Final Report on GRAPE-Dilepton Generator

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[1] Summary and Comparison with LPAIR

GRAPE
GRAce-based generator for **P**roton-**E**lectron collisions

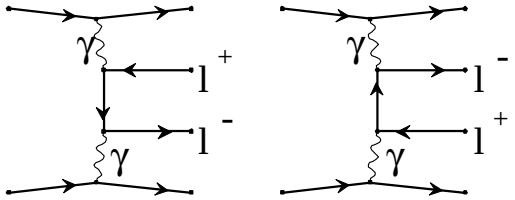
$$e\,p \to e\,X\;l^+l^-$$

	GRAPE-Dilepton	LPAIR
Included diagrams	All in Electroweak (EW)	Only Bethe-Heitler (BH)
Lepton type	e, μ, τ	μ, τ
Fermion masses	All are kept.	
Proton vertex	• Elastic (Dipole-formfactor) • Quasi-elastic (Structure function) • DIS (eq scattering with PDF)	
Hadronization	Performed by PYTHIA / JETSET	
Radiative corrections	ISR with SF* FSR by PYTHIA	Non
Calculation method	Helicity amplitudes + kinematics ($\to$ Polarized beam)	Special formula for $\lvert\mathcal{M}\rvert^2 d\Gamma$ of multi-peripheral diagrams
Numerical stability	OK in all phase space	
Weight of events	One	

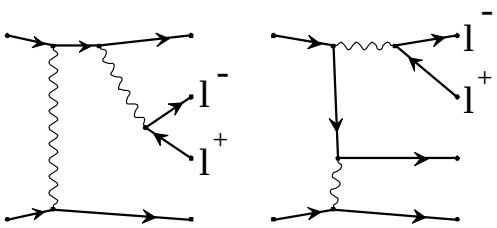
⋆ Suppl. Prog. Theor. Phys. **100** 1990, p285–

[2] Comparison with Bethe-Heitler

The main goal of this work is to estimate differences between the calculation with only BH (=LPAIR) and one including all diagrams.



2-γ Bethe-Heitler diagrams



Internal-conversion diagrams

Diffrences come from

- Internal conversion diagrams,
- Z^o propagators,
- e^+e^+ interference in di-e channel.

GRAPE agrees with LPAIR in BH process.

All calculations were done using GRAPE only.

Sample event-types

Elastic di-e

< Signature >

- 2 EM clusters in calorimeter with Pt>5GeV.
- The 2 EM clusters should be in the acceptance of central tracker.

Elastic μ + e^+

▷ BG for di-$\tau \longrightarrow e\mu$
▷ BG for $H^{\pm\pm} \longrightarrow e^{\pm}\mu^{\pm}$

< Signature >

- One μ in central region with Pt>5GeV.
- Scattered e^+ in central region with Pt>5GeV.

DIS μ + jet

▷ BG for CC, W, LFV, ...

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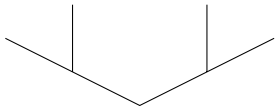
- One μ in central region with Pt>5GeV.
- Hadronic jet in calorimeter with high-Pt.

