Physics at LHC with the CMS experiment

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LIP

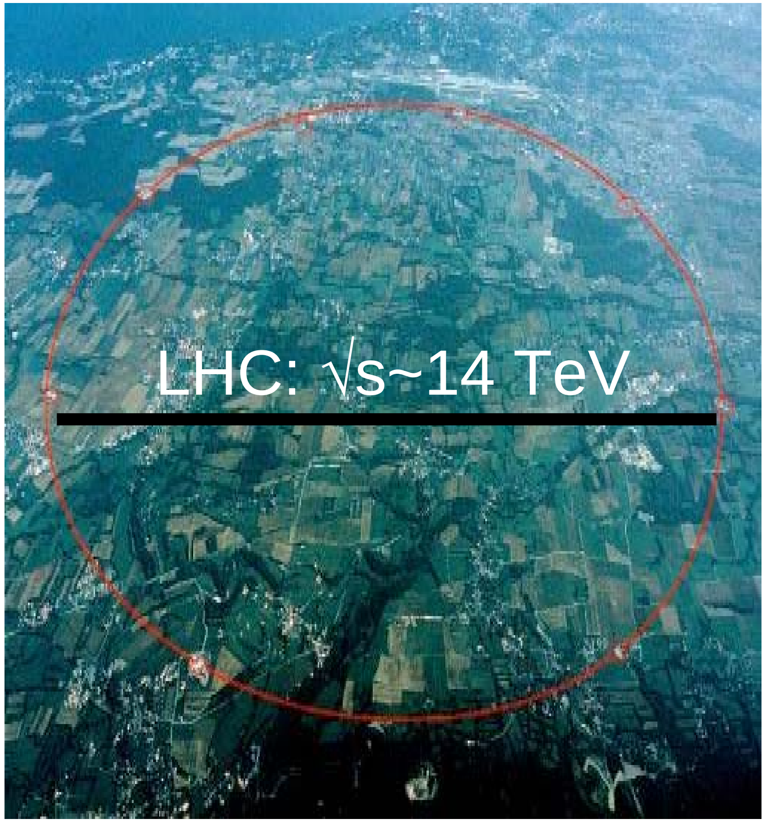
- **Top quark**
  - Cross section measurement
  - Tau identification
  - Measurement of V_{tb}
- **Extra-dimensions**
  - Searches with first data
  - Electron identification

[+] now at Warsaw

CMS and LHC

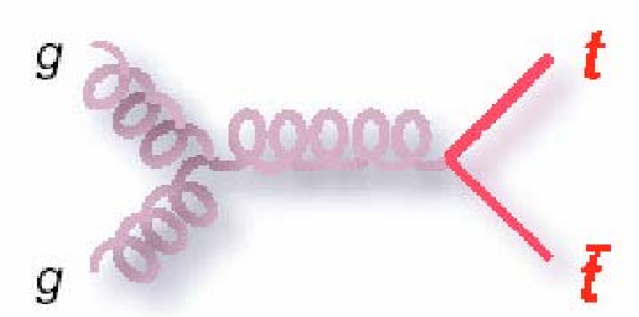
- explore new energy frontier
- colliding beams expected in 2008
- start with low luminosity
- 0.1-1.0 fb^{-1} expected in first year

- re-establish SM measurements
- access to new physics (?)



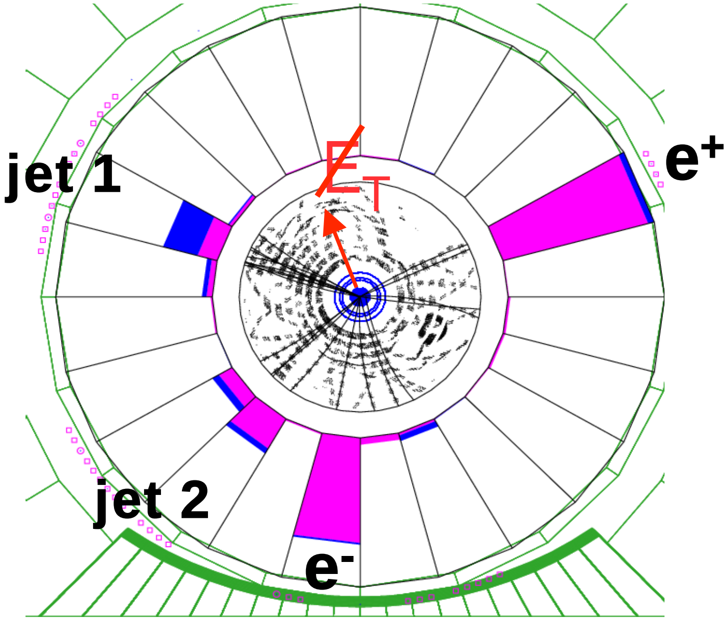
Top quarks at the LHC

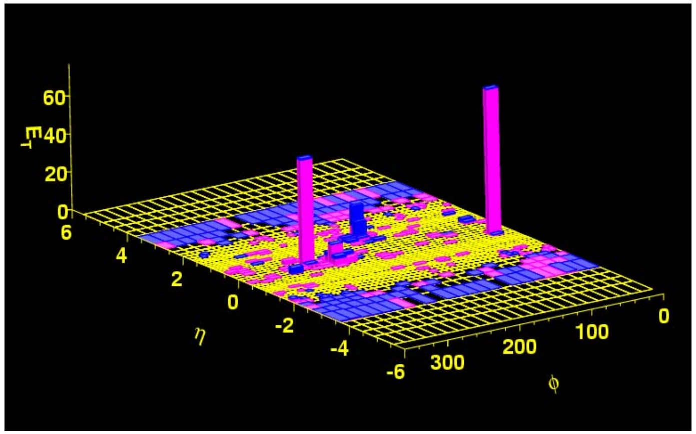
- LHC is a top factory
  - approx. 830k ttbar events/fb
- yield in 1/fb (after selection):
  - dilepton (e/μ): ~5k events
  - lepton+jets: ~35k events
- energy scale calibration ($W \rightarrow jj$)



	TeV	LHC
	ppbar	pp
E_{CM}	1.96TeV	14 TeV
qq	85%	15%
gg	15%	85%
σ_{tt}	6.7 pb	830 pb

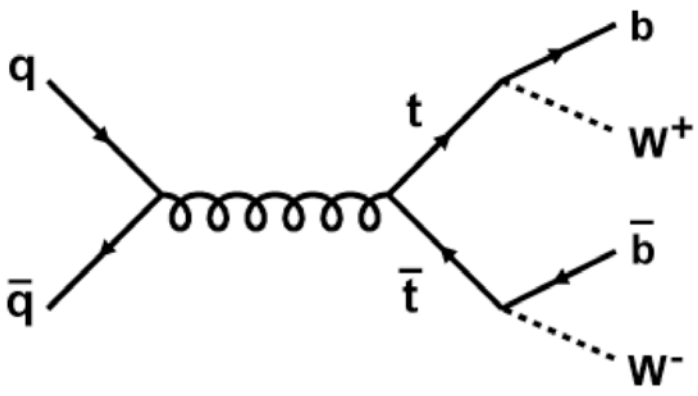
Detecting the Top





- Signal:
  - ✓ triggering on lepton
  - ✓ large missing transverse energy ($\not\!\!E_T$)
  - ✓ high E_T jets, central and spherical
  - ✓ two b-jets (displaced vertex)
- Background:
  - ✓ W+jets:
    - dominant in leptonic modes
    - fakes the second lepton
  - ✓ Drell-Yan (dileptons): no $\not\!\!E_T$
  - ✓ QCD: huge in all-jet mode

Taus in top decays



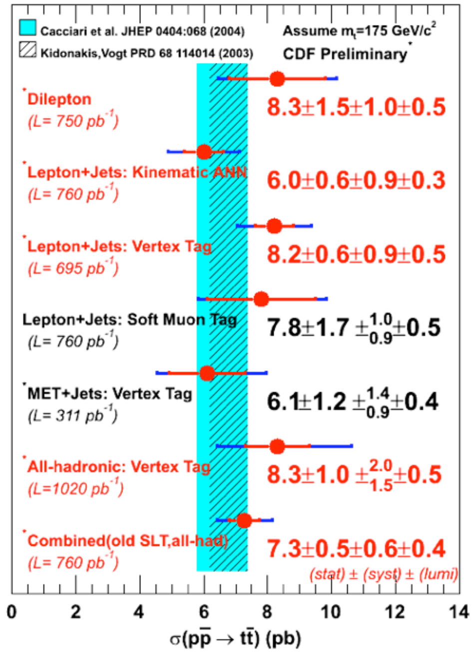
Channel	Signature	BR
Dilepton(e/μ)	*ee*,$\mu\mu$,*e*μ + 2*b*-jets	4/81
Single lepton	*e*,μ + jets + 2*b*-jets	24/81
All-hadronic	jets + 2*b*-jets	36/81
Tau dilepton	*e*τ, $\mu\tau$ +2 *b*-jets	4/81
Tau+jets	τ + jets + 2*b*-jets	12/81

- should have same rate as *e*μ dilepton channel
- challenging (lower p_T than *e* or μ due to ν's)
- probe New Physics processes

