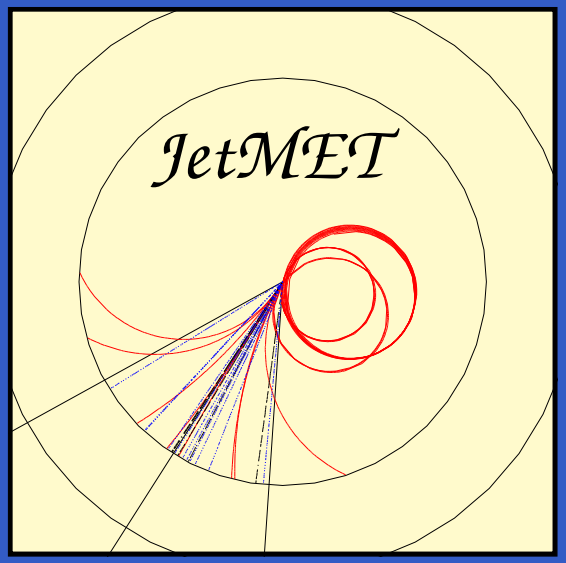
Introduction to

Jets and Missing E_T in CMS

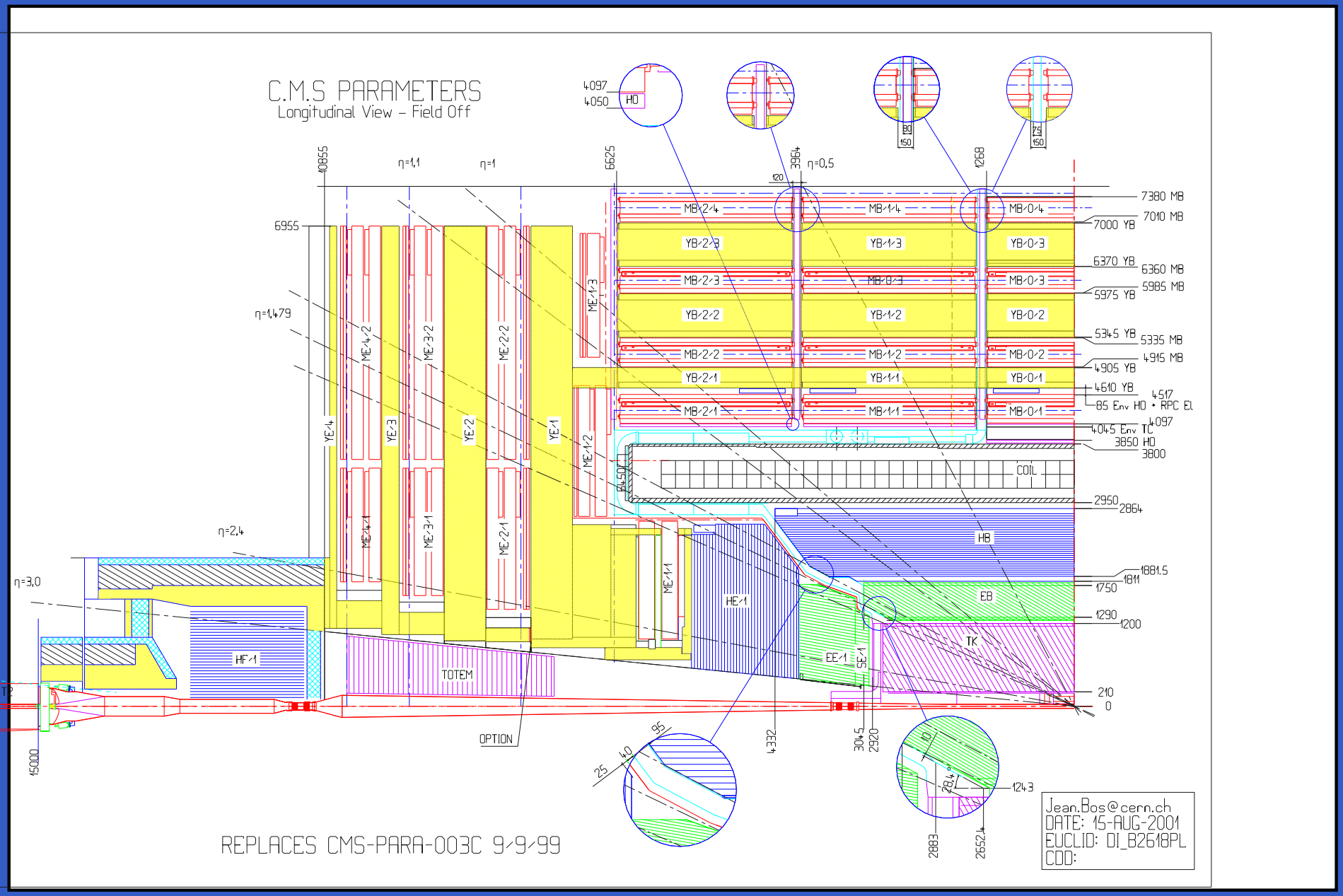
James W. Rohlf
Boston University



Greetings from the East Coast Jan. 28, 2004

CMS Assembly magnet test in 2005

CMS Detector geometry



CMS Compact Muon Solenoid links

CMS documentation page:
http://cmsdoc.cern.ch/cms.html
agendas, management organization, notes, pictures, *etc.*

CERN Documentation System (CDS):
http://agenda.cern.ch
meeting agendas and archived slides (searchable)

US CMS:
http://uscms.fnal.gov
activities based in US.

PRS Physics, Reconstruction, Selection

Coordinator: Paris Sphicas

http://cmsdoc.cern.ch/cms/PRS/www/prs.php

Detector Groups:

Tracker/b-tau Mannelli/Silvestris

ECAL/e-gamma Seez

HCAL/JetMET Rohlf/Tully

Muon Acosta/Gasparini

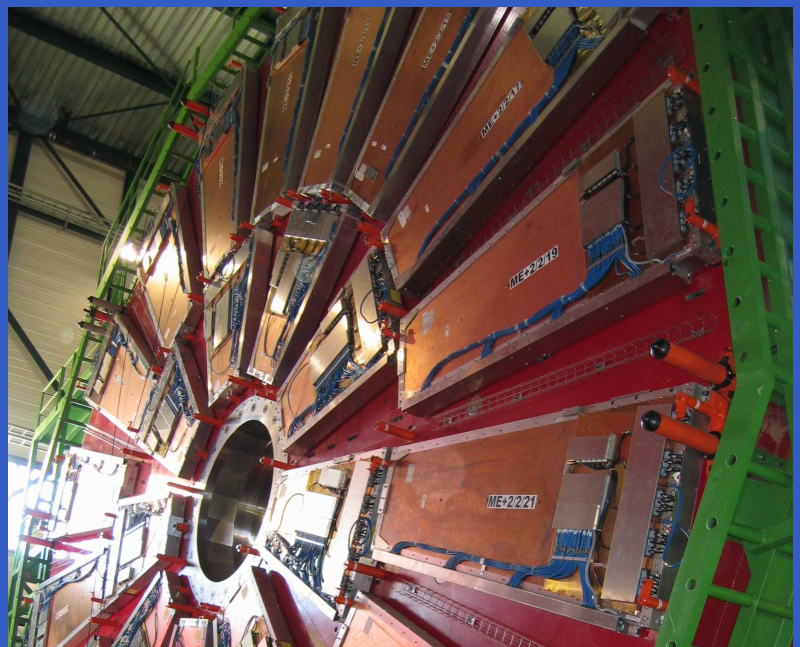
Analysis Groups:

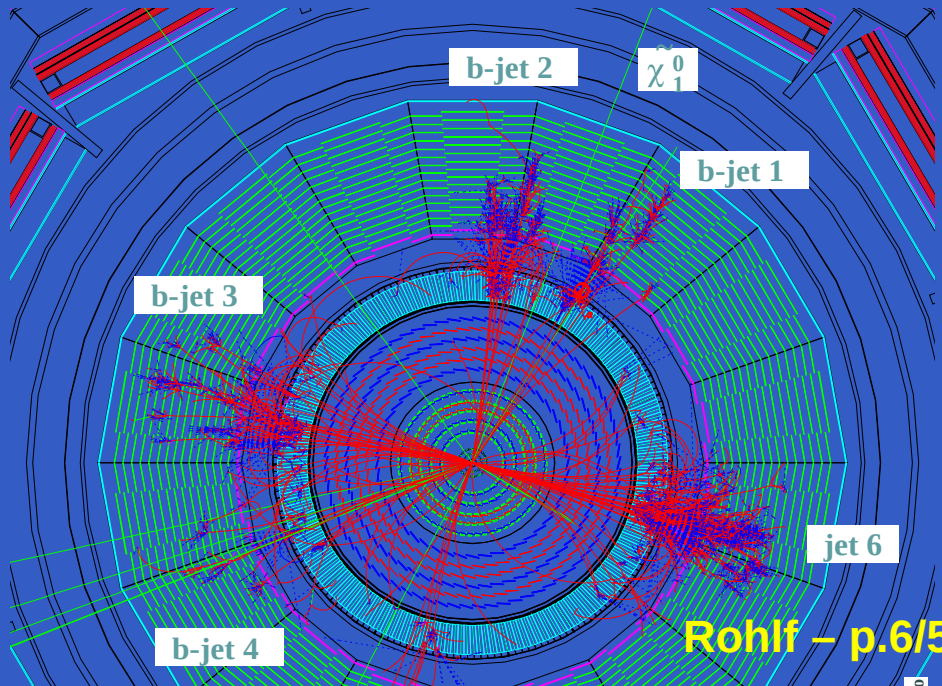
Standard Model Mnich

Higgs Pape

Supersymmetry Nikitenko

Heavy Ions Wyslouch





JetMET Activities Co-coordinator: Chris Tully

http://www.uscms.org/scpac/jetmet/

Everything software related to HCAL/Jets/Missing E_T:

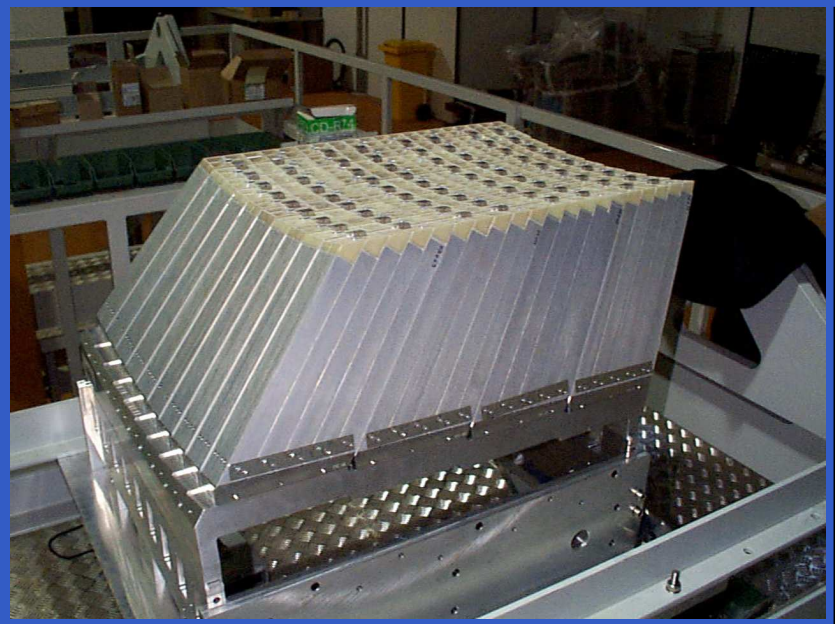
- HCAL calibration
  source, testbeam, and collisions
- HCAL data base
- High level trigger
  reconstruction of Jet and Missing E_T objects
- HCAL data monitoring
- Physics analysis
  anything to do with Jets and Missing E_T

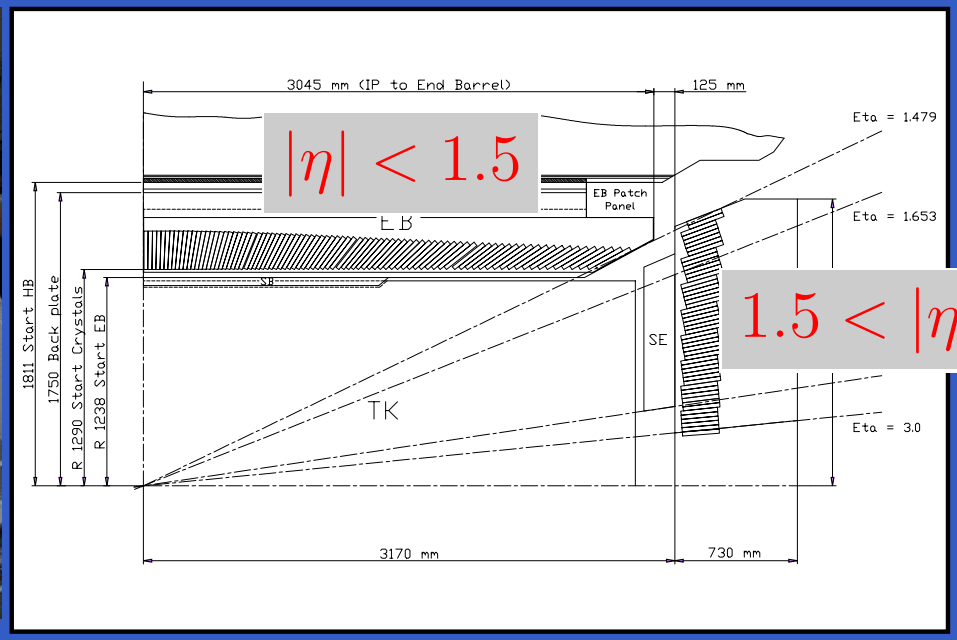
Jets CMS Jet Physics some examples

- light-quark and gluon jets
  event tagging (*e.g.* qqH) and central jet veto ($\mathrm{t\bar{t}}$)
  $\mathrm{W} \to \mathrm{q\bar{q}}$ *via* top for calibration
  high mass $\mathrm{Z}' \to \mathrm{q\bar{q}}$
  angular and p_{T} distributions in search of compositeness and other new physics
- b jets
  $\mathrm{H} \to \mathrm{b\bar{b}}$
- tau jets
  $\mathrm{H} \to \tau^+\tau^-$

CMS ECAL

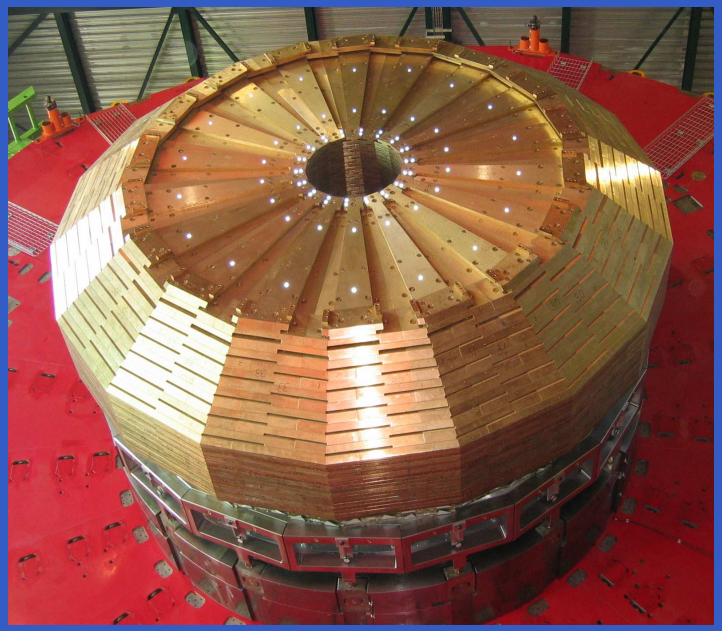
crystal ($PbWO_4$)





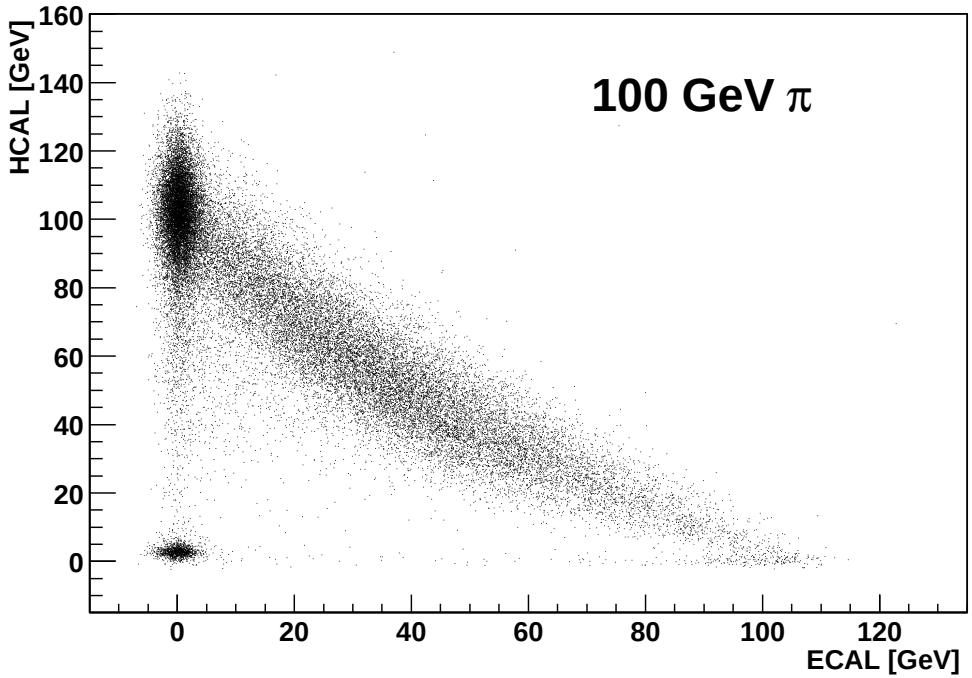
	res. @ 50 GeV	*material in front*	*thickness*	$\Delta\eta \times \Delta\phi$
ATLAS	1.5%	2-4 χ_0	21-36 χ_0	front 0.003×0.1 middle 0.025×0.025 back 0.05×0.025
CMS	0.8%	0.4-1.3 χ_0	25-27 χ_0	0.0174×0.0174

