Parity-Odd Asymmetries in W-Jet Events at the LHC

Hiroshi Yokoya (U. of Toyama)

Ref. K.Hagiwara, K.Hikasa, N.Kai, Phys.Rev.Lett.52 (1984) 1076,
K.Hagiwara, K.Hikasa, HY, Phys.Rev.Lett.97 (2006) 221802
and
R.Frederix(CERN), K.Hagiwara, T.Yamada(NCU,Taiwan), HY, in progress

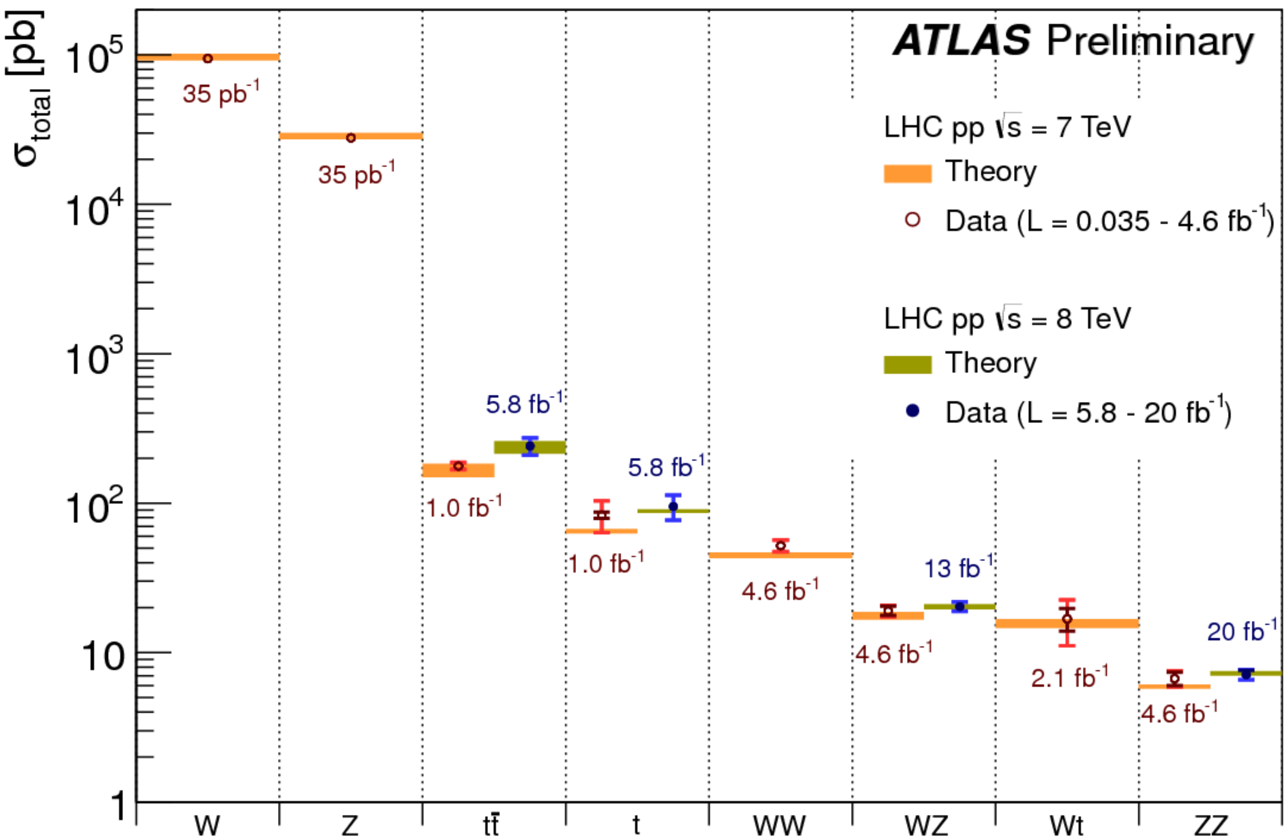
BURI2014, Toyama, 2/13-14 (2014)

