Final state effects for leptonic W, H and Z decays in LHC observables.

Z. Was*

*Institute of Nuclear Physics, Krakow

A: boson's decay channels with e, μ

B: boson's decay channels with τ leptons

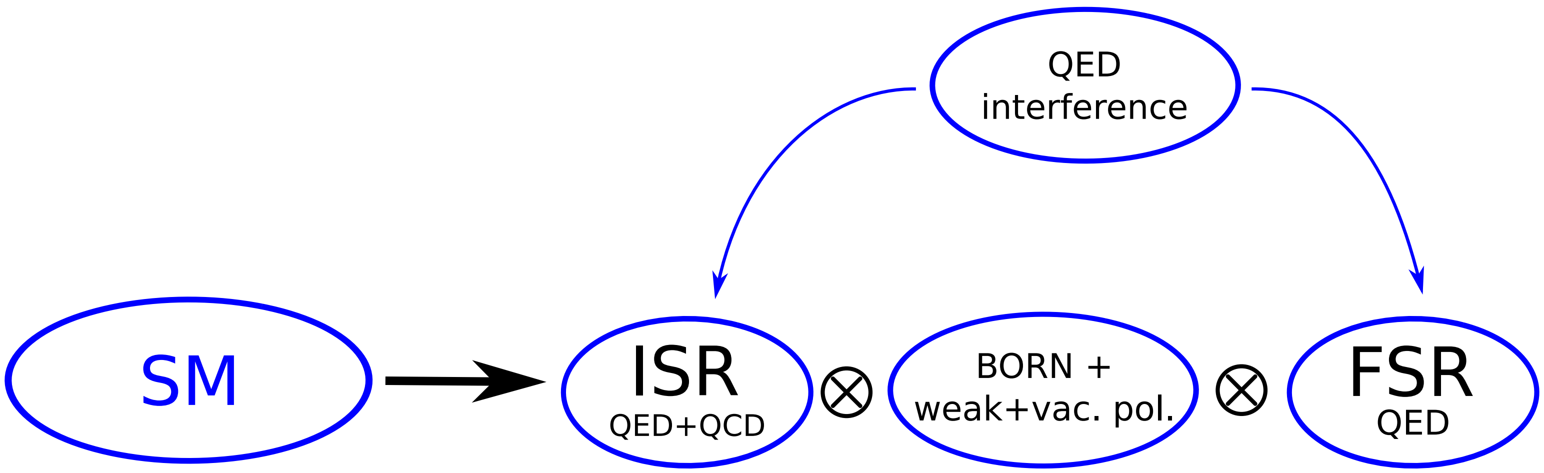
- major phenomenological aspects
- experimental conditions
- technical solutions:**examples**

What Z, W, H signatures may mean?

- At Born level of SM, W, H and Z propagators are singular: $\frac{1}{s-M^2}$.
  This seems trivial:
  Replace propagator with the effective one $\frac{1}{s-M^2+i\Gamma M}$.
  Partial resummation of loop corrections to all orders must be performed!
- We expect that resulting approach, make bosons into physics states of definite properties, production distinct from decay, well separated in time.
- **If** calculation scheme is physics friendly, we can expect the interferences to remain smaller than $\alpha\frac{\Gamma}{M} \simeq 0.001$.
- Even then, in case of experimental (veto) cuts this conjecture may not hold: consequence of uncertainty principle $\Delta E \; \Delta t \geq \frac{h}{2\pi}$.

Introduction

Production and decay for Bosons



- Use of leading pole approximation as in NLO calculation of U. Baur (Phys. Rev. D 47 (1993) 4889) simplifies the issues of QED ISR-FSR interference.
- QED Final State Radiation (FSR) must be understood in context of detector response.

  The same is true for τ decays.

Part A: boson's decay channels with e, μ

Lepton directions *are measured precisely by LHC experiments.*

1. *It is attractive to explore quantities which rely on them.*
2. *Better by the order of magnitude than any other quantity!*
3. *One of the observables aiming at this purpose is ϕ^*_η of the previous talk.*
4. *Measurements/reconstruction of lepton (directions) can not be separated from final state bremsstrahlung*

How to use lepton directions *in universal, hard process independent way*

1. What is the precision of QED FSR for LHC applications?
2. An example of Monte Carlo solution for that applications including discussion of systematic errors.

Presentation

- PHOTOS (by E.Barberio, B. van Eijk, Z. W., P.Golonka) is used to simulate the effect of radiative corrections in decays, since 1989.
- Full events combining complicated tree structure of production and subsequent decays are fed into PHOTOS, usually with the help of HEPEVT event record of F77
- PHOTOS version for HepMC event record used in C++ applications is in GENSER LCG library: F77 and C++ too.
- At every branching of event tree, PHOTOS intervene. With certain probability extra photon(s) are added and kinematics of other particles adjusted.
- PHOTOS algorithm is iterative. First over emitters; interference (or matrix element) weight is used. Iteration over consecutive emissions is external.
- Solution enables full multiphoton phase space coverage, compatibility with exponentiation and resummation of collinear terms at the same time.

Main References

- E. Barberio, B. van Eijk and Z. Was, Comput. Phys. Commun. **66**, 115 (1991): single emission
- E. Barberio and Z. Was, Comput. Phys. Commun. **79**, 291 (1994). double emission introduced, tests with second order matrix elements
- P. Golonka and Z. Was, EPJC 45 (2006) 97 multiple photon emisson introduced, tests with precision second order exponentiation MC.
- P. Golonka and Z. Was, EPJC 50 (2007) 53 complete QED ME in Z decay
- G. Nanava, Z. Was, Eur.Phys.J.C51:569-583,2007, best description of phase space
- G. Nanava, Z. Was, Q. Xu, Eur.Phys.J.C70:673,2010. complete QED ME in W decay
- N. Davidson, T. Przedzinski, Z. Was, arXiv:1011.0937 program C++ web page: http://photospp.web.cern.ch/photospp HepMC interface ME in W, Z decays.

Part B: boson's decay channels with τ leptons

The τ lepton decay products: *form very well separated part of many signatures*

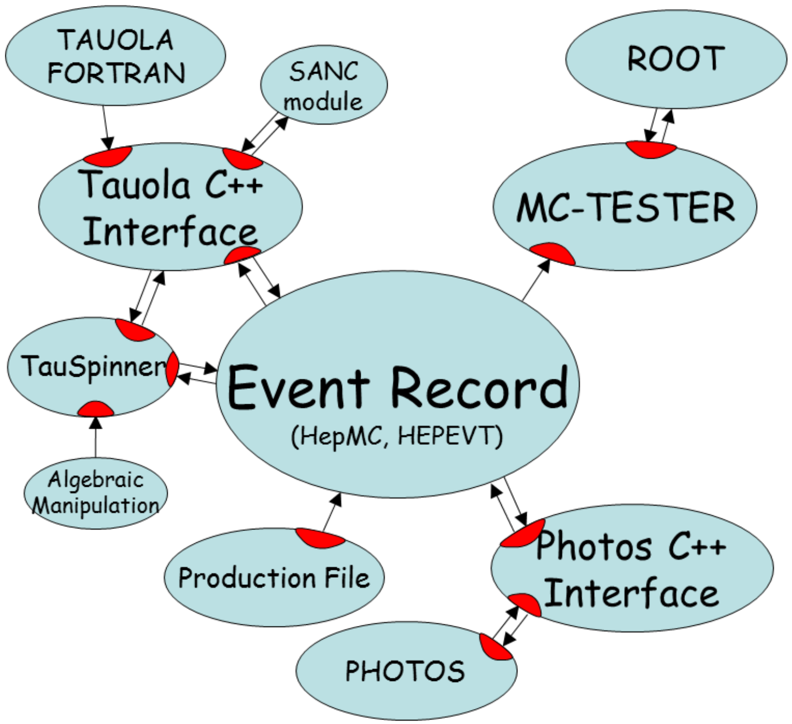
1. *It is attractive to explore quantities which rely on them because they offer a way to measure spin carried away by a lepton from the hard process.*
2. *Detector response to τ leptons is complicated because of multitude decay channels and neutrinos escaping decay.*
3. *Sophisticated studies in part independent from the particular channel may be very helpful*

