

Physics Summary I: Higgs, Top/QCD, Loops (incl. $\gamma\gamma$, $e\gamma$, e^-e^-)

Sven Heinemeyer, Zaragoza

Bangalore, 03/2006

20 minutes (minus discussion time) \Rightarrow the usual apologies

- Physics at the ILC
- Higgs
- Top/QCD
- LoopVerein
- Outlook

1. Physics at the ILC

(ILC always includes $\gamma\gamma$, $e\gamma$, e^-e^-)

Reality: ILC will start after the LHC

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A: The ILC will add **precision** \Rightarrow The ILC delivers \oplus needs precision!

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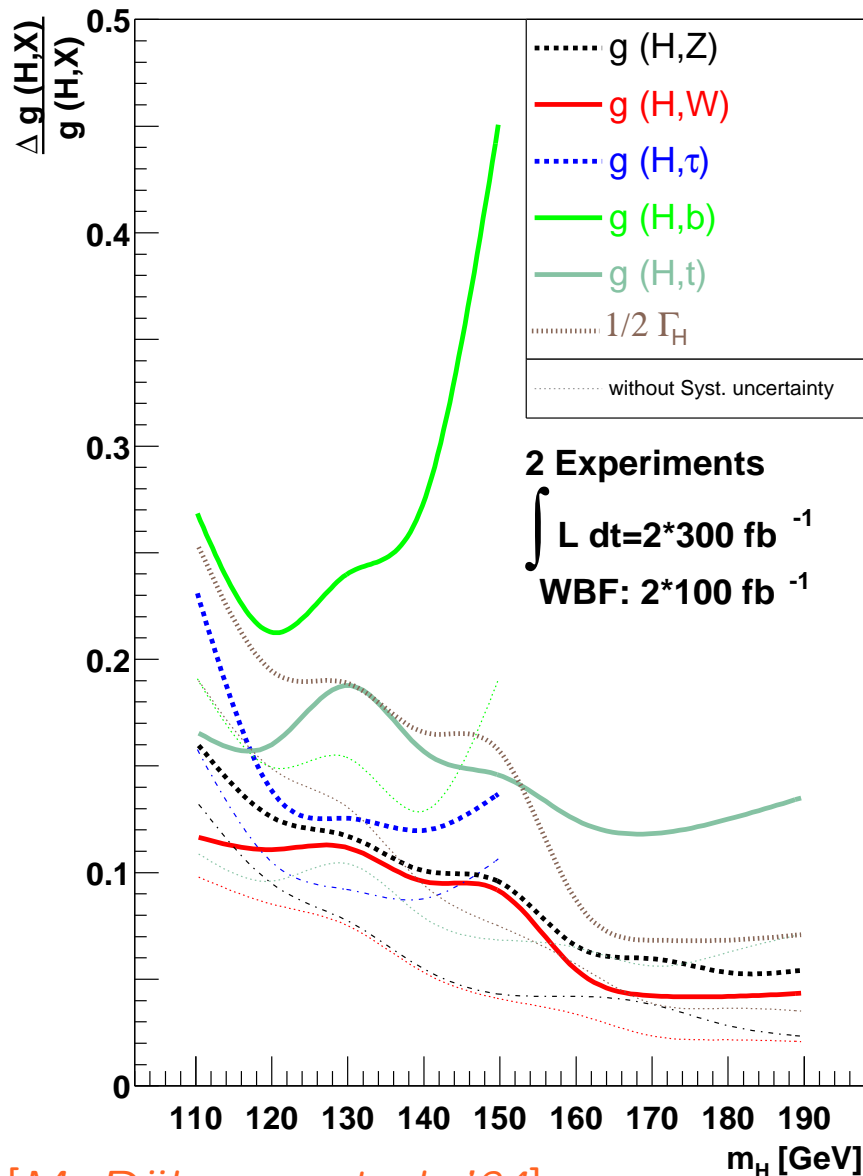
The ILC can make **discoveries** \Rightarrow What can the ILC detect/discover?

Where are we in this respect? (Status? What is needed? Achievement?)

- Higgs
- Top/QCD
- LoopVerein \Rightarrow relevant for all other topics!
- SUSY
- New Physics at TeV, precision electroweak
- Cosmological connections

2. Higgs

The LHC will find a Higgs and measure its characteristics:



[M. Dürrssen et al. '04]

– mass: $\delta M_h \approx 200 \text{ MeV}$

– couplings: $(2 * 300 + 2 * 100) \text{ fb}^{-1}$:
typical accuracies of 20-30%
for $m_H \leq 150 \text{ GeV}$

10% accuracies for HVV couplings
above WW threshold

Assumption:

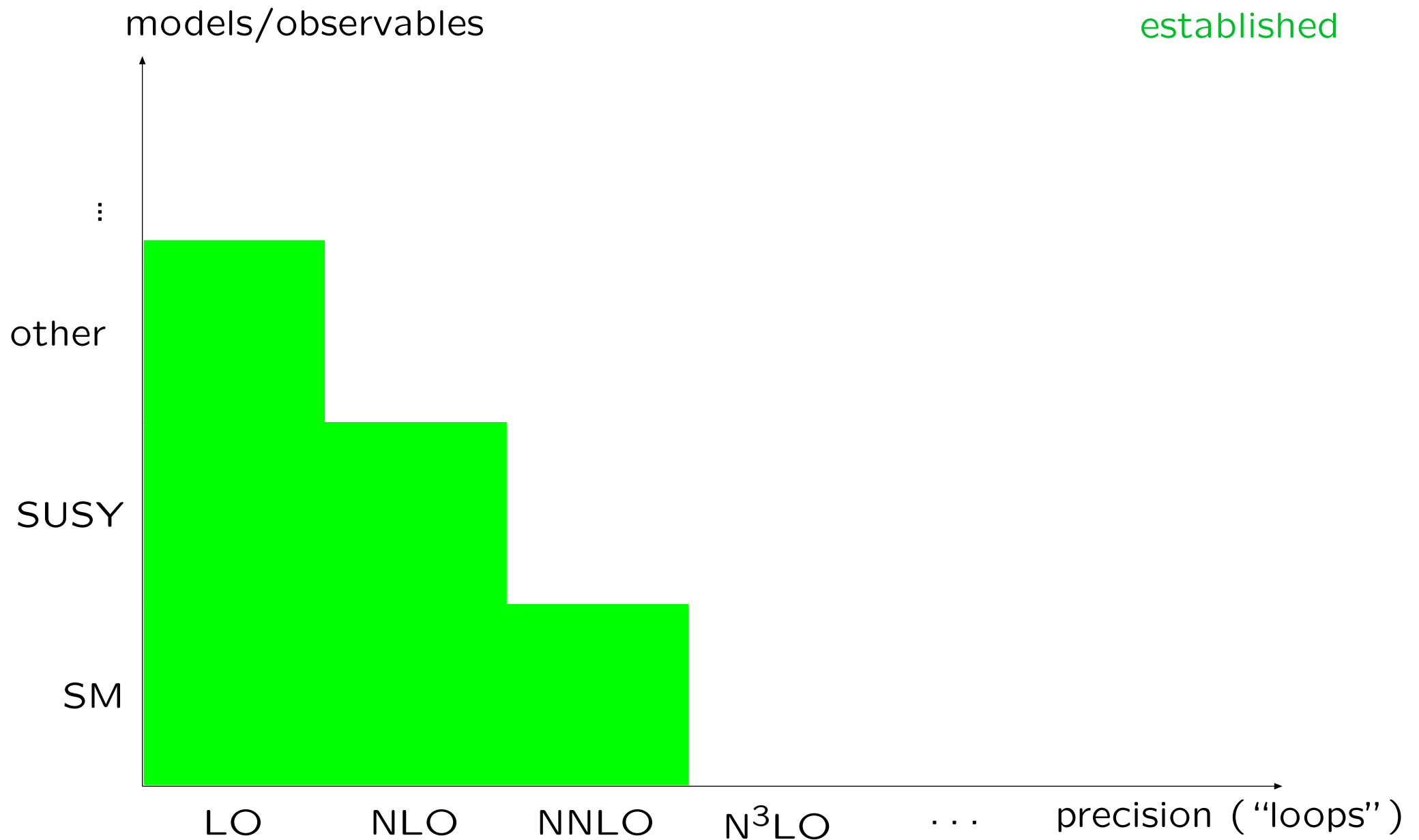
- $g_{HVV}^2 \leq g_{HVV,SM}^2 \times 1.05$
- SM rates for the Higgs

Problems:

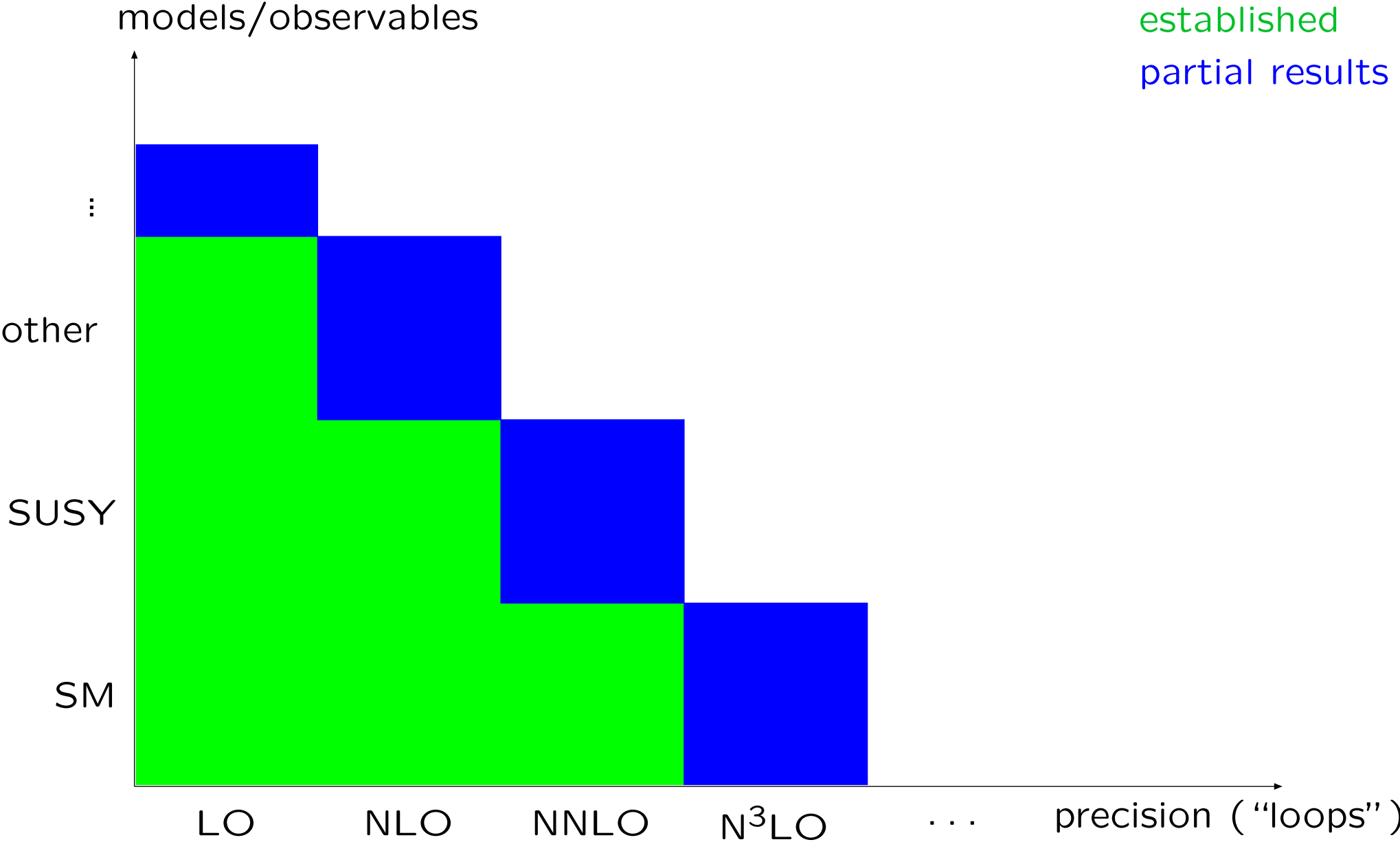
- valid in weakly interacting models
- rates much lower than in SM ??
- physics can/will hide in 5% margin
- self-couplings out of reach

⇒ ILC comes in

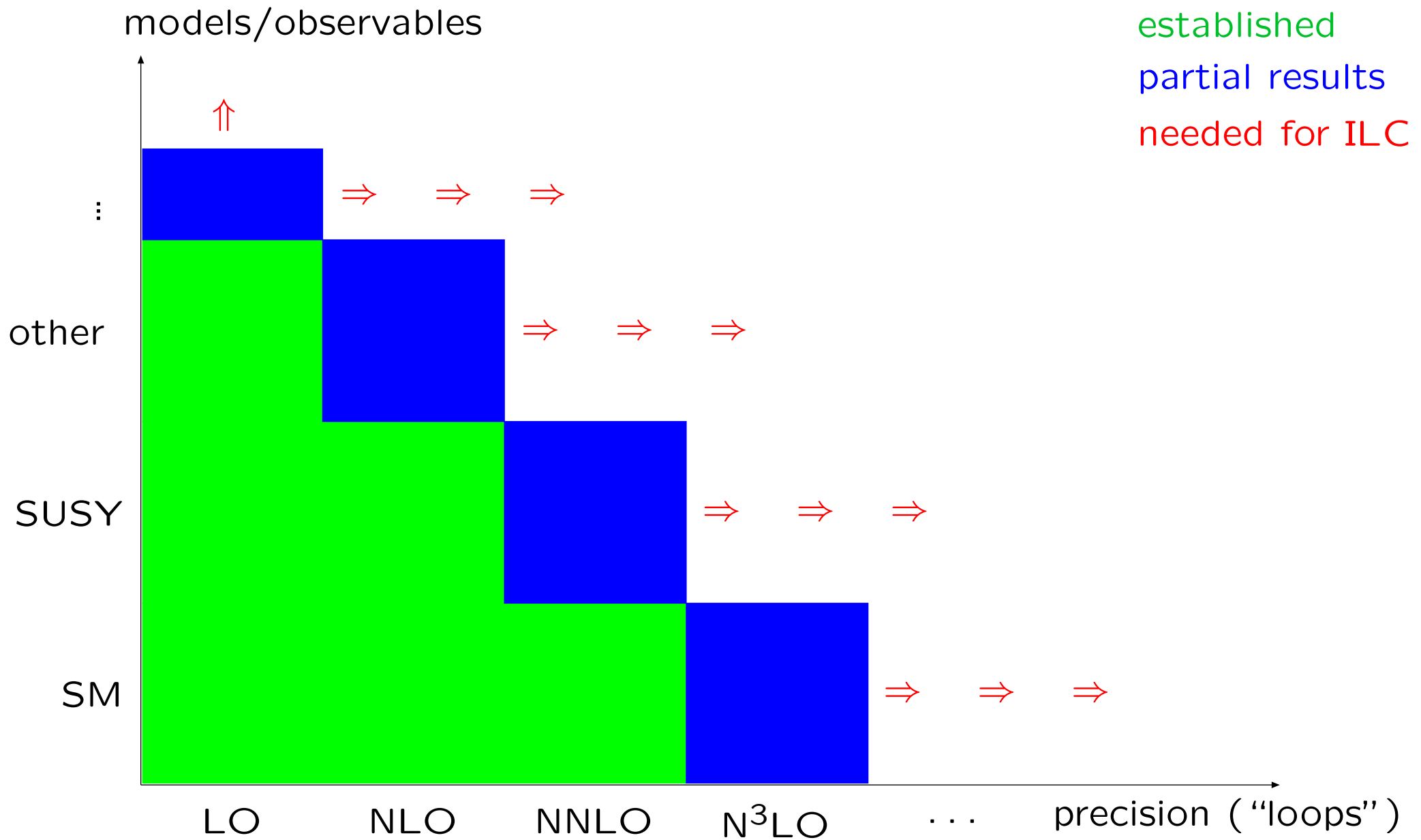
Higgs: theory situation



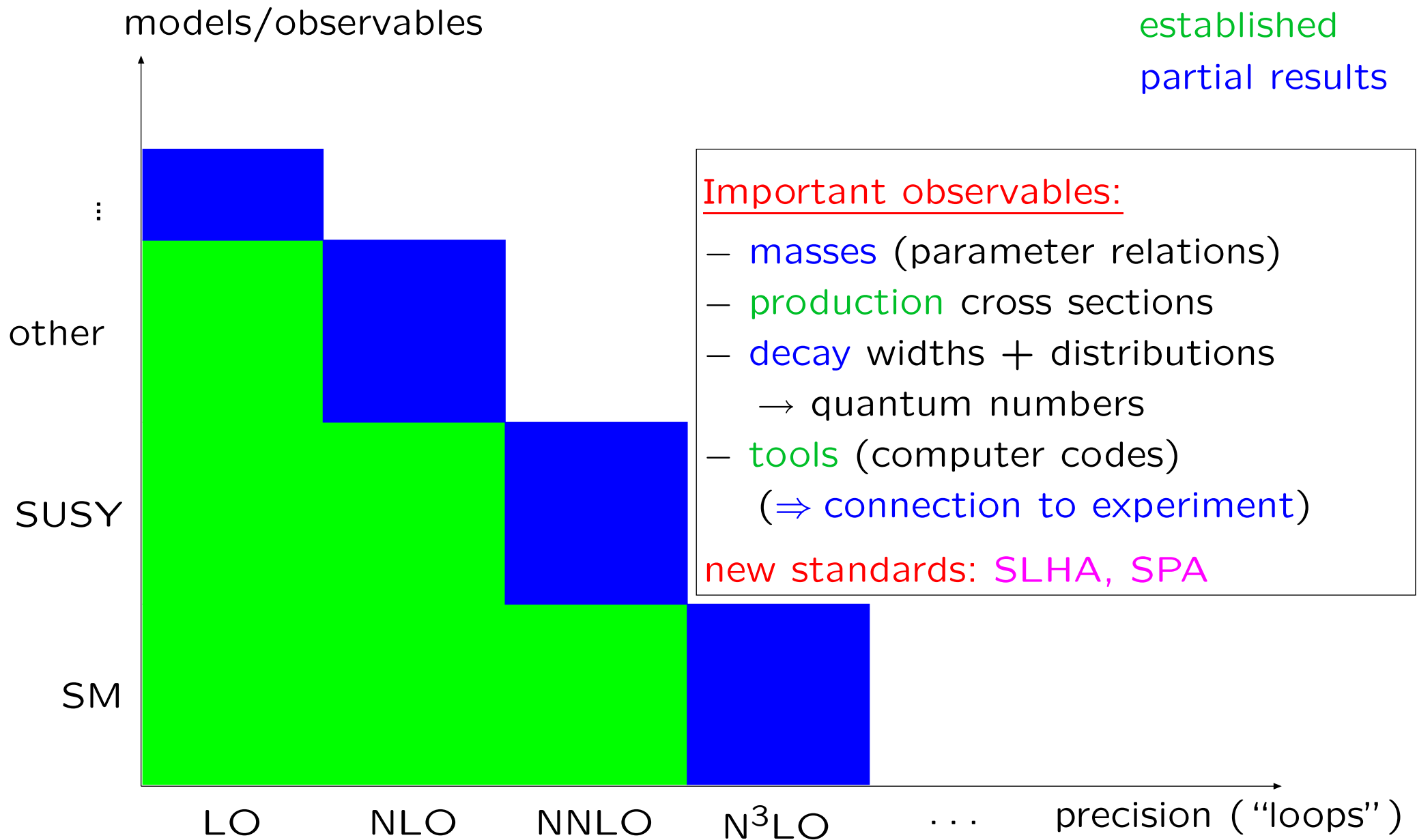
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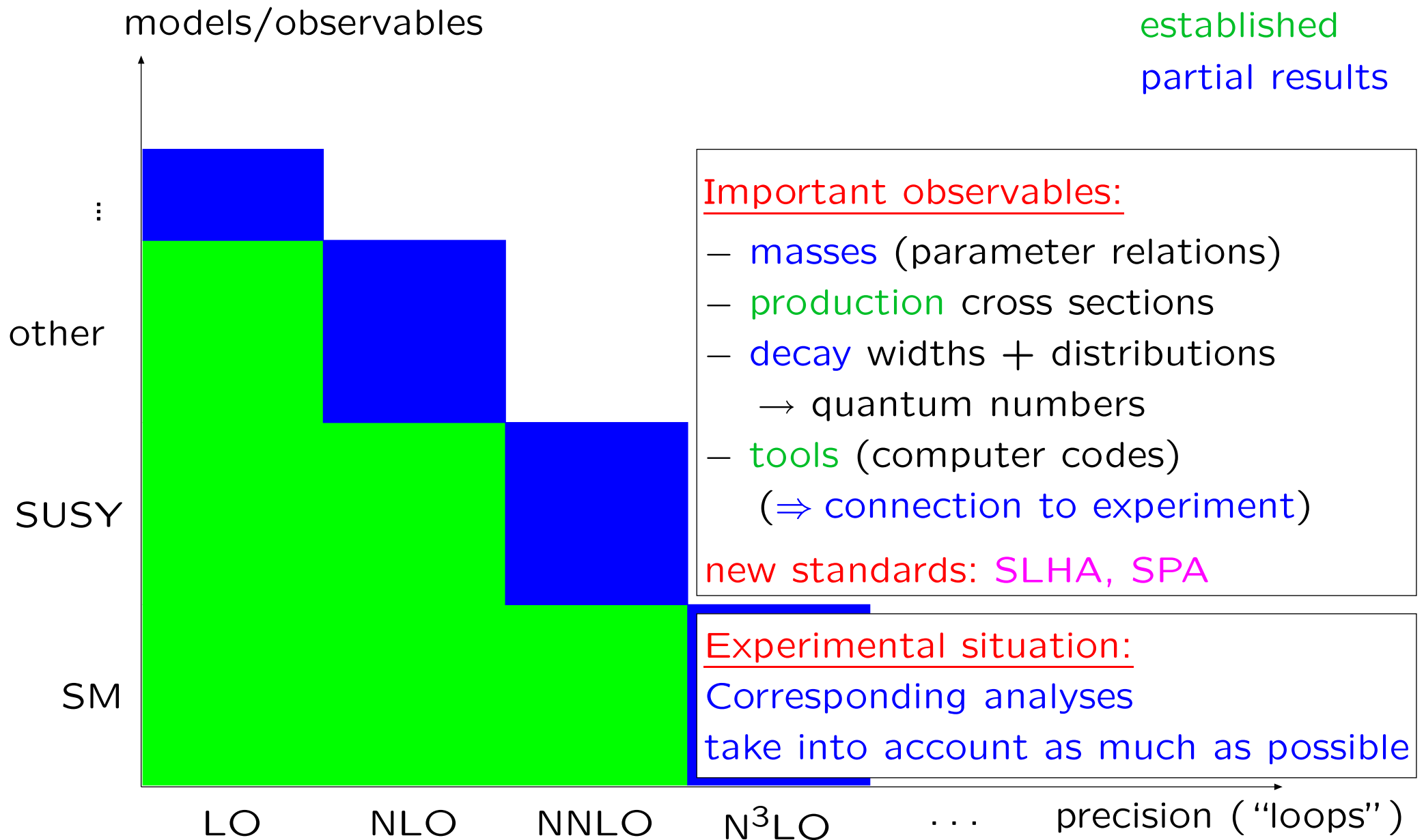
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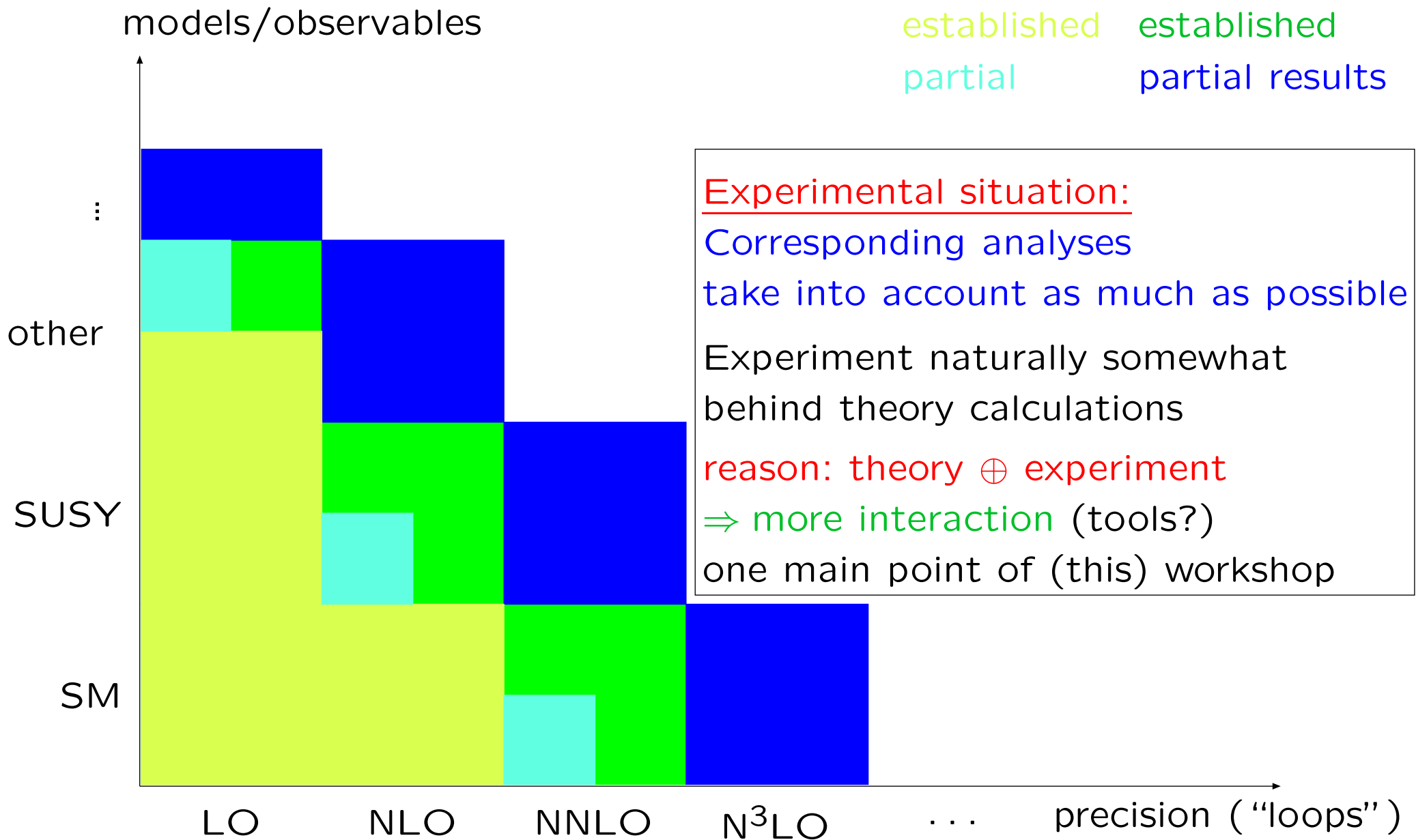


