The Race for Supersymmetry

Ben Gripaios

CERN

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Bainbridge, Buchmueller, Ellis, BMG, in progress

Discovering new physics

The race for the W

The race for the t

The race for SUSY

What is the best way to discover new physics?
(in jets $+\not{E}_T$)

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What is the fastest way to discover new physics?

Outline

- Discovering new physics
- The race for the W
- The race for the top
- The race for SUSY

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What is the best way to discover new physics?

ATLAS $> 4j + \not{E}_T$

1. At least four jets with $p_T > 50$ GeV at least one of which must have $p_T > 100$ GeV; and $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV.
2. $E_{\mathrm{T}}^{\mathrm{miss}} > 0.2 M_{\mathrm{eff}}$.
3. Transverse sphericity, $S_T > 0.2$.
4. $\Delta\phi(\mathrm{jet}_1 - E_{\mathrm{T}}^{\mathrm{miss}}) > 0.2$, $\Delta\phi(\mathrm{jet}_2 - E_{\mathrm{T}}^{\mathrm{miss}}) > 0.2$, $\Delta\phi(\mathrm{jet}_3 - E_{\mathrm{T}}^{\mathrm{miss}}) > 0.2$.
5. Reject events with an e or a μ.
6. $M_{\mathrm{eff}} > 800$ GeV.

ATL-PHYS-PUB-2009-066

Cut-based searches

Typical searches are multi-cut based

- Cuts on $p_T, \not{p}_T, \Delta\phi, \ldots$
- Signal enriched sample
- Wastes signal events
- What is the background contribution?

Likelihoods

The optimal search has no cuts

- Calculate L for all hypotheses of S and B
- Theoretically/practically impossible

What about a single cut?

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The race for the W

The race for the *W*

Volume 122B, number 1 PHYSICS LETTERS 24 February 1983

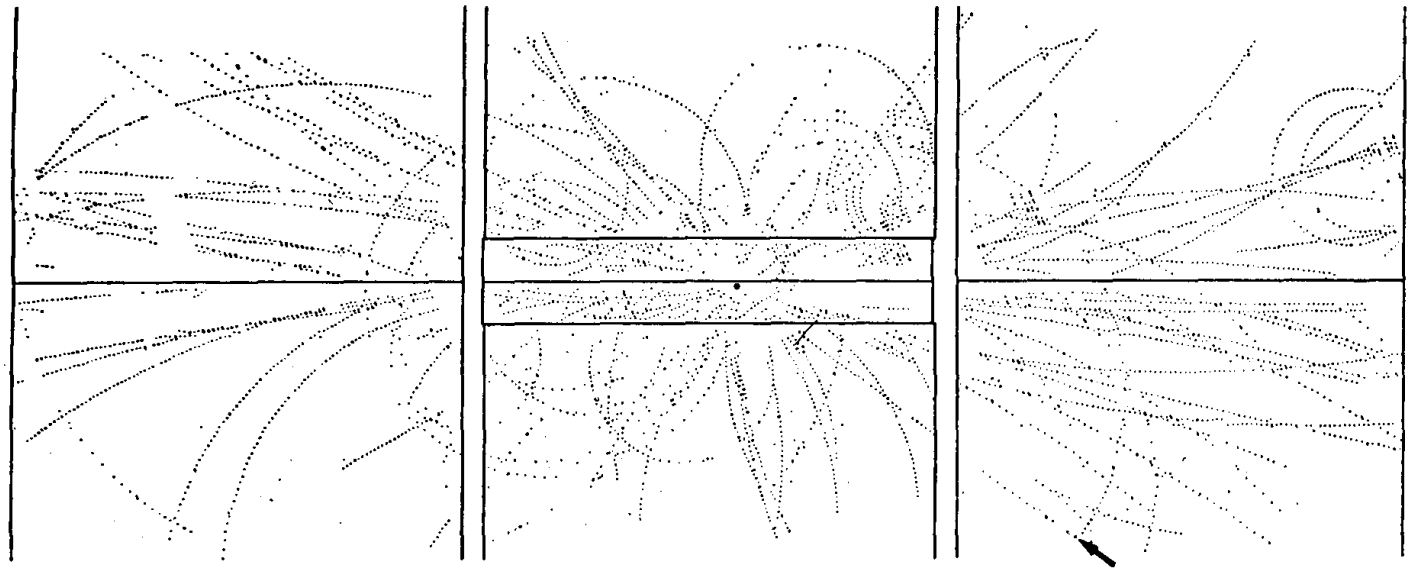
EXPERIMENTAL OBSERVATION OF ISOLATED LARGE TRANSVERSE ENERGY ELECTRONS WITH ASSOCIATED MISSING ENERGY AT $\sqrt{s}$ = 540 GeV

UA1 Collaboration, CERN, Geneva, Switzerland

Volume 122B, number 1 PHYSICS LETTERS 24 February 1983

a

EVENT 2958. 1279.



