Double transverse spin asymmetries as a probe for new physics

Wilco den Dunnen and Daniël Boer

VU University Amsterdam and KVI Groningen

March 18, 2010

vrije Universiteit *amsterdam*

outline

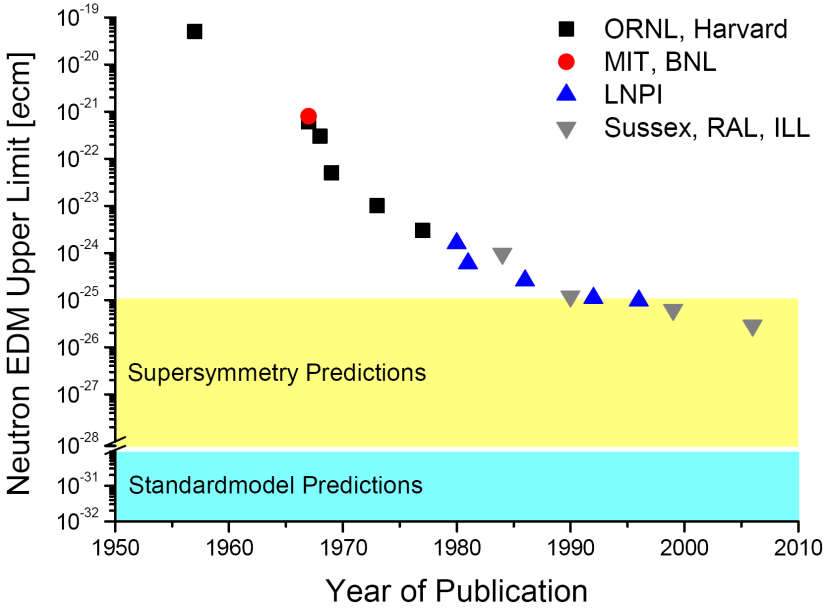
1. Left-Right models: motivation & features
2. Current bounds
3. Exploiting spin asymmetries at RHIC
4. Estimates of asymmetries & background
5. Summary

motivation

to explain the baryon asymmetry $\rightarrow$ need more CP violation

many extensions of the SM allow more CP violation

often *too much*:
(cf. neutron EDM measurements)



need

- small CP violation at low energy
- 'large' CP violation at high energy

Left-Right models

Left-Right models: gauge group $SU(2)_R \otimes SU(2)_L \otimes U(1)$

energy scale

$$SU(2)_R \otimes SU(2)_L \otimes U(1)$$

smaller $\not{P}, \not{C}$
larger $\not{CP}$

$$\downarrow$$

$$SU(2)_L \otimes U(1)_Y$$

$$\downarrow$$

$$U(1)_{EM}$$

large $\not{P}, \not{C}$
small $\not{CP}$

phenomenology of Left-Right models

$SU(2)_L$: W_L boson and V^L_{CKM} matrix
$SU(2)_R$: W_R boson and V^R_{CKM} matrix

mixing:

$$\begin{aligned} &\text{light} \qquad W = \cos\zeta W_L - e^{i\omega}\sin\zeta W_R \\ &\text{heavy} \quad W' = \sin\zeta W_L + e^{i\omega}\cos\zeta W_R \end{aligned}$$

- 6 new CP violating phases in V^R_{CKM}
- CP violating phase ω

manifest: $g_L = g_R$, $\omega = 0$ and $V^R_{CKM} = V^L_{CKM}$
pseudo-manifest: $g_L = g_R$, $\omega \neq 0$ and $V^R_{CKM} = (V^L_{CKM})^*$

phenomenology of Left-Right models II

low energy:	small CP violation, new phases suppressed by ζ or $M_{W'}$
high energy:	larger CP violation, new phases come into play

how to check this model?

