Technicolor Searches at LEP

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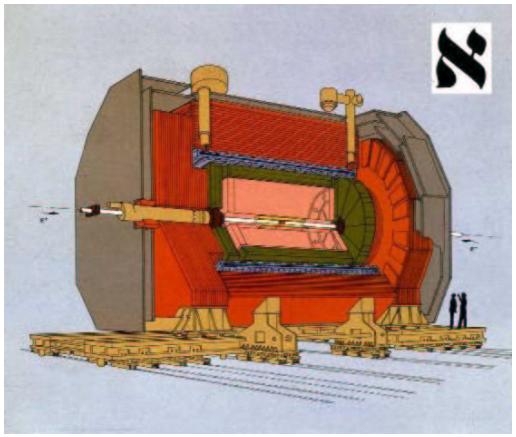
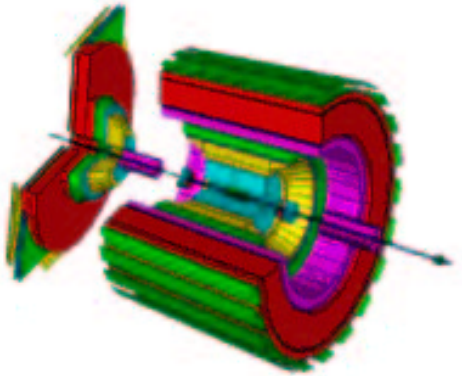
Lake Louise Winter Institute, 22. Feb. 2005

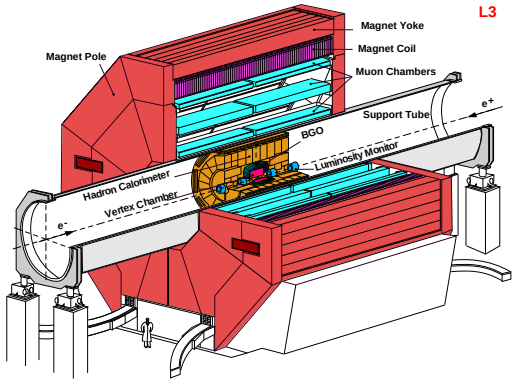
Technicolor — Search Channels — Results

† now at The University of Iowa

Large Electron Positron Collider





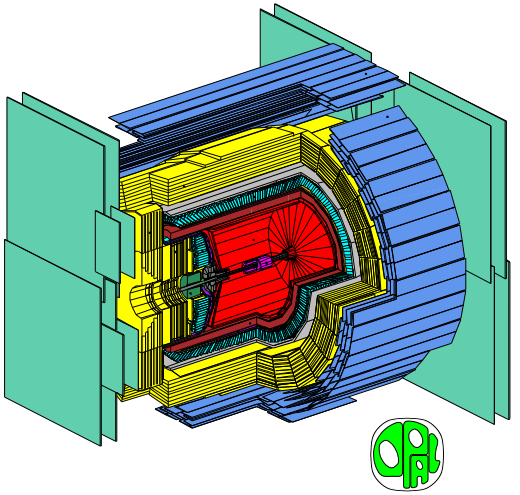


1998-2000 : $\sqrt{s} = 189 - 209\,\mathrm{GeV}$

Four experiments

Together $\int \mathcal{L} \sim 2\,500\,\mathrm{pb}^{-1}$

$40\,000\,\mathrm{WW}$, $1\,200\,\mathrm{ZZ}$



Electroweak Symmetry Breaking

- Electroweak symmetry is broken
- Dynamical EWSB
- Spontaneous EWSB
- Technicolor
- Extended Technicolor
- Unitarity violation in W_l scattering

- SM is based on local gauge invariance
- Gauge symmetry conserved only for massless particles
- W and Z bosons massive $\Longrightarrow$ gauge symmetry is broken
- Two popular approaches:
  - Dynamical EWSB (e.g. QCD)
  - Spontaneous EWSB (e.g. Higgs mechanism)

