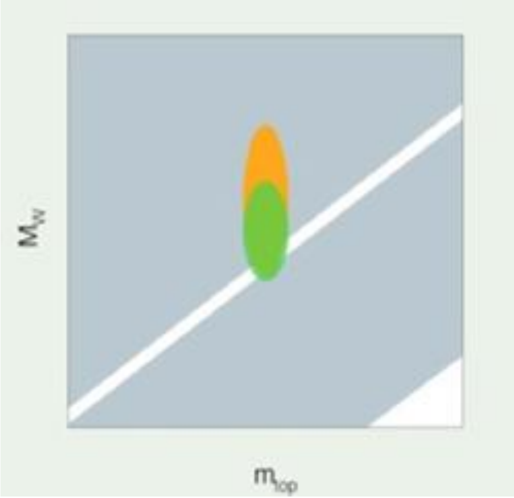
Measurement of the Mass of the W boson at DØ

- Motivation for the precise W mass measurement
- Signatures, Observables, Measurement strategy
- Data sample
- Electron Energy Response Model
- Hadron Recoil Model
- Measurement Results, Prospects
- Summary



T. Kurča on behalf of DØ collaboration

IPNL,Université Lyon 1, CNRS/IN2P3

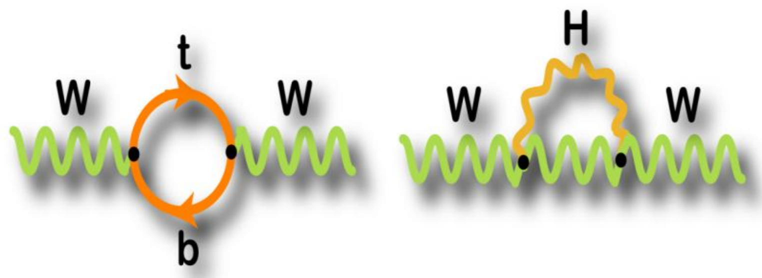
Motivation for precise W mass measurement

- In SM there is a relationship between M_W, M_t, M_H → W mass can be expressed:

$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}}\frac{1}{\sin\theta_W\sqrt{1-\Delta r}}$$

- Radiative corrections Δr recieve large contributions from top quark and Higgs loops

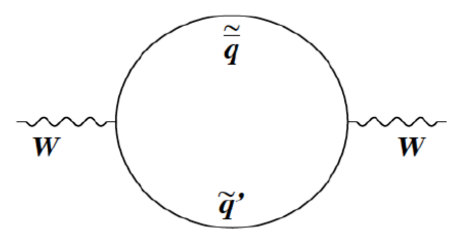
→ Precise M_W an M_t measurements constrain M_H (and vice-versa…)



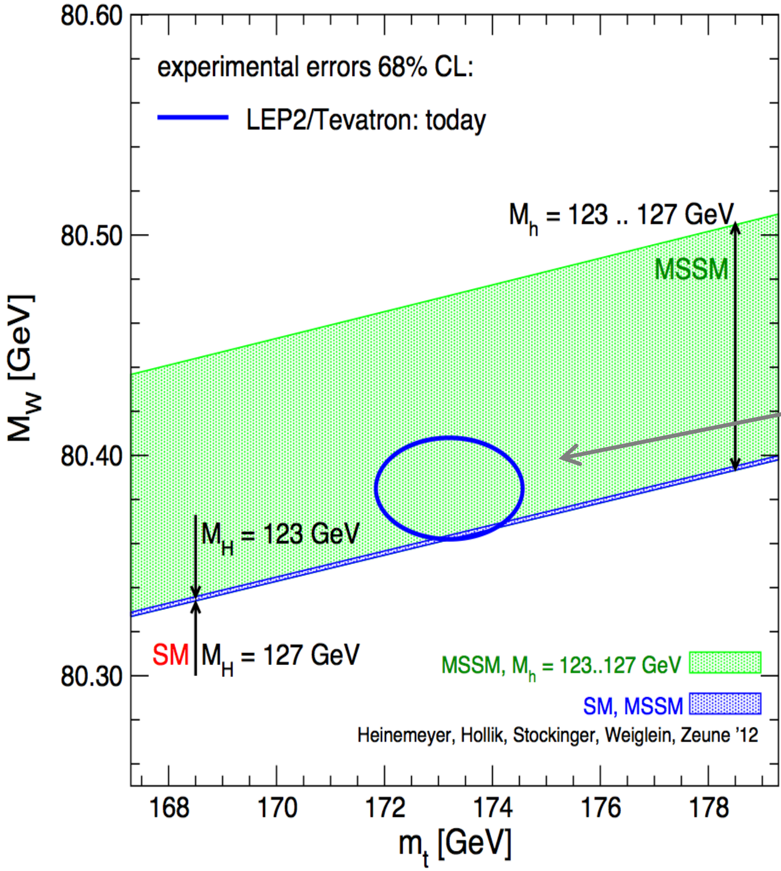
$$\Delta r \sim M_t^2 \qquad \Delta r \sim \ln(M_H)$$

- Additional loops can be generated in SM extensions ,e.g. SUSY

→ Sensitive to new physics



Motivation continued



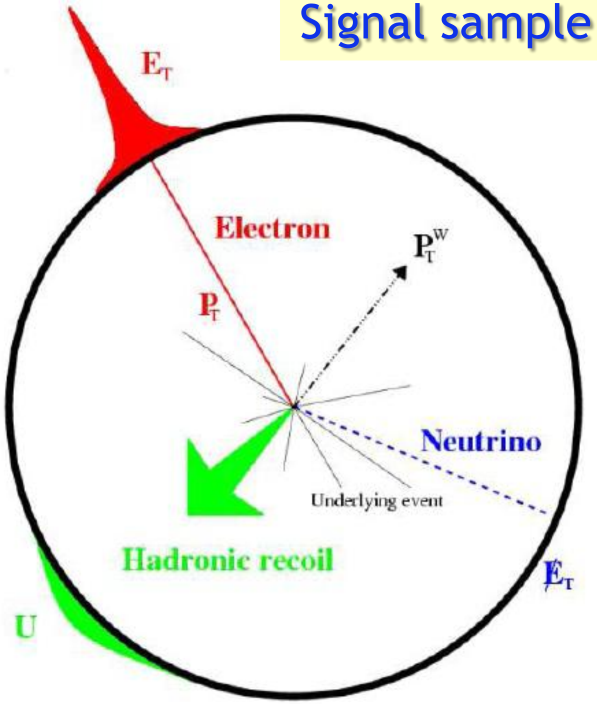
- Constraints inconsistent with direct searches would indicate new physics
- For equal contribution to M_H constraints the precision needed: $\Delta M_W \sim 5$ MeV