- produce W' boson (high energy experiment)
- look for right-handed W coupling ('low' energy experiment)

direct search: $M_{W'} > 800\text{GeV}$

$\Rightarrow$ mixing angle $\zeta \sim \mathscr{O}(1)\left(\frac{M_W}{M_{W'}}\right)^2 \sim \mathscr{O}(1)\%$

‘low’ energy searches

look for right-handed coupling of W boson

$$W = \cos\zeta W_L - e^{i\omega}\sin\zeta W_R$$

right-handed coupling:

$$\begin{aligned}
Wud: &\quad e^{i\omega}\sin\zeta g_R V^R_{ud} &\rightarrow\quad \omega_{ud} = \omega + \arg(V^R_{ud})\\
Wsc: &\quad e^{i\omega}\sin\zeta g_R V^R_{sc} &\rightarrow\quad \omega_{sc} = \omega + \arg(V^R_{sc})\\
We\nu_e: &\quad e^{i\omega}\sin\zeta g_R V^R_{e\nu_e} &\rightarrow\quad \omega_{e\nu_e} = \omega + \arg(V^R_{e\nu_e})\\
W\mu\nu_\mu: &\quad e^{i\omega}\sin\zeta g_R V^R_{\mu\nu_\mu} &\rightarrow\quad \omega_{\mu\nu_\mu} = \omega + \arg(V^R_{\mu\nu_\mu})
\end{aligned}$$

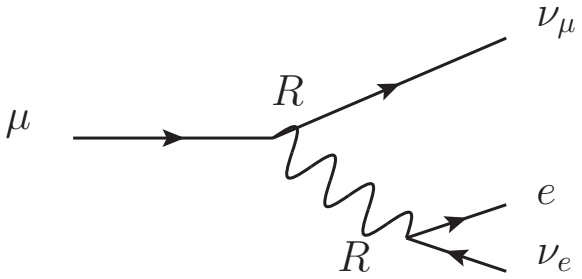
all right-handed couplings different

leptonic bounds

almost all bounds leptonic (measures $W\mu\nu_\mu$)

$\zeta < 0.02$	MacDonald et al. PRD 78, 032010 (2008)	μ decay
$\zeta < 0.12$	Ackerstaff et al. EPJC 8, 3 (1999)	τ decay
$\zeta < 0.03$	Barenboim et al. PRD 55, 4213 (1997)	μ decay

model dependent: *have to assume light right-handed neutrino!*



heavy quark bounds

many proposals to use top-quark decays

- Schmidt and Peskin, PRL 69, 410 (1992)
- Kane et al., PRD 45, 124 (1992)
- ...

For RHIC interested in Wud, in general $Wtb \neq Wud$

light quark bounds: N β-decay

- strong bound $\zeta < 0.003$ assuming (Aquino et al. PLB 261 (1991) 280)
  - manifest left-right symmetry
  - light right-handed neutrino

    $\Rightarrow Wud$ coupling $= We\nu_e$ coupling
- weak bound $\zeta < 10\%$? without assumptions (Severijns et al. RMP 78 (2006) 991)
- strong bound on CP violating part: $\zeta \sin\omega < 0.001$ (Severijns 2006), assuming
  - right-handed neutrino mass $m_{\nu_R} \gtrsim 800$keV

model dependent

light quark bounds: model independent

measurements of the light quark coupling, without assumptions

- νN DIS
  - (CCFR) Mishra et al. PRL 68 (1992) 3499
  - Abramowicz et al. ZPC 12, (1982) 225

  best: $\zeta < 0.04$, not sensitive to ω

just one method!

kaon decays

method by Bernard et al. JHEP 0801:015 (2008):

combine known data with dispersive scalar form factor in $K_L \to \pi^\pm \mu^\mp \nu_\mu$ decay

measurements:

NA48 (Lai et al. PLB 647 341 (2007))	$\log C = 0.14 \pm 0.01$
KLOE (Ambrosino et al. (2008))	$\log C = 0.20 \pm 0.02$
KTeV (E. Abouzaid et al. (2009))	$\log C = 0.19 \pm 0.01$
Standard Model:	$\log C = 0.218 \pm 0.004$

data not compatible!

