Electroweak B+L Violation at High Energies.

Part 2: Rate Estimates and Signatures

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BSM Physics Opportunities at 100 TeV
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HELMHOLTZ | ASSOCIATION

DESY

Recap

- Cross-sections for exclusive B+L violation rapidly growing below

$$4\pi \frac{M_W}{\alpha_W} \simeq 30 \text{ TeV}$$

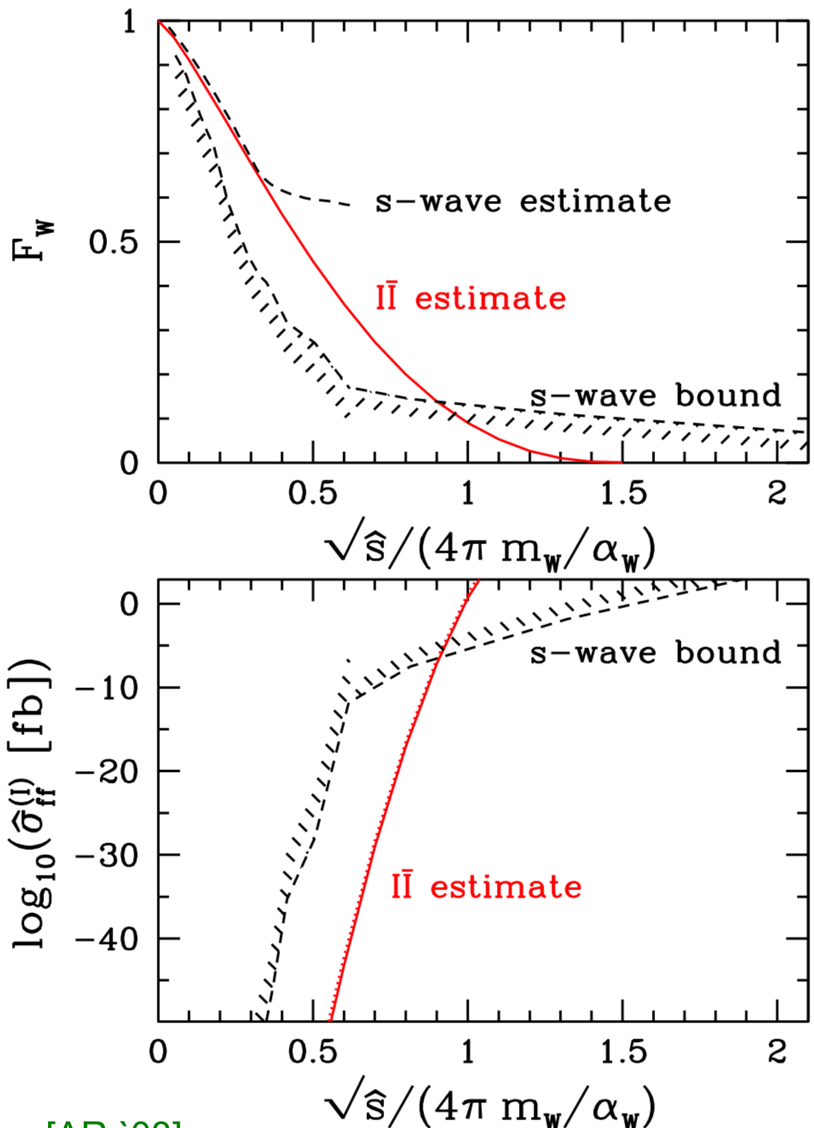
- Total cross-section grows exponentially; dominated by multiple emission of EW gauge bosons

$$\hat{\sigma}_{\rm ff}^{(I_W)} \approx \frac{1}{m_W^2}\left(\frac{2\pi}{\alpha_W}\right)^{7/2} {\rm e}^{-\frac{4\pi}{\alpha_W}F_W(\epsilon)}$$

$$\epsilon \equiv \sqrt{\hat{s}}/(4\pi m_W/\alpha_W) \simeq \sqrt{\hat{s}}/(30 \text{ TeV})$$

$$F_W(\epsilon) = 1 - \frac{3^{4/3}}{2}\epsilon^{4/3} + \frac{3}{2}\epsilon^2 + \mathcal{O}(\epsilon^{8/3})\,.$$