  $\Delta M_W \sim 0.006\ \Delta M_t$

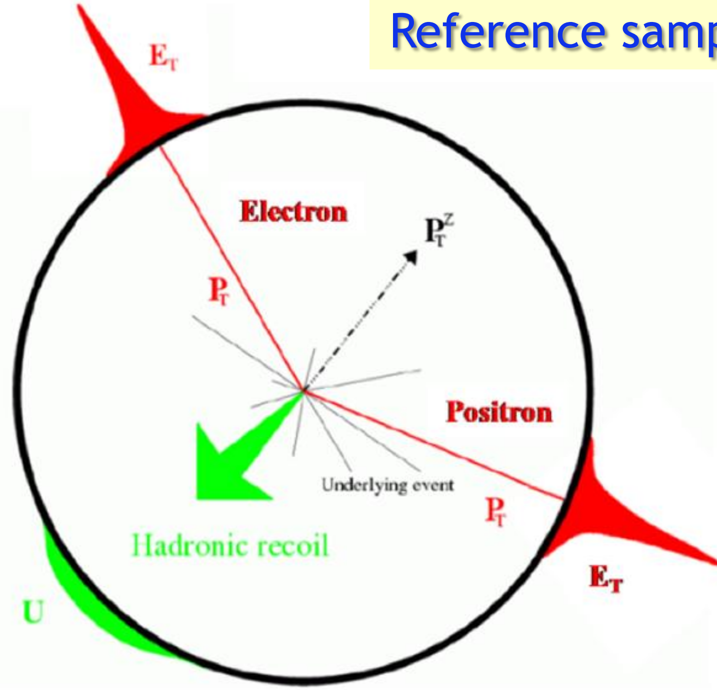
  World average 2012: $\Delta M_W = 15$ MeV
- **The limiting factor here is ΔM_W not ΔM_t !!!**
- **Improving the M_W measurement is an important contribution to our understanding of EW interactions**
- **one of the Tevatron legacy measurements**

Event Signatures

W→eν
Signal sample



Z→ee
Reference sample



- Isolated, high pT leptons
- Hadronic recoil energy

But the required measurement precision is of the $\mathcal{O}(0.01\%)$ resp. $\mathcal{O}(1\%)$!!!

Experimental Observables

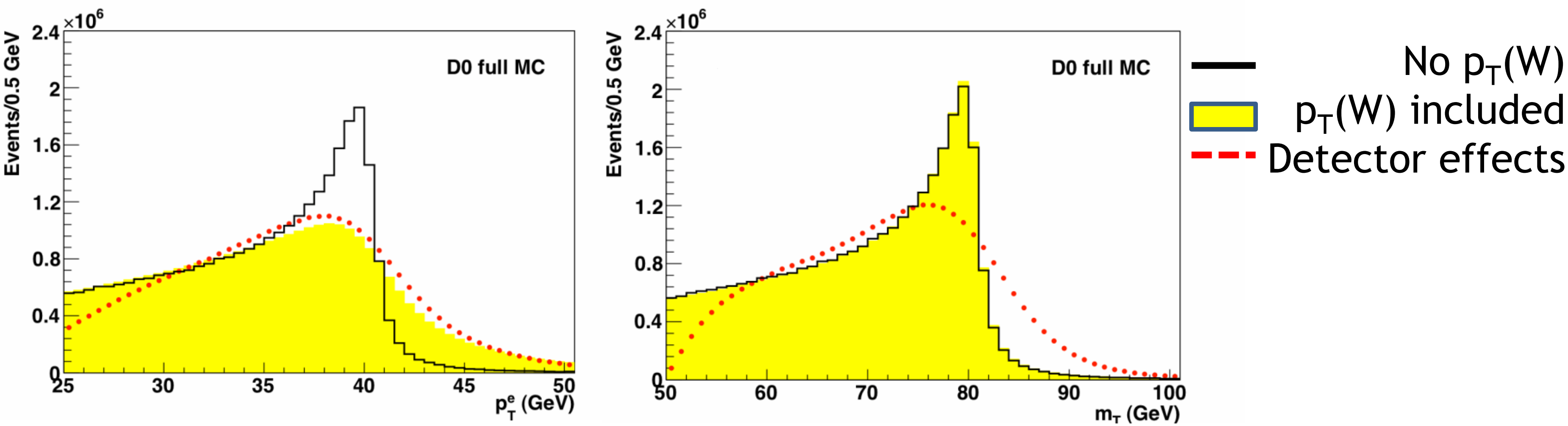
- extract W mass from 3 observables transversal to the beam direction:
  - Electron p_T
  - W transverse mass M_T
  - Missing E_T

$$M_T = \sqrt{2E_T^e E_T^\nu (1-\cos\Delta\phi_{e\nu})}$$

- complementary observables, not completely correlated

$p_T(e)$
most affected by $p_T(W)$

M_T
less sensitive to transverse motion of W
- sensitive to detector resolution effects



Measurement Strategy

- **Compare M_T, $p_T(e)$, $\not{E}_T$ data with MC templates** generated with different M_W hypotheses

