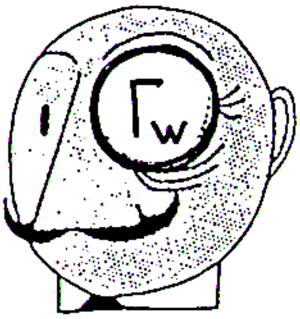
ECFA DESY
Linear Collider Workshop

2nd ECFA/DESY Study on Physics and Detectors for a Linear Electron - Positron Collider

Oxford 20-23rd March, 1999

EW WG



Γ_W as seen through the eyes of photons near W^+W^- threshold

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Motivation :

- Encouraged by G. Wilson's talk at Frascati on threshold measurement of M_W ($\Delta M_W \simeq 6$ MeV) ("theoretical-noise - free")
- Is the LC (experimental) community well aware that the pattern of soft photon radiation allows to probe the time delay $\Delta t \sim \frac{1}{\Gamma_W}$ between the W decays ?

Conventional Γ_W methods

- THRESHOLD SCAN @ 161 GeV

G. Wilson's talk
FRASCATI 9/11/98

- DIRECT KINEMATIC RECONSTRUCTION

$q\bar{q}q\bar{q}$, $q\bar{q}\ell\nu$ channels

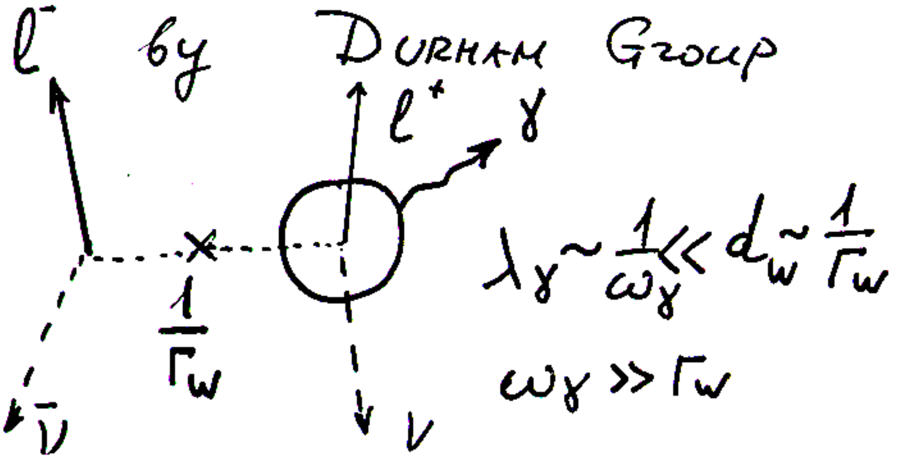
NOT WITHOUT THEIR OWN PROBLEMS
(beam-induced effects, QCD/EW corrections)

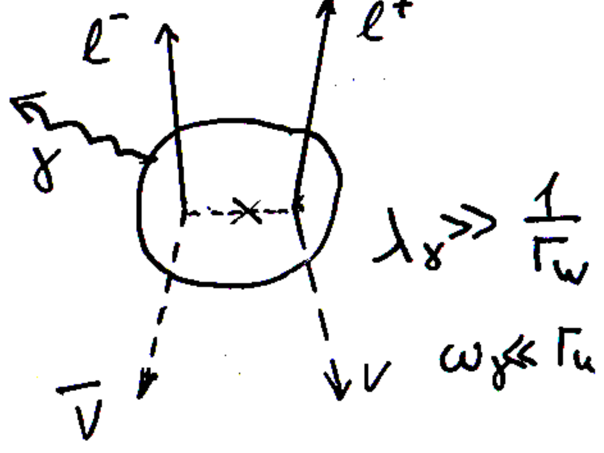
- 'INDIRECT' MESUREMENTS in $p\bar{p}$ (pp) colliders

Old idea to exploit the Bremsstrahlung Radiation Pattern to measure the TIME DELAY in nuclear reactions
(R.M. Eisberg, D.R. Yennie, D.H. Wilkinson, N.P. 18 (1960) 338-345)

L. Stodolsky

Resurrected in the W-physics context
by DURHAM Group





Has been on the market for years... (b)

