TeV4LHC, CERN, April 2005

First detailed study on the CMS SUSY discovery potential with two same sign muons in the mSUGRA model

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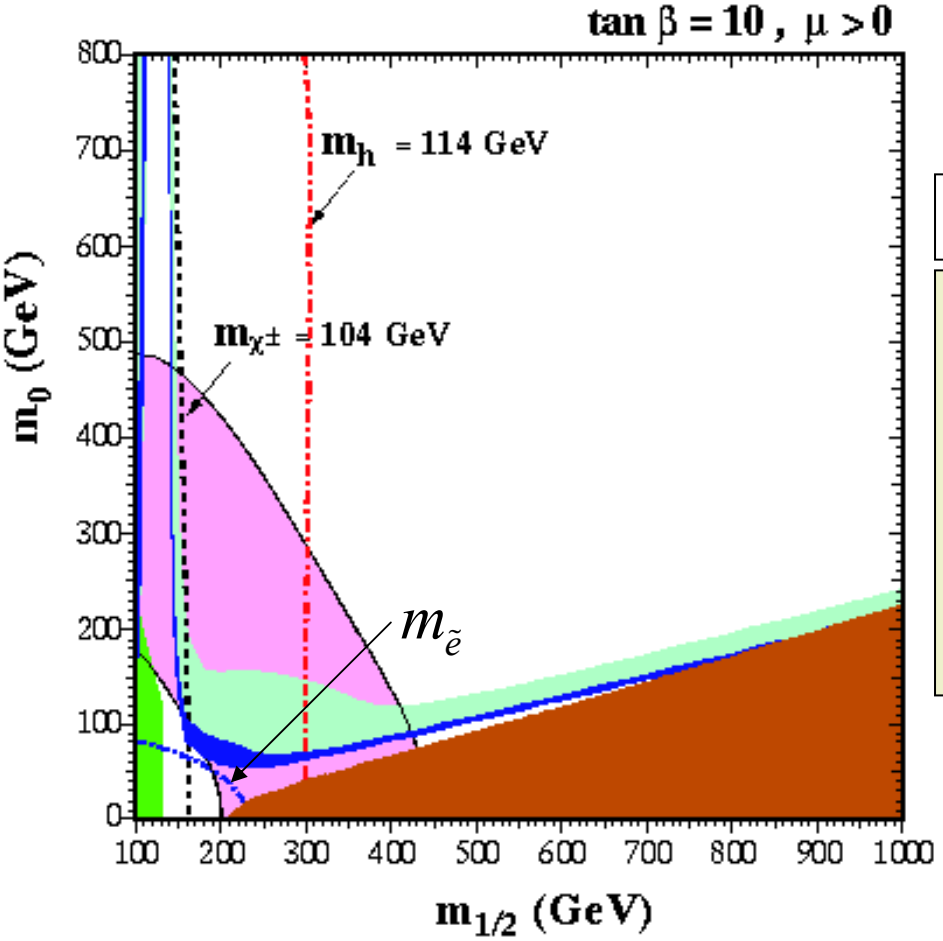
Outline

- Introduction
- Parameter space
- References
- Tools
- Backgrounds considered
- Signal points
- Cut variables selection
- Cuts "optimization"
- Selected cut sets
- Results: significance, sensitive area
- Results: stability
- Summary and Prospects

Note: all the results shown here approved by CMS in June'04. A few comments on current work will be given in "Prospects"

