Light 2HDM pseudoscalar search

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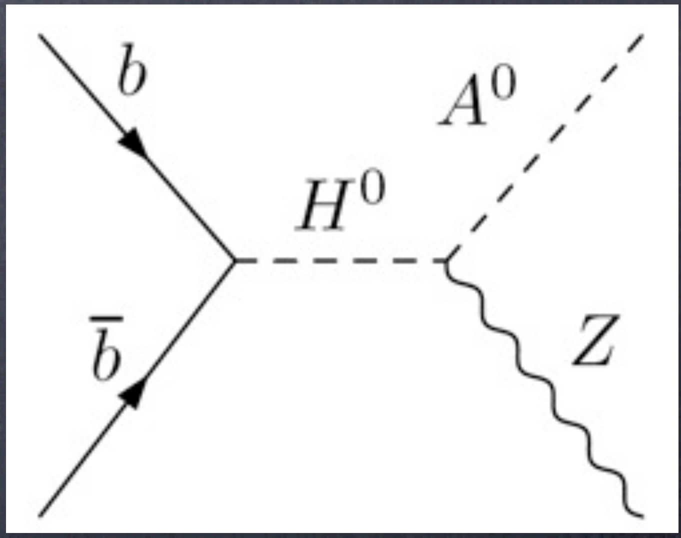
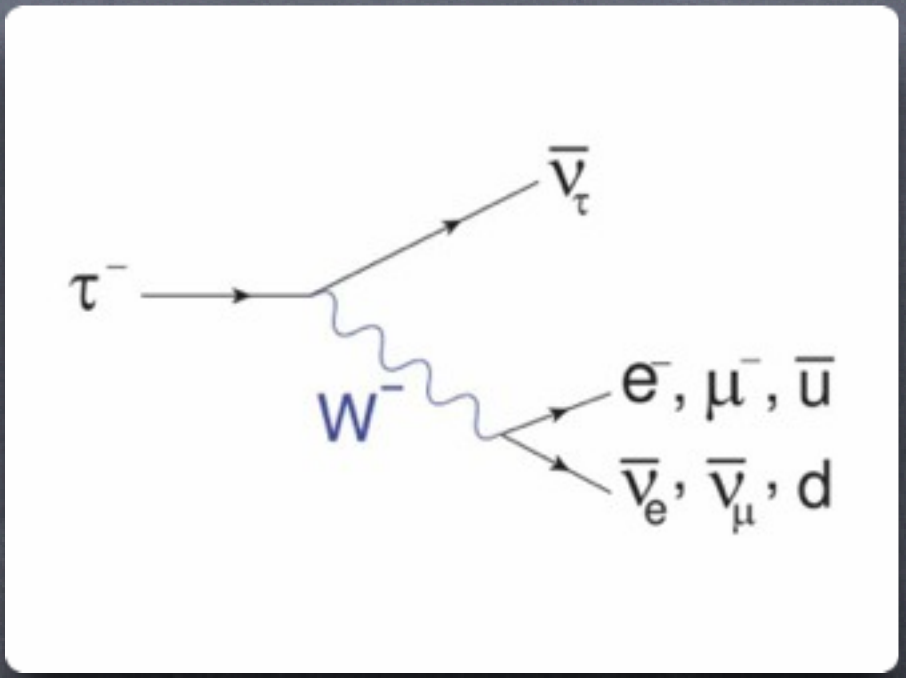
A Two Higgs Doublets Model

- SM Higgs scalar sector enlarged with an additional $SU(2)_L$ doublet:
  - A peculiar interplay of CP and custodial symmetries leads to the invariant scalar potential
    - $V = - m_1^2\varphi_1^\dagger\varphi_1 - m_2^2\varphi_2^\dagger\varphi_2 + \lambda_S/2(\varphi_1^\dagger\varphi_1 + \varphi_2^\dagger\varphi_2) + \lambda_{AS}/2(\varphi_1^\dagger\varphi_2 - \varphi_2^\dagger\varphi_1)$
  - with 4 free parameters:
    - m_h - mass of the SM-like higgs boson h^0
    - m_T - mass of the degenerate triplet $(H^\pm, H^0)$
    - m_A - mass of the pseudoscalar boson A^0
      - One of possible mass hierarchies: $m_A^2 < m_h^2 < m_T^2$
    - $\tan\beta$ (Higgs doublets VEVs ratio)
      - which rescales the non-SM bosons interactions
- Unconventional processes arise, interesting for collider physics
  - $h^0 \to A^0A^0, H^0H^0, H^+H^-$
  - $H^\pm \to W^\pm A^0$
  - $H^0 \to ZA^0$, the sought one, possibly with $m_A \lesssim 100$ GeV
- More about this on arXiv:0904.0705v2

