Search for Charginos and Neutralinos in the Trilepton Final State

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on behalf of the DØ Collaboration

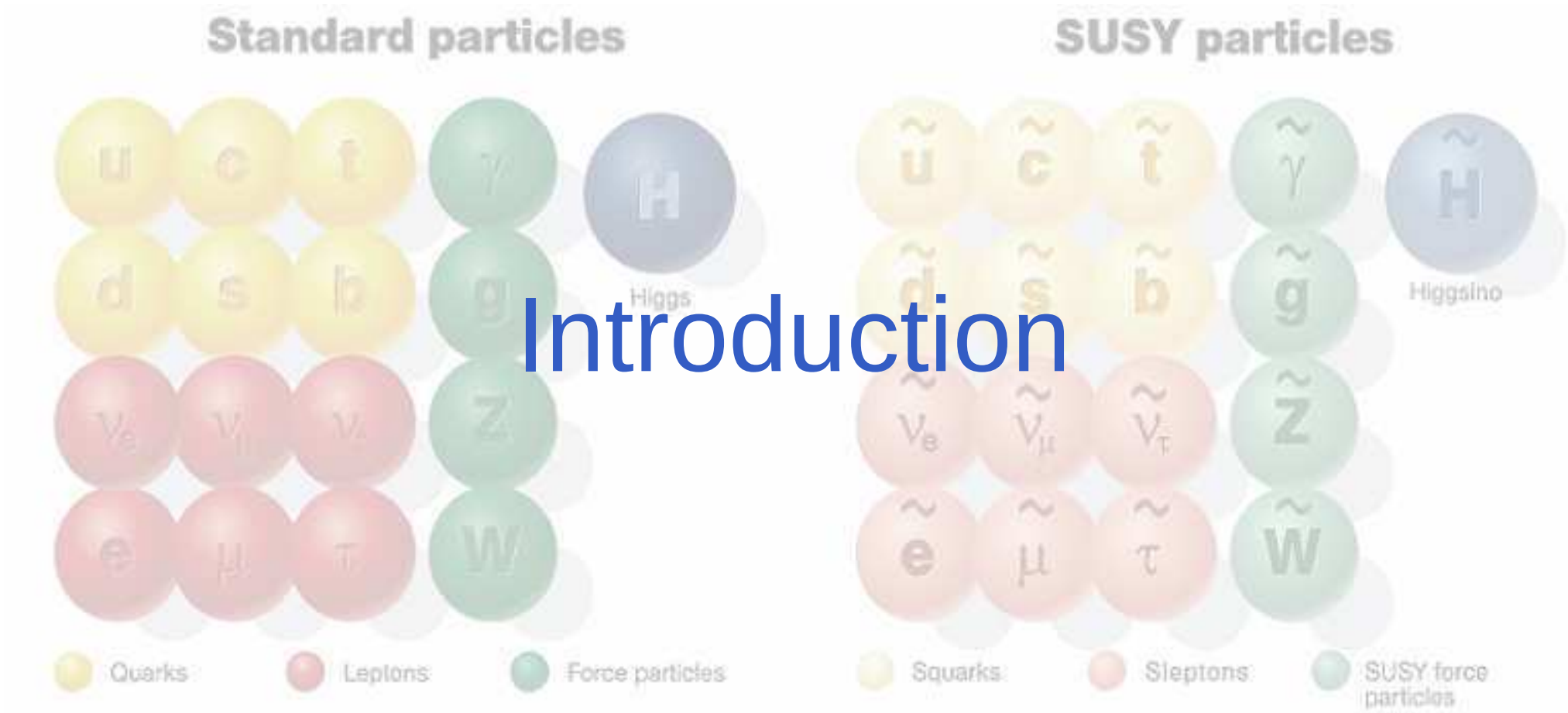
Wine and Cheese Seminar
01/23/2009

universitätbonn

Outline

- Introduction
- SUSY phenomenology
- Data taking and DØ detector
- Analysis
  - ▲ Selection strategy
  - ▲ Optimization
  - ▲ Efficiency determination
- Results
- Summary and outlook

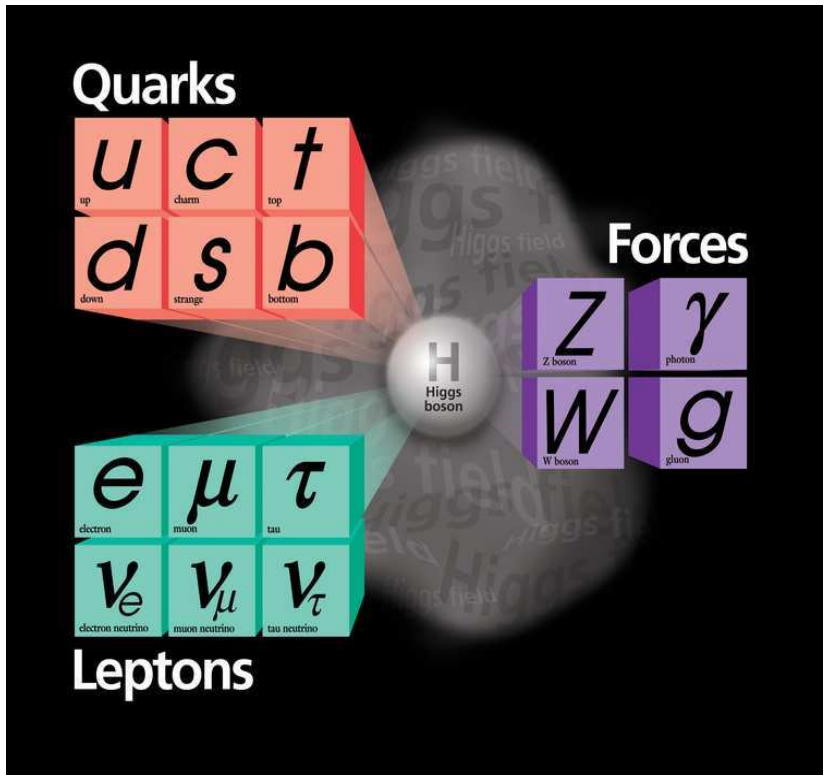
Introduction



Standard Model

- Standard Model is very successful
  - ▲ Description of matter and the interactions
  - ▲ Good agreement between predictions and precision data

- But there are a few problems
  - ▲ Gravity not included in the Standard Model
  - ▲ No explanation for dark matter in the Universe
  - ▲ No unification of couplings
  - ▲ Hierarchy problem
  - ▲ No explanation of the parameter values in the Standard Model



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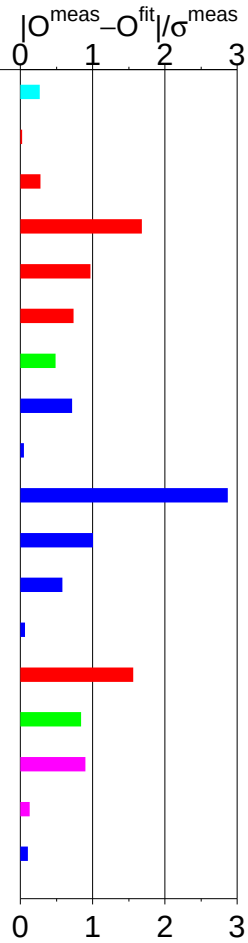
	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4958
σ^0_{had} [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.743
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01644
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21582
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.399 ± 0.025	80.376
Γ_W [GeV]	2.098 ± 0.048	2.092
m_t [GeV]	172.4 ± 1.2	172.5



July 2008

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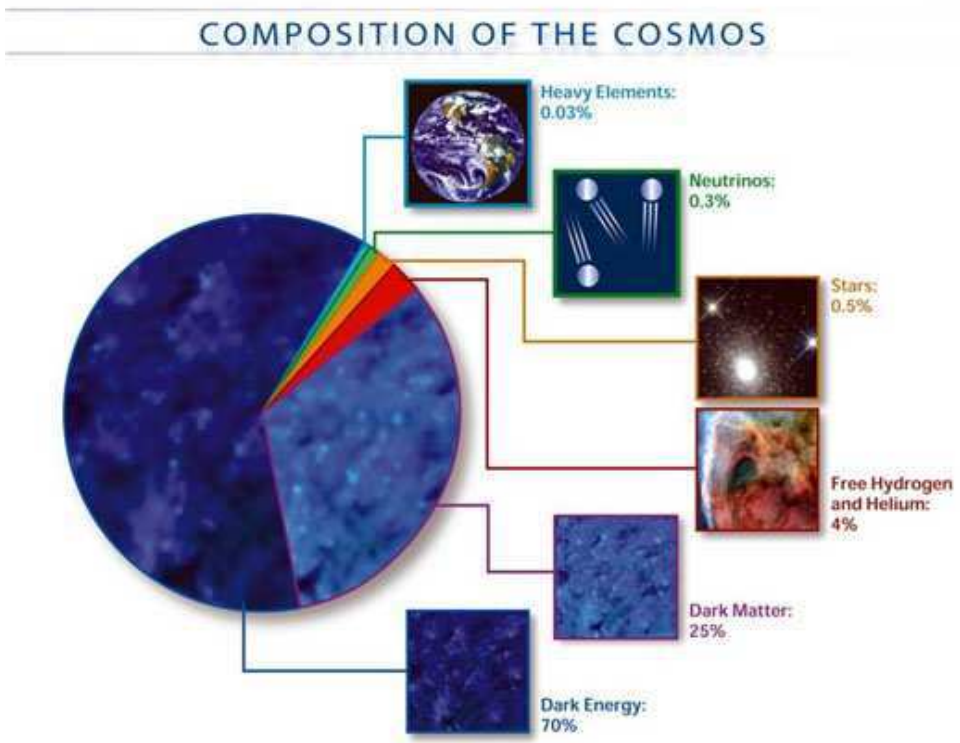

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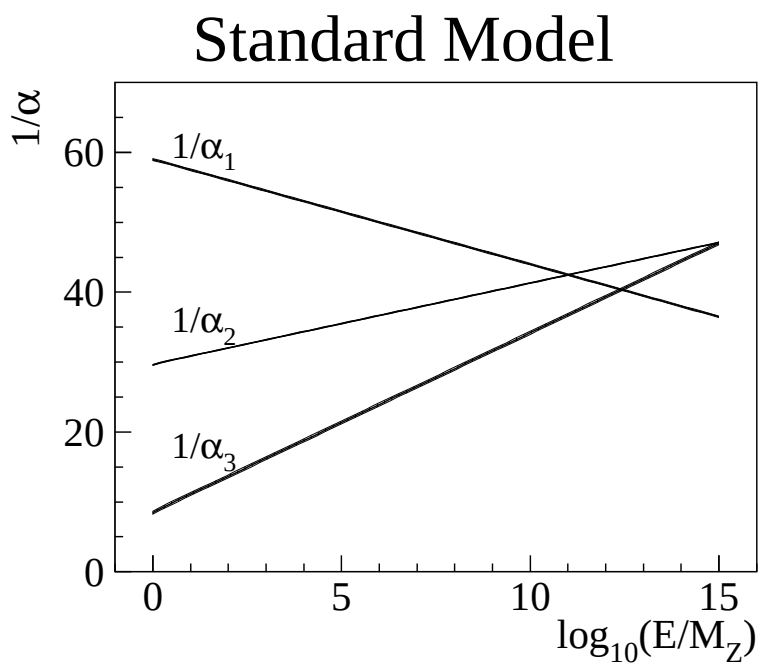

Supersymmetry

- Supersymmetry introduces a new symmetry between fermions and bosons
  - ▲ Every Standard Model particle gets a new partner differing in spin by 1/2
  - ▲ SUSY operator Q with

$$Q|\text{Fermion}\rangle = |\text{Boson}\rangle$$
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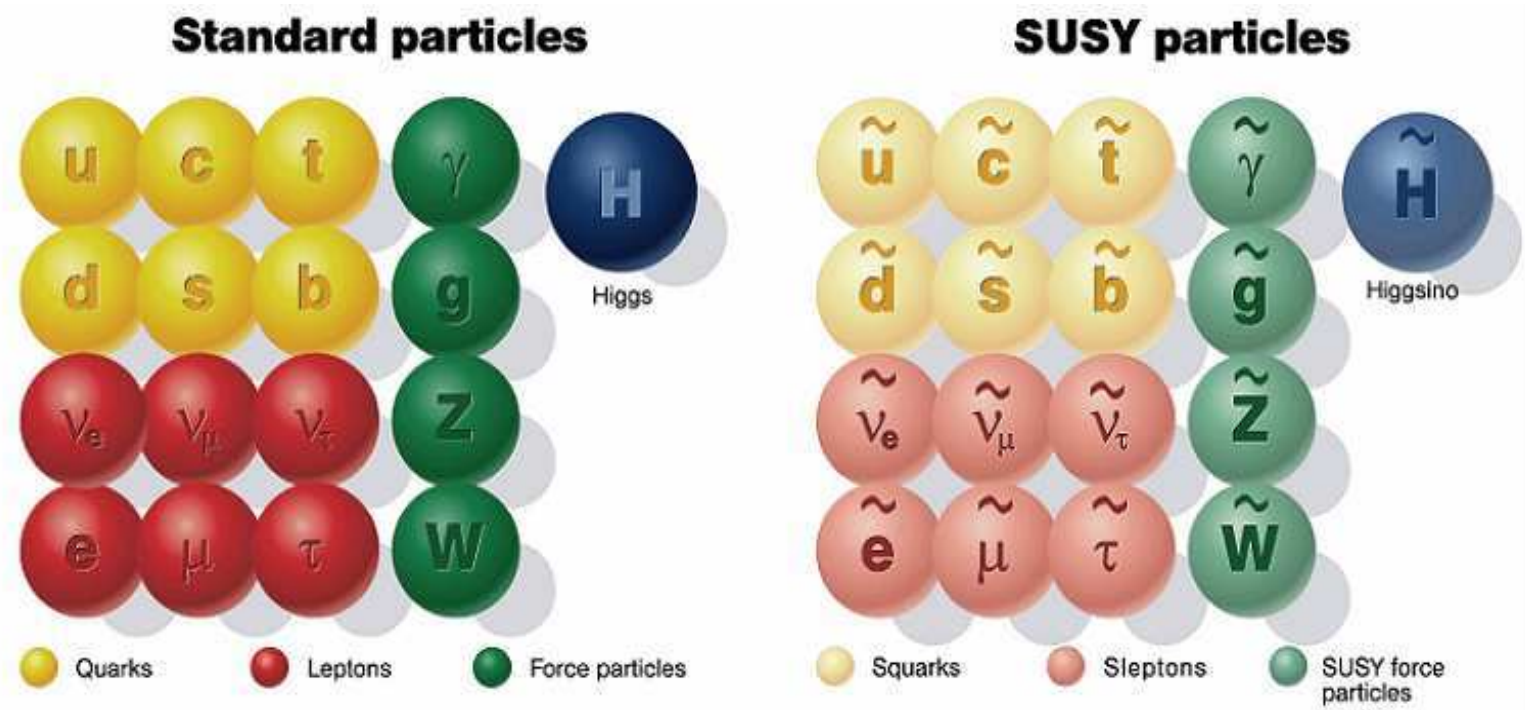
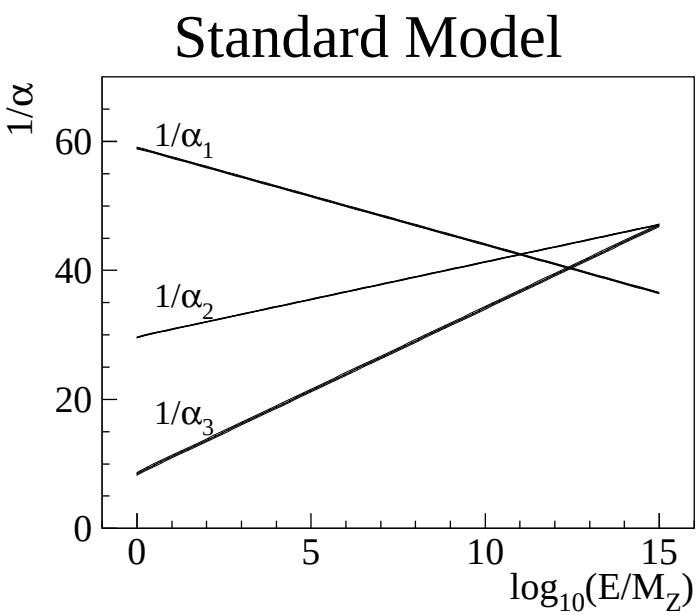
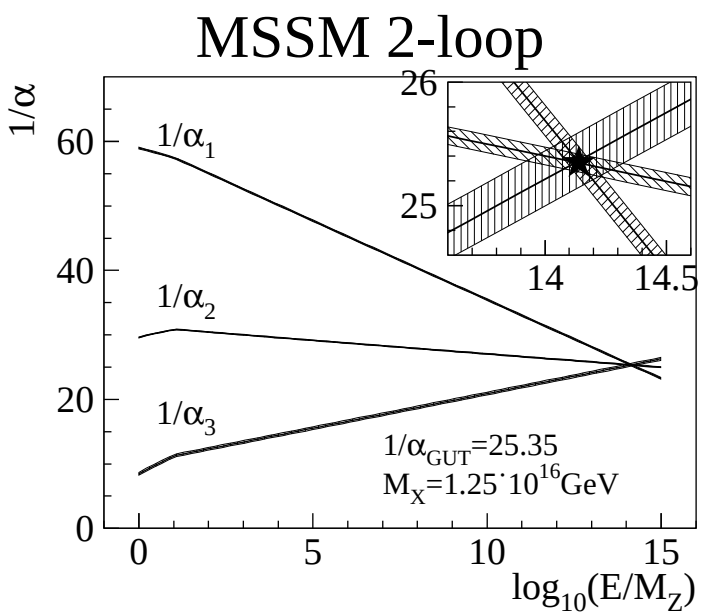


Why Supersymmetry?

- Supersymmetry can solve some of the problems of the Standard Model
  - ▲ Cancellation of radiative corrections for the Higgs mass
  - ▲ Unification of the couplings
  - ▲ If R–parity $R_p = (-1)^{3(B-L)+2S}$ is conserved the lightest supersymmetric particle (LSP) is stable
    - ► SUSY provides a dark matter candidate
  - ▲ Connection to gravity





Particle Content

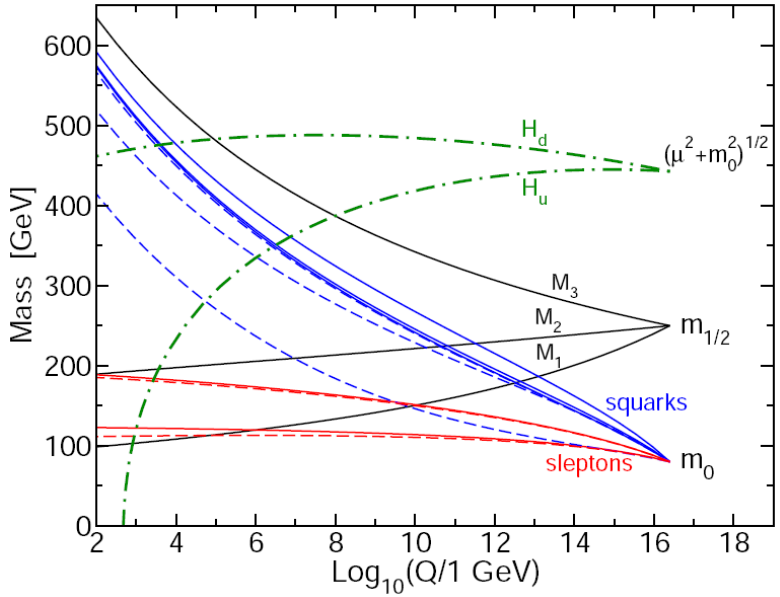
Particles in the Minimal Supersymmetric Model (MSSM)

R–parity = +1			R–parity = –1			R–parity = –1		
Particle	Symbol	Spin	Particle	Symbol	Spin	Particle	Symbol	Spin
Lepton	ℓ	$\frac{1}{2}$	Slepton	$\tilde{\ell}_L, \tilde{\ell}_R$	0			
Neutrino	ν	$\frac{1}{2}$	Sneutrino	$\tilde{\nu}$	0			
Quark	q	$\frac{1}{2}$	Squark	$\tilde{q}_L, \tilde{q}_R$	0			
Gluon	g	1	Gluino	$\tilde{g}$	$\frac{1}{2}$			
Photon	γ	1	Photino	$\tilde{\gamma}$	$\frac{1}{2}$			
Z Boson	Z	1	Zino	$\tilde{Z}$	$\frac{1}{2}$			
W Boson	$W^{\pm}$	1	Wino	$\tilde{W}^{\pm}$	$\frac{1}{2}$	4 Neutralinos	$\tilde{\chi}_i^0$	$\frac{1}{2}$
Higgs	$H^0, H^{\pm}$	0	Higgsino	$\tilde{H}_1^0, \tilde{H}_2^+$	$\frac{1}{2}$	2 Charginos	$\tilde{\chi}_i^{\pm}$	$\frac{1}{2}$
	h^0, A^0	0		$\tilde{H}_1^-, \tilde{H}_2^0$	$\frac{1}{2}$			

- Necessary assumptions for the analysis
  - ▲ Three leptons in the final state
  - ▲ Neutralino long lived enough to escape the detector
    - ► mSUGRA among the models that fulfill these constraints

mSUGRA

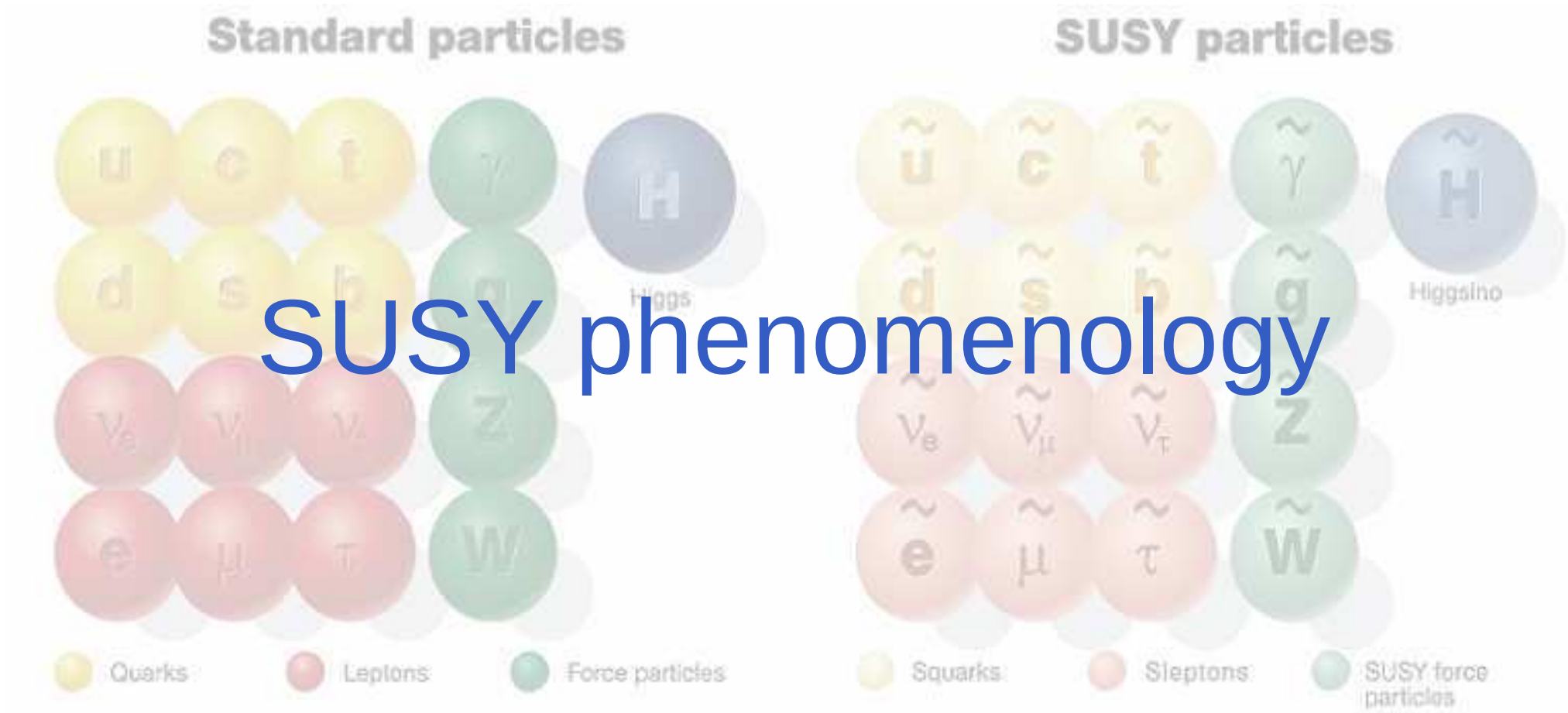
- mSUGRA (minimal SuperGravity) is one of the most considered SUSY models
  - ▲ Common scalar mass m_0, gaugino mass $m_{1/2}$ and trilinear coupling A_0 at GUT scale
    - ▶ Reduction to 5 model parameters
      $\Rightarrow \tan\beta$, m_0, $m_{1/2}$, A_0, sign(μ)
  - ▲ R–parity conservation
    - ▶ LSP (Neutralino) is stable



- Consider two representative signal points
  - ▲ m_0 = 150 GeV, $m_{1/2}$ = 170 GeV (250 GeV)
  - ▲ $\tan\beta$ = 3, A_0 = 0, sign(μ) positive
- SUSY particle masses for these points (in GeV)

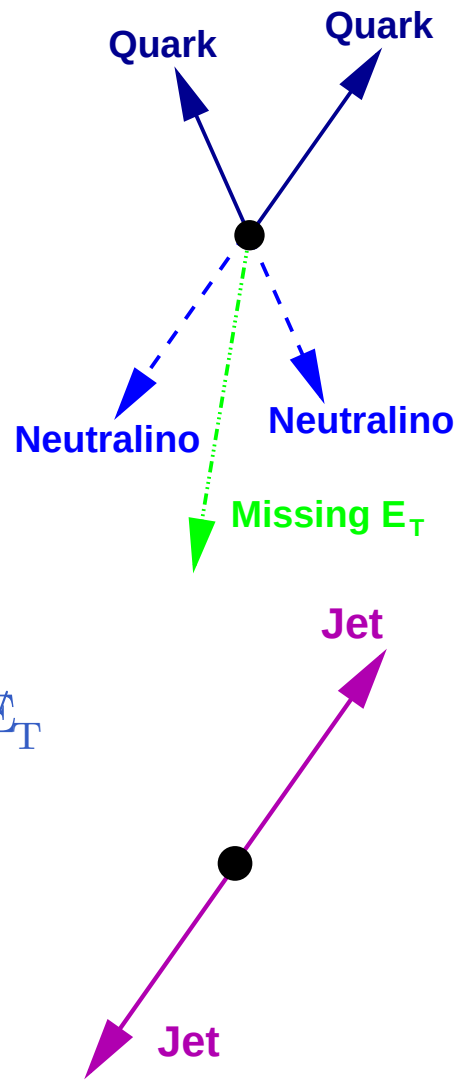
	m_0	$m_{1/2}$	$m_{\tilde{\chi}_1^\pm}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\ell}}$	$m_{\tilde{\nu}}$
SUSY 2	150	170	107	109	59	168	179
SUSY 1	150	250	177	176	95	161	220