NA48 implies $\zeta > 0.006$!

summary of bounds

- only one model independent bound
- $\zeta < 0.04$
- ω unknown

exploiting spin asymmetries at RHIC

physics beyond the standard model at RHIC:

- Taxil and Virey ('95 –'01)
  A_{LL} in $\vec{p}\vec{p} \to \mathrm{jet}X$
- Kovalenko, Schmidt & Soffer (2001)
  A_T in $p^{\uparrow}p \to \ell\nu$
- Rykov, ArXiv: hep-ex/9908050 (1999)
  A_{TT} in $p^{\uparrow}p^{\uparrow} \to \ell\nu$

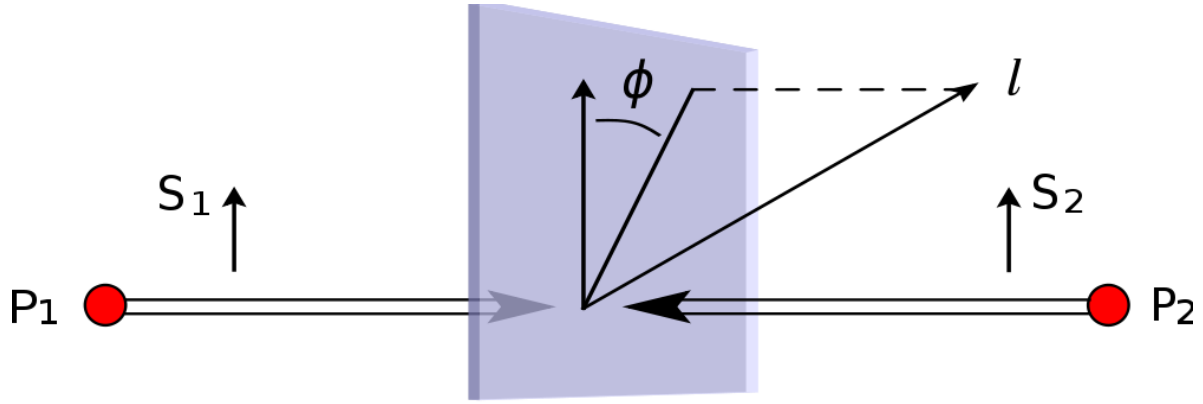
  $\to$ double transverse spin asymmetries in W production

probes for:

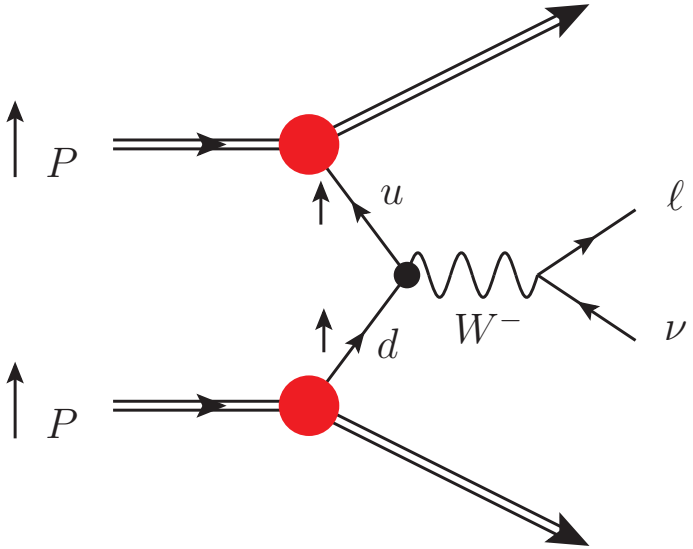
- right-handed W coupling $(\zeta > 0)$
- CP violation BYSM $(\omega \neq 0)$

