Prospect for precision measurements of $M_{W^+} - M_{W^-}$ & M_W at the LHC (Shortcuts revisited)

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• We considered the main systematic errors which were the most important in previous i.e. Tevatron measurements of W mass

ΔM_w [MeV]	$ES = 0.05\%$	$ES = -0.05\%$	$RF = 0.7$	$RF = 1.3$	$\Delta kT = -1$[GeV]	$\Delta kT = +1$[GeV]
Z Candle, C_{QCD}	-2.6 ± 6.2	1.0 ± 6.0	3.3 ± 5.9	-6.3 ± 6.3	-0.6 ± 6.0	-3.8 ± 6.1
χ^2/ndof	1.1	1.0	1.0	1.2	1.2	1.3
Standard	-29 ± 1.8	25 ± 1.8	14.1 ± 1.8	-22.8 ± 1.8	> 31	> 40
Simple Z Candle	-19 ± 4.91	15 ± 4.9	> 50	> 77	> 66	> 76

even larger shifts of K_T are also in the statistical errors:

ΔM_w [MeV]	$\Delta kT = -4$	$\Delta kT = -2$	$\Delta kT = -1$	$\Delta kT = 1$	$\Delta kT = 2$	$\Delta kT = 4$[GeV]
Z candle C_{QCD}	14.6 ± 6.1	5.6 ± 6.0	-0.6 ± 6.0	-3.8 ± 6.1	-6.8 ± 6.2	-26.7 ± 6.3
χ^2/ndof	1.3	1.4	1.2	1.3	1.1	1.5

• the results are mainly constrained by statistical errors but studies were preform for one year of low luminosity 10fb^-1 run.

• all this tricks are feasible at LHC (maybe in the mature stage ...) Filip's Moortgat question.

Then using PYTHIA[1] we opened Pandora's box... 

but this is the next part of this story

[1] and WINHAC + ZINHAC

Introduction

- Tevatron :
  - CDF II [Aaltonen *et al.*, Phys. Rev. D**77**, 112001 (2008)]

$W \to \mu\,\nu_\mu$	$M_{W^+} - M_{W^-}$	$=$	0.286	$\pm$	0.152 GeV
$W \to e\,\nu_e$	$M_{W^+} - M_{W^-}$	$=$	0.257	$\pm$	0.117 GeV
$W \to \mu\,\nu_\mu,\, e\,\nu_e$	M_W	$=$	80.413	$\pm$	0.048 GeV

  - Precision on M_W achievable *because* $W^+ \overset{CP}{\Longleftrightarrow} W^-$ in $p - \bar{p}$ collisions

- LHC :
  - Announce $\delta^{(sys.)}_{M_W} \sim 10\,\text{MeV}$,... but forgot $W^+ \overset{CP}{\not\Longleftrightarrow} W^-$ in $p - p$ collisions

–Our prospect–

Dedicated *systematic-robust* strategies/observables
for $M_{W^+} - M_{W^-}$ & M_W $p_{T,l}$-based measurements

..., but first some basics on W^+ and W^- in Drell–Yan-like at the LHC

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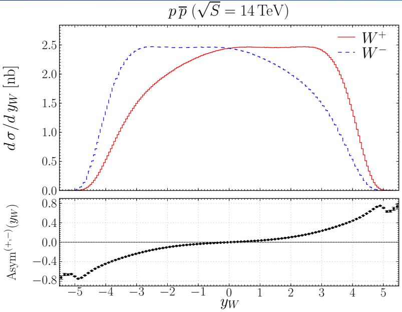
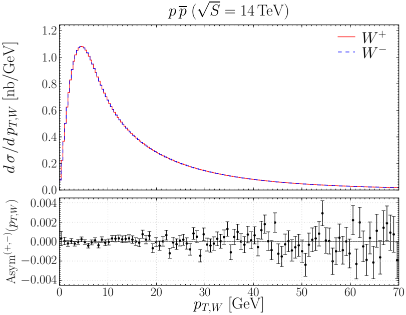
$W^{\pm}$ production in $p - \bar{p}$ & $p - p$ collisions





$$\text{Asym}^{(+,-)}(x) \equiv \frac{d\,\sigma^+/d\,x - d\,\sigma^-/d\,x}{d\,\sigma^+/d\,x + d\,\sigma^-/d\,x}$$