mSUGRA (m_0,$m_{1/2}$) plane



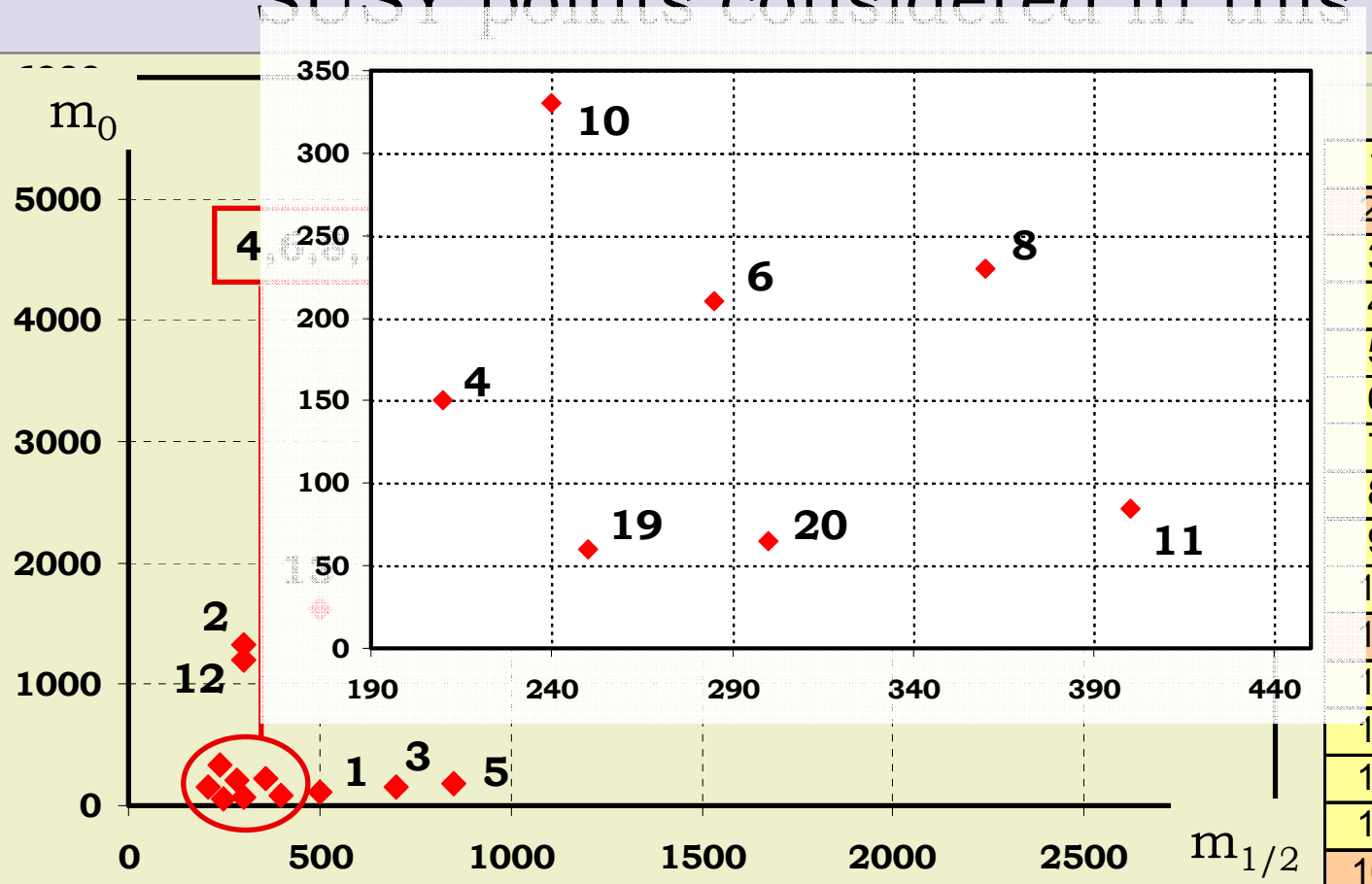
J.Ellis et al., hep-ph/0303043

- older cosmological constraint
  $0.1 < \Omega_x h^2 < 0.3$
- newer cosmological constraint
  $0.094 < \Omega_x h^2 < 0.129$
- $\tilde{\chi}_1^0$ is not LSP
- excluded by $b \to s\gamma$
- favored by $g_\mu - 2$ at 2-σ level

▷ mSUGRA - GUT sub-model of MSSM - is a popular simplification

▷ only 5 parameters (m_0, $m_{1/2}$, tanβ, A_0, signμ)

SUSY points considered in this study



	m12	m0	tanβ
1	500	107	10
2*	300	1330	10
3	700	149	10
4	210	150	10
5	850	181	10
6	285	210	10
7	700	2155	10
8	360	230	10
9	900	2530	10
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- Updated post-WMAP benchmark points (hep-ph/0306219) [* - with modification]
- More points (calculated by A.Birkedal (Cornell), K.Matchev (UF))
- Six of them, high-mass points found to have negligible cross-sections

- negligible σ

Signature choice

- For this study the "2 Same Sign Muons" signature was chosen
  - theoretical studies for Tevatron
    - hep-ph/9904282, *"Supersymmetry Reach of the Tevatron via Trilepton, Like-Sign Dilepton and Dilepton plus Tau Jet Signatures"*, K.T.Matchev, D.M.Pierce
  - experimental studies at Tevatron
    - see e.g. theses by M.Worcester and A.Yurkewicz
  - simple and clear trigger objects
  - reduced number of background events/processes in comparison to "multi-jets only" signatures

Luminosity

- In this study all calculations are done for the integral luminosity of 10 fb^{-1}

Tools

- To calculate coupling constants, cross sections for SUSY processes: ISAJET
  - http://www.phy.bnl.gov/~isajet/
- To calculate NLO corrections for SUSY processes: PROSPINO
  - hep-ph/9611232
- For event generation: CompHEP (Z/γ*bB, Single-top processes), PYTHIA (SUSY, tt, ZZ, ZW, WW)
  - hep-ph/9908288 (CompHEP)
  - http://www.thep.lu.se/~torbjorn/Pythia.html
- Full CMS detector simulation was used in this study: CMSIM, ORCA
  - http://cmsdoc.cern.ch/cmsim/cmsim.html
  - http://cmsdoc.cern.ch/cmsreco/

Cross sections, event numbers: SM processes

	tb	tqb	$\bar{t}b$	$\bar{t}qb$	ZZ	ZW	WW	$t\bar{t}$	$Zb\bar{b}$	*All*
σ, pb	0.212*	5.17*	0.129*	3.03*	18(NLO)	26.2	70.2	886(NLO)	232(NLO)*	
N1	2,120	51,700	1,290	30,300	180,000	262,000	702,000	8,860,000	2,320,000	
N2	112	1,798	71	1,067	256	727	39.7	142,691	12,924	160,000

main contribution into background

- Other process
  - generated with CompHEP

	WWW	ZWW	ZZW	ZZZ	$WWWW$	$ZWWW$	$ZZWW$	$ZZZW$	$ZZZZ$
σ, pb	0.129	0.0979	0.0305	0.00994	0.000574	0.000706	0.000442	0.000572	0.0000161
N1	1,290	979	305	99.4					
N2	<15	<10	<3	<1					

