LHC/LC Study, CERN, May 9, 2003

Measuring SUSY masses via cascade decays for SPS1a

Progress Report

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and Giacomo Polesello.

- ♢ "Edge" measurements at ATLAS
- ♢ Including LC inputs
- ♢ b-tagged cascade decays

SPS1a

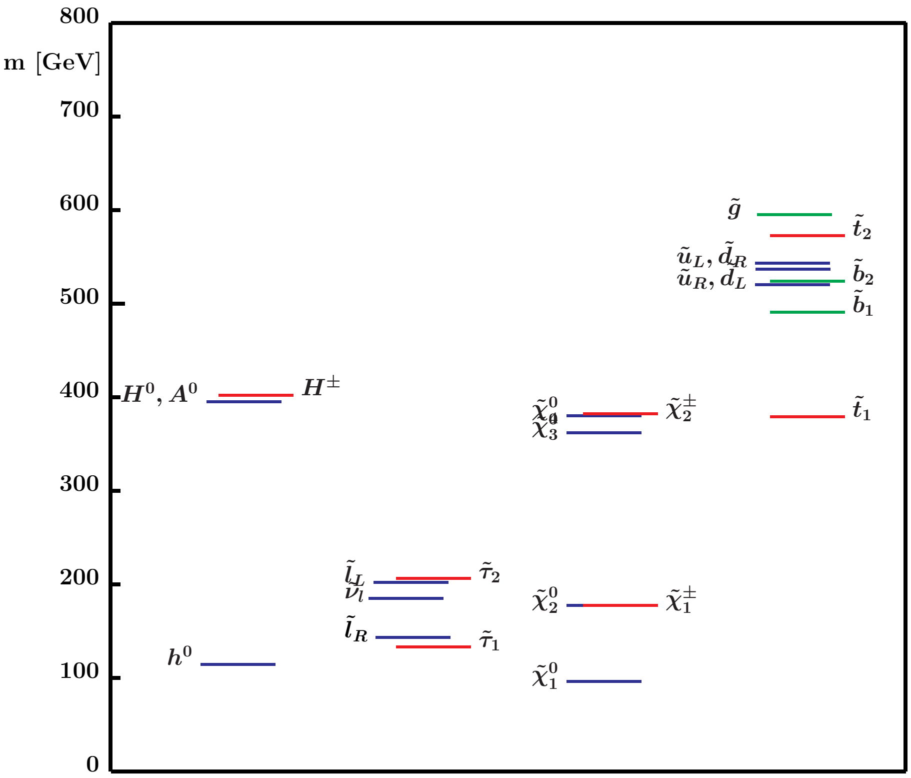
Snowmass "typical point"

◇ Gut scale universal boundary conditions:

$m_0 = 100$ GeV	$m_{1/2} = 250$ GeV	$A_0 = -100$ GeV
$\tan\beta = 10$	$\mu > 0$	

◇ Low scale masses according to ISAJET 7.58:

Ghodbane, Martyn hep-ph/0201233



In particular, important masses are:

$$M_{\tilde{g}} = 595.19 \text{ GeV} \qquad M_{\tilde{b}_1} = 491.91 \text{ GeV}$$
$$M_{\tilde{u}_L} = 537.25 \text{ GeV} \qquad M_{\tilde{e}_R} = 142.97 \text{ GeV}$$
$$M_{\tilde{\chi}_1^0} = 96.051 \text{ GeV} \qquad M_{\tilde{\chi}_2^0} = 176.820 \text{ GeV}$$

SUSY mass measurements

♢ All SUSY decay chains end with LSP ($\tilde{\chi}_1^0$ for SPS1a)

don't know LSP momentum
$\Rightarrow$ no 'direct' mass measurements

No mass peaks for SUSY like we had for Z boson

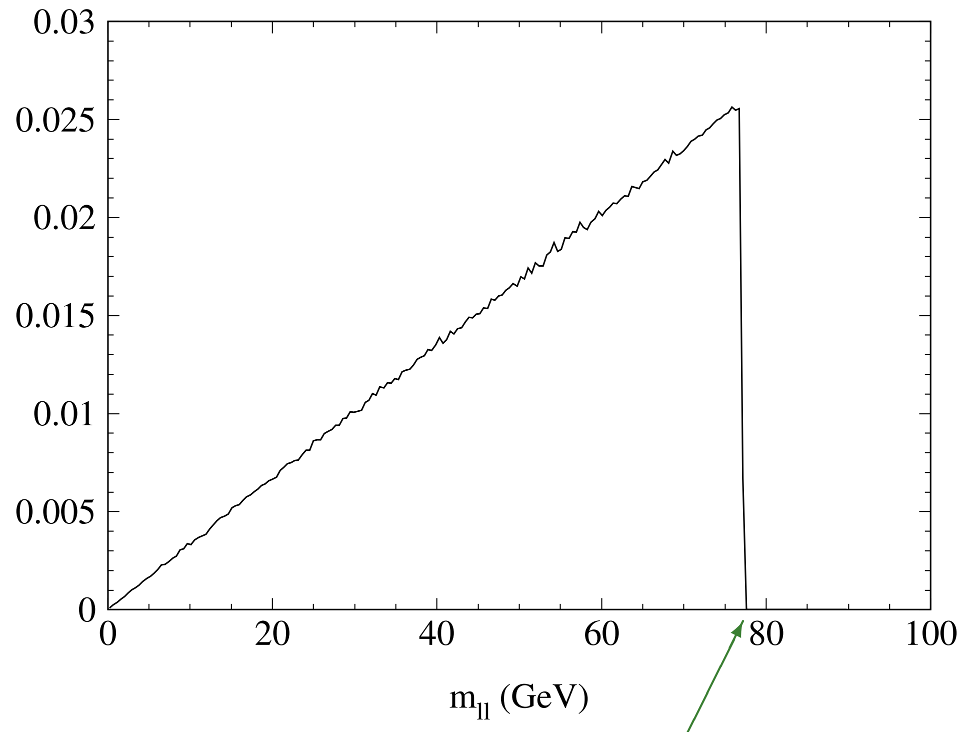
NB: problem lessened at LC since know $\sqrt{s}$
$\Rightarrow$ can reconstruct missing momentum