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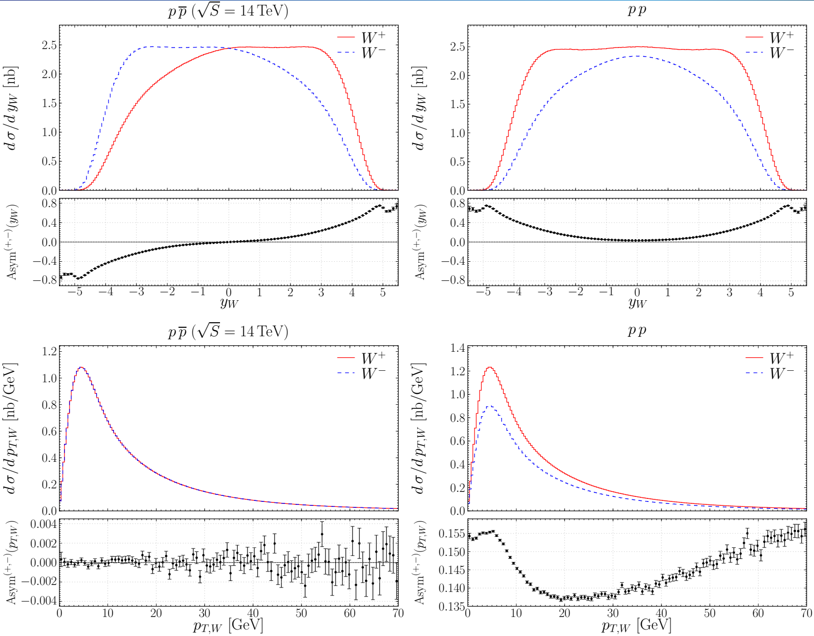
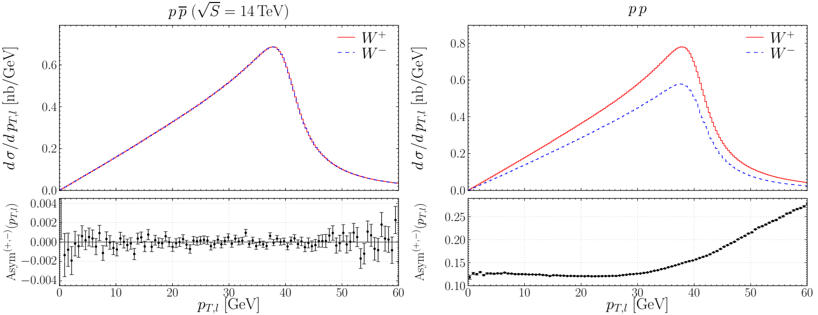


$W^{\pm}$ decay for $p - \bar{p}$ & $p - p$ collisions



- LHC: $\bar{q} < q \Rightarrow x_{\bar{q}} < x_q \Rightarrow p_{T,q^{(\mathrm{v})}} > p_{T,\bar{q}'^{(\mathrm{s})}}$ *in* $q^{(\mathrm{v})}\,\bar{q}'^{(\mathrm{s})}$, . . . $V - A$ does the rest

Charge asymmetry at the LHC = $\bar{q} < q \otimes p_{T,W} \otimes V - A$

- Lessons
  - Loss of symmetry - at the LHC the W^+ and the W^- bosons must be treated as distinct particles.
  - Stronger dependencies from *PDFs*
  - M_W measurement? Two equivalent solutions:

    (1) M_{W^+} & M_{W^-}

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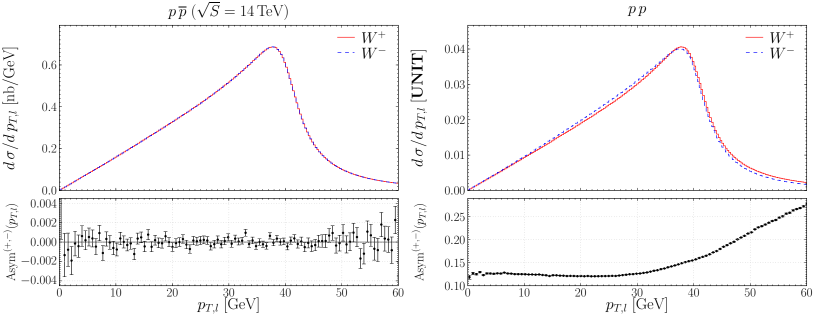

