LHC Days in Split
7th October 2006

Physics in the first year of CMS

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Boundary Conditions

- Assume that
  - Physics of the first year = Physics at 1 fb^{-1}
- First year is 2008, the calibration run at 900 GeV is marginally interesting for Physics
  - But quite interesting for first calib & align
- This talks is focused on Physics measurements
  - But calib & align will be an offline-analysis activity of paramount importance in 2008
  - Trigger commissioning plays a key role, too.

Use many results from CMS PTDR, but most arguments apply to ATLAS as well

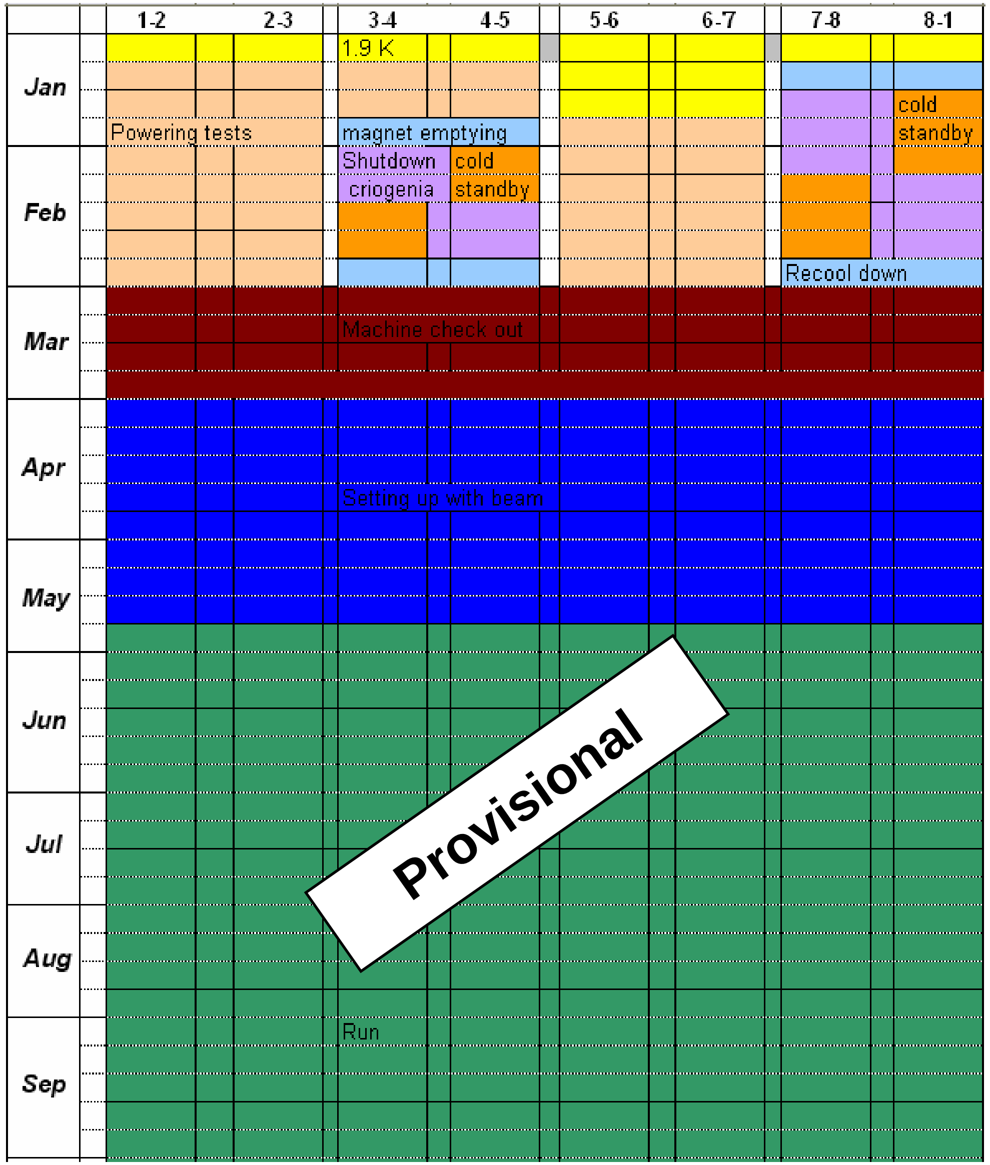
Calibration run at 900 GeV

			Reasonable	Maximum
k_b	43	43	156	156
intensity per beam	$8.6\ 10^{11}$	$1.7\ 10^{12}$	$6.2\ 10^{12}$	$1.6\ 10^{13}$
Luminosity ($cm^{-2}s^{-1}$)	$2\ 10^{28}$	$7.2\ 10^{28}$	$2.6\ 10^{29}$	$1.6\ 10^{30}$
event rate [1] (kHz)	0.4	2.8	10.3	64
W rate [2] (per 24h)	0.5	3	11	70
Z rate [3] (per 24h)	0.05	0.3	1.1	7

1. Assuming 450GeV inelastic cross section 40 mb
2. Assuming 450GeV cross section $W \rightarrow l\nu$ 1 nb
3. Assuming 450GeV cross section $Z \rightarrow ll$ 100 pb

2008

Should look something like…



Hardware commissioning to 7 TeV

Machine Checkout ≈ 1 month

Commissioning with beam ≈ 2 months

Pilot Physics ≈ 1 month

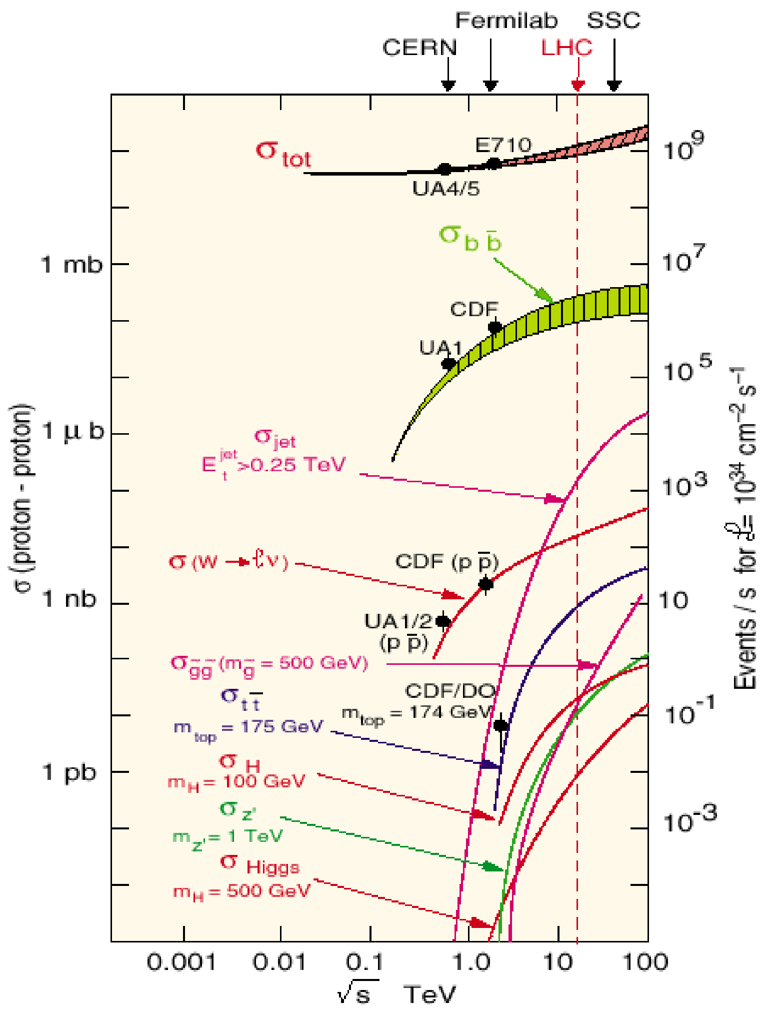
Reach 10^{31}

Running at 75 ns L~ 10^{32} cm^{-2}s^{-1}
~ 3 months of running
+some optimism ~ 1 fb^{-1}

Cross sections and rates at 10^{32} cm^{-2}s^{-1}

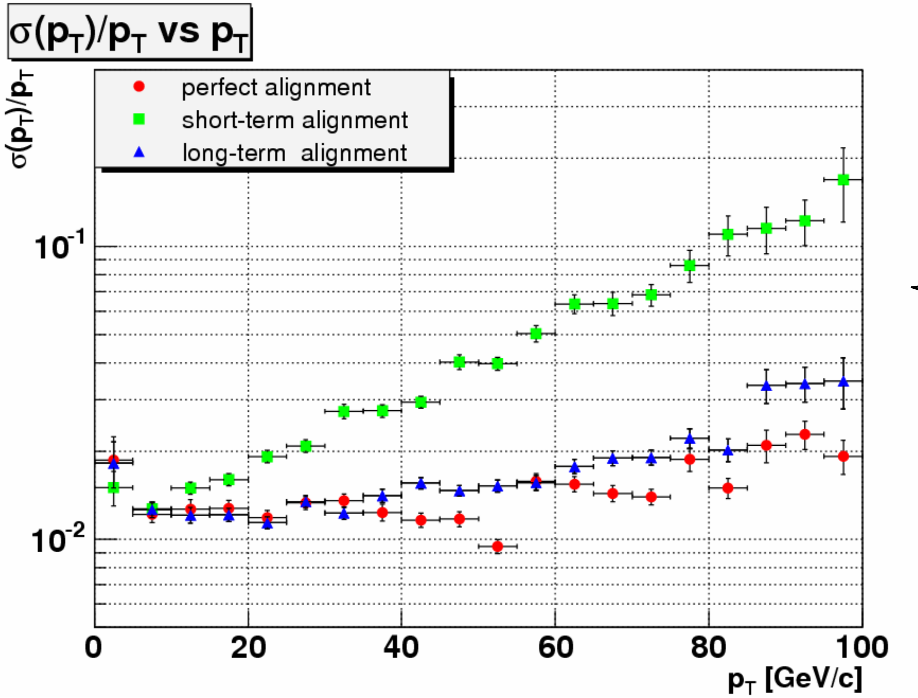
At Luminosity (10^{32} cm^{-2} s^{-1})

SM Higgs (115 GeV/c^2):	→0.001 Hz
t t production:	→0.1 Hz
W→ ℓ ν:	→1 Hz
bb production:	**→ 10^4 Hz**
Inelastic:	→10^7 Hz

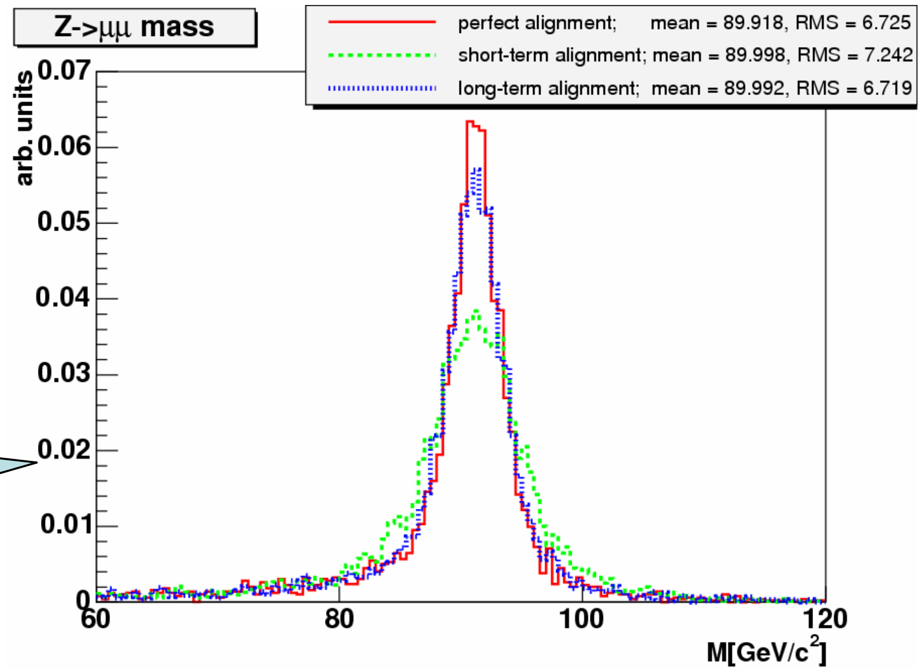


Just a few comments on calibrations with the first data

Momentum measurement with the Tracker : estimates for 100 pb^{-1} and a few fb^{-1}



p_T resolution integrated in η



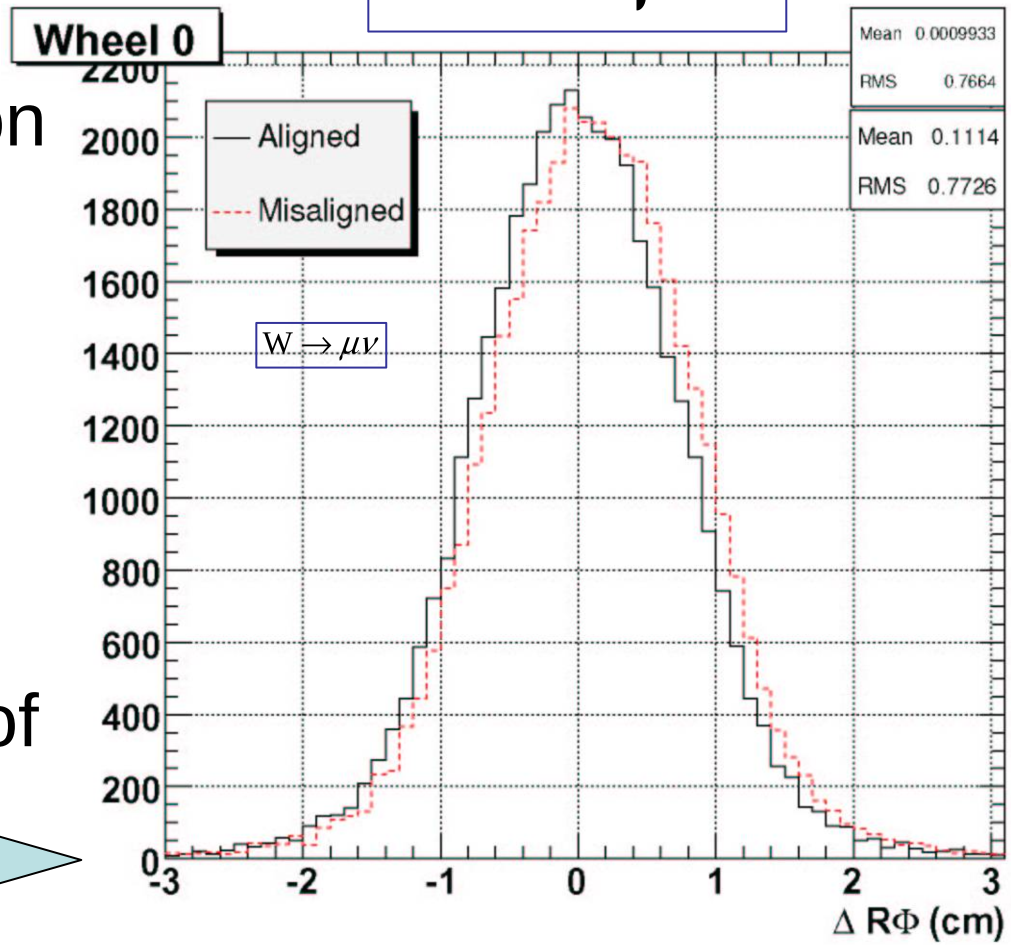
Z peak visible even with the first rough alignments