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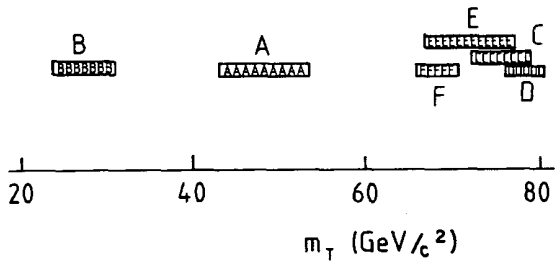
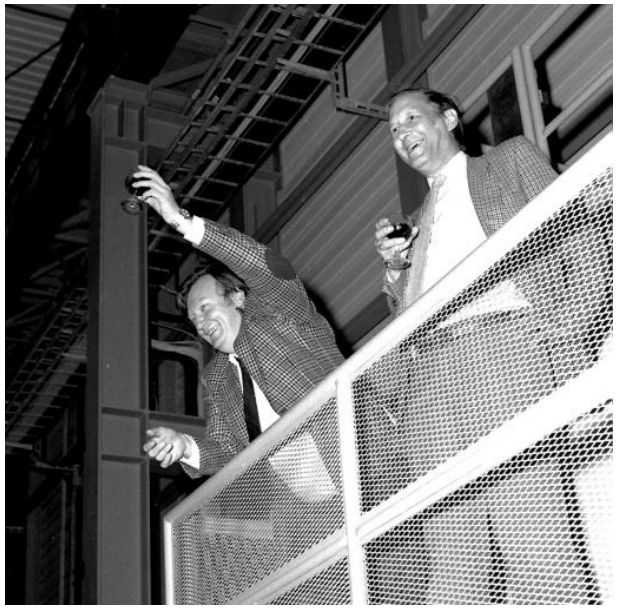
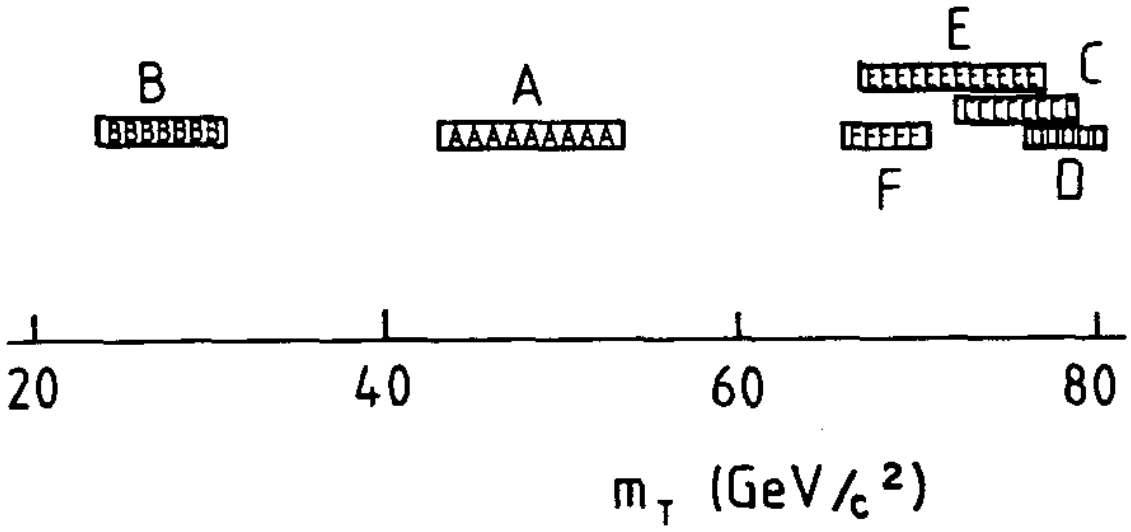


Fig. 9. The distribution of the transverse mass derived from the measured electron and neutrino vectors of the six electron events.



Why is this a discovery?
($B \to X l \nu \ldots$)

The m_T distribution: then



UA1: $m_W = 81 \pm 5$ GeV

Two-body kinematics

$$Y \to X + V$$

$$p_X^2 = m_X^2$$
$$(p_X + p_V)^2 = m_Y^2$$

- For all m_X, m_Y, get solutions with $p_{X,Y} \in \mathbb{C}$
- But momenta $\in \mathbb{R}$
- Energies $\in \mathbb{R}^+$
- An event restricts m_X, m_Y

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Two-body kinematics

Theorem: $m_Y \geq m_T(m_X)$, where

$$m_T^2(m_X) = m_V^2 + m_X^2 + 2(e_V e_X - \mathbf{p}_V \cdot \mathbf{p}_X)$$

- m_T is transverse mass
- $e = \sqrt{\mathbf{p} \cdot \mathbf{p} + m^2}$ is transverse energy

The race for the W

m_T discriminates S and B:

- Signal $W \to l\nu$: large $m_T \sim m_W$
- Background: small m_T
- e.g. $B \to Xl\nu$: $m_T \leq m_B$