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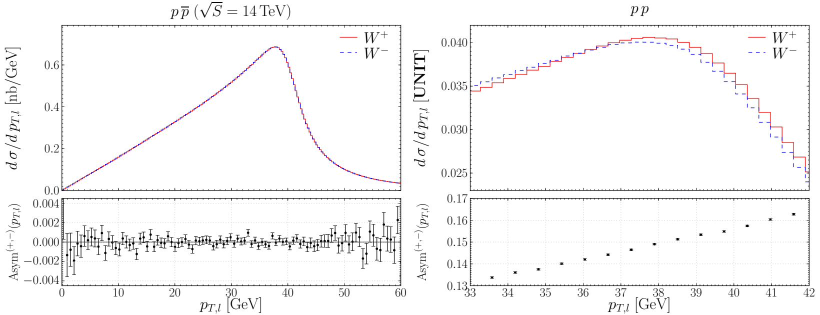

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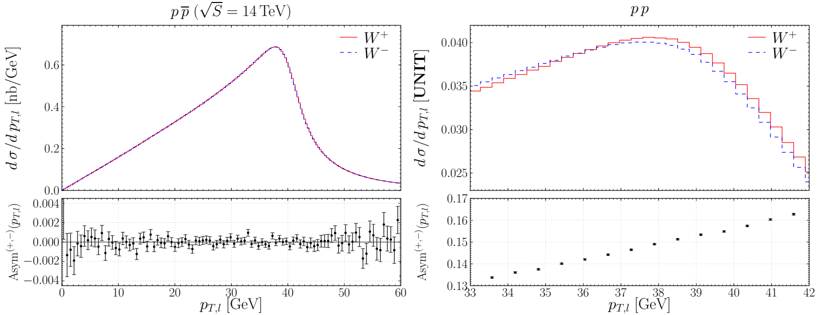

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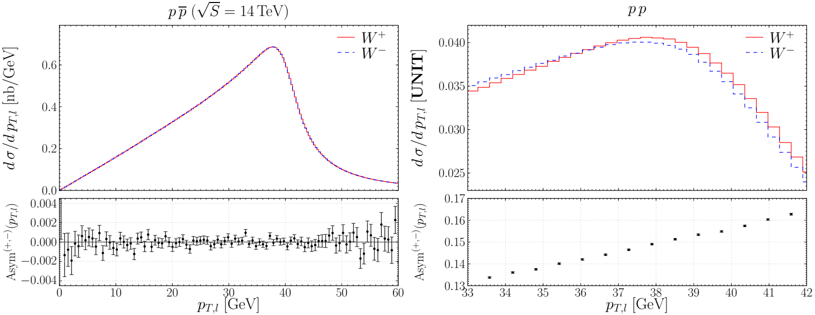

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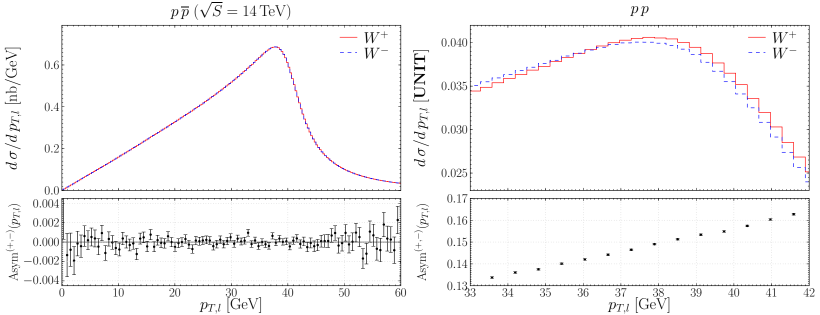

