中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Future Colliders

Lecture-2

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Chinese Academy of Sciences

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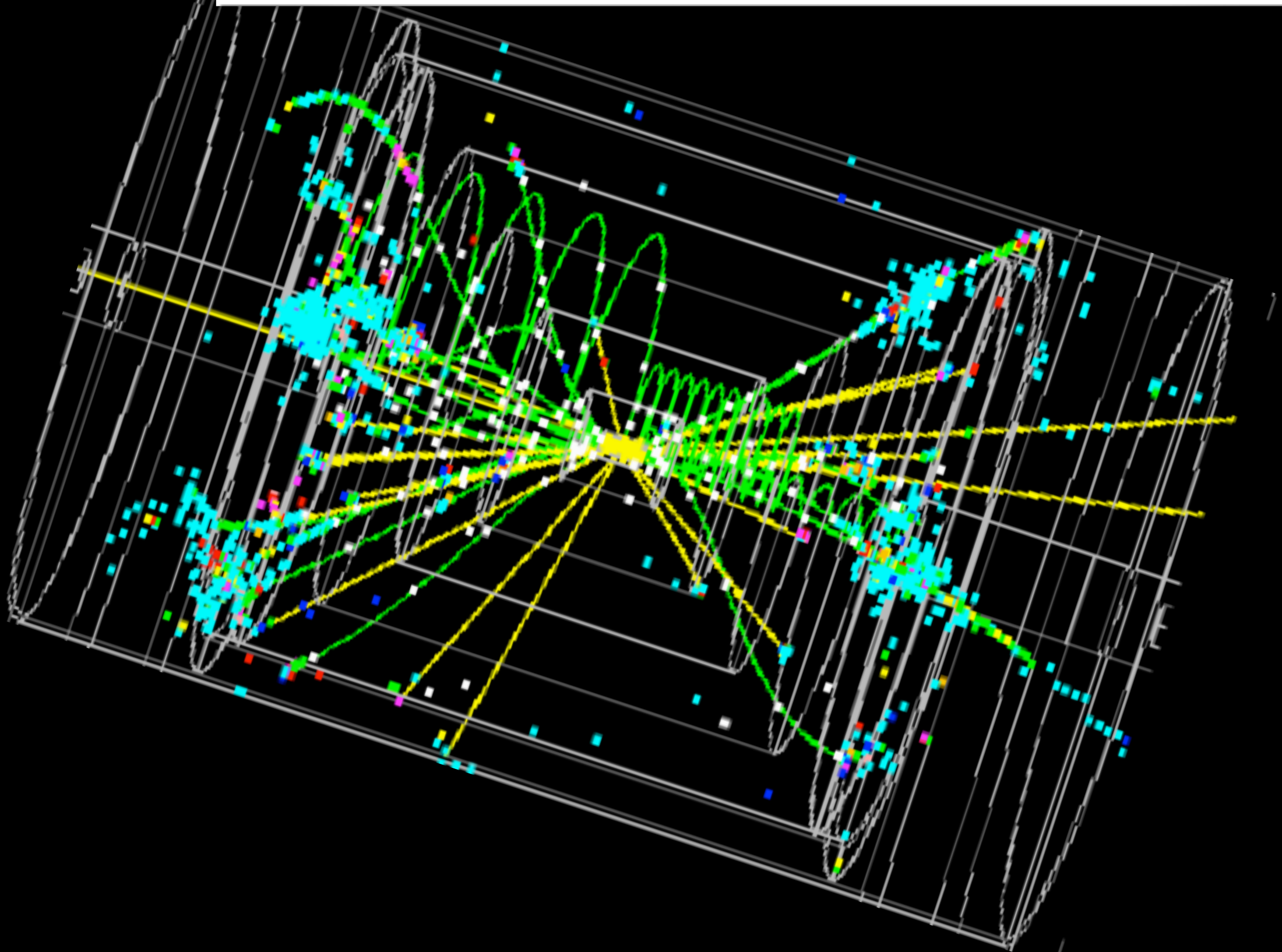
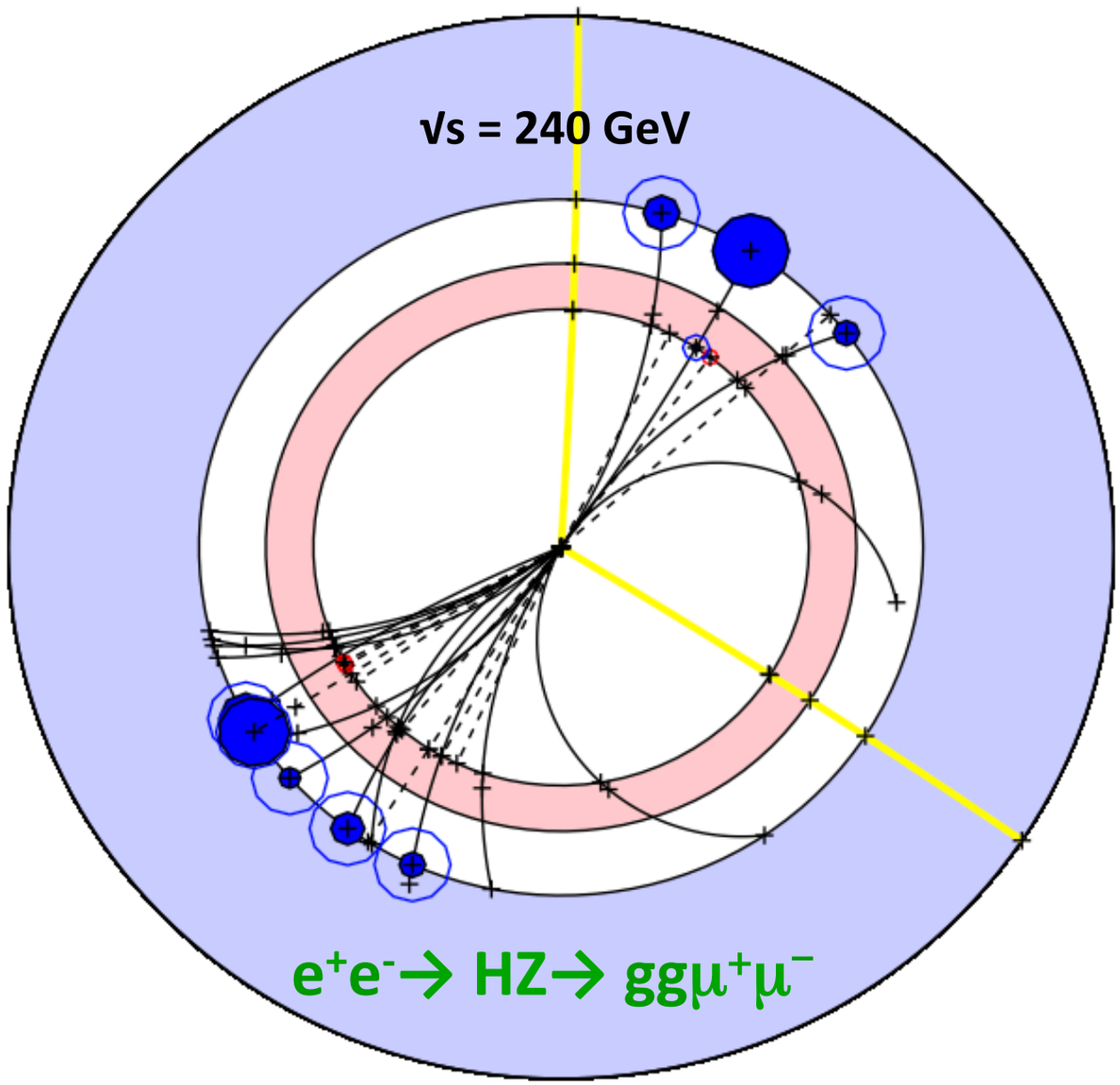
Lecture 3: Higgs Phenomenology at Higgs Factory (II), Top Quark Mass, and others



The Phenomenology

- The question: How to discover the Higgs boson at the Higgs factory?

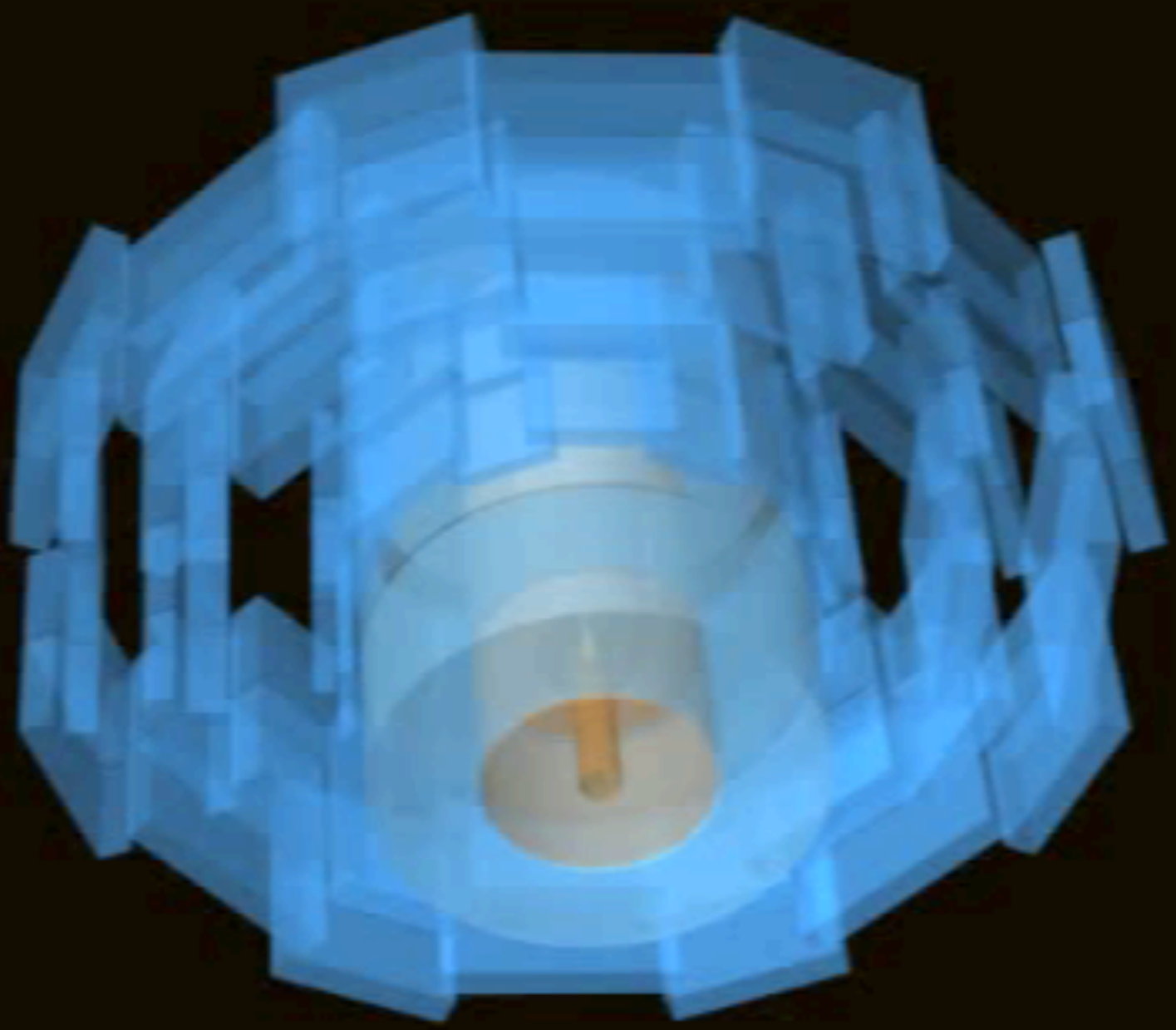


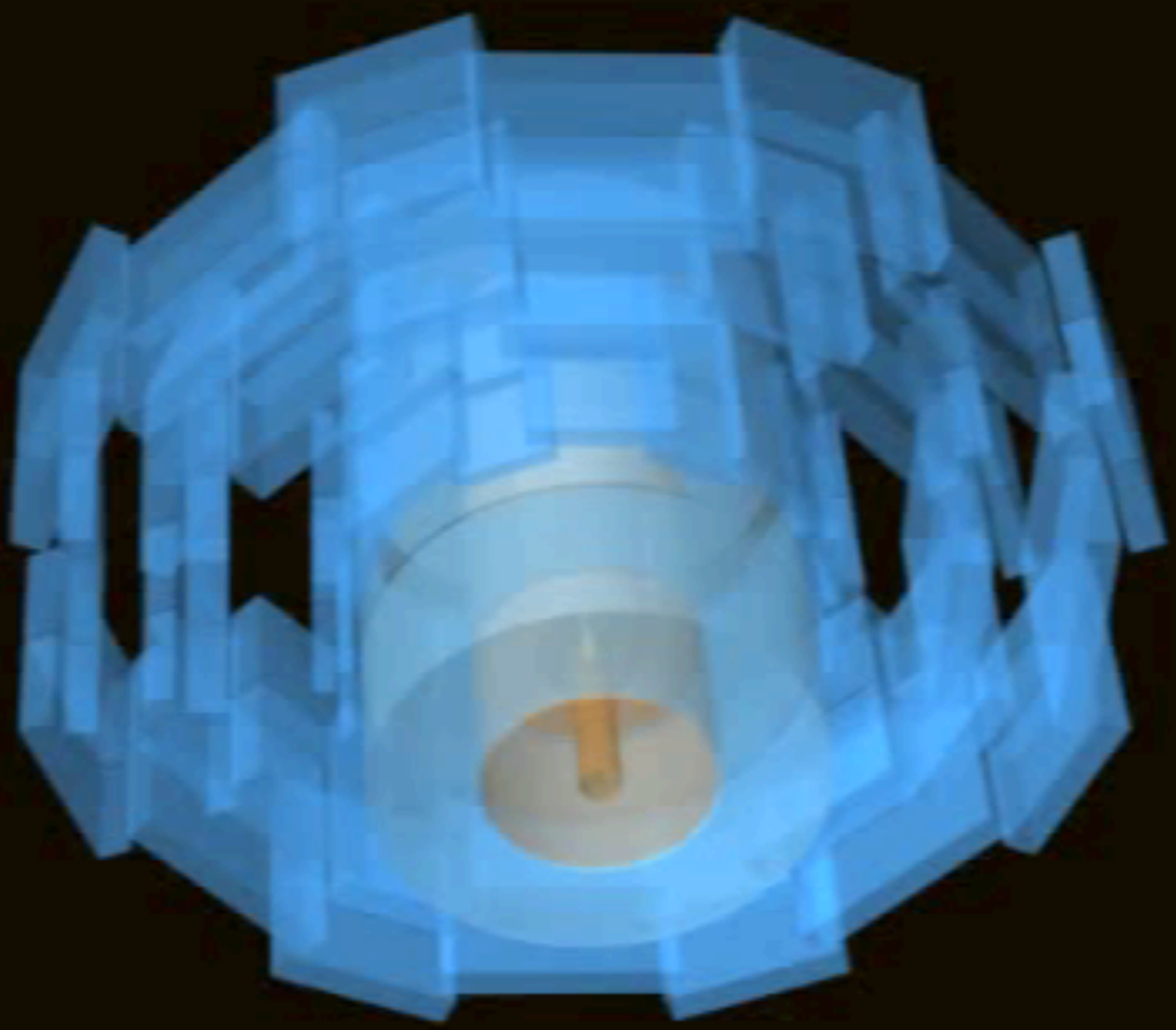
The Phenomenology

- The question: How to discover the Higgs boson at the Higgs factory?
- The recoil mass!

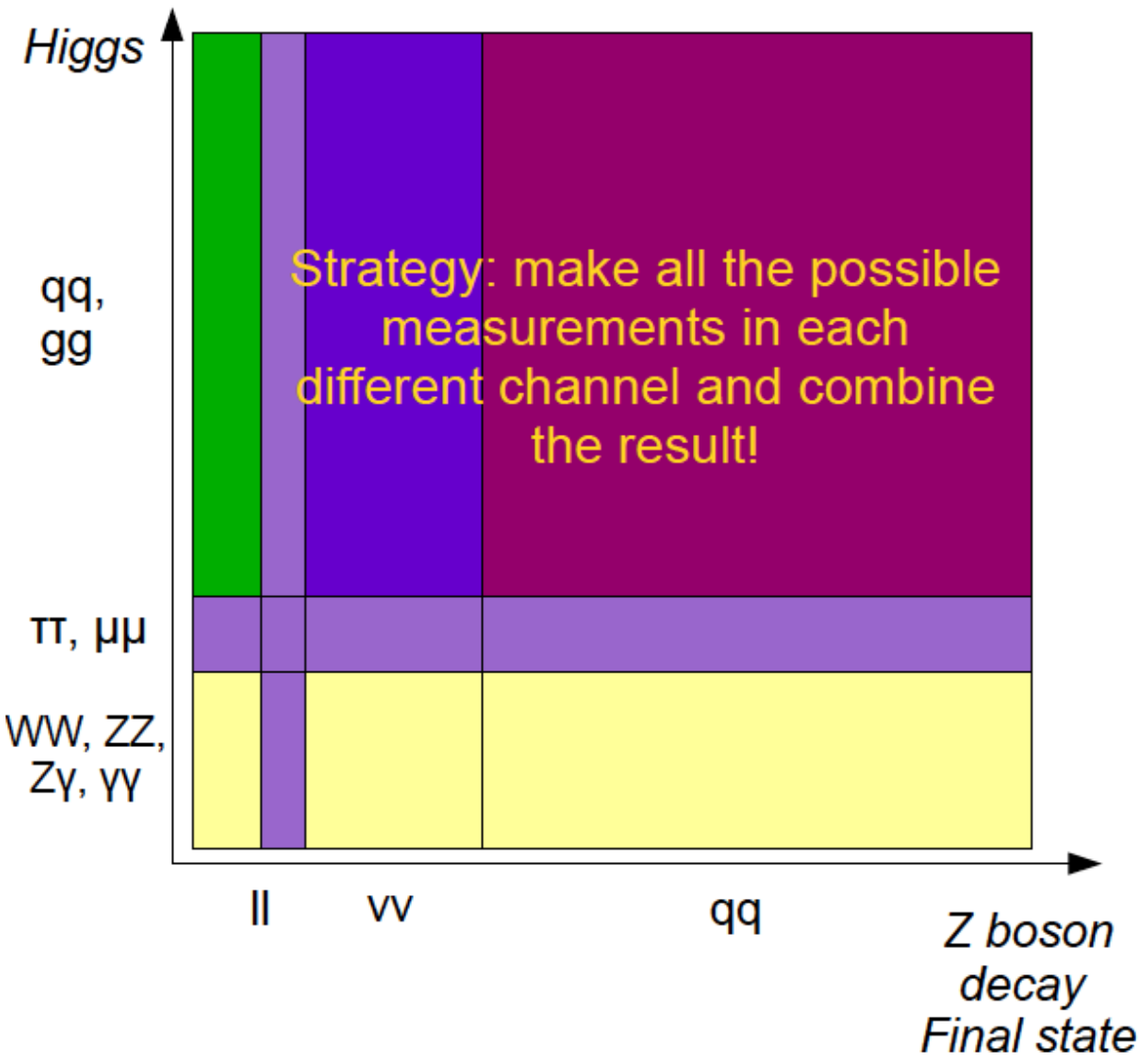
$$
\begin{aligned}
m_h^2 = p_h^2 &= ((\sqrt{s},0,0,0) - p_Z)^2 = ((\sqrt{s},0,0,0) - p_1 - p_2)^2 \\
&= (\sqrt{s} - E_1 - E_2)^2 - (\overrightarrow{p}_1 + \overrightarrow{p}_2)^2 \\
&= s - 2\sqrt{s}(E_1 + E_2) + (E_1 + E_2)^2 - (\overrightarrow{p}_1 + \overrightarrow{p}_2)^2 \\
&= s - 2\sqrt{s}(E_1 + E_2) + m_Z^2
\end{aligned}
$$

