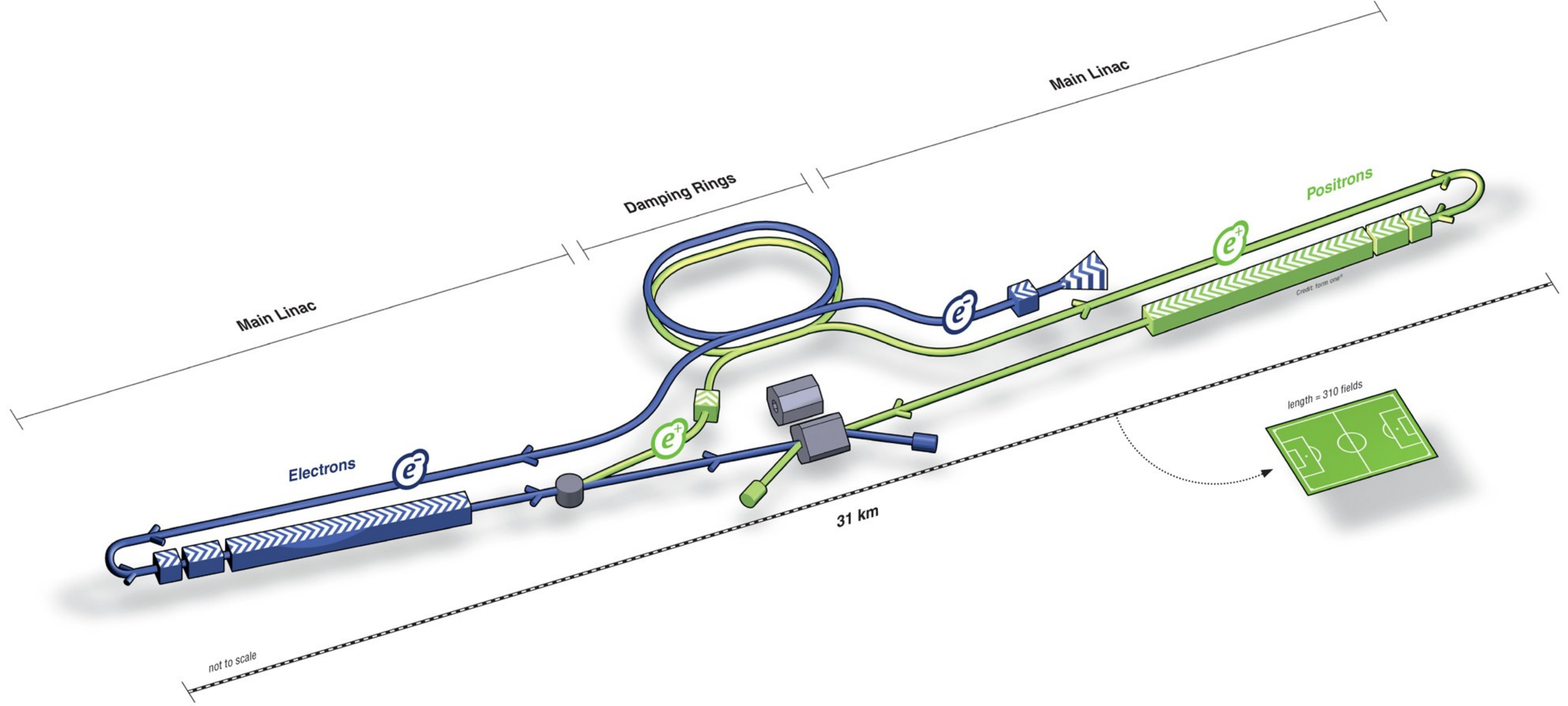


Heavy flavor studies at ILC

Andrej Saibel, ICHEP 2024 18th of July

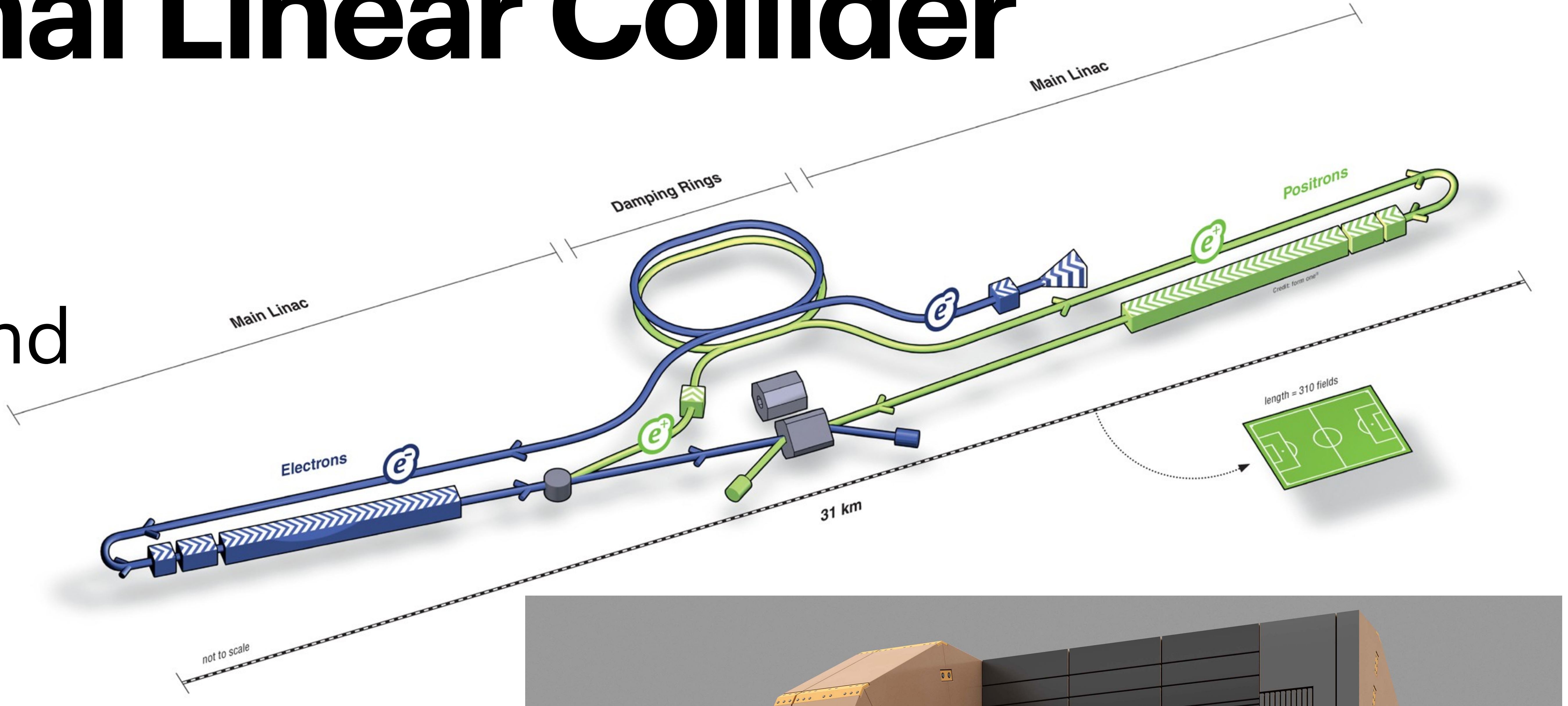
On behalf of the ILC International Development Team Physics and Detector Working Group

