Tau final states in SUSY

- attempted overview of German exclusive studies

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outline

- Introduction: different SUSY models considered in this talk
- Discovery potential with taus in GMSB
- $\tau\tau$ invariant mass spectra in RPC scenarios:
  - Endpoint determination with “low” integrated luminosity (~1 fb^{-1})
  - Endpoint and polarization measurement with “high” integrated luminosity (several 10 fb^{-1})
- Taus in mSUGRA-like RPV scenarios

SUSY models

R parity conserving:

- **mSUGRA (minimal SuperGRAvity)**

SUSY breaking mediated by gravity

★ **SU3:** bulk region point

m_0 = 100 GeV $\tan\beta$ = 6

$m_{1/2}$ = 300 GeV   sgnμ = +

A_0 = -300 GeV

LSP: $\tilde{\chi}^0_1$

- **GMSB (Gauge Mediated Susy Breaking)**

SUSY breaking mediated by gauge interactions

★ **GMSB6:**

Λ = 40 $\tan\beta$ = 30

M_{mes} = 250 TeV   sgnμ = +

N_5 = 3 C_{grav} = 1

LSP: $\tilde{G}$
NLSP: $\tilde{\tau}_1$

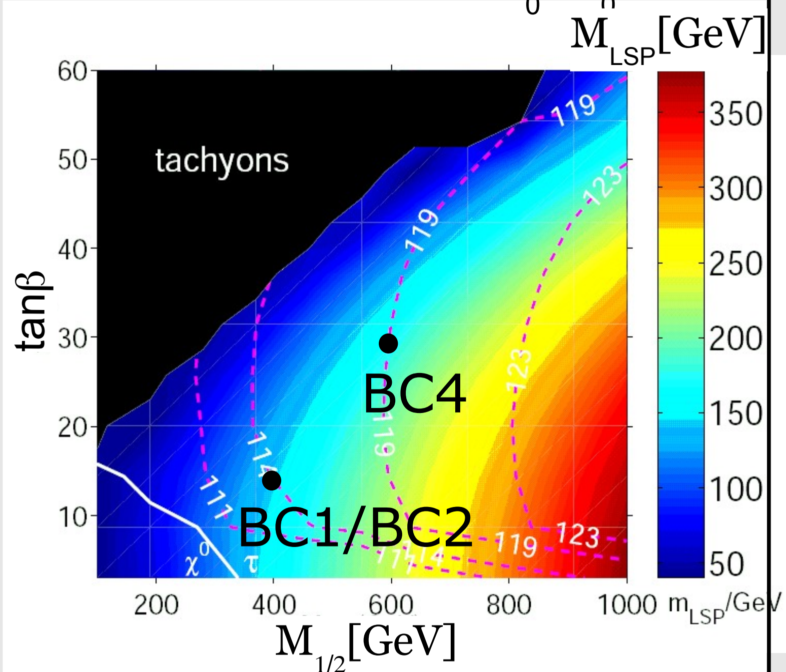
★ all models: tau production enhanced

R parity violating scenarios:

- only B **or** L violating couplings to prevent proton decay
- LSP not stable
  -> no MET signature
- benchmark points with stau LSP:

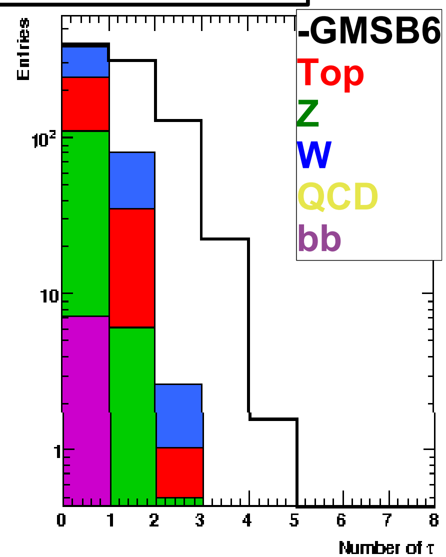
"no-scale" mSUGRA: m_0=A_0=0

LSP: $\tilde{\tau}_1$



GMSB parameter scan

Number of taus



selection cuts:

- p_T^{miss} > 360 GeV
- at least 4 Jets:

  p_T1 > 100 GeV, p_T3 > 50 GeV

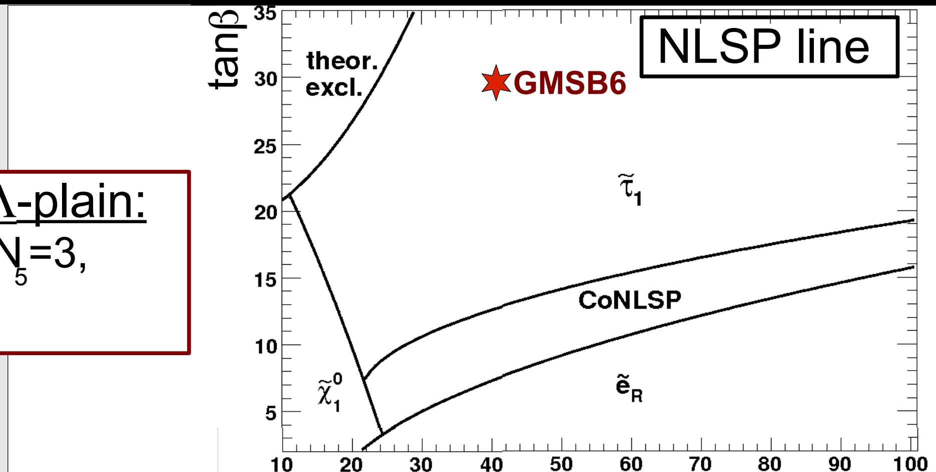
for parameter scan: require at least 2 taus

$$->GMSB6@1fb^{-1}: \frac{signal}{\sqrt{BG}} = 80$$

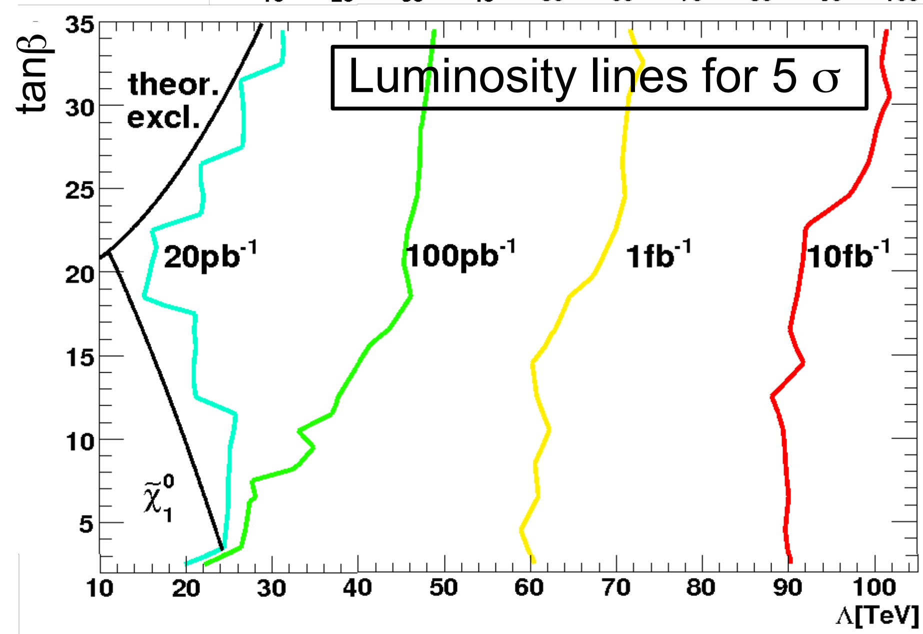
Scan in tanβ-Λ-plain:

M_{mes}=250 TeV, N_5=3, sgnμ=+, C_g=1

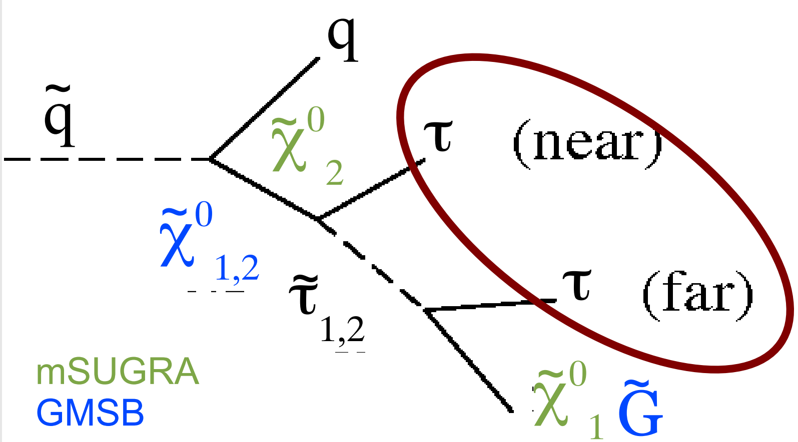
NLSP line

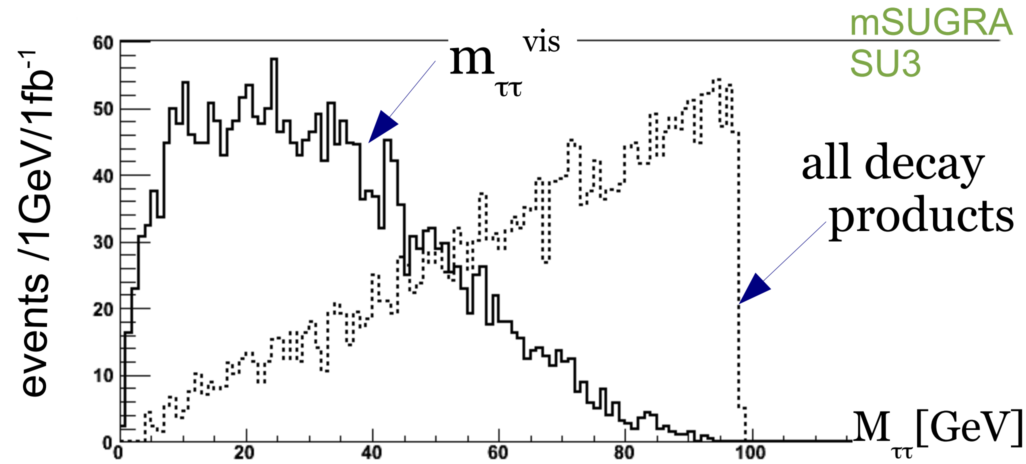


Luminosity lines for 5 σ



ditau mass spectrum





- for SUSY discovery: show it is SUSY -> measure masses -> parameters
- Ditau mass spectrum holds information about stau mass and mixing angle:
  - $m(\tilde{\tau}_{1,2})$ from $m_{\tau\tau}$ spectra:

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

  - Sum of tau polarizations -> stau mixing angle

SU3: $m(\tau_2) > m(\chi_1^0)$

GMSB6: $m(\tau_2) \approx m(\chi_2^0) > m(\chi_1^0)$

→ only decays via τ_1 relevant

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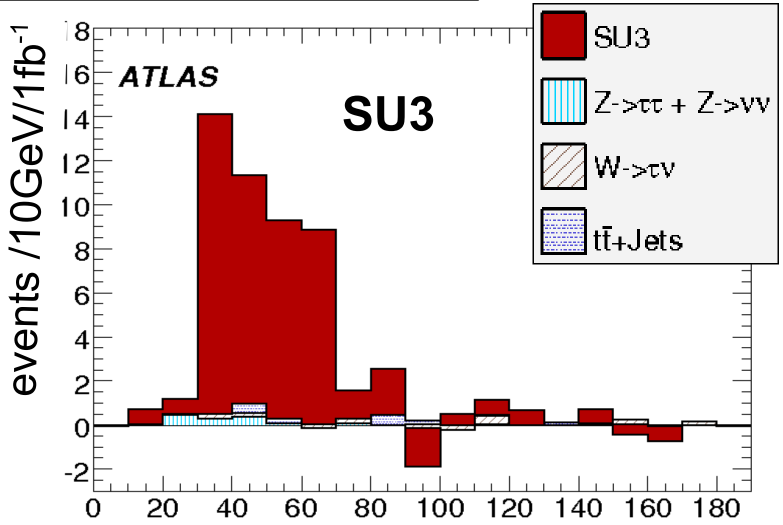
invariant mass at $1fb^{-1}$

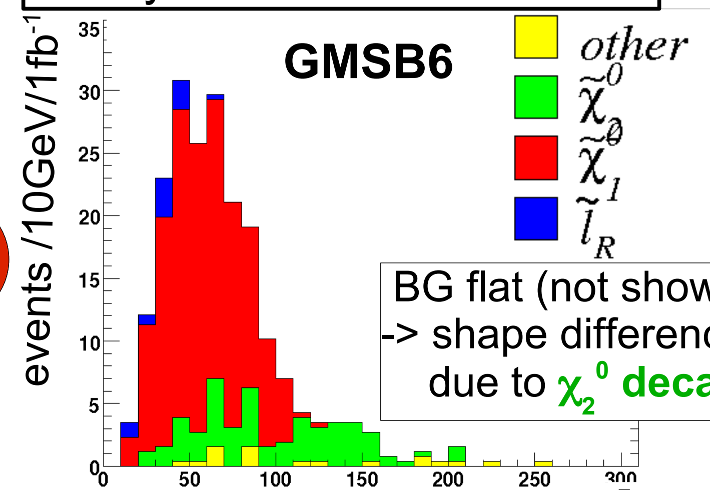
signal vs BG (OS-SS)



rel. 12 full simulation

1 fb^{-1}

different SUSY contributions: decay mother via truth match



BG flat (not shown)
-> shape difference mainly due to χ_2^0 **decays**

rel. 13 full simulation

selection cuts:

$$\frac{signal}{\sqrt{BG}}(1fb^{-1}) = 84$$

- p_T^{miss} > 230 GeV
- at least 4 Jets:

p_T1 > 200 GeV, p_T3 > 50 GeV, p_T4 > 40 GeV

- $\Delta R(\tau\tau) < 2$

selection cuts:

$$\frac{signal}{\sqrt{BG}}(1fb^{-1}) = 71$$

- at least 4 Jets:

  p_T1 > 100 GeV, p_T3 > 50 GeV

- elliptical cut:

$$\left(\frac{p_T^{miss}}{300GeV}\right)^2 + \left(\frac{lead.\ jet\ pt}{600GeV}\right)^2 > 1$$

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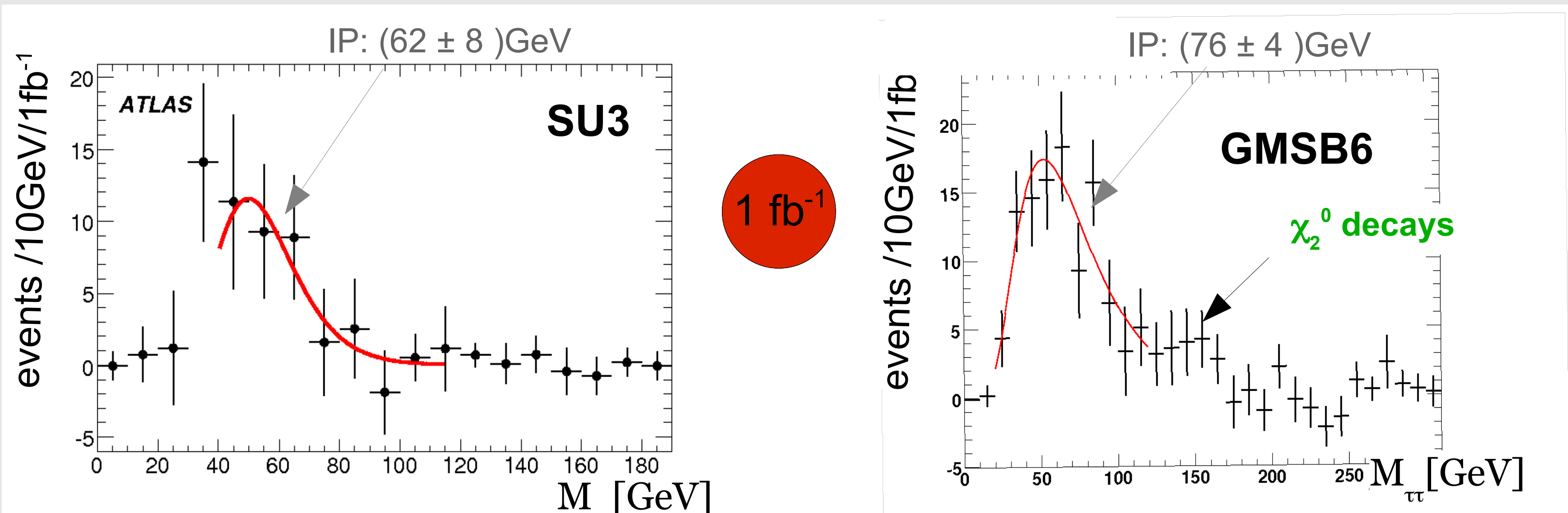
- **endpoint determination with inflection point method:** [ATL-PHYS-INT-2008-008]
  calibration made with Atlfast (SU3-like spectra): $m_{\tau\tau}^{IP}=(0.47\pm0.02)m_{\tau\tau}^{max}+(15\pm2)GeV$



rel. 12 full simulation

signal/BG: rel. 13/12 full simulation

SU3: (theoretical endpoint: **99** GeV)

