TAU PAIR PHYSICS

Bergen Particle Physics Seminar Oct 14 2009

(A deeper look at review posters)

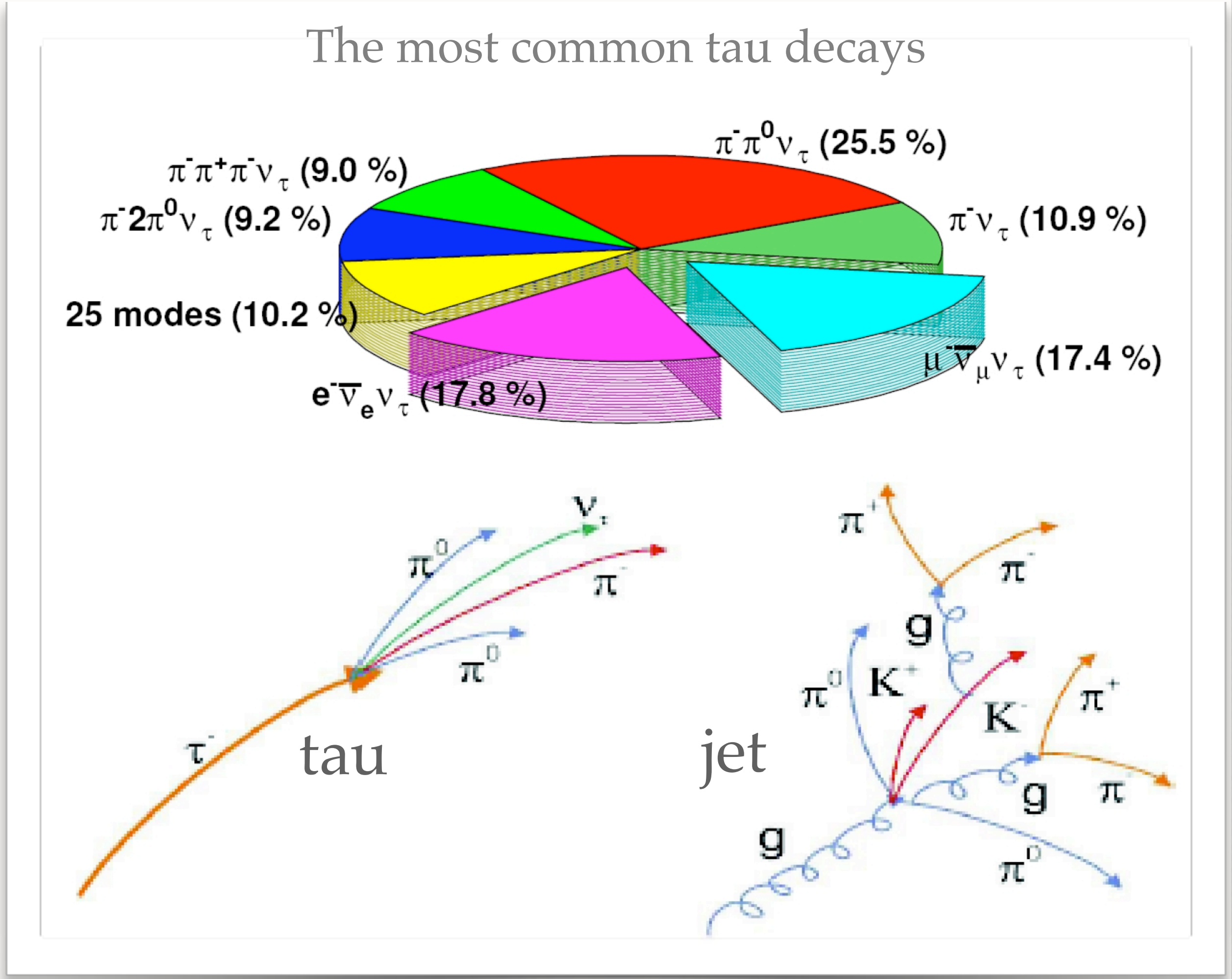
Thomas Burgess, Alette Aasvold,
Ørjan Svandal, Therese Sjursen

Also talking for:
Peter Rosendahl, Arshak Tonoyan, Alex Kastanas, Anna Lipniacka, Bjarne Stugu

THE TAU LEPTON & TAU PAIRS

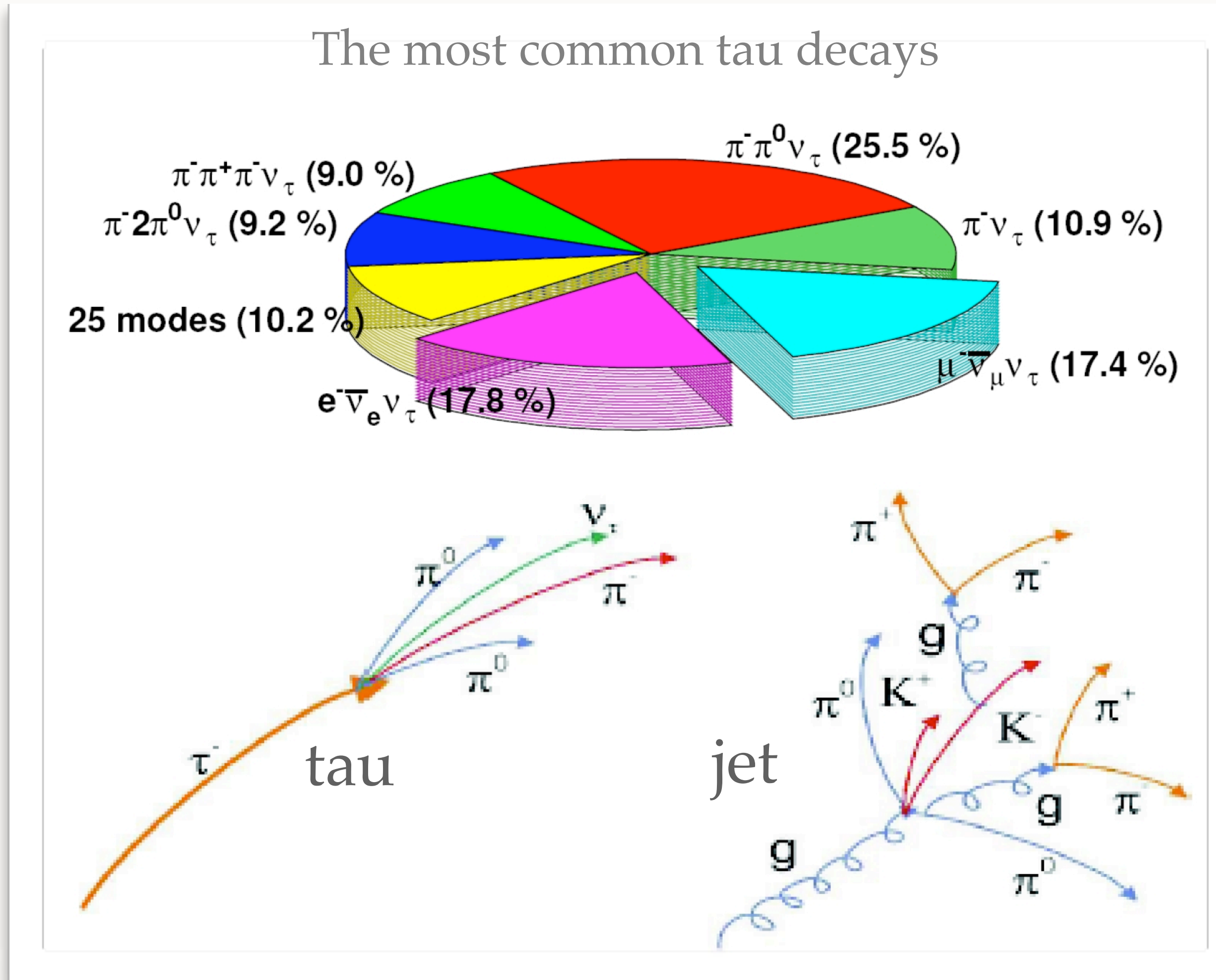
TAU LEPTONS

- Taus are the heaviest known leptons and decay rapidly (M_τ=1.7 GeV, $c\tau$=87 μm)
- Taus decay to hadrons in **~60%** of cases and to leptons in **~35%** of cases (remaining mostly Kaons)
- Most hadronic tau decays either has **1** or **3** charged meson tracks (prongs) (76% & 24% of cases respectively)



TAU LEPTONS

- Identification and reconstruction of taus is possible in hadronic decays
- Hadronic tau jets are more collimated than normal jets
- The leading prong reproduces the original tau direction well
- Missing energy through neutrino production limits the obtainable accuracy of the reconstruction



TAU PAIRS

- We mainly focus on the following tau signals
  - Tau pairs are well known from Standard Model $Z^0 \rightarrow \tau\tau$ decays. An understanding of these in data is essential to measure beyond SM $\tau\tau$
  - In low mass SM Higgs boson scenarios (M_H<120 GeV) $\tau\tau$ is a very important decay mode
  - In certain SUper SYmmetric models $\tau\tau$ modes are very important
- Important backgrounds include
  - QCD jets (~1% are miss-identified as taus) and $t\bar{t}$ decays (in SUSY)