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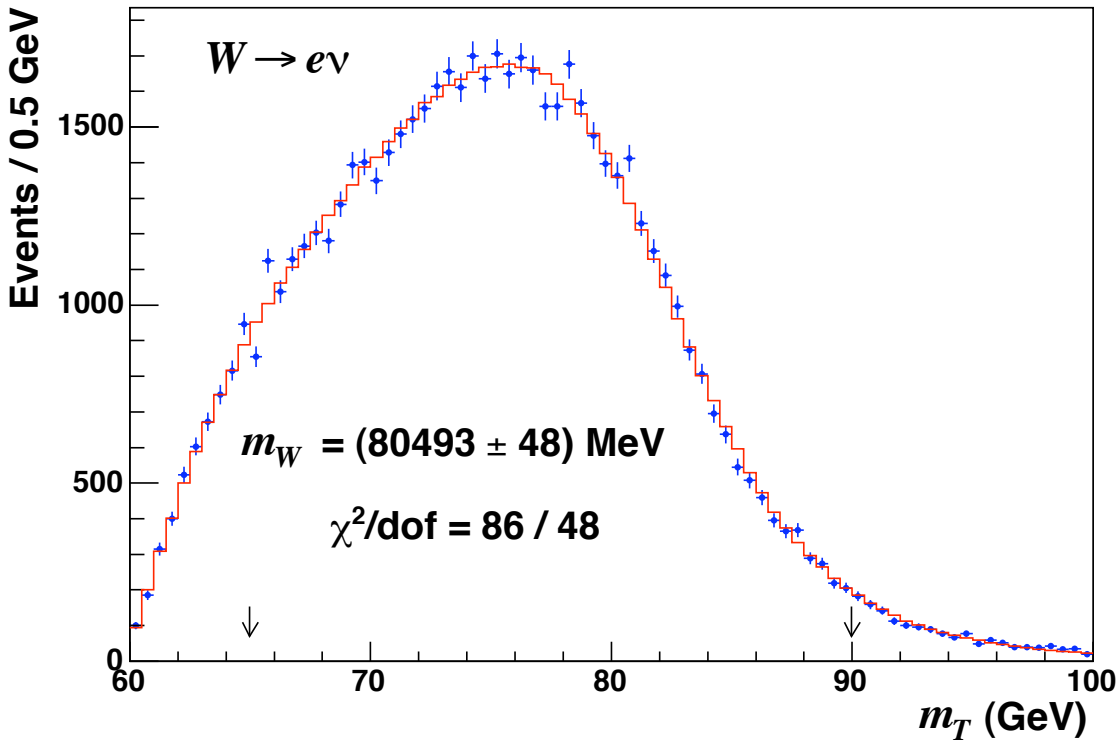

CDF: $m_W = 80.413 \pm 0.048$ GeV

arXiv:0708.3642

SUSY/DM is more problematic: pair production

Pair two-body kinematics

$2Y \to 2X + 2V$

- Another theorem: $m_Y \geq m_{T2}(m_X)$, where

Serna, 0804.3344

Cheng and Han, 0810.5178

Barr, BMG & Lester, 0908.3779

- $m_{T2} = \min\max(m_T, m_T')$

Lester & Summers, 9906349

Barr et al., 0304226

- Partition $\not{p}_T$ between two invisibles
- Take the larger m_T
- Minimize with respect to partitions
- Corollary: $m_Y \geq m_{T2}(m_X) \geq m_{T2}(0)$

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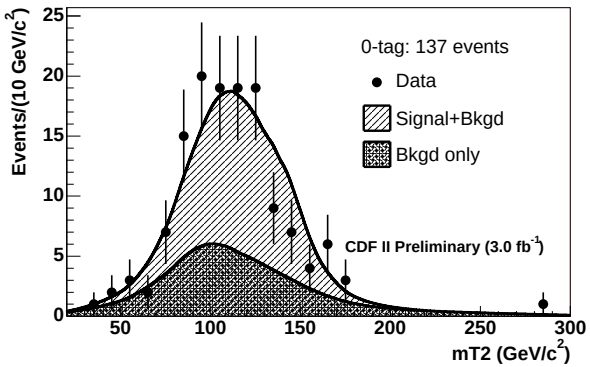
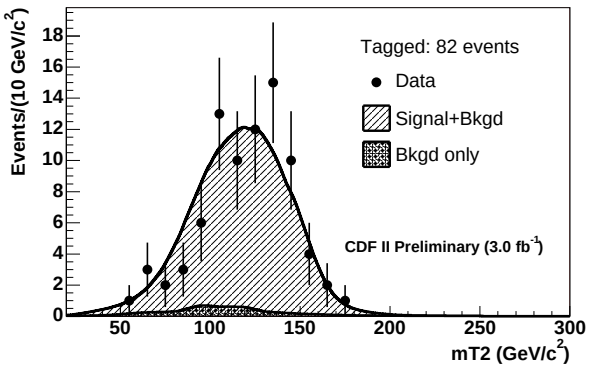
The race for the top

