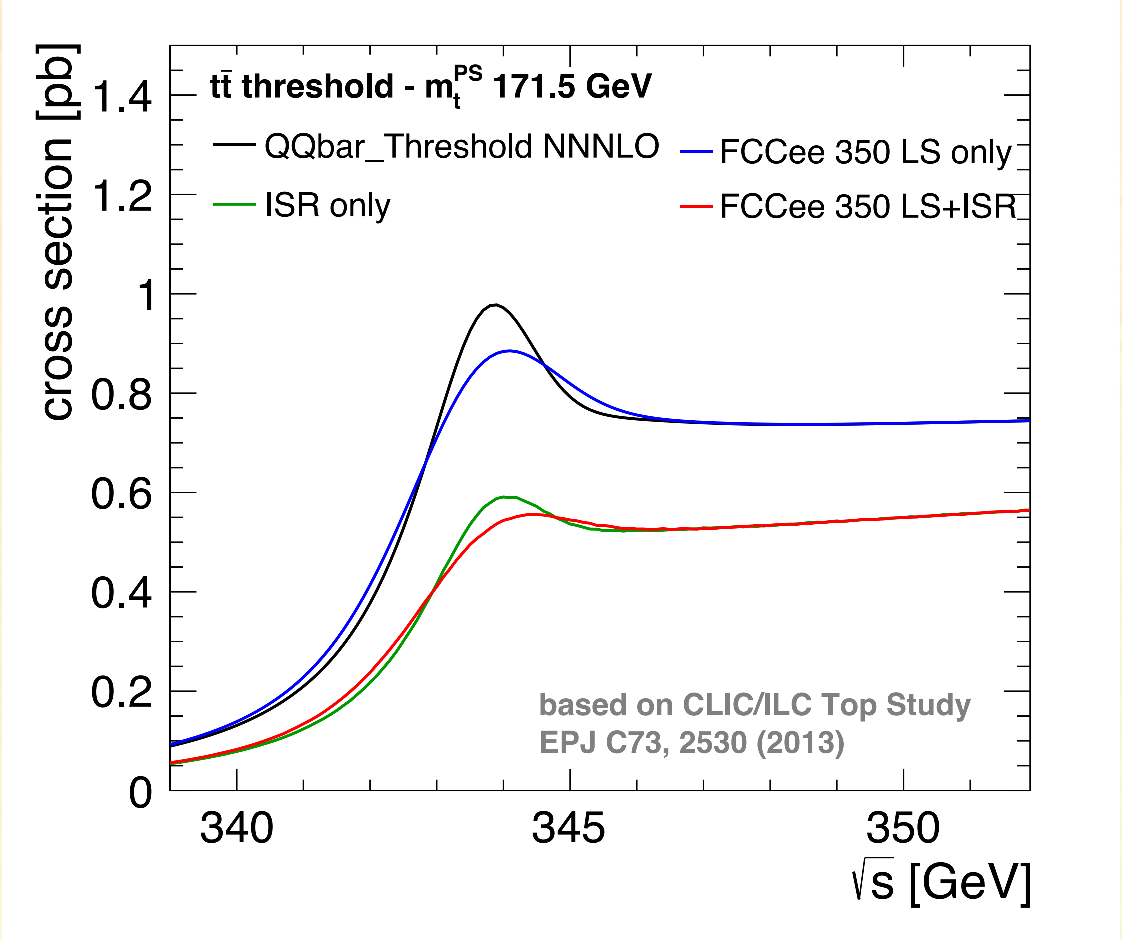


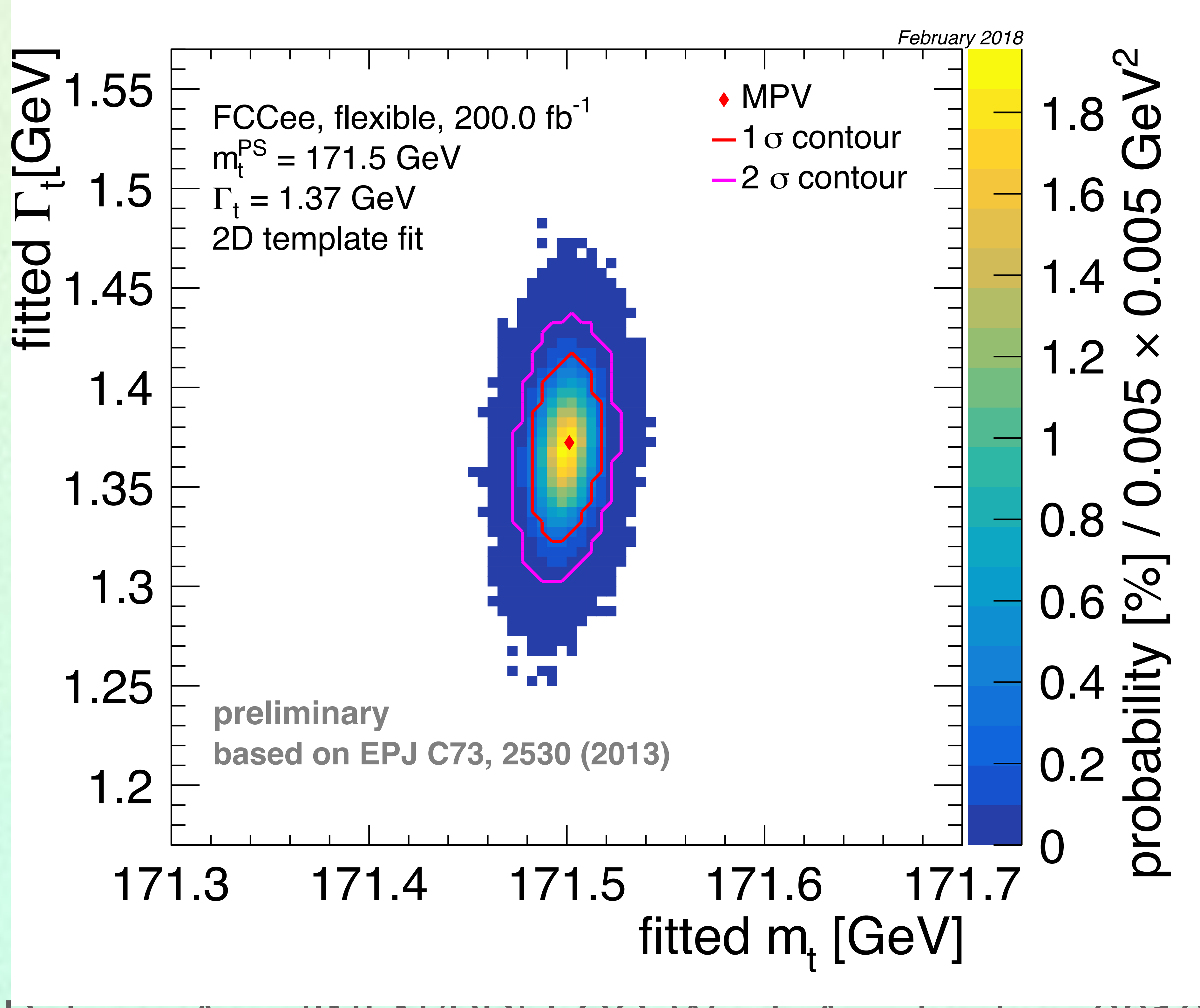


Theorists confirm that with 3-loop calculations in the next decade they can match the required precision

TOP

- Precise measurements of top quark properties at the FCC-ee, coupled with precise theoretical calculation provide excellent discovery potential
- Threshold region allows most precise measurements of mass, width, and estimate of Yukawa coupling. NEW Study of optimizing the scan strategy.
- Running at 365 GeV to be used for other measurements such as top couplings, FCNC etc.





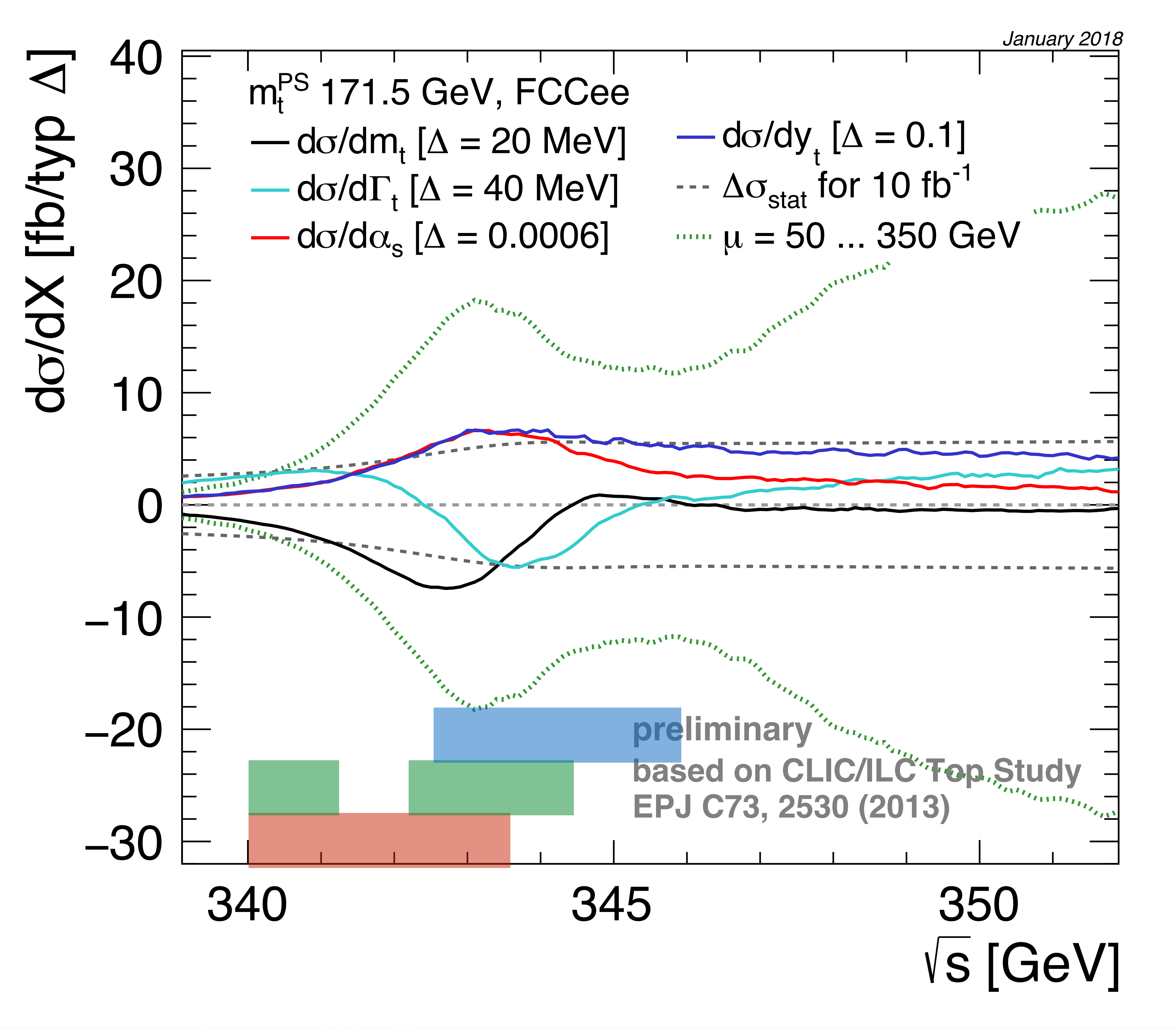
- Mass only: **8.8 MeV** (stat), **5.4 MeV** (α_s [2 x 10^{-4}]),
- **44 MeV** (theo)

