Charged Higgs 2010
-Experimental summary and outlook-
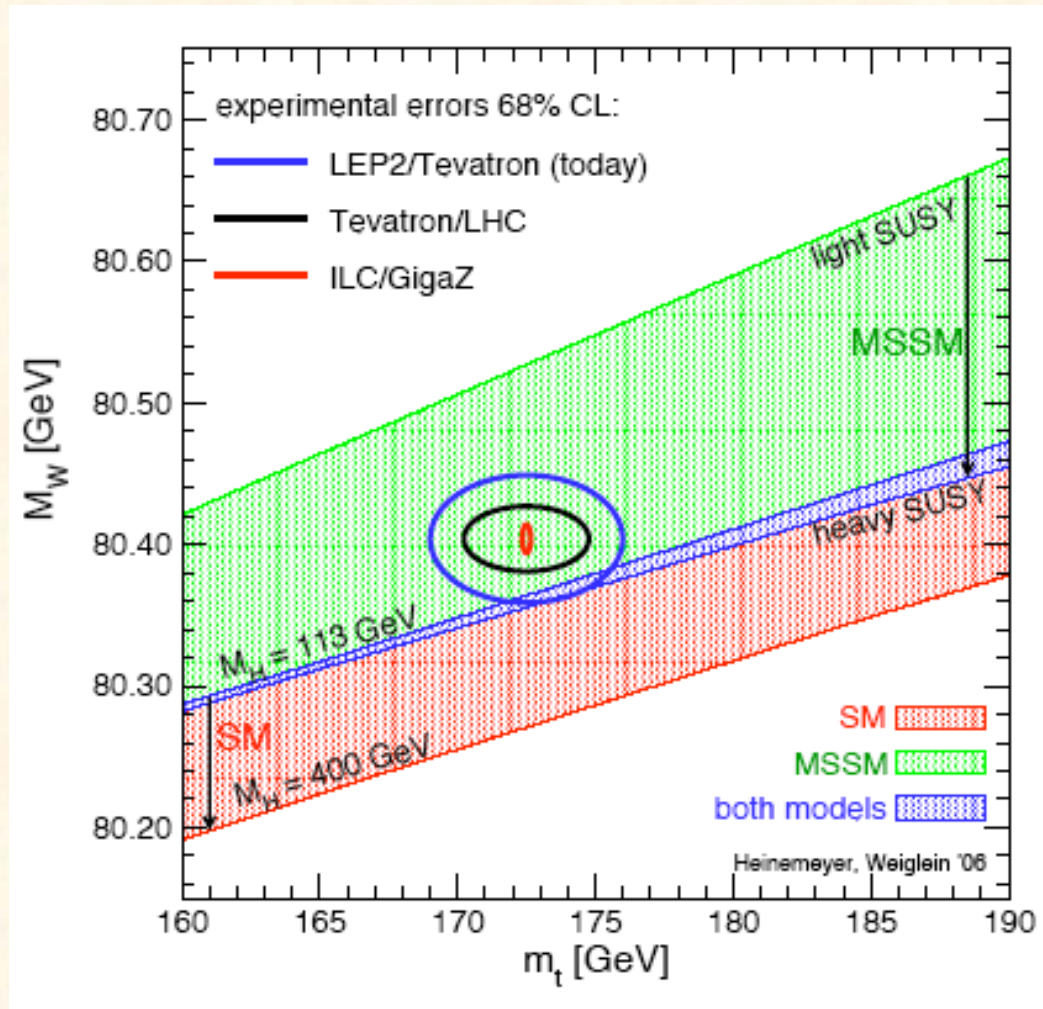

- Status of the accelerator

- ATLAS and CMS
  Detector performance with first data

- Results from the Tevatron

- Prospects for 2010/11 and beyond

Karl Jakobs
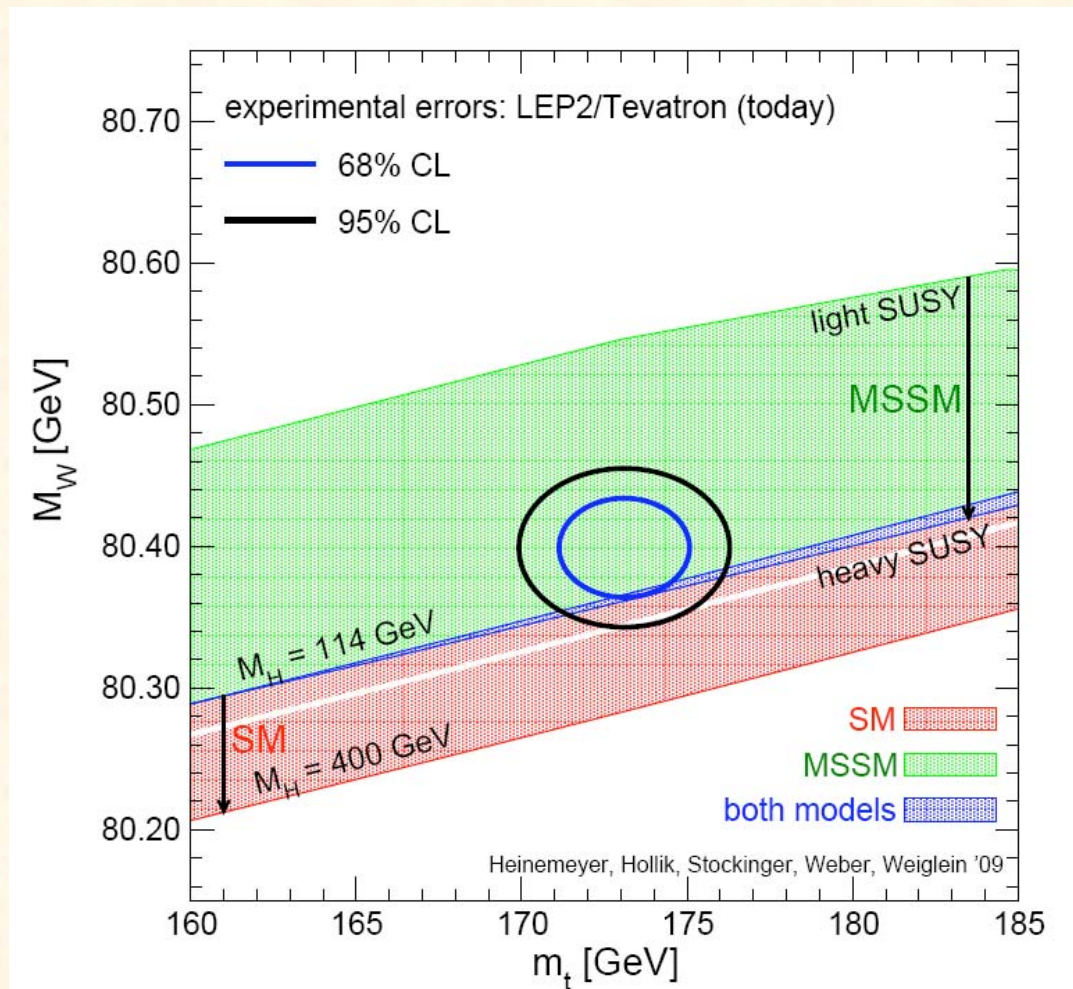**Physikalisches Institut**
University of Freiburg / Germany

Charged Higgs 2006

Sven et al. were telling us that the SM Higgs is light and that SUSY is around the corner
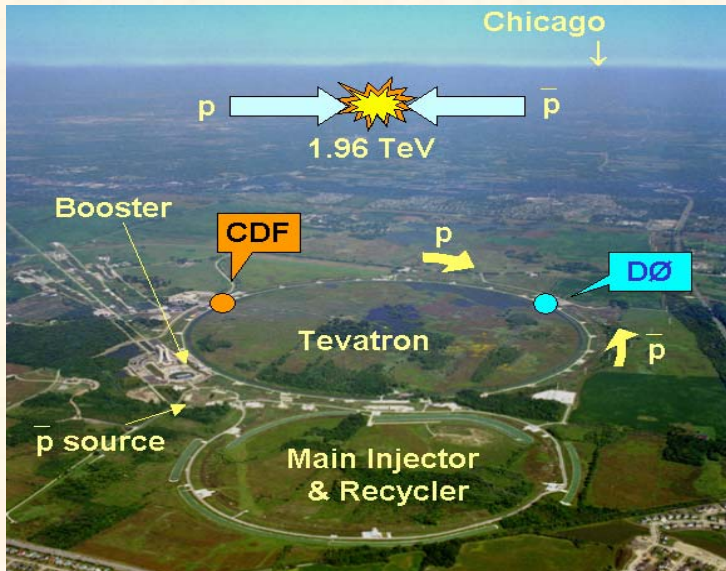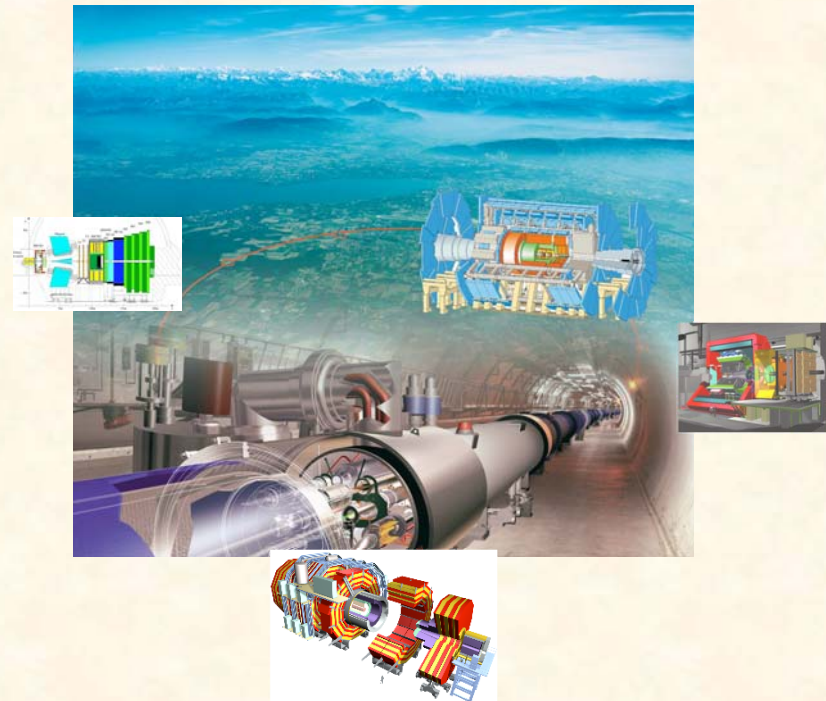
Charged Higgs 2010

Sven et al. keep telling us that the SM Higgs is light and that SUSY is around the corner

Progress on the experimental side

- Two colliders running

- First data at the LHC, Detector performance
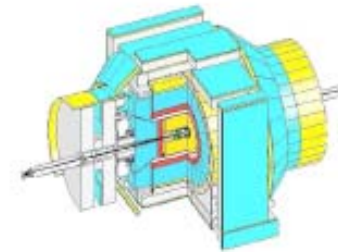
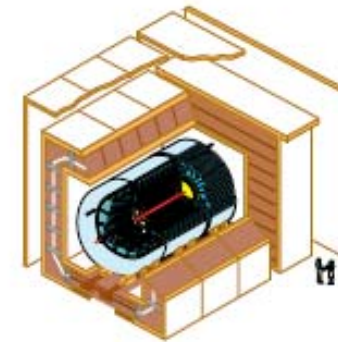- Less prospect and Monte Carlo talks

The Tevatron

$p\bar{p}$ $\sqrt{s} = 1.96$ TeV $\int \mathcal{L}dt \gtrsim 8$ fb^{-1}

CDF

DØ

The LHC machine...

