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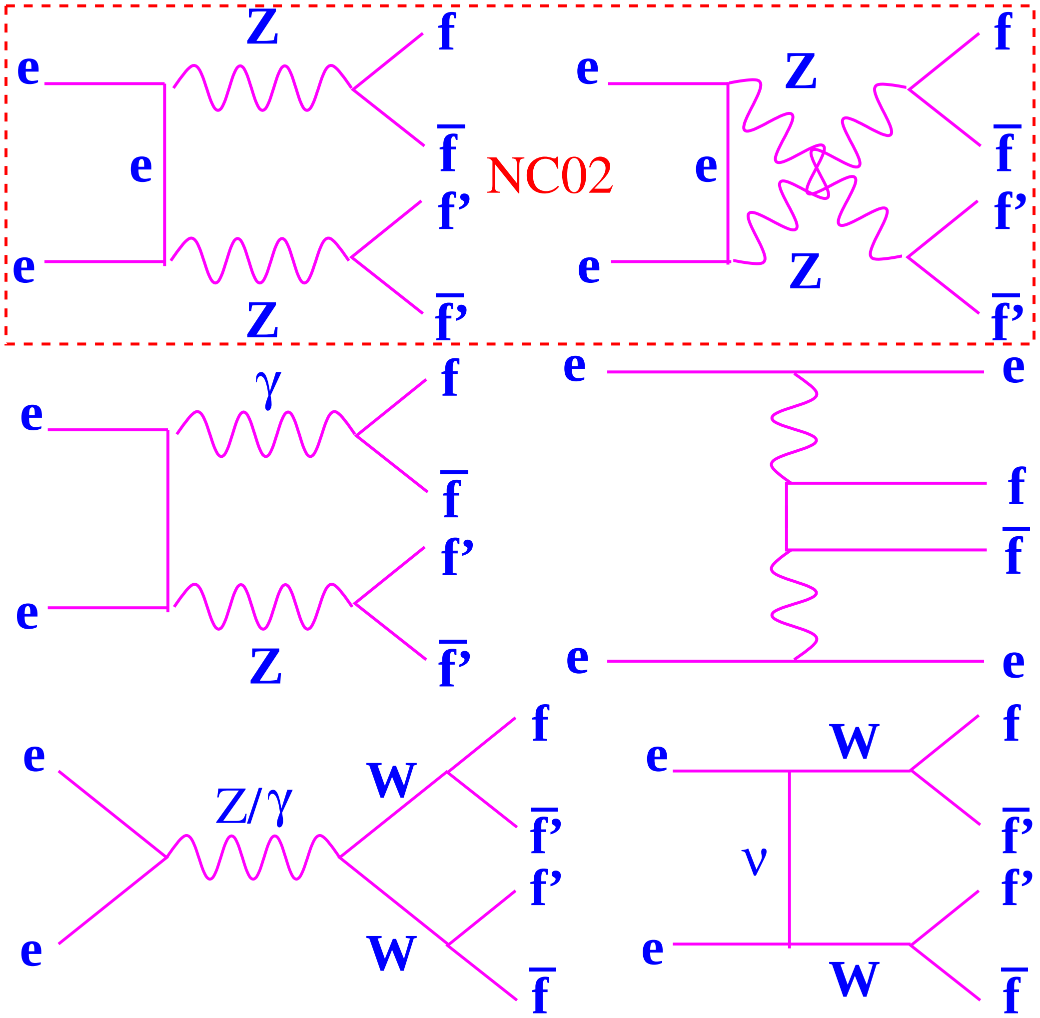
ZZ Cross-Section Measurements

On behalf of the four LEP Collaborations

- Signal Definition
- Physics Motivations
- Data Sample
- Analysis Procedure
- Results (also on $Z\gamma^{\star}$)
- (Some) Interpretations

ICHEP2000
XXX$^{\text{th}}$ International Conference on High Energy Physics
Osaka, Japan, July 27$^{\text{th}}$ – August 2nd 2000

Signal Definition



Aleph:
NC02

Delphi:
$|M_{f\bar{f}} - M_Z| < 10$ GeV
No CC

L3:
$M_{f\bar{f}} \in (70-105)$ GeV
$|\cos\theta_e| < 0.95$
$M_{f\bar{f}'} \notin (75-85)$ GeV

Opal:
NC02

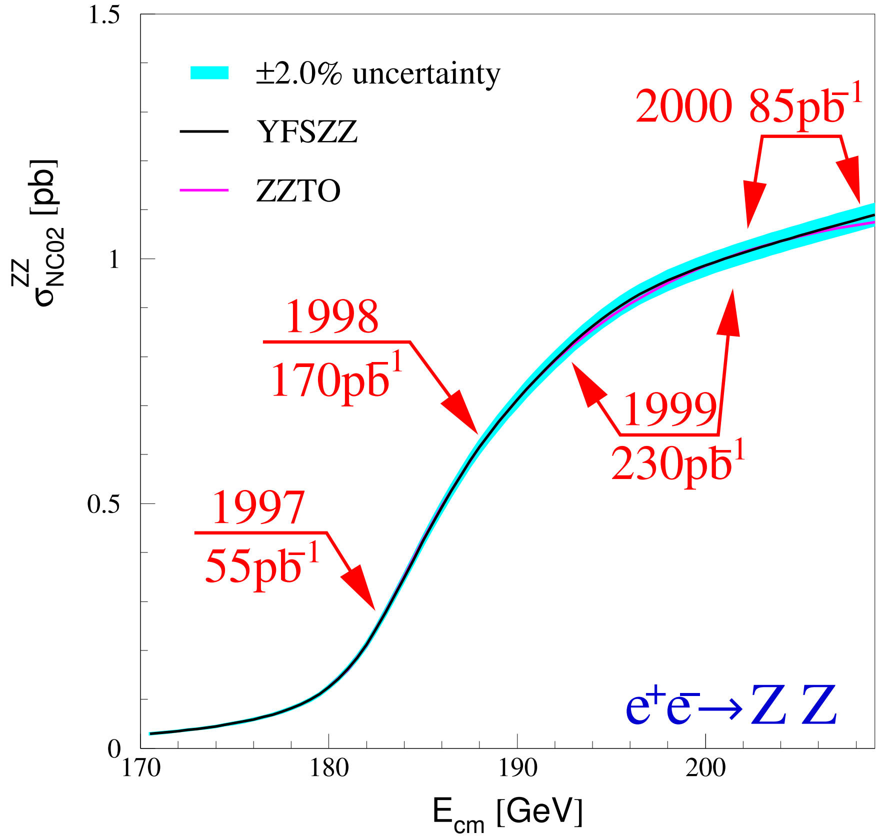
LEP Combination: NC02

Physics Motivations

- **Test of the Standard Model in the sector of Neutral Currents**
- **Study of possible Triple Vertices of Neutral Gauge Bosons (forbidden in the Standard Model) $\Longrightarrow$ Clara Matteuzzi's talk**
- **Sensitive to manifestations of new physics like Extra Spatial Dimensions (Low Scale Gravity)**
- **Also sensitive to excited electrons and SUSY, not yet studied experimentally**
- **Test Bench of the LEP detector capability to detect Higgs bosons**

