First Physics Results from LEP$^{(*)}$ at Centre-of-mass Energies of 130–140 GeV

DESY Seminar

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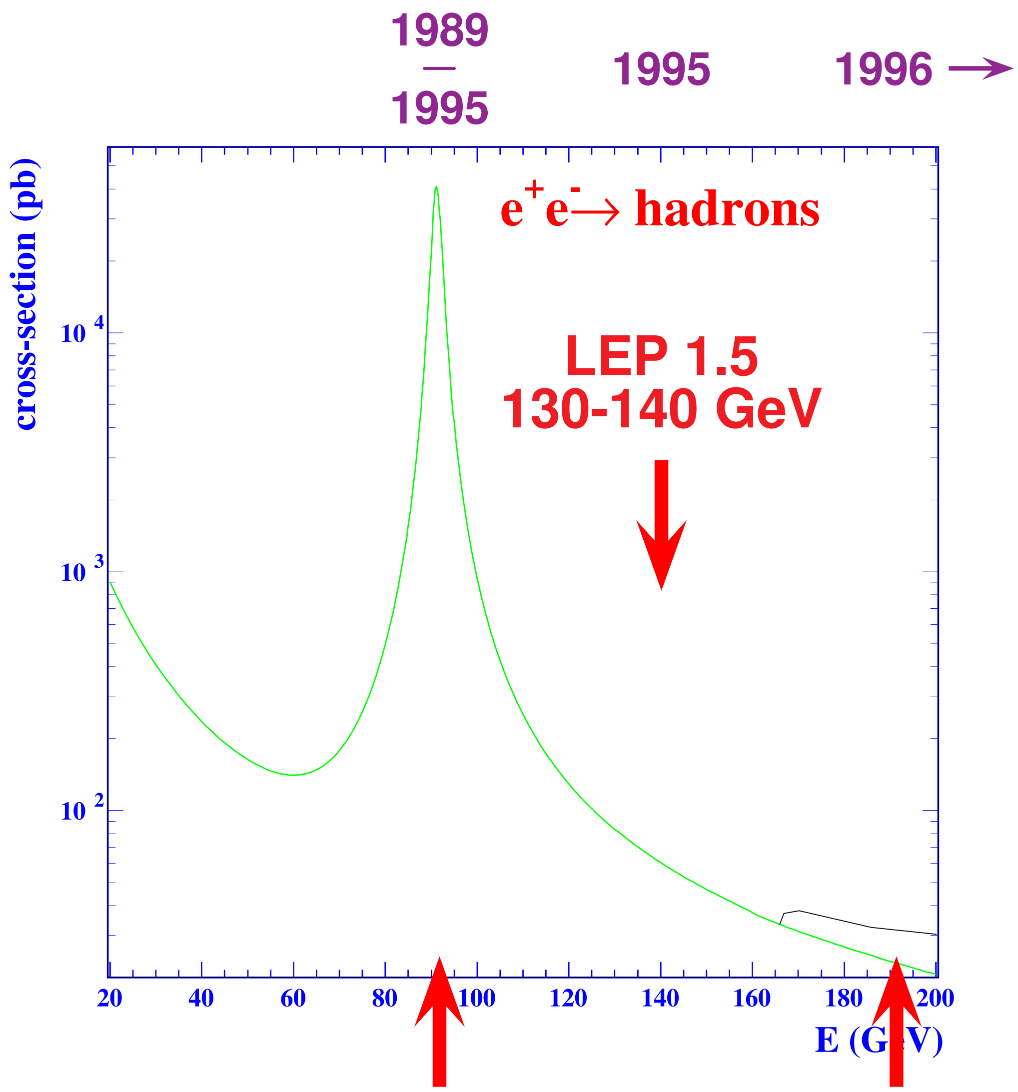
$^{(*)}$ biased by an OPAL member

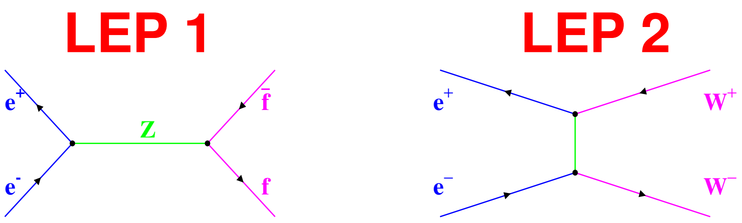
Outline

- Operation of LEP at 130–140 GeV
- Luminosity measurement
- Event classification
- Electroweak Physics
  - Cross sections
  - Asymmetries
  - γZ interference
- QED tests
- QCD studies
  - Event shape observables
  - Jet rates
  - Energy evolution
- Search for new physics
  - Charginos/Neutralinos
  - Sleptons/Stops
- Study of 4-fermion final states
- Study of 4-jet events
- Summary and Outlook

Most results shown are PRELIMINARY

LEP 1.5





- new energy regime
  - $\longrightarrow$ above the Z^0 resonance
  - $\longrightarrow$ below WW threshold

Motivation for LEP 1.5

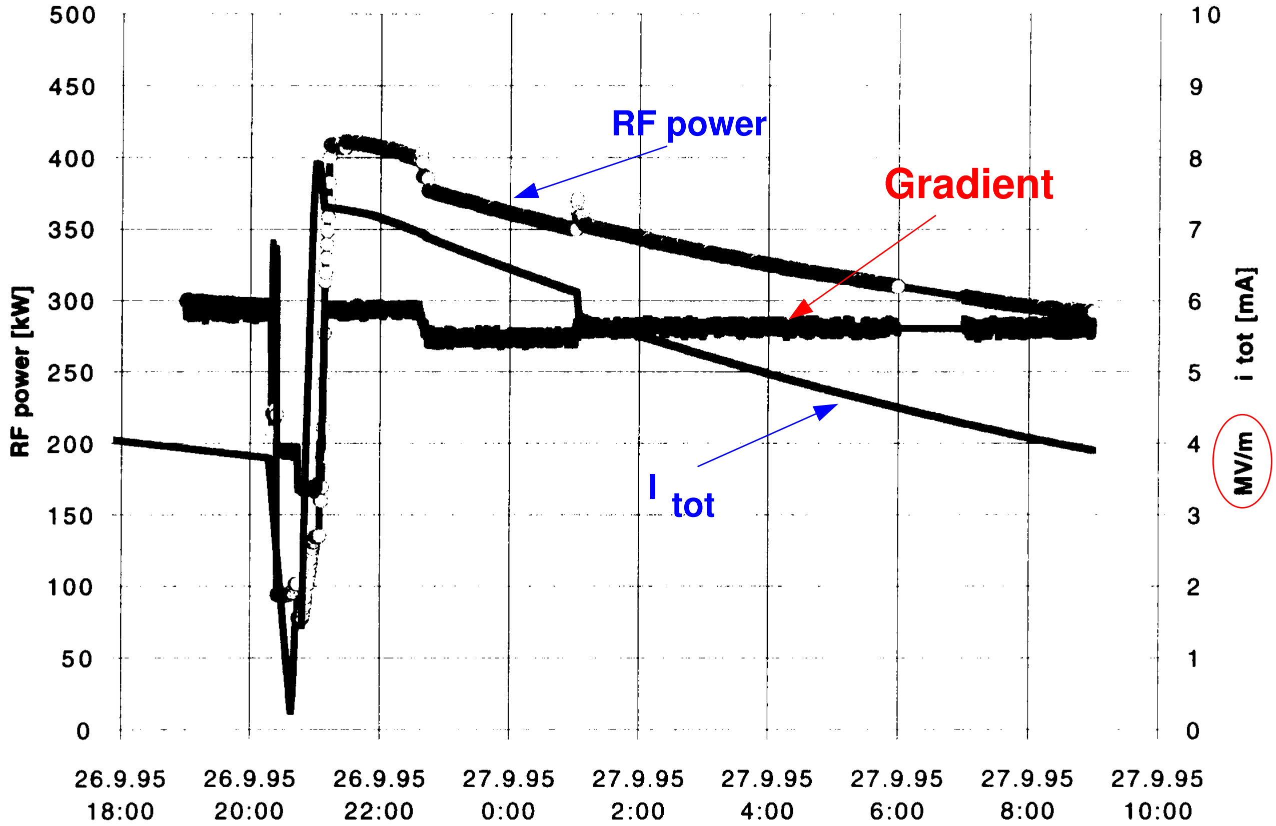
Machine

- milestone on the way to LEP 2
  $\longrightarrow$ W physics

$\Downarrow$

- study and exercise machine at high energies (130-140 GeV)
  - understand behaviour
  - work with many superconducting cavities (64: end 1995)

G. Geschonke, CERN SL



Motivation for LEP 1.5

Physics

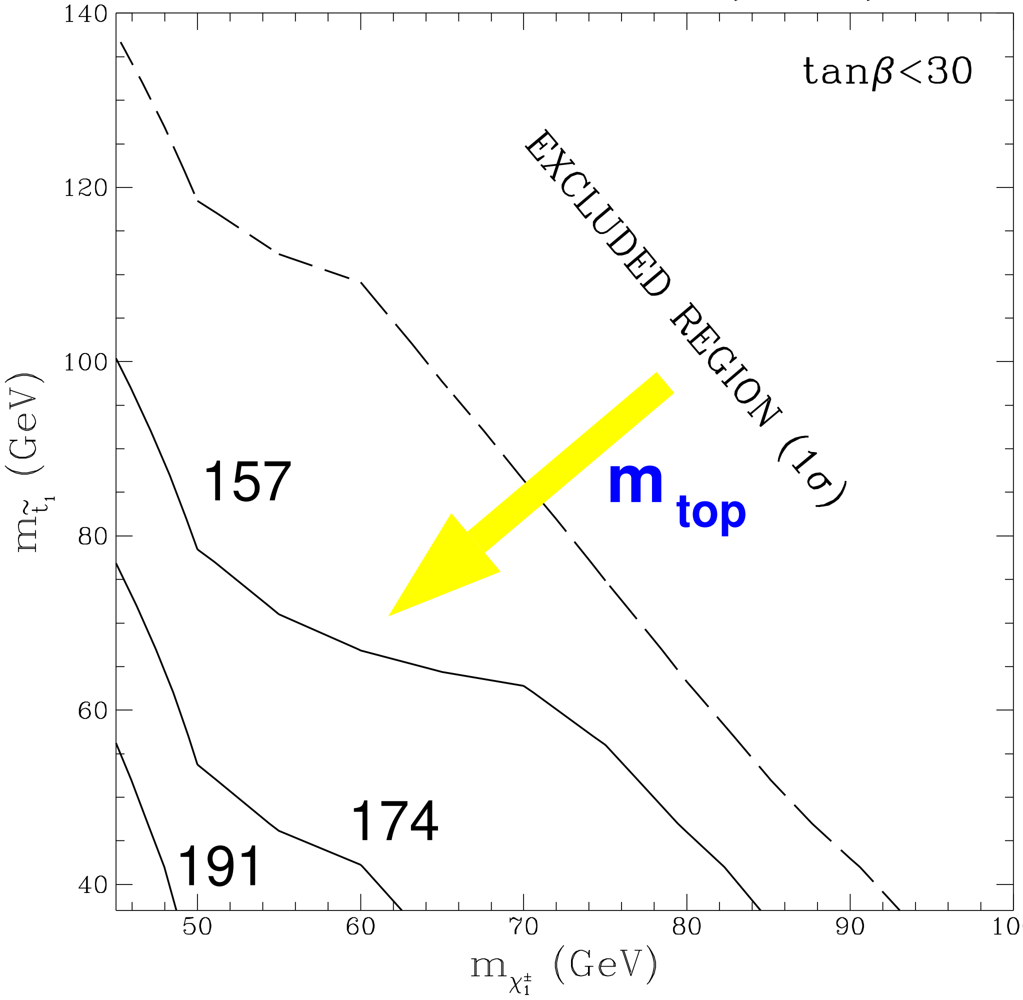
- check Standard Model physics
- look for supersymmetry

??? is low mass SUSY favoured ???

$\longrightarrow$ large $\mathrm{m_{top}}$ (TEVATRON, LEP)

$\longrightarrow$ small masses for stop and charginos are predicted

Wells, Kane, Kolda



Time Table of LEP 1.5

- 4.10.1995: last event from LEP 1

$\downarrow$

- 4.10.1995 $\longrightarrow$ 27.10.1995: Shutdown
  - upgrade machine
  - install additional superconducting RF

$\downarrow$

- 31.10.1995 19:48 h: first event at LEP 1.5

$\downarrow$

- 22.11.1995: End of datataking

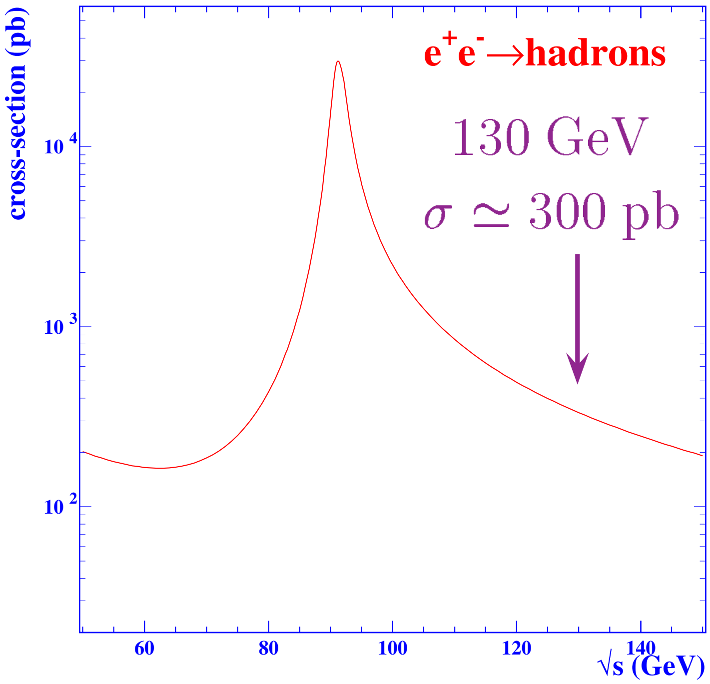
$\downarrow$

- 12.12.1995: First physics results are presented at CERN

LEP 1.5 Performance

- machine turned on very smoothly
- very low backgrounds for the experiments

$\sigma \simeq 30\text{nb}$

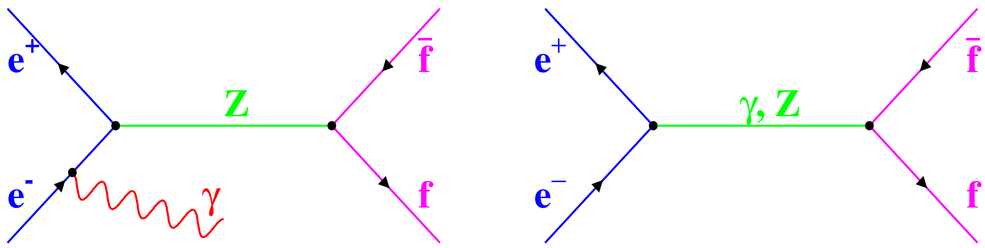


- very low event rates:

	♯ MH./day
LEP 1	$\simeq 7\,000$
LEP 1.5	$\simeq 70$

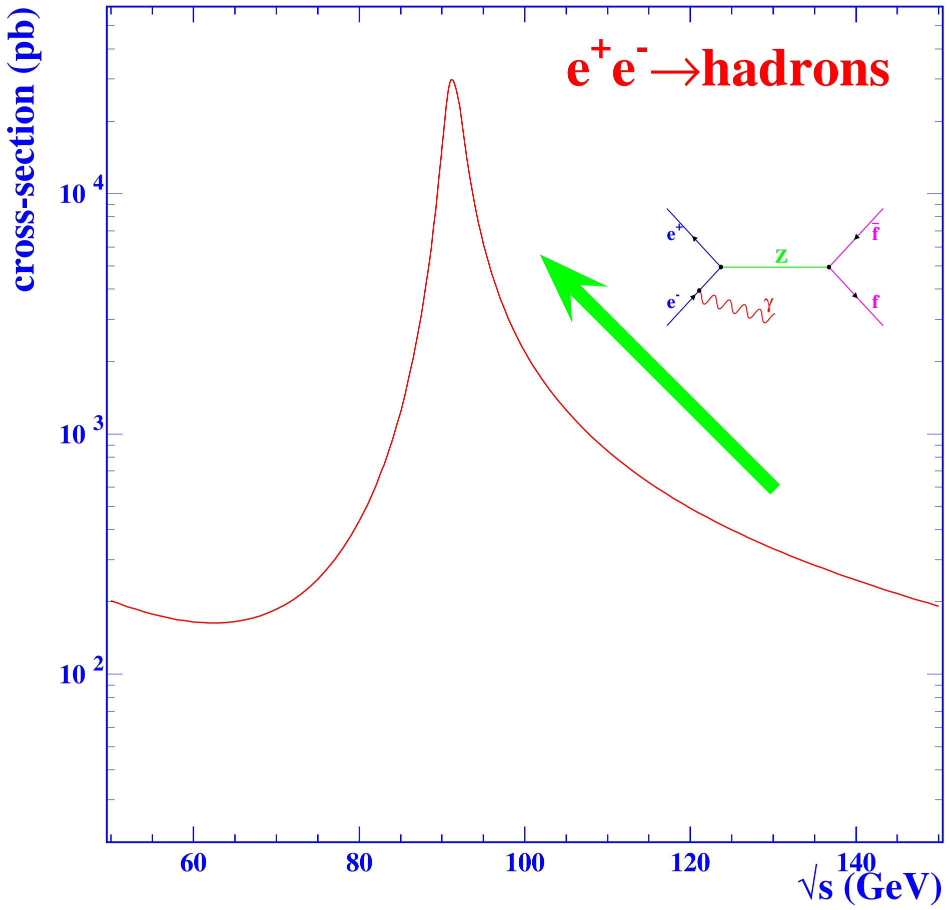
- collected luminosity: $\simeq \ 5.4\,\mathrm{pb}^{-1}$
  - 130 GeV: $\simeq \ 2.7\,\mathrm{pb}^{-1}$
  - 136 GeV: $\simeq \ 2.7\,\mathrm{pb}^{-1}$
  - 140 GeV: two short runs
- collected multihadrons: $\simeq \ 1500$ events

