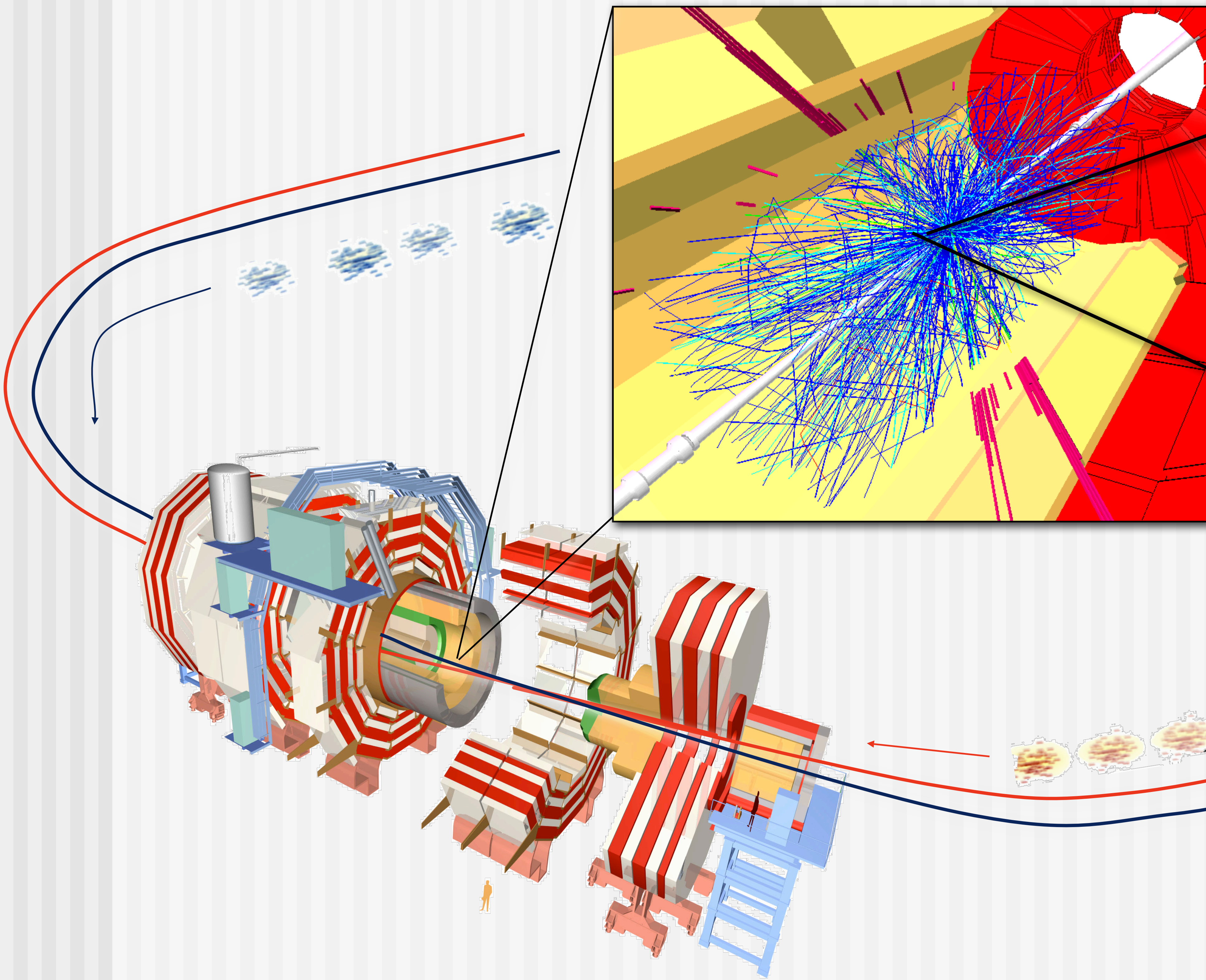
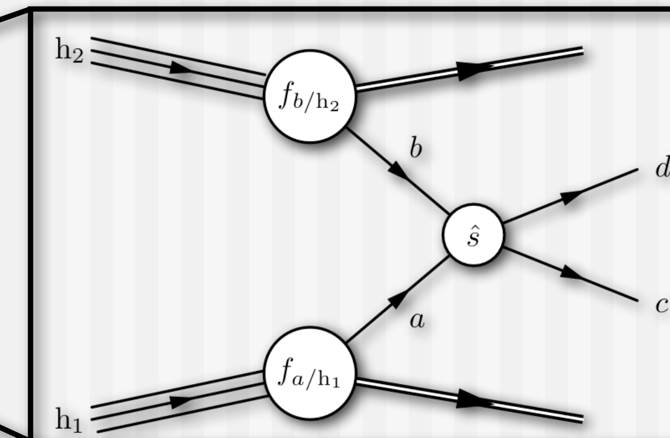
Prospects for measuring hard processes at the LHC





Günther Dissertori

ETH Zürich

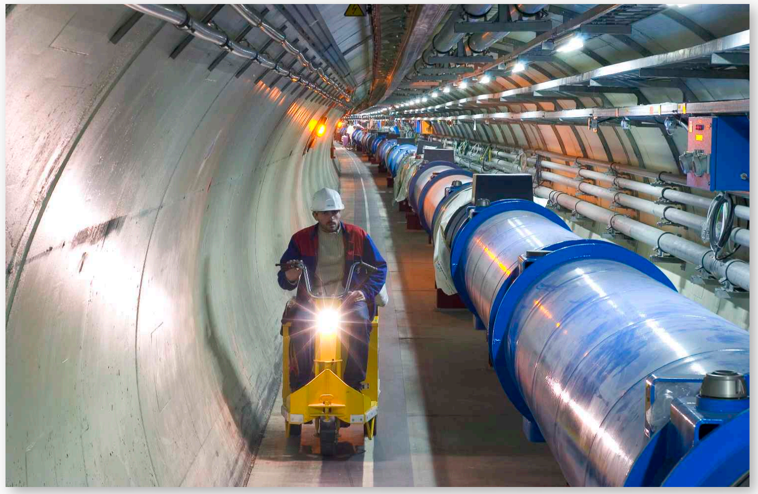
Edinburgh

February 2007

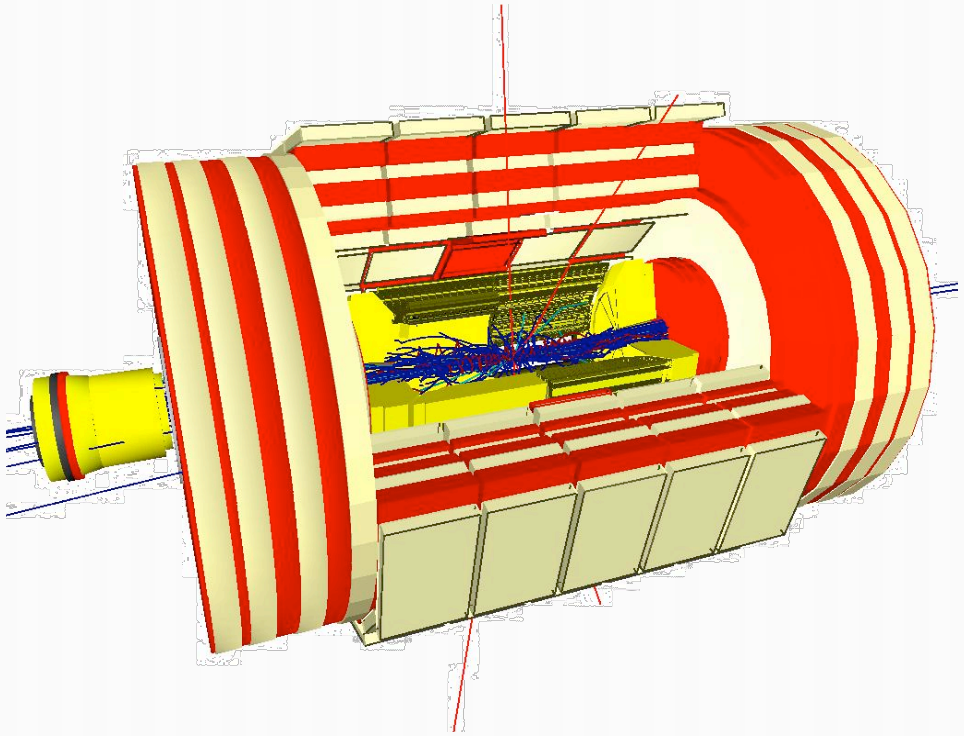
Outline

ETH Institute for Particle Physics

- Status of the
  - Machine
  - CMS
  - a few numbers and pictures only



- Measurements of hard processes
  - Introduction
  - Jets
  - Ws and Zs
  - Di-bosons
  - top production



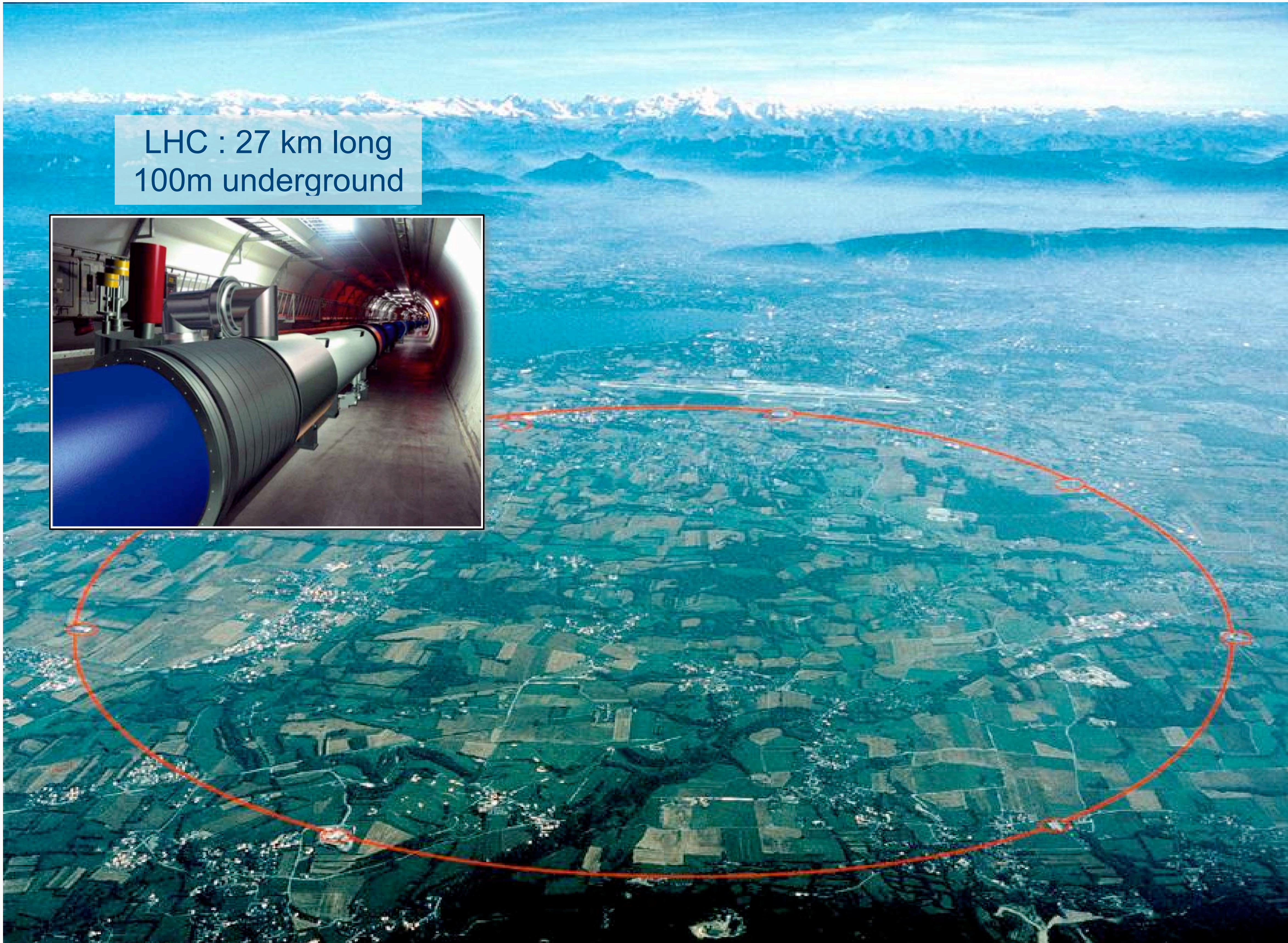
- Further aspects
  - Ratios are good
  - Some comments

Our future play ground

ETH Institute for Particle Physics

Our future play ground

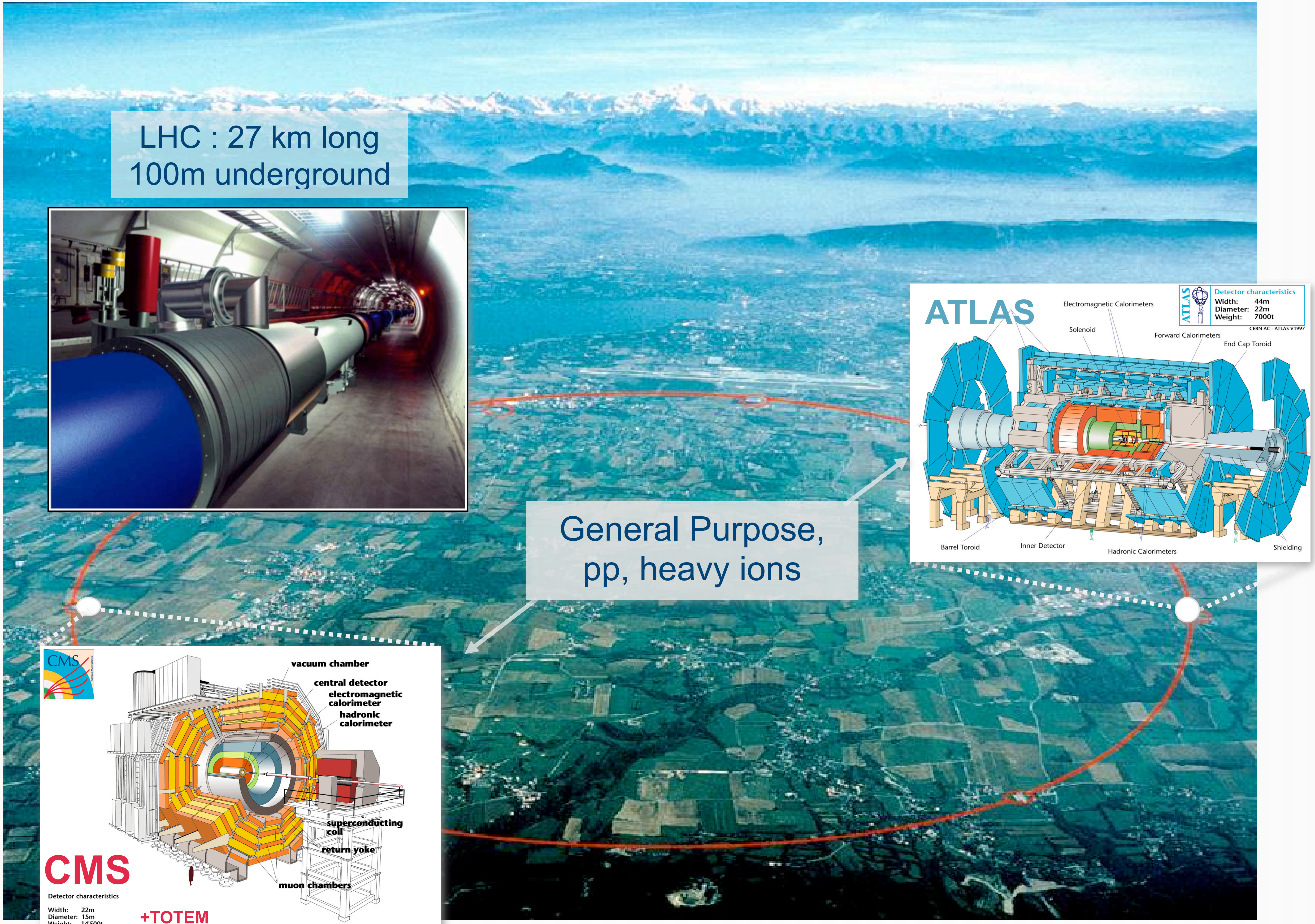
ETH Institute for Particle Physics



Our future play ground

ETH Institute for Particle Physics

- **Introduction**
- Status of
  - Machine
  - Detectors
- Processes
  - Jets
  - W/Z
  - Dibosons
  - Top
- Remarks



LHC : 27 km long
100m underground

General Purpose,
pp, heavy ions

+TOTEM

Our future play ground

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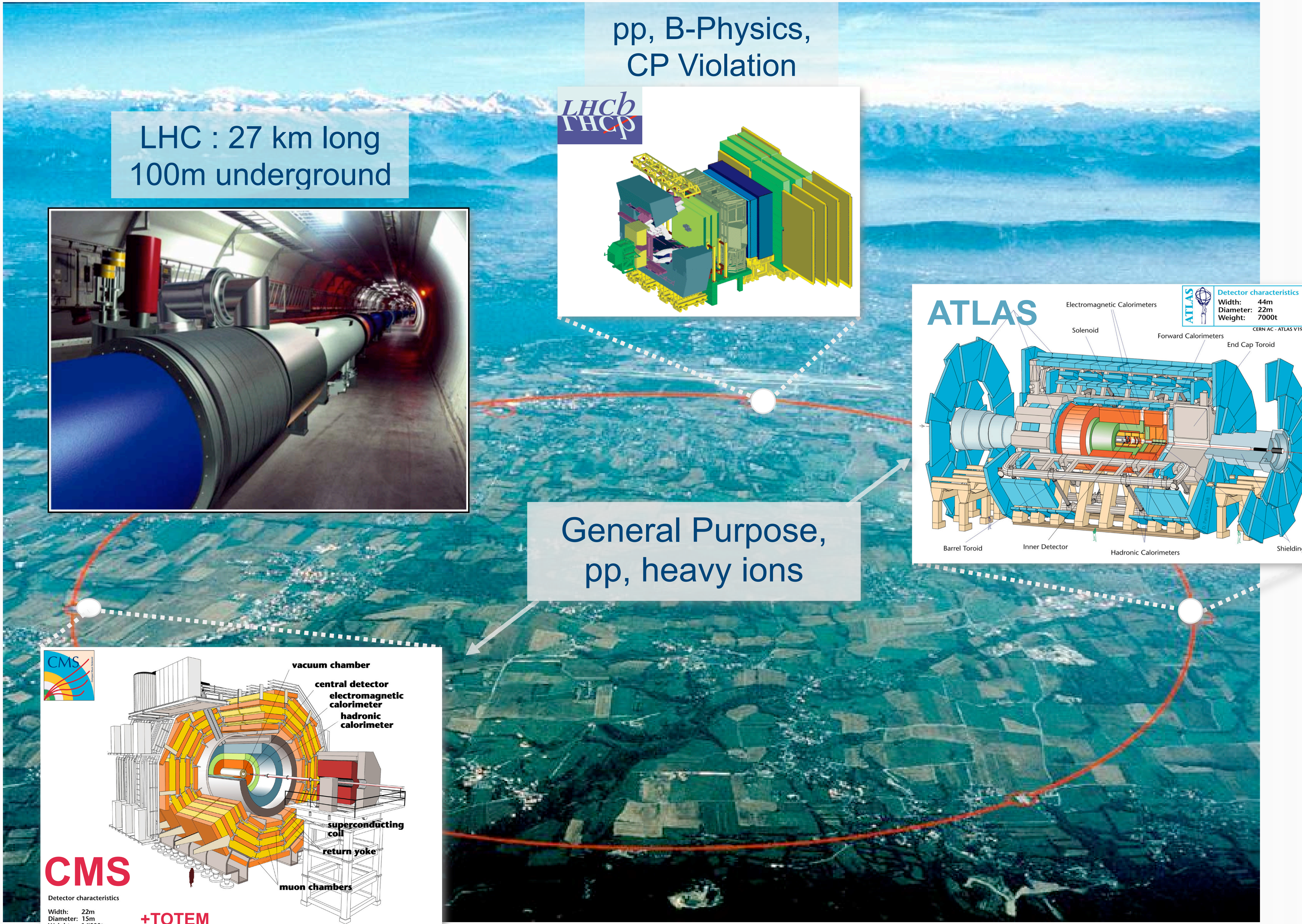

Our future play ground

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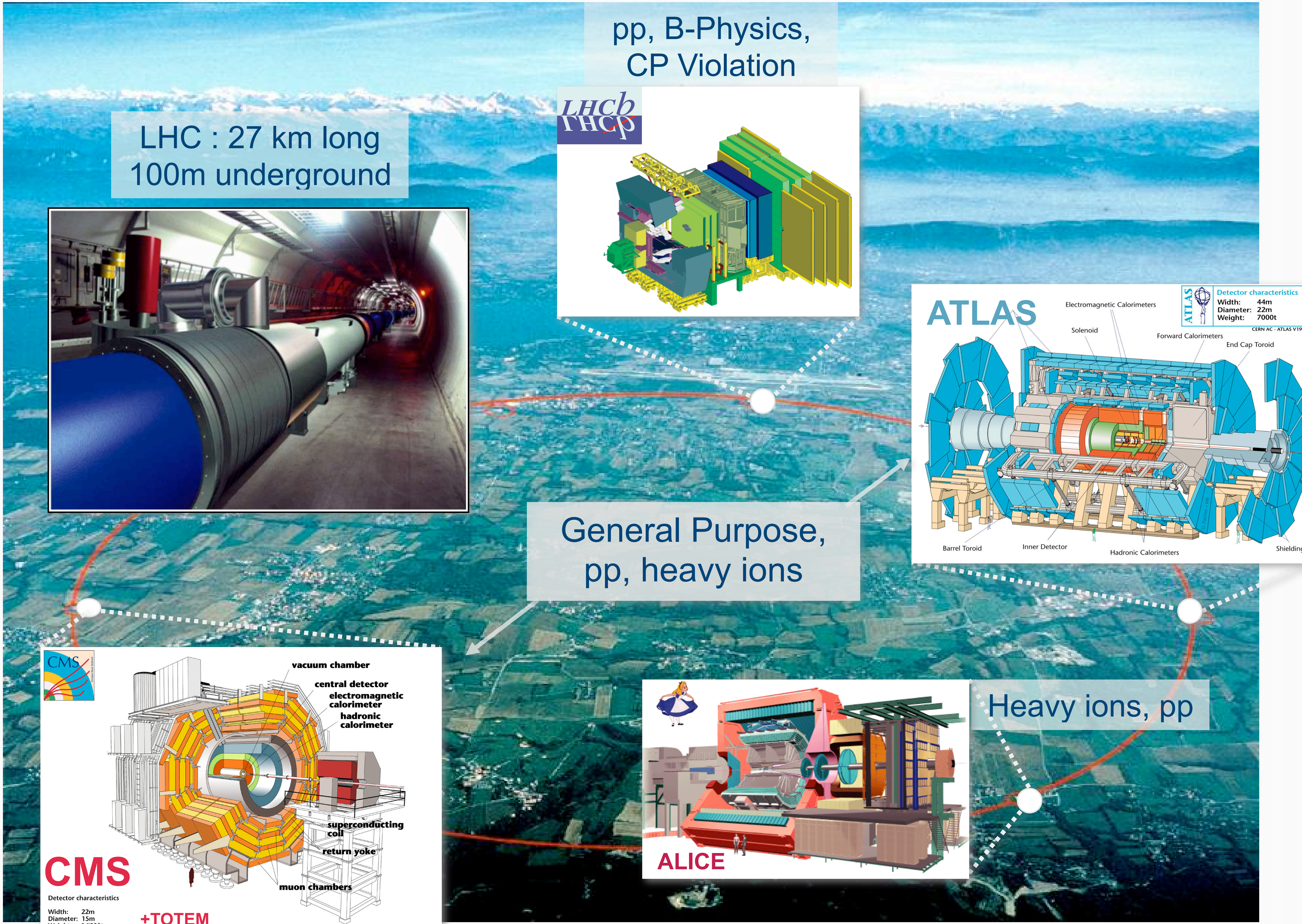
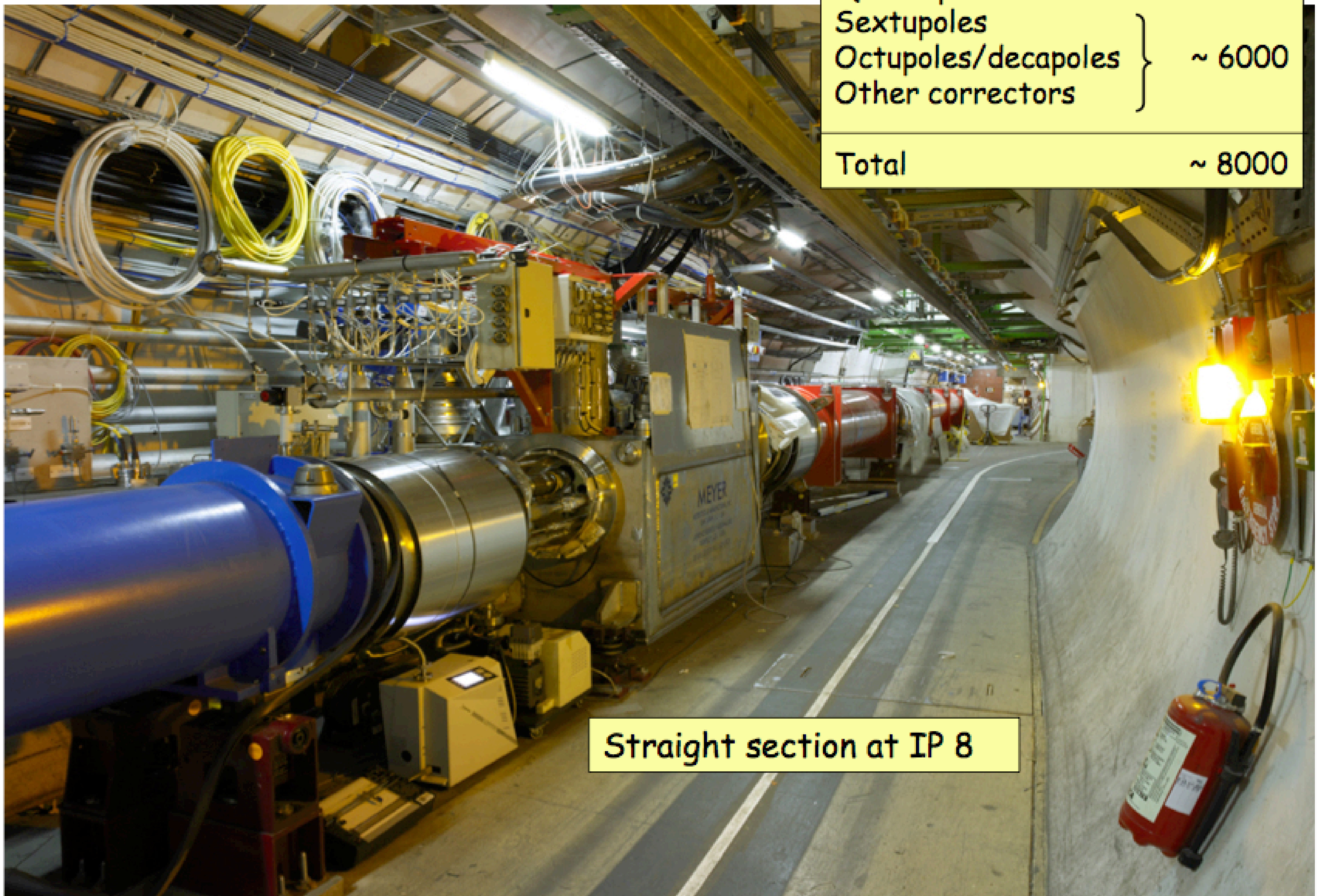


A glimpse into the status of the "hardware"

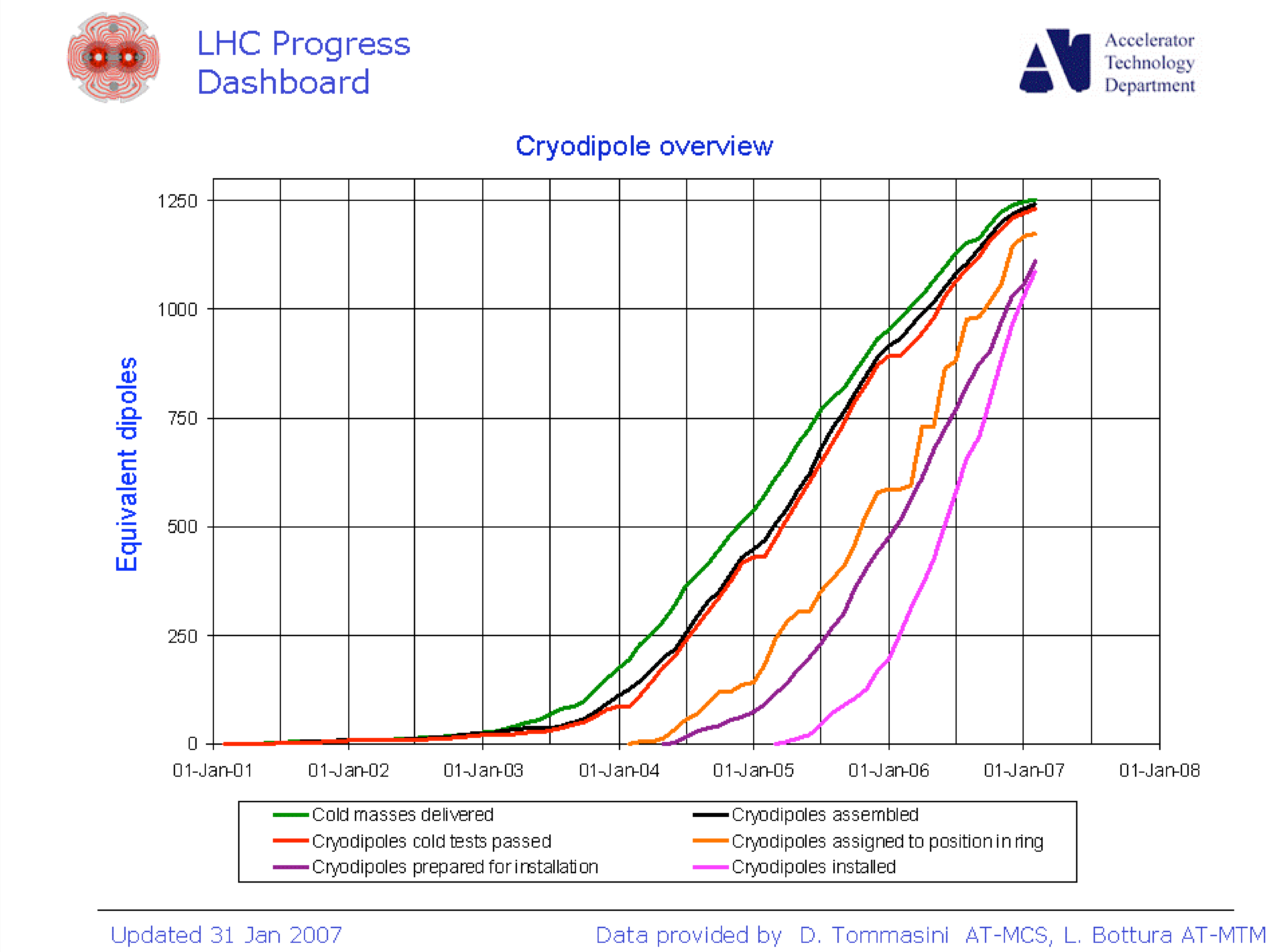
Not only dipoles...