	$t\bar{t}W$	$t\bar{t}Z$	$t\bar{t}WW$	$t\bar{t}ZW$	$t\bar{t}ZZ$
σ, pb	0.556	0.65	neg.	neg.	neg.
N1	5,560	6,500			
N2	<200	<200			

- negligible contribution

all but $t\bar{t}W$, $t\bar{t}Z$ are negligible

- Notations:
  - N1 – total number of expected events for integral luminosity of $10fb^{-1}$
  - N2 – number of events after pre-selection (two same sign muons, P_T>10 GeV)

Cross sections, event numbers: SUSY processes

	SUSY point number:									
	1	2	3	4	5	6	7	8	9	10
σ, pb	1.21	2.43	0.161	83.2	0.0511	17.6	0.0354	5.21	0.00911	31.8
N1	1,210	24,300	1,610	832,000	511	176,000	354	52,100	91	318,000
N2 (NLO)	470	1470	66	14,600	20.7	4,330	18,3	1,520	2.71	11,700
Significance	1.2	3.6	0.16	35.8	0.05	10.8	0.04	3.8		28.8
S/B	0.0029	0.0092	0.00041	0.091	0.00013	0.027	0.00011	0.0095		0.073

	SUSY point number:									
	11	12	13	14	15	16	17	18	19	20
σ, pb	2.27	2.77	0.214	0.00527	0.00504	0.00048	0.00006	0.000008	40.8	15.9
N1	22,700	27,700	2,140	52.7	50.4	4.8	0.6	0.08	408,000	159,000
N2 (NLO)	961	2,210	188						9,200	4,570
Significance	2.4	4.6	0.46						22.6	11.4
S/B	0.006	0.014	0.0012						0.058	0.029

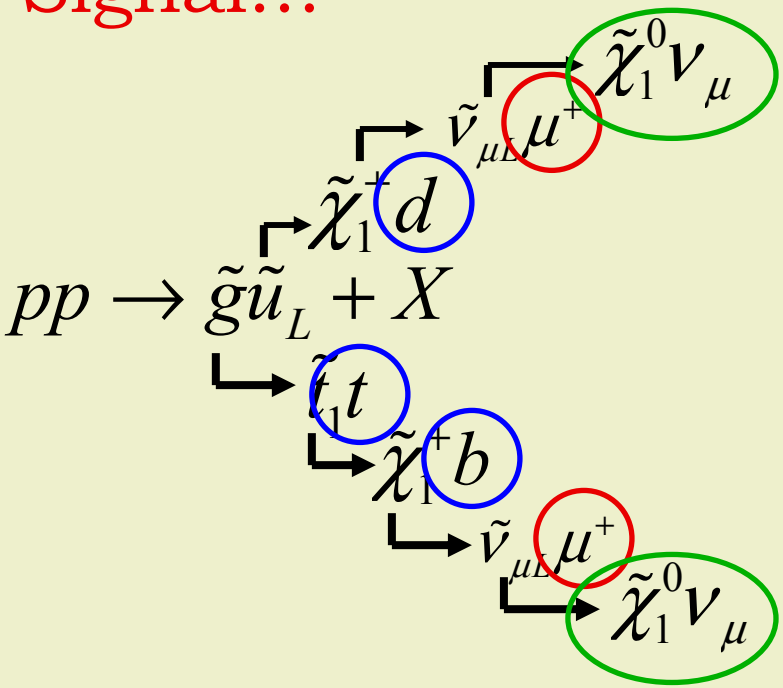
- excluded points

▷ Notations:

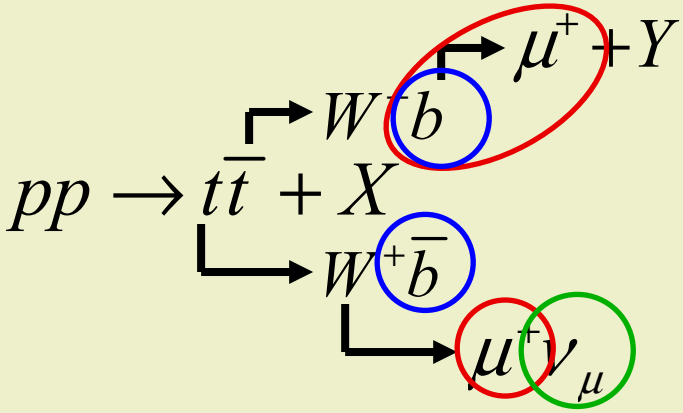
- ▷ N1 – total number of expected events for integral luminosity of $10 fb^{-1}$
- ▷ N2 – number of events after pre-selection (two same sign muons, P_T>10 GeV)
- ▷ Significance, $S_{12} = 2\left(\sqrt{N_S + N_B} - \sqrt{N_B}\right)$ (S.I.Bityukov,N.V.Krasniov)
- ▷ S/B – ratio: N_S / N_B