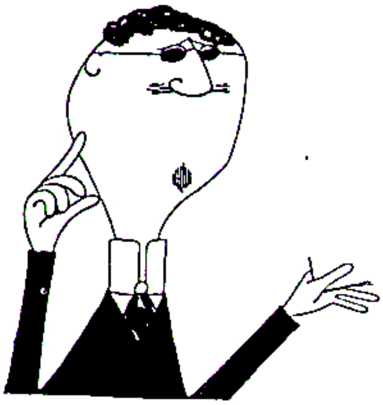
KOS (1992), D'KOS (1993)

T. Sjöstrand, VAK (1994) QCD context

Nuclear Physics B403 (1993) 65–100
North-Holland

NUCLEAR PHYSICS B

May [illegible] standard tool [illegible] widths [illegible] particles (Γ_t, $\Gamma_{\tilde{q}}$, $\Gamma_{\tilde{\ell}}$ ...)



Properties of soft radiation near $t\bar{t}$ and W^+W^- threshold

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Physics Letters B313 (1993) 171–179
North-Holland

PHYSICS LETTERS B

Soft photons in W^+W^- production at LEP200

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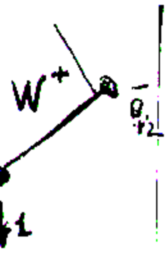
W.J. Stirling

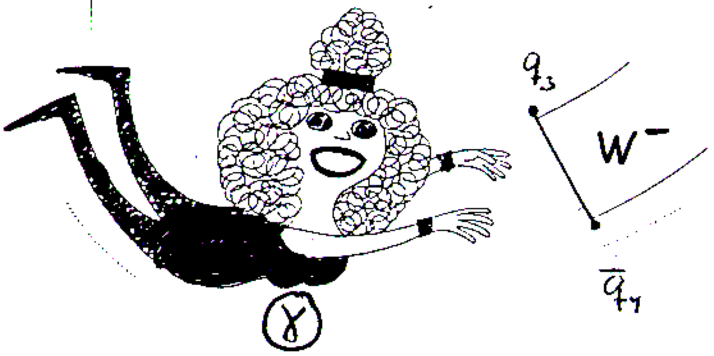
The current market price is still unclear

Could LC become a committed buyer?



Space-TIME HISTORY

EXAMPLE : QED RADIATION IN $W^+W^- \to q_1 \bar{q}_2 \bar{q}_4 q_3 \, (e^+\nu e^-\bar{\nu})$



$W = 170$ GeV

$\beta_W \simeq 0.34$

$t_1 \simeq 0.02$ fm

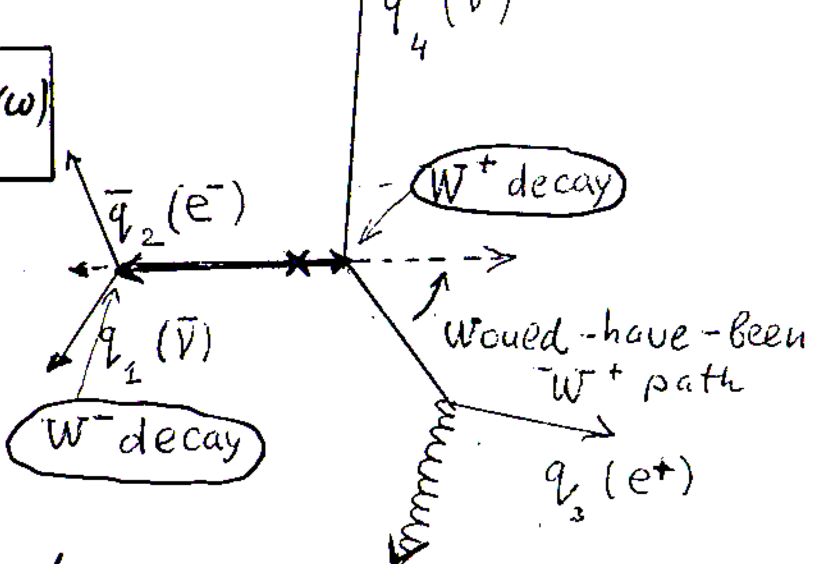
$t_2 \simeq 0.08$ fm

$\tau_{prod} \sim \frac{1}{W} \ll \frac{1}{\Gamma_W}$

$$dN \sim \frac{\bar{\alpha}}{\pi}\frac{d\omega_\gamma}{\omega_\gamma}\frac{d\Omega}{4\pi}\left\{R_{ind} + 2\mathrm{Re}\left\langle e^{i\omega_\gamma(t_1-t_2)}\right\rangle \cdot J\right\}$$

$$\left\langle e^{i\omega_\gamma(t_1-t_2)}\right\rangle_{1,2} = \boxed{\frac{\Gamma_W^2}{\Gamma_W^2+\omega_\gamma^2} = \chi(\omega)}$$

