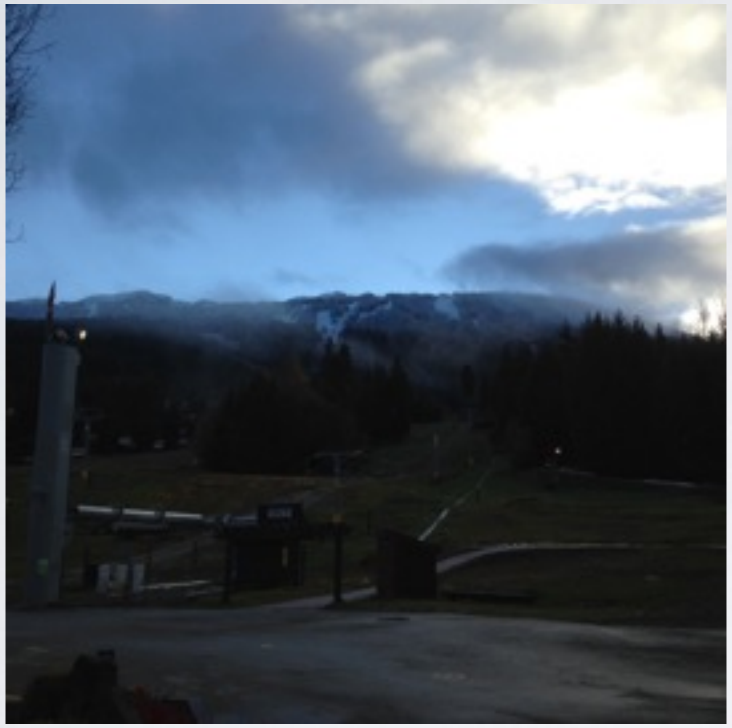
LCWS 2015: Whistler, Canada Theory/Theorist's recollection

Jürgen R. Reuter, DESY

LCWS in Whistler

Disclaimer: JRR's personal recollection



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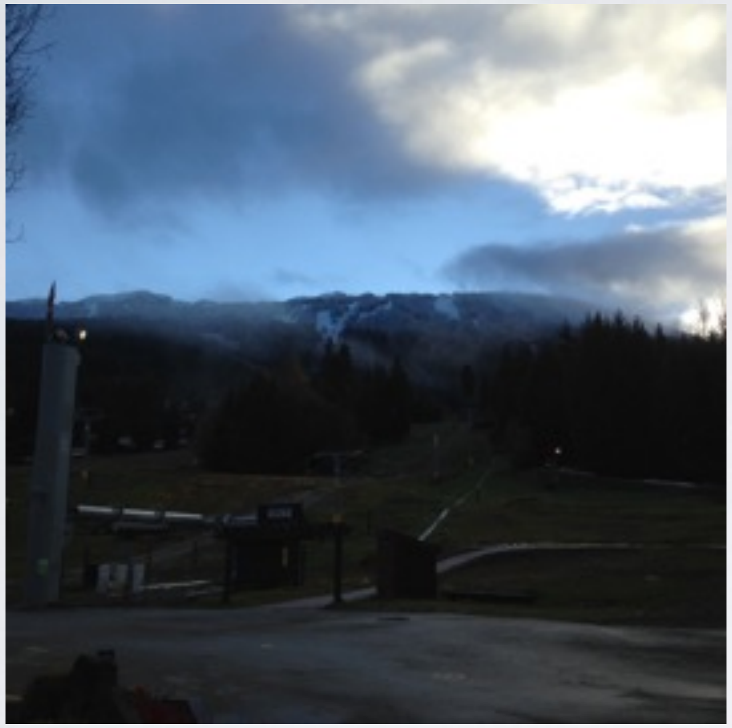

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  Work out pheno of existing models: discovery/discrimination potential compared to (HL-) LHC,

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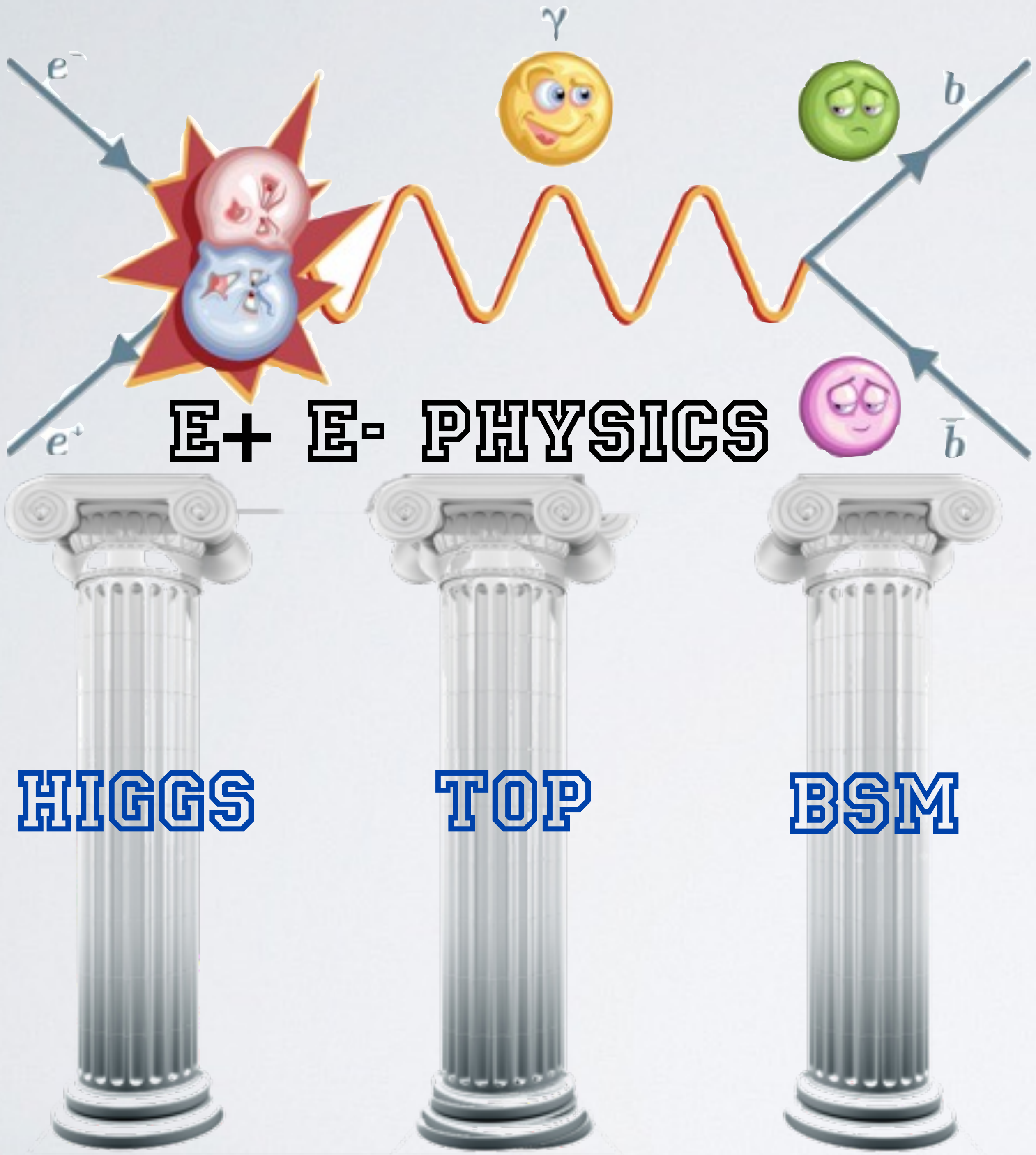
No discussions about 100 TeV pp sneaking in LCWS 2015 (yet) …

The Pillars of Lepton Physics



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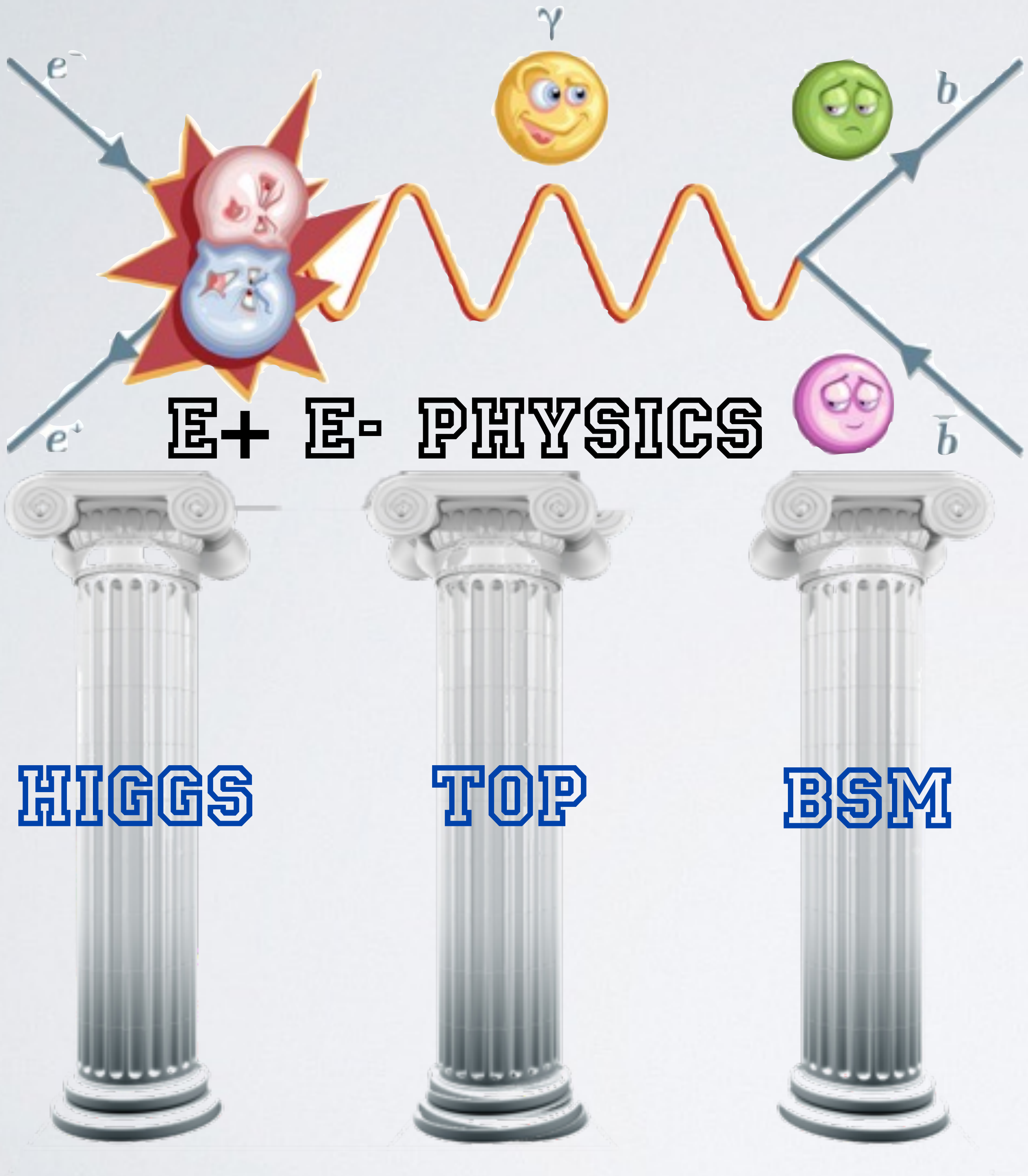
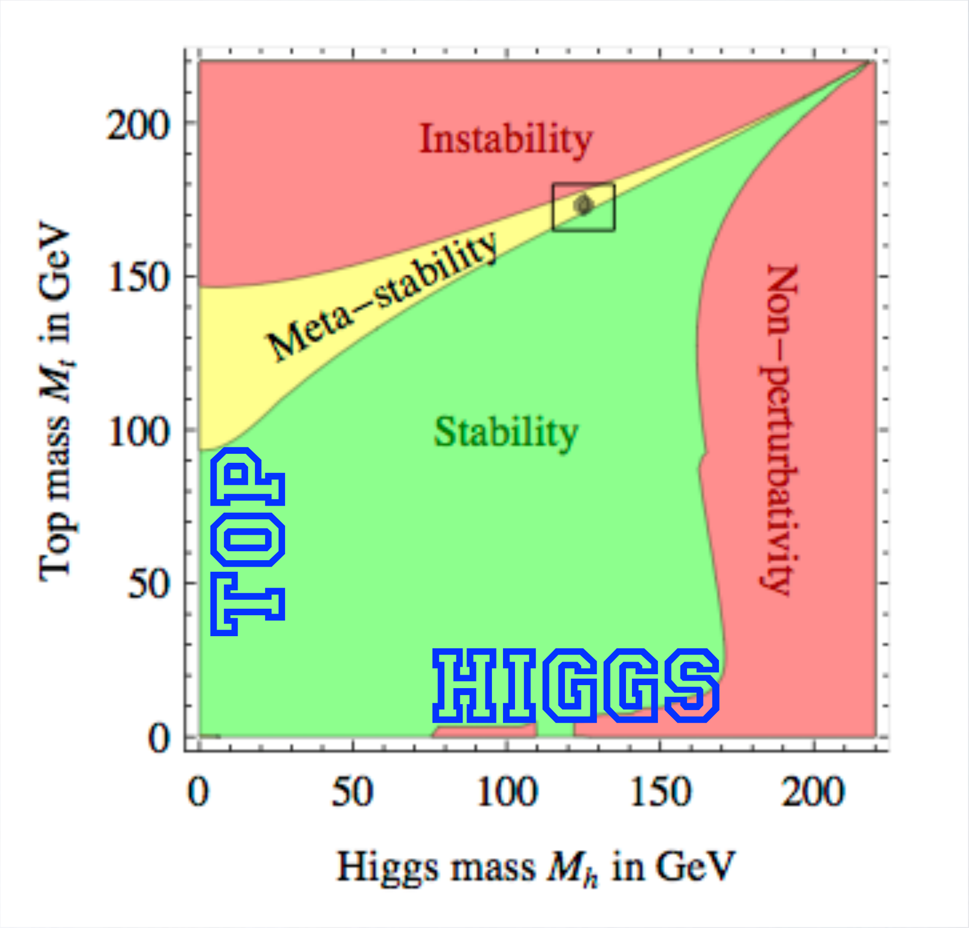


Electroweak vacuum & excitations:



(note: plot under assumptions of NO additional BSM)

TOP PHYSICS

Paradigmatic Standard Candle Telescopes

Standard (Model) candles can be used as
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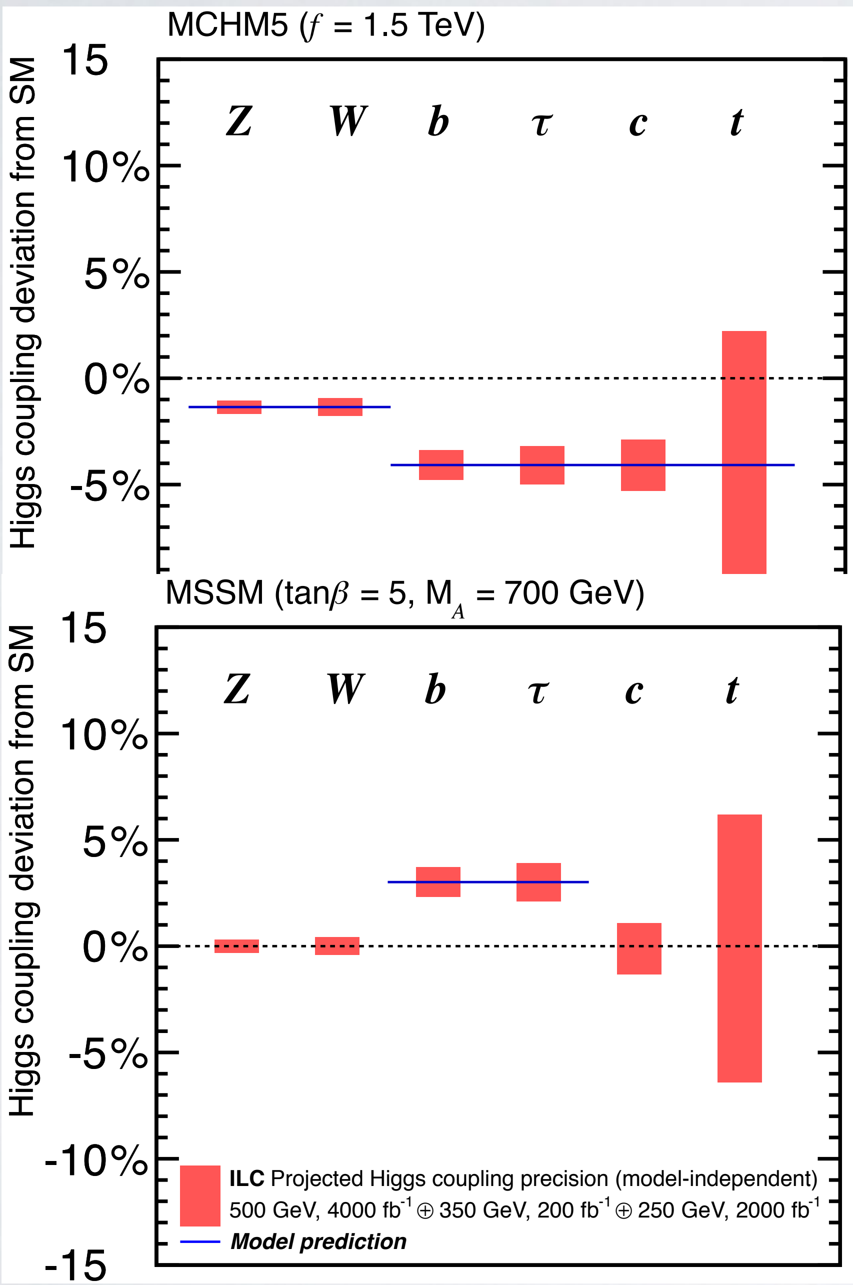
Search for anomalous Higgs couplings



Talks by S. Gori / M. Peskin

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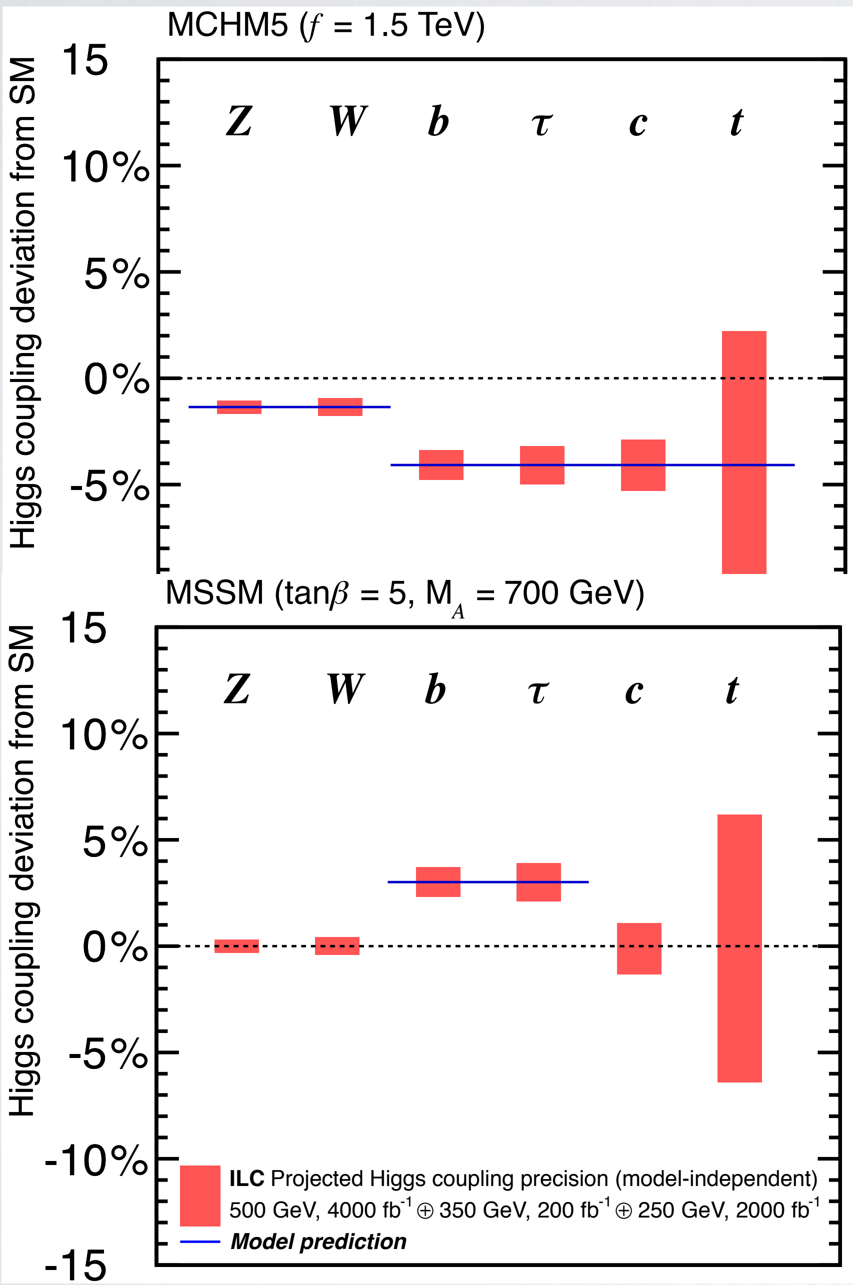
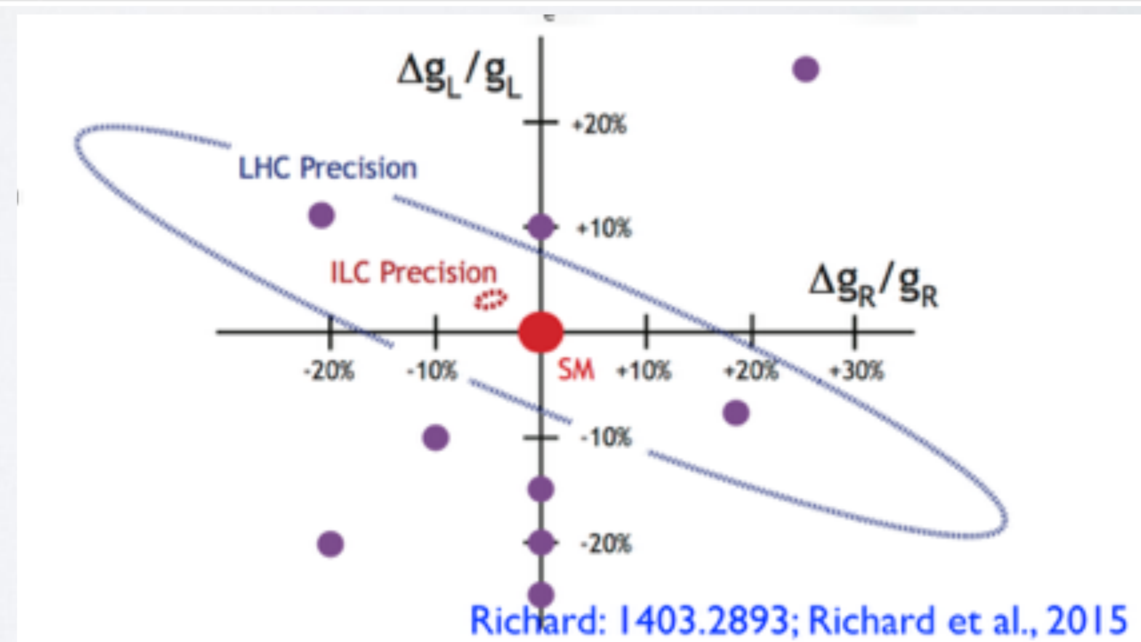


Anomalous Top couplings as BSM probes

$$\Gamma_\mu^{ttX}(k^2, q, \bar{q}) = ie\left\{\gamma_\mu\left(\widetilde{F}_{1V}^X(k^2) + \gamma_5\widetilde{F}_{1A}^X(k^2)\right) + \frac{(q-\bar{q})_\mu}{2m_t}\left(\widetilde{F}_{2V}^X(k^2) + \gamma_5\widetilde{F}_{2A}^X(k^2)\right)\right\}$$



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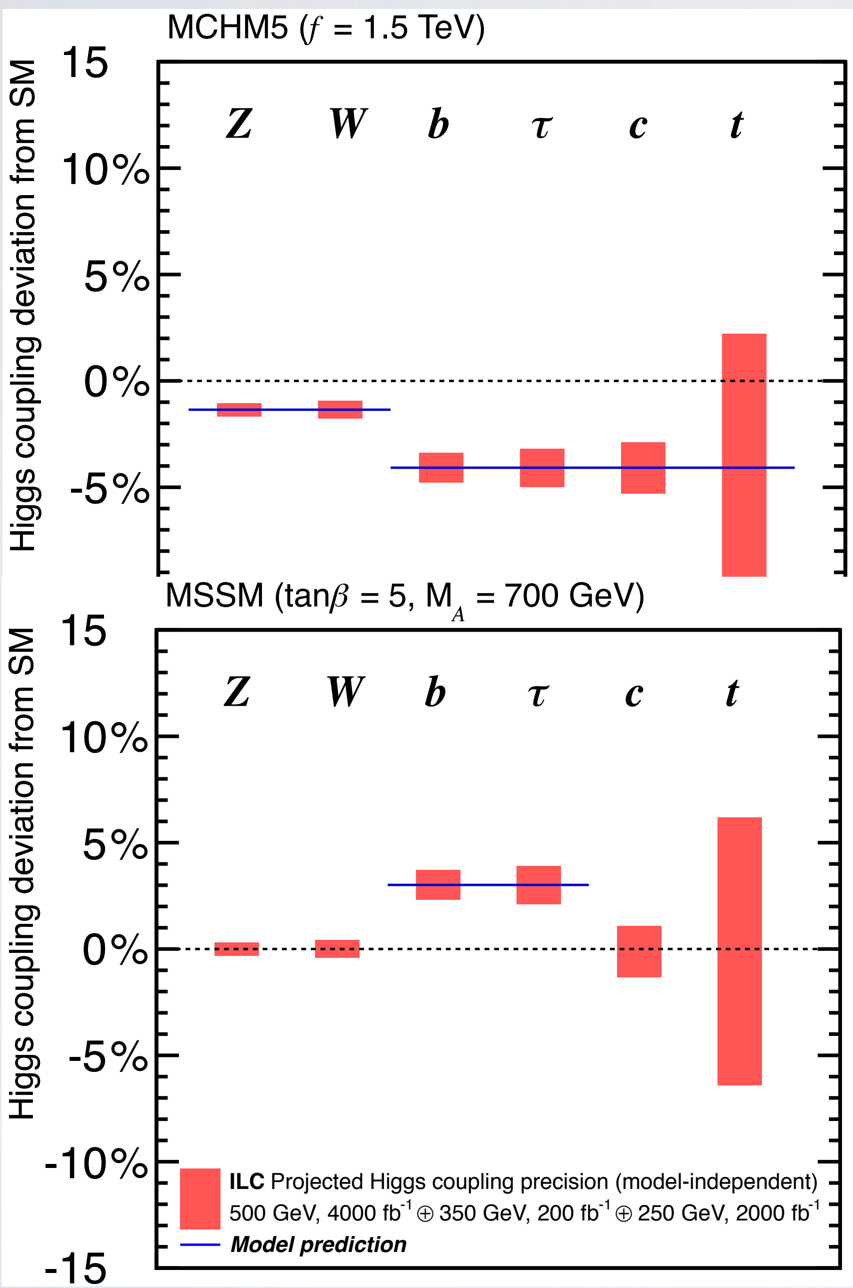

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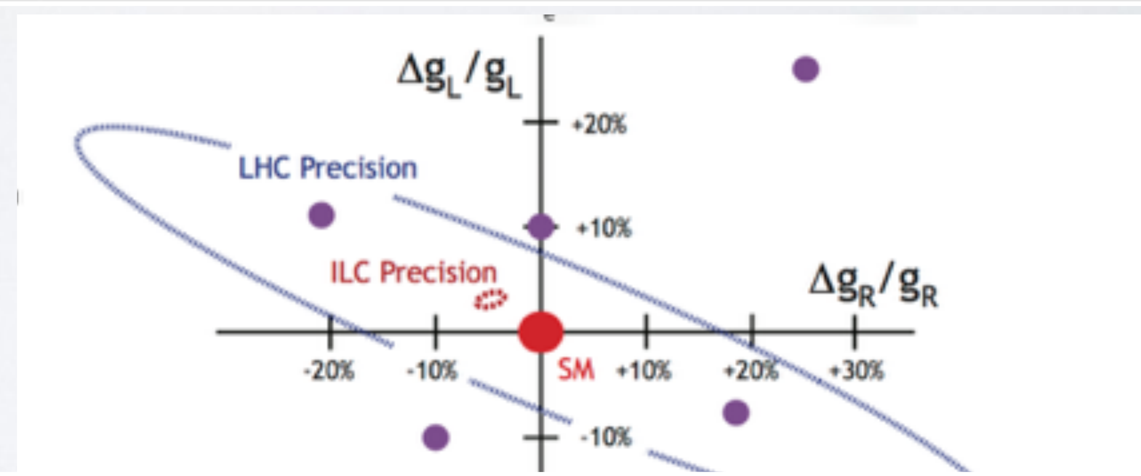


Is the top quark a heavy quark or an ordinary quark ?