Diagram examples

- Signal…

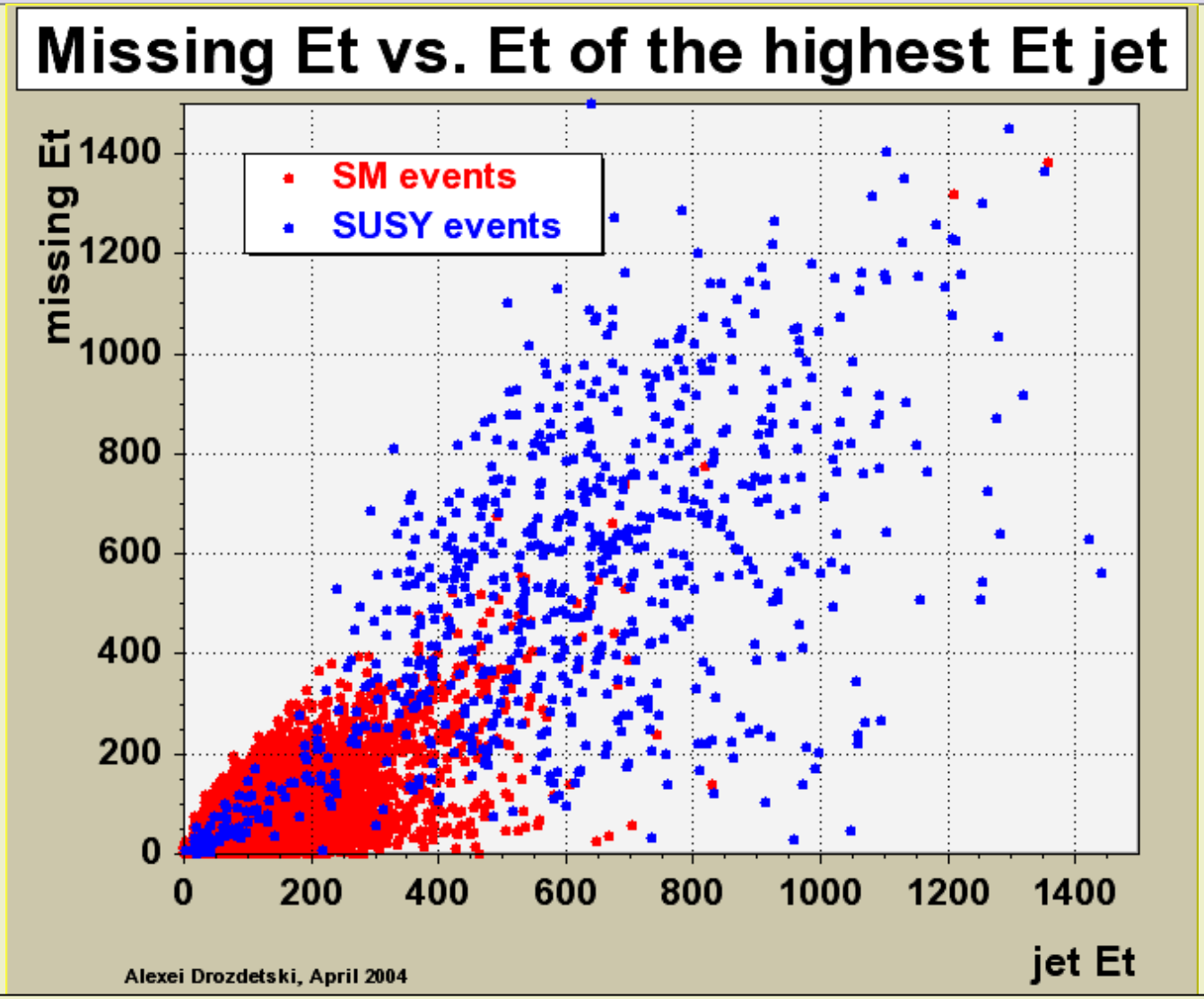


Background…



- Variables for cuts:
  - Missing E_T
  - Jets E_T
  - Muon P_T, Muon Impact Parameter
  - Plus: Muon Isolation, Muon η, Jet η, number of jets/muons, …