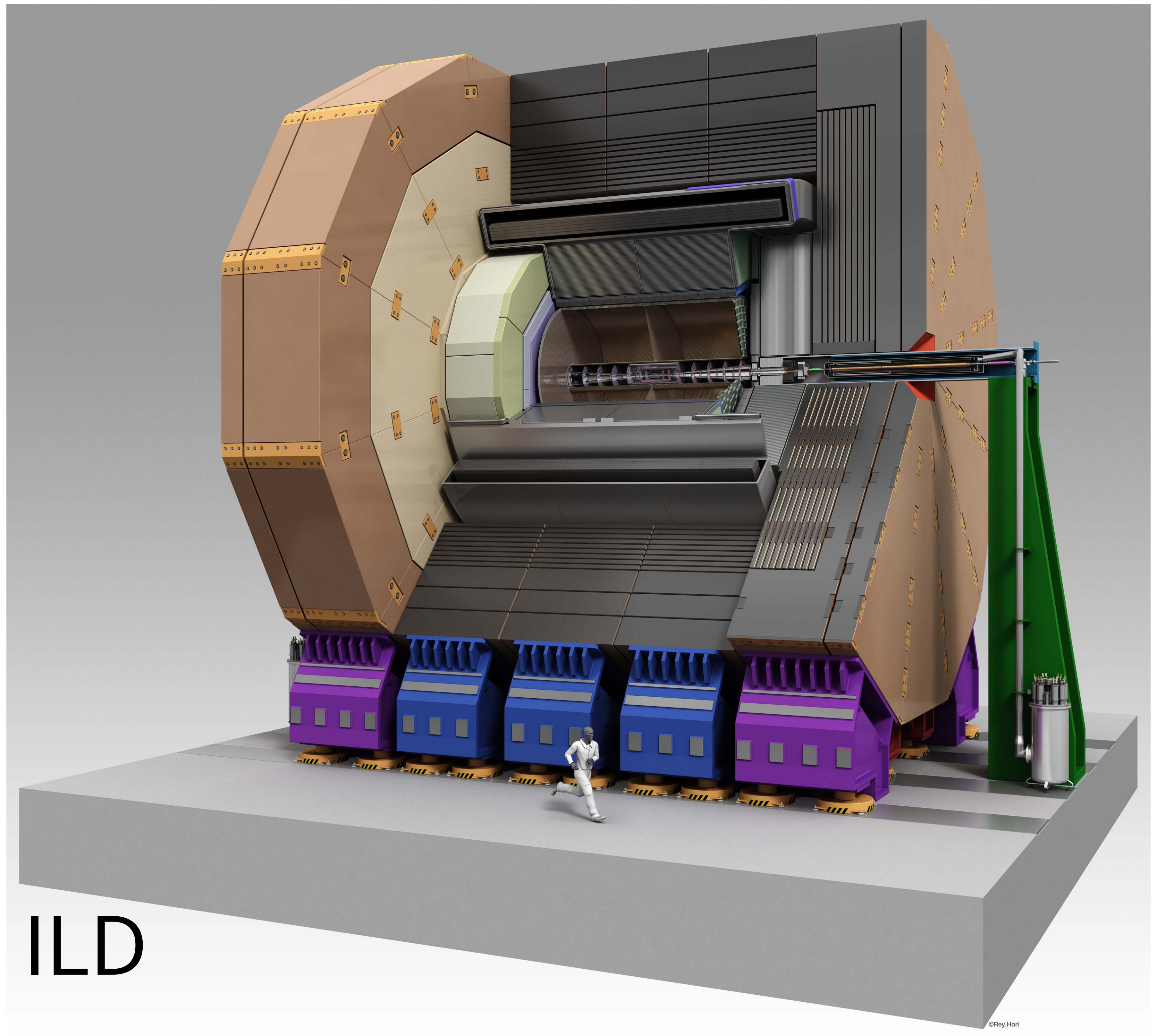
Universitat de València
IFIC Institut de Física Corpuscular
CSIC Consejo Superior de Investigaciones Científicas
Unterstützt von / Supported by Alexander von Humboldt Stiftung / Foundation

Agencia Estatal de Investigación
Gobierno de España Ministerio de Ciencia, Innovación y Universidades
Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
Generalitat Valenciana
GVANEXT Fondos Next Generation en la Comunitat Valenciana
Gen—T
AITANA

