

Technicolor Searches in the 4-Jet Channel

Niels Meyer

DESY

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Outline

- Introduction
- Search Channels and Strategy
- Old Selections
- New Combination
- Systematics
- Exclusion Limits
- Summary

Introduction

Why Technicolor?

- No fundamental Higgs
- No hierarchy problem
- No fine-tuning needed

Method:

Postulate new TC interaction

$$SU(N_{TC})$$

and new TC-fermions

$$\left(\begin{array}{c} T_U \\ T_D \end{array} \right)_1 \cdots \left(\begin{array}{c} T_U \\ T_D \end{array} \right)_{N_D}$$

Chiral symmetry breaking
via TC-fermion condensates

$$\langle T\bar{T} \rangle = v \sim F_{TC}$$

gives mass to weak bosons

Extended TC couples
TC-fermions and SM-fermions
 \implies massive fermions

Effective Model - TCSM

TechniColor Straw-man Model = scaled-up version of QCD
Phenomenology determined by lightest TC-doublet

Particle content:

- Spin 1: $\rho_T^{\pm, 0}, \omega_T^0$
- Spin 0: $\Pi_T^{\pm, 0}, \Pi_T^{0'}$

Mixing with weak Goldstone modes

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

⇒ new mass eigenstates

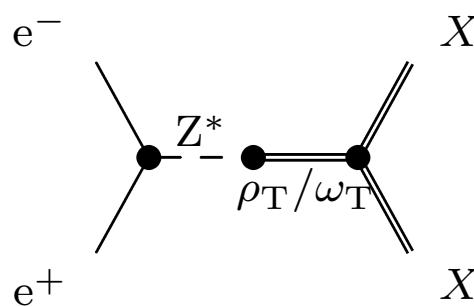
$$\pi_T^{\pm, 0} \quad \pi_T^{0'}$$

Model Parameters:

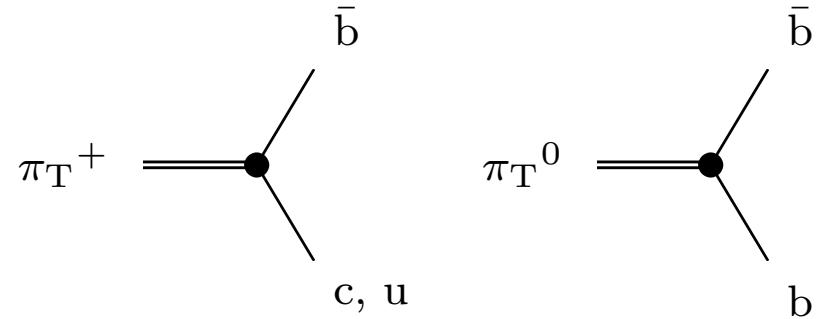
- Mixing angle
 $\sin \chi = 1/\sqrt{N_D} = 1/3$
- Mass parameter
 $m_A, m_V = 200 \text{ GeV}$
- Number of TC-degrees N_{TC}
- Neutral pion mixing
 $\sin \chi' = \sin \chi$
- TC-doublet charge $Q = 5/3$