Outline: W-jet production at hadron colliders,

Parity-odd and naïve-T-odd observables,

Simulation study

Summary

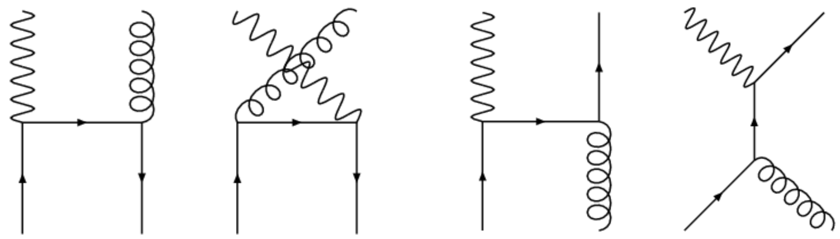


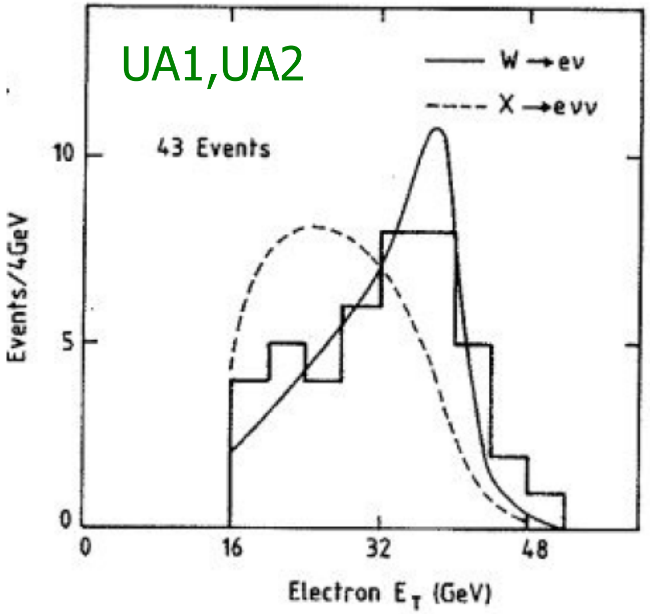
Introduction

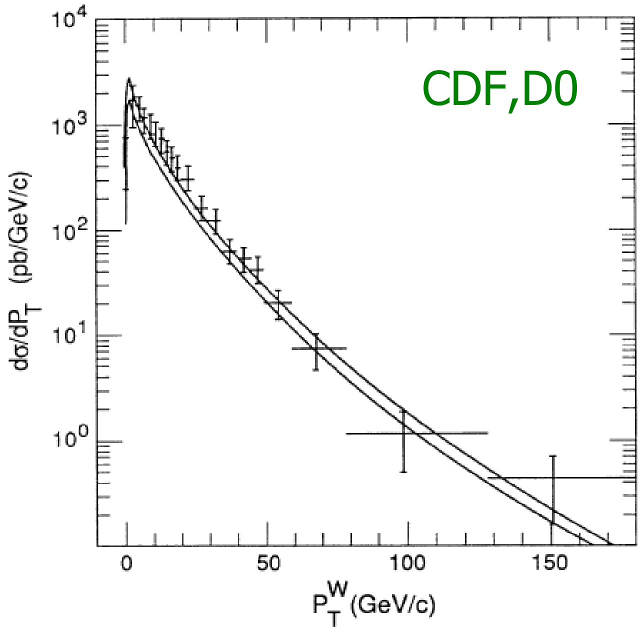
- High-q_T W-boson production at Hadron Colliders

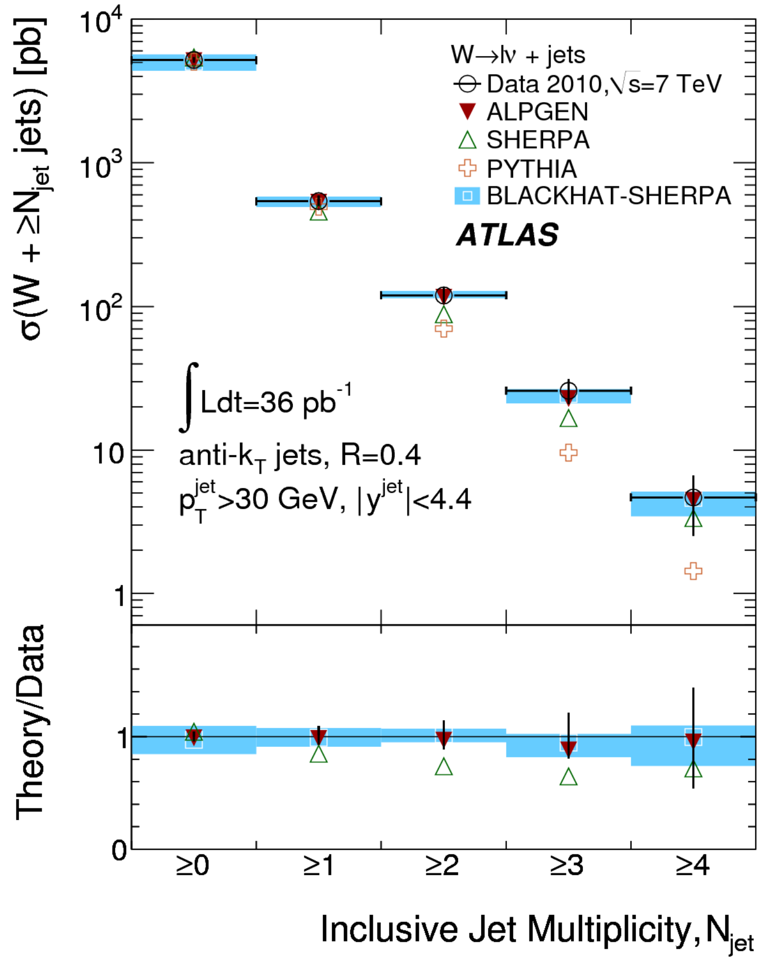
$$p + p(\bar{p}) \rightarrow W^{\pm} + X; W^{\pm} \rightarrow \ell^{\pm}\nu$$

QCD LO
→ NLO









Lepton Angular Distributions

- Information of the polarization of W-boson

  → details of production mechanism

- Distributions can be expressed by 9 structure functions.

