ELEMENTARY PARTICLE PHYSICS
Current Topics in Particle Physics
Laurea Magistrale in Fisica,
curriculum Fisica Nucleare e Subnucleare
Lecture 5

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Preliminaries

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Bibliography

♠ Bibliography

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♠ Other basic bibliography:

- A.Das and T.Ferbel, *Introduction to Nuclear Particle Physics* World Scientific,Singapore, 2^{nd} Edition(2009)(DF).
- D. Griffiths, *Introduction to Elementary Particles* Wiley-VCH,Weinheim, 2^{nd} Edition(2008),(DG)
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♠ Particle Detectors bibliography:

- William R. Leo *Techniques for Nuclear and Particle Physics Experiments*,
  Springer Verlag (1994)(LEO)
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  Cambridge University Press (2008)(CS)
- *The Particle Detector Brief Book*,(BB)
  http://physics.web.cern.ch/Physics/ParticleDetector/Briefbook/

Specific bibliography is given in each lecture

Lecture Contents - 1 part

1. Introduction. Lep Legacy
2. Proton Structure
3. Hard interactions of quarks and gluons: Introduction to LHC Physics
4. Collider phenomenolgy
5. The machine LHC
6. Inelastic cros section pp
7. W and Z Physics at LHC
8. Top Physics: Inclusive and Differential cross section $t\bar{t}$ W, $t\bar{t}$ Z
9. Top Physics: quark top mass, single top production
10. Dark matter
    - Indirect searches
    - Direct searches

Specific Bibliography

♠ Bibliography of this Lecture

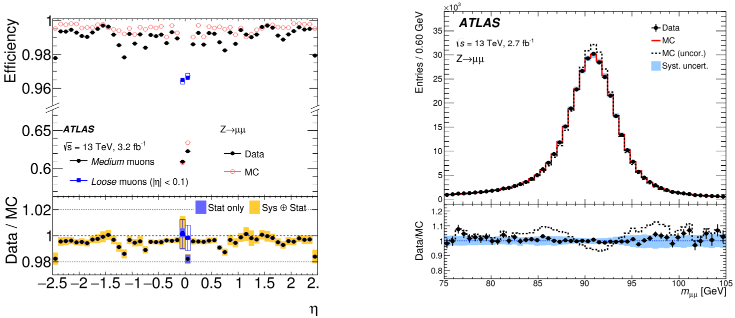
- ATLAS, ATLAS experiment
- CMS, CMS experiment

Contents

Identification of objects:muons

♠ Key points towards the discovery is to prove the capability (and quality)of identification of objects (electron, μ,tau,photons, jets ,missing transverse energy)and their reconstruction and the capability of reproduce the expected physics.

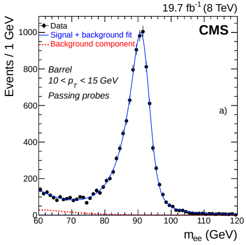
muons

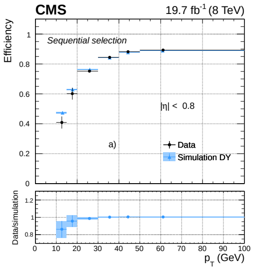


- Reconstruction **efficiency** $\approx 99\%$ $|\eta| < 2.5$ and $5 < p_T < 100$GeV)
- **Momentum resolution** 1.7% (2.3%) for muons from $J/\psi \to \mu\mu (Z \to \mu\mu)$

Identification of objects:electrons

electrons

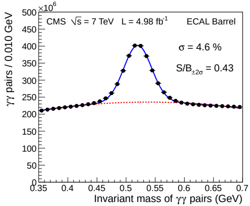




- The **momentum scale** is calibrated with an uncertainty smaller than **0.3%**.
- The **momentum resolution** ifor electrons produced in Z boson decays ranges from **1.7 to 4.5%**.

Identification of objects: photons

photons



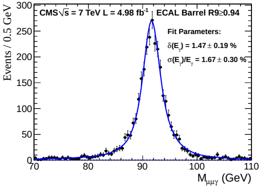


Figure : an example of the η-meson peak reconstructed from the invariant mass of photon pairs in barrel, $(m_\eta = 547.86\ \text{MeV}, \Gamma_\eta = 1.31\ \text{keV}, Br(\gamma\gamma) \to 72.12\%)$

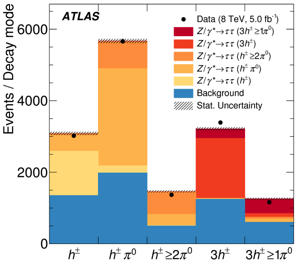
Figure : $Z \to \mu\mu\gamma$ events,deviation of the reconstructed photon energy from that expected from the decay kinematics δ, mean energy resolution.

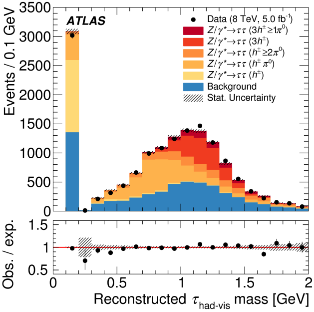
- The derived **energy resolution**for photons from 125 GeV Higgs boson decays varies across the barrel from **1.1%** to 2.6% and from 2.2% to 5% in the endcaps(CMS).