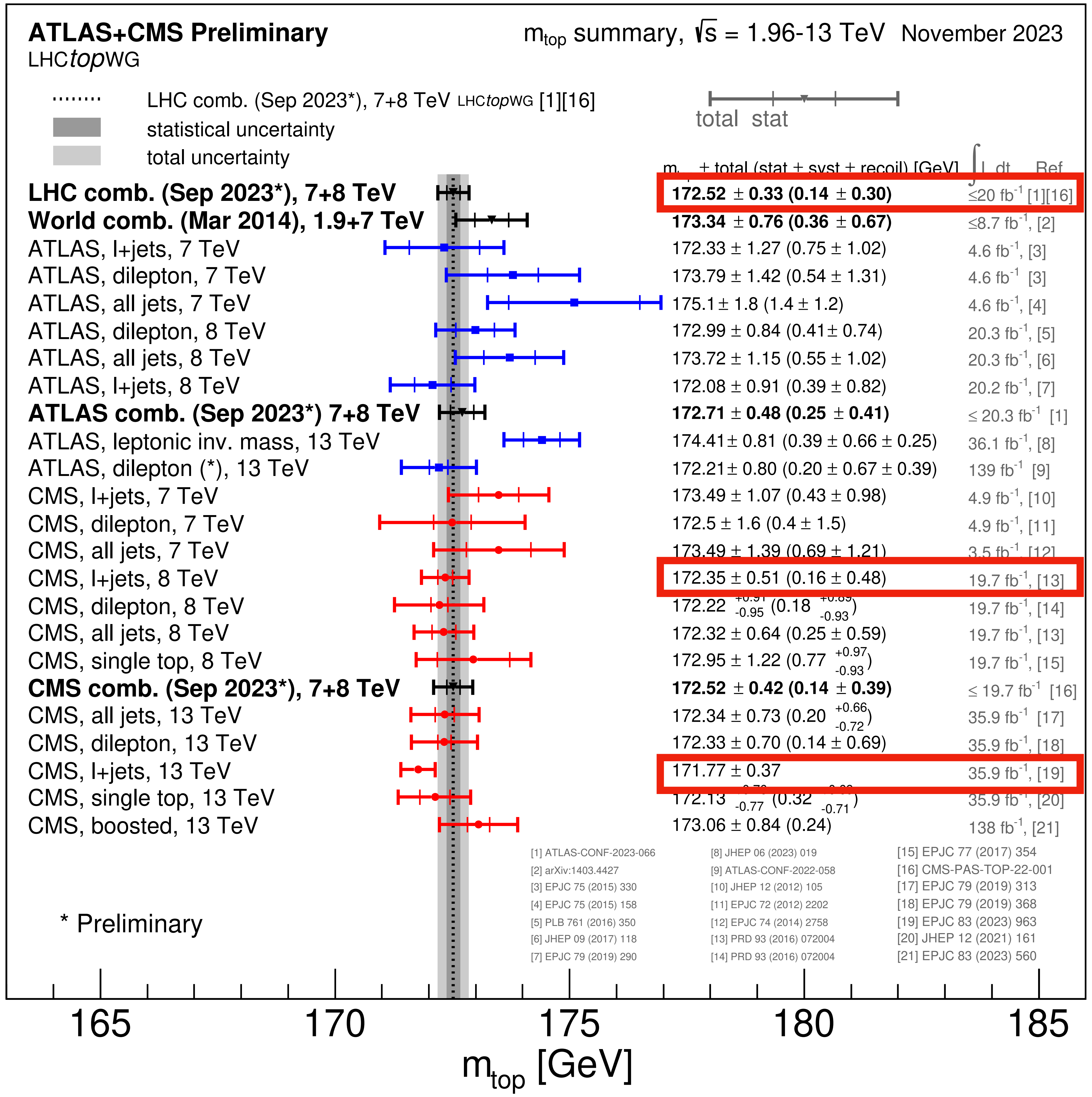
International Linear Collider

- ILC Runs: 250 - 500 - 1000 GeV and "GigaZ"
- Luminosity: 2 - 4 - 8 ab^{-1}
- **Polarisation**: $e^{+}(20/30\%), e^{-}(80\%)$
- Clean environment
- Detectors optimised for **Particle Flow**
- Precise tracking, vertexing, and PID