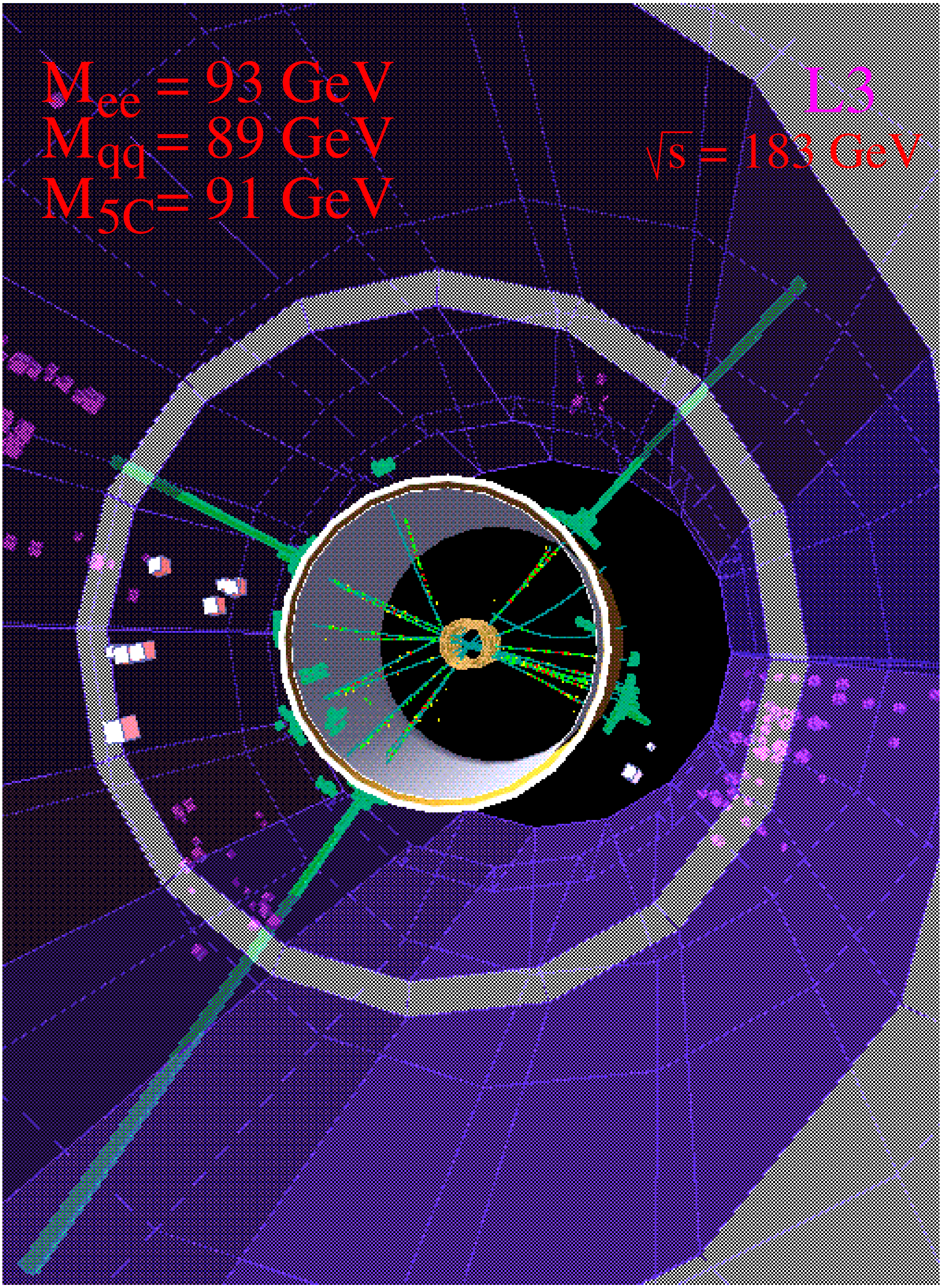
Predictions, data sample and signatures

~0.5 fb^{-1}/experiment ~2.2 fb^{-1} total

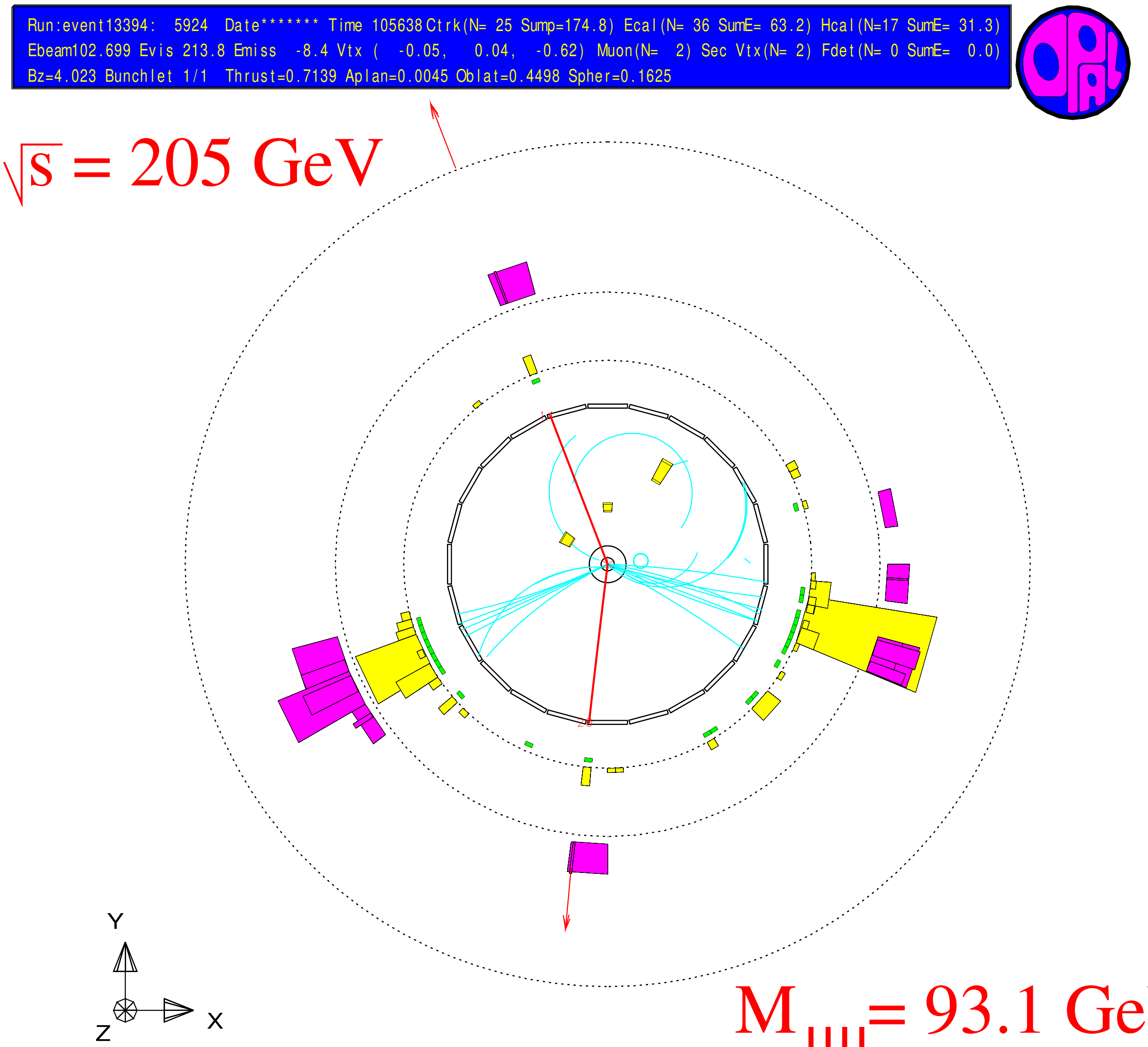


All ZZ results above 190GeV are preliminary

Channel	Statistics	Signature	Background	Contamination
$q\bar{q}q'\bar{q}'$	High	4 jets	QCD $W^+W^- \rightarrow$ 4 jets	High
$q\bar{q}\nu\bar{\nu}$	High	2 jets + Missing energy	QCD $W^+W^- \rightarrow q\bar{q}\ell\nu$ $We\nu$	Average
$q\bar{q}\ell^+\ell^-$	Average	2 jets + 2 leptons	W^+W^- 4f not ZZ	Low
$\ell^+\ell^-\nu\bar{\nu}$	Average	2 leptons + Missing energy	4f not ZZ W^+W^- $\ell^+\ell^-$	Average
$\ell_1{}^+\ell_1{}^-\ell_2{}^+\ell_2{}^-$	Low	4 leptons	4f not ZZ	Low


$M_{ee} = 93$ GeV
$M_{qq} = 89$ GeV
$M_{5C} = 91$ GeV
L3
$\sqrt{s} = 183$ GeV

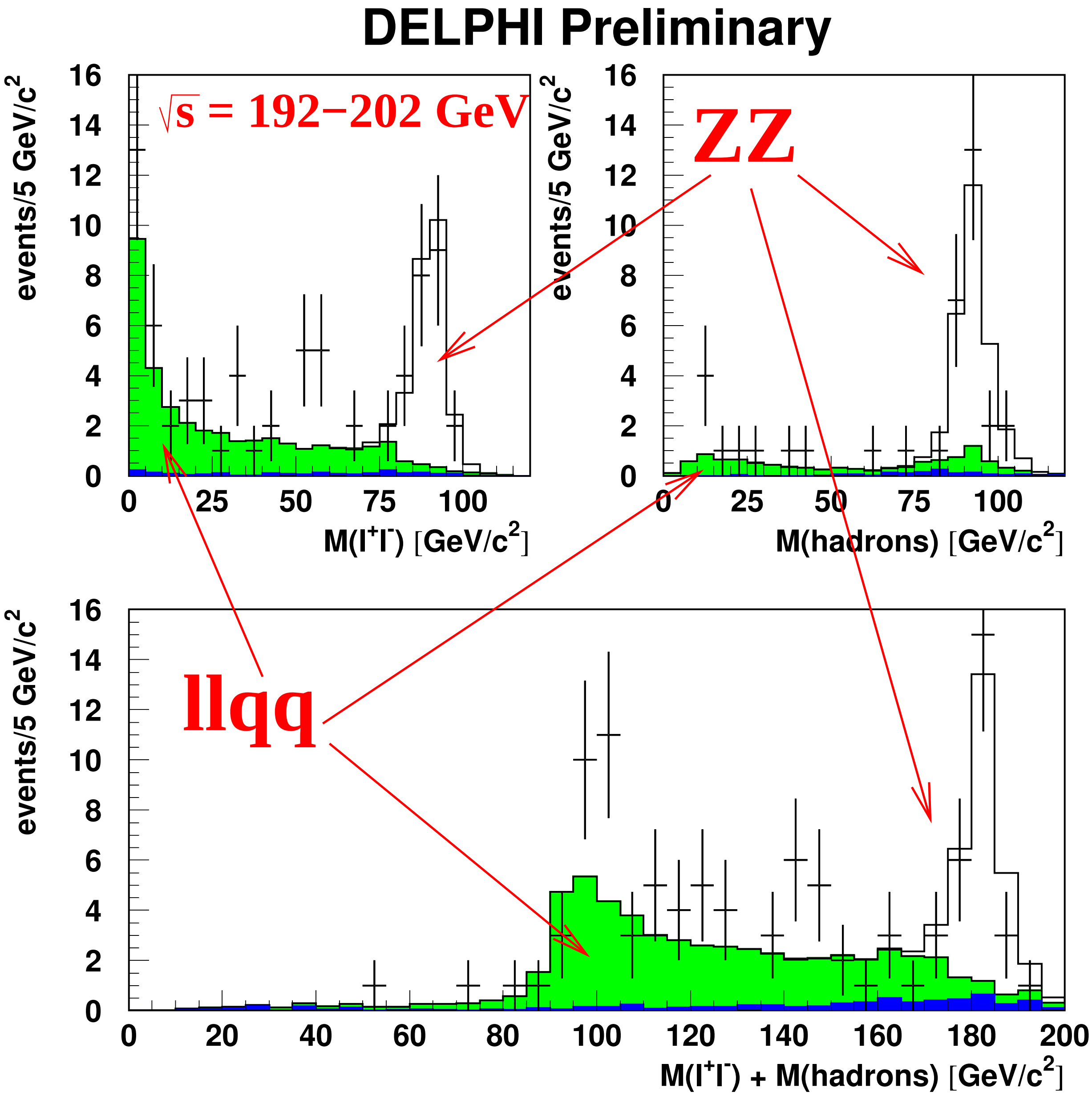
$e^+e^- \rightarrow ZZ \rightarrow q\bar{q}\mu^+\mu^-$



