TLEP Experiments: Challenges ahead

TLEP $HZ^0W^-W^+t\bar{t}$

- **Disclaimers :**
  - Not many "experiment" results so far
    - FCC design study just started and experimentalist have been lazy
  - Theory uncertainties are dominant (See next slides and John's talk)
    - Why bother about experimental issues now ?
  - State-of-the art detectors already developed for linear colliders

Are LC detector concepts suitable for TLEP ?

YES

but with some caveats

Mark Thomson
"A detector for TLEP: Synergies with ILC/CLIC"

- Why bother with an "Experiment Summary talk" anyway?

Theory uncertainties are dominant (1)

❑ Measurement of N_ν at TeraZ from the peak cross section

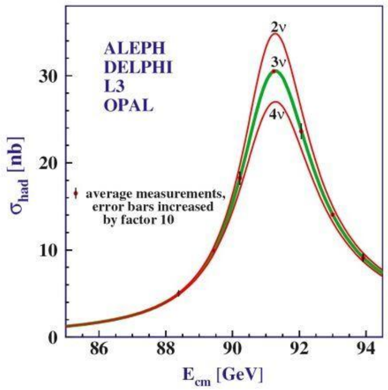
At the end of LEP:
Phys.Rept.427:257-454,2006

N_ν = 2.984 ±0.008

- 2 σ :^) !!

This is determined from the Z line shape scan and dominated by the measurement of the hadronic cross-section at the Z peak maximum ➔

The dominant systematic error is the theoretical uncertainty on the Bhabha cross-section (0.06%) which represents an error of ±0.0046 on N_ν



Improving on N_ν by more than a factor 2 would require a large effort to improve on the Bhabha cross-section calculation!

$$R^0_{\rm inv} = \frac{\Gamma_{\rm inv}}{\Gamma_{ll}} = \sqrt{\frac{12\pi R^0_l}{\sigma^0_{\rm had} m_Z^2}} - R^0_l - (3+\delta_\tau)$$

- assuming lepton universality

$$(R^0_{\rm inv})_{\rm exp} = N_\nu \left(\frac{\Gamma_{\nu\bar\nu}}{\Gamma_{ll}}\right)_{\rm SM}$$

- from LEP Z-peak measurements

$$N_\nu = 2.9840 \pm 0.0082$$
$$\delta N_\nu \simeq 10.5\frac{\delta n_{\rm had}}{n_{\rm had}} \oplus 3.0\frac{\delta n_{\rm lept}}{n_{\rm lept}} \oplus 7.5\frac{\delta\mathcal{L}}{\mathcal{L}}$$
$$\frac{\delta\mathcal{L}}{\mathcal{L}} = 0.061\% \Longrightarrow \delta N_\nu = 0.0046$$

ADLO, SLD and LEPEWWG, Phys. Rept. 427 (2006) 257, hep-ex/0509008

- δN_ν severely afftected by luminosity uncertainty (theory dominated at LEP)

Alain Blondel "The neutrino connection"	Fulvio Piccinini "Final states with γ's and $E_{\rm miss}$"

- ◆ **Instead, measure N_ν with $\nu\bar\nu\gamma$ events?**
  - ● **Important QED and EW cancellation**
    - ➨ **But cancellation not complete (different graphs)**

$$\frac{d\sigma(e^+e^- \to \nu\bar\nu\gamma)}{d\sigma(e^+e^- \to \mu^+\mu^-\gamma)}$$

Need $2 \to 3$ EW one-loop calculations

Theory uncertainties are dominant (2)

Christian Schwinn
"Theory status of
the W-pair threshold scan"

- **Measurement of m_W at OkuW ($\sqrt{s}$~161 GeV)**
  - **Projected accuracy:**

	LHC	LHC	ILC/GigaZ	ILC	ILC	ILC	TLEP	SM prediction
$\sqrt{s}$ [TeV]	14	14	0.091	0.161	0.161	0.250	0.161	-
$\mathcal{L}[\mathrm{fb}^{-1}]$	300	3000		100	480	500	3000×4	-
ΔM_W [MeV]	8	5	-	4.1-4.5	2.3-2.9	3.6	1.2	4.2(3.0)
$\Delta \sin^2 \theta^\ell_{\mathrm{eff}}$ $[10^{-5}]$	36	21	1.3	-	-	-	0.3	3.0(2.6)

- leading NNLO corrections: $\Delta\sigma_{WW} \sim \mathcal{O}(‰) \Rightarrow [\delta M_W]_{\mathrm{C2}} < 4\,\mathrm{MeV}$

- **ILC** $\Delta M_W \lesssim 4$ MeV from threshold scan
  $\Leftrightarrow \Delta\sigma_{WW} \ll 1\%$ prediction for $\sqrt{s} \sim 160 - 170$ GeV
- **TLEP** goal $\Delta M_W < 1$ MeV
  theory uncertainty dominant!

