GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

FSP 101 ATLAS

Reconstruction of tau leptons and prospects for SUSY in ATLAS

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Outline

I Introduction and Motivation

II Tau reconstruction and identification in ATLAS

III SUSY analyses with tau leptons
- Inclusive: discovery prospects
- Exclusive: measurement of properties

IV Summary

Motivation

Why are taus interesting for SUSY?

- 3rd generation special in SUSY: mixing of $\tilde{\tau}_L$ and $\tilde{\tau}_R$ to $\tilde{\tau}_1$, $\tilde{\tau}_2$
  → $\tilde{\tau}_1$ and therefore τ production enhanced
  - $\tilde{\tau}_1$ in many models lightest slepton
  → $\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1 \tau$ larger BR than analog e/μ decays, may even be only allowed (2body) decay
  → important discovery channel
- tau final states provide unique information not accessible otherwise, e.g. on stau masses
- tau decay offers opportunity to measure tau polarization
→ information about couplings of $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$ and $\tilde{\tau}_1$

Introduction: tau leptons

Tau characteristics:

- $m_\tau \simeq 1.7$ GeV, $c\tau \simeq 87\mu$m

→ decay within detector, visible only via decay products:

35% leptonically

- 17.8% $\tau \to e\nu_\tau\nu_e$
- 17.4% $\tau \to \mu\nu_\tau\nu_\mu$

65% hadronically

- 50.2% 1prong (1 charged track)
- 15.2% 3prong
- 0.1% 5prong

Towards tau reconstruction:

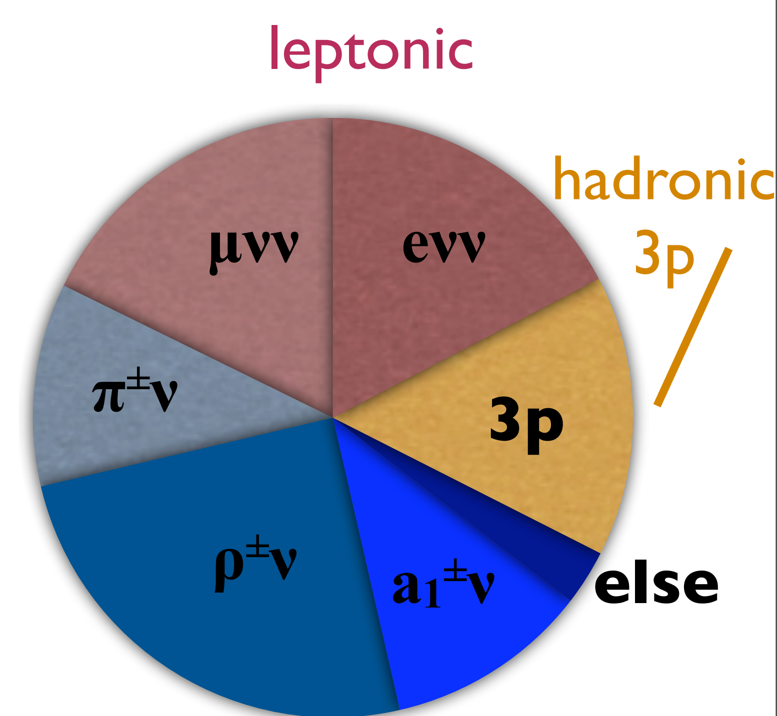
- e/μ from τ decay hard to distinguish from prompt e/μ

→ current algorithms focus on hadronic decays:

1 prong (1p):
- 22.4% $\tau \to \pi^\pm\nu_\tau$
- 73.5% $\tau \to \pi^\pm\nu_\tau + n\pi^0$

3 prong (3p):
- 61.6% $\tau \to 3\pi^\pm\nu_\tau$
- 33.7% $\tau \to 3\pi^\pm\nu_\tau + n\pi^0$

→tau lepton in detector: jet of charged and neutral pions

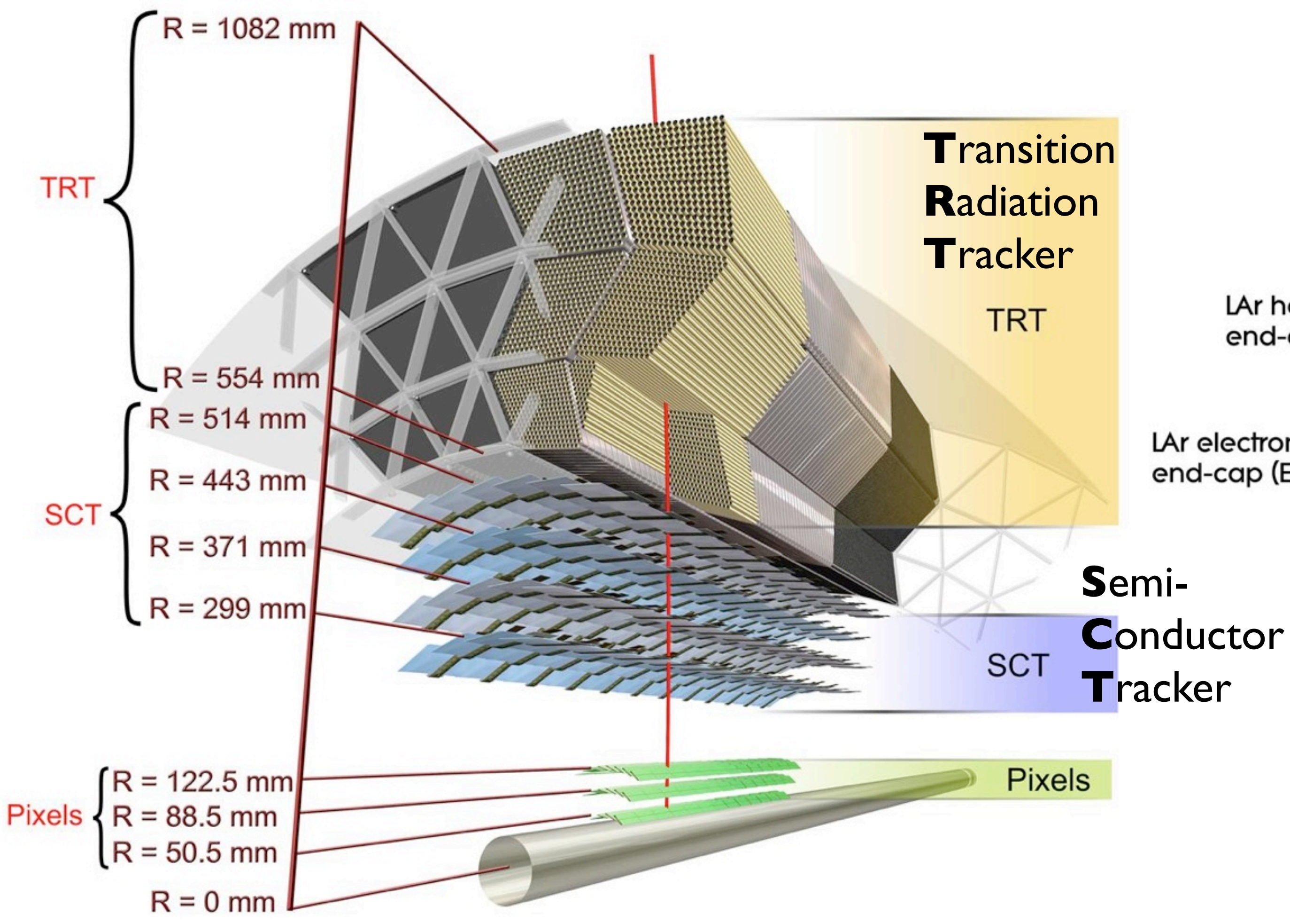


hadronic 1p
$\rho^\pm \to \pi^\pm + \pi^0$
$a_1^\pm \to \pi^\pm + 2\pi^0$
$\pi^0 \to \gamma\gamma$

The ATLAS detector

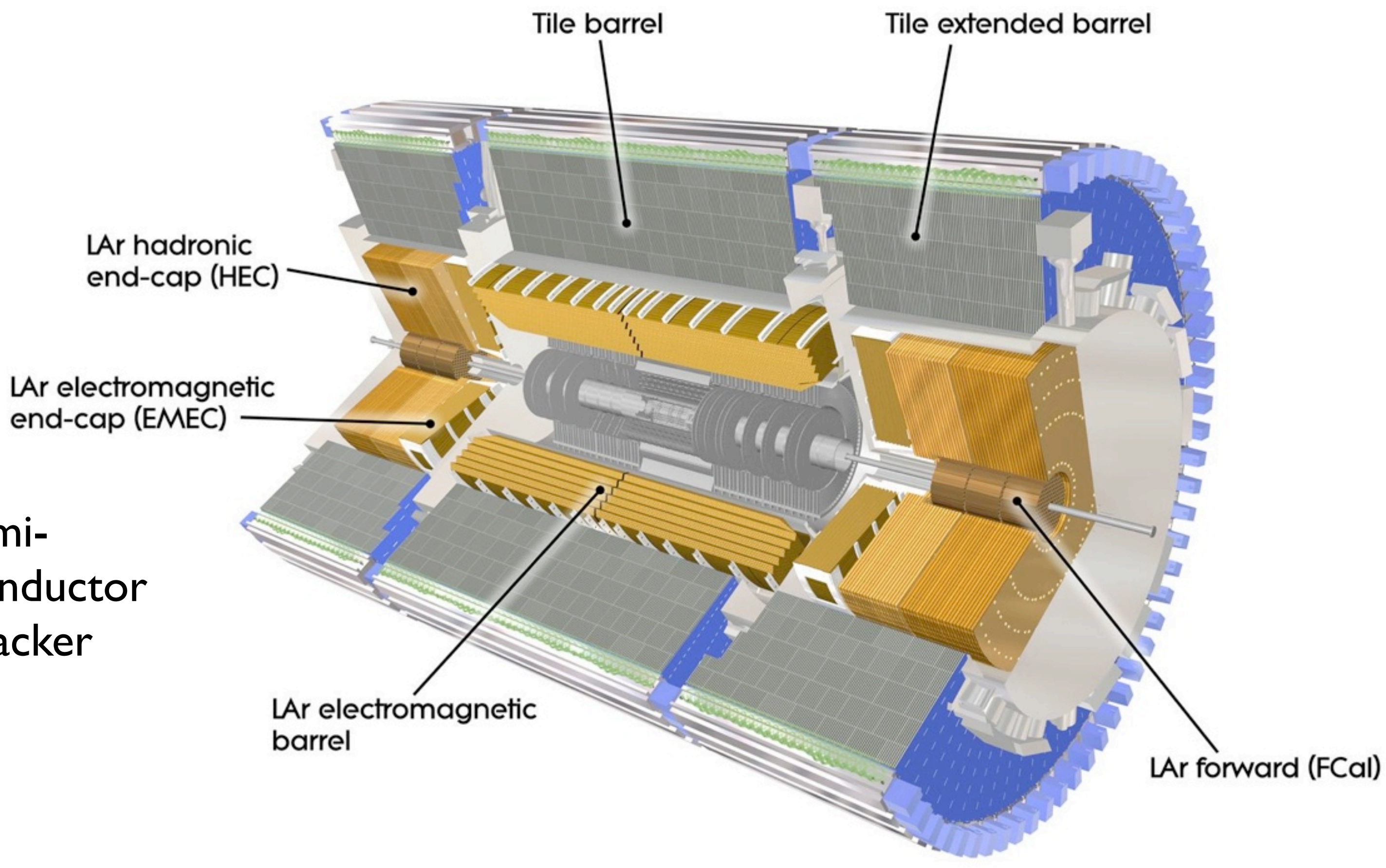
Ingredients for tau identification:

Tracking



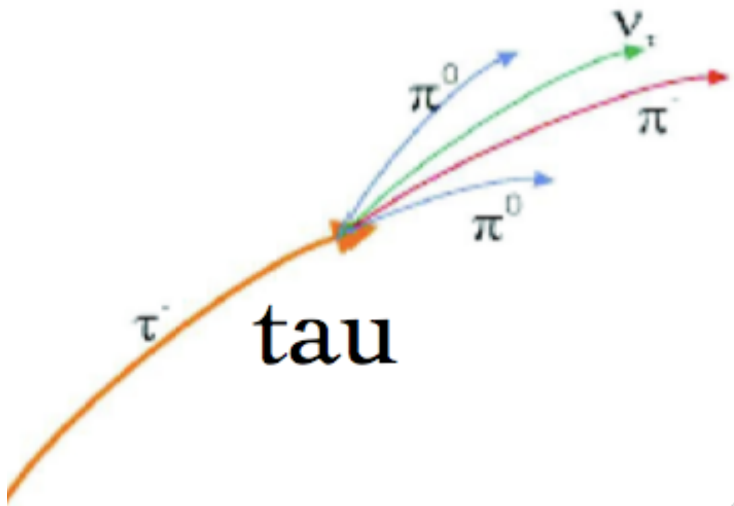
- $c\tau \approx 87 \mu m \rightarrow$ secondary vertex
- Tracking constraint for taus: $|\eta|<2.5$

Calorimetry



High granularity of sampling calorimeter allows
- good shower profile reconstruction
- reconstruction of π^0 subclusters

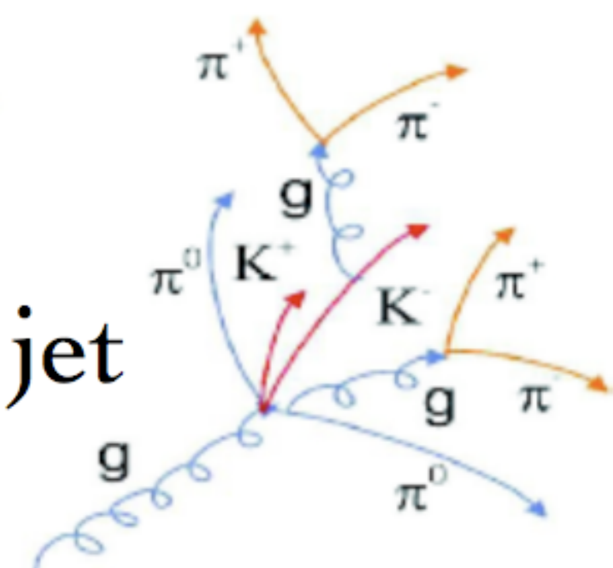
τs from the detector's point of view



Two reconstruction algorithms:

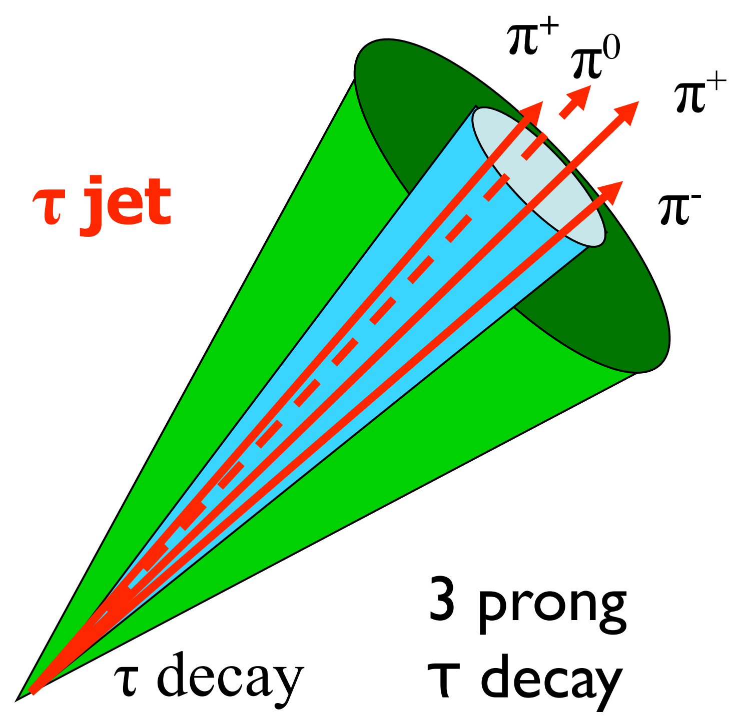
- track based: seeded by high quality tracks
- calorimeter based: seeded by calorimeter clusters

Main background: QCD jets



Basic distinctive τ features:

- collimated tracks and energy depositions
- low track multiplicity
- isolation
- impact parameter (1p), displaced vertex (3p)
- ratio of EM/HAD energy



Tau reconstruction

Reconstruction

use combination of track- and calorimeter-seeded algorithms

- Begin with track based algorithm
- search matching calorimeter seed
  - → no match: track-only candidate (5%)
  - → match: track+calorimeter seeded candidate (70%)
- remaining clusters: seeds for calorimeter-only candidates (25%)

Tau identification

Identification

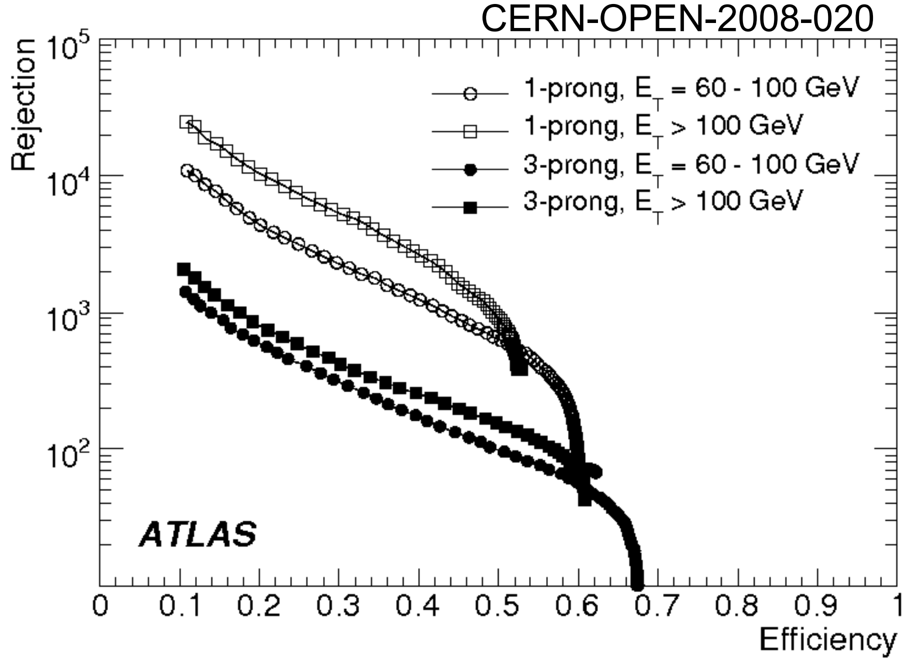
Many discriminating variables, using calorimeter and tracking information:

- #tracks in isolation cone and invariant mass of track system
- shower radius in electromagnetic calorimeter
- #hits with certain energy deposit in certain calorimeter layer
- E_T fraction in cone $0.1<\Delta R<0.2$ w.r.t. total energy in cone 0.4
- ...

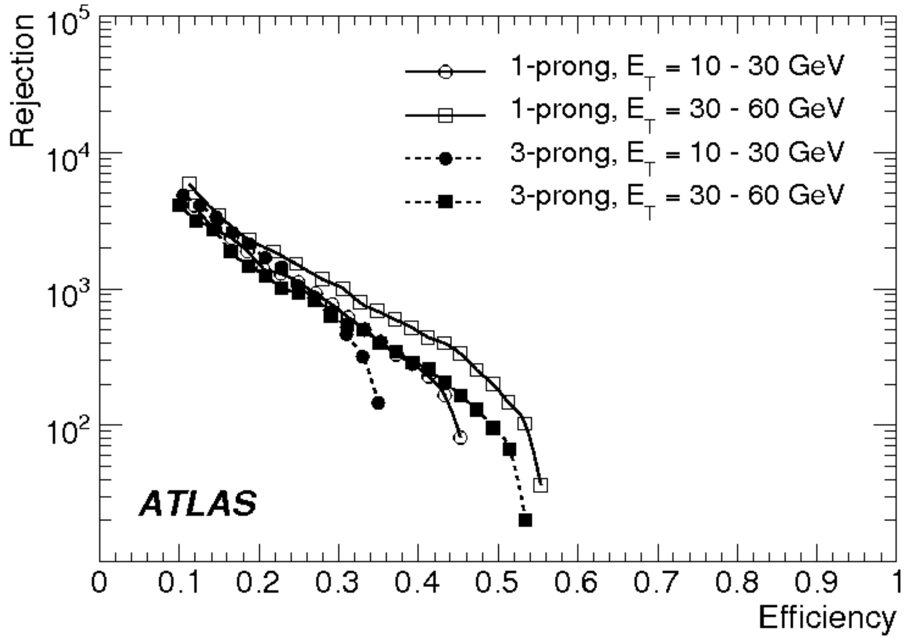
→ input for different discriminants: cut method, likelihood, neural network, boosted decision trees, PDRS

Identification in early data:* *"safe variables"

Reduce complex set of input variables to a few, well understood "safe" variables and use cut-based identification method for early data taking



expected performance:
↑calorimeter-based with likelihood selection
↓track-based, NN selection



SUSY analyses with tau leptons

- Inclusive search strategy: cover all possible signatures

  x jets + y leptons/taus + E_T^{miss} modes

  → defined complementary to simplify combination

  - development of selection cuts in chosen benchmark points in mSUGRA-like models
  - scans of subsets of SUSY parameter space with fast detector simulation

- Exclusive studies: focus on special signatures
  - often very little background
  - main goal: measurement of SUSY properties

- Plots and numbers here: $1 fb^{-1}$ of 14 TeV data
- τ identification: track- and calorimeter-based algorithms used separately, safe variables not implemented yet
- mSUGRA examples → R-parity conservation