Event kinematics: SM vs. SUSY, example



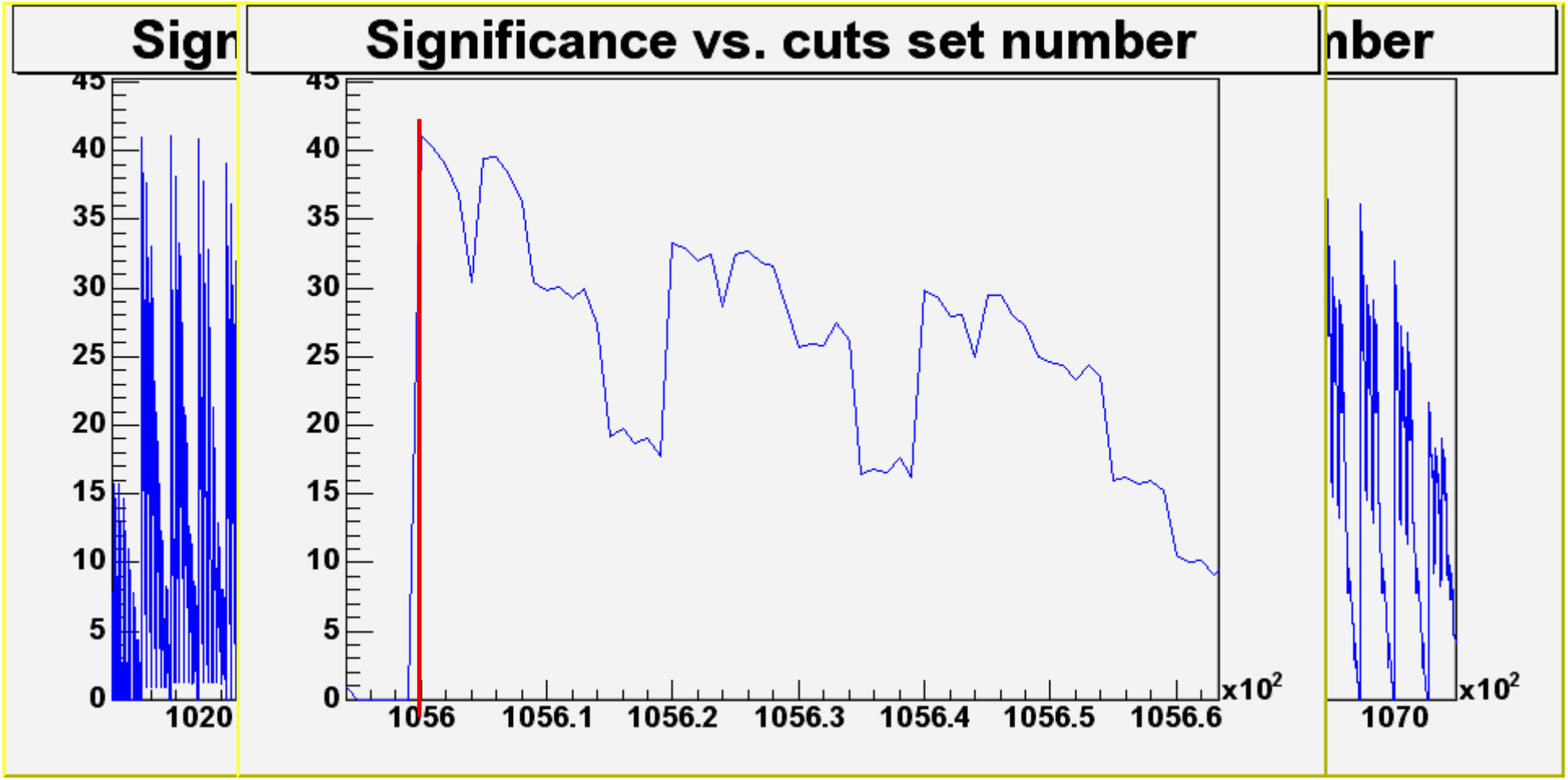
- SUSY point (#3):
  - m_0=149 GeV, $m_{1/2}$=700 GeV, tanβ = 10, A_0 = 0, signμ > 0

Analysis cuts

- For chosen cut variables, several values for optimization were chosen:
  - Missing E_T: 0, 100, 150, 200, 250, 400, 500 GeV
  - $E_T jet_1$: 0, 70, 100, 200, 300, 400 GeV
  - $E_T jet_3$: 0, 30, 50, 80, 100, 170, 250 GeV
  - $P_T \mu_1$: 10, 20, 30, 60, 100, 150 GeV/c
  - $P_T \mu_2$: 10, 15, 20, 50, 80 GeV/c
  - $IP\mu_{min}$: N/A, 0.005, 0.0015, 0.0005 cm
  - $IP\mu_{max}$: N/A, 0.1, 0.03, 0.01, 0.005 cm
- For each cuts set (Missing E_T, $E_T jet_1$, $E_T jet_3$, $P_T \mu_1$, $P_T \mu_2$, $IP\mu_{min}$, $IP\mu_{max}$)
  - Values of Significance, S/B and expected event numbers (N_{Final}) for 10 fb^{-1} calculated
    - about 176,000 cut sets used
  - Choice of final sets "optimized"

Final set choice "optimization": example

- Plot Significance for all sets of cuts…
- Then choose an "optimal" region: several iterations…
- Finally, choose a particular set…



Analysis cuts

- Chosen sets (in addition to the "signature cut": P_T of both same sign μ > 10 GeV):
  - Set #1:
    - Missing E_T > 200 GeV,
    - $E_T jet_3$ > 170 GeV,
    - $P_T \mu_1$ > 20 GeV
  - Set #2:
    - Missing E_T > 100 GeV,
    - $E_T jet_1$ > 300 GeV,
    - $E_T jet_3$ > 100 GeV
- All of the following results were done for these two sets

Results (example): cut set #2

SET 2	SM	1	2	3	4	5	6
N final	432 ± 8.8	184 ± 9.3	560 ± 29	30.4 ± 1.4	1590 ± 152	9.6 ± 0.45	1030 ± 67
Signif		8.06	21.4	1.44	48.4	0.46	35
S/B		0.43	1.3	0.07	3.7	0.002	2.4

SET 2	7	8	9	10	11	12	13
N final	8.31 ± 0.39	530 ± 28	n/a	1950 ± 151	322 ± 18	781 ± 42	86.9 ± 4
Signif	0.4	20.5	n/a	56.1	13.4	28.1	4
S/B	0.019	1.2	n/a	4.5	0.75	1.8	0.2

SET 2	14	15	16	17	18	19	20
N final	n/a	n/a	n/a	n/a	n/a	1220 ± 106	996 ± 67
Signif	n/a	n/a	n/a	n/a	n/a	39.8	34
S/B	n/a	n/a	n/a	n/a	n/a	2.8	2.3

Monte Carlo statistical errors shown for number of events after all cuts (N final)

All final events accepted by L1 and HLT.