Theory uncertainties are dominant (3)

TLEP
$HZ^0W^-W^+t\bar{t}$

- **Measurement of Hbb coupling at MegaHiggs**

Hans Kuehn
"Precision calculations for TLEP"

TLEP: $\sigma_{HZ} \times Br(H \to bb)$: aim 0.2%

Higgs WG, arXiv:1307.1347

$$\frac{\delta\Gamma_b}{\Gamma_b} = \mp 2.3\%|_{\alpha_s} \pm 3.2\%|_{m_b} \pm 2.0\%|_{th} \quad \Rightarrow 7.5\%$$

- **Note: Ultimate precision at HL-LHC for κ_b : 4 – 7 %**

- **Global EW fit at TLEP**

Max Baak
"The EW fit of the SM and beyond"

- Predicted uncertainties on M_W, $\sin^2\theta^l_{eff}$ dominated by:
  - ILC: δM_Z
  - TLEP: external inputs: δ(theory), $\delta\Delta\alpha_{had}$

Theory uncertainties are dominant (4)

- So far, HL-LHC and ILC/CLIC projections have driven the necessary theoretical accuracy
  - The TLEP projected experimental precisions now justify extra work
    - And extra funding for theorists to match theory precision
      - ➨ After all, it is very cost effective to hire 100 theorists to work for 10 years on TLEP observable theoretical predictions

        100 theorists × 10 years × 100 kCHF / year = 0.1 BCHF

        i.e., 1% of the ILC cost – or 1% of the CERN budget
      - ➨ Then, build TLEP for a third of the ILC cost

        But order-of-magnitude better potential precision
      - ➨ Hence be ready to build suitable detectors

        To match the TLEP potential, without exploding the bill

- Question: Is it possible to reduce the theory uncertainties ?

Theory uncertainties are dominant (5)

TLEP $HZ^0W^-W^+t\bar{t}$

- **Many reasons to be optimistic**

SUMMARY

Hans Kuehn
"Precision calculations for TLEP"

- theory predictions do not (yet?) fulfill TLEP requirements,
- missing corrections are presumably feasible (QCD),
- important experimental input from low-energy e^+e^- annihilation:

  $m_b, m_c, \Delta\alpha, (\alpha_s?)$, **(SuperKEKb, TLEP – guidance needed for $\Delta\alpha$)**
- m_b determiantion $\Rightarrow \Gamma(H \to bb)$

  usage of $m_b(pole)$ is strongly disfavoured compared to $m_b(10\text{ GeV})$

perspectives: (assume $\delta\alpha_s = 2 \times 10^{-4}$)

$\delta m_b(10\text{GeV})/m_b \sim 10^{-3}$ conceivable (dominated by $\delta\Gamma(\Upsilon \to e^+e^-)$)

$$\Rightarrow \frac{\delta\Gamma_b}{\Gamma_b} = \pm 2 \times 10^{-3}|_{m_b} \pm 1.3 \times 10^{-3}|_{\alpha_s,\text{running}} \pm 1 \times 10^{-3}|_{\text{theory}}$$

Aim at $\Delta\kappa_b$ ~ 0.4% at TLEP

Redundancies with TLEP measurements (1)

TLEP $HZ^0W^-W^+t\bar{t}$

- **Data will help with theoretically unknown quantities**
  - Example: Measurements of $\alpha_s(m_Z)$
    - From BR(Z → hadrons)
      - ➨ Sensitive to new physics at the Zbb vertex

        Assume no new physics at Zbb vertex ?
    - From BR(W → hadrons)
      - ➨ Sensitive to knowledge of CKM matrix elements

        Assume unitarity of CKM matrix ?
    - From BR(τ → hadrons)
      - ➨ Sensitive to running of α_s from τ to Z

        Assume QCD prediction ?
      - ➨ Sensitive to non-perturbative QCD

        Rely on ALEPH measurement $\delta_{NP} = -0.0059 \pm 0.0014$

Guenther DIssertori
"Extracting α_s at TLEP"

Toni Pich
"τ physics at TeraZ"

  - Each individual measurement come with its own assumption(s)

Redundancies with TLEP measurements (2)

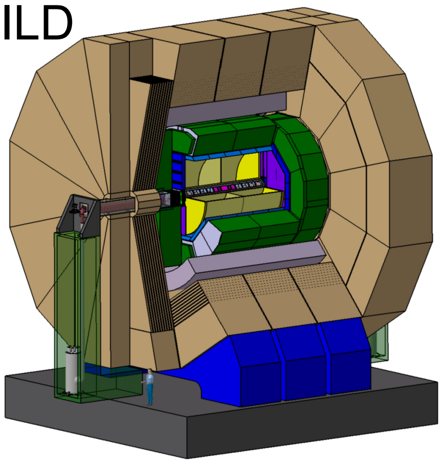
- **Alternative: Use all the measurements in a global approach**
  - **Build a "Global QCD fit" on the model of the "Global EW fit"**
    - **Guenther's proposal:**