D'KOS 1993

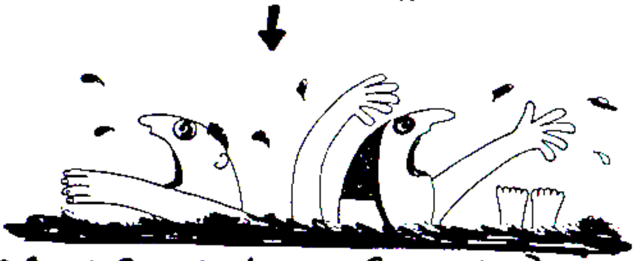


• at $\omega_\gamma \Delta t \sim \omega_\gamma / \Gamma_W \gg 1$

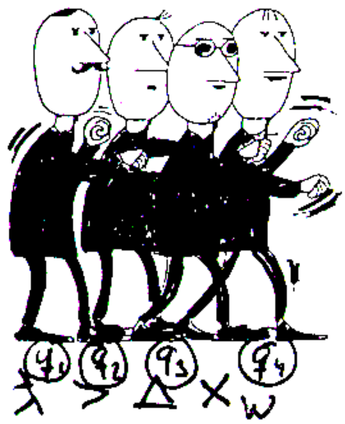
INTERFERENCE VANISHES

RESULT OF AVERAGING OVER THE INSTANCES OF THE DECAYS

$\lambda \ll \Delta x_W \sim d_W$



(coherence gets lost)



$\lambda > \Delta x_W$

← ONLY FAIRLY SOFT EMISSON FEELS THE JOINT ACTION OF THE ALL CHARGES

$\omega_\gamma < \Gamma_W$

(Coherence remains UNDISTURBED)

W width as a Bremsstrahlung Filter

$$e^- e^+ \rightarrow W^+ W^- \rightarrow f_1 \bar{f}_2 \; f_3 \bar{f}_4 + \gamma$$

Through the eyes of a photon $\qquad \ell^- \bar{\nu}_e \;\; \ell^+ \nu_e + \gamma$

- $\omega_\gamma \ll \Gamma_W$

$(\ell^- \bar{\nu}_e)$ and $(\ell^+ \nu_e)$ appear almost instantaneusly and radiate almost coherently

as if produced in the same vertex

- $\omega_\gamma \gg \Gamma_W$

$(\ell^- \bar{\nu}_e)$ and $(\ell^+ \nu_e)$ appear at very different times t_1, t_2 after W^+W^- production

$$\tau_p \sim \frac{1}{M_W} \ll \Delta t = |t_1 - t_2| \sim \frac{1}{\Gamma_W}$$

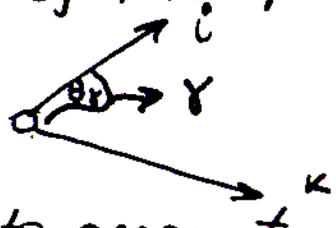
ℓ^- and ℓ^+ radiate photons INDEPENDENTLY

$$\omega_\gamma \frac{dN^{(\alpha\beta)}}{d\omega_\gamma} = \frac{\alpha}{\pi} \frac{d\Omega}{4\pi} \left[\left(1 - \mathcal{X}(\omega_\gamma)\right) R^{(\alpha\beta)}_{ind} + \mathcal{X}(\omega_\gamma) R^{(\alpha\beta)}_{coh} \right]$$

$(\alpha\beta) = (\ell\ell), (q\ell), (qq)$

$$\boxed{\mathcal{X}(\omega_\gamma) = \frac{\Gamma_W^2}{\Gamma_W^2 + \omega_\gamma^2}}$$

- ω_γ / Γ_W dependence vanishes for emission close to the direction of one of the primary charged particles