Main dipoles	1232
Quadrupoles	~ 400
Sextupoles, Octupoles/decapoles, Other correctors	~ 6000
Total	~ 8000



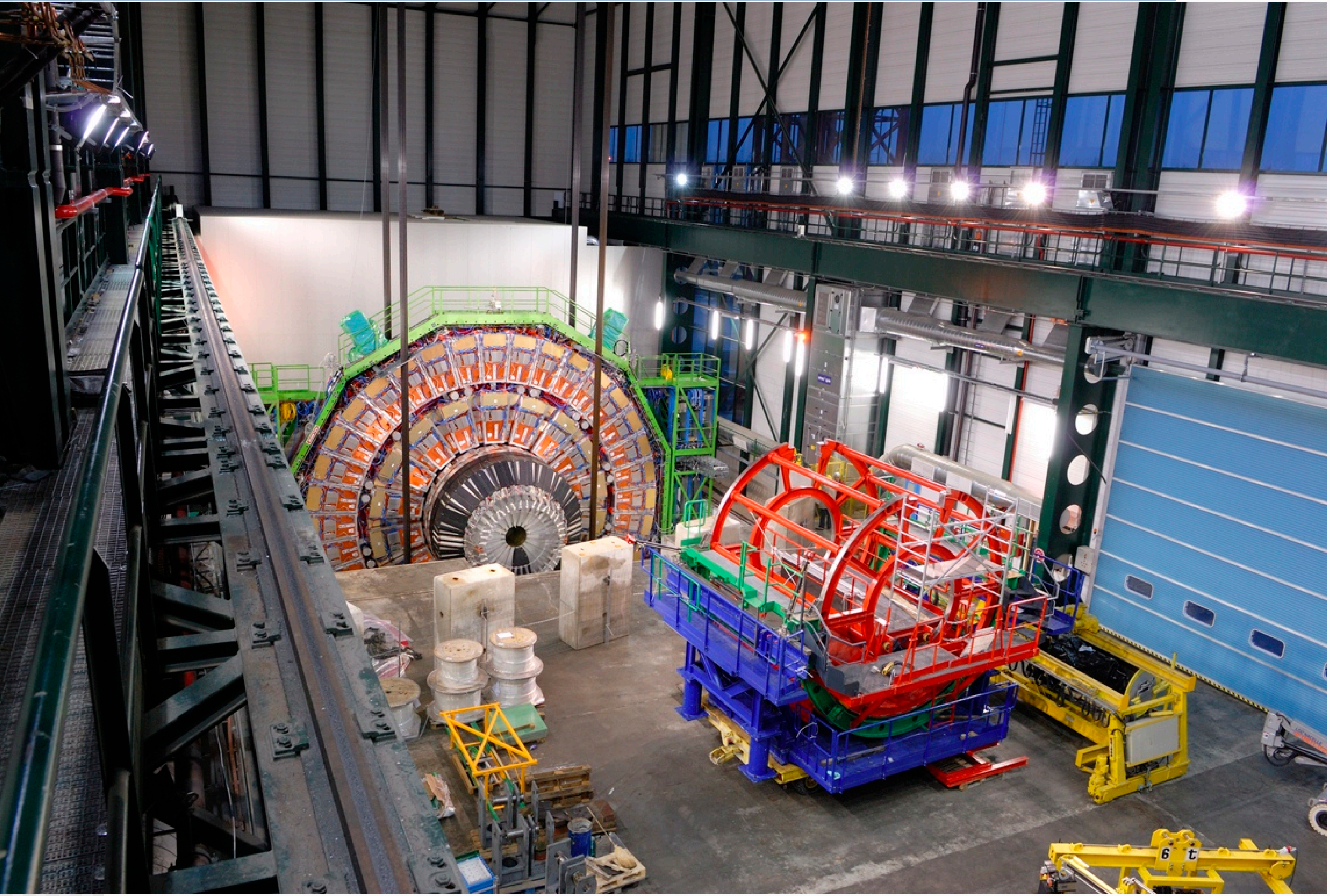
F. Gianotti, ICHEP06

LHC Dashboards



See : http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/DashBoard/index.asp

Heavy Lowering ongoing...



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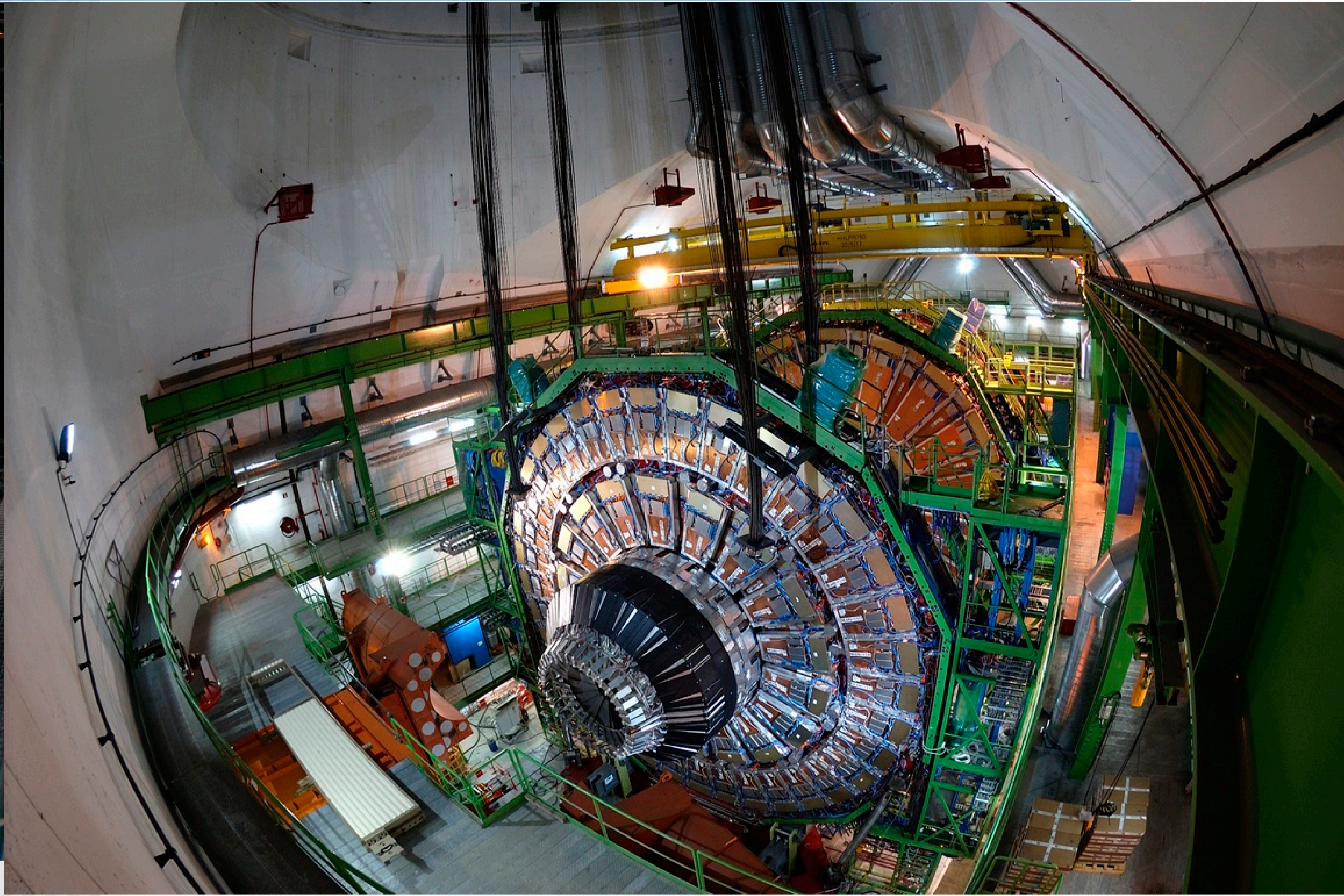

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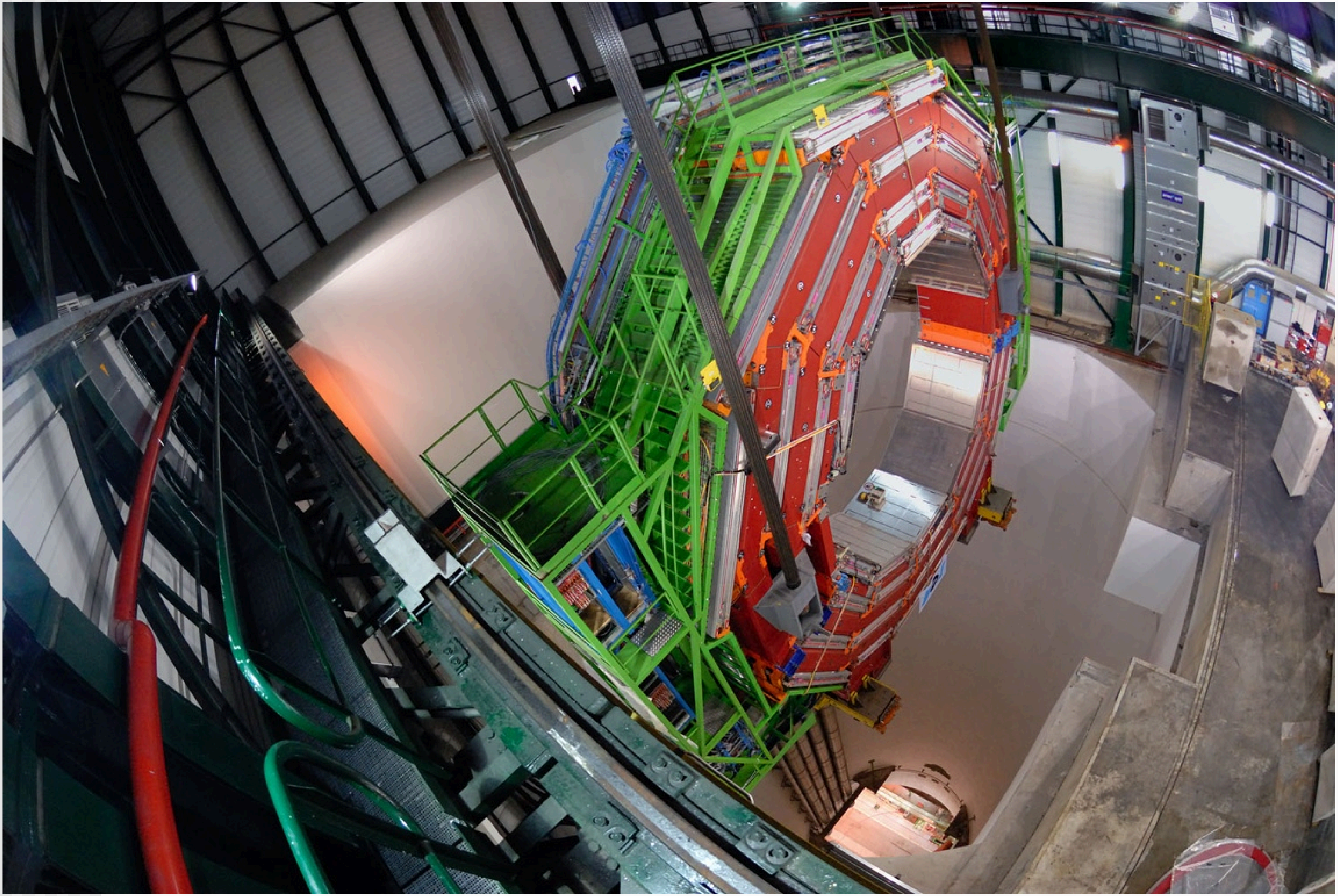

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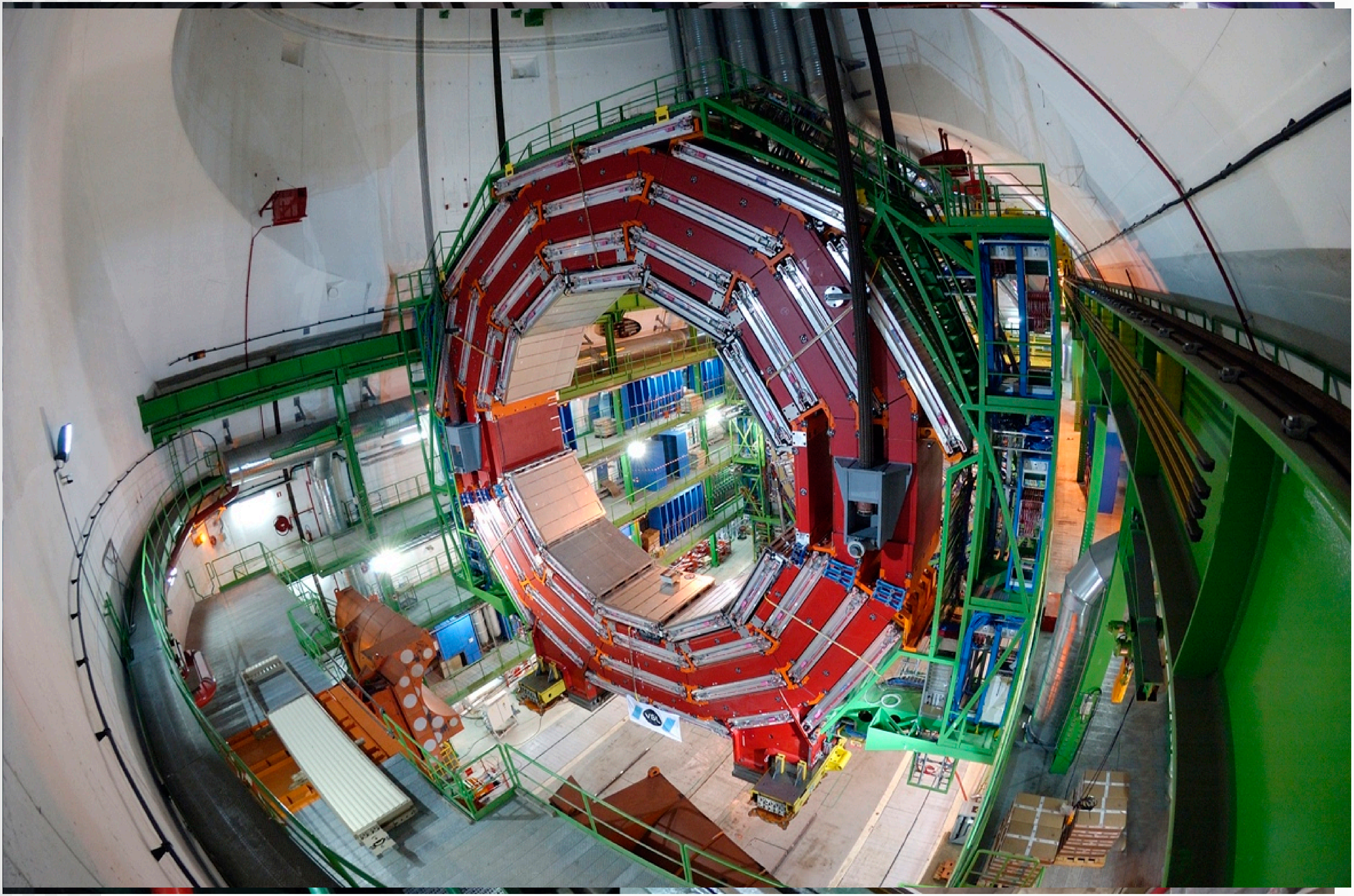

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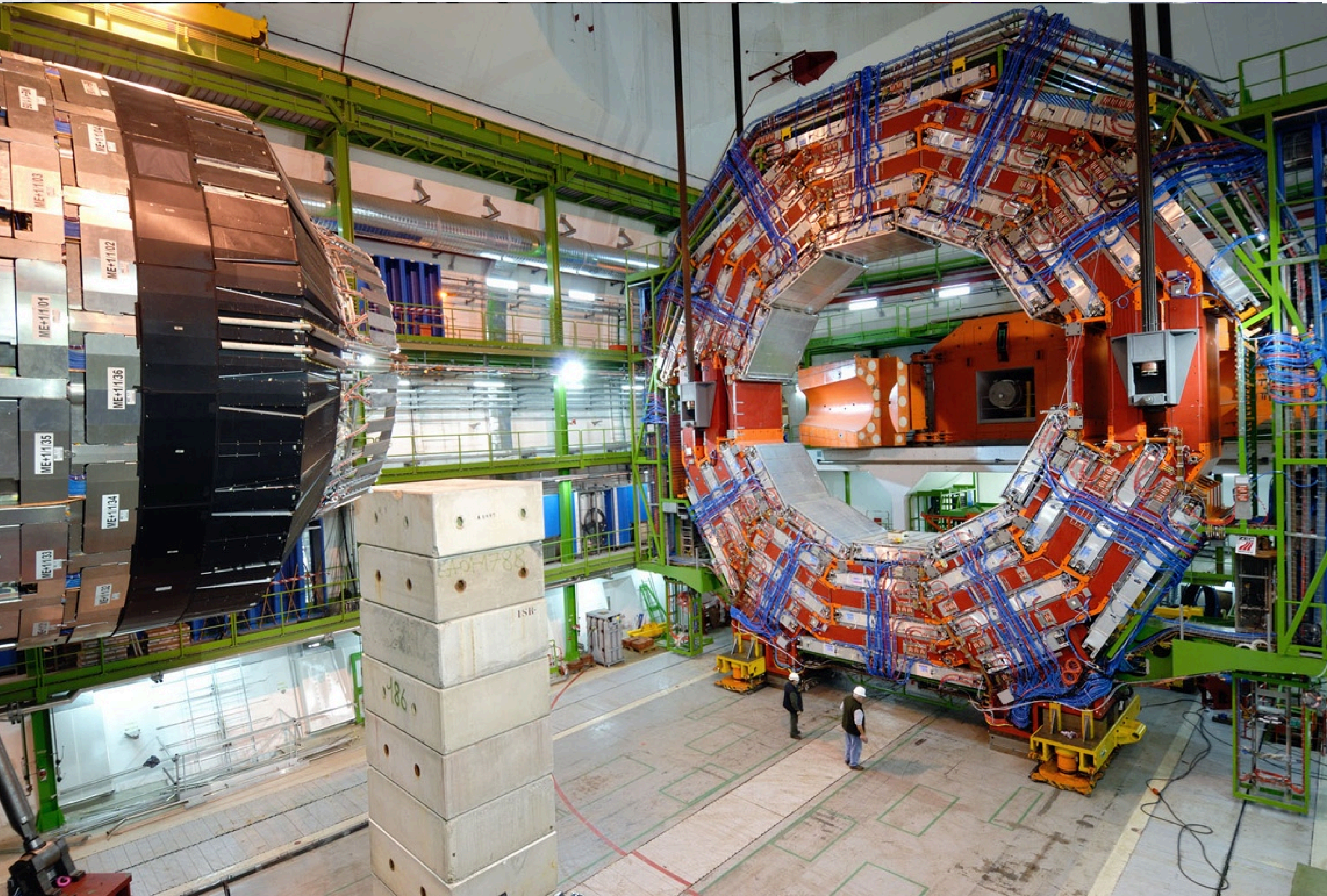

Expted Detector Performance

ETH Institute for Particle Physics

- Construction quality checks and beam tests of series detector modules show that the detectors as built should give a good starting-point performance

	Expected performance day 1	Physics samples to improve (examples)
ECAL uniformity e/γ scale	~ 1% (ATLAS), 4% (CMS) 1-2 % ?	Minimum-bias, $Z \to ee$, $W \to e\nu$ $Z \to ee$
HCAL uniformity Jet scale	2-3 % < 10%	Single pions, QCD jets $Z (\to ll) +1j$, $W \to jj$ in tt events
Tracking alignment	20-500 μm in $R\phi$?	Generic tracks, isolated μ, $Z \to \mu\mu$

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  - Understand "basic" physics at 14 TeV and normalize (tune) the MC generators
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- Using in-situ calibration, control samples, and based on experience from previous exps: an educated guess :

Expted Detector Performance

ETH Institute for Particle Physics

"Isolated" electrons, photons: $\Delta E/E_{e,\gamma} =$ few % $/\sqrt{E}$ + 0.5%(goal)

excellent angular resolution, "high" efficiency and "small/negligible" backgrounds

for $p_t \geq 10$ GeV (?) and $|\eta| \leq 2.5$(?) $\delta\epsilon \approx 1\%$

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Missing transverse momentum: depends on final state!
in general a mixture between lepton and jet accuracies

Measurements of hard processes

Our Master Equation

$$\sigma_{\text{meas}} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\varepsilon \; L}$$

Our Master Equation

Event rates (absolut, relative, differential)
Stat vs syst errors, backgrounds from data or MC? Signal Significance

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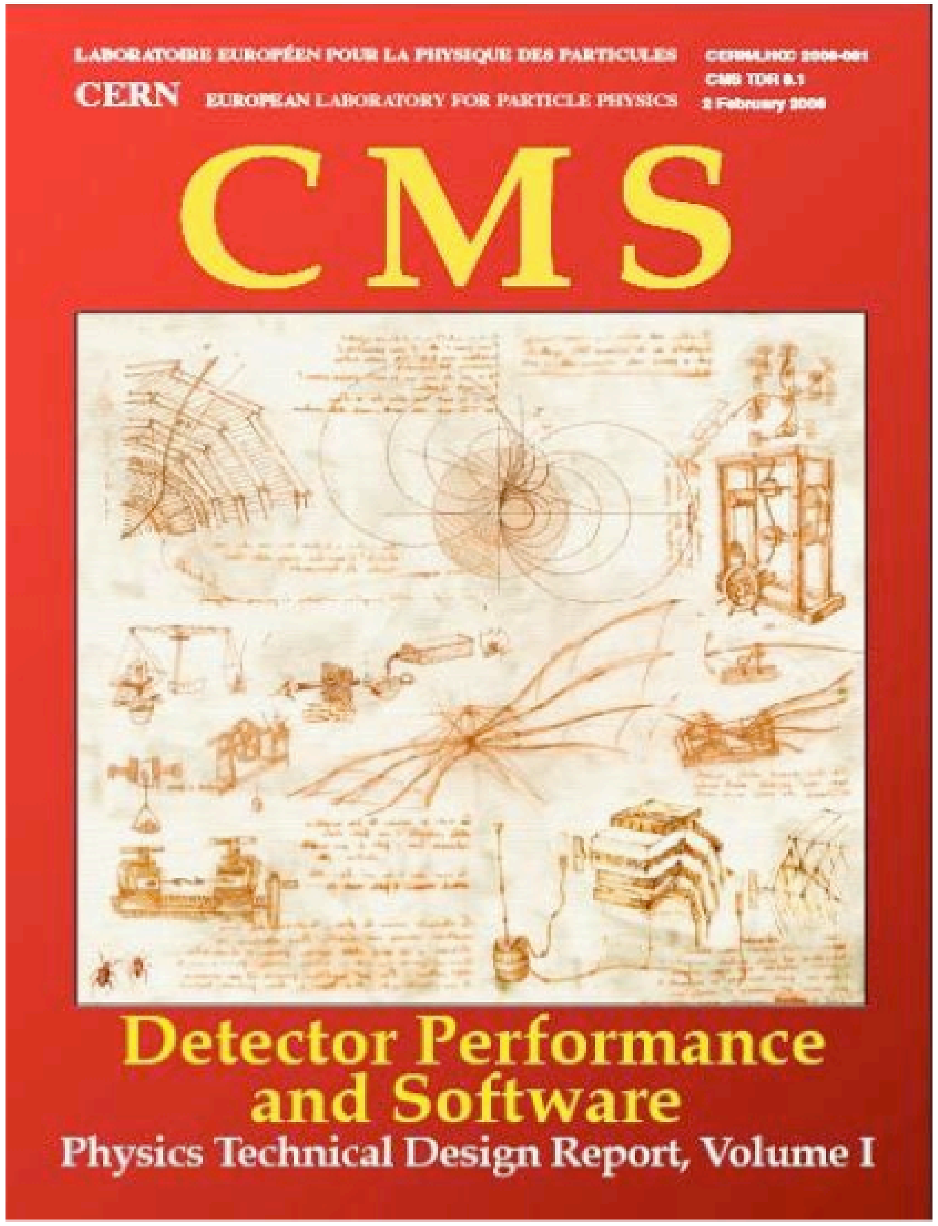
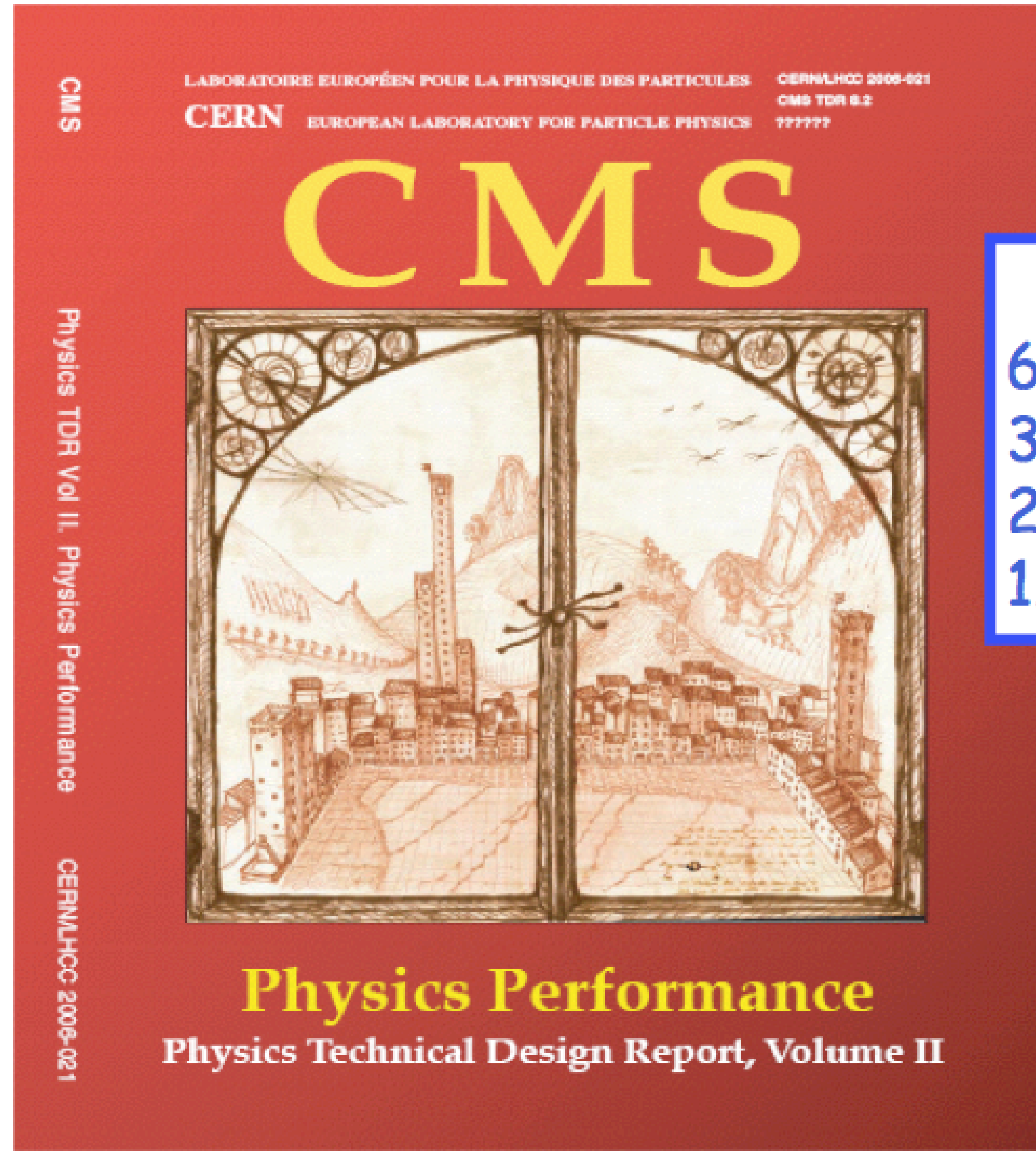
Goal : test SM (in)consistency : $\sigma_{\text{exp}} \pm \Delta_{\text{exp}} \stackrel{?}{=} \sigma_{\text{SM}} \pm \Delta_{\text{th}}$

Many results taken from...