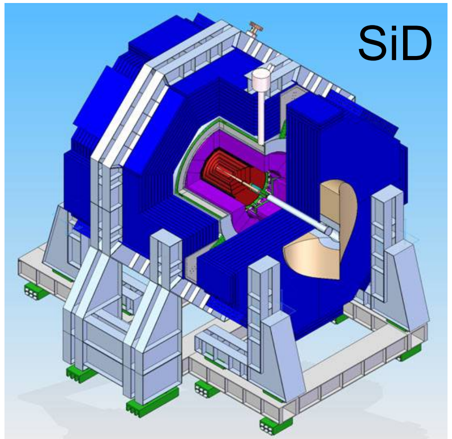
- Perform measurements of the hadronic BRs of the Z, the W and Tau at TLEP at the best possible precision, eg. ~ 5×10^{-5}
- Assume that the running of α_s as predicted by QCD is correct at the per-mille level
  - to be studied: exact impact on precision achievable when running to low scales, and passing the charm threshold
- Extract $\alpha_s(M_Z)$ from the hadr. BR of the Z, at precision of ~0.0002, calculate $\alpha_s(M_W)$
- and use this to constrain V = Sum($V^2_{qq'}$) at the **sub per-mille level**!
- Run the $\alpha_s(M_Z)$ extracted above to $\alpha_s(M_{tau})$ and constrain the non-pert. coefficients and possible unknown HO terms to a precision of a few per-cent.
- Thus, a nice overall set of measurements to constrain a number of relevant terms.

Guenther DIssertori
"Extracting α_s at TLEP"

What detector for TLEP ? (1)

- **First approach (ILC/CLIC)**
  - **Push detector design towards highest achievable performance**





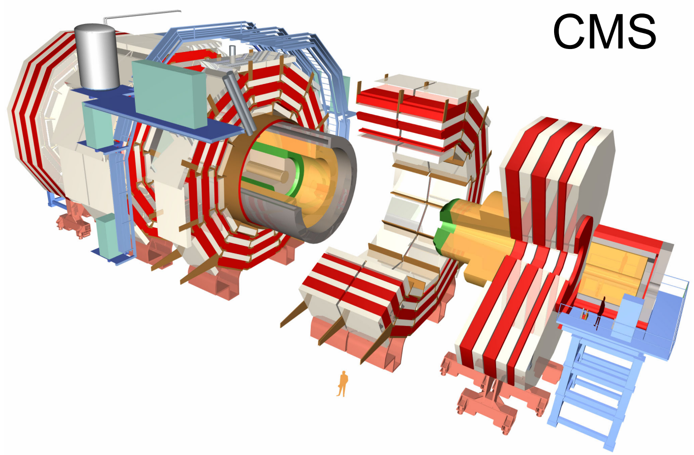
Mark Thomson
"A detector for TLEP:
Synergies with ILC/CLIC"

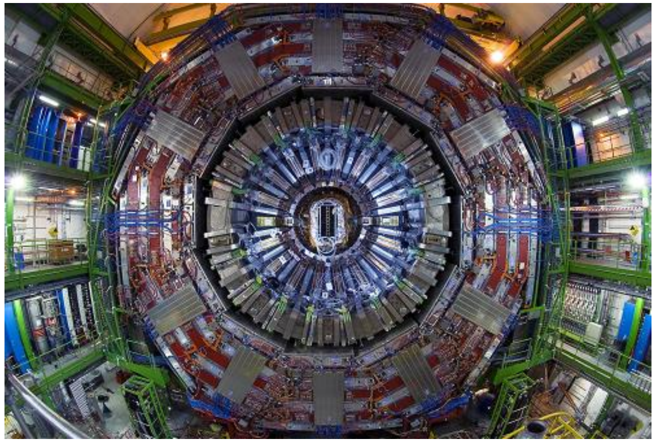
- **+++ Clearly suitable to cover the full TLEP physics programme**
- **– Might be over-designed ?**
- **– – Power pulsing is not a option at TLEP**
  - ➨ **Either more cooling (material) or less channels (granularity)**
- **– – – Cost !**
  - ➨ **0.5 to 1 B$ each – and TLEP may want to have 4 of them**

What detector for TLEP ? (2)