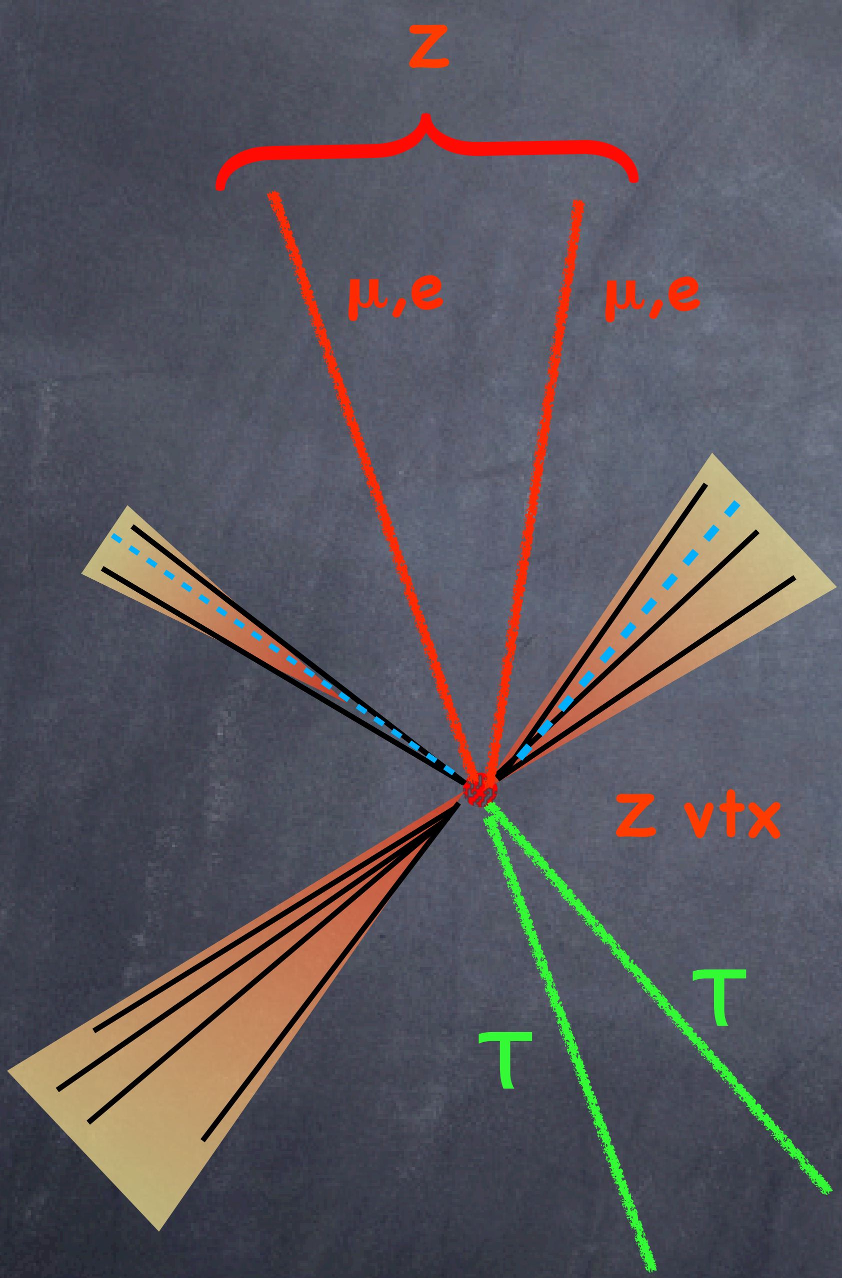


Characteristics of tau decay

- Tau is the heaviest (known) lepton
  - Mass: 1.78 GeV
  - $c\tau$ = 87 μm
- Electroweak decay, with neutrinos
- It decays into other leptons (~17% μ,e)
- It mainly decays into hadrons (usually π's)
- Jets from tau decays are collimated due to large boost.
- Tau jets can be identified due to low detector activity around decay products (isolation)



