The TAUOLA generator for tau decays

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- **(1)** The τ lepton decays: fascinating laboratory for intermediate energy QCD; that may explain, why I am a bit biased against New Physics in τ decays.
- **(2)** I will adress TAUOLA in context of New an SM physics, both for production and τ lepton decay.
- **(3)** How to optimize work of inhomogeneous community. From model builders to people managing large experimental data files. From F77 to C++ and Python.
- **(4)** My concern is on how to handle different component of systematc errors: experiment, theory, choice of quantities for comparisons.
- **(5)** Also on what can/should be the role of MC (authors) in this respect.
- **My talk would not be possible without effort of many people and experiments**

Target points: what people may need

(1) Simulate detector response

(2) Provide distributions of τ decay products and of the τ itself: starting from lagrangian of Old and New physics

(3) Environment to study prototypes for matrix elements and prototypes for τ decay observables.

Technical detail: narrow width limit for intermediate resonances is often needed.

(4) For studies where τ leptons are used to constrain else, like Higgs CP or B physics.

(5) New challenges: multidimensional distributions? ML? Experimental systematic errors for that?

- **First some theory and software organization**

General formula for tau production and decay.

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, e.g. for 20 τ decay channels we would have 400 distinct processes. Also picture of production and decay are mixed.

- Below 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 $\mathcal{M}_{\lambda_1 \lambda_2}$ by contraction with Pauli σ^i matrices and similarly 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^- first in some given ' quantum state' and later perform separatelly decays of τ^+ and τ^-

- It can be done only if approximations are used !!!

- May be reasonable in e.g. ultrarelativistic regime, but nonetheless approximation.

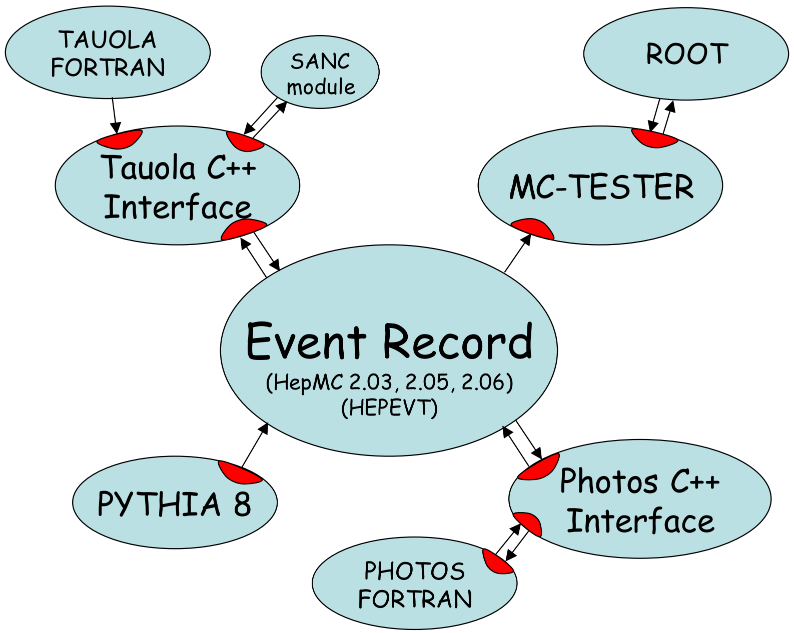
TAUOLA universal interface

- To run, generator for tau decays must be combined with production.
- In cases of packages for e^+e^- colliders, such as ours KORALB, KORALZ, KKMC, they provide environment for TAUOLA use.
- often information from event stored in production files can be used.
- I will skip technicalities, there is a lot to that!
- Interface to store events offer benefits but require competence.
- `TAUOLA universal interface` reads information from event record. Once τ leptons to be decayed are found it acts.
- τ lepton(s) spin states are calculated from kinematical configurations of hard processes. User control.
- `TauSpinner` reads information and calculate weights (ratios of matrix element^2) for distinct assumptions only.

An example when τ decays are modified.

Communication though event record: (for program inerfaces or data files).

Solution for phase space $\times |M|^2$ algorithms.



Parts:

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

\- High precision achieved

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

Such organization requires:

- Good control of factorization (theory)
- Good understanding of tools on user side.

Techniques of weighted events

`TauSpinner`

An example when τ decays are modified.

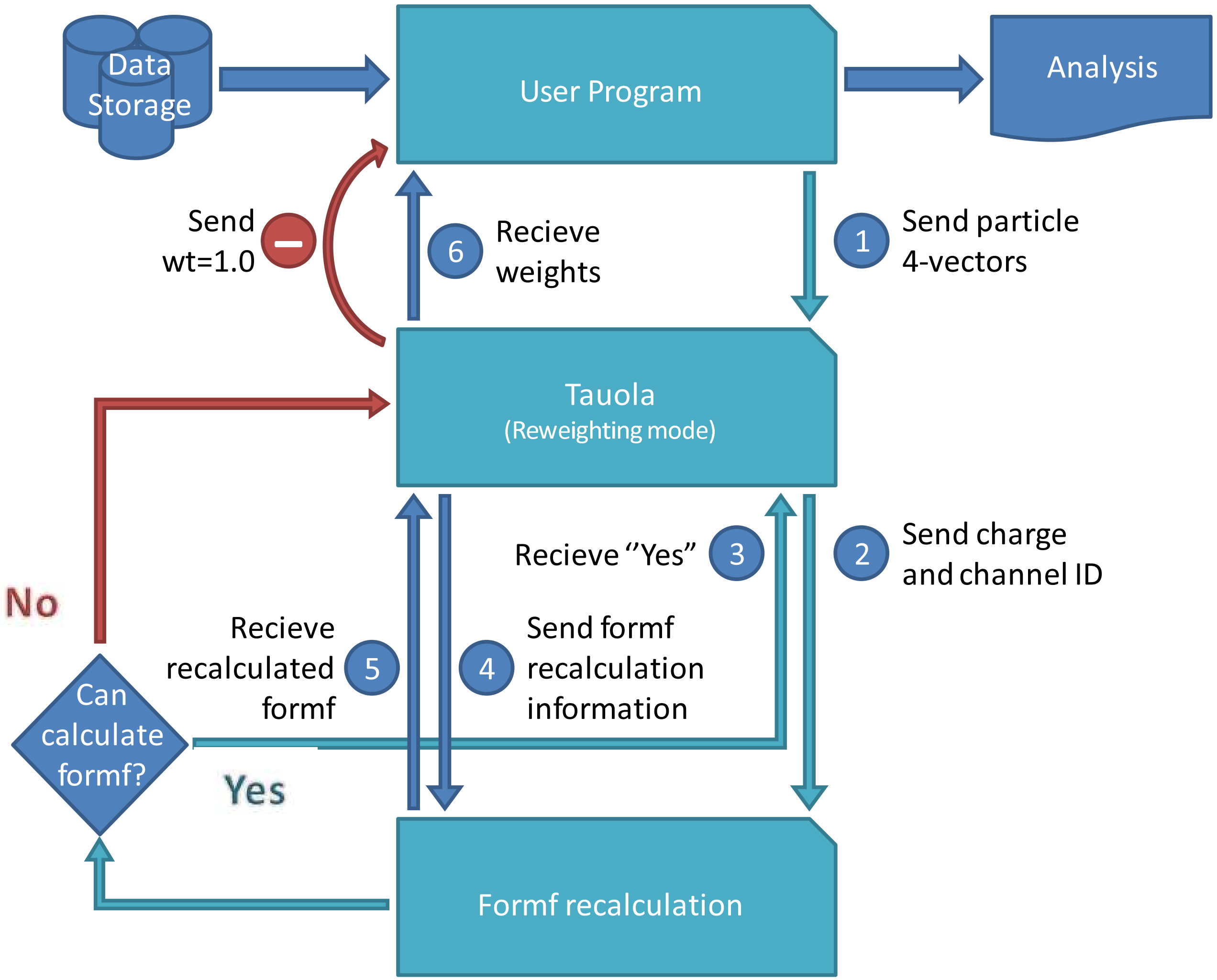
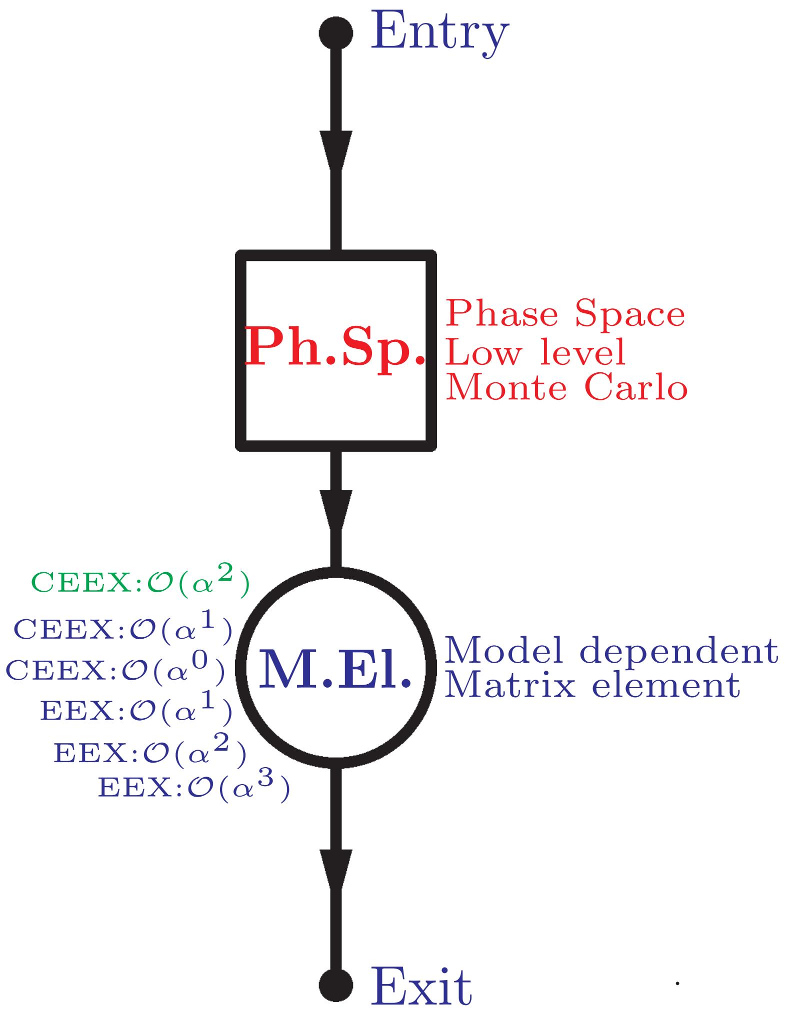