CERN/LHCC 2006-001



CERN/LHCC 2006-021

650 pages
308 figures
207 tables
1.50 Kg

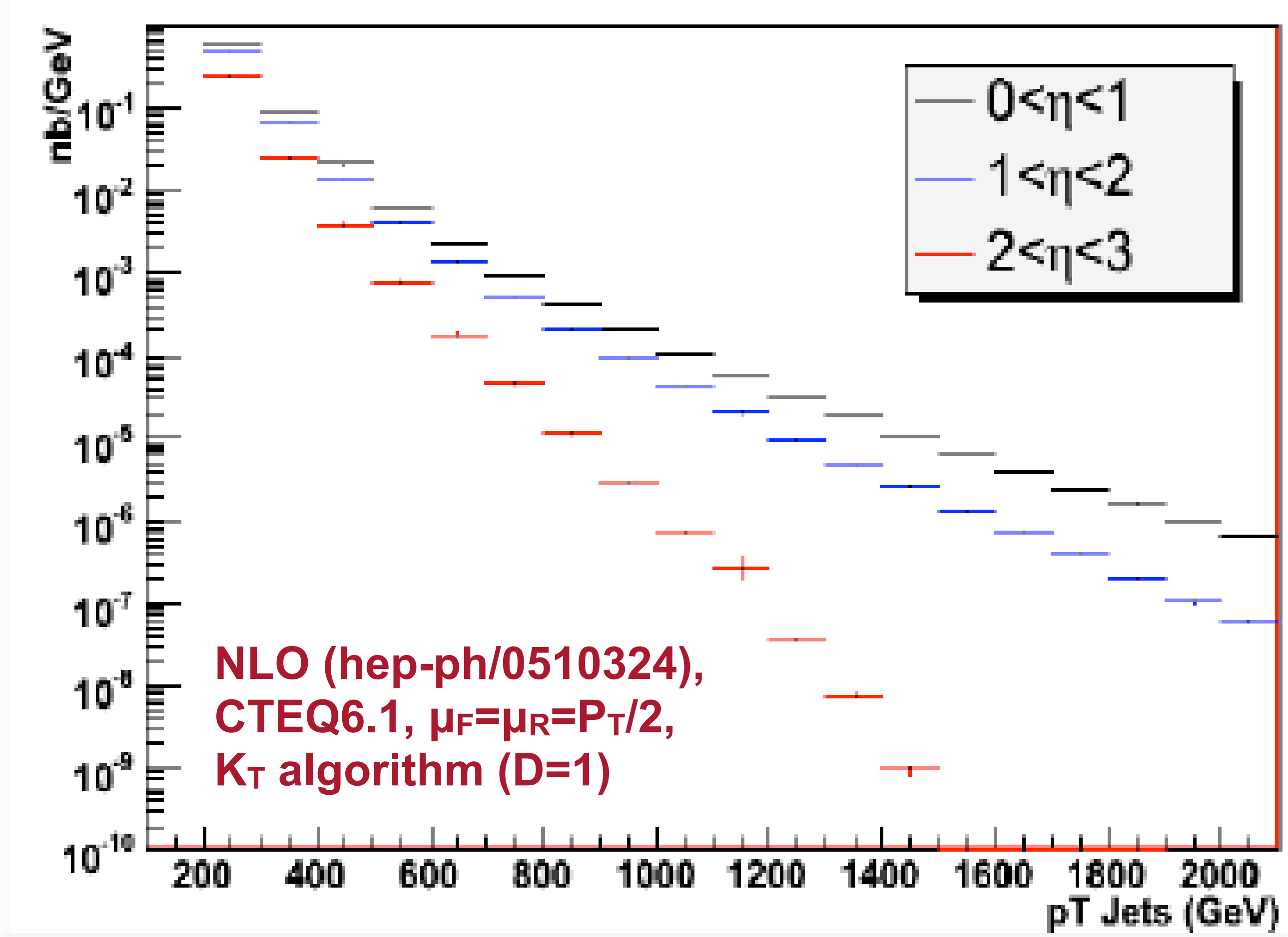
see http://cmsdoc.cern.ch/cms/cpt/tdr/

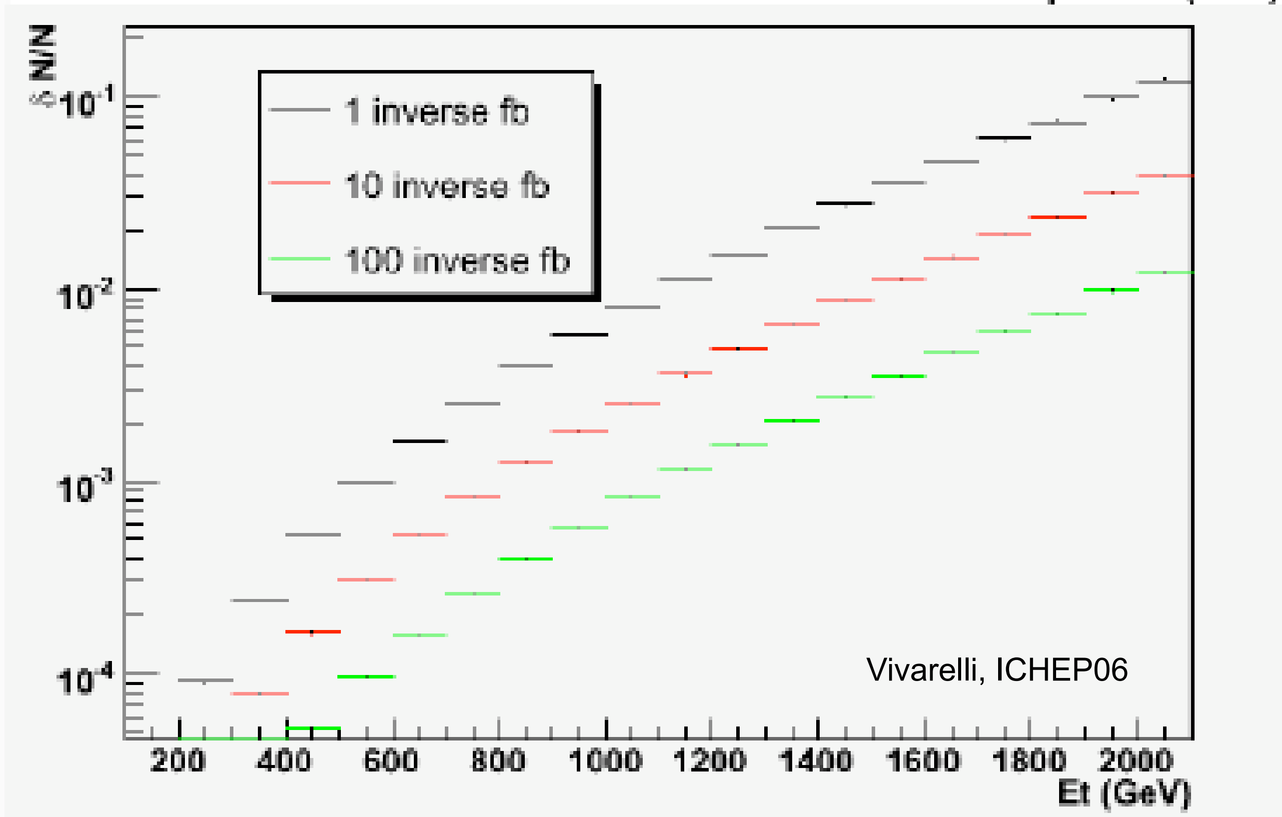
will be appreviated as CMS PDTR in the following

Jets

Inclusive Jet cross section

- After MB studies, jets will be the first objects seen and measured
- Enormous cross section, so statistical errors quickly negligible
  - 1% at p_T=1 TeV for 1 fb^{-1} (central)
  - 10% for $3 < \eta < 5$
- Steeply falling cross section : energy scale knowledge most relevant





Inclusive Jets : Systematics

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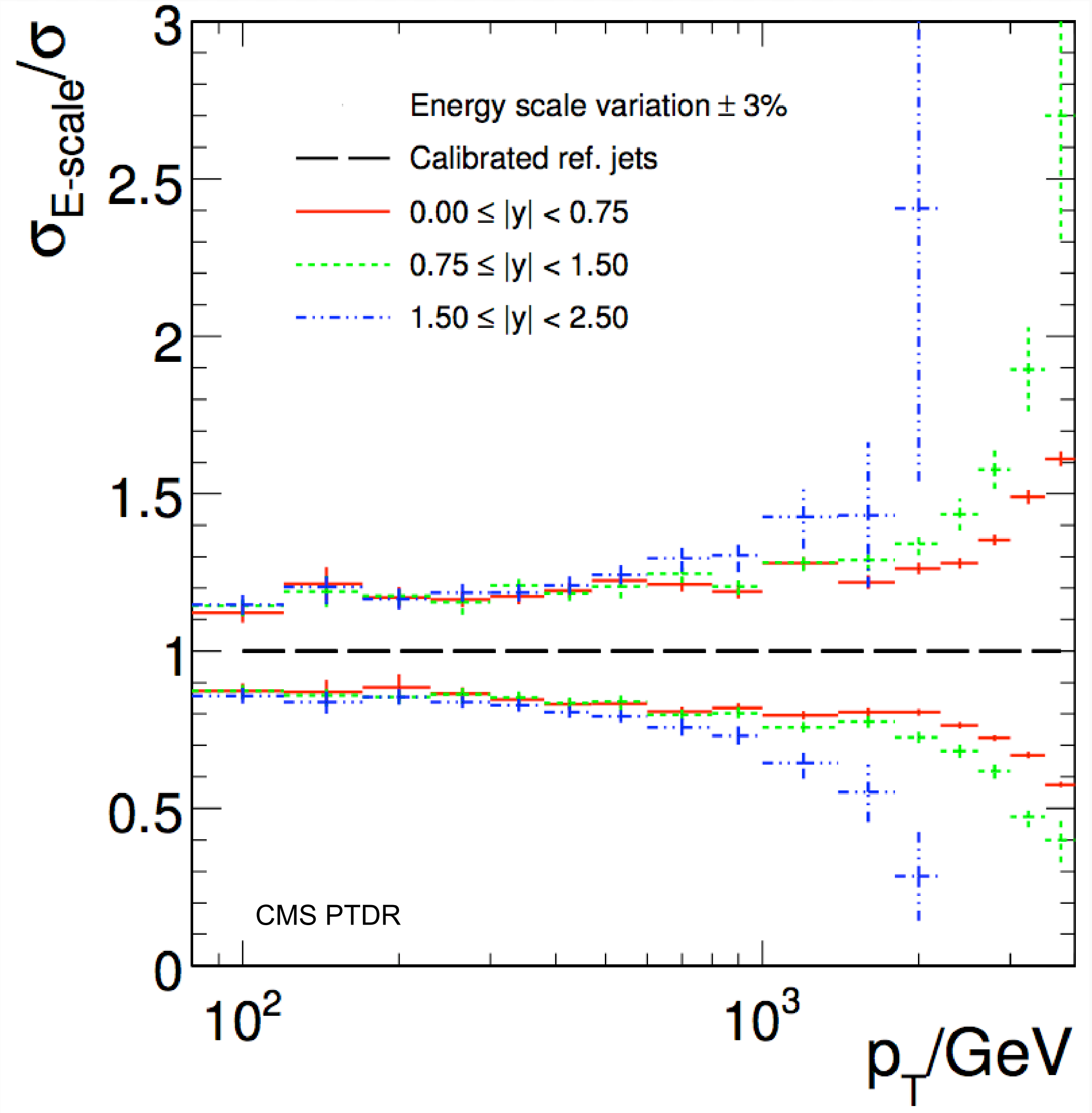

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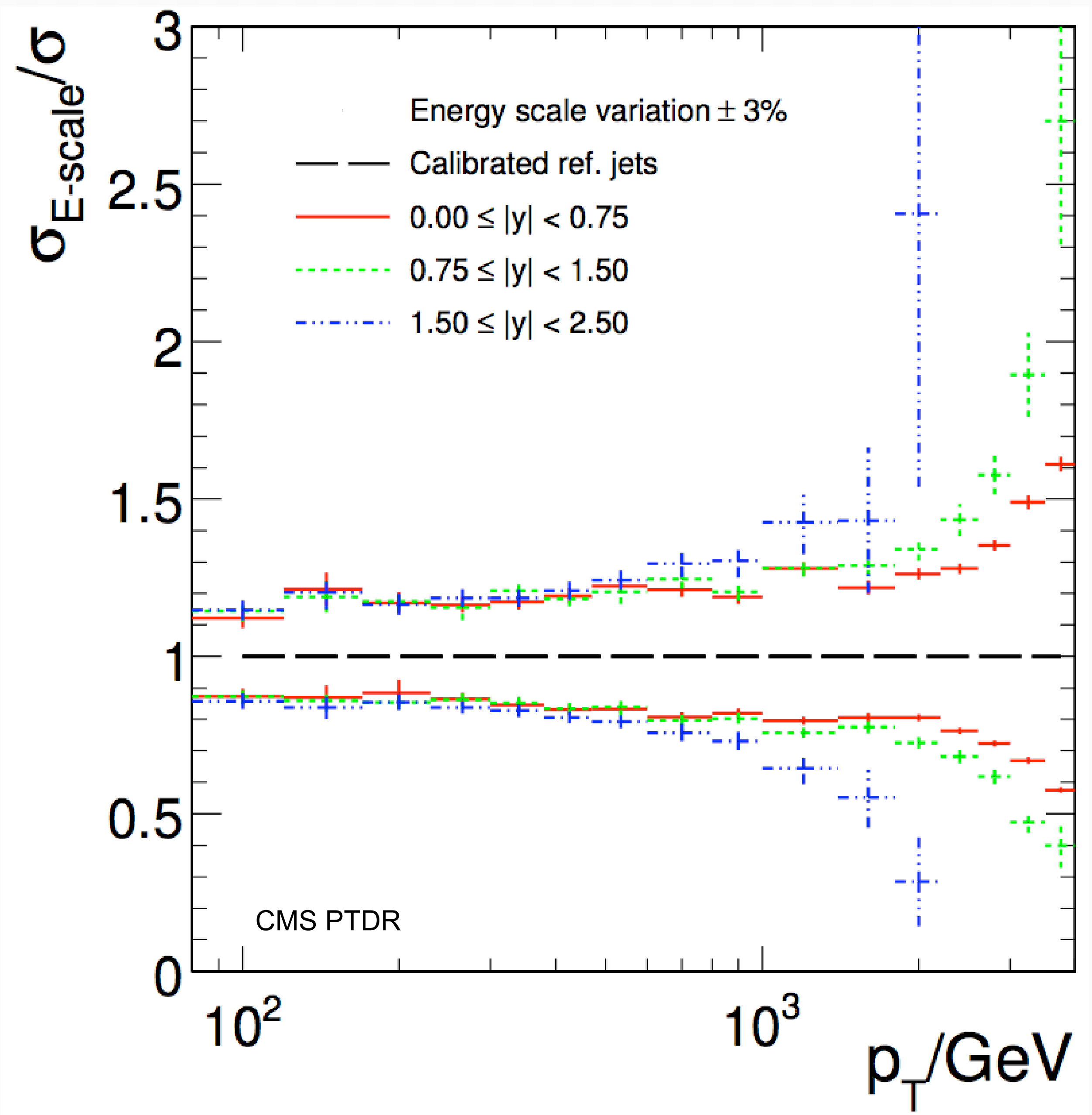

- a **5% jet energy scale** uncertainty (which is more realistic at start-up) gives a **30% error** on the cross section!
- Control in-situ with : photon/Z+jets and W➔ JJ in top decays
- Other sources : jet corrections (det ➔ had ➔ part), UE subtraction

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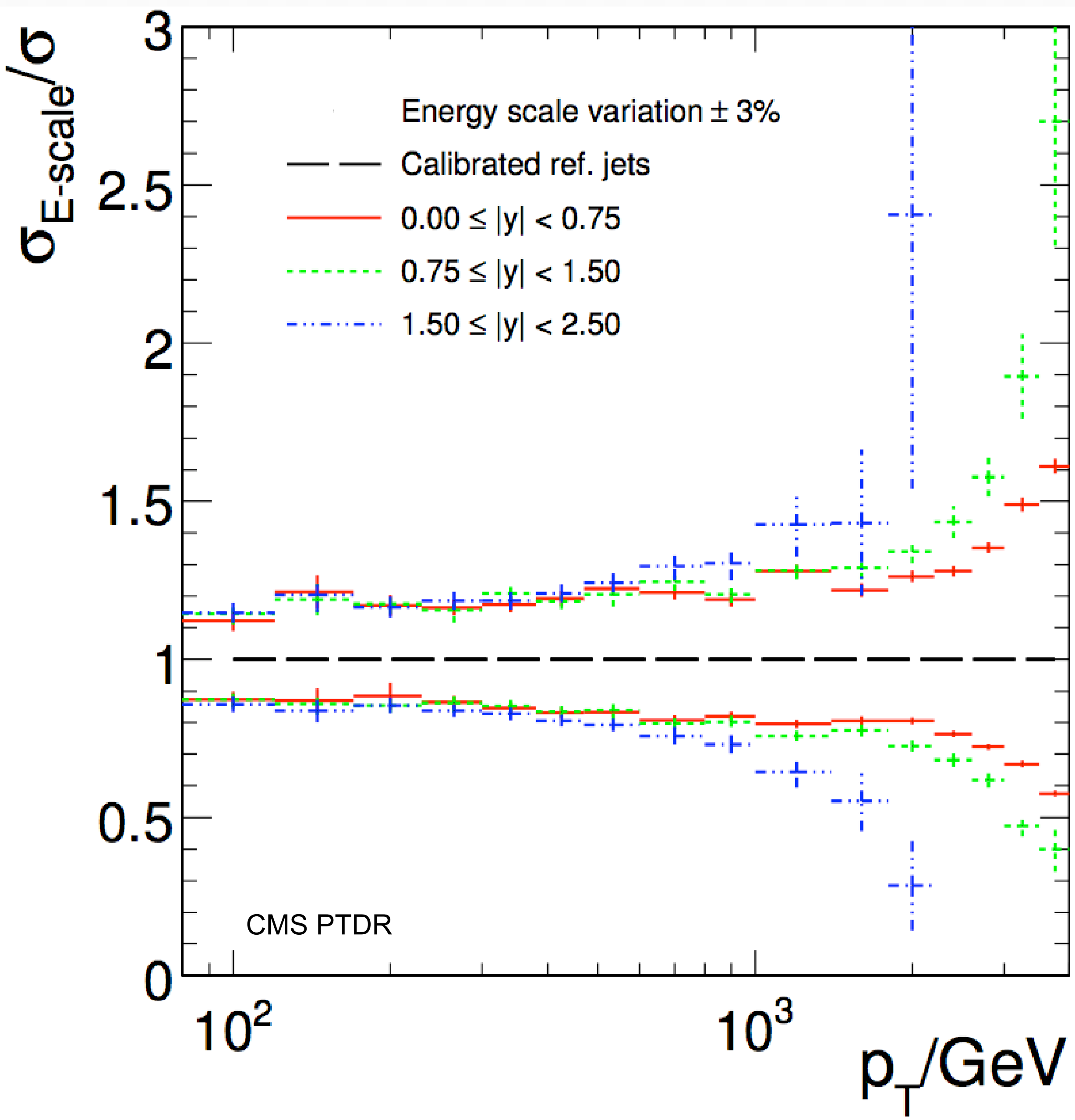

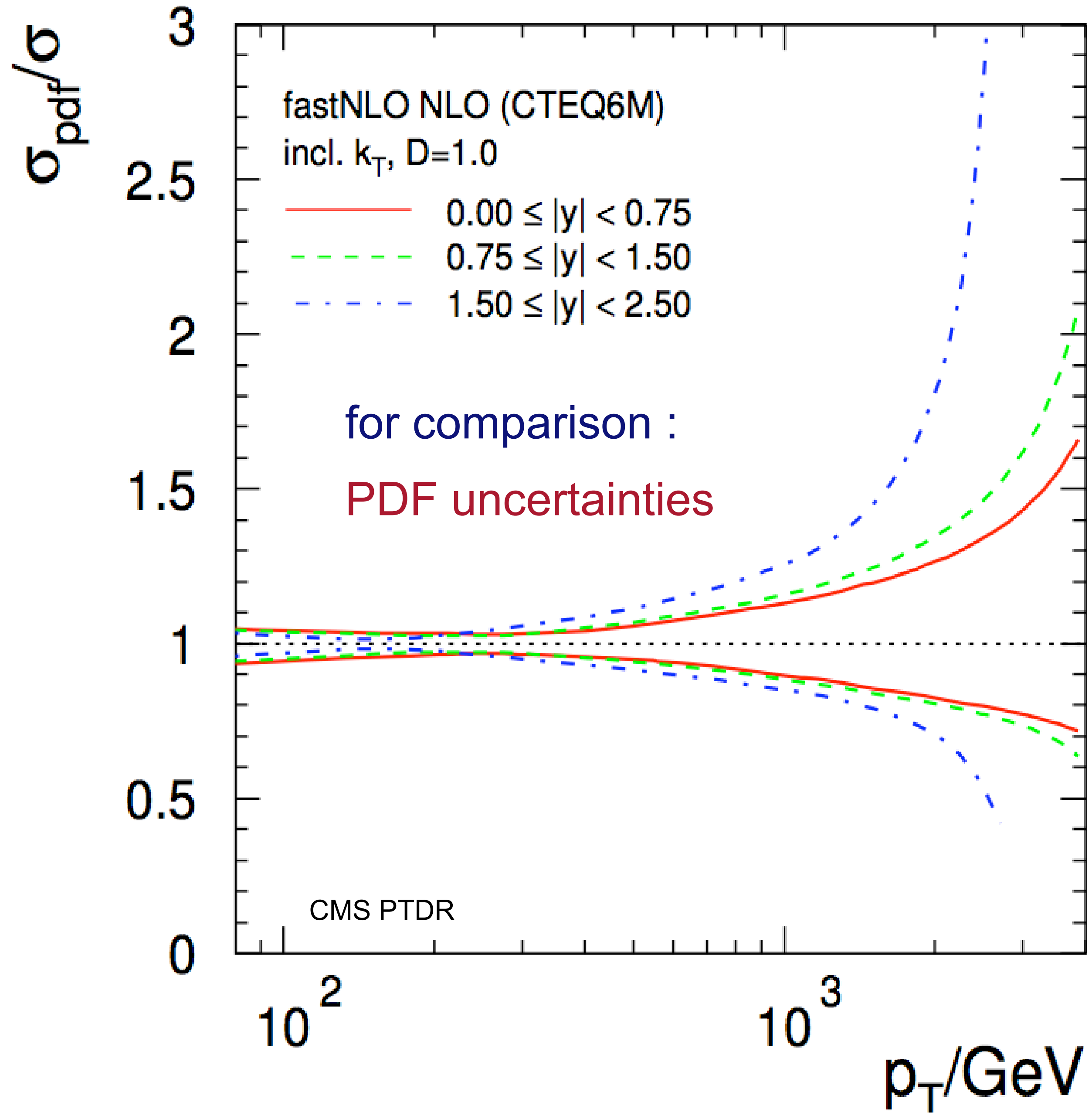

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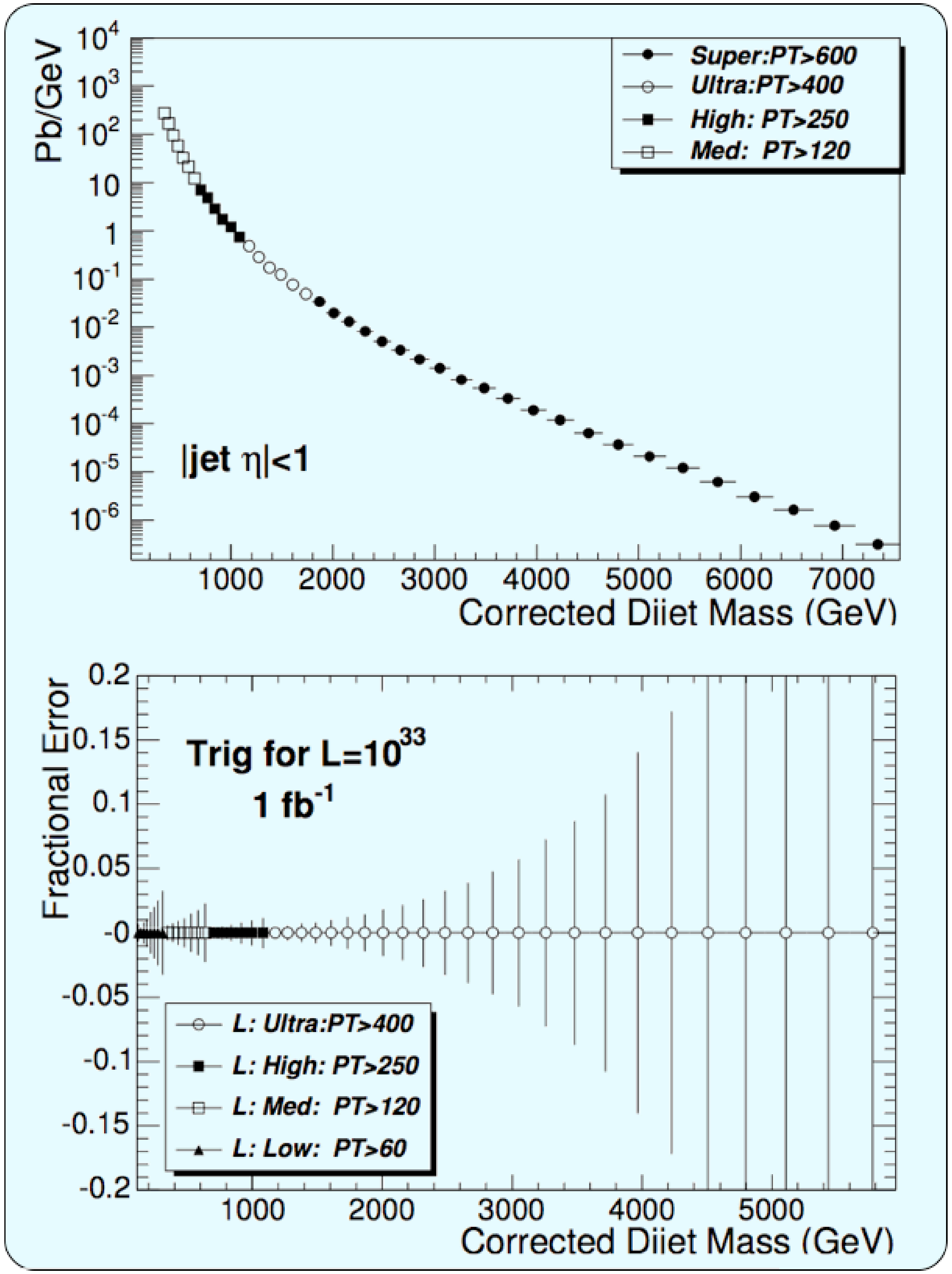
Di-Jets (CMS PDTR)



