Search for Exotica

(Preliminary Exotica results up to $\sqrt{s}$=209 GeV from the LEP experiments)

Javier Cuevas

University of Oviedo

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Outline

- LEP **EXOTICA WG**: Combination of all non-Higgs and non-SUSY searches at LEP2.
  - **Technicolor**
  - **Excited leptons**
  - Single top production, FCNC
  - Leptoquarks
  - Gravity in extra dimensions
- Data Samples used:
  - About 2.4 fb^{-1} (~600 pb^{-1} per experiment) at $\sqrt{s}$ =189-209 GeV
- Statistical procedure adopted for the combination of the different channels (same or different experiments), is the likelihood ratio method

Technicolor model

- Technicolor Model is an alternative to the Standard Model Mechanism of Electroweak symmetry breaking.
- Role of Higgs boson is performed by bound states of new fundamental fermions, techniquarks, which mix with W and Z and generate their masses.
- Minimal TC model with one doublet of TC-quarks is not confirmed by LEP1 and elsewhere precision measurements
- Extensions of TC model with many doublets, **Walking Technicolor**, overcome disagreement with experimental results. A large number of doublets is required, which generate huge number of bound states.

Technicolor model

- These extensions call for a large number N_D of technidoublets (T_U, T_D), with $Q_U=Q_D+1$
- Important simplification: "**Technicolor Straw Man Model**" the lowest lying bound states of the lightest technifermion model can be considered in isolation.
  - **Pseudoscalars:** $\Pi_T^{\pm,0}$, Π_T'
  - **Vectors:** $\rho_T^{\pm,0}$, ω_T (nearly mass degenerate)
- Scalar bound states are mixtures of $W_L^{\pm}$, Z_L^0, and the lightest **mass-eigenstate technipions** $\pi_T^{\pm}$ π_T^0

$$|\Pi_T> = \sin\chi\ |W_L> + \cos\chi\ |\pi_T>$$

- Mixing angle χ is related with the number of TC-doublets: $\sin^2\chi = 1/N_D$

Decays of ρ_T

- The dominant decay modes of the ρ_T mediated by the TC interaction are:

$$
\begin{aligned}
\rho_T \rightarrow \Pi_T \Pi_T &\rightarrow \pi_T \pi_T (\sim \cos^4 \chi) \\
&\rightarrow W_L \pi_T (\sim \sin^2 \chi \cos^2 \chi) \\
&\rightarrow W_L W_L (\sim \sin^4 \chi)
\end{aligned}
$$

- In addition the ρ_T decays via the electroweak interaction either into one technipion and a SM gauge boson or into a pair of SM fermions (becomes important if other decay channels are kinematically closed)

- **Total width** depends on many parameters but does not exceed **~15 GeV for m_{ρ_T} ≤200 GeV**.

Decays of π_T

- The technipions $\pi_T^{\pm}$ π_T^{0} decays, are induced mainly by ETC interactions which couples them to fermions

$$\pi_T^- \to f_i \overline{f_i};\Gamma(\pi_T^- \to f_i \overline{f_i}) \propto (m_f + m_{f'})^2$$

- The π_T preferentially decay into the **heaviest fermion pairs allowed**, main modes being:

$$\pi_T^- \to b\overline{c}(\approx 90\%), s\overline{c}(\approx 5\%), \tau\overline{\nu_\tau}(\approx 5\%)$$

$$\pi_T^0 \to b\overline{b}(\approx 90\%), c\overline{c}(\approx 5\%), \tau\overline{\tau}(\approx 5\%)$$

- Total width **< 1 GeV** for **M_π ~ 100 GeV**.

Technicolor at LEP

- Although TC model is rather complicated, the phenomenology of the lightest bound states which it predicts is relatively simple with few free parameters:
  - **$M\pi_T$ mass of π_T**
  - **$M\rho_T$ mass of ρ_T**
  - **$\sin^2\chi=1/N_D$ number of doublets , or mixing angle of π_T and W_L**
- For ω_T production and decay, a scale parameter and Q_U+Q_D must be specified. By analogy with QCD it is supposed that $M\rho_T \sim M\omega_T$, and $M\pi_T^0 \sim M\pi_T^+$.

Technicolor production at LEP

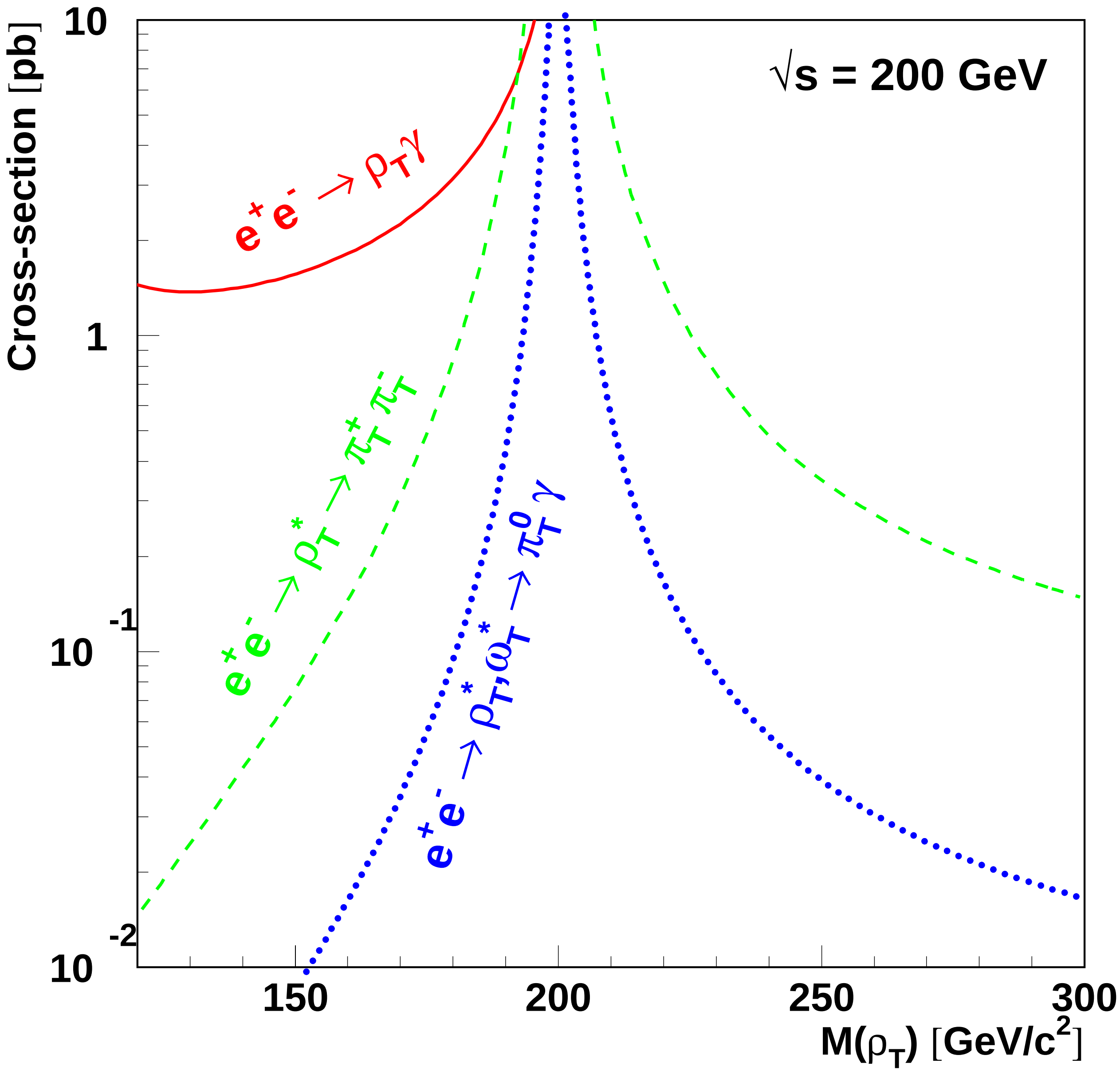
- ρ_T couples with γ and Z^0 and can be produced at LEP in s-channel.
- If $M\rho_T < \sqrt{s}$, ρ_T can be produced in RR process and can be observed as a narrow resonance in s' distribution.
- Technipions can be produced through virtual ρ_T exchange in pairs or in association with W_L:

$$e^+e^- \to \rho_T^* \to \pi_T\pi_T$$

$$e^+e^- \to \rho_T^* \to \pi_T W_L$$

- Production cross-section of TC objects was expected to be **reasonably high**, which allowed search at LEP.