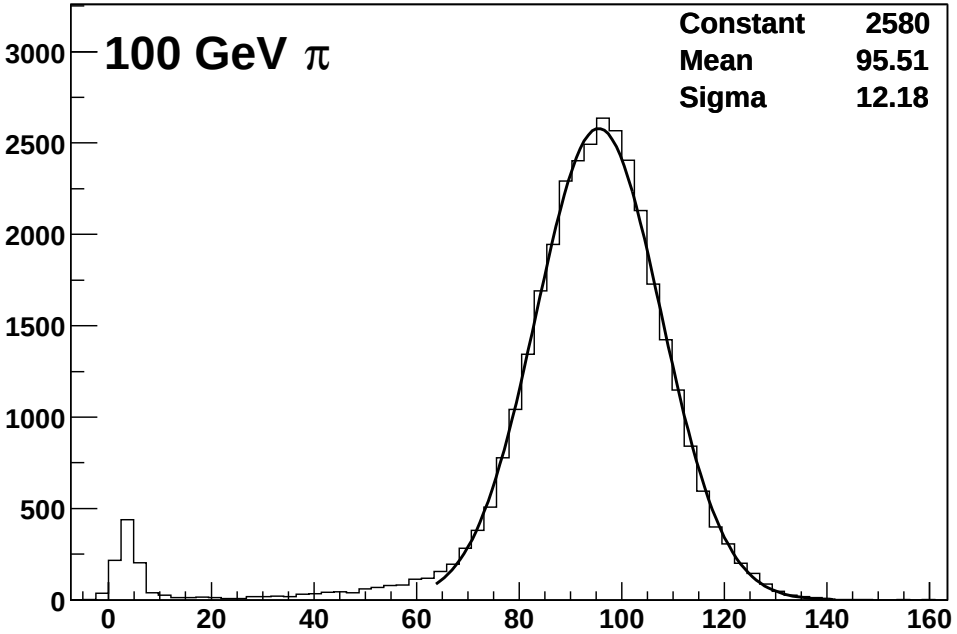
CMS HCAL



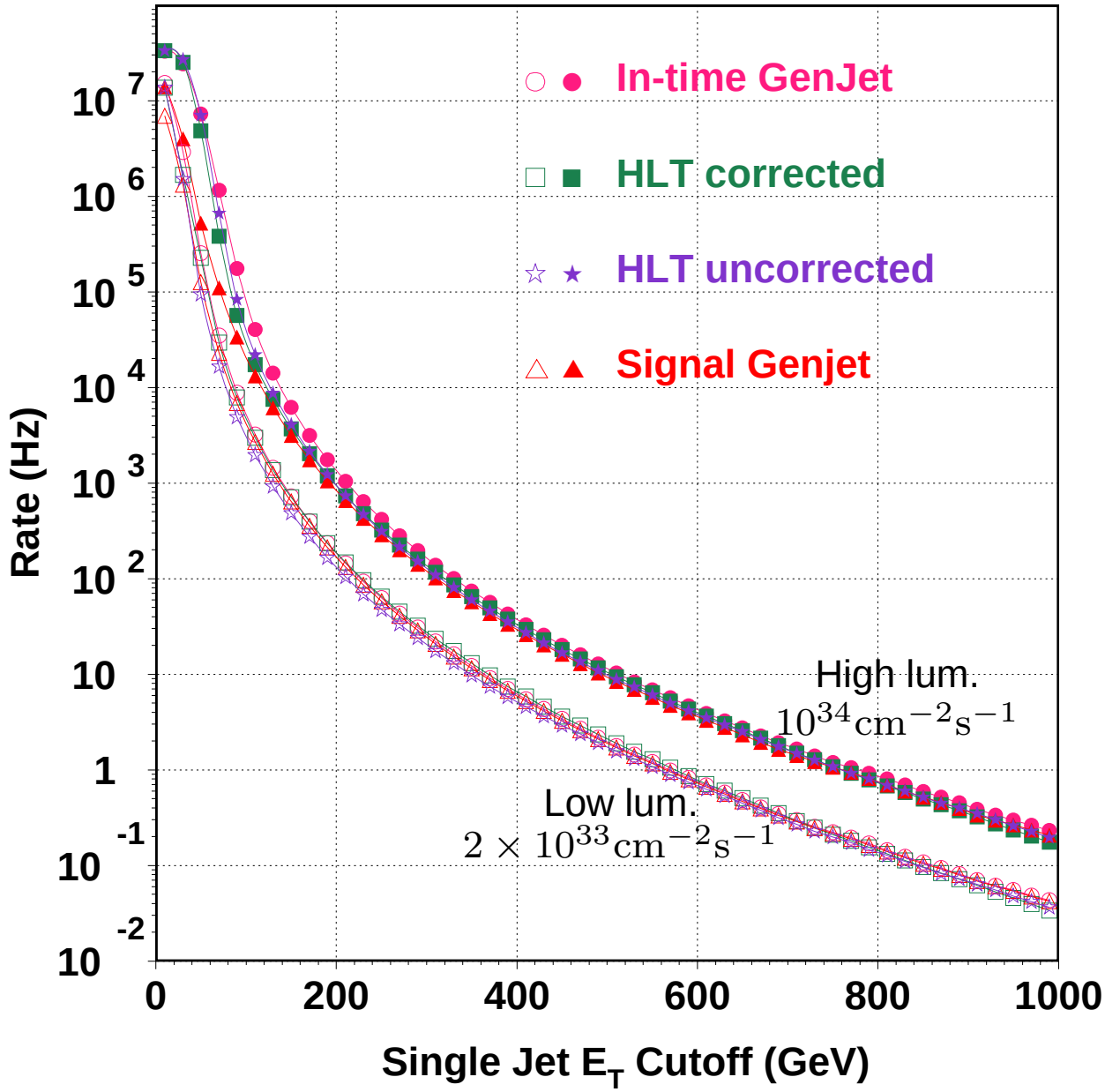
	coverage	*res@100GeV*	*thickness*	$\Delta\eta \times \Delta\phi$
barrel	$\lvert\eta\rvert < 1.4$	10%	11-15 λ	0.087 $\times$ 0.087
endcap	$1.4 < \lvert\eta\rvert < 3.0$	10%	11 λ	$1.4 < \lvert\eta\rvert < 1.7$ 0.087 $\times$ 0.87 $1.7 < \lvert\eta\rvert < 3.0$ 0.087 $\times$ 0.17
forward	$3.0 < \lvert\eta\rvert < 5.0$	20%	10 λ	0.17 $\times$ 0.17

JetMET Response to beam 100 GeV pions



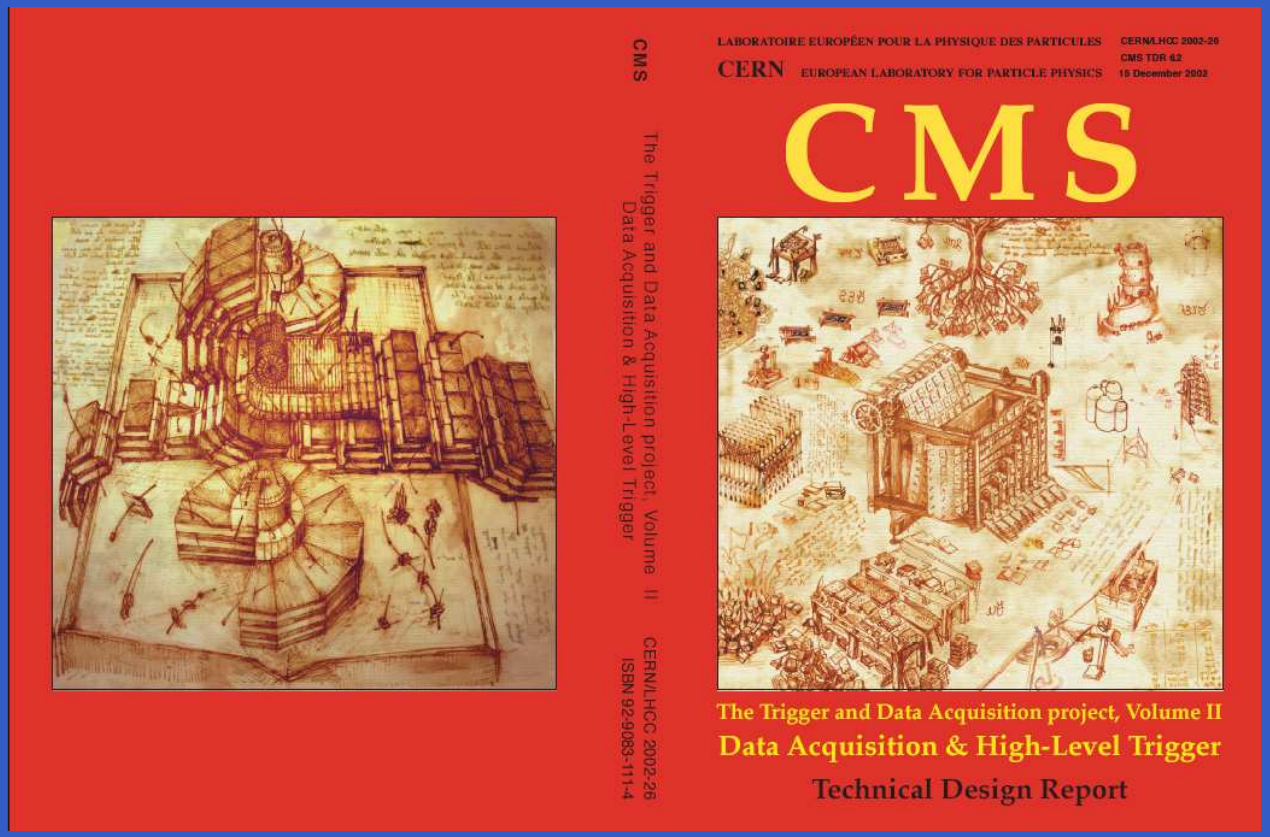


HCAL Rates generator level

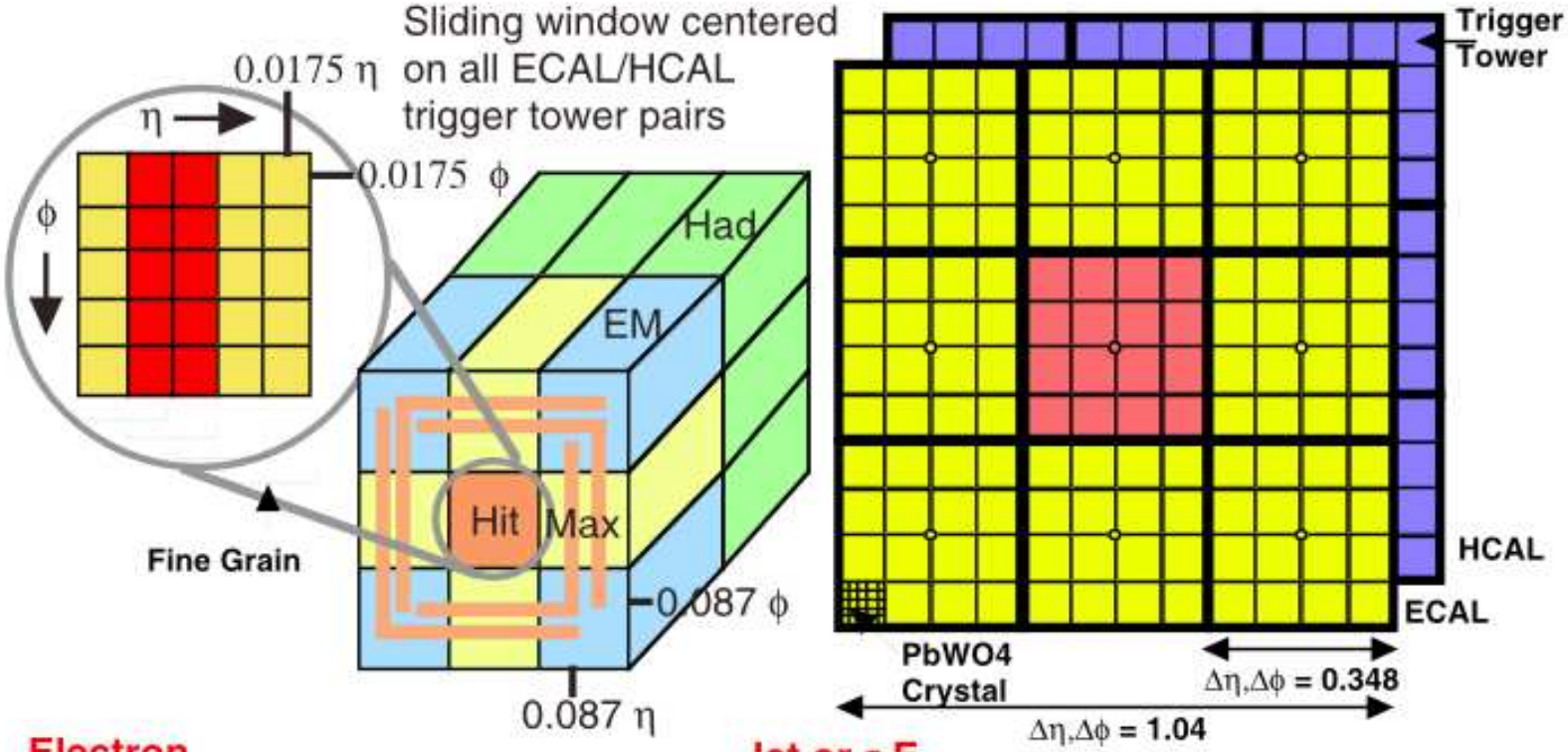


TDR Trigger and DAQ Technical Design Reports

- Vol. I: Level-1 Trigger, CERN/LHCC 2000-38
- Vol. II: DAQ and HLT, CERN/LHCC 2002-26



Current Algorithms



Electron

- 2-tower ΣE_T + H/E

Isolated Electron

- 2x5-crystal strips>90% energy in 5x5 (Fine Grain)
- Neighbor EM + Had Quiet

Jet or τ E_T

- 12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 > rest

τ algorithm (isolated narrow energy deposits)

- Call Jet τ if all 9 4x4 region τ-vetoes off
- τ-veto: Patterns of E or H towers in 4x4

Trigger Level-1 Rates

	Low lum.		High lum.	
Channel	*Thresh.* (GeV)	*Rate* (kHz)	*Thresh.* (GeV)	*Rate* (kHz)
isolated μ	14	2.7	20	6.2
μ pair	$3 \cdot 3$	0.9	$5 \cdot 5$	1.7
isolated e/γ	29	3.3	34	6.5
e/γ pair	$17 \cdot 17$	1.3	$19 \cdot 19$	3.3
tau jet	86	2.2	101	5.3
tau jet pair	$59 \cdot 59$	1.0	$67 \cdot 67$	3.6
$\mu \cdot$ jet			$15 \cdot 40$	0.8
e $\cdot$ jet	$21 \cdot 45$	0.8	$25 \cdot 52$	1.3
1,3,4 jet	177,86,70	3.0	250,110,95	3.0
jet $\cdot$ MET	$88 \cdot 46$	2.3	$113 \cdot 70$	4.5
min. bias		0.9		1.0
TOTAL		16		33.5

ref.	
pp	GHz
W	kHz
top	10 Hz
TEV ex.	mHz

$\mathcal{HLT}$ Physics Requirements high-level trigger

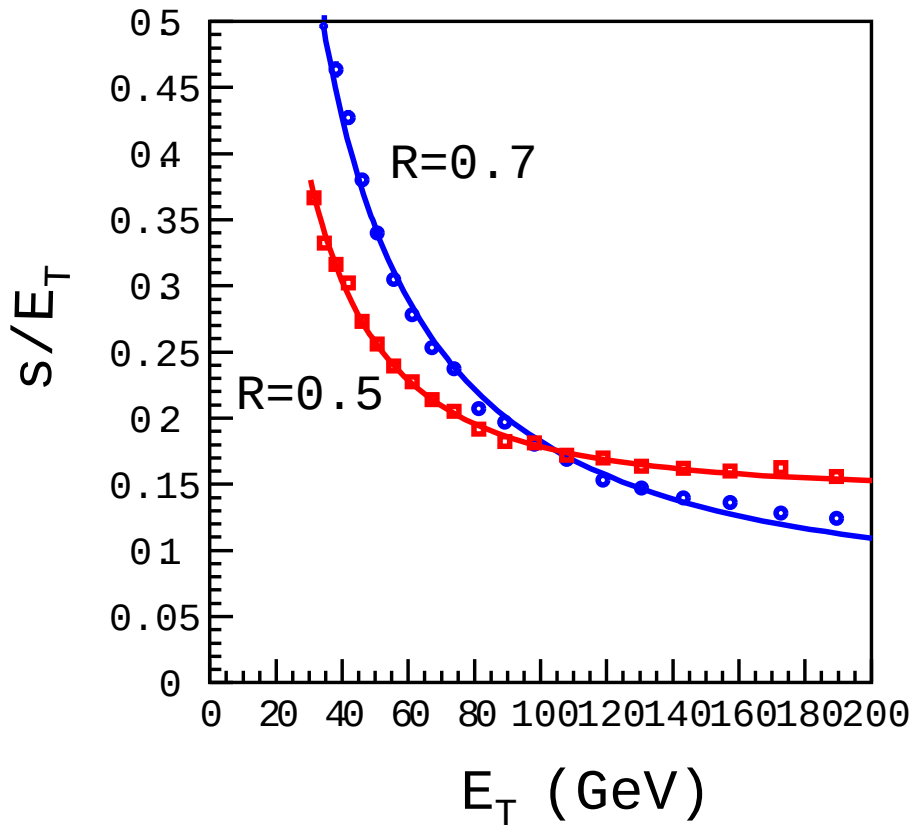
- input rate up to 100 kHz
- high efficiency for physics objects
- inclusive selection to not miss unanticipated physics
- must work independent of detailed calibration
- includes samples for offline efficiency calculation
- output rate limited to 100 Hz
- continuous monitoring of algorithms and code
- event tagging to know origin of selection
- code maintained as close as possible to offline