- $m_{\tau\tau}^{max}$= (102 ± 17^{stat} ± 5.5^{syst})GeV

(10 fb^{-1}: $m_{\tau\tau}^{max}$= (103 ± 5^{stat} ± 4.5^{syst})GeV)

GMSB6: (theoretical endpoint: **122** GeV)

$m_{\tau\tau}^{max}$= (132 ± 10^{stat})GeV

- **χ_2^0 bump causes syst. uncertainty at low int. luminosity**

trigger issues

trigger efficiency ε:

trigger	all SU3	cuts
j200	0.83	0.99
2j120	0.64	0.78
3j65	0.53	0.84
4j55	0.31	0.68
“jetsHLT”	0.88	1.00
tau20i_j70	0.44	0.96
tau20i_3j23	0.42	0.96
tau35i_4j23	0.26	0.82
tau25i_xe40	0.39	0.92

“jetsHLT”:j160||2j120||3j65||4j55

efficiency here:

$$\epsilon = \frac{N(pass\,trigger)}{N(all\,SU3)}$$

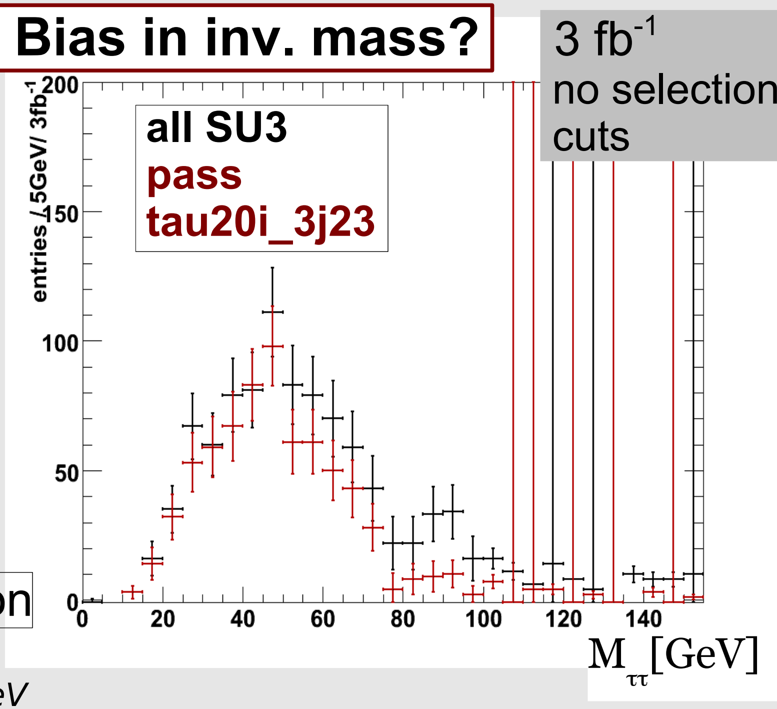
“cuts”:
MET > 230 GeV
4 Jets:
40/50/50/220 GeV
at least 2 taus

rel. 13 full simulation

	$m_{\tau\tau}^{max}$ /GeV
all SU3	104 +- 7
3j65	99 +- 8
4j55	102 +- 12
“jetsHLT”	97 +- 7
tau20i_j70	96 +- 7
tau20i_3j23	92 +- 8
tau35i_4j23i	96 +- 8
tau45i_xe40	92 +- 14

high efficiencies with jet, tau and MET trigger

Bias in inv. mass?

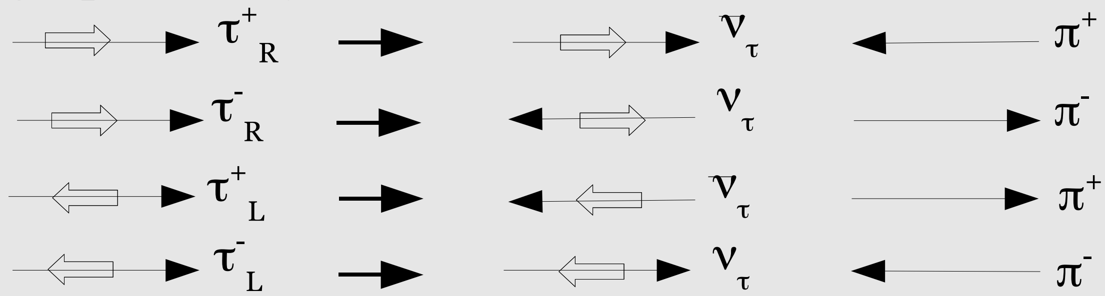


spectra shifted to lower values:
endpoints systematically (?) underestimated, though differences separately not significant

not yet understood

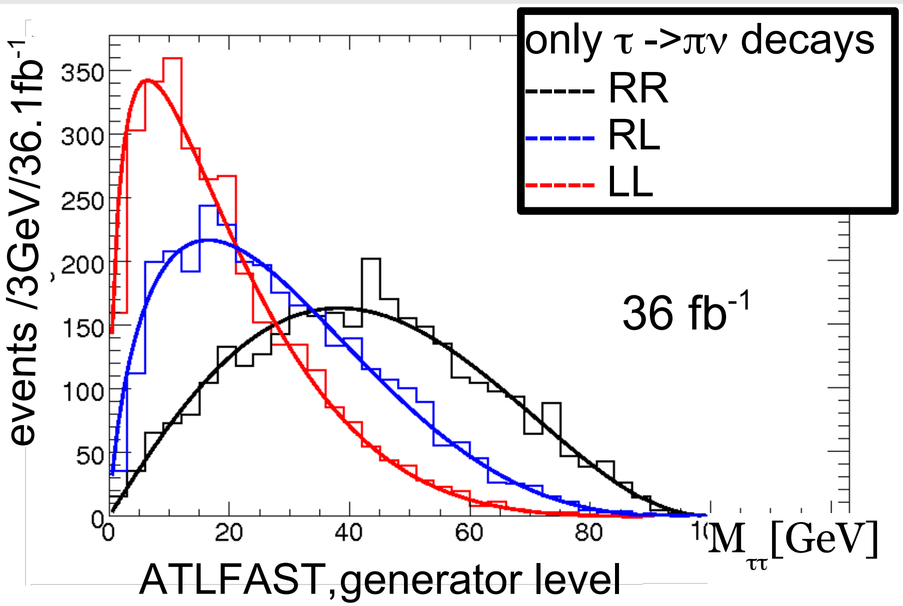
polarization effects

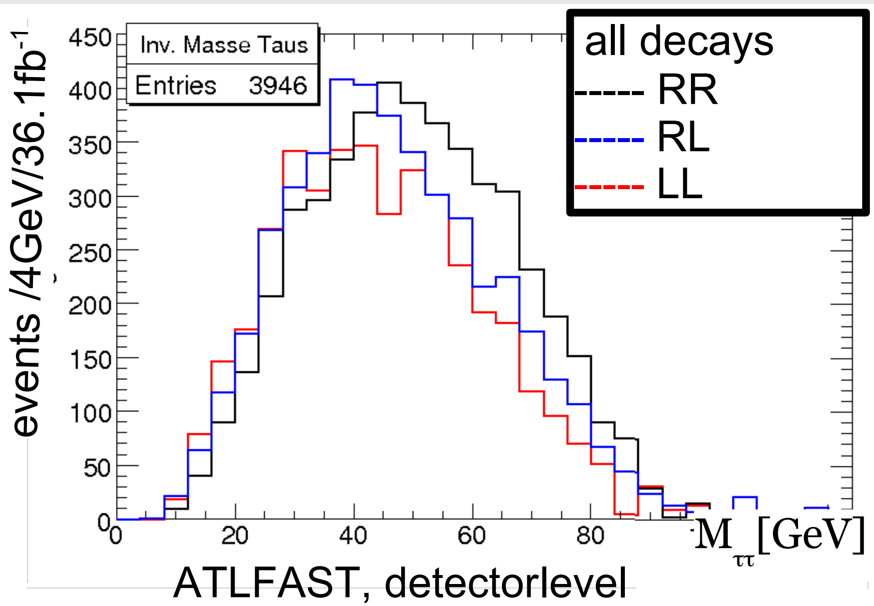
single pion decay:



- angular momentum / momentum conservation + helicity of neutrino
- ➔ pion momentum direction determined by tau charge and helicity
- ➔ pion boosted (anti)parallel to tau momentum direction

➔ **shape also depends on tau polarization, inflection point shifted**

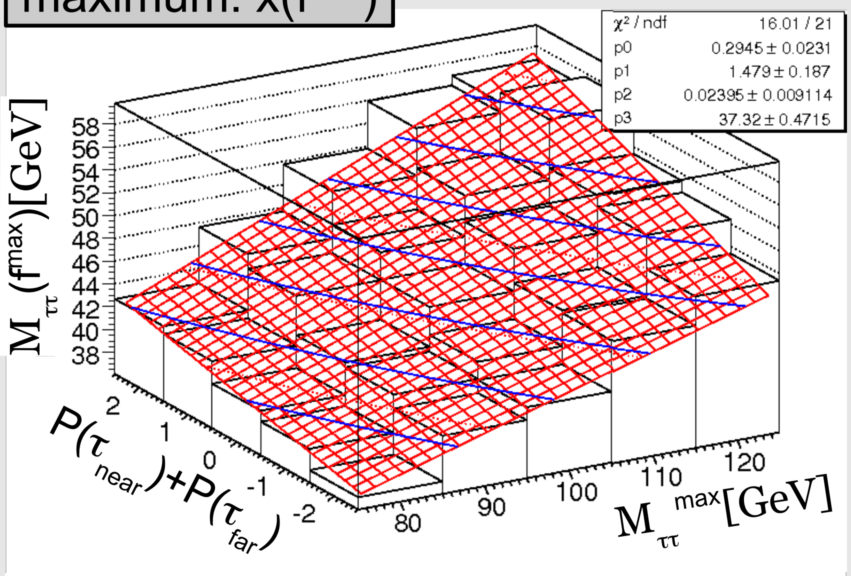




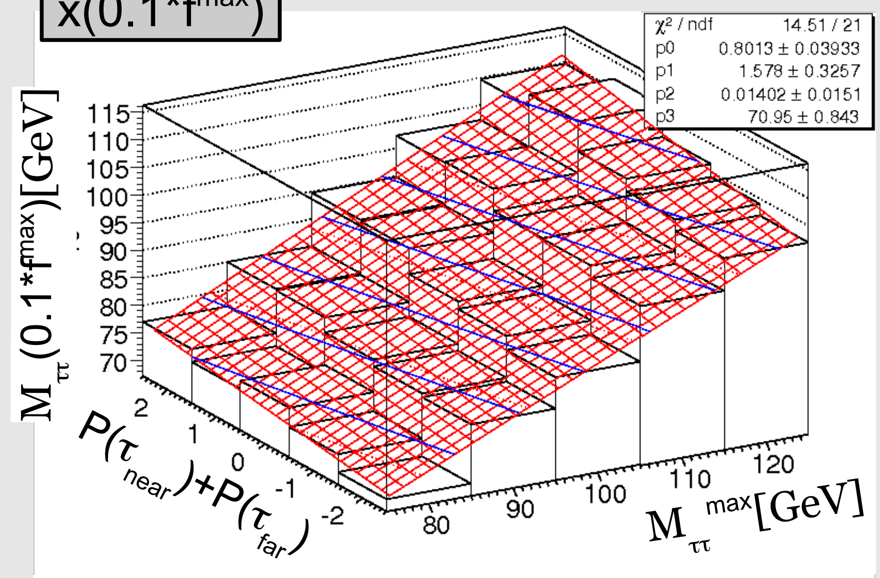
2dim calibration

Calibration: measure x(f^{max}), x(0.1*f^{max}) with 1dim gauss fit: $f(x) = p_0 \cdot \exp\left(-\frac{(p_1 - x)^2}{2p_2^2}\right)$

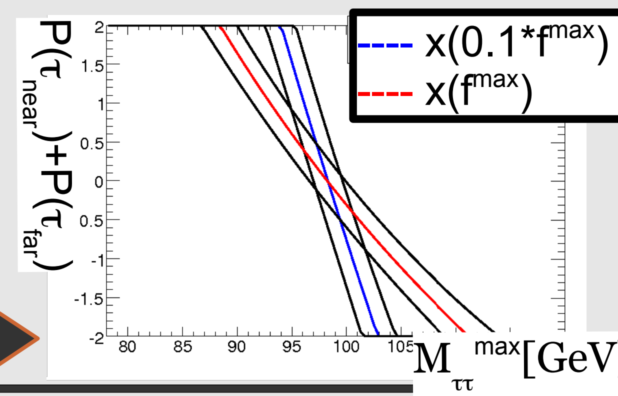
maximum: x(f^{max})



x(0.1*f^{max})

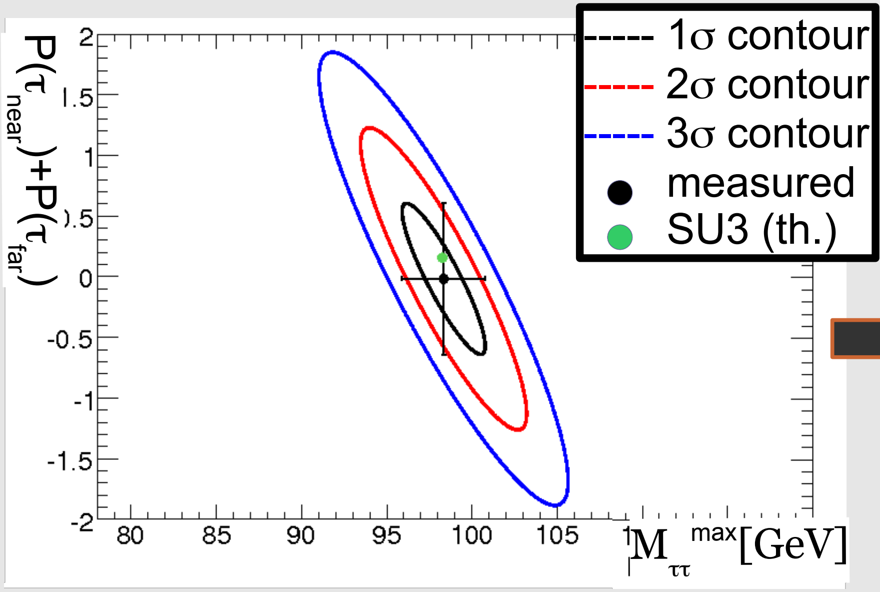


- 2dim fit function: $g(P,m) = p_0 P + p_1 m + p_1 Pm + p_3$
- equipotential line from each of the two observables
- determine intersection in endpoint-polarization plane



result

- measured SU3 values:



theory: $m_{\tau\tau}^{max}$ = 99 GeV
P(ττ)= +0.08

*systematic error inculded

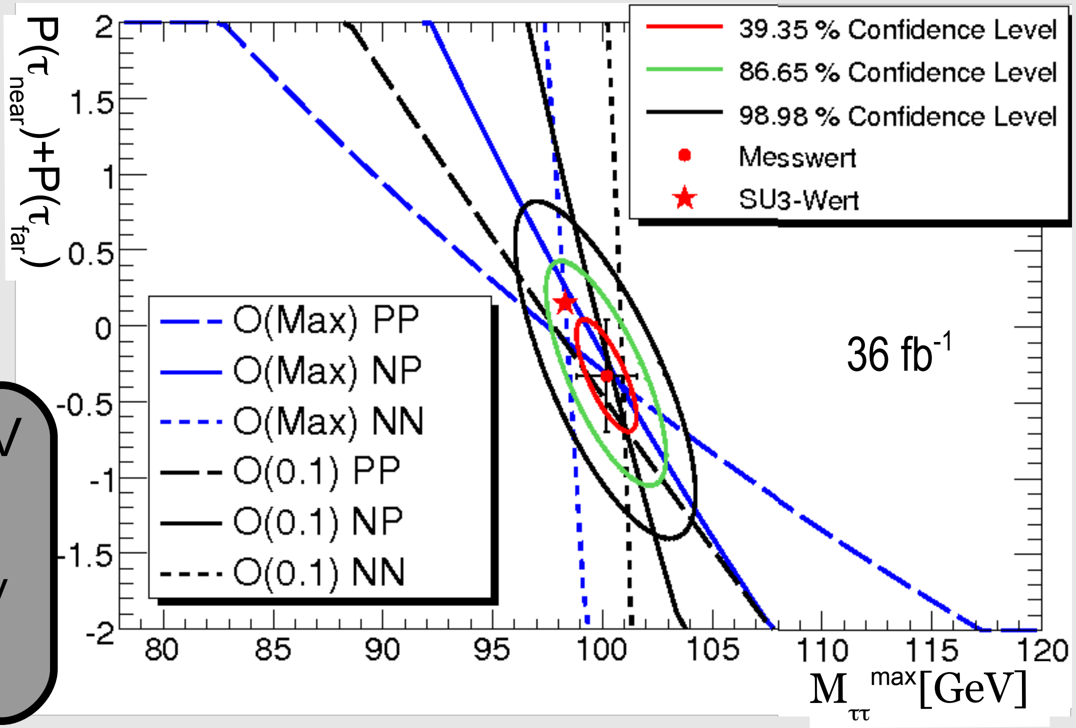
$m_{\tau\tau}^{max}$ = (98.3 ± 2.5*) GeV
P(ττ) = P(τ_{near})+P(τ_{far})
= (-0.02 ± 0.6*)
for 36 fb^{-1}

- Results could be improved by **separation of different tau decay modes**: a_1 decays not affected by polarization effects
  - ρ/a_1: same (opp.) momentum direction as π for long. (transv.) meson
  - ρ: longitudinal share bigger than transversal -> overall effect like pion
  - a_1: longitunal and transversal share equal -> mass spectrum not shifted

in an ideal-tau-decay-separation world

How much ***could*** be gained by such a separation?