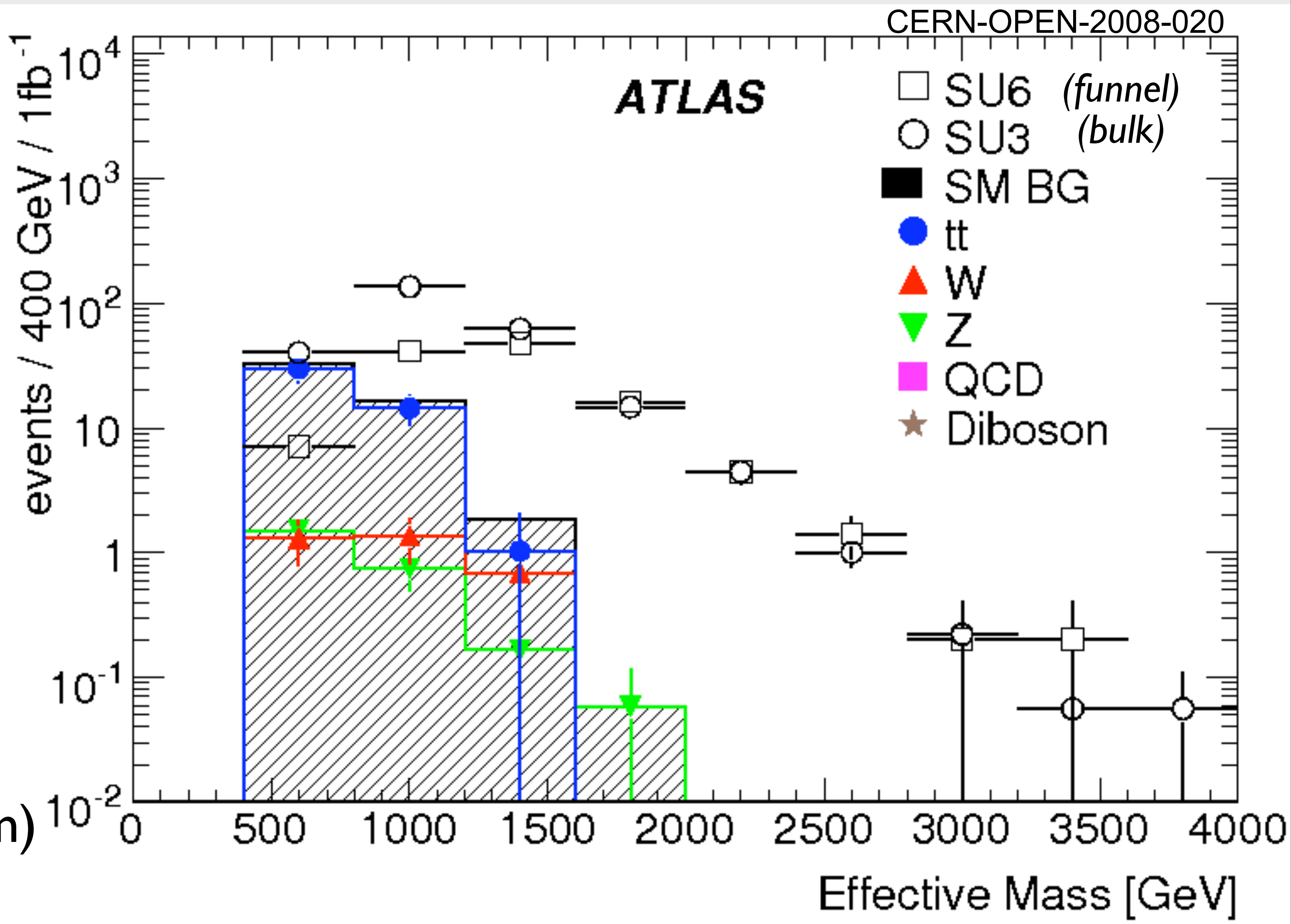
Inclusive searches: tau mode

Tau mode:

leptonic τ decays: part of lepton modes

event selection:

- $\geq 1\tau$ (p_T>40GeV, $|\eta|$<2.5, calorimeter-based)
  → *efficiency≈50%, purity≈80% (SU3)*
- no isolated lepton
- 4 jets: p_T>50GeV, leading jet: p_T>100GeV
- E_T^{miss} >100GeV, E_T^{miss} >0.2*Meff
  (Meff = $E_T^{mis} + \Sigma_{i=1}^{4} p_T^{jet\ i} + \Sigma_{i=1} p_T^{lepton\ i}$)
- $\Delta\Phi(jet_{1,2,3}, E_T^{miss})$>0.2
- transverse mass of hardest τ (vis. momentum) and E_T^{miss}: M_T>100GeV



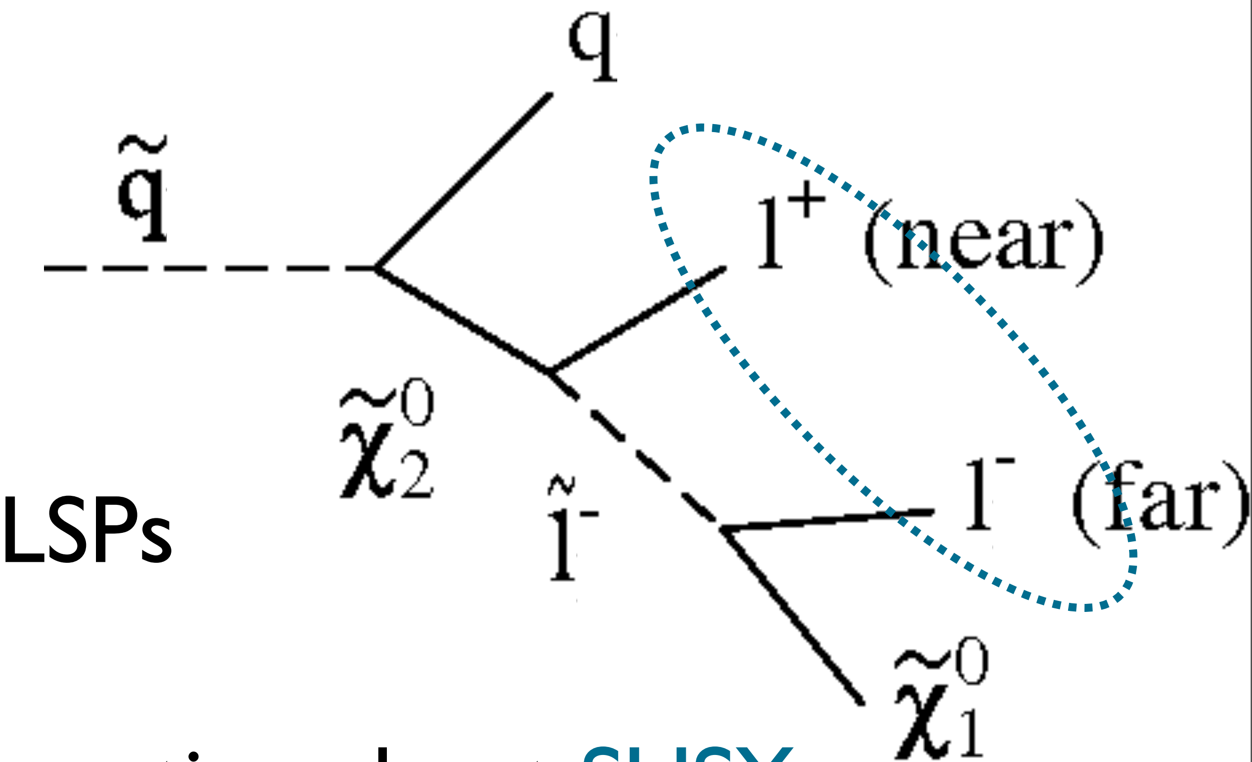
Trigger: 97-100% efficiency expected when triggering on 1 jet (p_T>70GeV) plus E_T^{miss} (>70GeV)
(trigger rate: ~20 Hz (for $2\times10^{33}cm^{-2}s^{-1}$))

→ Expected events at $1fb^{-1}$ after tau mode selection cuts:
(S: signal, B: background)

	S	B	$S/\sqrt{B}$
SU3	259	51	36.3
SU6	119	51	16.7

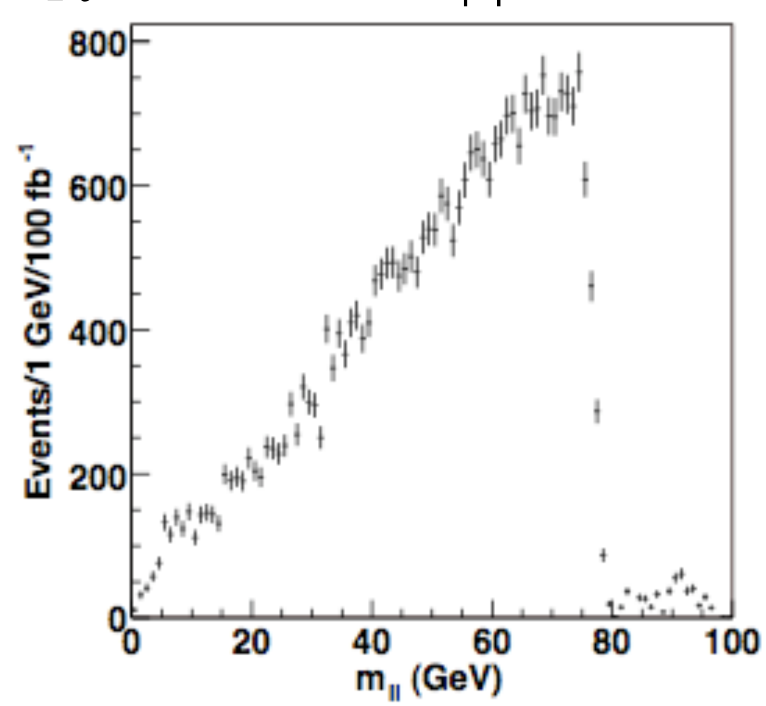
Exclusive studies: measurements

Exclusive studies:



- For SUSY discovery: show it ***is*** SUSY
  → need to measure properties
- no mass peaks because of missing LSPs
  → kinematic edges
- dilepton mass spectrum holds information about SUSY masses involved in the decay chain: $\tilde{\chi}_1^0$, $\tilde{e}/\tilde{\mu}/\tilde{\tau}$, $\tilde{\chi}_2^0$

hep-ph/0410364v1



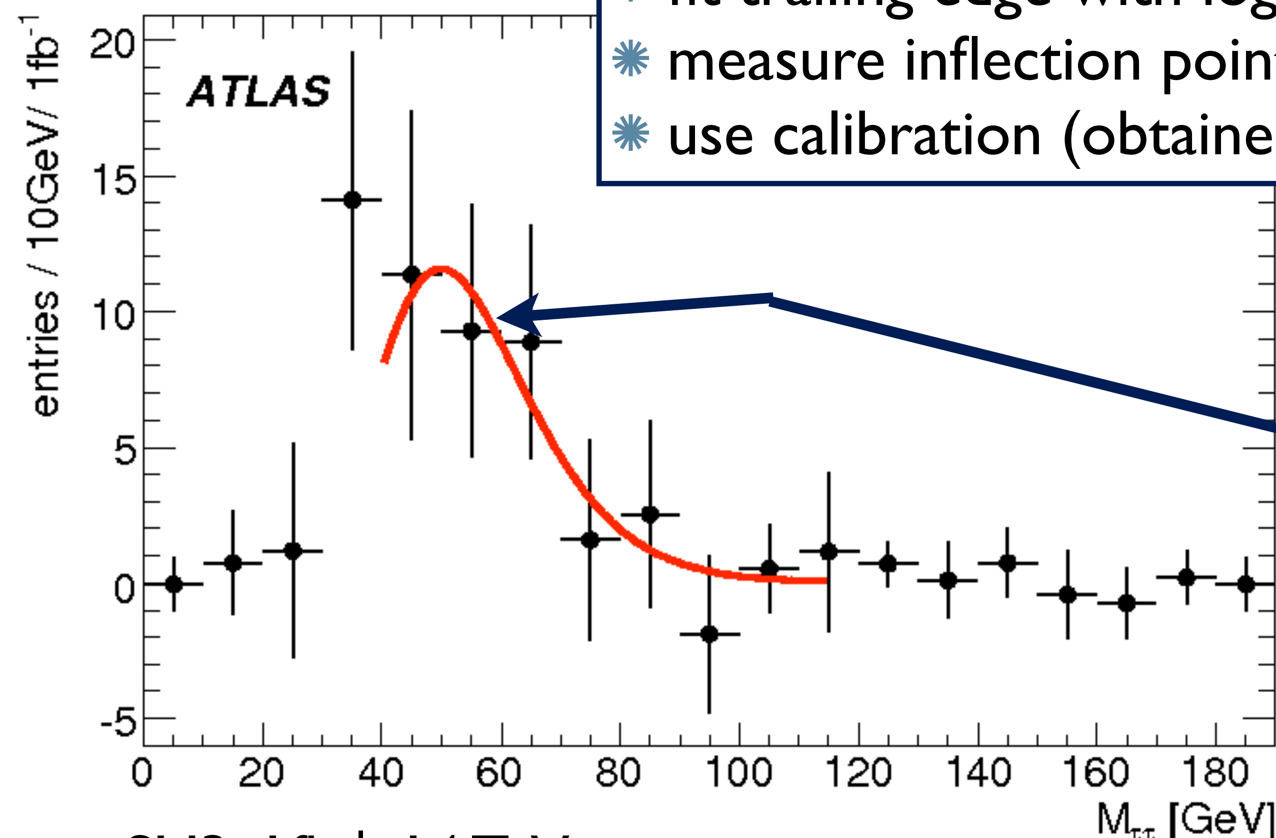
$$m_{\tau\tau}^{max} = \sqrt{\frac{\left(m(\tilde{\chi}_2^0)^2 - m(\tilde{\tau}_1)^2\right)\cdot\left(m(\tilde{\tau}_1)^2 - m(\tilde{\chi}_1^0)^2\right)}{\left(m(\tilde{\tau}_1)^2\right)}}$$