Higgs: experimental situation



Higgs: experimental situation

<u>experiment</u>	<u>theory</u>
established	established
partial	partial results



Higgs: experimental situation

experiment

theory

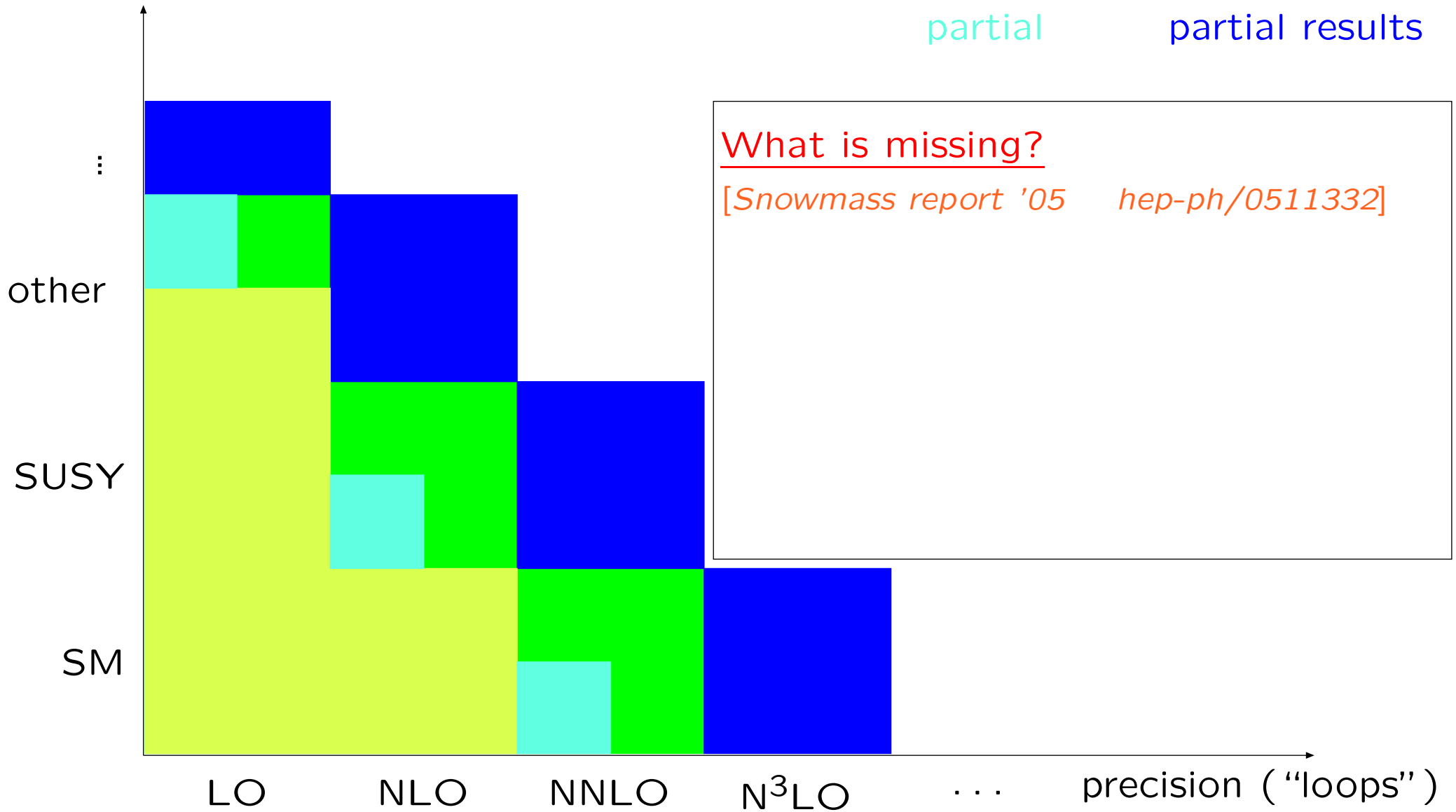
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partial results

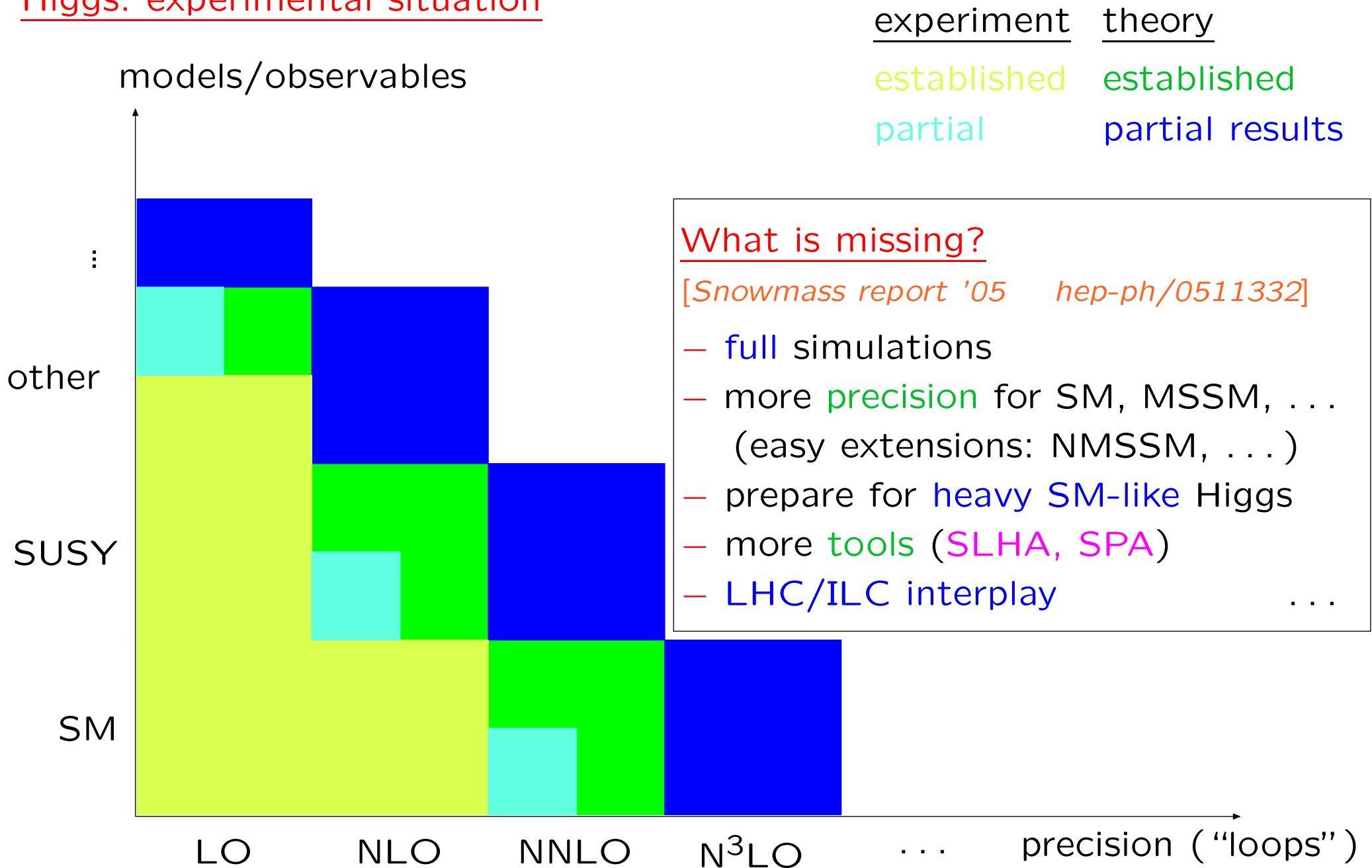
models/observables



What is missing?

[Snowmass report '05 hep-ph/0511332]

Higgs: experimental situation



Higgs: contributions in Bangalore

experiment

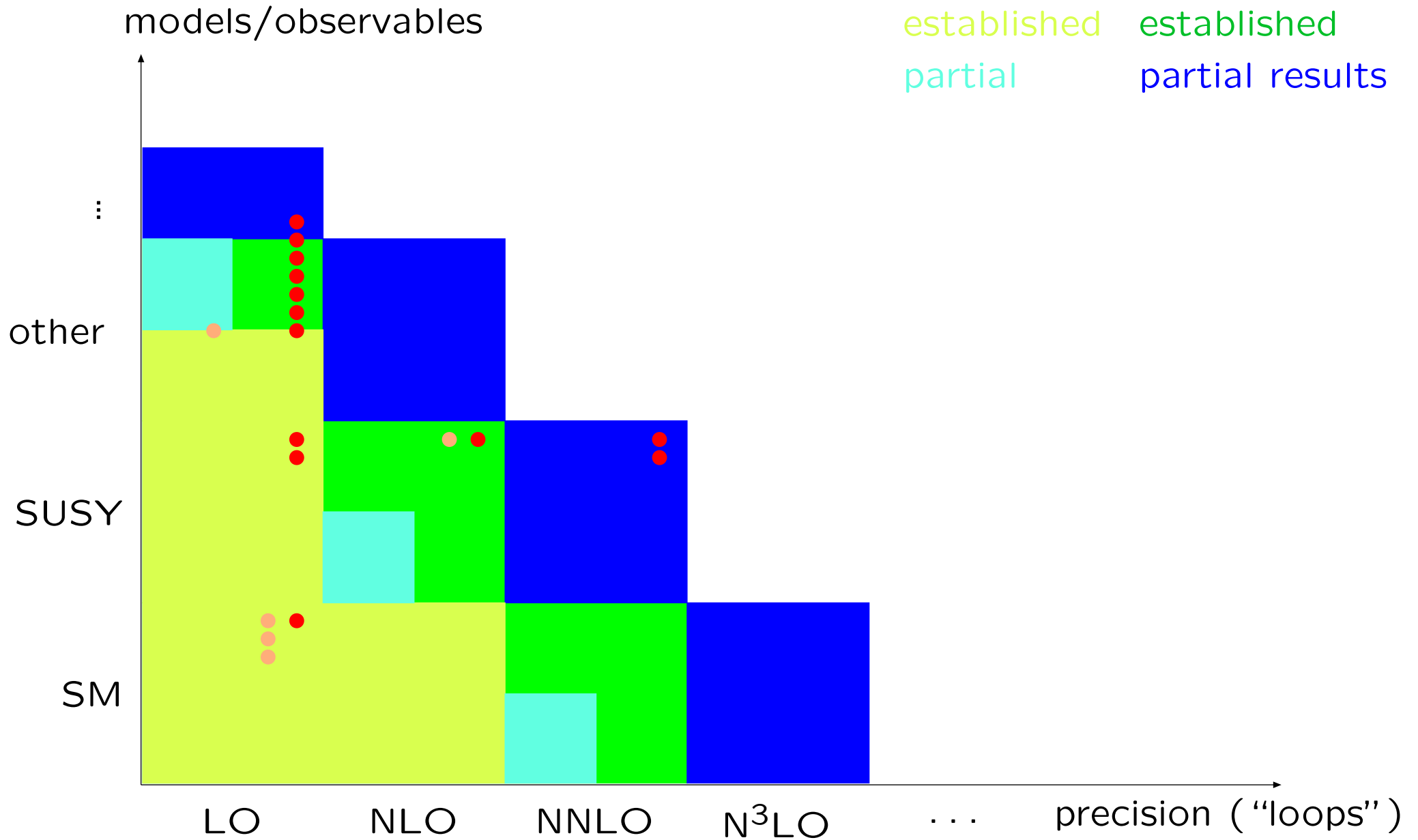
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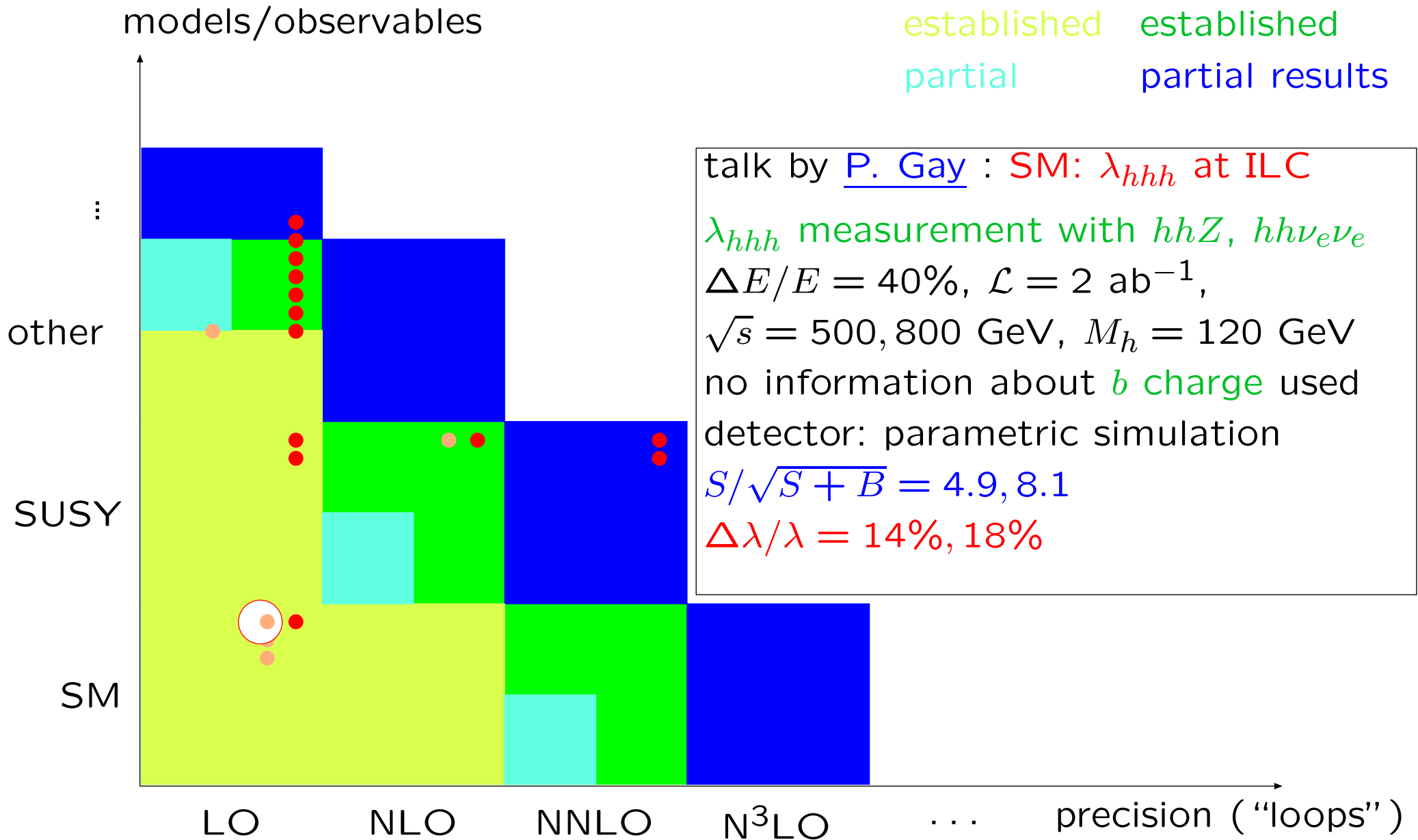
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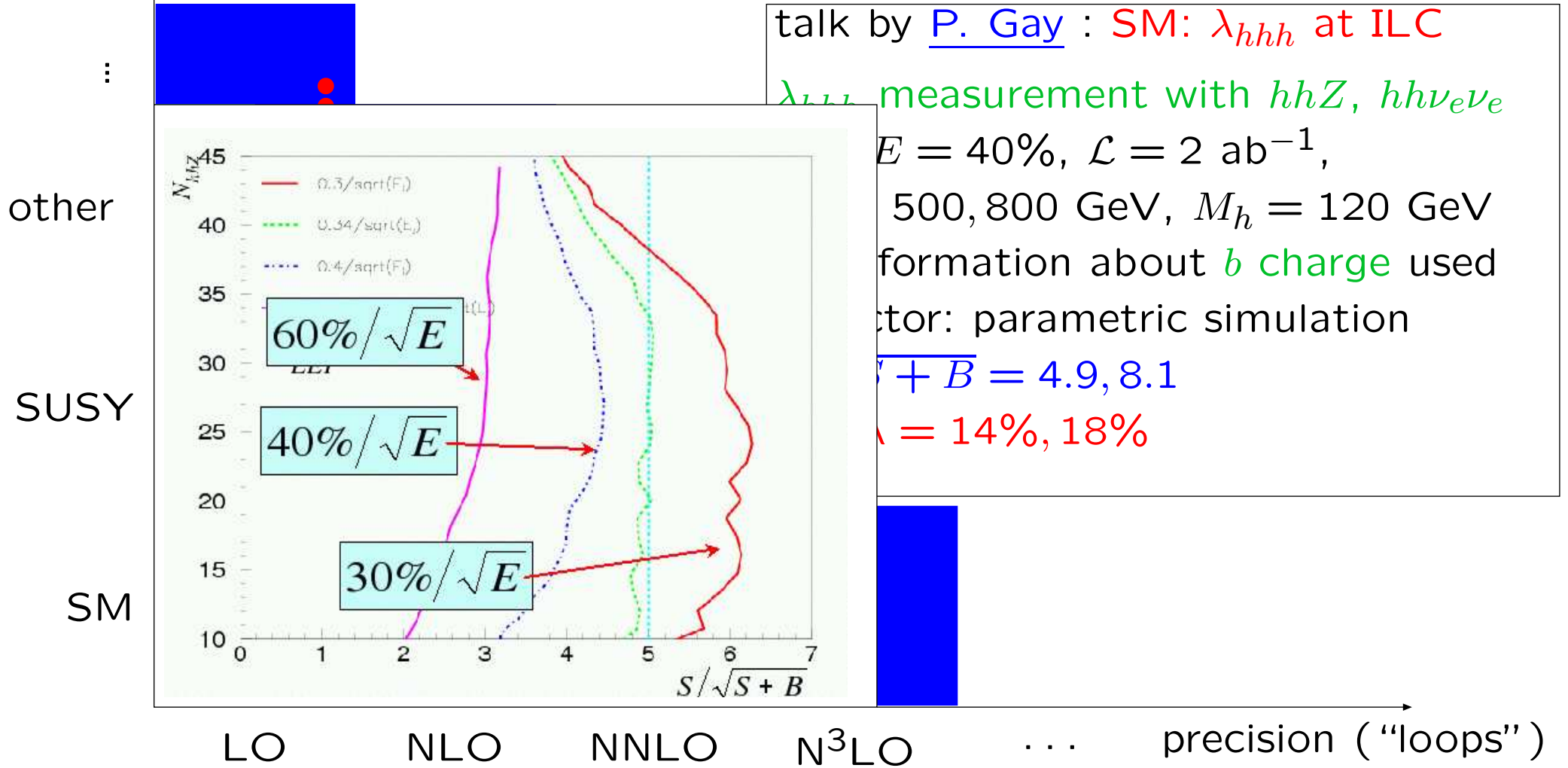
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Higgs: contributions in Bangalore

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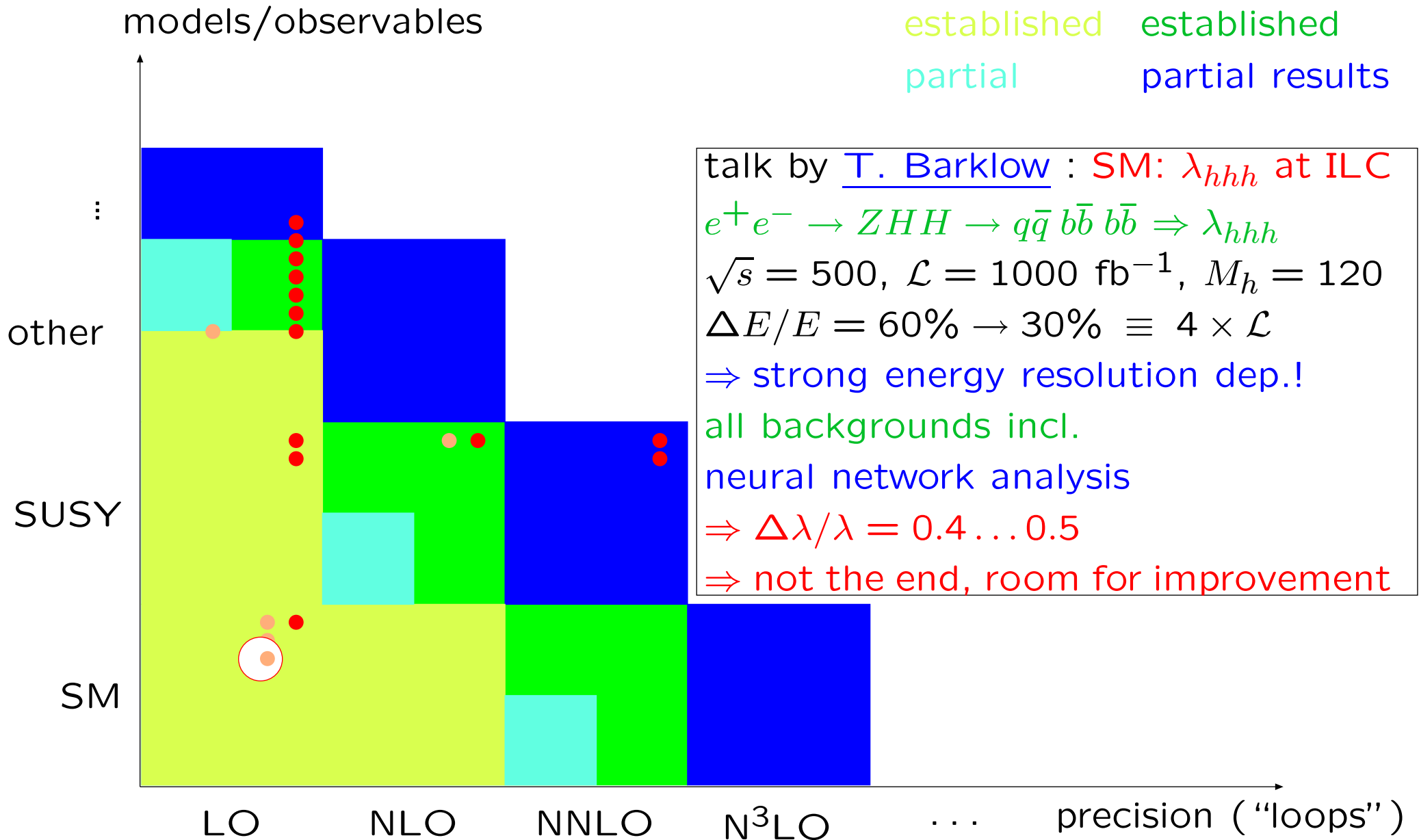
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talk by [T. Barklow](#) : SM: λ_{hhh} at ILC

$e^+e^- \rightarrow ZHH \rightarrow q\bar{q} b\bar{b} b\bar{b} \Rightarrow \lambda_{hhh}$

$\sqrt{s} = 500$, $\mathcal{L} = 1000 \text{ fb}^{-1}$, $M_h = 120$

$E = 60\% \rightarrow 30\% \equiv 4 \times \mathcal{L}$
 strong energy resolution dep.!

backgrounds incl.

