Studying Supersymmetry with Tau Leptons at the LHC

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universitätbonn

Outline

1. The LHC and the ATLAS Experiment

2. SUSY discovery prospects

3. Why Tau Leptons? , Tau-ID

4. Discovery and Mass Measurements in Di-Tau Events

5. Tau-Polarisation

6. Global Parameter Fits

The group (…which is doing the work)

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PhD-Students:
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Carolin Zendler

Diploma Students:
Till Nattermann
Mathias Uhlenbrock

Disclaimer: most of the studies shown are preliminary not (yet) official ATLAS results

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The Large Hadron Collider LHC

1998-2005 Civil engineering and preparation of tunnel
2003-2007 Installation
2008 Commissioning

pp-Collsions at 7+7 TeV
Design Luminosity 10^{34} $cm^{-2}s^{-1}$

Several thousand magnets (1132 15m-long Dipoles, all installed)
Various minor & major problems solved
- heat exchanger tubes
- inner triplet support structure
- interconnect bellows

last magnet lowered in April 2007

Towards first physics

The LHC schedule to achieve collisions at 14 TeV
is “success-oriented” ☺☺☺

Further serious problems/delays make collissions in 2008 less and less likely

First physics at 14 TeV (still speculative…)

Stage A (still 2008): 30 days 10^{27}–10^{30} $cm^{-2}s^{-1}$ (30 days at 10^{30} = 2.5pb^{-1})

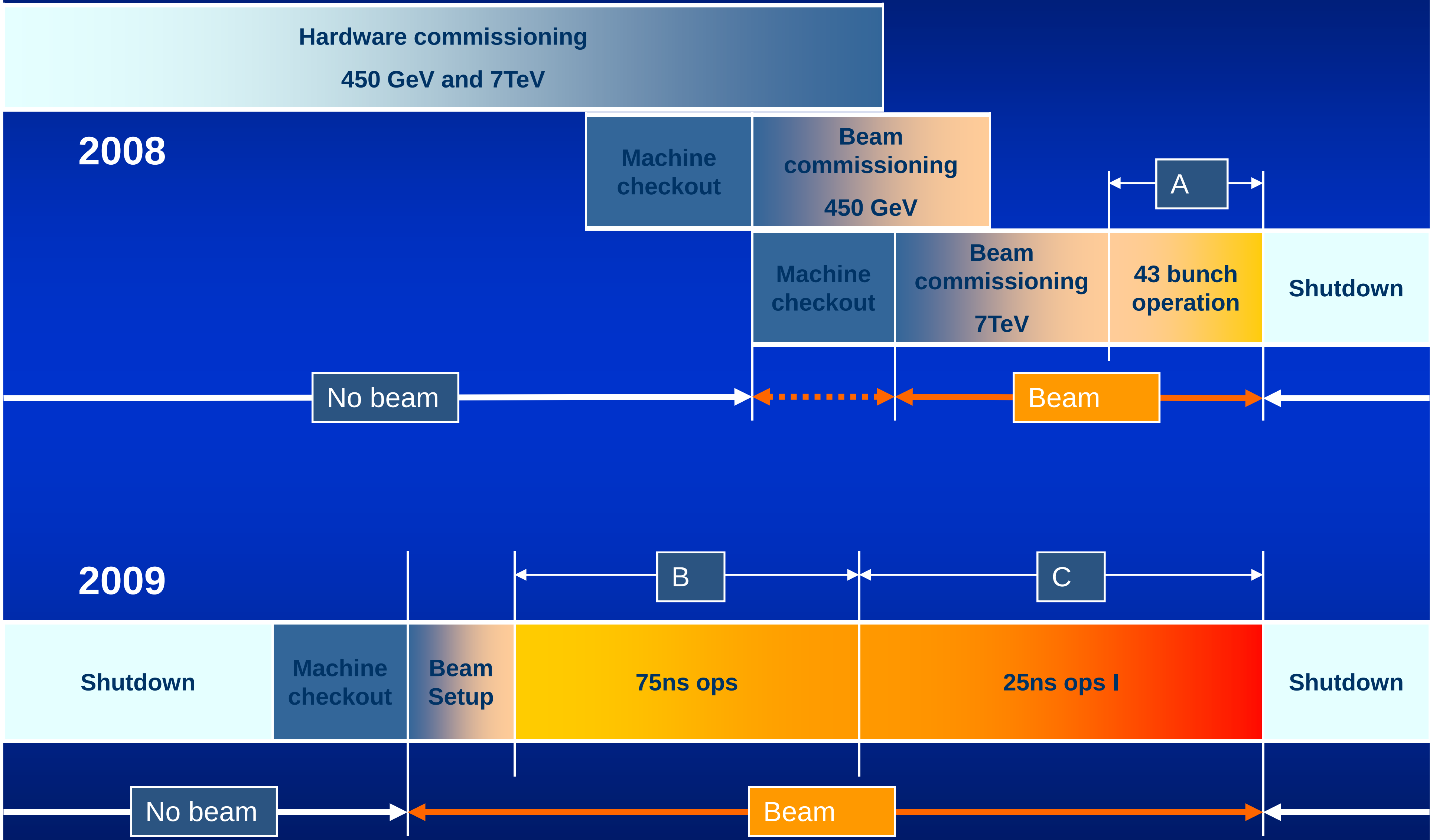
Stage B (2009, 75ns) 10^{31} – 10^{33} $cm^{-2}s^{-1}$ (30 days at 10^{32} = 250 pb^{-1})

Stage C (still 2009, 25ns) goal 2 10^{33} (30 days at 10^{33} = 2.5 fb^{-1})

Data for first discoveries may well be on tape by the end of next year!

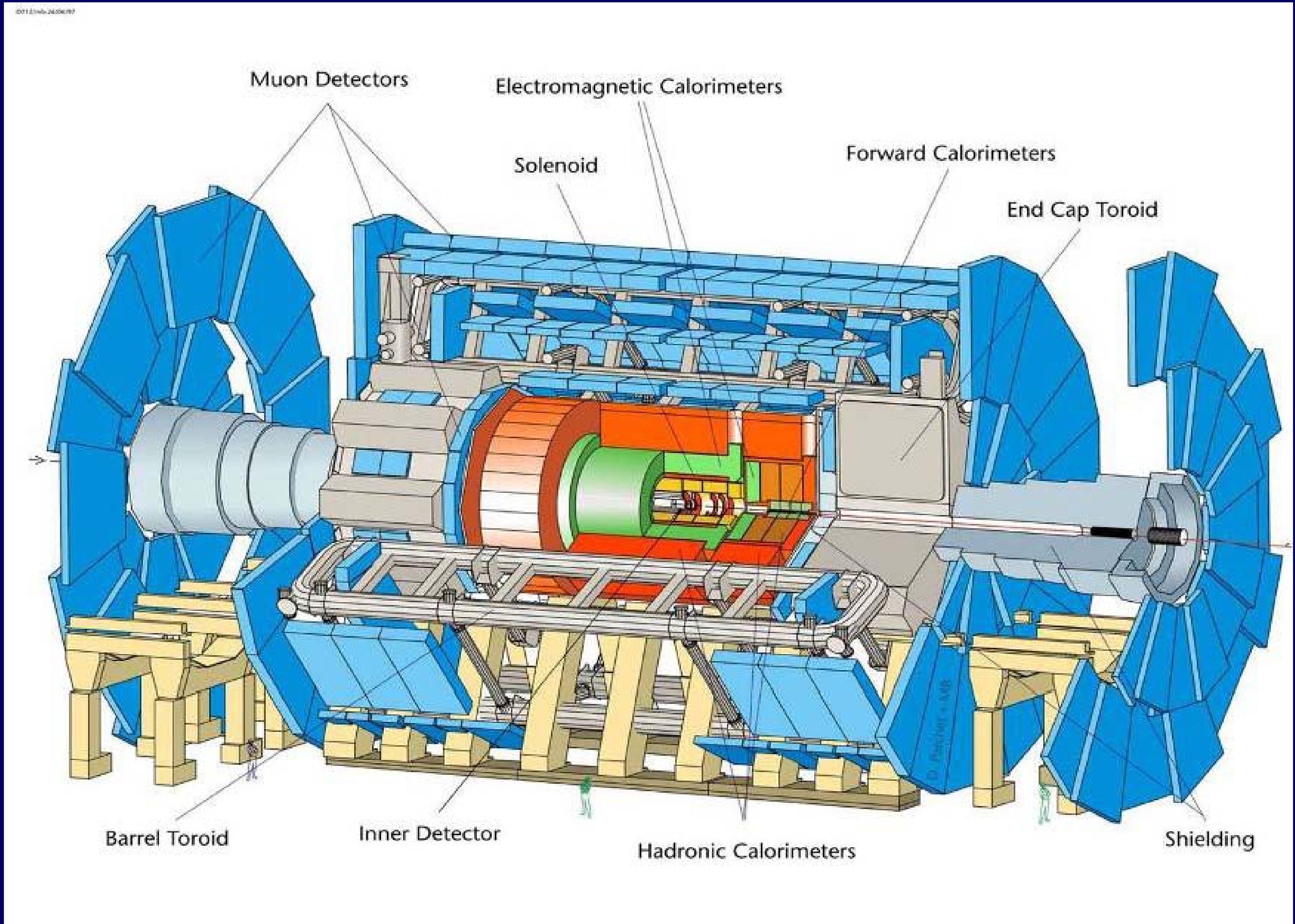
When will these discoveries be made? → Detectors

Staged commissioning plan for protons



R.Bailey, DESY, December 2007

The ATLAS detector

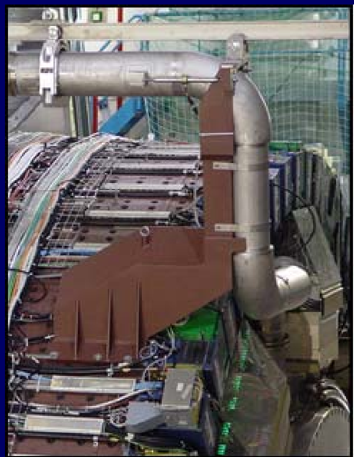


The ATLAS detector

- on a good way to completion

- no major problems
  (recent „moving magnet“ incident didn‘t cause major damage)

“Barring any incident or unexpected calamity, the ATLAS detector should be fully installed, functional and tested in time and according to schedule. But let’s not count our chickens before they hatch …It will not be done until it’s all done!” (Marzio Nessi, ATLAS technical coordinator)



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SUSY discovery at the LHC

- Supersymmetry (after all those years) most attractive model(s) for physics beyond the Standard model

- Huge variety of experimental signatures

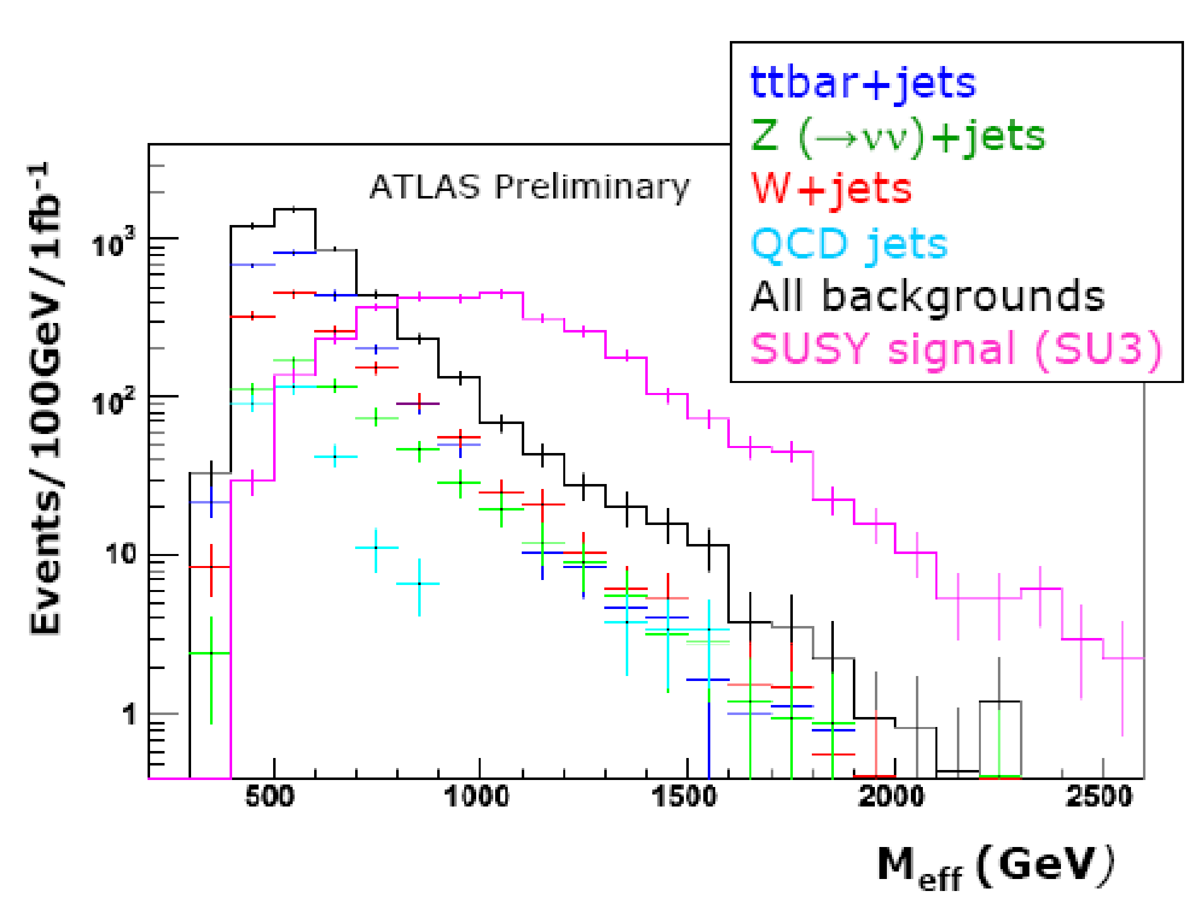
- MSSM with R-parity conservation „canonical“ model for expiremtal searches (NB: other signatures are studied as well…)

- key signature: missing transverse energy from undetected LSPs (augmented by high-p_t leptons and jets)

most generic search strategy:

Inclusive search for E_T^{miss} excess

Inclusive SUSY discovery



SU3 benchmark Point:

$m_0 = 100$ GeV, $m_{1/2} = 300$ GeV, $\tan\beta = 6$, $A = -300$ GeV, $\mu > 0$

simple selection:

$E_T^{miss} > 100$ GeV

$\geq$ 1jet with $p_T > 100$ GeV

$\geq$4jets with $p_T > 50$ GeV

$M_{eff} = \Sigma p_T^{jets} + E_T^{miss}$

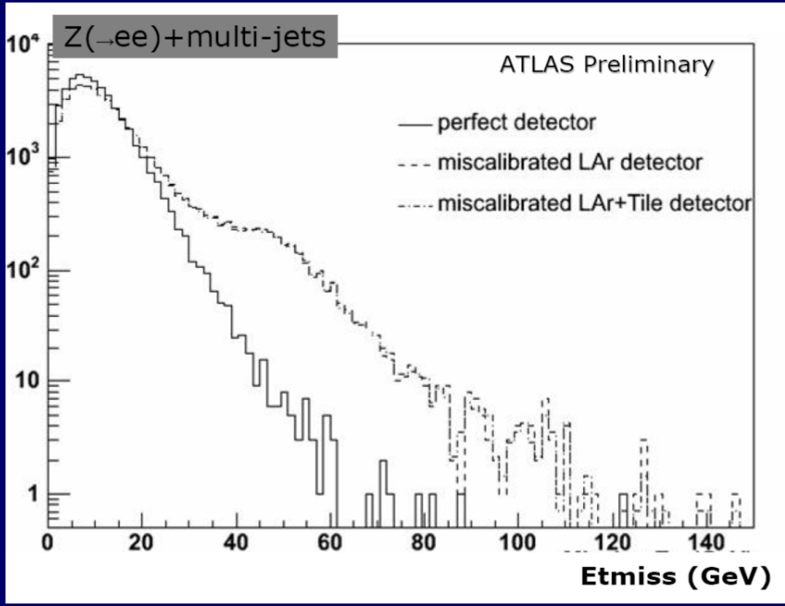
challenge:

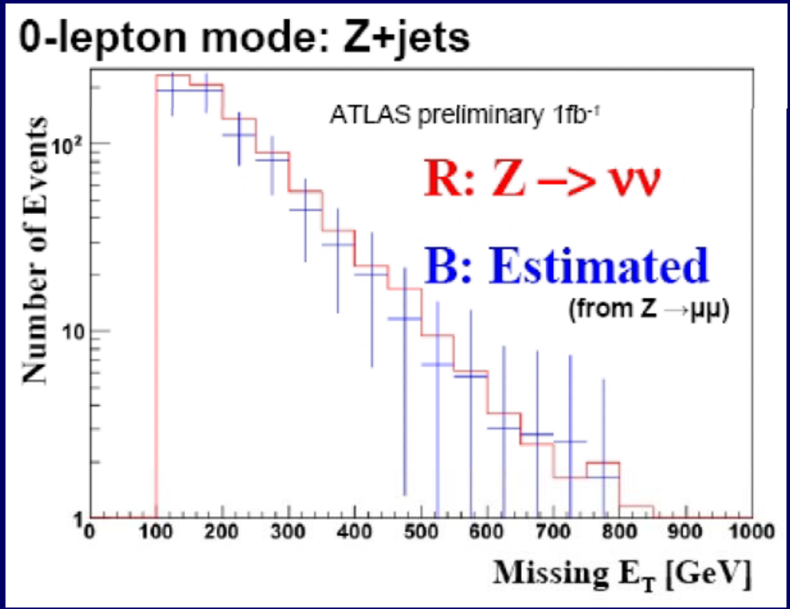
control and calibrate E_T^{miss} measurement in presence of

- noisy cells
- different cell-to-cell response
- pile-up
- imperfect energy calibration

E_T^{miss} calibration strategies with data

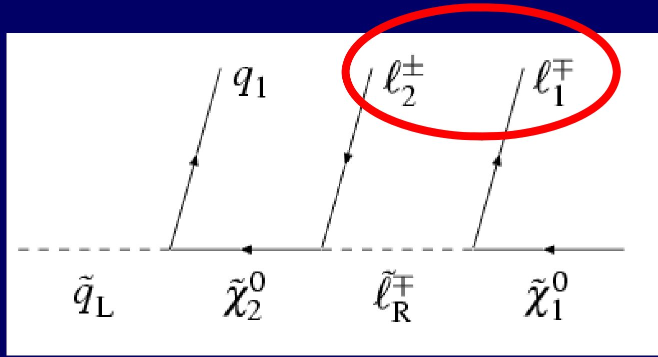
- E_T^{miss} is one of the hardest quantities to measure
- Understanding of all detector components required
- Strategy: "calibrate" E_T^{miss} with known SM processes from data
- Example: DY-Production of $Z \rightarrow \mu\mu$
  1. Tune $Z \rightarrow \mu\mu$ MC with data
  2. Remove muons and compare with $Z \rightarrow \nu\nu$
  3. Tune E_T^{miss} from observed differences

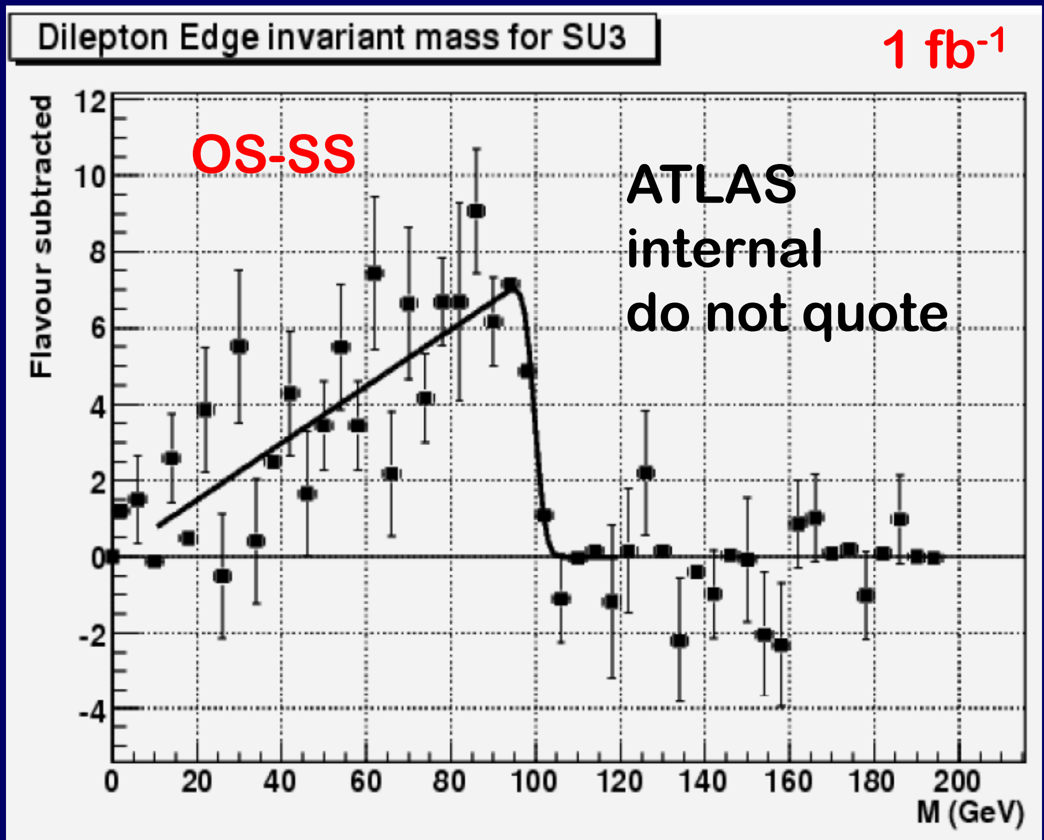




Leptons: a more robust signature

Although more rare leptons (e,μ) in addition to large E_T^{miss}
may provide a more robust signature
(and thus faster result)
Almost background free



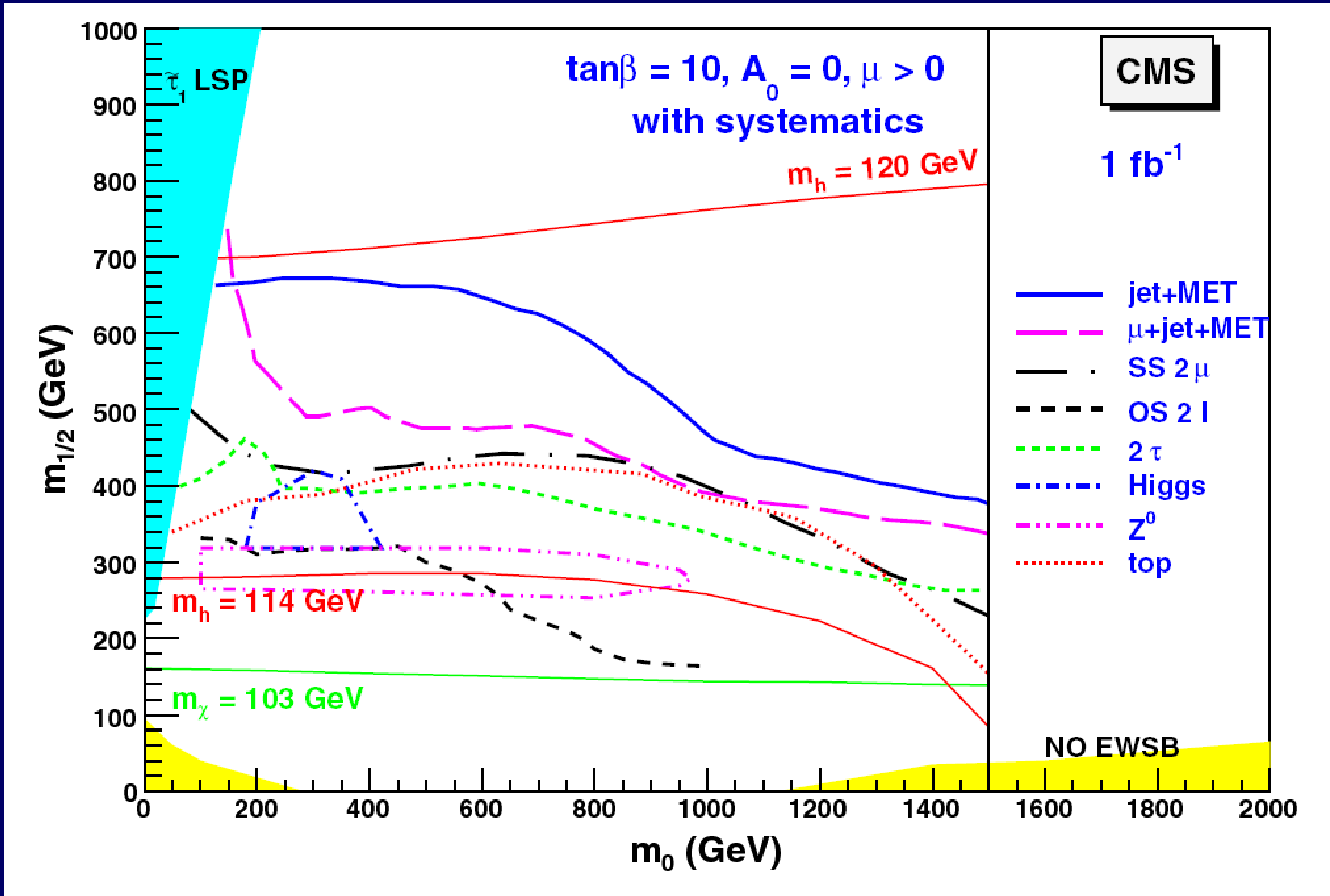


appearance of a kinematic edge most strinking signature of SUSY

no SM processes with this feature

(but SUSY does not always guarantee such a feature)

Discovery potential



(stolen from CMS – stay tuned for ATLAS prospects)

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Why tau leptons at all?

Taus:

rapid decay ($c\tau$ = 87 μm) into several, partly invisible particles

Electrons/muons:

stable (on time scales relevant for detection)

☹ Momentum of taus cannot be reconstructed due to escaping neutrinos

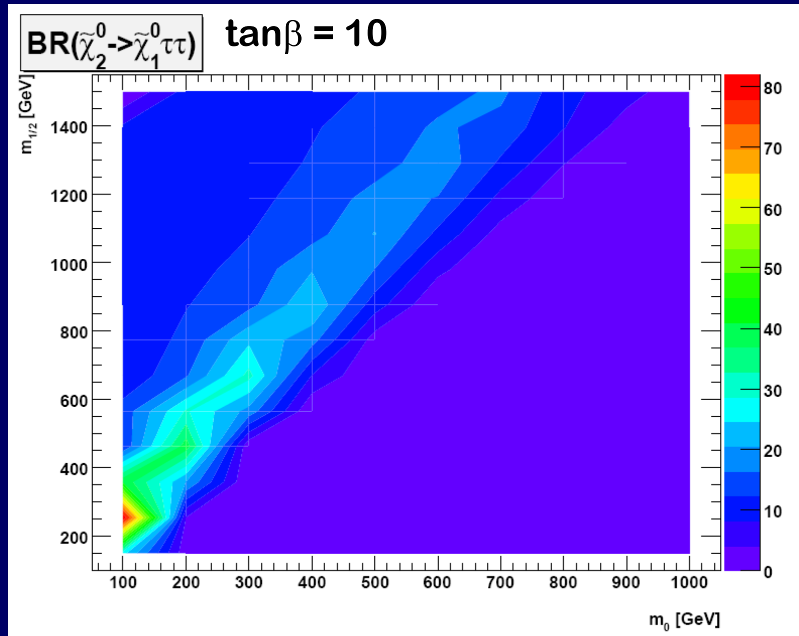
Hadronic tau decays hard to distinguish from (low-multiplicity) jets

☺ Good reasons to study SUSY with tau probes:

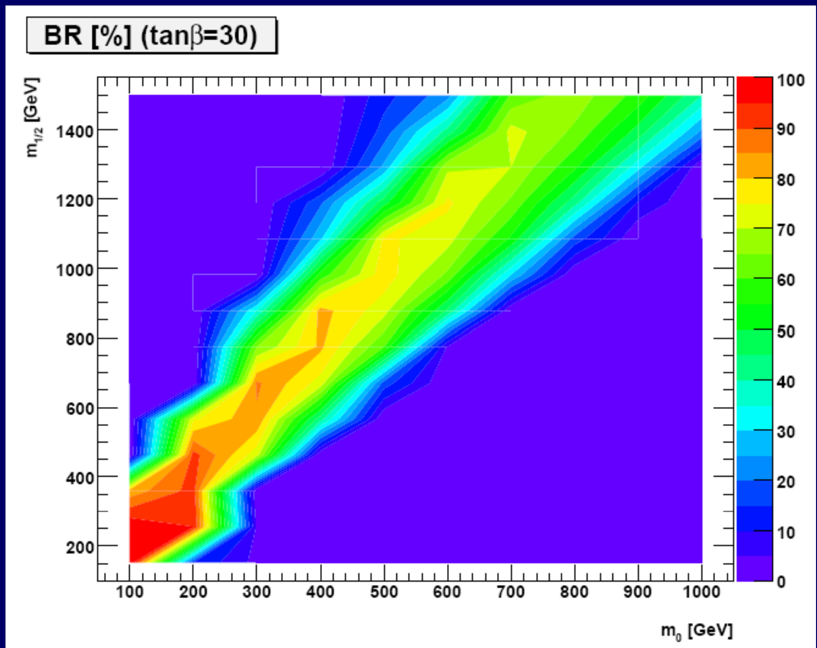
- only direct access obtain stau mass information
- lightest slepton in models with high scale unification (mixing)
- in mSUGRA large L-admixture in τ_1 causes larger coupling to wino-like χ_2^0
- many other models (GMSB with stau NLSP, RPV SUSY with stau LSP, SUSY with LFV, ...) in which taus may play important role
- only lepton that grants access to polarisation information

