

**DELPHI**

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**On behalf of the DELPHI Collaboration**

**LEP Jamboree**

**6 March 2003**

# Outline

- EW
  - $\sigma(WW)$  and  $\sigma(ZZ)$
- QCD/ $\gamma\gamma$ 
  - $\alpha_s$  from event shapes
  - Coherence
- B-physics (LEP I)
  - $b$  branching fractions
  - $b$ -hadron lifetimes
  - $B_s^0$  oscillations
- Higgs Searches
  - SM Higgs
  - Invisible Higgs
- SUSY/EXOTICA Searches
  - Resonant  $\tilde{\nu}$  production
  - $\gamma + \cancel{E}$
- Unless stated
  - Limits 95% C.L.
  - Results to be published
  - $y$ -axis: Number of event/bin

# Status of EW Measurements

## DRAFTS

$\sigma(\mathbf{WW})$     $\sigma(\mathbf{ZZ})$   
WW $\gamma$  production

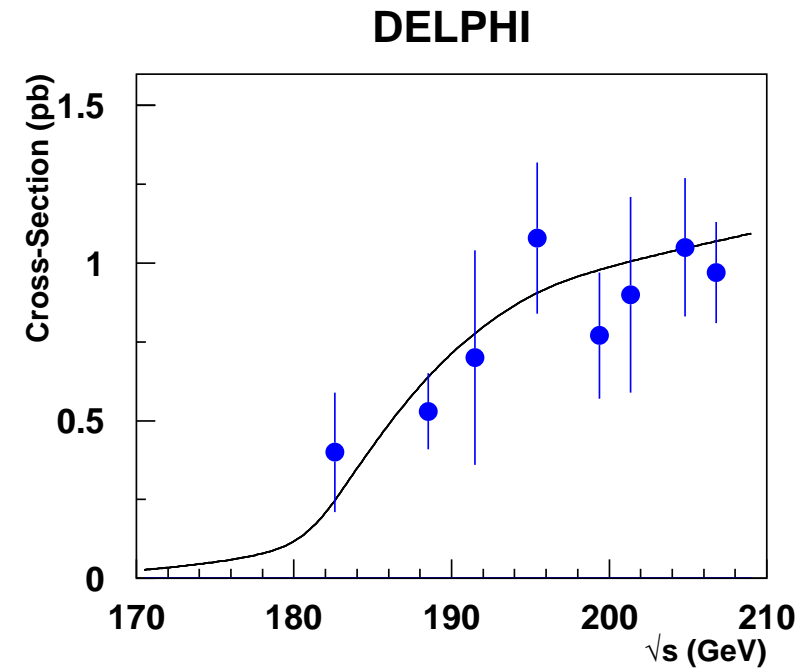
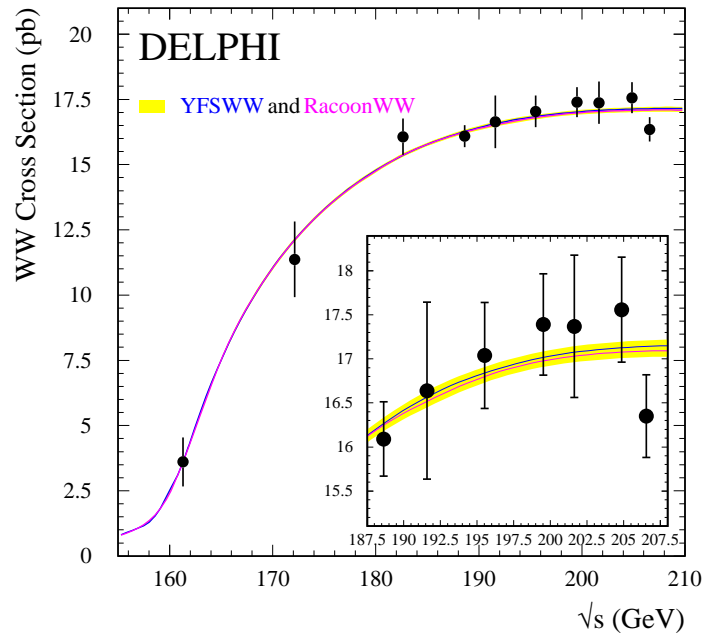
$A_{\text{FB}}(\text{b})$  inclusive    $A_{\text{FB}}(\text{b})$  with leptons

## PLANNED

W mass and Width   Z $\gamma^*$   
Single-boson production   Spin Density Matrix  
Charged TGCs   Neutral TGCs

$f\bar{f}$  production at LEP II    $\gamma\gamma$  production at LEP II  
 $Q\bar{Q}$  production at LEP II

# WW/ZZ cross-sections



$$\mathcal{R}_{WW} = 1.001 \pm 0.012(\text{stat}) \pm 0.011(\text{syst}) \quad \mathcal{R}_{ZZ} = 0.91 \pm 0.08(\text{stat}) \pm 0.02(\text{syst})$$

Average over energies  $\mathcal{R} = \left\langle \frac{\sigma_{\text{measured}}}{\sigma_{\text{predicted}}} \right\rangle$  include correlations

# Status of QCD/ $\gamma\gamma$ Measurements

## PUBLISHED

Energy evolution of event shapes

## DRAFTS

$\alpha_s$  from event shapes

hadr.  $\gamma$  struct. func.

$f_1$  production

$\gamma\gamma \rightarrow J/\psi$

$\Xi^\pm$  production

$\gamma\gamma \rightarrow \eta_c$

## PLANNED

BEC in WW

CR in WW

Transverse radii in BEC

W hadronic decays

Gluon fragm.