- take reconstructed taus + information about decay mode from truth-match
- fake taus: probability according to branching fraction
- 6 separate calibrations:
  - 2/1/0 taus decayed in polarization sensitive mode
  - 2 observables: $x(0.1*f^{max})$, $x(f^{max})$



- $m_{\tau\tau}^{max}$ = (100.2± 1.4) GeV
- $P(\tau\tau)$ = (-0.33± 0.37)

theory: $m_{\tau\tau}^{max}$ = 99 GeV
$P(\tau\tau)$= +0.08

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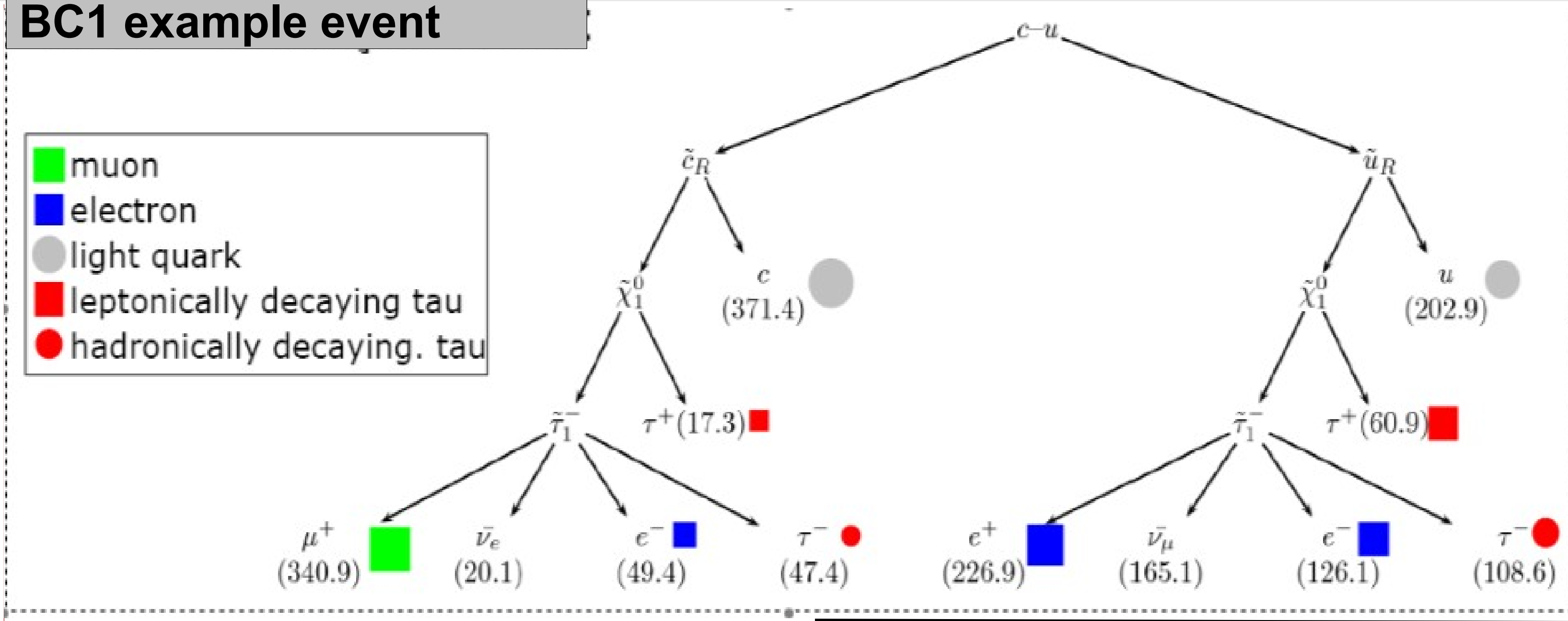
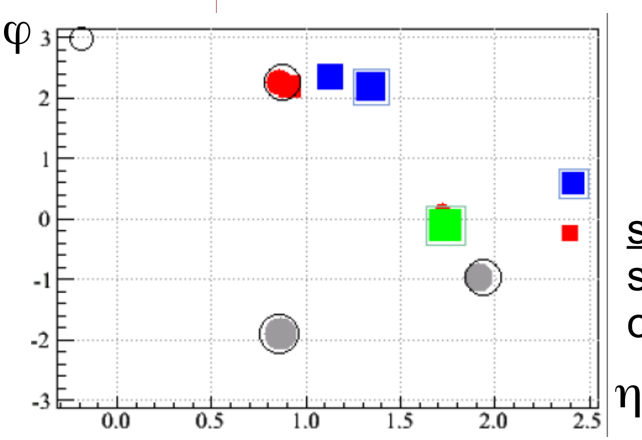
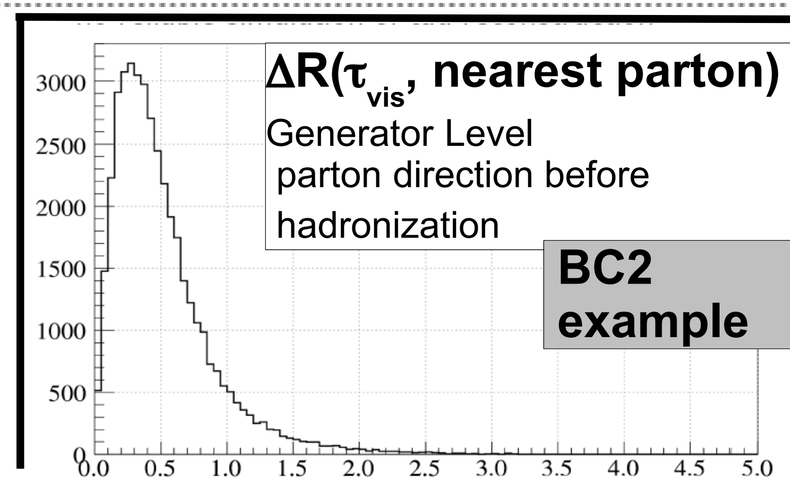
RPV – tau ID challenges

BC1 example event





symbols:
solid: generator level
open: Atlfast I



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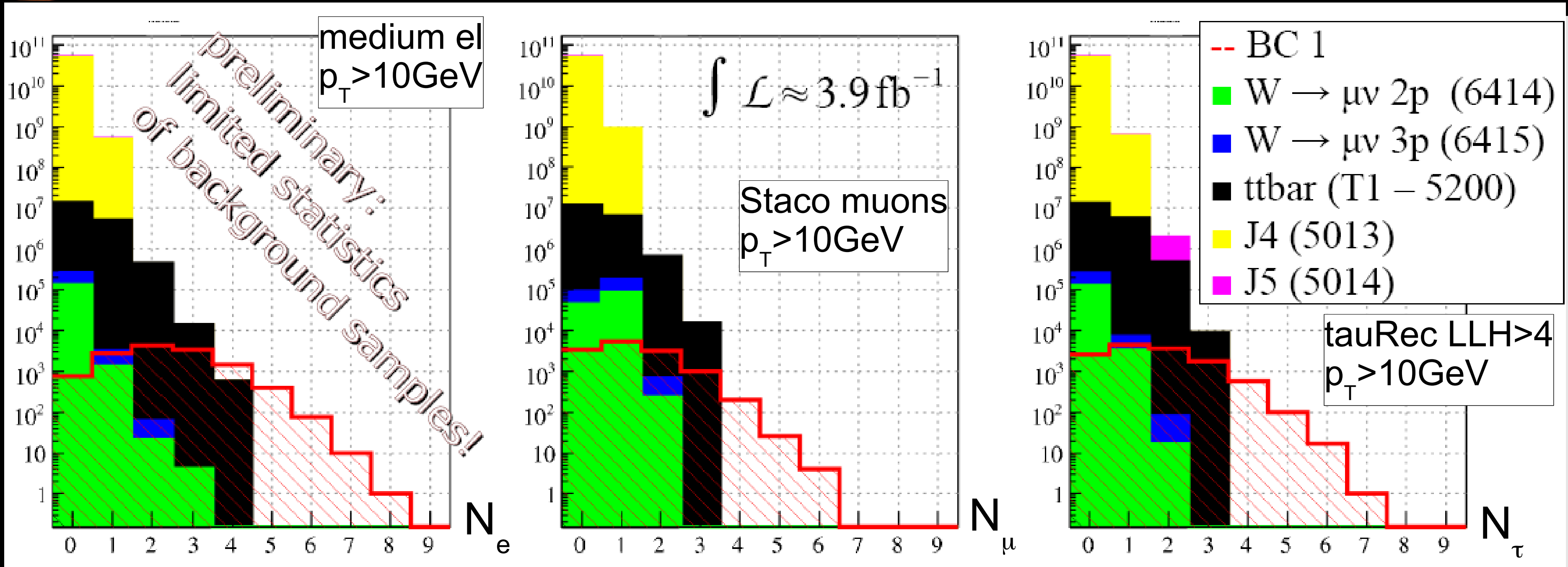
RPV vs SM



Number of leptons:
(preselection cut: MET > 65 GeV)

- good discriminant against most important standard model backgrounds (note: no overlap removal in these plots)
- no sophisticated selection yet, but BC1 might be interesting for first data (i.e. easy to discover)

summary and outlook

- Tau signatures are important for SUSY:
  - enhanced production -> great discovery potential
  - taus yield valuable information for SUSY parameter determination
- Cross-check of methods in different SUSY scenarios is crucial to test model independence

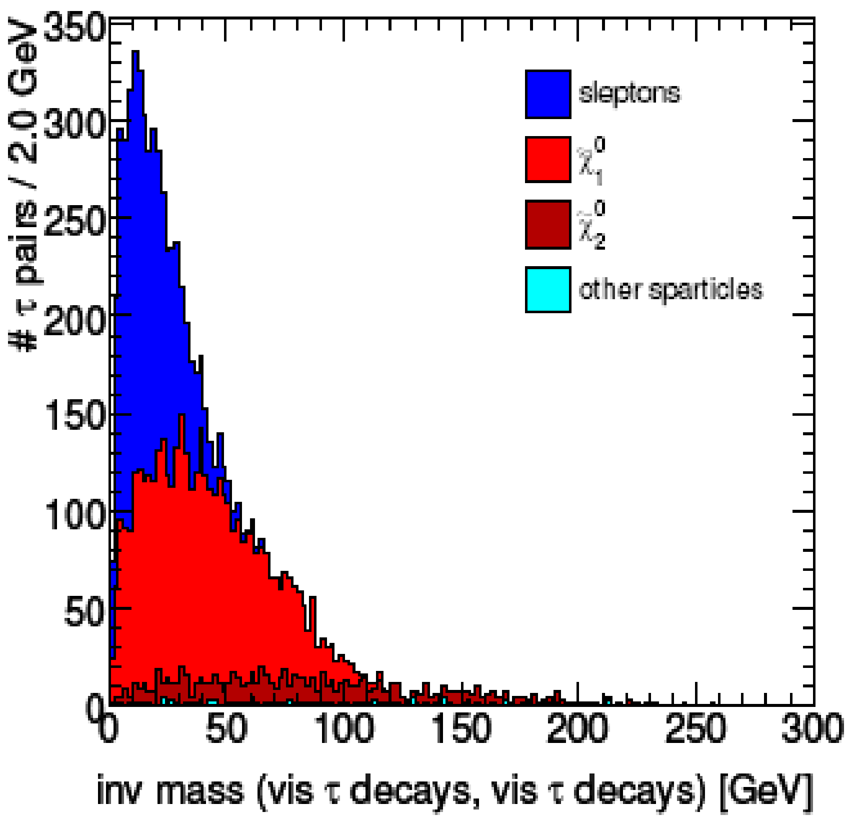
Outstanding issues:

  - pile-up not taken into account yet
  - difference in tau reconstruction efficiency for different tau decay modes could lead to bias
- further RPV studies:
  - increase BG statistics
  - develop selection cuts, study systematics (also with 10 TeV data)

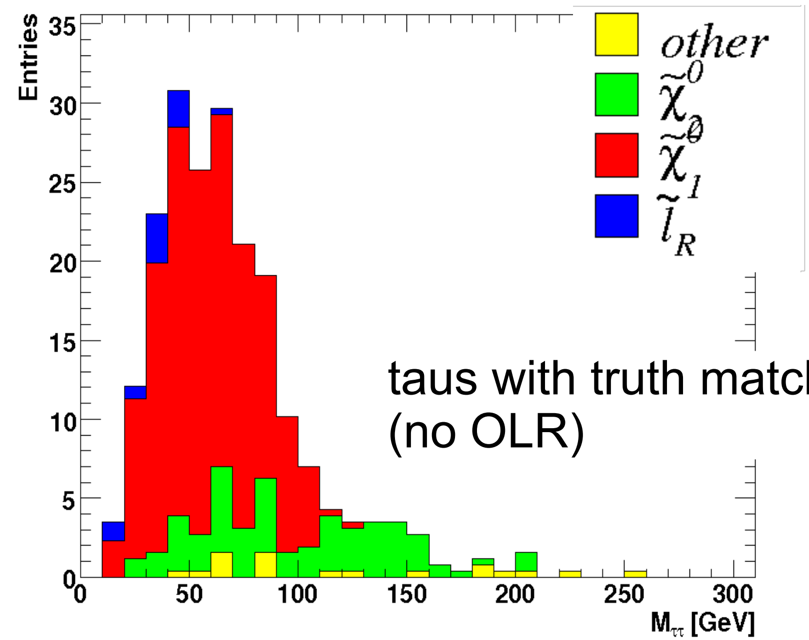
backup

GMSB slepton peak

Visible part of the invariant mass of 2τ (Generator Level)