Tau dileptons

- Measure: $R = \dfrac{BR(tt \to l\tau\nu\nu jj)}{BR(tt \to ll\nu\nu jj)}$ $(l = e, \mu)$
- Advantages:
  - increase statistics
  - cross-check to other BRs
- Disadvantages:
  - small statistics/larger background
  - soft tau p_T due to neutrinos

tau dileptons PRL79(1997)3585

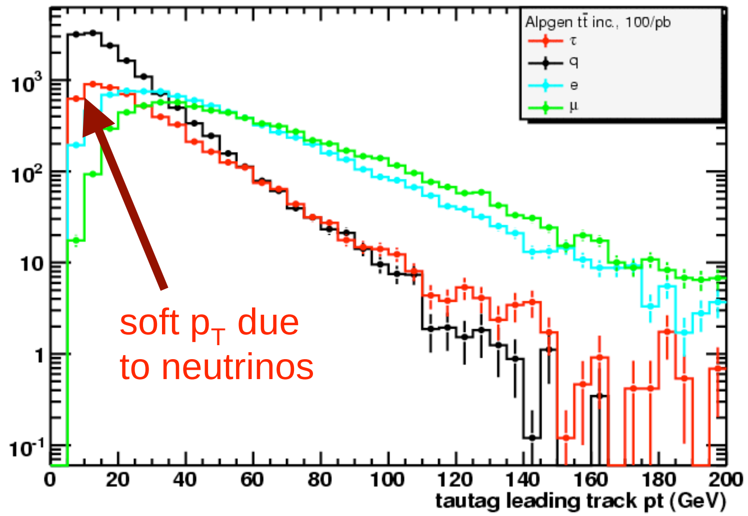


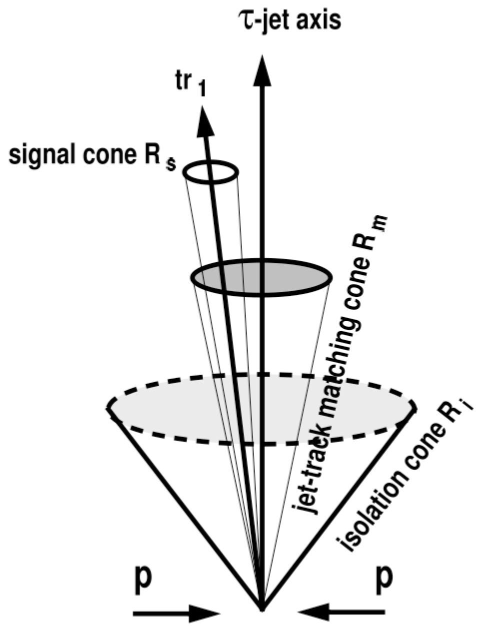
⇨ test lepton universality

⇨ probe non-standard physics ($t \to H^{\pm}b$, …)

Hadronic tau decays

- Look for taus in their hadronic decay
  - $\tau \rightarrow$ 1charged hadron (BR~50%)
  - $\tau \rightarrow$ 3 charged hadrons (BR~14%)
- Hadronic taus are identified using tracking/calorimeter information





Requires track isolation to discriminate against QCD jets

Tau identification

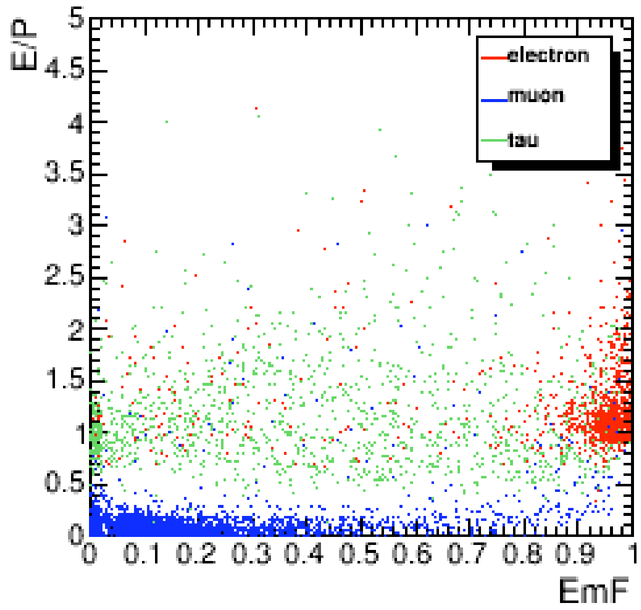
Pick up the discriminated TauTagged objects in each samples

Apply a kinematical cut in the tau tagged candidates

- p^{LT}_{T} > 15GeV
- $|\eta| < 2.4$

Apply different electron/muon veto on these candidates:

- EmFraction < 0.9
- Energy HCAL > 1GeV
- Energy HCAL + HCAL > 10GeV
- E_{jet}/p_{LT}> 0.5
- maxET on HCAL Tower > 1GeV

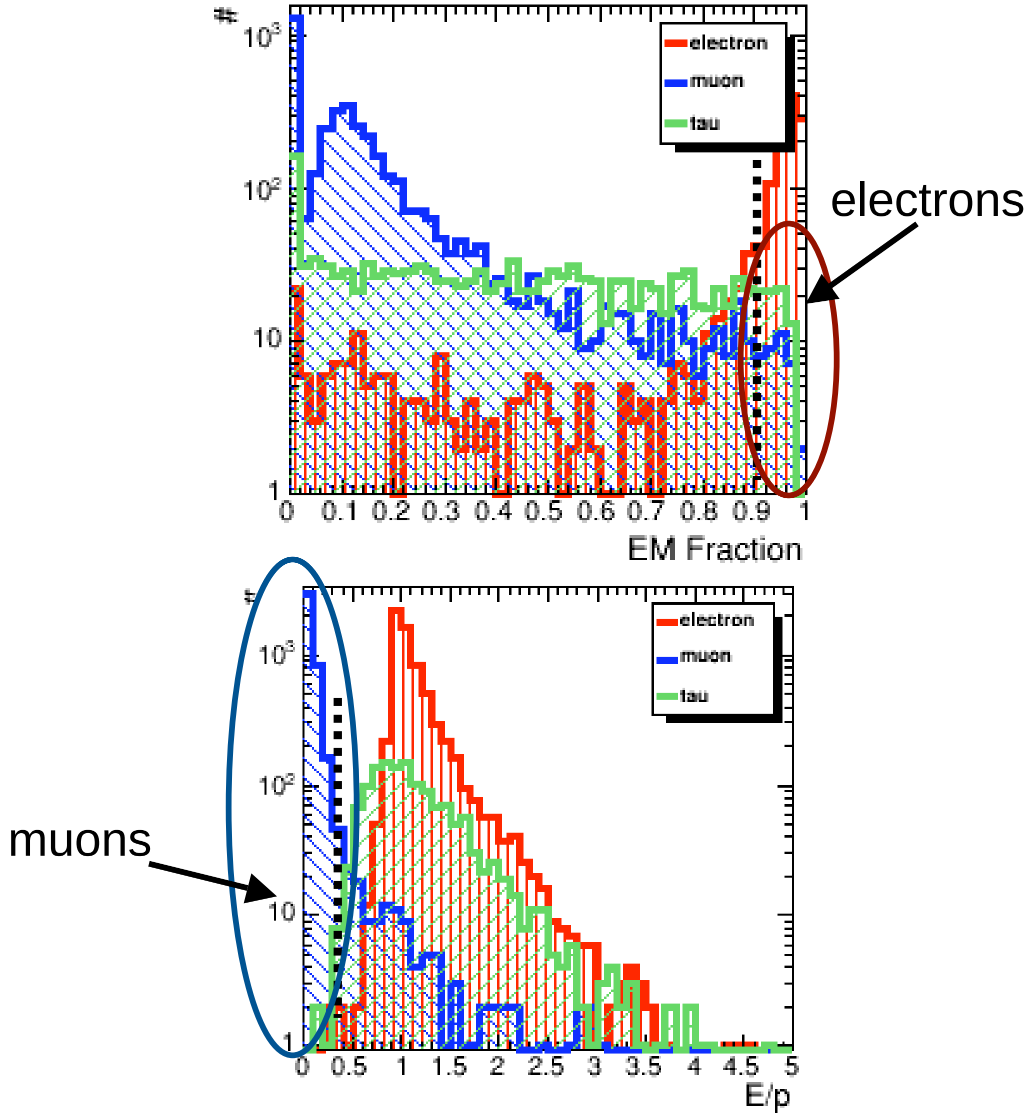


Combine these values in order to obtain the best rejection factor.

Electron/muon rejection

- e/μ contamination in tau-ID is large
- study DY(ee,μμ,ττ) samples
- electron veto:
  - EMF>0.9
  - accepts ~4% of generated electrons
- muon veto:
  - E/P>0.5
  - accepts ~2% of generated muons

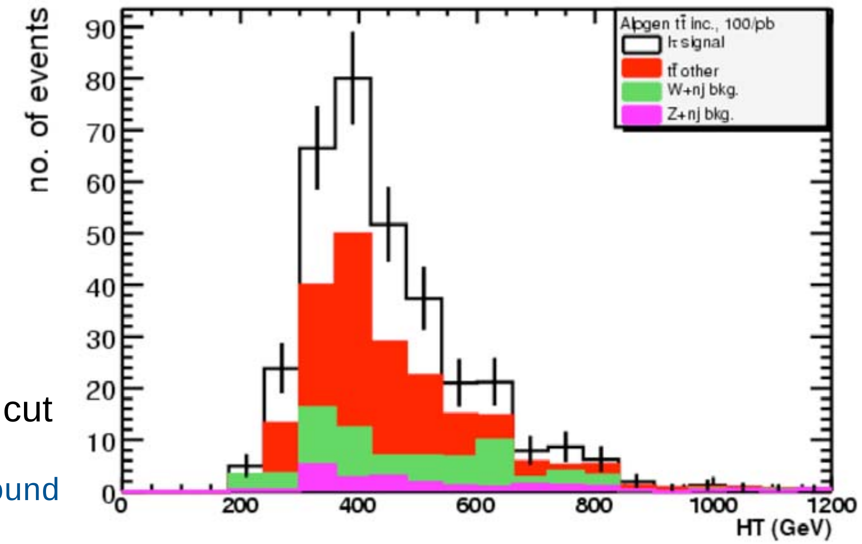
⇨ tau efficiency: ~89%



Event yield in 100/pb

- Isolated lepton: p_T>20 GeV
- ≥2jets E_T>30 GeV $|\eta|$<2.4
- Missing E_T>60 GeV