$t\bar{t} \rightarrow 2b2W \rightarrow 2b2l2\nu$

Cho et al. 0804.2185





CDF m_{T2} only: $m_t = 167.9^{+5.6}_{-5.0}$ GeV

CDF note 9769

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The race for supersymmetry

m_{T2} discriminates between S and B:

- Signal: large m_{T2}
- Physics/detector backgrounds: small m_{T2}
- e.g. $t\bar{t}$: $m_{T2} \leq m_t$
- e.g. $\not{\mathbf{p}} \propto \mathbf{p}_j$: $m_{T2} = m_j \sim 0$

Barr & Gwenlan, 0907.2713

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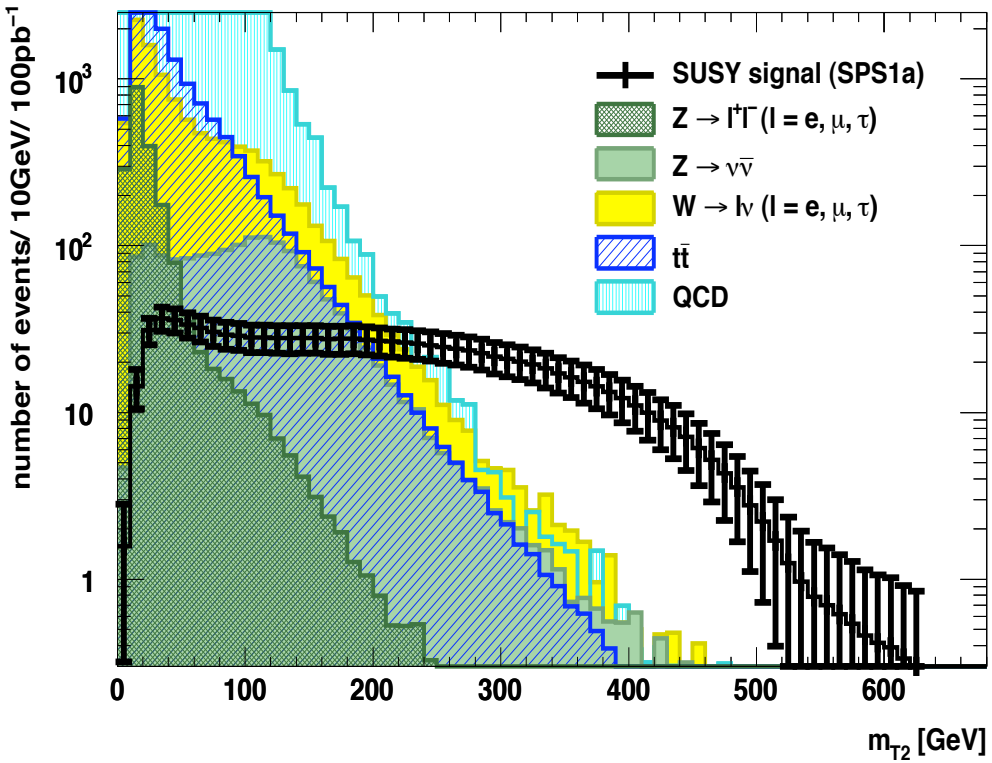
The race for supersymmetry

Single m_{T2} cut discovers SUSY in $2j + \not{E}_T$

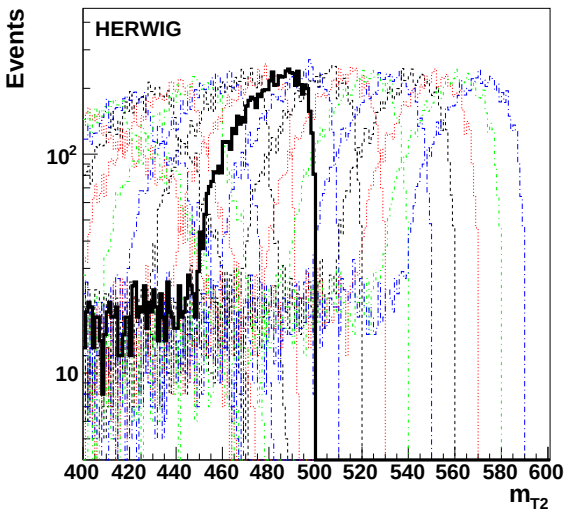


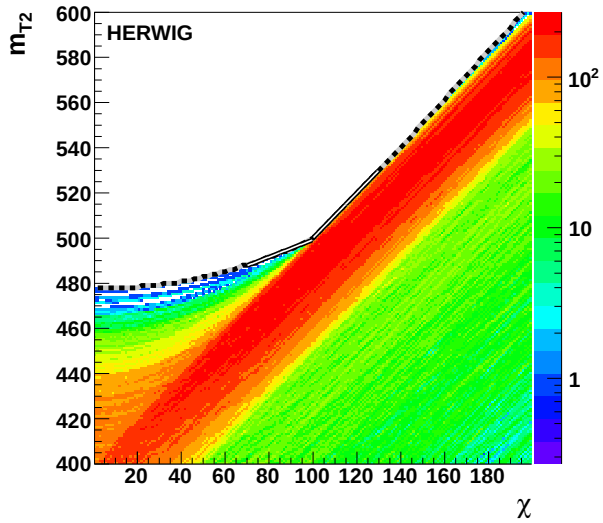
- 100 pb^{-1} of SPS 1a @ 10 TeV
- $m_{T2} > 230 GeV \implies \frac{S}{\sqrt{S+B}} = 15$