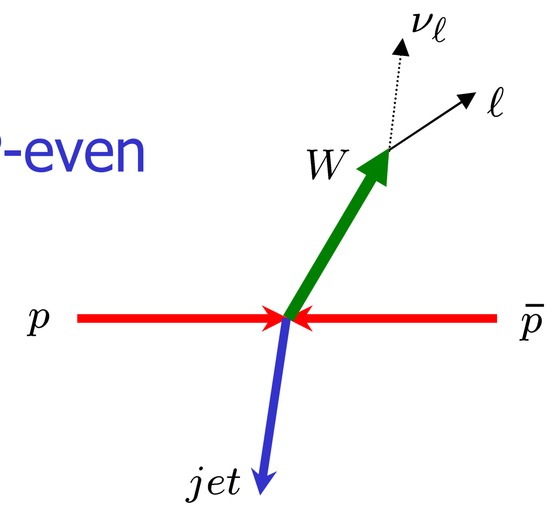
$$\frac{d^4\sigma}{dq_T^2 d\cos\hat{\theta} d\cos\theta d\phi} = F_1(1+\cos^2\theta) + F_2(1-3\cos\theta^2) + F_3\sin 2\theta\cos\phi + F_4\sin^2\theta\cos 2\phi + F_5\cos\theta + F_6\sin\theta\cos\phi$$

P-even

$$+ F_7\sin\theta\sin\phi + F_8\sin 2\theta\sin\phi + F_9\sin^2\theta\sin 2\phi$$

P-odd

P : $\phi \rightarrow -\phi$



$\cos\hat{\theta}$: scattering angle

θ, ϕ: lepton angles in W-rest frame

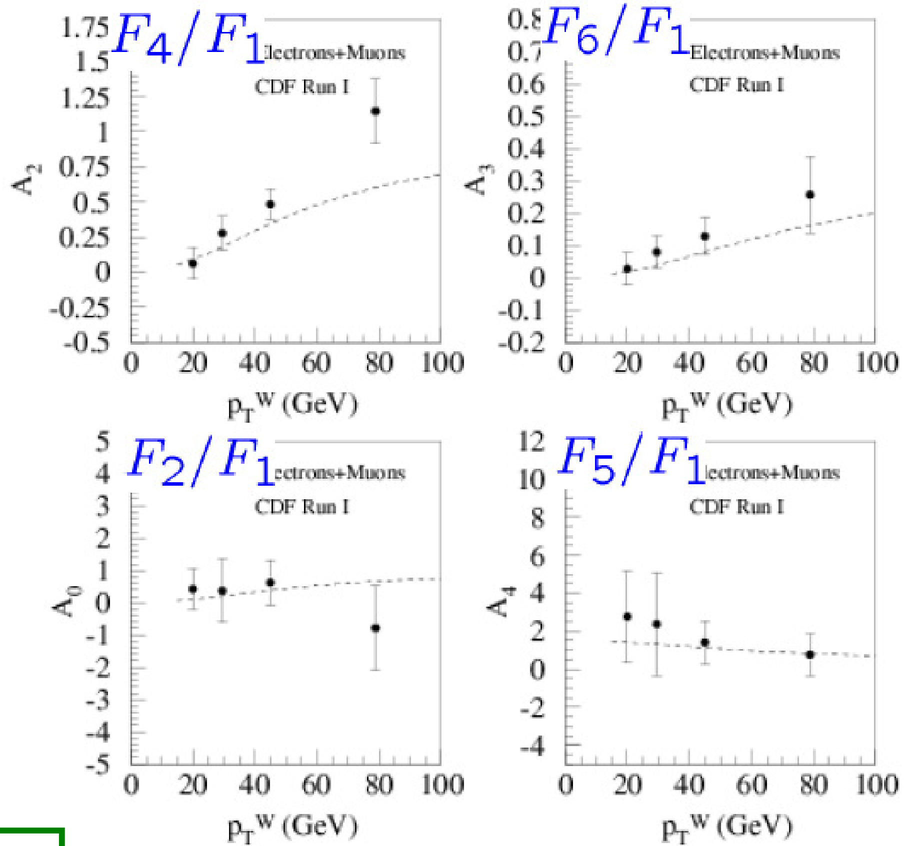
- pQCD prediction : $F_i(q_T^2, \cos\hat{\theta}) = \sum_{a,b}\int dY f_{a/p}(x_+, \mu_F^2) f_{b/\bar{p}}(x_-, \mu_F^2) \hat{F}_i^{ab\rightarrow W^- j}$

Measurement of P-even distribution by CDF

PRD73,052002 ('06)

- Some of P-even distributions have been measured by CDF collaboration.
  → agree with pQCD (NLO) calc.

