# Measurement of d$\sigma$/d$p_T$ $(Z/\gamma^* \to e^+e^-)$ at D0

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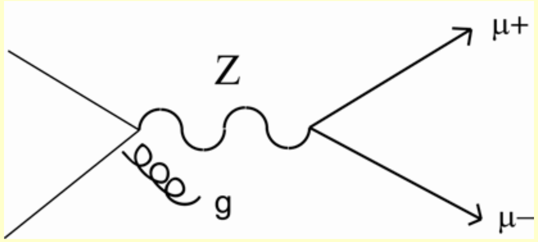
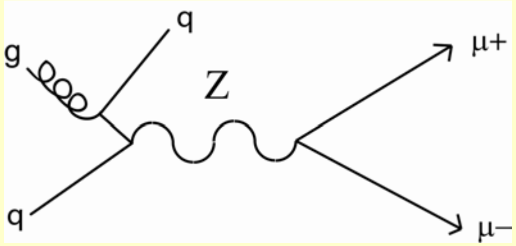
# Outline of the Talk

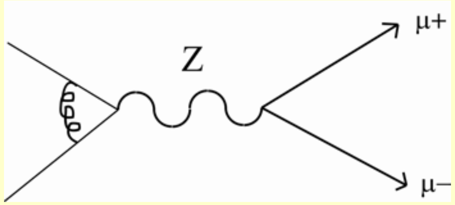
- Motivation
- D0 detector
- $Z/\gamma^* \to e^+e^-$ event selection
- Single electron efficiencies
- Monte Carlo simulation
- Background
- Unfolding of detector smearing
- Systematic uncertainty estimate
- Preliminary result and conclusions

# Motivation

- Z boson production: QCD $q\bar{q} \rightarrow Z$
- $p_T$ of Z boson : **initial state gluon radiation of the colliding partons**




$\dfrac{d^2\sigma}{dp_T^2\,dy}$ calculation:

- **High $p_T$, perturbative QCD**

$$\frac{d^2\sigma}{dp_T^2\,dy} \propto \frac{\alpha_w \alpha_s}{p_T^2} \ln\left(\frac{Q^2}{p_T^2}\right) \rightarrow \infty \;\; as \;\; p_T^2 \rightarrow 0$$

- **Low $p_T$, soft and collinear gluon resummation**

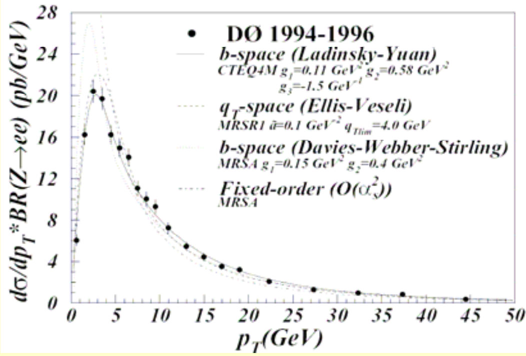
# Motivation

- CSS(Collins,Soper, Sterman) formalism:

$$\frac{d^2\sigma_{ij\to V}}{dp_T^2 dy} \approx \int_0^\infty d^2 b e^{i\overrightarrow{p_T}\cdot\vec{b}} W(b,Q) + Y(b,Q)$$

- **W(b,Q) resumming the perturbative series $p_T^{-2}\times[1 \, or \ln(Q^2/p_T^2)]$ to all orders in $\alpha_s$**
- **Y(b,Q) diff between the fix order perturbative result and the singular part**
- **To extend to pT->0 region, where non-perturbative QCD dominate the production**

$$W(b,Q) \to W(b_*,Q)e^{-S_{NP}(b,Q)} \quad b_* \equiv b/\sqrt{1+(b/b_{\max})^2} \le b_{\max}$$




- **$S_{NP}$: non-perturbative Sudakov form factor**
- **Lindasky-Yuan form:**

$$S_{NP}^{LY}(b,Q^2) = g_1 b^2 + g_2 b^2 \ln(\frac{Q^2}{2Q_0^2}) + g_1 g_3 b \ln(100 x_i x_j)$$

- **Provide sensitive test of the weak boson production formalism**
- **Help to reduce theory uncertainty of the precision W mass measurement**

# Motivation

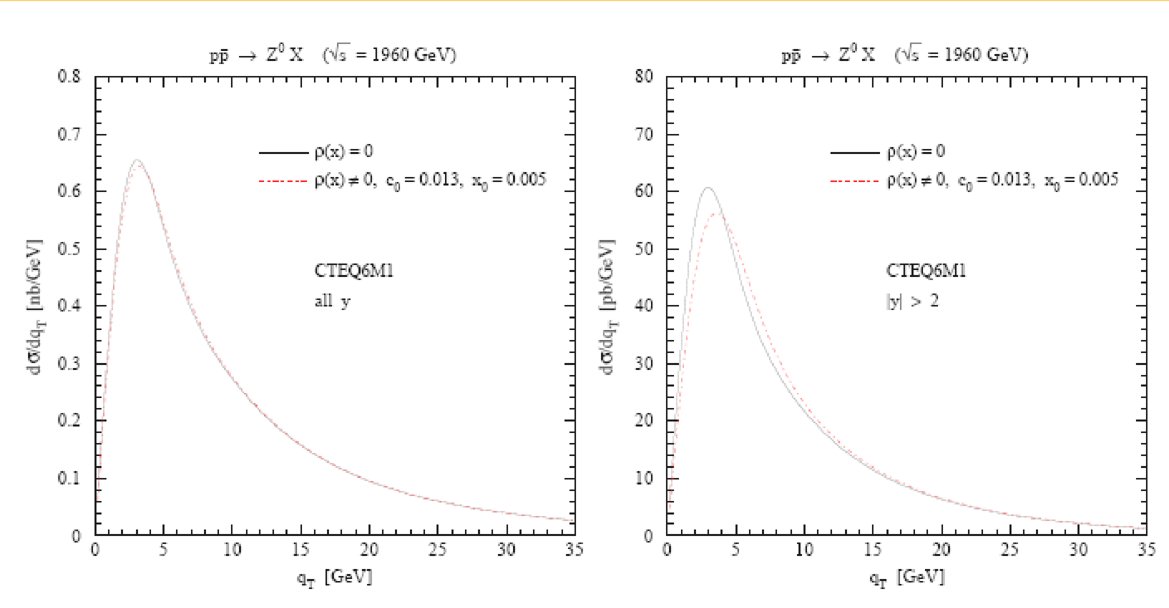
Hep-ph/0401128: Berge, Nadolsky, Olness, Yuan