Production and Decay

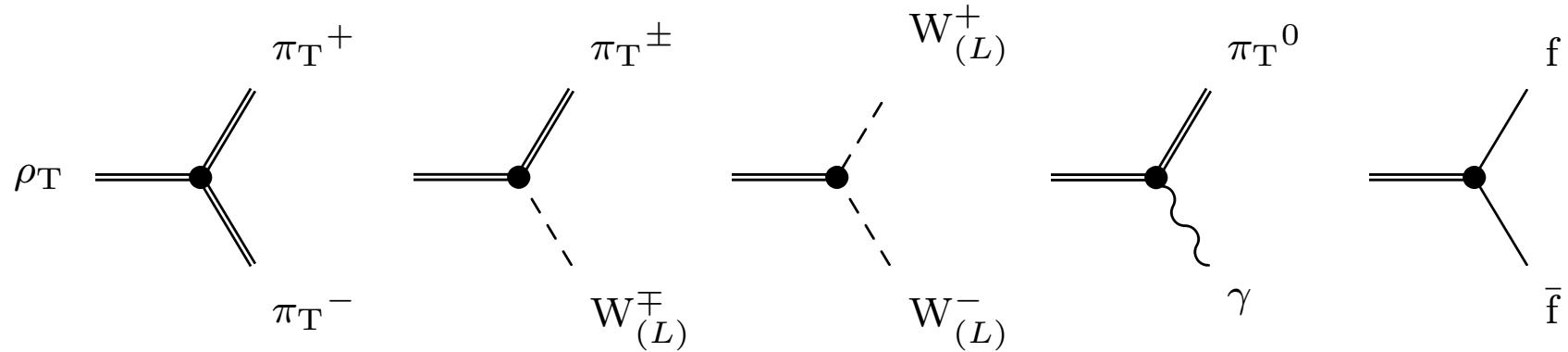
Vector production through mixing



Pion decays to quarks



Vector decays via TC or weak interaction



LEP Search Channels

a) Searches for π_T

- $e^+e^- \rightarrow \pi_T^+\pi_T^-$
Final state: $b\bar{q}q\bar{b}$
Limit: $m_{\pi_T} \lesssim \sqrt{s}/2$
- $e^+e^- \rightarrow \pi_T^\pm W^\mp$
Final states: $b\bar{q}q\bar{q}$ and $b\bar{q}\ell\nu$
Limit: $m_{\pi_T} \lesssim \sqrt{s} - m_W$
- $e^+e^- \rightarrow \gamma\pi_T^0$
Final state: $\gamma b\bar{b}$
Limit: $m_{\pi_T} \lesssim \sqrt{s}$

b) Re-interpret SM cross-sections

- Re-interpret
 $e^+e^- \rightarrow W^+W^-$
- Re-interpret $e^+e^- \rightarrow q\bar{q}$

TC at LEP

Delphi paper (2001):

- $\sqrt{s} = 192\text{-}208 \text{ GeV ('99-'00)}$
- $\pi_T^+ \pi_T^-$ and $\pi_T^\pm W^\mp$ 4-jet and semi-leptonic
- SM re-int.

L3 conference note (1999):

- $\sqrt{s} = 189 \text{ GeV ('98)}$
- $e^+ e^- \rightarrow WW$ re-int.
- $\pi_T^+ \pi_T^-$ 4-jet
- $\pi_T^\pm W^\mp$ semi-leptonic
- $\gamma \pi_T^0 \rightarrow \gamma b\bar{b}$

OPAL PN485 (2001):

- $\sqrt{s} = 205 - 209 \text{ GeV (Y2K)}$
- $\pi_T^+ \pi_T^-$ 4-jet
- $\gamma \pi_T^0 \rightarrow \gamma b\bar{b}$