- However, P-odd distributions have not been measured yet.



Our work : revisit the P-odd effects and study the method to measure the P-odd distributions experimentally.

Parity-odd asymmetry

General arguments of parity-odd asymmetry

- Parity transformation : $(\vec{p}, \vec{s}) \to (-\vec{p}, \vec{s})$

- Parity-odd observables :

  - with spin : $\langle \vec{p}_\ell \cdot \vec{s} \rangle \to -\langle \vec{p}_\ell \cdot \vec{s} \rangle$

  - without spin : $\langle \vec{p}_p \times \vec{q} \cdot \vec{p}_\ell \rangle \to -\langle \vec{p}_p \times \vec{q} \cdot \vec{p}_\ell \rangle$

(need a source of parity-violation, e.g. weak int.)

Parity-odd and Naïve-T ($\tilde{\mathrm{T}}$)-odd

- P-odd observables without spins are interesting, because these are naïve-T ($\tilde{\mathrm{T}}$)-odd at the same time.

$\tilde{\mathrm{T}}$-transformation :
(unitary)

$$(\vec{p}, \vec{s}) \to (-\vec{p}, -\vec{s})$$

$$\widetilde{\mathrm{T}} |i(\vec{p}, \vec{s})\rangle = |\tilde{i}(-\vec{p}, -\vec{s})\rangle$$

T-transformation :
(anti-unitary)

$$(\vec{p}, \vec{s}) \to (-\vec{p}, -\vec{s})$$

$$\mathrm{T} |i(\vec{p}, \vec{s})\rangle = \langle\tilde{i}(-\vec{p}, -\vec{s})|$$

Unitarity and $\tilde{\mathrm{T}}$-odd quantity

- Unitarity of S-matrix $S_{fi} = \delta_{fi} + i(2\pi)^4\delta^4(P_f - P_i)T_{fi}$

$$T_{fi} - T^*_{if} = iA_{fi} \quad \text{where } \underline{A_{fi} = \sum_n T^*_{nf} T_{ni} (2\pi)^4 \delta^4(P_n - P_i)}$$

absorptive part

gives $$|T_{fi}|^2 = |T_{if}|^2 - 2\,\mathrm{Im}(T^*_{if}A_{fi}) + |A_{fi}|^2$$

- $\tilde{\mathrm{T}}$-odd quantity

subtract $|T_{\tilde{f}\tilde{i}}|^2$

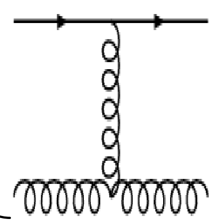
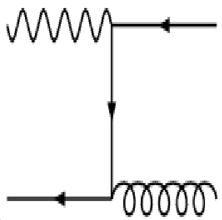
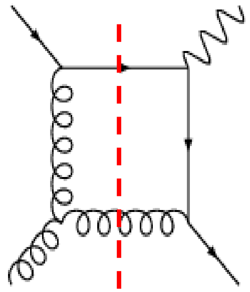
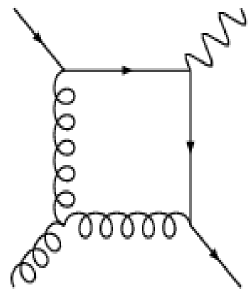
$$|T_{fi}|^2 - |T_{\tilde{f}\tilde{i}}|^2 = (|T_{if}|^2 - |T_{\tilde{f}\tilde{i}}|^2) - 2\,\mathrm{Im}(T^*_{fi}A_{fi}) - |A_{fi}|^2$$

Time-reversal violation

→ emerges from the absorptive parts of the scattering amplitude

Unitarity and $\tilde{T}$-odd quantity

In perturbation theory, the absorptive part of scattering amplitudes can be calculated by the imaginary part of the amplitudes.

$\int d\Phi_2$ () ()* =  = Im ()

Cutkosky rule

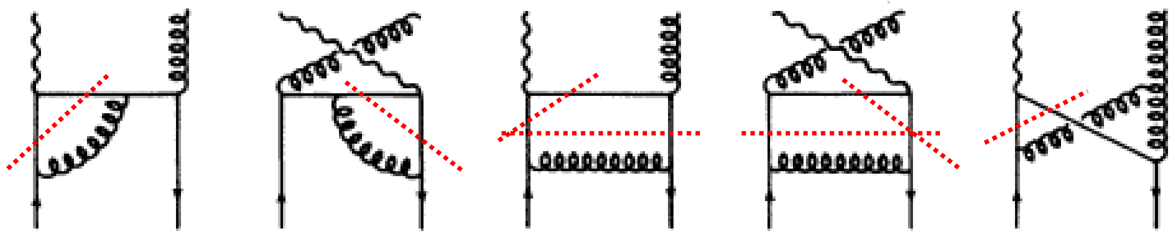
Therefore, measurement of naïve-T-odd quantities can test the perturbative predictions for the absorptive part of scattering amplitudes, or the scattering phase.