**Problem: resummation can not describe $P_T$ in semi-inclusive DIS**

**Solution? Two large logs. Normal resummation handles**

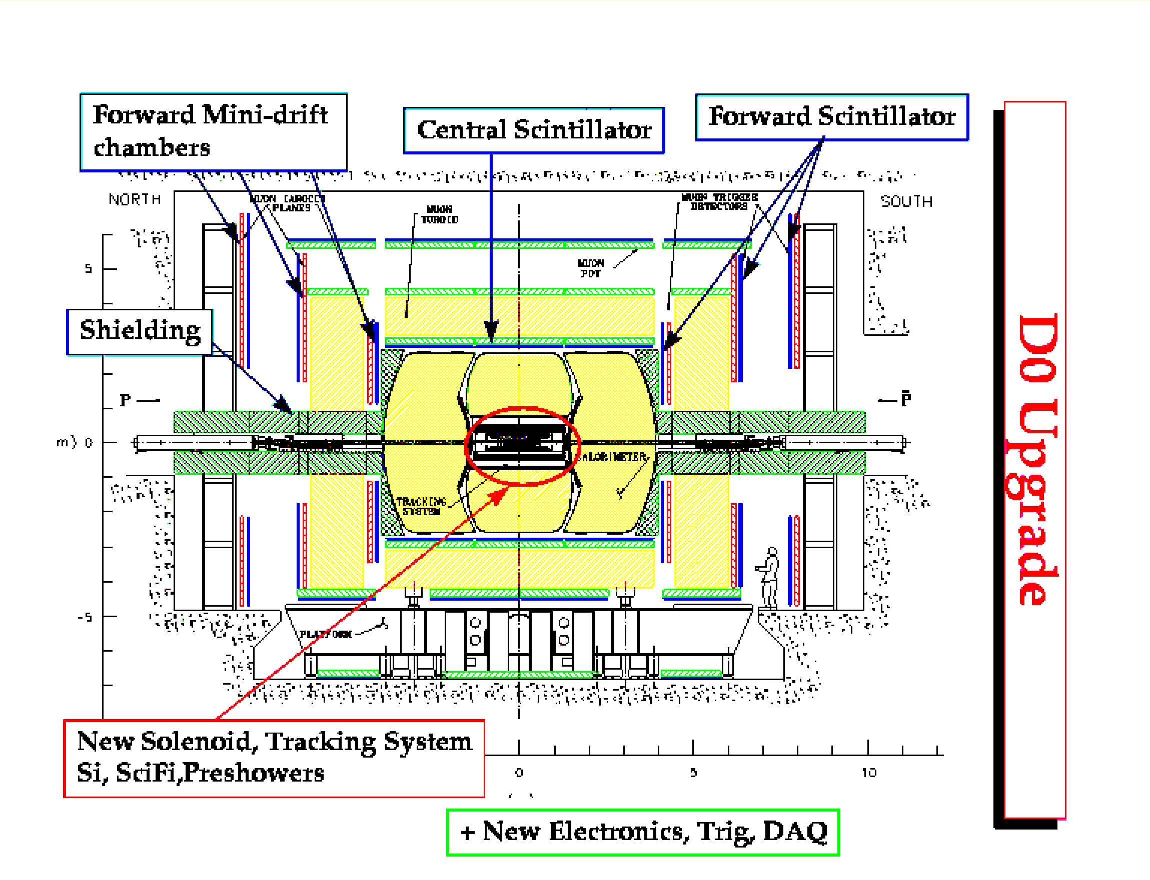
$$\frac{1}{\sigma}\frac{d\sigma}{dp_T^2} \simeq \frac{1}{p_T^2}[A_1\alpha_s \ln(\frac{Q^2}{p_T^2}) + A_2\alpha_s^2 \ln^3(\frac{Q^2}{p_T^2}) + \ldots + A_n\alpha_s^n \ln^{2n-1}(\frac{Q^2}{p_T^2}) + \ldots]$$

**Normal resumation does not handle** $\alpha_s^n \ln^n(1/x)$ **terms. Mock this in nonpert part**




Small x broadening

# D0 detector




- Tracking system:
  - Silicon microstrip tracker
  - Scintillating fiber tracker
  - Super conducting solenoid

- Uranium/liquid argon calorimeter

coverage:

Central: |η|<1.1

Endcaps: 1.5<|η|<4.2

- Muon detector with toroid

# Data Sample and Event Selection

- Data collected in D0 Run II between Oct 2002 and Jan 2006, bad runs removed. $\int Ldt \sim 965 \pm 58\, pb^{-1}$

**Two high $p_T$ electrons each satisfying:**

  - **$p_T > 25$ GeV**
  - **isolated**
  - **in good region of calorimeter**
  - **matches typical electron shower shape**
  - **have a track match**

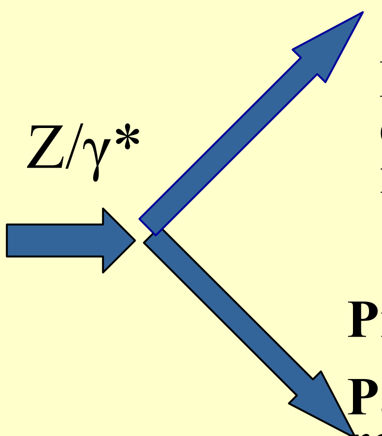
- **Invariant mass between [70,110] GeV**
- **At least one electron fires a single electron trigger**

| CCCC | CCEC | ECEC | All |
|---|---|---|---|
| 23957 | 30116 | 9583 | 63656 |

TABLE I: Results of event selection

# Single Electron Efficiencies

- Tag and probe method




**Tag electron:**

**Passes all single electron requirements**

**Probe electron:**

**Passes loose electron requirements and check for each selection requirement**

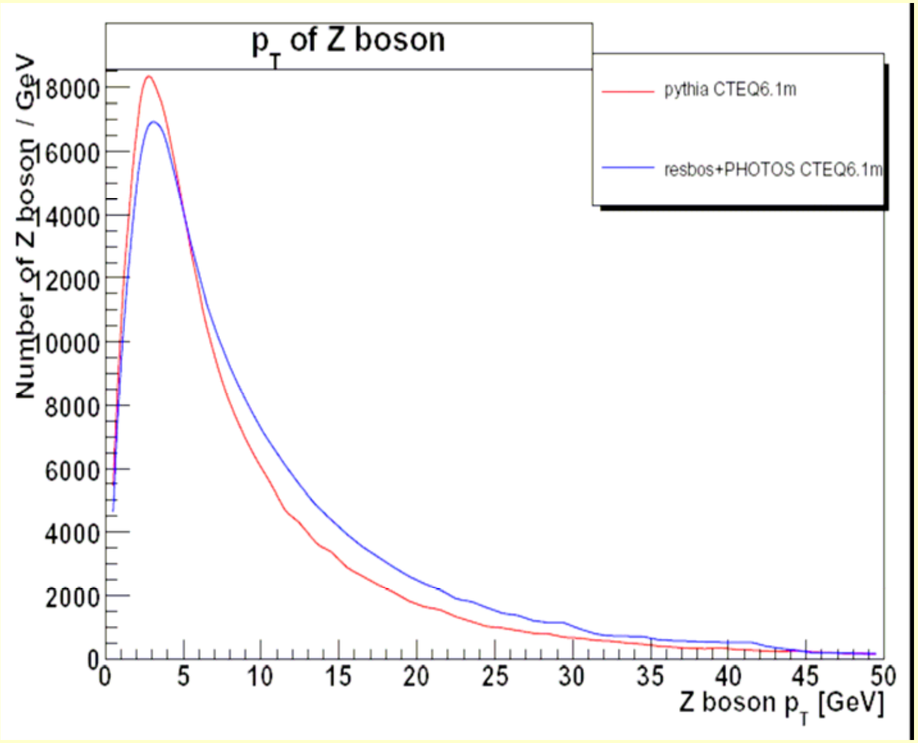
| | CC | EC |
|---|---|---|
| Electron identification | (99.5 ±0.1)% | (99.1 ±0.1)% |
| Trigger | (98.5 ±0.1)% | (97.9 ±0.1)% |
| Shower shape | (97.1 ±0.1)% | (96.9 ±0.1)% |
| Track match | (90.5 ±0.1)% | (61.7 ±0.1)% |