here: analysis of the feasibility

W production in transversely polarized proton collisions



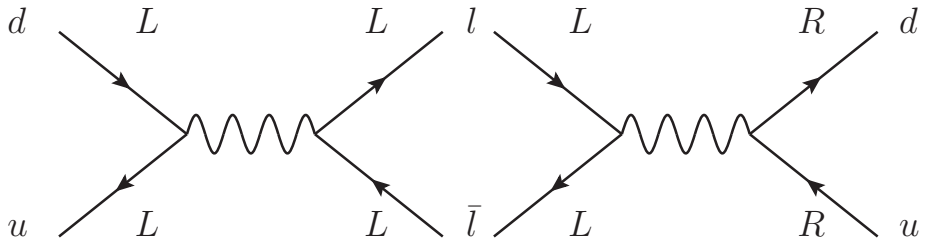
one lepton out $\rightarrow$



angular distribution w.r.t. spins?

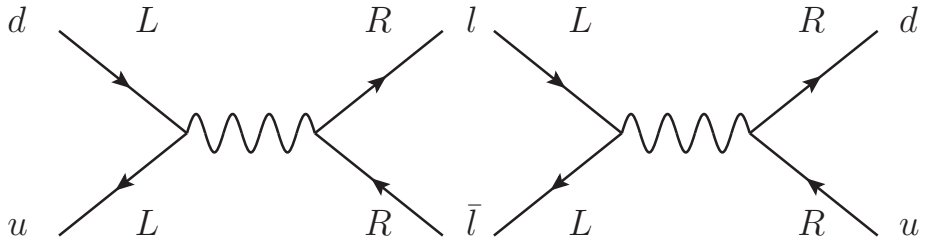
no angular distribution in the SM

Bourrely & Soffer, NPB 423, 329 (1994):
transversity is helicity flip $\rightarrow$ no S_T dependence in W production



$\propto \zeta$

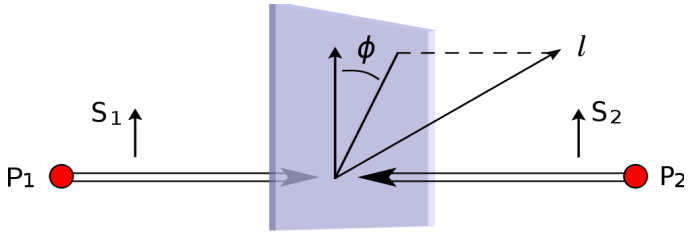
independent of $W_R l\nu$ coupling (double suppression)



$\propto \zeta^2 m_l^2$

LO calculation

LO calculation,
collinear factorization



need

- quark transversity distribution $h_1(x)$
- anti-quark transversity distribution $\bar{h}_1(x)$

$$\delta\sigma \equiv \frac{1}{2}(\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}) \propto \zeta \cos(\omega) h_1 \bar{h}_1 \cos(2\phi) + \zeta \sin(\omega) h_1 \bar{h}_1 \sin(2\phi)$$

$$\sigma \equiv \frac{1}{2}(\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}) \text{ indep. of } \phi.$$

asymmetries

define:

$$A_{TT} \equiv \left(\int_{-\pi/4}^{\pi/4} - \int_{\pi/4}^{3\pi/4} + \int_{3\pi/4}^{5\pi/4} - \int_{5\pi/4}^{7\pi/4} \right) d\phi \delta d\sigma / \int_0^{2\pi} d\phi d\sigma$$

$$A_{TT}^{\perp} \equiv \left(\int_{0}^{\pi/2} - \int_{\pi/2}^{\pi} + \int_{\pi}^{3\pi/2} - \int_{3\pi/2}^{2\pi} \right) d\phi \delta d\sigma / \int_0^{2\pi} d\phi d\sigma$$

