Colored States

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SLAC

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Aspen Winter Conference

work in progress with
S. Rajendran, M. Lisanti
and completed work with
S. Dimopoulos, A. Pierce S. Rajendran, A. Arvanitaki

Outline

* Motivations
* non-mSugra Gluinos
* Long Lived Gluinos
* Outlook

LHC

Can produce new colored particles to 3 TeV

Many signatures

LHC

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Many signatures

$$Nj$$

$$Nj + \not{E}_T$$

$$Nj + \not{E}_T + W^{\pm}, Z^0$$

$$Nj + \not{E}_T + \ell^{\pm}\ell^{\pm}$$

$$Nj + \not{E}_T + \gamma$$

LHC

Can produce new colored particles to 3 TeV

Many signatures

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$$Nj + \not{E}_T + \gamma$$

Difficult to make sure that all
new physics is being looked for

MSSM has sense of generality

Has particles of all gauge and flavor quantum numbers

Reasonably useful to extensively explore this model for discovery signals

(TeV-scale Extra Dimensions also general framework for searching for collider signals)

mSugra/CMSSM

Not generic and restricting to the
5 parameters could be dangerous

can give very model dependent correlations

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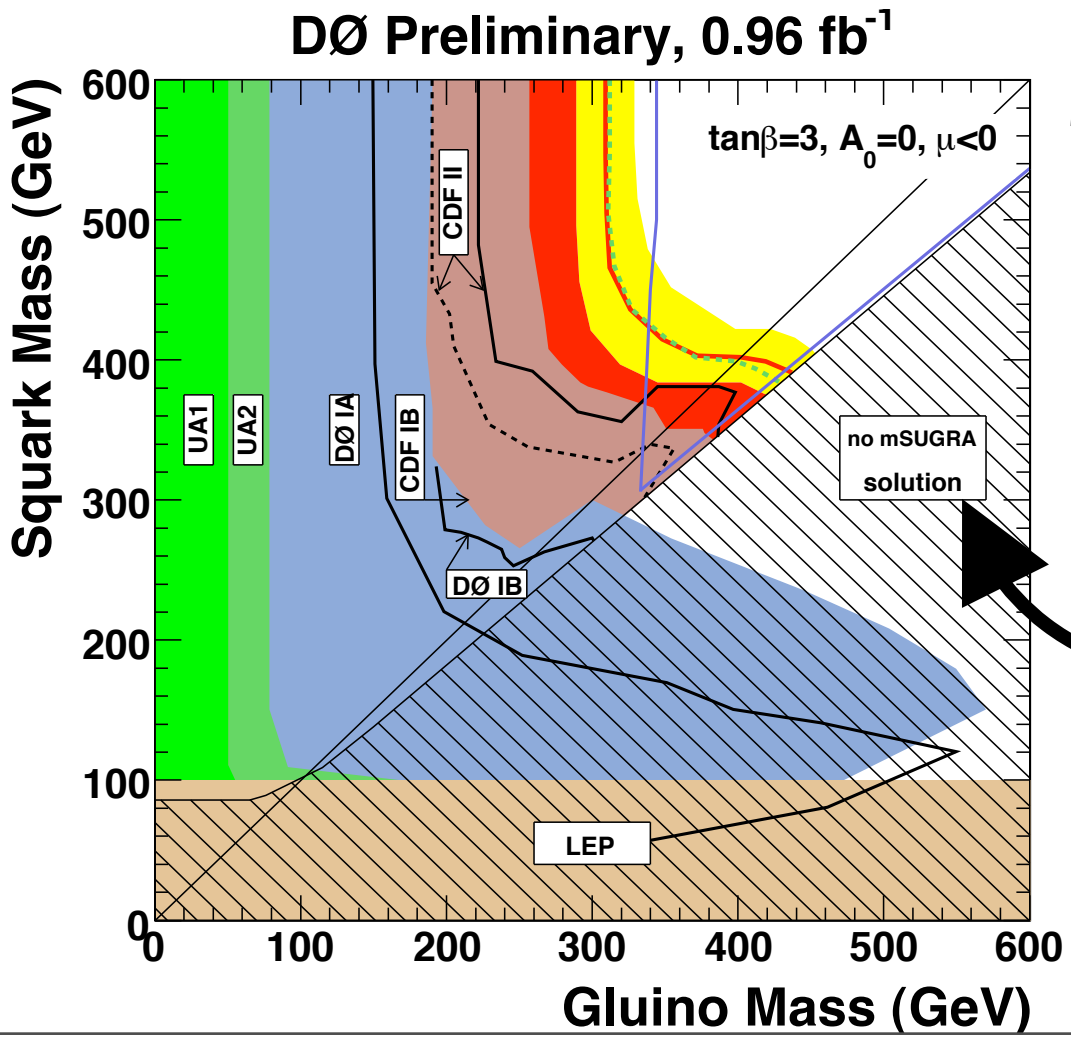

Theory trumping searches!?

Split Susy

Different direction in MSSM parameter space from mSugra

Make sure all signals are being searched for

Split Susy

Arkani-Hamed & Dimopoulos hep-th/0405159
Giudice & Romanino hep-ph/0406088
Wells hep-ph/0306127

$M_{\mathrm{Pl.}}$ 10^{16} TeV

M_{susy}
M_{weak} 1 TeV

M_{CC} 10^{-15} TeV

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(Squarks, sleptons, ...)

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Chiral symmetry

Fermions
(Higgsinos, gauginos)

Fine tuned

SM Higgs

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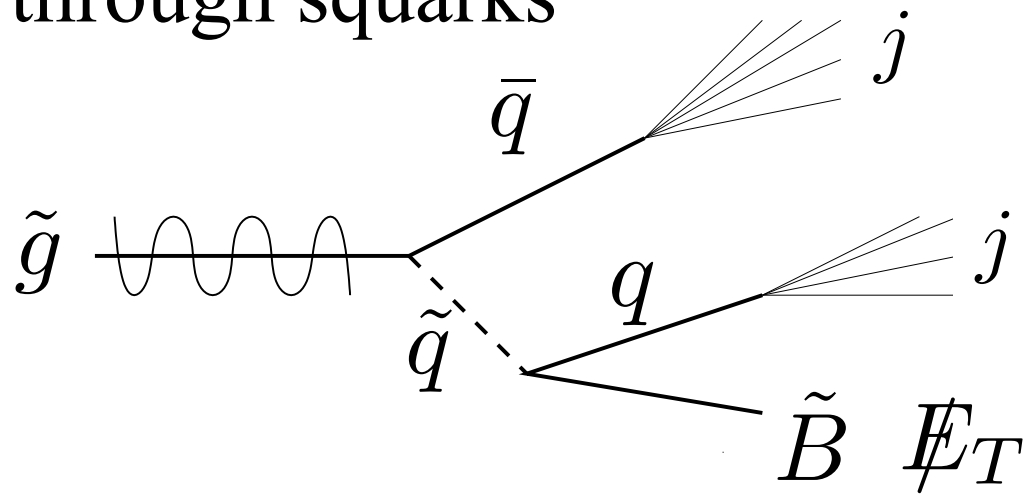
Dark Matter + Unification

Long Lived Gluinos

Must decay through squarks



$$\tau_{\tilde{g}} \simeq 2 \text{ sec.} \left(\frac{350 \text{ GeV}}{m_{\tilde{g}}} \right)^5 \left(\frac{M_{\text{Susy}}}{10^6 \text{ TeV}} \right)^4$$

Lifetime varies from prompt decays to the age of the universe

Other Split Susy Couplings

Higgs Quartic

$$\lambda|H|^4 - m^2|H|^2$$

$$\lambda(M_s) = \frac{1}{8}\left(g^2 + g'^2\right)\cos^2 2\beta$$

Gaugino Yukawas

$$\kappa_u H \widetilde{H}_u \widetilde{W} + \kappa_d H^\dagger \widetilde{H}_d \widetilde{W}$$
$$\kappa'_u H \widetilde{H}_u \widetilde{B} + \kappa'_d H^\dagger \widetilde{H}_d \widetilde{B}$$

$$\kappa_u(M_s) = g \sin\beta$$
$$\kappa_d(M_s) = g \cos\beta$$

Run from M_s to weak scale

Gluino lifetime measures M_s

Split Susy "mSugra"

Unified BCs for gauginos

$$m_1 = m_2 = m_3 = m_{\frac{1}{2}} \Big|_{M_{\mathrm{GUT}}}$$

$$\mu$$

$$M_S \qquad \tan\beta \qquad \phi$$

Split Susy "mSugra"

Unified BCs for gauginos

$$m_1 = m_2 = m_3 = m_{\frac{1}{2}} \Big|_{M_{\rm GUT}}$$

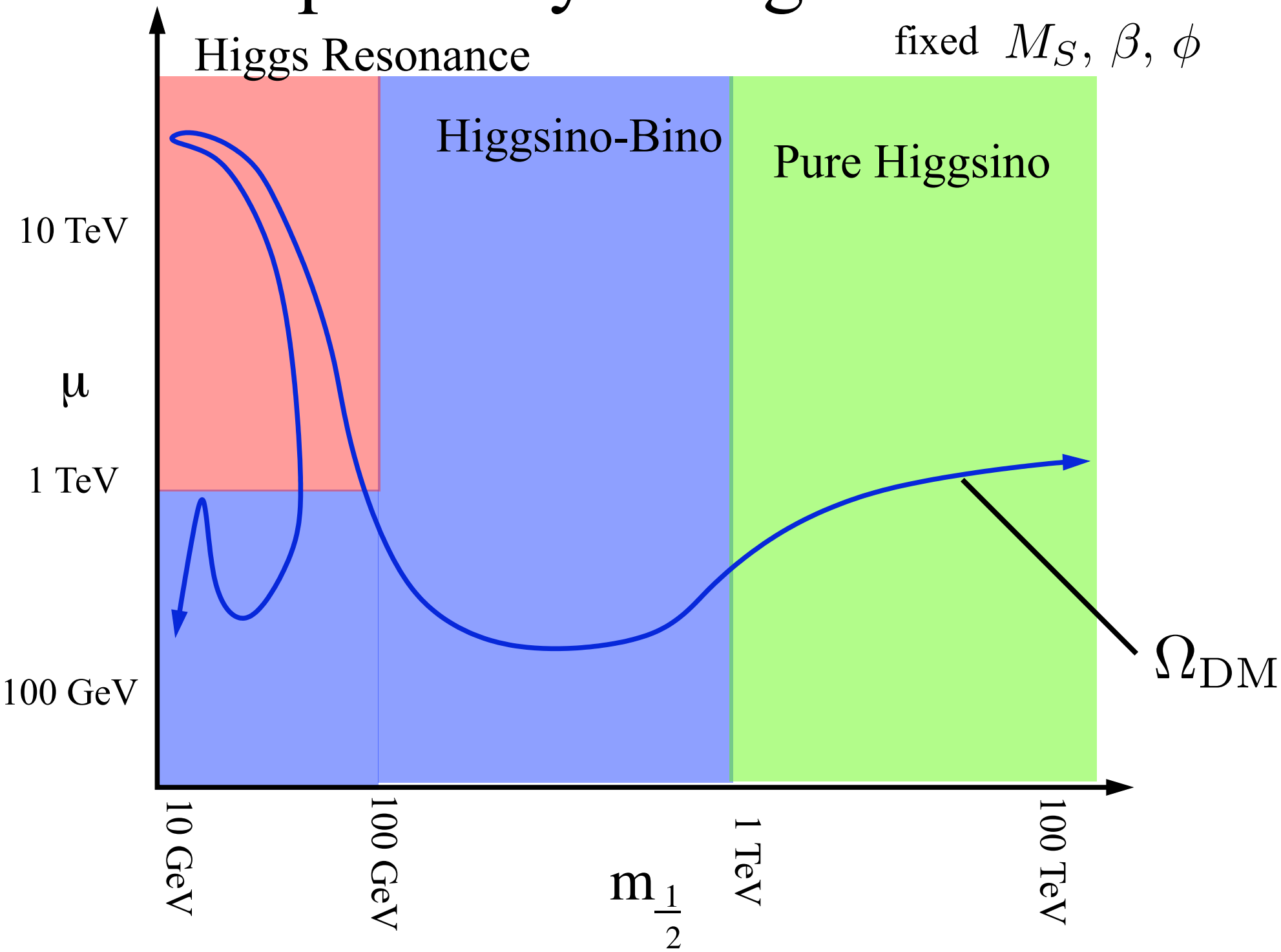
$$\mu$$

$$M_S \qquad \tan\beta \qquad \phi$$

The correct amount of dark matter fixes a line through parameter space

$$m_{\frac{1}{2}} \text{ vs } \mu$$

Split Susy mSugra



Split Susy vs MSSM Running

$$\frac{dm_1}{dt} \sim g_1^2 m_1$$

$$\frac{dm_2}{dt} \sim g_2^2 m_2$$

$$\frac{dm_3}{dt} \sim g_3^2 m_3$$

$$m_1 : m_2 : m_3$$

$$1 : 2 : 7$$

Split Susy vs MSSM Running

$$\frac{dm_1}{dt} \sim g_1^2 m_1 + g_1^2 \mu$$

$$\frac{dm_2}{dt} \sim g_2^2 m_2 + g_2^2 \mu$$

$$\frac{dm_3}{dt} \sim g_3^2 m_3$$

$$m_1 : m_2 : m_3$$

$$1 : 3 : 9$$

Split Susy vs MSSM Running

$$\frac{dm_1}{dt} \sim g_1^2 m_1 + g_1^2 \mu$$

$$\frac{dm_2}{dt} \sim g_2^2 m_2 + g_2^2 \mu$$

$$\frac{dm_3}{dt} \sim g_3^2 m_3$$

$$m_1 : m_2 : m_3$$

$$1 : 3 : 1$$

Split Susy vs MSSM Running

$$\frac{dm_1}{dt} \sim g_1^2 m_1 + g_1^2 \mu$$

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$$m_1 : m_2 : m_3$$

$$1 : 3 : 1$$

Gluino can be degenerate with Bino!