Figure 1: Flow chart for communication when already stored events are modified with the weights. Useful at LHC and at low energy applications as well.

TAUOLA perspective of τ decays themselves.

Textbook principle “matrix element $\times$ full phase space” useful



- Phase-space Monte Carlo module producing “raw events”.
- Library of models for provides input for “model weight”
- **Useful for any application, not only τ production/decay.**
- Ratios of matrix elements squared define probability that event could be of model B if generated with mode A.
- Convenient for Machine Learning too.
- No compromises on precision are required.

Formalism for semileptonic decays at 0.2% precision level

- Matrix element used in TAUOLA for semileptonic decay of τ with P momentum and spin s

$$\tau(P,s) \to \nu_\tau(N) X$$
$$\mathcal{M} = \frac{G}{\sqrt{2}} \bar{u}(N)\gamma^\mu(v + a\gamma_5)u(P)J_\mu$$

- J_μ – the current, depends on the momenta of all hadrons ($h_\mu = H_\mu/H_t$)

$$|\mathcal{M}|^2 = G^2 \frac{v^2+a^2}{2}(\omega + H_\mu s^\mu)$$
$$\omega = P^\mu(\Pi_\mu - \gamma_{va}\Pi^5_\mu)$$
$$H_\mu = \frac{1}{M}(M^2\delta^\nu_\mu - P_\mu P^\nu)(\Pi^5_\nu - \gamma_{va}\Pi_\nu)$$
$$\Pi_\mu = 2[(J^* \cdot N)J_\mu + (J \cdot N)J^*_\mu - (J^* \cdot J)N_\mu]$$
$$\Pi^{5\mu} = 2\,\mathrm{Im}\,\epsilon^{\mu\nu\rho\sigma}J^*_\nu J_\rho N_\sigma$$
$$\gamma_{va} = -\frac{2va}{v^2+a^2}$$
$$\hat{\omega} = 2\frac{v^2-a^2}{v^2+a^2}m_\nu M(J^* \cdot J)$$
$$\hat{H}^\mu = -2\frac{v^2-a^2}{v^2+a^2}m_\nu\,\mathrm{Im}\,\epsilon^{\mu\nu\rho\sigma}J^*_\nu J_\rho P_\sigma$$

TAUOLA perspective of τ decays themselves.

- Improvements for ρ channel are technically straightforward: single distribution to be fitted with real function to fit:
  $J^\mu = (p_{\pi^\pm} - p_{\pi^0})^\mu F_V(Q^2) + (p_{\pi^\pm} + p_{\pi^0})^\mu F_S(Q^2)$ ($F_S \simeq 0$).
- For 3-scalar channels: 4 complex function of 3 variables to fit. Role of theoretical assumptions (oversimplifications?) is essential. Agreement on 1-dim distribution is just a consistency check.
- No go for model independent measurements? Not necessarily. Use of all dimensions for data distributions: invariant masses Q^2, s_1, s_2 as arguments of form-factors. Angular asymmetries help to separate currents: scalar $J_4^\mu \sim Q^\mu = (p_1 + p_2 + p_3)^\mu$, vector $J_1^\mu \sim (p_1 - p_3)^\mu|_{\perp Q}$ and $J_2^\mu \sim (p_2 - p_3)^\mu|_{\perp Q}$ and finally pseudovector $J_5^\mu \sim \epsilon(\mu, p_1, p_2, p_3)$.
- Model independent methods, if: (i) enough data, (ii) absolute precision, (iii) no background, (iv) full detector coverage can assured. We need that for orthogonality conditions.
- It is a challenge but worth a try. It was easier for Cleo, where τ were produced nearly at rest.

TAUOLA perspective of τ decays themselves.

1. **I want to adress following contexts: fit strategy, experimental, theoretical syst. errors., cooperation between sub-communities.**
   (a) I am introducing changes into TAUOLA keeping this constraints in mind.
   (b) TAUOLA with new hadronic currents, 200+ decay channels, which can be manipulated by user with c++ coded currents, ME and with any decay products:
   Comput.Phys.Commun. 232 (2018) 220
   (c) What should be included in standard initialization(s).
   (d) Quality stamps from the side of theory, experiment, technical precision.

New theory model + precision simulation: easy.

Channel	Width [GeV]	reference	In tauola/RChL-currents directory channel's current: file $\longrightarrow$ routine
$\pi^- \pi^0$	$5.2678 \cdot 10^{-13} \pm 0.01\%$	Subsection 2.4	frho_pi.f $\longrightarrow$ CURR_PIPI0
$K^- \pi^0$	$5.853 \cdot 10^{-15} \pm 0.02\%$	Subsection 2.4	fkpipl.f $\longrightarrow$ CURR_KPI0
$\pi^- K^0$	$1.1025 \cdot 10^{-14} \pm 0.03\%$	Subsection 2.4	fkpipl.f $\longrightarrow$ CURR_PIK0
$K^- K^0$	$2.415 \cdot 10^{-15} \pm 0.02\%$	Subsection 2.4	fk0k.f$\longrightarrow$ CURR_KK0
$\pi^- \pi^- \pi^+$	$2.08 \cdot 10^{-12} \pm 0.017\%$	Subsection 2.1	f3pi_rcht.f $\longrightarrow$ F3PI_RCHT*
$\pi^0 \pi^0 \pi^-$	$2.126 \cdot 10^{-12} \pm 0.017\%$	Subsection 2.1	f3pi_rcht.f$\longrightarrow$ F3PI_RCHT*
$K^- \pi^- K^+$	$3.8467 \cdot 10^{-15} \pm 0.04\%$	Subsection 2.2	fkkpi.f$\longrightarrow$ FKKPI*
$K^0 \pi^- \bar{K}^0$	$3.5935 \cdot 10^{-15} \pm 0.03\%$	Subsection 2.2	fkkpi.f$\longrightarrow$ FKKPI*
$K^- \pi^0 K^0$	$2.769 \cdot 10^{-15} \pm 0.04\%$	Subsection 2.3	fkk0pi0.f$\longrightarrow$ FKK0PI0*
			* The F_i of form-factors.