Distribution of H_T after OS cut
✓Empty histogram - signal
✓Filled histogram - background



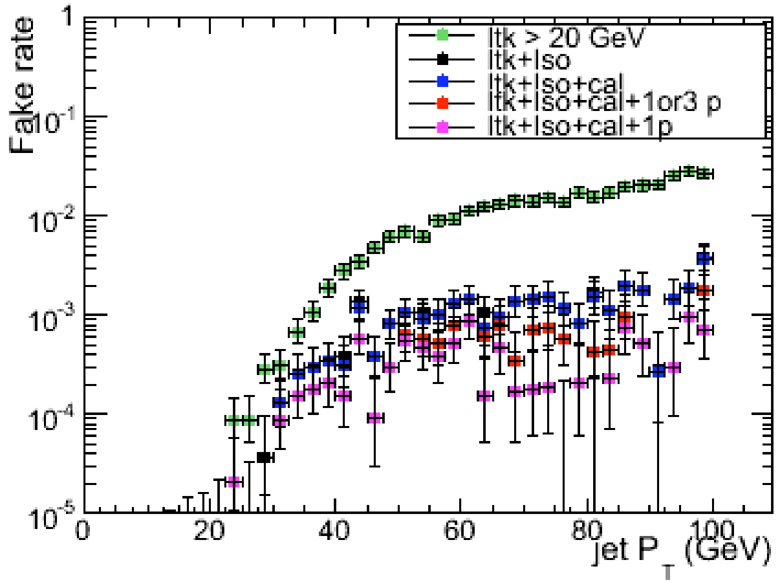
cut	signal		other $t\bar{t}$			background		
	$e\tau$	$\mu\tau$	$\ell\ell$	$\ell(q\bar{q})$	full-had.	$W+nj$	$Z+nj$	S/B
Expected	1559.8	1559.8	5751.8	29246.5	45532.0	–	–	–
HLT all	820.0 ± 23.4	1019.3 ± 25.9	4757.4 ± 56.2	17090.6 ± 106.6	1903.9 ± 35.4	156616.3 ± 741.7	69361.8 ± 718.4	0.007
$N_{lep} \geq 1$	533.0 ± 13.4	781.1 ± 17.2	4175.1 ± 41.5	12741.8 ± 69.4	38.6 ± 2.5	106917.7 ± 382.1	55240.3 ± 358.4	0.007
$N_{tau} \geq 1$	76.6 ± 5.1	112.8 ± 6.6	188.6 ± 8.9	201.1 ± 8.7	1.1 ± 0.4	657.1 ± 29.2	2647.3 ± 78.1	0.051
$N_{tau-ID} \geq 1$	73.0 ± 5.0	106.3 ± 6.4	66.7 ± 5.3	184.1 ± 8.3	1.1 ± 0.4	631.9 ± 28.6	893.2 ± 44.2	0.101
$N_{jet} \geq 2$	50.0 ± 4.0	65.5 ± 4.9	31.0 ± 3.5	151.7 ± 7.5	0.8 ± 0.4	132.4 ± 10.3	164.2 ± 10.9	0.240
MET> 60GeV	40.3 ± 3.6	49.5 ± 4.2	25.3 ± 3.1	72.6 ± 5.2	0.8 ± 0.4	34.5 ± 5.0	13.2 ± 1.9	0.614
op. sign	39.3 ± 3.6	48.5 ± 4.2	21.6 ± 2.9	52.1 ± 4.4	0.8 ± 0.4	23.5 ± 4.2	12.9 ± 1.9	0.793
$N_{b-tag} \geq 1$	33.7 ± 3.4	44.4 ± 4.0	19.4 ± 2.8	46.4 ± 4.2	0.8 ± 0.4	8.3 ± 2.6	8.3 ± 1.5	0.963
$N_{b-tag} \geq 2$	18.6 ± 2.5	22.5 ± 2.9	9.1 ± 1.9	18.6 ± 2.6	0.6 ± 0.3	0.9 ± 0.7	2.8 ± 0.7	1.288

Table 1: Number of selected events, 1-prong

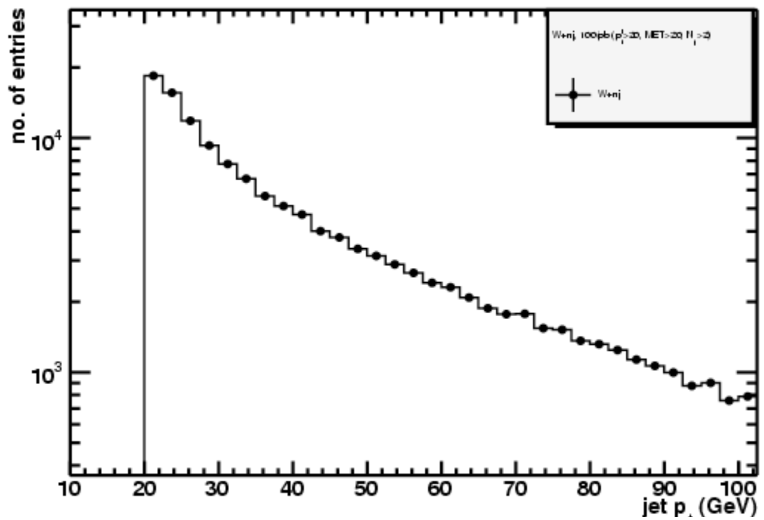
QCD background

Evaluate fake rate from data:

1) inclusive Jet E_T distribution
2) jet identified as tau candidate
3) fake probability for a tau candidate



Apply to W+≥3jets distribution



Acceptance

Total acceptance: A_{tot} = A x BR (normalized to inclusive tt)

Note: τ stands for hadronic-τ only

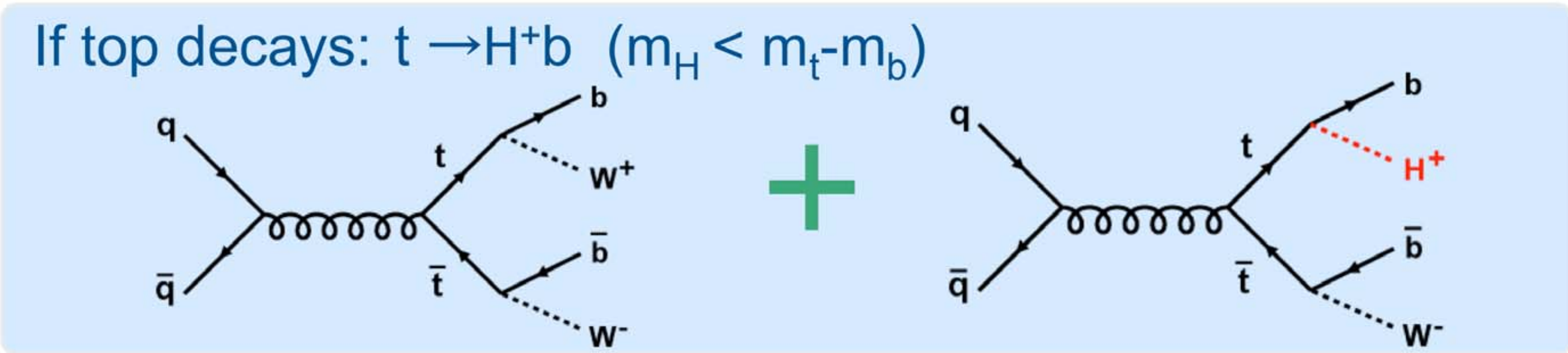
cut	1-prong $e\tau$	1-prong $\mu\tau$	1-prong total $\ell\tau$	3-prongs $e\tau$	3-prongs $\mu\tau$	3-prongs total $\ell\tau$
Expected	1.86469	1.86469	3.72938	1.86469	1.86469	3.72938
$N_{lep} \geq 1$	0.83954 ± 0.02112	1.09344 ± 0.02409	1.93297 ± 0.03204	0.83954 ± 0.02112	1.09344 ± 0.02409	1.93297 ± 0.03204
$N_{tau} \geq 1$	0.12062 ± 0.00809	0.15788 ± 0.00924	0.27850 ± 0.01228	0.04278 ± 0.00468	0.05672 ± 0.00539	0.09951 ± 0.00936
$N_{tau-ID} \geq 1$	0.11501 ± 0.00788	0.14879 ± 0.00896	0.26380 ± 0.01194	0.04232 ± 0.00467	0.05541 ± 0.00534	0.09773 ± 0.00920
$N_{jet} \geq 2$	0.07873 ± 0.00638	0.09163 ± 0.00684	0.17036 ± 0.00935	0.02435 ± 0.00340	0.03674 ± 0.00423	0.06109 ± 0.00712
MET> 60GeV	0.06351 ± 0.00569	0.06925 ± 0.00593	0.13276 ± 0.00823	0.02051 ± 0.00312	0.02961 ± 0.00379	0.05012 ± 0.00635
op. sign	0.06194 ± 0.00562	0.06789 ± 0.00589	0.12983 ± 0.00814	0.01069 ± 0.00229	0.01531 ± 0.00271	0.02600 ± 0.00536
$N_{b-tag} \geq 1$	0.05625 ± 0.00538	0.06214 ± 0.00564	0.11839 ± 0.00779	0.00993 ± 0.00219	0.01402 ± 0.00260	0.02394 ± 0.00514
$N_{b-tag} \geq 2$	0.02937 ± 0.00394	0.03146 ± 0.00401	0.06083 ± 0.00562	0.00713 ± 0.00185	0.00728 ± 0.00186	0.01441 ± 0.00384

Table 1: Efficiency of selection with respect to inclusive $t\bar{t}$ (in %).

- estimated acceptance from MC
  - ❖ ~0.16% for eτ/μτ
- additional cuts may be used to further reduce the background
  - ❖ H_T, b-tagging (?)