Split Susy vs MSSM Running

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$$\frac{dm_2}{dt} \sim g_2^2 m_2 + g_2^2 \mu$$

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$$m_1 : m_2 : m_3$$

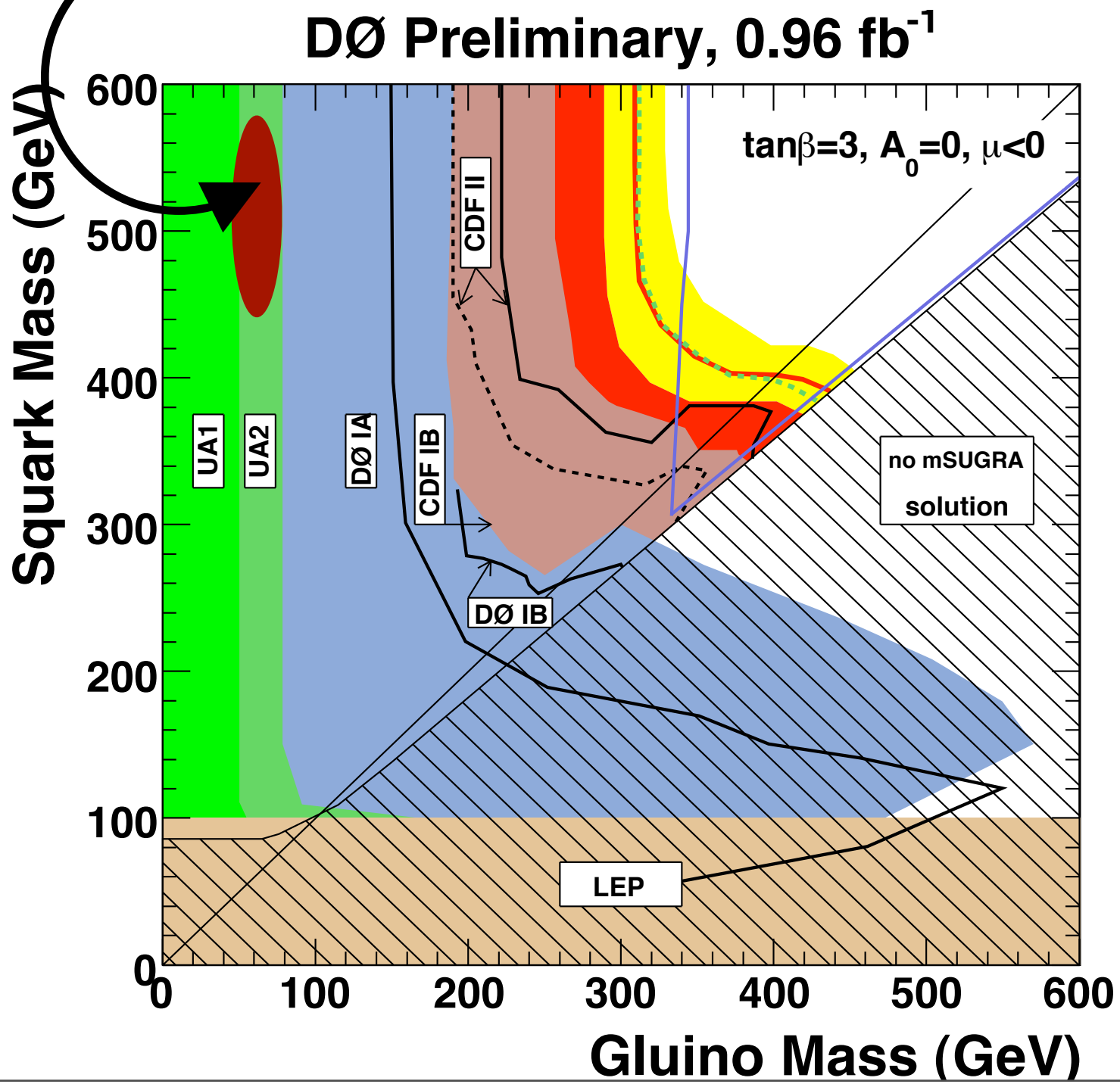
$$1 : 3 : 1$$

Gluino can be degenerate with Bino!

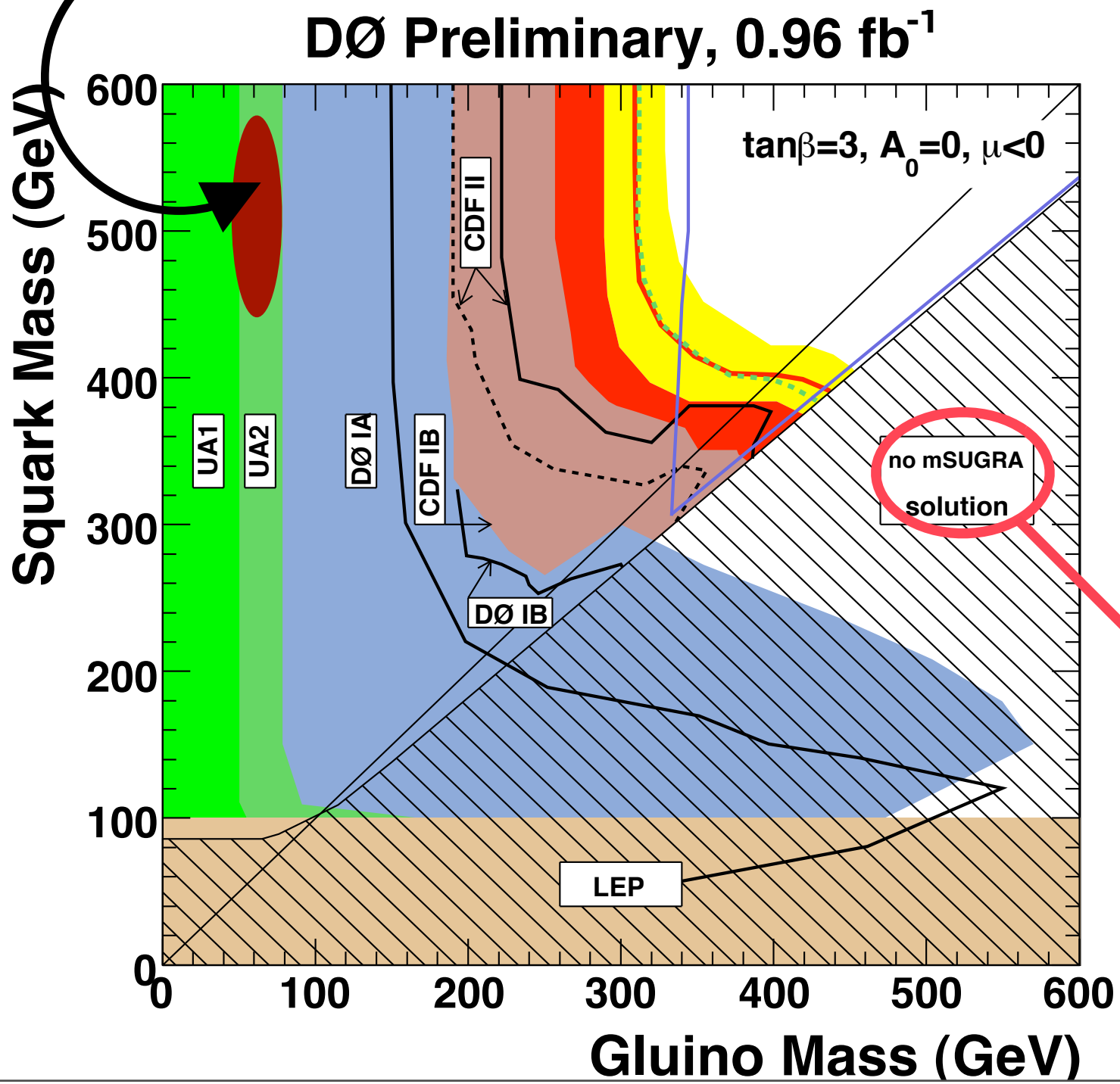
Extreme benchmark
with prompt gluino decays

$$m_{\tilde{g}} = 70 \text{ GeV}$$
$$m_{\tilde{B}} = 60 \text{ GeV}$$

70 GeV Gluinos!??



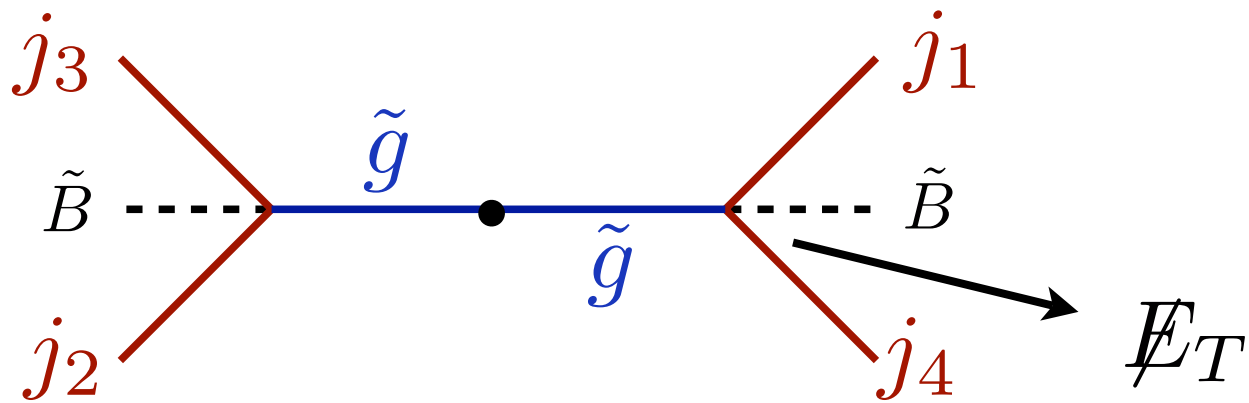
70 GeV Gluinos!??



$$m_1 = \frac{1}{7} m_3$$

Existing Searches

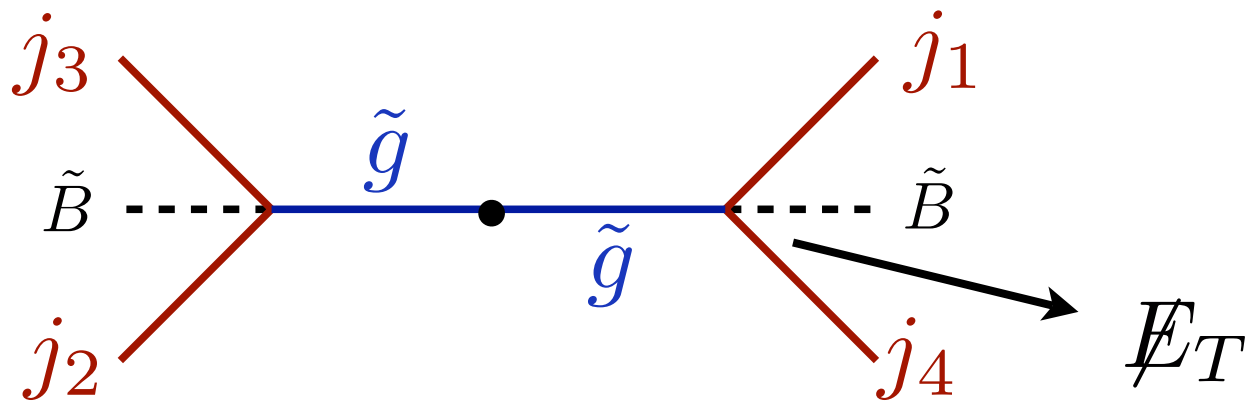
Multijet + MET



Useful when not phase space limited $Q = m_{\tilde{g}} - m_{\tilde{B}} > m_{\tilde{B}}$

Existing Searches

Multijet + MET



Useful when not phase space limited $Q = m_{\tilde{g}} - m_{\tilde{B}} > m_{\tilde{B}}$