$\gamma\gamma \sigma(\text{total})$

no-tag high- $p_t$  jets

double-tag  $\sigma$

single-tag  $\sigma$

Mult. in 3-jet events

Charged part. mult. at 206 GeV

Mult. in b and light quark events

Fragm. functions and  $\alpha_s$

Running  $m_b$

$\gamma\gamma \rightarrow c\bar{c}/b\bar{b}$

$\gamma\gamma \rightarrow \pi\pi/KK$

$\gamma\gamma \rightarrow p\bar{p}$

$\gamma\gamma \rightarrow \rho\rho$

Running  $m_b$  in 4-jet events

$\alpha_s$  in 4-jets events

Angular distr. in 4-jet events

Soft photon excess in qq

QCD overview paper

$\gamma\gamma \rightarrow \eta_b$

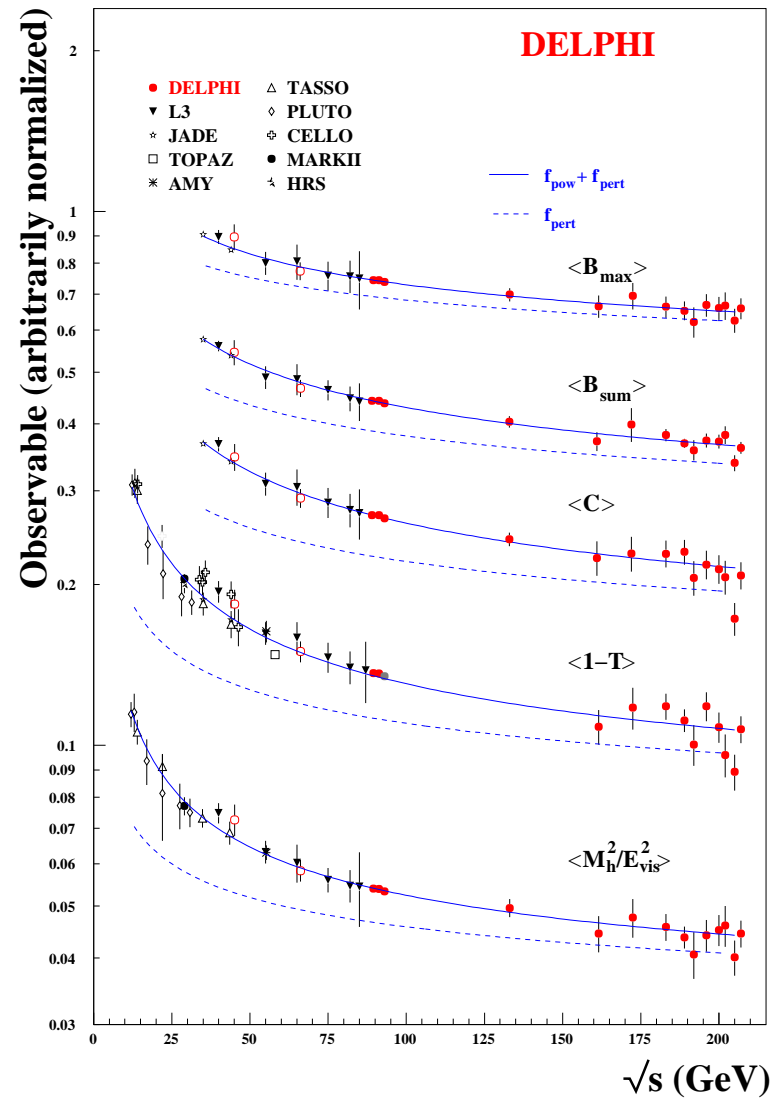
$\gamma\gamma \rightarrow 4\pi$

$\gamma\gamma \rightarrow KK\pi$

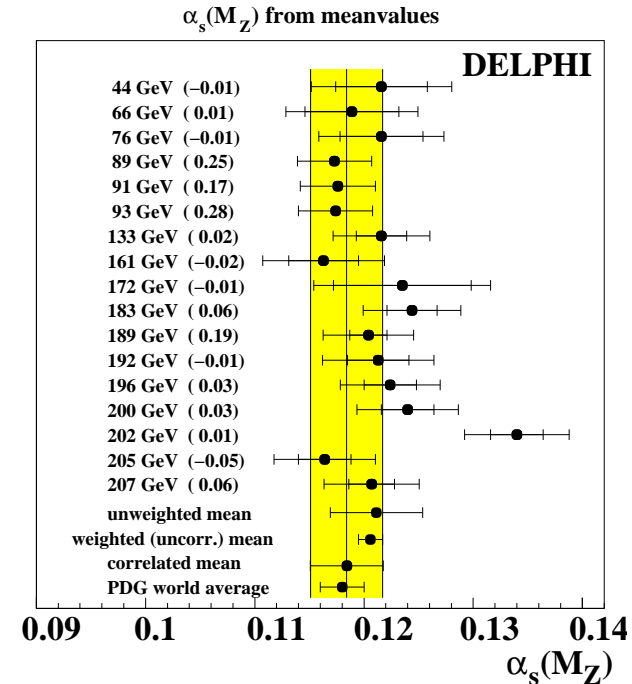
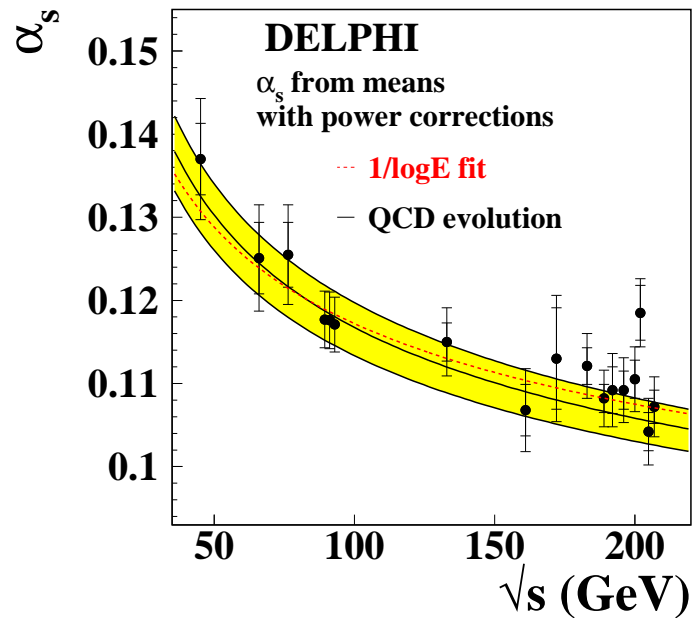
electron struct. func.

# Determination of $\alpha_s$

- Fit means of 5 event shapes including power corrections
  - Fit means vs  $\sqrt{s}$  to obtain non-perturbative contribution to each event shape and  $\alpha_s(s)$



## Determination of $\alpha_s$ (II)



- Check running of  $\alpha_s(s)$

- Fit  $b = \frac{d\alpha_s^{-1}}{d\log\sqrt{s}}$

- $b = 1.11 \pm 0.09(stat) \pm 0.19(syst)$

- [QCD(5 flavours) 1.27]

- Extrapolate all measurements to  $\alpha_s(M_Z)$

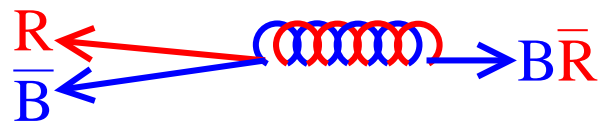
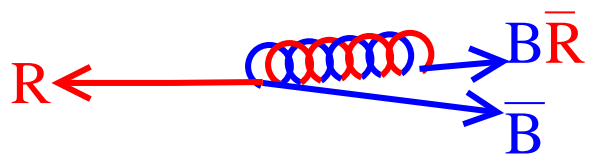
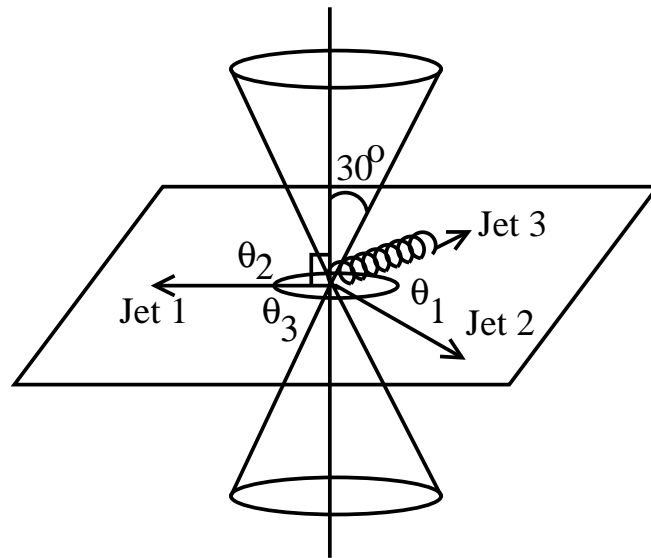
- $\alpha_s(M_Z) = 0.1184 \pm 0.0004(stat) \pm 0.0033(syst)$

- LEP II/LEP I weights similar
    - LEP II smaller had. and scale errors

- Scale uncertainty dominates

# Coherence

## NEW ANALYSIS



- Test coherence in different topologies of  $q\bar{q}g$  events
- Use rate of production of hadrons at  $90^\circ$  to the plane of the  $q\bar{q}g$  events
  - Measure  $\langle N_{ch} \rangle$ /event in cone at  $90^\circ$

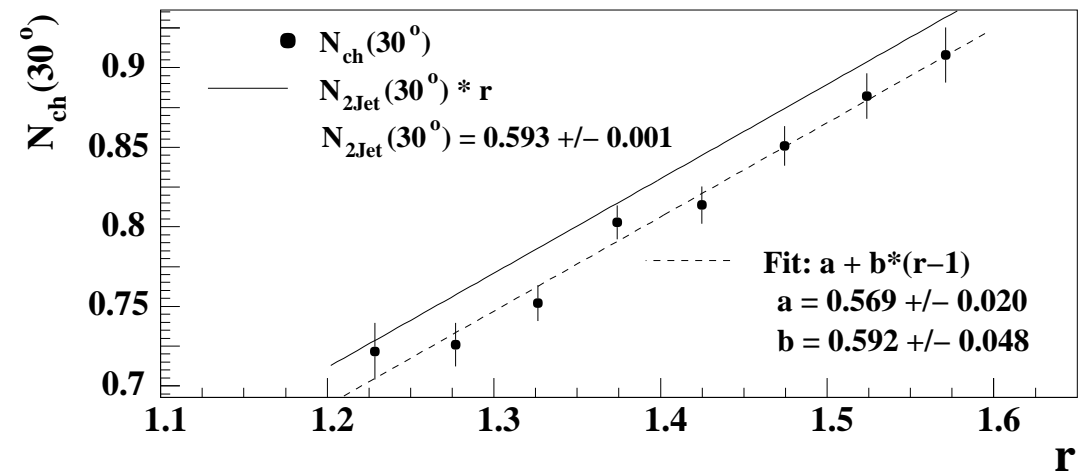
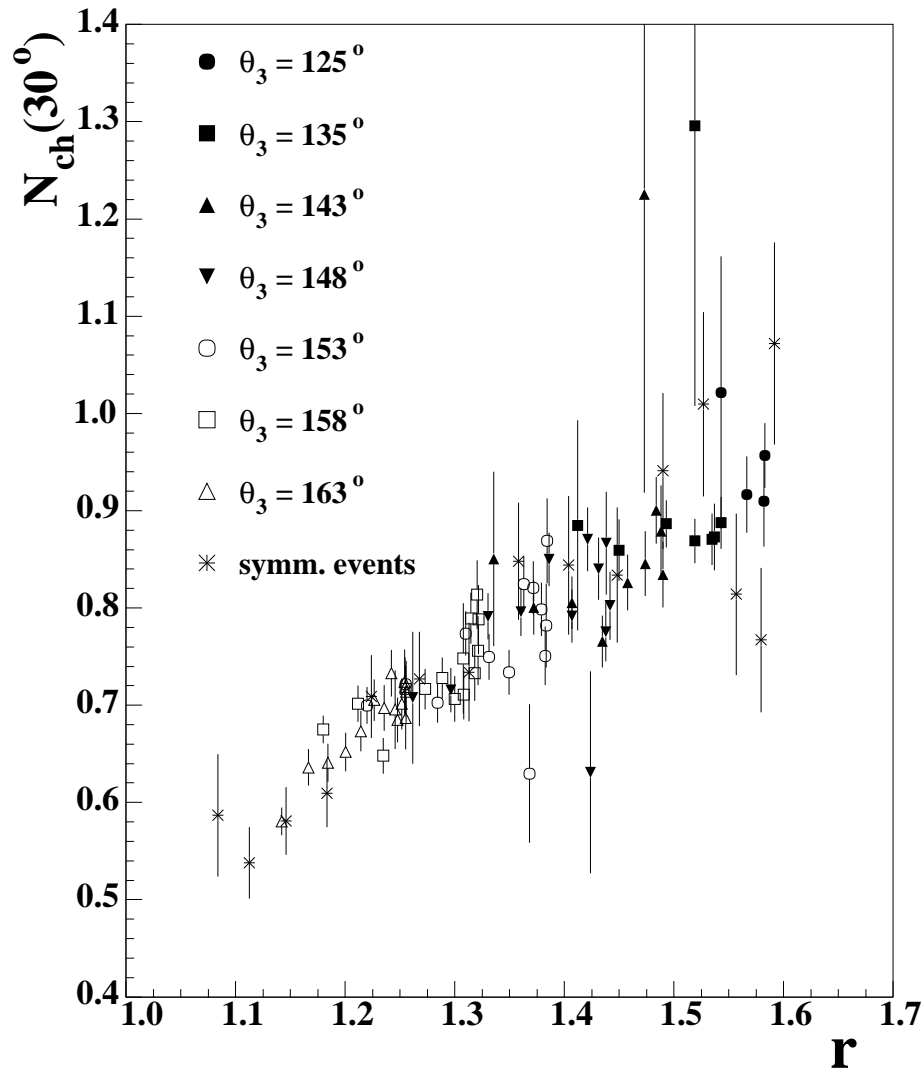
- Prediction