sensitivity to:

mass

width

Yukawa



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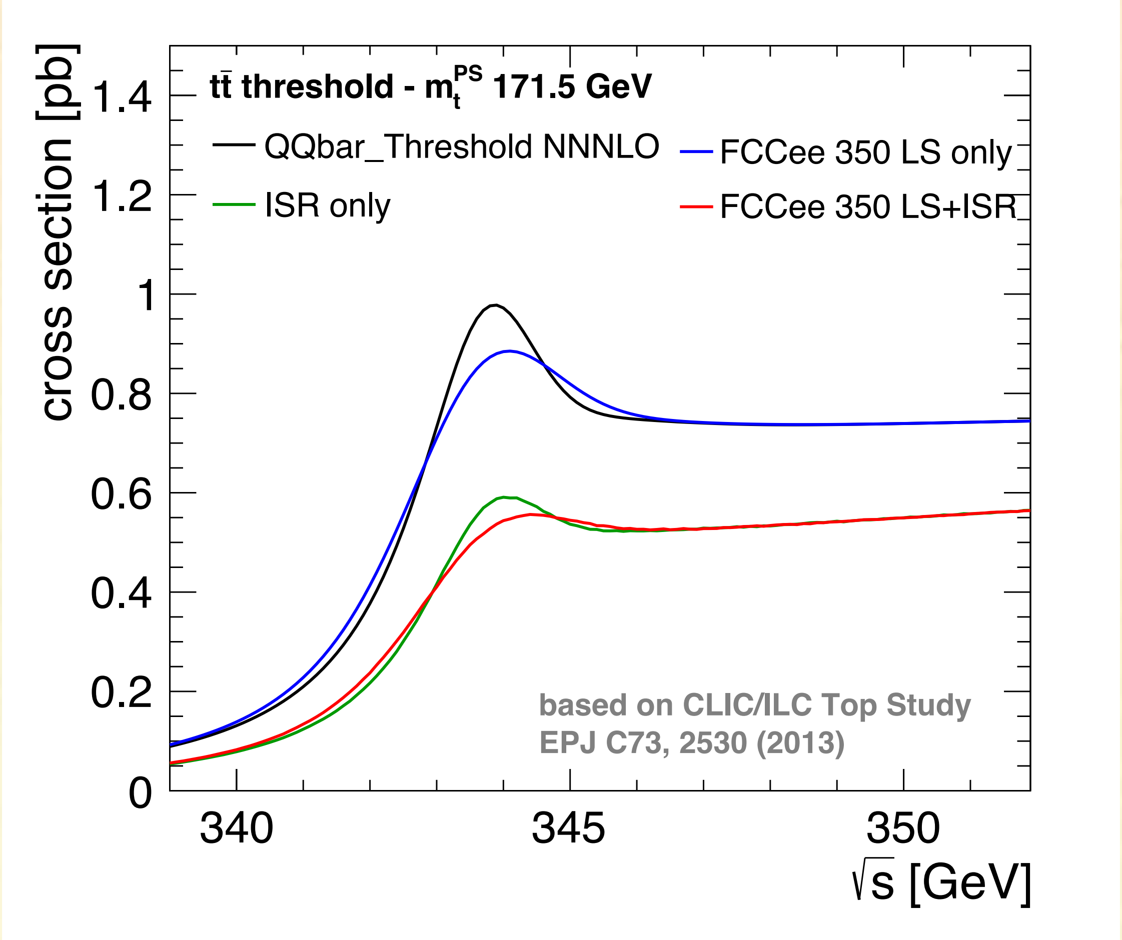