SUSY phenomenology



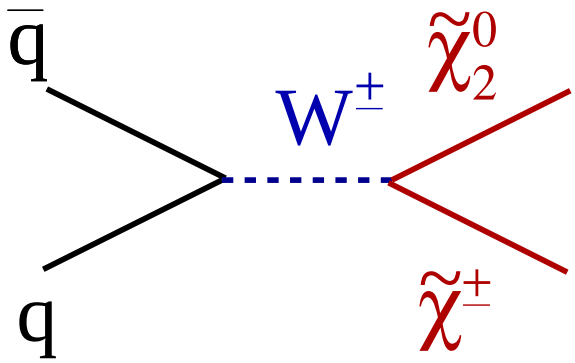
SUSY at the Tevatron

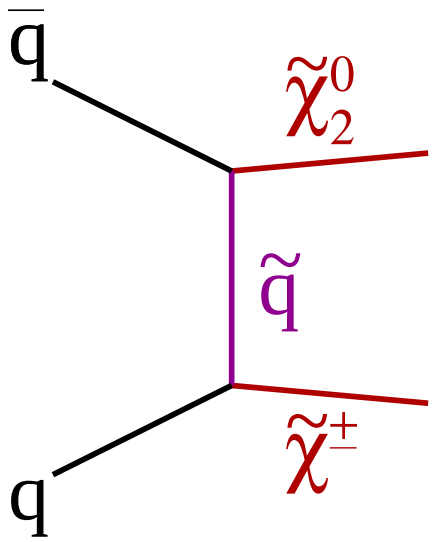
- Main signals
  - ▲ Squarks and Gluinos
    - ▶ Large cross section because of strong production
    - ▶ Final state characterized by jets and $\not{E}_T$
    - ▶ Large backgrounds from multijet production
  - ▲ Charginos and Neutralinos (“Trileptons”)
    - ▶ Electroweak production $\Rightarrow$ Small cross section
    - ▶ Final state characterized by charged leptons and $\not{E}_T$
    - ▶ Very clean signature



Search for Charginos and Neutralinos

- Associated production of Charginos and Neutralinos
  - s–channel: via W boson
  - t–channel: Squark exchange
  - Destructive interference





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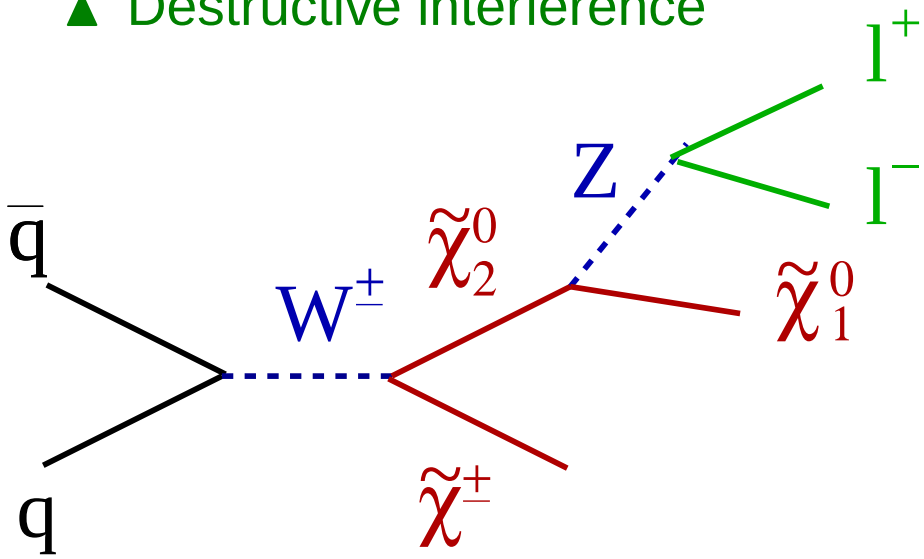

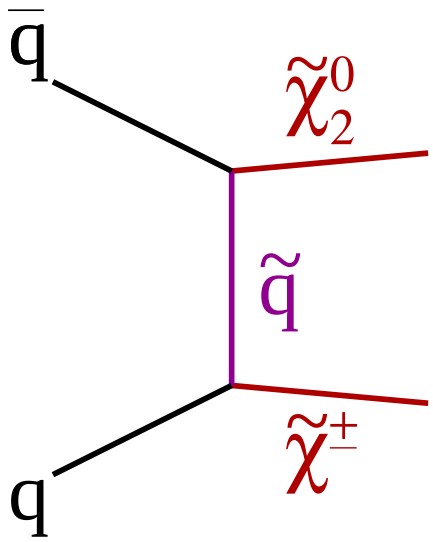

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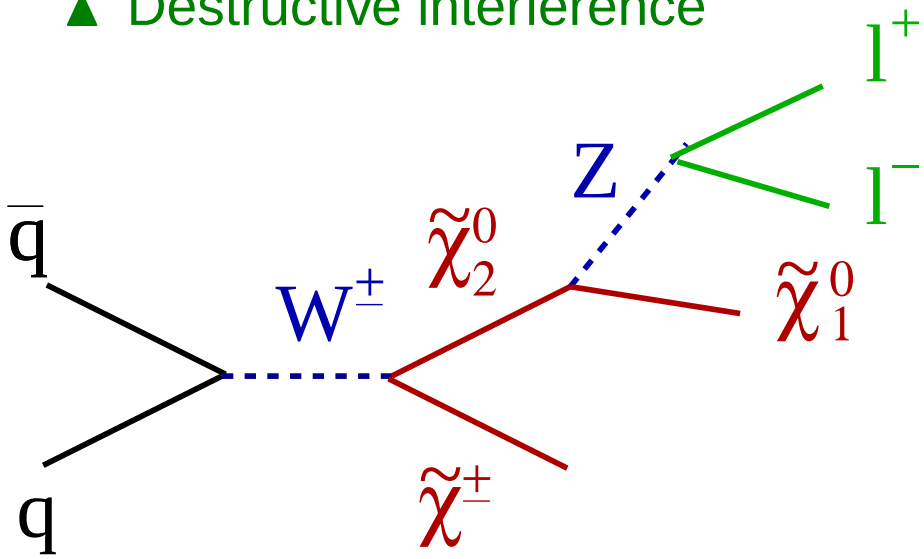

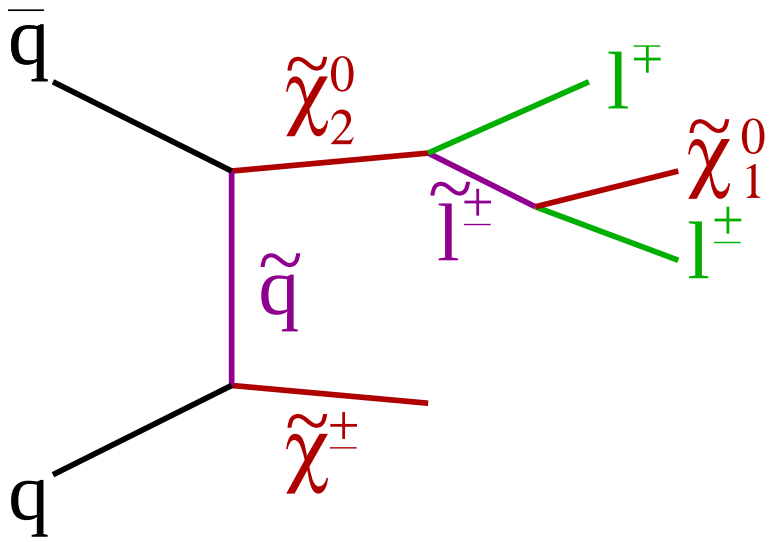

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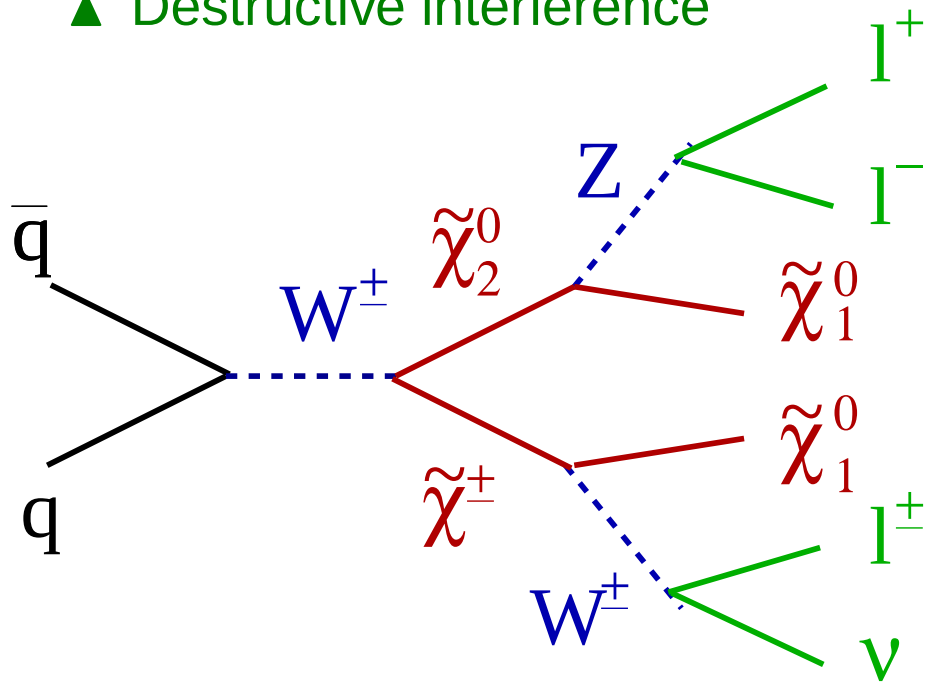

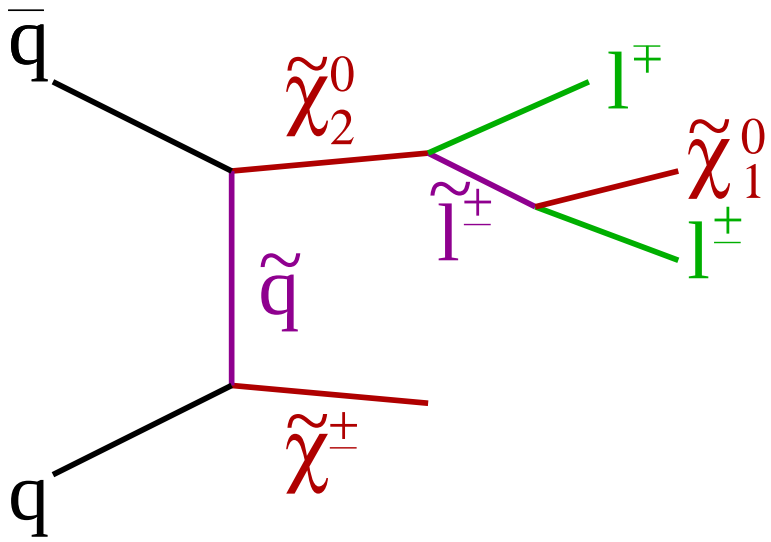

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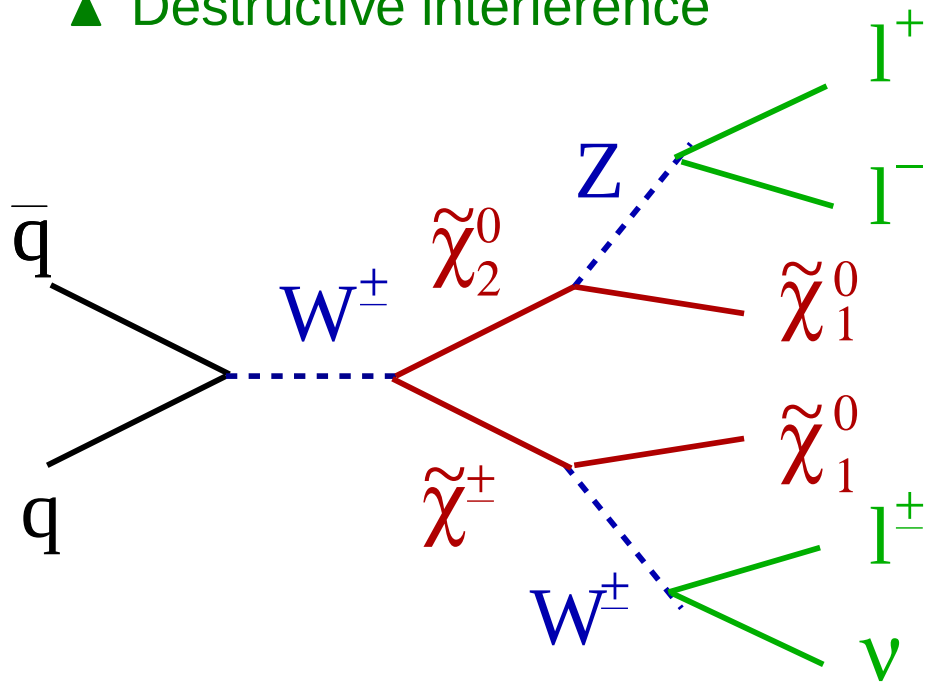

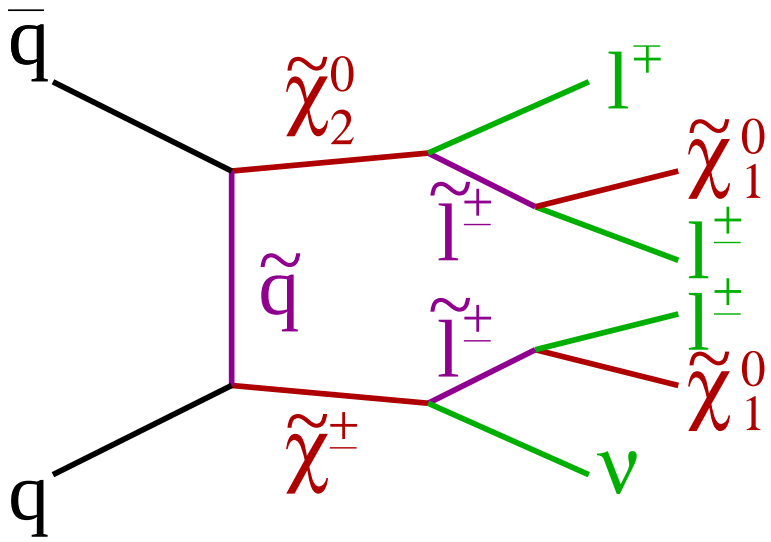

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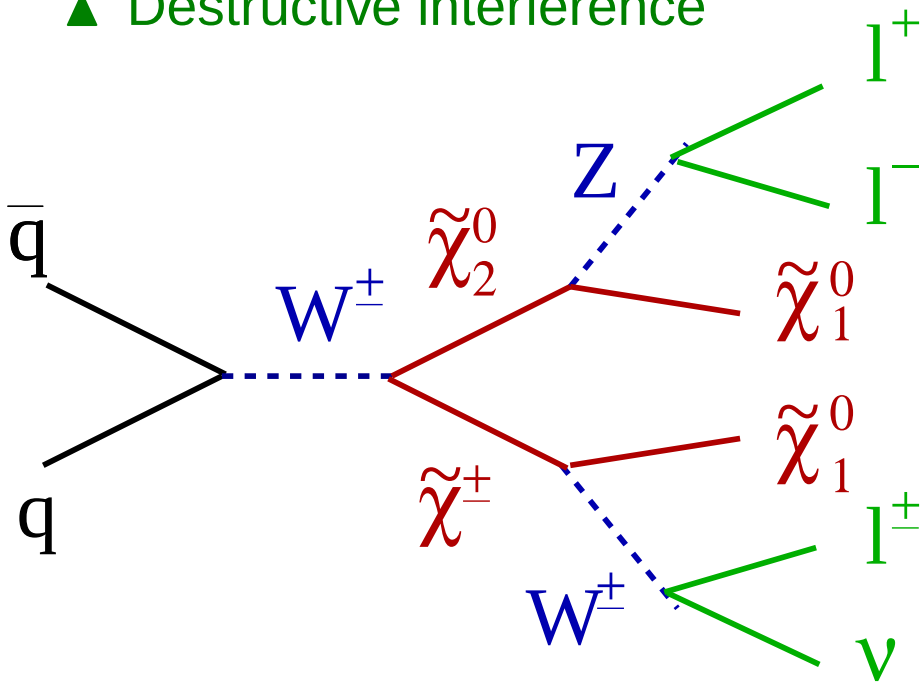
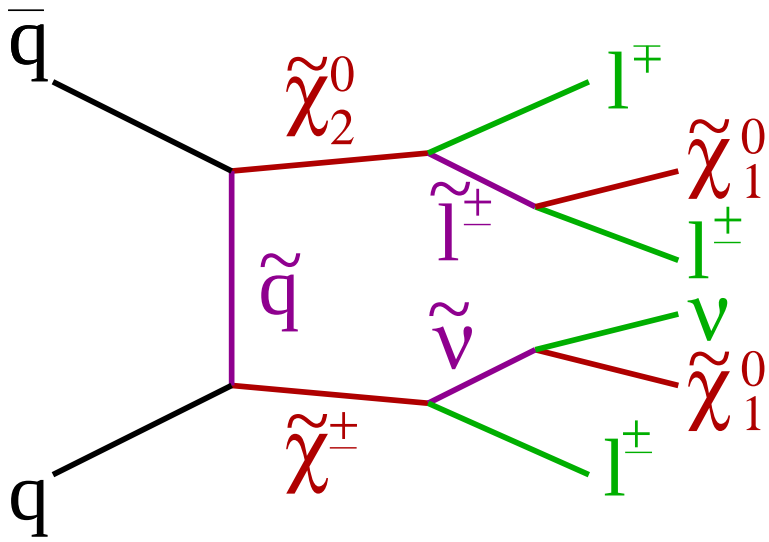
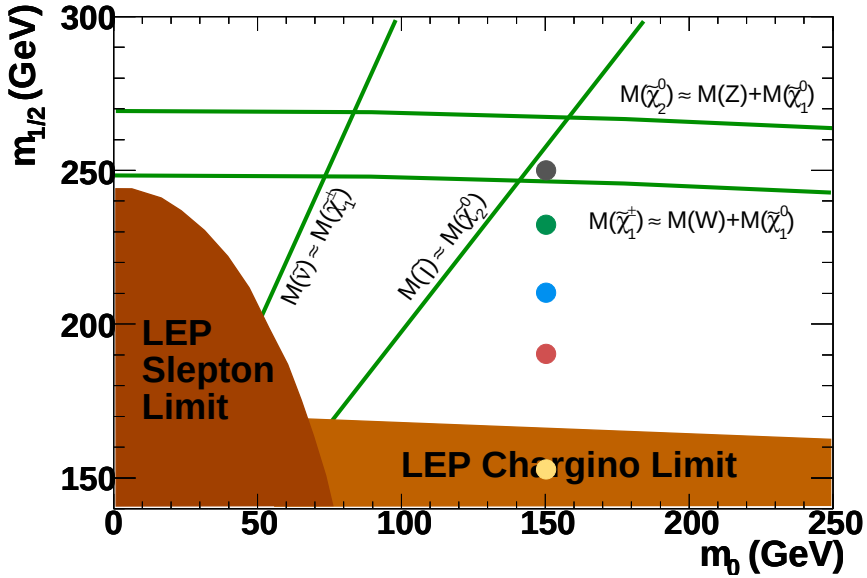


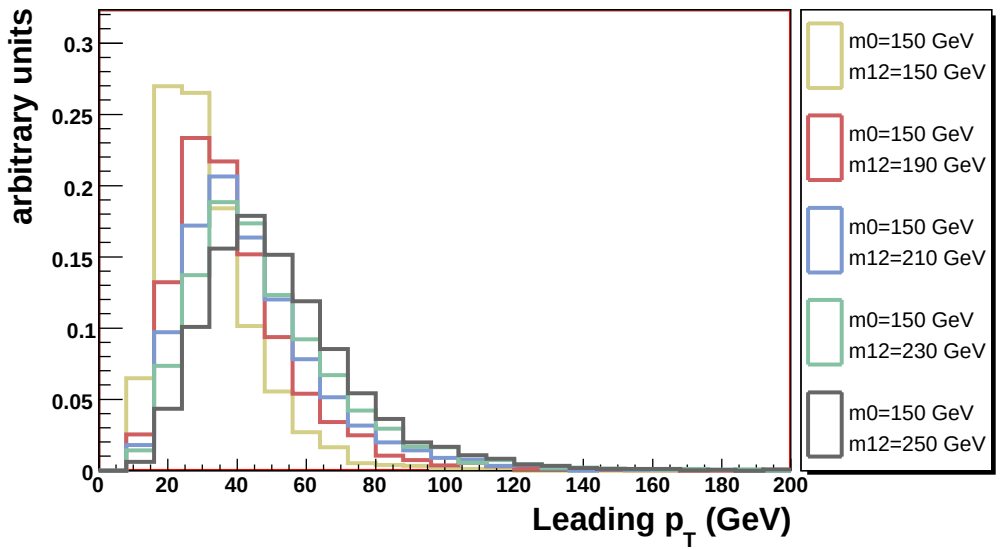


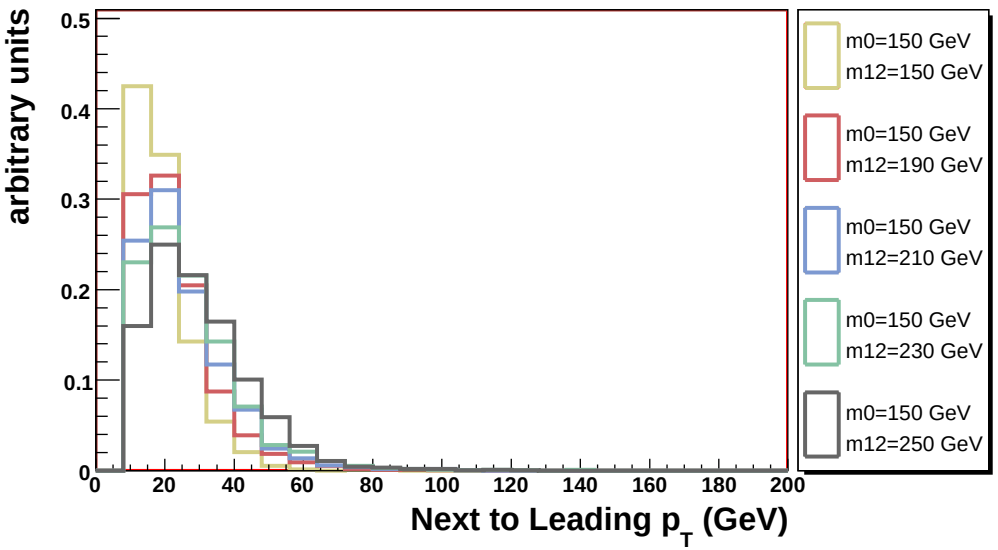
- Final state consists of
  - Three charged leptons
  - Two Neutralinos (LSP)
  - One or more neutrinos

Kinematics in the Plane

- Kinematics change in the m_0–$m_{1/2}$–plane
  - Harder lepton momenta with increasing $m_{1/2}$
  - $\not{E}_T$ is increasing as well
  - Similar behavior for larger mass differences of SUSY decay products







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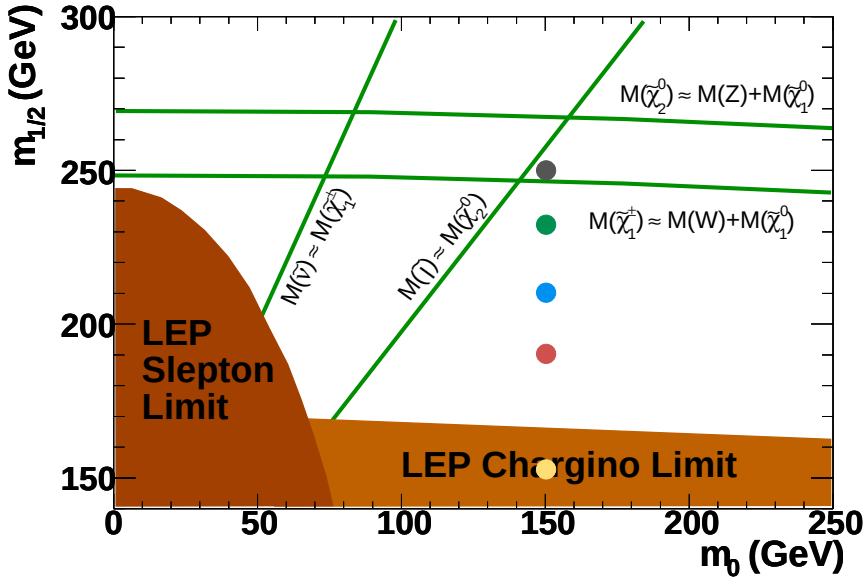
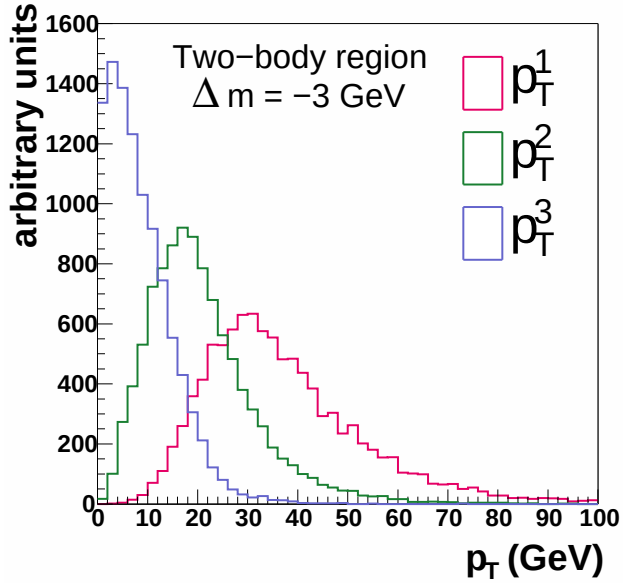
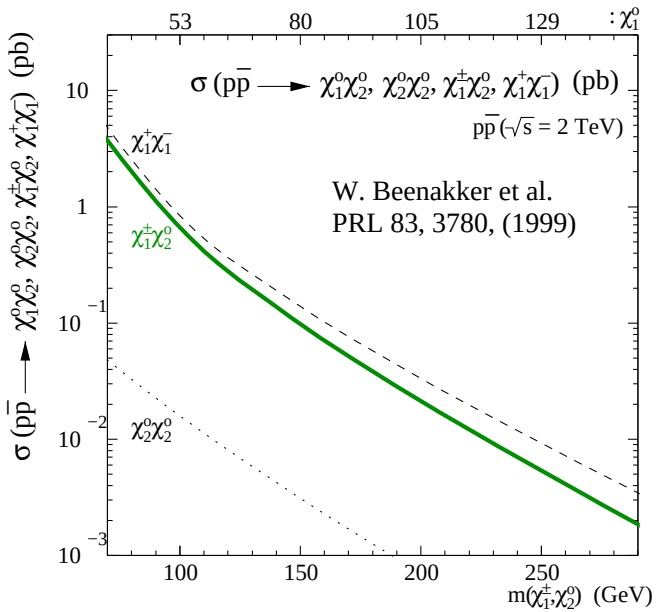


- Three–body region ($m_{\tilde{\chi}_1^\pm} < m_{\tilde{\chi}_1^0} + M_W$ and $m_{\tilde{\chi}_1^\pm} < m_{\tilde{\ell}}$)
  - ▲ Kinematics mainly dominated by the mass of the Chargino
- Two–body region ($m_{\tilde{\chi}_1^\pm} > m_{\tilde{\ell}}$ ($m_{\tilde{\nu}}$))
  - ▲ Dominated by the mass difference of Chargino and Slepton (Sneutrino): $\Delta m_{\tilde{\ell}} = m_{\tilde{\ell}} - m_{\tilde{\chi}_1^\pm}$ ($\Delta m_{\tilde{\nu}} = m_{\tilde{\nu}} - m_{\tilde{\chi}_1^\pm}$)