How to use τ leptons *in universal, hard process independent way*

1. What is the significance of the spin effects.
2. Effects of PDF and p_T on spin effects?
3. Fortunately separation of τ production and decay is not a problem at all $\Gamma_\tau / M_\tau \ll 1$
4. How to evaluate significance of spin and matrix elements for new objects to be added to SM predictions for event samples where detector response effects were simulated.

Introduction: part A+B

`Photos`, `Tauola++` **and** `TauSpinner` **communicate through event record:**



- Parts:

- hard process: (Born, weak, new physics),
- parton shower,
- τ decays
- -QED bremsstrahlung

- Detector studies: acceptance, resolution lepton with or without photon.

Such organization requires:

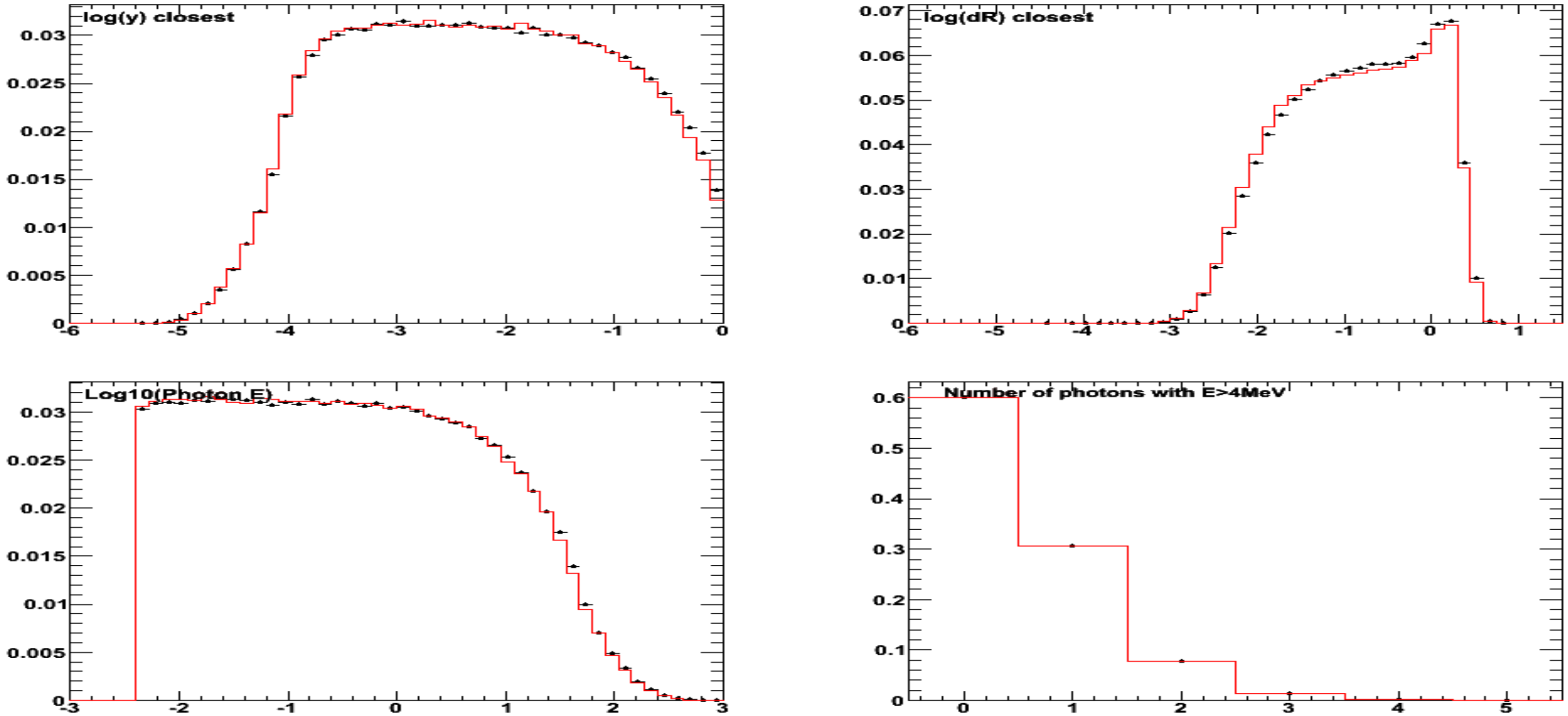
- Good control of factorization (theory)
- Good understanding of tools on user side.
- For `Tauola++`:

Web page **http://tauolapp.web.cern.ch/tauolapp/**

Reference **Comp.Phys.Comm. 183 (2012) 821**

A: boson's decay channels with e, μ

Early tests used theoretically motivated distributions:



Comparison of PHOTOS *and* HORACE *for FSR in* $Z \to \mu^+\mu^-$ **(2010, private communication, CDF experiment)**.

This was my starting point for accessing QED uncertainties of W mass measurements. The studies for ϕ^*_η measurement followed.

A: boson's decay channels with e, μ

- For the first results on ϕ^*_η measurements ATLAS claimed the **systematic error of 0.3%** due to implementation of QED final state radiation (FSR) of Monte Carlo generators. Estimate was in proportion of differences between PHOTOS+PYTHIA and SHERPA simulations:

  ATLAS Collaboration. *Measurement of angular correlations in Drell-Yan lepton pairs to probe Z/γ^* boson transverse momentum at $\sqrt{s} = 7$ TeV with the ATLAS detector* Phys.Lett. B720 (2013) 32.

