Run II Physics Commissioning in DØ

Kristian Harder, Kansas State University
for the DØ Collaboration

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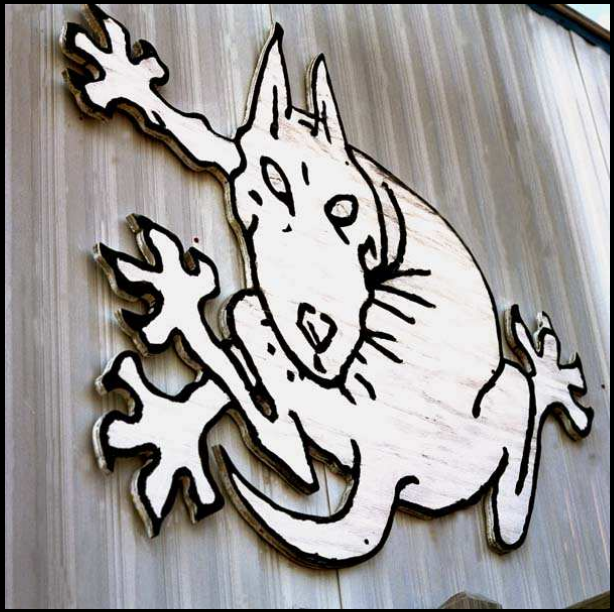
Tev4LHC workshop, CERN

Overview

- DØ Run II detector and trigger system
- calorimeter: jets, missing E_T
  electrons, photons, tau
- muon system: triggers
  muon identification
- tracking: triggers
  track reconstruction
  vertices
  b-tagging



the d0g

mostly a broad overview;
some recent topics in more detail
main focus on high-level physics objects

Disclaimer

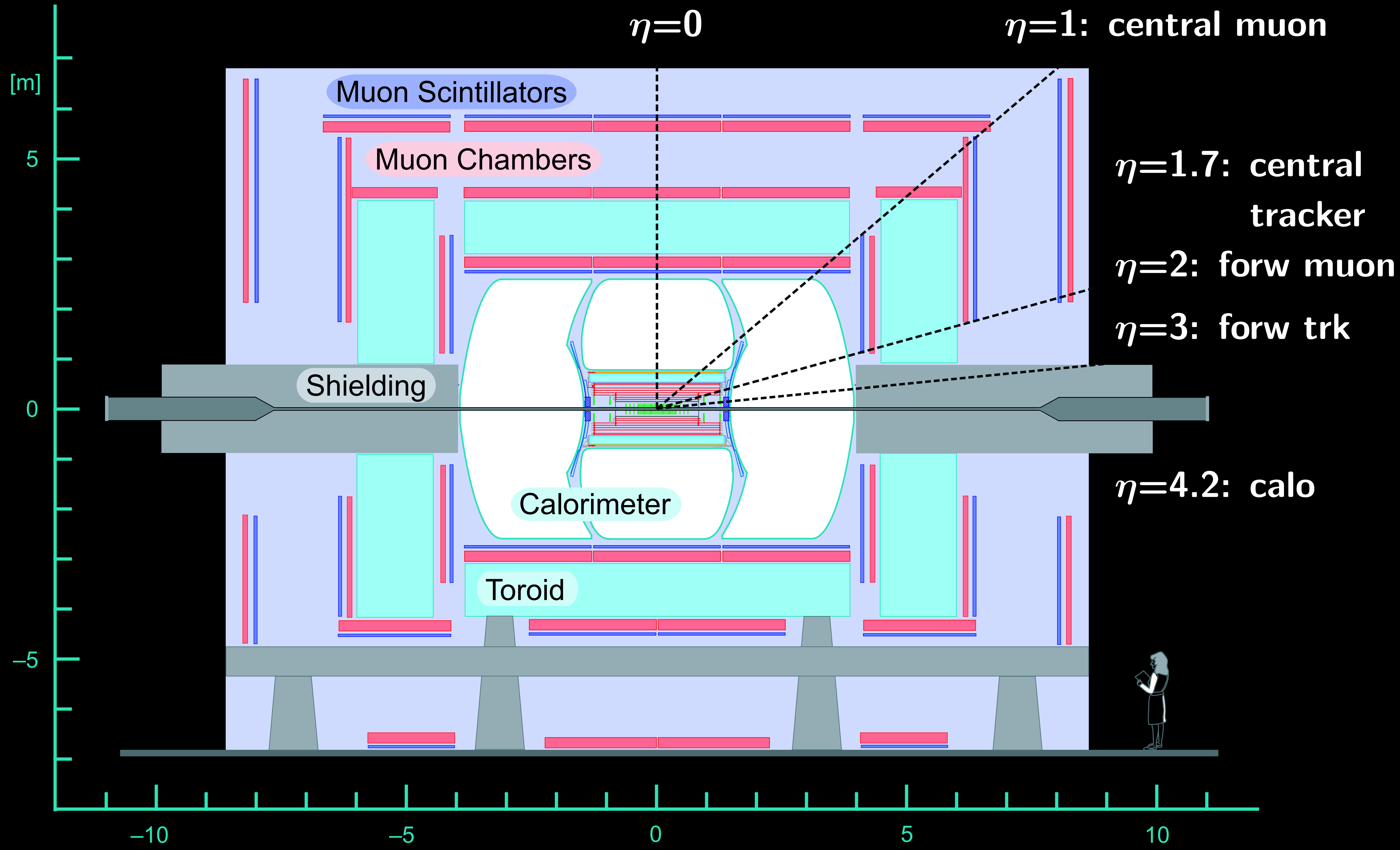
I am not showing *any* official DØ physics results here!

see Daniel Bloch's talk this afternoon for those
plus a number of parallel session talks

All plots and numbers are for illustrative purpose only

demonstrating the hard work put into understanding
the detector response and physics objects

DØ Run II detector

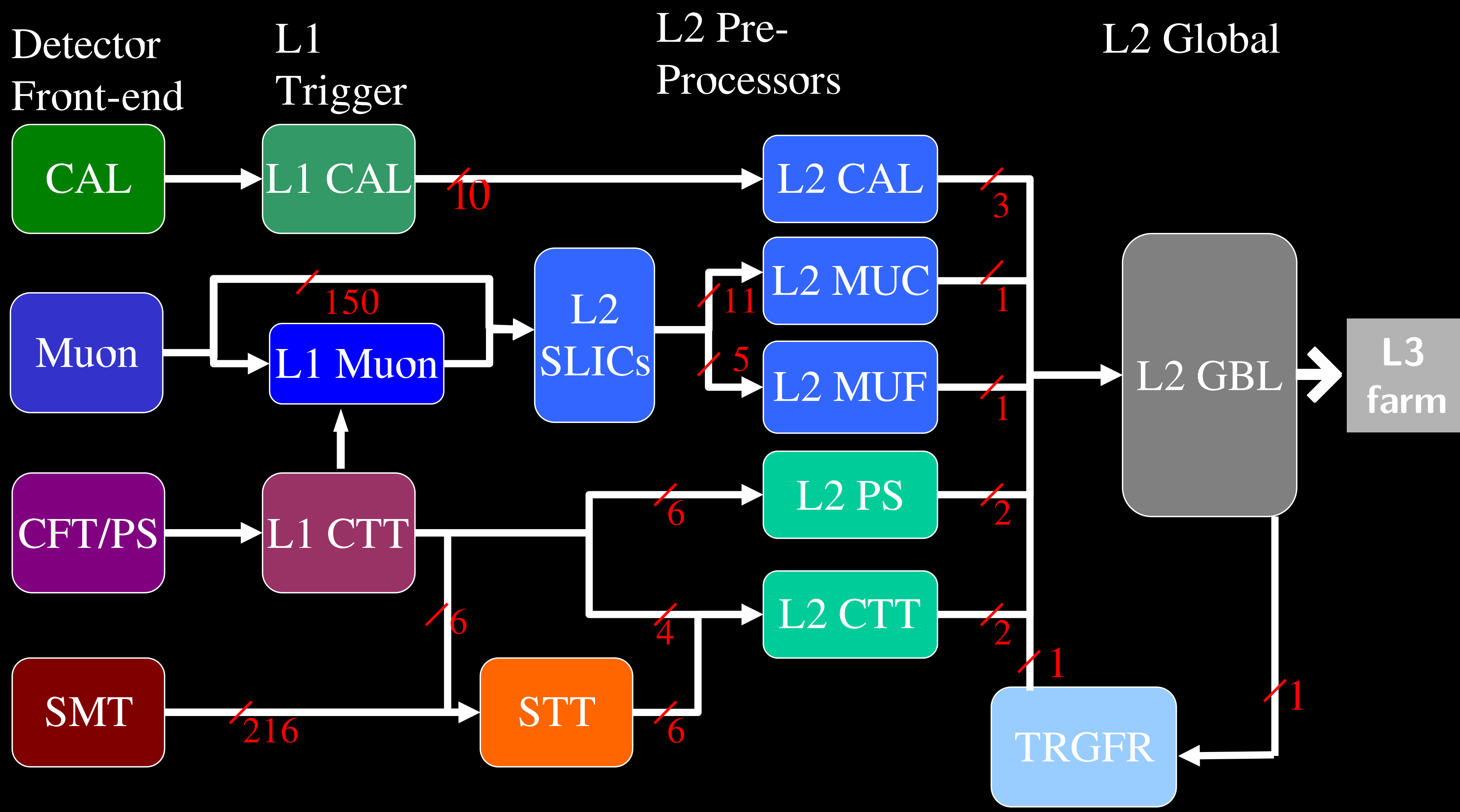


DØ detector features

- large η coverage of tracking, calorimeter and muon system
- small outer radius of tracking detector
  $\longrightarrow$ limited charged particle momentum resolution
- larger inner radius of tracking detector: 2.6 cm
  (compared to 1.5 for CDF — to be matched by DØ soon)

- small number of hits per track
  $\longrightarrow$ not much redundancy
- toroid magnet for muon momentum measurement independent of tracking

DØ trigger system



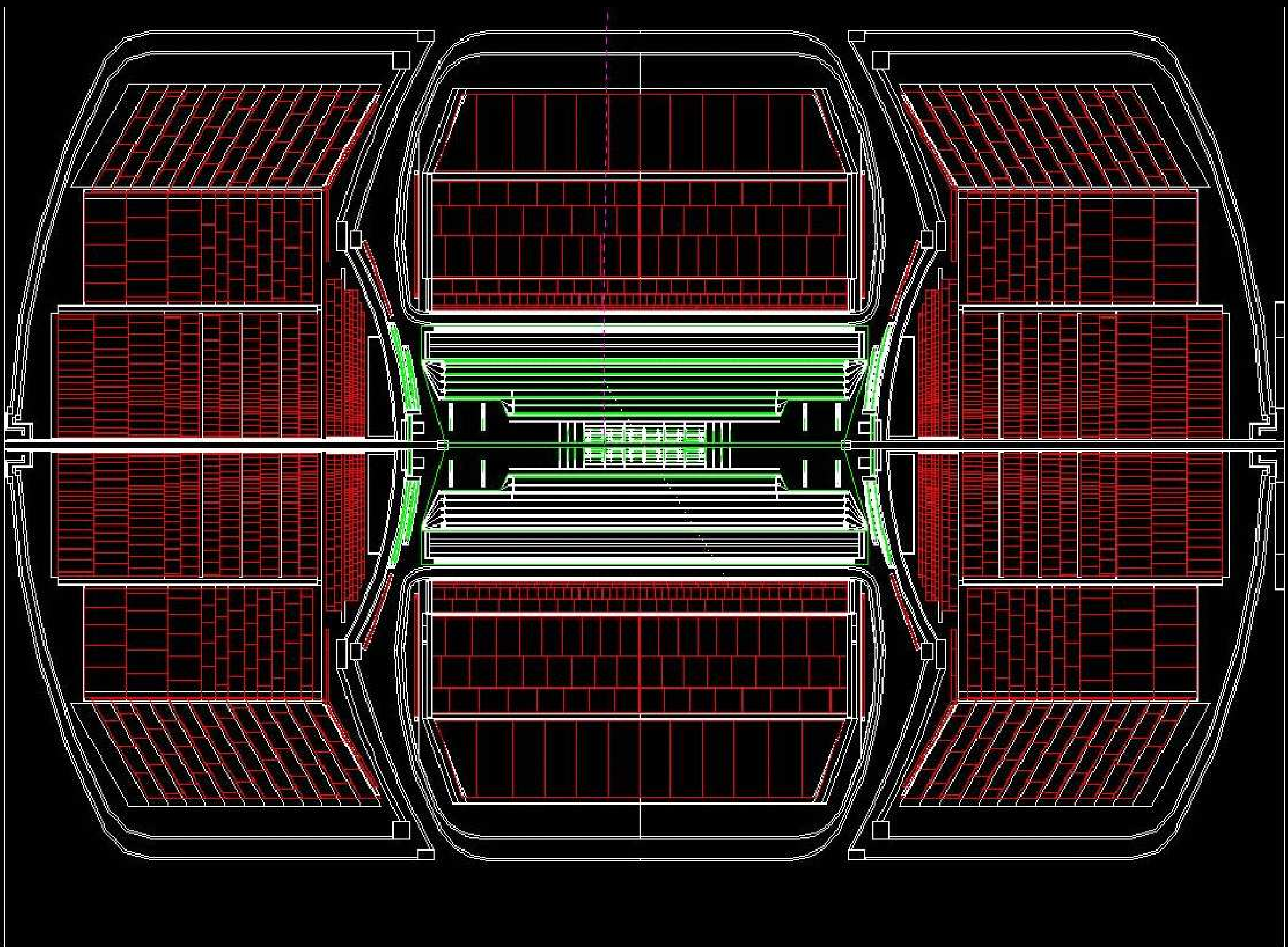
Trigger rates

- L1 input rate: 7.6 MHz (132 ns)
- L1 output rate: initial design 10 kHz
  limited to 1.5 kHz for tracking readout with $\leq$5% deadtime
- L2 output rate: 1 kHz
  more refinement, less rejection than initially planned
- L3 output rate: 50 Hz
  doing full (fast) event reconstruction for L3 decision

making efficient use of available bandwidth:

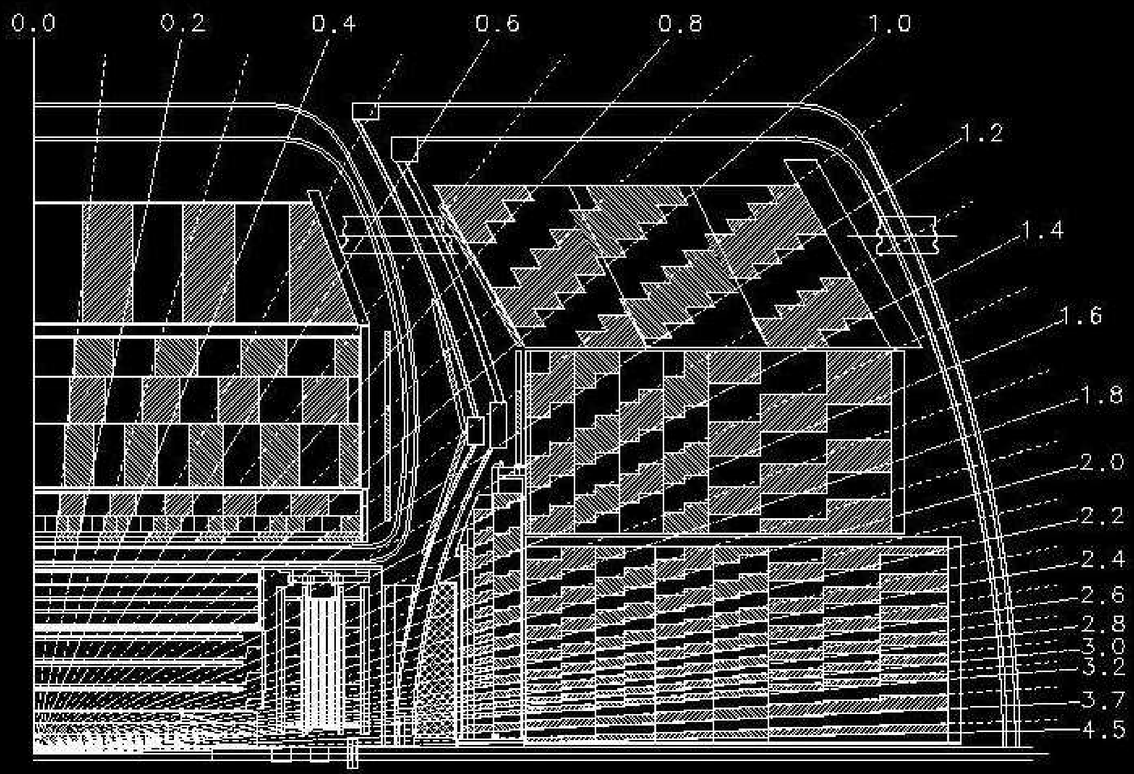
- two years ago: transition from physics group-requested triggers
  to more generic triggers
- additional systems commissioned (STT, L2PS)
  $\longrightarrow$ better rejection at early stages
- detailed trigger list evolving with increasing luminosity

Calorimeter



Calorimeter triggers

pseudo-projective towers with $(\Delta\varphi,\Delta\eta)=(0.1,0.1)$



L1 triggers on fast energy sum in $(\Delta\varphi,\Delta\eta)=(0.2,0.2)$ regions,
total E_T sum,
missing E_T

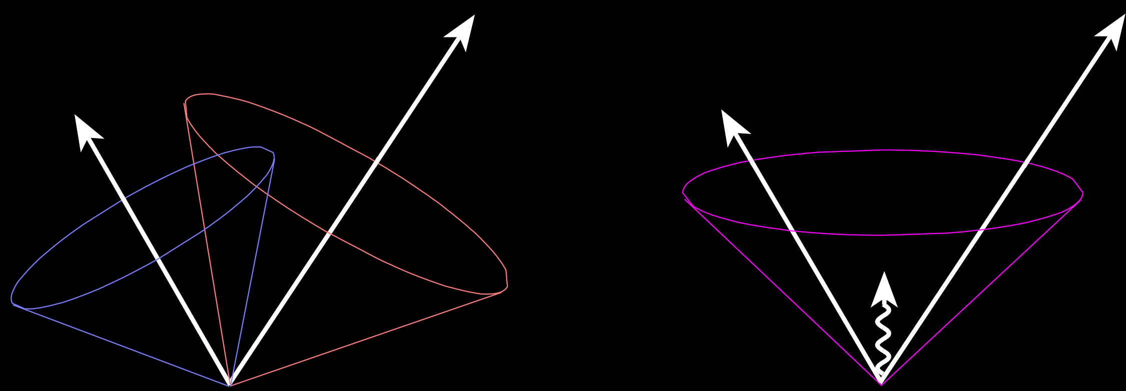
L2 does E_T ordering and fast clustering for jets and EM objects

Jet definition

DØ jet definition based on calorimeter only
(track jets treated separately and matched at later stage)

DØ is typically using a cone algorithm:

- all particles (calo towers, MC particles, partons) are seeds
- four-vector sum of all particles in cone ($\longrightarrow$ jet axis)
- move cone axis to jet axis
- iterate until stable jet axis = cone axis
- introduce mid-points between jet candidates as additional seeds
  $\longrightarrow$ address issues with infrared safety
- merge/split overlapping jets according to momentum fraction in overlap



Jet history

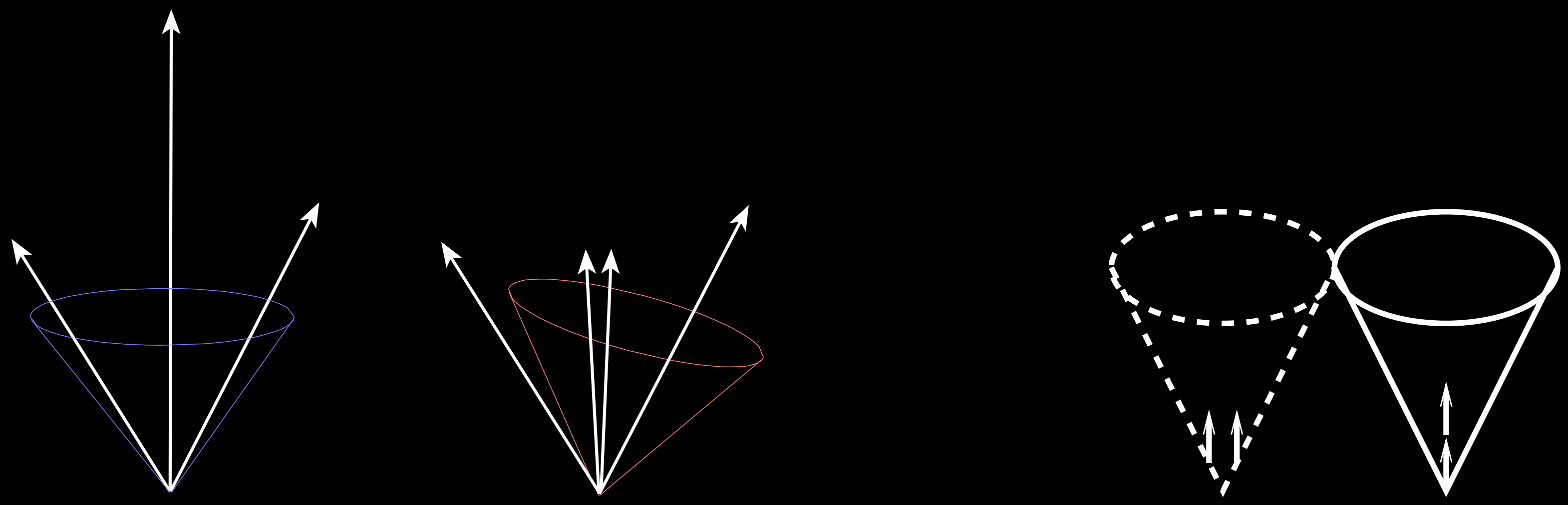
jet algorithm evolved from Run I. improvements:

- boost-invariant R and recombination scheme (four momenta)
- infrared safety due to mid-point seeds

  allows consistent treatment of parton level

clearly an improvement. but open issues remain:

- collinearity issues due to p_T ordered seeds may impact low p_T jets



k_T algorithm does better here, but detector effects harder to control.
minor issue in practice for large p_T physics

- detector response! $\longrightarrow$jet energy scale

Jet energy scale

reconstruction of jet energy is distorted by

- additional interactions
- electronic noise
- noise from Uranium decay
- pileup from previous bunch-crossings
- energy deposition outside jet cone
- different response for different particles

(first four: offsets; last two: factors)

$$E = \frac{E_{meas} - E_{offset}}{R_{cone} * R_{response}}$$

additional problem: ≈20% of b-jets have muon + neutrino

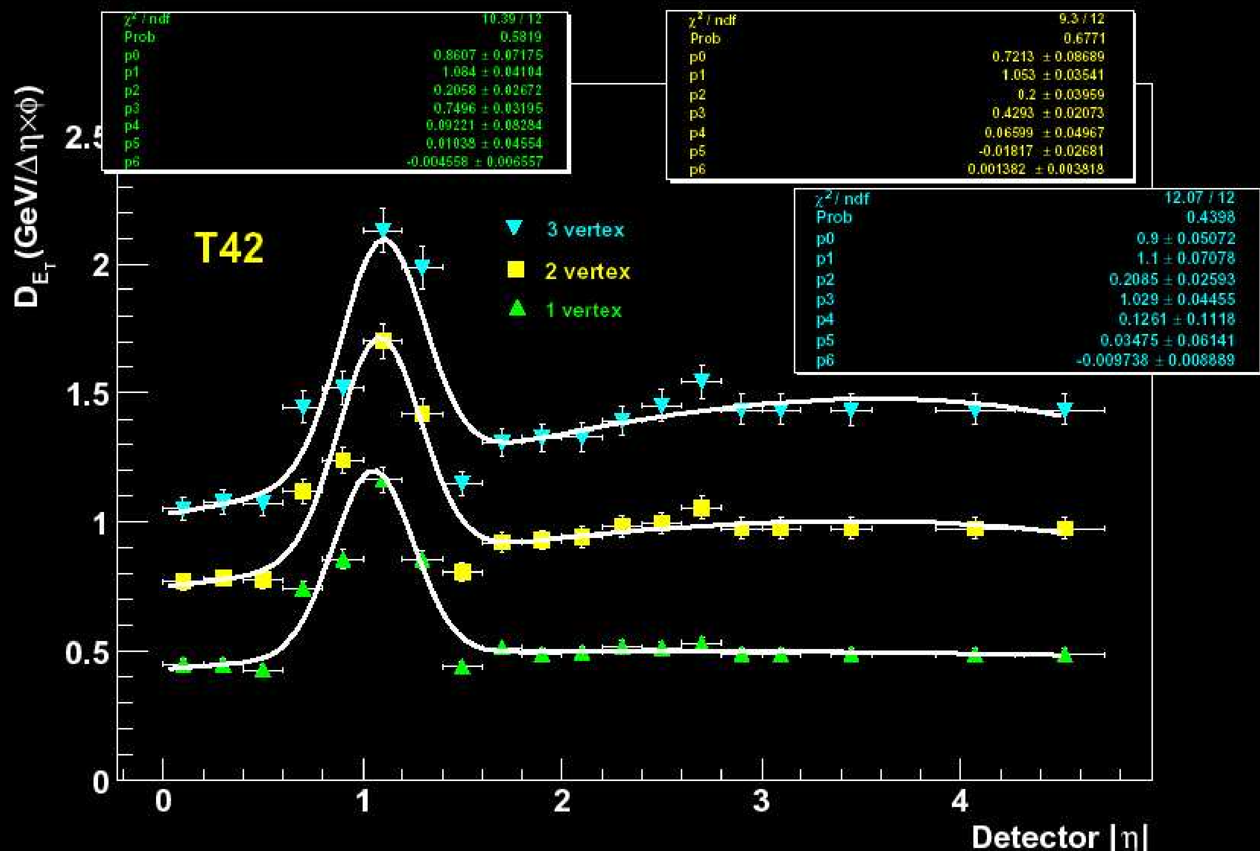
JES dominates systematic uncertainties for e.g. top mass measurement

→ ongoing effort towards better understanding

JES: offset energy

- additional interactions
- electronic noise
- noise from Uranium decay
- pileup from previous bunch-crossings

can be evaluated with triggers on bunch-crossings without hard interaction



clear dependence on num of underlying events

bump in central/endcap overlap region: different ADC to energy conversion factors

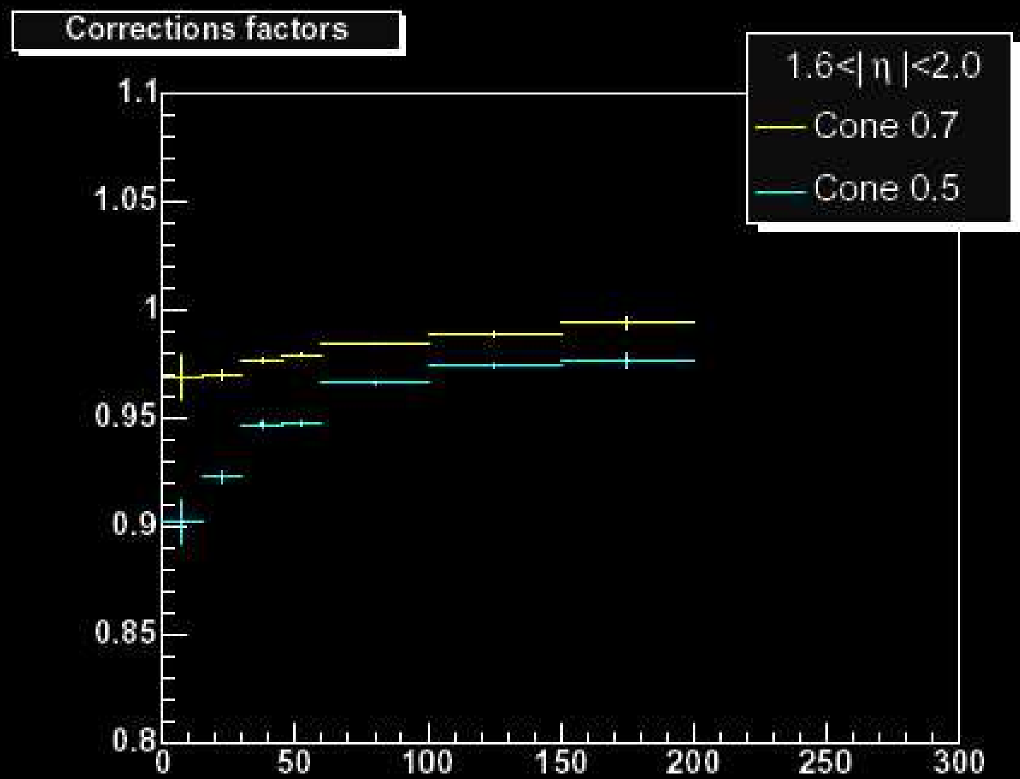
uncertainties:
- statistical
- luminosity dependence
- φ dependence

reminder: no official DØ results!