Identification of objects: taus

Lepton τ : $m_\tau = 1776$ MeV lifetime $\tau \simeq 290 \cdot 10^{-15}$s $\Longrightarrow$ $c\tau = 87.03\mu$m

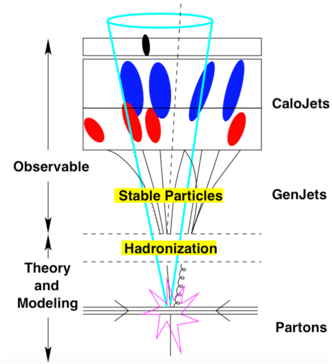
main decays: $\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau(\sim 17.4\%)$,$\tau^- \to e^-\bar{\nu}_e\nu_\tau(\sim 17.4\%)$,$\tau^- \to \pi^-\nu_\tau(\sim 10.8\%)$,$\tau^- \to K^-\nu_\tau(\sim 7\%)$ and $\tau^- \to h^-\nu_\tau(\simeq 11\%), \tau^- \to h^-h^+h^-\nu_\tau(\simeq 15\%)$,





Identification of objects: jets

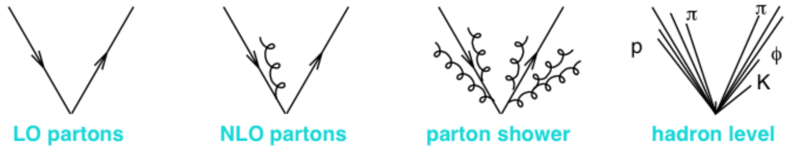
- **What are jets?**



- Collimated bunches of stable hadrons, originating from **partons** (quarks & gluons) after **fragmentation** and **hadronization**
- Jet Finding is the **approximate** attempt to reverse-engineer the quantum mechanical processes of fragmentation and hadronization.Not a unique procedure $\Longrightarrow$ several different approaches.
- Jets are the observable objects to relate experimental **observations** to theory **predictions** formulated in terms of quarks and gluons

Identification of objects: jets

A **hadronic jet is a collimated cone of particles associated with a final state parton**, produced through fragmentation. The jet has a four momentim: $E = \sum_i E_i, \vec{p} = \sum_i \vec{p_i}$. Where the constituents (i) are hadrons detected as **charged tracks** and **neutral energy** deposits.



How to define experimentally a *jet*?

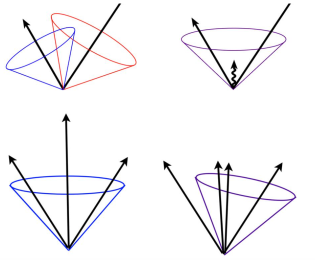
A few different approach.

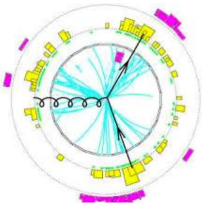
- Cone algorimth: include all particles inside a cone of given radius
- Particle Flow Algorithms (used at LHC, next generation of collider):for each individual particle in a jet, use the detector part with the best energy resolution.

Identification of objects: jets

typical jet:

- $\sim$ 60%charged particles
- $\sim$ 30% photons
- $\sim$ 10%neutral hadrons
- $\sim$ 1% neutrinos





Identification of objects: jet algorithm

K_T/anti K_T algorithm. Based on the following distance measures:

•Distance d_{ij} between two particles i, j:

$$\boxed{d_{ij} \equiv \min(p_{ti}^{2p}, p_{tj}^{2p})\frac{\Delta R_{ij}^2}{R^2}}$$

$$\Delta R_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

• Distance between any particle i and beam (B) d_{ib}

$$\boxed{d_{iB} \equiv p_{T,i}^{2p}}$$

1. From the list of all final state particles, determine all the distances d_{ij} and d_{iB}
2. Find the minimum distance
3. If smallest is a d_{ij} recombine particles i and j (sum four momenta)and go back to the first step: update distance and find again smallest
4. If smallest is a d_{iB}, declare particle i to be a jet and remove from the list of particles.
5. Stop the algorithm when no particles remain and all particle are clustered into jet

Identification of objects: jet algorithm

K_T/anti K_T algorithm. Based on the following distance measures:

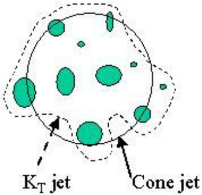
•Distance d_{ij} between two particles i, j:

$$d_{ij} \equiv \min(p_{ti}^{2p}, p_{tj}^{2p}) \frac{\Delta R_{ij}^2}{R^2}$$

$$\Delta R_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

• Distance between any particle i and beam (B) d_{ib}

$$d_{iB} \equiv p_{T,i}^{2p}$$

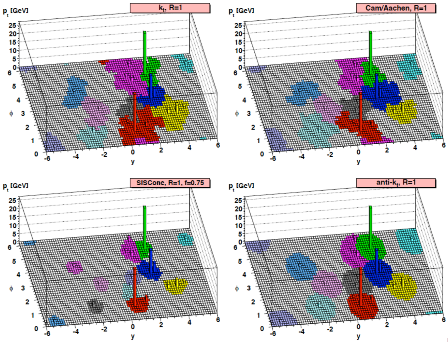


- Parameter **R**: Scales the d_{ij} w.r.t. the d_{ib} such that any pair of final jets a and b are at least separated by $\Delta_{ab}^2 = R^2$
- Parameter **p** : governs the relative power of of energy vs geometrical scales to distinguish the three algorithms KT, anti-KT...

Comparison jet algorithm

p=+1: kT algorimth. p =-1: anti-kT algorithm (favoring recombination of high-pt particles)

- It is important to emphasize that sequential recombination algorithms **can be applied** exactly in the same way to **QCD partons, hadrons or at the detector level**. Allows straightforward comparison between data and theory.**anti K_T** algorithm used at LHC gives **more regular jet**.