$\mathcal{HLT}$ Jet Finding high-level trigger

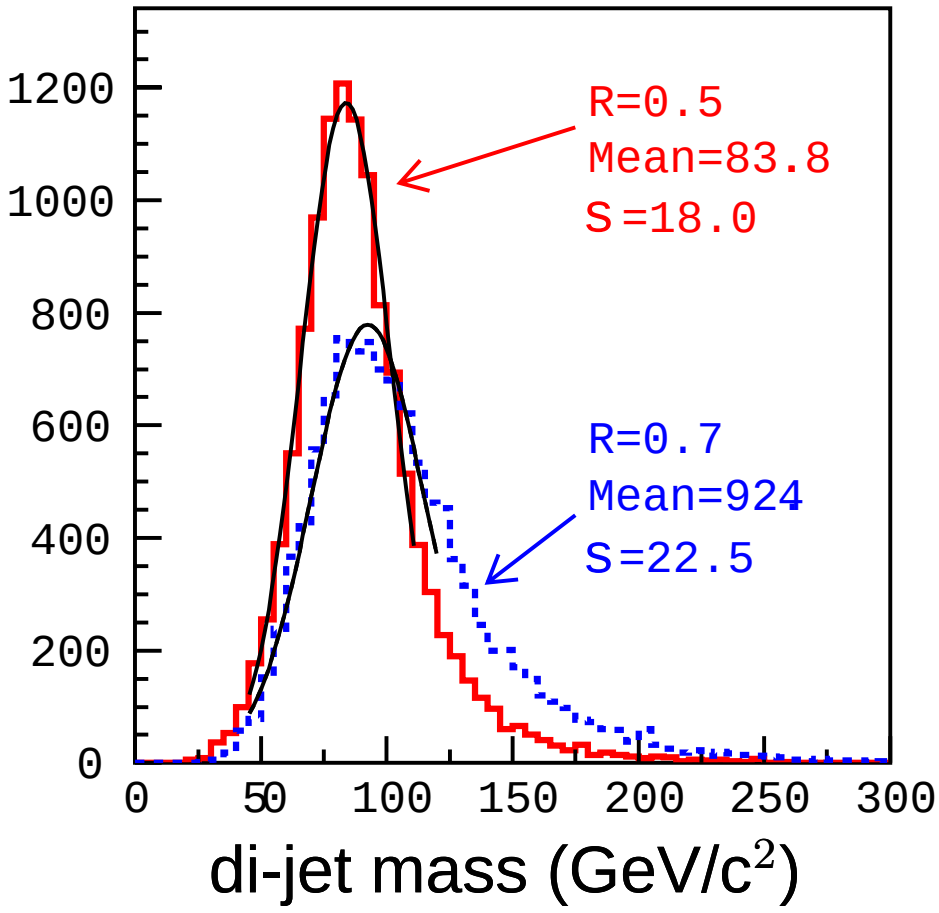
- data sorted into 4176 towers
  $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$
- each tower treated as a massless particle
  with energy equal to the scalar sum and
  angle determined from nominal vertex position
- simple iterative cone
  (no sophisticated splitting or merging for speed)
- 0.5 cone size, 2 GeV seed threshold,
  10 GeV jet threshold

See talk of Arno Heister.

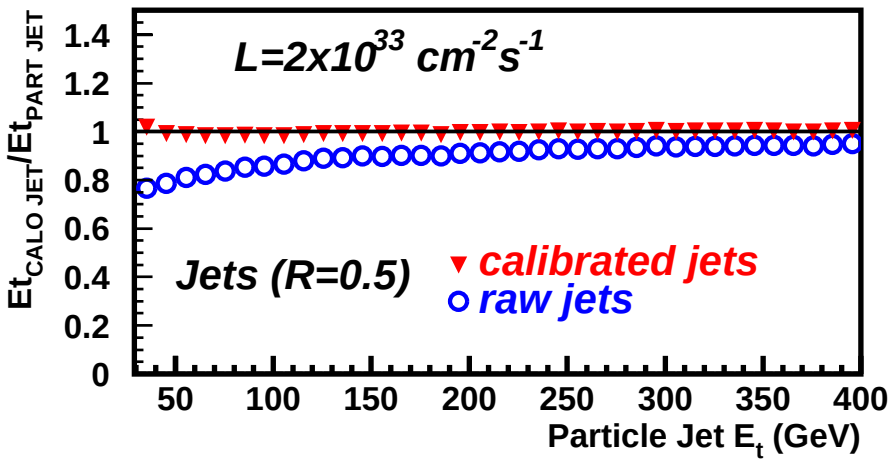
$\mathcal{HLT}$ Jet Cone Size high-level trigger

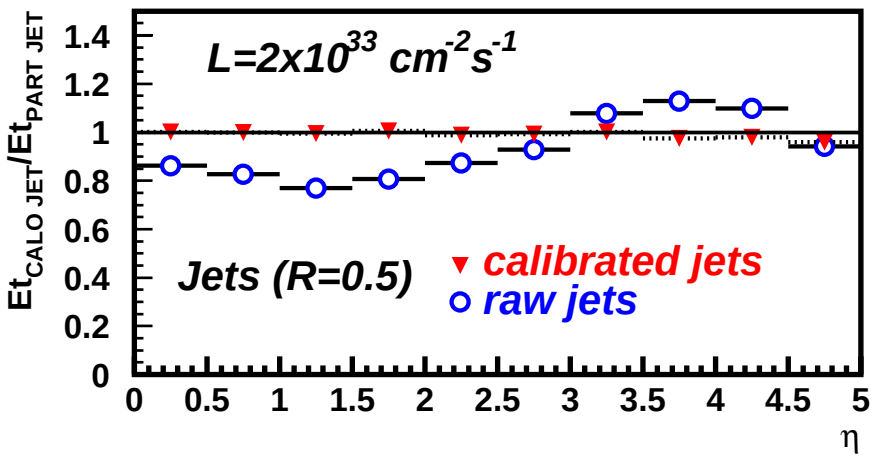


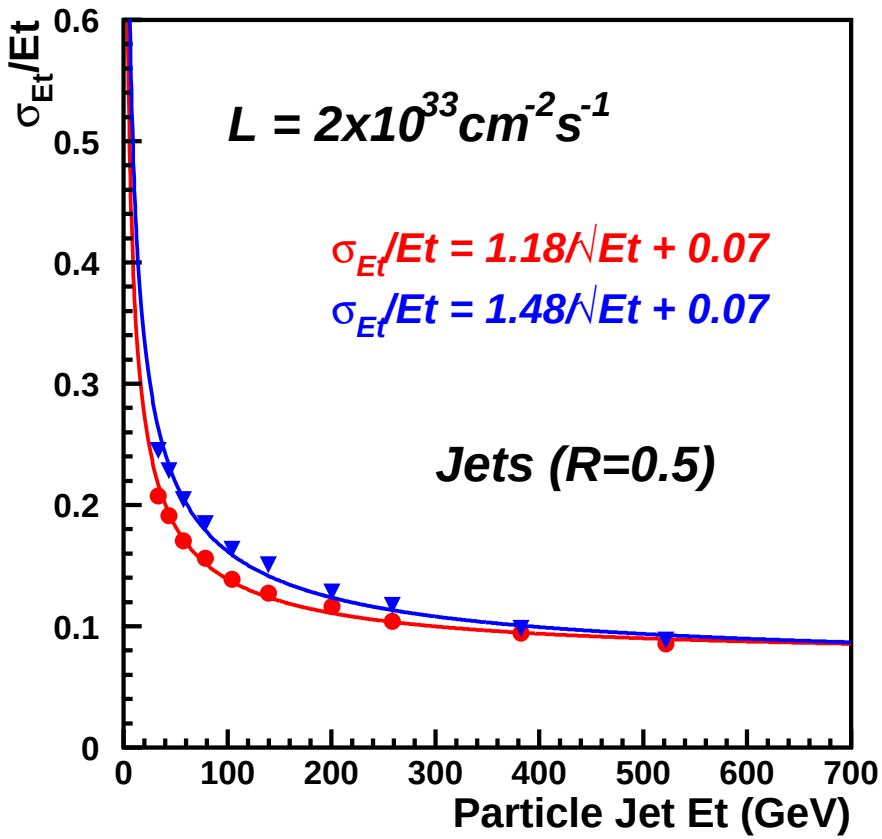
top → W → jet+jet



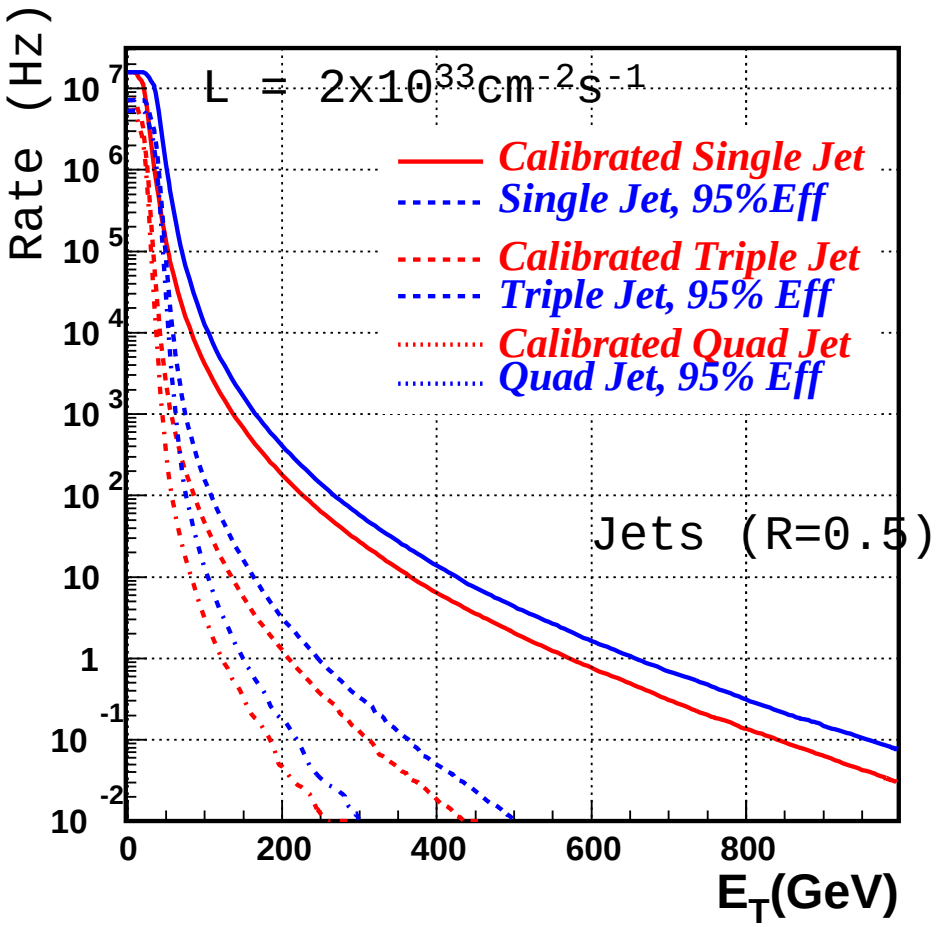
$\mathcal{HLT}$ Jet Scale Correction high-level trigger

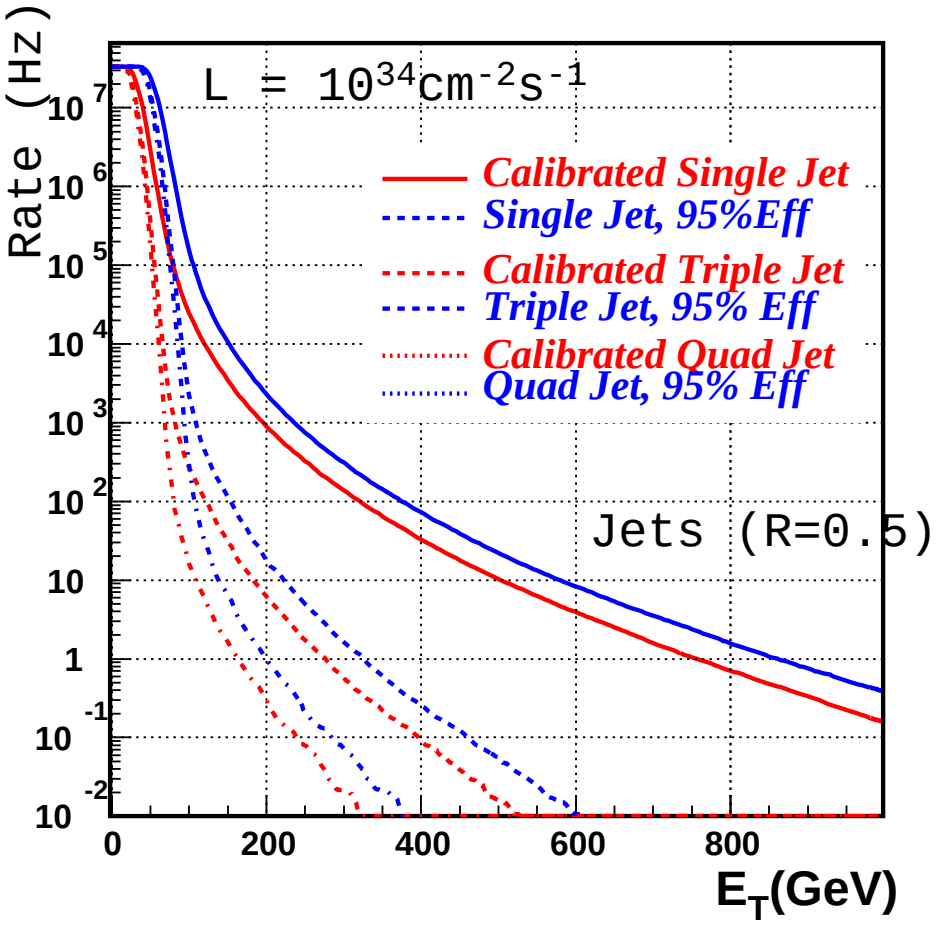






$\mathcal{HLT}$ Jet Rates high-level trigger





Trigger **Jet Rates** $10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Thresholds in GeV

Channel	*L1 95% eff.*	*L1 1kHz*	*HLT 95% eff.*	*HLT 1 Hz*
1 jet	195	248	752	860
2 jet	153	190	652	748
3 jet	79	112	275	326
4 jet	64	95	162	199

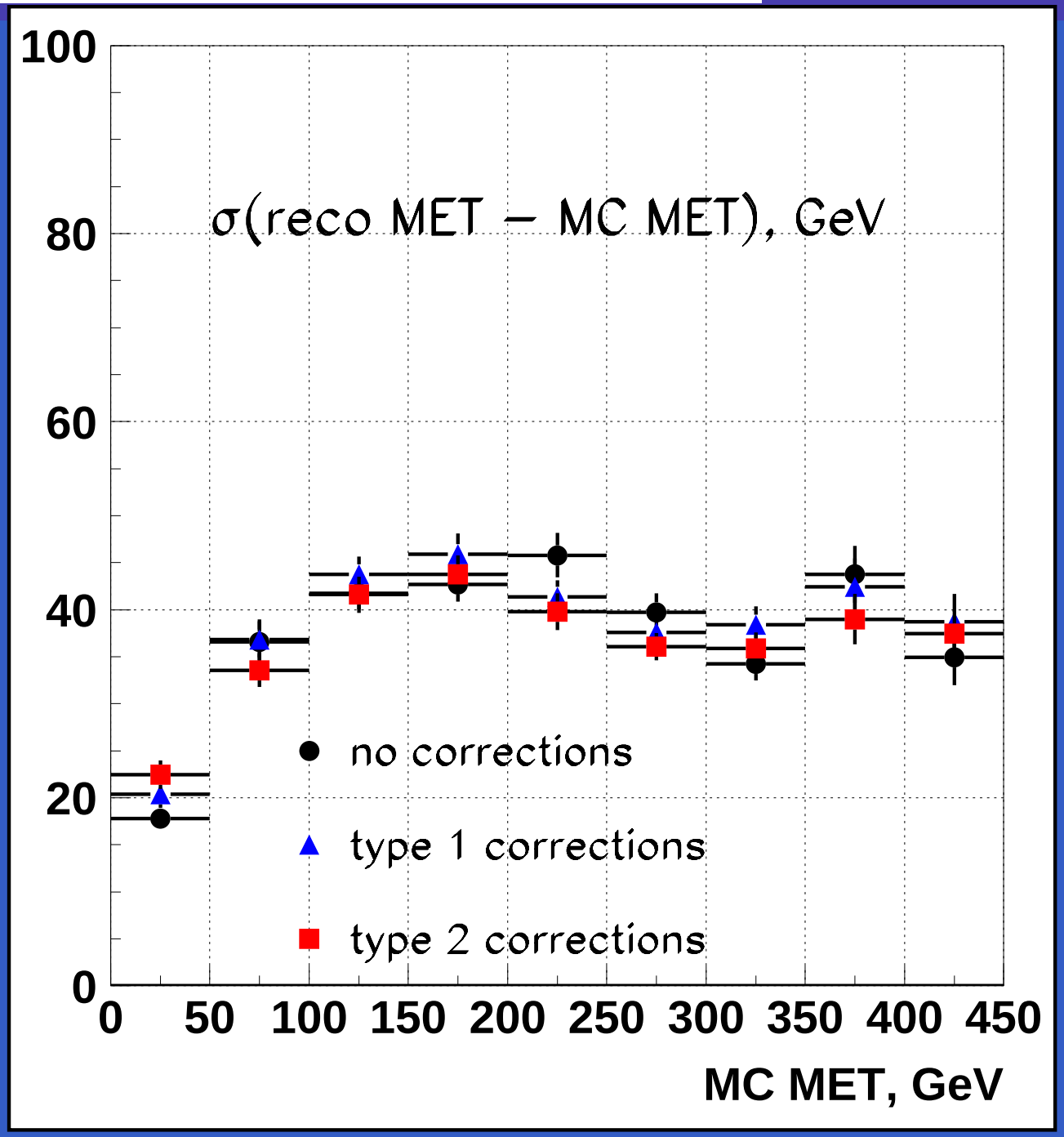
$\mathcal{HLT}$ MET Algorithm high-level trigger