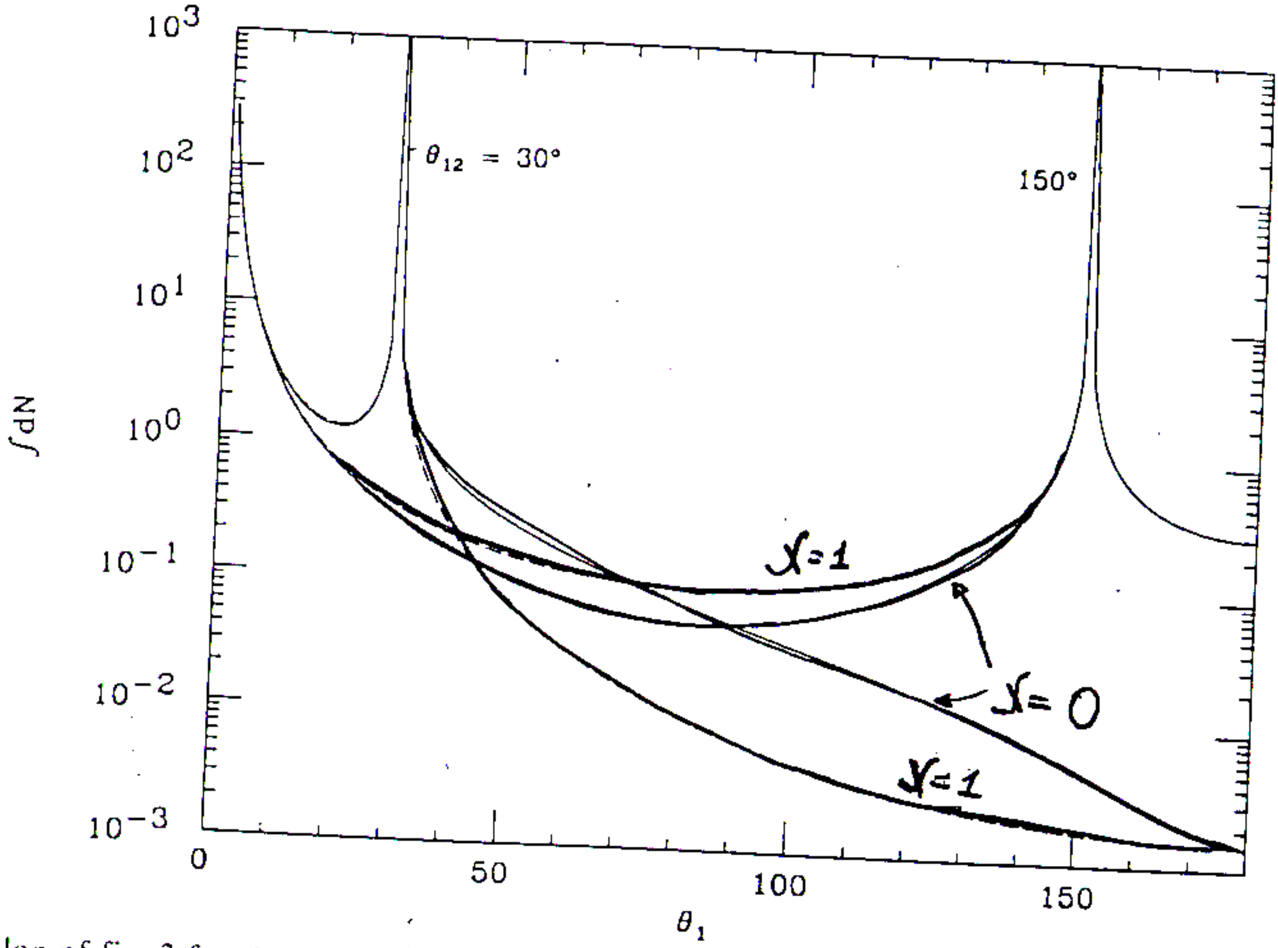
$$\boxed{\theta_\gamma \sim \theta_{ik}}$$

ISR can be easily taken into account
(ISR - FSR interference can be explicited)