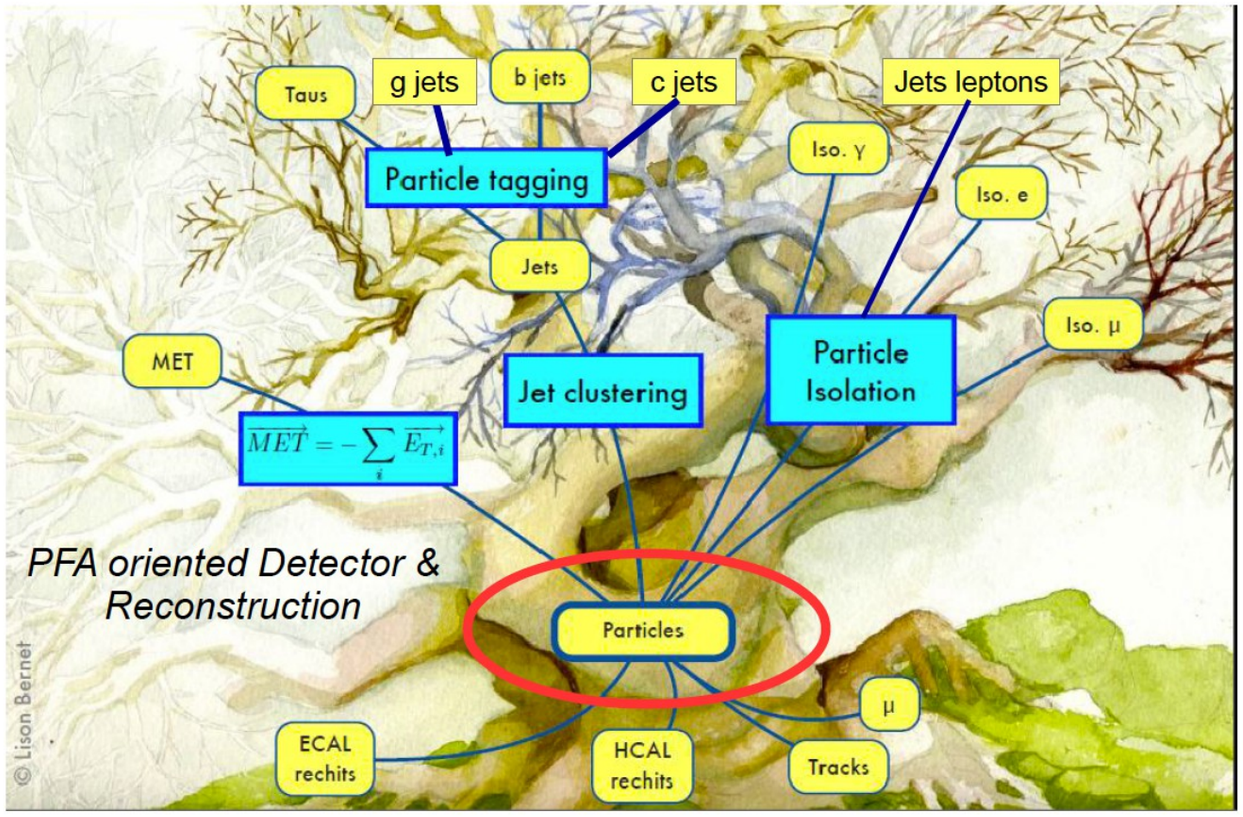
- Smearing effects:
  - C.m. energy uncertainty;
  - Energy resolution of the particle 1 and 2 from Z decay;
  - Width of the Z boson (~2.5GeV).





The Phenomenology



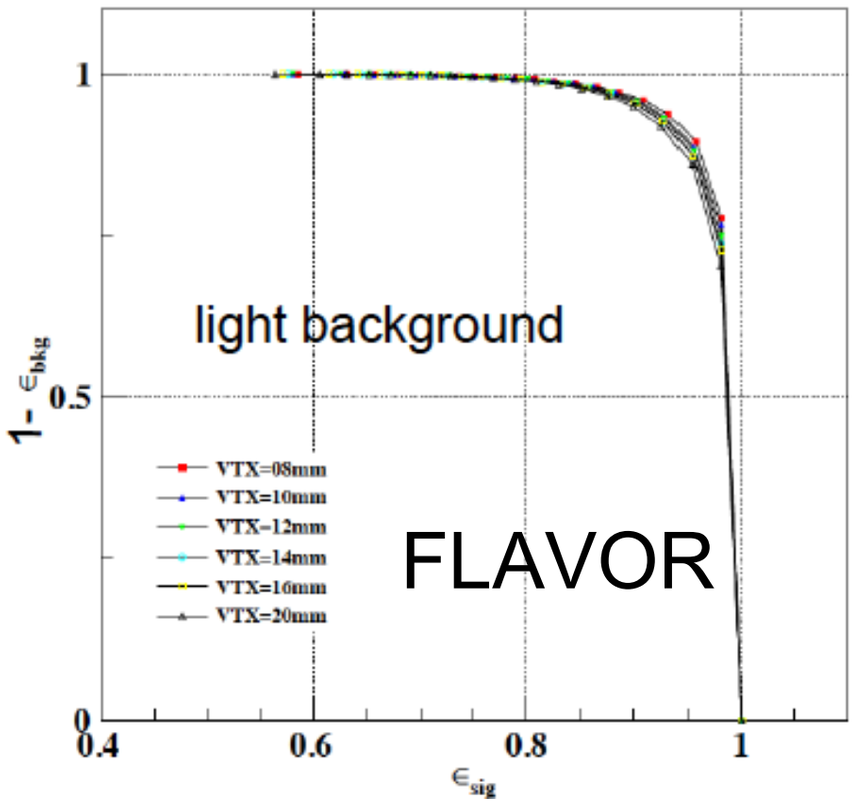


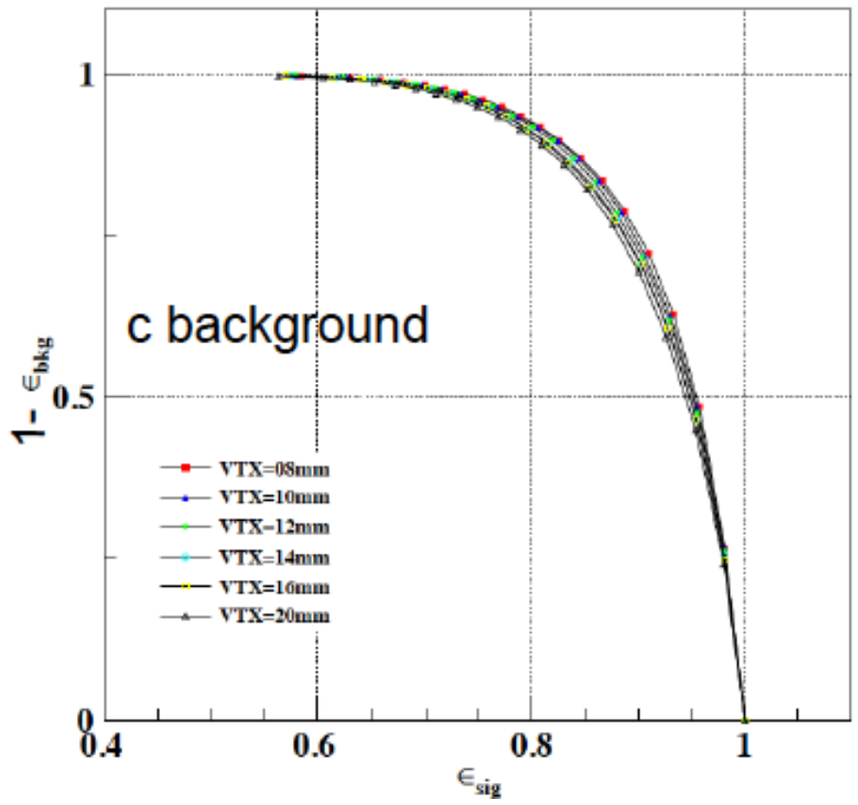
Reconstruct **ALL** the physics objects (lepton, γ, tau, Jet, MET, ...) with high efficiency/precision

High Precision VTX close to IP: b, c, tau tagging
High Precision & light Tracker:
PFA *oriented Calorimeter: Tagging, ID, JER, etc*

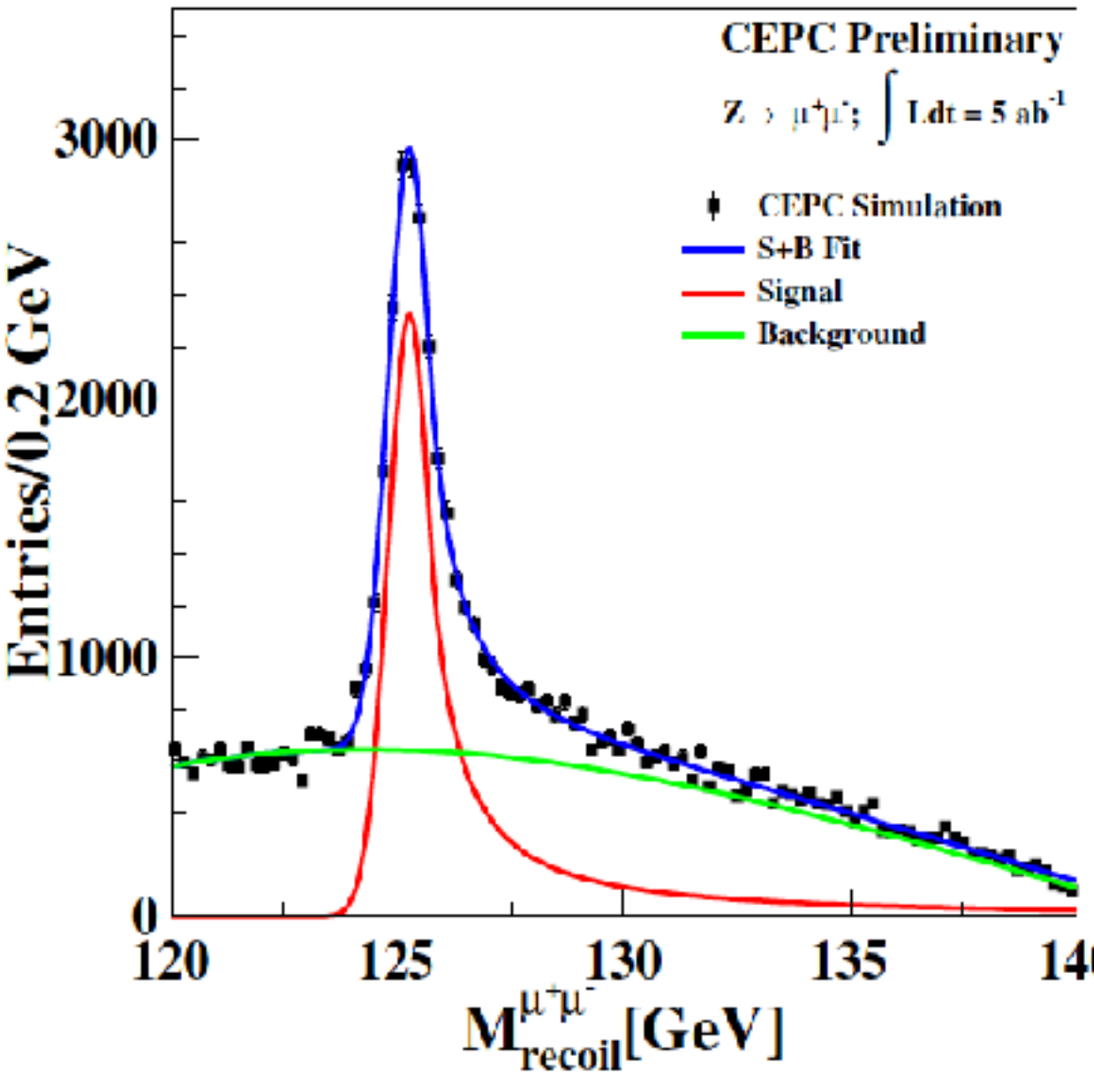
The Phenomenology

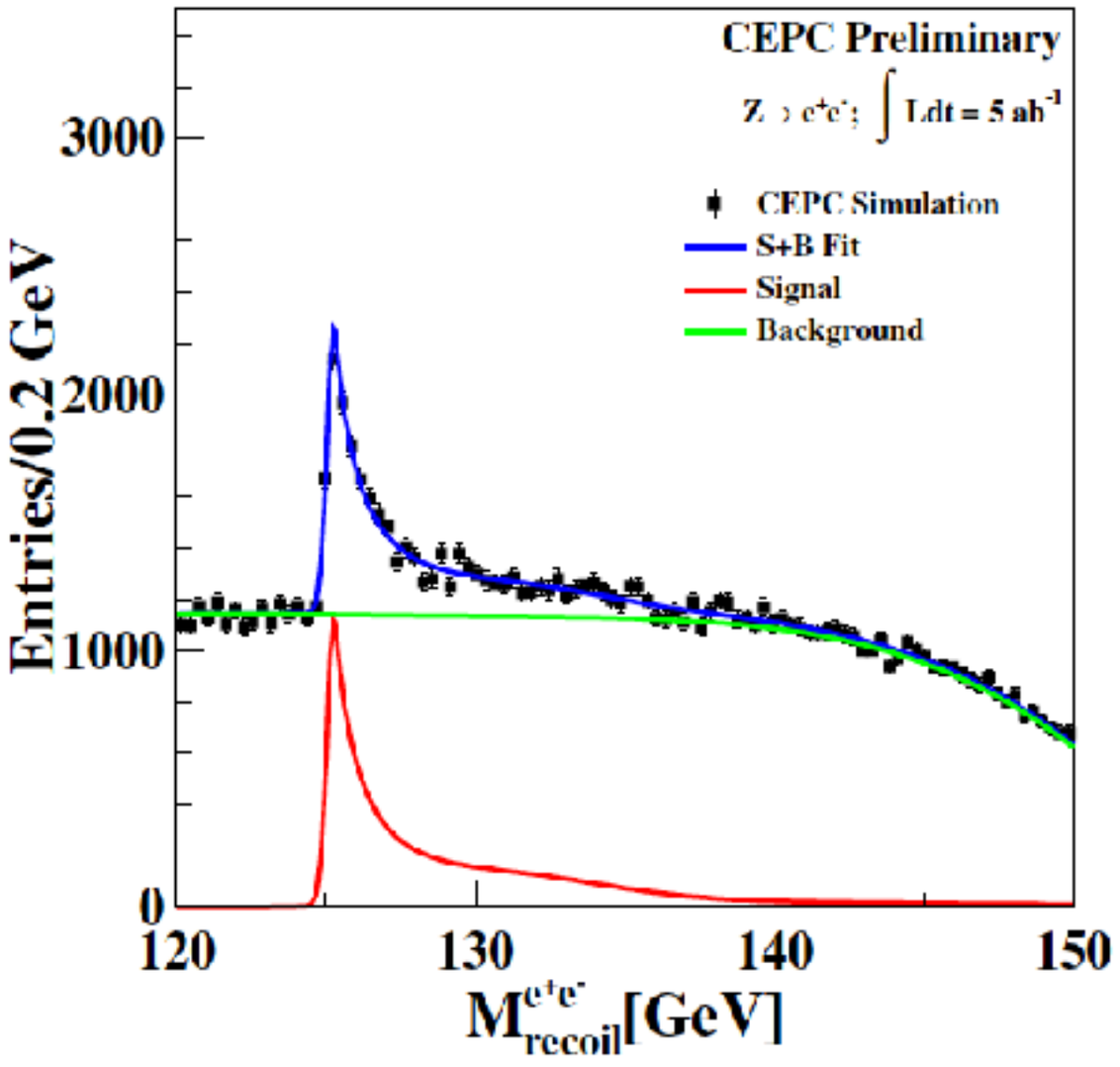
Charged particle reconstruction efficiency ($E > 10$ GeV)	99.5%
Muon identification efficiency ($E > 10$ GeV)	98.5%
Electron identification efficiency ($E > 10$ GeV)	99.5%
Photon tagging efficiency ($E > 1$ GeV)	98%
Neutral hadron tagging efficiency ($E > 5$ GeV)	90%
Jet energy resolution	3 - 4%
b-tagging efficiency	90%
c-tagging efficiency	60%