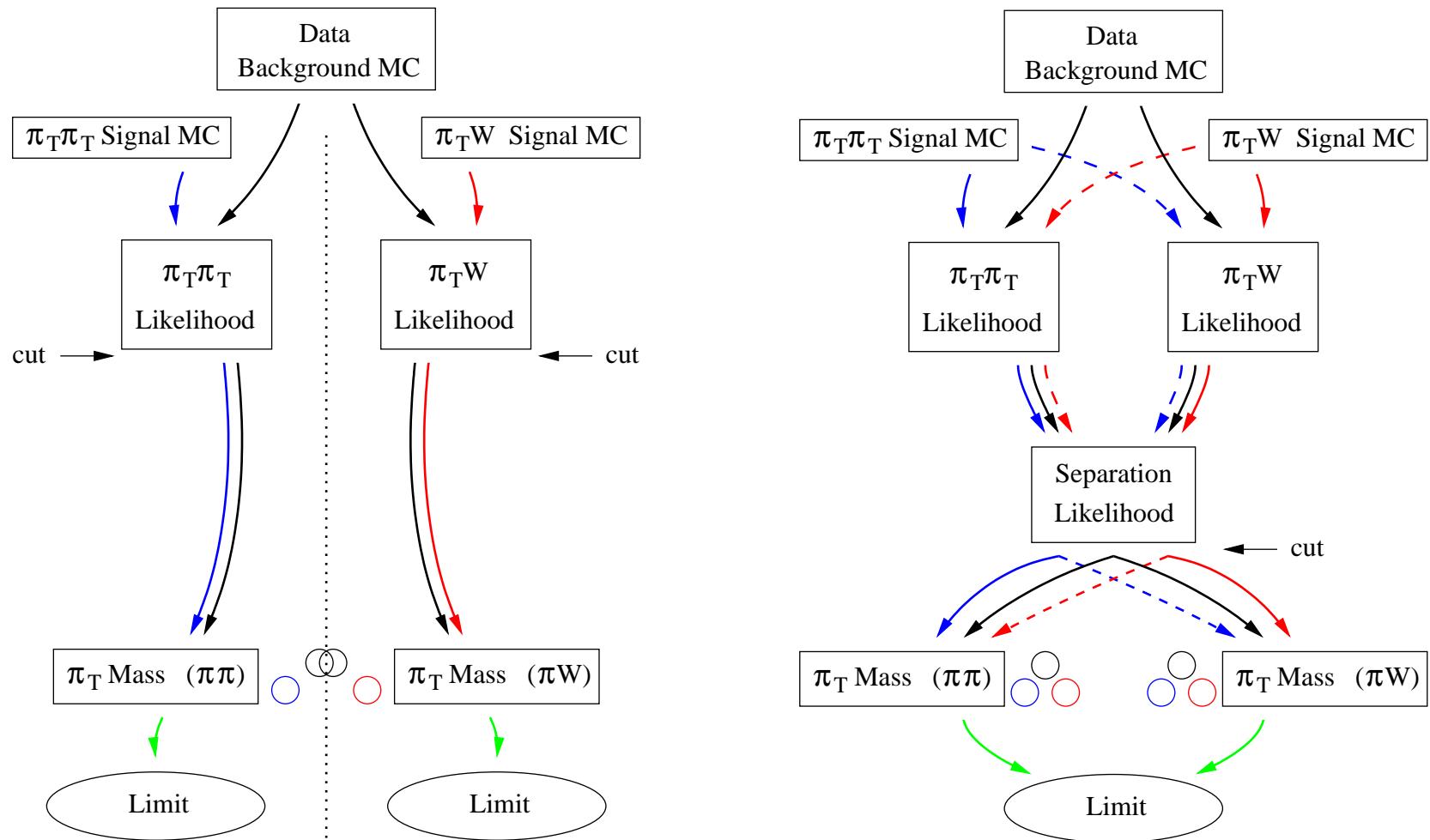
Diploma thesis N. Gollub (2001):

- $\sqrt{s} = 205 - 209 \text{ GeV (Y2K)}$
- $\pi_T^\pm W^\mp$ 4-jet

This analysis:

- $\sqrt{s} = 189\text{-}209 \text{ GeV ('98-'00)}$
- Combined analysis of 4-jet from $\pi_T^+ \pi_T^-$ and $\pi_T^\pm W^\mp$

Search Strategy



Pre-Selection

Adopted from 4-jet Higgs search:

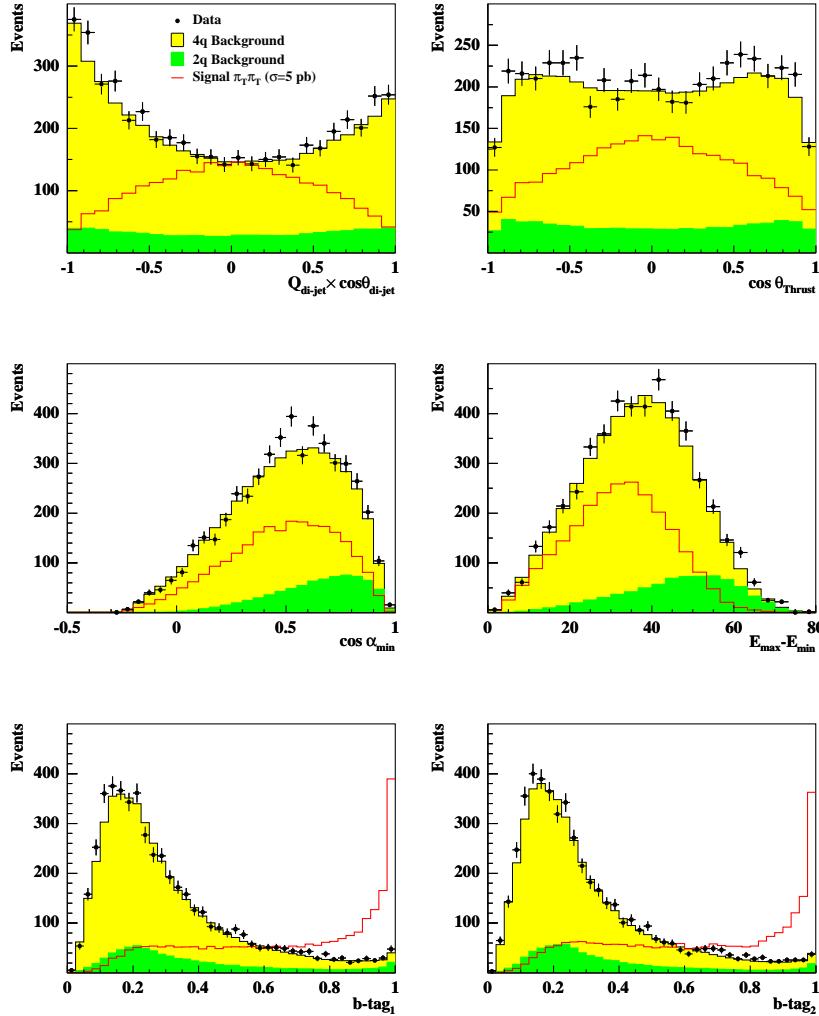
- Multi-hadron events
- $\sqrt{s'}/\sqrt{s} > 0.82$
- $Y_{43} > 0.003$
- $C_{par} > 0.6$
- ≥ 2 tracks / jet
- $PROB(\chi^2) > 10^{-5}$ in 4C fit
- $PROB(\chi^2) > 10^{-5}$ in 5C fit
 - $4C + m_{jj} = m_{jj}$
 - $4C + m_{jj} = m_W$

Data	4909
4q background	3940
2q background	772

Jet pairing

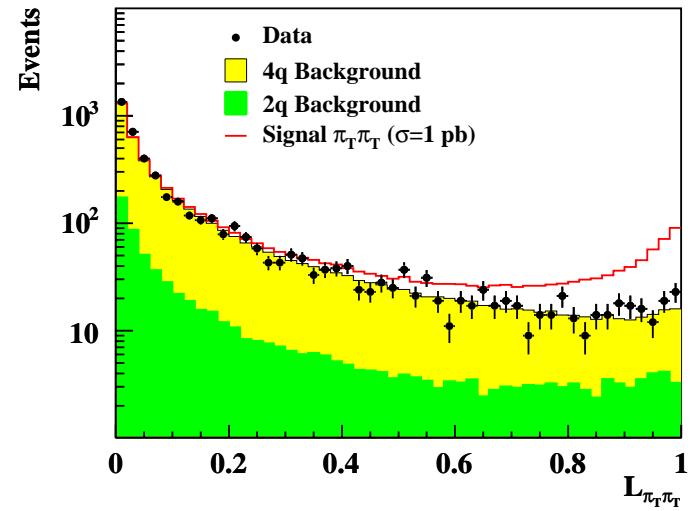
- $\pi_T^+ \pi_T^-$ hypothesis:
Best 5C fit $PROB(\chi^2)$
- $\pi_T^\pm W^\mp$ hypothesis:
Likelihood from
 - Best 5C fit $PROB(\chi^2)$
 - Flavor content