The plentiful production of W and Z bosons are main tools for Detector Commissioning

$$W \rightarrow \mu\nu$$

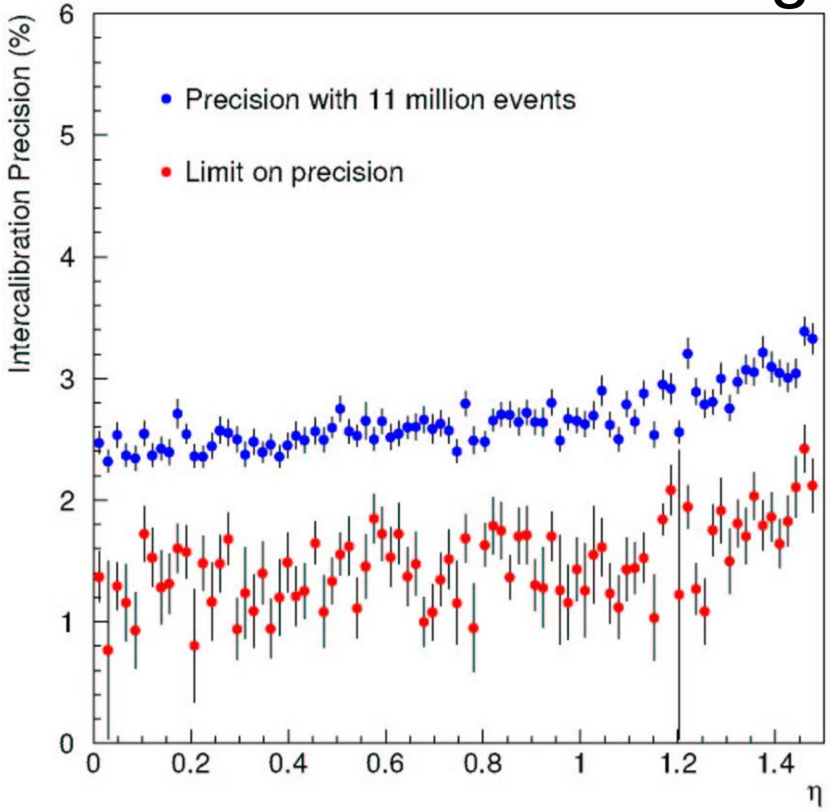
- Example: CMS Muon System alignment using real tracks
- Ten days at

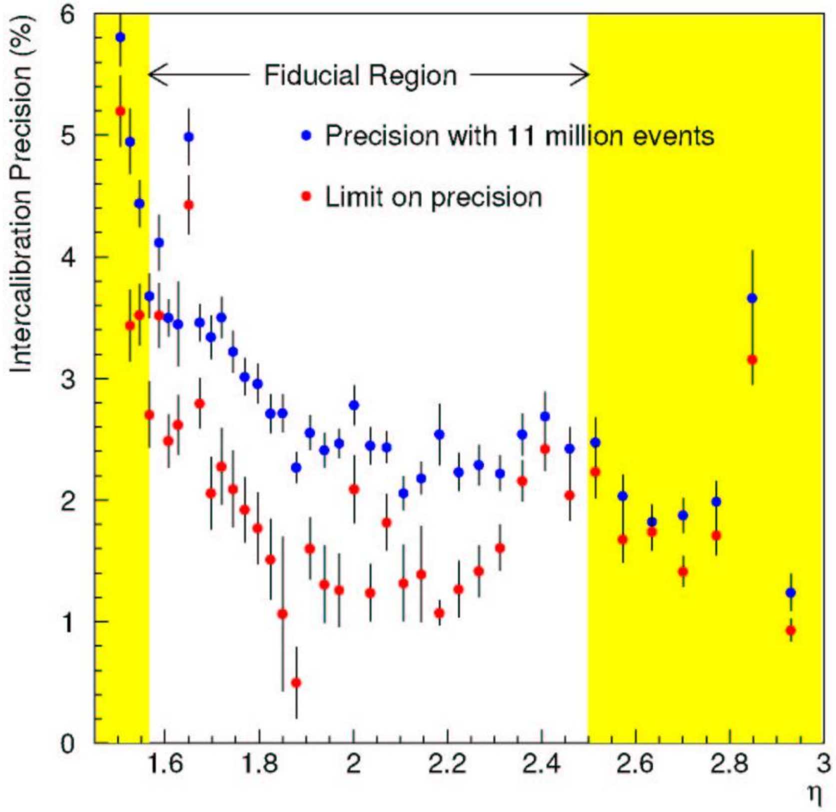
  $L=10^{32}$ $cm^{-2}s^{-1}$ is enough to show misalignment of the order of one fourth of mrad



Electrons and photons: initial intercalibration with jets

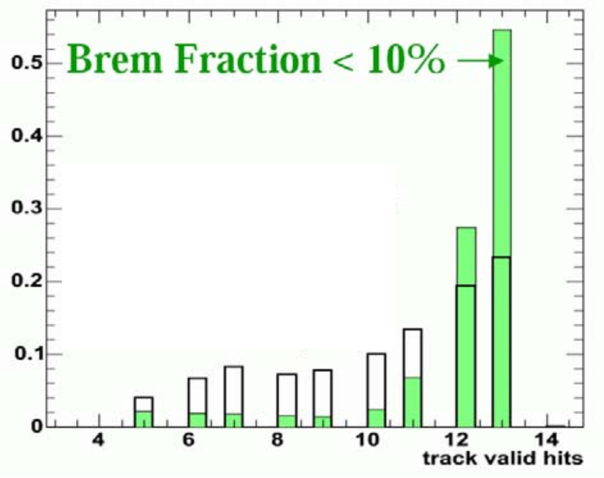
- The azimuthal simmetry can be exploited for a first intercalibration with inclusive jets
- Use the Z->ee to get eta calibration

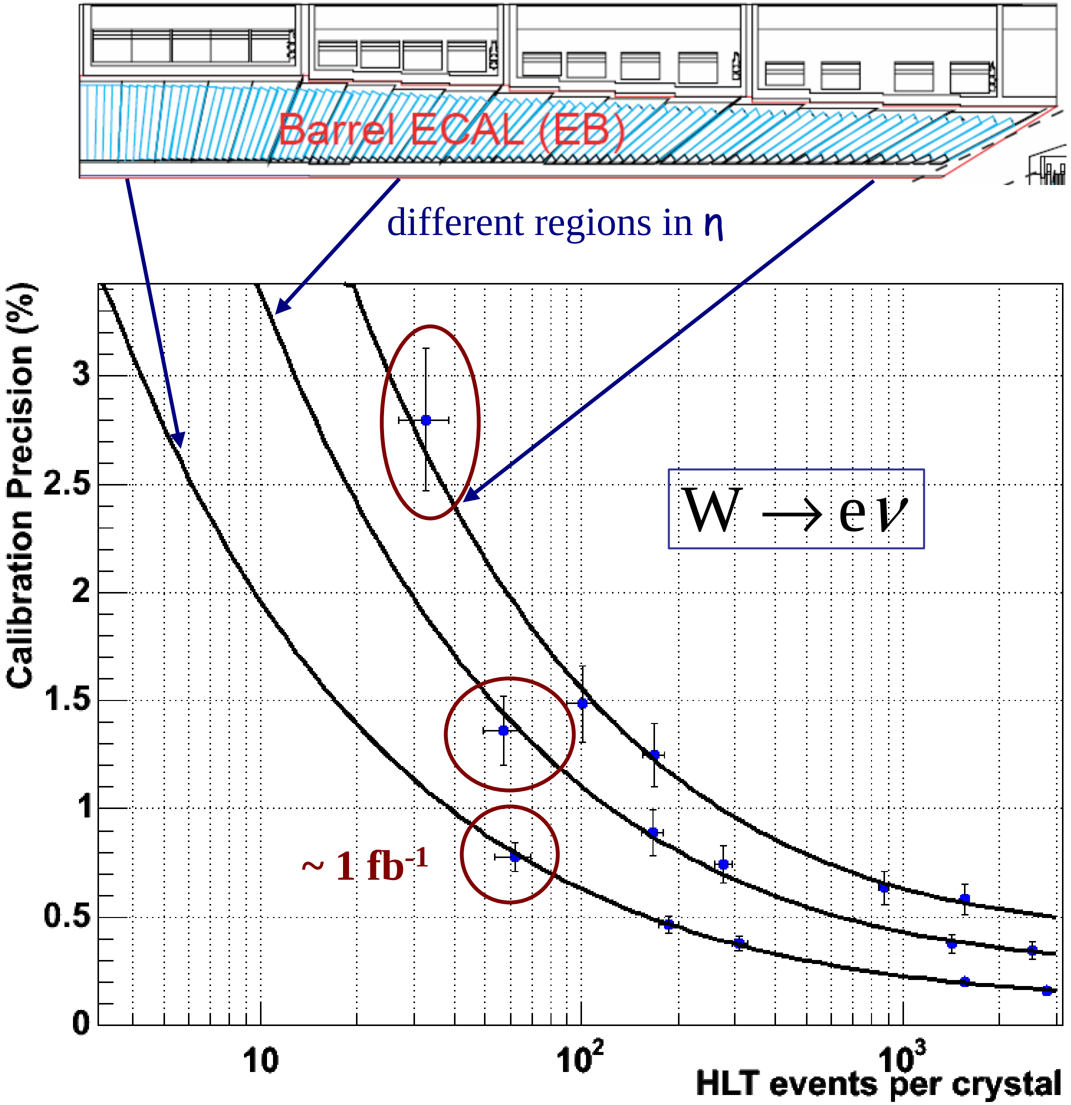




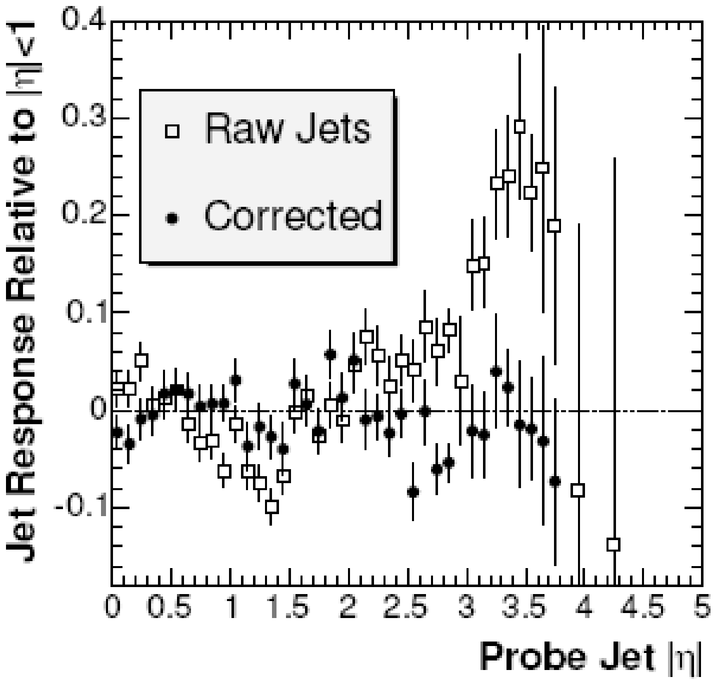
Electrons and photons: calibration with tracks

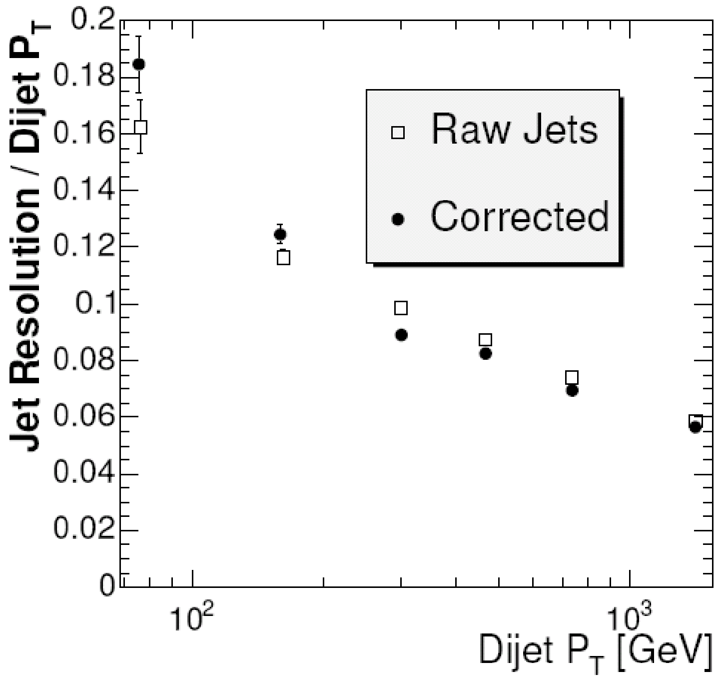
Important to select tracks with low bremsstrahlung

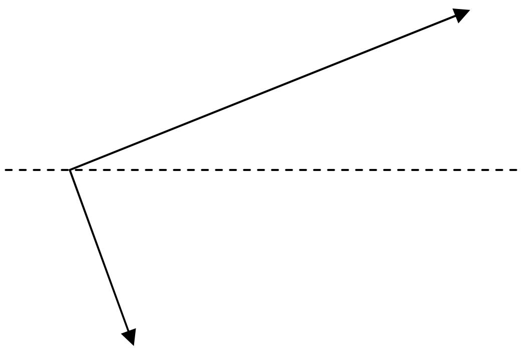




Jet Equalization with dijet balancing







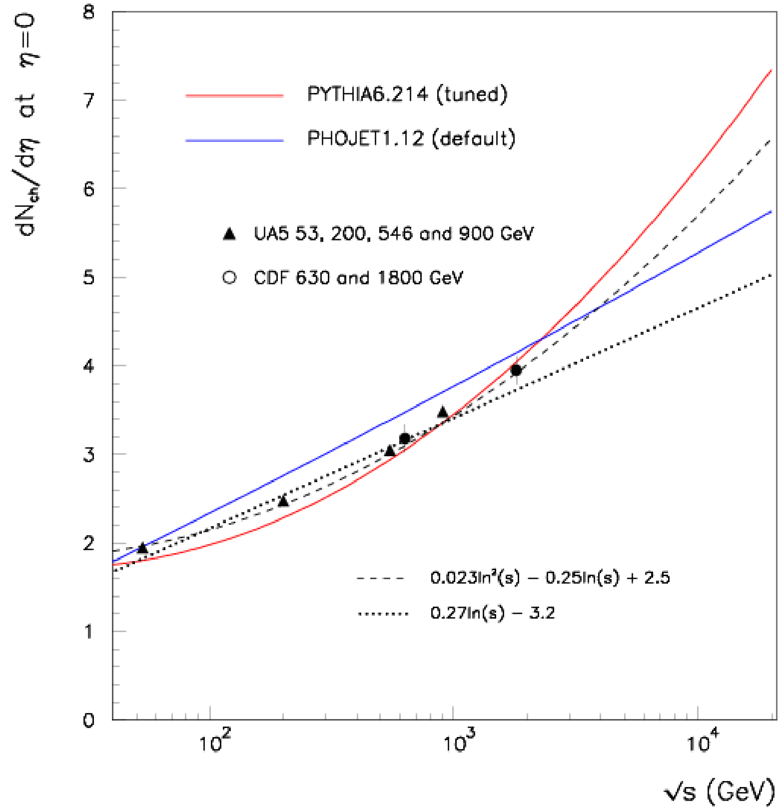
- Corresponds to one day at 10^{32}. In ten days reach 0.5% in the barrel and 2% in endcaps
- In a few days reach an absolute calibration at ~5% with jet – gamma balancing
- In both cases need MC to extrapolate to high energy jets