Comparison jet algorithm

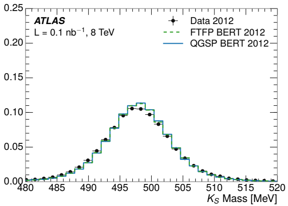


Figure : $m_{K0} \simeq 497.6$ MeV. Decays $\pi^0\pi^0(39\%)$ $\pi^+\pi^-(69\%)$

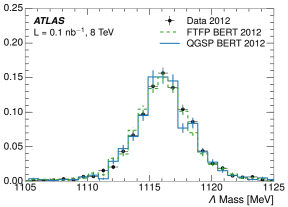


Figure : $m_\Lambda \simeq 1115$ MeV. Decays $p\pi^-(63.9\%) n\pi^0(35.8\%)$

Issues for Jet Observables

- Jet triggers and Jet selection
  - lower p_T thresholds, matching sample with different triggers
- Choice of Jet algorithm and jet size
  - use different algorithm (collinear safe algorithms)
  - Standard in CMS: anti-KT, R= 0.5 0.7; standard in ATLAS: anti-KT, R= 0.4,0.7
- Jet Energy Scale
  - Absolute and relative (as function of rapidity)
  - jet cross section falls like power law, power =-5-6
  - great progress reached $< 1\%$ [1]
- Jet energy resolution
  - smearing of distribution
  - CMS jet energy resolutions at η central 15-20% at 30 GeV, about 10% at 100 GeV, and 5% at 1 TeV

Comparison with theory at "hadron (or particle) level"

[1] CMS Coll Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV, subm J of Instr arXiv:1607.03663

A six-jets event at $\sqrt{s} = 7$ TeV

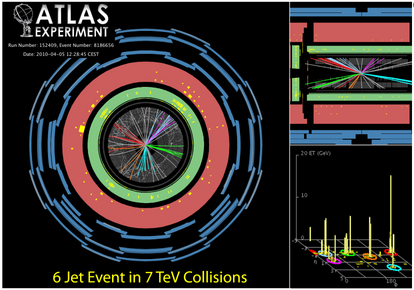
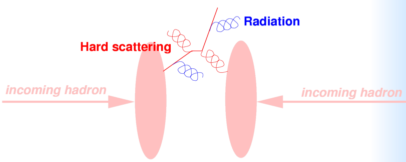
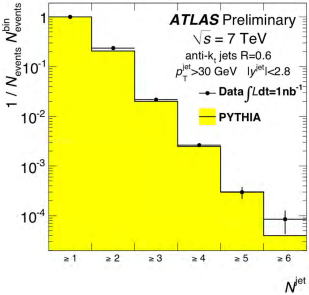


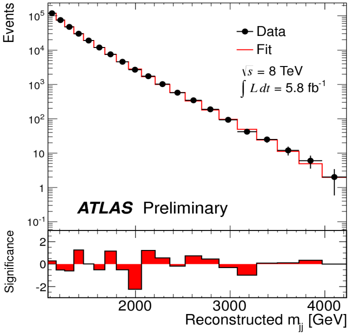
Figure : 6 Jet event in 7 TeV Collisions



- Jet multeplicity
  - Another possible test of QCD is obtained by checking the jet multiplicity.
  - tests also the modelling of the radiation.



Jet production



- Crucial energy measurements in the quest for new physics
- ATLAS and CMS use different approaches:
  - Calorimetric (ATLAS)
  - Particle Flow (CMS)

Particle flow use the most appropriate system to measure particle in the event.

Jet composition:
$\sim$ 60%charged particles
$\sim$ 30% photons
$\sim$ 10% neutral hadrons
$\sim$ 1% neutrinos

Particle Flows basic

- **Jet composition** : $\sim$ 60%charged particles, $\sim$ 30% photons, $\sim$ 10% neutral hadrons, $\sim$ 1% neutrinos
- **Traditional calorimetric approach**
  - Measure all components of jet energy in ECAL/HCAL
  - $\sim$ 70% of energy measured in HCAL, limits jet energy resolution

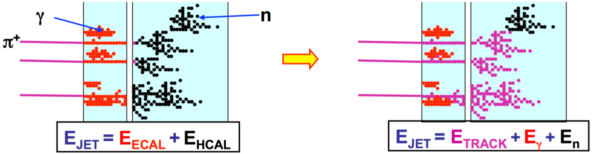


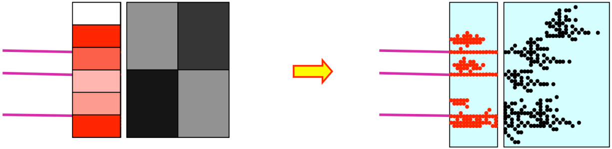
Figure : Particle Flow paradigm

Particle Flows basic

- **Particle Flow Calorimetry paradigm** :
    - charged particles measured in tracker (essentially perfectly)
    - Photons in ECAL
    - Neutral hadrons (ONLY) in HCAL
    - **Only 10 % of jet energy from HCAL** $\Longrightarrow$ much improved resolution

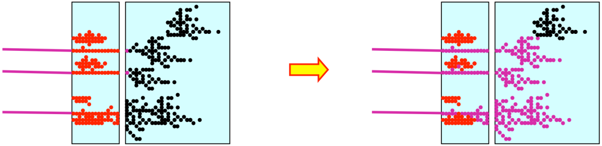
Hardware

Need to be able to **resolve energy deposits from different particles** $\Longrightarrow$ **Highly granular detectors**



Software

Need to be able to **identify energy deposits from individual particles** $\Longrightarrow$ **Sophisticated reconstruction software**



Used in Aleph and CMS.