- For $\epsilon > 0.3 \div 0.75$ only estimates, educated guesses and bounds
- Need future hadron collider or search for analogous QCD processes



[AR `03]

Recap

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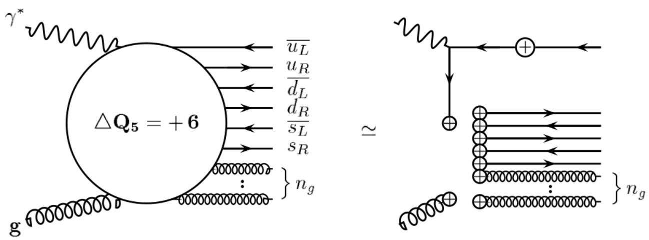
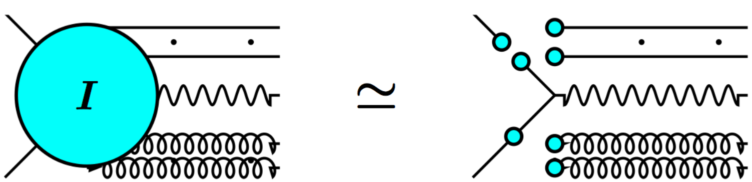
- Small-size QCD-instanton induced processes in
  - DIS



  - virtual vector boson production



Instanton-Antiinstanton Valley Cross-Section Estimate

- Total cross-section via optical theorem [V.V. Khoze, AR `91; AR, F. Schrempp `98]

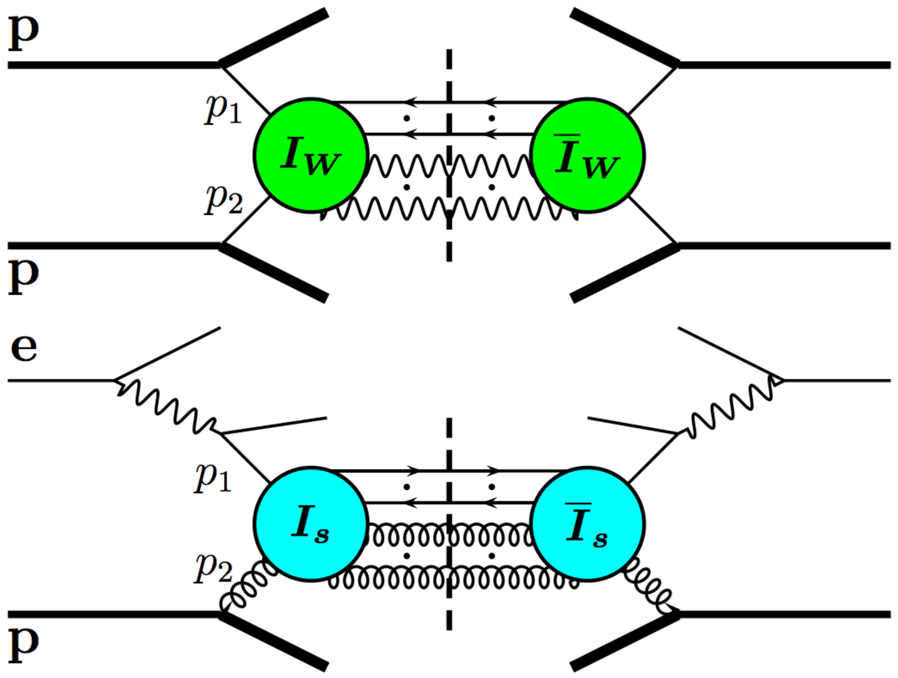
$$\hat{\sigma}^{(I)}_{\mathrm{p_1p_2}} \sim \int \mathrm{d}^4 R \int_0^\infty \mathrm{d}\rho \int_0^\infty \mathrm{d}\overline{\rho}\, D(\rho) D(\overline{\rho}) \int \mathrm{d}U \mathrm{e}^{-\frac{4\pi}{\alpha_g}\Omega\left(U, \frac{R^2}{\rho\overline{\rho}},\ldots\right)}\, \mathrm{e}^{\mathrm{i}(p_1+p_2)\cdot R - \sum_{i=1}^{2} \sqrt{-p_i^2}\,(\rho+\bar{\rho})}$$