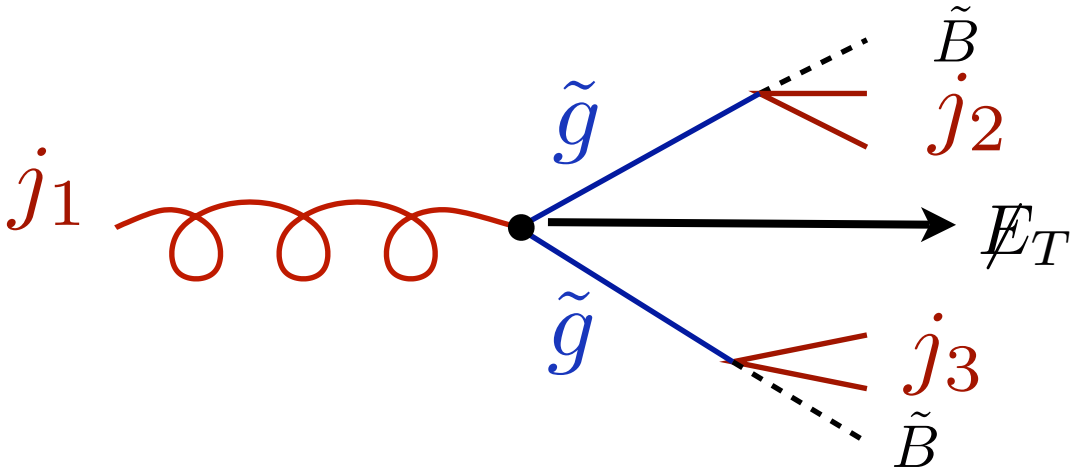
If $Q < m_{\tilde{B}}$

Bino carries away energy but not momentum $\not{E}_T \sim \frac{Q^2}{m_{\tilde{B}}}$

As gluinos get boosted, jets become collinear and $\not{E}_T$ aligned with jets $\Delta\Phi^{j\,\not{E}_T} \sim \frac{1}{\gamma_{\tilde{g}}}$