JES: out of cone energy

★ energy deposition outside jet cone

can be evaluated with back-to-back di-jet events:
— get jet energy density dependence on $\sqrt{\Delta y^2 + \Delta\varphi^2}$ wrt jet axis
— subtract baseline (see previous transparency)
— calculate fraction of jet energy inside cone radius in bins of E and η



BUT: need correction for *physics* out of cone showering! $\longrightarrow$ from MC

JES: calorimeter response

★ different response for different particles

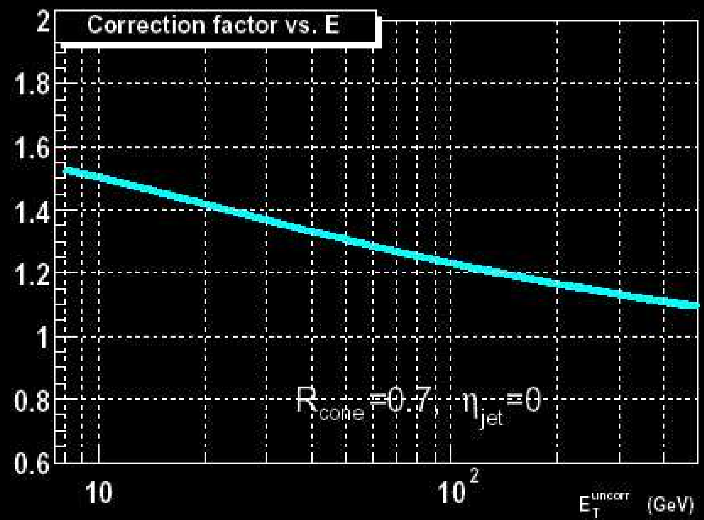
the dominant effect (both value and uncertainty)!
measured using *missing E_T projection fraction method* (like Run I):
— take γ + 1 jet events
— different response to γ and jet $\longrightarrow$ apparent missing E_T
— hadronic response can be derived from EM response
— EM response can be measured in Z$\longrightarrow$ee events
(many complex details not mentioned here)

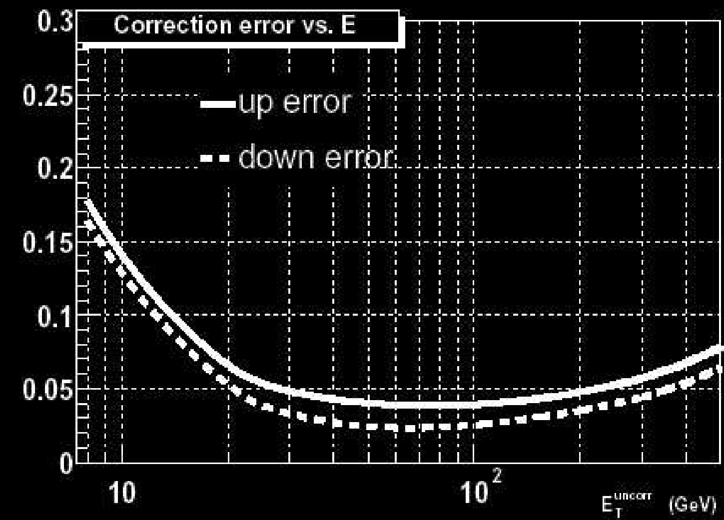
★ special treatment of semileptonic b jets

— subtract 1 MIP from calorimeter energy
— add muon energy from tracking or muon system
— correct for neutrino momentum using Monte Carlo

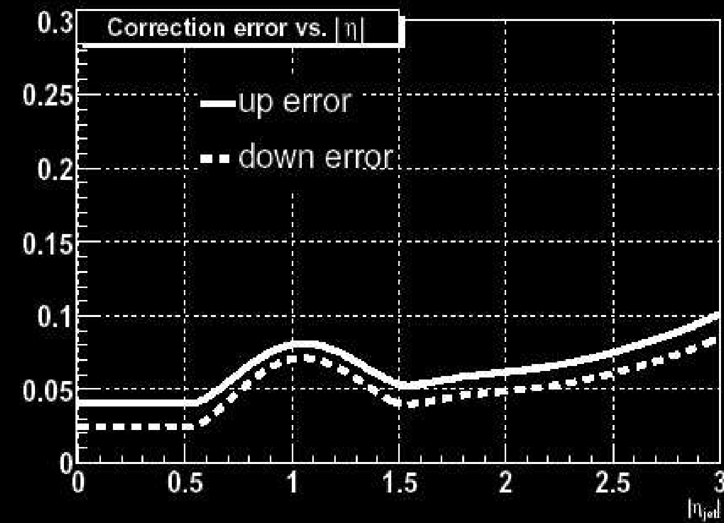
Overall jet energy scale

correction vs E:





correction vs η:

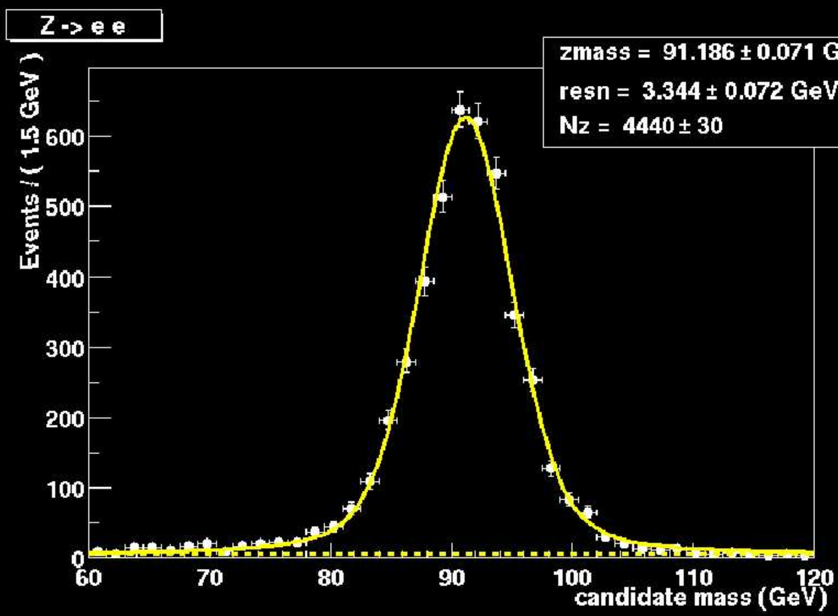


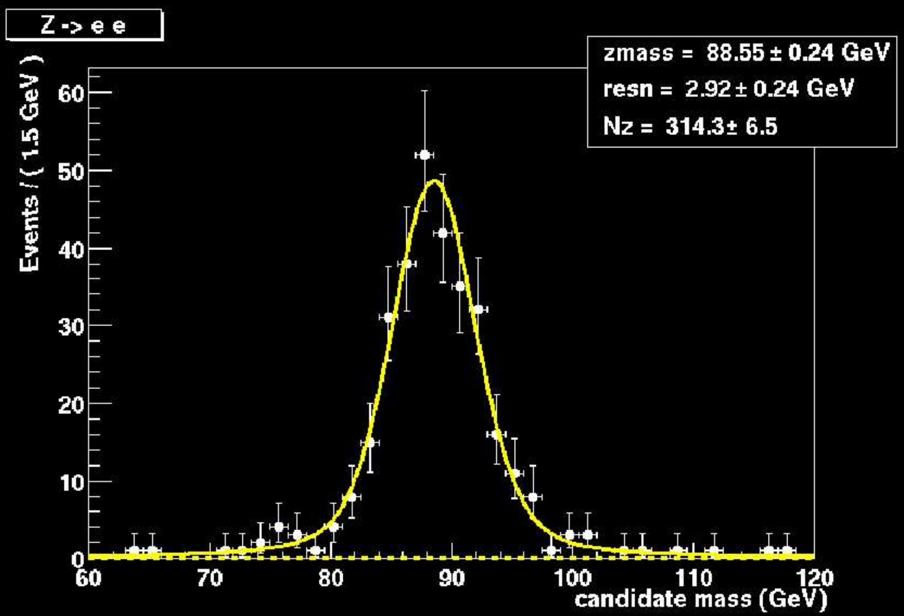
two of the effects potentially limiting jet response understanding:

- **calorimeter calibration**
- **calorimeter resolution**

Calorimeter calibration

proper calibration of calorimeter response is crucial!
DØ calibrates ADC response by charge injection
No calibration of the cell response itself
Cell response varies as well! (Run I mech tolerances vs. Run II timing...)
Extreme example:





Z⟶ee test sample
mass 91.2 GeV
width 3.3 GeV

same sample, one e in module 17
mass 88.6 GeV !!!
width 2.9 GeV

reminder: neither plot represents official DØ Z results!

Calorimeter calibration II

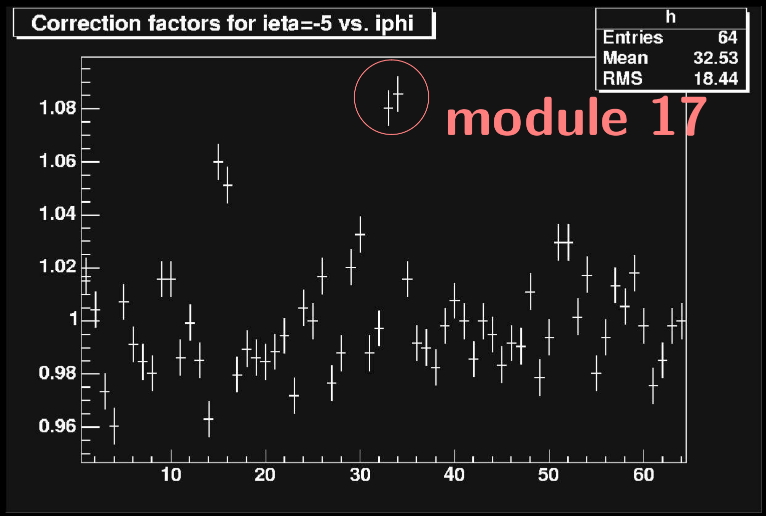
response calibration using physics signal like Z⟶ee:

not enough statistics to do this on cell level with individual process,
but Tevatron physics is φ-independent! (unpolarized beams)

apply φ intercalibration (here: EM calorimeter)

- take data sample with EM trigger
- in η bins, correct cell energies by scale factor ⟶ φ uniformity
- use e.g. Z⟶ee events for absolute calibration of each η bin

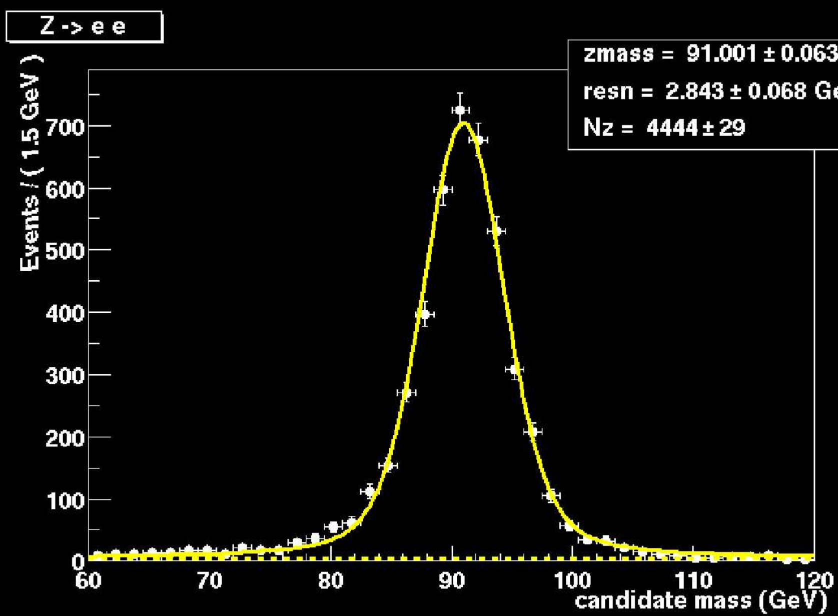
1.10
1.00
0.97



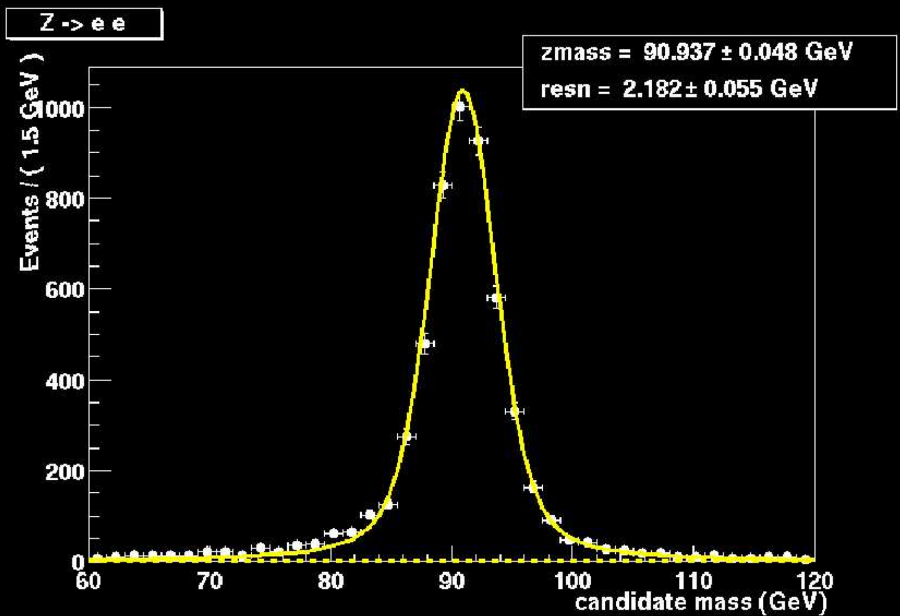
Z width on this sample reduced from 3.3 GeV to 2.8 GeV (using a simplified procedure!)