TAU PAIR SYSTEM ANALYSIS

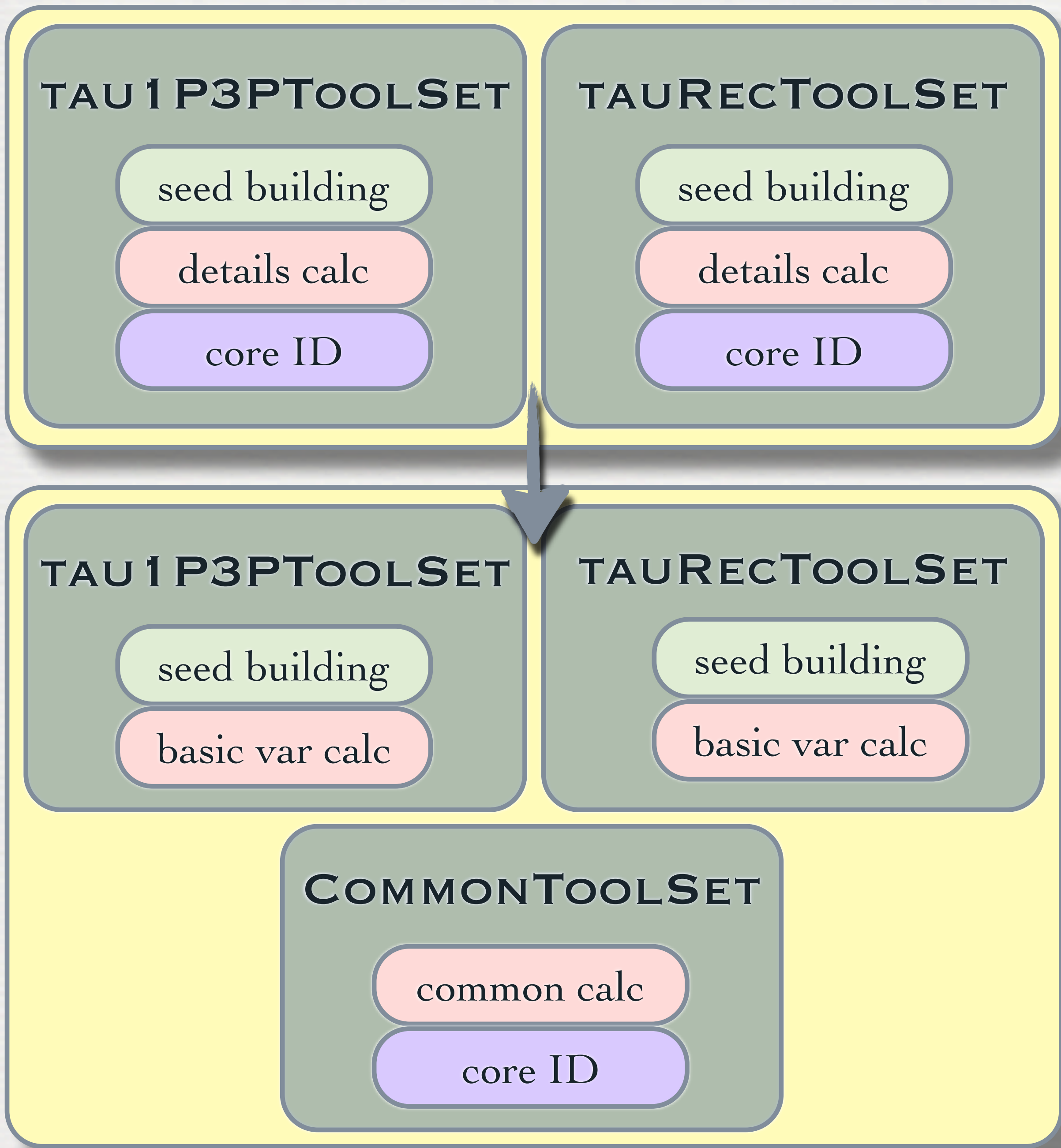
- Acquire expertise on the tau reconstruction software by actively developing the code (Thomas Burgess)
- Exploiting symmetry of τ and μ to understand SM backgrounds (Arshak Tonoyan)
- Optimizing tau candidate selection using tools recently developed by the ATLAS tauWG, starting by analyzing Z^0 signal (Ørjan Svandal)
- Create a tool set to study correlations between energies and variables in the final states of the two taus (Peter Rosendahl)
- Studying invariant mass distributions from the reconstructed tau pair system including corrections from missing energy due to neutrino production (Alette Aasvold)
- Study certain SUSY scenarios with high tau production (Therese Sjursen & Alex Kastanas)

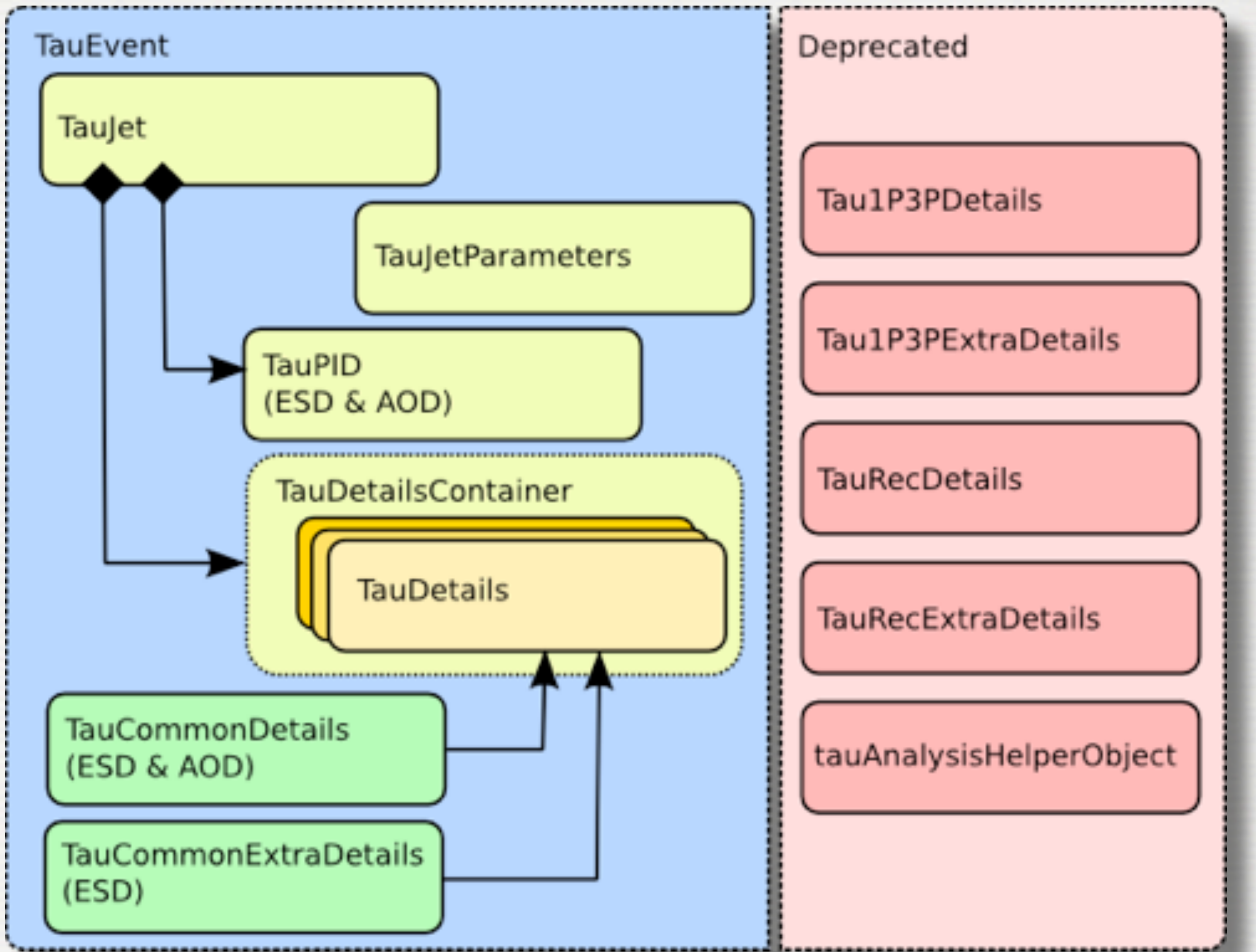
RECONSTRUCTION OF HADRONIC TAU JETS

RECONSTRUCTING HADRONIC TAU JETS

- **Tracking and calorimeter seeded reconstruction**
  - Use high quality track as seed ($p_T > 6$ GeV)
  - Use candidates with 1-8 quality tracks ($p_T > 1$ GeV) within $\Delta R < 0.2$
  - Reconstruct η, ϕ using p_T-weighting of tracks
  - Check charge consistency
  - Find matching cone4 jets ($E_T > 10$ GeV, $\Delta R < 0.2$) as calorimeter seed
  - E_T using cells from calorimeter seed
  - Energy flow algorithm
  - Reconstruct π^0 sub-clusters
- **Calorimeter only seeded reconstruction**
  - Use remaining clusters as seed
  - Define η, ϕ of τ candidate from cluster
  - Looser track quality selection ($p_T > 1$ GeV)
- **Tracking only seeded reconstruction**
  - Very rare events (a few %)

TAUREC MERGING





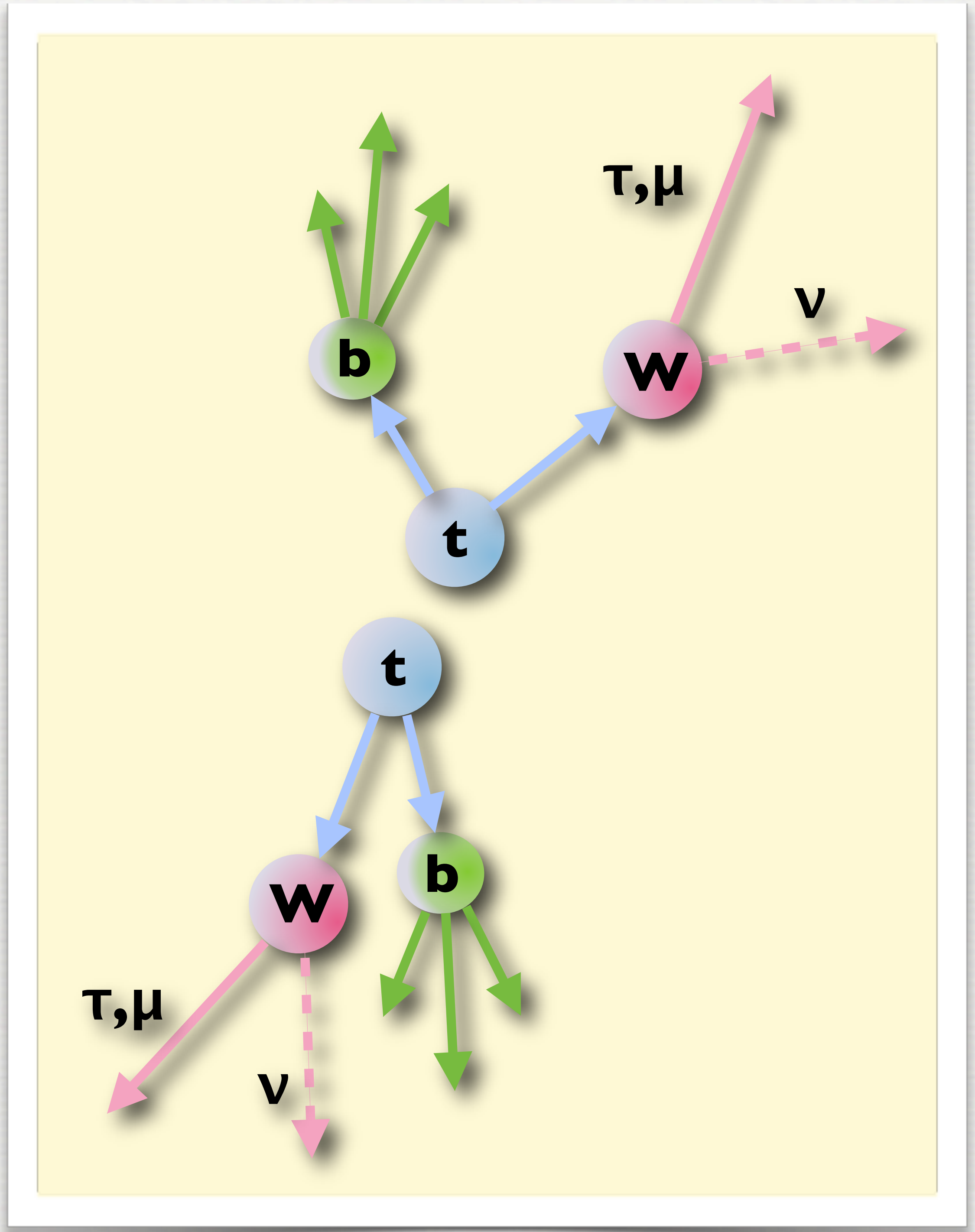
The two independent tau reconstruction codes has been merged both in the event data model (rel 15) and the algorithm implementation (rel 15.+)