Expected cross-section



M_{π_T}=90 GeV
N_D=9

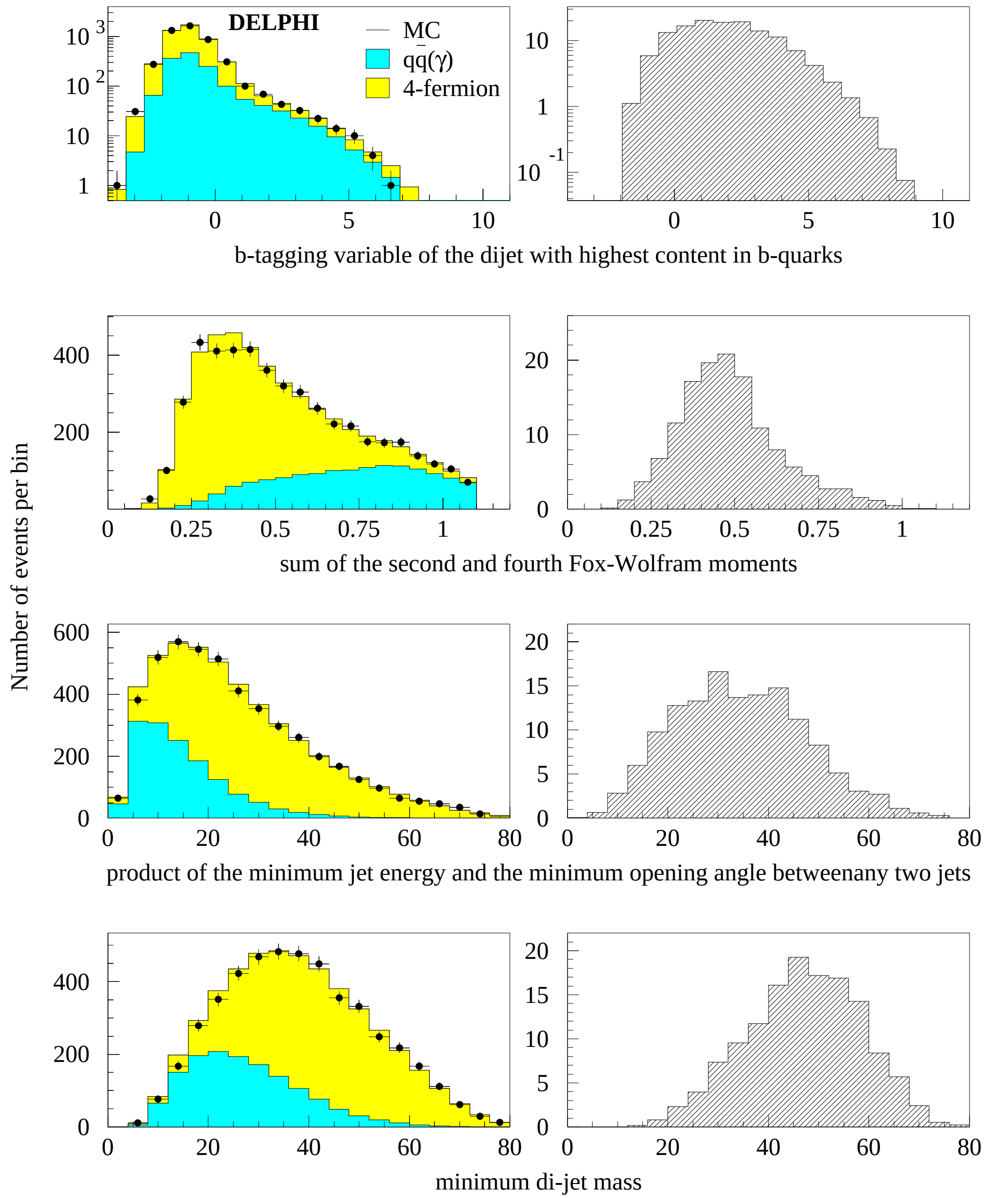
M_V=200 GeV
(Q_U+Q_D)=4/3

α_ρ=2.91(3/N_{TC})
(TC coupling constant)
N_{TC}=4

$e^+e^- \rightarrow \rho_T^* \rightarrow \pi_T \pi_T, \pi_T W_L$

- This process is searched for in **4 jet** and in **2 jet+ lepton+neutrino final** states.
- In both cases, a Neural Network is used which combines **topological variables** and **b-tagging**
- The most important background for π_T search is $e^+e^- \rightarrow W^+W^-$. The main difference between W^+W^- and $\pi^+\pi^-$ production is the presence of b-quark in the decays of π_T. **b-tagging is essential.**
- The mass is estimated after a **5c** constrained fit imposing energy and momentum conservation and **equal masses** of the two fermion objects (qq or $l\upsilon$).

Discriminating Variables



- **NNW (4j channel) :**
  - **2 b-tagging variables.**
  - **7 topological (antiQCD, almost same as higgs 4j)**
  - **3 based on boson production properties.**

