New Monte Carlo Generator of Lepton-Pair Production in ep Collisions using the GRACE System

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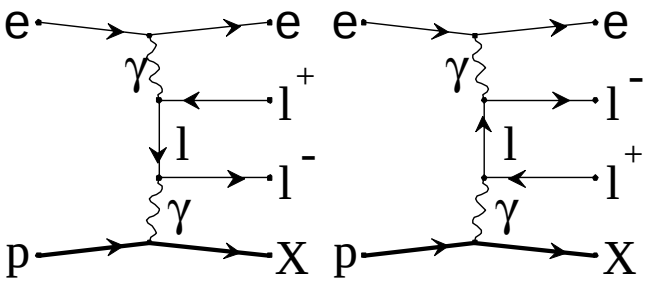
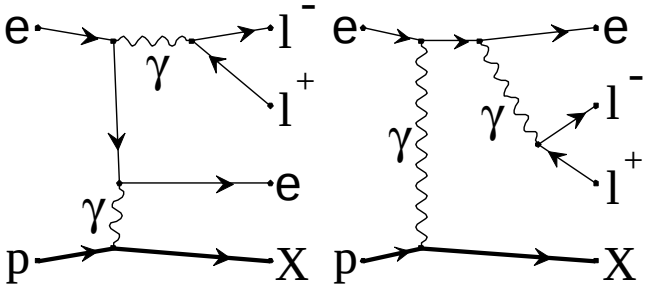
Processes for Lepton-Pair Production

(In case of the lowest order QED)



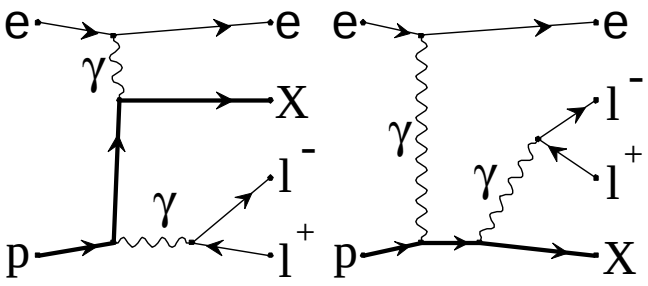
Bethe-Heitler (BH) diagrams

(2-photon process)



Compton-like diagrams (CO1)

(Radiation from electron line)



Compton-like diagrams (CO2)

(Radiation from proton line)

⟶ Off-shell proton

⟶ Time-like photon

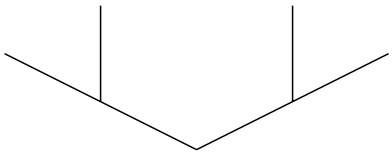
$\Longrightarrow$ Not considered in this talk

(Motivation of this work)

Existing Generators

	LPAIR*	**TRIDENT**†
Calculation	Exact ME with numerically stable formula to avoid gauge cancellations	Exact ME with REDUCE
Numerical stability	Stable at any phase space point	Unstable at low scattering angles
Included diagrams	Bethe-Heitler (BH)	BH + CO1 including ee interference in ee channel
Weight	Unweighted	Weighted

$\star, \dagger$: Please see PHYSICS at HERA vol.3



We want to have an event generator with

- the exact ME calculation,
- all diagrams,
- and numerical stableness.

a

The GRACE System

— *Automatic calculation of Feynman amplitudes* —

Successful experience in e^+e^- physics (ex. LEP)