But always have (at least) 2 LSPs in final state
$\Rightarrow$ problem remains

♢ At kinematic extremes, LSP momentum constrained

$\Rightarrow$ measure masses from end points of invariant mass spectra e.g. $\tilde{\chi}_2^0 \to l^+ \tilde{l}_R^- \to l^+ l^- \tilde{\chi}_1^0$

Theory plot



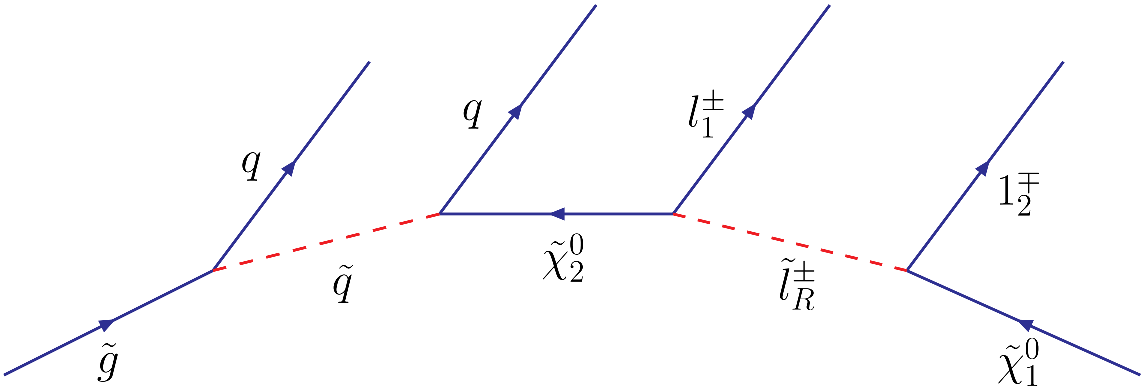
maximum value when l^+ and l^- back-to-back in $\tilde{l}_R^-$ rest frame
$\Rightarrow$ constrains $\tilde{\chi}_1^0$ momentum

$$(m_{ll}^2)_{\mathrm{max}} = (m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R^\pm}^2)(m_{\tilde{l}_R^\pm}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{l}_R^\pm}^2$$

One edge contains many masses $\Rightarrow$

measure many different "edges" to determine masses

Cascade Decay



Gluino from $pp \to \tilde{g}\tilde{g}$ or $\tilde{q}\tilde{g}$

$\tilde{q}_R \to \tilde{\chi}_1^0 q$ (100%)

$$\tilde{q}_L \to \begin{cases} \tilde{\chi}_2^0 q \text{ (32\%)} \\ \tilde{\chi}_1^{\pm} q \text{ (66\%)}, \quad \tilde{\chi}_1^{\pm} \to \tilde{\tau}_1 \nu_\tau \text{ } (\sim 100\%) \end{cases}$$

$$\tilde{\chi}_2^0 \to \begin{cases} \tilde{l}_R l \text{ (12.6\%) (i.e. } e \text{ or} \mu) \\ \tilde{\tau}_1 \tau \text{ (87\%)} \end{cases}$$

Do not consider decay to $\tilde{\tau}_1\tau$ due to poor energy resolution (something for the future?)

Signal has at least 2 leptons and 3 or 4 jets (depending on the parent of the other decay chain).