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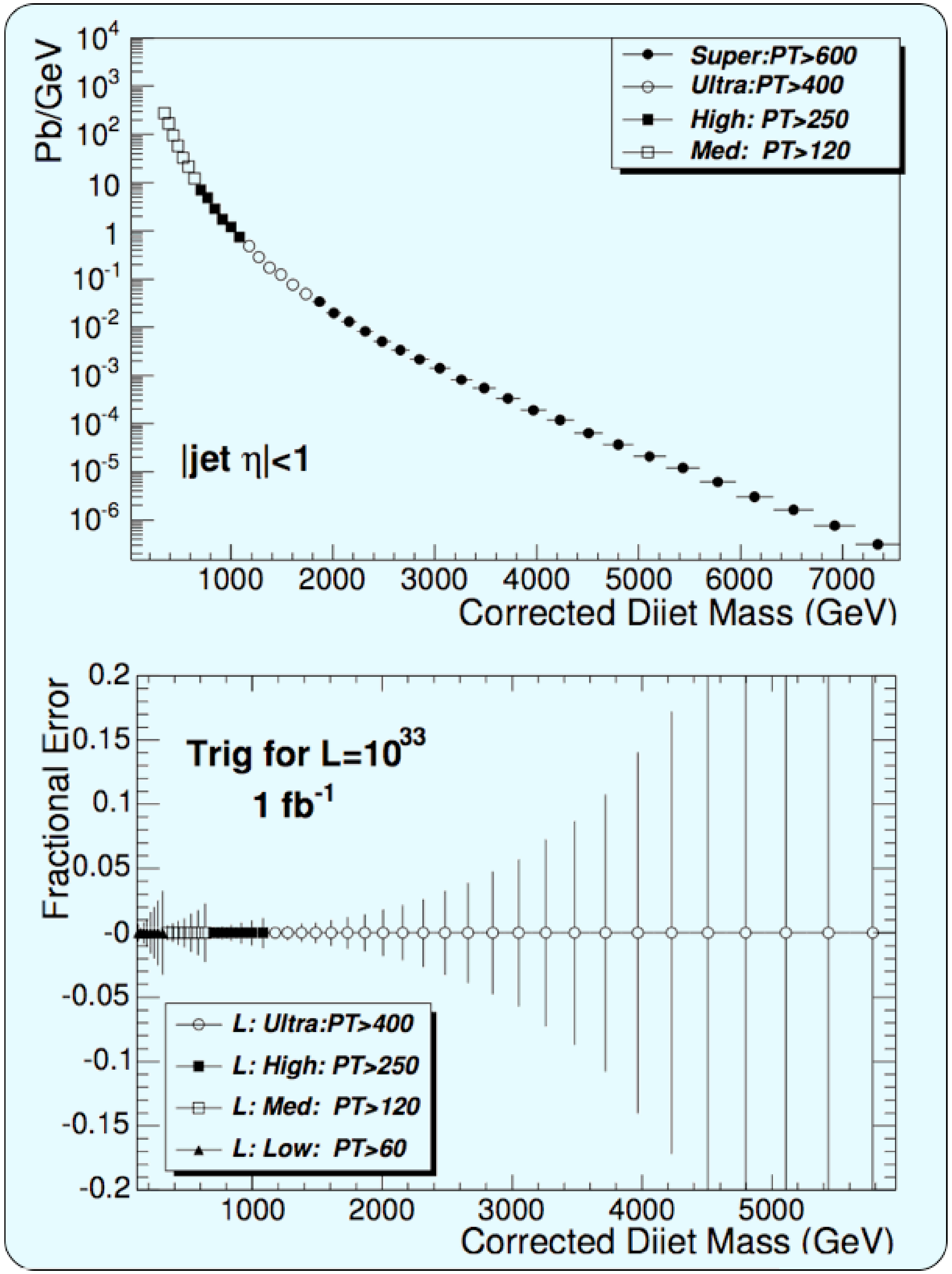

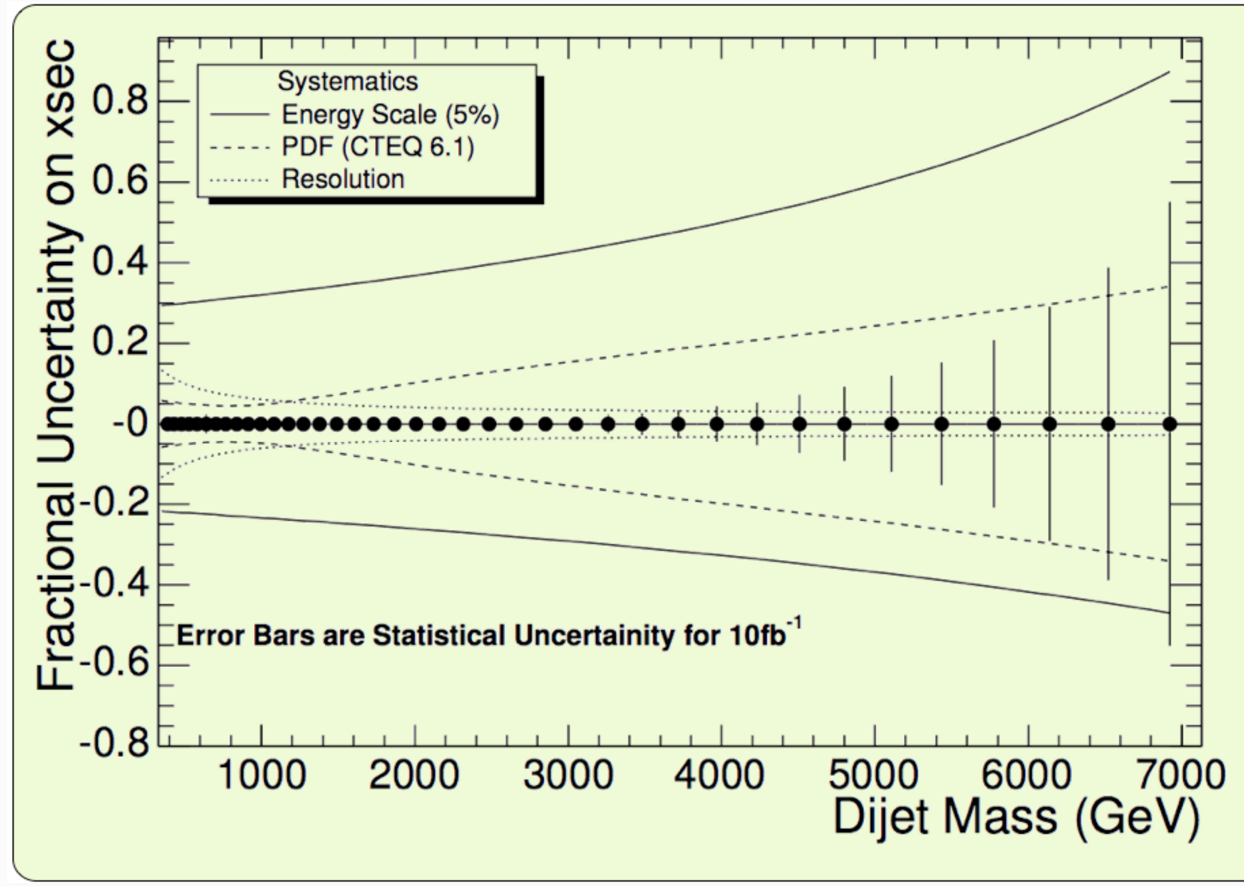

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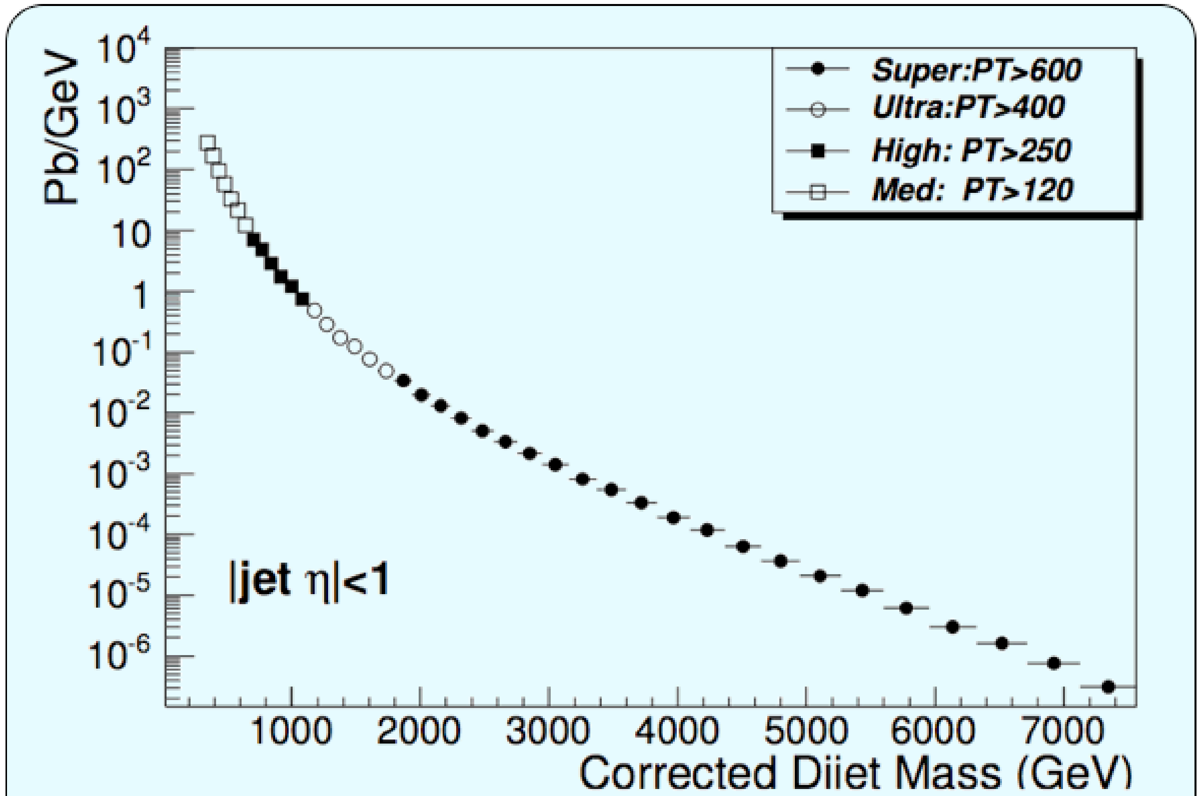

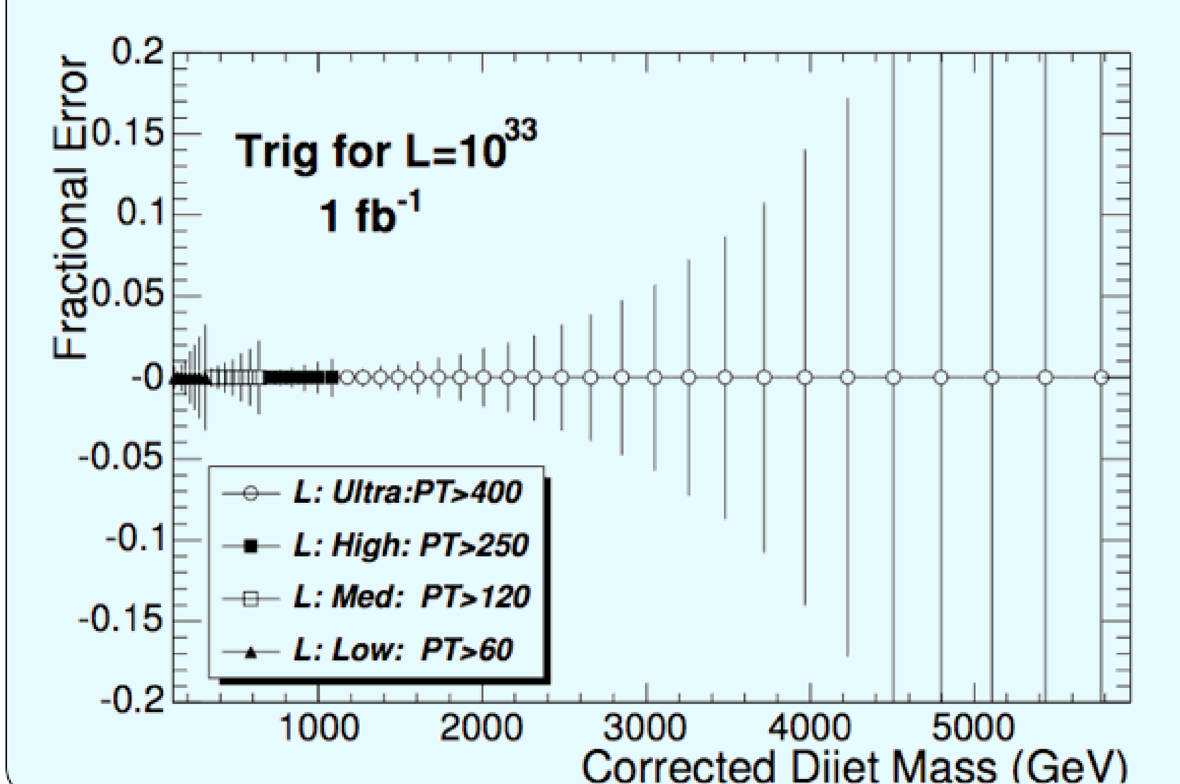

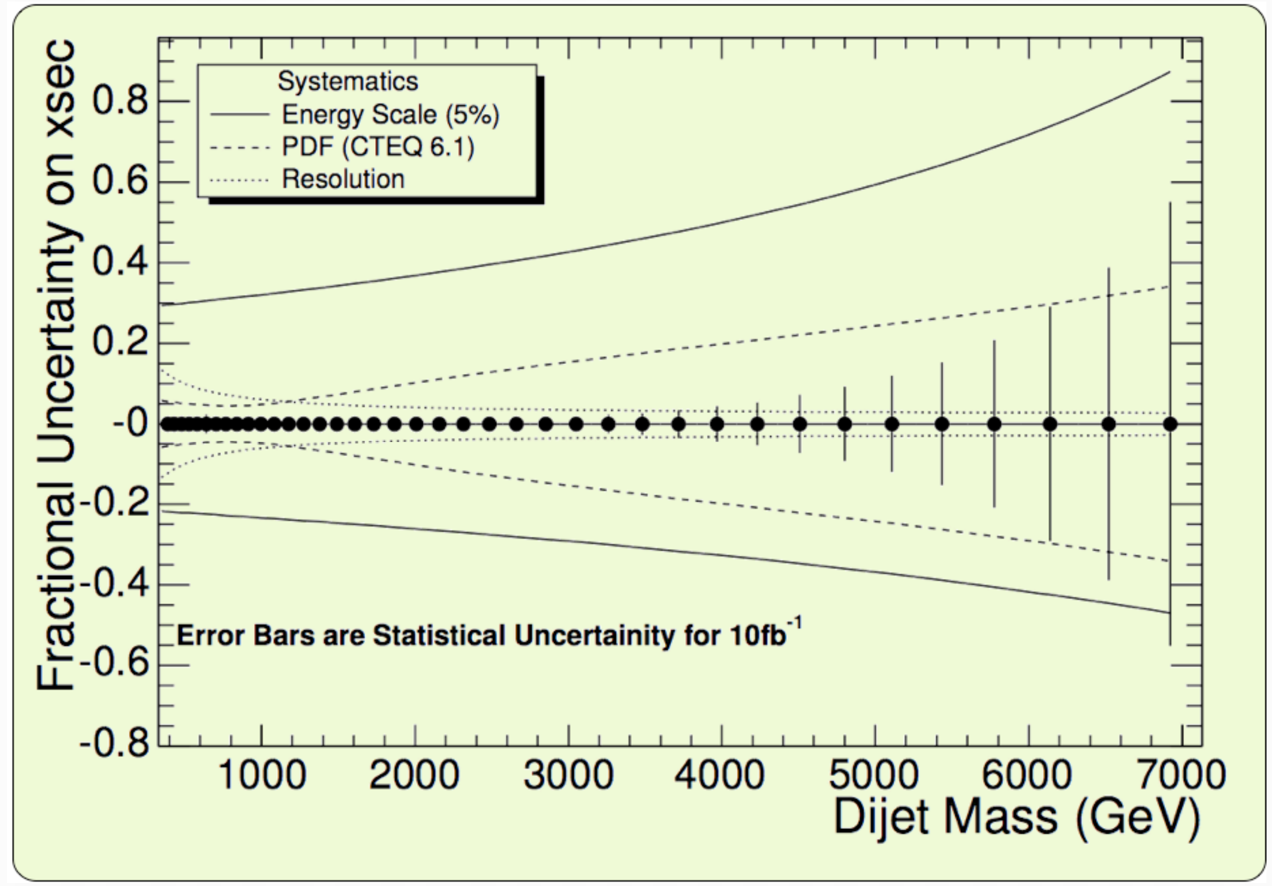

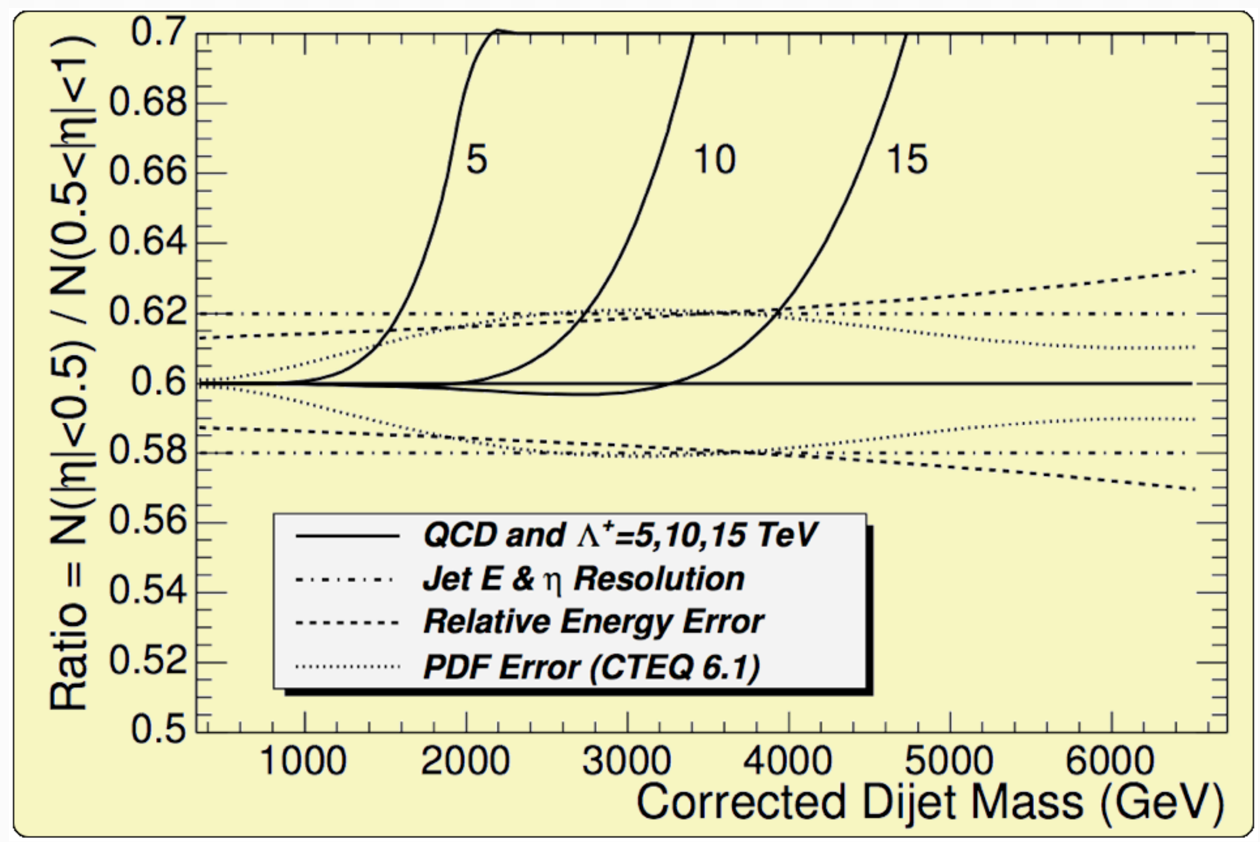

Note : Ratio of cross-section central / forward !

Jet + Photon/Z

- Jet calibration using p_T balance
  - Selection : isolated photons, no high-p_T secondary jet, photon and jet well separated in transverse plane
  - Statistical error well below 1% after 10 fb^{-1}

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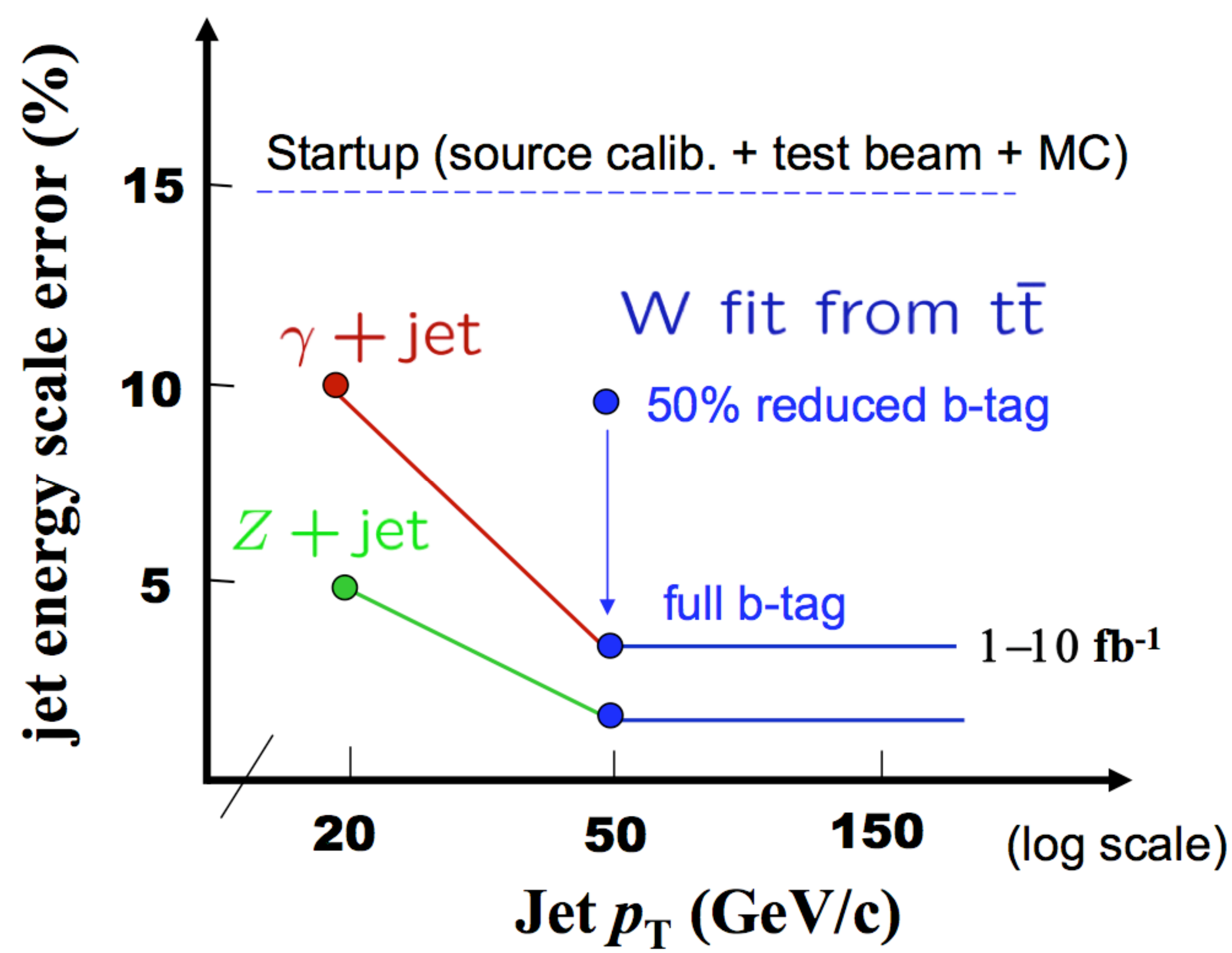