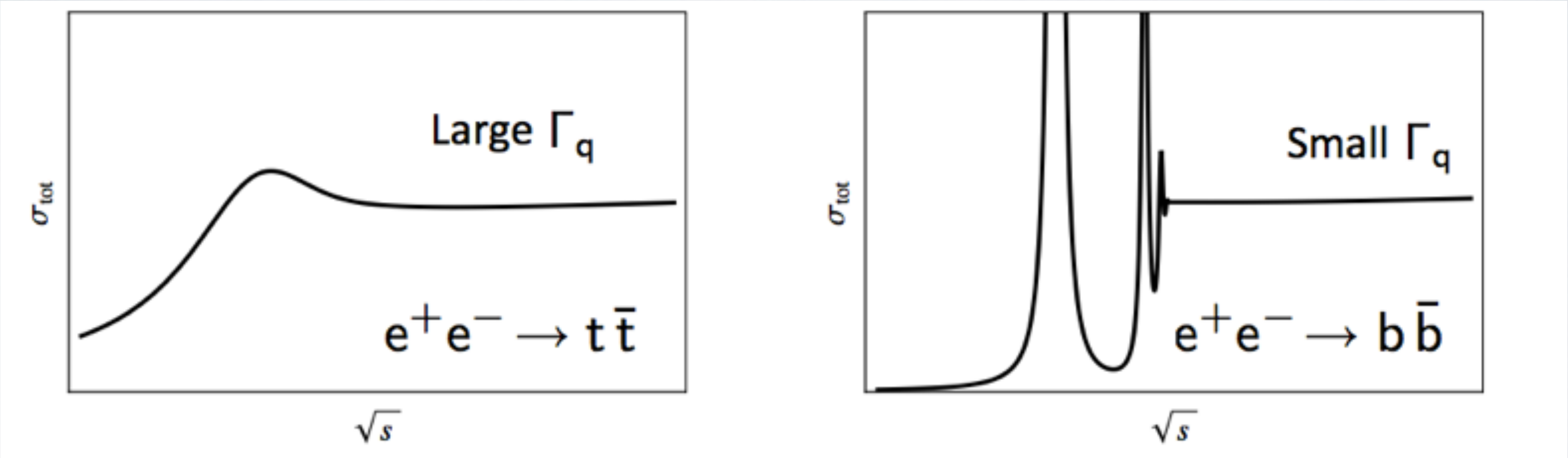
Richard: 1403.2893; Richard et al., 2015

Talks by S. Gori / M. Peskin

Top threshold at lepton colliders

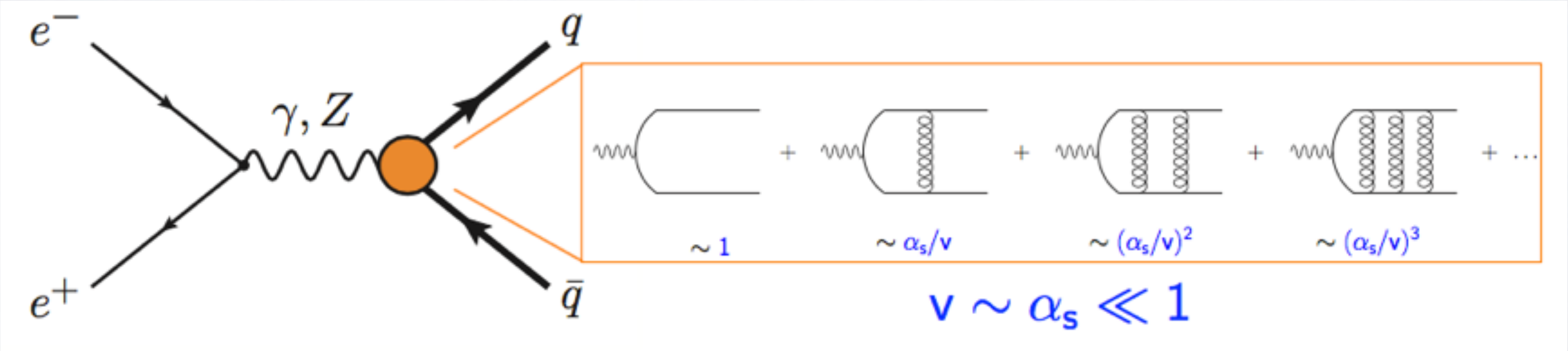
ILC top threshold scan best-known method to measure top quark mass, ΔM ~ 30-50 MeV

Heavy quark production at lepton colliders, qualitatively:



Threshold region: top velocity $v \sim \alpha_s \ll 1$

$$\nu = \sqrt{\frac{\sqrt{s} - 2m_t + \mathrm{i}\Gamma_t}{m}}$$



Top Mass Definition

[P. Marquard, DESY]

- Measured top (close to) top mass
- QCD needs more theoretical / Lagrangian top mass
- Translation perturbatively calculable
- New: 4-loop order known

- pole mass
- $\overline{\rm MS}$ mass
- PS mass
- 1S mass
- kinetic mass
- ...

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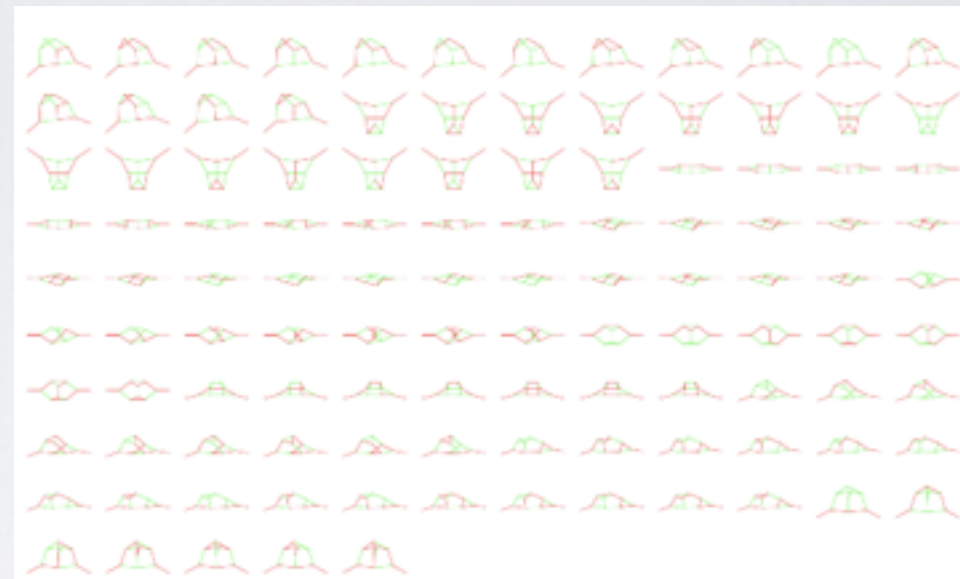

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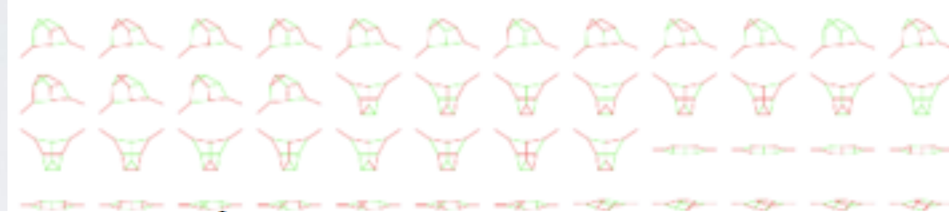

$$M_t = m_t \Big(1 + 0.4244\,\alpha_s + 0.8345\,\alpha_s^2 + 2.375\,\alpha_s^3 + (8.49 \pm 0.25)\,\alpha_s^4\Big)$$
$$= 163.643 + 7.557 + 1.617 + 0.501 + 0.195 \pm 0.005 \text{ GeV}$$

input #loops	$m^{\text{PS}} =$ 171.792	$m^{1\text{S}} =$ 172.227	$m^{\text{RS}} =$ 171.215	
1	165.097	165.045	164.847	
2	163.943	163.861	163.853	1-2 GeV
3	163.687	163.651	163.663	$\lesssim$ 250 MeV
4	163.643	163.643	163.643	$\lesssim$ 40 MeV
4 (×1.03)	163.637	163.637	163.637	6 MeV

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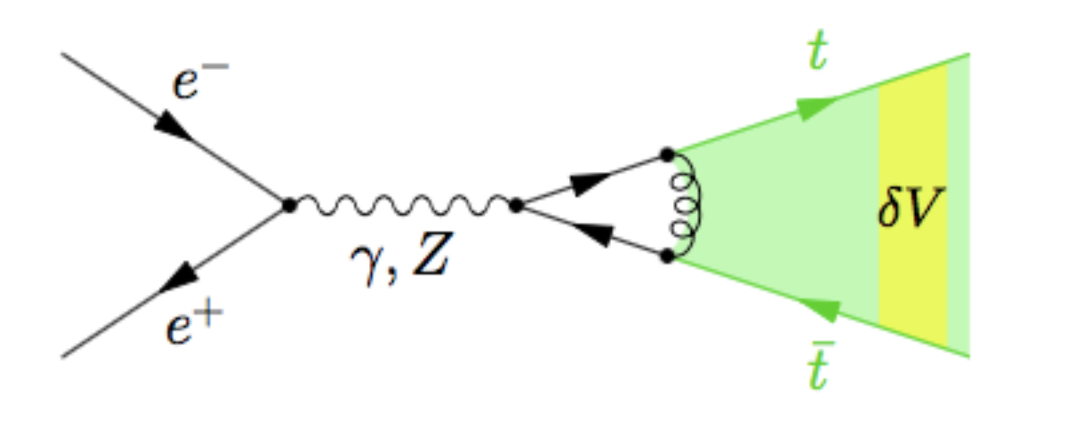
QCD uncertainties top threshold

[Beneke/Kiyo/Penin/Piclum/Marquard/Steinhauser, 2015]

Potential non-relativistic QCD

N^3LO QCD corrections



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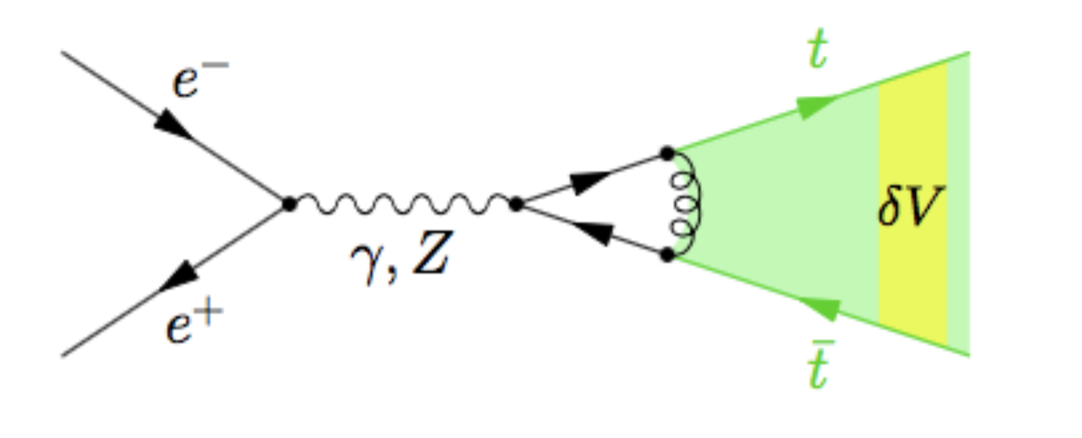
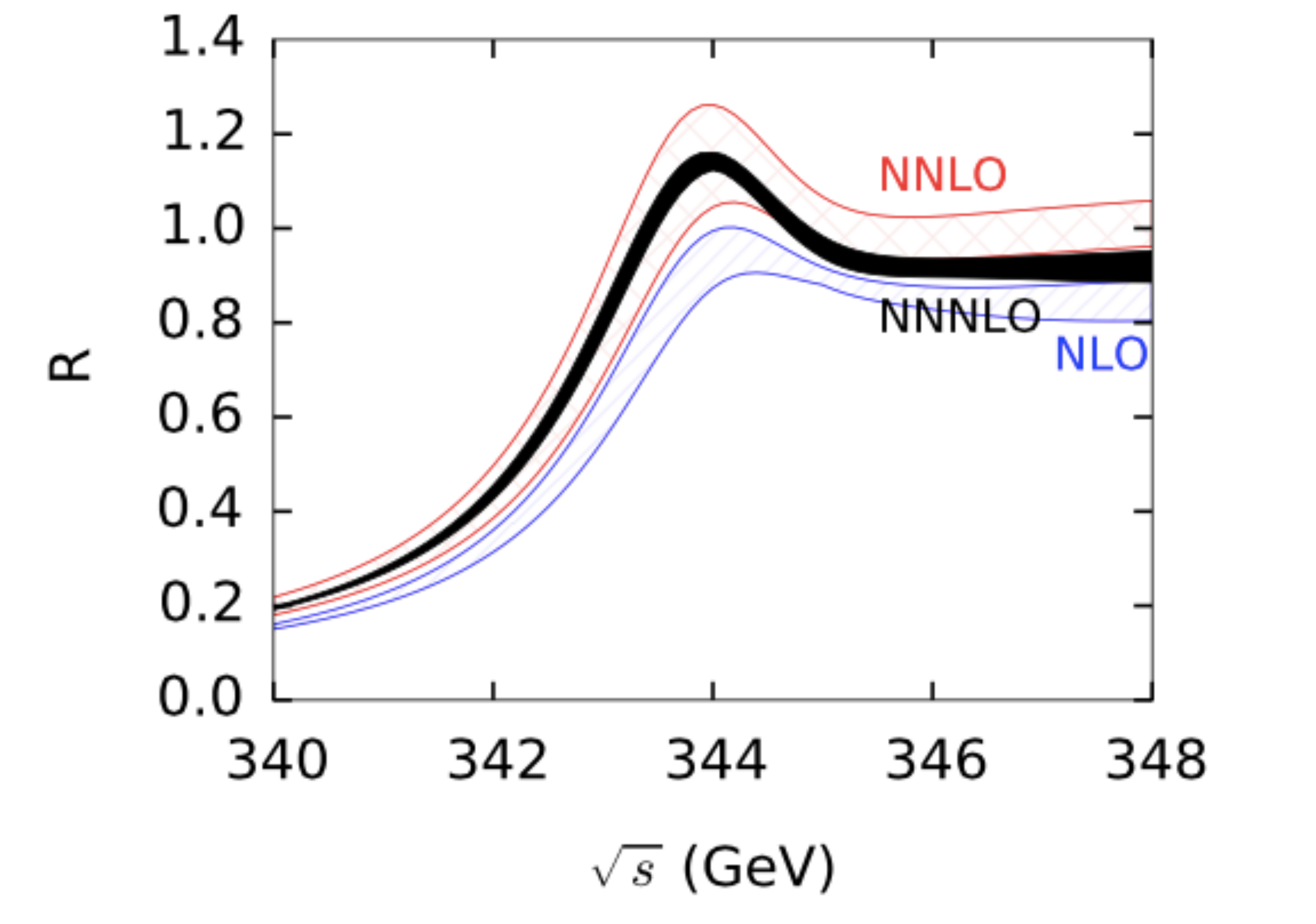