$$\varepsilon = \frac{N_{pass}^{probe}}{N_{All}^{probe}}$$

Their dependence on electron location and $P_T$ are modeled in Monte carlo

# Monte Carlo simulation

- Event generator: **Resbos(Ladinsky+Yuan)+PHOTOS**
- **Resbos(hep-ph/9704258):initial state gluon resummation;g1,g2,g3;**
- **PHOTOS(hep-ph/0506026):final state QED radiation.**



# Detector response- Parameterized Monte Carlo Simulation

**Parameterized Monte Carlo simulation(PMCS): smear electron energy, η and φ position;**

**Merge nearby photons to electrons;**

**Apply single electron efficiencies and acceptance cuts.**

**Energy smearing:**

$$E' = \alpha * E_{gen} + \beta$$

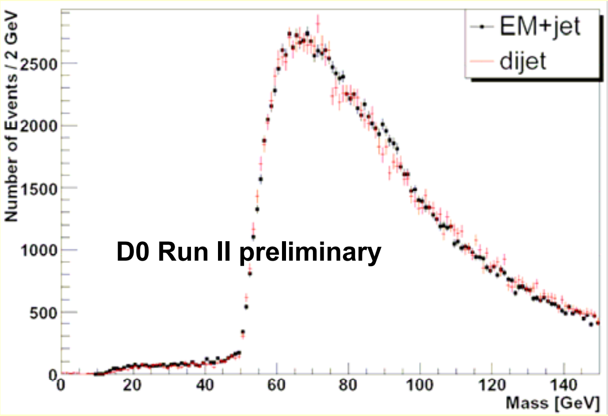
$$\frac{\sigma_E}{E} = \sqrt{C^2 + \frac{S^2}{E} + \frac{N^2}{E^2}}$$

$$E_{smear} = E' + x * \sigma_E$$

**Parameters(α,β,C) are determined from Z data by comparing invariant mass distribution.**

# Backgrounds

- QCD backgrounds:
  - **Main source of backgrounds is QCD background with jets faking electrons. (Di-jet, EM+jet)**
  - **Selection: inverse shower shape cut on the electrons.**




- Non-QCD backgrounds:

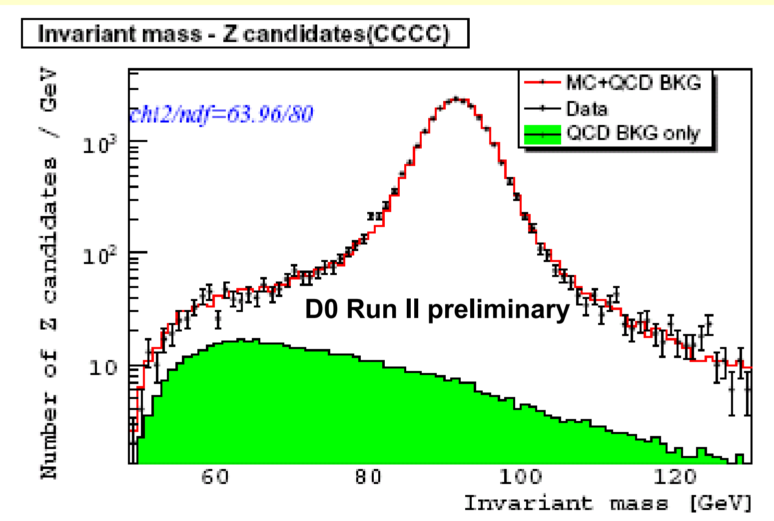
**PYTHIA as generator, PMCS as detector smearing**

| | ε*A | σ*Br(pb) | N(0.968fb$^{-1}$) |
|---|---|---|---|
| $Z \rightarrow \tau\tau \rightarrow ee$ | 0.0025 | 7 | 16.7 |
| WW | 0.059 | 0.1 | 6.2 |
| WZ | 0.17 | 0.009 | 15.5 |
| Wγ | 0.005 | 12.2 | 61 |

**the non-QCD backgrounds are negligible**

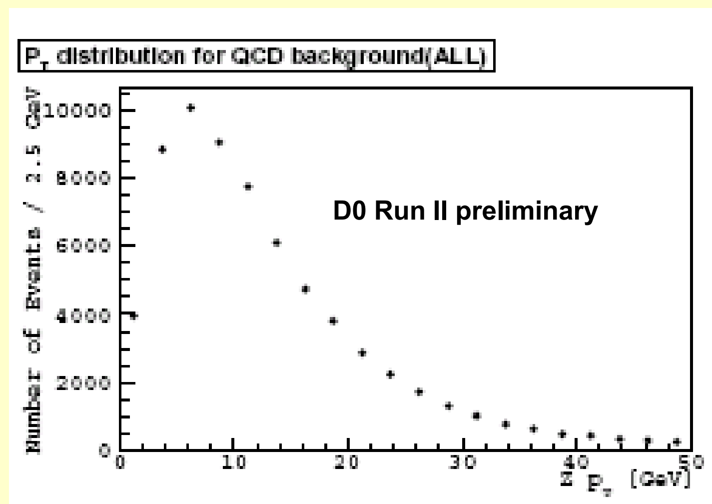
# Background fraction and $p_T$-shape

- **Minimum $\chi^2$ fit: invariant mass of the Z candidates as linear sum of those of signal(MC) and background to get the background fraction**