1. Specification of a model file, order of perturbation, and initial / final state particles

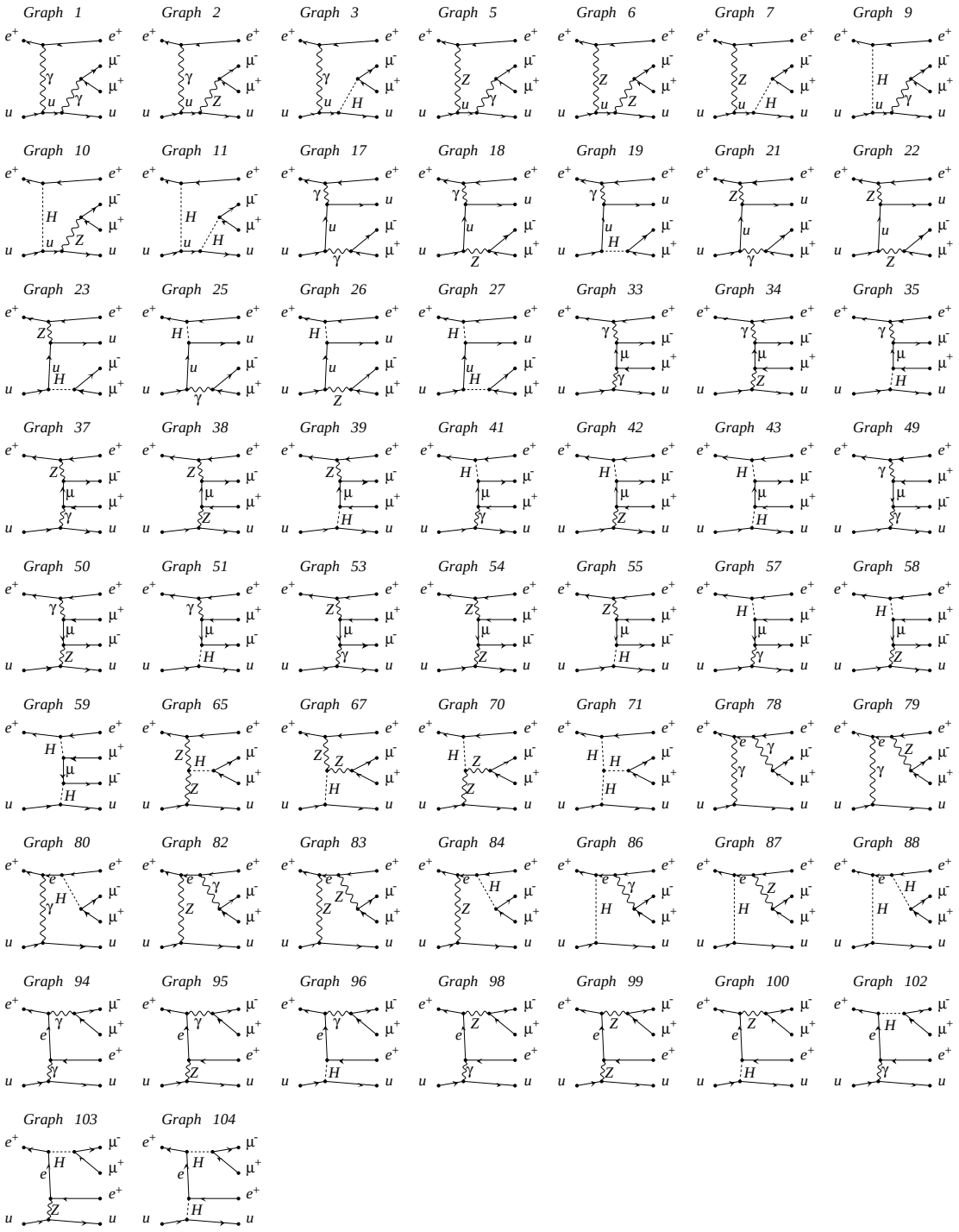
2. Generation of all Feynman diagrams
3. Generation of FORTRAN source code to calculate the Feynman amplitudes $\Longrightarrow$ Exact ME calculation
4. Integration / event generation by BASES/SPRING program $\Longrightarrow$ Unweighted events

In an input file

- Model : SM
- EW=4, QCD=0
- Initial= $\{e^+, u\}$
- Final = $\{e^+, u, \mu^+, \mu^-\}$