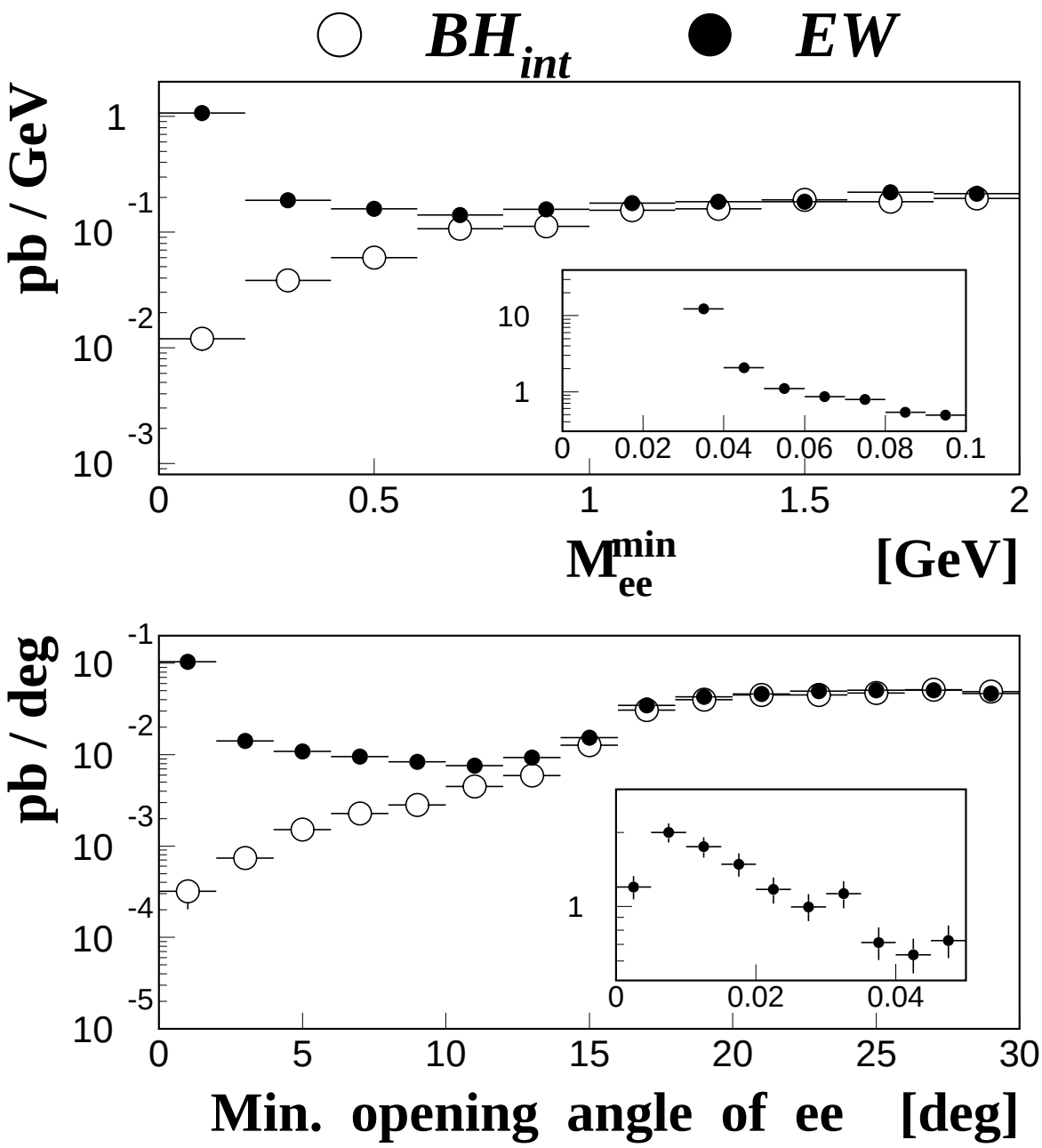
Elastic di-e

$$e^+ p \to e^+ p \; e^+ e^-$$

- At least 2 of e^+ e^+, e^- satisfy
  $\mathrm{Pt}_e > 5$ GeV in $15° < \theta_e < 164°$.
- ISR is included.
- Sets of included diagrams:
  - BH excluding interference (**BH**$_{dir}$)
    (**= LPAIR**)
  - BH including interference (**BH**$_{int}$)
  - All in Electroweak (**EW**)



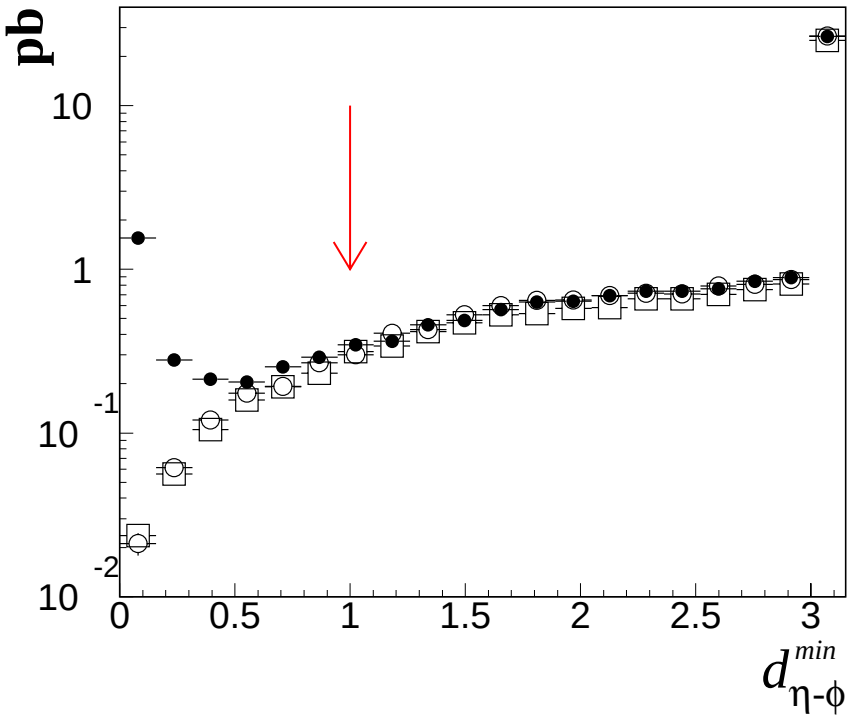
$$\begin{cases} \mathrm{BH}_{dir} : 5.23 \pm 0.02 \text{ pb} \\ \mathrm{BH}_{int} : 5.60 \pm 0.02 \text{ pb} \\ \mathrm{EW} \quad : 5.89 \pm 0.03 \text{ pb} \end{cases}$$


BH_int
EW
pb / GeV
1
10^-1
10^-2
10^-3
0
0.5
1
1.5
2
10
1
0
0.02
0.04
0.06
0.08
0.1
M^min_ee [GeV]
pb / deg
10^-1
10^-2
10^-3
10^-4
10^-5
0
5
10
15
20
25
30
1
0
0.02
0.04
Min. opening angle of ee [deg]