$$\frac{\langle N_{ch}(3j) \rangle}{\langle N_{ch}(2j) \rangle} = r(\theta_2, \theta_3)$$

- 2 jet events  
Gluon soft and collinear  
 $r = 1$
- Y-events:  
2 COLOUR –  $\overline{\text{COLOUR}}$  sources  
 $r = C_a/C_f$



## Coherence (II)



- $\langle N_{ch} \rangle / \text{event}$  depends only on  $r$
- Slope of  $\langle N_{ch} \rangle / \text{event}$  vs  $r$  as expected

# Status of Heavy Flavour Measurements

## PUBLISHED

$B_s$  osc. with incl. vertex     $b \rightarrow$  wrong sign charm

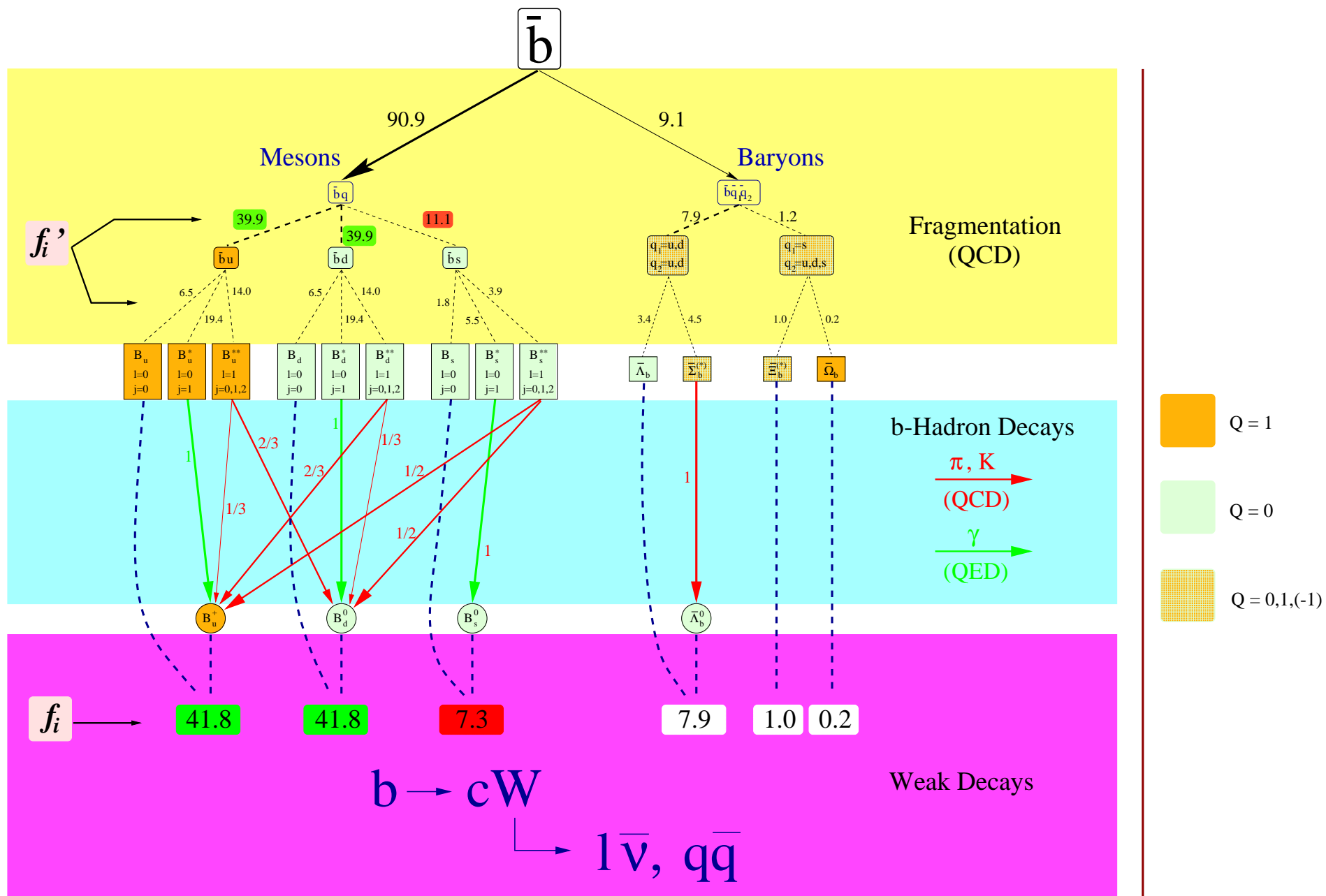
## DRAFTS

**b branching fractions**     $B_s$  osc. with incl.  $l/D_s l$   
 $B^0/B^+$  lifetimes     $\Lambda_b$  form factor  
B decays     $V_{cb}$

BR( $\tau \rightarrow$  had)     $\tau$  lifetime  
 $\gamma\gamma \rightarrow \tau^+\tau^-$

## PLANNED

$b$  fragmentation    Moments analysis  
 $B^{*(*)}$      $\Xi_c$



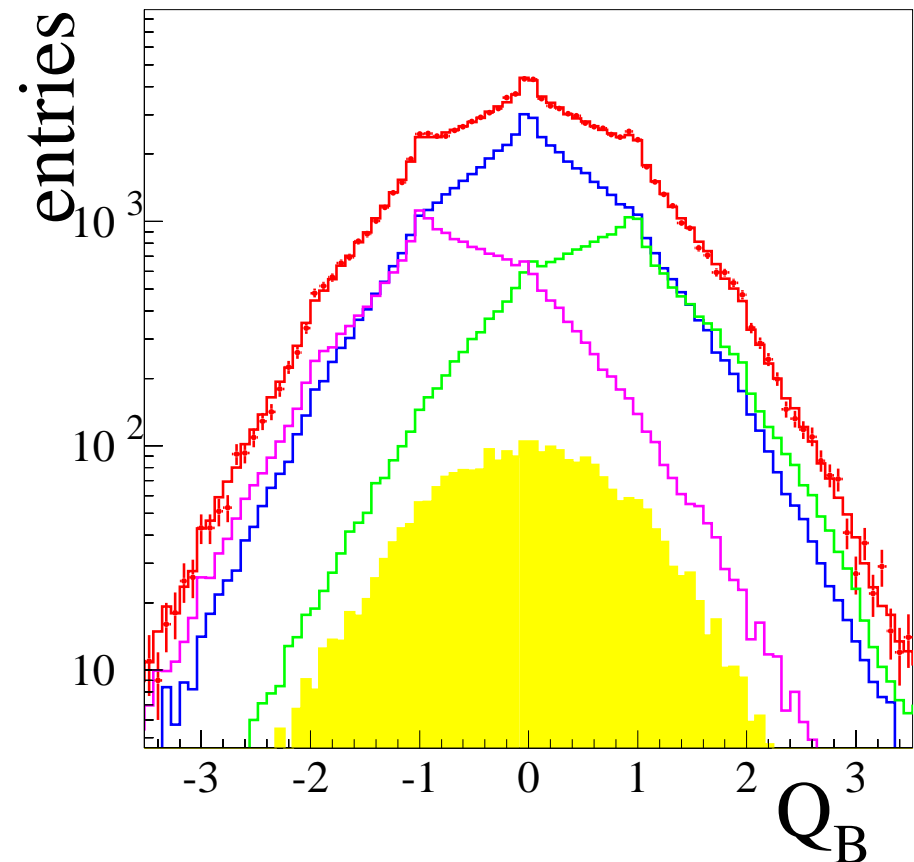
(numbers from simulation)

## $b$ branching fractions (II)

- First direct measurement of  $b$  fragmentation rates into weakly decaying charged and neutral  $b$ -hadrons
- Probability that a track comes from a  $b$ -decay given by a **Neural Net**
- Compute  $b$  hadron charge

$$Q_b = \sum_{hem} Q_i \cdot P_b^i$$

- Calibrate  $Q_b$  distributions from data by comparing opposite hemispheres
  - Fraction of events with opposite sign  $Q_b$