Calorimeter resolution

Let's look at Z plots again:



Z⟶ee with φ intercalibration
width 2.8 GeV

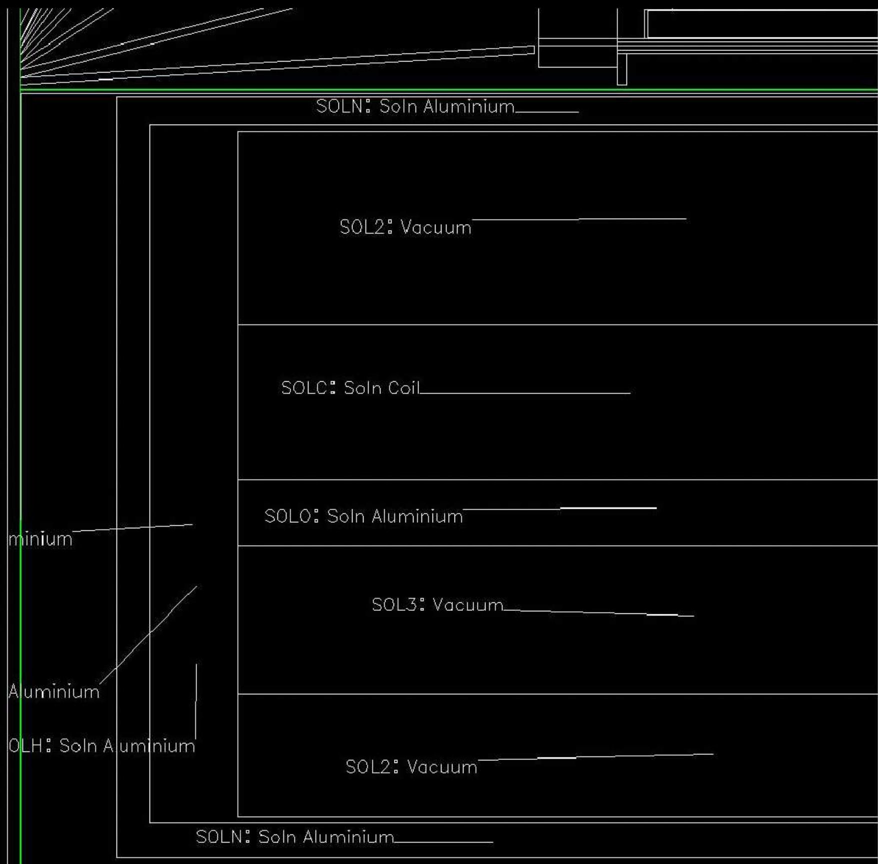


Monte Carlo sample
width 2.2 GeV

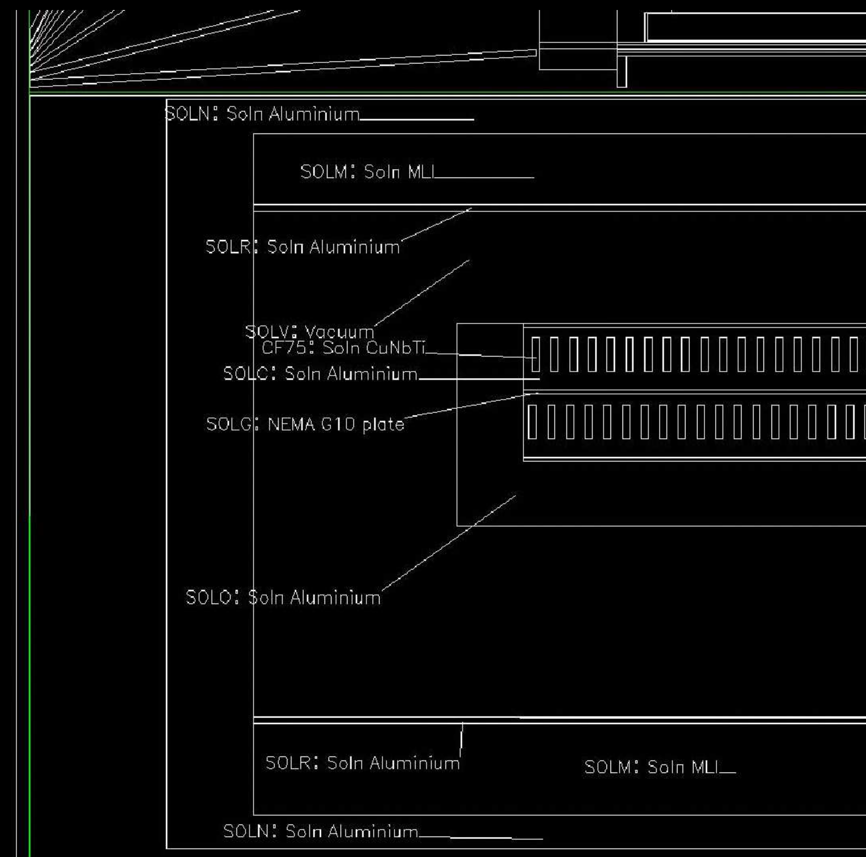
Potential reasons for worse resolution in data than MC:

- different response depending on where particles hit the cell?
- material simulation (esp. amount and inhomogeneity) in front of calo!

Material simulation: solenoid



current simulation



improved simulation

- solenoid was just a homogenous cylinder. now: a real coil!
- inner calorimeter cryostat wall was way too thin

→ lesson: sooner or later this will hit you, so better fix it now!

impact on agreement data/MC to be evaluated...

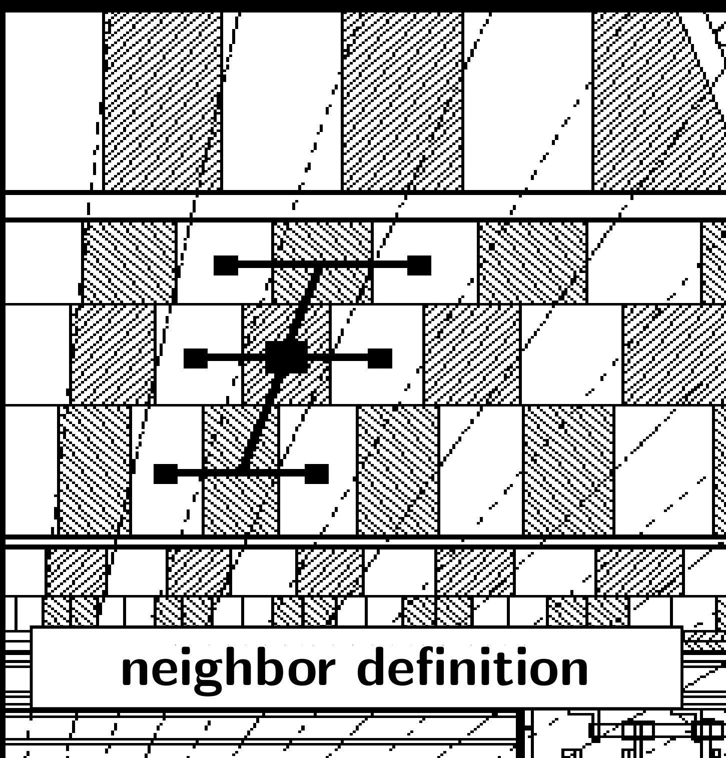
Calorimeter noise suppression

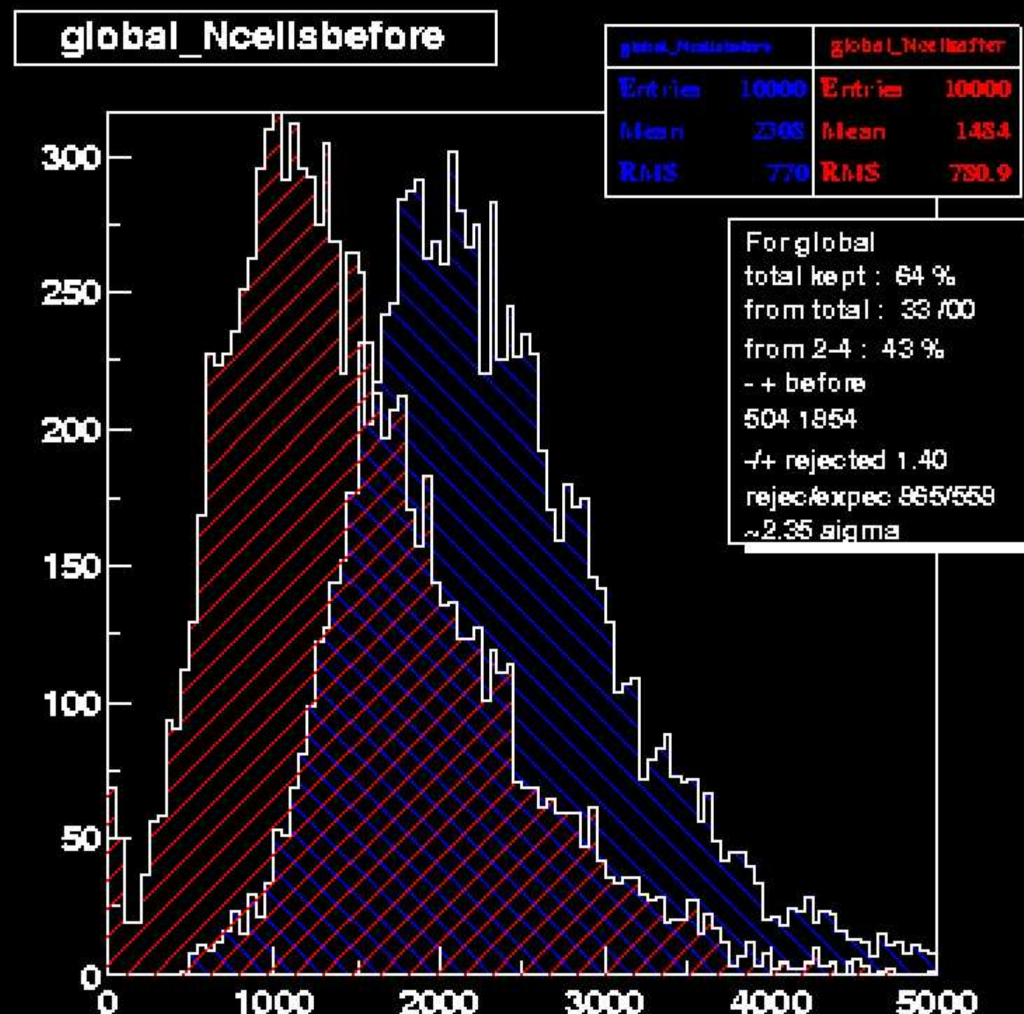
T42 algorithm (before actual clustering!):

- keep only cells 4 sigma above threshold
- keep neighboring cells that are 2 (actually 2.5) sigma above threshold

(inspired by H1)

removes about 40% of the cells!
positive impact on physics (resolutions!)





More calorimeter objects

- missing E_T
- electrons
- photons
- τ leptons $\longrightarrow$ dedicated talk on τ ID by M. Heldmann on Friday

Missing transverse energy

"neutrino identification" (and other non-interacting particles)
crucial e.g. for distinction tt di-lepton events vs. leptonic Z decays plus jets

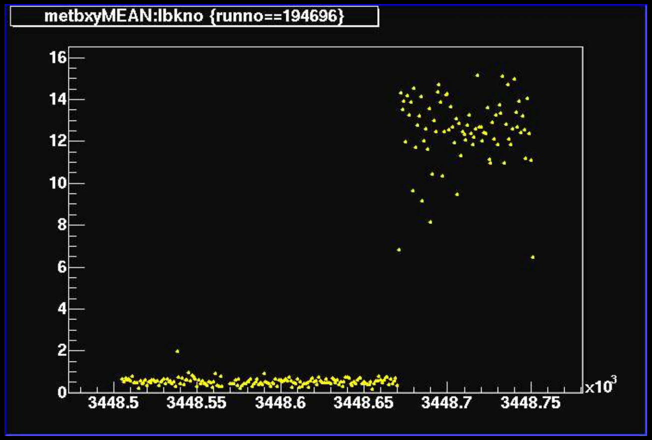
big concern: how to distinguish actual MET from

- detector resolution effects
- primary vertex misidentification
- calorimeter noise
- "hot" or missing calorimeter cells

approach:

- propagate EM scale and hadronic jet energy scale to MET
- detailed monitoring of DØ data for detector problems:
  - non-isotropic φ distribution of good jets
  - large $\sqrt{\langle \mathrm{MET_x} \rangle^2 + \langle \mathrm{MET_y} \rangle^2}$

real MET should be symmetric in φ on average!



EM objects I

typical selection criteria for (isolated) electrons at DØ :

- electromagnetic energy fraction >0.9
- calorimeter isolation cut
- p_T cut
- track match with χ^2 probability requirement
  matching either calo $\longrightarrow$ preshower $\longrightarrow$ track
  or track $\longrightarrow$ preshower $\longrightarrow$ calo
- shower shape likelihood ("H-Matrix") cuts:
  full H-matrix has 8 variables:
  energy fraction in 4 EM layers
  total EM energy
  vertex z position
  transverse shower width in φ
  transverse shower width in z (bad MC description $\longrightarrow$ typically excluded)

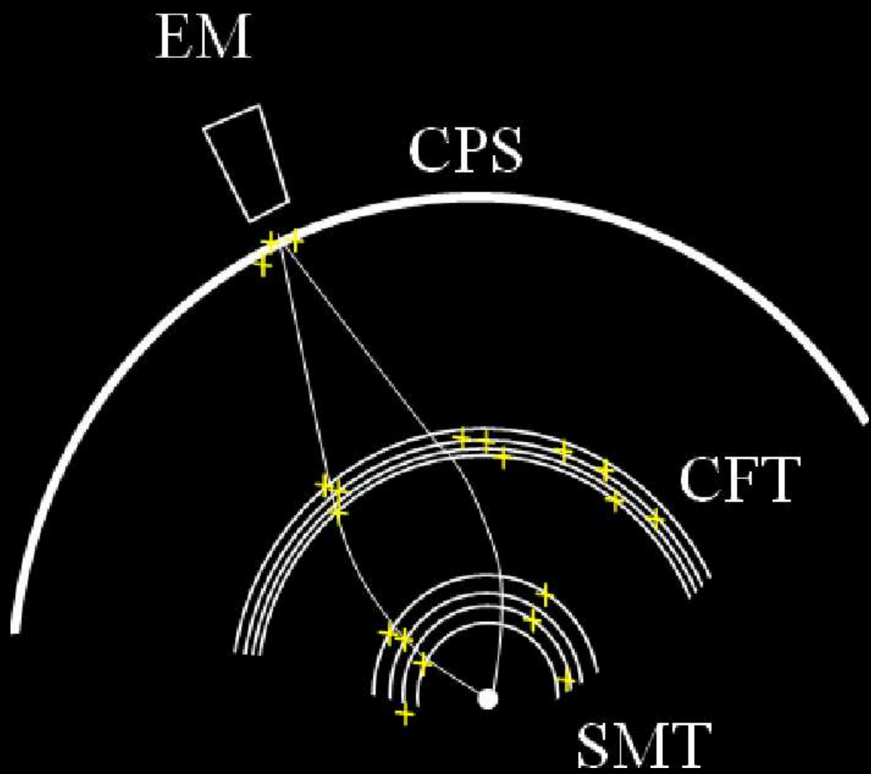
EM objects II

typical selection criteria for photons at DØ :
same as electrons, but no track match

but: large background from electrons with missing track/bad matching
especially in forward region