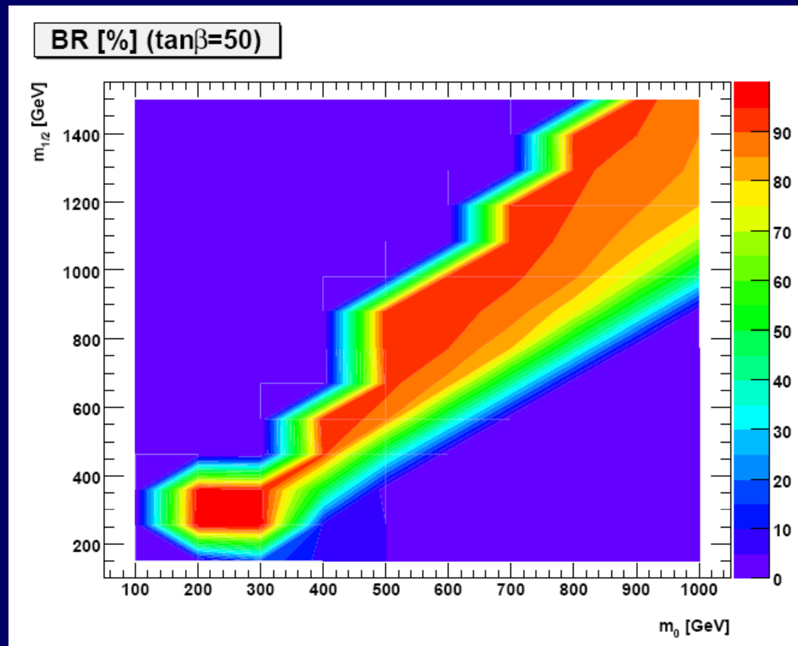
Why tau leptons

mSugra:
BR($\chi^0_2 \rightarrow \chi^0_1\ \tau\tau$) strongly enhanced for large tanβ sometimes ~ 100%



A_0 = 0, sgn(μ)=+





Identifying Taus

- 35% leptonic tau decays: hard to distinguish from prompt leptons

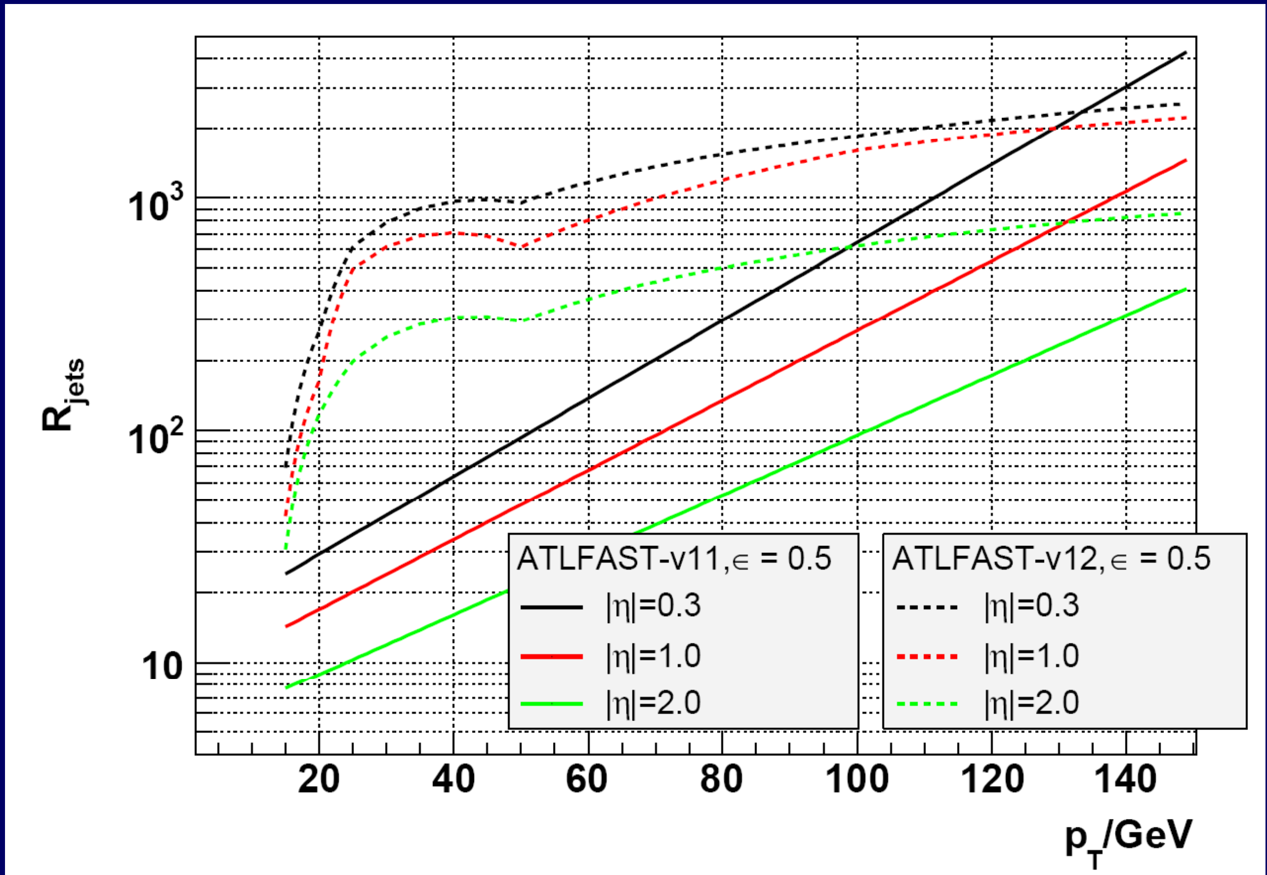
- aim at identifying hadronic tau decays „tau jets“

- handles:
  - low ($\leq$3) track multiplicity
  - track isolation
  - narrow cone of energy deposit in calorimeter
  - tracks with positive impact parameter (lifetime)
  - secondary vertex (only for 3-prongs)

- combine everything into multivariate discriminator (likelihood, neural network)

further discrimination through seperate reconstruction of different hadronic modes ($\pi\nu$, $\rho\nu$, $a_1\nu$, ...)

Taus Identification Performance in ATLAS

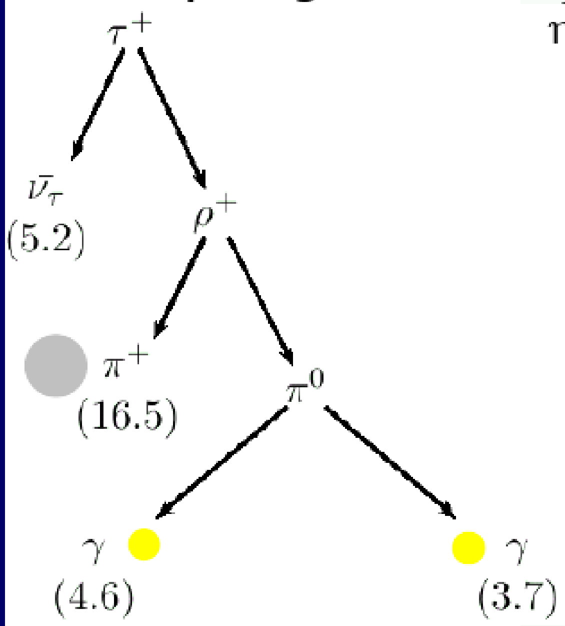


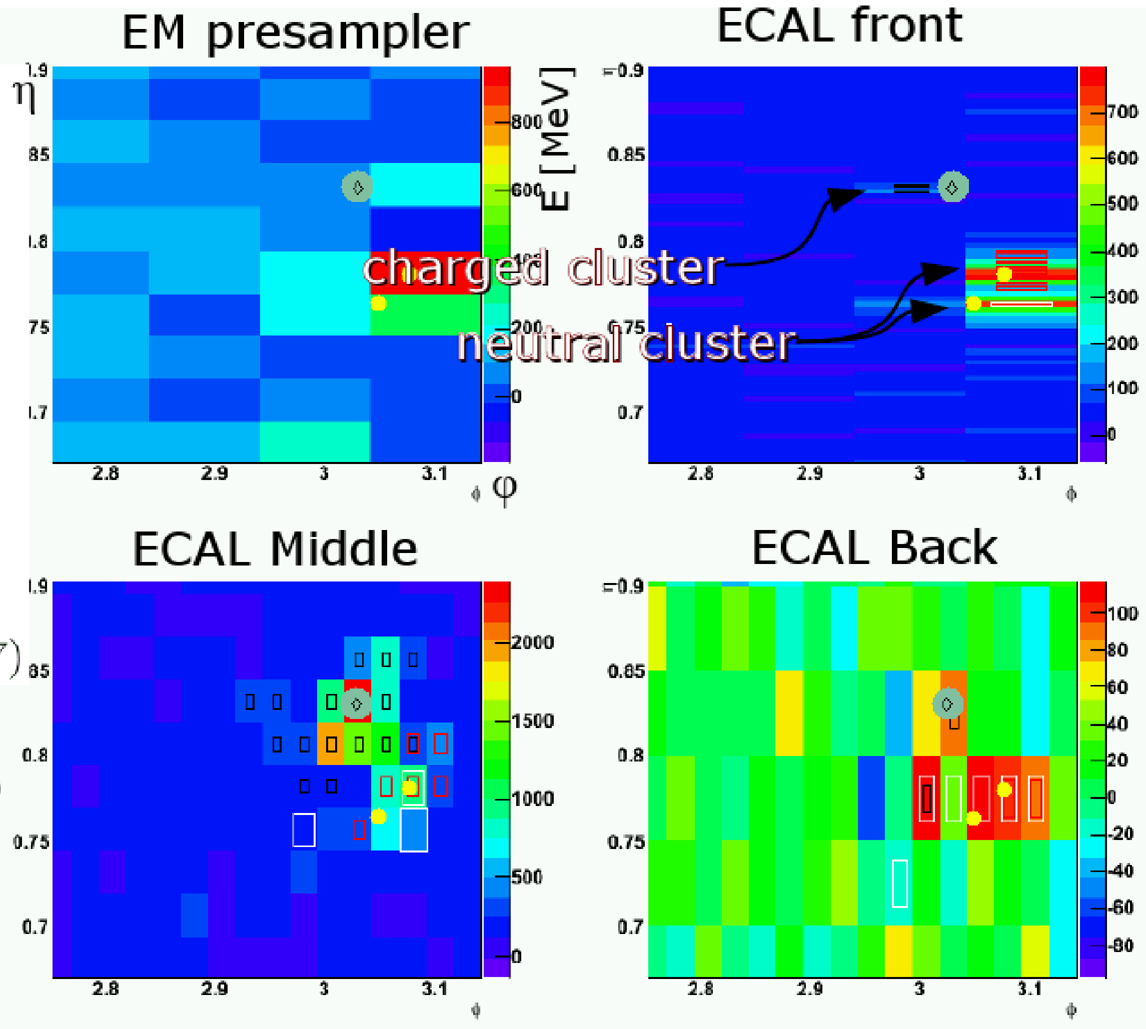
unfortunately jets are much more frequent than taus…
particular difficult: „low“ p_T (<20 GeV)

Ideas for further improvement (work in progress)

example event:

- 1-prong + 1 π^0





- Try to use sub-structure ("splitting") to identify components of the tau jet
- default parameters of topo clusterization not optimal for tau ID

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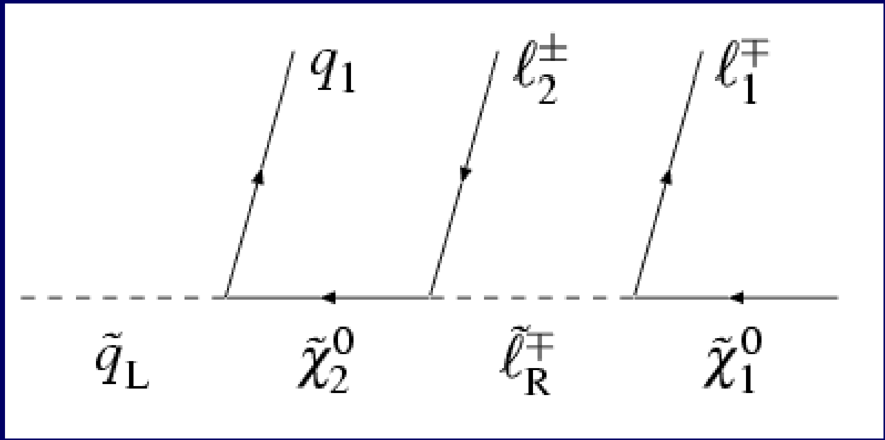
Main target: taus from χ^0_2 decay chain



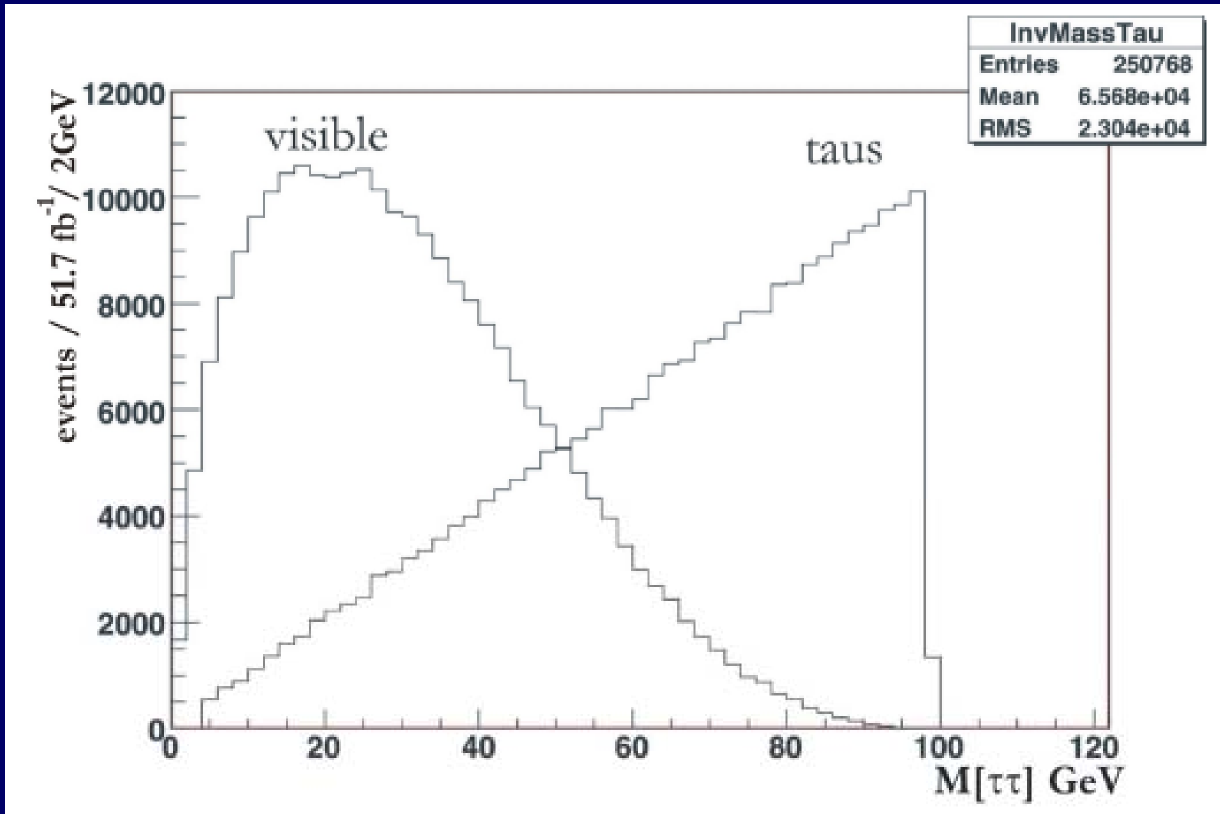
benchmark points

	SU1	SU3
m_0	70 GeV	100 GeV
$m_{½}$	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*

a discovery channel?