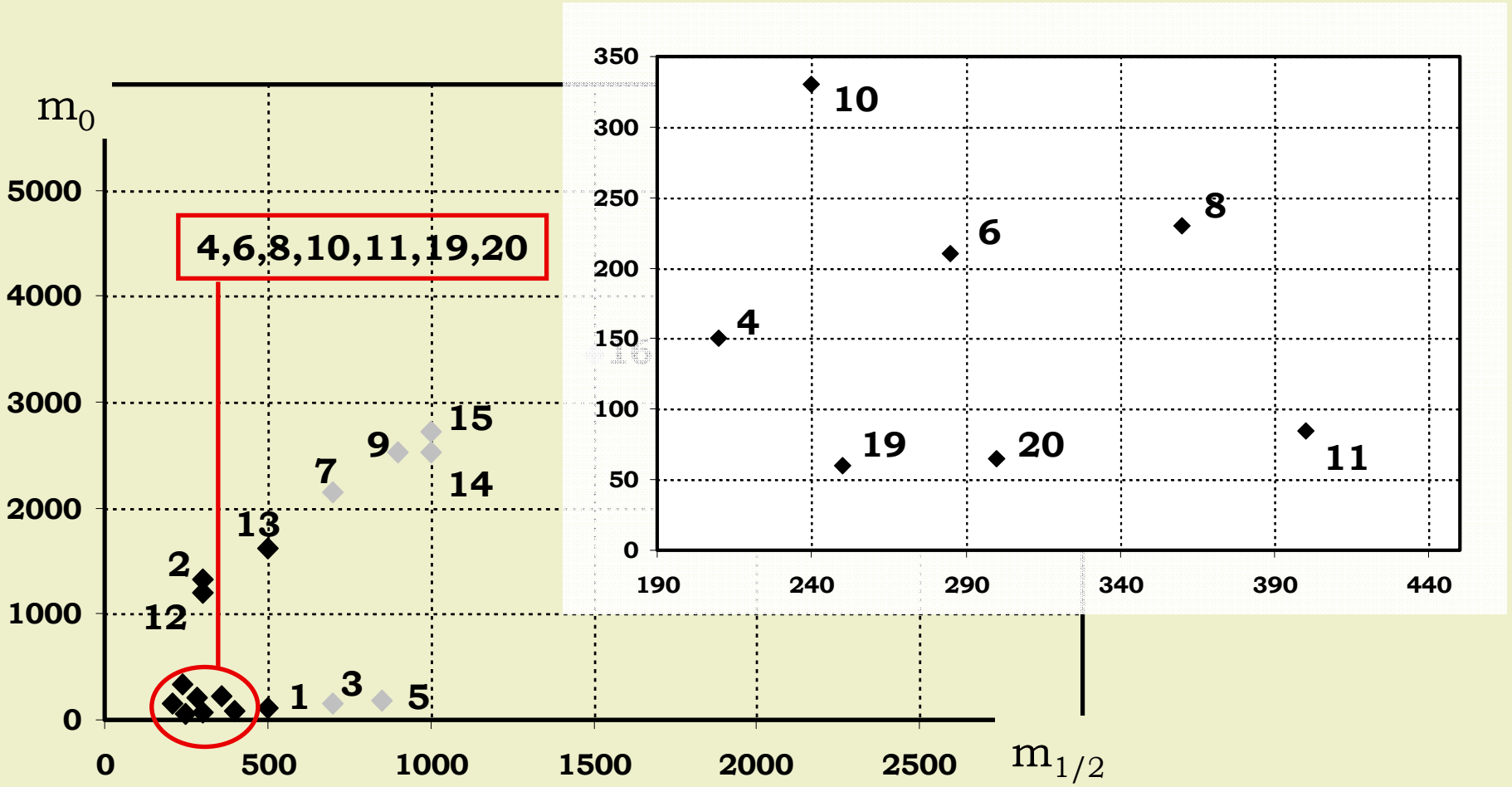
- ▷ L1: single μ with P_T>14 GeV, di-μ with P_T > 3 GeV
- ▷ HLT: di-μ with P_T>7 GeV

Results: significance

- Number of points out of reach for 10 fb^{-1} for two cut sets varies: 9-10
  - Significance < 5
- Potential "discovery points" for 10 fb^{-1}
  - Significance > 5
  - in addition for those points
    - S/B > 0.4 (a 40% excess of events or more over expected number of the SM events)

	Significance	
	SET 1	SET 2
1	9.05	8.06
2	20.8	21.4
3	2	1.44
4	25	48.4
5	0.77	0.46
6	20.6	35
7	0.78	0.4
8	15.5	20.5
9	n/a	n/a
10	31.7	56.1
11	12.1	13.4
12	27.1	28.1
13	6	4
14	n/a	n/a
15	n/a	n/a
16	n/a	n/a
17	n/a	n/a
18	n/a	n/a
19	25.6	39.8
20	20.6	34

Results: sensitive area at 10 fb^{-1}



- Many points will be visible with $\int L << 10\ fb^{-1}$
  - Significance for many points >> 5 for $\int L = 10\ fb^{-1}$

First estimate of systematic effects (preliminary)

- To estimate stability of the results, a variation has been made:
  - +30% SM events AND –30% SUSY events at the same time
    - only one background process survive after final cuts: $t\bar{t}$
    - expected precision of measuring its cross section (including theoretical systematic) is about 10%
  - +20% (and -20%) shift in cut values simultaneously was tried
- Only one "SUSY discovery" point (#13) goes out of reach

Summary

- mSUGRA model was used for the study
  - $\tan\beta=10$, $\mathrm{sign}(\mu)>0$, $A_0=0$
- Many benchmark points are in sensitive area for $\int L << 10 fb^{-1}$
  - up to 600 GeV in $m_{1/2}$ and at least up to 1600 GeV in m_0
- Full detailed simulation, trigger emulation and reconstruction was used
- Results are optimistic for SUSY discovery