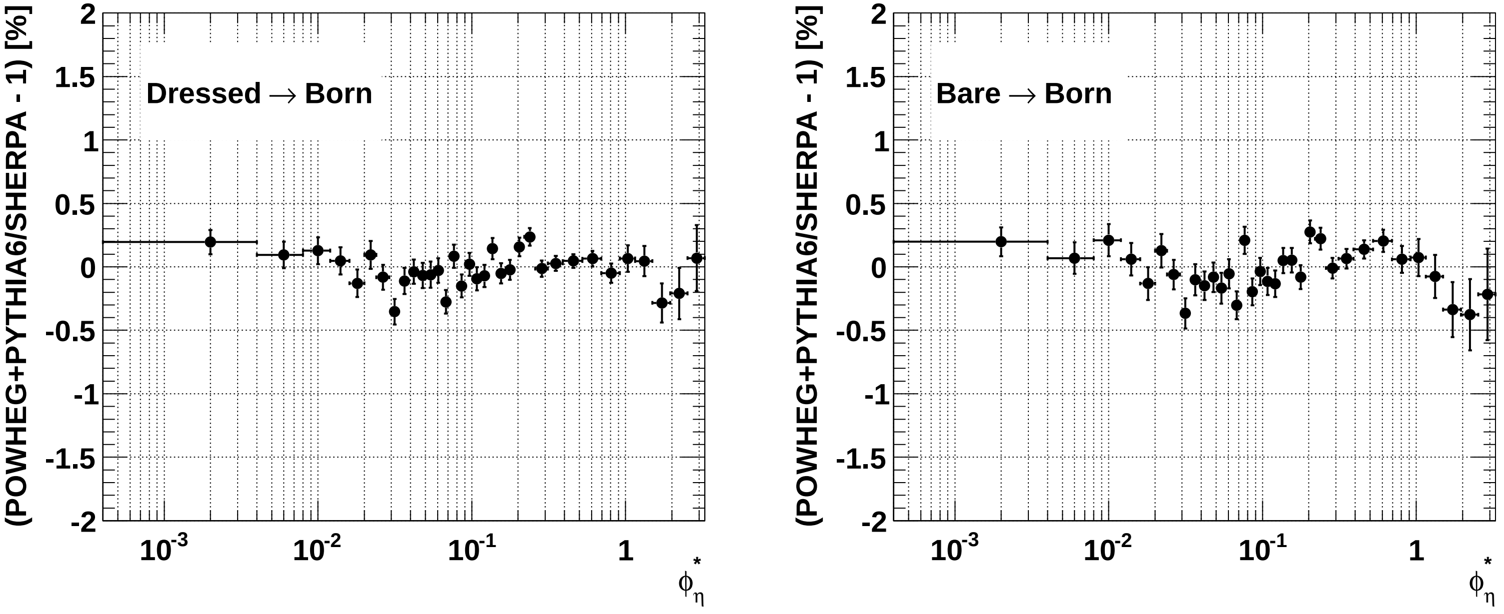
- The demonstrated comparisons is an iceberg peak of CDF, D0, ATLAS and LHCb work. Note LEP time results too.

- Last slide comparisons of PHOTOS with HORACE on QED FSR, were performed by experiments.

- Principle of PHOTOS, HORACE and SHERPA algorithms for QED FSR are different. The comparisons provide insight into the theoretical systematic error.

- HOWEVER: sound estimation of systematic errors for each of these simulation algorithms/(program results) is important for high precision measurements. We will return to that later.

A: boson's decay channels with e, μ



(a) . (b) .

Figure 1: The difference of the QED FSR correction in PHOTOS and in SHERPA as a function of ϕ^*_η, for dressed leptons (a) and bare leptons (b). Corrections are calculated with respect to Born. Statistical uncertainties and acceptance cuts are **taken from CERN-THESIS-2013-001**.

A: boson's decay channels with e, μ

This was motivation for our papers:

- T. Doan, W. Placzek, Z. Was, "Observable ϕ^*_η at LHC and second-order QED matrix element in $Z/\gamma \to l^+l^-$ decays," Phys. Lett. B725 (2013) 92; arXiv:1303.2220 .
- A. B. Arbuzov, R. R. Sadykov and Z. Was, "QED Bremsstrahlung in decays of electroweak bosons," Eur. Phys. J. C (2013) 73:2625; arXiv:1212.6783.
- S. Jadach, B.F.L. Ward, Z. Was "KK MC 4.22: CEEX EW Corrections for $f\bar{f} \to f'\bar{f}'$ at LHC and Muon Colliders", arXiv:1307.4037, Phys Rev D in print.
- The following questions were addressed:
- What lesson come from comparison of results for QED simulation from PHOTOS and SHERPA for observables like ϕ^*_η and how to continue with this work.
- What is the syst. error for results of MC programs simulating FSR in Z or W decays?
- What is the systematic error for separation of QED FSR from the rest of Electroweak/hadronic interaction, or for separation of complete electroweak effects from initial state hadronic interactions.
- What is an overall systematic error for ϕ^*_η observable, and what is supposed to be measured?

A: boson's decay channels with e, μ

Main references for the programs:

1. PHOTOS P. Golonka and Z. Was, *Eur. Phys. J.* **C45** (2006) 97
2. KK MC S. Jadach, B. F. L. Ward, and Z. Wąs *Comput.Phys.Commun.* **130** (2000) 260
3. SHERPA T. Gleisberg *et al.*, *JHEP* **0902** (2009) 007
4. SANC A. Andonov *et al. Comput.Phys.Commun.* **174** (2006) 481
5. HORACE C. Carloni Calame,*JHEP* **0710** (2007) 109.
6. WINHAC W. Płaczek and S. Jadach, *Eur. Phys. J.* **C29** (2003) 325

A: boson's decay channels with e, μ

QED second order matrix element $\rightarrow$ from to be checked list

- Algorithms of KK MC and SHERPA are based on exclusive exponentiation. SHERPA features first order QED FSR matrix element only. The LEP legacy generator KK MC features second order matrix element as default.
- KK MC offers excellent benchmark for evaluating importance of the second order matrix element as it can be also downgraded to first order only.

  LIMITATION, RECENT IMPROVEMENT: it can be used for fixed flavour incoming quarks with PDF distributions but so far no p_T.

  Net effect of second order matrix element embedded in exclusive exponentiation can be calculated. **It is the only program available for this purpose.**

  We use this opportunity regularly for benchmarking PHOTOS, we have used it for ϕ^*_η observable.