To look at interference

< Additional cut >

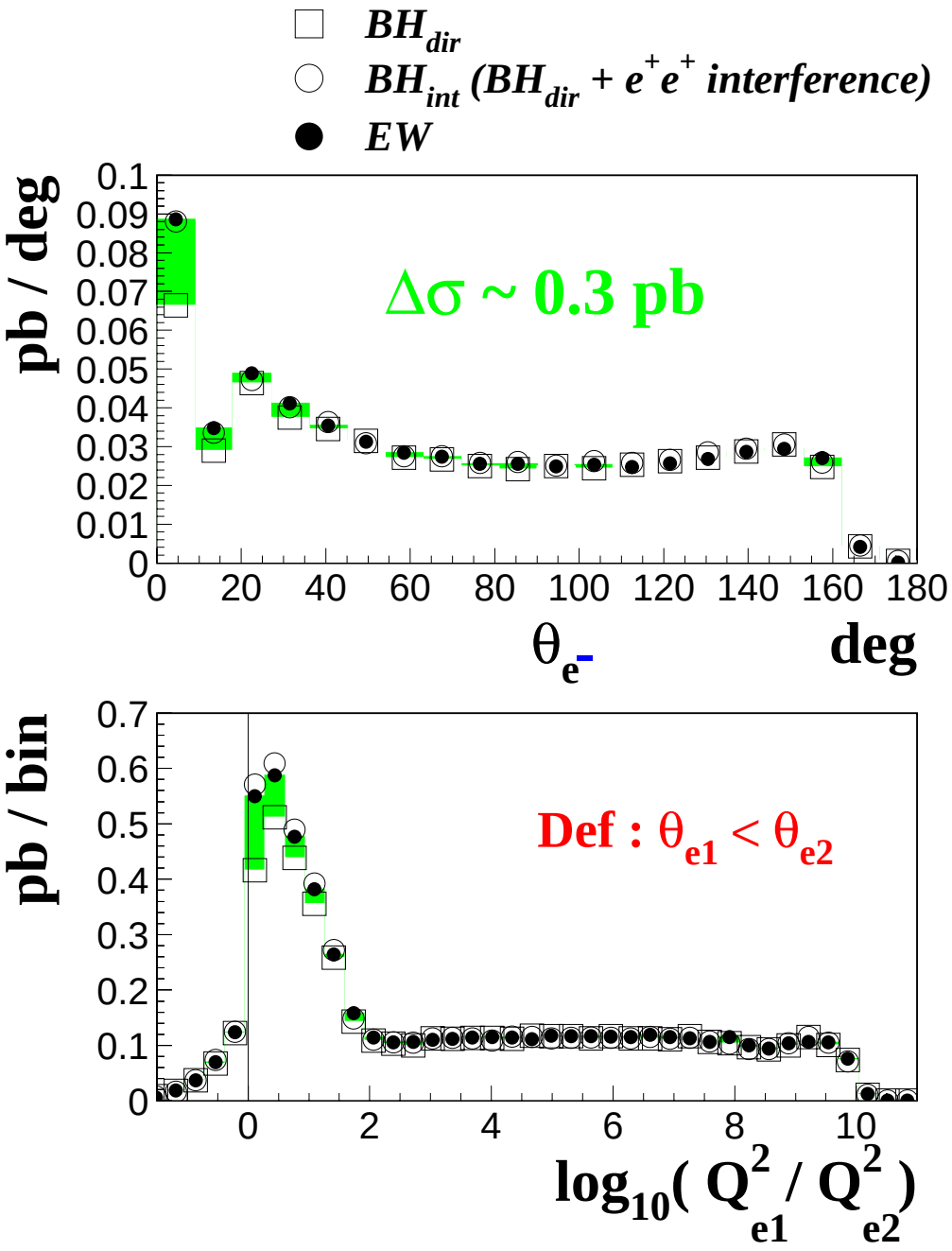
$d^{min}_{\eta-\phi}$: Minimum distance among e^+, e^+, e^- in $\eta - \phi$ space



$d^{min}_{\eta-\phi} > 1$

$$\begin{cases} \mathrm{BH}_{dir} : 5.10 \pm 0.02 \text{ pb} \\ \mathrm{BH}_{int} : 5.46 \pm 0.02 \text{ pb} \\ \mathrm{EW} \quad : 5.43 \pm 0.02 \text{ pb} \end{cases}$$

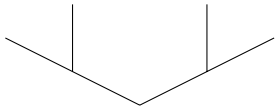
$$e^+ p \to e^+ p \; e^+ e^-$$



$$Q_e^2 \equiv \left| \left\{ p_{e^+_{beam}} - p_{e^+_{(out)}} \right\}^2 \right|$$