... became a reality after ~15 years of hard work

Beam energy	$3.5 \rightarrow 7$ TeV
Luminosity (nominal)	$10^{32} - 10^{34}$ cm^{-2}s^{-1}
	$\rightarrow$ **1 - 100 fb^{-1} / year**
Superconducting dipoles	1232, 15 m, 8.33T
Stored energy	350 MJ/beam

LHC re-start as seen from the experiments
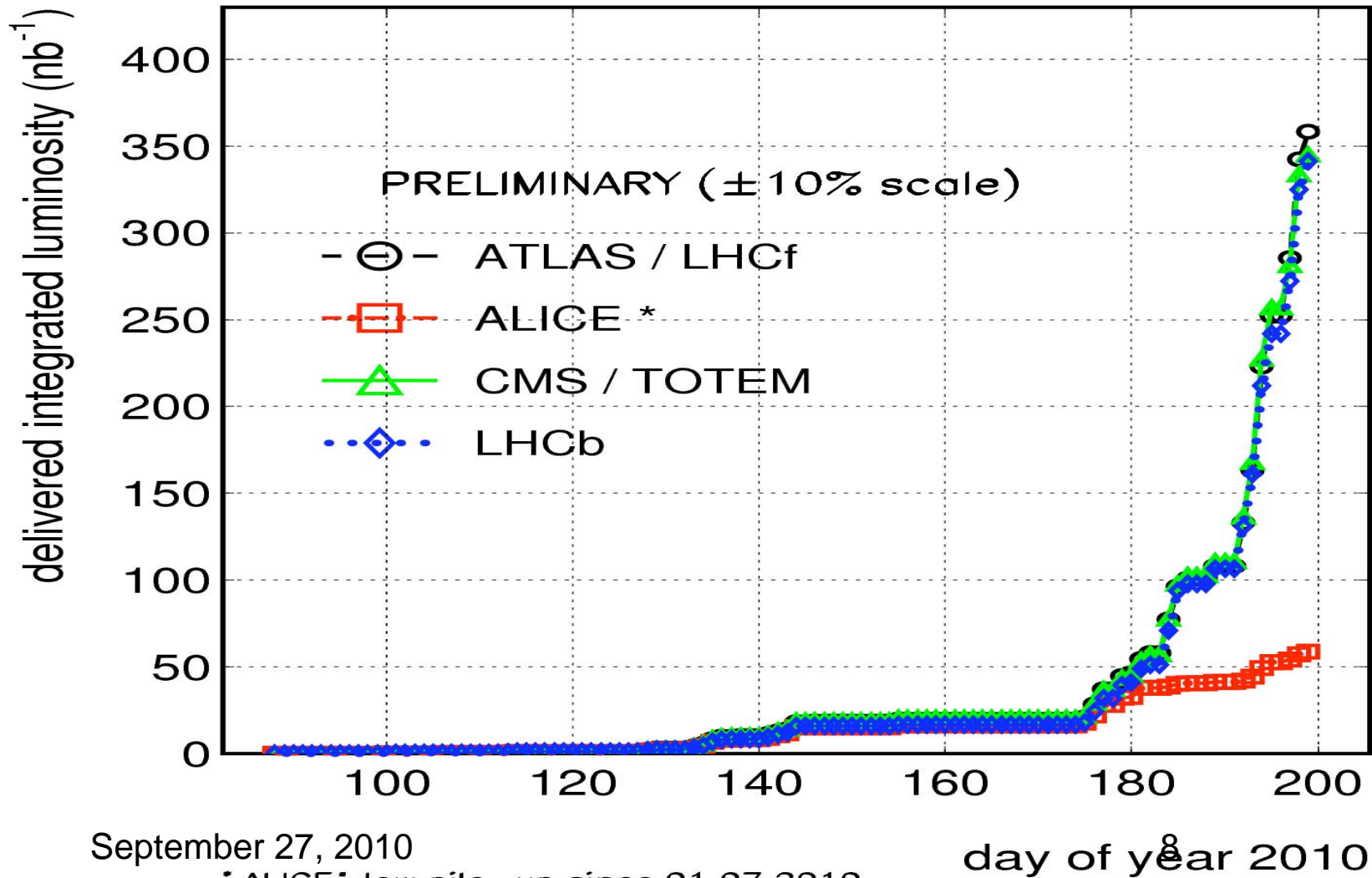
Praying for beam

Integrated Luminosity ICHEP10 (350nb-1)

2010/07/19 11.54

LHC 2010 RUN (3.5 TeV/beam)

September 27, 2010

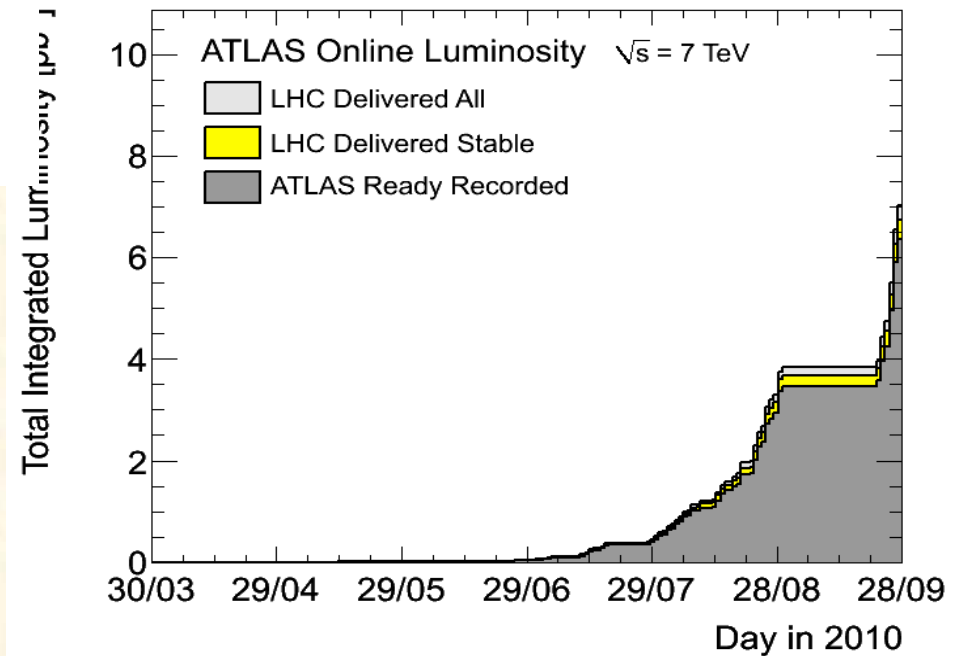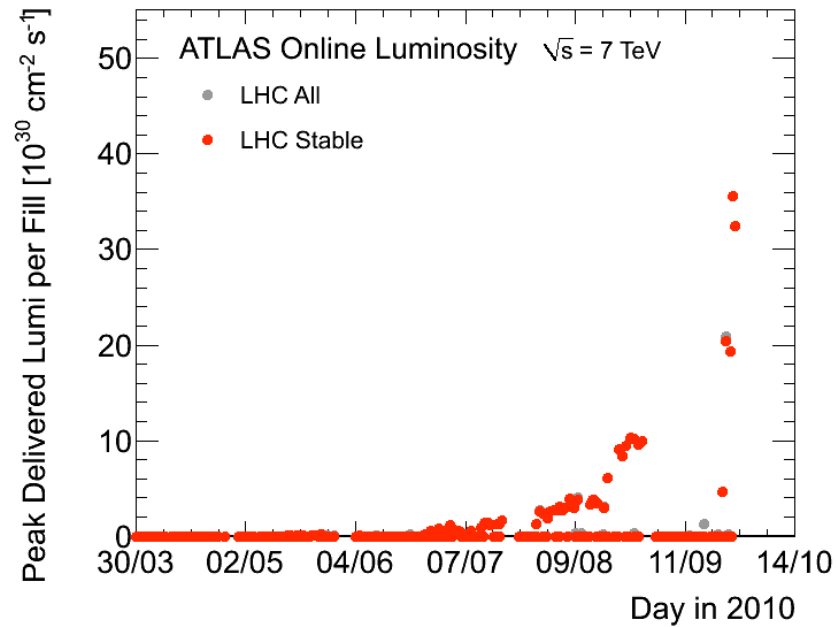* ALICE: low pile-up since 01.07.2010

Plan for getting to 10^{32} before ion run

LMC 18th August.

S. Meyers

- Parameters and Conditions
  - Nominal bunch intensity 1.1E11
  - Stick to $\beta^* = 3.5$ m

  - Commission bunch trains
    - Complete re-do of the whole machine protection set-up
  - Go to 150 ns bunch spacing

  - Commission faster ramp (10 A/s)

Reached luminosities as of Monday, 27. Sept 2010

Aggressive Schedule (short term)

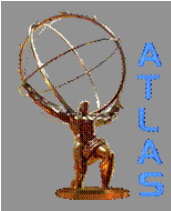# *Status of the*
ATLAS and CMS Detectors

- Impressive performance figures

- High data taking efficiencies

- Trigger and detector components working well

- Grid computing performing well

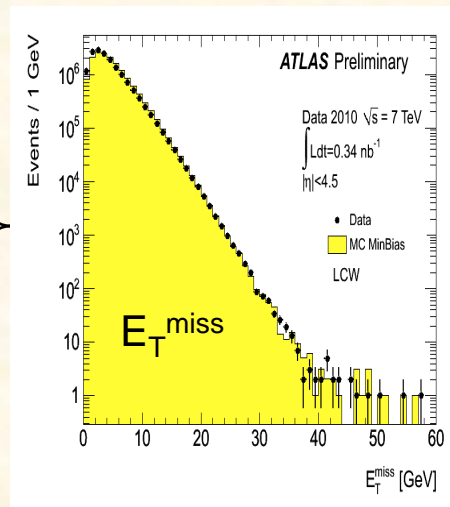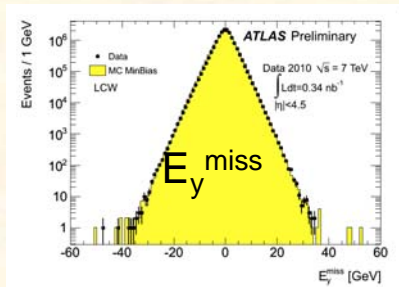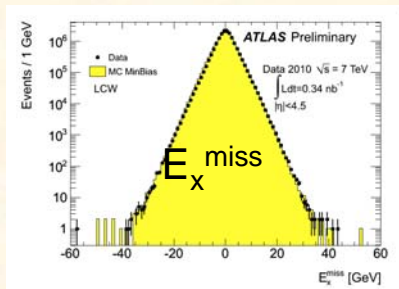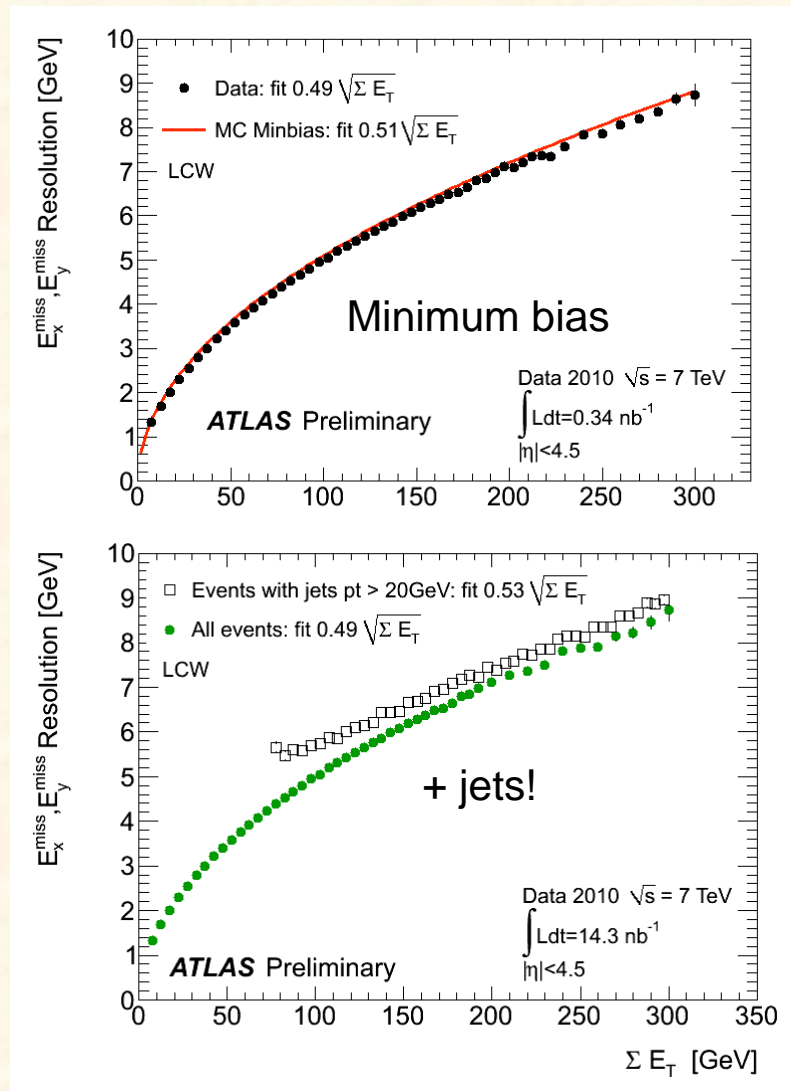- Standard Model Physics re-discovered

D. Orestano

A. Nikitenko

Missing E$_T$

- A complex object!
- Relative energy scales need careful intercalibration

Detector hermeticity in minimum bias events

B-tagging efficiency

$$\epsilon_b^{data} = \frac{f_b^{tag} \cdot N_{data}^{tag}}{f_b^{tag} \cdot N_{data}^{tag} + f_b^{untag} \cdot N_{data}^{untag}}$$

Extract f_b^{tag}, f_b^{untag} from fit of $p_{t\mu}^{rel}$ for b-tagged (untag) jets with muons