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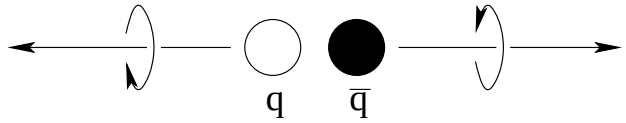
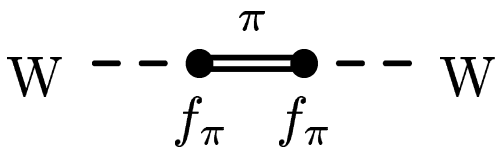
- Vacuum: Chiral pairs of quarks



- Strong condensates (π) break chiral symmetry
- Effective boson masses through interactions



- From QCD: $m_{\mathrm{W}} \sim 30\,\mathrm{MeV}$

Electroweak Symmetry Breaking

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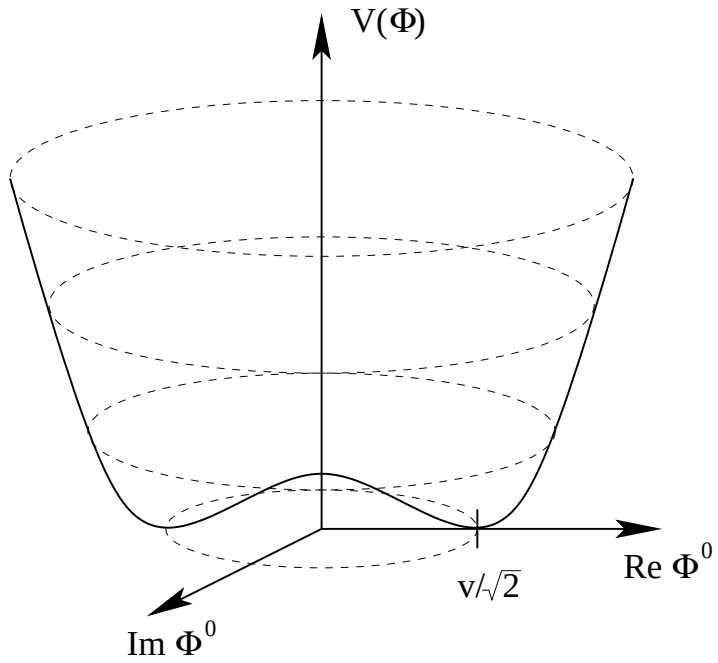
- Broken vacuum symmetry



- Predicts new scalars (e.g. SM Higgs boson)

Electroweak Symmetry Breaking

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- In favor of dynamical EWSB:
  - No fundamental scalars
  - Dynamical origin
    - $\Rightarrow$ No hierarchy problem
    - $\Rightarrow$ No fine-tuning needed
- Technicolor:
  - New strong interaction with $f_\pi \sim v$
  - Plus new TC-fermions F

Electroweak Symmetry Breaking

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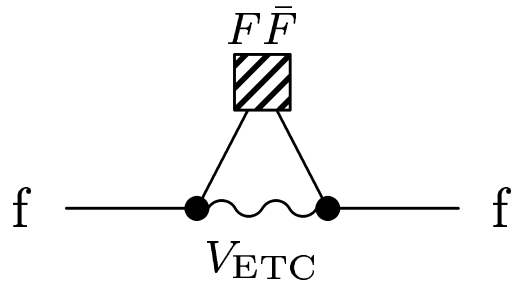
- Higgs mechanism:
  Fermion masses via Yukawa couplings with Higgs field
- Extended Technicolor:
  Yet another interaction, couples SM and TC fermions



Electroweak Symmetry Breaking

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- W_l scattering violates unitarity at high energies
- Two ways out:
  - Additional scalar particles with proper couplings
  - Strong W-interaction
- Technicolor:
  Exchange of vector states ρ_{T}, yields anomalous contributions to TGC's