Physics at 1 fb^{-1} in a nutshell

- Measure track multiplicities and Jets
- B physics
- Measure W's and Z's
- Top top top and top !
- BSM = Beside or Below (or Beyond ?) SM
- Higgs wants more luminosity (in general)

Measure $dN_{ch}/d\eta$, dN_{ch}/dp_T

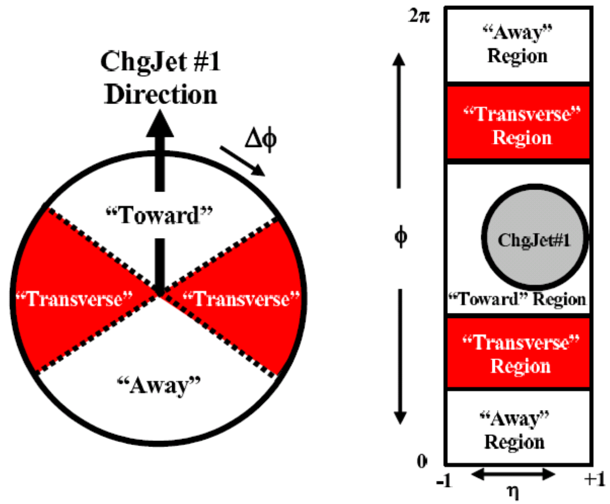
- We know W, Z cross sections at ~ 3%, ttbar cross section at ~ 10%, but minimum bias charge multiplicity only at ~ 50%
- Candidate for very early measurement
  - few 10^4 events enough to get $dN_{ch}/d\eta$, dN_{ch}/dp_T
  - Caveat: need to understand occupancy, beam backgrounds, pile-up can be not negligible even at low lumi (depend on single bunch density)



Charged particles measured in the Tracker: initial alignment OK since <pt> = 0.7 GeV
but GOOD UNDERSTANDING OF TRACKING EFFICIENCY AT LOW MOMENTA required

Measure the Event Structure: the Underlying Event

- From charged jet (using MB and jet triggers)
- Topological structure of p-p collision from charged tracks
- The leading Ch_jet1 defines a direction in the ϕ plane
- Transverse region particularly sensitive to UE



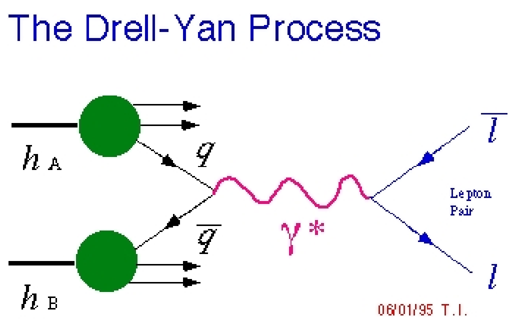
Main observables:

+ $dN/d\eta d\phi$, charged density

+ $d(PT_{sum})/d\eta d\phi$, energy density

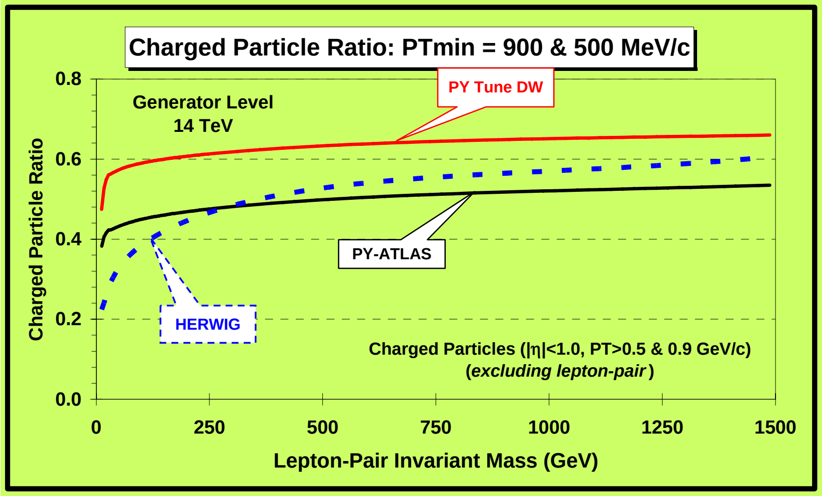
•**From D-Y muon pair production (using muon triggers)**

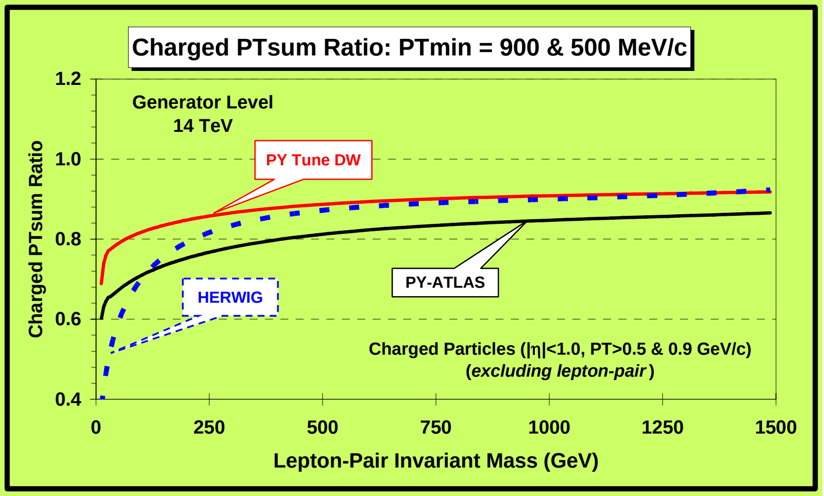
•**Observables are the same but defined in all the ϕ plane (after removing the μ pairs everything else is UE)**



UE: Generator level studies – Drell Yan

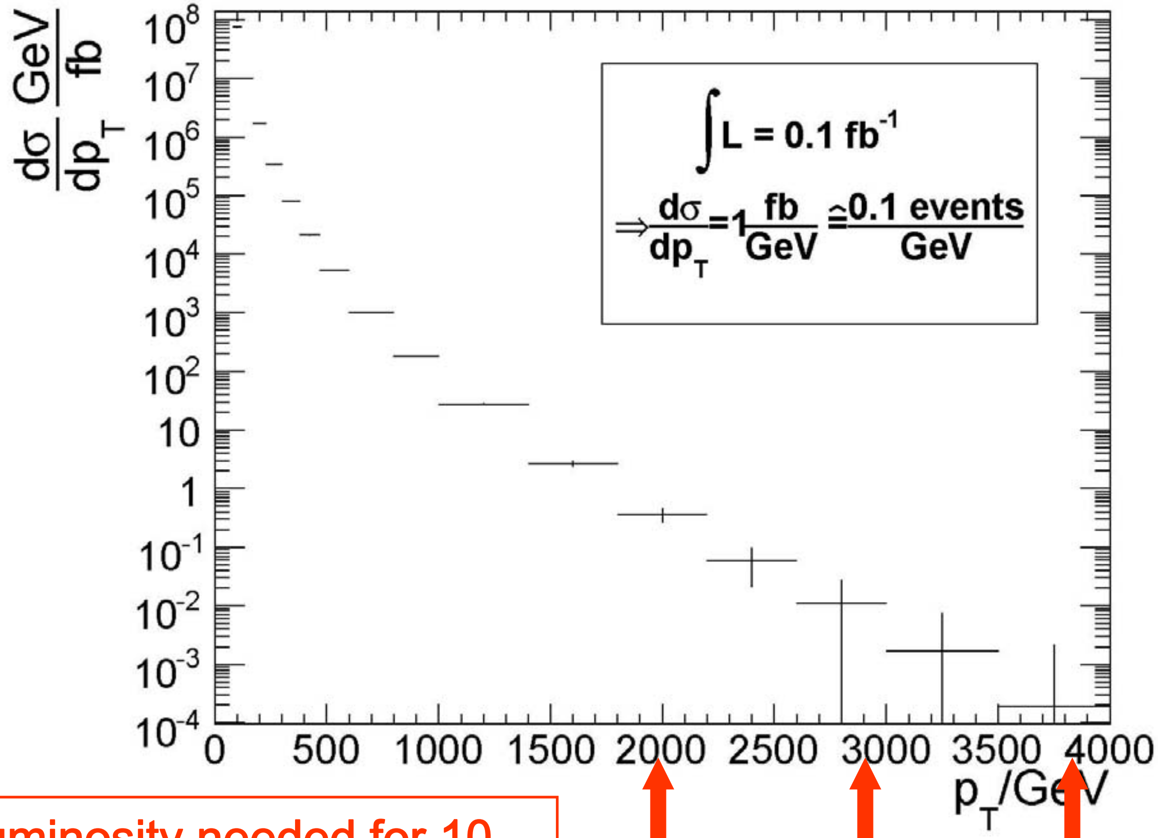
- **Ratio PT>0.9GeV/PT>0.5GeV (PT tracks threshold) sensitive to differences between models**





Jet inclusive statistics at 100 pb-1

- Produced at high rate. Physics interest is in the high mass tail.



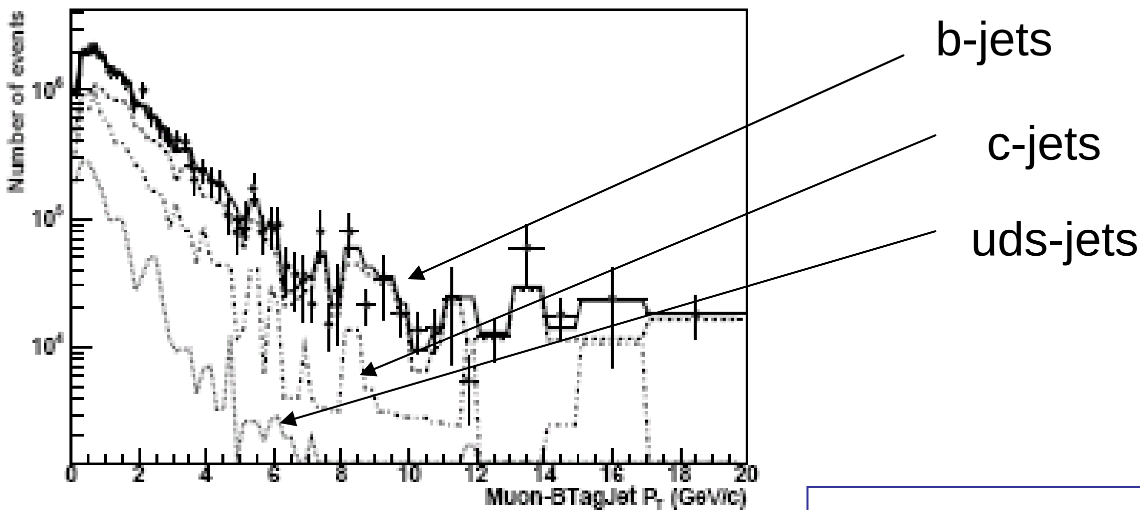
Luminosity needed for 10 events above threshold

1 10 100 pb^{-1}

- Sensitivity to excited quarks, RS Gravitons, W', Z', etc.
- Limits from CDF and D0 are in the range **0.4 - 1 TeV**
- With **few pb-1** at **14 TeV** we can extend the range
- **Crucial** experimental parameter is the **energy resolution** in measuring jet energy (**They are narrow resonances**)

B inclusive production

- Selection of inclusive jet+muon
- Compute muon Pt vs jet axis
- Measurement limited by syst uncertainties already at 1 fb-1 (jet energy scale) . Expect ~ 20% precision
- Check agreement between pQCD and experiments



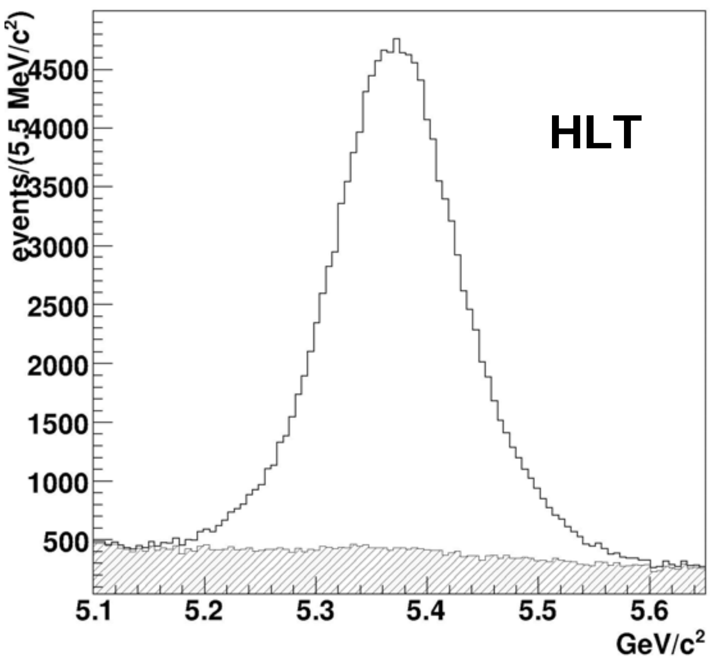
Pt vs the closest b tagged jet

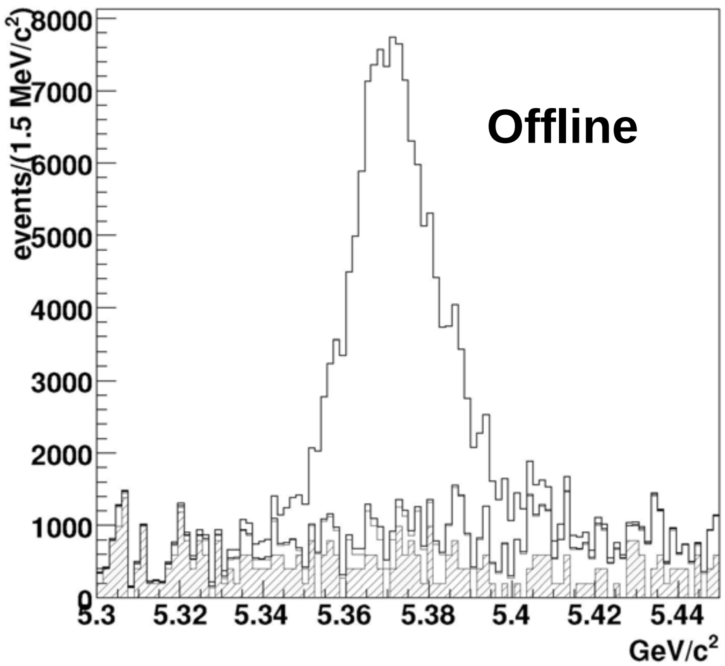
CMS Note-2006/077

CMS Note-2006/121

B physics at low lumi : $B_s \rightarrow J/\psi\, \varphi$

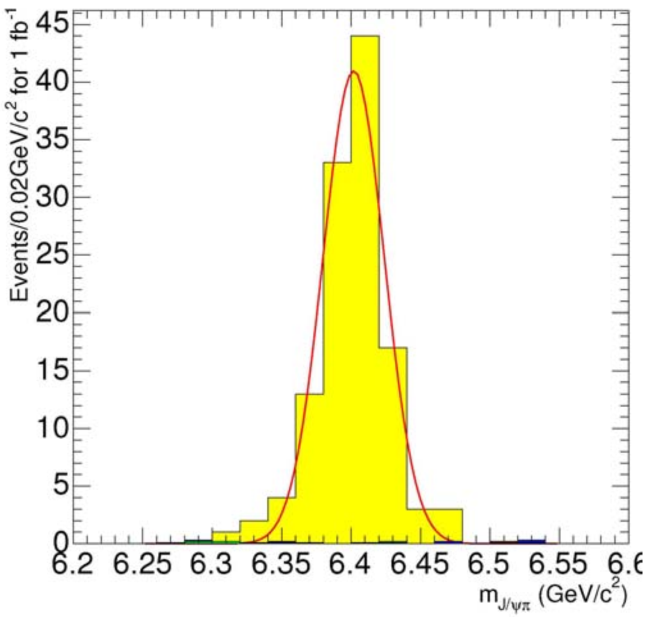
- Lifetime difference in two B_s weak eigenstates expected to be large: can measure $\Delta\Gamma_s / \Gamma_s$
- Use J/psi to di-muons and ϕ to di-kaons
- Reject large bkg from prompt J/psi at HLT trigger level
- About 10'000 signal events with 1 fb-1, measurement at 20%