# of generated diagrams

- 109 in covariant gauge
- 58 in unitary gauge



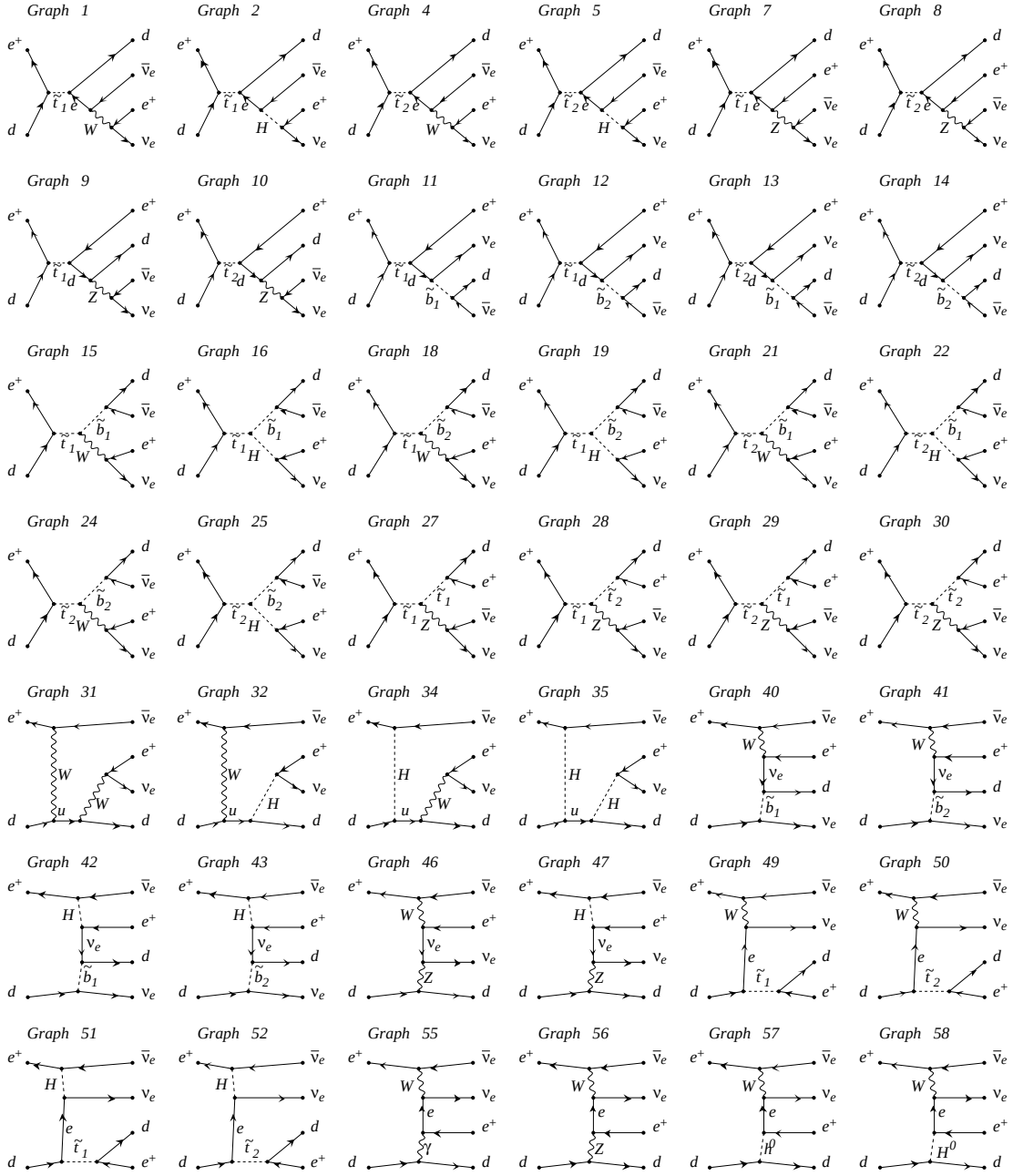
produced by GRACEFIG

In an input file

- Model : MSSM with $\not{R}_p$
- EW=4, QCD=0
- Initial= $\{e^+,\ d\}$
- Final = $\{e^+,\ d,\ \nu_e,\ \bar{\nu}_e\}$

# of generated diagrams

- 237 in covariant gauge
- 164 in unitary gauge



etc...

GRACE has only fundamental particles.

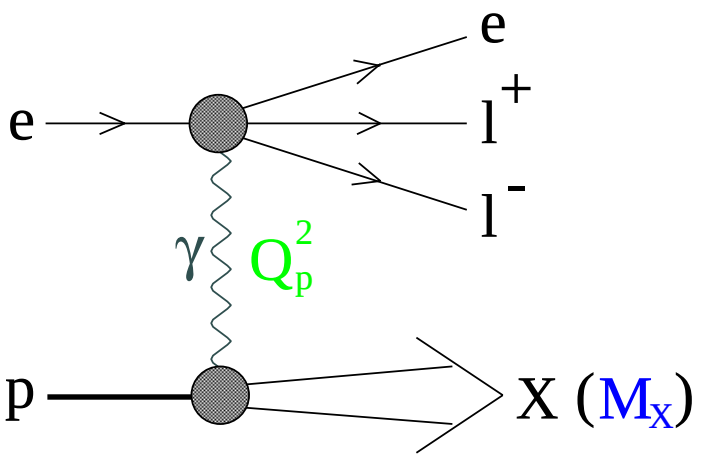
$\longrightarrow$ **Calculation for the Proton Side**

$\ll$ Methods $\gg$

[1] Elastic process ($M_X = M_p$)
- (a) Adding *proton* as a fundamental particle into GRACE system
- (b) Definition of $pp\gamma$ vertex

[2] DIS ($M_X > M_p$ & $Q_p^2 > \sim 4$ GeV)
- (a) eq scatterings (calculable with GRACE)
- (b) Parton Distribution Function (PDFLIB)

[3] Resonance region ($M_X > M_p$ & $Q_p^2 < \sim 4$ GeV)
- (a) Hadron tensor : $W_{\mu\nu}$
  with Structure Functions : W_1, W_2
  (In this study, W_1, W_2 in EPVEC source code are used)



[1] $pp\gamma$ vertex and Dipole-Formfactor

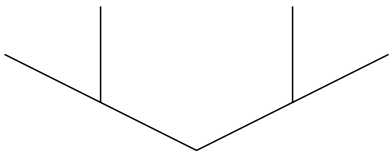
$$\Gamma^{\mu}_{pp\gamma} = e_p \left(F_1(q^2)\gamma^{\mu} + \frac{\kappa}{2M_p} F_2(q^2) i\sigma^{\mu\nu} q_{\nu} \right)$$

κ : Anomalous magnetic moment of proton
$F_1(q^2), F_2(q^2)$: Independent formfactors

$$\begin{pmatrix} G_E(q^2) \\ G_M(q^2) \end{pmatrix} = \begin{pmatrix} F_1(q^2) + \frac{\kappa q^2}{4M_p^2} F_2(q^2) \\ F_1(q^2) + \kappa F_2(q^2) \end{pmatrix}$$