Charged Higgs

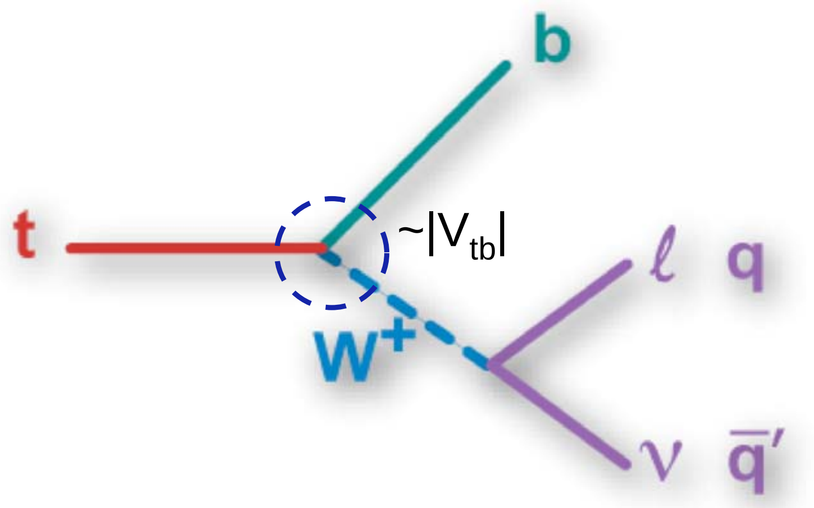
- Tau dilepton channel is of particular interest as existence of charged Higgs can give rise to **anomalous** tau lepton production



⇨directly observable in this channel

Is BR(t→Wb)~100% ?

- In the SM, $R = \dfrac{BR(t\rightarrow Wb)}{BR(t\rightarrow Wq)} \approx |V_{tb}|^2$ (q=b,s,d) $0.9980<R<0.9984$
- measure R by comparing the number of ttbar events with 0, 1 and 2 b-tags
- $R \approx O(10^{-1})$ ⇨evidence for New Physics (e.g. 4th generation hep/ph-0607115)



$R = 1.03^{+0.17}_{-0.15}(\text{stat})^{+0.09}_{-0.07}(\text{syst})$

$|V_{tb}|>0.71$ @95% CL (lepton+jets)

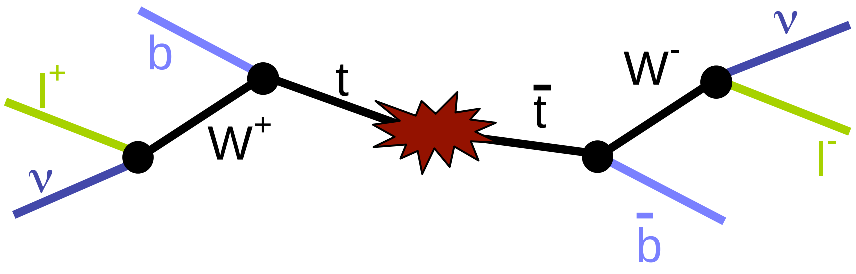
$|V_{tb}|>0.68$ @95% CL (single top)

(hep/ex-0612052)

Not yet sensitive to SM

Di-lepton channel

- Complementary to lepton+jets
- Advantages:
  – less combinatorial ambiguity
  – less background
- Disadvantages:
  – lower statistics



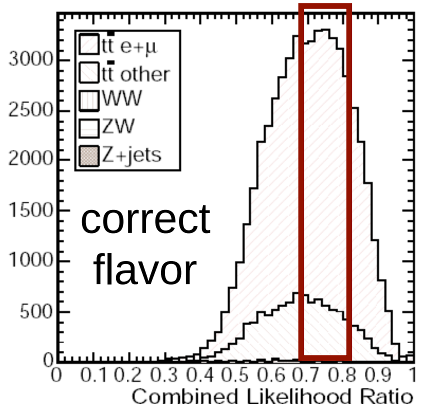
- Selection:
  – 2 leptons+ ≥2 jets + MET
  – no b-tagging in preselection
  – 4% uncertainty achieved on b-tagging efficiency
- S/B = 529/70 ~8 with 100/pb (CMS 2007/025)

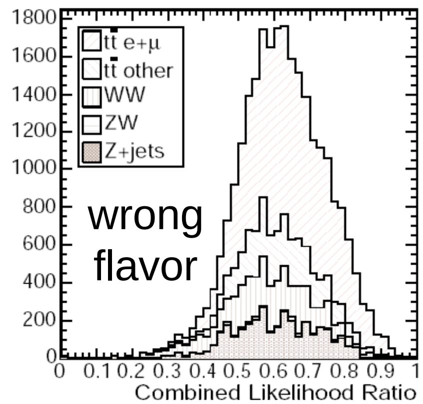
- Plan:
  – reproduce/improve efficiencies
  – study background:
    - W/Z+jets, single top, gluon splitting, etc.
  – simultaneous extraction of R and ε(b)
    - 2 unknowns with 2 observables: N(2tag)/N(1tag) and N(1tag)/N(0tag)

b-tagging with first data

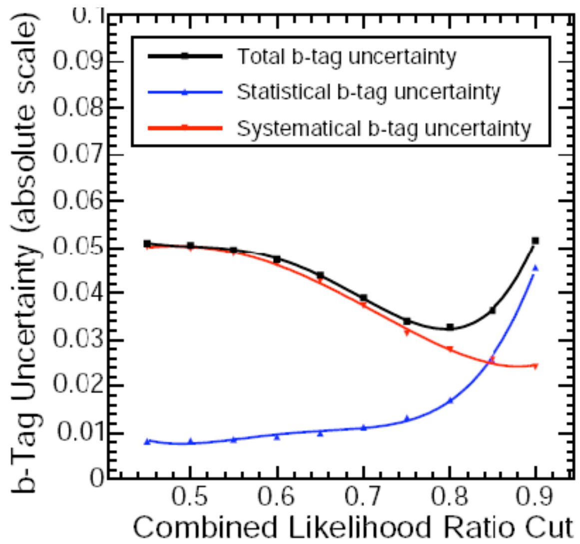
A Likelihood Ratio method parametrizes the ratio f=S/(S+B) for different kinematical distributions – $x_i = p_T(top)$, $p_T(b_{lep})$, $\Delta\phi$, $\Delta\theta$, $E_T(jet)$, etc.

$$L = \prod_i \frac{f_i(x_i)}{1 - f_i(x_i)}$$





- For L=100/pb, an uncertainty of 6%(stat) + 6%(syst) is expected (assuming a cut for 75% b-jet purity)
- Misalignment simulations give: ε_b=65.7% e_{udsg}=3.0%, ε_c=7.1% for the same luminosity



Measuring V_{tb}

Results indicate a statistical error of ~0.02 in measuring R with L = 100/pb:

TABLE 3 –EVENT YIELDS AT L = 100pb $^{-1}$ *(WITH TOY MC MODEL FOR b-tagging)*				
N_{evts}(expected) w/ dileptonic decay		441 ± 4		
MC SAMPLE		*All b*	*Mix*	*All q*
$R_{generated}$		1	0.9	0
N_{evts} with *k* b-tags	0	43 ± 2	60 ± 3	429 ± 7
	1	181 ± 4	203 ± 5	11 ± 1
	2	217 ± 5	177 ± 5	0.243 ± 0.1
$R_{measured}$		1.00 ± 0.02	0.90 ± 0.02	$0.002^{+0.006}_{-0.002}$

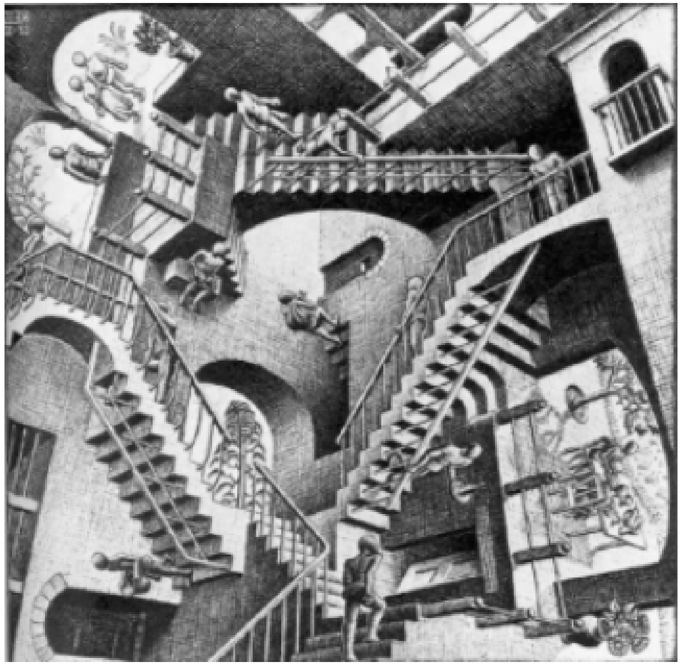
a) 100% to b (All b)
b) 90% to b, 10% to q (Mix)
c) 100% to q (all q)

Taking into account the detector response and resolution:

- σ_R=0.08 (stat)
- σ_R=0.09 (syst)

Extra Dimensions

- Can we imagine more than 3-D?