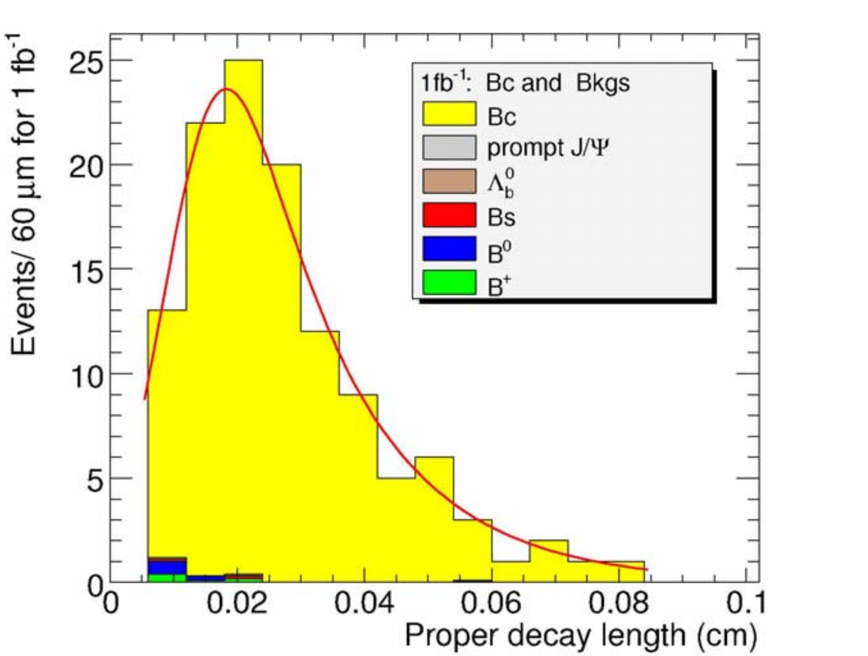




B exclusive states : B_c

- With 1 fb-1 can measure mass and lifetime in $B_c \rightarrow J/\psi\ \pi$
- Low trigger threshold on muons (Pt > 4 GeV) required





Select displaced J/psi,
require J/psi-pi inv mass in window

CMS Note-2006/118

CMS Note-2006/124 CMS Note-2006/082

Production of W and Z boson

- Large W (Z) cross section: 10 nb (1 nb) and clean leptonic signatures
- Compare to theo. prediction or assume prediction and use to measure luminosity
  - Example : uncertainties with 1 fb-1 in the muon channel in detector fiducial volume

$$\frac{\Delta\sigma}{\sigma}(pp \rightarrow Z + X \rightarrow \mu^{+}\mu^{-} + X) = 0.13\,\% \pm 2.3\,\% \pm \text{lumi uncert.}$$

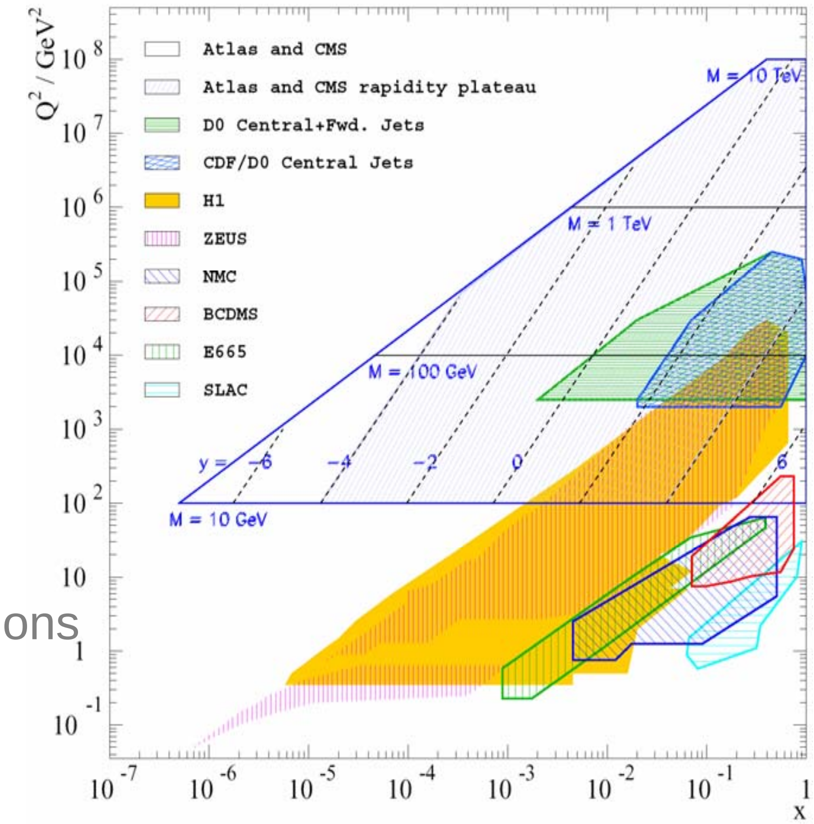
$$\frac{\Delta\sigma}{\sigma}(pp \rightarrow W + X \rightarrow \mu\nu + X) = 0.04\,\% \pm 3.3\,\% \pm \text{lumi uncert.}$$

Measure the PDFs with W and Z

Kinematic regime for LHC much broader than currently explored

➡ Test of QCD:

- Test DGLAP evolution at small x:
  - Is NLO DGLAP evolution sufficient at so small x ?
  - Are higher orders $\sim \alpha_s^n \log^m x$ important?
- Improve information of high x gluon distribution



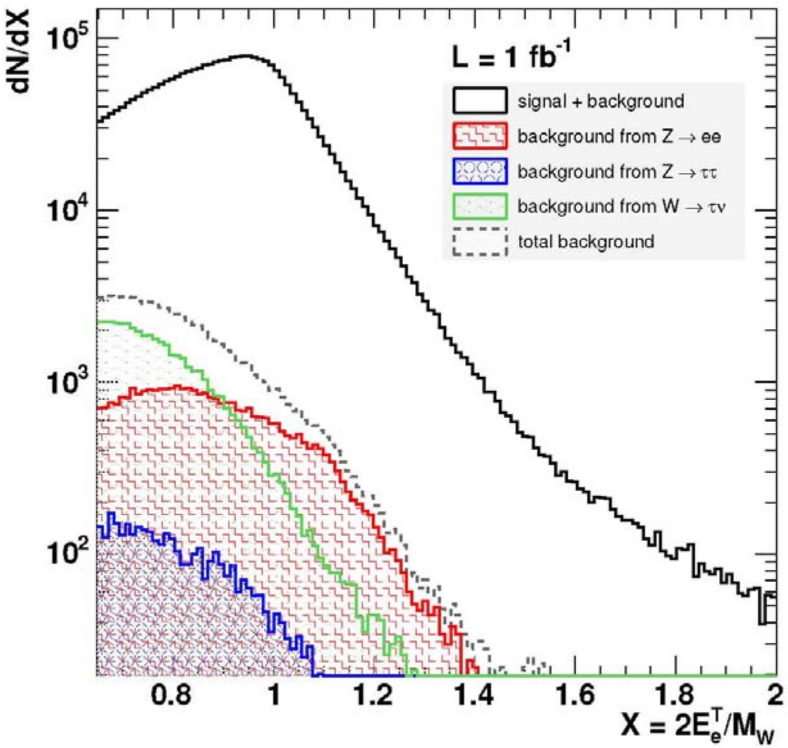
At TeV scale New Physics cross section predictions are dominated by **high-x gluon** uncertainty
(not sufficiently well constrained by PDF fits)

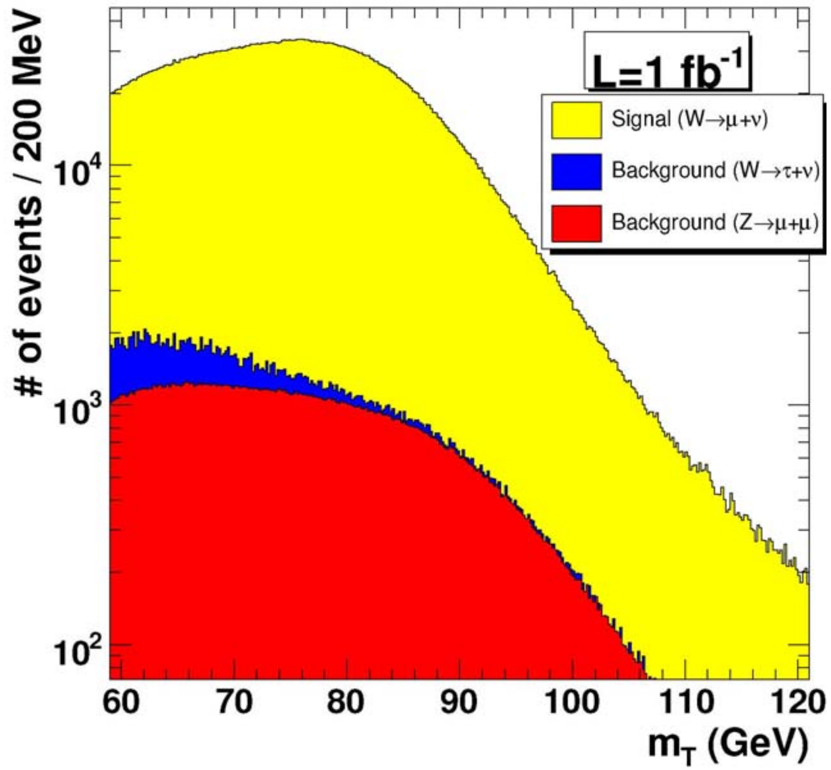
At the EW scale theoretical predictions for LHC are dominated by **low-x gluon** uncertainty
(i.e. W and Z masses)

$$x_{1,2} = \frac{M}{\sqrt{s}} \exp(\pm y) \qquad Q = M \qquad y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

Constrain PDF's at LHC from selected W and Z bosons measuring their rapidities from leptonic decays

Measuring the W mass at 1 fb-1





CMS Note-2006/061

The crucial point is to control systematic uncertainties:
<u>Use the Z to mimic the W !</u>

Measuring the W mass at 1 fb-1

Source of uncertainty	uncertainty (with 1 fb^{-1})	ΔM_W [MeV/c^2] (with 1 fb^{-1})	uncertainty (with 10 fb^{-1})	ΔM_W [MeV/c^2] (with 10 fb^{-1})
scaled lepton-p_T method applied to W$\rightarrow e\nu$				
statistics		**40**		15
background	10%	10	2%	2
electron energy scale	0.25%	10	0.05%	2
scale linearity	0.00006/ GeV	30	<0.00002/ GeV	<10
energy resolution	8%	5	3%	2
MET scale	2%	15	<1.5%	<10
MET resolution	5%	9	<2.5%	< 5
recoil system	2%	15	<1.5%	<10
total instrumental		**40**		**<20**
PDF uncertainties		20		<10
Γ_W		15		<15
p_T^W		30		30 (or NNLO)
transformation method applied to W$\rightarrow \mu\nu$				
statistics		**40**		15
background	10%	4	2%	negligible
momentum scale	0.1%	14	<0.1%	<10
$1/p^T$ resolution	10%	30	<3%	<10
acceptance definition	η-resol.	19	$< \sigma_\eta$	<10
calorimeter E_T^{miss}, scale	2%	38	≤1%	<20
calorimeter E_T^{miss}, resolution	5%	30	<3%	<18
detector alignment		12	–	negligible
total instrumental		**64**		**<30**
PDF uncertainties		≈20		<10
Γ_W		10		< 10

CMS Note-2006/061

Top production, from Tevatron to LHC

	1.96 TeV	14 TeV	
ttbar pairs	$5.06^{+0.13}_{-0.36}$ pb	833^{+52}_{-39} pb	(x170)
Single top (s-channel)	0.88±0.12 pb	10±1 pb	**(x10)**
Single top (t-channel)	1.98±0.22 pb	245±17 pb	(x120)
Single top (Wt channel)	0.15±0.04 pb	60±10 pb	(x400)
Wjj (*)	~1200 pb	~7500 pb	(x6)
bb+other jets (*)	~2.4x10^5 pb	~5x10^5 pb	(x2)

(*) with kinematic cuts in order to better mimic signal

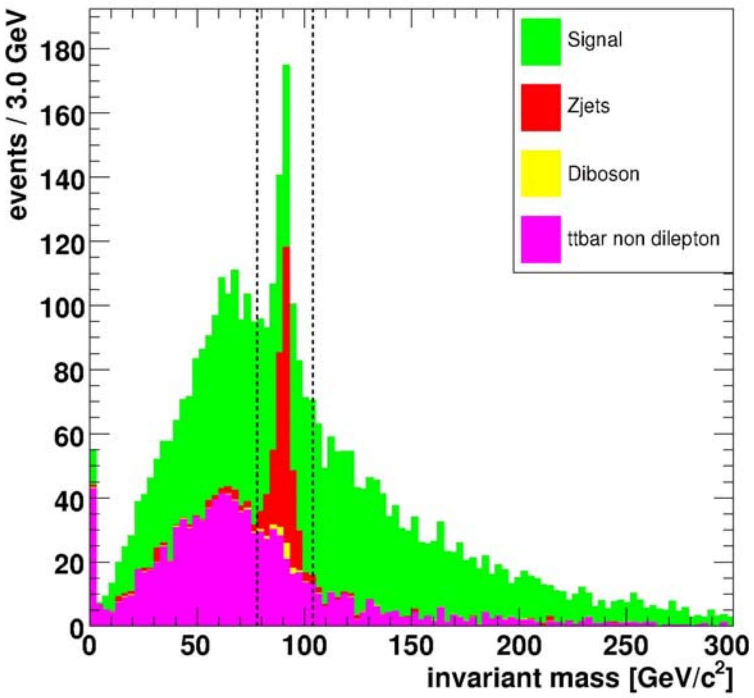
Belyaev, Boos, and Dudko [hep-ph/9806332]

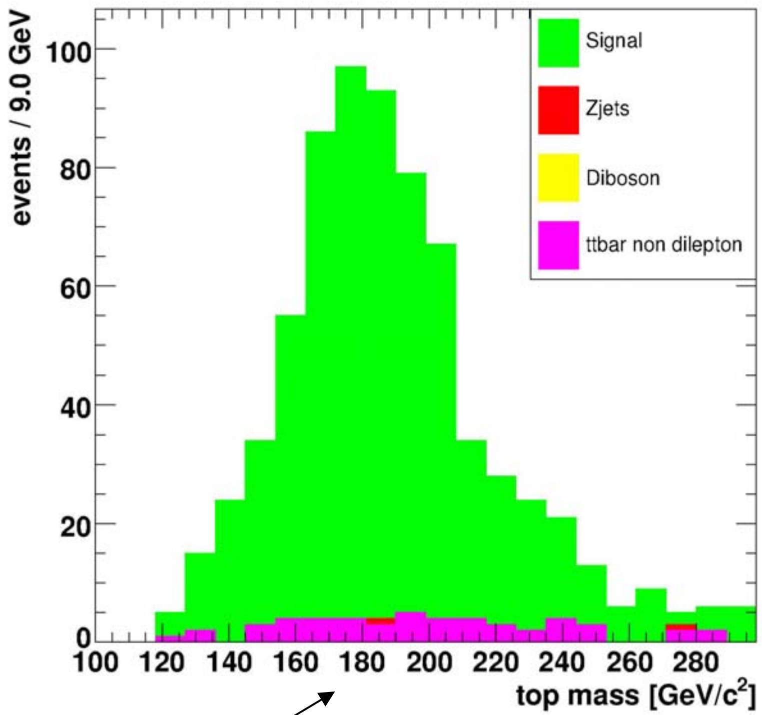
Top physics in the early phase

- Measure total ttbar cross section:
  - test of pQCD calculations (predicted at ~ 10%)
  - sensitive to top mass $$\frac{\delta m}{m} \approx 0.2 \frac{\delta\sigma}{\sigma}$$
- Measure differential cross sections $$\frac{d\sigma}{dp_t}, \frac{d\sigma}{d(M_{t\bar{t}})}$$
  - sensitive to new physics
- Make initial direct measurement of top mass
- Measure single top production (t-channel)