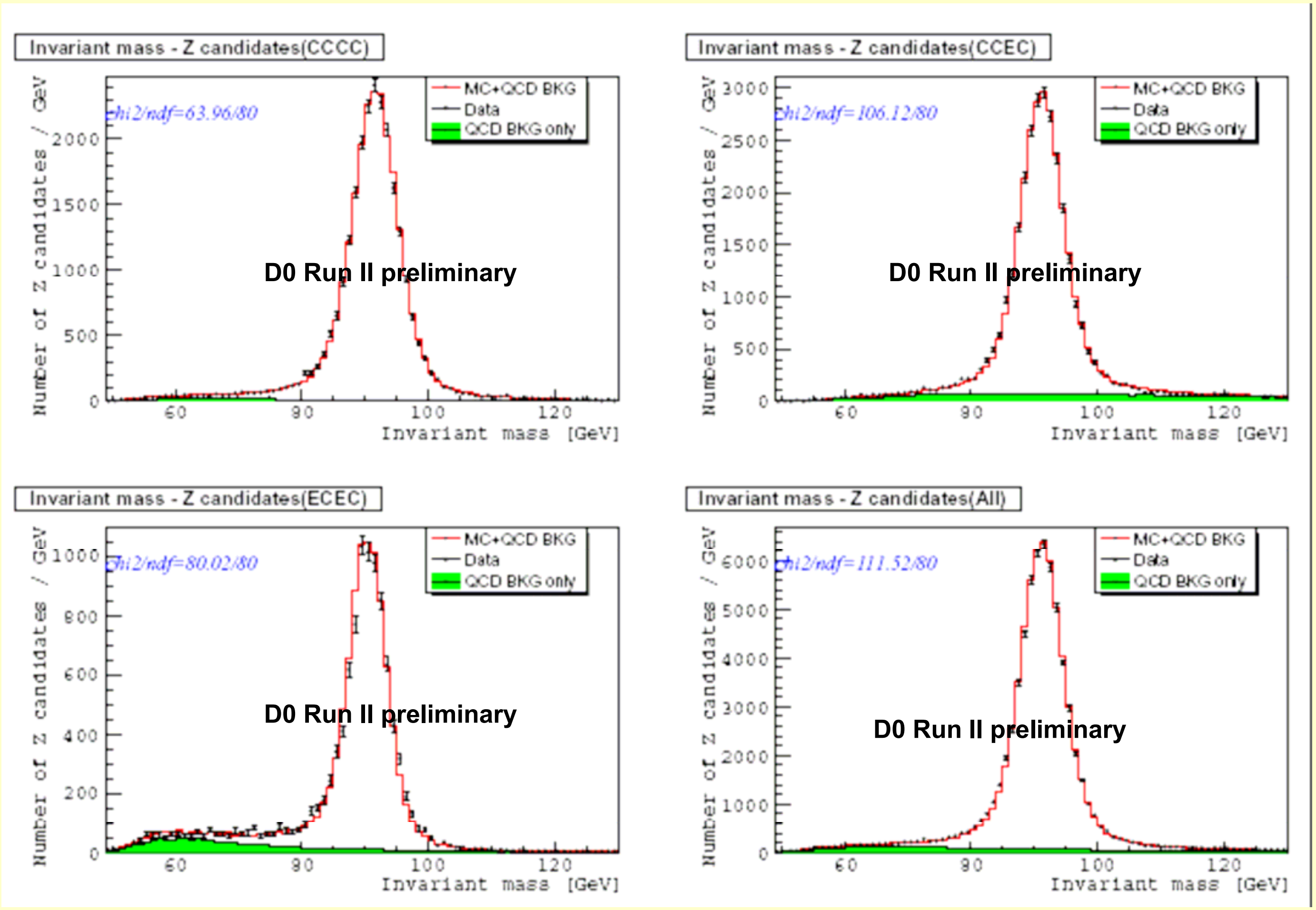

| Region | $\chi^2$/ndf | background fraction |
|---|---|---|
| CCCC | 64/80 | 1.30±0.14% |
| CCEC | 106/80 | 8.55±0.26% |
| ECEC | 80/80 | 4.71±0.30% |
| All | 111/ 80 | 4.70±0.13% |

**QCD background shape:**



# Data/MC Comparisons

**Put measured efficiency and tuned parameters in the PMCS**

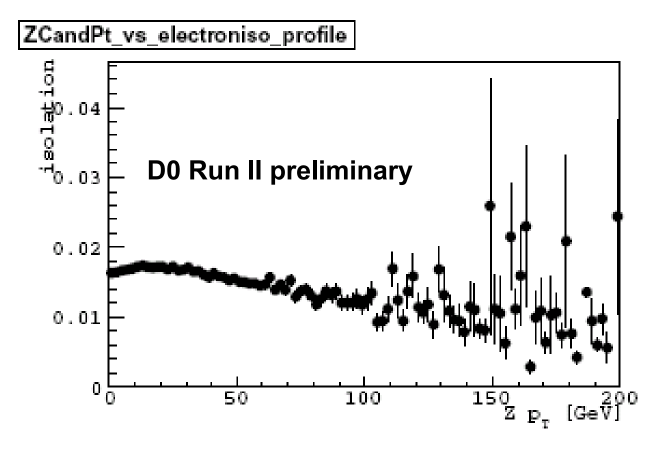


# Efficiency*Acceptance Z $p_T$ dependence

Data selection affect Z pT spectrum;

Jet activity affect the isolation of the electrons

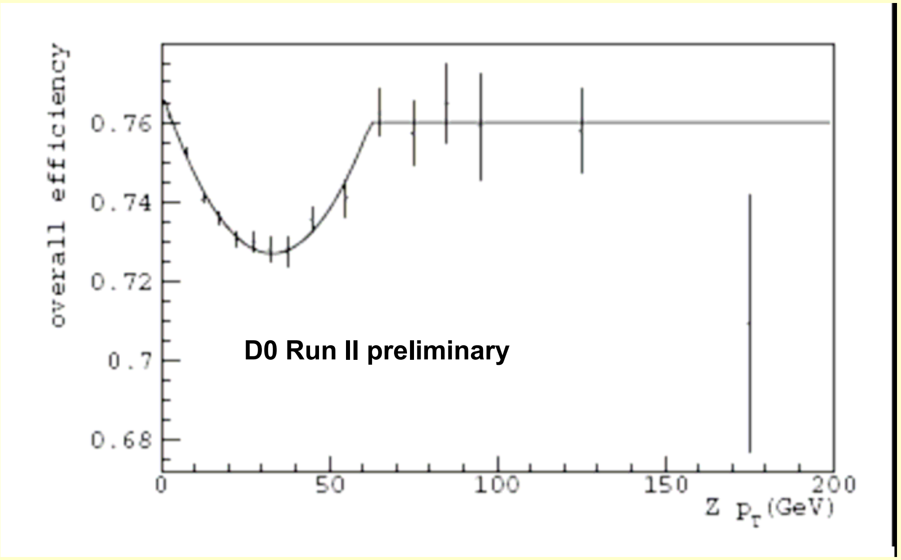
Dependence studied from Monte Carlo




Efficiency Z pT dependence: full Monte Carlo(GEANT-based);