$e^+e^- \to W^+W^- \to \ell^+\nu\ell^-\bar{\nu} + \gamma$

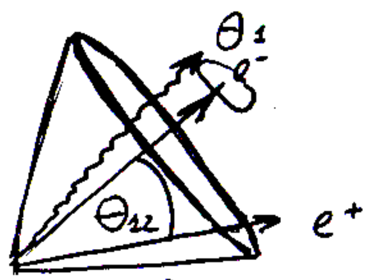
$$\int_0^{2\pi} d\phi \, \omega_\gamma \left(dN / d\omega_\gamma d\Omega \right)$$

NO ISR



ig. 4. Analog of fig. 3 for the W^+W^- case: angular ordering effects in the soft *photon* distribution in $\gamma\gamma \to W^+W^- \to \ell^+\ell^-\nu\bar{\nu}$, for $\theta_{12} = 30°$ and $150°$. $\int dN \equiv \omega(dN/d\omega \, d\cos\theta)$ as in fig. 3. Solid lines: $\chi = 0$; dashed lines: $\chi = 1$. (The $\gamma\gamma \to W^+W^-$ case is equivalent to the $e^+e^- \to W^+W^-$ case with no initial state radiation.)

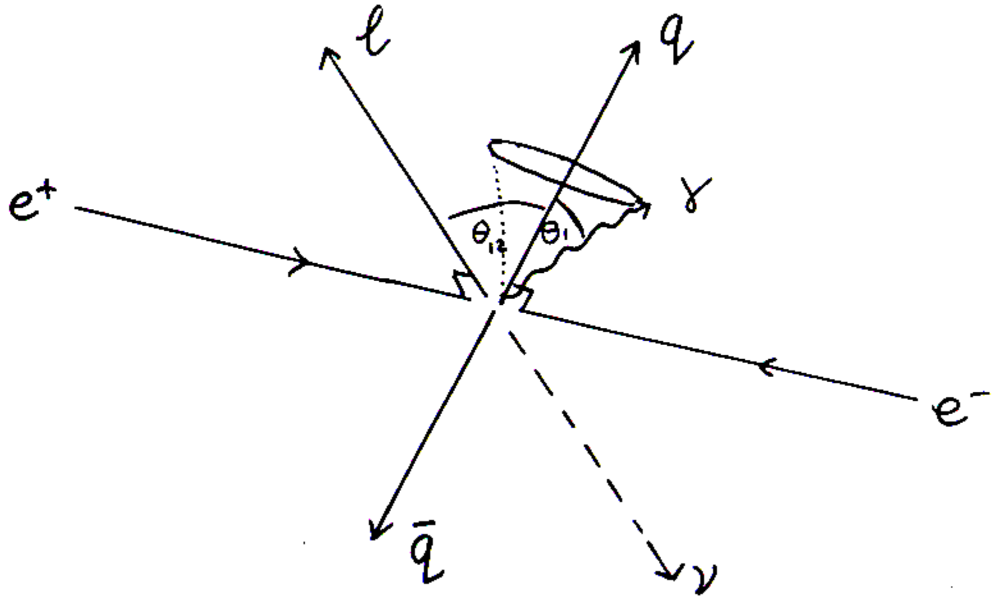
$$\chi = \frac{\Gamma_W^2}{\Gamma_W^2 + \omega_\gamma^2}$$