$\sqrt{s} = 205$ GeV

$M_{\mu\mu} = 93.1$ GeV
$M_{qq} = 90.6$ GeV

$e^+e^- \to ZZ \to q\bar{q}\ell^+\ell^-$



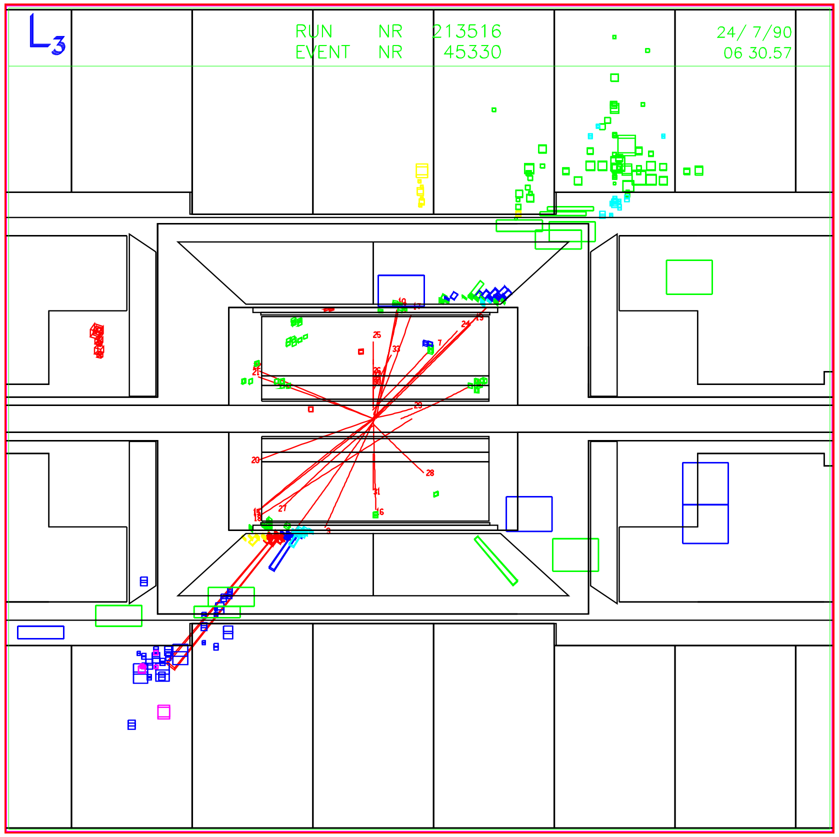
- Invariant masses of leptons and hadrons
- Opening angles

Removing one of the mass constraints for $\mu^+\mu^- q\bar{q}$:

$$\sigma^{183\ \mathrm{GeV}-208\ \mathrm{GeV}}_{e^+e^-\to Z\gamma^\star\to\mu^+\mu^- q\bar{q}} = 0.22 \pm 0.05 \pm 0.02\,\mathrm{pb}$$

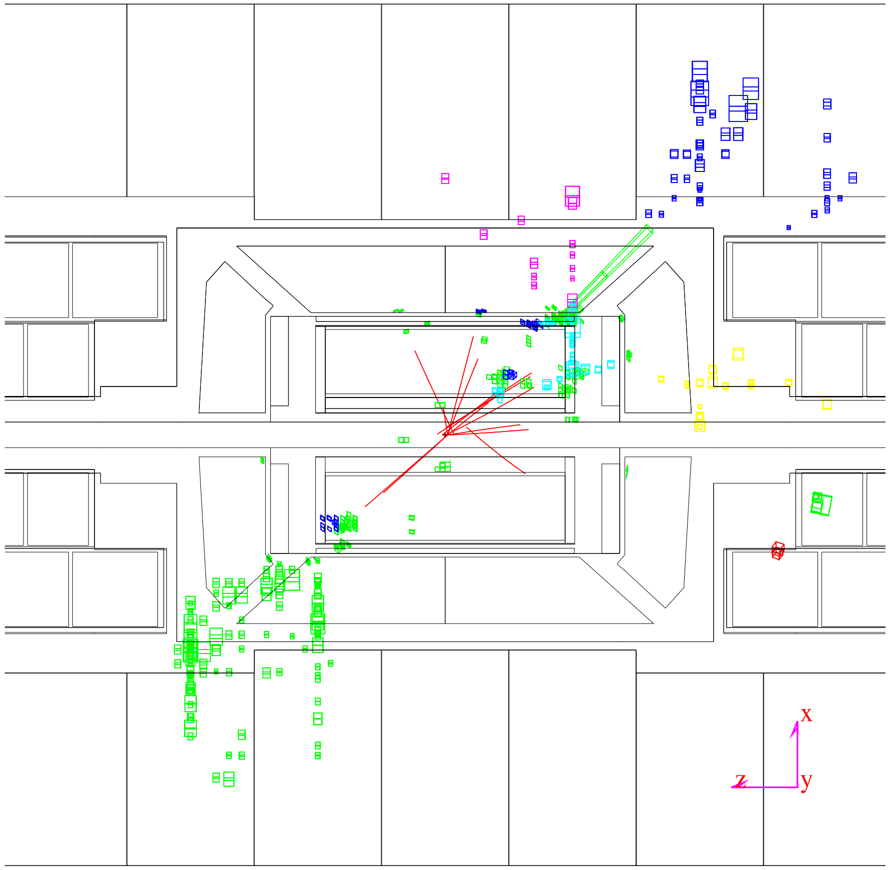
$$(\mathrm{SM}\,0.19 - 0.25\,\mathrm{pb})$$

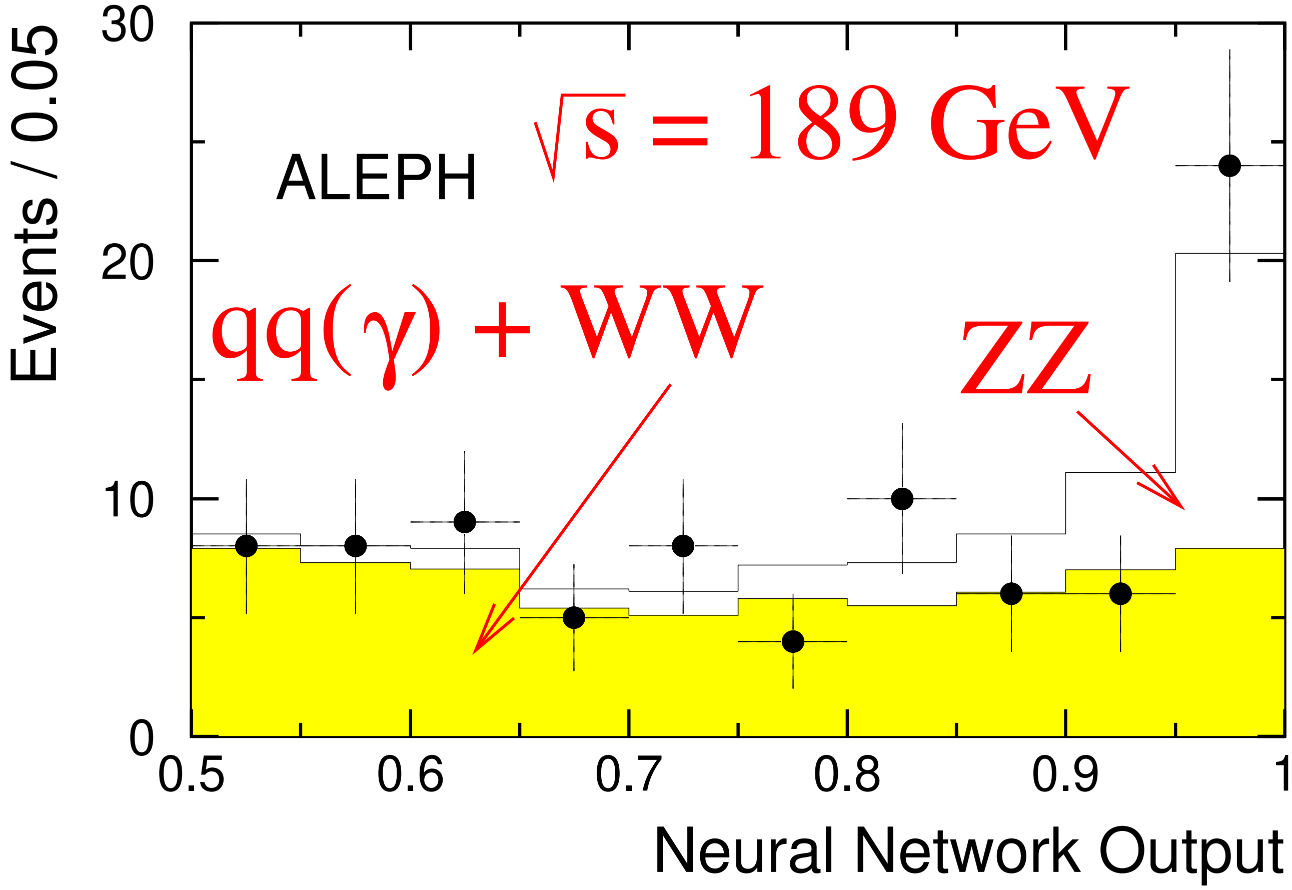
$e^+e^- \to \mathbf{Z} \to \mathbf{q\bar{q}}$ @ $\mathbf{91}$ GeV