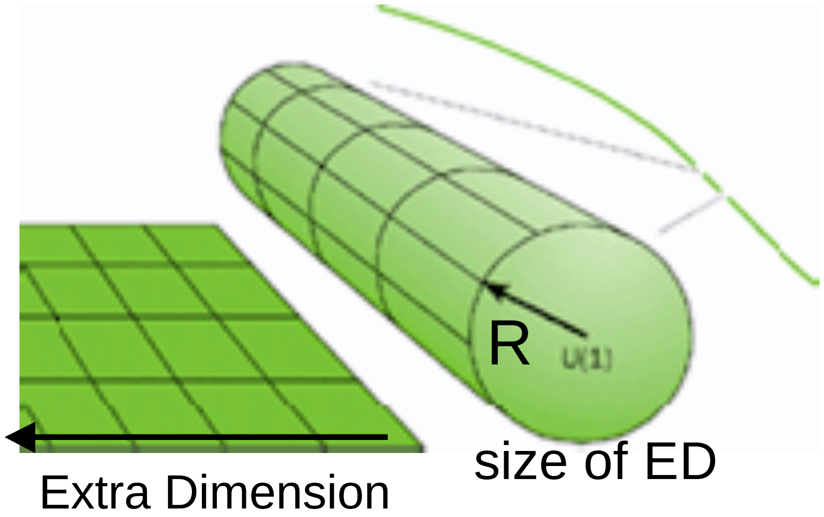


- Attempt to unify gravity and electromagnetism in a five dimensional (5D) theory (Kaluza-Klein)

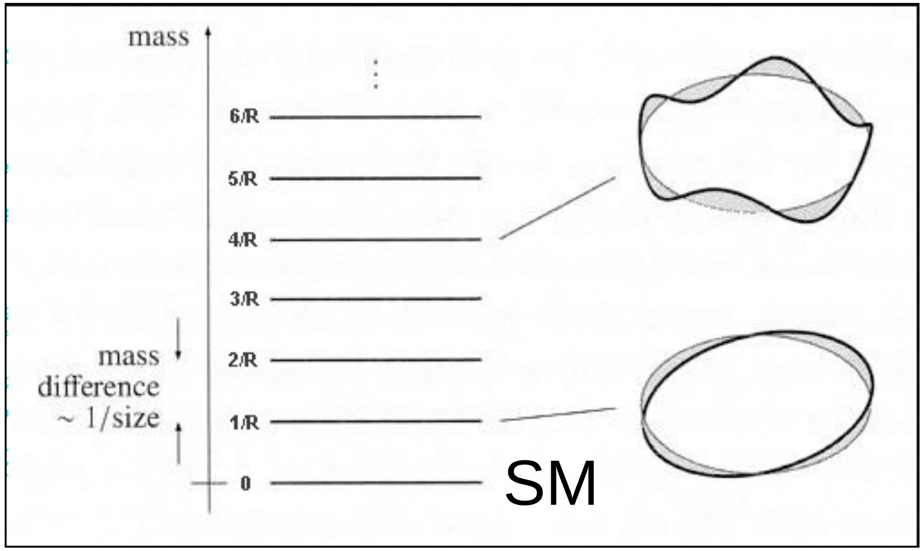
- All SM particles "feel" extra-dimensions
  - each particle has a "tower" of KK excitation

Clean signature

- Like in SUSY, strongly interacting particles are produced
- KK quarks/gluinos may be produced at LHC
- Four leptons in the final state:
  - $pp \rightarrow g_1 g_1 \rightarrow$ 4leptons + 4jets + MET



KK levels ⇔ excitation modes



Universal ED

SM in 5D –Minimal UED (MUED)

- electroweak observables are insensitive to the unknown physics above the cutoff scale
- **1/R** and Λ are the only parameters relevant for collider phenomenology

(Cheng, Matchev and Schmaltz, hep-ph/0205314)

- Experimental Bounds
  - Tevatron direct search $\rightarrow$ 1/R > 280 GeV (C.Lin, fermilab-thesis-2005-069
  - Dark matter $\rightarrow$ 600 GeV <1/R< 1050 GeV (Servant and Tait , hep-ph/0206071)

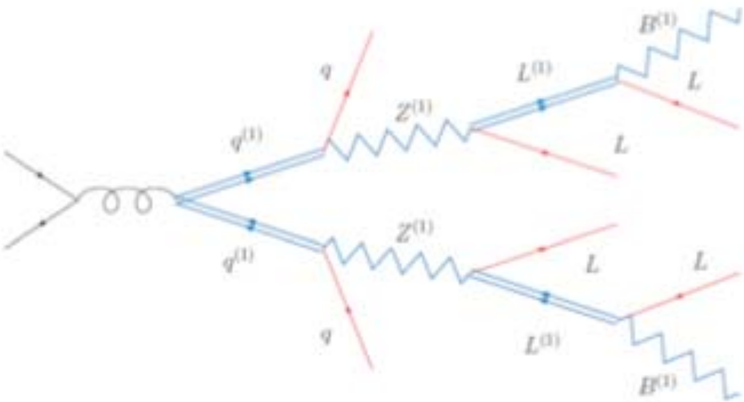
SM in 6D

- anomaly cancellations predict that # fermion generations = 3n
- remnant of 6D Lorentz symmetry enforces long proton lifetime

(Dobrescu, Kong and Mahbubani, hep-ph/0703231)

- Experimental Bounds : 1/R >~270 GeV (trilepton search: Phys.Rev.Lett.99:191806,2007 & AIP Conf.Proc.903:173-176,2007)

Signal and background



$$pp \to g_1 g_1 \;\; \to 2(\ell^{\pm}\ell^{\mp}) + 4q + 2\,\gamma_1^{\rm LKP} \;\; \to 4\ell + 4{\rm jets} + \not{E}_T$$

$$pp \to g_1 q_1 \;\; \to 2(\ell^{\pm}\ell^{\mp}) + 3q + 2\,\gamma_1^{\rm LKP} \;\; \to 4\ell + 3{\rm jets} + \not{E}_T$$

$$pp \to q_1 q_1 \;\; \to 2(\ell^{\pm}\ell^{\mp}) + 2q + 2\,\gamma_1^{\rm LKP} \;\; \to 4\ell + 2{\rm jets} + \not{E}_T$$

- four points: 1/R = 300, 500, 700, 900 GeV ; ΛR=20 ; m_h=120 GeV
- total cross section = 2190, 165, 26, 5.9 pb
- three leptonic decay channels : 4e, 4μ, 2e2μ
- B.R. to each leptonic channel ~ 10^{-4} — 10^{-3}

SM backgrounds considered :

$t\bar{t}$

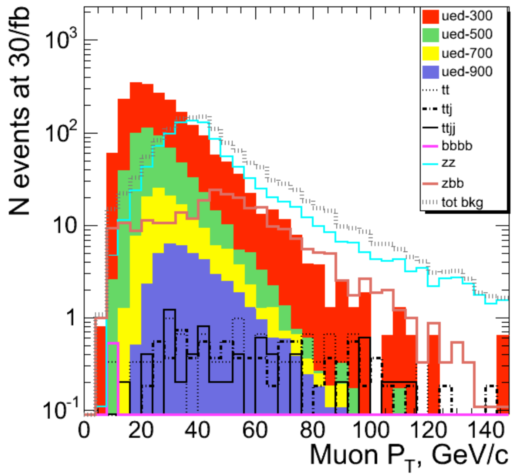
$ZZ(Z^*/\gamma^*)$

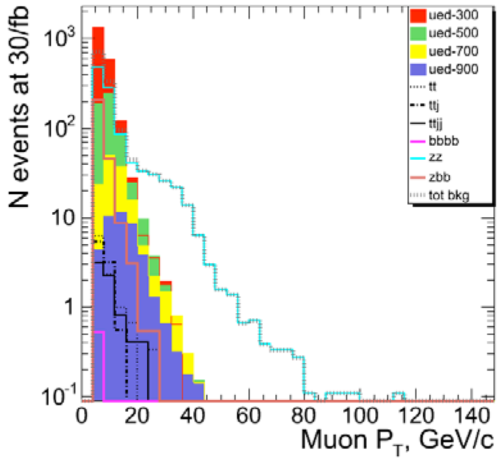
$Zb\bar{b}$

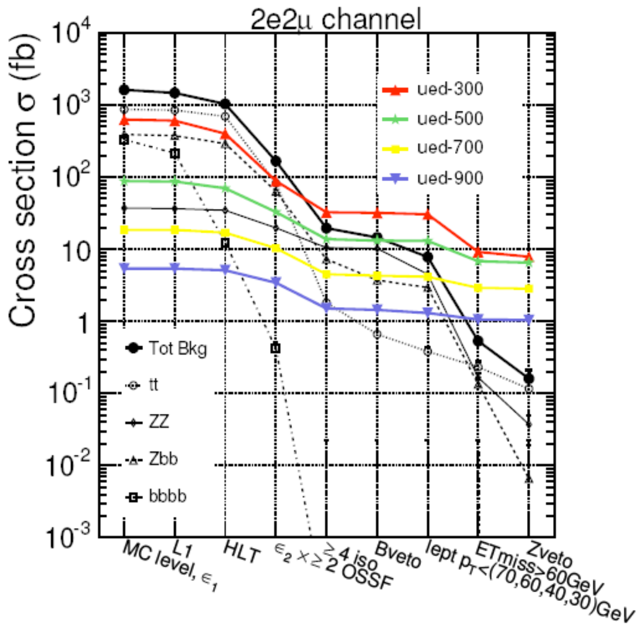
$b\bar{b}b\bar{b}$

Event selection

- 4 isolated leptons
- 2 pairs of OSSF leptons
- b-tag veto
- missing p_T>20 GeV
- Z veto