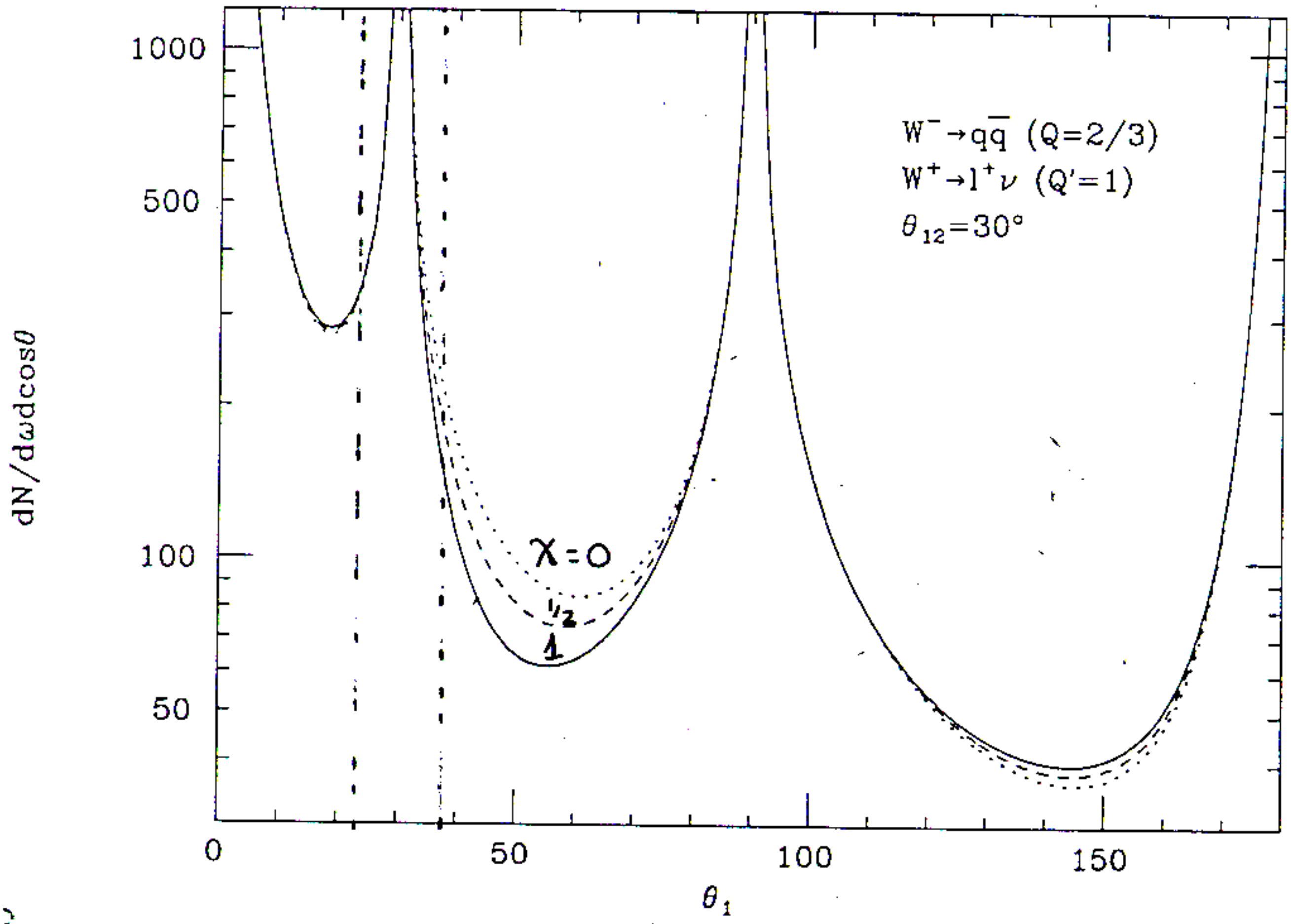


$\chi = 0$ (no QED interconnection)

$\chi = 1$ (Instantaneous interconnection)

- Normalization at small θ_1, cuts $\theta_{12} > \theta_{cut}$, $\theta_1 > \theta_0$





$$\chi = \frac{\Gamma_W^2}{\omega_\gamma^2 + \Gamma_W^2}$$

- To achieve a higher event rate there is a great demand for (at least one) hadronically decaying W
- Subject to additional experimental problems

price to pay – limited statistics

NEED TO UTILIZE ALL EVENTS

$\int d\Omega_\gamma$

$$\omega\frac{\mathrm{d}N^{(\alpha\beta)}}{\mathrm{d}\omega} = \frac{\alpha}{\pi}\left[\mathcal{R}_{\rm ind}^{(\alpha\beta)} + 2\chi(\omega)\mathcal{F}^{(\alpha\beta)}(\Theta_{12})\right],$$

where $(\alpha\beta) = (ll), (ql), (qq)$. The important point is that the first, χ-independent term does not depend on

depend on Θ_{12}. At $\Theta_{12} > \Theta_{crit}$ radiation is enhanced. ($\Theta_{12} < \Theta_{crit}$ suppressed)

ql, qq – $\Theta_{crit} \simeq 47.4°$ (q and $\bar{q}$-jets not discriminated)