Event generation and selection

◇ Total SUSY cross section is $\sigma_{susy} = 49.6$pb

◇ Generate 100 fb^{-1} worth of events using:
Pythia (6.208)

◇ Detector simulation:
Atlfast (00-02-20) set at high luminosity

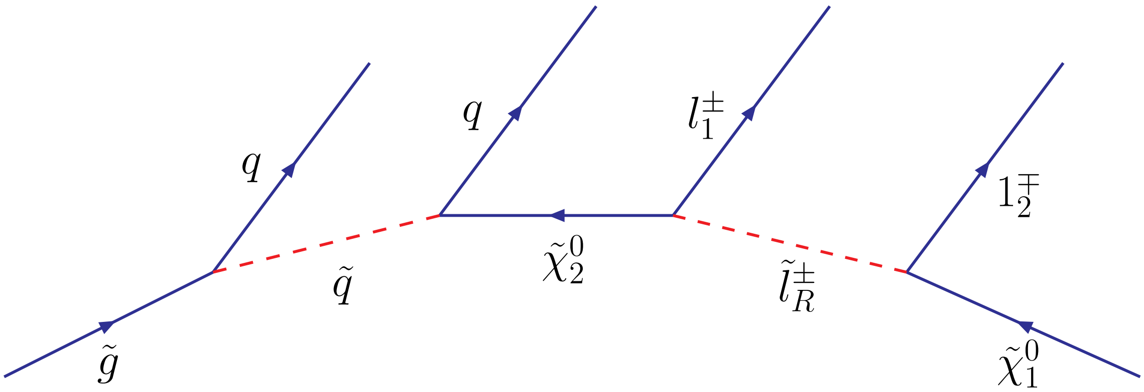
◇ Atlas trigger (Atlfast) accepts 60% of SUSY events

◇ Cuts used to select desired decay chain
(c.f. Giacomo Polesello's talk Feb 14):

- At least four jets, with three hardest satisifying:
  $p_{T,1} > 150$GeV, $p_{T,2} > 100$GeV, $p_{T,3} > 50$GeV
- Two isolated same-flavour opposite-sign (SFOS) leptons (not τ) with:
  $p_T(l_1) > 20$GeV and $p_T(l_2) > 10$GeV.
- $M_{\text{eff}} \equiv E_{T,miss} + p_{T,1} + p_{T,2} + p_{T,3} + p_{T,4} > 600$GeV
- $E_{T,miss} > max(100\text{GeV}, 0.2M_{eff})$

◇ SFOS backgrounds remain - expect same as opposite-flavour opposite-sign (OFOS) lepton background
$\Rightarrow$ Add OFOS contribution with negative weight

Edges



Order quarks by p_T: q_1, q_2, q_3 etc.

(Alanach et al. hep-ph/0007009)

◇ l^+l^- invariant mass
$(m_{ll}^{\max})^2 = (m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R}^2)(m_{\tilde{l}_R}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{l}_R}^2$

◇ $q_1 l^+l^-$ invariant mass
$(m_{qll}^{\max})^2 = (m_{\tilde{q}}^2 - m_{\tilde{\chi}_2^0}^2)(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{\chi}_2^0}^2$

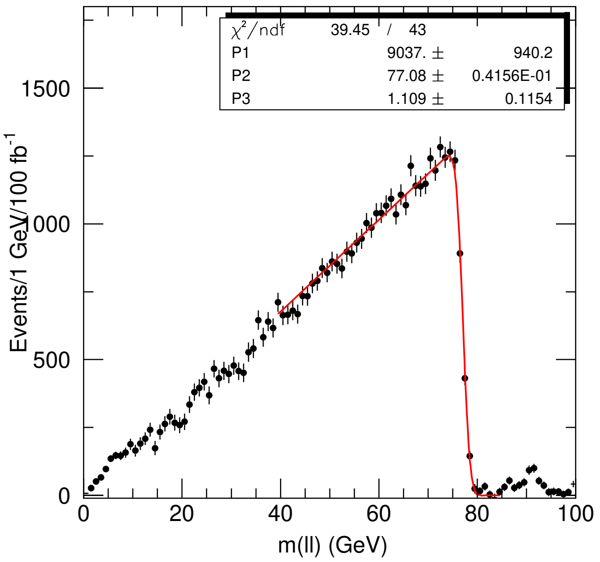
◇ maximum of two possible $q_1 l$ invariant masses
$(m_{qll}^{\max,\max})^2 = (m_{\tilde{q}}^2 - m_{\tilde{\chi}_2^0}^2)(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R}^2)/m_{\tilde{\chi}_2^0}^2$

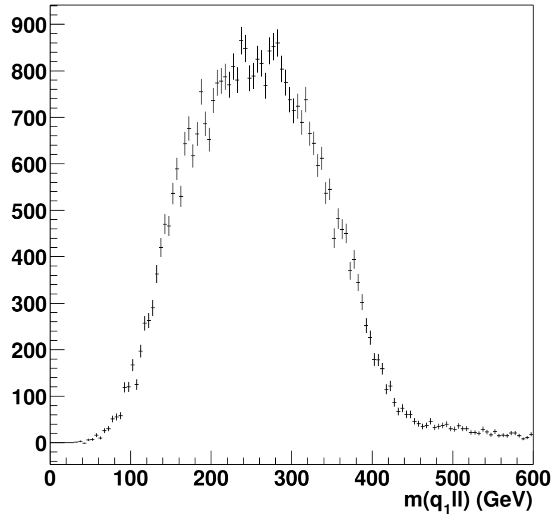
◇ minimum of two possible $q_1 l$ invariant masses
$(m_{qll}^{\min,\max})^2 = (m_{\tilde{q}}^2 - m_{\tilde{\chi}_2^0}^2)(m_{\tilde{l}_R}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{l}_R}^2$