μ + e events

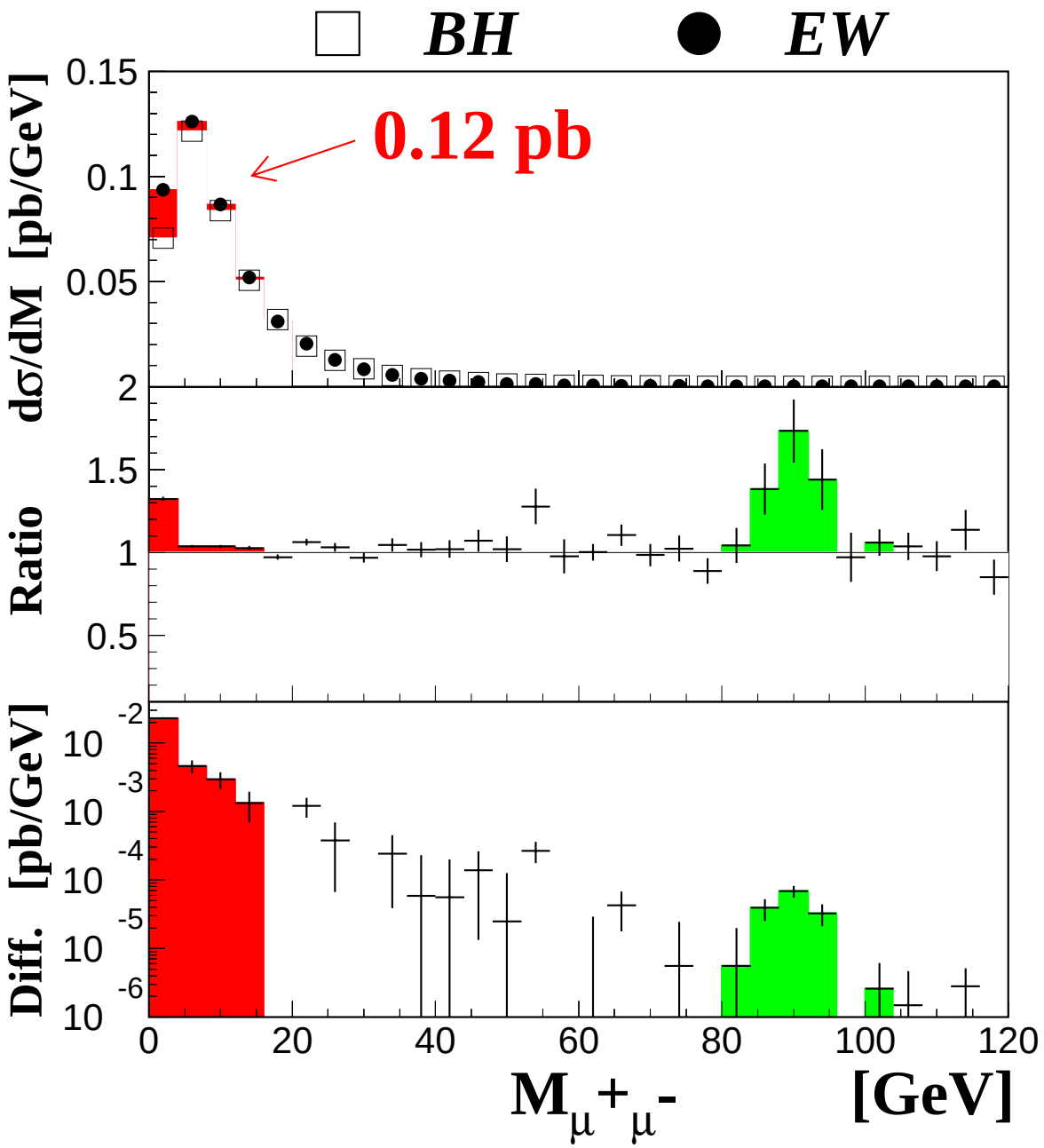
- Process : $e^+ p \to e^+ p\ \mu^+\mu^-$
  ($E_p = 820$ GeV, $E_e = 27.5$ GeV)
- $pp\gamma$ vertex : dipole-formfactor
- ISR is included.
- Sets of included diagrams:
  - Only Bethe-Heitler (**BH**) ($\Longrightarrow$ **LPAIR**)
  - All in Electroweak (**EW**)
- Selecting μ + e events
  - For one or both of μ^+, μ^-:
    $\mathrm{Pt}_\mu > 5$ GeV in $18° < \theta_\mu < 160°$
  - For scattered positron:
    $\mathrm{Pt}_e > 5$ GeV in $15° < \theta_e < 164°$



$$\sigma = \begin{cases} \mathrm{BH}: 1.674 \pm 0.005 \text{ pb} \\ \mathrm{EW}: 1.803 \pm 0.005 \text{ pb} \end{cases}$$