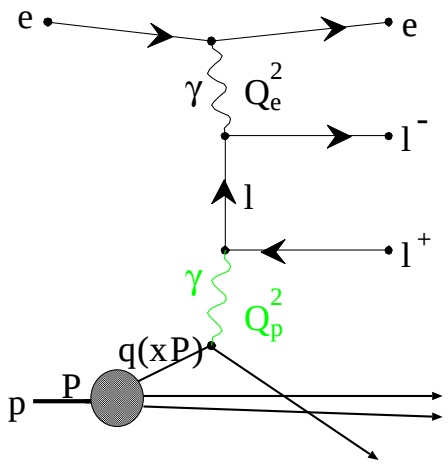
Dipole-Formfactor

$$G_E(q^2) = \frac{1}{\left(1 - \frac{q^2}{0.71}\right)^2} = \frac{G_M(q^2)}{\mu_p}$$



$$\Gamma^{\mu}_{\gamma pp} = e \left(\mu_p G_E(q^2)\gamma^{\mu} - \frac{(p^{\mu} + p'^{\mu})}{2M_p} \frac{\kappa}{1 - \frac{q^2}{4M_p^2}} G_E(q^2) \right)$$

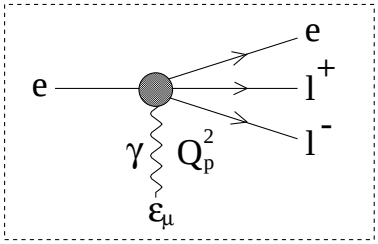
[2] Lepton-Pair Production in DIS



- Quark-Parton model
- QCD scale $\longleftarrow Q_p^2$
- Quark momentum $\longleftarrow x$ of PDF

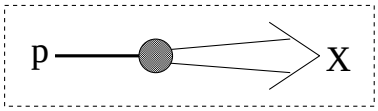
$$\sigma_{ep\to eXl^+l^-}(s) = \sum_i \int dx\, f_i(x)\, \sigma_{eq_{(i)}\to eq_{(i)}l^+l^-}(\tilde{s})$$

[3] Resonance region ($M_X > M_p$ & $Q_p^2 < \sim 4$ GeV)



$\longleftarrow$ calculated by GRACE

$\equiv l_\mu \Longrightarrow L_{\mu\nu} \sim l_\mu l_\nu^*$



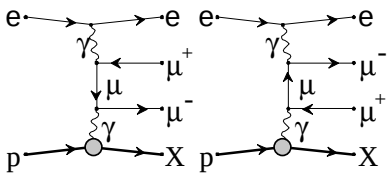
$\Longrightarrow W^{\mu\nu}$

$$W^{\mu\nu} = W_1\left(-g^{\mu\nu} + \frac{q^\mu q^\nu}{q^2}\right) + W_2 \frac{1}{M_p^2}\left(p^\mu - \frac{p\cdot q}{q^2}q^\mu\right)\left(p^\nu - \frac{p\cdot q}{q^2}q^\nu\right)$$

$$d\sigma = \frac{1}{(flux)} L_{\mu\nu}\left\{W^{\mu\nu} e^2 4\pi M_p\right\} d\Gamma$$

Cross Section Comparisons with LPAIR

Process : $ep \to eX\mu^+\mu^-$
(at HERA energy)
with Bethe-Heitler only



Detector cuts

- Cut(1) — $15° < \theta_\mu < 164°$, $E_\mu > 2\,\mathrm{GeV}$ (for both muons)
- Cut(2) — $15° < \theta_\mu < 164°$, $E_\mu > 2\,\mathrm{GeV}$ (for both muons) & $15° < \theta_e < 164°$, $E_e > 4\,\mathrm{GeV}$ (for scattered positron)

Stableness of the GRACE calculation

Elastic

	GRACE	LPAIR
No cut	$9.742(\pm0.003) \times 10^4$	$9.736(\pm0.003) \times 10^4$
Cut(1)	$8.493(\pm0.005) \times 10$	$8.496(\pm0.008) \times 10$
Cut(2)	$6.094(\pm0.008) \times 10^{-1}$	$6.091(\pm0.005) \times 10^{-1}$

(in unit of pb)

DIS ($Q_p^2 > 1\,\mathrm{GeV}^2$)

	GRACE	LPAIR
No cut	$9.463(\pm0.002) \times 10^2$	$9.464(\pm0.002) \times 10^2$
Cut(1)	$3.651(\pm0.005) \times 10$	$3.649(\pm0.004) \times 10$
Cut(2)	$4.311(\pm0.005) \times 10^{-1}$	$4.313(\pm0.004) \times 10^{-1}$

(in unit of pb)

Resonance region ($W > 1$ GeV)