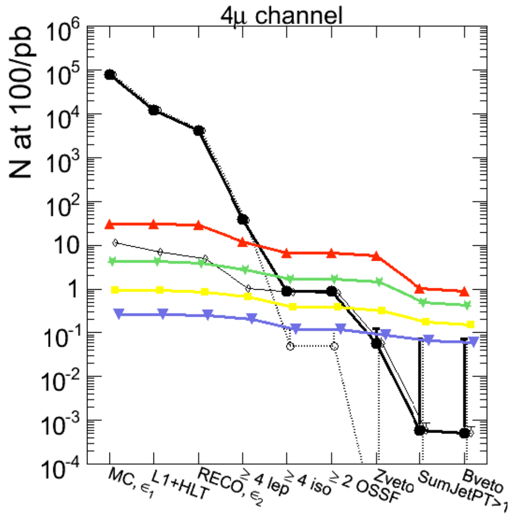


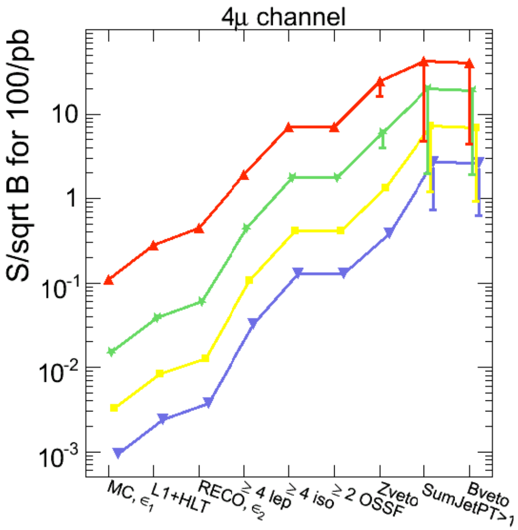




⇨ a few events expected in 100/pb

Event yield for 100/pb





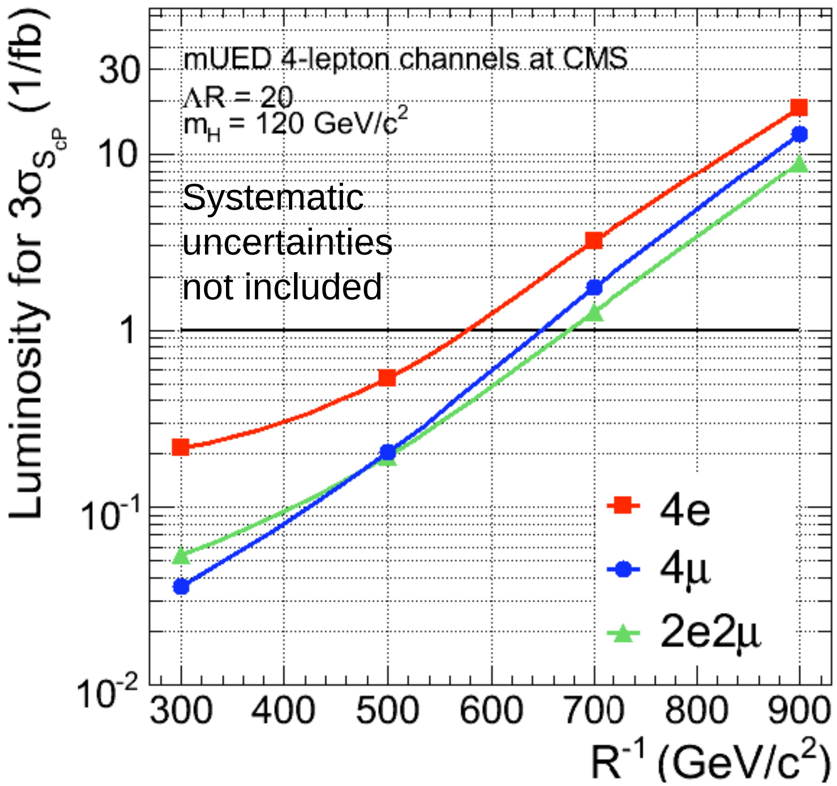
$4e$ channel	Number of events for 100/pb								
Sample	MC,ϵ_1	L1+HLT	RECO,ϵ_2	$\geq$4 lep	$\geq$4 iso	$\geq$2 OSSF	Z-Veto	$\Sigma P_T Jet > 100 GeV$	B-Veto
Ued-300	33	29	26	4	1.3	1.2	1	0.21	0.19
Ued-500	4.5	4.1	3.7	1.5	0.62	0.58	0.52	0.18	0.16
Ued-700	0.94	0.9	0.8	0.44	0.18	0.17	0.14	0.08	0.073
Ued-900	0.27	0.26	0.23	0.14	0.063	0.06	0.046	0.034	0.031
Tot bkg	8e+04	9.5e+03	4.4e+03	3.1e+02	0.38	0.35	0.018	0.0005	0.00042
$t\bar{t}$	8e+04	9.5e+03	4.4e+03	3.1e+02	0	0	0	0	0
ZZ	12	6.3	4.2	0.54	0.38	0.35	0.018	0.0005	0.00042

4μ channel	Number of events for 100/pb								
Sample	MC,ϵ_1	L1+HLT	RECO,ϵ_2	$\geq$4 lep	$\geq$4 iso	$\geq$2 OSSF	Z-Veto	$\Sigma P_T Jet > 100 GeV$	B-Veto
Ued-300	31	31	29	12	6.5	6.5	5.7	1	0.9
Ued-500	4.3	4.3	3.9	2.8	1.6	1.6	1.4	0.48	0.42
Ued-700	0.91	0.91	0.83	0.66	0.39	0.39	0.31	0.17	0.15
Ued-900	0.26	0.26	0.24	0.2	0.12	0.12	0.089	0.066	0.059
Tot bkg	8e+04	1.2e+04	4.2e+03	39	0.87	0.87	0.056	0.00058	0.0005
$t\bar{t}$	8e+04	1.2e+04	4.2e+03	38	0.048	0.048	0	0	0
ZZ	12	6.9	5	1	0.82	0.82	0.056	0.00058	0.0005

$2e2\mu$ channel	Number of events for 100/pb								
Sample	MC,ϵ_1	L1+HLT	RECO,ϵ_2	$\geq$4 lep	$\geq$4 iso	$\geq$2 OSSF	Z-Veto	$\Sigma P_T Jet > 100 GeV$	B-Veto
Ued-300	62	60	56	13	5.6	5.3	5.1	0.97	0.88
Ued-500	8.7	8.4	7.7	4.2	2	1.9	1.9	0.66	0.59
Ued-700	1.9	1.8	1.6	1.1	0.56	0.55	0.54	0.31	0.28
Ued-900	0.54	0.53	0.47	0.34	0.17	0.17	0.17	0.13	0.11
Tot bkg	8e+04	2.1e+04	1.3e+04	5.7e+02	1.8	1.2	0.15	0.055	0.0017
$t\bar{t}$	8e+04	2.1e+04	1.3e+04	5.7e+02	0.59	0.1	0.054	0.054	0
ZZ	12	9.8	9.2	1.6	1.2	1.1	0.093	0.0018	0.0017

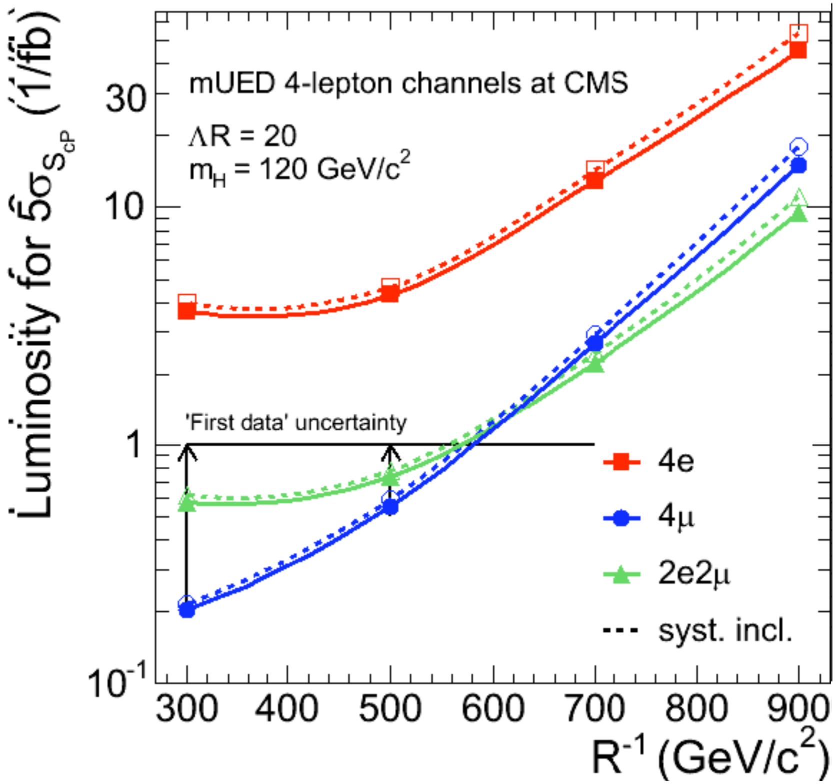
Exclusion limits

- No towers are yet observed in nature, below few hundred GeV
  - Extra-dimensions are small
- With first LHC data there may be indication for UED
- Sensitivity for low mass UED with <1/fb