Use the best system you have to measure particle in the event

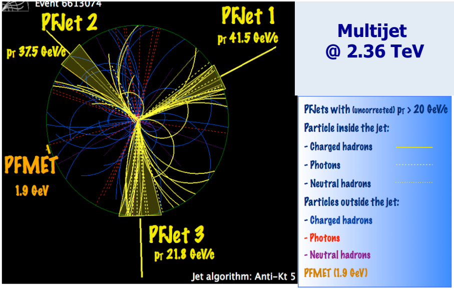


Figure : CMS-Particle Flow jets [2]

CMS: high B, excellent tracker, granular ECAL

⇓

Strong improvement in JET and Missing energy (MET) resolution

[2] kindly from R.Paramatti presentation

CMS particle ID in Calorimeters

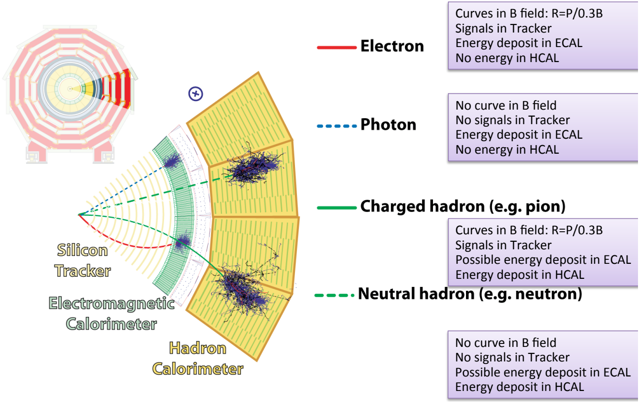
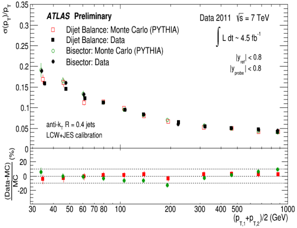
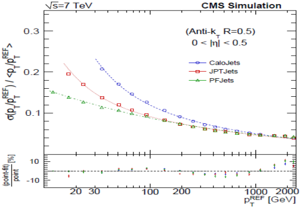


Figure : CMS-Particle ID in Calorimeters [3]

[3] kindly from R.Paramatti presentation





$\sigma(p_T)/p_T \sim 20\%$ @ $p_T = 30$ GeV
$\sigma(p_T)/p_T < 10\%$ $p_T > 100$ GeV

$\sigma(p_T)/p_T \sim 12\%$ @ $p_T = 30$ GeV
$\sigma(p_T)/p_T < 10\%$ $p_T > 100$ GeV

Figure : ATLAS CMS jet resolution [4]

Similar performance in the region relevant for new physics with CMS Particle Flow. Atlas is better comparing calorimetric resolution

[4] kindly from R.Paramatti presentation

Particle Flow vs Calorimetric Jets in CMS

Jet response : $(p_T^{rec} - p_T^{gen})/p_T^{gen}$

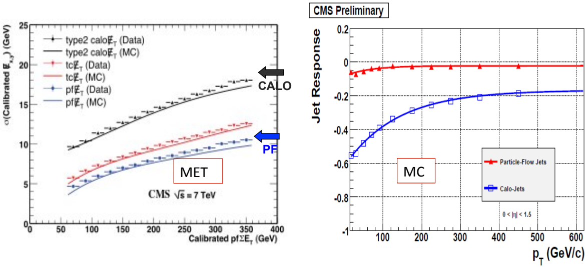


Figure : Resolution for the calibrated MET for multijet events with two jets with p_T>25 GeV(left)≈ 60% of Jet Energy measured with tracks(right)

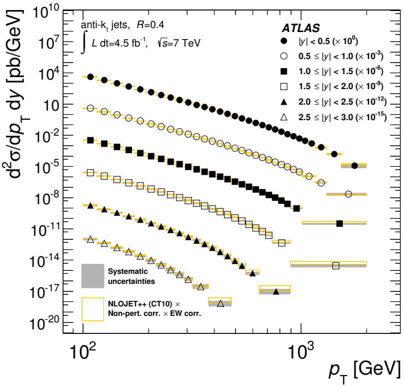


Figure : Double-differential inclusive jet cross-sections as a function of the jet pT in bins of rapidity, for anti-kt jets

Rate spans 10 order of magnitude[5]

[5] Atlas Coll. *Measurement of the inclusive jet cross-section in proton–proton collisions at* $\sqrt{s}$*=7 TeV using 4.5∼ fb?1 of data with the ATLAS detector* JHEP02(2015)153
http://arxiv.org/abs/1410.8857

Identification of objects: Transverse missing energy

The primary motivation of E_T^{miss} is to provide as complete of a picture as possible of the event, including the presence of one or more energetic neutrinos or other weakly-interacting stable particles though apparent missing energy.

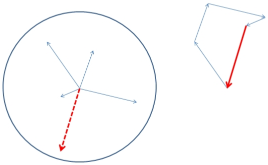
Energetic particles produced in the direction of the beam pipe make it impossible to directly measure missing energy longitudinal to the beam direction,however, the **transverse energy balance can be measured**.

- Transverse momentum, $\vec{p}_T$ is the momentum of an object transverse to the beam.
- Transverse energy is defined as $E_T = \sqrt{m^2 + p_T^2}$.

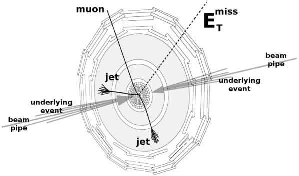
Identification of objects: Transverse missing energy

- The **initial $\vec{p}_L$ in a parton collision is unknown**, because the partons that make up a proton share the momentum.
- The **initial $\vec{p}_T$ was zero**.
- Missing transverse momentum $\vec{p}_T^{miss} = -\sum_i \vec{p}_T(i)$, i extended to all visible particles.$E_T^{miss} = -\sum_i \vec{p}_T(i)$is missing transverse energy or MET (only for massless missing particle(s))

A significant missing transverse energy results from a non-null vectorial sum of all observed particles momenta coming out of a proton-proton collision: as the colliding protons do not possess any momentum in the direction transverse to the beams, the product of their collision must retain that property; hence the vectorial sum must vanish, give or take the experimental resolution with which momenta are determined by the experimental apparatus.



energy.pdf



Finding missing transverse momentum would indicate that new, unaccounted for particle(s) had escaped the detector.