global network analysis

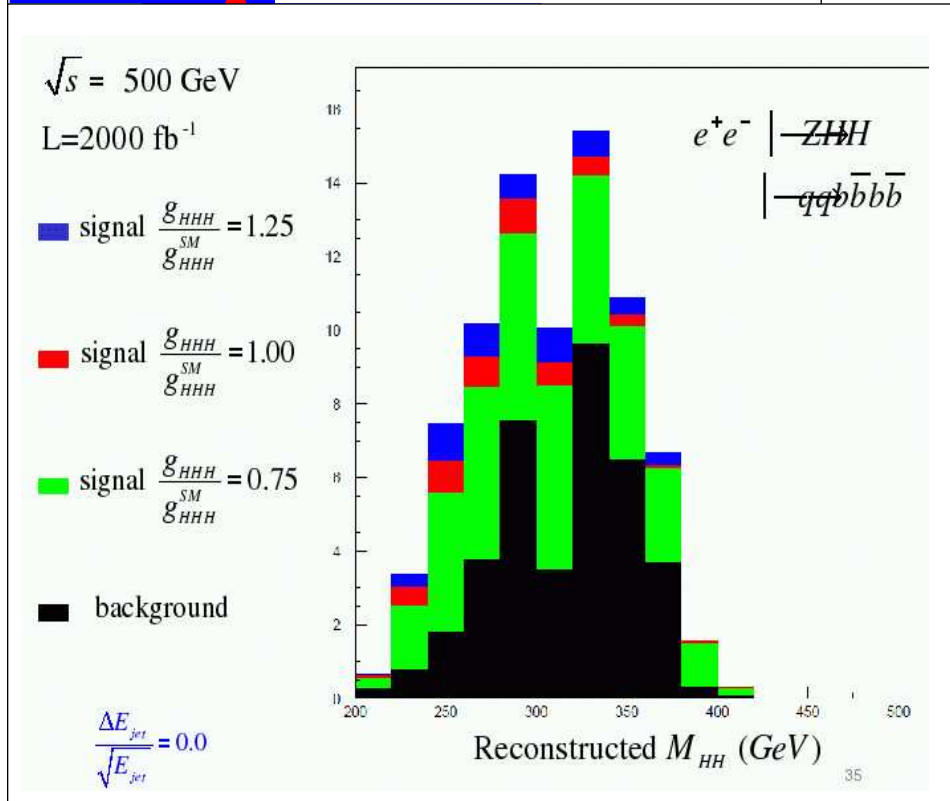
$\lambda/\lambda = 0.4 \dots 0.5$

at the end, room for improvement

other

SUSY

SM



LO

NLO

NNLO

N³LO

...

precision ("loops")

Higgs: contributions in Bangalore

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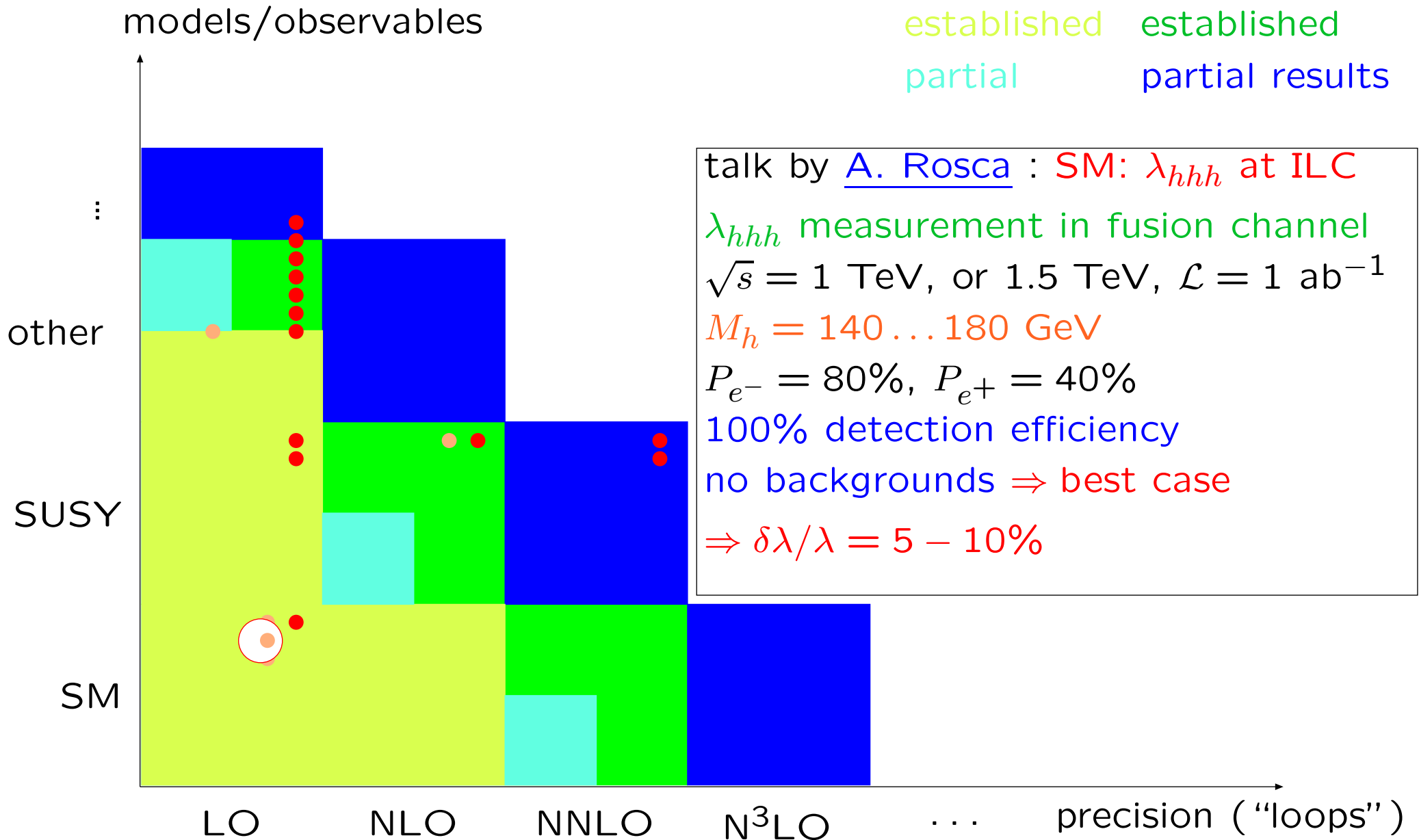
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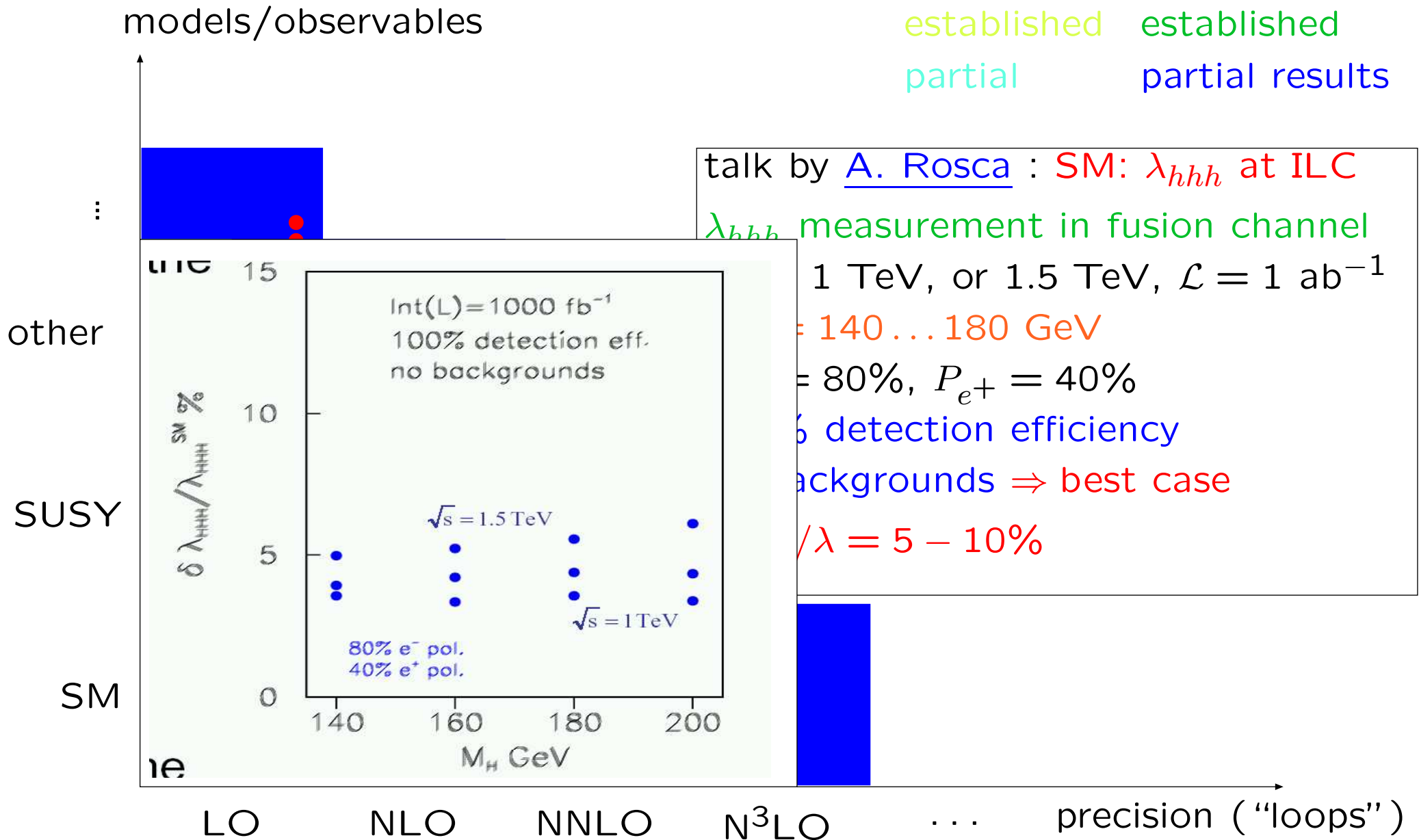
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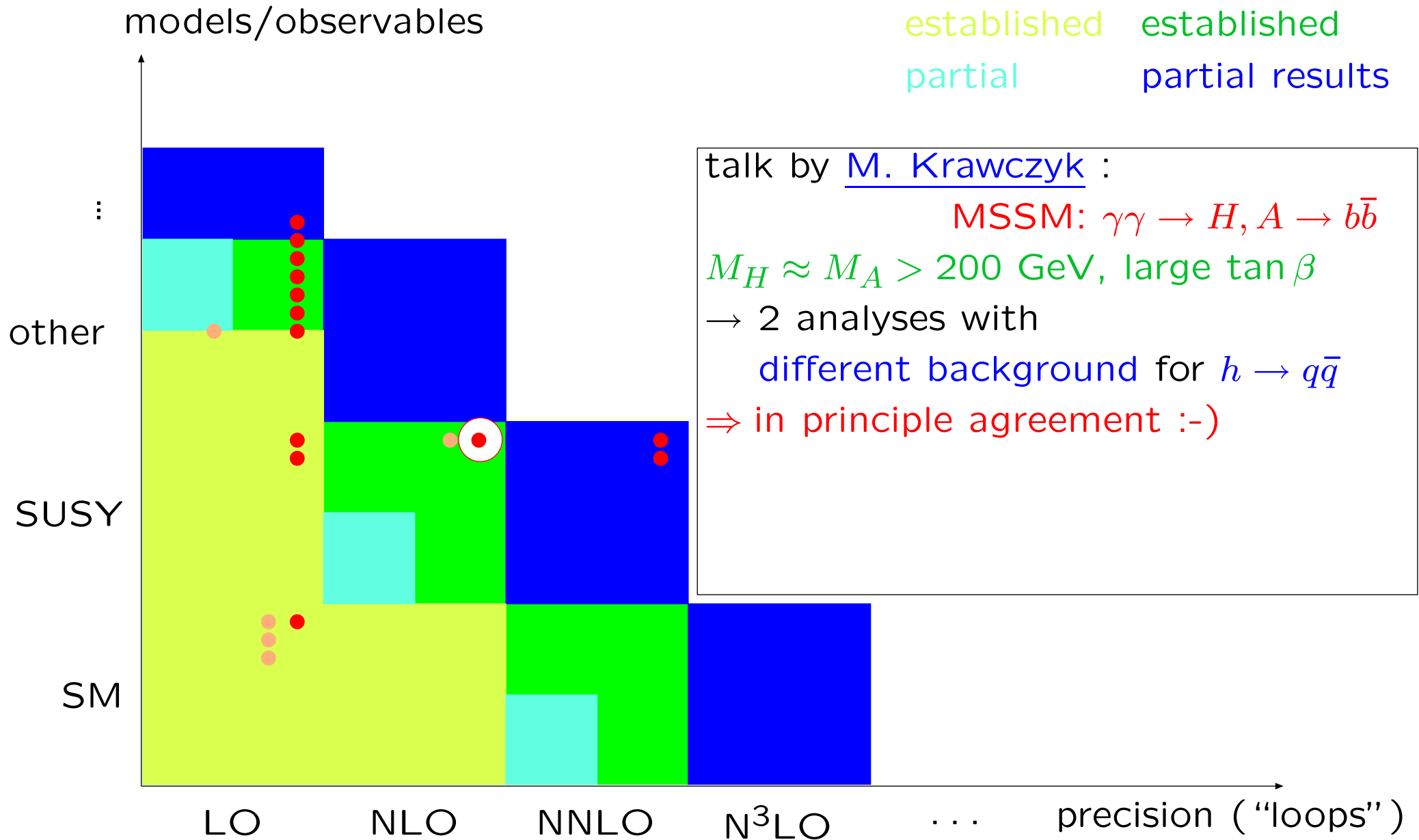
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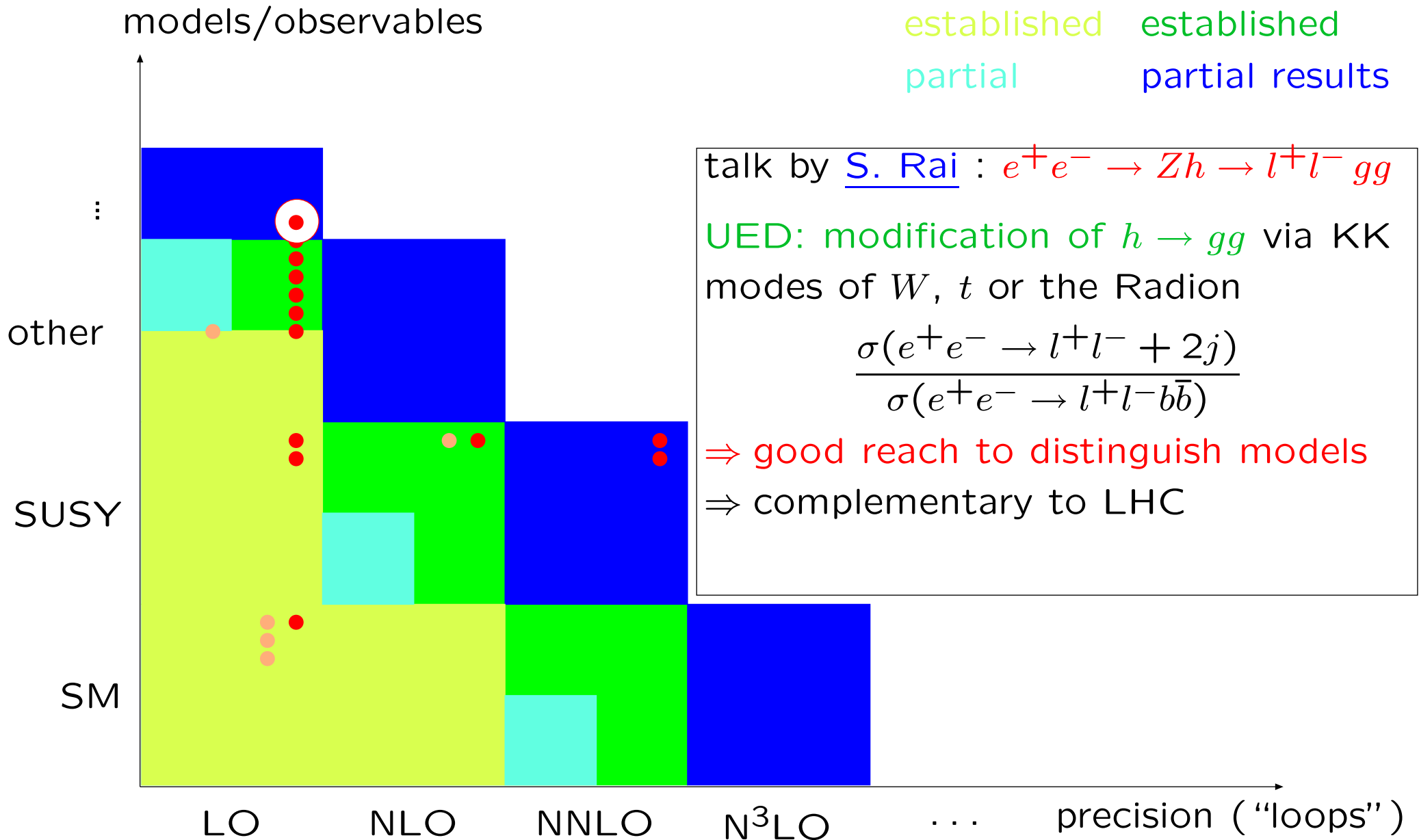
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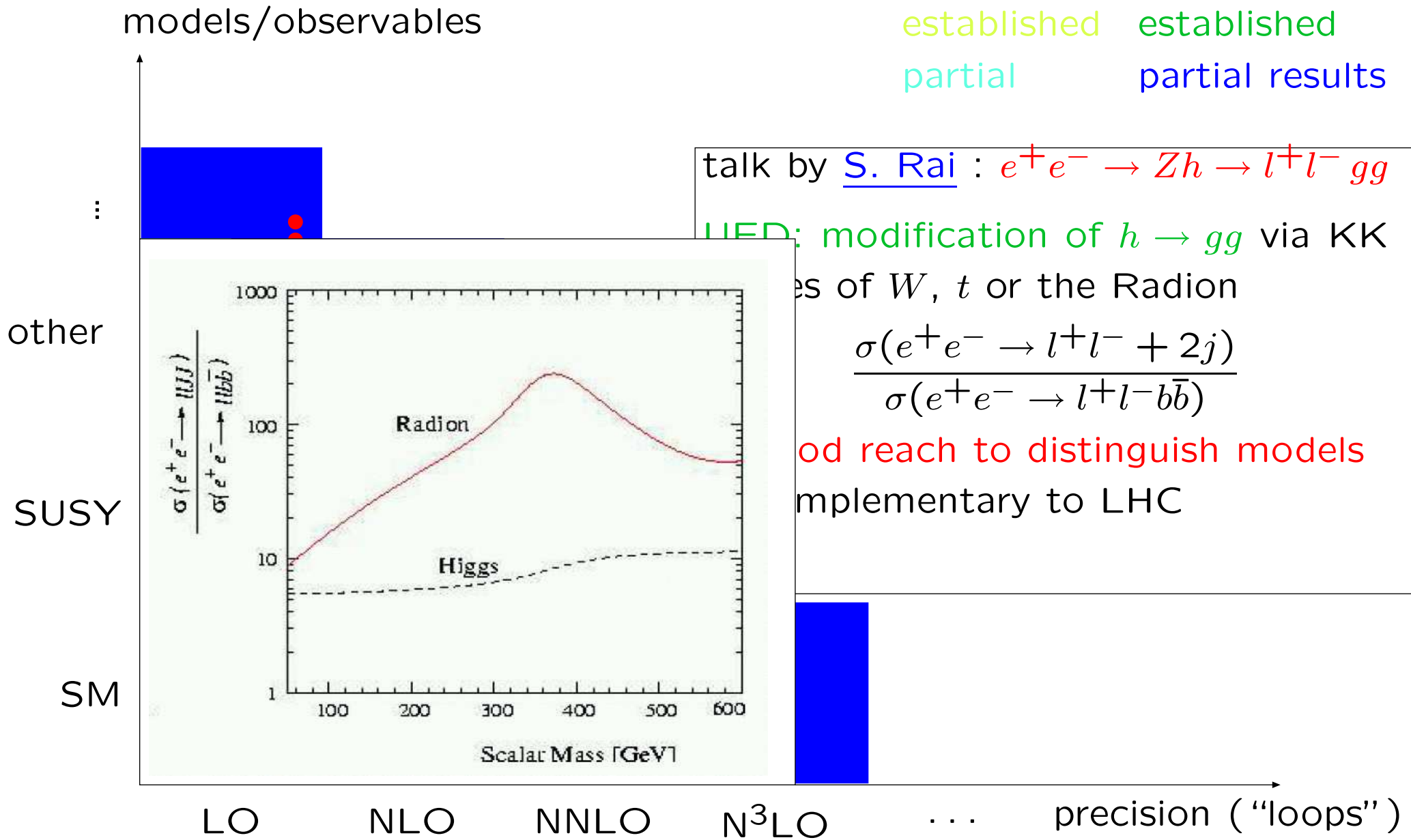
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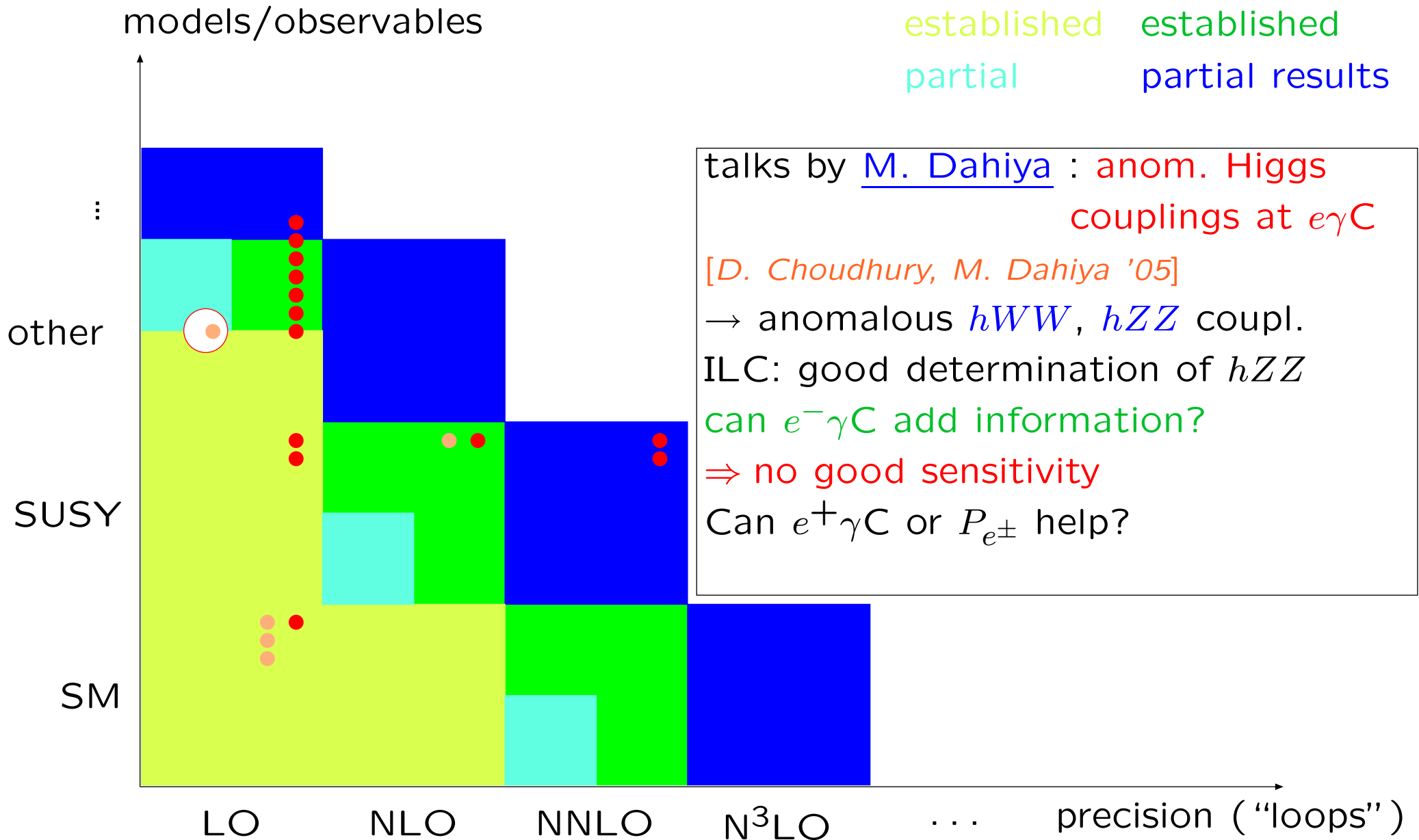
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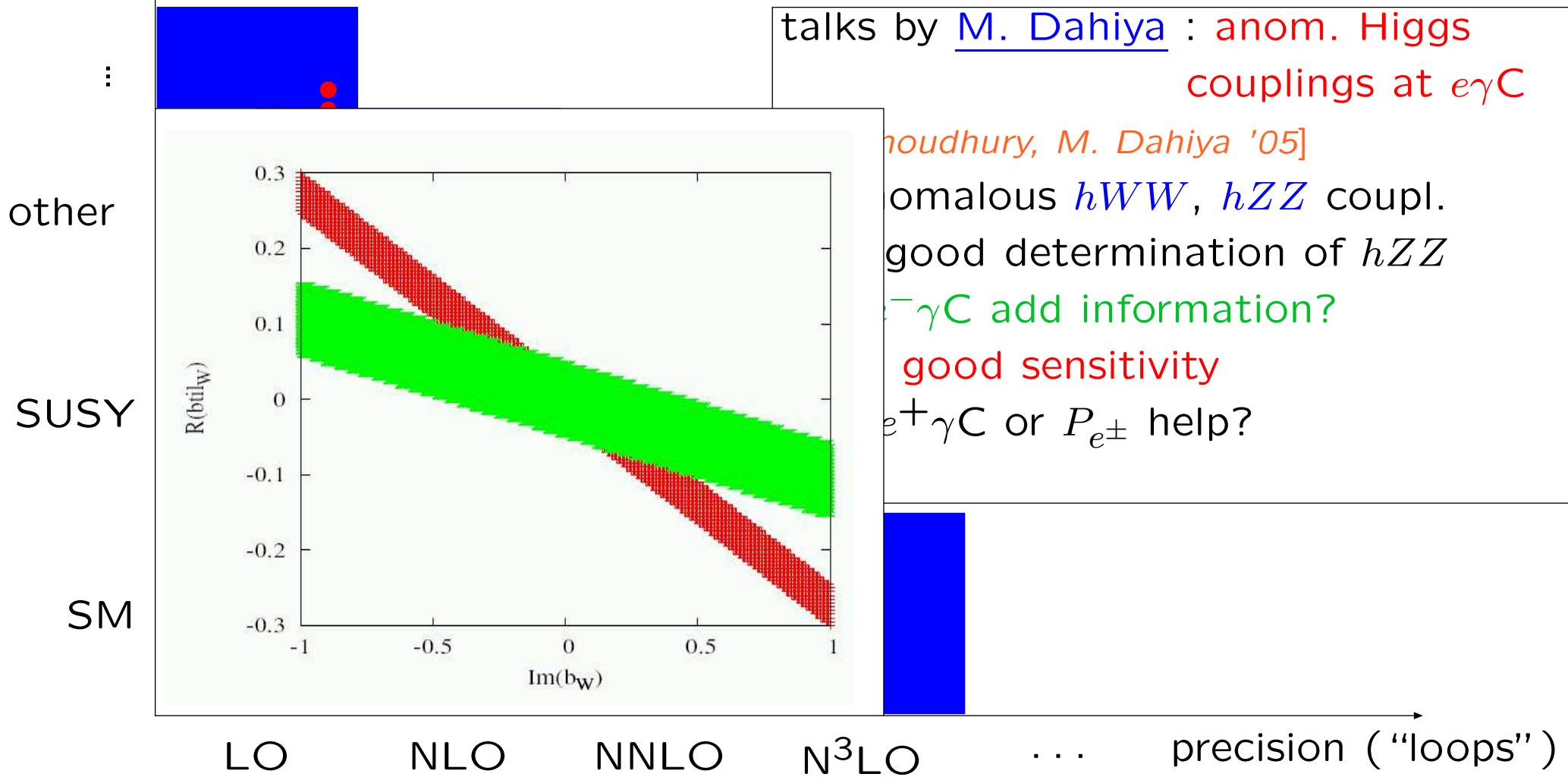
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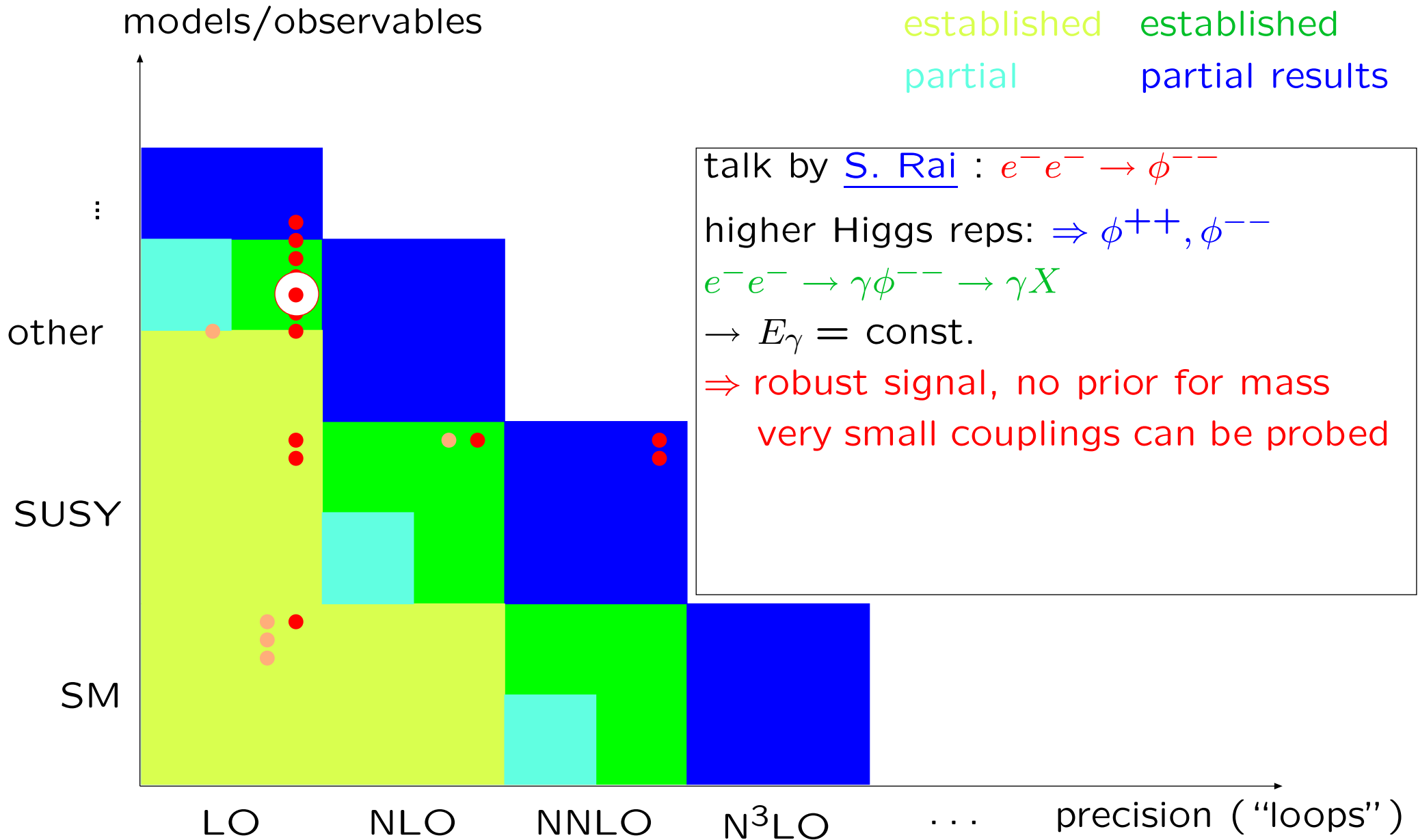
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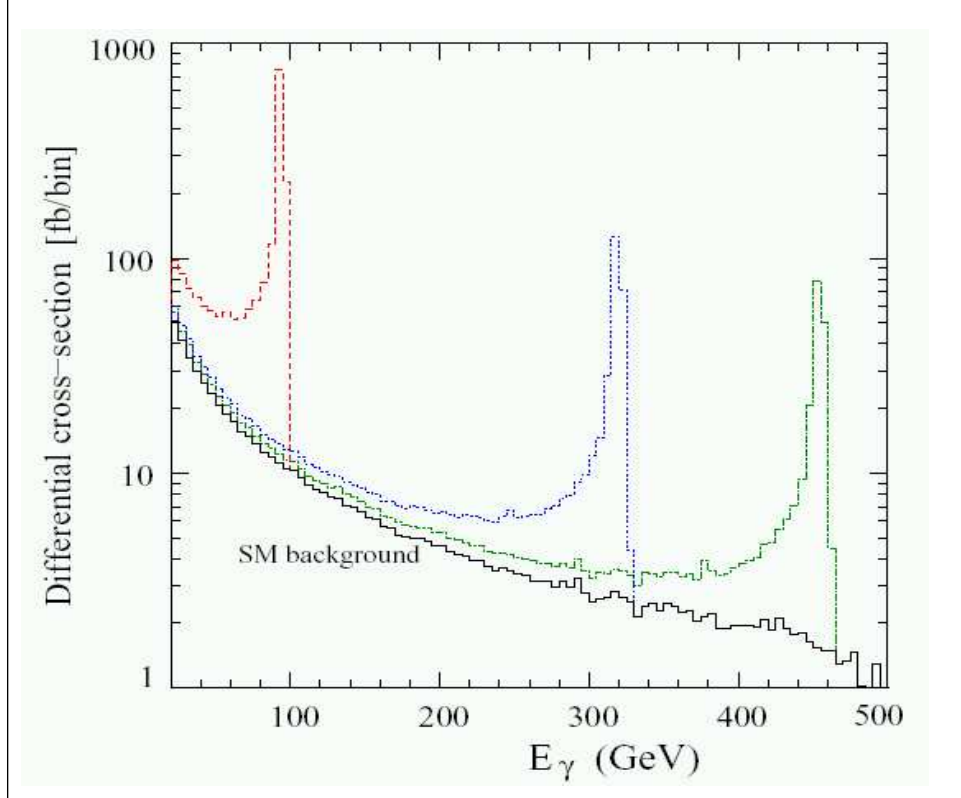