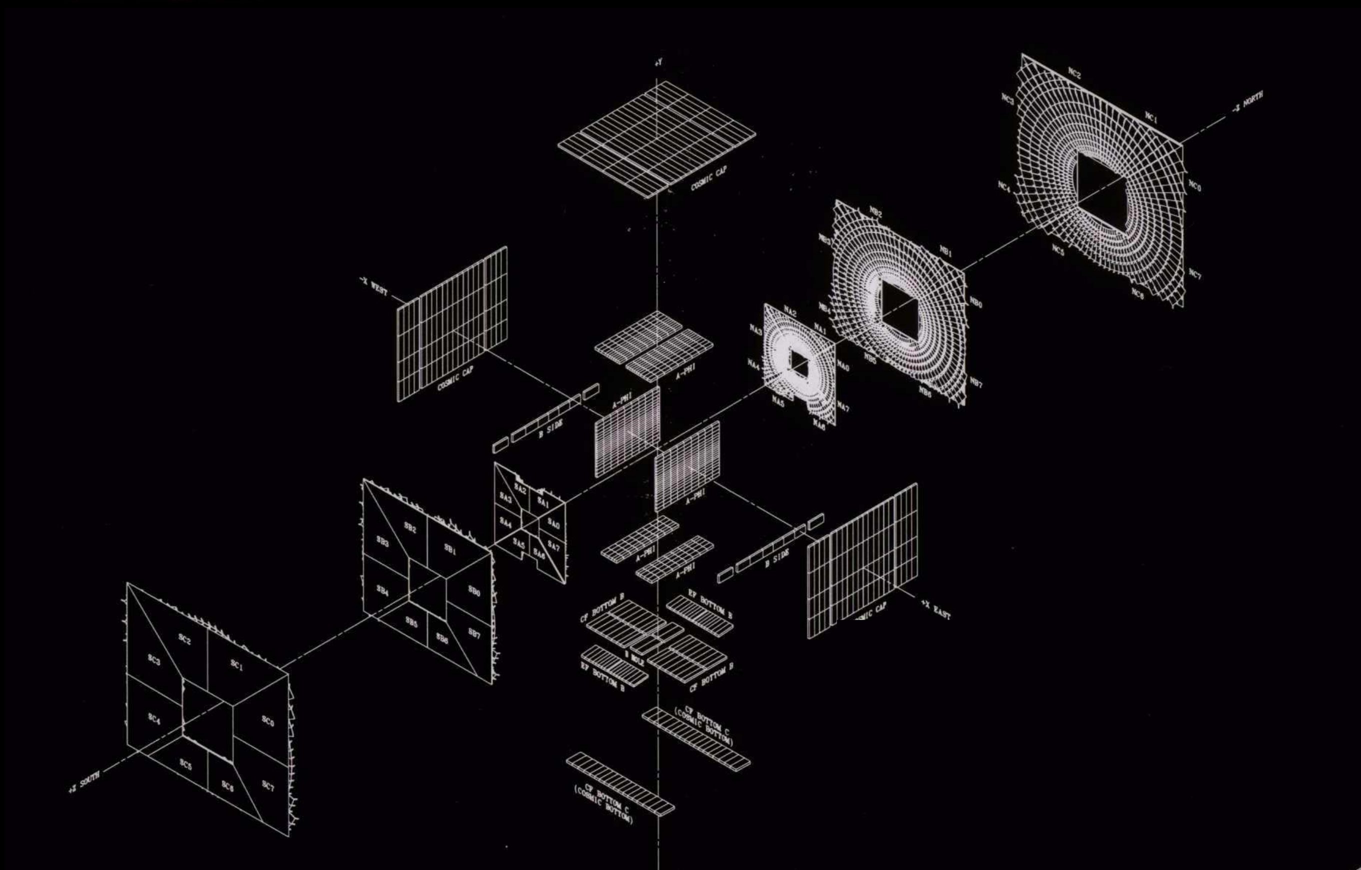
new development: “hits on the road” method

- calculate road of charged particle from primary vertex to preshower assuming E_T of EM object (two possibilities)
- count number of tracker hits close to trajectories

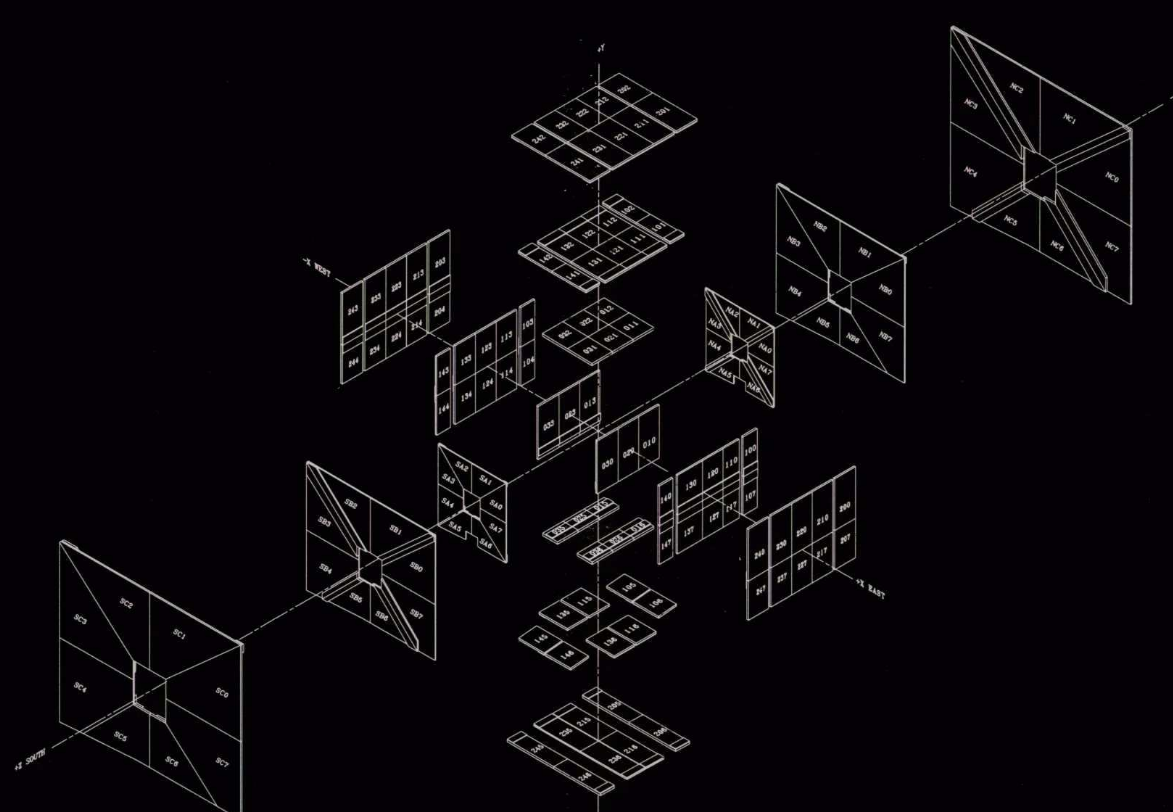


→ rate of electrons misidentified as photons decreased by factor of four!

DØ muon system

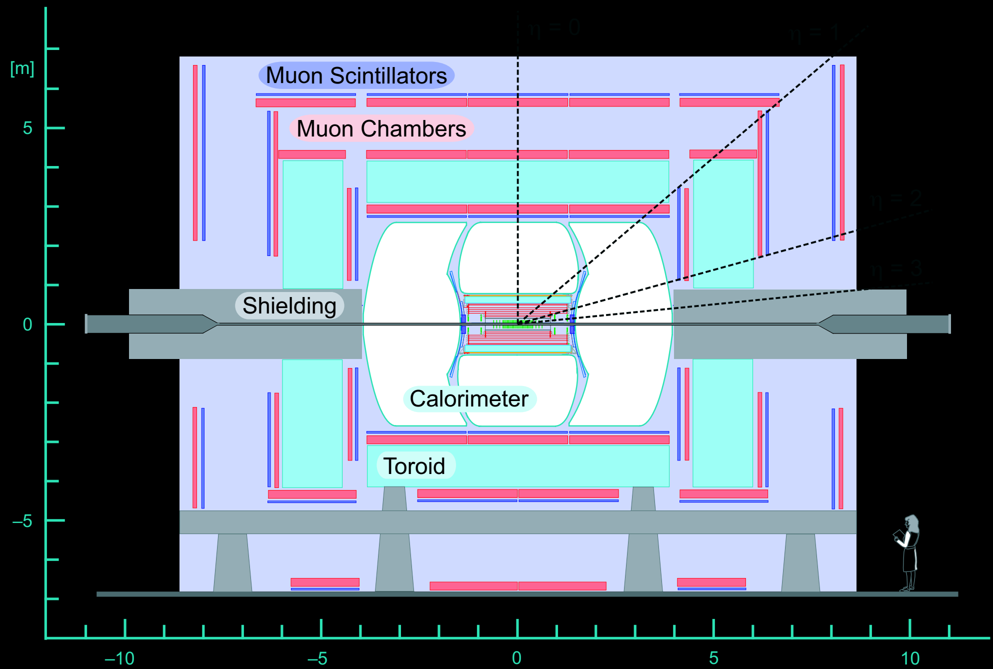


scintillators



drift chambers

DØ muon trigger



L1

- look for track stubs in drift chamber
- merge with scintillator hits
- independently, merge CFT tracks with scintillator hits

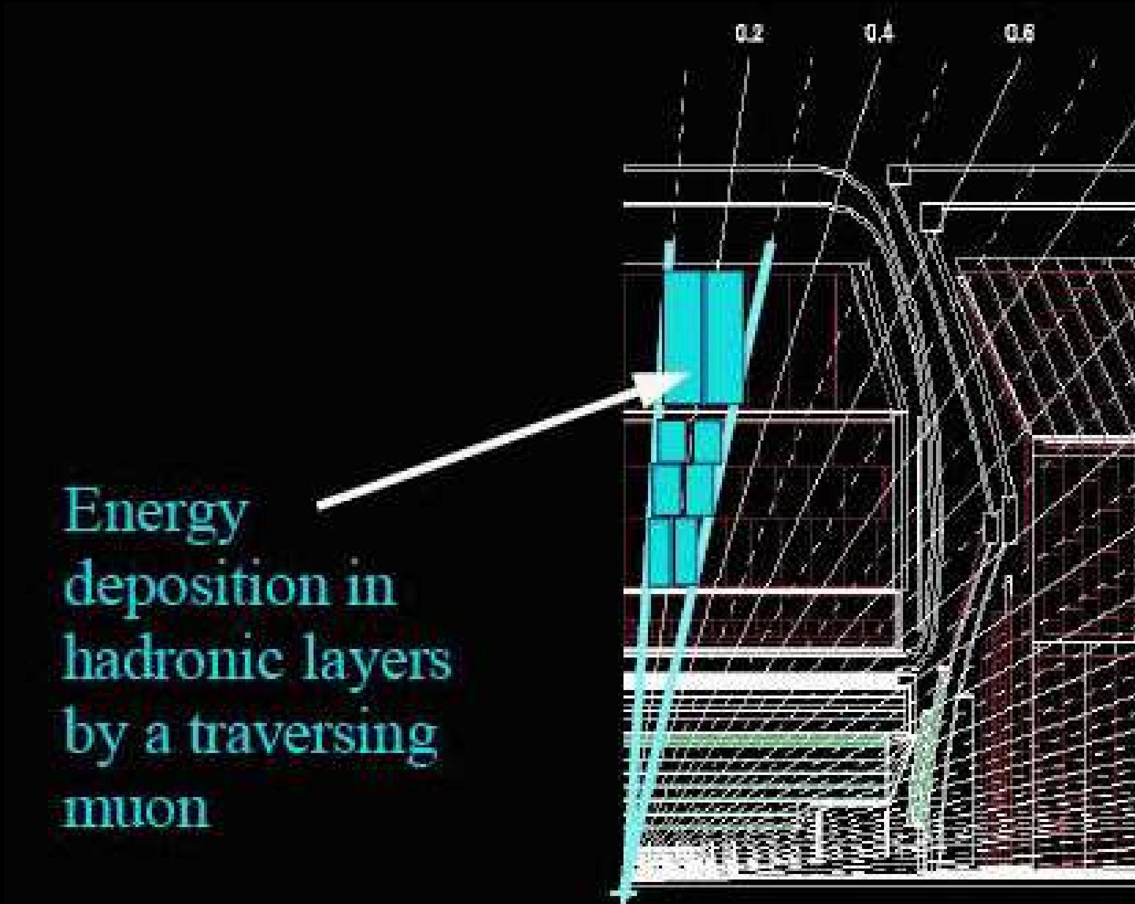
L2

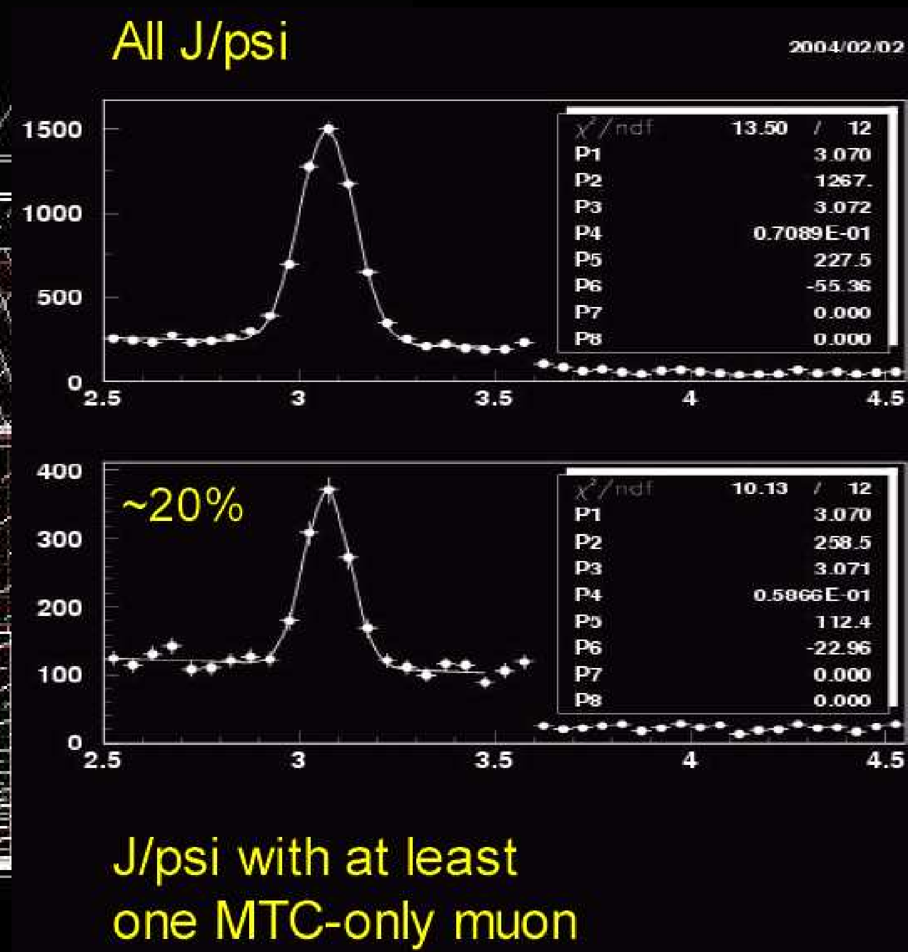
- redo track fit in each muon layer
- merge all layers to muon track
- track matching to central tracker (in global L2 system)