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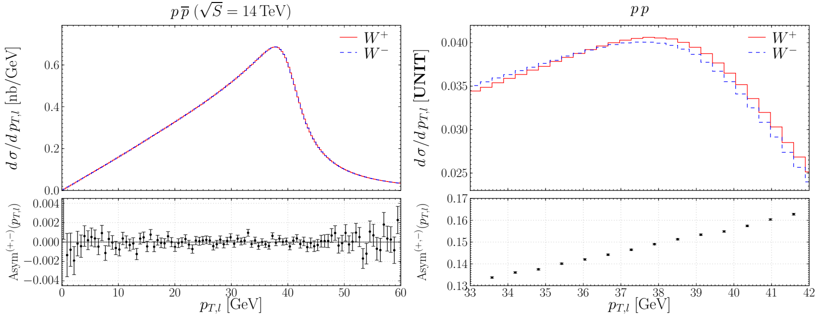

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Addressed systematics errors in our studies

- Apparatus :
  - Energy Scale (ES)
    - $\epsilon_{l^+} = +\epsilon_{l^-}$
    - $\epsilon_{l^+} = -\epsilon_{l^-}$ *NEW!*
  - Track parameter reconstruction
- Phenomenology :
  - Quarks $< k_T >$
  - *PDF* (global)
  - $u^{(v)} - d^{(v)}$ *NEW!*
  - $s - c$ *NEW!*
  - b (for M_W) *NEW!*
- Analysis :
  - Monte Carlo : WINHAC ($W \to e\,\nu_e,\ \mu\,\nu_\mu$), ZINHAC ($Z \to e^+e^-,\ \mu^+\mu^-$)
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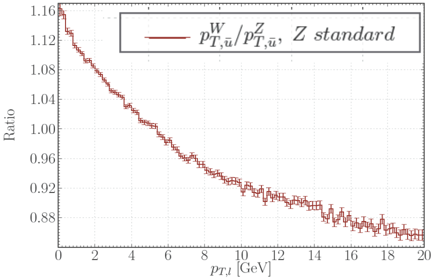
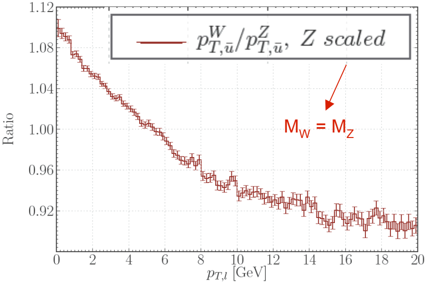




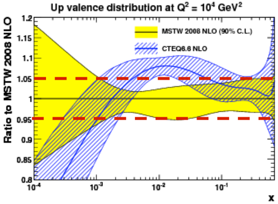
- The momentum distribution of the “matching parton“ (the one needed to create W and Z-bosons) is the dominant source of the biases in the relative transverse momentum distribution of the W and Z bosons!!!
- Note: $u^{(v)} \neq d^{(v)}$ for the proton beam !

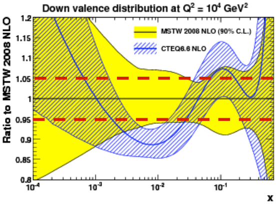
Expected biases in the measured values of M_{W+}-M_{W-}

$u^{(v)},\ d^{(v)(*)}$	$u^{(v)}_{max} = 1.05\,u^{(v)}$ $d^{(v)}_{min} = d^{(v)} - .05\,u^{(v)}$	114.5
	$u^{(v)}_{min} = 0.95\,u^{(v)}$ $d^{(v)}_{max} = d^{(v)} + .05\,u^{(v)}$	-138.5
	$u^{(v)}_{max} = 1.02\,u^{(v)}$ $d^{(v)}_{min} = 0.92\,d^{(v)}$	85.2
	$u^{(v)}_{min} = 0.98\,u^{(v)}$ $d^{(v)}_{max} = 1.08\,d^{(v)}$	-85.9

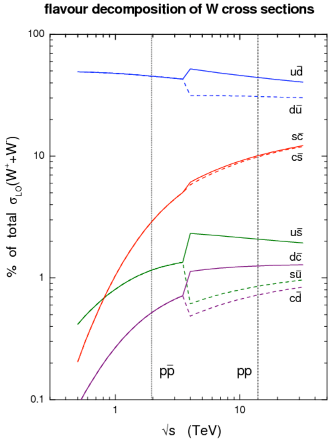
Expected biases in the measured values of M_W

