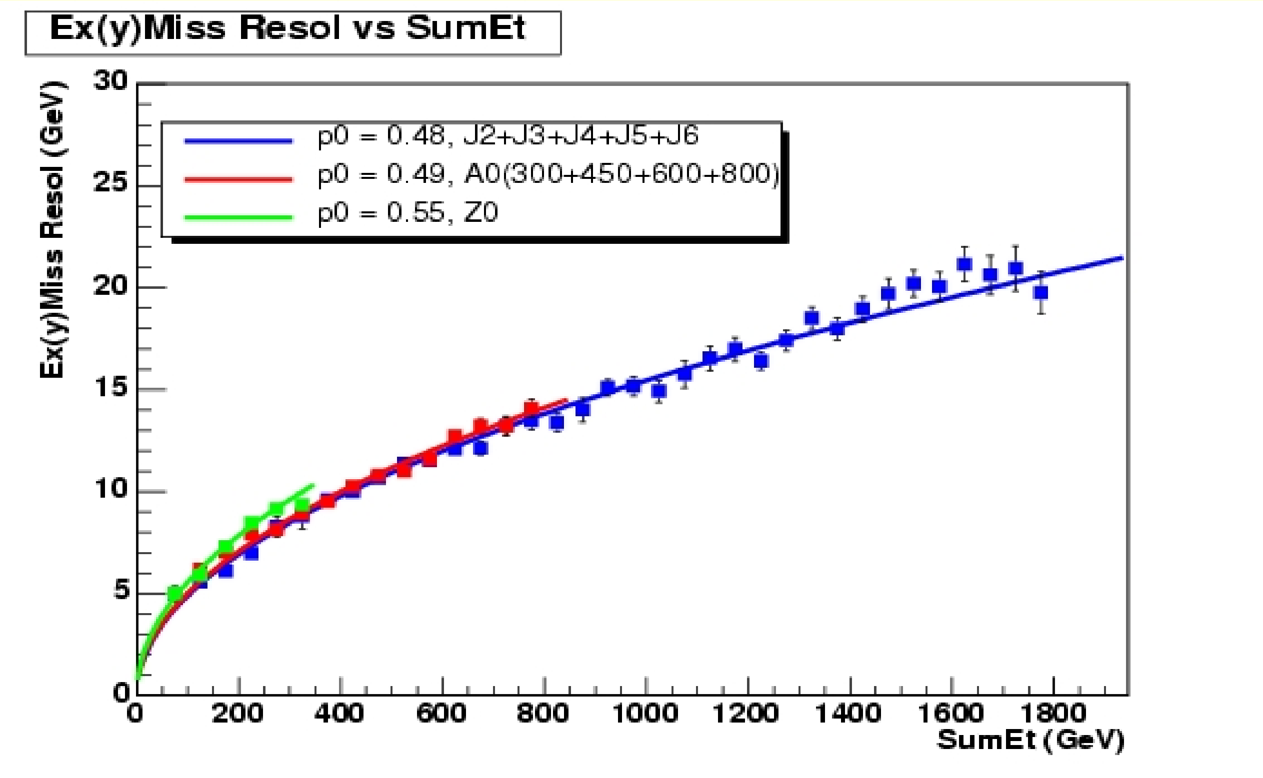
Missing Transverse Energy

Missing ET

Calculated from all Calo Cells within $|\eta \text{ cell}| < 5$

- $E_{x(y)Miss} = \Sigma\, E_{x(y)}\text{cells}$

$$E_{TMiss} = \sqrt{E_{yMiss}^{2} + E_{yMiss}^{2}}$$



– Calorimeter coverage important for resolution

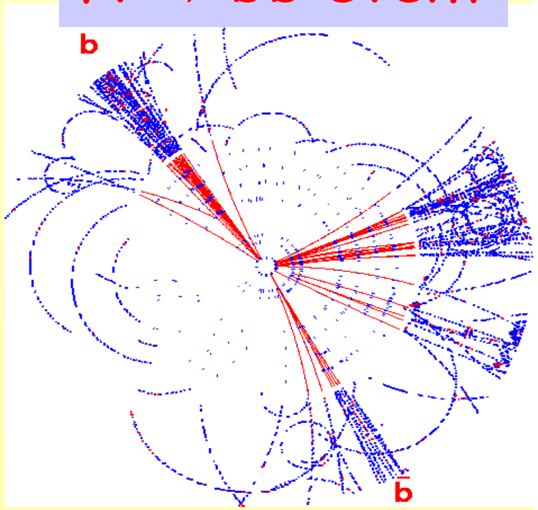
Tracking

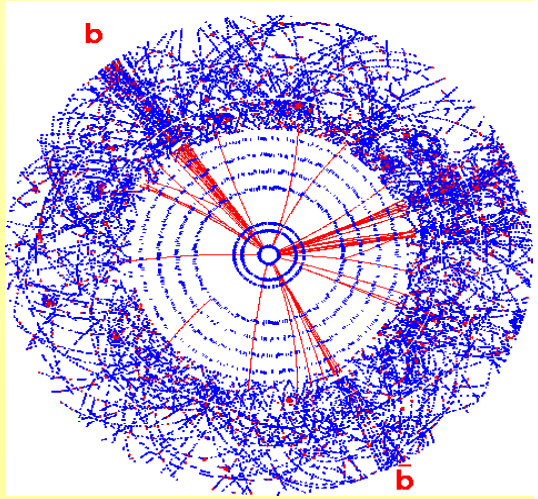
Tracking at LHC

- p-p collision @ $\sqrt{s}$ = 14 TeV
- bunch spacing of 25 ns
- Luminosity
  - low-luminosity: $2*10^{33}cm^{-2}s^{-1}$ (first years)
  - high-luminosity: $10^{34}cm^{-2}s^{-1}$
    - ~20 minimum bias events per bunch crossing
    - ~1000 charged tracks per event

Radius:	2cm	10cm	25cm	60cm
$N_{Tracks}/(cm^2*25ns)$	10.0	1.0	0.10	0.01

H → bb event





H → bb event
@ high luminosity

Tracker Requirements

- **Efficient & robust Pattern Recognition algorithm**
  - **Fine granularity to resolve nearby tracks**
  - **Fast response time to resolve bunch crossings**
- **Ability to reconstruct narrow heavy object**
  - **1~2% p_t resolution at ~ 100 GeV**
- **Ability to operate in a crowded environment**
  - **Nch/(cm^2*25ns) = 1.0 at 10 cm from PV**
- **Ability to tag b/τ through secondary vertex**
  - **Good impact parameter resolution**
- **Reconstruction efficiency**
  - **95% for hadronic isolated high p_t tracks**
  - **90% for high p_t tracks inside jets**