PJ et al. (arXiV:1208.1662, 1308.6176)
“First look at the physics case of TLEP

- **Second approach (LHC)**
  - **Use existing LHC detectors**





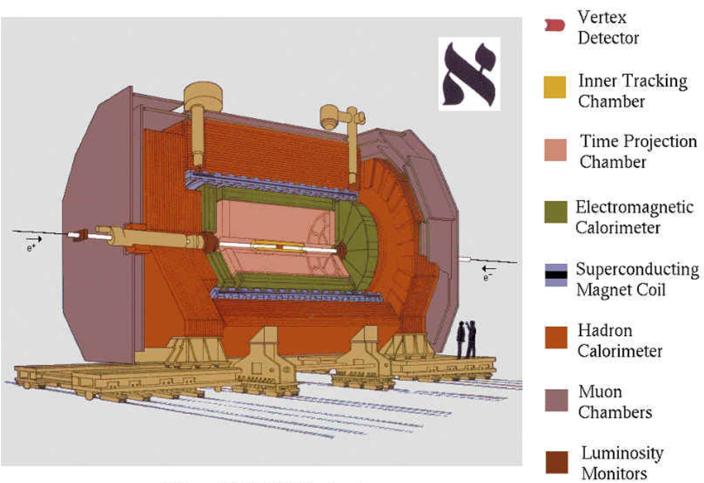
- +++ Realistic, most conservative
  - ➨ sub-optimal hadron calorimetry, lots of material, $\Delta p_T/p_T$
- ++ can cope with TLEP-Z event rate
- − not thought for e^+e^- collisions
- −− cost !
  - ➨ Almost 0.5 BCHF / detector

What detector for TLEP ? (3)

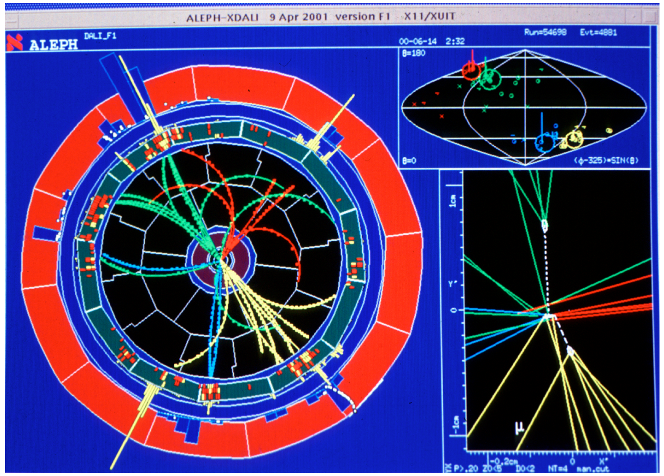
Tried back in the mid 1990's
For the studies of "NLC"

❑ Third approach (LEP)

- Use LEP-like detectors



The ALEPH Detector

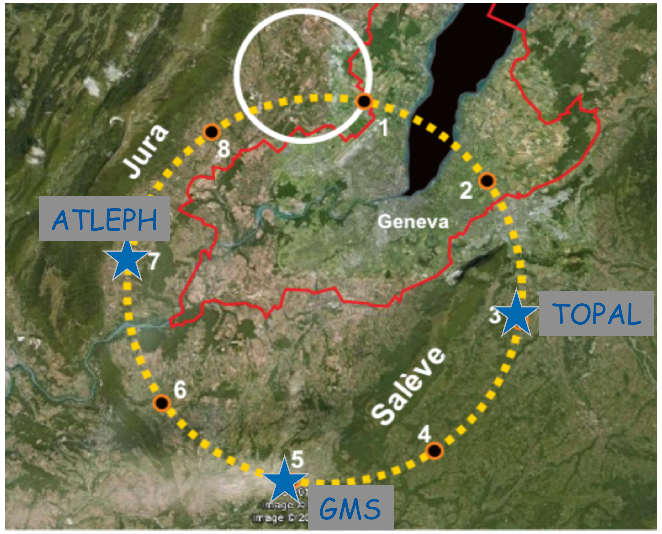


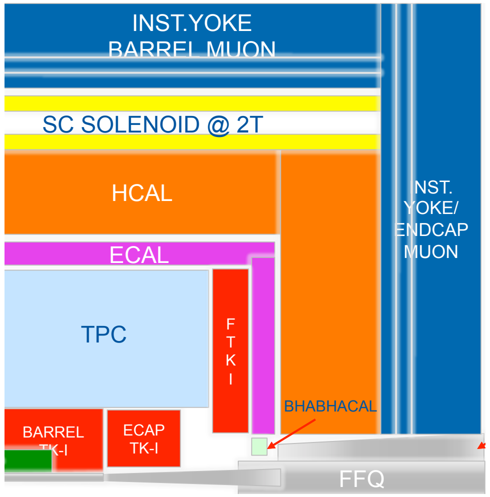
- +++ Cost !
  - ➨ 100 MCHF / detector – Could easily afford four of them.
- ++ Realistic, conservative enough, globally suitable
- – TLEP-Z event rate ?
- – – Outdated/not challenging technology ?