Identification of objects: Transverse missing energy

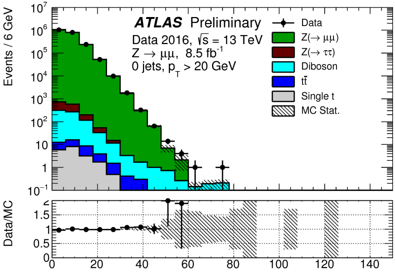


Figure : E_T^{miss} in $Z \to \mu\mu$(ATLAS)

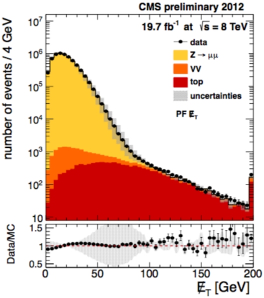
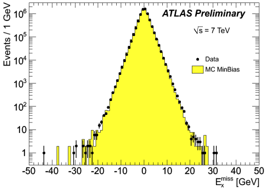
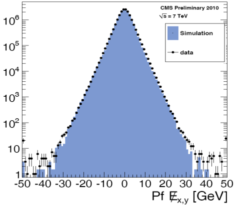


Figure : E_T^{miss} in $Z \to \mu\mu$ (CMS)

Distributions after detector cleaning, including tails, very well reproduced by MC.

Identification of objects: Transverse missing energy





With the Particle Flow reconstruction, CMS recovers ATLAS performance on jets and MET and circumvents the non brilliant performance in hadron energy measurement

Our master equation

$$\sigma_{\text{meas}} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\epsilon \mathcal{L}}$$

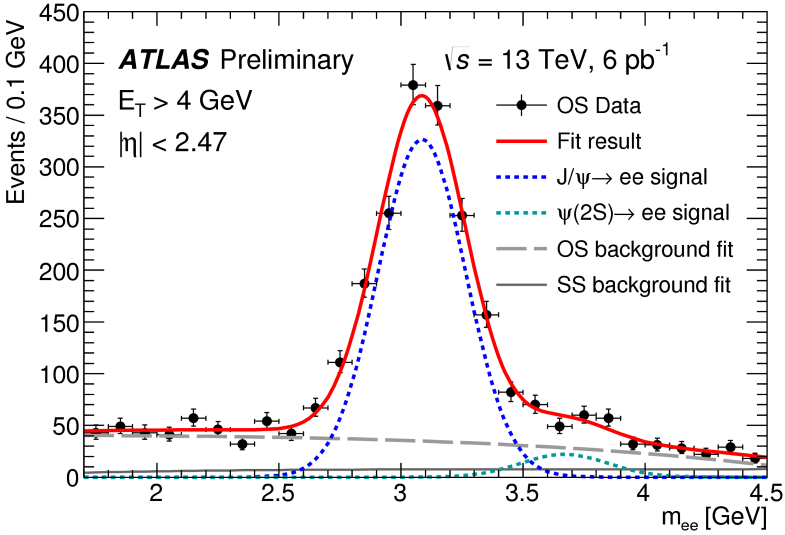
- N_{obs}
  - Event rate
  - Stat vs syst errors, backgrounds from data or MC?
  - Resolution, Energy scale; Signal significance
- N_{bkg} as N_{obs}
- ϵ
  - Experimental issues: Trigger, reconstruction, isolation cuts,low- p_T jets,(jet veto), acceptance, efficiency determination, (tag & probe)
  - Theoretical issues issues:p_T distributions at NL + resummation; differential calculations for detectable acceptance
- $\mathcal{L}$ pp Luminosity uncertainty $< 2\%$

$$\sigma_{\text{theo}} \; = \; \text{PDF}(\text{x}_1, \text{x}_2, \text{Q}^2) \otimes \hat{\sigma}_{\text{hard}}$$

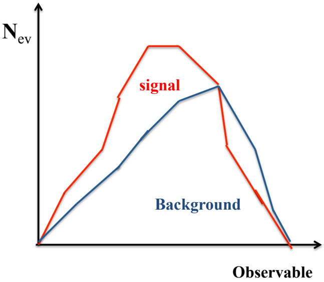
- $PDF(x_1, x_2, Q^2)$, constrains, define uncertainties
- $\hat{\sigma}$ NLO calculations, implemented in MC

$$\sigma_{\text{theo}} \; = \; \text{PDF}(\text{x}_1, \text{x}_2, \text{Q}^2) \otimes \hat{\sigma}_{\text{hard}} \Rightarrow \; \sigma_{\text{meas}} \; = \; \frac{\text{N}_{\text{obs}} \; - \; \text{N}_{\text{bkg}}}{\epsilon \mathcal{L}}$$

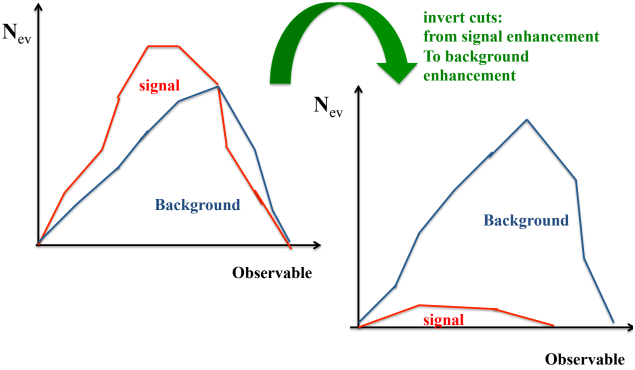
Side bands: a easy case for background evaluation