Three algorithms

- tower sum over threshold (500 MeV)
  $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$
  angle determined from nominal vertex position
- type-1 corrections
  jet scale for $E_{\mathrm{T}} > 30\ \mathrm{GeV}$
- type-2 corrections
  jet scale and unclustered towers correction

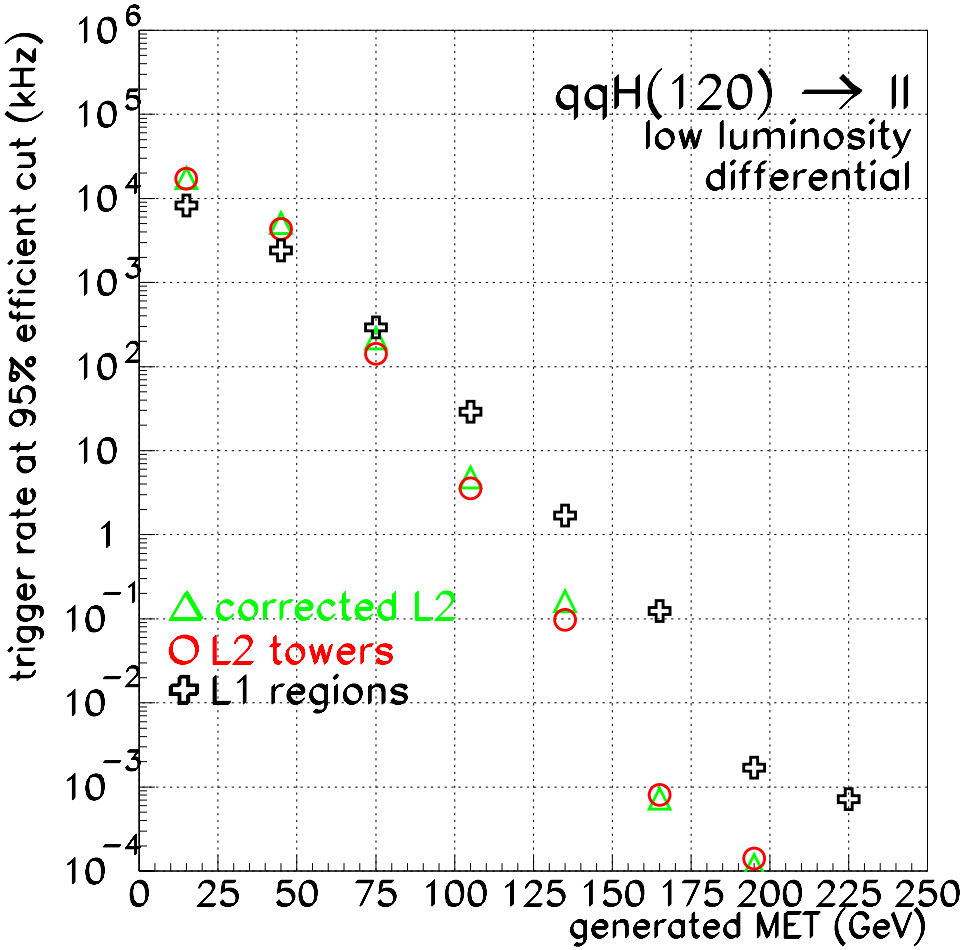
See talk of Haifeng Pi.

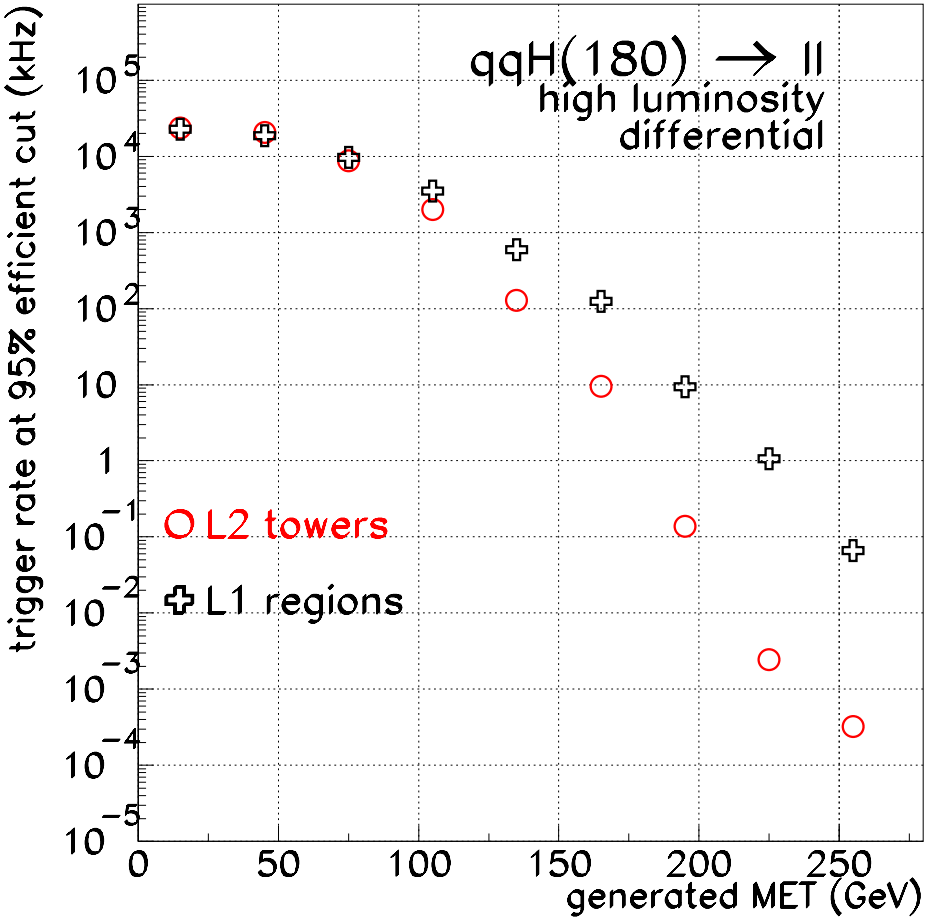
$\mathcal{HLT}$ MET Resolution SUSY events (500 GeV)



$\mathcal{HLT}$ MET Trigger Performance $qq\ell\nu\ell\nu$

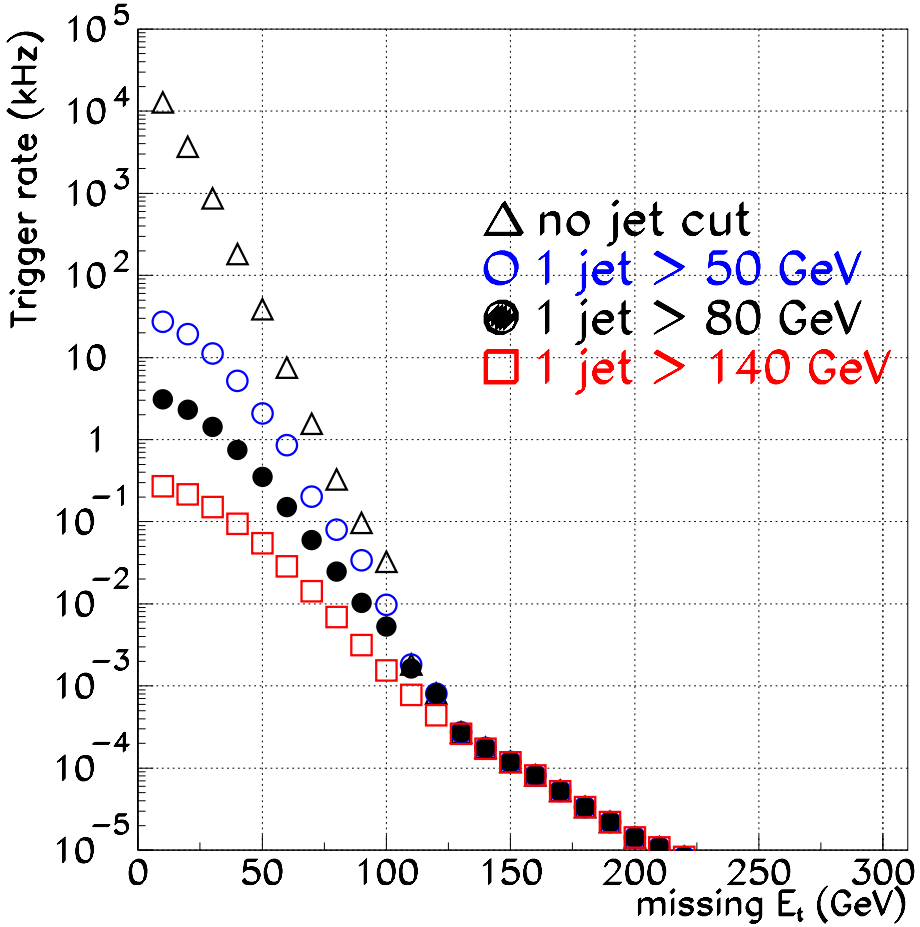
$qqH \rightarrow qqWW \rightarrow qq\ell\nu\ell\nu$



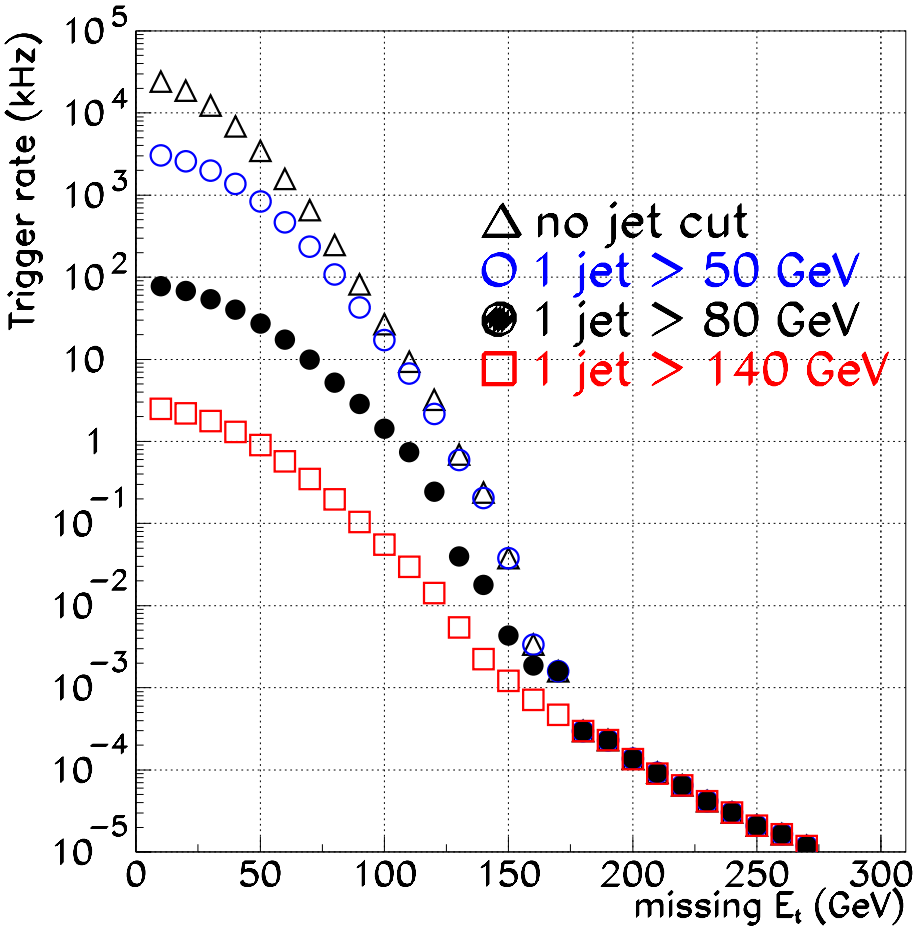


$\mathcal{HLT}$ MET Rates high-level trigger

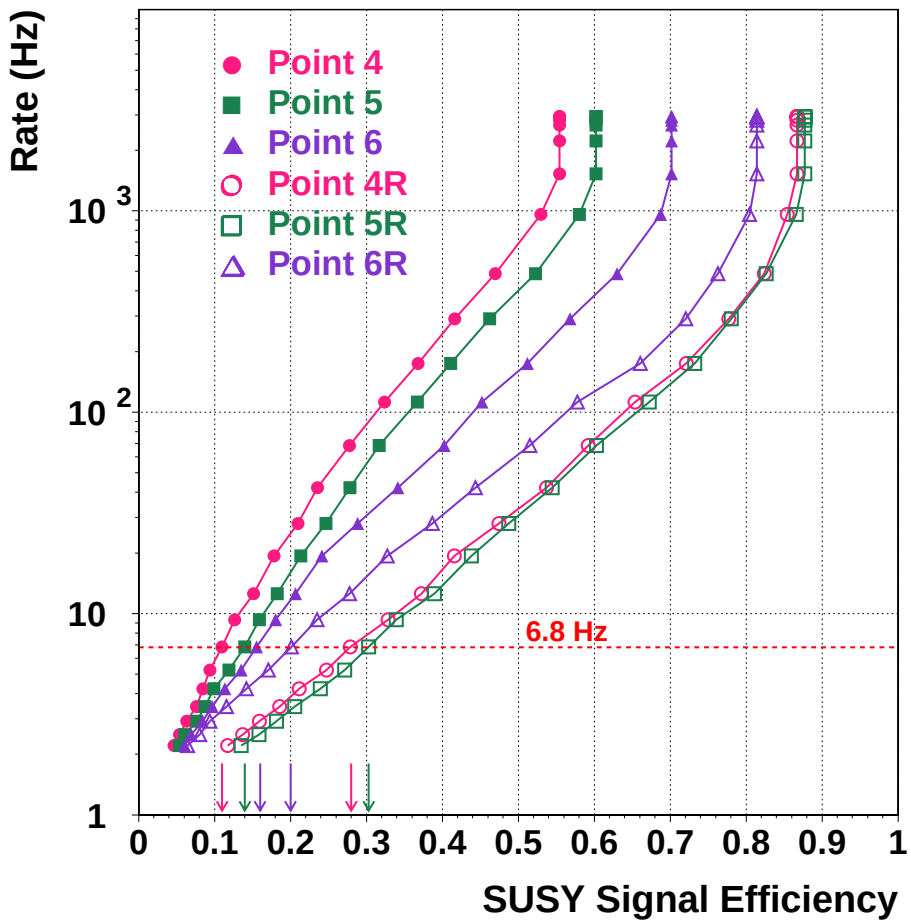
Low lum.

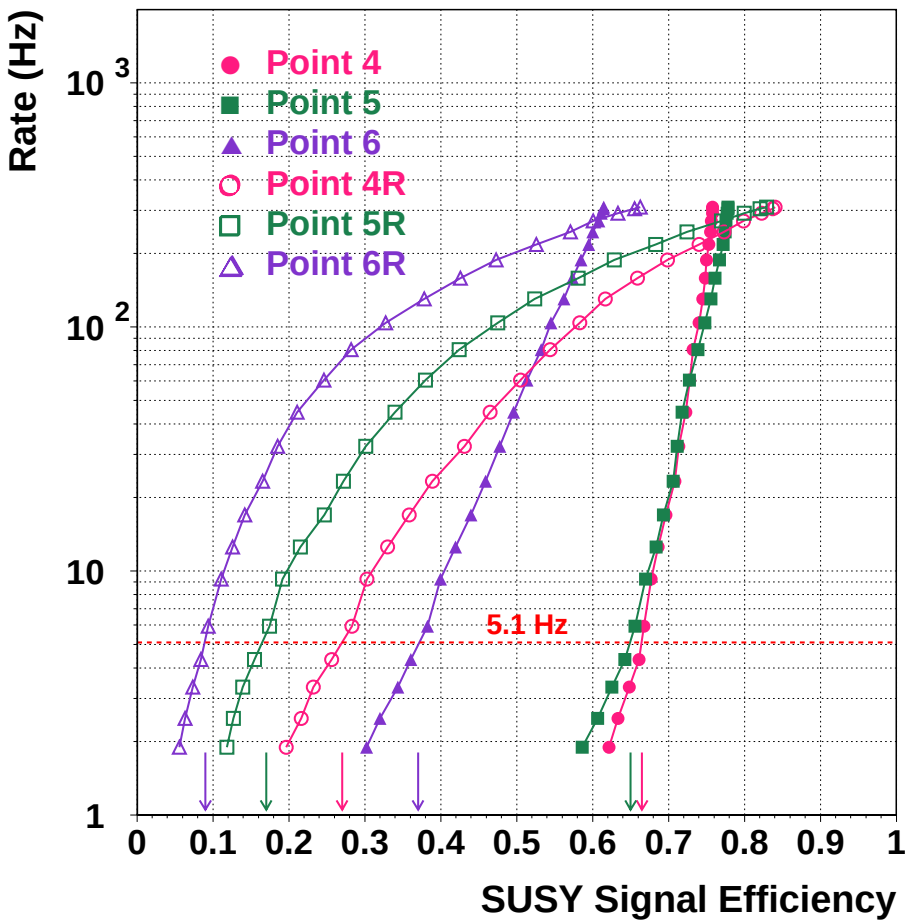


High lum.