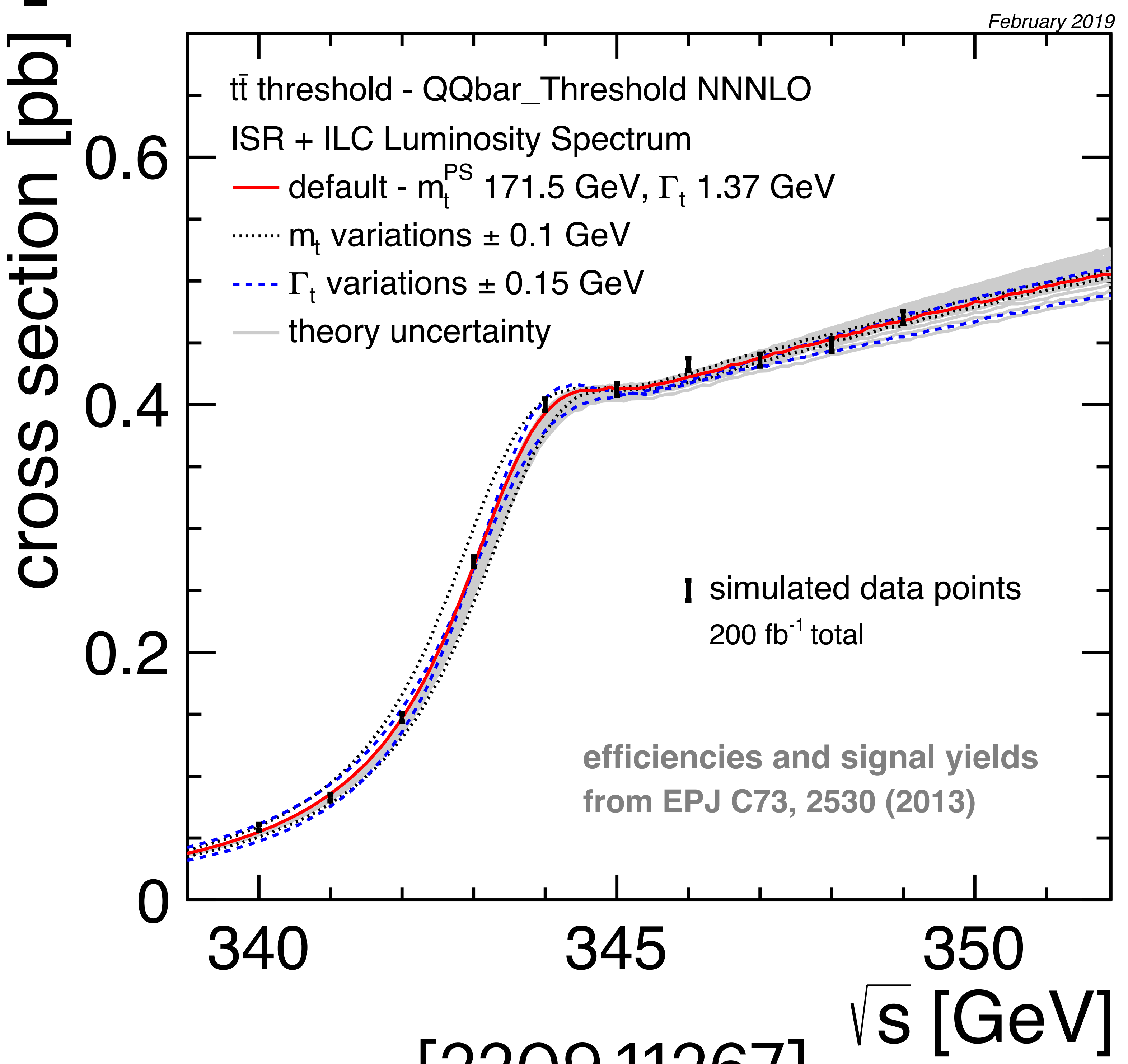
Top-quark and its properties



- Fundamental parameter of SM
- Only particle with **Yukawa coupling** ≈ 1
- Contribution to many Higgs processes
- Stability of **electroweak vacuum**
  - Limited by m_t precision
  - Necessity of new physics/SUSY

Threshold scan of $t\bar{t}$ production

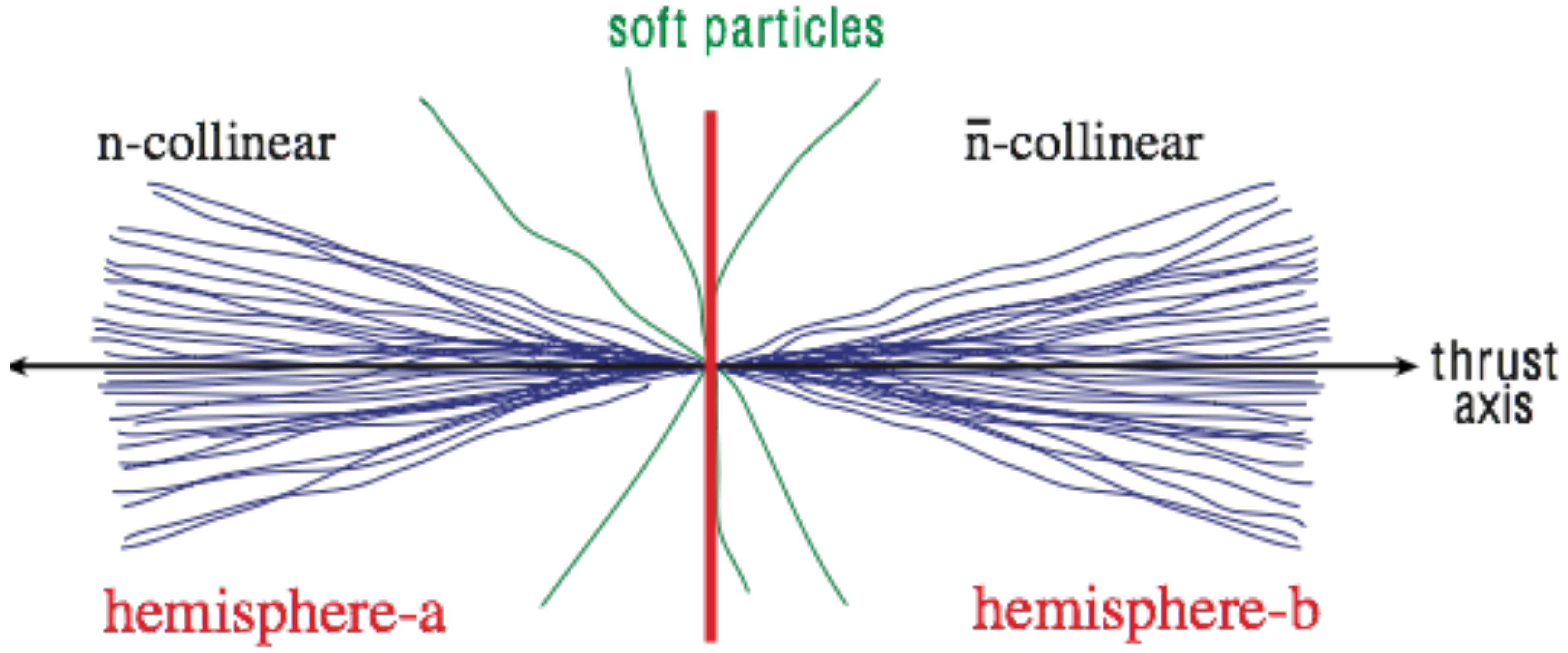
- "Golden channel" for top quark mass
  - Scan: 340 - 350 GeV
- Simultaneous measurement of **width** and **mass** in optimised scan
- Access to non-relativistic QCD and toponium
- Achievable **precision < 50 MeV**
  - Limited by theory