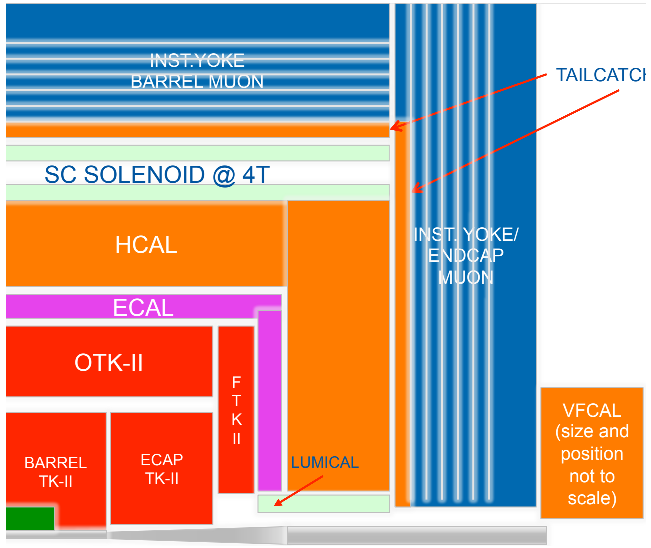
What detector for TLEP ? (4)

Emilio Meschi
Talks at TLEP Workshops

- **Fourth approach (FCC)**
  - A detector common to TLEP and VHE-LHC ?







- Pros and cons need to be worked out
  - ➨ Can a detector and its electronics survive half a century ?

    Is it actually desirable ?

Goal of the TLEP design study: First year

TLEP $HZ^0W^-W^+t\bar{t}$

- For your favourite benchmark physics channel
  - Scan the performance of the various subsystems
    - With, initially, a fast-simulation strategy [to be developed]
      - ➨ From a CMS-like or a LEP-like detector to a LC-like detector

Colin Bernet
"5th TLEP Workshop"

  - Decide of the adequate performance
    - i.e., the minimal performance beyond which the quality of your measurement would not "significantly" improve
  - After all, the CMS performance is not far from adequate
    - And so was that of ALEPH
      - ➨ Need to identify physics channels where either choice is not sufficient
  - Propose hardware solutions that would meet the requirements

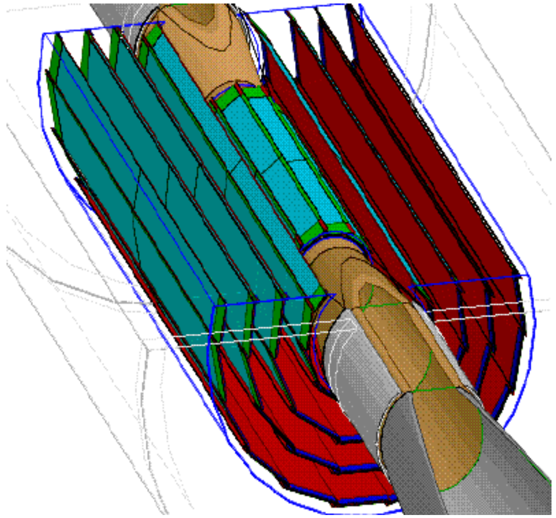
Vertex detector

- **Neither CMS nor ALEPH vertex detector capable of c-tagging**
  - No measurement of BR($H \rightarrow cc$) possible
    - Need I.P. resolution better than 20 μm
      - Small inner radius (how small?)

        Q: What is the TLEP beam pipe radius ?
      - Little material (how little?)

        To minimize multiple scattering
      - Many channels (how many?)

        Cooling will become an issue



Mark Thomson
"A detector for TLEP: Synergies with ILC/CLIC"

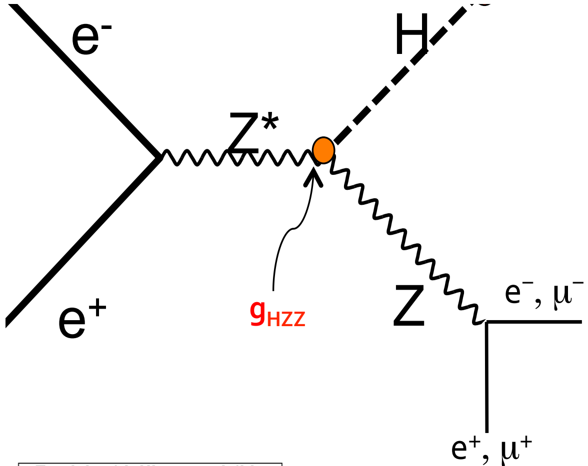
  - Is there any other physics for which such a vertex detector is relevant ?
    - e.g., measurement of the FCNC Z decay : $Z \rightarrow cu$
      - Is this measurement possible at all ?

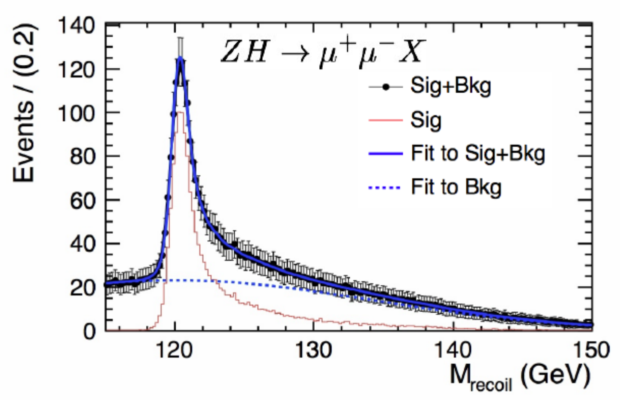
        (Current upper limit ~ 5×10^{-7})