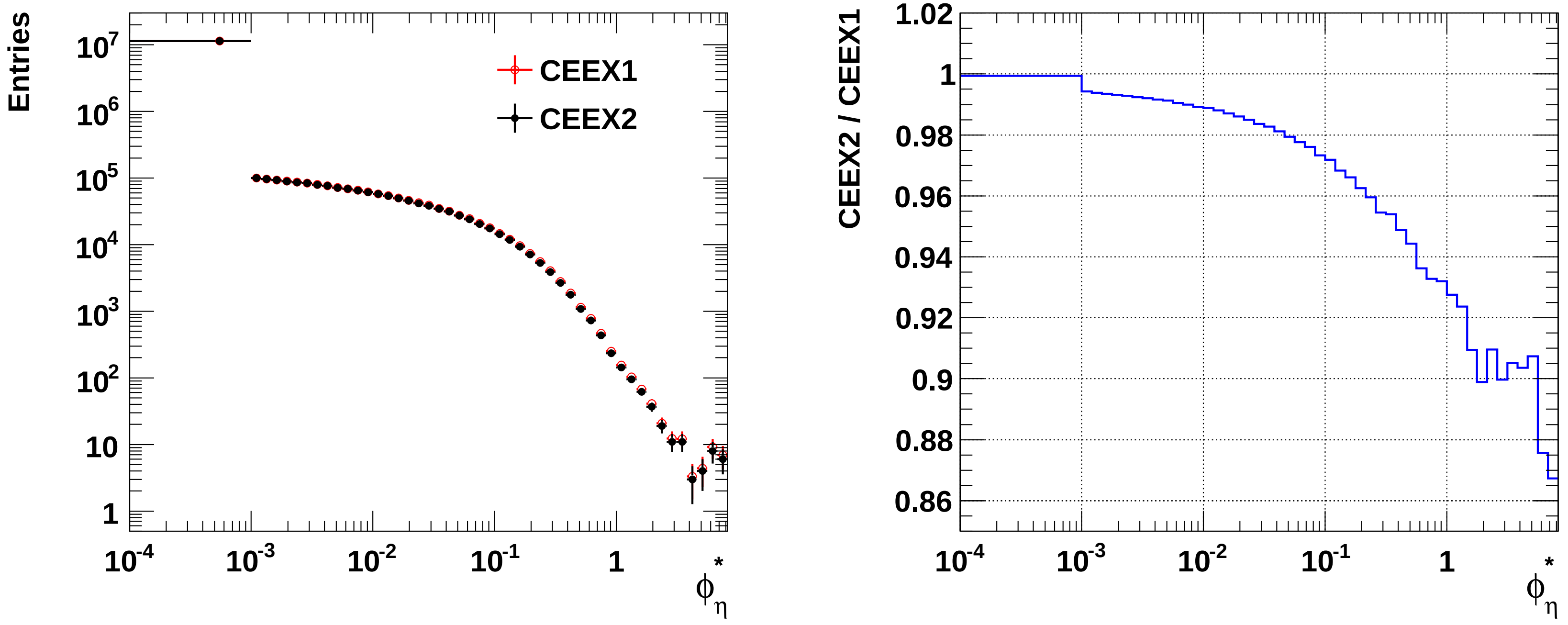


Figure 2: **arXiv:1303.2220**: the ϕ^*_η distribution: the comparisons of the CEEX2 and CEEX1 results. The sample of $u\bar{u} \to e^+e^-(n\gamma)$ events is generated. The virtuality of the Z boson equal to its mass is used. The boost to the laboratory frame of Z is performed prior to histogramming with cuts. The longitudinal momentum of Z is generated according to WINHAC in pp collision at $\sqrt{s} = 7$ TeV, while $p_T^Z = 0$. In the first bin, the configurations with ϕ^*_η smaller than 0.001 are collected.

A: boson's decay channels with e, μ

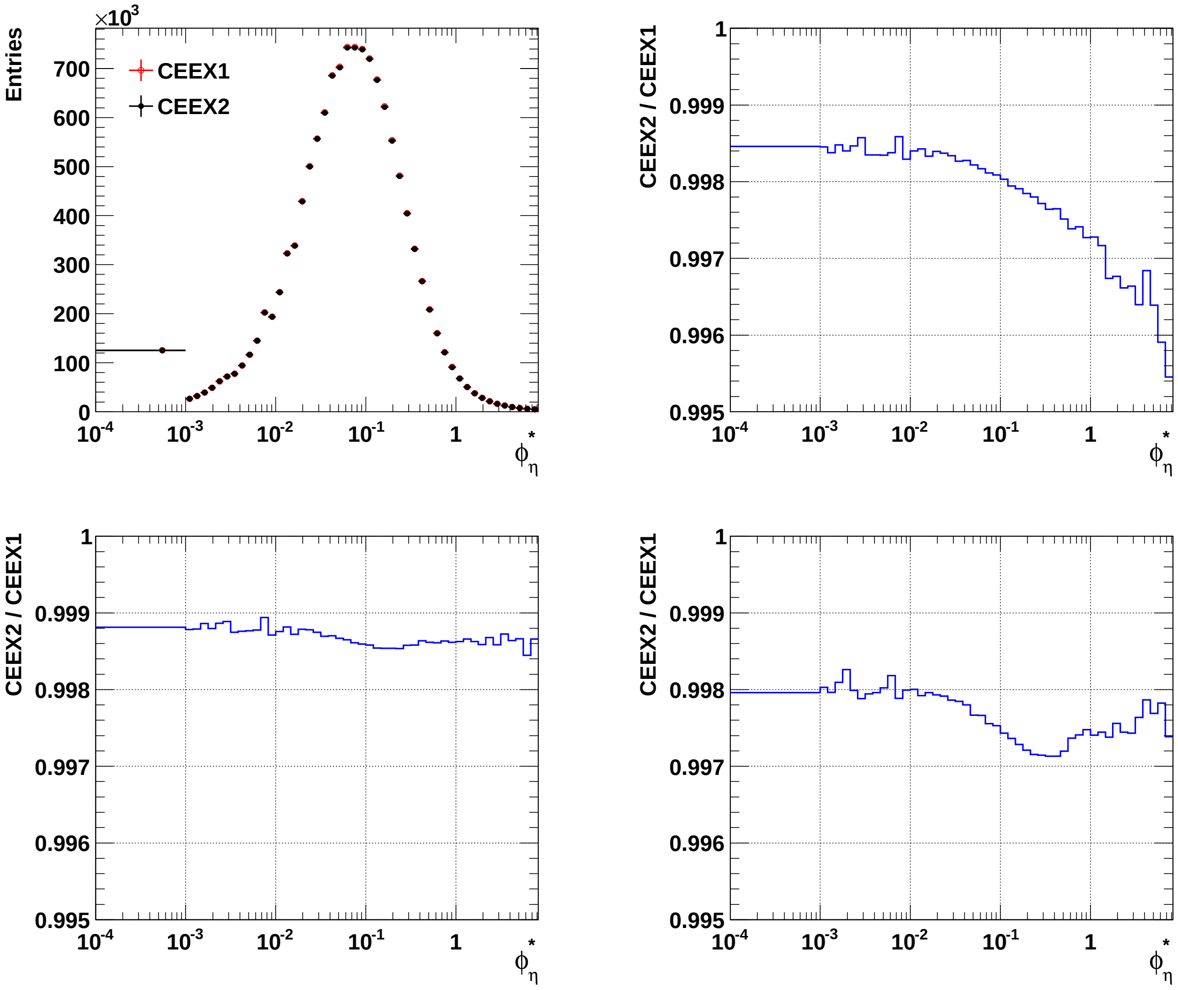


Figure 3: **arXiv:1303.2220**: the ϕ^*_η distribution: the comparisons of the CEEX2 and CEEX1 results. The $u\bar{u} \to e^+e^-(n\gamma)$ events. The boost to the laboratory frame of Z is performed prior to **histogramming with typical exp. cuts**. The plot with extra 66 GeV $< m_{ee} < 116$ GeV is on the bottom-left side. Bottom-right side, in addition, events with the Z/γ^* virtuality of 115 GeV (instead of 92 GeV) are taken, a wavy structure appears.

A: boson's decay channels with e, μ

- The first results of ϕ^*_η measurements with ATLAS experiment quoted systematic error of 0.3% to ϕ^*_η due to implementation of QED final state radiation (FSR) in their Monte Carlo generators. It was estimated in proportion of differences observed between PHOTOS and SHERPA.

  ATLAS Collaboration. *Measurement of angular correlations in Drell-Yan lepton pairs to probe Z/γ^* boson transverse momentum at $\sqrt{s} = 7$ TeV with the ATLAS detector* Phys.Lett. B720 (2013) 32.

- **Thanks to the tests with KK MC we could confirm:** Missing in SHERPA second order matrix element of QED FSR is not a problem at precision level for ϕ^*_η of 0.3% .

- However, observed differences should be traced further. Missing terms will be needed when precision will improve further, to 0.1%.

- There is room for improving TH precision on leptonic degrees of freedom! Total systematic error for luminosity (Bhabha scattering) **at LEP reached 0.04%**.