Existing Searches

Multijet + MET



D0

$P_T^{j1}, P_T^{j2}, P_T^{j3} > 35$ GeV

$H_T > 400$ GeV

$\not{E}_T > 75$ GeV

$\Delta\Phi^{j_1 \not{E}_T} > 90^\circ$

$\Delta\Phi^{j_2 \not{E}_T} > 50^\circ$

CDF

$P_T^{j1}, P_T^{j2}, P_T^{j3} > 25$ GeV

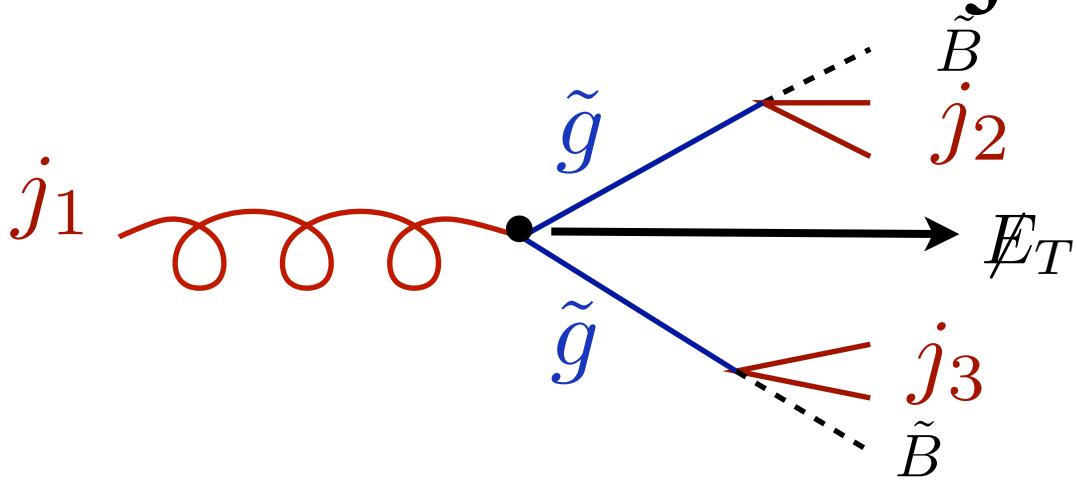
$\not{E}_T > 70$ GeV

$\Delta\Phi^{j_i \not{E}_T} > 0.7$

Benchmark usually fails kinematic/isolation cuts

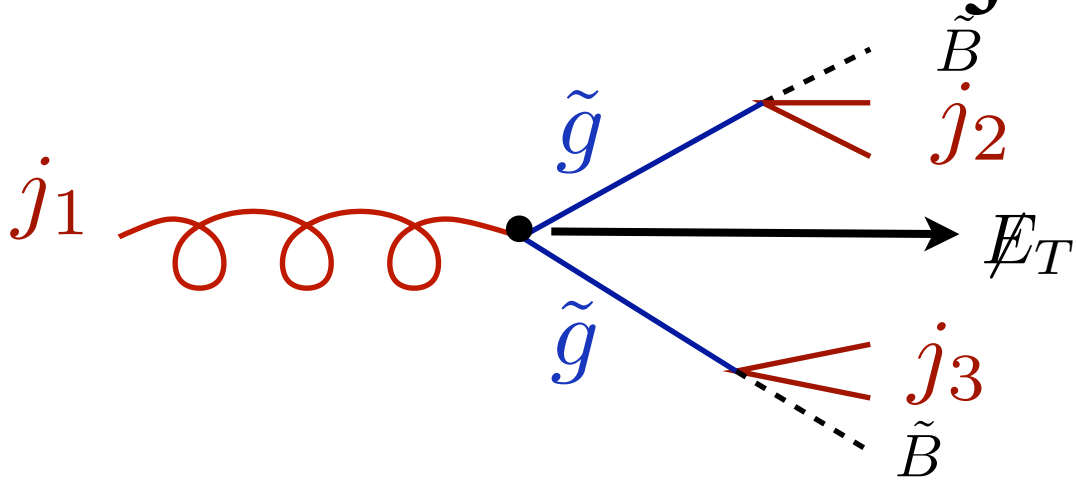
Existing Searches

Monojet + MET



Existing Searches

Monojet + MET



CDF

$P_T^{j1} > 150$ GeV

$P_T^{j2} < 60$ GeV

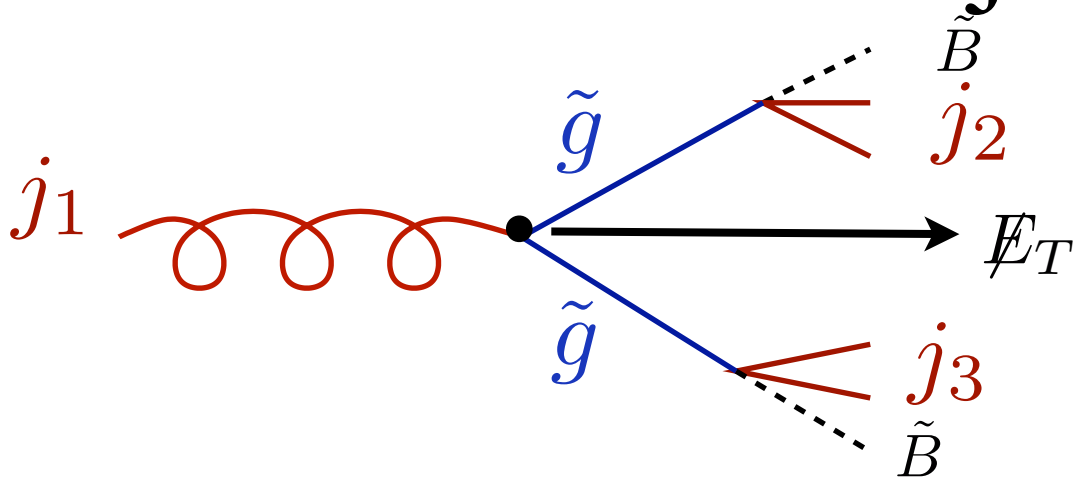
$P_T^{j3} < 20$ GeV

$\not{E}_T > 120$ GeV

$\Delta\Phi^{j2\not{E}_T} > 0.3$

Existing Searches

Monojet + MET



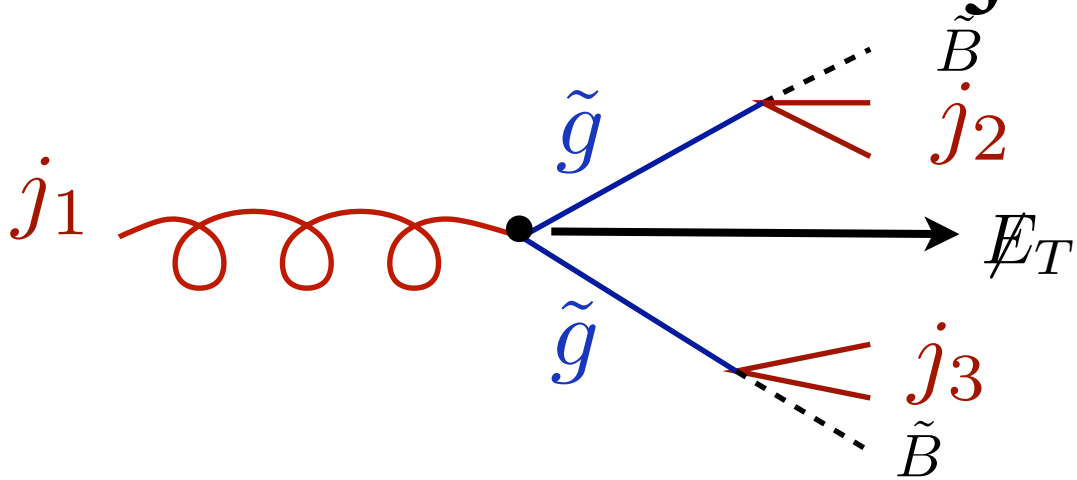
D0

$P_T^{j1} > 150$ GeV $\quad \not{E}_T > 150$ GeV

$P_T^{j2} < 50$ GeV $\quad \Delta\Phi^{j\not{E}_T} > 30°$

Existing Searches

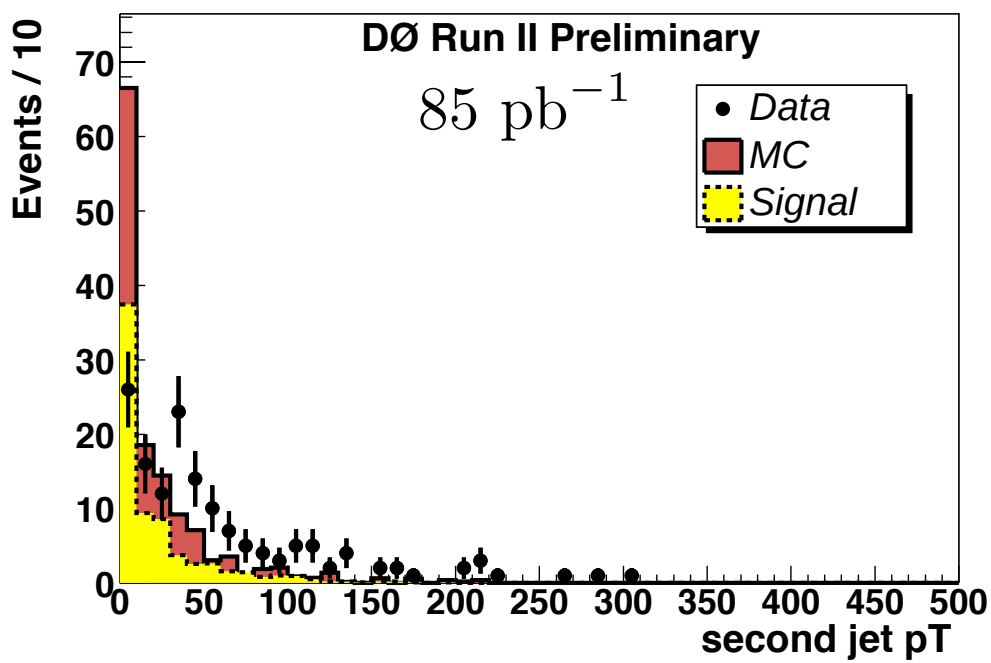
Monojet + MET



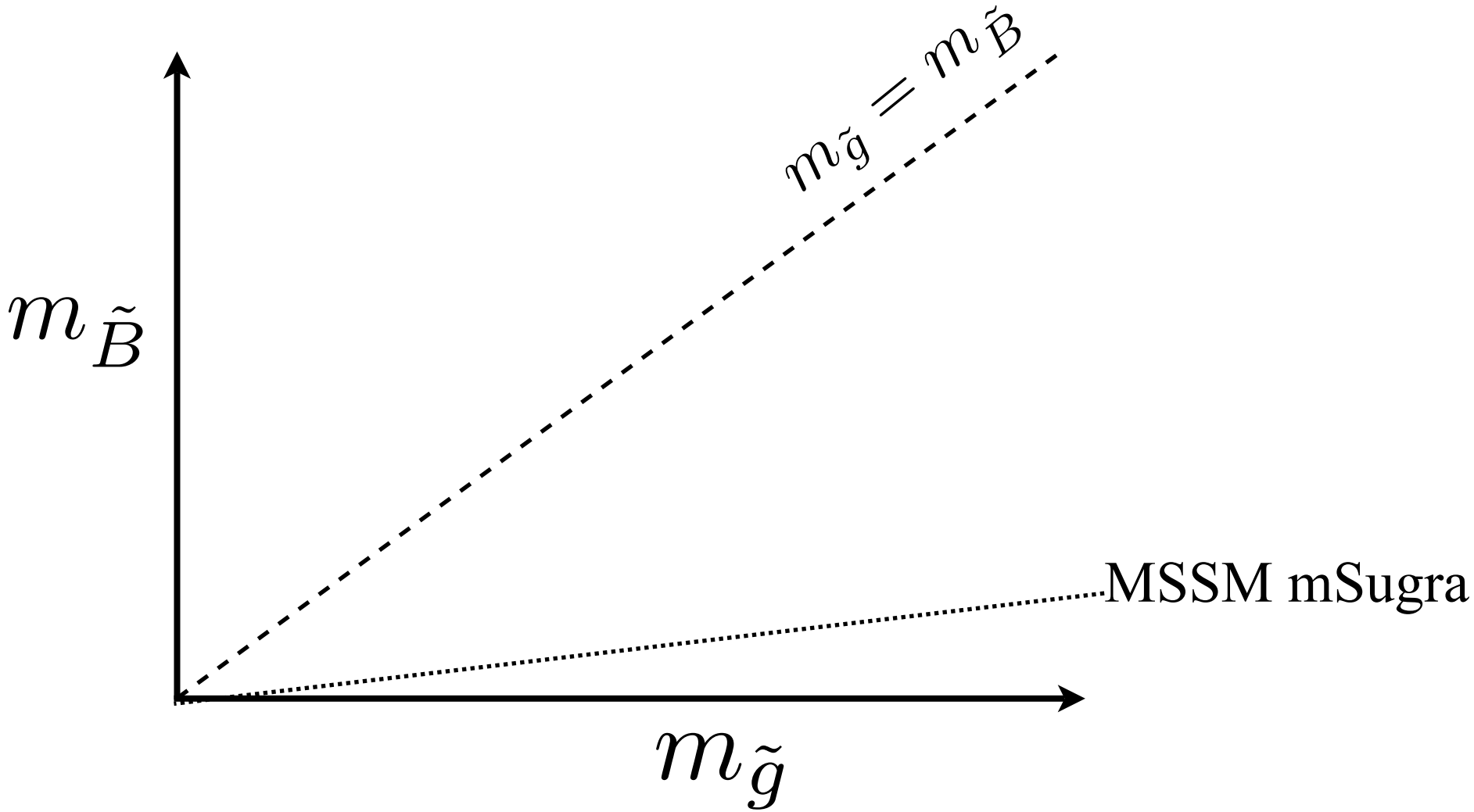
D0

$$P_T^{j1} > 150 \text{ GeV} \qquad \not{E}_T > 150 \text{ GeV}$$

$$P_T^{j2} < 50 \text{ GeV} \qquad \Delta\Phi^{j\not{E}_T} > 30^\circ$$



Motivates Bino vs Gluino Plot



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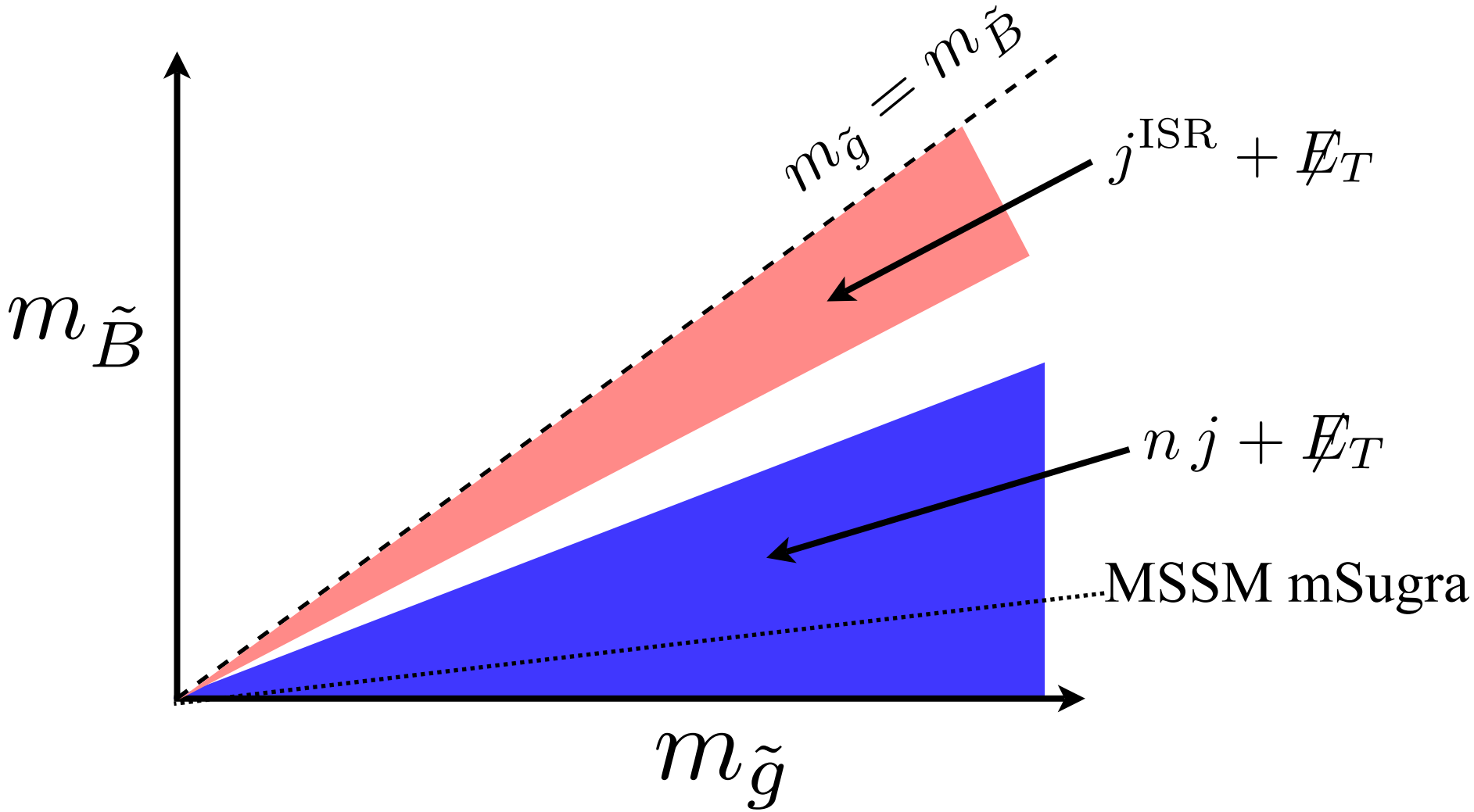

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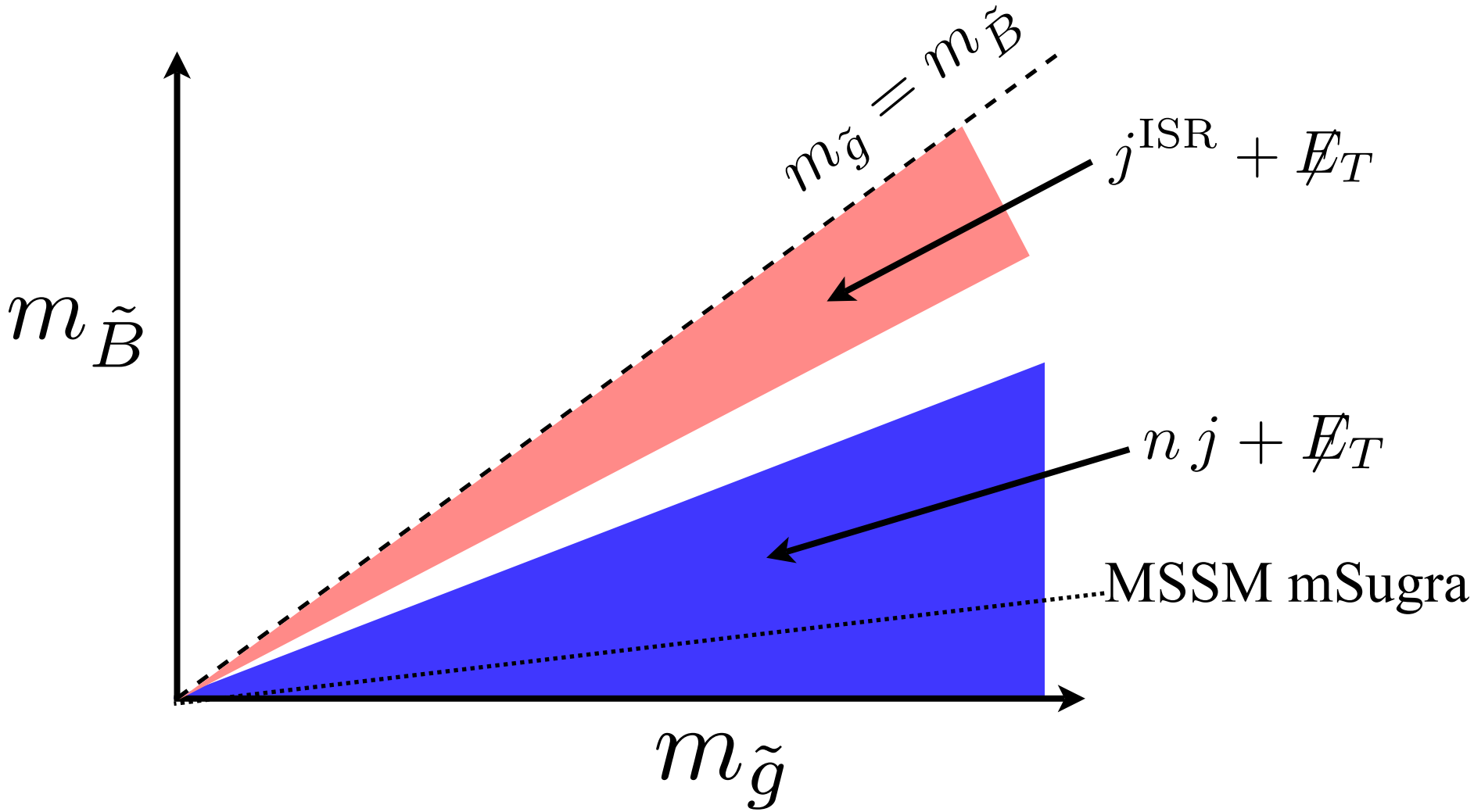
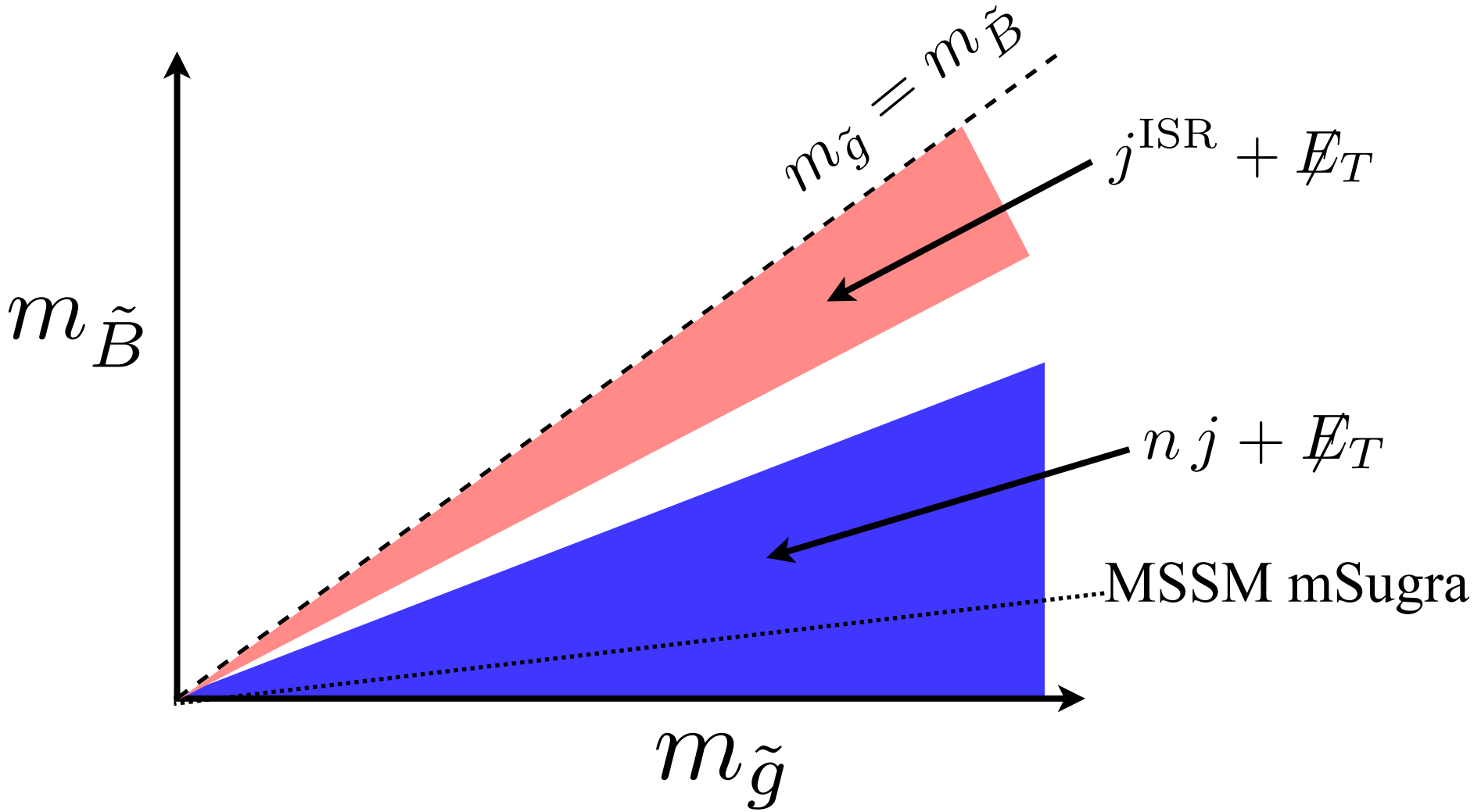


very general: $\mathbf{8}^{\rm new} \to q + \bar{q} + \mathbf{1}^{\rm new}_{\rm stable}$