CMS Preliminary; $\sqrt{s}$=7 TeV; L= 8.0 nb^{-1}

b-tagged jets with μs
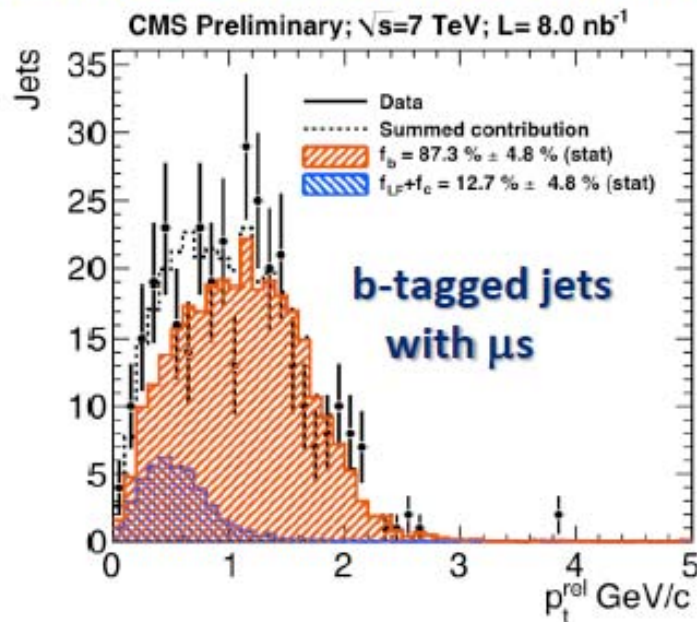
- **in general good agreement between ϵ_b^{data} and ϵ_b^{MC}**

Fake rate

CMS Preliminary, $\sqrt{s}$ = 7 TeV, L= 12 nb^{-1}
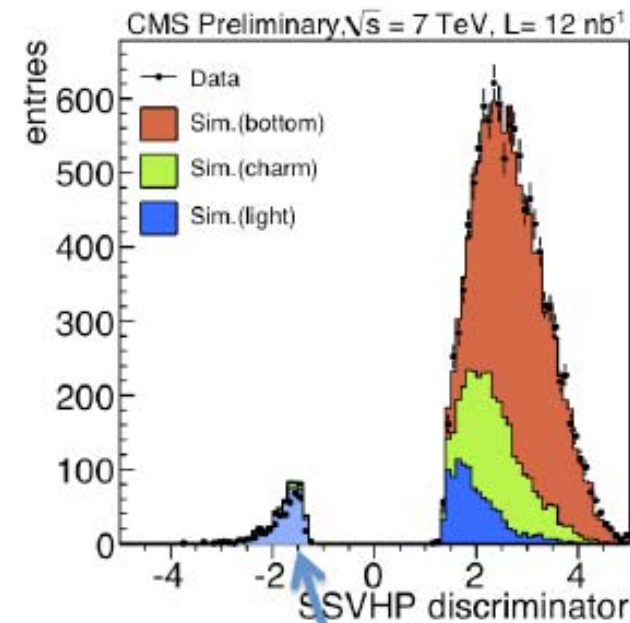
$$\epsilon_{data}^{mistag} = \epsilon_{data}^{-} \cdot R_{light}$$

$$R_{light} = \epsilon_{MC}^{mistag} / \epsilon_{MC}^{-}$$

- $\epsilon_{data}^{mistag}/\epsilon_{MC}^{mistag} = f(p_T^{jet}, \eta^{jet})$ **slightly less than 1.**
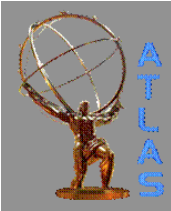
QCD cross-sections
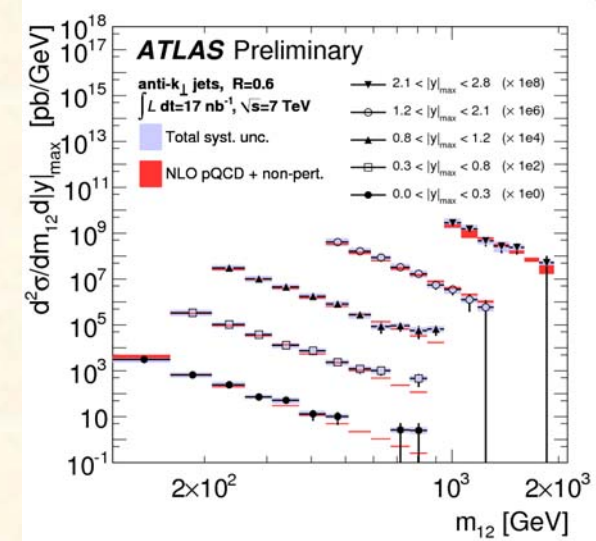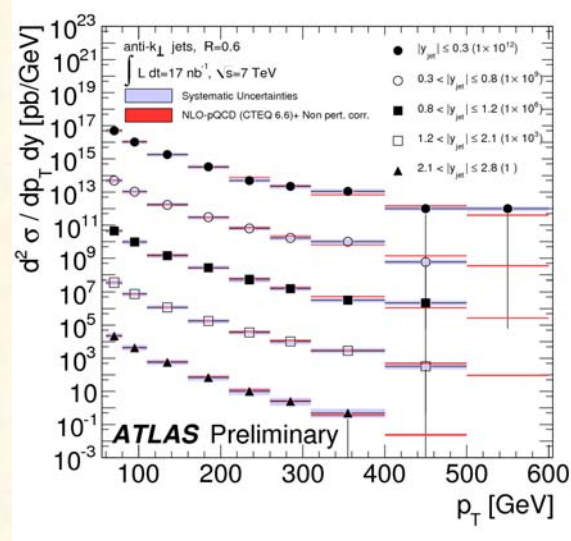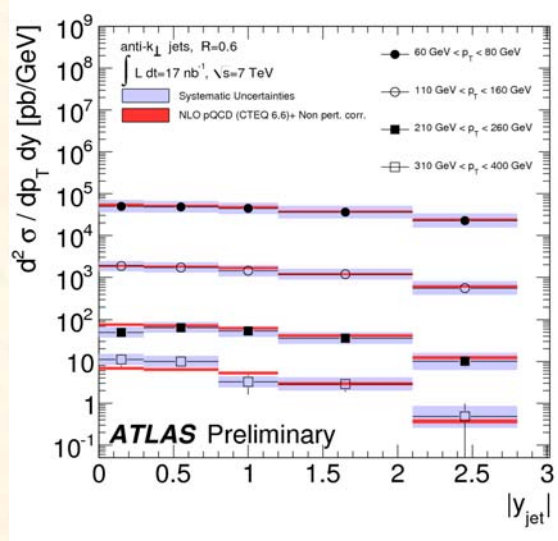
Double differential cross-sections in very good agreement with NLO predictions
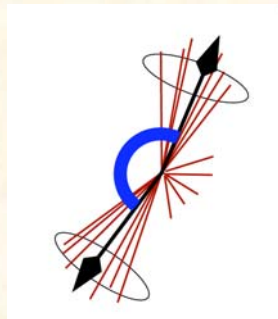
Soft radiation probed by di-jets angular decorrelation

D.Orestano
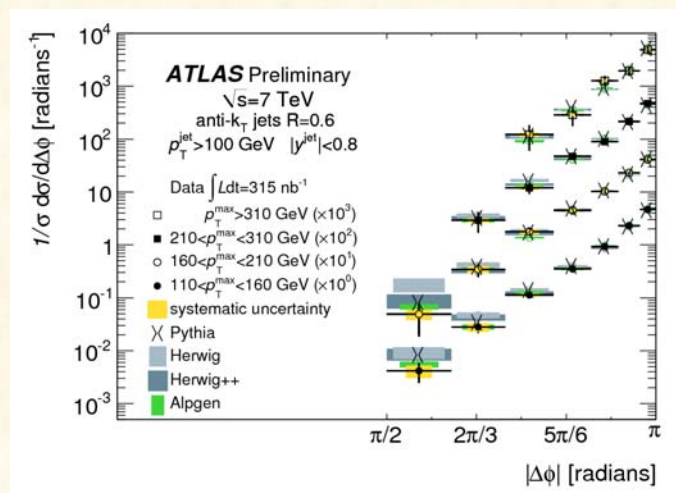
"Tight muons"

- Tight muon: is "global" AND "tracker" muon, $\chi_{gl.trk}^2 < 10$, > 0 muon hits, > 1 matched muon segments, > 10 trk. Hits, >0 pixel hits, $ip_{xy} < 2$ mm, $p_T > 3$ GeV

  - "tracker muon" : inside-out approach
  - "global muon": outside-in approach+global fit
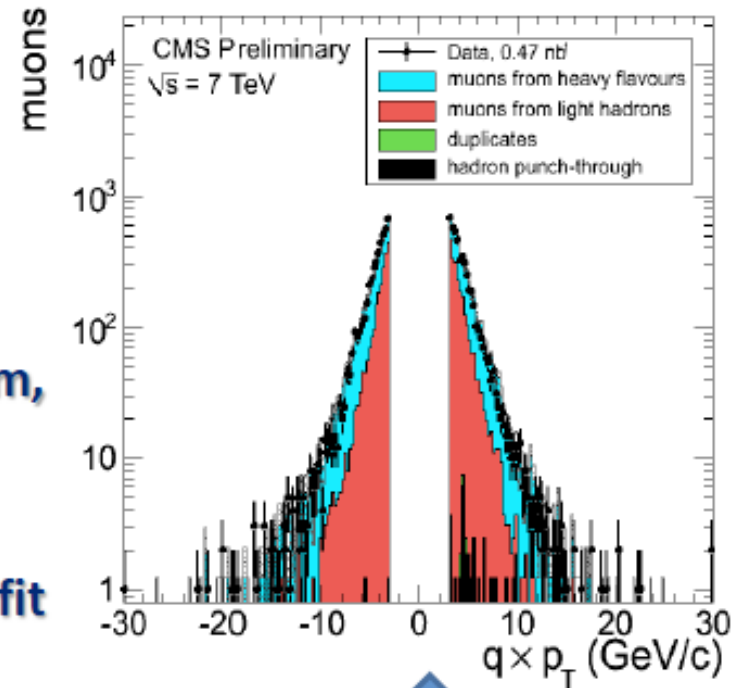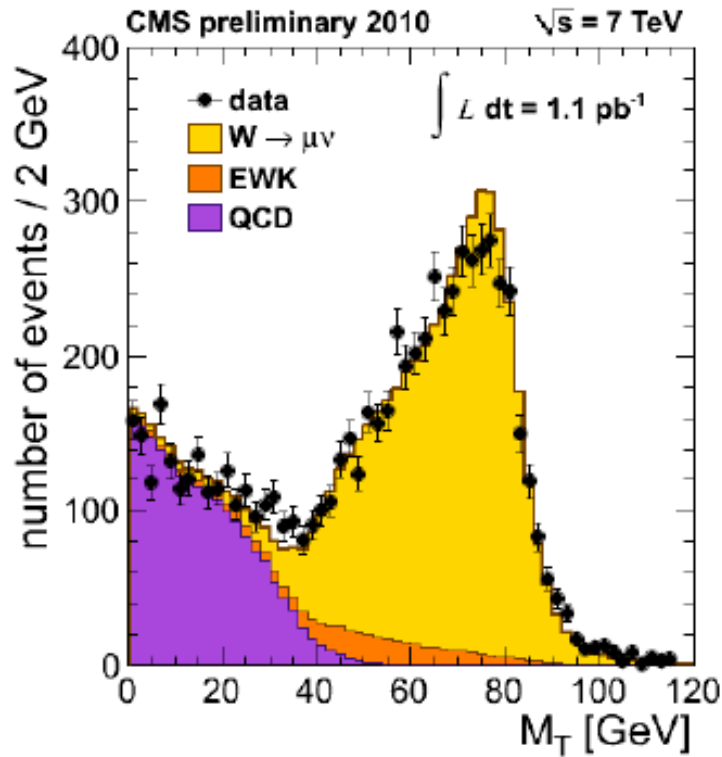
from min. bias trigger

used in W->μν and tt~ analyses

A. Nikitenko

To Physics of the Charged Higgs
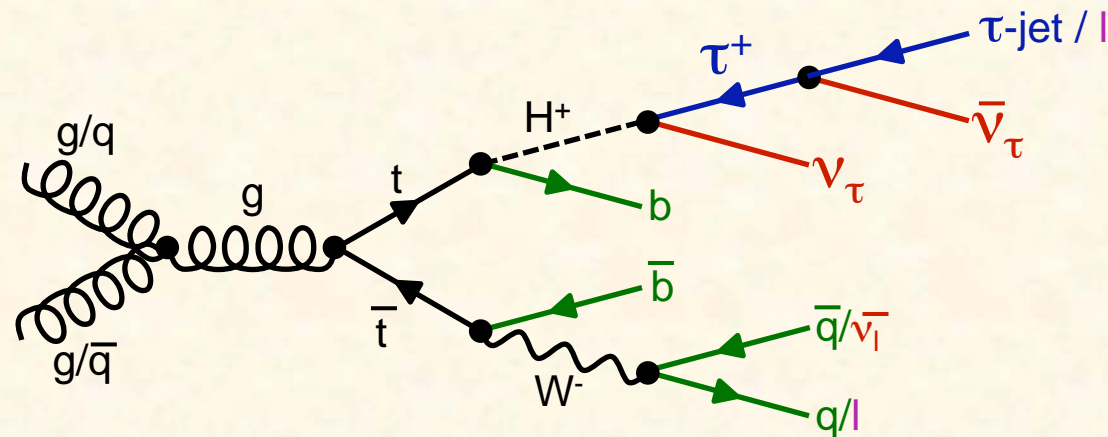
What is important ??