- shape of ditau mass spectrum also holds information about stau mixing angle

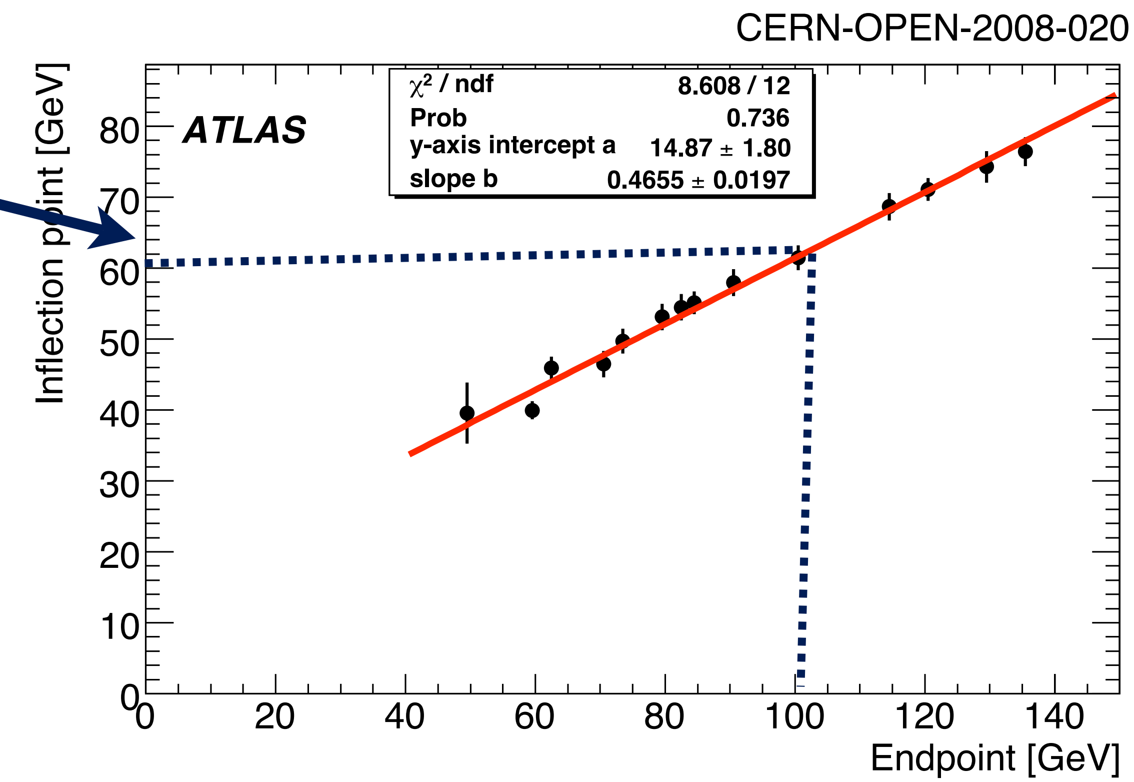
Endpoint measurement

$\tau\tau$ Invariant mass spectrum: triangular shape washed out due to tau decay

- fit trailing edge with log-normal function
- measure inflection point
- use calibration (obtained with fast detector simulation) to derive endpoint



SU3, $1 fb^{-1}$, 14 TeV



Event selection for bulk region point (SU3):

- $\geq 2\tau$ (calorimeter-seeded reconstruction)
- 4 jets: p_T>220/50/50/30GeV
- E_T^{miss} >230GeV
- $\Delta R_{\tau\tau}$<2

→ measured endpoint: (nominal value: 99 GeV)
$m_{\tau\tau}^{max} = 102 \pm 17^{stat} \pm 5.5^{syst}$ GeV (1 fb^{-1})

systematic error: includes fit uncertainty (binning, fit range) and 5% jet energy scale uncertainty

Endpoint measurement

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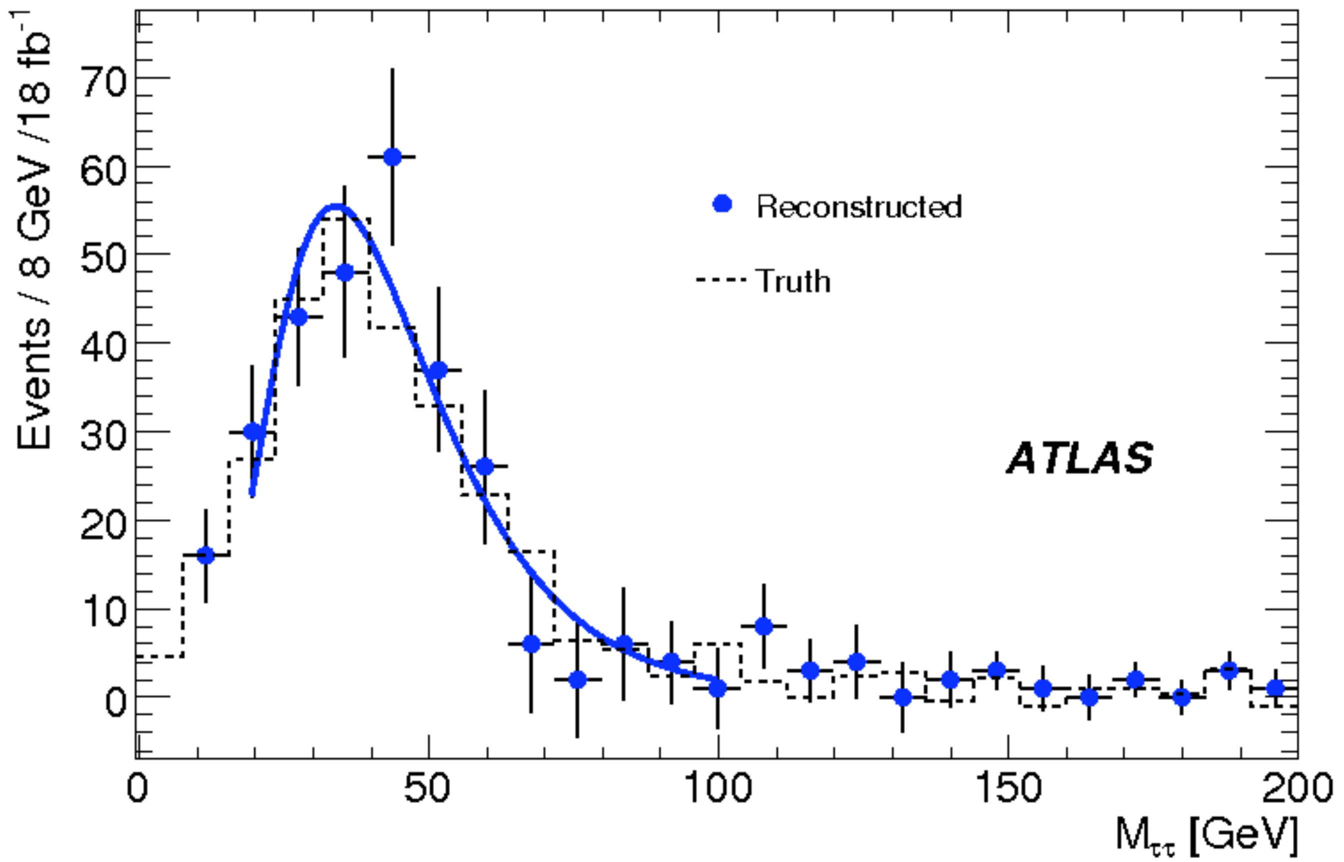
Model independence of endpoint method

- use same fit function and calibration for coannihilation point (SU1):
  - lower cross section (factor 0.4)
  - far tau very soft, hard to reconstruct

→ different event selection:

- $\geq 2\tau$ (track-seeded reconstruction)
- 2 jets: p_T>100/50GeV
- E_T^{miss} >100GeV
- elliptical cut in (E_T^{miss}, $p_T^{jet1}+p_T^{jet2}$) plane
  (semi-axes 450GeV (E_T^{miss}), 500GeV (sum jet p_T))



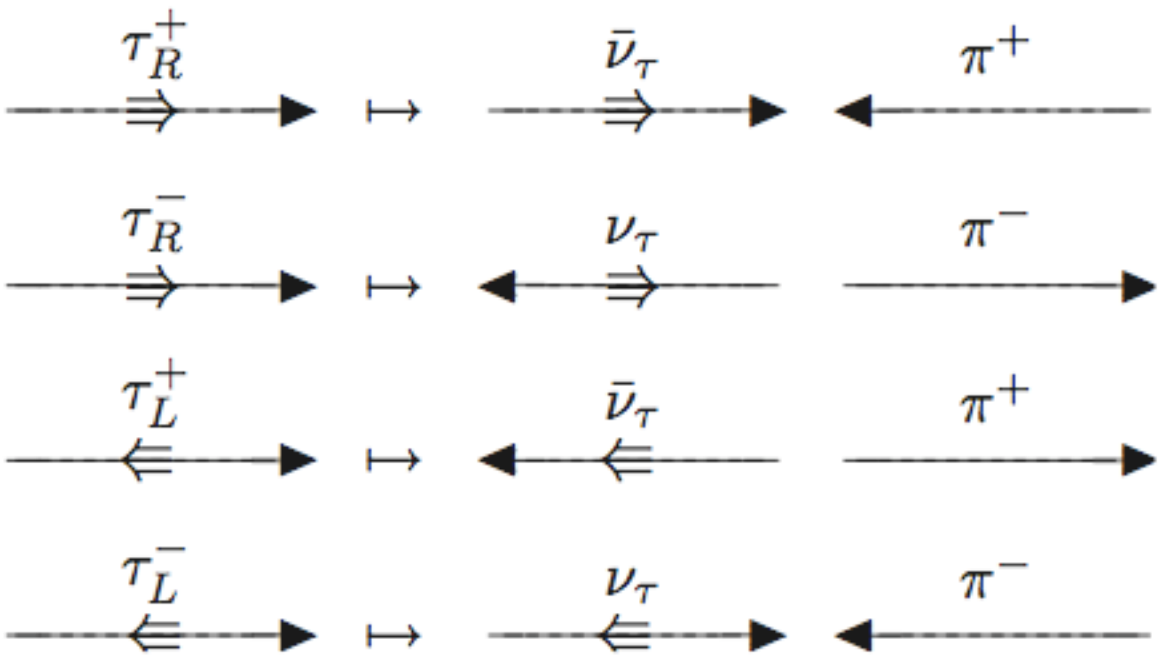
SU1, 18fb^{-1}, 14 TeV

→ measured endpoint: (nominal value: 78 GeV)
$m_{\tau\tau}^{max}$ = 70 ± 6.5^{stat} ± 5^{syst} GeV (18 fb^{-1})