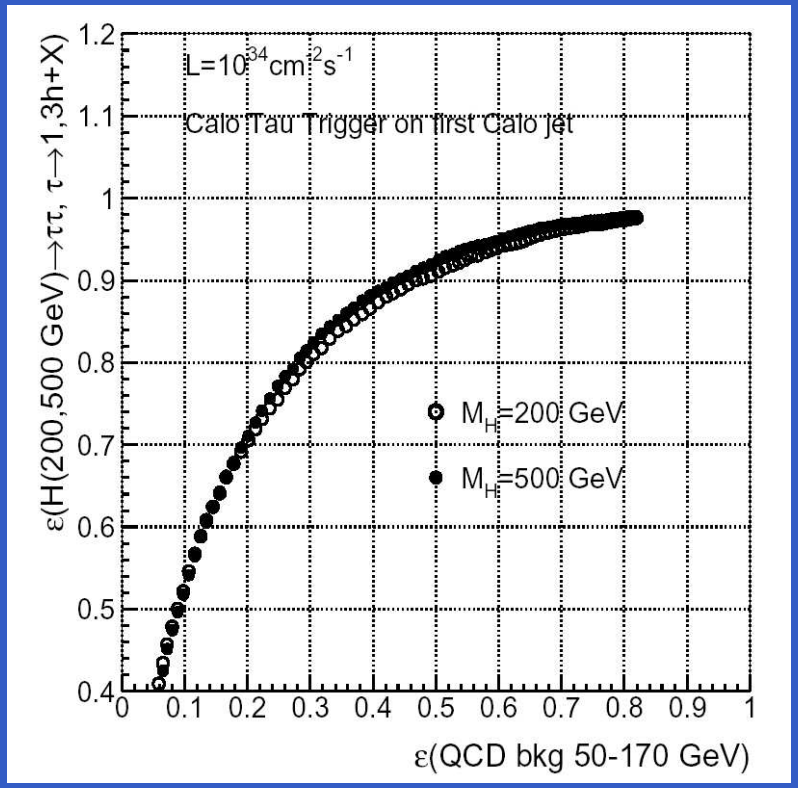
$\mathcal{HLT}$ SUSY Rates varying thresholds



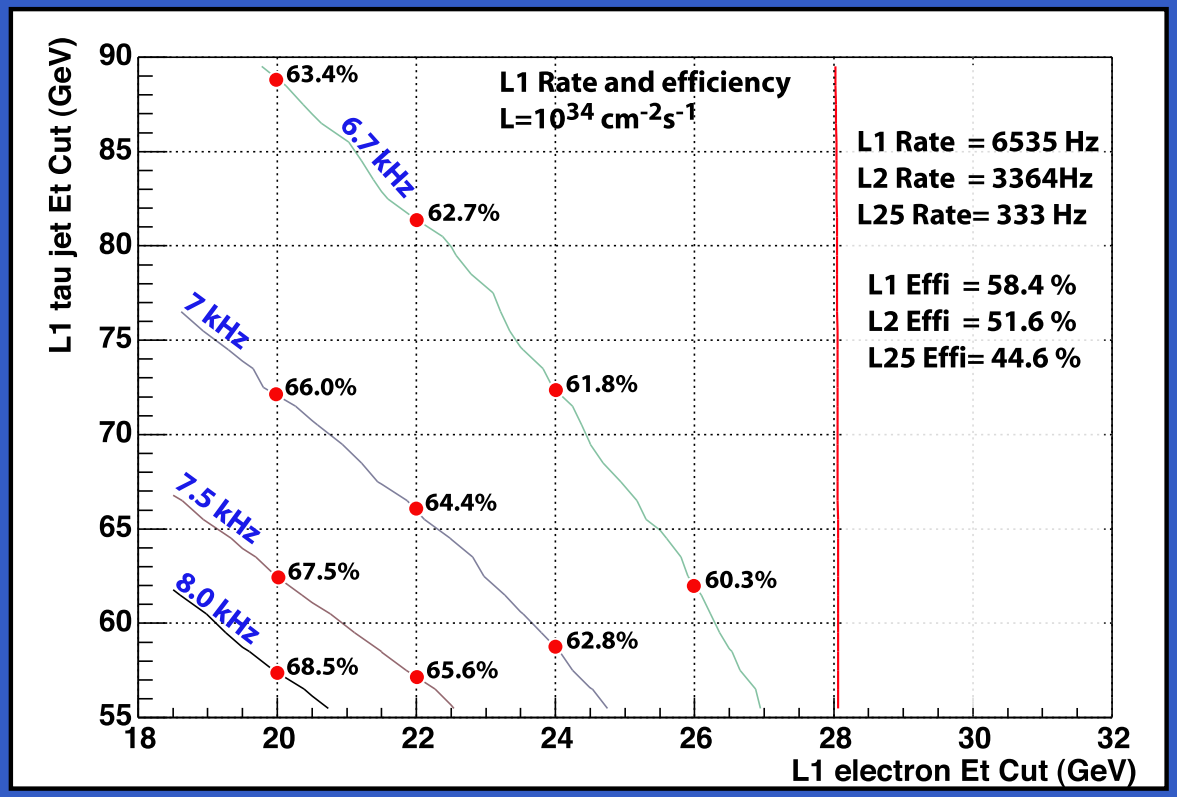


$\mathcal{HLT}$ Tau jet

eff. *vs.* QCD reject.

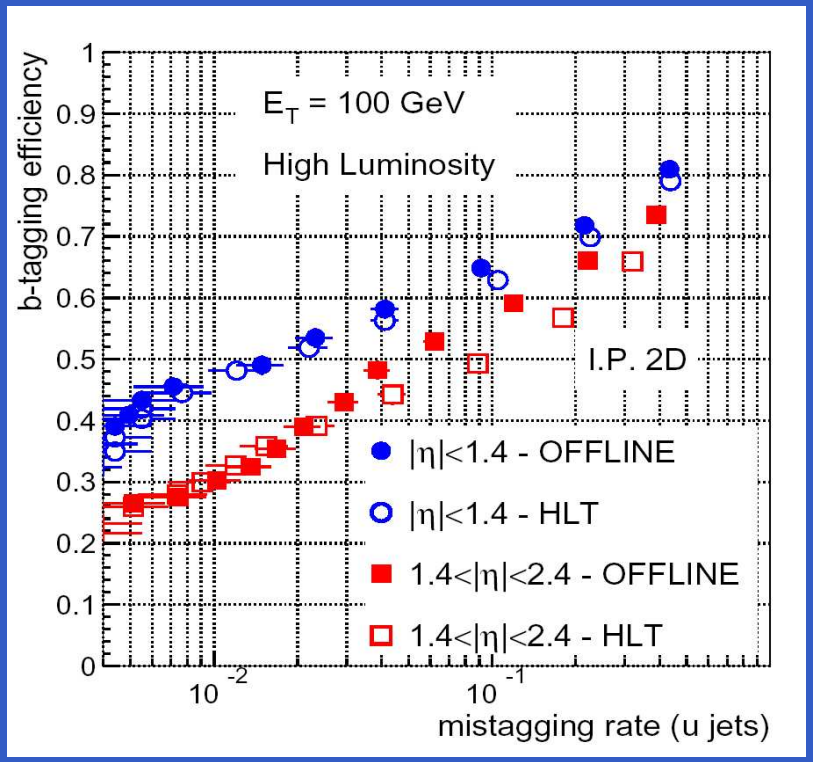


$\tau\tau \longrightarrow$ e/jet

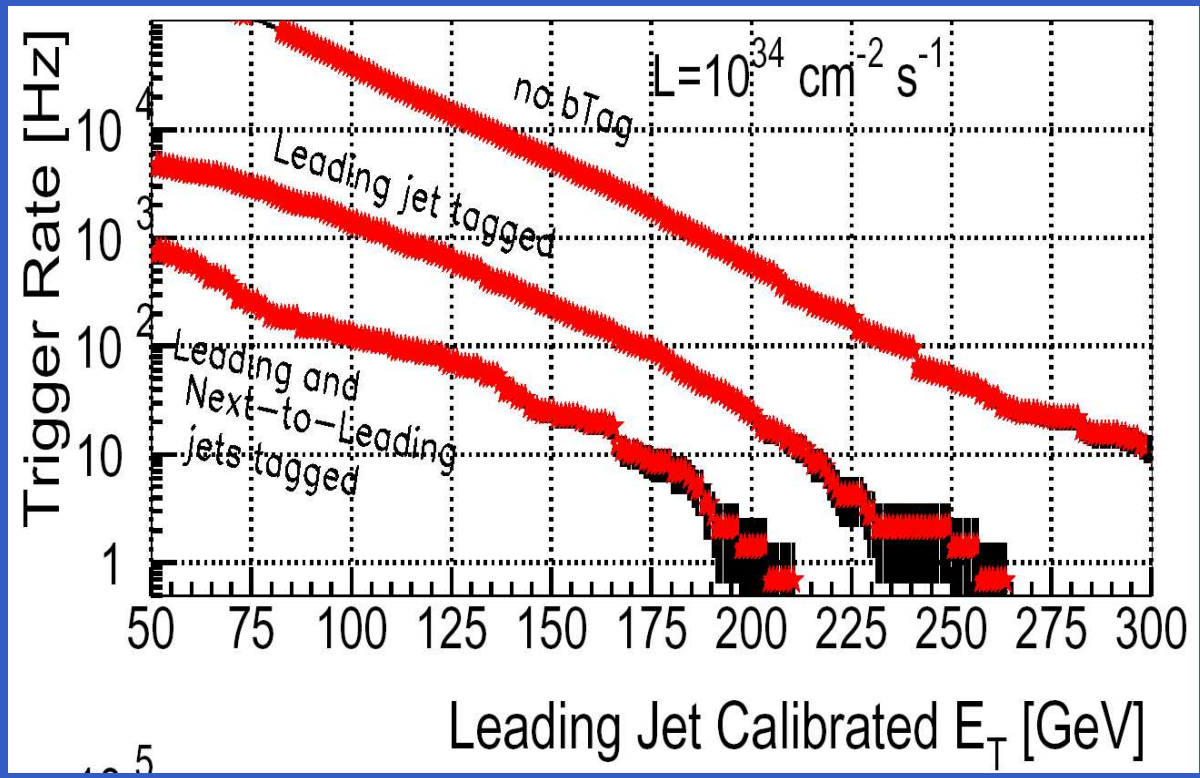


$\mathcal{HLT}$ **b jet** fed by L1 inclusive jet

eff. *vs.* mistag



rate: HLT b-tag gives $\times$ 20

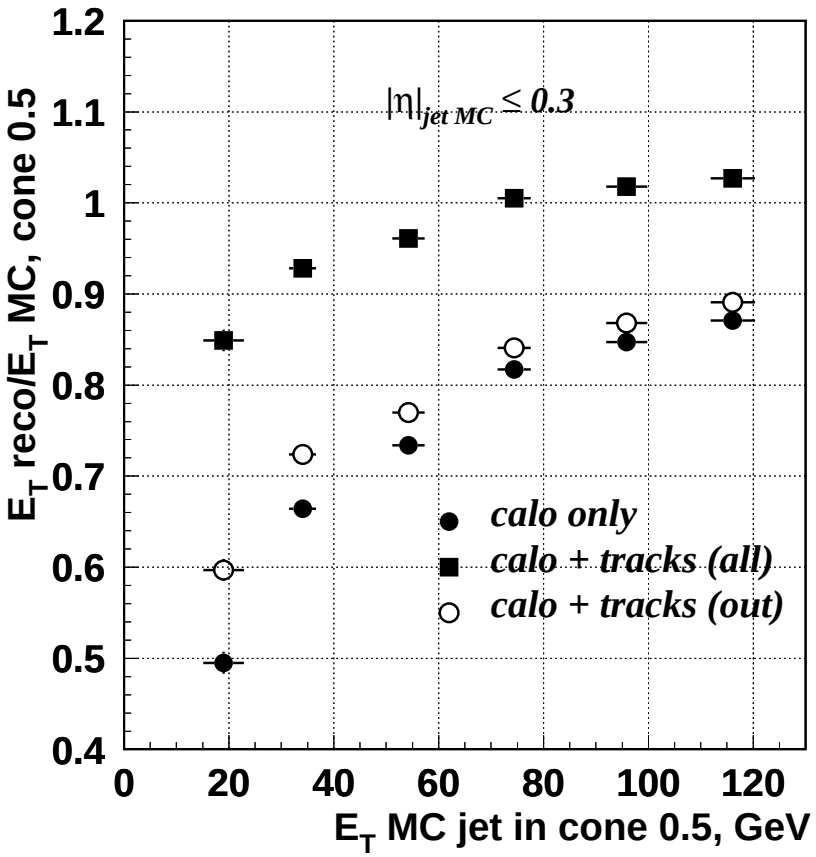


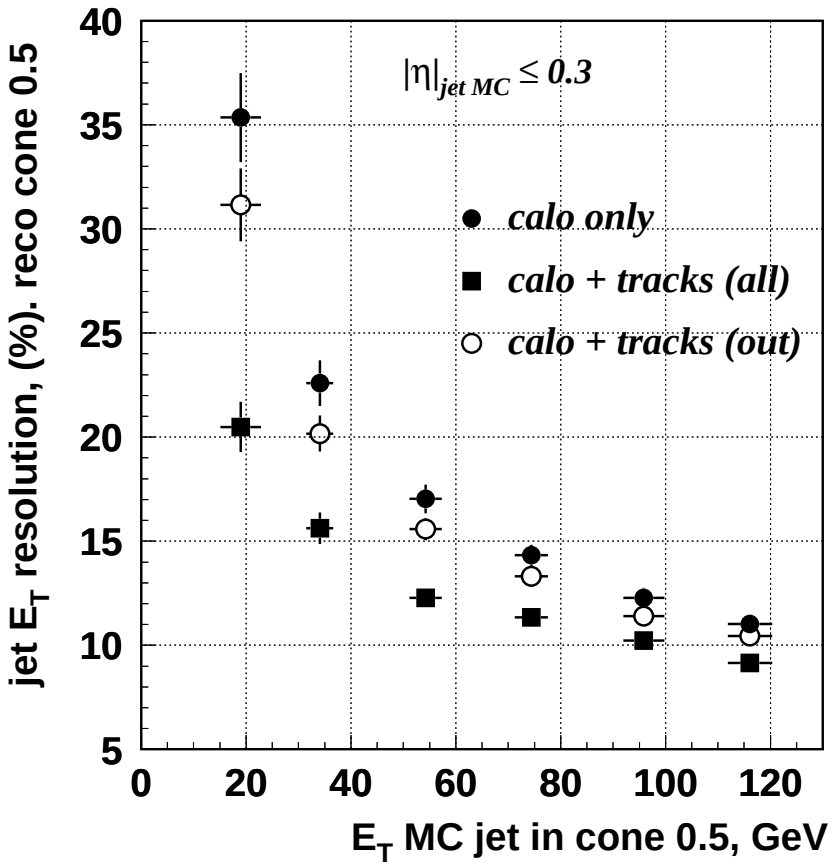
Trigger L1/HLT Rates $2 \times 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$

Channel	*L1 Thresh.* (GeV)	*L1 Rate* (kHz)	*HLT Thresh.* (GeV)	*HLT Rate* (Hz)
isolated μ	14	2.7	19	25
μ pair	3	0.9	7	4
isolated e	29	3.3	29	33
isolated γ	29	3.3	80	4
e pair	17·17	1.3	17·17	1
γ pair			40·25	4
tau jet	86	2.2	86	3
tau jet pair	59	1.0	59	1
e · jet	21· 45	0.8	21· 45	2
1,3,4 jet	177,86,70	3.0	657,247,113	9
jet · MET	88·46	2.3	123·80	5
b jet			237	5
calibration				10
TOTAL				105

JetMET JetPlusTracks

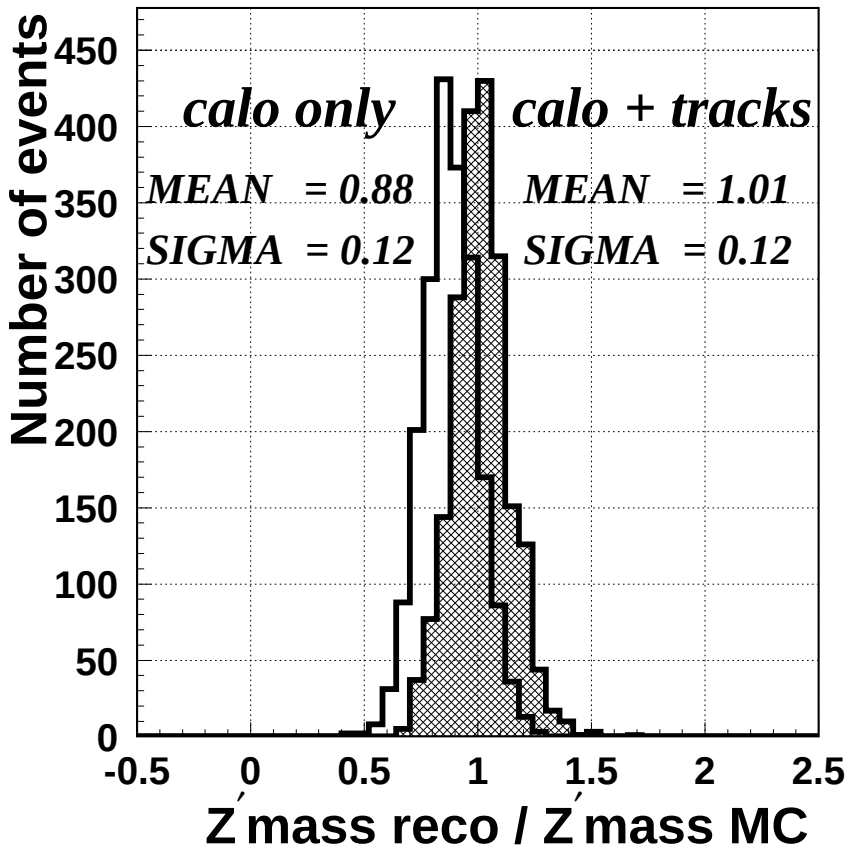
Correction for magnet sweep and cal. linearity