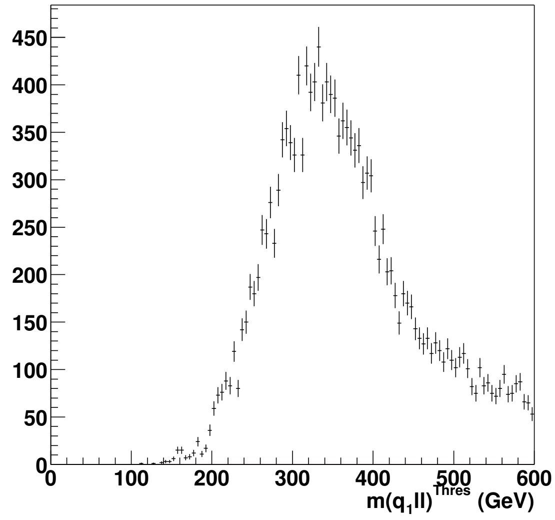
◇ $q_3 l^+l^-$ threshold: minimum of $q_1 l^+l^-$ invariant mass for events with $m_{ll} > m_{ll}^{\max}/\sqrt{2}$
complicated expression!

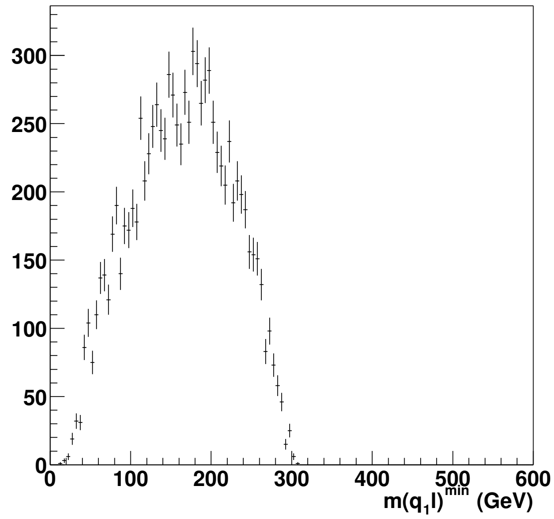
+ other invariant masses involving q_3

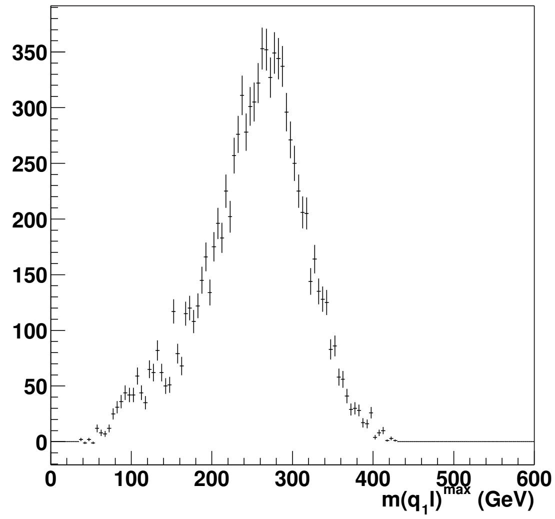
Invariant mass distributions











Edge fitting

◇ Fit edge to a straight line

Edge	Nominal value	Fitted value	Fit Error Statistical	Fit Error Systematic	Error Energy Scale
$m(ll)$	77.07	76.86	0.15	0.15	0.11
$m(q_1ll)$	431.08	437.2	2.6	2.9	4.3
$m(q_1ll)^{\mathrm{Thr}}$	202.99	209.6	3.8	1.1	2.0
$m(q_1l)^{\mathrm{min}}$	302.12	294.3	1.6	0.9	3.0
$m(q_1l)^{\mathrm{max}}$	380.31	376.8	2.5	3.1	3.8

All masses in GeV

Mass determination

♢ Use Minuit (ROOT) to fit masses to edge values (χ^2)

♢ Edges are "fundamental" measurement
Masses are only "derived" measurement

Also different edges sensitive to different masses
Expect edge measurement to have guassian error

$\Rightarrow$ $\boxed{\text{Repeat fitting } 10^5 \text{ times to give error estimate}}$

$$
\begin{aligned}
m^2_{\tilde{\chi}^0_1} &= 96.8 \pm 12.3 \text{ GeV} \\
m^2_{\tilde{l}_R} &= 143.7 \pm 12.1 \text{ GeV} \\
m^2_{\tilde{\chi}^0_2} &= 177.6 \pm 12.0 \text{ GeV} \\
m_{\tilde{q}_L} &= 544.1 \pm 20.2 \text{ GeV} \\
m_{\tilde{g}} &= 596.2 \pm 19.7 \text{ GeV}
\end{aligned}
$$