- **The KK MC v. 4.22 will be useful.**

Uncertainty due to pair emission:

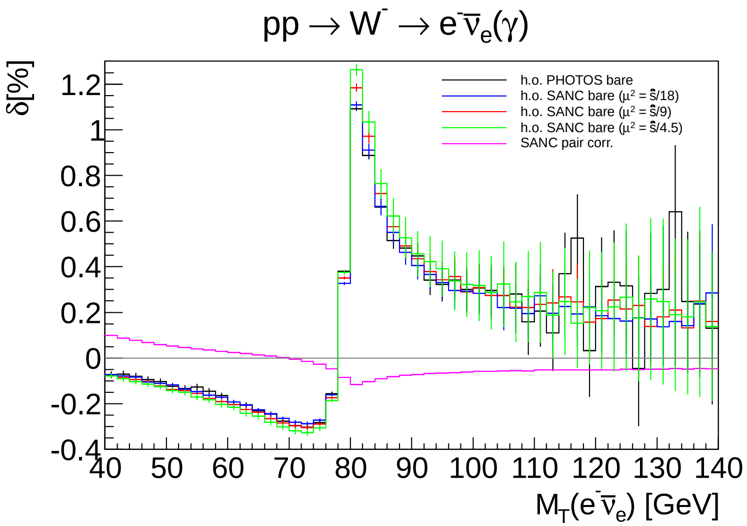


Figure 4: **arXiv:1212.6783**: *higher order photonic and pair corrections (δ in %) for basic distributions from* PYTHIA+PHOTOS *and* SANC *in* $W^- \to e^- \bar{\nu}$ *decay.*

In PHOTOS emission of additional pairs is not taken into account

Size of this missing effect has to be evaluated

Let me demonstrate just one plot prepared for that purpose on the basis of SANC generations

Effects are even smaller for ϕ^*_η and can be neglected for 0.3% precision level.

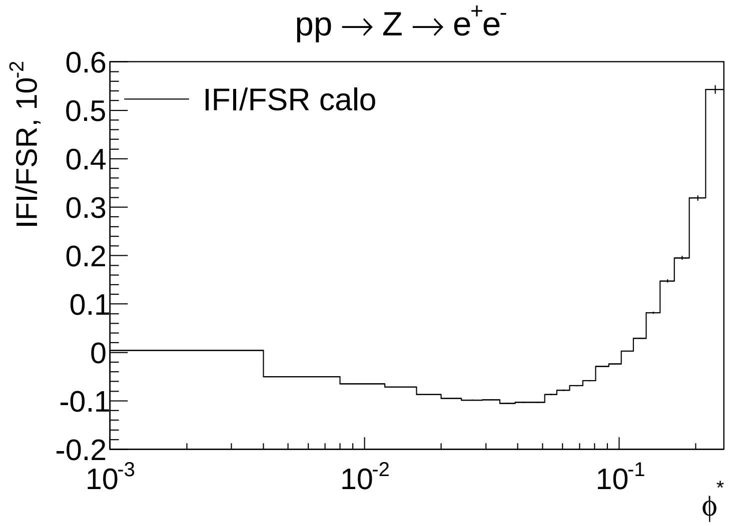


Figure 5: **arXiv:1212.6783**: *IFI/FSR ratio in Z decay for ϕ^*_η distribution. For $\phi^*_\eta > 0.2$ interference effects become sizable.*

In PHOTOS only QED FSR emission is taken into account

ISR-FSR radiation interference is omitted

In general, this effect is expected to be of order of α_{QED} but for Z or W observables suppression factor $\frac{\Gamma}{M}$ is expected for large class of cuts

Effect is small, can be neglected for 0.3% precision level and present day selection cuts for ϕ^*_η.

It is important that proper calculation scheme is used. Mismatch between QED FSR and remaining genuine weak corrections must be avoided.

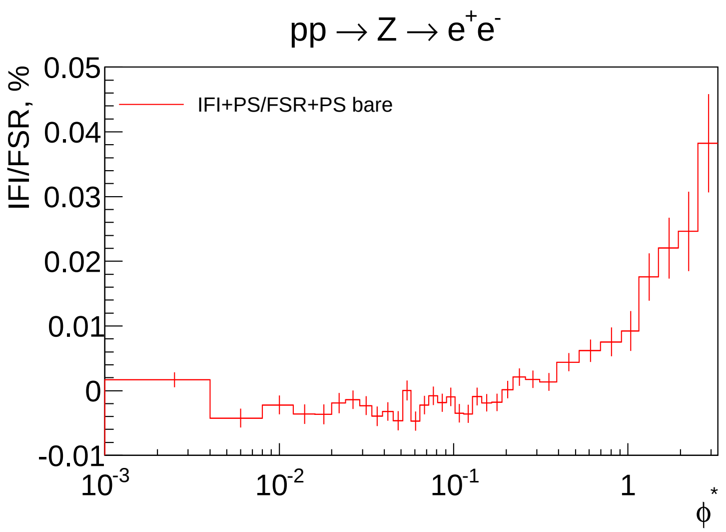


Figure 6: **arXiv:1212.6783**: *IFI/FSR ratio in Z decay for ϕ^*_η distribution. For $\phi^*_\eta > 0.2$ interference effects is negligible because parton shower brings dominant effect.*

In **PHOTOS** only QED FSR emission is taken into account

ISR-FSR radiation interference is omitted

In general, this effect is expected to be of order of α_{QED} but for Z or W observables suppression factor $\frac{\Gamma}{M}$ is expected for large class of cuts

It can be neglected for 0.3% precision level and present day selection cuts for ϕ^*_η.

It is important that proper calculation scheme is used. Mismatch between QED FSR and remaining genuine weak corrections must be avoided.

KK MC for LHC applications

A. KK MC is LEP time Monte Carlo, featuring exclusive exponentiation of second order QED matrix element and also complete electroweak corrections.

B. It was tested to a very high precision.

C. In particular numerical effects of QCD corrections (perturbative and not) for Z propagator were taken into account.

D. For tests one can switch on/off:

- second order QED matrix element,
- genuine weak corrections, parts of higher order QCD corrections to line-shape of Z.
- QED ISR/FSR interference, QED ISR, QED FSR
- extra pair emission contribution to vertex corrections .

E. In the past initial state had to be e^+e^-. Now it feature fixed flavour quarks of $p_T = 0$ too.

F. I used KK MC for the tests of PHOTOS.

i QED FSR only, incoming quarks of fixed momentum, flavour.

ii Fixed invariant mass of the annihilating quark pair.

KK MC for LHC applications

G. KKMC was equipped with an algorithm for beamstrahlung: it is used for generating incoming quarks accordingly to PDF distributions.

H. That means 5 runs to get complete predictions for pp collisions

I. The p_T^Z can be generated independently, as in our paper on ϕ_η^* and implemented at the time of histograming for observables with cuts.

J. It is not ideal solution, but already good step forward...

H. Work on how to combine KKMC with Monte Carlo simulation chain, such as HERWIG is on-going. See e.g. S. Yost, V. Halyo, M. Hejna, and B.F.L. Ward, 1201.590

** Lot of new tests for theoretical systematic errors of observables with cuts is possible already now!

KK MC for LHC applications

CEEX σ and $A_{\rm FB}$, energy cut-off study

$d\bar{d} \to \mu^-\mu^+$, at 91.187GeV. Energy cut: $v < v_{\rm max}$, $v = 1 - M^2_{f\bar{f}}/s$.