talk by [S. Rai](#) : $e^-e^- \rightarrow \phi^{--}$
 higher Higgs reps: $\Rightarrow \phi^{++}, \phi^{--}$
 $\rightarrow \gamma\phi^{--} \rightarrow \gamma X$
 $\gamma = \text{const.}$
 robust signal, no prior for mass
 very small couplings can be probed

other

SUSY

SM



LO

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N³LO

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Higgs: contributions in Bangalore

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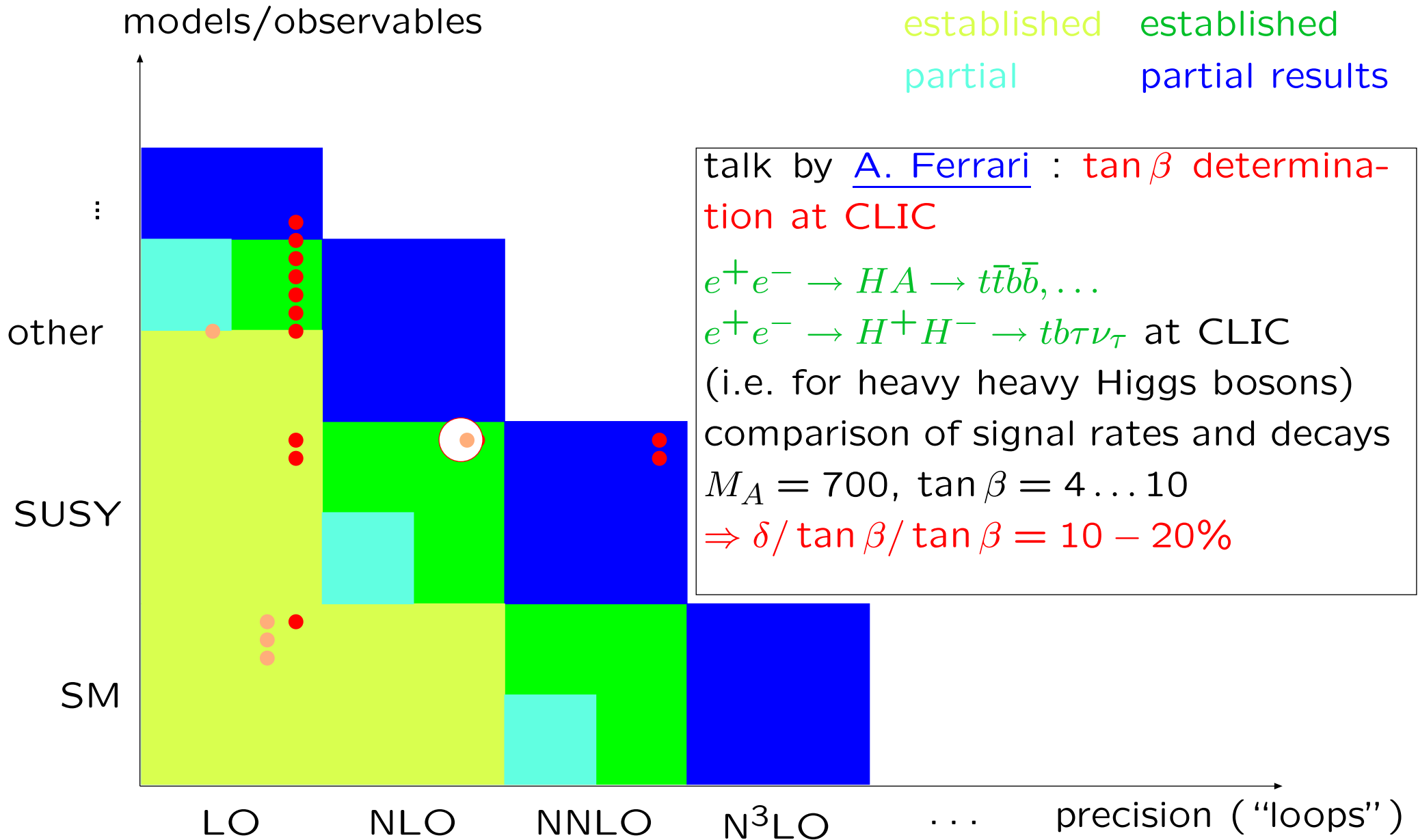
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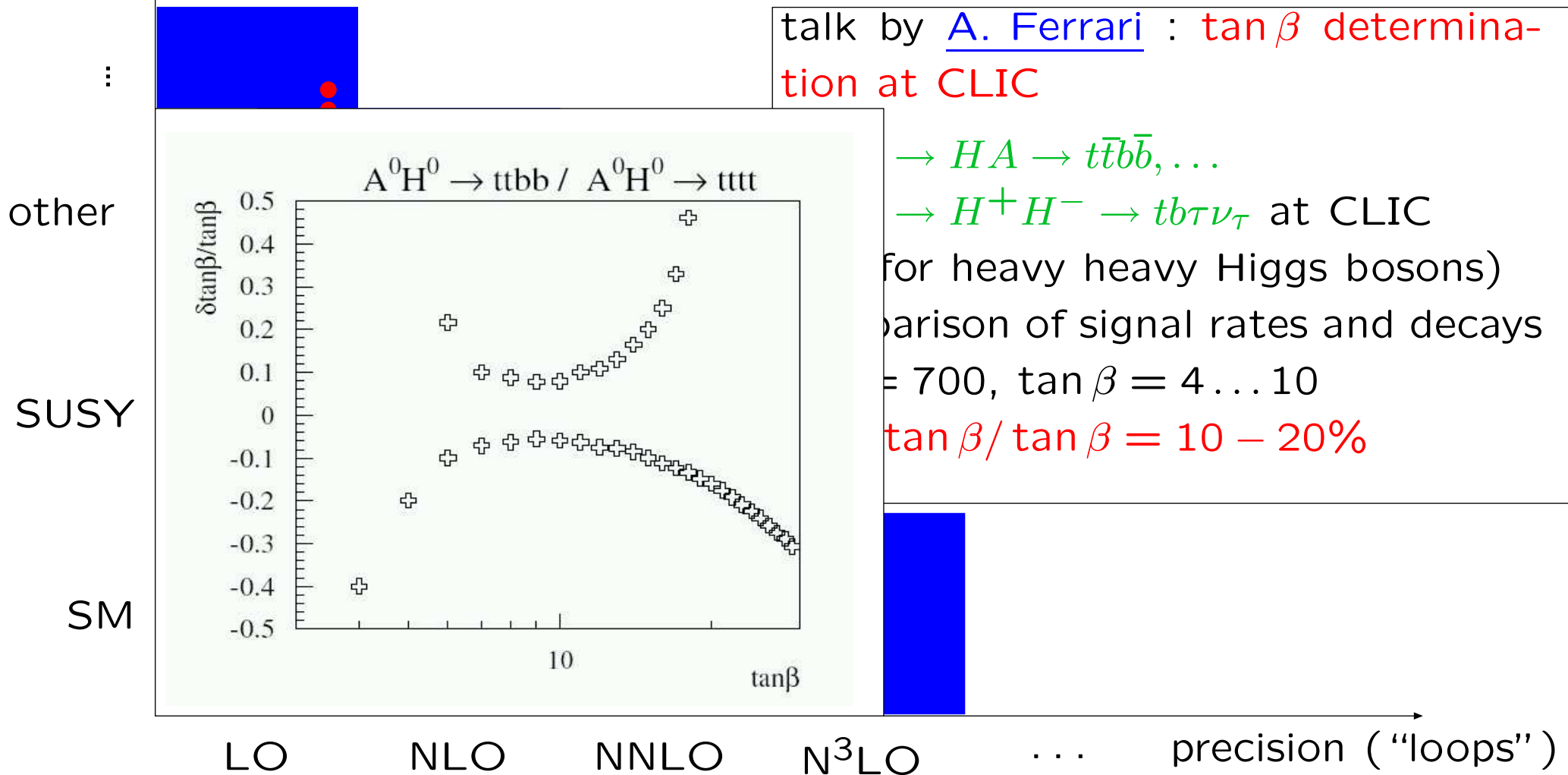
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talk by [A. Ferrari](#) : $\tan\beta$ determination at CLIC



Higgs: contributions in Bangalore

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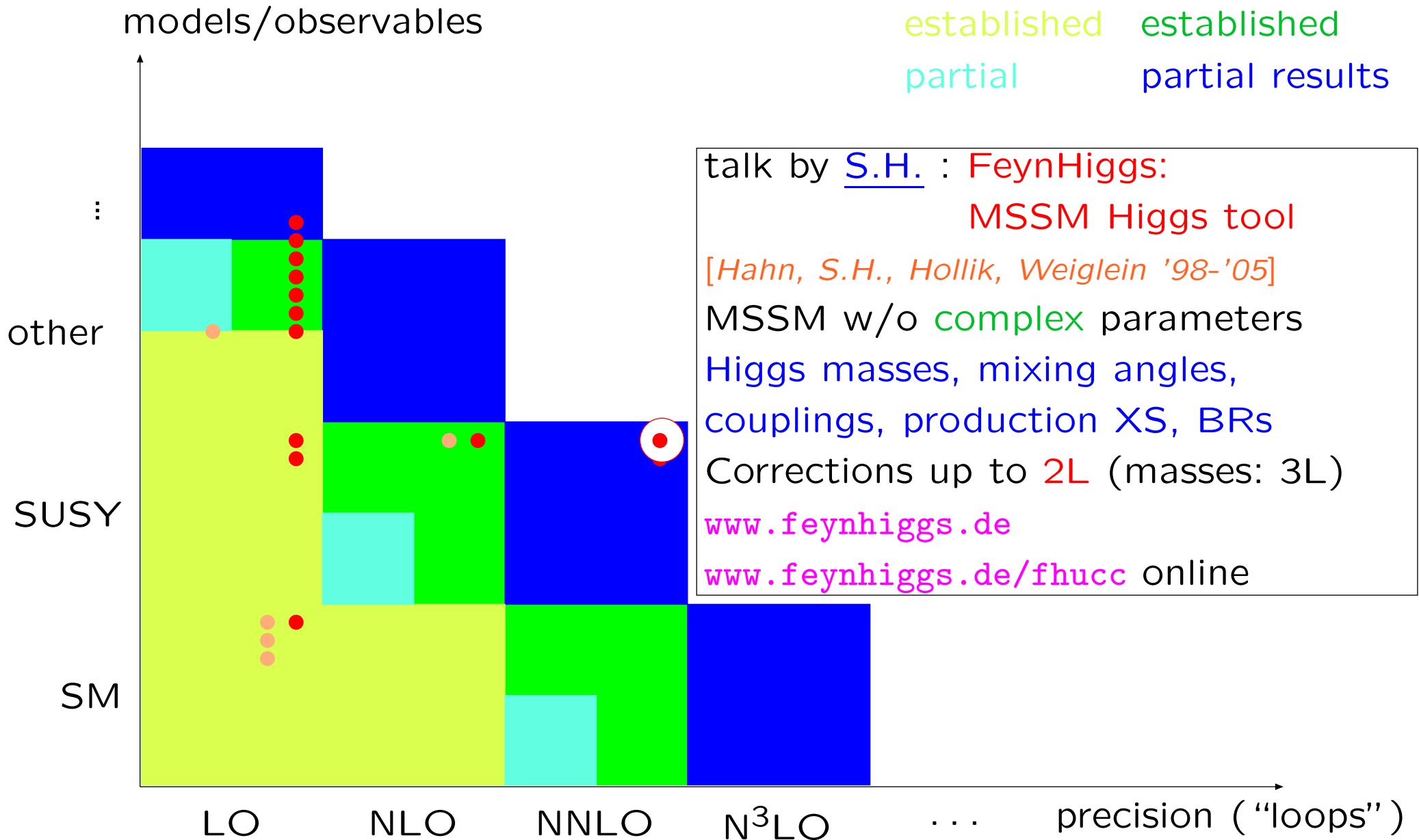
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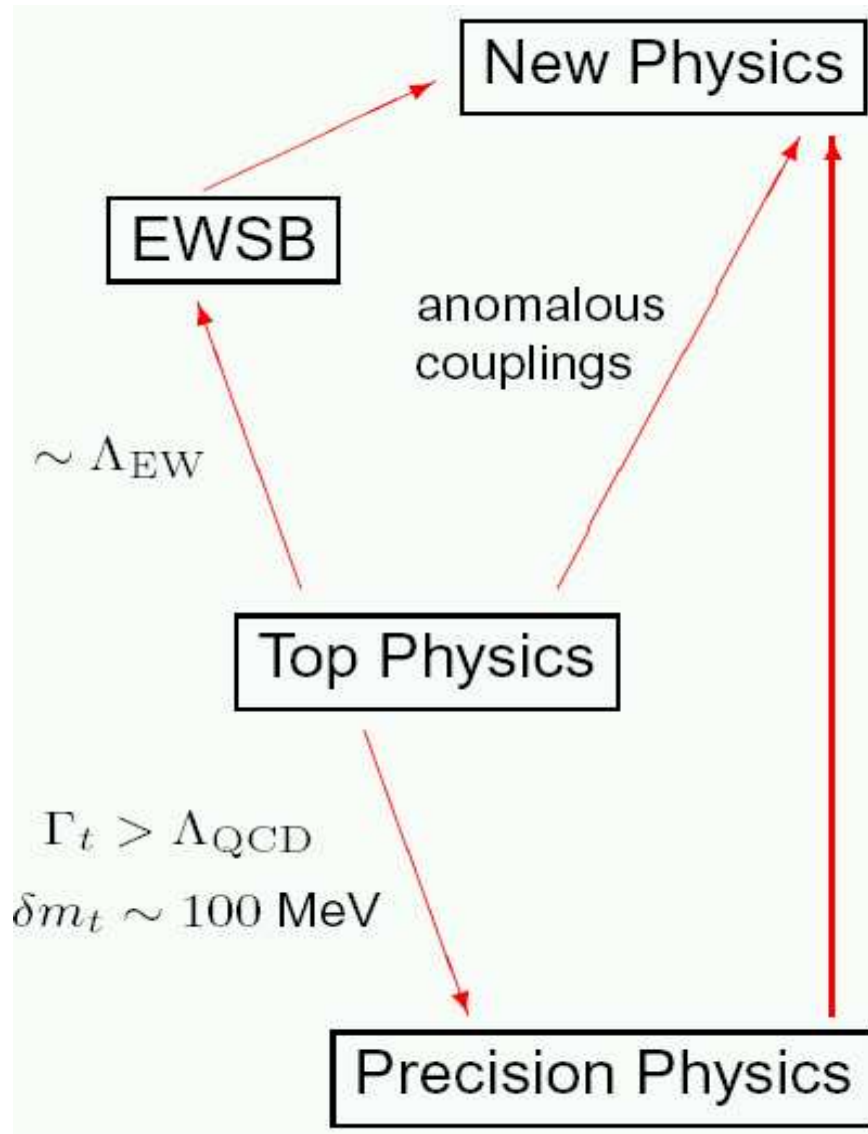
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3. Top/QCD (few QCD, more top)

The top is guaranteed at the ILC \Rightarrow sure physics case!