$\pi_T^+ \pi_T^-$ Likelihood $\mathcal{L}_{\pi_T \pi_T}$



From PN485, separate

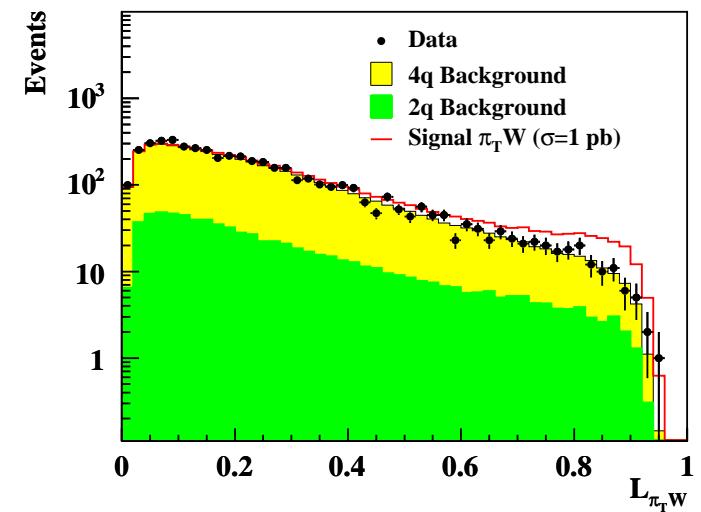
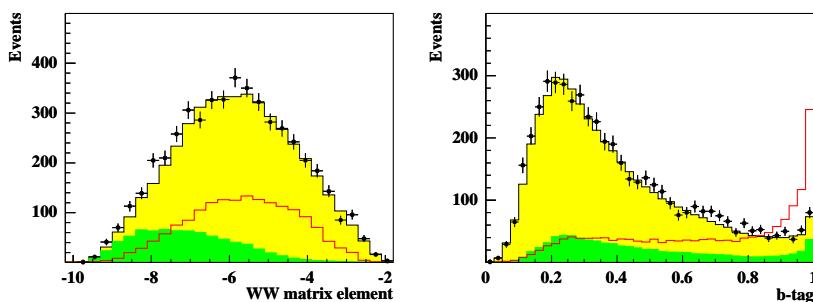
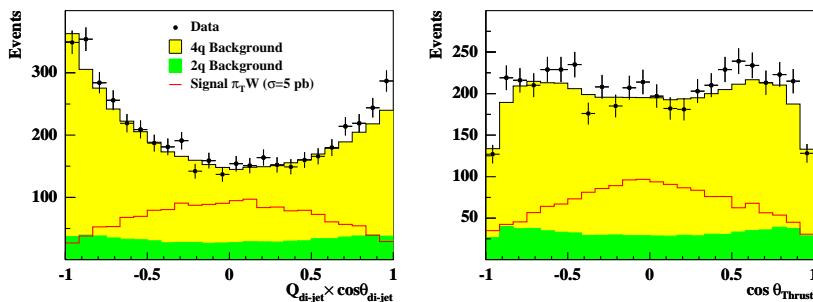
- 4f Background
- 2f Background
- $\pi_T^+ \pi_T^-$ Signal



$\pi_T^\pm W^\mp$ Likelihood $\mathcal{L}_{\pi_T W}$

From thesis NG, separate

- 4f Background
- 2f Background
- $\pi_T^\pm W^\mp$ Signal



Separation Likelihood \mathcal{L}_{sep}

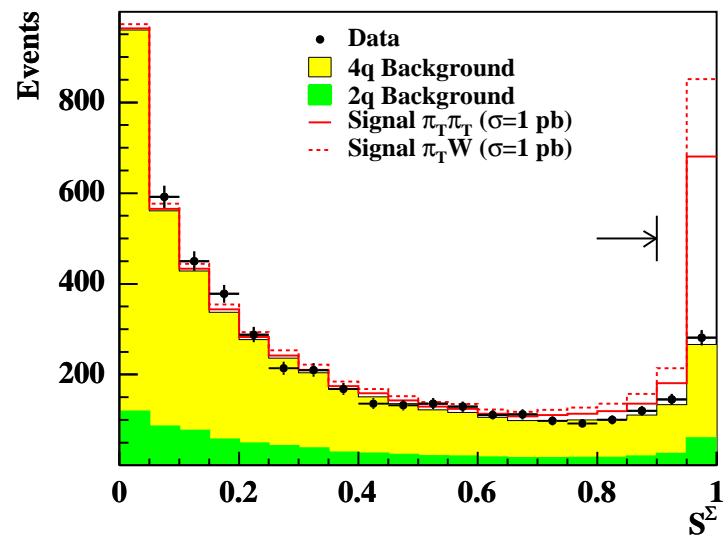
Combine $\mathcal{L}_{\pi\pi}$ and $\mathcal{L}_{\pi W}$ output
in one likelihood \mathcal{L}_{sep}