Problem: Børge's errors larger than Giacomo's (see talk, Feb 14)

e.g. Giacomo has $m^2_{\tilde{\chi}^0_1} = 96.5 \pm 7.9$ GeV

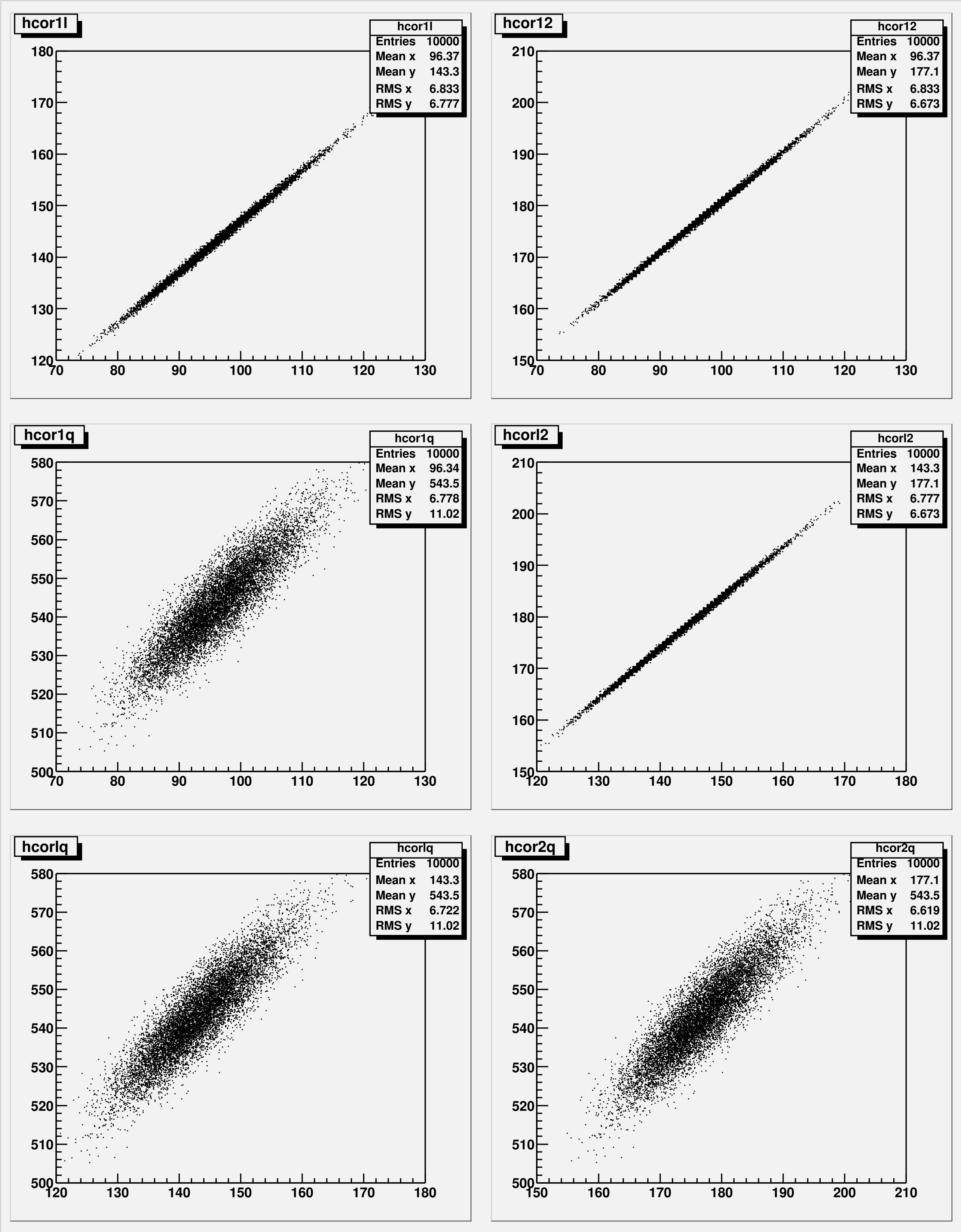
(this is coming from the edges - not the mass fit)

Giacomo – didn't use Atlfast trigger
has 90% lepton identification

Børge – used Atlfast trigger
has no lepton identification

Can this explain the difference?

♢ Correlations between different masses $\longrightarrow$


hcor1l
hcor1l
Entries 10000
Mean x 96.37
Mean y 143.3
RMS x 6.833
RMS y 6.777
hcor12
hcor12
Entries 10000
Mean x 96.37
Mean y 177.1
RMS x 6.833
RMS y 6.673
hcor1q
hcor1q
Entries 10000
Mean x 96.34
Mean y 543.5
RMS x 6.778
RMS y 11.02
hcorl2
hcorl2
Entries 10000
Mean x 143.3
Mean y 177.1
RMS x 6.777
RMS y 6.673
hcorlq
hcorlq
Entries 10000
Mean x 143.3
Mean y 543.5
RMS x 6.722
RMS y 11.02
hcor2q
hcor2q
Entries 10000
Mean x 177.1
Mean y 543.5
RMS x 6.619
RMS y 11.02

Including LC mass measurements

◇ χ^2 fit is over many masses
— What if we input a mass from LC?