## $b$ branching fractions (III)

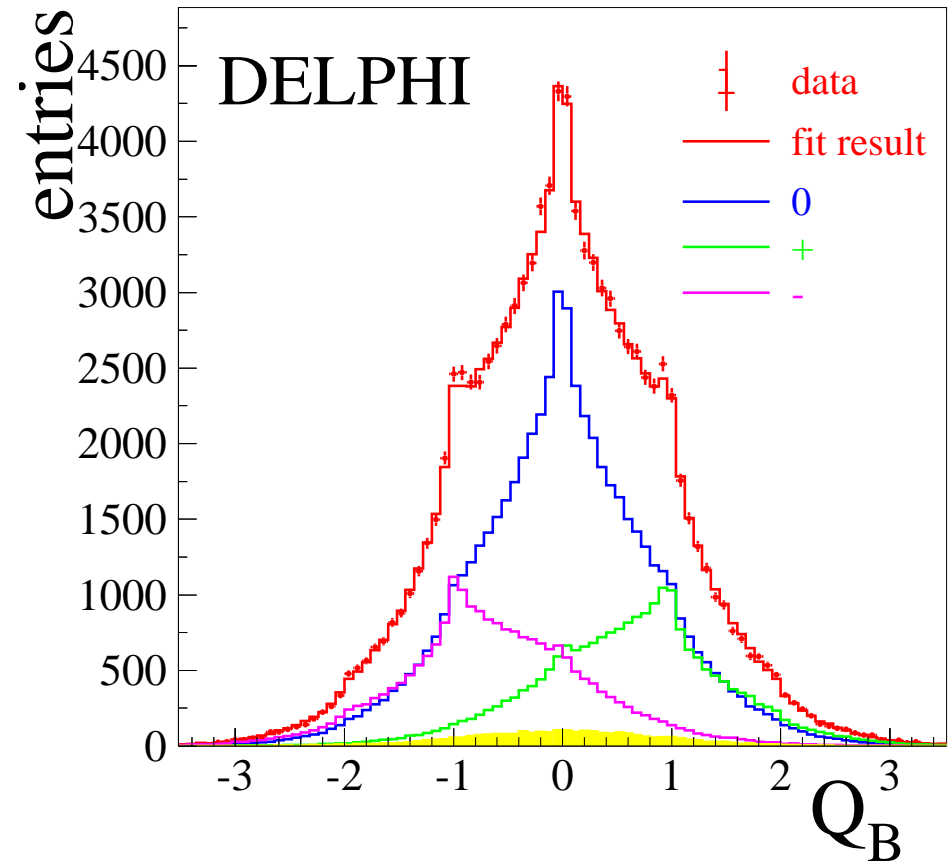
- Fit  $Q_b$  in data to expected shapes for charged and neutral  $b$ -hads.

$$f^+ = 42.06 \pm 0.81(\text{stat.}) \pm 0.91(\text{syst.})\%$$

- Subtract  $b$ -baryons

$$f_{B_u} = 40.96 \pm 0.81(\text{stat.}) \pm 1.14(\text{syst.})\%$$

- Dominant systematic comes from calibration of  $Q_b$
- Single most precise measurement of  $f^+$

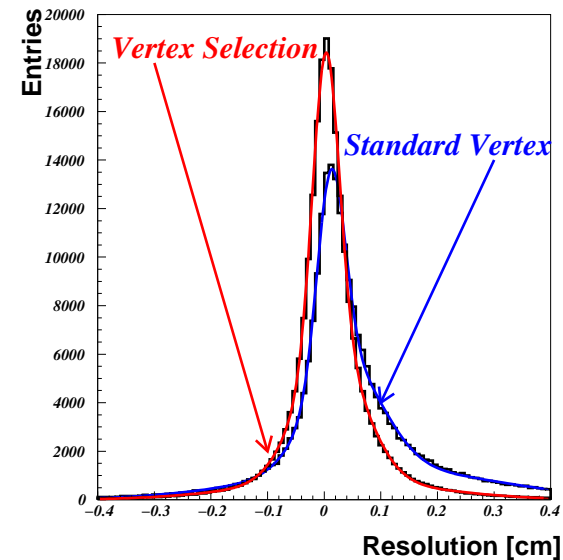
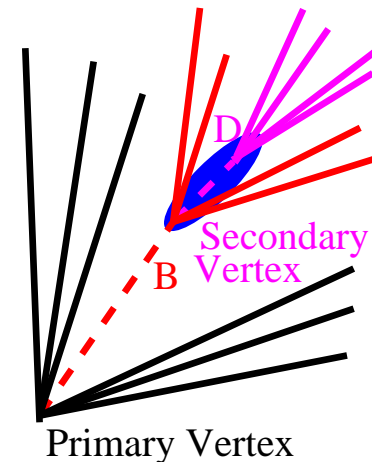


103285  $b$ -hadron candidates

## Precise $b$ -hadron lifetimes

- Measure  $\langle \tau_{b\text{-hadron}} \rangle$  and  $\tau_{B^+}$ ,  $\tau_{B^0}$
- Reduce bias from cascade D decays
- **Neural Nets** used to
  - Order tracks from B decay/D decay for reconstruction of B vertex
  - Weight tracks from  $b$  decays/primary vertex
  - Estimate of the B hadron momentum
  - Select  $B^0$  and  $B^+$  events for  $\tau$  fits
- Binned  $\chi^2$  fit to proper time distribution
- Weight events in MC for, *e.g.*
  - $B_s^0$  and  $B^+$  fractions

best model of hadronisation and decays



## Precise $b$ -hadron lifetimes (II)

- Reweight MC events for different lifetimes

- don't need many samples with different lifetimes

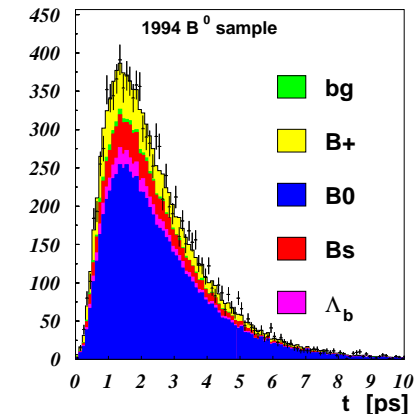
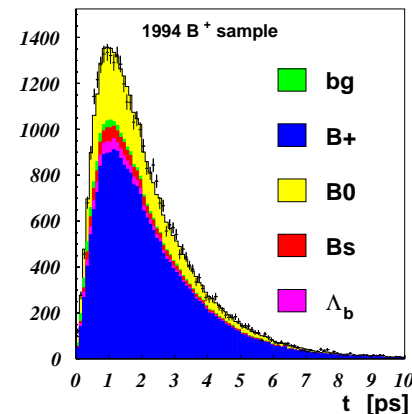
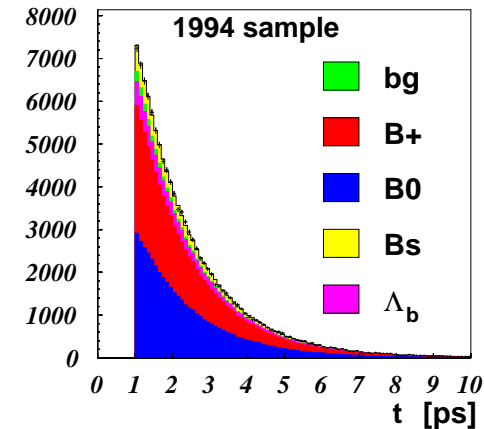
- Results

$$\begin{aligned} \langle \tau_b \rangle &= 1.568 \pm 0.005 \pm 0.009 \quad [\text{ps}] \quad (170\text{k } b) \\ \tau_{B^+} &= 1.625 \pm 0.013 \pm 0.017 \quad [\text{ps}] \quad (54\text{k } B^+) \\ \tau_{B^0} &= 1.543 \pm 0.020 \pm 0.033 \quad [\text{ps}] \quad (16\text{k } B^0) \\ \frac{\tau_{B^+}}{\tau_{B^0}} &= 1.051 \pm 0.019 \pm 0.024 \end{aligned}$$

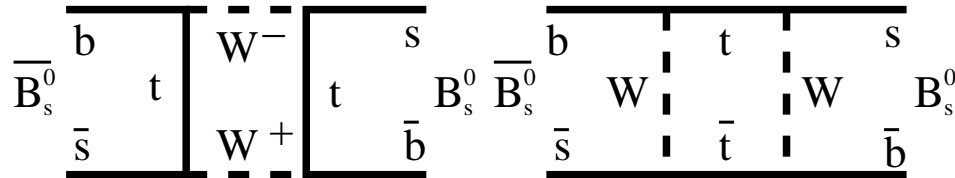
- Main sources of systematic errors

- NN cuts to separate  $B^0/B^+$
- Detector resolution

Preliminary

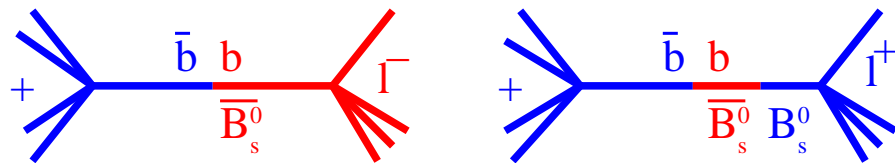


## $B_s^0 - \overline{B}_s^0$ Oscillations



- **Oscillation**

$$\mathcal{P}^{\frac{unmix}{mix}} = \frac{1}{2\tau} e^{-\frac{1}{\tau}} [1 \pm \cos(\Delta m_s t)]$$