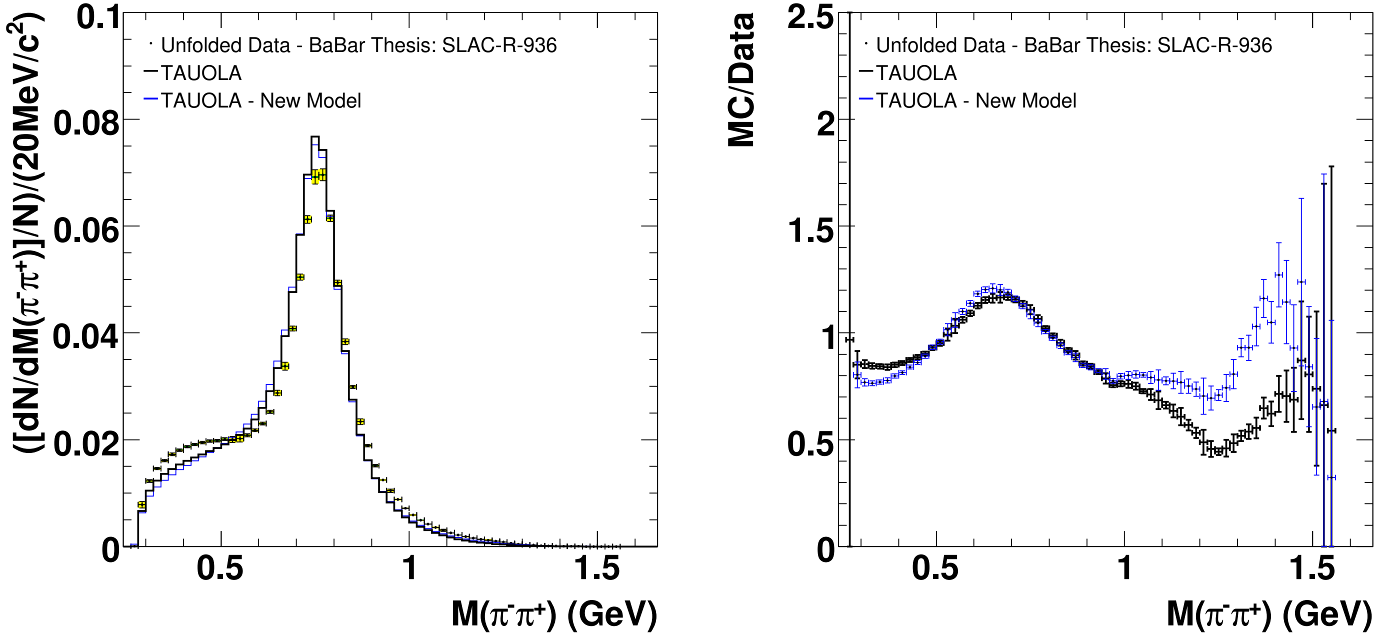
Table 1: Collection of numerical results from paper: O. Shekhovtsovaa, T. Przedzinski, P. Roig and Z. Was *Resonance Chiral Lagrangian currents and τ decay Monte Carlo*, Phys.Rev. D86 **(2012)** 113008. References to subsections of that paper. Last column includes references to routines of the currents code. It looked like mission accomplished. Just fine tuning of some parameters.

New theory model + precision simulation: easy.

- Those new hadronic currents (more than 88 % of hadronic τ decay width) version installed with the 0.05 % technical tag: O. Shekhovtsovaa, T. Przedzinski, P. Roig and Z. Was *Resonance Chiral Lagrangian currents and τ decay Monte Carlo*, Phys.Rev. D86 (2012) 113008
- **But** physics precision was definitely **NOT** as good as 0.05 %.
- Over the last two years we worked on preparing confrontation env. with the data keeping precision in mind.
- But despite partial success for 3π modes, we are nearly as far from the complete solution as in 2012.

- **Useful for further work:**
- We have investigated technical aspects for fitting using weights.
  It is of interest in case when experimental cuts are present, multidimensional distributions are used and no semi-analytical results can be easily obtained.
- We have returned to the semi-analytical 1-dim distributions for fits. Similar as in 90's, may be ML will help (systematics?)
- Such distributions are essential for technical tests of our code, but also for fits and evaluation how experimental errors propagate to parameters of the models.

Attempt: comparison with experimental distr.



(a) A (b) B

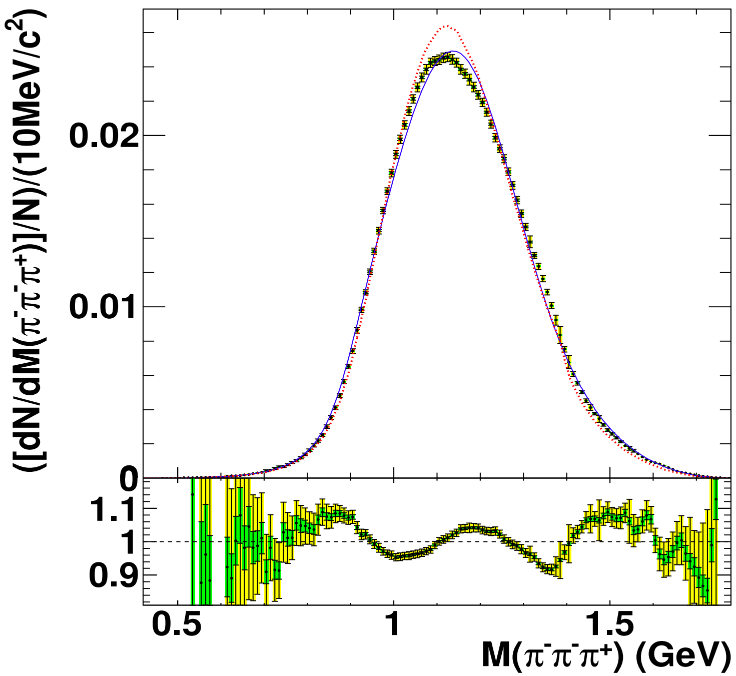
Figure 2: Invariant mass distribution of the $\pi^+\pi^-$ pair in $\tau \to \pi^+\pi^-\pi^-\nu$ decay. Histogram is from our model. Unfolded BaBar data are taken from PhD thesis of Ian Nugent. Left hand side, mass distribution. On the right hand side, ratios of Monte Carlo results and data. Homework to do.

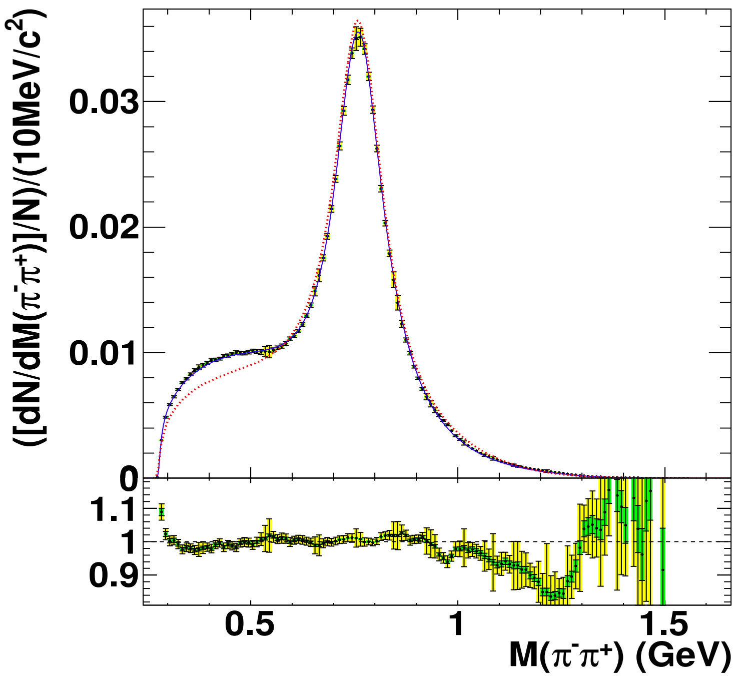
Attempt: comparison with experimental distr.