MUON AND TAU LEPTON SWITCHING

for
Arshak Tonoyan

ARSHAK TONOYAN - TAU↔MUON SWITCHING

- At sufficient energy Standard Model processes are symmetric in leptons
- Muon measurements can be used as a control to tau measurements
- An anomalous rate of tau leptons may indicate physics beyond SM
- By switching muons and taus around in known data one can gain a better understanding of SM taus
- Prospects of such swapping methods to use for modeling backgrounds in our ongoing SUSY search are investigated



TAU IDENTIFICATION USING SAFE VARIABLES

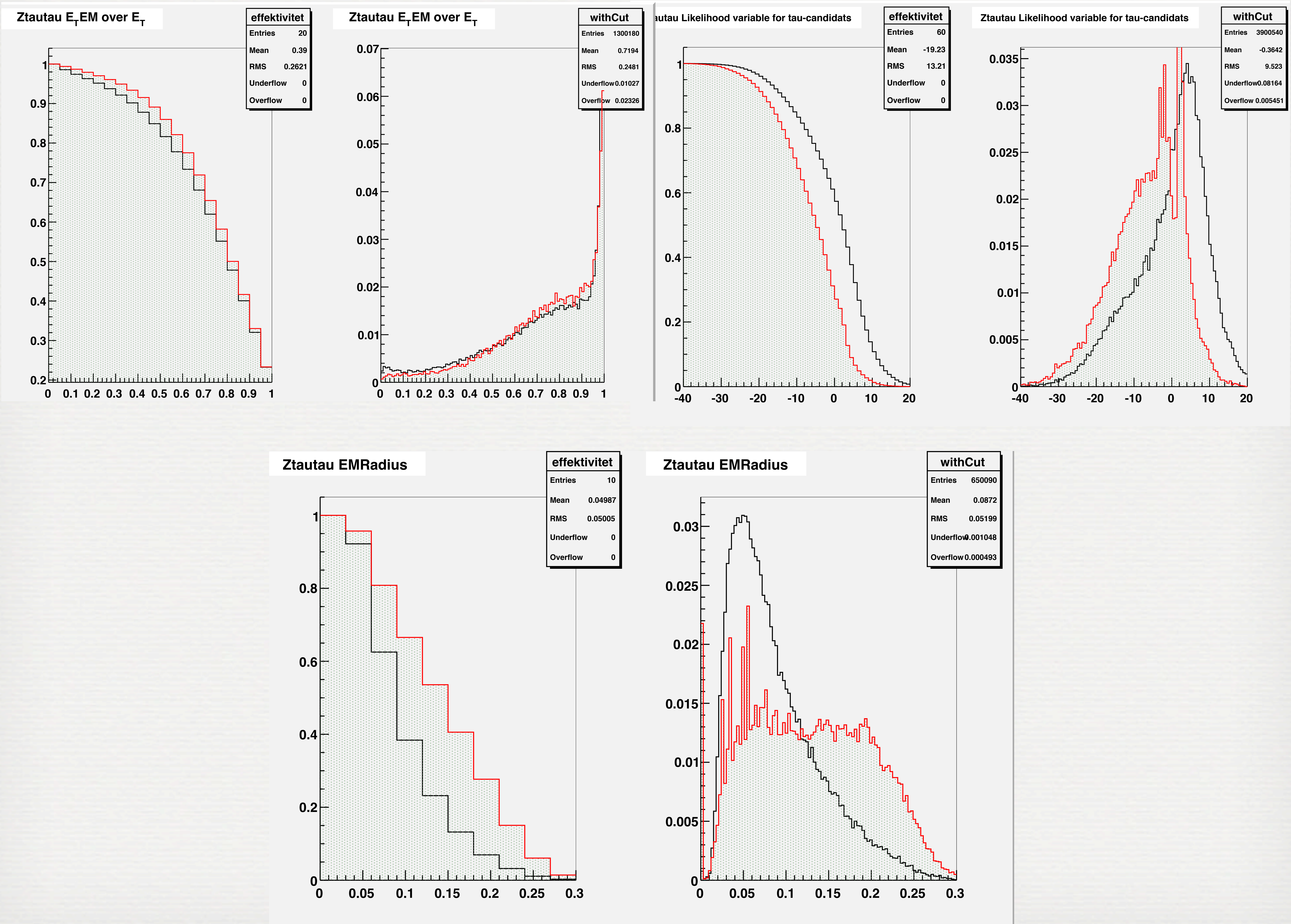
Ørjan Svandal

TAU IDENTIFICATION USING SAFE VARIABLES

- Taus are produced in many Standard Model processes
- Furthermore taus are expected in many beyond SM scenarios
- Safe variables
  - Small correlation and well understood even at the early stages of ATLAS data taking
  - 9 safe variables
  - Separate background from signal
  - Cut on safe variable

Ørjan Sva

- Shower Radius in EM calorimeter
- Isolation Fraction
- Width in strip layer
- $\frac{E_T(EM)}{E_T}$
- Width of track momenta
- $\frac{E_T}{P_T}$ (Lead track)
- $\frac{E_T(Had)}{\sum P_T}$
- $\frac{E_T(EM)}{\sum P_T}$
- $\frac{\sum P_T}{E_T}$



Ztautau E_TEM over E_T
effektivitet
Entries 20
Mean 0.39
RMS 0.2621
Underflow 0
Overflow 0
Ztautau E_TEM over E_T
withCut
Entries 1300180
Mean 0.7194
RMS 0.2481
Underflow 0.01027
Overflow 0.02326
autau Likelihood variable for tau-candidats
effektivitet
Entries 60
Mean -19.23
RMS 13.21
Underflow 0
Overflow 0
Ztautau Likelihood variable for tau-candidats
withCut
Entries 3900540
Mean -0.3642
RMS 9.523
Underflow 0.08164
Overflow 0.005451
Ztautau EMRadius
effektivitet
Entries 10
Mean 0.04987
RMS 0.05005
Underflow 0
Overflow 0
Ztautau EMRadius
withCut
Entries 650090
Mean 0.0872
RMS 0.05199
Underflow 0.001048
Overflow 0.000493

SAFE CUTS

- Cut variables
  - Cut loose(0.7)
  - Cut medium (0.5)
  - Cut tight (0.3)
- Next steps

- Look at cut variables (loose, medium and tight)
- Make cuts on safe variables
- Look at di jet background and $H \rightarrow \tau\tau$

TAU HELICITY CORRELATION STUDIES

for
Peter Rosendahl

WHY STUDY TAU POLARIZATION?

- Generate multipurpose tool for athena to calculate the tau polarization.
- Some of the use cases will be
  - Measuring tau pair polarization correlations
  - Enhance Higgs/Z-boson discrimination
  - Enhance SUSY selection

HOW TO RECONSTRUCT POLARIZATION?

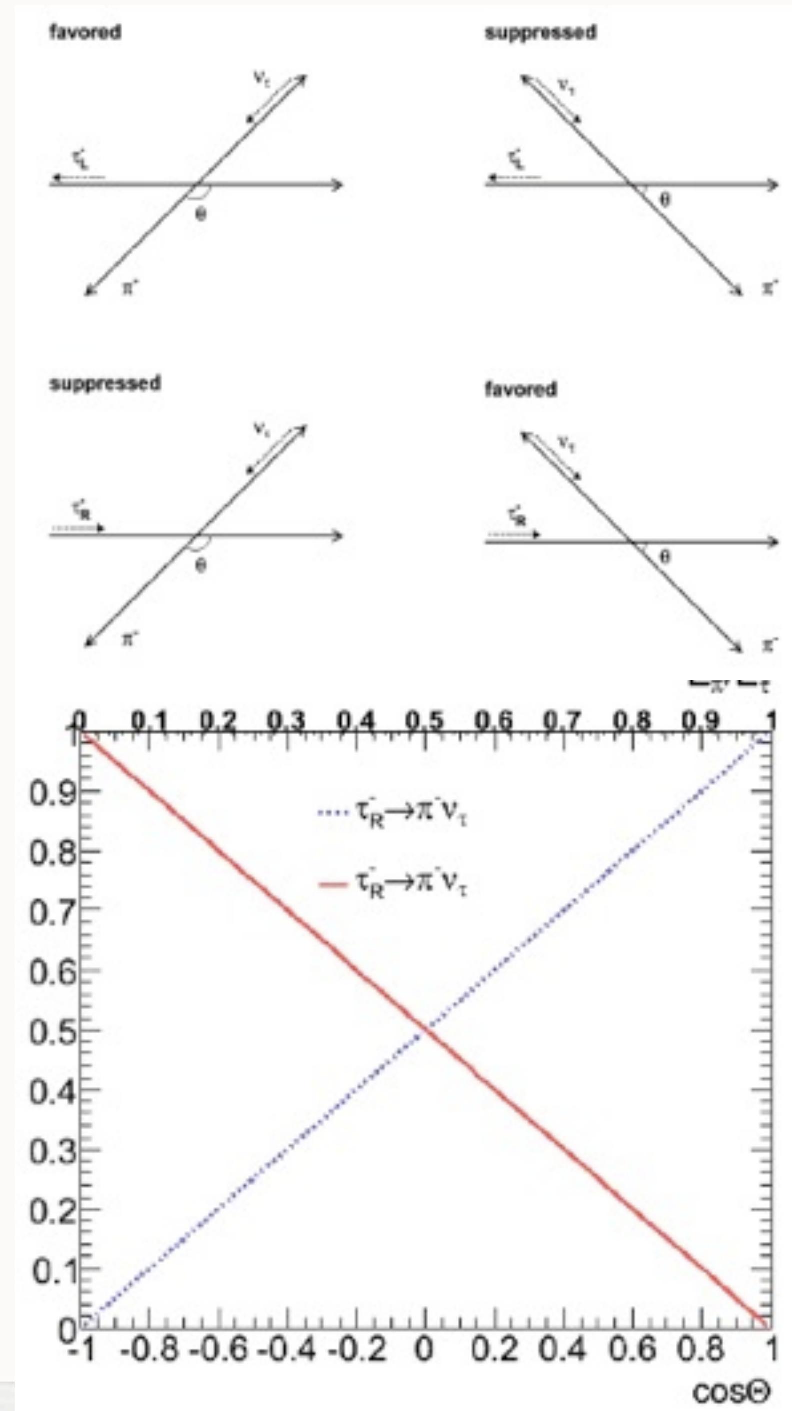
- No truth polarization kept in the event record! Therefore we must first calculate the true polarization in order to be able to verify our reconstructed results.
- Reconstruction of the tau polarization is done be studying the decay angle and energy sharing of the decay products.
- So far I concentrate on the following decay modes:
  - The pion channel: $\tau^- \to \pi^- + \nu_\tau$
  - The rho channel: $\tau^- \to \rho^- + \nu_\tau \to \pi^- + \pi^0 + \nu_\tau$