No Oscillation

Oscillation

- **Fit fractions of *like/unlike-sign* events vs *t***

- **Inclusive leptons \*New\***

- High statistics ( $\sim 68k$  events)
- Use NN to improve  $B_s^0$  purity

- **$D_s$ -lepton \*Update\***

- Exclusive reconstruction of the  $D_s$
- Low stats ( $\sim 400$  events)
- High  $B_s^0$  purity

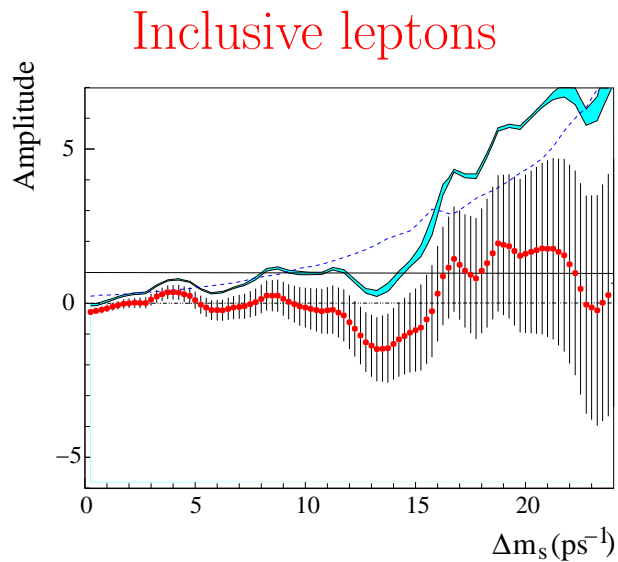
- **For rapid oscillations (large  $\Delta m_s$ )  
Need good control of *t* resolution**

- Separate events with good *t* resolution
- Good decay length resolution
- Good  $B_s^0$  energy resolution



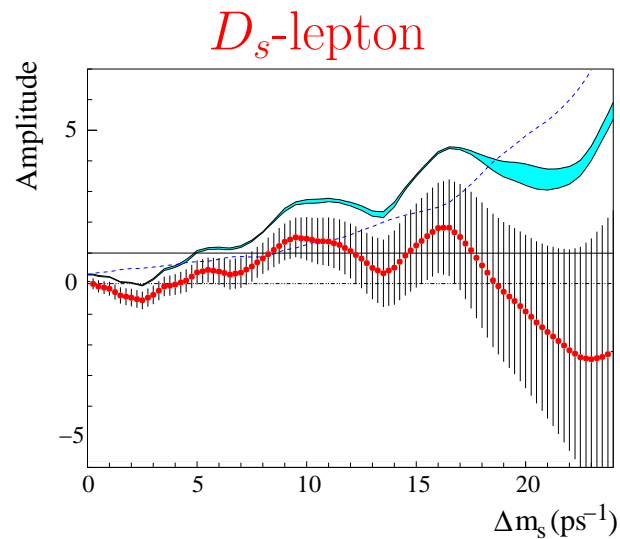
## $B_s^0 - \overline{B}_s^0$ Oscillations (II)

- Fit using the *amplitude method*
- $\mathcal{P}_{mix}^{unmix} = \frac{1}{2\tau} e^{-\frac{1}{\tau}} [1 \pm \mathcal{A} \cos(\Delta m_s t)]$
- $\mathcal{A} = 1 \rightarrow$  mixing at  $\Delta m_s$
- $\mathcal{A} = 0 \rightarrow$  no mixing at  $\Delta m_s$



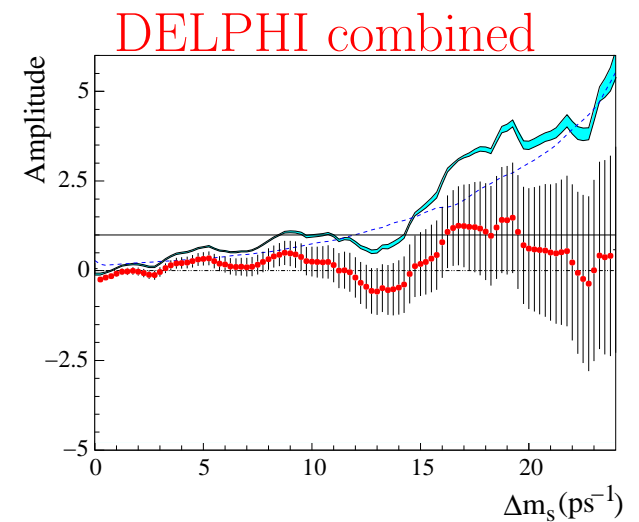
$$\Delta m_s > 8.0 \text{ps}^{-1}$$

$$\text{Sensitivity } \Delta m_s = 9.1 \text{ps}^{-1}$$



$$\Delta m_s > 4.9 \text{ps}^{-1}$$

$$\text{Sensitivity } \Delta m_s = 8.6 \text{ps}^{-1}$$



$$\Delta m_s > 8.5 \text{ps}^{-1}$$

$$\text{Sensitivity } \Delta m_s = 12.0 \text{ps}^{-1}$$

# Status of Higgs Searches

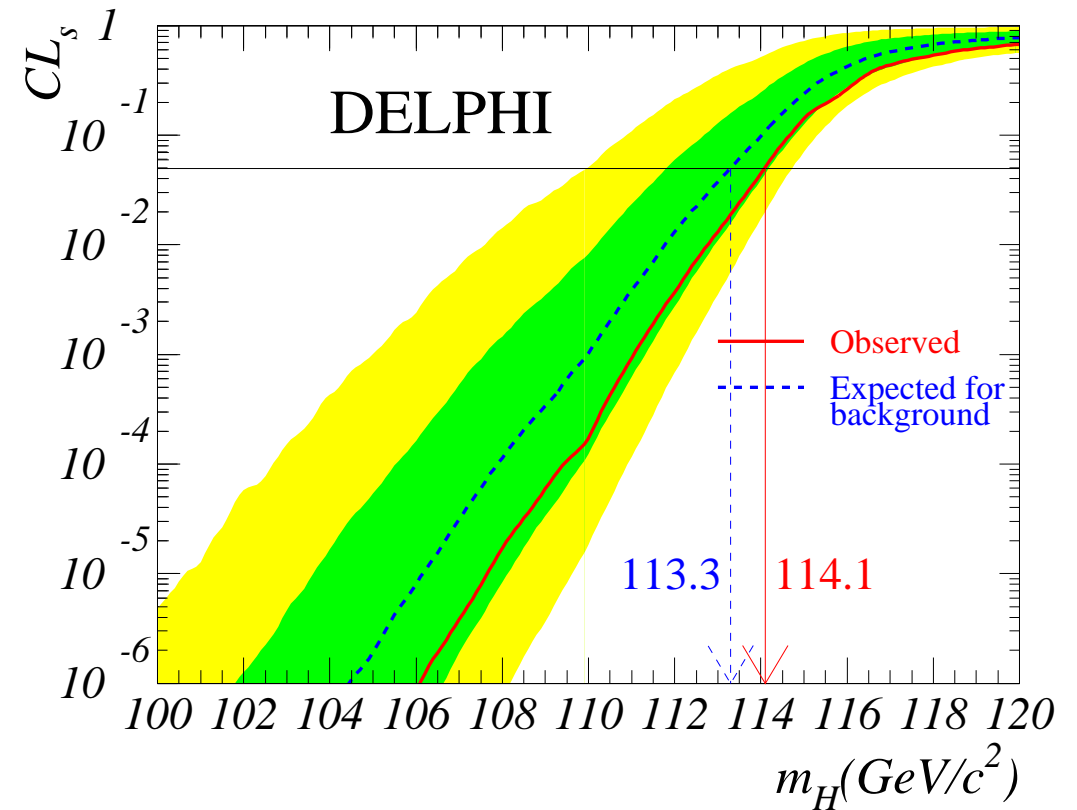
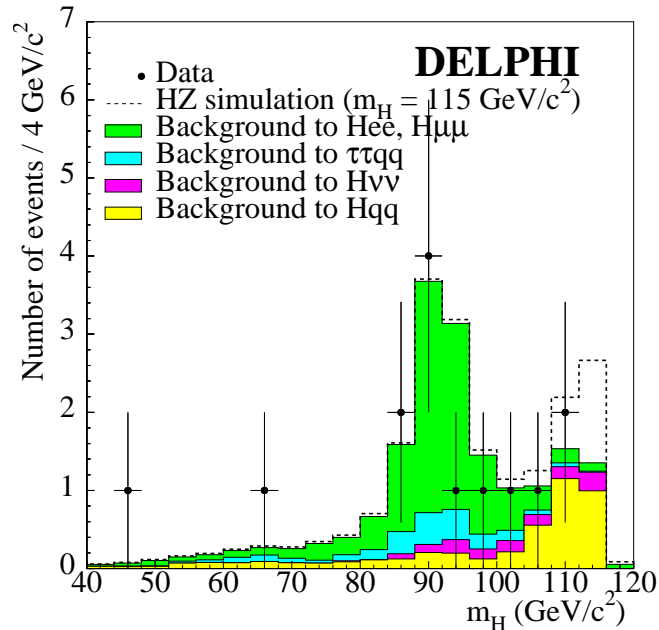
## DRAFTS