- **Templates generation:** Parametrized MC Simulation (~10^9 events)
  → detector efficiencies, energy response and resolutions

  Generator :
  - ResBos - W, Z/γ^* production and decay kinematics
    perturbative NLO at high boson p_T, gluon resummation at low p_T
  - Photos - FSR radiations up to 2 photons
  - WGRAD, ZGRAD – for full QED corrections estimation

  Detector simulation :
  parametric functions, binned look-up tables based on detailed GEANT simulations + fine-tuning on control data samples
  Z→ee, Zero Bias, Minimum Bias

- **Blinded analysis :** - M_W from binned likelihood fits - common offset for all observables by some hidden value
  - results were unblinded after completing all consistency checks for W/Z events

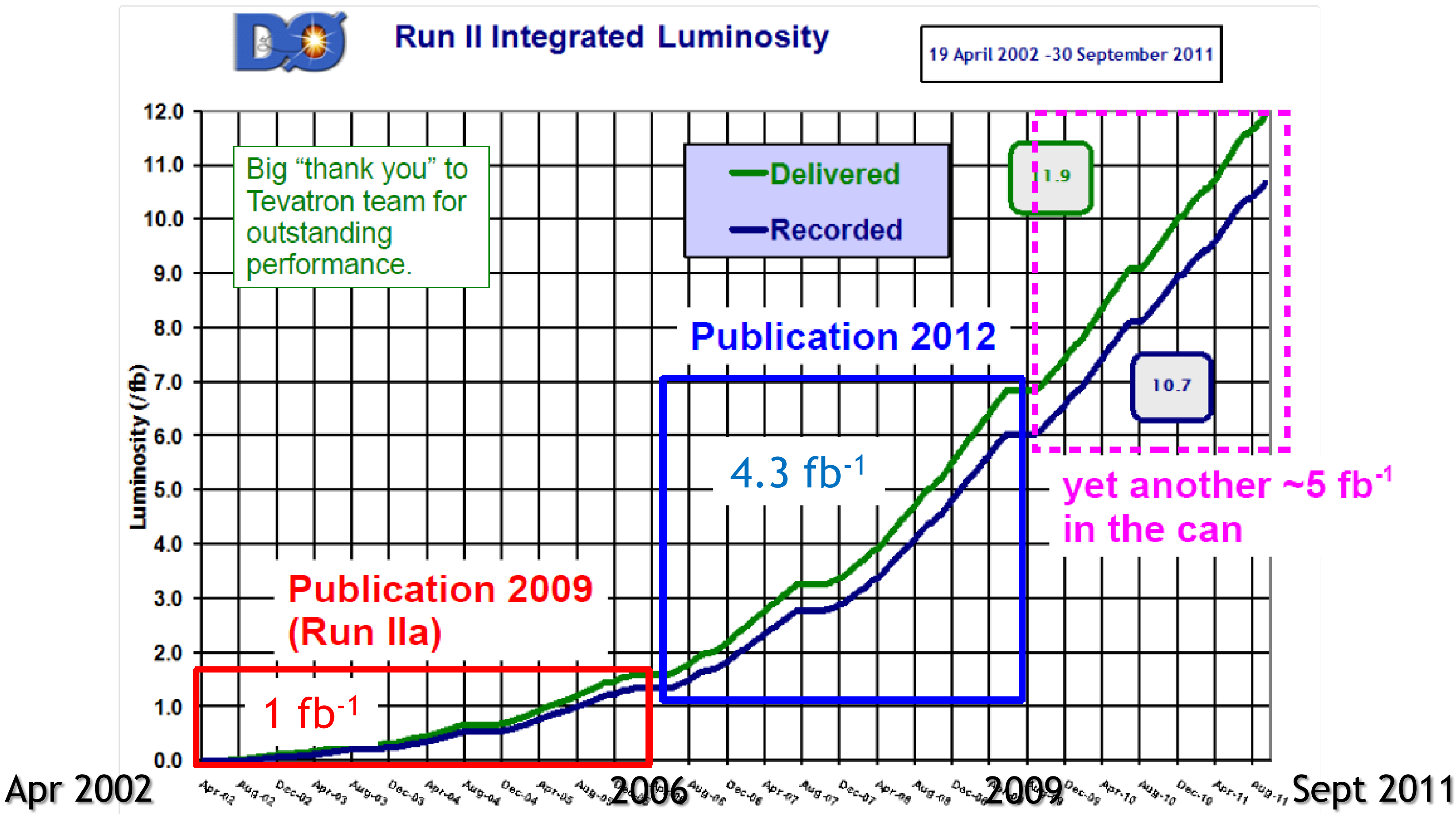
- **Combination of results from different distributions**

Data Taking Periods

Analysis 4.3 fb^{-1} of data collected 2006-2009 in $W \rightarrow e\nu$ decay mode

(DØ calorimeter well-suited for a precise electron energy measurements)

+ combination with results from Run IIa



Event Selection

Event selection

- CAL only trigger (single EM)
- vertex $z < 60\,cm$

Electron selection

- $p_T > 25GeV$
- HMatrix7 < 12, emf > 0.9 and iso < 0.15
- $\eta_{\text{det}} < 1.05$ in the calorimeter fiducial region
- In the calorimeter ϕ fiducial region, as determined from the track
- Spatial track match, track with $p_T > 10GeV$ and at least one SMT hit

$Z \to ee$ selection

- At least two good electrons
- Hadronic recoil transverse momentum $u_T < 15\,GeV$
- Invariant mass $70 < m_{ee} < 110\,GeV$

$W \to e\nu$ selection

- At least one good electron
- Hadronic recoil transverse momentum $u_T < 15\,GeV$
- Transverse mass $50 < m_T < 200\,GeV$
- $\not{E}_T > 25GeV$

Number of candidates after selection: 54,512 ($Z \to e\ e$)
1,677,394 ($W \to e\nu$)