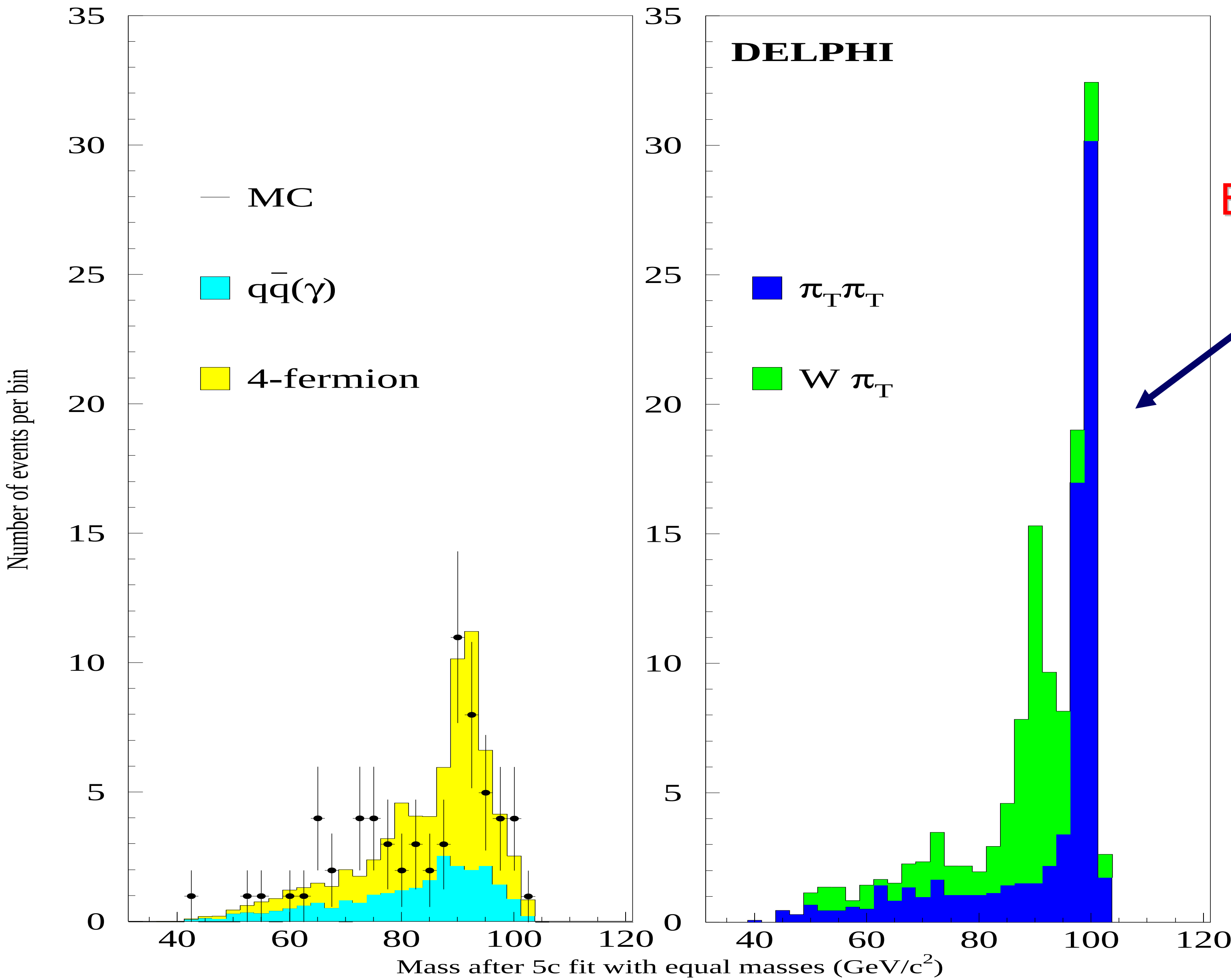
- **Semileptonic channel:**

$$\pi_T^+ \pi_T^- \rightarrow \tau \nu q \bar{q}$$

$$W_L^+ \pi_T^- \rightarrow l \nu q \bar{q}$$

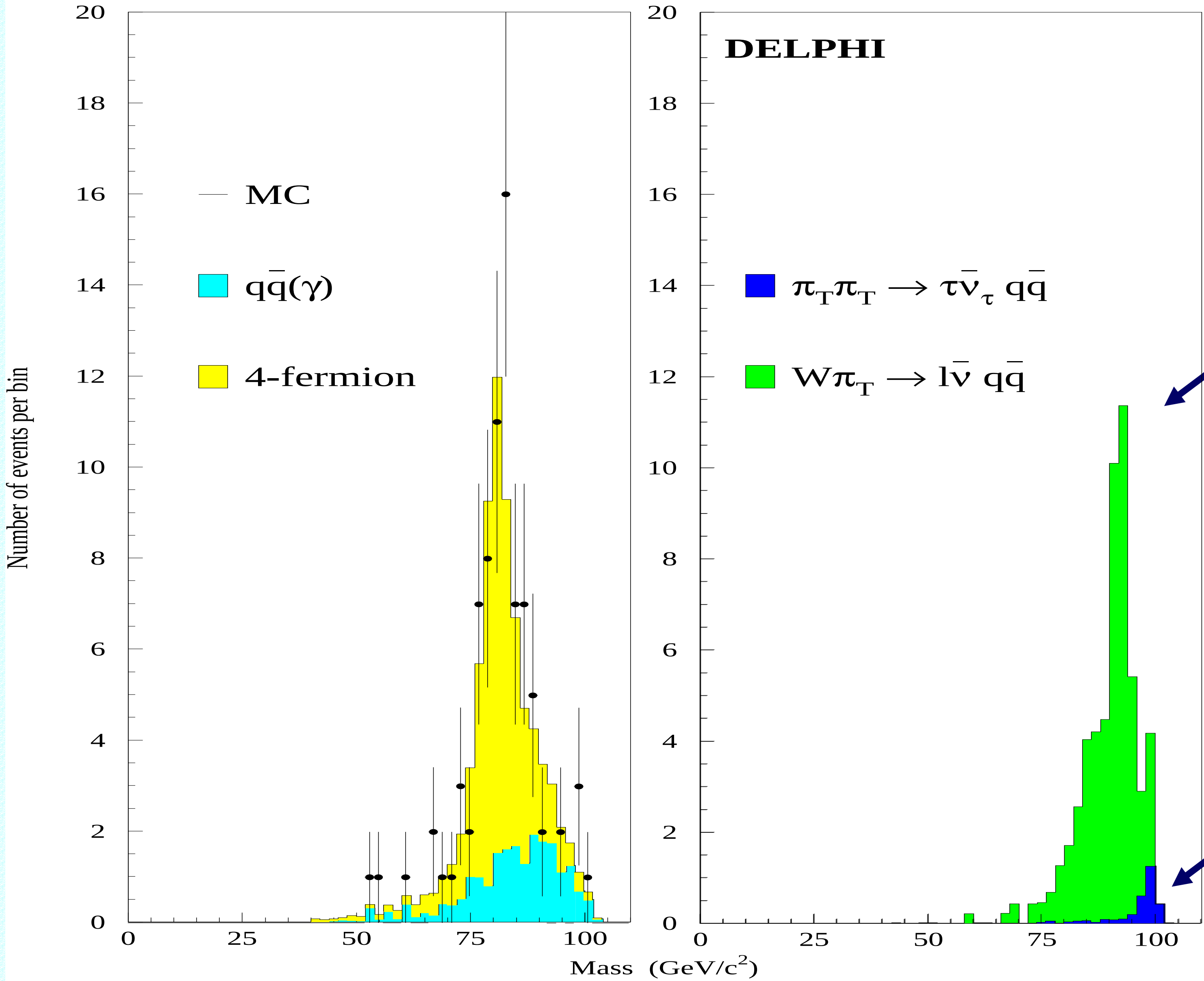
  - **isolated lepton (3 NN)**
  - **b-tagging (jet)**
  - **boson production angle**