EWSB: just a heavy quark?
special role for t in EWSB?
strong constraint on any model

Precision physics:
 δm_t^{exp} leading parametric uncertainty
 \rightarrow could obscure new physics

SUSY: m_t crucial input parameter
drives SSB/unification

Little Higgs: heavier top

Tevatron/LHC: “rough” measurements
of mass, couplings, BRs

ILC: high precision of everything
... if we are ready

Few QCD:

⇒ one talk :-)

Most important top observables:

- top quark mass: m_t (most important input parameter)
measurement from production **peak position**
experiment: **ok** – theory: **not yet** ($m_t^{\text{shortdistance}} \rightarrow m_t^{\overline{\text{MS}}}$)
⇒ no news here :-)
- top quark width: Γ_t ⇒ no news here :-)
- top quark production cross section: σ_{tt}
precise prediction needed for m_t
new physics contributions? experiment: **ok** – theory: **nearly...?**
⇒ no news here :-)
- top quark **branching ratios**
→ **anomalous couplings** → $\mathcal{O}(\%)$ at ILC, polarization crucial
ToDo: fully exploit polarization ⇒ one talk :-)
vary more than 1 coupling
QCD corrections to SM
tools for $e^+e^- \rightarrow 6f, 8f$ at $\mathcal{O}(\alpha_s)$ (6f: **Lusifer**)
- top Yukawa coupling: Y_t
→ connection to Higgs sector ⇒ two talks :-)

Few QCD:

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Most important top observables:

QCD talk by [R. Godbole](#): $\sigma(\gamma\gamma \rightarrow \text{had})$

→ use data from $p\bar{p} \rightarrow \text{hadrons}$
model with 3 free parameters

⇒ predict $\sigma(\gamma\gamma \rightarrow \text{had})$

⇒ new (preliminary) results similar
to old results (but more solid now)

input parameter)

position

shortdistance $\rightarrow m_t^{\overline{\text{MS}}}$

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-(

$t\bar{t}$

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⇒ two talks :-)

Few QCD:

⇒ one talk :-)

Most important top observables:

talk by R. Singh: lepton characteristics
in t decay

⇒ new physics probe

angular distribution of secondary lepton
insensitive to anomalous Wtb coupling

E_l dist. for anomalous Wtb coupling

use of polarization advantageous

input parameter)

position

shortdistance $\rightarrow m_t^{\overline{\text{MS}}}$

⇒ no news here :-)

-(

tt

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top/Higgs: contributions in Bangalore

experiment

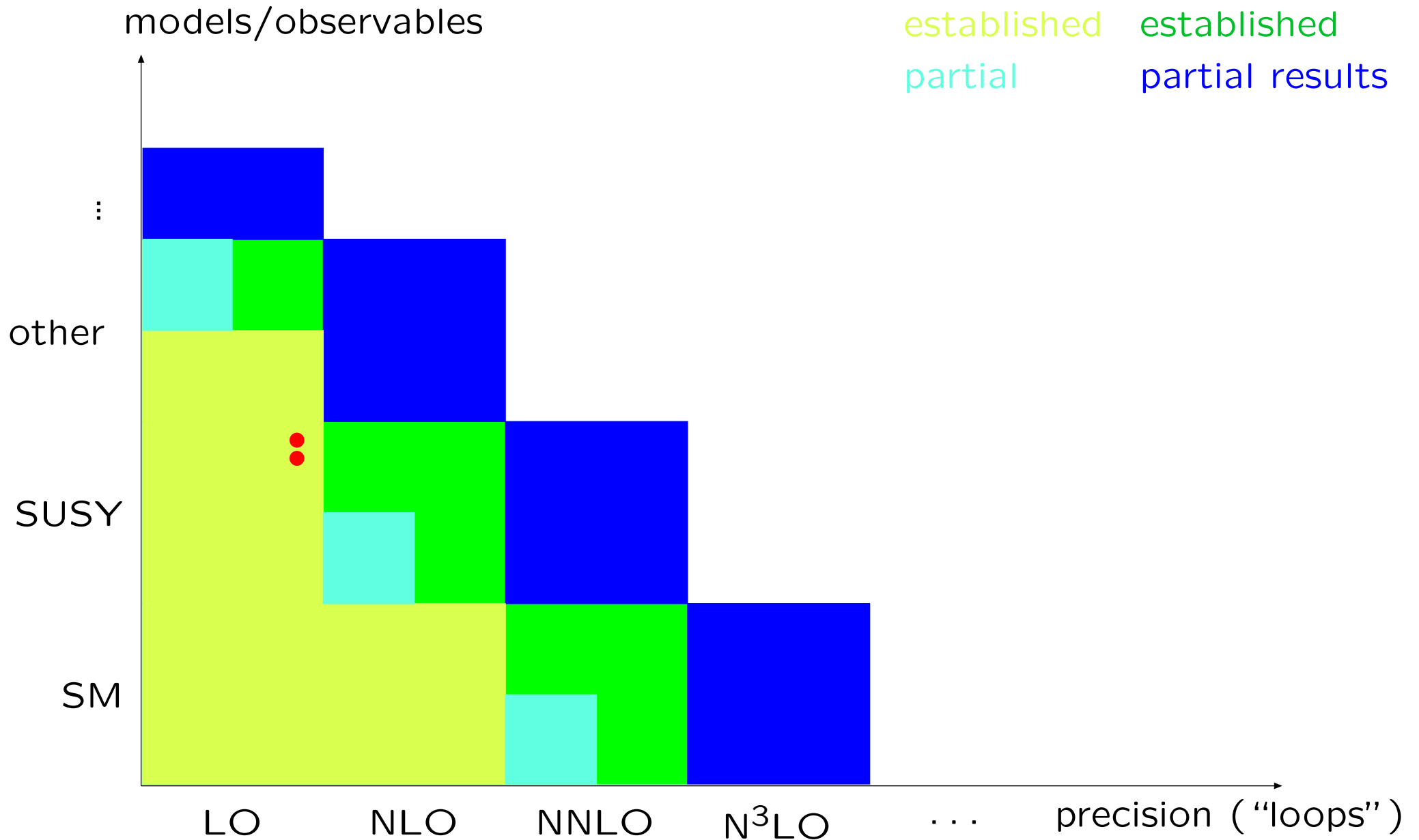
theory

established

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partial results



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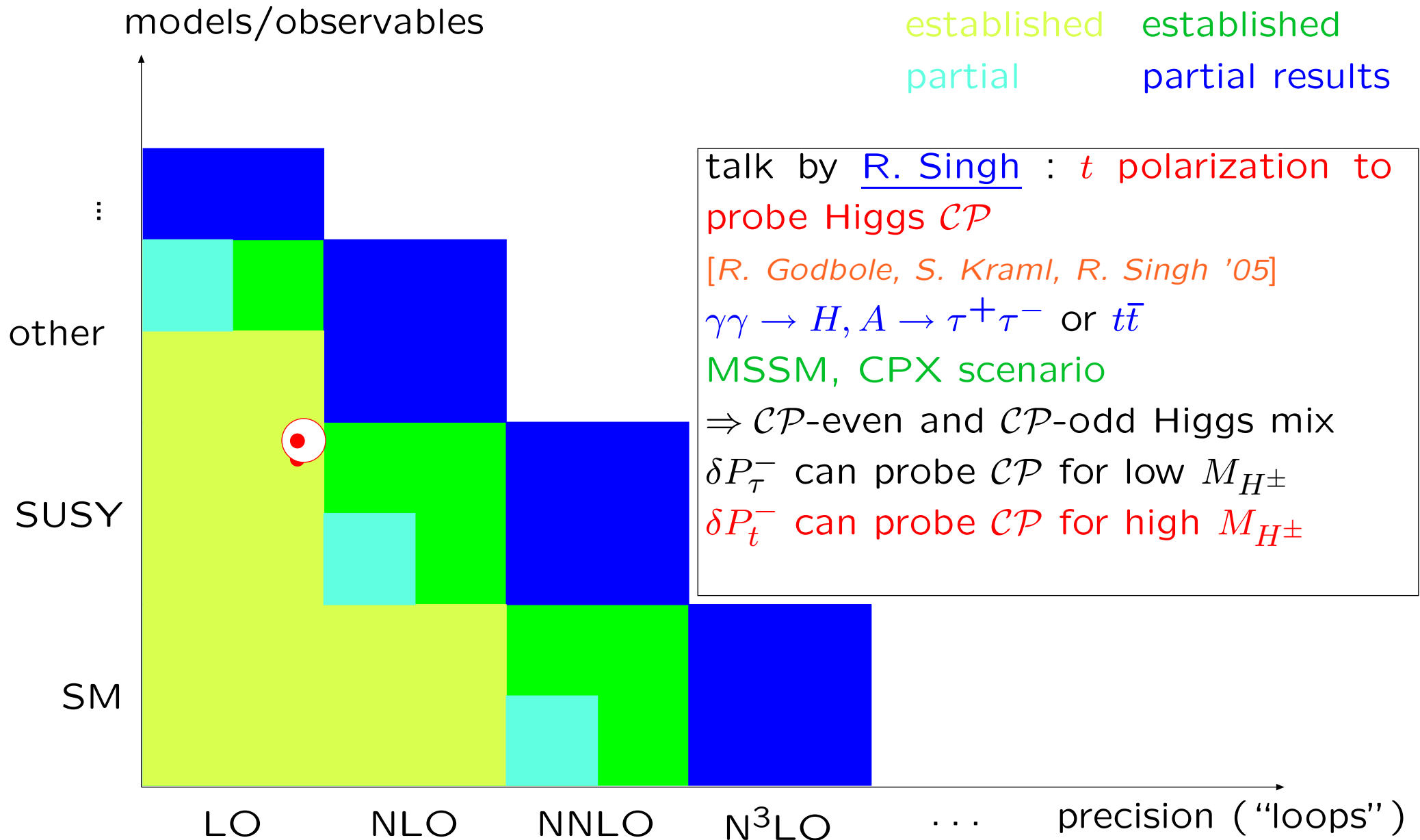
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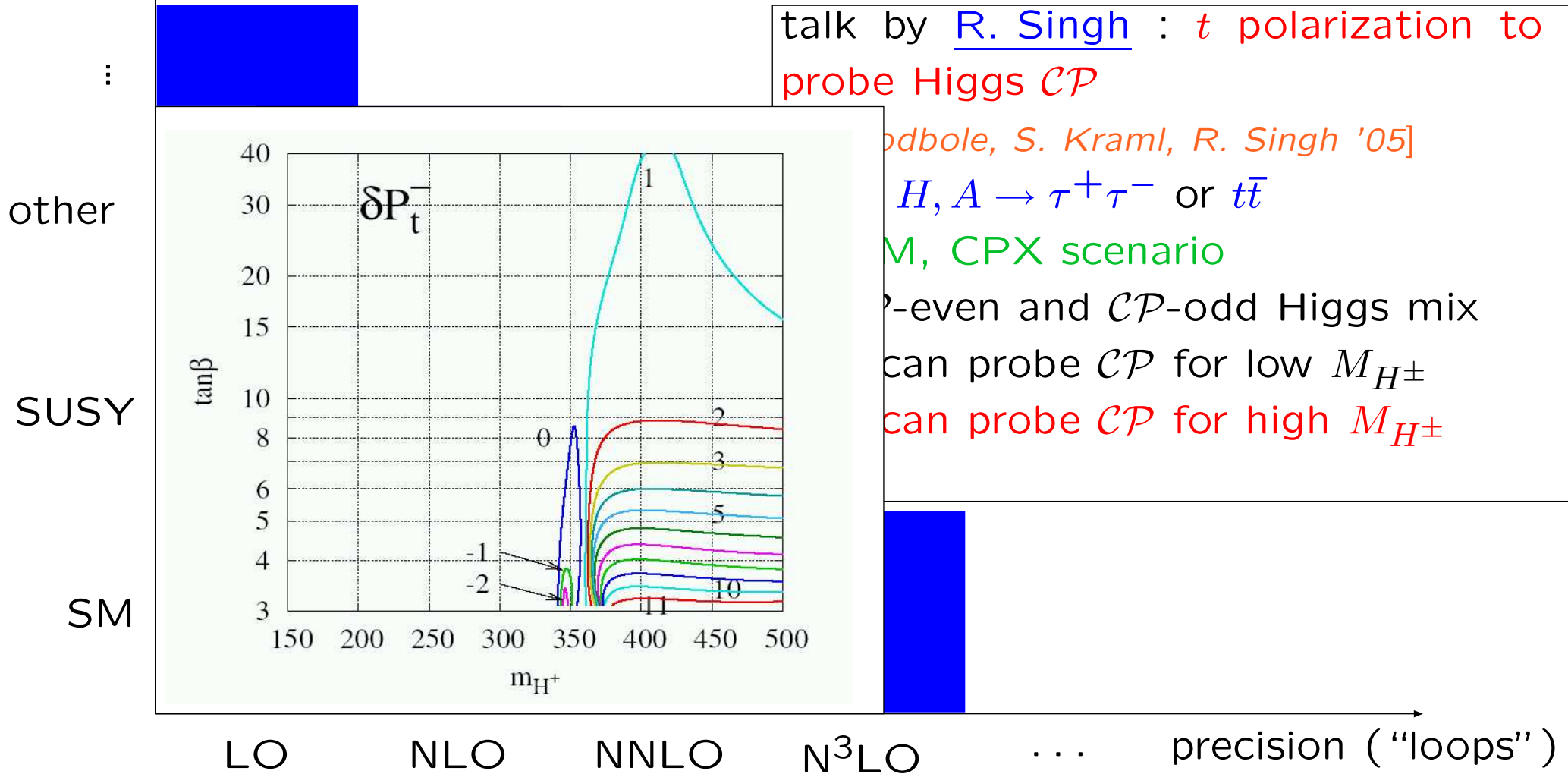
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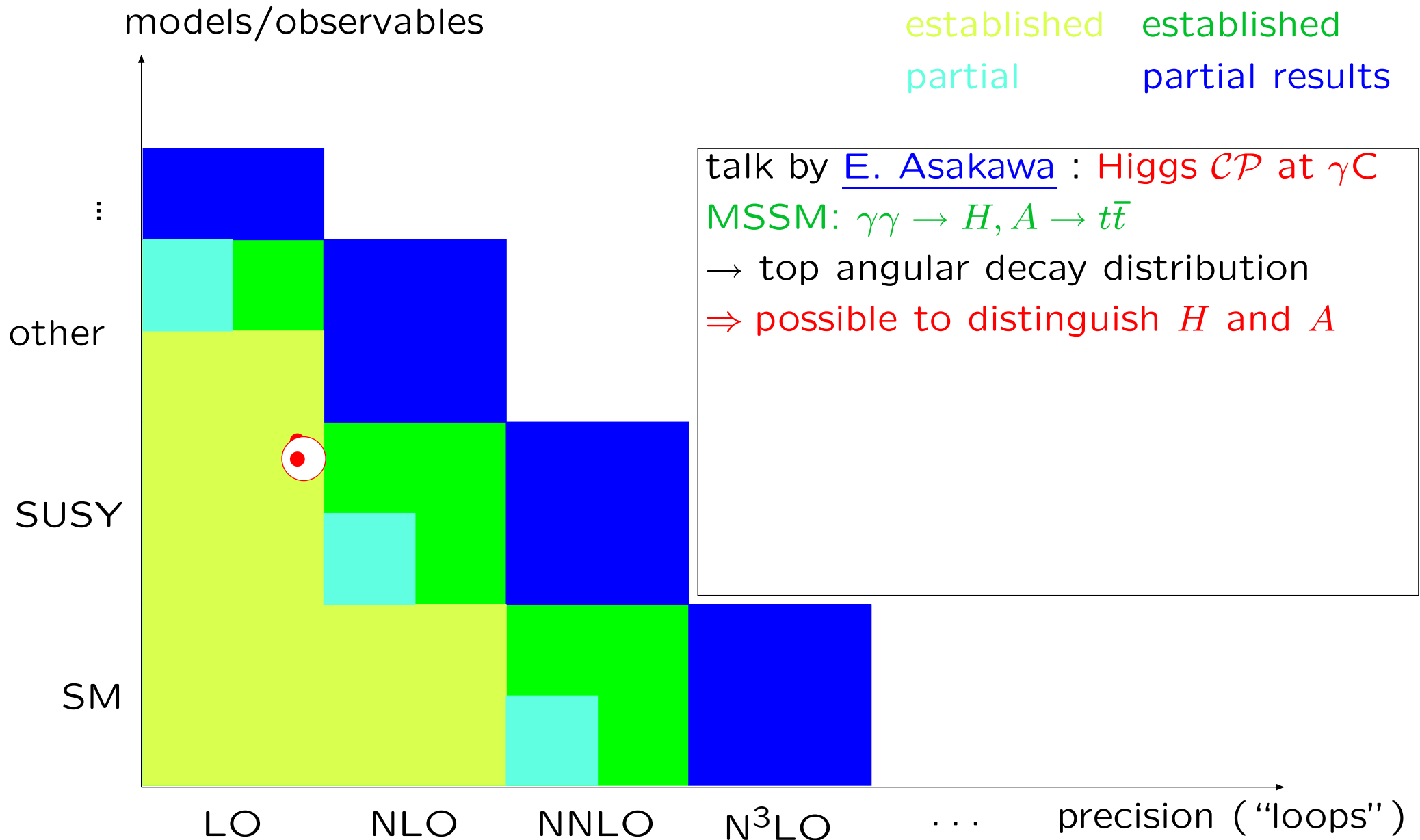
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4. LoopVerein

Why is it necessary to include all those loop corrections?

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Experimental situation:

ILC → provide high accuracy measurements !

Theory situation:

measured observables have to be compared with theoretical predictions
(of your favorite model)

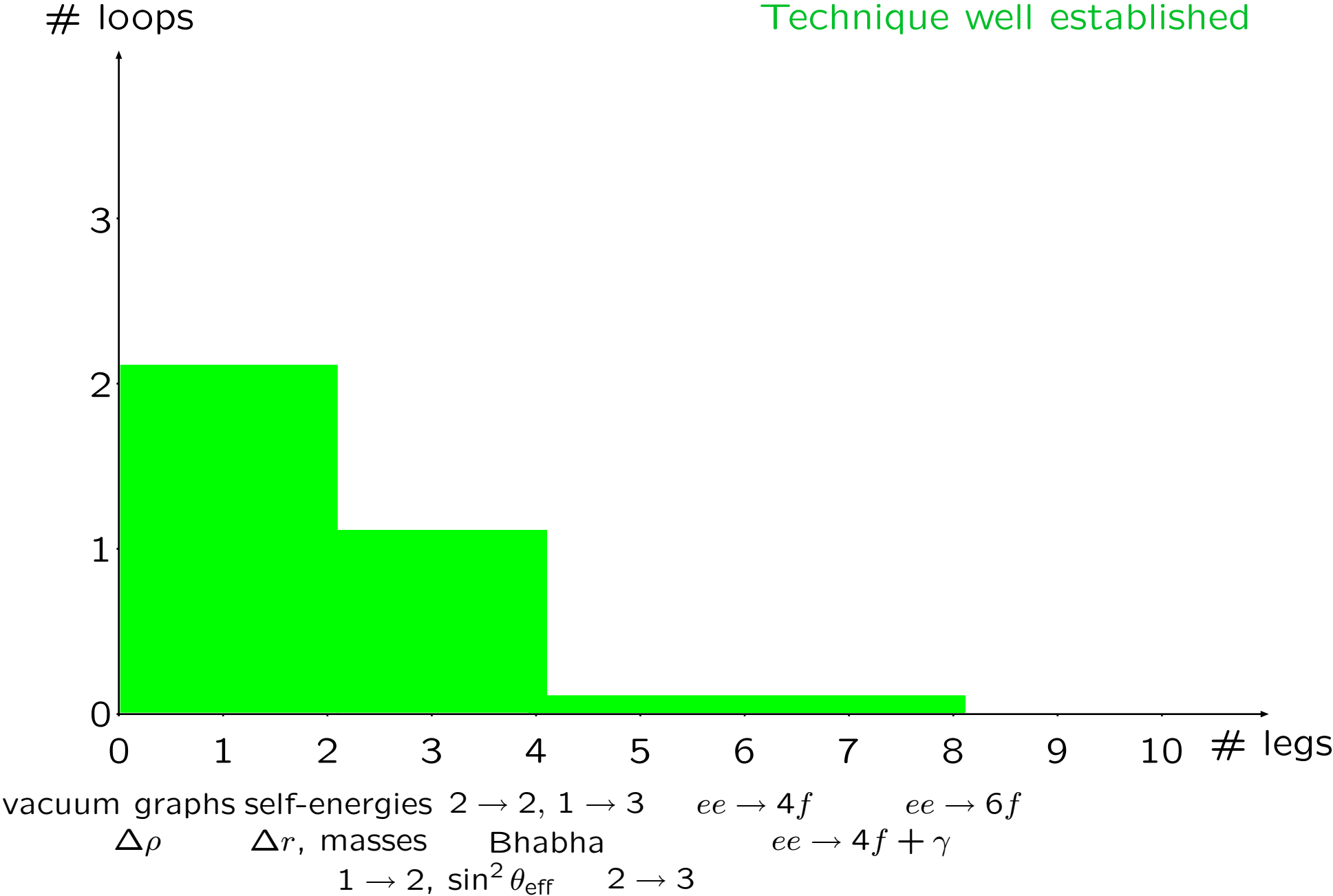
High precision of data can only fully be exploited if it is matched with
theoretical calculations at the same level of accuracy

We could not make full use of the great ILC precision
without corresponding loop calculations

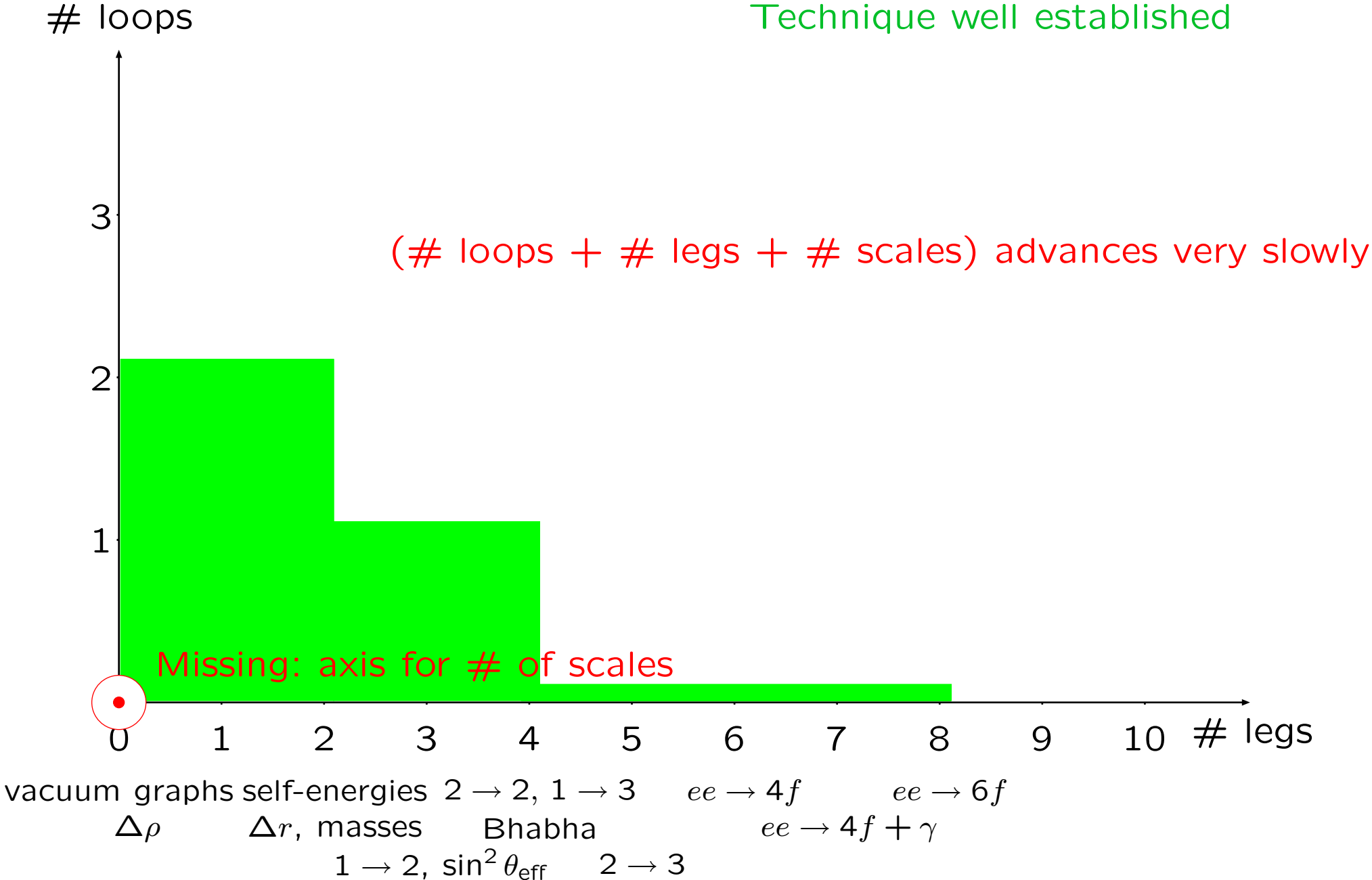
We have to work **NOW** to achieve necessary accuracy in time

Theory/Loop calculations should be viewed as an essential part of
the ILC Physics program