$e^+e^- \to \mathbf{ZZ} \to \mathbf{q\bar{q}}\nu\bar{\nu}$ @ $\mathbf{183}$ GeV

Run # 671506 Event # 1534 DAQ Time: 03-08-1997 15:18:18

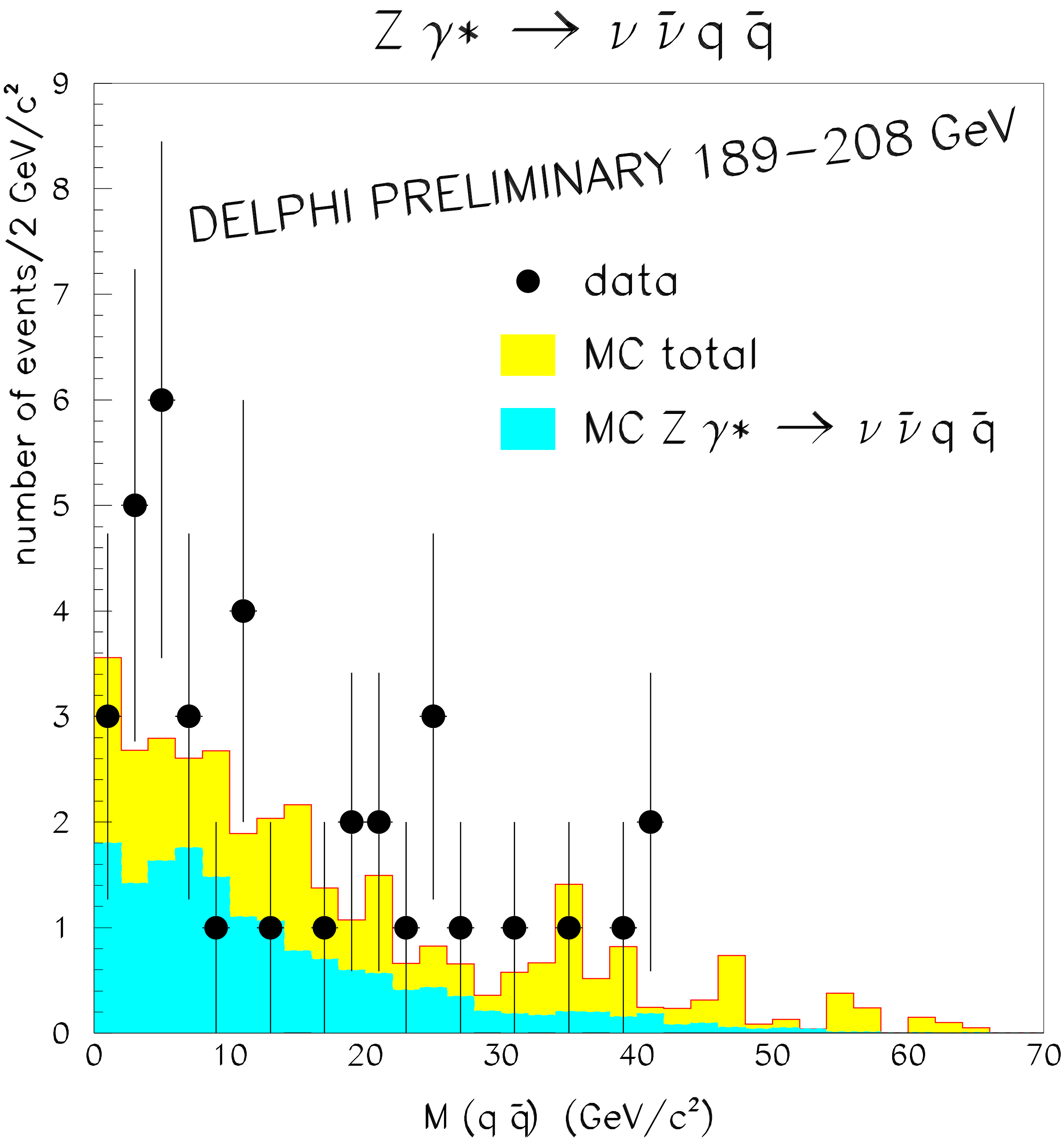




Neural Networks/Likelihoods with:

- Visible mass and energy
- Missing mass and momentum
- Two *vs* three jet topology
- (b-quark content)

$e^+e^- \to Z\gamma^\star \to q\bar{q}\nu\bar{\nu}$

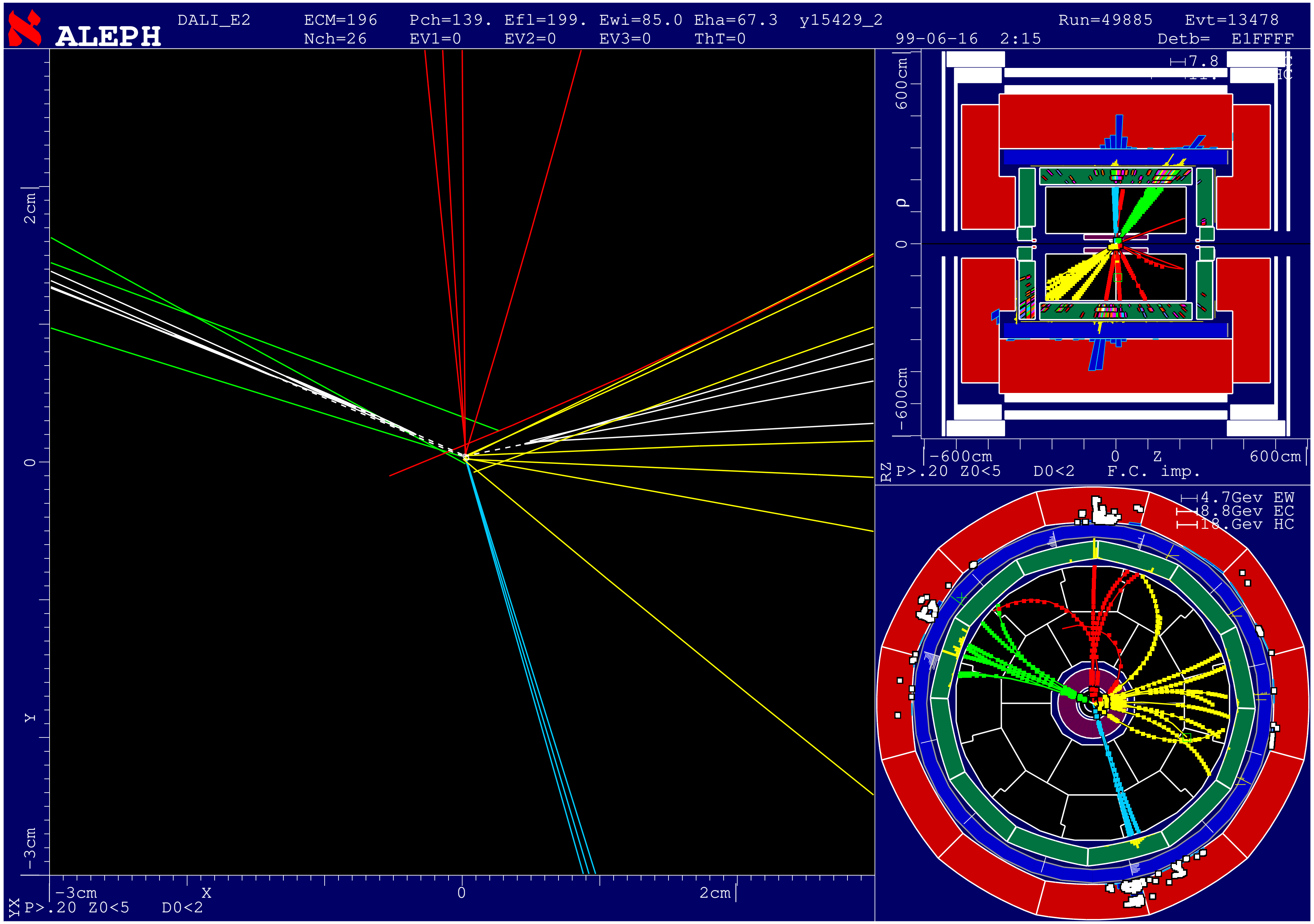


Defining the signal as $M_{q\bar{q}} < 60$ GeV:

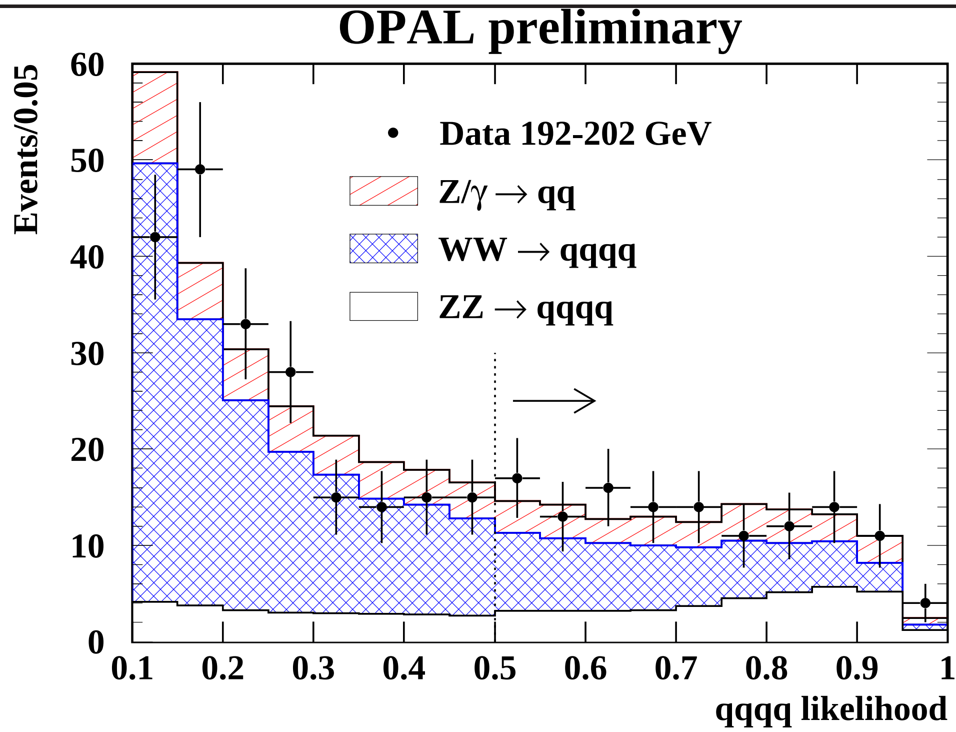
$$\sigma^{183\ \mathrm{GeV}-208\ \mathrm{GeV}}_{e^+e^-\to Z\gamma^\star\to\nu\bar{\nu}q\bar{q}} = 0.19 \pm 0.06 \pm 0.02\,\mathrm{pb}$$

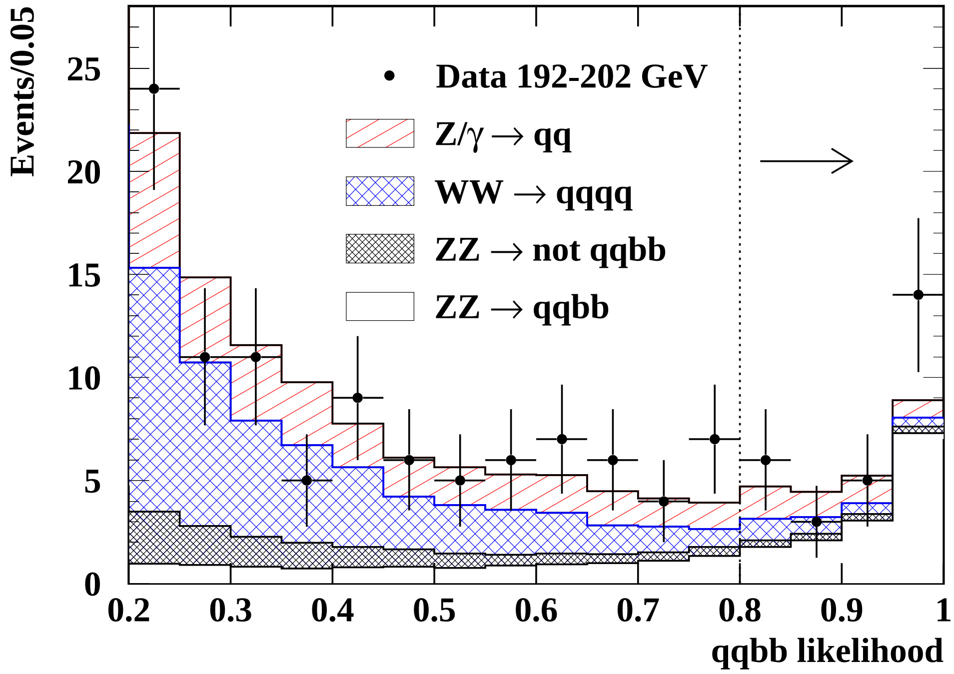
$$(\mathrm{SM}\,0.13 - 0.16\,\mathrm{pb})$$