Search for Charginos and Neutralinos (2)

- Trilepton channel is the “golden mode” for Chargino/Neutralino search
  - ▲ Signature: three charged leptons plus missing transverse energy
- Challenges
  - ▲ Leptons have low transverse momenta
  - ▲ Small cross sections: $\sigma \times$BR $<$ 0.5 pb





- Five different final states
  - ▲ $\mu\mu$+track: $\int \mathcal{L}dt \sim 2.3\ \mathrm{fb}^{-1}$
  - ▲ ee+track: $\int \mathcal{L}dt \sim 2.3\ \mathrm{fb}^{-1}$
  - ▲ $e\mu$+track: $\int \mathcal{L}dt \sim 2.3\ \mathrm{fb}^{-1}$
  - ▲ $\mu\tau$+track: $\int \mathcal{L}dt \sim 1.0\ \mathrm{fb}^{-1}$
  - ▲ $\mu\tau$+τ: $\int \mathcal{L}dt \sim 1.0\ \mathrm{fb}^{-1}$

Selection Strategy

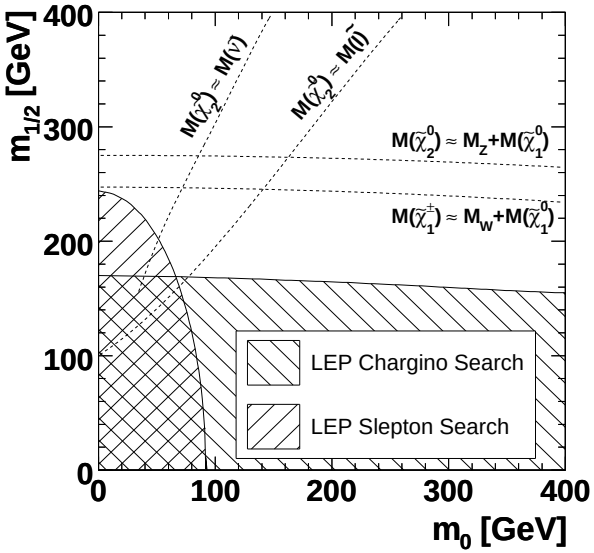
1. Dilepton+track analysis
   - ▲ Require two reconstructed leptons (either e, μ or τ)
   - ▲ Require significant $\not{E}_T$ to account for escaping Neutralinos/neutrinos
   - ▲ Require one additional isolated track
     - ▶ Higher efficiency than reconstructed third lepton
     - ▶ Efficient for e, μ and τ

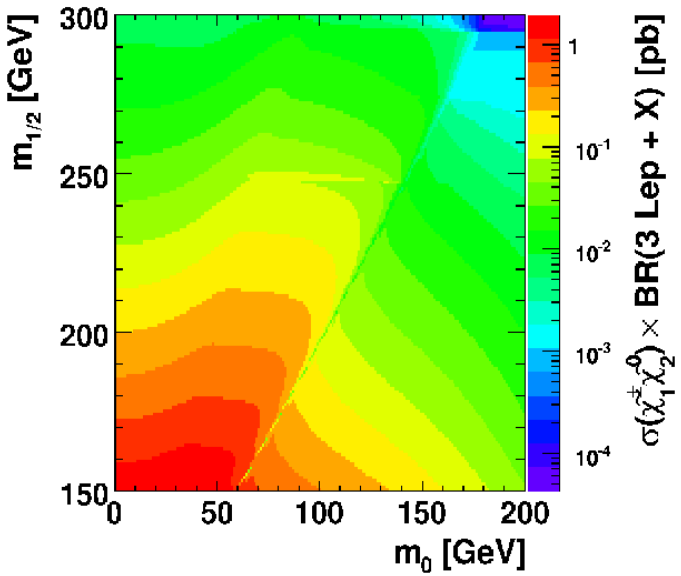
- For some SUSY parameter points the third lepton has very low p_T
  - ▲ Dilepton+track analysis becomes inefficient

2. Like–sign dilepton analysis (not part of this presentation)
   - ▲ Require two reconstructed leptons of the same charge

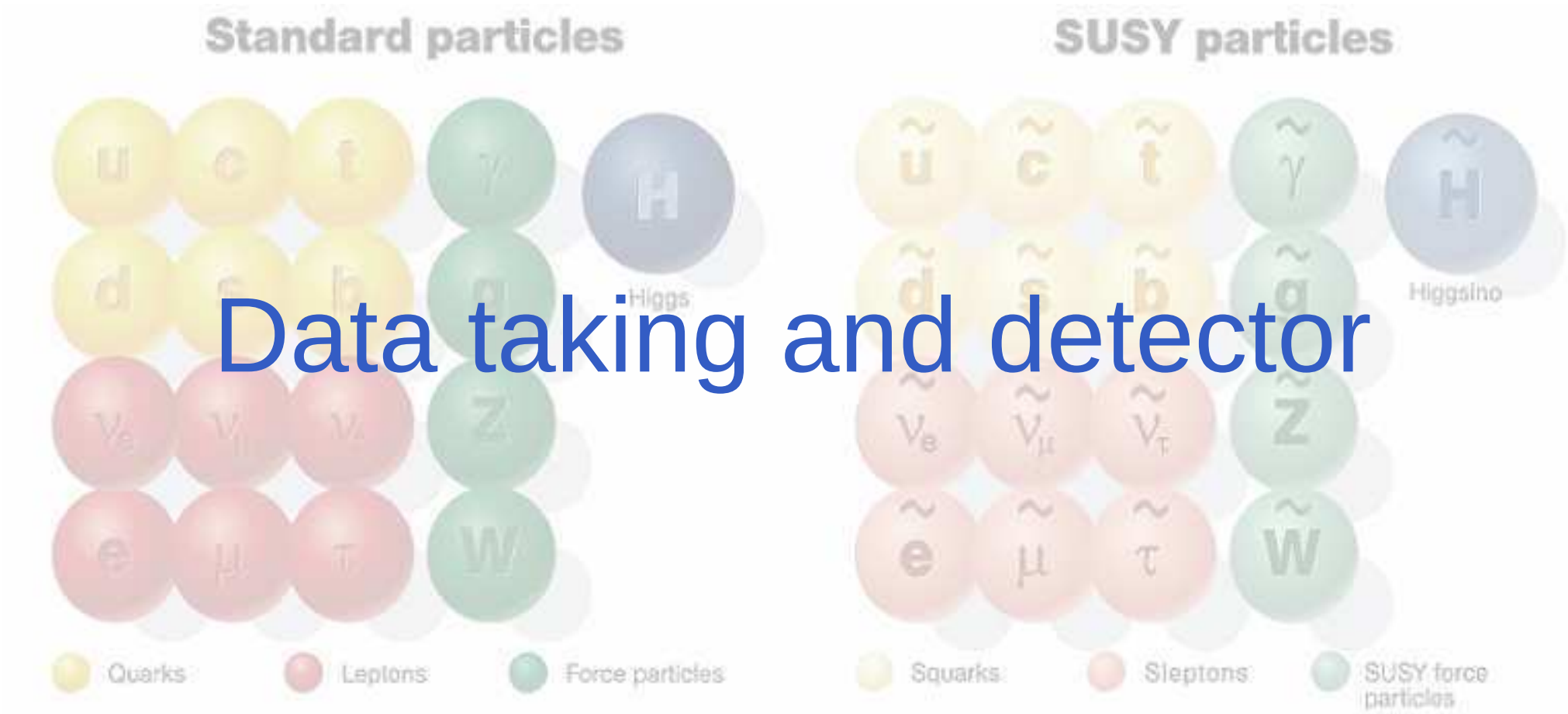
Signal Monte Carlo

- Les Houches Accord (LHA) input files are generated with SOFTSUSY
  - ⇒ SUSY spectra within the MSSM (RGE), one–loop finite corrections
- Events are generated with Pythia using LHA files
- Signal cross sections are calculated with Prospino
  - ⇒ Next–to–Leading order cross sections for SUSY particles at hadron colliders
- Branching fraction are reweighted using SDECAY to properly take into account Stau mixing
  - ⇒ Calculation of decay width and branching fractions in MSSM

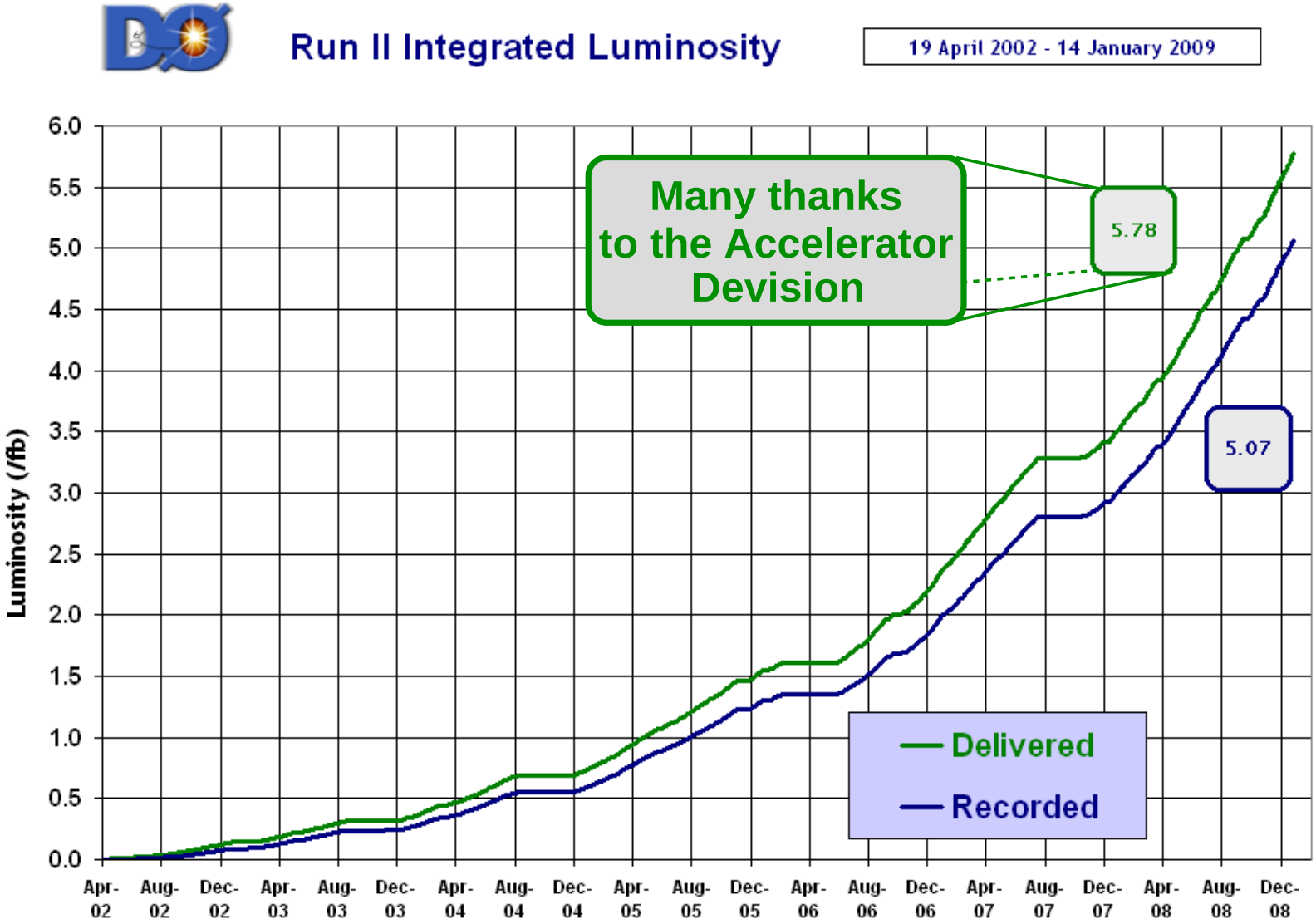




Data taking and detector



Data Taking


Run II Integrated Luminosity
19 April 2002 - 14 January 2009
Many thanks to the Accelerator Devision
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5.07
Delivered
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Luminosity (/fb)
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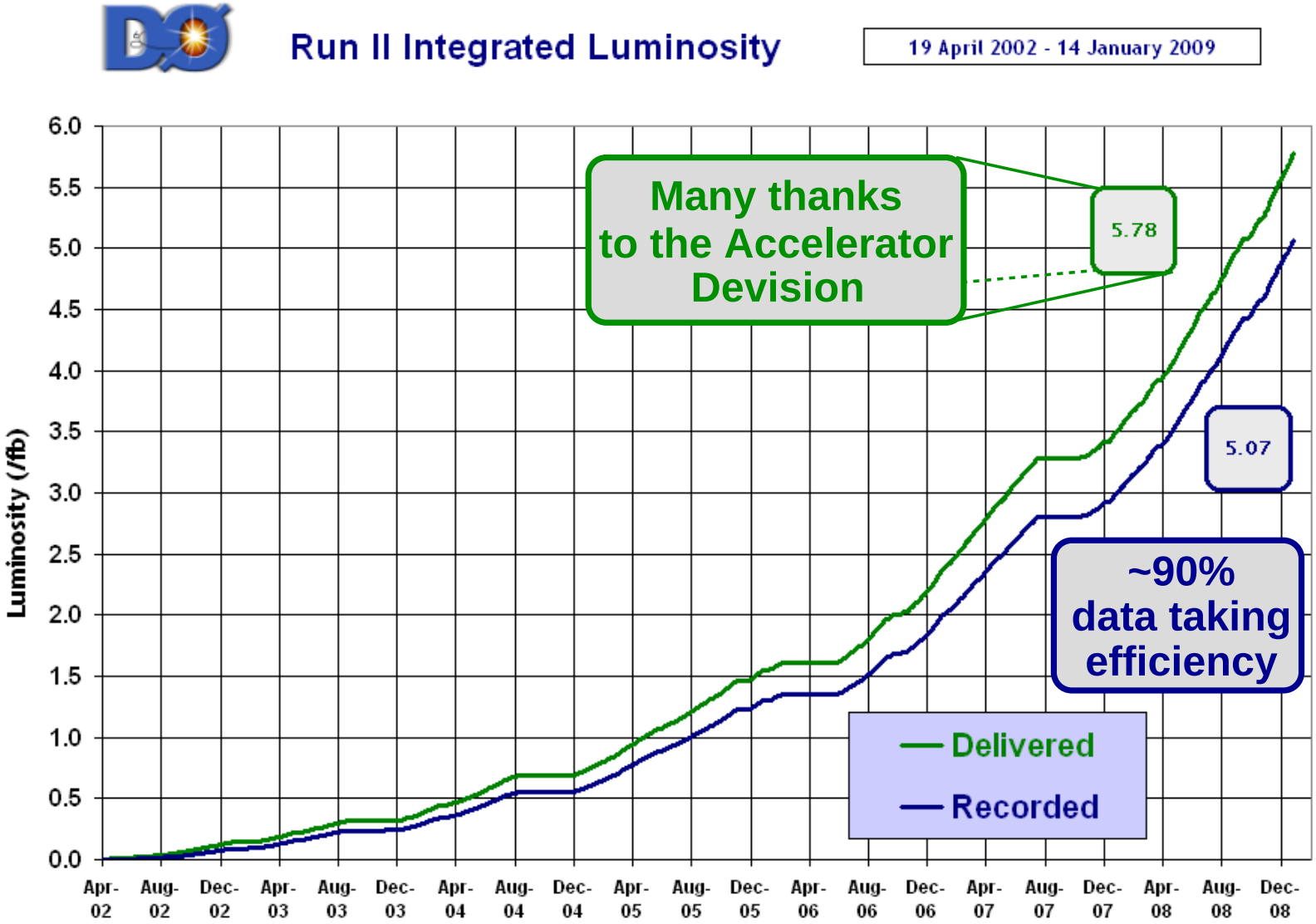
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Dec-06
Apr-07
Aug-07
Dec-07
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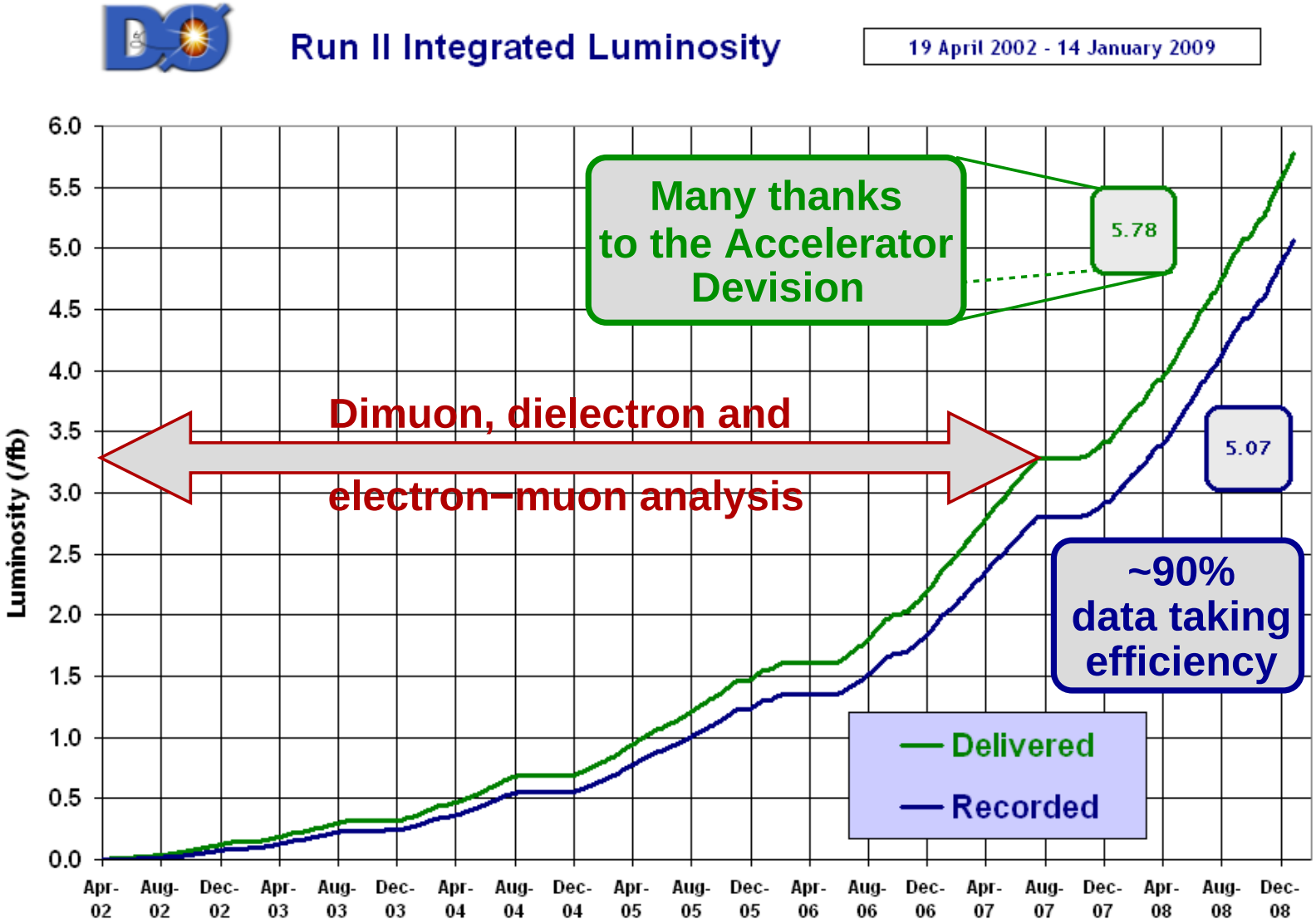
Aug-08
Dec-08
Many thanks to the Accelerator Devision
5.78
5.07
~90% data taking efficiency
Delivered
Recorded

Data Taking


Run II Integrated Luminosity
19 April 2002 - 14 January 2009
Luminosity (/fb)
6.0
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Many thanks to the Accelerator Devision
5.78
Dimuon, dielectron and
electron−muon analysis
5.07
~90% data taking efficiency
Delivered
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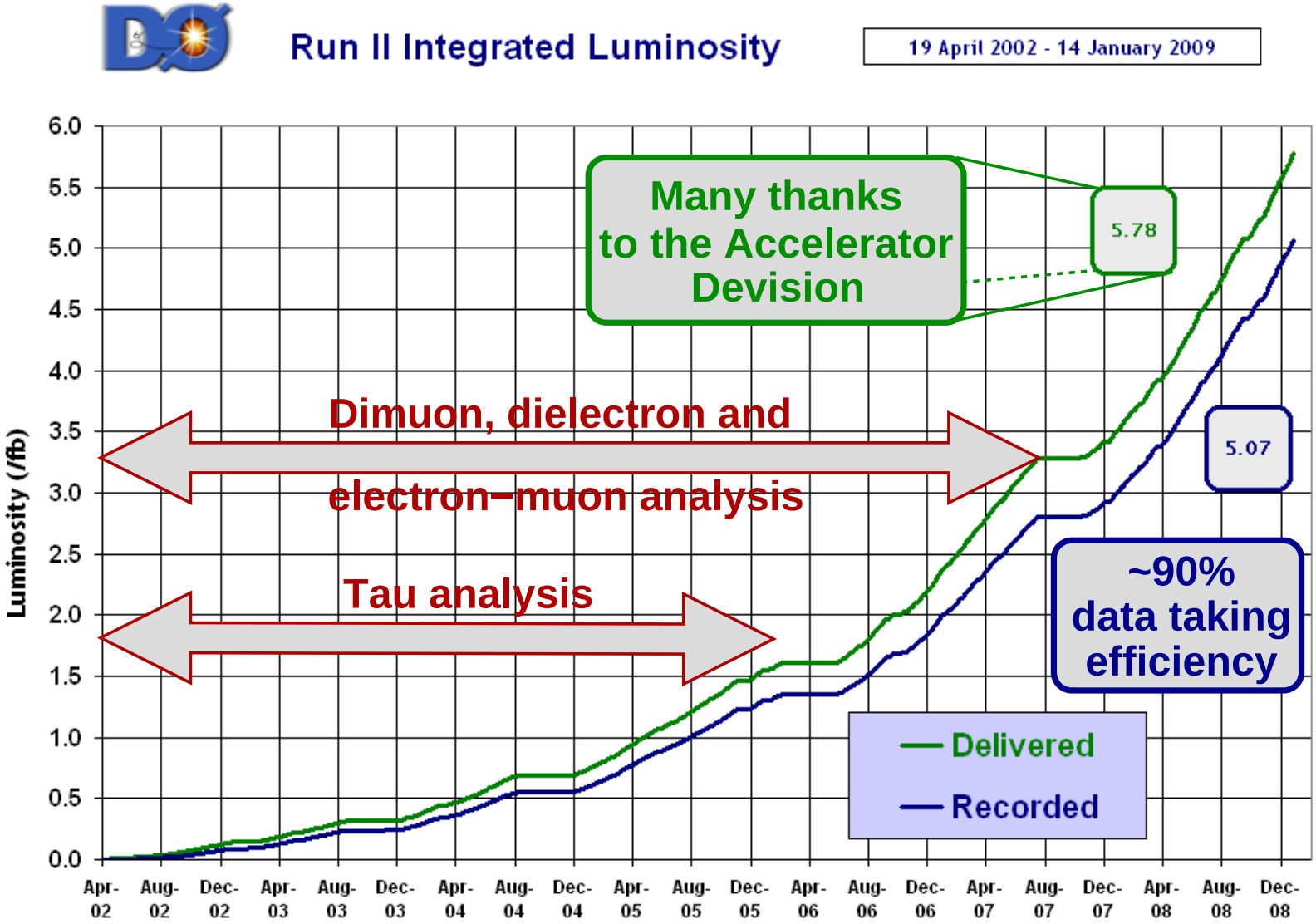
Data Taking


Run II Integrated Luminosity
19 April 2002 - 14 January 2009
Luminosity (/fb)
6.0
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4.0
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2.5
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1.5
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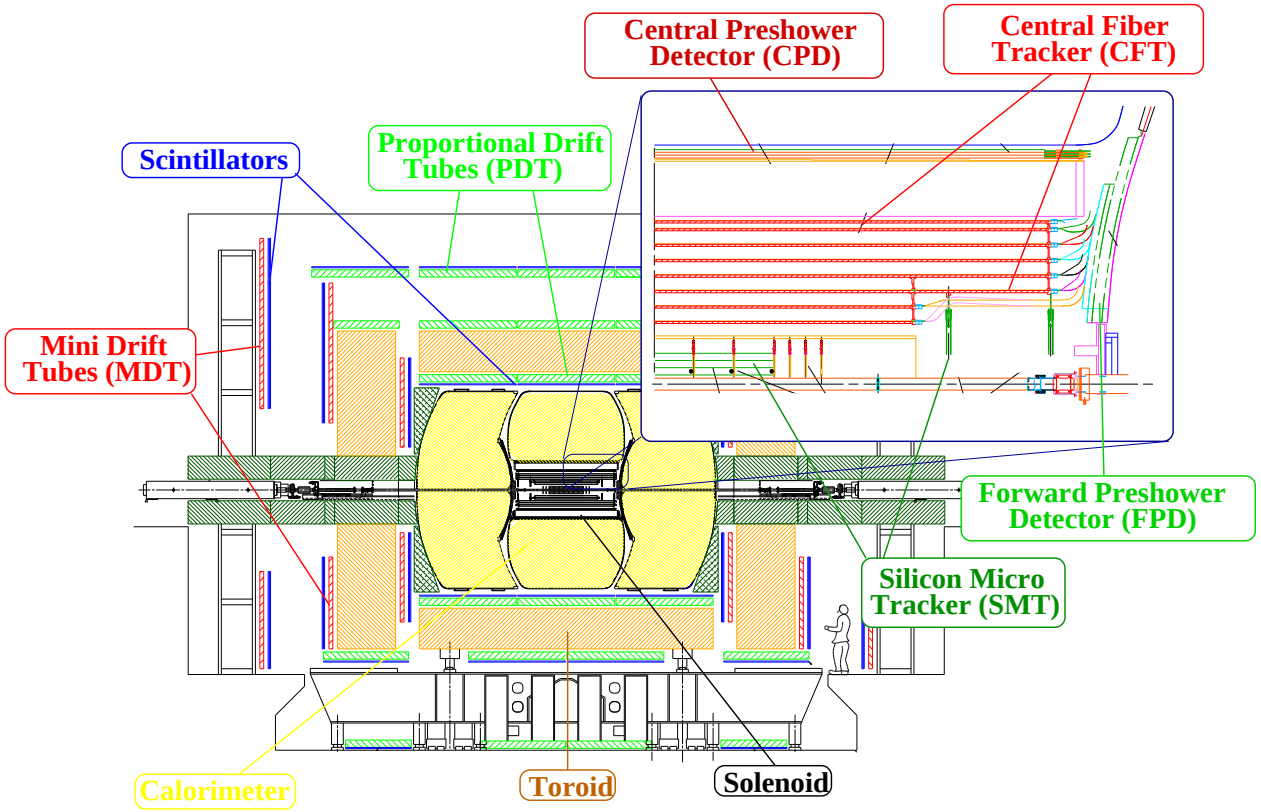
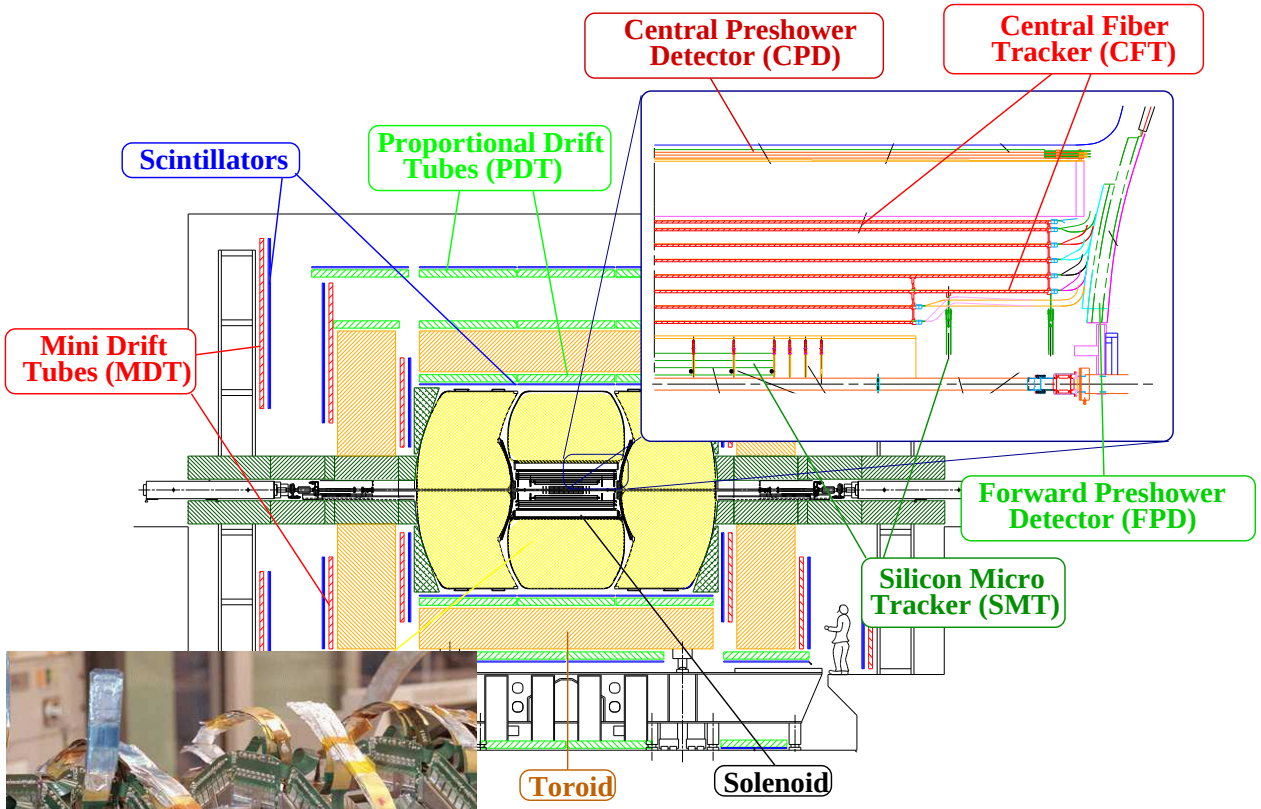
Dec-08
Many thanks to the Accelerator Devision
5.78
5.07
Dimuon, dielectron and
electron−muon analysis
Tau analysis
~90% data taking efficiency
Delivered
Recorded