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. Software environment for fits was prototyped but used in non automated way. 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).





Attempt: comparison with experimental distr.

To progress in case of $\tau \to 3\pi\nu_\tau$ we had to:

- Modify the model (contribution of σ)
- Work simultaneously with fits using weights (at this time only to cross-check results for big mistakes). We had difficulties with stability because of strong correlations of parameters. Template method I have learned at ALEPH time requires better understanding if model parameters are strongly correlated and for some of them dependencies is weak. Necessity to linearize dependencies because of CPU-time constraints in case when model was not giving perfect predictions complicated things further.
- We relied on fitting semi-analytical formulas.
  - We had to assure that derivaties of results are continuous.
  - We had to speed up calculations using different methods of pretabulation/interpolation of results for Q-dependent a_1 width (unitarity constraint).
  - We relied on 1-dimensional invariant mass distributions.

Attempt: comparison with experimental distr.

- Not anymore separation into theoretical, experimental and computing aspects. Even for the simple case of 1-dimensional unfolded distribution.
- **NONETHELESS:**
- We got substantial improvement for 3π modes.
- Control of experimental systematic errors.
- No control beyond 1-dim histograms/distributions.
- Experience for the future steps, but no organized software solution.
- What is the best input from experimental side?
- Multidimensional histograms, number of bins comparable with size of measured sample? Moments, bias due to model assumptions?
- How to coordinate work?
- **Not acceptable: theorist/experimentalist have to wait for ...**

Possible warning message

- Biases in art, Giuseppe Arcimboldo (1572 - 1593).

- Already for 3-scalar final states theoretical predictions and experimental data: distributions over 8-dimensional space. We fit 1- (2-) dim. histos. Result depend on model assumptions. Models inspired with results ... Fitting setup $\rightarrow$ biases.
- Our algorithms are far less elaborate than human eye/brain.
- Who in charge? (TH, EXP?)
- How to facilitate dialog, role of MC. Defalut initialization, but also from user defined objects. In c++ in F77.

Low energies

- **Achieved:**
- TAUOLA MC with 200 decay channels, solution similar as presented on TAU04 and used by BaBar. Neutrinoless channels available.
- **Default BaBar Tauola initialization.**
- Alternatively, for 2 and 3 π's, new currents with comparison with experimental data prepared.
- Theoretically motivated currents, 4 and 5 π's decay modes, also as alternative.
- No fits to global properties such as average charged energy. For alternatives, no experimental quality stamps.
- User can re-initialize TAUOLA with own (C++ coded) currents (or matrix elements).
- **Non complete tasks:**
- Results for 3-scalar modes with K's are not incorporated, need quality fits.
- Many alternative parametrizations, eg. for 2K 2π modes (BaBar) are not incorporated, even though these are missing channels, left at flat phase space.
- Environments for fits are not well structured for model independent use.
- Work in experiments needed: hope that S. Banerjee BaBar savy will continue in Belle2.

Jakub Zaremba Adapting TAUOLA to new needs.

1. With the ever improving precision of new experiments doors open for exploring extremely rare τ decays.
2. Attention is on decays that could provide evidence for New Physics.
3. Last release of Tauola gave tools for easy addition of user-defined models, but further update necessary and under way.
4. The goal is to facilitate features expected from lfv decays and**their background**.
5. Phase space generation required new presamplers for distribution peaks e.g. of e^+e^- pairs.

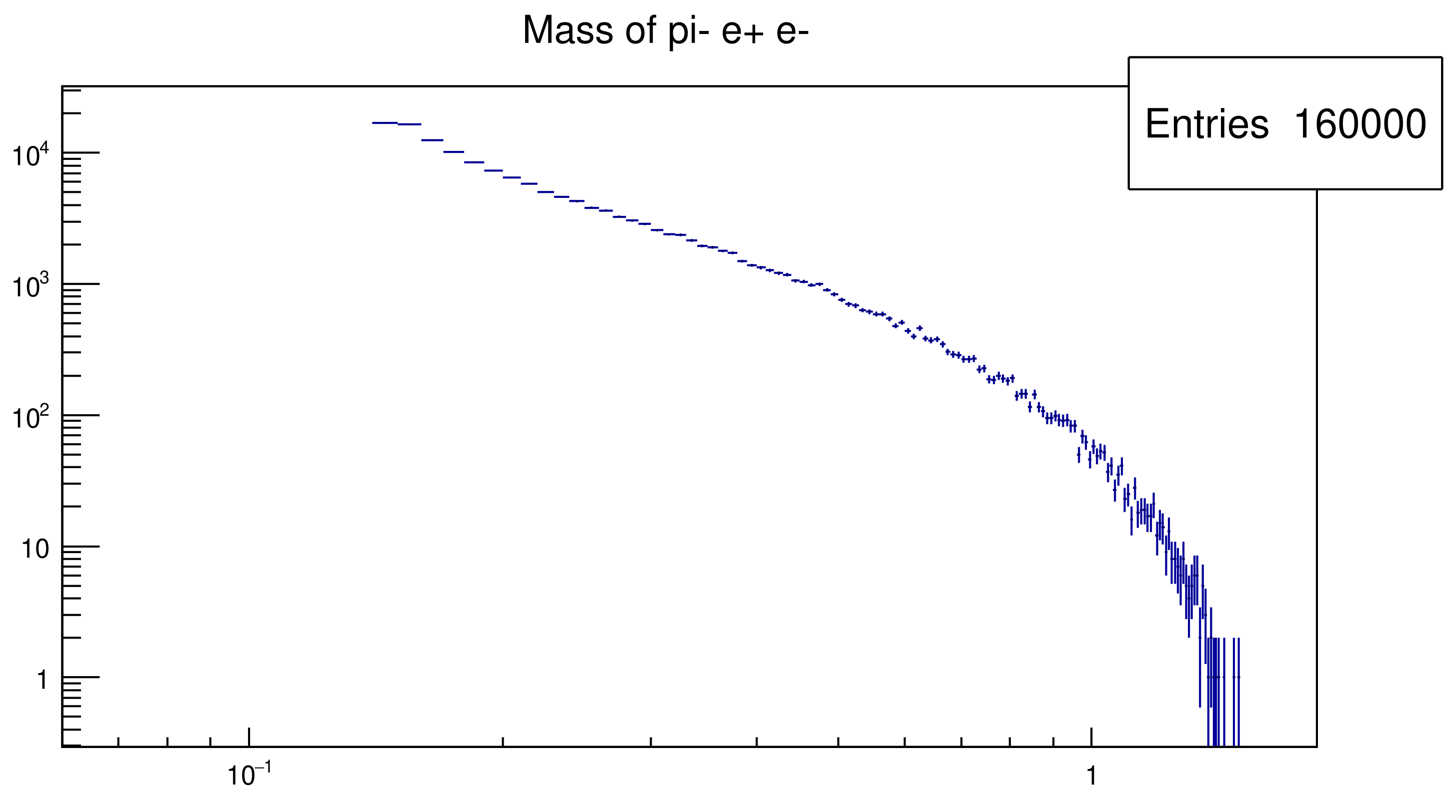


Figure 3: Preliminary results. Invariant mass of the $\pi e^+ e^-$ system in $\tau \to \pi e^+ e^- \nu_\tau$ decay. Matrix elements as for bremstrahlung from 10.1103/PhysRevD.88.033007(DOI). MC calculated branching ratio reproduced up to 5%.