Mass distribution in the 4jet channel



Expected technicolor signal for
$M_{\pi T}$=100 GeV
N_D=9
$M_{\rho T}$=220 GeV

Mass distribution in the semileptonic channel

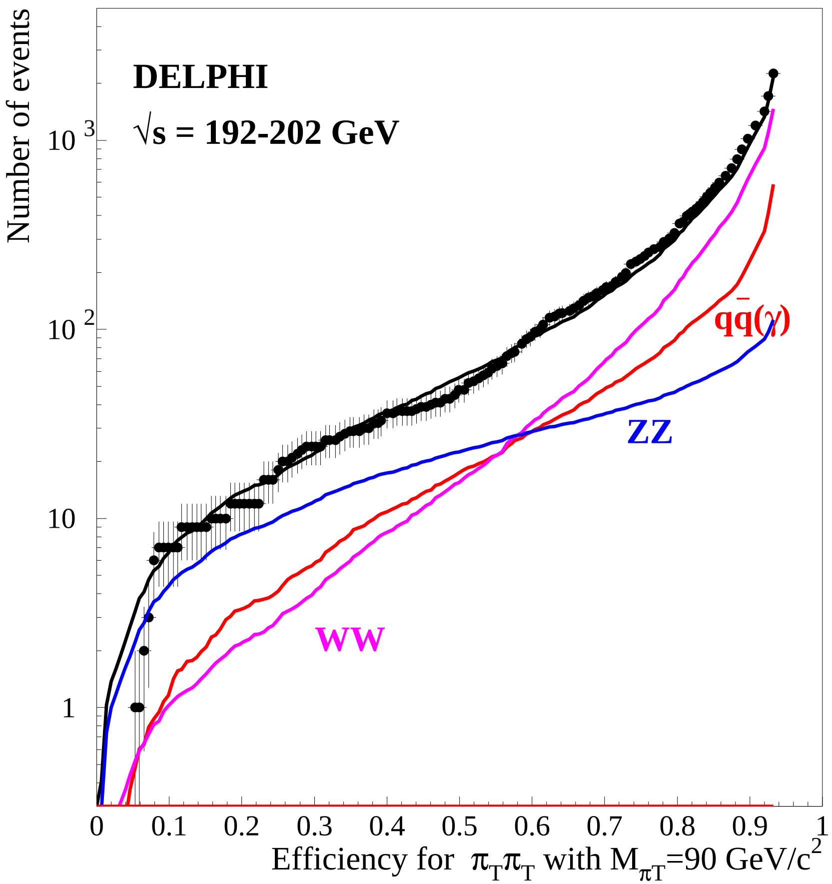


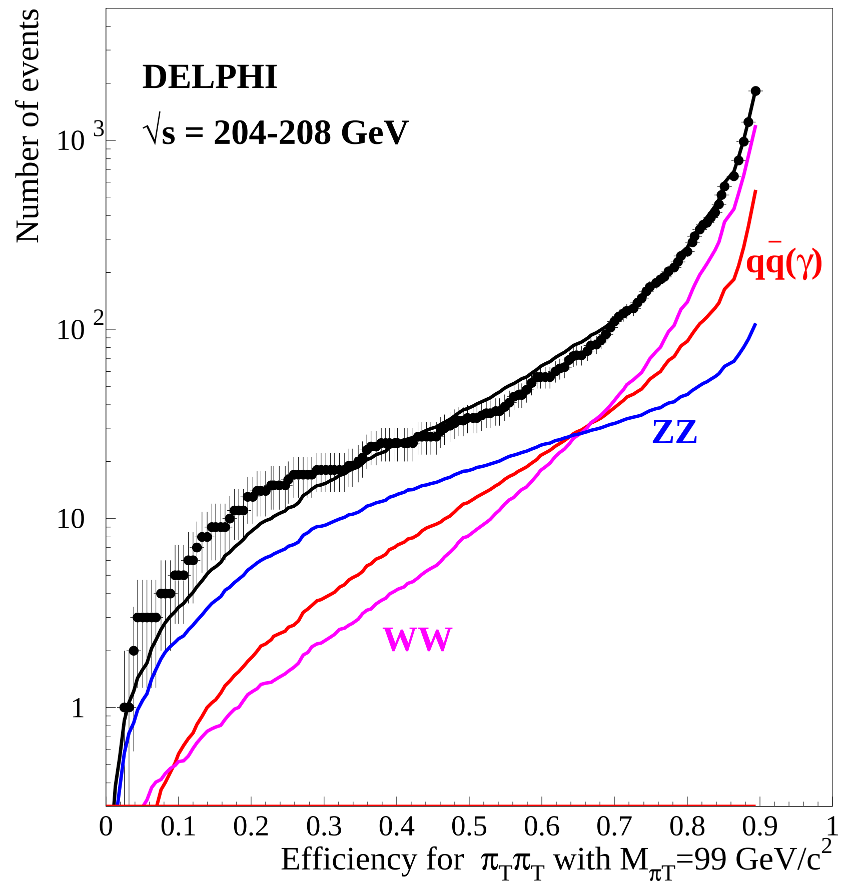
Expected technicolor signal for
$M_{\pi T}$=100 GeV
N_D=9
$M_{\rho T}$=220 GeV

Small decay rate
$\pi \rightarrow \tau\upsilon$

Background supresion

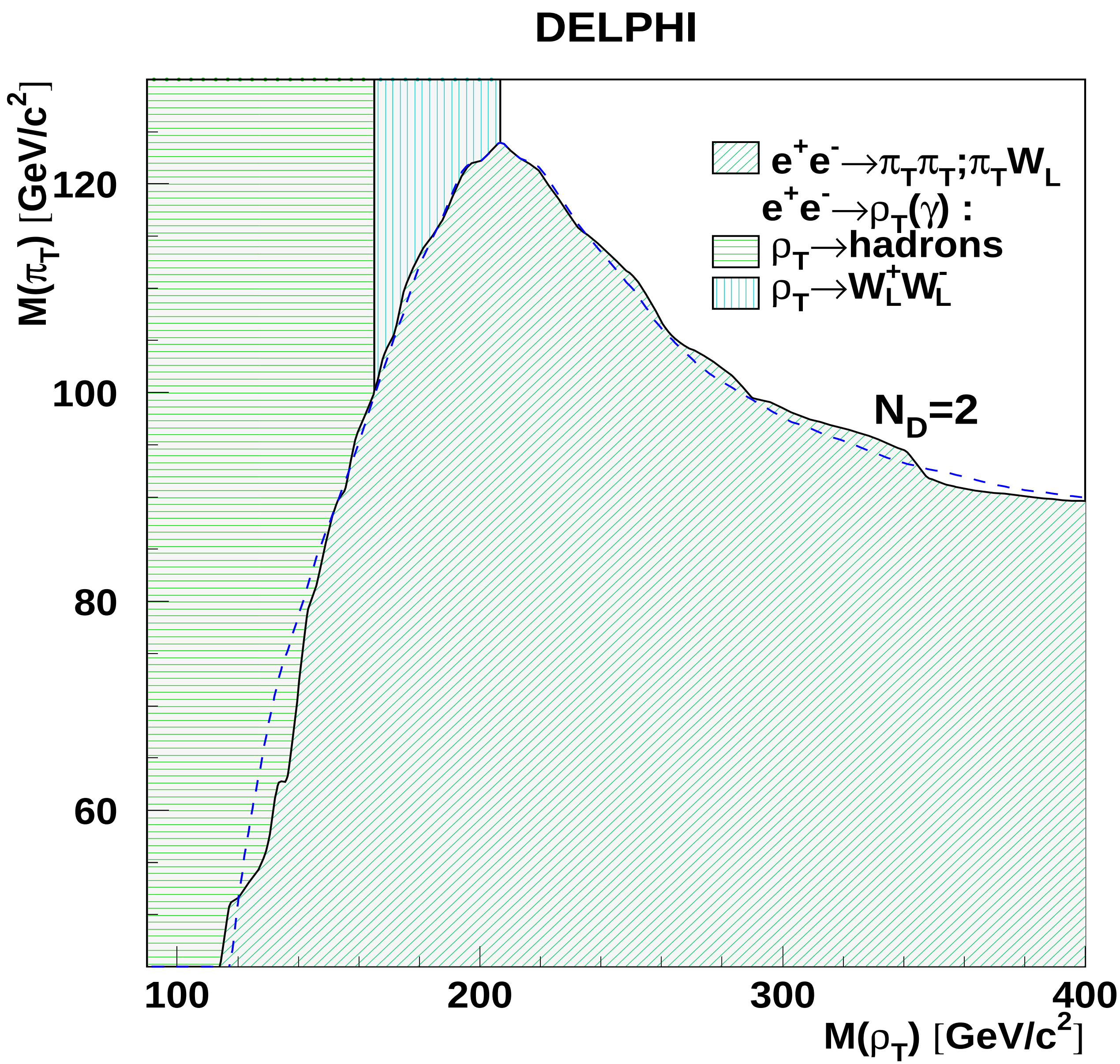
Good agreement between data and SM prediction