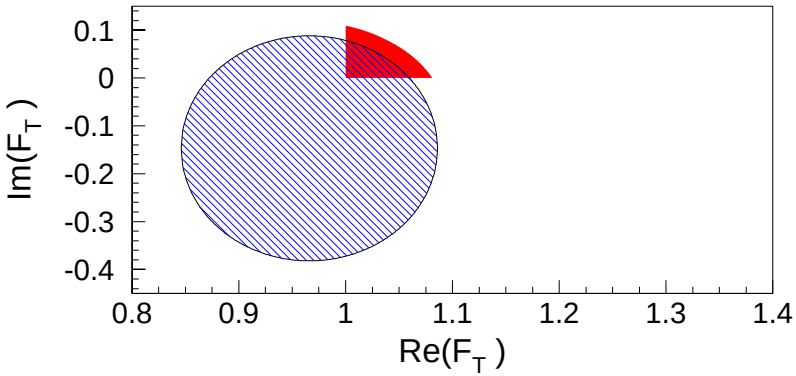
Anomalous Couplings

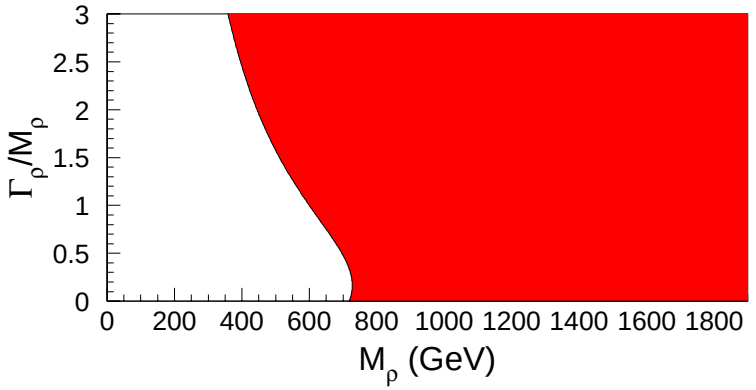
- Measure TGC's in $e^+e^- \to WW$
- Fit form factor F_T
- Constrain ρ_T mass and width

$$F_T = \frac{M^2 - i\Gamma M}{M^2 - s - i\Gamma M}$$

- ALEPH, $\sqrt{s} = 183 - 209\,\mathrm{GeV}$, $\int \mathcal{L} = 683\,\mathrm{pb}^{-1}$

ALEPH, CERN-PH-EP/2004-065





Effective Model: TCSM

- Particle spectrum
- Production processes
- Decays
- Signatures at LEP
  - Enhancement of SM cross sections
  - Hadronic or semi-leptonic 4-fermion
  - Two jets plus photon

- QCD: $\pi^{\pm,0}$, $\rho^{\pm,0}$
- Technicolor:
  $|\Pi_{\mathrm{T}}\rangle = \sin\chi\,|\mathrm{W}_l\rangle + \cos\chi\,|\pi_{\mathrm{T}}\rangle$
  Vector state ρ_{T}
- Mixing angle
  $$\sin\chi = 1/\sqrt{N_D}$$
- $N_D \gg 1$ favored to avoid large FCNC

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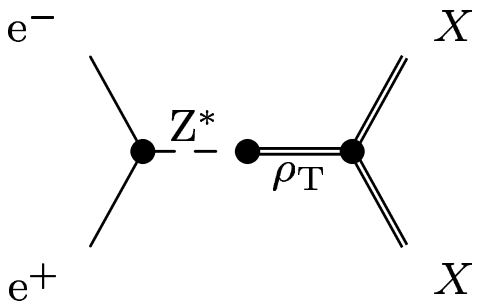
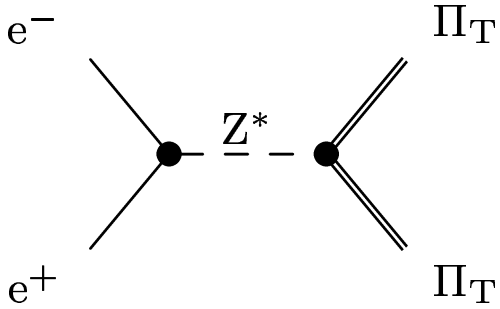
- Vector states:
  s-channel production through propagator mixing