Electron Energy Response Model

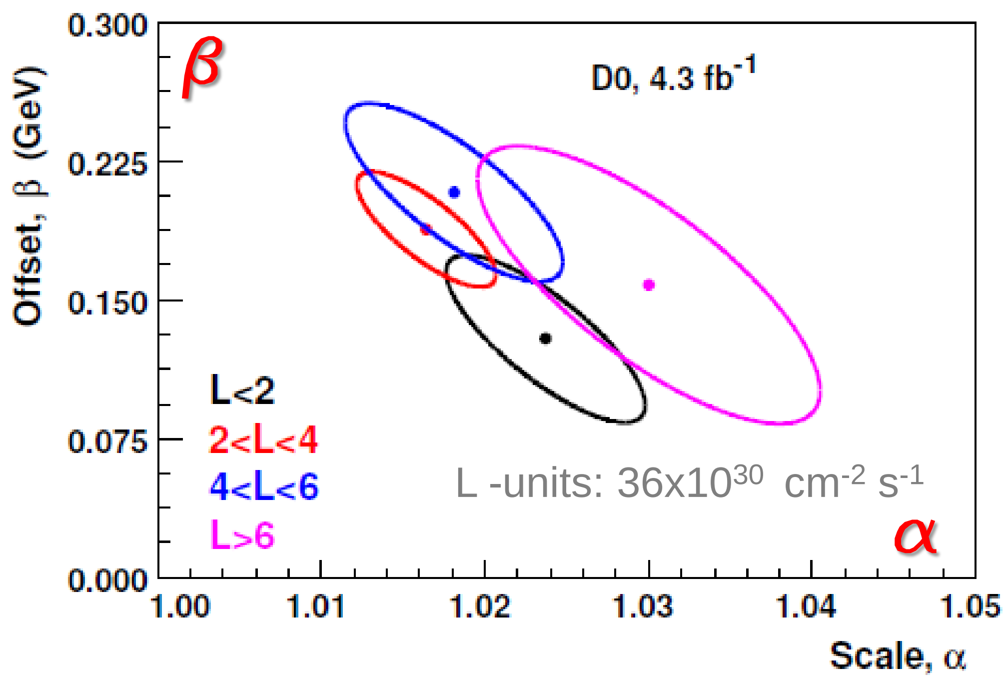
- Z→ee used to calibrate the EM calorimeter response
  - Z (m,Γ) known with high precision from LEP

- model corrections for dead material, underlying event, noise etc.

- $E_{meas} = \alpha\ E_{true} + \beta$
  use energy spread of electrons in Z→ee decays to constrain scale α, offset β

- consistency checks
  - e.g. at different luminosities

- closure test with full MC



Electron Energy Resolution

- driven by two components:
  sampling fluctuations (S) and constant term (C)

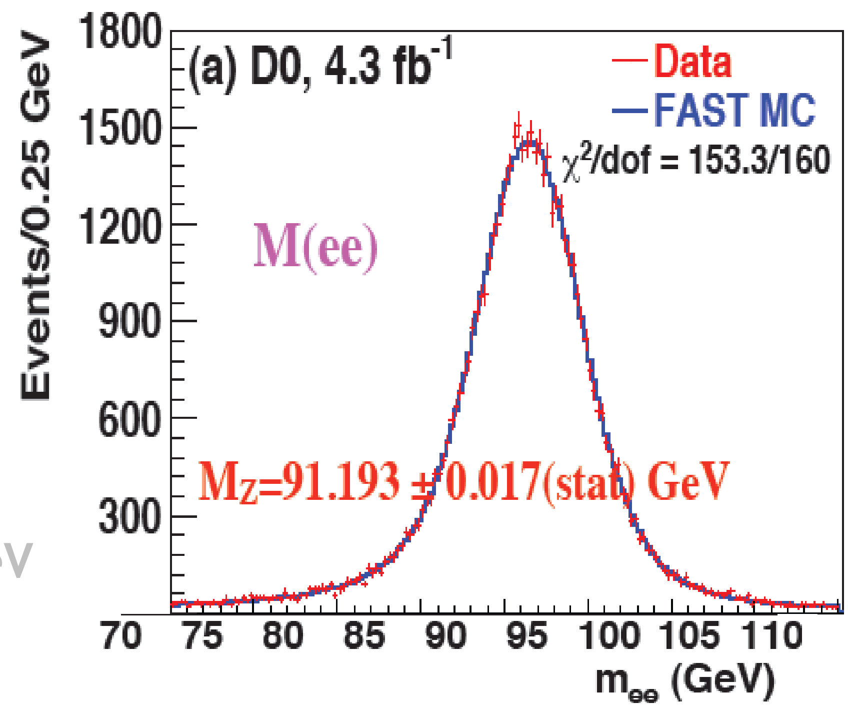
$$\frac{\sigma_{\rm EM}(E)}{E} = \sqrt{C_{EM}^2 + \frac{S_{EM}^2(E,\theta)}{E}}$$

- correct simulation verified by Z mass peak from the data

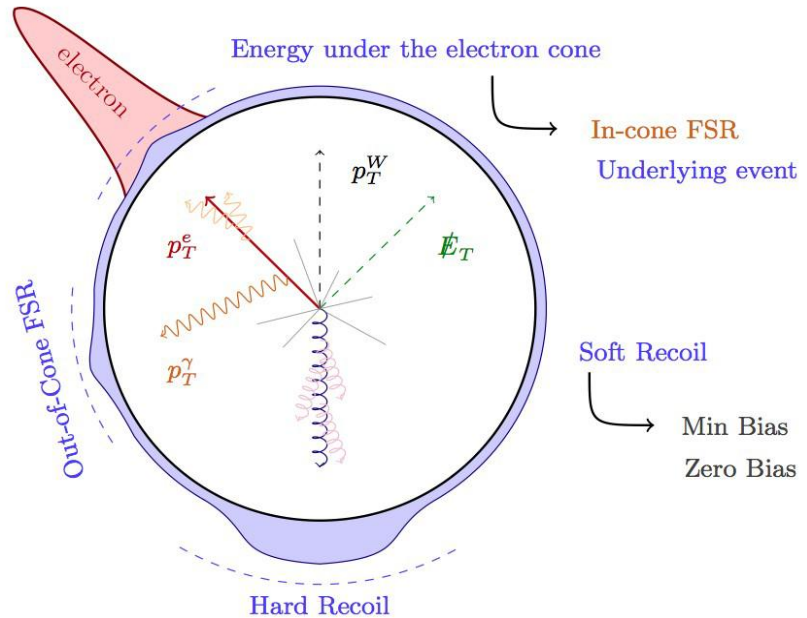
- constant term C=(2.00+- 0.07)%
  essentially fit to observed width of Z peak
  - Run II design goal (2%)