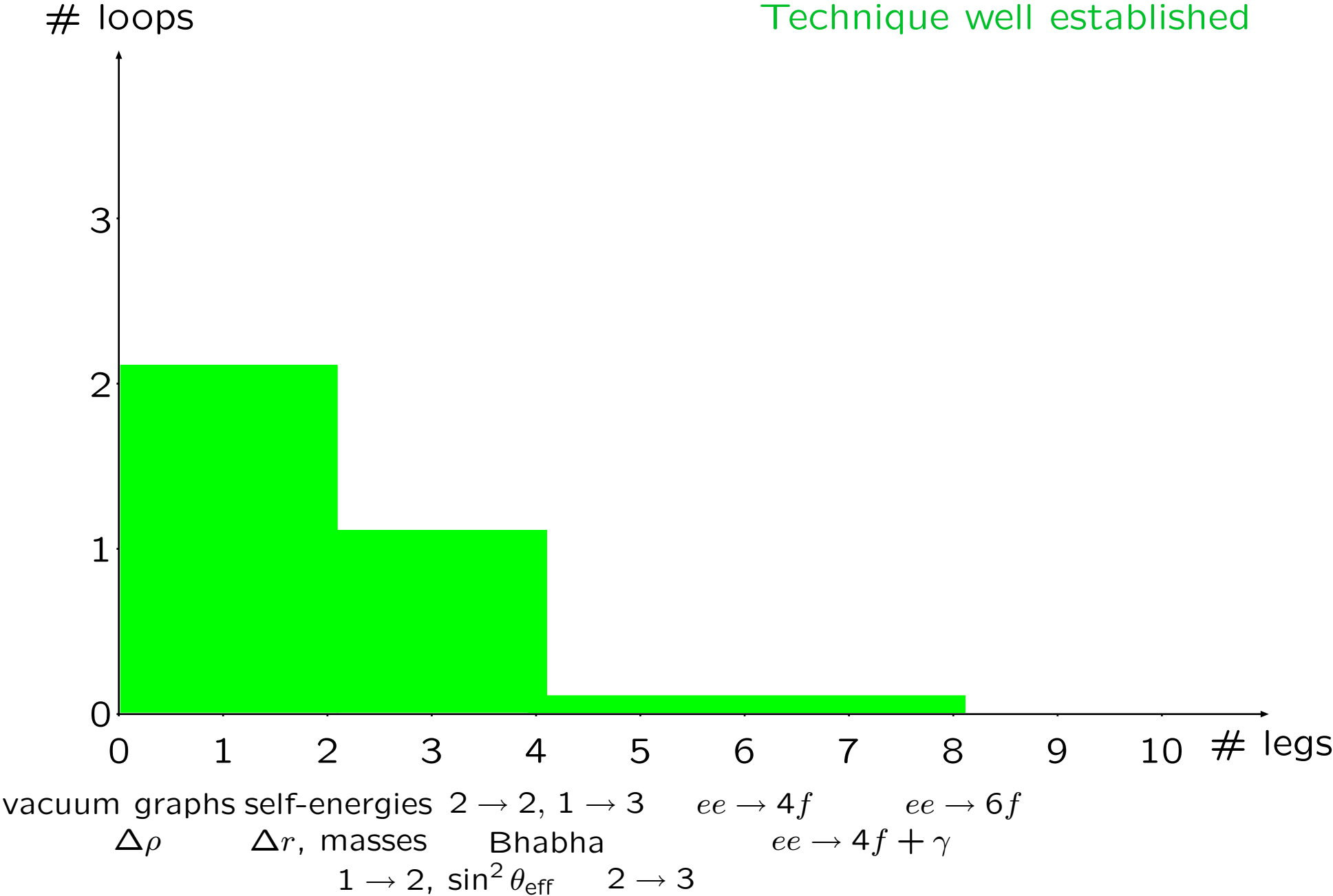
Technique well established



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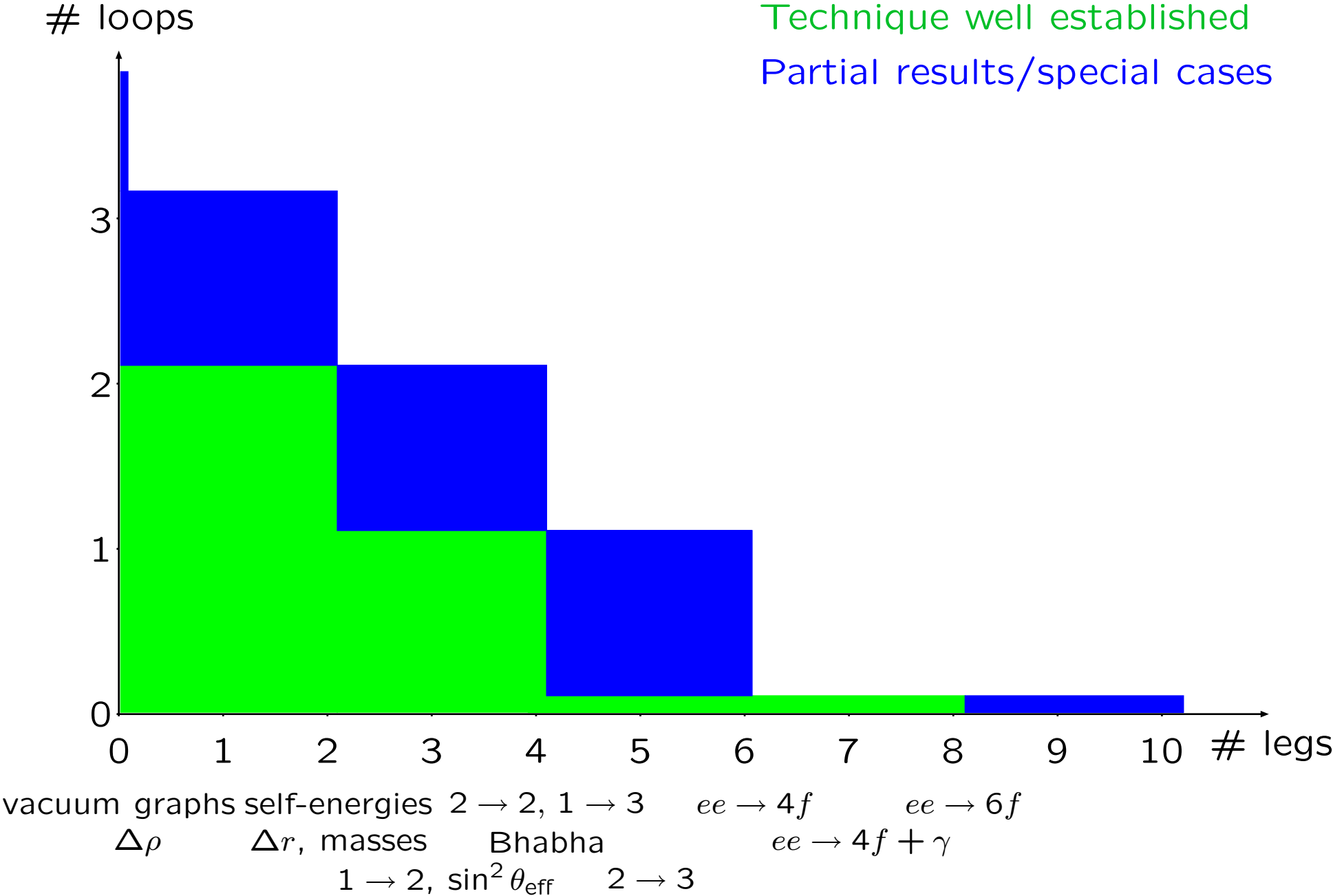


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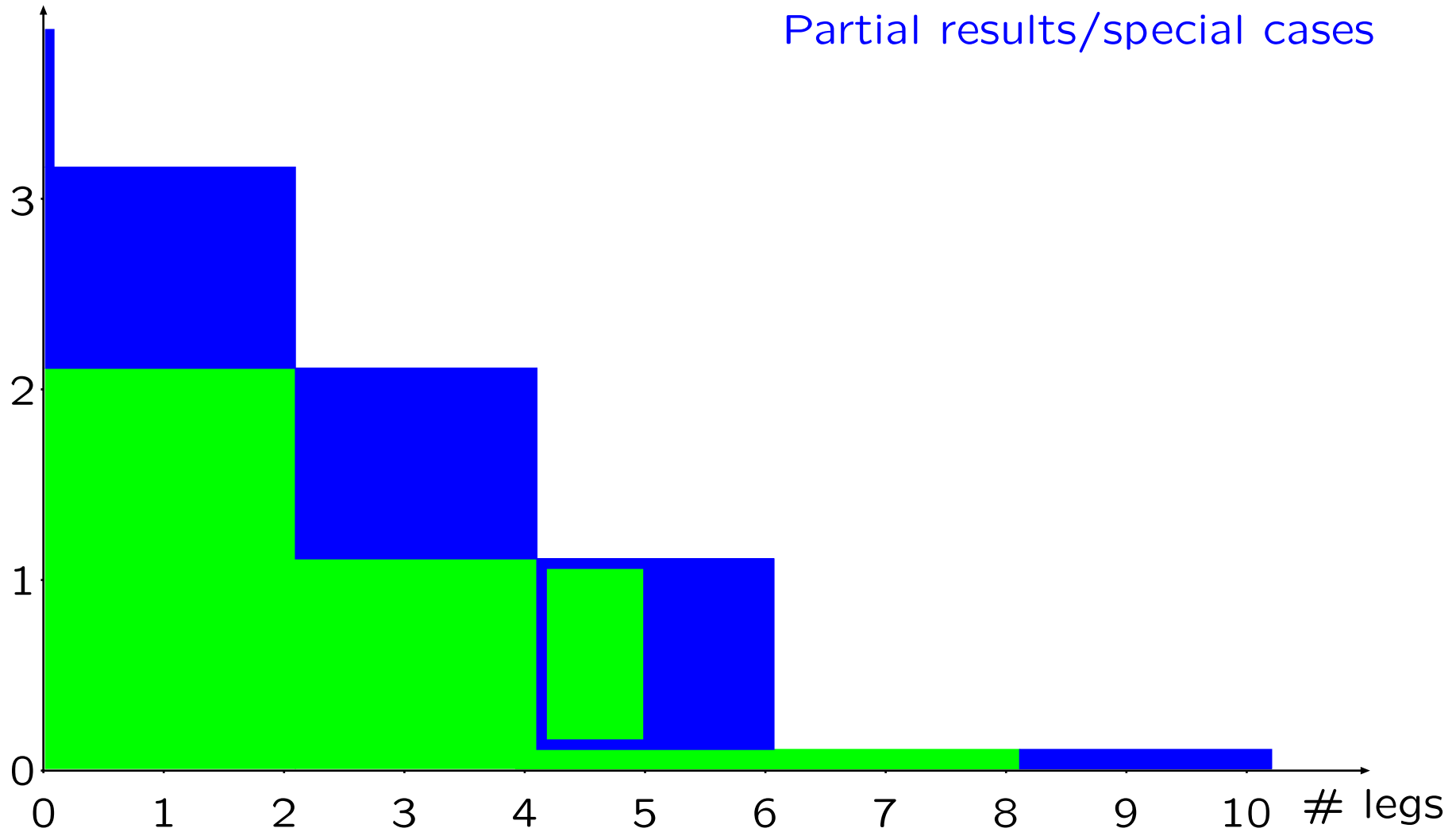
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Partial results/special cases



loops

Technique well established
 Partial results/special cases

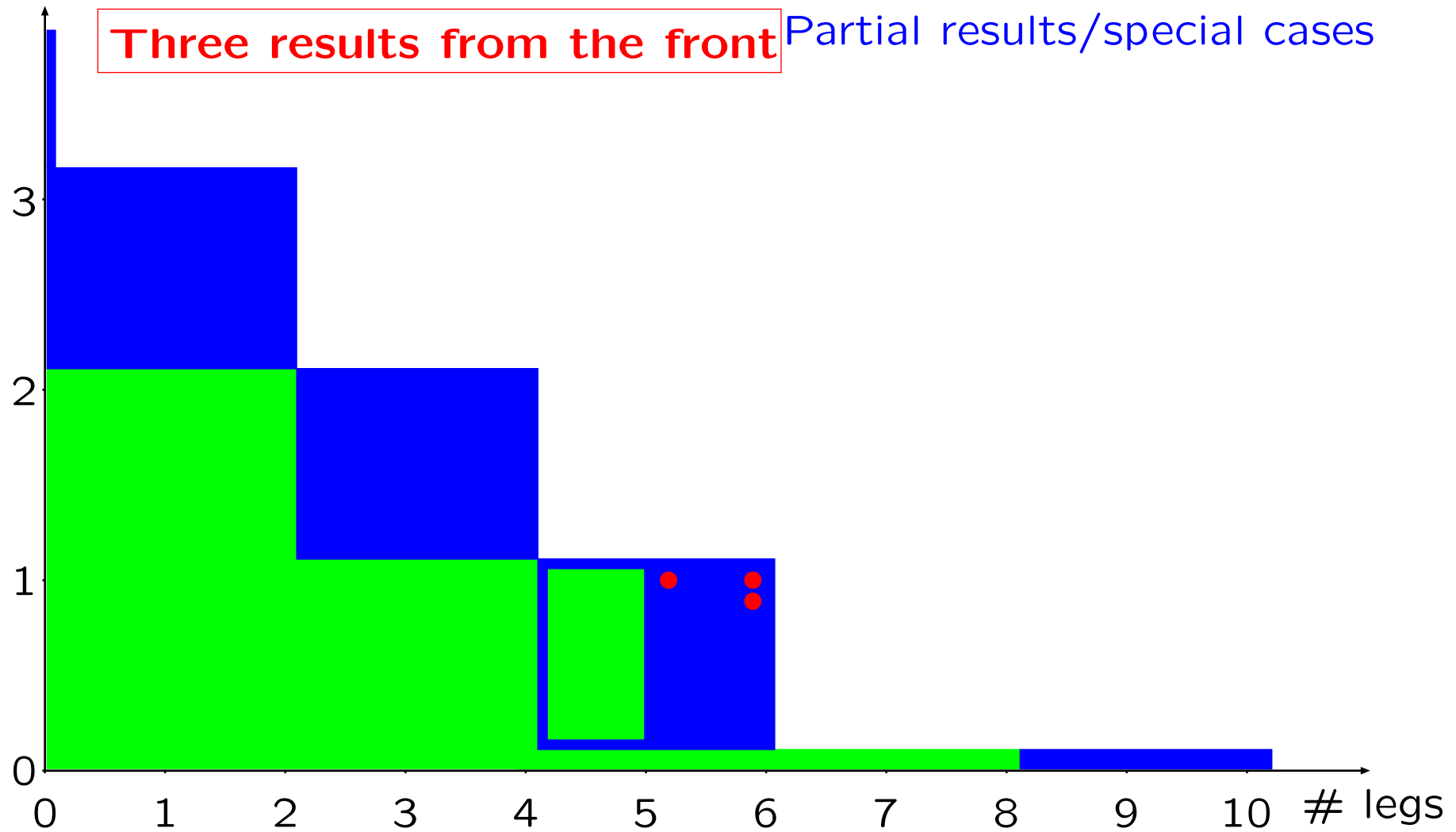


vacuum graphs $\Delta\rho$
 self-energies Δr , masses
 $2 \rightarrow 2$, $1 \rightarrow 3$ Bhabha
 $1 \rightarrow 2$, $\sin^2 \theta_{\text{eff}}$ $2 \rightarrow 3$
 $ee \rightarrow 4f$
 $ee \rightarrow 4f + \gamma$
 $ee \rightarrow 6f$

loops

Technique well established

Three results from the front Partial results/special cases



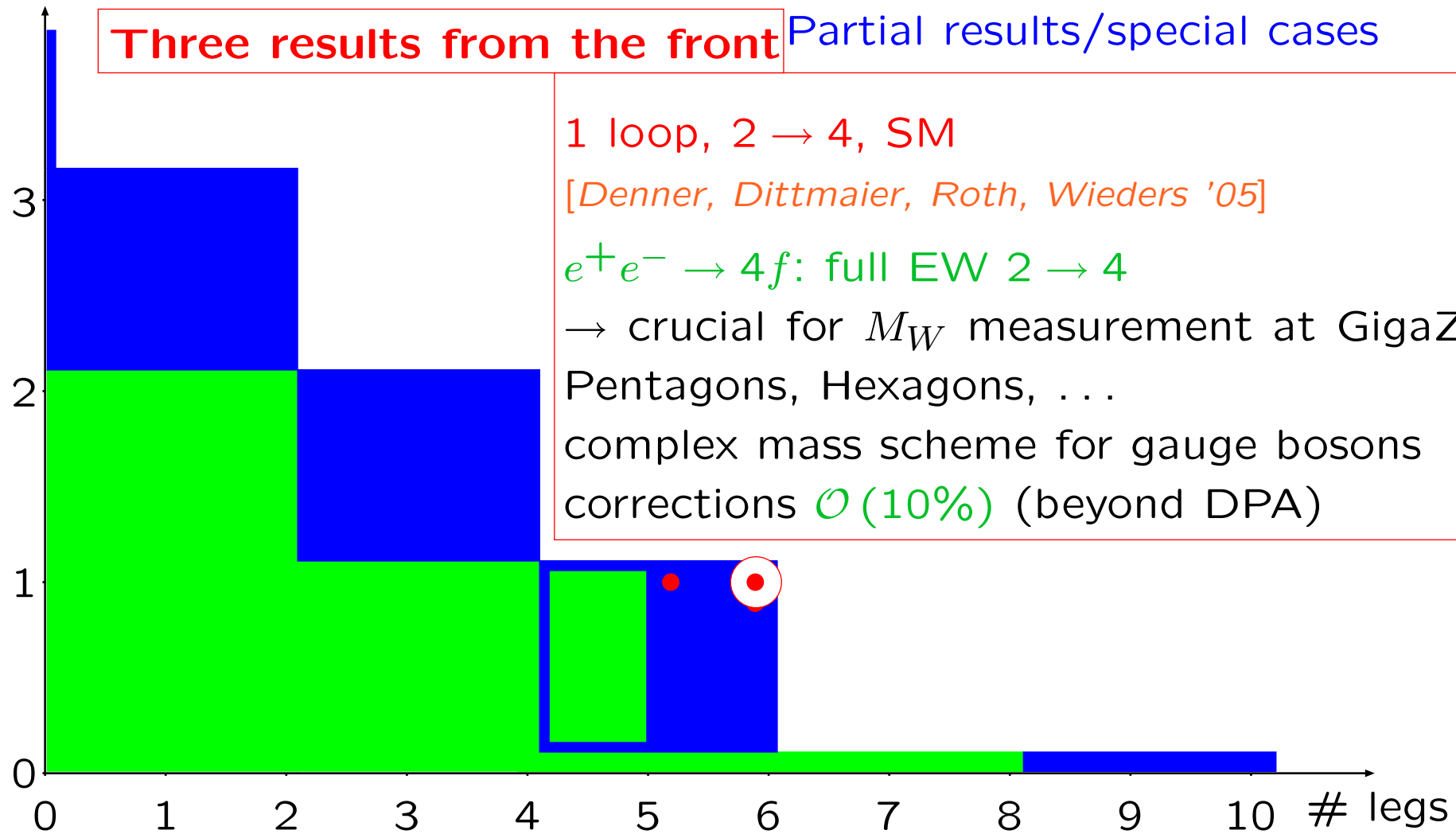
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loops

Technique well established

Three results from the front

Partial results/special cases



1 loop, $2 \rightarrow 4$, SM

[Denner, Dittmaier, Roth, Wieders '05]

$e^+e^- \rightarrow 4f$: full EW $2 \rightarrow 4$

\rightarrow crucial for M_W measurement at GigaZ

Pentagons, Hexagons, ...

complex mass scheme for gauge bosons

corrections $\mathcal{O}(10\%)$ (beyond DPA)

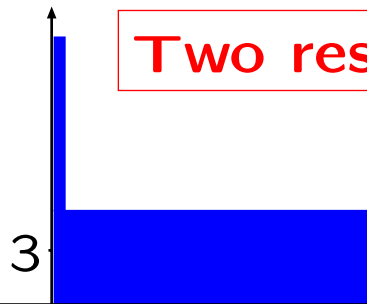
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loops

Technique well established

Partial results/special cases

Two results from the front



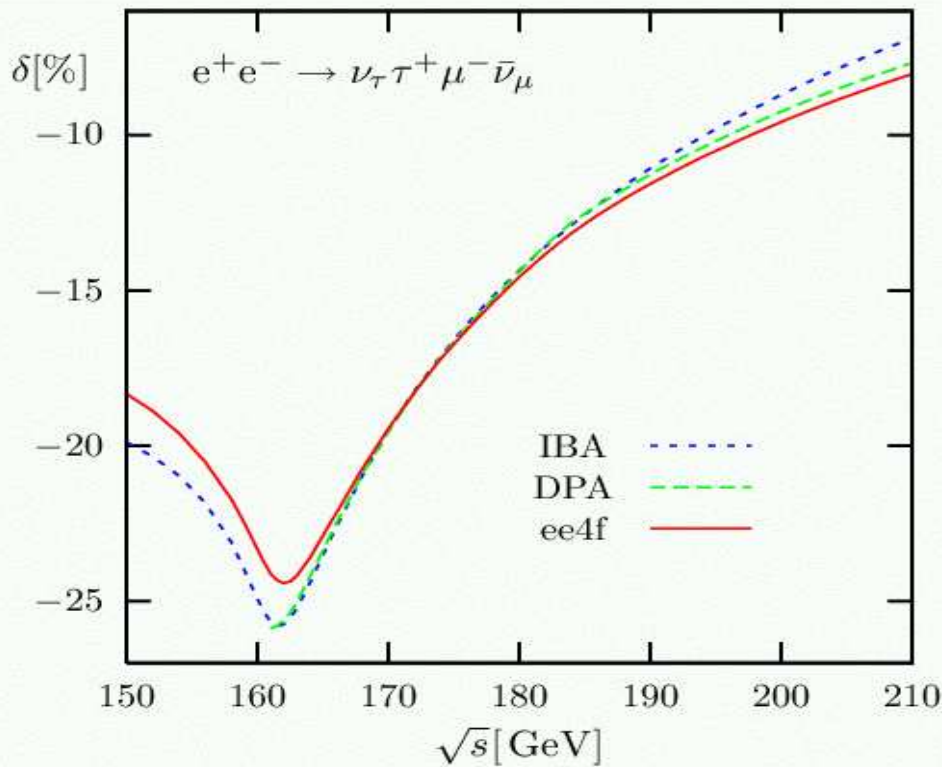
1 loop, 2 → 4, SM

[Denner, Dittmaier, Roth, Wieders '05]

full EW 2 → 4

for M_W measurement at GigaZ
Hexagons, ...

mass scheme for gauge bosons
 $\mathcal{O}(10\%)$ (beyond DPA)



4f ee → 6f
ee → 4f + γ

loops

Technique well established

Three results from the front

Partial results/special cases

1 loop, $2 \rightarrow 4$, SM

[GRACE '05]

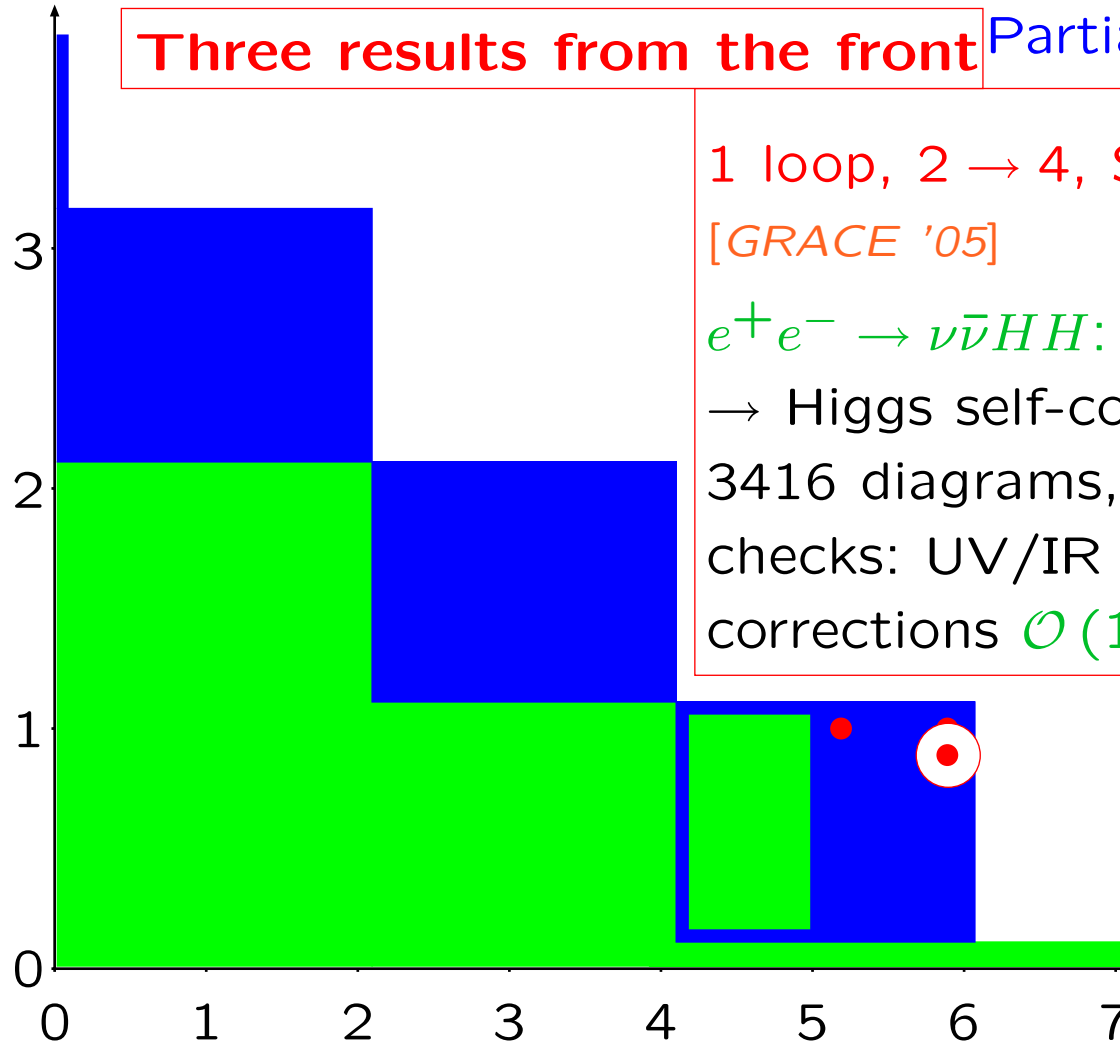
$e^+e^- \rightarrow \nu\bar{\nu}HH$: first full EW $2 \rightarrow 4$