- Background
- $\pi_T^+ \pi_T^-$ Signal
- $\pi_T^\pm W^\mp$ Signal

Define:

- $S^\Sigma = \mathcal{L}_{sep}^{\pi\pi} + \mathcal{L}_{sep}^{\pi W}$
- $S^\Delta = \mathcal{L}_{sep}^{\pi\pi} - \mathcal{L}_{sep}^{\pi W}$

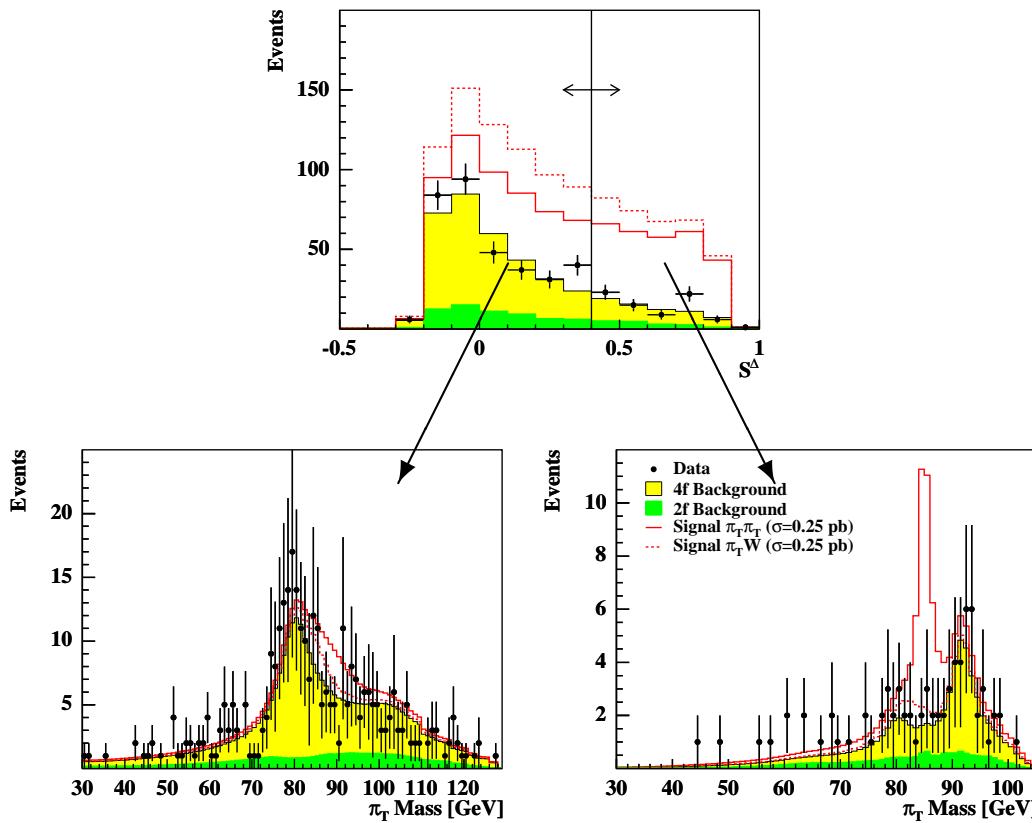
Sum of signal S^Σ :



Data	416
4q Background	308
2q Background	79

Independent Mass Distributions

Difference of signal S^Δ :