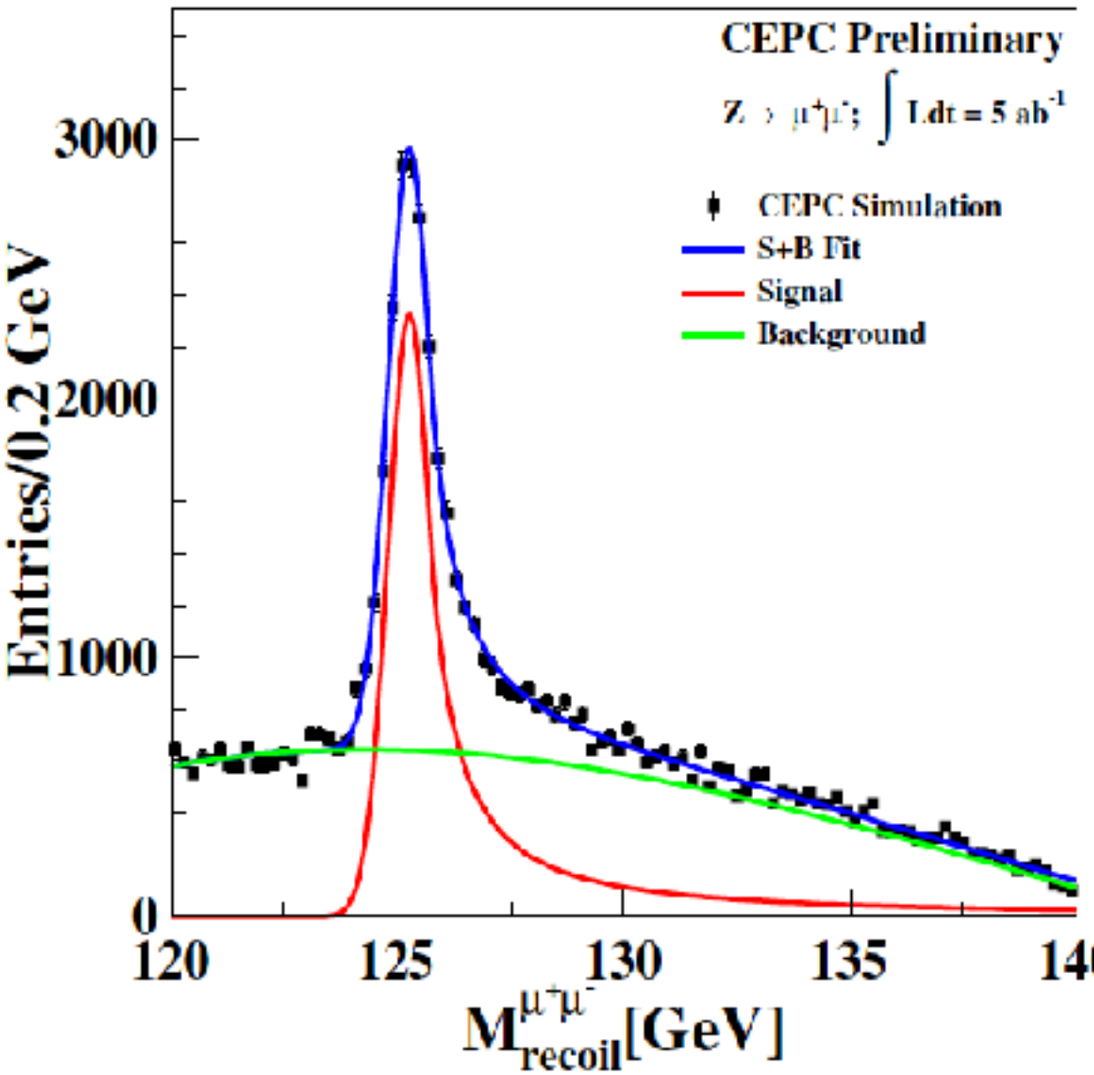


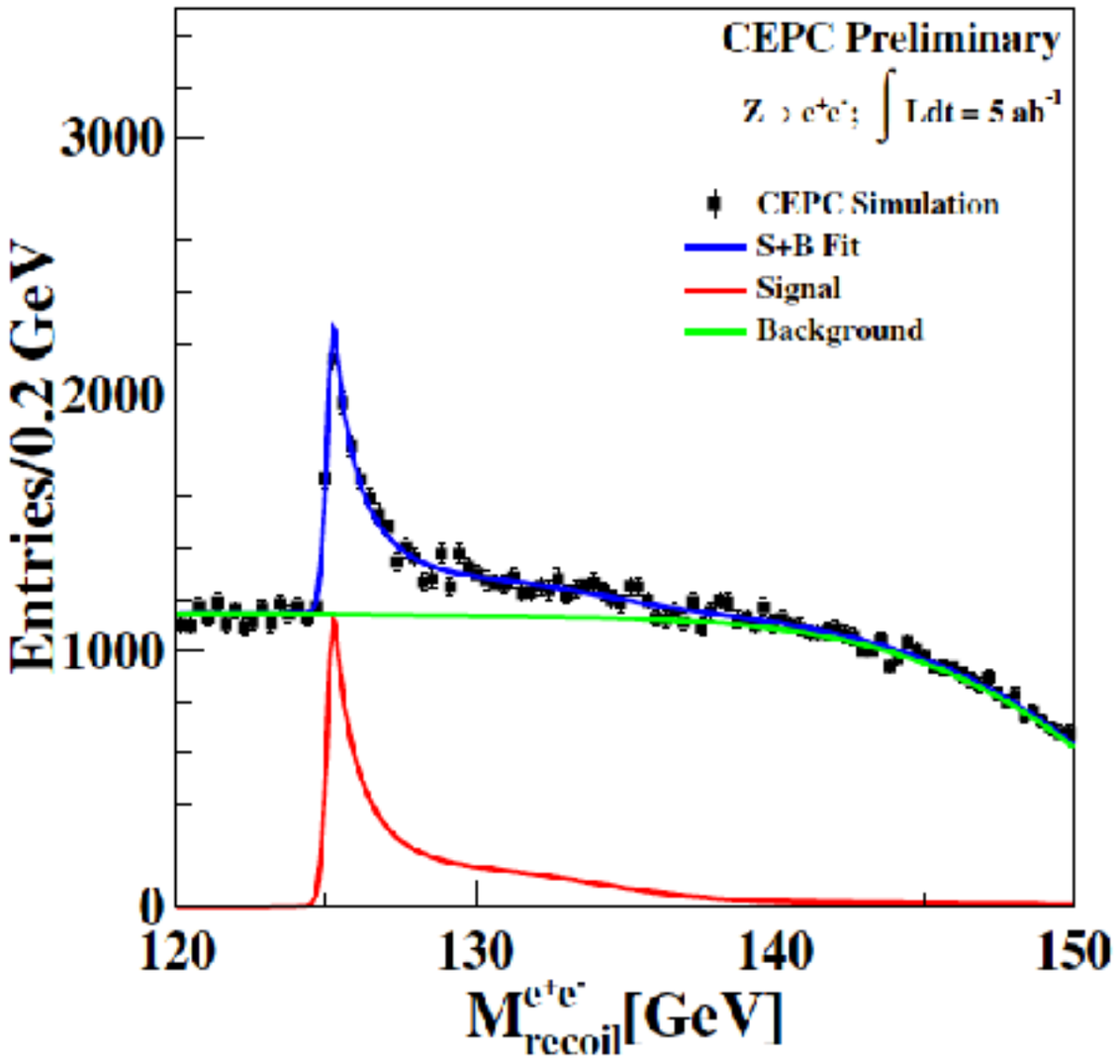
The Phenomenology





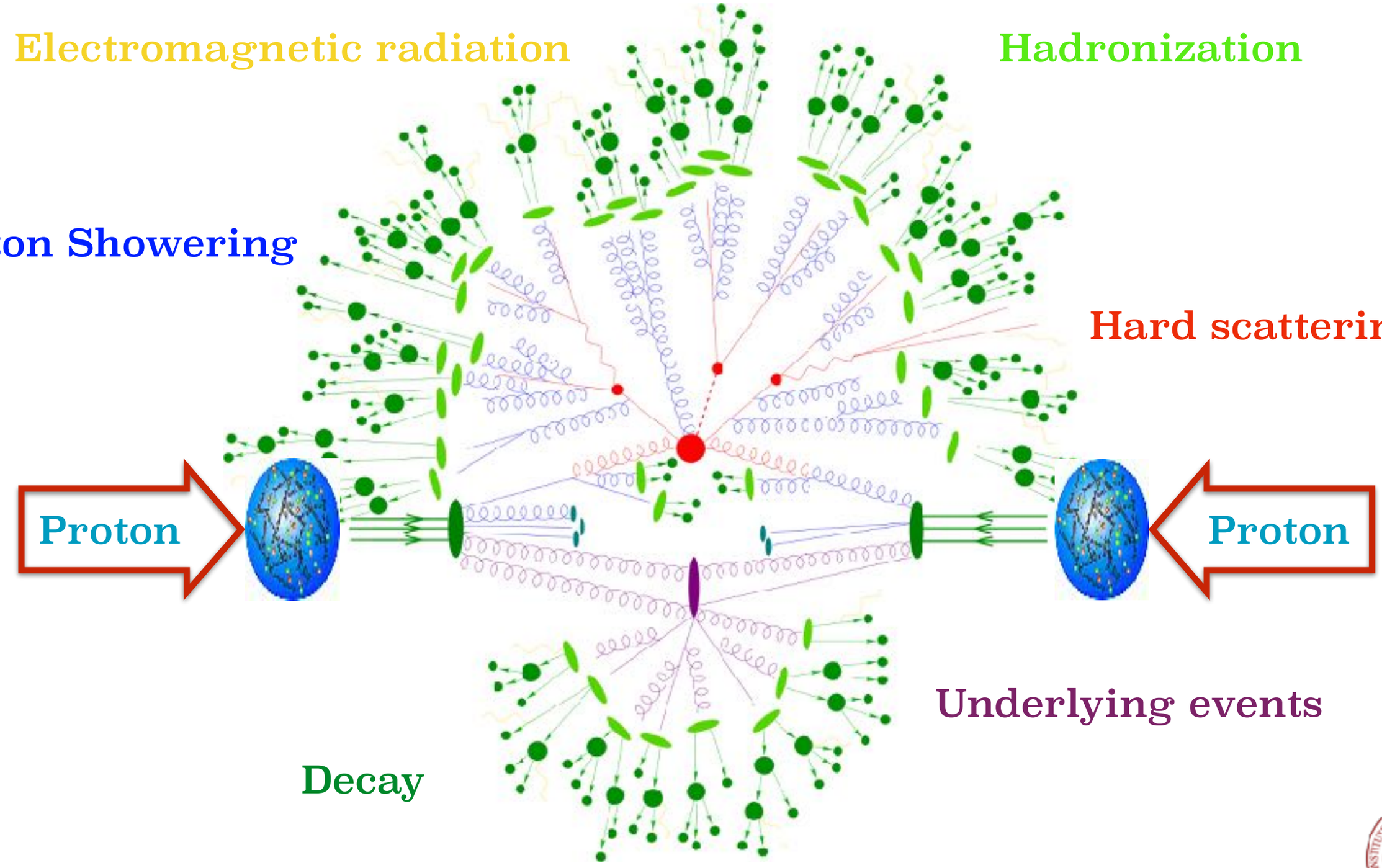
The Phenomenology



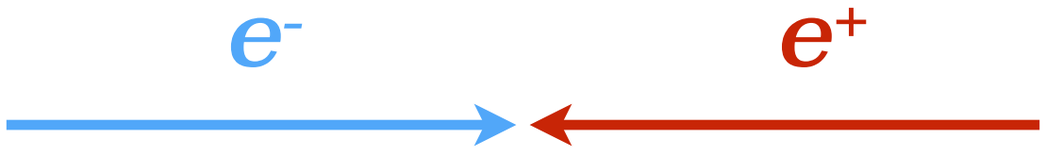


- Where is the long tail from?

The Phenomenology

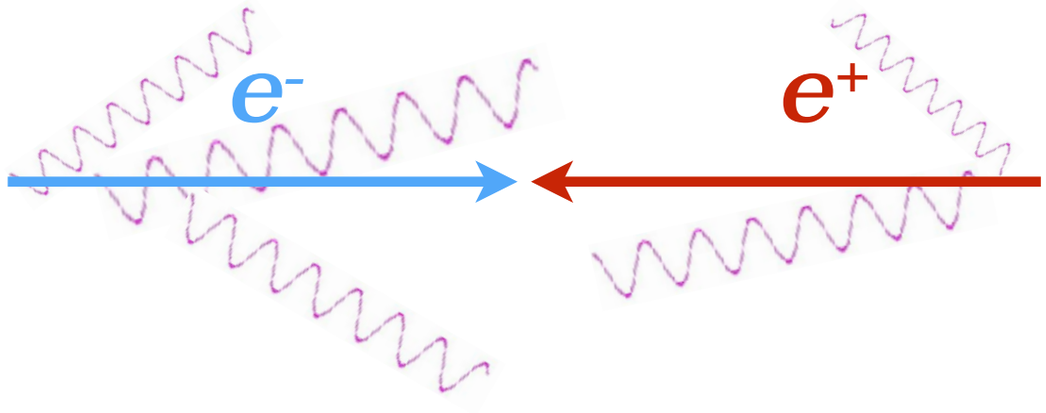


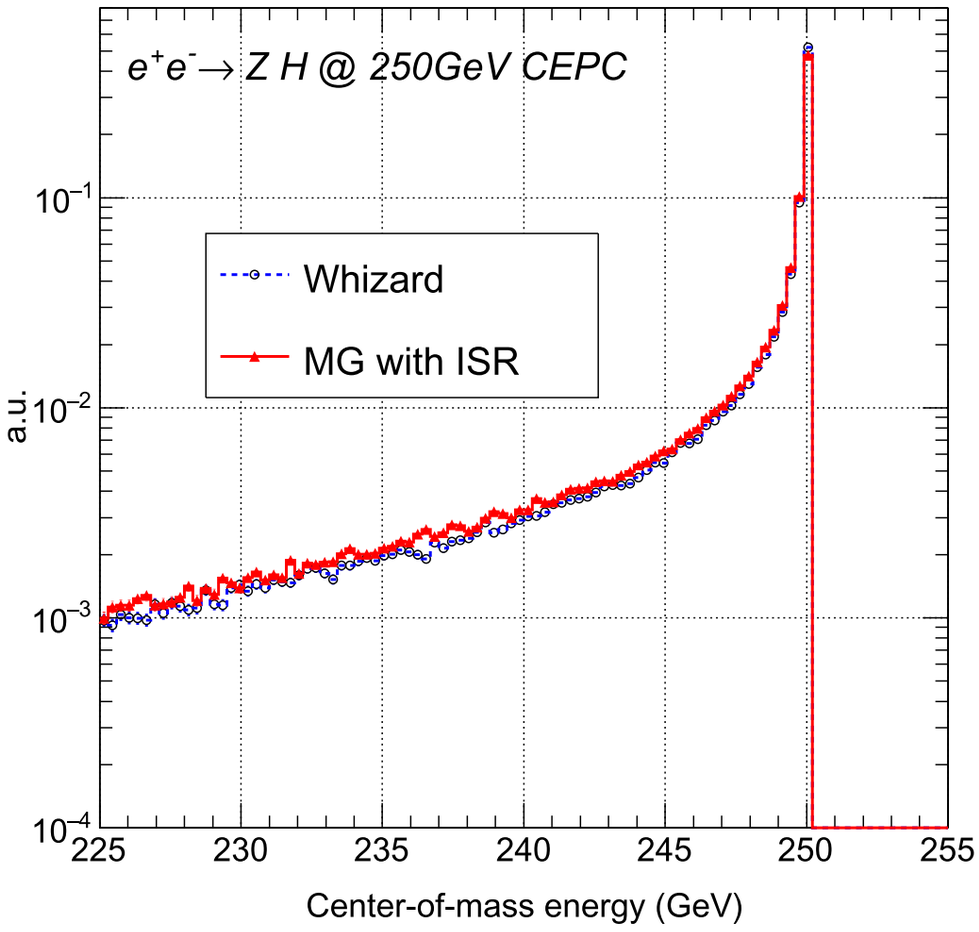
The Phenomenology

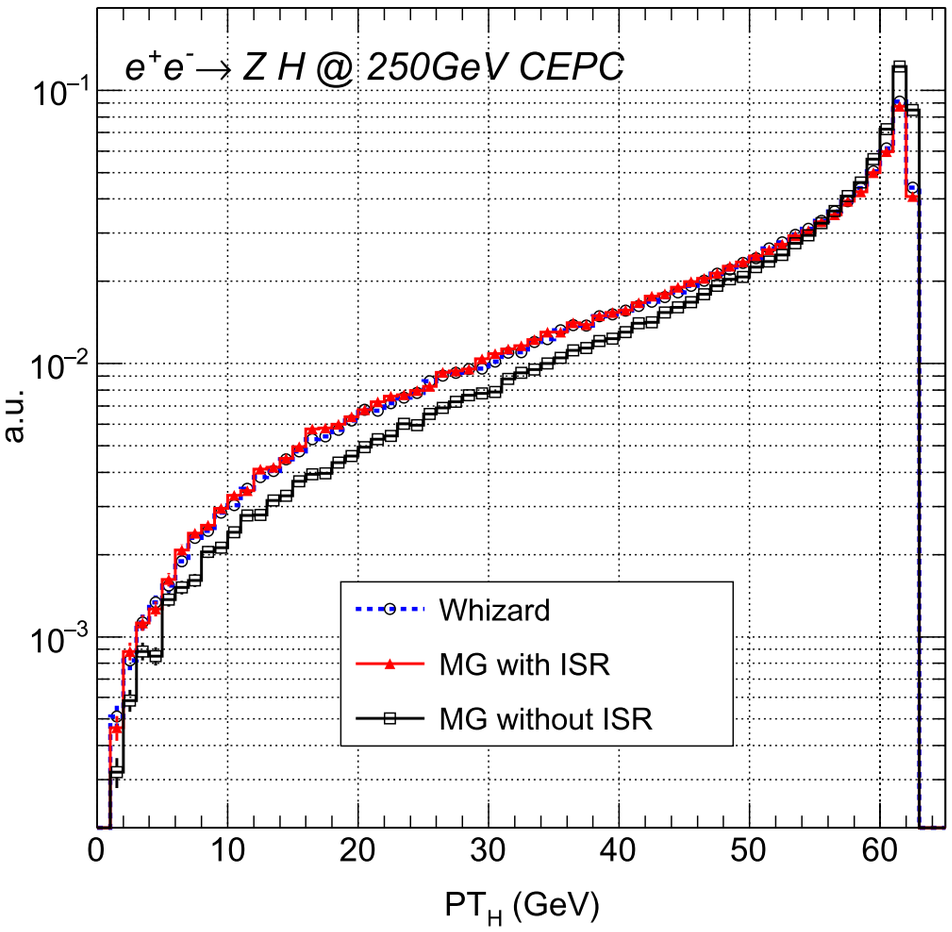


The Phenomenology

- The Initial State Radiation (ISR).







The Phenomenology

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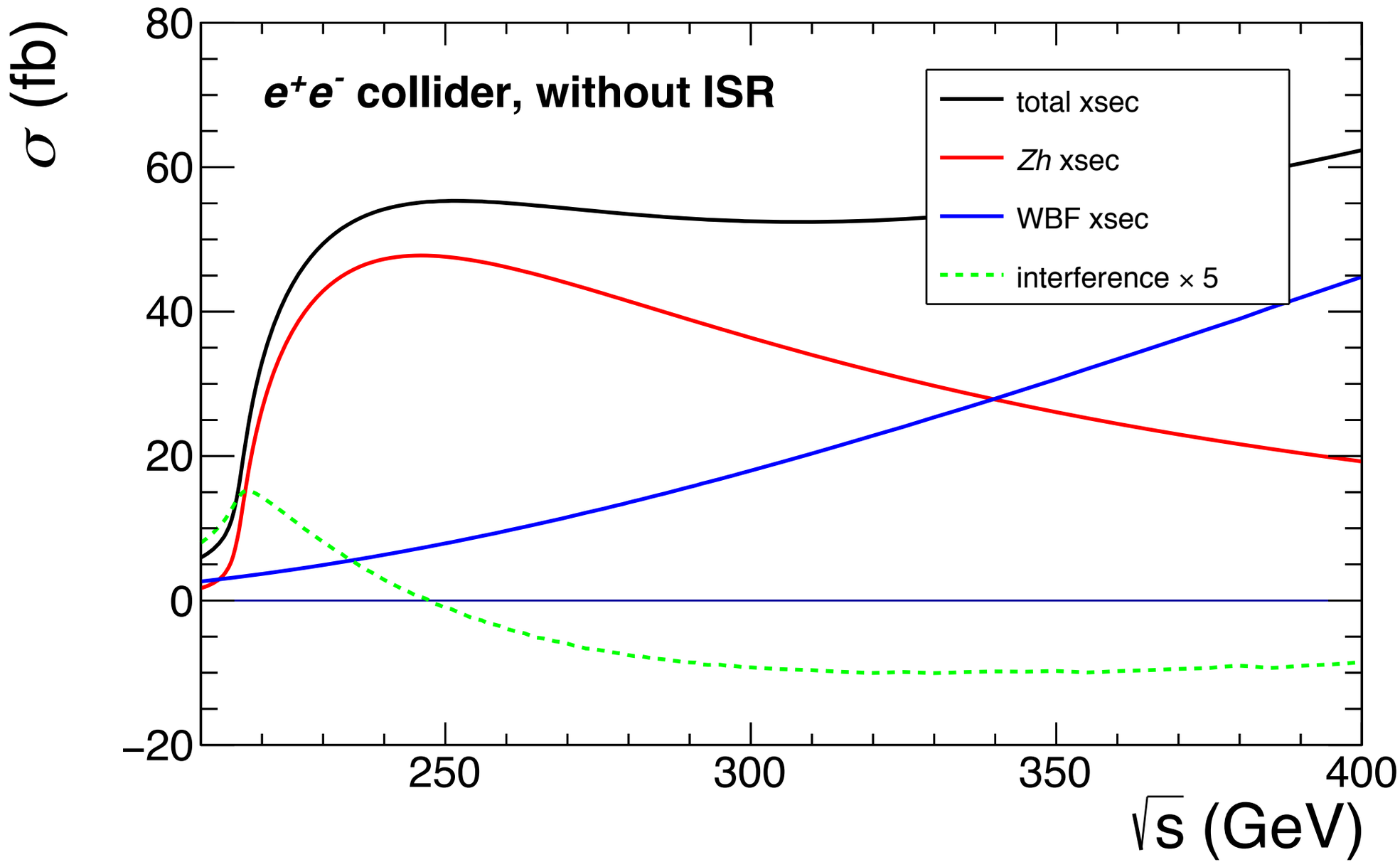