Muons in offline reconstruction

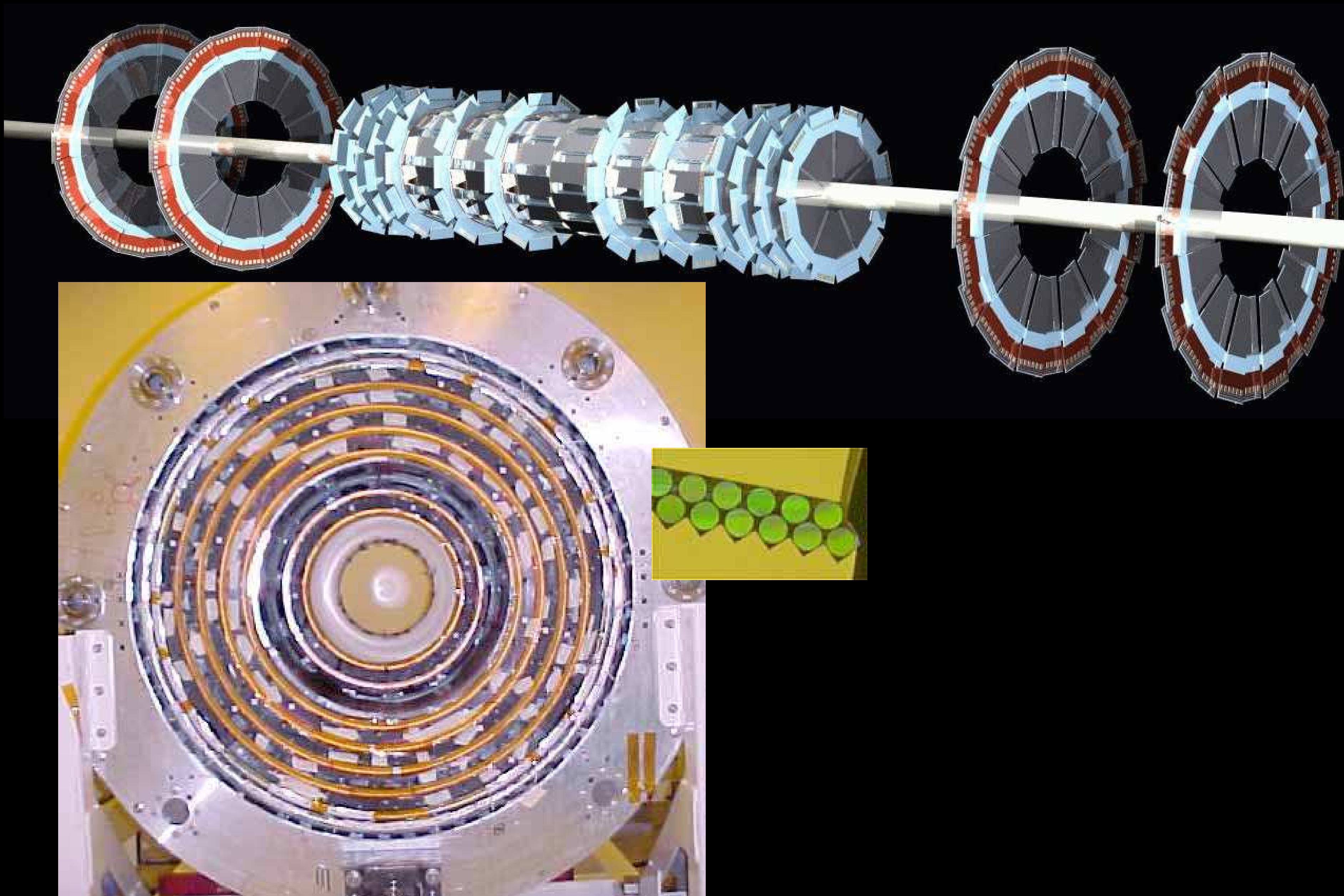
selected current issue:

- large hole of inner muon layer on bottom of detector
  $\longrightarrow$ track match to muon system difficult (through toroid!)
- can we reconstruct muons without the muon system?





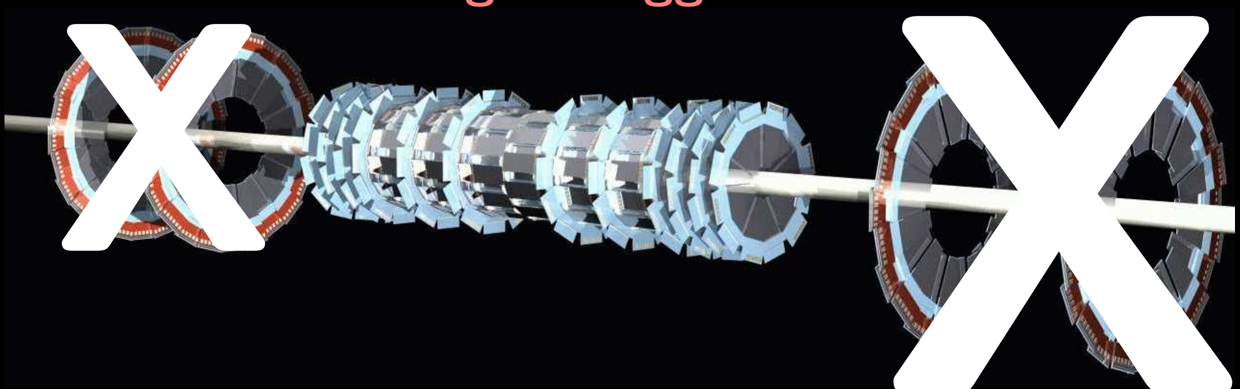
DØ tracking detectors



DØ track triggers

- L1CTT: p_t ordered list of fiber tracker tracks
  - input for L1 muon trigger
  - input for L2 silicon track trigger
- L2STT: p_t and impact parameter ordered lists of global tracks
- L2CTT: input either from L1CTT or from L2STT
  - (currently both for commissioning)
  - b-tagging at L2?
- several fast L3 tracking algorithms (different strategies)
- primary vertex finder for z cuts, jet ID, missing E_T

no forward tracking at trigger level!



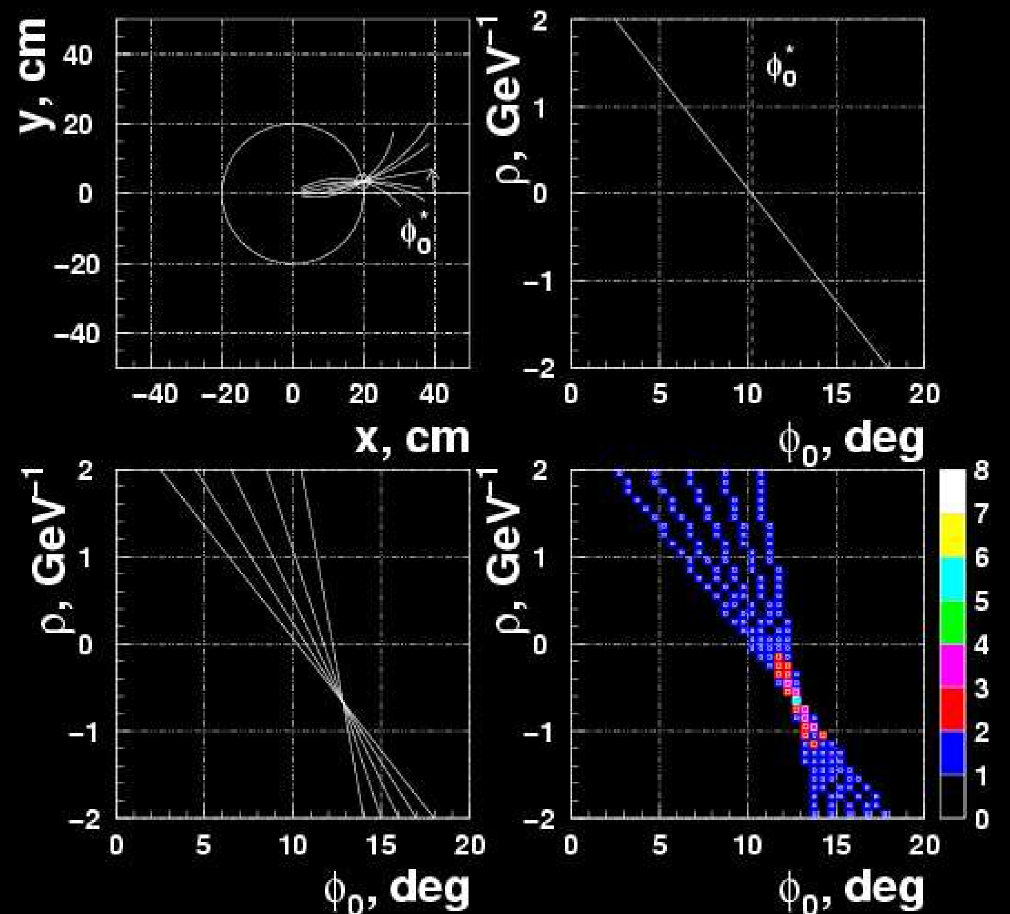
track reconstruction history

small tracker, not much redundancy! (≈ 20 hits per track)

Original tracking algorithm:
standard road search with Kalman filter fit
did not cope well with high track densities, noise, inefficiencies

later supplemented by histogram track finder (Hough transform)

- find peaks in φ_0-p_t plane
- 2d Kalman filter
- histogram filter for r-z
- 3d Kalman filter
- do this separately for SMT/CFT and extrapolate to CFT/SMT



combination of the algorithms:
very efficient, but high fake rate

track reconstruction today

alternative algorithm tuned for b physics:

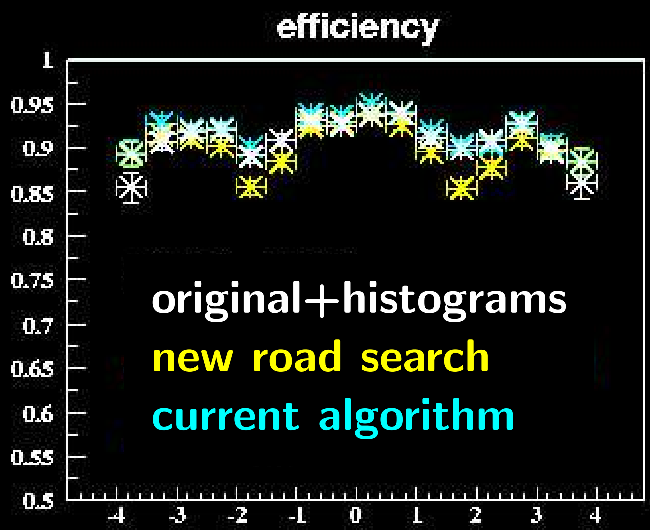
- low p_t tracks
- long-lived particles (K_s^0, Λ γ conversions)

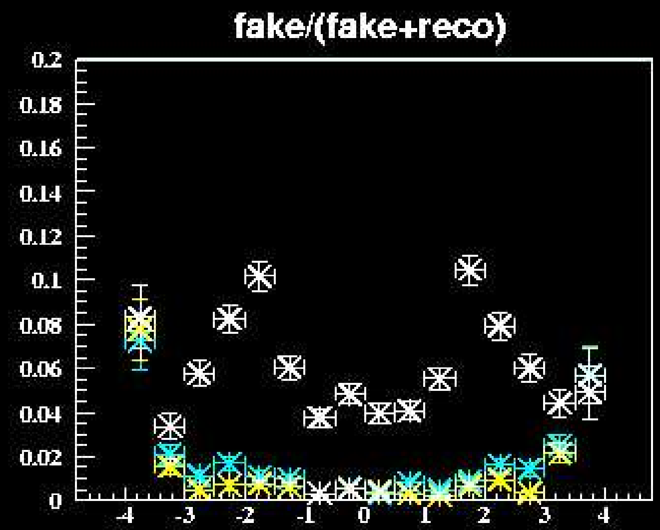
approach: another road search algorithm, BUT:

- allow many missed detector layers
- primary vertex hypothesis for non-SMT tracks
- keep ambiguities until final stage
  (several track candidates sharing hits, multiple stereo projections)
- when finally resolving ambiguities, prefer "better" tracks

best bet: extend new road search with histogram seeds!

performance study:
$Z \rightarrow \mu\mu$
+4 min bias evts
$p_T > 0.5$ GeV
plotted vs. η





checking track uncertainties

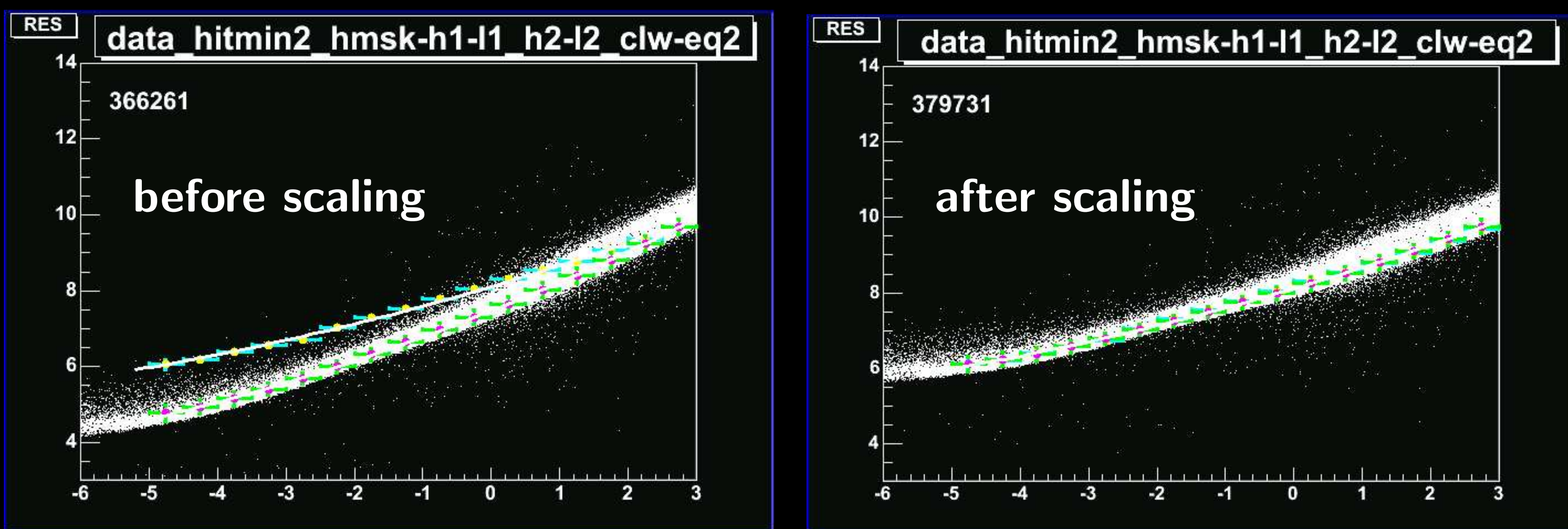
do our track covariance matrices make sense?