- *ongoing work: use method in non-mSUGRA scenario*

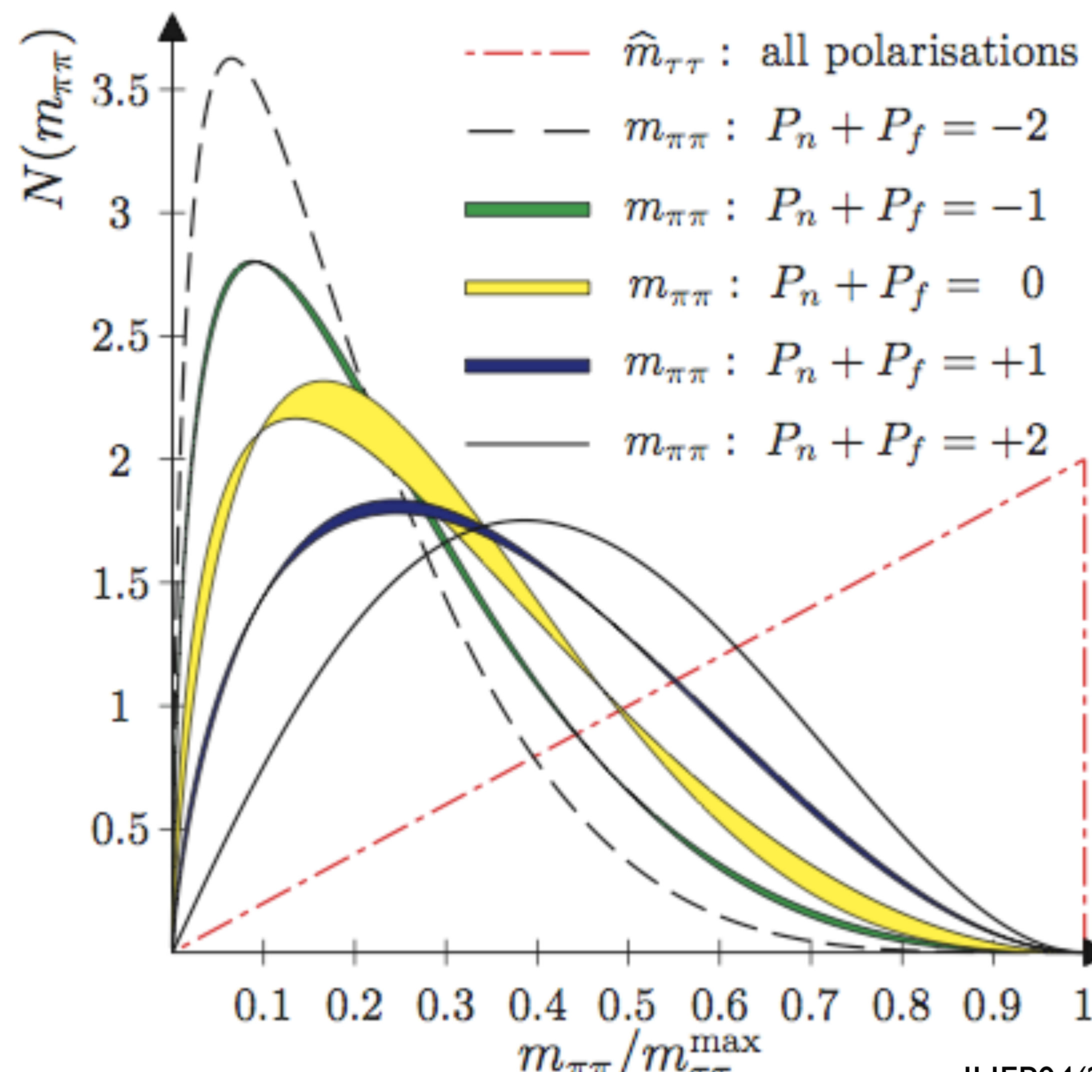
Polarization dependence

Influence of τ polarization on ττ mass spectrum:



$\tau \rightarrow \pi^{\pm}\nu_\tau$: fixed neutrino handedness
→ pion momentum boosted (anti)parallel to tau momentum, dependent on tau polarization

→ mass spectra shifted for different τ polarizations:
- ττ spectrum depends on combination of near and far τ polarization P_n+P_f and P_n*P_f
- Sum P_n+P_f has far more impact than product
- Product P_n*P_f → variation bands



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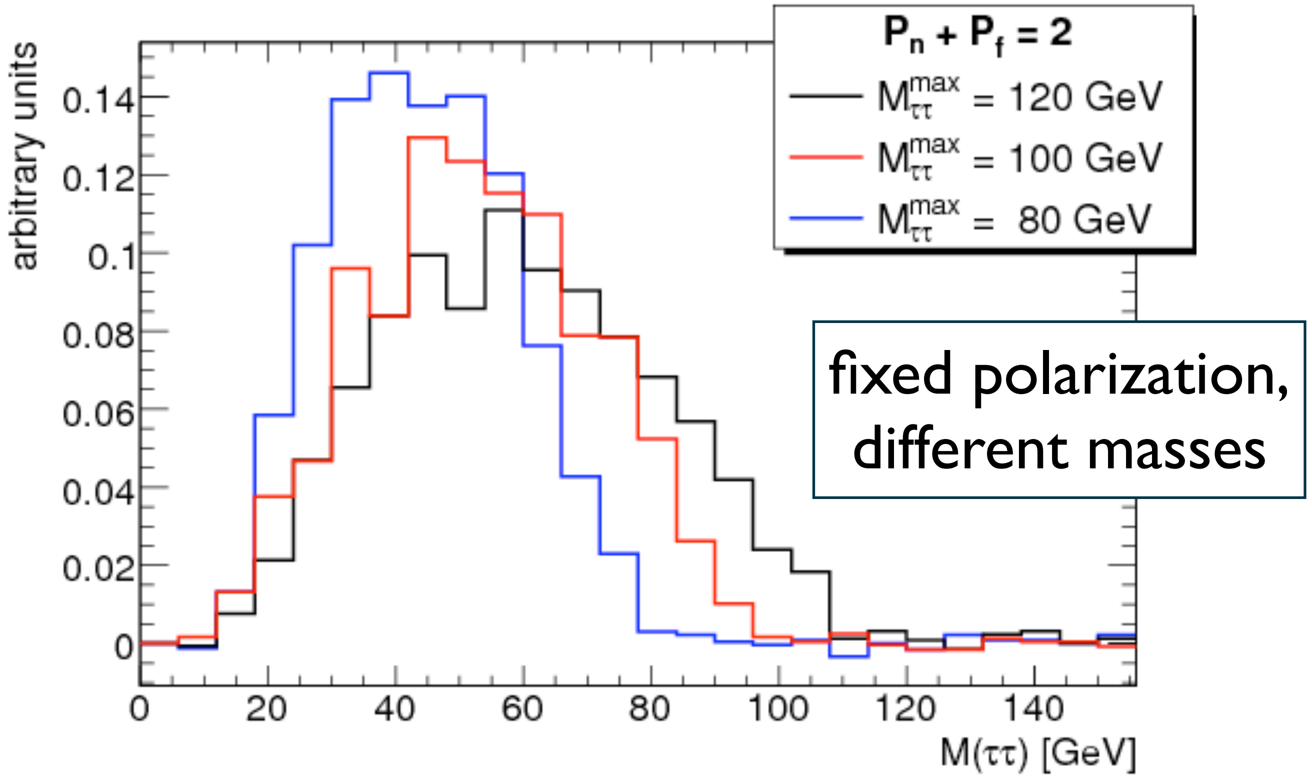
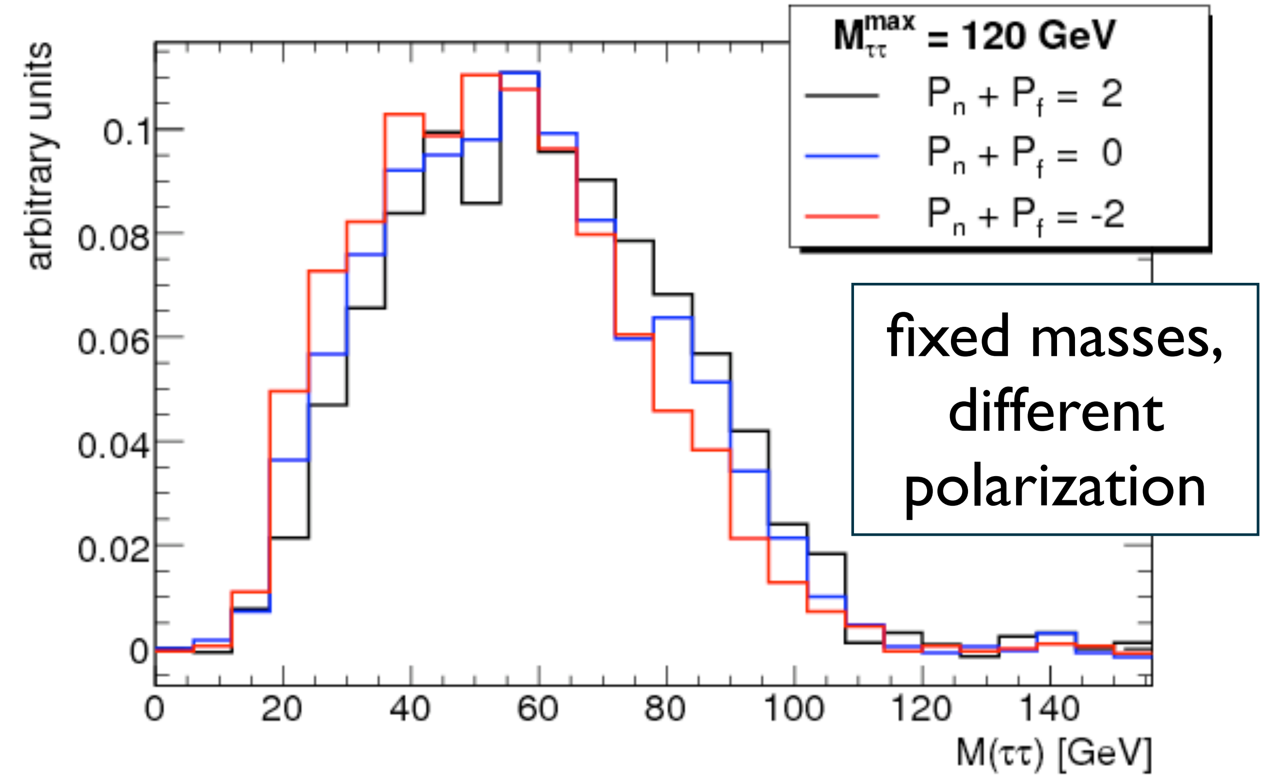
Endpoint and polarization measurement

SUSY masses and τ polarizations change spectrum in different way

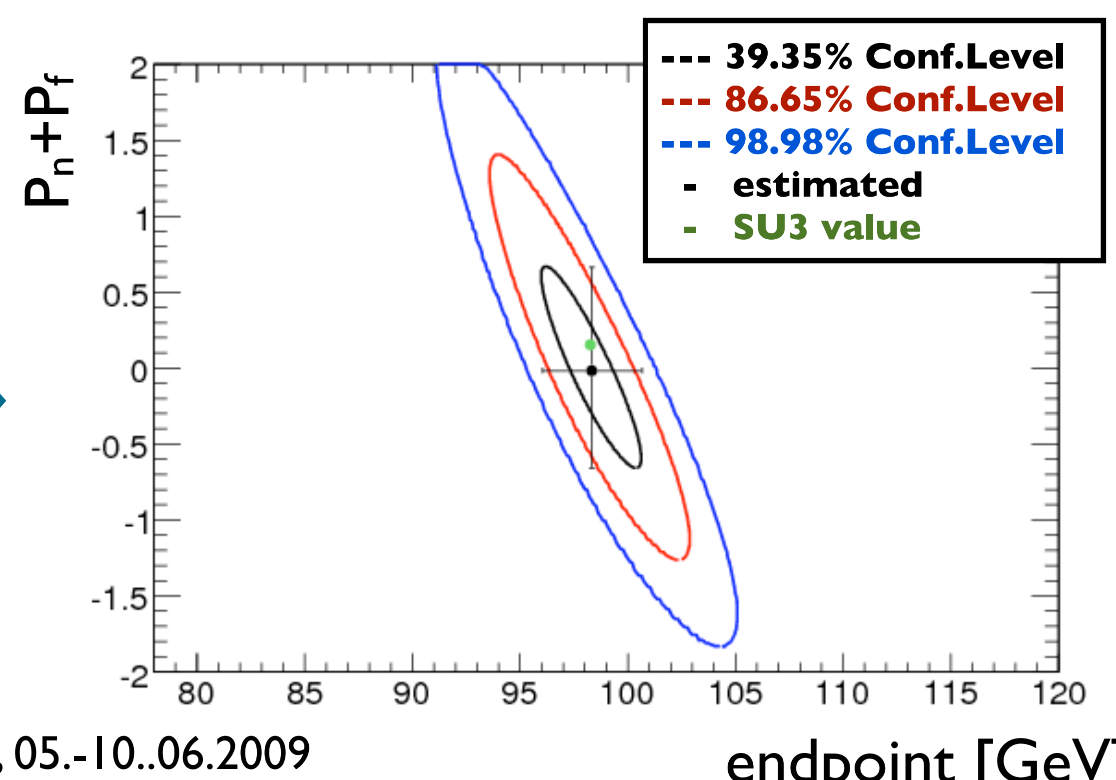
→ fit spectrum with gaussian: more stable to polarization effects than log-normal function