Scattering angle for $A_{\rm FB}$ is $\theta = \theta^\bullet$. No cut in $\theta^\bullet$. E-W corr. in $\mathcal{KK}$ according to DIZET 6.x.

EEX3 is $\mathcal{O}(\alpha^3)_{\rm LL}$ EEX3 matrix element without ISR⊗FSR interf.

$\mathcal{KK}$sem is semianalytical part of $\mathcal{KK}$. (Angle $\theta^\bullet$ is from Phys. Rev. **D41**, 1425 (1990).)

$v_{\rm max}$	$\mathcal{KK}$sem Refer.	$\mathcal{O}(\alpha^3)_{\rm EEX3}$	$\mathcal{O}(\alpha^2)_{\rm CEEX}$ intOFF	$\mathcal{O}(\alpha^2)_{\rm CEEX}$
	$\sigma(v_{\rm max})$ [pb]			
0.01	2265.5701 ± 0.0000	2265.7449 ± 0.1721	2265.7796 ± 0.1721	2267.2517 ± 0.1796
0.10	2602.0228 ± 0.0000	2602.4244 ± 0.1519	2602.3968 ± 0.1520	2602.3923 ± 0.1620
0.30	2745.7157 ± 0.0000	2745.9432 ± 0.1385	2746.0304 ± 0.1387	2745.9989 ± 0.1500
0.50	2801.7613 ± 0.0000	2801.7212 ± 0.1317	2802.1262 ± 0.1324	2802.0849 ± 0.1443
0.70	2832.7832 ± 0.0000	2832.3374 ± 0.1275	2833.2354 ± 0.1286	2833.1826 ± 0.1409
0.90	2852.5000 ± 0.0000	2851.5051 ± 0.1246	2853.0535 ± 0.1262	2852.9951 ± 0.1388
0.99	2858.8368 ± 0.0000	2857.5479 ± 0.1237	2859.4417 ± 0.1254	2859.3787 ± 0.1381
	$A_{\rm FB}(v_{\rm max})$			
0.01	0.1034 ± 0.0000	0.1033 ± 0.0001	0.1033 ± 0.0001	0.1090 ± 0.0001
0.10	0.1032 ± 0.0000	0.1031 ± 0.0001	0.1031 ± 0.0001	0.1034 ± 0.0001
0.30	0.1031 ± 0.0000	0.1031 ± 0.0001	0.1031 ± 0.0001	0.1031 ± 0.0001
0.50	0.1031 ± 0.0000	0.1031 ± 0.0001	0.1031 ± 0.0001	0.1031 ± 0.0001
0.70	0.1031 ± 0.0000	0.1031 ± 0.0001	0.1031 ± 0.0001	0.1031 ± 0.0001
0.90	0.1031 ± 0.0000	0.1030 ± 0.0001	0.1031 ± 0.0001	0.1030 ± 0.0001
0.99	0.1031 ± 0.0000	0.1030 ± 0.0001	0.1030 ± 0.0001	0.1030 ± 0.0001

`TauSpinner` for re-weighting τ-lepton events in Z, W, H production and decays at LHC

- **(1)** τ leptons can not be observed directly, also ν_τ escapes detection. This is a nuisance making observables difficult.
- **(2)** How to turn this complexity into advantage?
- **At the same time:** τ is the only lepton of measurable spin state.
- **Large mass large coupling to H.**
- **(3)** `TauSpinner` is a tool which is devoted to manipulation of spin effects on previously generated samples of events with the help of weights which can be calculated after events are generated and stored on production files.

Part B: boson's decay channels with τ leptons

1. To calculate weight = $\frac{|matrix\ element\ new|^2}{|matrix\ element\ old|^2}$ one has to:
2. get phase space point at which weight is to be calculated
3. $|matrix\ element\ old|^2$ with which this point was calculated.
4. That also means that variables used for calculation of matrix elements have to be reconstructed from information stored in event record or in production files.
5. This is possible, no numerical precision loss problems for present ATLAS/CMS production file formats.
6. I will review main ideas only. Basic principles how `TAUOLA interface` work and how `TauSpinner` work. More formal considerations, like for PHOTOS, would take too much time.
7. Thanks to extremely narrow width of τ lepton its production and decay can be fully separated.

http://tauolapp.web.cern.ch/tauolapp/

Formalism for $\tau^+\tau^-$

- Because narrow τ width approximation can be obviously used for phase space , cross section for the process $f\bar{f} \to \tau^+\tau^- Y; \tau^+ \to X^+\bar{\nu}; \tau^- \to \nu\nu$ reads:

$$d\sigma = \sum_{spin} |\mathcal{M}|^2 d\Omega = \sum_{spin} |\mathcal{M}|^2 d\Omega_{prod}\; d\Omega_{\tau^+}\; d\Omega_{\tau^-}$$

- This formalism is fine, but because of over 20 τ decay channels we have over 400 distinct processes. Also picture of production and decay are mixed.

- but (only τ spin indices are explicitly written):

$$\mathcal{M} = \sum_{\lambda_1\lambda_2=1}^{2} \mathcal{M}^{prod}_{\lambda_1\lambda_2}\; \mathcal{M}^{\tau^+}_{\lambda_1} \mathcal{M}^{\tau^-}_{\lambda_2}$$

- Cross section can be re-written into **core formula of spin algorithms**

$$d\sigma = \Big(\sum_{spin} |\mathcal{M}^{prod}|^2\Big)\Big(\sum_{spin} |\mathcal{M}^{\tau^+}|^2\Big)\Big(\sum_{spin} |\mathcal{M}^{\tau^-}|^2\Big) wt\; d\Omega_{prod}\; d\Omega_{\tau^+}\; d\Omega_{\tau^-}$$

- where

$$wt = \Big(\sum_{i,j=0,3} R_{ij} h^i h^j \Big)$$

$$R_{00} = 1, \quad < wt >= 1, \quad 0 \leq wt \leq 4.$$

R_{ij} can be calculated from $\mathcal{M}_{\lambda_1 \lambda_2}$
and h^i, h^j respectively from $\mathcal{M}^{\tau^+}$ and $\mathcal{M}^{\tau^-}$.

- Bell inequalities tell us that it is impossible to re-write wt in the following form

$$wt \neq \Big(\sum_{i,j=0,3} R_i^A h^i \Big) \Big(\sum_{i,j=0,3} R_j^B h^j \Big)$$

that means it is impossible to generate first τ^+ and τ^- in some 'quantum states' and later perform separately decays of τ^+ and τ^-

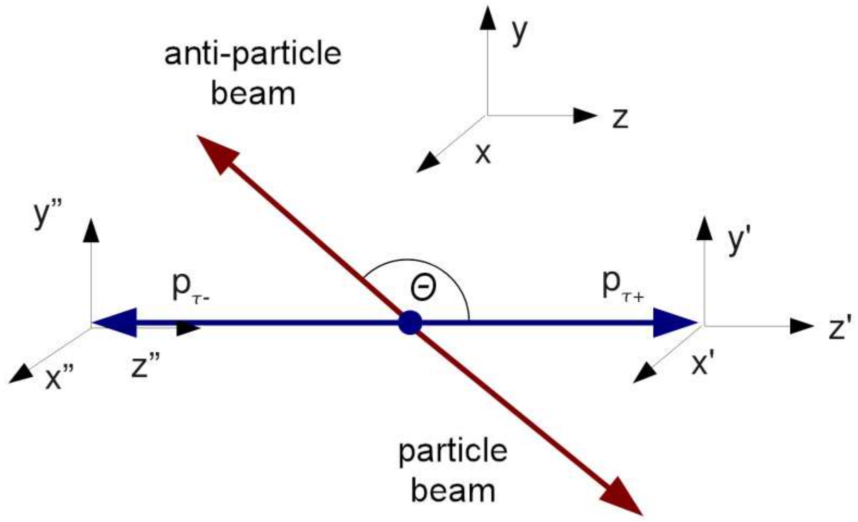
- It can be done only if approximations are used !!! (like in `TauSpinner` at present, no transverse spin effects. Critical topic: reconstruction of π^0's.