	GRACE	LPAIR
No cut	$7.029(\pm0.003) \times 10^3$	$7.025(\pm0.002) \times 10^3$
Cut(1)	$4.855(\pm0.005) \times 10$	$4.846(\pm0.004) \times 10$
Cut(2)	$4.254(\pm0.004) \times 10^{-1}$	$4.255(\pm0.004) \times 10^{-1}$

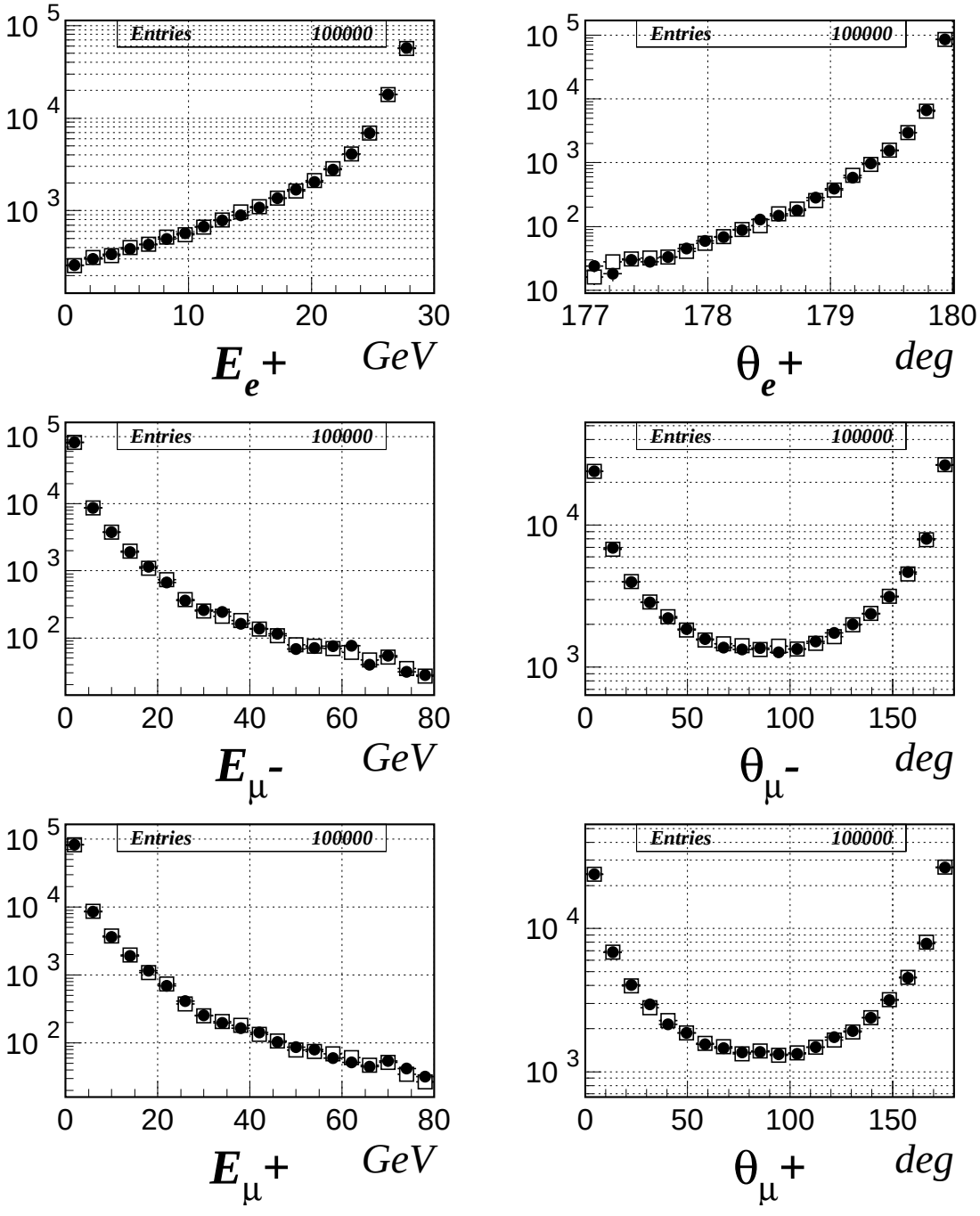
(in unit of pb)

Good Agreement in all cases

within statistical error ($\sim$ 0.1 %)