Signal overlaid on underlying events

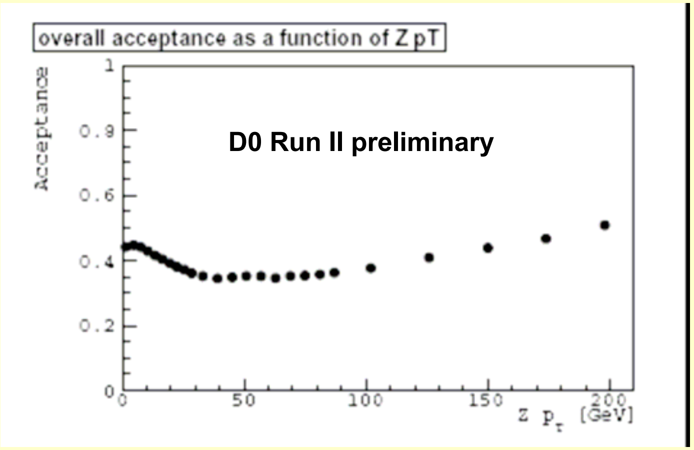
$$\frac{smeared\ Z\ p_T(accep\ cuts, eff\ cuts)}{smeared\ Z\ p_T\ (accep\ cuts)}$$



# Efficiency*Acceptance Z $p_T$ dependence

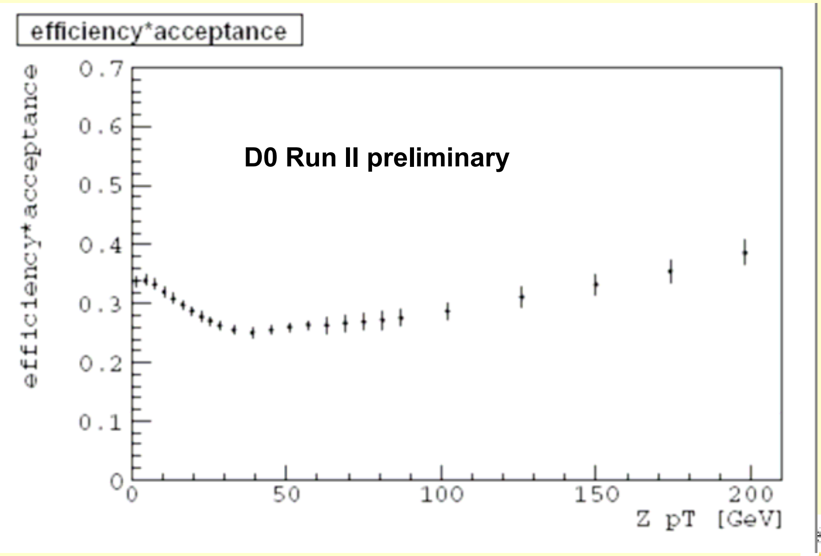
**Acceptance (electron pT, position and invariant mass) Z pT dependence: PMCS**

$$\frac{smeared\ Z\ p_T\ distribution\ with\ accep\ cut(s)}{smeared\ Z\ p_T\ distribution\ with\ no\ cuts}$$



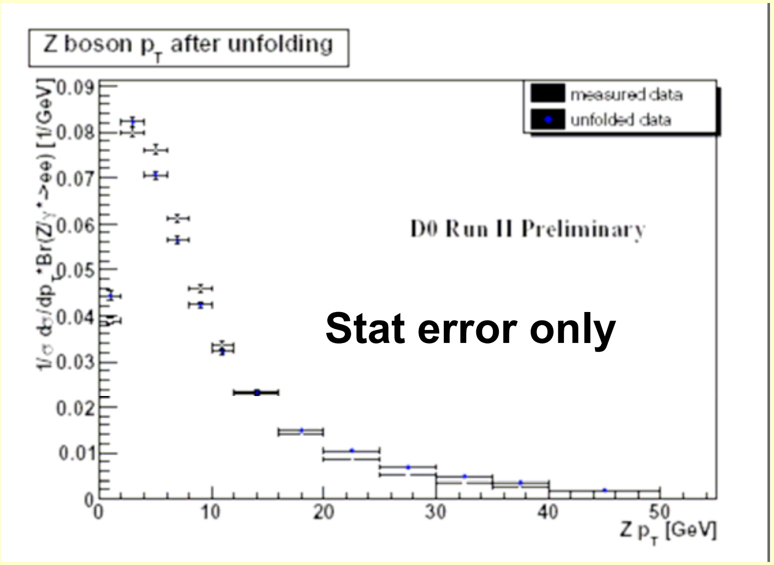

## Efficiency*Acceptance $p_T$ dependence

**Measured Z $p_T$ spectrum need to correct for this dependence**



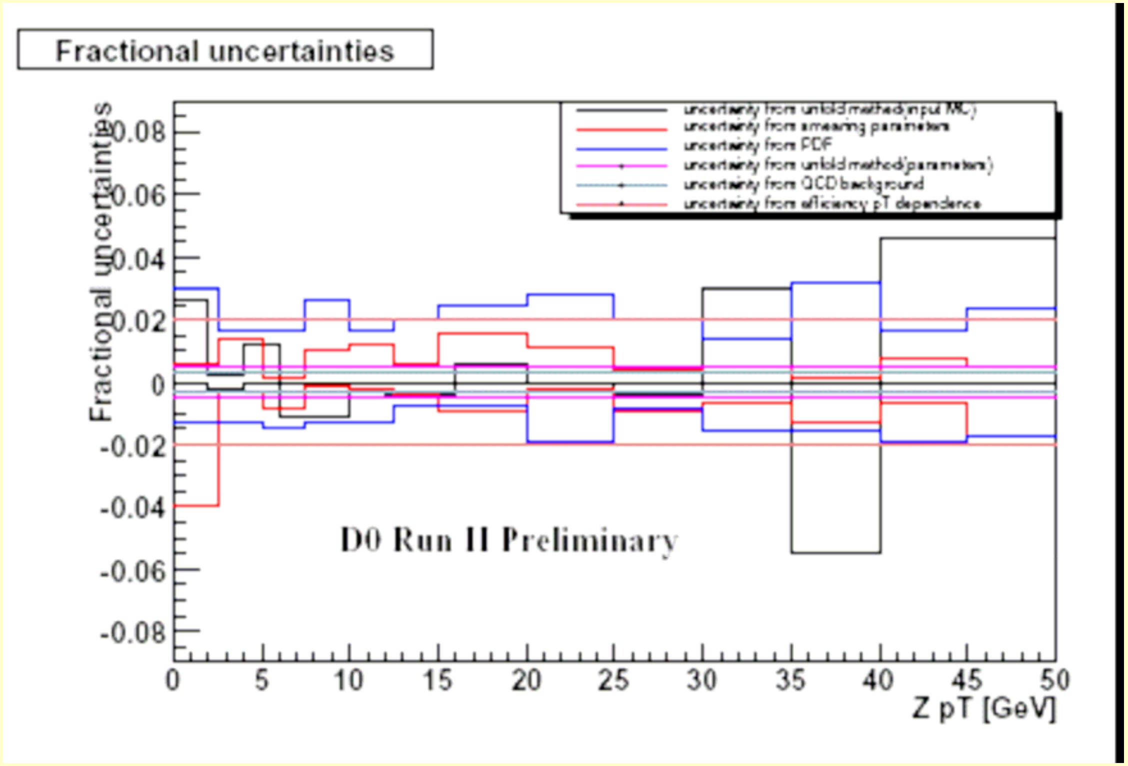
# Unfolding of Detector Smearing

- *RUN*(*R*egularized *Un*folding)**(hep-ex/0208022)** by V.Blobel
  - Maximum likelihood fit(data and trial result with parameters) with regularization term to smooth oscillations due to large correlations between adjacent bins.
  - Input:
  - ✓ Ntuples of Z pT data
  - ✓ Ntuples of Z pT MC: generator, smeared(contains smearing information)
  - ✓ Ntuples of pT of QCD background