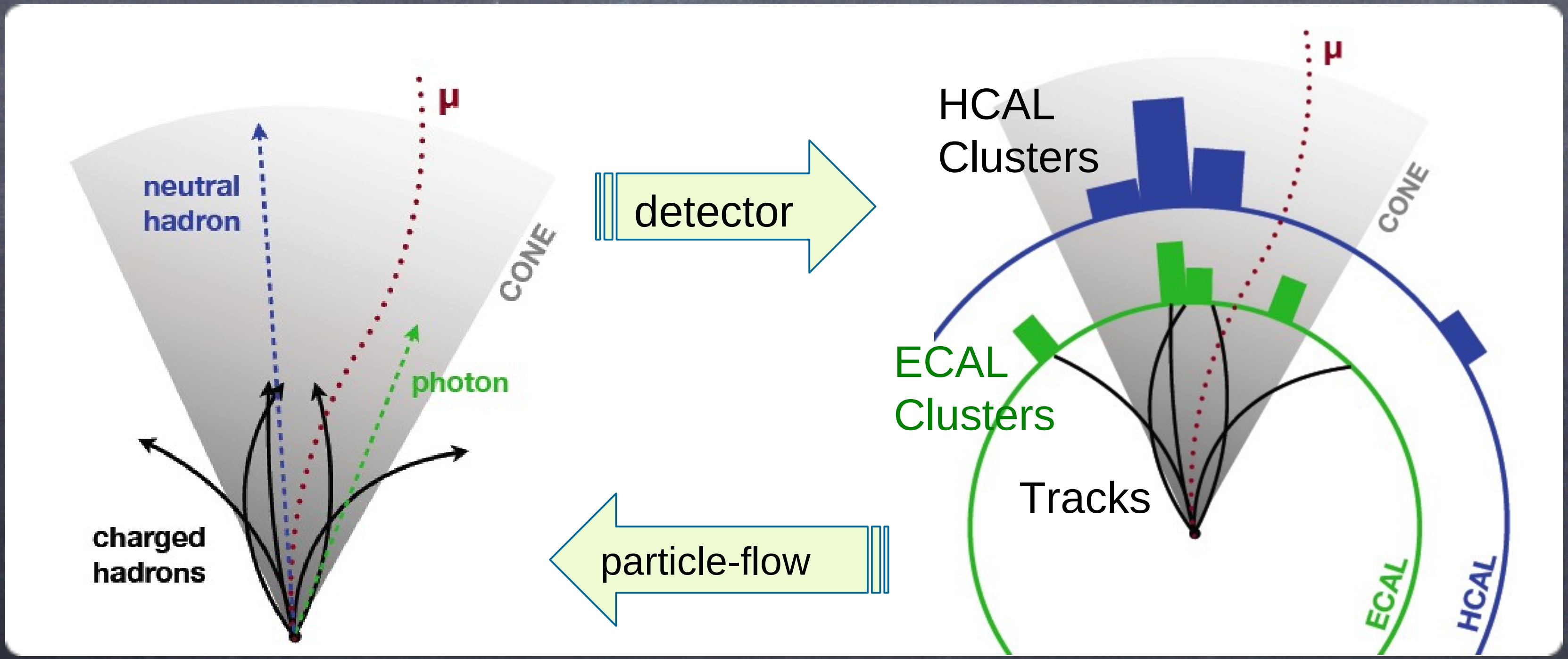
Event Topology



- DiMuon side: a pair of same type, opposite sign leptons (e or μ)
- DiTau side: opposite sign taus:
  - τ_μ τ_e: cleanest channel available, but low statistics
  - τ_{had} τ_μ: large statistics and good purity, the most interesting one
  - τ_{had} τ_e: same statistics as the previous, but much lower purity
  - τ_{had} τ_{had}: probably hopeless due to problems in treating collinear taus and very large backgrounds.

Particle Flow

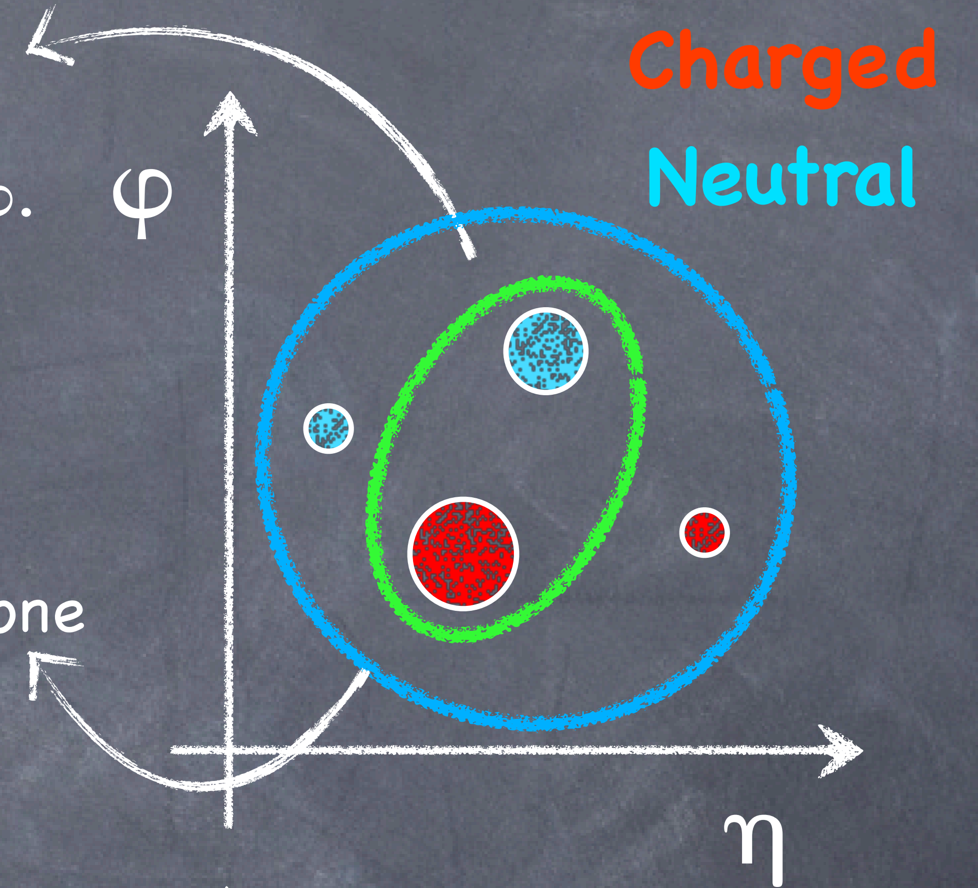
- Particle Flow (PF) is an algorithm that gives a complete description of the event
- Links all the signals from different subdetectors
- produces a list of particle candidate (e, μ, γ, hadron)
- Taus are built from PF objets