Main Physics Processes



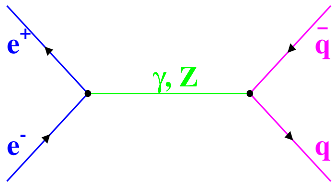
- fermion pair production
- initial state radiation is much more important

  $\longrightarrow$ 'radiative return to Z^0'

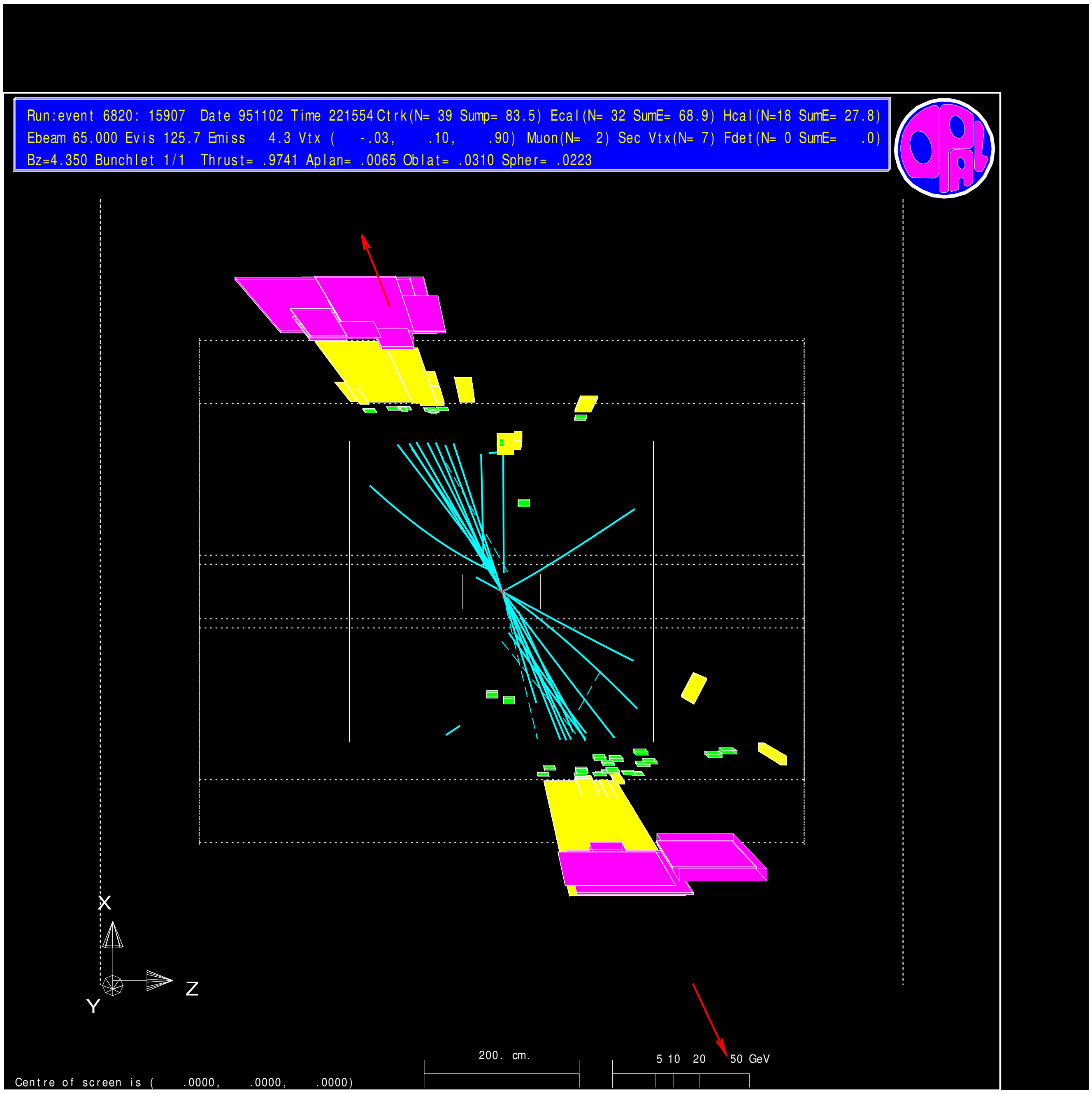


- radiative events: isolated γ or
  unbalanced event

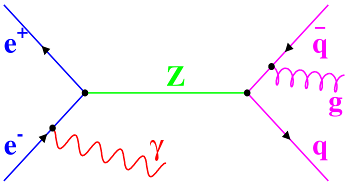
Multihadronic Event



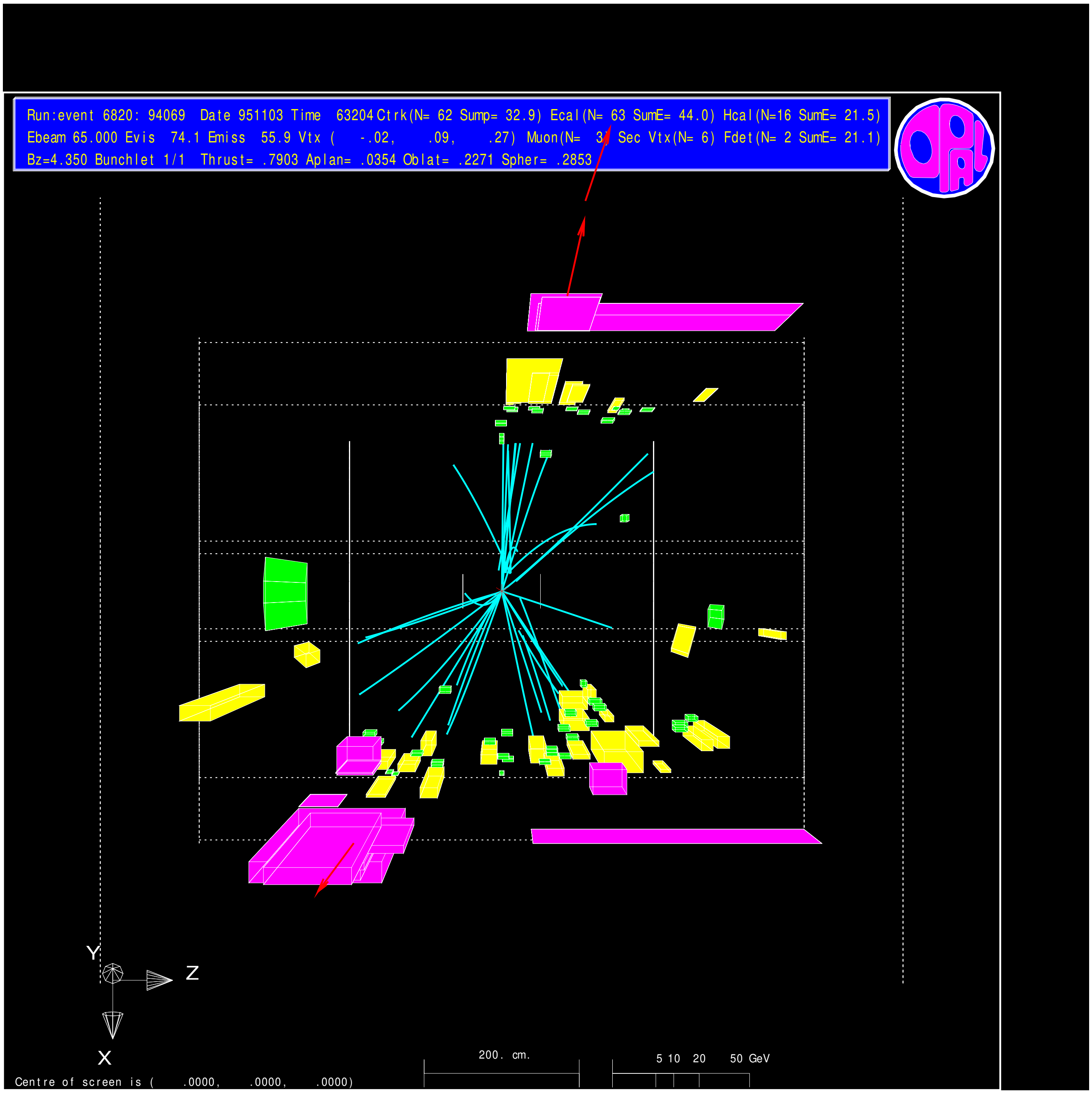
- $E_{\text{vis}} \simeq 130$ GeV



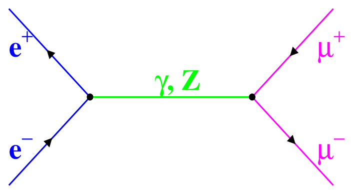
Radiative 3-Jet Event



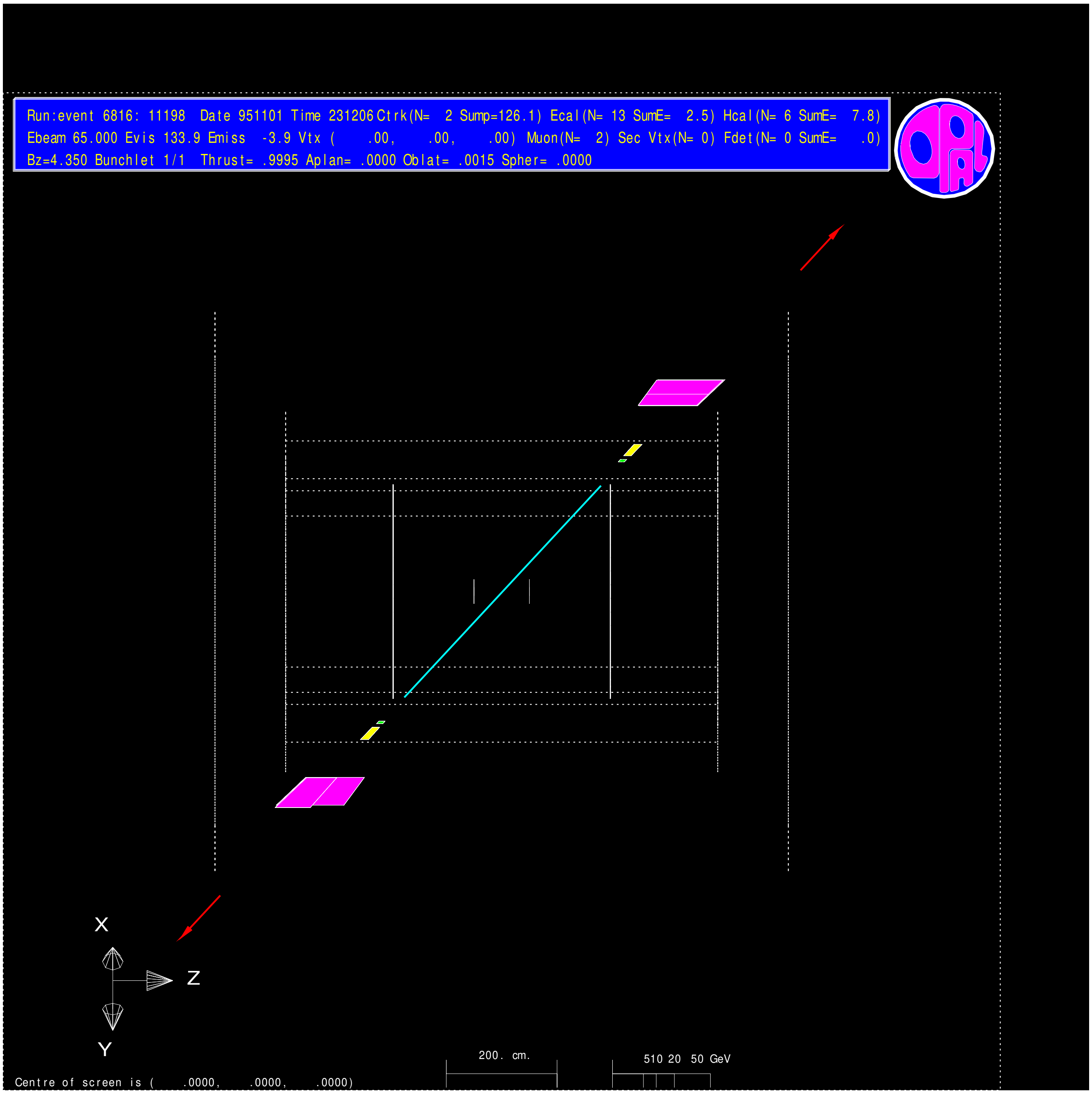
- $E_{vis} < 130$ GeV



Muon Pair

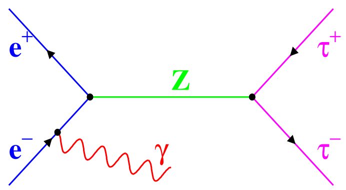


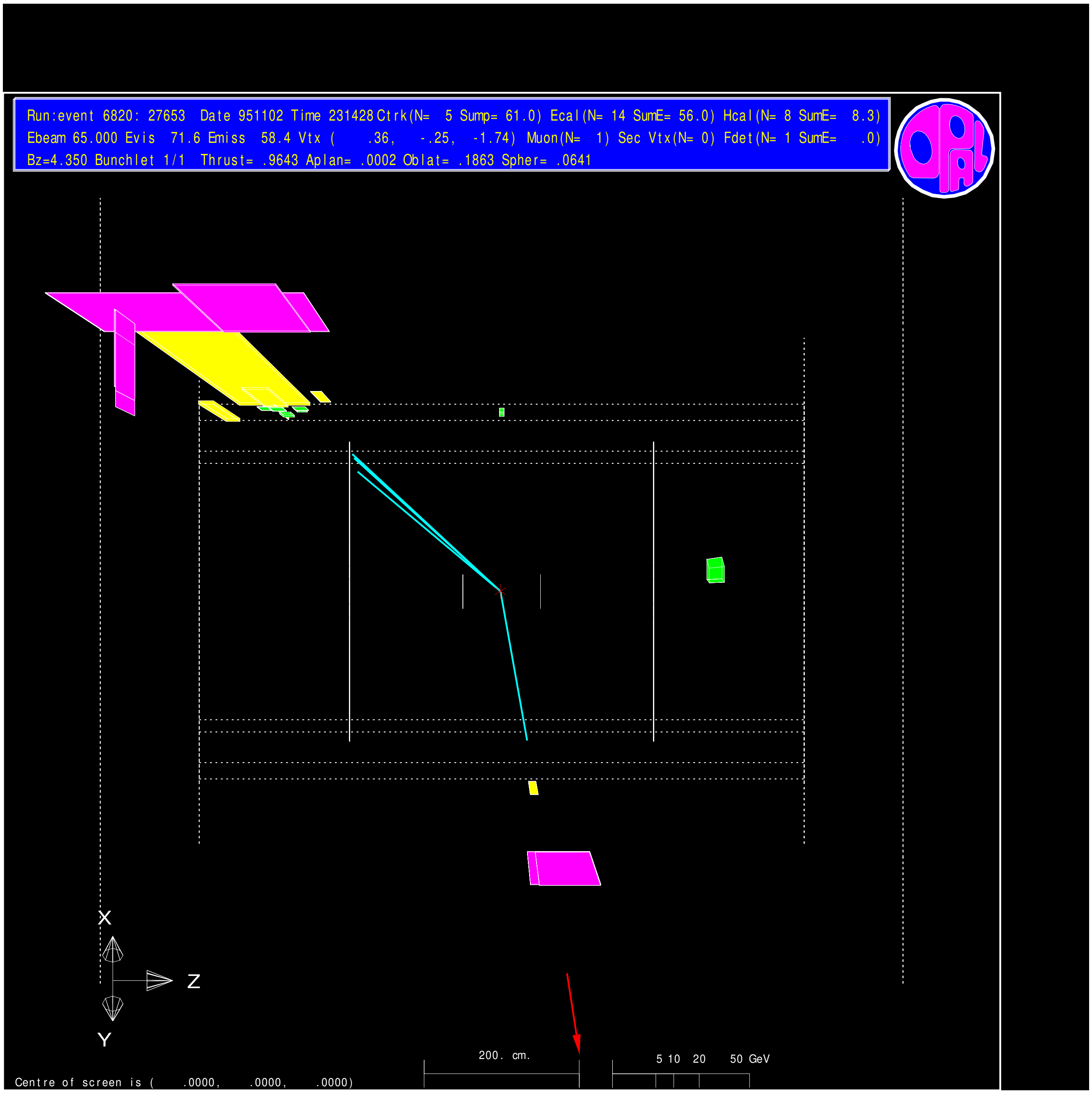
e+
e−
γ, Z
μ+
μ−



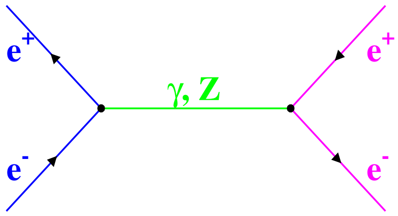
Run:event 6816: 11198 Date 951101 Time 231206 Ctrk(N= 2 Sump=126.1) Ecal(N= 13 SumE= 2.5) Hcal(N= 6 SumE= 7.8)
Ebeam 65.000 Evis 133.9 Emiss -3.9 Vtx (.00, .00, .00) Muon(N= 2) Sec Vtx(N= 0) Fdet(N= 0 SumE= .0)
Bz=4.350 Bunchlet 1/1 Thrust= .9995 Aplan= .0000 Oblat= .0015 Spher= .0000
X
Z
Y
200. cm.
5 10 20 50 GeV
Centre of screen is (.0000, .0000, .0000)