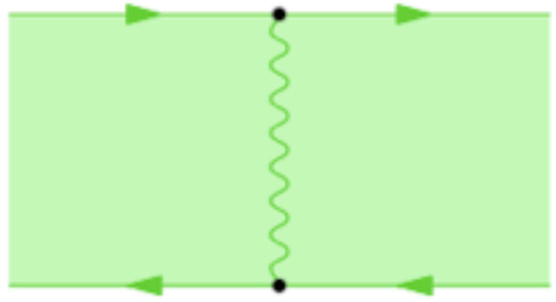
Top threshold: top Yukawa etc.

[A. Maier, TU München]

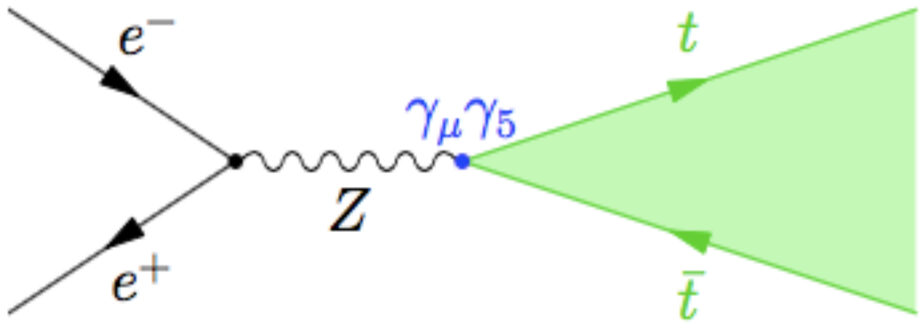
QCD@NNNLL (3% uncertainties) under control: worry about non-QCD corrections

- QED Coulomb potential

Starting at NLO:



- P-wave production



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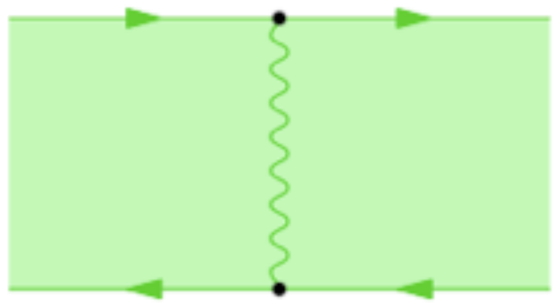

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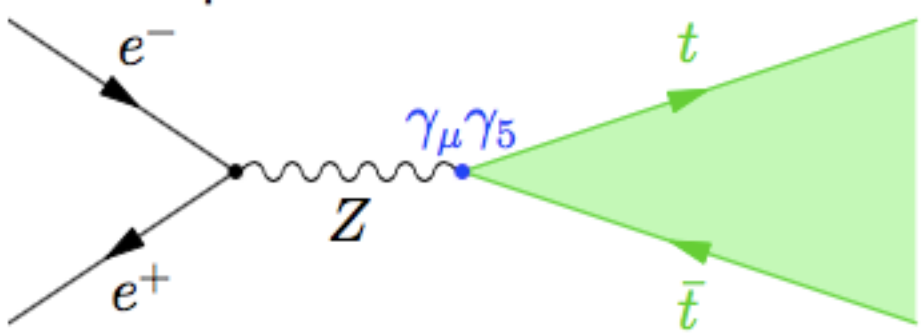

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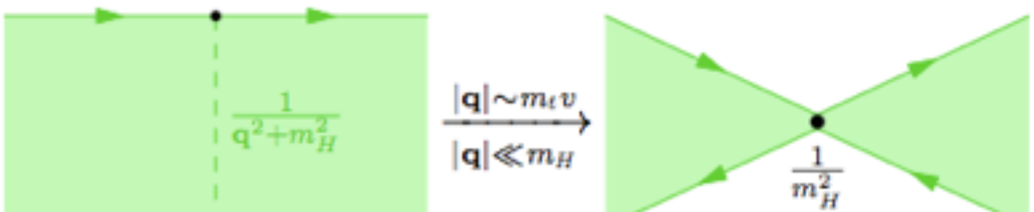
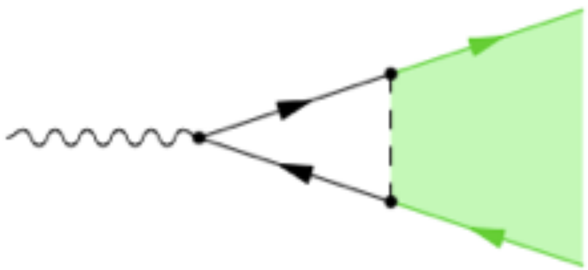
  - Potential (NNNLO):



  - Production current (NNLO + NNNLO):



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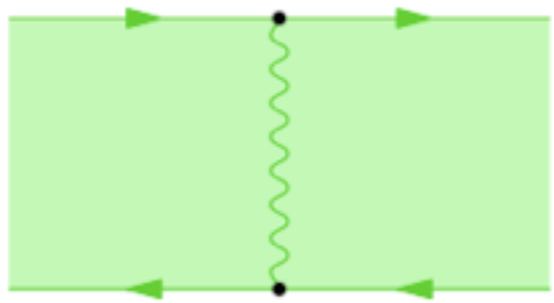

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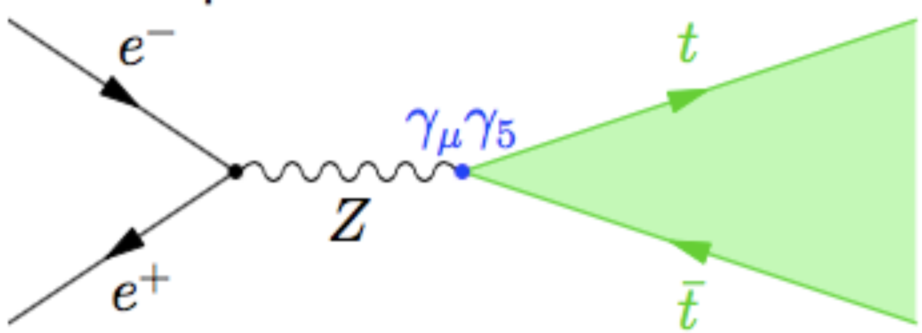

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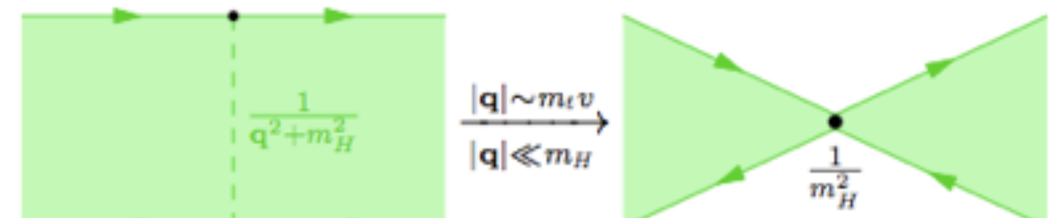

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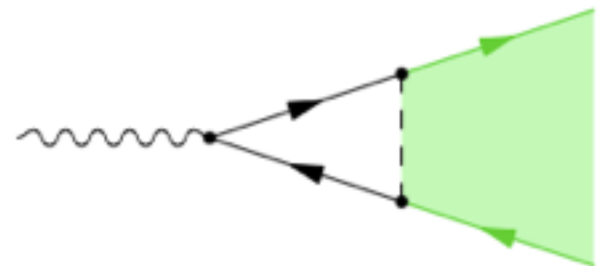
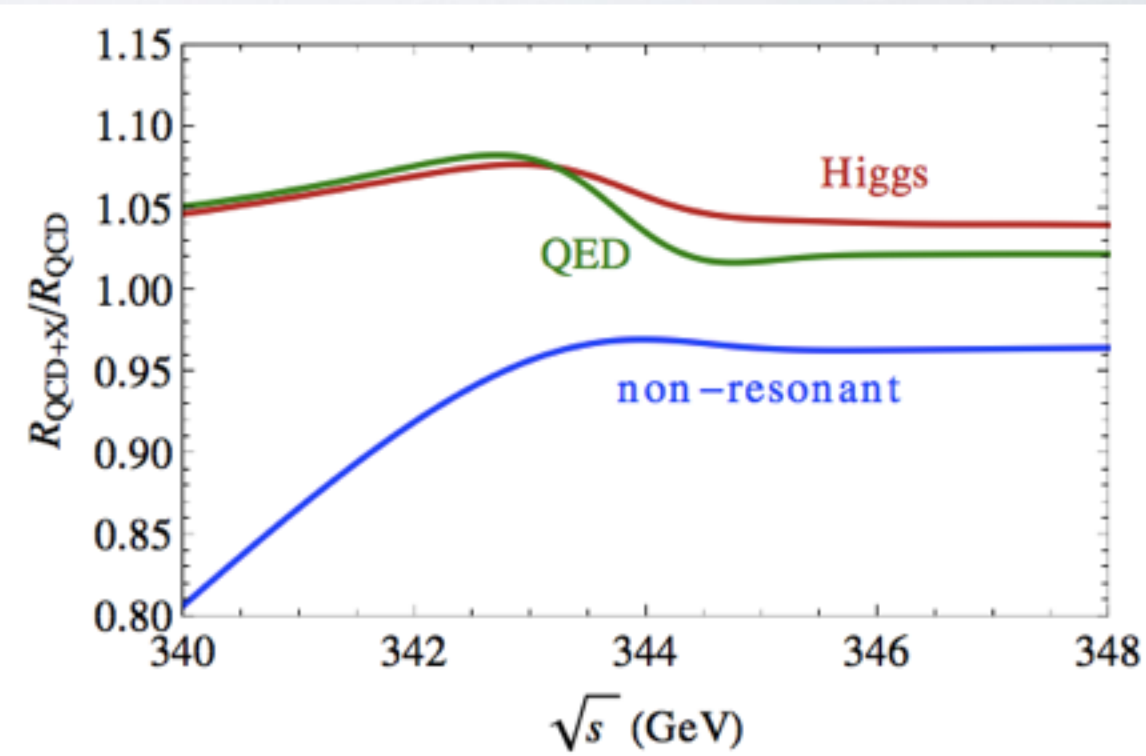




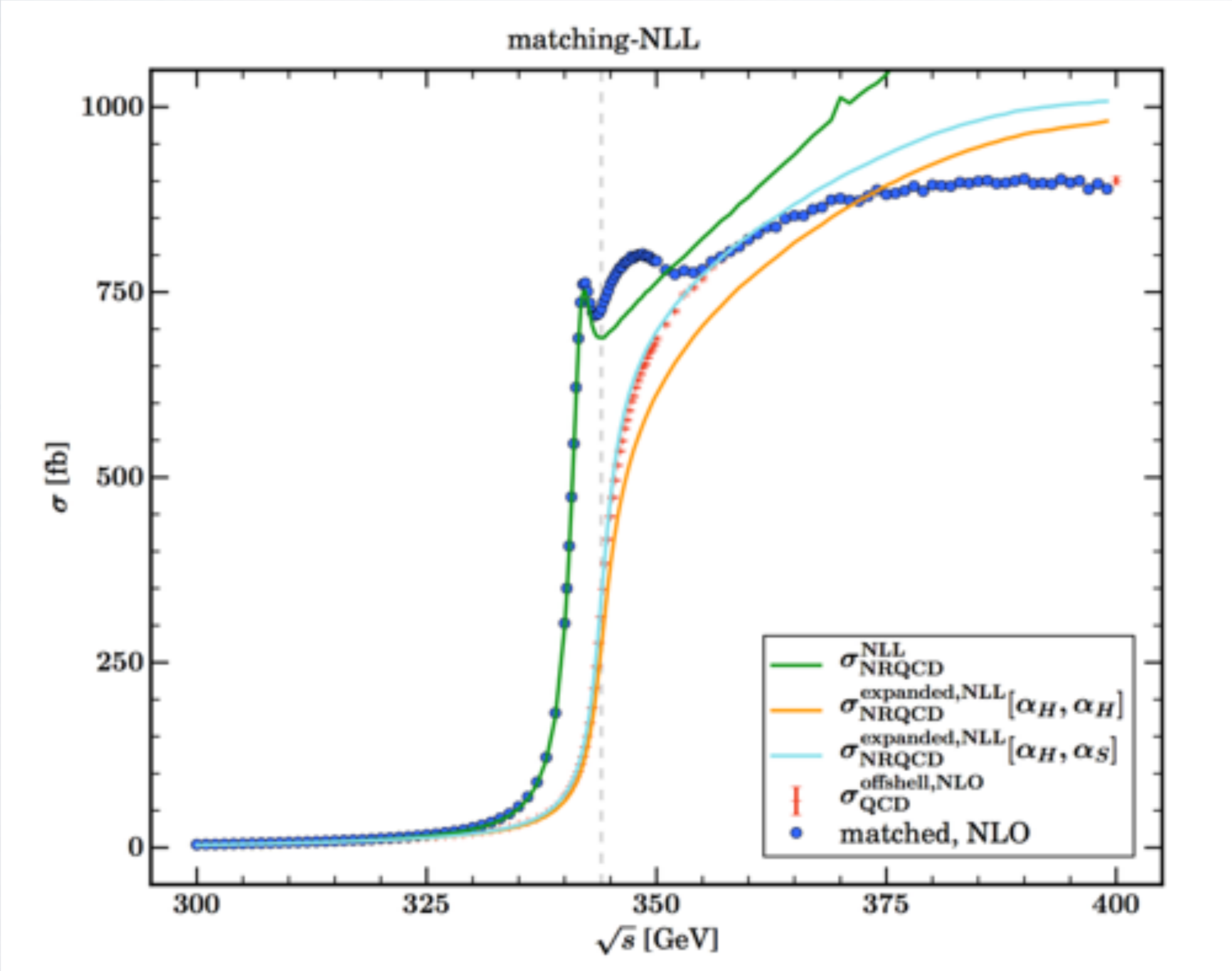
Top threshold in WHIZARD

[JRR, DESY]
with F. Bach, B. Chokoufe, A. Hoang, M. Stahlhofen, C. Weiss

- Default parameters:

$$M^{1S} = 172 \text{ GeV}, \quad \Gamma_t^{\text{NLO}} = 1.409 \text{ GeV}$$
$$\Gamma_t^{\text{LO}} = 1.541 \text{ GeV}, \; \alpha_s(M_Z) = 0.118$$

Subtle gauge cancellations between signal process and non-resonant diagrams!
Exact value of top width crucial!