- Open the road to more sophisticated studies
  - Polarization in ttbar and single top systems
  - FCNC

Selection of dileptonic tt at 1 fb-1



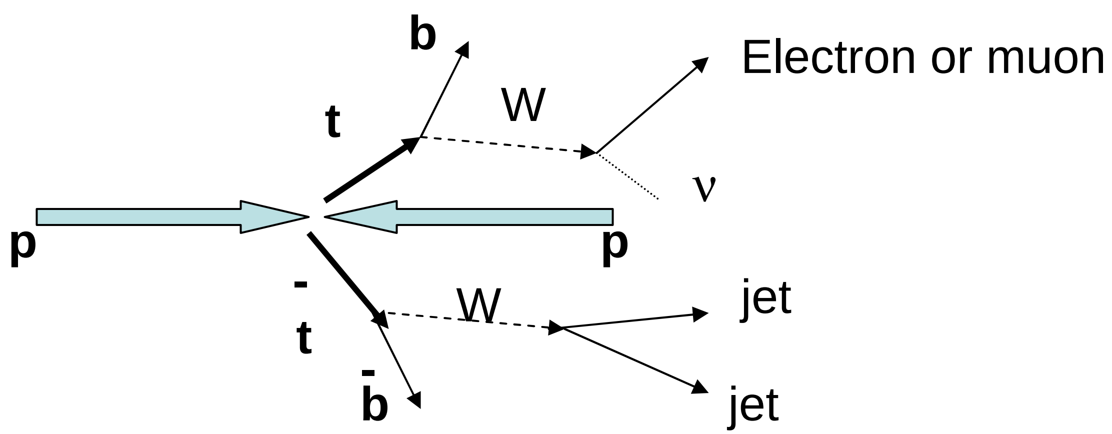


tt dileptonics are underconstrained (two neutrinos) but can fit assuming top mass and assign weight to different solutions

CMS Note-2006/077

Selection of tt semileptonics at fb-1

	Semi-lept. $t\bar{t}$	Other $t\bar{t}$	W+4j	Wbb+2j	Wbb+3j	S/B
Before selection	365k	1962k	82.5k	109.5k	22.5k	5.9
L1+HLT Trigger	62.2%	5.30%	24.1%	8.35%	8.29%	7.8
Four jets $E_T > 30\,\mathrm{GeV}$	25.4%	1.01%	4.1%	1.48%	3.37%	9.9
$p_{\mathrm{T}}^{lepton} > 20\,\mathrm{GeV/c}$	24.8%	0.97%	3.9%	1.41%	3.14%	10.3
b-tag criteria	6.5%	0.24%	0.064%	0.52%	0.79%	25.4
Kinematic fit	6.3%	0.23%	0.059%	0.48%	0.72%	26.7
Selected cross section (pb)	5.21	1.10	0.10	0.08	0.05	26.7
Scaled $\mathcal{L} = 1\,\mathrm{fb}^{-1}$	5211	1084	104	82	50	26.7



CMS Note-2006/064

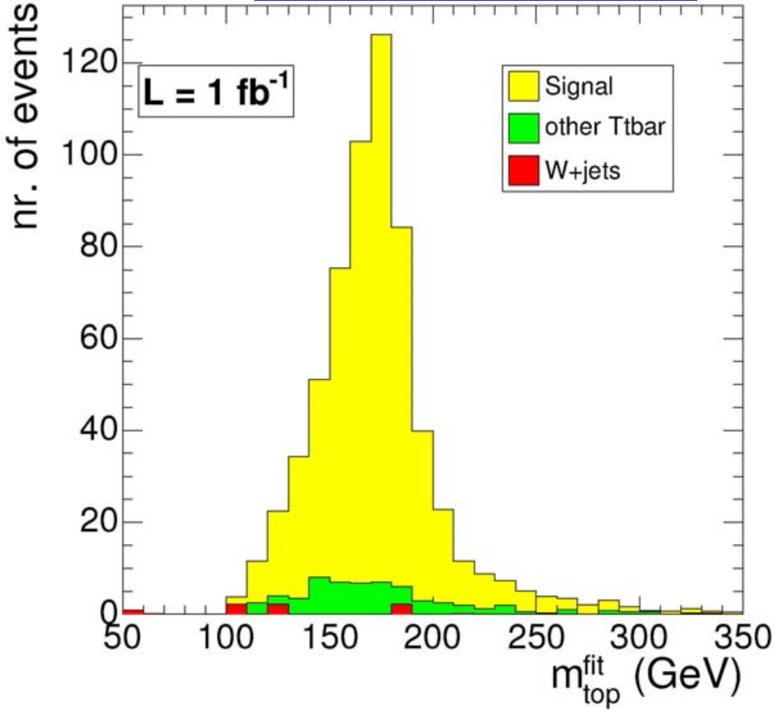
Selection of tt semileptonics at fb-1

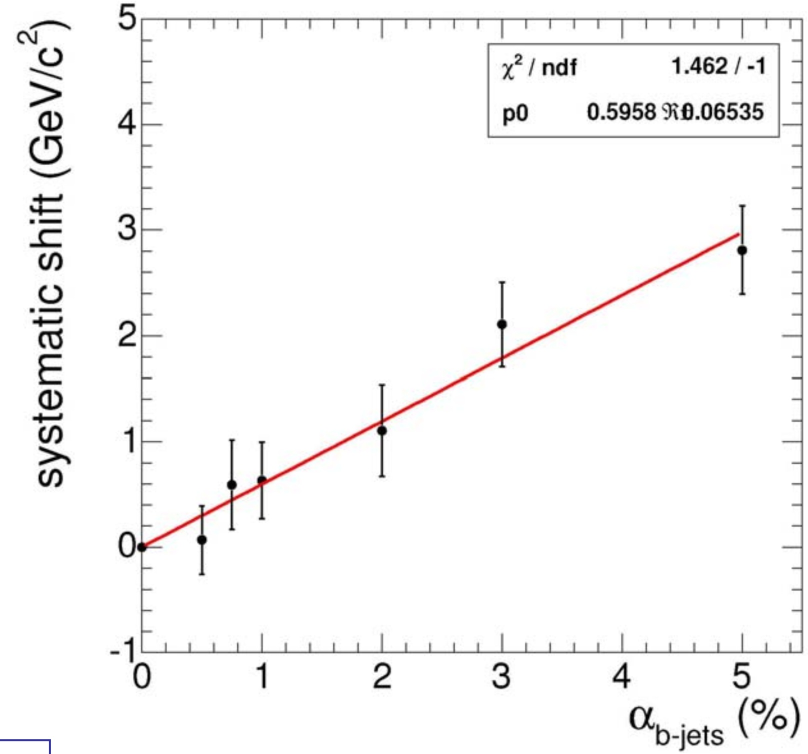
	$\Delta\hat{\sigma}_{t\bar{t}(\mu)}/\hat{\sigma}_{t\bar{t}(\mu)}$		
	$1\,\mathrm{fb}^{-1}$	$5\,\mathrm{fb}^{-1}$	$10\,\mathrm{fb}^{-1}$
Simulation samples (ϵ_{sim})	0.6%		
Simulation samples (F_{sim})	0.2%		
Pile-Up (30% On-Off)	3.2%		
Underlying Event	0.8%		
Jet Energy Scale (light quarks) (2%)	1.6%		
Jet Energy Scale (heavy quarks) (2%)	1.6%		
Radiation (Λ_{QCD}, Q_0^2)	2.6%		
Fragmentation (Lund b, σ_q)	1.0%		
b-tagging (5%)	7.0%		
Parton Density Functions	3.4%		
Background level	0.9%		
Integrated luminosity	10%	5%	3%
Statistical Uncertainty	1.2%	0.6%	0.4%
Total Systematic Uncertainty	13.6%	10.5%	9.7%
Total Uncertainty	13.7%	10.5%	9.7%

CMS Note-2006/064

Top mass measurement at fb-1

ttbar semileptonics





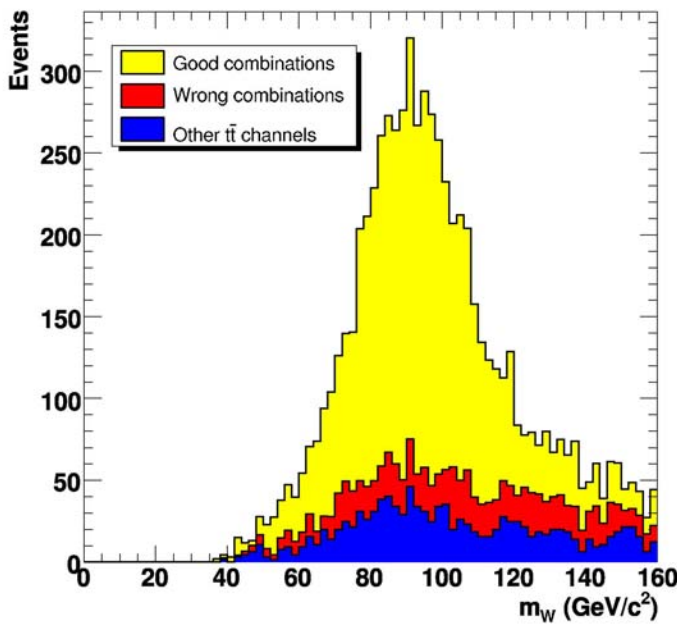
- Should be able to measure top mass at ~ 1% in both dileptonic and semileptonic channel
- Need control of the jet energy scale !
- Larger error ~2-3% in the hadronic channel

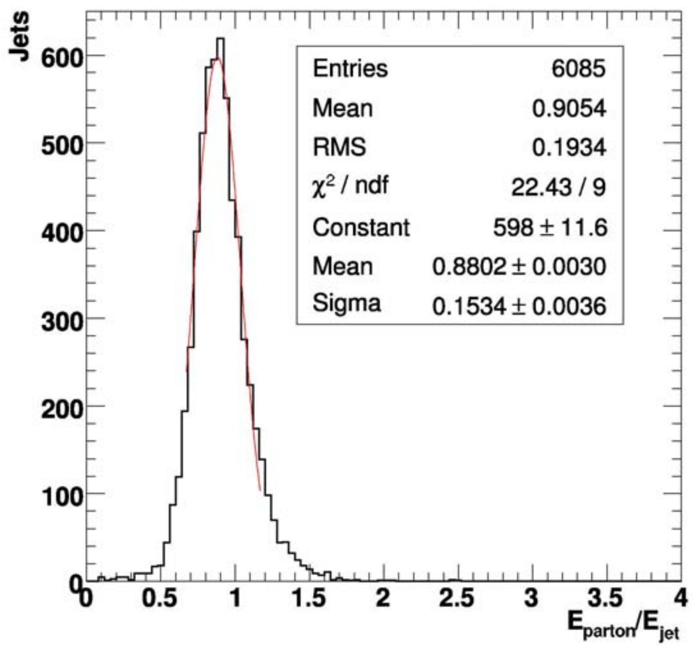
CMS Note-2006/066

Jet energy calibration from top events from W mass constraint

- Select semileptonic tt events

$$t\bar{t} \rightarrow bWbW \rightarrow bq\bar{q}b\mu\upsilon_{\mu}$$



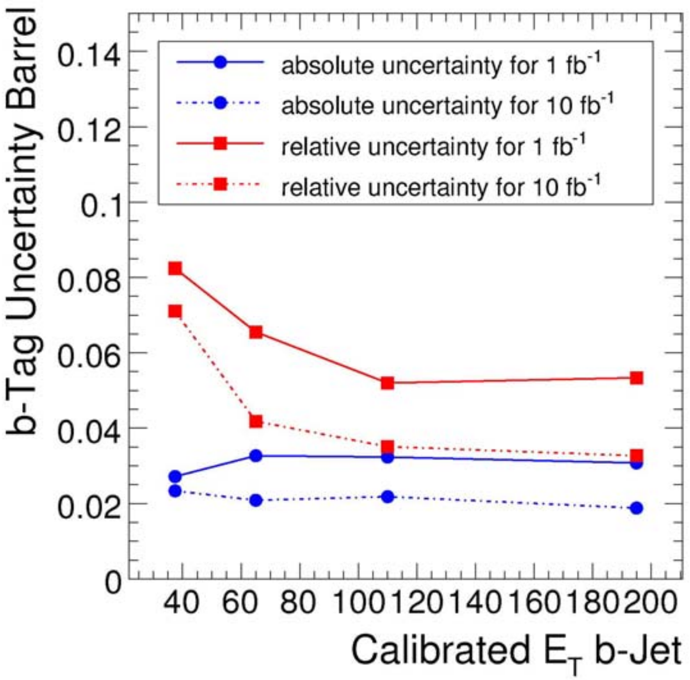


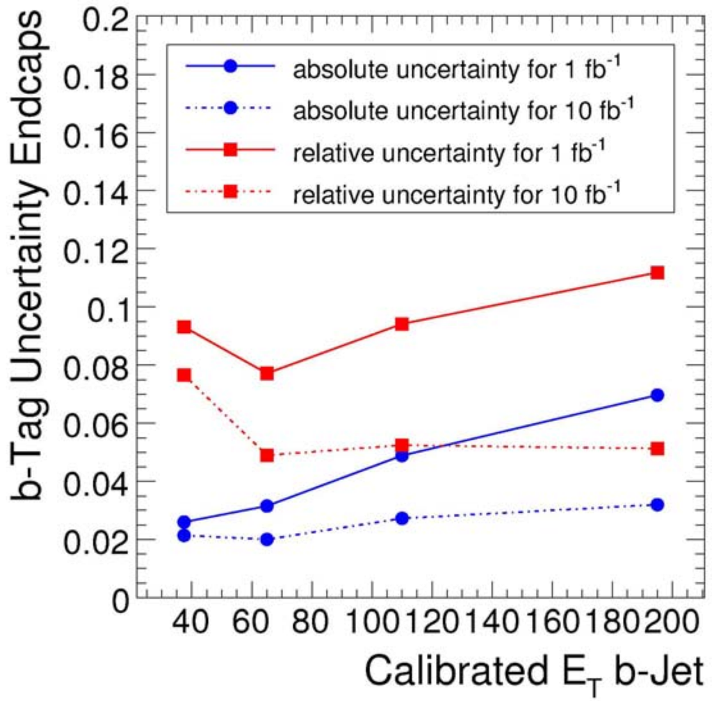
•For 1 fb-1 expect ~ 700 signal and ~150 bkg events
•Expect statistical uncertainty of less than 1% (can add elec.)
•Systematics ~ 3% from pileup