Radiative τ Pair

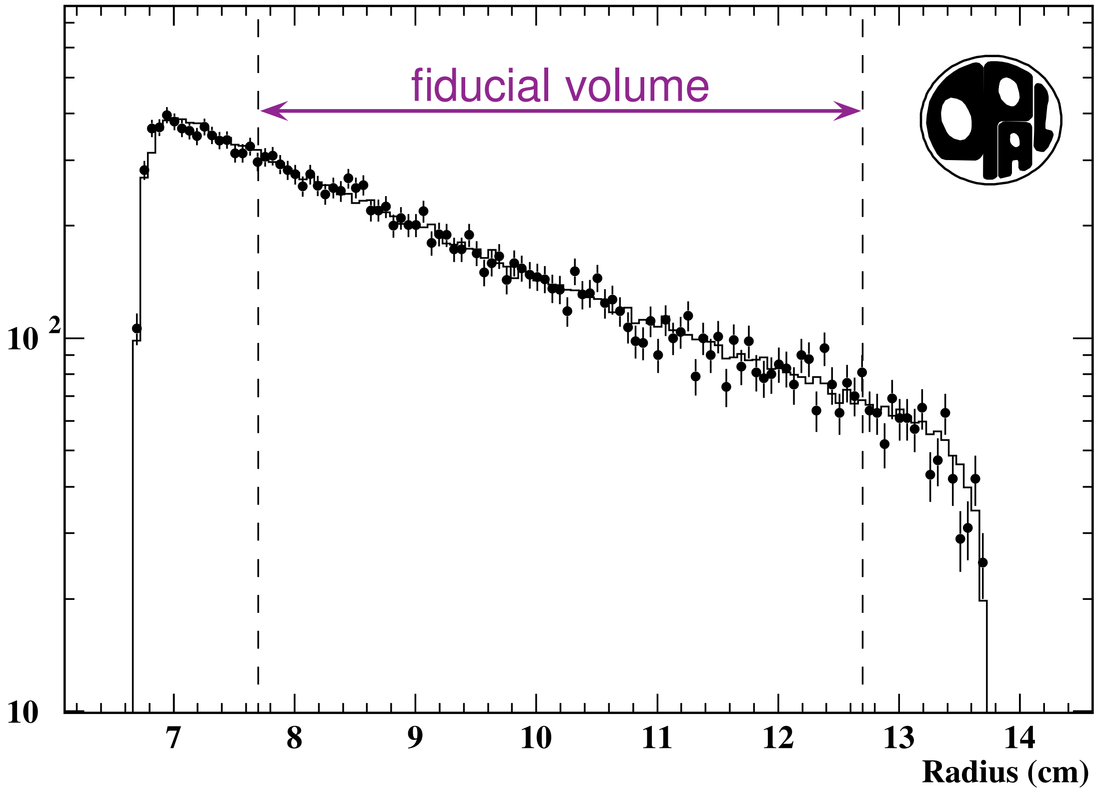




Luminosity Measurement



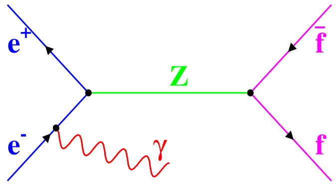
- Small angle Bhabha scattering $e^+e^- \rightarrow e^+e^-$ in forward calorimeters
- understanding of geometrical acceptance is important:



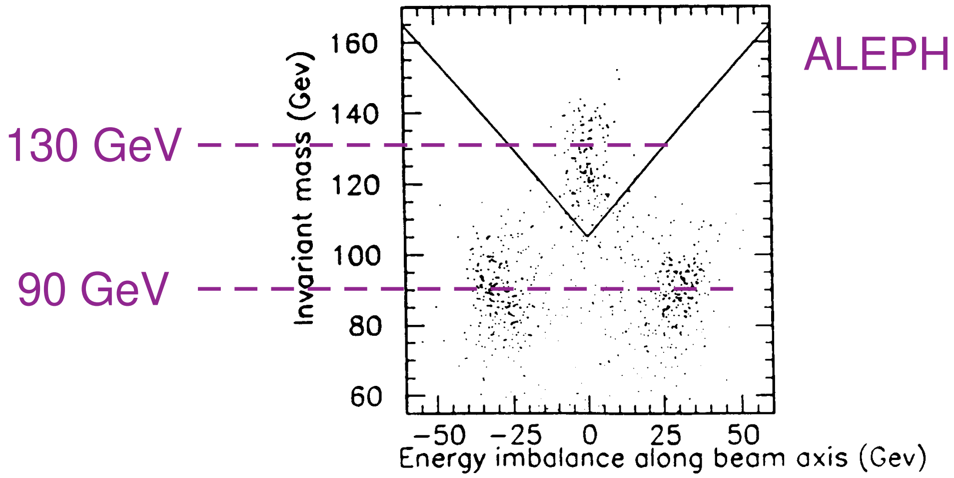
- typical experimental error on luminosity: 1% (compare with LEP 1: $< 0.1\%$)
- luminosity measurement is NOT the dominating error for analyses

Selection of Non–radiative Events

- Definition:
  - radiative: γ with $E_\gamma > E_{cut}$
  - non-radiative: 'no' γ: $E_\gamma < E_{cut}$



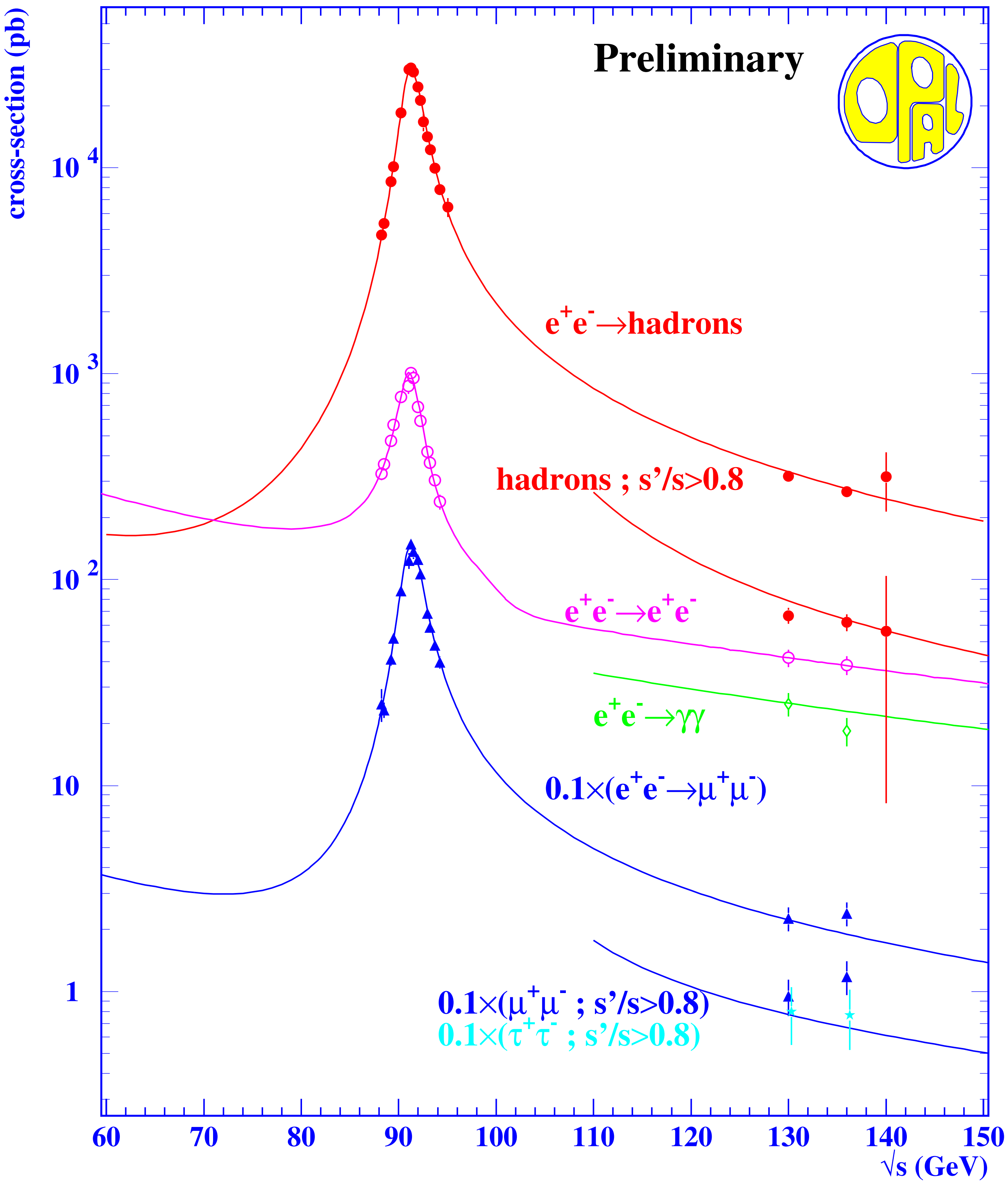
- Photon found in the detector $\longrightarrow$ simple
- Photon NOT found:
  - reconstruct:
    - $\ast$ invariant mass
    - $\ast$ missing momentum of hadronic system



- typical efficiencies: 80-90%
- typical purities: 80%
- complications:
  - γ hidden in jet
  - reconstruction inefficiencies
- slightly different selection by experiments

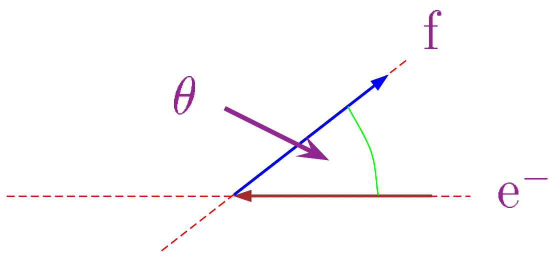
$\longrightarrow$ direct comparison NOT straight forward

Cross–Sections



$\longrightarrow$ good agreements of measurement with expectation

Asymmetries



- Definition:

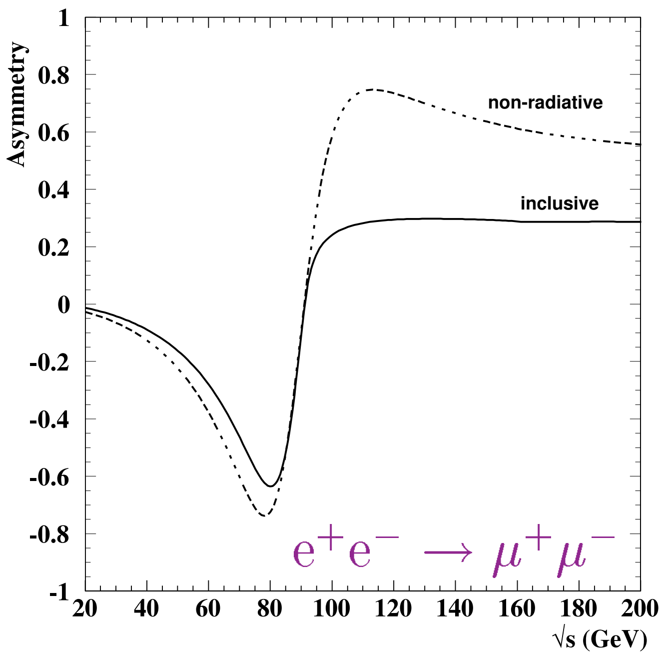
$$A_{FB} = \frac{n^+ - n^-}{n^+ + n^-}$$

  - n^+: Number of events with $q_f \cos\theta > 0$
  - n^-: Number of events with $q_f \cos\theta < 0$

- Asymmetry is consequence of interference:
  - $\gamma - Z$, $V - A$ (Vector–Axialvector)

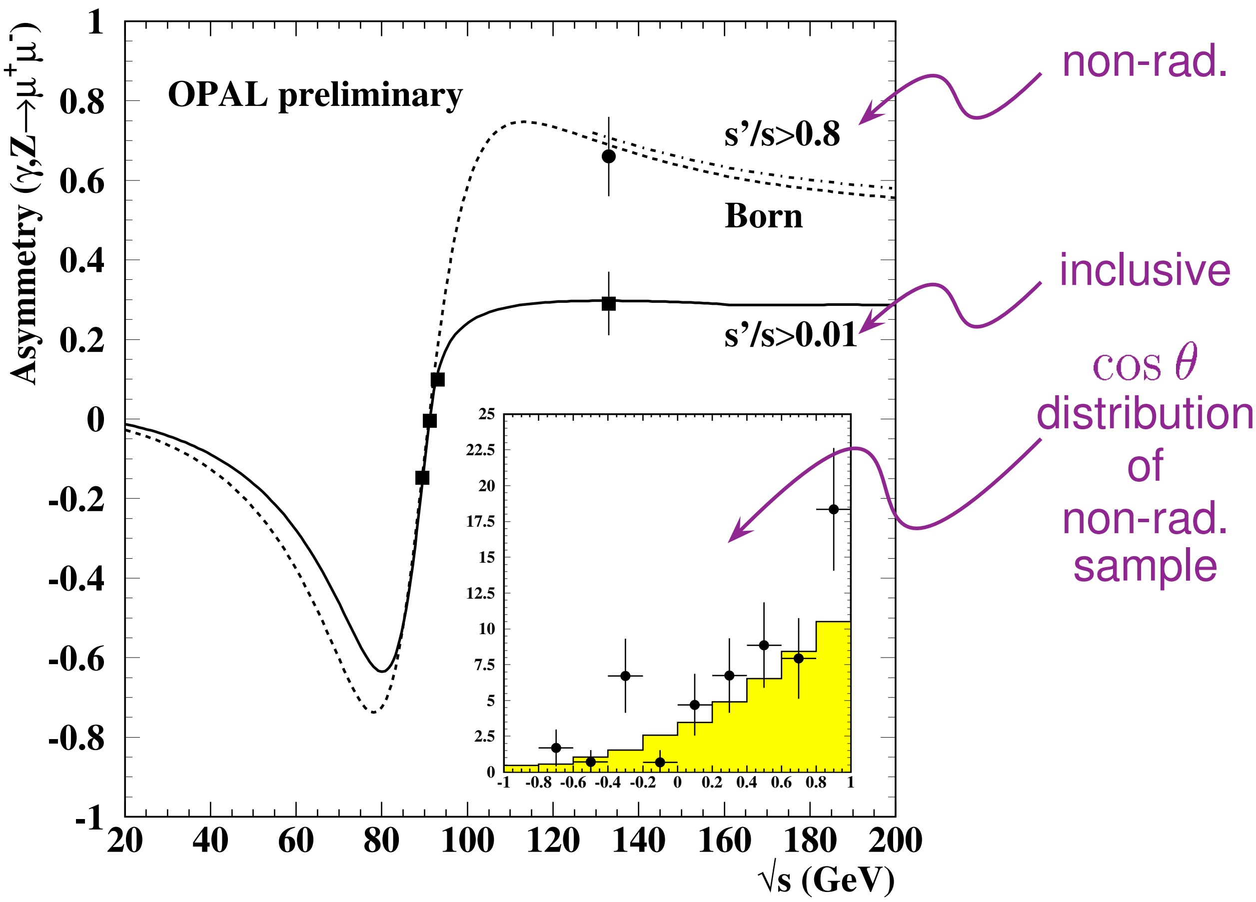
  $\longrightarrow$ access to structure of the currents in standard model

- strongly dependent on $\sqrt{s}$



Muon Asymmetries

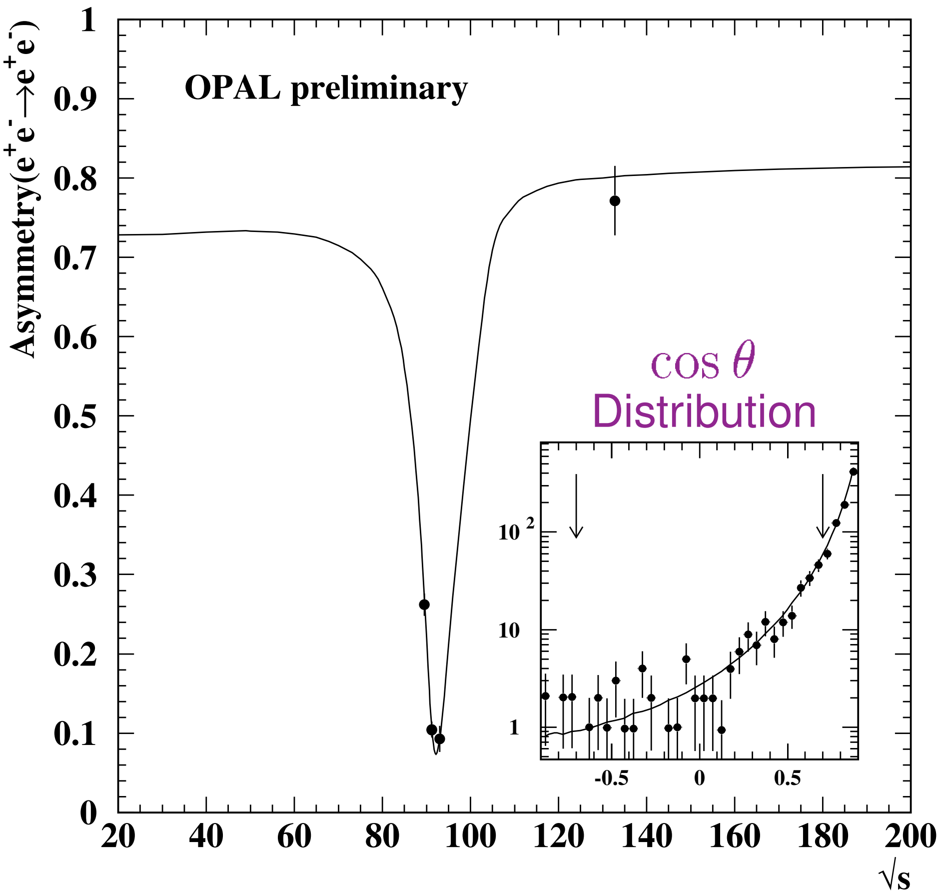
- result for averaged $\mathrm{E_{cms}}$
- consider inclusive and non-rad. sample
- predictions: ZFITTER with and without QED radiative effects