One-loop calculation

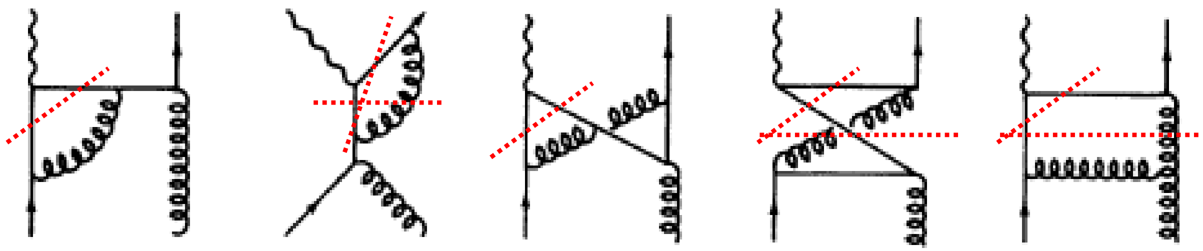
Hagiwara,Hikasa,Kai('84)

- Absorptive part for the W-jet production in one-loop level :

1. Annihilation subprocess : $q\bar{q}' \to Wg$



2. Compton subprocess : $qg \to Wq'$ $(\bar{q}g \to W\bar{q}')$



Parity-odd asymmetries

$$A_i(q_T^2, \cos\hat{\theta}) = F_i \,/\, F_1 \text{ for } i = 7, 8, 9$$

LHC

pp, $\sqrt{S} = 8$ TeV

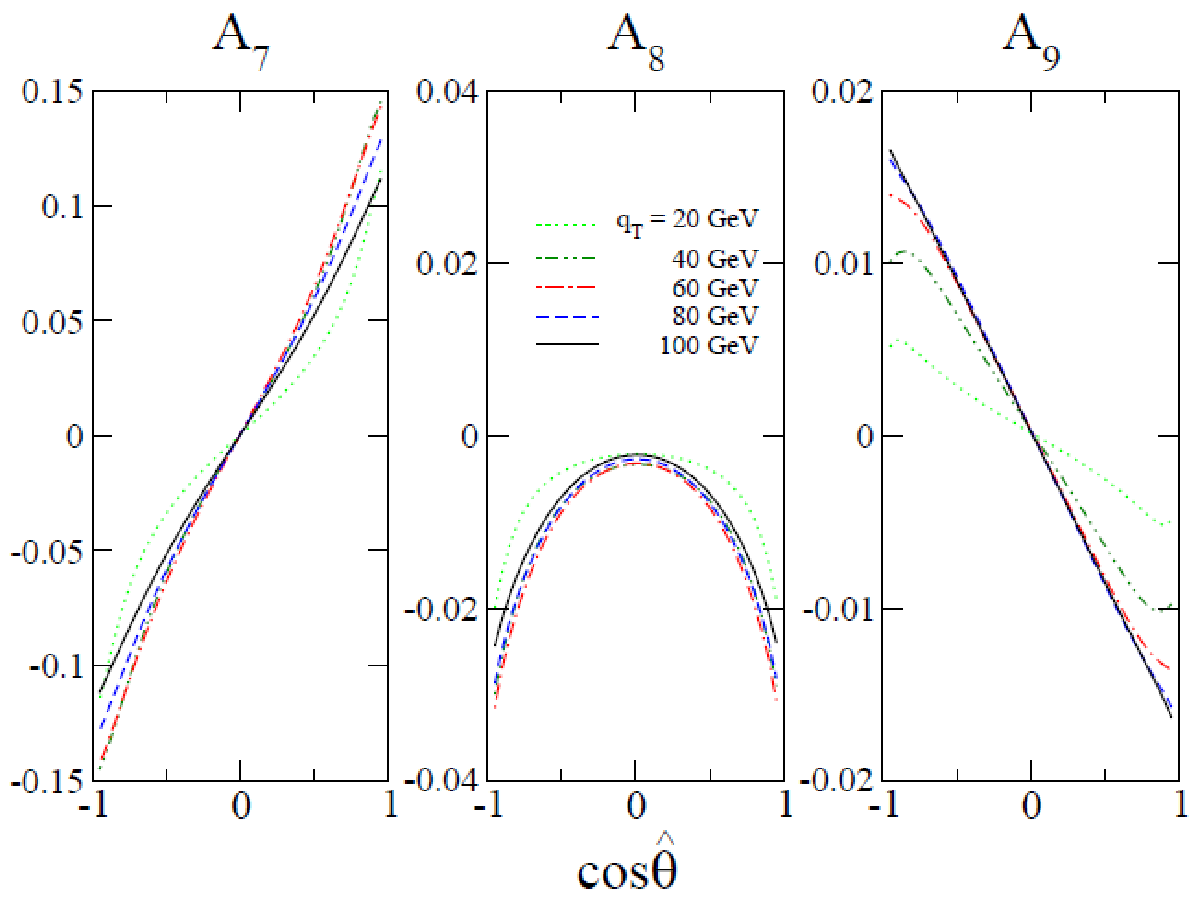
with CTEQ6M

A_7 ~ 10-15%,

A_8 ~ a few %,

A_9 ~ a few %

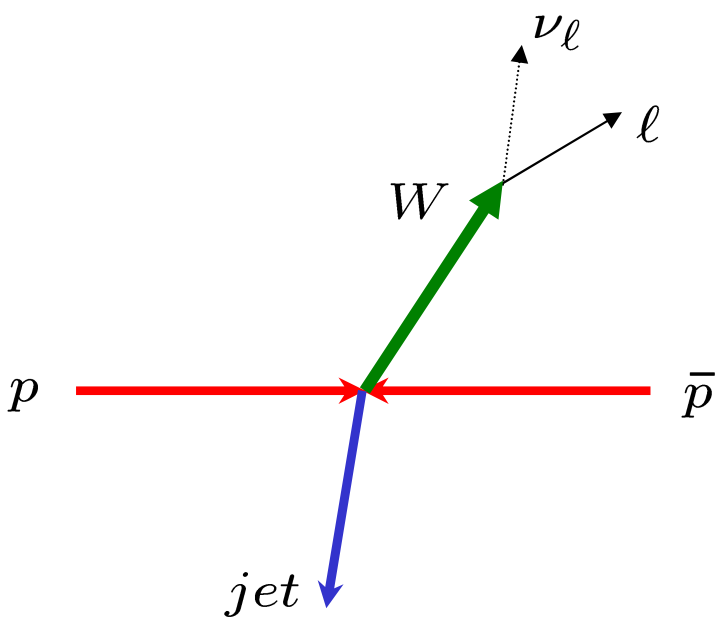
Hereafter, we focus on A_7 measurement



$\sin\theta \sin\phi$ $\sin 2\theta \sin\phi$ $\sin^2\theta \sin 2\phi$

Measurement at collider experiments

- Two-fold ambiguity



- (longitudinal) neutrino momentum cannot be measured, but is solved by using W-boson on-shell condition.

→ Two-fold ambiguity in determining

- W-jet c.m. frame $\cos\hat{\theta},\ \hat{s},\ x_{\pm},,,$
- W-rest frame $\cos\theta,\ \phi$

- However, to measure A_7, we only need to know

$\sin\theta \sin\phi$ → y-component of p_l in the lab. frame

$\cos\hat{\theta}$ → use pseudo-rapidity difference of lepton and jet, instead. $\Delta\eta = \eta_\ell - \eta_{jet}$