CMS Note-2006/025

b-tagging calibration from B hadrons from top events

- Select semileptonic and dileptonic tt events

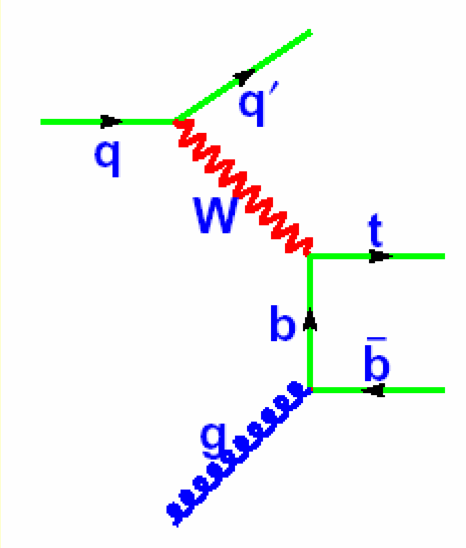




CMS Note-2006/013

Single top in the t-channel

- Cross section 1/3 of top pair production
- Other production mechanism (tW, s-ch) much lower s
- Marginal for TeVatron, may collect high statistics at LHC even in the initial phase

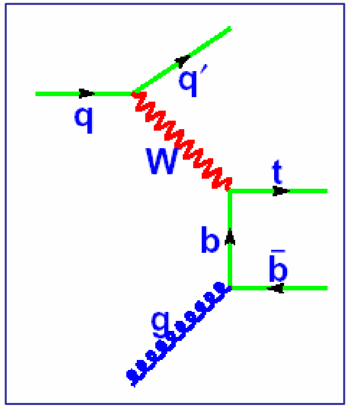


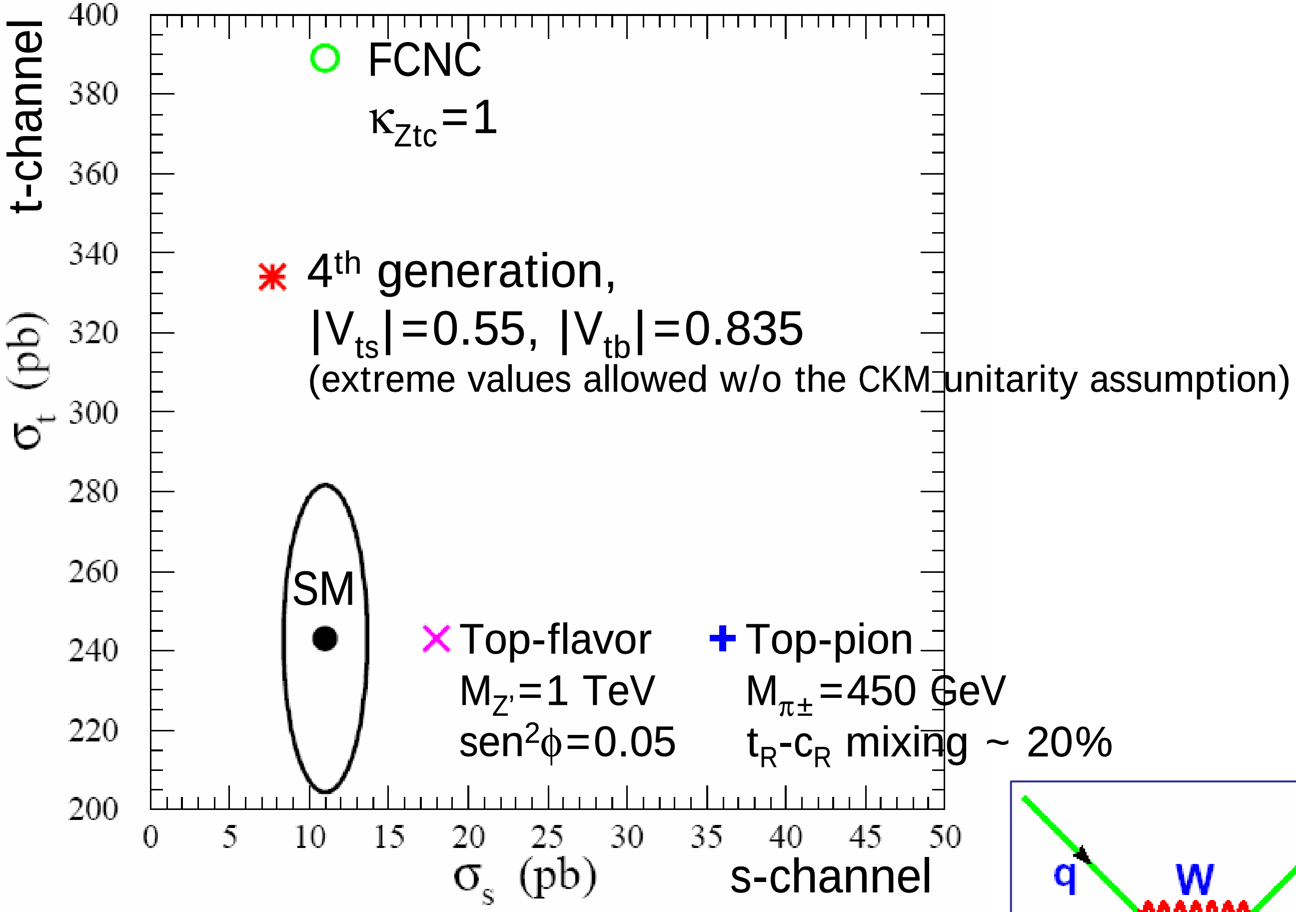
σ= 245 pb

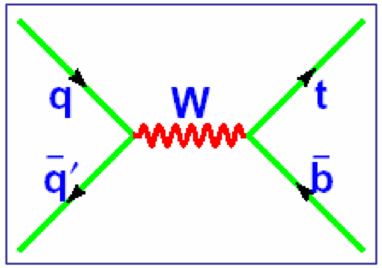
•Sensitivity to new physics: FCNC, H±→tb …
•Background to tt, WH→lνbb, some SUSY and BSM final states
•Possibility to study top properties (mass, polarization, charge) with reduced reconstruction ambiguities

Single top and New Physics

T.Tait, C.-P.Yuan, Phys.Rev. D63 (2001) 0140018



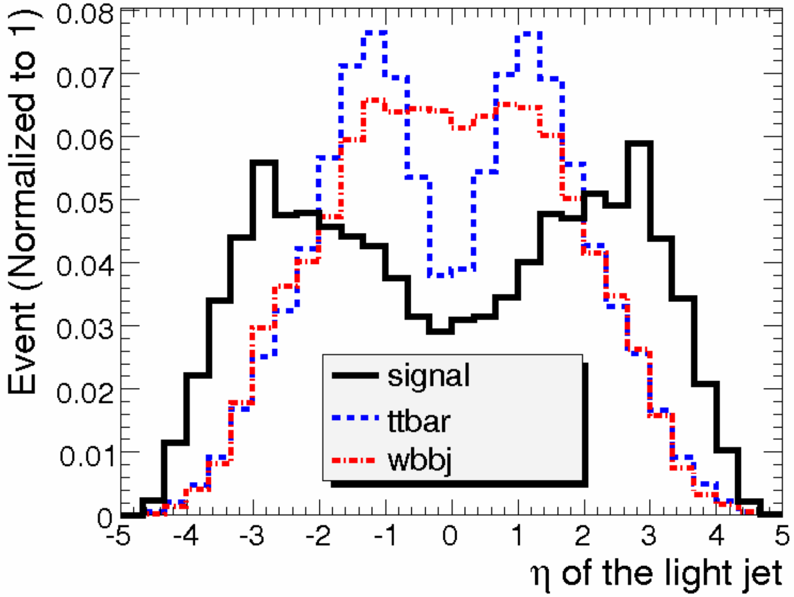


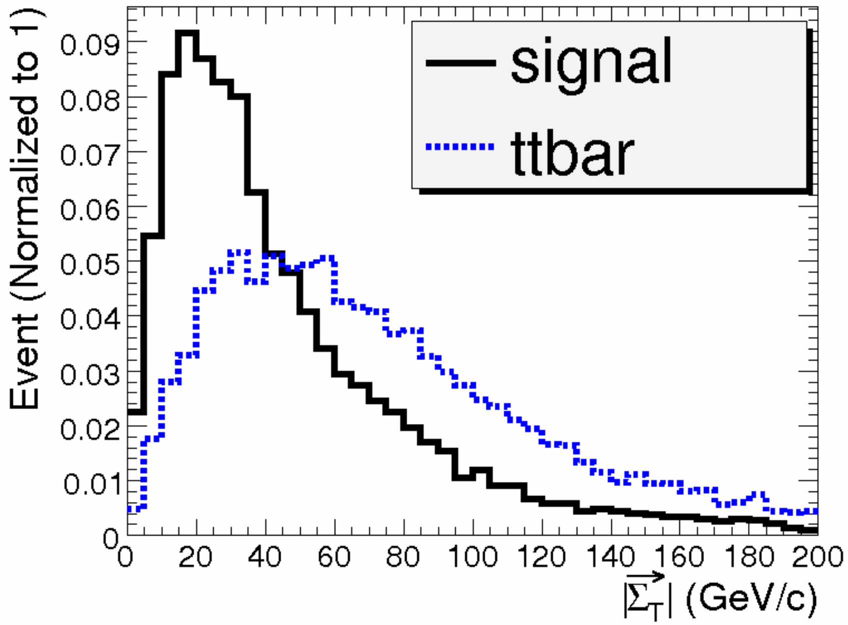


Single t-channel selection

Separate from pair production using recoil of spectator quark

Lower sum-ET that ttbar



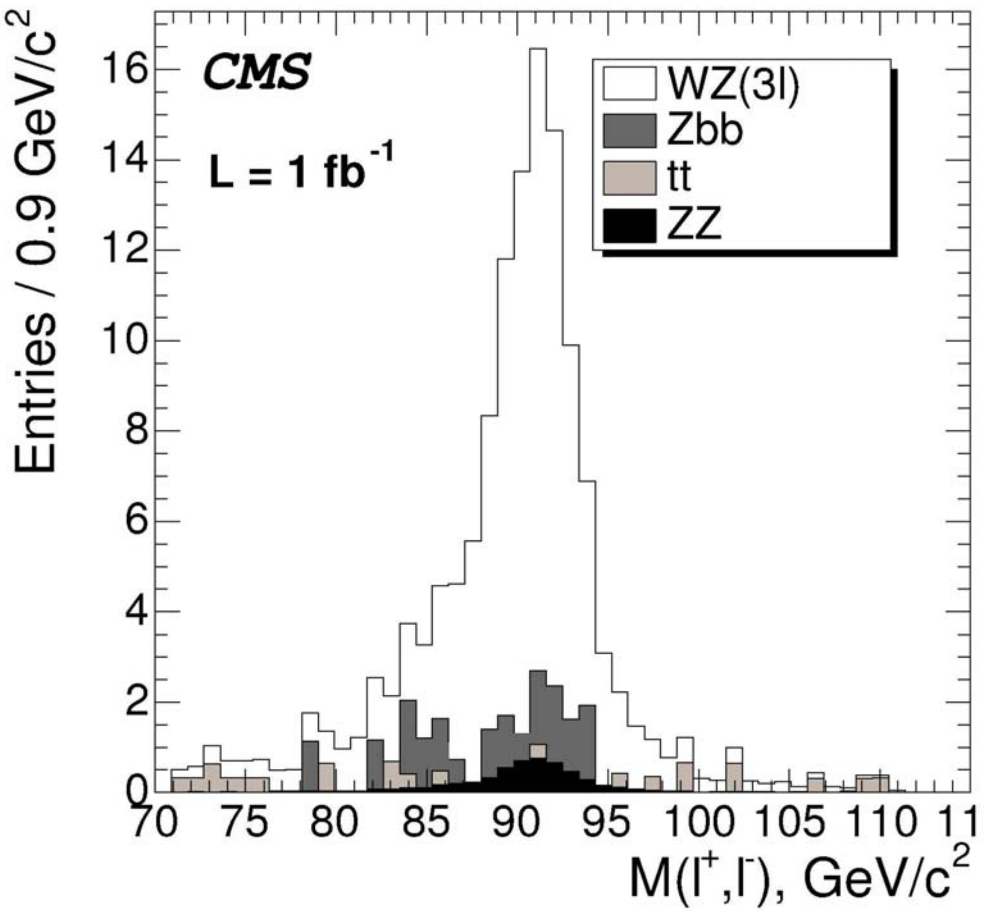


$$\frac{\Delta\sigma}{\sigma} \approx 15\% \text{ with } 1\,\text{fb}^{-1}$$

CMS Note-2006/084

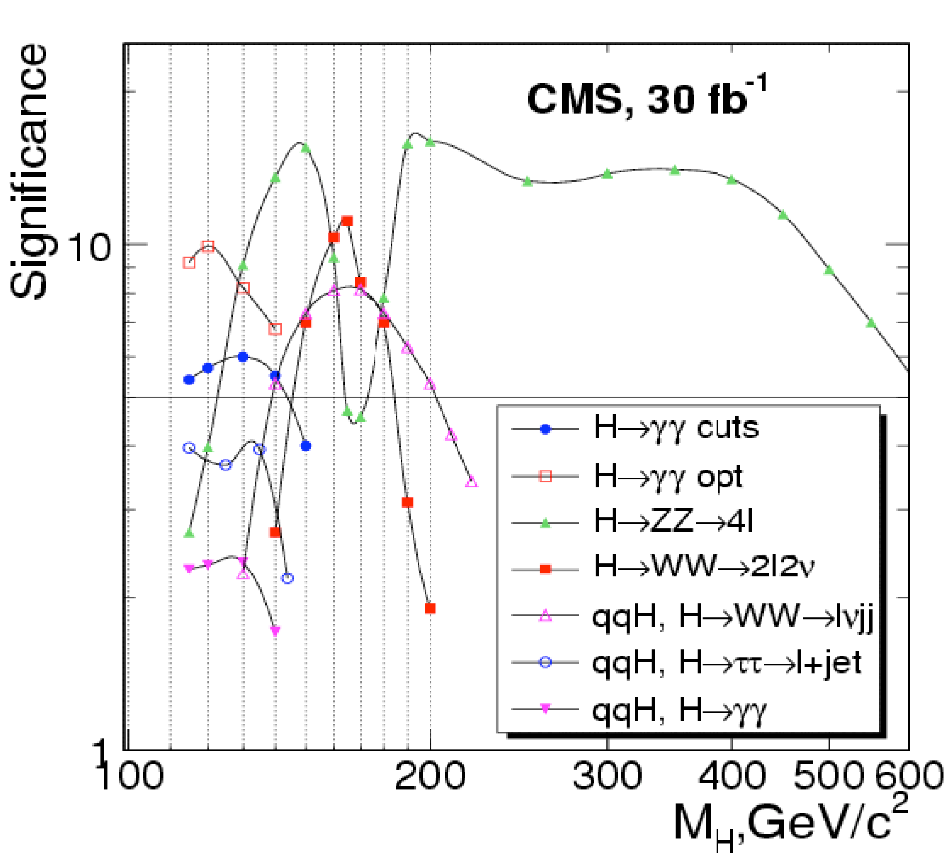
Multiboson Production at 1 fb-1

- Important test of background to searches
- Check Triple Gauge Couplings



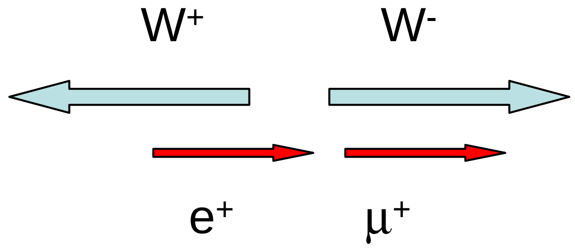
CMS Note-2006/108

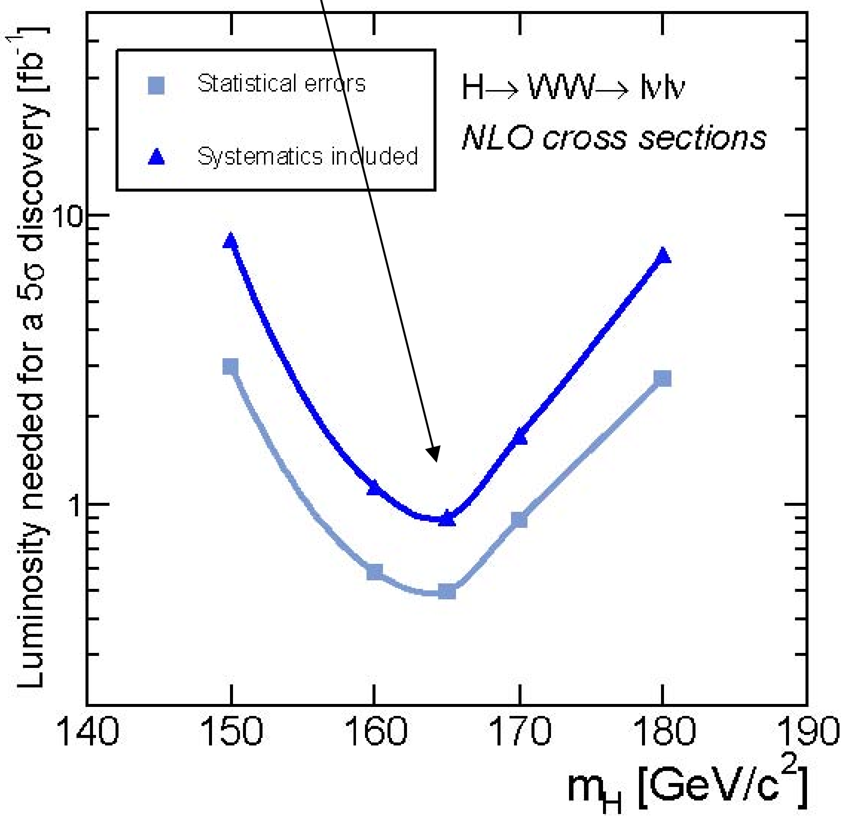
The Higgs Boson is for higher luminosities (unless some special cases…)