- Ingredients:
  - Instanton-size distribution

    $$D(\rho) \propto \mathrm{e}^{-2\pi/\alpha_g}$$

  - Instanton-Antiinstanton interaction

    $$\Omega\left(U, R^2/(\rho\bar{\rho}), \ldots\right)$$



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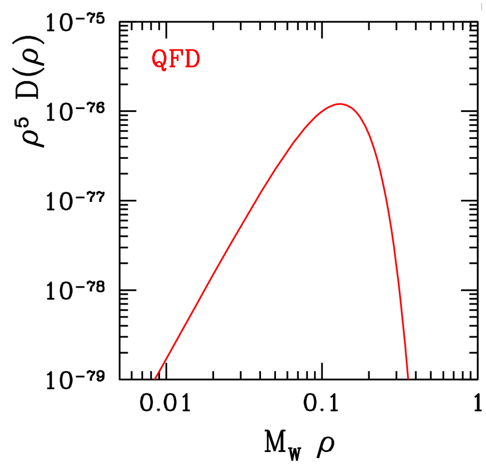
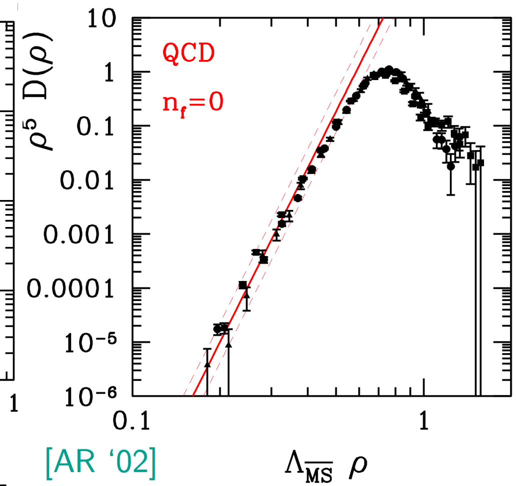
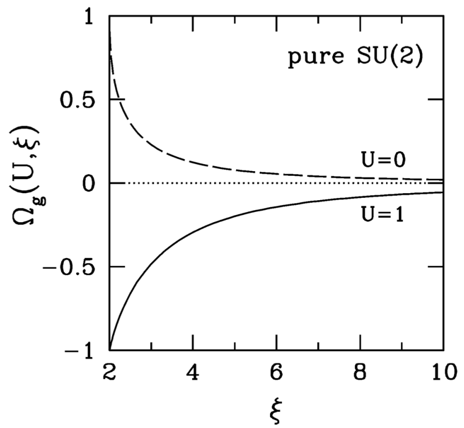




[AR ‘02]



$$\xi = \frac{R^2}{\rho\bar{\rho}} + \frac{\bar{\rho}}{\rho} + \frac{\rho}{\bar{\rho}} \geqslant 2$$

Instanton-Antiinstanton Valley Cross-Section Estimate

- **Saddle point evaluation:**

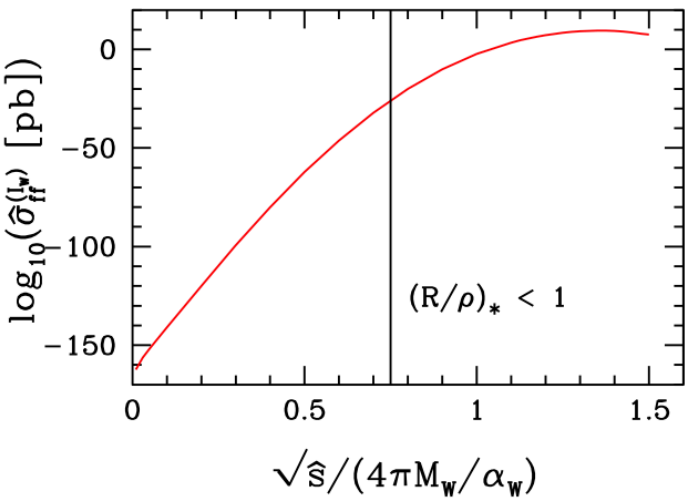
$$\hat{\sigma}^{(I)} \propto e^{-\Gamma_*} \equiv e^{-\frac{4\pi}{\alpha g} F_g(\epsilon)},$$