$u^{(v)},\ d^{(v)}$	$u^{(v)}_{max} = 1.05\,u^{(v)}$ $d^{(v)}_{min} = d^{(v)} - .05\,u^{(v)}$	79
	$u^{(v)}_{min} = 0.95\,u^{(v)}$ $d^{(v)}_{max} = d^{(v)} + .05\,u^{(v)}$	-64
	$u^{(v)}_{min} = 1.02\,u^{(v)}$ $d^{(v)}_{max} = d^{(v)} - .02\,u^{(v)}$	32
	$u^{(v)}_{min} = 0.98\,u^{(v)}$ $d^{(v)}_{max} = d^{(v)} + .02\,u^{(v)}$	-18
	$u^{(v)}_{max} = 1.02\,u^{(v)}$ $d^{(v)}_{min} = 0.92\,d^{(v)}$	48
	$u^{(v)}_{min} = 0.98\,u^{(v)}$ $d^{(v)}_{max} = 1.08\,d^{(v)}$	-32





<u>Note:</u> Only mutually compensating shifts leave the Z-boson rapidity distributions invariant



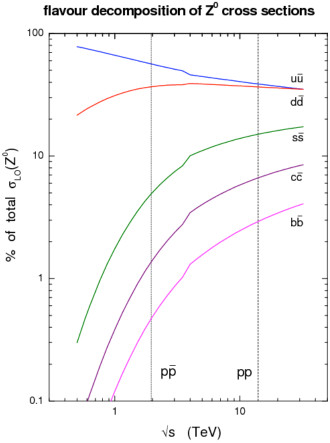


TABLE I. Partial contributions $\sigma_{q\bar{q}'}/\sigma_{\rm tot}$ of quark-antiquark annihilation subprocesses to the total Born cross sections in W^+ and Z^0 boson production at the Tevatron and LHC (in percent).

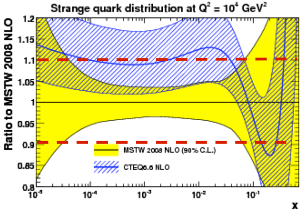
	W^+					W^-					Z^0				
Subprocesses	$u\bar{d}$	$u\bar{s}$	$c\bar{d}$	$c\bar{s}$	$c\bar{b}$	$d\bar{u}$	$s\bar{u}$	$d\bar{c}$	$s\bar{c}$	$b\bar{c}$	$u\bar{u}$	$d\bar{d}$	$s\bar{s}$	$c\bar{c}$	$b\bar{b}$
Tevatron Run-2	90	2	1	7	0	90	2	1	7	0	57	35	5	2	1
LHC	74	4	1	21	0	67	2	3	28	0	36	34	15	9	6

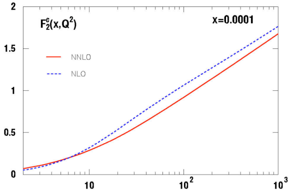
Expected biases in the measured values of M_{W+}-M_{W-}

$s,\ c^{(*)}$	$c_{\min} = 0.9\,c$, $s_{\max} = s + 0.1\,c$	17.1
	$c_{\max} = 1.1\,c$, $s_{\min} = s - 0.1\,c$	-10.8
	$c_{\min} = 0.8\,c$, $s_{\max} = s + 0.2\,c$	38.8
	$c_{\max} = 1.2\,c$, $s_{\min} = s - 0.2\,c$	-29.0

Expected biases in the measured values of M_W

$s,\ c$	$c_{\min} = 0.8\,c$, $s_{\max} = s + 0.2\,c$	257
	$c_{\max} = 1.2\,c$, $s_{\min} = s - 0.2\,c$	-237
	$c_{\min} = 0.9\,c$, $s_{\max} = s + 0.1\,c$	148
	$c_{\max} = 1.1\,c$, $s_{\min} = s - 0.1\,c$	-111
	$c_{\min} = 0.95\,c$, $s_{\max} = s + 0.05\,c$	78
	$c_{\max} = 1.05\,c$, $s_{\min} = s - 0.05\,c$	-58