such that

$A_{TT} \propto \zeta \cos \omega$

$A_{TT}^{\perp} \propto \zeta \sin \omega$

can, in principle, determine full coupling including CP-violating part

transversity

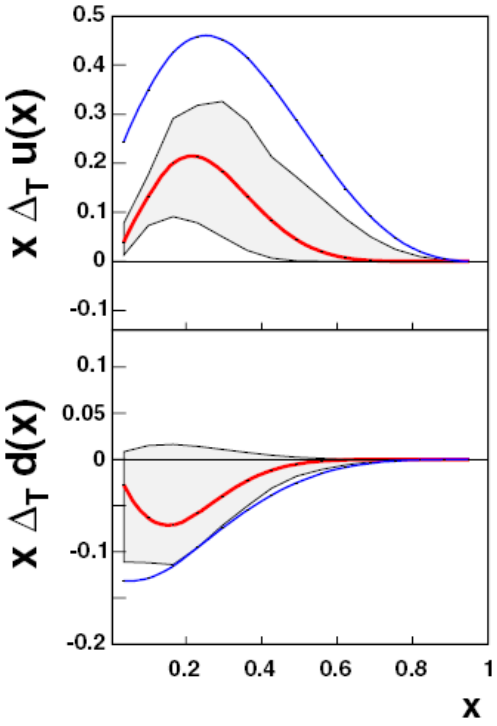
$$\boxed{\text{Soffer bound: } |h_1(x)| \leq \frac{1}{2}(f_1(x) + g_1(x))}$$

$h_1(x)$ known to some extent
(Anselmino et al. PR D75, 054032 (2007))

we take, for simplicity, $h_1(x) = f_1(x)/2$

$\rightarrow$ compatible with Soffer bound and first extraction

$\bar{h}_1(x)$ unknown



size of the asymmetries

If we assume $\bar{h}_1(x) = \bar{f}_1(x)/2$ (compatible with Soffer bound)

$$\zeta \cos\omega = 0.04 \qquad \rightarrow \qquad |A_{TT}| = \begin{cases} 1.2\% & W^+ \\ 1.0\% & W^- \end{cases}$$

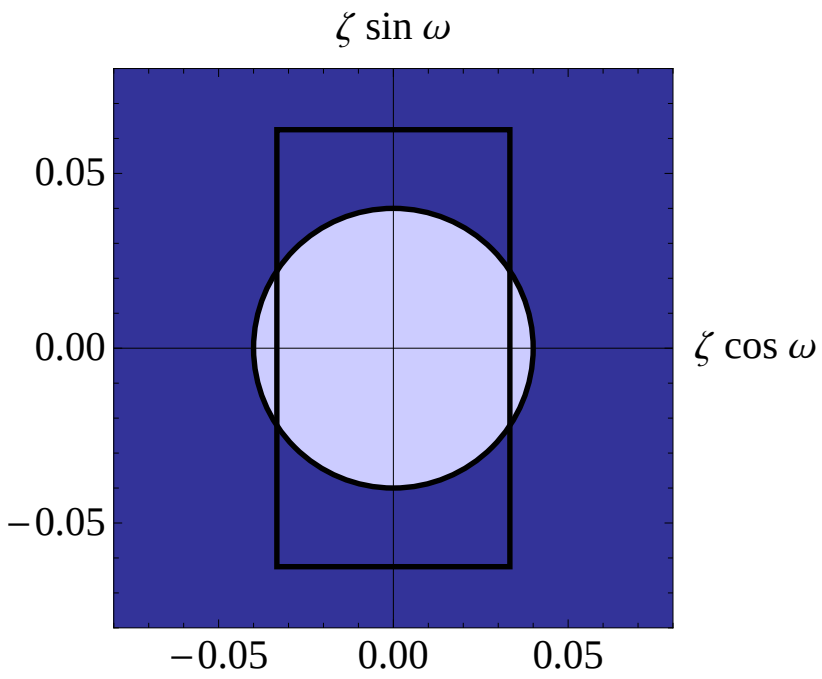
$$\zeta \sin\omega = 0.04 \qquad \rightarrow \qquad |A_{TT}^{\perp}| = \begin{cases} 0.6\% & W^+ \\ 0.4\% & W^- \end{cases}$$

optimal (realistic) cuts:

$$A_{TT}: \qquad |Y| < 1, \qquad 35 < \ p_T < 45\text{GeV}$$

$$A_{TT}^{\perp}: \quad 0.2 < |Y| < 1, \qquad 35 < \ p_T < 45\text{GeV}$$

potential exclusion



- model independent
- but h_1 and $\bar{h}_1$ needed (DY)