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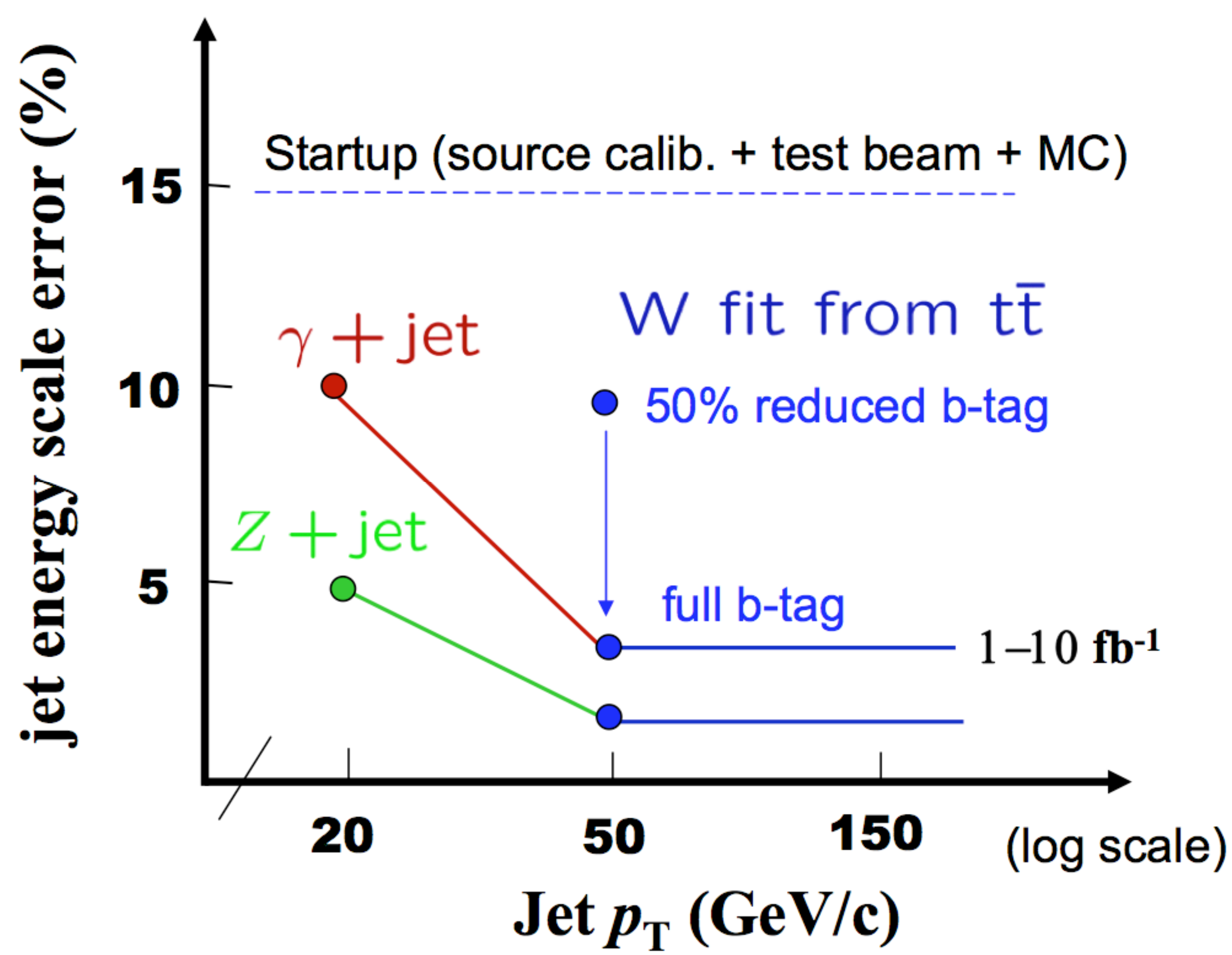
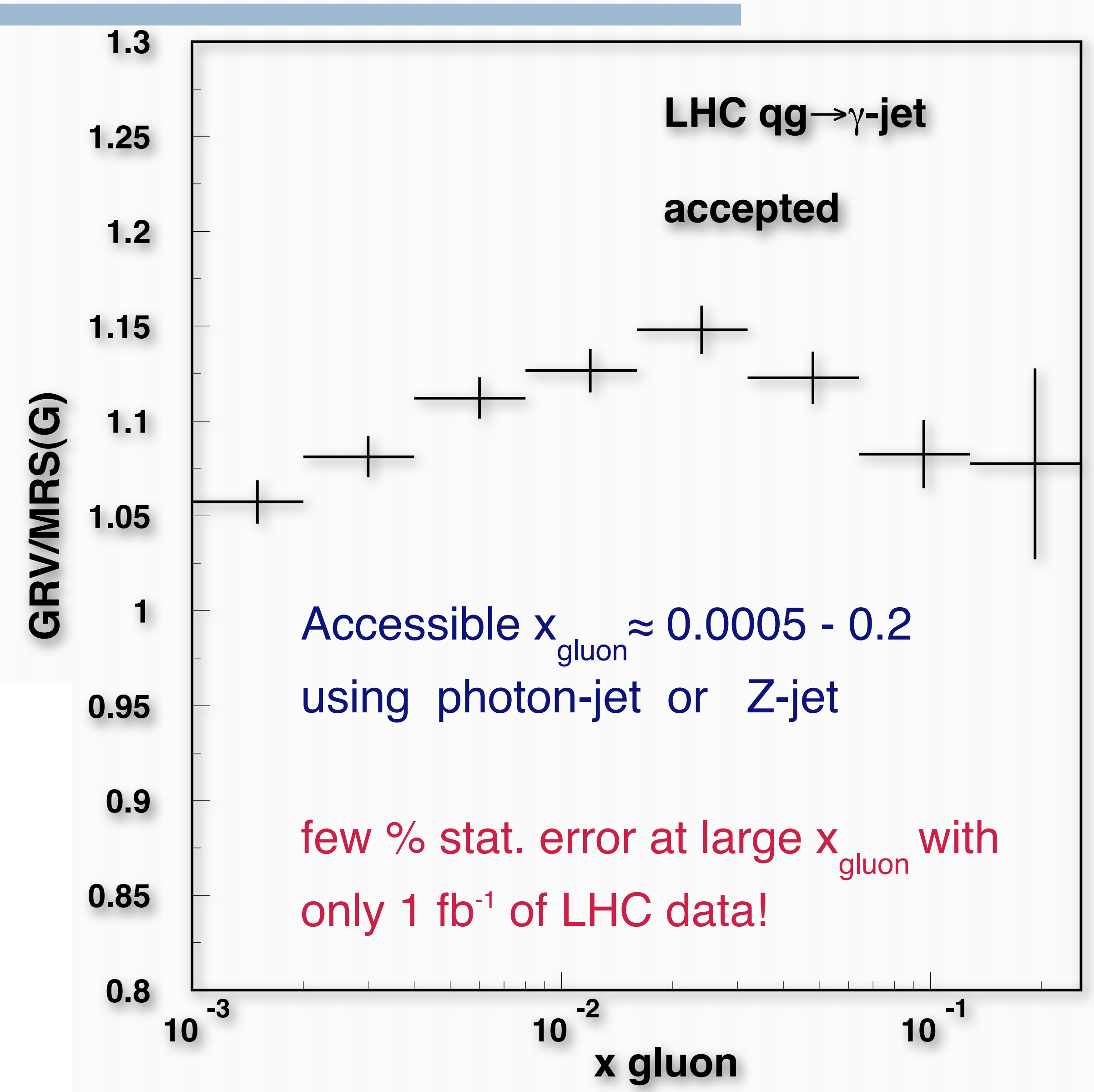


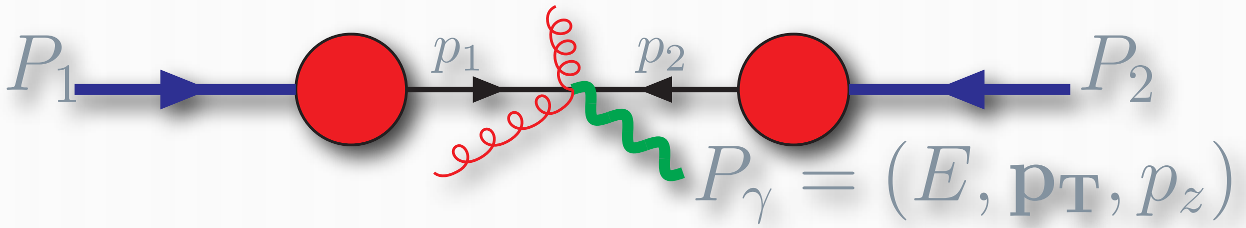


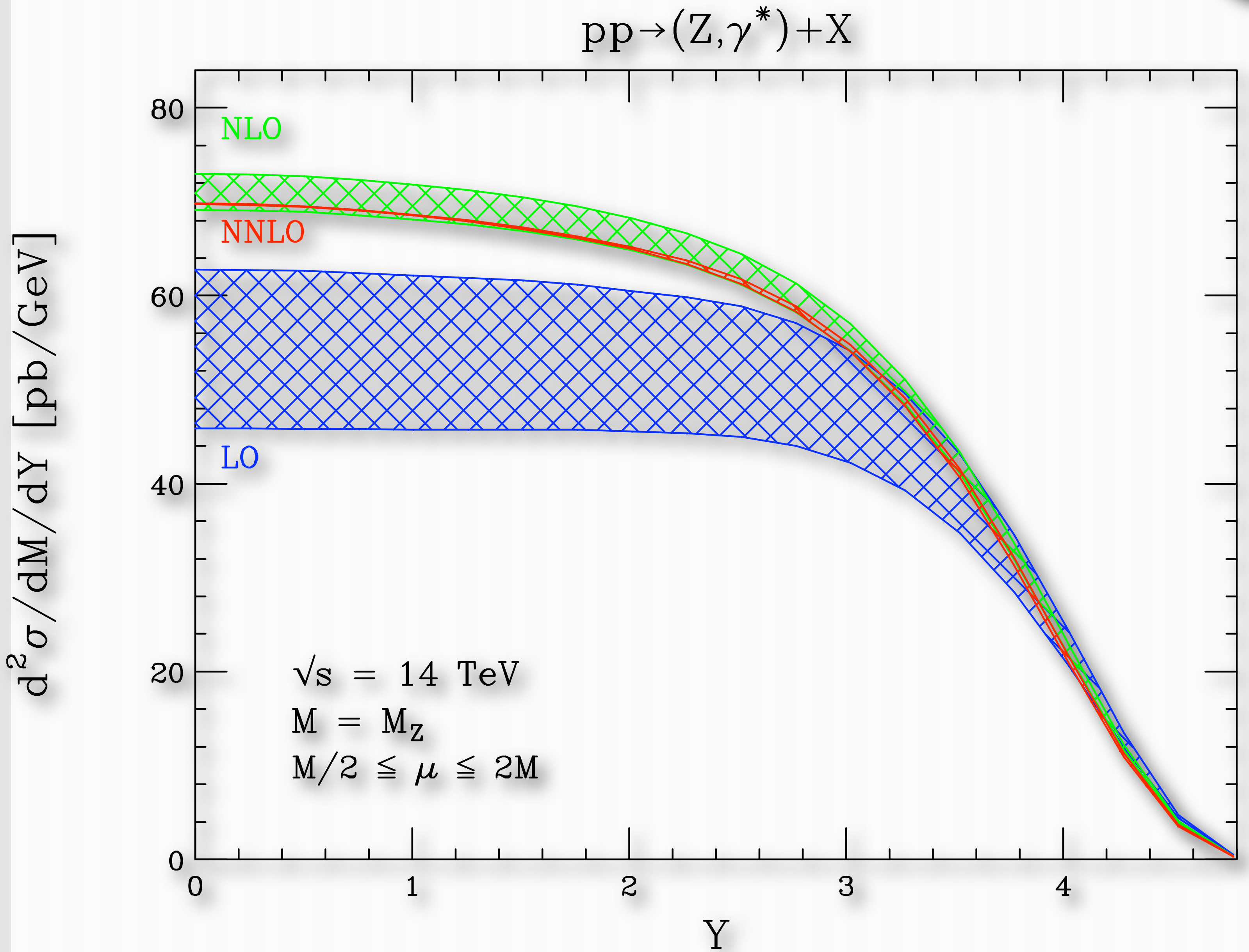
- constrain gluon pdf
- energy scale well controlled by photon
- other issues there:
  interplay real radiation - fragmentation
- Z+jet : smaller rate, best possible prediction needed

W and Z production

Predictions

- Probably best known cross section at LHC, NNLO, differentially
- a well suited normalization process





Anastasiou, Dixon, Petriello, Melnikov : differential in W/Z rapidity
Petriello, Melnikov : fully differential in lepton momenta

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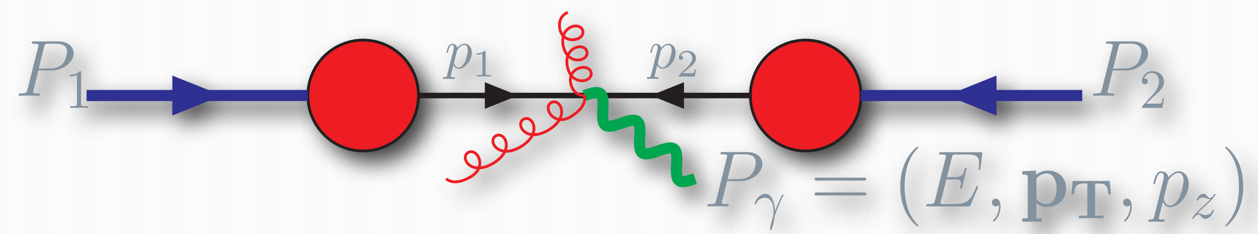

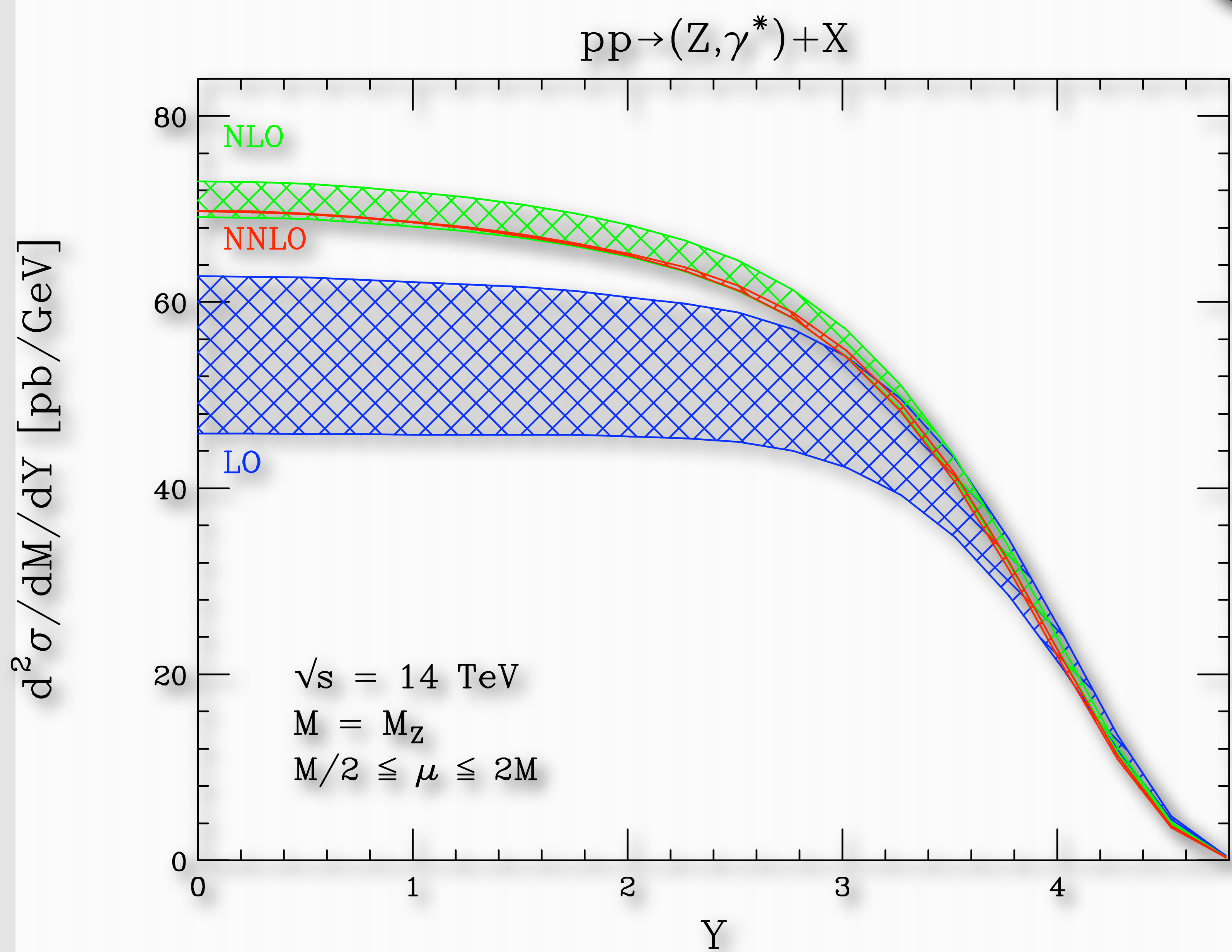

small NNLO scale uncertainty:

LO : 25% - 30%
NLO : 6%
NNLO : 0.1 % (Y=0) -
1% (Y<3) -
3% (Y ~ 4)

shape stabilizes at NNLO

Anastasiou, Dixon, Petriello, Melnikov : differential in W/Z rapidity
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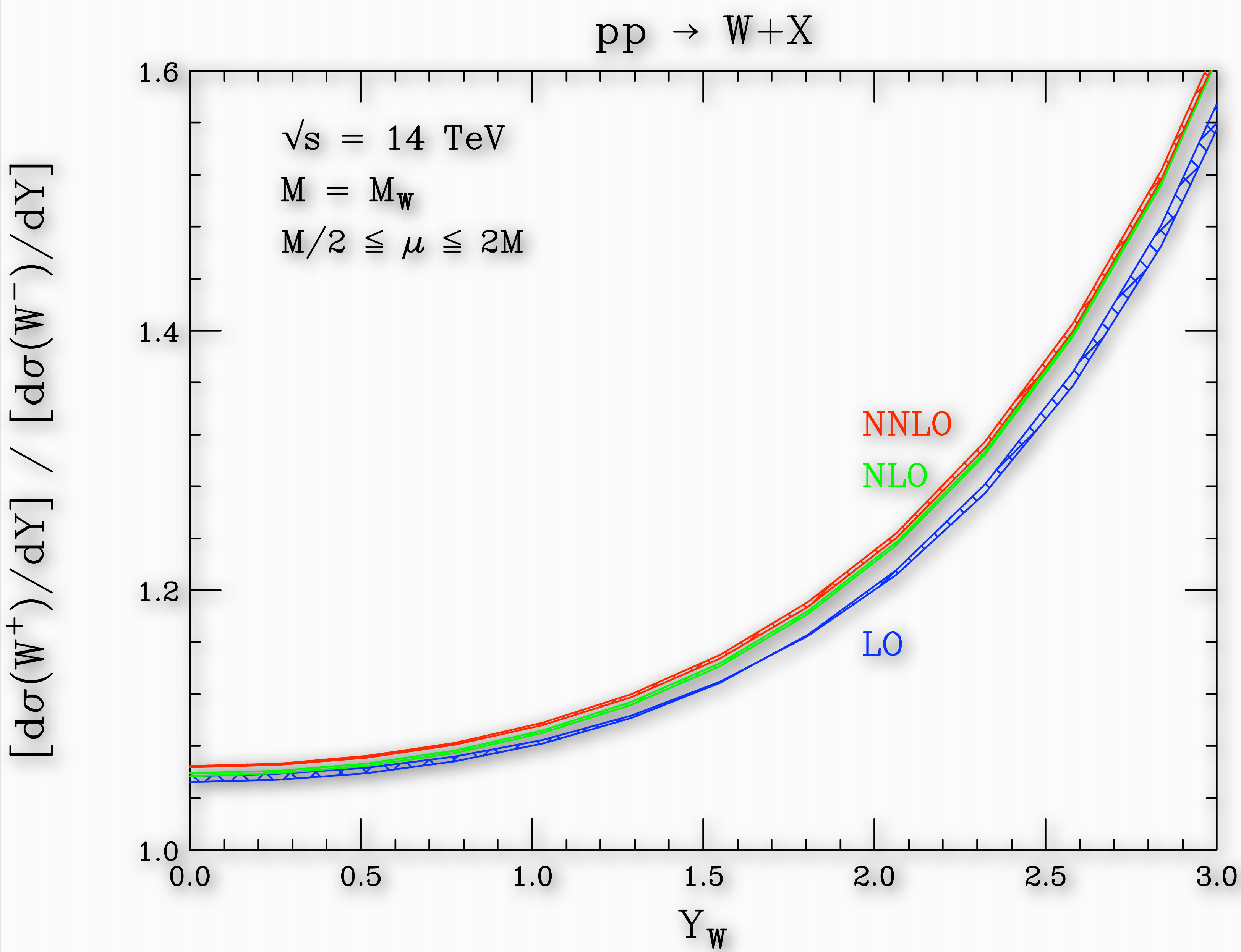
Predictions

ETH Institute for Particle Physics

similarly for W^+/W^- : very small
NNLO scale uncertainty: 0.5 - 0.7 %



Predictions

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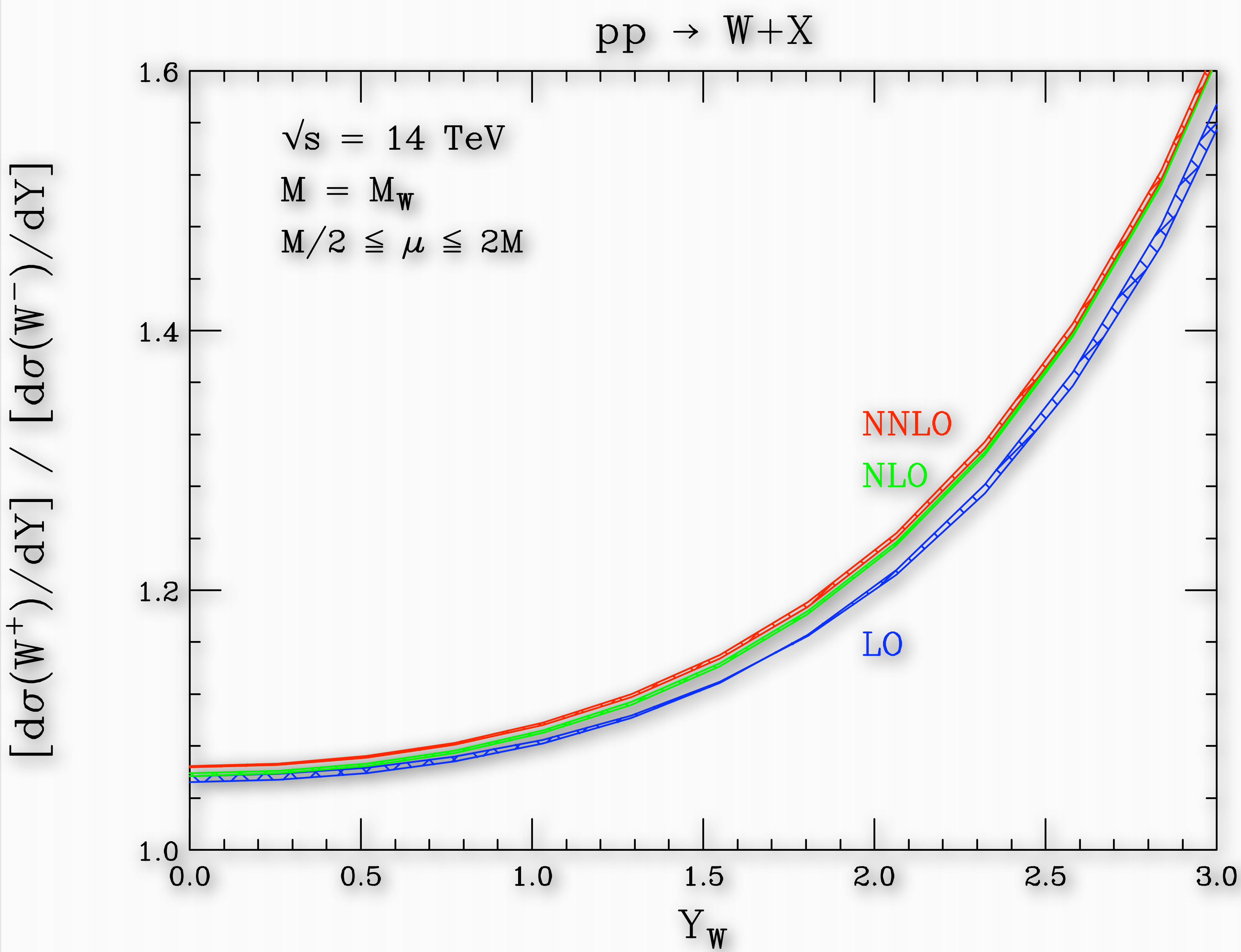

However : dominant uncertainty for **absolute** W and Z cross section:

PDFs : 4 - 5 %

Issue of acceptance...

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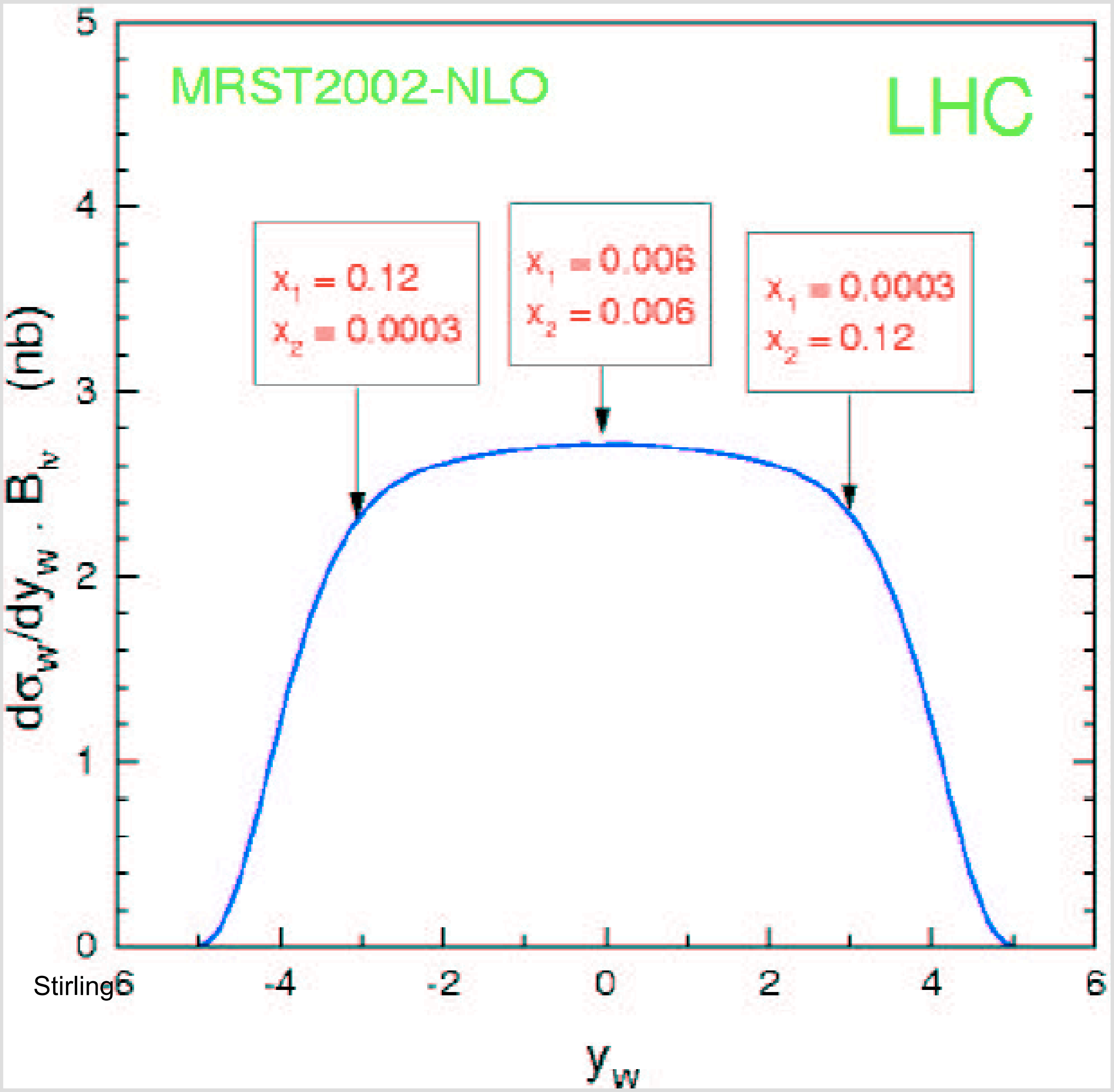
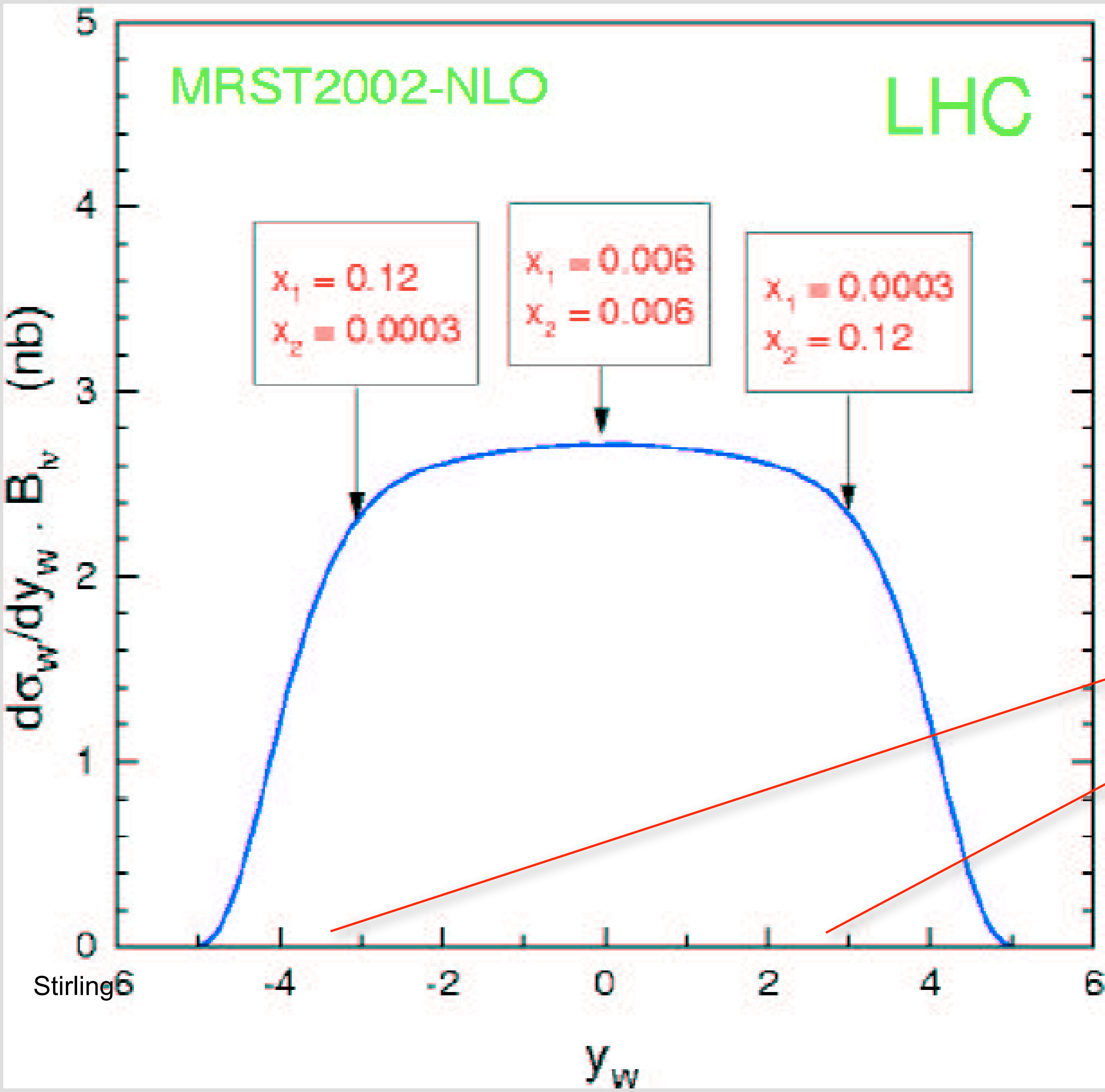


Stirling

Issue of acceptance...