ATLAS Inner Detector

ATLAS Inner Detector

ID inside 2T solenoid field

Tracking based on many points

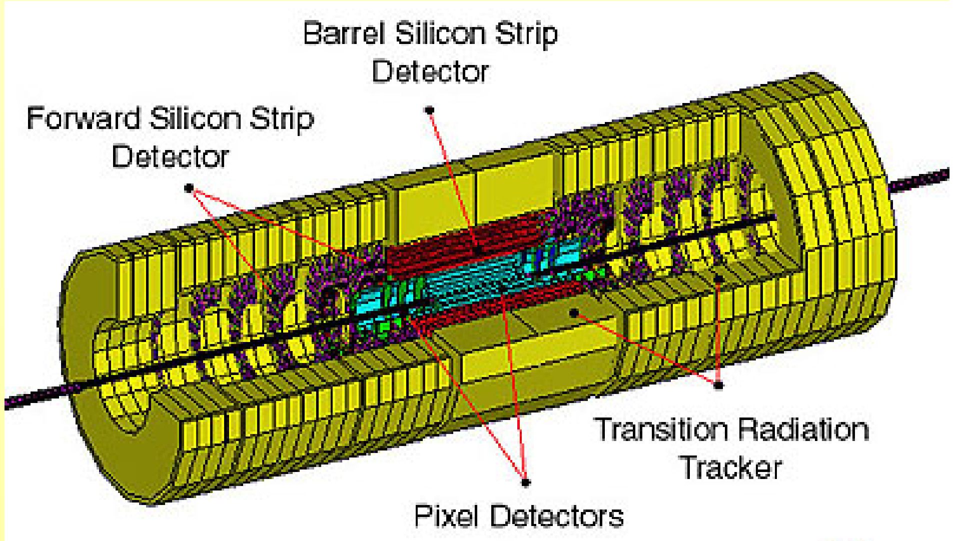
Precision Tracking:

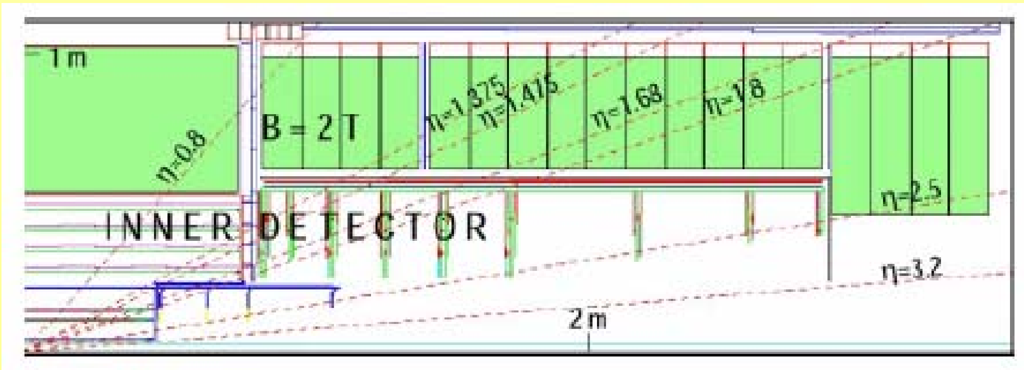
- Pixel detector (2-3 points)
- Semiconductor Tracker – SCT (4 points)

Continuous Tracking:

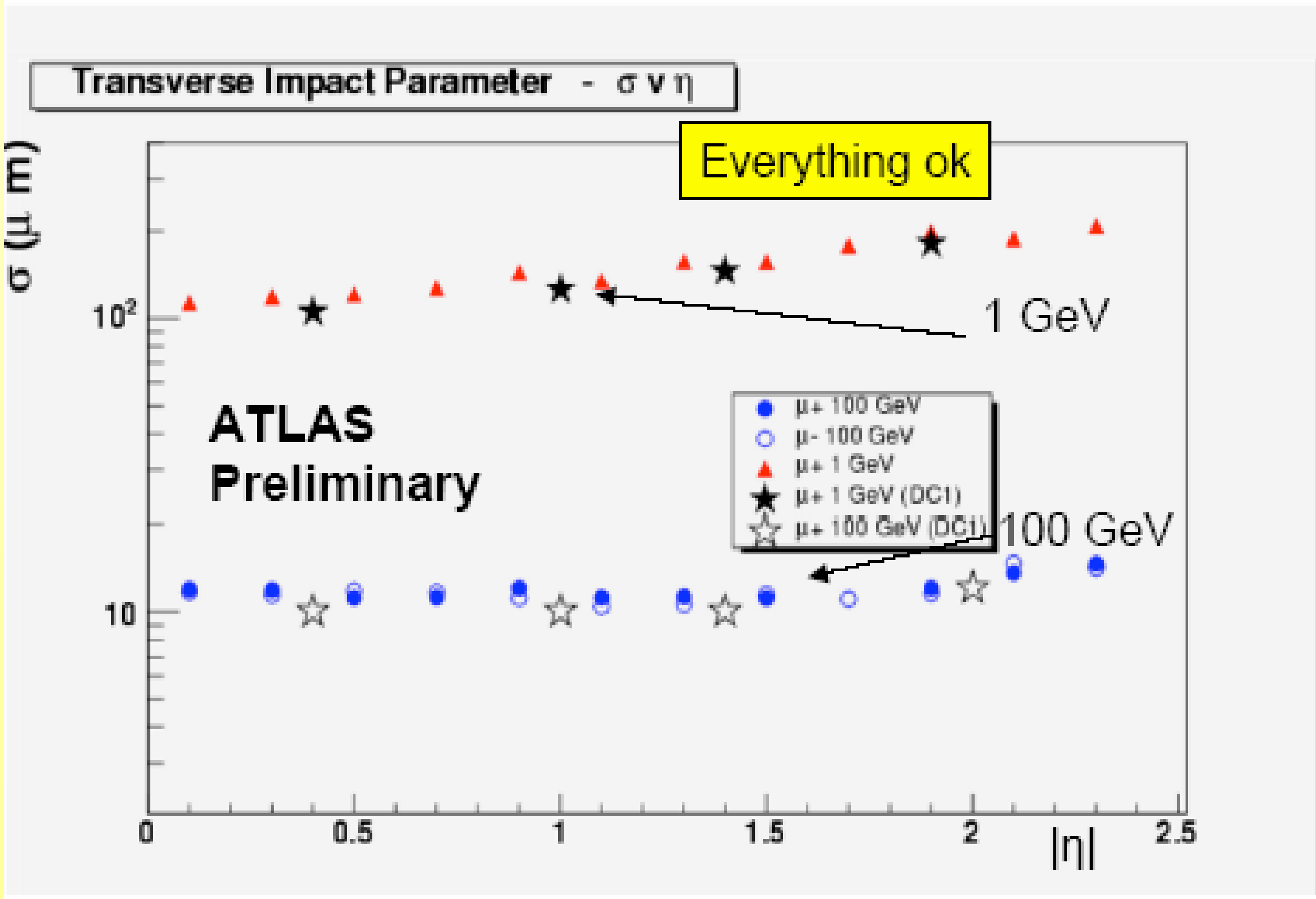
(for pattern recognition & *e* id)

- Transition Radiation Tracker – TRT (36 points)



