Experiment CDF and participation of Slovakia

Stanislav Tokár

Univerzita Komenského

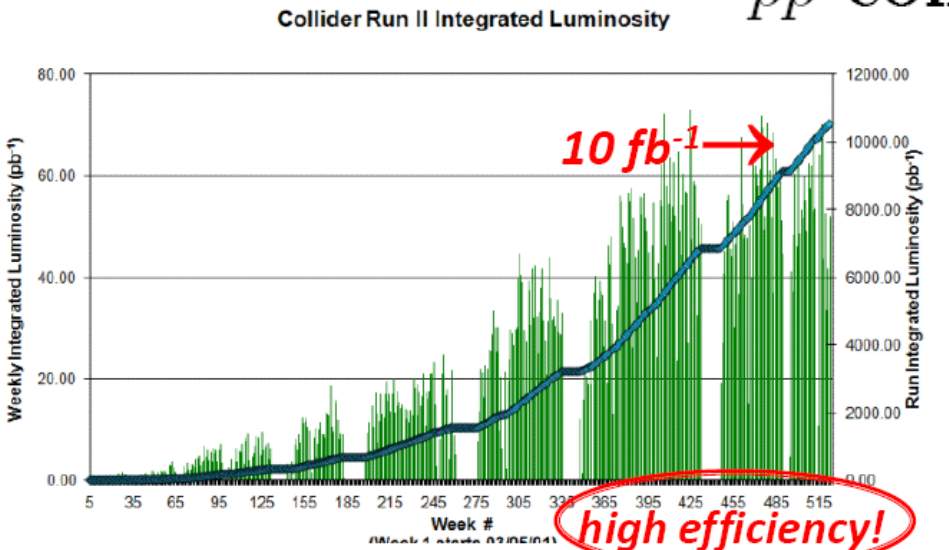
Fakulta matematiky, fyziky a informatiky

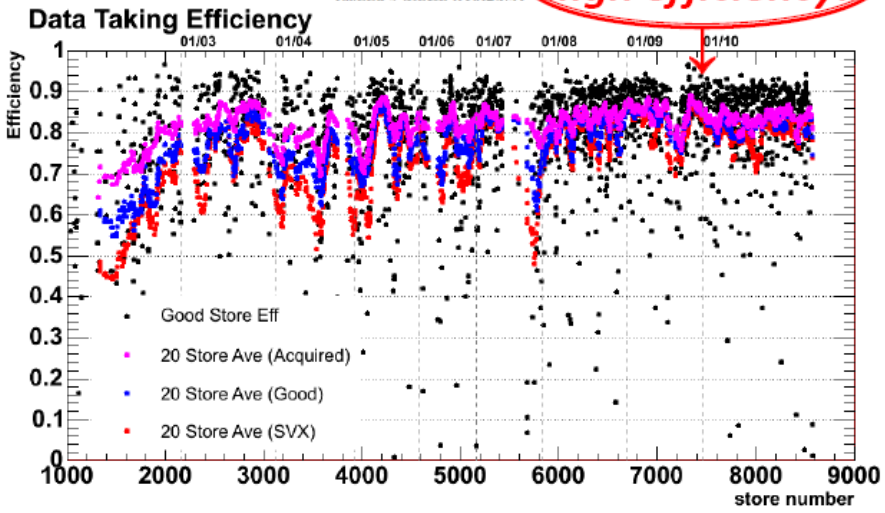
Katedra jadrovej fyziky a biofyziky

Bratislava

Tevatron at Fermilab

$p\bar{p}$ collisions at $\sqrt{s}$= 1.96 TeV





Tevatron performing very well:

10.3 fb^{-1} delivered per experiment

50 pb^{-1} per week

experiment efficiency ~90%

peak: 3.5 x 10^{32} cm^{-2}s^{-1}

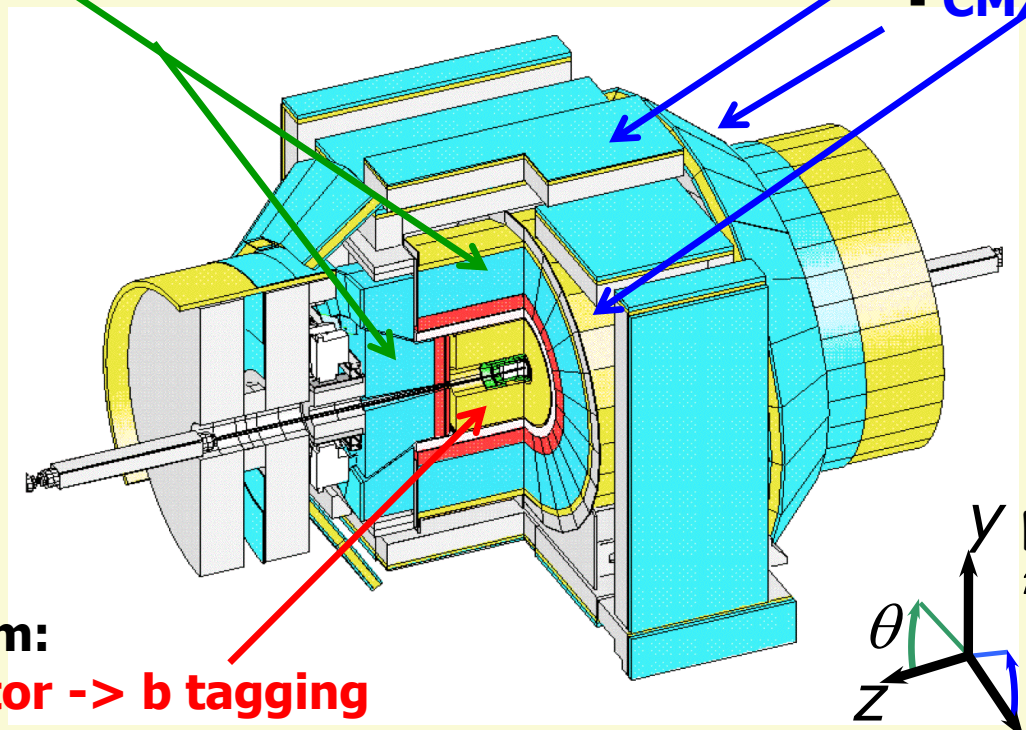
expecting 12fb^{-1} by end of FY11

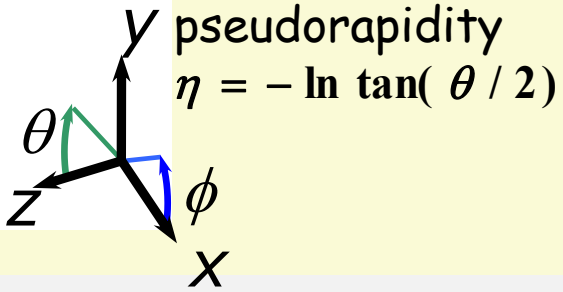
CDF detektor/Tevatron

Muon system

- **CMP ; CMU $|\eta|<0.6$**
- **CMX $0.6<|\eta|<1.0$**

calorimeters
Up to $|\eta|<3.6$





Tracking system:

- **Silicon detector -> b tagging**
- **COT : central outer tracker**

Eff. for charged particle tracks:

- **~100% for $|\eta|<1.0$**
- **~40% for $|\eta| \approx 2.0$**

Excellent lepton ID:
~80% eff. for central electrons
~90% eff. for high p_T muons

Slovakia group activity at Tevatron

2006: Joint team of Kosice and Bratislava's physicists joined to CDF experiment

1993: first contact of Kosice group with CDF (J. Antos via Sinica Univ. Taiwan)

2001: first contact of Bratislava group with CDF (S.Tokar via JINR Dubna)

Kosice team: J. Antos, R. Lysak,M., Zvada M.

Bratislava team: S.Tokar, P. Bartos, P.Bednar, A. Brisuda, L. Lovas

PHD thesis:

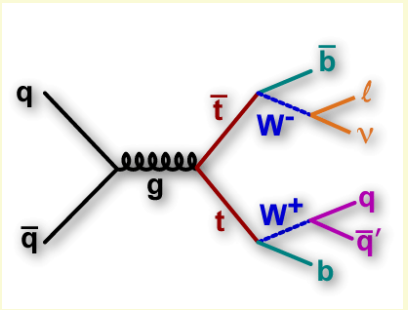
Defended: R. Lysak(2007), P. Bednar(2008), L. Lovas (2009)

Submitted: P. Bartos (April 2011)

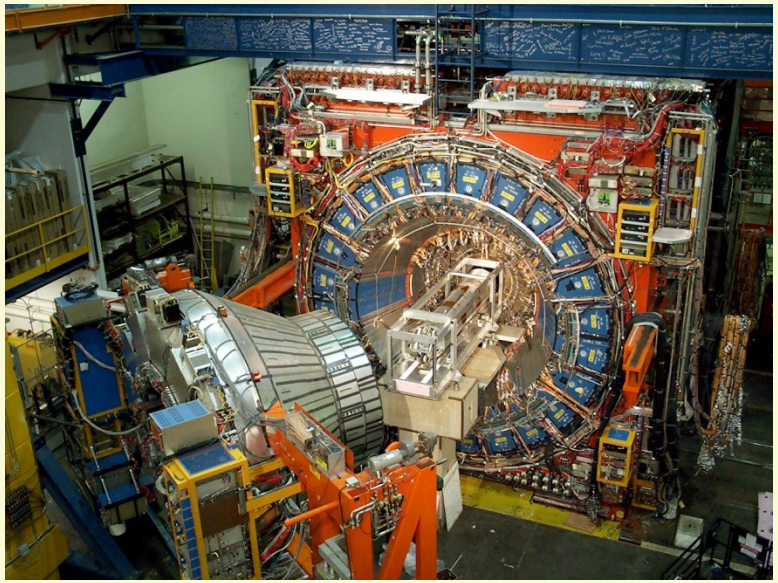
Master thesis: J. Novak, R.Lysak, L. Lovas

Activities of Slovak teams

- Top quark properties:
  - ✓Forward –backward asymmetry in ttbar productio
  - ✓W boson helicity
  - ✓top quark charge charge
  - ✓ttbar spin correlations
  - ✓top quark mass in Dilepton channel (2 analysis)



- Higgs boson search:
  - ✓ H-> WW
- Soft QCD
  - ✓Bose Einstein correlations
- service work:
  - ✓ CDF Offline management
  - ✓Muon efficiency calculation
  - ✓ FNAL GRID management
  - ✓Jet energy scale calculations
  - ✓ CDF Computing on GRID FARM in IEP

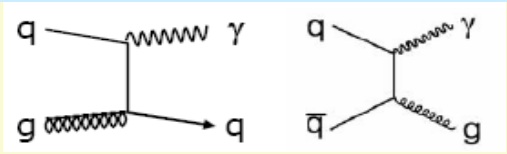


Jet energy scale via gamma + jets events

γ +jet events are used for jet calibration

$$p_T^{parton} = (p_T^{jet} \times C_\eta - C_{MI}) \times C_{Abs} - C_{UE} + C_{OOC}$$

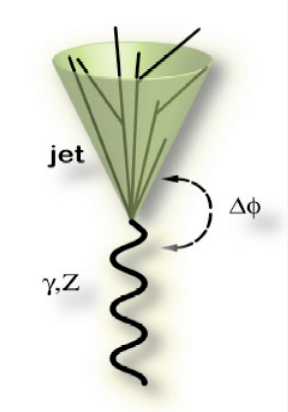
Excellent resolution of EM calorimeter used



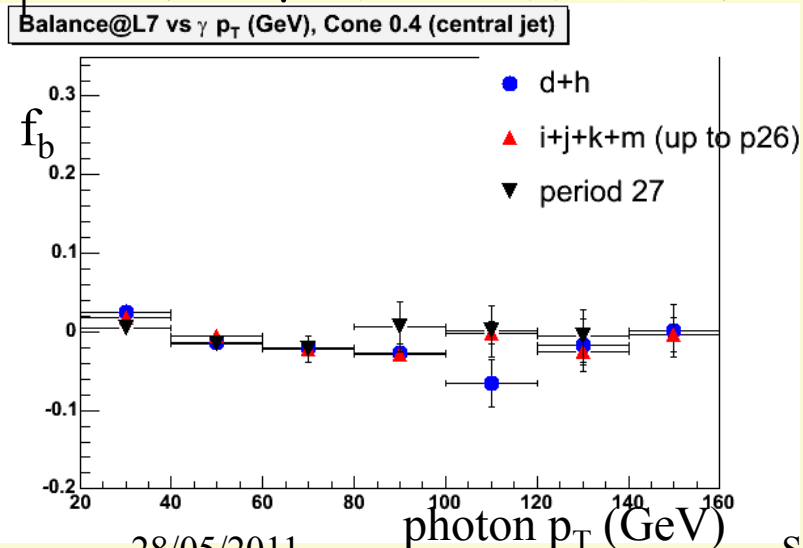
- ✓ Photon with: $p_T^\gamma > 27\,GeV\,,\ |\eta| < 0.9$
- ✓ angle photon - jet : $\Delta\varphi(\gamma, jet) > 3$
- ✓ 2nd jet $p_T^{jet2} < 3\,GeV$