Motivates Bino vs Gluino Plot



very general: $\mathbf{8}^{\rm new} \to q + \bar{q} + \mathbf{1}^{\rm new}_{\rm stable}$

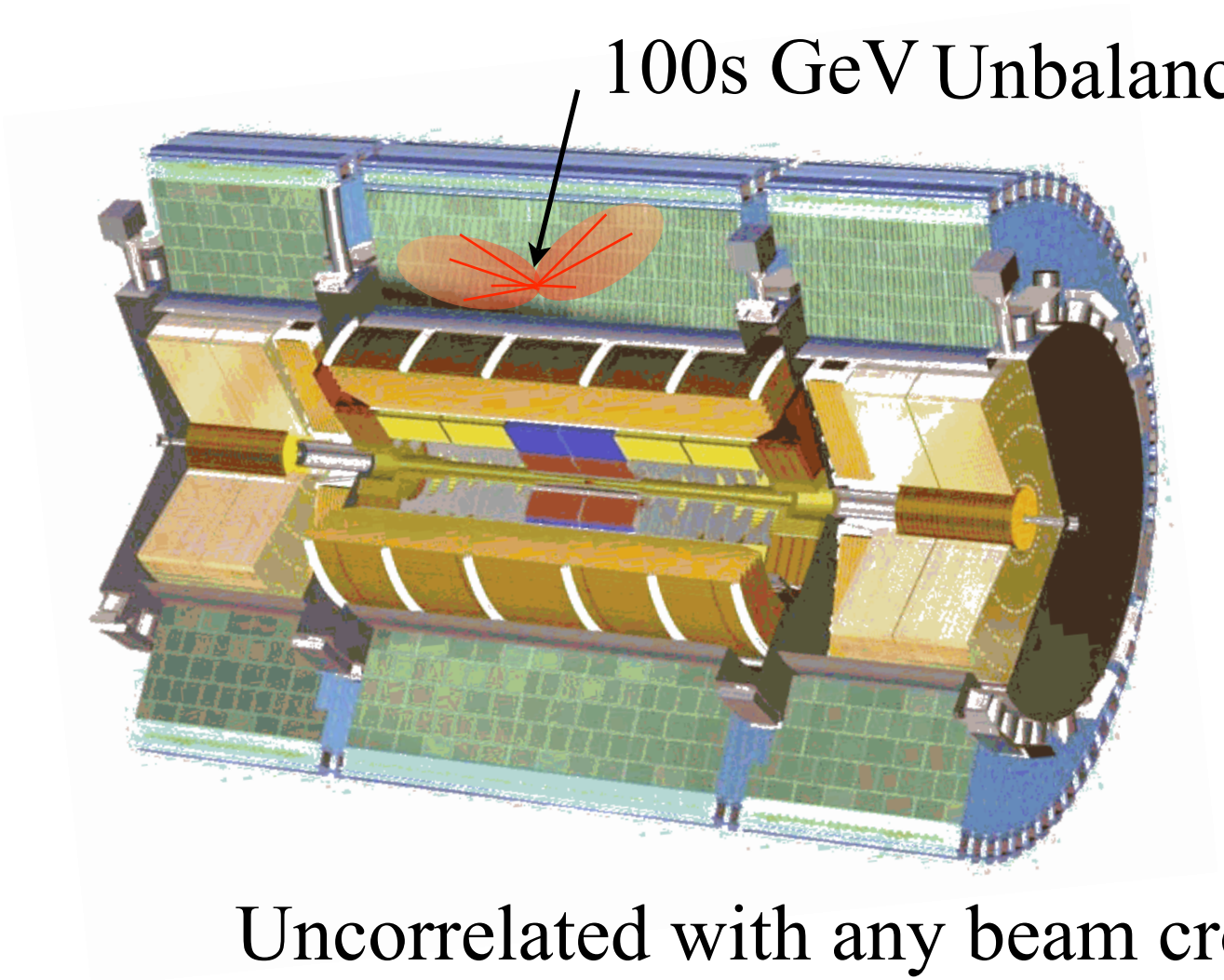
also should do: $\mathbf{3}^{\rm new} \to q + \mathbf{1}^{\rm new}_{\rm stable}$

Long Lived Gluinos

$\tau_{\tilde{g}} > 100$ ns

looking for stopped gluinos that later decay

100s GeV Unbalanced $= \not{E}_T$



Uncorrelated with any beam crossing

No tracks going to or from activity

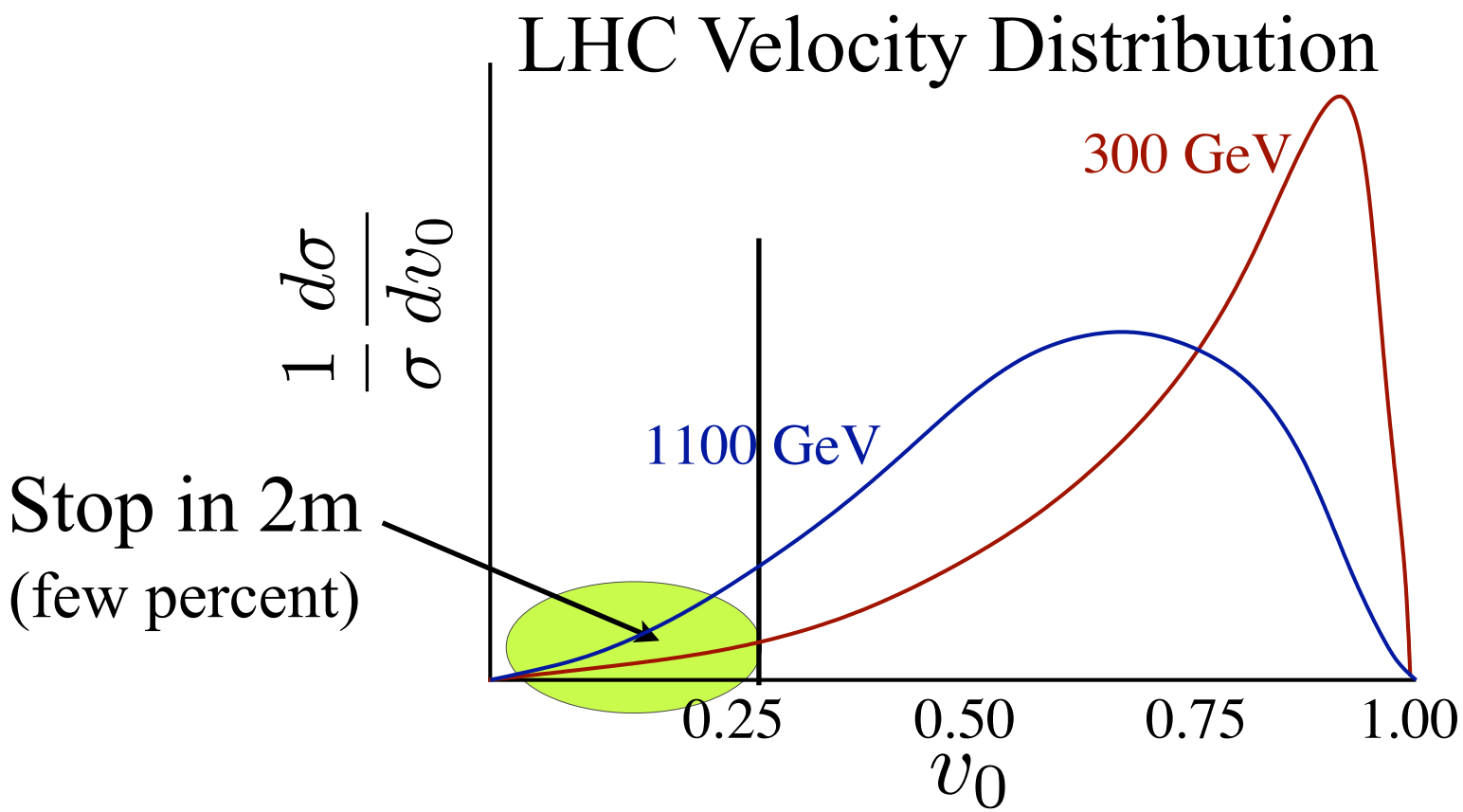
Stopping of Charged Particle

Bethe-Bloch $$\frac{dv}{dx} \simeq \frac{1}{x_0 v^3}$$

$$x_0 \simeq 500 \text{ m} \left(\frac{m_{\tilde{g}}}{500 \text{ GeV}}\right)$$

$$x_{\text{stop}} = \frac{1}{4} v_0^4 x_0$$

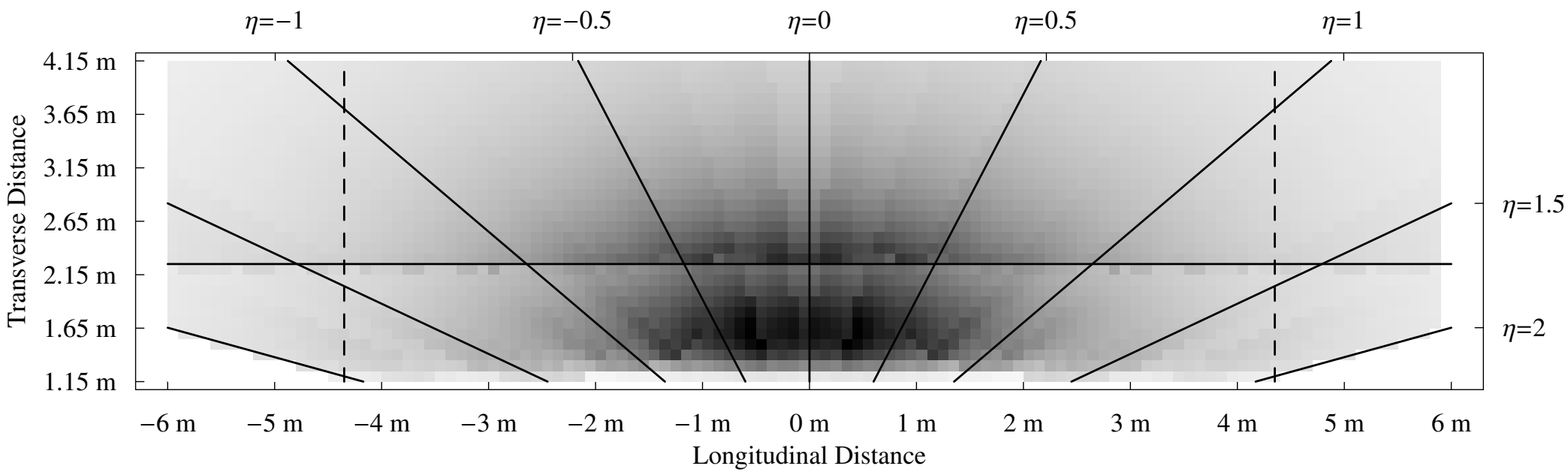
for $x_{\text{stop}} = 2\text{m}$ $\quad v_0 = 0.3$