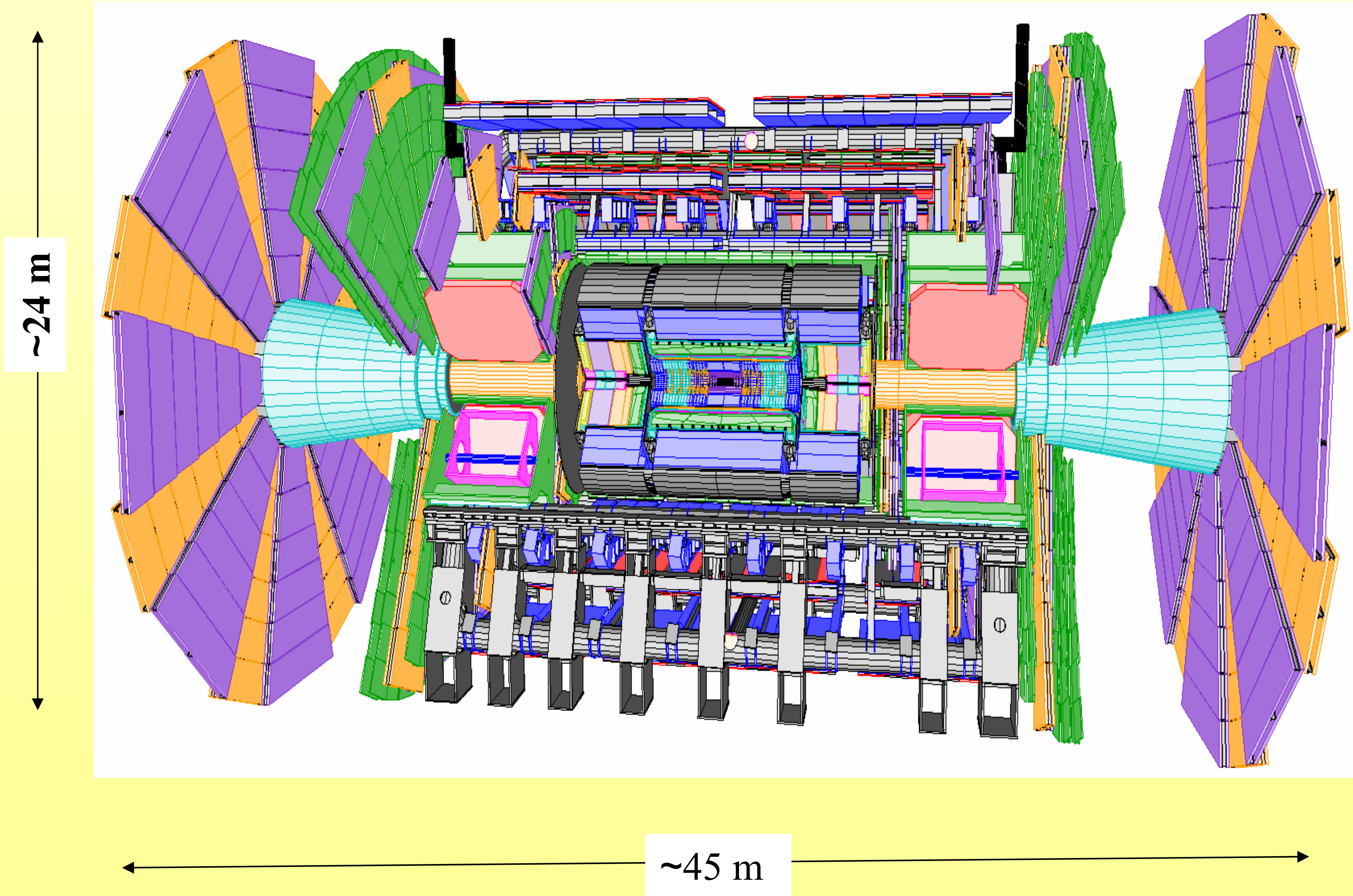


ID performance



Muons

Muon System



Muon measurement

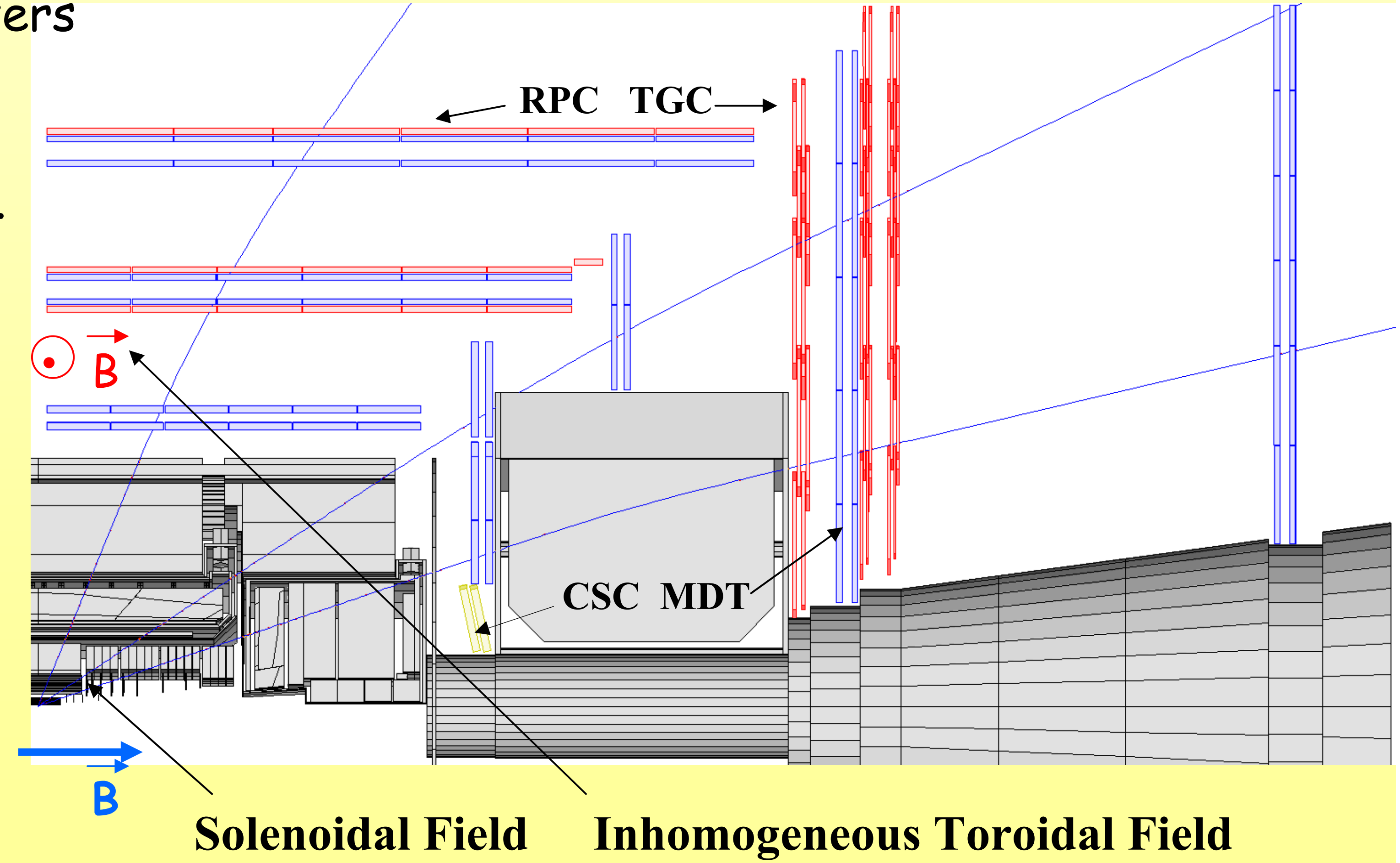
Traversing Atlas a μ is detected in

- 2 high precision tracking systems: Inner Detector and μ System
- Calorimeters

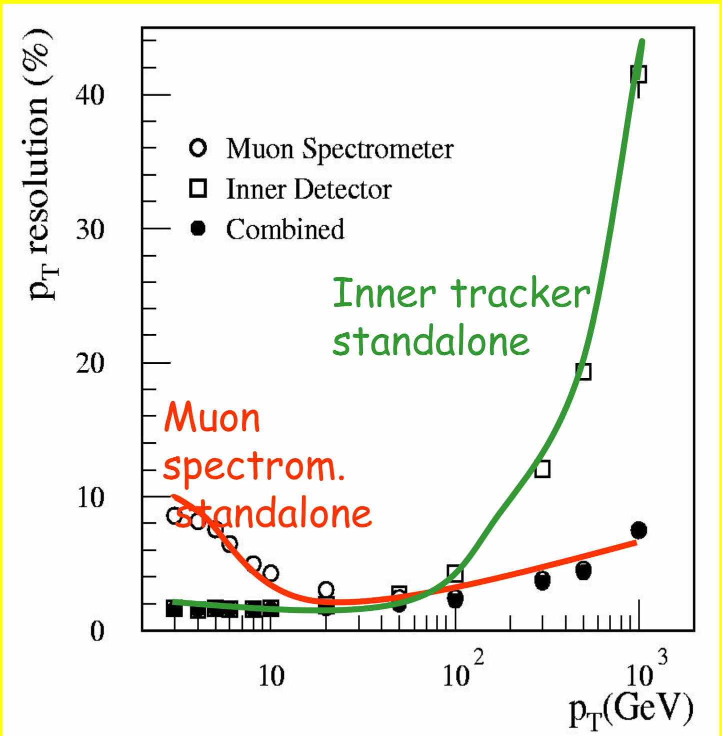
μ Syst Best at higher p_T

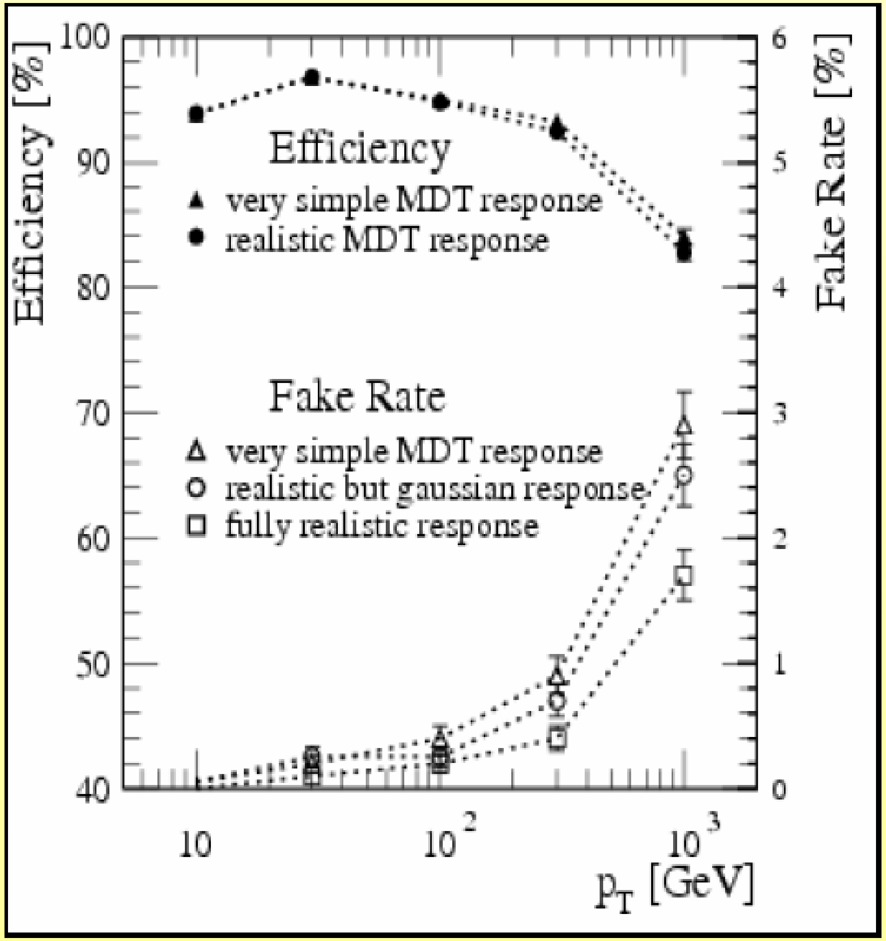
E loss >3GeV

ID Best at lower p_T



Muon Performance





- Muon Spectrometer resolution dominates for P_T > 100 GeV/*c*
- Resolution fairly constant over whole eta range
- Coverage $|\eta|$ < 2.7

Fake rate increases at high luminosity to ~ 5%

Tau

Lepton

τ Decays

- τ decay modes
  - Leptonical decay modes
    - $\tau \rightarrow \nu_\tau + \nu_e + e$ (17.4%)
    - $\tau \rightarrow \nu_\tau + \nu_\mu + \mu$ (17.8%)
  - Hadronical decay modes
    - 1 prong
      - $\tau \rightarrow \nu_\tau + \pi^\pm$ (11.0%)
      - $\tau \rightarrow \nu_\tau + \pi^\pm + \pi^0$ (25.4%)
      - 77% $\tau \rightarrow \nu_\tau + \pi^\pm + \pi^0 + \pi^0$ (10.8%)
      - $\tau \rightarrow \nu_\tau + \pi^\pm + \pi^0 + \pi^0 + \pi^0$ (1.4%)
      - $\tau \rightarrow \nu_\tau + K^\pm + \nu\pi^0$ (1.6%)
    - 3 prong
      - 23% $\tau \rightarrow \nu_\tau + 3\ \pi^\pm + \nu\pi^0$ (15.2%)

How to identify them?