The Phenomenology

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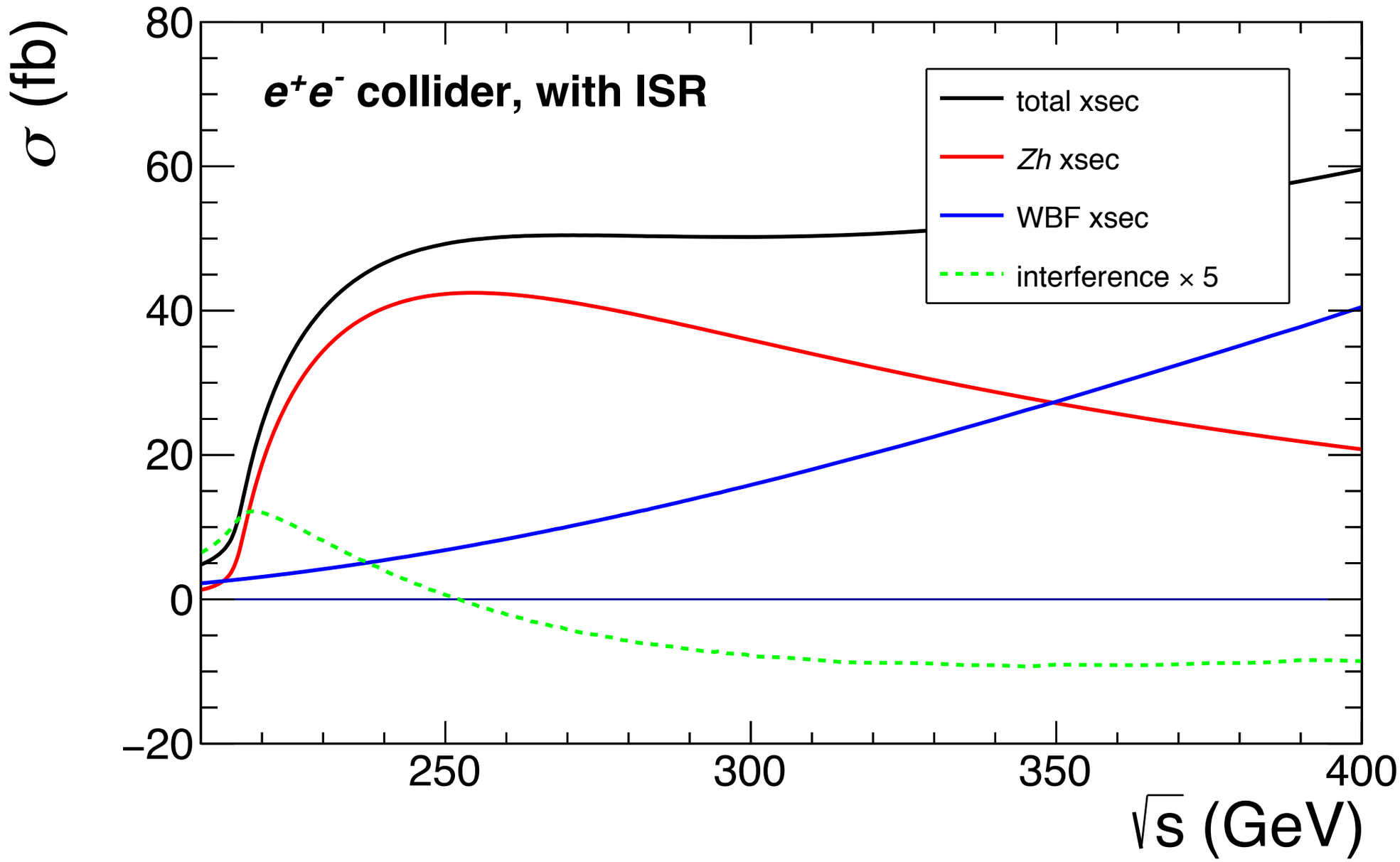
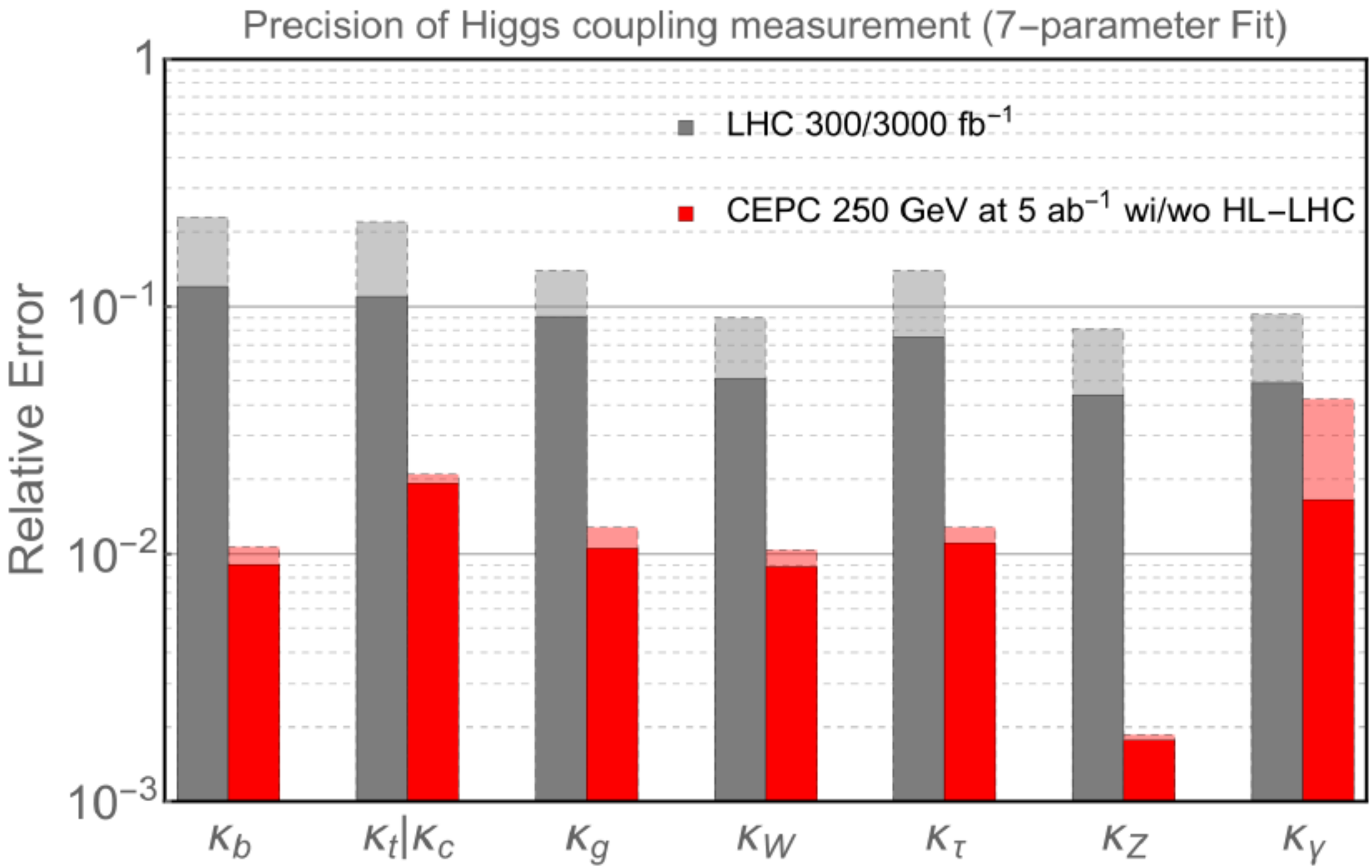


The Phenomenology

- Now we can understand the result.



The Phenomenology

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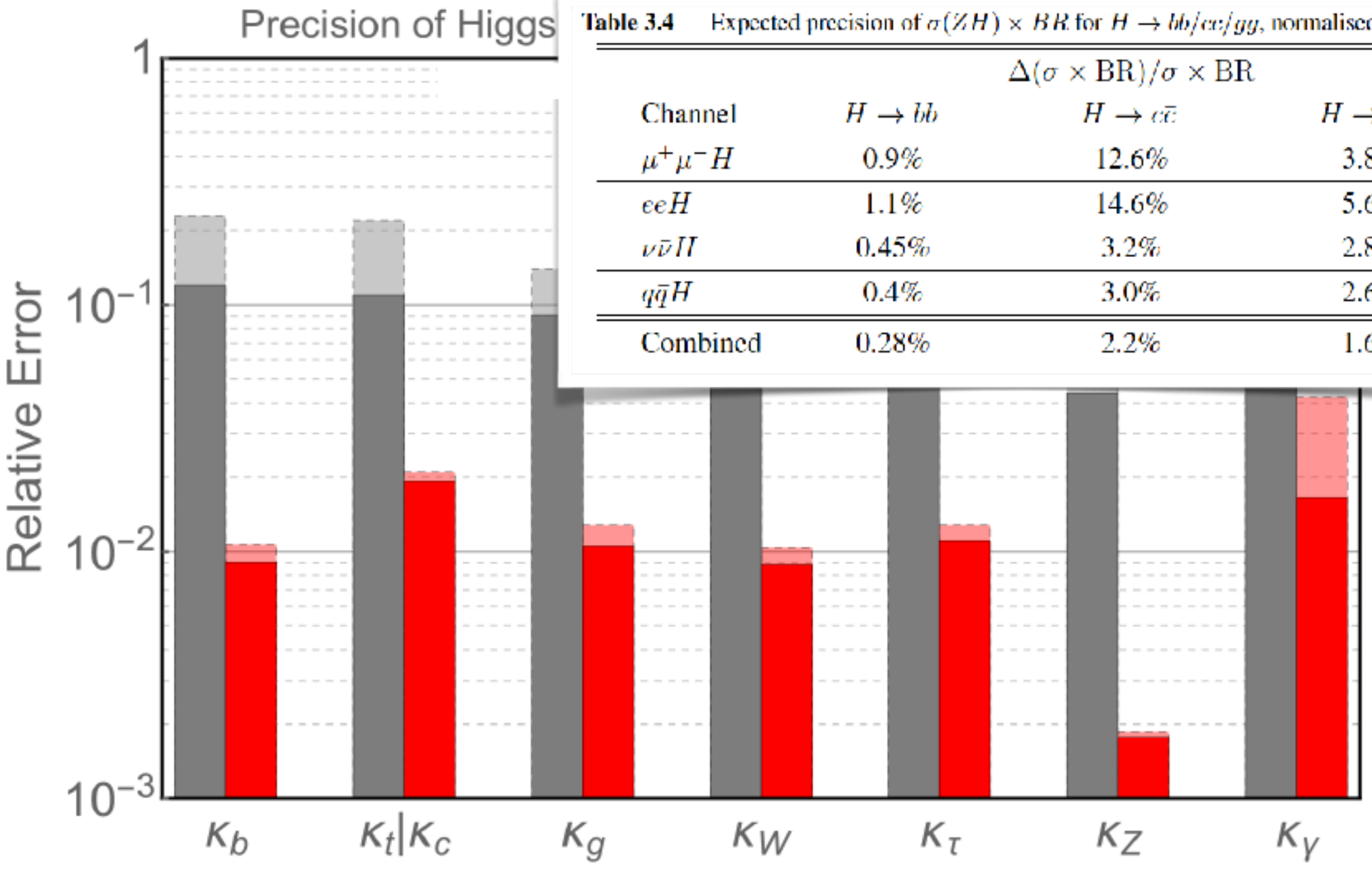


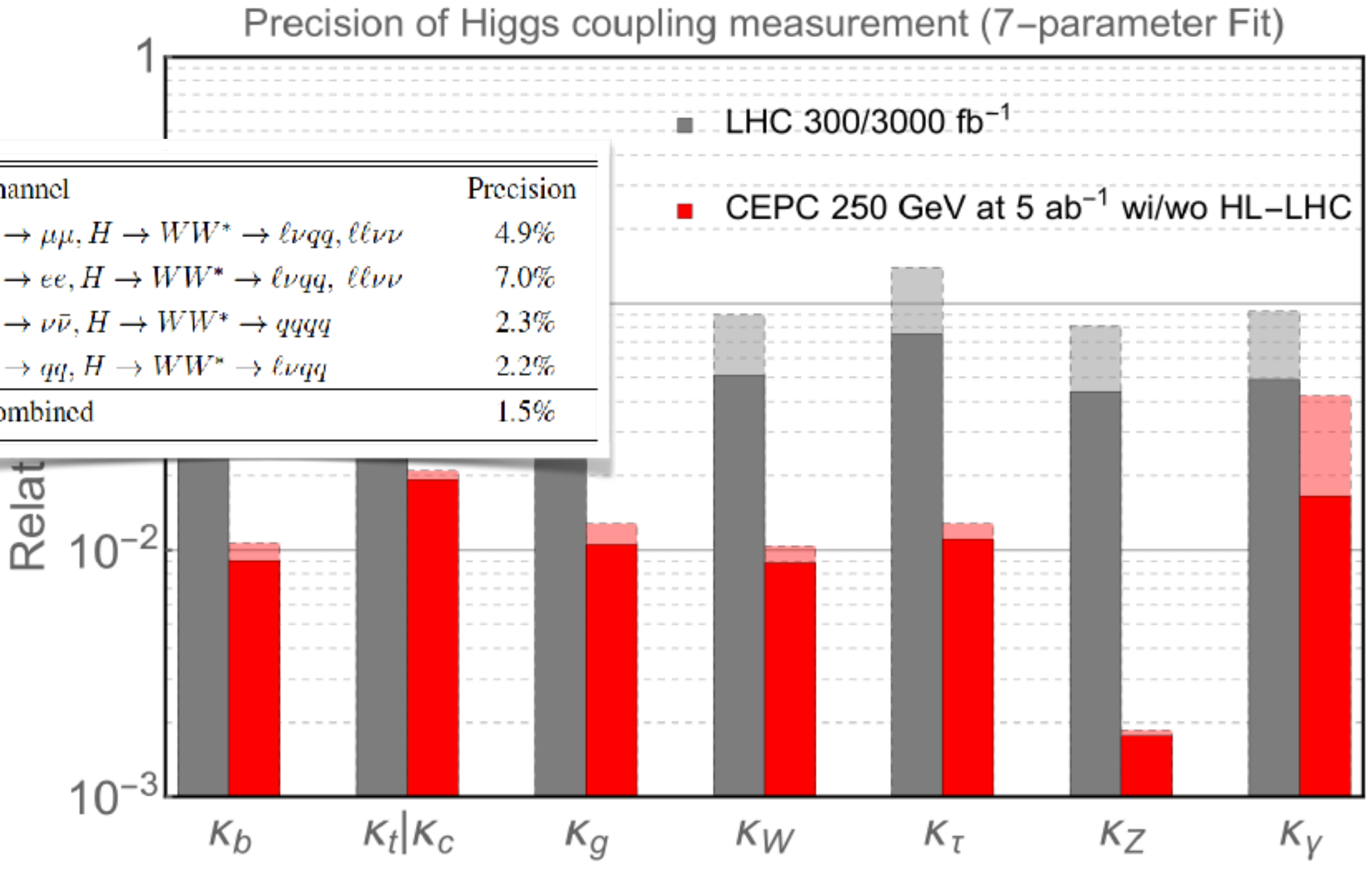
Table 3.4 Expected precision of $\sigma(ZH) \times BR$ for $H \to bb/cc/gg$, normalised to 5 ab^{-1}.

	$\Delta(\sigma \times \mathrm{BR})/\sigma \times \mathrm{BR}$		
Channel	$H \to bb$	$H \to c\bar{c}$	$H \to gg$
$\mu^+\mu^- H$	0.9%	12.6%	3.8%
eeH	1.1%	14.6%	5.6%
$\nu\bar{\nu} H$	0.45%	3.2%	2.8%
$q\bar{q}H$	0.4%	3.0%	2.6%
Combined	0.28%	2.2%	1.6%

The Phenomenology

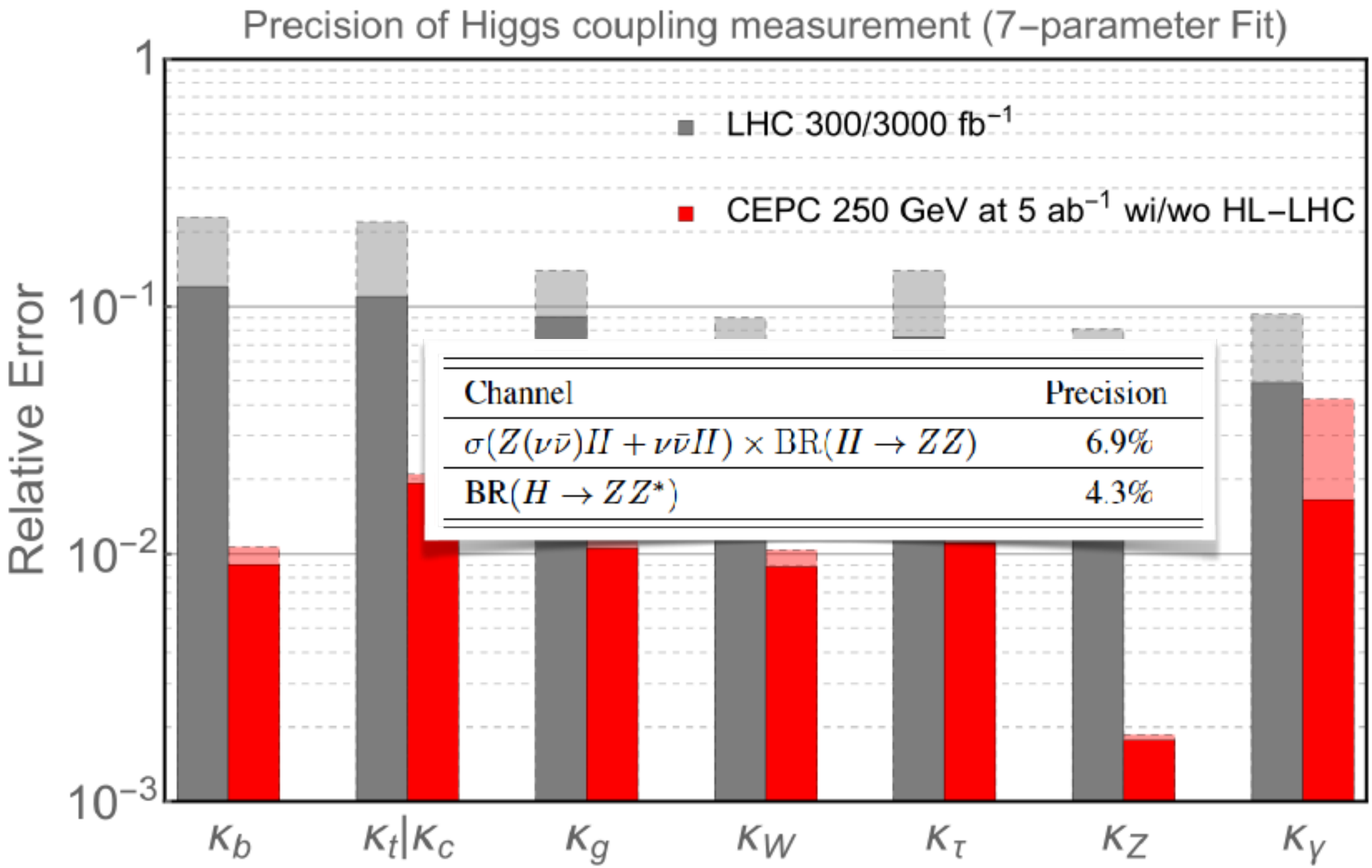
- Now we can understand the result.