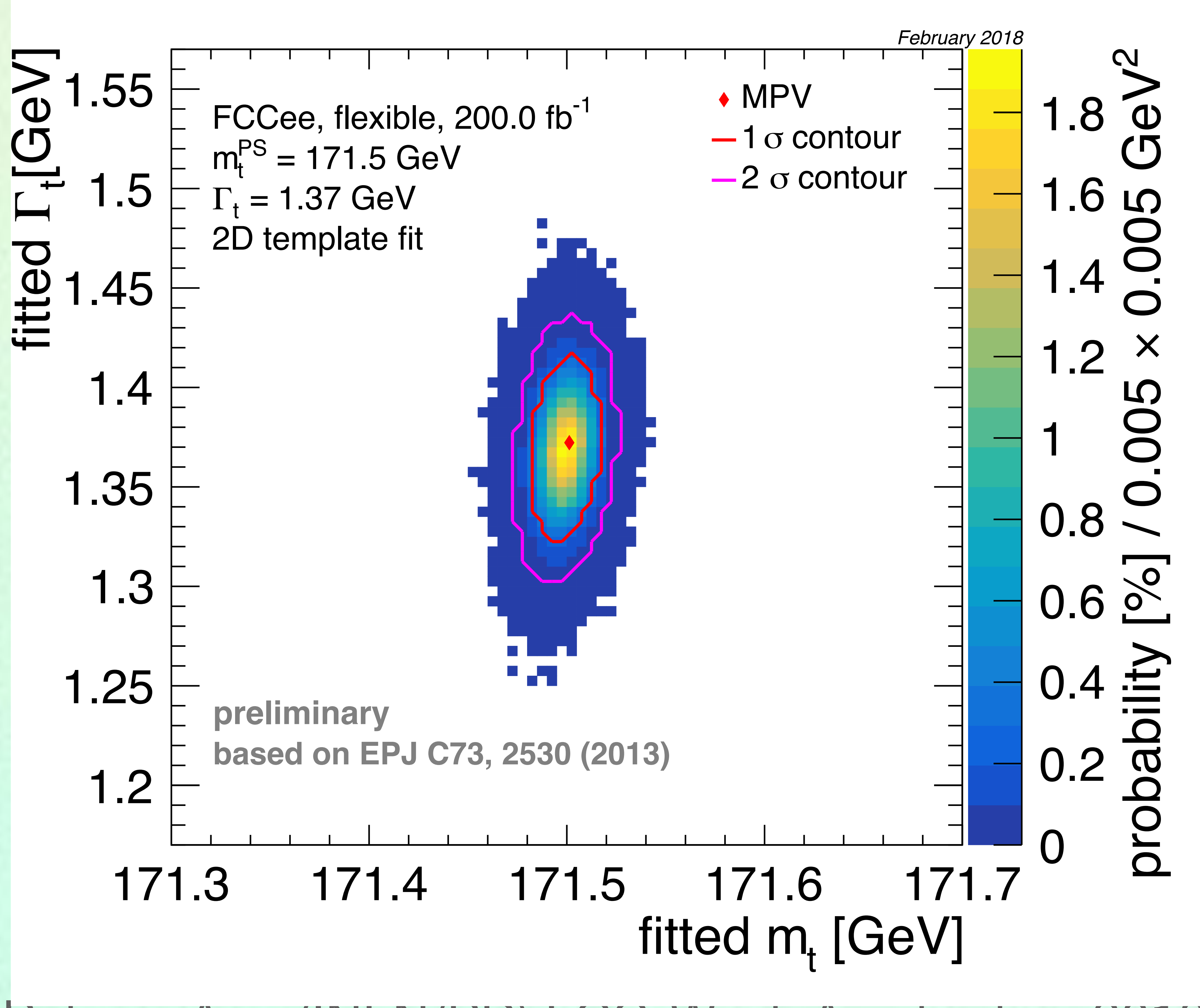

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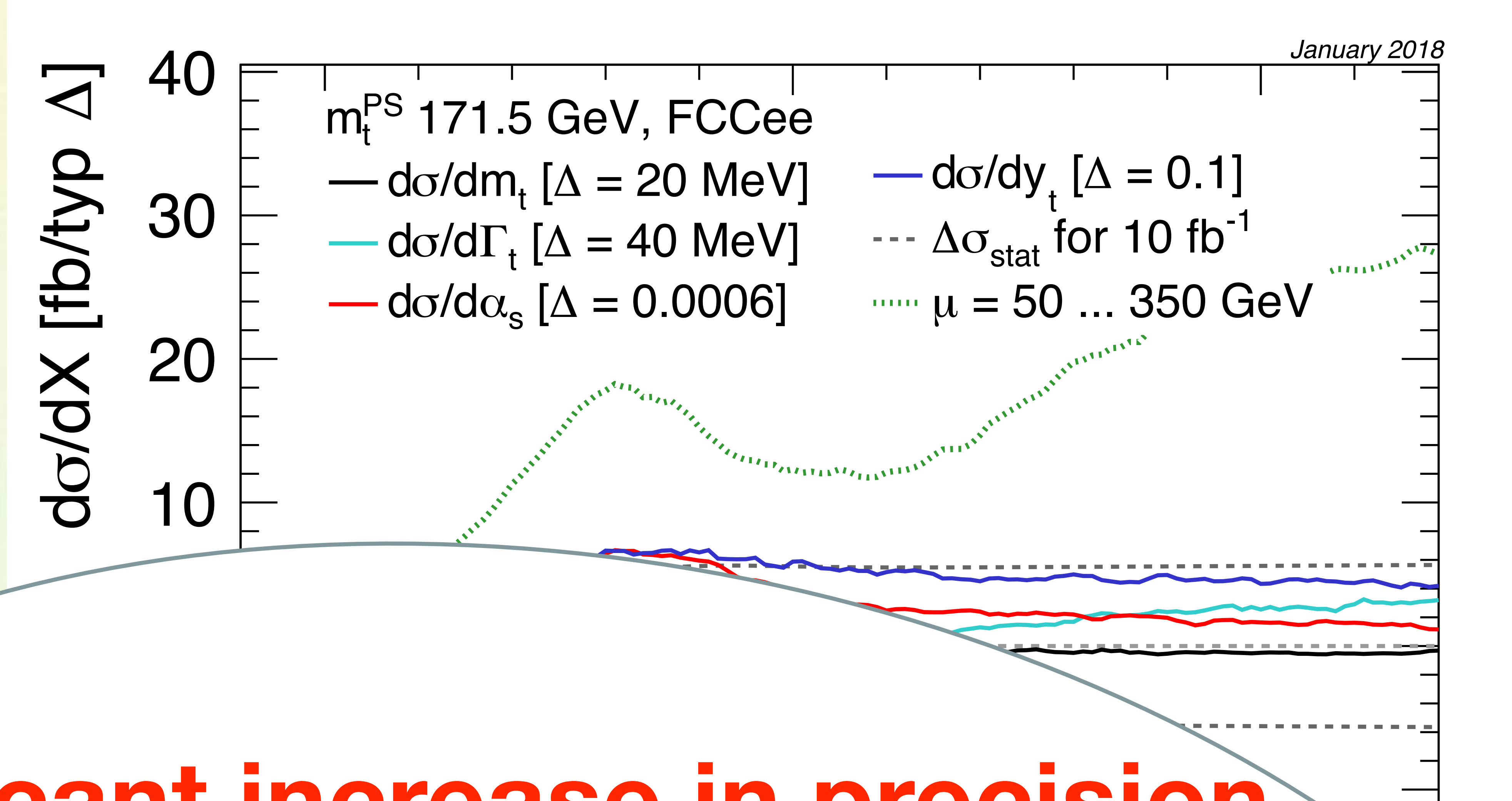


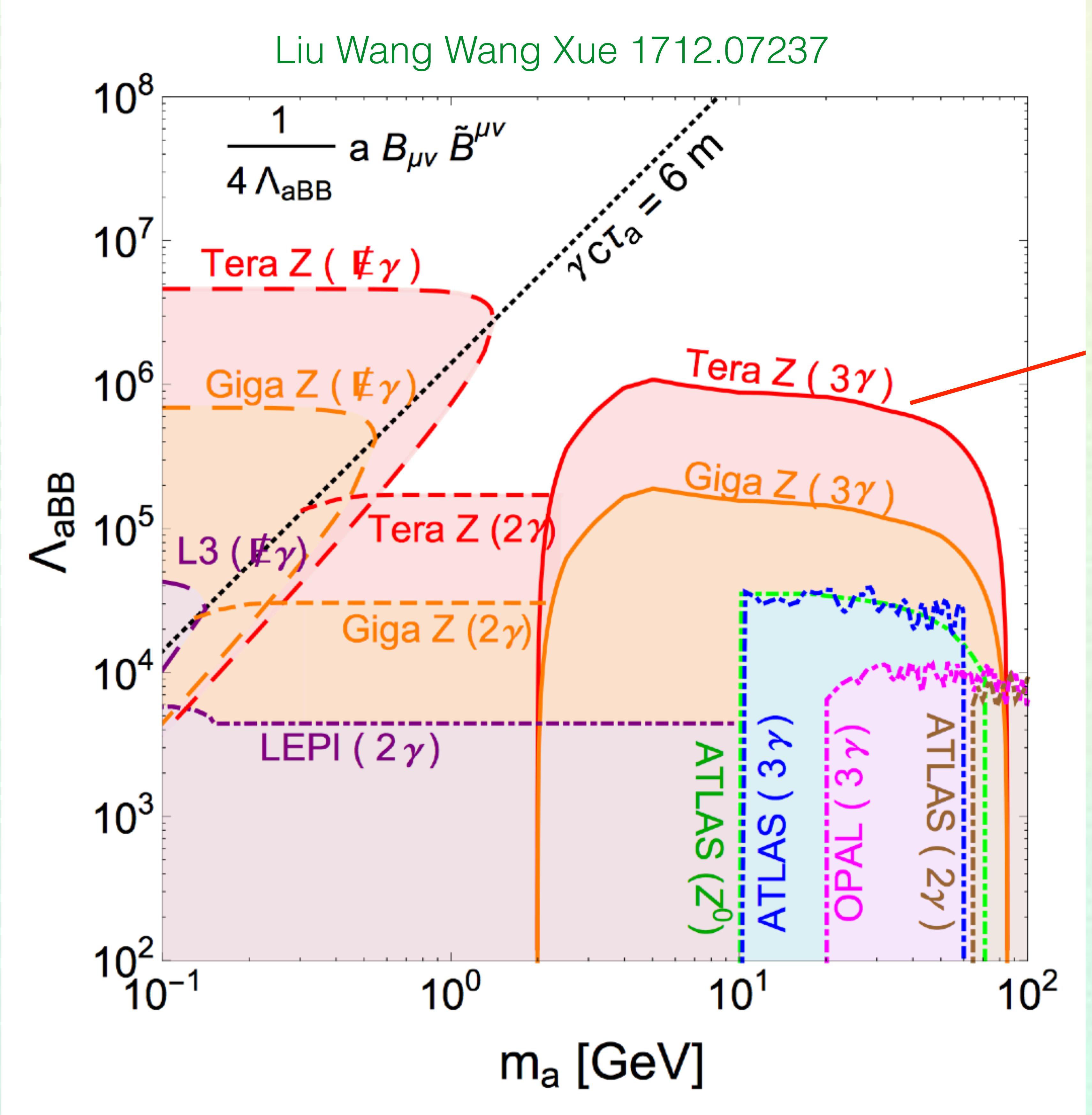
sensitivity

Significant increase in precision of top mass, Γ, Y (w/ reduction of theory uncertainties) with an optimized scan strategy

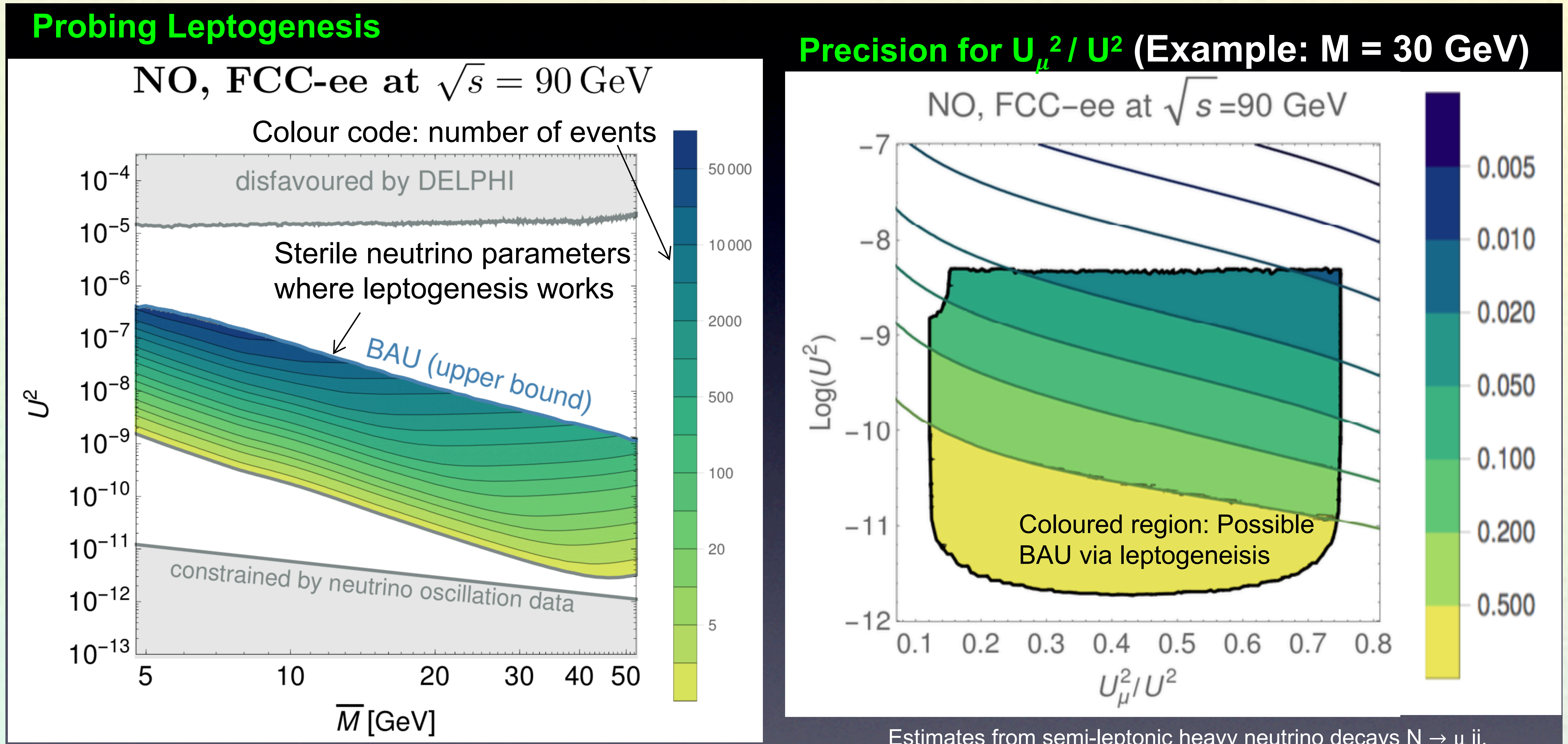
BSM DIRECT SEARCHES

- Axion Like Particles (ALPS) appear in several extensions of the SM
- if no coupling with gluons FCC-ee could reach $f_a \lesssim 100$ TeV

For Tera Z $\mathrm{BR}[Z \to \gamma a(\gamma\gamma)] \lesssim 3 \times 10^{-9}$
[current LEP limit $\lesssim 5 \times 10^{-6}$]



- Long Lived Particles: recent study with a SiD inspired detector and 110ab^{-1} at Z pole 1710.03744



With: $U^2 = |\theta|^2$ and, for example, $U_\mu^2 = |\theta_\mu|^2$
(NO = normal light neutrino mass ordering)

Estimates from semi-leptonic heavy neutrino decays N → μ jj, measurements also possible for the other flavours e and τ!