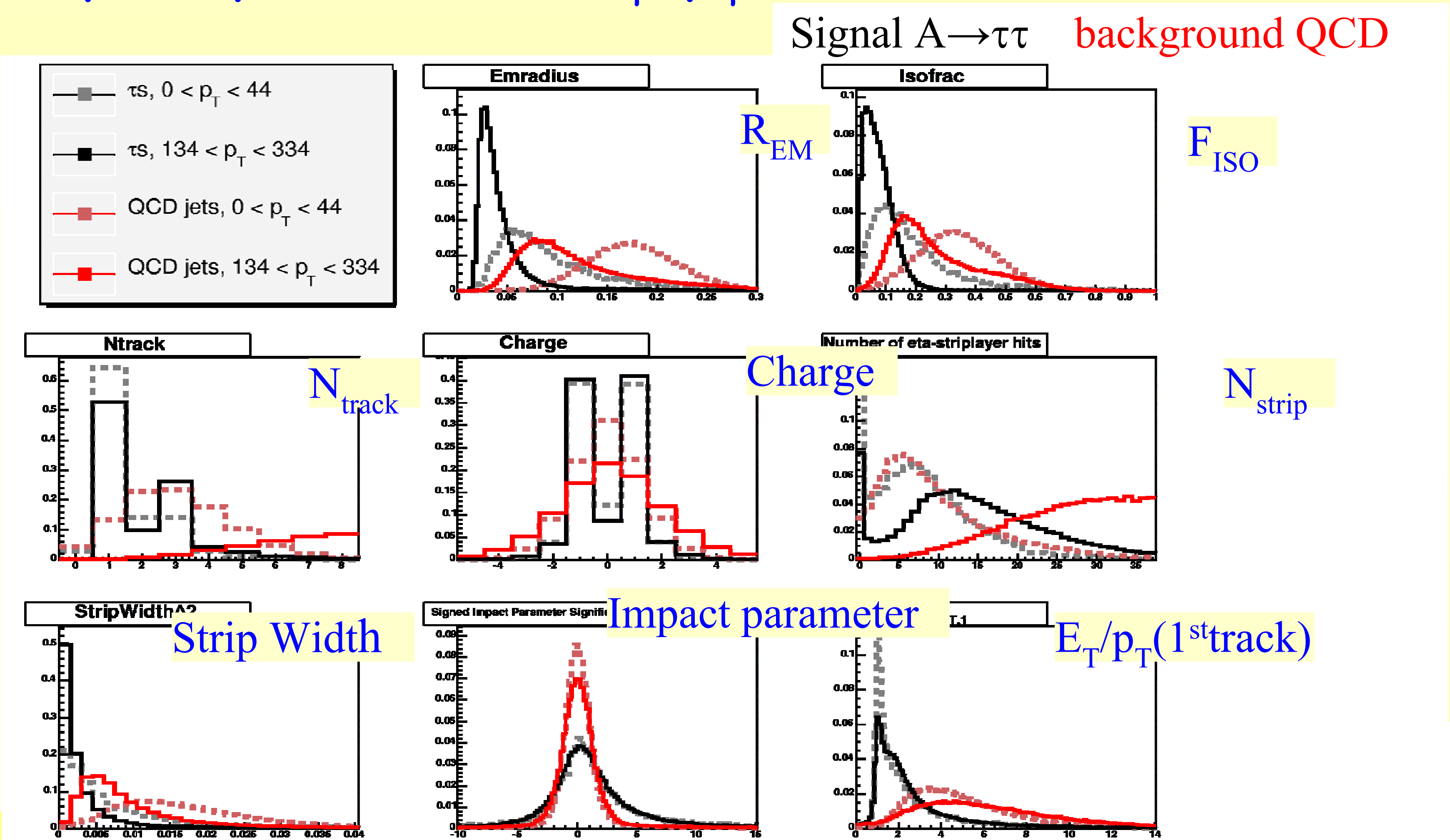
1 track,
impact parameter

shower shape,
energy sharing

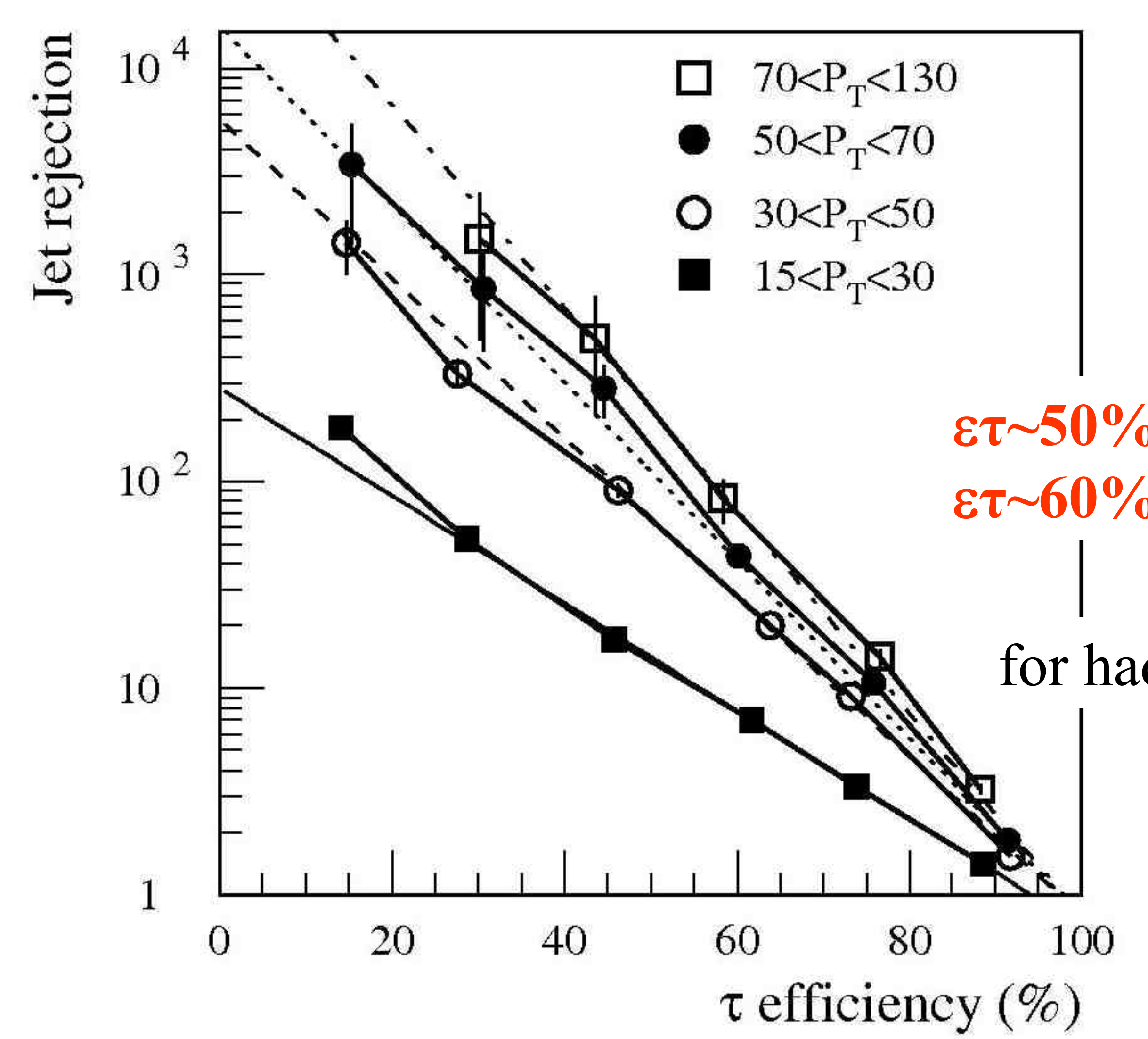
3 tracks,
impact parameter
secondary vertex
shower shape,
energy sharing