$e^+e^- \to ZZ \to q\bar{q}b\bar{b}$



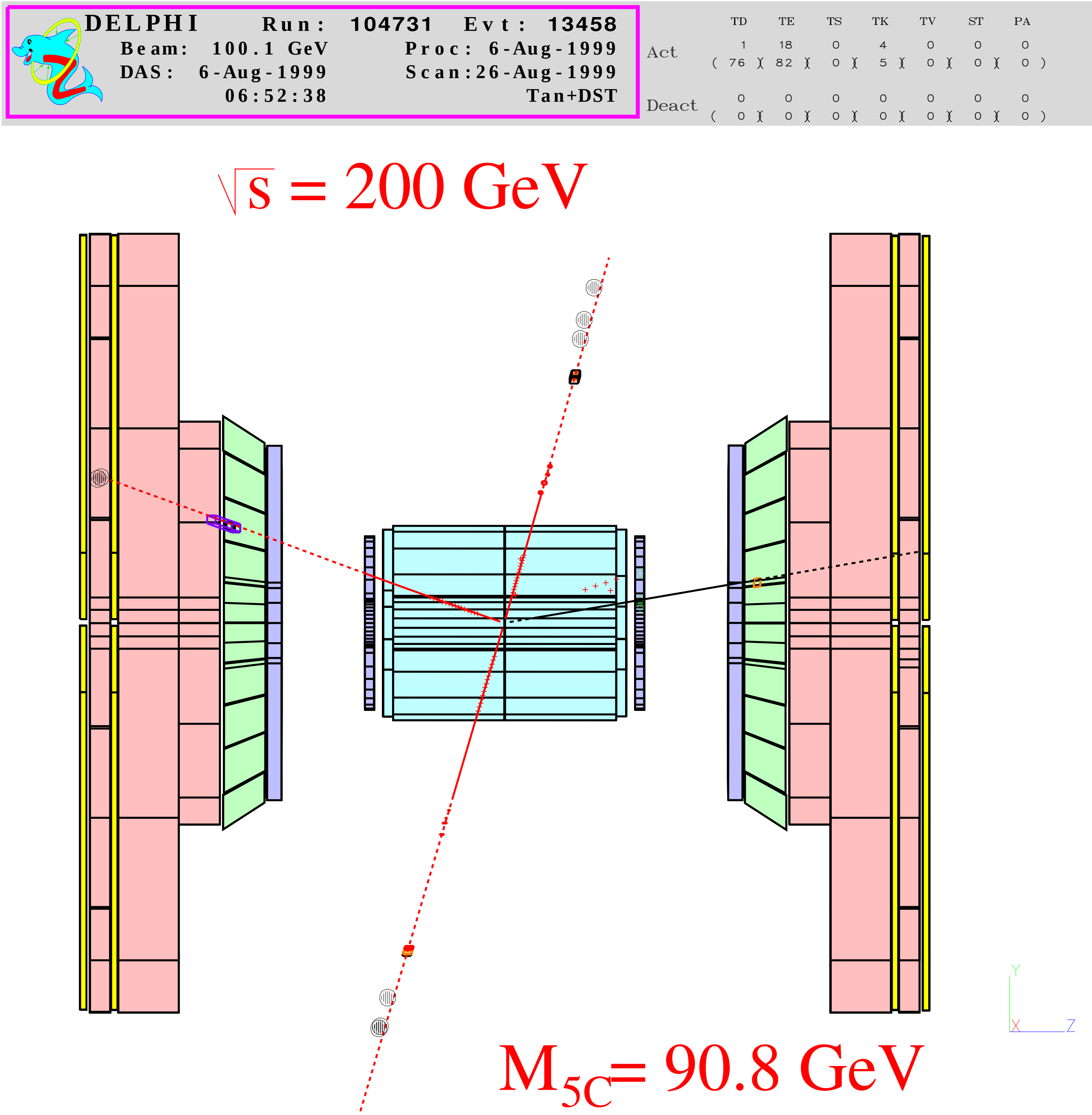
$e^+e^- \to ZZ \to q\bar{q}b\bar{b}$



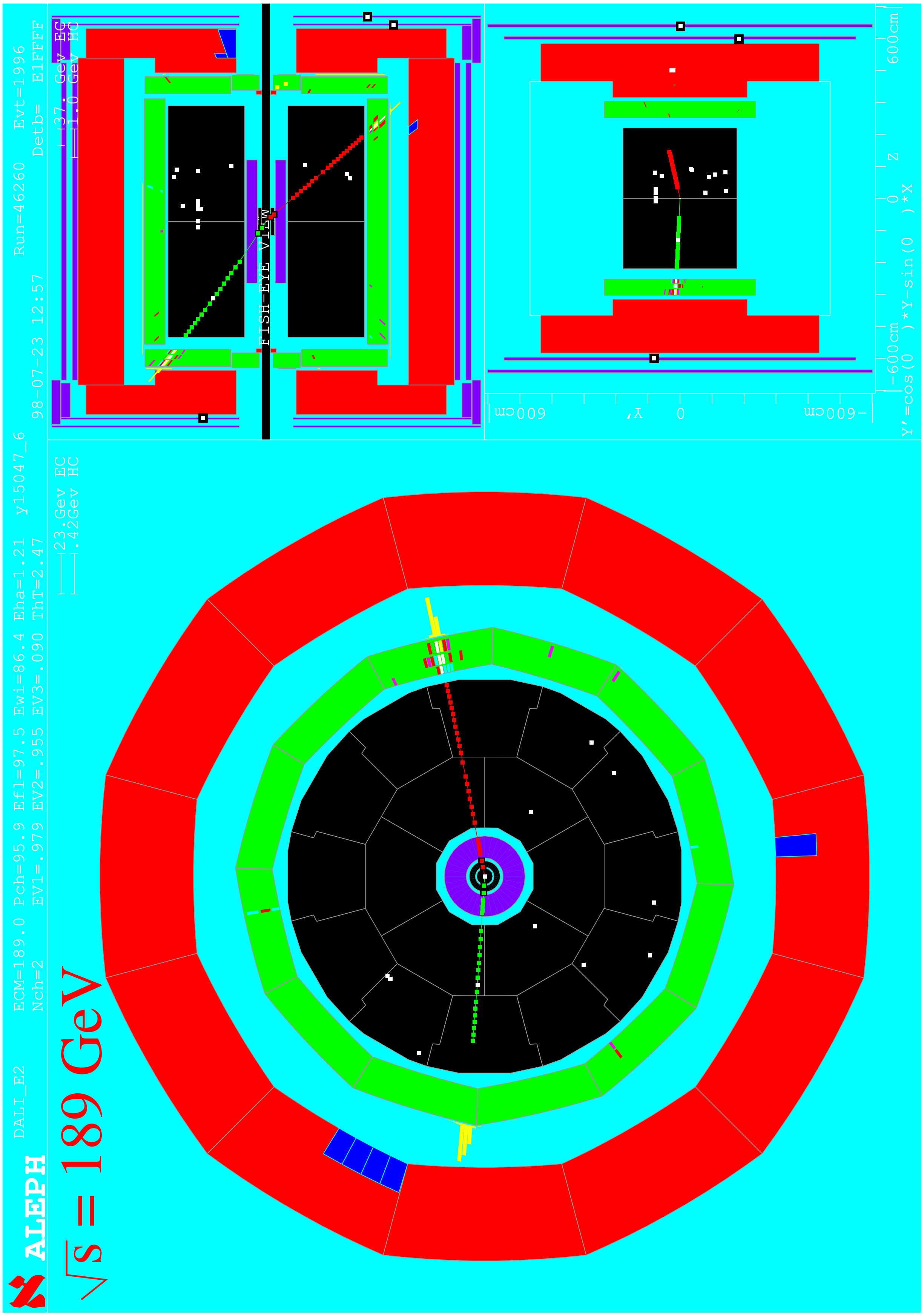


Neural Networks/Likelihoods with:

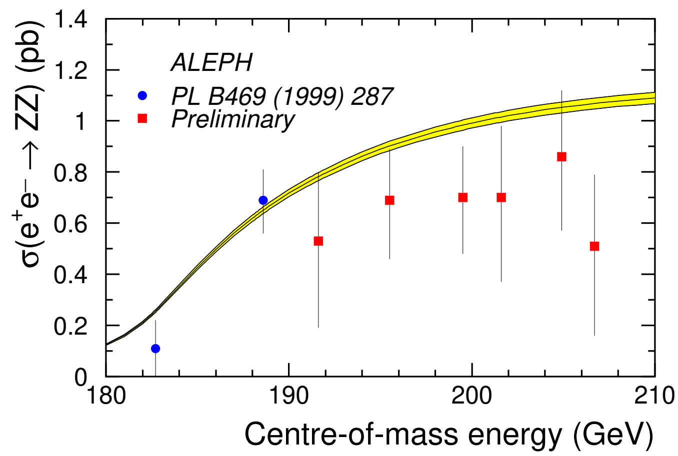
- Two *vs* four jet topology
- Kinematic fit to equal mass particles
- b-quark content

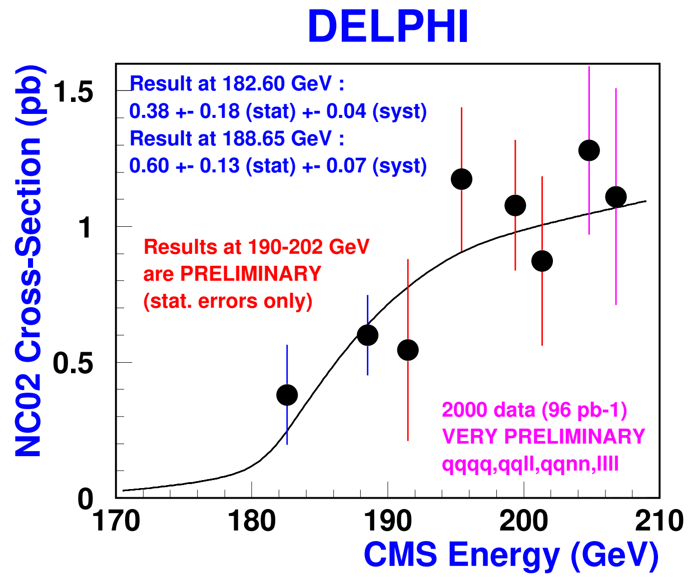


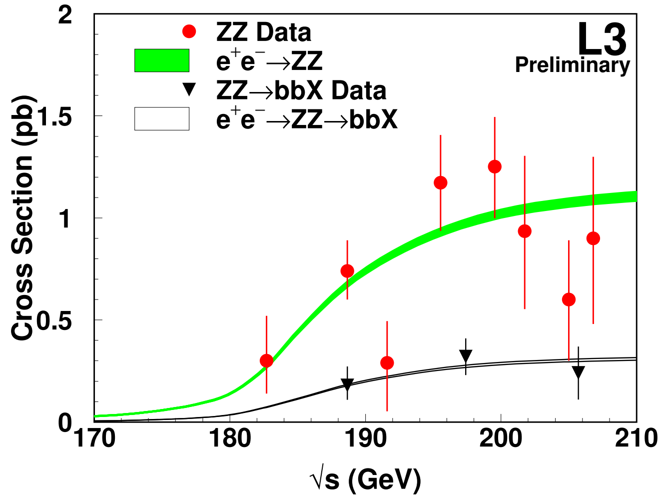
- **Identified leptons**
- **Invariant masses and opening angles**

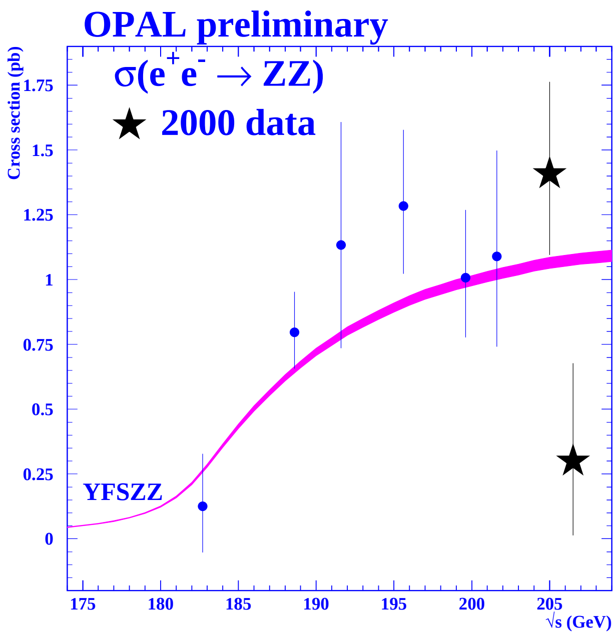

ALEPH
DALI_E2
ECM=189.0 Pch=95.9 Efl=97.5 Ewi=86.4 Eha=1.21 y15047_6
Nch=2 EV1=.979 EV2=.955 EV3=.090 ThT=2.47
98-07-23 12:57
Run=46260 Evt=1996
Detb= E1FFFF
√s = 189 GeV
23.Gev EC
.42Gev HC
37. Gev EC
1.0 Gev HC
FISH-EYE VIEW
600cm
Y'
0
-600cm
Z
Y'=cos(0)*Y-sin(0)*X