THE PION CHANNEL

- Polarized taus have a preferred decay direction

- Therefore studying the decay angle θ in the tau rest frame will give us information about the tau polarization

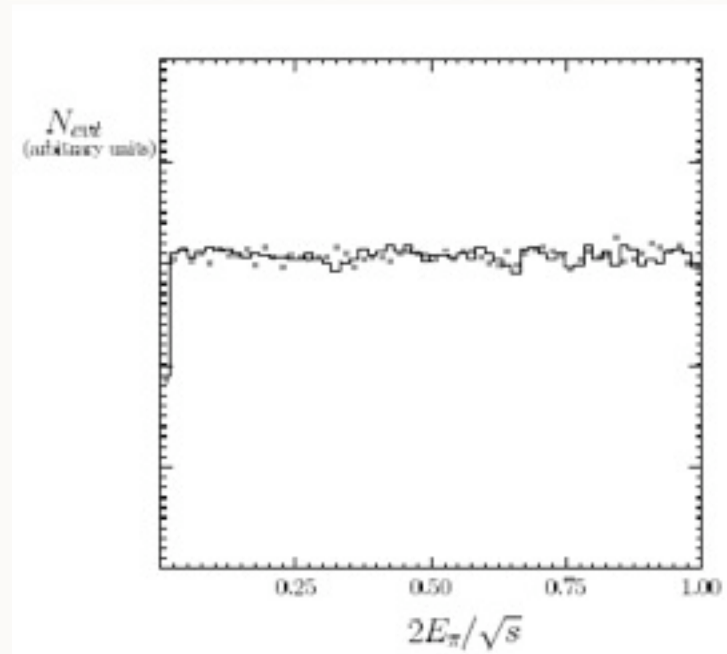
- The decay angle can be expressed following detector frame values: $\theta \simeq x = \frac{E(\pi^-)}{E(\tau^-)}$

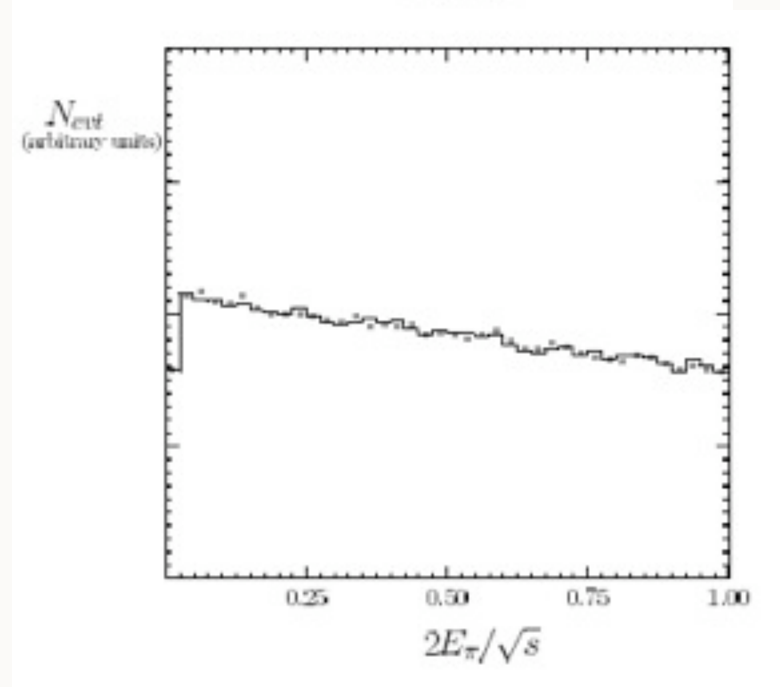


plots taken from talk by Z.Czyczula

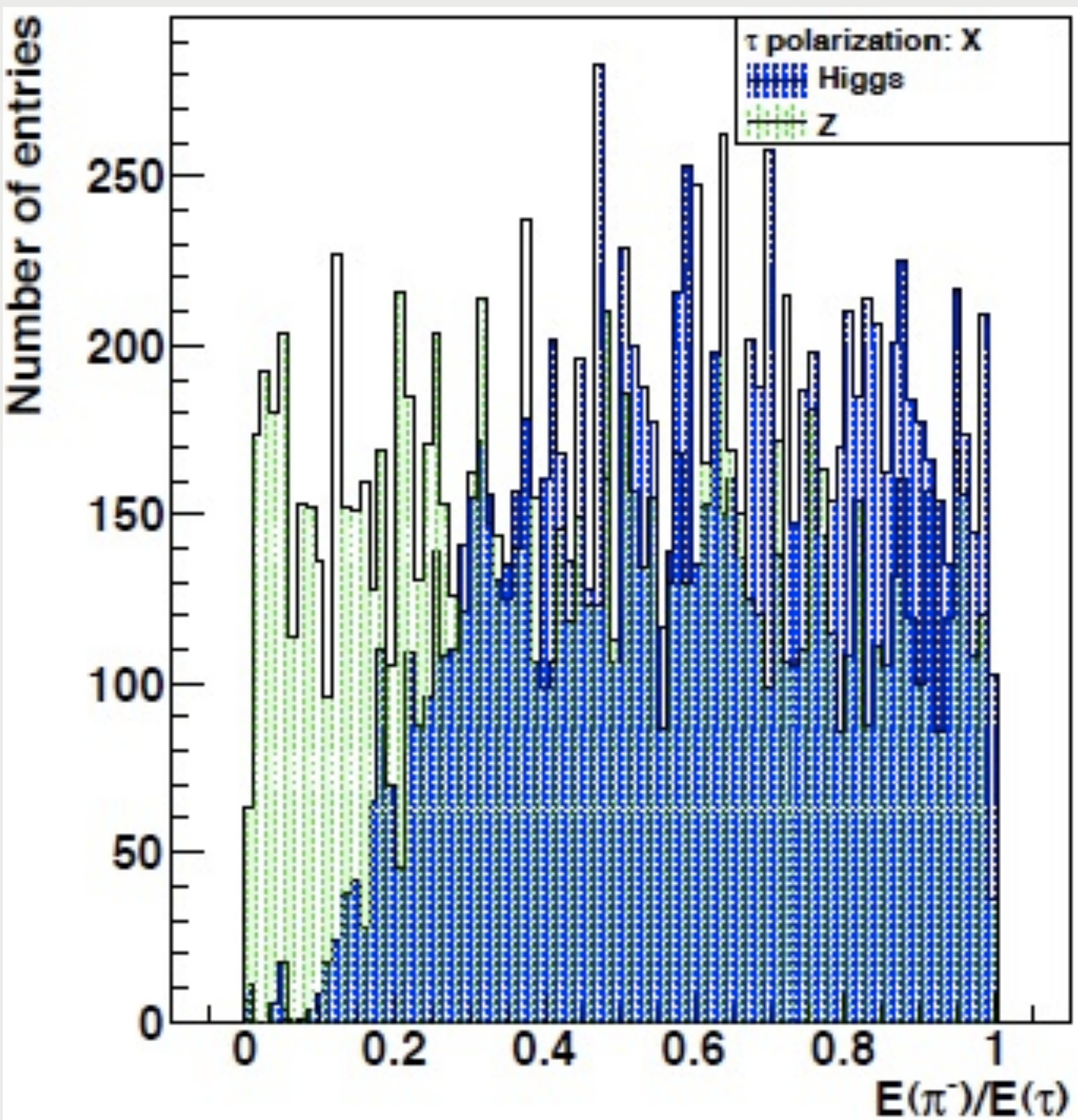
THE PION CHANNEL

- Since the Higgs boson produces a pair of taus with opposite helicity we expect a flat distribution of x when summing over all taus from Higgs bosons
- Since Z bosons produces tau pairs with the same helicity and only are "slightly" polarized, we expect an "almost" flat distribution of x when summing over all taus from Z bosons





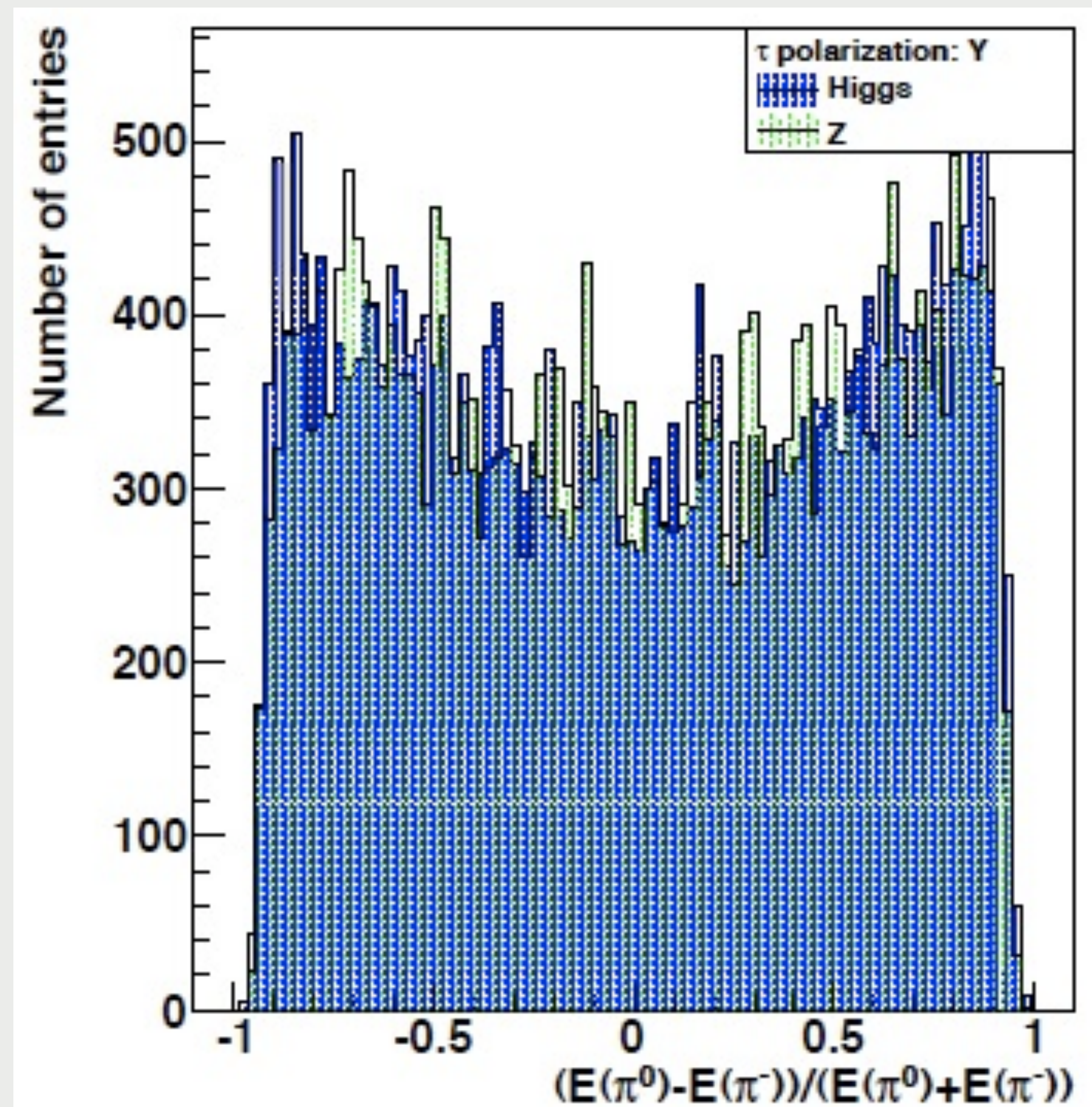
PION CHANNEL



- Initial studies shows
  - The expected distribution from Z bosons
  - But not the expected from Higgs bosons