◇ TESLA TDR: 0.2% precision on $m_{\tilde{\chi}_1^0}$
$\Rightarrow$ input $m_{\tilde{\chi}_1^0} = 96.1 \pm 0.2$ GeV

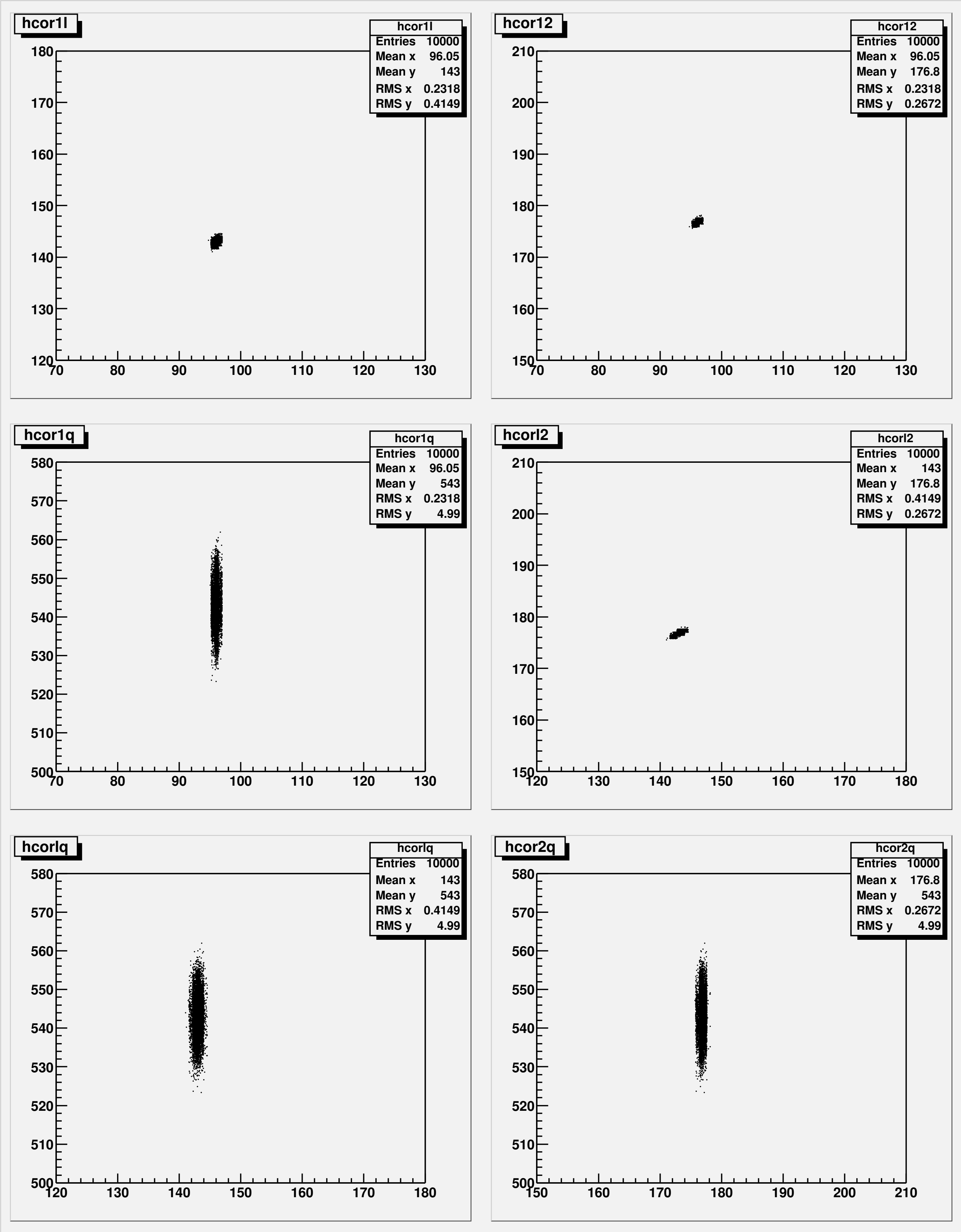
◇ Improvement remarkable:

$$\boxed{\begin{aligned} m^2_{\tilde{l}_R} &= 143.0 \pm 0.8 \text{ GeV} \\ m^2_{\tilde{\chi}_2^0} &= 176.8 \pm 0.5 \text{ GeV} \\ m_{\tilde{q}_L} &= 543.1 \pm 5.5 \text{ GeV} \\ m_{\tilde{g}} &= 595.3 \pm 7.7 \text{ GeV} \end{aligned}}$$