SM+MSSM Neutral Higgs    Invisible Higgs  
Charged Higgs    2HDM Extended Models

## PLANNED

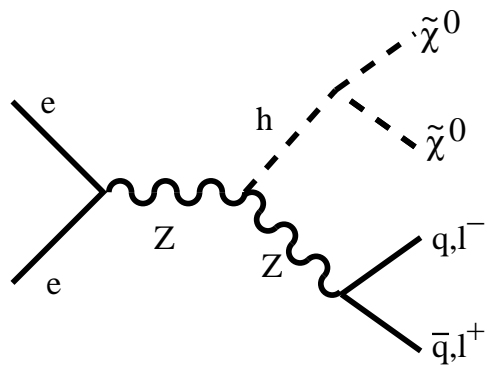
Extensions to the MSSM Neutral Higgs Searches

# SM Higgs

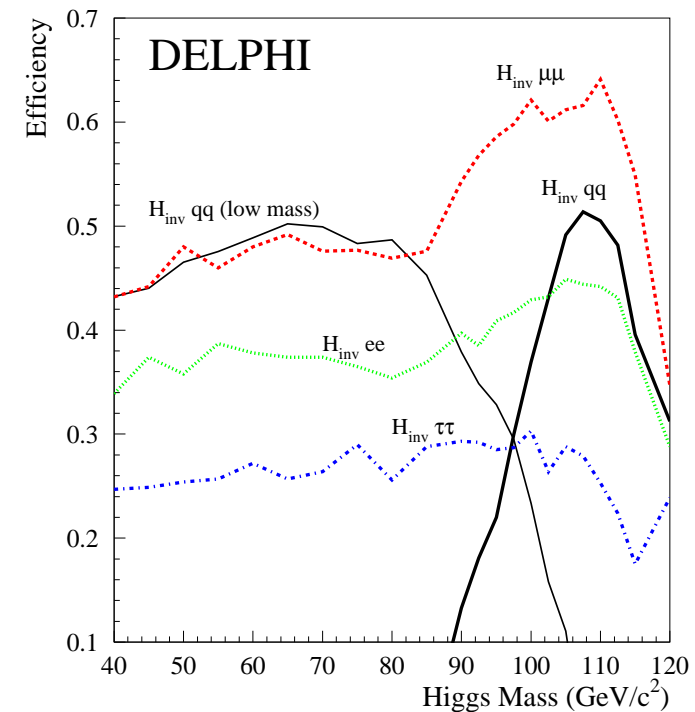


- Result unchanged since summer 2002
- Limit:  $M_H > 114.1 \text{ GeV}/c^2$   
(expected  $113.3 \text{ GeV}/c^2$ )
- Paper with EP referee

# Invisible Higgs



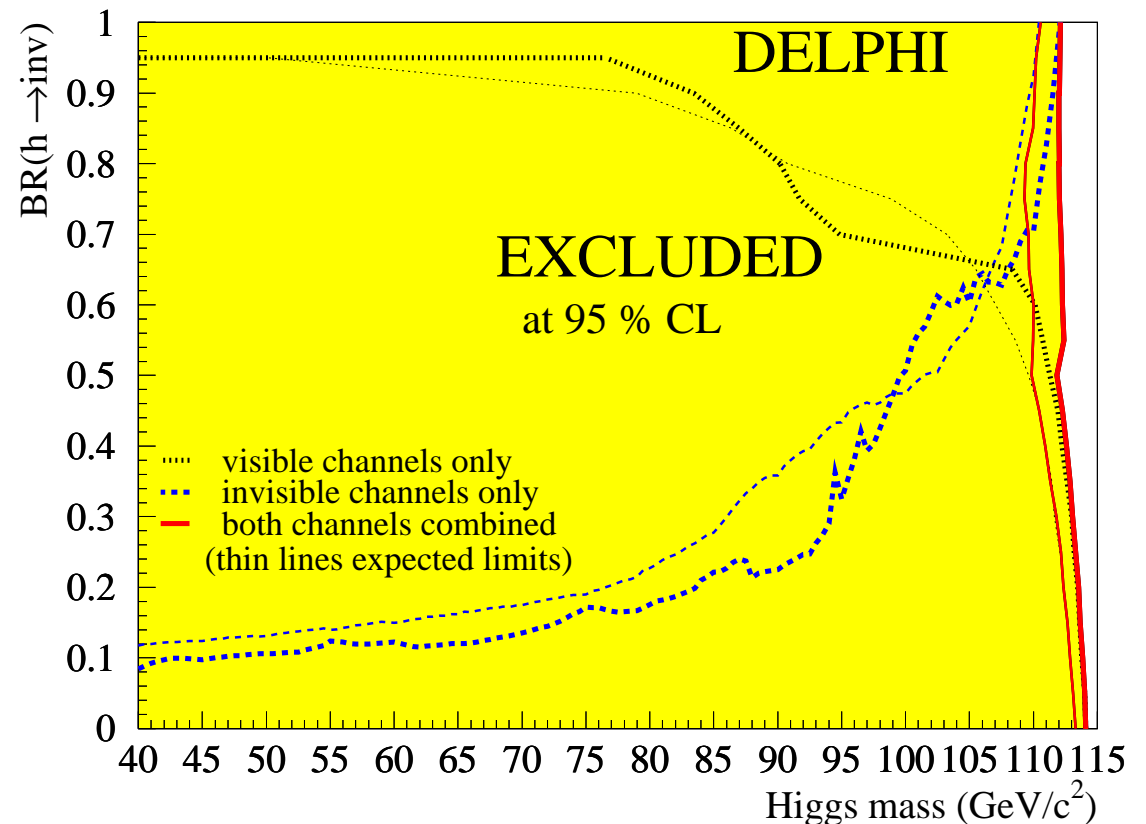
- Signatures:  $m_{vis} \sim M_Z$ ;  $\cancel{E}$
- 5 search channels
  - $q\bar{q}$ : high Higgs mass; low Higgs mass  
use IDA tuned for different  $M_H$
  - $l^+l^-$ :  $e^+e^-$   $\mu^+\mu^-$   $\tau^+\tau^-$   
use cuts ; no overlap in samples



Channel	Obs	Expected
$q\bar{q}$ (high)	153	$160.6 \pm 8.1$
$q\bar{q}$ (low)	213	$226.8 \pm 5.6$
$\mu^+\mu^-$	18	$25.7 \pm 0.9$
$e^+e^-$	20	$29.7 \pm 1.1$
$\tau^+\tau^-$	37	$43.9 \pm 1.6$

## Invisible Higgs (II)

- Limit  $BR(h \rightarrow \text{inv}) = 1$   
 $M_H > 112.1 \text{ GeV}/c^2$   
 (expected 110.5 GeV)
- Combine with SM Higgs search  
 $M_H > 112.0 \text{ GeV}/c^2$   
 For any  $BR(h \rightarrow \text{inv})$



# Status of SUSY and Exotica searches

## PUBLISHED

**Resonant  $\tilde{\nu}$  production** Doubly charged Higgs,  
Glauino as LSP GMSB  
SUGRA

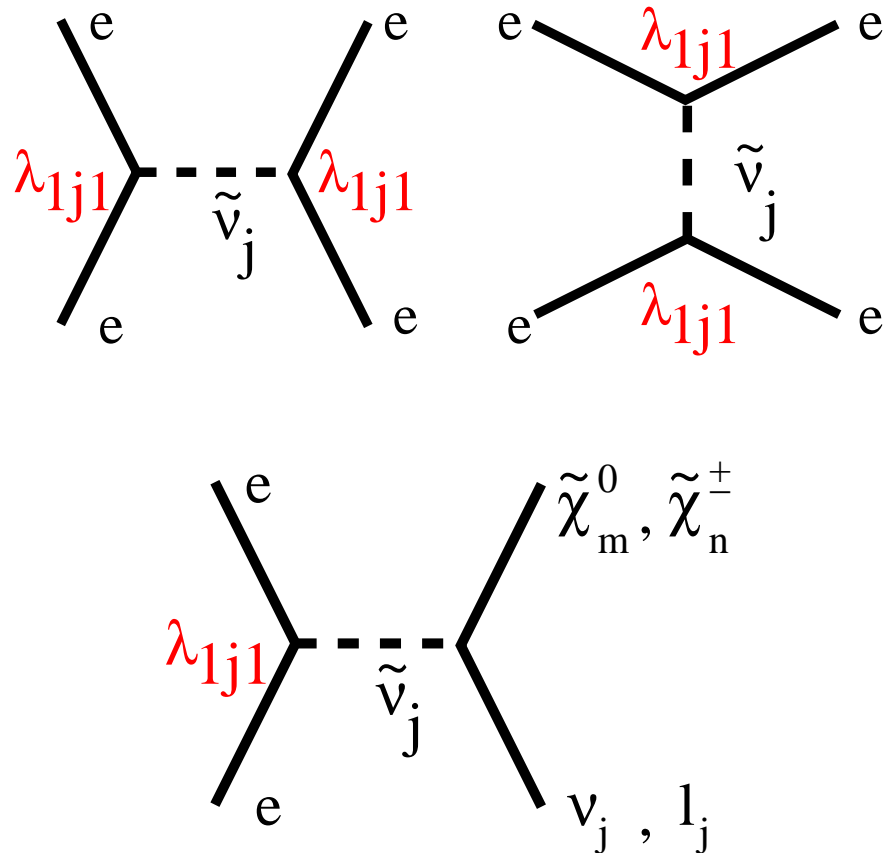
## DRAFTS

AMSB RPV  
 $\gamma \tilde{E}$  Single top via FCNC

## PLANNED

2HDM SUSY Searches Flavour indep. Higgs  
Single top production Single top via contact int.  
Leptoquarks Fermiophobic Higgs  
Excited leptons  $b'$