Barr & Gwenlan, 0907.2713

Mass measurement

m_{T2} can also measure squark/LSP masses





Cho, Choi et al., 0709.0288

BMG, 0709.2740

Barr, BMG & Lester, 0711.4008

Cho, Choi et al., 0711.4526

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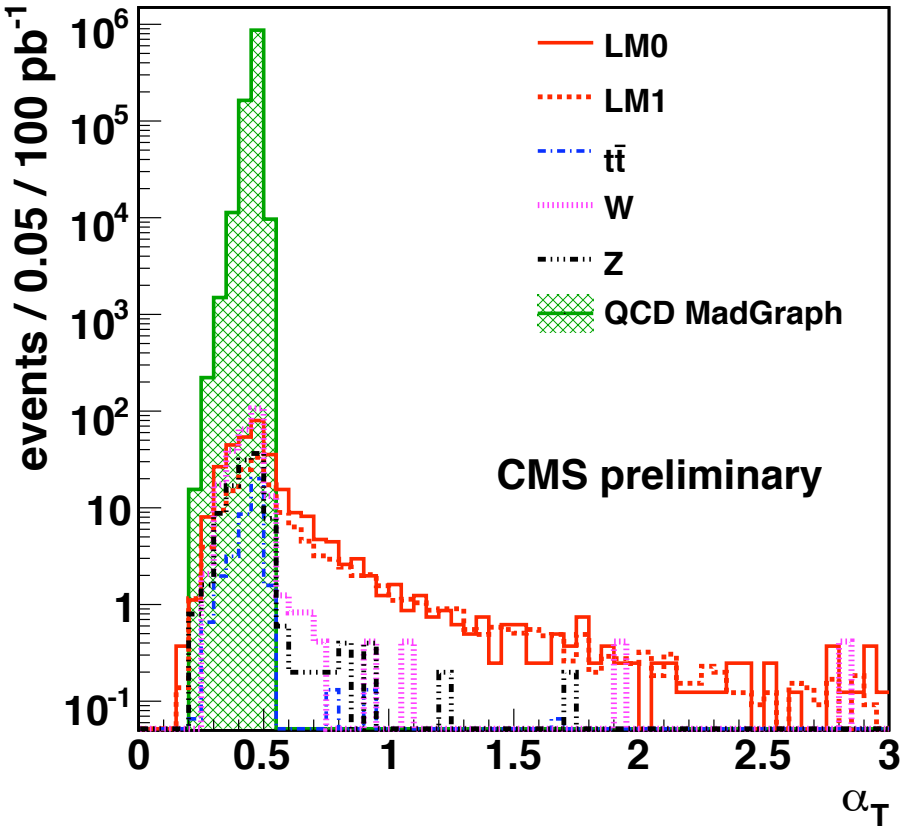
Low mass susy

QCD 2-jet background

- Mis-measured jet
- $\Delta\phi_{12} < \pi$
- $\alpha_{(T)} \equiv \frac{p_2}{m_{(T)12}} > \frac{1}{2}$

Randall & Tucker-Smith, 0806.1049



(a) Distribution of α_T for di-jet events.

