Study of supersymmetric tau final states with Atlas at LHC: discovery prospects and endpoint determination

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Outlook:

- supersymmetry: overview and signal
- LHC and ATLAS
- invariant mass distribution
- background and selection cuts
- endpoint measurement

Motivation for Supersymmetry

Standard Model:

- fermions → matter
  bosons → force mediation
- generation of mass via Higgs mechanism

quarks	u d	s c	b t
leptons	e ν_e	μ ν_μ	τ ν_τ

+ anti

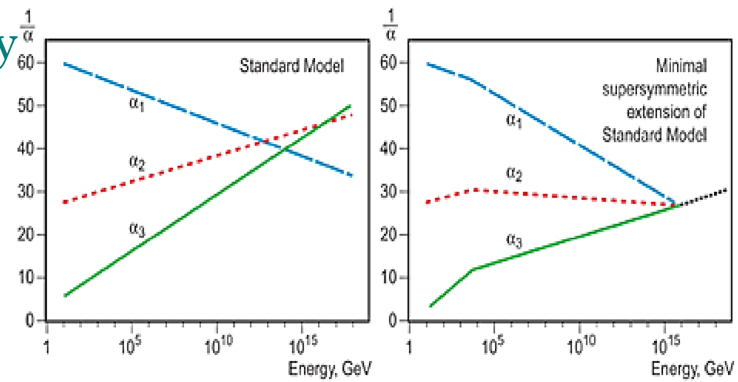
- γ (em), g (strong), Z^o, $W^\pm$ (weak)

Shortcomings:

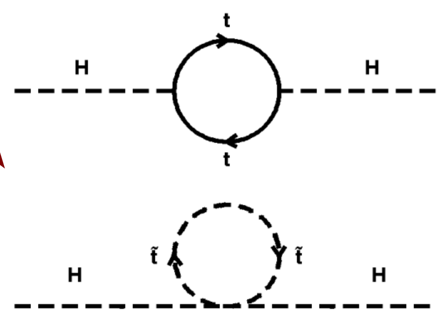
if R-Parity is conserved:
stable LSP

- no explanation for dark matter and dark energy
- unification of the coupling constants
- hierarchy problem / finetuning

with supersymmetric extension:



energy dependence changes with particle content of the theory



bosonic and fermionic contributions cancel

Supersymmetry - Overview

Supersymmetric Extension of the Standard Model:

- symmetry of fermions and bosons: every particle has a supersymmetric partner with spin ±1/2
- known particles don't built superpartners ► particle number doubles
- SUSY particles not observed so far ► heavy SUSY particles ► symmetry must be broken

Minimal Supersymmetric Standard Model (MSSM):

- soft susy breaking terms lead to 105 add. free parameters
- R-parity conservation: R = -1 SUSY-particles, +1 SM

$$R=(-1)^{3(B-L)+2s}$$

► pair production of SUSY particles

► lightest SUSY particle (LSP) must be stable

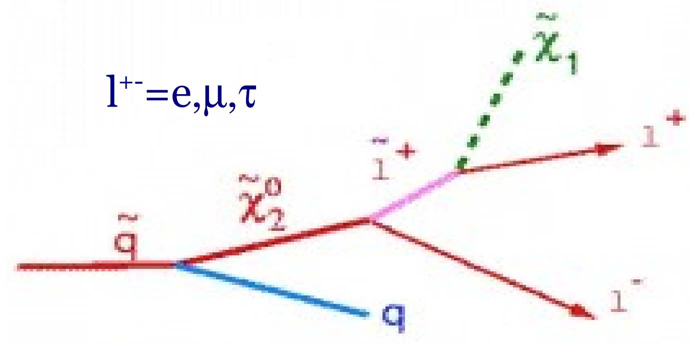
particle content with supersymmetry				
quarks	q	squarks	$\tilde{q}$	
leptons	l	sleptons	$\tilde{l}$	
neutrinos	ν	sneutrinos	$\tilde{\nu}$	
photon	γ	photino	$\tilde{\gamma}$	$\tilde{\chi}^0_{1,2,3,4}$
W, Z-Bosons	$W^{\pm}, Z$	wino, zino	$\tilde{W}^{\pm}, \tilde{Z}$	
gluons	g	gluinos	$\tilde{g}$	$\tilde{\chi}^{\pm}_{1,2}$
higgs-bosons	$h, H, A, H^{\pm}$	higgsinos	$\tilde{H}^0_1, \tilde{H}^0_2, \tilde{H}^-_1, \tilde{H}^+_2$	

mSUGRA:

- SUSY breaking via gravity
- only 5 additional free parameters left:
  - m_0: scalar mass at GUT scale
  - $m_{1/2}$: fermion mass at GUT scale
  - tanβ: ratio of Higgs vacuum expectation values
  - A_0: coupling constant Higgs-Sfermion-Sfermion
  - sgnμ: sign of higgsino mixing parameter μ

Signal

- Signal Channel: $\chi_2^o \rightarrow \tau^{\pm}\tau^{\mp}\chi_1^o$
- two typical ATLAS points in the **mSUGRA** parameter space:
  - SU1: *coannihilation-region*
  - SU3: *bulk-region*

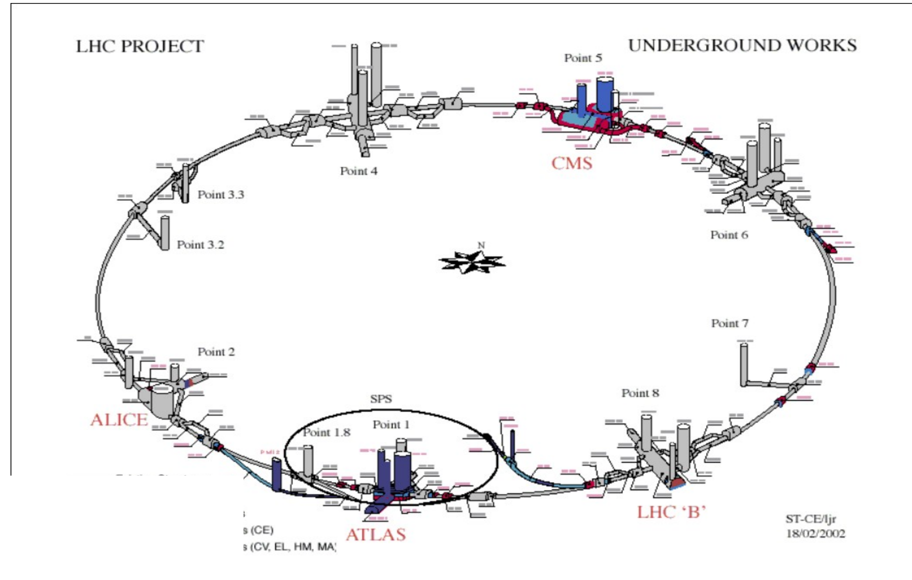


	SU1	SU3
m_0	70 GeV	100 GeV
$m_{1/2}$	350 GeV	300 GeV
A_0	0 GeV	-300 GeV
Tanβ	10	6
Sgnμ	+	+
$\Delta m(\tilde{\tau}_1-\chi_1^0)$	9GeV	32GeV

- $BR(\chi_2^0 \rightarrow e^+e^- \chi_1^0) \approx BR(\chi_2^0 \rightarrow \mu^+\mu^- \chi_1^0)$
  $\approx 0.25 * BR(\chi_2^0 \rightarrow \tau^+\tau^- \chi_1^0)$ *(SU1)*
  $\approx 0.1 * BR(\chi_2^0 \rightarrow \tau^+\tau^- \chi_1^0)$ *(SU3)*
  -> ***factor 4 to 10 more taus*** *than electrons/muons from* χ_2^0*-decays*

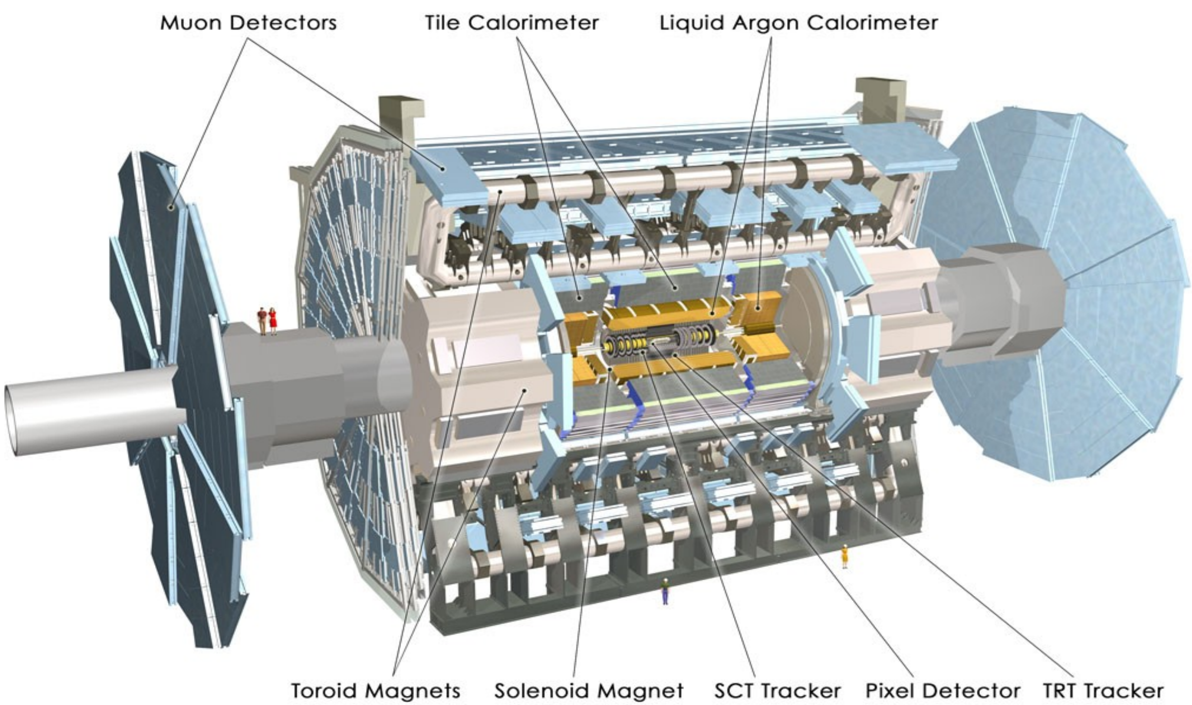
- goal:
  SUSY-masses can be measured via combinations of invariant masses in the decay chain – here: $\mathbf{m_{\tau\tau}}$

The Atlas-Detector at the LHC



Large Hadron Collider:

- 27 km circumference (built in LEP-tunnel)
- proton-proton-collisions at 14 TeV
- luminosity: 10^{33}-10^{34} $cm^{-2}s^{-1}$
- bunch crossing every 25 ns
- 10^{11} particles per bunch



A Toroidal LHC Apparatus:

- length: 46m
- diameter: 22m
- weight: 7000 t
- study done with fast simulation (ATLFAST) of the detector: four-vectors of particles "smeared" with gaussian