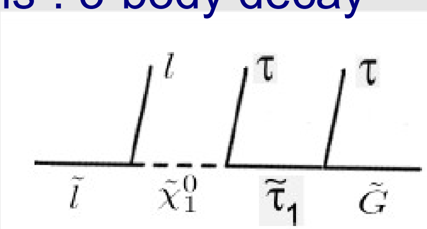


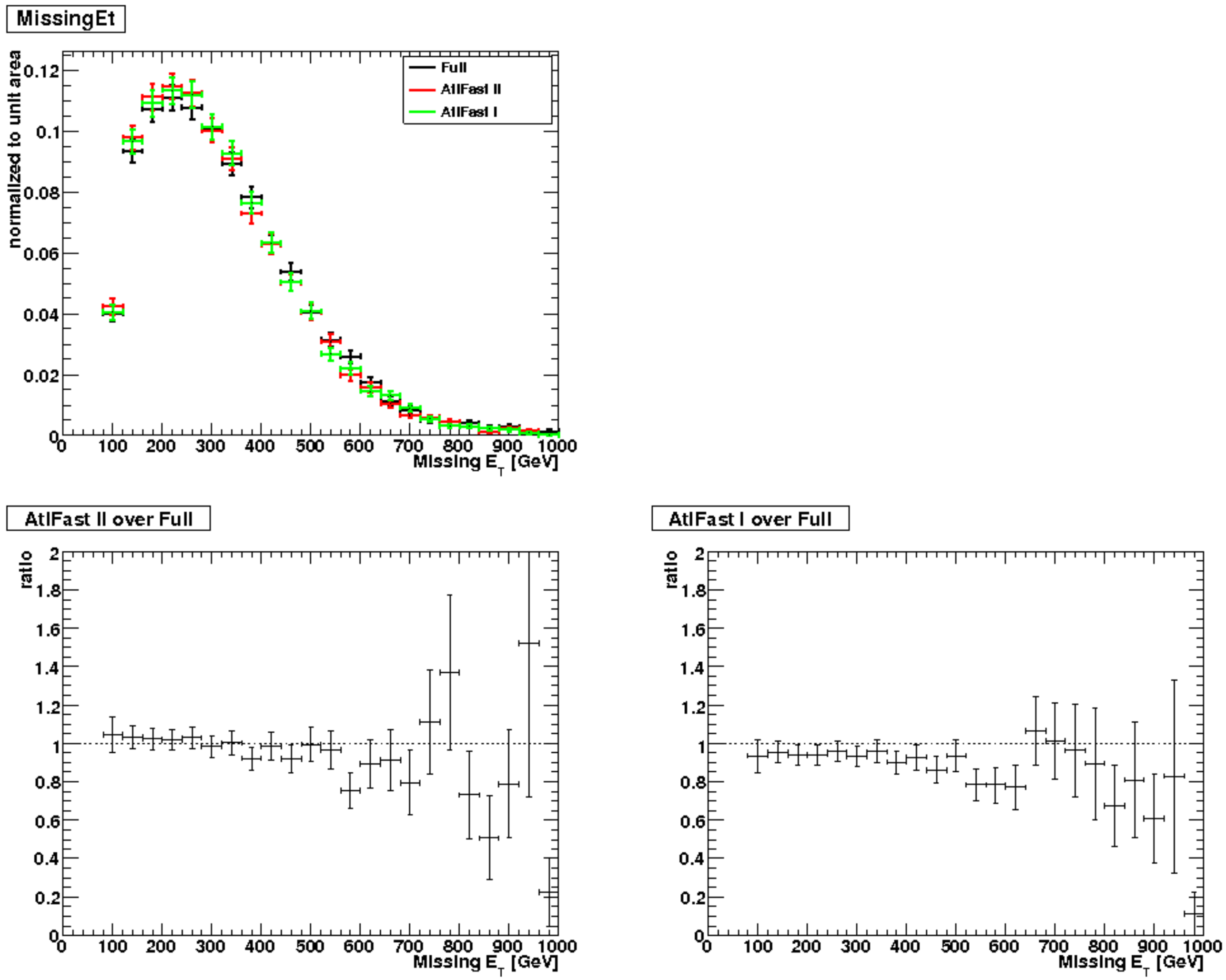
Detector level – taus with truth match

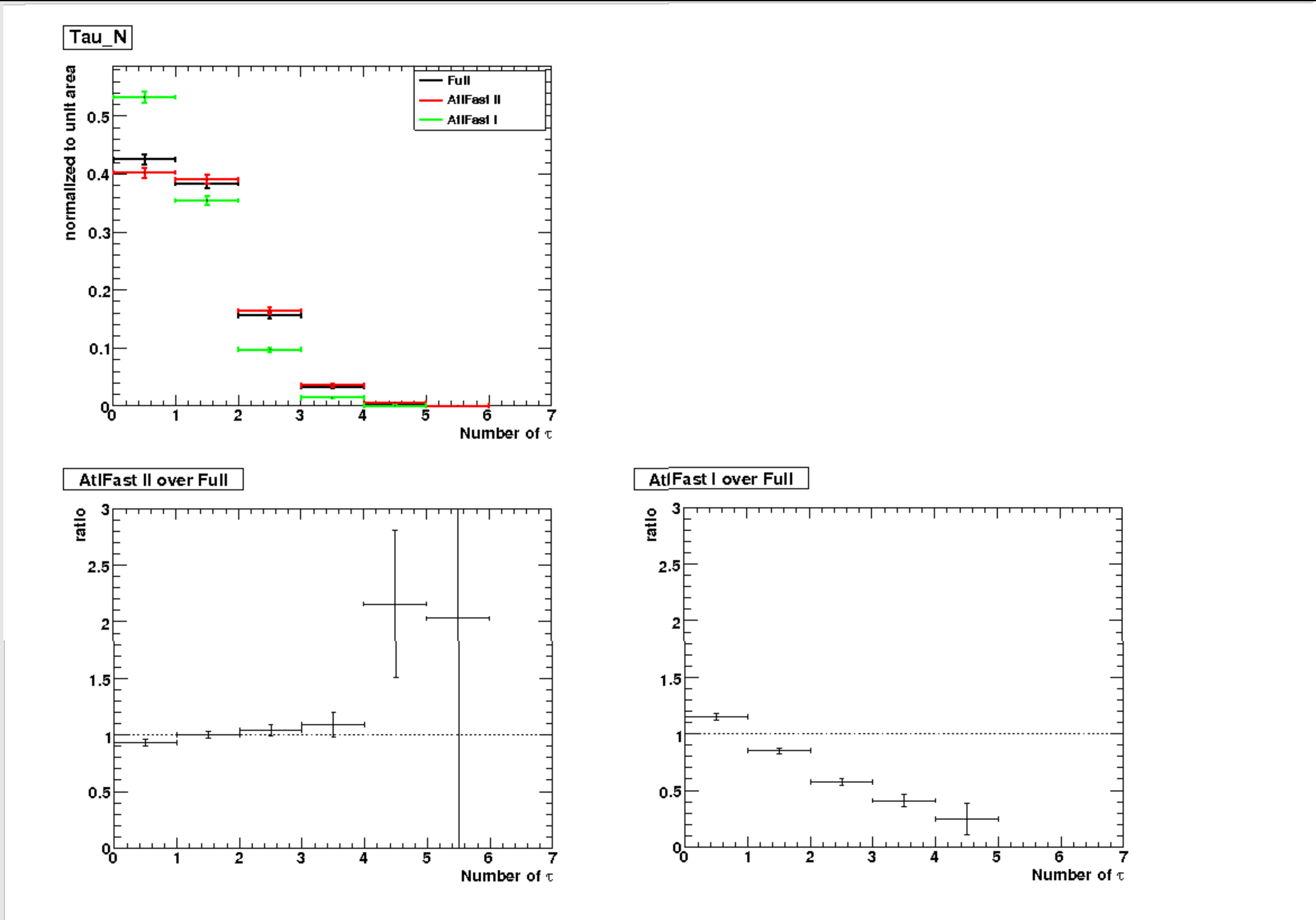


taus with truth match (no OLR)

"sleptons": 3-body decay

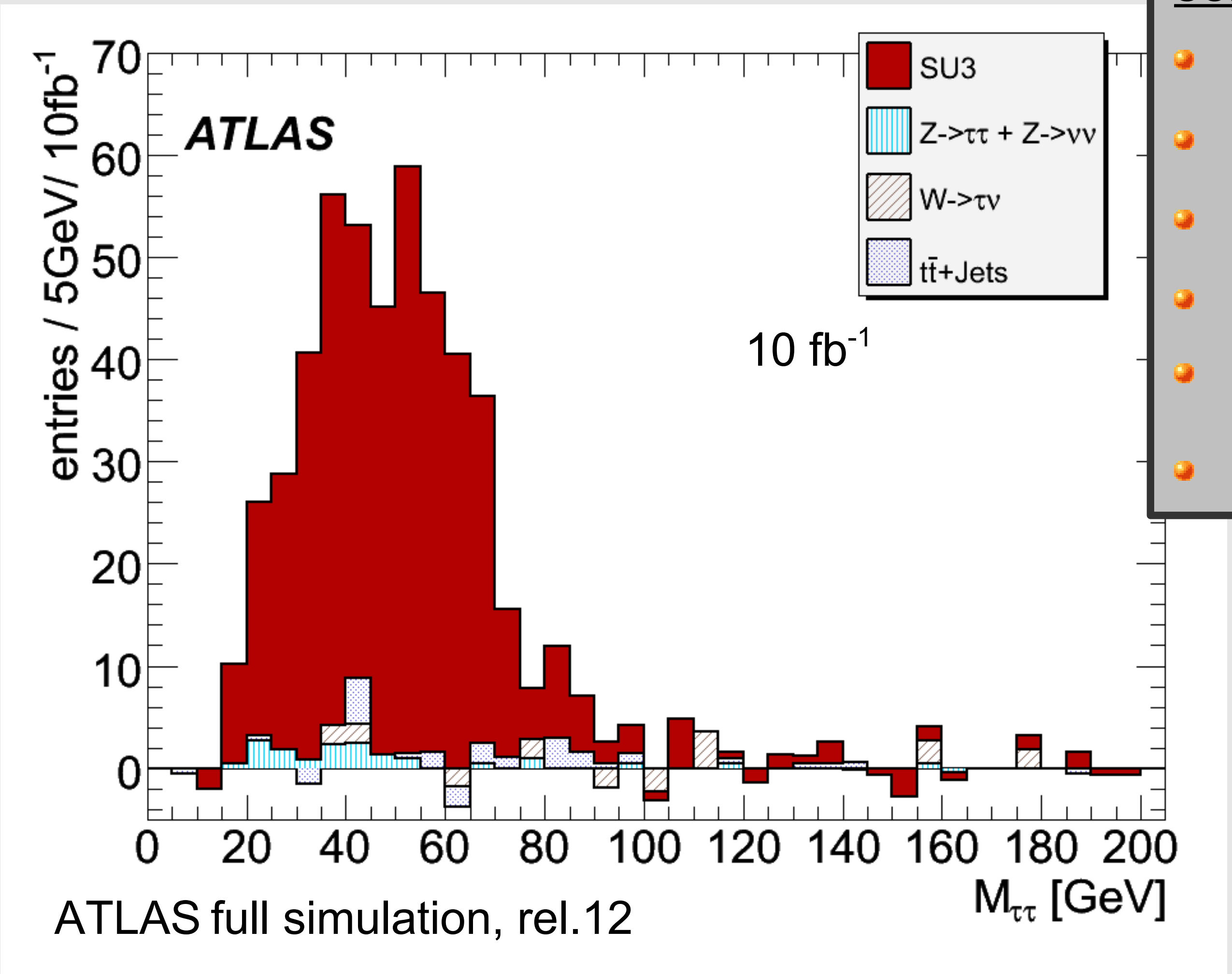



MissingEt
normalized to unit area
0.12
0.1
0.08
0.06
0.04
0.02
0
Full
AtlFast II
AtlFast I
0 100 200 300 400 500 600 700 800 900 1000
Missing E_T [GeV]
AtlFast II over Full
ratio
2 1.8 1.6 1.4 1.2 1 0.8 0.6 0.4 0.2 0
0 100 200 300 400 500 600 700 800 900 1000
Missing E_T [GeV]
AtlFast I over Full
ratio
2 1.8 1.6 1.4 1.2 1 0.8 0.6 0.4 0.2 0
0 100 200 300 400 500 600 700 800 900 1000
Missing E_T [GeV]


Tau_N
normalized to unit area
Full
AtlFast II
AtlFast I
Number of τ
AtlFast II over Full
ratio
Number of τ
AtlFast I over Full
ratio
Number of τ

mass spectrum II

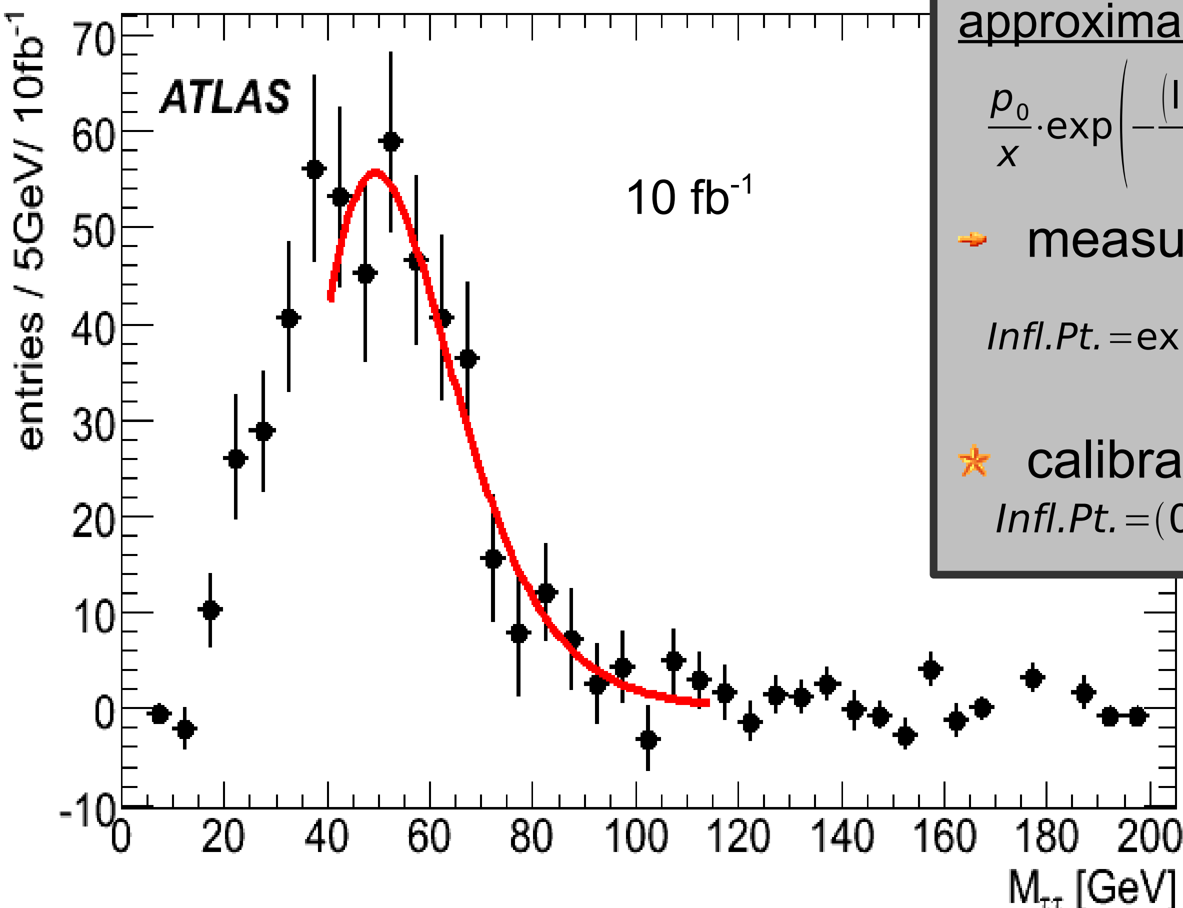
OS-SS



selection cuts:

- $p_T^{miss} > 230$ GeV
- 4 Jets: $p_T > 40$ GeV
- 3 Jets: $p_T > 50$ GeV
- 1 Jet: $p_T > 220$ GeV
- $\Delta R(\tau\tau) < 2$
- OS-SS

endpoint measurement method



ATLAS full simulation, rel.12

approximate shape:

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

- measure inflection point:

$$Infl.Pt. = \exp\left(\frac{-1}{2} p_2^2 \left(3 - \sqrt{\left(1 + \frac{4}{p_2^2}\right)}\right) + p_1\right)$$

- calibration done with ATLFAST:

$$Infl.Pt. = (0.47 \pm 0.02) m_{\tau\tau}^{max} + (15 \pm 2) GeV$$

- measured endpoint:

(theory: **99** GeV)