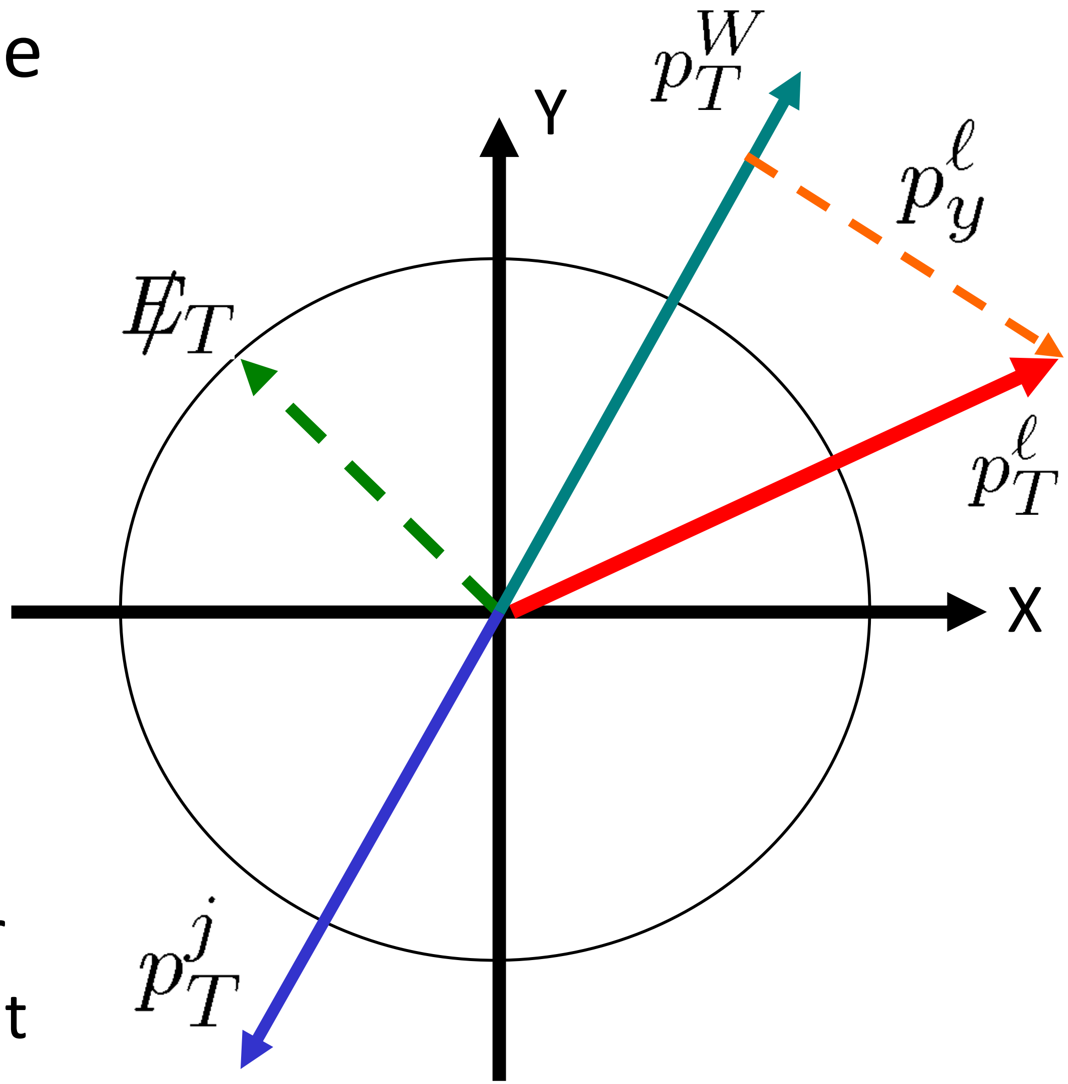
Measurement at collider experiments

Event in the transverse plane

$(p^l)_y$ is invariant under the Lorentz Boost from lab. frame to the W-rest frame

$$p_y^\ell = \frac{m_W}{2} \sin\theta \sin\phi$$

Missing E_T resolution is crucial for the accuracy of $(p^l)_y$ measurement



Measurement at collider experiments

- Standard cuts for W+jets events:

  - One lepton with high-p_T > 25 GeV
  - Large missing E_T > 25 GeV
  - Large transverse mass, M_T > 60 GeV
  - Hard jets with p_T > 30 GeV

- For our purpose, we may further require

  - Veto on the second leading jet p_T > 30 GeV
  - q_T > 20 GeV
  - etc.

MC simulation by aMC@NLO

An automated NLO cross-section calculator + event generator

http://amcatnlo.web.cern.ch/amcatnlo/

- We confirmed that it calculates the absorptive part correctly.
- MC sim. with parton-shower, hadronization and detector effect.
- Able to check the effect of jet smearing, MET resolution etc.

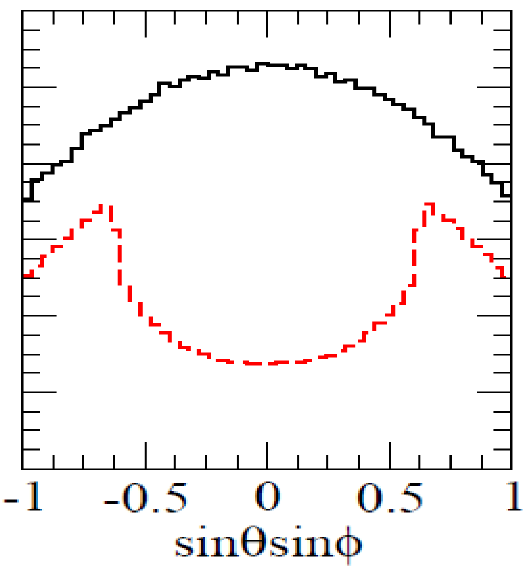
This is very important for experimentalists to handle with such theory prediction in Monte-Carlo simulation

→ We demonstrate the aMC@NLO simulation for the realistic P-odd observables at the LHC.