Complications with taus

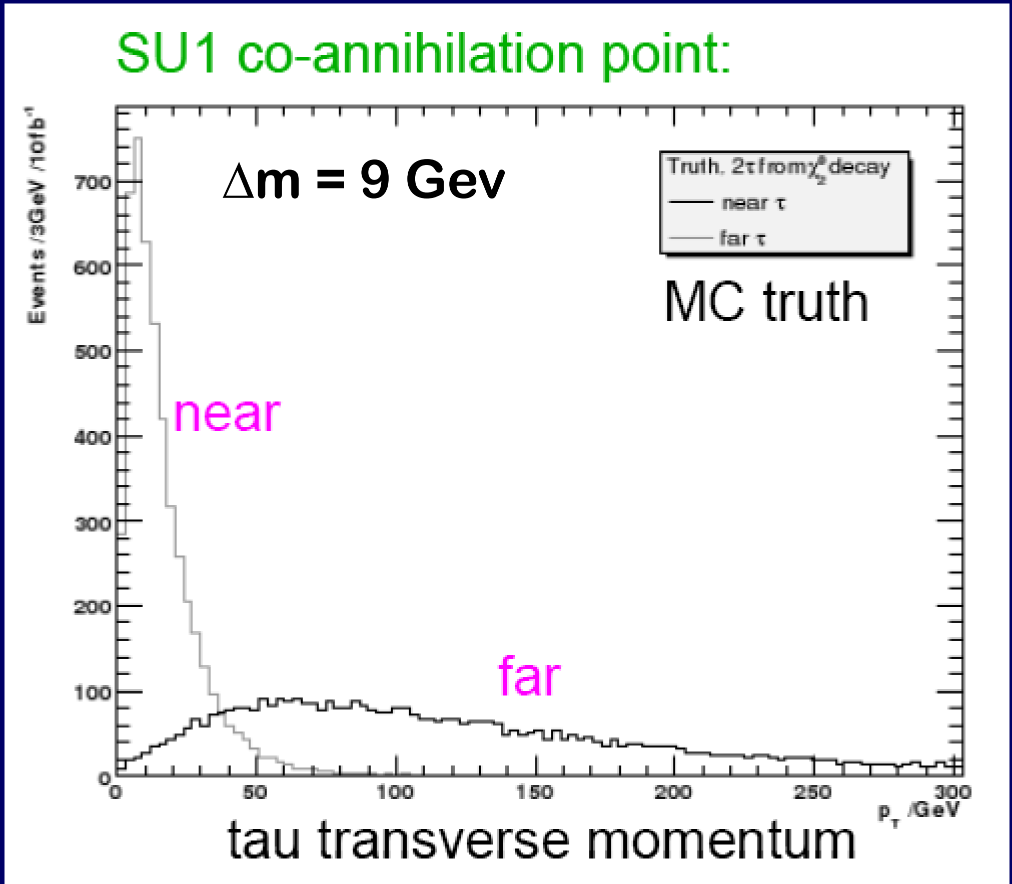


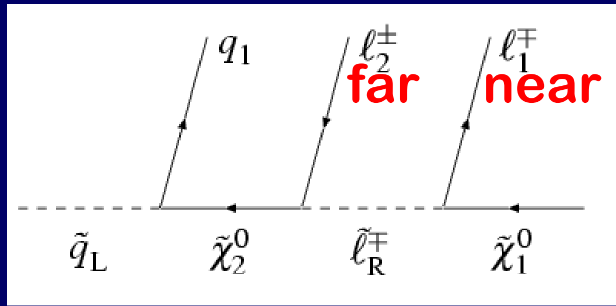
kinematic endpoint
of di-tau mass spectrum

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

Complications with taus

Typically small mass difference Δm of stau and LSP makes „near“ tau very soft





Discovery

Rather simple selection
(example for SU3-point)

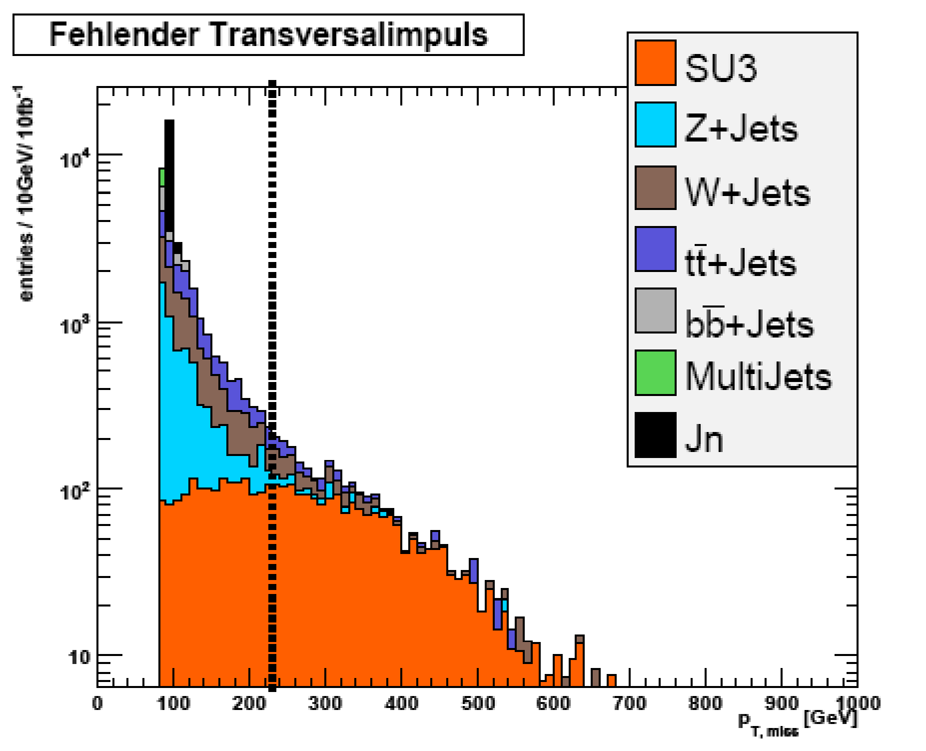
two reconstructed τ's

E_T^{miss} > 230 GeV

at least 4 jets with p_T>30 GeV

at least 1 jet with p_T>220 GeV

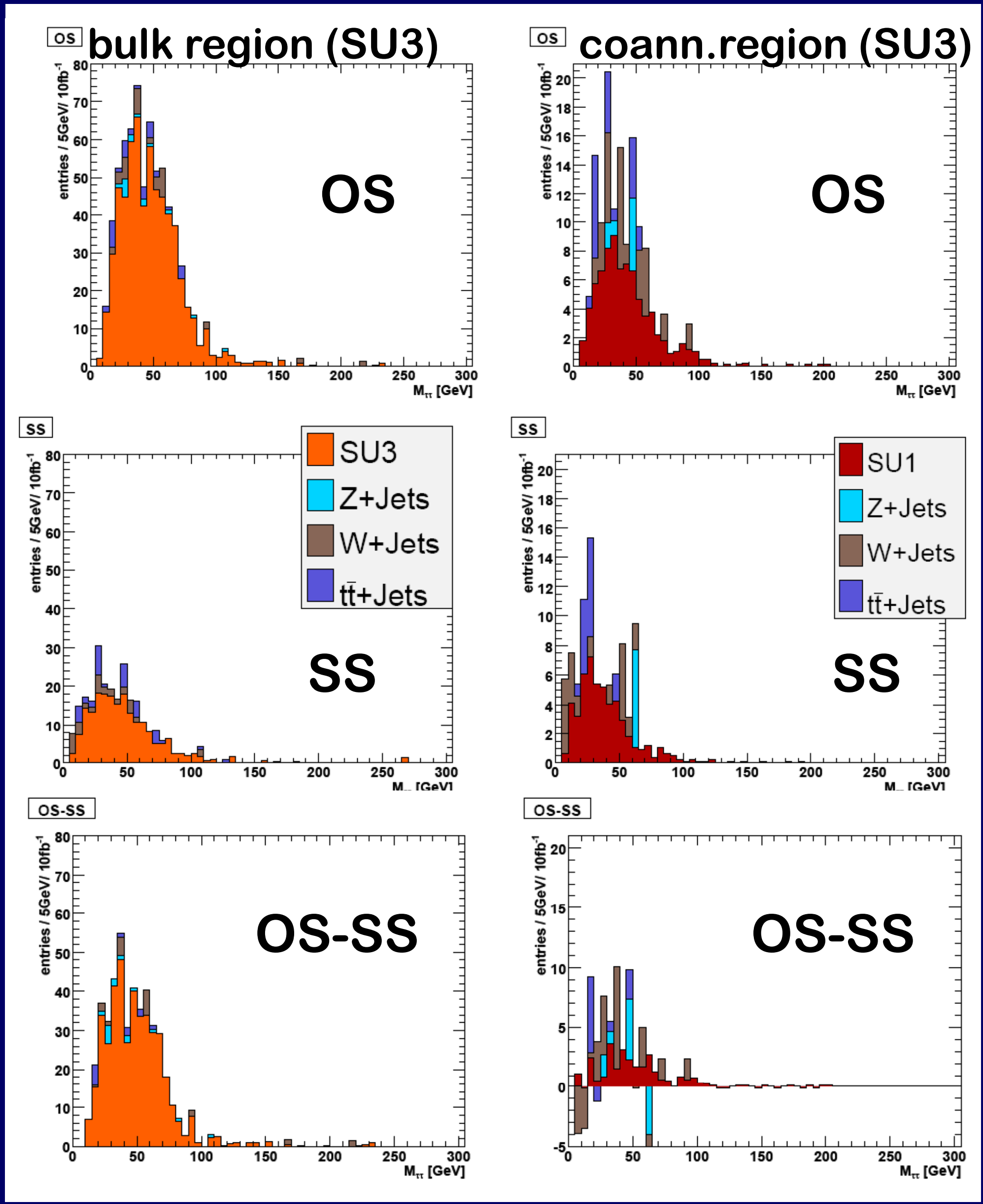
Presence of tau candidates allows for softer selections than in inclusive search



(a) **Fehlender Transversalimpuls** nach
- Vorselektion ($p_{T,miss}$ > 80 GeV)
- mind. 2 Taus

→ **Schnitt 1:** $p_{T,miss}$ > 230 GeV

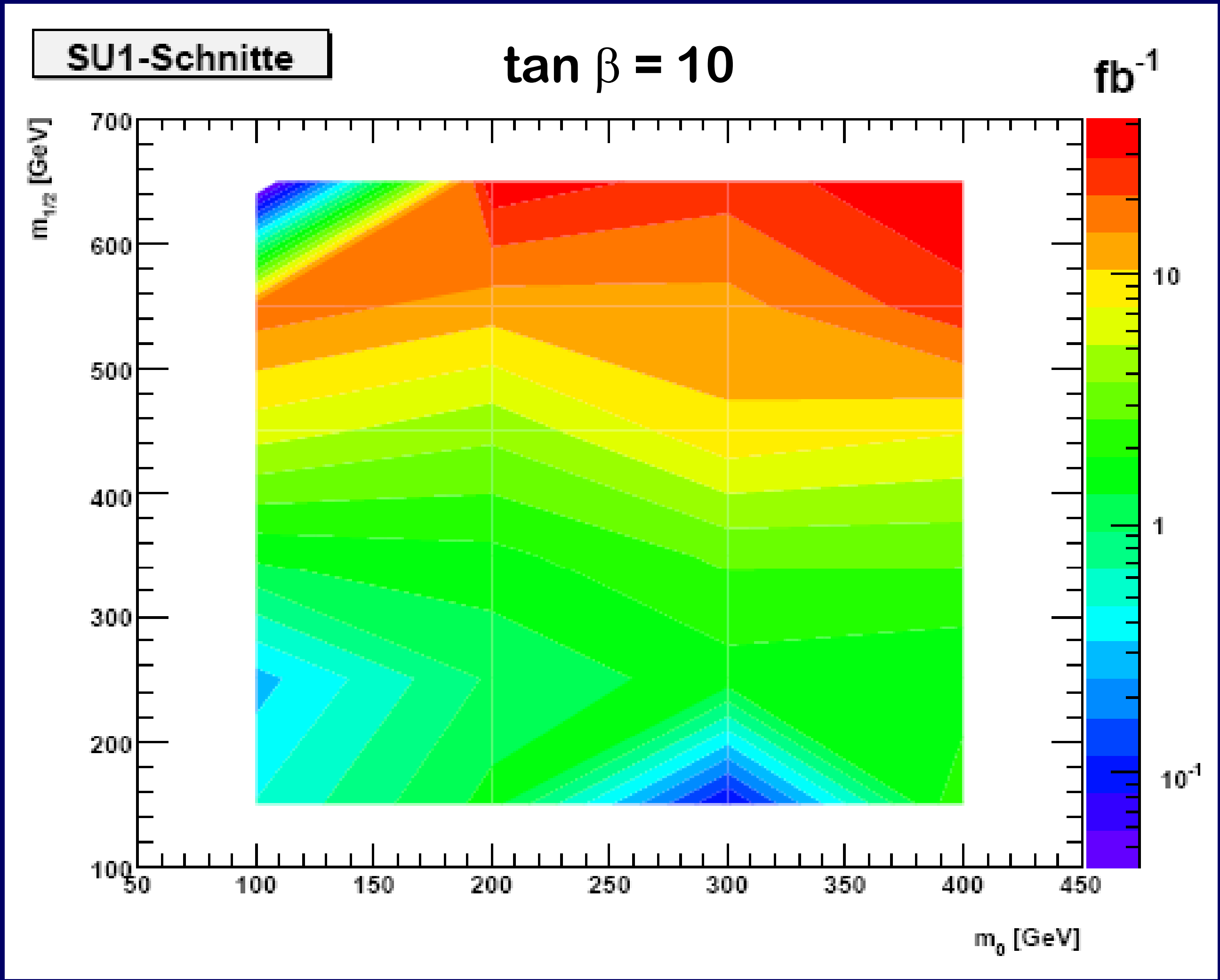
Discovery



10 fb^{-1}

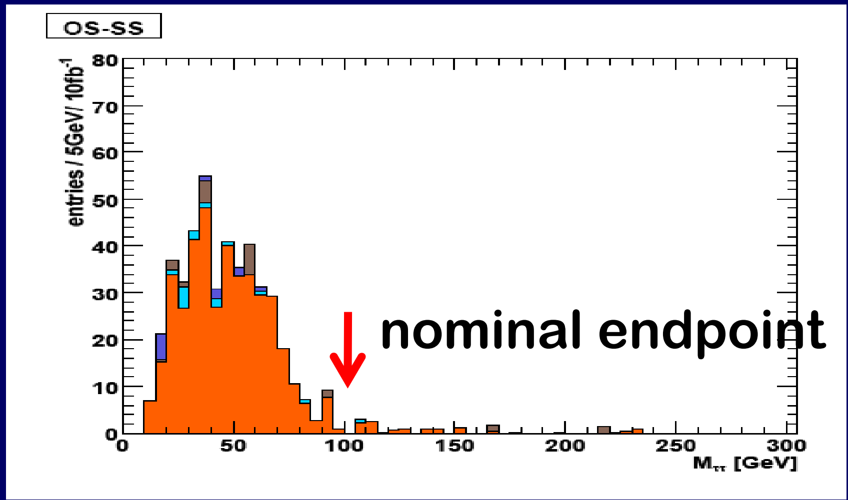
- very clean selection
- many „fake“ SS events (charge mismeasurement)

Discovery (scan of mSugra parameter space)

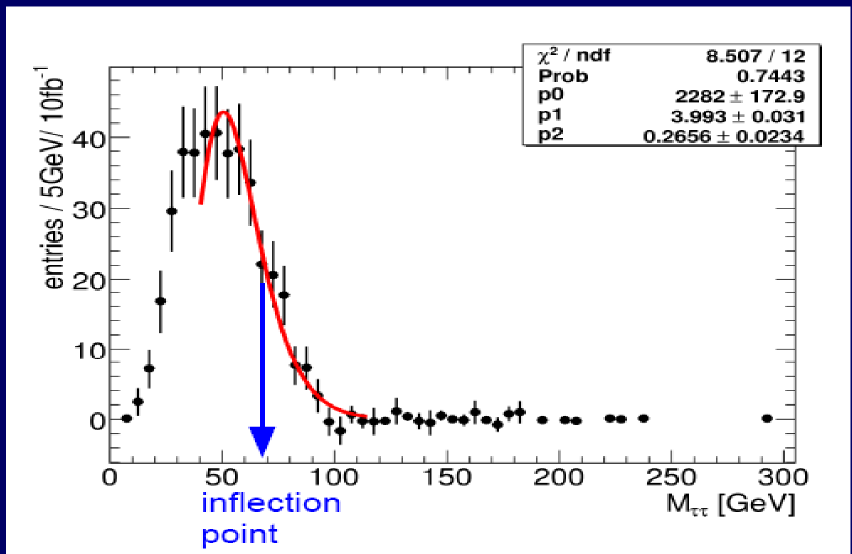


integrated luminosity for 5σ effect in OS-2τ channel (statistical only)

Mass measurement



how to measure kinematic endpoint?