Z-mass from the fit corresponds to the input that was used in the determination of the calorimeter response

Compare to PDG: MZ = 91.188 ± 0.002 GeV



Hadronic Recoil Model



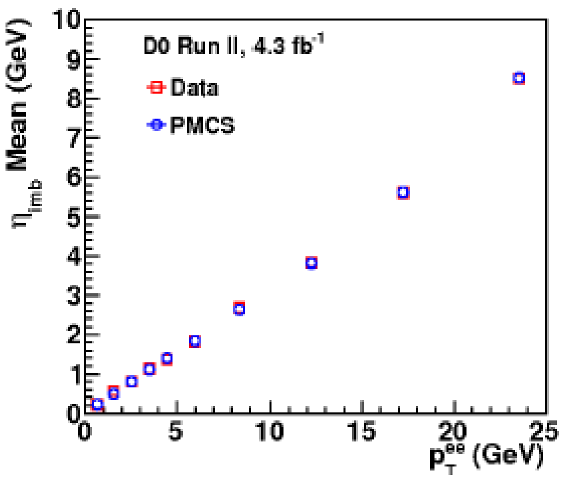
$$\vec{u}_T = \vec{u}_T^{\,\mathrm{HARD}} + \vec{u}_T^{\,\mathrm{SOFT}} + \vec{u}_T^{\,\mathrm{ELEC}} + \vec{u}_T^{\,\mathrm{FSR}}$$

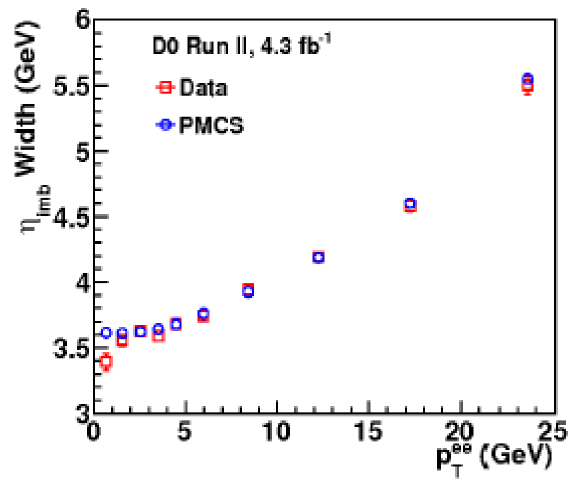
- $\vec{u}_T^{\,\mathrm{HARD}}$ models the hadronic energy from the W recoil.
- $\vec{u}_T^{\,\mathrm{SOFT}}$ models the soft hadronic activity from zero bias and minimum bias activity.
- $\vec{u}_T^{\,\mathrm{ELEC}} = -\sum_e \Delta u_{||} \cdot \hat{p}_T(e) + \vec{p}_T^{\,\mathrm{LEAK}}$ models the recoil energy that was reconstructed under the electron cone, as well as any energy form the electron that leaked outside the cone.
- $\vec{u}_T^{\,\mathrm{FSR}}$ models the out–of–cone FSR that is reconstructed as hadronic recoil.

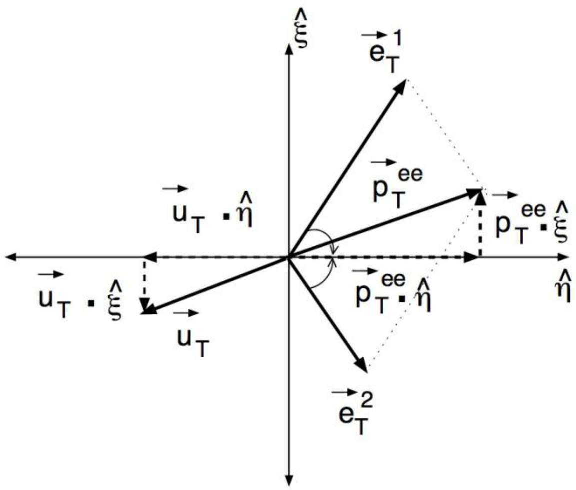
Recoil Calibration

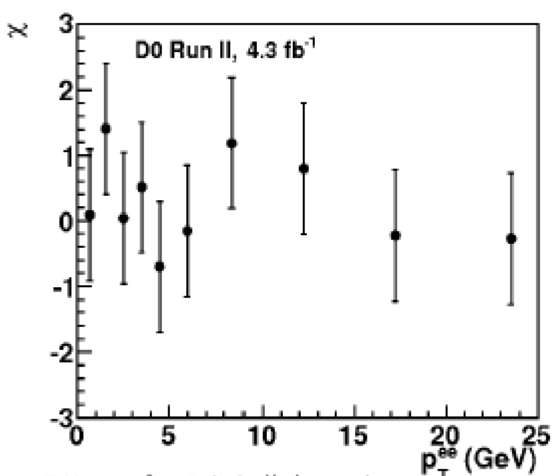
- tuning of the momentum imbalance η_{Imb} with standard UA2 observables