ll – $\Theta_{crit} \approx 74.7°$

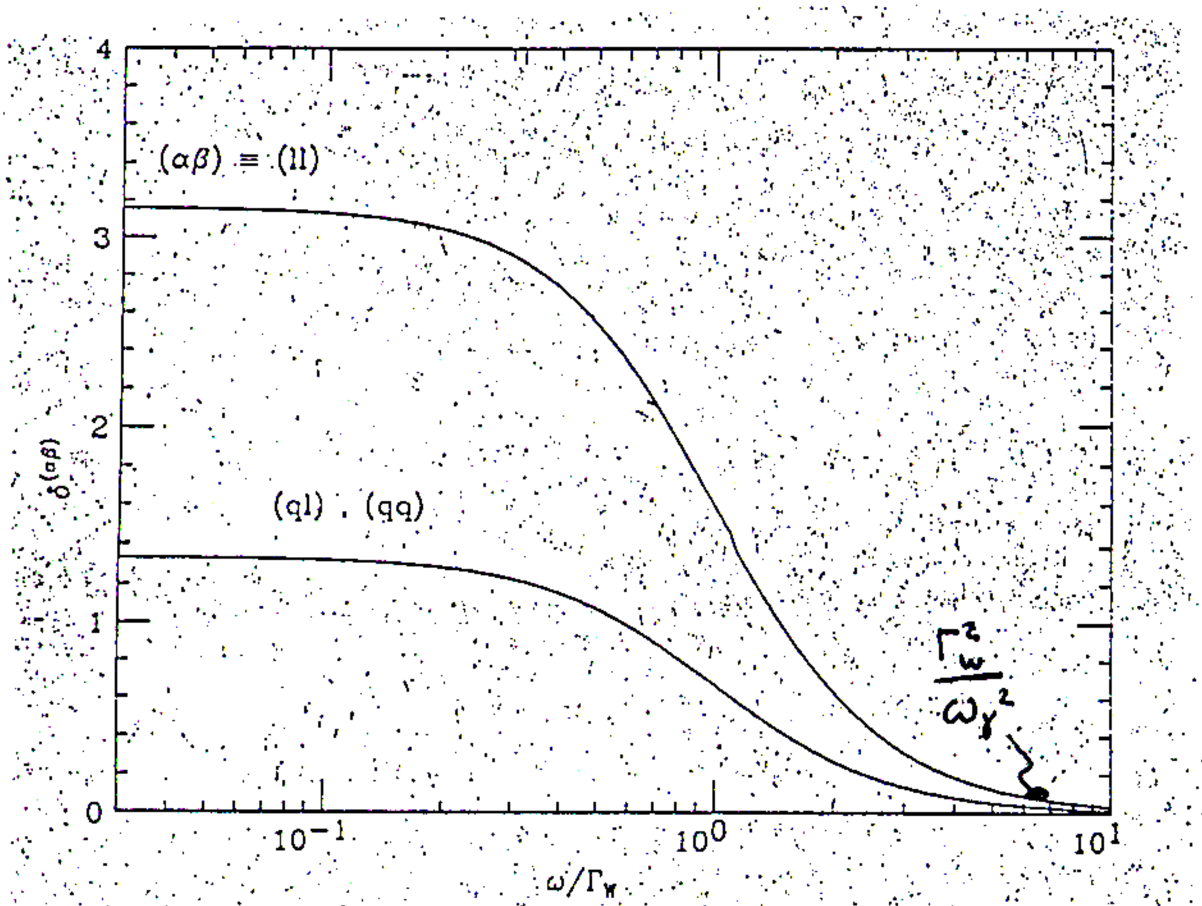
$$\delta^{(ll)} = \frac{1}{1+\cos\Theta_{\rm crit}}\int_{\Theta_{\rm crit}}^{\pi}\omega\frac{\mathrm{d}N^{(ll)}}{\mathrm{d}\omega}\sin\Theta_{12}\,\mathrm{d}\Theta_{12} - \frac{1}{1-\cos\Theta_{\rm crit}}\int_{0}^{\Theta_{\rm crit}}\omega\frac{\mathrm{d}N^{(ll)}}{\mathrm{d}\omega}\sin\Theta_{12}\,\mathrm{d}\Theta_{12},$$