τ identification

Shower shape, N_{strip}, Charge, N_{track}, Impact parameter, E_T/p_T(1st track)



τ id : efficiency vs Background rejection

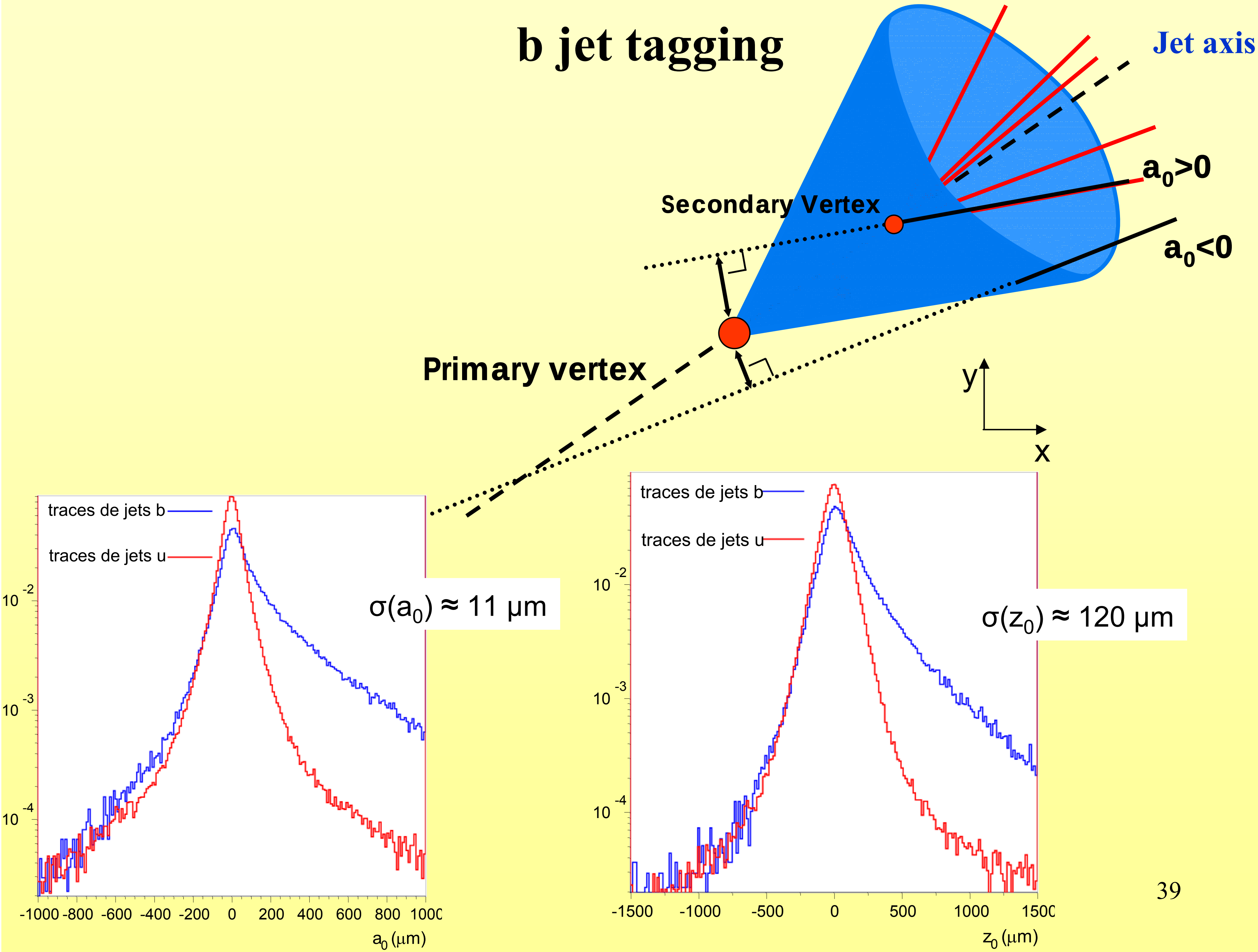


ετ~50% R~200
ετ~60% R~60

for hadronic decays

b-quark
jet tagging

b jet tagging



Reconstructed primary vertex low luminosity pile-up

<u>signal:</u>

WH(120,400)-> bb,uu

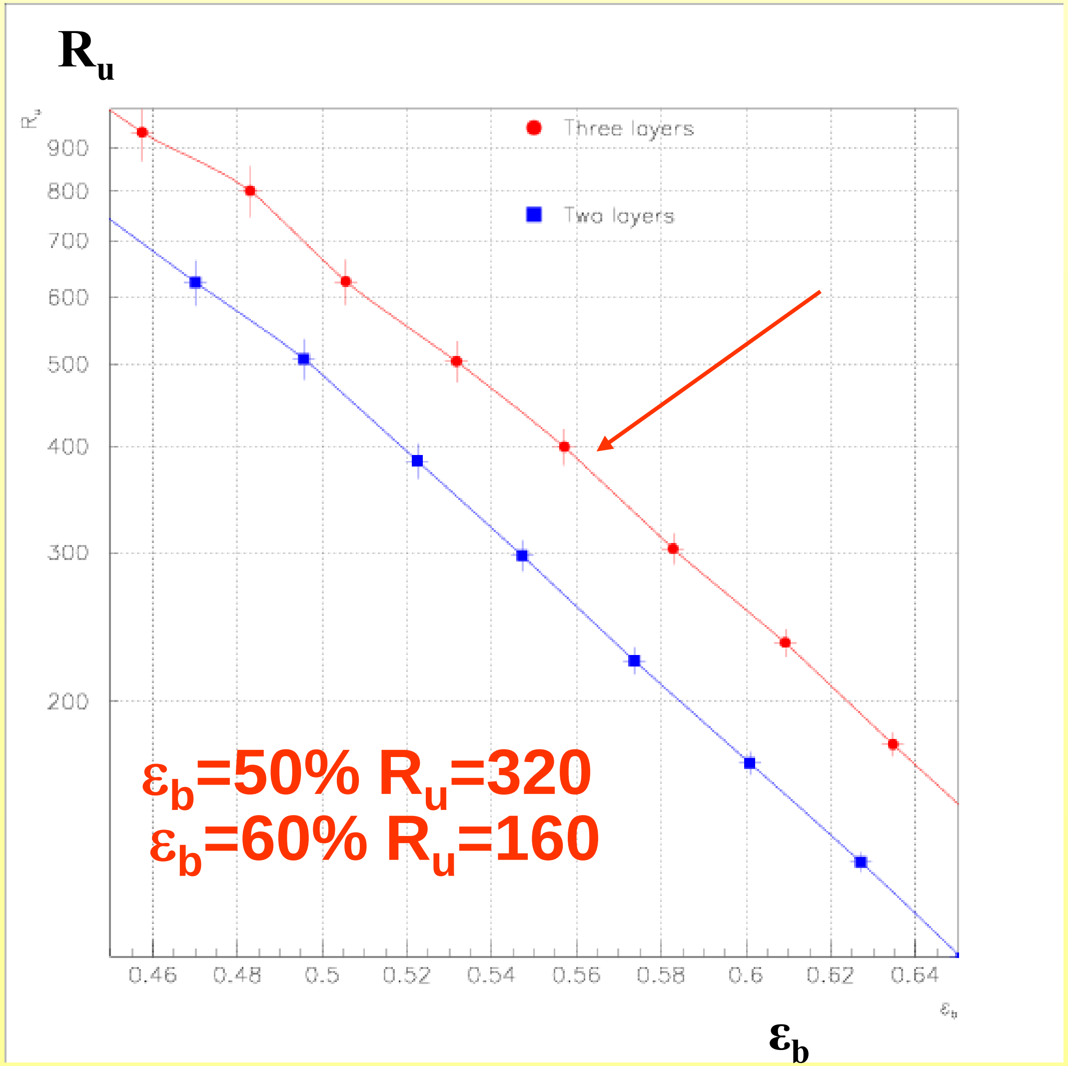
ttH-> bb

<u>background:</u>

ttjj -> b l ν b jjjj

b-tagging performance is limited by physics:

gluon splitting and occasional coincidence between light jet and b-quark directions.