Results used to set limits on Technicolor production

Limits on Technicolor



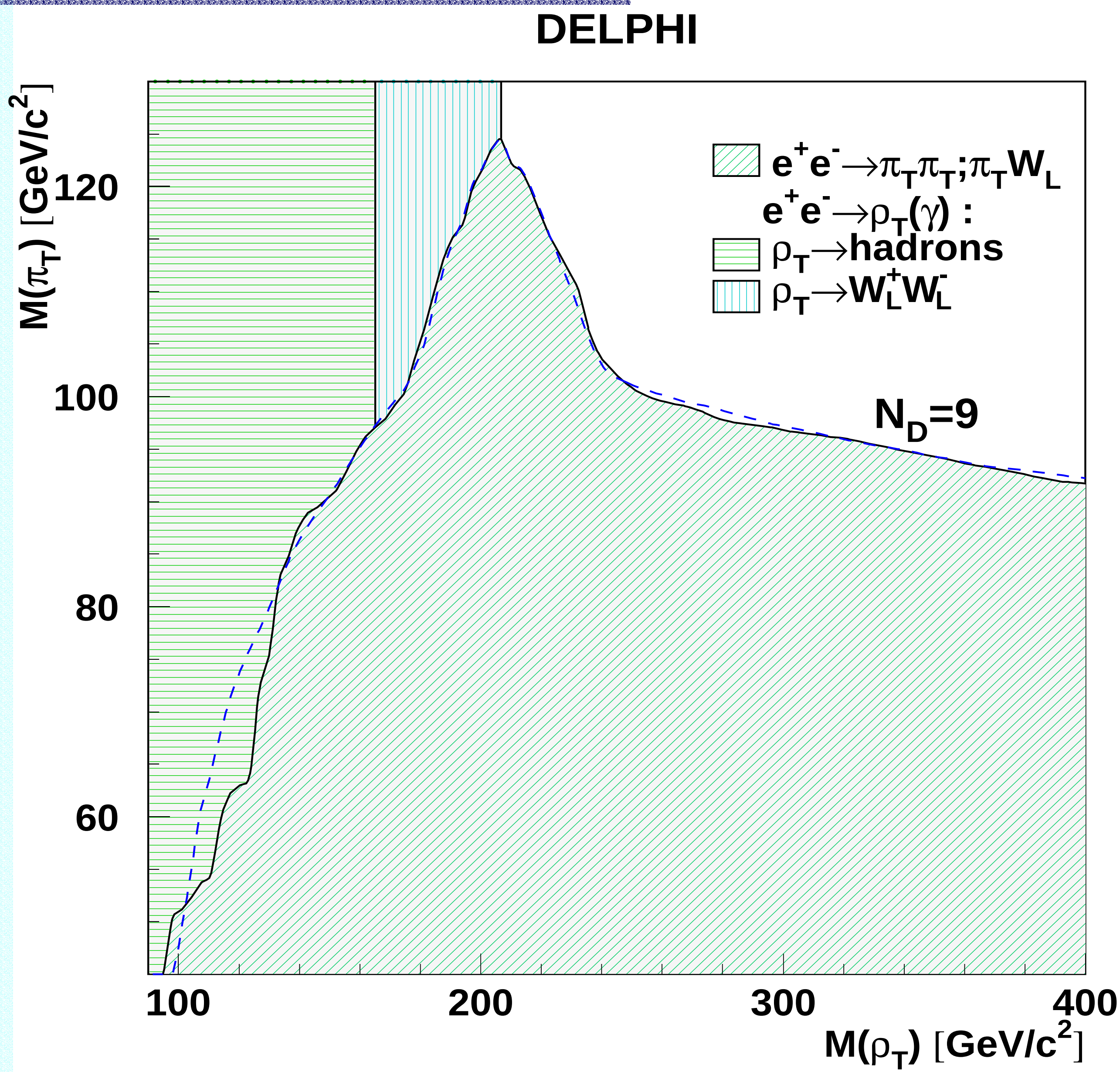
Limit based on CL_s, using NN and mass.

Lower limit on $M_{\pi T}$ for $M_{\rho T} \to \infty$, point like coupling between gauge bosons and $\pi_T\pi_T$

$M_{\pi T} > 79.8$ GeV/c^2 (95% CL)

(81.1 GeV/c^2 expected)

Limits on Technicolor



Lower limit on $M_{\pi T}$ for $M_{\rho T} \to \infty$, point like coupling

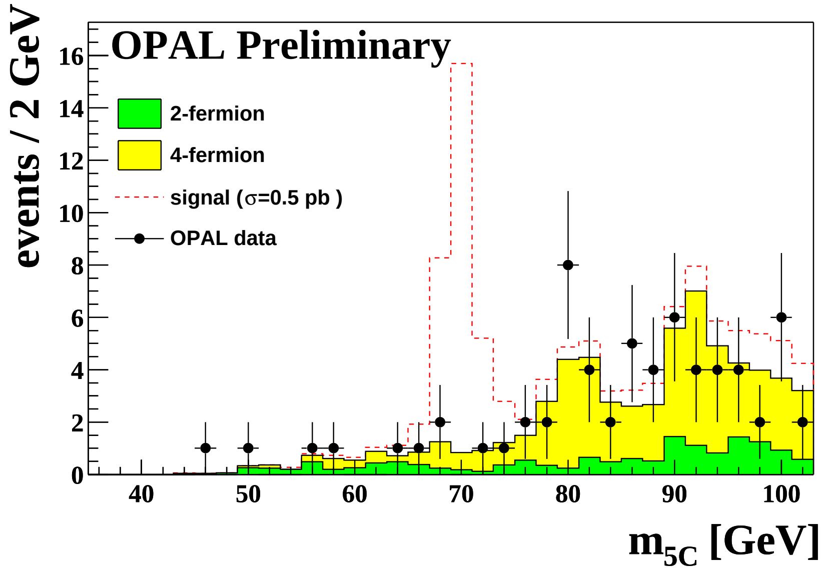
$M_{\pi T} > 89.1$ GeV/c^2 (95% CL)

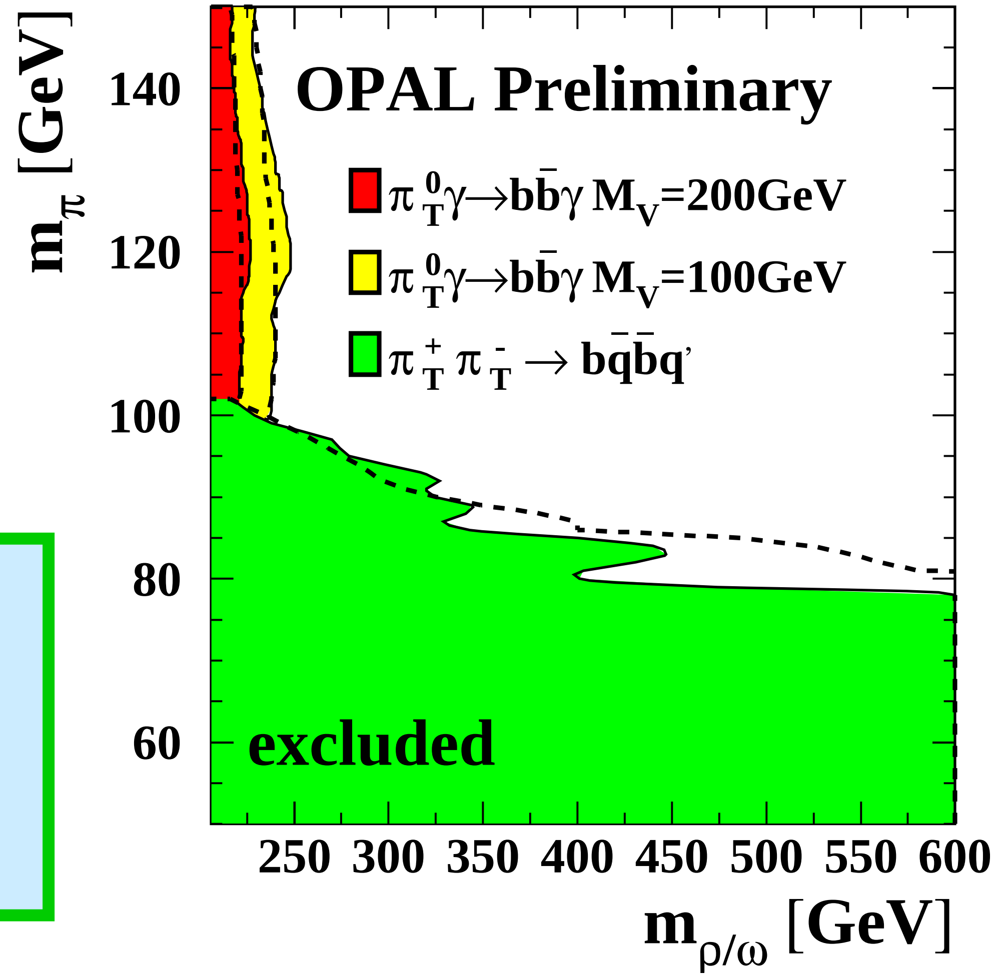
(88.1 GeV/c^2 expected)