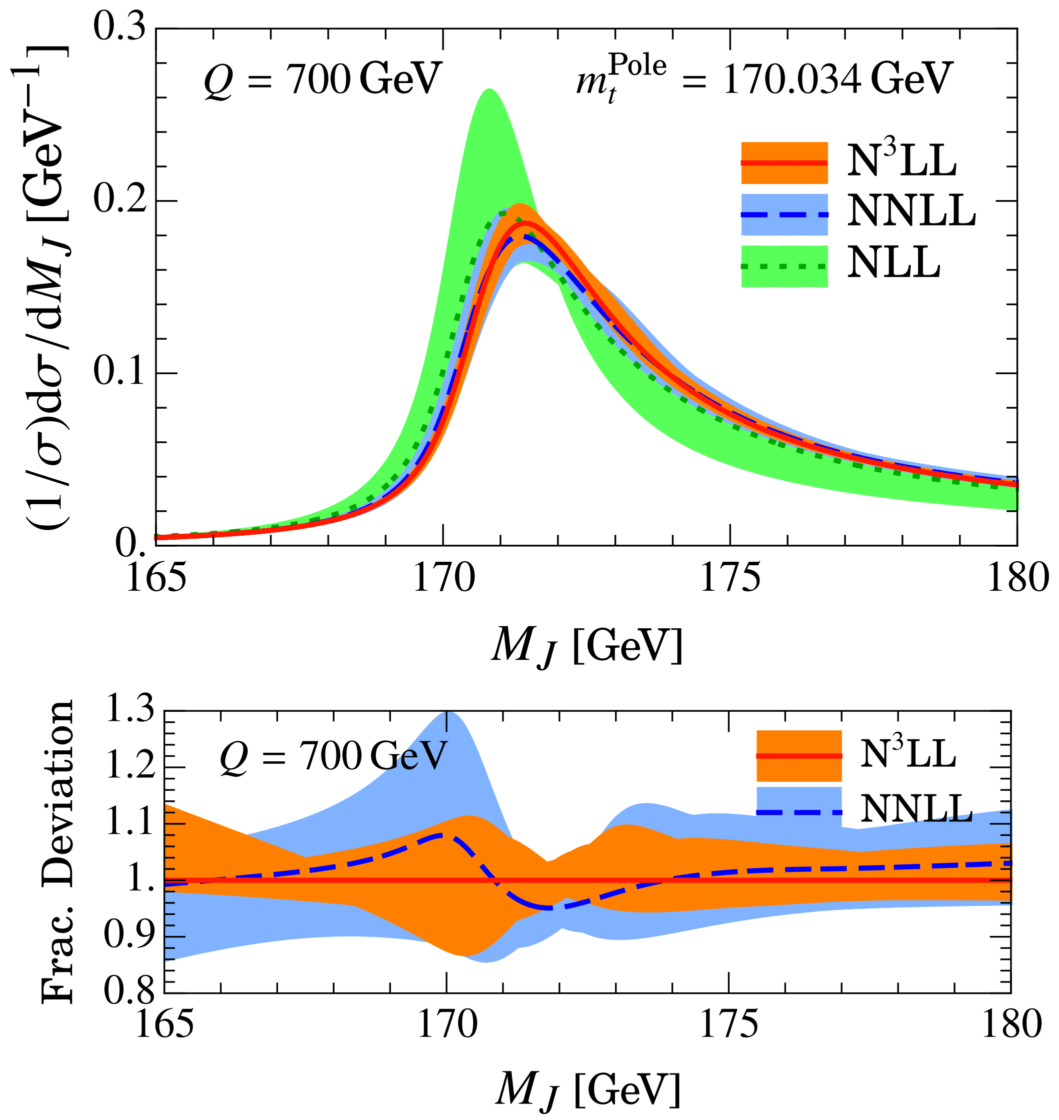


[2209.11267]

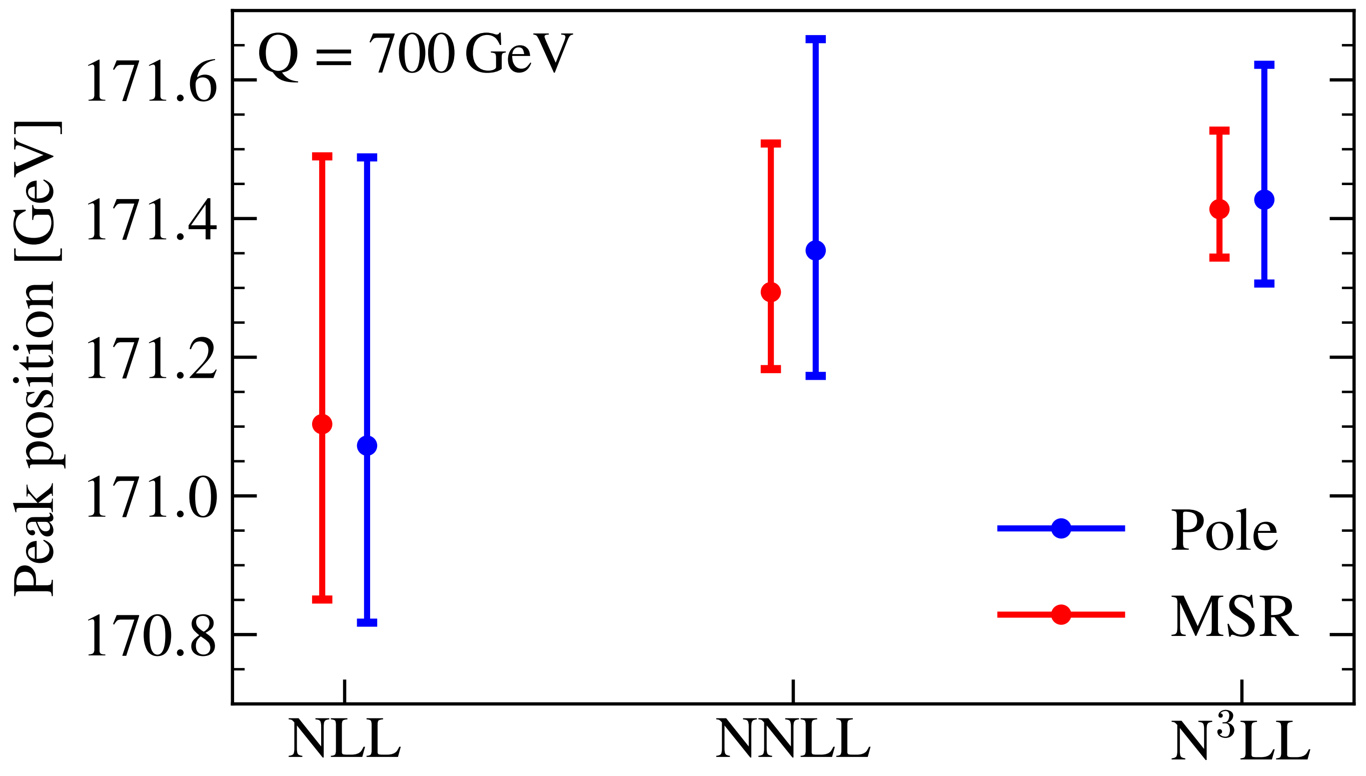
δm_t^{PS} [MeV]	ILC	CLIC	FCC-ee
$\mathcal{L}$[fb^{-1}]	200	100 [200]	200
Statistical uncertainty	10	20 [13]	9
Theoretical uncertainty (QCD)	40 – 45		
Parametric uncertainty α_s	26	26	3.2
Parametric uncertainty y_t (HL-LHC)	5		
Non-resonant contributions	< 40		
Experimental systematic uncertainty	15 – 30		11 – 20
Total uncertainty	40 – 75		