Invariant Mass Distribution: Exspectation

- LSP not detectable

  ► no mass peak

- kinematic endpoint at

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

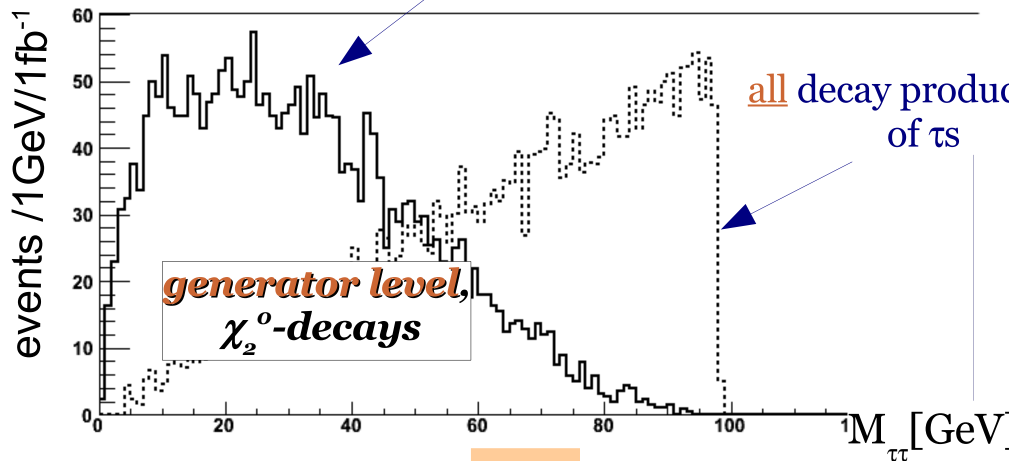
► $m_{\tau\tau}^{max}= {}^{76\,GeV\,(SU1)}_{98\,GeV\,(SU3)}$

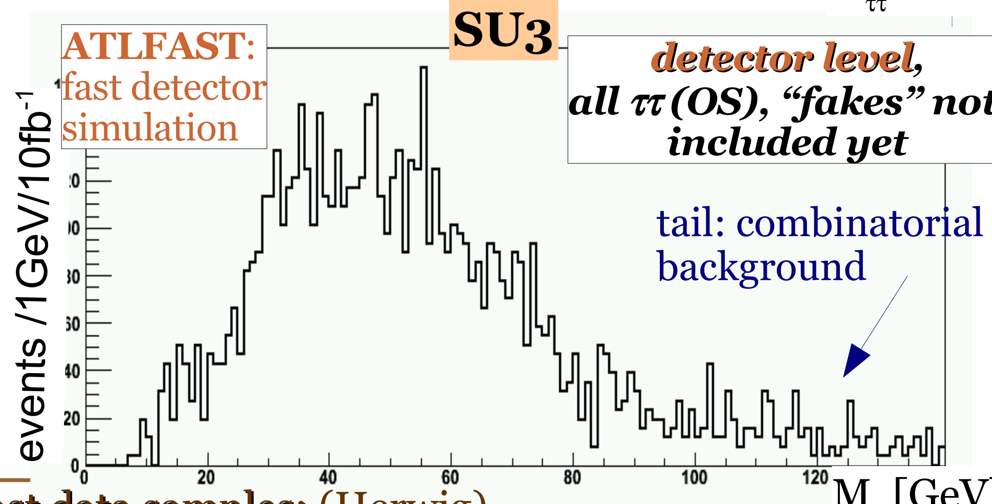
- endpoint for ττ washed out due to neutrinos (not detectable)

! only hadronically decaying taus are considered:

$\tau^{\pm}\rightarrow\pi^{\pm}\nu+n\pi^0$ (1 prong)

$\tau^{\pm}\rightarrow\pi^{\pm}\pi^{\mp}\pi^{\pm}\nu+n\pi^0$ (3 prong)





Atlfast data samples: (Herwig)
- 11.0.42: 1.4M ev. ≃ 73 fb^{-1} **SU3**, 600k ev. ≃ 77 fb^{-1} **SU1**
- 12.0.64 + 12.0.7: 1.5 M ev. ≃ 79 fb^{-1} **SU3**

Tau-ID: parameterizations based on full simulation

11.0.4: Atlfast B

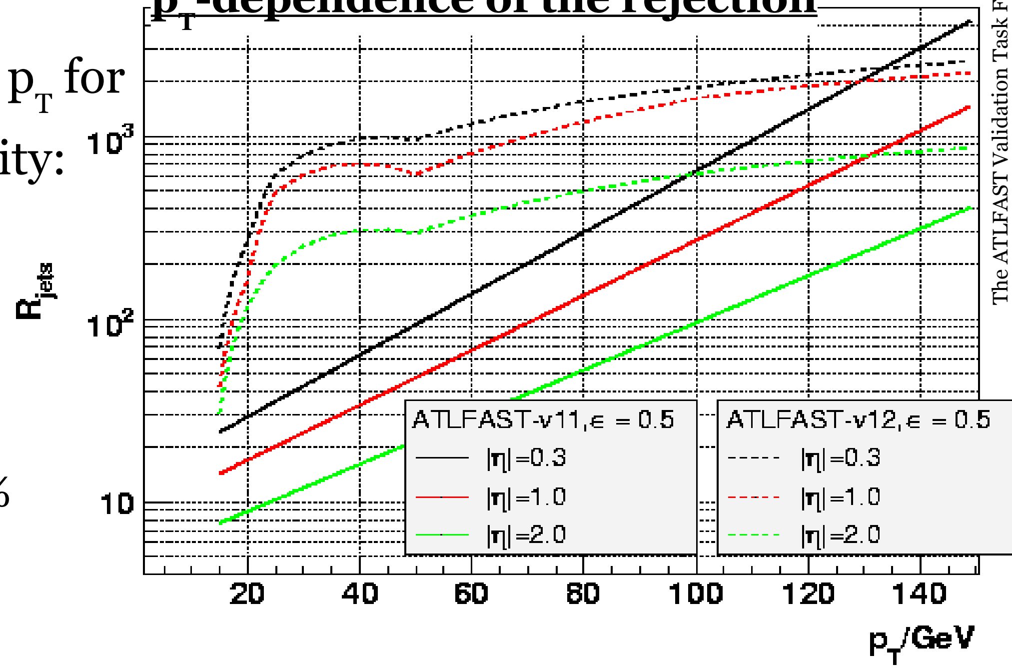
- fake tau jets parameterized in p_T for three ranges of pseudorapidity: $|\eta| < 0.7$, $0.7 < |\eta| < 1.5$ and $1.5 < |\eta| < 2.5$

$$\eta = -\ln(\tan(\frac{\theta}{2}))$$

tested different efficiencies: 30 %: poor statistics 70 %: too many fakes

→ 50%

p_T-dependence of the rejection



The ATLFAST Validation Task Force: Performance of the ATLAS fast simulation ATLFAST ATL-COM-PHYS-2007-012

12.0.6: TauRec/Tau1p3p

- performance of *calorimeter based* TauRec and *track based* Tau1p3p algorithm parametrized via tables of efficiency and rejection values for different p_T and ´
- default mean efficiencies (used here):
  - TauRec: 50 %
  - Tau1p3p: 35 % (1p) / 8 % (3p)

◆ whole study done in Athena **11.0.4** ◆ currently confirming results in Athena **12.0.6**

Background

Took subsample of official production done by SUSY WG, gen. with Alpgen:
- 11.0.41: Z, tt, W, multijets, bb
- 12.0.64: Z, tt, Wbb, sliced multijets

Z + (1-5)Jets:

- Z -> νν
- Z -> *ll*: ττ, μμ, ee

L (fb^{-1}):
0.2-20 per sample
2-20 per sample

tt + (0-3)Jets:

- tt -> bb + *l*ν *l*ν
- tt -> bb + *l*ν qq
- tt -> bb + qq qq

L (fb^{-1}):
1-12 per sample
2-18 per sample

W + Jets:

- W + (2-5) Jets

L (fb^{-1}):
3-8 per sample
not included yet

QCD-Jets:

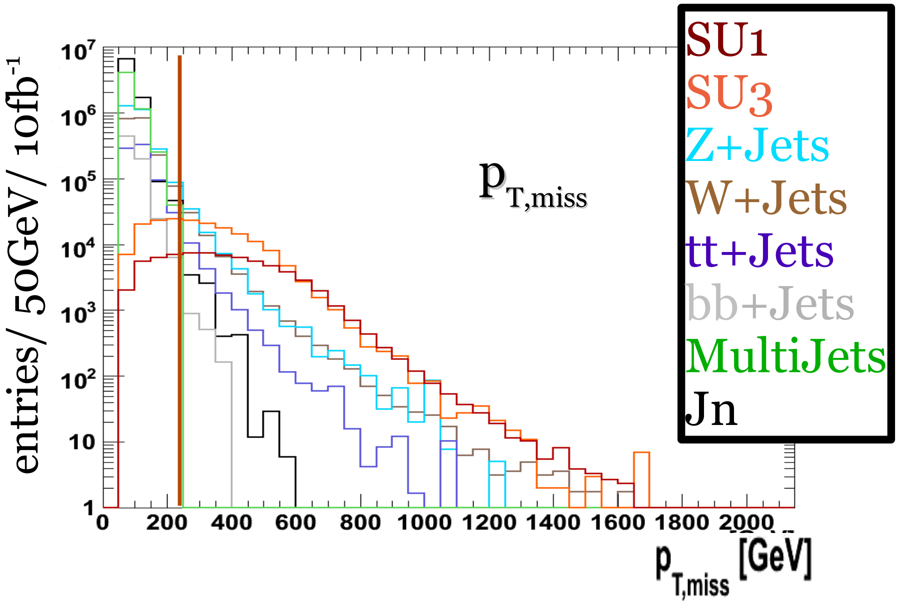
L (fb^{-1}):
10^{-5}-400 per sample
not included yet

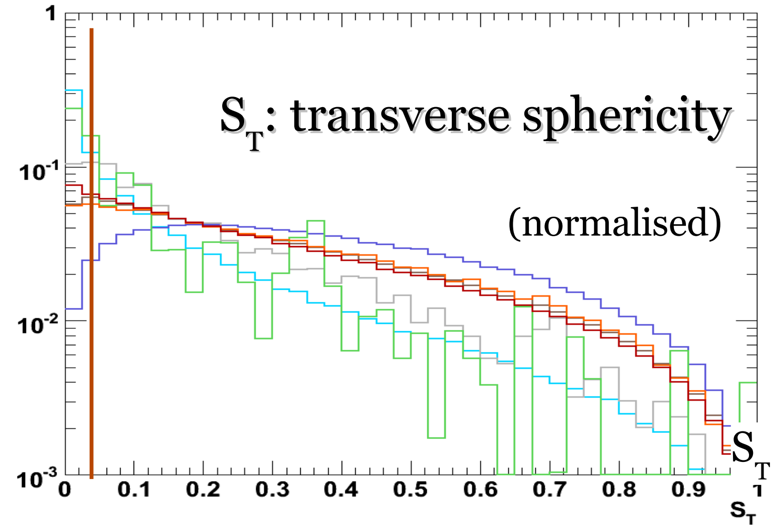
11.0.4:
- Multijets (2-5 Jets)
  bb + (1-3)Jets
- Dijets, Pythia, in p_T-bins
  (private production, with 10.0.4)