Status Whistler last week

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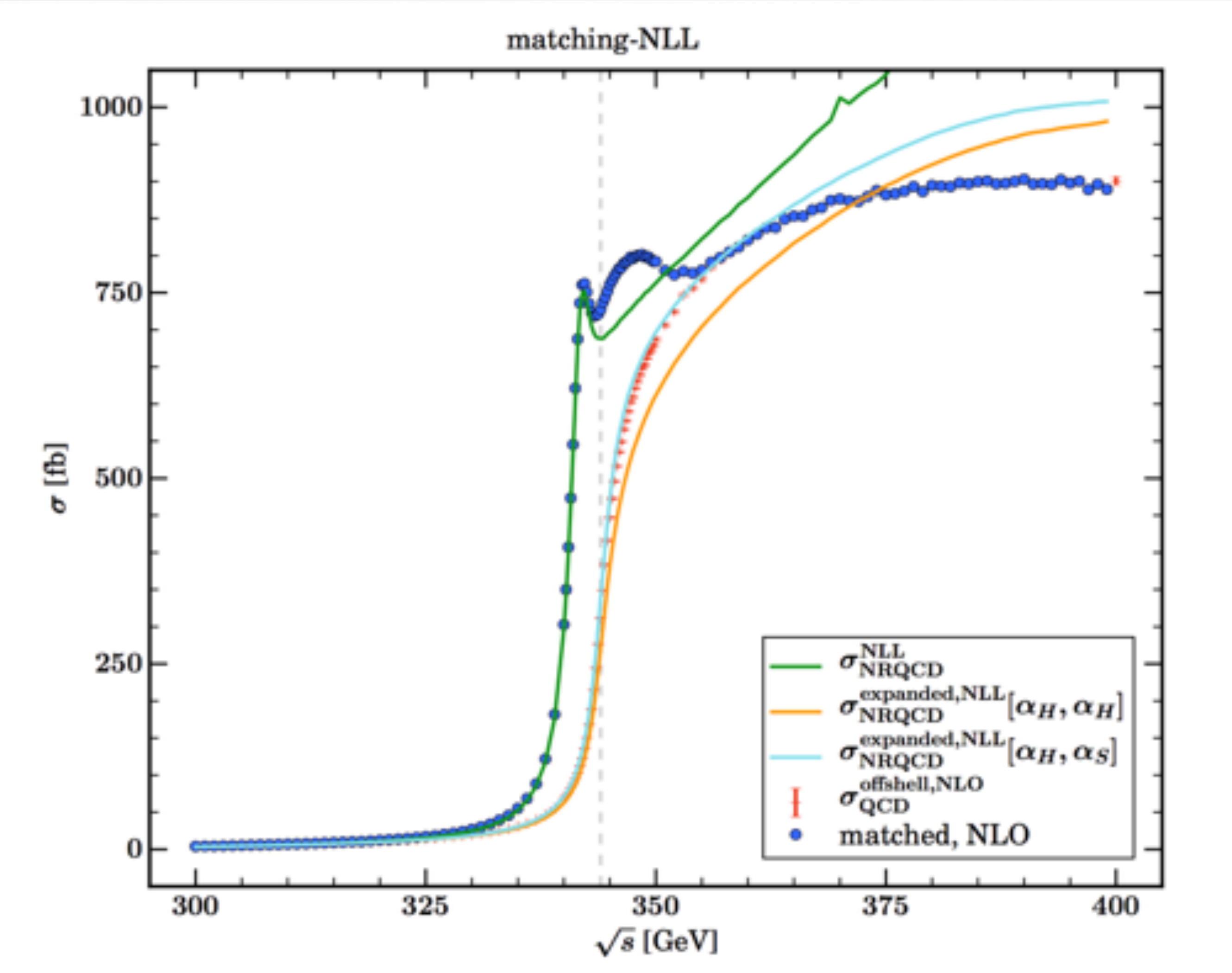

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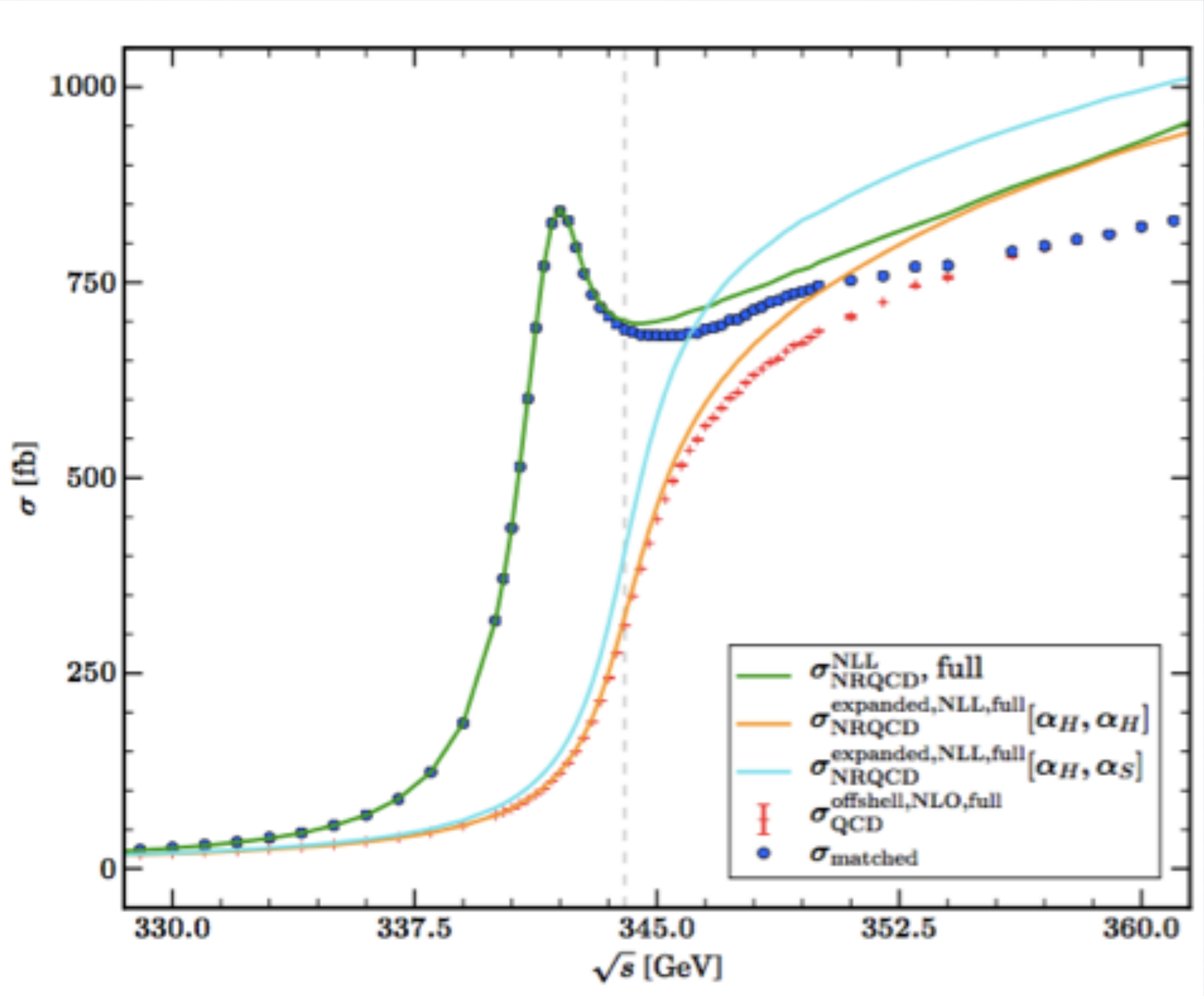
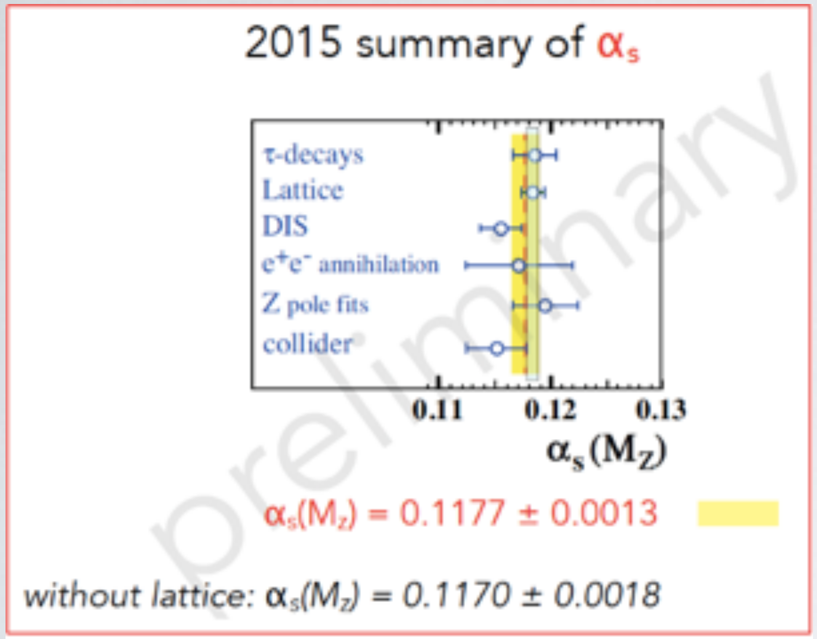


Status DESY yesterday,
based on discussions with A. Hoang in Whistler

oh yes, there is still …. the strong coupling

[A. Hoang, Vienna]

World Average 2015



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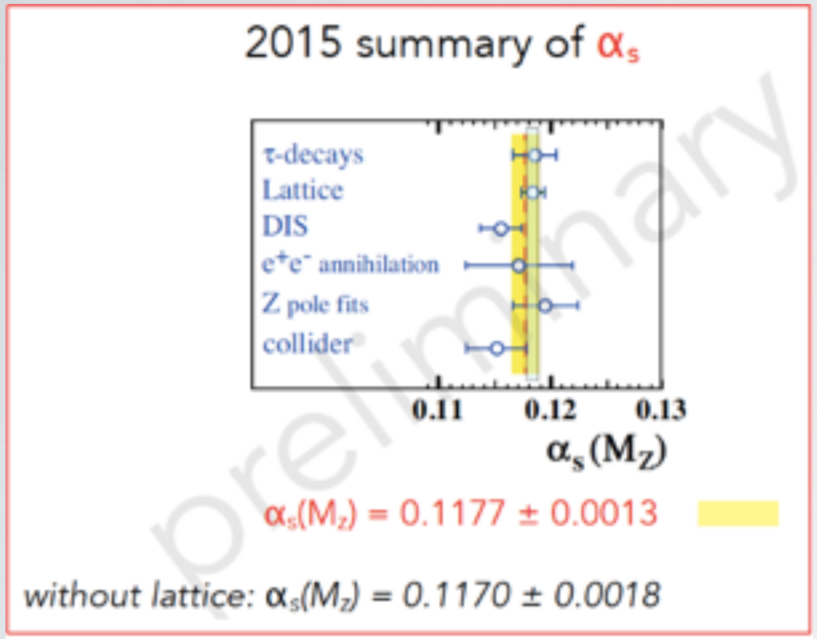