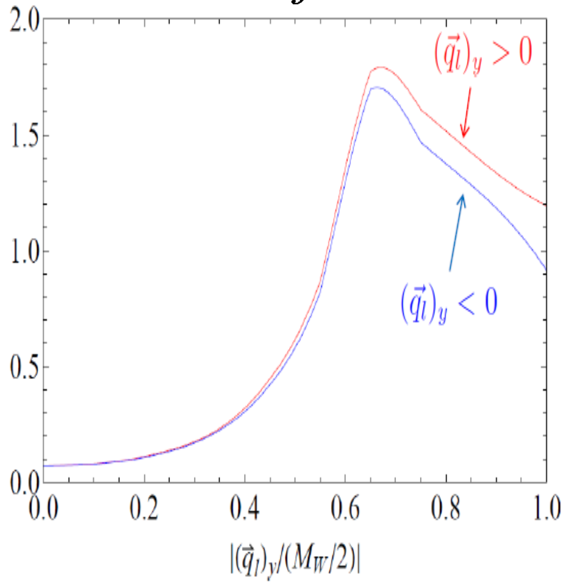
MC simulation by aMC@NLO

Check of distributions by MC simulation

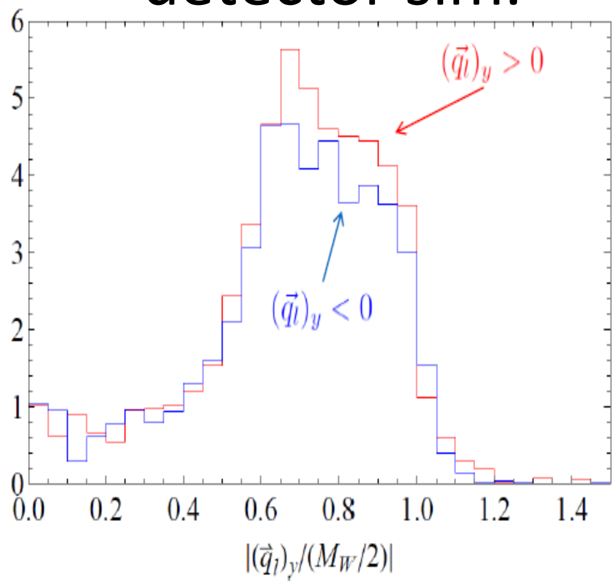
- $\sin\theta\sin\phi$ $\{=p^{l}_{y}/(m_W/2)\}$ distribution before/after cuts (LHC 8TeV)



$\eta_\ell - \eta_j > 1$



detector sim.



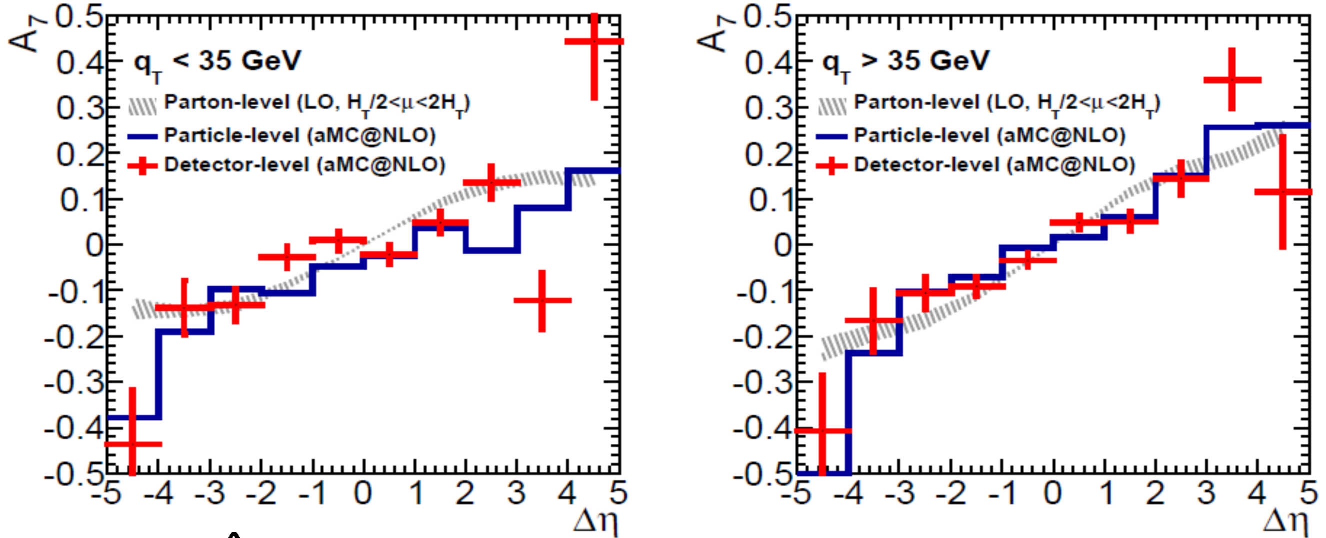
- Small $\sin\theta\sin\phi$ events are suppressed by cuts

  → good for A_7, since smearing effect by MET resolution can be reduced.

MC simulation by aMC@NLO

- Comparison of the Asymmetries at parton-level,
  particle-level(Herwig) and detector-level(Delphes).

$$A_7 = \langle 4 \sin\theta \sin\phi \rangle \propto \langle (p_\ell)_y \rangle$$



$\Delta\eta = \eta_\ell - \eta_j$

(LHC 8TeV)

error bar
= statistic error
in our sim. (~1fb^{-1})

- We find that asymmetry can be retained after smearing effects.

Summary

- Naïve-T-odd asymmetry emerges from the absorptive part of the scattering amplitudes. In hard process it can be predicted, and comparison with experiments would be an interesting test.

- We study the naïve-T-odd (P-odd) asymmetry in W-jet production at the LHC at one-loop level with detailed simulation study for the realistic experimental situations.

- It will be a first observation of naïve-T-odd observables in hard process.