Boosted top quarks





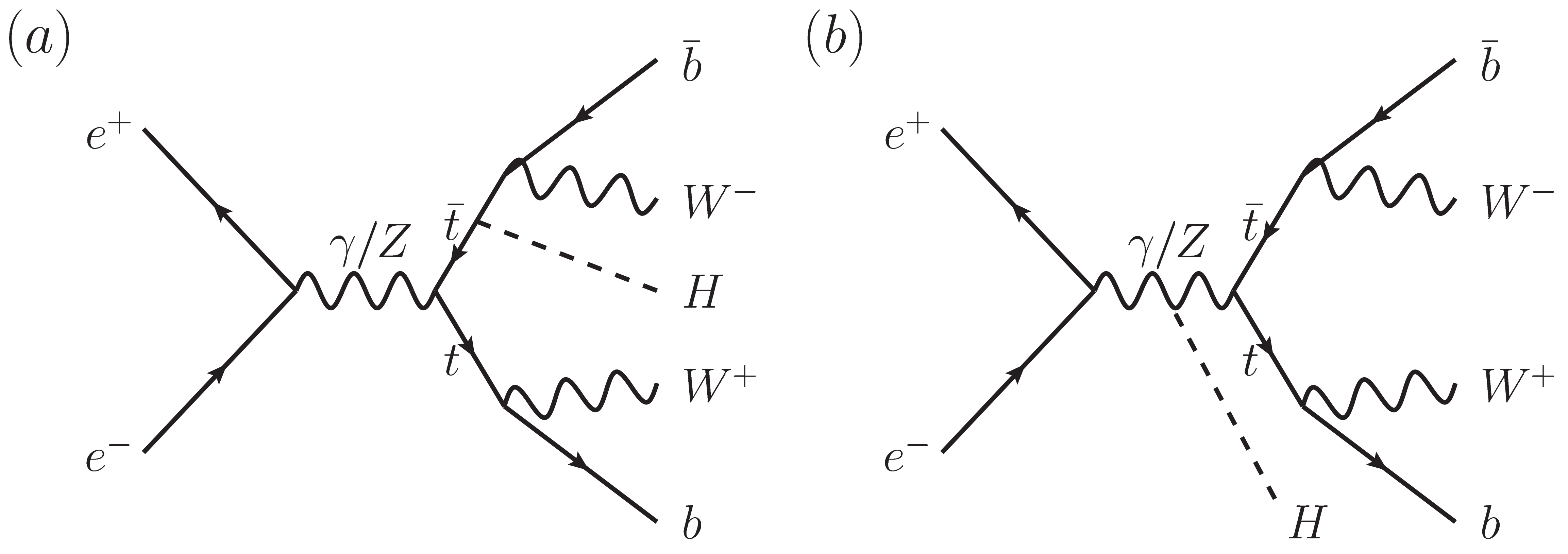
[PhysRevD.104.014026]



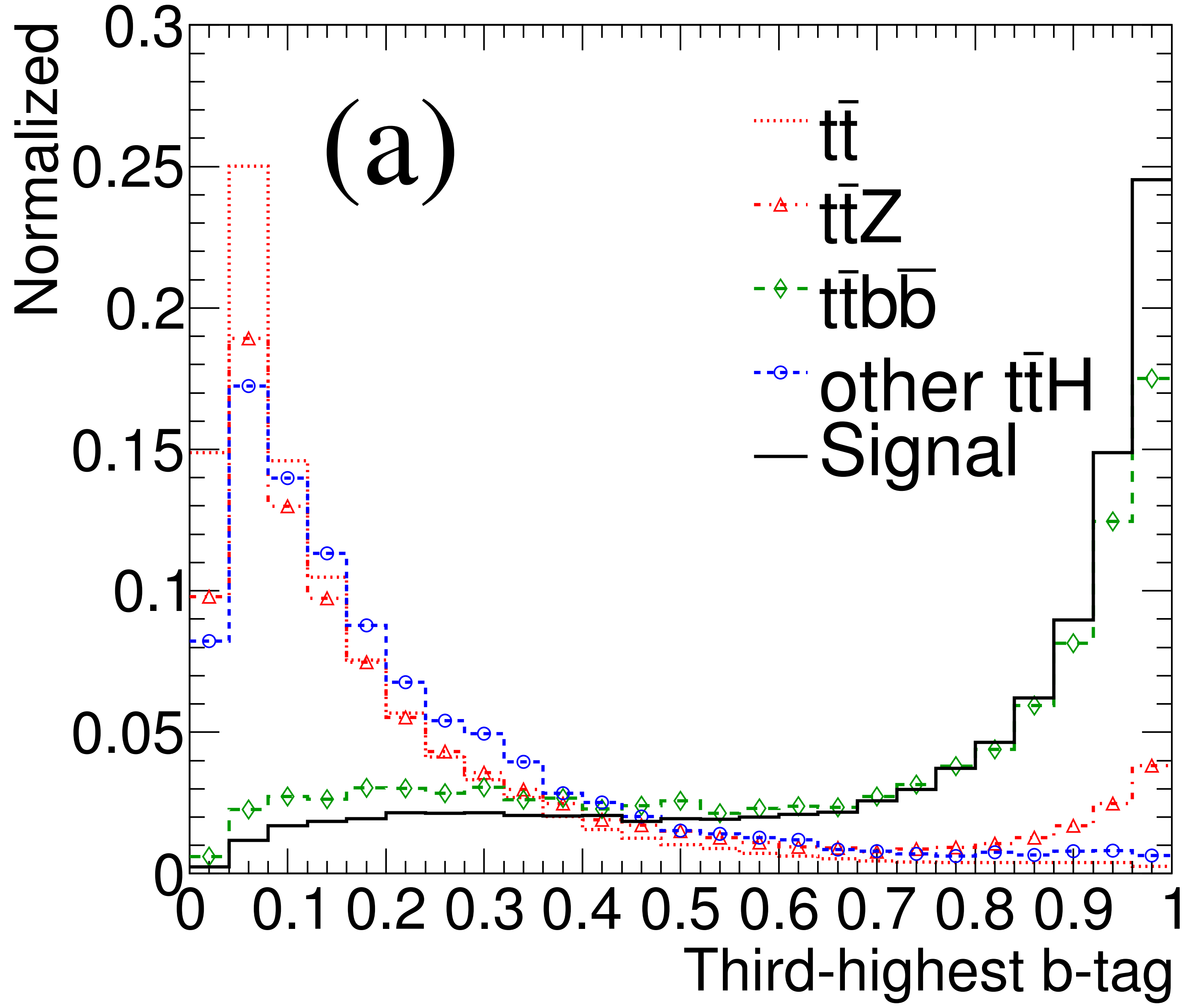
- Measurement of collimated “top jets”, thrust
  - Accesible at ILC - 1 TeV
- Interpretation of measured value in theory
  - $m_t^{\text{MC}} \rightarrow m_t^{\text{Pole}}$
- Achievable precision ≈ 100 MeV