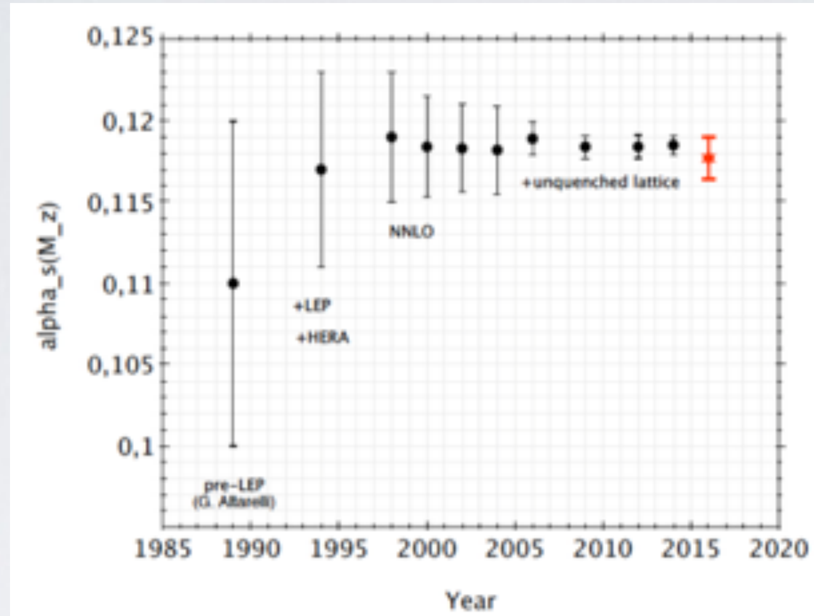

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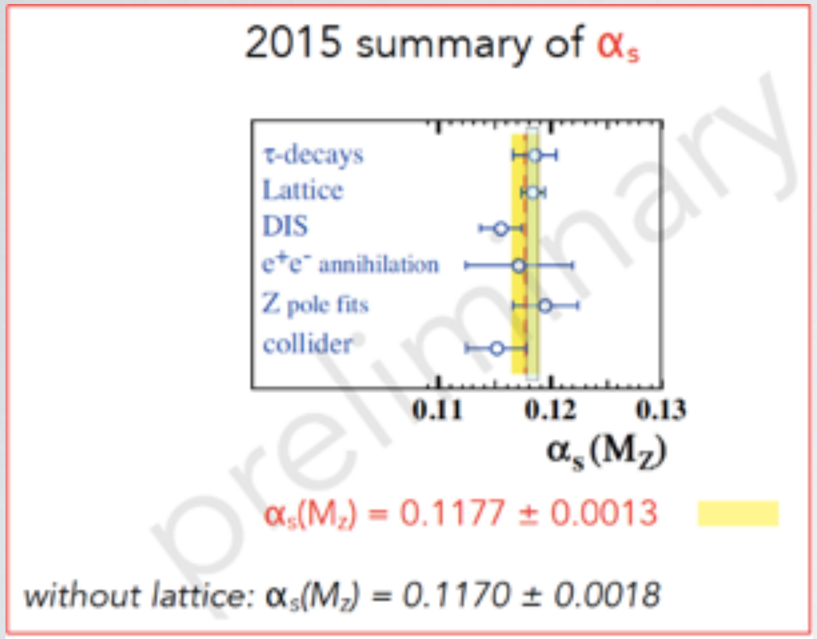

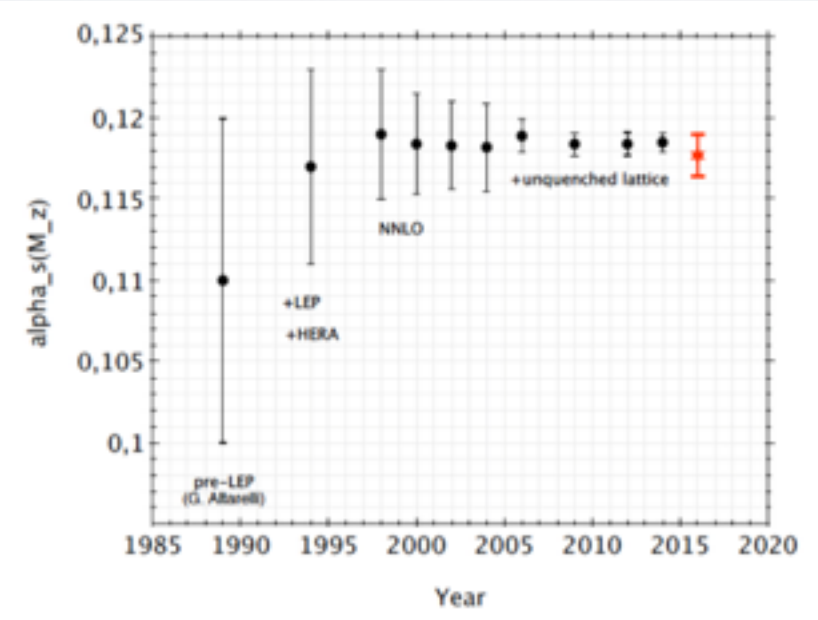

- new **preliminary** value of world $\alpha_s(M_z)$: = 0.1177 ± 0.0013
- change from 2013 value ($\alpha_s(M_z)$=0.1185 ± 0.0006) mainly due to:
  - decreased weight (increased error) of lattice results
  - decreased central value from τ-decays
  - result from new class (hadron collider, ttbar x-section), with only one published result, however known to be systematically low
- known but unresolved issues for almost all classes
- no convergence of issues in sight

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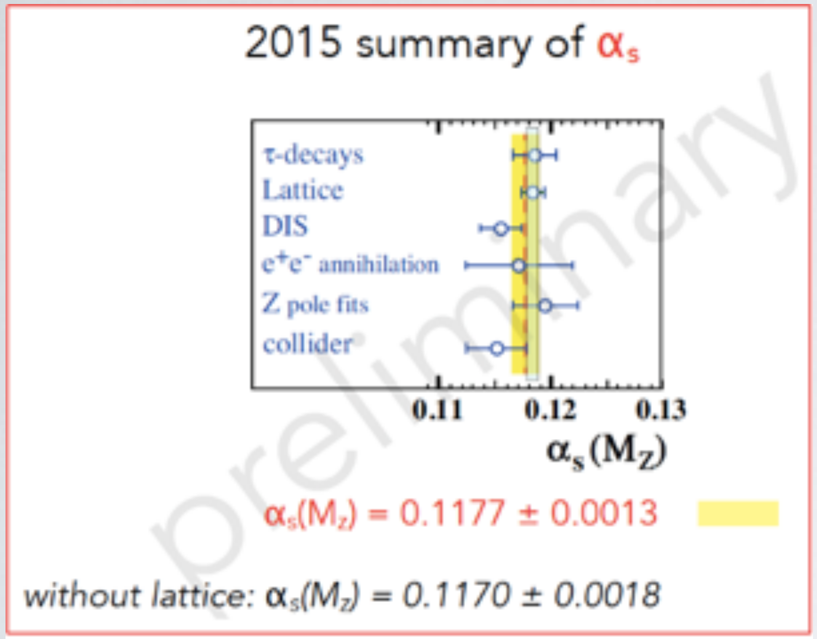

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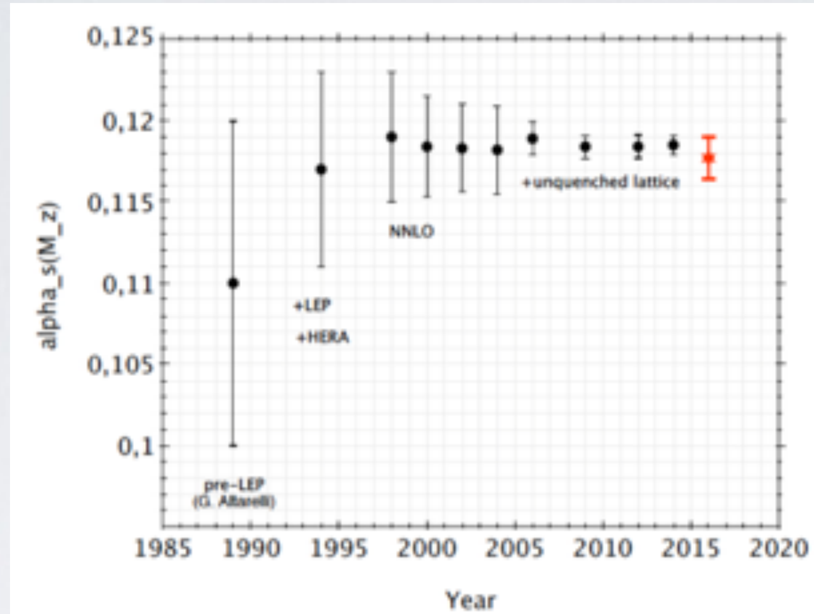
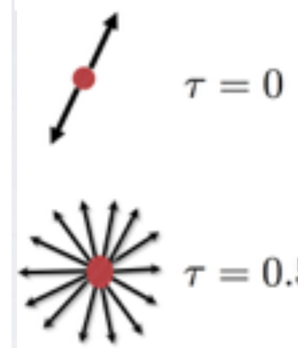
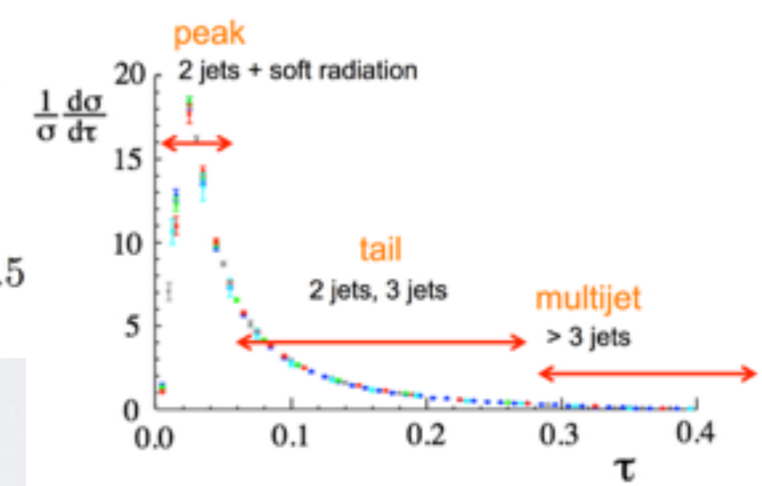


e.g. Thrust $\quad \tau = 1 - \max_{\hat{n}} \frac{\sum |\vec{p}_i \cdot \hat{n}|}{\sum |\vec{p}_i|}$

C-parameter $\quad C = \frac{3}{2} \frac{\sum_{i,j} |\vec{p}_i||\vec{p}_j| \sin^2 \theta_{ij}}{(\sum_i |\vec{p}_i|)^2}$





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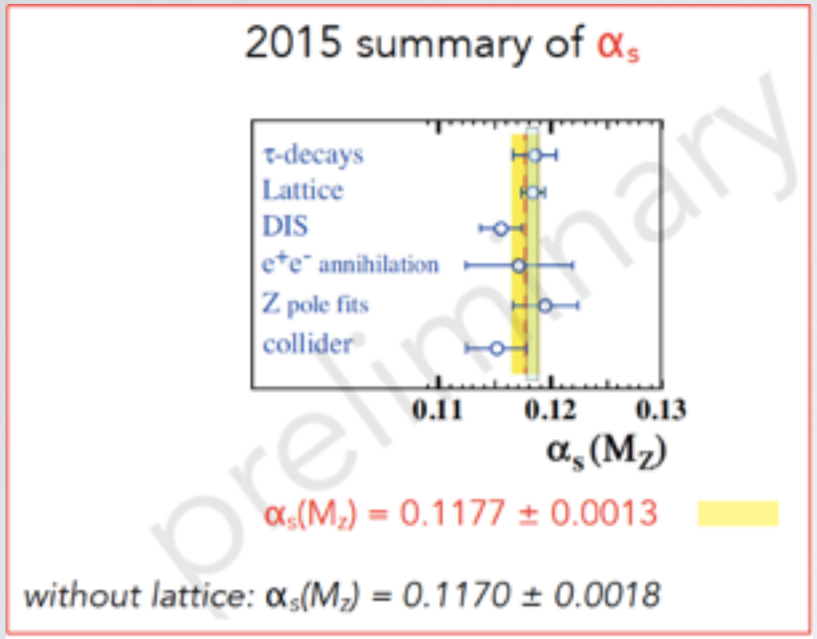

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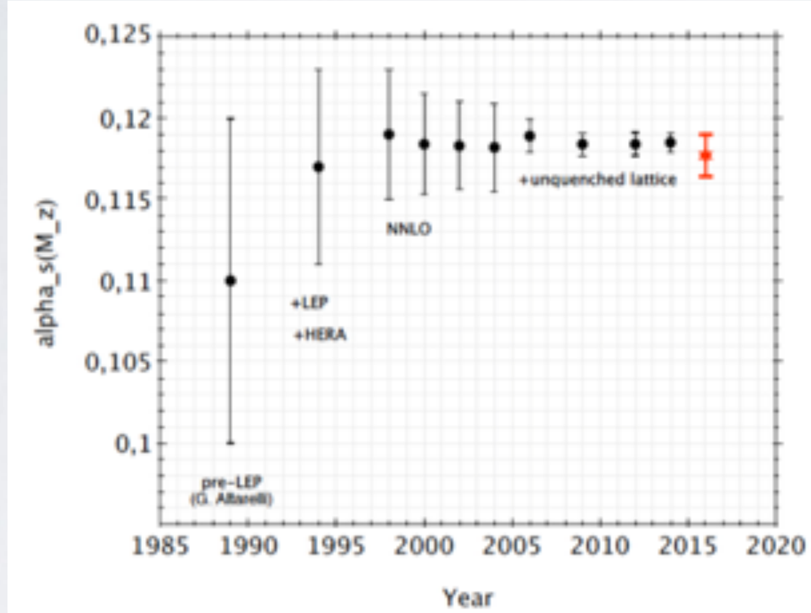
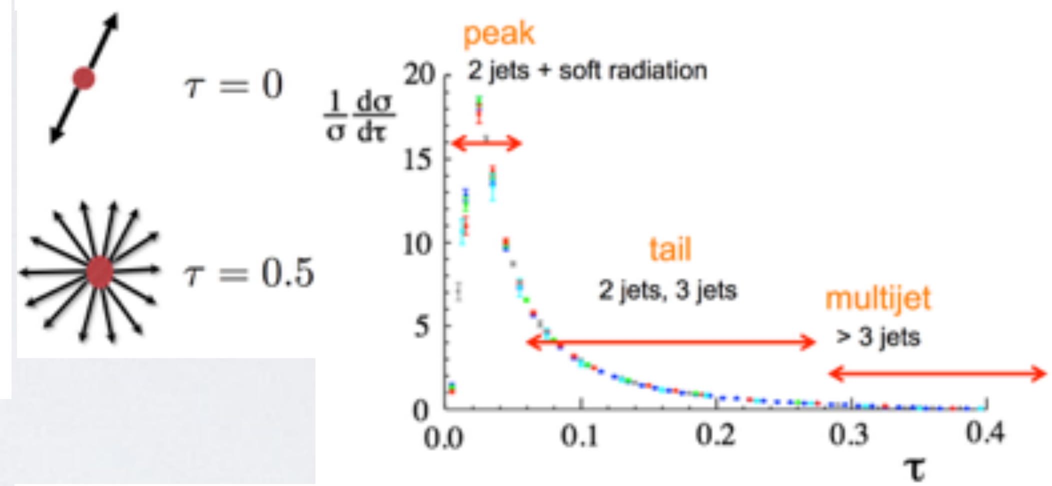
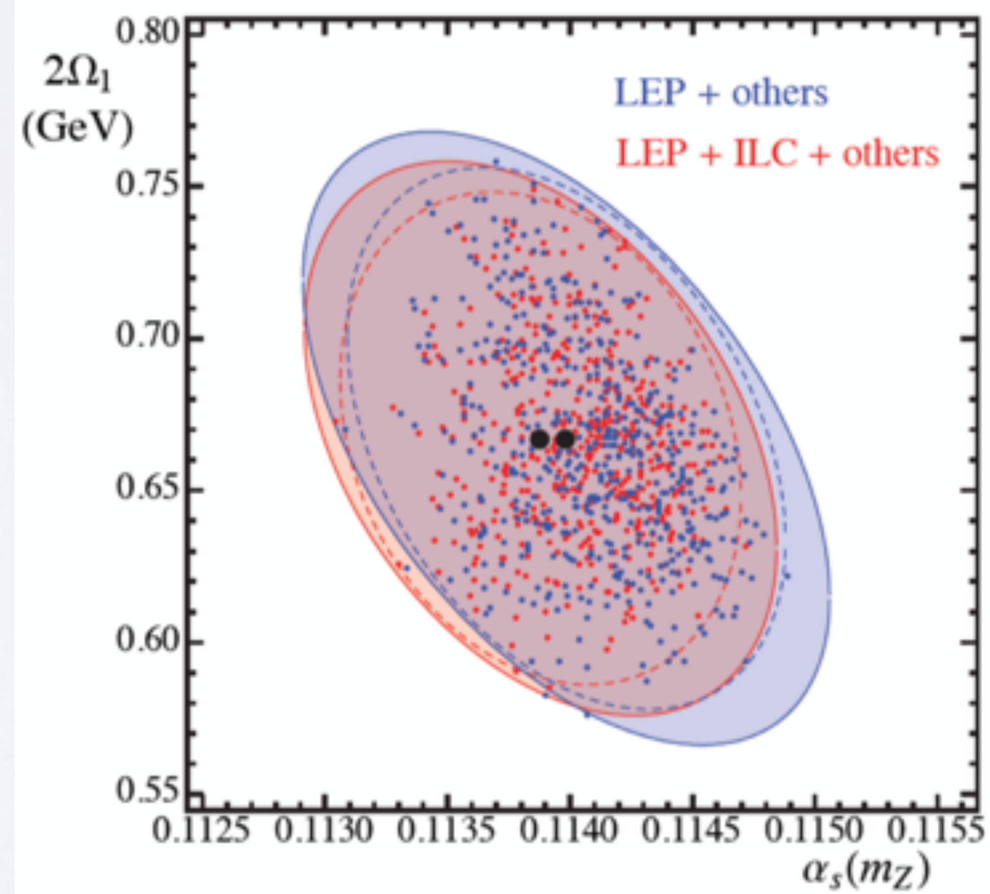