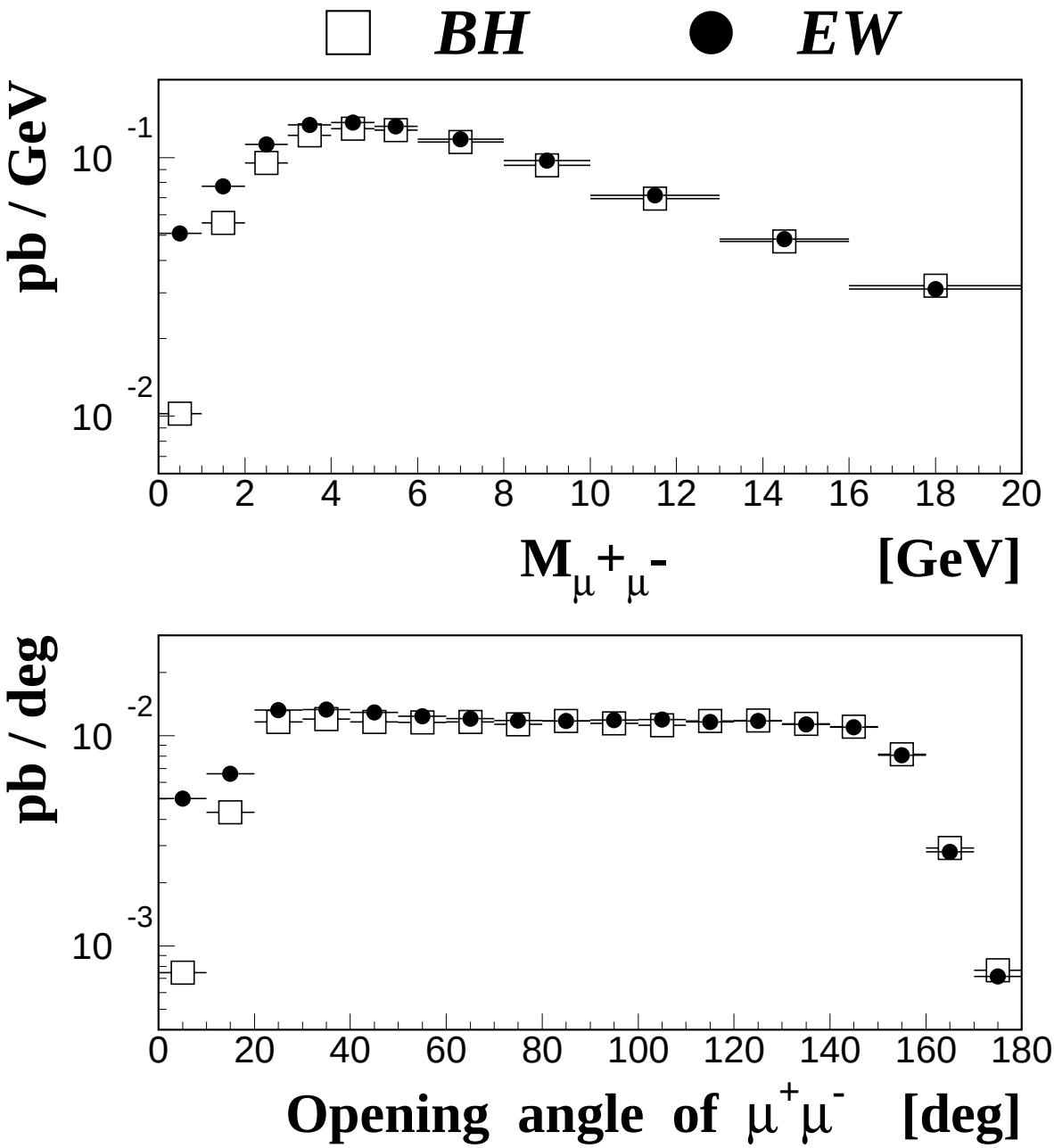
μ + e events

$$e^+ p \to e^+ p \ \mu^+ \mu^-$$



μ + e events

$$e^+ p \to e^+ p \ \mu^+\mu^-$$



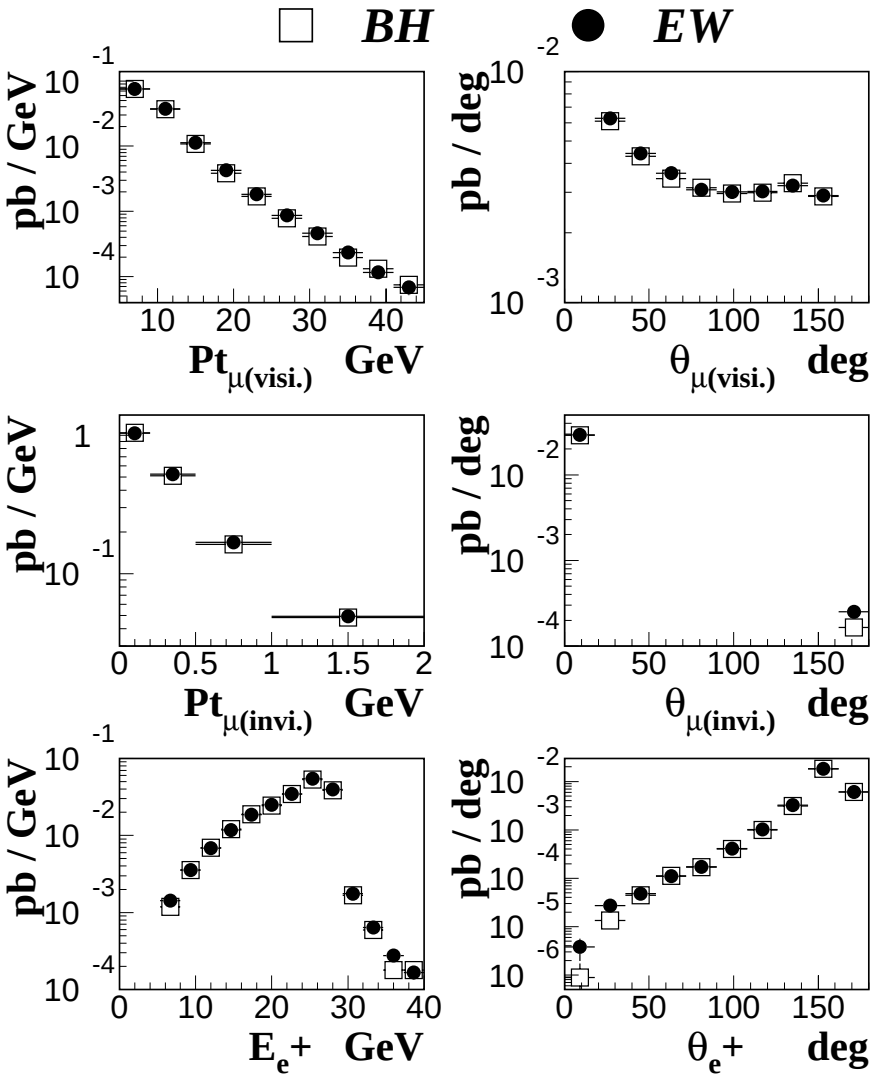
Single-μ + e events

$$e^+ p \to e^+ p \ \mu^+\mu^-$$

Additional cut to μ + e selection :