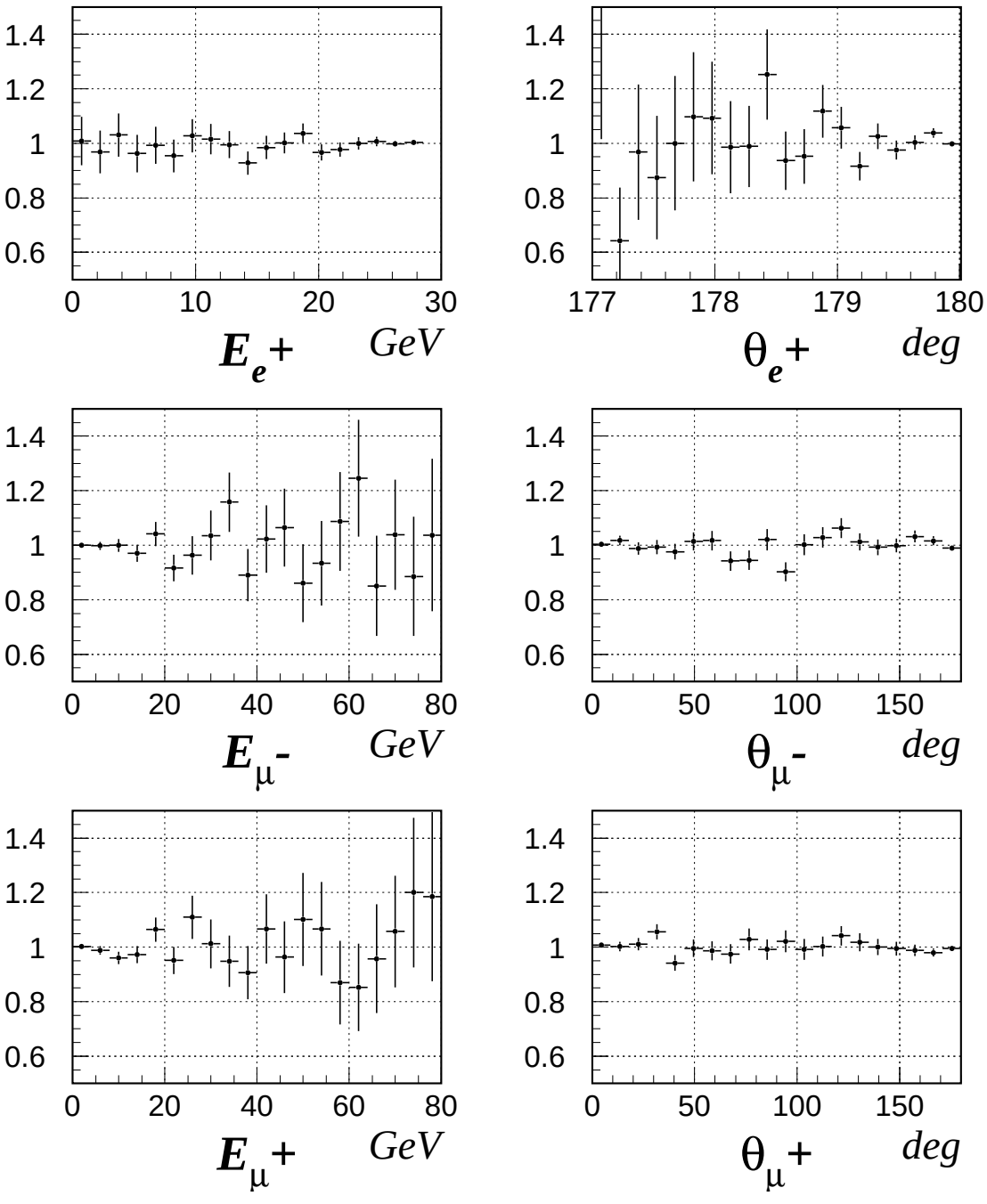
Elastic (No Cut)

● *GRACE* □ *LPAIR*



Elastic (No Cut)

GRACE / LPAIR



Electron-Pair Production in QED

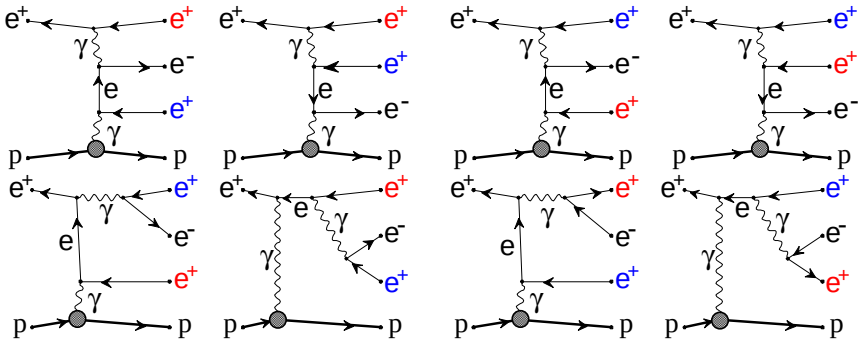
$e^+p \longrightarrow e^+p\ e^+e^-$ (at HERA energy)