where

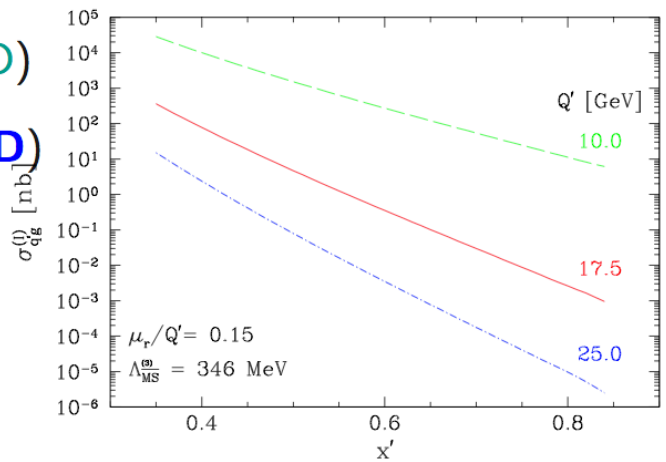
$$\epsilon \equiv \begin{cases} \sqrt{\hat{s}}/(4\pi M_W/\alpha_W) & \text{(QFD)} \\ \sqrt{\hat{s}}/Q' \equiv \sqrt{1/x' - 1} & \text{(QCD)} \end{cases}$$

is a scaled cm energy and

$$F_g = 1 + \Omega_g(1,\xi_*) + \begin{cases} -(\xi_* - 2)\frac{\partial}{\partial \xi_*}\Omega_g(1,\xi_*)_{|\xi_*=2+\left(\frac{R}{\rho}\right)^2_*} & \text{(QFD)} \\ 0 & \text{(QCD)} \end{cases}$$



[AR '02]

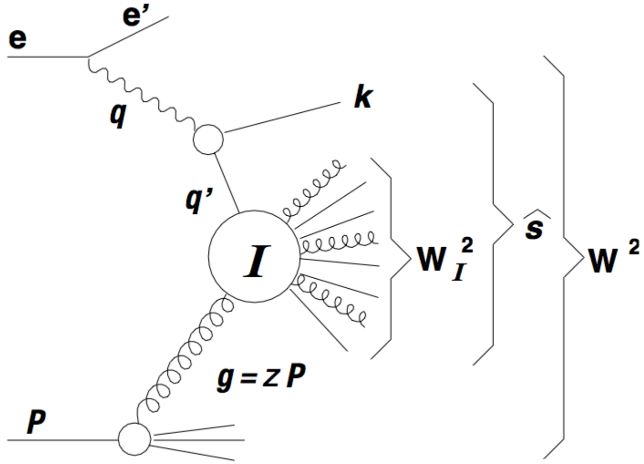


[AR,F.Schrempp '98,'00]

- Increasing $\epsilon \Rightarrow$ smaller $(R/\rho)_*$ probed $\Rightarrow$ cross-section grow due to attractive nature of Ω_g in perturbative semi-classical regime

QCD-Instanton Induced Processes in DIS at HERA

- **Kinematics:**



Deep-inelastic scattering variables:

$S = (e+P)^2$

$Q^2 = -q^2 = -(e-e')^2$

$x_{\rm Bj} = Q^2/\,(2P\cdot q)$

$y_{\rm Bj} = Q^2/\,(S\,x_{\rm Bj})$

$W^2 = (q+P)^2 = Q^2(1/x_{\rm Bj}-1)$

$\hat{s} = (q+g)^2$

$z = x_{\rm Bj}\,(1+\hat{s}/Q^2)$

Variables of instanton-subprocess:

$Q'^2 = -q'^2 = -(q-k)^2$

$x' = Q'^2/\,(2\,g\cdot q')$

$W_I^2 = (q'+g)^2 = Q'^2(1/x'-1)$

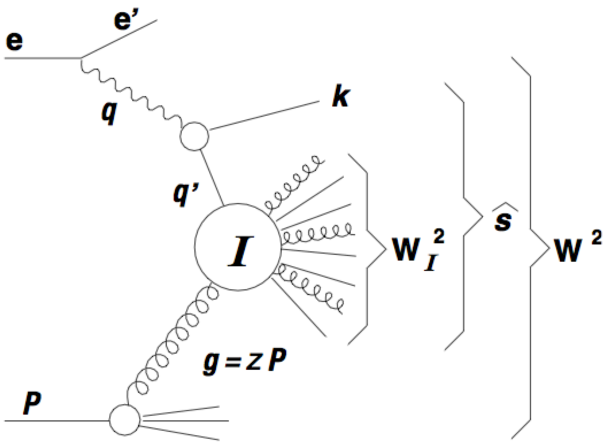
- "Fiducial" kinematical region from lattice constraints: [AR,F.Schrempp '99;'01]

$$\left(\rho^*\Lambda^{(0)}_{\overline{\rm MS}}\lesssim 0.4, \frac{R^*}{\rho^*}\gtrsim 1.0\right) \Rightarrow \left(Q'/\Lambda^{(n_f)}_{\overline{\rm MS}}\gtrsim 30.8, x'\gtrsim 0.35\right)$$

QCD-Instanton Induced Processes in DIS at HERA

Event generator QCDINS 2.0:

[Gibbs,AR,F.Schrempp '95; AR,F.Schrempp '00]

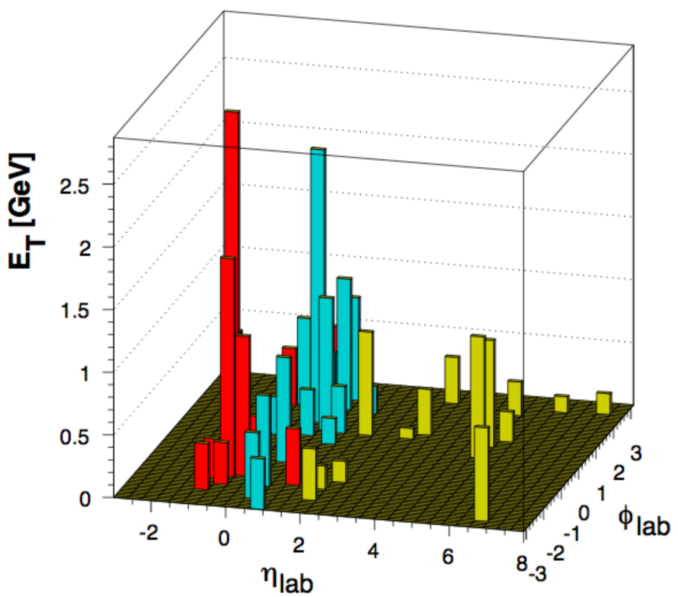


- **Hard subprocess:**
  - isotropic in $q'g$ CM
  - flavour democratic
  - large parton multiplicity