e.g. Thrust $\tau = 1 - \max_{\hat{n}} \frac{\sum |\vec{p}_i \cdot \hat{n}|}{\sum |\vec{p}_i|}$

C-parameter $C = \frac{3}{2} \frac{\sum_{i,j} |\vec{p}_i||\vec{p}_j| \sin^2 \theta_{ij}}{(\sum_i |\vec{p}_i|)^2}$



- new **preliminary** value of world $\alpha_s(M_z)$: = 0.1177 ± 0.0013
- change from 2013 value ($\alpha_s(M_z)$=0.1185 ± 0.0006) mainly due to:
  - decreased weight (increased error) of lattice results
  - decreased central value from τ-decays
  - result from new class (hadron collider, ttbar x-section), with only one published result, however known to be systematically low
- known but unresolved issues for almost all classes
- no convergence of issues in sight



- ILC500 doesn't improve (RGE down to M(Z)
- ILC measurement lifts degeneracy α_s, Ω_1

MONTE CARLOS

- Great overview over generator issue [M. Berggren, DESY]

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HIGGS PHYSICS

Theory news about the Higgs

S. Heinemeyer, UAM Madrid

- SUSY Higgs: cMSSM renormalised
- Higgs decays, EWino production @ NLO
- Theory uncertainty still $\Delta M(H)$ ~ 3 GeV
- but: dedicated working group → KUTS

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- If these NP particles are light ($m_{NP} < m_H/2$), the Higgs will have new decay modes: $H \longrightarrow$ NP particles

Models for DM, neutral naturalness, baryogenesis, ...

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Models for DM, neutral naturalness, baryogenesis, ...

The interactions can be mediated by a (small set of) renormalizable "portals":

$Z_{\mu\nu} Z_D^{\mu\nu}$	$\|H\|^2 \|S\|^2$	HLN
$H \to Z Z_D$	$H \to ss$	$H \to LN$

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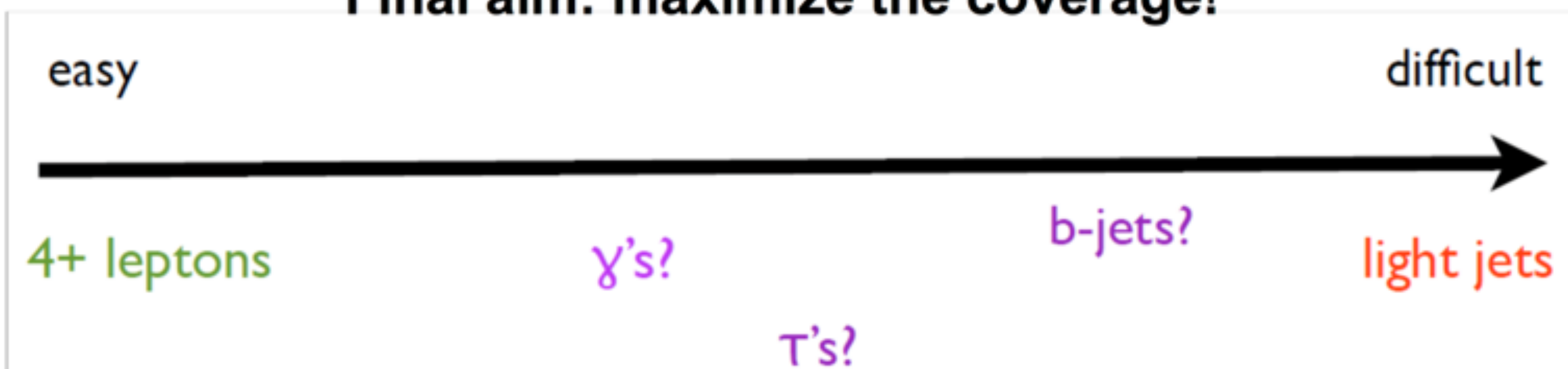
Final aim: maximize the coverage!



Possibility to discover Higgs branching ratios to NP particles below 2%?

Looking "directly" for rare new decays of the Higgs

Example exotic Higgs decay: dark photon

M. Heikinheimo, U. Helsinki

Effective Lagrangian:

$$\mathcal{L}_{\mathrm{DP_H}} = \frac{\alpha}{\pi}\left(\frac{C_{\gamma\bar{\gamma}}}{v}\gamma^{\mu\nu}\bar{\gamma}_{\mu\nu}H + \frac{C_{Z\bar{\gamma}}}{v}Z^{\mu\nu}\bar{\gamma}_{\mu\nu}H + \frac{C_{\bar{\gamma}\bar{\gamma}}}{v}\bar{\gamma}^{\mu\nu}\bar{\gamma}_{\mu\nu}H\right)$$

- The kinetic mixing of massless Dark Photons can be transformed away by field redefinitions. Generally this results in millicharges for the particles initially charged under the hidden $U(1)$.

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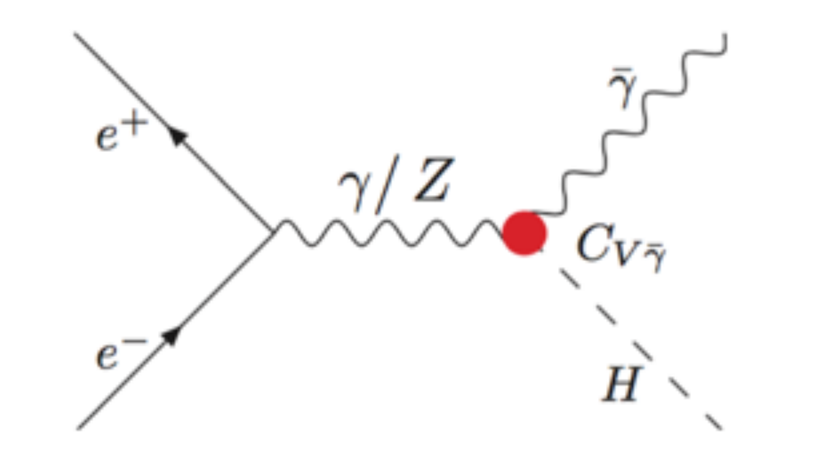

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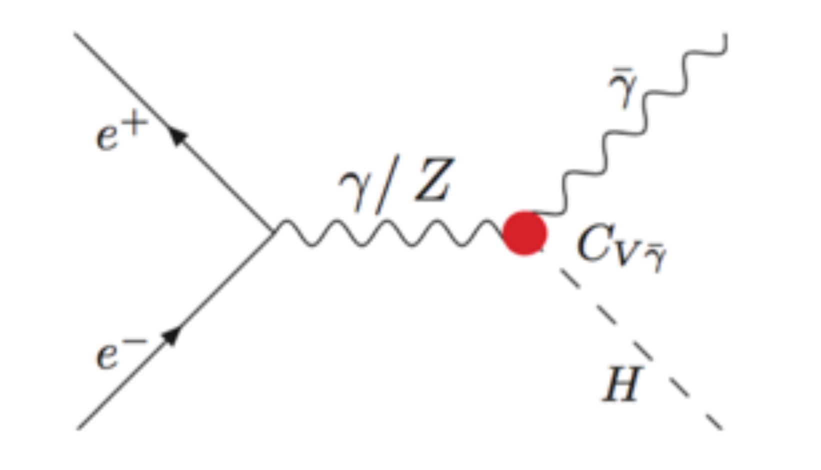

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Process	Cross section (fb)	Acceptance (%)
$H\bar{\gamma}$ $(C_{Z\bar{\gamma}} = 0)$	$10.1 \times 10^{-3}\ C^2_{\gamma\bar{\gamma}}$	17.3
$H\bar{\gamma}$ $(C_{\gamma\bar{\gamma}} = 0)$	$4.8 \times 10^{-3}\ C^2_{Z\bar{\gamma}}$	17.3
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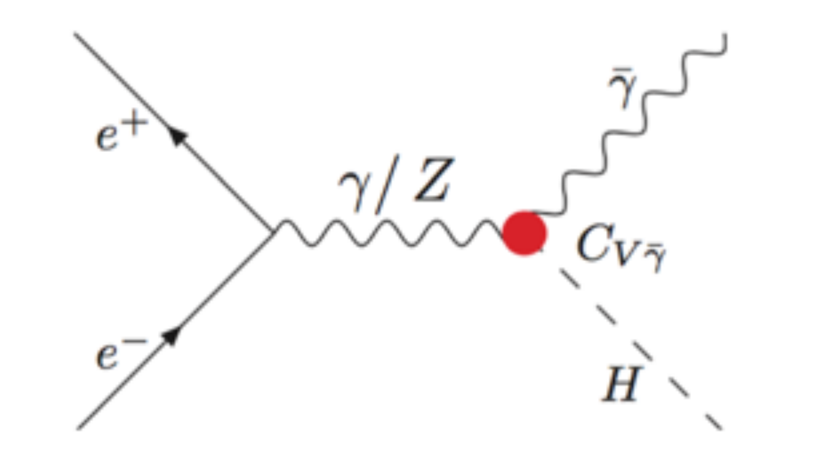

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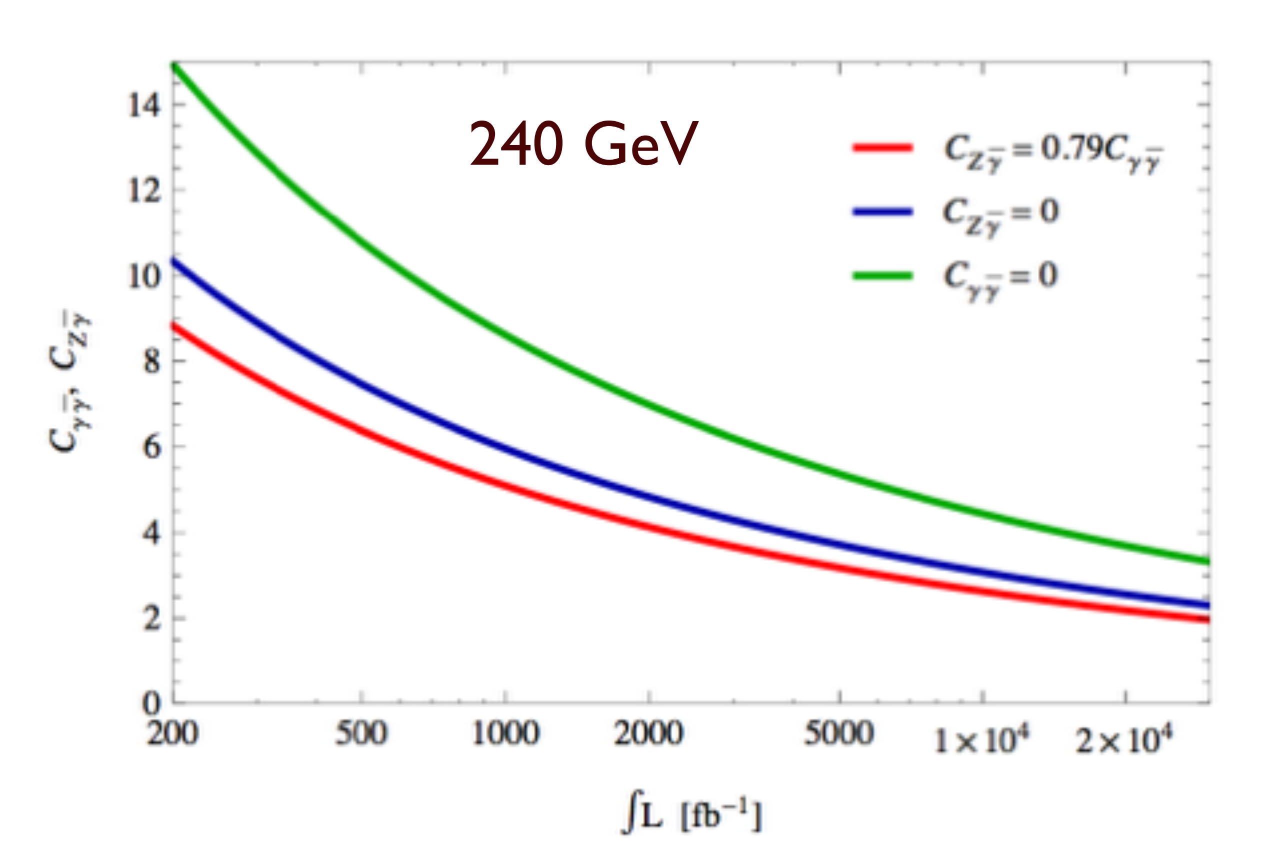