ρ_T production excluded $90 < M\rho_T < 206.7$ GeV/c^2

OPAL results

Based on ~ 209.4 pb-1 up to 209 GeV. **No excess was observed**





Lower limit on $M_{\pi T}$ for $M_{\rho T} \rightarrow \infty$,

$M_{\pi T} > 62$ GeV/c^2 ($N_d=2$)

$M_{\pi T} > 77$ GeV/c^2 ($N_d=9$)

(95% CL)

Search for ρ_T with $M_{\rho_T} < \sqrt{s}$

- ρ_T with $M_{\rho_T} < \sqrt{s}$ can be produced on mass shell in RR process $e^+e^- \to \rho_T(\gamma)$ with subsequent decays into different final states.
- It can be observed as relatively narrow resonance in the corresponding mass distribution $\Gamma_{\rho_T} \leq 15$ GeV for $m_{\rho_T} \leq 200$ GeV
- It also gives additional contribution in the production cross-sections of SM final states, e.g.

$$e^+e^- \to \rho_T^* \to W^+W^-$$

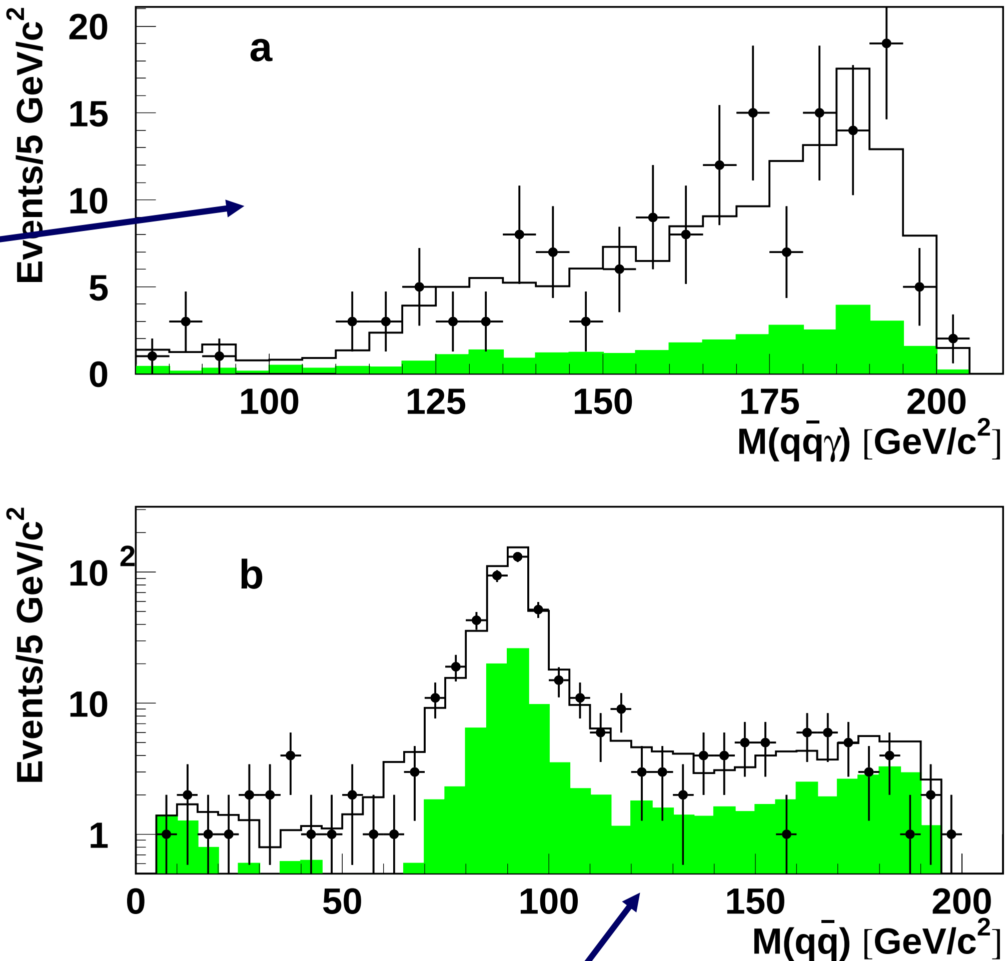
- ρ_T is searched for in all main decay modes:

$$\rho_T \to \textbf{hadrons } (\pi_T\pi_T, qq), \pi_T^0\gamma, W_L^+W_L^-$$

Direct Search for $\rho_T \rightarrow \pi_T^0\gamma$

- Narrow resonance should be observed in the mass spectra of:

$$q\bar{q}\gamma \text{ from } \rho_T$$
$$\pi_T^0 \rightarrow q\bar{q}$$



- Again the use of b-tagging is important, since the main π_T^0 decay is into b-quarks.
- Result obtained:

$BR(\rho_T \rightarrow \pi_T^0\gamma) < 7\%$, (95%CL)

$M\rho_T > \sqrt{s}$

Indirect search for $\rho_T \to W^+W^-$

- In the presence of $\rho_T \to W^+W^-$, measured cross section $e^+e^- \to W^+W^-$ should differ significantly from the SM prediction. Predicted additional contribution are quite large:

M_{ρ_T} (GeV/c^2)	$\sqrt{s}(GeV)$					
	183	189	200	202	205	207
175	7.00	4.39	2.57	2.38	2.15	2.01
185	–	10.68	3.87	3.45	2.97	2.71
195	–	–	8.69	6.83	5.15	4.42

- These values can be compared with experimental precision, e.g. Delphi at $\sqrt{s}$ =189 GeV gives $\sigma(e^+e^- \to W^+W^-)$ =15.83±0.38±0.20 pb and the expected SM value is ~16.25 pb
  - As no additional contribution is observed in the cross-section,