Channel	Precision
$Z \to \mu\mu, H \to WW^* \to \ell\nu qq, \ell\ell\nu\nu$	4.9%
$Z \to ee, H \to WW^* \to \ell\nu qq, \ell\ell\nu\nu$	7.0%
$Z \to \nu\bar{\nu}, H \to WW^* \to qqqq$	2.3%
$Z \to qq, H \to WW^* \to \ell\nu qq$	2.2%
Combined	1.5%



The Phenomenology

- Now we can understand the result.



Channel	Precision
$\sigma(Z(\nu\bar{\nu})II + \nu\bar{\nu}II) \times \mathrm{BR}(II \to ZZ)$	6.9%
$\mathrm{BR}(H \to ZZ^*)$	4.3%

The Phenomenology

- The width of the Higgs boson ~ several %.

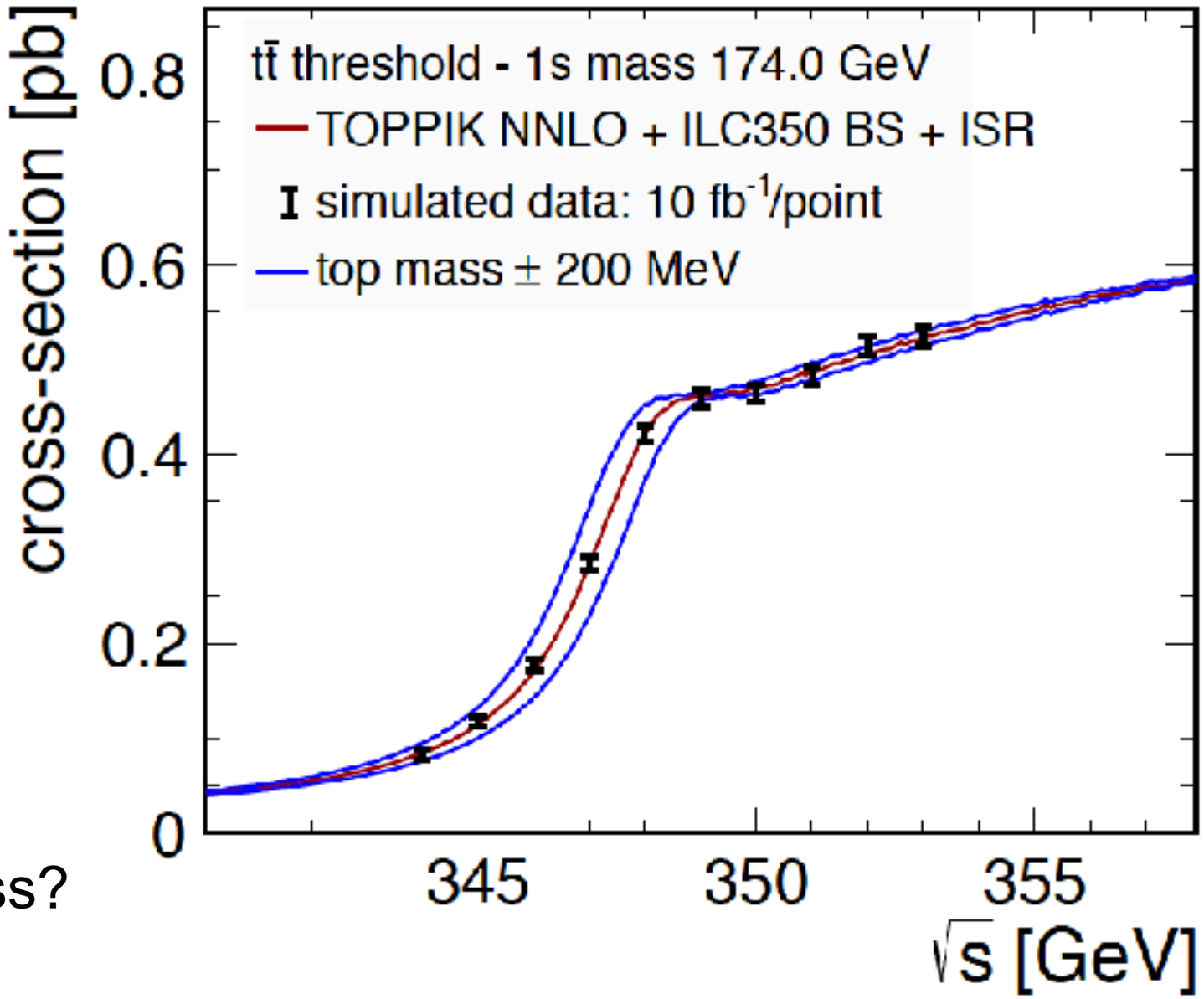
$$\Gamma_H = \frac{\Gamma(H \to ZZ^*)}{\mathrm{BR}(H \to ZZ^*)} \propto \frac{\sigma(ZH)}{\mathrm{BR}(H \to ZZ^*)}.$$

$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{\mathrm{BR}(H \to bb)} \propto \frac{\sigma(\nu\bar{\nu}H \to \nu\bar{\nu}bb)}{\mathrm{BR}(H \to bb) \cdot \mathrm{BR}(H \to WW^*)}.$$

Top Quark at Future Lepton Colliders

The “Mass” of the Top Quark

- Lepton collider:



- What mass?

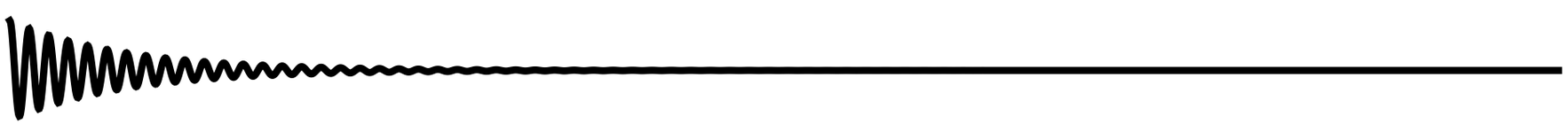
The “Mass” of the Top Quark

- What is the mass?

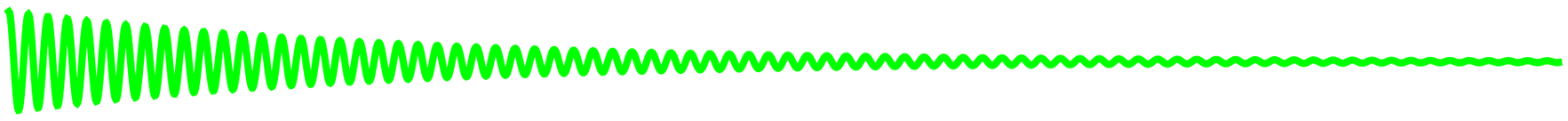
The "Mass" of the Top Quark

- What is the mass?

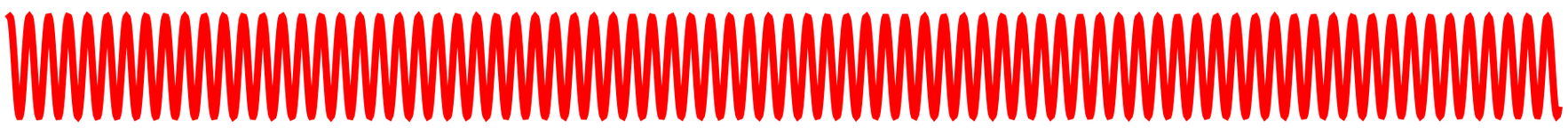
$\frac{\Gamma}{M} \sim 0.03$



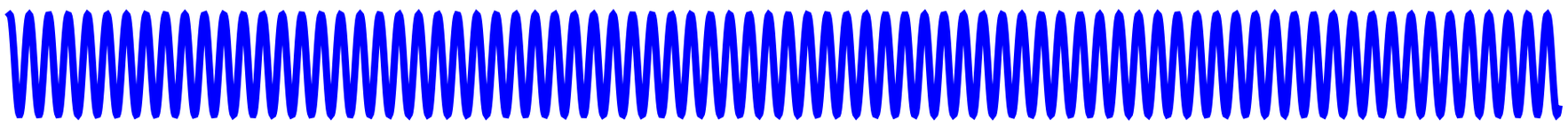
$\frac{\Gamma}{M} \sim 0.008$



$\frac{\Gamma}{M} \sim 0.00003$

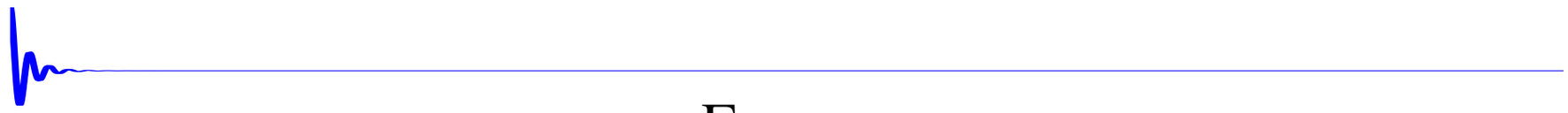


$\Gamma = 0$

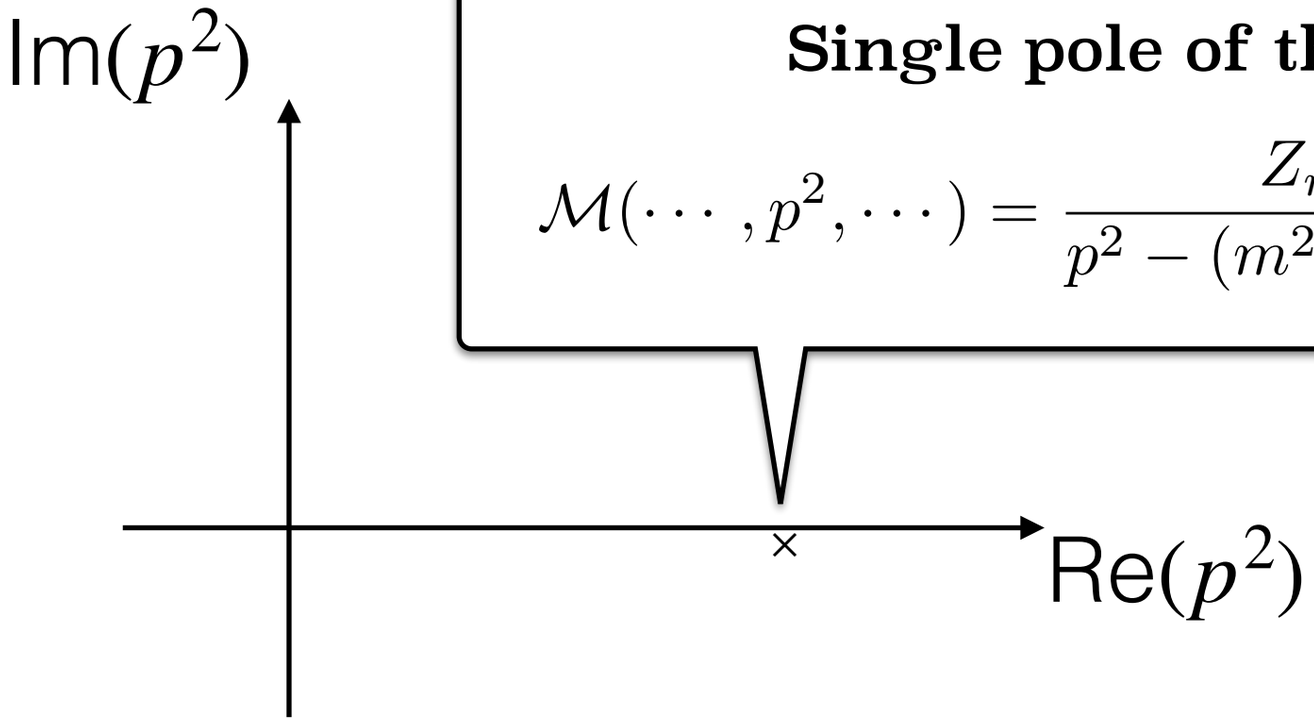


The “Mass” of the Top Quark

- What is the mass?



$$\frac{\Gamma}{M} \sim 0.1$$



Single pole of the amplitude:

$$\mathcal{M}(\cdots, p^2, \cdots) = \frac{Z_m}{p^2 - (m^2 - im\Gamma)} + f(\cdots, p^2, \cdots)$$

The “Mass” of the Top Quark

- What is the mass?
- How to measure it?

The “Mass” of the Top Quark

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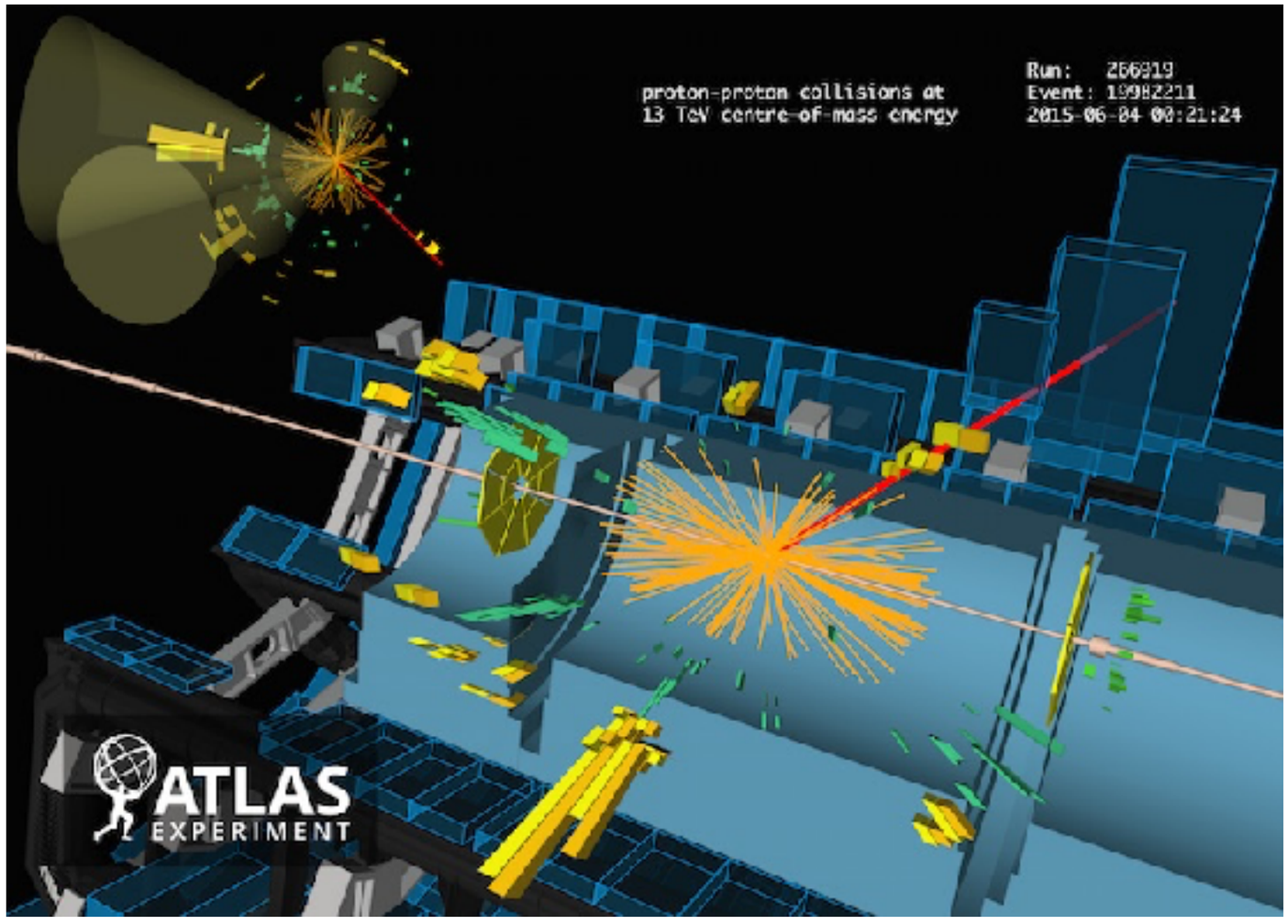

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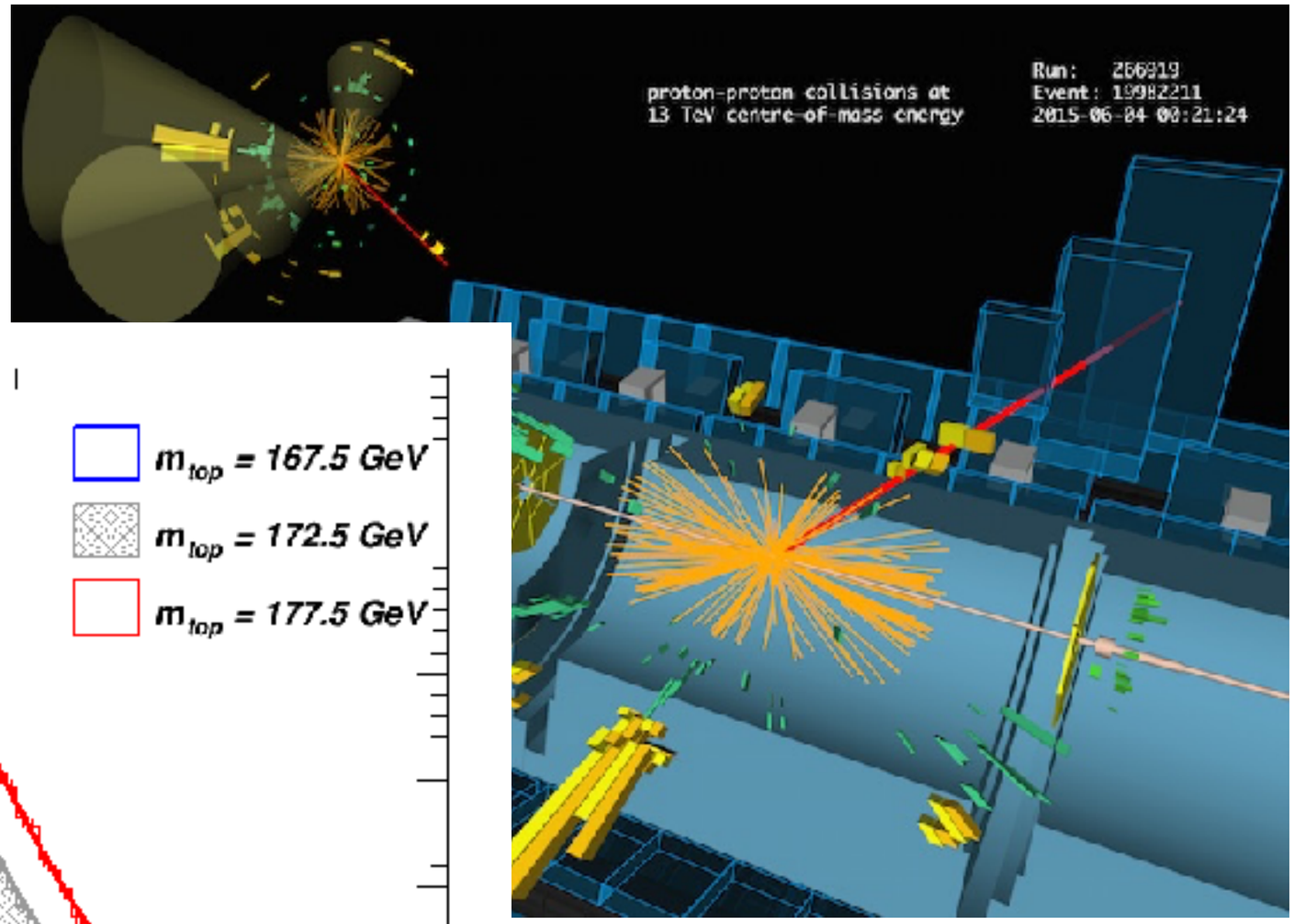