Everything !!   Taus, b-jets, leptons, missing E_T, jets,.....

Tevatron Higgs Boson Searches

P. Gutierrez

- Analysis are based on type 2 models

  - Concentrate on $m_{H\pm} < m_t + m_b$
  - Search for: $H^\pm \to \tau\nu_\tau$ $H^\pm \to cs$ $H^\pm \to h^0 W^\pm$
    $H^\pm \to A^0 W^\pm$ $H^\pm \to t^* b \to W^\pm \bar{b}b$

Branching Ratio for all modes MH=100

Branching Ratio for all modes MH=120
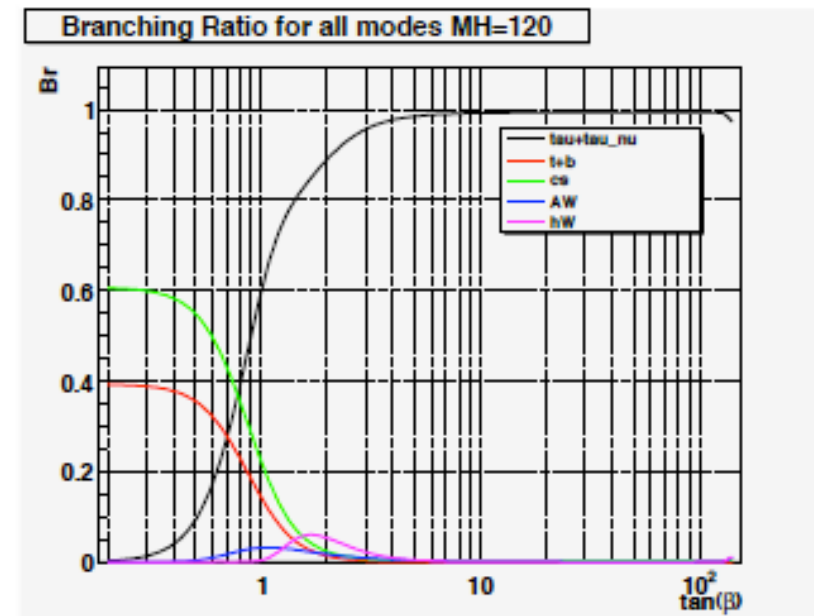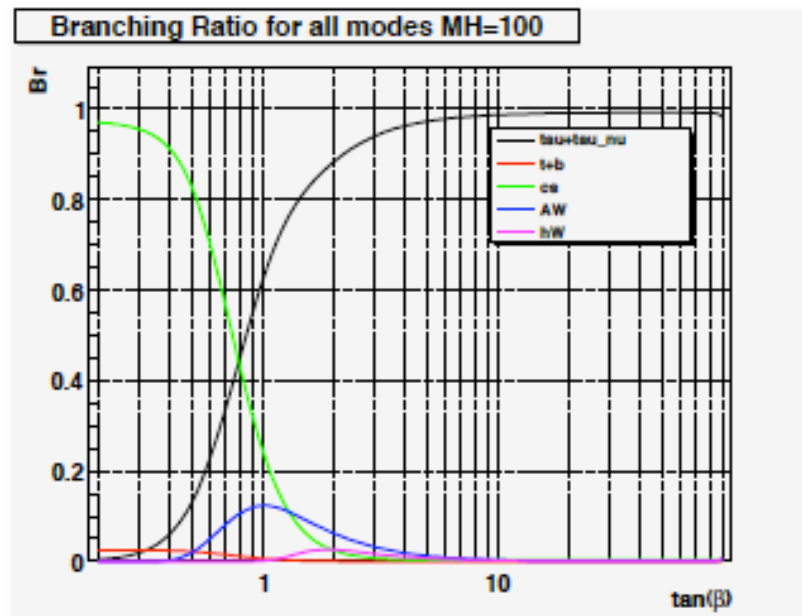
Tevatron Higgs Boson Searches

$$\sigma_{t\bar{t}}^{\text{exp}} = \frac{[\sigma_{t\bar{t}} \cdot B(t\bar{t} \to X)]_{\text{exp}}}{[B(t\bar{t} \to X)]_{\text{SM}}} = \sigma_{t\bar{t}} \cdot f_X$$

$$\sum_X B(t\bar{t} \to W^{\pm}b \to X) + \sum_X B(t\bar{t} \to H^{\pm}b \to X) = 1$$

$\ell + \text{jets}$ $\ell + \ell$

N_{event}

DØ, L=1.0 fb^{1}

$\sigma_{t\bar{t}}$=8.18 pb

· Data

$t\bar{t}$ + background

background

l+jets 1 tag | l+jets 2 tag | dilepton | τ+lepton

Tevatron *=preliminary

DO $\sigma_{ll} / \sigma_{lj}$ 1 fb^{-1} $\quad 0.86^{+0.19}_{-0.17}$

DO $\sigma_{l\tau} / \sigma_{ll+lj}$ 1 fb^{-1} $\quad 0.97^{+0.32}_{-0.29}$

CDF $\sigma_{ll} / \sigma_{lj}$ * 0.2 fb^{-1} $\quad 1.45^{+0.83}_{-0.55}$

SM

0.5   1   1.5   2

t̄t Cross Section Ratio
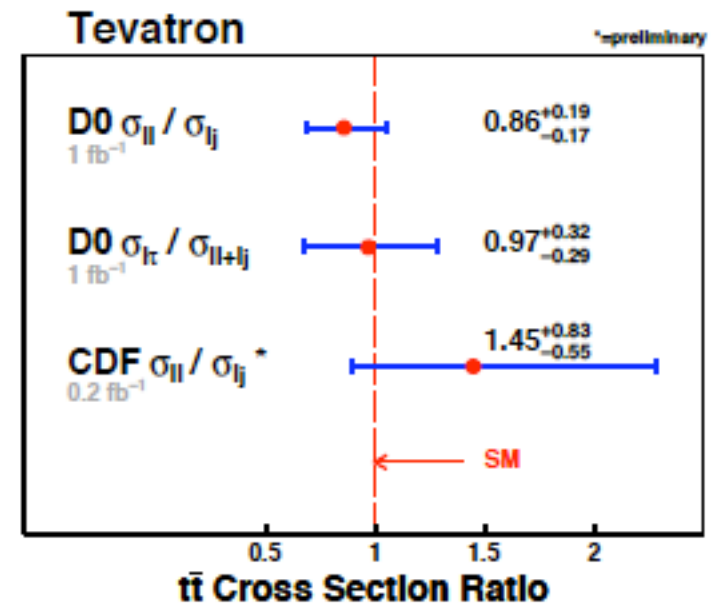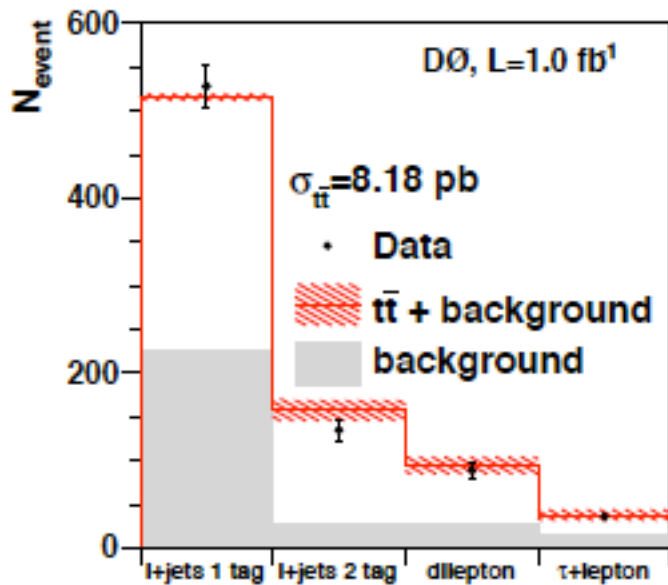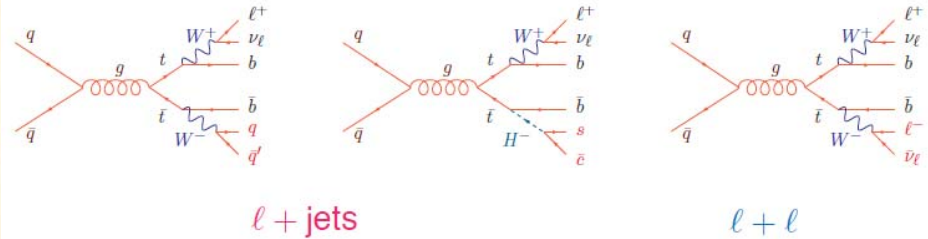
95% C.L. limits on branching ratios from indirect searches (tt decays)

assuming BR (H+ → τν = 1)
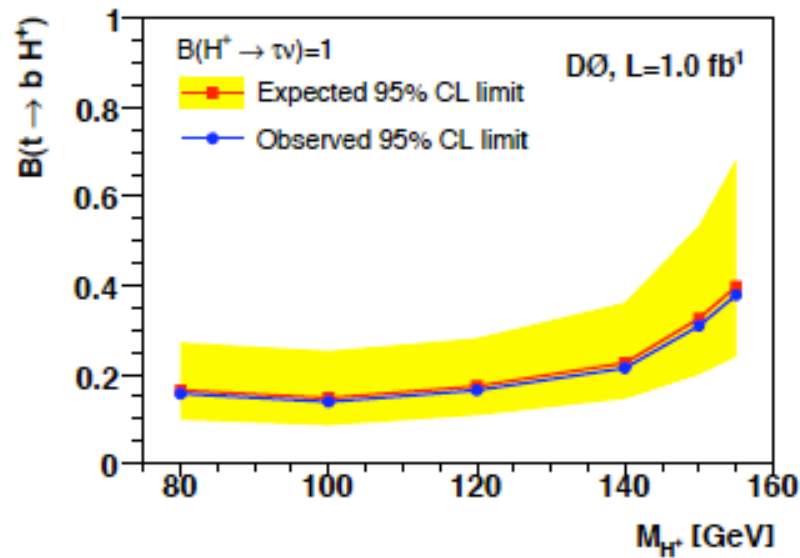
95% C.L. limits on branching ratios from direct searches
assuming BR (H+ → cs = 1)
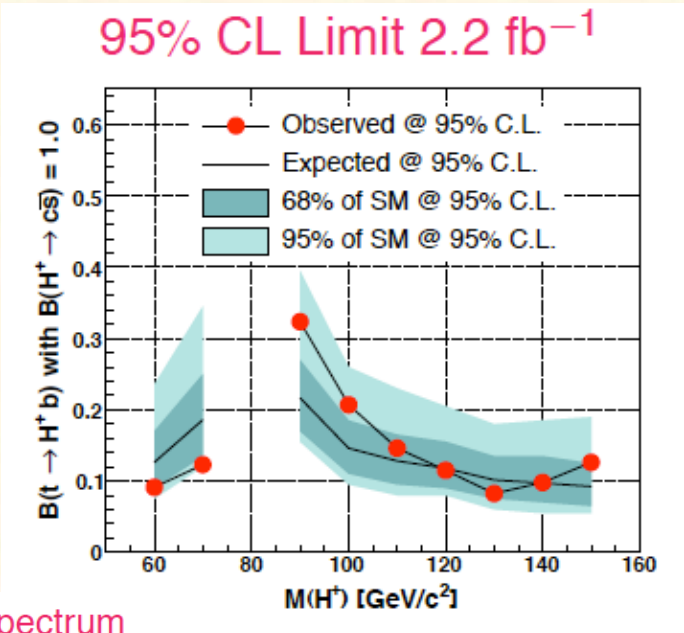
Dijet Mass Spectrum
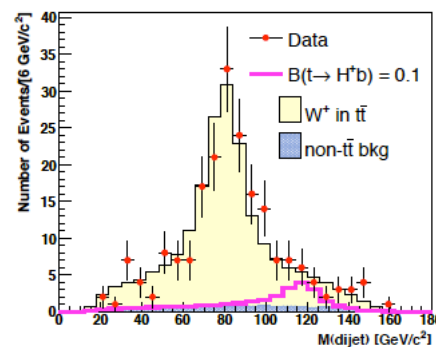
Phys. Rev. Lett. 103, 101803 (2009) CDF

CDF MSSM

- $\int Ldt = 193\ \text{pb}^{-1}$

- Covers full $\tan\beta$ range

- Expected number of events SM, MSSM (2HDM)