p_T balance

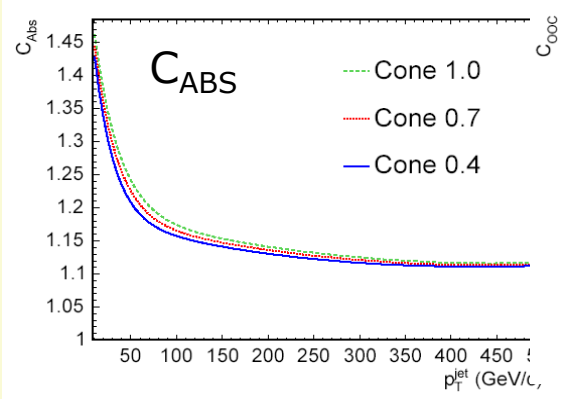
$$f_b = \frac{p_T^{jet}}{p_T^\gamma} - 1$$

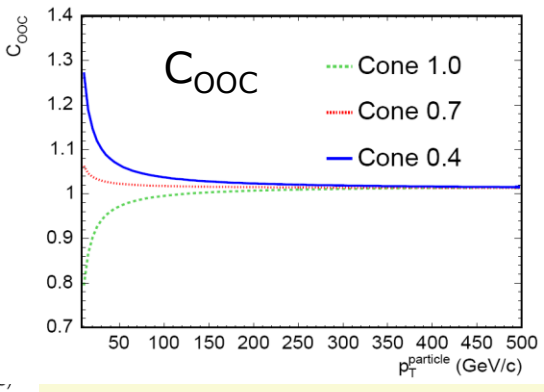


p_T balance after all corrections



Absolute and out-of-cone calibrations

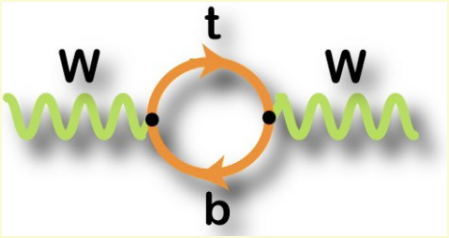




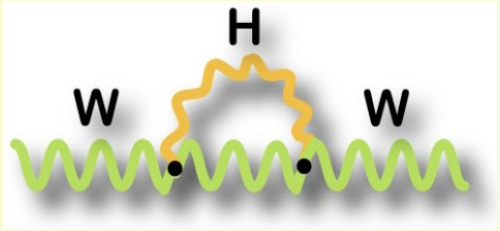
Top Quark Mass in Dilepton Channel

Participation in 2 analyses

- ✓ Top quark is the heaviest particle of the SM
- ✓ Yukawa coupling is ~1 ⇒ special role in EW symmetry breaking?
- ✓Can be used to infer Higgs mass via radiative corrections:



$$\Delta M_W \propto M_{top}^2$$



$$\Delta M_W \propto \ln M_H$$

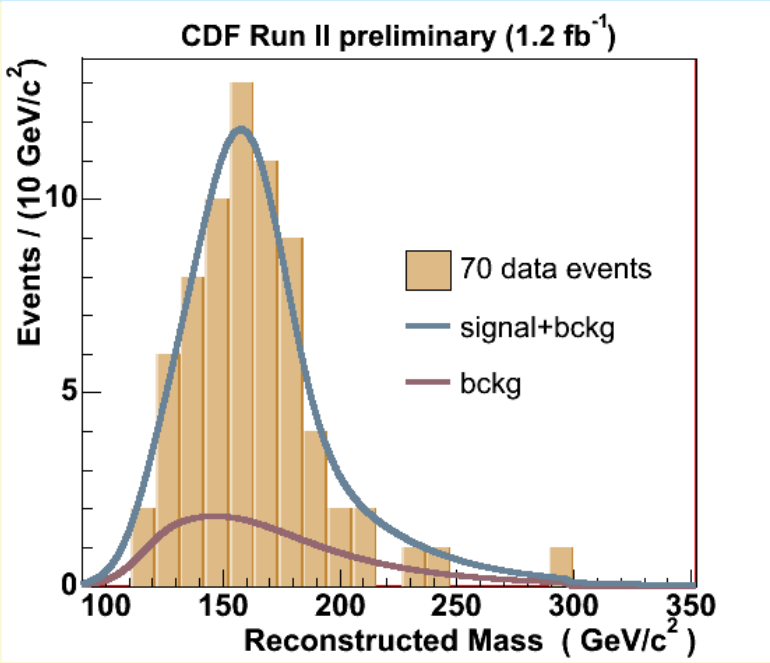
- ✓Dilepton channel: independent measurement of top quark mass with low background (the cleanest channel)

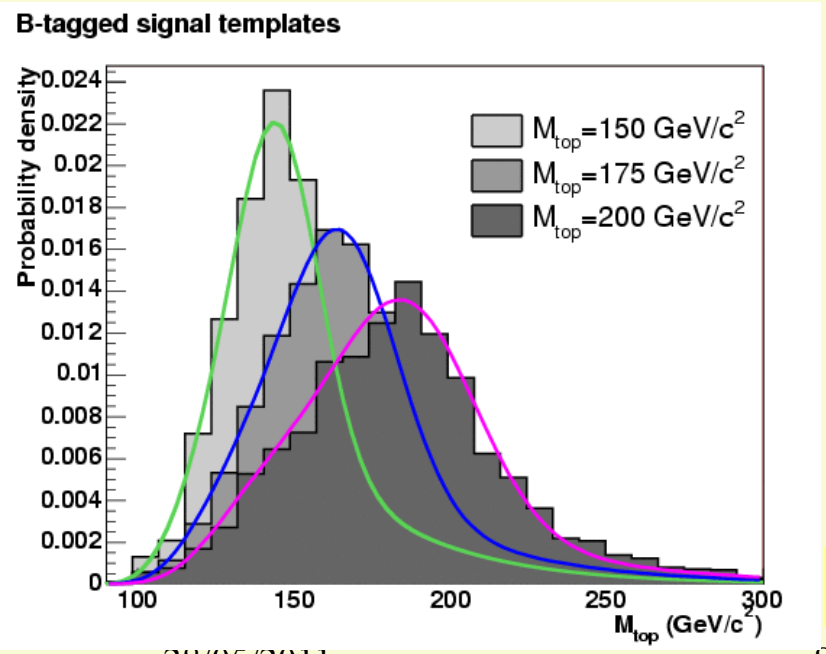
Top mass in DIL channel: templates

✓ Top quark mass measured in dilepton channel using a template method.