- measurement is statistics limited
- excellent agreement with expectation

Electron Asymmetries

- additional contribution from t-channel diagram
- result for averaged $\mathrm{E_{cms}}$
- select non-rad. events in central detector ($|\cos\theta| < 0.7$)
- predictions: ALIBABA generator



- measurement is statistics limited
- excellent agreement with expectation

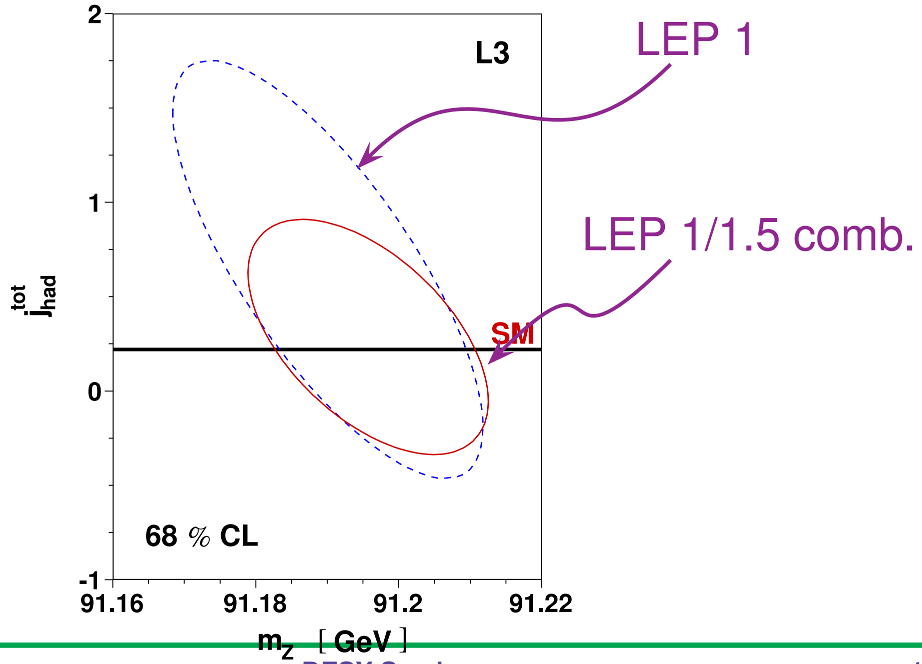
γZ Interference

- data at high energy: more sensitivity to interference term
- Hadronic cross section without radiative corrections:

$$\sigma_{q\bar{q}}(\sqrt{s}) = \frac{A_\gamma}{s} + \frac{A_{\gamma Z}}{D}(s - M_Z{}^2) + \frac{A_Z s}{D}$$

with $D = (s - M_Z{}^2)^2 + s^2 \Gamma_Z{}^2 / M_Z{}^2$

- Standard model fit of electroweak parameters: fix relative sizes of $(A_\gamma, A_{\gamma Z}, A_Z) \longrightarrow M_Z, \Gamma_Z$
- fewer theoretical assumptions in 'S-matrix' ansatz:
  - γZ interference term is free parameter
  - resulting uncertainty in J^{tot}_{had} enters directly into M_Z measurement
  - large correlation between J^{tot}_{had} and M_Z



$\gamma\gamma(\gamma)$ Final State

- Reconstruction of multi-photon final state:
  - $e^+e^- \to \gamma\gamma(+n\gamma),\ n \geq 0$

  $\longrightarrow$ Test of QED at highest available energy
- Analysis is also sensitive to
  - $e^+e^- \to \nu\bar{\nu}\gamma\gamma$
  - new physics signatures with production of invisible particles ($\tilde{\chi}^0$ production)
- Efficiency: $e^+e^- \to \gamma\gamma(\gamma)$: $(91.1 \pm 0.9)\%$

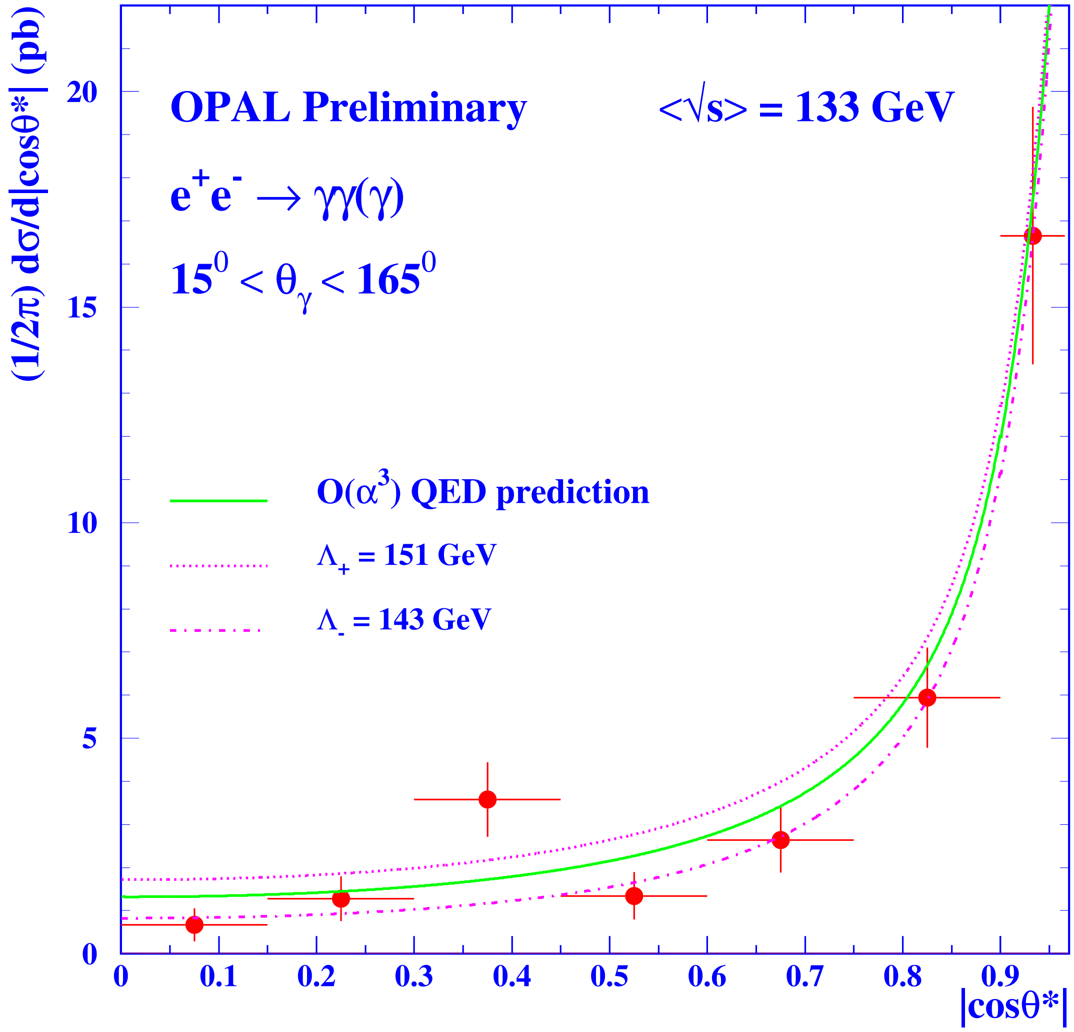
  $e^+e^- \to \nu\bar{\nu}\gamma\gamma$: $(80 \pm 3)\%$
- Deviation from QED
  - mass scale up to which QED is valid
  - deviation from point-like behaviour

  $\longrightarrow$ parameter $\Lambda_\pm$

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_{\mathcal{O}(\alpha^3)} \left(1 \pm \frac{s^2}{2{\Lambda_\pm}^4}(1 - \cos^2\theta)\right)$$

- in principle higher sensitivity of LEP 1.5 data due to s^2 dependence compared to LEP 1

$\gamma\gamma(\gamma)$ Final State (II)



- Fit for Λ:

$$\Lambda^{-4} = -0.7 \pm 1.1 \cdot 10^{-9}\ \mathrm{GeV}^{-4}$$

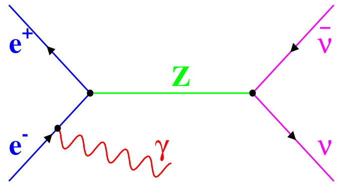
- Result is consistent with zero
- Limits at 95% confidence level:

$\longrightarrow$ $\Lambda_{\pm} \simeq 150$ GeV (LEP 1: $\simeq 150$ GeV)

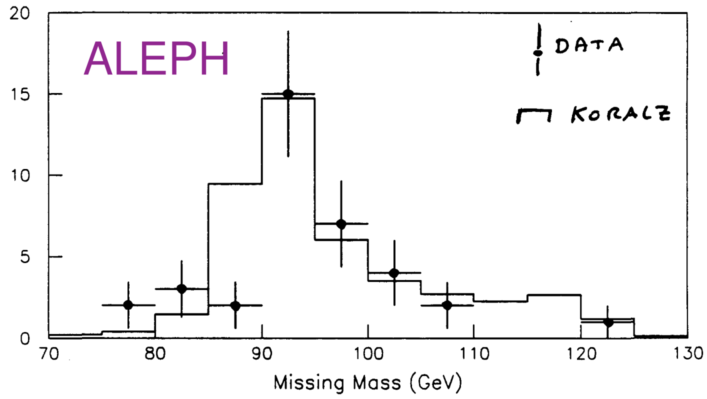
$\longrightarrow$ QED is valid up to LEP 1.5 energy scale

Single Photon Production

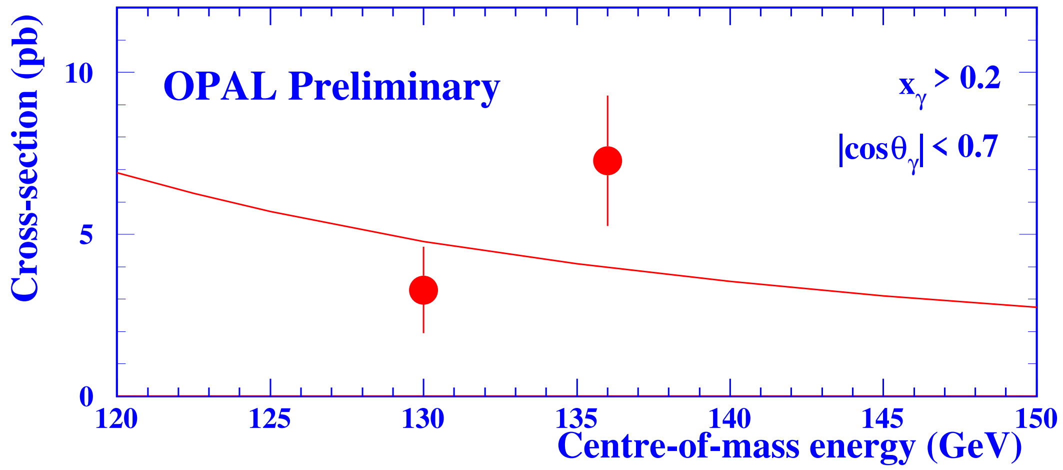
- Standard Model process:



- look for $\gamma(\gamma)$ final state
- also sensitive to new physics: $e^+e^- \to \gamma X$
- missing mass distribution: $(m_{\nu\bar{\nu}})$



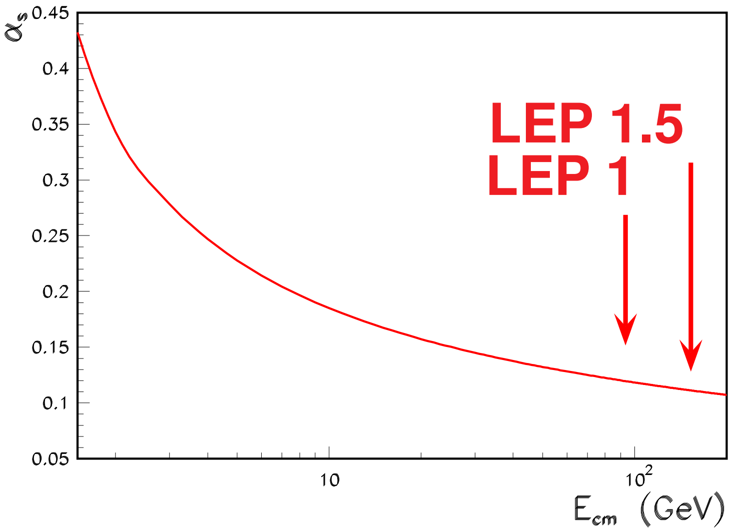
- Cross sections for $\gamma(\gamma)$ + invisible particle(s):



- Results are consistent with expectations from Standard Model

QCD studies

- Two main effects compared to QCD physics at LEP 1:
  - running of strong coupling constant α_s



  - change in flavour composition:
    - LEP 1: dominated by Z^0 exchange:

      $\longrightarrow \ (\Gamma_\mathrm{u}/\Gamma_\mathrm{d})_\mathrm{Z} \simeq 0.8$
    - LEP 1.5: γ exchange is more important:

      $\longrightarrow \ (\Gamma_\mathrm{u}/\Gamma_\mathrm{d})_\gamma \simeq 4.0$

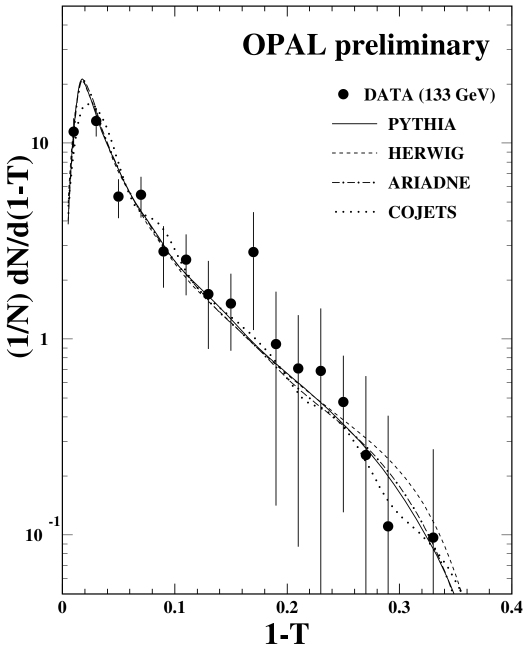
- measure inclusive variables
- study energy behaviour
- compare with predictions:
  - QCD calculations
  - empirical ansatz

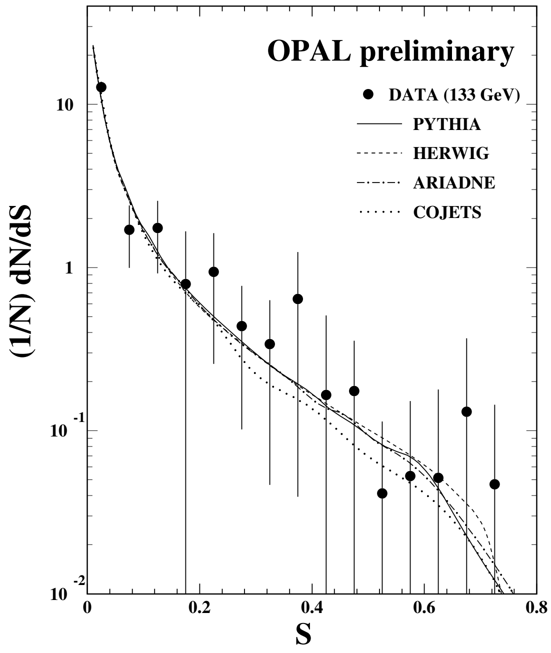
Event Shape Observables

- Select non-radiative events: Def.: $\mathrm{E}_\gamma < 5\,\mathrm{GeV}$
- Definition of some observables:
  - Thrust (T): $T = \max\left(\frac{\sum_i |\vec{p}_i \cdot \vec{n}|}{\sum_i |\vec{p}_i|}\right)$
  - Sphericity(S): $S^{\alpha\beta} = \frac{\sum_i p_i^\alpha p_i^\beta}{\sum_i p_i^2} \quad , \quad \alpha, \beta = 1, 2, 3$

    Eigenvalues $Q_i : \quad Q_1 < Q_2 < Q_3$

    $S = \frac{3}{2}(Q_1 + Q_2)$





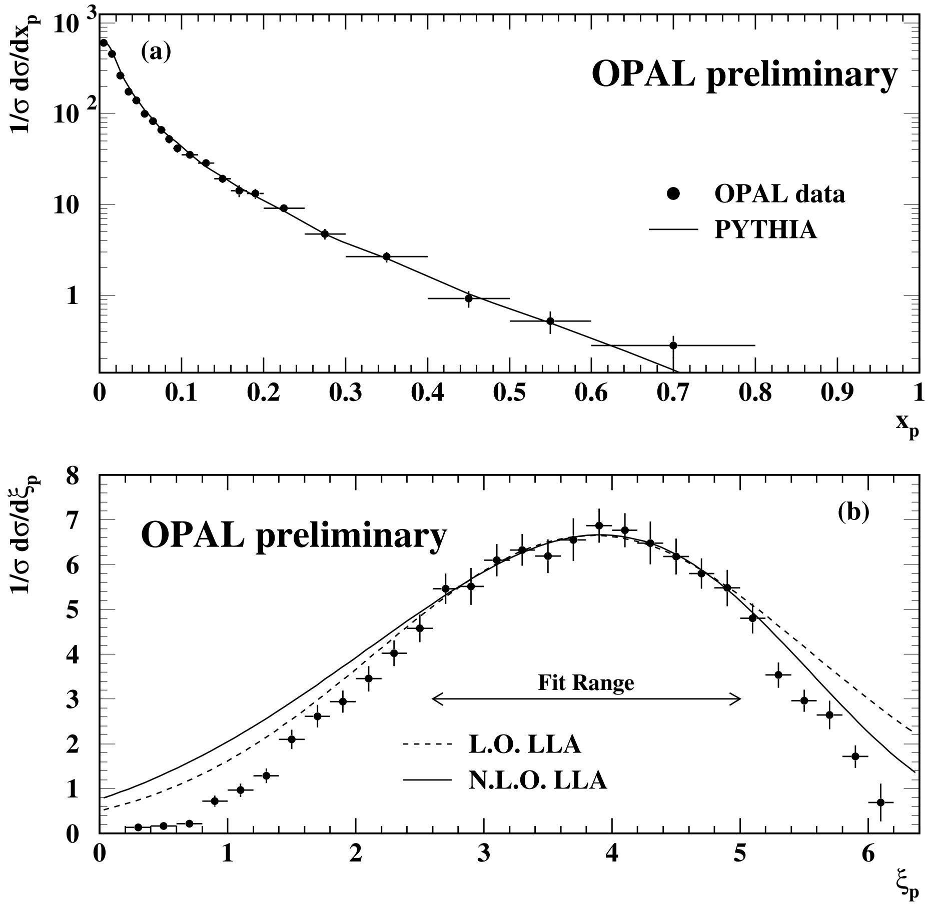
- Parameters of MC are tuned at Z^0 peak!!