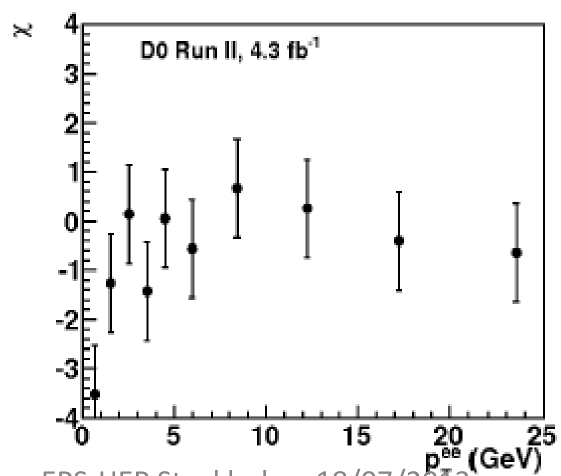
η_{Imb} : $\vec{p}_T(ee) + \vec{u}_T$ projection on the axis bisecting the dielectron opening angle







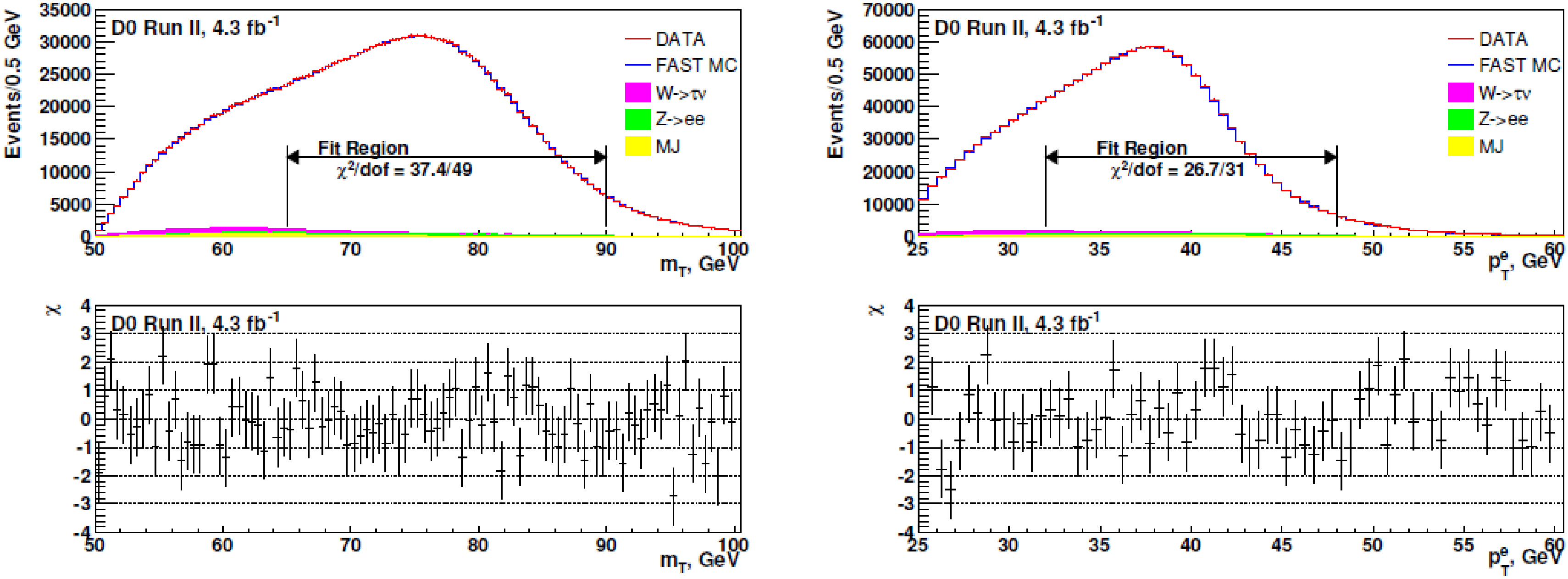




- 5 free parameters allow adjustment of the response and the resolution

W Mass Measurement Results

PRL 108, 151804 (2012)
arXiv:1203.0293

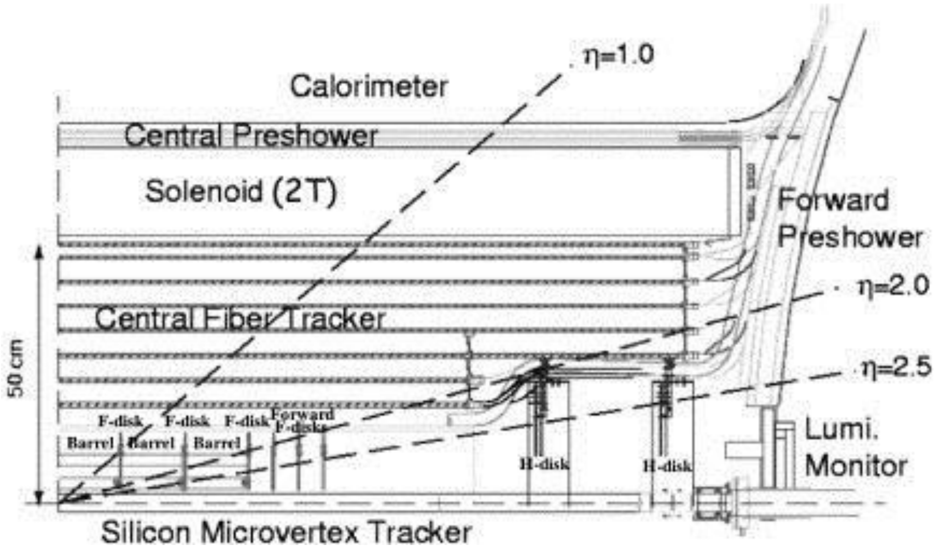


Method $(4.3\ fb^{-1})$	M_W (MeV)
$m_T(e,\nu)$	80371 ± 13(stat)
$p_T(e)$	80343 ± 14(stat)
$\not{E}_T(e,\nu)$	80355 ± 15(stat)
Combination $m_T \oplus p_T$ $(4.3\ fb^{-1})$	80367 ± 26(syst + stat)
Combination $(5.3\ fb^{-1})$	**80375 ± 23**(syst + stat)