mass scheme	Q [GeV]	Peak Positions [GeV] NLL	NNLL	N^3LL
MSR	700	$171.104^{+0.386}_{-0.253}$	$171.294^{+0.214}_{-0.111}$	$171.414^{+0.113}_{-0.070}$
	2000	$175.008^{+1.858}_{-0.910}$	$176.403^{+1.287}_{-0.690}$	$176.541^{+0.574}_{-0.367}$
Pole	700	$171.073^{+0.416}_{-0.255}$	$171.354^{+0.305}_{-0.181}$	$171.427^{+0.195}_{-0.121}$
	2000	$174.377^{+2.087}_{-0.938}$	$176.126^{+1.461}_{-0.915}$	$176.448^{+0.750}_{-0.587}$

$t\bar{t}H$ production



[Eur. Phys. J. C 75, 309 (2015)]

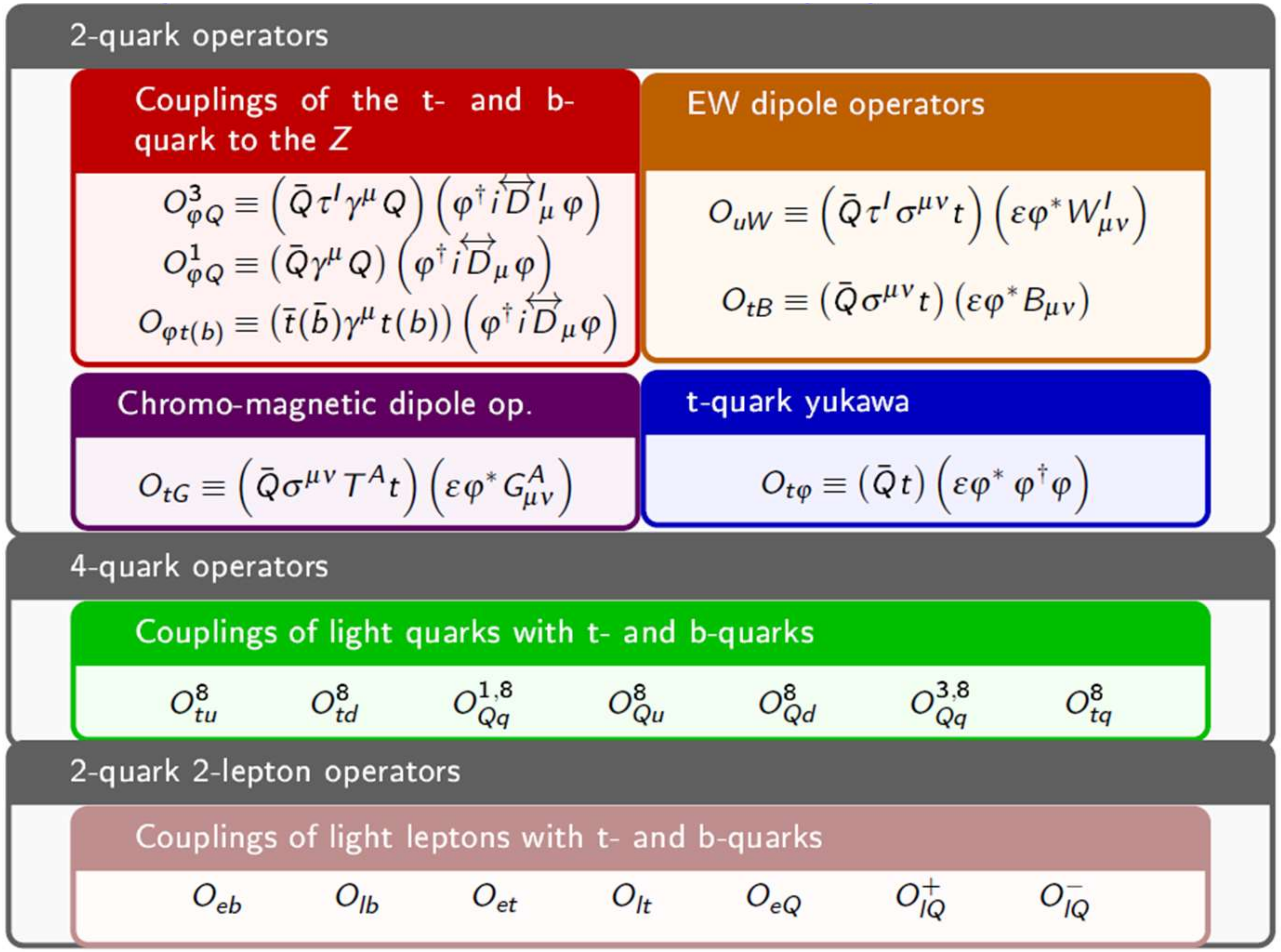


- Direct measurement of top-Higgs Yukawa coupling
- Accesible at 500 and 1000 GeV
- CP nature of the Higgs field
- Using BDTs to distinguish signal and backgrounds
- Combination of 6 and 8 jet final-state:
  - **Top Yukawa**: 4.5% uncertainty at ILC 1 TeV and 0.5 ab^{-1}