  $\longrightarrow$ nevertheless: good agreement between data and simulation

Inclusive Charged Particle Measurements

- Fragmentation functions:

$$x_p = p/E_{beam}; \quad \xi_p = \ln(1/x_p)$$



- Peak of ξ_p distribution:

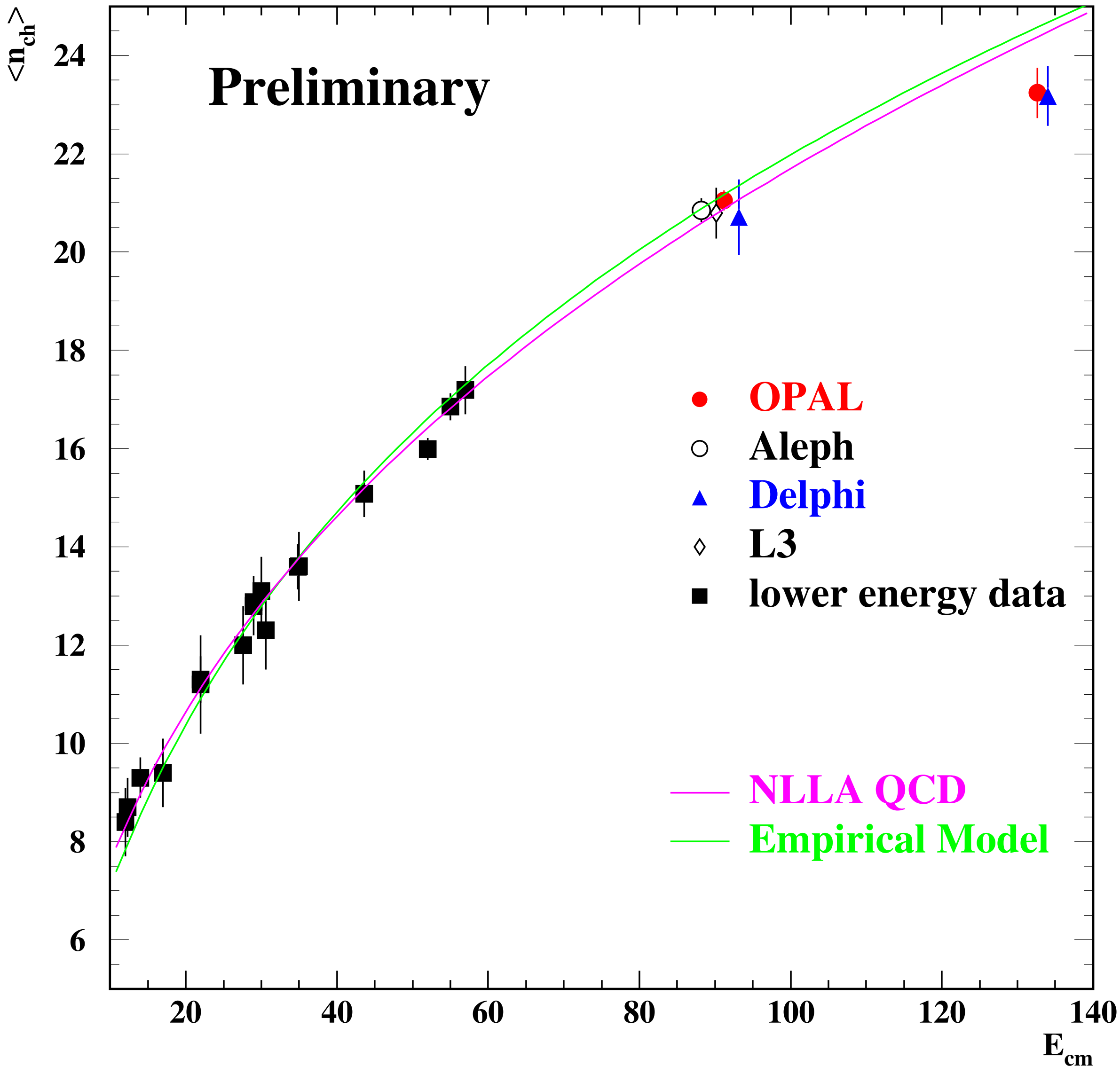
$$\xi_0 = 3.91 \pm 0.05(\text{stat.}) \pm 0.07(\text{syst.})$$

- Mean charged multiplicity:

$$\langle n_{ch} \rangle = 23.24 \pm 0.32(\text{stat.}) \pm 0.40(\text{syst.})$$

Energy Evolution

- Mean charge multiplicity:

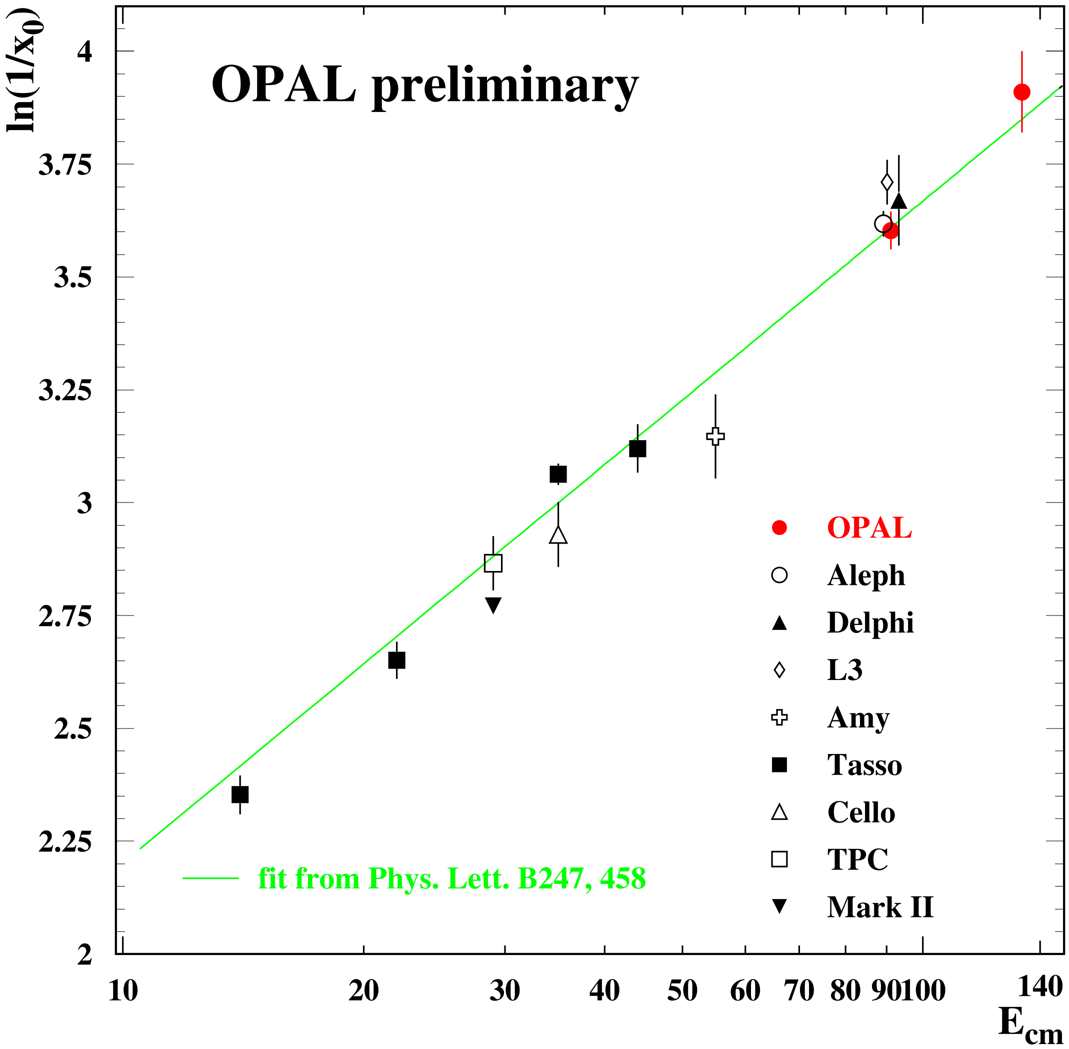


- New data points are NOT included in the fits
- Measurements are slightly lower than the extrapolation

(Data from LEP 1 are displaced for clarity)

Energy Evolution (II)

- Fragmentation of light flavours: non-perturbative process
- Peak of fragmentation function:

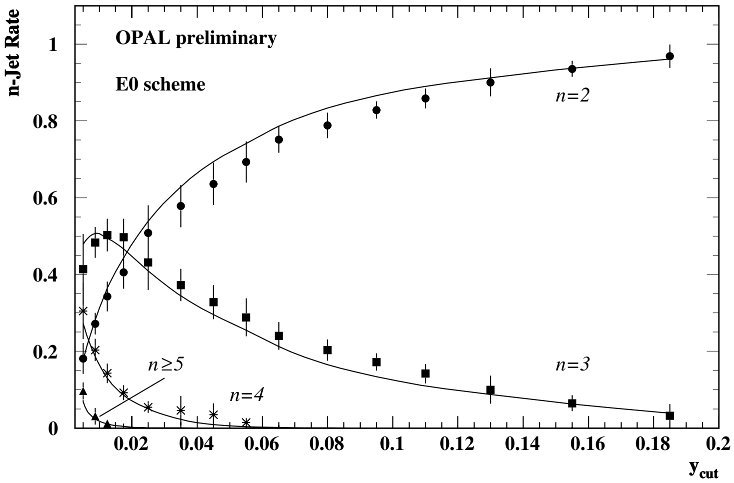


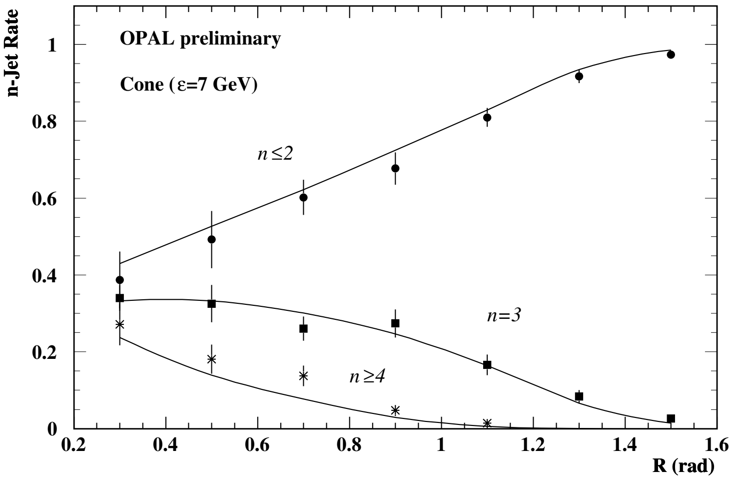
- New data point is NOT included in the fits
- Linearity expected by MLLA QCD calculation
  $\longrightarrow$ consistency with extrapolation

(Data from LEP 1 are displaced for clarity)

Jet Rates

- Different jet algorithms:
  - E0 scheme: JADE scheme
    D scheme: Durham scheme
  - Cone jet finder
- Resolution parameter y_{cut}: scaled invariant mass
- MC: prediction from PYTHIA





- points and errors are highly correlated

  $\longrightarrow$ observe slight excess of data over MC simulation for 3- and 4-jet events (depending on jet definition)

Strong Coupling Constant

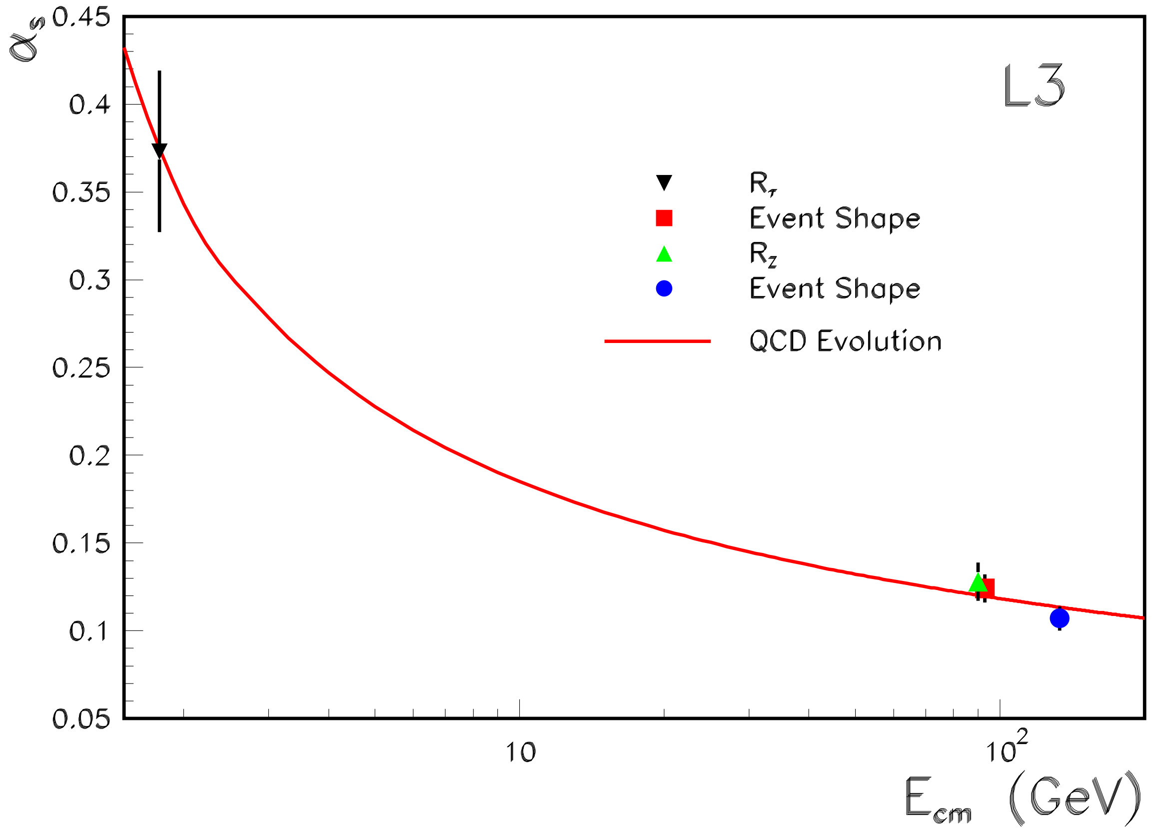
L3

- Fit a 2nd order and resummed QCD description to a number of events shape variables.