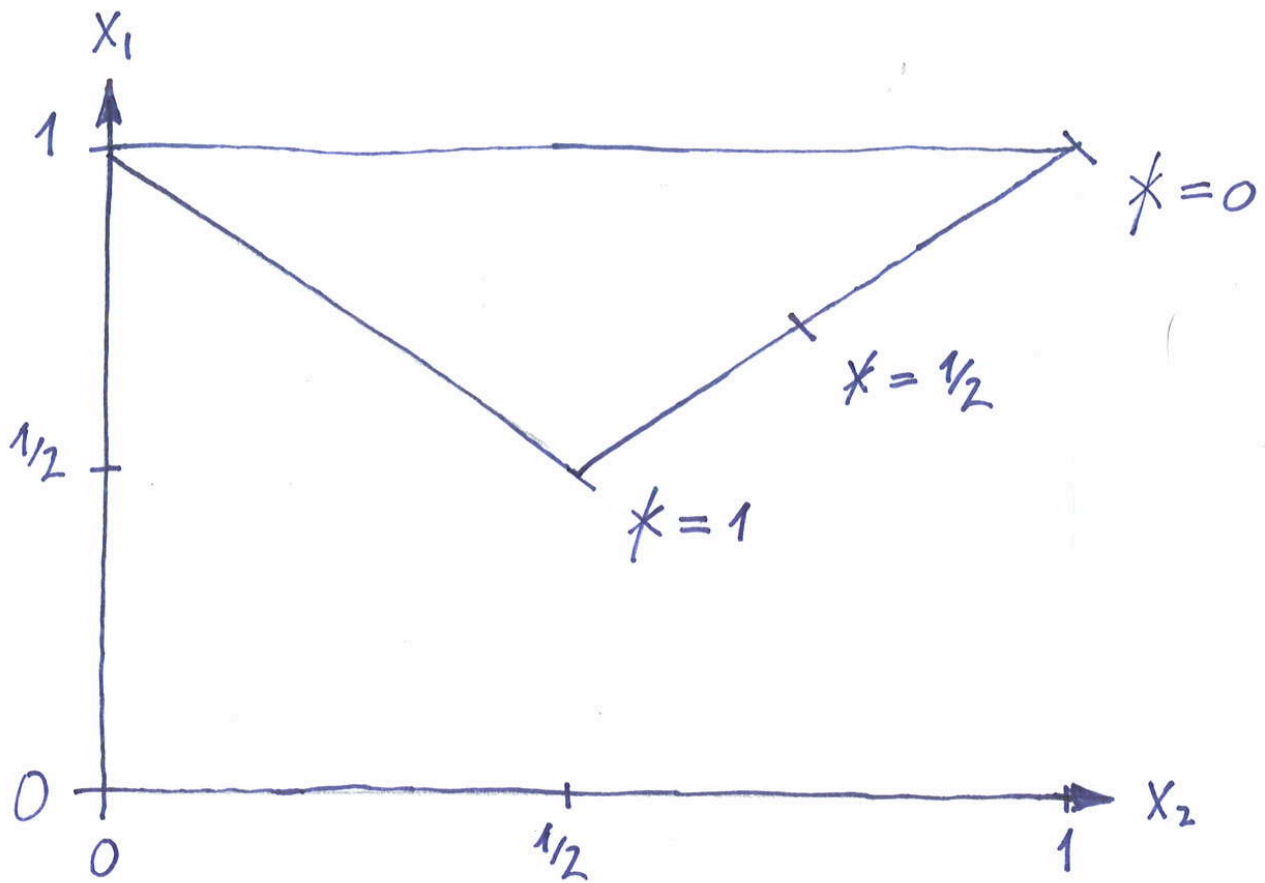
CMS-SUS-09-001-PAS

QCD 3-jet background

$$x_1 \equiv \frac{2p_1}{p_1+p_2+\not{p}}, \qquad x_2 \equiv \frac{2p_2}{p_1+p_2+\not{p}}, \qquad \not{x} \equiv \frac{2\not{p}}{p_1+p_2+\not{p}}$$