Summary of particle identification

- Good identification capability of detectors
  - **ε_e~70% R_j~10^6 ε_e~80% R_j~10^5** ****
  - **ε_γ~80% R_j~few 10^4** ****
  - **ε_τ~50% R_j~200 ε_τ~60% R_j~60** **
  - **ε_b~50% R_u~320 ε_b~60% R_u~160** **
  - **ε_μ~90% fakes <<%** ****
- Always some trade-off between efficiency and rejection (except muons)
- Every analysis has its optimum "working point" depending on the background

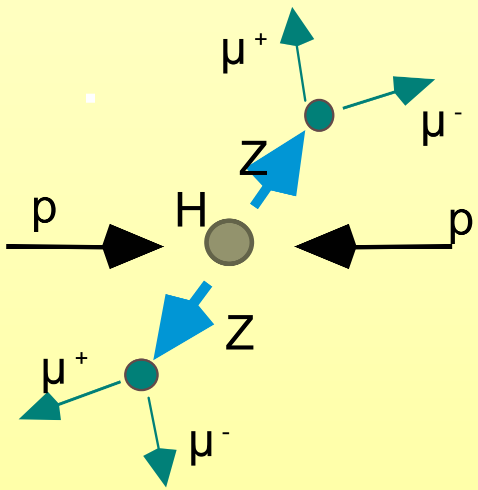
Is that all you need?

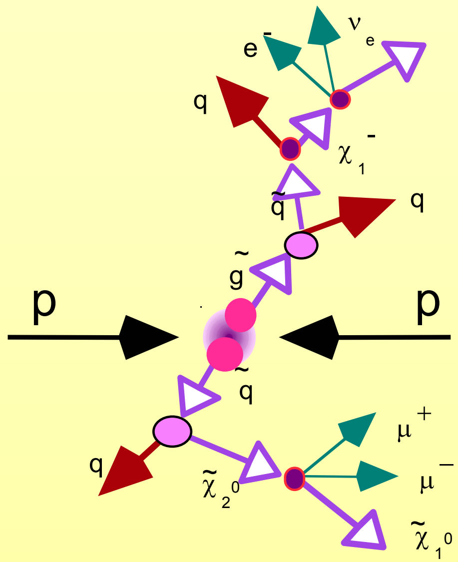
- Do not forget, you have to trigger on the interesting events!!!

  - Otherwize, you will only keep QCD background

Physics and Trigger

- High p_T Physics





Production of heavy objects may be detected via one or more of the following signatures:

One or more isolated, high-p_T charged leptons

Large missing E_T (from neutrinos, dark matter candidates)

High multiplicity of large p_T jets

Isolated high-pT photons

Copious b production relative to QCD

Inclusive Selection Signatures

- To select an extremely broad spectrum of "expected" and "unexpected" Physics signals (hopefully!).
- The selection of Physics signals requires the identification of **objects** that can be **distinguished** from the high particle density environment.

Object	Examples of physics coverage	Nomenclature
Electrons	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W/Z, top	e25i, 2e15i
Photons	Higgs (SM, MSSM), extra dimensions, SUSY	γ60i, 2γ20i
Muons	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W/Z, top	μ20i, 2μ10
Jets	SUSY, compositeness, resonances	j360, 3j150, 4j100
Jet+missing E_T	SUSY, leptoquarks, "large" extra dimensions	j60 + xE60
Tau+missing E_T	Extended Higgs models (e.g. MSSM), SUSY	τ30 + xE40

also inclusive missingET, SumET, SumET_jet

& many prescaled and mixed triggers

The list must be non-biasing, flexible, include some redundancy, extendable, to account for the "unexpected".

Region of Interest (RoI) Mechanism

Hardware 40 Mhz ↓

LVL1 triggers on high p_T objects

- calorimeter cells and muon chambers to find $e/\gamma,\tau,jet,\mu$ candidates above thresholds
- identifies Regions of Interest
- fixed latency 2.5 μs

Software 75 khz ↓

LVL2 uses Regions of Interest

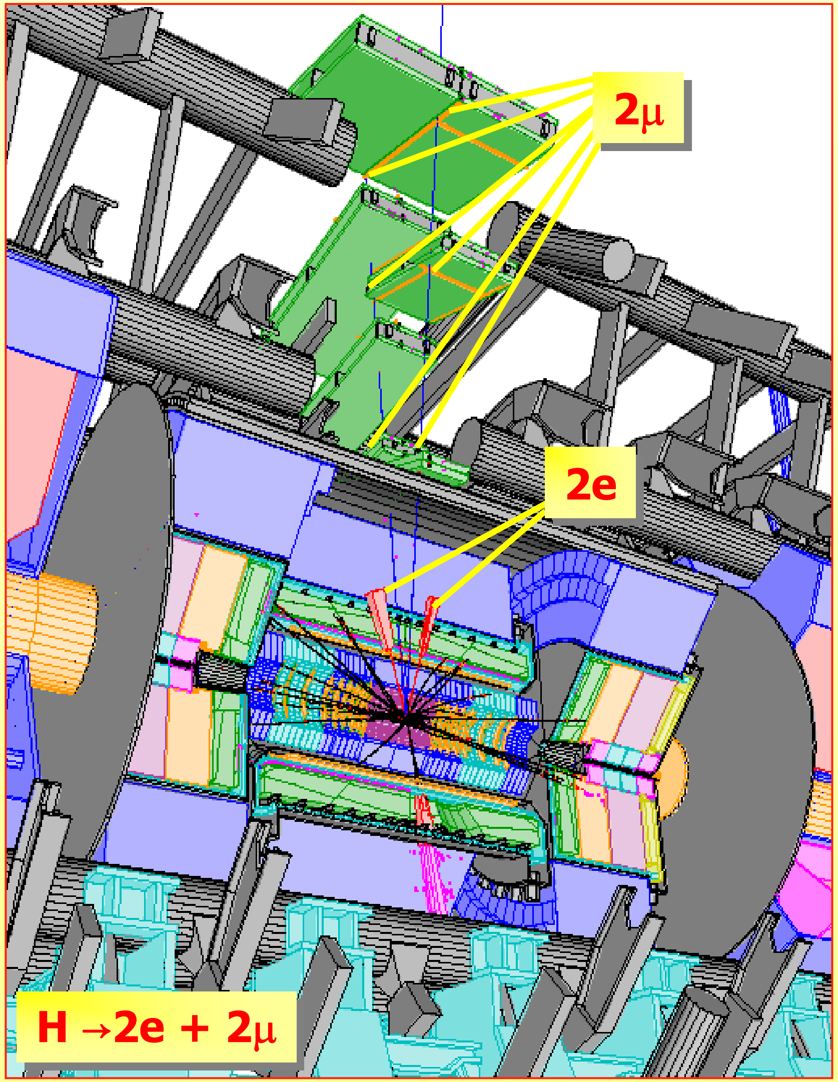
- local data acces, reconstruction & analysis
- sub-detector matching of RoI data
- produces LVL2 result
- average latency ~10 ms