Stirling

if we want **precise measurement** of Luminosity or some parameter in hard-interaction cross section, it is essential to have HO calc.

restricted to measurable acceptance

⇒ avoid **extrapolation errors** (extrapolation to large y_W)

Experimental Z/W counting

- Selection
  - Z : 2 isolated leptons, p_T>20 GeV, $|\eta| < 2.5$, W : 1 isolated lepton + MET
  - Studied : electrons, muons.
  - Difficult issue : MET (=neutrino reconstruction)

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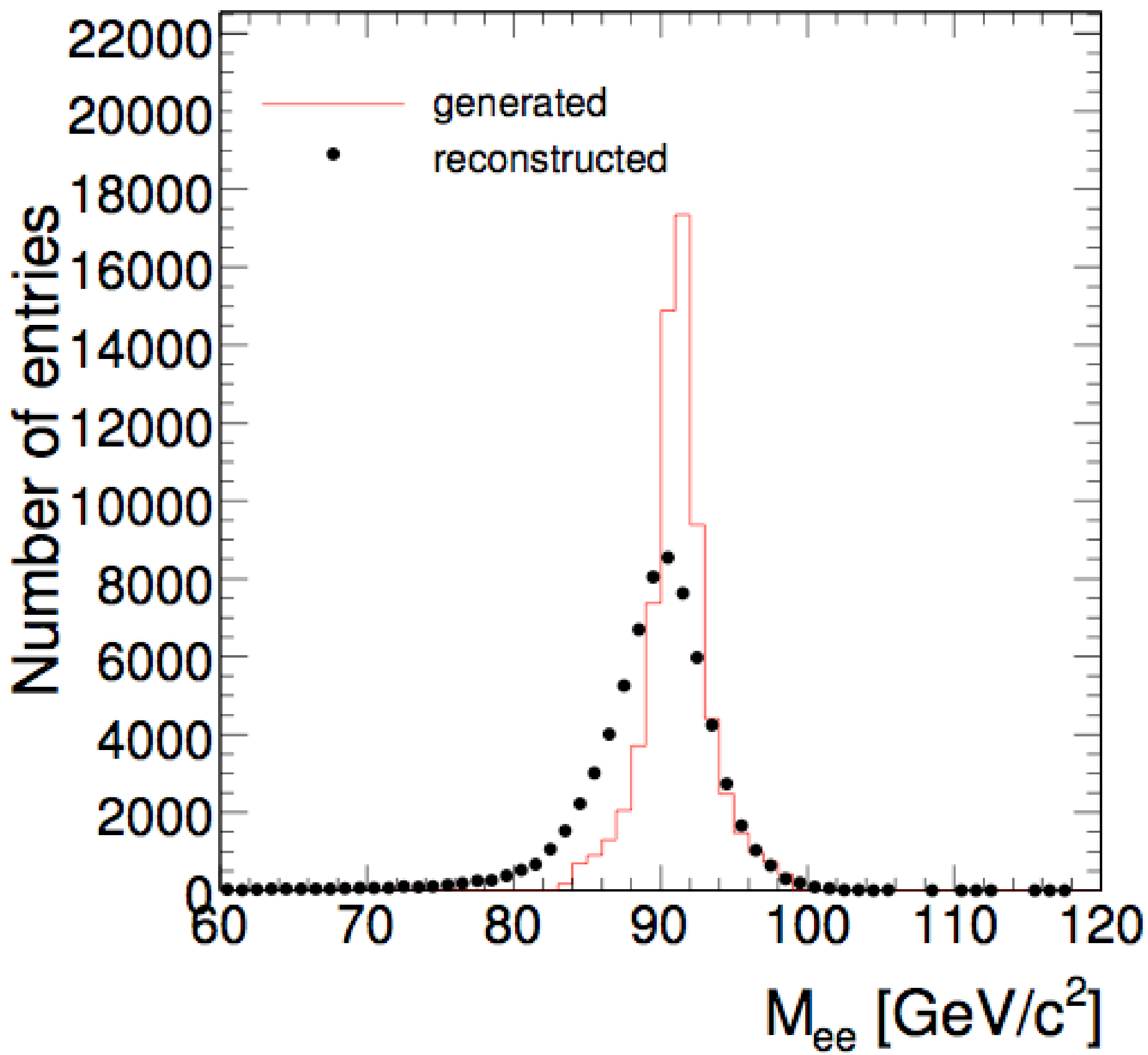
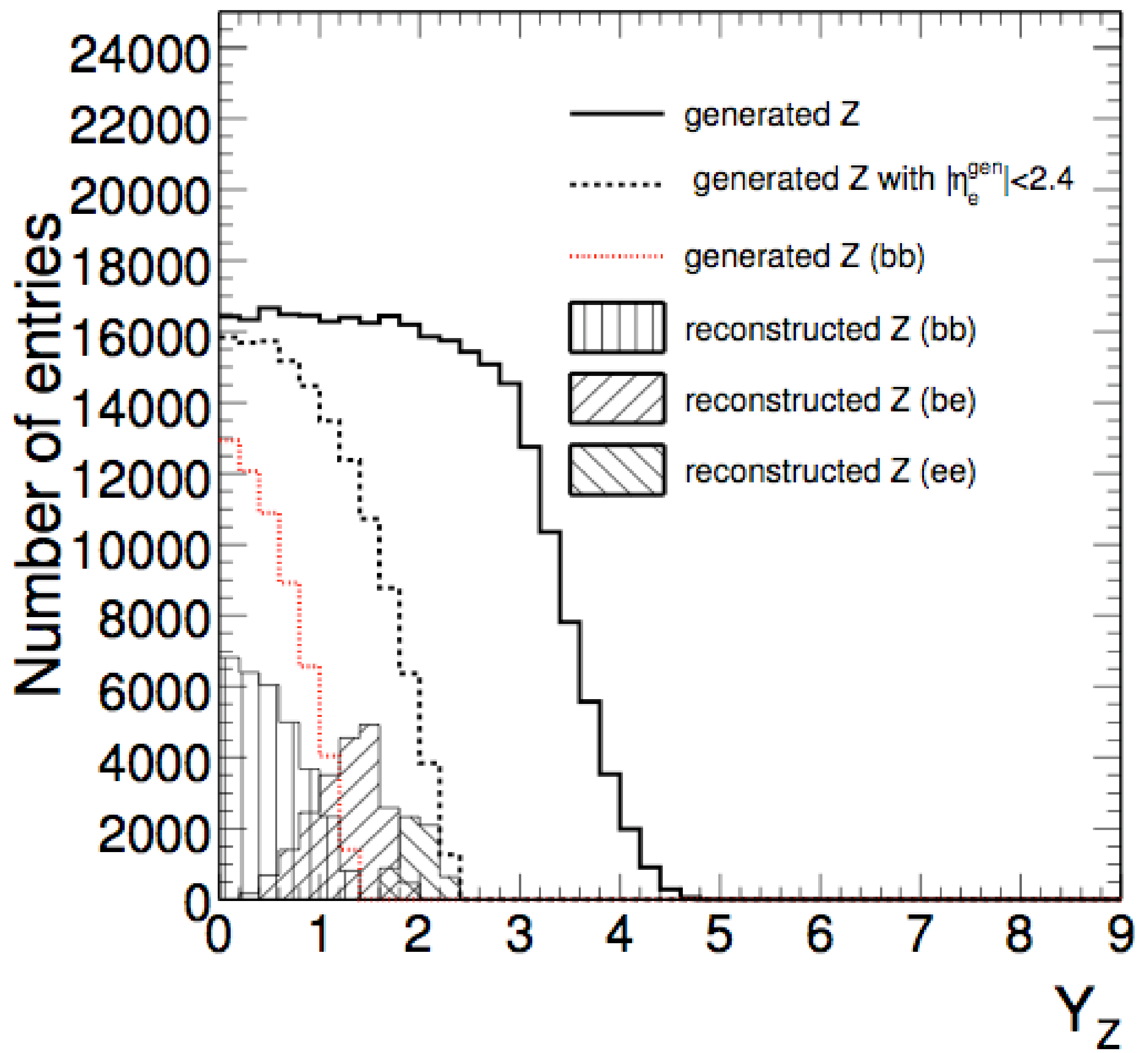
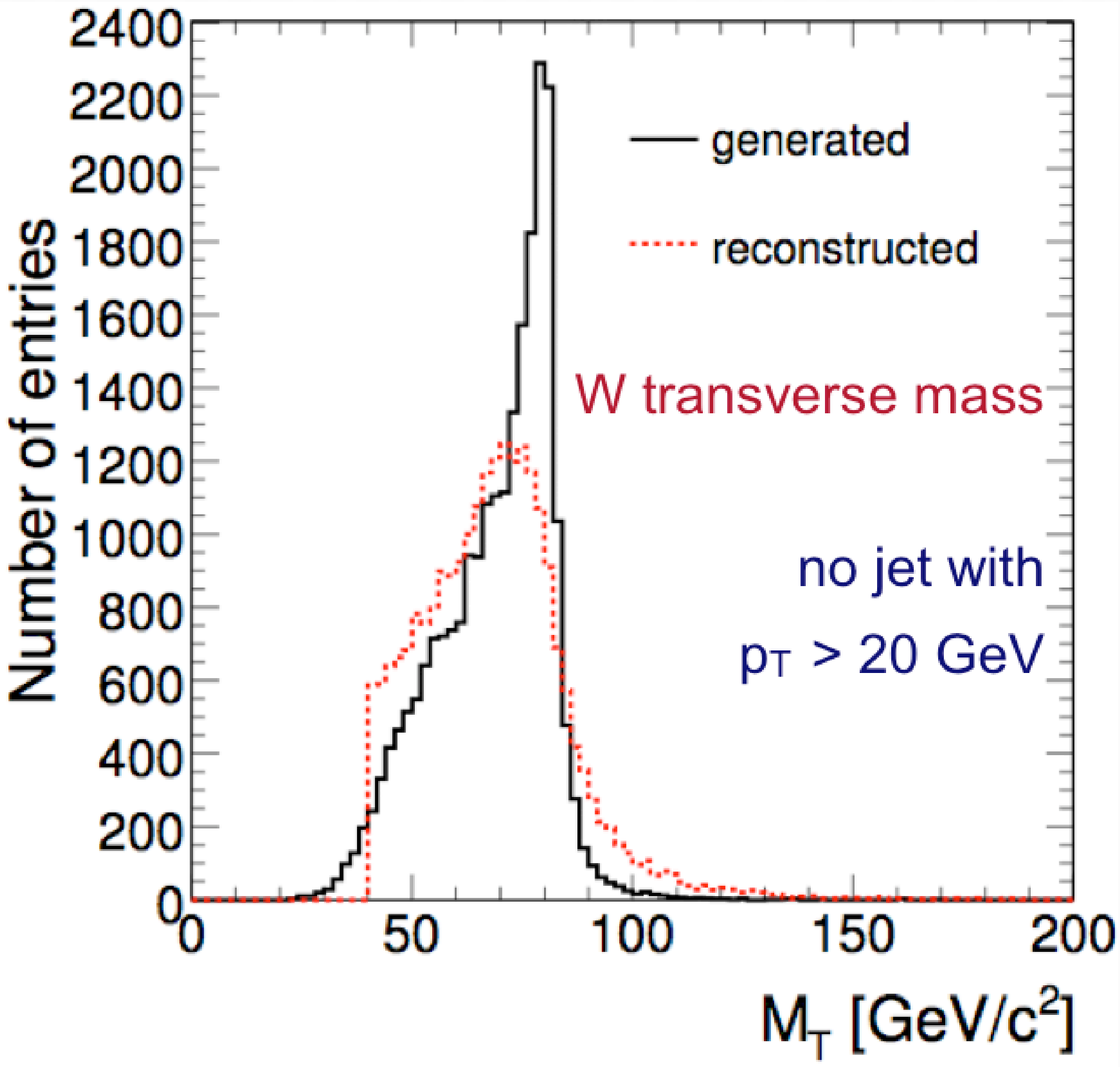
CMS PTDR, G.D., Dittmar, Ehlers, Holzner





Experimental Z counting precision of 1 - 2 % appears feasible, even after 1. year

Experimental Z/W counting



CMS PTDR

Experimental Z/W counting

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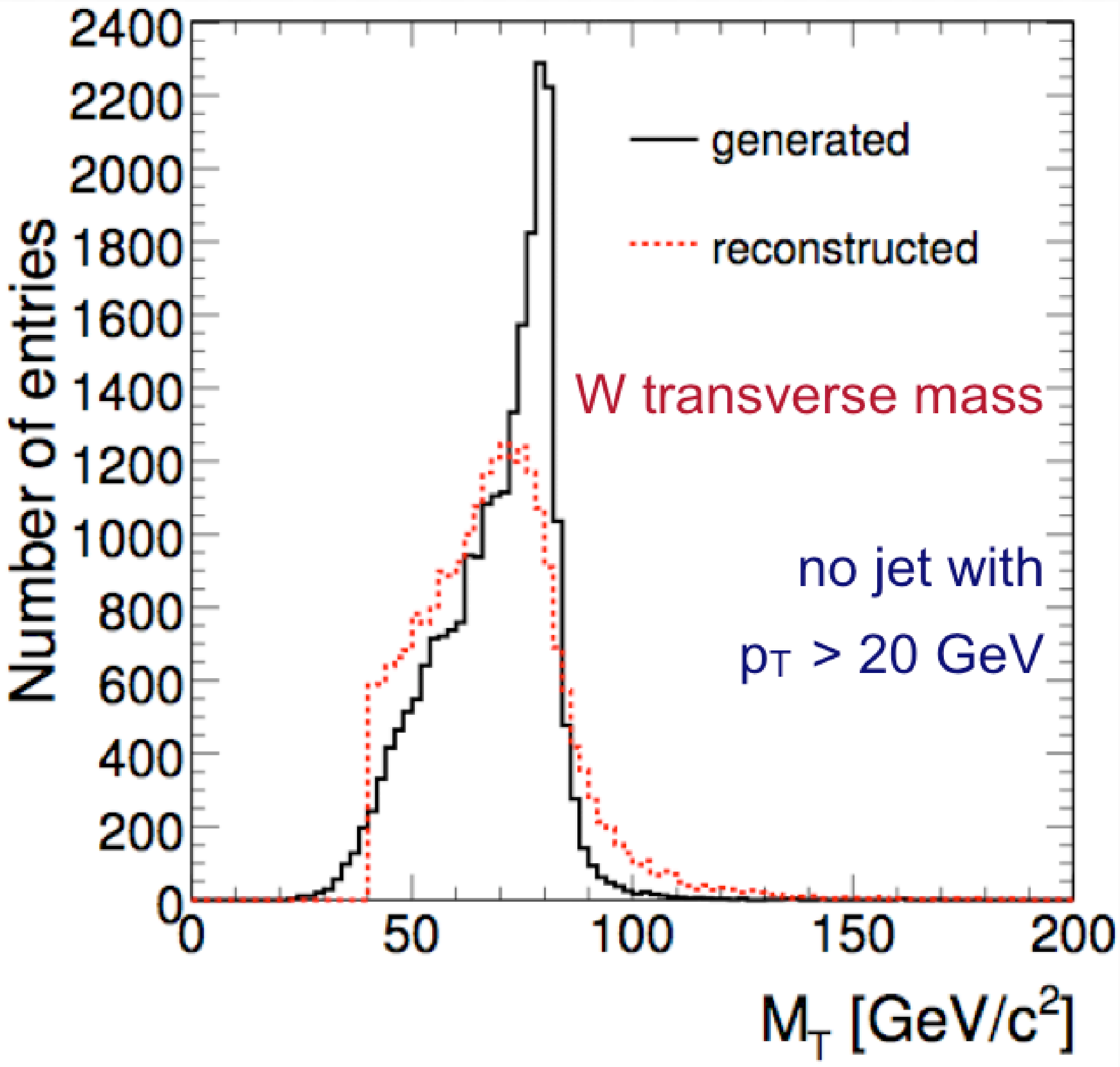

CMS PTDR

MET- resolution :

6 (12) GeV with (without) jet veto.

However :

jet veto → sensitive to resummation effects

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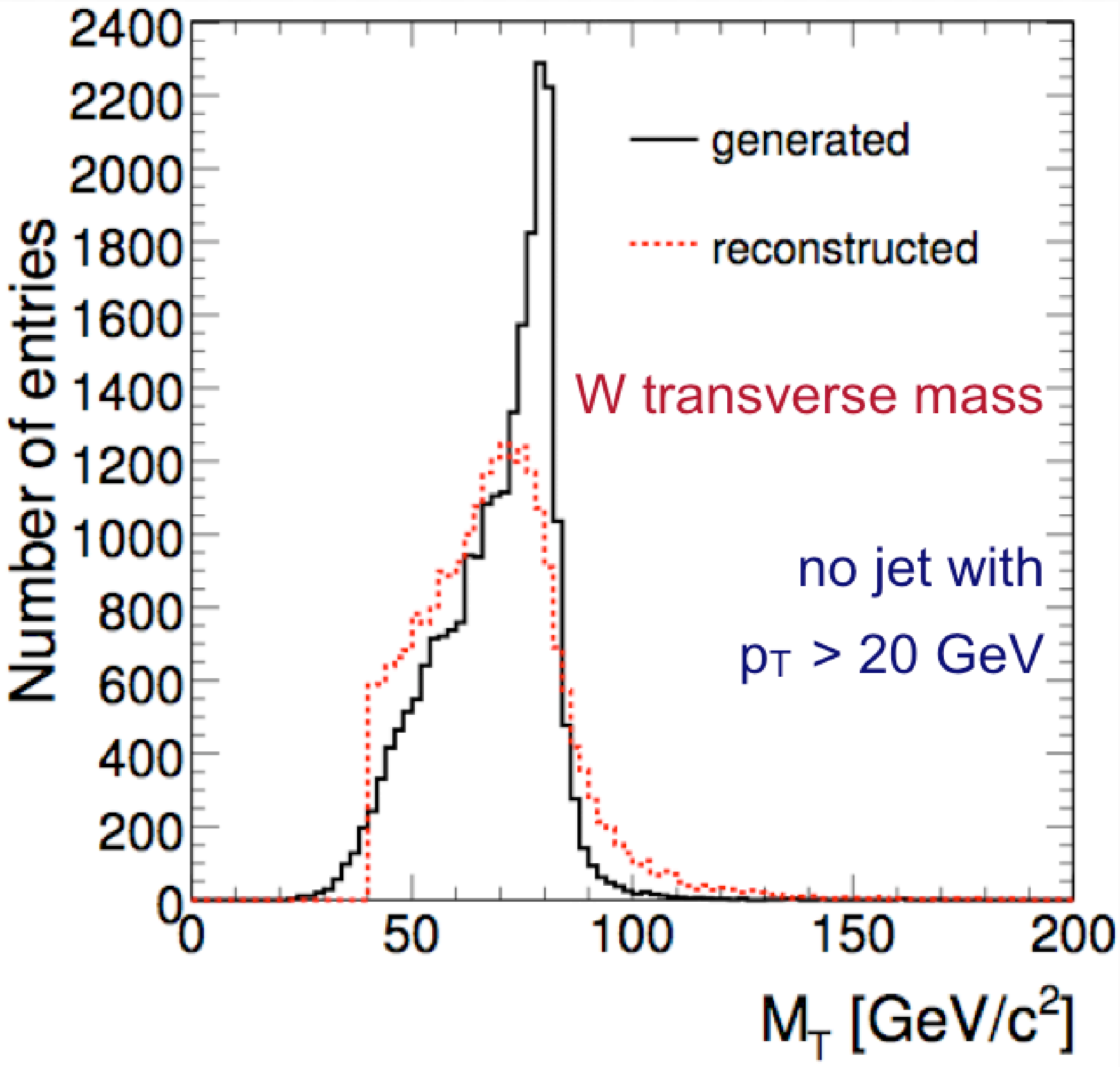

CMS PTDR

Inclusive W→μ ν analysis

Source	Uncertainty (%)
Tracker efficiency	0.5
Muon efficiency	1
Magnetic field knowledge	0.05
Tracker alignment	0.84
Trigger efficiency	1.0
Transverse missing energy	1.33
Pile-up effects	0.32
Underlying event	0.24
Total exp.	2.2

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W/Z and PDF constraints

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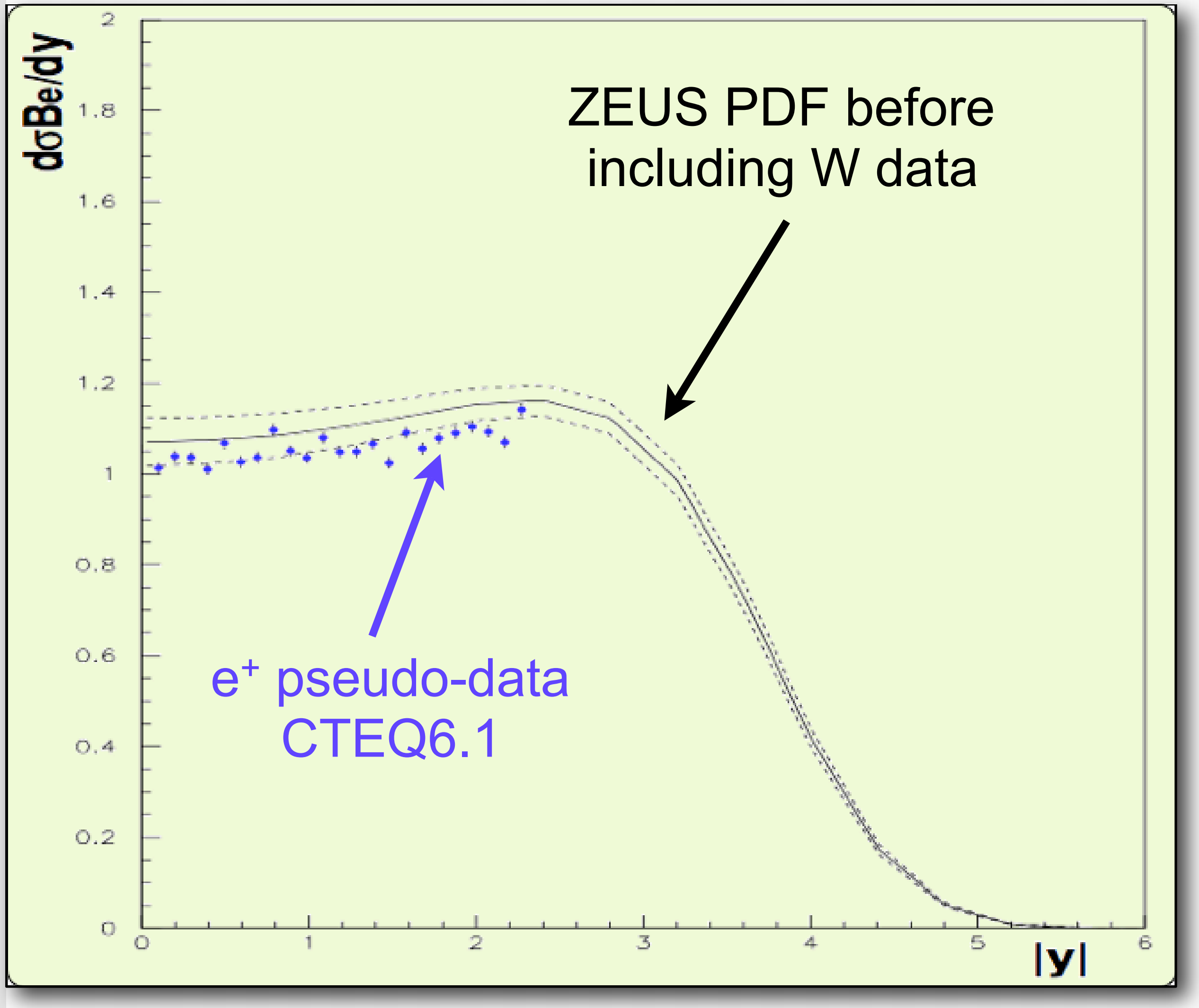

- Fast simulation study by ATLAS (HERA-LHC workshop, hep-ph/051119)
  - produce W sample with CTEQ6.1, using a random 4% error on “data”
  - correct back for detector acceptance, using ZEUS-PDFs and include these data into the ZEUS fit
  - Fit shows : error on parameter λ ($x\,g(x) \sim x^{-\lambda}$) reduced by 35 %

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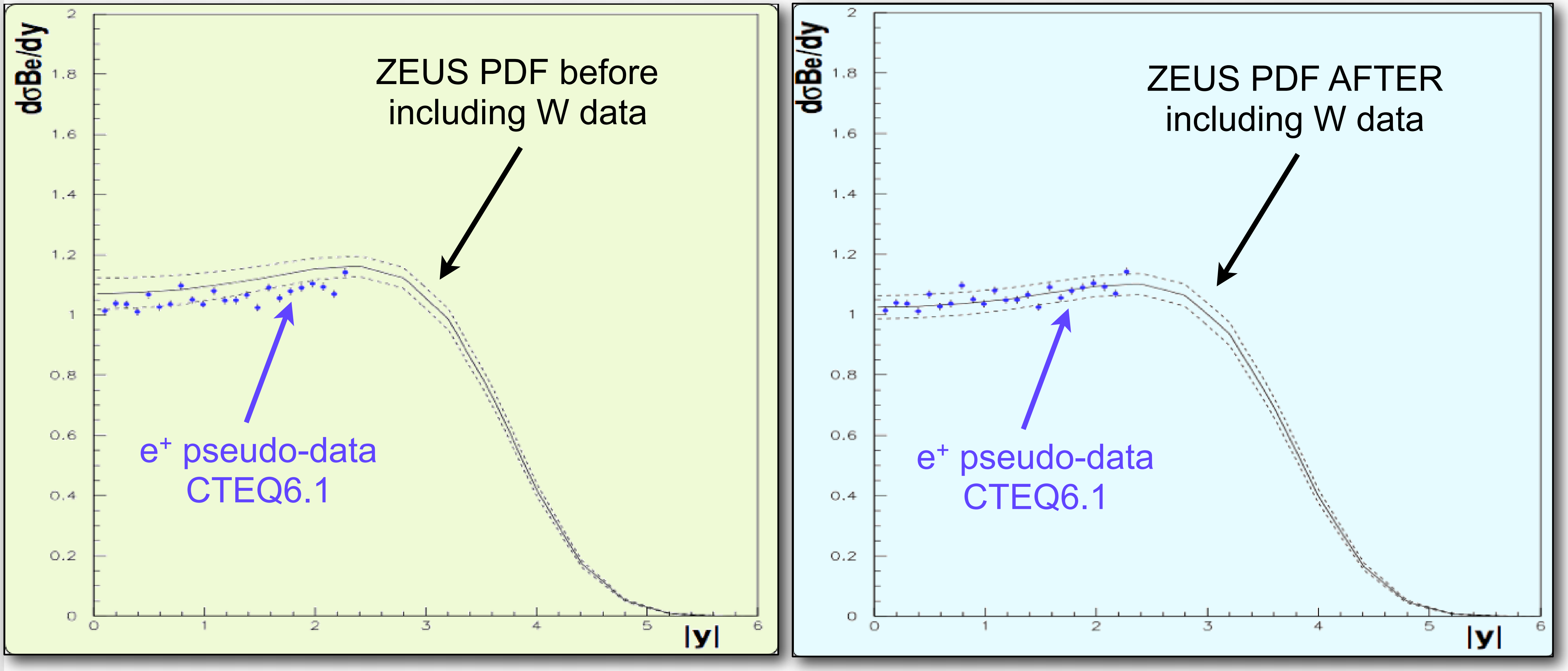

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W/Z + jets

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- Extremely important background for many searches

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- Remember : Jet scale uncertainty extremely important (xsec as function of jet p_T), also here
  - can expect some 30 % uncertainty from that. Probably less in case of rate measurements.