IP uncertainty assigned to tracks by tracker is crucial for vertexing.

compare:

- errors assigned by track reconstruction
  (based on material in propagator + on assumed hit resolution)
- actual spread of IP on track associated with primary vertex
  (QCD sample with V0 removal):

(done for DØ B_s mixing study)

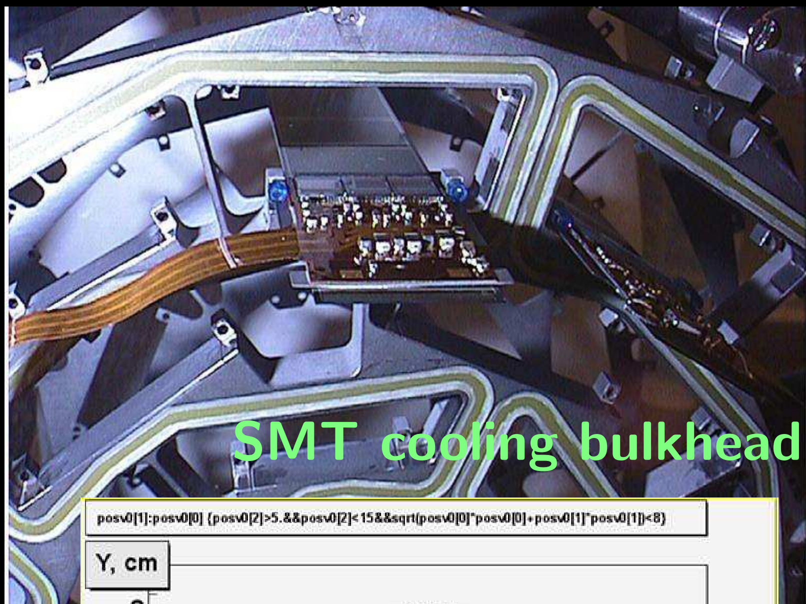


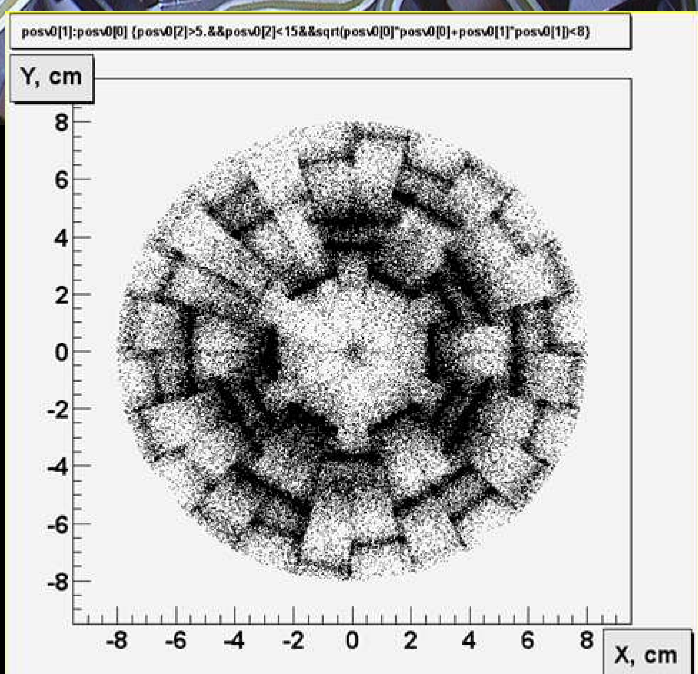
horizontal: $-\ln(p^2\sin^3\theta)$, vertical: $\ln(\sigma^2_{IP})$

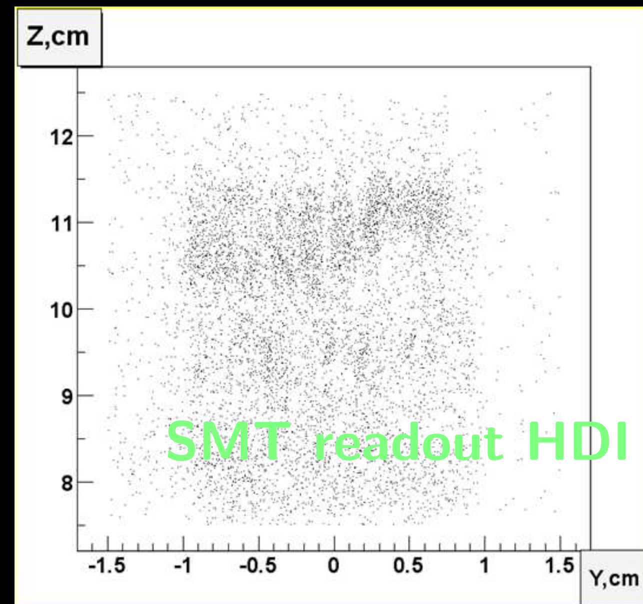
material simulation

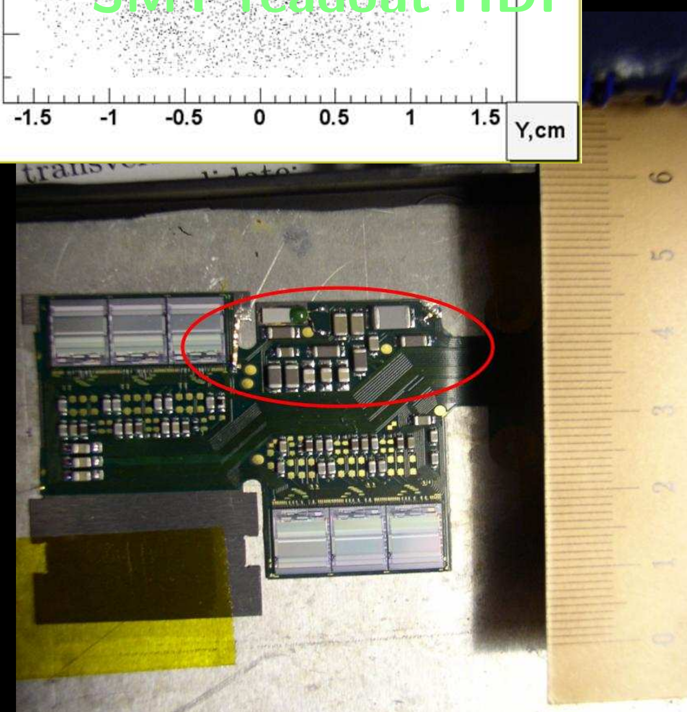
most likely reason for underestimated errors:
improper material representation in simulation and track propagators

material distribution can be evaluated by conversions:



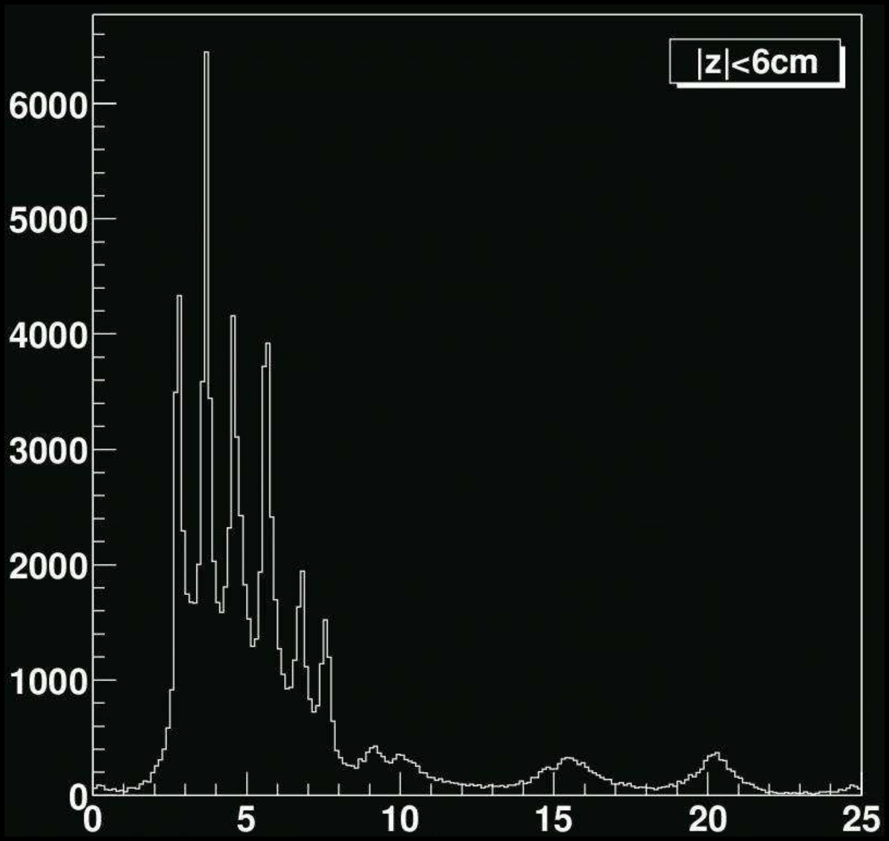


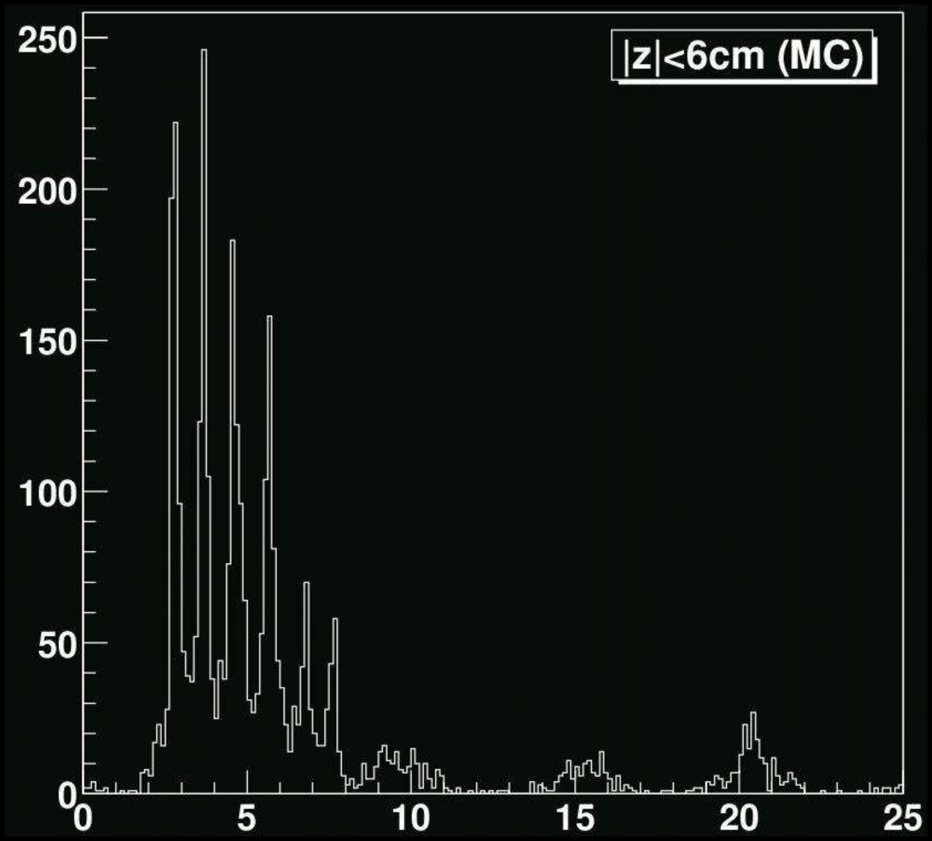




conversion tomography

tracker volume cross-section as seen with conversions:





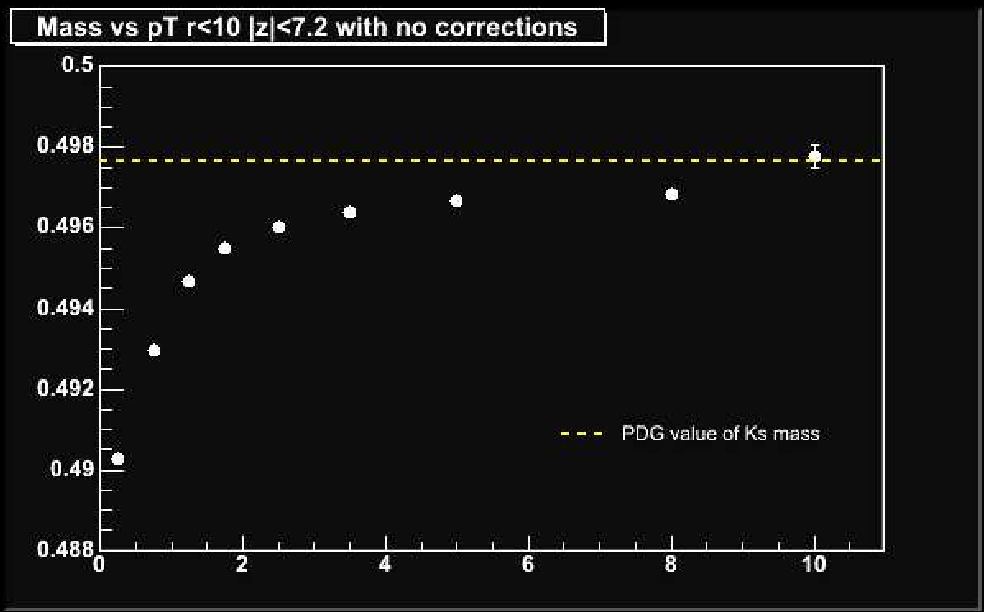
data

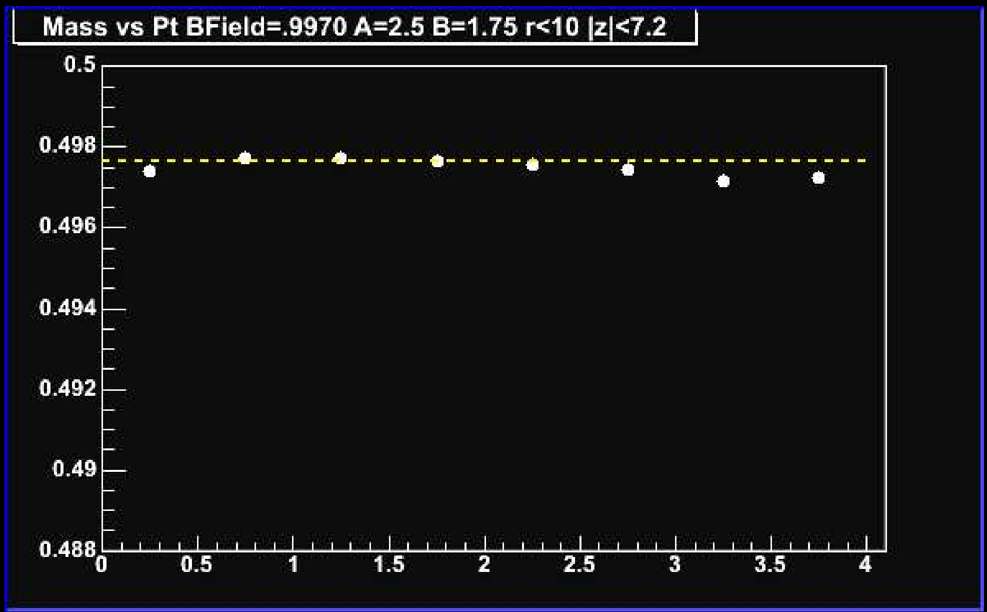
Monte Carlo

conversions show clear differences!