Software 2 khz ↓

Event Filter

- can be "seeded" by LVL2 result
- potential full event access,
- offline-like Algorithms O(1 s) latency

200 hz ↓



LVL1 Trigger Rates

Illustrative menu

Selection		$2*10^{33}$ $cm^{-2}s^{-1}$	10^{34} $cm^{-2}s^{-1}$
MU20	(20)	0.8	4.0
2MU6		0.2	1.0
EM25I	(30)	12.0	22.0
2EM15I	(20)	4.0	5.0
J200	(290)	0.2	0.2
3J90	(130)	0.2	0.2
4J65	(90)	0.2	0.2
J60 + xE60	(100+100)	0.4	0.5
TAU25 + xE30	(60+60)	2.0	1.0
MU10 + EM15I		0.1	0.4
Others (pre-scales, calibration, …)		5.0	5.0
Total		~ 25	~ 40

- Rates given in kHz

No safety factor included!

→ E_T values imply 95% efficiency w.r.t. to asymptotic value

LVL1 rate is dominated by candidate electromagnetic clusters: 78% of physics triggers

Inclusive High Level Trigger Event Selection

Current global understanding of trigger rates

No safety factors - large uncertainties !

Selection	2×10^{33} cm^{-2}s^{-1}	Rates (Hz)
Electron	e25i, 2e15i	~40
Photon	γ60i, 2γ20i	~40
Muon	μ20i, 2μ10	~40
Jets	j400, 3j165, 4j110	~25
Jet & E_T^{miss}	j70 + xE70	~20
tau & E_T^{miss}	τ35 + xE45	~5
B-physics	2μ6 with m_B / $m_{J/\psi}$	~10
Others	pre-scales, calibration, …	~20
Total		~200

Summary

- Detectors have been built following the requirements of LHC physics
- A lot of effort went into R&D, test beam, simulation
- Still, it will not be easy to get the detector to work at their nominal performance levels
- In the next lectures we will see examples of physics channels that rely on the properties that were shown: resolution, efficiency, rejection ….
- It will not be enough to try to get the detector to work as well as possible, one needs also to quantify resolution, reconstruction efficiency and trigger efficiciencies

  $\rightarrow$ to calculate cross-sections, to substract backgrounds, etc…
- It will take a while untill the detector is at its best and fully understood

Back-up slides

Back-up slidesCross sections @ LHC and Tevatron

Tevatron	ratio	LHC	Process
		~ few mb	>20 GeV Jet
10 nb	1/2000	~20 μb	>100 GeV Jet
		~ 200 nb	> 250 GeV Jet
~ 1 nb	1/10	~ 10 nb	$W \to \ell \nu$
	1/10	~ 1.5 nb	$Z \to \ell\ell$
Few pb	1/500	~ 1 nb	ttbar
0.1 pb	1/200	~ 20 pb	Higgs(100GeV)
-		~ 20 pb	Gluino(500 GeV)

0.001 Hz for L= 10^{31} cm^{-2}s^{-1}

1 Hz for L= 10^{33} cm^{-2}s^{-1}

LHC phenomenology – problem I

Simple numerology

TEVATRON		LHC	
$L=10^{31}cm^{-2}s^{-1}$	$10^{32}cm^{-2}s^{-1}$	$L=10^{33}cm^{-2}s^{-1}$	$10^{34}cm^{-2}s^{-1}$

One year (30%)= 10^7s

Calculate integrated luminosity in one year

Event rates for cross-section σ = 1nb

LHC phenomenology – problem I

Simple numerology

TEVATRON		LHC	
$L=10^{31}cm^{-2}s^{-1}$	$10^{32}cm^{-2}s^{-1}$	$L=10^{33}cm^{-2}s^{-1}$	$10^{34}cm^{-2}s^{-1}$

One year (30%)= 10^7s

1 barn = 10^{-24} cm^2 1 pb = 10^{-12} barn 1 fb = 10^{-15} barn

1 pb^{-1} = 10^{36} cm^{-2} 1 fb^{-1} = 10^{39} cm^{-2}

Integrated luminosity in one year:

100 pb^{-1}	1 fb^{-1}	10 fb^{-1}	100 fb^{-1}

Event rates: σ = 1nb

0.01 Hz	0.1 Hz	1 Hz	10 Hz

Event collected in one year:

10^5 events	10^6 events	10^7 events	10^8 events

LHC phenomenology – problem II

QCD as a background for SM Higgs searches:

- **Higgs production cross-section dominated by gluon-gluon fusion: $gg \rightarrow H$ σH(100GeV)~20pb**
- **Light SM Higgs Br($H \rightarrow bb$) ~ 40%**
- **QCD cross-section for jets with pT>20GeV is 10^8 x Higgs production cross-section**
- **pT jets from H decays >~ 20 GeV**
- **Jet rejection in b-tagging ε_b~50% R_j~320**

Se puede observar $H \rightarrow bb$?

LHC phenomenology – problem II

QCD as a background for searches:

- Higgs production cross-section dominated by gluon-gluon fusion: gg → H: σH(100GeV)~20pb
- Light SM Higgs Br(H → bb) ~ 40%
- QCD cross-section for jets with pT>20GeV is 10^8 x Higgs production cross-section
- pT jets from H decays >~ 20 GeV
- Jet rejection in b-tagging ε_b~50% R_j~320

Se puede observar H → bb ?

- identify 2 b-jets: rejection factor $(1/R_j)^2 \sim 10^{-5}$
- branching fraction for H → bb is ~ 40% ~ 0.4
- efficiency for identifying 2 b-jets $(\sim 50\%)^2 \sim 0.25$

⇒ S/B ~ BRxEff(b-tagging)^2 / (q/g jet rejection)^2

⇒ S/B ~ (0.4 X 0.25) / (10^8 x 10^{-5}) ~ 10^{-4}

LHC phenomenology – problem II

QCD as a background for searches:

- **Higgs production cross-section dominated by gluon-gluon fusion: $gg \rightarrow H$: $\sigma H(150GeV) \sim 10pb$**
- **one year at $L=10^{33}cm^{-2}s^{-1} \rightarrow 10^5$ Higgs produced**
- **10^4bb decays tagged – 10^8 background jets**

Significance ~ 1

to reach 5, needs factor 25 in statistics!

And what do you trigger on ?????