Density of Stopped Gluinos

300 GeV gluino

Atlas Detector



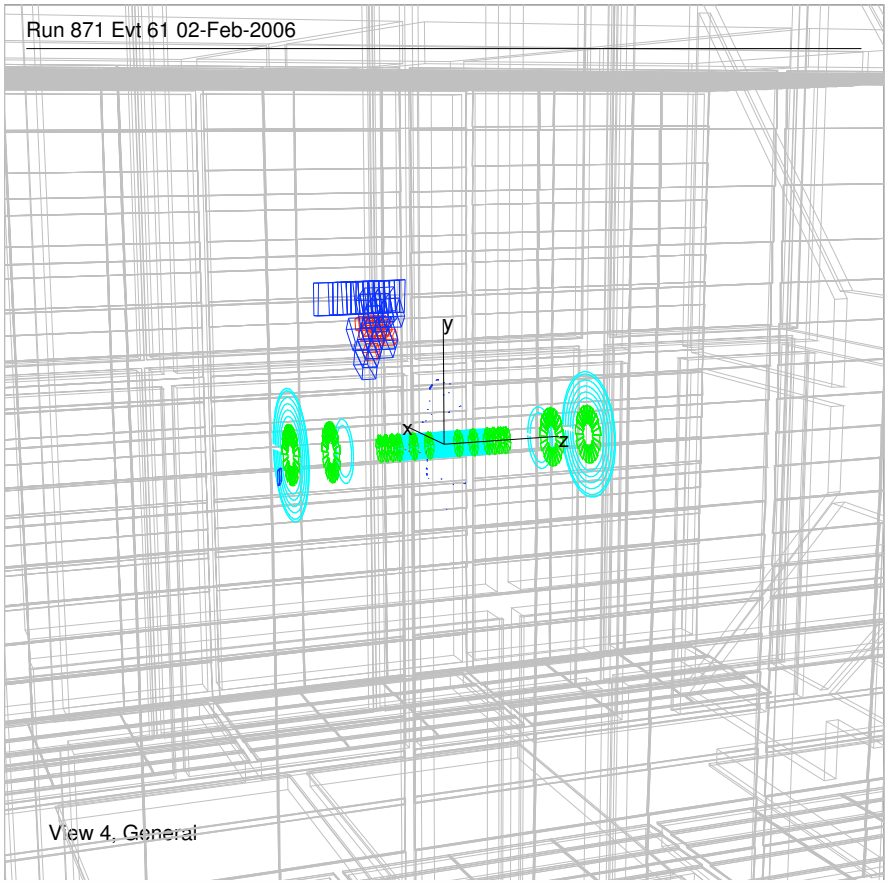
Beamline

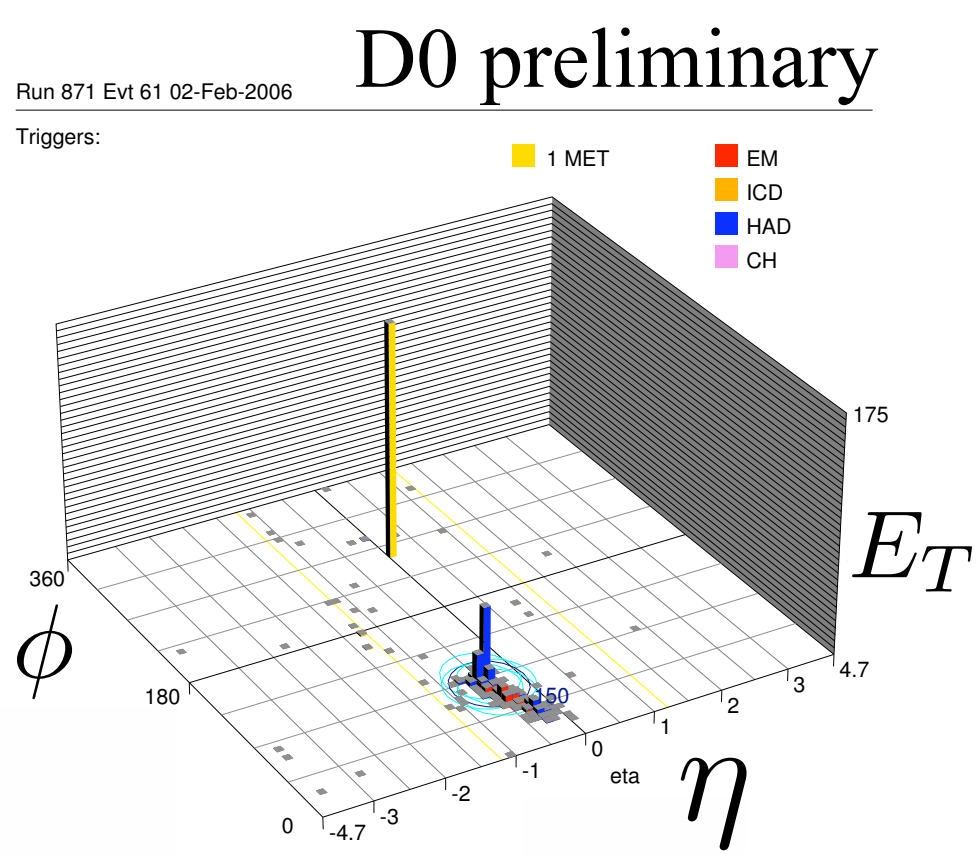
Not uniformly distributed in detector

No tracks going into or out of calorimeter

Arvanitaki, Dimopoulos, Pierce, Rajendran, JW hep-ph/0506242

Long Lived Gluinos





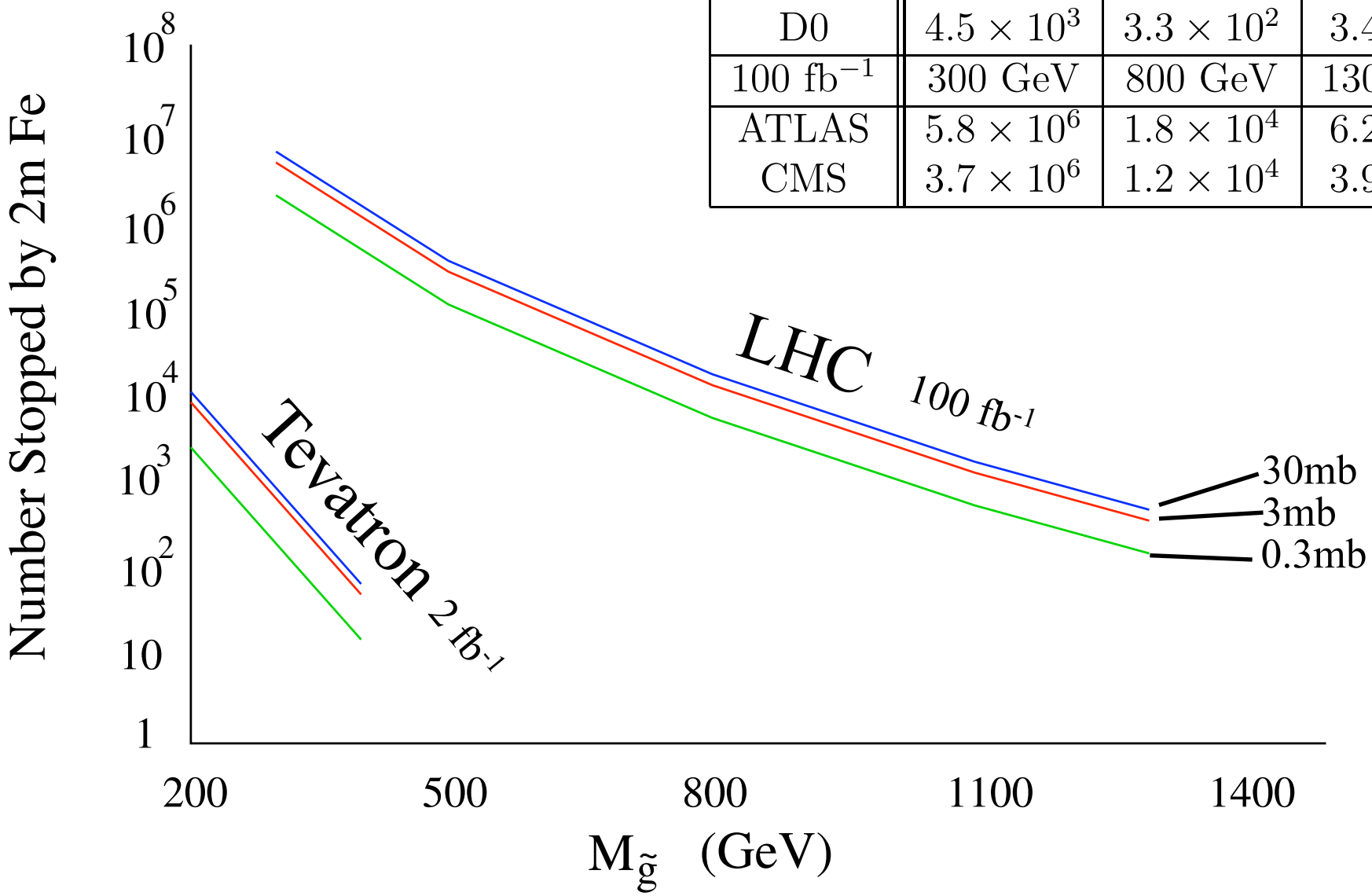
$$\text{“}\tilde{g}\text{”} \rightarrow g + Z^0 \hookrightarrow \nu\nu$$

Mimics 90 GeV LSP

Total Number of Stopped Gluinos

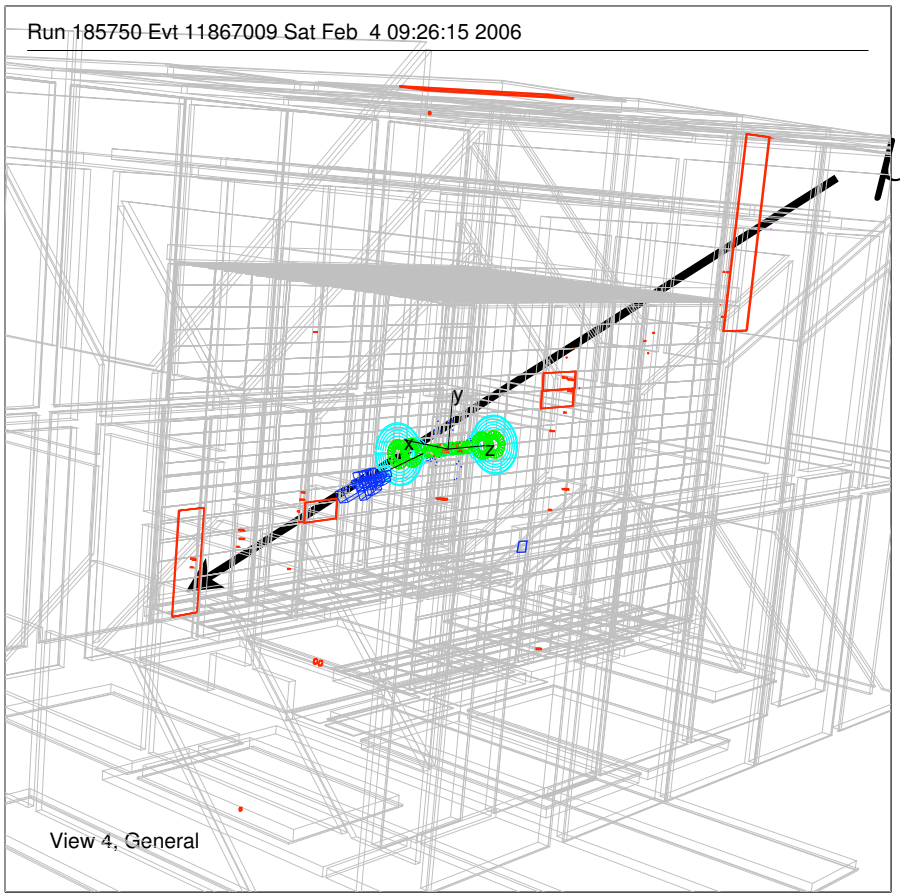
Arvanitaki, Dimopoulos, Pierce, Rajendran, JW hep-ph/0506242

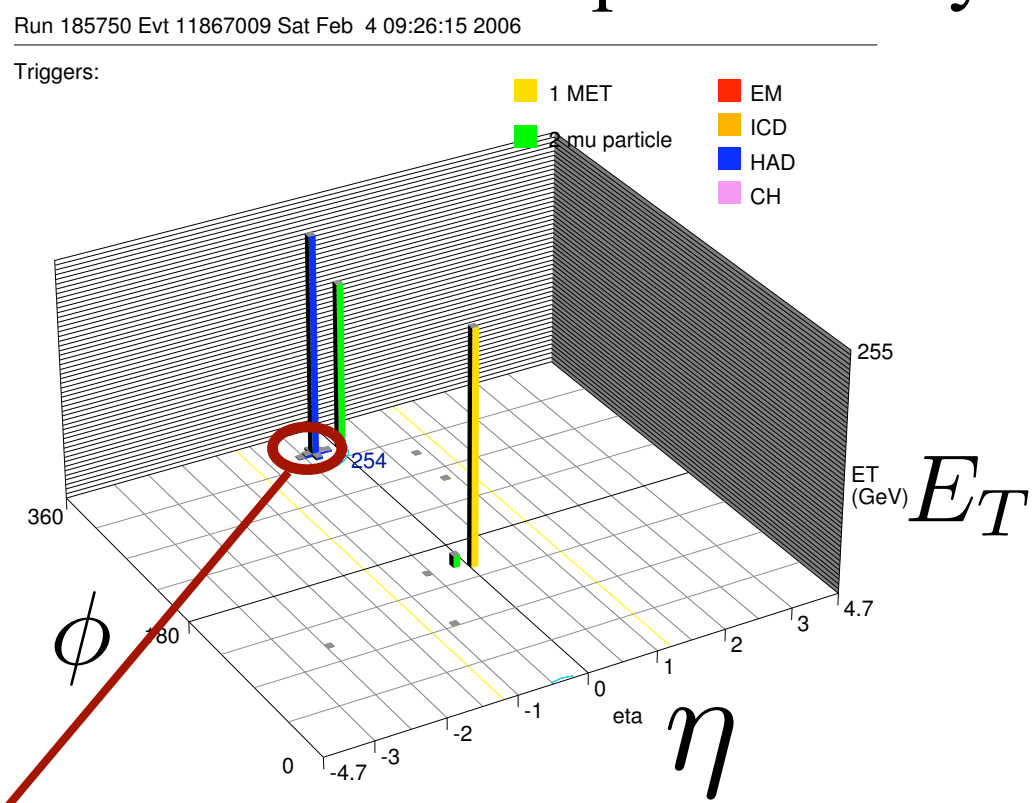
2 fb^{-1}	200 GeV	300 GeV	400 GeV
CDF	4.1×10^3	3.1×10^2	3.3×10^1
D0	4.5×10^3	3.3×10^2	3.4×10^1
100 fb^{-1}	300 GeV	800 GeV	1300 GeV
ATLAS	5.8×10^6	1.8×10^4	6.2×10^2
CMS	3.7×10^6	1.2×10^4	3.9×10^2