Further Improvements: 10 fb^{-1}

- Central electrons only: **ΔM_W = 19 MeV**
  improvements due to the higher statistics
    - electron shower model, electron energy loss based still on 1fb^{-1} analysis
    but higher instantaneous luminosity → bigger pileup, underlying events
  better estimation of QED corrections (Powheg generator)

- Central + end cap electrons η → 2.5 : **ΔM_W = 15 MeV**
  - strong reduction of PDF uncertainty
  detector instrumentation, pileup → very challenging analysis:
  material tune and calorimeter calibration
    →new electron shower, energy, reconstruction and efficiency models



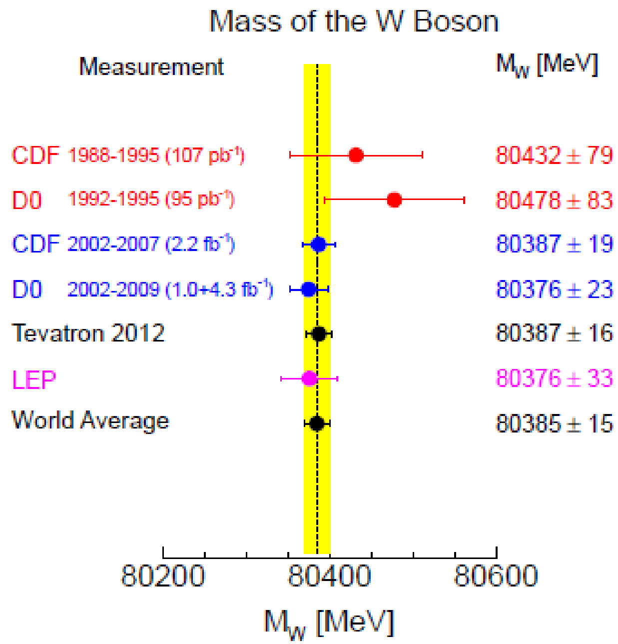
Status - Projections

Source	Public. 2009 (1.0 fb^{-1})	Public. 2012 (4.3 fb^{-1})	Proj. 10 fb^{-1}	Proj. 10 fb^{-1} improv.	Proj. 10 fb^{-1} improv. + EC
Statistical	23	13	9	9	8
Experimental syst.					
Electron energy scale	34	16	11	11	10
Electron energy resolution	2	2	2	2	2
EM shower model	4	4	4	2	2
Electron energy loss	4	4	4	2	2
Hadronic recoil	6	5	3	3	2
Electron ID efficiency	5	1	1	1	1
Backgrounds	2	2	2	2	2
Subtotal experimental syst.	35	18	13	12	11
***W* production and decay model**					
PDF	9	11	11	11	5
QED	7	7	7	3	3
boson p_T	2	2	2	2	2
Subtotal W model	12	13	13	12	6
Total systematic uncert.	37	22	19	17	13
Total	**44**	**26**	**21**	**19**	**15**

combination: 23

Summary

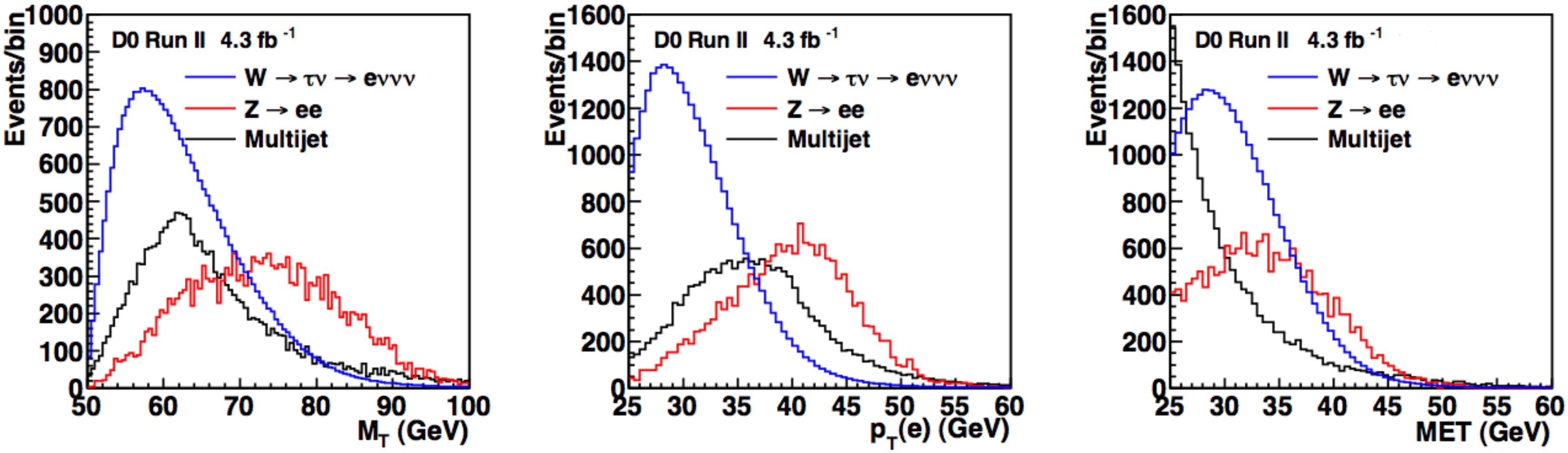
- W boson mass measured in $W \rightarrow e\nu$ channel with 4.3 fb^{-1} of D0 data with the precision **of ΔM_W = 26 MeV**
- combined with data from RunIIa 1 fb^{-1} **ΔM_W = 43 MeV**
  → achieved the precision of the previous world average **ΔM_W = 23 MeV**
- DØ-only prospects to improve the precision:
  - analysis with full dataset (central electrons only) → **ΔM_W = 19 MeV**
  - plus inclusion of end cap electrons ($\eta \rightarrow 2.5$) → **ΔM_W = 15 MeV**
  dramatical reduction of PDF uncertainties
- Current world average **ΔM_W = 15 MeV**
  → The experimental precision on m(W) continues to be the limiting factor in the test of the standard model
  (compare to ~5 MeV)
- Not the final word from Tevatron yet
  - work in progress on further improvements of the precision