- Scalar states: pair-wise



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- ρ_{T} decays via Technicolor
  $\rho_{\mathrm{T}} \to \pi_{\mathrm{T}}\pi_{\mathrm{T}}, \pi_{\mathrm{T}}\mathrm{W}_l, \mathrm{W}_l\mathrm{W}_l$
- ρ_{T} decays via weak int.
  $\rho_{\mathrm{T}} \to \mathrm{W}_t\pi_{\mathrm{T}}, \mathrm{Z}_t\pi_{\mathrm{T}}, \gamma\pi_{\mathrm{T}}, \mathrm{f\bar{f}}$
- π_{T} decays via ETC
  $\pi_{\mathrm{T}}^{-} \to \mathrm{b\bar{c}}, \mathrm{b\bar{u}}$
  $\pi_{\mathrm{T}}^{0} \to \mathrm{b\bar{b}}$

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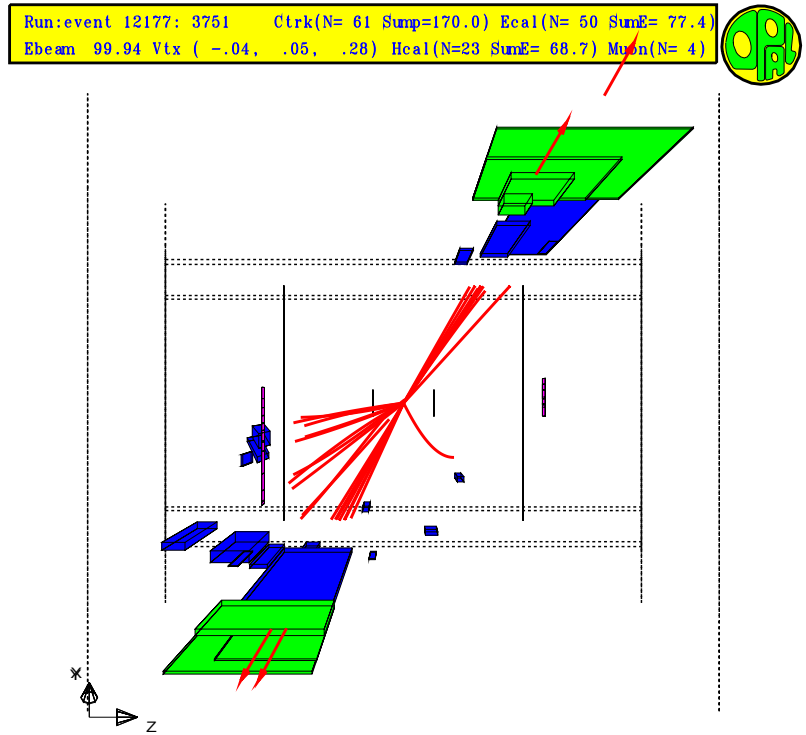
- $e^+e^- \to W_{(l)}W_{(l)}$
  $e^+e^- \to f\bar{f}$



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- Signatures at LEP
  - Enhancement of SM cross sections
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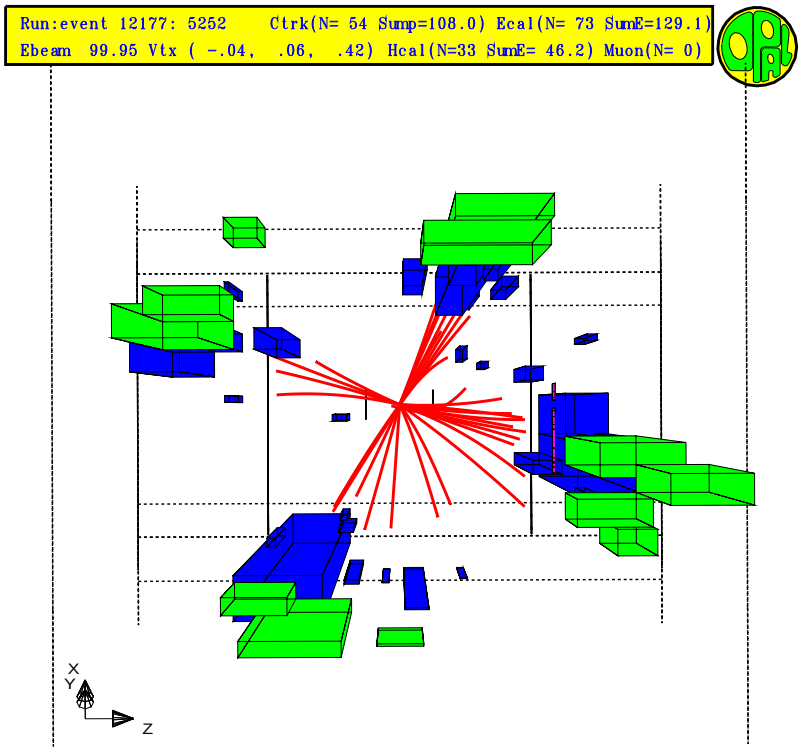
- $e^+e^- \to \pi_T\pi_T \to bq\,bq$
  $e^+e^- \to \pi_T W \to bq\,qq,\ bq\,\ell\nu$