✓ Due to 2 neutrinos M_{top} reconstruction from dilepton events is underconstrained $\Rightarrow$ $p_z^{t\bar{t}}$ fixed to solve event kinematics

✓The sample is separated into b-tagged and non-tagged samples.





For each event M_{top}^{r} reconstructed assum.:

$$M_{W^{\pm}} = 80.4\,\mathrm{GeV/c^2},\ M_t = M_{\bar{t}} \text{ and } p_z^t + p_z^{\bar{t}}$$

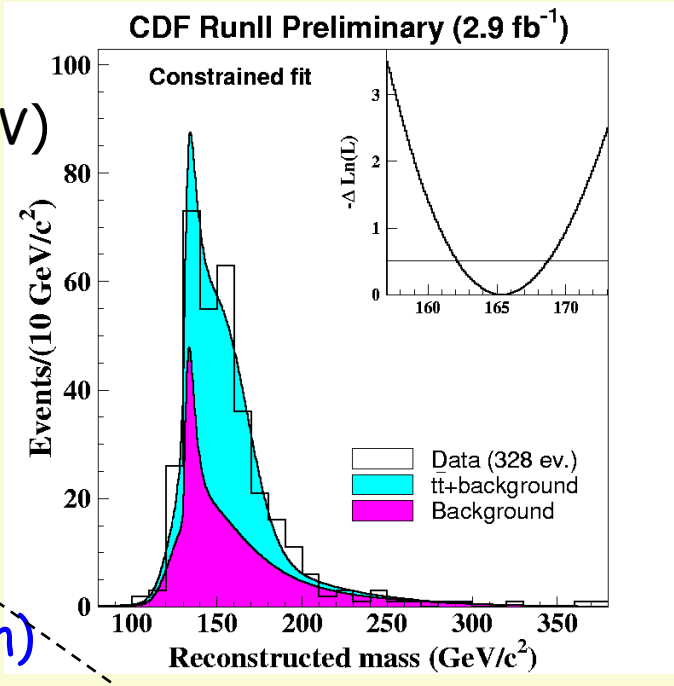
$$M_{top} = 169.7^{+5.2}_{-4.9}\ (\mathrm{stat.})\ \pm 3.1\ (\mathrm{syst.})\ \mathrm{GeV/c^2}$$

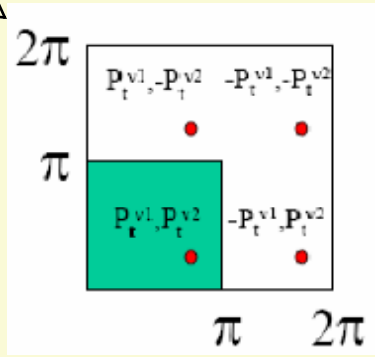
using a cross-section constraint

$$M_{top} = 170.7^{+4.2}_{-3.9}\ (\mathrm{stat.})\ \pm 2.6\ (\mathrm{syst.})\ \pm 2.4\,(\mathrm{th.})\ \mathrm{GeV/c^2}$$

Top Quark mass in DiL: neutrino weighting

- Tight lepton and isolated track sample
  - ✓ Tight lepton (E_T>20 GeV), track lepton (p_T>20 GeV)
  - ✓ 2 jets (E_T > 20GeV), MET > 20 GeV
- PHI method for constraining the kinematics
  - ✓ Assume φ_1, φ_2 of the neutrinos as known
  - ✓ A 144 points grid is created in (0,π)x(0,π)
  - ✓ 2.9 fb^{-1} of data used for top mass
- For each (φ_1, φ_2) $M^{reco}_{\varphi_1\varphi_2}$ is reconstructed (χ^2 min)
- Weighted average of the 144 masses is performed
  - ✓ Weights depend on minimized χ^2
  - ✓ 1 reconstructed top mass per event





Fitted top mass from 328 data events (2.9 fb^{-1}):

$$M_{top} = 165.4^{+3.4}_{-3.2}\ (\text{stat.}) \pm 3.1\ (\text{syst.})\ \text{GeV}/c^2$$

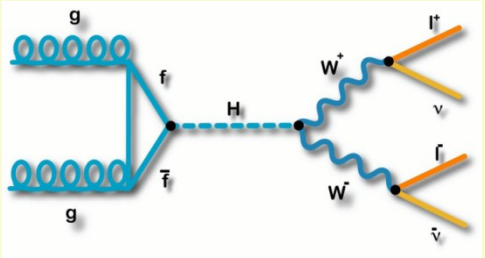
SM Higgs boson search

High mass search

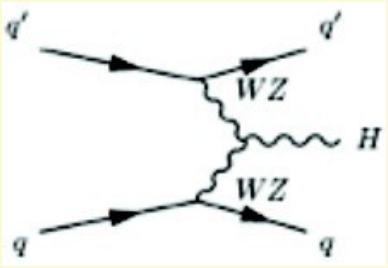
Higgs boson production and decay

H boson production:

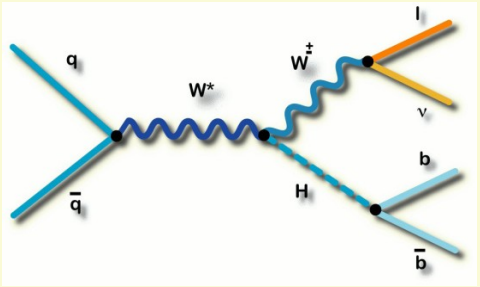
✓ Gluon fusion

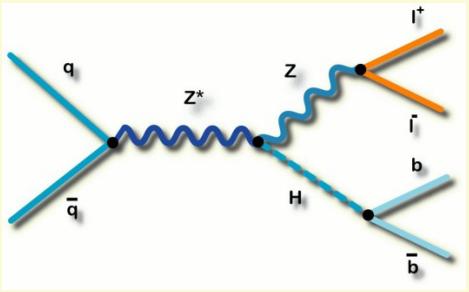


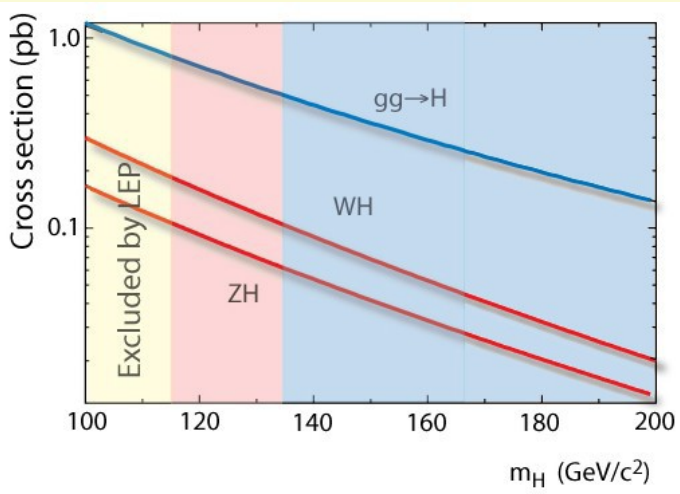
✓ Vector boson fusion

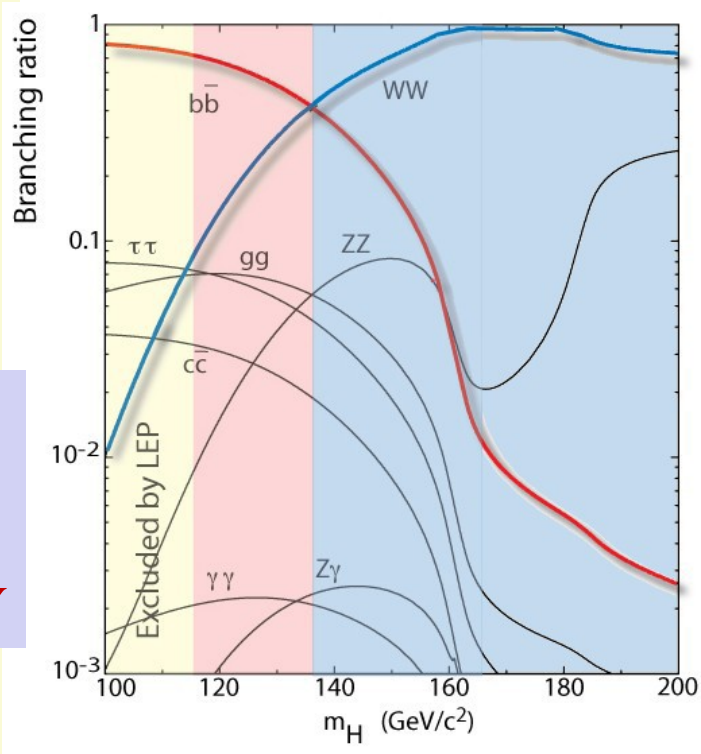


✓ Associated production









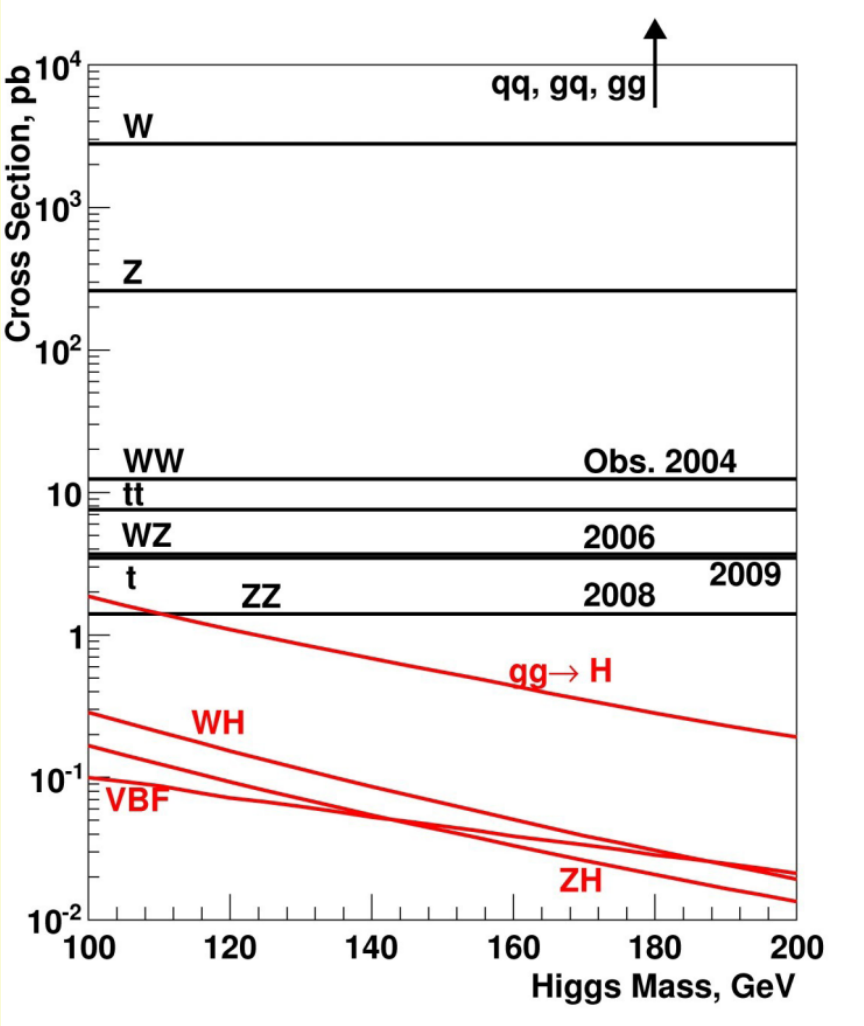
Low H mass

WH→lνbb *H→γγ*
ZH→ll(νν)bb *ttH→ttbb*
VH/VBF→bbjj
H/VH/VBF→ττ+jets

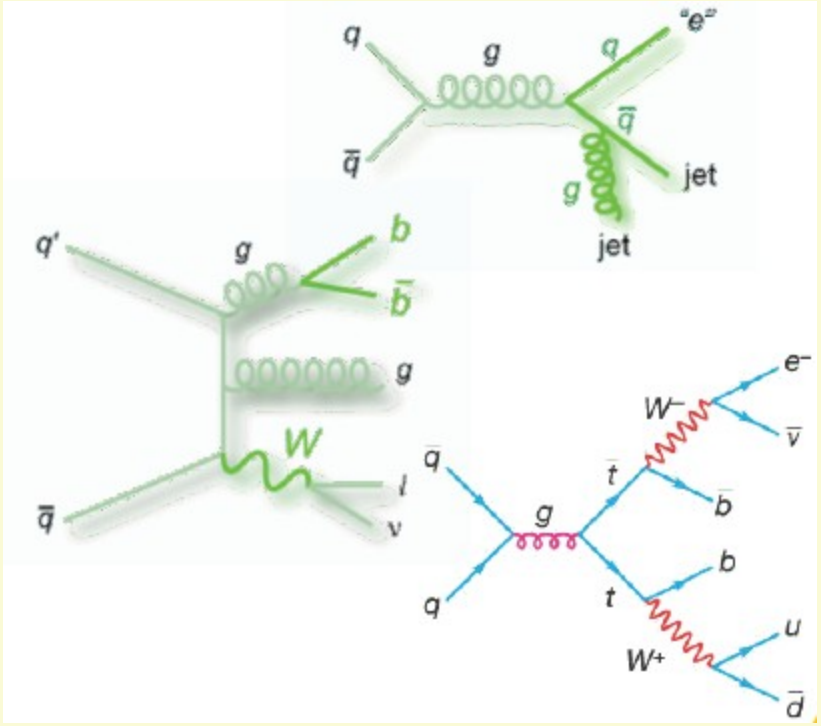
High H mass

$H \rightarrow WW \rightarrow l\nu l\nu$
$\rightarrow l\nu\tau_{had}\nu$
$\rightarrow l\nu jj$
$WH, ZH \rightarrow WWW, ZWW$

Higgs boson: background



Higgs boson: a small signal in a sea of background:
QCD, W+jets, di-bosons, tt-bar, single top



Tevatron SM Higgs limits-high mass

Candidate events $H \rightarrow WW \rightarrow l\nu l\nu, \rightarrow l\nu\tau_{had}\nu, \rightarrow l\nu jj$