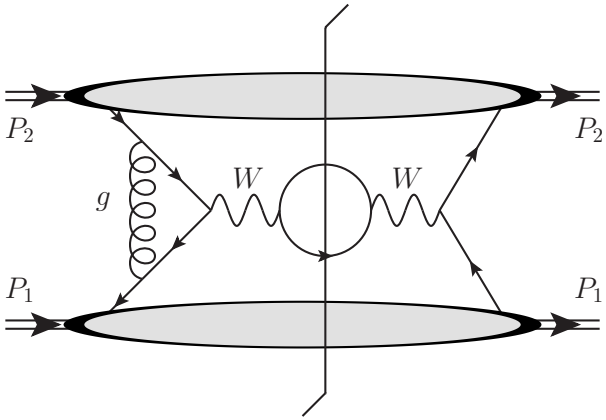
NLO likely not much smaller
$\rightarrow$ Martin et al. PRD 57, 3084 (1998)

potential exclusion
given $|A_{TT}^{(\perp)}| < 1\%$

likely requires $\mathscr{O}(800)\mathrm{pb}^{-1}$
@70% polarization

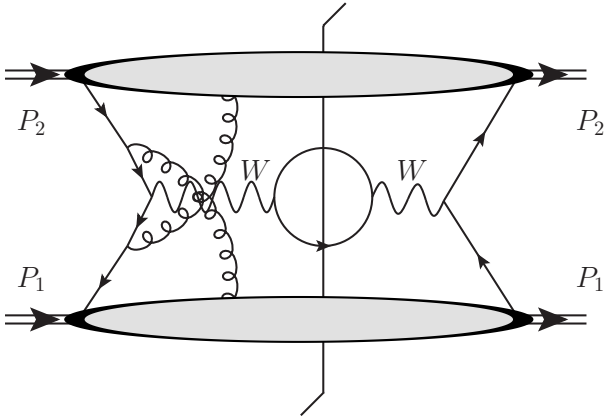
SM background I

- effective right-handed coupling:



$$\propto \frac{m_u m_d}{M_W^2} \alpha_S$$

- higher twist contributions (Boer PRD 62, 094029 (2000)):



$$\lessapprox \mathscr{O}\left(\frac{M_P^2}{M_W^2}\right) + \text{diff. angular dep.}$$

$A_{TT} \ll 10^{-4} \rightarrow$ *not measurable*

SM background II

- background from missing e^- in the neutral current process $p^\uparrow p^\uparrow \to \gamma, Z \to X e^+ e^-$