Effective Model: TCSM

- Particle spectrum
- Production processes
- Decays
- Signatures at LEP
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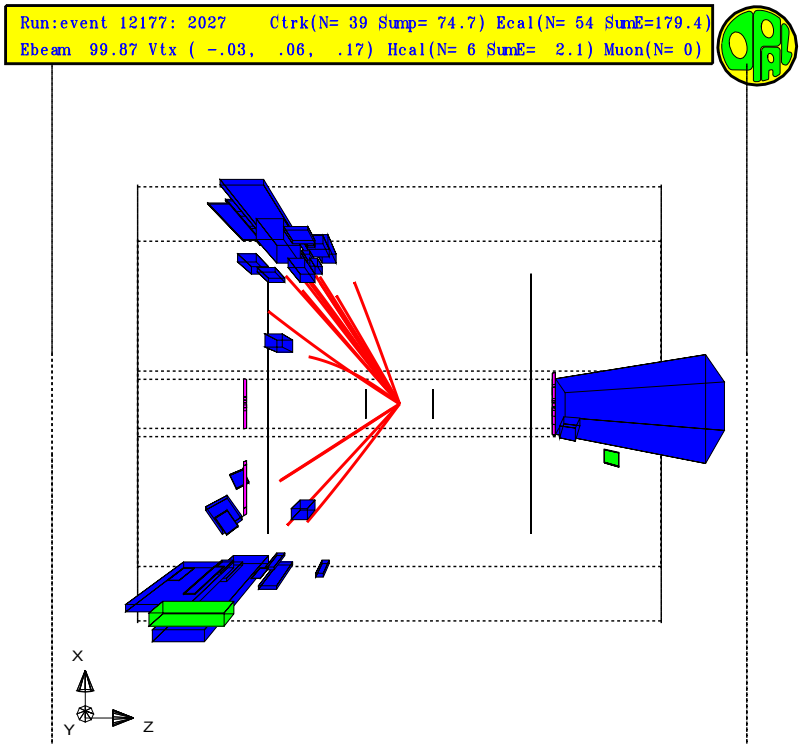
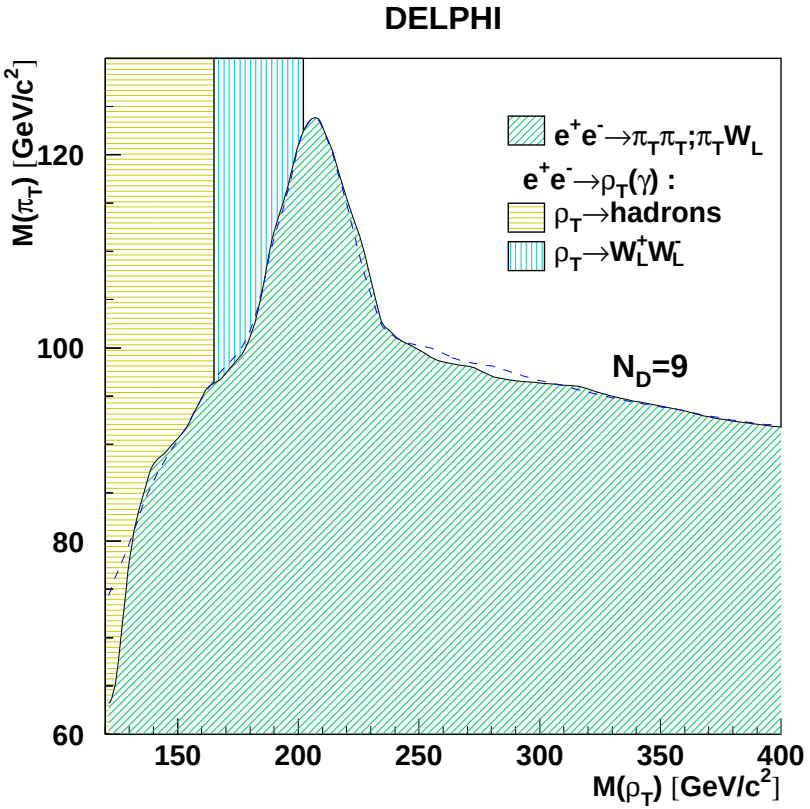
- $e^+e^- \to \pi^0_T \gamma \to b\bar{b}\,\gamma$