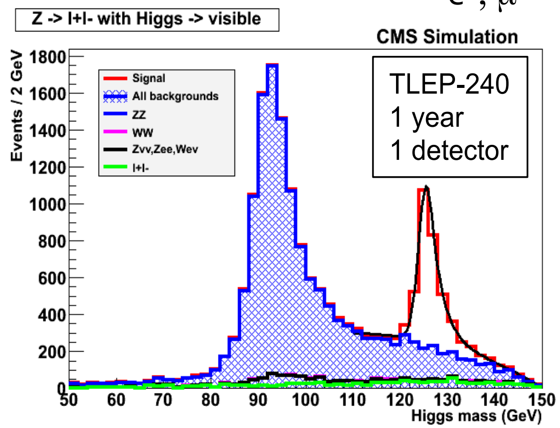
Luca Silvestrini
"Rare decays at TLEP"

Tracker (1)

- **CMS and ALEPH sufficient to measure σ_{HZ} from recoil mass**
  - With $\sigma(1/p_T) = 6 \times 10^{-4}$ (ALEPH) or 2×10^{-4} (CMS)
    - And vastly different amounts of material
      - ➨ σ_{HZ} known to 0.55% with $Z \to \mu^+\mu^-$ (CMS)
  - With $\sigma(1/p_T) = 2 \times 10^{-5}$ (ILC, SiD)
    - σ_{HZ} known to 0.45% with $Z \to \mu^+\mu^-$



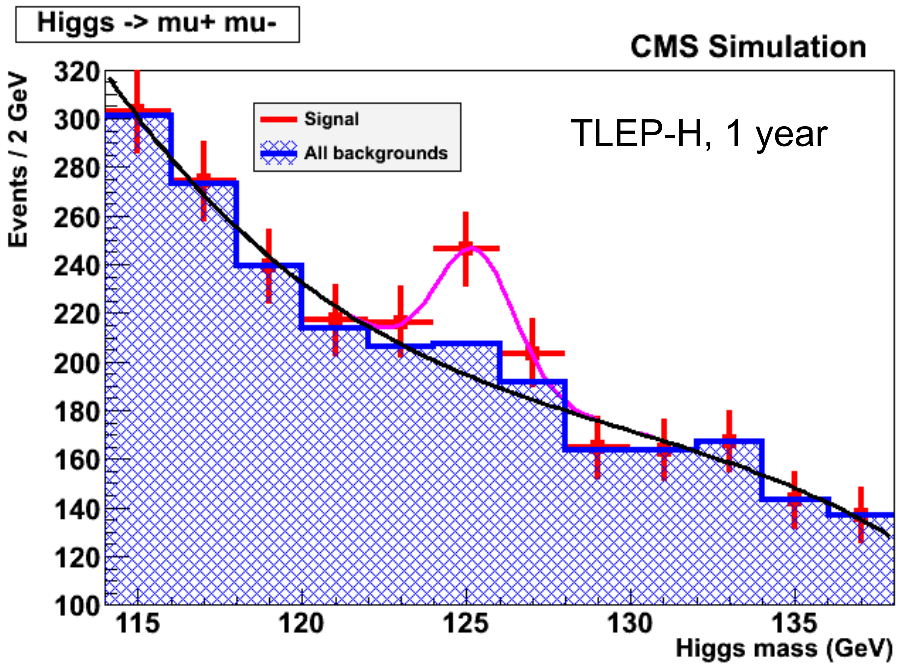




  - Tracker performance to be revisited

Tracker (2)

- **H decay where tracker performance may be more relevant**
  - $e^+e^- \to$ HZ with H $\to \mu^+\mu^-$