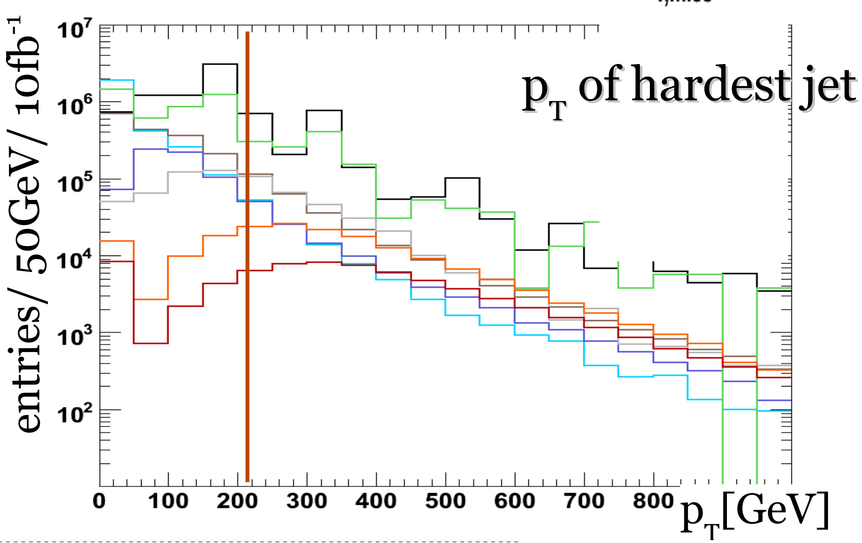
12.0.6:
sliced Alpgen Multijets

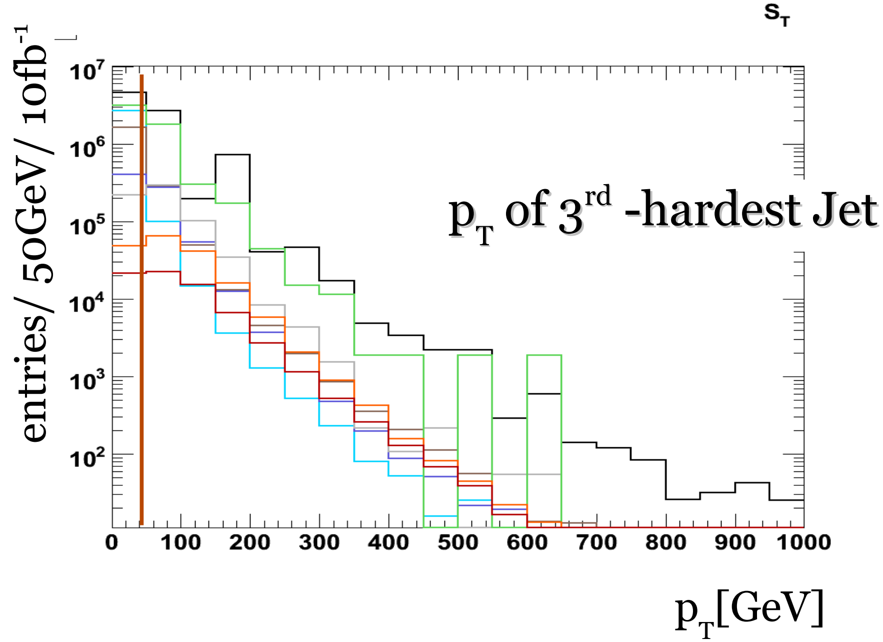
Cut Variables

- pair production of SUSY-particles, long decay-chains to LSP → phenomenology:
- spheric events, many jets, large missing Energy





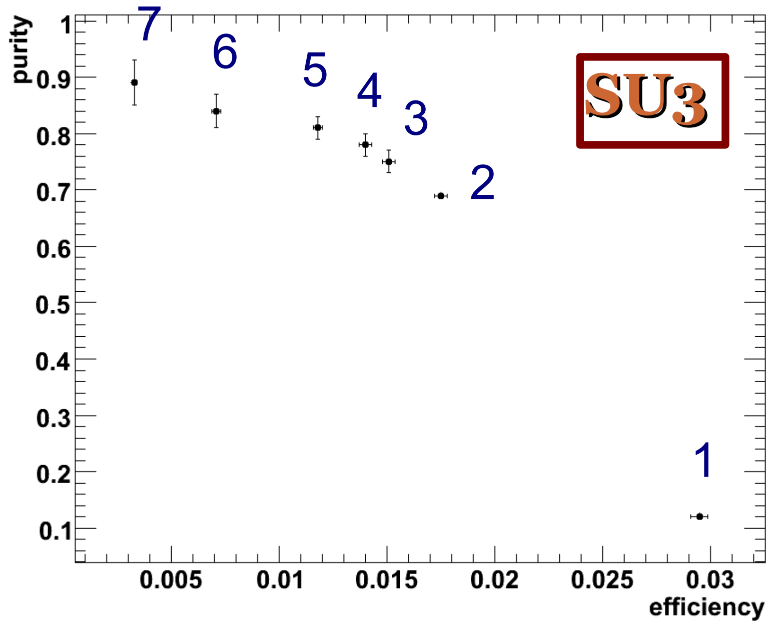


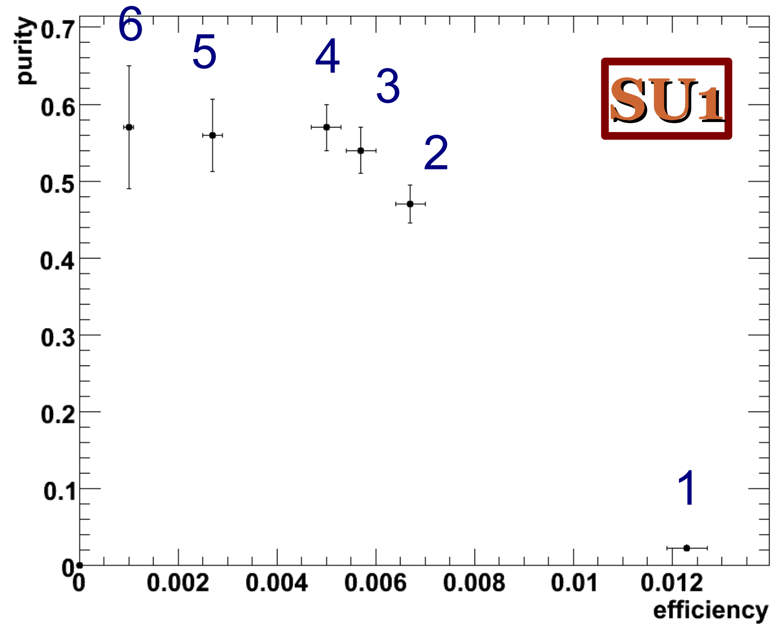


All plots with preselection-cut: $p_{T,miss}$>80GeV , and at 10 fb^{-1}

Cut Flow

$10fb^{-1}$





SU3:

1 *preselection* ($p_{T,miss}$>80GeV) + ≥ 2 τ's (28)

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2 + $p_{T,miss}$>230GeV (83)

3 + $p_T(4^{th})$>30GeV (95)

4 + $p_T(3^{rd})$>50GeV (97)

5 + $p_T(1^{st})$>220GeV (100)

6 + OS (OS=opposite sign)

7 + $\Delta R_{\tau\tau}$<2 $(\Delta R=\sqrt{\eta^2+\phi^2})$

red: significance

$$s=\frac{SUSY}{\sqrt{(BG)}}$$

$$purity=\frac{SUSY}{(BG+SUSY)}$$

$$efficiency=\frac{(SUSY\ after\ cuts)}{(all\ SUSY\ events)}$$

SU1:

1 *preselection* ($p_{T,miss}$>80GeV) + ≥ 2 τ's (5)

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2 + $p_{T,miss}$>300GeV (22)

3 + $p_T(3^{rd})$>50GeV (23)

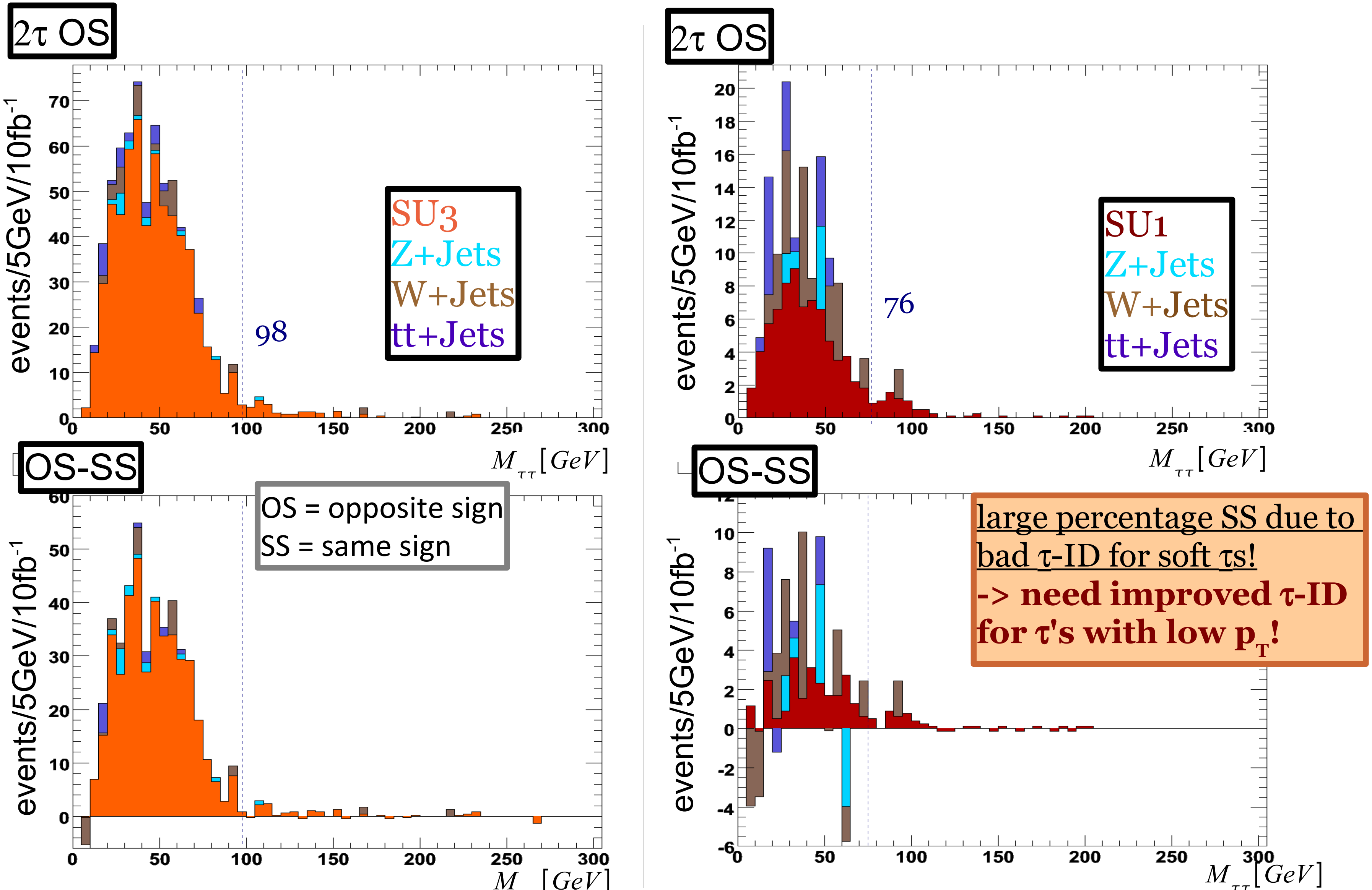
4 + S_T>0.05 (24)