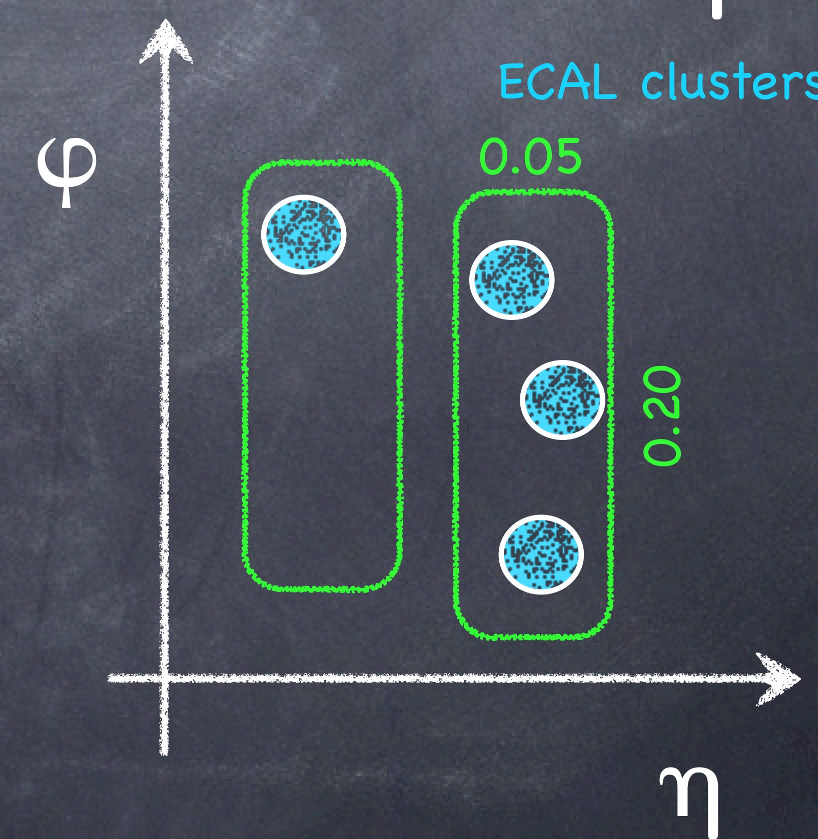


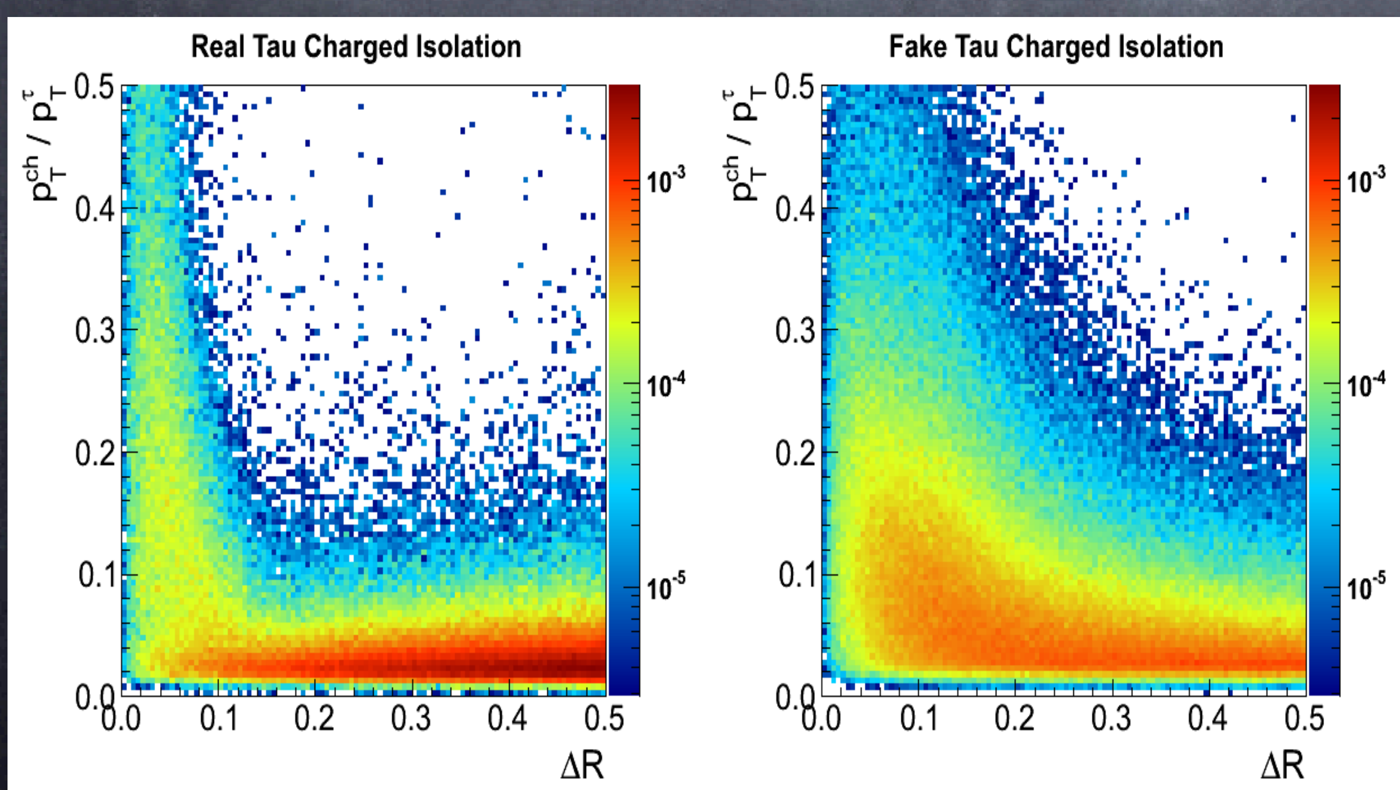
Hadron Plus Strip

Two main features:

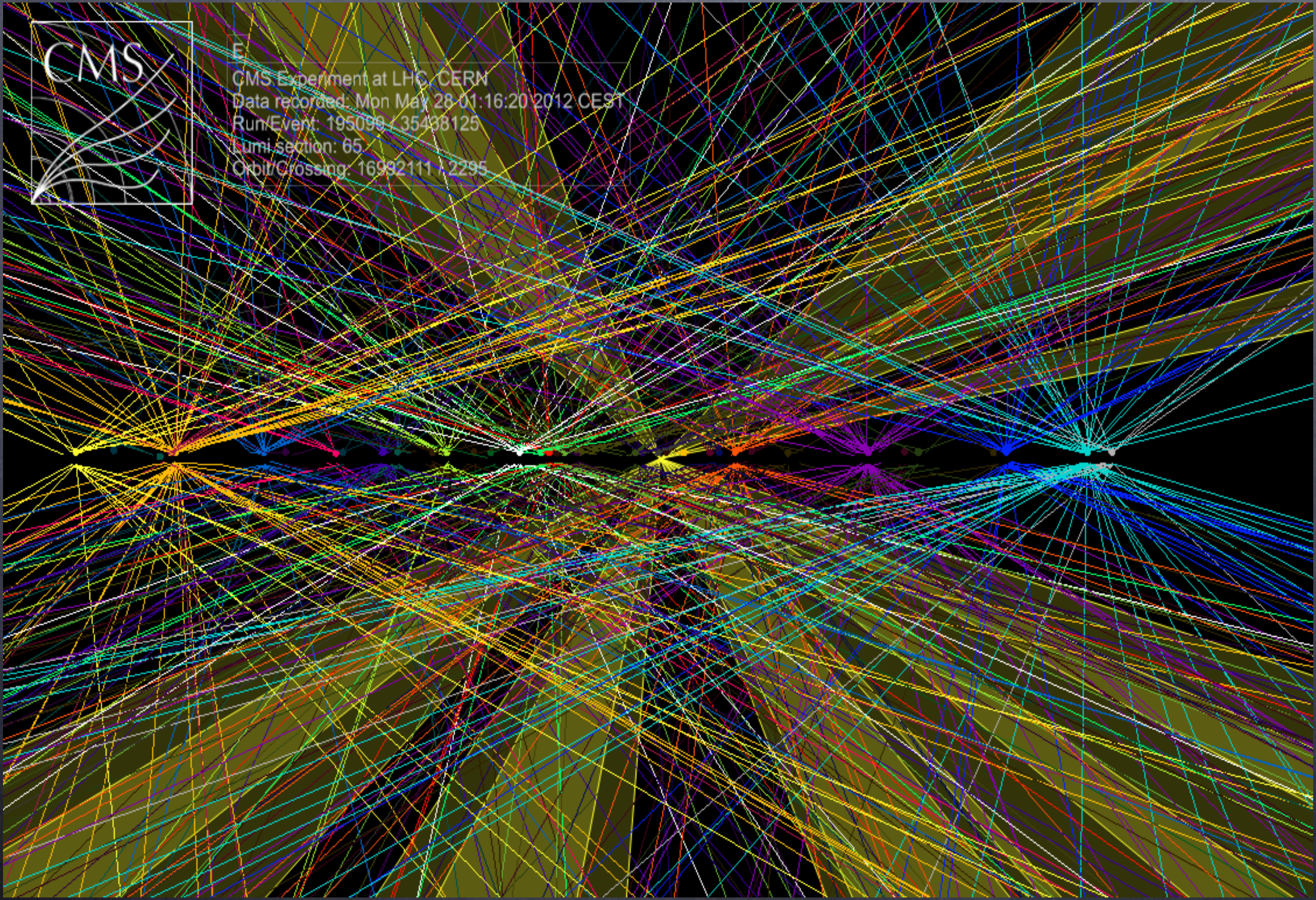
- π^0's are formed summing clusters in a strip along φ.
- Decay Mode Finding:
  - Builds all possible combinations within (π,$\pi\pi^0$,$\pi\pi\pi$)
  - Chooses among them the most isolated with compatible visible mass
- The tau candidate is then passed to a MVA that discriminates real from fake taus using energy deposits around the candidate





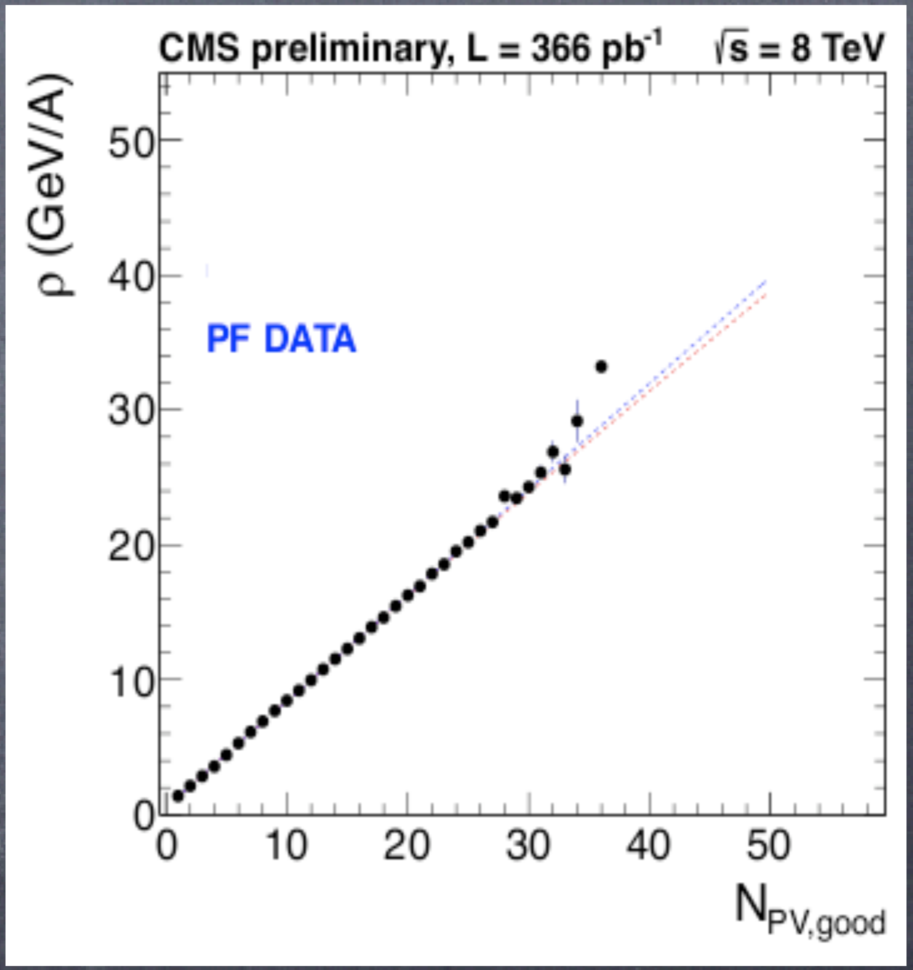


Pile Up


CMS
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295

Lepton Isolation

- In hadronic environment leptons coming form heavy resonances (Z,W,h,J/Ψ, Υ...) are identified by low detector activity around the candidates
- This quantity is known as isolation
- The effect of charged pileup can be directly taken out exploiting vertex information but the effect of neutral deposits in calorimeters must be estimated
- ρ: average energy density computed by fast-jet k_T algorithm with r = 0.6