S.A., E. Cazzato, M. Drewes, O. Fischer, B. Garbrecht, D. Gueter, J. Klaric (arXiv:1407.6607)

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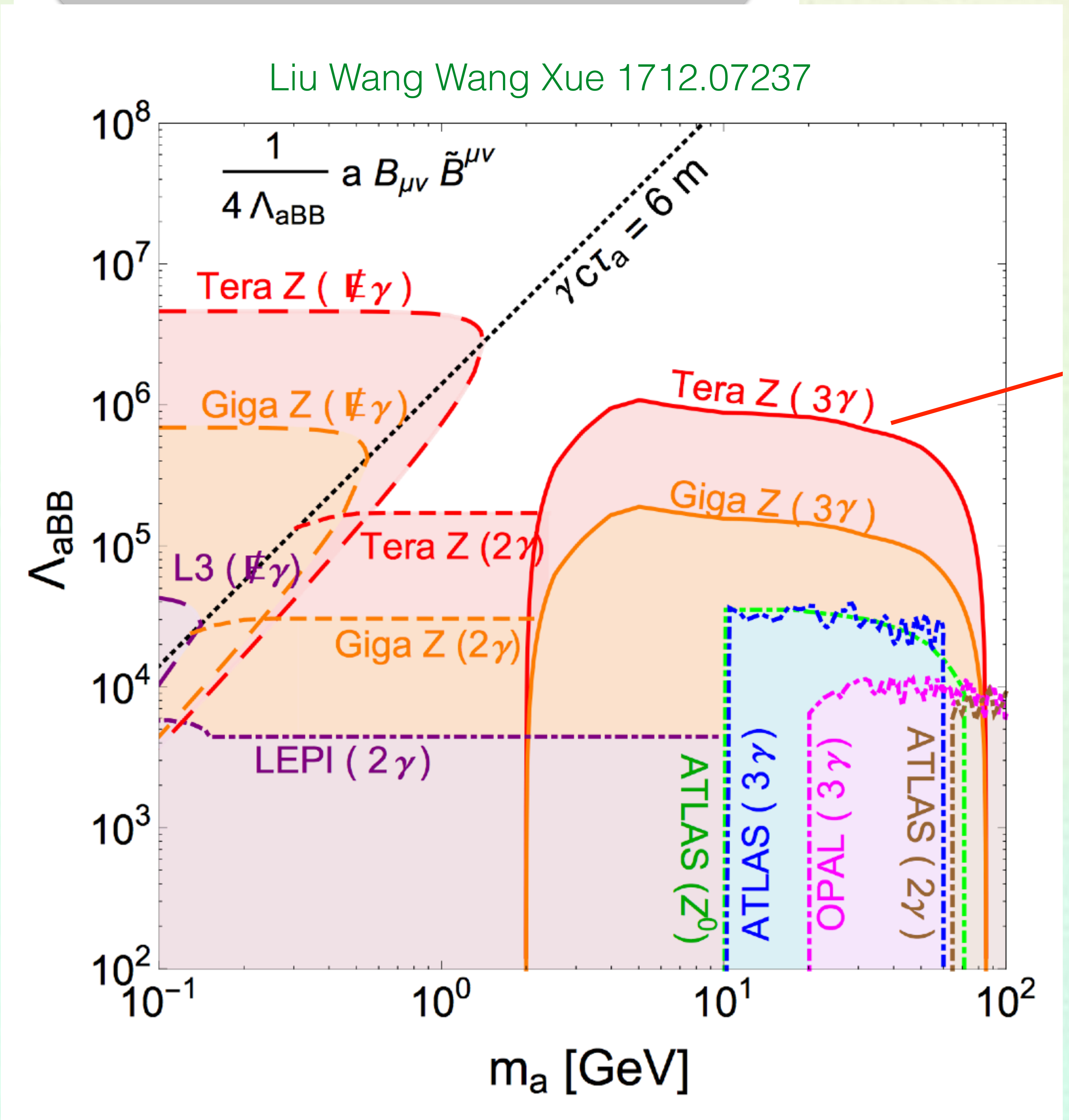
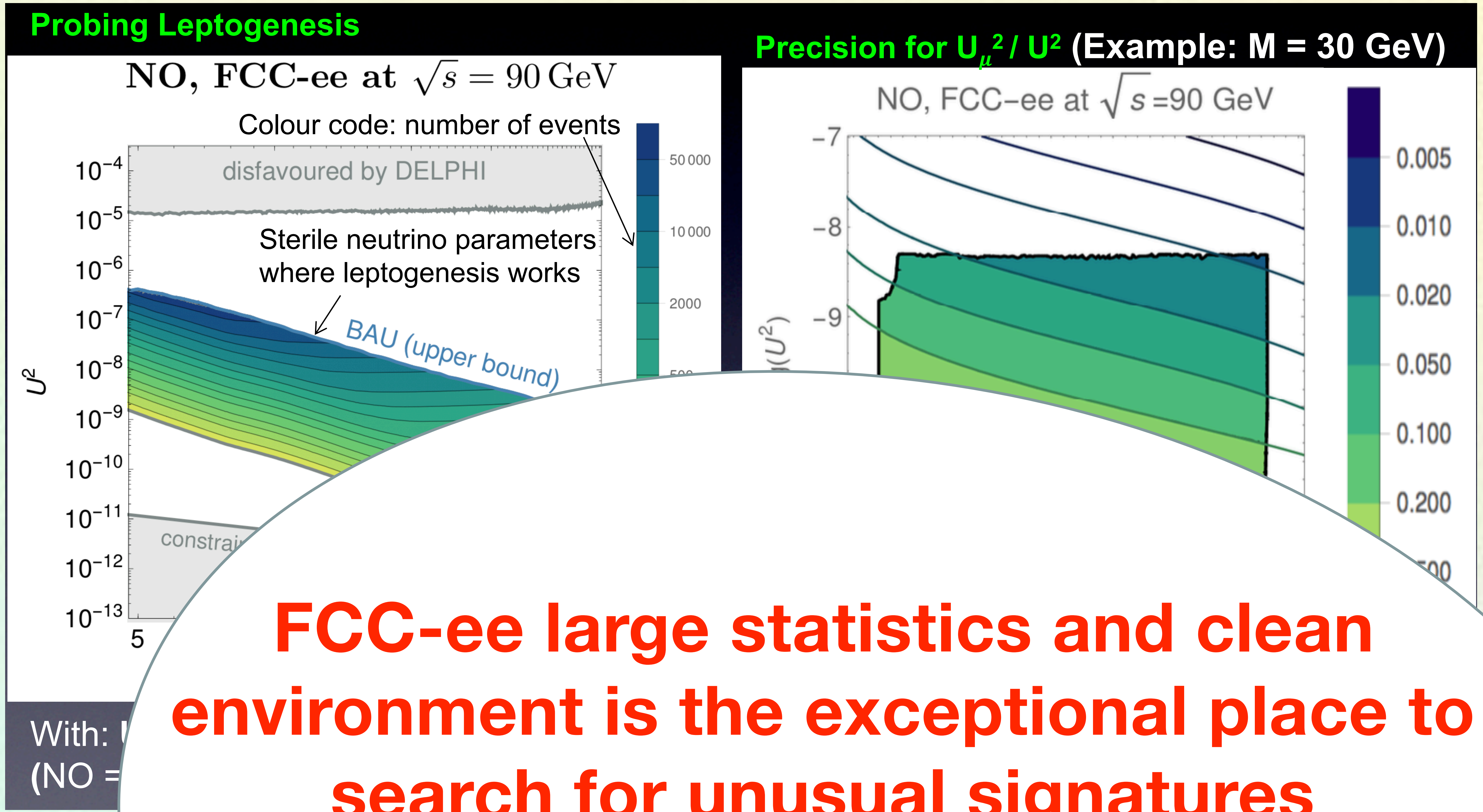


2018

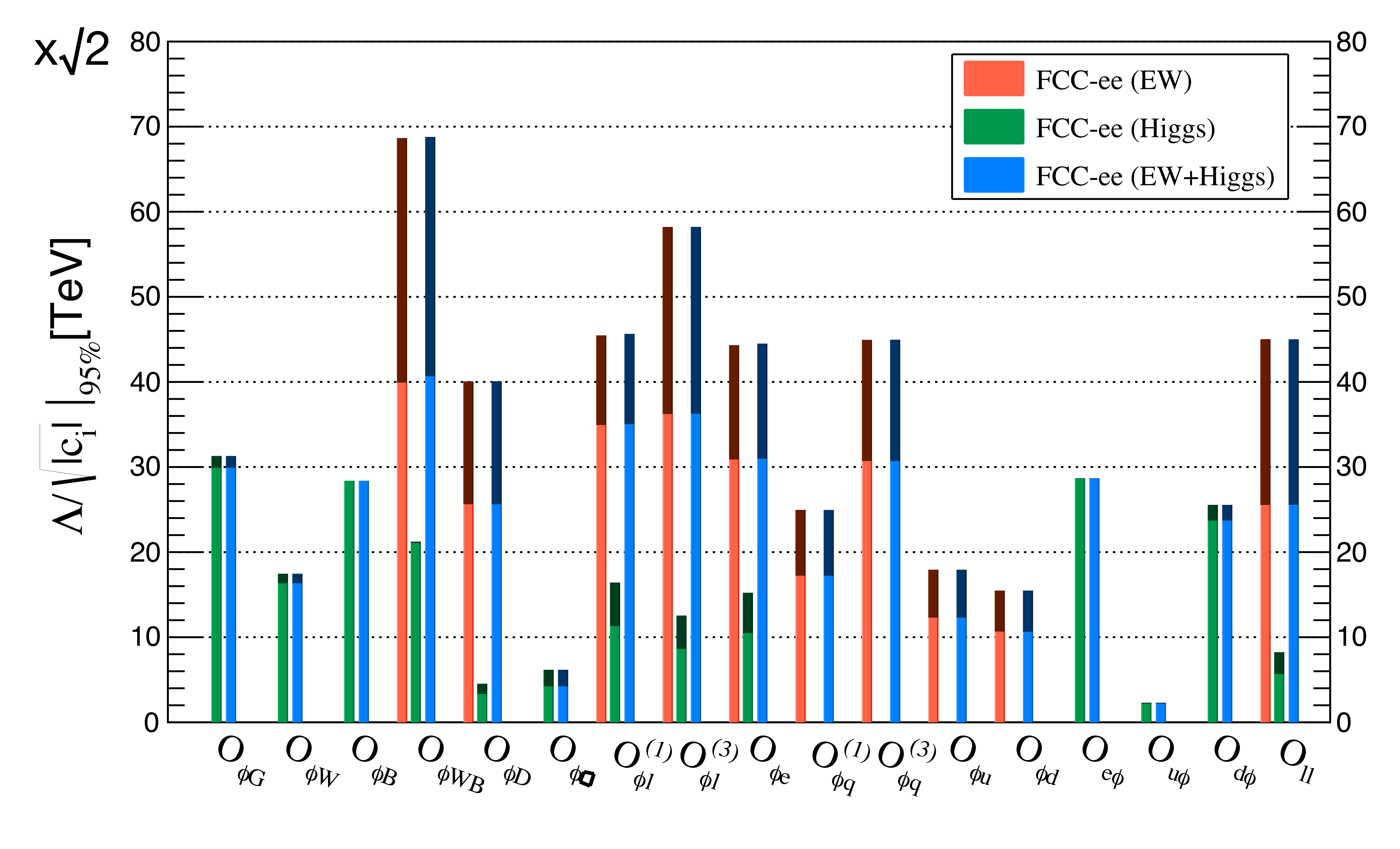
- Long Lived Particles: recent study with a SiD inspired detector and 110ab^{-1} at Z pole 1710.03744