→ measure both with 2 observables:
$x(f^{max})$, $x(0.1*f^{max})$

→ 2dim calibration



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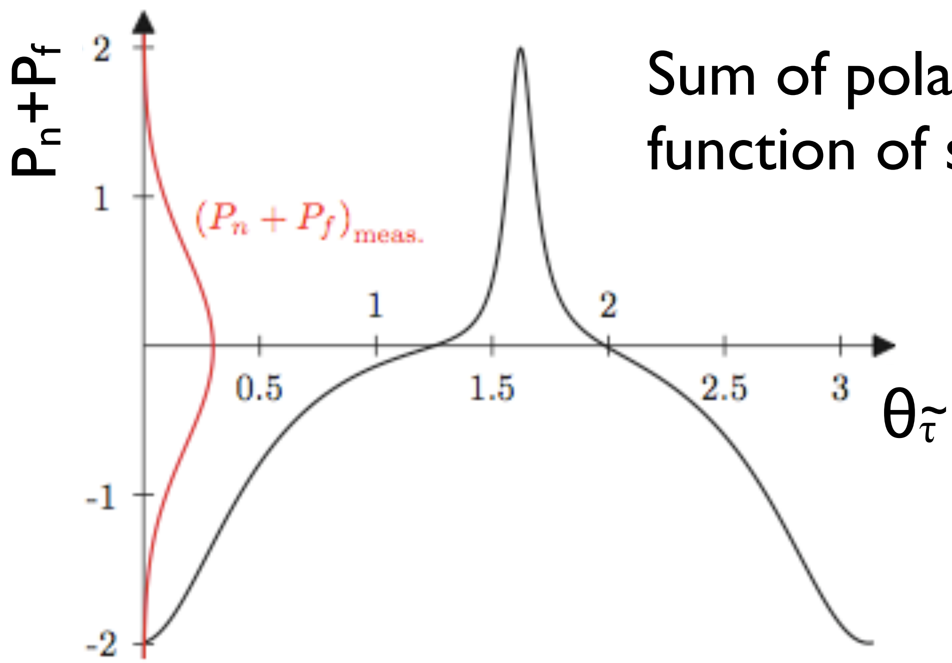
Fast detector simulation

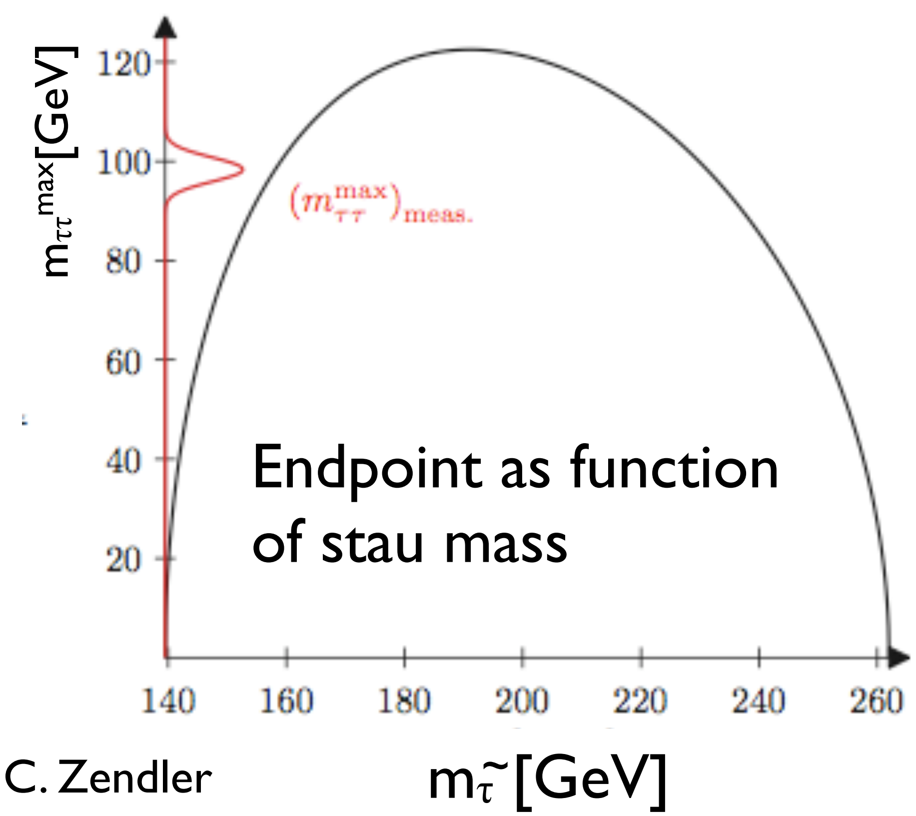
Constraints on mixing angle and stau mass:

Sum of polarizations as function of stau mixing angle



assumption:
neutralino sector known from other measurements
here: nominal values of SU1

Endpoint as function of stau mass



Implication of measured values on SUSY parameters

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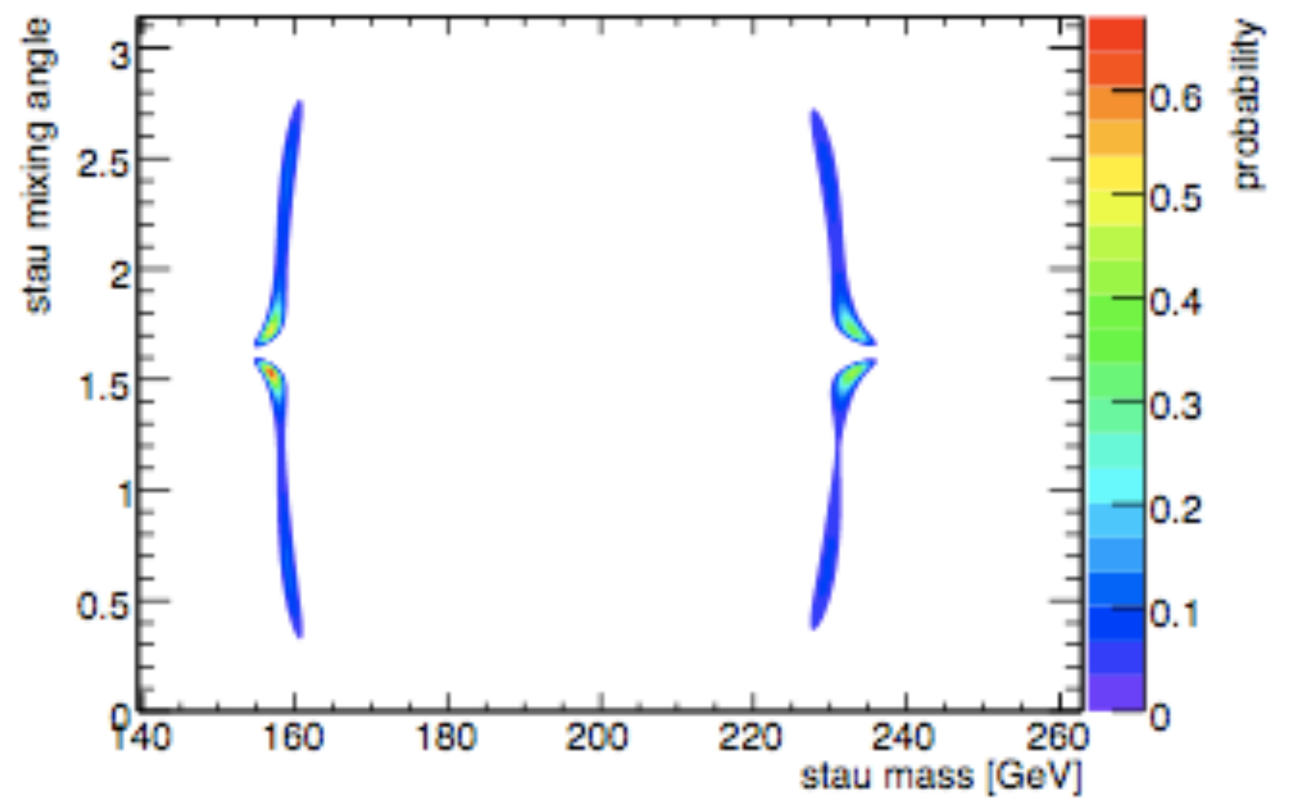
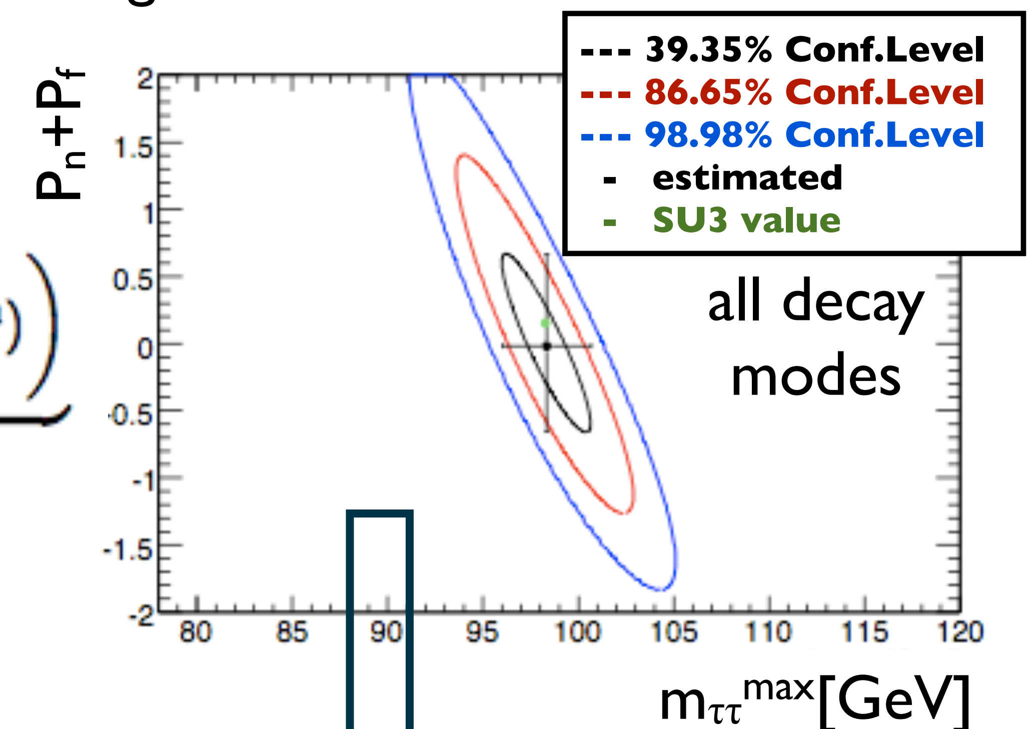


Improvement by separation of decay modes

Possible improvement by separation of τ decay modes:

- τ decay via vector mesons ρ, a_1: direction of boost different for longitudinal/tranversal mesons:
  - longitudinally polarized: same as pion
  - transversally polarized meson: opposite behaviour
  - → overall effect depends on relative branching ratio