- Exclusion based on CPsuperH

- Bayesian limit

$$t \rightarrow H^{\pm}b$$
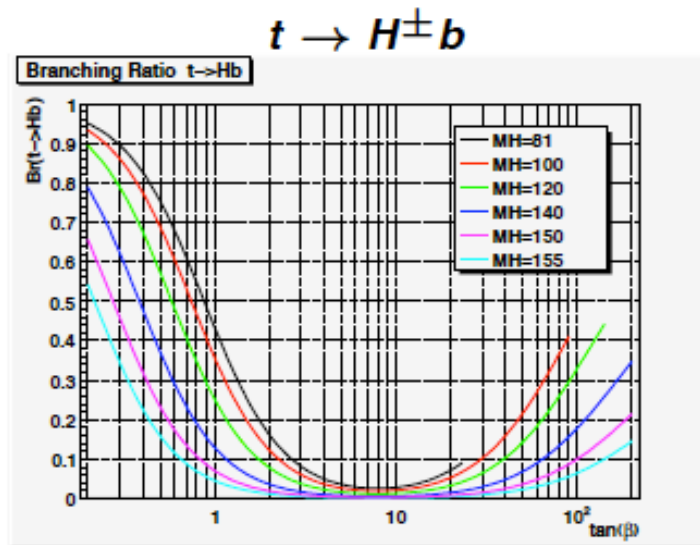
FeynHiggs

CDF MSSM

- $\int Ldt = 193 \text{ pb}^{-1}$

- Covers full $\tan \beta$ range

- Expected number of events SM, MSSM (2HDM)

- Exclusion based on CPsuperH

- Bayesian limit

Excluded MSSM

Phys. Rev. Lett 96, 042003 CDF

MSSM Higgs Boson Search at the LHC

Important channels in the MSSM Higgs boson search:

1. The Standard Model decay channels
   - $h \rightarrow \gamma\gamma$
   - $tt\,h$, $h \rightarrow bb$
   - $qq\,h$, $h \rightarrow \tau\tau$

   evaluation of performance is based on SM results

2. Modes strongly enhanced at large $\tan\beta$:
   - **H/A** $\rightarrow \tau^+\tau^-$ $H^+ \rightarrow \tau\,\nu$
   - **H/A** $\rightarrow \mu^+\mu^-$

3. Other interesting channels:
   - $H/A \rightarrow tt$
   - $H/A \rightarrow Zh \rightarrow \ell\ell\,\gamma\gamma$
     $\rightarrow \ell\ell\,bb$
   - $H \rightarrow hh$

MSSM benchmark plot for nearly 10 years
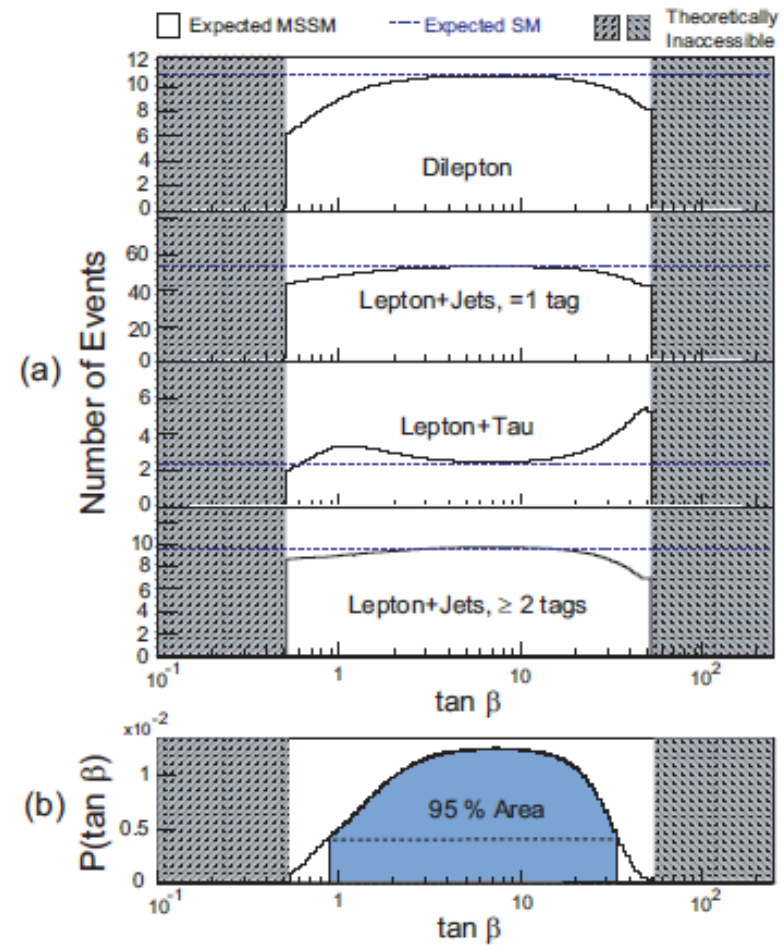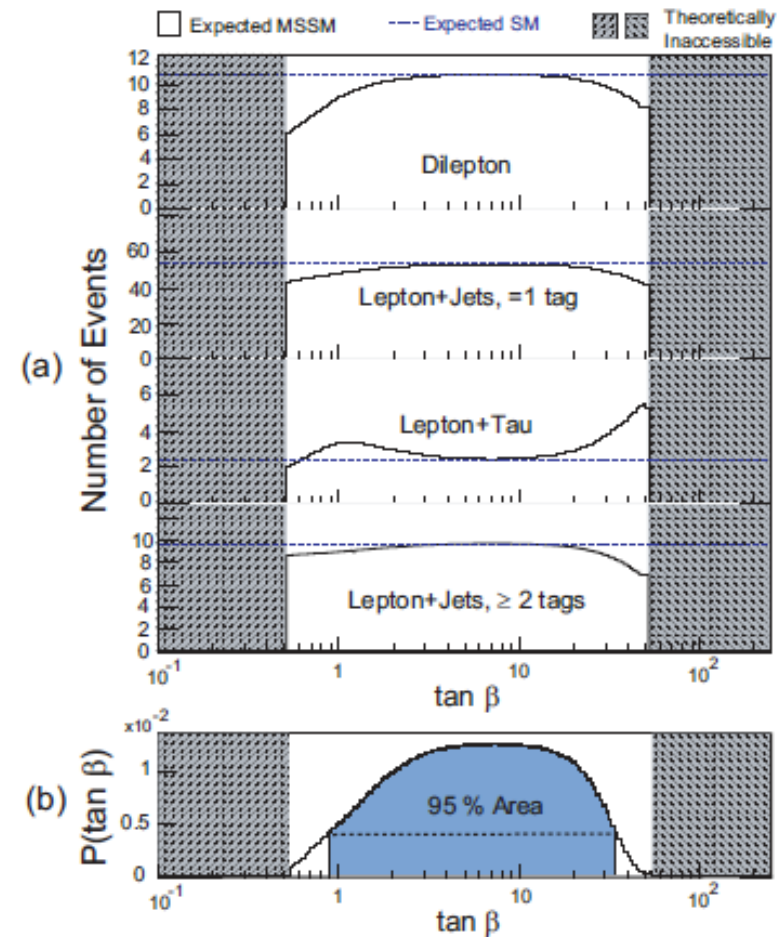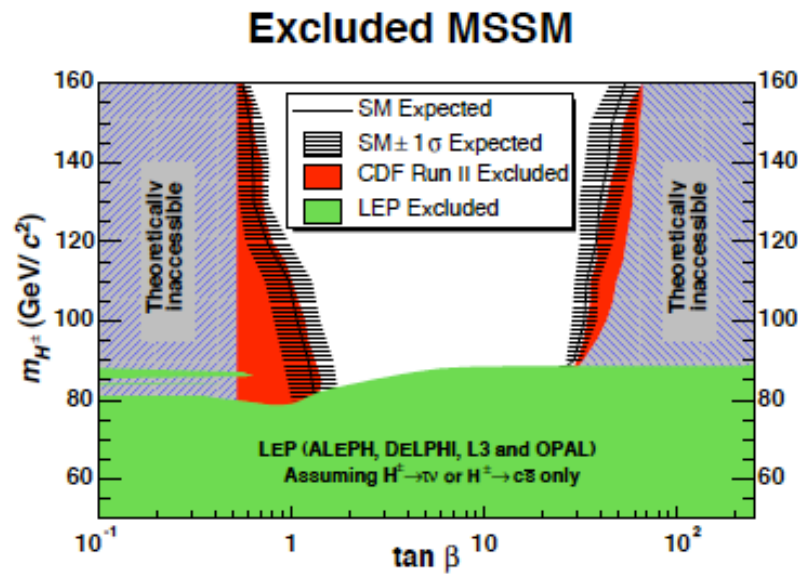
Updated LHC discovery potential for charged Higgs bosons

A. Ferrari

- Strategy has to be changed, according to LHC energy and luminosity expectations

- More attention now on the „low mass region" $m_H^+ < m_t - m_b$

  $\sqrt{s} = 7$ TeV, $L_{int} \approx 1$ fb^{-1}

- In addition, high mass studies relevant for higher luminosity

  $\sqrt{s} = 14$ TeV, $L_{int} \approx 10\text{-}30$ fb^{-1}

Plans for search

M. Gallinaro

- 1-10 pb^{-1}:
  - study tau fake rates in multi-jet samples
  - leptons/jets/MET
  - validate data-driven background methods

- 10-100 pb^{-1}:
  - estimate tau fake background
  - look for ttbar events with taus

- 100-1000 pb^{-1}:
  - set limits/find signal
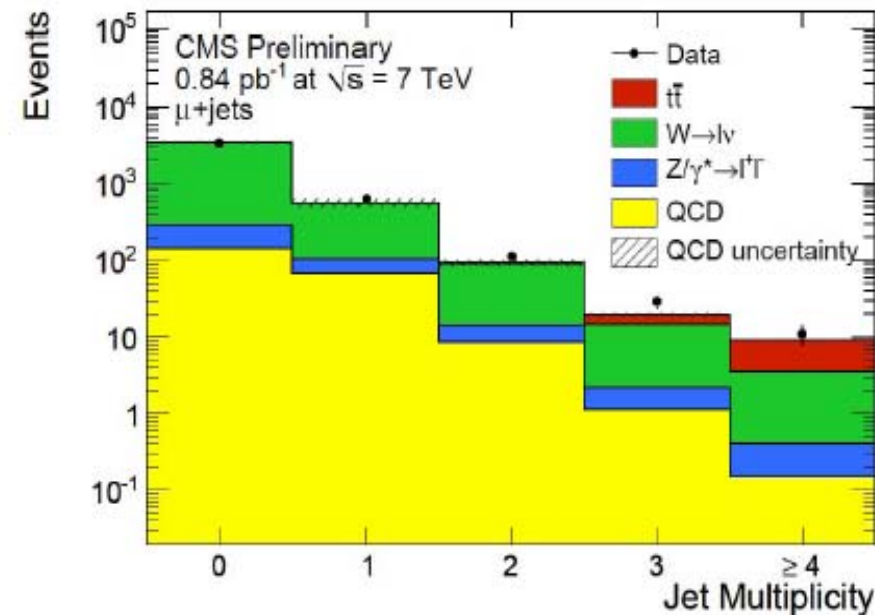
LHC discovery potential for charged Higgs bosons

ATLAS CSC studies, √s = 14 TeV

Two channels considered:

gg/gb → t (b) H+ → bqq (b) τ_{had} ν
gg/gb → t (b) H+ → t(b) tb → blν (b) b qqb
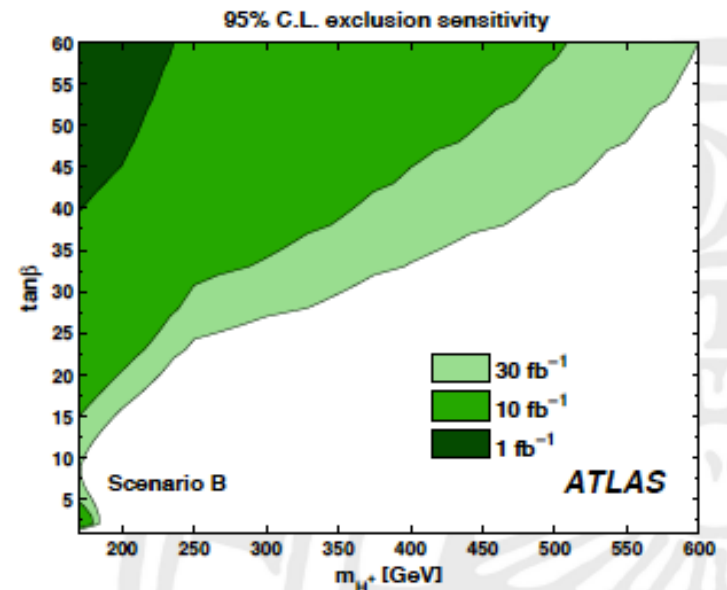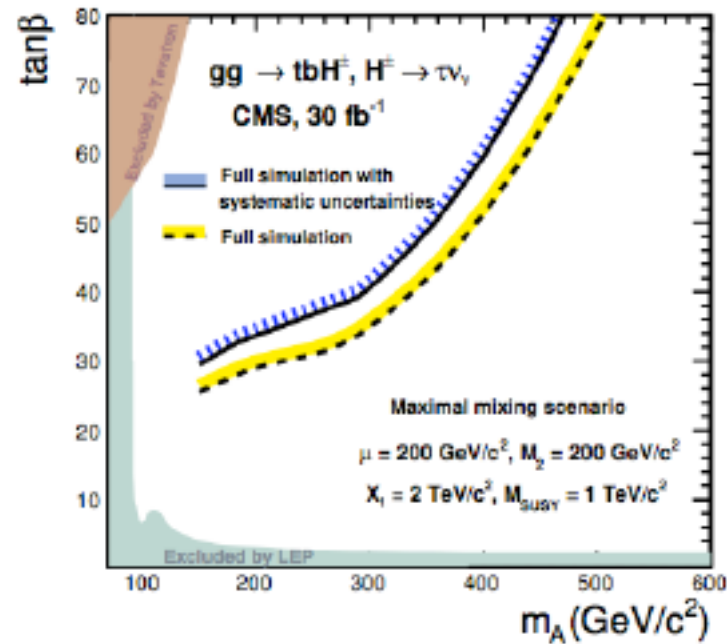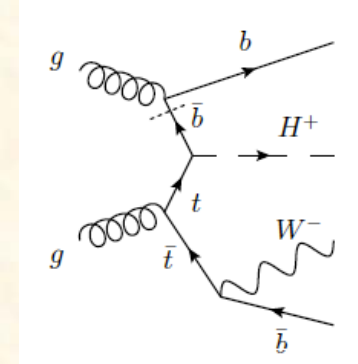
mhmax scenario,   systematic uncertainties included