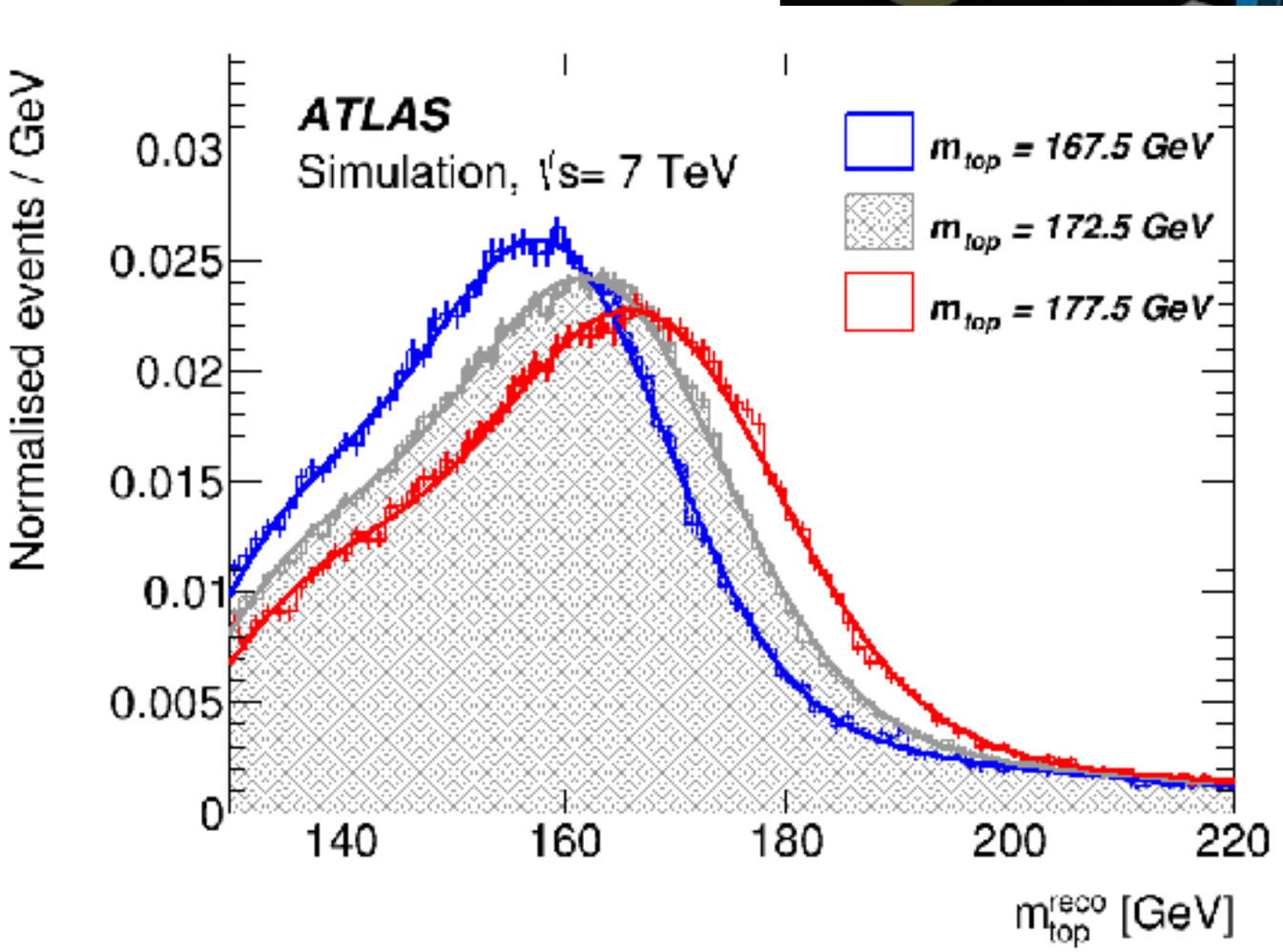

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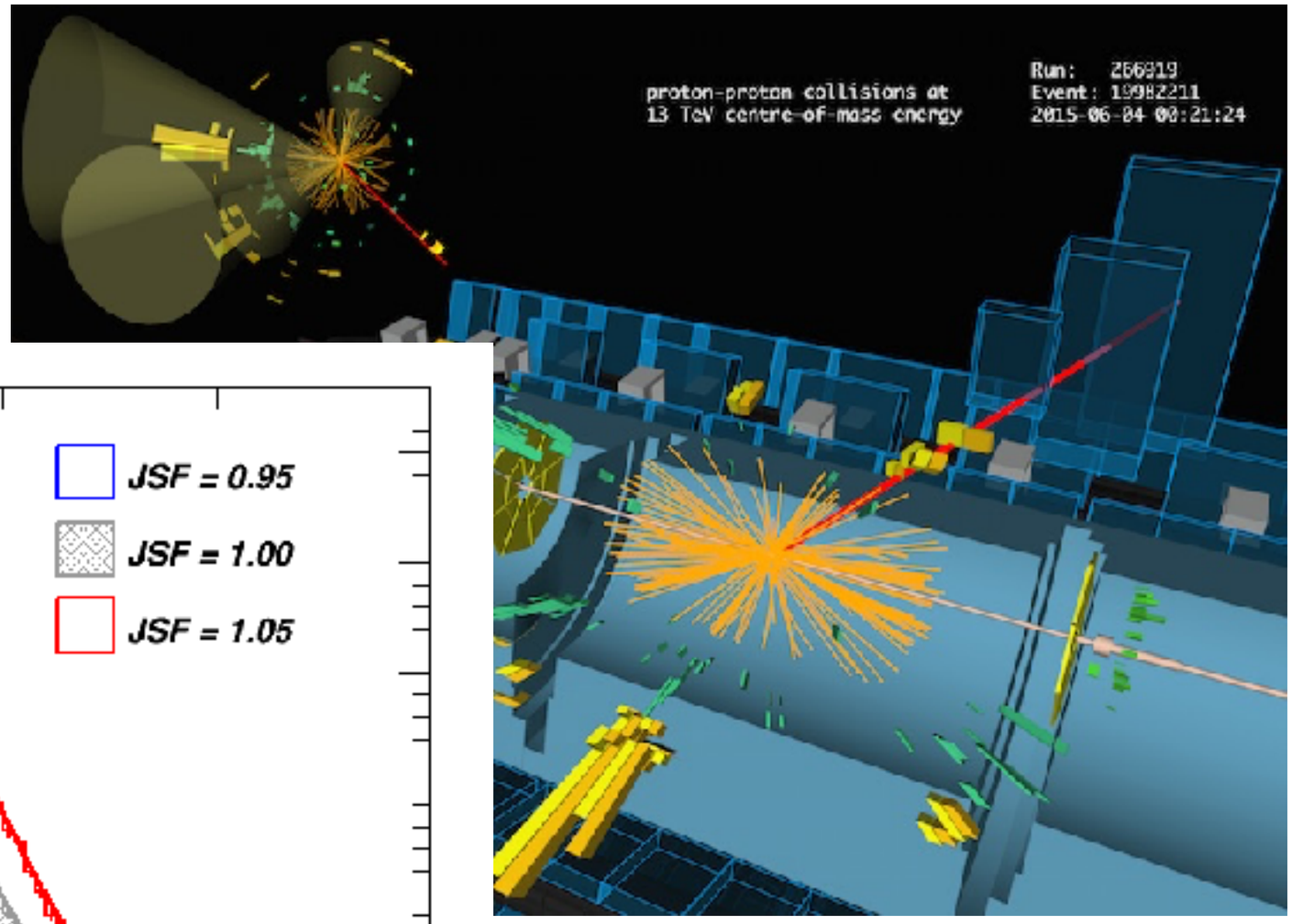
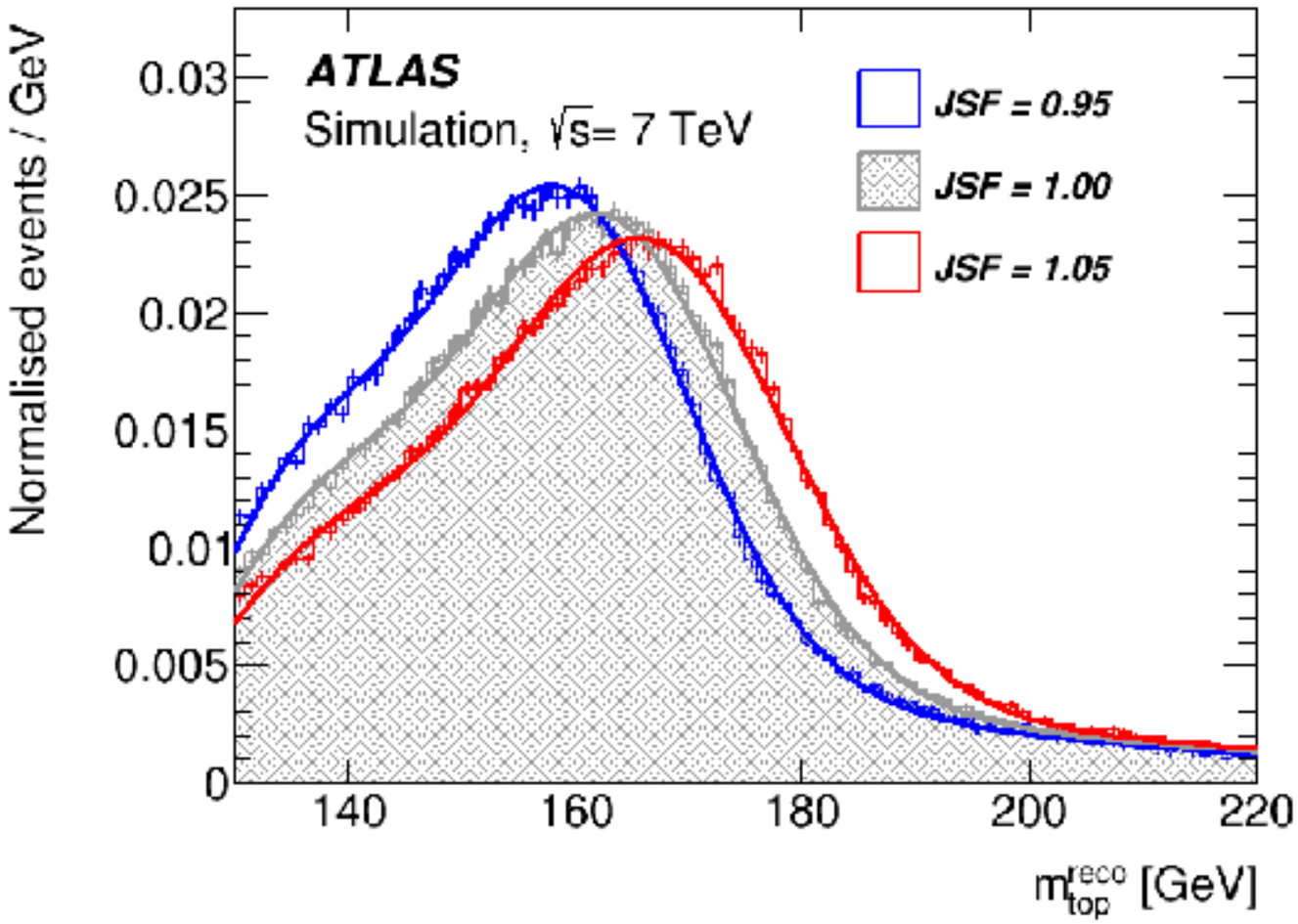
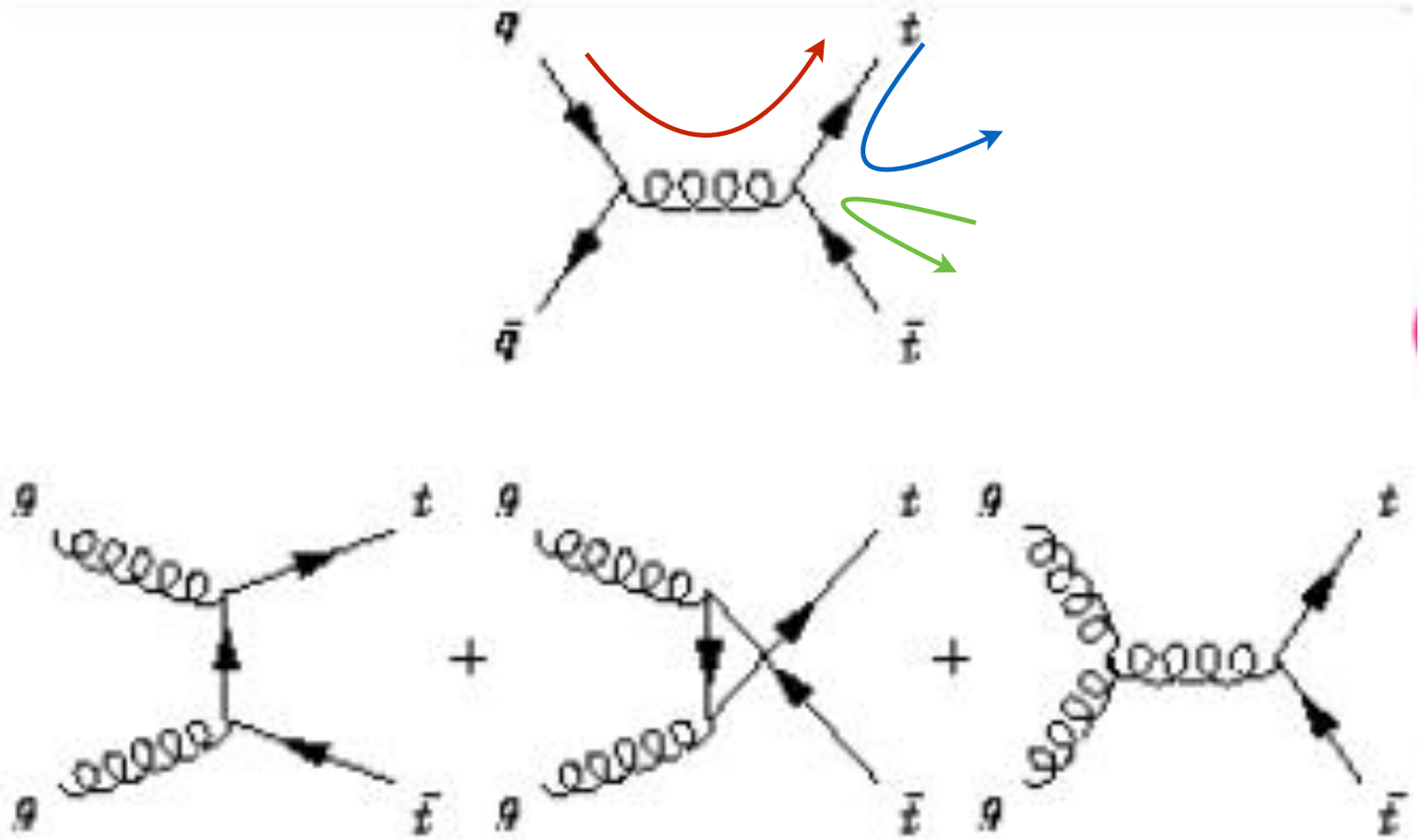




The "Mass" of the Top Quark

- Whose mass?

Extra contribution to the jet momentum in hadronization, ~Λ_{QCD}



The “Mass” of the Top Quark

- Pole mass vs. Monte Carlo mass?
- To compare the prediction and the data, we need to do a Monte Carlo simulation.
- There is a parameter named “top quark mass” in the phenomenological model used by the MC code. But …

$$m_t^{\text{pole}} \neq m_t^{\text{MC}}$$

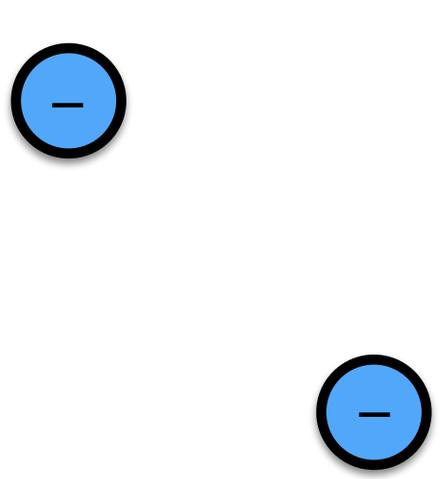
- People believe that they are close to each other. The error is ~GeV…

The “Mass” of the Top Quark

- What is the mass?
- How to measure it?

The “Mass” of the Top Quark

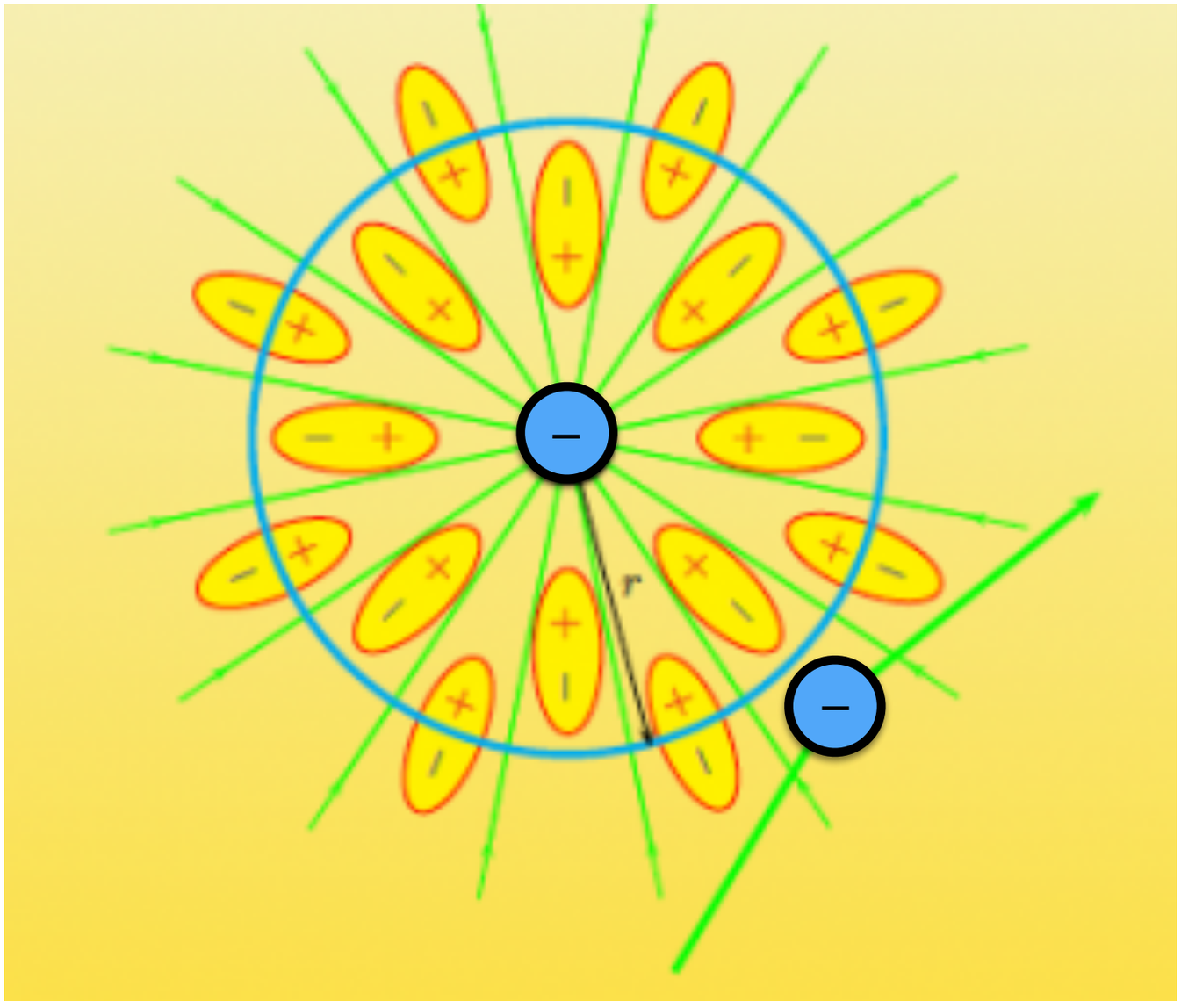
- Running coupling constants?