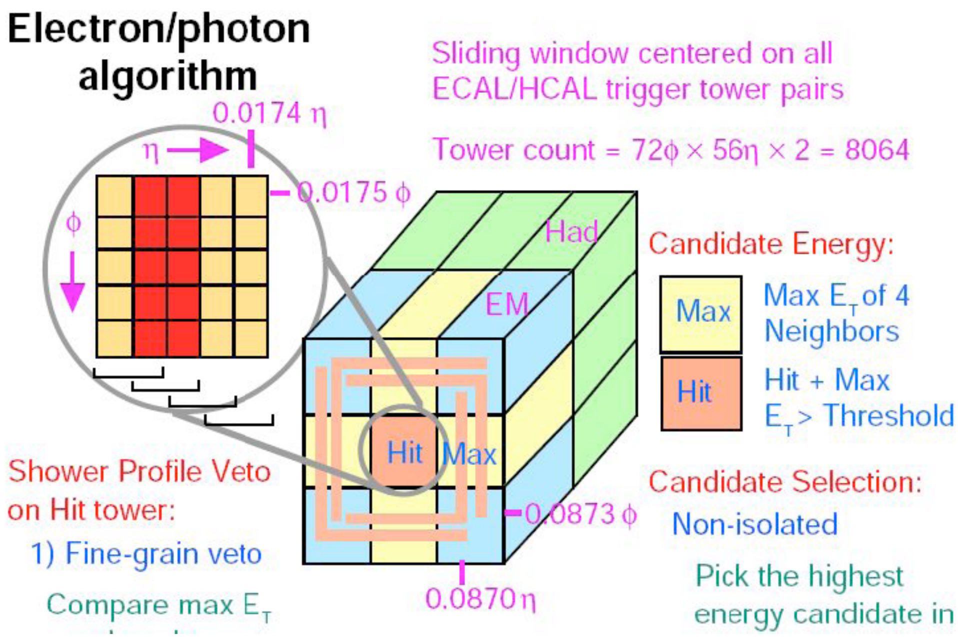
Discovery potential

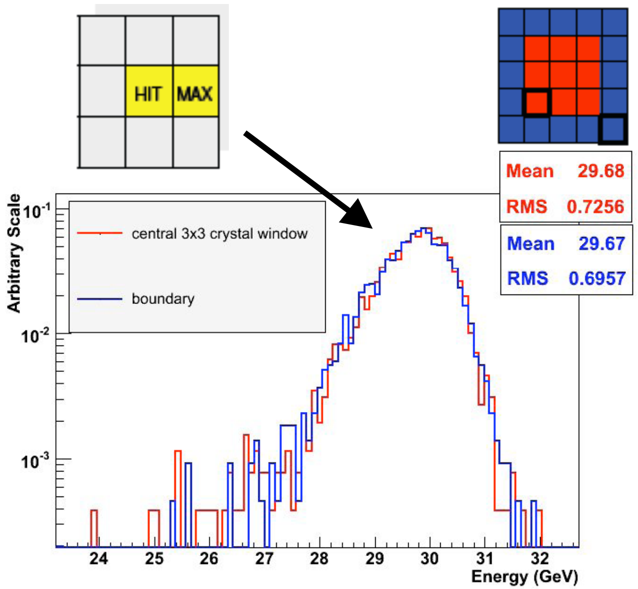
- No towers are yet observed in nature, below few hundred GeV
  - Extra-dimensions are small
- With first LHC data there may be indication for UED
- Sensitivity for low mass UED with <1/fb



Electron/photon trigger

- Use test beam data
- L1 trigger algorithm: 8 nearest neighbors around *hit* tower
  - Electron $E_T = E_T^{hit} + \max E_T$ (of 4 neighbors)
  - Non-isolated/isolated candidates





Electron trigger efficiency

- ~4% of high-energy (100 GeV) electrons is classified as non-isolated
- They can be recovered through the non-isolated electron stream

	Electron Selection Efficiency in percentage			
	Non Isolated Stream		Isolated Stream	
Energy (GeV)	$E_{thr}^{FG} = 3$ GeV	$E_{thr}^{FG} = 5$ GeV	$E_{thr}^{FG} = 3$ GeV	$E_{thr}^{FG} = 5$ GeV
9	95	95	95	95
15	98	98	98	98
20	98	98	97	98
30	98	98	97	98
50	99	99	90	99
100	100	100	89	96

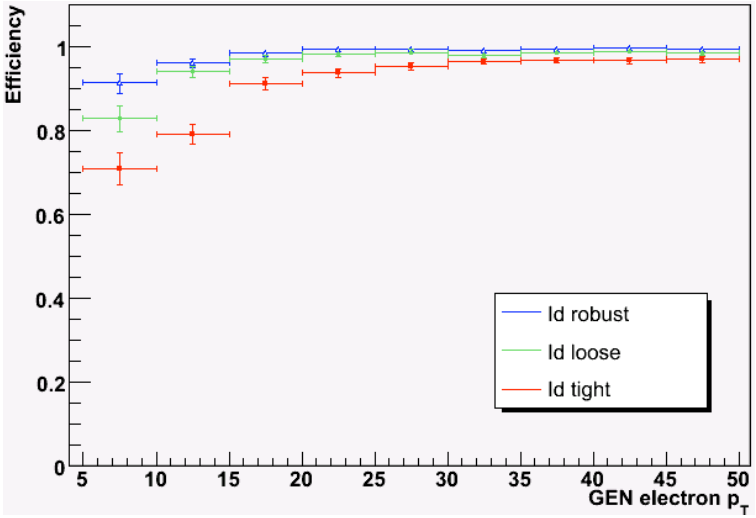
P. Ribeiro et al., JINST 2:P12001,2007

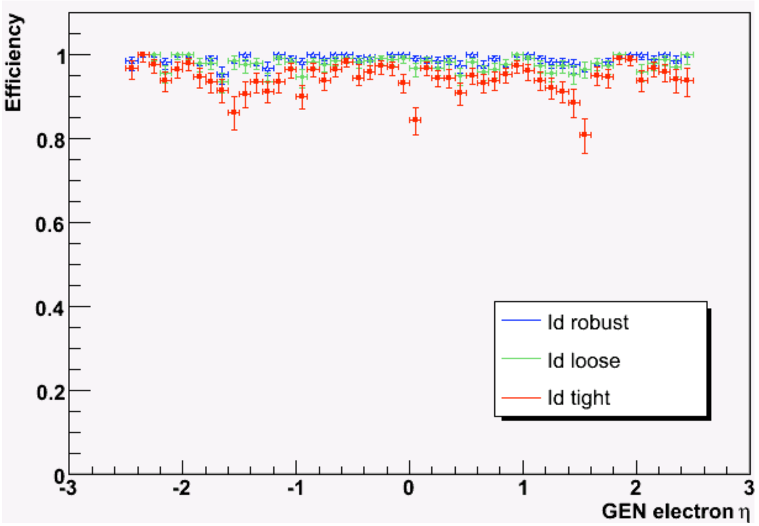
⇨ high trigger efficiency can be achieved for electrons/photons

Electron ID

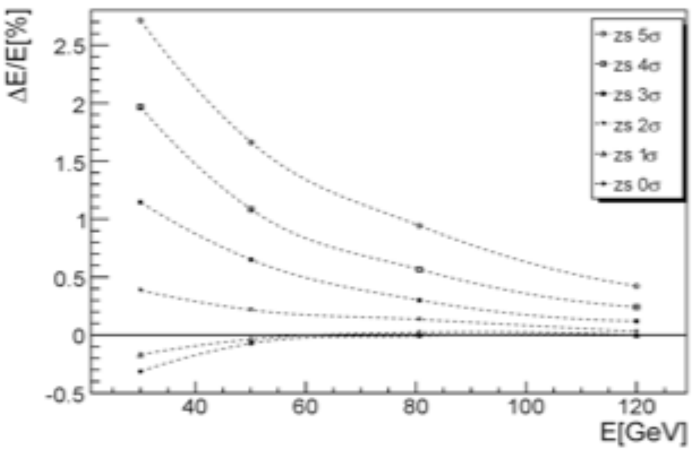
- Need high efficiency for:
  - H→4 leptons
  - low E_T electrons
- Selection cuts:
  - match in ϕ and η between track/cluster
  - E/P
  - Shower shape
  - H/E
- Divide electrons in 3 categories