one of di-μ in $\theta < 5°$ or $\theta > 175°$

BH : 0.523 $\pm$ 0.003 pb
QED : 0.524 $\pm$ 0.003 pb
EW : 0.532 $\pm$ 0.003 pb

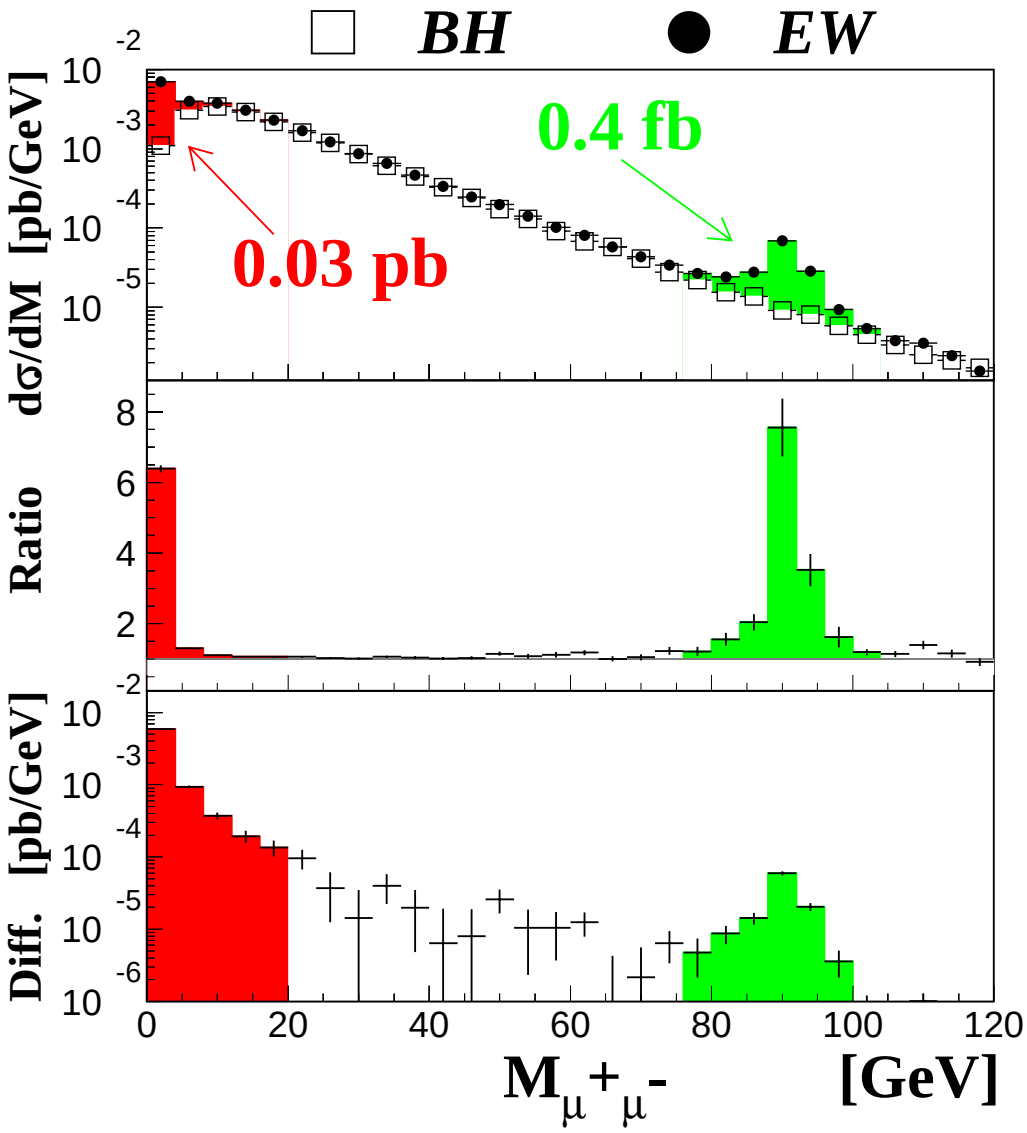


μ + jet events

- Process : $e^+ q \to e^+ q\ \mu^+\mu^-$
  ($E_p = 820$ GeV, $E_e = 27.5$ GeV)
- $q = u + \overline{u} + d + \overline{d} + s + \overline{s}$ (Light quarks)
- PDF : CTEQ4L
- (QCD scale)$^2 \equiv \left|\left\{p_{q(in)} - p_{q(out)}\right\}^2\right| > 3\,\mathrm{GeV}^2$
- $u \equiv \left|\left\{p_{q(in)} - (p_{l+} + p_{l-})\right\}^2\right| > 25\,\mathrm{GeV}^2$
- $M_{q\,\mu^+\mu^-} > 5$ GeV
- ISR is included.