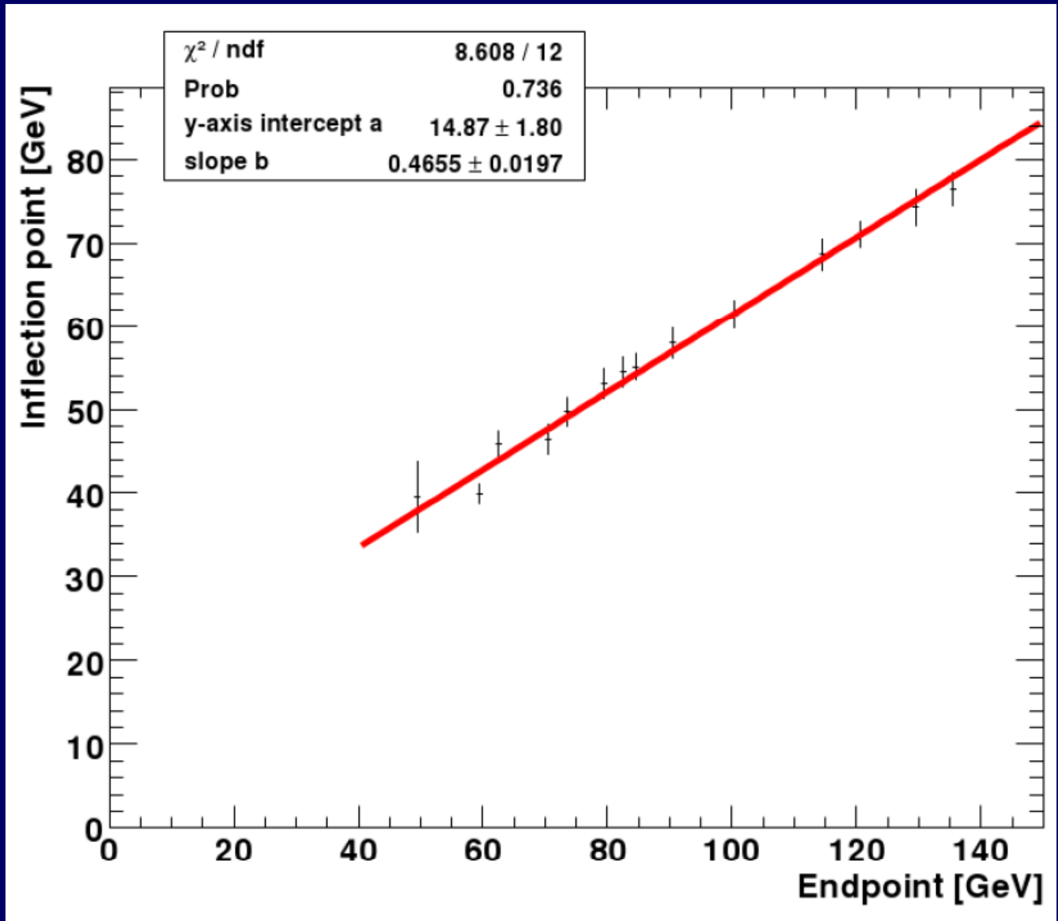
inflexion point method:

-fit log normal distribution (because it fits well...)

$$f = \frac{p_0}{x} \cdot \exp\left(-\frac{1}{2p_2^2}(\ln(x) - p_1)^2\right)$$

- calibration translation of inflection point into end point with MC

Calibration of inflexion point to endpoint



Precision for 10 fb^{-1}: $\pm$ 4 GeV (stat) $\pm$ 6 GeV (syst) (preliminary!)

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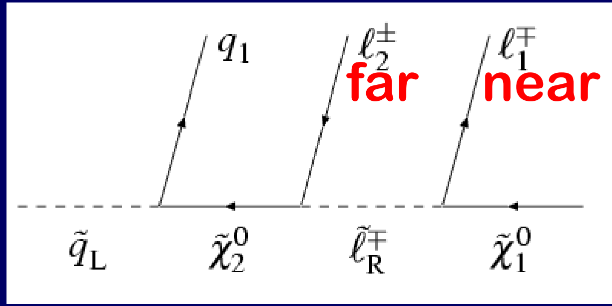
Tau Polarisation in SUSY

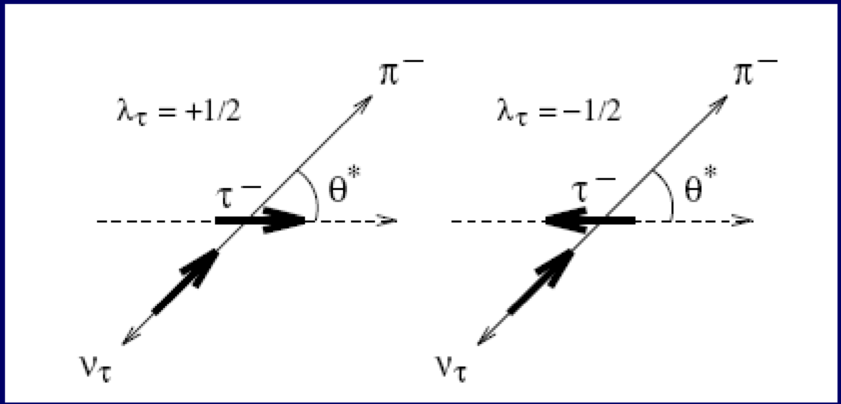


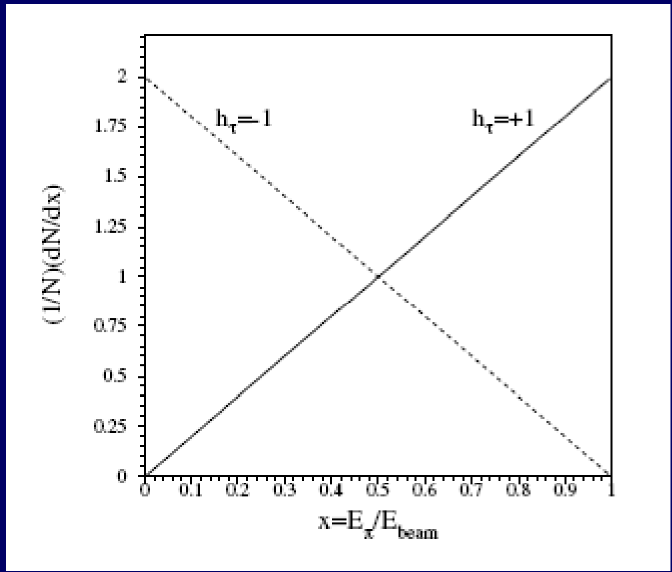
Polarisation of taus from stau decay („near tau“) probes $\chi^0{}_1$ composition

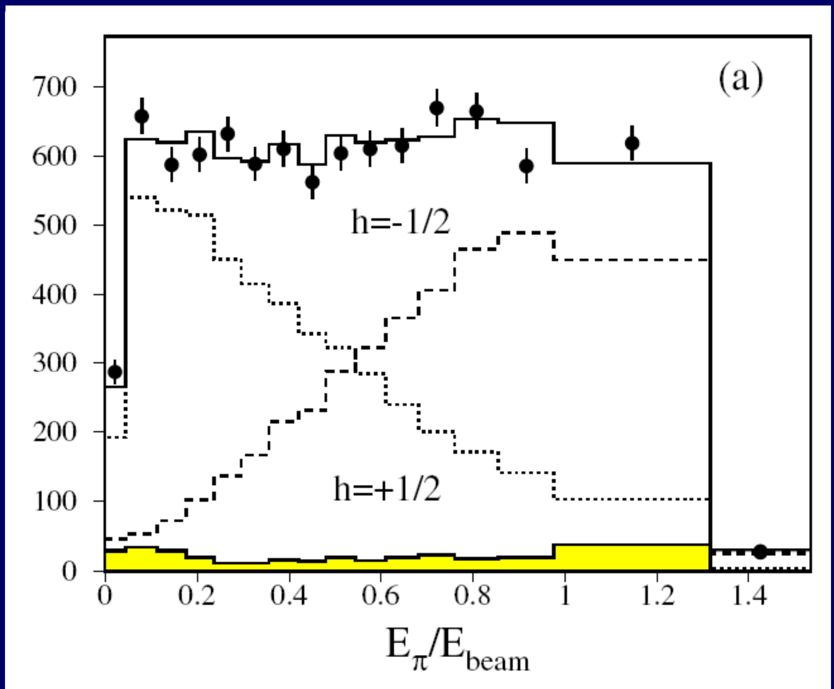
- Distinguish SUSY breaking models
- Sensitivity to stau mixing angle

- Universal SUGRA models: $P_\tau \simeq +1$
- For most non-universal SUGRA models: $P_\tau \simeq \cos^2\theta_\tau - \sin^2\theta_\tau$
- AMSB models: $P_\tau \simeq -1$
- For many GMSB models: $P_\tau = \sin^2\theta_\tau - \cos^2\theta_\tau$

Tau polarisation: Remember LEP when life was easy…







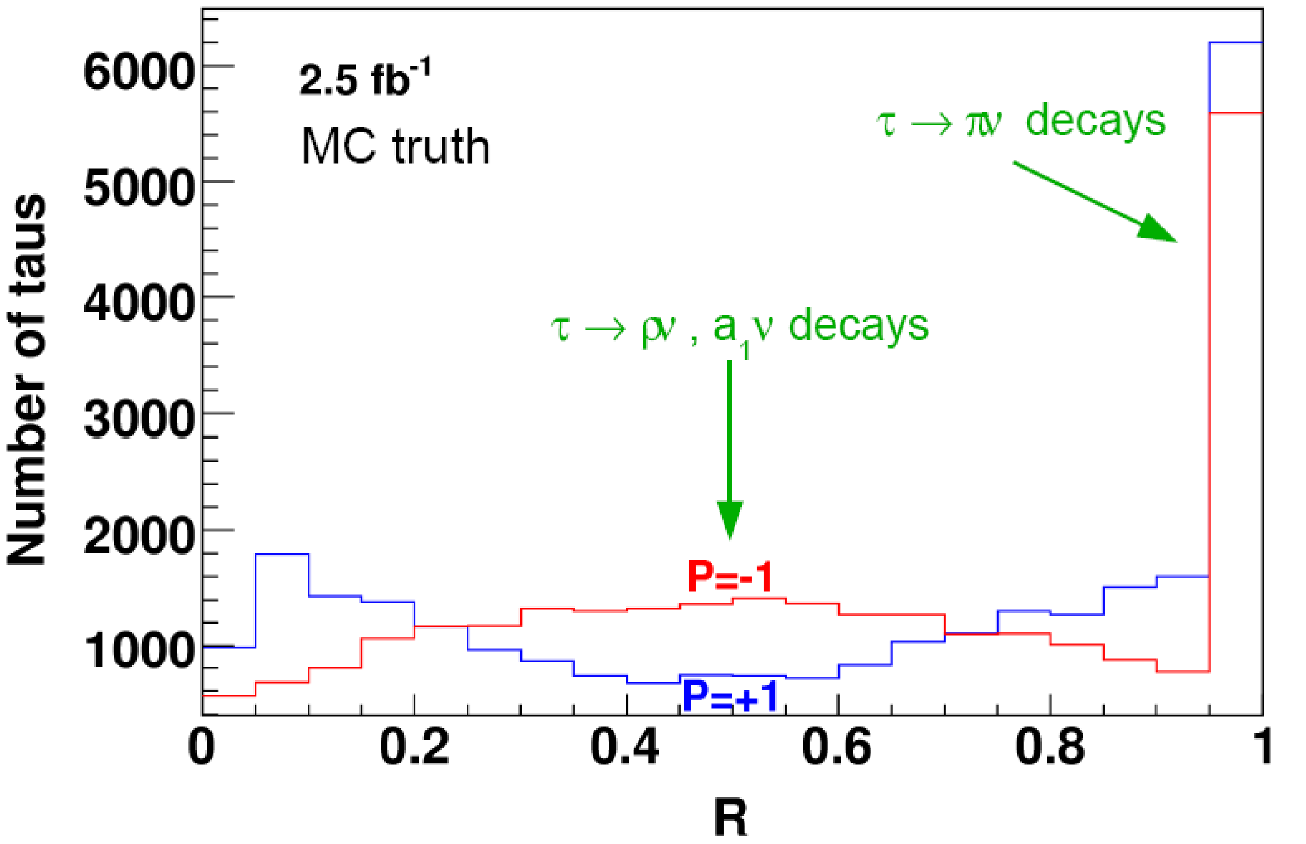
At LHC, the tau momentum is not known (no beam constraint)

need trickier methods

The "R-method" hep-ph/010996 Guchait,Roy

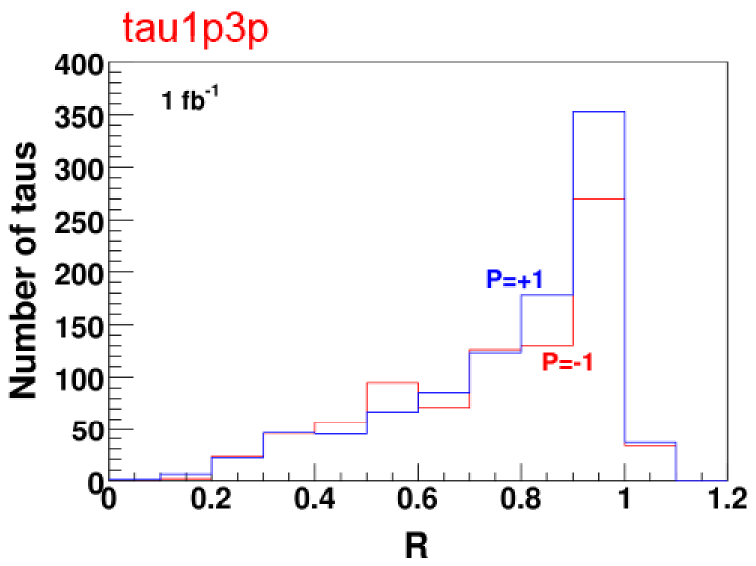
$$R = p_{\pi^\pm}/p_{\tau-\mathrm{jet}}$$

~ boost invariant

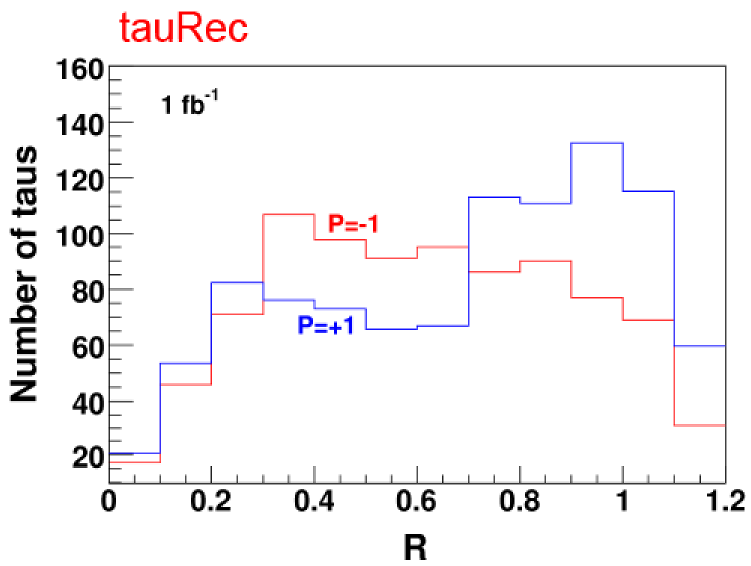


The "R-method": What remains after simulation of the detector response?