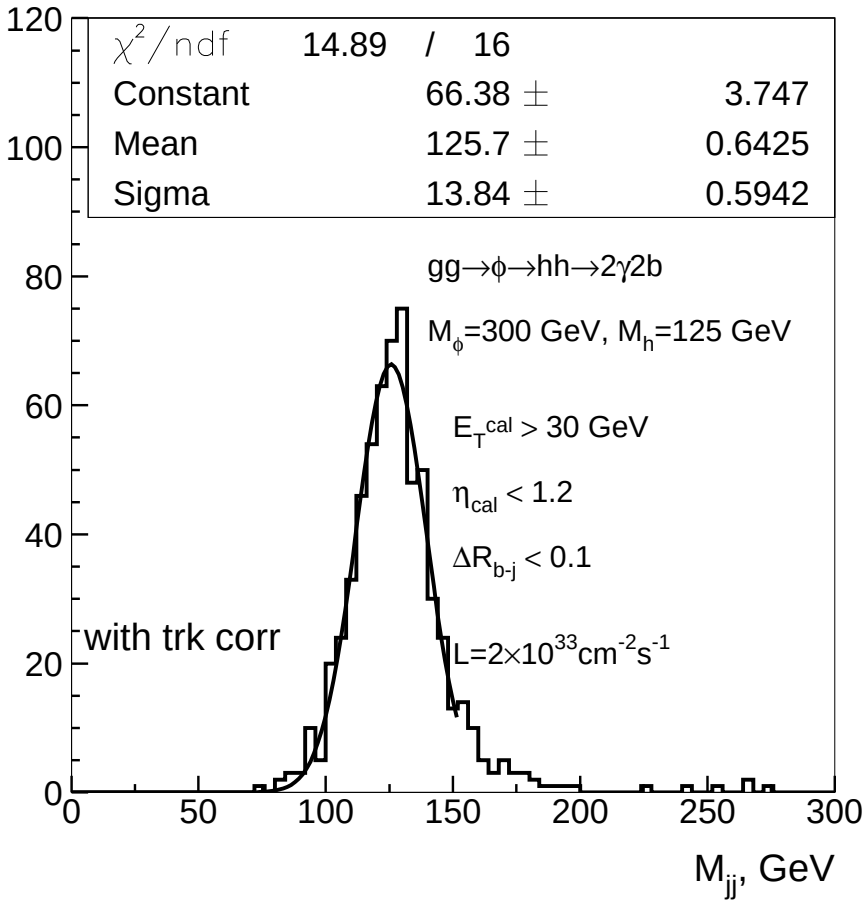




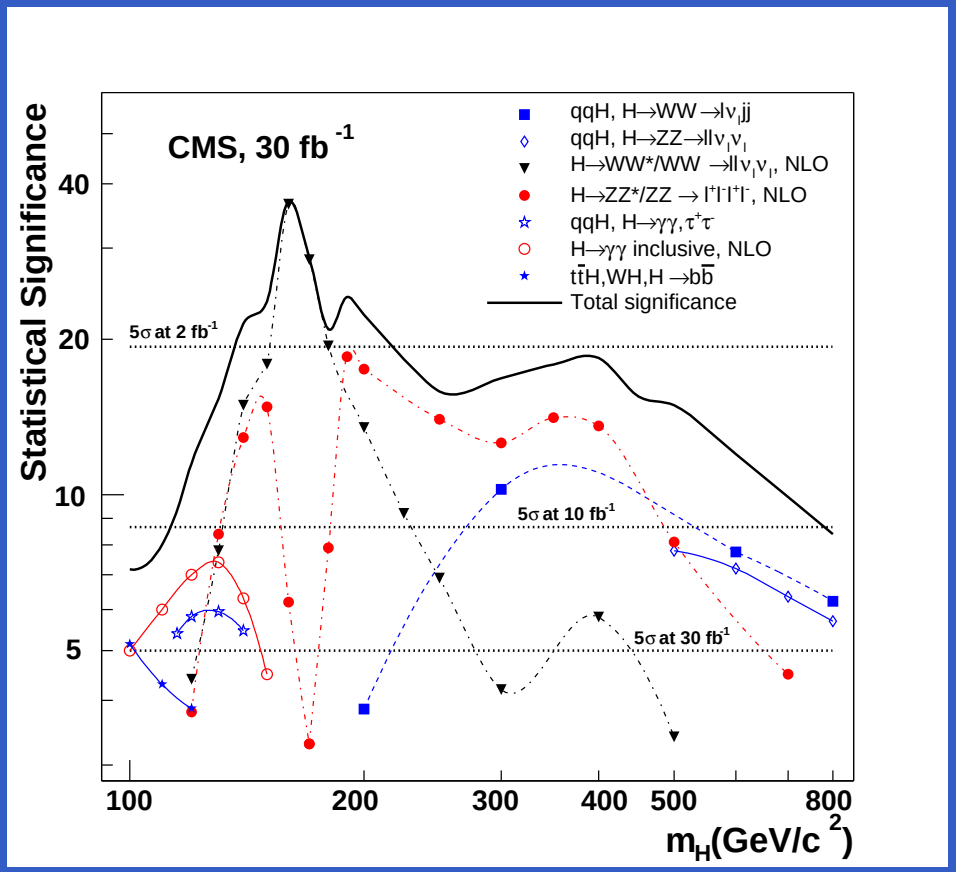
Olga Kodolova *et al.*, CMS CMS AN 2003/016.

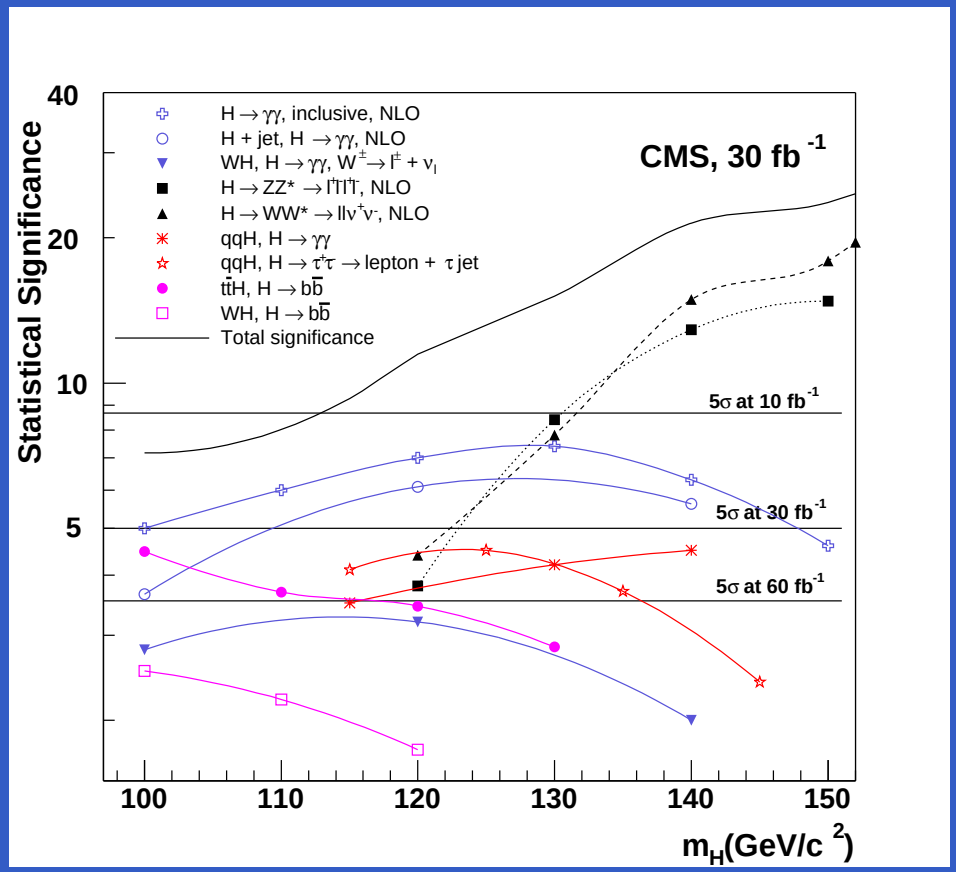
JetMET JetPlusTracks result





Higgs SM Higgs Mass Reach





S. Abdullin *et al.*, CMS Note 2003/033.

PRS Data Challenge DC04

- Purpose: demonstrate validity of software baseline for Physics and Computing TDRs
- Timesale and scope: Process one month of HLT output at 25% luminosity (50M events)
- Challenge: Reconstruction and selection of digitized data (150 CPU $\times$ 2 months, storage of 75,000 GBytes)
- Future:
  DC05, 50% data challenge
  Physics TDR, $t_0 - 1.5\ \mathrm{y}$
  DC06, 100% data challenge

JetMET Data Challenge 2004

Physics studies:

- Higgs by W fusion... tag jets, missing E_{T}, W reconstruction
- Z' mass resolution
- SUSY Sparticle multiple jets, missing E_{T}

Background studies:

- Di-jet
- W+jet
- Z+jet
- top (calibration)
- γ+jet (calibration)

JetMET Data challenge DC04

The JetMET summary request (maintained by Haifeng Pi) is available at http://cms00.phys.ufl.edu/cms/DC04/PCP/

Mozilla

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CMS JetMET Production Request in DC04

(Last update Dec 12, 2003)

Physics Channels (Background)	Event Generator	Number of Events	Datacards	Configuration	Dataset (Number of Evernt per Channel-Configuration)	Current Status
W + jets	Pythia	3,150,000	jm03b_Wjets_0_20_Id_857.txt jm03b_Wjets_20_50_Id_858.txt jm03b_Wjets_50_85_Id_859.txt jm03b_Wjets_85_150_Id_860.txt jm03b_Wjets_150_250_Id_861.txt jm03b_Wjets_250_400_Id_862.txt jm03b_Wjets_400_700_Id_863.txt jm03b_Wjets_700_1100_Id_864.txt jm03b_Wjets_1100_1600_Id_865.txt jm03b_Wjets_1600_2200_Id_866.txt	W leptonic-decaying	jm03b_Wjets_0_20 (0.4 M) jm03b_Wjets_20_50 (0.6 M) jm03b_Wjets_50_85 (0.8 M) jm03b_Wjets_85_150 (0.6 M) jm03b_Wjets_150_250 (0.3 M) jm03b_Wjets_250_400 (0.2 M) jm03b_Wjets_400_700 (0.1 M) jm03b_Wjets_700_1100 (0.08 M) jm03b_Wjets_1100_1600 (0.05 M) jm03b_Wjets_160_2200 (0.02 M)	in production
W + 1 jet	Comphep + Pythia	1000,000	Datacards,similar to W+jets	W leptonic-decaying		in pre-production
W + 2 jets	Comphep + Pythia	1000,000	Datacards,similar to W+jets	W leptonic-decaying		in pre-production
W + 3 jets	Comphep + Pythia	1000,000	Datacards,similar to W+jets	W leptonic-decaying		in pre-production
W + 4 jets	Comphep + Pythia	500,000	Datacards,similar to W+jets	W leptonic-decaying		in pre-production

DC04 Tracker data samples

Tracker – b/τ : Physics Channel for DC04

Physics channels:

A/H→ττ→2jets requests ready (Sasha, Ritva…) Signal and Bkg

e-jet more studies needed (Olivier…)

μ-jet more studies needed (Marcin…)

ttH,H→bb some requests ready other needs further studies on different generators for BkG (Susanna, Lucia, Thomas…)

Bs → J/ψ φ request ready (Andrei) I need to contact the Belkov group..)

For CMS Week all requests will be ready..

DC04 e/gamma data samples

Data samples for DC04

(The numbers are initial targets)

Generated

Request submitted

Ready for submission

Common request (Sasha N)

compHEP
Common request?
Sasha?

Sample	HLT output	Sim. + dig.	Gen.
W→eν (in one 1/8)	5M	10M	20M
Z→ee	1M	2M	3M
"2γ" from jets	1M	10M	50M
"1e" from jets	0.005M	5M	20M
"2 γ" from γ+jet	2M	6M	12M
H→γγ	0.2M	0.4M	1M
H→ZZ*→4e	0.2M	0.3M	1M
2 γ intrinsic	1M	2M	4M
ZZ*→4e intrinsic	0.2M	0.4M	0.8M
tt →4e	0.1M	0.3M	
Zbb →4e	0.1M	0.3M	
TOTAL:	**11M**	**34M**	**100M**

DC04 Muon data samples

Muon PRS Samples for DC04

Events to be passed to full simulation/reconstruction:

topology:	1-muon	2-muon	4-muon
QCD bb		1M	300K
W	1.5M		
Z/γ^*		3M	
Zbb			100K
WW,WZ,ZZ		200K	5K*
tt		600K	65K
single top		100K	
High Mass Drell-Yan		70K	

← With evt weights

Useful for in-situ alignment studies

L >100 fb^{-1}

From PRS/Higgs

+ Signals... **Total is about 8 M events**

PYTHIA 6.2 used for most samples
COMPHEP for Zbb (coordinated with PRS/Higgs)

PRS Physics TDR Due end of 2005

Volume I

Detector response, physics objects, calibrations, parametrization Detector groups

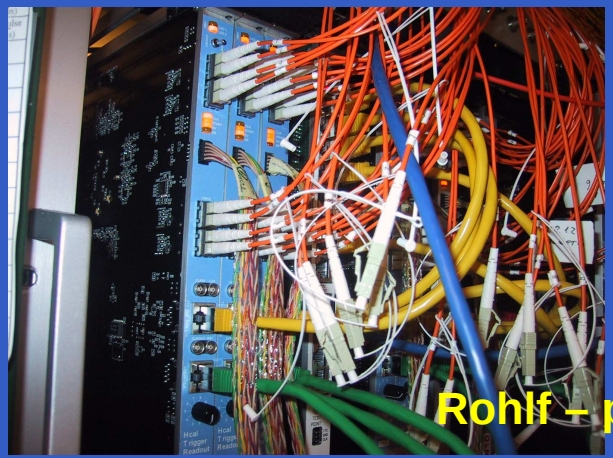
Volume II

High-level analyses (Higgs, SUSY, *etc.*)

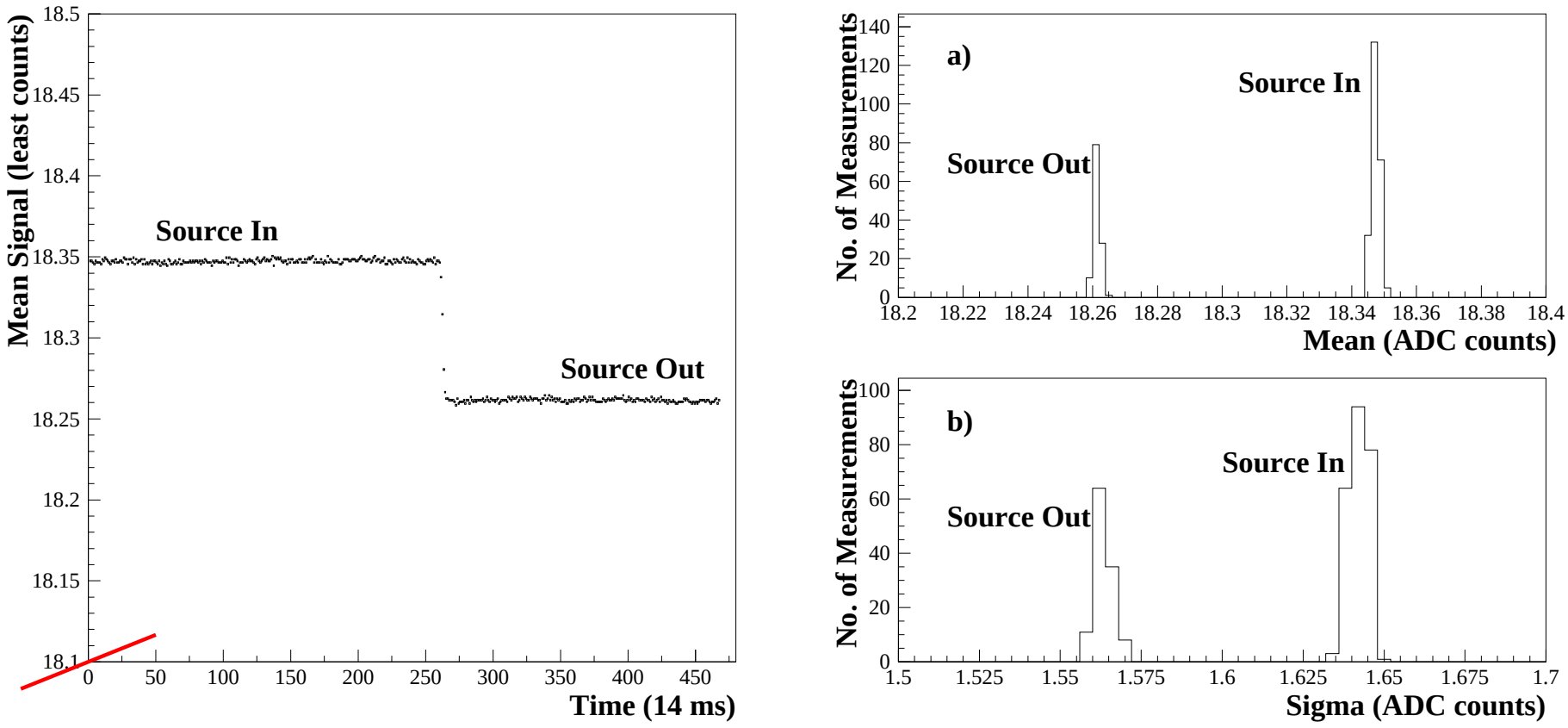
- Small number of full analyses
  shows how physics is done Detector groups
- Physics topics (simulation and parameterization)
  shows what physics we can do Analysis groups

JetMET Test Beam

- 2002:
  - calibration of several HB production wedges
  - measurement of HO trigger signals
- 2003:
  - 40 MHz structured beam
  - calibration of several HF production wedges
  - calibration of HO
  - study of barrel/endcap transition region
  - successful operation of FED with SLINK-64
- (future) 2004:
  - calibration of HF wedges
  - low energy beams
  - Geant-4 tuning