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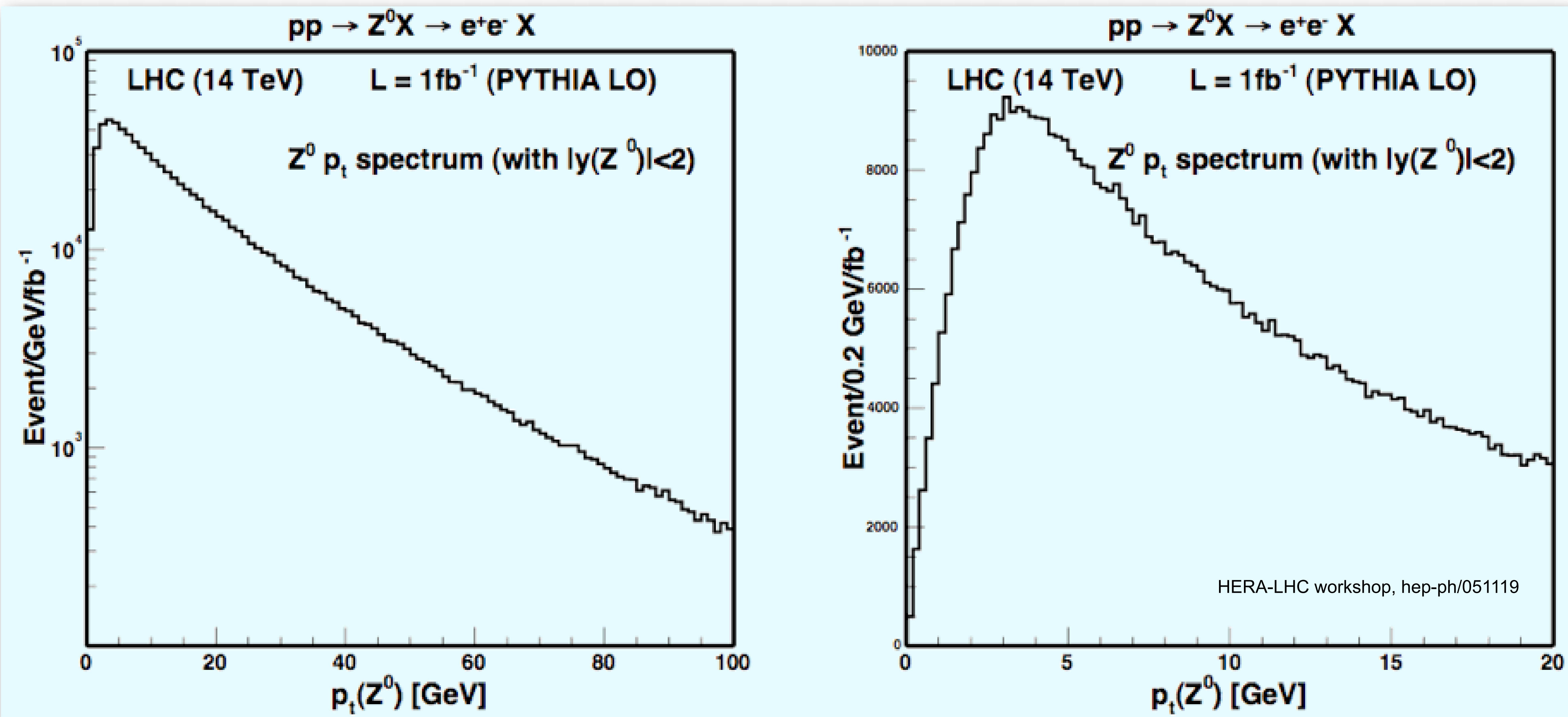
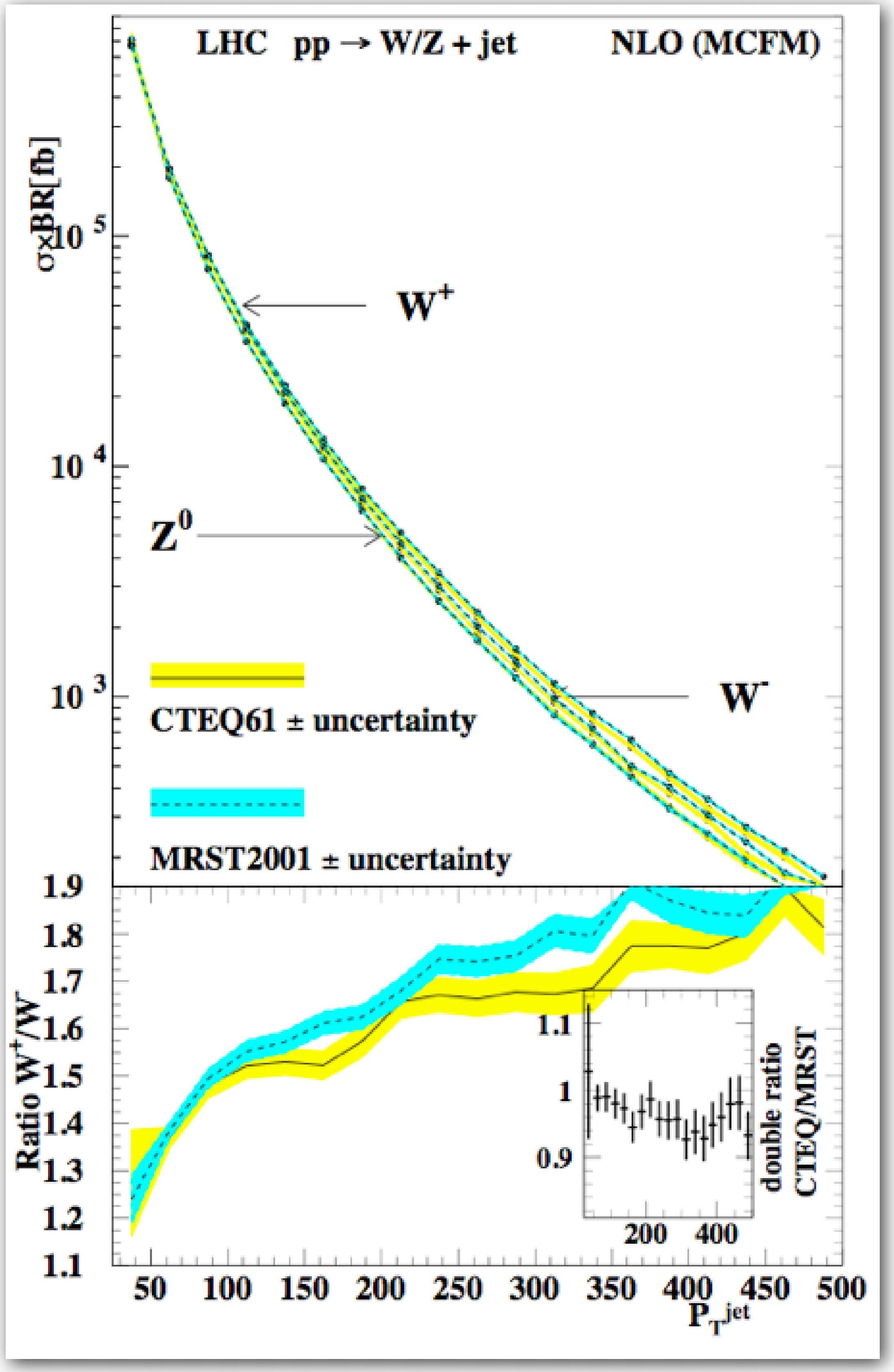
- Extremely important background for many searches
- Remember : Jet scale uncertainty extremely important (xsec as function of jet p_T), also here
  - can expect some 30 % uncertainty from that. Probably less in case of rate measurements.
- Should also have a more “inclusive” look at it : Measuring the Z p_T can be done with a relative precision at the per-cent level (leptons (!) again), will be invaluable for checking predictions and tuning MCs
  - “transport” to W case will induce slight additional uncertainty



W/Z + jets : Ratios

- Look at “clever” ratio, where some uncertainties cancel...

HERA-LHC workshop, hep-ph/051119



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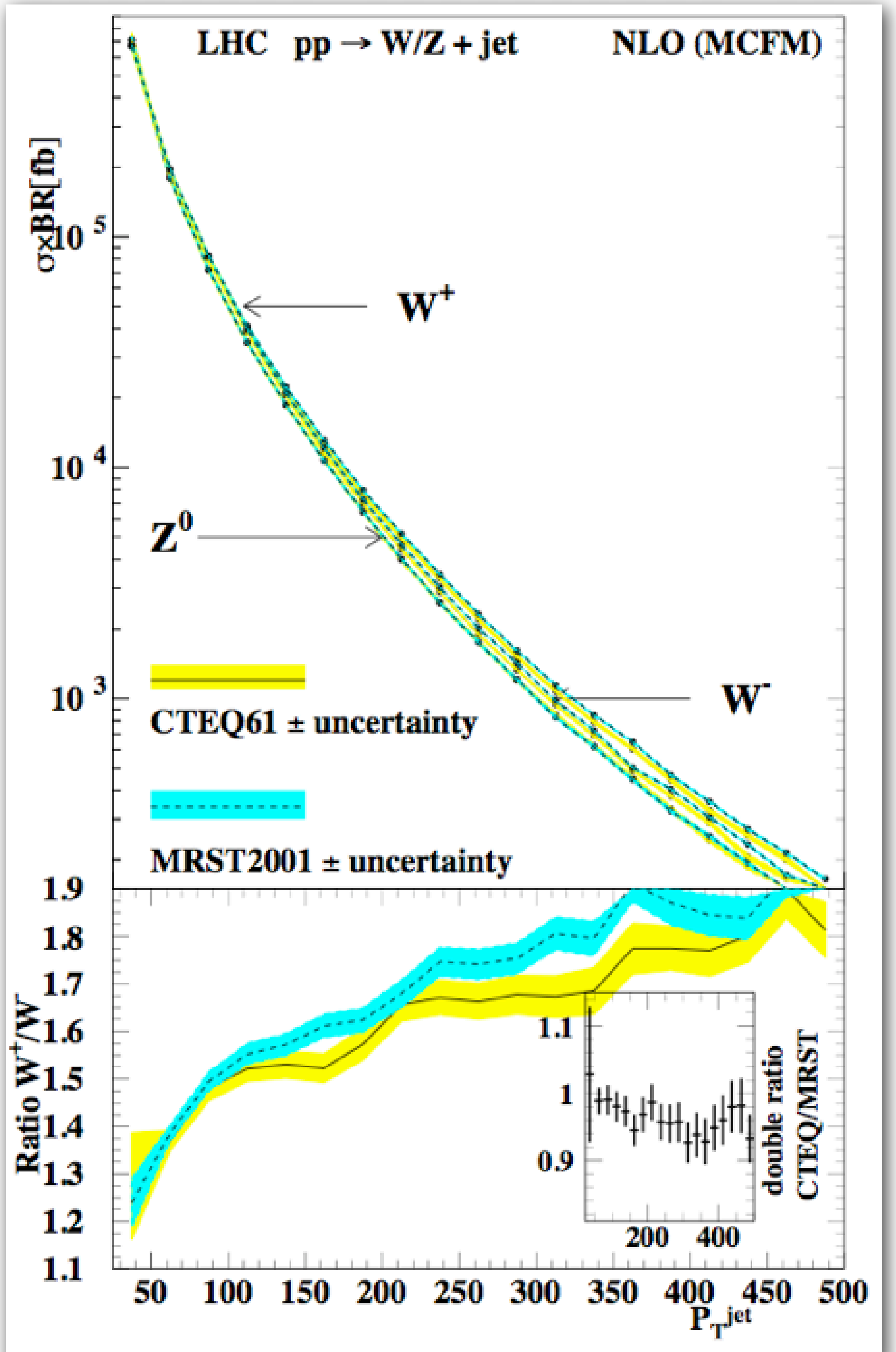

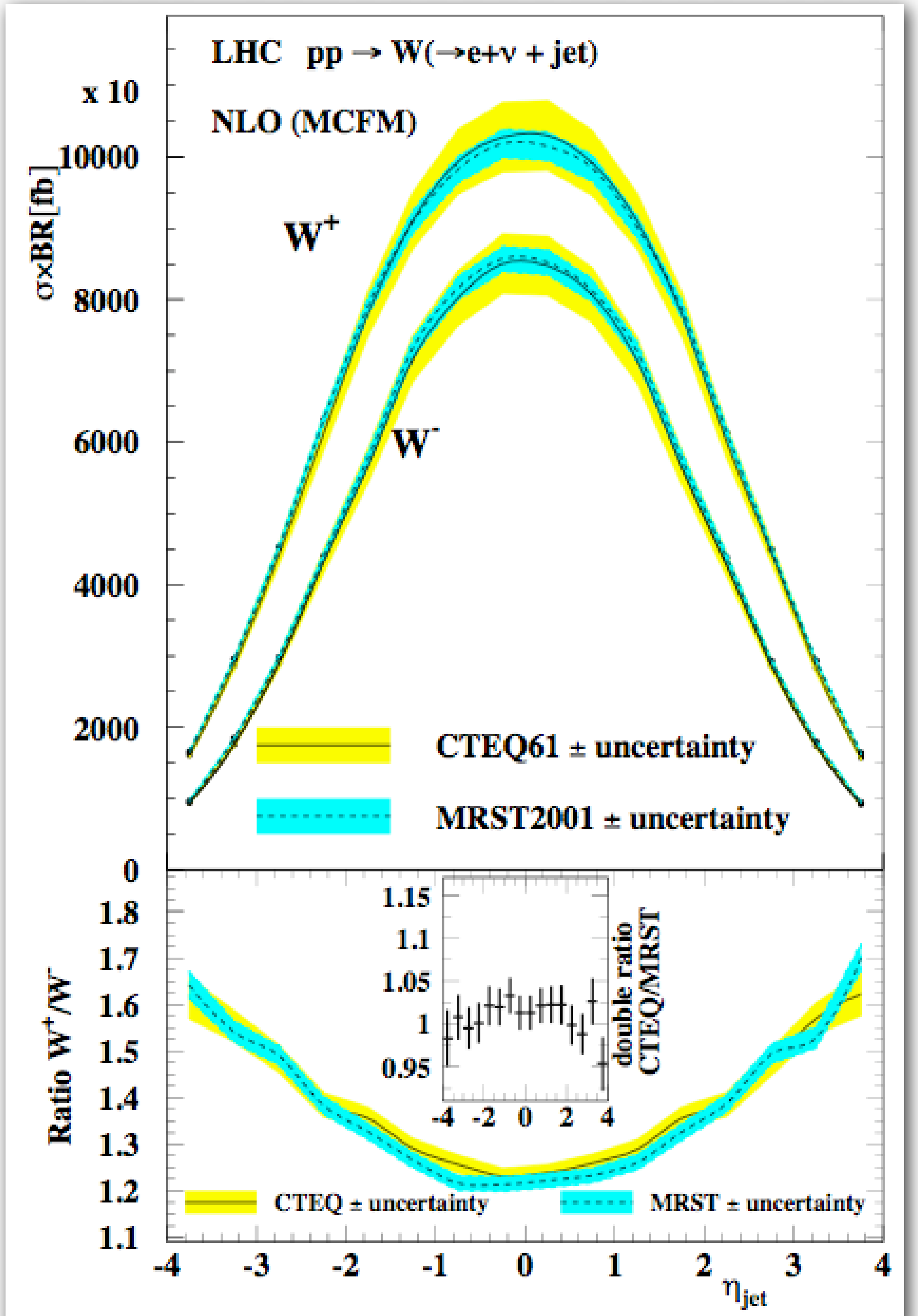

Diboson production

Dibosons

- WW, WZ, ZZ, Wγ
- expect clean event samples,
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  - suppressed with strong lepton isolation and **jet veto !**

reaction $pp \to X$	K	K (Jet veto)	K (P_t(jet) 150–400 GeV)
$pp \to W^+W^- \to \ell\nu\ell\nu$	1.5	1.3	67(!)
$pp \to W^\pm Z \to \ell\nu\ell\ell$	1.9	1.4	30(!)
$pp \to ZZ \to \ell\ell\ell\ell$	1.4	1.4	6(!)

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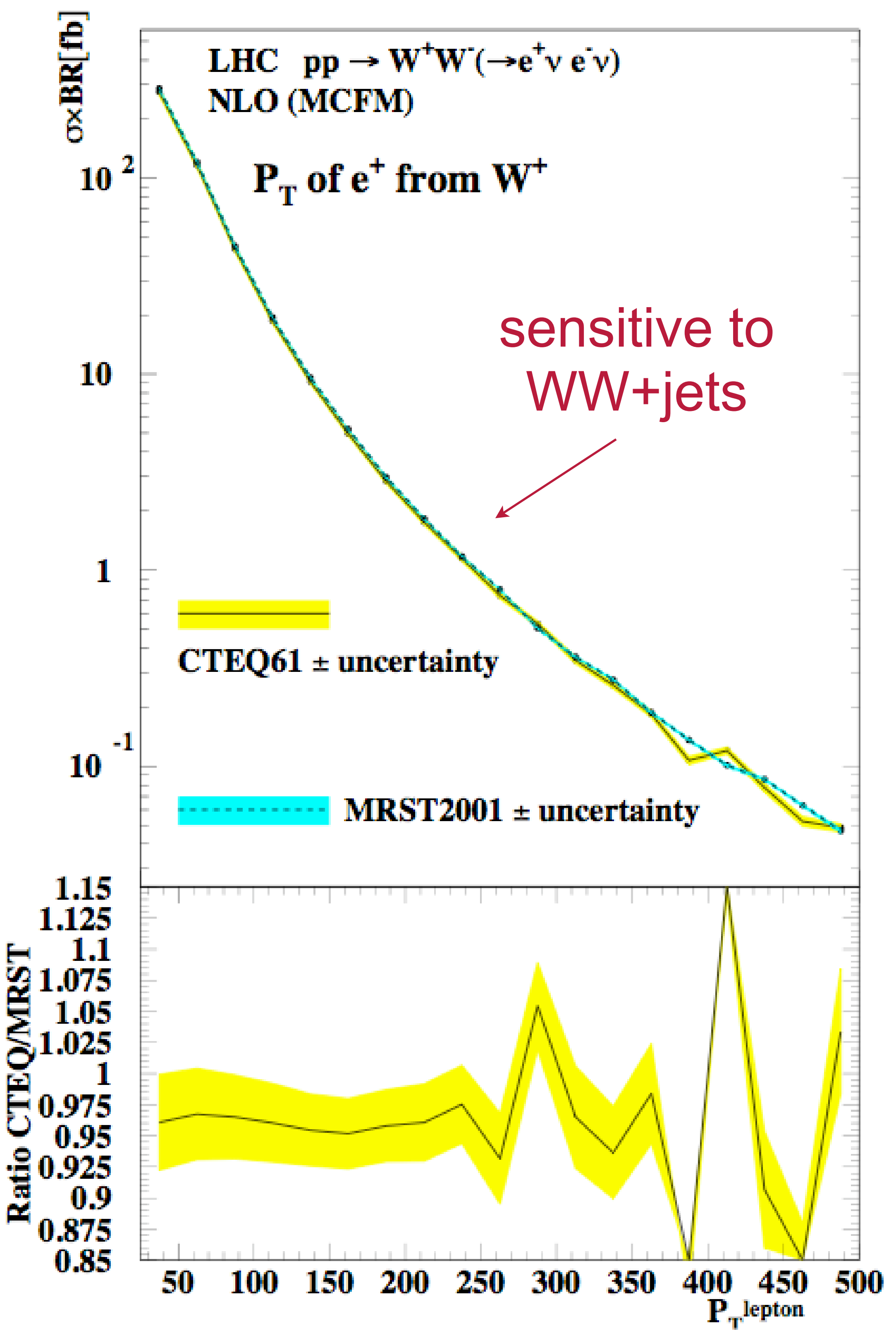
- Systematic uncertainties (for 1 fb^{-1}, CMS PTDR) : ~10 -15 %
  - excluding the lumi. uncertainty

Dibosons : Observables...

- look at lepton p_T (well measured) and ratios!



Dibosons : Observables...

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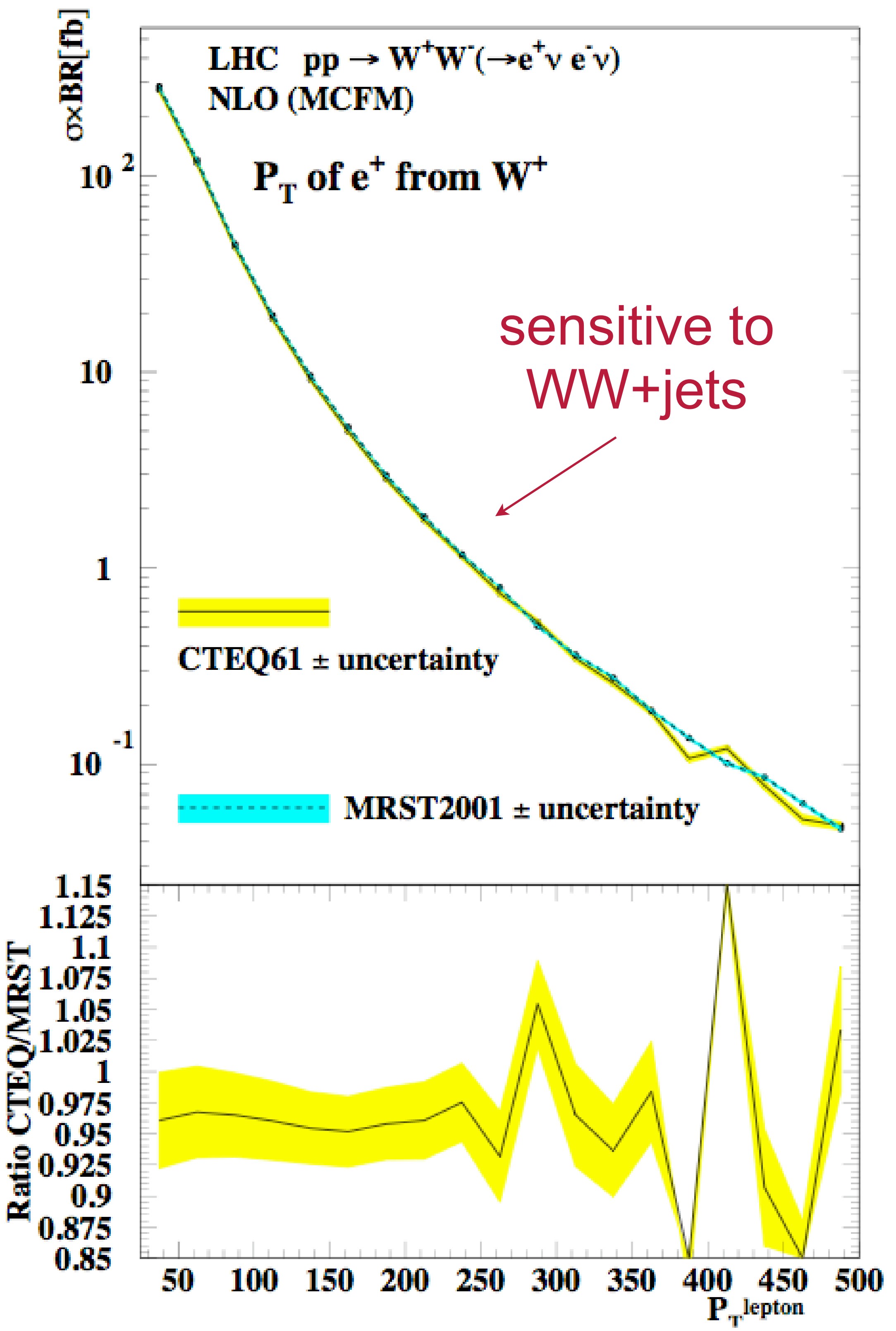
Dittmar, Pauss, Zürcher