. Most of the events are of $e^+ e^-$ pairs soft and/or collinear to π.

Channel	FORTRAN generation time	C++ generation time
$\tau^- \to \pi^-\pi^0\nu_\tau$	78918ms	81354ms (+3%)
$\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$	579100ms	807278ms (+40%)
$\tau^- \to \mu^-\bar{\nu_\mu}\nu_\tau$	153852ms	121132ms

Table 2: Generation efficency of C++ interface for user provided ME.

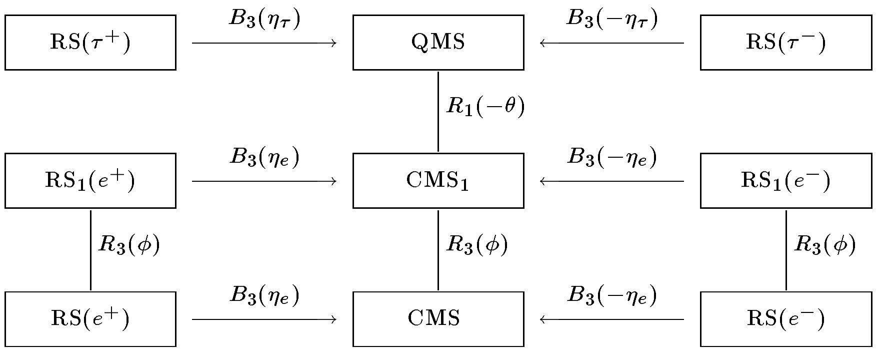
Generation times for selected decay channels as obtained using TAUOLA: (i) FORTRAN only and (ii) with c++ coded ME through user interface. Those times were obtained using laptop with Intel(R) Core(TM) i7-9750H. Generated 10M events samples. Note that for decay into muon FORTRAN program prepares itself for bremstralung.

Some results for high energies

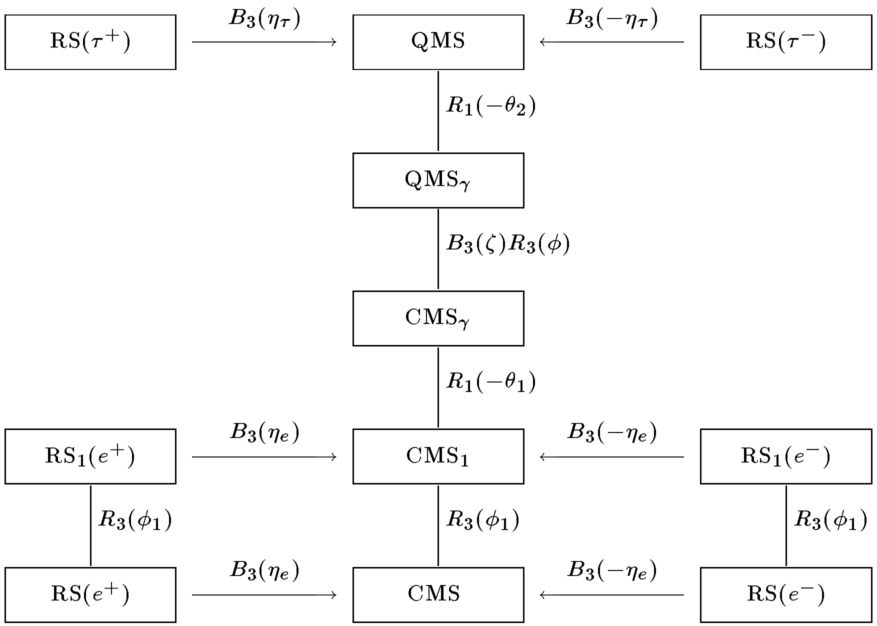
1. **TauSpinner: replace, with the help of weights, properties of hard process: spin effects, hard process, tau decay reconstruction options.**
2. **Main publications:**
   (a) *"TauSpinner: a tool for simulating CP effects in H to tau tau decays at LHC"*, T. Przedzinski, E. Richter-Was and Z. Was,arXiv:1406.1647
   (b) *"Ascertaining the spin for new resonances decaying into tau+ tau- at Hadron Colliders"*, S. Banerjee, J. Kalinowski, W. Kotlarski, T. Przedzinski and Z. Was, Eur. Phys. J. C **73**, 2313 (2013)
   (c) *"TauSpinner Program for Studies on Spin Effect in tau Production at the LHC"*, Z. Czyczula, T. Przedzinski and Z. Was, Eur. Phys. J. C **72**, 1988 (2012)

Tree of frames used for spin; must be tuned between production and decay

Figure 2



(2a)



(2b)