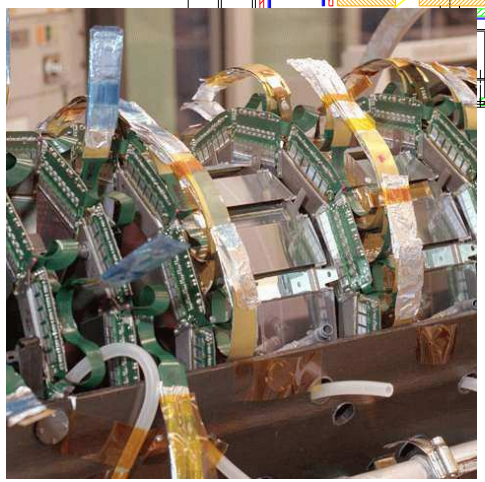
The DØ Detector



- Detector comprises several subdetectors

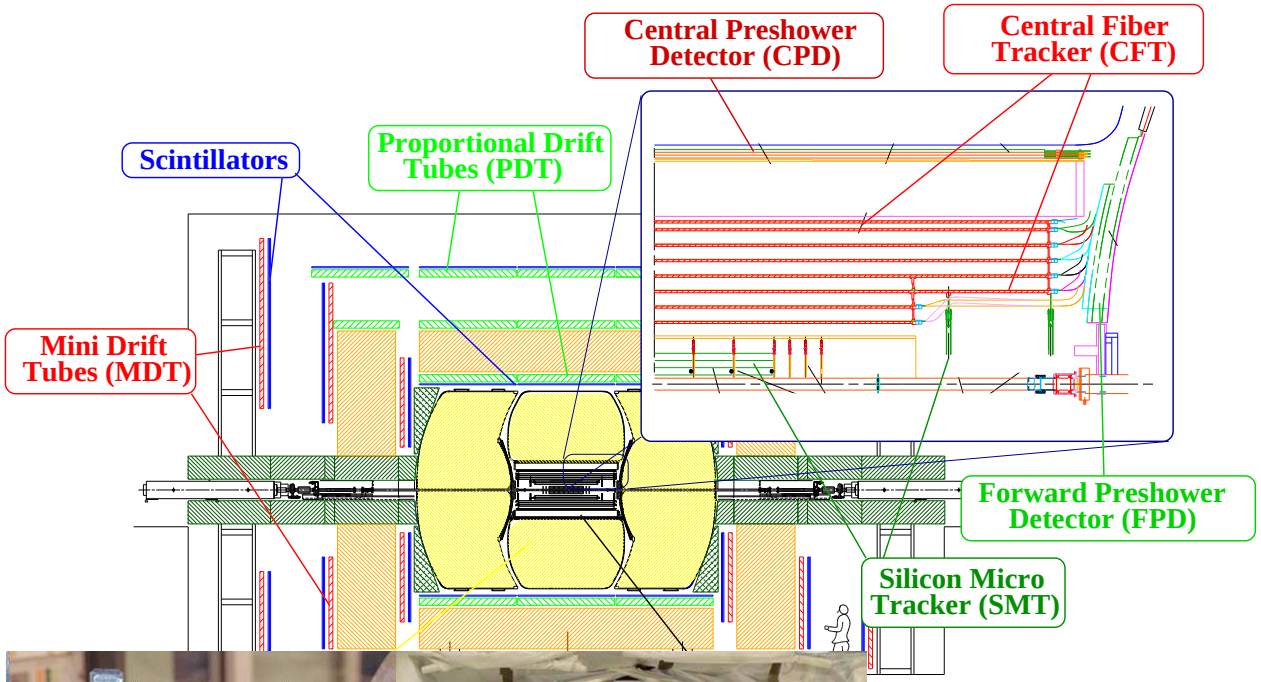
The DØ Detector

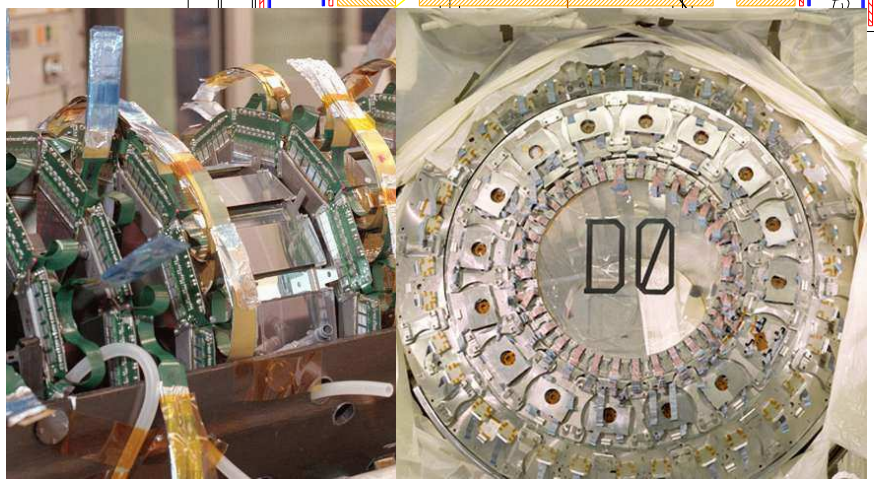




- Detector comprises several subdetectors
- Vertex– and tracking detector
  - ▲ Tracks up to $|\eta| < 2.5$

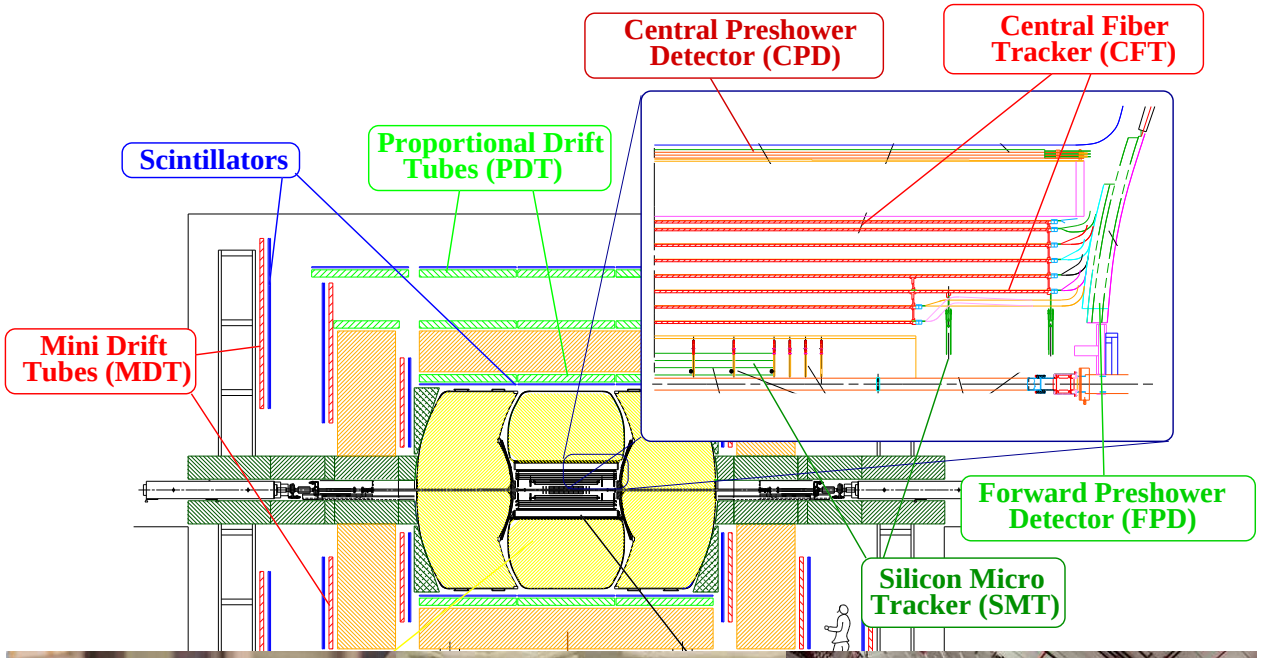
The DØ Detector

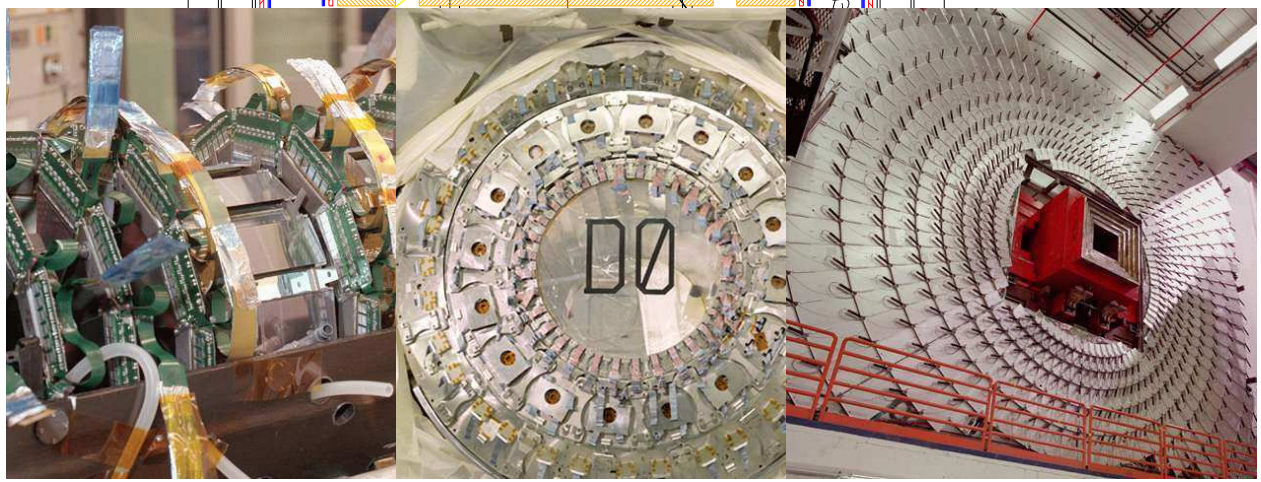




- Detector comprises several subdetectors
- Vertex– and tracking detector
  - ▲ Tracks up to $|\eta| < 2.5$
- Calorimeter
  - ▲ Electrons up to $|\eta| < 3.2$
  - ▲ Jets up to $|\eta| < 2.5$

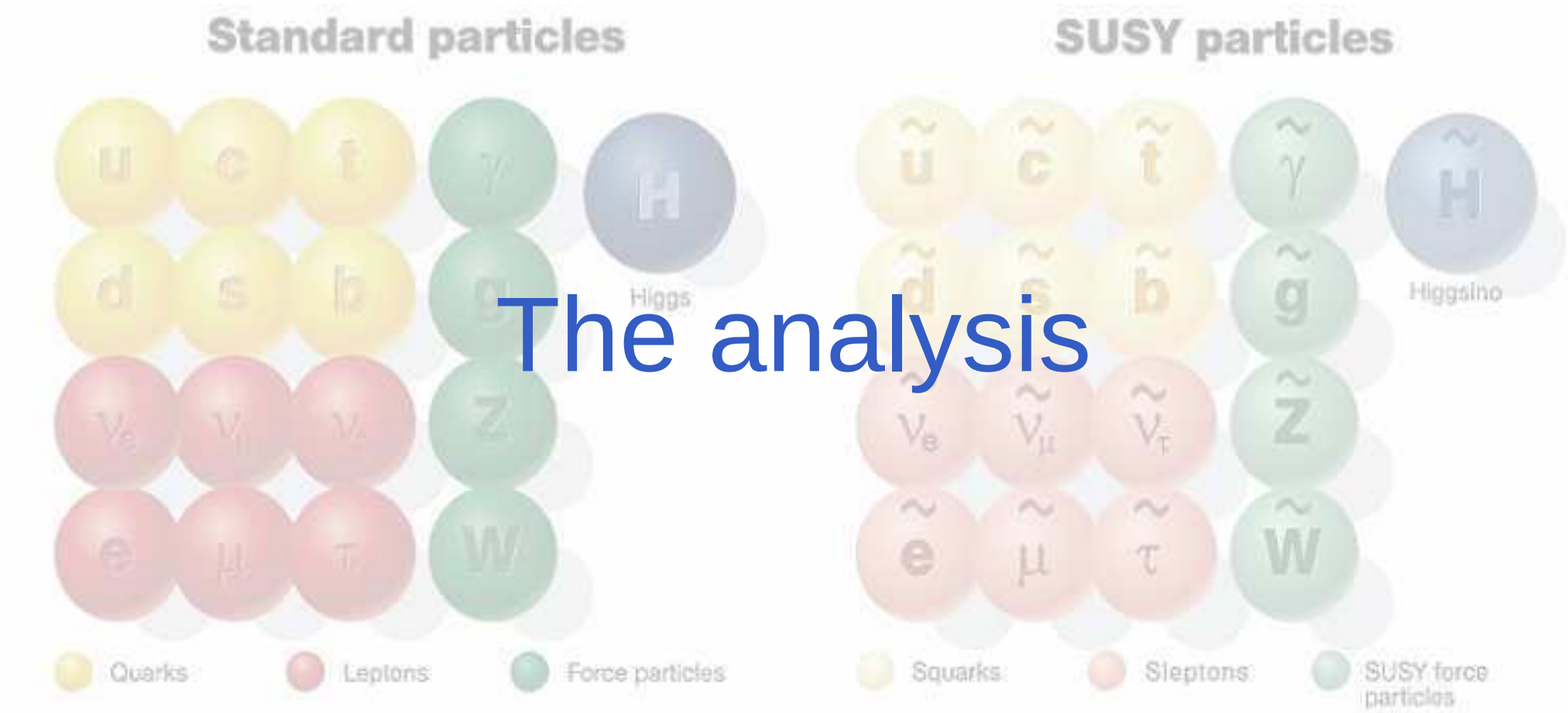
The DØ Detector





- Detector comprises several subdetectors
- Vertex– and tracking detector
  - ▲ Tracks up to $|\eta| < 2.5$
- Calorimeter
  - ▲ Electrons up to $|\eta| < 3.2$
  - ▲ Jets up to $|\eta| < 2.5$
- Muon spectrometer
  - ▲ Reconstruction of muons up to $|\eta| < 2$

The analysis

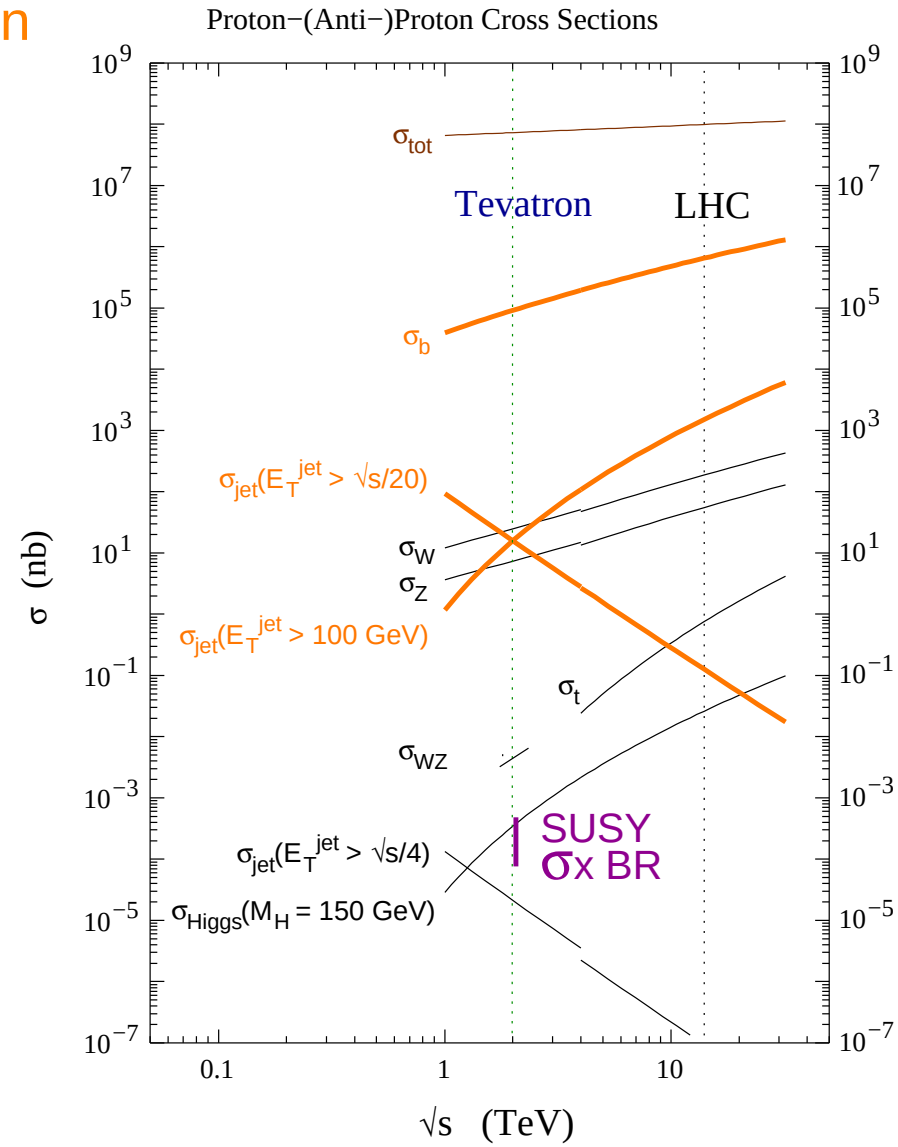


Background Samples

Background	Cross Section (pb)	Generator	Signal Like
Z/$\gamma^* \to \ell\ell$	700	Pythia	Only 2 leptons, no $\not\!\!E_T$ ($\ell = e, \mu$)
$\Upsilon \to \ell\ell$	3000	Pythia	Only 2 leptons, no $\not\!\!E_T$
QCD		Data	No leptons, no $\not\!\!E_T$
$t\bar{t}$	7	Pythia	Only 2 leptons
W$\to \ell\nu$	2500	Alpgen	Only 1 lepton
WW	12	Pythia	Only 2 leptons
ZZ	2	Pythia	Either only 2 leptons or no $\not\!\!E_T$
WZ	4	Pythia	3 leptons and $\not\!\!E_T$

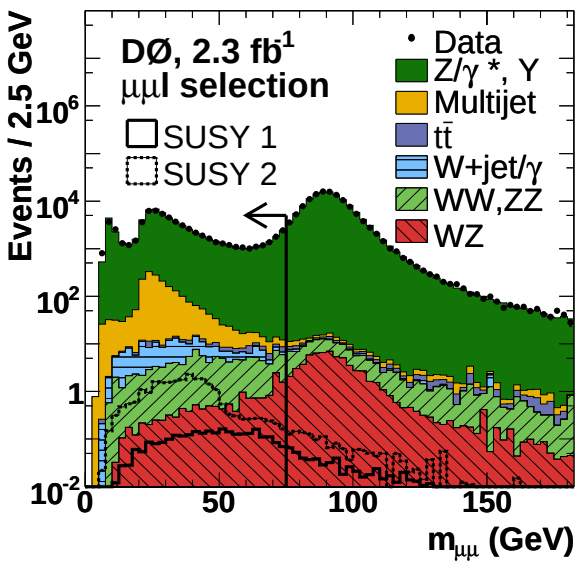
Backgrounds and Selection

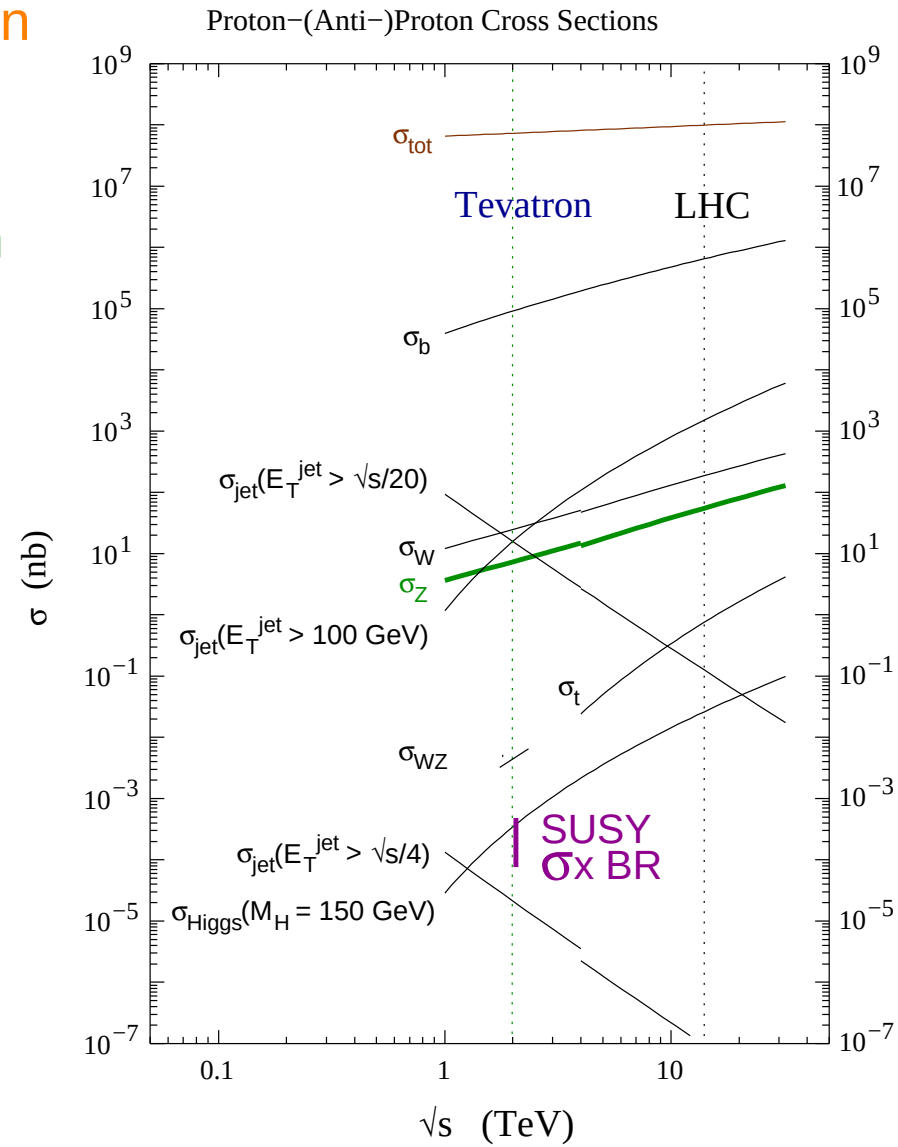
- Main background is QCD multijet production
  - ▲ Very large cross section



Backgrounds and Selection

- Main background is QCD multijet production
  - ▲ Very large cross section
- ▲ Require two isolated leptons
  - ▲ Main contributions from Z/γ production