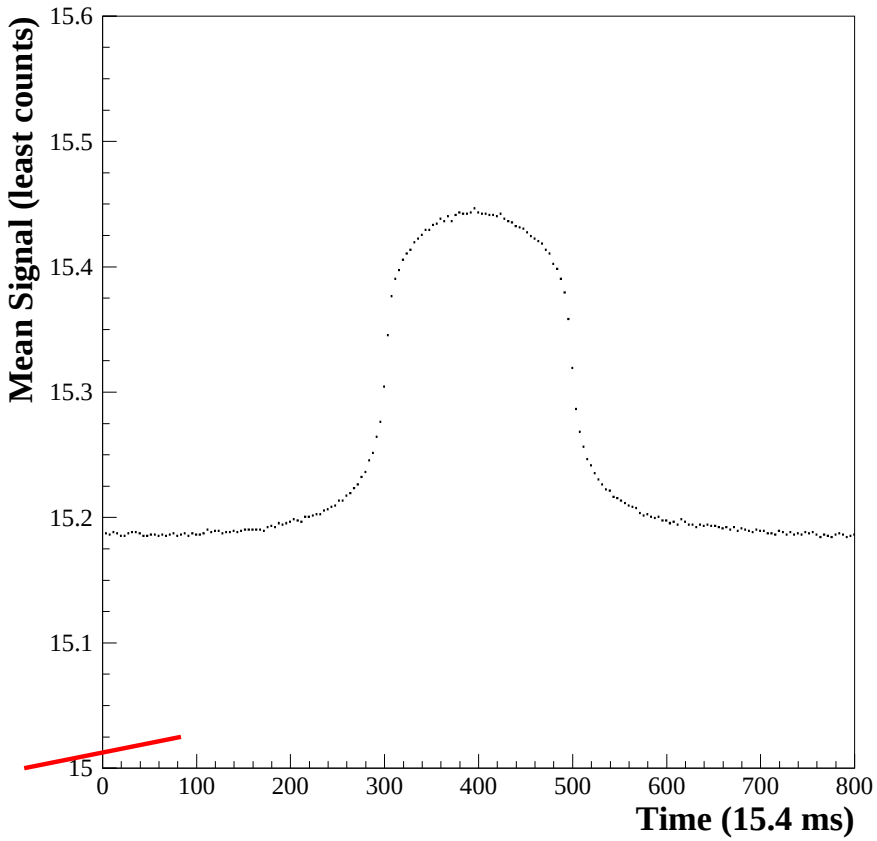


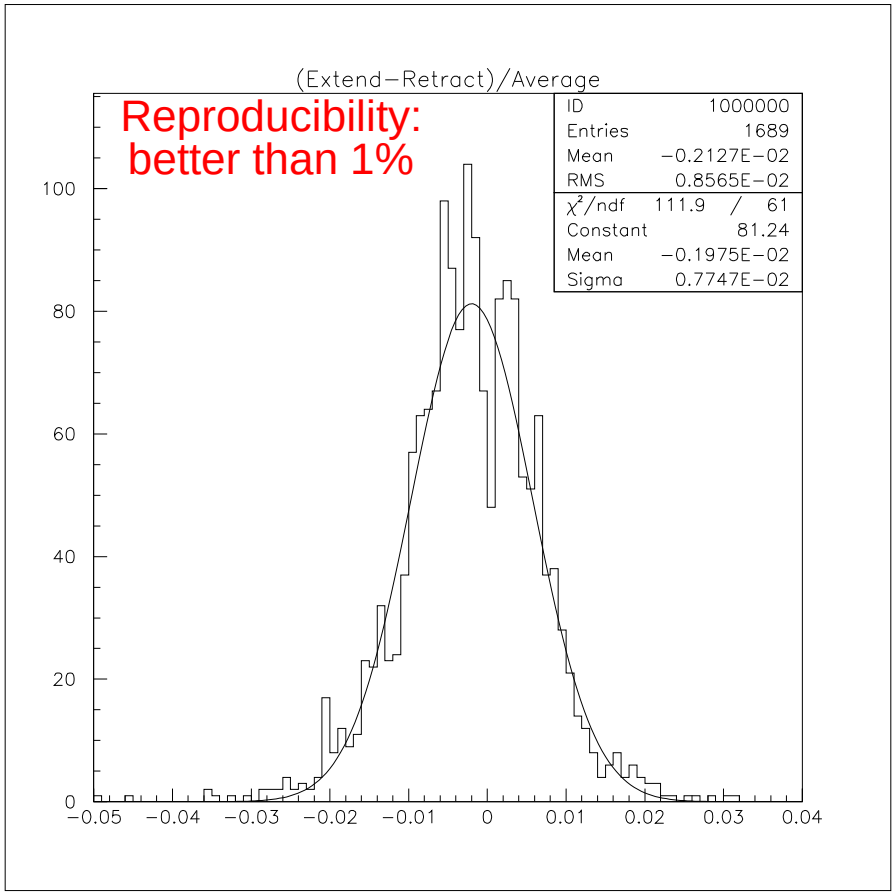
JetMET Radioactive source calibration



E. Hazen *et al.*, *Radiactive Source Calibration Technique for the CMS Hadron Calorimeter*, Nucl. Instr. & Meth. A511/3, 311 (2003).

JetMET Tile scan





$\mathcal{JetMET}$ Gain source → GeV

The gain of each tower is

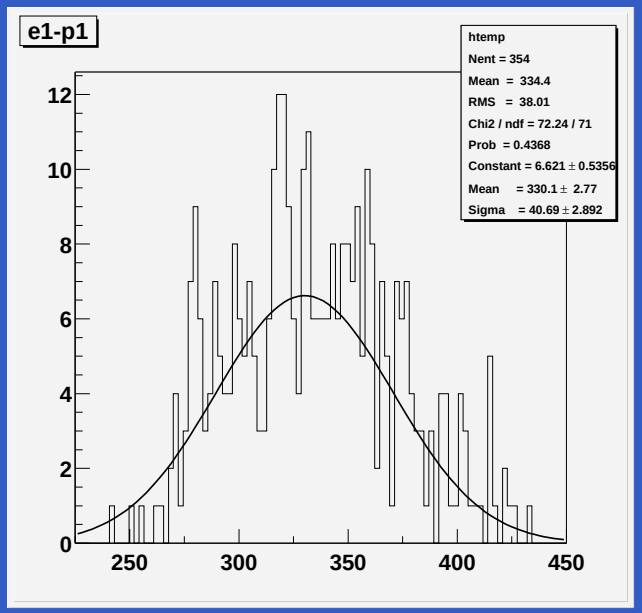
$$G = \Sigma \frac{W_i P_i}{R_i}$$

where

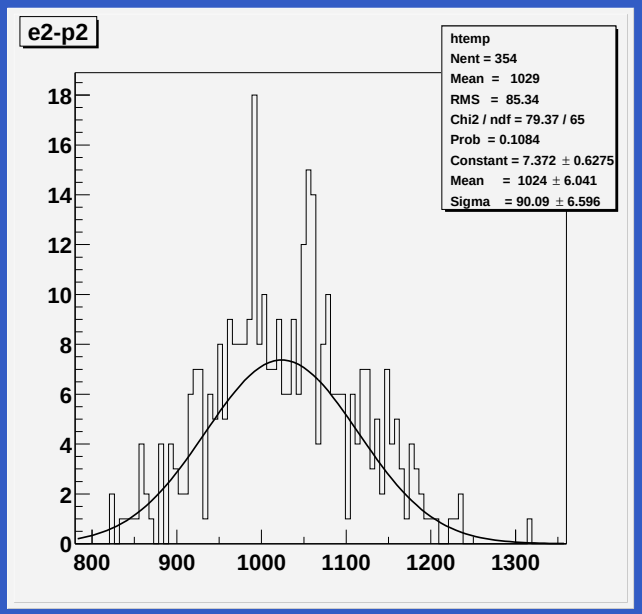
- W_i is the moving wire source response (depends on tile size).
- P_i is the measured particle response in test beam.
- R_i is the ratio of moving wire source to columnated source measured for each tile during construction (corrects for tile size).

JetMET Test beam 2003 Muons in HE

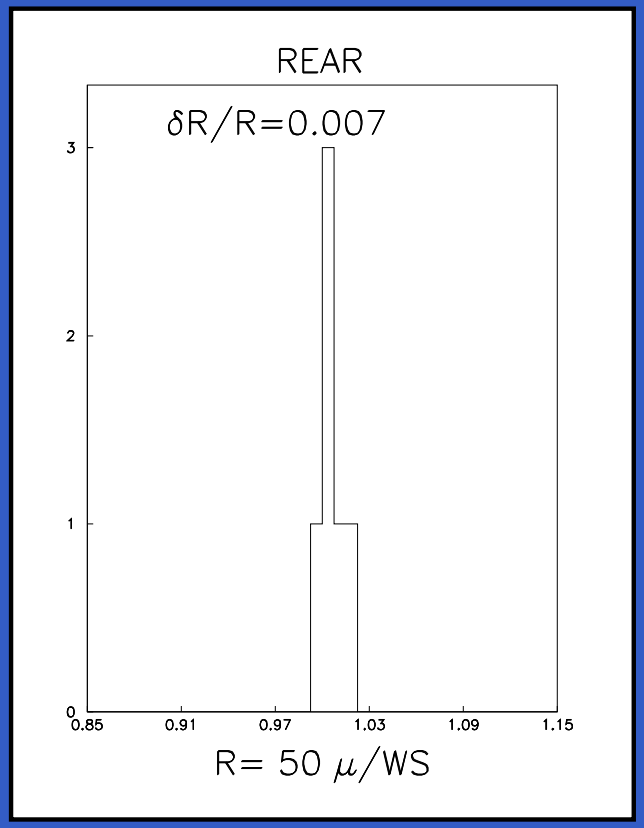
front



back



Sum of 50 muon events (200 GeV energy deposit).

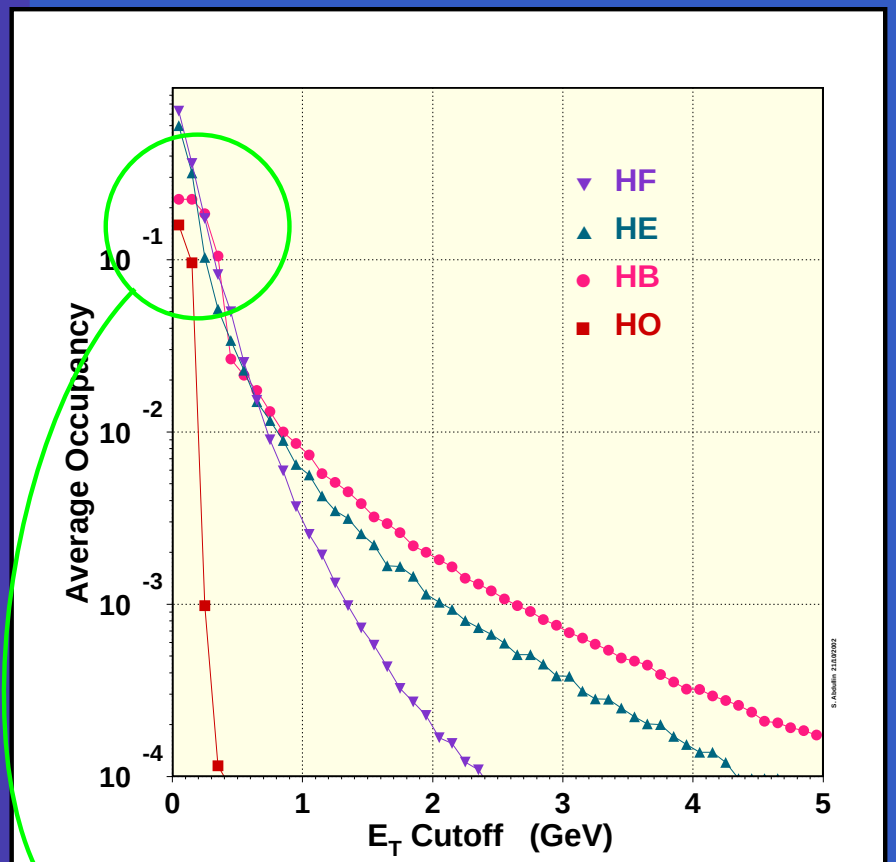


The source tracks the beam!

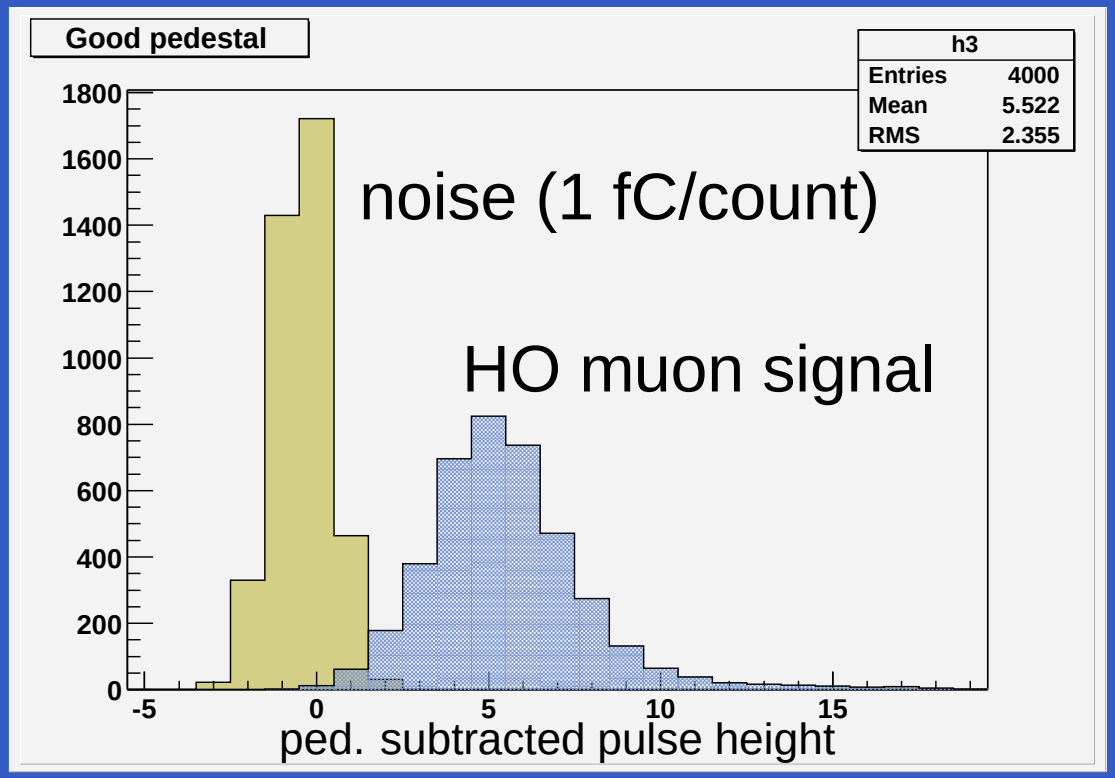
Vladimir Ladygin *et al.*

JetMET Electronics noise

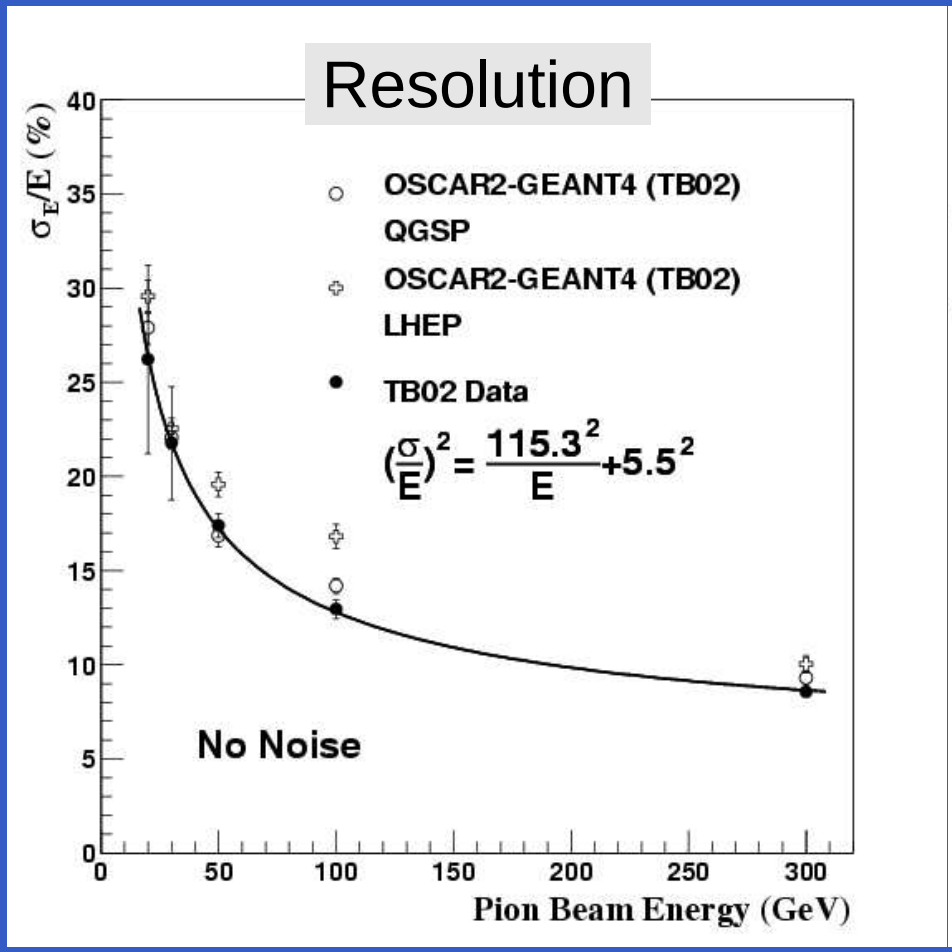
- Impacts occupancy/threshold for zero suppresion
- Low noise allows acceptible muon tag for RPC trigger

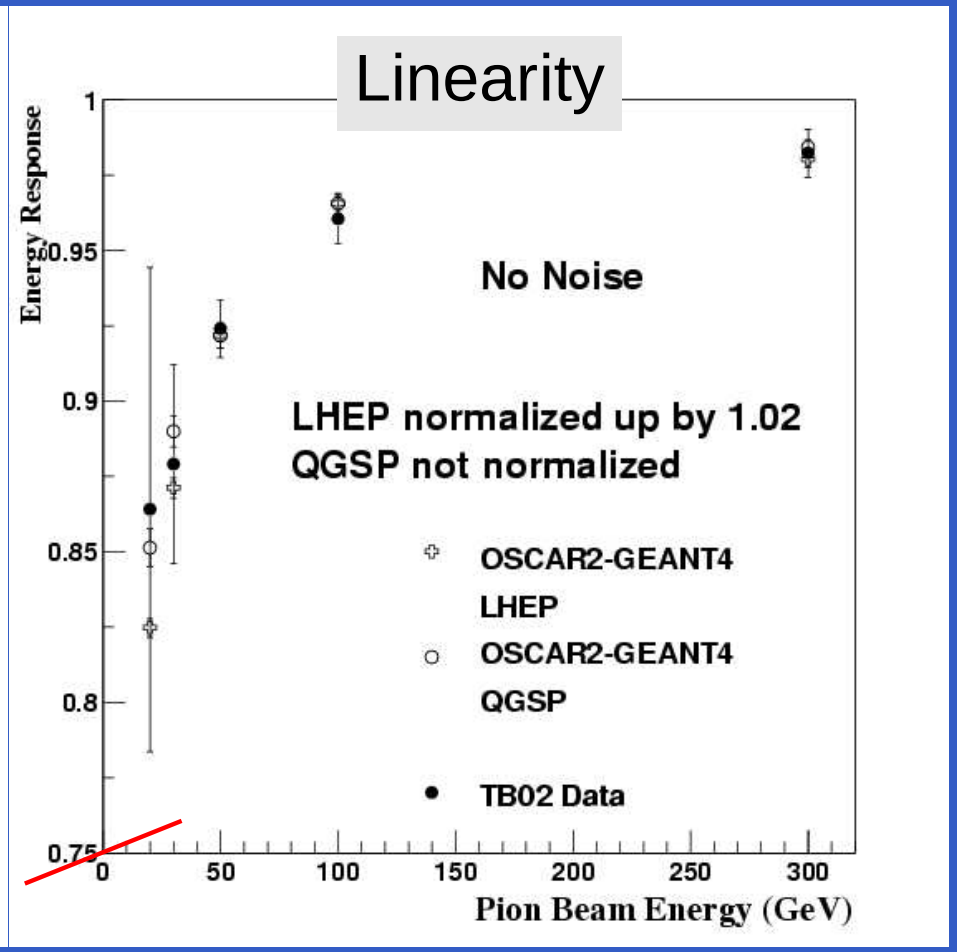


10-15% at 300 MeV



JetMET HB Resolution & Linearity GEANT-4





See talk of V. Daniel Elvira.