Selection for $l\nu l\nu$ final states:

- ✓2 opposite-sign leptons: E_T > 20 GeV (p_T > 20 GeV/c) for electrons (muons)
- ✓ Large missing E_T: $\not{E}_T > 25\,GeV$ (reduced to $\not{E}_T > 15\,GeV$ for eμ-pairs)
- ✓ dilepton invariant mass: $M_{ll} > 16\ GeV/c^2$
- ✓Individually considered states with: no jets, 1 jet, two jet and more jets

Expected background for 1 jet case and signal for m_H = 165 GeV/c^2

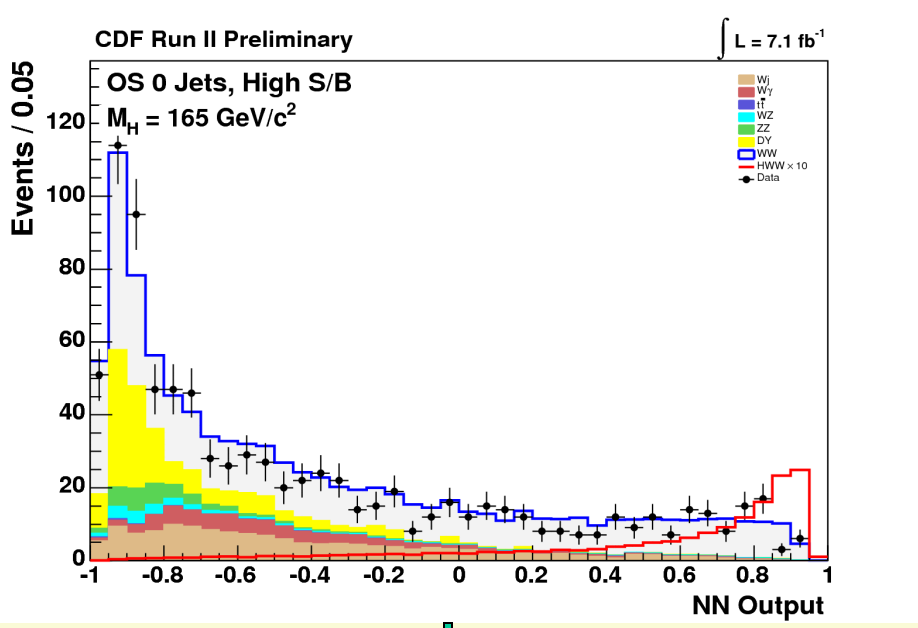
CDF Run II Preliminary $\int \mathcal{L} = 7.1\ \mathrm{fb}^{-1}$			
$M_H = 165\ \mathrm{GeV}/c^2$			
$t\bar{t}$	68	±	14
DY	264	±	59
WW	181	±	23
WZ	30.1	±	4.2
ZZ	12.3	±	1.8
W+jets	94	±	24
$W\gamma$	27.5	±	4.7
Total Background	676	±	84
$gg \rightarrow H$	9.7	±	3.0
WH	1.34	±	0.21
ZH	0.521	±	0.079
VBF	0.88	±	0.15
Total Signal	12.4	±	3.1
Data	637		