\rightarrow Higgs self-coupling measurement

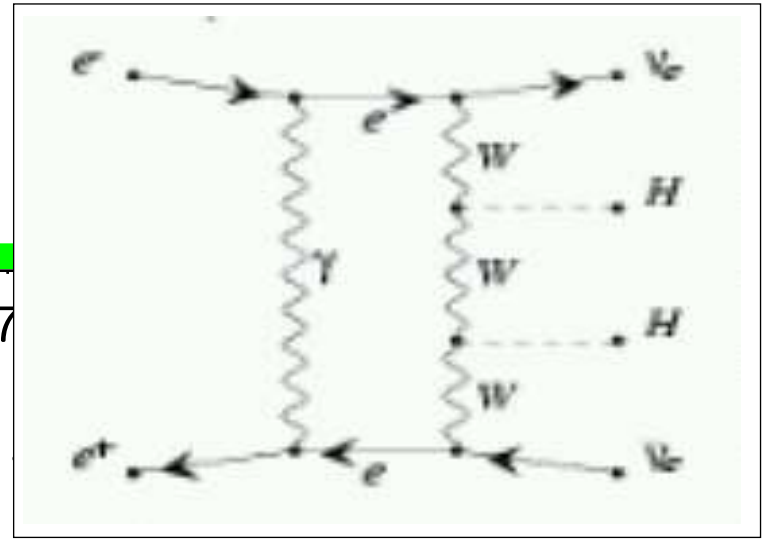
3416 diagrams, 218 Pent. 74 Hex.

checks: UV/IR div., gauge par. independ.

corrections $\mathcal{O}(10\%)$ (top-loop in HHH)



vacuum graphs $\Delta\rho$
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 $ee \rightarrow$



loops

Technique well established

Partial results/special cases

Two results from the front

3

1 loop, 2 → 4, SM

[GRACE '05]

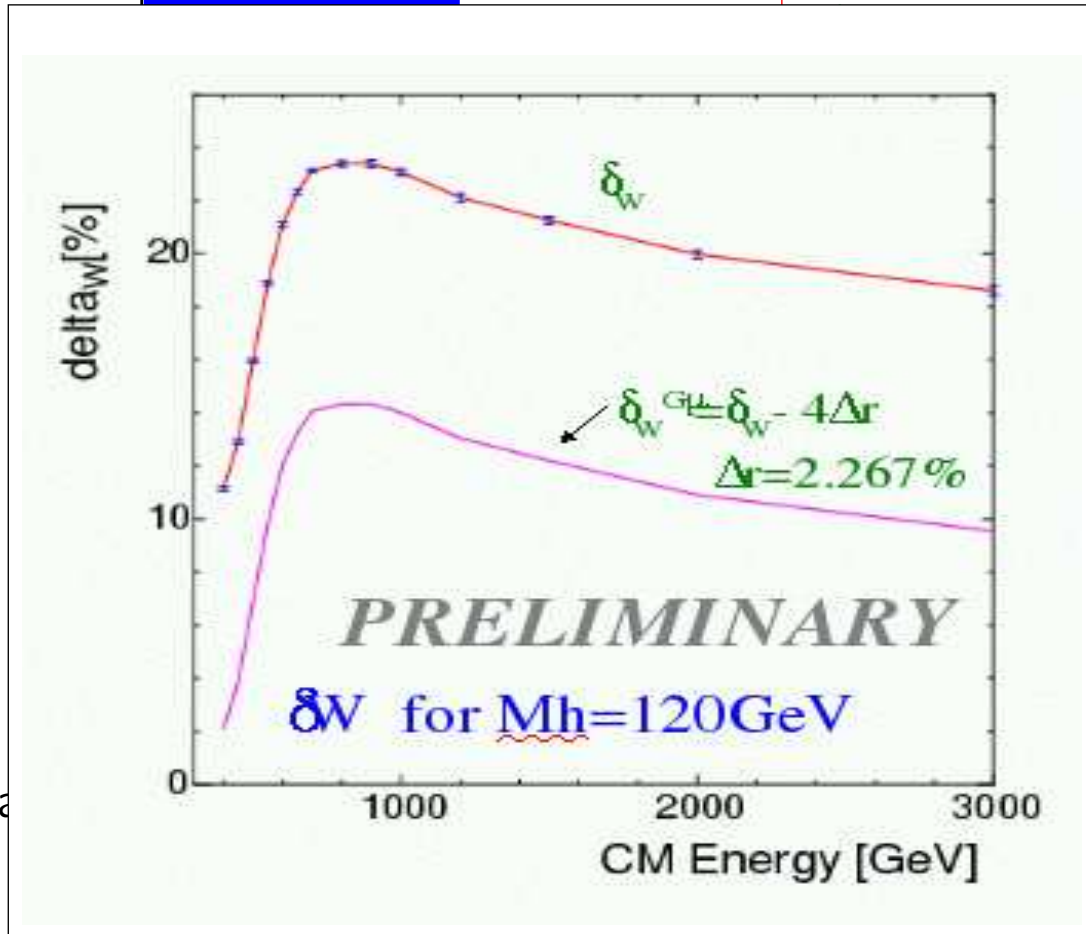
HH: first full EW 2 → 4

1f-coupling measurement

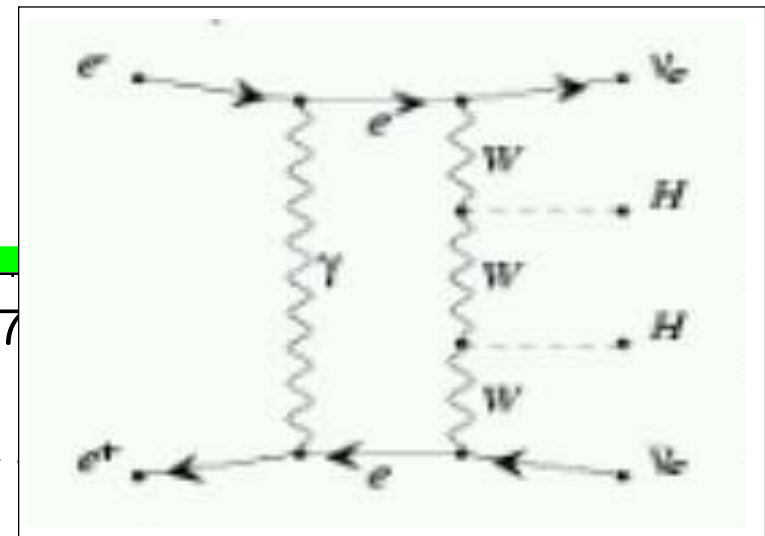
ms, 218 Pent. 74 Hex.

/IR div., gauge par. independ.

$\mathcal{O}(10\%)$ (top-loop in HHH)



4f
ee →

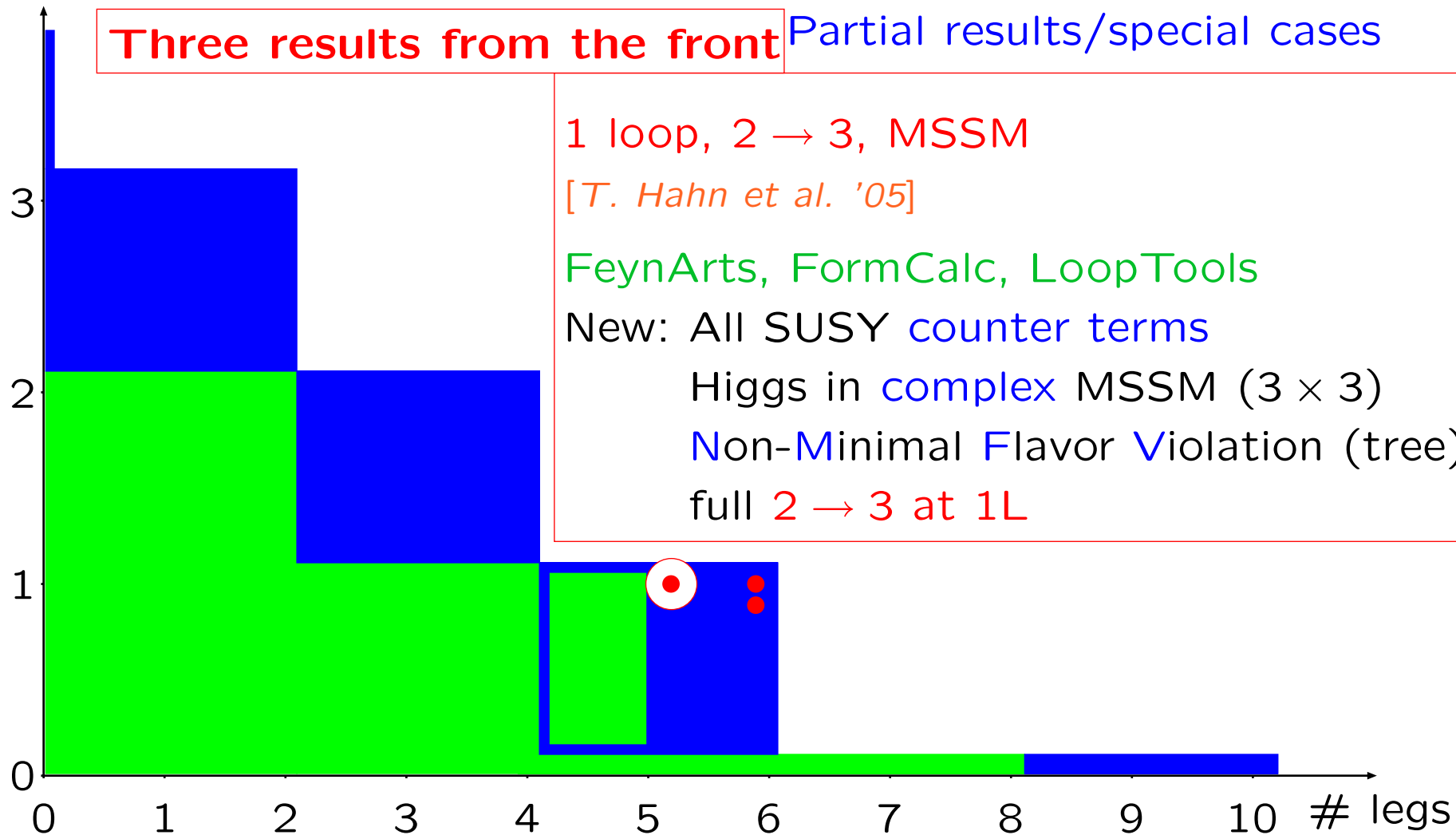


loops

Technique well established

Three results from the front

Partial results/special cases



1 loop, $2 \rightarrow 3$, MSSM

[T. Hahn et al. '05]

FeynArts, FormCalc, LoopTools

New: All SUSY counter terms

Higgs in complex MSSM (3×3)

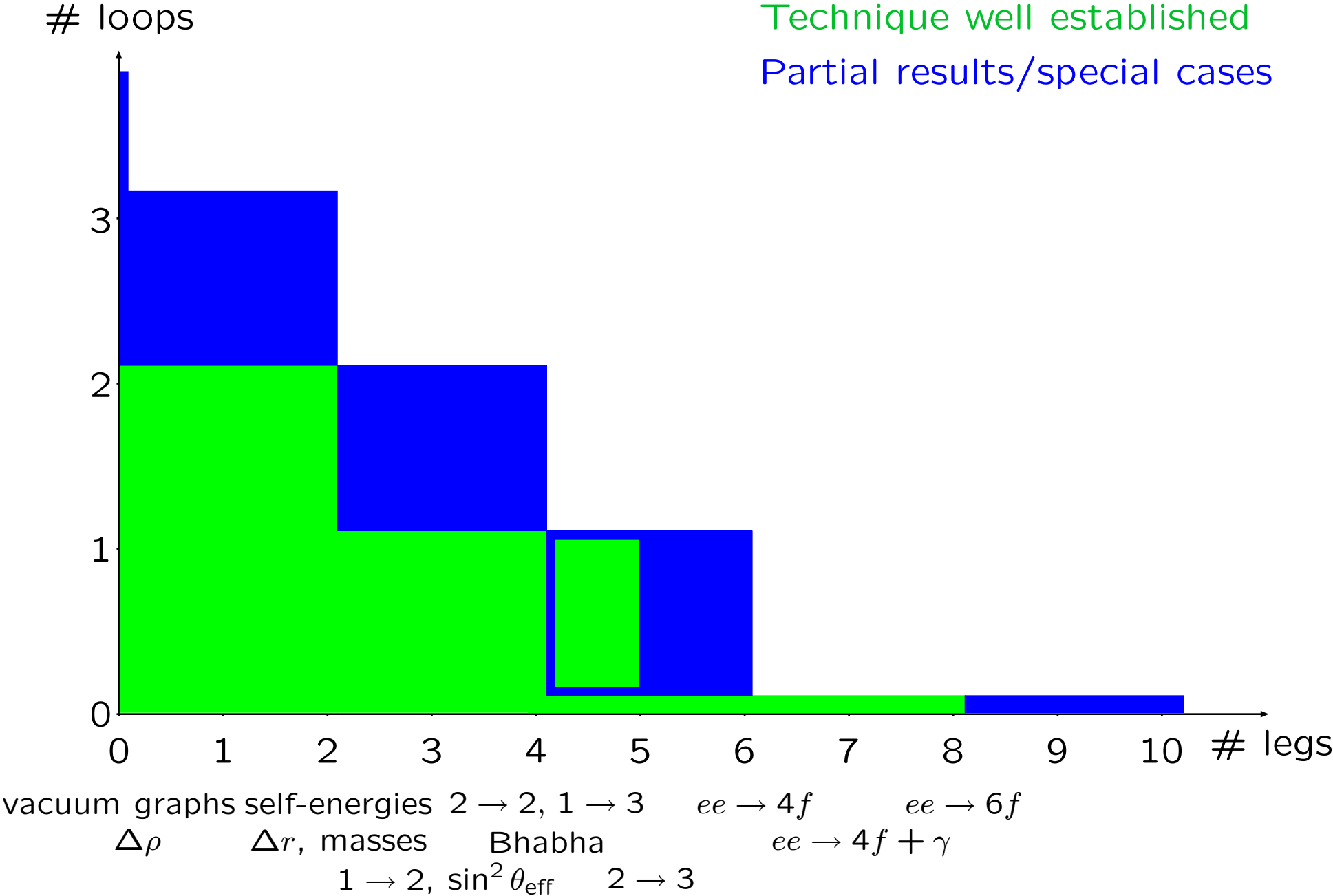
Non-Minimal Flavor Violation (tree)

full $2 \rightarrow 3$ at 1L

vacuum graphs $\Delta\rho$ self-energies Δr , masses $2 \rightarrow 2$, $1 \rightarrow 3$ Bhabha $1 \rightarrow 2$, $\sin^2 \theta_{\text{eff}}$ $2 \rightarrow 3$ $ee \rightarrow 4f$ $ee \rightarrow 4f + \gamma$ $ee \rightarrow 6f$

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Partial results/special cases



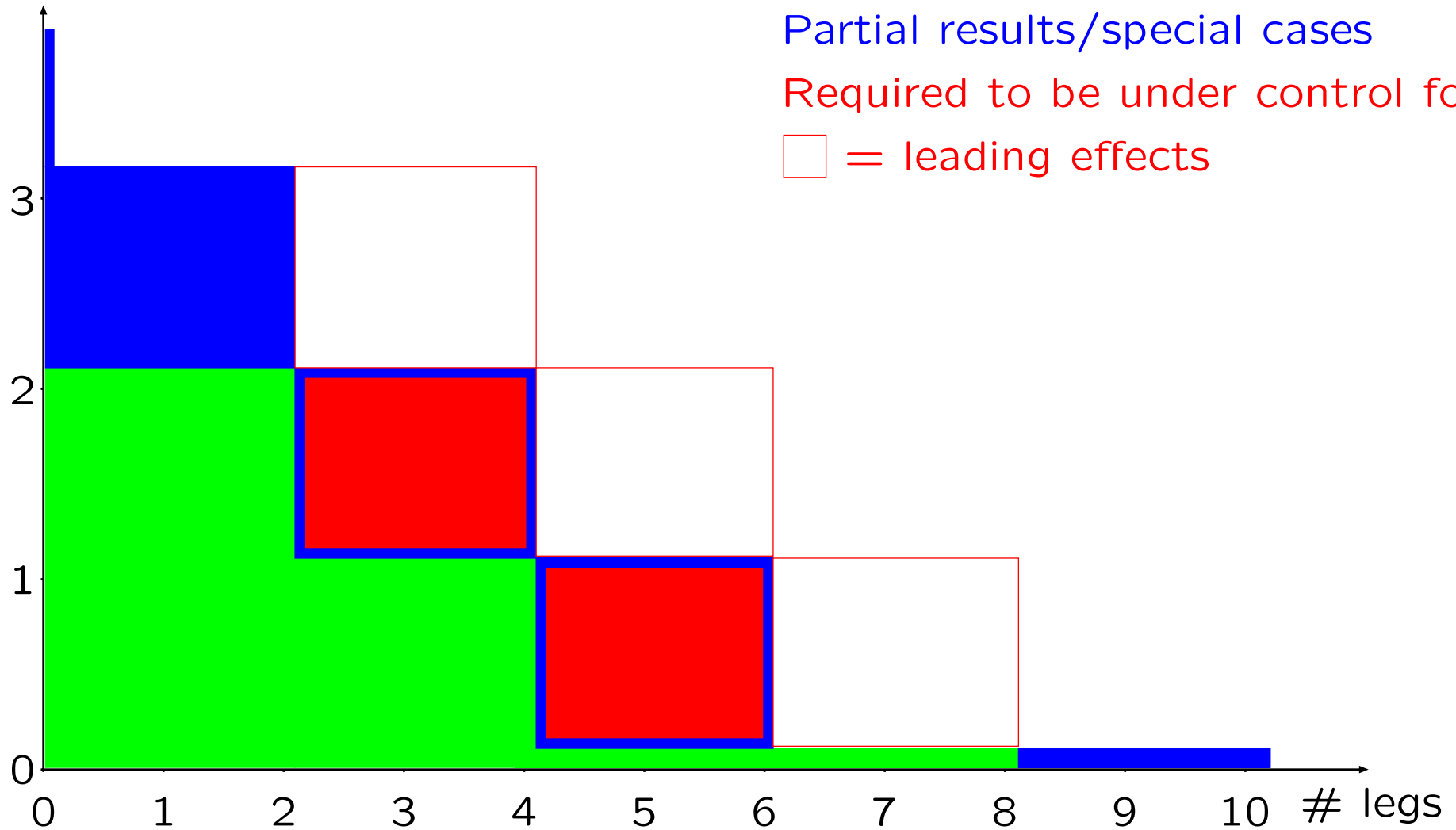
loops

Technique well established

Partial results/special cases

Required to be under control for ILC

□ = leading effects



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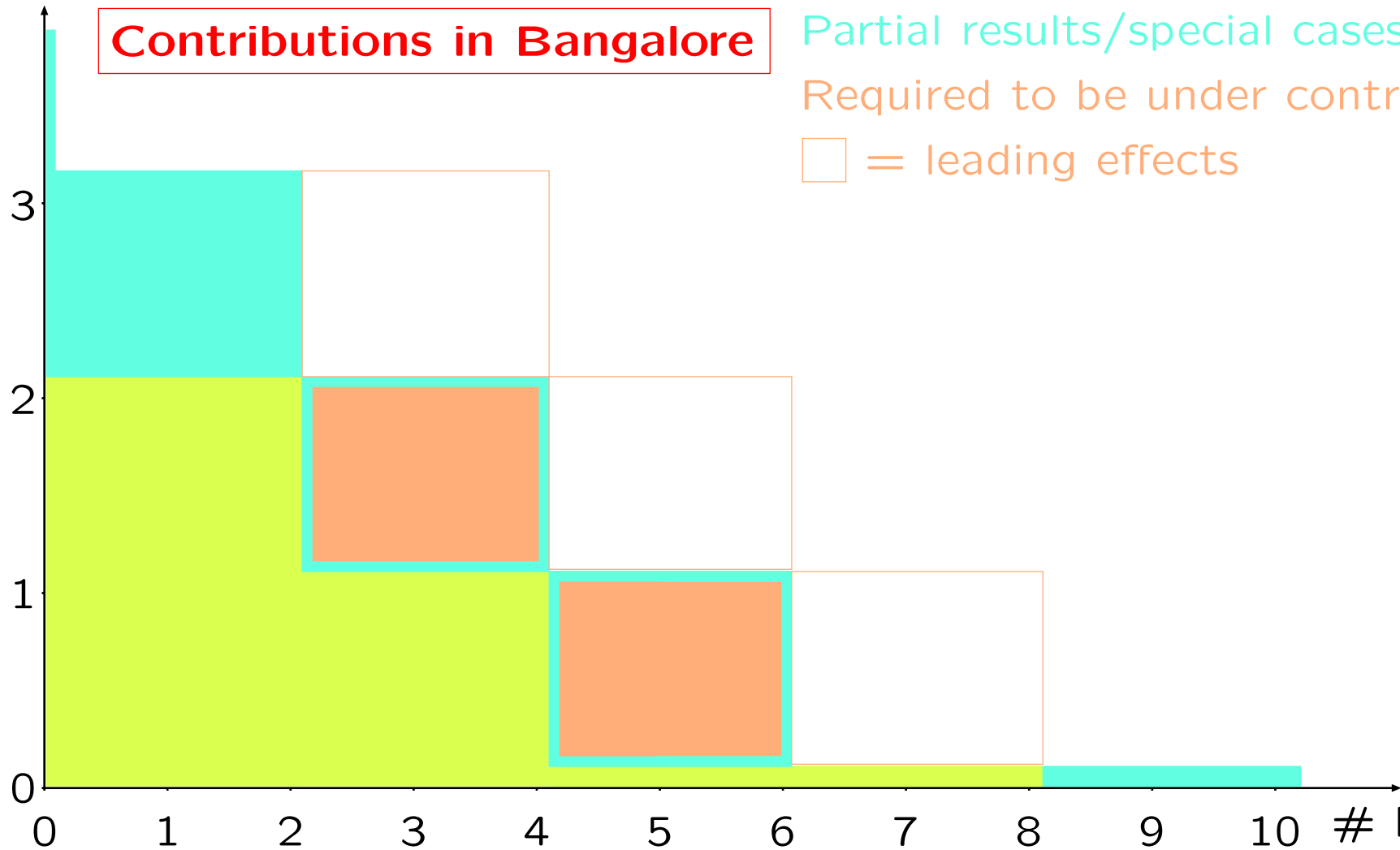
Contributions in Bangalore