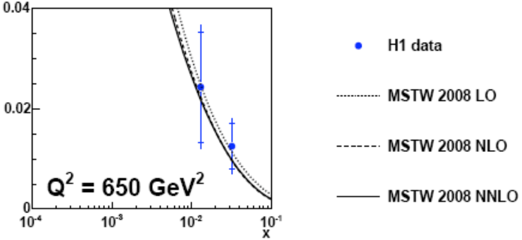




Note: Only mutually compensating shifts leave the Z-boson rapidity distributions invariant

Expected biases in the measured values of M_W

b	$b_{\max} = 1.4\,b$	77
	$b_{\min} = 0.6\,b$	−56
	$b_{\max} = 1.2\,b$	42
	$b_{\min} = 0.8\,b$	−39
	$b_{\max} = 1.1\,b$	13
	$b_{\min} = 0.9\,b$	−12



Note: b-quarks influence the biases while relating the spectra for W-bosons to the corresponding ones for Z-bosons

Summary

- Tevatron : $W^+ \overset{CP}{\Longleftrightarrow} W^- \Rightarrow$ Precision measurement for M_W
- LHC : $W^+ \overset{CP}{\not\Longleftrightarrow} W^-$
  - Loss of symmetry $\Rightarrow$ *New important* sources of $\delta^{(sys.)}$ (PDFs)
- Solutions :
  - Energy Scale :
    (1) "Z^+" & "Z^-", or...
    (2) $\vec{B} \to -\vec{B}$
  - Improve valence sector knowledge :
    (1) the proton structure functions measured with better precision then available today Muon DIS (SPS)
    - LOI for such an experiment by F. Dydak and M.W. Krasny or...
    (2) $d-d$ LHC-runs the LHC with deuteron beams (elegant)

Final Warning : These problems will have to be considered in other LHC processes (eg. single top)

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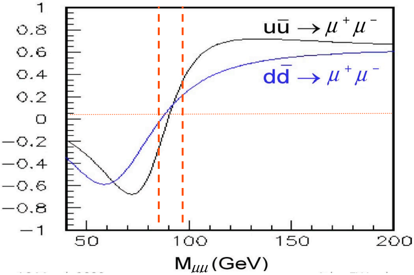
Expected biases in the measured values of M_{W+} - M_{W-} [MeV]

	Systematic ξ	pp - $\|\eta_l\| < 2.5$	pp - $\|\eta_l\| < 0.3$	pp - $\|y_W\| < 0.3$	dd - $\|\eta_l\| < 2.5$
$u^{(v)}$, $d^{(v)(*)}$	$u_{max}^{(v)} = 1.05\, u^{(v)}$ $d_{min}^{(v)} = d^{(v)} - .05\, u^{(v)}$	114.5	74.4	-38.1	2.4
	$u_{min}^{(v)} = 0.95\, u^{(v)}$ $d_{max}^{(v)} = d^{(v)} + .05\, u^{(v)}$	-138.5	-83.8	59.8	2.9
	$u_{max}^{(v)} = 1.02\, u^{(v)}$ $d_{min}^{(v)} = 0.92\, d^{(v)}$	85.2	51.2	-34.7	4.1
	$u_{min}^{(v)} = 0.98\, u^{(v)}$ $d_{max}^{(v)} = 1.08\, d^{(v)}$	-85.9	-53.2	47.2	-0.1

Dedicated relative calibration of the positive and negative lepton momentum (energy) scale.

$$A_{FB} = \frac{3}{4}\frac{-2q_q a_q a_\ell \operatorname{Re}(\chi) + 2v_q a_q 2v_\ell a_\ell |\chi|^2}{q_q^2 - 2q_q v_q v_\ell \operatorname{Re}(\chi) + (v_q^2 + a_q^2)(v_\ell^2 + a_\ell^2)|\chi|^2}; \qquad \chi(\hat{s}) = \frac{\sqrt{2}G_F}{16\pi\alpha}\frac{\hat{s}M_Z^2}{\hat{s} - M_Z^2 + i\hat{s}\Gamma_Z/M_Z}$$

$$a_f = 2I_3^f; \qquad v_f = 2I_3^f - 4q_f \sin^2\theta_W; \qquad f = q, \ell$$



- Exploit the lucky coincidence that the $\sin^2(\theta_W)$ value chosen by nature happens to:

  (1) "equalize" the forward-backward asymmetry in the Z-resonance region (statistics)

  (2) gives rise to a very small F/B asymmetry in the chosen region

- Use the lepton-pair events in the mass region where the FB asymmetries for u and d quark cross each other - in order to be independent of the u/d structure of protons.