AllSB-1JOS

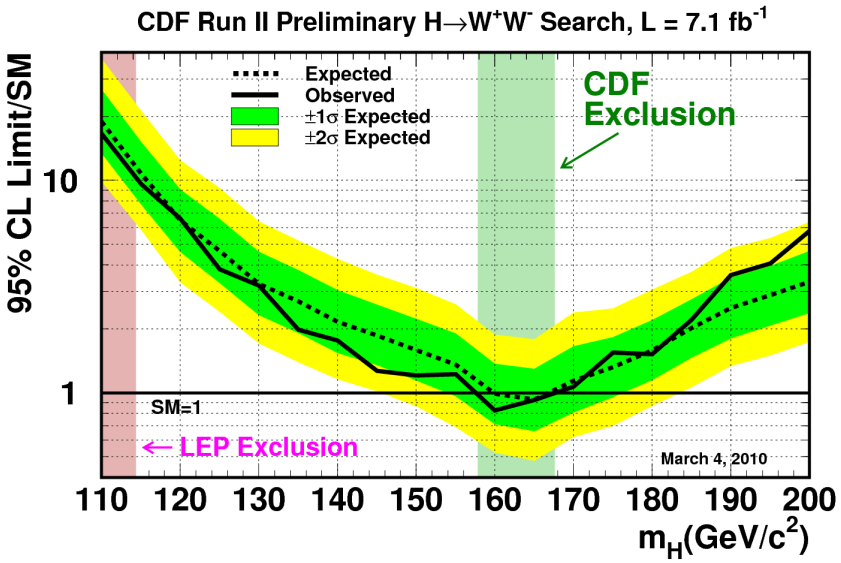
Tevatron SM Higgs limits-high mass

Neural network is trained for

- ✓ weighted combination of S and B
- ✓ 19 Higgs mass points treated
- ✓ 0-jet analysis : 9 input variables



No excess above background



CDF (7.1 fb^{-1}) exclusion:
expected: 159 – 168 GeV
observed: 158 – 168 GeV

Top Quark Charge

Is the top quark really a SM particle?

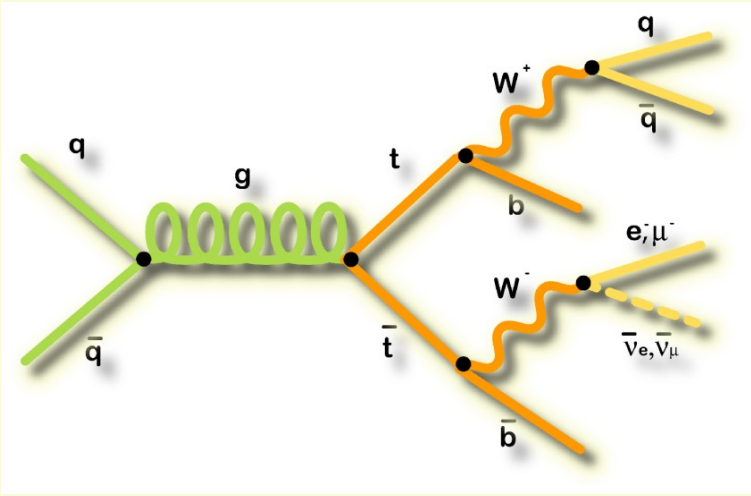
Top quark charge determination

Top quark charge can:

- ✓ confirm SM theory (Q_{top} = 2/3)
- ✓ find 4th generation quark (Q_{exo} = -4/3)

3 steps:

- ✓ charge of W boson via leptonic decay
- ✓ pairing of b-jet + W using kinematic fitter
- ✓ flavor of b-jet using b-jet charge



SM: $t \to W^+ b$, XM: [illegible]

Expectations for L=5.6fb^{-1}

N+ ≡ # of SM like pairs N- ≡ # of XM like pairs

Lepton b-jet pair:

- ✓ SM-like: $Q_{bjet} \times Q(l) < 0$
- ✓ XM-like: $Q_{bjet} \times Q(l) > 0$

$$Q_{bjet} = \frac{\sum_i^N q_i |\vec{j} \cdot \vec{p}_i|}{\sum_i^N |\vec{j} \cdot \vec{p}_i|}$$

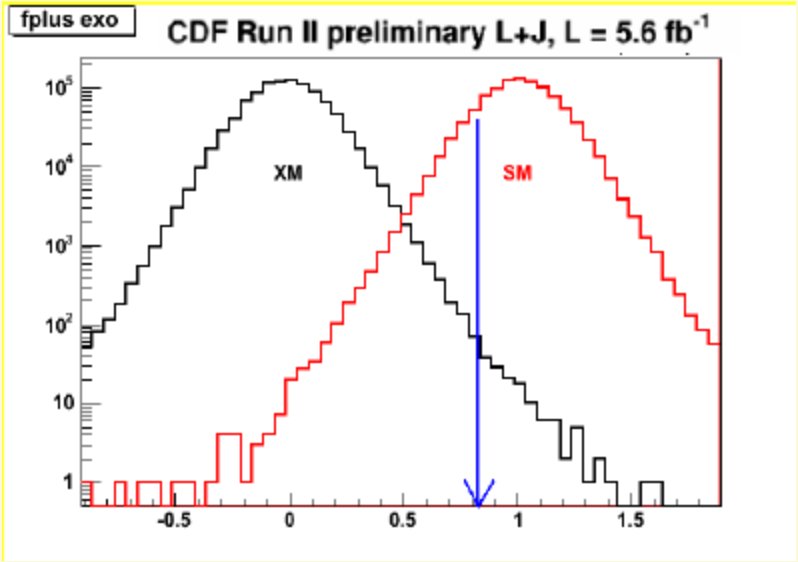
background	"measured" purity	used purity	N+ (pairs)	N- (pairs)
L+J MII4U (5.6 fb-1)				
W+HF	0.48 ± 0.01	0.5 ± 0.0	9.73 ± 3,21	9.73 ± 3.21
QCD fakes	0.48 ± 0.06	-	2.57 ± 2.33	2.78 ± 2.52
Diboson	0.50 ± 0.03	0.5 ± 0.0	0.98 ± 0.17	0.98 ± 0.17
Mistag	0.56 ± 0.04	0.5 ± 0.0	1.39 ± 0.41	1.39 ± 0.41
Singletop	0.51 ± 0.01	-	2.25 ± 0.28	2.15 ± 0.27
Total	0.498 ± 0.010	-	16.9 ± 4.0	17.0 ± 4.1
Signal	0.562 ± 0.004 ± 0.011	-	393.5 ± 65.6	306.1 ± 51.3