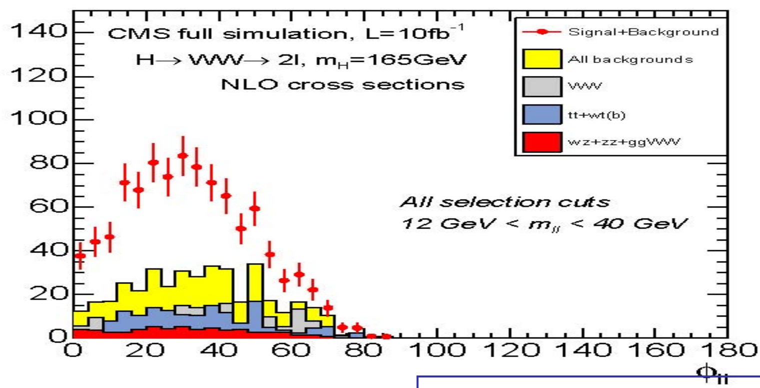
Mass around 160 GeV: H -> WW*

Use the fact that H is spin 0





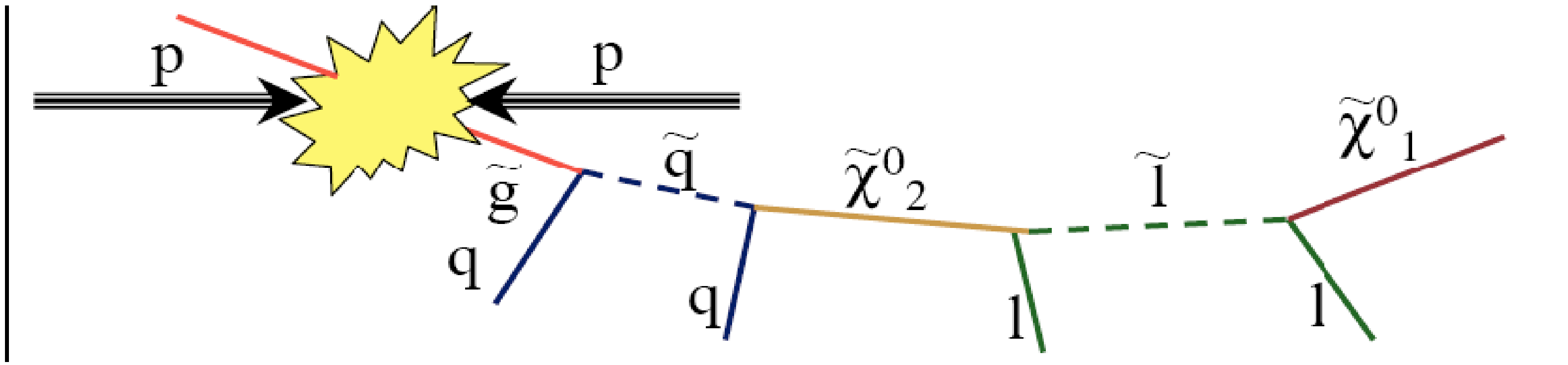
Counting experiment :
Need to normalize
WW and ttbar background from data !
Predicting effects from, for instance, jet-vetoes from Monte Carlo is dangerous ….



CMS Note-2006/055

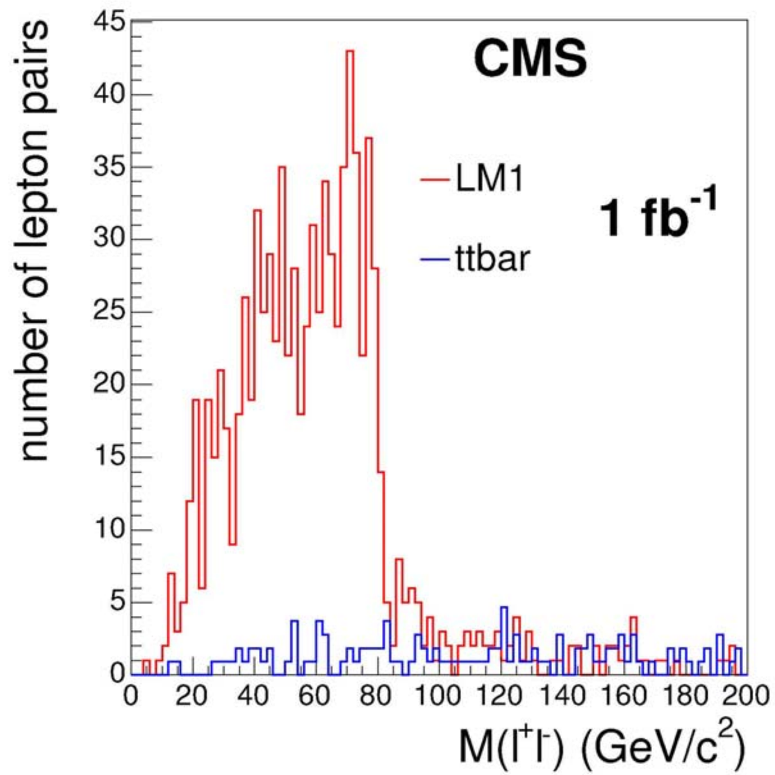
Direct Search for SUSY particles

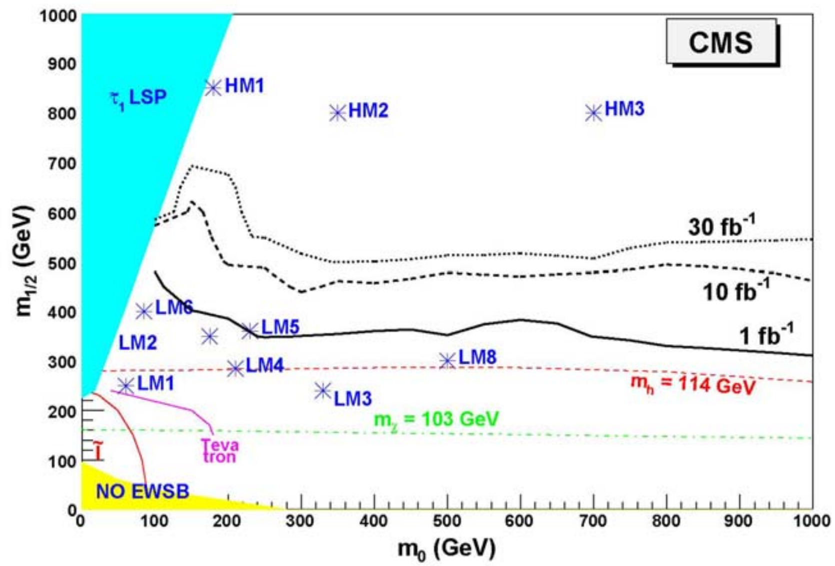
- Production of Susy Particles at LHC is dominated by gluinos and squarks
- The production is followed by a SUSY+SM cascade.



SUSY: Endpoint from dileptons

- In some case the possible SUSY signature is striking even at low luminosity

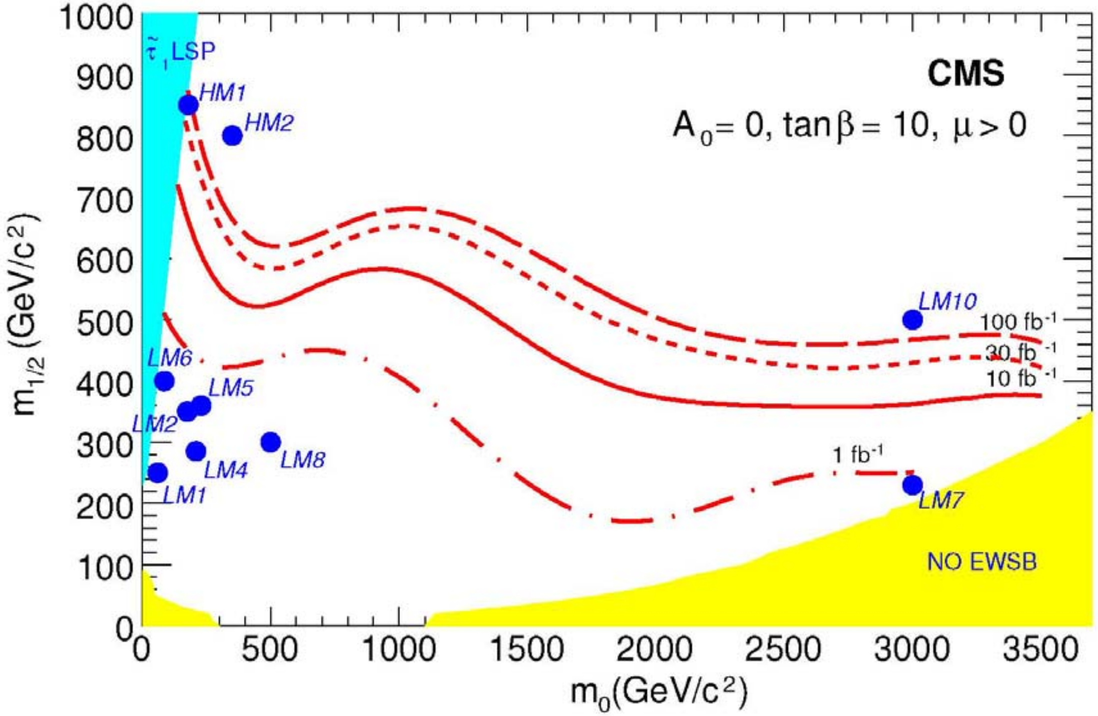




CMS Note-2006/133

SUSY: leptons + Jets + MET

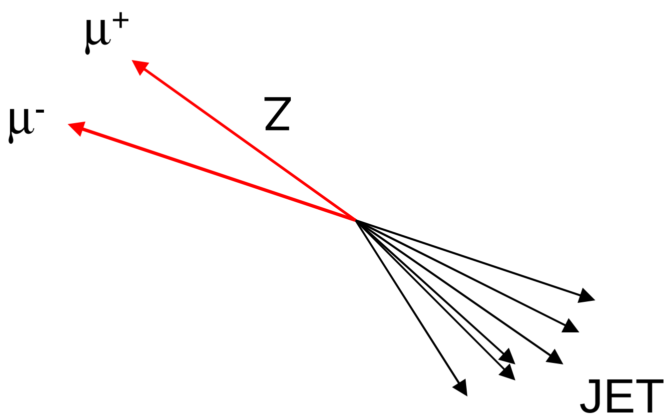
- Even better for same sign dileptons (less background)

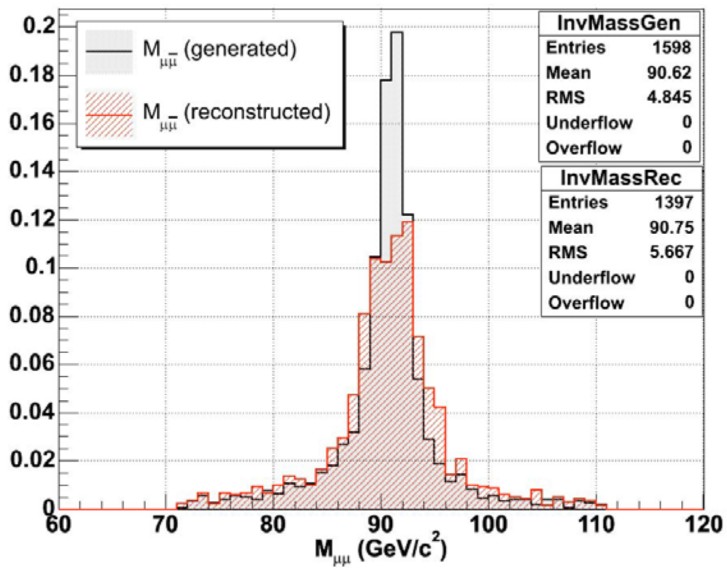


CMS Note-2006/134

SUSY: Jets + Missing ET

- In other cases need careful control from data
- Jets + MET provide a powerful signature for SUSY, but need to calibrate from Z+jets !