$\pi_T^+ \pi_T^-$ hypothesis

Data	77
4q Bkg.	49
2q Bkg.	18

$\pi_T^\pm W^\mp$ hypothesis

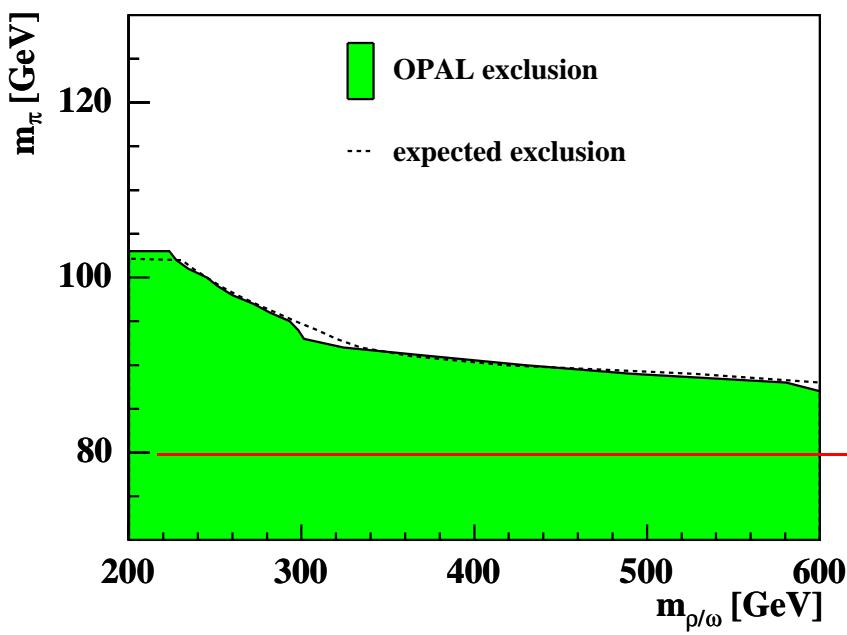
Data	339
4q Bkg.	259
2q Bkg.	61

Systematic Uncertainties

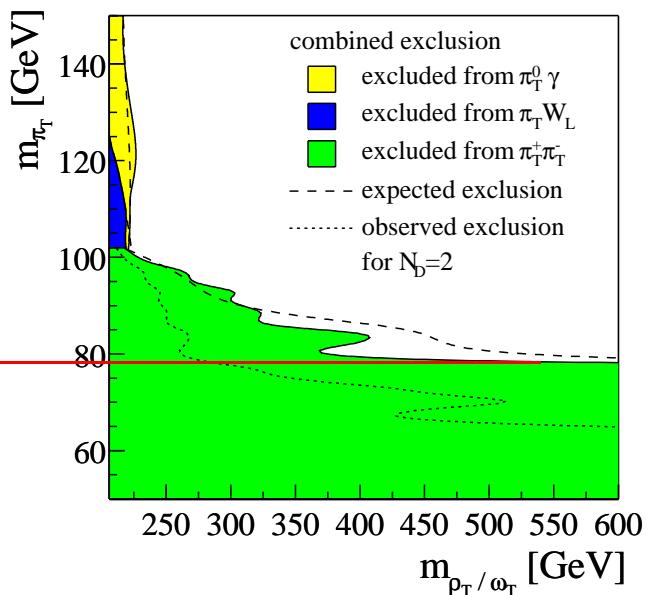
[%]	Signal $\pi_T^+ \pi_T^-$		Signal $\pi_T^\pm W^\mp$		Background	
	$\pi_T \pi_T$	$\pi_T W$	$\pi_T \pi_T$	$\pi_T W$	$\pi_T \pi_T$	$\pi_T W$
MC stat.	2.0	2.0	2.0	2.0	5.4	2.6
Var. mod.	5.3	6.5	6.9	6.0	5.5	7.5
B/D decays	2.4	2.8	5.2	3.0	3.2	1.6
Si eff.	1.3	1.0	2.7	0.8	1.4	0.2
Trk. res.	1.9	1.8	4.0	2.4	6.0	6.7
Fragmentation					5.4	5.4
Total	6.6	7.6	10.1	7.5	11.7	11.8

Exclusion Limits

This analysis (1998-2000):



Old OPAL Y2K analyses:



- Better $\pi_T^+ \pi_T^-$ sensitivity, worse $\pi_T^\pm W^\mp$ than separate searches
 - Use $\pi_T^\pm W^\mp$ -analysis to explore $m_{\pi_T} \lesssim 128$ GeV
- Missing: Correct implementation of systematics

Summary and Outlook

- Combined 4-jet analysis based on $\sqrt{s} = 189 - 209 \text{ GeV}$
- Improved results with respect to separate searches
- Results final for $m_{\pi_T} < \sqrt{s}/2$
- Missing: $\pi_T^\pm W^\mp$ for $m_{\pi_T} \sim 100 - 128 \text{ GeV}$
- PN in preparation
(presentation of results at winter conferences)
- Wait for $\gamma\pi_T^0$ analysis to publish paper