ZINHAC

Search

Description of the project

ZINHAC will be a Monte Carlo event generator written in C++ for Drell–Yan processes in proton–proton, proton–antiproton and nucleus–nucleus collisions . It features multiphoton radiation in Z-boson decays within the Yennie–Frautschi–Suura (YFS) exclusive exponentiation scheme and the O(α) electroweak radiative corrections for Z decays. Implementation of the total O(α) electroweak radiative corrections to the full nutral-current Drell–Yan proces is under way in the collaboration with the SANC group. A similar event generator for the W-boson production, called WINHAC, is available here. Our group also works on constrained MC algorithms for the QCD ISR parton shower that could be applied to Drell–Yan processes see, e.g. arxiv:0703281

Related Talks and Publications

- *"Z-boson as "the standard candle" for high precision W-boson physics at LHC"* arXiv
- *"Measurement of M_{W^+} - M_{W^-} at LHC"* - arXiv.
- *"W-boson mass measurement at LHC"* - available soon.

Help and User Guides

1. FAQ
2. Bug reporting / tracking Anyone can view the list of bug tickets: click View Tickets in the titlebar. To submit new bug reports, however, you will first need to register with the ZINHAC authors. Send a preferred login and password to andrzej.siodmok at cern.ch. Please do not send a password that you use for anything important, the current login mechanism transmits it in clear text. After registration, you can use your login name to file new bug reports. First, click on Login in the title bar, then New Ticket. To get email updates about progress on your ticket, specify an email address in the Settings.

Download

1. SVN repository

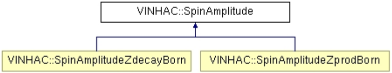
C++, XML, SVN, Trac, Doxygen

Comparison with D. Bardin et al. "SM-BSM physics at the LHC" CERN TH Institute 3-28 Aug. 2009, CERN

VINHAC::SpinAmplitude Class Reference

`#include <SpinAmplitude.h>`

Inheritance diagram for VINHAC::SpinAmplitude:



List of all members.

Public Member Functions

	SpinAmplitude () *A constructor.*
complex< double >	**S** (HepLorentzVector p1, HepLorentzVector a, HepLorentzVector p2, int lambda1, int lambda2, int alpha) *Function S provides a value of the spinorial function* $S(p_1, a, p_2)^{\alpha}_{\lambda_1,\lambda_2}$.
complex< double >	**S** (HepLorentzVector p1, HepLorentzVector a1, HepLorentzVector a2, HepLorentzVector a3, HepLorentzVector p2, int lambda1, int lambda2, int alpha) *Function S provides a value of the spinorial function* $S(p_1, a_1, a_2, a_3, p_2)^{\alpha}_{\lambda_1,\lambda_2}$.
double	**omega** (int imp, double En, double pp) *A method for calculating* $\omega_{\pm}(p) = (E \pm \lvert\vec{p}\rvert)^{1/2}$, *where* $p^{\mu} = (E, \vec{p}) = (E, p_x, p_y, p_z)$.
void	**MxV2dC** (complex< double > matrix[2][2], complex< double > vec[2], complex< double > res[2]) *A method which multiply 2-dim. complex matrix matrix by complex vector.*
void	**HelEig** (HepLorentzVector p, int hel, complex< double > chip[2]) *Function provides a helicity eigenstate (Pauli spinor) for a fermion with helicity ihel and 4-momentum p.*
HepLorentzVector	**VecPol** (HepLorentzVector p, int lambda) *Polarization vectors of a vector boson in the rectangular basis, see K. Hagiwara and D. Zeppenfeld, Nucl. Phys. B274 (1986) 1, eq. (3.47).*
void	**MvtoWm** (HepLorentzVector p, complex< double > as[][2], int alpha)
void	**setCr** (double coupling)
void	**setCl** (double coupling)
void	**setQe** (double current)

Thank you for the attention!