- M_{had} : (Mass of hadronic system)
  $\equiv \sqrt{\left\{(p_{e_{beam}} + p_{P_{beam}}) - (p_{e^+} + p_{l^+} + p_{l^-} + p_{ISR})\right\}^2}$
  > 5 GeV
- Sets of included diagrams:
  - Only Bethe-Heitler (**BH**) (**= LPAIR**)
  - All in Electroweak (**EW**)

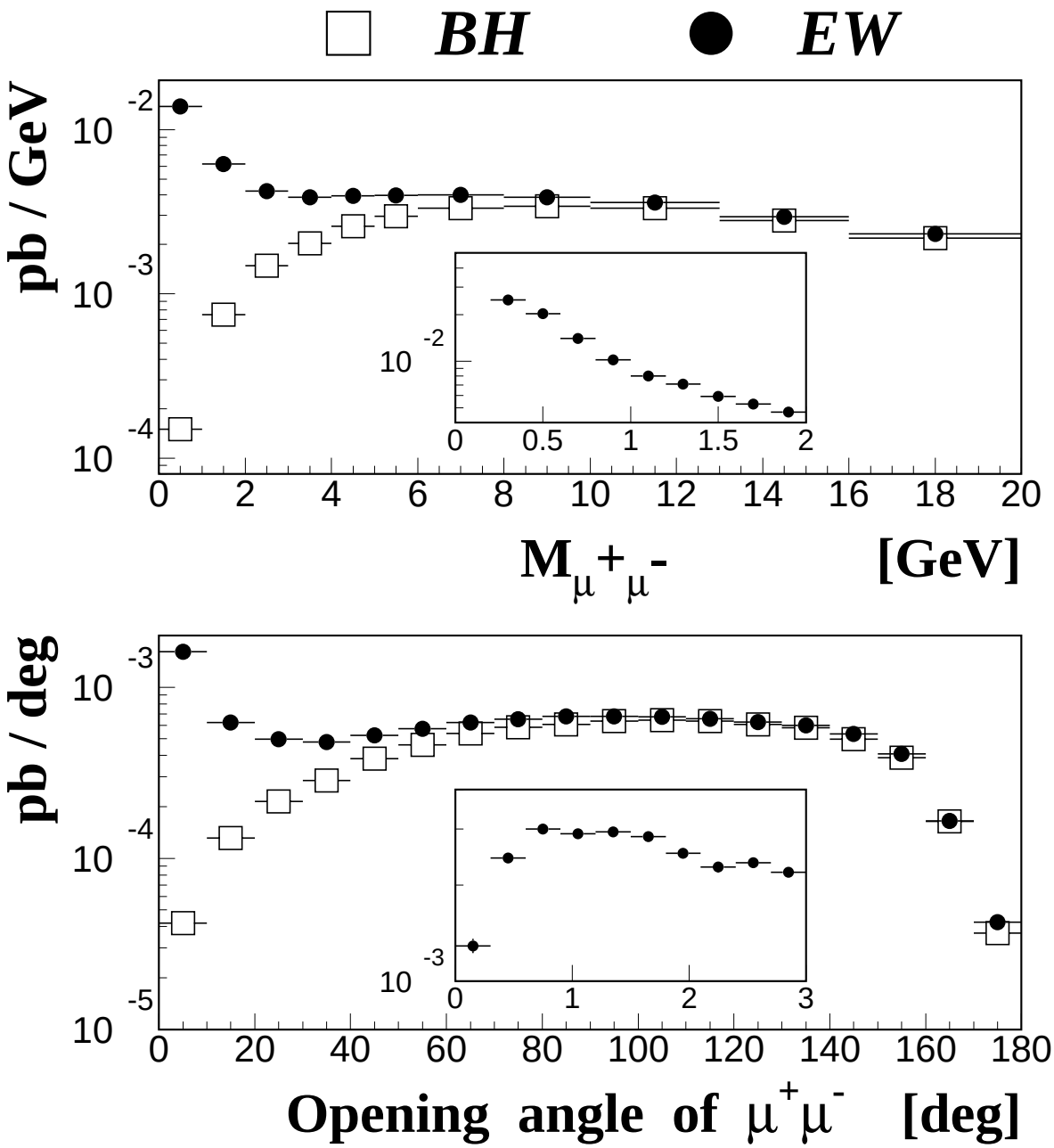
- Selecting μ + jet events
  - For one or both of μ^+, μ^-:
    $\mathrm{Pt}_\mu > 5$ GeV in $18° < \theta_\mu < 160°$
  - For scattered quark:
    $\mathrm{Pt}_q > 15$ GeV in $\theta_q > 10°$

$$\sigma = \begin{cases} \mathrm{BH}: 0.0743 \pm 0.0003 \text{ pb} \\ \mathrm{EW}: 0.1061 \pm 0.0003 \text{ pb} \end{cases}$$