- Spin weight can be calculated after event is constructed, detector response simulated and stored in file. It can be even embedded τ event.

What do we need to calculate spin and/or matrix element weight?

1. For matrix element of τ decay we need 4-momenta of all decay products.
2. For hard process we need to know flavours and 4-momenta of incoming quarks/gluons.
3. incoming quarks/gluon states can be attributed stochastically on the basis of quark level matrix elements and PDF's (`TauSpinner`) or information read from event record (`Tauola`).
4. then weights for distinct assumptions on spin and/or hard processes can be attributed. Also for decay matrix element.
5. In either case (`TauSpinner` `Tauola`) work on factorization has to be performed. For multi-photon (multi gluon) emissions experience of work for `KK MC` was used. Second order spin amplitudes were used not only for tests of `PHOTOS`, but for `TauSpinner` as well!.

Part B: boson's decay channels with τ leptons



- Configuration of hard process: flavors and 4-momenta of incoming quarks and outgoing τ's (ν_τ)
- algorithm for spin correlations has no approximation.
- However, method to calculate density matrix from that input usually will impose approximations.
- Density matrix including EW corrections is an option. This arrangement can be used to add Z' or to play with spin correlation component by component.
- Helicity states are attributed at the end (approximation is then used). Useful for some LEP style analyses.

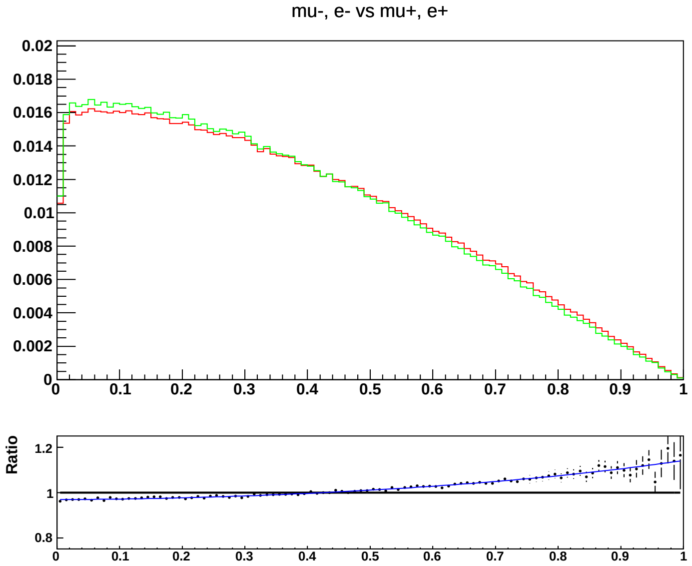
Using wt

Evaluating size of the spin effect

Left: $\tau \to l\nu_l\nu_\tau$ green line – spin effects removed with TauSpinner

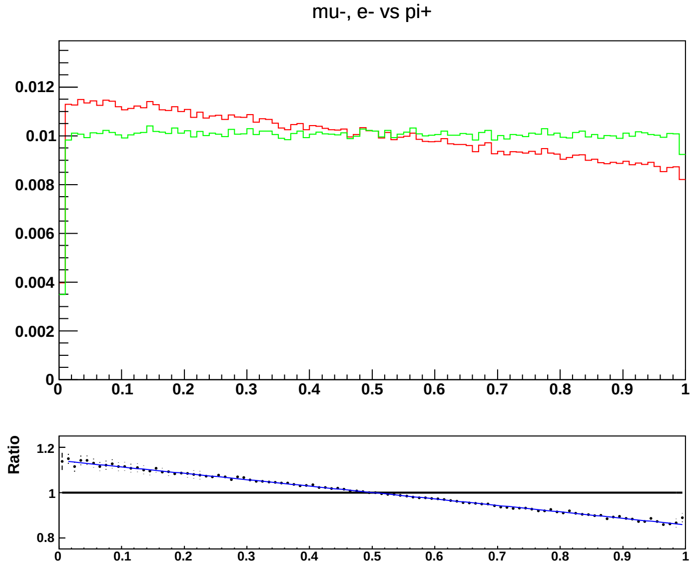
Right: $\tau \to \pi\nu_\tau$

Similar plots for other τ decay channels automatically created for events stored on the production files. Also for spin correlation effects. Taken from *Application of* `TauSpinner` *for studies on τ-lepton polarization and spin correlations in Z, W and H decays at LHC*, A. Kaczmarska J. Piatlicki, T. Przedziński, E. Richter-Wąs and Z. Wąs, IFJPAN-IV-2013-19 in preparation



P_{orig} = -1.89e-01 ± 3.70e-03

$P_{unweighted}$ = -3.98e-02 ± 4.20e-03



P_{orig} = -1.48e-01 ± 1.98e-03

$P_{unweighted}$ = -6.20e-03 ± 2.41e-03

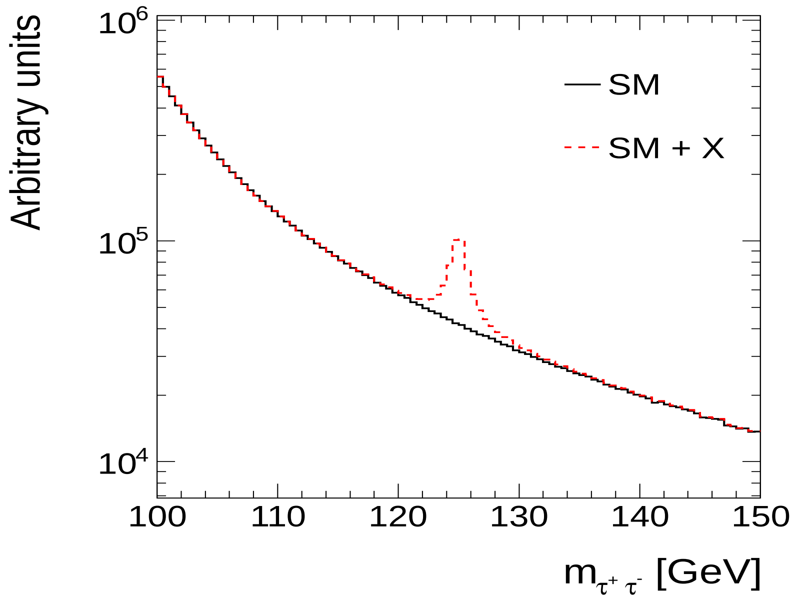
Using $\left(\sum_{spin} |\mathcal{M}^{prod}|^2\right)$