5 + OS (OS=opposite sign)

6 + $\Delta R_{\tau\tau}$<2 $(\Delta R=\sqrt{\eta^2+\phi^2})$

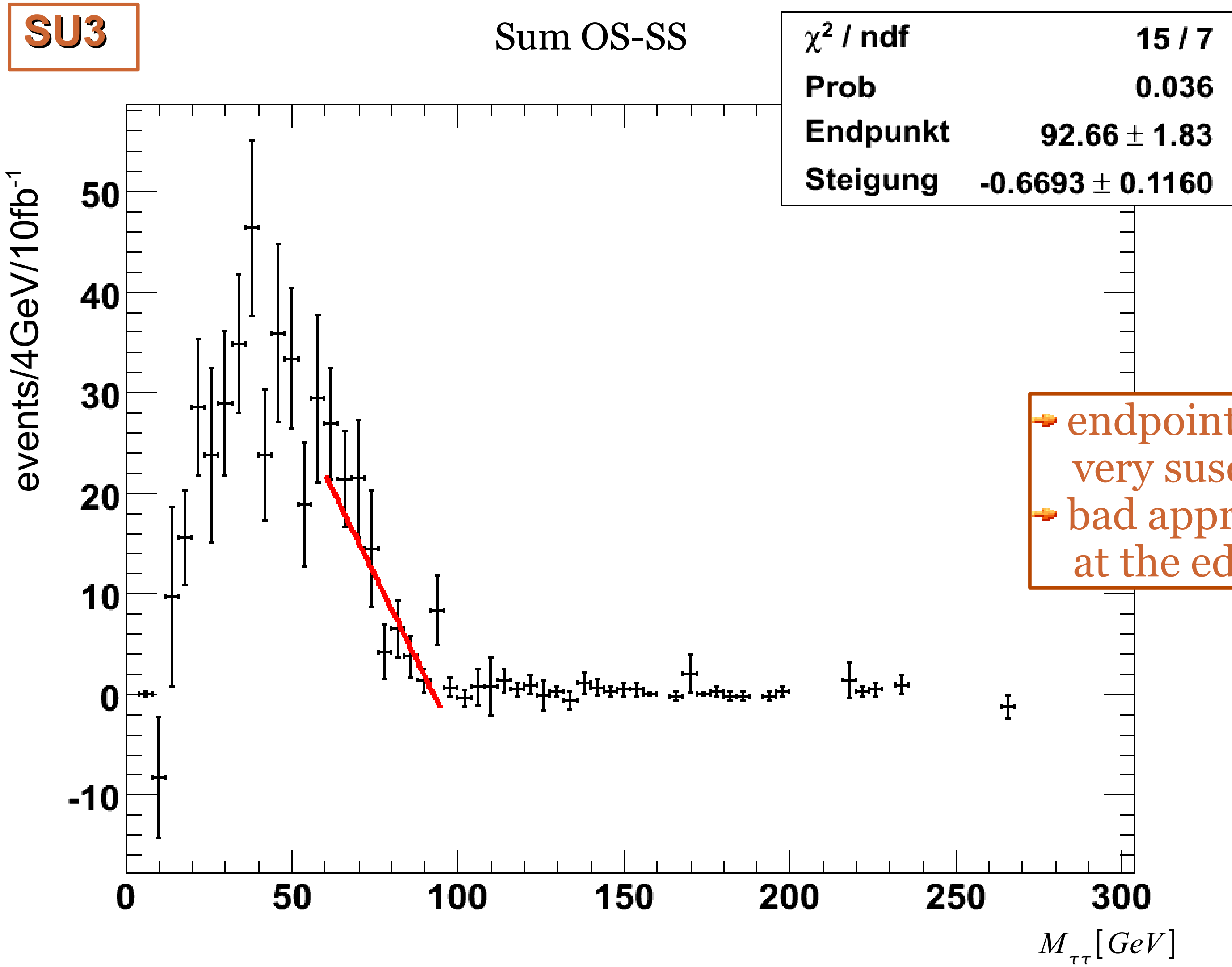
11.0.4

Invariant Mass after Cuts



Endpoint Determination

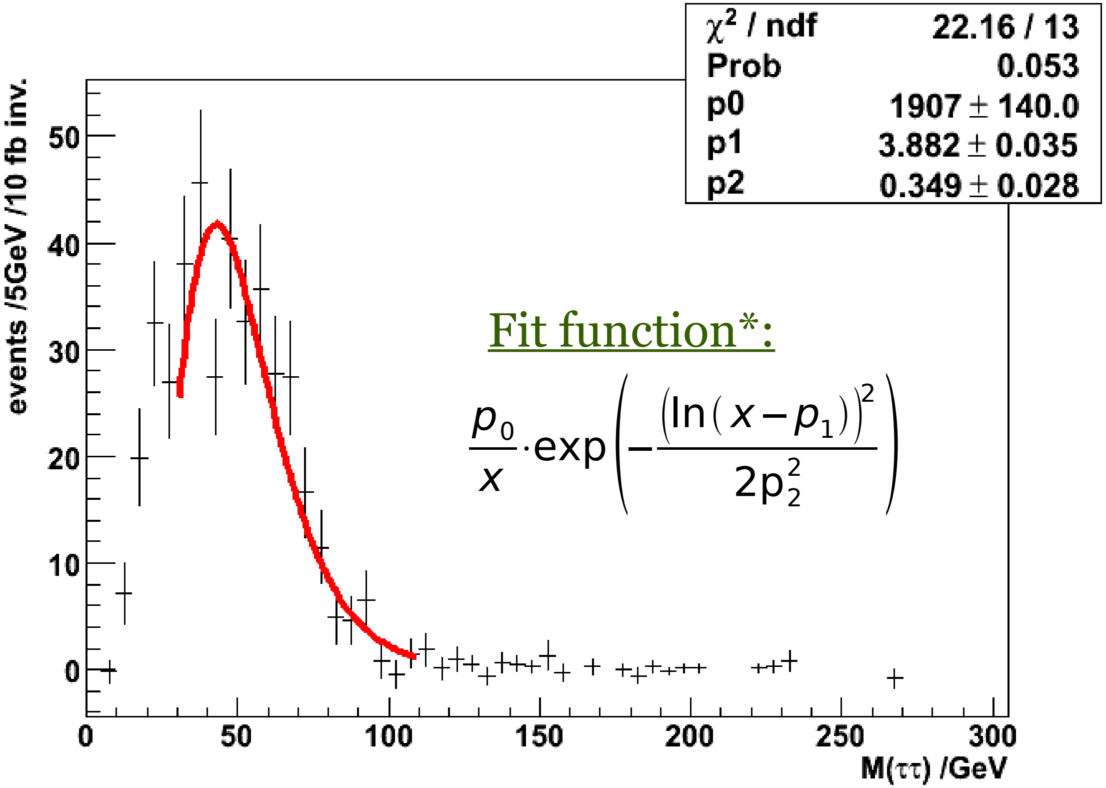
SU3



- endpoint from linear fit very susceptible to fit range
- bad approximation of shape at the edge

New approach:

- approximate shape
- extract endpoint from other trait



Fit function*:

$$\frac{p_0}{x}\cdot\exp\left(-\frac{\left(\ln(x-p_1)\right)^2}{2p_2^2}\right)$$

measure **inflection point**

-> more stable to change of fitting range or binning

-> need calibration for endpoint:

-> *change involved masses*

$$m(\tilde{\chi}_2^0), m(\tilde{\tau}_1), m(\tilde{\chi}_1^0)$$

-> measure inflection point as function of known endpoint

inflection point:

$$x_{IP}=\exp\left(\frac{1}{2}p_2^2\left(3+\sqrt{\left(1+\frac{4}{p_2^2}\right)}\right)+p_1\right)$$

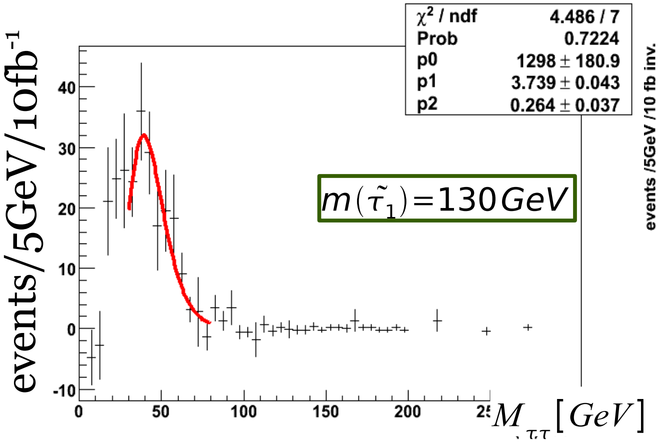
error:

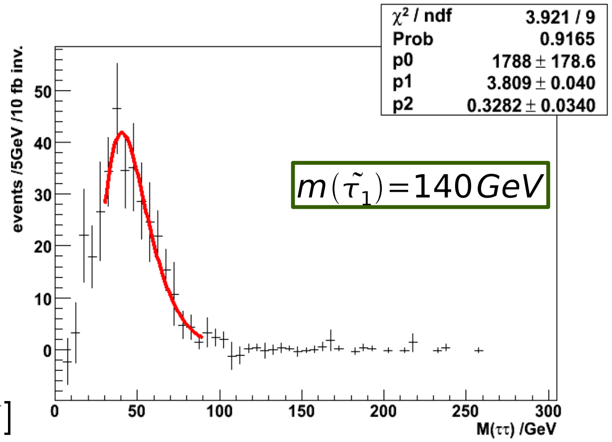
$$s_x^2=s_{p1}^2\left(\frac{\partial x}{\partial p_1}\right)^2+s_{p2}^2\left(\frac{\partial x}{\partial p_2}\right)^2$$