$$\langle n_q + n_g \rangle = 2\,n_f - 1 + \mathcal{O}(1)/\alpha_s \gtrsim 8,$$

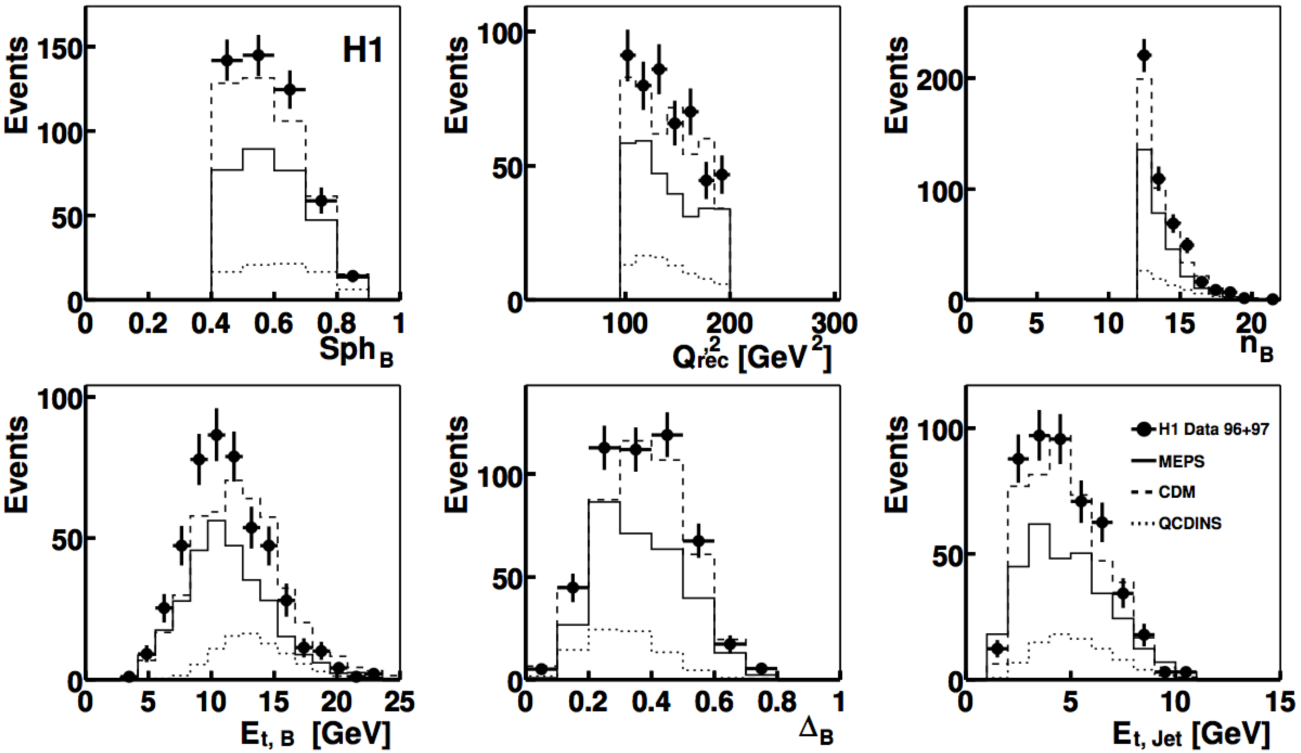
- **Parton shower** (**HERWIG**)

- **Hadronization** (**HERWIG** or **JET-SET**)



QCD-Instanton Induced Processes in DIS at HERA

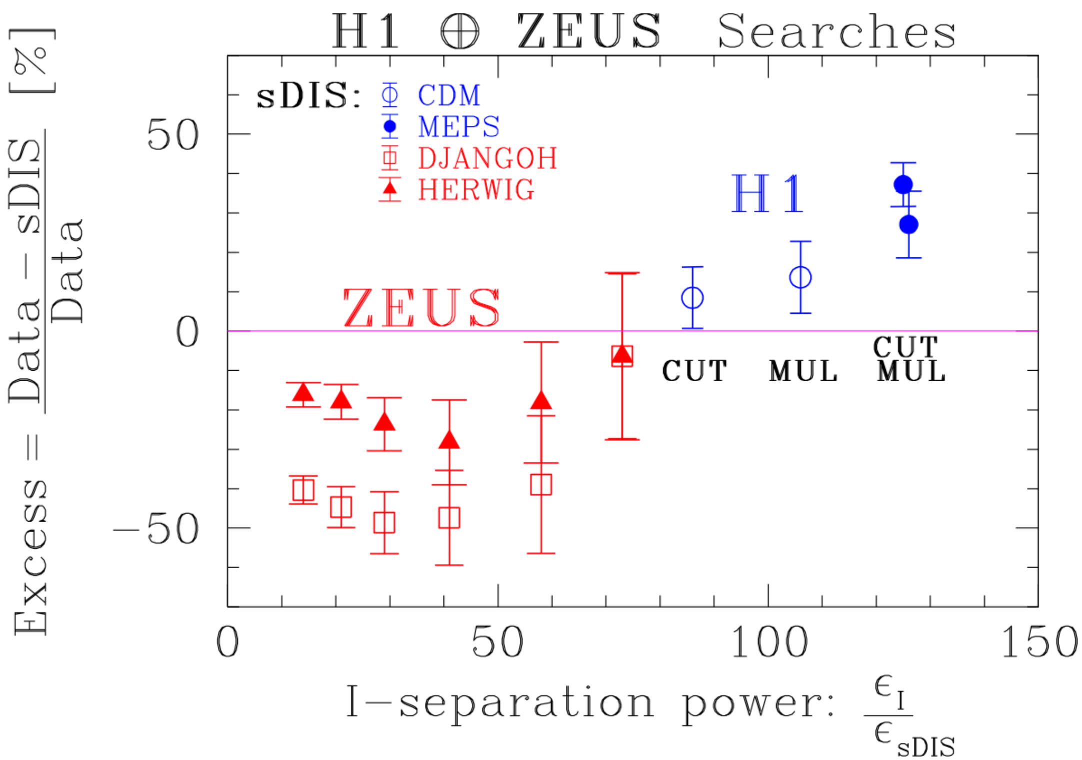
- Instanton-enriched samples by cuts on discriminating observables
- Large uncertainties in predictions of standard DIS processes