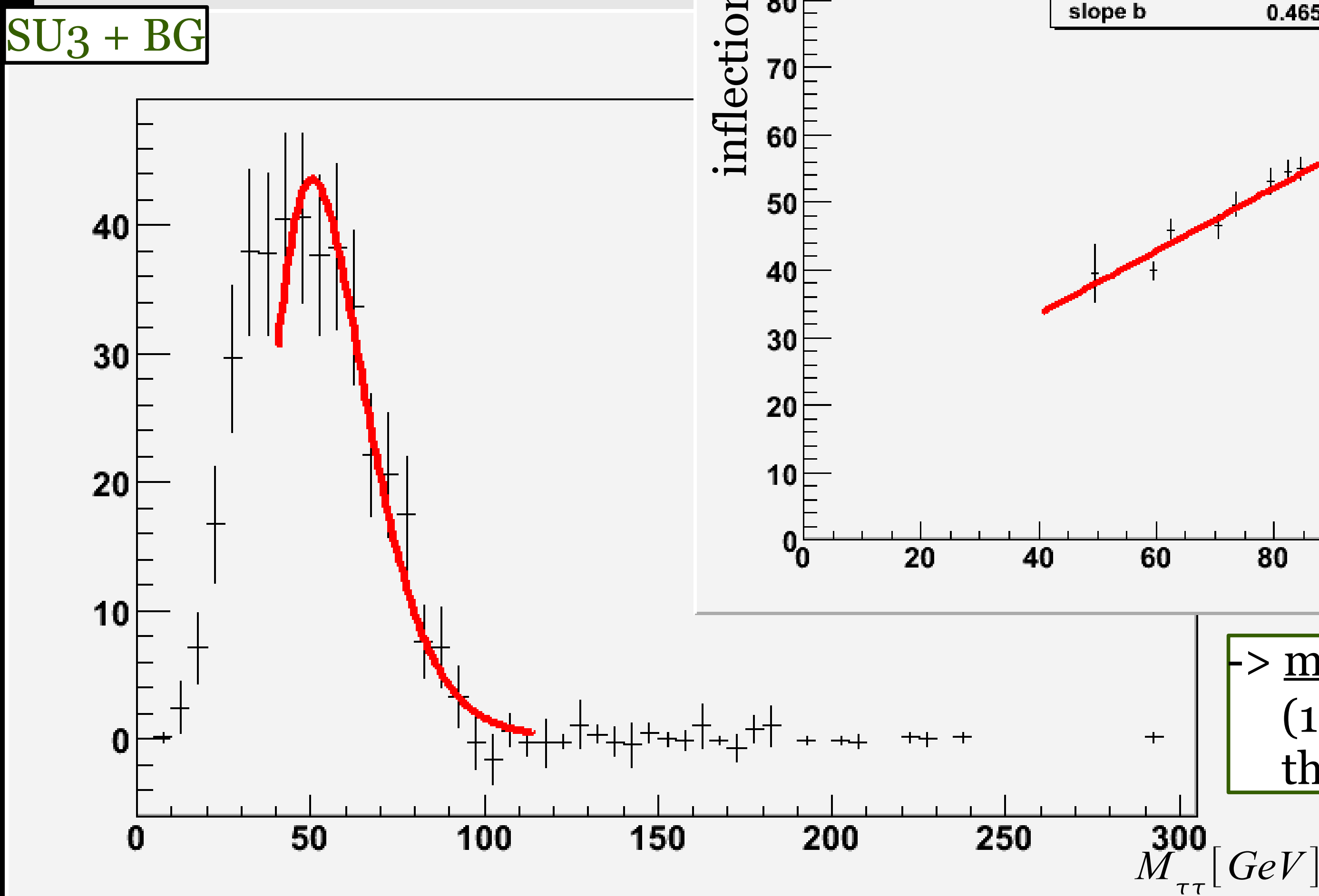
$103 \pm 5^{stat} \pm 4.5^{syst*}$ GeV

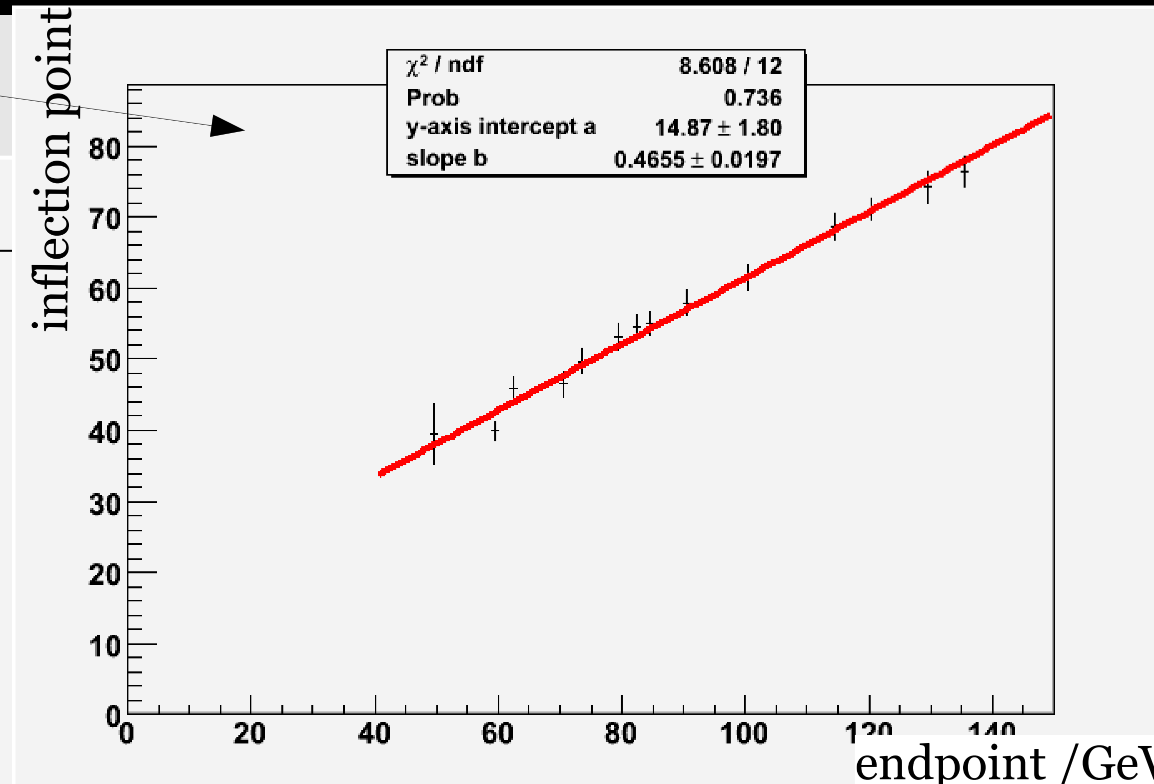
for 10 fb^{-1}

* syst. error: fast simulation

Atlfast Calibration

$y = (0.47 \pm 0.02)\,x + (15 \pm 2)\,GeV$





-> <u>measured endpoint:</u>
(105 § 4^{stat}) GeV
theoretical: 98 GeV

SU1: 70 +- 6.5 (theory: 78)

trigger issues

	efficiency			#events			
	ohne cuts	met/jet cuts	**Ntau>=2**	ohne cuts	met/jet cuts	Ntau>=2	
j160	0.82	0.99	**1.00**	73560	22782	367	HLT
j200	0.83	0.99	**0.99**	73711	22682	365	
j400	0.27	0.40	**0.39**	24276	9159	144	SUSY
2j120	0.64	0.80	**0.78**	56881	18450	287	HLT
3j65	0.53	0.81	**0.84**	47090	18566	308	HLT
3j165	0.08	0.16	**0.14**	6820	3621	50	SUSY
4j55	0.31	0.57	**0.68**	27417	13111	251	HLT
4j110	0.06	0.12	**0.14**	4952	2787	50	SUSY
jets**HLT***	0.88	1.00	**1.00**	78644	22910	368	
j42_xe50	0.90	1.00	**1.00**	80580	22821	367	
j70_xe70	0.85	0.99	**0.99**	75907	22706	364	SUSY
xe80	0.83	0.99	**0.98**	73982	22603	362	
te650	0.51	0.80	**0.89**	45817	18339	328	
tau20i_j70	0.44	0.51	**0.96**	39511	11590	354	
tau20i_j120	0.41	0.51	**0.96**	36853	11588	354	
tau20i_2j70	0.40	0.49	**0.95**	35361	11267	348	
tau20i_3j23	0.42	0.51	**0.96**	37668	11586	354	
tau20i_xe30	0.44	0.50	**0.96**	39439	11571	354	
tau25i_j70	0.40	0.46	**0.92**	35503	10459	339	
tau25i_j120	0.37	0.46	**0.92**	33127	10457	339	
tau25i_xe40	0.39	0.45	**0.92**	34515	10422	339	HLT
tau45i_xe40	0.26	0.32	**0.72**	23305	7221	266	
xe90	0.81	0.98	**0.98**	72062	22494	359	
tau150	0.17	0.20	**0.27**	15153	4684	101	
tau35i_4j23	0.26	0.37	**0.82**	23373	8570	301	
3j100	0.39	0.64	**0.61**	34544	14672	225	
j300	0.57	0.81	**0.78**	51248	18600	287	

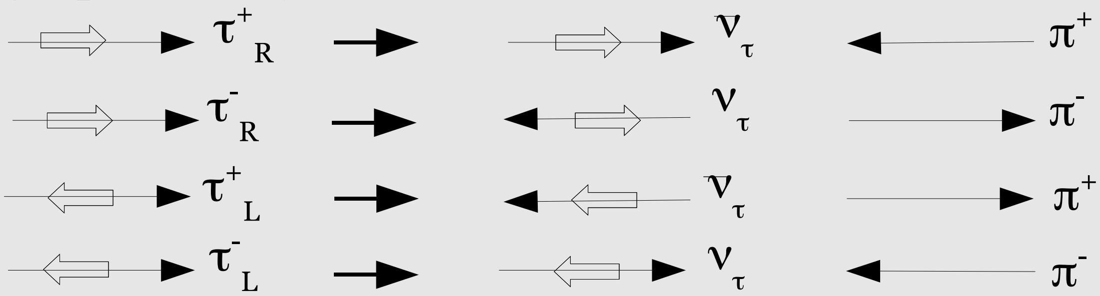
* jets**HLT** = j160 || 2j120 || 3j65 || 4j55

Sheet3

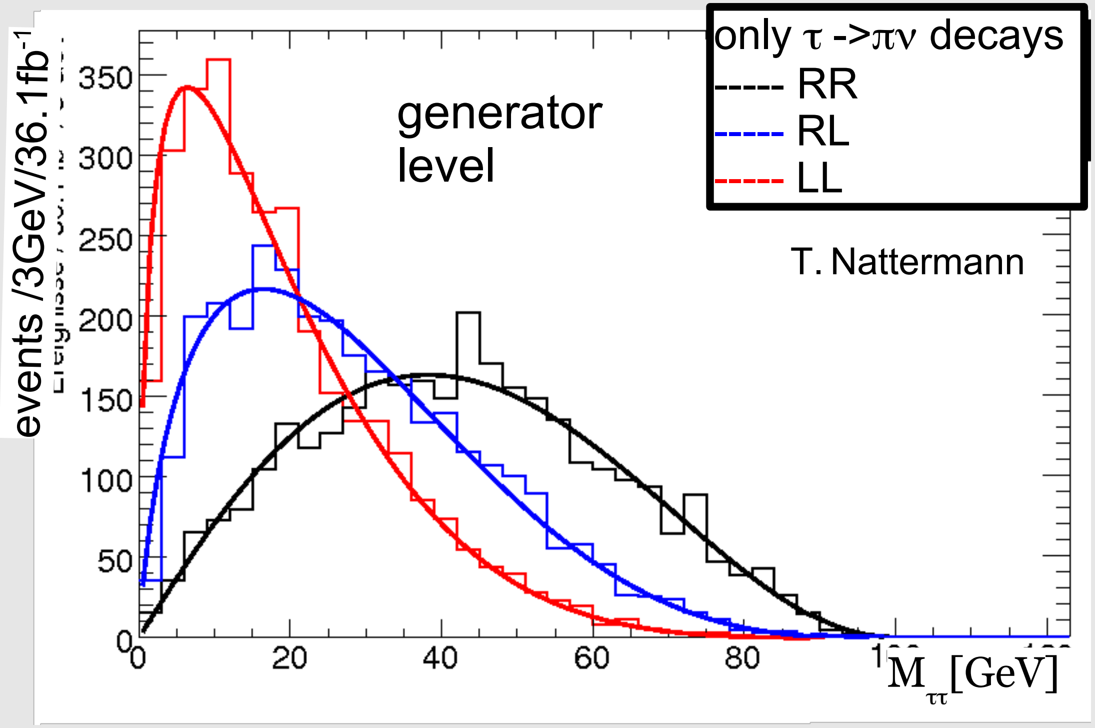
	prescale 1	
10^(31)	10^(32)	10^(33)
te650 xe70,xe80 j120, j200 4j23 tau20i_4j23 tau100	te800 xe70,xe80 j200 3j50,3j70 4j35,4j50 tau25i_4j23 tau150	te900 xe90 j300 3j100 4j50 tau35i_4j23 tau150
tau20i_xe30 tau35i_xe40 tau45_xe40	tau35i_xe40	tau45i_xe40
2tau25i 2tau35i	2tau35i	2tau45i
tau20i_j120 tau20i_3j23 tau25i_j70 tau20i_j70 tau20i_2j70		

polarization effects

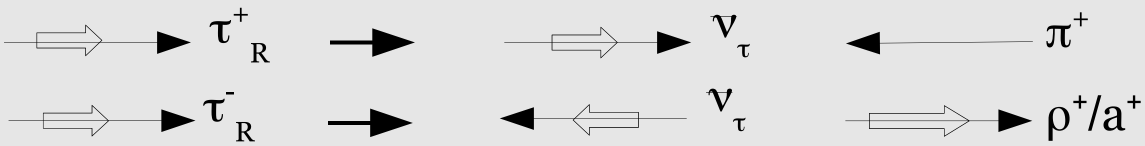
<u>single pion decay:</u>



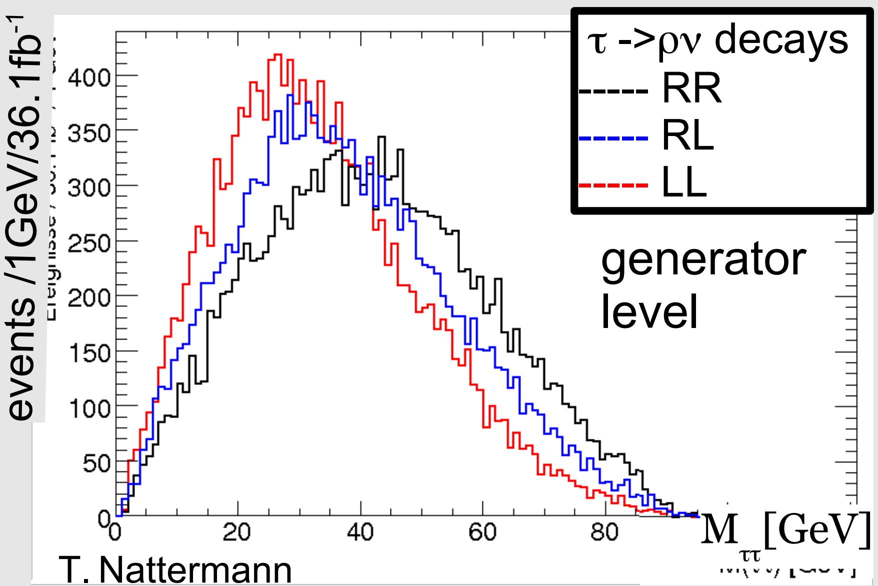
- angular momentum /
  - momentum conservation
  - + helicity of neutrino
- pion momentum direction determined by tau charge and helicity
- pion boosted (anti)parallel to tau momentum direction

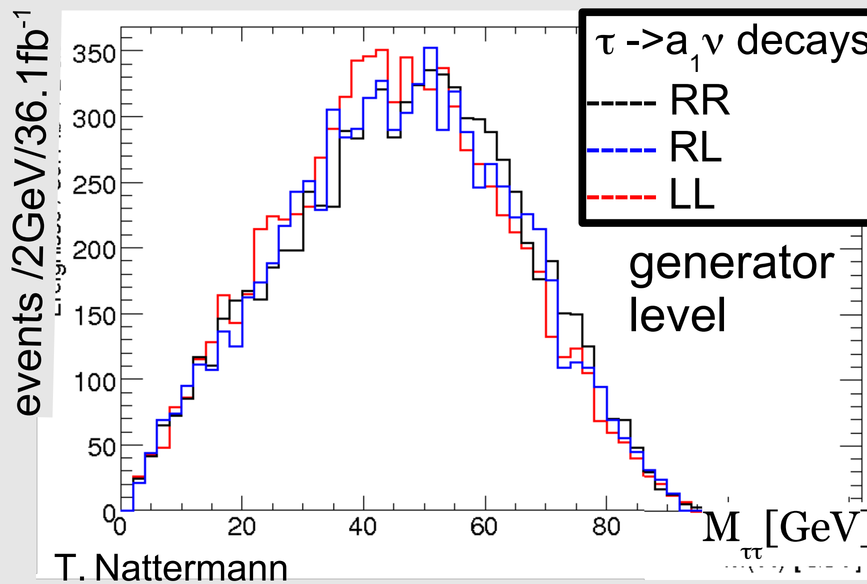


- shape of mass spectrum depends on tau polarization
- inflection point shifted



- ρ/a_1: same (opp.) momentum direction as π for long. (transv.) meson
  - ρ: longitudinal share bigger than transversal
  - a_1: longitunal and transversal share equal -> mass spectrum not shifted

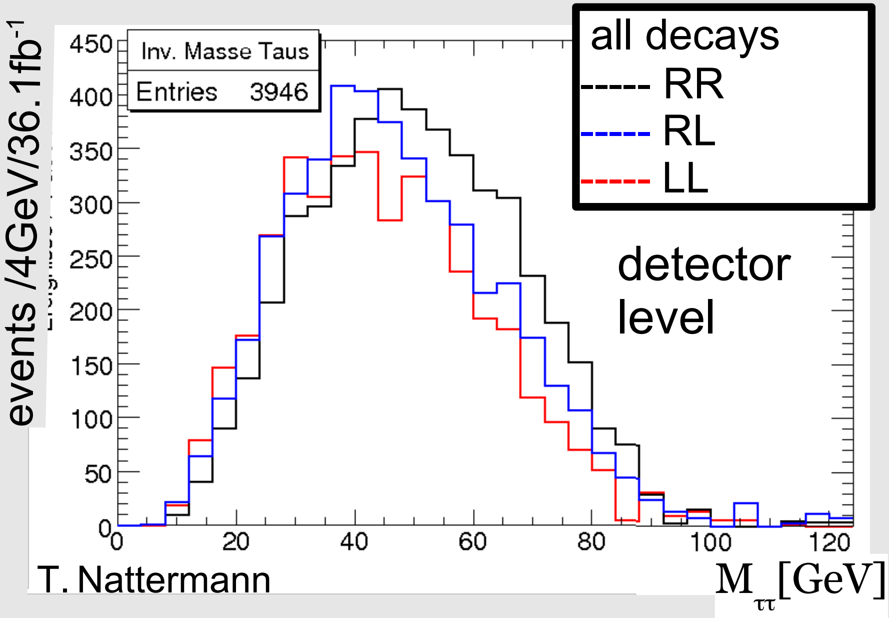




- rho/a1 difference:

$$\frac{d\Gamma}{d\cos\theta} \propto \underbrace{\left(\frac{m_V^2}{m_\tau^2 + 2m_V^2}(1 - P_\tau \cos\theta)\right)_T}_{\text{transversal}} \underbrace{\left(\frac{(1/2)m_\tau^2}{m_\tau^2 + 2m_V^2}(1 + P_\tau \cos\theta)\right)_L}_{\text{longitudinal}}$$