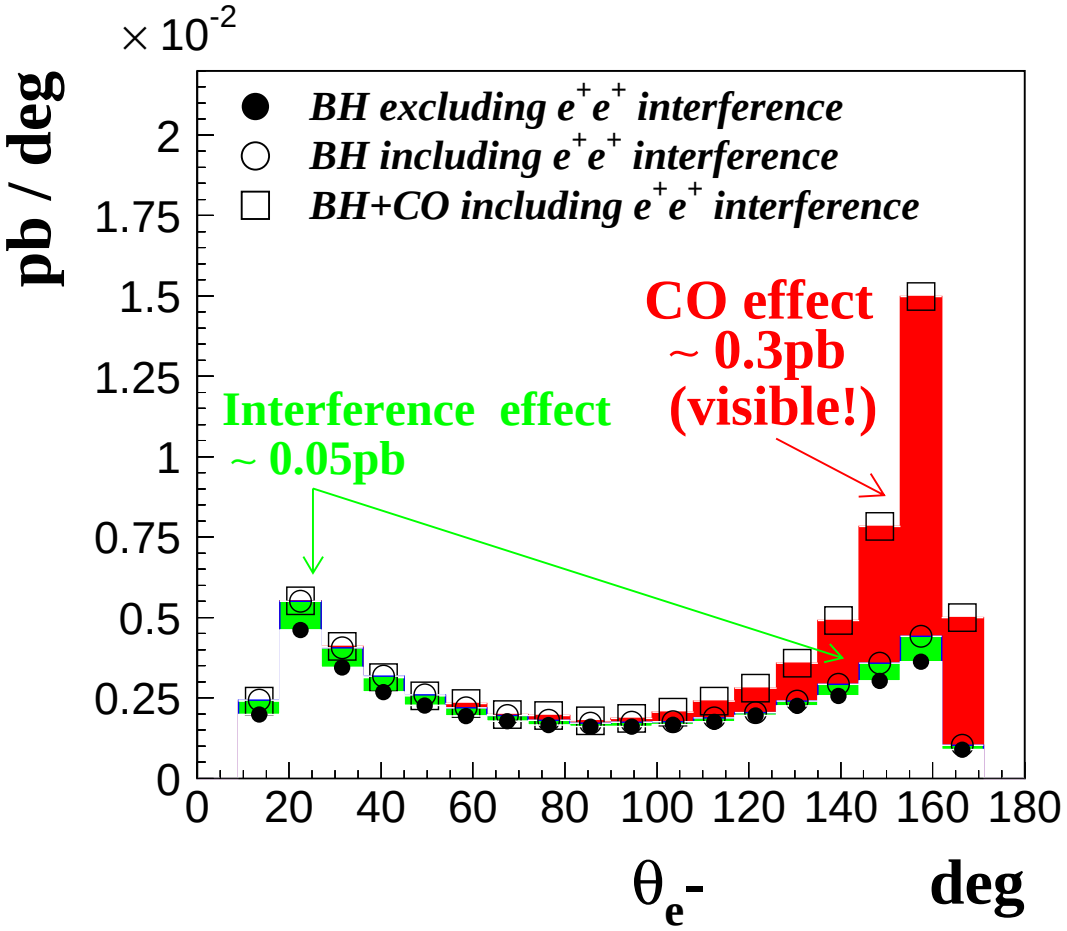
Detector cuts (3e visible)

$15° < \theta_\mu < 164°,\ \ E_e > 4\,\text{GeV}$
(for a electron and 2 positrons)