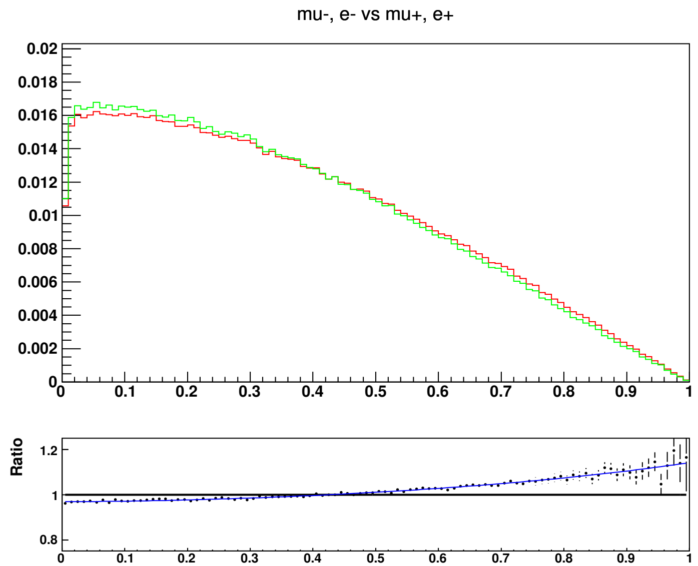
TauSpinner, using wt at LHC

Evaluating size of the spin effect

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

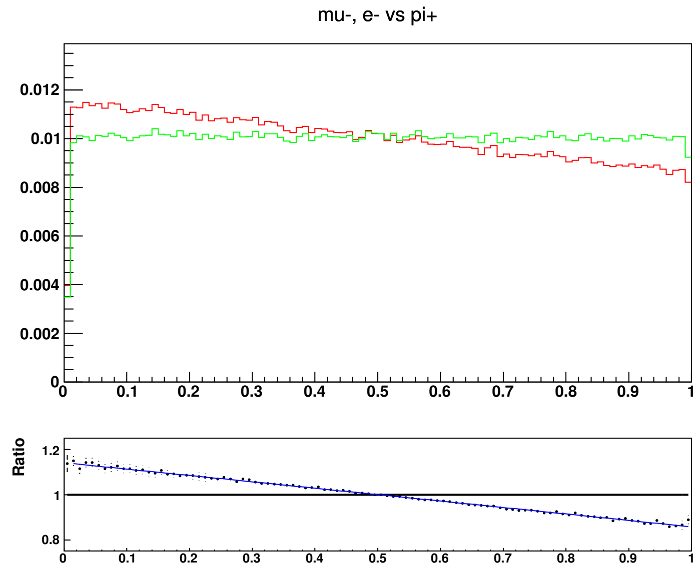
Right: $\tau \rightarrow \pi\nu_\tau$

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, arXiv:1402.2068



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

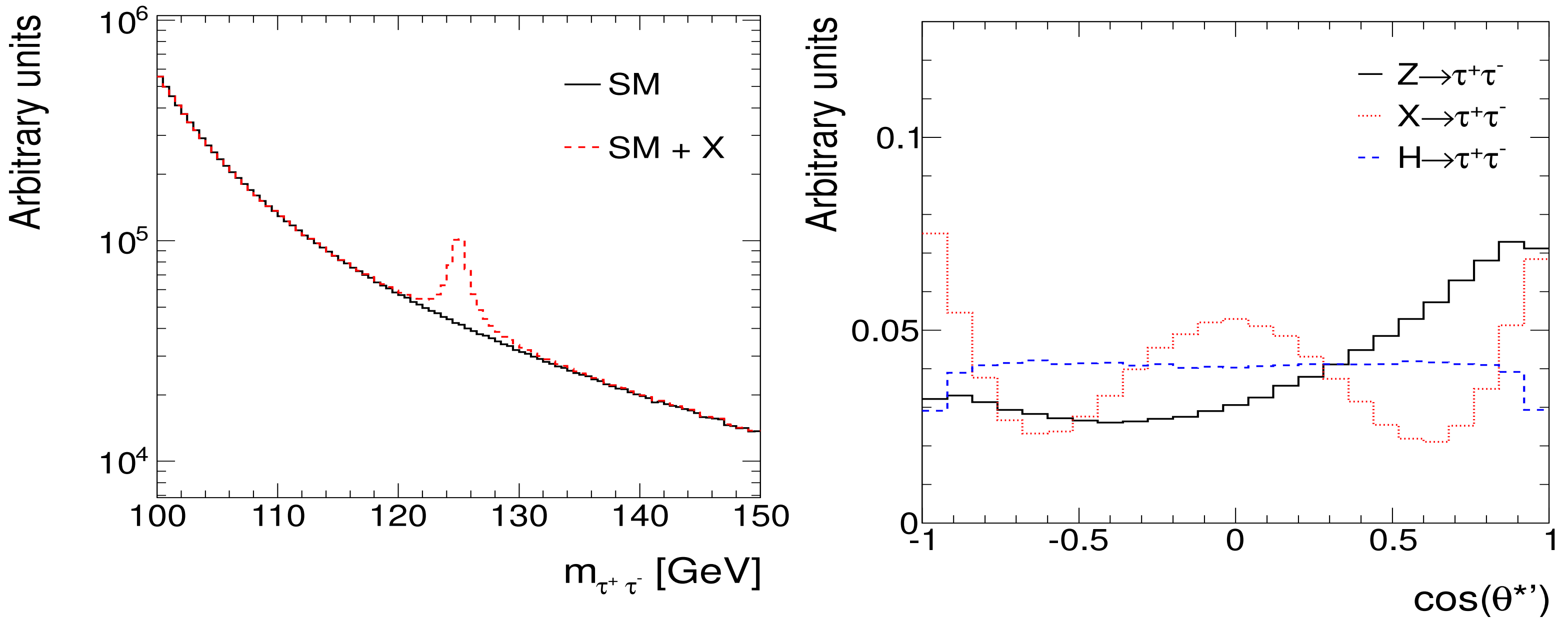
TauSpinner, using $\left(\sum_{spin} |\mathcal{M}^{prod}|^2\right)$ at LHC

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



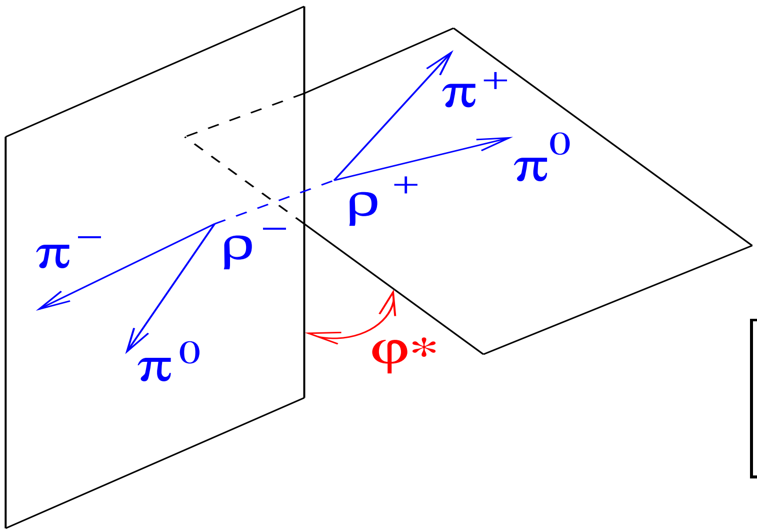
Pure Scalar And Pseudoscalar Higgs Boson

- *Case of* $\tau \to \rho\nu_\tau$ *decay,* $\mathcal{BR}(\tau \to \rho\nu_\tau) = 25\%$
- *In def. of polarimeter vector* h^i q *denotes 4-vectors of* $\pi^\pm$ *minus* π^0 *and,* N *of* ν_τ.

$$h^i = \mathcal{N}\Big(2(q\cdot N)q^i - q^2 N^i\Big)$$

$$q \cdot N = (E_{\pi^\pm} - E_{\pi^0})m_\tau$$

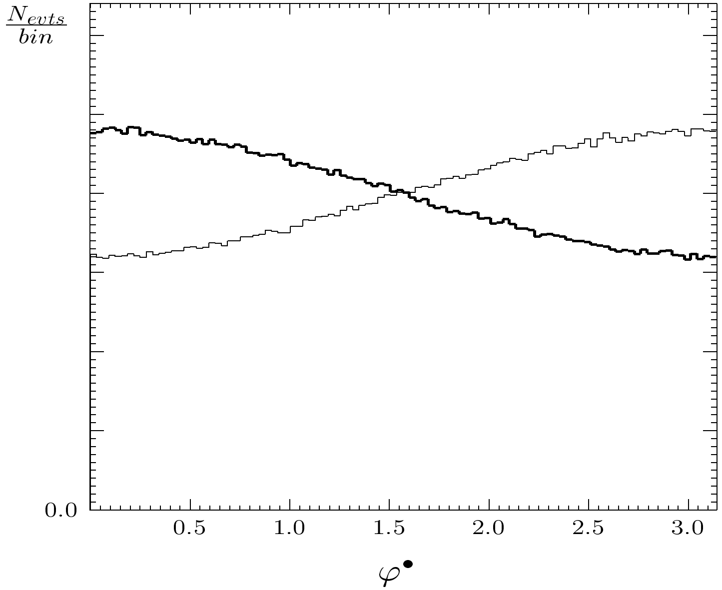
- *Acoplanarity of* ρ^+ *and* ρ^- *decay prod. (in* $\rho^+\rho^-$ *r.f.) and events separation.*

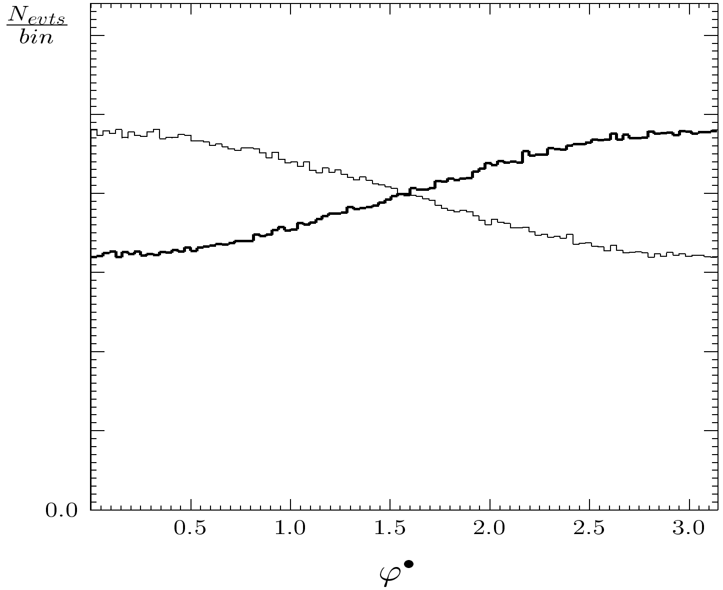


$$y_1 y_2 > 0\,; \qquad y_1 y_2 < 0 \text{ (in } \tau^\pm \text{ r.f.'s)}$$

$$y_1 = \frac{E_{\pi^+} - E_{\pi^0}}{E_{\pi^+} + E_{\pi^0}}\,; \qquad y_2 = \frac{E_{\pi^-} - E_{\pi^0}}{E_{\pi^-} + E_{\pi^0}}.$$

Results With Tesla Detector Effects





- *Gaussian spreads of the 'measured' quantities with respect to the generated.*
- *Resolutions verified with SIMDET. Replacement $\tau^{\pm}$ r.f.'s were used for $y_{1,2}$.*
- *Clearly distinguish the different parity states — 3σ effect (0.5 ab^{-1}).*

$e^+e^- \to ZH \to \mu^+\mu^- H$ | $m_H = 120\ GeV$ | $\sqrt{s} = 500\ GeV$

After many years and for LHC

Phenomenology Of Mixed Parity: also from M.E.