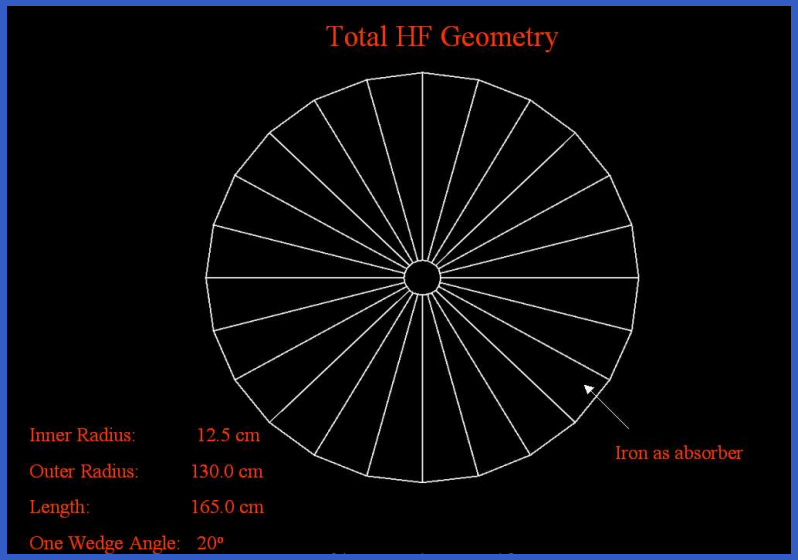
JetMET HF resolution

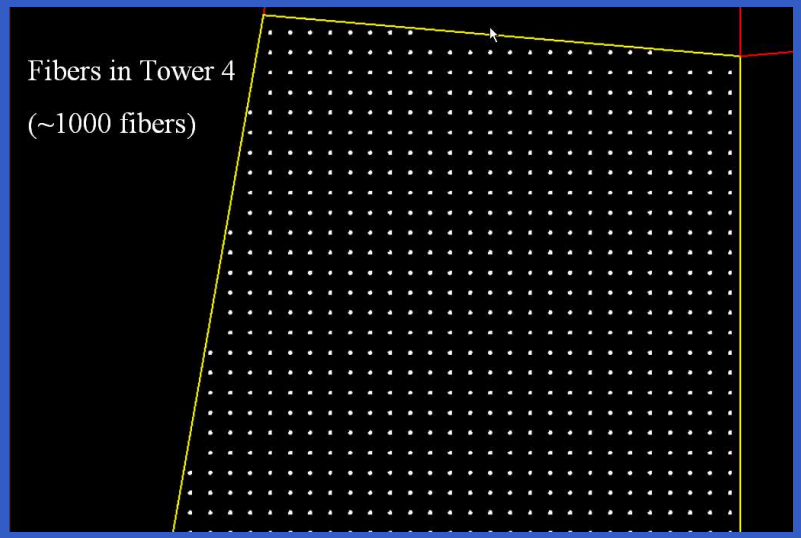
HF resolution for pions from Test Beam 2003.

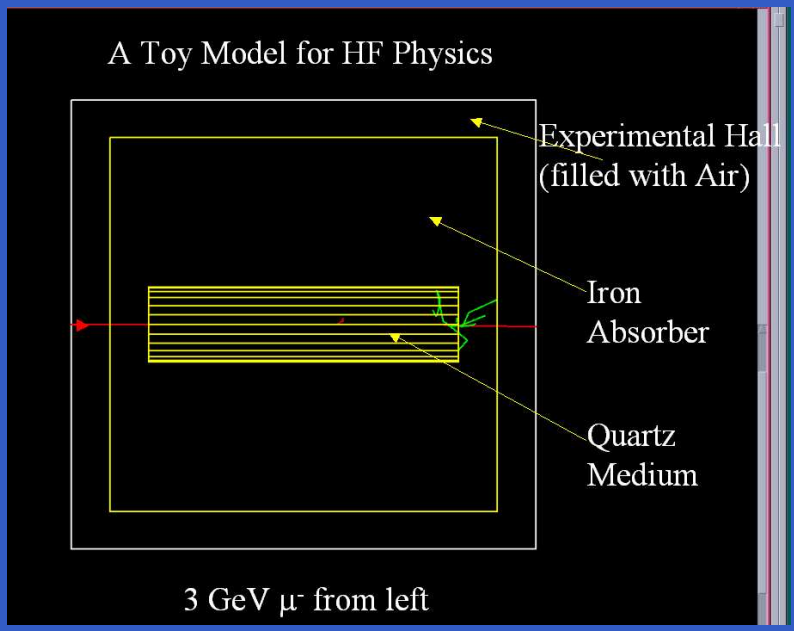
$$\frac{\sigma}{E} = \sqrt{\frac{a^2}{E} + b^2}$$

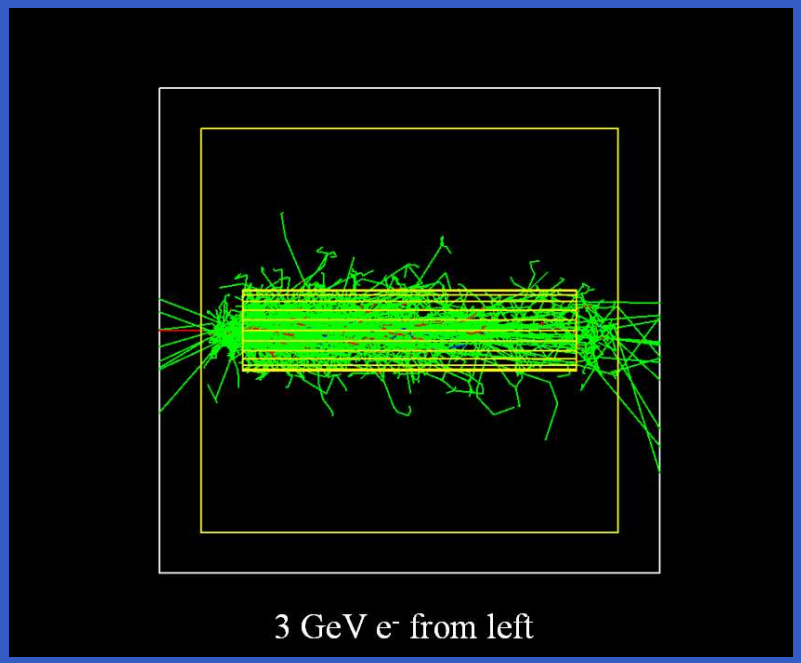
$a = 2.48$ $b = 0.007$

JetMET HF GEANT-4



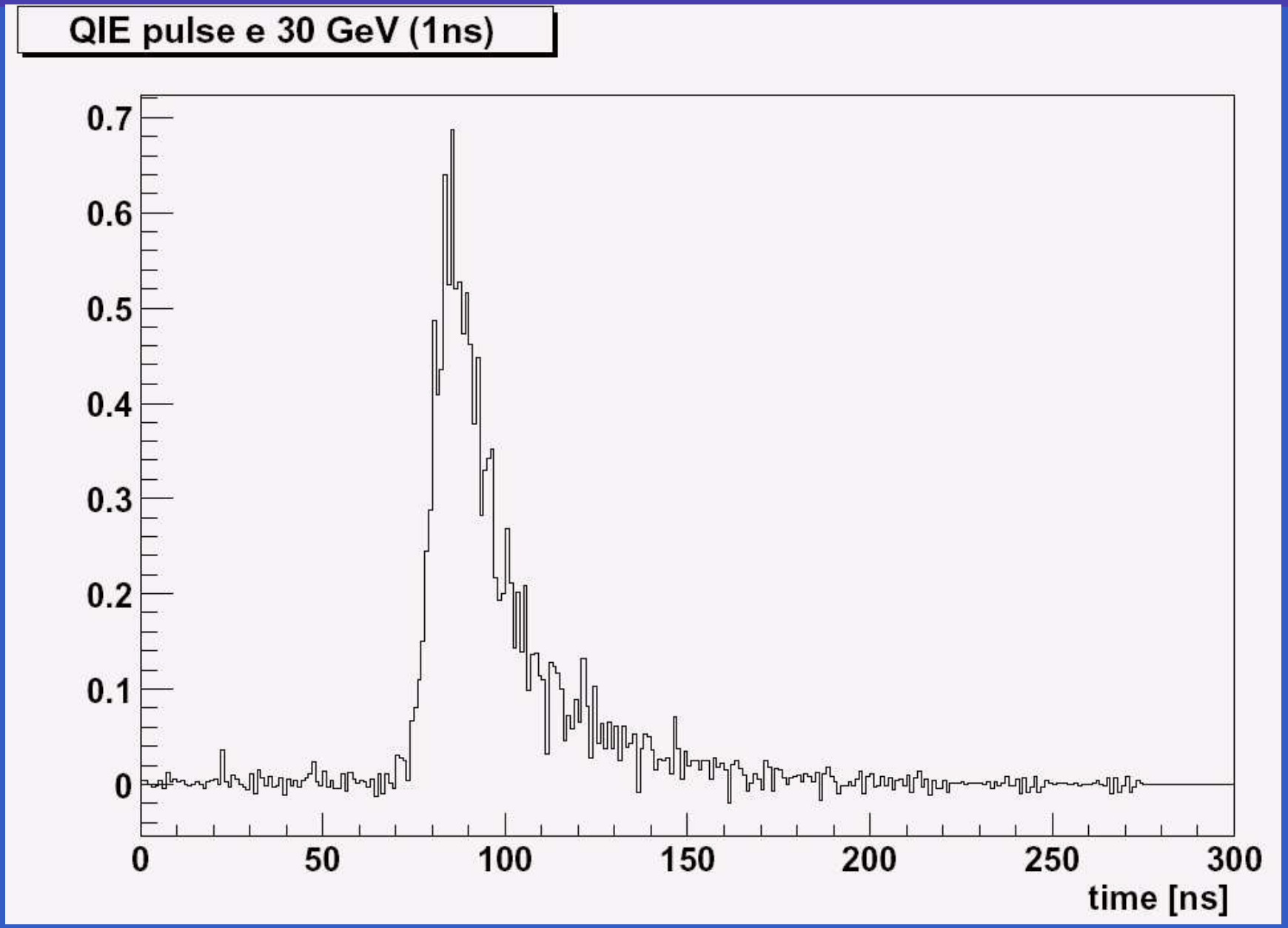




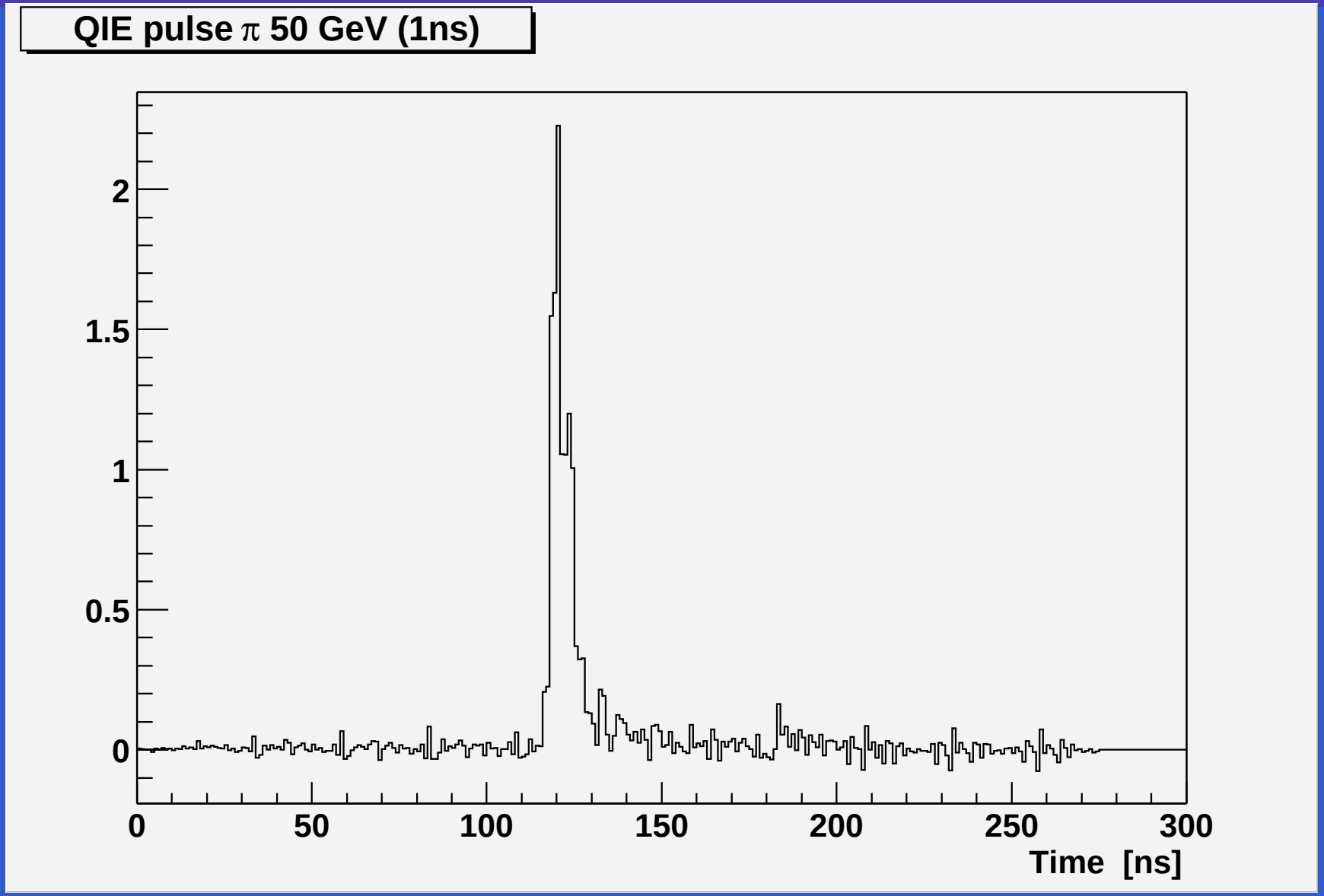


Taylan Yetkin

JetMET Test beam 2003 HB pulse



JetMET Test beam 2003 HF pulse shape



JetMET Data Base

- Construction data base
  absorber geometry, tiles, optical cables, mapping, HPD, PMT, FE, TPG electronics, FED, etc.
- Equipment management data base
  detector assembly and integration
- Configuration data base
  e.g. FPGA firmware, detector running
- Conditions data base
  information needed for event reconstruction
  "calibration data base"

Talk of Shuichi Kunori

$\mathcal{J}etMET$ Physics Studies

- Higgs by Vector Boson Fusion D. Green, H. Pi *et al.*
- SUSY S. Abdullin *et al.*
- WW scattering A. Krokhotine *et al.*
- ZZ$\rightarrow \ell\ell\nu\nu$ L. Levchuk *et al.*
- Heavy neutrino M. Kirsanov *et al.*
- Gravitation exotica Fermilab group
- Heavy Ion B. Wyslouch *et al.*

other?

PRS Plans

PRS goals for next 12 months

- Complete OSCAR, use it in DC04
- Revive ORCA code with POOL, resume work
  - Persistent physics objects
- Calibration software: put methods and first code in place
  - Need help from detector projects
- Participate in DC04 with some "analysis" examples
  - Reproduce/update DAQ TDR results
- Complete FAMOS, release it to analysis-PRS groups
  - Get OO analysis started in analysis-PRS groups
- Increase training efforts; improve documentation
- Outline of Physics TDR

From Annual/LHCC review