FCC-ee large statistics and clean environment is the exceptional place to search for unusual signatures

NEW PHYSICS SENSITIVITIES

- Fit to new physics effects parameterized by dim 6 SMEFT operators
- single operator fit can be informative
- model independent result only for global fit



What do we mean by "Sensitivity to NP up the scale of N TeV?" e.g.

$$\frac{c}{\Lambda^2} \sim \frac{g^2_{\rm NP}}{M^2_{\rm NP}} < 0.01\ {\rm TeV}^{-2} \longrightarrow M_{\rm NP} > 10\, g_{\rm NP}\ {\rm TeV}$$

(**Weakly coupled NP** $M_{\rm NP} > 10$ TeV $(g_{\rm NP} \sim 1)$)

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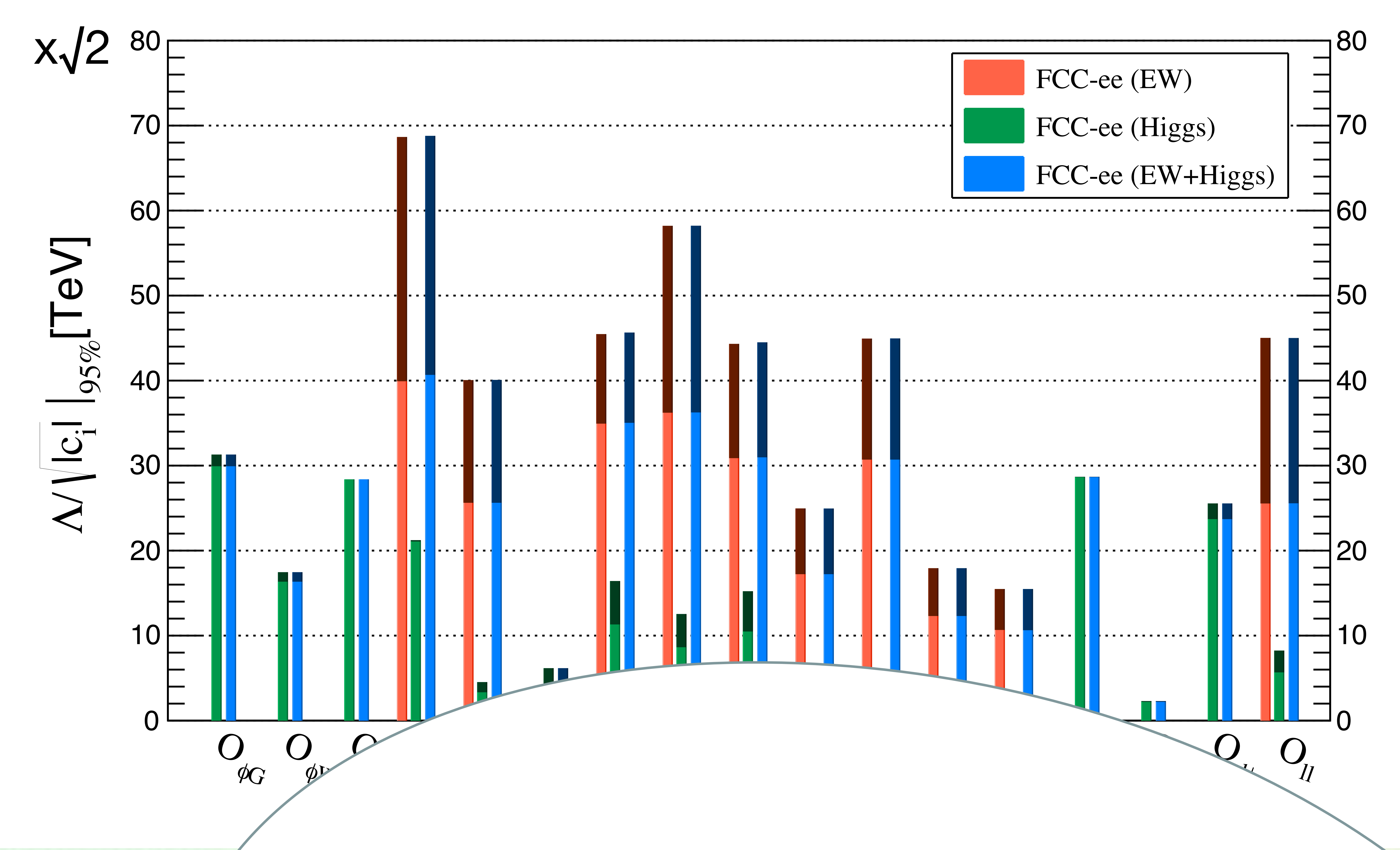

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FCC-ee program sensitive to (weakly coupled) new physics up to scales of tens of TeV

HIGHLIGHTS OF NEXT STEPS

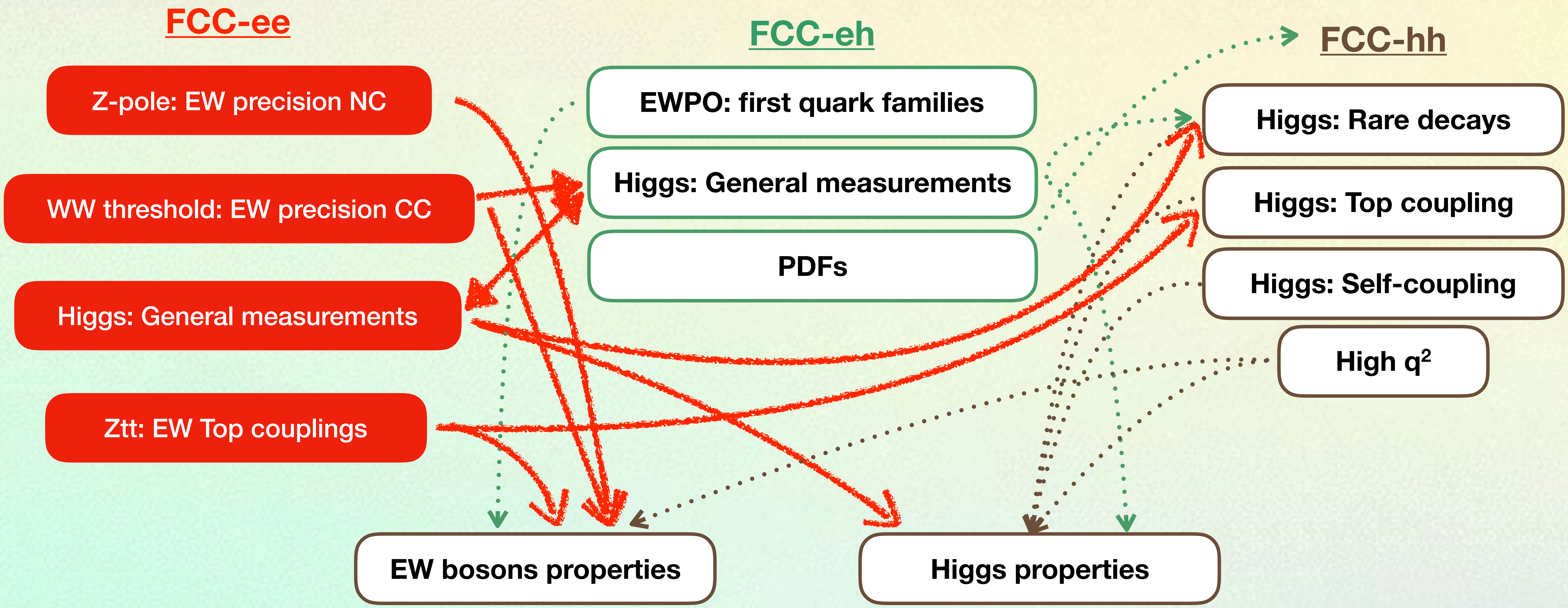
- **Preparing the CDR and beyond!**
- Detailed design and integration of: interaction region, polarization system, luminosity calorimeter
- Study of backgrounds and reachable precision
- R&D of detectors toward experimental collaborations
- Detector performance with full simulation & event reconstruction
- Develop new experimental paths to consolidate sensitivity to new physics
- Develop new methods for theory computation to match and exceed experimental capabilities

RECAP

- **There *must* be something beyond the Standard Theory (or totally different!)**
- Experimental proofs: Cosmological Dark Matter, Baryon Asymmetry of the Universe, non-zero neutrino masses
- Which way to go?
  - **Direct observation of new particles**
  - **New phenomena**
  - **Deviations from precise predictions**
- Physics absolutely needs an e+e- factory that covers the whole range: Z, W, H and top at the highest luminosities
- **FCC-ee is the best first step to pave the way for FCC-hh:**
  - **preview of new physics to be searched for**
  - **brings a significant reduction of systematics measurements**
  - **handles to understand underlying theory in case of discovery**

COMPLEMENTARITIES IN FCC PROGRAM

- **All three FCC options complement each other very well and are useful to complete the whole picture:**