BSM PHYSICS

Discussion session led by K. Fujii,
ILC BSM case talk by JRR

The Virtue of Lepton Colliders

[JRR, DESY]

(FALSE) PARADIGM: *"Hadron colliders are discovery machines, lepton colliders are precision machines."*

first *ex positivo* hadron colliders:

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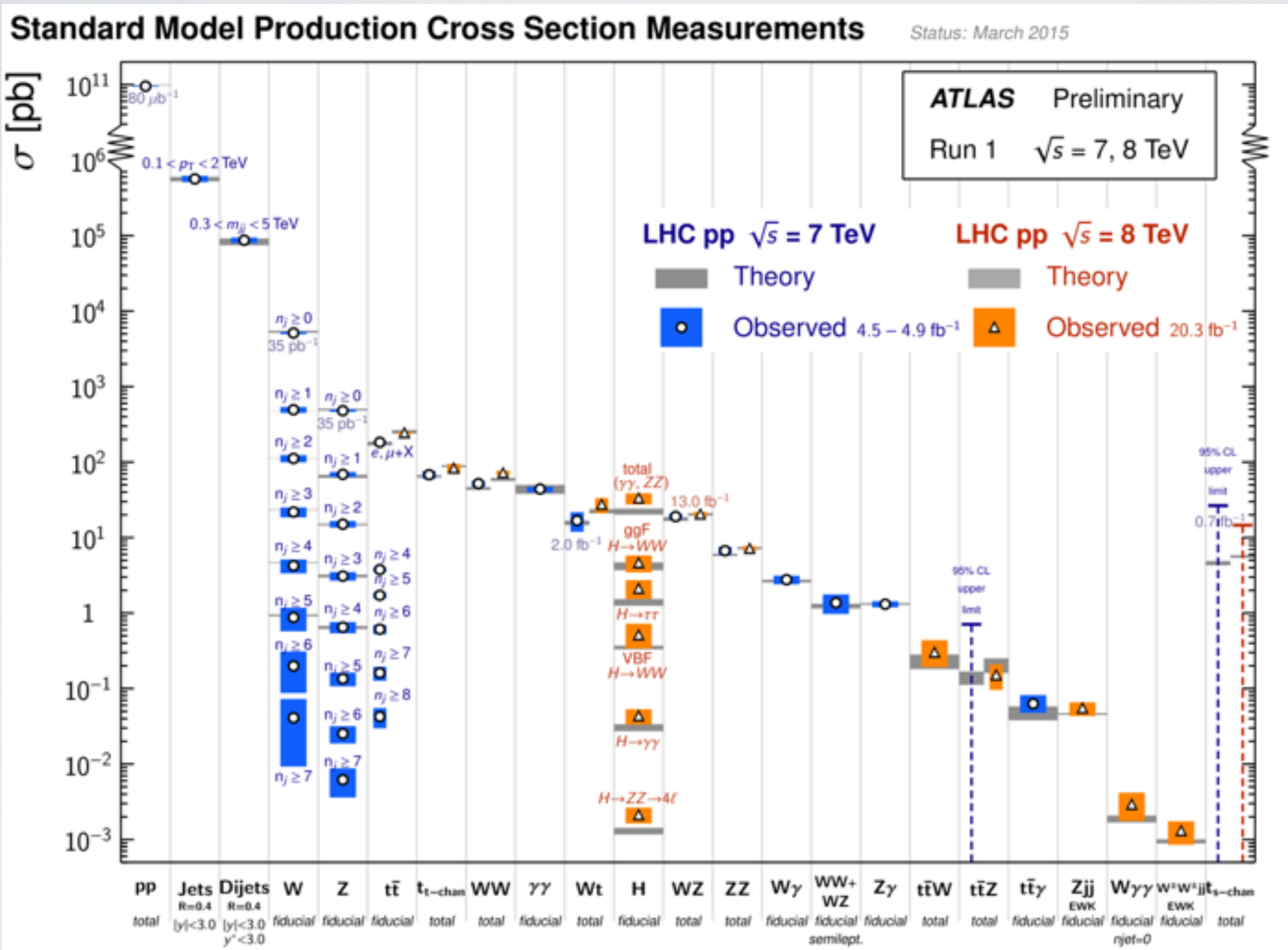

precision hadron collider physics

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C) Charm/tau discovery: 1974/76
SLAC: **SM flavor structure**
(e^-e^+ beams)

Not only unexpected…also predicted/partially unpredicted

D) First jet physics in e+e-: 1978, PETRA, DESY: **Gluon discovery** (e^-e^+ beams)

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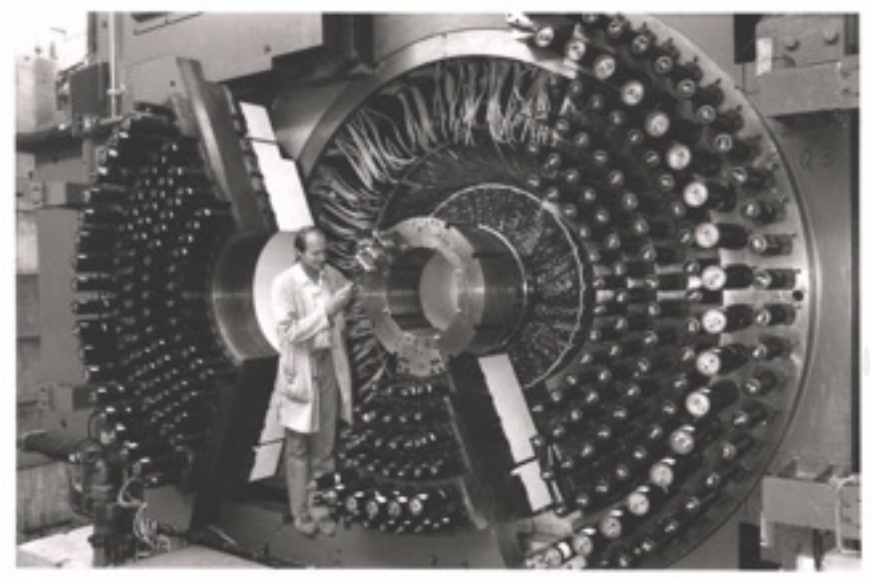

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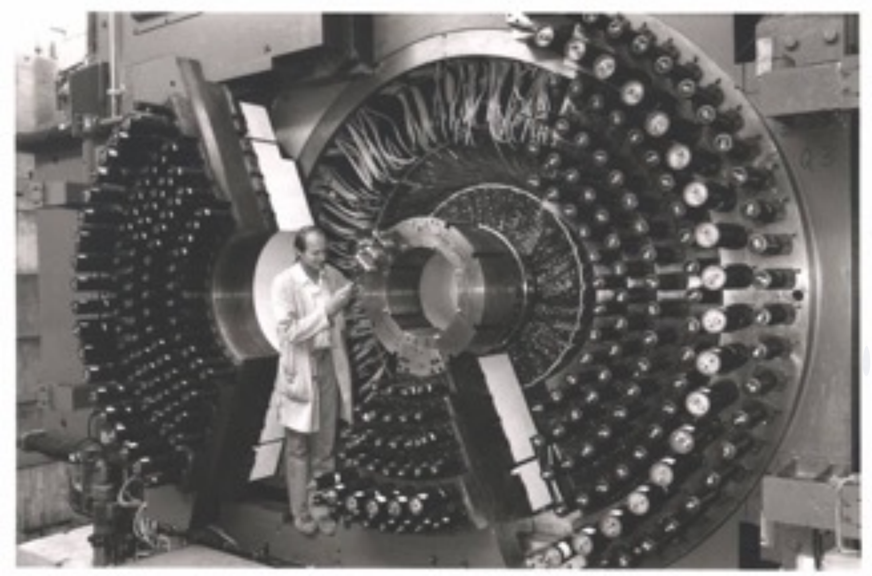

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$(e^-e^+$ beams)

F) Electroweak Precision: 1989-96,
LEP, CERN: **Higgs mass < 200 GeV**
$(e^-e^+$ beams)

The Discovery Conundrum

[JRR, DESY]

$Sp(\bar{p})S$ $p\bar{p}$ @ 0.54 TeV		
Tevatron $p\bar{p}$ @ 1.8,1.96 TeV		
LHC pp @ 7,8,13,14 TeV		
"FCC-hh" pp @ 60,80,100 TeV (?)		

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Conditions for (lepton) collider discoveries

[JRR, DESY]

- **New particle in kinematic reach of your collider**
  - Example: Charm discovery, electroweakino
  - Difficult to predict: might need symmetry, coupling strength, indirect evidence [DM]
- **New physics in (rare) decays of known particles**
  - Example: anomalies in rare *B* decays, anomalies in Higgs decays
  - Difficult to predict: needs tremendous technical knowledge of known physics
- **Deviations within existing interactions**
  - Example: e+e- → hadrons below charm threshold, *Z'* in contact interactions
  - Difficult to predict: needs theoretical hint, experimental hint from somewhere else
- **Decipher structure of new but known interactions**
  - Example: gluon discovery (massless carrier of confining theory), Higgs self-interaction
  - Has guidance from existing experimental data; correct theory needs to be known
- **Discovery of new strong interactions**
  - Example: quark substructure, composite Higgs
  - Mostly for non-perturbative physics;

Proposal for presentation of discovery scenarios

[K. Fujii, KEK]

If Some New Physics Signal Seen at 13 TeV LHC

	Precision Higgs	Precision Top	Other Indirect Methods	Direct Searches
SUSY				
Compositeness				
DM				
...				

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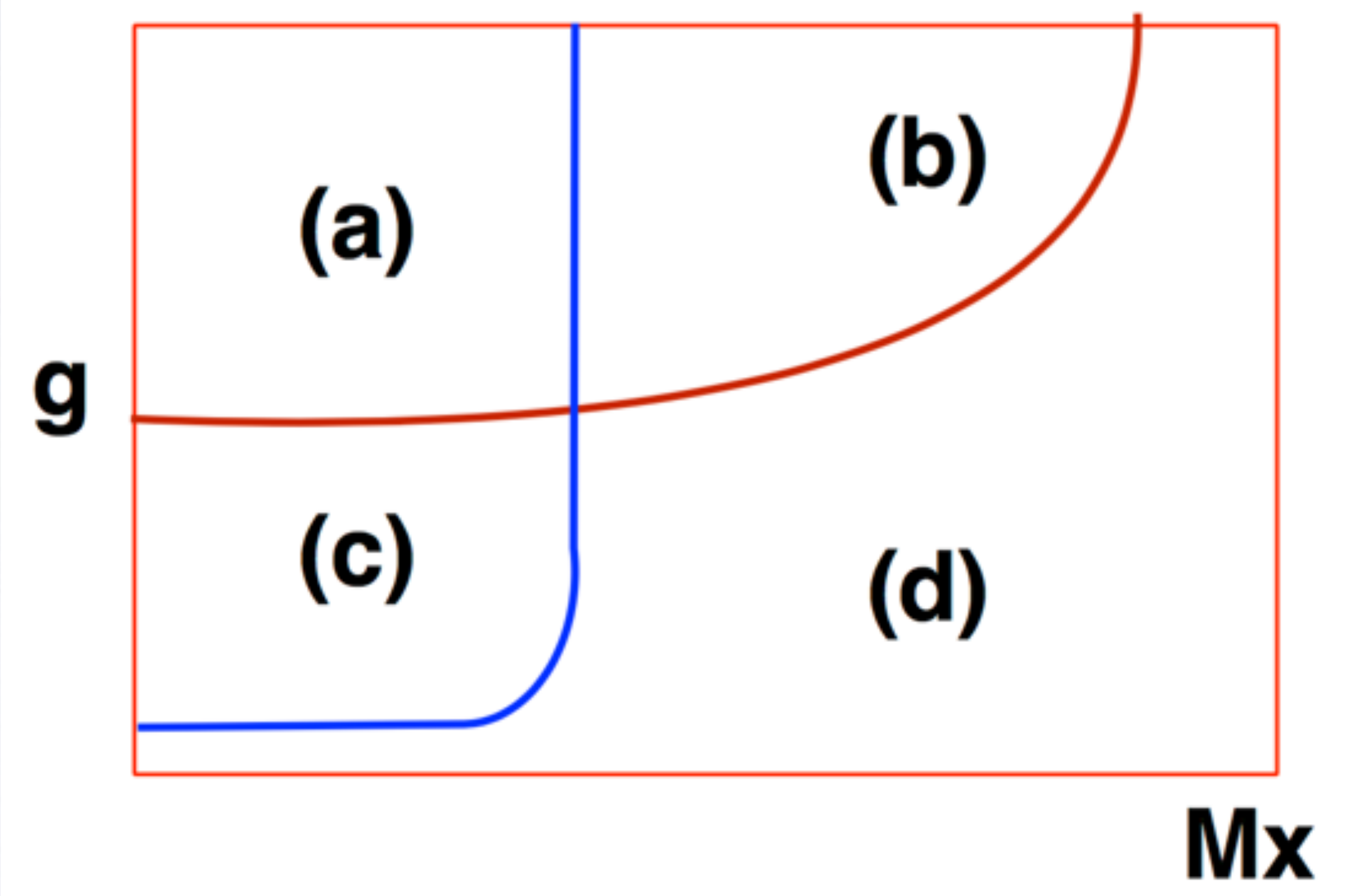

Conclusions

- Again: way too few theorist at LCWS
- Focus a lot on top physics: NLO, Threshold, Matching, strong coupling
- Still waiting for Dark Matter, but not much new
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[S. Heinemeyer, UAM Madrid]

Final words …

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… is not a partner of this workshop