BH

CO



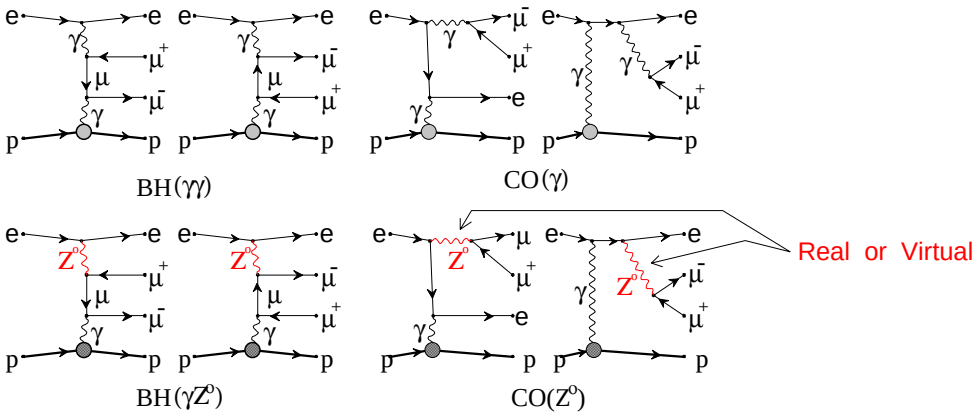


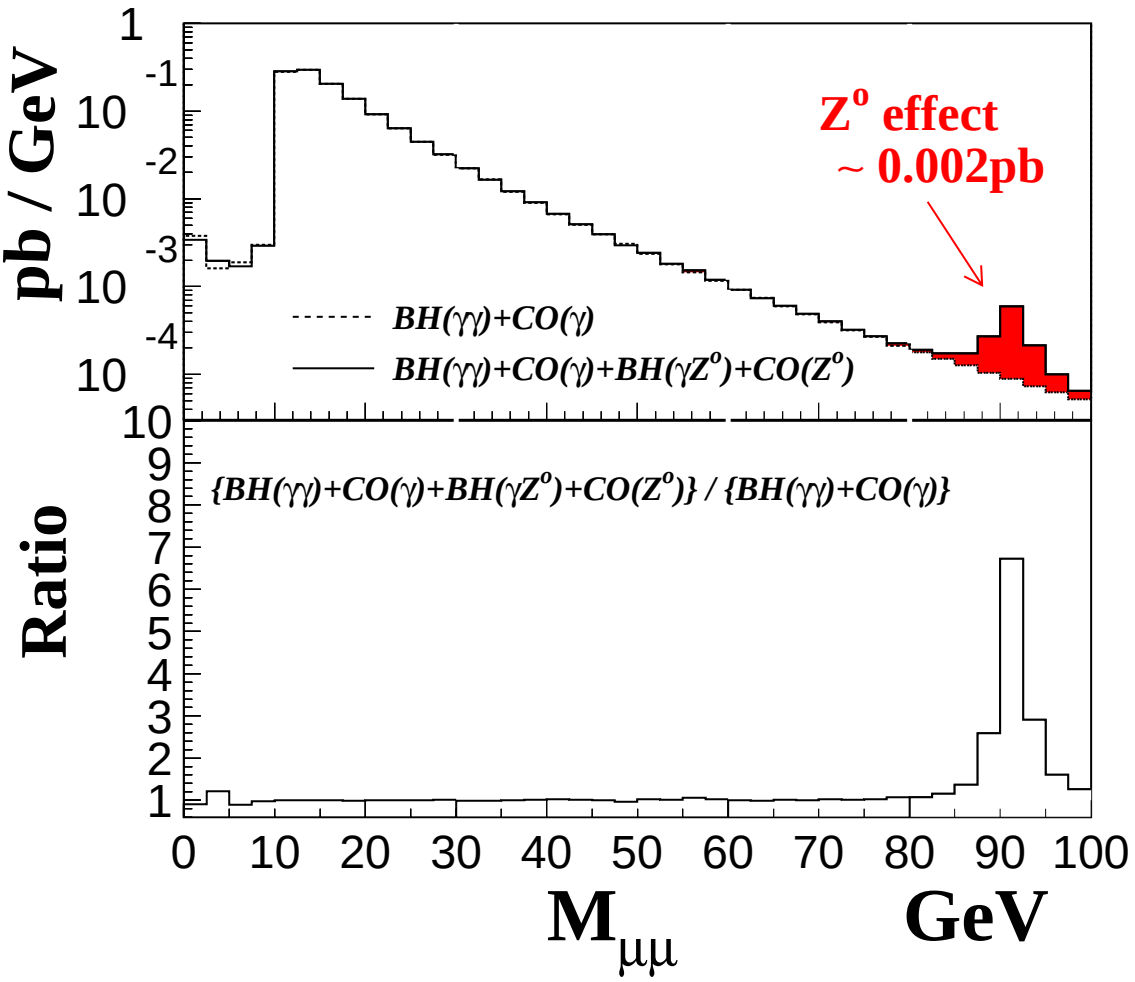
Z^o Effect

$e^+p \longrightarrow e^+p\ \mu^+\mu^-$ (at HERA energy)

Detector cuts (2μ visible)

$15° < \theta_\mu < 164°,\ \ P_t > 5$ GeV/c
(for both muons)





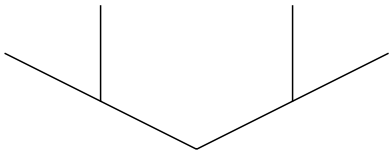
Summary and Conclusions

- A new lepton-pair production event generator has been developed,
  which includes
  - the exact matrix element calculation,
  - all diagrams in the lowest order EW,
  - numerical stableness
  - the calculations for the proton side
    (Elastic, DIS, Structure Function in resonance region).
- Comparison with LPAIR generator was made.
  $\longrightarrow$ Good Agreement

★ CO1 effect is not negligible for the current HERA statistics.

★ Z° effect is accessible if we can get more than 100 pb^{-1}.

★★ $\longrightarrow$ These effects are not included in LPAIR,
but exactly calculated by this generator.



This generator is useful.

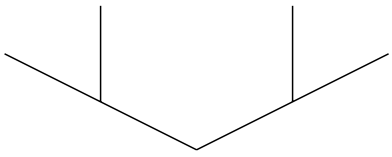
Future

≪ Tasks ≫

- Hadronization $\longrightarrow$ complete hadronic final state
  (with JETSET, HERWIG)
- Higher order QCD correction
  $\longrightarrow$ correct hadronic energy flow
  (with LEPTO, ARIADNE,,,?)

≪ Prospects ≫

- Other processes
  (other SM processes, MSSM with $\not{R}_p$, etc...)



"GRAEPIA" project

GRACE-based generator for ep collisions
including various (complicated) processes

GRAEPIA

has just started with

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