For 2 different Tau-ID algorithms:



- track seeded
- E from energy flow

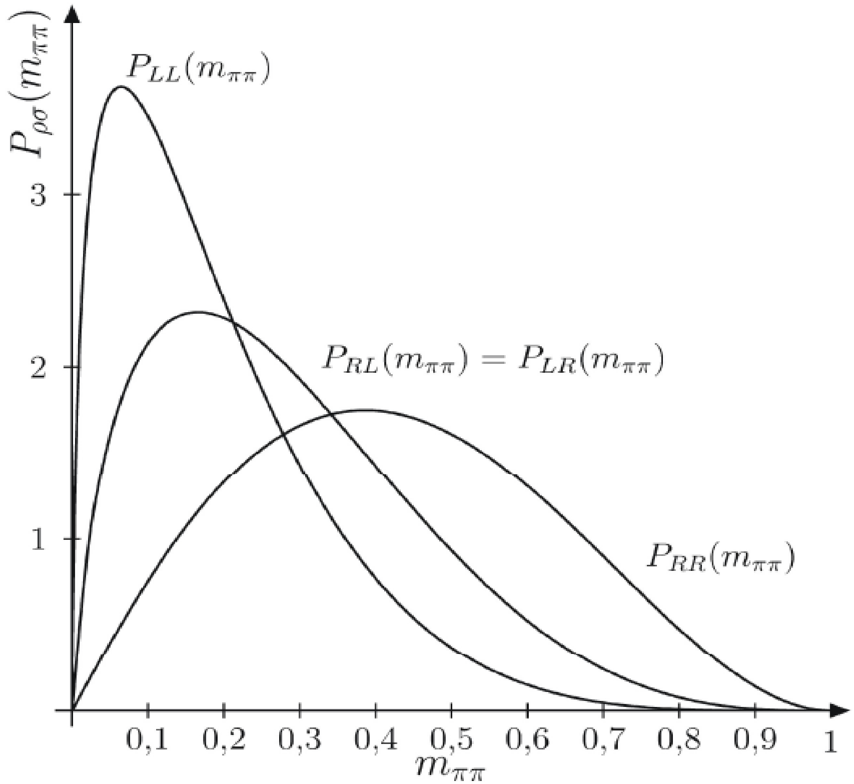


- calorimeter seeded
- E from calorimeter

Distributions get completely distorted
but some discrimination power remains → need more quant. study

The "pi-pi mass" method

Shape of $\pi\pi$ mass spectrum of two $\tau \rightarrow \pi\nu$ decays determined by polarisation effects



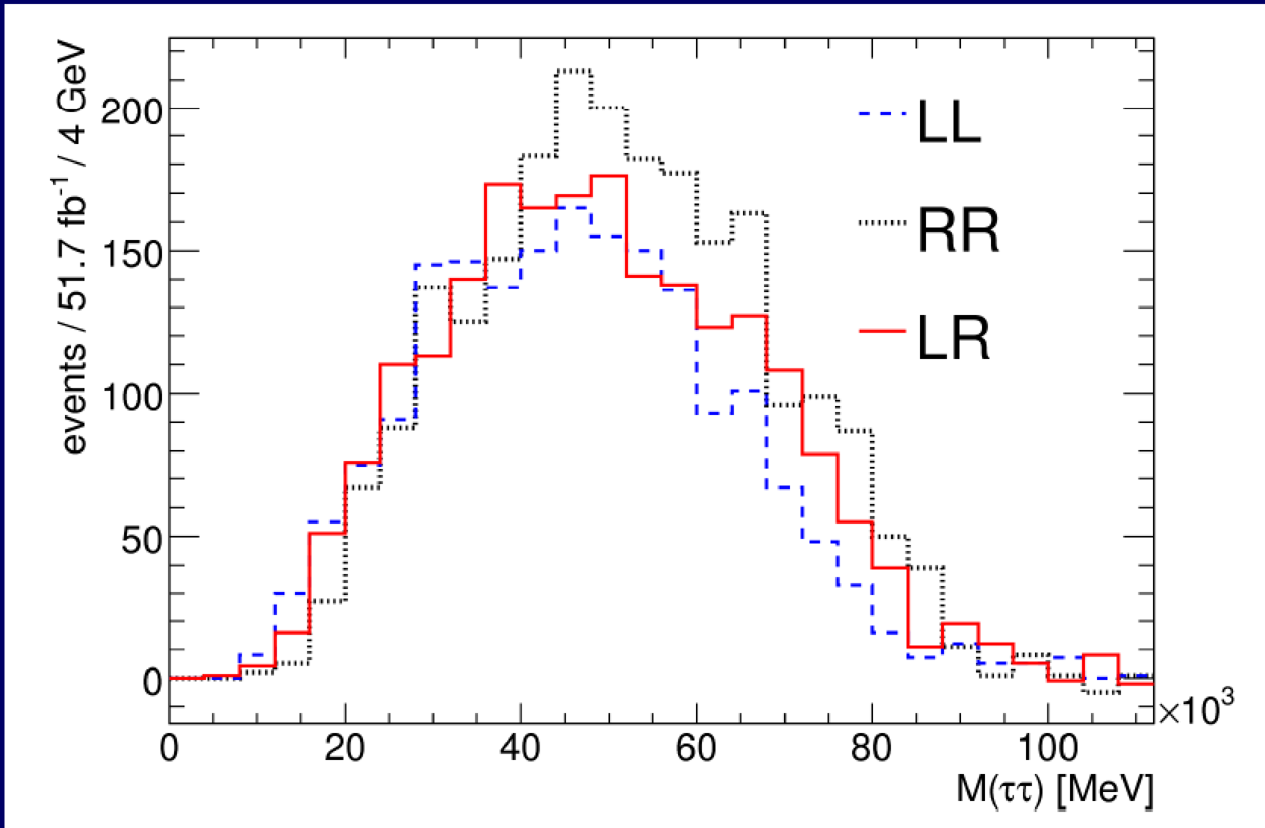
- $\tau \longrightarrow \pi\nu_\tau$
- $m^2_{\pi\pi} = (p_{\pi_n} + p_{\pi_f})^2$
- $m_{\pi\pi}$ sensitive to polarization
- allows distinction between $RL = LR$, LL and RR (chiralitys)
- but: no distinction between τ_n and τ_f

[1]

[1] S.Y. Choi, K. Hagiwara, Y.G. Kim, K. Mawatari, P.M. Zerwas, τ *Polarization in SUSY Cascade Decays*, hep-ph/0612237

The "pi-pi mass" method

Even if we were not interested in tau polarision this dependence impacts on inflexion point method

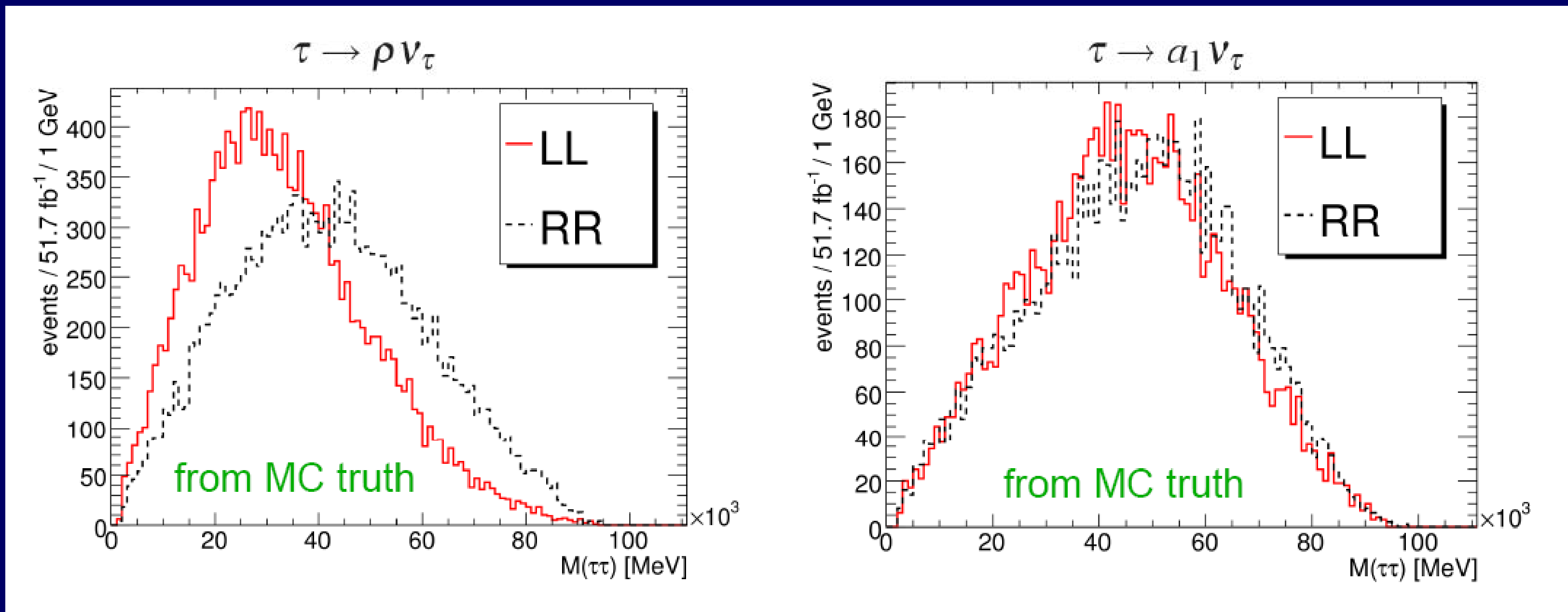


needs to be controlled

The "pi-pi mass" method

Polarisation dependence of visible $\tau\tau$ mass spectra is different for different tau decays! (e.g. almost vanishes for a_1a_1 decays)

- hope to disentangle mass and polarisation effects
- needs improved tau-identification



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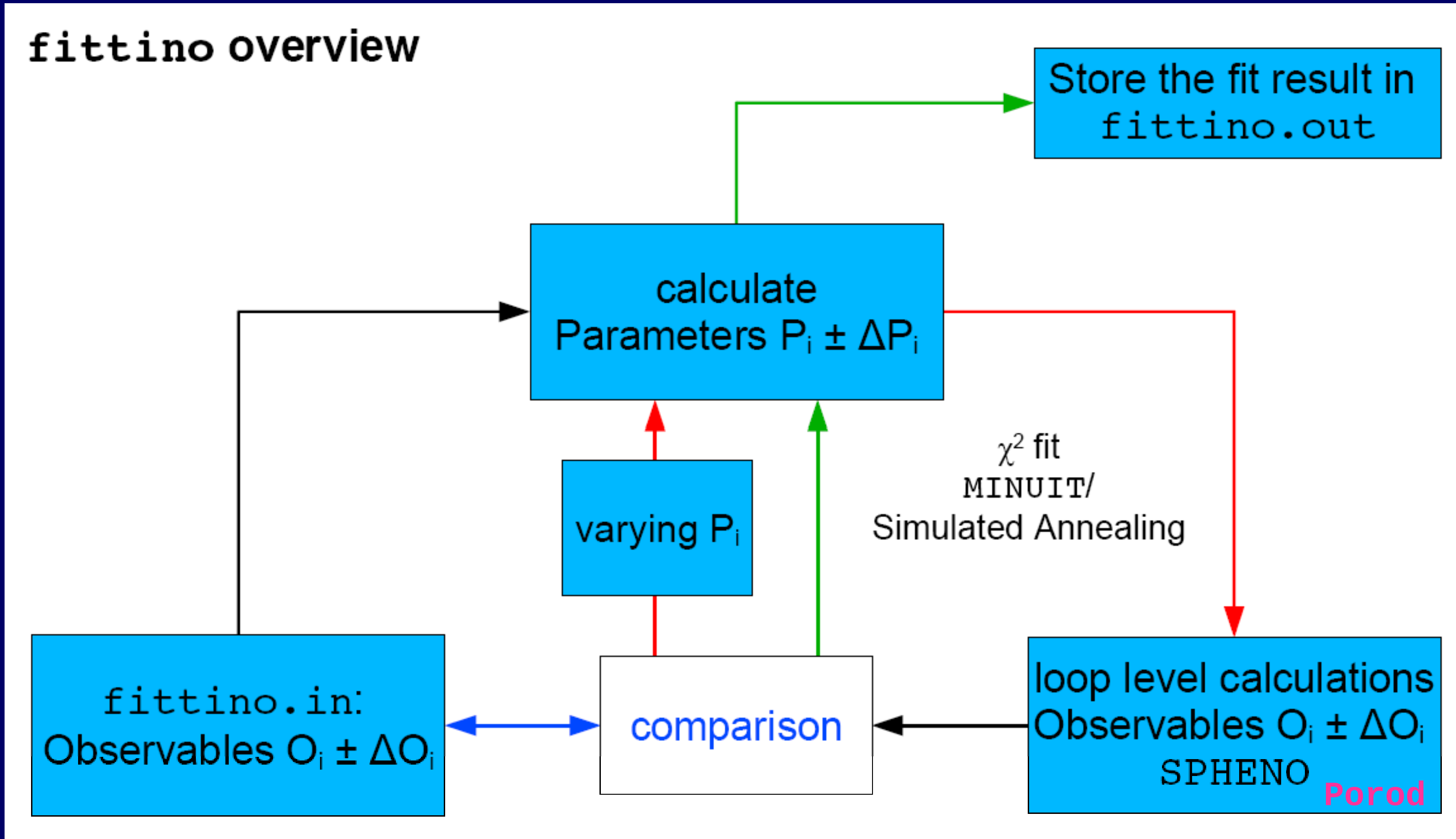
Global SUSY Parameter Fits