Prospects (work in progress)

- We plan to do further optimization
  - other cut variables may be used for S/B and Significance optimization, e.g.:
    - μ isolation
    - b-tagging
    - η of jets, η of muons
- Other backgrounds to consider
  - QCD multi-jet production (including fake muons contribution)
- Extend μ-acceptance in off-line reconstruction up to 2.4 (now used up to 2.1)
  - about 30% more signal events
- Systematic effects will be addressed in details and included into the significance calculation
- More sophisticated optimization algorithm (like genetic one) may be used for optimization
- Other SUSY point (and models) may be studied

Thanks

- Andreas Birkedal (Cornell)
- Nancy Marinelli (University of Athens)
- Konstantin Matchev (UF)
- Luc Pape (CERN)
- Albert de Roeck (CERN)
- Michael Spira (PSI)
- Maria Spiropulu (CERN)
- Grzegorz Wrochna (Soltan Institute for Nuclear Studies)

ADDENDUM

Analysis scheme

- Tools
  - Generators: σ (LO/NLO), coupling constants, matrix elements
  - Generators: showering, event development
  - Full detector simulation
  - Trigger emulation
  - Full events reconstruction
  - Analysis: optimization of significance and N_S/N_B
    - variables for cuts choice
    - cuts optimization
    - results, error analysis (stat. & system.)

Technical details: generators

- From PYTHIA 6.2 manual: "ISASUSY… provides a more precise solution…" than possible option for mSUGRA in PYTHIA

- ISAJET 7.69 + PYTHIA 6.220 → compilation → private version → CMKIN 1_3_0 + kis_user.F

- CompHEP 4.2p1 → CMKIN 2_0_1 (PYTHIA 6.220) + kis_user.F

More technical details: simulation/reconstruction

- CMSIM_133
  - $|\eta|<5.3$, all φ, $0.05 < P_T$
- ORCA 7_3_0
  - Write: SimHits, RecHits → ROOT DB
  - MuonReco package → *.root
    - no off-line Muon analysis yet
    - L3MuonReconstructor used
  - jpgcode (jets and MET reconstruction) → *.root
    - iterative cone algorithm used for jet reconstruction
    - cone size 0.5
  - Relevant parts of the both jpgcode.root and MuonReco.root were merged and written to one file
- In the analysis jet E_T corrections were also applied