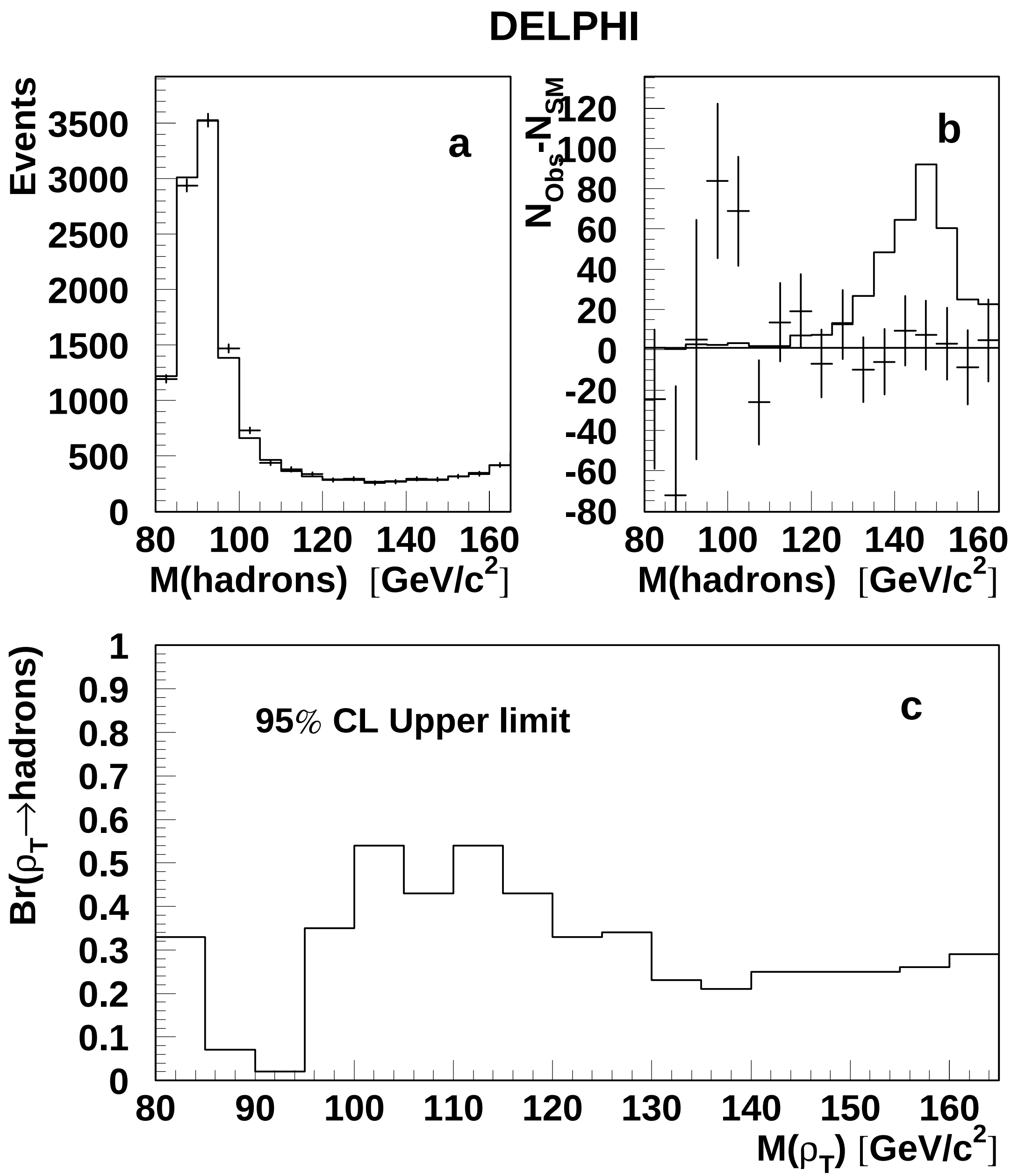
$BR(\rho_T \to W^+W^-)<30\%$, (95%CL)

Indirect Search for $\rho_T \rightarrow$ hadrons ($\pi_T\pi_T$,qq)

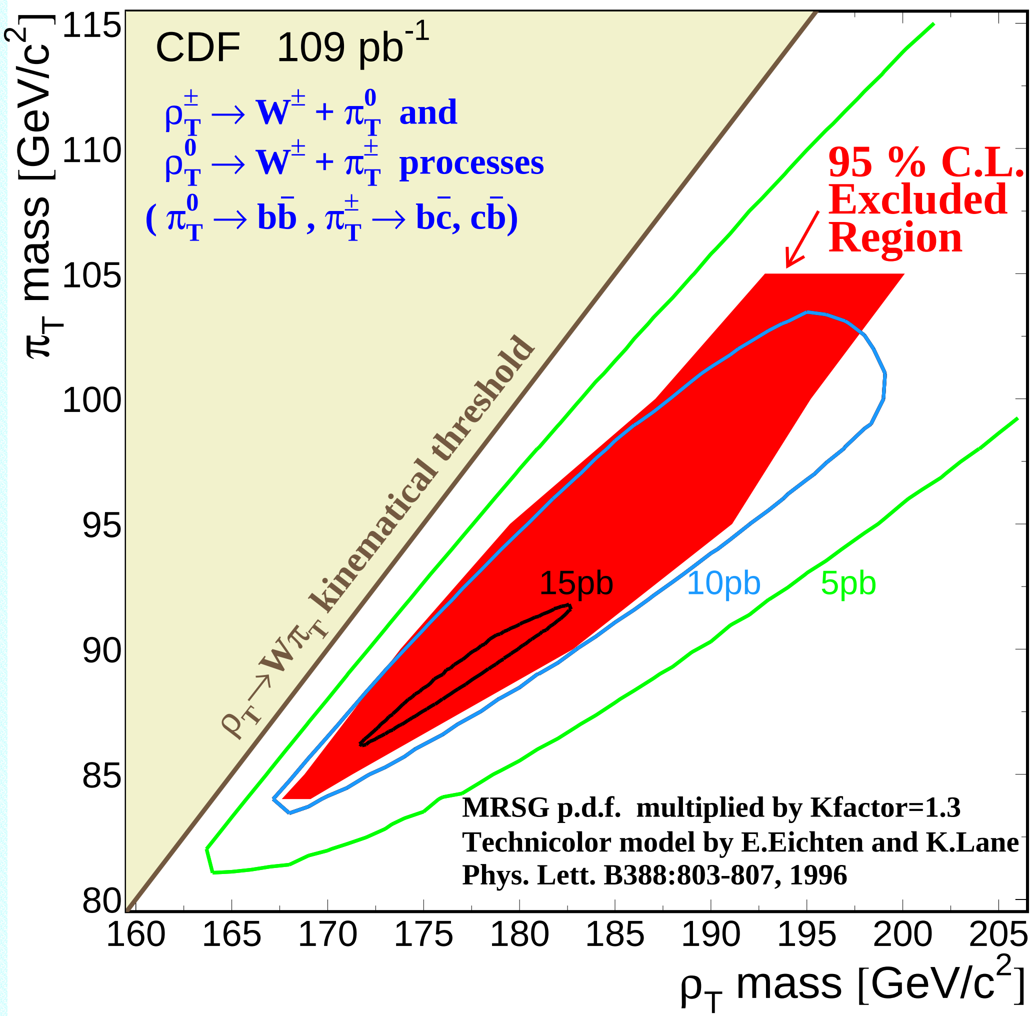
- ρ_T should also give an additional contribution to the process

$$e^+e^- \rightarrow q\bar{q}(\gamma)$$

- It should be observed as a peak in the hadronic mass distribution.
- BR($\rho_T \rightarrow$hadrons)<55%, (95%CL)