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- Main background is QCD multijet production
  - ▲ Very large cross section
- Require two isolated leptons
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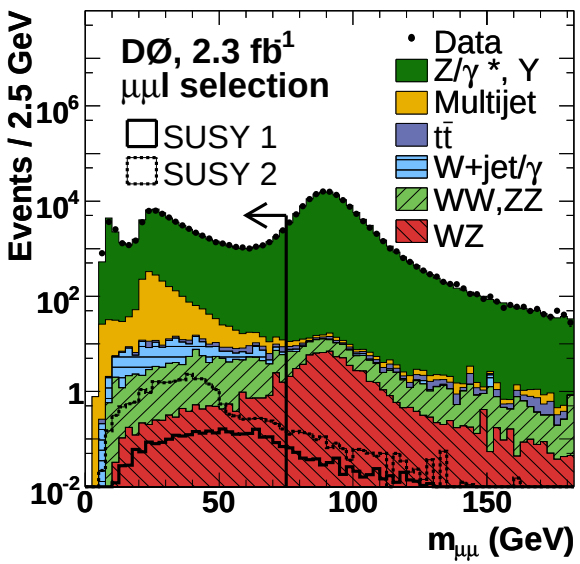
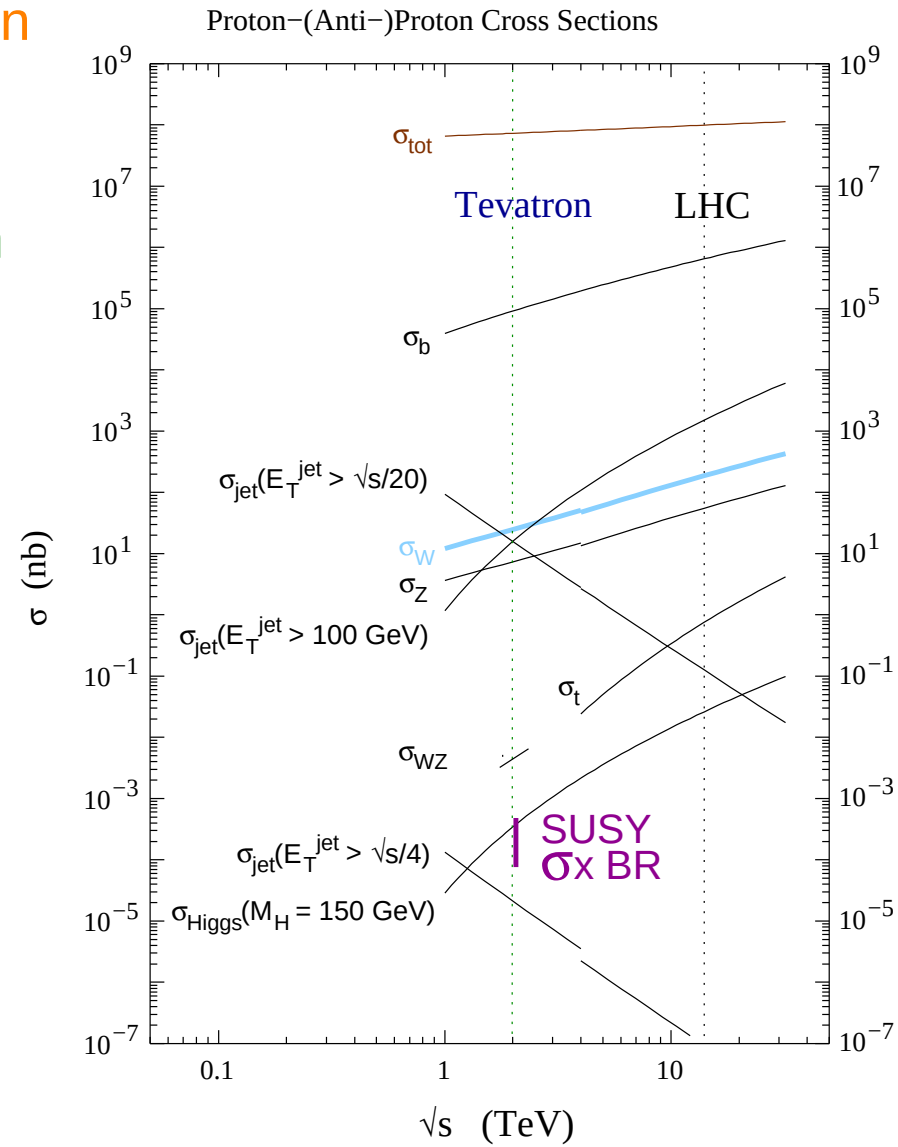
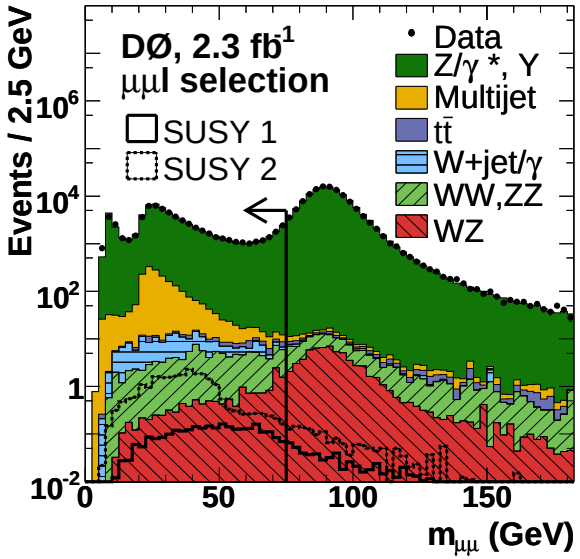
- $\not{E}_T$ requirements
  - ▲ W+jet/γ dominant

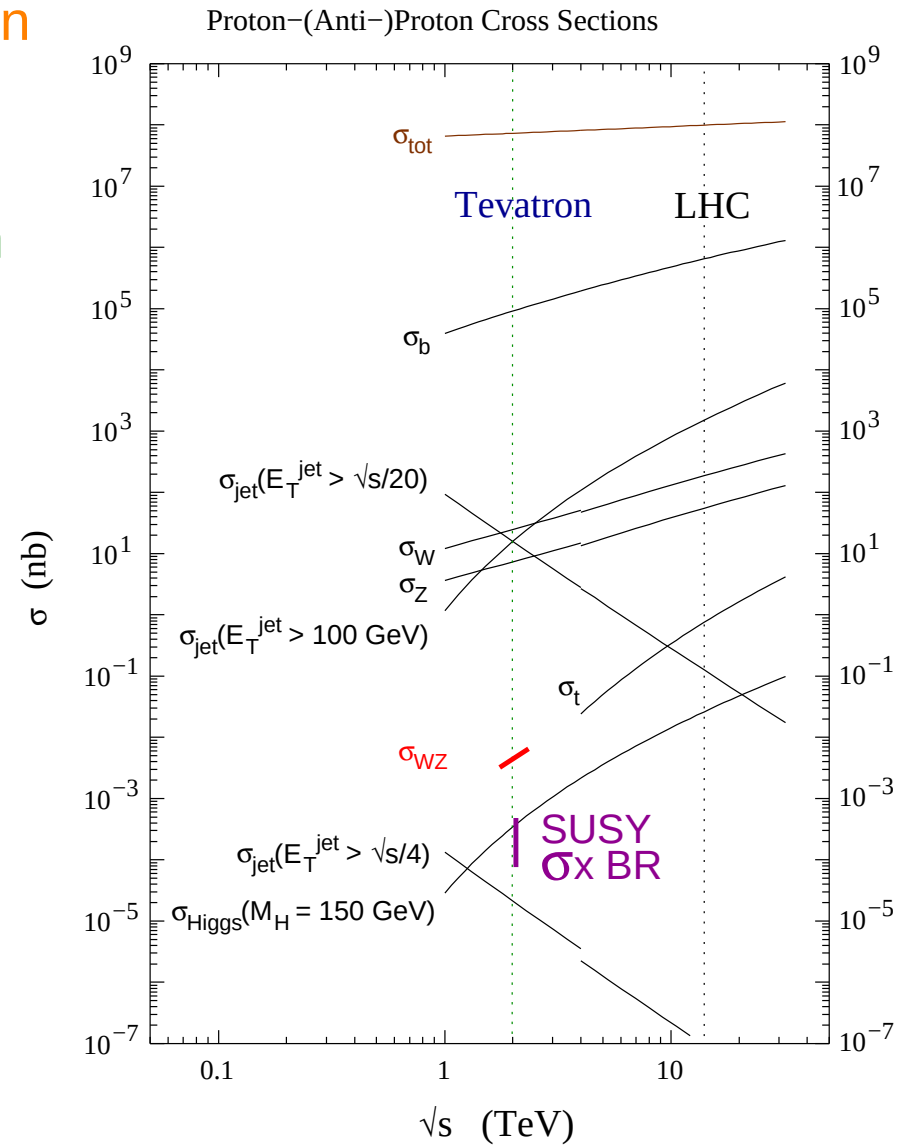




Backgrounds and Selection

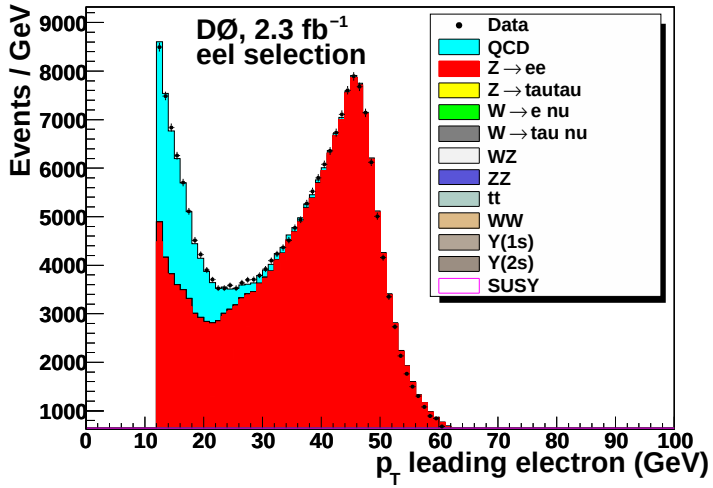
- Main background is QCD multijet production
  - ▲ Very large cross section
- Require two isolated leptons
  - ▲ Main contributions from Z/γ production
- $\not{E}_T$ requirements
  - ▲ W+jet/γ dominant
- Require a third object (track)
  - ▲ Diboson production main contributor



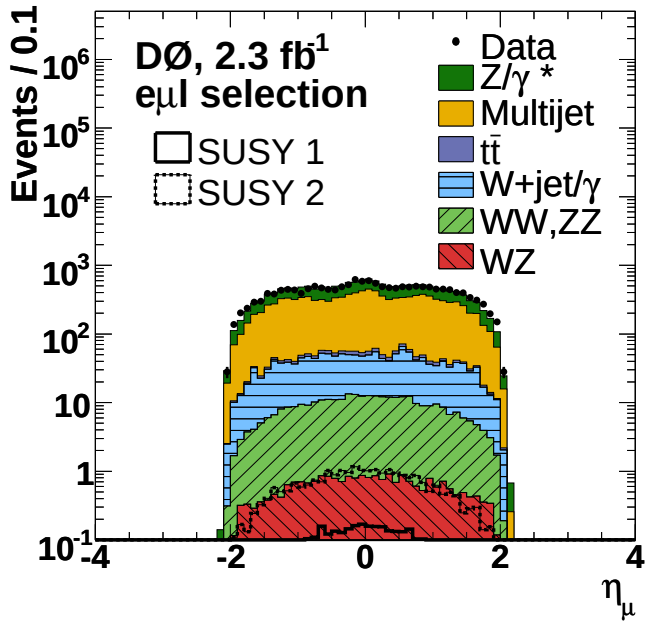


Object Selection

- Electrons: $|\eta| < 3.2$
  - ▲ Electromagnetic fraction > 0.9
  - ▲ Isolation < 0.2
  - ▲ Loose Likelihood requirement
    - ▶ Transverse and longitudinal shower shape
    - ▶ Track based variables: χ^2 match, isolation and number of tracks

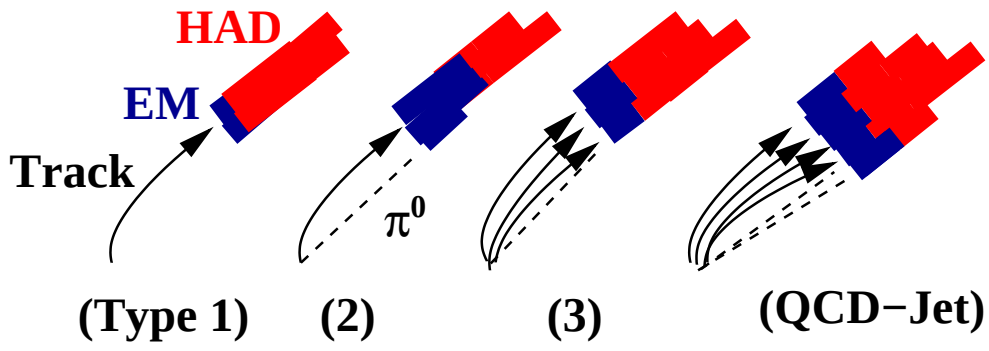


- Muons: $|\eta| < 2.0$
  - ▲ Loose hit requirements in the muon system
  - ▲ Match to track in the inner detector
  - ▲ Loose (tight) track and calorimeter isolation

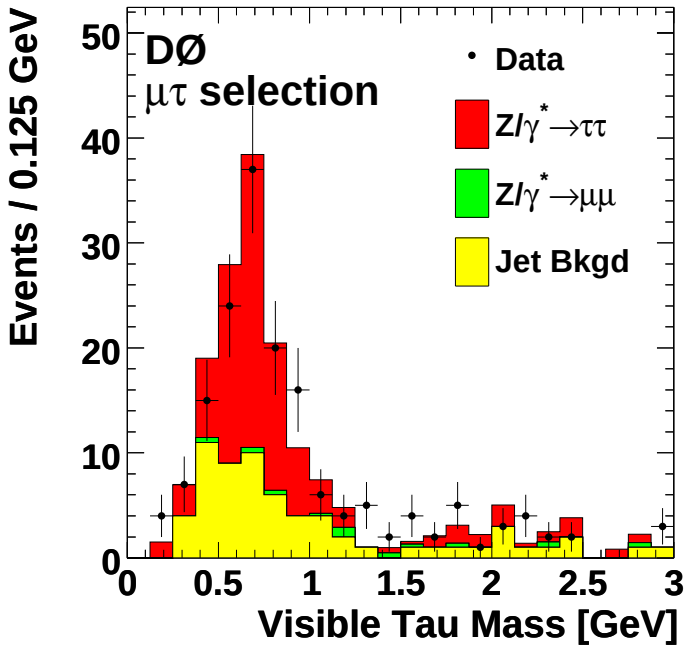


Object Selection (II)

- Taus: $|\eta| < 2.5$
  - ▲ Two different τ types
  - ▲ One neural network (NN) per type
    - ▶ Variables describing the shower profile and isolation
  - ▲ Vary NN cut as function of p_T^τ to keep constant efficiency



- Jets: $|\eta| < 2.5$
  - ▲ Iterative midpoint cone algorithm with cone radius of 0.5



- Missing transverse energy
  - ▲ Negative vector sum of the transverse energy in the calorimeter cells
  - ▲ Correct for electron and jet energy scale
  - ▲ Correct for reconstructed muons

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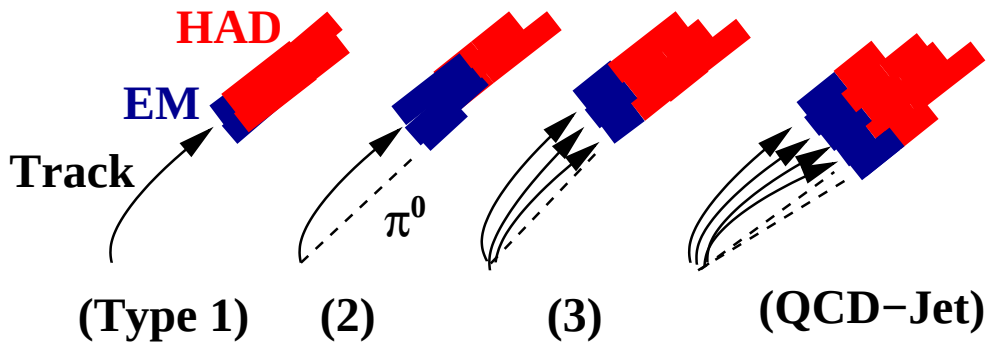

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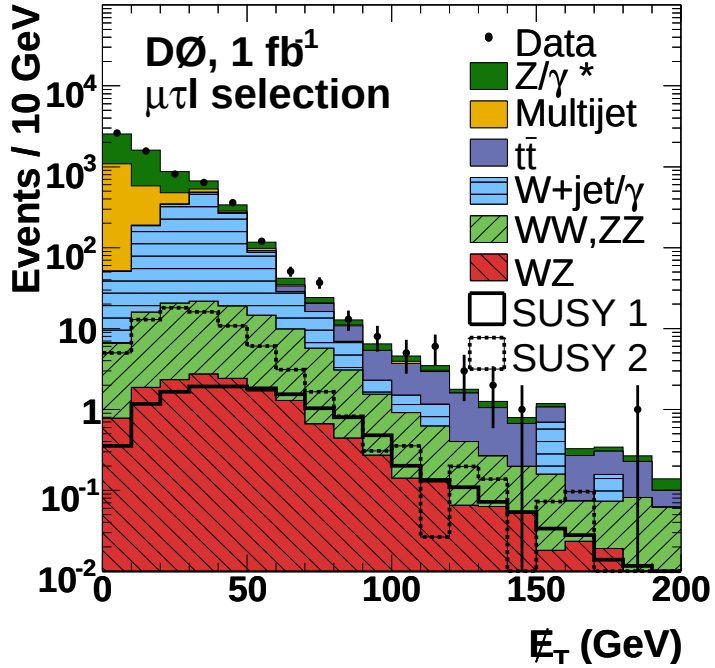
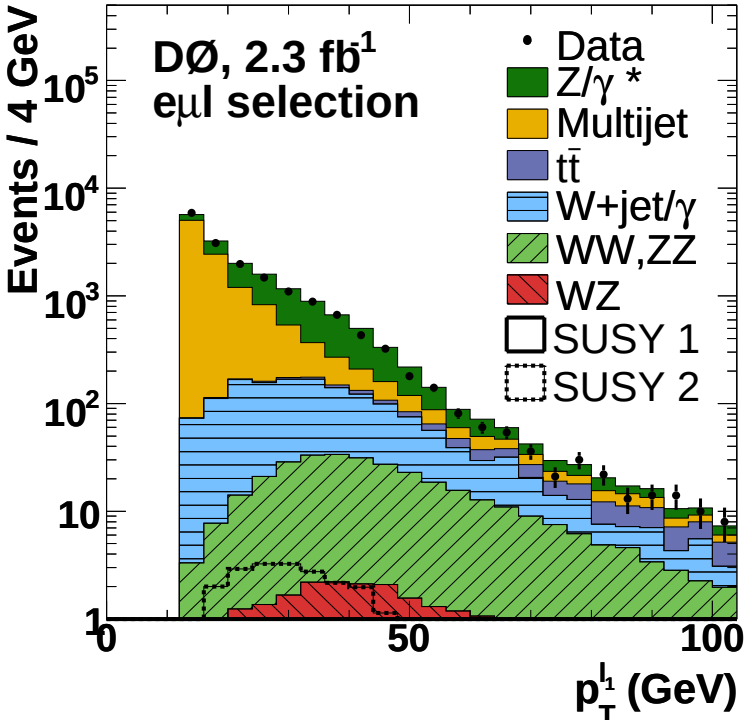
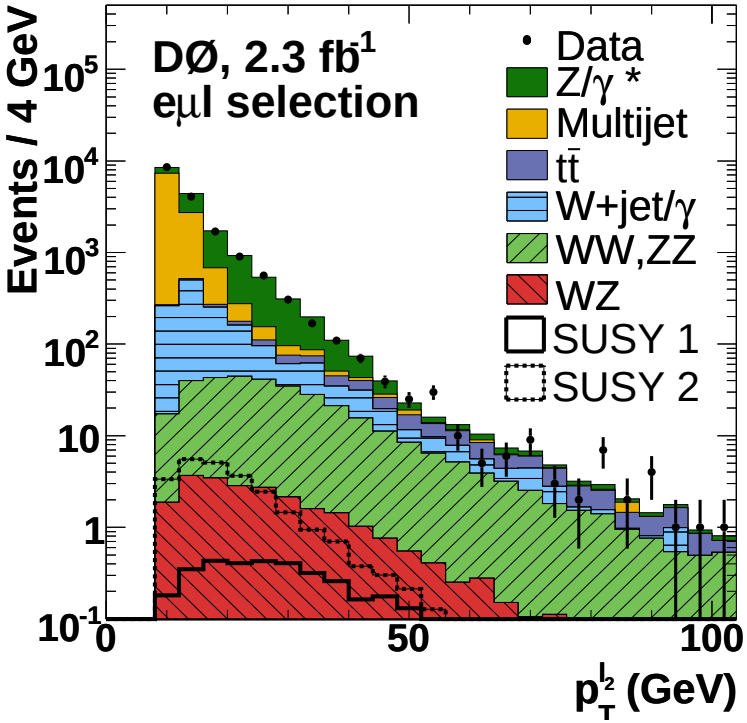


Preselection

- Combination of single lepton, dilepton and lepton+track triggern
- Require two leptons from the same vertex

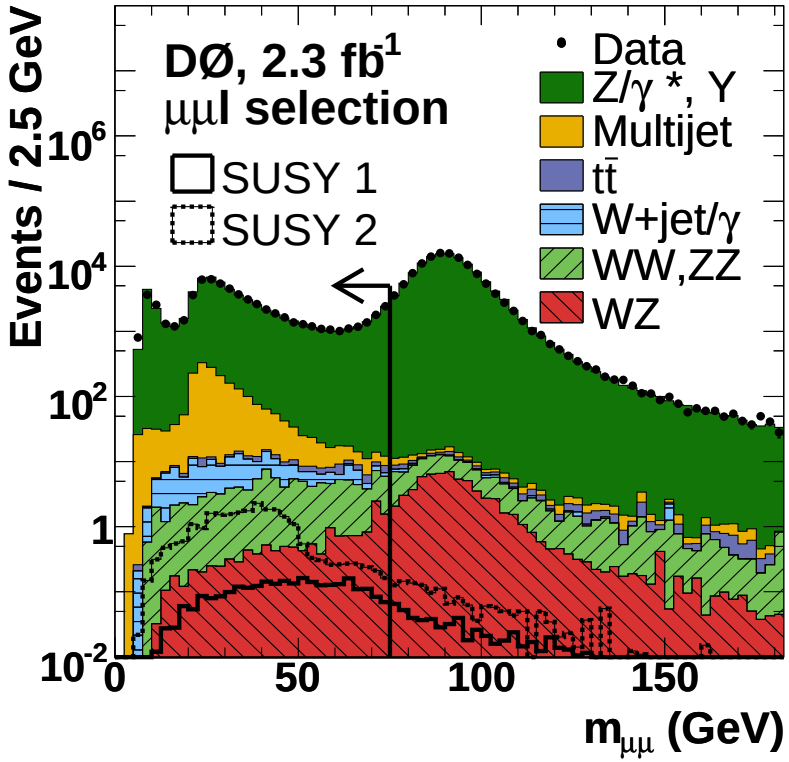
Selection	$\mu\mu\ell$	$ee\ell$	$e\mu\ell$	$\mu\tau$
$p_T^{\ell_1}$ (GeV)	12	12	12	15
$p_T^{\ell_2}$ (GeV)	8	8	8	8





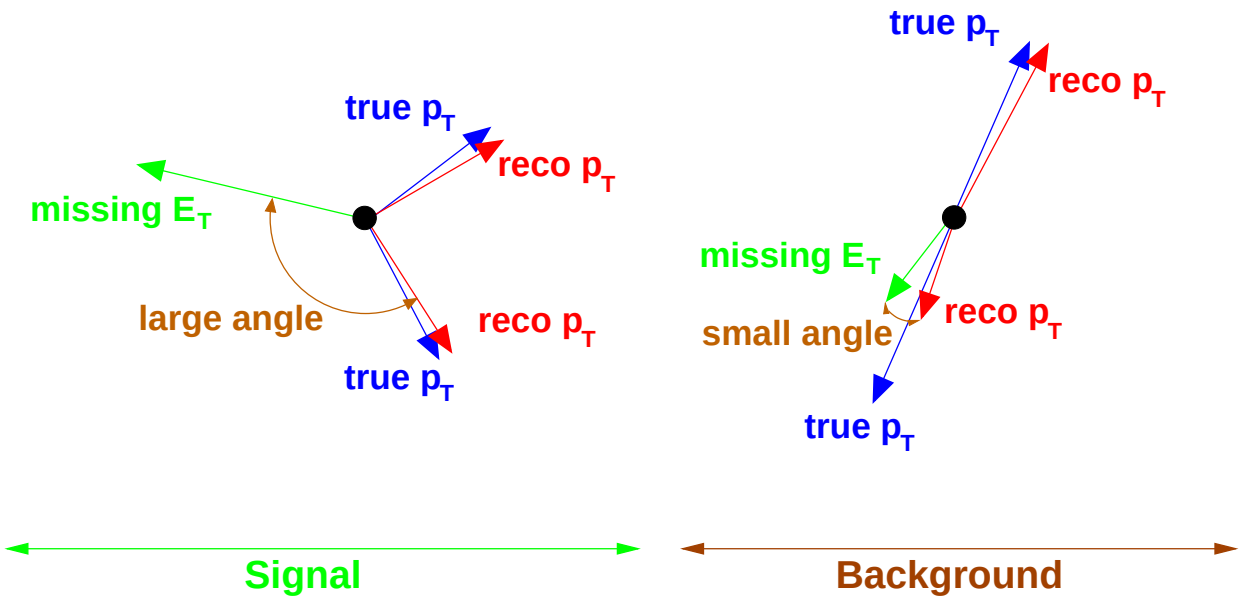
Preselection (II)

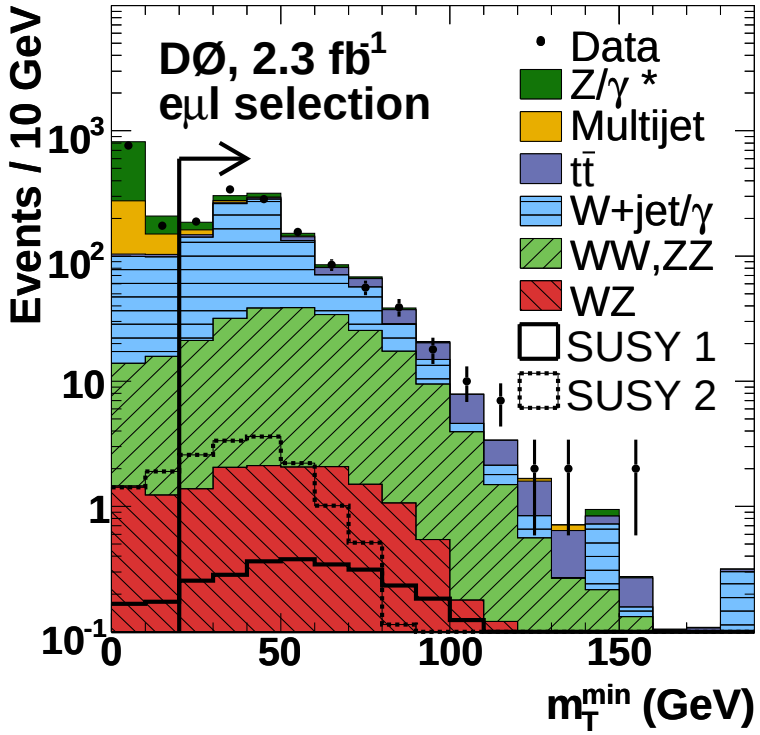
- Selection dominated by Z→ $\ell\ell$ events
  - ▲ Use events from Z resonance for several cross checks
    - ► Trigger efficiency measurements
    - ► Normalization of number of events, cross check of integrated luminosity
    - ► Measurement of lepton reconstruction efficiencies and resolutions



Cuts using Missing Transverse Energy

- $\not{E}_T$ related cuts
  - Cut of 20 GeV on $\not{E}_T$ itself
  - Transverse mass cut: $m_T = \sqrt{2 \cdot p_T^{\ell} \cdot \not{E}_T \cdot (1 - \cos \Delta\Phi(\ell, \not{E}_T))}$
    - Rejects events with mismeasured lepton energies