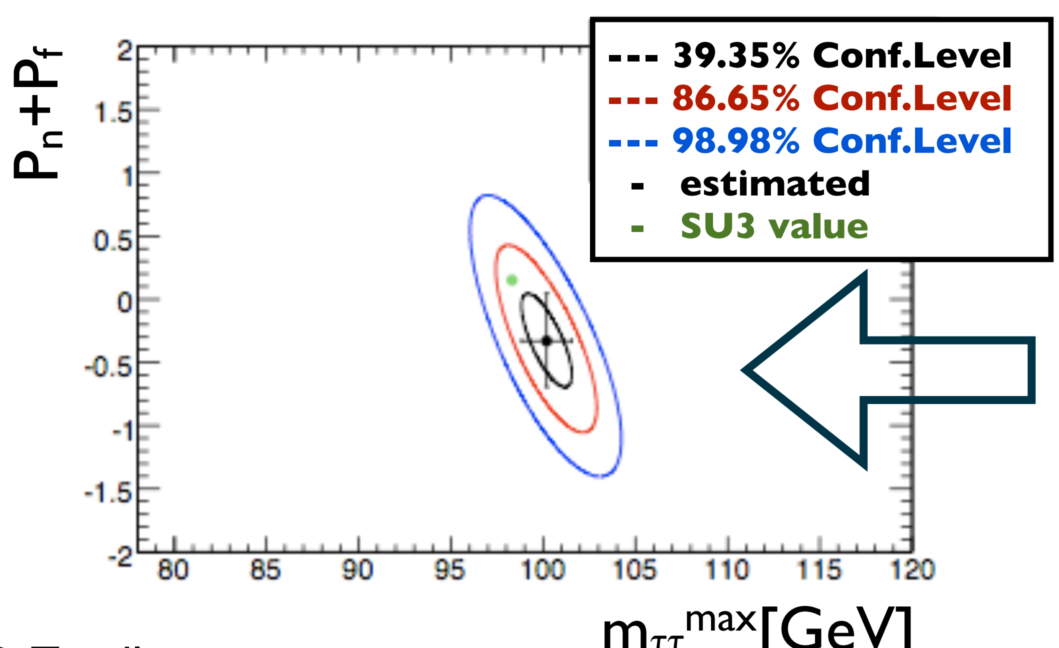
$$\frac{1}{\Gamma_v}\frac{d\Gamma_v}{d\cos\vartheta} = \underbrace{\left(\frac{m_v^2}{m_\tau^2 + 2m_v^2}(1 - P_\tau \cos\vartheta)\right)}_{\text{transversal}} + \underbrace{\left(\frac{\frac{1}{2}m_\tau^2}{m_\tau^2 + 2m_v^2}(1 + P_\tau \cos\vartheta)\right)}_{\text{longitudinal}}$$



- a_1: same amount of longitudinal and transverse states
  - → inv. mass spectrum not affect by polarization effects
- ρ: more longitudinal than transverse states
  - → inv. mass spectrum shifted in same direction as for π decays

- Assume ideal tau decay mode separation
- Fake taus: assigned to decay mode with probability of BR

- divide spectrum in affected (π,K, ρ)/ not affected
  → 3x2 observables



Fast detector simulation

Tau decay mode reconstruction

Reconstruction of π^0 subclusters:

- High granularity of ATLAS electromagnetic calorimeter allows reconstruction of isolated subclusters from π^0

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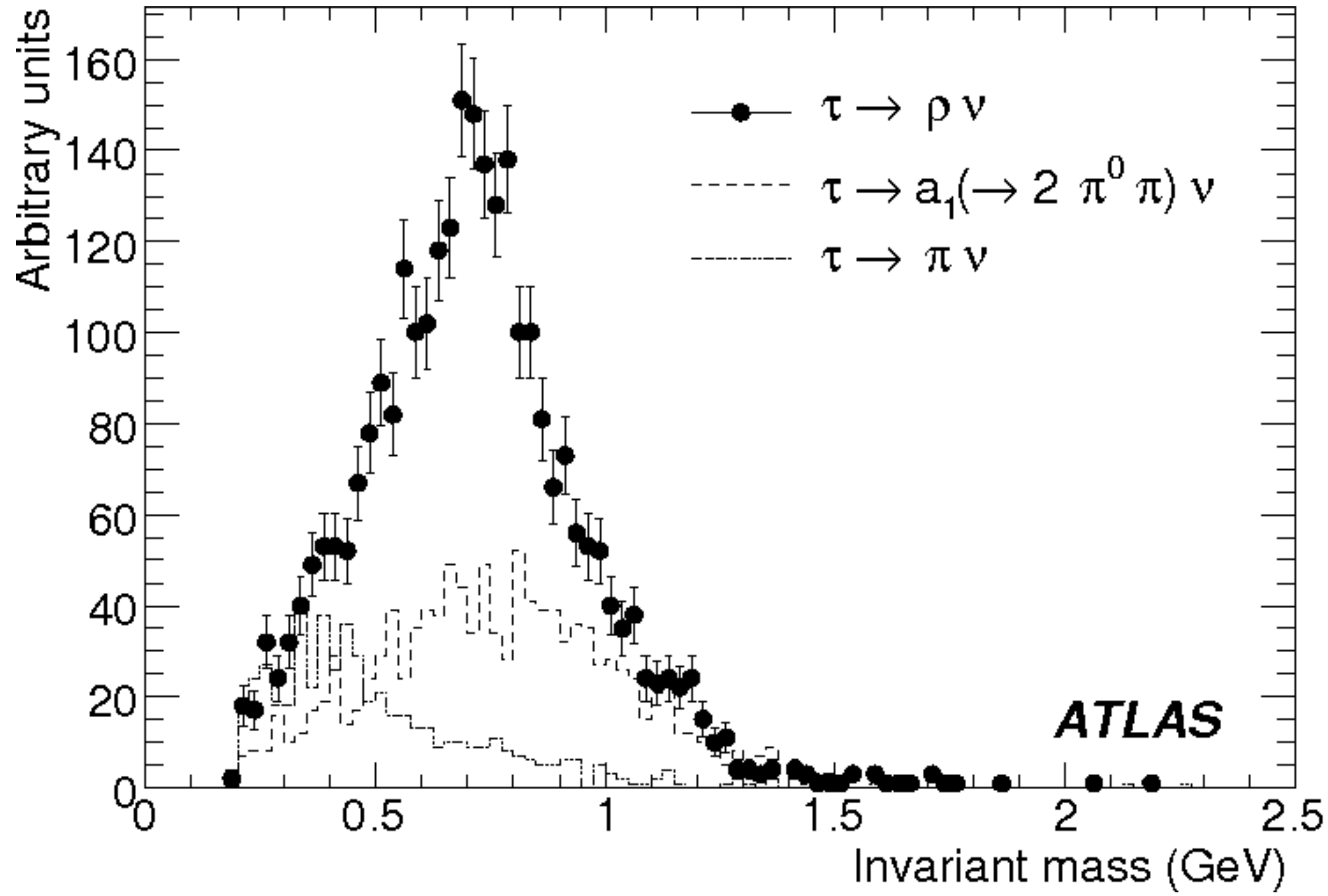


Invariant mass: candidates with at least one reconstructed π^0 subcluster, from $W\to\tau\nu_\tau$

1prong candidates:

decay mode	no π^0 subclusters	1 π^0 subcluster	≥ 2 π^0 subclusters
$\tau\to\pi\nu_\tau$	65%	20%	15%
$\tau\to\rho\nu_\tau$	15%	50%	35%
$\tau\to a_1(\to 2\pi^0\pi)\nu_\tau$	9%	34%	57%

Summary

- Taus are important for SUSY
  → needed for searches and measurements
- Endpoint of $\tau\tau$ invariant mass spectrum can be measured accurately with ~1fb^{-1}
  → constraint on $\tilde{\tau}_1$ mass
- Sum of polarizations can be measured additionally with ~35fb^{-1}
  → constraint on $\tilde{\tau}$ mixing angle $\theta_{\tilde{\tau}}$
- Performance of tau reconstruction and identification crucial
  → high reconstruction efficiency for visible signals
  → high purity for meaningful signals
  → information about tau decay could improve measurements significantly

backup

Tau reconstruction

Reconstruction

- Begin with track based algorithm
  - Seed: high quality track (p_T>6GeV, requirements on #hits in subdetectors and χ^2/ndf)
  - additional quality tracks (p_T>1GeV) in cone $\Delta R<0.2$
  - η, ϕ reconstruction with p_T-weighting of tracks
  - check charge consistency
- search matching calorimeter seed
  - Jet "Cone4H1TopoJet" (E_T>10GeV, $|\eta|<2.5$) within $\Delta R<0.2$

→ no match: track-only candidate (5%)

- E_T from EnergyFlow algorithm

→ match: track+calorimeter seeded candidate (70%)

- E_T from cells of calorimeter based algorithm

- remaining clusters: seeds for calorimeter-only candidates (25%)
  - η, ϕ reconstruction from cluster
  - looser track quality selection (p_T>1GeV)

Tau reconstruction and identification

Identification

Discriminating variables:

- variance W_{tracks} (multiprong only)
- invariant mass of track system
- #tracks in isolation cone
- electromagnetic radius R_{em}
- # η strips with certain energy deposit
- width of the energy deposit
- E_T fraction in cone $0.1<\Delta R<0.2$ w.r.t. total energy in cone 0.2
- transverse energy at EM scale in core cone and isolation cone E_T^{core}, E_T^{isol}, $E_T^{isolHAD}$
- hadronical E_T fraction in core region w.r.t. sum p_T of tracks
- visible mass

- transverse impact parameter
- transverse flight path
- π^0 subclusters

safe variables:

Calorimter-based:

- radius in EM calorimeter
- isolation fraction
- width in strip layer
- $E_T(EM)/E_T$

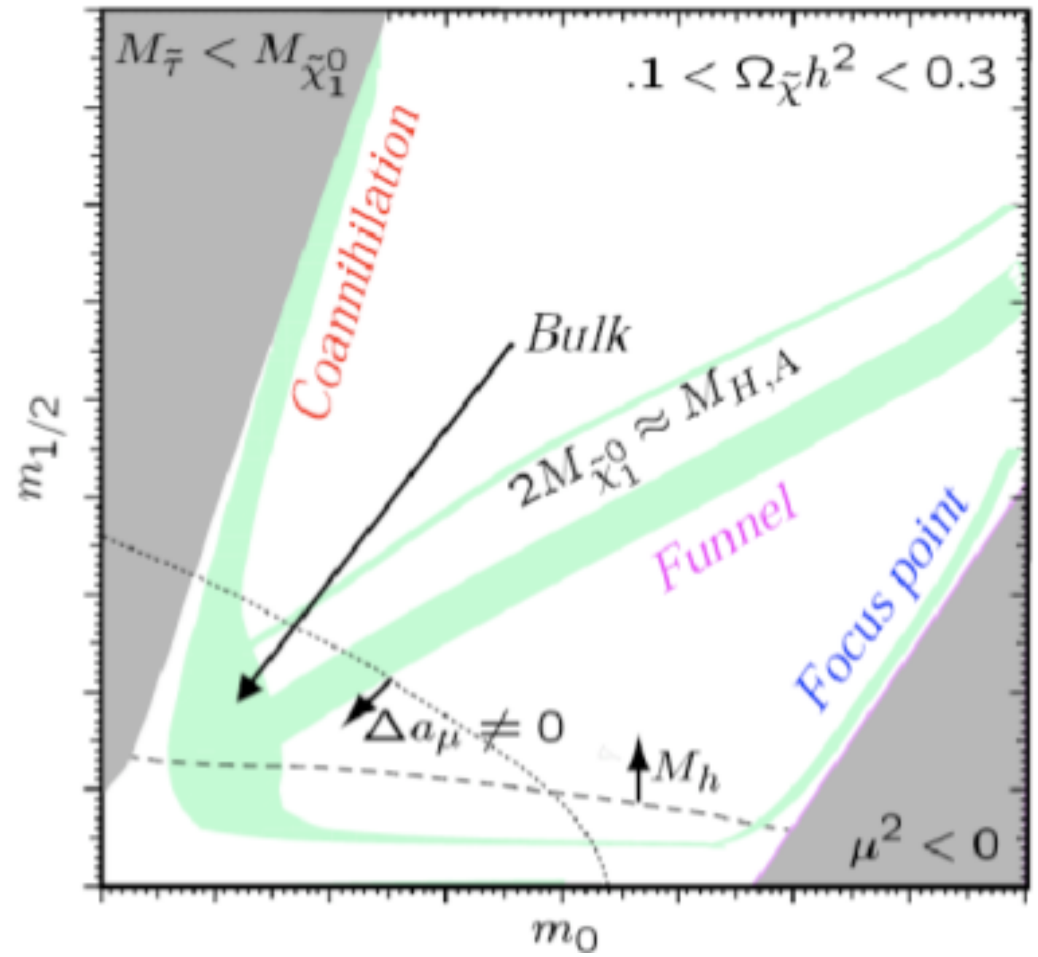
→ uses only calorimeter information

additional for track+calorimter-based:

- width of track momenta
- E_T/p_T of leading track
- electromagnetic and hadronic E_T fraction w.r.t. sum p_T of tracks
- sum p_T of tracks / E_T

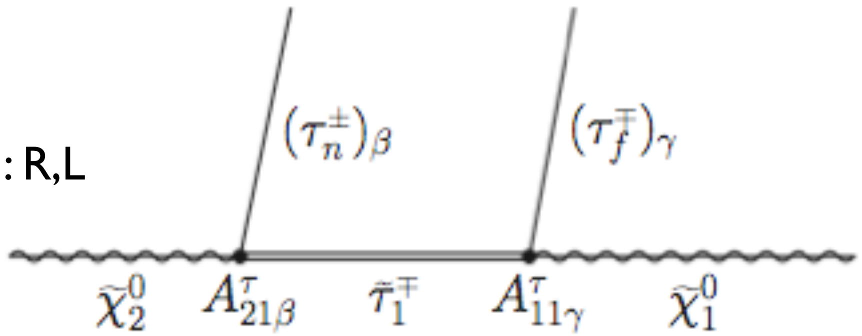
mSUGRA benchmark points used:

	m_0 [GeV]	$m_{1/2}$ [GeV]	A_0 [GeV]	tanβ	sgn μ
SU1 coannihilation	70	350	0	10	+
SU3 bulk	100	300	-300	6	+
SU6 funnel	320	375	0	50	+



Tau polarization

β,γ : R,L



$$A^{\tau}_{j1L} = -\frac{m_\tau}{\sqrt{2} m_W \cos\beta} N^*_{j3} \sin\theta_{\tilde{\tau}} + \frac{1}{\sqrt{2}} \left(N^*_{j2} + N^*_{j1} \tan\theta_W\right) \cos\theta_{\tilde{\tau}}$$

$$A^{\tau}_{j1R} = -\frac{m_\tau}{\sqrt{2} m_W \cos\beta} N_{j3} \cos\theta_{\tilde{\tau}} - \sqrt{2} N_{j1} \tan\theta_W \sin\theta_{\tilde{\tau}} \,,$$

→ polarization: $P = \frac{\left(A^{\tau}_{j1R}\right)^2 - \left(A^{\tau}_{j1L}\right)^2}{\left(A^{\tau}_{j1R}\right)^2 + \left(A^{\tau}_{j1L}\right)^2} \,,$

Ditau mass spectrum for **$\tau \to \pi^{\pm} \nu_\tau$**

$$N(m_{\pi\pi}) = 4m \Big\{ (P_n \cdot P_f) \Big[\ln m \left(\ln m + 4m^2 + 4\right) + 4\left(1 - m^2\right) \Big] + $$
$$+ (P_n + P_f) \Big[m^2 - 2\ln m - 1 - \ln^2 m \Big] + \ln^2 m \Big\}$$

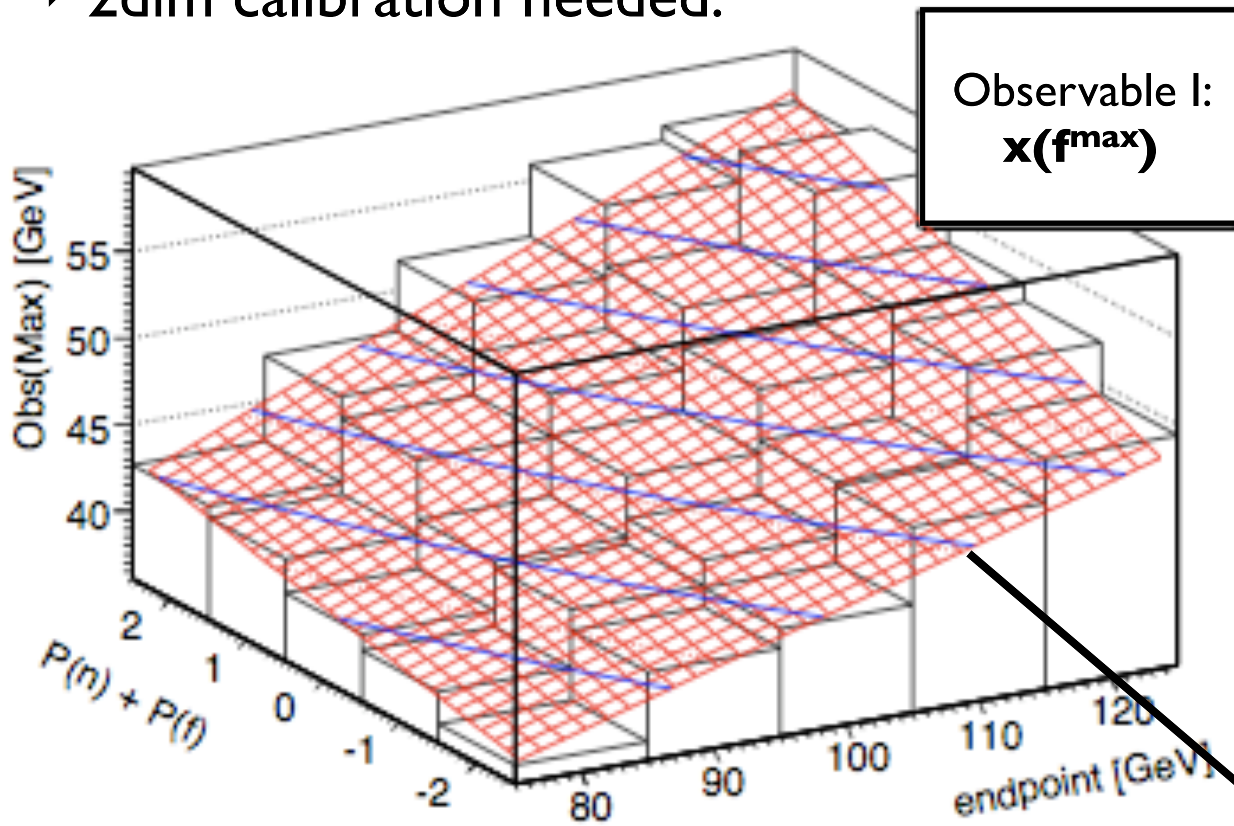
Endpoint and polarization measurement

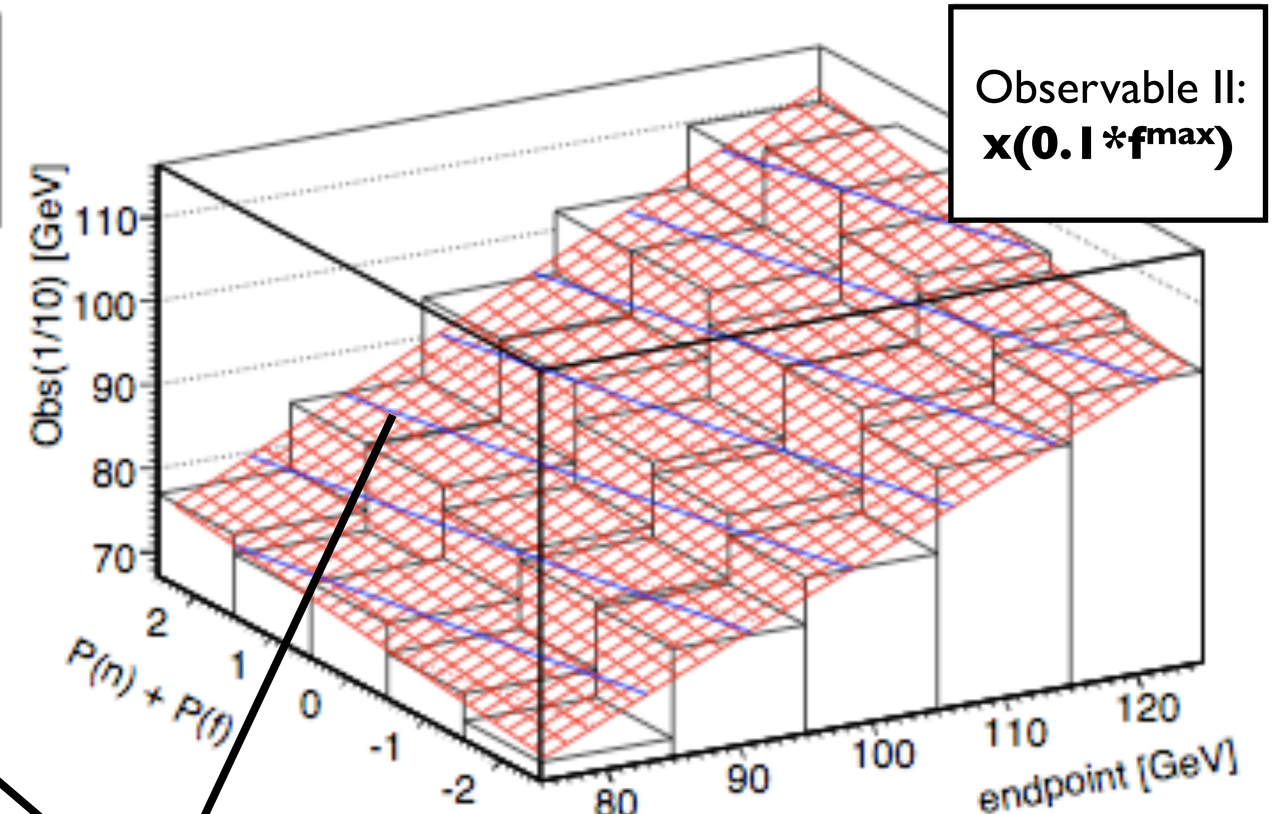
SUSY masses and τ polarizations change spectrum in different way

→ fit spectrum with gaussian: more stable to polarization effects that log-normal function

→ possible to measure both with 2 ovservables: x(f^{max}), x(0.1*f^{max})

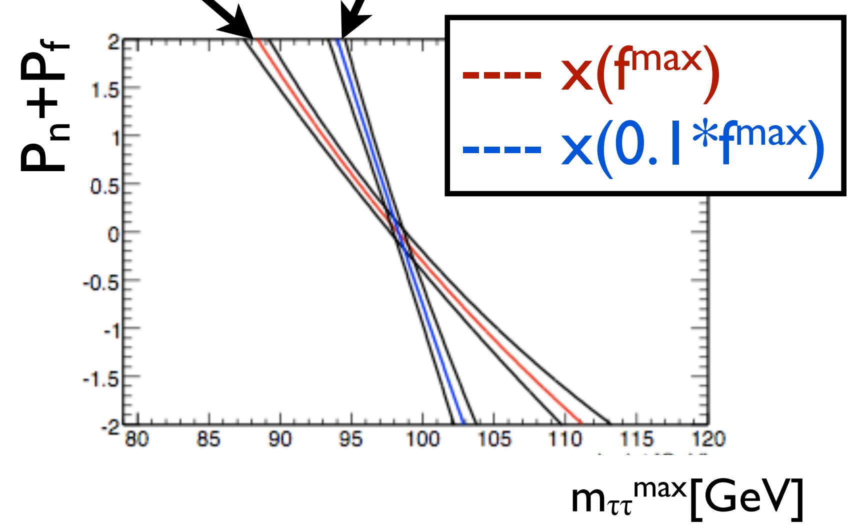
→ 2dim calibration needed:





Red plane: calibration function

Blue lines: equipotential lines



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Fast detector simulation