- Determination of the strong coupling constant at 133 GeV:

$$\alpha_s(133\mathrm{GeV}) = 0.107 \pm 0.005(\mathrm{exp.}) \pm 0.006(\mathrm{theory})$$

- Compare with L3 results at lower energy:



- decent agreement with expectation

Search for New Physics

- One possible candidate beyond the Standard Model:

$\downarrow$

Minimal Supersymmetric Standard Model

$\downarrow$

- SM: 1 complex Higgs doublet field

$\longrightarrow \ \mathrm{H}^0$

- MSSM: 2 complex doublet fields: $\Phi_1, \ \Phi_2$

$\longrightarrow$ 5 Higgs bosons

$\mathrm{h}^0, \ \mathrm{H}^0$	scalar $(\mathrm{m}_{\mathrm{h}^0} < \mathrm{m}_{\mathrm{H}^0})$
A^0	pseudoscalar
$\mathrm{H}^\pm$	scalar

  - free parameters:
    - $\tan\beta = \langle\Phi_1\rangle / \langle\Phi_2\rangle$
    - m_0: mass scale for scalar leptons
    - 2 further mass scales: $\mathrm{M}_2, \ \mu$

Supersymmetric Particles

- new 'zoo' of supersymmetric particles

$\Downarrow$

- the degrees of freedom of normal and supersymmetric particles are the same
- corresponding fermion for each boson:

$$\begin{array}{cc} \mathrm{g} & \tilde{\mathrm{g}} \\ \mathrm{W}^{\pm} & \tilde{\mathrm{W}}^{\pm} \\ \mathrm{H}^{\pm} & \tilde{\mathrm{H}}^{\pm} \end{array} \Bigg\} \text{ mix to mass eigenstates } \tilde{\chi}^{\pm} \text{ (Chargino)}$$

$$\begin{array}{cc} \gamma & \tilde{\gamma} \\ \mathrm{Z}^0 & \tilde{\mathrm{Z}}^0 \\ \mathrm{h}^0, \mathrm{H}^0 & \tilde{\mathrm{h}}^0, \tilde{\mathrm{H}}^0 \\ \mathrm{A}^0 & \tilde{\mathrm{A}}^0 \end{array} \Bigg\} \text{ mix to mass eigenstates } \tilde{\chi}^{0} \text{ (Neutralino)}$$

- corresponding boson for each fermion:

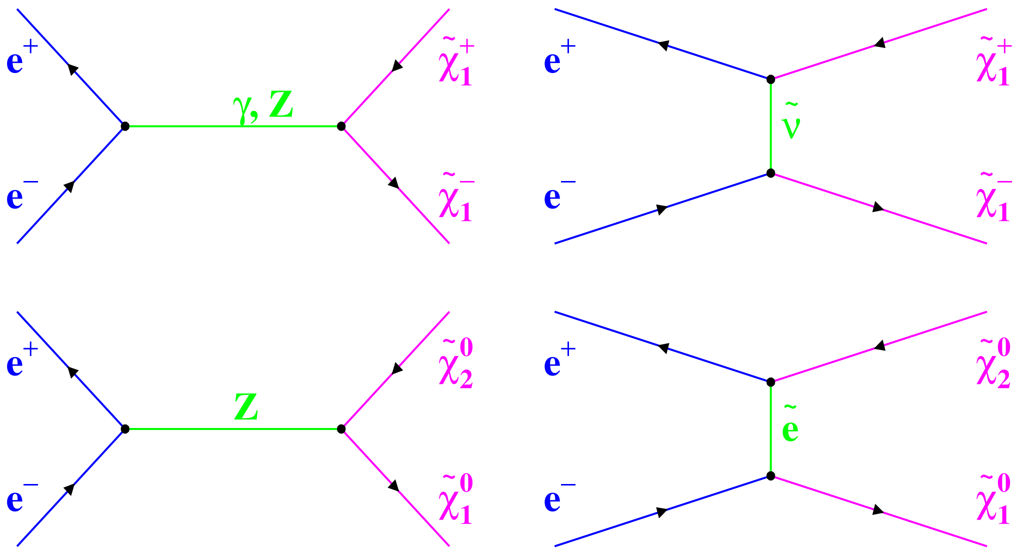
$$\begin{array}{cc} \mathrm{q} & \tilde{\mathrm{q}}_{\mathrm{L}}, \tilde{\mathrm{q}}_{\mathrm{R}} \\ \ell & \tilde{\ell}_{\mathrm{L}}, \tilde{\ell}_{\mathrm{R}} \\ \nu & \tilde{\nu} \end{array}$$

$\Downarrow$

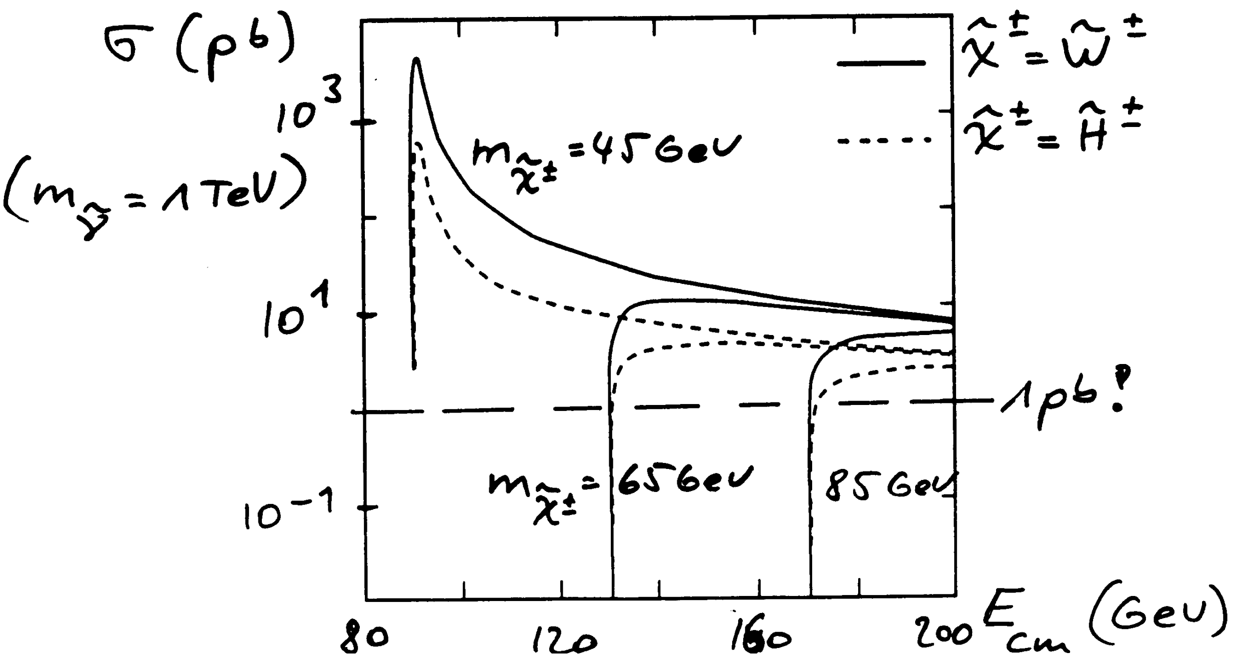
- if R-parity is conserved:
  $\longrightarrow$ lightest SUSY particle should be stable
  $\longrightarrow$ $\tilde{\chi}^0_1$

Production of Charginos/Neutralinos

- Production mechanism:
  - identical final states interfere ($\tilde{\chi}_1^{\pm}$: destructive)

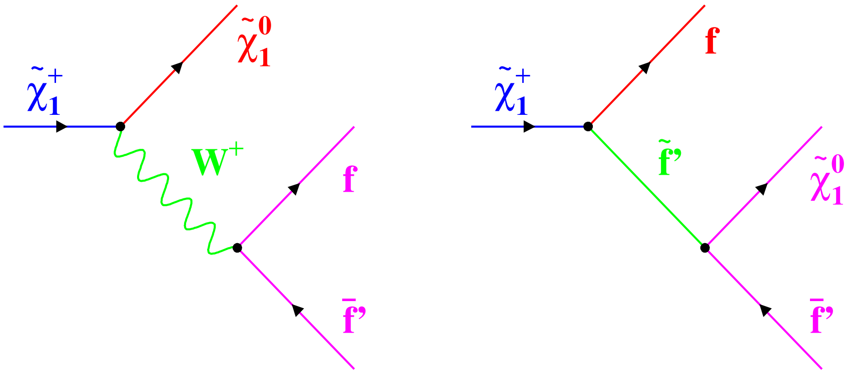


- Expected cross-section:



Decays of Charginos/Neutralinos

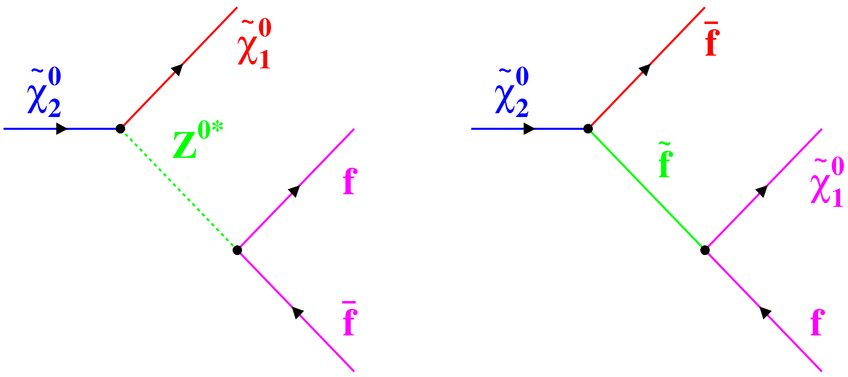
- Decays of $\tilde{\chi}_1^+$:



  - via virtual $\mathrm{W}, \tilde{\ell}, \tilde{\mathrm{q}}$ emission:

$$\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 \ell^+ \nu$$
$$\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 \mathrm{q}\overline{\mathrm{q}}'$$

- Decays of $\tilde{\chi}_2^0$:

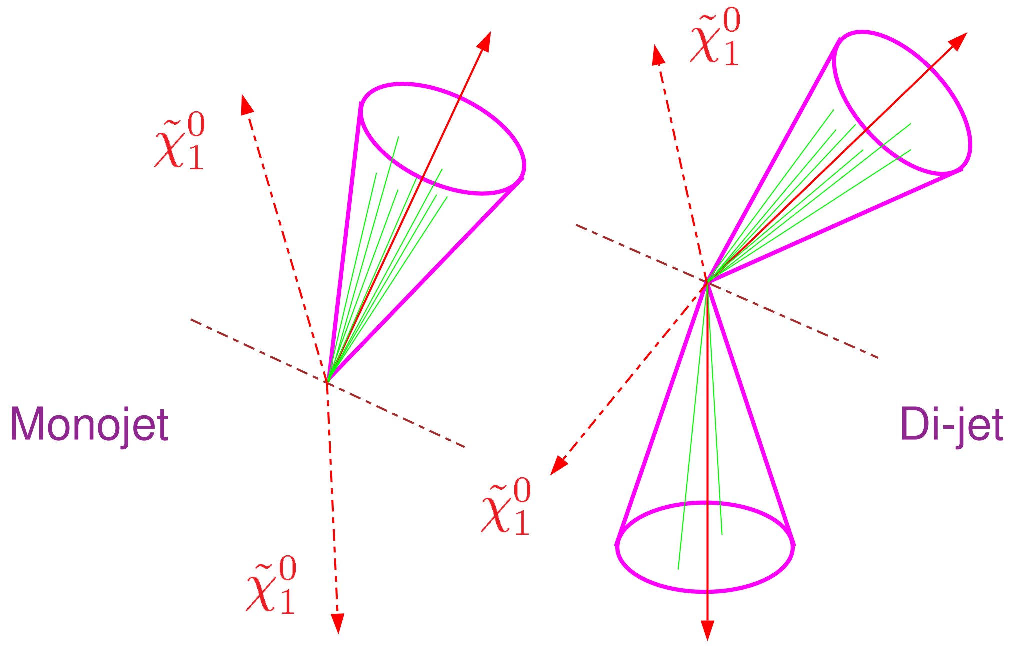


  - via a Z^*, Higgs boson, $\tilde{\ell}$ or $\tilde{\mathrm{q}}$:

$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+ \ell^-$$
$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \mathrm{q}\overline{\mathrm{q}}$$

Analysis Procedure

- Select event topology:

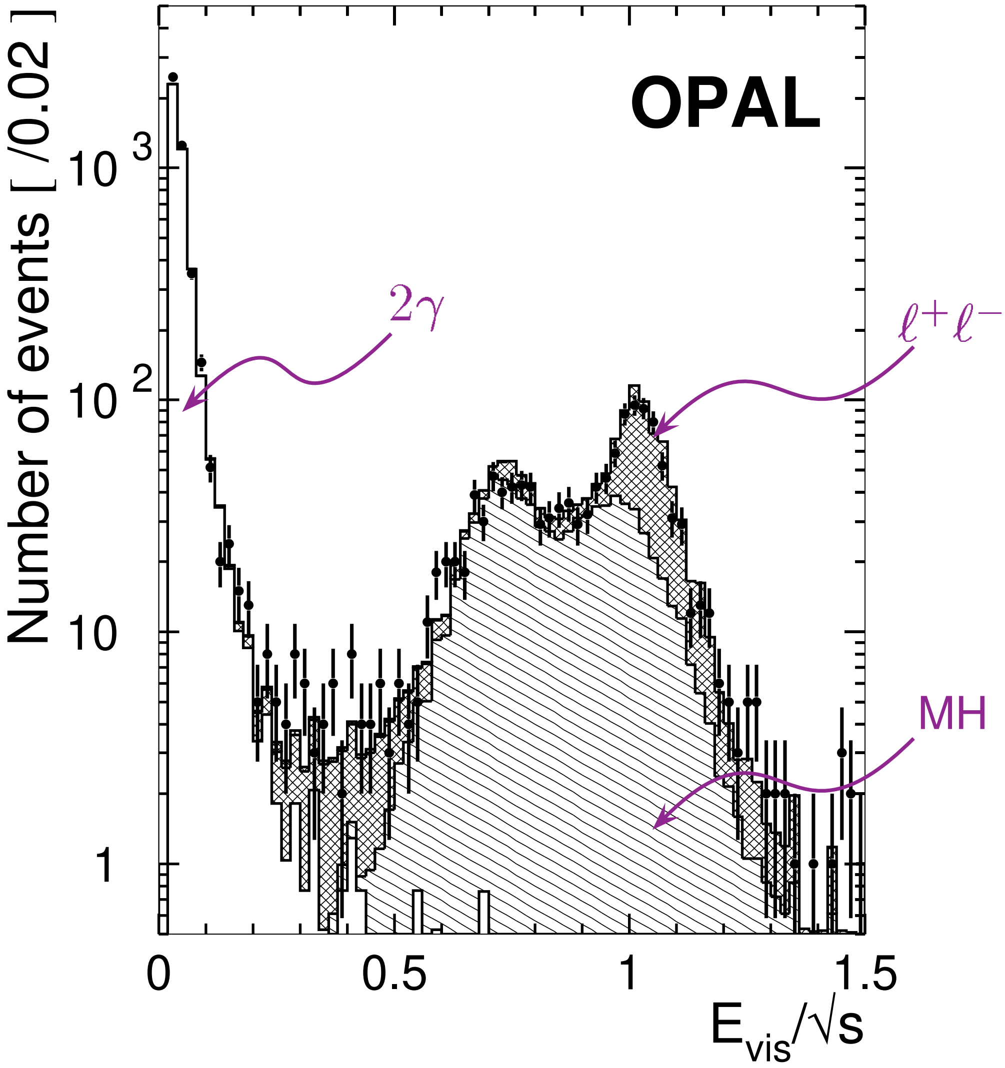


  - Acoplanar 'jets' (Di-jet)
    'Jet': jet(s) or lepton(s)
  - Monojet

- Signal efficiencies:
  - depend on topology
  - most important parameters:
    $\longrightarrow$ chargino search: $\mathrm{m}_{\tilde{\chi}_1^+}$; $\Delta\mathrm{M}_+ = \mathrm{m}_{\tilde{\chi}_1^+} - \mathrm{m}_{\tilde{\chi}_1^0}$
    $\longrightarrow$ neutralino search: $\mathrm{m}_{\tilde{\chi}_2^0}$; $\Delta\mathrm{M}_0 = \mathrm{m}_{\tilde{\chi}_2^0} - \mathrm{m}_{\tilde{\chi}_1^0}$
  - large $\Delta\mathrm{M}$: $\mathrm{E}_{\mathrm{vis}}$ is large
    $\longrightarrow$ efficiency: $\simeq$ 40%
  - small $\Delta\mathrm{M}$: $\mathrm{E}_{\mathrm{vis}}$ is small
    $\longrightarrow$ efficiency: $\simeq$ 15%

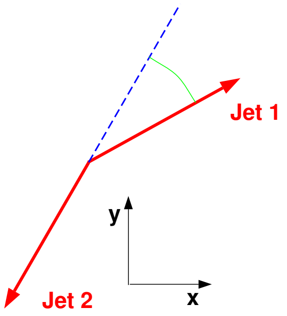
Backgrounds

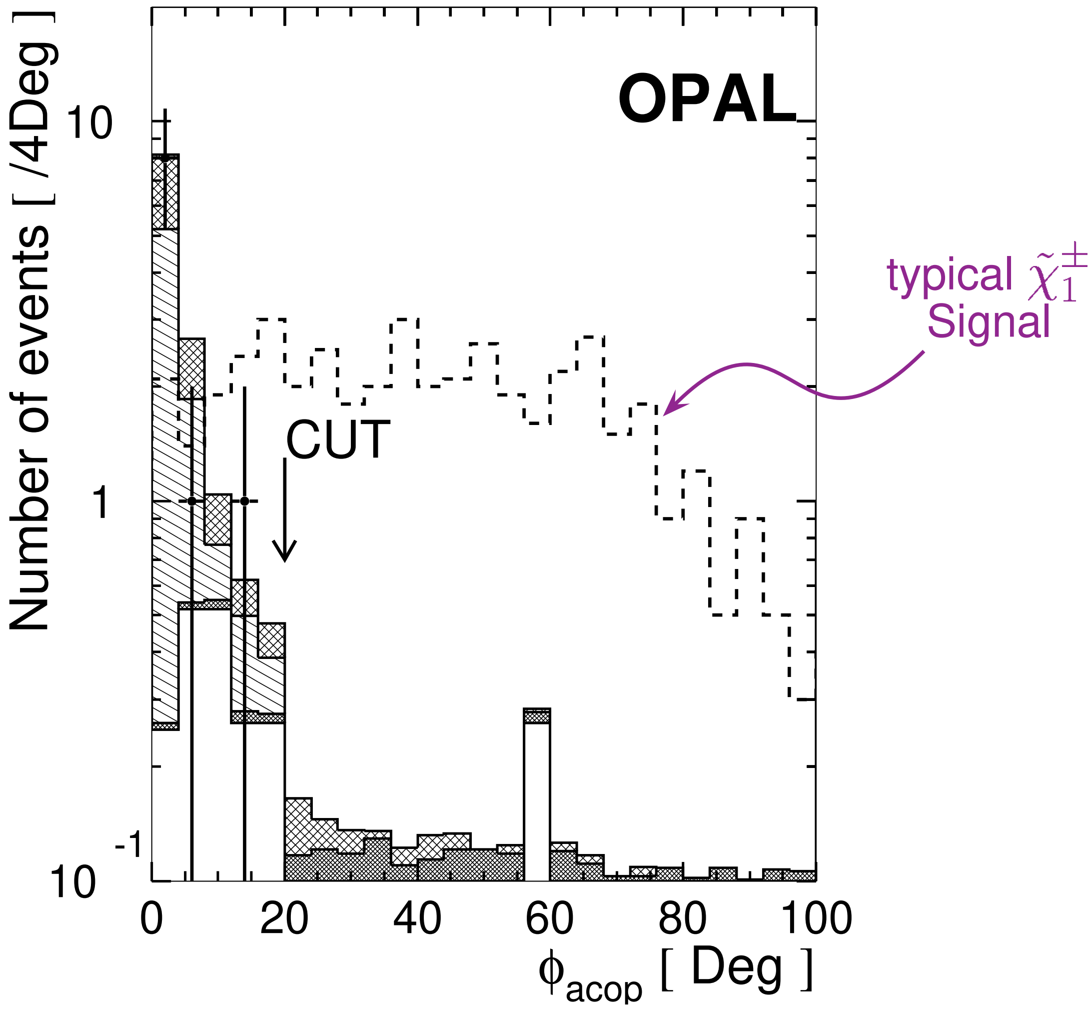
- Various background sources:
  - Two-photon processes
  - Multihadronic events
  - Leptonic events
  - $\tau^+\tau^-$ decays and four-fermion events
- Visible energy distribution after preselection