[H1 '02]

QCD-Instanton Induced Processes in DIS at HERA

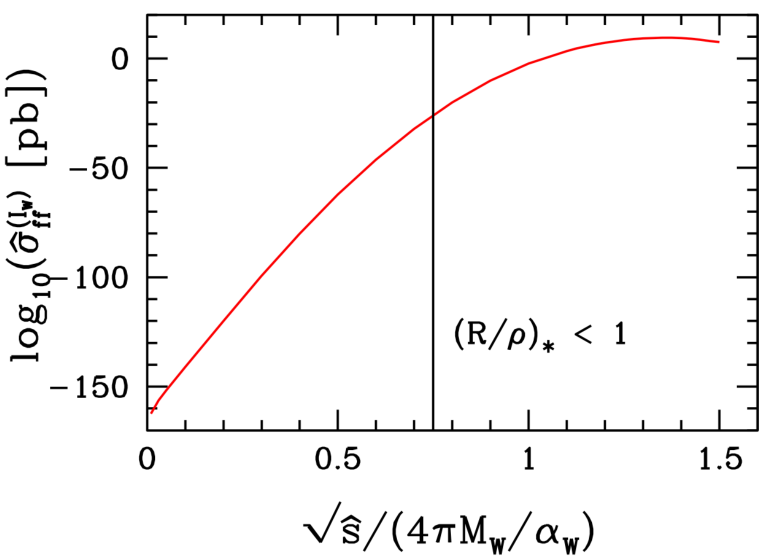
- Instanton-enriched samples by cuts on discriminating observables
- Large uncertainties in predictions of standard DIS processes
- H1/ZEUS "excess" increases with separation power (ratio of efficiencies)



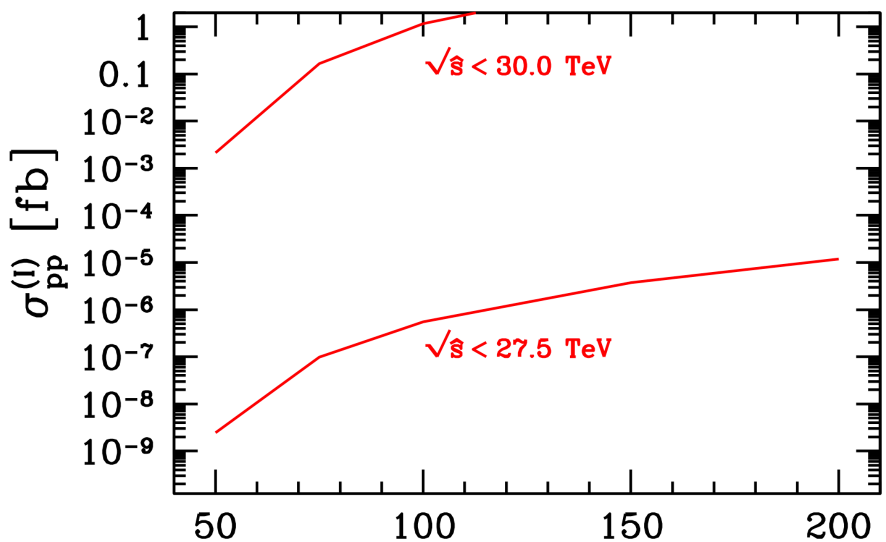
[F. Schrempp '04]