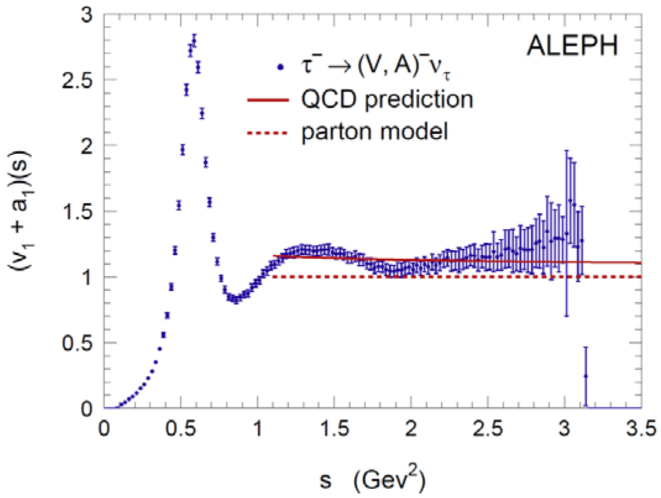


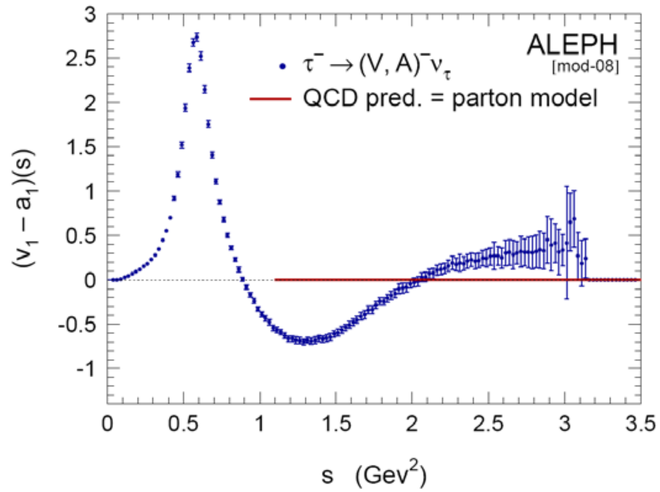
arXiv:1208.1662

- Direct impact of μ momentum resolution on the H$\mu\mu$ coupling precision
  - ➨ May improve the precision on κ_μ from 6% to 2%

Tracker (3)

- **Other physics where tracker performance might be relevant**
  - τ spectral functions: determination of $\alpha_s(m_\tau)$





Better data needed

Toni Pich
"τ physics at TeraZ"

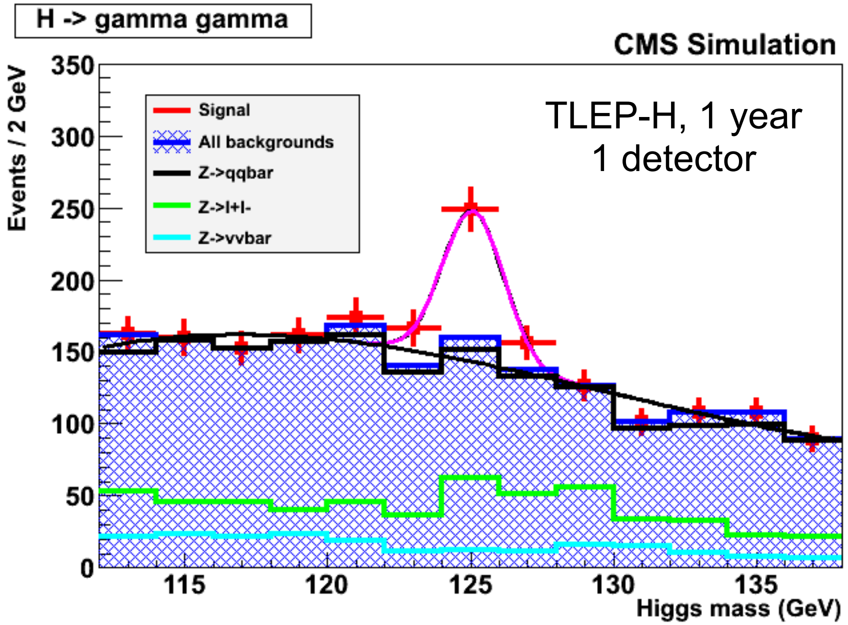
  - Rare decay $Z \to \tau\mu$, must probe BR < 10^{-9}
    - Must reduce background from $Z \to \tau\tau$ with $\tau \to \mu\nu_\mu\nu_\tau$
      - Can only rely on the muon momentum determination

And to a lesser extent, to the muon impact parameter (?)

Luca Silvestrini
"Rare decays at TLEP"

Electromagnetic Calorimetry

- ECAL energy resolution can be optimized for
  - $e^+e^- \to HZ$ with $Z \to e^+e^-$ (Measurement of σ_{HZ})
  - $H \to \gamma\gamma$