Selection

- Final cut of di-jet topology: ϕ_{acop}





- Apply all selection criteria:
  - Expected background from all sources: 0.93 events

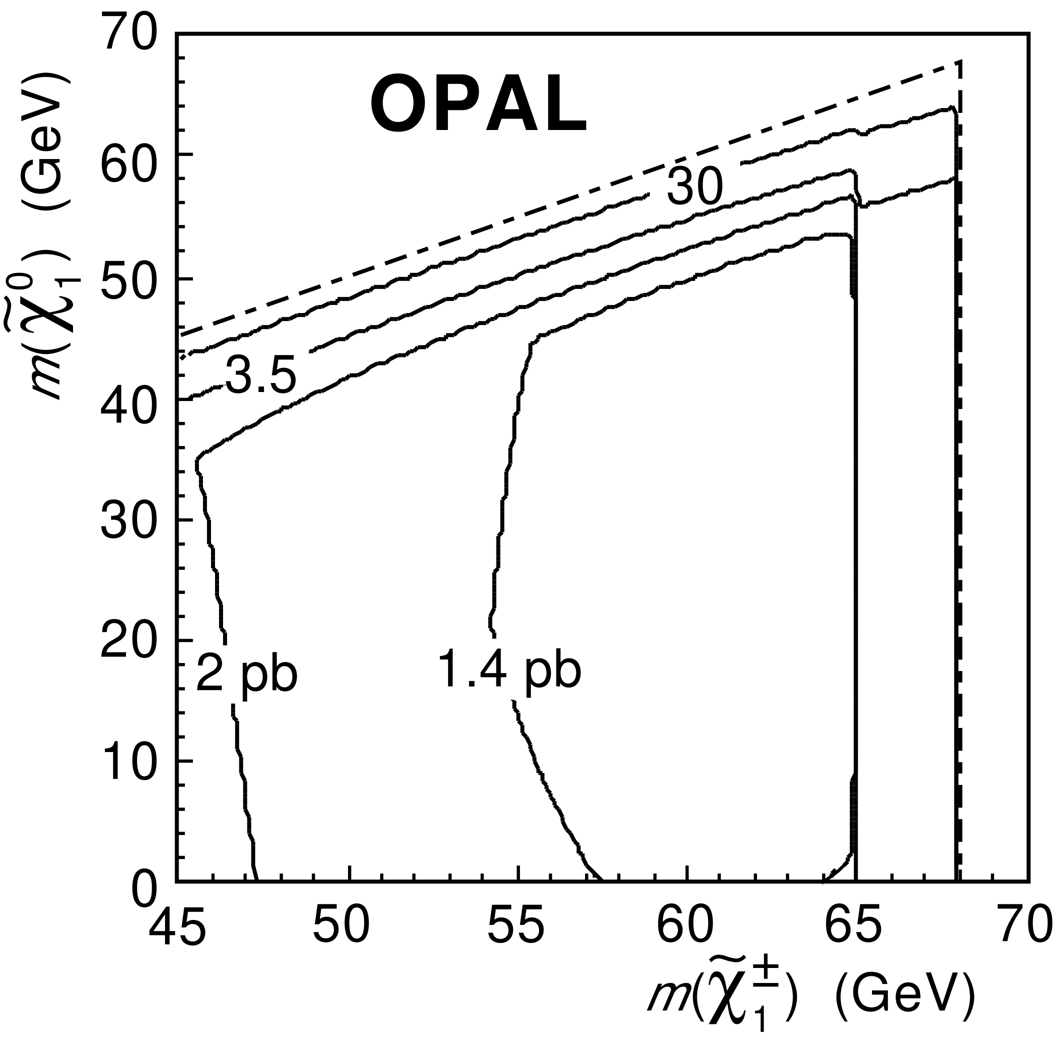
$\tau\tau$	0.18 ev.
2γ	0.26 ev.
4f	0.49 ev.

  - NO data event survives

$\longrightarrow$ calculate limits

Limits on Cross Section

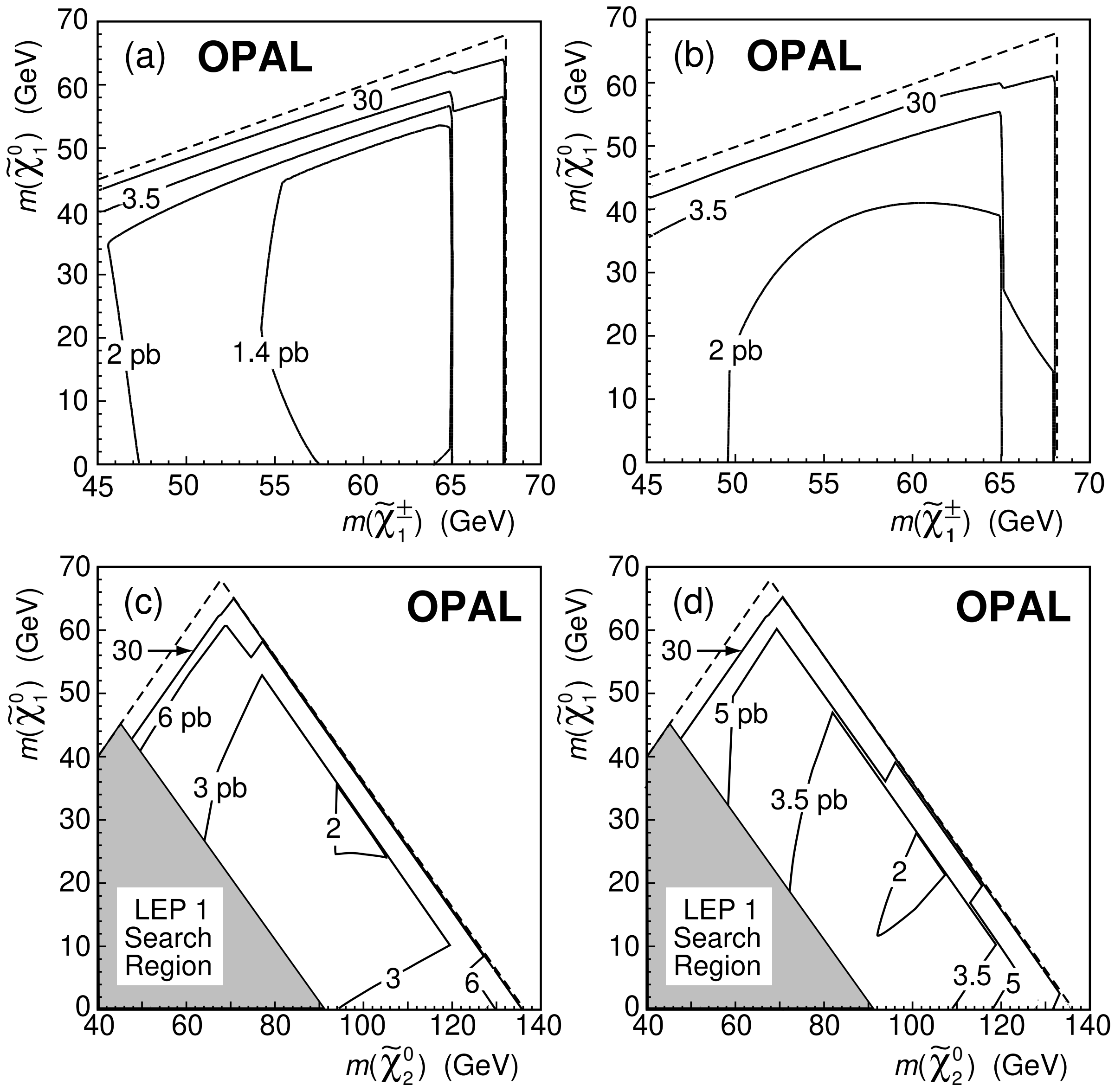
- discuss special case:
  - chargino production
  - assume: 100% $\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 W^{+*}$
- calculate 95% confidence level contour plots of upper limits on the production cross sections



- dashed line: kinematical limit

Model Independent Limits

- 95% confidence level contour plots of upper limits on the production cross sections:



  – dashed line: kinematical limit

- Assumptions of specific decay modes:

  (a) 100% $\tilde{\chi}^+_1 \to \tilde{\chi}^0_1 \mathrm{W}^{+*}$ (b) 100% $\tilde{\chi}^+_1 \xrightarrow{\tilde{\ell}} \tilde{\chi}^0_1 \ell\nu$

  (c) 100% $\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 \mathrm{Z}^{0*}$ (d) 100% $\tilde{\chi}^0_2 \xrightarrow{\tilde{\ell}} \tilde{\chi}^0_1 \ell\nu$

MSSM Interpretation

- Limits depend on MSSM parameters:
  - M_2, μ, $\tan\beta$, m_0
- assume $\Delta\mathrm{M} \geq 10\ \mathrm{GeV}$
- scan the (M_2, μ) plane for the smallest limit

↓

- 95% CL limits for minimal m_0
  minimal: masses of $\tilde{\nu}$, $\tilde{\ell}$ do not conflict with present limits

	$\mathrm{m}_{\tilde{\chi}_1^0}$ [GeV]	$\mathrm{m}_{\tilde{\chi}_2^0}$ [GeV]	$\mathrm{m}_{\tilde{\chi}_1^\pm}$ [GeV]
$\tan\beta = 1.5$	12.0	45.3	60.7
$\tan\beta = 35$	32.0	61.0	58.7

- 95% CL limits for $\mathrm{m}_0 = 1\ \mathrm{TeV}$

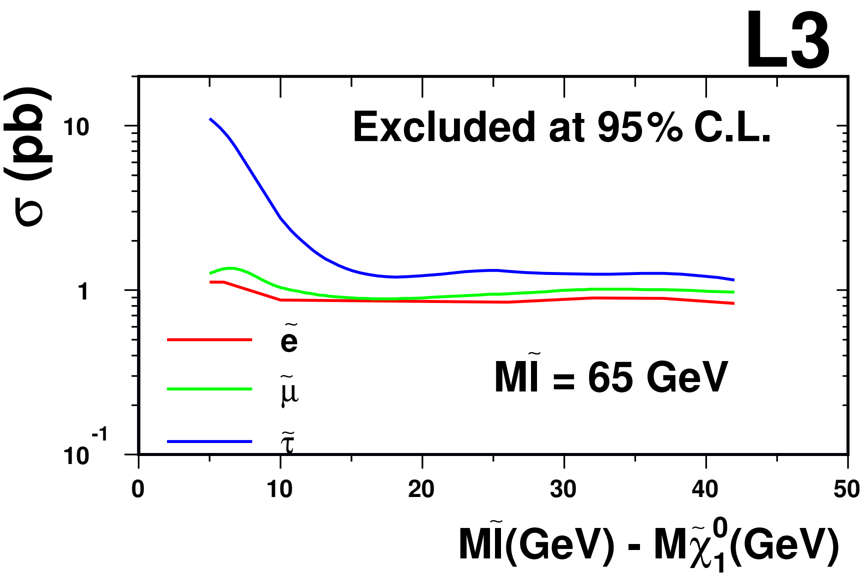
	$\mathrm{m}_{\tilde{\chi}_1^0}$ [GeV]	$\mathrm{m}_{\tilde{\chi}_2^0}$ [GeV]	$\mathrm{m}_{\tilde{\chi}_1^\pm}$ [GeV]
$\tan\beta = 1.5$	21.4	47.5	65.4
$\tan\beta = 35$	35.2	67.5	65.6

$\longrightarrow$ $\tilde{\chi}_1^\pm$ mass limits near kinematic limit

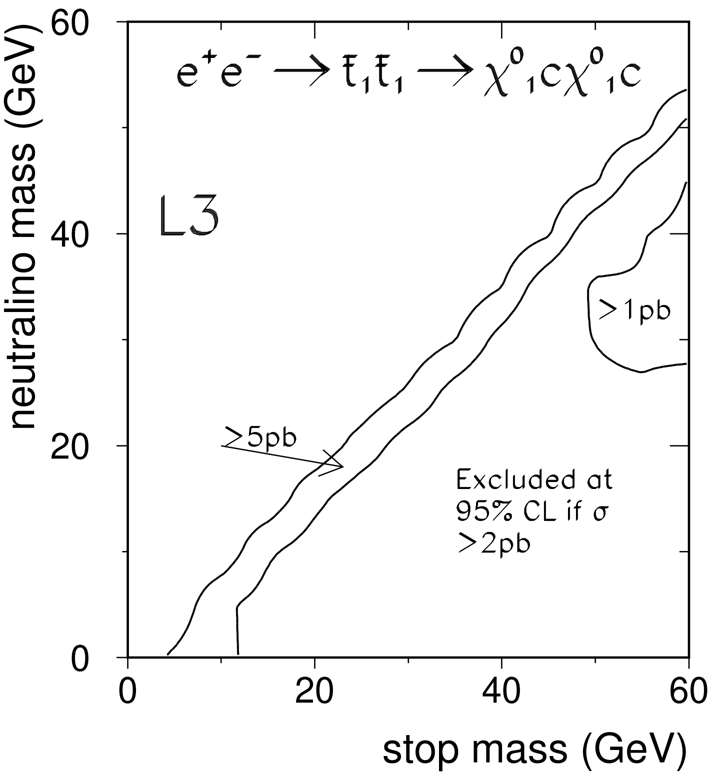
Results from Other Searches

L3

- Limits on scalar lepton cross-sections

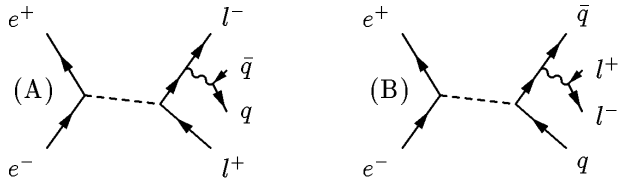


- Limits on scalar top cross-sections:

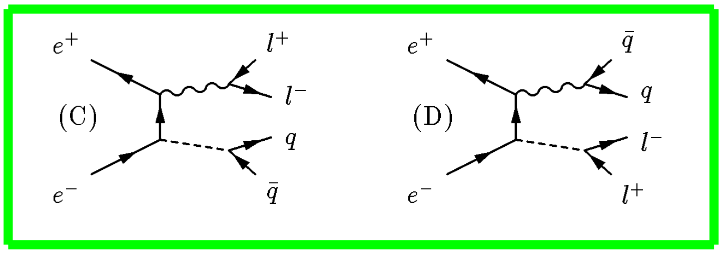


Study of 4 Fermion Events by OPAL

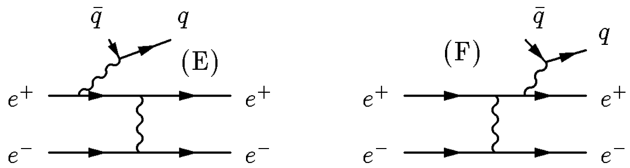
- Background for Higgs searches
- Other production mechanism relevant compared to LEP 1
- Study $\ell^+\ell^-\mathrm{q}\overline{\mathrm{q}}$ final states
- Contributing diagrams:



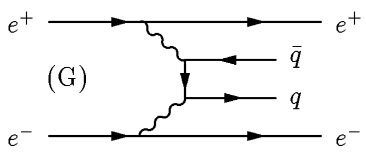
'Annihilation'



'Conversion'



'Bremsstrahlung'

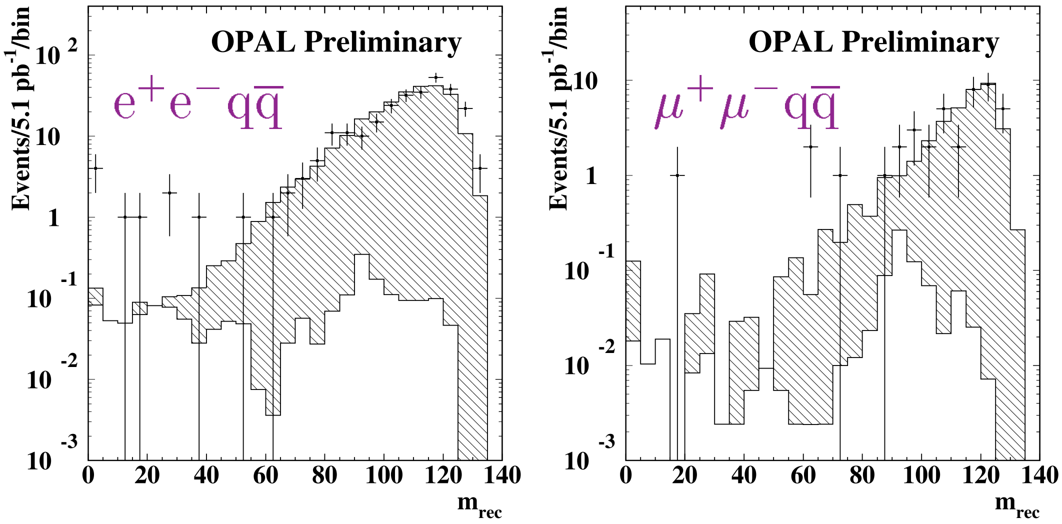


'Multiperipheral'