QFD-Instanton Induced Processes at Future Hadron Coll.

- H1/ZEUS limits on QCD-instanton induced processes suggest:
  - Instanton-antiinstanton estimate reliable, as long as $(R/\rho)_* \geq 1$
  - For $(R/\rho)_* \;<\; 0.5 \div 1$, rapid growth, as implied by Ω, stops.
- Implications for QFD-instantons:
  - $(R/\rho)_* \;<\; 0.5 \div 1$ corresponds to $\epsilon < 0.75 \div 1.15$, $\sqrt{\hat{s}} < 22 \div 35$ TeV
  - At these energies, cross-section estimate reaches observable values



[AR '02]



[AR,Tu (unpublished)]

Phenomenology of QFD-instantons

[AR,F.Schrempp,Wetterich '91; Gibbs,AR,Webber,Zadrozny '94]

- No background from perturbative Standard Model processes by requiring
  - ≥ 4 identified charged e's or μ's
  - $E_T \geq$ several TeV
- **Event generator HERBVI:**

[Gibbs,Webber '95]

  - B-violation cannot be established
  - **L-violation verifiable:** measure

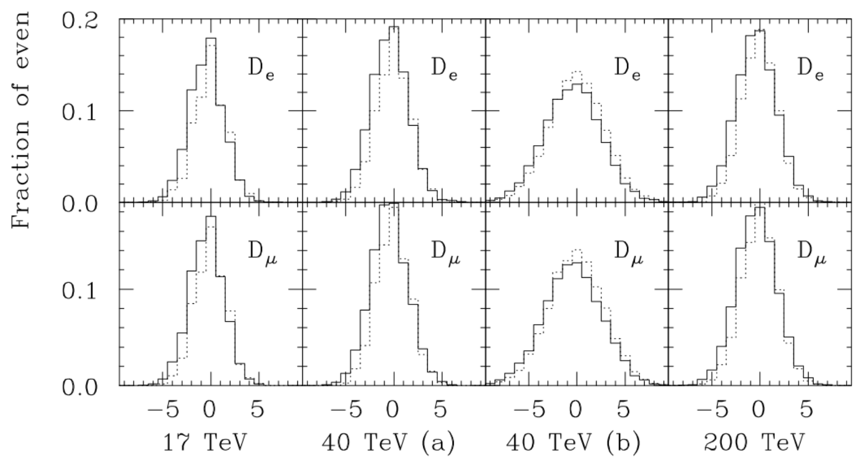
$$D_\ell = N_{\ell^-} - N_{\ell^+} \, ;$$

need $\sim 10^3$ events

[Gibbs,AR,Webber,Zadrozny '94]

Simulations performed		
Energy (TeV)	n_B estimate	$\sqrt{\hat{s}_0}$ (TeV)
17	$1/\alpha_W$	5
40 (a)	$1/\alpha_W$	18
40 (b)	LOME	18
200	$1/\alpha_W$	18

[Gibbs,AR,Webber,Zadrozny '94]



Summary

- Electroweak B+L violation central building block of our understanding of baryogenesis in big bang cosmology
- Characteristic scale of B+L violation

$$4\pi \frac{M_W}{\alpha_W} \simeq 30 \text{ TeV}$$

- Cross-sections for B+L violating processes
  - exponentiall small below this scale
  - exponentially growing below this scale
  - may reach observable values near this scale
- New computational methods needed
- Unique opportunity for a 100 TeV collider!
- In the meantime, search for small-size QCD-instanton induced processes