Current goal: what can be done with LHC data alone?
restrict to few-parameter models (e.g. mSugra), then extend…

Global SUSY Parameter Fits

Fit most „simple“ 4-parameter model and improve realism

mSUGRA SPS 1a benchmark point parameters

```
fitModel mSUGRA

fitParameter M0         100
fitParameter M12        250
fitParameter A0        -100
fitParameter TanBeta     10
fixParameter SignMu       1
```

LHC observables (up 300 fb^{-1}: kinematic edges, Higgs, Masses
Include correlated errors in convienient way

→ Implementation of syntax that allows comfortable error correlation handling

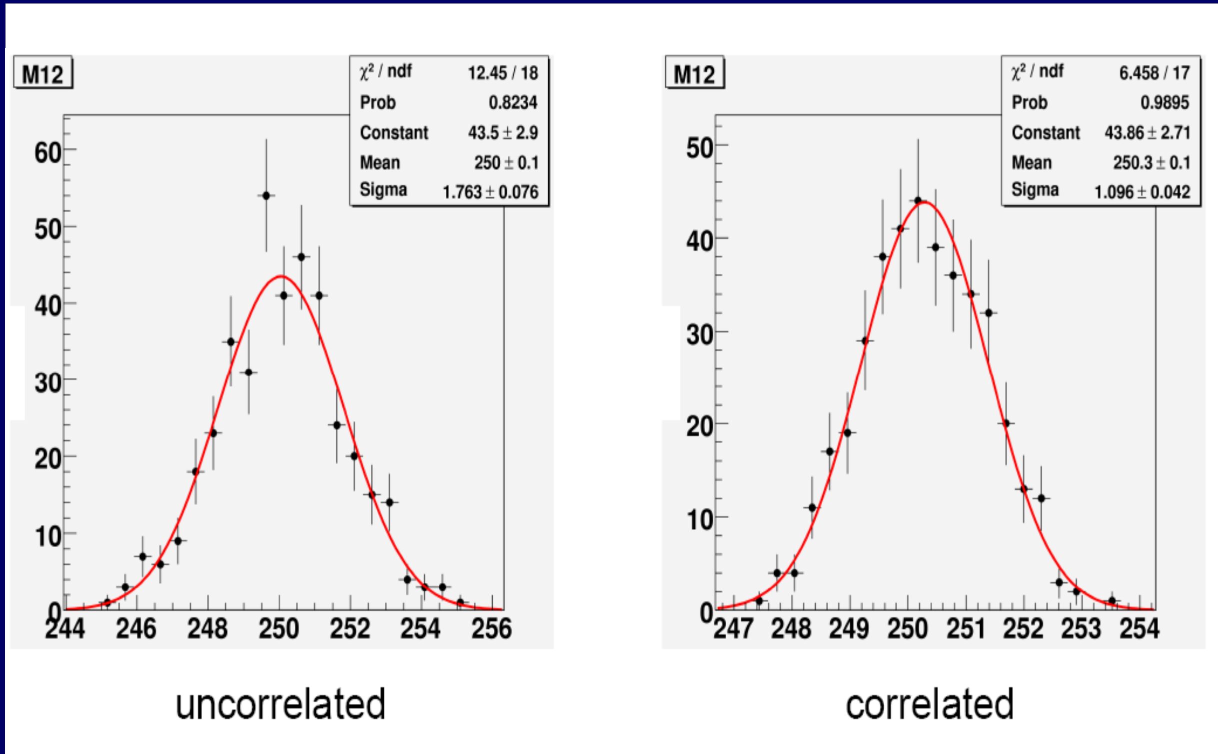
```
edge 3 massNeutralino1 massNeutralino2 massSelectronR               80.8784 GeV +- 0.05 GeV           +- (LES) 0.08 GeV
edge 3 massNeutralino1 massSupL        massNeutralino2             454.834  GeV +- 2.4  GeV           +- (JES) 4.3  GeV
edge 3 massSelectronR  massSupL        massNeutralino2             326.201  GeV +- 1.5  GeV           +- (JES) 3.0  GeV
edge 4 massNeutralino1 massNeutralino2 massSelectronR  massSupL    398.124  GeV +- 1.8  GeV           +- (JES) 3.8  GeV
edge 5 massNeutralino1 massNeutralino2 massSelectronR  massSupL    217.257  GeV +- 2.8  GeV           +- (JES) 2.0  GeV
edge 5 massNeutralino1 massNeutralino2 massSelectronR  massSbottom1 197.01  GeV +- 6.3  GeV           +- (JES) 1.8  GeV
edge 3 massNeutralino1 massNeutralino2 massStau1                    83.75   GeV +- 9.0  GeV +- 6.0 GeV +- (LES) 0.08 GeV
edge 3 massNeutralino1 massNeutralino4 massSelectronL              284.703  GeV +- 4    GeV

edge 6 massTop massStop1 massChargino1 massGluino                  380.81   GeV +- 4.8  GeV +- (JES) 3.8  GeV

massh0          110.294 GeV +-  0.5   GeV
massSelectronL  202.565 GeV +-  3     GeV +-  6 GeV
massChargino1   180.58  GeV +- 25     GeV
massGluino      607.528 GeV +-  4     GeV          +- (JES) 10   GeV
massSupR        551.384 GeV +-  3.6   GeV          +- (JES) 10   GeV
massSbottom1    517.57  GeV +-  1.5   GeV          +- (JES)  5.2 GeV
massSbottom2    550.811 GeV +-  2.5   GeV          +- (JES)  5.5 GeV
```

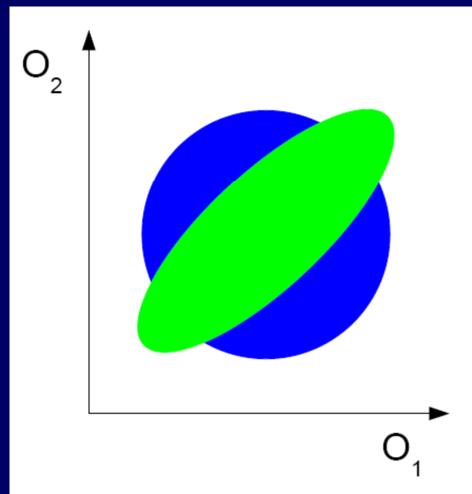
Correlated errors: consequences

Example: Distribution of 500 fits for $m_{1/2}$:



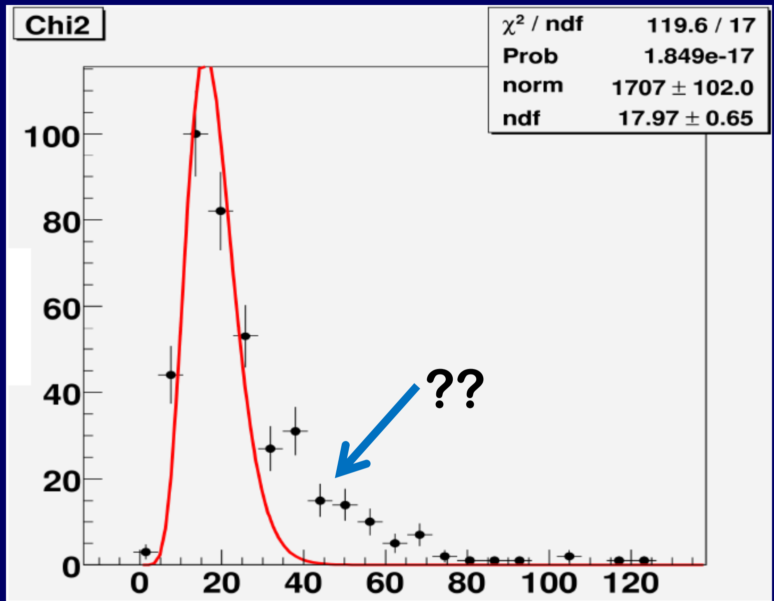
Correlated errors may yield smaller errors

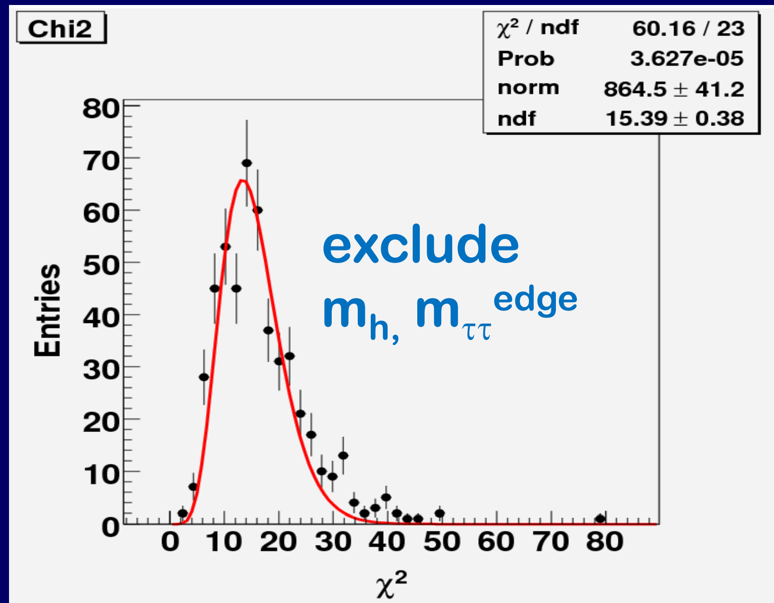
(P-space corresponding to corr. error ellipse may be smaller than than P-scape of uncorr. ellipse)



Global SUSY Parameter Fits: (preliminary) results

	correlated	uncorrelated
$\tan\beta$	9.749 +- 2.303	10.47 +- 3.088
A_0	-98.20 +- 41.34	-97.64 +- 56.07
m_0	99.970 +- 1.022	99.92 +- 1.997
$m_{1/2}$	250.3 +- 1.128	250.1 +- 1.739





Global SUSY Parameter Fits: next steps

- results as a function of integrated luminosity (1,10,30,300 fb^{-1})
- likelihood maps
- include low-energy observables ($b \to s\gamma$, $(g-2)_\mu$, …)
- include polarisation observables, shapes, …

(be ready when SUSY is discovered ☺)

Summary and conclusions

- LHC and ATLAS on a good way to completion by 2008
- LHC comissioning in progress – first collisions by end 2008 in a success-oriented schedule
- Excellent SUSY discovery prospects of ATLAS and CMS once detector effects + backgrounds are understood ($t_{data\text{-}on\text{-}tape} < t_{paper\text{-}on\text{-}arxiv}$)
- τ lepton signatures may provide a complementary discovery channel and allow access to additional SUSY properties (stau mass, stau mixing angle, χ-couplings)
- global SUSY fits with Fittino being optimized for LHC data

On the way to get ready for real data

BACKUP

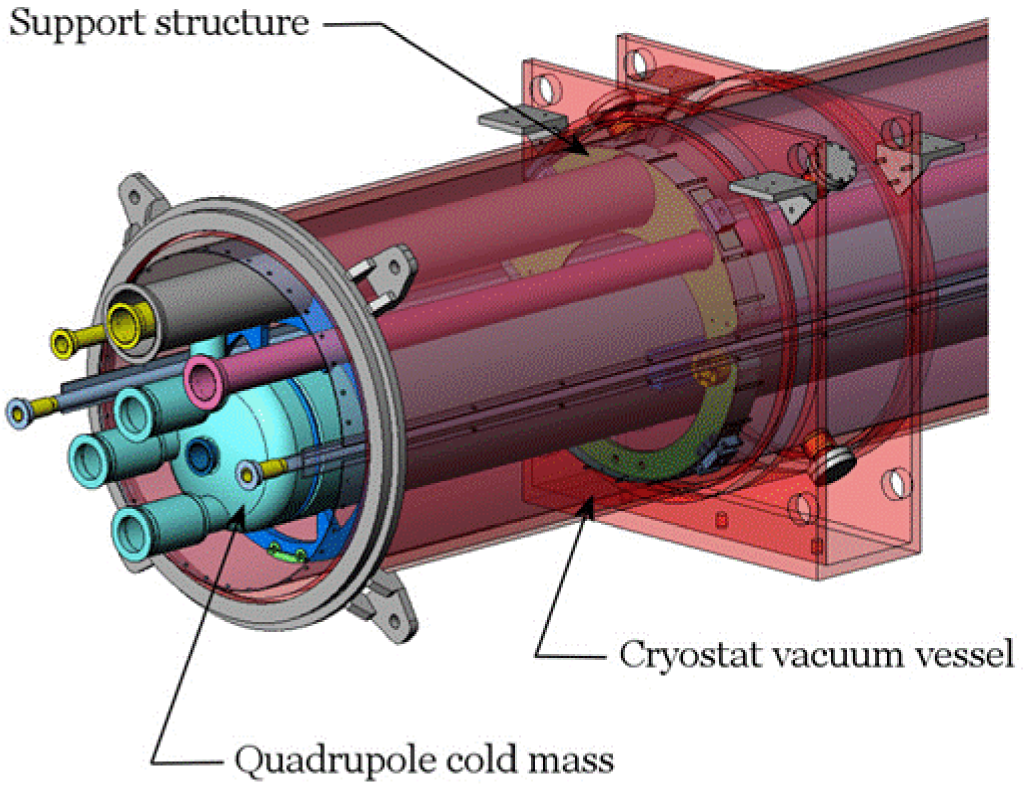
Lest we forget – Triplets – Heat exchanger problem

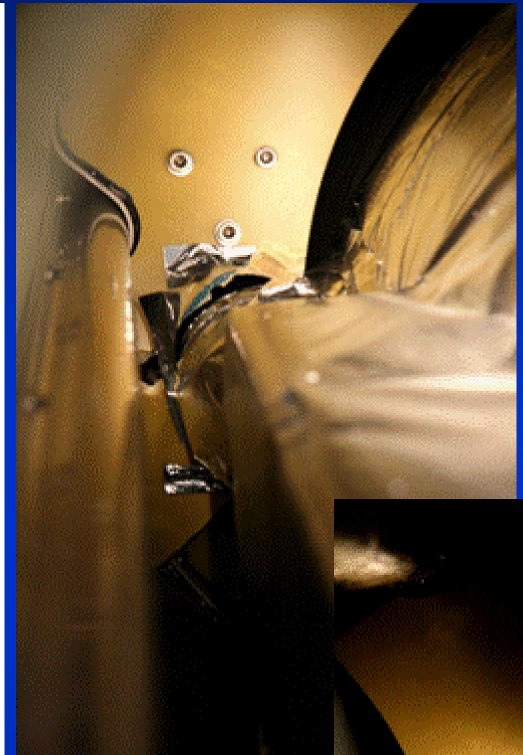
- Design and execution of the brazed joints anneals the extremities of the tubes (including fixed points in Q1 and Q3).
- Length of heat affected zone ~ 250-300 mm.
- Absence of mechanical support in the heat affected length.