μ + jet events

$e^+ q \to e^+ q \ \mu^+\mu^-$



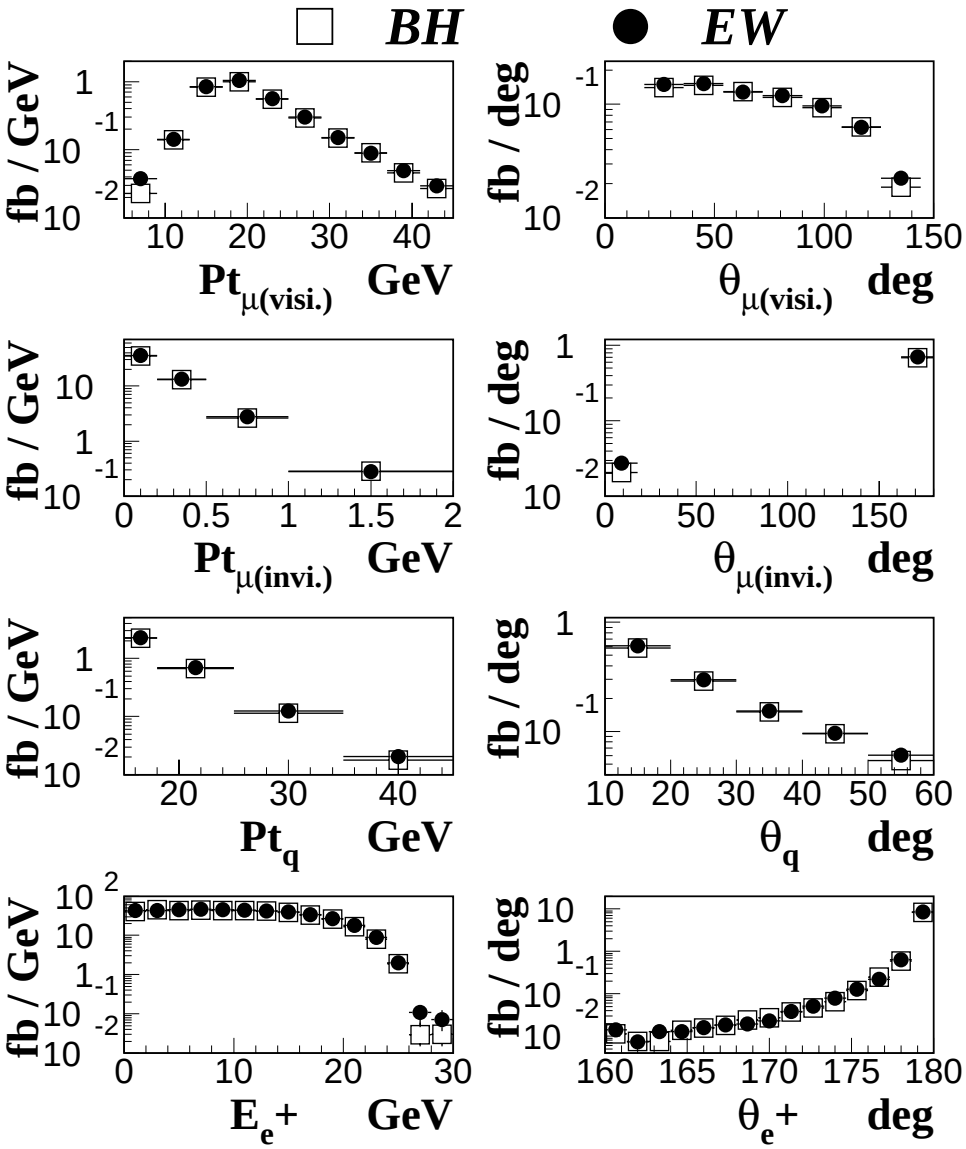
Single-μ + jet events

$$e^+ q \to e^+ q \;\; \mu^+\mu^-$$

Additional cut to μ + jet selection :

one of di-μ in $\theta < 5°$ or $\theta > 175°$

BH : 12.9 $\pm$ 0.1 fb
EW: 13.1 $\pm$ 0.1 fb

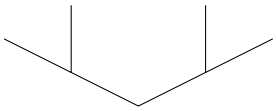


Summary

Using GRAPE-Dilepton generator which includes all diagrams in EW, differences between BH and EW can be estimated.

- **Internal conversion diagrams,**
- **Z^o propagators,**
- **e^+e^+ interference in di-e channel.**

Dilepton production is $2 \to 4$ process.
$\Longrightarrow$ Complicated!



It's the best way for YOU to use this program.

GRAPE-Dilepton_v0.0 (Preliminary version)

/afs/desy.de/user/a/abe/public/grape/grape-dilepton_v0.0_BEAM_positron.tgz
will be prepared within a few days.

—— Future Plans ——

- Preparing Web page. (Up-to-date information)
  http://www-zeus.desy.de/~abe/grape
- Writing a complete manual for proceedings.
- Publication to CPC.