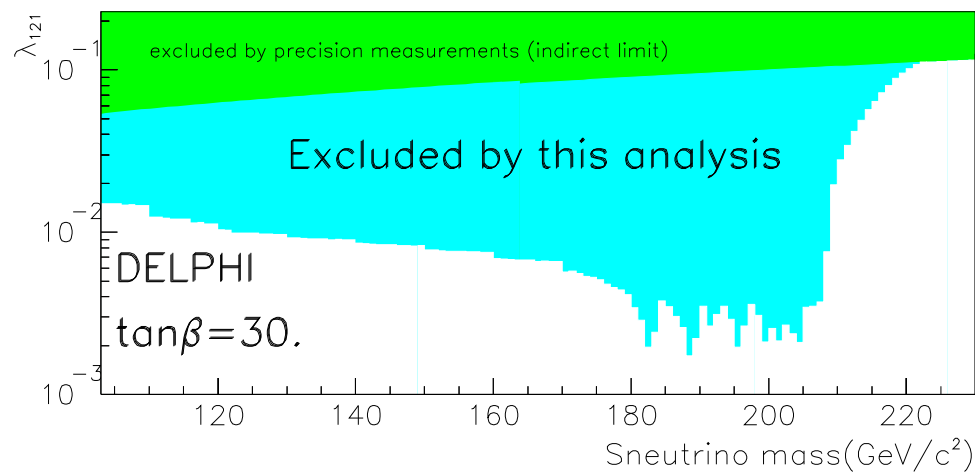
## Resonant $\tilde{\nu}$ Production



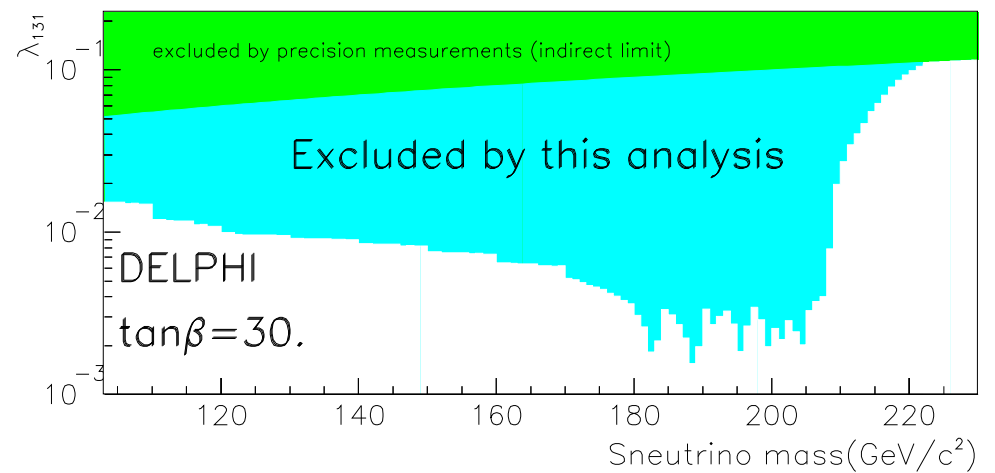
- $\mathcal{R}$ - superpotential  $\lambda_{ijk} L_i L_j \bar{E}_k$
- For  $M_{\tilde{\chi}} < M_{\tilde{\nu}}$  indirect decay of  $\tilde{\nu}$  possible
- For small  $\lambda$  may dominate over direct decay
  - $\sigma \sim \Gamma(ee)\Gamma(X)$
  - Direct decay  $\sim \lambda_{1j1}^4$
  - Indirect decay  $\sim \lambda_{1j1}^2$
- 3 topologies - depending on  $\tilde{\chi}$  decay modes
  - 2 leptons +  $\cancel{E}$
  - 4/6 leptons with/without  $\cancel{E}$
  - $\geq 2$  leptons +  $\geq 2$  jets
  - Semi-leptonic analyses different for  $j = 2, 3$  due to  $l_j$

# Resonant $\tilde{\nu}$ Production (II)

## FINAL RESULT

 $\lambda_{121}$ 


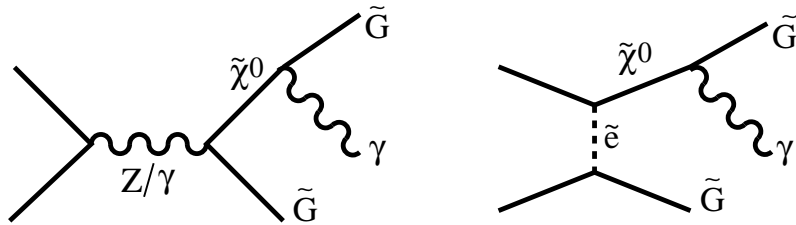
Total expected  $155.6 \pm 1.6$  events  
 Total observed 150 events  
 Limits for  $\Gamma_{\tilde{\nu}} = 150$  MeV

 $\lambda_{131}$ 


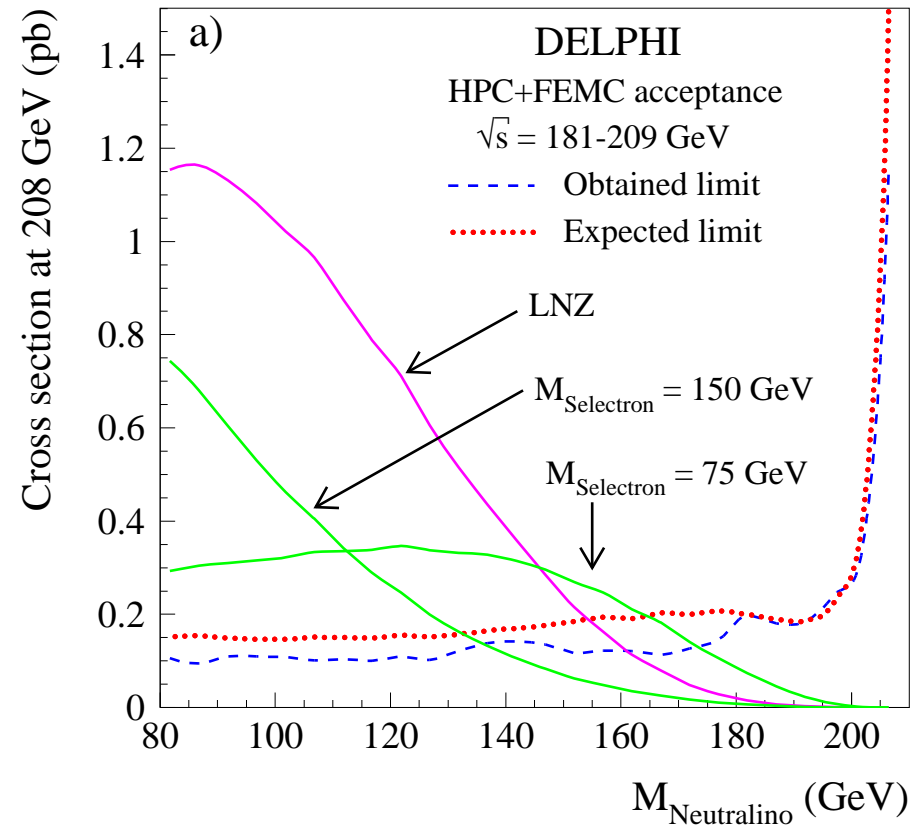
Total expected  $154.3 \pm 1.6$  events  
 Total observed 129 events  
 Limits for  $\Gamma_{\tilde{\nu}} = 150$  MeV