- detector effects: ATLFAST (fast simulation)

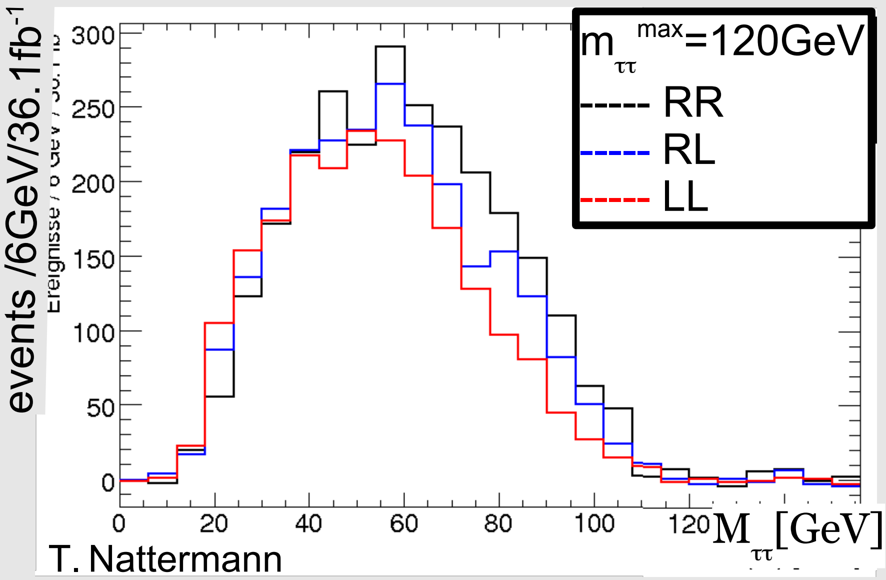


- shape deformed by low tau reconstruction efficiency at low p_T
- reduced shape information, rising edge determined by τ ID

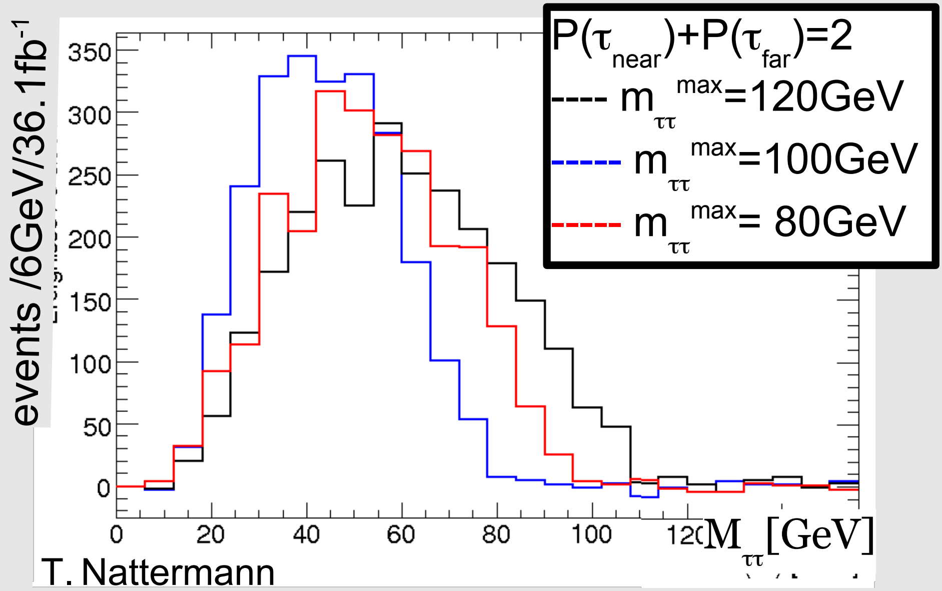
- shift in trailing edge affects inflection point but not endpoint
- additional uncertainty on calibration showed before
- add. error on endpoint measurement: **$\pm$ 3.5$^{(pol)}$ GeV**

- to measure both endpoint and polarization: disentangle mass and polarization effects
  - search traits with max. different sensitivity to mass / polarization:

polarization effect: fixed masses



mass effect: fixed polarization

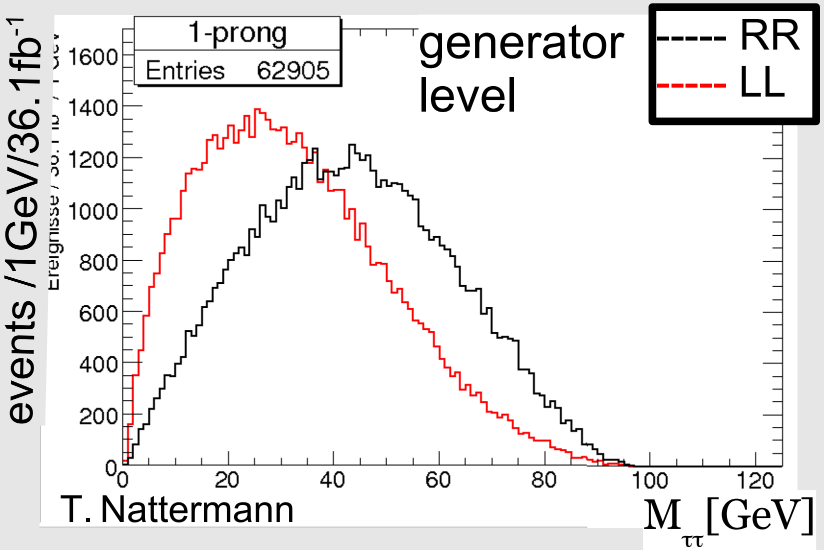


- max. difference close to maximum
- max. difference at high $m_{\tau\tau}$
- traits for calibration: maximum plus position of 0.1*maximum

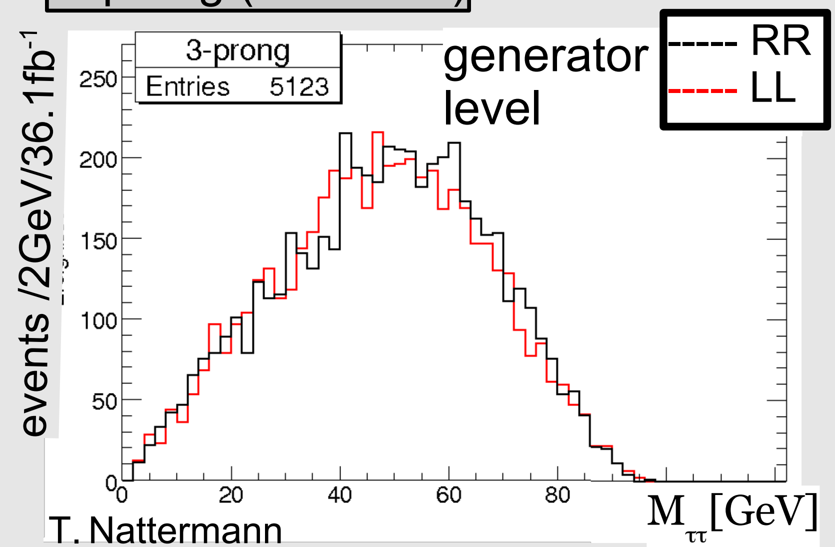
separation via 1p/3p

- <u>separation of 1prong and 3prong decays:</u>
  3p dominated by a_1 (~2/3) and “others” (=not ρ,π,a_1) -> indepent of polarization

1 prong (both taus)



3 prong (both taus)



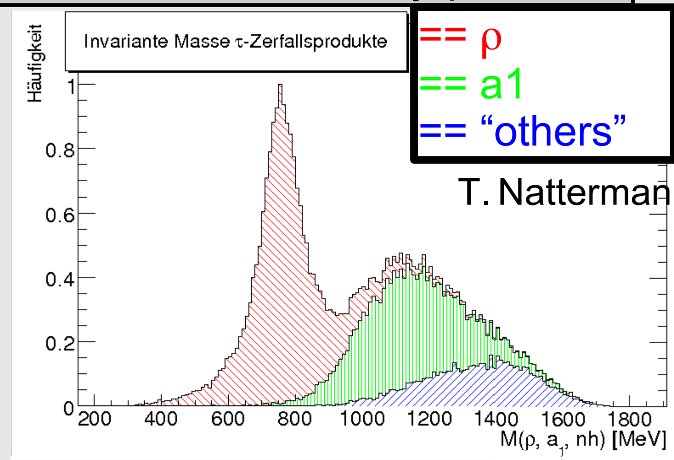
<u>but:</u> only 5% of double-hadronic decays are double-3prong
+ some a_1 also decay 1prong

- on detector level and after selection cuts, not enough double-3prongs for endpoint determination

- use invariant mass of single tau decay products:

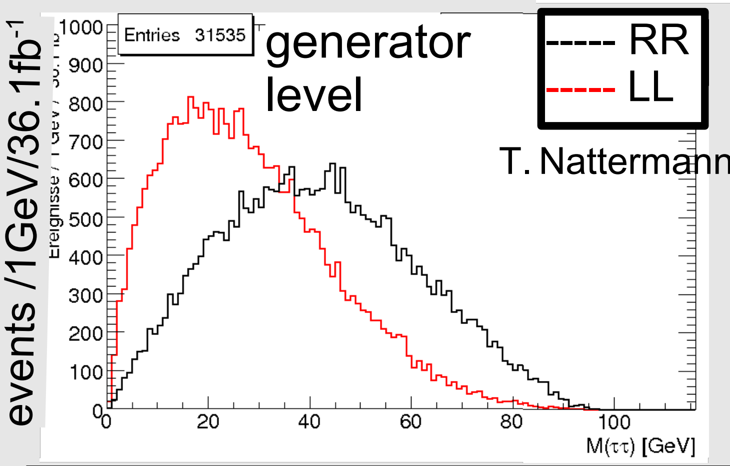
Inv. Mass of tau decay products

generator level

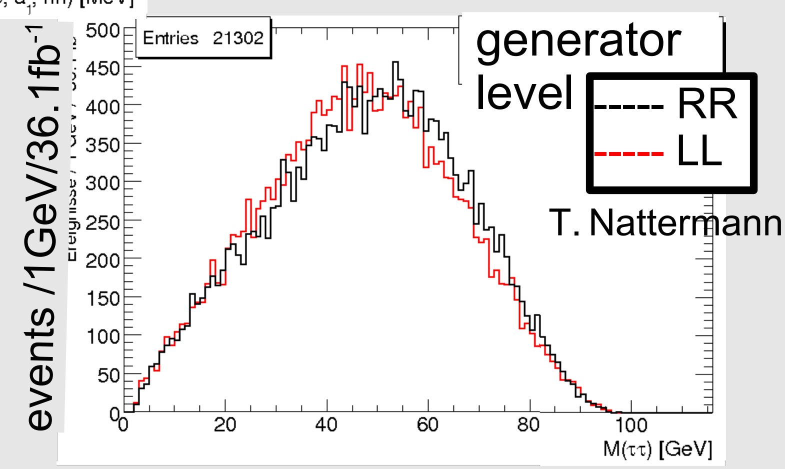


- **but:** need to reconstruct
- all decay products correctly
- currently not possible
- also not in ATLFAST