$$\Longrightarrow \; x_1 + x_2 + \not{x} = 2$$

Ellis, Gaillard & Ross, 1976



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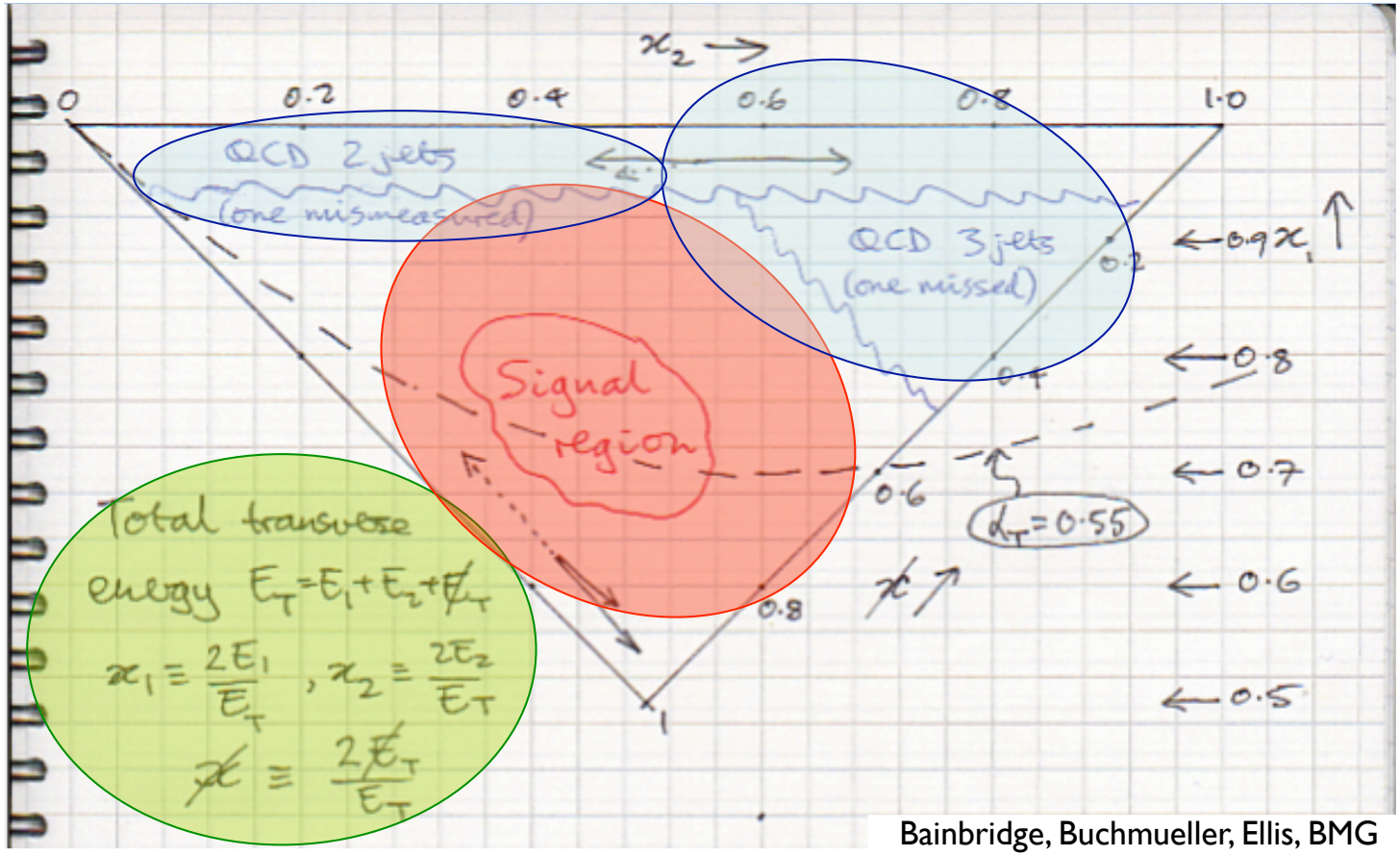

Bainbridge, Buchmueller, Ellis, BMG

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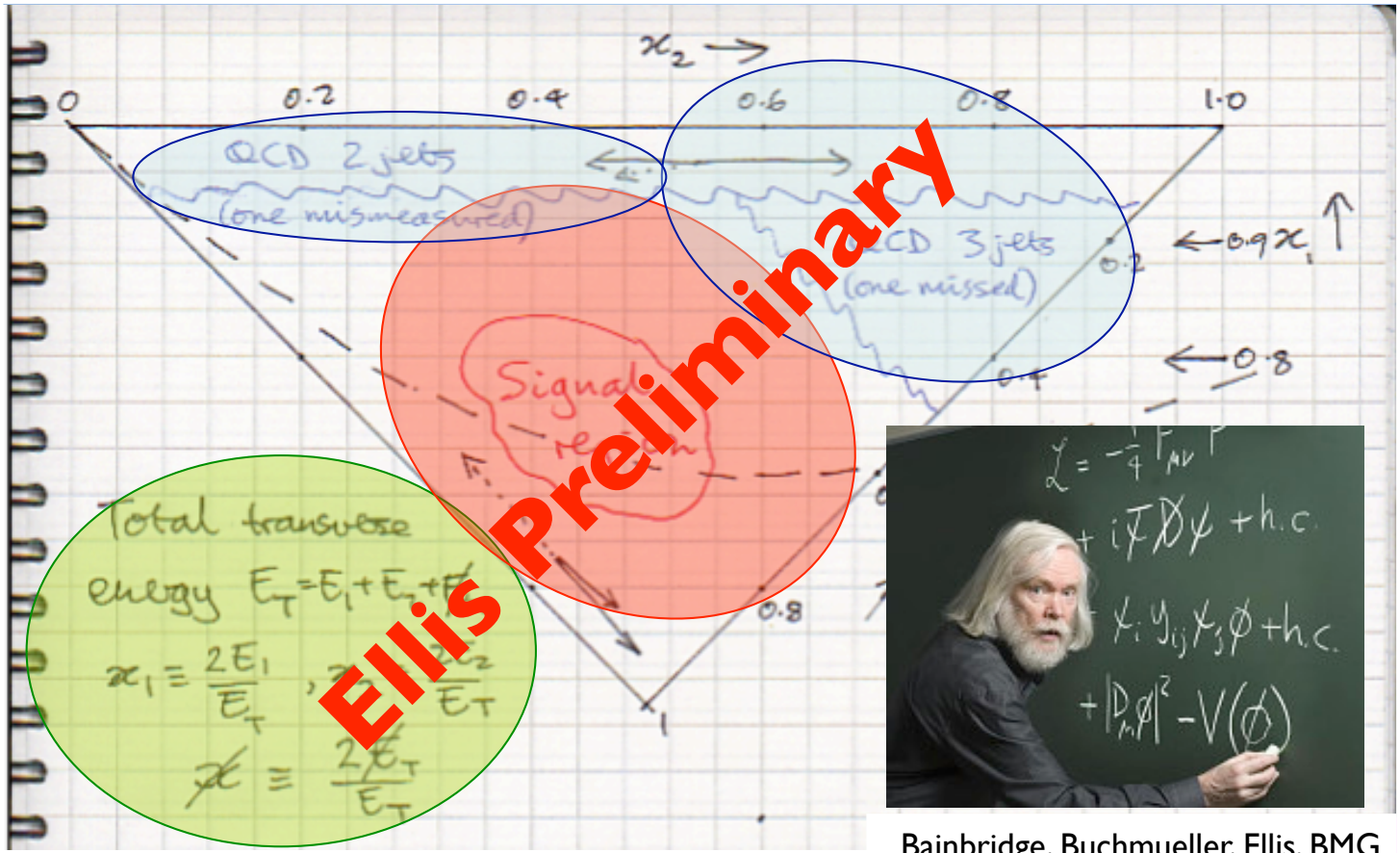