◇ Doesn't depend much on which mass is inputed

◇ Multiple LC mass inputs do not improve other mass measurements much

◇ Correlations between masses disappear $\longrightarrow$



hcor1l
hcor1l
Entries 10000
Mean x 96.05
Mean y 143
RMS x 0.2318
RMS y 0.4149
180 170 160 150 140 130 120
70 80 90 100 110 120 130
hcor12
hcor12
Entries 10000
Mean x 96.05
Mean y 176.8
RMS x 0.2318
RMS y 0.2672
210 200 190 180 170 160 150
70 80 90 100 110 120 130
hcor1q
hcor1q
Entries 10000
Mean x 96.05
Mean y 543
RMS x 0.2318
RMS y 4.99
580 570 560 550 540 530 520 510 500
70 80 90 100 110 120 130
hcorl2
hcorl2
Entries 10000
Mean x 143
Mean y 176.8
RMS x 0.4149
RMS y 0.2672
210 200 190 180 170 160 150
120 130 140 150 160 170 180
hcorlq
hcorlq
Entries 10000
Mean x 143
Mean y 543
RMS x 0.4149
RMS y 4.99
580 570 560 550 540 530 520 510 500
120 130 140 150 160 170 180
hcor2q
hcor2q
Entries 10000
Mean x 176.8
Mean y 543
RMS x 0.2672
RMS y 4.99
580 570 560 550 540 530 520 510 500
150 160 170 180 190 200 210

b-tagging

- ♢ b-tag quarks in decay chain
  $\Rightarrow$ measure $\tilde{b}_1$ mass
- ♢ much less background
- ♢ much less signal
  $\Rightarrow$ edges harder to find $\longrightarrow$

Find (systematic error?):

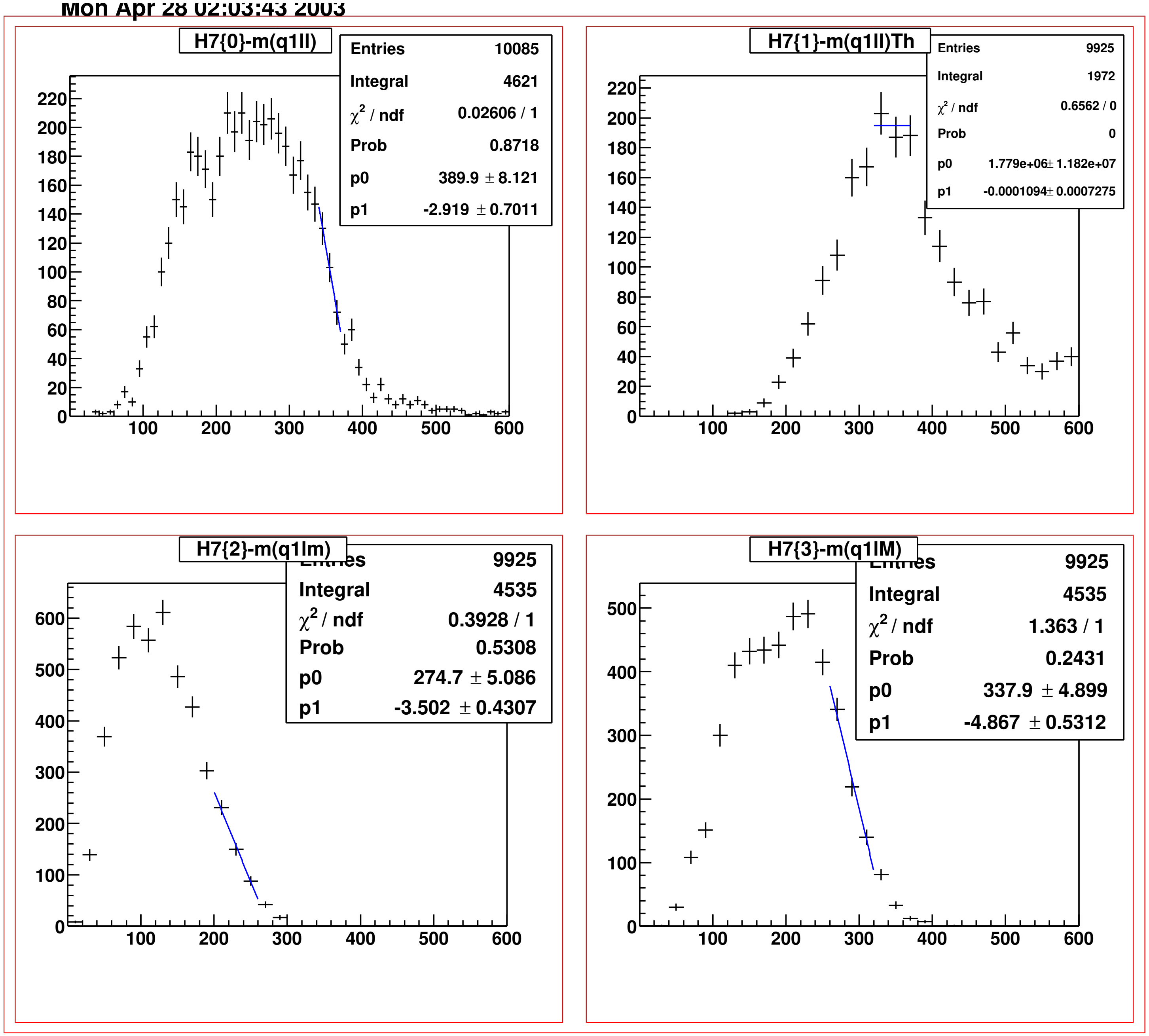
$$m_{\tilde{b}_1} = 491.9 \pm 7.3 \text{ GeV}$$