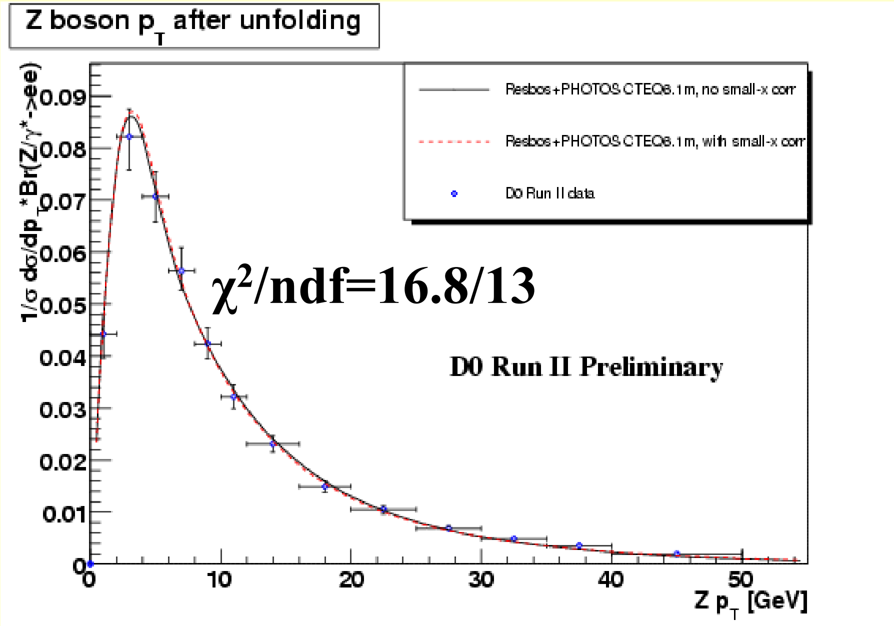
# Systematic Uncertainty

**Energy resolution parameters:constant term and sampling term;Energy scale parameter;PDFs, background, unfolding method(input,parameters), data/full MC discrepancy of efficiency pT dependence**



# Preliminary result, conclusions and further studies

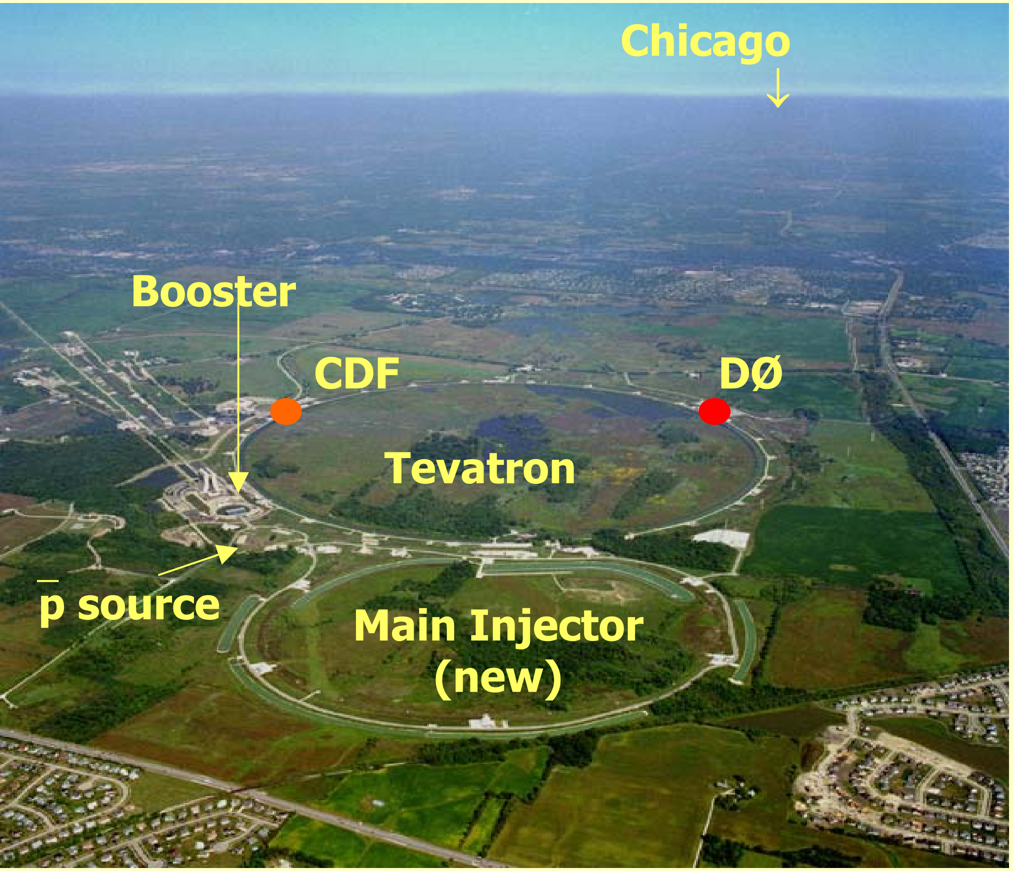
- **Preliminary result for 0.965 $fb^{-1}$ data**
- **All y region result consistent with CSS resummation calculation**
- **Next to perform tuning of Resbos g2**
- **Small x broadening test in progress for |y|>2**