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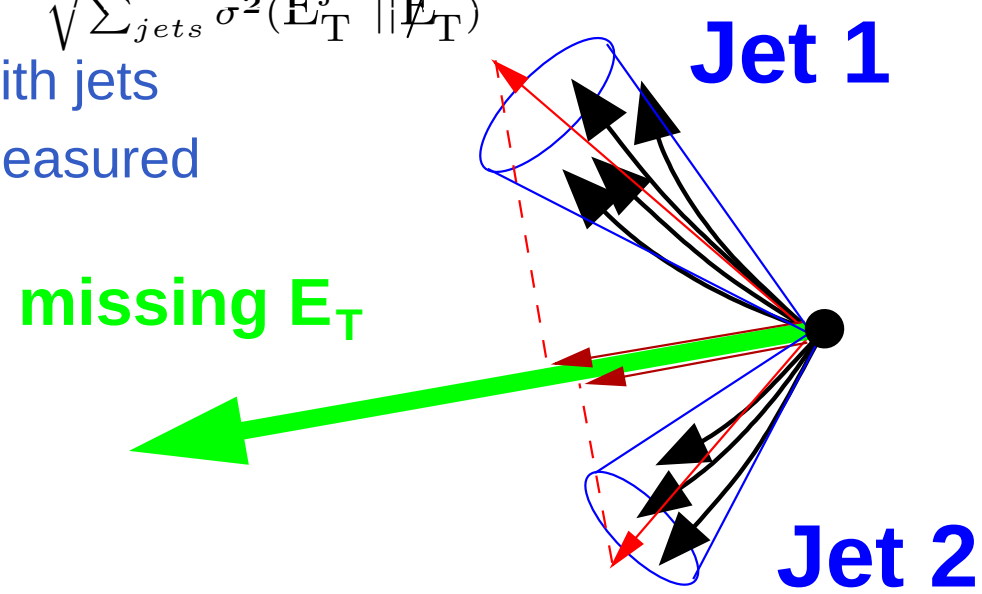
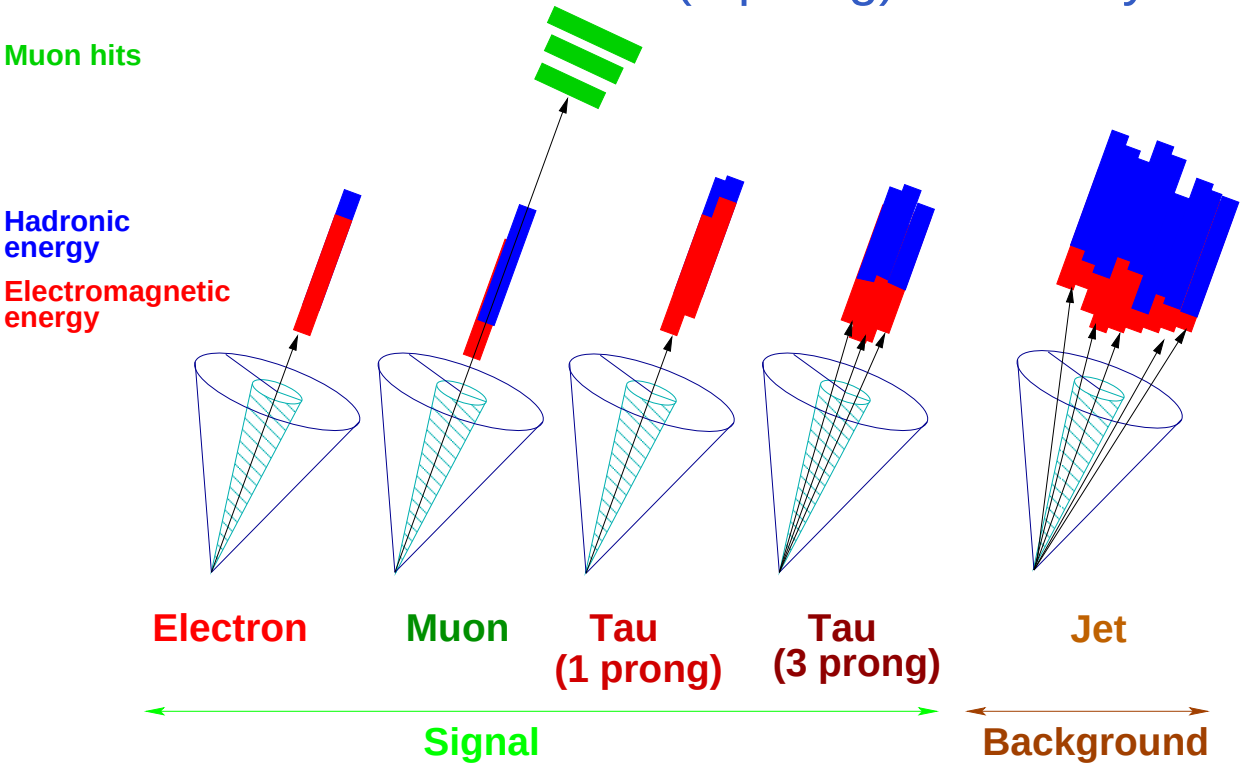
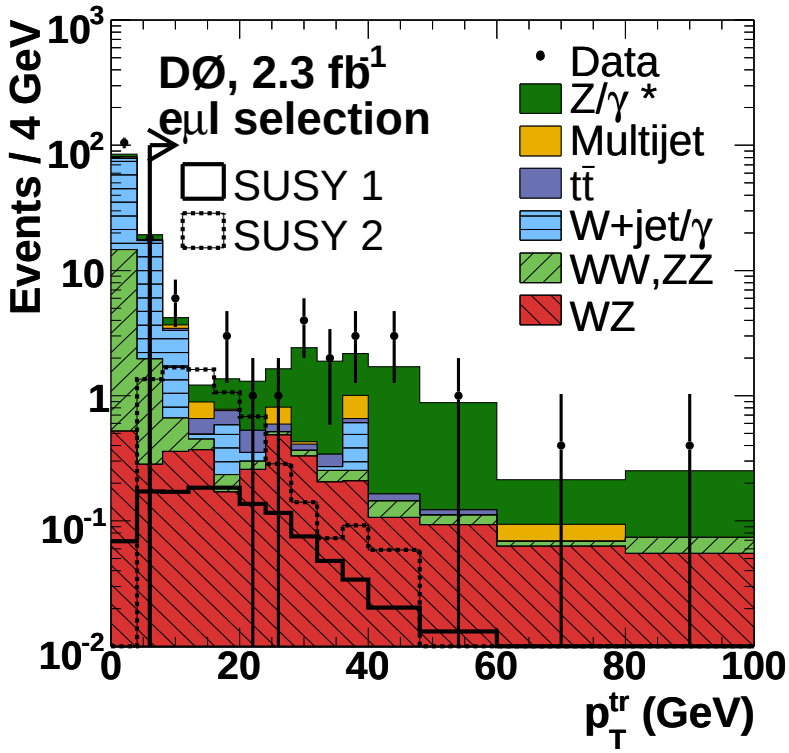
  - Transverse mass cut: $m_T = \sqrt{2 \cdot p_T^{\ell} \cdot \not{E}_T \cdot (1 - \cos \Delta\Phi(\ell, \not{E}_T))}$
    - Rejects events with mismeasured lepton energies
  - Significance of $\not{E}_T$: $\mathrm{Sig}(\not{E}_T) = \frac{\not{E}_T}{\sqrt{\sum_{jets} \sigma^2(E_T^{jet} || \not{E}_T)}}$
    - Only defined for events with jets
    - Rejects events with mismeasured jet energies



Third Object Selection

- Select high quality track to account for the third lepton
  - ▲ Track must be isolated in the tracker and calorimeter
    - ► Efficient for electrons, muons and taus, suppresses tracks in jets
  - ▲ Use hollow cone for isolation
    - ► Also efficient for (3 prong) tau decays





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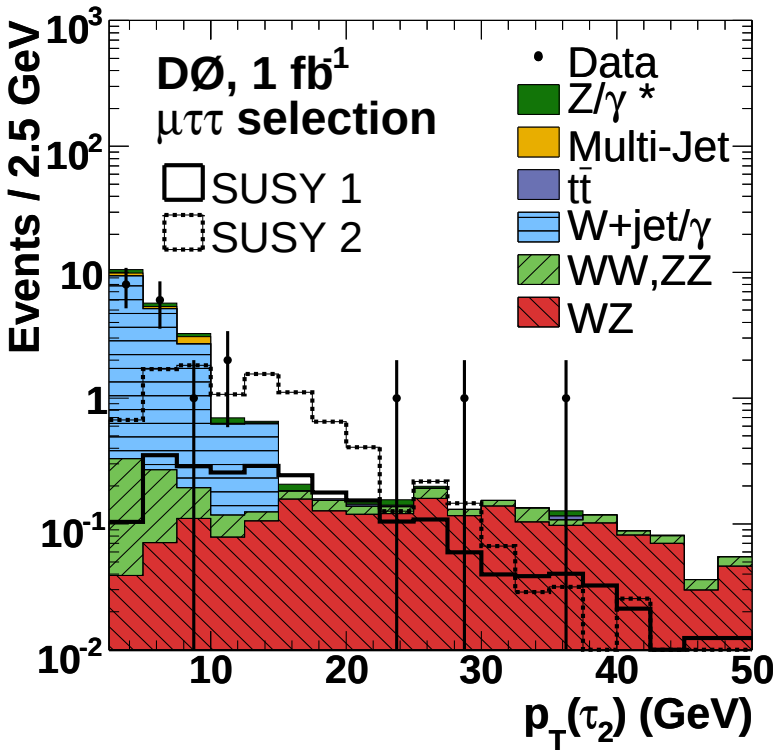
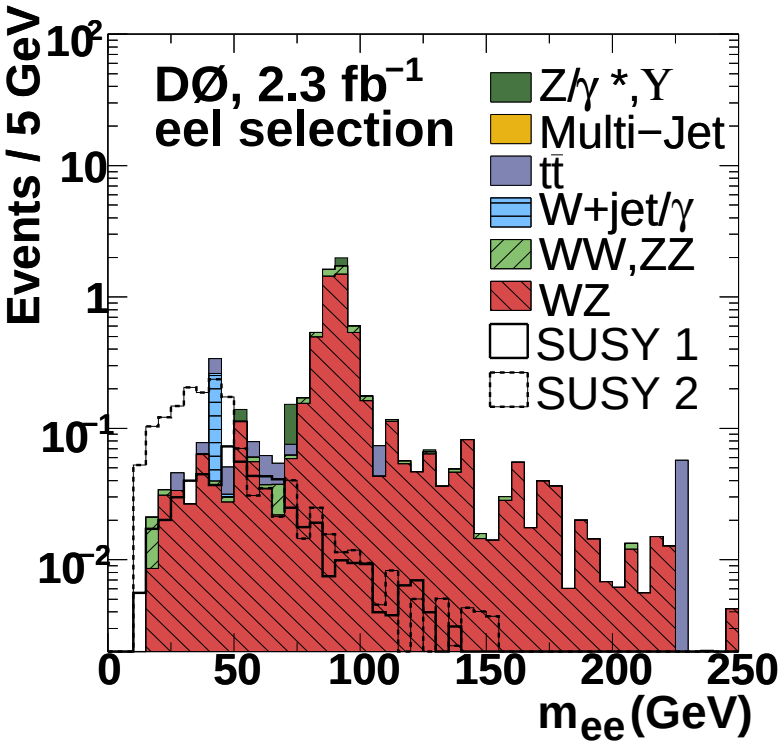
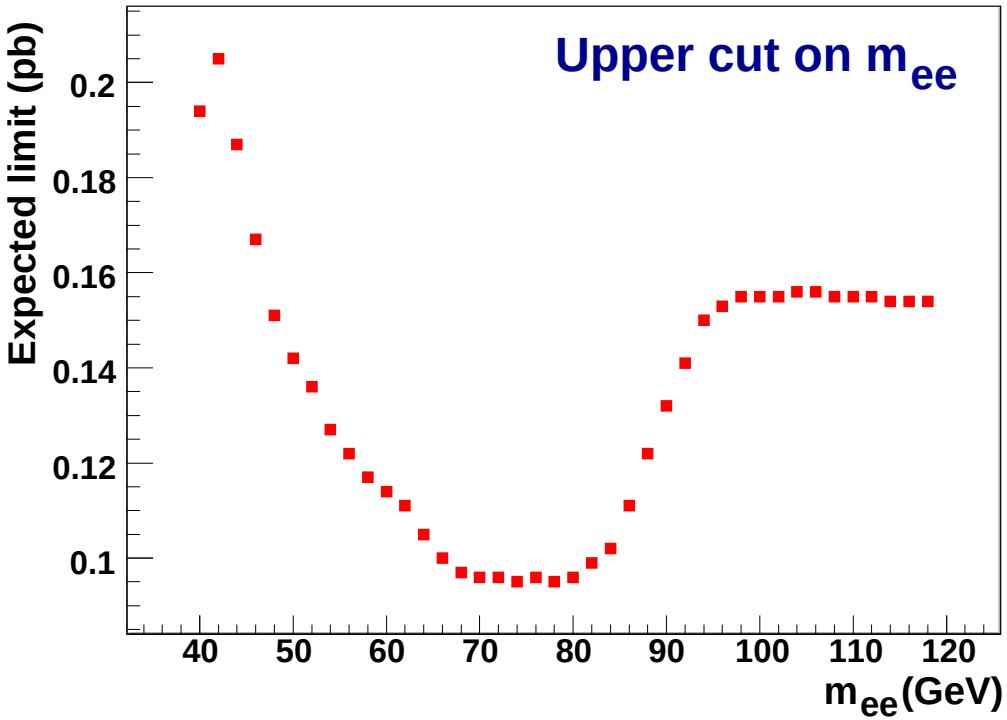
- Instead of track require fully reconstructed hadronic tau
  - ▲ Orthogonal to the track selection
  - ▲ Recover events lost in the track selection
  - ▲ Tighter requirement ⇒ Cleaner selection



Optimization Procedure

- An optimization procedure is performed on every analysis
  - ▲ Separately for every final state and low–/high–p_T selection
- Scan marginal distributions to find optimal cut value
  - ▲ Optimize for best expected cross section limit
- Optimization performed in an iterative approach





Selection Criteria

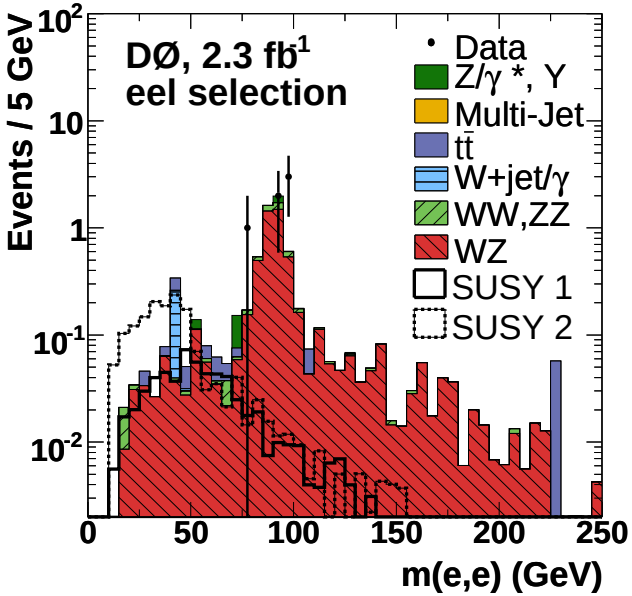
	Cut	$\mu\mu+\ell$		$ee+\ell$		$e\mu+\ell$	
I	$p_T^{\ell_1}, p_T^{\ell_2}$	>12, >8	>18, >16	>12, >8	>20, >10	>12, >8	>15, >15
II	$m_{\ell\ell}$	$\in [20, 60]$	$\in [0, 75]$	$\in [18, 60]$	$\in [0, 75]$	–	–
	$\Delta\phi_{\ell\ell}$	<2.9	<2.9	<2.9	<2.9	–	–
III	$\not{E}_T$	>20	>20	>22	>20	>20	>20
	Sig($\not{E}_T$)	>8	>8	>8	>8	>8	>8
	$m_T^{\min}$	>20	>20	>20	>14	>20	>15
	jet-veto H_T	–	<80	–	–	–	–
IV	p_T^{tr}	>5	>4	>4	>12	>6	>6
V	m_T^{tr}	>10	>10	>10	>10	>10	>8
	$m_{\ell\ell}$	$\notin [80, 110]$	–	–	–	<70	<70
VI	Anti W	–	–	Lhood>0.8		Lhood>0.8 Hit in layers 1, 2 Muon iso<1	
VII	$\lvert\Sigma_{p_T}\rvert/p_T^{tr}$	<4	<4	<4	<4	<2	<2
	$\not{E}_T \times p_T^{tr}$	>200	>300	>220	–	–	–

Selection Criteria (II)

		$\mu\tau\ell$		$\mu\tau\tau$
I	$p_T^{\ell_1}$, $p_T^{\ell_2}$		>15, >8	
II	$\Delta\phi_{\ell_1\ell_2}$		<2.9	
III	$\not{E}_T$		>20	
	Sig($\not{E}_T$)		>8	
	m_T^{μ}		>20	
	jet-veto H_T		<80	
IV	p_T^{tr}	>3	$p_T^{\tau_2}$	>4
V	$\Delta\phi_{tr,\not{E}_T}$	>0.5	$\Delta\phi_{\tau_2,\not{E}_T}$	>0.5
	$m_{\ell\ell}$	<60		<60
VI	Anti W	Lhood		Lhood
			$NN_{\tau_1} \times NN_{\tau_2}$	>0.7
VII	$\not{E}_T \times p_T^{tr}$	>300	$\lvert\Sigma_{p_T}\rvert / p_T^{tr}$	<3.5

Cutflow

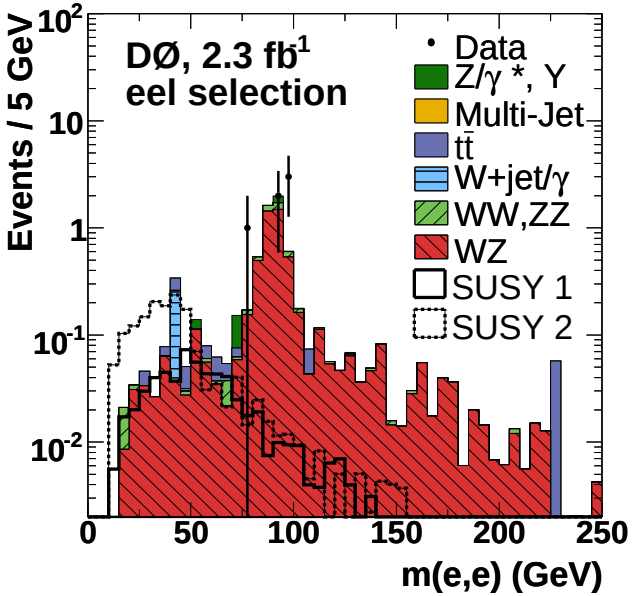
Cut	$\mu\mu\ell$ Data	$\mu\mu\ell$ Backgrd.	$\mu\mu\ell$ Eff. (%)	$ee\ell$ Data	$ee\ell$ Backgrd.	$ee\ell$ Eff. (%)	$e\mu\ell$ Data	$e\mu\ell$ Backgrd.	$e\mu\ell$ Eff. (%)
I	194006	195557±177	19.9±0.3	235474	232736±202	15.5±0.2	16630	16884±75	10.5±0.1
IV	7	2.9±0.7	3.4±0.1	16	9.3±2.0	3.0±0.1	22	18.0±1.2	2.4±0.1
VII	4	1.2±0.2	2.8±0.1	2	1.8±0.2	2.1±0.1	2	0.8±0.2	1.3±0.1
I	140417	141781±120	19.6±0.2	171001	170197±175	18.1±0.2	4617	4709±23	11.5±0.2
IV	7	3.8±0.5	5.9±0.1	0	1.5±0.3	4.0±0.1	11	12.7±0.9	4.1±0.1
VII	4	2.0±0.3	5.0±0.1	0	0.8±0.1	3.6±0.1	0	0.5±0.1	2.1±0.1



- Low p_T selection (including $\mu\tau$ analyses)
  - Background at final selection stage dominated by diboson production: 50%
  - Other background components
    - $Z \to \ell\ell$: 10%
    - $W \to \ell\nu$: 30%
    - $t\bar{t}$: 5%
  - Total signal expectation: 9.3 events

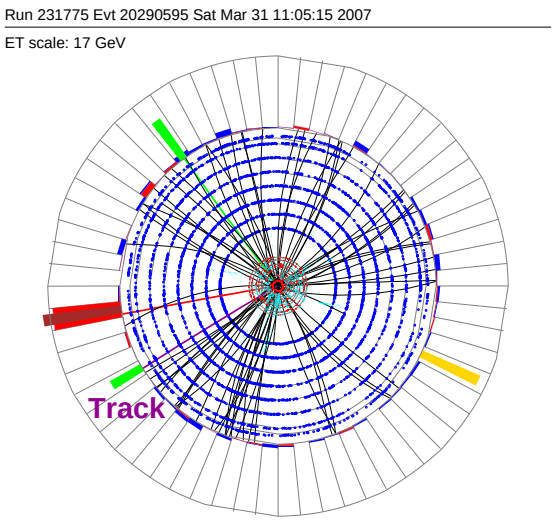
Cutflow

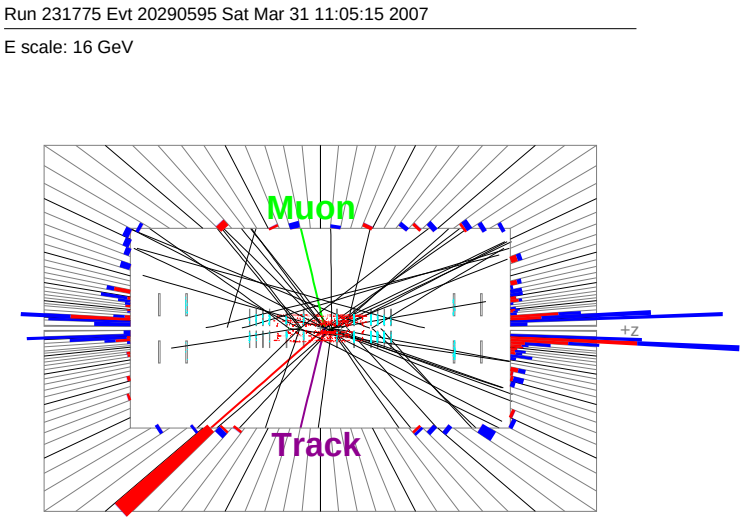
Cut	$\mu\mu\ell$ Data	$\mu\mu\ell$ Backgrd.	$\mu\mu\ell$ Eff. (%)	$ee\ell$ Data	$ee\ell$ Backgrd.	$ee\ell$ Eff. (%)	$e\mu\ell$ Data	$e\mu\ell$ Backgrd.	$e\mu\ell$ Eff. (%)
I	194006	195557±177	19.9±0.3	235474	232736±202	15.5±0.2	16630	16884±75	10.5±0.1
IV	7	2.9±0.7	3.4±0.1	16	9.3±2.0	3.0±0.1	22	18.0±1.2	2.4±0.1
VII	4	1.2±0.2	2.8±0.1	2	1.8±0.2	2.1±0.1	2	0.8±0.2	1.3±0.1
I	140417	141781±120	19.6±0.2	171001	170197±175	18.1±0.2	4617	4709±23	11.5±0.2
IV	7	3.8±0.5	5.9±0.1	0	1.5±0.3	4.0±0.1	11	12.7±0.9	4.1±0.1
VII	4	2.0±0.3	5.0±0.1	0	0.8±0.1	3.6±0.1	0	0.5±0.1	2.1±0.1

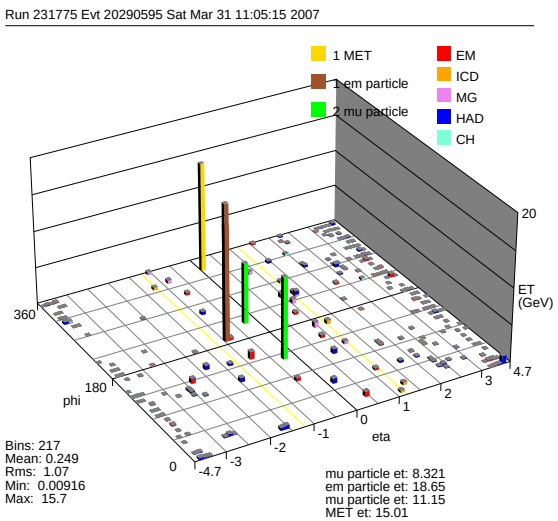


- High p_T selection
  - ▲ Background at final selection stage dominated by diboson production: 70%
  - ▲ Other background components
    - ▶ $Z \to \ell\ell$: 20%
    - ▶ $W \to \ell\nu$: 5%
    - ▶ $t\bar{t}$: 5%
  - ▲ Total signal expectation: 0.9 events

Event Displays







	p_T	η	ϕ
Electron	18.7 GeV	–0.92	3.31
Muon	11.2 GeV	–0.23	2.22
Track (2nd muon)	8.3 GeV	–0.24	3.67
Missing transverse energy	26.8 GeV		
Invariant mass of two muons	18.6 GeV		
Electron transverse mass	43.4 GeV		
Muon transverse mass	33.1 GeV		

Systematics

Main sources	Background	Signal
trigger, lepton identification , reconstruction efficiencies	4%	4%
Jet and tau energy Scale	2–9%	2–6%
Track momentum	1%	1%
Track reconstruction	1%	1%
PDF/scale errors on the cross section	4.5%	4.5%
Luminosity	6%	6%

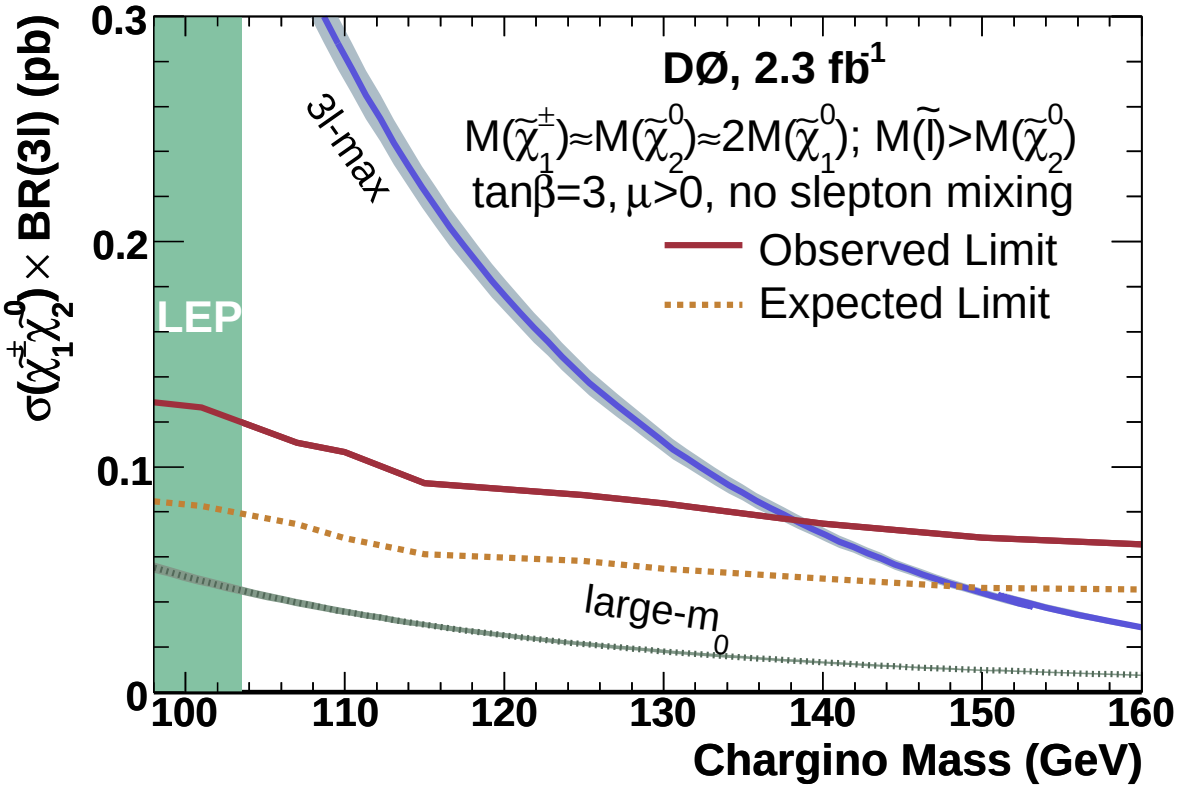
- Comparison of data and Monte Carlo
  - Low p_T selection
    - N_{Bg} = 5.4 $\pm$ 0.4 (stat.) $\pm$ 0.4 (syst.) events, N_{data} = 9 events
  - High p_T selection
    - N_{Bg} = 3.3 $\pm$ 0.3 (stat.) $\pm$ 0.3 (syst.) events, N_{data} = 4 events