$$V(r) = -\frac{\alpha}{r}$$

The “Mass” of the Top Quark

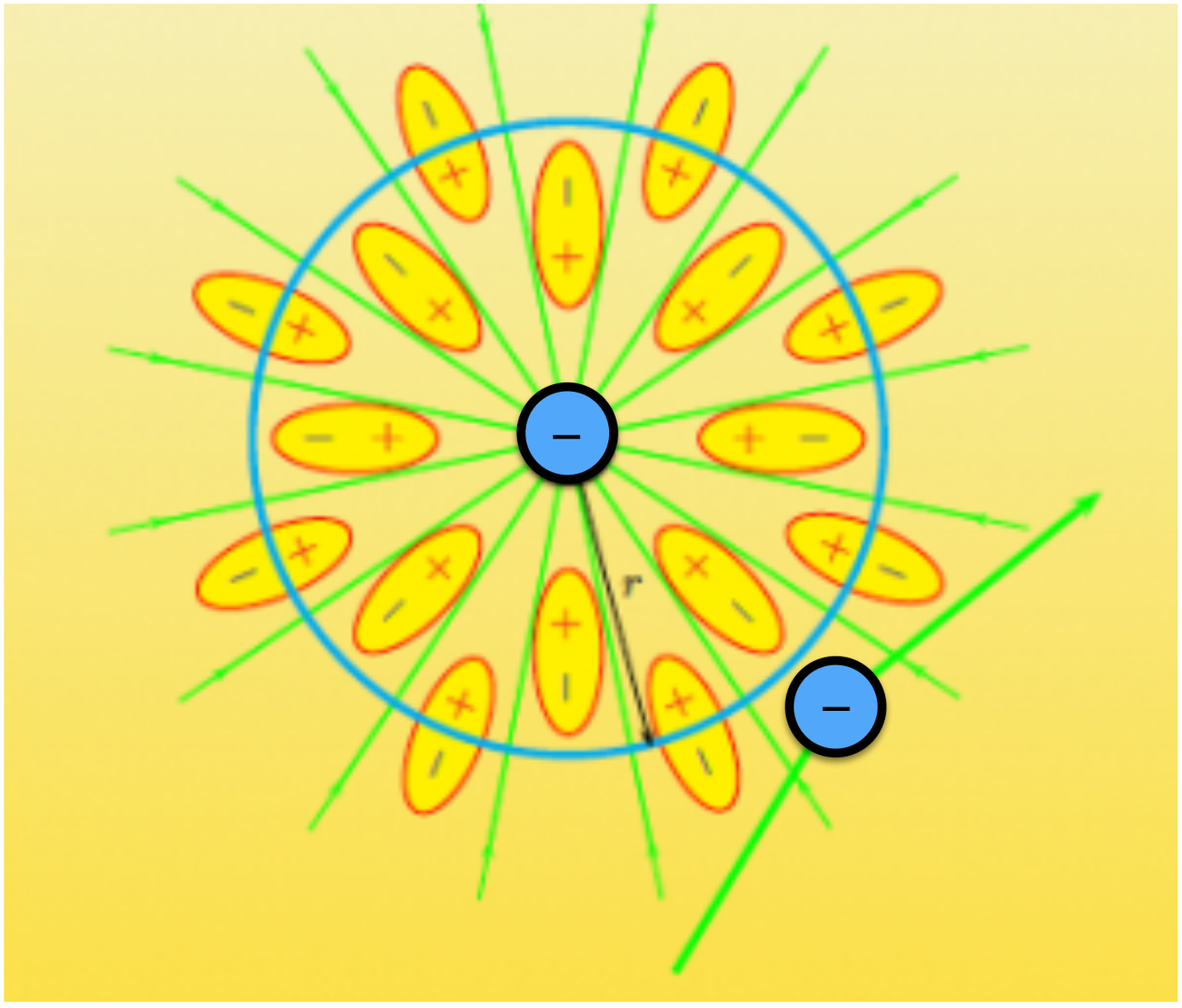
- Running coupling constants?



$$V(r) = -\frac{\alpha}{r}$$

The “Mass” of the Top Quark

- Running coupling constants?



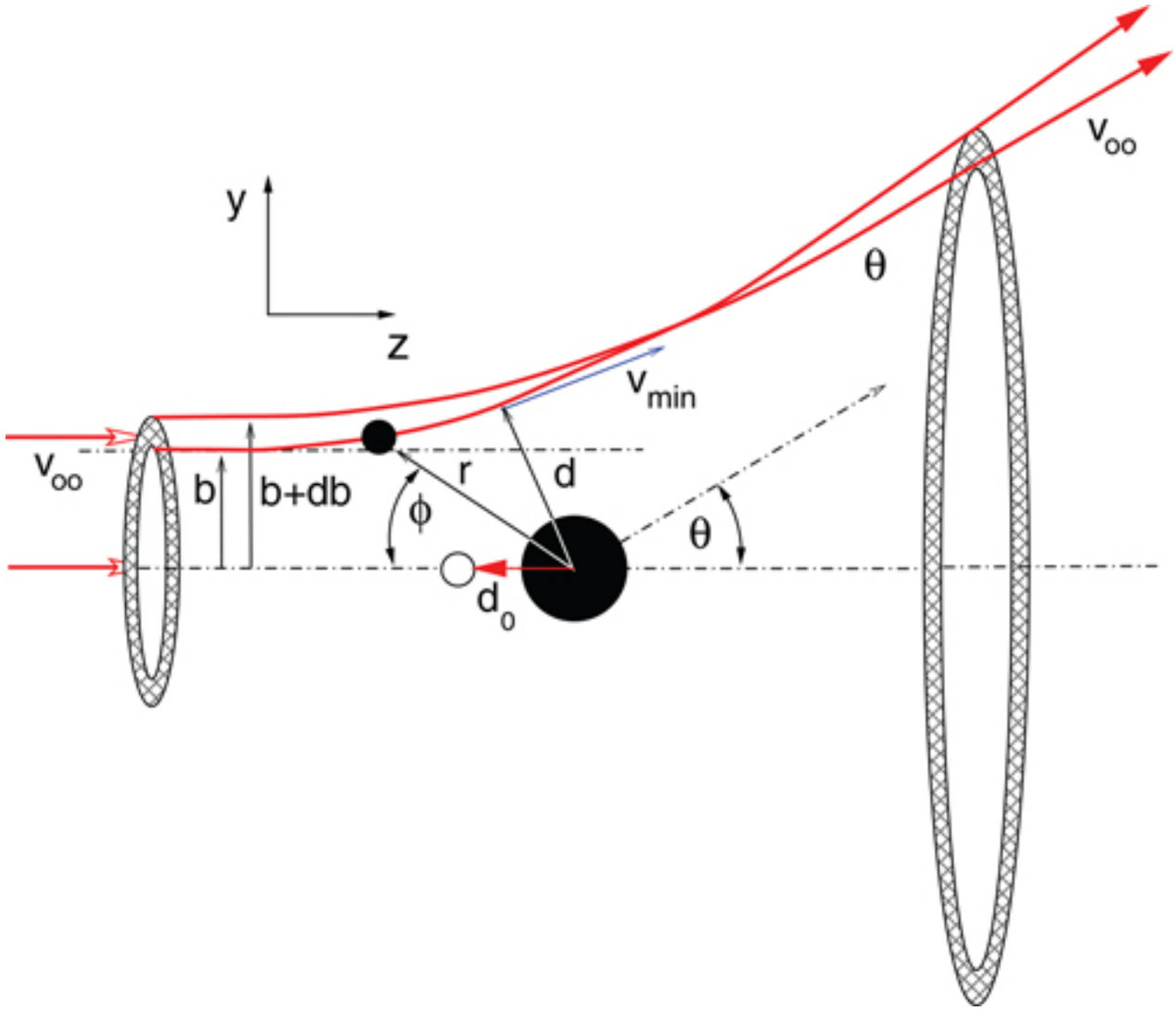
$$V(r) = -\frac{\alpha}{r} \quad \Rightarrow \text{Form invariance} \Rightarrow \quad V(r) = -\frac{\alpha(r)}{r}$$

The “Mass” of the Top Quark

- The parameters in the Lagrangian need explanations.

$$\mathscr{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m^2\phi^2$$

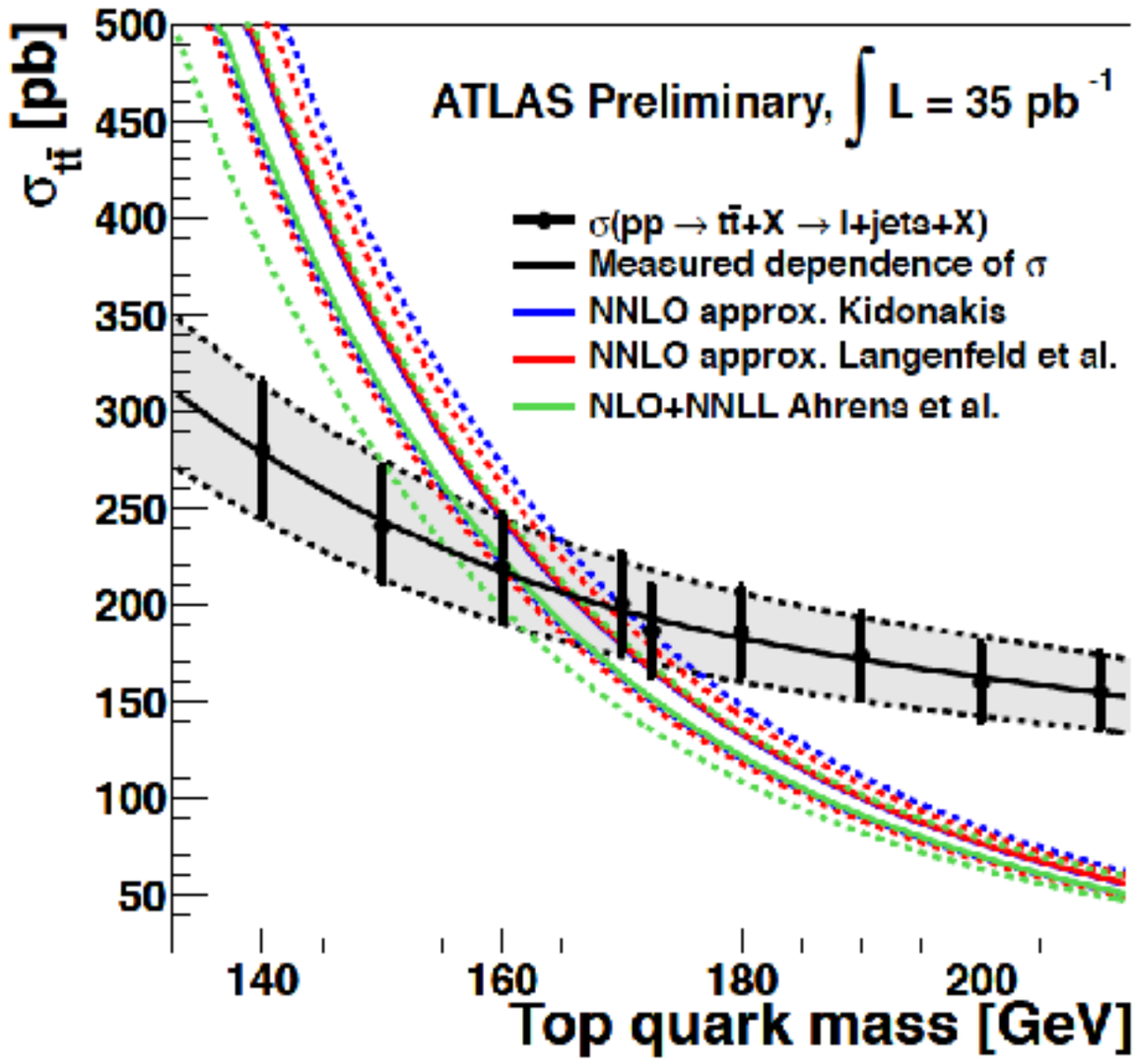
$$\mathscr{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4!}\phi^4$$



The “Mass” of the Top Quark

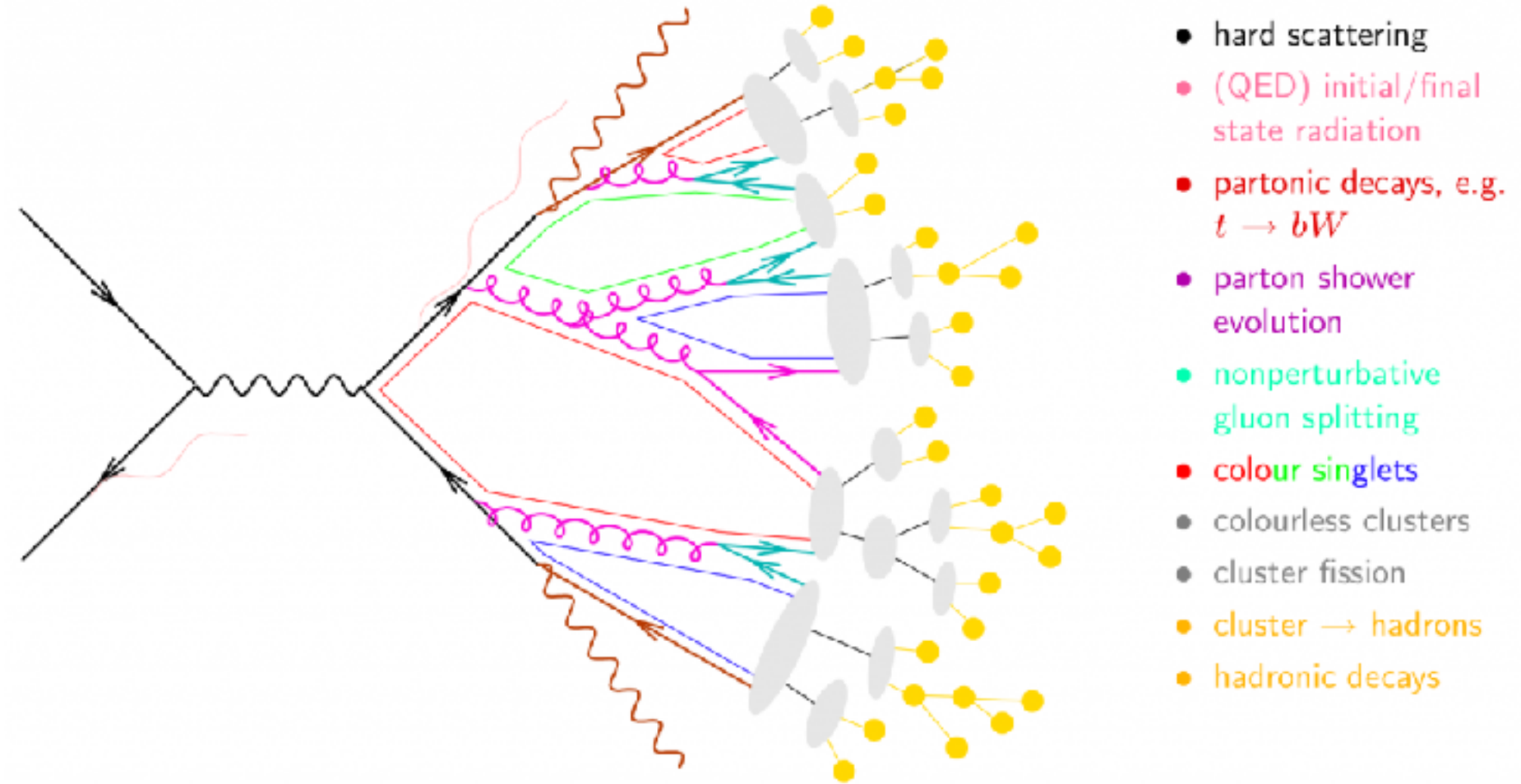
- MS bar mass and cross section.

$$\frac{d\sigma_{t\bar{t}}}{dx} = f^{(N)}(\alpha_s^X(\mu), m_t^X(\mu), \mu)$$



The “Mass” of the Top Quark

- Lepton collider:



- What mass?