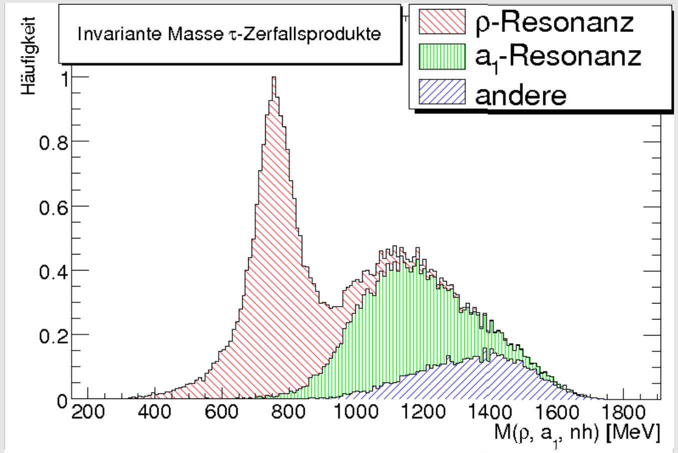
$p_\mu p^\mu < 900$ MeV

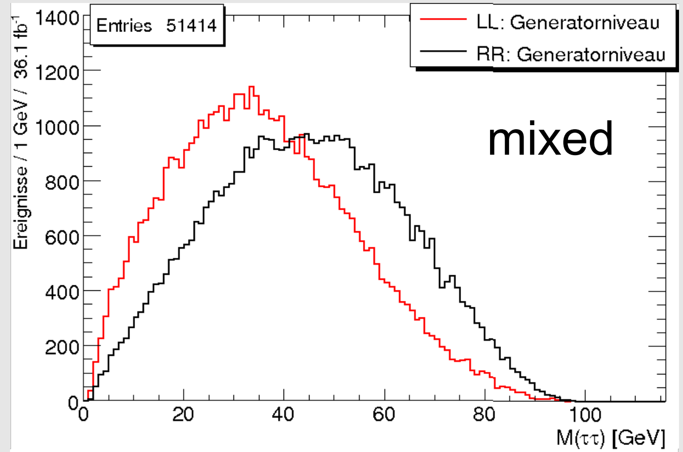


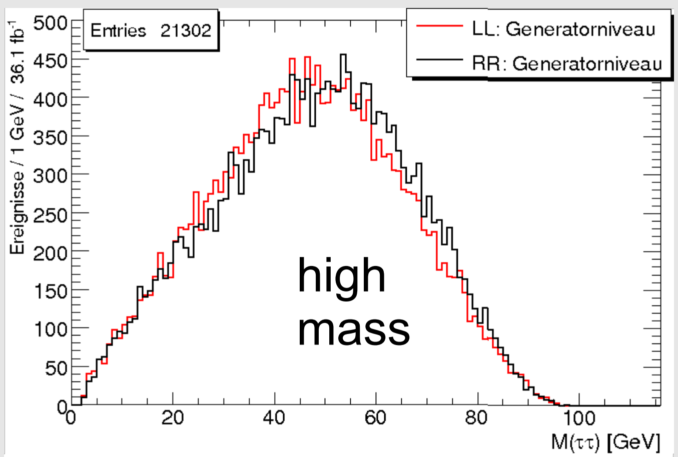
$p_\mu p^\mu > 900$ MeV

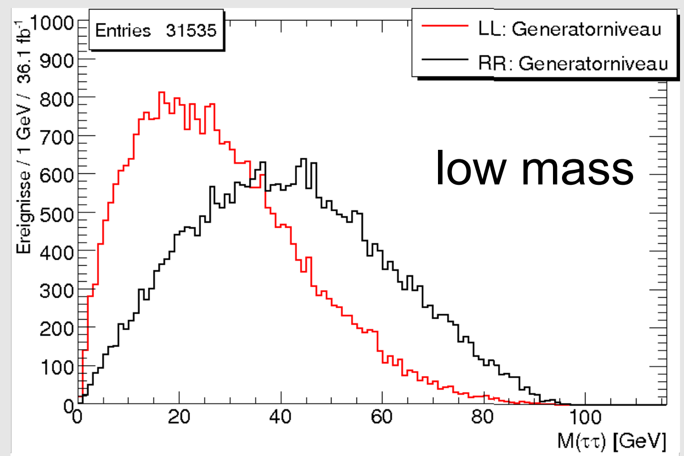


inv mass dec prod









R-Parity violating terms

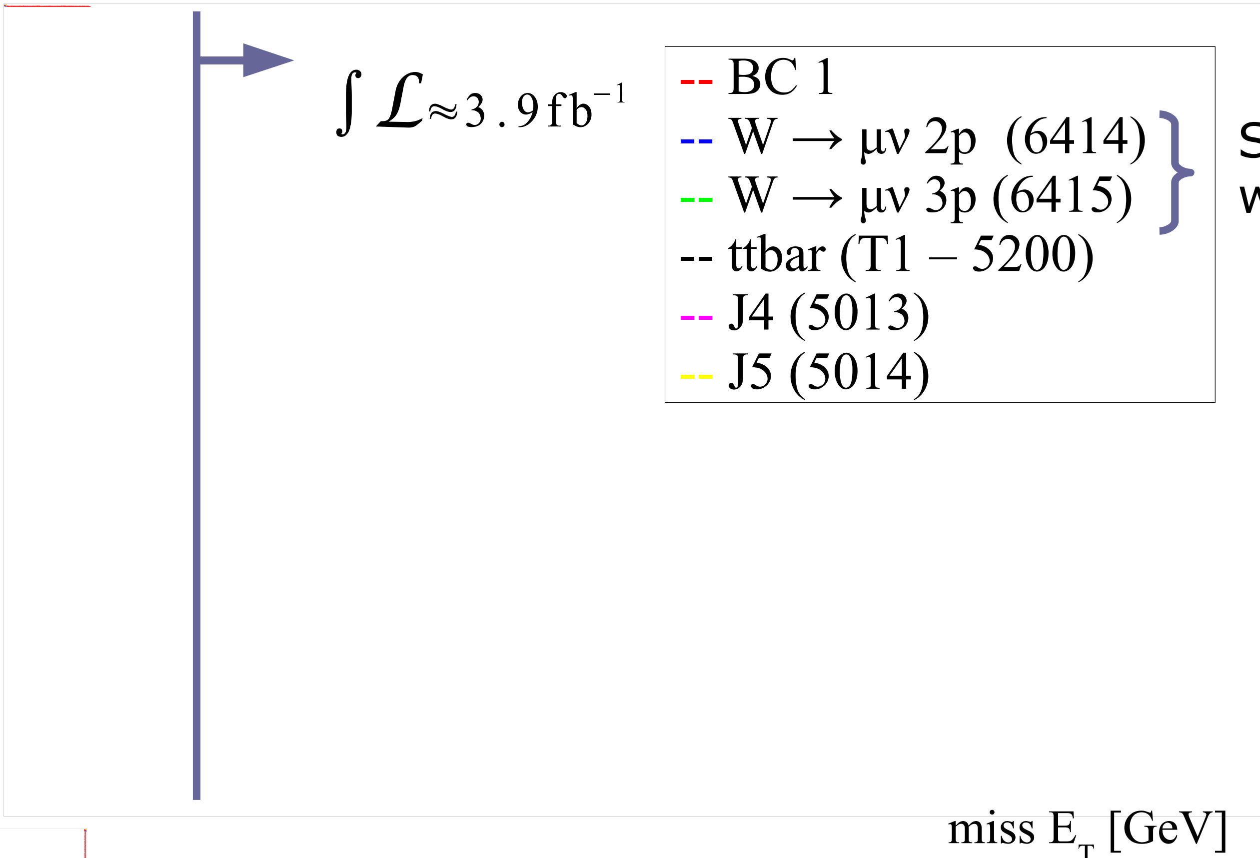
- All possible fully-renormalizable gauge invariant terms: Introduce Baryon number (*B*) or Lepton number (*L*) violating couplings

$$W_{\not R_P} = \epsilon_{ab}\left[\frac{1}{2}\underbrace{\lambda_{ijk}L_i^a L_j^b \bar{E}_k}_{\text{violates } L} + \underbrace{\lambda'_{ijk}L_i^a Q_j^{bx} \bar{D}_{kx}}_{\text{violates } L}\right] + \frac{1}{2}\epsilon_{xyz}\underbrace{\lambda''_{ijk}\bar{U}_i^x \bar{D}_j^y \bar{D}_k^z}_{\text{violates } B} - \epsilon_{ab}\underbrace{\kappa^i L_i^a H_u^b}_{\text{violates } L}$$

i, j, k: generation ind.
x, y, z: SU(3) gauge ind.
a, b: SU(2) gauge ind.

- Only *B* **or** *L* violating couplings allowed to prevent proton decay

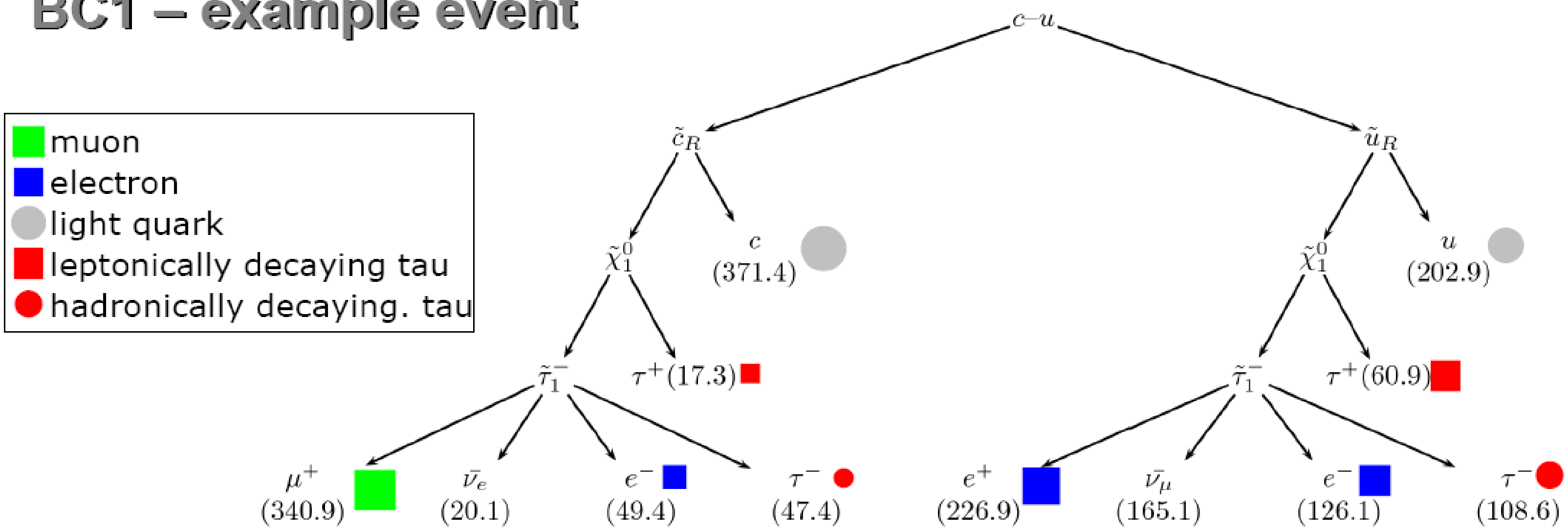
BC1 ($\tilde{\tau} \rightarrow l l \tau \nu$) Event variables:
Missing transverse energy



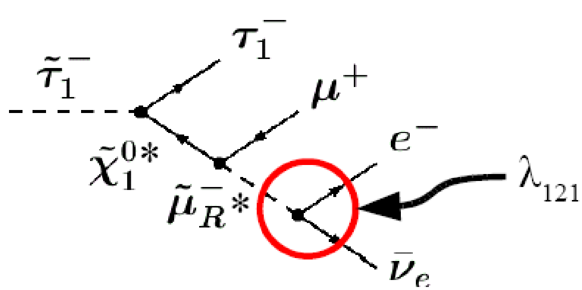
SUSY WG samples with EF cut $\mathrm{MET} > 50\ \mathrm{GeV}$

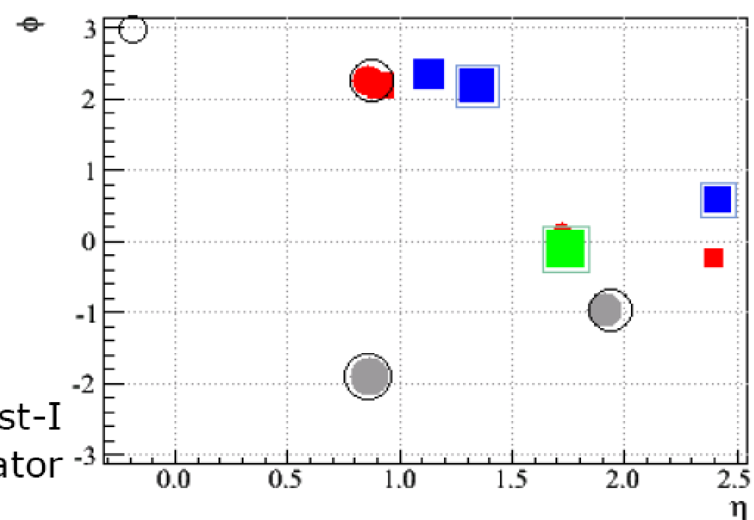
- Introduce "artificial" cut on missing transverse energy ($\mathrm{MET} > 65\ \mathrm{GeV}$) in the following plots to be able to use SUSY WG background samples
  - Especially with first data it may be appealing to avoid an $E_T$miss cut

RPV mSUGRA Benchmark Points:
BC1 – example event



Cross section @ 14 TeV: $\sigma = 3{,}8$ pb



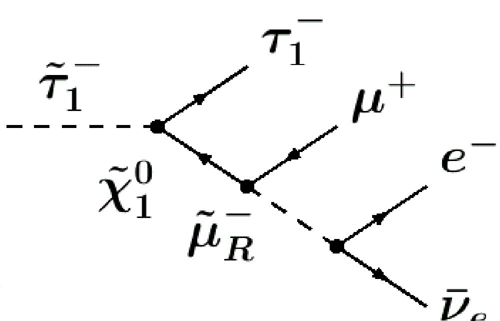


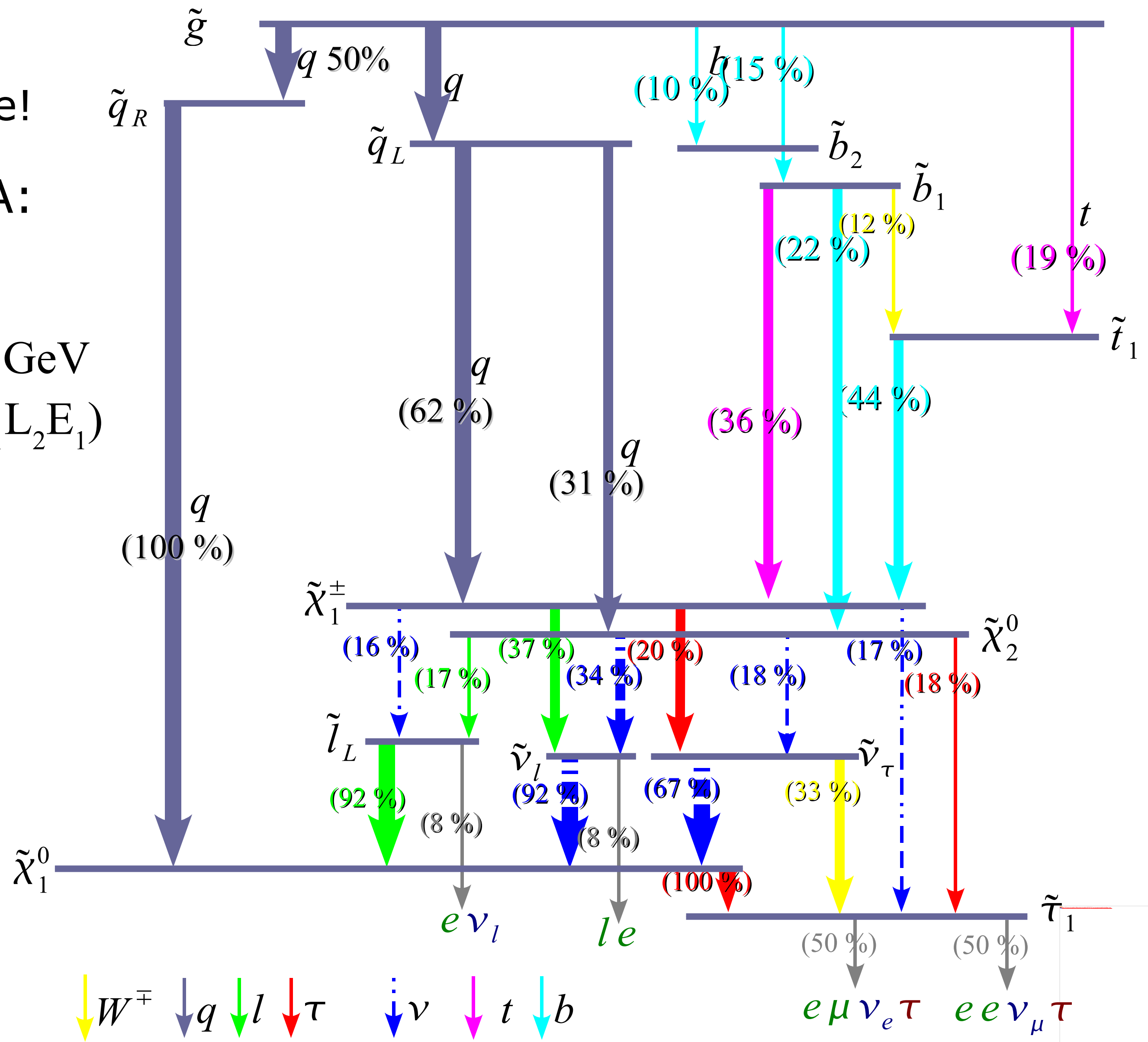
Open symbols: ATLfast-I
Solid symbols: Generator

RPV mSUGRA Benchmark Points: BC1

Spectrum not to scale!

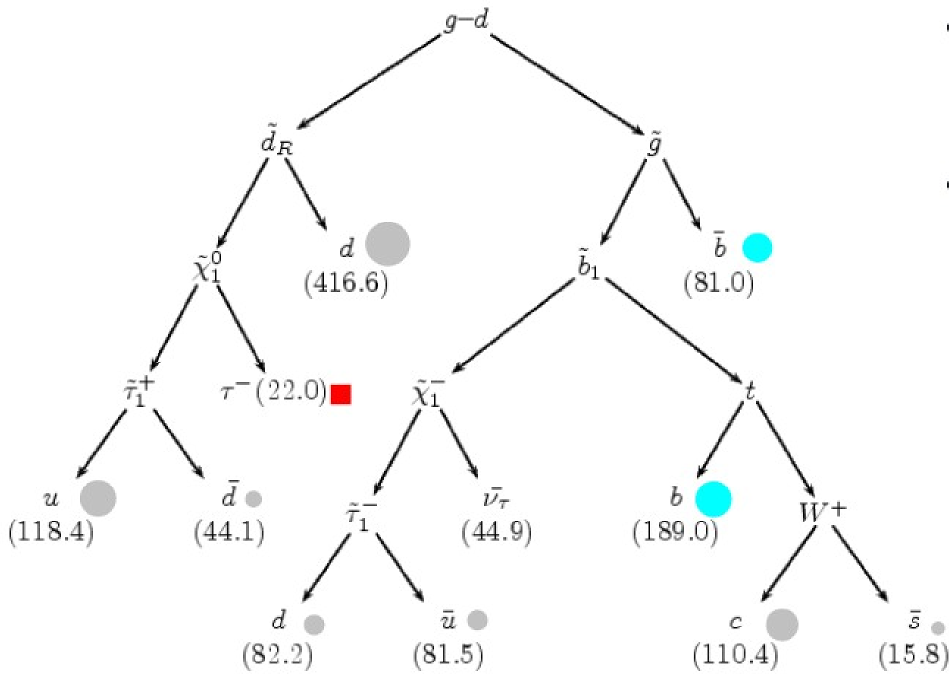
- no-scale mSUGRA: $A_0 = M_0 = 0$ @ M_{GUT}, $\mathrm{sgn}(\mu) = +1$, $\tan\beta = 13$, $M_{1/2} = 400$ GeV
- $\lambda_{121}(M_{GUT}) = 0.032$ $(L_1L_2E_1)$





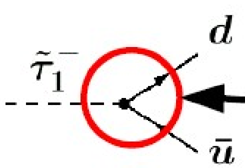
RPV mSUGRA Benchmark Points:

BC2 – Example event



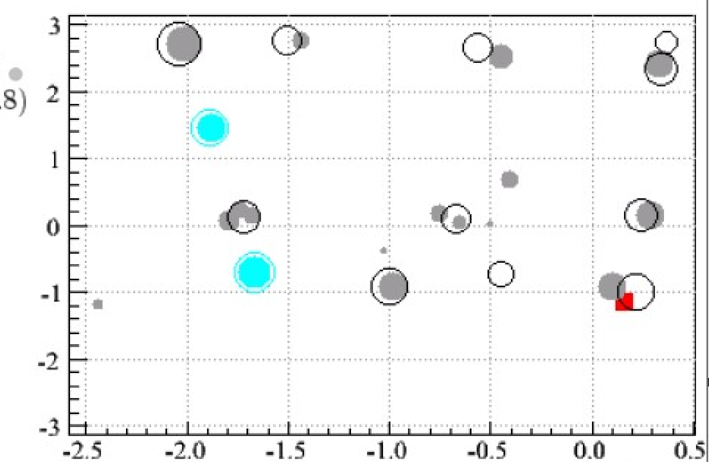
- Upper part of cascade similar to BC1
- More jets and less leptons due to decay $\tilde{\tau} \rightarrow d\,u$