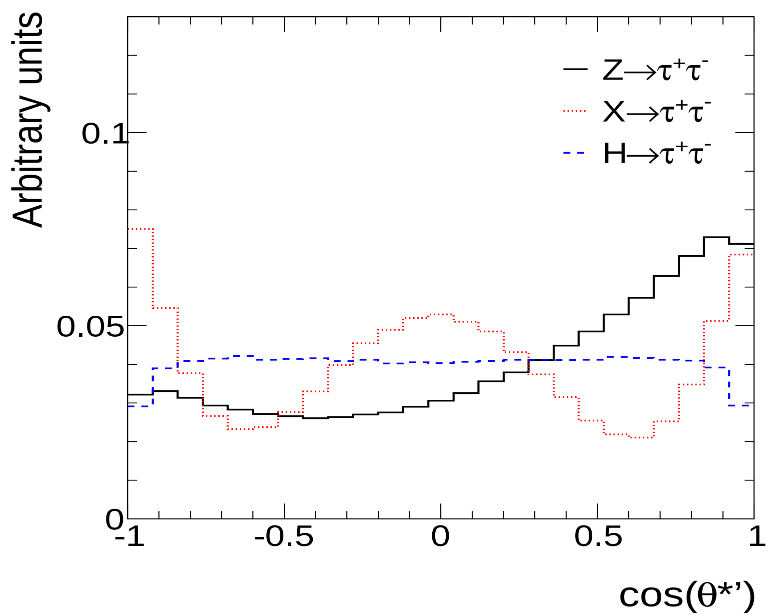
Implementing resonance with `TauSpinner` weights case of X_2

Left: invariant mass of the τ pair, SM black line, red line with effect from X.

The $\cos(\theta^\star)$ for $Z \to \tau^+\tau^-$, $X \to \tau^+\tau^-$, and $H \to \tau^+\tau^-$ events, invariant mass of $\tau^+\tau^-$ pair: 125 GeV a $\pm$ 3 GeV.

Ascertaining the spin for new resonances decaying into tau+ tau- at Hadron Colliders S. Banerjee, J. Kalinowski, W. Kotlarski, T. Przedzinski, Z. Was, Eur.Phys.J. C73 (2013) 2313





Using $\left(\sum_{spin}|\mathcal{M}^{\tau^\pm}|^2\right)$

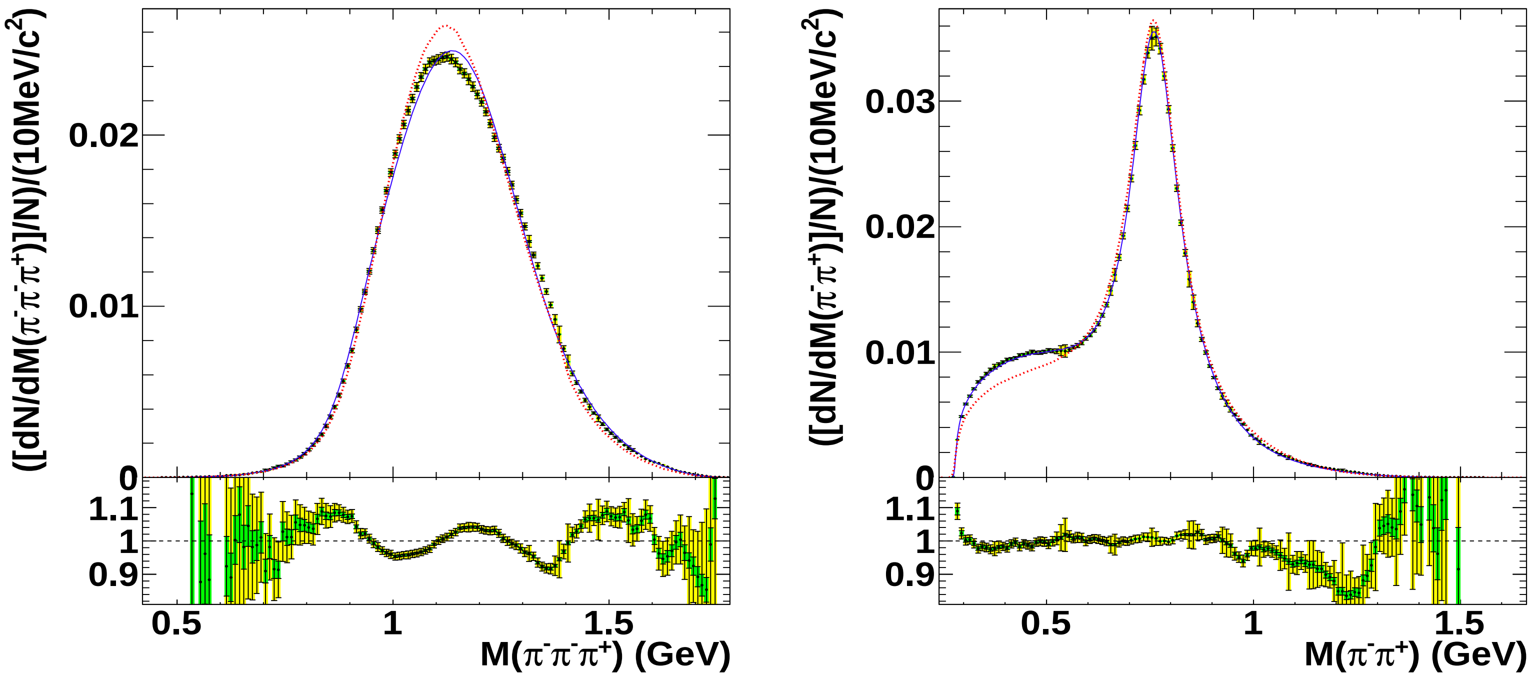
New currents for $\tau \to 3\pi$ and $\tau \to 2\pi$ decays

Currents based on Resonance Chiral Lagrangian approach and fits to BaBar data.

Experimental systematic errors considered. Special software environment was used.

It is now available for simulations with `Tauola++` and `TauSpinner`.

From: *Resonance Chiral Lagrangian Currents and Experimental Data for* $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$, I.M. Nugent, T. Przedzinski, P. Roig, O. Shekhovtsova, Z. Was, Phys. Rev. D 88, 093012 (2013).



Summary e, μ

1. Arguments why it is useful to have QED Final State bremsstrahlung separated from other parts of theoretical predistions and why it is possible without loss of the precision were given.
2. Results for theoretical systematic error evaluation for QED FSR and ϕ^*_η observable were presented as an example.
3. Programs used in tests, such as SANC were presented.
4. KK MC Monte Carlo was also found useful for these tests.
5. New version of the KK MC program where initial quark state can be distributed accordingly to PDFs is now available.
6. With KK MC tests on numerical importance of Higher Order QED corrections: ISR, FSR, their interference and finally genuine weak corrections can be performed for observables defined with complex cuts.
   If needed, p_t^Z can be implemented following arXiv:1303.2220, i.e. in factorized manner.
7. Work on interface with Monte Carlo programs featuring QCD parton shower of initial state is on-going, see e.g. 1201.590

Summary τ

1. The general principles of formalism for calculation of spin effects were presented.

2. It was explained how information necessary for calculation of hard matrix element is obtained in `Tauola` (from event record) and `TauSpinner` (with the help of PDFs).

3. Question of systematic errors was mentioned only.

4. However as $H \to \tau\tau$ was reported at 4.1 σ only, important aspect of tools precision could be skipped today.

5. Progress of work for matrix element in $\tau \to 3\pi\nu$ was nonetheless mentioned.