With LC $m_{\tilde{\chi}_1^0}$ input from LC, bcomes

$$m_{\tilde{b}_1} = 488.1 \pm 6.2 \text{ GeV}$$

- ♢ Why does this not change much?
- ♢ Need to investigate systematics

Mon Apr 28 02:03:43 2003



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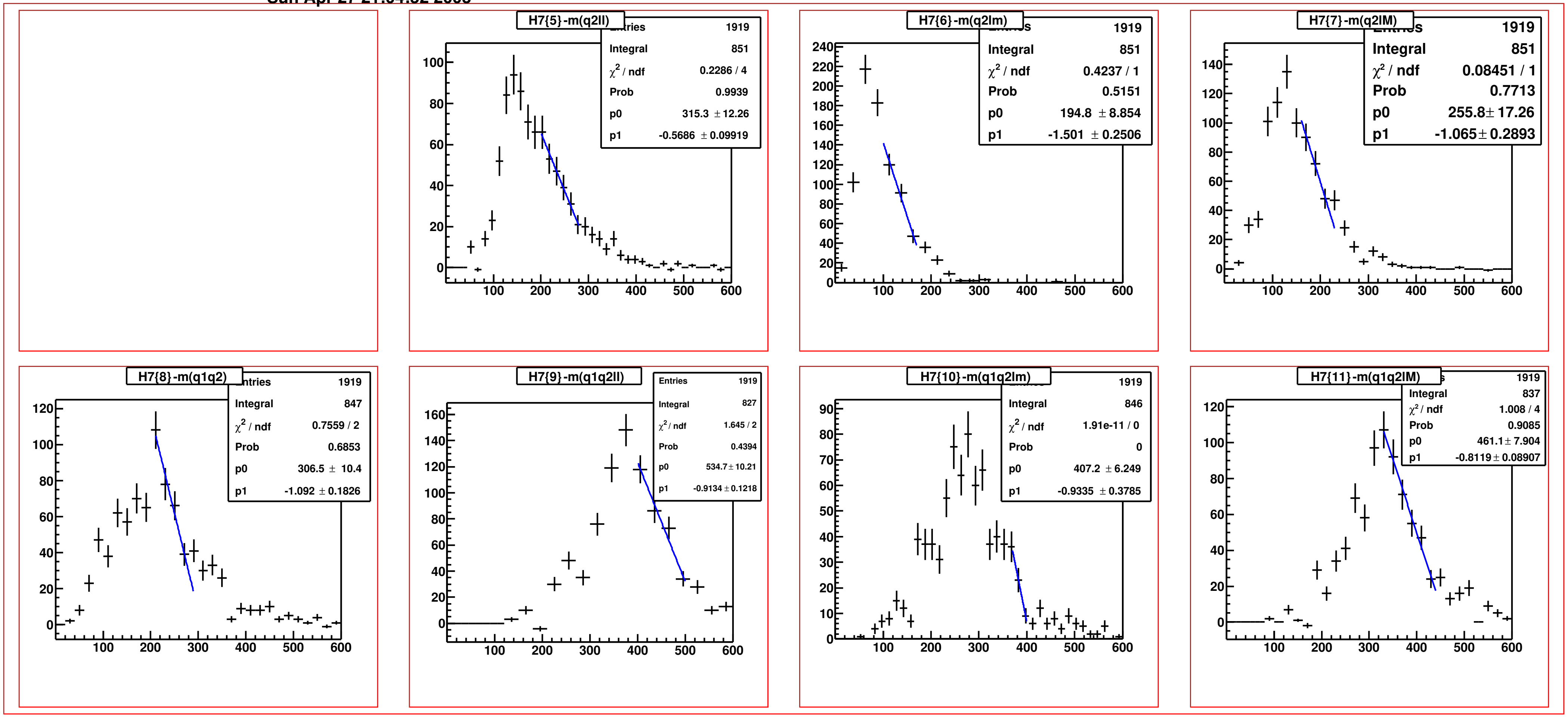

Things to do

◇ Find source of dissagreement on errors

◇ Include lepton identifictaion and Atlfast trigger

◇ Investigate better ways of finding edges

◇ Investigate $\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau$

◇ Atlas trigger not symmetric w.r.t. SFOS and OFOS
$\Rightarrow$ OFOS subractions not really correct
Find a better way!

◇ Look more closely at systematics
– are we estimating them correctly?
– can we improve fitting of edges?
– comparison with theory plots

◇ try and understand interplay with LC better
– why is sbottom mass not improved much?

◇ double cascade decays

◇ more integral approach (regard edges as more fundamental)

◇ Is this a truely model independent analysis?