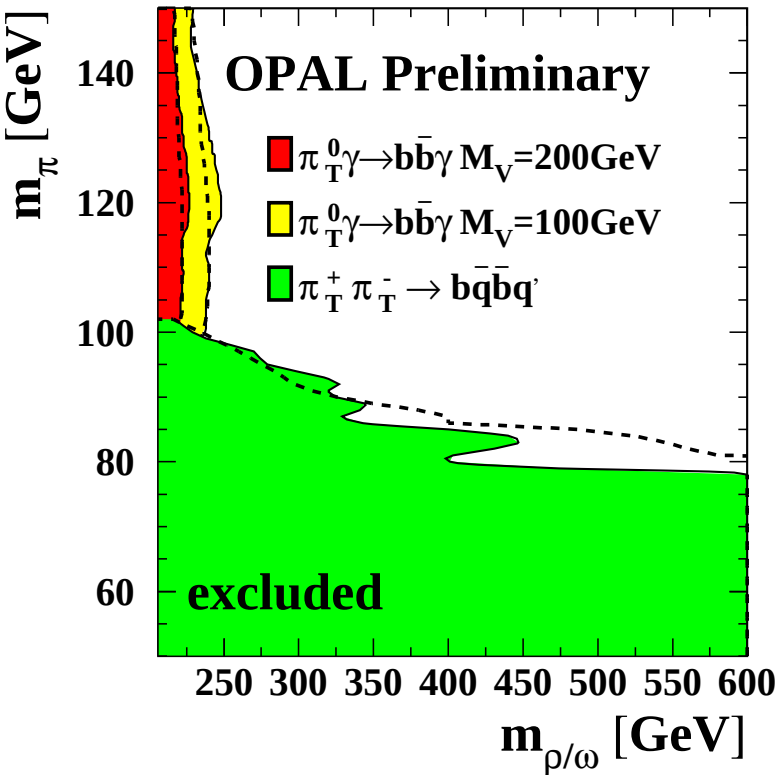


Direct Search Limits

- DELPHI, EPJ C22 (2001)
  $192 - 209\,\mathrm{GeV}, 450\,\mathrm{pb}^{-1}$



- OPAL, PN485 (2001)
  $205 - 209\,\mathrm{GeV}, 210\,\mathrm{pb}^{-1}$

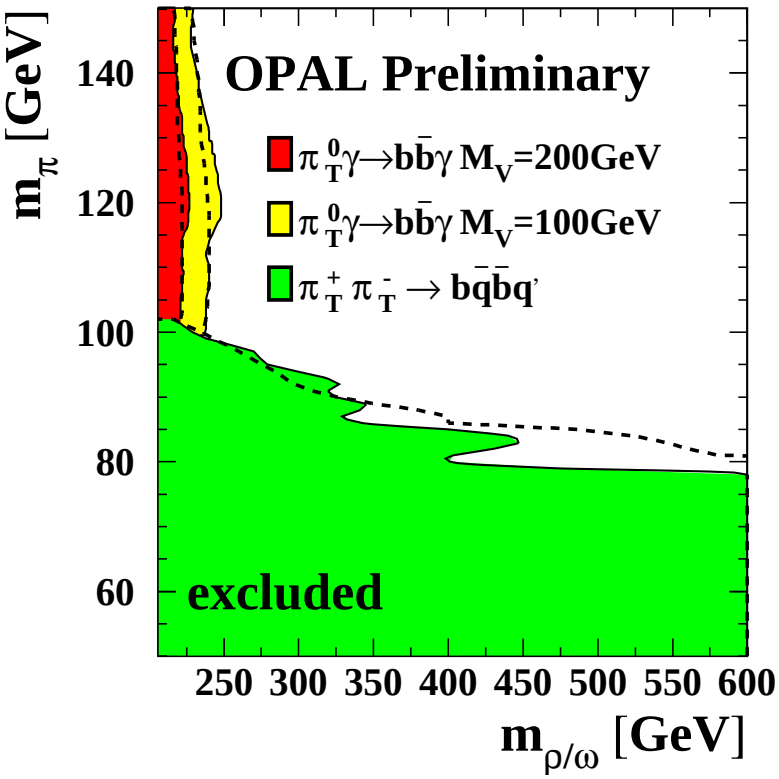


Direct Search Limits

- OPAL, PN485 (2001)
  $205 - 209\,\mathrm{GeV}, 210\,\mathrm{pb}^{-1}$

Ongoing improvement at OPAL

- Extend data set
- Include $\pi_\mathrm{T}\mathrm{W} \to 4\,\mathrm{jets}$
- Similar topology to
  $\pi_\mathrm{T}\pi_\mathrm{T} \to 4\,\mathrm{jets} \Rightarrow$
  overlap of event candidates
- Likelihood based