RHO CHANNEL

- For the rho decay channel we study the angle between the rho and the charged pion
- This angle will reflect the polarization of the rho

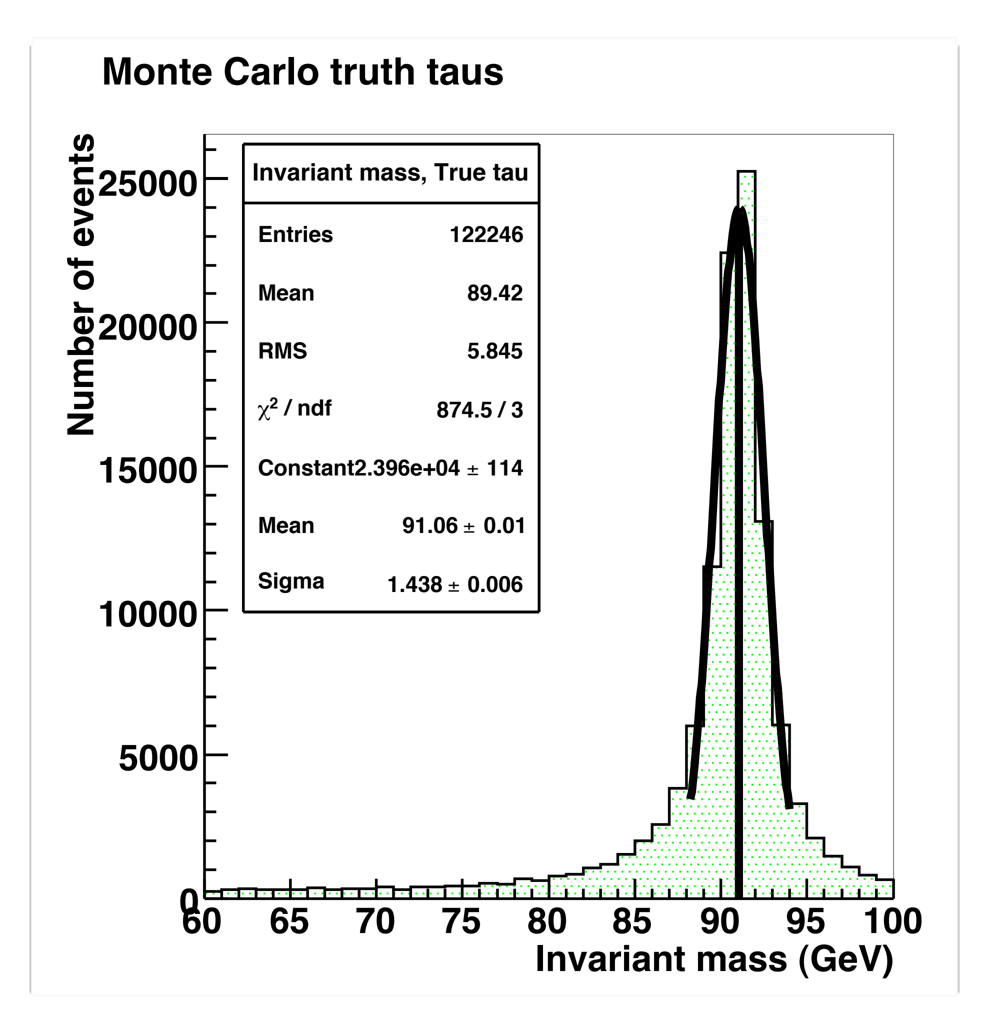


TAU PAIR INVARIANT MASS CORRECTIONS

Alette Aasvold

INVARIANT MASS

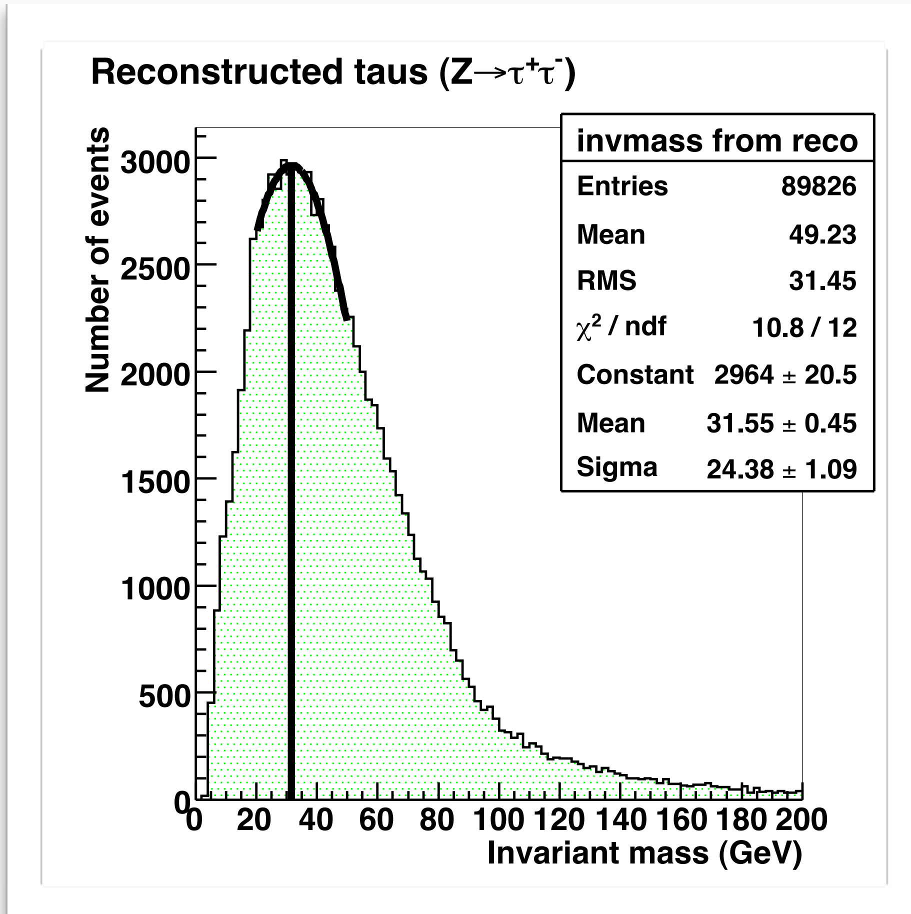
- If a particle Z^0 is decaying into two particles τ^- and τ^+, the invariant mass of Z^0 can be reconstructed from the measured momenta of τ^- and τ^+
- The invariant mass can be calculate with the equation below
- The histogram shows the Monte Carlo simulated truth information



$$m_Z = 2(m_\tau)^2 + 2\sqrt{(m_\tau^2 + \vec{p}_{\tau+}^{\,2})(m_\tau^2 + \vec{p}_{\tau-}^{\,2})} - 2\vec{p}_{\tau+} \cdot \vec{p}_{\tau-}$$

Peak at 91 GeV!