$$\rho = \mathrm{median}\left\{\frac{p_T^{Jet_i}}{A^{Jet_i}}\right\}$$

- Neutral isolation can be corrected on event by event basis

Analysis strategy

- Trigger on two good muons/electrons
- Select two good opposite sign μ/e isolated (ρ correction!)
  - coming from the same vertex
  - inv. mass compatible with the Z
- The mass hierarchy hints we may have a very boosted A^0 which would turn into very collimated taus (more on that later).
- Two other taus are required to be identified in the event coming from the same vertex of the Z

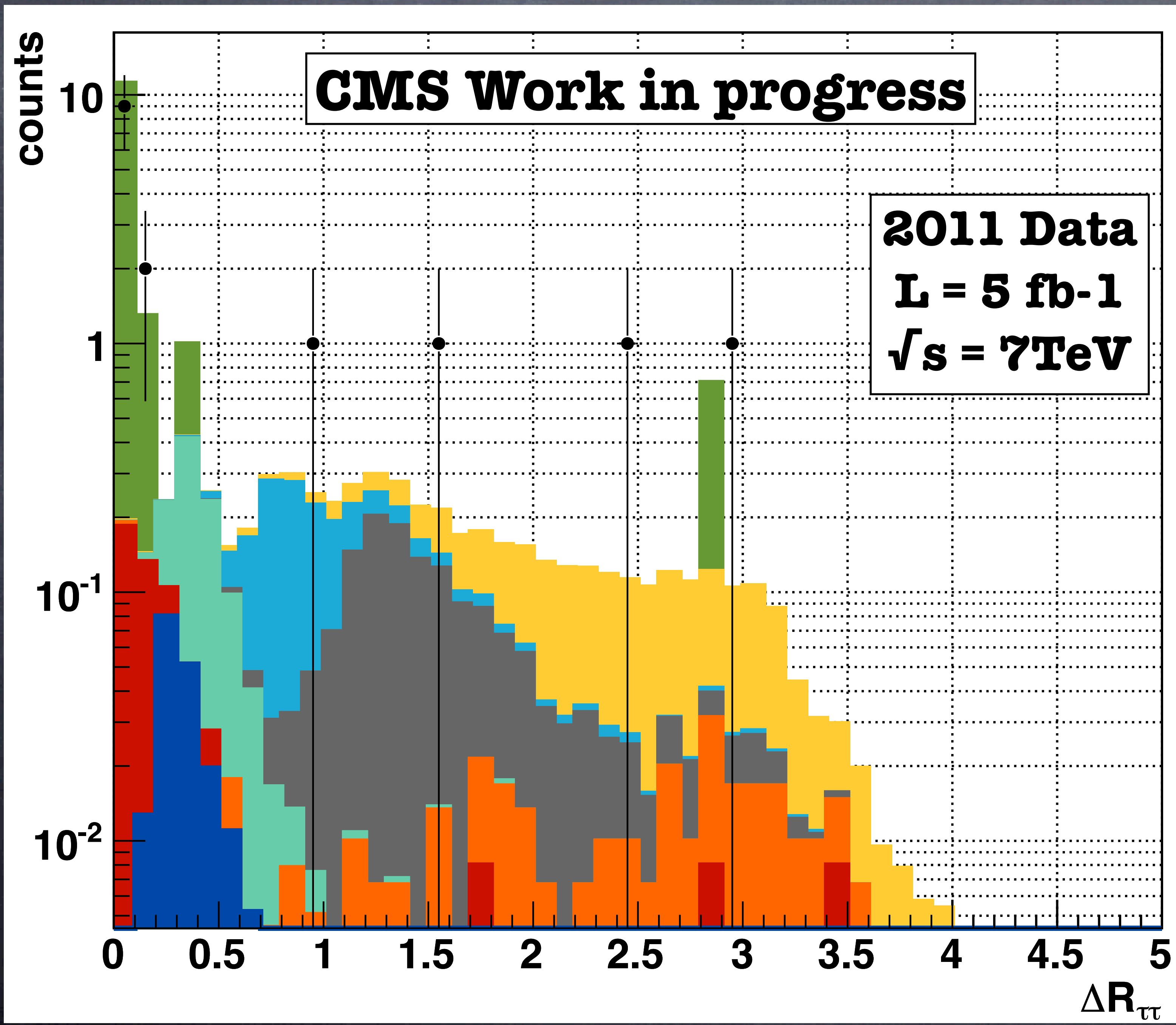
Collinear taus handling

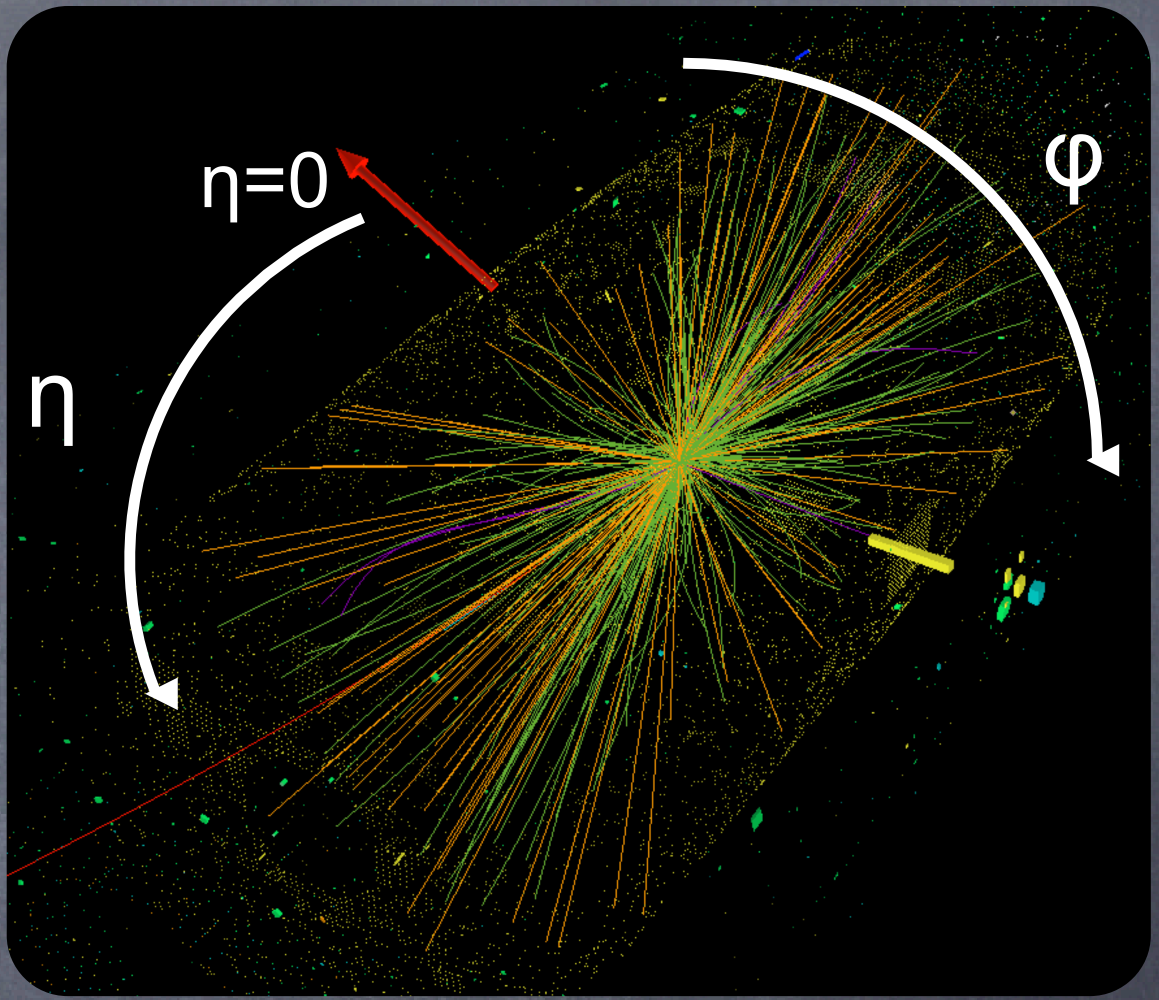
Several tricks to treat collinear taus ($\Delta R \lesssim 0.3$) correctly

- Tau Building:
  - Problem: the hard lepton coming from one tau may spoil several steps of the hadronic tau building process.
  - Solution: to avoid any bias the lepton is removed from PF collection and the jets and taus are built again
- Measuring isolation:
  - Is the key tool to discriminate signal from background
  - Problem: if constituents coming from different taus are too close they may spoil each other isolation.
  - Solution:
    - hadronic tau need no correction since correctly treated in building
    - isolation of leptons are corrected for other signal particles within isolation cone

Results (I)