$H^+ \rightarrow tb$: contribution to H^+ sensitivity

No discovery or exclusion power was extracted for this channel on its own, but it contributes to the combined ATLAS sensitivity for charged Higgs bosons.
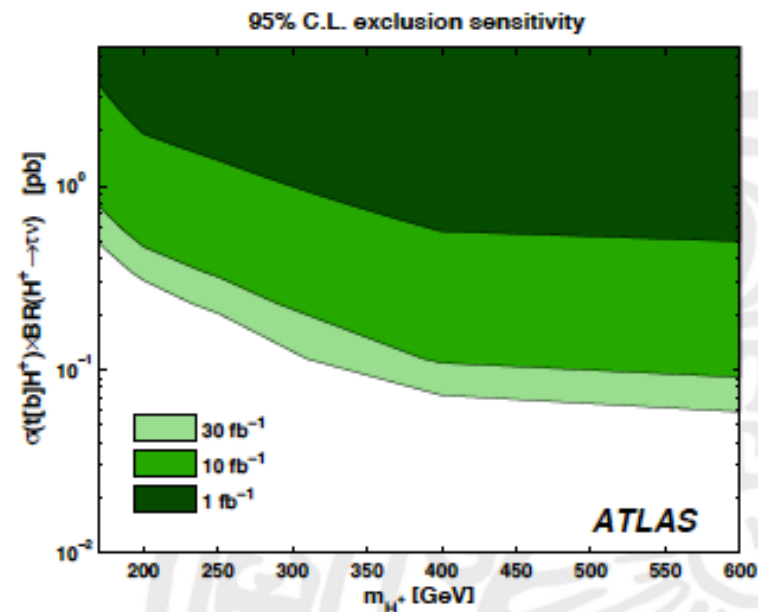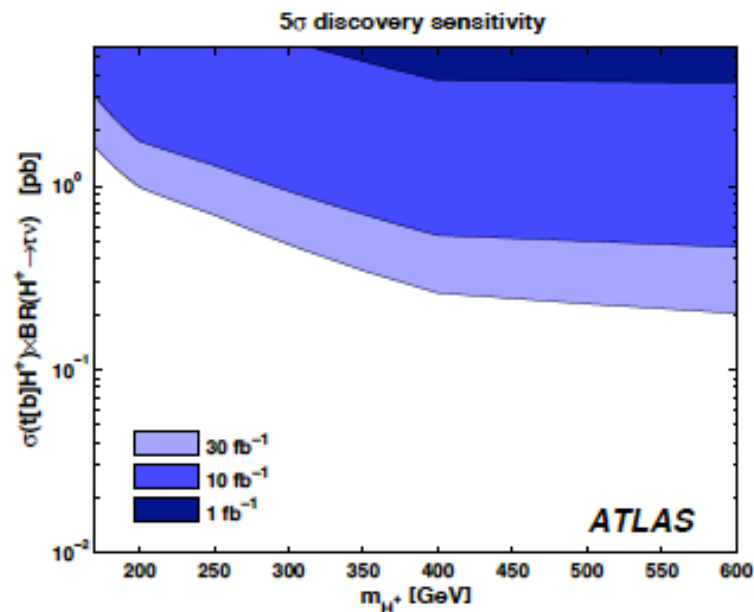
Model-independent contours, with systematic and statistical uncertainties.

LHC discovery potential for charged Higgs bosons

A. Ferrari

ATLAS / CMS Studies, $\sqrt{s}$ = 7 TeV

Two channels considered:

tt $\rightarrow$ bb W⁻H⁺ $\rightarrow$ bb lν τ_{lep}ν
tt $\rightarrow$ bb W⁻H⁺ $\rightarrow$ bb lν cs
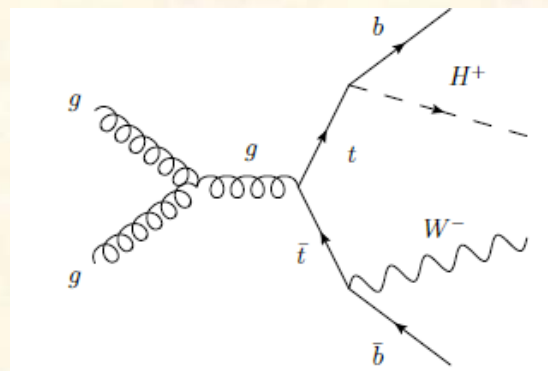
M. Klemetti
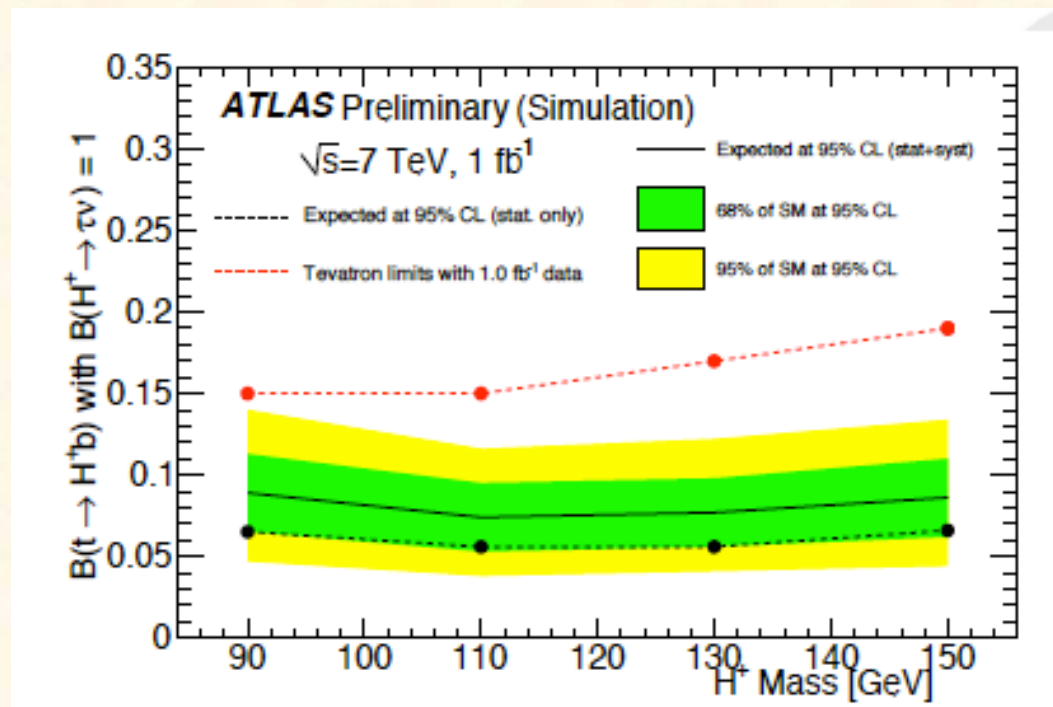
interesting approach to use kinematic fitting,
generalized transverse mass

Hadronic mass spectrum,
difficult to separate
→large improvements using kinematical fits

QCD backgrounds to be checked / addressed
with data

$H^+ \to c\bar{s}$: upper limits on $\mathcal{B}(t \to bH^+)$
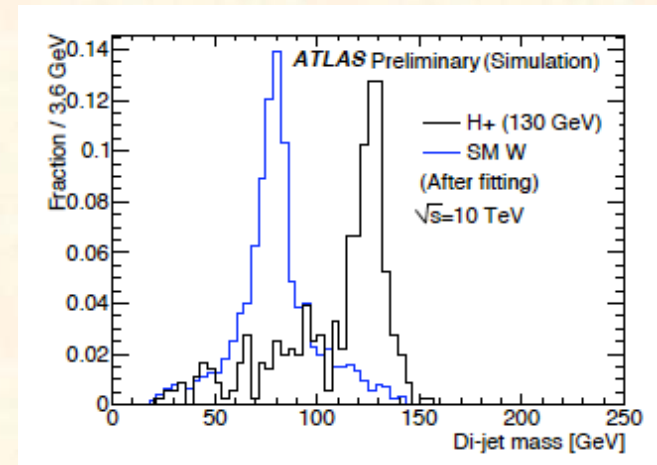
Better sensitivity expected
than at the Tevatron
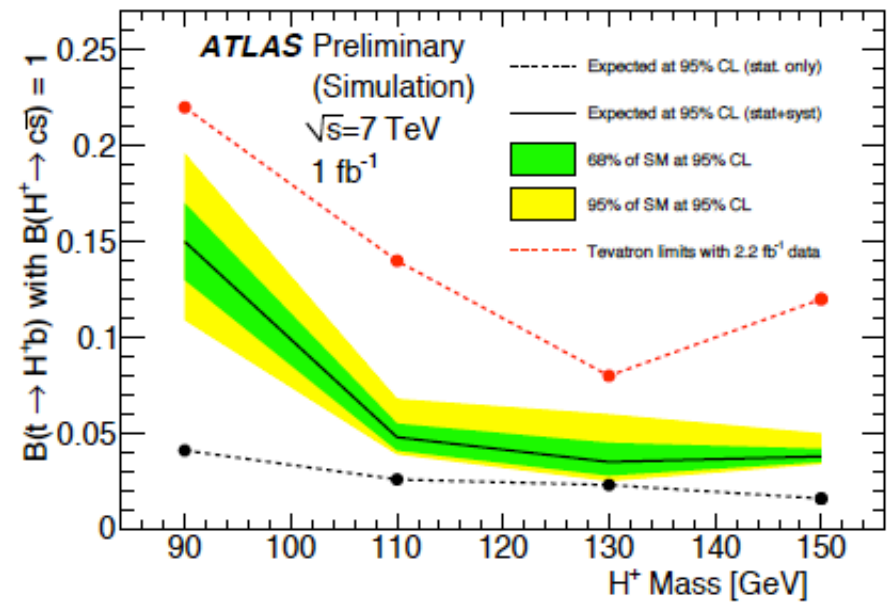
Systematic effects are imported, detailed studies presented by ATLAS and CMS

S. Gentile

$\sqrt{s}=7\ TeV$ $L_{int}=1fb^{-1}$ $\mathscr{B}(t \to bH^+)$

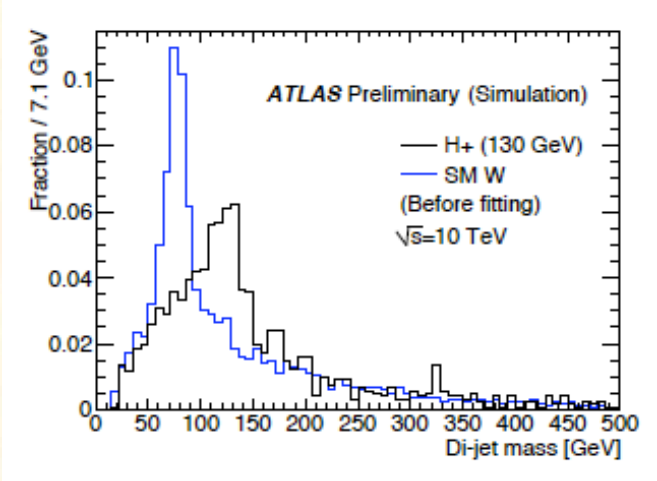| m_{H^+}	$H^+ \to \tau^+\nu$			$H^+ \to c\bar{s}$		
			at 95% CL (with systematics)			without systematics
(GeV)	Tevatron	ATLAS expected		Tevatron	ATLAS expected	
90	15%	9%	6.5%	22%	15%	4.0%
110	15%	7%	5.6%	15%	5%	2.5%
130	17%	8%	5.6%	8%	3.4%	2.3%
150	19%	9%	6.6%	13%	3.7%	1.5%

$\mathscr{B}(H^+ \to \tau^+\nu) = 1$ $\mathscr{B}(H^+ \to c\bar{s}) = 1$

- Systematic uncertainties may lead to a degradation of the limits by factors of 2-3

- However, data will help enormously to constrain some of these uncertainties

Systematic effects are imported, detailed studies presented by ATLAS and CMS

L. Wendland

Summary

- Cross-section uncertainties
  - ttbar cross-section — 16 %
  - W/Z + jets cross-sections — 100 % — estimate
  - QCD multi-jet cross-sections — 100 % — estimate
- Luminosity measurement — 11 % — EWK-10-004
- Underlying event — 10 % — QCD-10-010
- Electrons
  - reconstruction and identification efficiency — ~3 % — ICHEP, 198 nb^{-1}
  - fake rate — ~5 % — ICHEP, 78 nb^{-1}
- Muons
  - reconstruction and identification efficiency — ~3 % — EWK-10-002, 198 nb^{-1}
  - fake rate — negligible — MUO-10-002, 0.47 nb^{-1}
- Electromagnetic calorimeter energy scale — 0.9/2.2 % — EGM-10-003, 123 nb^{-1}
- Jet energy scale — 5-10 % — JME-10-003, 73 nb^{-1}
- Missing E_T — ~10 % — JME-10-004, 11.7 nb^{-1}
- tau-jets energy scale — n.a. — to be determined
- tau-jet reconstruction and identification efficiency — ~10 % — estimate
- jet→tau fake-rate — 20-40 % — PFT-10-004, 8.4 nb^{-1}
- b-tagging
  - b-tagging efficiency — 19 % — BTV-10-001, 8 nb^{-1}
  - b-mistag rate — 3-60 % — BTV-10-001, 12 nb^{-1}
- Work ongoing on background measurements from data

Where do we stand today ?