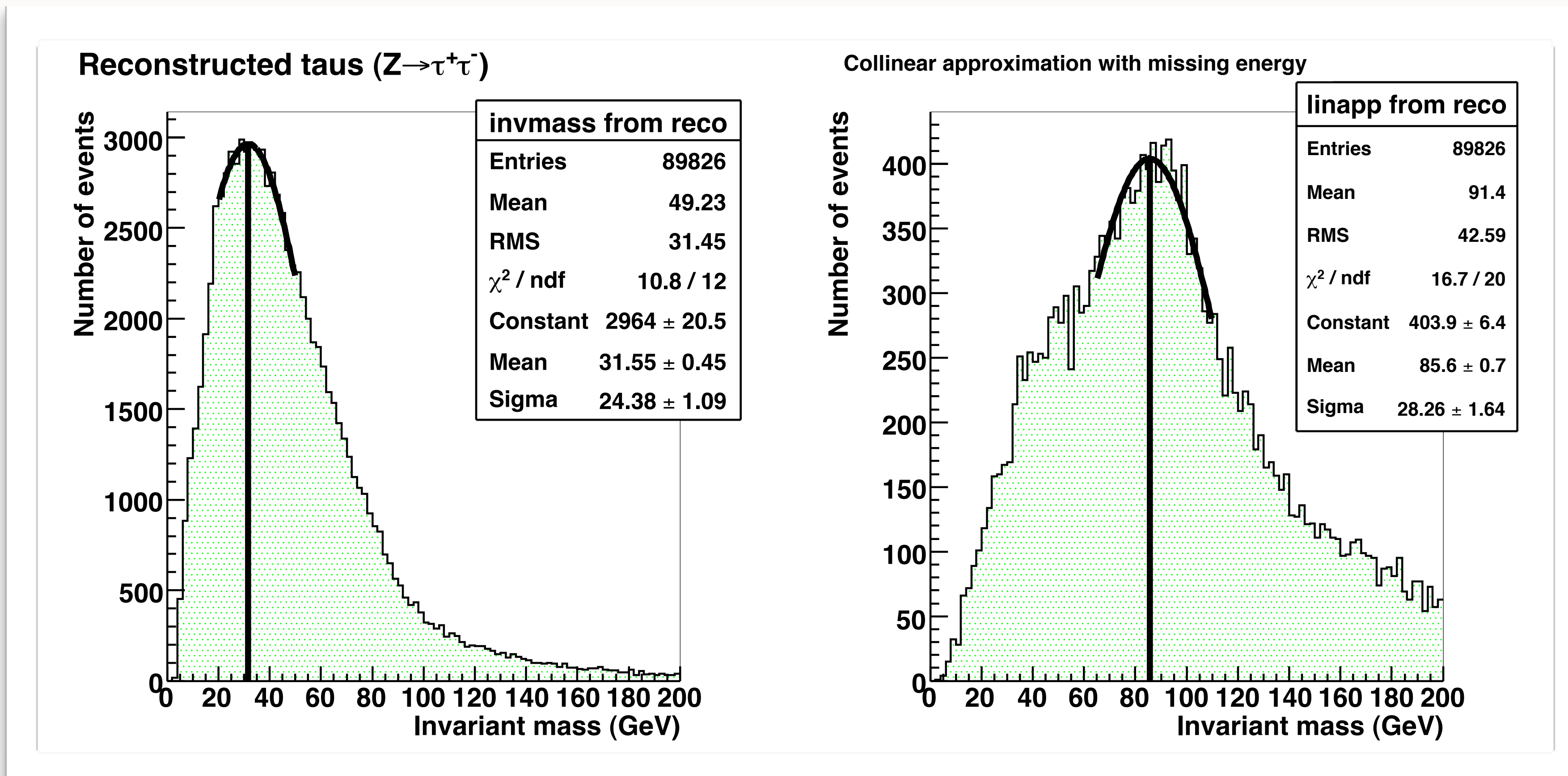
NEUTRINO ENERGY LOSS

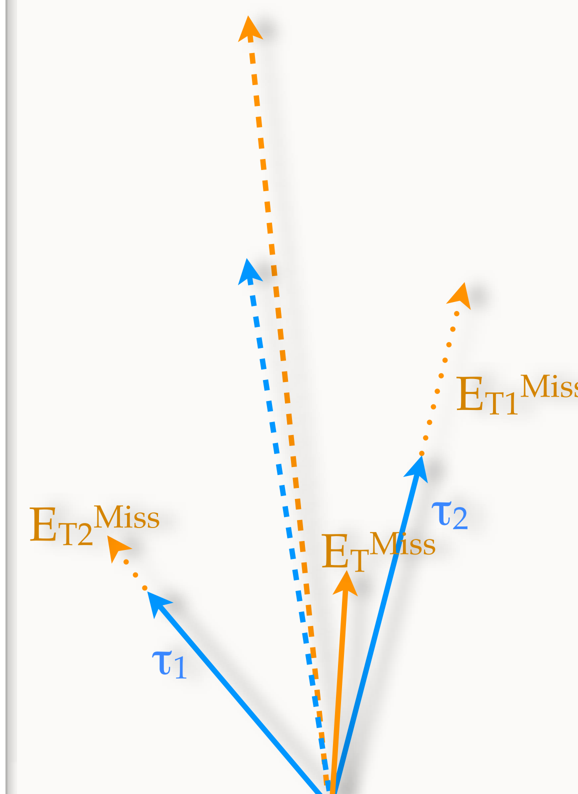


Peak at 32 GeV!

- The taus are decaying so fast that we cant reconstruct their tracks
- Instead we reconstruct the taus from the tau decay products, and from the reconstructed tau pair we calculate M_Z
- However we do not have all the energy as neutrinos escapes with some of it
- Because of this the resulting observed M_Z is lower than expected

COLLINEAR APPROXIMATION





Peak at 87 GeV!

- By assuming the missing energy is from only neutrinos and that the neutrinos are collinear with the taus the invariant mass can be corrected

MEASURING SUSY WITH TAUS IN ATLAS

Therese Sjursen

SU1-point in the Coannihilation region

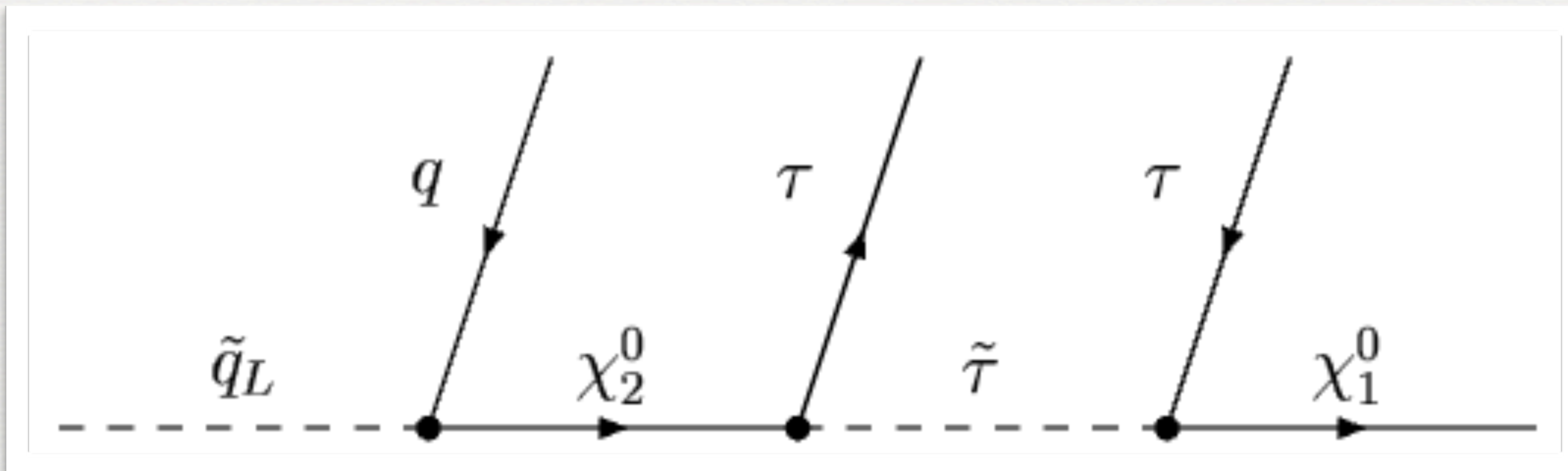
$$\tilde{q}_L \to q\tilde{\chi}_2^0 \to q\tau\tilde{\tau} \to q\tau^{\pm}\tau^{\mp}\tilde{\chi}_1^0 \quad , \tag{1}$$

Parameters	Values	Particle	Mass [GeV]
m_0	70 GeV	$\tilde{\chi}_2^0$	262.0
$m_{1/2}$	350 GeV	$\tilde{\chi}_1^0$	136.7
A_0	0 GeV	$\tilde{\tau}_1$	147.7
$\tan(\beta)$	10	$\tilde{\tau}_2$	253.2
sgn μ	$+$	$\tilde{u}_L, \tilde{d}_L$	$\sim$ 765.0

Table: mSUGRA parameters of SU1 together with some sparticle masses at the EW scale.

Maximum value of invariant mass distributions

$$
\begin{aligned}
(m_{\tau\tau}^{max})^2 &= \frac{(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\tau}}^2) \cdot (m_{\tilde{\tau}}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{\tau}}^2} \\
(m_{q\tau\tau}^{max})^2 &= \frac{(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2) \cdot (m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{\chi}_2^0}^2} \\
(m_{q\tau_{near}}^{max})^2 &= \frac{(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2) \cdot (m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\tau}_1}^2)}{m_{\tilde{\chi}_2^0}^2} \\
(m_{q\tau_{far}}^{max})^2 &= \frac{(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2) \cdot (m_{\tilde{\tau}_1}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{\chi}_1^0}^2}
\end{aligned}
\qquad (2)
$$


q
τ
τ
$\tilde{q}_L$
χ_2^0
$\tilde{\tau}$
χ_1^0

And what do we measure?

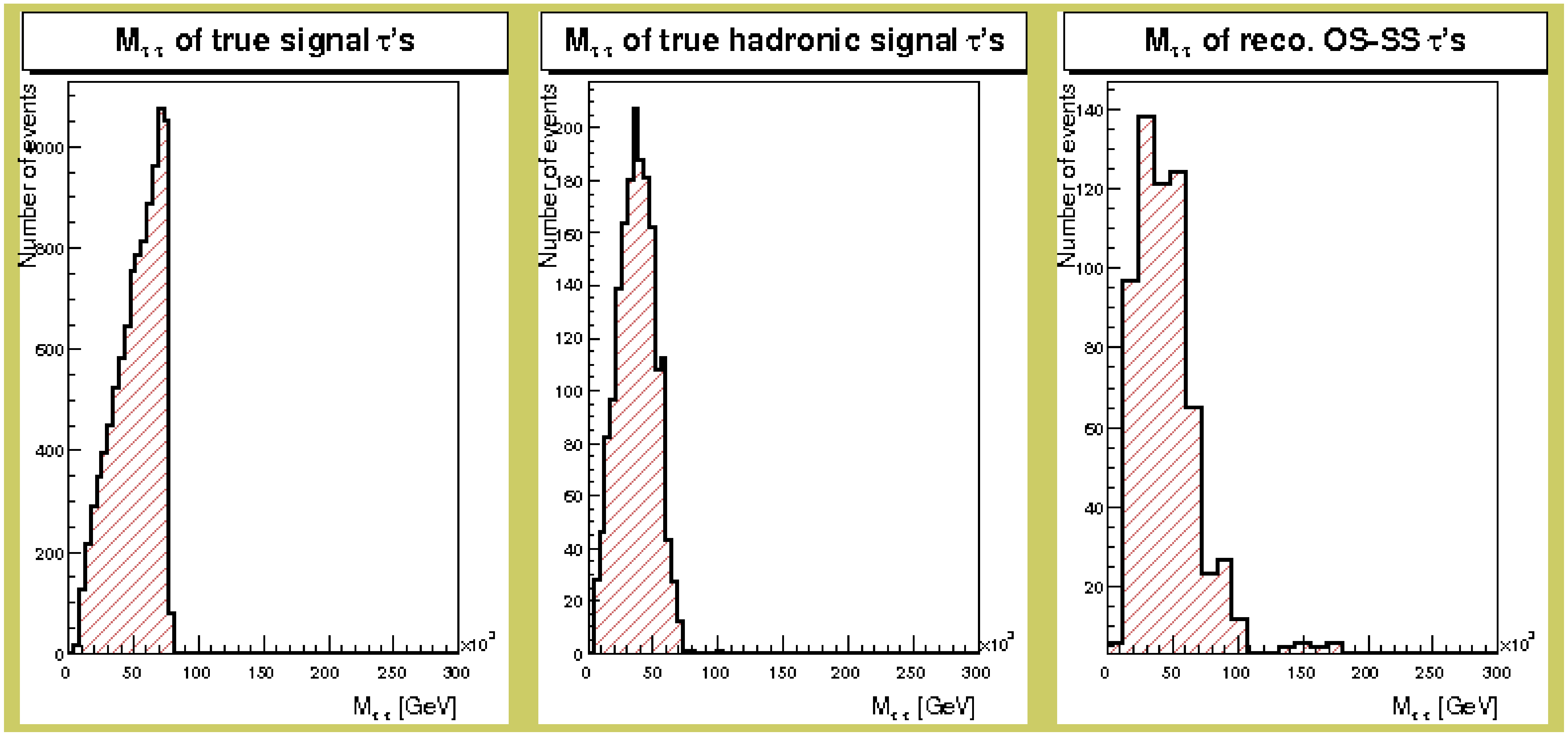


Figure: Invariant mass distribution of two taus.

Selecting the right jet is not straightforward

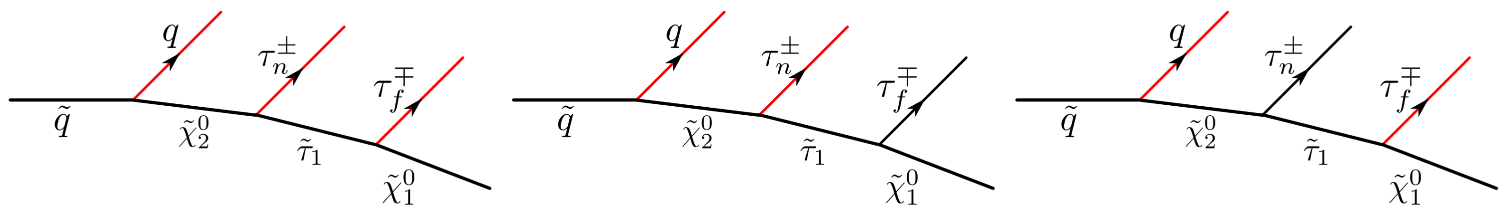


Figure: The signal decay chain indicating from which SM particles invariant mass distributions are constructed.