- Higgs boson Yukawa coupling expressed with the help of the scalar–pseudo-scalar mixing angle ϕ

$$\bar{\tau} N (\cos\phi + i \sin\phi \gamma_5) \tau$$

- *Decay probability for the mixed scalar–pseudo-scalar case*

$$\Gamma(h_{mix} \to \tau^+\tau^-) \sim 1 - s_{\parallel}^{\tau^+} s_{\parallel}^{\tau^-} + s_{\perp}^{\tau^+} R(2\phi)\, s_{\perp}^{\tau^-}$$

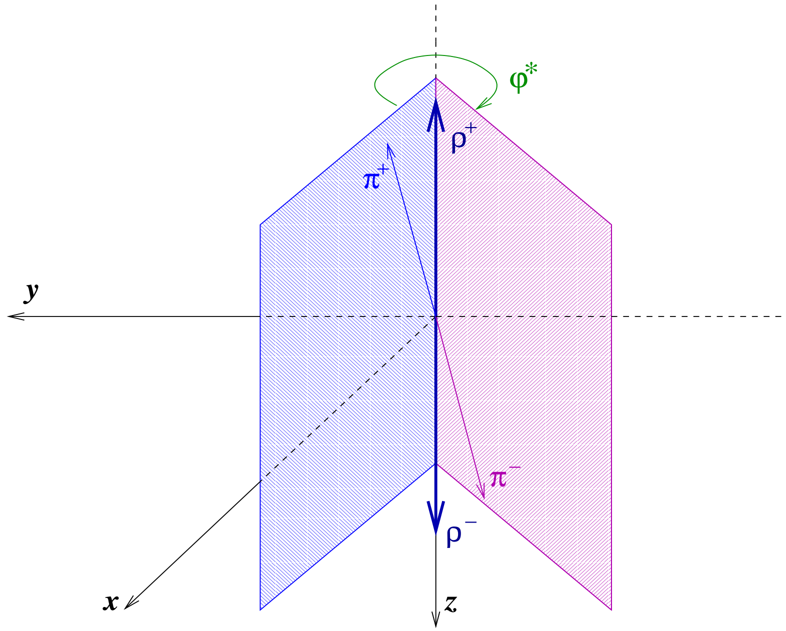
- $R(2\phi)$ − *operator for the rotation by angle* 2ϕ *around the* $\parallel$ *direction.*

$$R_{11} = R_{22} = \cos 2\phi \qquad R_{12} = -R_{21} = \sin 2\phi$$

- *Pure scalar case is reproduced for* $\phi = 0$.
- *For* $\phi = \pi/2$ *we reproduce the pure pseudo-scalar case.*

Optimal Observable Mixed Scalar–Pseudoscalar Case

- *For mixing angle ϕ, transverse component of τ^+ spin polarization vector is correlated with the one of τ^- rotated by angle 2ϕ.*
- *Acoplanarity $0 < \varphi^* < 2\pi$ is of physical interest, not just $\arccos \mathbf{n}_- \cdot \mathbf{n}_+$.*
- *Distinguish between the two cases $0 < \varphi^* < \pi$ and $2\pi - \varphi^*$*
- *If no separation made the parity effect would wash itself out.*



Normal to planes: $\mathbf{n}_\pm = \mathbf{p}_{\pi^\pm} \times \mathbf{p}_{\pi^0}$

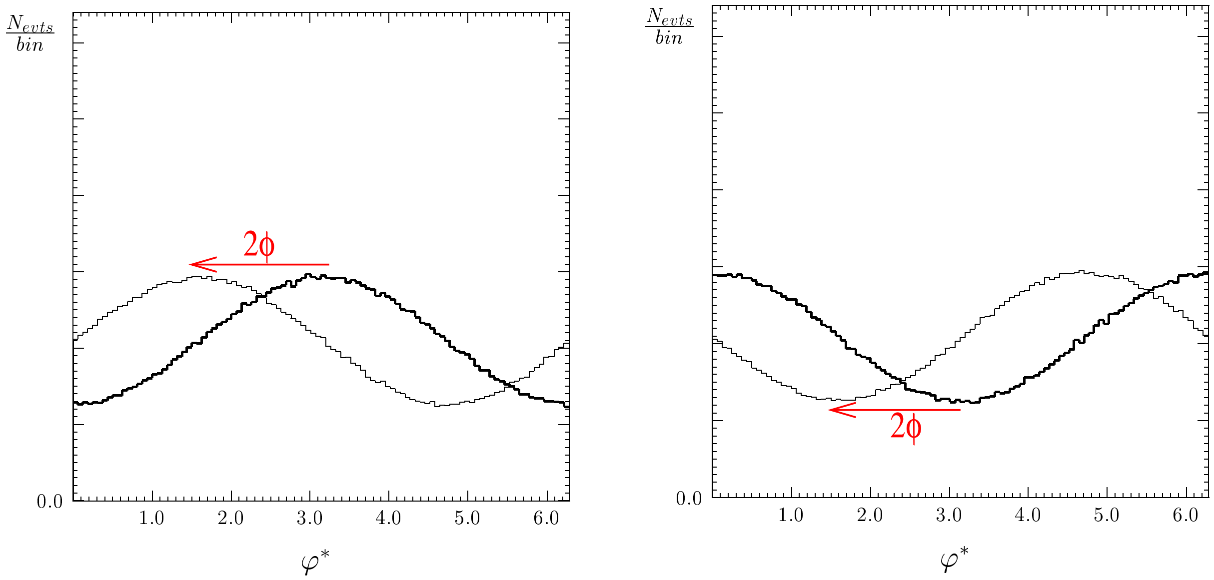
Find the sign of $\mathbf{p}_{\pi^-} \cdot \mathbf{n}_+$