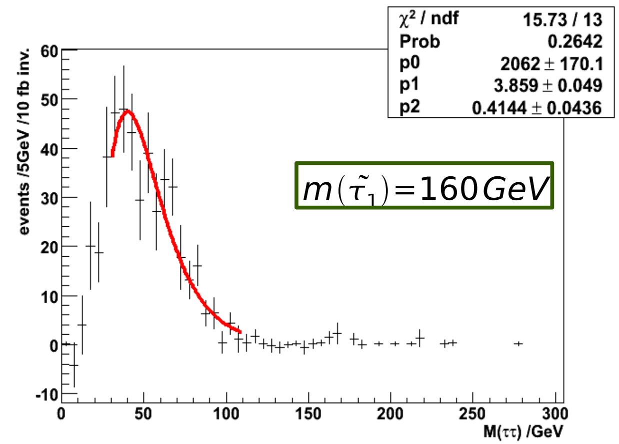
$$+2\,cov(p_1,p_2)\left(\frac{\partial x}{\partial p_1}\right)\left(\frac{\partial x}{\partial p_2}\right)$$

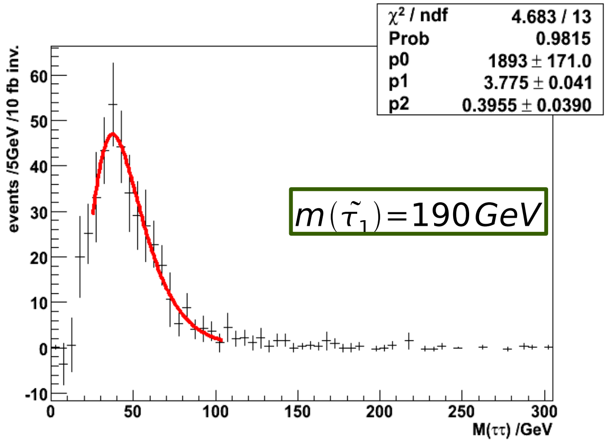
* modified adoption from: CMS NOTE 2006/096

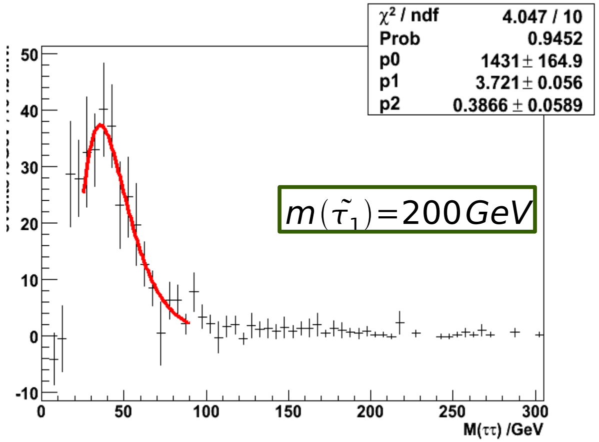
Calibration: example of variation of $\tilde{\tau}_1$-mass (SU3: 150 GeV) for fixed $m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0)$



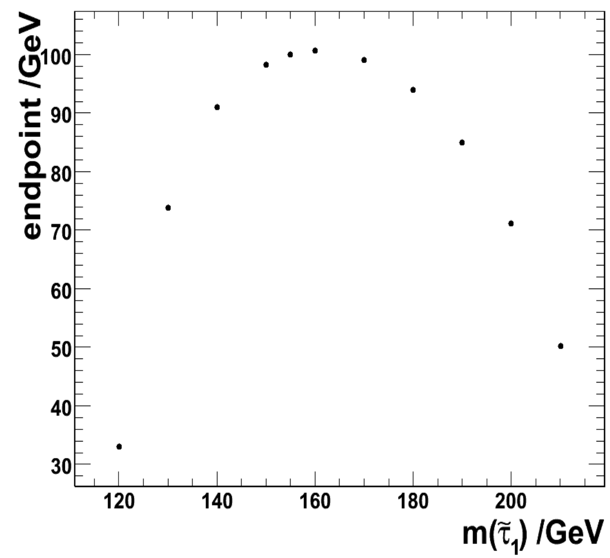








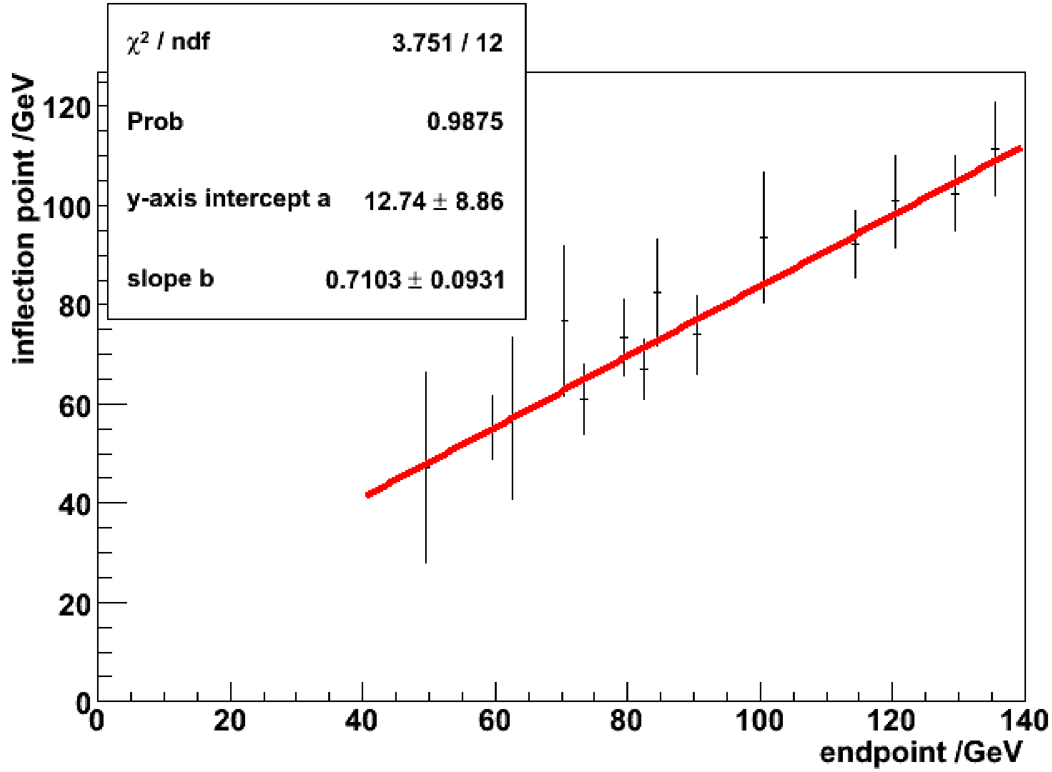
$$m_{\tau\tau}^{max}=\sqrt{\frac{(m(\tilde{\chi}_2^0)^2-m(\tilde{\tau}_1)^2)\cdot(m(\tilde{\tau}_1)^2-m(\tilde{\chi}_1^0)^2)}{(m(\tilde{\tau}_1)^2)}}$$

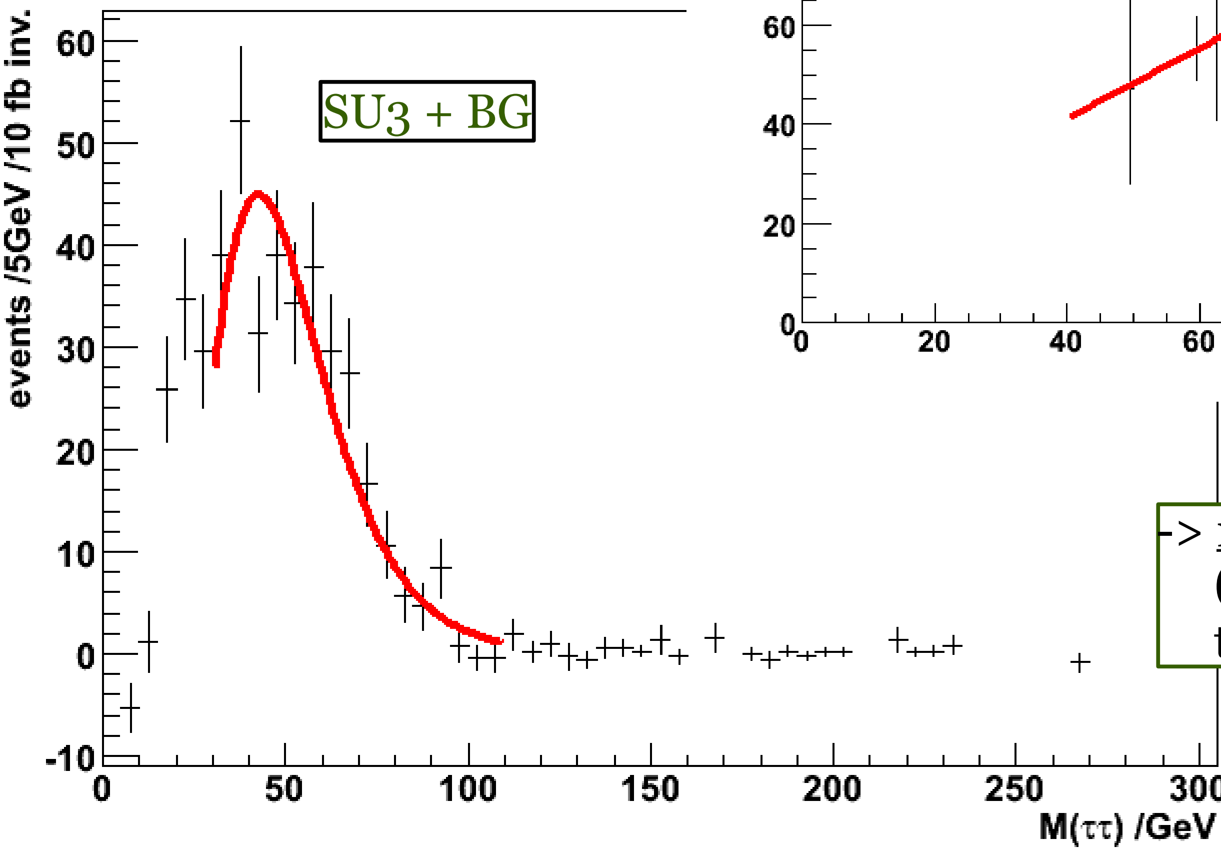


$m(\tau_1)$ [GeV]	endpoint (theoret.) [GeV]	Inflection point [GeV]
130	74	61 +- 7
140	91	74 +- 8
160	101	94 +- 13
190	85	83 +- 11
200	71	77 +- 15
210	50	47 +- 19

calibration line:

$$y = (0.71 \pm 0.09)\,x + (13 \pm 9)\,GeV$$





-> measured endpoint:
$(97 \pm 9^{stat} \pm 6^{syst})$ GeV
theoretical: 98 GeV

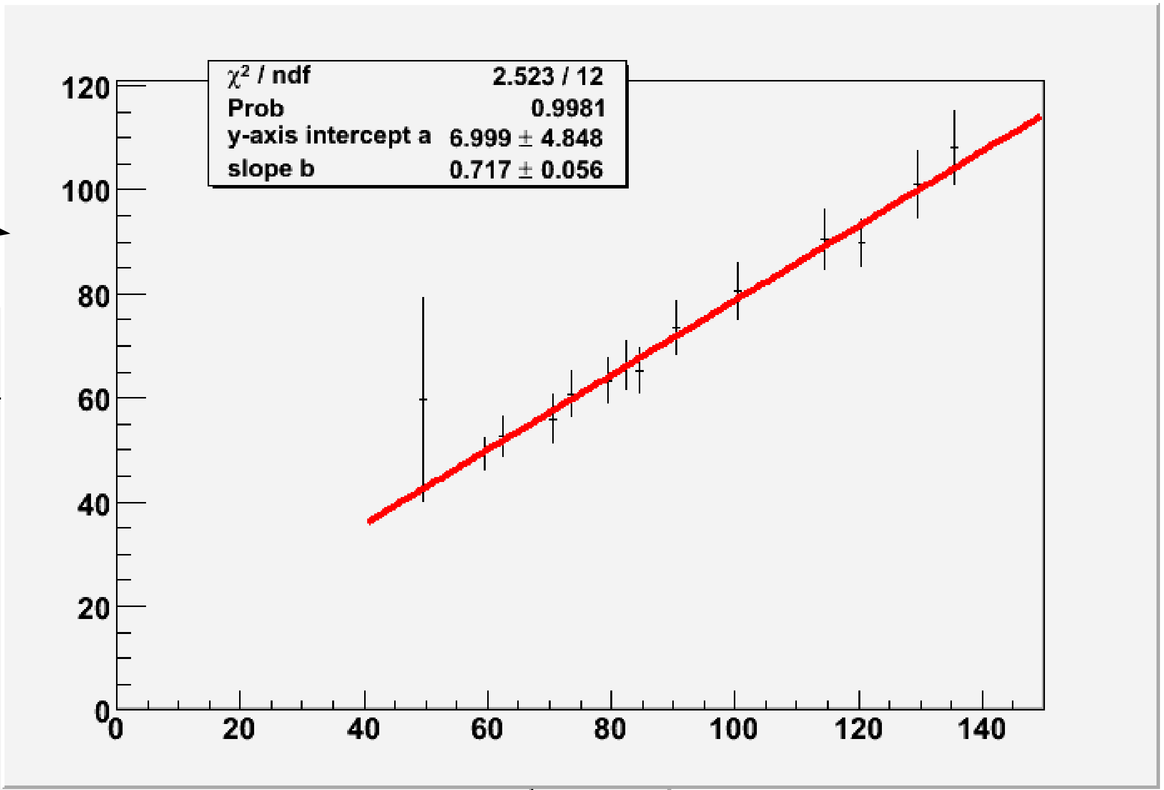
12.0.6

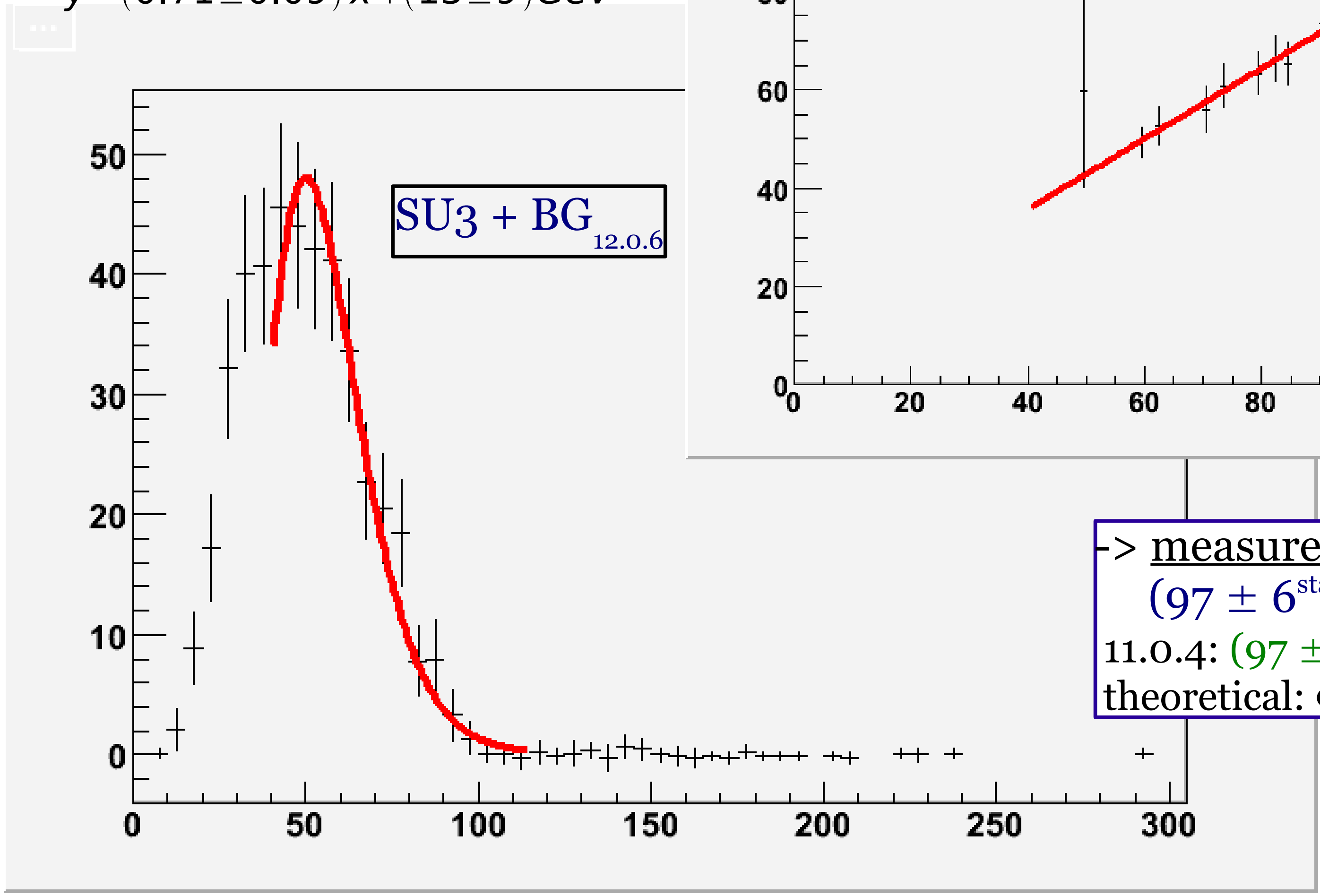
calibration line:

$y = (0.72 \pm 0.06)\,x + (7 \pm 5)\,GeV$

11.0.4:

$y = (0.71 \pm 0.09)\,x + (13 \pm 9)\,GeV$





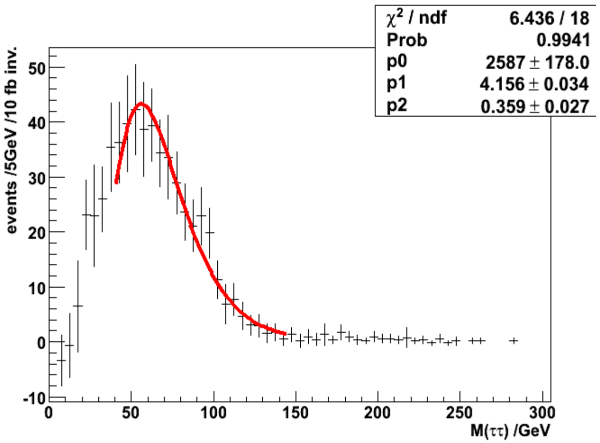
-> measured endpoint:
(97 ± 6^{stat}) GeV
11.0.4: $(97 \pm 9^{stat} \pm 6^{syst})$ GeV
theoretical: 98 GeV

Summary and Conclusions:

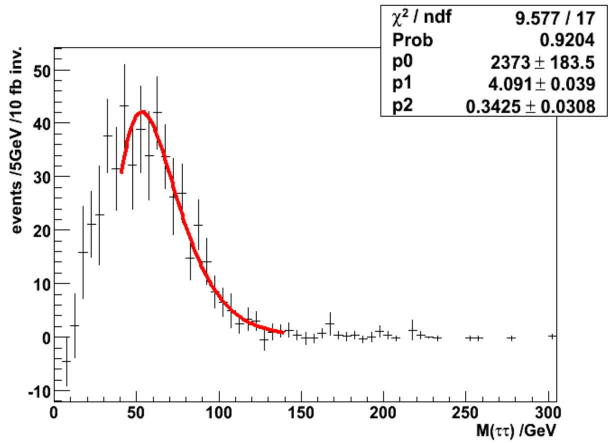
- Study of SUSY signals with τ-leptons
- Cut based selection delivers clear signal over BG in both SU1 (coannihilation region) and SU3 (bulk region)
- Kinematic endpoint of $\chi_2^0 \rightarrow \tau^{\pm}\tau^{\mp}\chi_1^0$ measurable in SU3
- Inflection point method is applicable for endpoint determination
- Endpoint can be measured in SU3 with 10 fb^{-1} (15% precision)
- Previous results (11.0.4) could be confirmed with new Atlfast Tau-ID (12.0.6)

backup

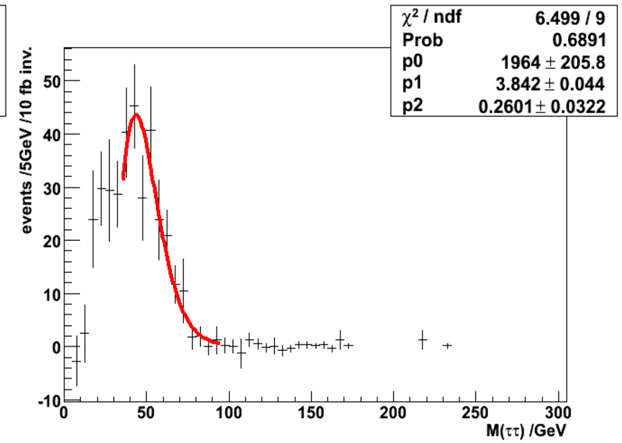
variation of $\tilde{\chi}_1^0$ -mass (SU3: 150 GeV) for fixed $m(\tilde{\chi}_2^0), m(\tilde{\tau}_1)$