All the experiments fit the discriminating distributions and/or count events, finding a good agreement with the Standard Model predictions:

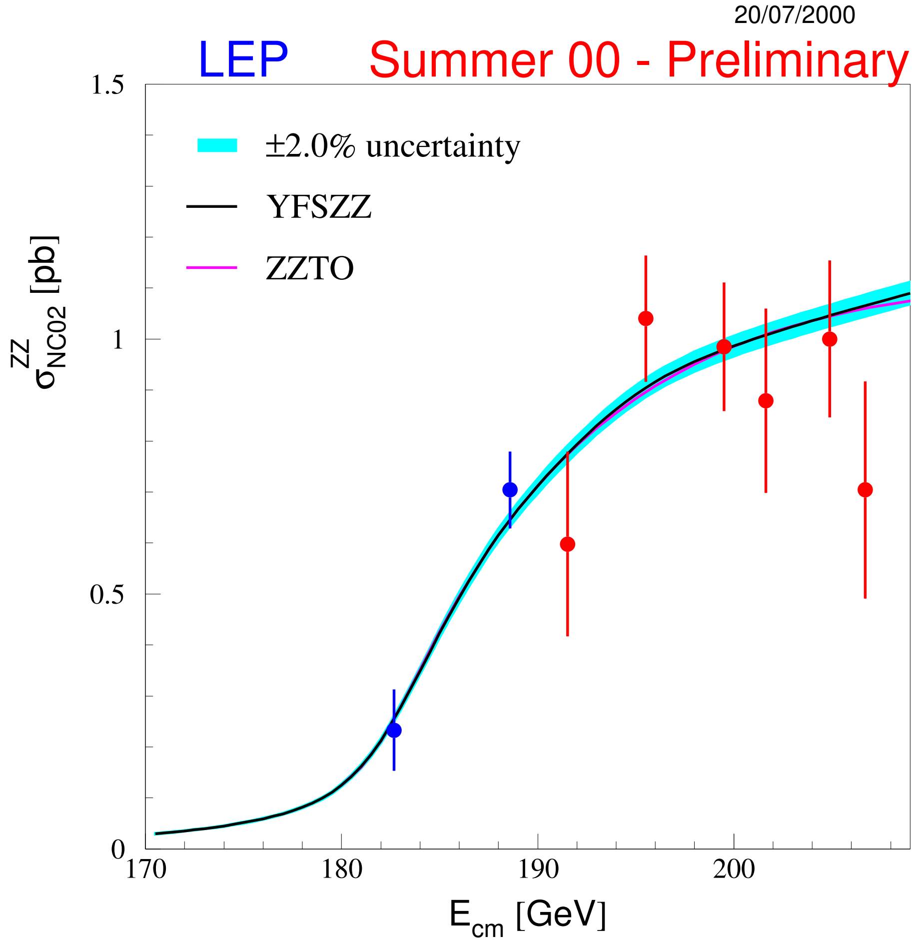






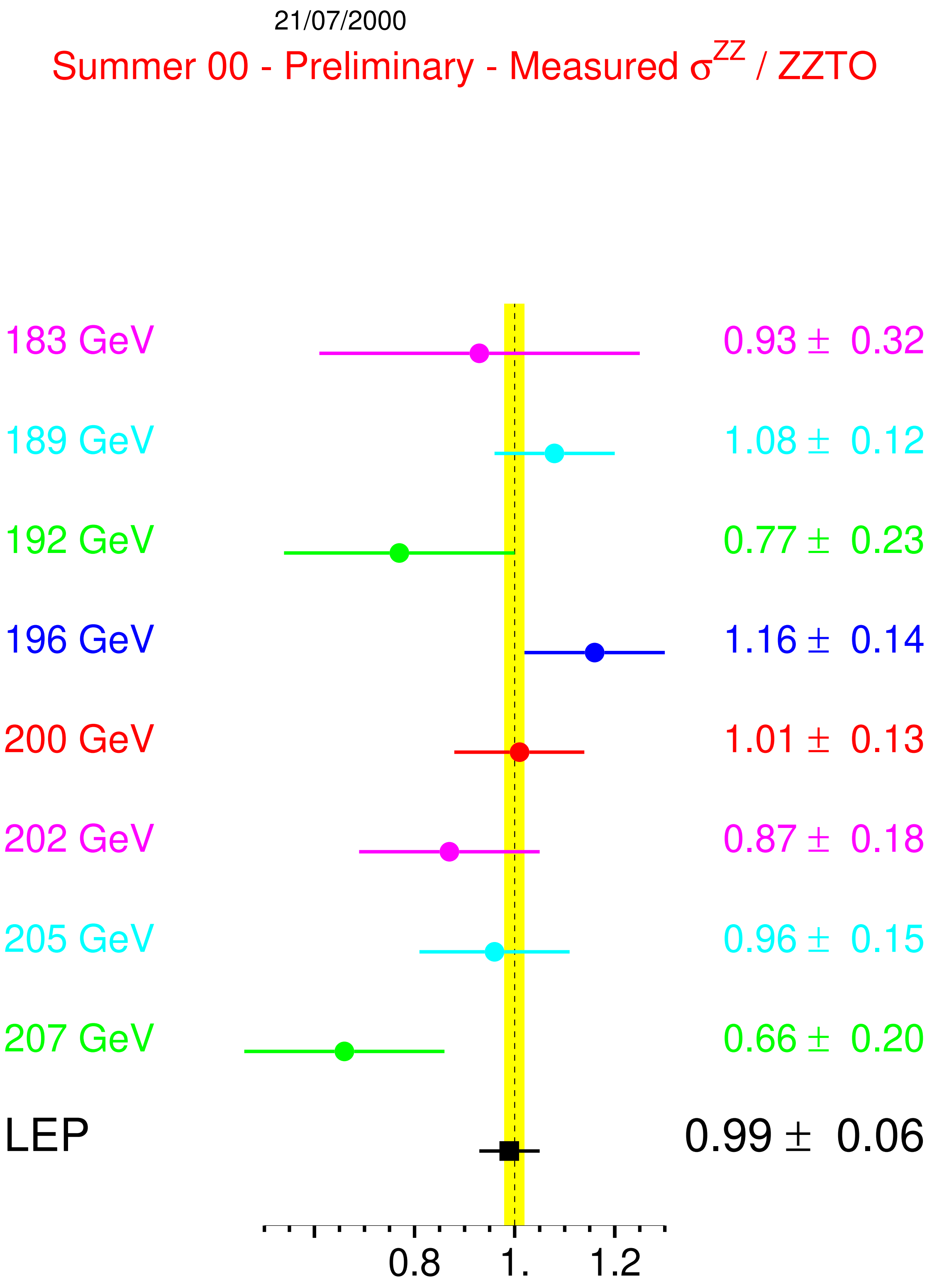


Combining the results in the NC02 assumption:

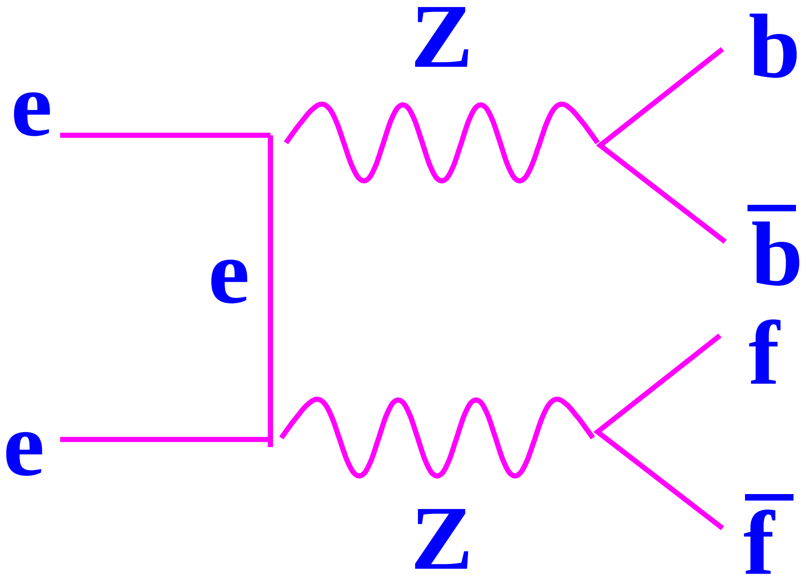


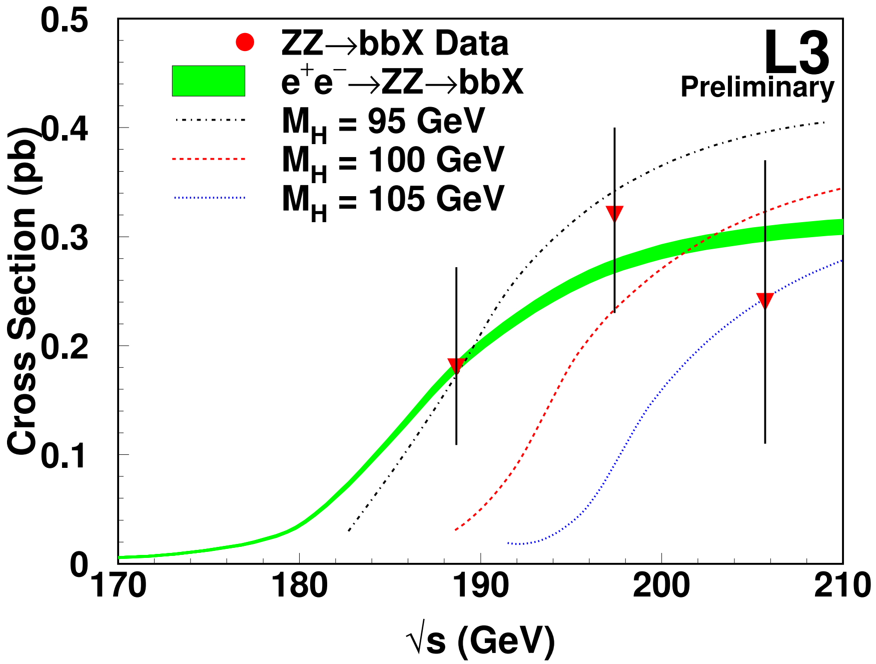
$$\sigma_{ZZ}(182.7\ \mathrm{GeV}) = 0.23 \pm 0.08 \pm 0.02\,\mathrm{pb}$$
$$\sigma_{ZZ}(188.7\ \mathrm{GeV}) = 0.70 \pm 0.07 \pm 0.03\,\mathrm{pb}$$
$$\sigma_{ZZ}(191.5\ \mathrm{GeV}) = 0.60 \pm 0.18 \pm 0.04\,\mathrm{pb}$$
$$\sigma_{ZZ}(195.6\ \mathrm{GeV}) = 1.04 \pm 0.12 \pm 0.04\,\mathrm{pb}$$
$$\sigma_{ZZ}(199.6\ \mathrm{GeV}) = 0.98 \pm 0.12 \pm 0.04\,\mathrm{pb}$$
$$\sigma_{ZZ}(201.7\ \mathrm{GeV}) = 0.88 \pm 0.08 \pm 0.04\,\mathrm{pb}$$
$$\sigma_{ZZ}(205.0\ \mathrm{GeV}) = 1.00 \pm 0.15 \pm 0.05\,\mathrm{pb}$$
$$\sigma_{ZZ}(206.8\ \mathrm{GeV}) = 0.70 \pm 0.21 \pm 0.05\,\mathrm{pb}$$

Excellent agreement with the Standard Model predictions

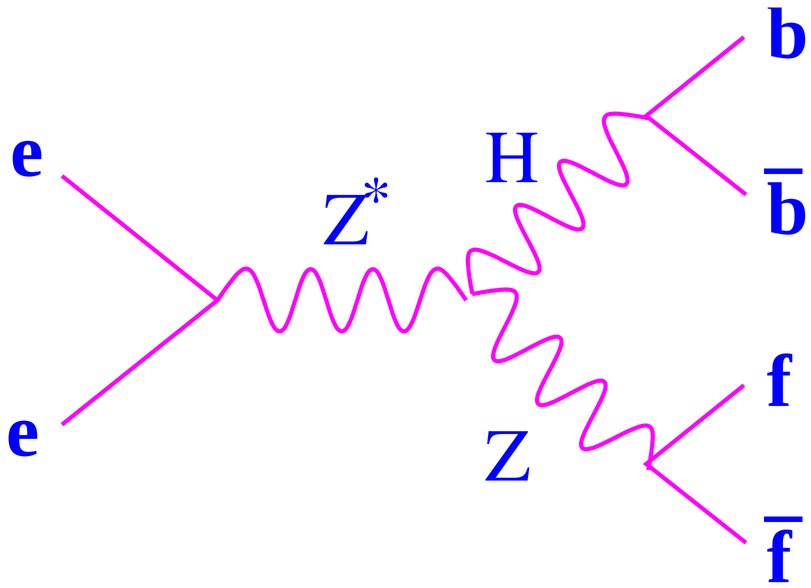


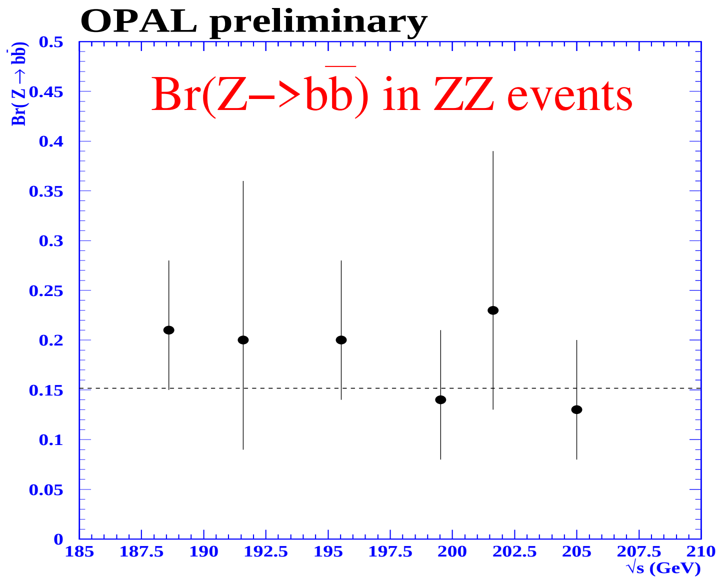
If we can observe

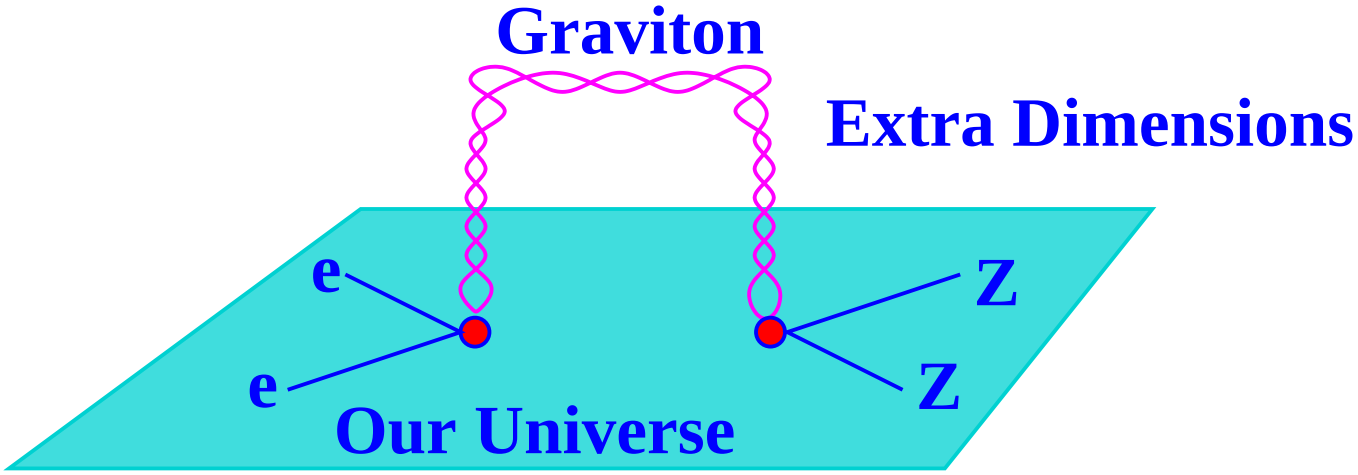




We are also sensitive to:







$$\frac{d\sigma}{d\Omega}(s,t) = \frac{d\sigma^{SM}}{d\Omega}(s,t) +$$

$$+\frac{\lambda}{M_S{}^4}\alpha_{\mathrm{Interf.}}(s,t) + \frac{\lambda^2}{M_S{}^8}\beta_{\mathrm{Low\,Scale\,Gravity}}(s,t)$$

Extract 95% CL lower limits from a fit to total cross-section/angular information one extracts

	$\lambda = -1$ M_S (TeV)	$\lambda = +1$ M_S (TeV)
L3	1.2	1.2
OPAL	0.6	0.8

Conclusions

- The LEP experiments measure the ZZ cross-section at all the centre–of–mass energies
- Perfect agreement with the Standard Model
- The combined precision of the measurement is 6%
- The measurements of the cross-section into b quarks give confidence to the sensitivity to Higgs boson signals
- No signs of Extra Spatial Dimensions show up in ZZ events, and severe limits are posed on the scale of the so called Low Scale Gravity

I'd like to thank my colleagues for having provided me with their preliminary results, and the LEP Electroweak working group for their combination.