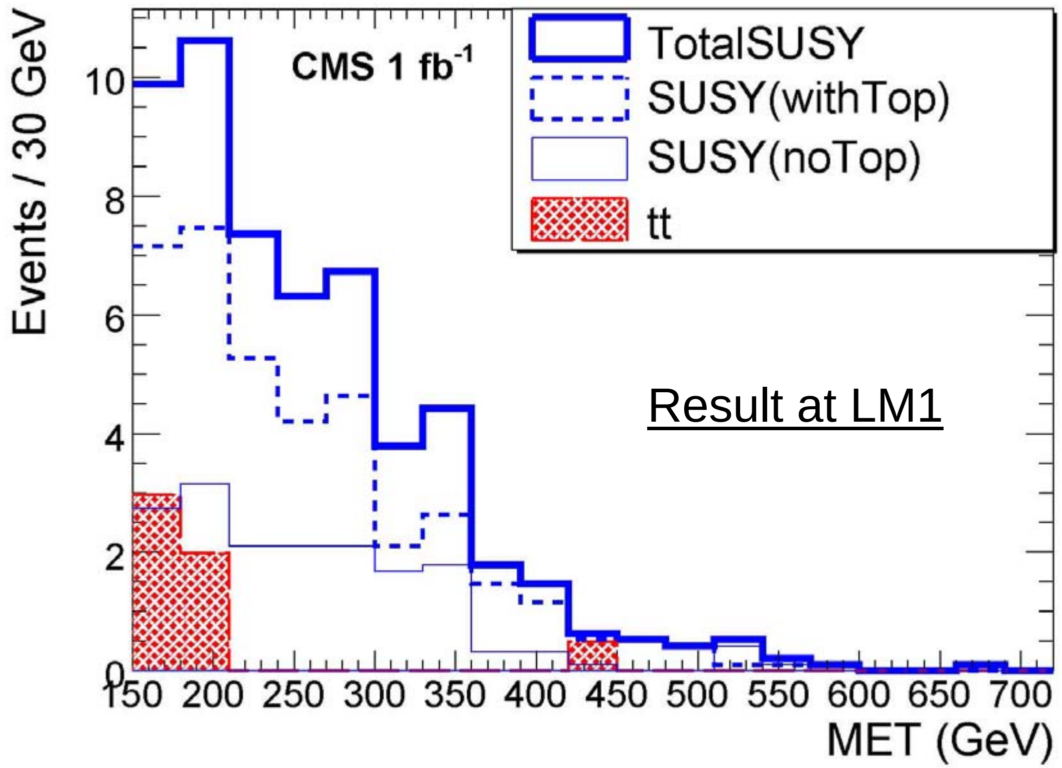


CMS Note-2006/102

SUSY : inclusive analyses with top

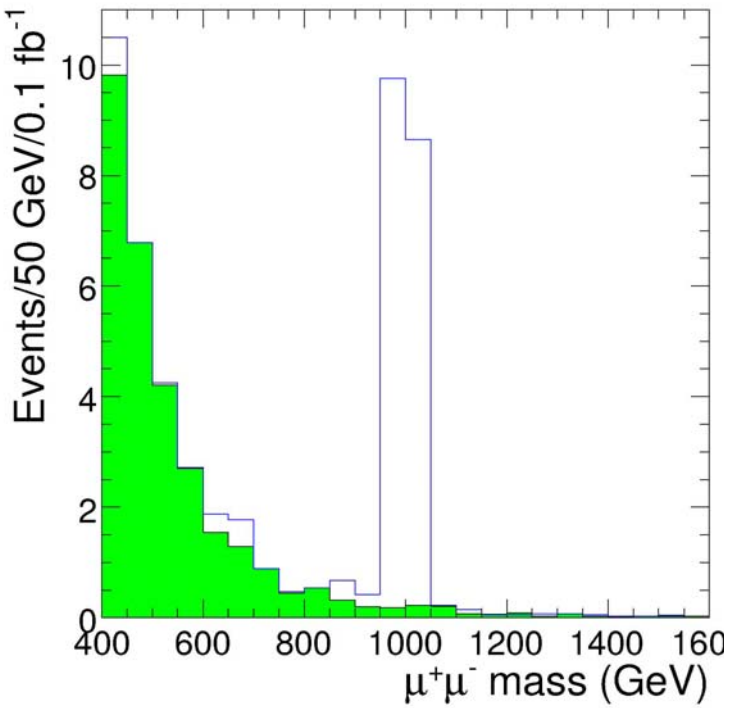
- Stop is generally the lightest squark.
- Reconstruct top quark and leptons
- Require missing transverse energy

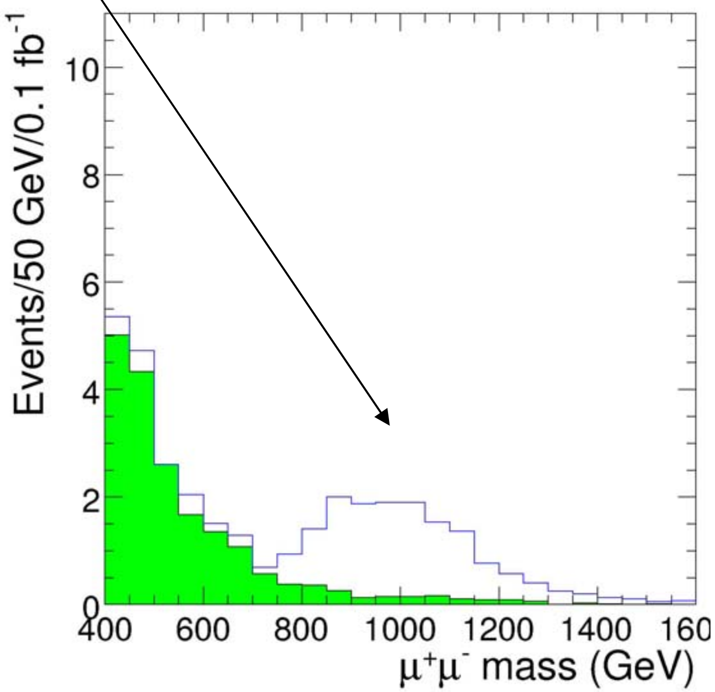
$$\tilde{t} \rightarrow t\chi_2^0 \rightarrow t\,\ell\,\tilde{\ell} \rightarrow t\,\ell\ell\chi_1^0$$



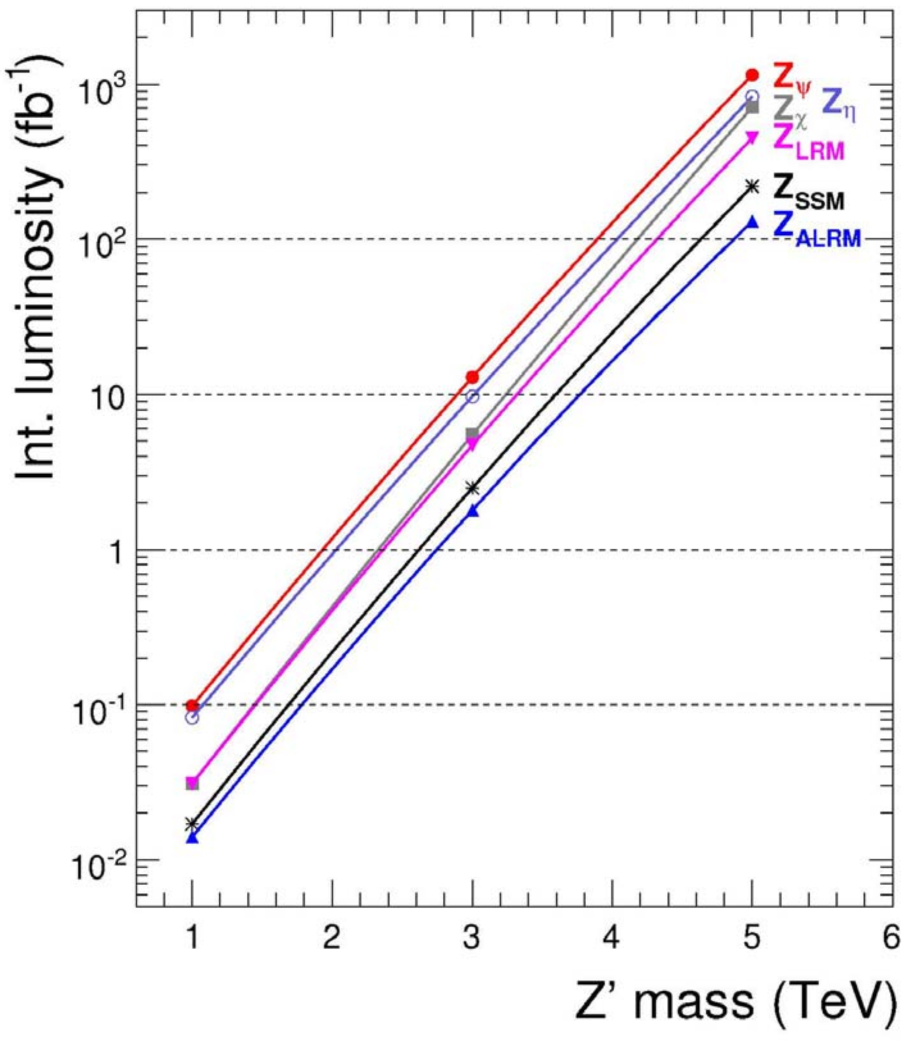
Additional Heavy Neutral Gauge Bosons (Z')

At **100 pb-1** , 1 TeV Z' with initial alignment





Additional Heavy Neutral Gauge Bosons (Z’)



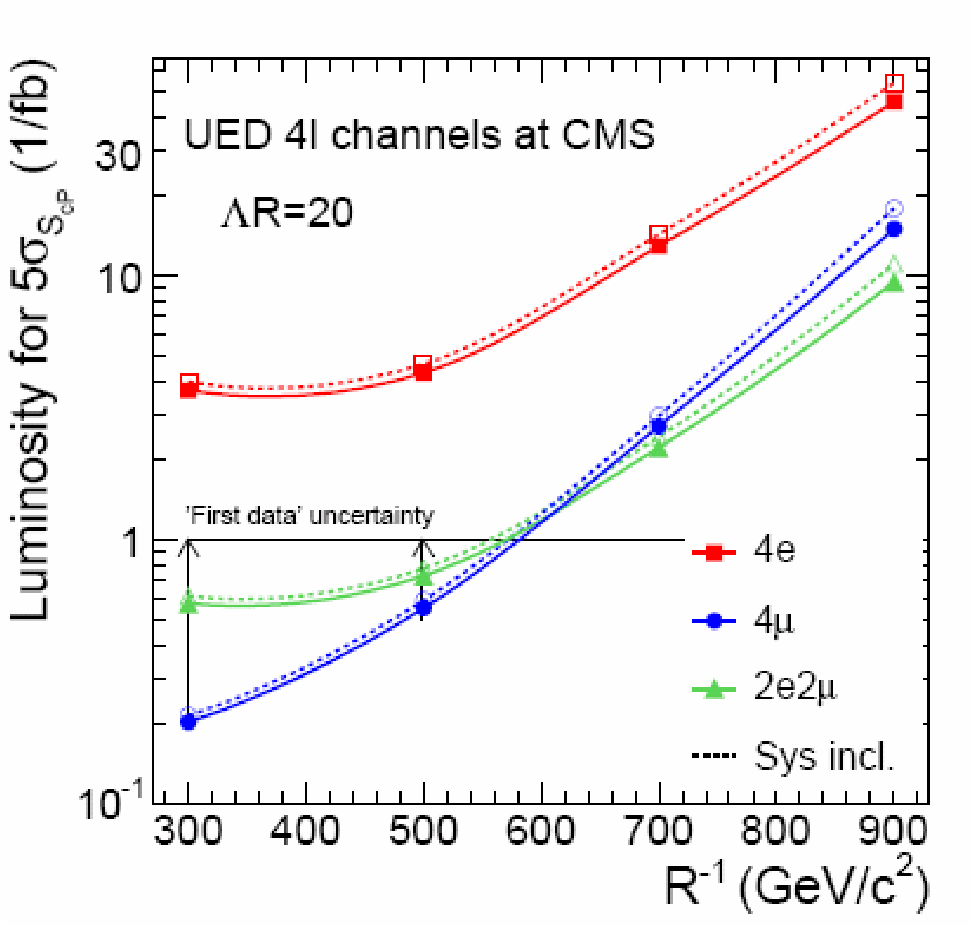
CMS Note-2006/062

Universal Extra Dimension with four leptons in the final state

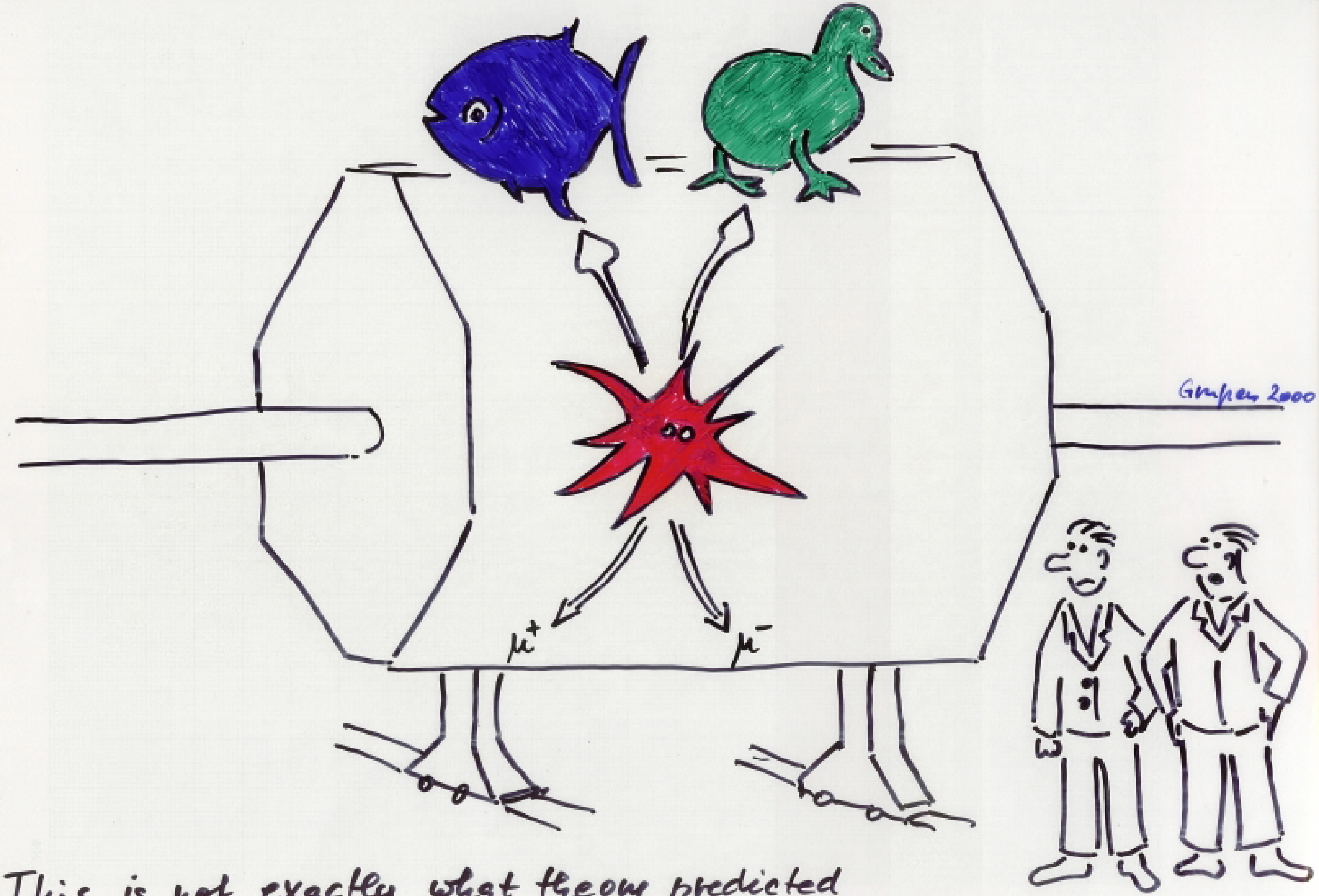
- All SM particles have KK partners, e.g. $g_1, Q_1, Z_1, L_1, \gamma_1$
- Total cross section strongly depends on compactification radius
- LKP (γ_1) is stable

$$pp \to g_1 g_1$$

$$g_1 \to Q_1 + Q$$
$$\quad \hookrightarrow Z_1 + Q$$
$$\quad\quad \hookrightarrow L_1 + \ell^{\pm}$$
$$\quad\quad\quad \hookrightarrow \ell^{\mp} + \mathrm{LKP}(\gamma_1)$$



CMS CR-2006/062



"This is not exactly, what theory predicted for the Higgs decay!"

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- Mike Lamont
- Dan Green
- Gigi Rolandi
- Andrea Giammanco
- Maria Spiropulu
- Fabiola Gianotti
- Juan Alcaraz
- And many others …….