SMEFT at ILC

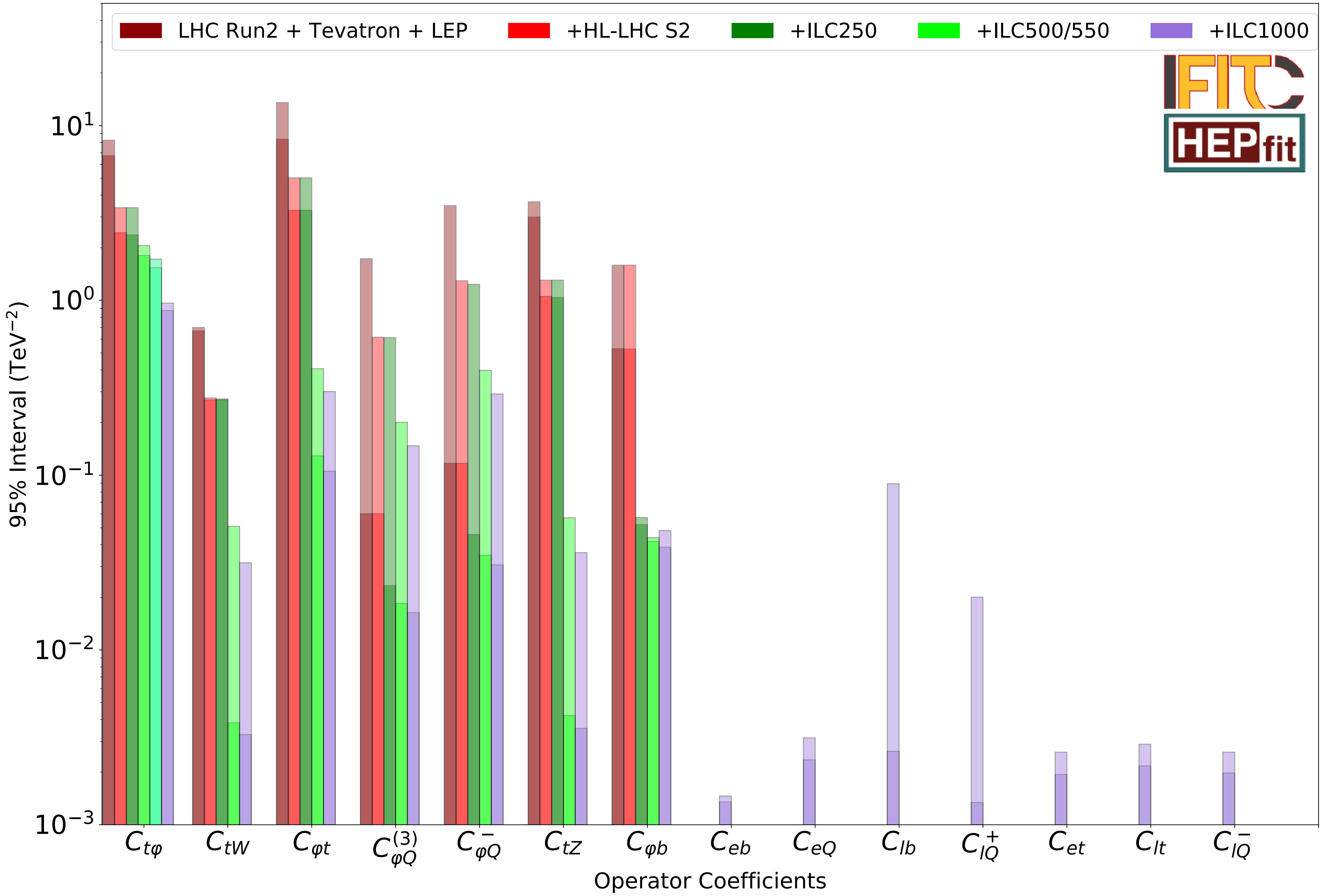
- Model independent search/exclusion of new physics at high energies
- Measurements above $t\bar{t}$ threshold give access to **electroweak couplings**
- Two and four fermion operators
- Contributions from Z and photon can be disentangled through **beam polarisation**

[F. Cornet, V. Miralles]



SMEFT at ILC

[2206.08326]



Improvements of up to two orders of magnitude compared to HL-LHC

Two Fermion Final State and BSM Physics

NEW

- Precise measurements of Z-boson fermion couplings enable study of BSM physics
- **Gauge Higgs Unification** models predict new Bosons at high energies
  - New contributions + Modification of couplings
- **Measurements of differential cross-sections** at $\sqrt{s} > m_Z$ at ILC can lead to observation/exclusion of BSM
- Dedicated talk 19th July, 09:00 South Hall 2A

[Eur. Phys. J. C 84, 537 (2024)]

ILD

GHU vs SM discrimination power (σ-level)

	ILC250◆ (no pol.) C	ILC250◆ (no pol.) R	ILC250◆ (no pol.) Z	ILC250 C	ILC250 R	ILC250 Z	ILC250 +500 C	ILC250 +500 R	ILC250 +500 Z	ILC250 +500 +1000* C	ILC250 +500 +1000* R	ILC250 +500 +1000* Z
B_3^+	0.1	0.4	0.5	0.1	0.7	0.8	0.5	1.3	1.3	1.6	2.5	2.5
B_3^-	0.1	0.4	0.5	0.3	0.9	0.9	0.9	2.7	2.7	3.3	6.7	6.8
B_2^+	0.2	0.7	0.8	0.3	1.5	1.6	0.9	2.2	2.3	3.0	4.4	4.5
B_2^-	0.2	0.7	0.7	0.5	1.4	1.5	1.7	4.6	4.8	6.3	>10	>10
B_1^+	0.3	1.6	1.7	0.7	3.2	3.5	1.5	4.4	4.7	4.3	6.8	7.0
B_1^-	0.5	1.4	1.4	0.9	2.7	2.8	3.3	9.6	9.9	>10	>10	>10
A_2	0.6	3.3	3.6	0.9	4.8	5.3	4.3	>10	>10	>10	>10	>10
A_1	0.8	3.9	4.2	1.0	5.0	5.5	5.3	>10	>10	>10	>10	>10

Z-fermion couplings
- *C: Current precision*
- *R: ILC250 (Rad. Ret.)*
- *Z: Giga-Z*

< 3 σ
3-4 σ
4-5 σ
> 5 σ

Conclusion

- Rich heavy flavor physics program at ILC
- **Clean environment** enables precise measurements
- The top-quark is properties are important ingredients for SM and BSM physics
- **Beam polarisation** improves sensitivity of measurements
- Improvements compared to HL-LHC often orders of magnitude
- Two interesting ILC summary talks
  - BSM at ILC: 19th July 15:04 South Hall 1A, M. T. Núñez Pardo De Vera
  - Higgs physics at ILC: 18th July 17:53 South Hall 2A, A. F. Zarnecki

BACKUP

SMEFT all future colliders