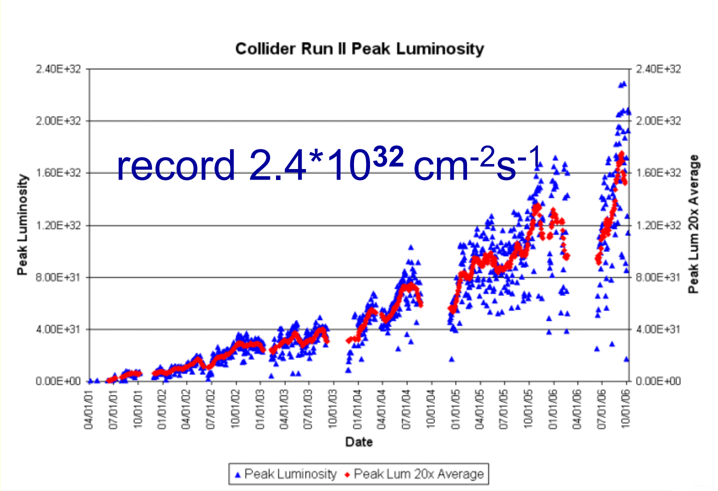
# Backup slides

# Tevatron for Run II

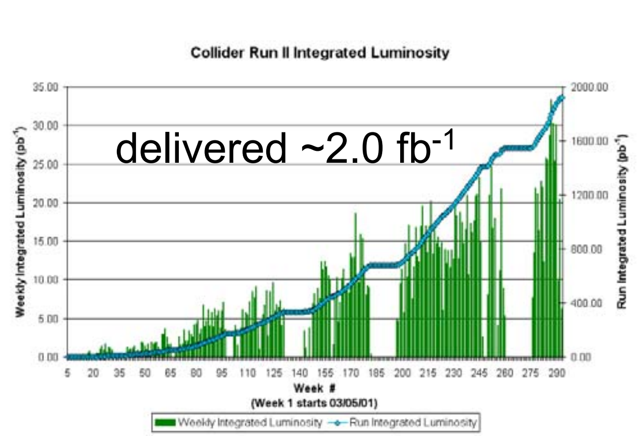
New 120 GeV Main Injector
CM increased form 1.8 TeV to 1.96 TeV




Collider Run II Peak Luminosity

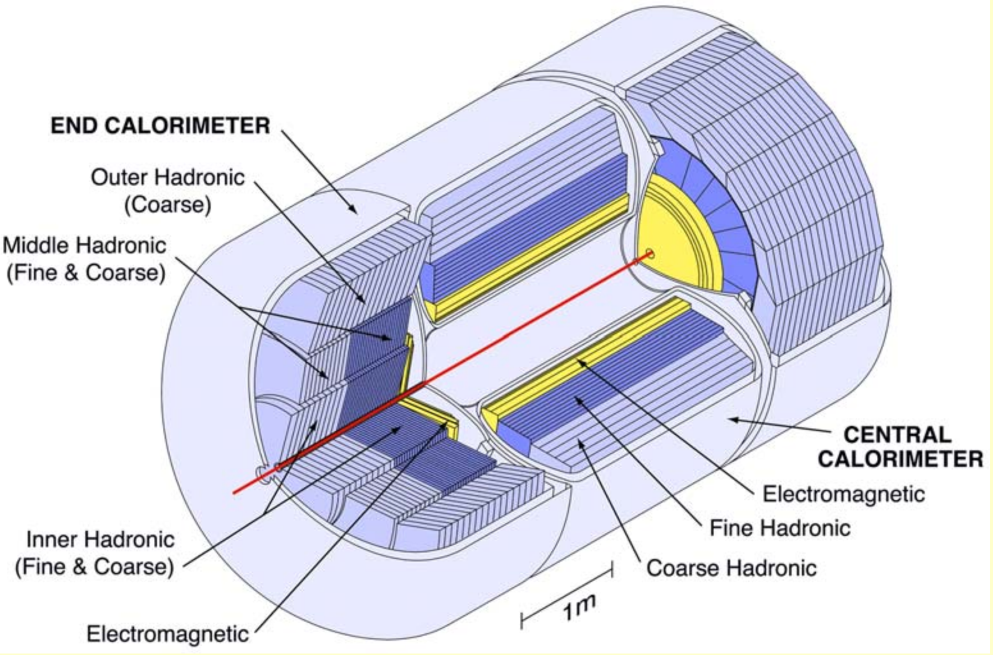



Collider Run II Integrated Luminosity



# D0 calorimeter

- **Compensating sampling calorimeter:uranium/liquid argon**




Eta coverage:

Central: $|\eta|<1.1$

Endcaps: $1.5<|\eta|<4.2$

$(\sigma/E)^2 = C^2 + S^2/E + N^2/E^2$

Interpretation:

C = contant term (due to non-uniformities in the response; "intercalibration errors")

S = sampling term (due to sampling fluctuations; "intrinsic performance of the CAL")

N = noise term (due to "noise", e.g. from Uranium, the readout electronics, and, in collision data, the "underlying event")