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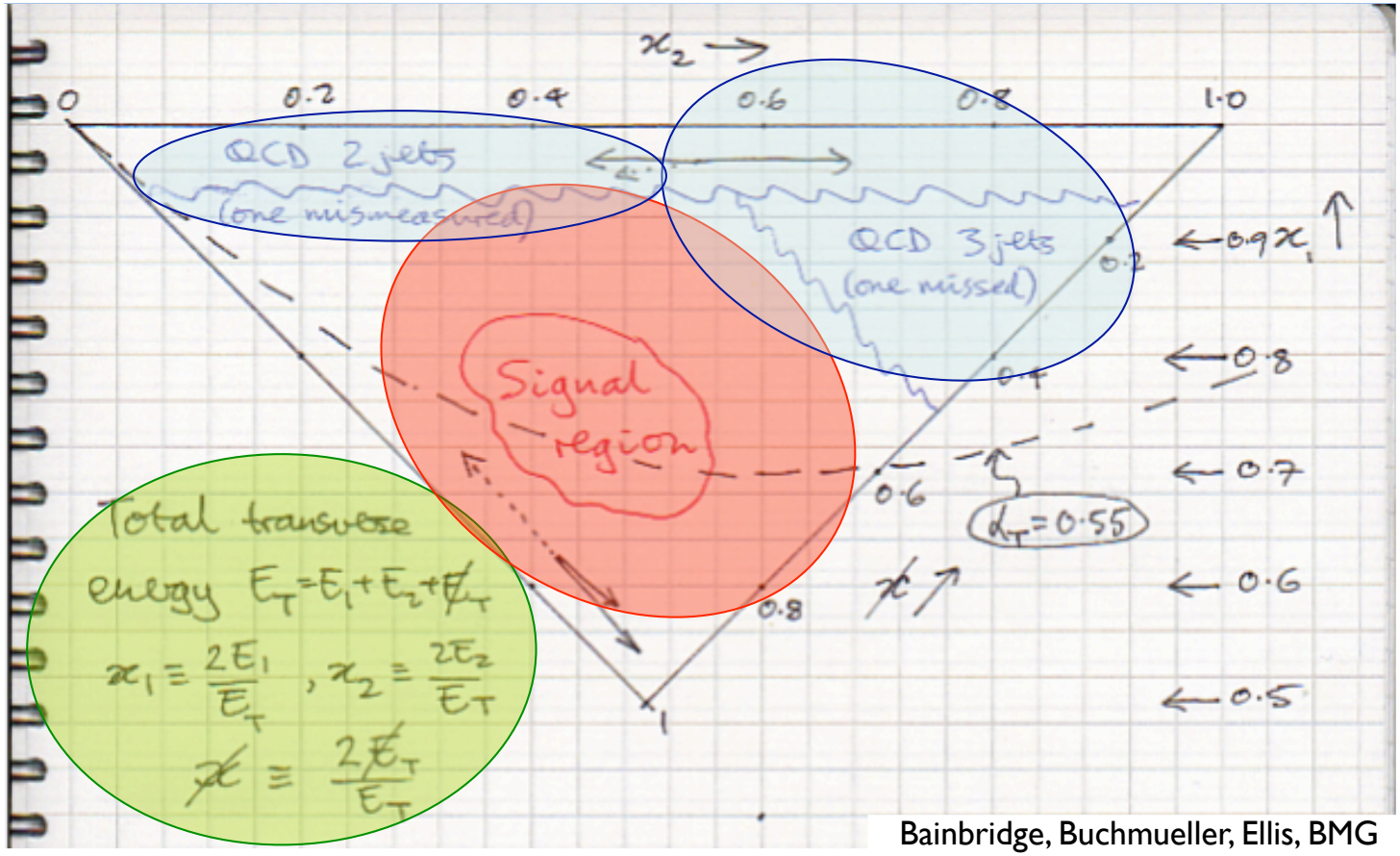

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Summary

- Minimize cuts
- Motivate cuts
- High/low mass regions