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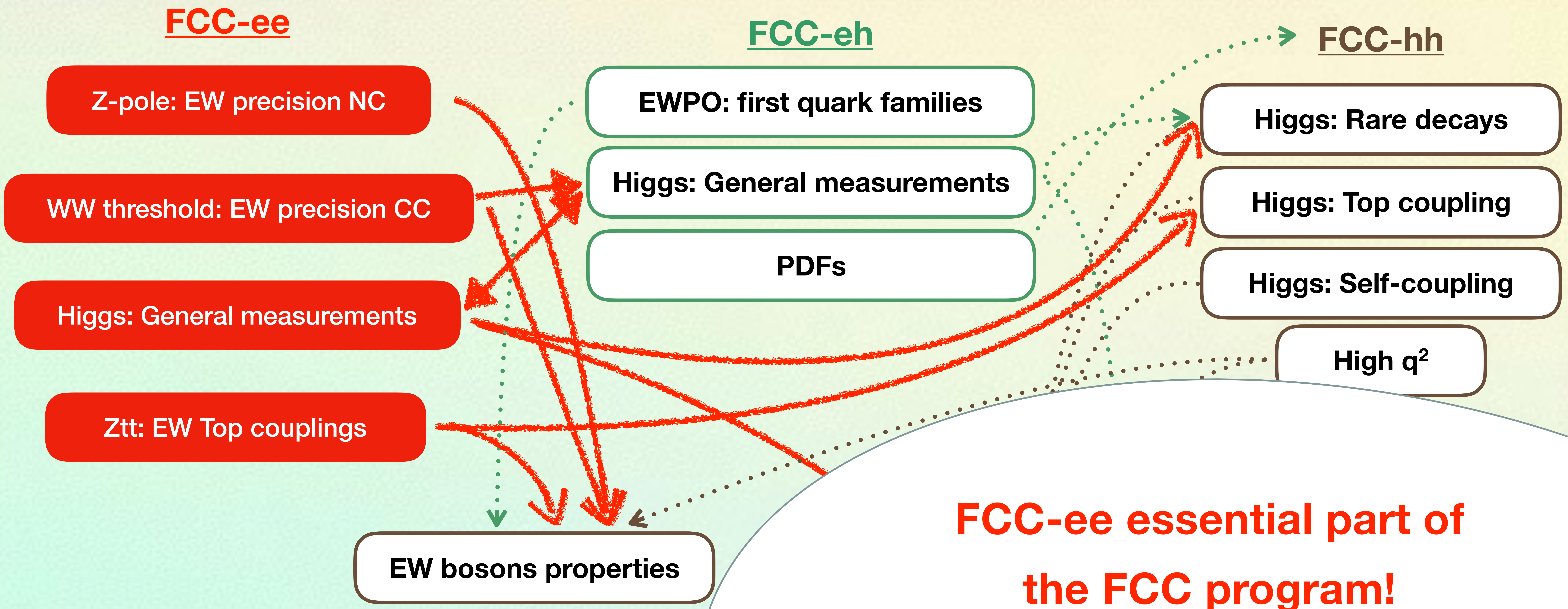

FCC-ee essential part of the FCC program!

FCC-EE TAKE AWAY MESSAGE

known knowns	known unknowns
Standard Model	"known" new physics
unknown knowns	**unknown unknowns**
new physics modifies known physics .... and maybe we already measured it!	surprises

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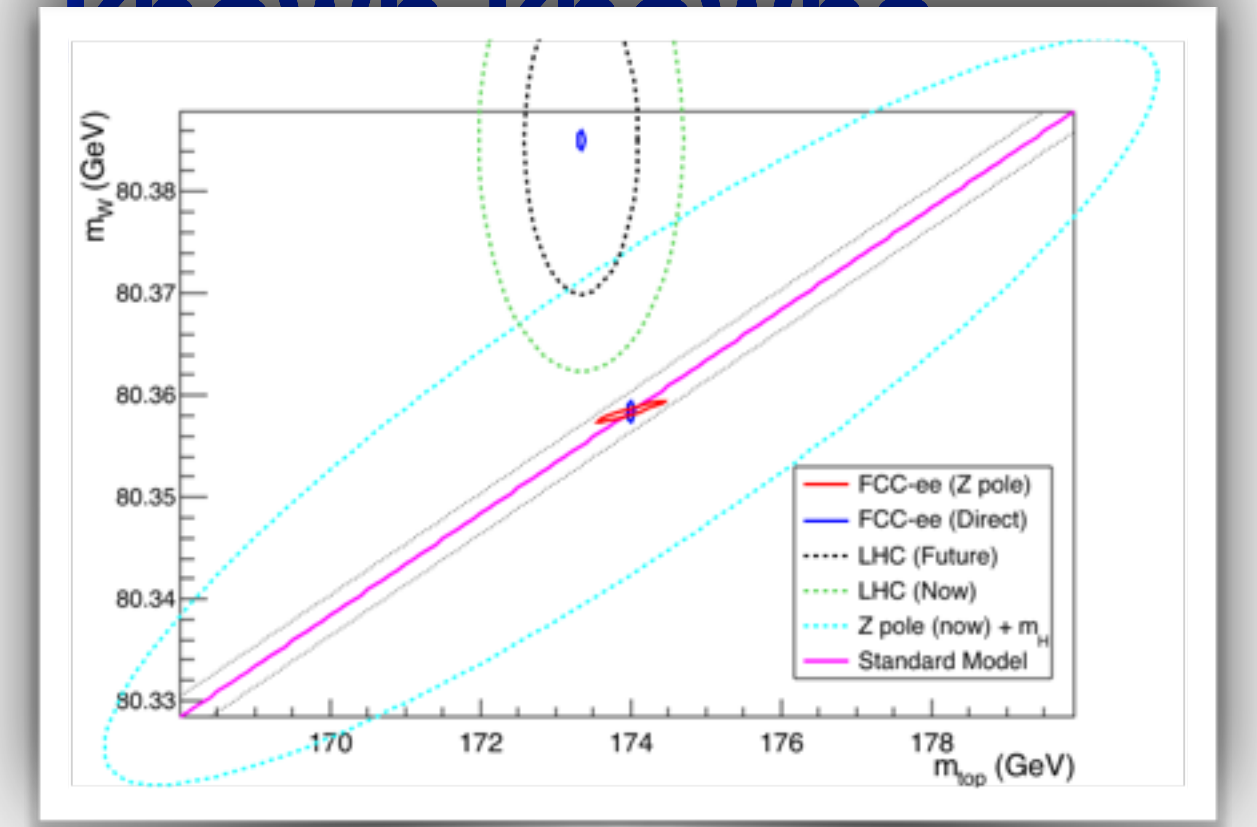

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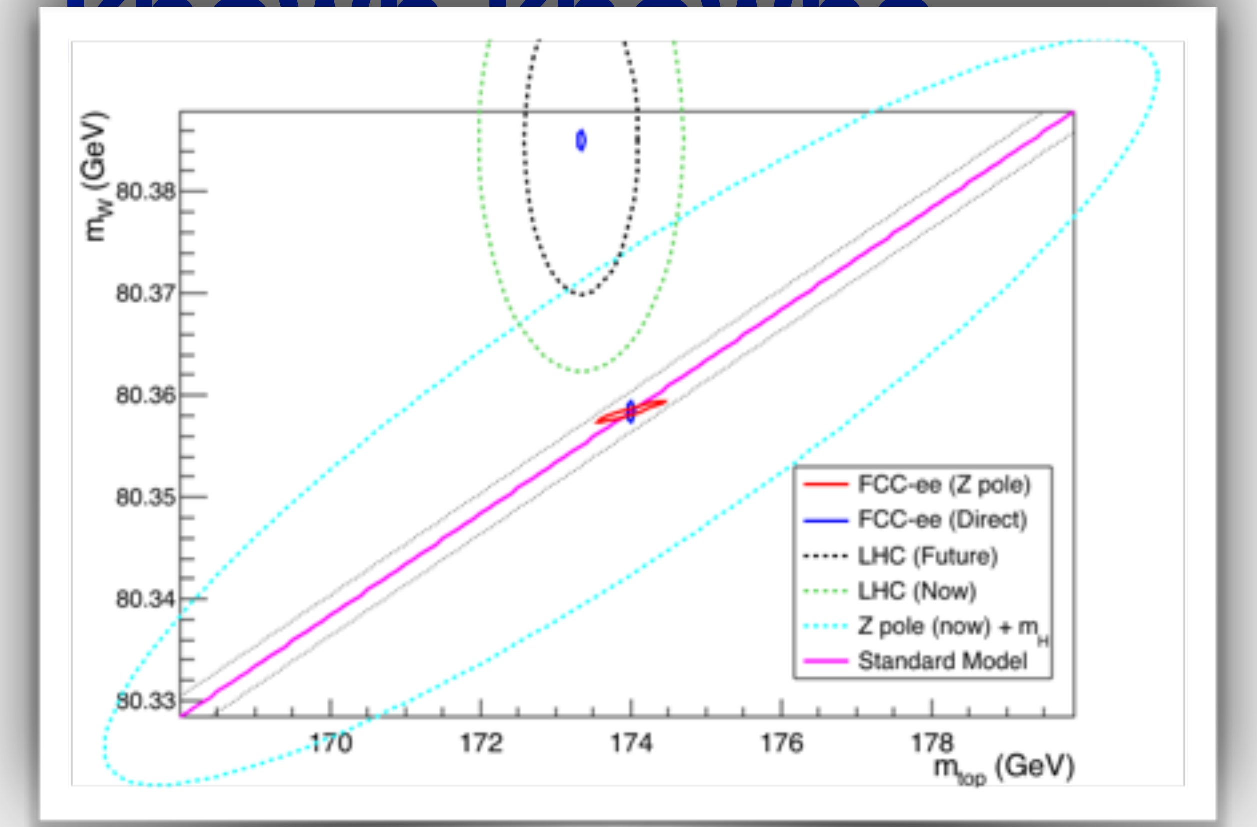