  $1 < |Y_{e^-}|$ and $|Y_{e^+}| < 1$

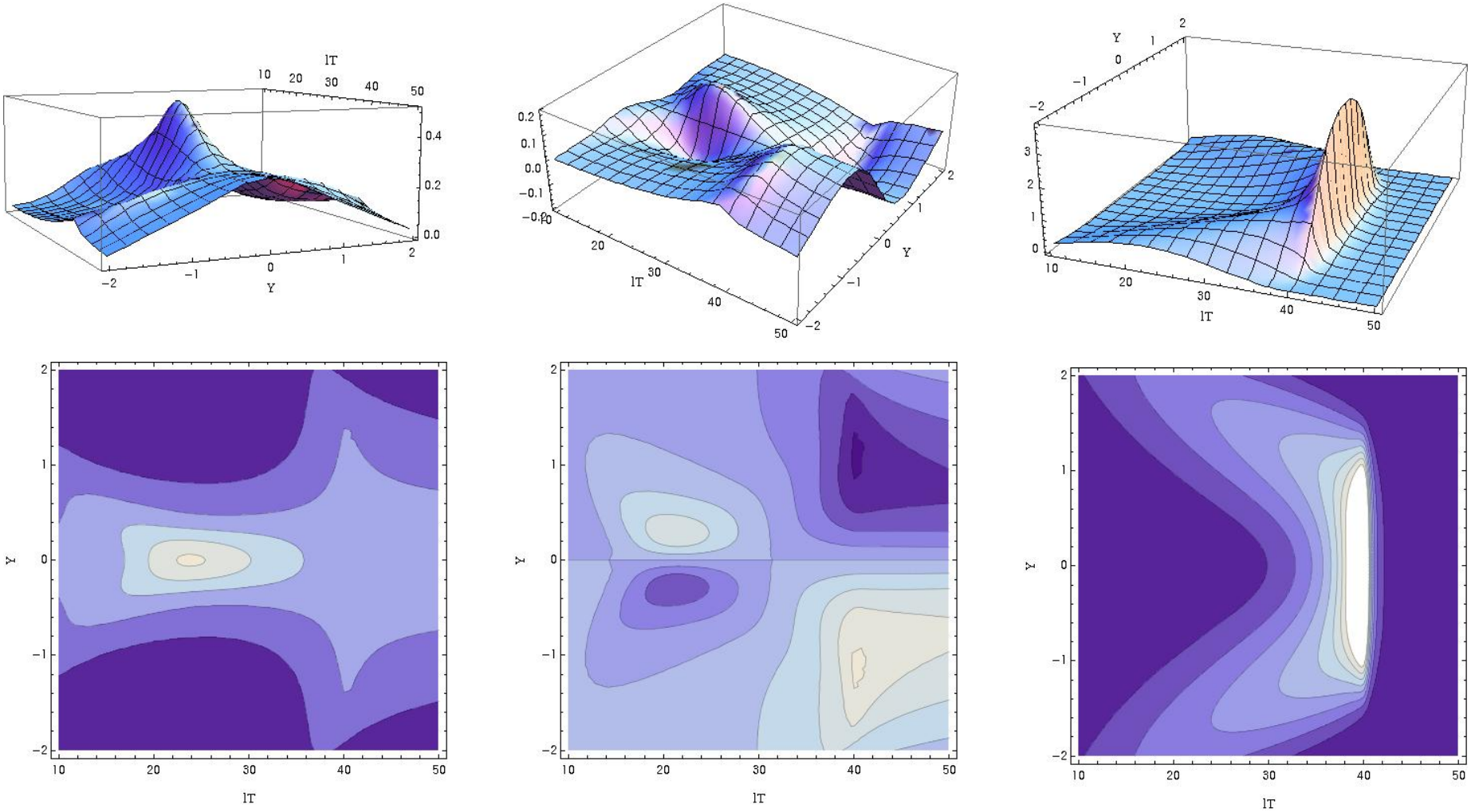
  $$\to \begin{array}{c} A_{TT}^{BG} \sim 0.1\% \\ A_{TT}^{\perp BG} \sim 0.03\% \end{array}$$

not measurable, so

$\Rightarrow$
- $A_{TT}^{(\perp)} \neq 0 \Rightarrow$ new physics
- but h_1 and $\bar{h}_1$ needed for bound on ζ and ω

conclusion

prospects for measuring W' physics at RHIC

- RHIC can, in principle, set bounds on ζ and ω independently
- determining CP violation BYSM ($\omega \neq 0$) likely too optimistic
- so far only one bound on $\zeta \rightarrow$ needs confirmation
- possible if
  - original design goals are met
  - $\bar{h}_1$ not negligible

differential asymmetries