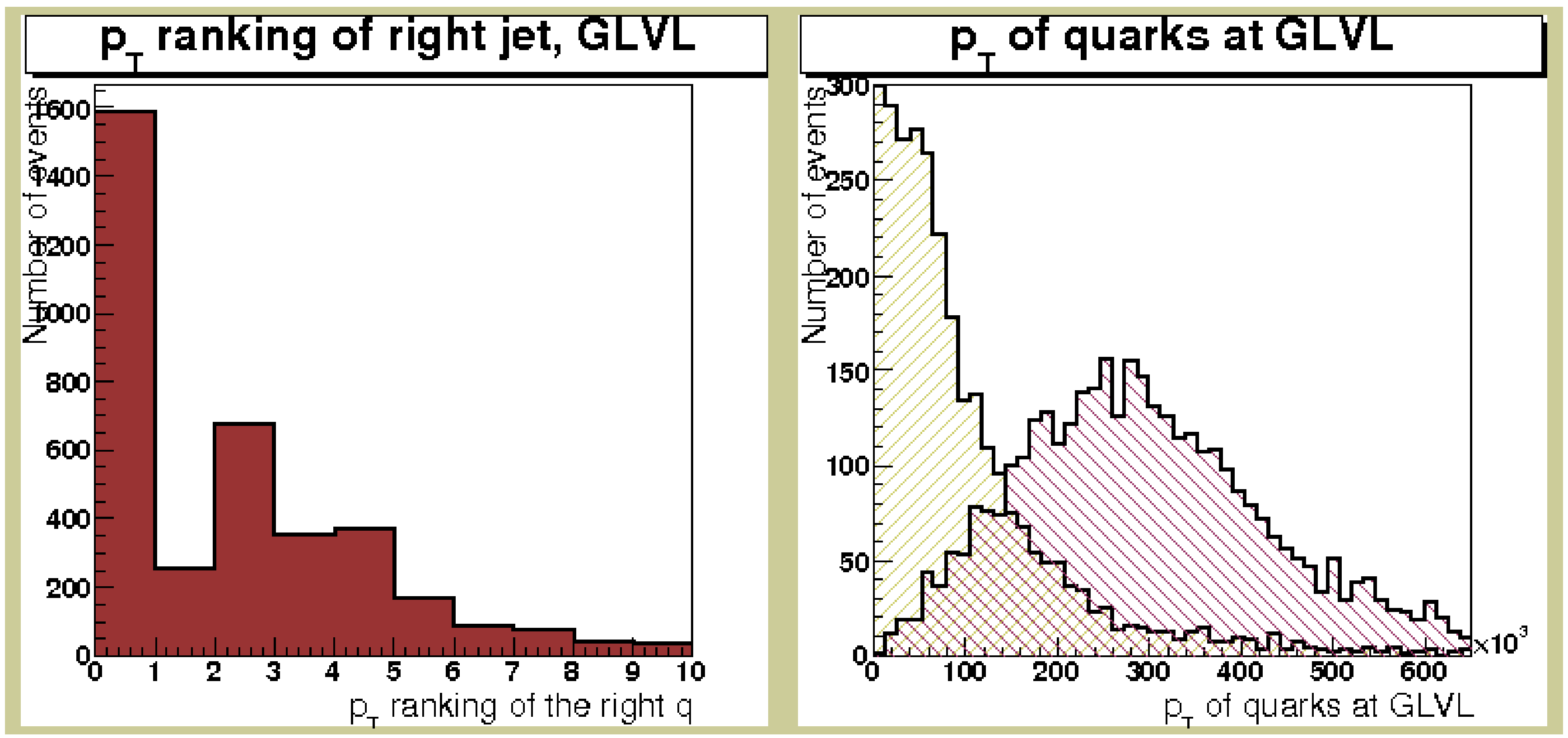


Figure: Information from GLVL on how to select the right jet. Right side: The right jet is in pink.

Inv. mass distributions involving a jet

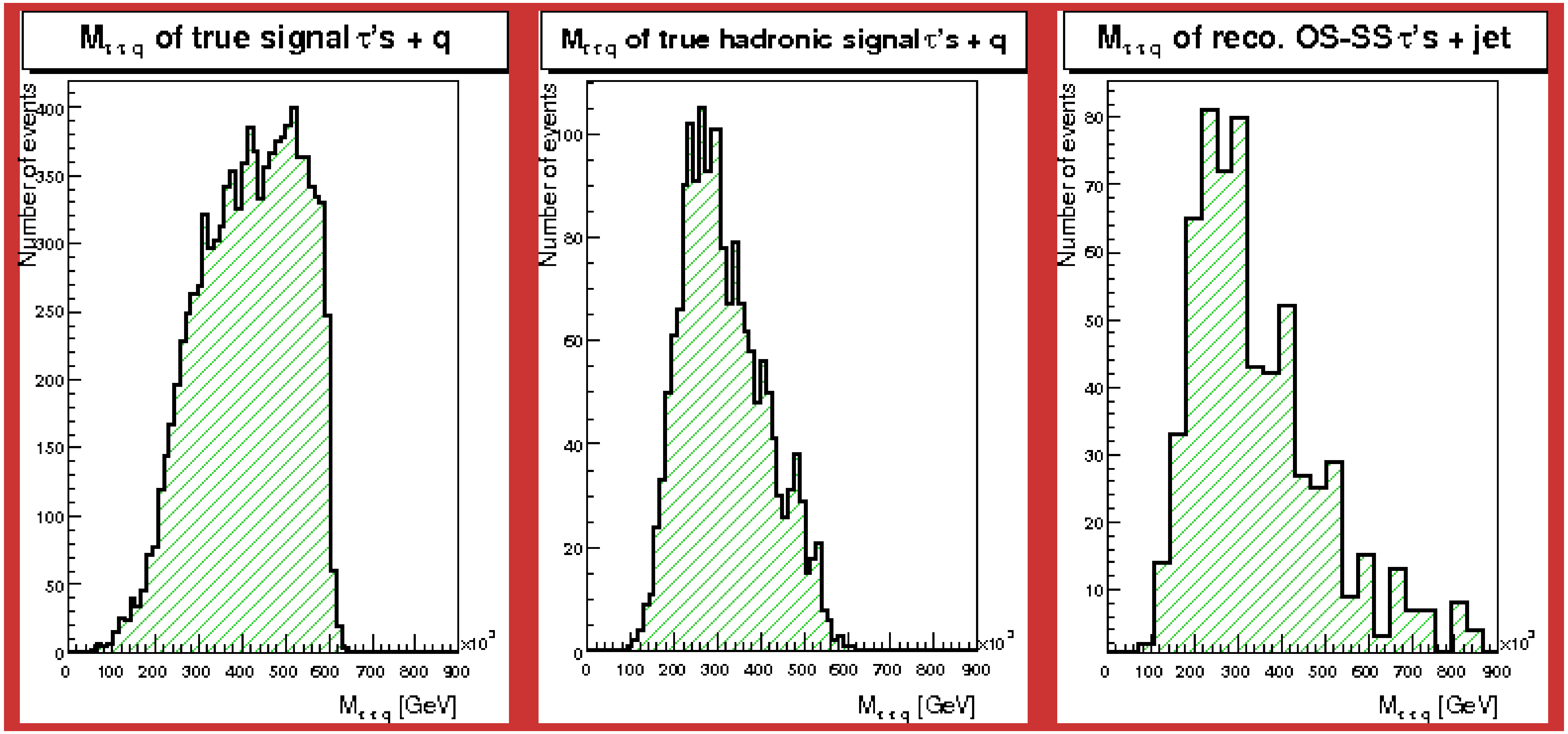


Figure: Invariant mass distribution of two taus.

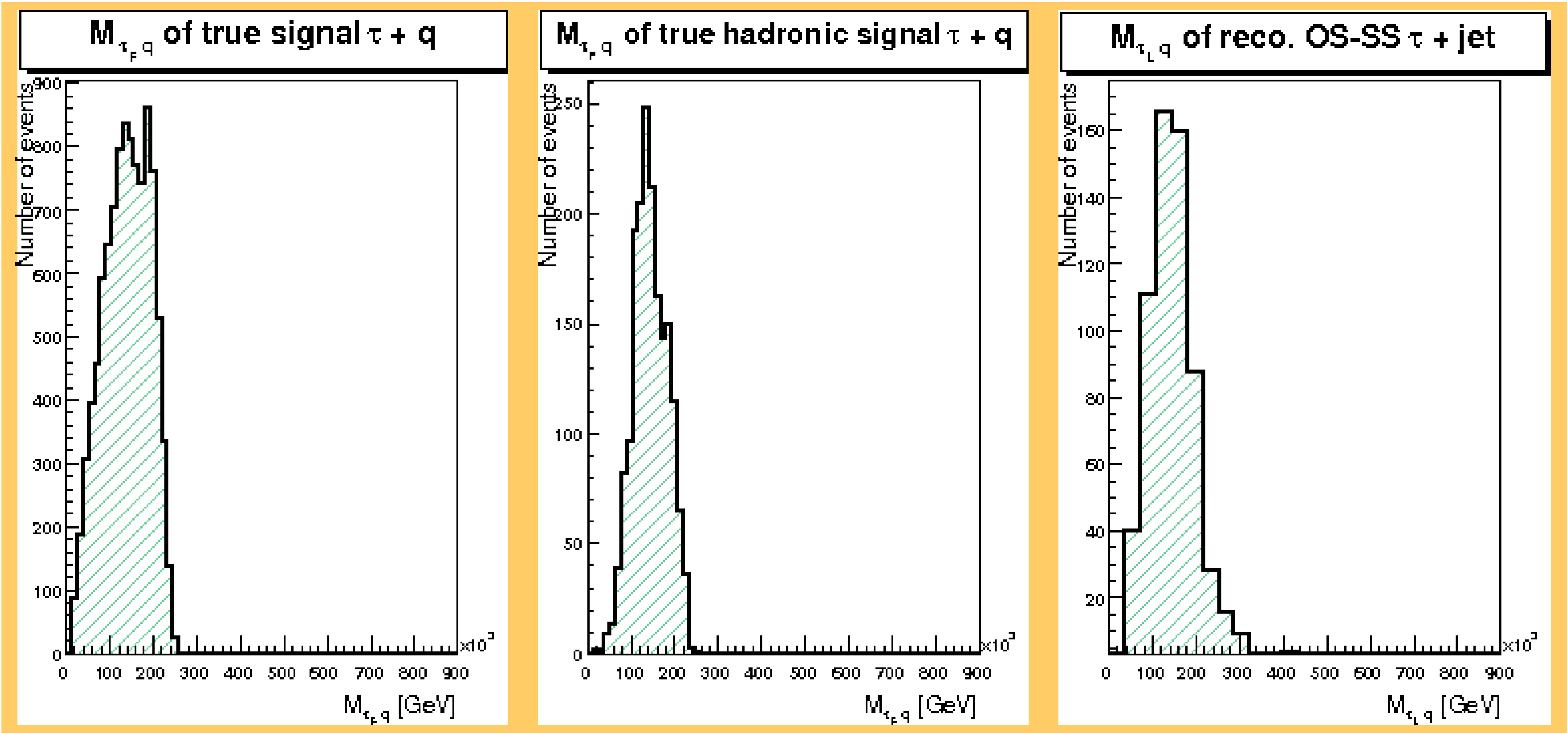


Figure: Invariant mass distributions of τ_F (τ_L) and q (jet).