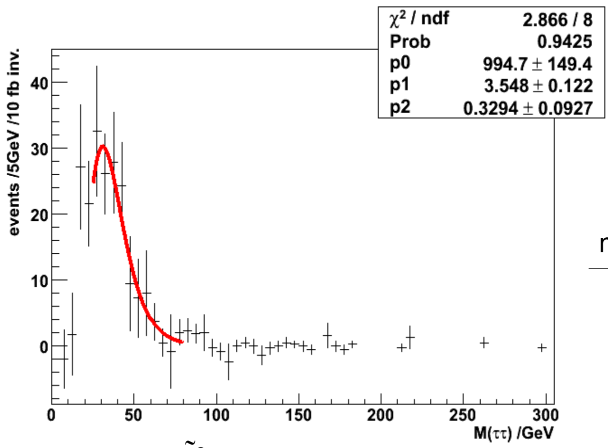
$m(\tilde{\chi}_1^0) = 77.9\,GeV$



$m(\tilde{\chi}_1^0) = 97.9\,GeV$

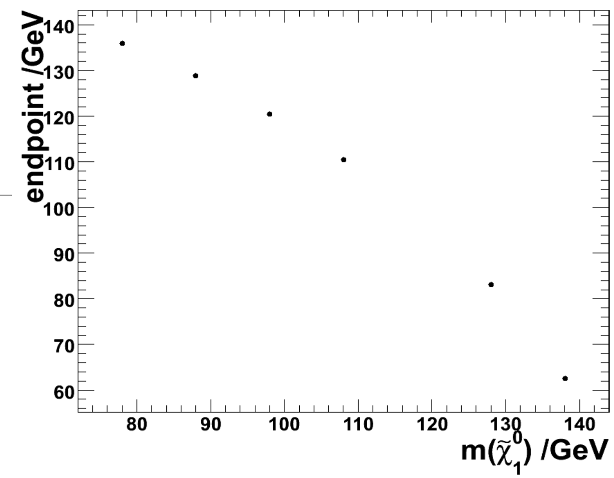


$m(\tilde{\chi}_1^0) = 127.9\,GeV$

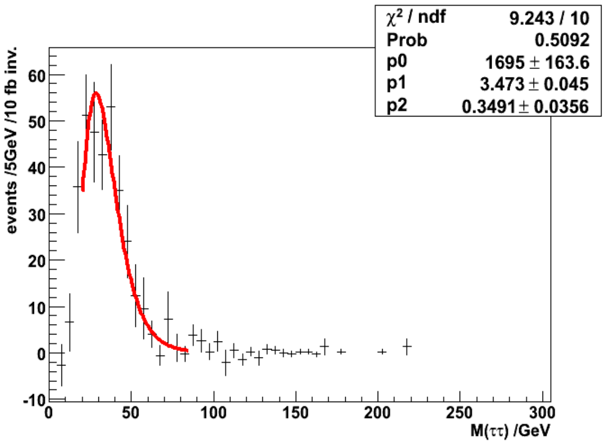


$m(\tilde{\chi}_1^0) = 137.9\,GeV$

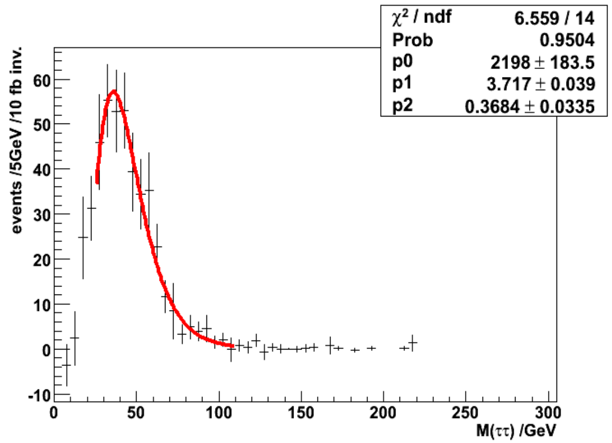
$m(\chi_1)$ [GeV]	endpoint [GeV]	Infl. point [GeV]
77.9	136	112 +- 9
97.9	121	101 +- 9
127.9	83	67 +- 6
137.9	63	57 +- 16



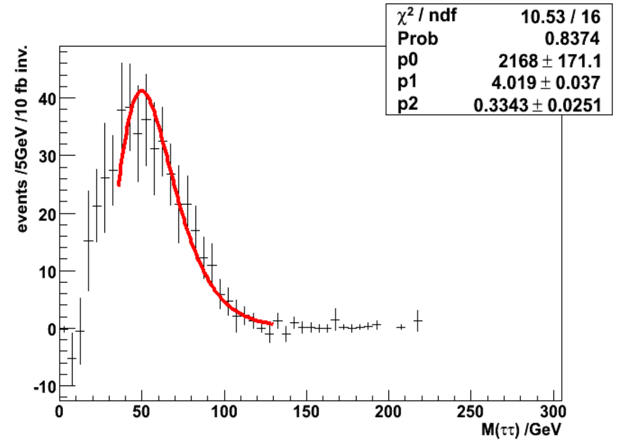
variation of $\tilde{\chi}_2^0$ -mass (SU3: 150 GeV) for fixed $m(\tilde{\tau}_1), m(\tilde{\chi}_1^0)$



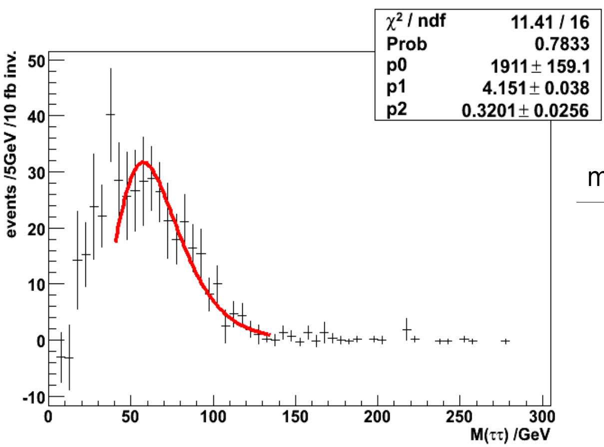
$m(\tilde{\chi}_2^0)=178.6\,GeV$



$m(\tilde{\chi}_2^0)=198.6\,GeV$

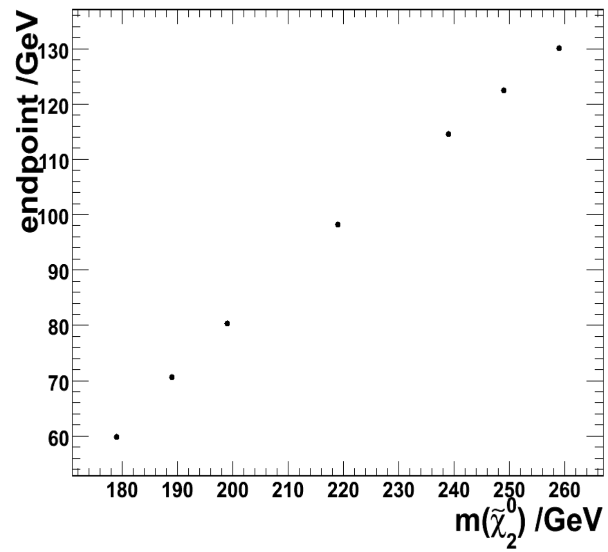


$m(\tilde{\chi}_2^0)=238.6\,GeV$



$m(\tilde{\chi}_2^0)=258.6\,GeV$

$m(\chi_2)$ [GeV]	endpoint [GeV]	Infl. point [GeV]
178.6	60	55 +- 6
198.6	80	73 +- 8
238.6	115	92 +- 7
258.6	130	102 +- 8



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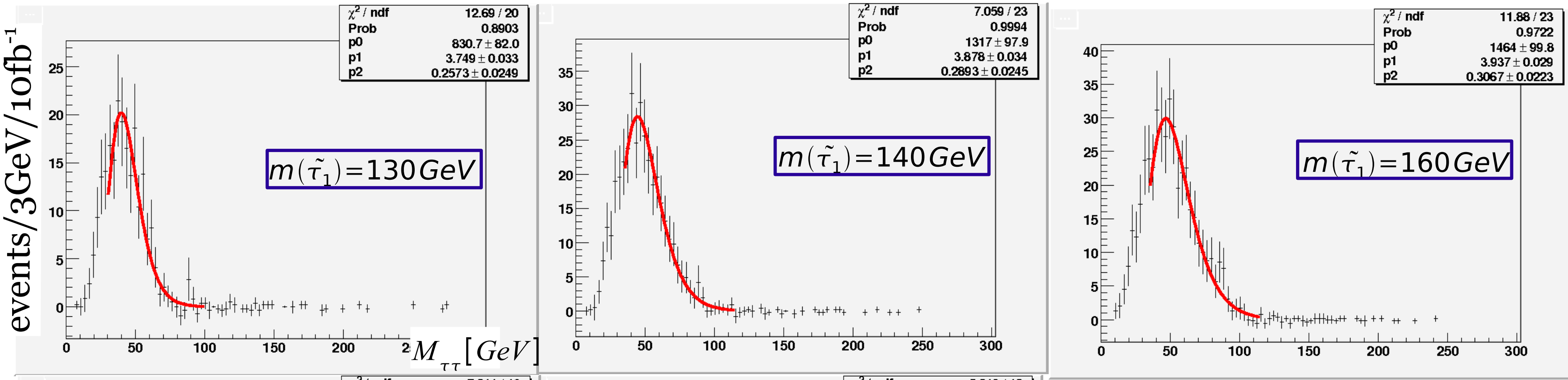

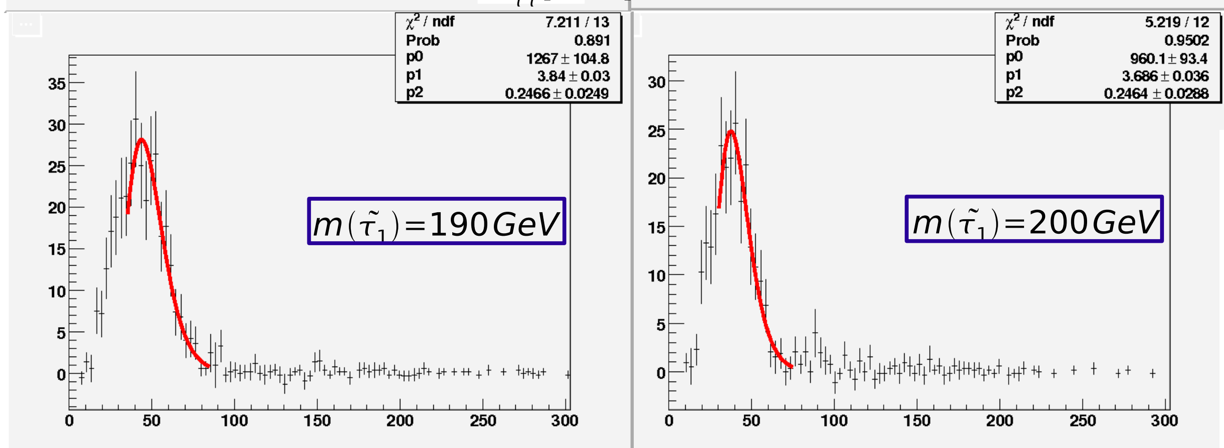

$$m_{\tau\tau}^{max}=\sqrt{\frac{(m(\tilde{\chi}_2^0)^2-m(\tilde{\tau}_1)^2)\cdot(m(\tilde{\tau}_1)^2-m(\tilde{\chi}_1^0)^2)}{(m(\tilde{\tau}_1)^2)}}$$