The “Mass” of the Top Quark

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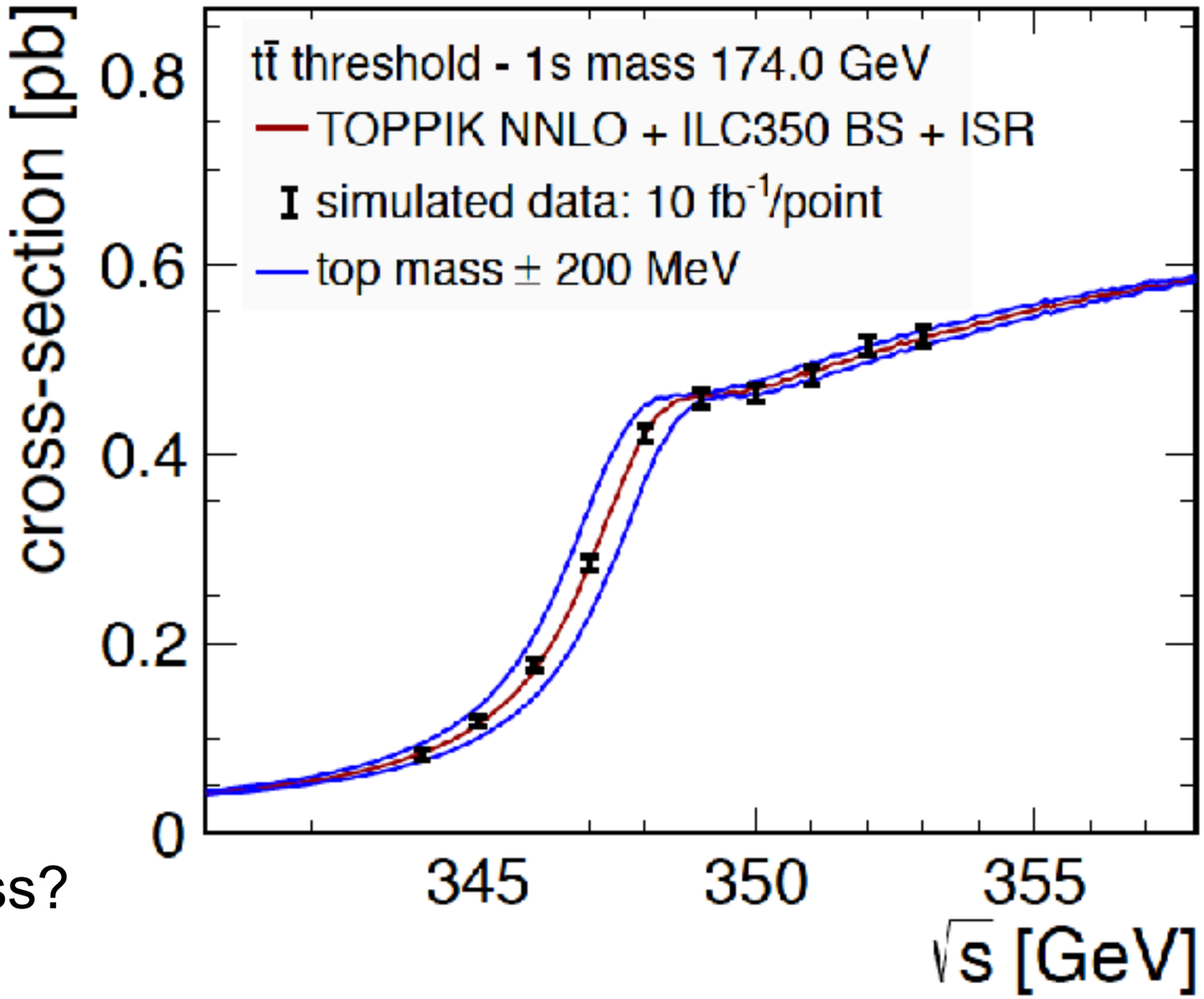

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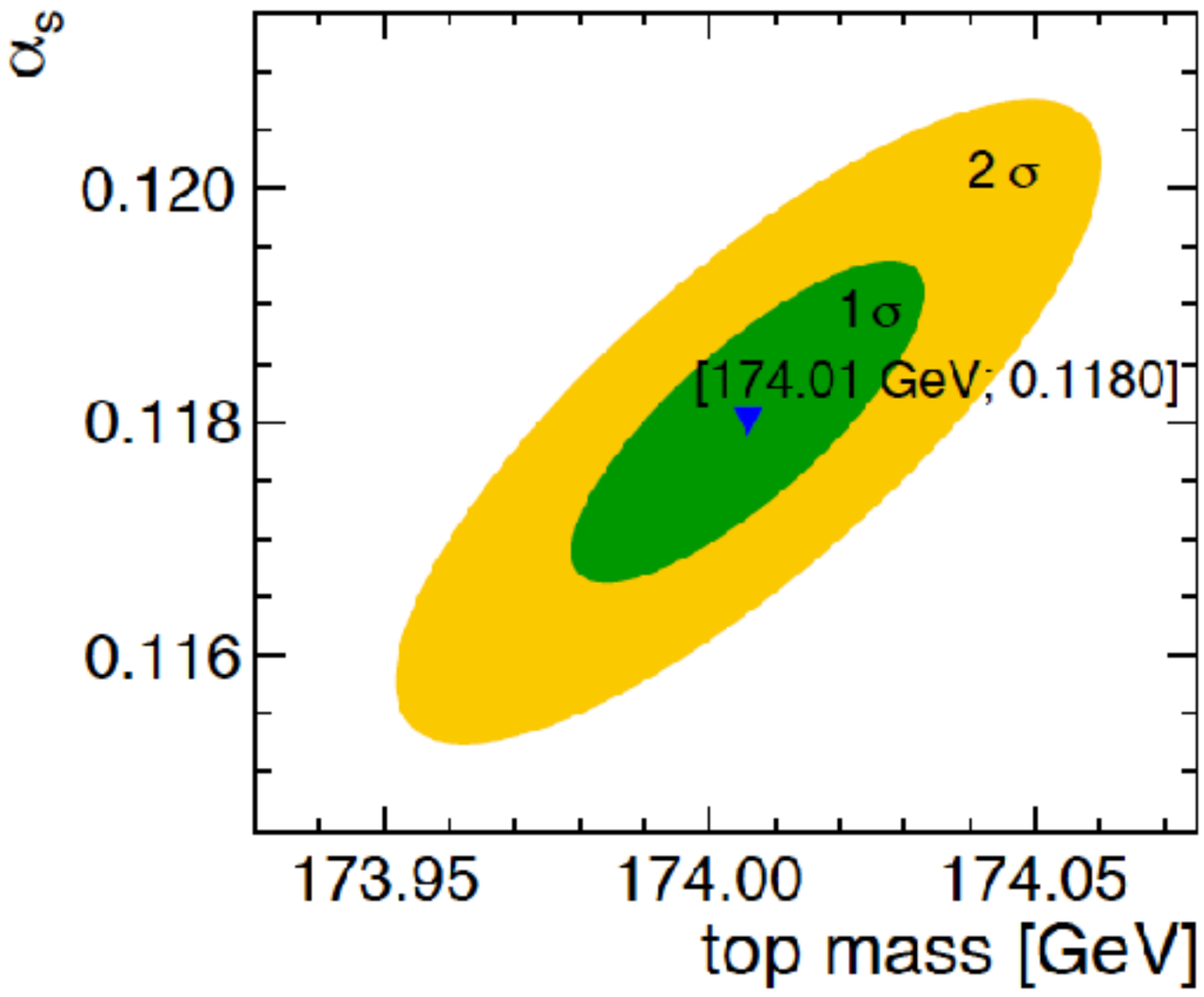
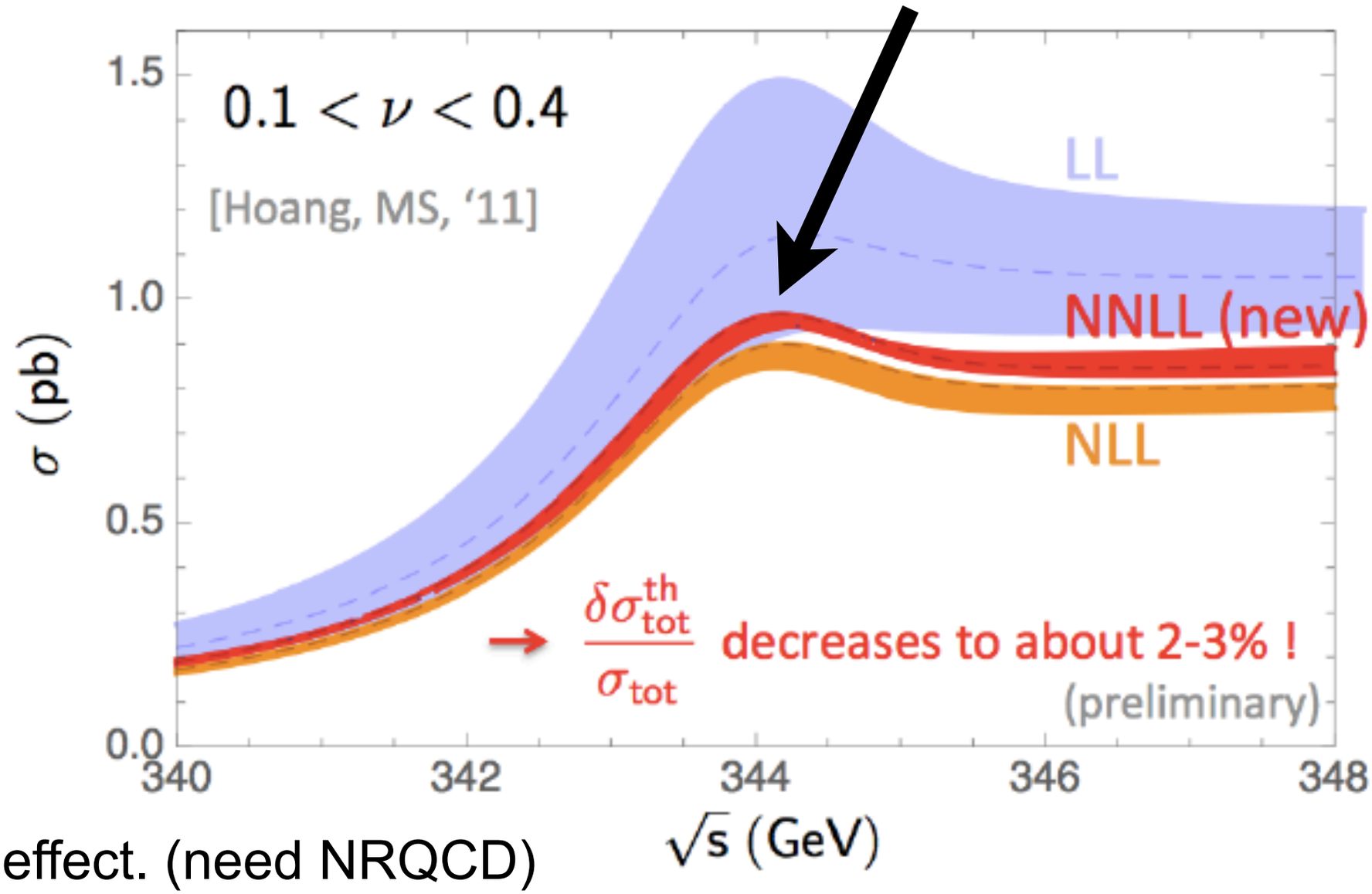


- What mass?

The “Mass” of the Top Quark

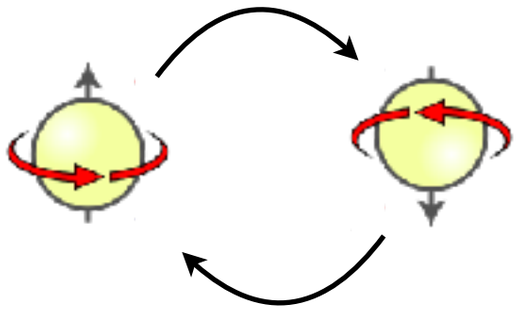
- Lepton collider:

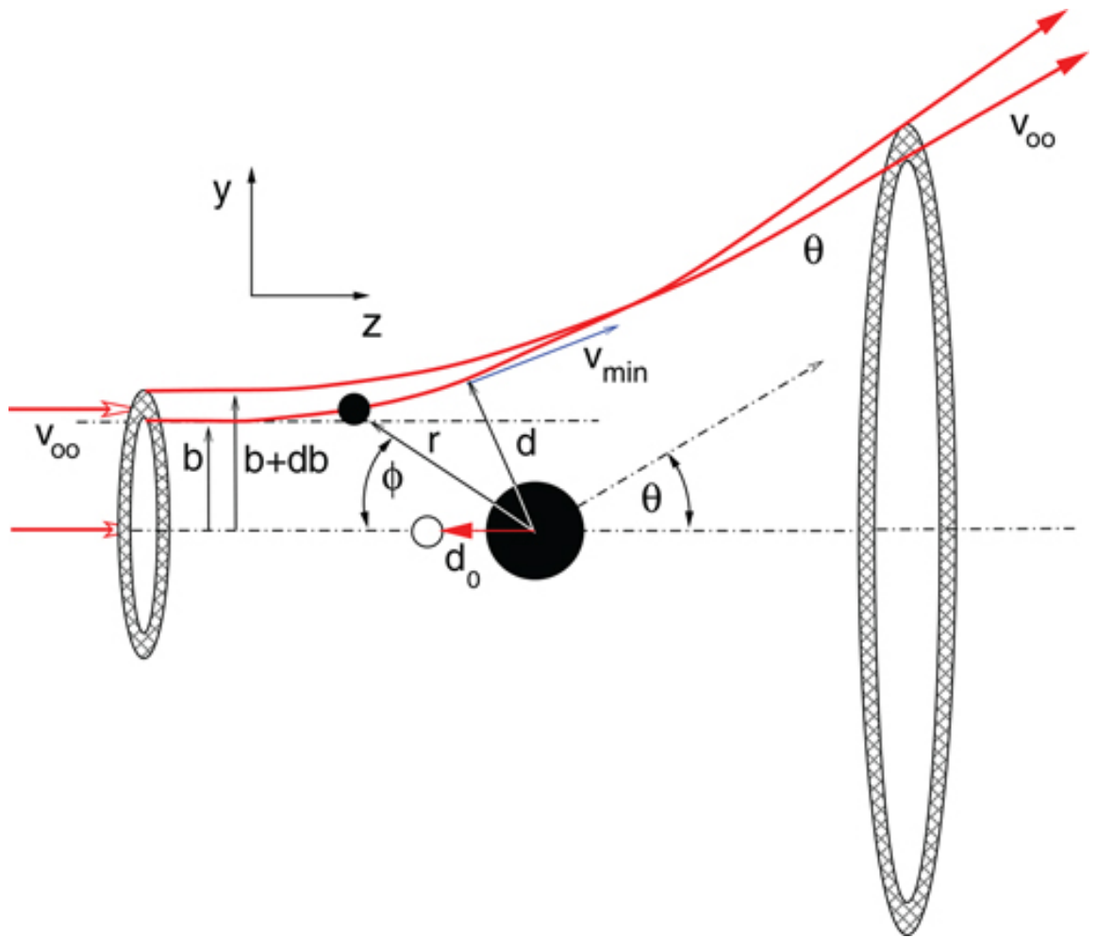


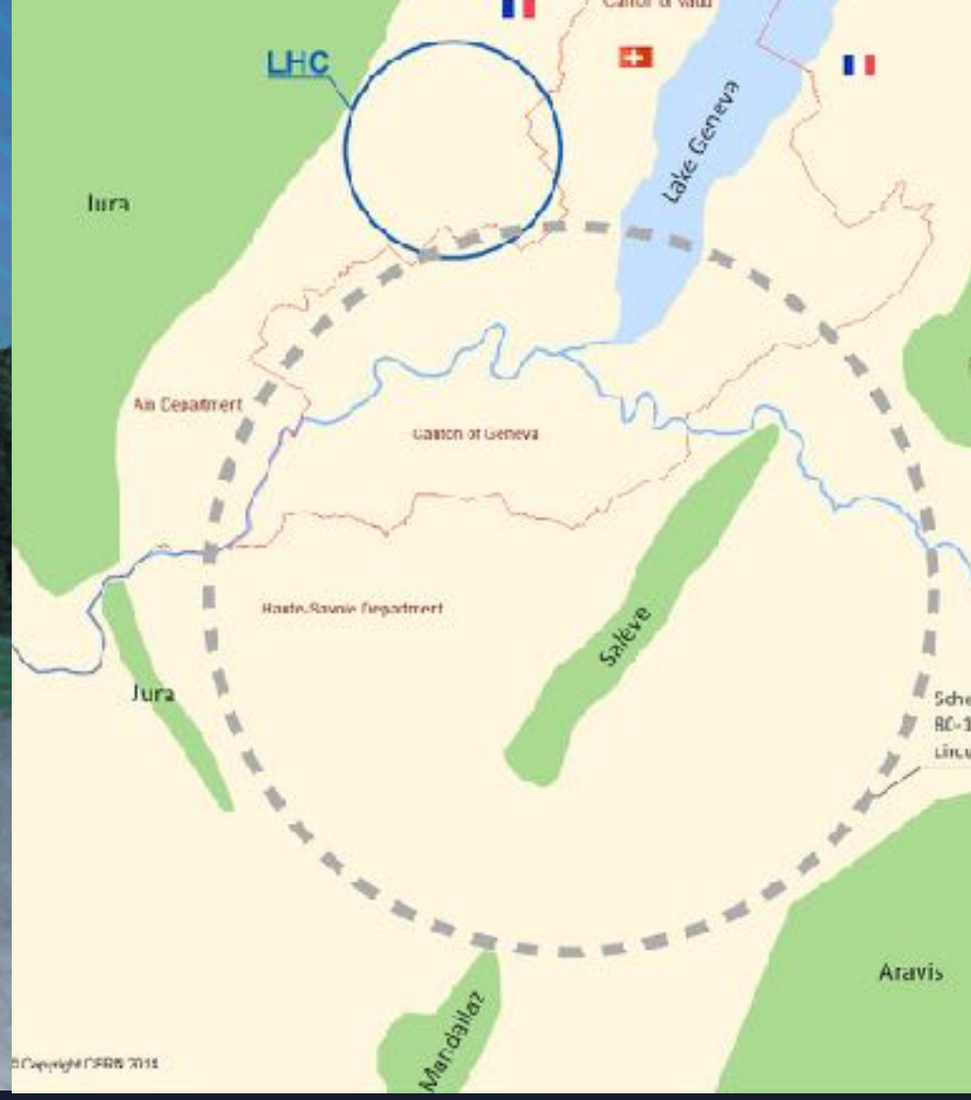
- Threshold effect. (need NRQCD)

The “Mass” of the Top Quark

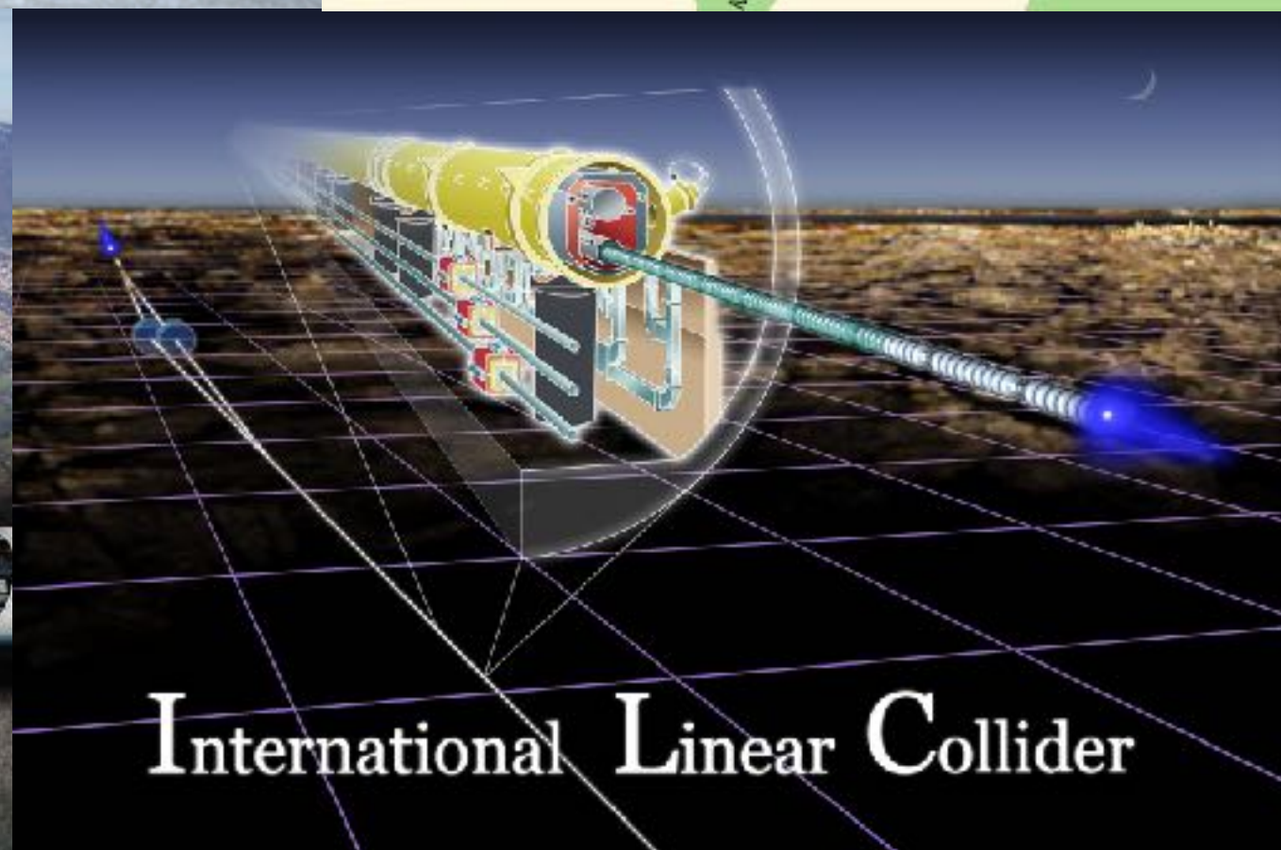
- Lepton collider:
- 1S mass.






LHC
Lake Geneva
Jura
Ain Department
Canton of Geneva
Haute-Savoie Department
Salève
Jura
Aravis
Mandallaz


Compact Linear Collider


International Linear Collider