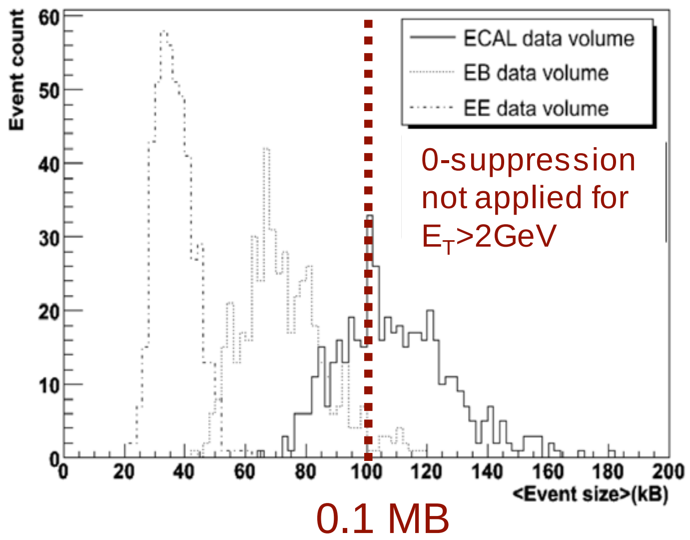
⇨ 98% efficiency and low fake rate





ECAL data filtering





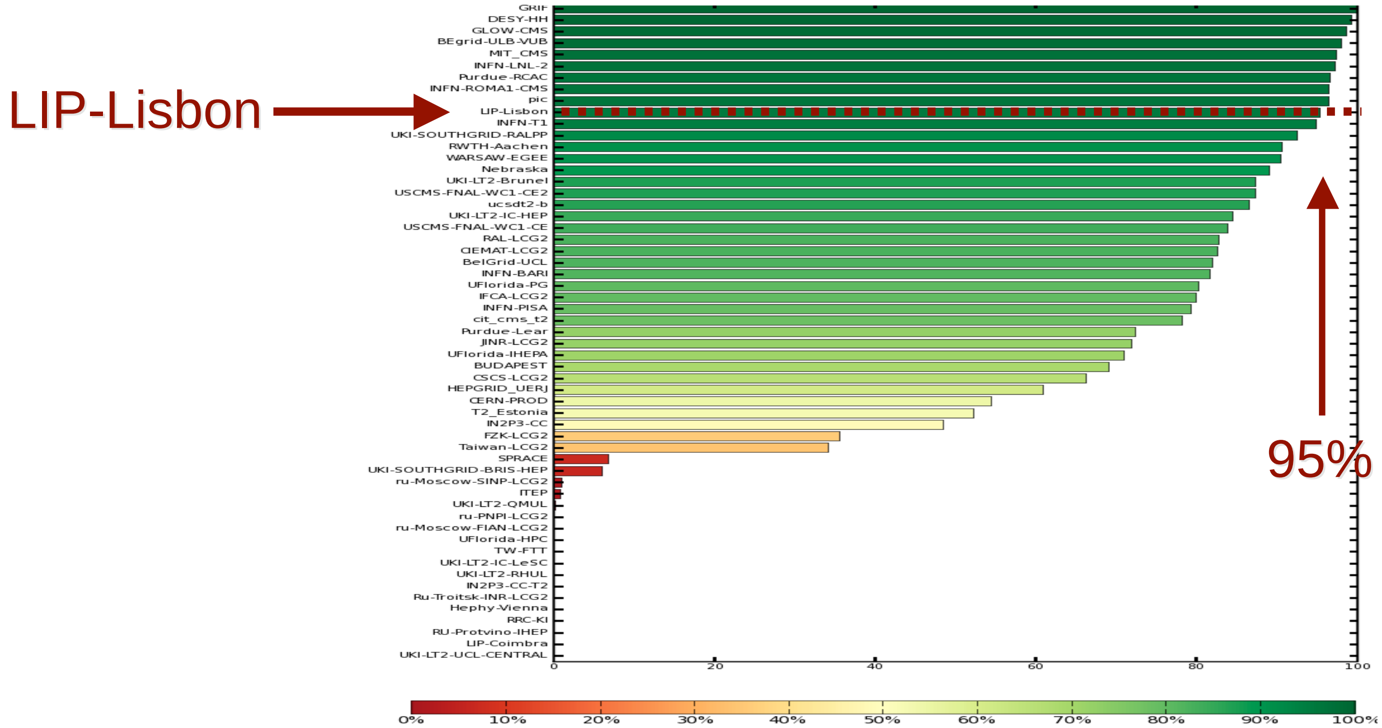
- ECAL data limited to 10% of the full CMS event size (1MB)
  - reduction factor of 20 is needed
  - could lead to energy degradation

- LIP contributed to the development of the ECAL Selective Readout
  - algorithm based on energetic towers E_T (+neighbors)
  - filtering can be achieved with low suppression thresholds and no energy degradation

- N. Almeida et al., CMS Note 2008/002 submitted to JINST

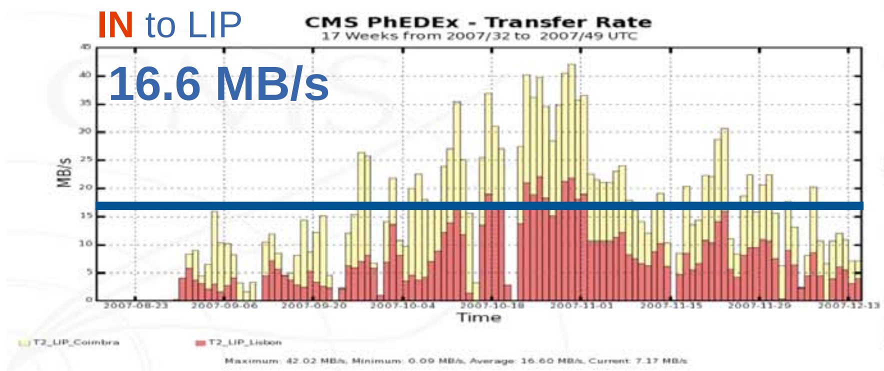
LIP/CMS GRID

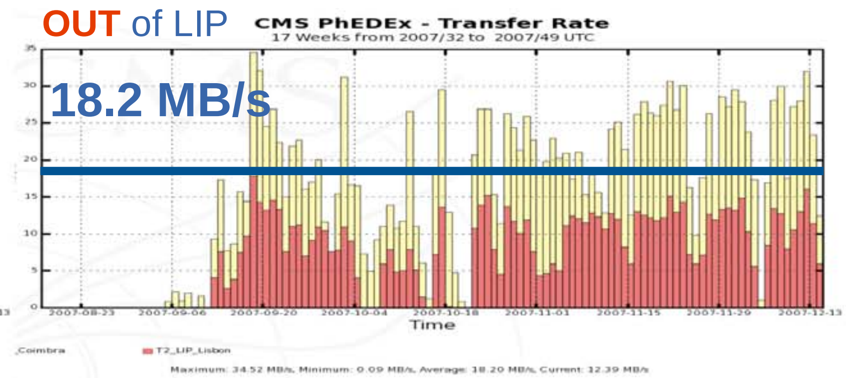
During CSA07

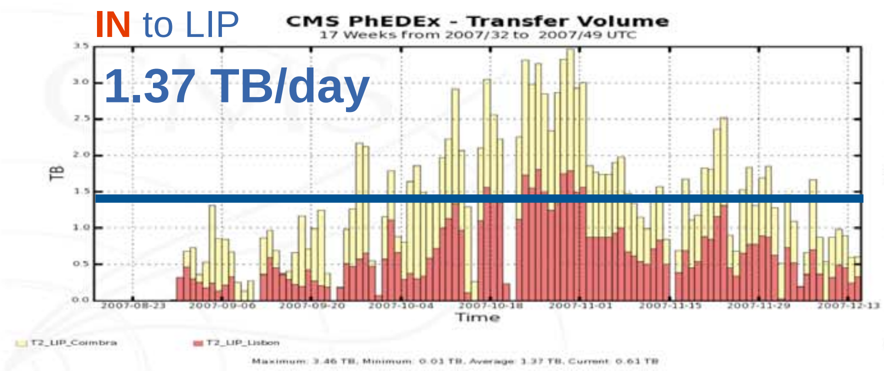


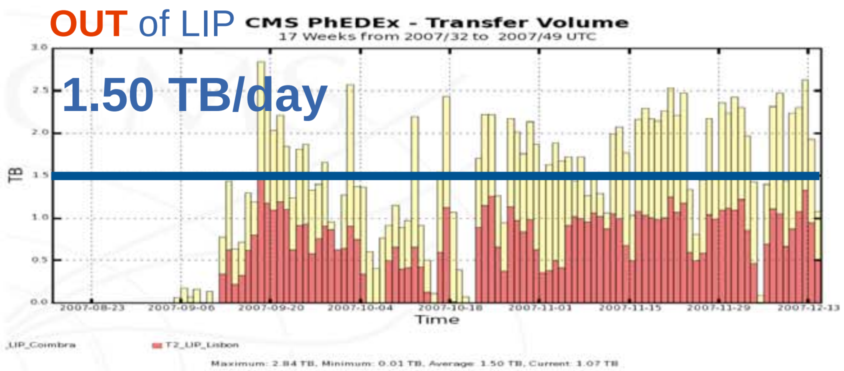
- ➢ CMS site availability for computing and storage
- ➢ LIP-Lisbon site availability higher than 95% during CSA07 exercise
- ➢ Participation in MC production for CSA07
- ➢ Storage of top/electron/tau samples for analyses

CMS/GRID link commissioning









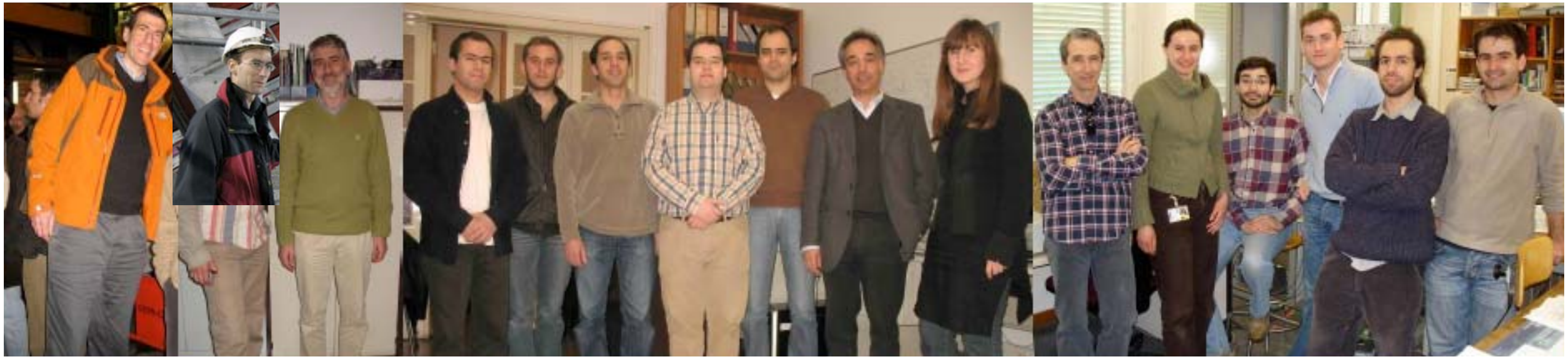
- Successful participation in the CSA07 data transfer program with download and upload commissioned links to/from PIC & CERN and LIP-Lisbon/LIP-Coimbra

Thanks to the support of the LIP “computing” team!

Summary

- LIP/CMS group is active in SUSY/Top analyses
- Studies with leptons in the final state
- Top quark is not well known and interesting for new physics
- The LHC will soon start colliding beams
- “New” physics is within reach

LIP/CMS group



- In the picture (from the left) :
  - M. Gallinaro, M. Bluj, J. Seixas, J. Pela, M. Jordão. M. Ferreira, P. Ribeiro, N. Almeida, J. Varela, M. Kazana, J.C. Silva, A. Vila Verde, A. David, M. Husejko, P. Musella, P. Silva

- 16 collaborators affiliated to LIP-Lisbon
  - 3 senior physicists, 3 Post Doc. fellows, 3 PhD. students, 4 Master students and 3 engineers/technicians