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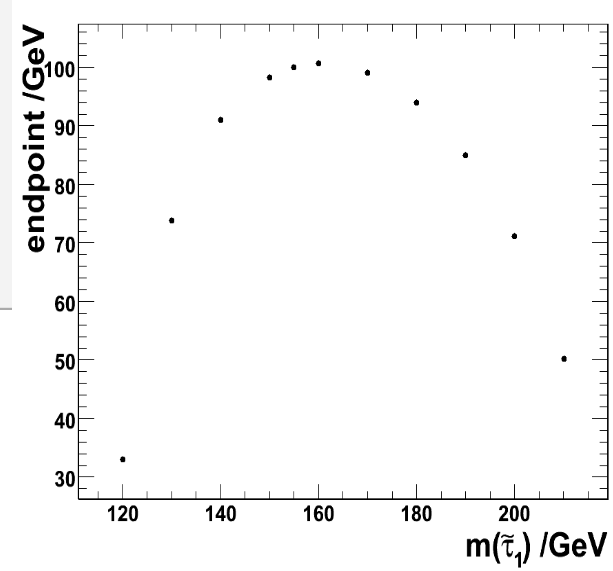
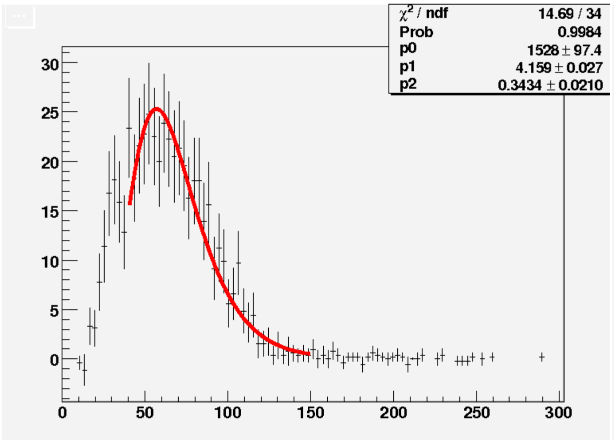
160	101	81 +- 5
190	85	65 +- 4
200	71	56 +- 6
210	50	60 +- 19

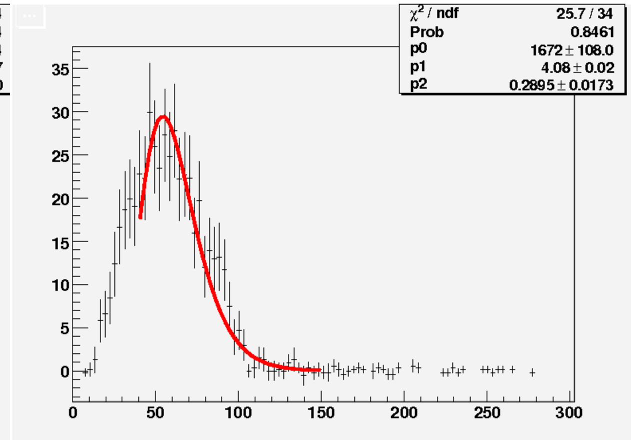


12.0.6

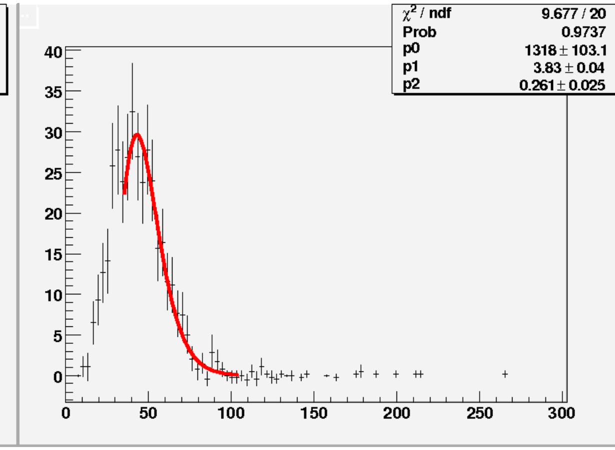
variation of $\tilde{\chi}_1^0$ -mass (SU3: 150 GeV) for fixed $m(\tilde{\chi}_2^0), m(\tilde{\tau}_1)$



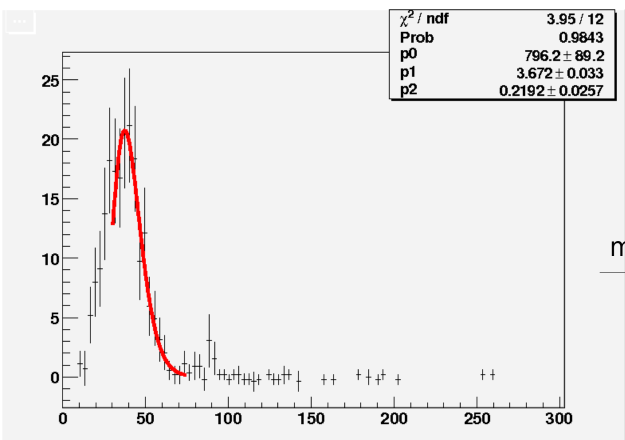
$m(\tilde{\chi}_1^0) = 77.9\,GeV$



$m(\tilde{\chi}_1^0) = 97.9\,GeV$

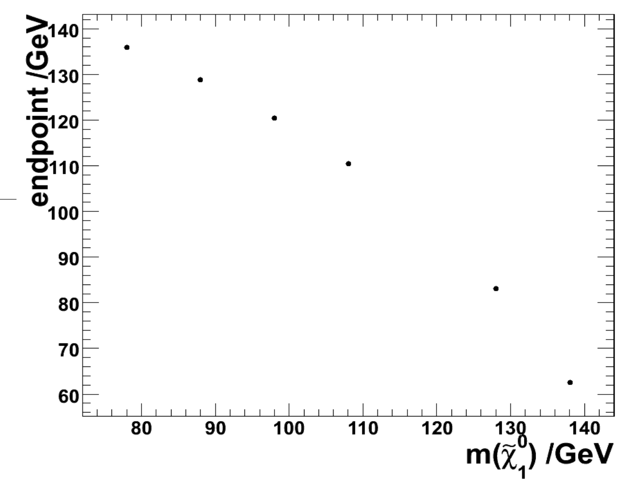


$m(\tilde{\chi}_1^0) = 127.9\,GeV$



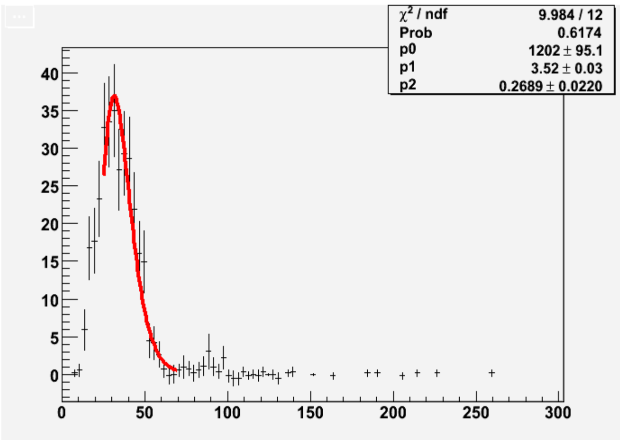
$m(\tilde{\chi}_1^0) = 137.9\,GeV$

$m(\chi_1)$ [GeV]	endpoint [GeV]	Infl. point [GeV]
77.9	136	108 +- 7
97.9	121	90 +- 4
127.9	83	66 +- 5
137.9	63	53 +- 4

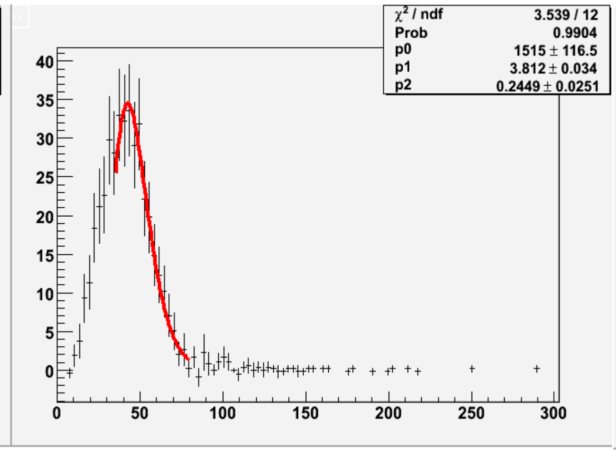


12.0.6

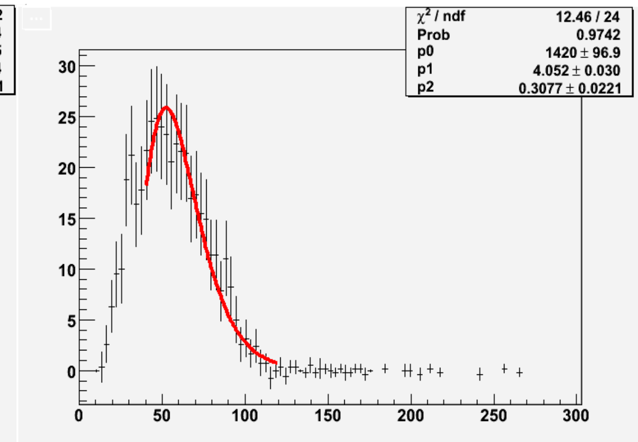
variation of $\tilde{\chi}_2^0$ -mass (SU3: 150 GeV) for fixed $m(\tilde{\tau}_1), m(\tilde{\chi}_1^0)$



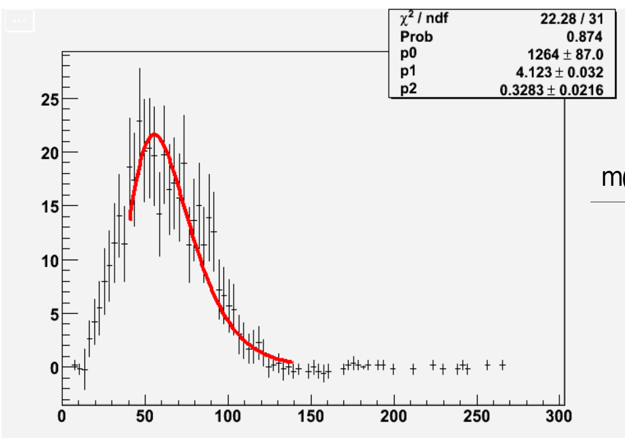
$m(\tilde{\chi}_2^0)=178.6\,GeV$



$m(\tilde{\chi}_2^0)=198.6\,GeV$



$m(\tilde{\chi}_2^0)=238.6\,GeV$



$m(\tilde{\chi}_2^0)=258.6\,GeV$

$m(\chi_2)$ [GeV]	endpoint [GeV]	Infl. point [GeV]
178.6	60	49 +- 3
198.6	80	63 +- 4
238.6	115	90 +- 6
258.6	130	101 +- 6