The important issues are:

1. Tau Identification

2. Z $\rightarrow$ $\tau\tau$ is an important milestone

3. b-tagging, missing E_T

4. Understanding of the backgrounds

   - W + jets
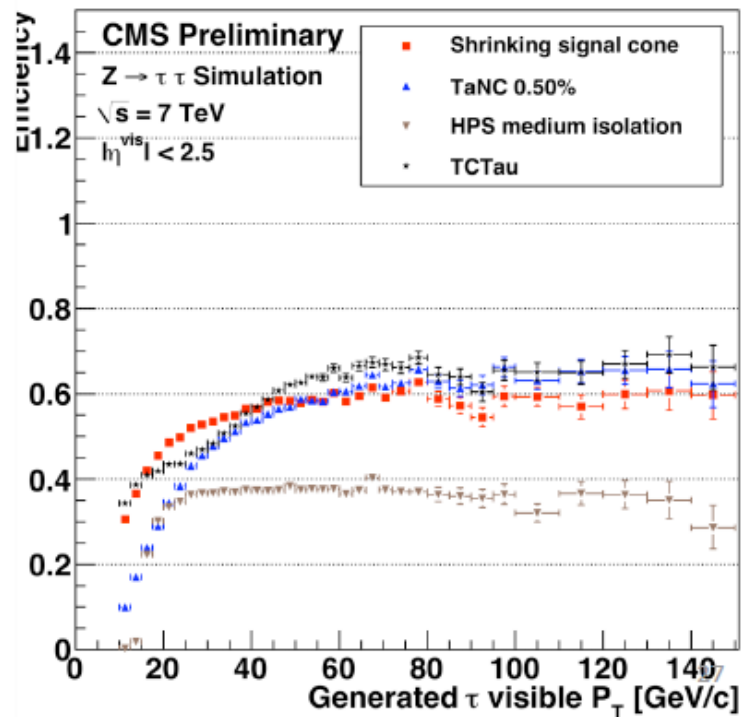   - tt
   - QCD

M. Kortelmainen
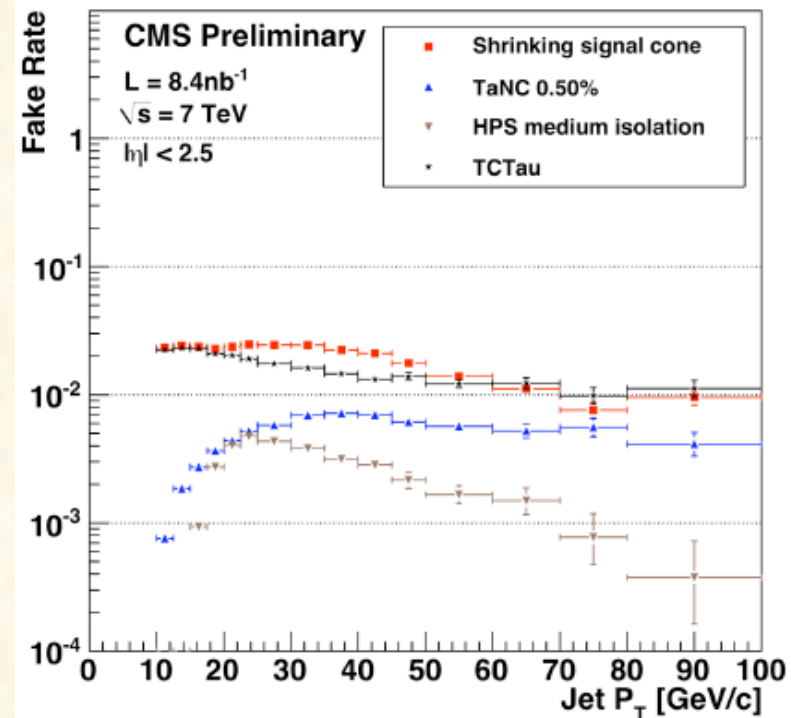
A. Attikis

F. Terrade

M. Flechl

Tau ID and fake rates (CMS)

A. Nikitenko

τ_{had} efficiency: Monte-Carlo
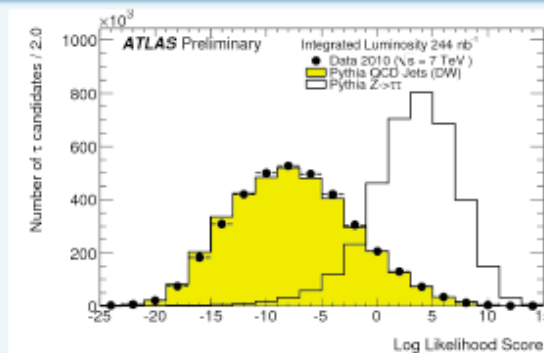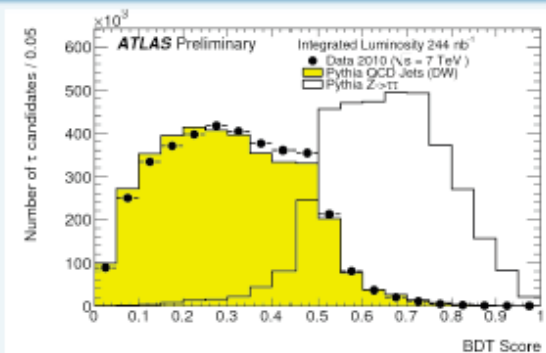

Jet->τ_{had} fake rate: data

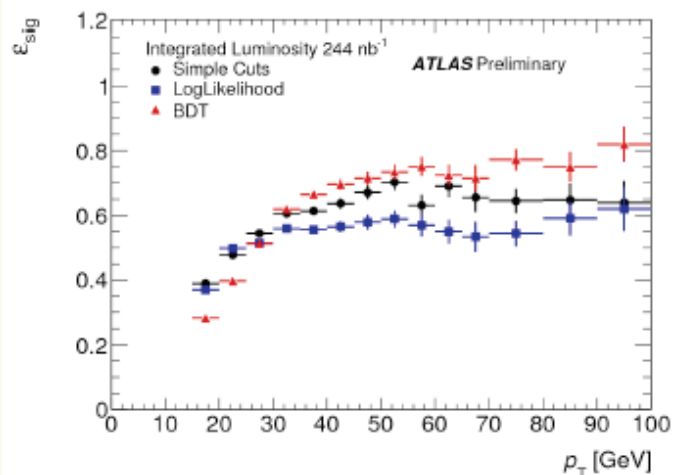# Tau ID and fake rates (ATLAS)

Y. Coadou

Discriminant output

- Boosted decision trees (BDT) use all seven variables

- Log likelihood (LL) excludes core energy fraction (correlations)

- Output well described by MC, quite discriminating

Signal efficiency ($Z \to \tau\tau$ MC)

Background efficiency (medium)
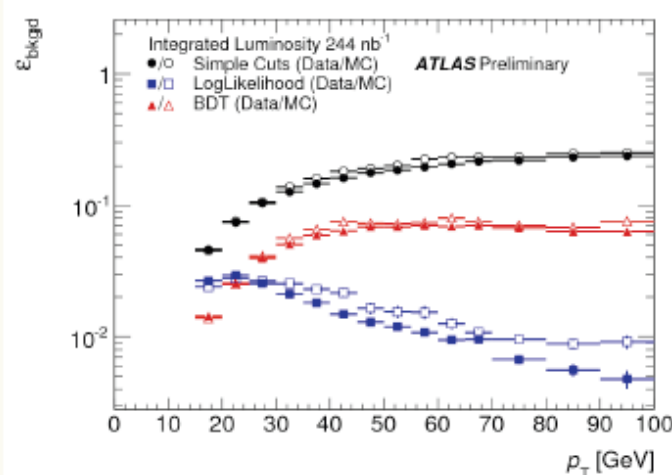
Performance of ATLAS and CMS comparable for the best methods (log likelihood, ...)

First $W \to \tau\nu$ candidate observed in ATLAS

- Hadronically decaying tau (1-prong), $p_T = 29$ GeV, $\not{E}_T = 39$ GeV, $\Delta\phi(\tau, \not{E}_T) = 3.1$, transverse mass $m_T = 68$ GeV

Z → ττ on the horizon
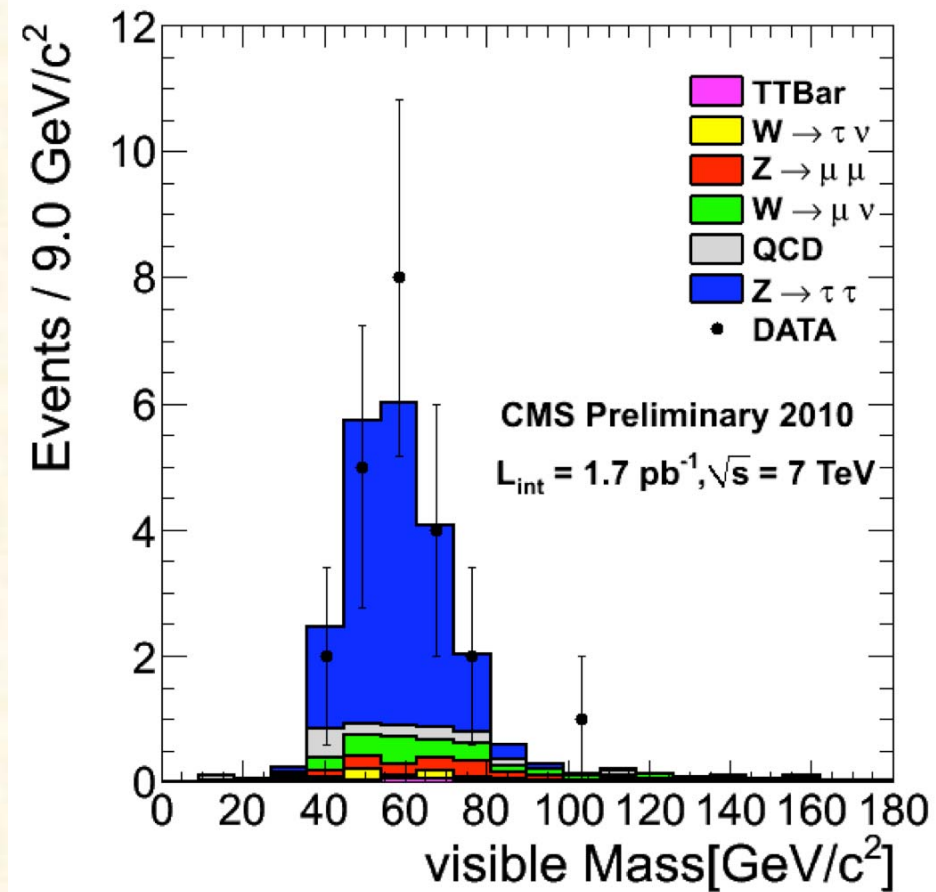
.... an important benchmark towards charged Higgs physics