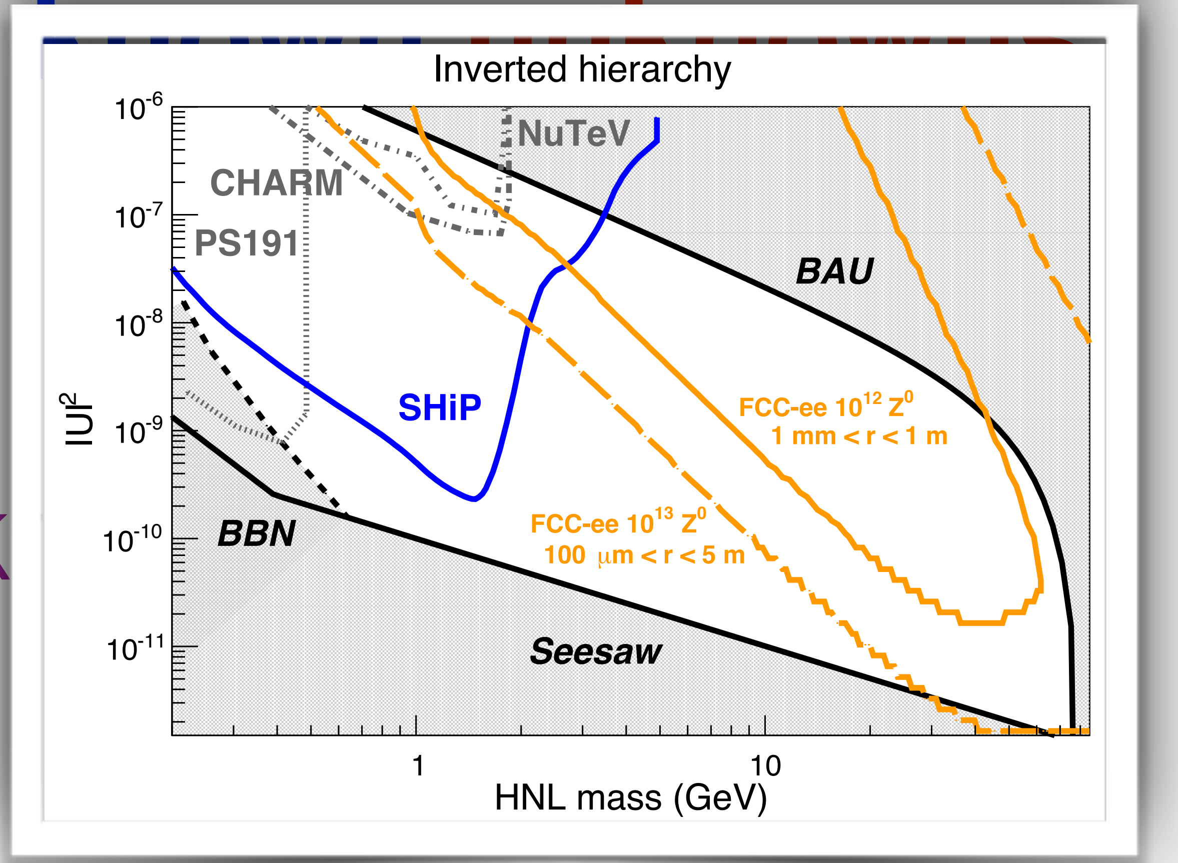

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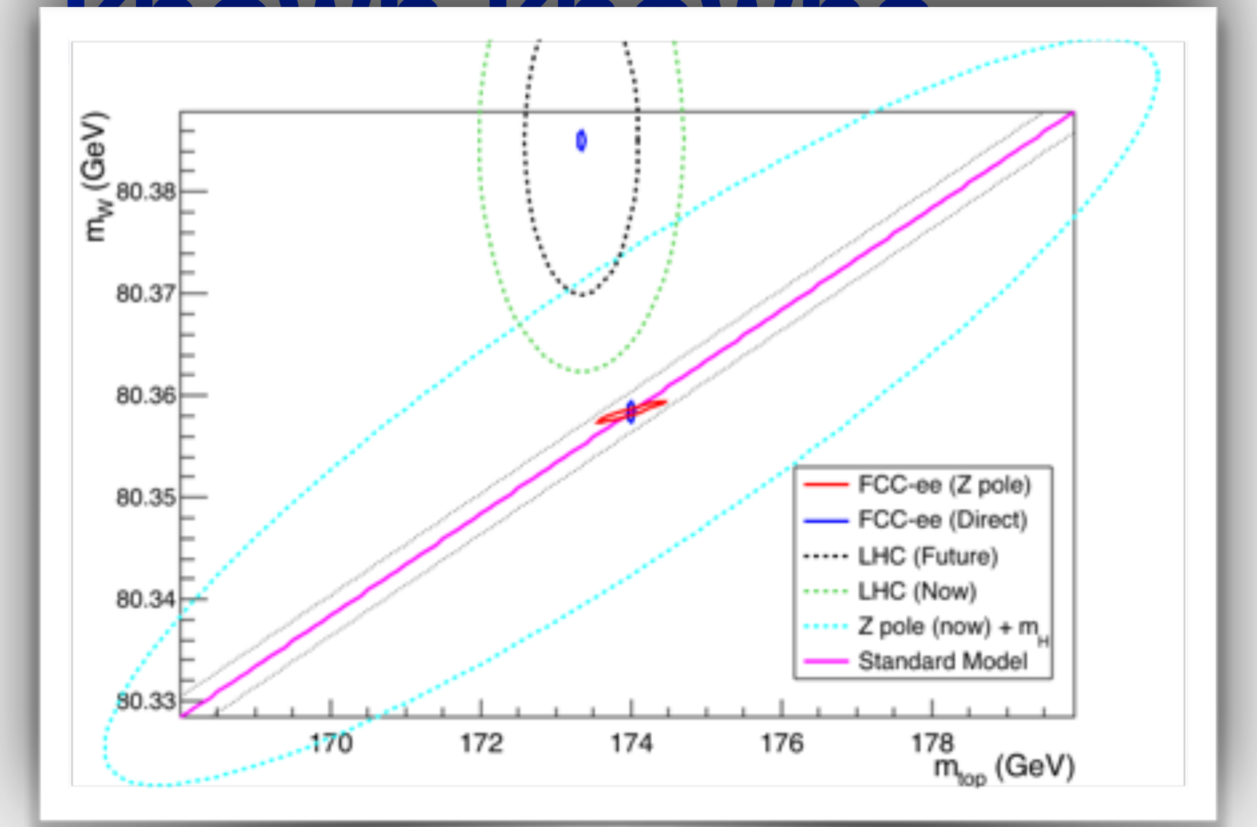