- Conversion diagrams are dominating at LEP 1.5
- Bremsstrahlung and Multiperipheral events are strongly forward peaked

Event Selection

- Preselection:
  - reconstruct leptons
  - momentum requirements on leptons
  - reconstruct jets
  - selected events in data and MC simulation:



    * m_{rec}: inv. mass of hadronic system
    * crosses: data
    * open area: 4-fermion signal prediction
    * hatched area: 2-fermion background

- Main Selection:
  - further cuts on leptons:
    * harder momentum cuts
    * isolation criteria

  $\longrightarrow$ suppress backgrounds

Preliminary Results

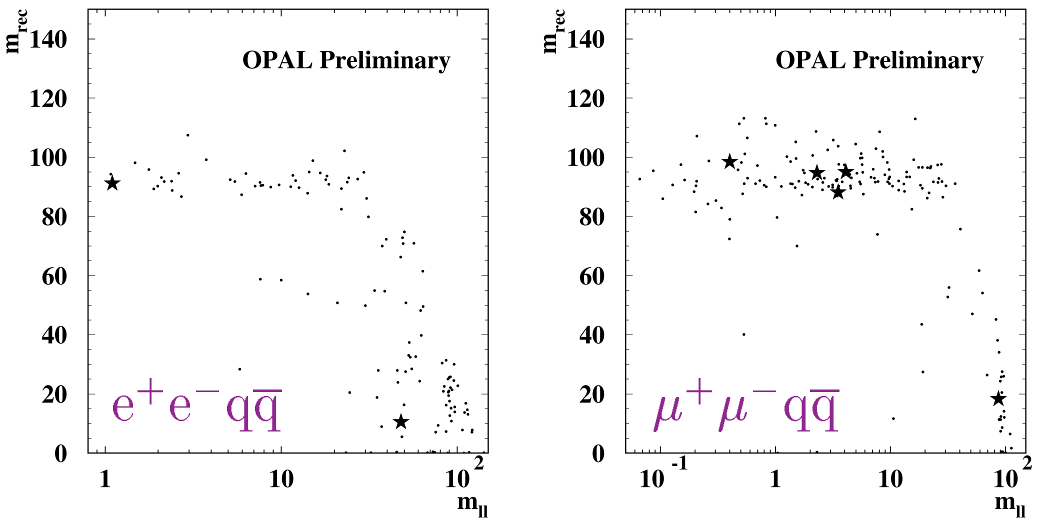
- Number of events passing the selection:

	$e^+e^-q\bar{q}$	$\mu^+\mu^-q\bar{q}$
Data	2	5
Expected	1.02±0.14±0.17	$0.65 \pm 0.08^{+0.12}_{-0.07}$

- Composition of the MC expectation:

	$e^+e^-q\bar{q}$	$\mu^+\mu^-q\bar{q}$
$\ell^+\ell^-q\bar{q}$:	0.66	0.51
$e^+e^- \to f\bar{f}(\gamma)$	0.28	0.11
4f 'bkgd'	0.07	0.02
quarkonia	0.01	0.01

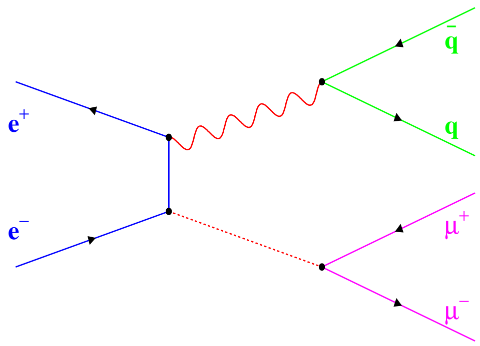
- Some properties of the selected events:

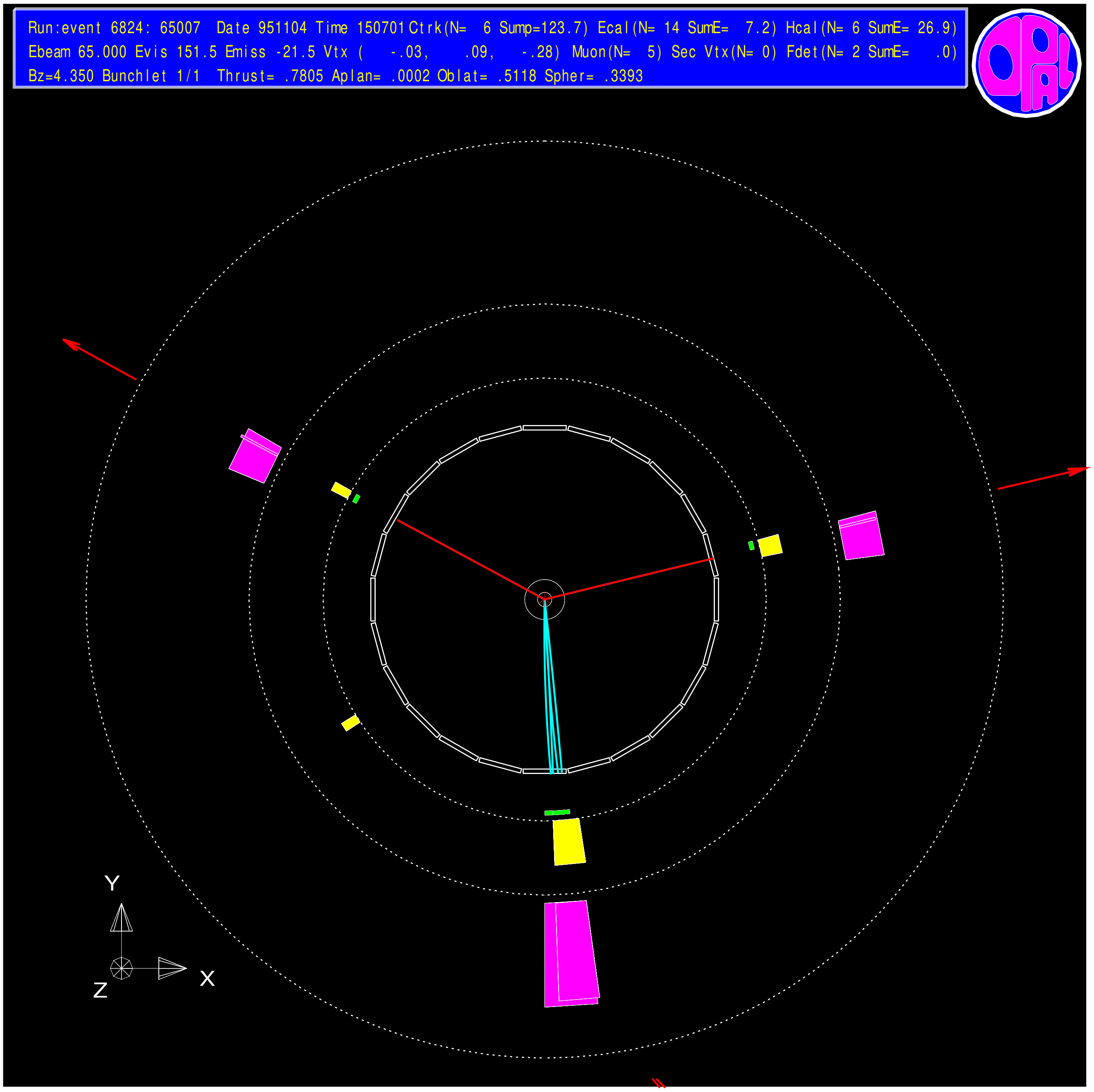


  – points: MC prediction (FERMISV)
  – symbols: selected candidate events

- Probability for a statistical fluctuation: 0.26%

$q\bar{q}\mu^+\mu^-$ Event





Search for 4–Jet Events by ALEPH

- Search was motivated by

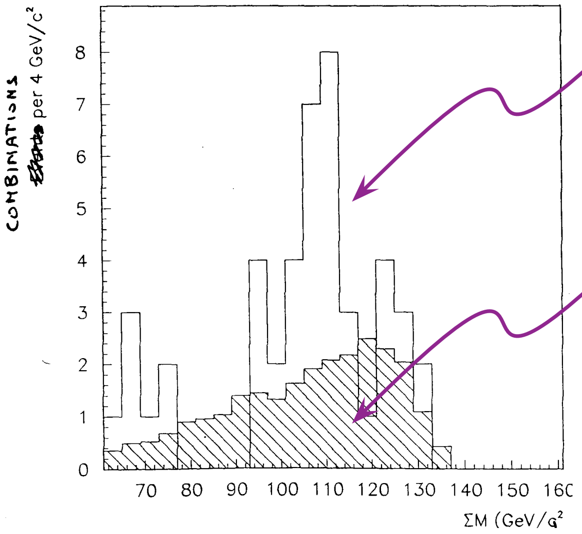
$$e^+e^- \rightarrow h^0A^0 \rightarrow 4\,\text{jets} \quad (b\bar{b}b\bar{b})$$

- Preselection:
  - $N_{ch} \geq 8$; $E_{ch} \geq 0.1 \cdot \sqrt{s}$
  - $M_{vis} \geq 0.7 \cdot \sqrt{s}$
  - select 4 or 5 jets (D scheme, $y_{cut} = 0.008$)
  - reject γ-like jets: $E_{had}/E_{jet} > 0.2$
- Rescale the jet-energies using jet directions and energy/momentum conservation:
  - require $E_i > 0$ GeV
- Four jet selection:
  - $\text{Min}(m_{ij}^{rec}) \geq 25$ GeV
  - $\text{Min}(m_i^{rec} + m_j^{rec}) \geq 10$ GeV
  - $\text{Min}(n_{ch,i} + n_{ch,j}) \geq 10$

in [102,116] GeV:

Data (22 comb.)

MC (6.1 comb.)



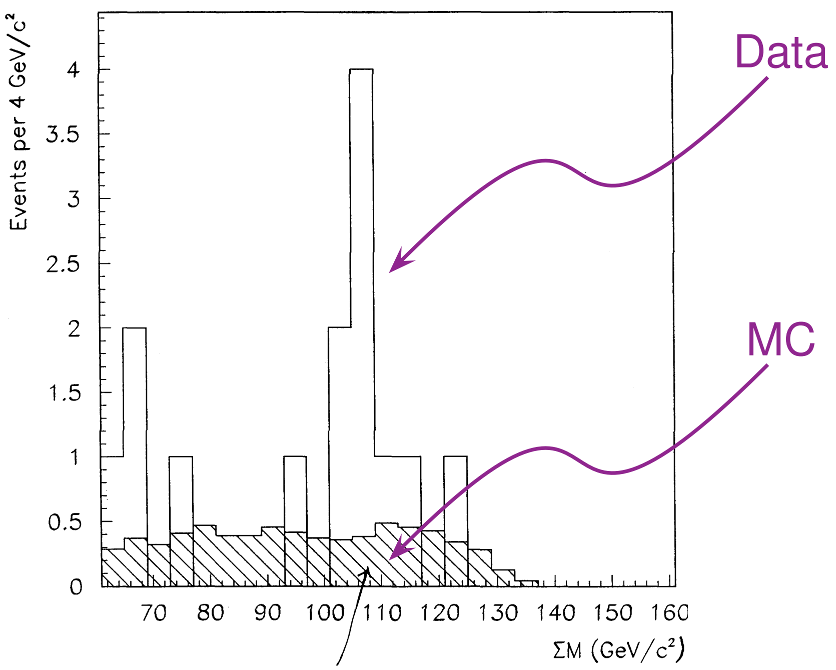
$$\Sigma M = m_{ij} + m_{kl}$$

Search for 4–Jet Events by ALEPH (II)

- Bias selection towards equal di-jet masses:
  - choose the combination with smallest mass difference:

$$\mathrm{Min}(|m_{ij} - m_{kl}|) \leq \ 20 \ \mathrm{GeV}$$

- Expected mass resolution: $\simeq$ 2 GeV
- Observed mass sum distribution: $\Sigma\mathrm{M} = m_{ij} + m_{kl}$
  - Data: 14 events
  - Expected: 7.1 events



- look in mass window $[102, 116]$ GeV:
  - Data: 8 events
  - Expected: 1.35 events

  $\longrightarrow$ Probability: $\sim 10^{-3}$ in any bin

Search for 4–Jet Events by ALEPH (III)

- Detailed investigations:
  - events have only small missing energy
  - search for events compatible with $\mathrm{b\bar{b}b\bar{b}}$ hypothesis (hA signature):
    - ∗ only one event shows separated vertices
    - ∗ no high $\mathrm{p_t}$ leptons identified
  - Events do not match with $\mathrm{e^+e^-} \to \mathrm{H^+H^-}$; $\mathrm{H^-} \to \tau\bar{\nu}$ not seen

- Conclusions:
  - Observation of an excess of 4-jet events (14 observed, 7.1 expected)
  - 8 events peak at $\Sigma\mathrm{M} \simeq 109\ \mathrm{GeV}$
  - Probability for a fluctuation of the background: 10^{-3} in any bin
  - If these events were signal: $\sigma = (2.5 \pm 1)\ \mathrm{pb}$
  - Events do not match with:

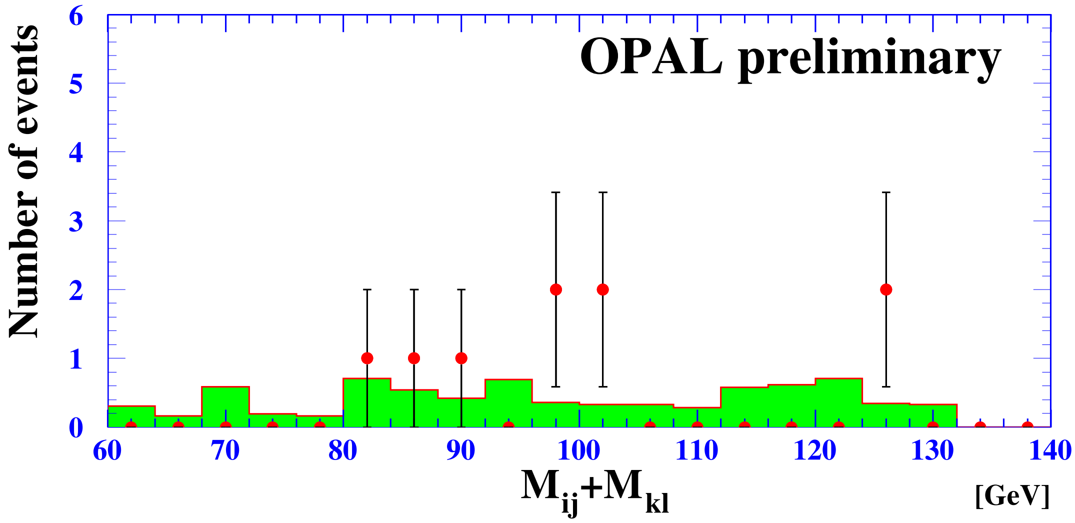
$$\mathrm{e^+e^-} \to \mathrm{h^0A^0}$$
$$\mathrm{e^+e^-} \to \mathrm{H^+H^-}$$

$\longrightarrow$ no canonical explanation

Study of 4–Jet Final States by OPAL

- Motivation: Presentation of ALEPH collaboration
- Repeat analysis of ALEPH:
  - Selection criteria
  - Distributions

  $\longrightarrow$ similar mass resolution
- Find 9 events after selection (expectation: 7.9±0.6 $q\overline{q}$ background events) (ALEPH: 7.1 events)



$\longrightarrow$ No significant peak in di-jet sum distribution

- 4 events around 100 GeV: 2 are consistent with having a missing initial state photon
- Independent analysis with different selection:

  $\longrightarrow$ Also no signal evident
- DELPHI: nothing seen

Summary

- LEP energy upgrade is progressing
- e^+e^- collisions at highest energies so far
- Standard Model physics:
  - Cross-sections
  - Forward-backward asymmetries
  - QED tests
  - QCD tests

  $\longrightarrow$ agreement with prediction from Standard Model
- Search for new physics:
  - Charginos/Neutralinos
  - Scalar particles

  $\longrightarrow$ No signal present

  $\longrightarrow$ limits were established
- OPAL: Excess of data events in $\ell^+\ell^- q\bar{q}$ channel

  $\longrightarrow$????
- ALEPH: Clustering of 4-jet events

  $\longrightarrow$????

LEP 1.5 was an exciting and productive period and very successful for both machine and experiments

Outlook

Machine

- Promising perspectives for 1996 and beyond
  - machine has shown capability to run at high energies
  - reliable operation of new superconducting cavities
  - more cavities will be installed in shutdown

$\downarrow$

- $\mathrm{E_{cms}} = 162\ \mathrm{GeV}$ (June 1996)

  $\longrightarrow$ near WW threshold

  $\longrightarrow$ 136 SC cavities in operation

- $\mathrm{E_{cms}} = 174\ \mathrm{GeV}$ (October 1996)

  $\longrightarrow$ above WW threshold

  $\longrightarrow$ 168 SC cavities in operation

- $\mathrm{E_{cms}} \simeq 194\ \mathrm{GeV}$ (1998)

  $\longrightarrow$ 272 cavities in operation

  $\longrightarrow$ ultimate limit

Outlook

Physics

- study Standard Model physics
- measure properties of W
  - $\longrightarrow$ mass
  - $\longrightarrow$ triple boson couplings
- 2 photon physics
- expand searches for new phenomena
  - $\longrightarrow$ Standard Model Higgs
  - $\longrightarrow$ Supersymmetric particles
  - $\longrightarrow$ ...

$\Downarrow$

LEP experiments have an exciting time ahead!