Negative $0 < \varphi^* < \pi$

Otherwise $2\pi - \varphi^*$

From visible products in $H \to \tau^+\tau^- \to \pi^+\pi^0 \;\; \pi^-\pi^0$

Old attempts, at the end 1-dim plot 'easy' to understand

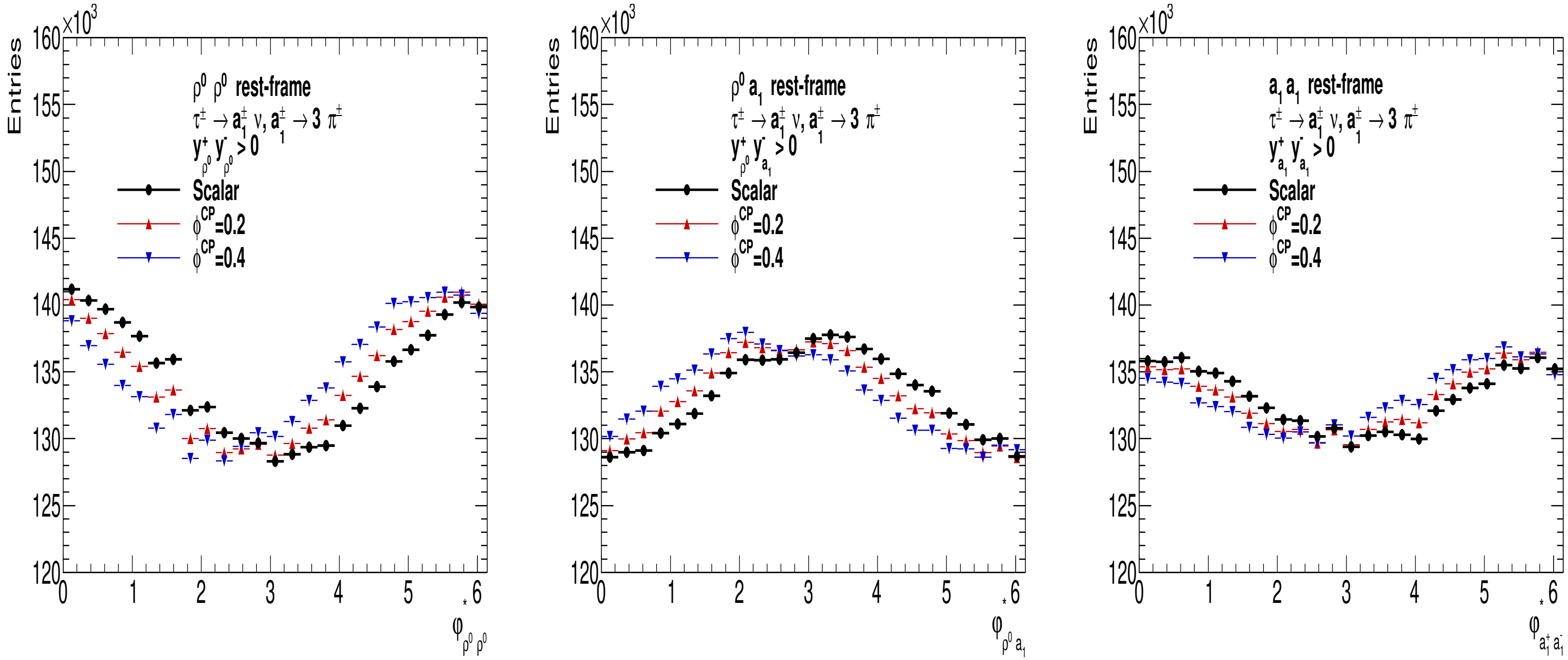


- *Only events where the signs of y1 and y2 are the same whether calculated using the method without or with the help of the τ impact parameter.*
- *Tesla-like set-up SIMDET used,* *K. Desch, A. Imhof, ZW,, M. Worek, Phys.Lett. B579 (2004) 157.*
- *The thick line corresponds to a scalar Higgs boson, the thin line to a mixed one.*

Precision on $\phi \sim 6^\circ$, for $1ab^{-1}$ and 350 GeV CMS.

LHC is real, enrich small samples with $\tau \to 3\pi\nu$

Acoplanarity angles of oriented half decay planes: $\varphi^*_{\rho^0\rho^0}$ (left), $\varphi^*_{a_1\rho^0}$ (middle) and $\varphi^*_{a_1 a_1}$ (right), for events grouped by the sign of $y^+_{\rho^0} y^-_{\rho^0}$, $y^+_{a_1} y^-_{\rho^0}$ and $y^+_{a_1} y^-_{a_1}$ respectively. Three CP mixing angles ϕ^{CP} = 0.0 (scalar), 0.2 and 0.4. Note scale, effect on individual plot is so much smaller now. But up to **16 plots like that** have to be measured, correlations understood. Physics model depends on 1 parameter only ϕ^{CP} mixing scalar pseudo-scalar angle, which brings linear shift. I remained frustrated for 15 years, how to digest...



LHC is real, enrich small samples with $\tau \to 3\pi\nu$

Features/variables	$\rho^{\pm} - \rho^{\mp}$ $\rho^{\pm} \to \pi^0 \pi^{\pm}$	$a_1^{\pm} - \rho^{\mp}$ $a_1^{\pm} \to \rho^0 \pi^{\mp}$, $\rho^0 \to \pi^+ \pi^-$ $\rho^{\mp} \to \pi^0 \pi^{\mp}$	$a_1^{\pm} - a_1^{\mp}$ $a_1^{\pm} \to \rho^0 \pi^{\pm}$, $\rho^0 \to \pi^+ \pi^-$
True classification	0.782	0.782	0.782
$\varphi^*_{i,k}$	0.500	0.500	0.500
$\varphi^*_{i,k}$ and y_i, y_k	0.624	0.569	0.536
4-vectors	0.638	0.590	0.557
$\varphi^*_{i,k}$, 4-vectors	0.638	0.594	0.573
$\varphi^*_{i,k}$, y_i, y_k and m_i^2, m_k^2	0.626	0.578	0.548
$\varphi^*_{i,k}$, y_i, y_k, m_i^2, m_k^2 and 4-vectors	0.639	0.596	0.573

Table 3: Average probability p_i that a model predicts correctly event x_i to be of a type A (scalar), with training being performed for separation between type A and B (pseudo-scalar).

$\varphi^*_{i,k}$ and y_i: expert variables In rest frame of all visible, aligned along z. Essential for measure of event distance.

With detector smearing: Phys.Rev. D96 (2017) 073002

Features				Ideal ± (stat)	Smeared ± (stat) ± (syst)
ϕ^*	4-vec	y_i	m_i		
				$a_1 - \rho$ Decays	
✓	✓	✓	✓	0.6035 ± 0.0005	$0.5923 \pm 0.0005 \pm 0.0002$
✓	✓	✓	-	0.5965 ± 0.0005	$0.5889 \pm 0.0005 \pm 0.0002$
✓	✓	-	✓	0.6037 ± 0.0005	$0.5933 \pm 0.0005 \pm 0.0003$
-	✓	-	-	0.5971 ± 0.0005	$0.5892 \pm 0.0005 \pm 0.0002$
✓	✓	-	-	0.5971 ± 0.0005	$0.5893 \pm 0.0005 \pm 0.0002$
✓	-	✓	✓	0.5927 ± 0.0005	$0.5847 \pm 0.0005 \pm 0.0002$
✓	-	✓	-	0.5819 ± 0.0005	$0.5746 \pm 0.0005 \pm 0.0002$
				$a_1 - a_1$ Decays	
✓	✓	✓	✓	0.5669 ± 0.0004	$0.5657 \pm 0.0004 \pm 0.0001$
✓	✓	✓	-	0.5596 ± 0.0004	$0.5599 \pm 0.0004 \pm 0.0001$
✓	✓	-	✓	0.5677 ± 0.0004	$0.5661 \pm 0.0004 \pm 0.0001$
-	✓	-	-	0.5654 ± 0.0004	$0.5641 \pm 0.0004 \pm 0.0001$
✓	✓	-	-	0.5623 ± 0.0004	$0.5615 \pm 0.0004 \pm 0.0001$
✓	-	✓	✓	0.5469 ± 0.0004	$0.5466 \pm 0.0004 \pm 0.0001$
✓	-	✓	-	0.5369 ± 0.0004	$0.5374 \pm 0.0004 \pm 0.0001$

Table 4: AUC for NN to separate scalar and pseudo-scalar hypotheses. Inputs with a ✓used. Results in column “Ideal" - from NNs trained/used with particle-level simulation, in column “Smeared" - from NNs trained/used with smearing. NN trained on smeared samples, for used on exact samples give similar results as “Ideal".

Summary

- How should we proceed to get most from experimental data
- (i) Experimental systematic errors (ii) Theoretical systematic errors
- What are the constraints on organization of Monte Carlo and fitting environments?
- I have prepared version of TAUOLA based on our recent experience.
- Flexibility for re-definition of dynamic of tau decays and initialization inspired by work of BaBar/Belle collaborations. I delegate details to private discussions.
- We have collected some experience on requirements for building fitting environments.
- Context of systematic errors, in case of fits to multi-dimensional representation of data, is a challenge.
- Question of manpower and training as well as motivation of involved people.
- τ **leptons for high and medium energy physics.**
- **Do not forget that narrow width approximation availability in MC is useful for: (i) tests (ii) model development and tuning (iii) observable construction interpretation.**