LEP vs. Tevatron



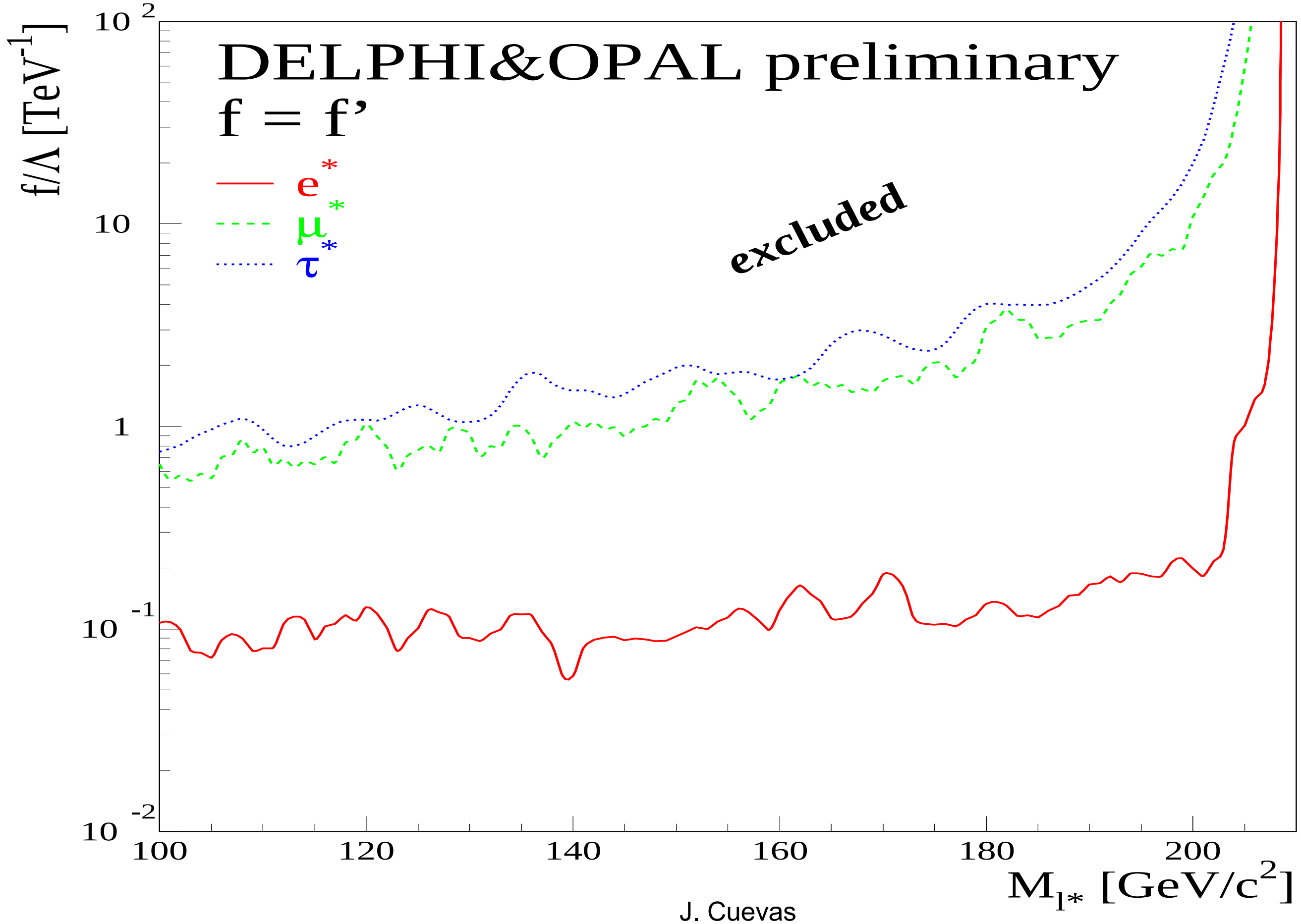
- Results at Tevatron using the same TC model are based on l+2j channel (counting experiment, in mass windows).
- No **excess was observed**, then, data is used to exclude mass regions in the M_{ρ_T} vs. M_{π_T} plane.
- Using **INDIRECT** searches at **LEP** this plane is almost completely **covered**.

Excited leptons (Compositeness)

- Substructure at an energy scale $\Lambda \rightarrow$ Excited leptons
  - Decay promptly:
    - **$l^* \rightarrow l\gamma, \upsilon W, lZ$**
    - **$\upsilon^* \rightarrow \upsilon\gamma, lW, \upsilon Z$**
  - **f/Λ, f'/Λ vs. m_{l*}** $(|f|=|f'|)$
- Direct searches were performed in pairs (**$\sim\sqrt{s}/2$**), and in single production (**$\sim\sqrt{s}$**).
- Indirect searches for excited electrons, using the measured $\gamma\gamma(\gamma)$ differential cross-section.
- Opal and Delphi results already combined, Aleph and L3, similar sensitivities.

Excited leptons (direct searches)

- No excess of events was observed with respect the Standard Model prediction:
- Exclusion for **f/Λ vs. M_{l*}** at $\sqrt{s}$ =189-210 GeV



Excited leptons (indirect searches)

- No excess of events was observed with respect the Standard Model expectation:
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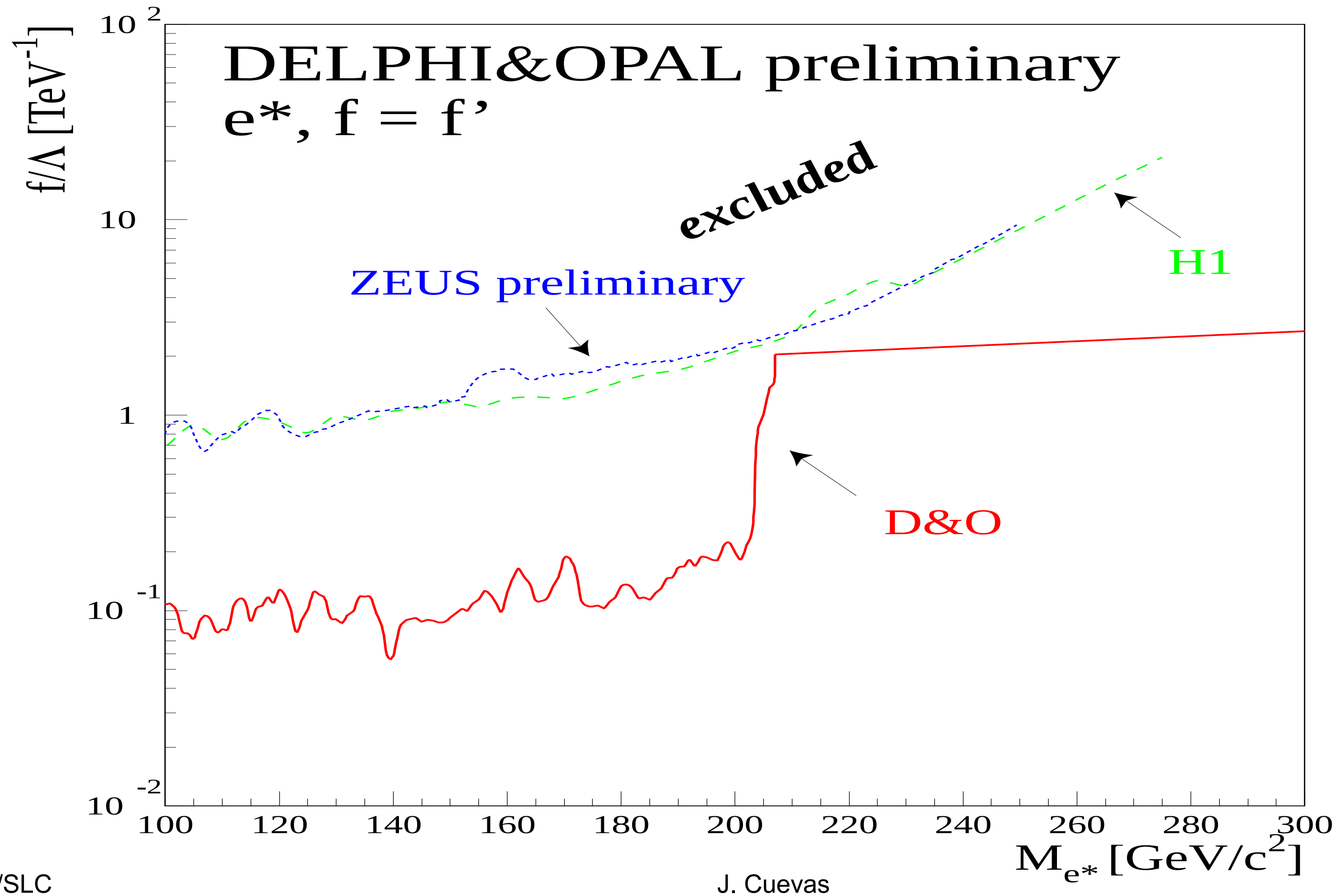

Summary

- **LEP provided data samples to look for new physics beyond the Standard Model, allowing investigation of new phenomena and search for new particles.**
- **Results obtained, either combined among the four LEP experiments or coming from individual experiments gives NO evidence of the presence of new physics,**
  - **No evidence of Technicolor contribution** is observed
  - A 95% CL lower mass limit of **79.8 GeV/c²** is set independently of other parameters of the TC model.
  - **$90<M\rho_T<206.7$ GeV/c²** is set regardless other model parameters.
  - **$f/\Lambda \leq 0.1$ TeV^{-1} (e*), 1 TeV^{-1} (μ*,τ*)**
- **Final LEP combined results, coming soon from LEP EXOTICA WG.**