All low-beta quadrupoles need to be repaired.

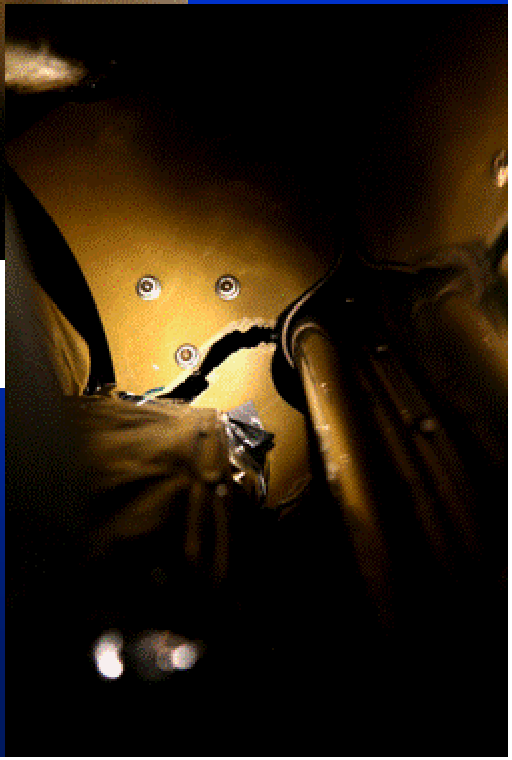
- **During the pressure test of Sector 7-8 (25 November 2006) the corrugated heat exchanger tube in the inner triplet failed by buckling at 9 bar (external) differential pressure.**
- **The inner triplet was isolated and the pressure test of the whole octant was successfully carried out to the maximum pressure of 27.5 bar, thus allowing it to be later cooled down.**
- **Reduced-height of corrugations and annealing of copper near the brazed joint at the tube extremities accounted for the insufficient resistance to buckling.**
- **New tubes were produced with higher wall thickness, no change in corrugation height at ends, and e-beam welded collars to increase distance to the brazed joint.**
- **Installation of these tubes was made *in situ*.**

Lest we forget – Triplets – Supports problem





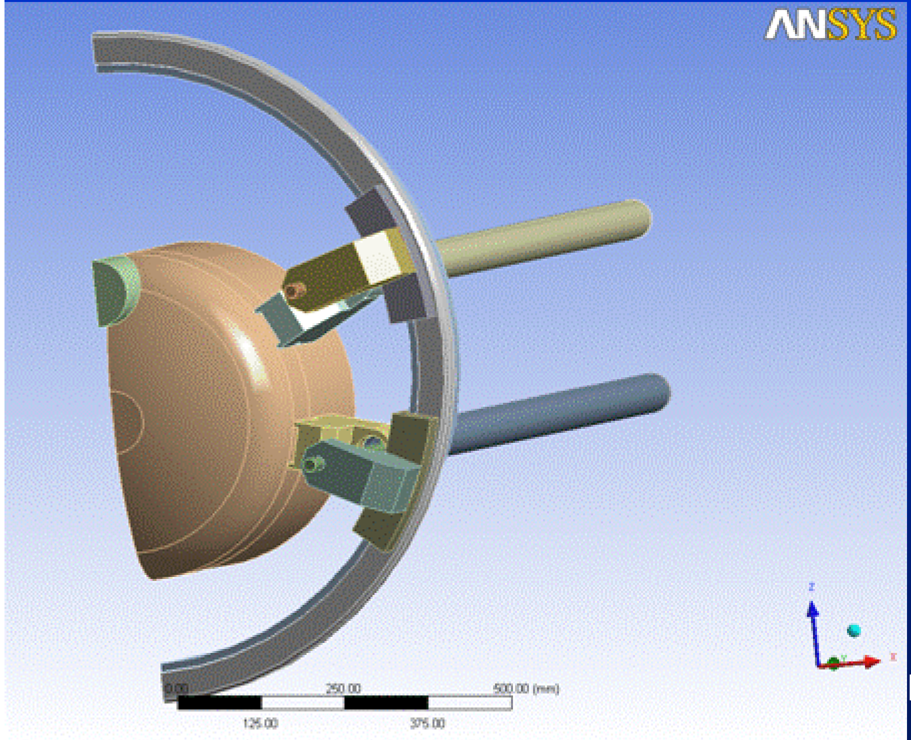
Q1 supports at IP 5L



On Tuesday March 27 2007 there was a serious failure in a high-pressure test at CERN of a Fermilab-built "inner-triplet" series of three quadrupole magnets

Lest we forget – Triplets – Supports solution

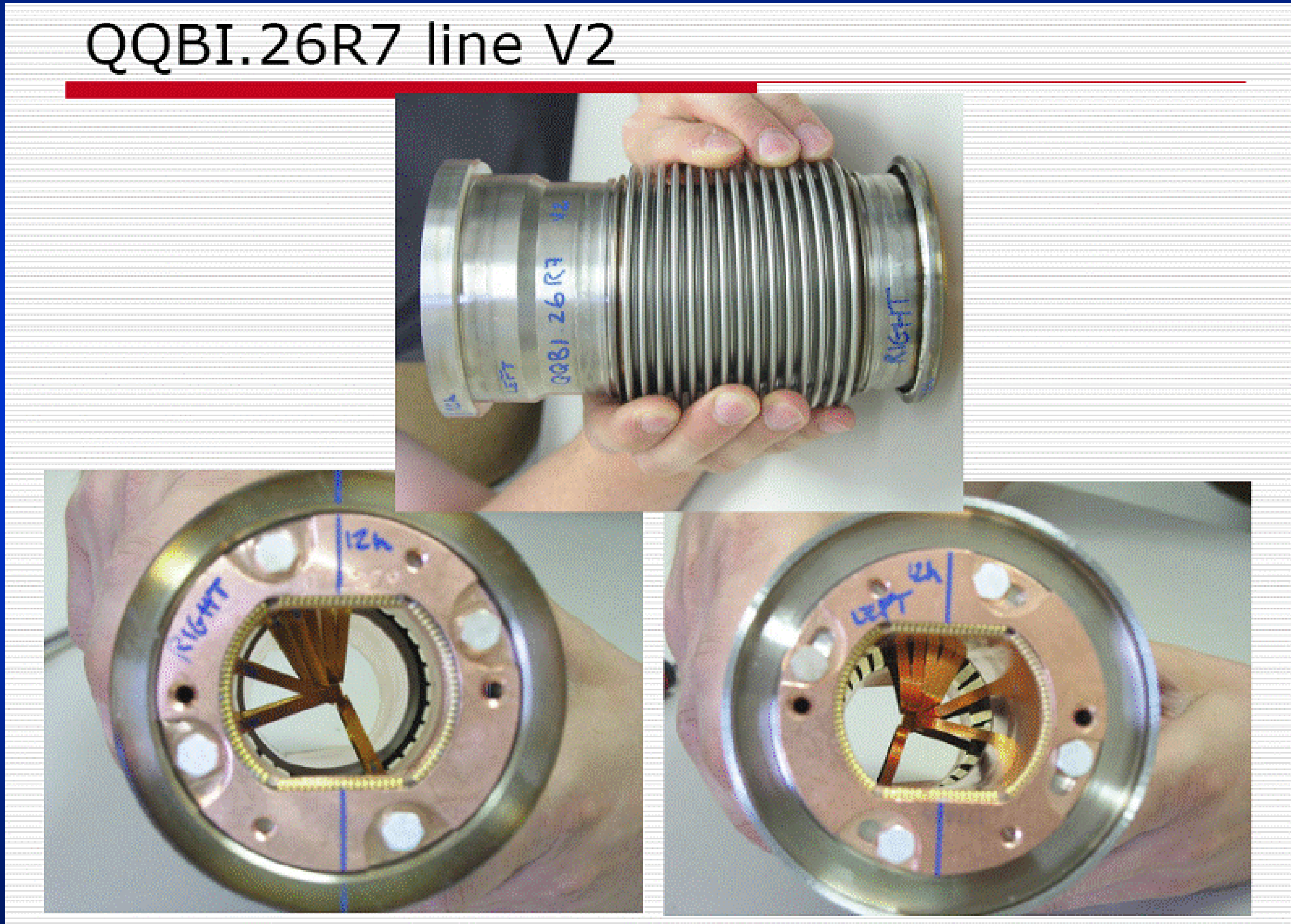
- Requirements for repair
  - Must be implemented *in situ*
  - Does not displace the fixed points of the assembly
  - React loads with sufficient stiffness to limit deflection at 150 kN design load
  - Acts at any temperature between 300K and 2K
  - To be implemented in Q1 and Q3



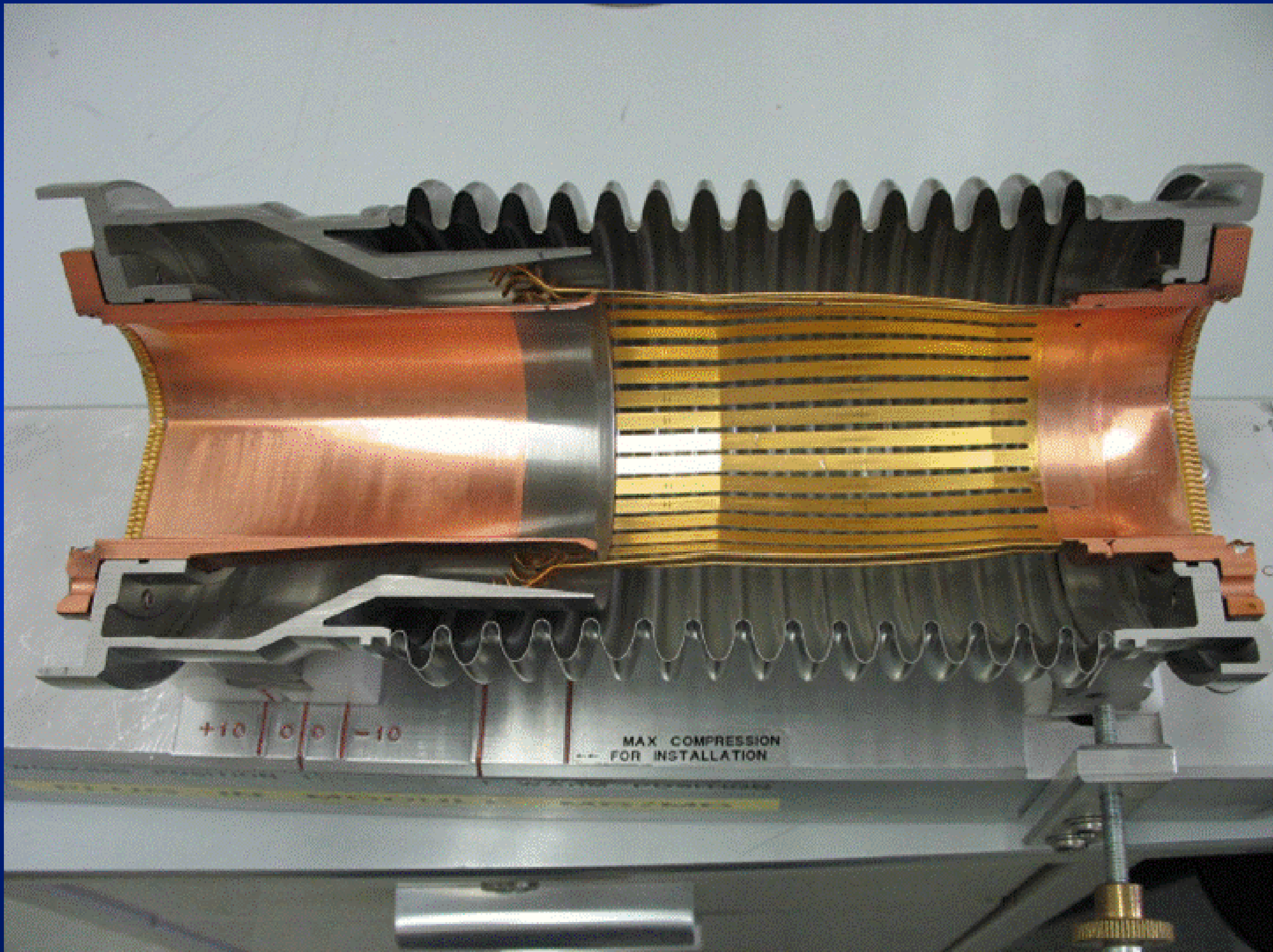
- Solution adopted
  - Affixed at Q1 non-IP end and at Q3 IP end
  - Transfer load at all temperatures
  - Limits support deflections
  - Compound design with Invar rod and aluminium alloy tube
  - Attached with brackets to cold mass and cryostat outer vessel

- Status
  - All triplets repaired by September
  - Problem solved

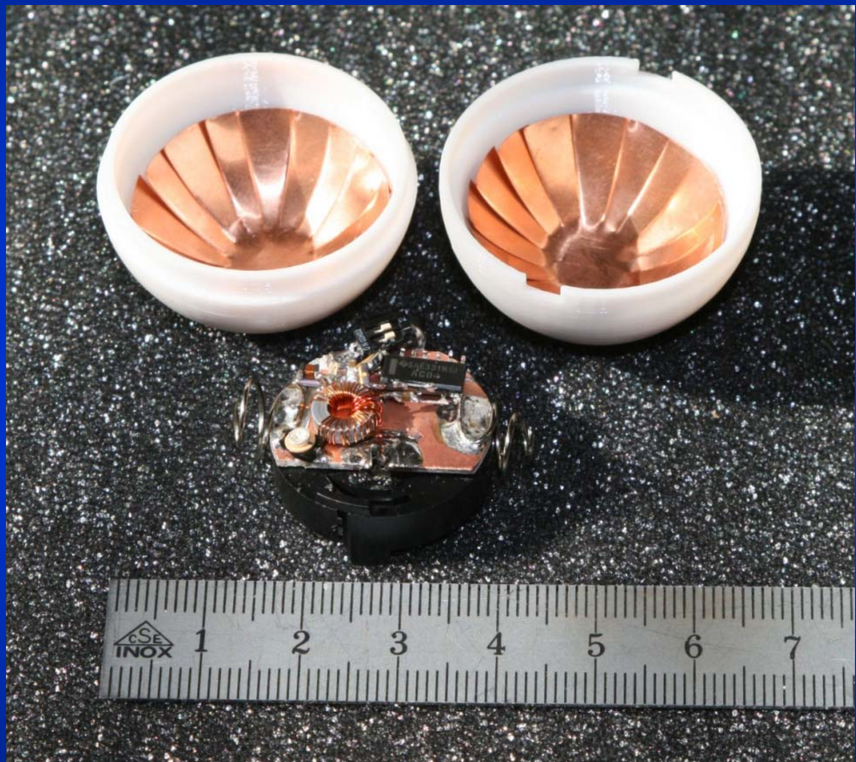
Shielded bellows on the cold interconnects (PiMs)



Plug in Module in equivalent cold position



RF mole



- Polycarbonate shell
  - Diameter
    - 34mm exterior
    - 30mm interior
  - Total weight
    - ~15 g (ball 8g)
- RF characteristics
  - 40MHz resonantcircuit
    - Generates 20V between copper electrodes
  - Battery powered
    - Over 2hr lifetime
  - Capacitive coupling to BPM electrodes
    - 1V ⇒~5mV
    - -45db Coupling
  - BPM trigger threshold at ~3mV