Result

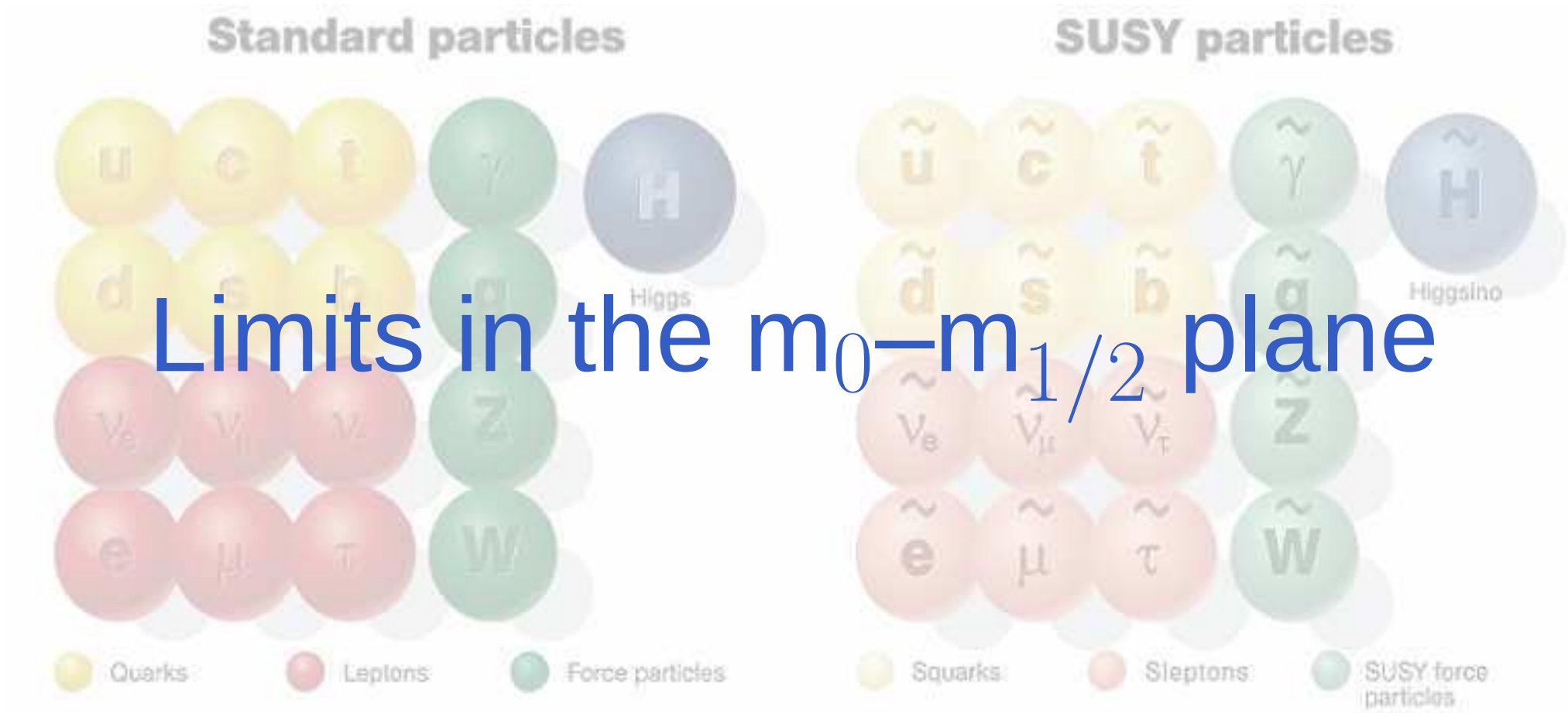
- No evidence for SUSY observed
  - Set limit on production cross sections times branching ratio $\sigma \times BR(3\ell)$
  - 3ℓ–max scenario
    - $m_{\tilde{\chi}_1^\pm} \approx m_{\tilde{\chi}_2^0} \approx 2m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\ell}}$ slightly heavier than $m_{\tilde{\chi}_2^0}$
    - Maximized branching ratio into three leptons

- Cross section limit $\sigma \times BR(3\ell)$
  - Observed: 0.06–0.12 pb
  - Expected: 0.04–0.08 pb

- Mass limits for $m_{\tilde{\chi}_1^\pm}$
  - Observed: 138 GeV
  - Expected: 148 GeV

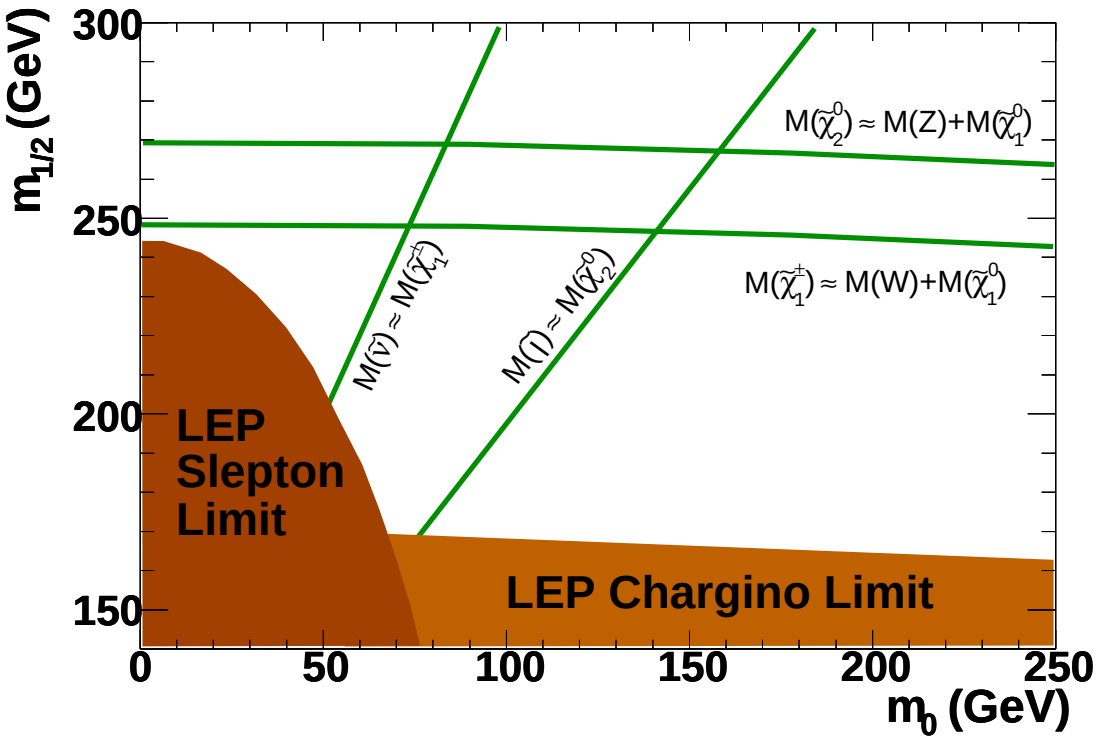


Limits in the m_0–$m_{1/2}$ plane



m_0–$m_{1/2}$–Plane

- m_0–$m_{1/2}$–plane can be subdivided in different regions corresponding to different decay chains



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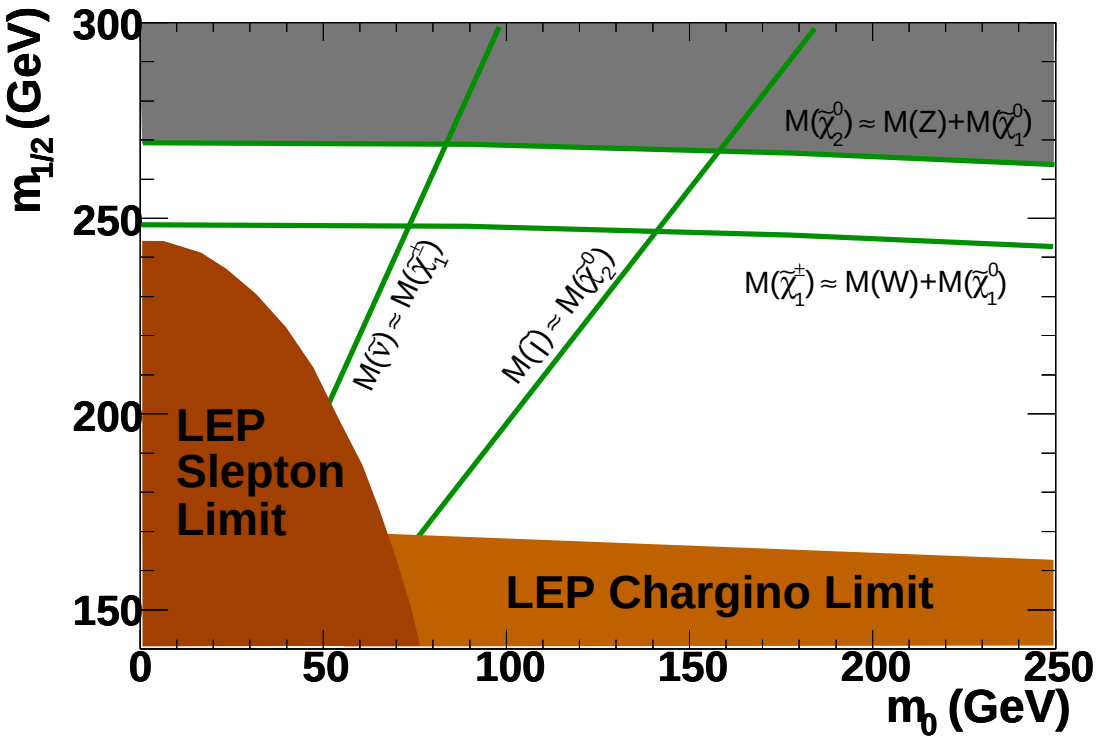

- $m_{\tilde{\chi}_2^0} > m_{\tilde{\chi}_1^0} + M_Z$
  - ▲ Decays via real Z bosons

m_0–$m_{1/2}$–Plane

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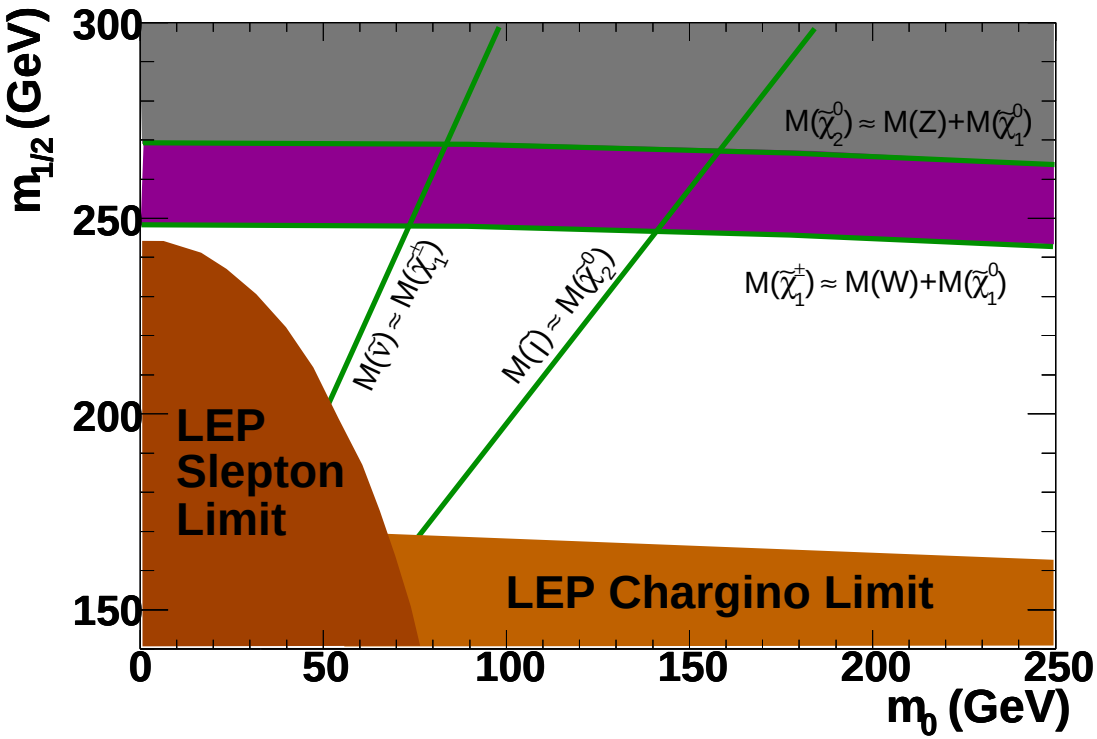

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  - ▲ Decays via real Z bosons
- $m_{\tilde{\chi}_1^\pm} > m_{\tilde{\chi}_1^0} + M_W$
  - ▲ Decays via real W bosons

m_0–$m_{1/2}$–Plane

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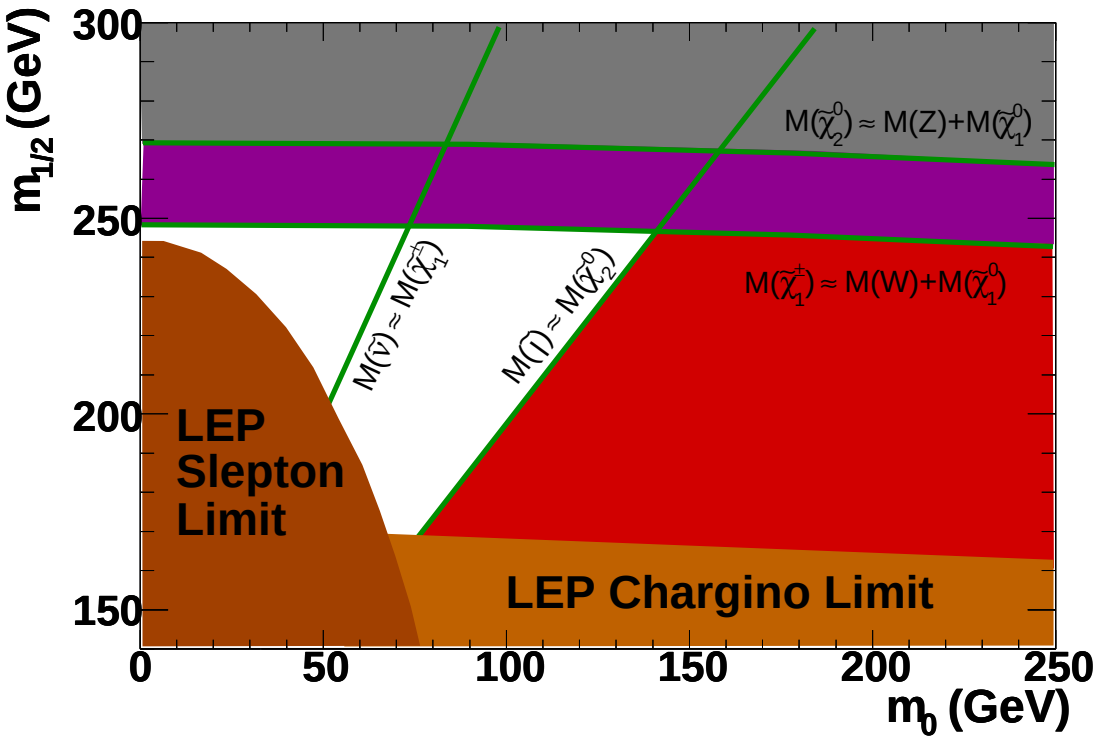
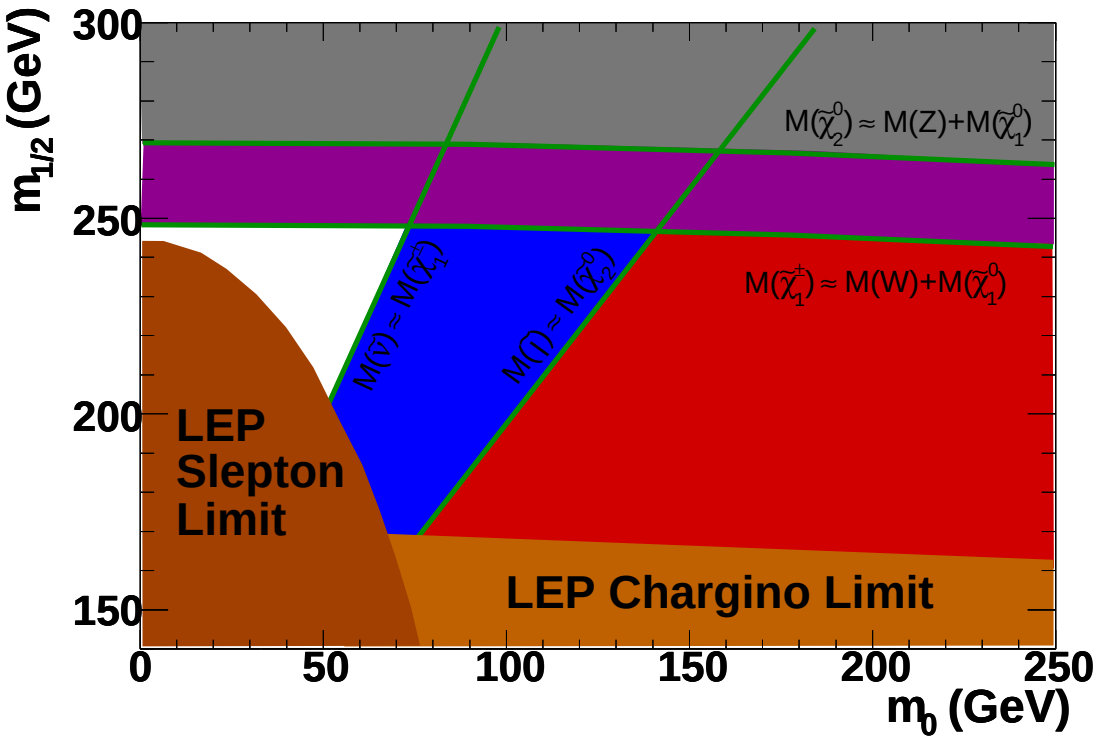


- $m_{\tilde{\chi}_2^0} > m_{\tilde{\chi}_1^0} + M_Z$
  - ▲ Decays via real Z bosons
- $m_{\tilde{\chi}_1^\pm} > m_{\tilde{\chi}_1^0} + M_W$
  - ▲ Decays via real W bosons
- $m_{\tilde{\chi}_1^\pm} < m_{\tilde{\chi}_1^0} + M_W$ and $m_{\tilde{\chi}_1^\pm} < m_{\tilde{\ell}}$
  - ▲ Decays via virtual Sleptons and W bosons

m_0–$m_{1/2}$–Plane

- m_0–$m_{1/2}$–plane can be subdivided in different regions corresponding to different decay chains



- $m_{\tilde{\chi}_2^0} > m_{\tilde{\chi}_1^0} + M_Z$
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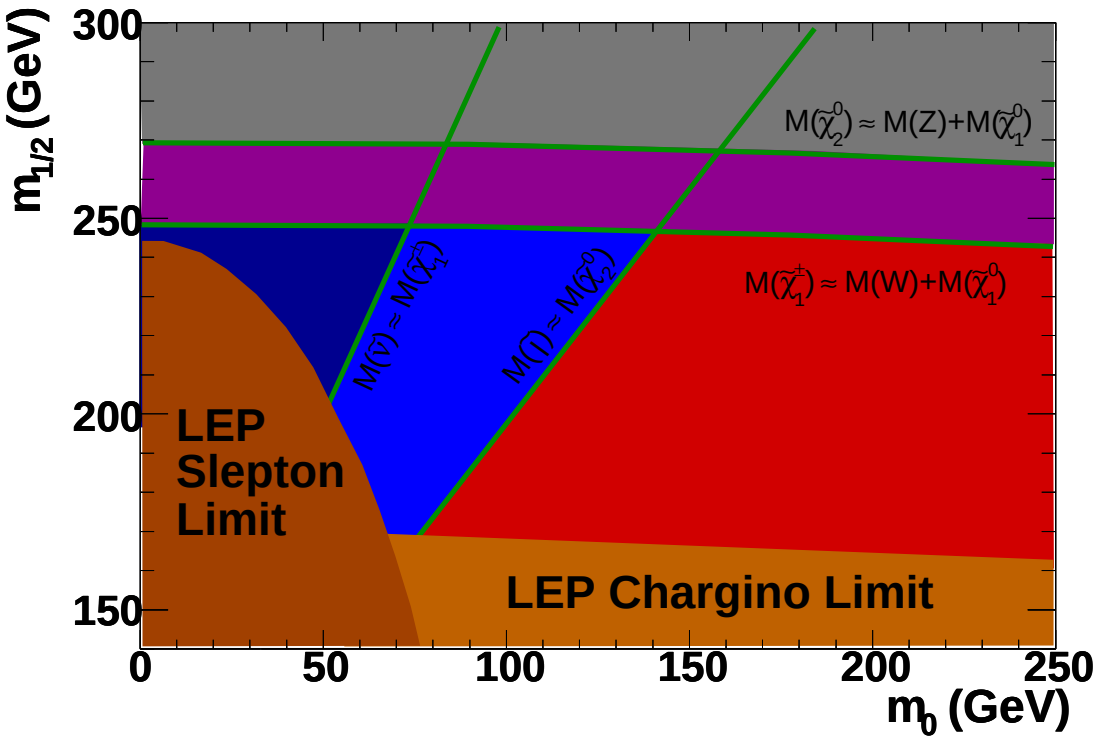
- $m_{\tilde{\chi}_1^\pm} < m_{\tilde{\chi}_1^0} + M_W$ and $m_{\tilde{\chi}_1^\pm} < m_{\tilde{\ell}}$
  - ▲ Decays via virtual Sleptons and W bosons
- $m_{\tilde{\chi}_2^0} > m_{\tilde{\ell}}$
  - ▲ Decays via real Sleptons

m_0–$m_{1/2}$–Plane

- m_0–$m_{1/2}$–plane can be subdivided in different regions corresponding to different decay chains



- $m_{\tilde{\chi}_2^0} > m_{\tilde{\chi}_1^0} + M_Z$
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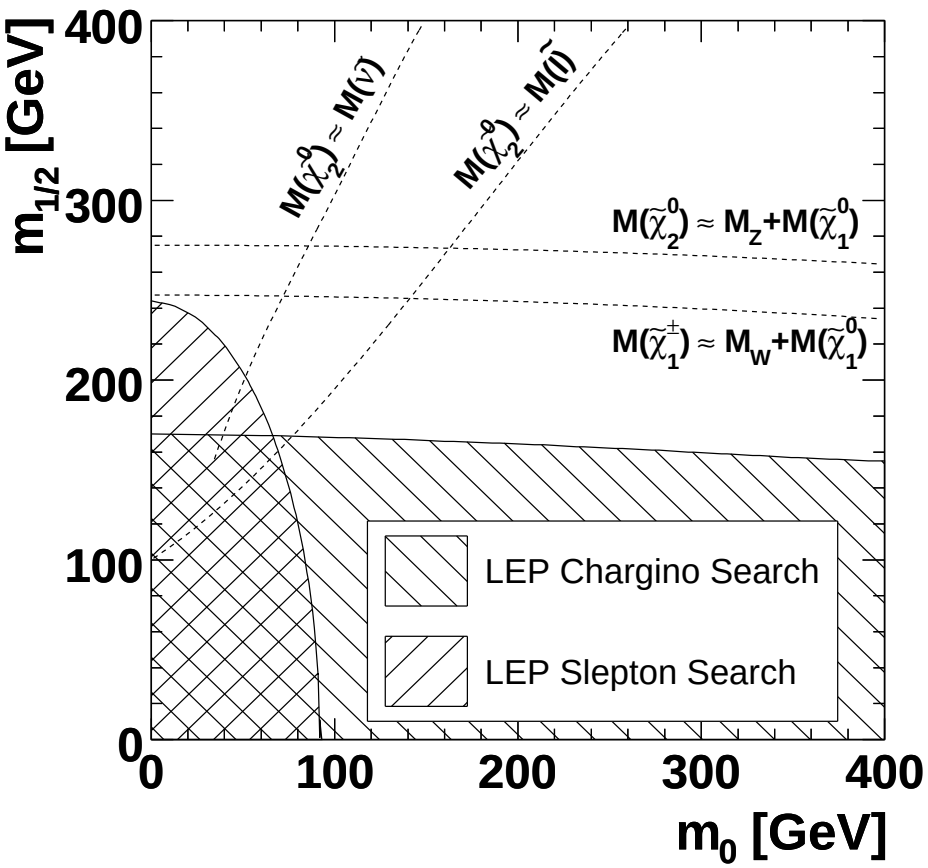
  - ▲ Decays via virtual Sleptons and W bosons
- $m_{\tilde{\chi}_2^0} > m_{\tilde{\ell}}$
  - ▲ Decays via real Sleptons
- $m_{\tilde{\chi}_1^\pm} > m_{\tilde{\nu}}$
  - ▲ Decays via real sneutrinos

m_0–$m_{1/2}$ Plane

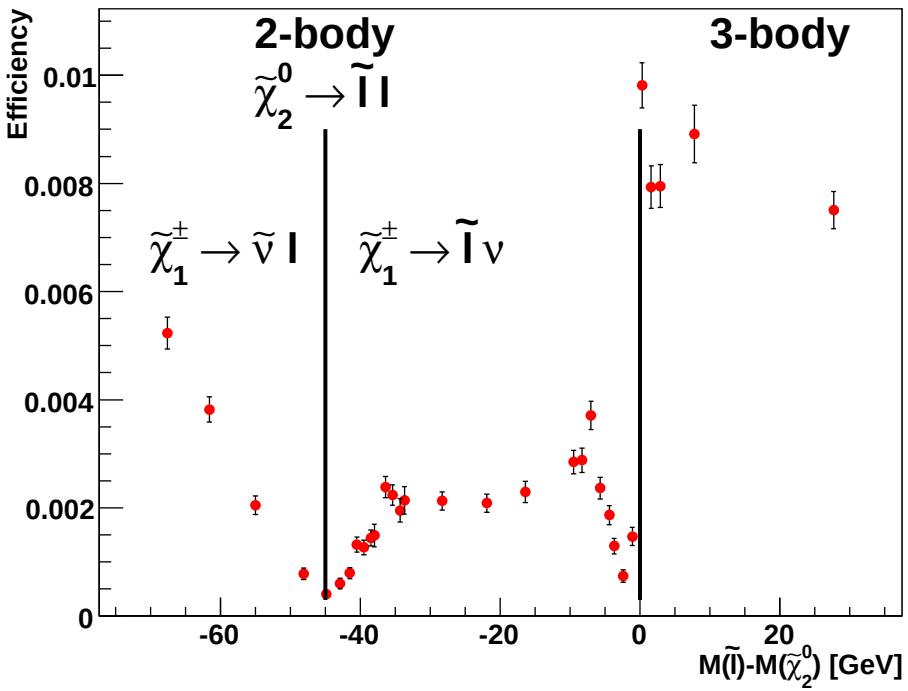
- Extend limit in m_0–$m_{1/2}$ plane and for different $\tan\beta$
  - ▲ Generate Monte Carlo in the plane
  - ▲ Extract efficiency as function of masses