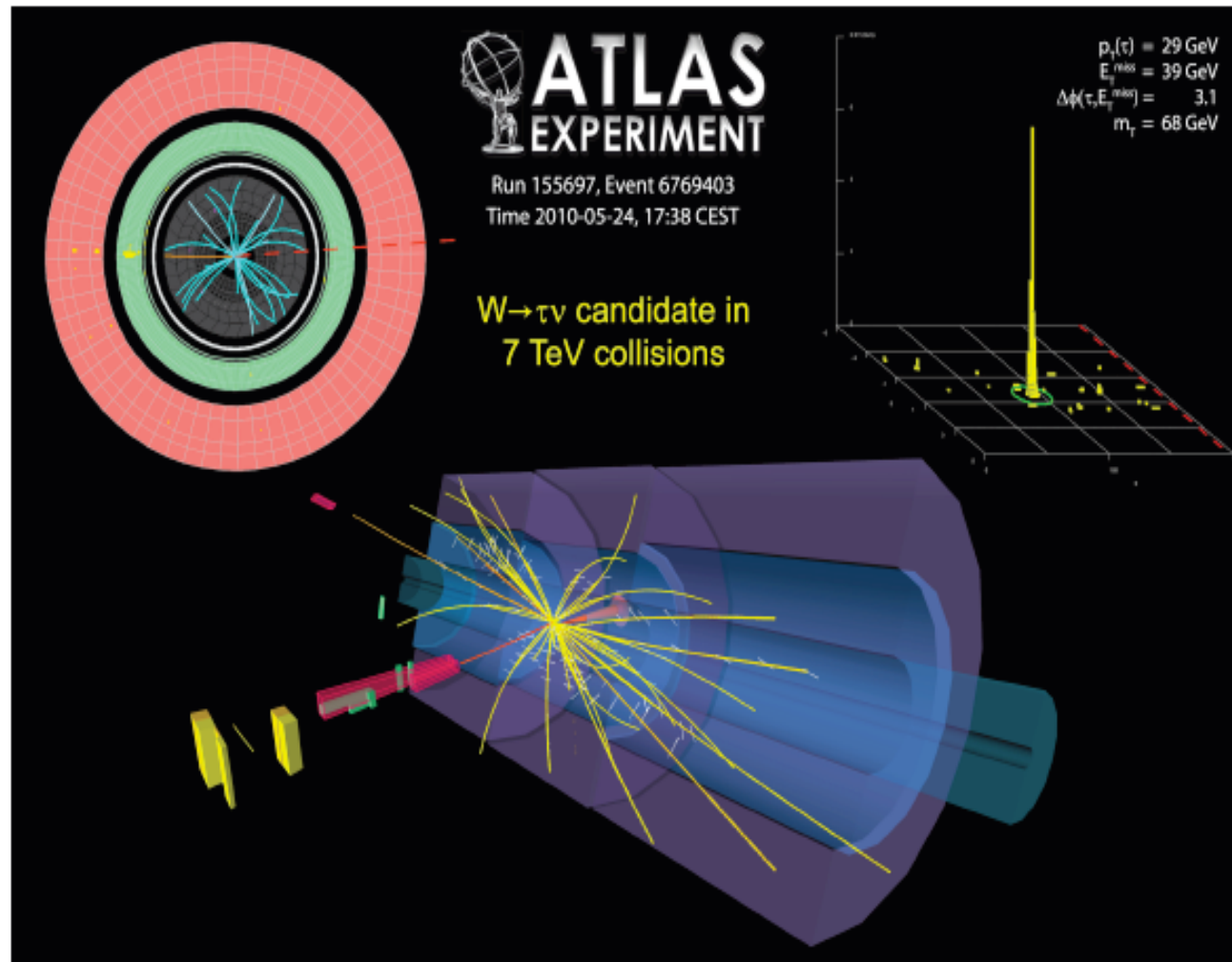# b-tagging

J. Komaragiri

- Very good agreement between data and Monte Carlo

- Good performance, given that we are at that early stage of data taking

- Efficiencies and mistag rates already estimated from data

QCD background

- Jets may "fake" hadronic tau decays
  - from `W+jets' and from `ttbar→l+jets'
- It is a large background
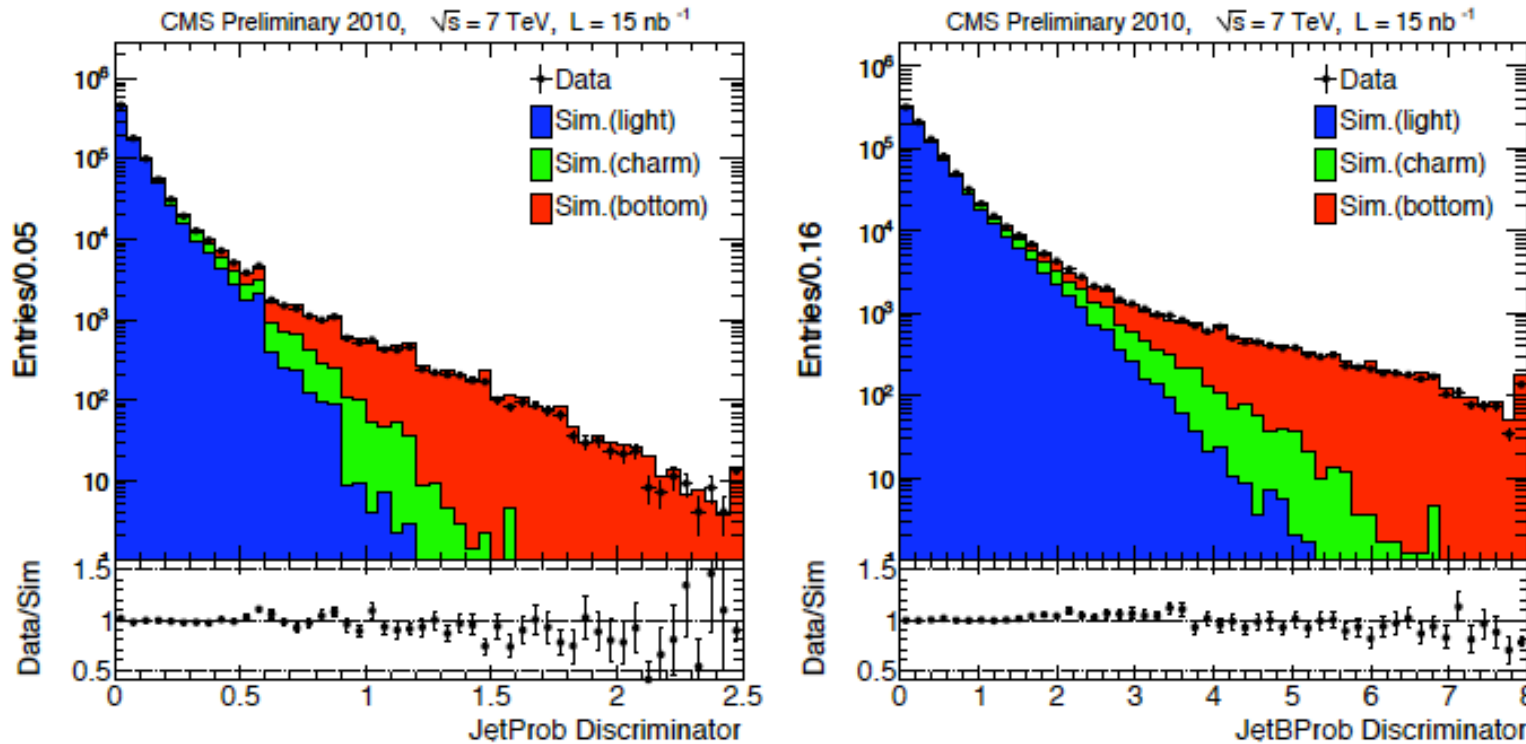- Estimate background from data
  - inclusive jet pT distribution
  - jet identified as a tau
  - estimate "fake" probability from ratio
- Apply to W+≥3 jet distribution
- Estimates within 10-15% of expectations

<u>Early data:</u>

- look at low/high pT tracks
- Tau ID/PF
- validate bkg studies (fake rates, etc)
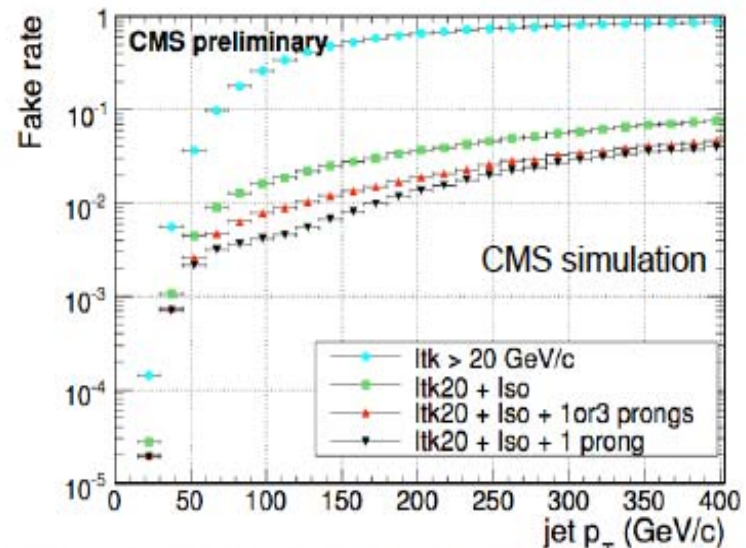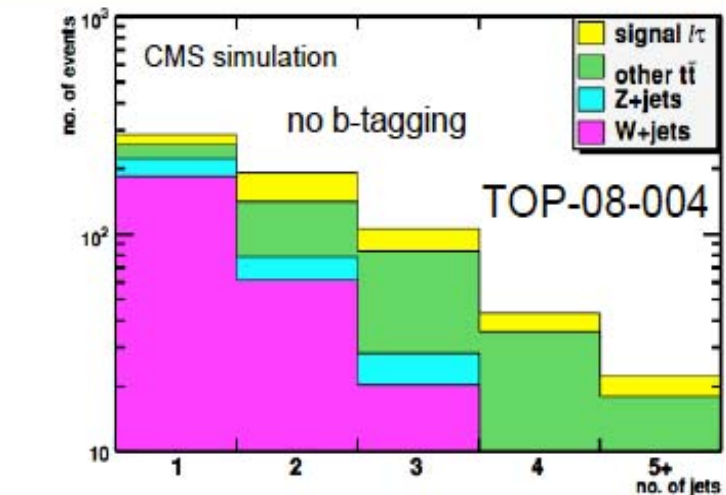
Summary on Charged Higgs potential in 2010/11

- Direct / indirect charged Higgs boson limits so far from Tevatron and B-factories

- LHC enters the game now...

- First data used to study the performance of the detectors
  Look very promising (both ATLAS and CMS)

- Search for low mass charged Higgs boson looks promising with present tools and detector performance

- Present studies indicate that existing limits on branching ratios from the Tevatron can be superseded

- ….however, still challenges ahead of us
  (understanding of the backgrounds, but also there, a lot of activity is going on…)

LHC vs. Tevatron

- Tevatron has reached sensitivity to SM Higgs bosons
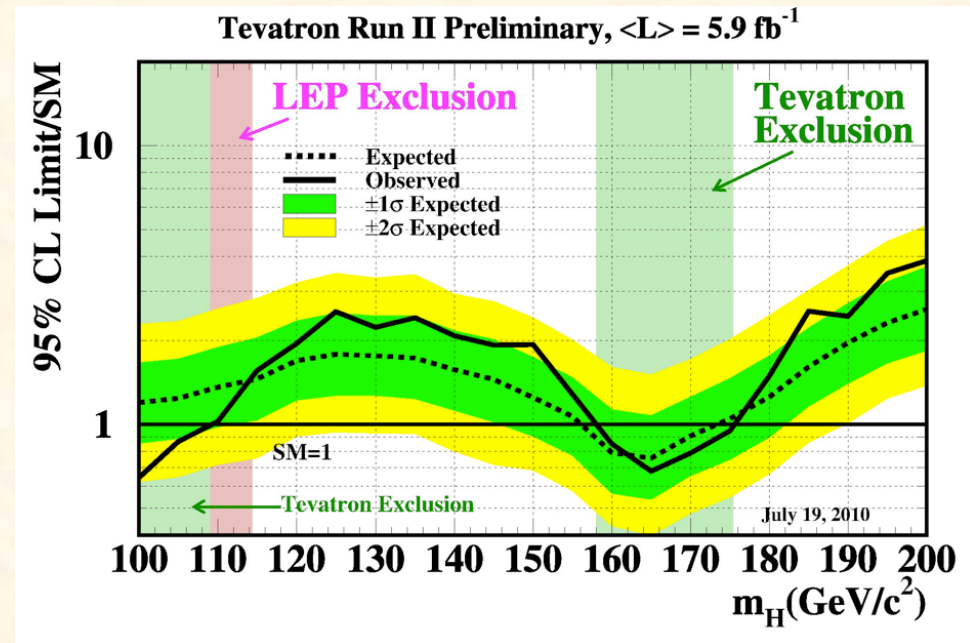
- Tevatron does / will add complementary information on the H → bb decay mode which is difficult –and not for the early days- at the LHC.

- However, present sensitivity studies in low mass region assume improvements on the analysis

- On Charged Higgs: so far only a small fraction of the data analyzed; Factor four in Branching ratio sensitivity...can be reached with 17 fb^{-1}

- LHC is very competitive ! already with 1 fb^{-1}
  → concentrate on the New LHC Data   (Monte Carlo scan times are over)
  ……

...and help theorists to find the right model

Conclusions (cont.)

Uppsala is a nice place to be, looking forward to forthcoming workshops

Possible Roadmap:

→ 2008:   work on tooling (tau, btags, methods to get efficiencies from first data)

→ 2010: first results from data ….

→ 2012: I hope that we know whether a Charged Higgs exists or not

regardless of the outcome: we could continue to get lectures on how to drink the "Uppsala Schnaps"

A big Thanks to the Organizers (Tord, Johan, ….) for the perfect organization