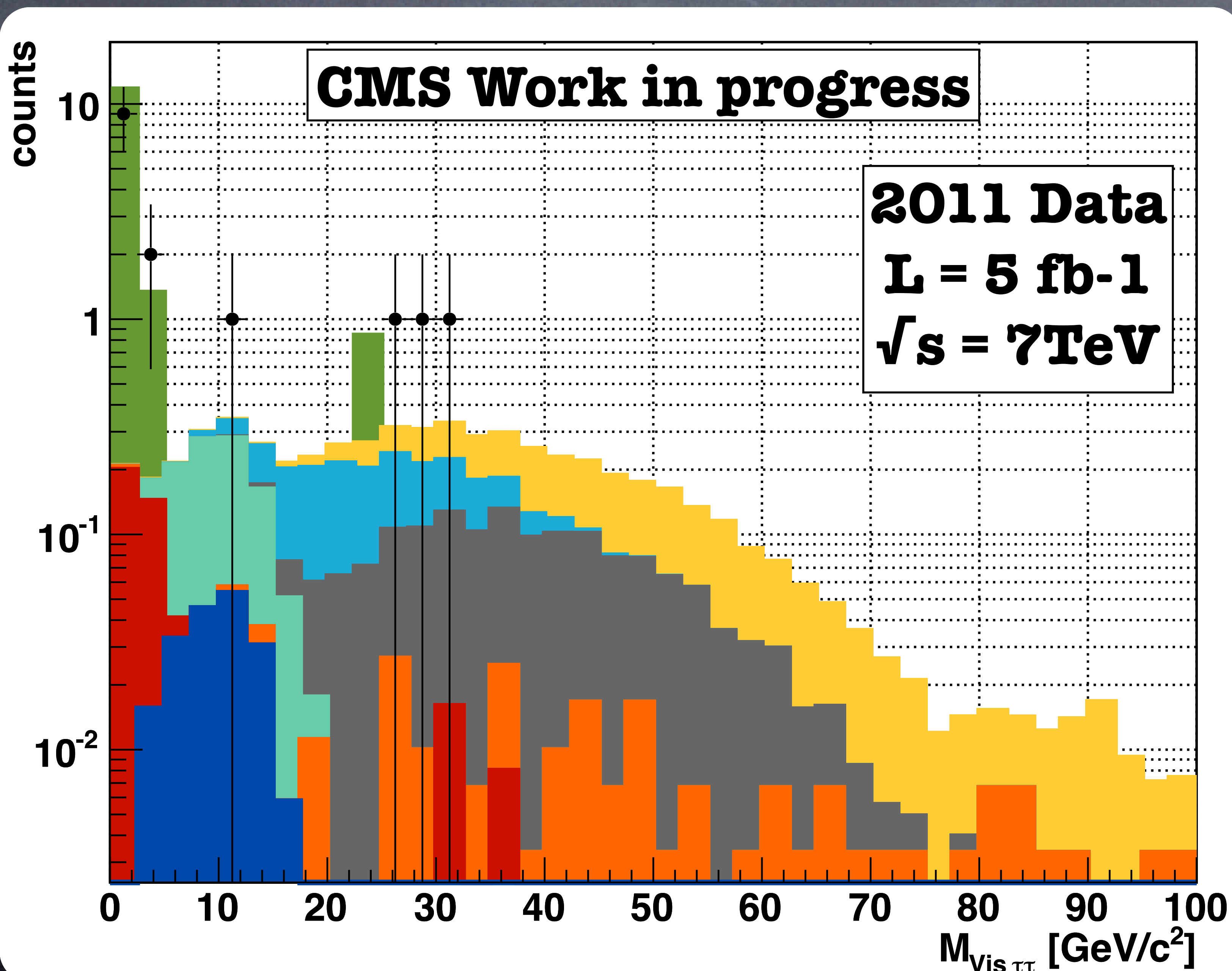
$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

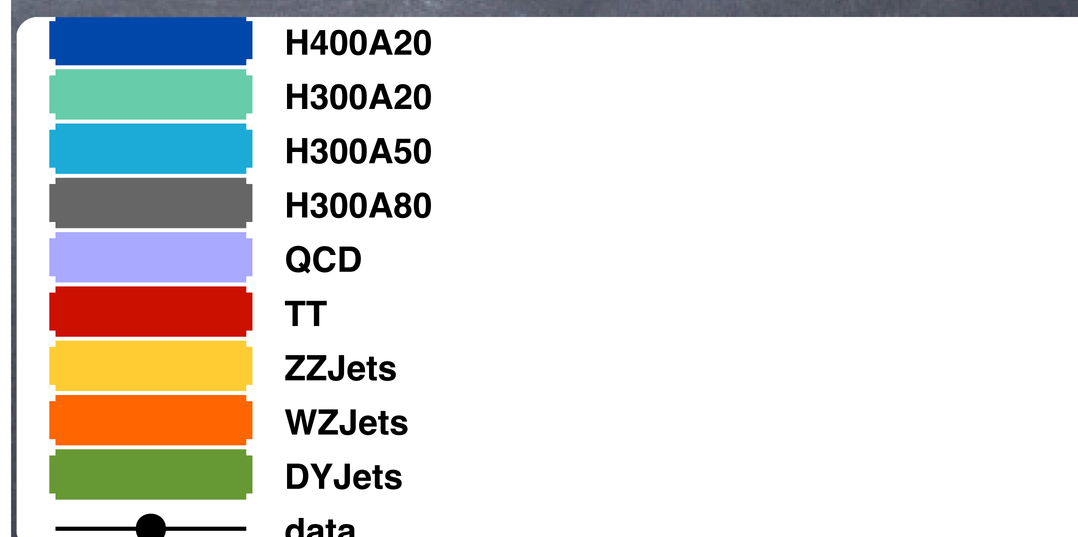




Results (II)

Sample	Expected Counts
QCD	0
TT	0.359
WZJets	0.309
ZZJets	1.832
DYJets	13.242
Sum SM	15.742
data	15.0





Improvements

Several improvements are currently ongoing:

- Usage of 2012 full dataset (~30/fb @ 8TeV)
- Better mass reconstruction using SVFit
  - Takes as input visible product and missing E_T
  - Likelihood based on phase space and spin of the tau is numerically integrated up to 0.5 giving the value of the most probable di-tau invariant configuration
  - No spin-parity assumed for the decaying resonance (taus unpolarized)
  - Very slow, up to 6" per event!
- Cuts to be fine tuned on different benchmark mass points (no more one-size-fit-all)

Conclusions

- Feasibility of a light pseudoscalar boson produced in association with a Z was studied.
- Despite the high purity of the channel used main problems are the very low signal yield and low p_T of the final probes
- More integrated luminosity is certainly a big advantage
- 2012 data analysis campaign is ongoing, and will provide final result

Example: $\mu\mu\tau_\mu\tau_h$ events

- $\mu\mu$ (Z) system (Opposite Sign)
  - 75 GeV < $M_{\mu\mu}$ < 105 GeV
  - $p_{T\mu}$ > 20, 10 GeV
  - relative isolation < 0.15 rho corrected
- $\tau_\mu\tau_h$ (A^0) system (OS)
  - τ-ID: anti-electron, anti-muon, very loose isolation
  - $|\eta_\tau| < 2.3$
  - $p_{T\mu}$ > 5 GeV, $p_{T\text{vis } \tau}$ > 15 GeV
  - same isolation of the μ as the Z