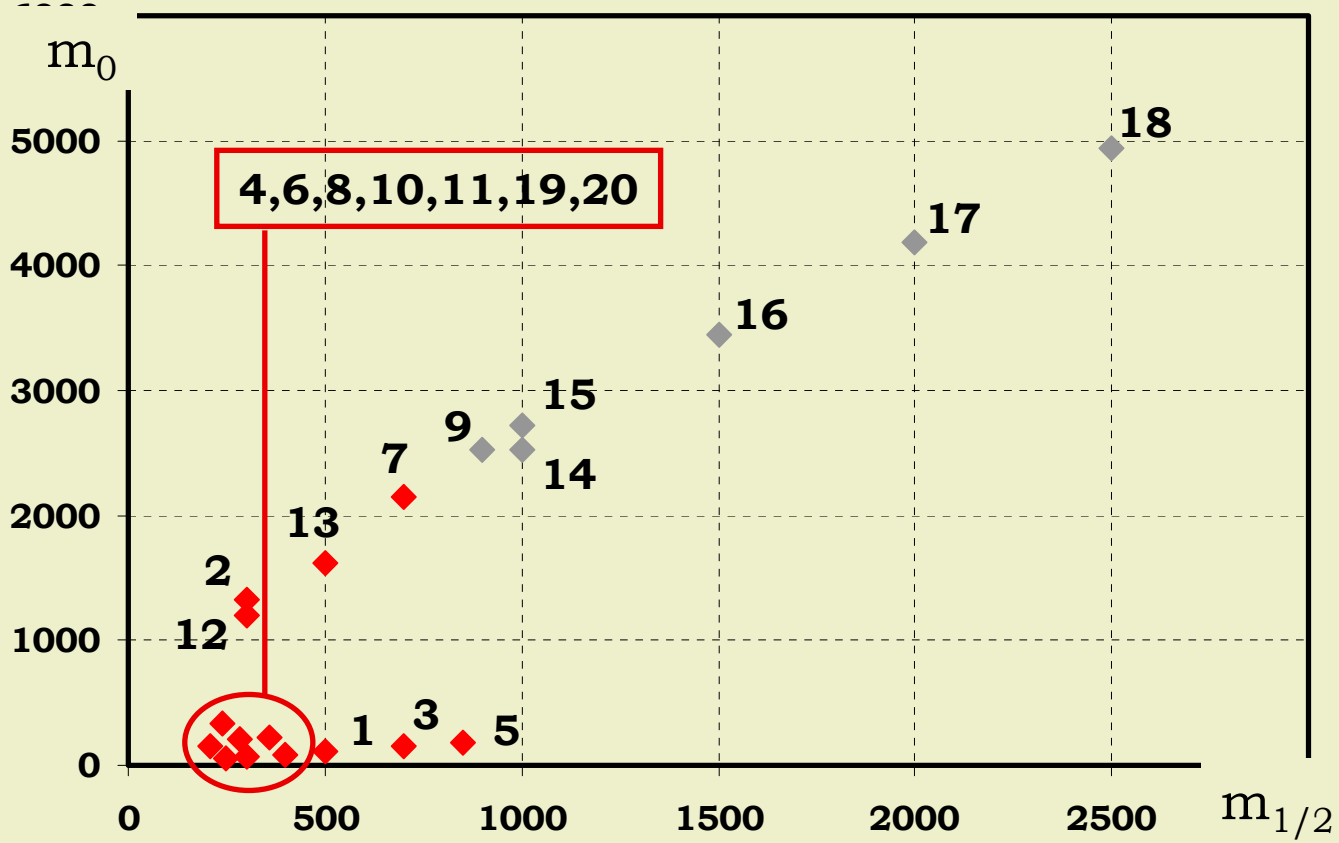
Results, Cuts Set #1

SET 1	SM	1	2	3	4	5	6
N final	69.5±6.0	95.9±6.7	282±20	17.7±1.1	365±73	6.54±0.37	277±35
Signif		9.05	20.8	2	25	0.77	20.6
S/B		1.38	4.06	0.25	5.26	0.094	4

SET 1	7	8	9	10	11	12	13
N final	6.7±0.35	188±17	n/a	515±78	137±11	409±30	58.8±3.3
Signif	0.78	15.5	n/a	31.7	12.1	27.1	6
S/B	0.096	2.71	n/a	7.41	1.98	5.89	0.85

SET 1	14	15	16	17	18	19	20
N final	n/a	n/a	n/a	n/a	n/a	377±59	279±36
Signif	n/a	n/a	n/a	n/a	n/a	25.6	20.6
S/B	n/a	n/a	n/a	n/a	n/a	5.43	4.01

SUSY points considered in this study



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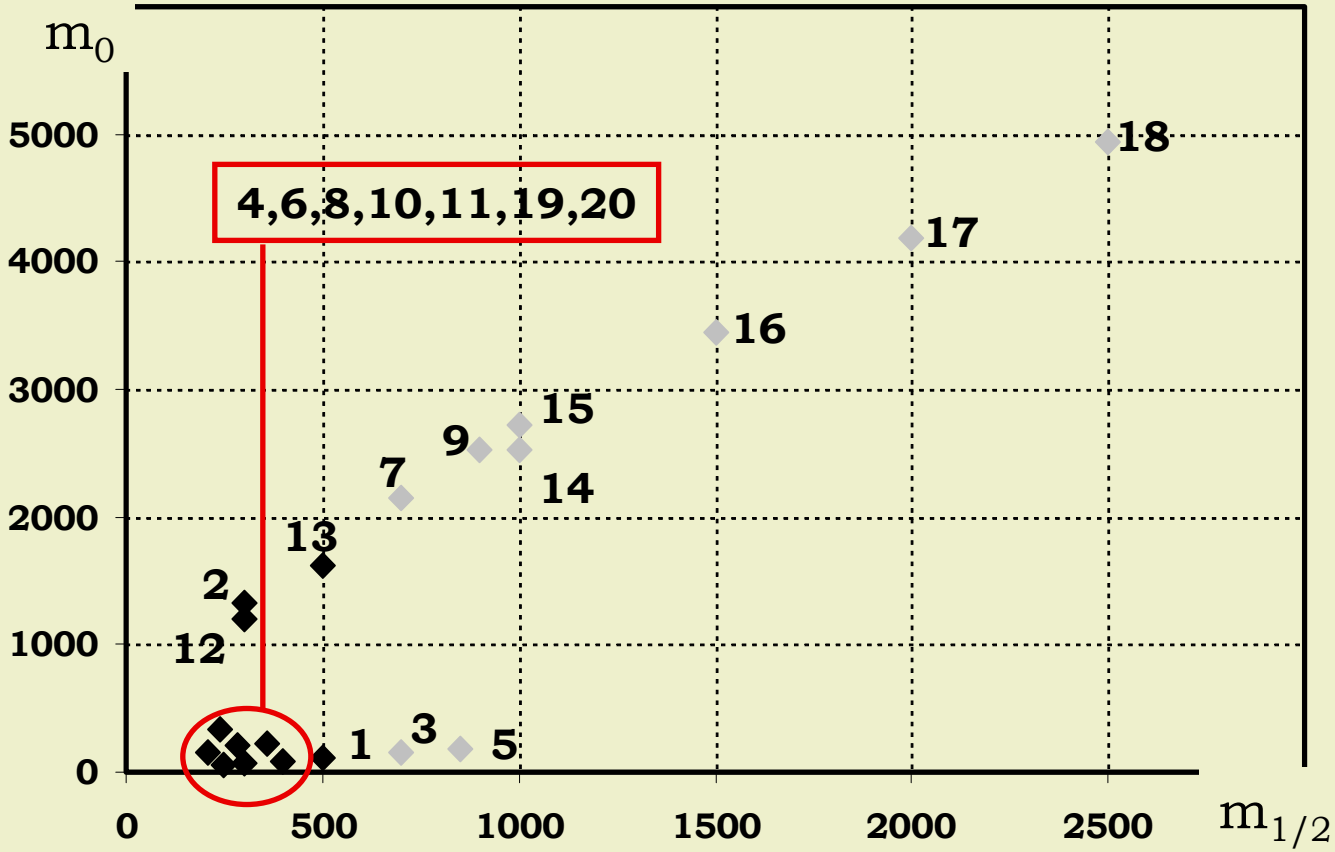

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