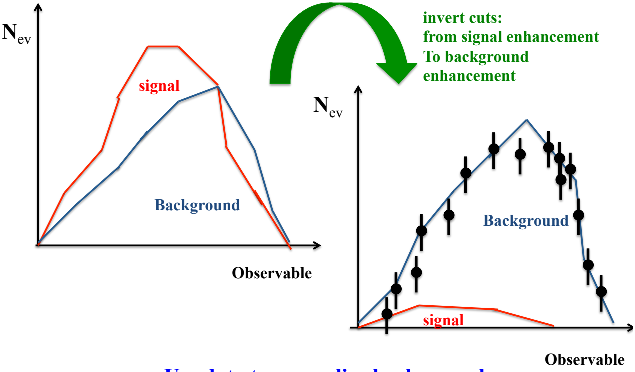
Data-driven Background estimate



Data-driven Background estimate

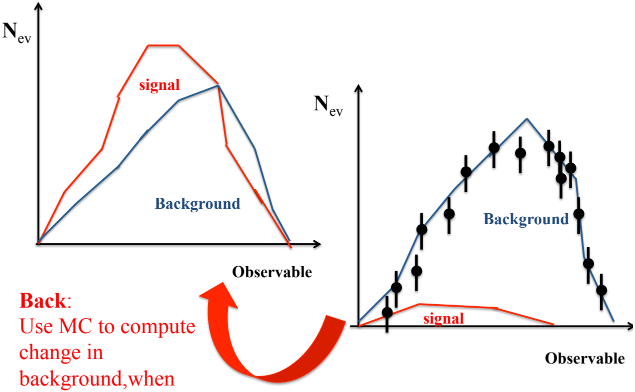


Data-driven Background estimate



Use data to normalize background

Data-driven Background estimate



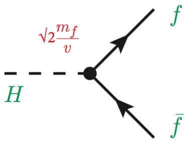
Back:
Use MC to compute change in background,when unverting the cuts

Data-driven Background estimate

Issues:

- Is left any signal after the inversion?
- Any bias in the control region?
- How well does theory/MC model cut the inversion?

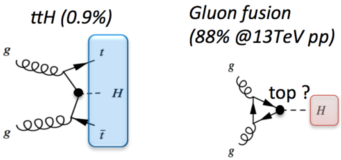
Measuring Yukawa coupling quark top-Higgs

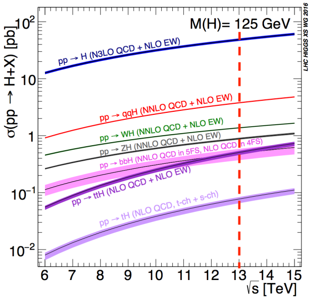


Yukawa coupling: **proportional to fermion mass**. Top is the heavy fermion in SM → largest Yukawa coupling $\lambda_t = 2m_t/v \approx 1$.

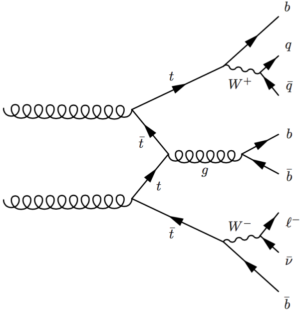
- Indirect constrain on top-Higgs Yukawa coupling derived from gluon-gluon fusion and $H \rightarrow \gamma\gamma$
- $t\bar{t}H$ production: best way to measure top-quark Higgs Yukawa coupling
- **Any deviation might be hint for new physics**

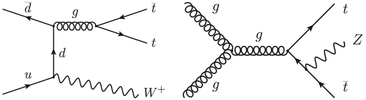
Data-driven Background:example ttH





- $t\bar{t}H$ production cross-section at $\sqrt{s}$ = 13 TeV: $0.507pb^{+5.8\%}_{-9.2\%}(QCDscales)\pm$ 3.6%(PDF,α_s)
- Only ∼ 1% of the total Higgs cross-section.
- Complex final states, with many objects: jets, b-jets, light leptons (ℓ), hadronic taus (τ_{had}), photons





Large irreducible backgrounds:

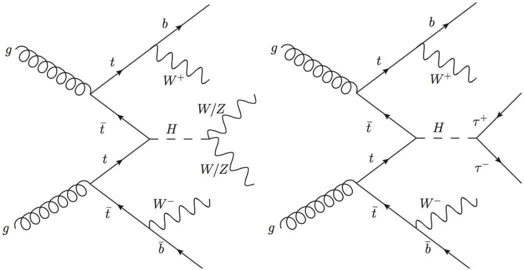
- $t\bar{t}b\bar{b}$: $\mathcal{O}(15)$ pb
- $t\bar{t}W, t\bar{t}Z$: $\mathcal{O}(1.5)$ pb

ATLAS Coll.*Evidence for the associated production of the Higgs boson and a top quark pair with the ATLAS detector* ttHmultileptons submitted for pub.

ttH multilepton

Choose a channel as example multilepton final state:

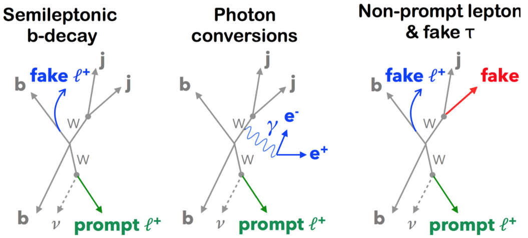
- Targeting $H \to WW, \tau\tau, ZZ$ decay modes, combined with leptonic $t\bar{t}$ decays
- Main background: $t\bar{t} \to$ Rely on signature with same-sign (SS) or three leptons
- Light lepton channel most sensitive to $H \to WW$
- τ_{had} channel more sensitive to $H \to \tau\tau$



ttH multilepton: background estimation

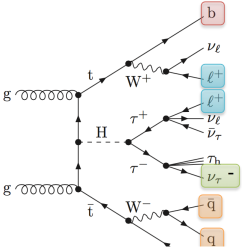
Main background sources:

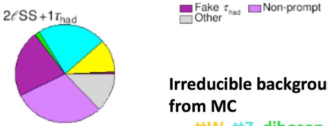
- Processes with all prompt ℓ/τ_{had} → Estimated with MC
- Electron charge mis-identification for 2lSS and 2lSS+1τ_{had}
  - Estimated from data using charge mis-id rates measured in $Z \to e^+e^-$ and $Z \to e^\pm e^\pm$
- **Events with fake/non-prompt light leptons:**
  - Mainly from semileptonic b-hadron decays
  - Sizeable contribution also from photon conversions
- **Events with fake tau leptons:**
  - Mainly from light flavour jets and electrons mis-identified as τ_{had}



ttH multilepton: hadronic tau

Multilepton channel with a τ decaying hadronically:





Irreducible backgrounds from MC

- **ttW, ttZ, diboson**

Reducible backgrounds: → Data-driven estimates

- **Non-prompt leptons**
- **Fake hadronic τ** from light/b-jets
- **Mis-identified charge** Lepton

- Irreducible backgrounds: $t\bar{t}W$, $t\bar{t}Z$, other SM rare process

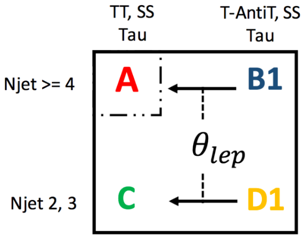
ttH multilepton: hadronic tau

The 2 same sign ℓ and 1 τ_{had} has both.

- Fake lepton majority from b-jets
- Fake taus majority from light additional jet

- ABCD method to determine data-driven background from non-prompt lepton
- data/MC fake tau rate derived from opposite sign τ_{had} control region
- the main problem is statistics in control region

ttH multilepton: hadronic tau, background



T= lepton selection *tight*, SS= same sign, Njet= numer of jets, θ_{lep} corretction factor **A** = signal region, **B1** = control region, **C** = control region,**D1** = control region

Total lepton fakes in A

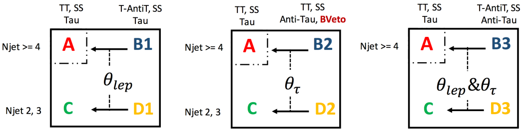
$$= B1 \times \frac{\text{C (lep1pT)}}{D1}$$

- A control region (CR)(D1) with an anti-tight selection is constructed by reversing the identification or isolation variables of the lepton, enriched in the fake leptons and it is orthognal to the signal region (SR) A *Tight lepton* selection.

ttH multilepton: hadronic tau, background

- The *Fake Factor CR* is constructed using low number of jets and the fake factor $\frac{C\ (\text{lep1pT})}{D1}$ is calculated as a function of pT of the fake lepton.
- The fake factor is then applied to a CR B1 which is identical to the SR but with at least one anti-tight lepton.

- why we have not used as well fot τ fakes ?



$$\text{Total fakes in } A = \underbrace{B1 \times \frac{C\ (lep1\ pT)}{D1}}_{\text{Lepton fakes}} + \underbrace{B2 \times \frac{C\ (tau\ pT)}{D2}}_{\text{Tau fakes}} - \underbrace{\text{B3} \times \frac{C(lep1\ vs\ Tau\ pT)}{D3} \times}_{\text{Correction to “Double counted fakes”}}$$

For stat reason we preferred to use τ fakes from opposite sign sample

Contents

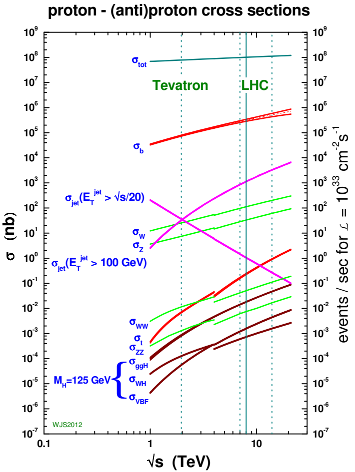


Figure : from W.J. Stirling, private communication http://www.hep.ph.ic.ac.uk/~wstirlin/plots/plots.html

Example of calculation of expect events rate:

$$\text{Event rate: } \frac{dN}{dt} = \mathcal{L} \cdot \sigma$$

$$\sqrt{s} = 7\text{ TeV}, \mathcal{L} = 10^{33}\text{cm}^{-2}\text{s}^{-1}$$

$$\text{nb} = 10^{-33}\text{cm}^{-2}$$

process	$\sqrt{s}$ 8 TeV rate[1/s]	$\sqrt{s}$ 14 TeV rate[1/s]
inel pp coll.	10^8	10^8
$b\bar{b}$	$3 \cdot 10^5$	$5 \cdot 10^5$
$t\bar{t}$	0.2	1
$W \to e\nu$	10	20
$Z \to ee$	1	2
Higgs	~ 0.02	~ 0.05