- Generate more MC in regions where larger changes in efficiencies are expected
  - ▲ Equal Neutralino and Slepton masses: $\Delta m_{\tilde{\ell}} = m_{\tilde{\ell}} - m_{\tilde{\chi}_2^0}$
  - ▲ Equal Neutralino and Sneutrino masses: $\Delta m_{\tilde{\nu}} = m_{\tilde{\nu}} - m_{\tilde{\chi}_2^0}$

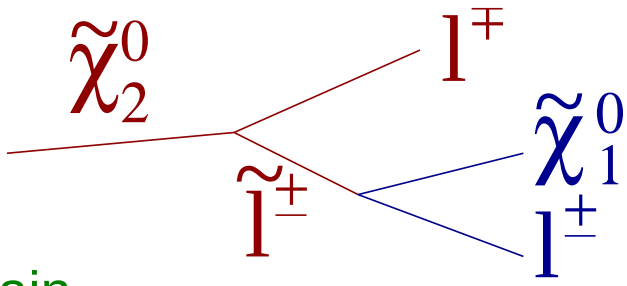
Parametrization of Efficiencies

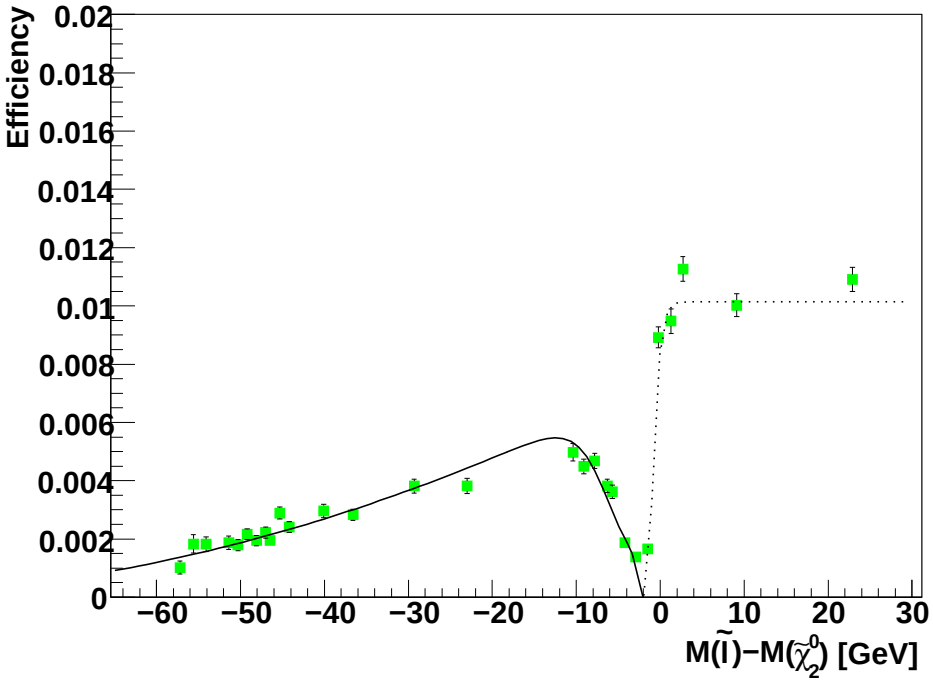
- Determine efficiencies separately for all different decay chains
  - 3–body decays
  - 2–body decays
    - Decay via Sleptons: $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\ell}\nu$
    - Decay via sneutrinos: $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\nu}\ell$
    - Decay via real W bosons: $\tilde{\chi}_1^{\pm} \rightarrow W\tilde{\chi}_1^0$



Two–Body Region

- Decays via Sleptons
  - ▲ For small Δm, third lepton is very soft
    $\Rightarrow$ Small efficiency
  - ▲ With increasing Δm, $\mathrm{p_T}$ spectrum gets harder
    $\Rightarrow$ Increase in efficiency
  - ▲ For large negative Δm, third lepton is very soft again
    $\Rightarrow$ Small efficiency





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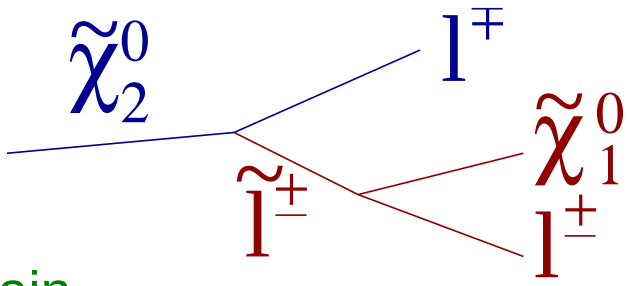
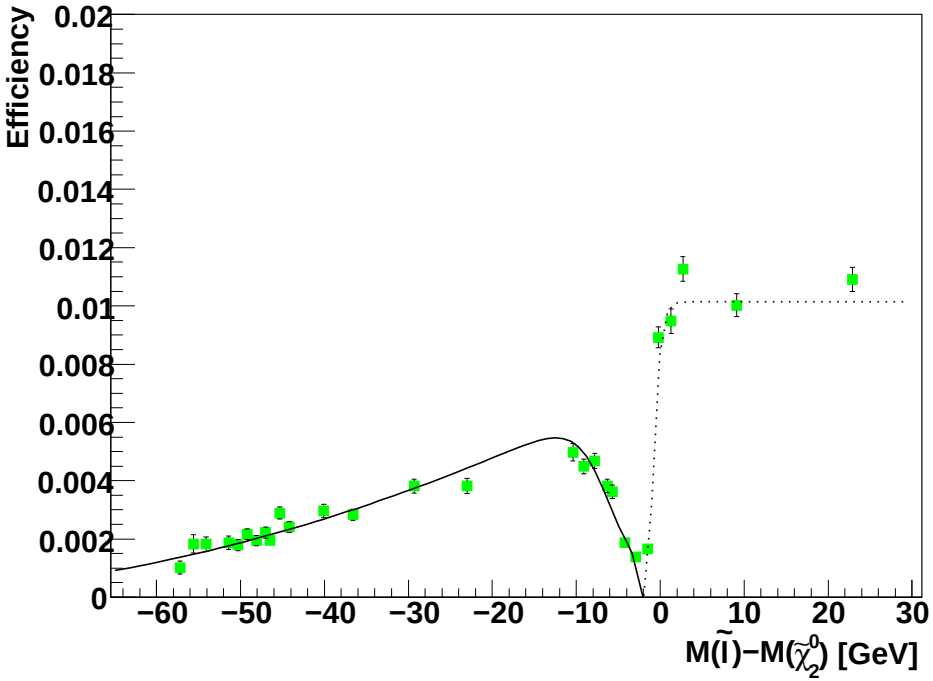
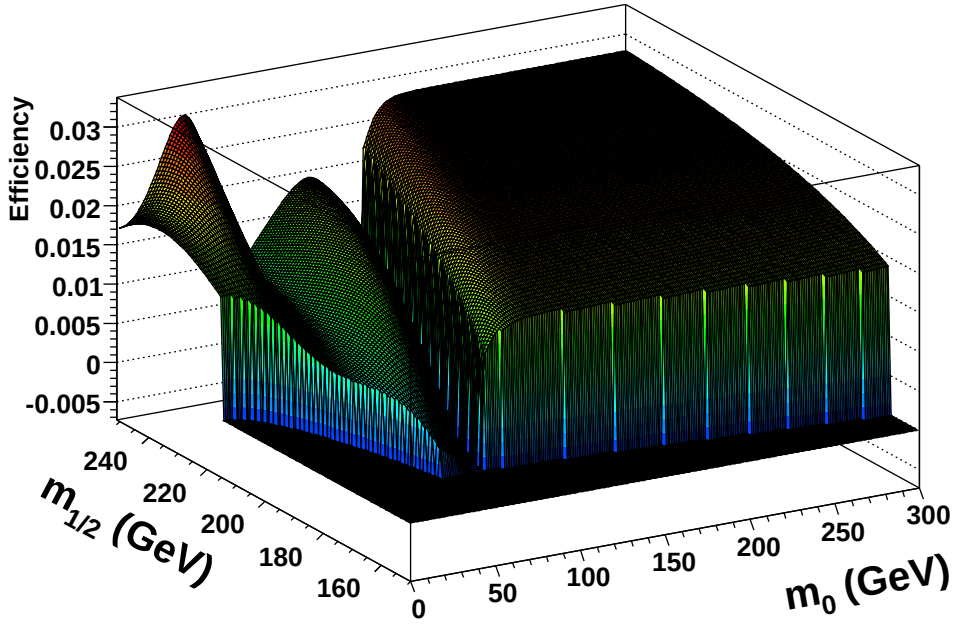




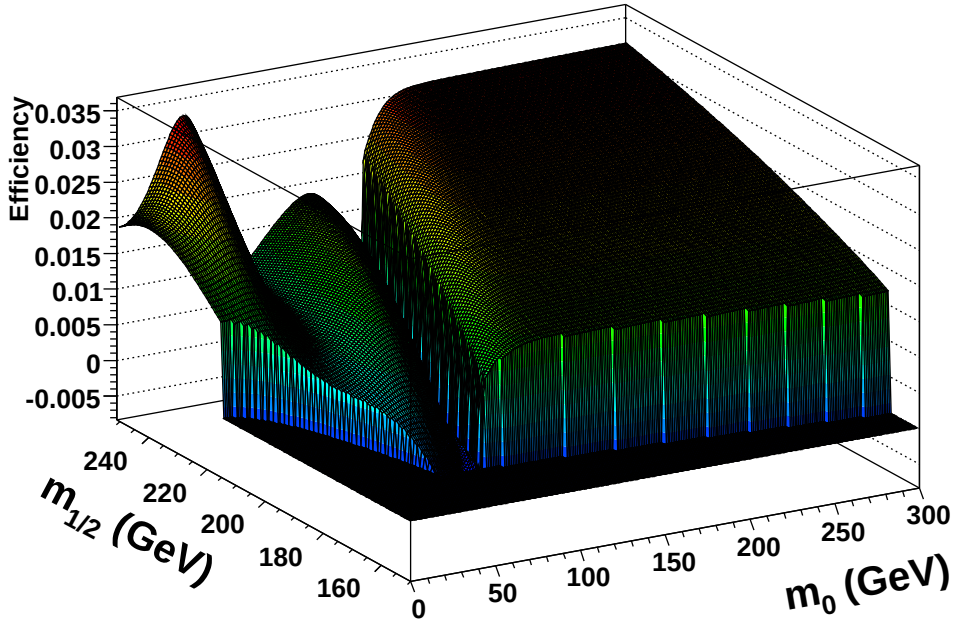
Parametrization of Efficiencies

- Fit distributions for all different final states and selections
- From individual fits, extrapolate into the plane

$\mu\mu\ell$ analysis

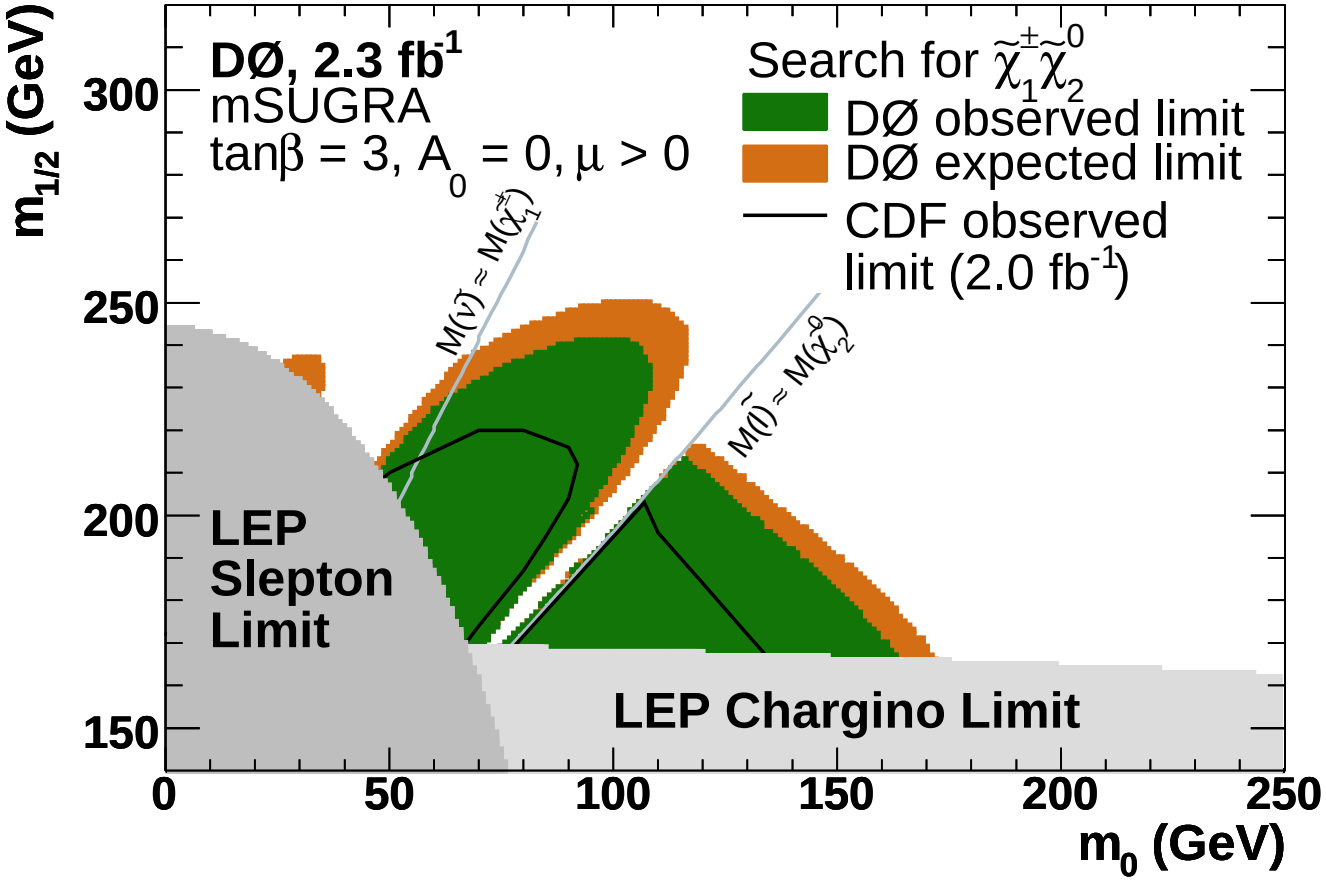


$ee\ell$ analysis



- Combine different decay chains according to the branching fractions
- Combine different channels according to their luminosity
- Calculate limit for every single point in the plane in 1GeV steps

Limits in the m_0–$m_{1/2}$ Plane

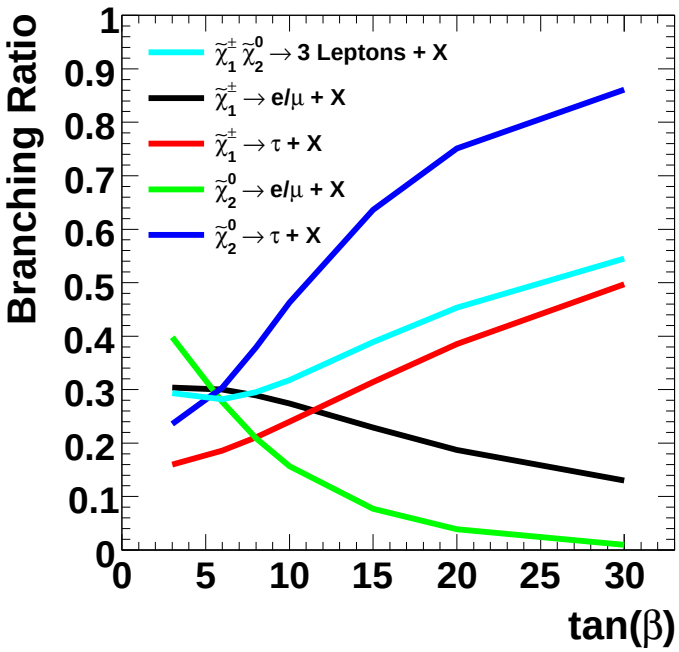


- Exclusion plane extends well above existing limits
  - ▲ Chargino masses up to 167 GeV are excluded
  - ▲ Probing Chargino masses up to 176 GeV

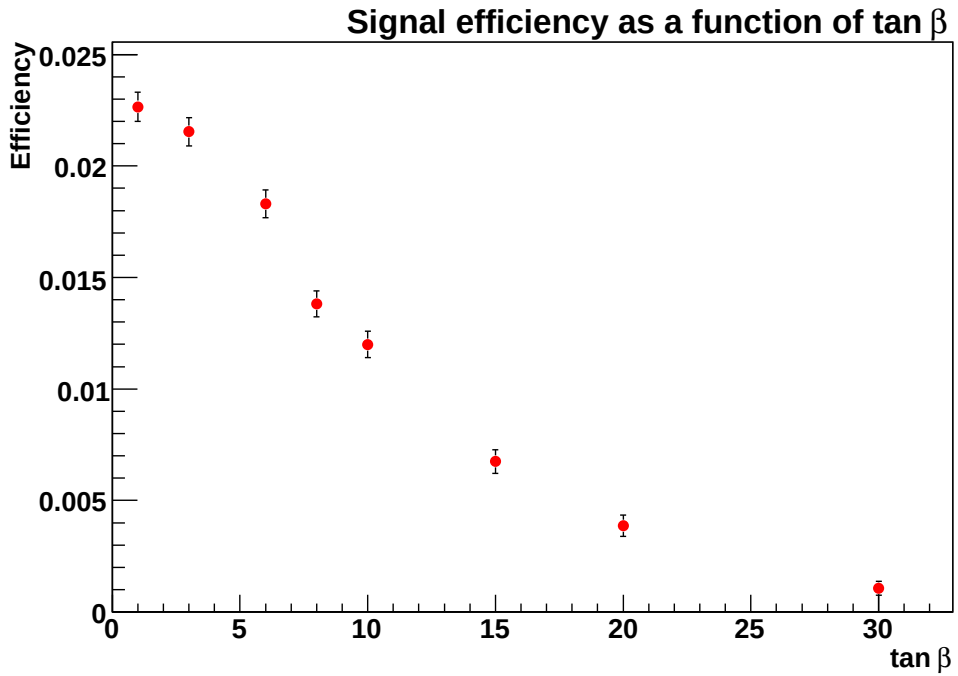
Result as Function of $\tan\beta$

- With increasing $\tan\beta$ the final state consists of more tau leptons due to increased Stau mixing $\Rightarrow$ Light Stau
- Sensitivity of $ee+\ell$, $\mu\mu+\ell$ and $e\mu+\ell$ decreases
  - ▲ Limit in the m_0–$m_{1/2}$ plane will get worse
- Analyses selecting at least one ($\mu\tau\ell$) or two hadronic taus ($\mu\tau\tau$) help to keep efficiency reasonable

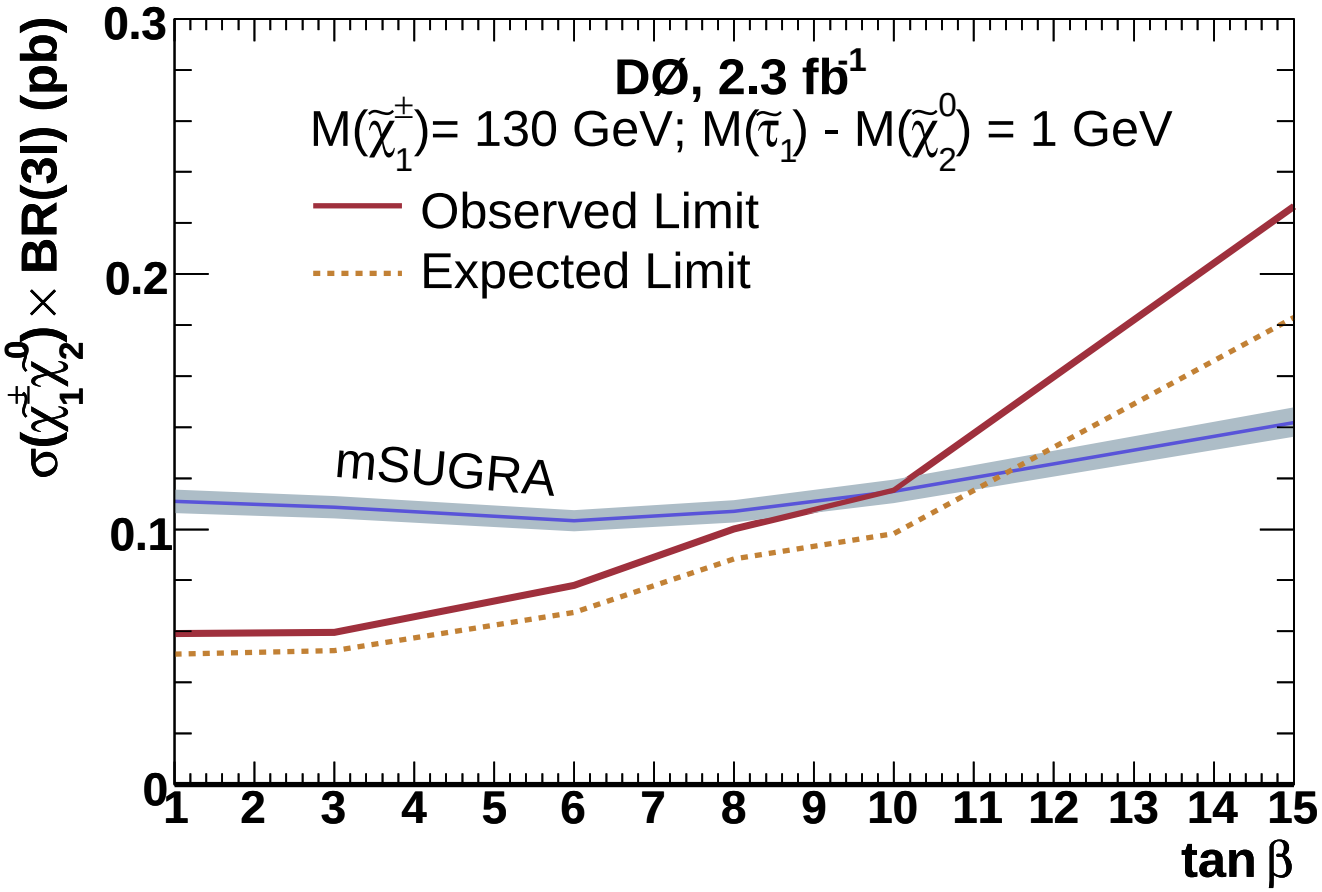
Leptonic BR in 3 τ leptons



Efficiency of $ee+\ell$ analysis



Result as Function of $\tan\beta$ (II)

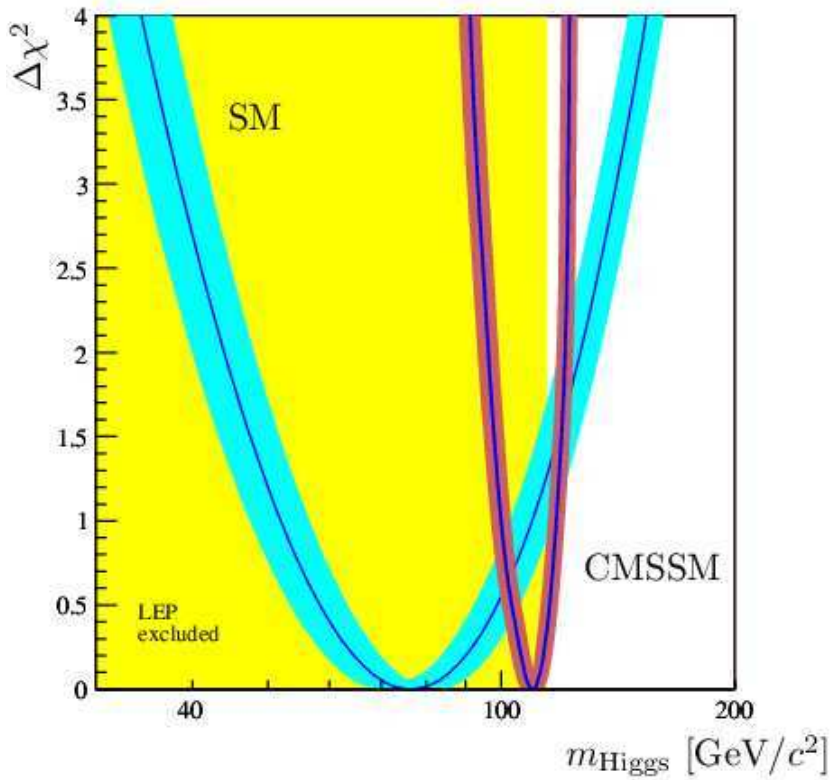


- Select points with $m_{\tilde{\chi}_1^{\pm}}$ = 130 GeV, $m_{\tilde{\tau}} - m_{\tilde{\chi}_2^0}$ = 1 GeV
- Limit remains stable within a factor of 2
  - ▲ Can exclude Charginos of 130 GeV up to $\tan\beta$ = 9.6

Conclusion

- Summary
  - ▲ Search for Charginos and Neutralinos using five different final states
  - ▲ No observation of SUSY particles
  - ▲ Exclusion limits as function of Chargino mass, $\tan\beta$ and in m_0–$m_{1/2}$ plane
    - ▶ $m_{\tilde{\chi}_1^\pm} > 138$ GeV in 3ℓ–max scenario
    - ▶ World best limits in m_0–$m_{1/2}$ plane
  - ▲ Analysis is published
    arXiv:0901.0646v1$[\mathrm{hep-ex}]$
  - ▲ Combination with CDF planned
- More than twice data are already on tape
  - ▲ Still some room for SUSY at the Tevatron

STAY TUNED



O. Buchmüller et al., arXiv:0707.3447v2

Conclusion

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  - ▲ Search for Charginos and Neutralinos using five different final states
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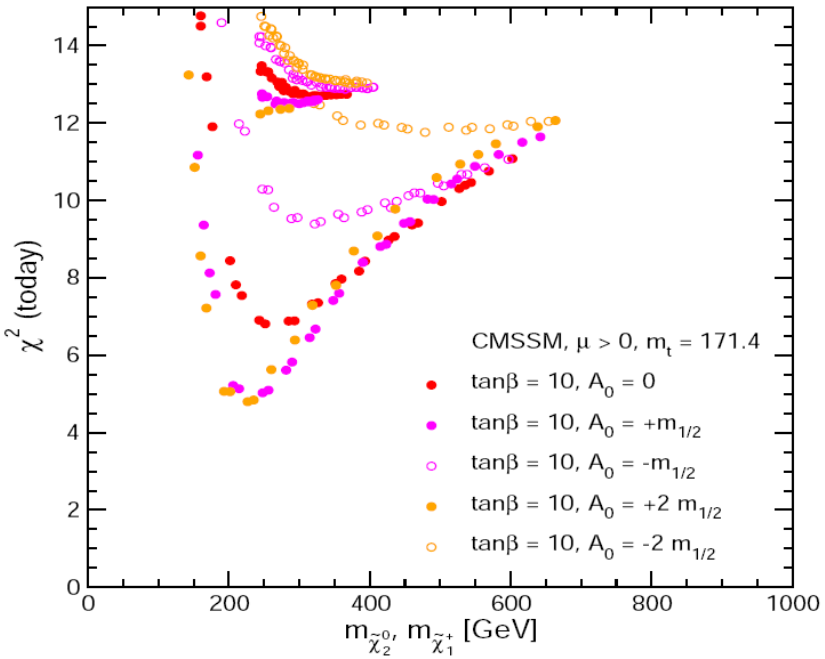

J. Ellis et al.,
arXiv:0706.0652v1