Backgrounds Cosmic Muons

D0 preliminary

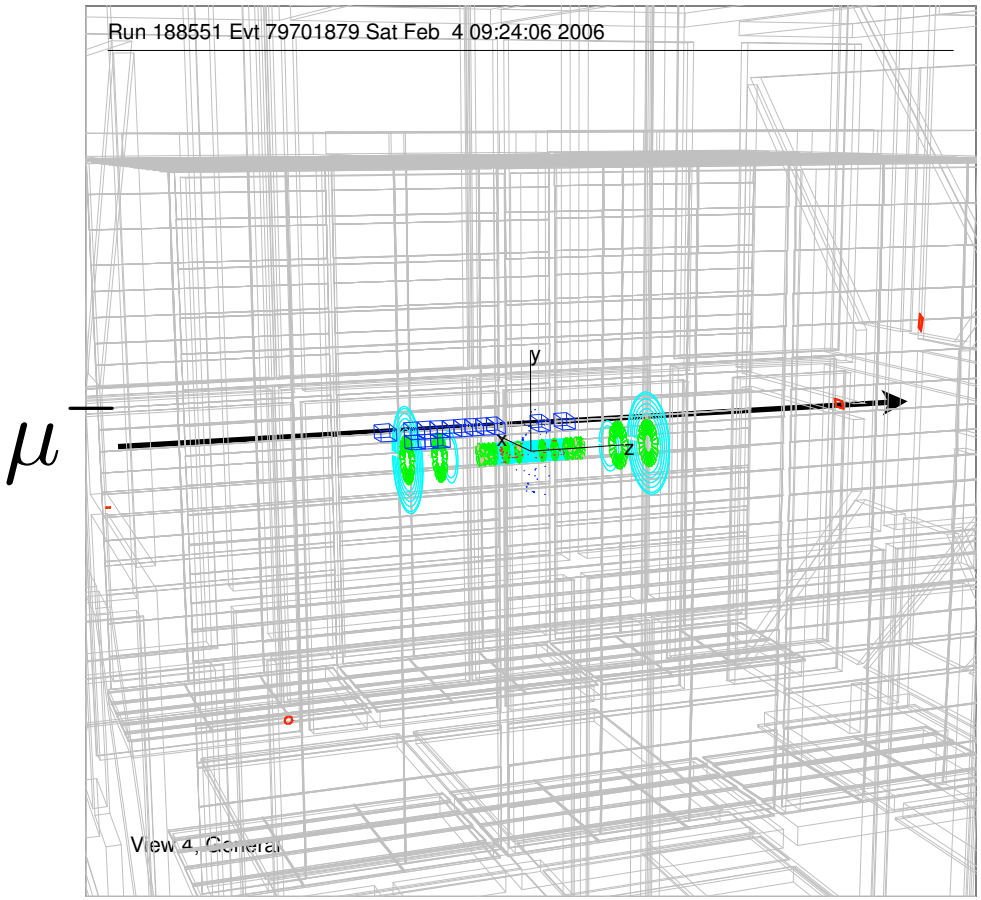




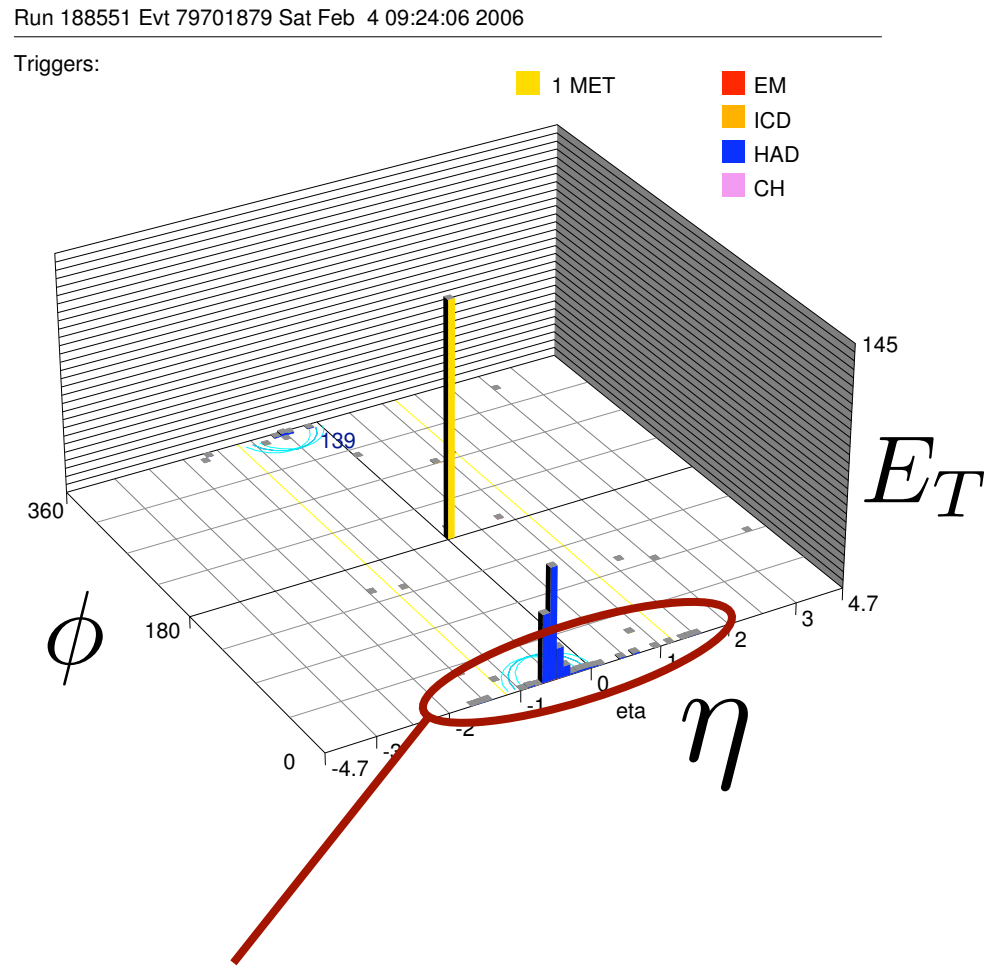
Narrow Shower

Veto on muon chamber hits

Backgrounds Beam Muons

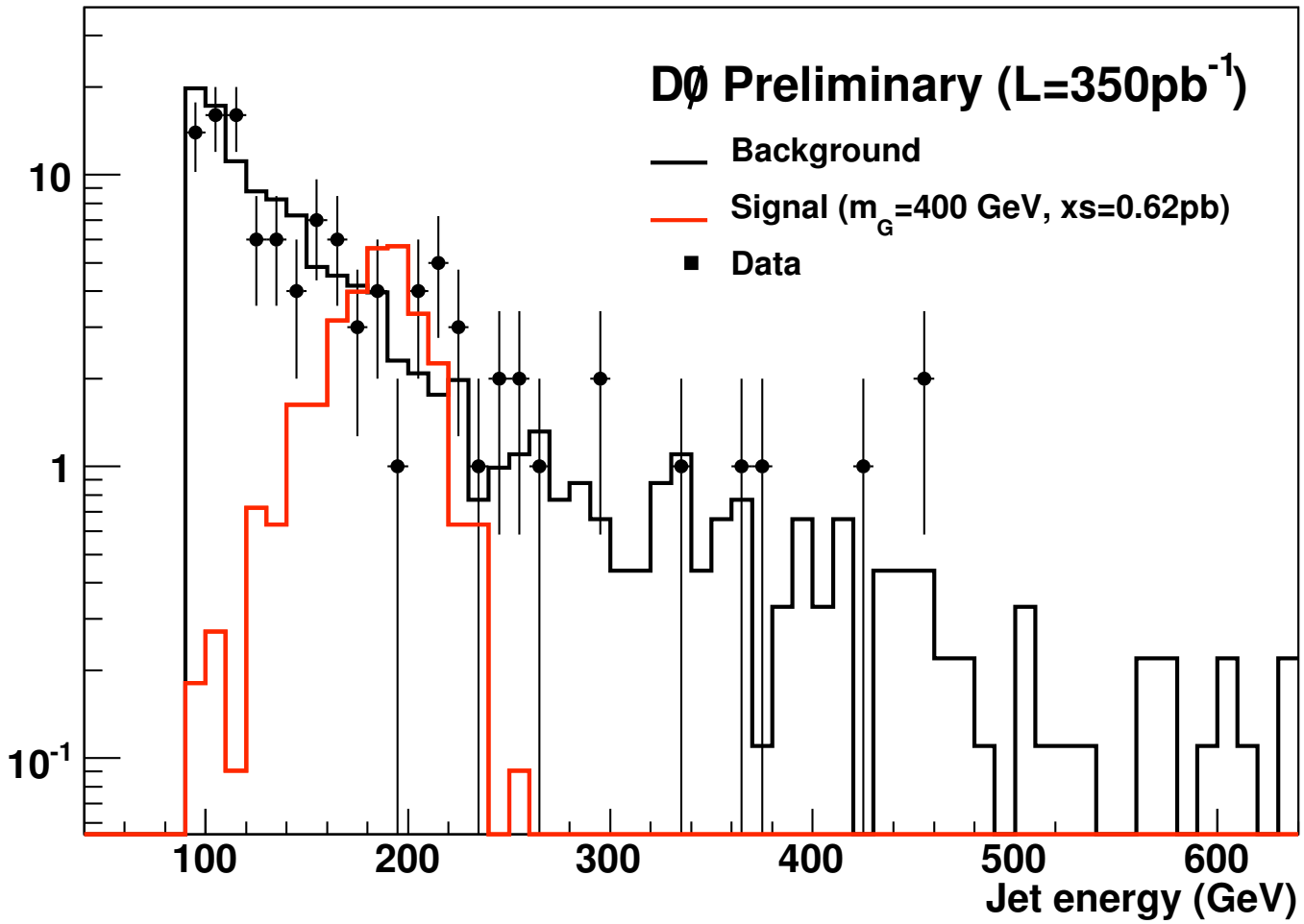


D0 preliminary



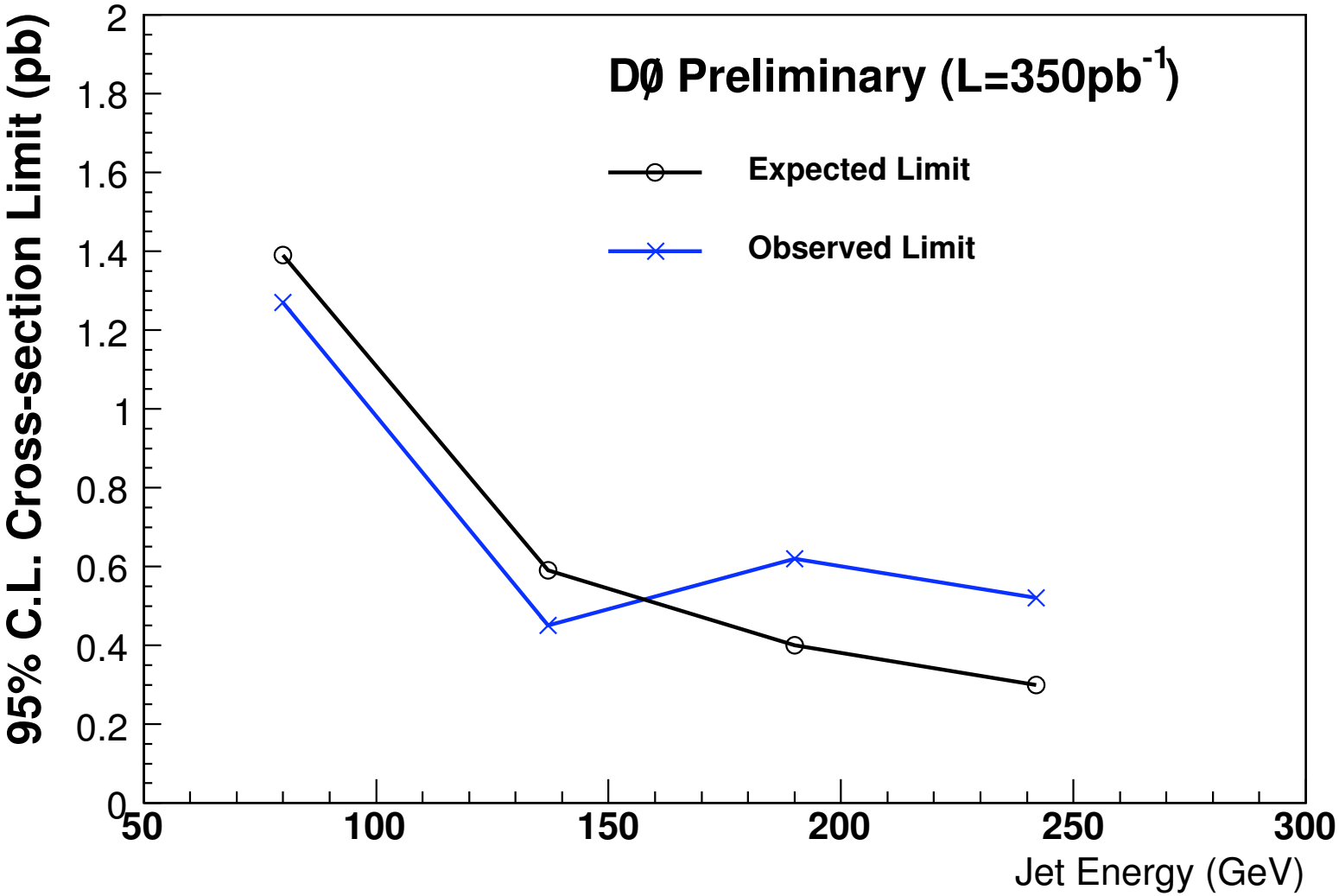
Wide in η

D0 Results



Reasonable background

D0 Results

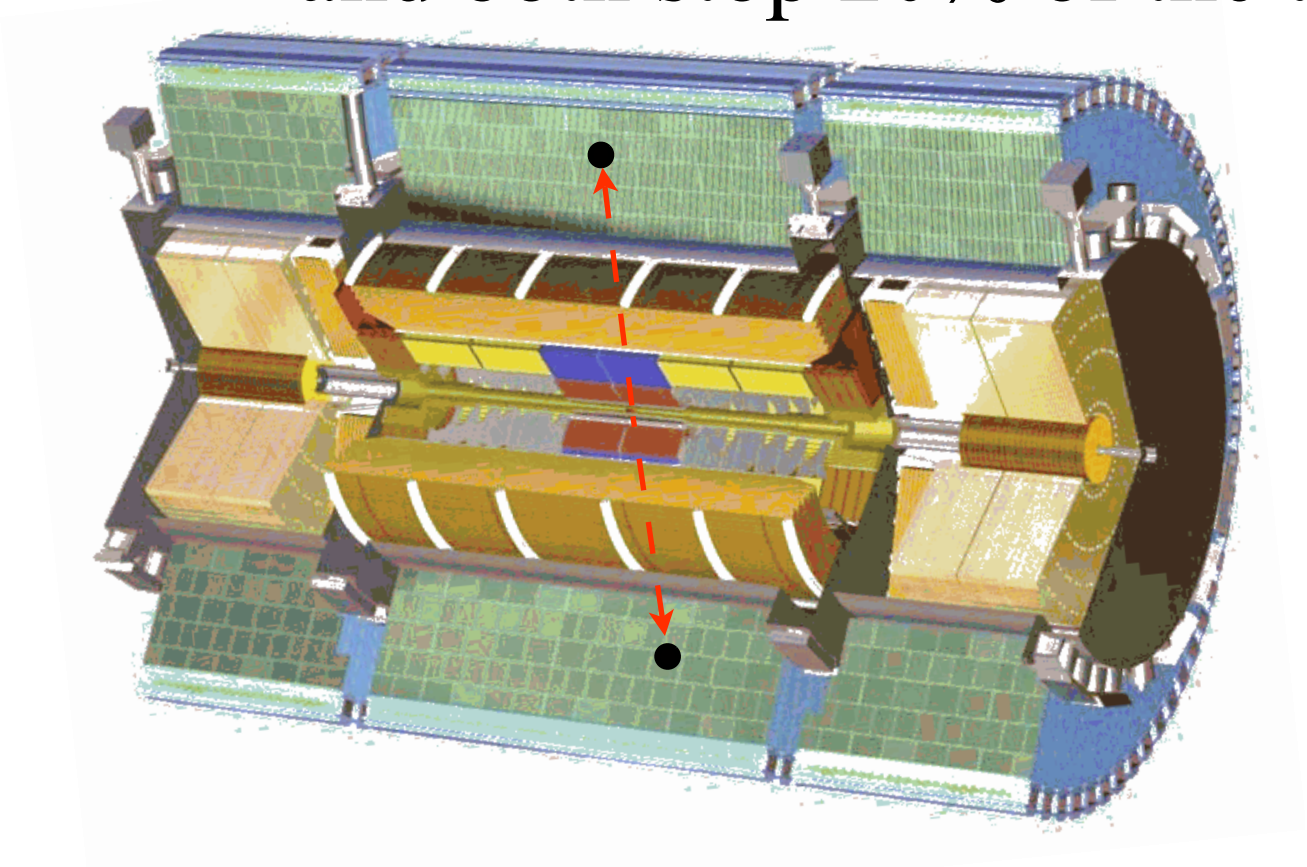

DØ Preliminary (L=350pb^{-1})
Expected Limit
Observed Limit
95% C.L. Cross-section Limit (pb)
Jet Energy (GeV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
50
100
150
200
250
300

Lifetime Measurement