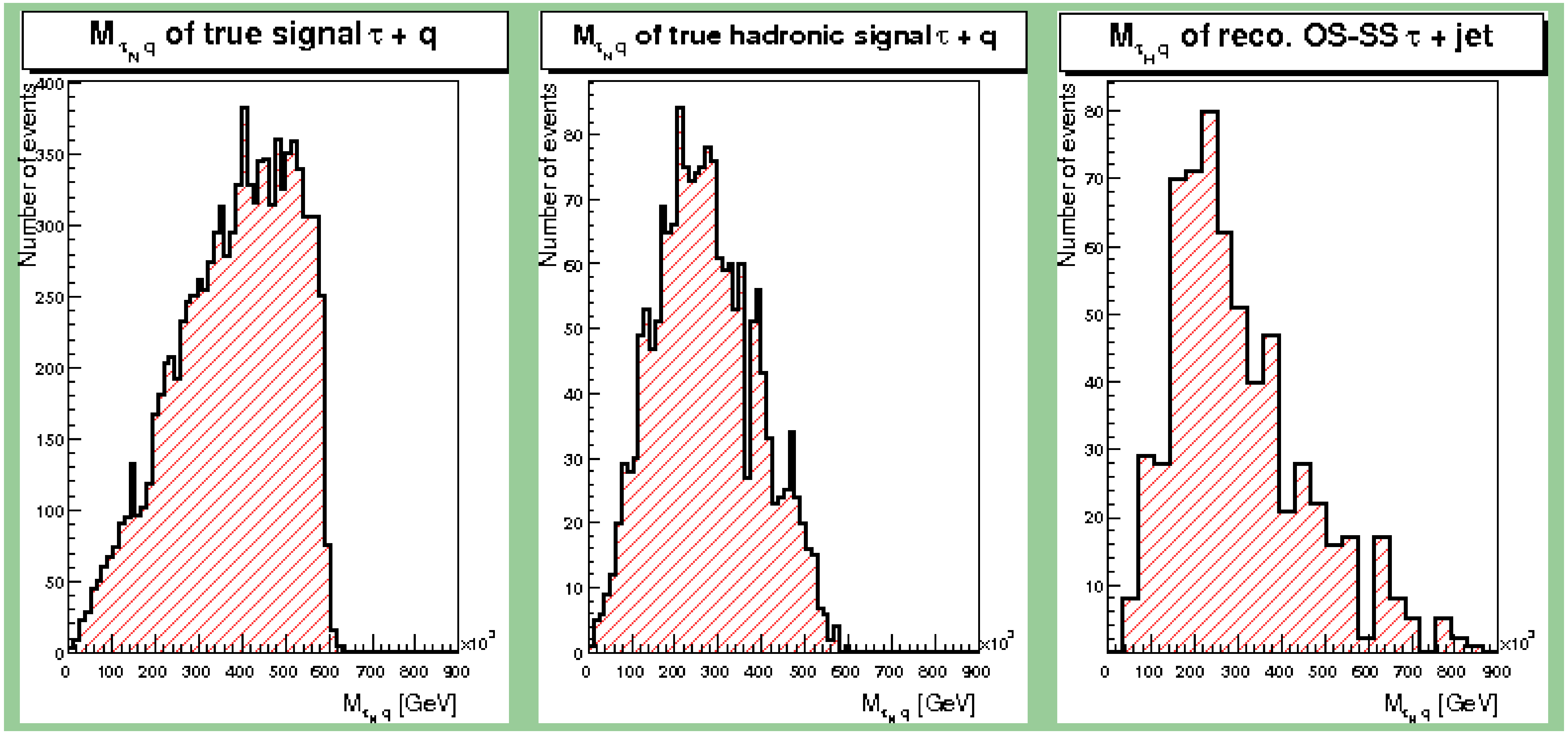
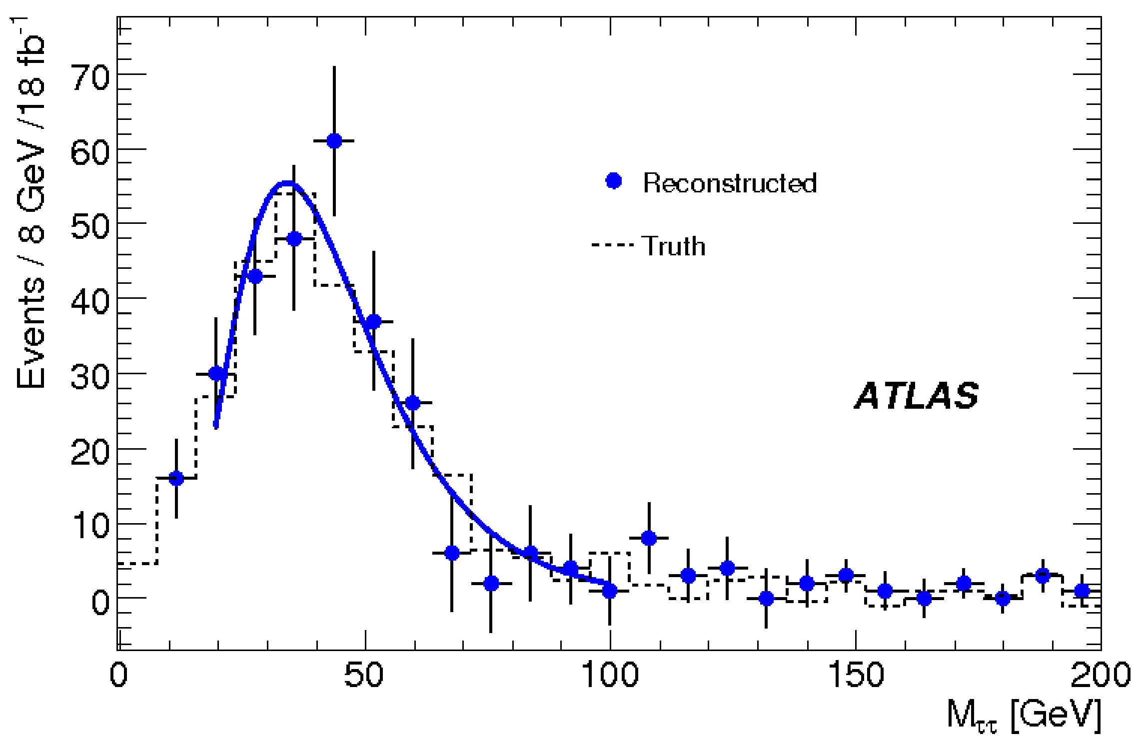


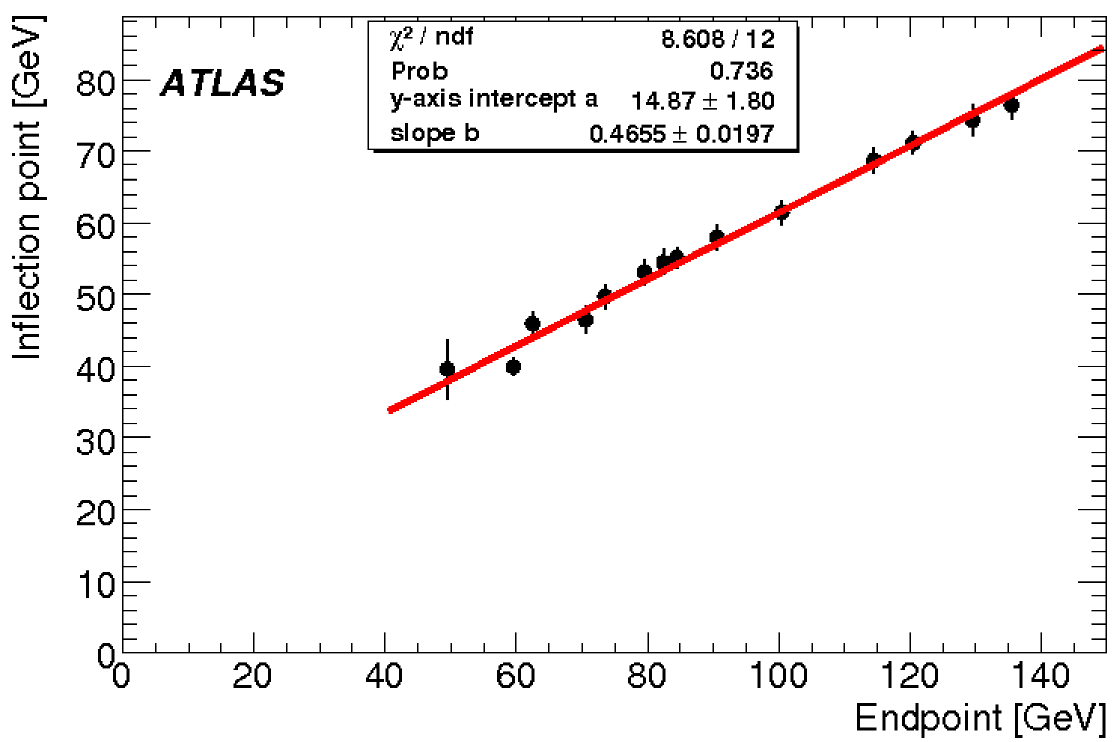
Figure: Invariant mass distributions of τ_N (τ_H) and q (jet).

And what can we learn from this?

- So, can we extract some useful information from this, or is the situation hopeless?
- we need a (plausible) method to convert the endpoint from reconstructed data to the one we observe from the pure MC generated data.
- if possible, we should optimise the jet selection criteria! We have studied various angular distributions between the three particles, but without useful results. Suggestions are welcome!

Possible method to convert endpoint to the MC value; use a function that fits the entire distribution returning an inflection point (IP):





The IP can be converted to some value corresponding to the "MC endpoint" with help from a calibration curve

Is this valid for all possible outcomes?

- This however should be done very carefully!
- We need to check the validity in a wide range of mSUGRA points.
- So we change the mSUGRA parameters $(m_0, m_{1/2}, \tan(\beta))$, simulate new data sets and repeat the analysis)
- We choose points where branching fraction of $\widetilde{\chi}_2^0 \rightarrow \widetilde{\tau}\tau$ is enhanced w.r.t other $\widetilde{ll}$-pair production

SUMMARY AND CONCLUSIONS

MORE SEMINARS AHEAD

Upcoming deeper looks at our posters

- 3D and the lab - Dominic, Lars-Halvor, Kristine
- Black holes, $B_S \rightarrow \mu\mu$, Magnetic field perturbations - Maren, Jørn
- Particle Physics Theory - Mahdi & Nils-Erik
- DAMARA - Heidis proposal presentation :)