  event-by-event separation



Direct Search Limits

- OPAL, expected improvement
  $189 - 209\,\mathrm{GeV}$, $570\,\mathrm{pb}^{-1}$

Ongoing improvement at OPAL

- Extend data set
- Include $\pi_\mathrm{T}\mathrm{W} \to 4\,\mathrm{jets}$
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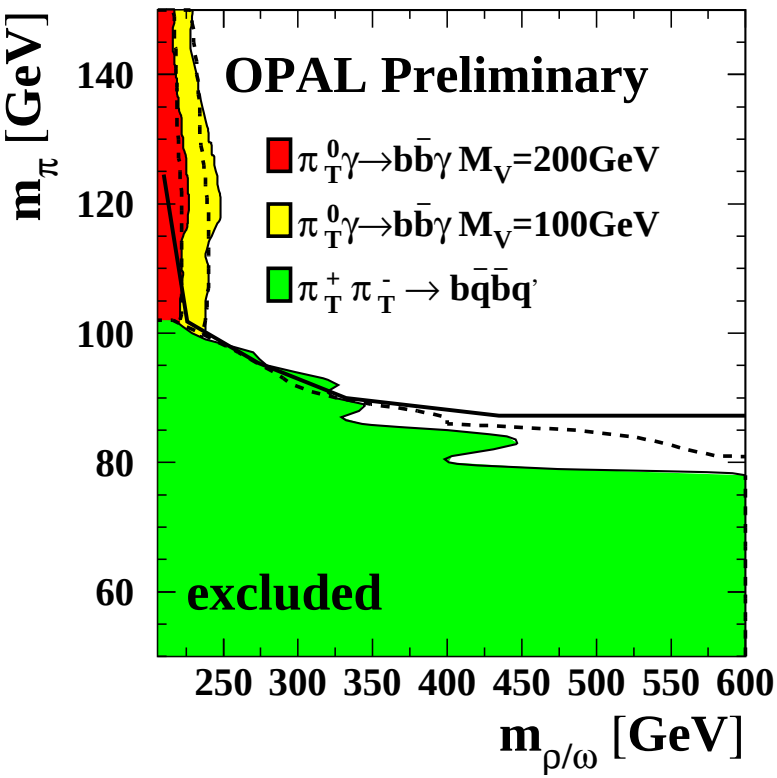

Summary

- Different TC schemes tested at LEP
  - Strong interaction in W-scattering
  - Direct searches using QCD-inspired model
- No evidence found, mass limits placed on π_{T} and ρ_{T}
- Final results published by ALEPH and DELPHI
- OPAL analysis to be finalized very soon