$$\delta^{(ql,qq)} = \frac{1}{1-\cos\Theta_{\rm crit}}\int_{\Theta_{\rm crit}}^{\pi/2}\omega\frac{\mathrm{d}N^{(ql,qq)}}{\mathrm{d}\omega}\sin\Theta_{12}\,\mathrm{d}\Theta_{12} - \frac{1}{\cos\Theta_{\rm crit}}\int_{0}^{\Theta_{\rm crit}}\omega\frac{\mathrm{d}N^{(ql,qq)}}{\mathrm{d}\omega}\sin\Theta_{12}\,\mathrm{d}\Theta_{12},$$

then the χ independent term in (17) cancels and we are left with

$$\boxed{\delta^{(ll)} = \frac{\alpha}{\pi}\frac{4\chi(\omega)}{1+\cos\Theta_{\rm crit}} = \frac{\alpha}{\pi}3.164\chi(\omega),}$$

ISR cancels



$\delta^{\alpha\beta}$ in units of $\frac{\alpha}{\pi}$

EVENT SELECTION NOT OPTIMIZED

assuming $\mathcal{L} = 10^{34}$ and 10^7s year

$\longrightarrow \int \mathcal{L} = 100\ fb^{-1}$

$\longrightarrow 10^6\ W^+W^-$ (possibly more)

- optimal $\sqrt{s}$, using polarized beams
  (~1.5) (~3)
  much more flexibility in $\sqrt{s}$ as compared to threshold scan.
- BRP is less sensitive to beam-induced effects

WW →	'BR'	
$l\nu l\nu$	10.5 %	gold-plate
$q\bar{q} l\nu$	44 %	$\mu^+\mu^-$ events
$q\bar{q} q\bar{q}$	45.5 %	

- $q\bar{q}$ – 'indirect' photons from hadron decays
  (but practically insensitive to the event geometry)
  QCD interconnection
- Not very severe requirements on
  $\frac{\Delta\theta_\gamma}{\theta_\gamma}$, $\frac{\Delta E_\gamma}{E_\gamma}$, primary lepton/quark directions

Experimental partners are WANTED

NON-EXPERT ROUGH ESTIMATES

$\int \mathcal{L} = 100\ fb^{-1} \to N_{WW} \sim 10^6$

$N_0^\gamma = \frac{\alpha}{\pi} N_{WW} \sim 2.5\ k$

$(N_0^\gamma)^{(\ell\ell)} \sim 250 \qquad (N_0^\gamma)^{(q\ell)} \sim 1\ k \quad (N_0^\gamma)^{(qq)} \sim 1k$

Optimal $\sqrt{s}$ + polarization ~ 5
fully hadronic decays ?
Optimised FS characteristics ? (to be studied)
Higher $\int \mathcal{L}$?

$(\omega_\gamma)_{min} \sim 300$ MeV

Efficiences, cuts – need systematic (MC) studies
~ (50 – 75 %) ?

Possible strategy

- keep away from the 'main stream' directions (beams, final leptons, jets) $\theta_{cut} \sim 10\text{-}20^\circ$
- separate events with $\theta_{12} > \theta_{cut}$ and $\theta_{12} < \theta_{cut}$
- study the difference in a few ω_γ-intervals

If $\omega_0 < \omega_\gamma < \omega_{max} \gg \Gamma_W$

$f(\ell\ell) \sim 3.5 \cdot 10^{-4} \ln\left(1 + \frac{\Gamma_W^2}{\omega_0^2}\right)$

$f(q\ell) \sim 6 \cdot 10^{-4} \ln\left(1 + \frac{\Gamma_W^2}{\omega_0^2}\right)$

Concluding Remarks

- Soft photon BRP in WW production near threshold is a sensitive tool to probe Γ_W.
  FSR, IRS/FSR

- By no means, being obviously statistically competitive for precise determing the W width.
  may appear to be only a complementary approach (though with a different systematics)

- Further studies are worth pursuing.
  on the theoretical side: validity of approximations ($\beta_W^2 \ll 1$ ...), optimized configurations, energies... [A. Chapovsky + VAK ...
  on the experimental side: detector capabilities, dedicated electromagnetic calorimeter, optimized event rates...

Recall: TRADITIONAL STRATEGIES ARE NOT WITHOUT THEIR OWN CAVEATS