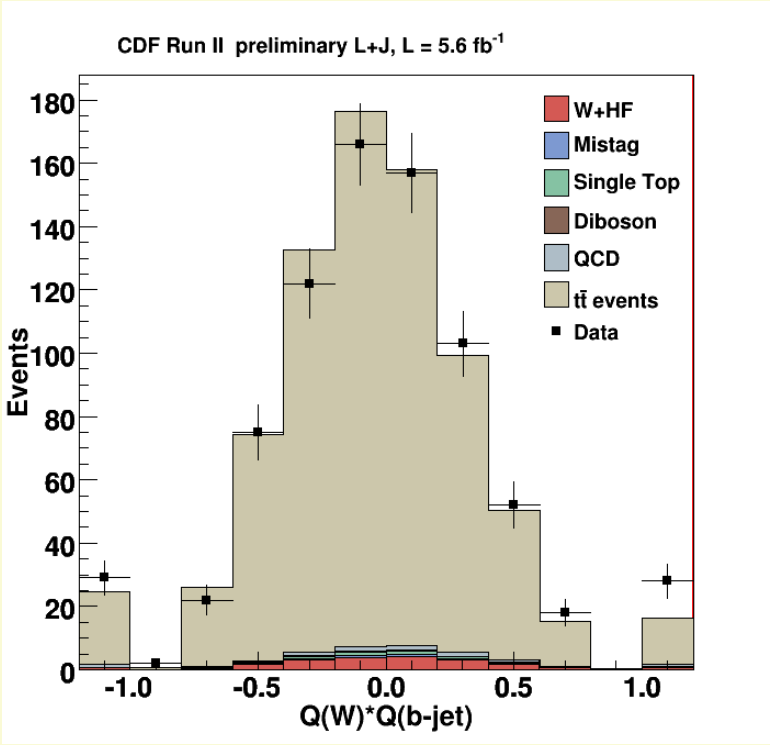
Top quark charge determination

- ✓Data of L=5.6fb^{-1}, analysed
- ✓Lepton + jets with 2 btags
- ✓ f_+ ≡fraction of signal SM pairs

lb pairs	SM	XM
Expected from MC	394 ± 66	306 ± 51
Observed in data	416	358

Observed f_+ compared to MC trials for SM and XM





P-values: P_{SM} = 13.4%, P_{XM}=0.014%
Bayes factor: 2ln(BF) = 19.6

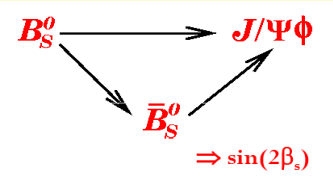
Strong preference for SM

Conclusions

- Slovak physicists have participated in many CDF analyses and made a significant contribution:
  - ✓ Top quark properties
  - ✓ Higgs search
  - ✓ Soft QCD
  - ✓ Important service works
- It was and still is an excellent school for young scientists
- A very good preparation for LHC physics
- Not mentioned: our PhD student in postdoc positions outside of Slovakia (M. Kreps, Karlsruhe, B-physics at CDF)

CP Violation in $B_s \rightarrow J/\psi\phi$

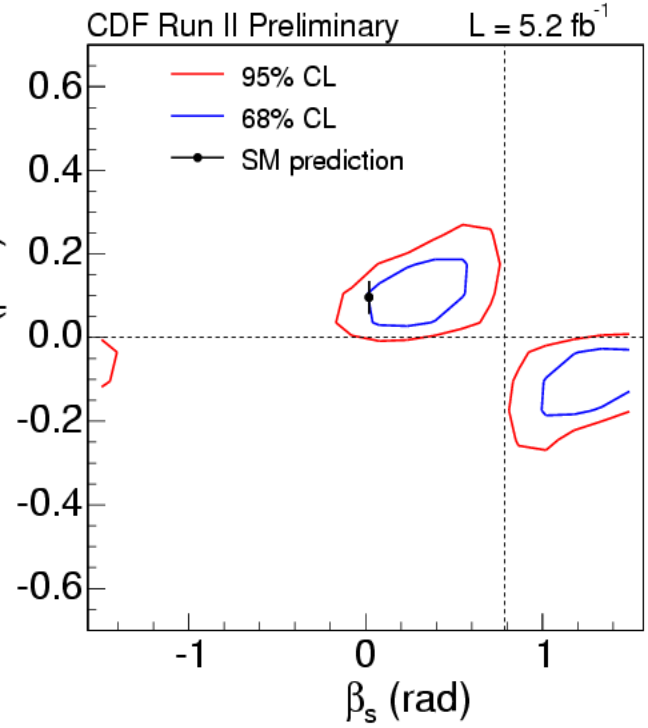
- ✓ CP violation in $B_s \rightarrow J/\psi\phi$ is important probe for new physics in B_s mixing

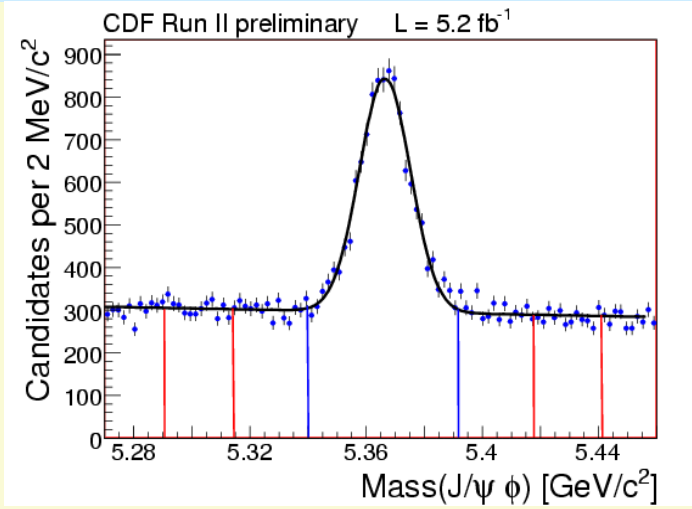


$$\phi_s = \arg\left(-M_{12}/\Gamma_{12}\right), \quad \mathrm{SM}: \phi_s = 4\cdot 10^{-3}$$

$$\Delta\Gamma = \Gamma_L - \Gamma_H = 2\left|\Gamma_{12}\right|\cos\phi_s$$

- ✓ In SM CPV in mixing is tiny ($\mathrm{Im}V_{ts} \approx 0$)





$B_0^s \rightarrow J/\psi\,\phi$ final state: a mixture of CP-even and CP-odd states – distinguished using decay product angular distribution

$$\beta_s^{SM} = \arg\left(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*\right) \approx 0.02$$

- ✓ About 6500 signal events
- ✓ Consistency with SM: 44%
- ✓ Large contribution from new physics cannot be excluded

Thank You !