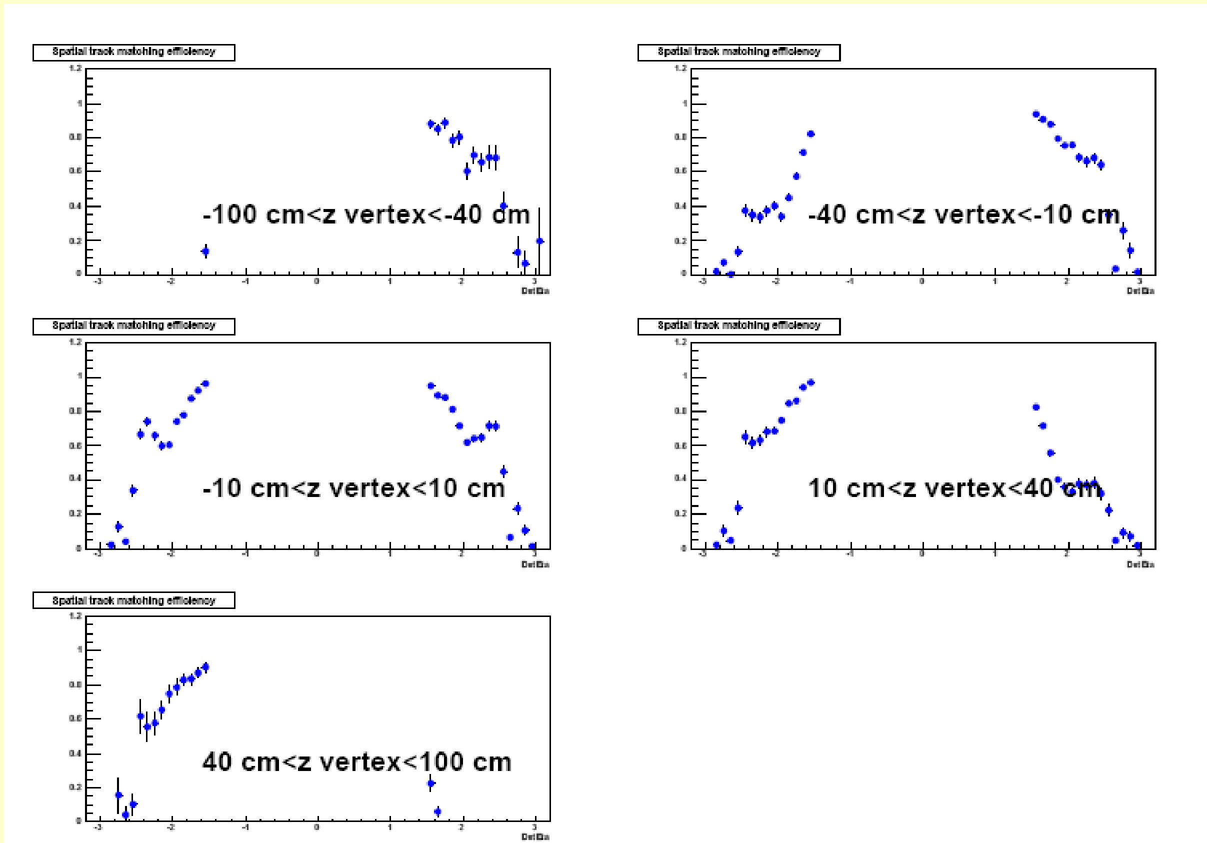
**D0 Run I CC:**

$$S = 15\%\, GeV^{1/2}$$

$$C = 1.0\%$$

$$N = 0.38\, GeV$$

# Typical parameterization

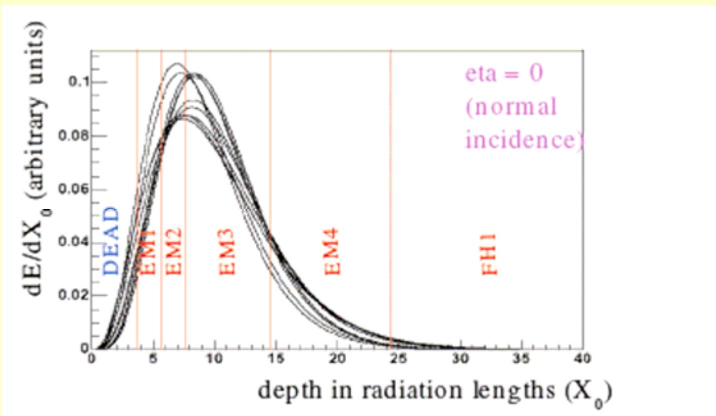


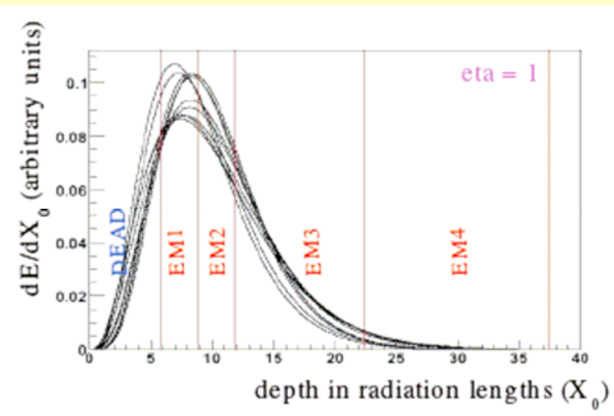

**Tracking matching efficiency for EC electrons versus vertex z position**

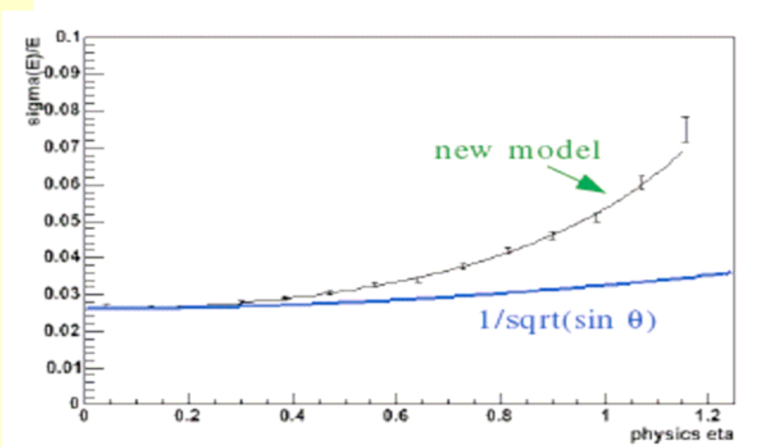
# CC Energy resolutions

Calorimeter suffers from the materials added in D0 Run II. Sampling is no longer constant, but depend on position.

Constant Term tuned from Z(2.8%)

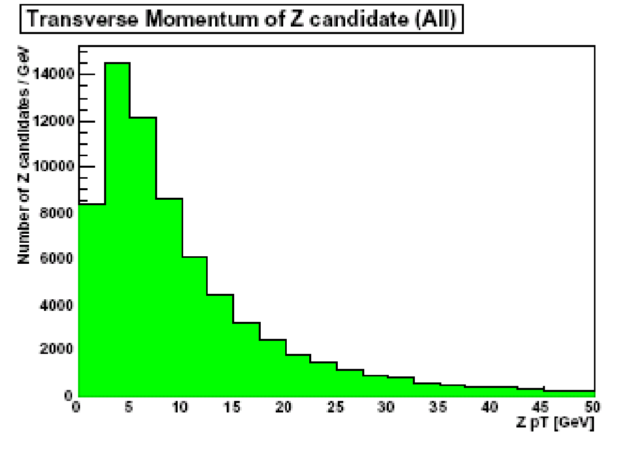


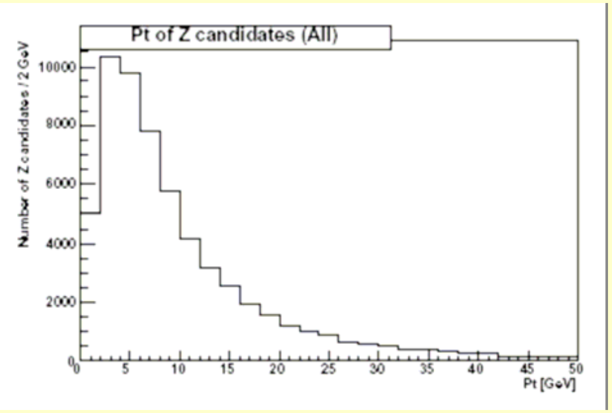




$$\sigma_{E'}/E' = \sqrt{C^2 + N^2/E'^2 + (p_0 \times \exp(\sin(\theta))/\exp(p1))^2}$$

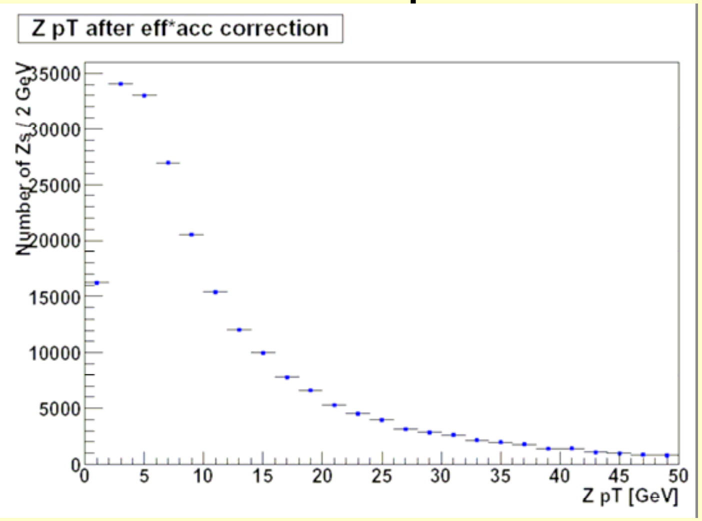
# Correct Z pT spectrum




Subtract background




Correct for eff and accep




Correct for smearing effect

?