magnetic field correction

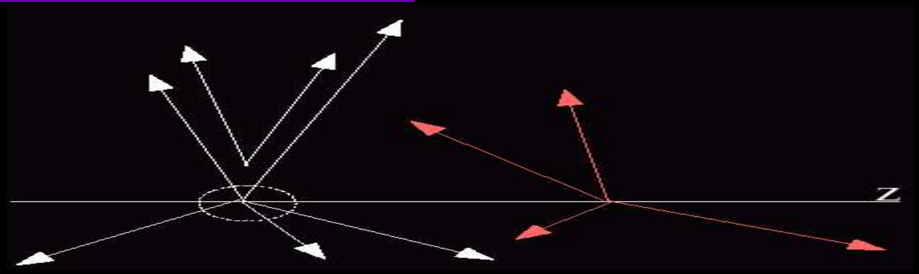
powerful tool for evaluation of material + magnetic field:
masses versus p_T for K_s, J/ψ, ...





before and after: fit energy loss and magnetic field to match K_s PDG mass

Primary vertex reconstruction



primary vertex fit:

- group tracks along z, $\Delta z < 2\,\mathrm{cm}$
- each cluster: fit all tracks to common point $\longrightarrow$ beam spot
- run tear down vertex finder on tracks with ip/σ(ip)<3
  - fit vertex
  - reject track with largest χ^2 contribution
  - iterate until $\chi^2 < 10$

identify hard scatter vertex according to p_t spectrum of tracks

a lot of pitfalls on the way:

- split vertices: two track vertices very close to primary
  - $\longrightarrow$ retuned vertex χ^2 cut
- min bias vertex select as hard due to single high p_T track
  - $\longrightarrow$ moved from Sum(Log(p_T)) to vertex probability
- initial track selection had DCA cut relative to (0,0,0) $\longrightarrow$ vertex biased
  - $\longrightarrow$ went to two pass fit

b-tagging

DØ uses several b-tag algorithms:

- secondary vertex tag
  - run cone algorithm on tracks
  - reject tracks likely from K_s, Λ, conversions
  - build up vertices from large impact parameter tracks
  - select vertex with largest 2d decay length
- tag number of tracks with large impact parameter
- jet-based b probability based on track impact parameters
- soft muon in jet (not yet certified)

mid-term trend is towards combination of taggers!

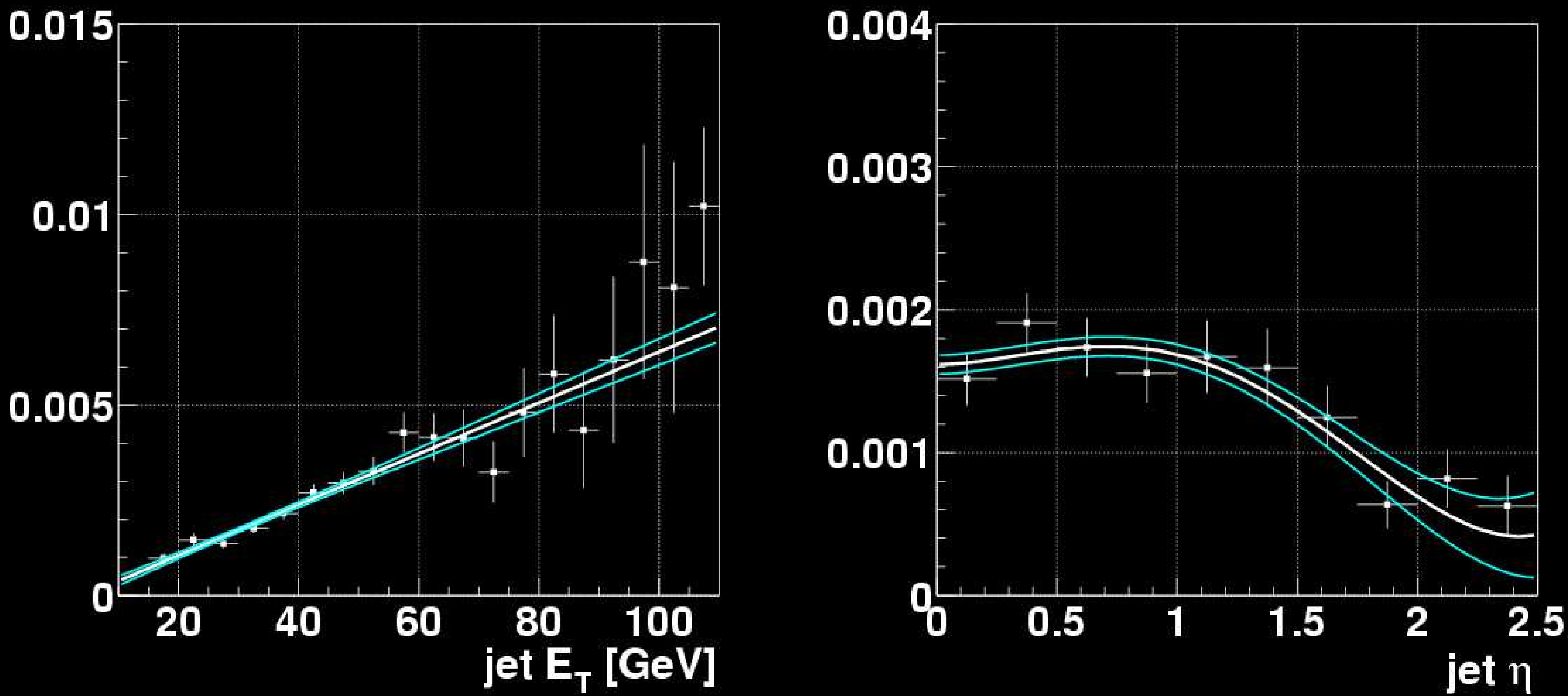
- lose secondary vertex
- additional variables (e.g. vertex mass, fit quality, other taggers, ...)

need to evaluate performance without relying too much on MC

- material simulation under construction
- noise simulation inadequate (to be fixed by min bias overlay)

b-tagging fake rate

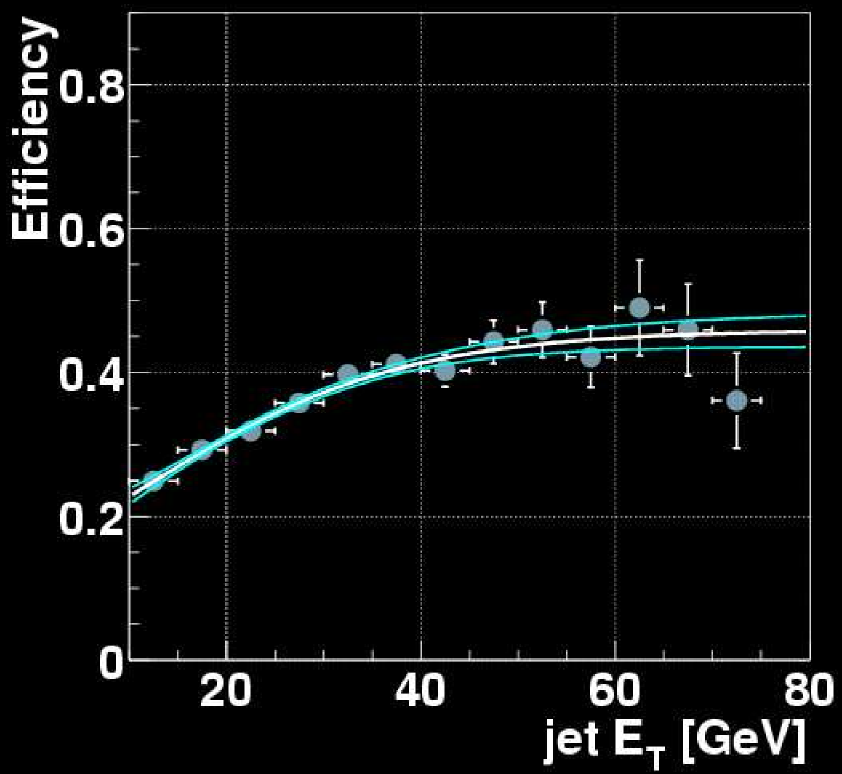
- light quark mistag rate: from negative tags + MC correction



(secondary vertex tag)

b-tagging efficiency

- tagging effiency from "System8"



(secondary vertex tag)

System8

- use two data samples with different b content
  e.g. μ in jet sample, μ in jet sample with b-tagged away jet
- run same tagger plus another uncorrelated tag on muon-jets

→ have 2×2 single tag rates
2 double-tag rates
2 initial sample sizes
=8 known parameters

unknowns: 2 b-tag efficiencies
2 background tag efficiencies
2 true b content
2 true non-b content
=8 unknown parameters

- obtain efficiencies (+uncertainties) from non-linear equation system

Conclusion

many topics not discussed, e.g.

- understanding of triggers
- detector alignment

Run II physics commissioning is basically complete;
still working on improvements/fixes, e.g.

- reduction of jet energy scale uncertainty
- improvements of calorimeter calibration
- more realistic detector simulation
- tuning of track reconstruction

DØ is producing good physics results!

Daniel Bloch will prove that this afternoon

...let's start with Run IIb commissioning!

BACKUP SLIDES

System8: equations

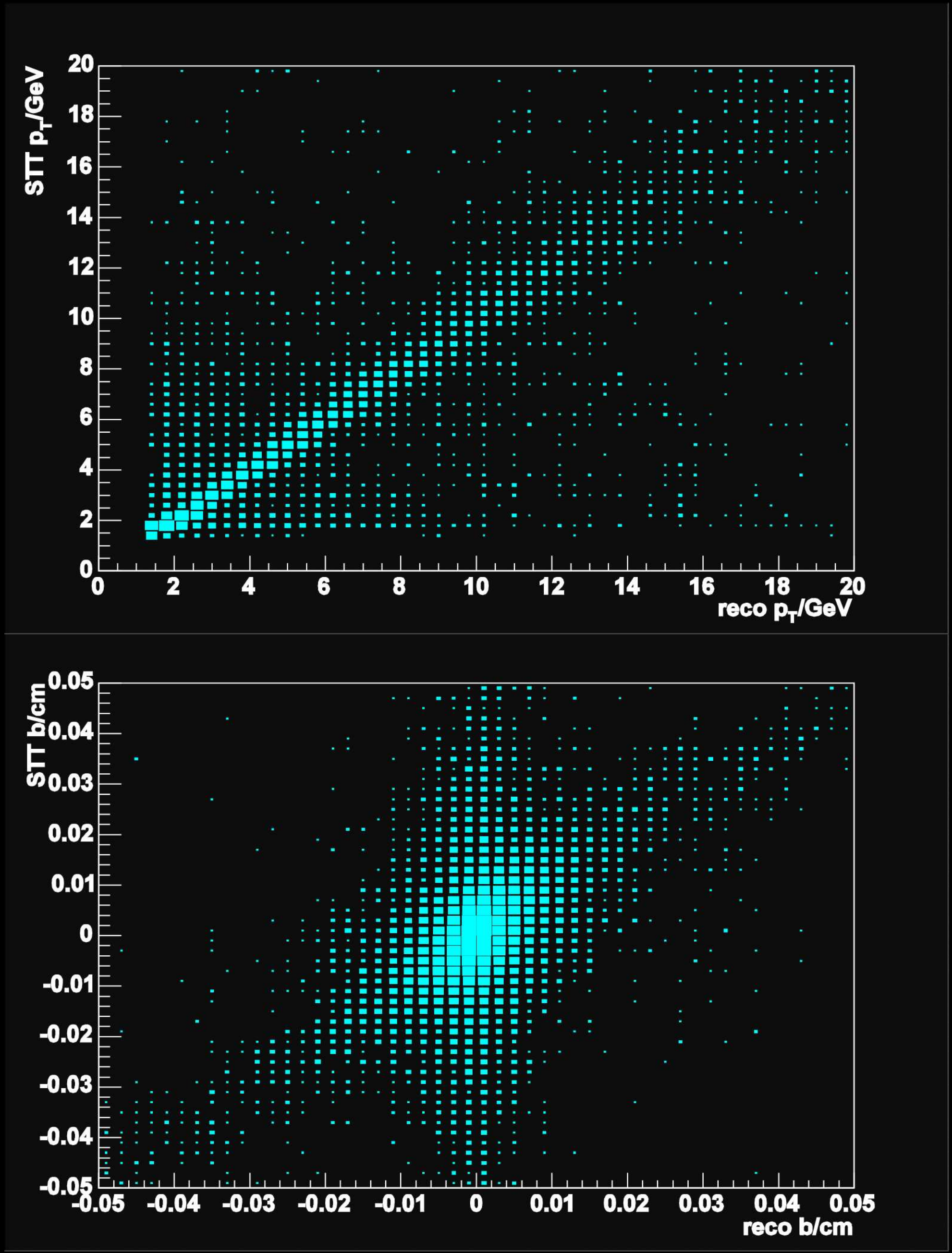
$$n = n_b + n_l$$
$$p = p_b + p_l$$

$$n^{SVT} = n_b \epsilon_{btag}^{SVT} + n_l \epsilon_{non-b}^{SVT}$$
$$p^{SVT} = p_b \epsilon_{btag}^{SVT} + p_l \epsilon_{non-b}^{SVT}$$

$$n^{SLT} = n_b \epsilon_{btag}^{SLT} + n_l \epsilon_{non-b}^{SLT}$$
$$p^{SLT} = p_b \epsilon_{btag}^{SLT} + p_l \epsilon_{non-b}^{SLT}$$

$$n^{DT} = n_b \epsilon_{btag}^{SVT} \epsilon_{btag}^{SLT} + n_l \epsilon_{non-b}^{SVT} \epsilon_{non-b}^{SLT}$$
$$p^{DT} = p_b \epsilon_{btag}^{SVT} \epsilon_{btag}^{SLT} + p_l \epsilon_{non-b}^{SVT} \epsilon_{non-b}^{SLT}$$

Silicon Track Trigger



physics certification ongoing:

- excellent agreement with trigger simulation
- ≈80% track efficiency wrt offline tracking
- good track parameter correlation wrt offline tracking

a powerful tool:

bb trigger (2 jets, 1 b-tag at L3):
introduction of STT reduced
rate by 30%, only 3% efficiency loss
(M. Michaut)

Trigger tool: D0TrigSim

Almost all trigger systems included in trigger simulation:

- operating on MC samples or actual recorded data
- simulates response of hardware triggers (L1)
- uses actual trigger software for L2, L3 response

→ excellent tool for trigger studies
and for commissioning!

... e.g. of our new Silicon Track Trigger

track reconstruction today