Technique well established

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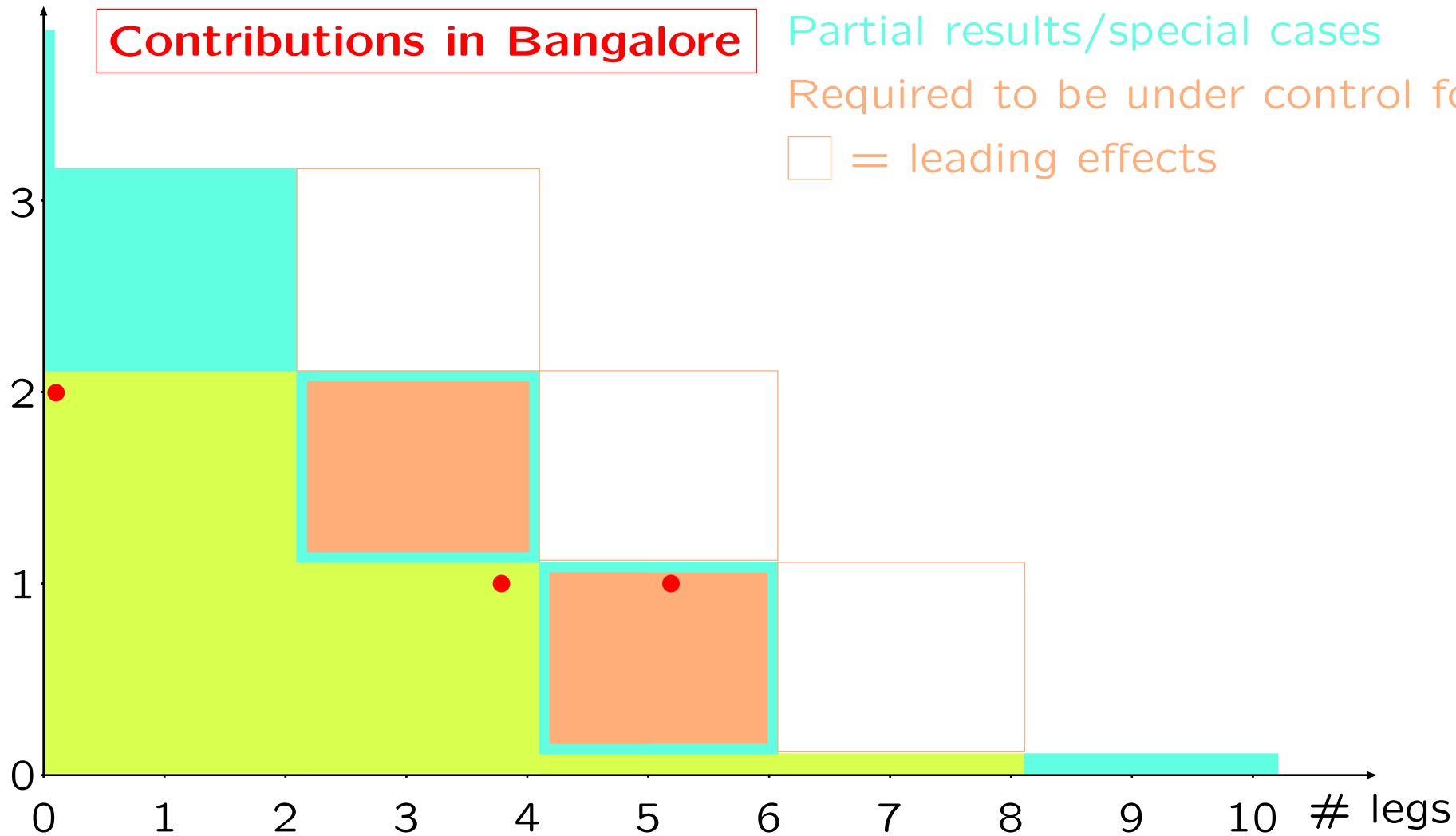
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vacuum graphs $\Delta\rho$ self-energies Δr , masses $1 \rightarrow 2, \sin^2 \theta_{\text{eff}}$ $2 \rightarrow 2, 1 \rightarrow 3$ Bhabha $2 \rightarrow 3$ $ee \rightarrow 4f$ $ee \rightarrow 4f + \gamma$ $ee \rightarrow 6f$

loops

Contributions in Bangalore

talk by [Y. Yasui](#) : 1 loop, 2 → 2, MSSM

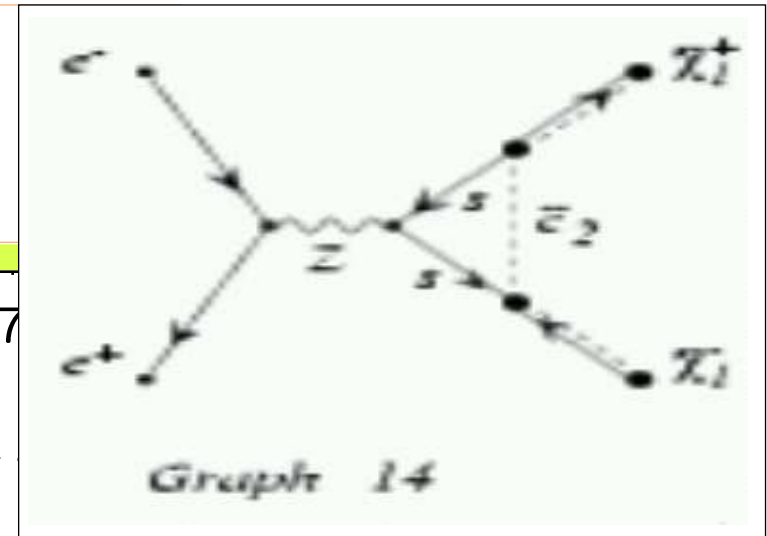
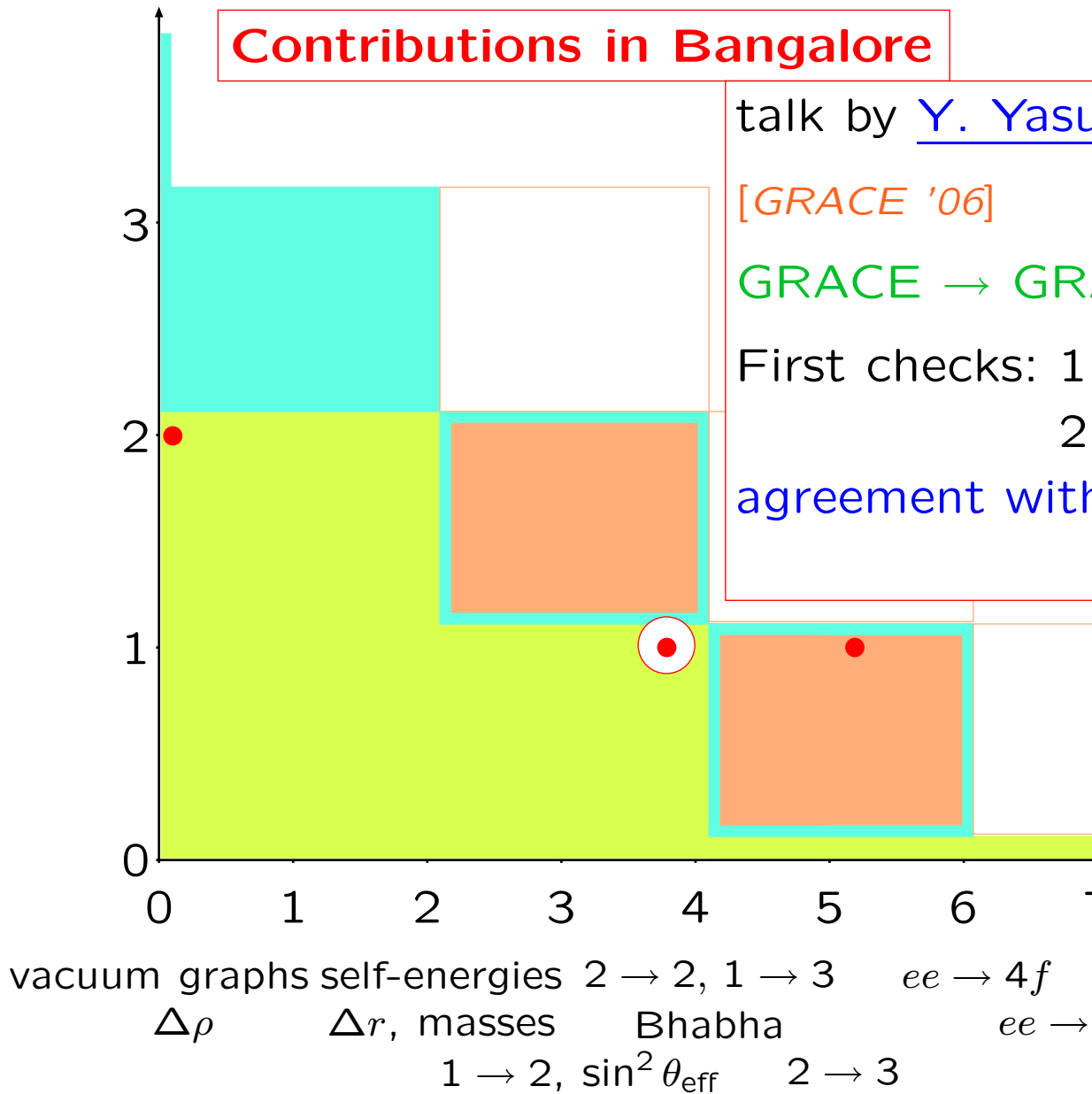
[GRACE '06]

GRACE → GRACE/SUSY

First checks: 1 → 2 (~ 10 procs)

2 → 2: $e^+e^- \rightarrow \tilde{\chi}_i^\pm \tilde{\chi}_j^\pm$

agreement with older results



loops

Contributions in Bangalore

talk by [E. Berger](#) : 1 loop: 2 → 3, SM

[Balazs, Berger, Nadolski, Qiu, Yuan '06]

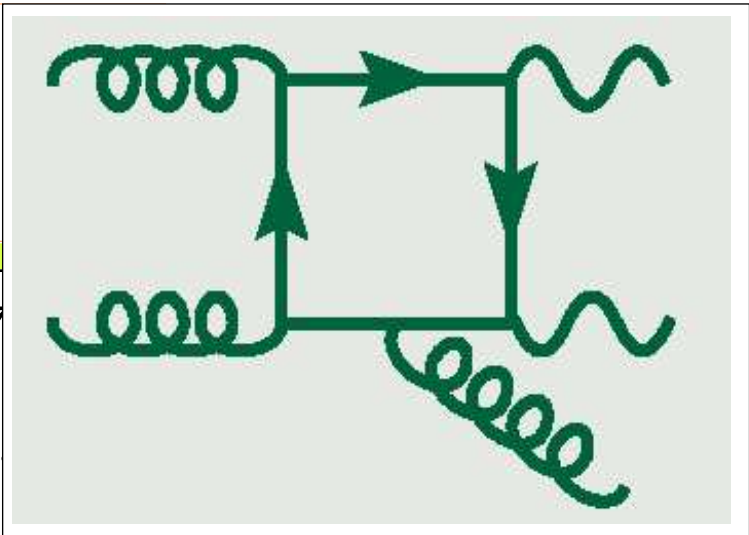
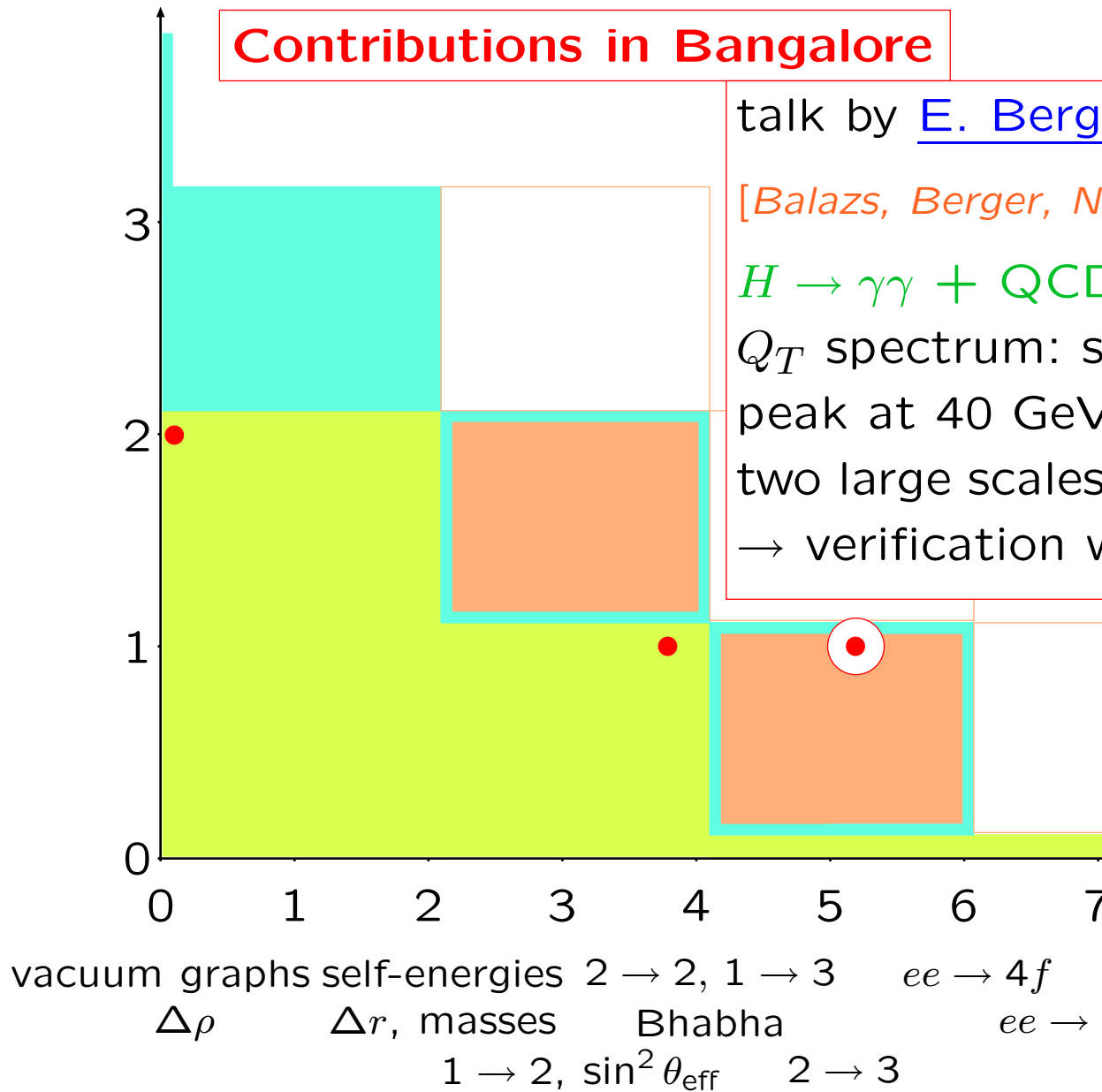
$H \rightarrow \gamma\gamma$ + QCD background

Q_T spectrum: signal vs. bgr:

peak at 40 GeV vs. 27 GeV

two large scales: $m_{\gamma\gamma}$ and $Q_T \Rightarrow$ LL resum.

→ verification with CDF data



loops

Contributions in Bangalore

talk by [S.H.](#) : 2L vacuum, MSSM + Ren.

[S.H., W. Hollik, H. Rzehak, G. Weiglein '06]

2L top/stop corr. to M_h : $\mathcal{O}(\alpha_s \alpha_t)$ complex

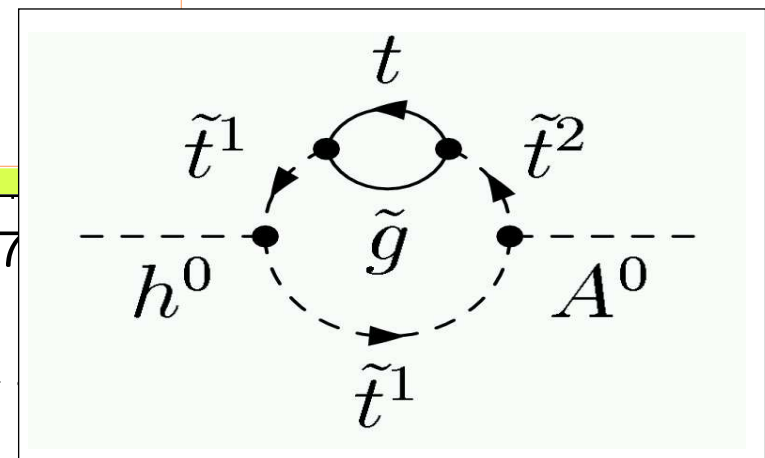
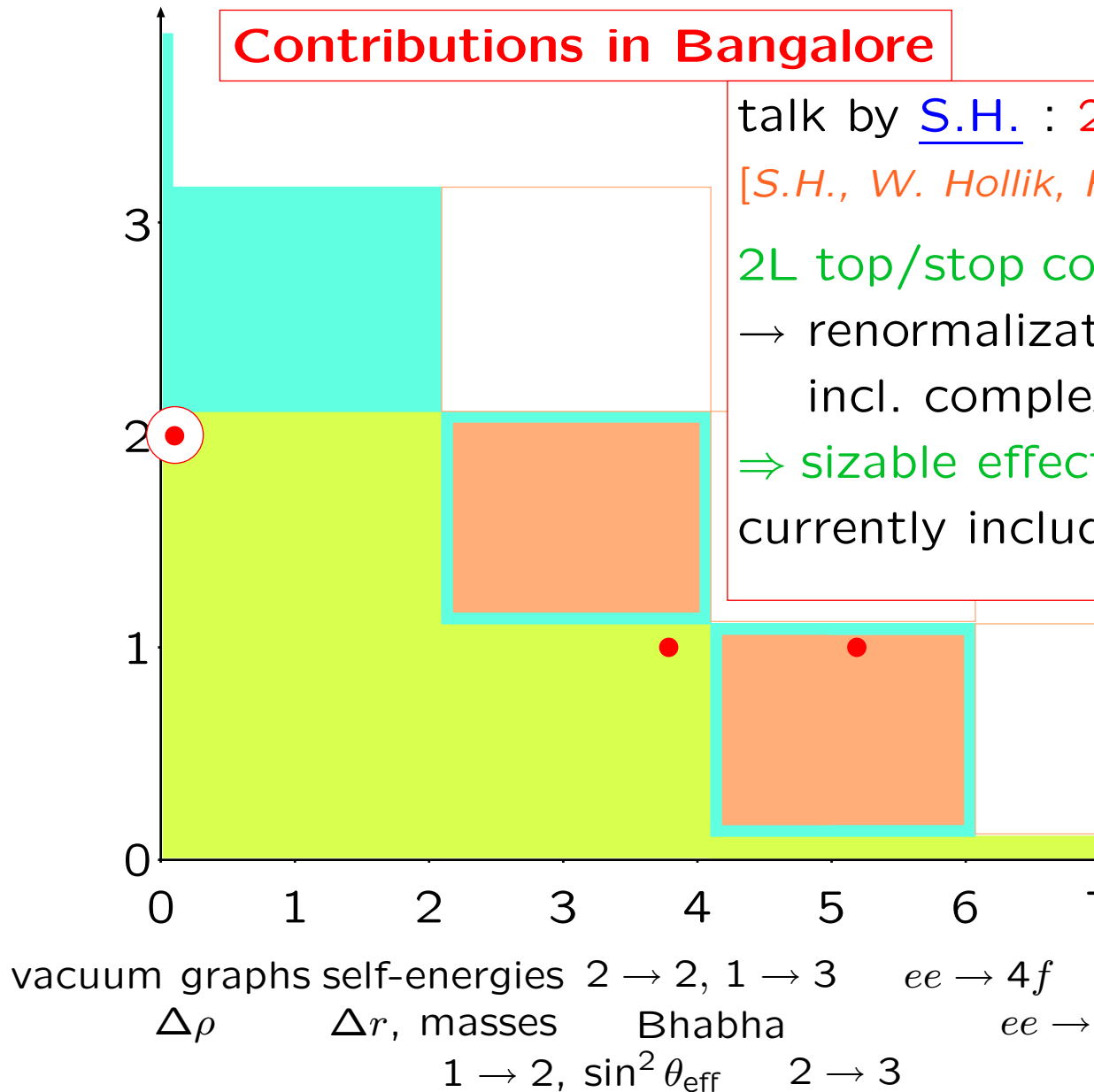
→ renormalization at 2L/1L level

incl. complex phases

⇒ sizable effects for M_h

currently included in **FeynHiggs**

LC: $\delta M_h^{\text{exp}} = 0.05 \text{ GeV}$



loops

Contributions in Bangalore

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2L top/stop corr. to M_h : $\mathcal{O}(\alpha_s \alpha_t)$ complex

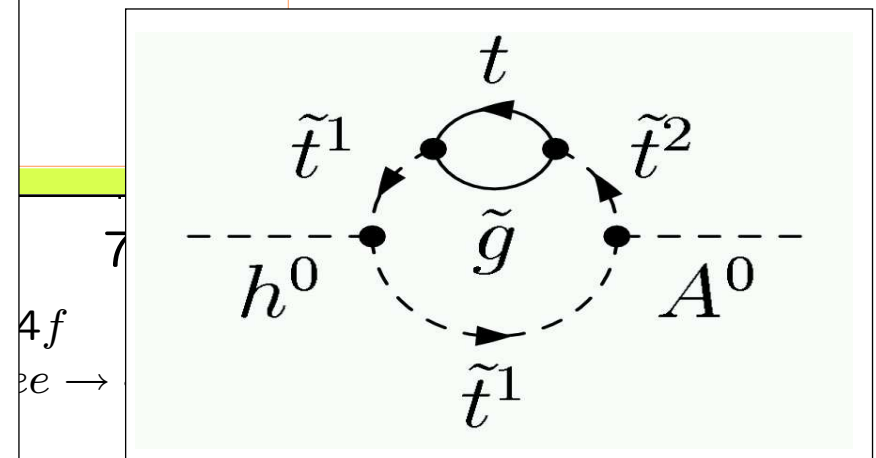
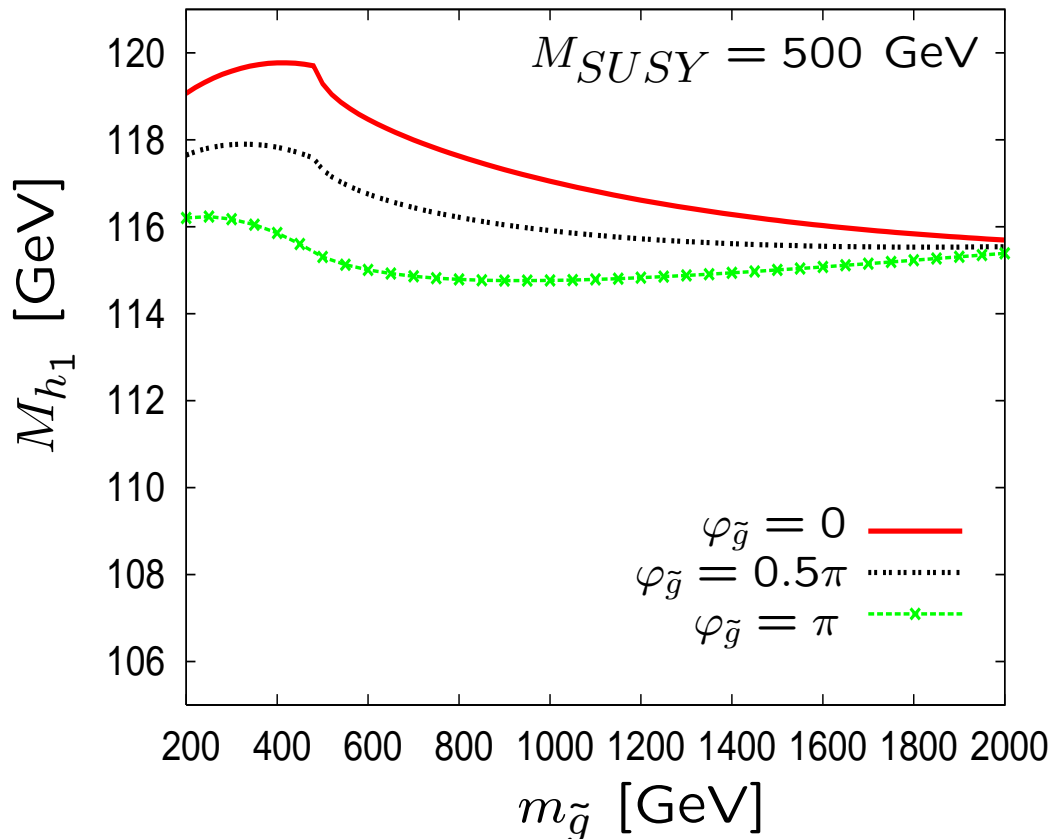
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5. Outlook

... no time left ...

There is progress in the right direction,
at least for Higgs, top/QCD, loops, ...
(sometimes one might wish for more activities)

Some goals can be met without problems, other are harder (as usual)
and some are **very** difficult!

⇒ We must not stop in our efforts

⇒ We must support the people doing the really hard work

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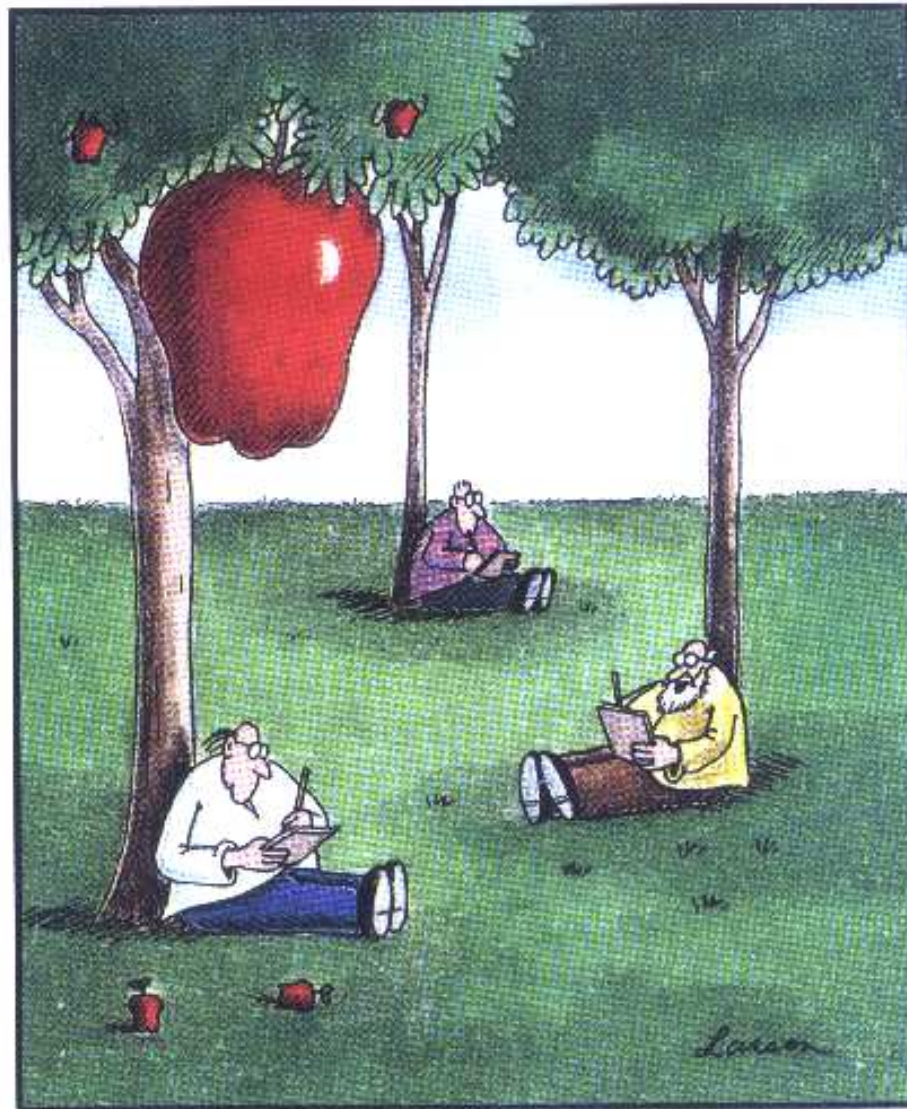
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⇒ We must support the people doing the really hard work

**If we continue with the hard work, physics will be ready
for the ILC start**

So let's work while we await the ILC:



"Nothing yet. ... How about you, Newton?"