$W \to e\nu \sim 10.71\%, Z \to ee \sim 3.36\%$

Expectect physics: act 1

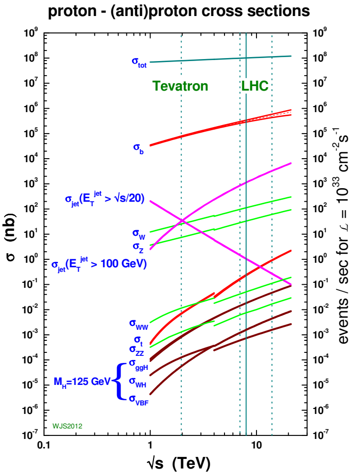


Figure : from W.J. Stirling, private communication http://www.hep.ph.ic.ac.uk/~wstirlin/plots/plots.html

$\Longrightarrow$ **Inelastic low-p_T collisions**

- Most processes are due to soft and semi-soft interactions between incoming protons.
- particle in final state have large longitudinal , but small transverse momentum $\approx$ several hundreds MeV.

Low-p_T inelastic pp-collisions are Minimum Bias events Some parameters(multiplicity etcc.) have to be tuned by MC simulation.

Expectect physics: act 2

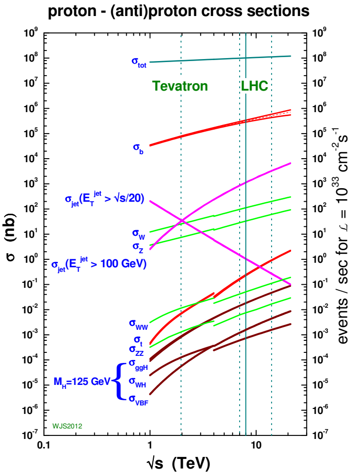


Figure : from W.J. Stirling, private communication http://www.hep.ph.ic.ac.uk/~wstirlin/plots/plots.html

$\Longrightarrow$ **Measure Jet cross sections**

- requires a good understanding of jets (jet energy scale, number of jets)
- a good calorimeter is necessary

Expectect physics: act 3

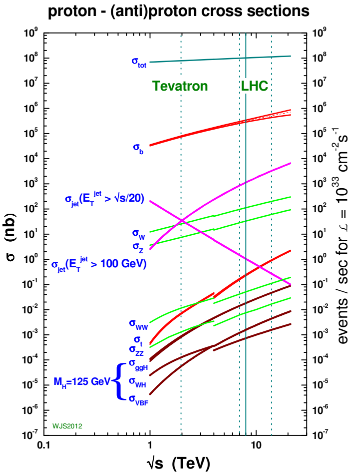


Figure : from W.J. Stirling, private communication http://www.hep.ph.ic.ac.uk/~wstirlin/plots/plots.html

$\Longrightarrow$ **Electroweak sector**

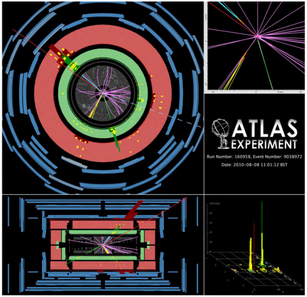
- test SM
- most SM cross sections are significantly higher than at the TEVATRON
  - *e.g* 100 x larger top-pair production cross sections
  - the LHC is a top,b, W, Z..... Higgs... factory.

First top in Europe

Important:

Concentrate on **final states with high-p_T** and **isolated leptons and photons** (+jets), otherwise overwhelmed by QCD jet background.

First top in Europe



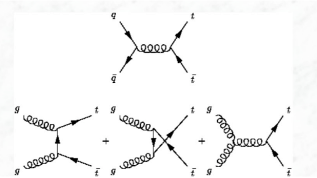


Figure : Diagrams

$$tt \quad \rightarrow \quad Wb \;\; Wb \quad \rightarrow \quad e\nu b \;\; \mu\nu b$$

The fragmentation products of b-quarks(B-hadrons) have a life times of 1.5 ps
$=$ decay distance of $\sim$ 2.5 mm.

$WW \to \; ee\nu\nu$

•

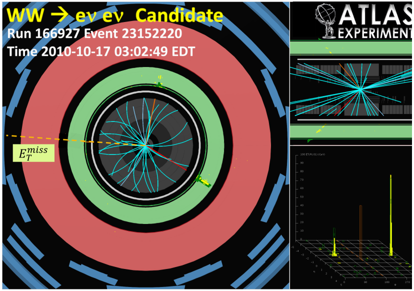


Figure : $WW \to \; ee\nu\nu$

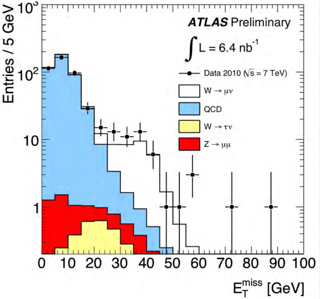


Figure : E_T^{miss}

Goals

- Benchmark processes defining main machine/detector parameters
- Basic processes relevant for study of SM
- All cross sections($\times$ Br) $\sim$ $1 - 100 fb^{-1}$ determines the statistics needed
- W mass
- top mass
- $B_s \to \mu\mu \quad B_s \to J/\psi$
- $pp \to W^+W^- \to \mu^+\nu_\mu\mu^-\bar{\nu}_\mu$
- $pp \to H \to ZZ \to \mu^+\mu^-\mu^+\mu^-$
- $pp \to H \to \gamma\gamma$
- $pp \to Z' \to \mu^+\mu^-$
- SUSY with R-parity, SUSY Higgs

Goals

The things appeared with time, accumulating statistics:

1. MinBias/ low-p_T Physics
2. jets
3. W/Z
4. Top
5. Search Higgs & new Physics

The Standard Model at LHC