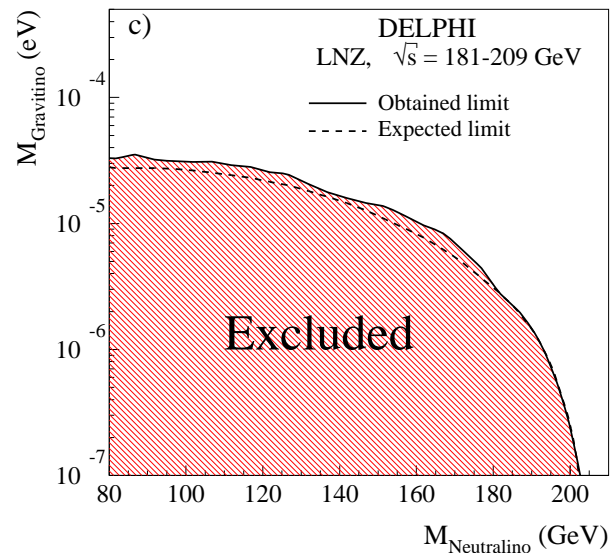
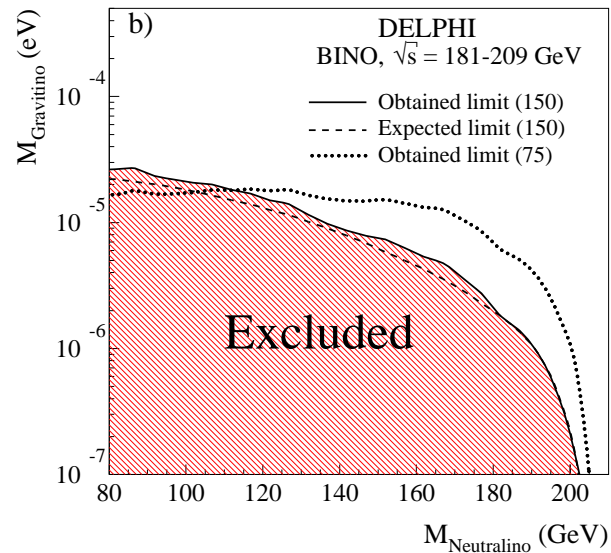


$$\gamma + \cancel{E}$$



- Cross-section depends on
  - Composition of the  $\tilde{\chi}^0$
  - $M_{\tilde{\chi}}$  and  $M_{\tilde{G}}$
  - $M_{\tilde{e}}$
- Obtain  $\sigma$  limits at 208 GeV vs  $M_{\tilde{\chi}}$ 
  - $\sqrt{s}$  and  $\cos\theta_\gamma$  dependence of limits only weakly model dependent

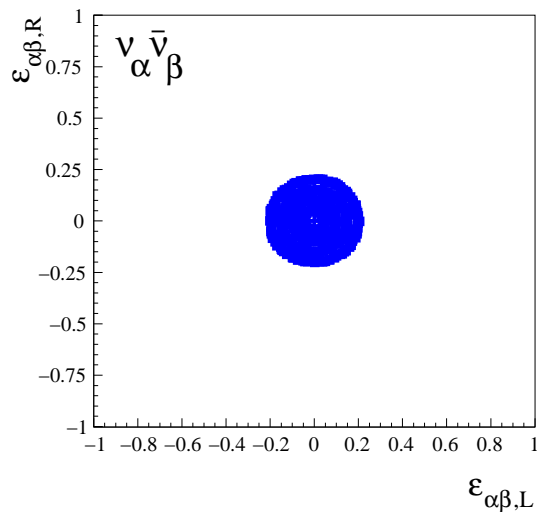
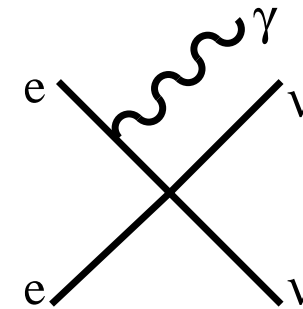
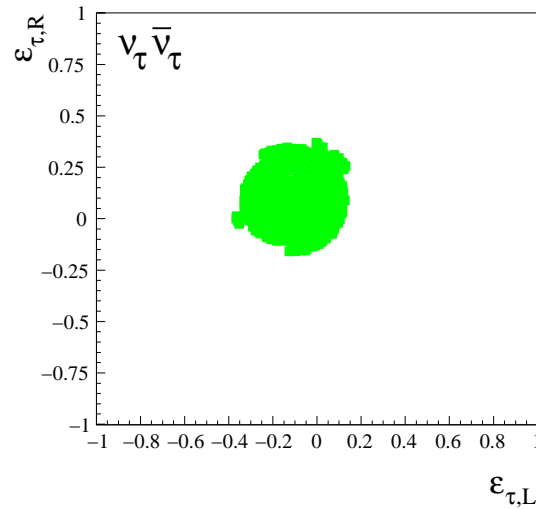
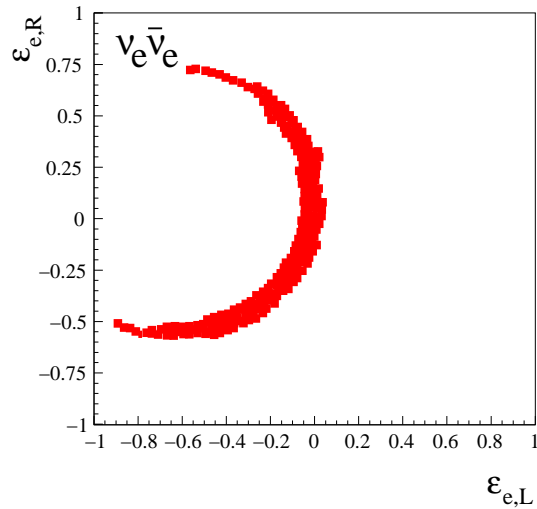


$\gamma + \cancel{E}$  (II)


- For  $\tilde{\chi}^0$  bino-like, obtain limits on  $M_{\tilde{\chi}}$  vs.  $M_{\tilde{G}}$ 
  - for given  $M_{\tilde{e}}$

- LNZ model of SUSY breaking
  - only 2 free parameters  $M_{\tilde{G}}$  and  $M_{\tilde{\chi}}$ 
    - These fix the composition of the  $\tilde{\chi}^0$
    - Favourable for significant  $\sigma$

# $\gamma + \cancel{E}$ (III)



- Search for C.I. between  $e$  and  $\nu$

- Put limits on  $\epsilon_{L/R} = g_{L/R}^2 / \Lambda_{L/R}^2$

- 3 different interpretations

Consider coupling to

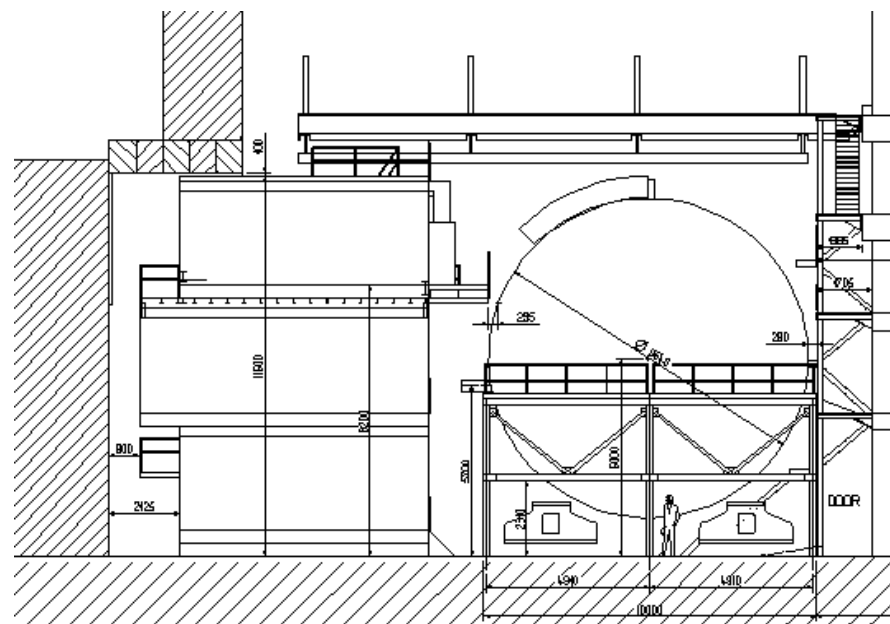
- $\nu_e \bar{\nu}_e$  - interf. with  $s/t$ -chan. SM
- $\nu_\mu \bar{\nu}_\mu / \nu_\tau \bar{\nu}_\tau$  - interf. with  $s$ -chan. SM
- $\nu_\alpha \bar{\nu}_\beta$  ( $\alpha \neq \beta$ ) - no interf. with SM

## Data archiving: a reminder

- Data are stored in **/castor**
  - To allow access to low level information in case features need to be investigated in detail
  - Raw data from the pit: 6003 GB in 58186 files
  - Real data DSTs: 7370 GB in 76292 files
  - MC DSTs: 10043 GB in 215915 files
- We have produced a CD with all DELPHI analysis software
- Would like longterm support for **FORTRAN**
- Have developed an **OO** framework for data access
  - Less well used/tested within DELPHI
- Starting internal discussion about who will be given access to data
  - Existing collaboration members only
  - ↓
  - The whole world

## Status of DELPHI

- Dead - but not buried
- DELPHI will be reopened to the general public in Summer
  - Thanks to our friends on LHCb
- DELPHI has been moved to rear/side of UX8
- Civil engineering
  - Erection of a platform
  - Discussing creation of extra elevator stop



## Conclusions

- Status of Physics Analysis
  - Since July 2002 Published 8 papers
  - Currently 28 drafts in circulation
  - Expect to produce  $\sim 30$  additional publications
  - *i.e.*  $\sim 60$  publications to come
- Support now will ensure
  - High quality final publications on complete DELPHI data set
  - Combination of results between LEP experiments
  - Maximising the scientific return on the total investment in DELPHI and LEP