Cross section @ 14 TeV: $\sigma = 3{,}8\ \mathrm{pb}$



$\lambda'_{311}(M_{GUT}) = 3.5 \times 10^{-7}$

$(L_3Q_1D_1)$

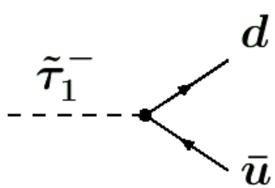


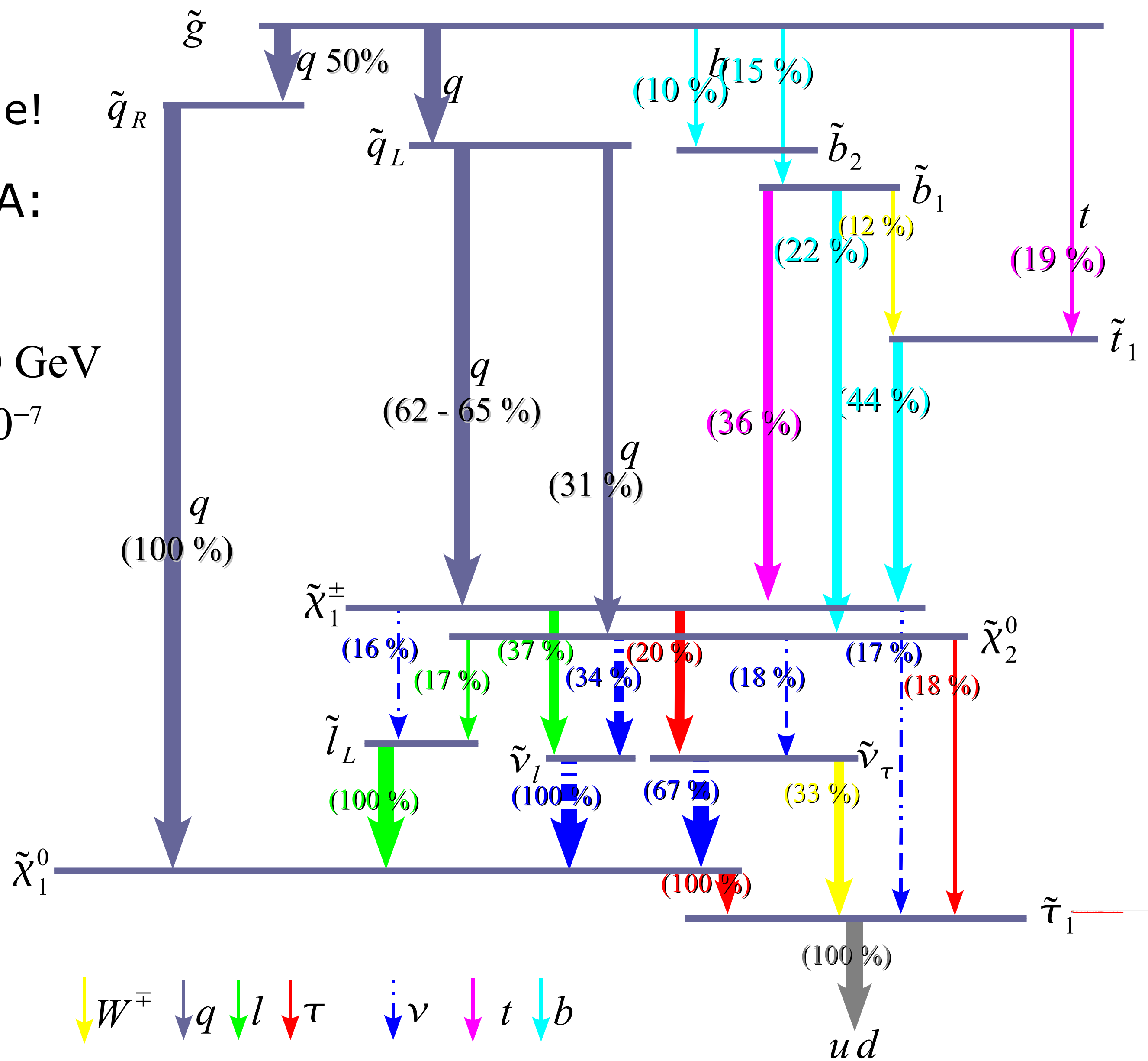
universität bonn

RPV mSUGRA Benchmark Points: BC2

Spectrum not to scale!

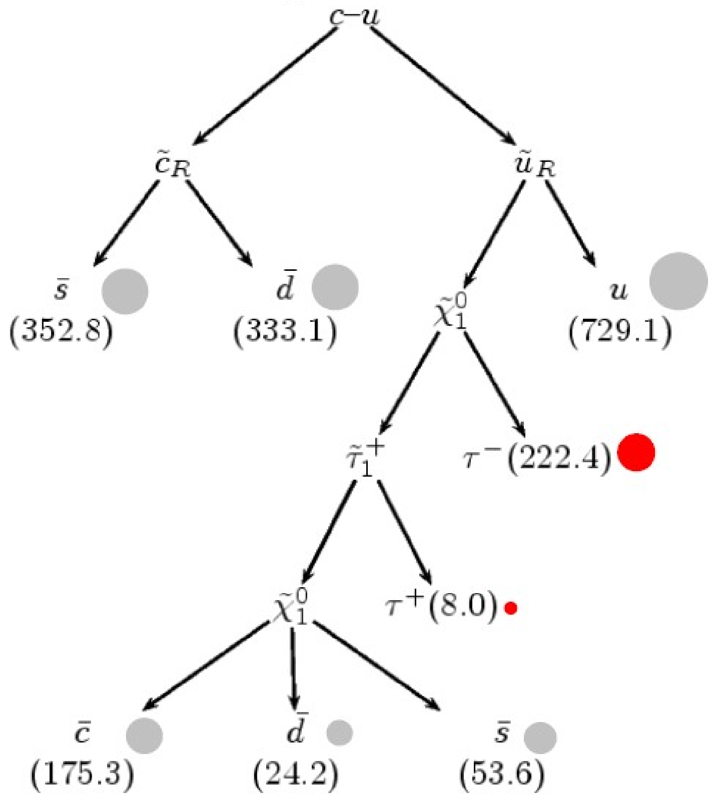
- no-scale mSUGRA:
  $A_0 = M_0 = 0$ @ M_{GUT},
  $\mathrm{sgn}(\mu) = +1$,
  $\tan\beta = 13$, $M_{1/2} = 400$ GeV
- $\lambda'_{311}(M_{GUT}) = 3.5 \times 10^{-7}$
  $(L_3Q_1D_1)$



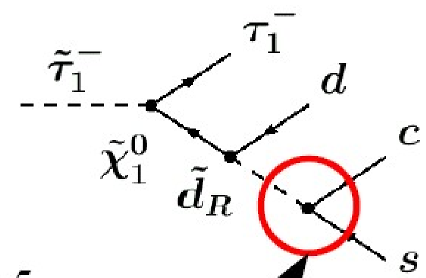


RPV mSUGRA Benchmark Points:

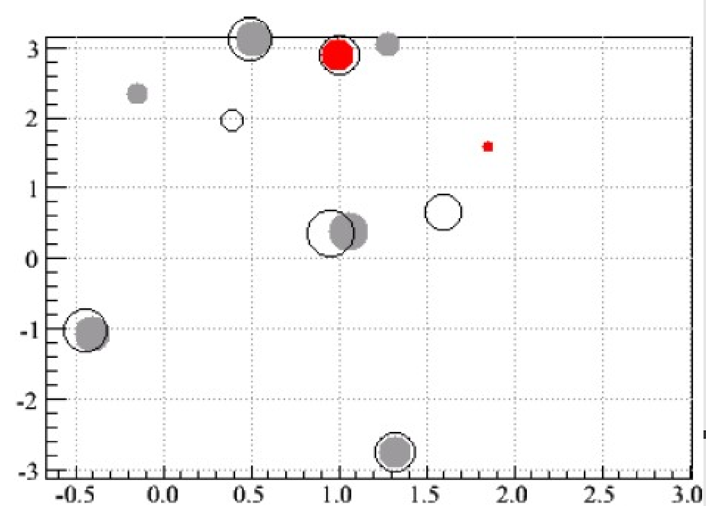
BC4 – Example event



- heavier scenario than BC1, BC2



$\lambda''_{212}(M_{GUT}) = 0.5$
$(U_2D_1D_2)$

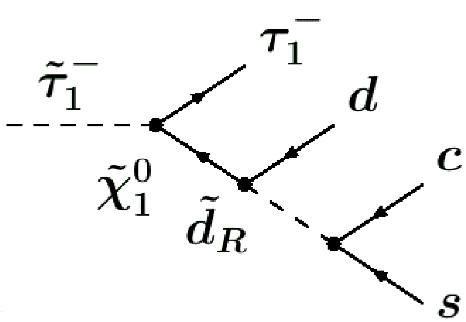


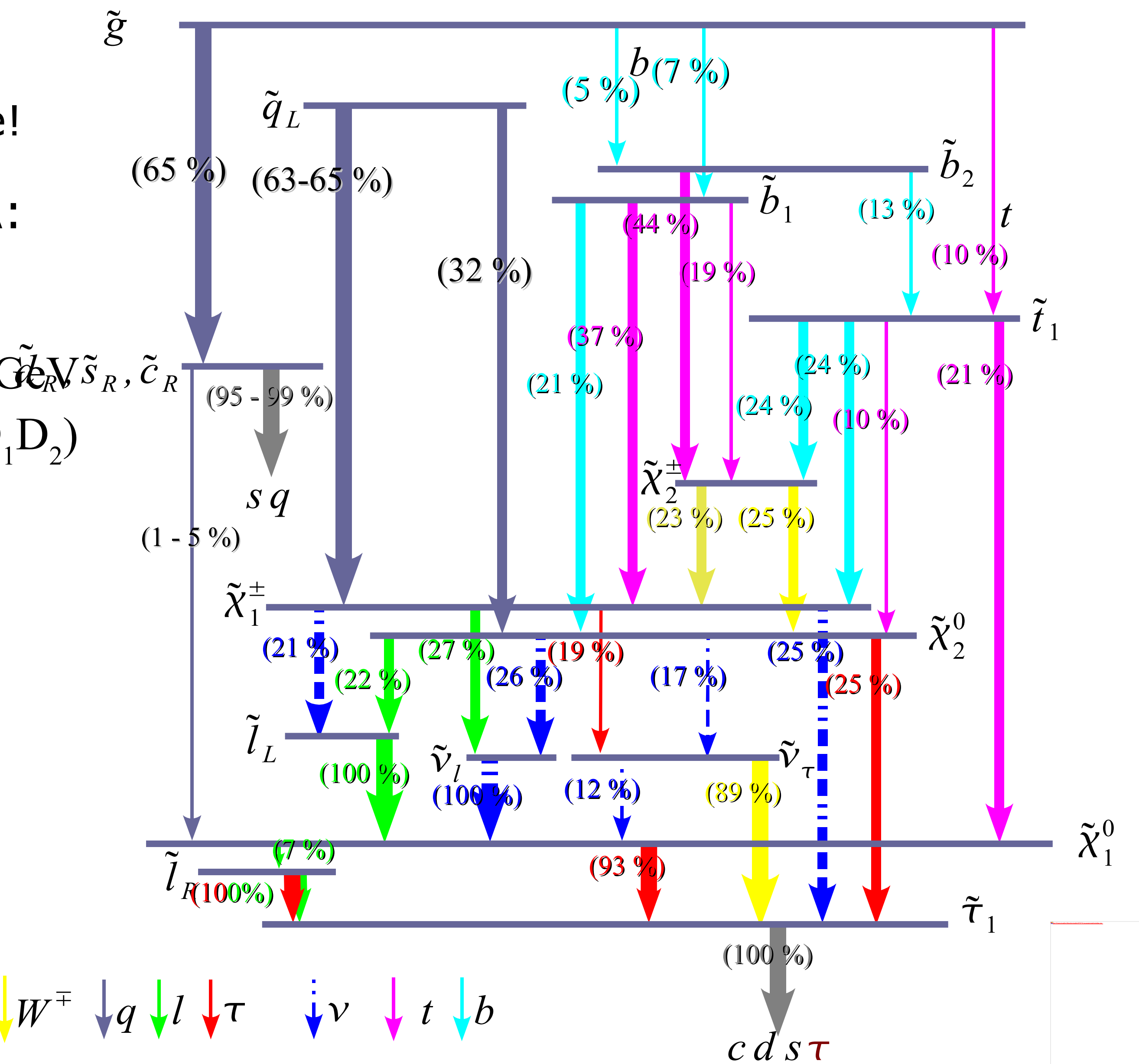
Cross section @ 14 TeV: $\sigma = 0{,}6$ pb

RPV mSUGRA Benchmark Points: BC4

Spectrum not to scale!

- no-scale mSUGRA:
  $A_0 = M_0 = 0$ @ M_{GUT},
  $\mathrm{sgn}(\mu) = +1$,
  $\tan\beta = 30$, $M_{1/2} = 600$ GeV
- $\lambda''_{212}(M_{GUT}) = 0.5$ $(U_2 D_1 D_2)$

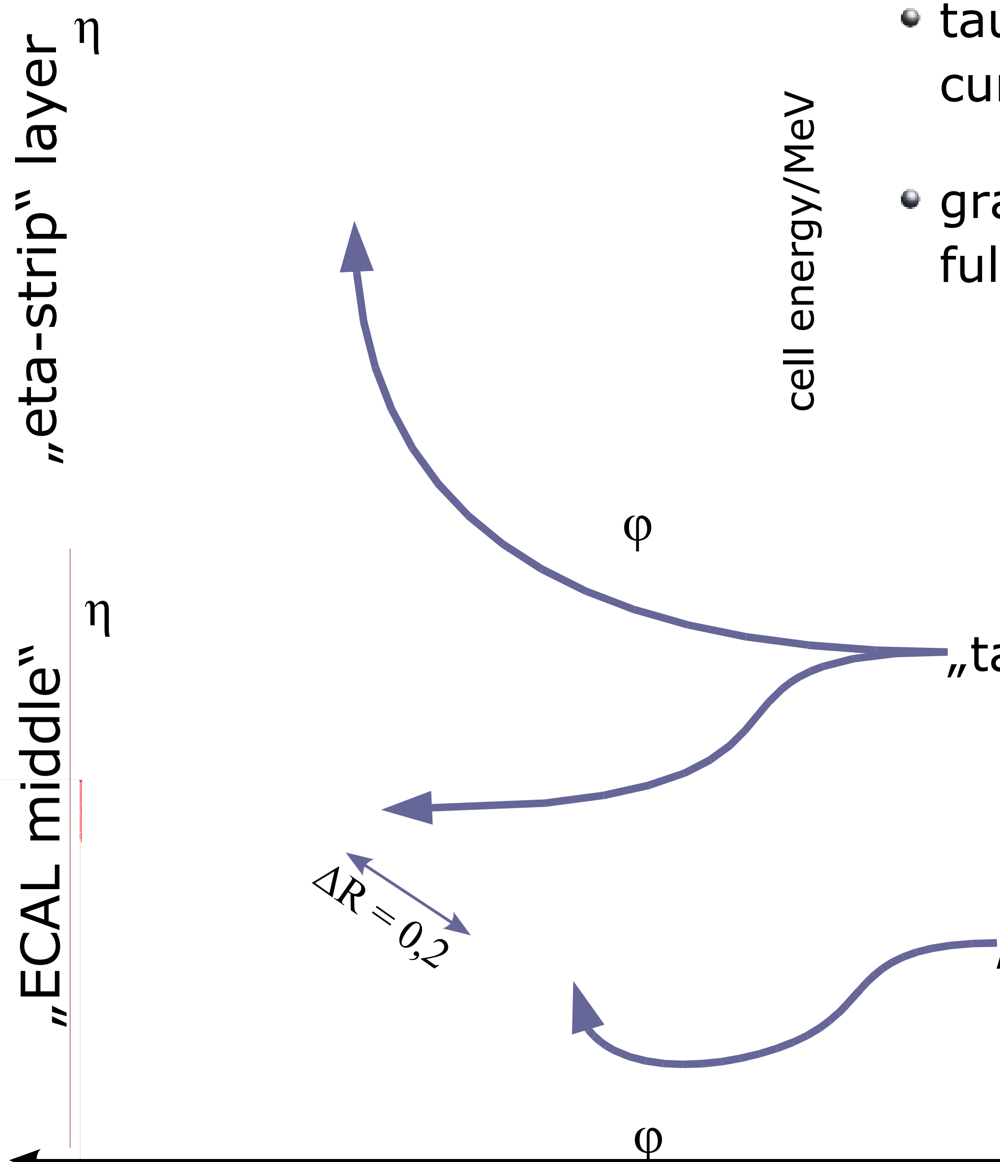




Detectorsignal for RPV mSUGRA events (BC2)

Energy deposition in EM calorimeter

- tau jet “hidden” by other jet in current tau ID algorithms
- granularity of ATLAS calorimeter not fully exploited yet



BC1 / BC2 mass spectrum