$$\tau_{\tilde{g}} \simeq 2 \text{ sec.} \left(\frac{350 \text{ GeV}}{m_{\tilde{g}}}\right)^5 \left(\frac{M_{\text{Susy}}}{10^6 \text{ TeV}}\right)^4$$

gluinos are pair produced

and both stop 20% of the time

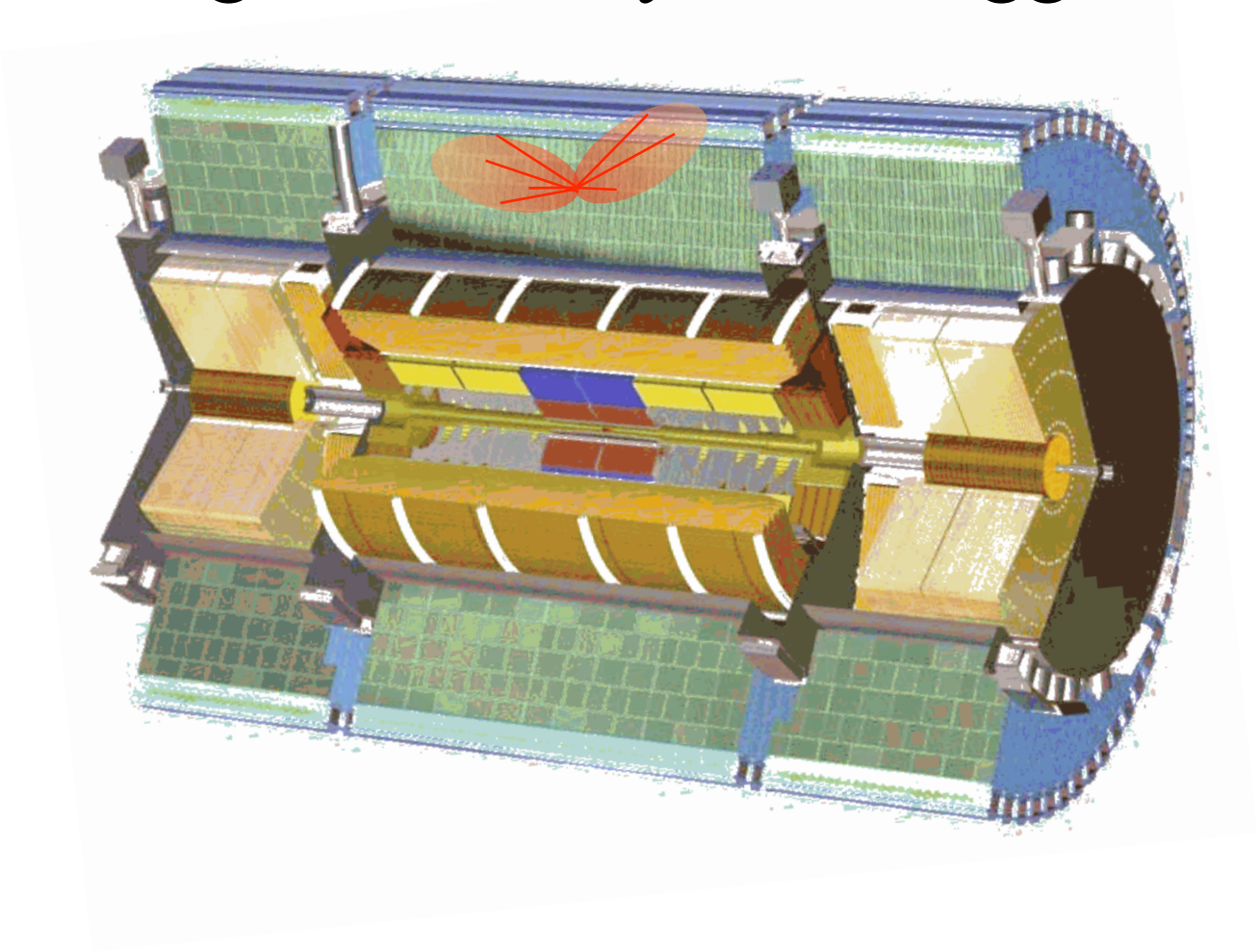


Won't trigger on the initial event

Lifetime Measurement

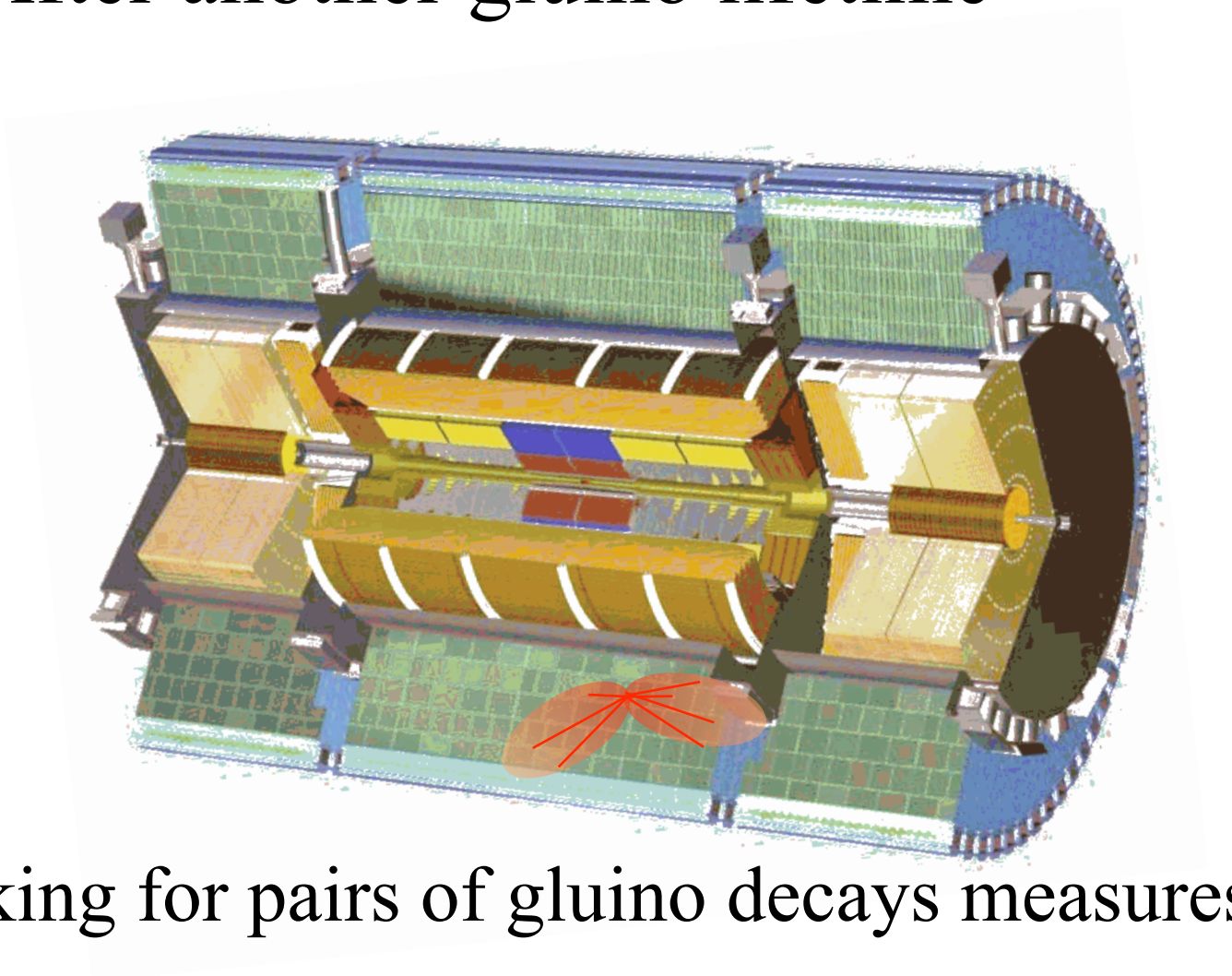
After a gluino lifetime

one gluino decays and triggers and is recorded



Lifetime Measurement

After another gluino lifetime



Looking for pairs of gluino decays measures the lifetime

We are probing the energy frontier

Need to make sure we are looking in all the available channels

Worst tragedy would be to have the discovery on tape, but not to discover it because we didn't look