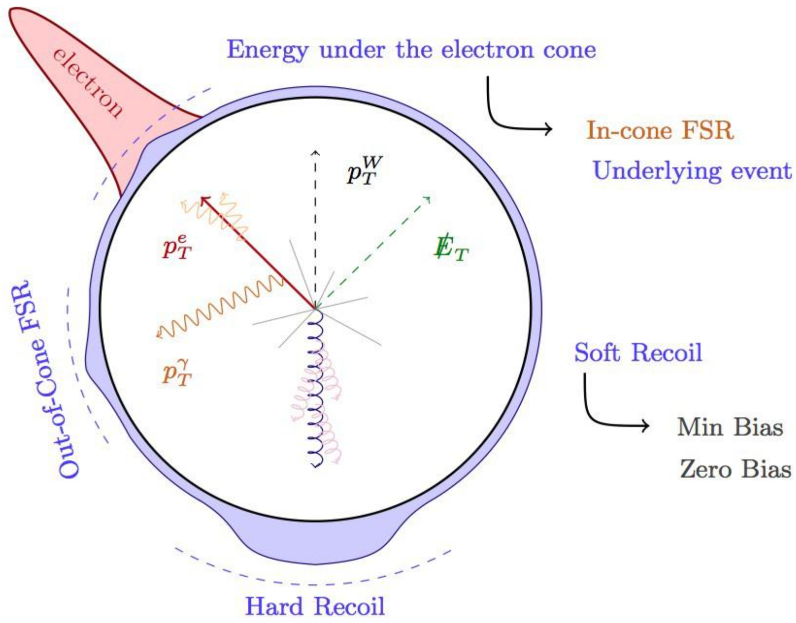
Backup slides

Backgrounds

Z→ee ~ 1.08% , QCD ~ 1.02%, W→$\tau\nu$→e$\nu\nu\nu$ ~1.67%

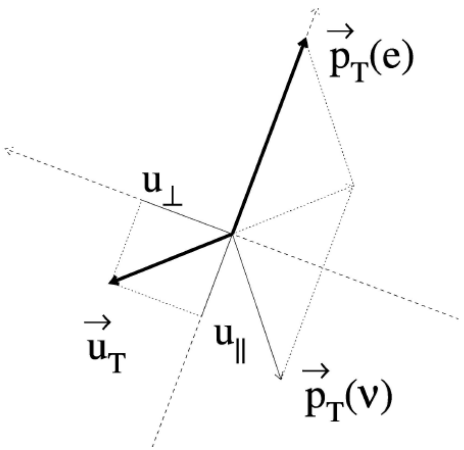


Hadronic Recoil Model



Variables useful to study the recoil system and the e-direction correlations:

$$u_{II} = \vec{u}_T \cdot \hat{p}_T^e \qquad u_\perp = \vec{u}_T \cdot (\hat{p}_T^e \times \hat{z})$$



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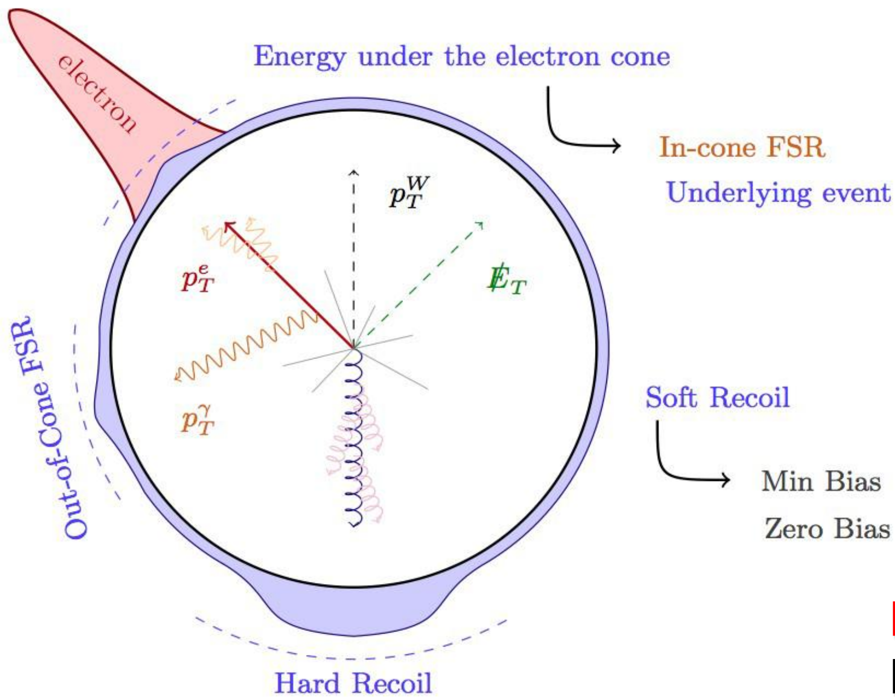
Energy Flows



- EM calorimeter provides very good electron Energy measurement
  → Energy resolution 3.3% (at E=45 GeV)
  → Energy scale calibration focus
  → Detailed calorimeter, E flow model

Energy flow $\mathcal{O}$():

Electron	50 GeV
Hadronic recoil	5 GeV
Hadronic energy under cone	200 MeV
Final state radiation	100 MeV
Electron shower leakage	50 MeV