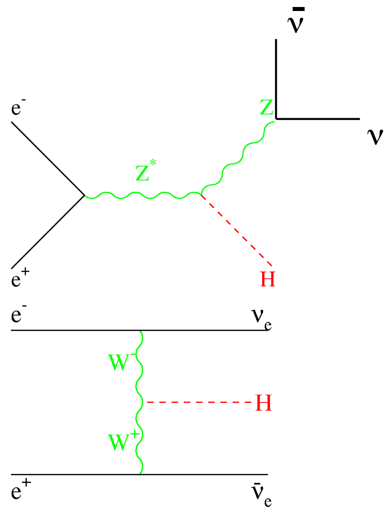


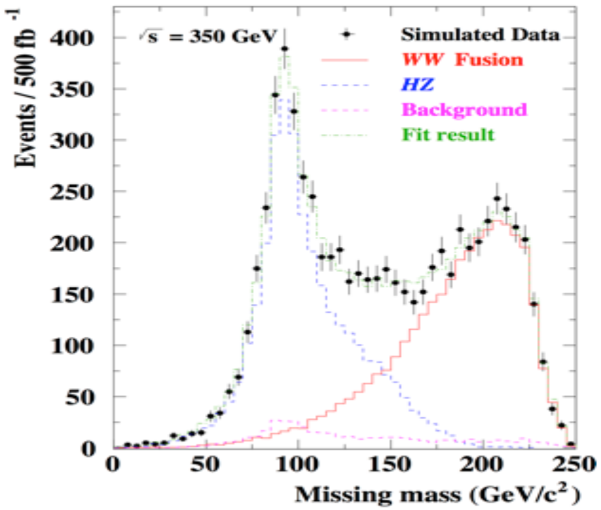
arXiv:1208.1662

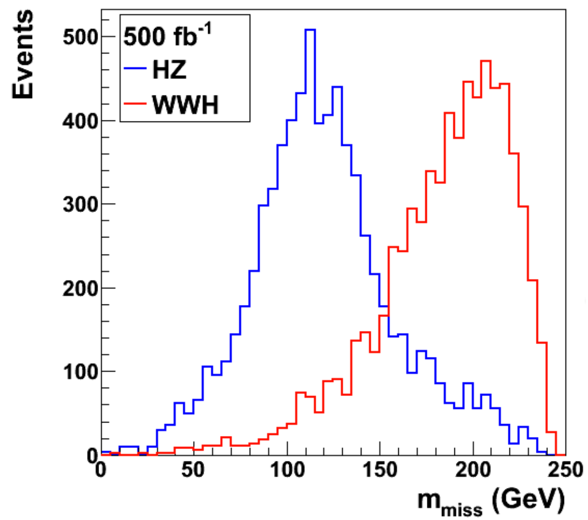
- Rare example for which CMS performance exceed ILD/SiD
  - ➨ Is CMS ECAL energy resolution needed ?

Calorimetry and Particle Flow

- **Ultimate calo. granularity probably not needed @ TLEP**
  - Event kinematics most often constrained
    - Total energy-momentum conservation
    - Z, W, H masses
      - ➨ Jet directions more important than jet energies
  - Even without constraints, jet energies are limited at TLEP
    - Particle-flow concept works even with moderate granularity
      - ➨ Cf. use of CMS for TLEP studies (or ALEPH for NLC studies)

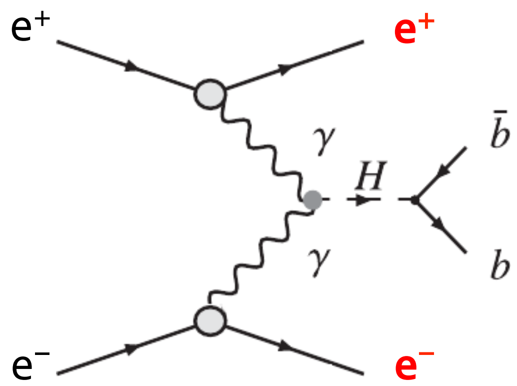






Other detectors

- **Luminosity detector**
  - To measure luminosity from Bhabha scattering with a 10^{-5} precision !?
    - Need to evaluate the possible effects of final focus
      - ➨ synchrotron radiation
      - ➨ beam divergence



David d'Enterria
"The case for QCD and γγ physics at TLEP"

- **Very forward detectors**
  - To tag an possibly measure e± in a γγ interaction
    - e.g., to measure Γ_H from $\sigma(\gamma\gamma \to H \to bb)$
      - ➨ (I have no idea of the feasibility)

- **Transverse polarimeter at $\sqrt{s} = m_Z, 2m_W$**
  - Might have to detect small levels of polarization
    - Hence with great precision, to detect depolarization
      - ➨ (Improve the LEP Compton-scattering laser polarimeter)

TLEP Design Study (2013 – 2018)

26 Working Groups: Accelerator / Experiment / Phenomenology

FCC ↔ Institutional board — Steering group: web site, mailing lists, speakers board, etc.. — International Advisory board ↔ FCC

Aleksan, Azzi, Blondel, Ellis, Janot, Klute, Koratzinos, Zanetti, Zimmermann

Accelerator — Zimmermann

1. Optics, low beta, alignment and feedbacks
2. Beam beam interaction
3. Magnets
4. RF system
5. Top-up injection
6. Injector system & sources
7. Integration w/(VHE)-LHC
8. MDI, Interaction region
9. Vacuum
10. Polarization &E-calib.
11. Civil Engineering
12. Elements of costing

Experiments — Janot

1. EW physics at Z pole
2. WW, ZZ, Zγ physics
3. H(126) properties
4. Top quark physics
5. Flavour (b,c, τ , ν) physics
6. QCD and γγ physics
7. rare decays & new physics
8. Experimental environment
9. offline computing
10. Online computing
11. Detector design

Phenomenology — Ellis

1. model building
2. Precision EW calculations
3. Flavour (b,c, τ , ν) physics
4. QCD and γγ physics
5. rare decays & new physics
6. Combination + complementarity with LHC and other machines ; global analysis

(Slide slightly outdated)

Let's make it real !

- We have no excuses now
  - TLEP has become an official project at CERN
    - And we all share the same vision

Sergio Bertolucci: "Welcome address"