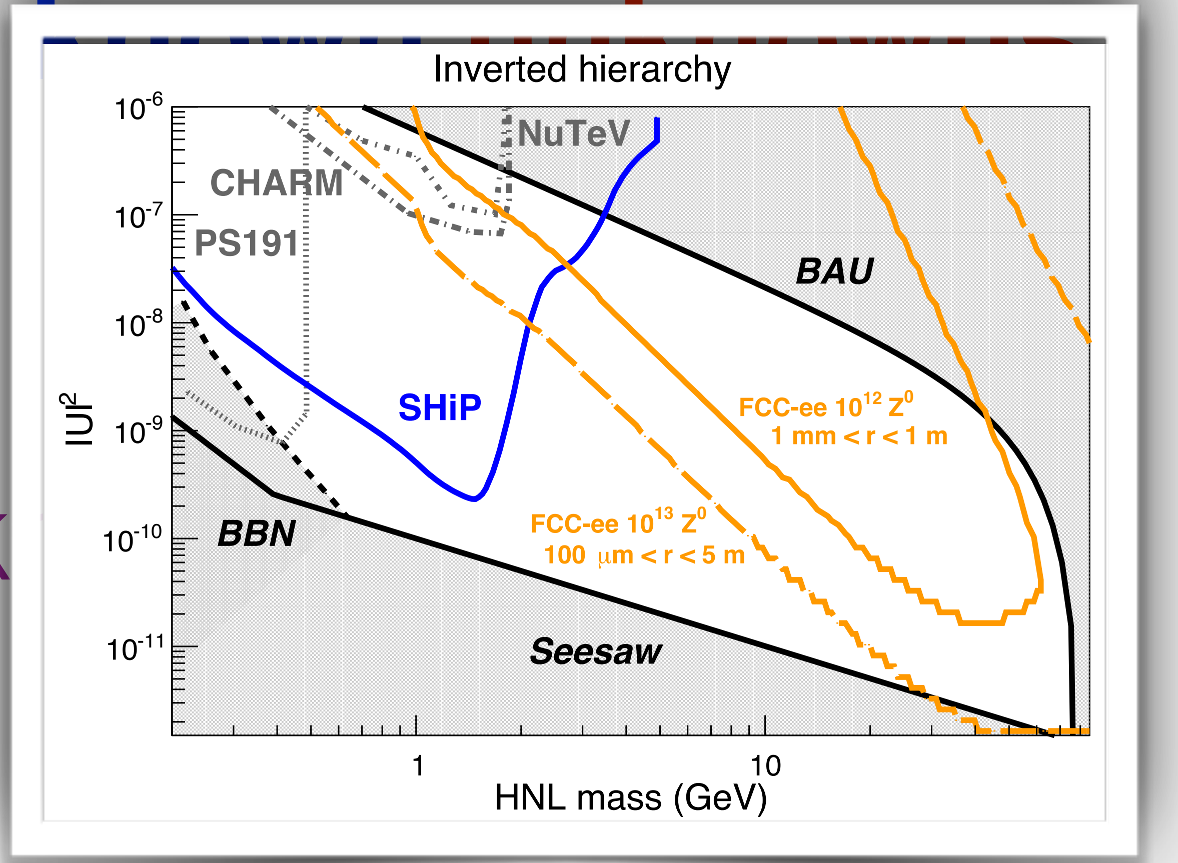

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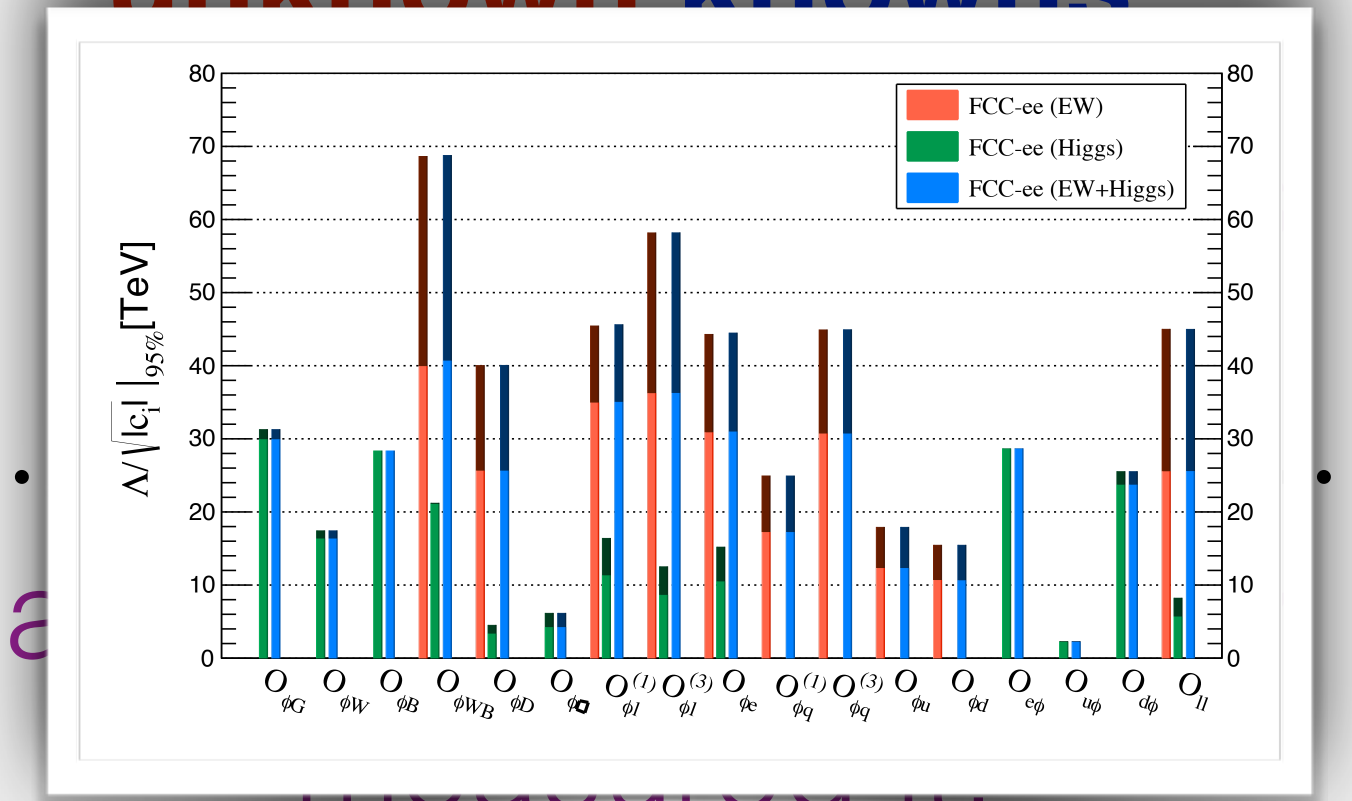

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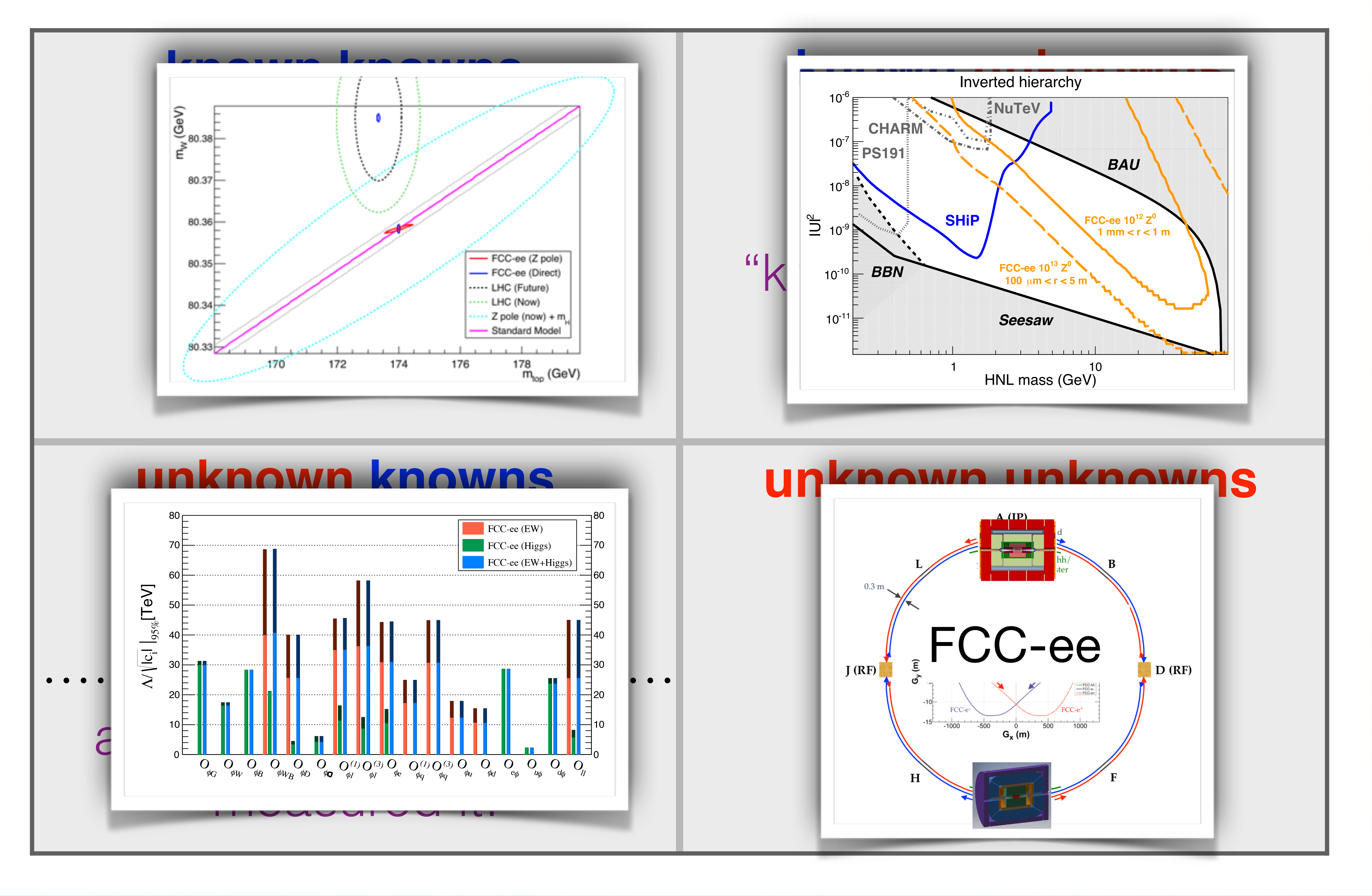

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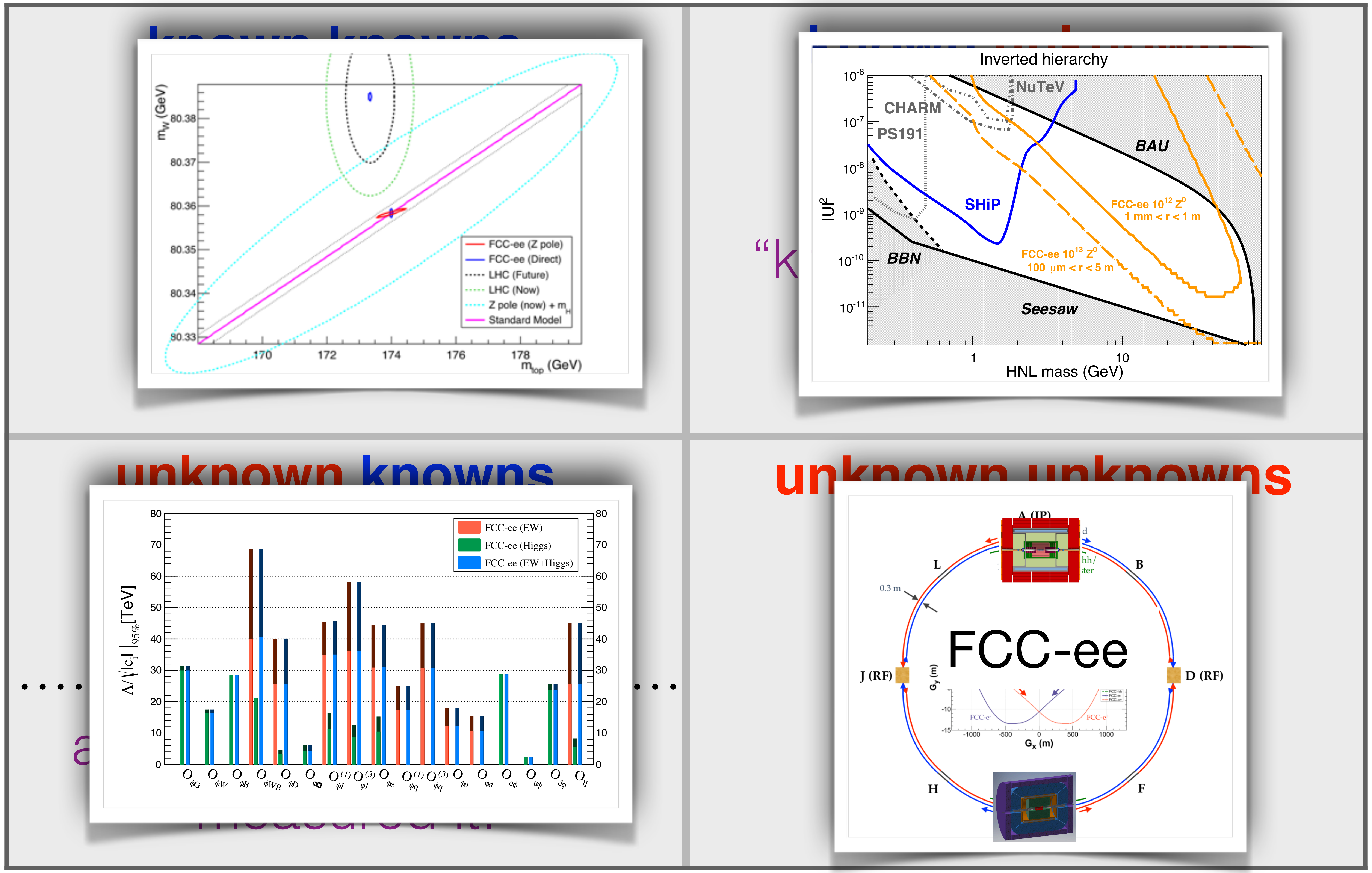

…ready for the unexpected!