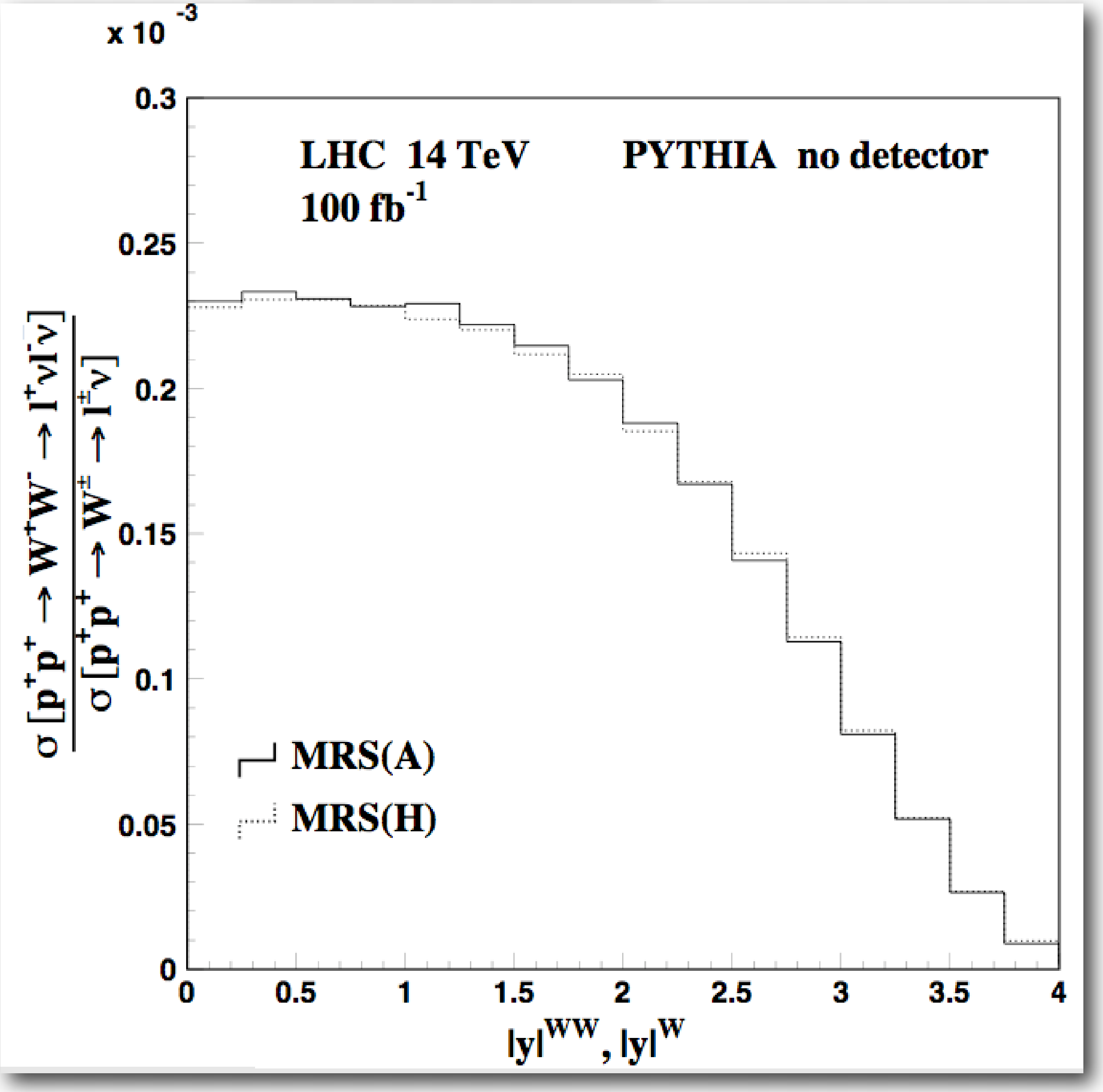
$$N_{pp\to WW} = N_{pp\to Z} \cdot \frac{\sigma_{q,\bar{q}\to WW}}{\sigma_{q,\bar{q}\to Z}} \cdot \frac{PDF(x_1', x_2', Q'^2)}{PDF(x_1, x_2, Q^2)}$$

$\Delta L_{pp} = 0!$

Normalization process



sensitive to WW+jets



Top (and bottom) production

Top Production (example : semi-leptonic case)

See the top immediately
with simple selection :
Missing E_T, 1 lepton, ≥4 jets ,
NO b-tag (!),
cut on hadronic W mass

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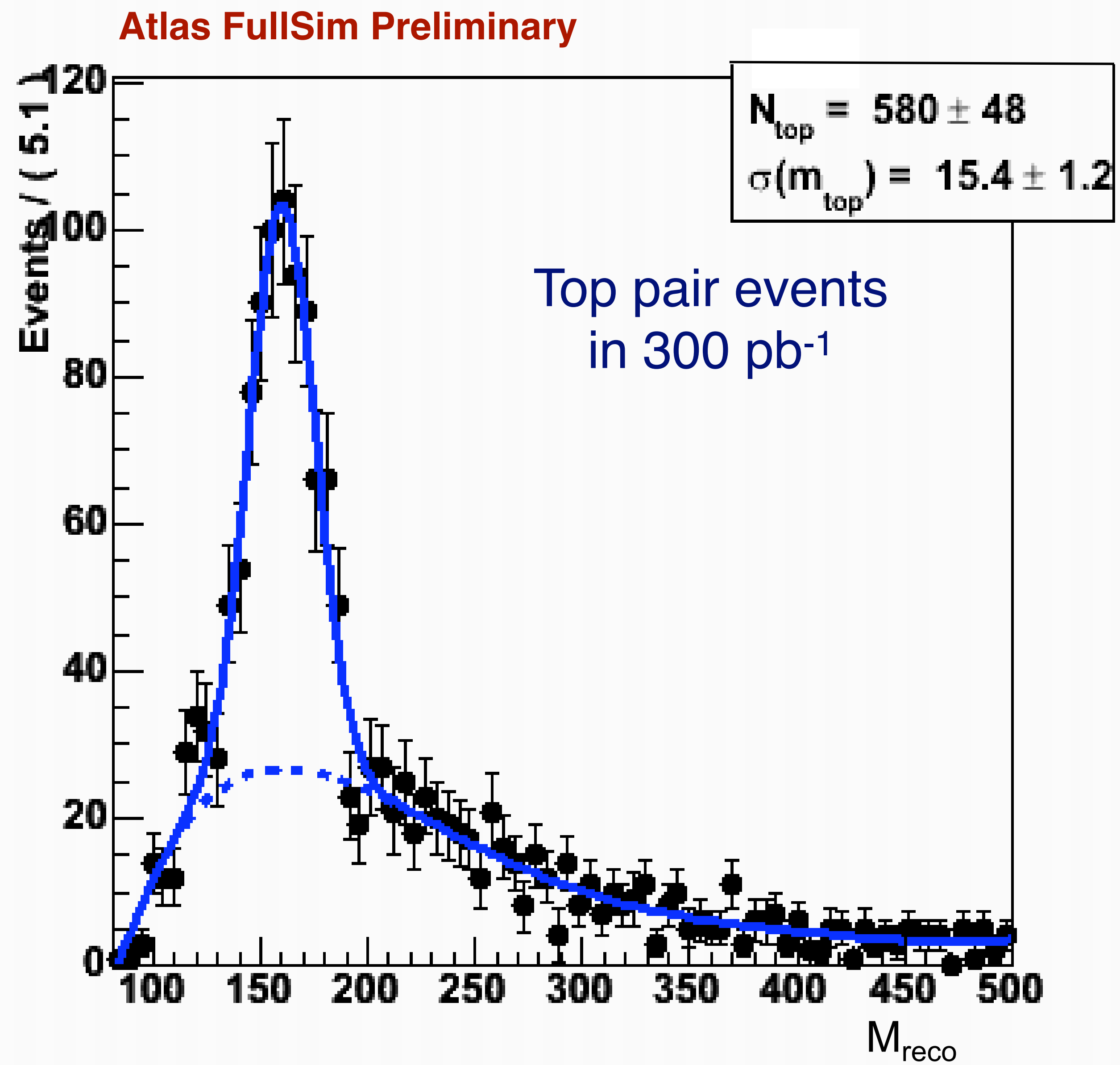

Study the top quark properties
mass, charge, spin, couplings, production and decay,
ΔM_{top} ~ 1 GeV ?

important background for searches

Jet energy scale from W→jet jet,

commission b-tagging

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See the top immediately
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Missing E_T, 1 lepton, ≥4 jets ,
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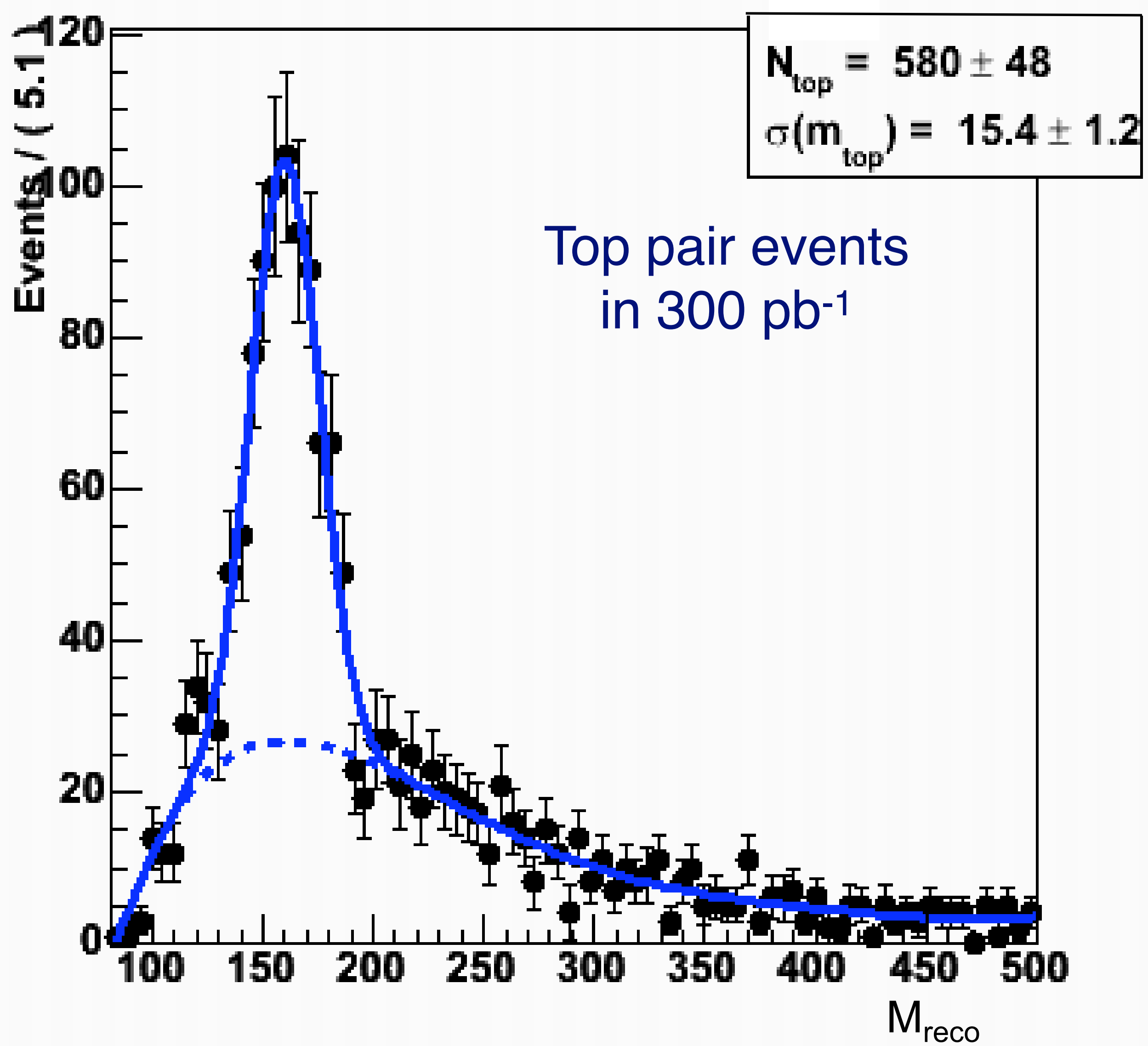
Once b-tagging is understood:
Very high S/B achievable ~ 27 !

Backgrounds :
W+4j, Wbb+2j(3j) (minor here)

relevant also for single-top

Atlas FullSim Preliminary



Top pair events
in 300 pb^{-1}

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	$\Delta\hat{\sigma}_{t\bar{t}(\mu)}/\hat{\sigma}_{t\bar{t}(\mu)}$		
	$1\,\mathrm{fb}^{-1}$	$5\,\mathrm{fb}^{-1}$	$10\,\mathrm{fb}^{-1}$
Simulation samples (ϵ_{sim})	0.6%		
Simulation samples (F_{sim})	0.2%		
Pile-Up (30% On-Off)	3.2%		
Underlying Event	0.8%		
Jet Energy Scale (light quarks) (2%)	1.6%		
Jet Energy Scale (heavy quarks) (2%)	1.6%		
Radiation (Λ_{QCD}, Q_0^2)	2.6%		
Fragmentation (Lund b, σ_q)	1.0%		
b-tagging (5%)	7.0%		
Parton Density Functions	3.4%		
Background level	0.9%		
Integrated luminosity	10%	5%	3%
Statistical Uncertainty	1.2%	0.6%	0.4%
Total Systematic Uncertainty	13.6%	10.5%	9.7%
Total Uncertainty	13.7%	10.5%	9.7%

CMS PTDR

Top Production (example : semi-leptonic case)

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	$\Delta\hat{\sigma}_{t\bar{t}(\mu)}/\hat{\sigma}_{t\bar{t}(\mu)}$ 1 fb^{-1}	5 fb^{-1}	10 fb^{-1}
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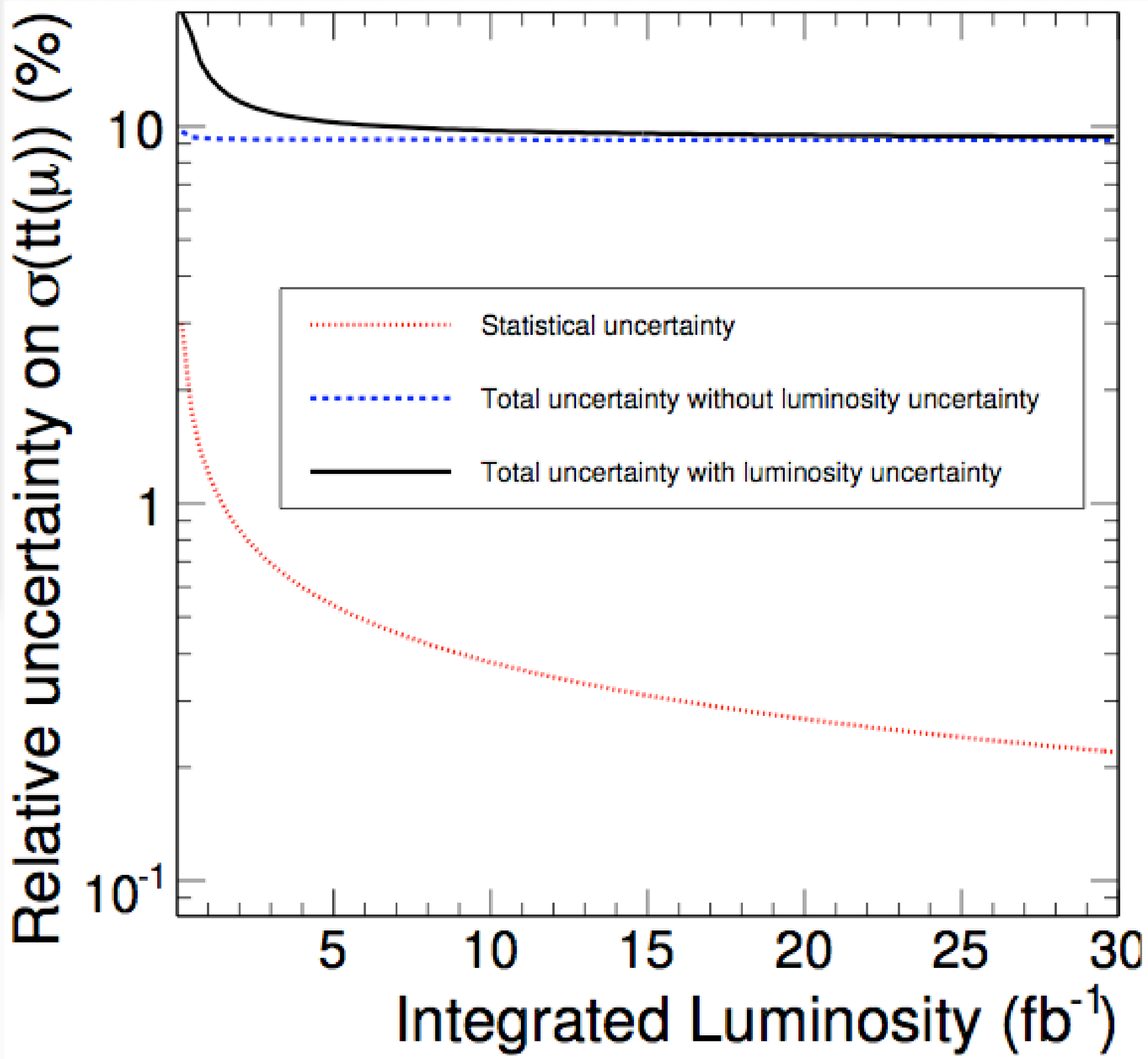

b-jet production

CMS PTDR

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- b-jets (jets with B-Hadrons) with p_T > 50 GeV and $|\eta| < 2.4$
- triggered on muon from B-decay + b-tag (secondary vertex tag)
- b-tag eff. ~ 65% in barrel; b-purity 55% - 70 %

Source	uncertainty, %
jet energy scale	12
event selection	6
B tagging	5
luminosity	5
trigger	3
muon Br	2.6
misalignment	2
muon efficiency	1
$t\bar{t}$ background	0.7
fragmentation	9
total	18

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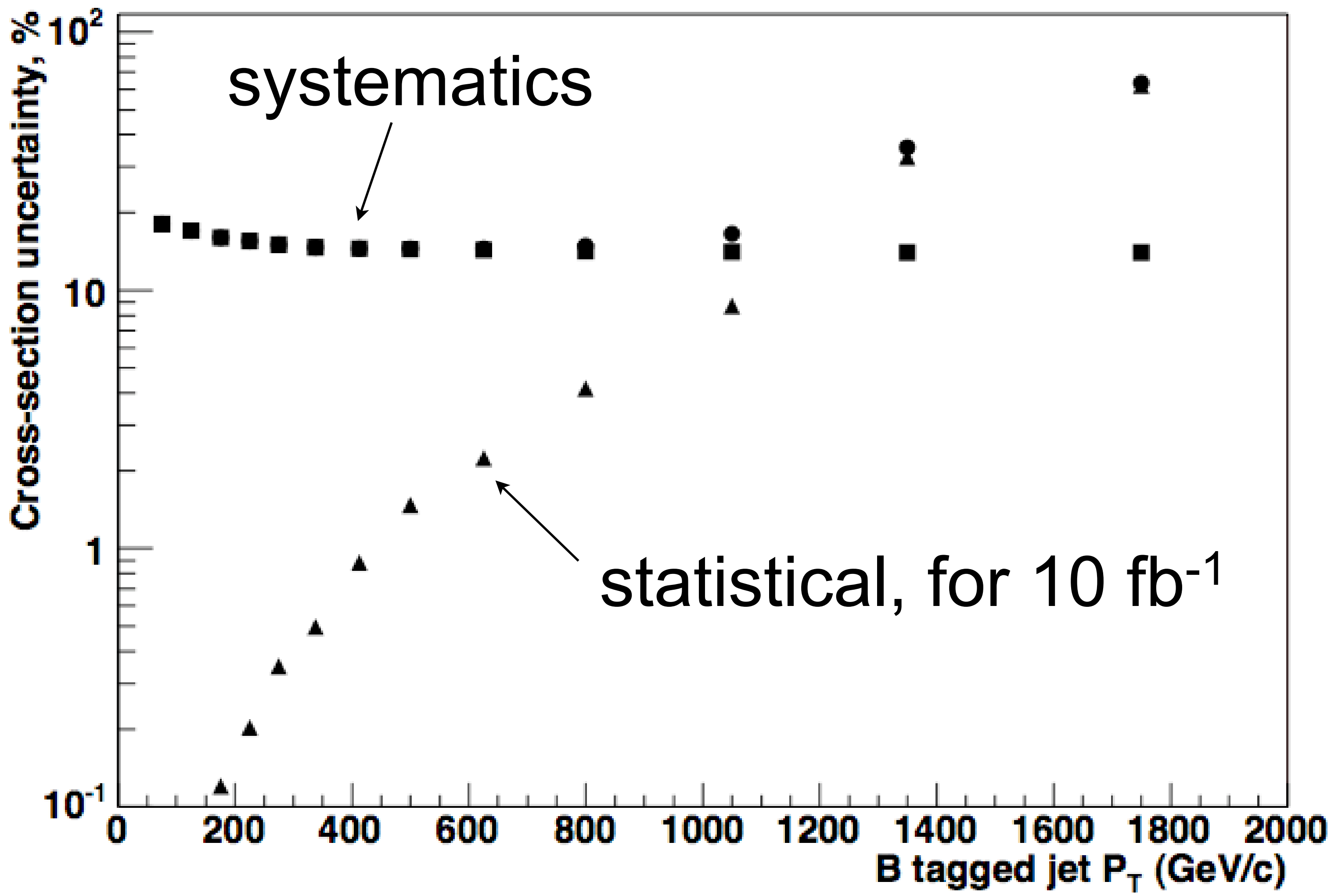

Other issues

Background extrapolation

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Backgrounds to H→WW →$\ell\nu\ell\nu$: WW, $t\bar{t}$ for gluon fusion, $t\bar{t}j$ for qqH

Background extrapolation

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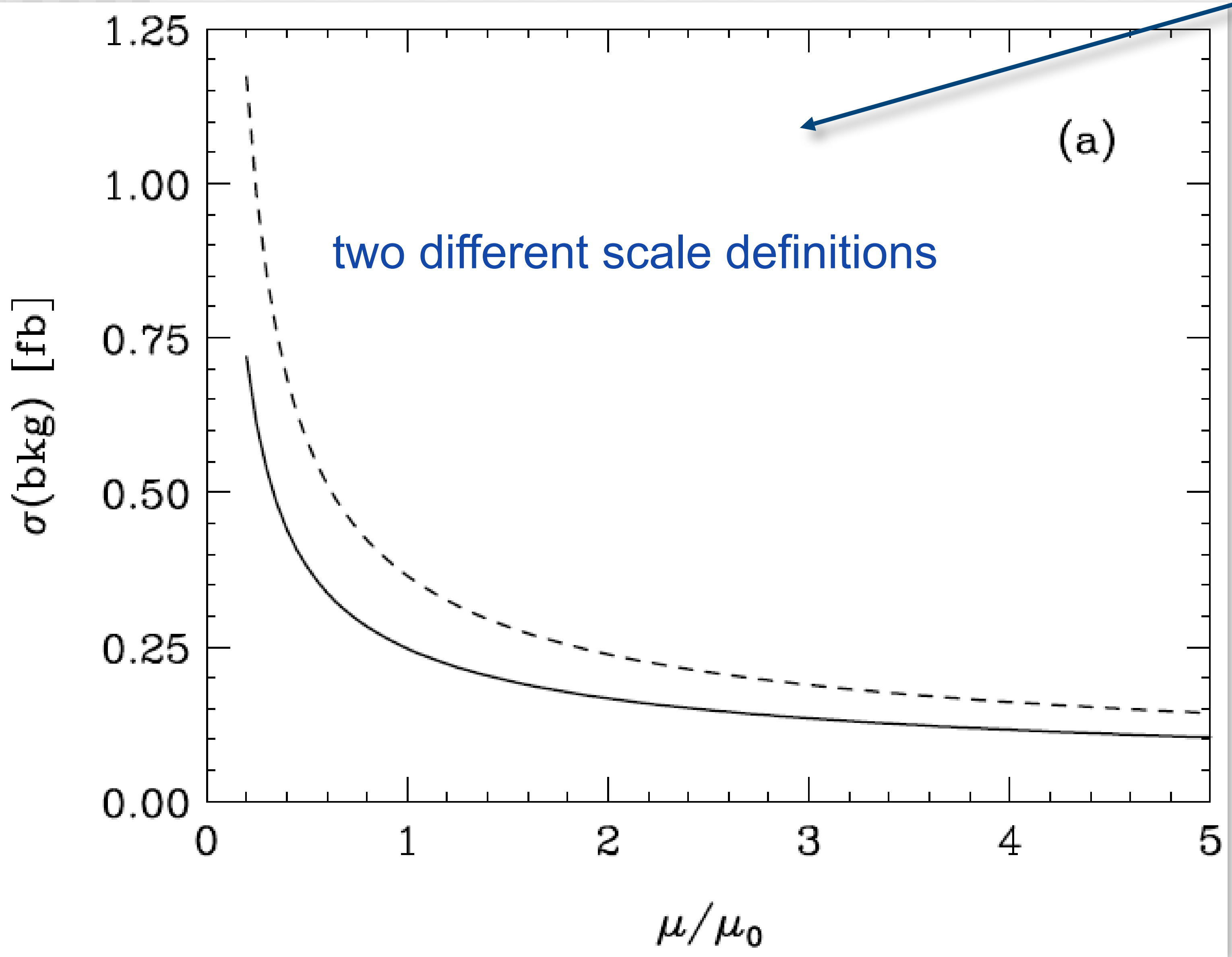
Backgrounds to $H \to WW \to \ell\nu\ell\nu$: WW, $t\bar{t}$ for gluon fusion, $t\bar{t}j$ for qqH



40-50% scale uncertainty at LO

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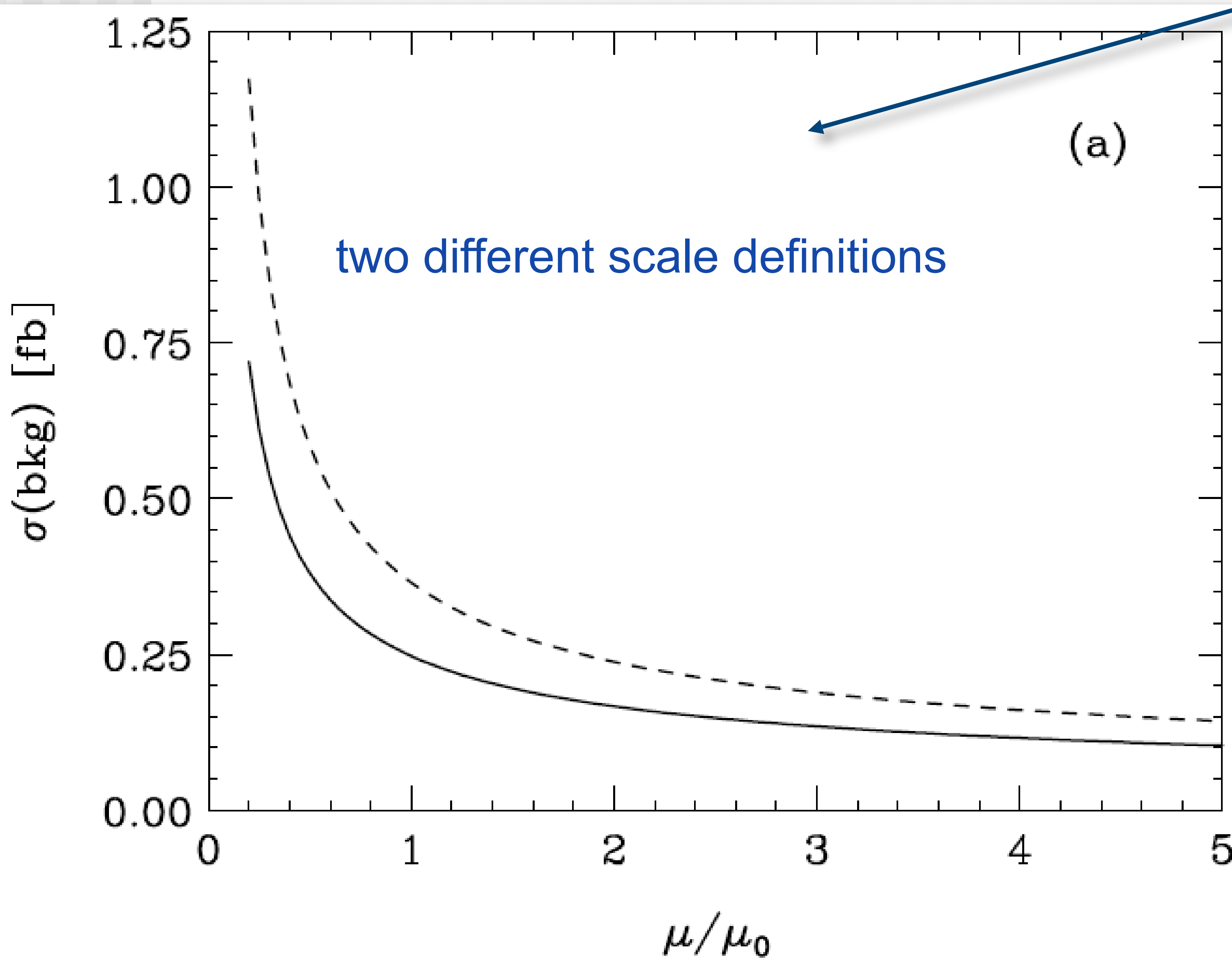

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Idea of extrapolation:

Kauer et al.

$$\sigma_{bkg} \approx \underbrace{\left(\frac{\sigma_{bkg,\,\mathrm{LO}}}{\sigma_{ref,\,\mathrm{LO}}}\right)}_{\text{low theoret. uncertainty}} \cdot \underbrace{\sigma_{ref}}_{\text{low experim. uncertainty}}$$

$\sigma_{\mathbf{bkg}}$: background with cuts optimized for finding signal

$\sigma_{\mathbf{ref}}$: background with cuts to enrich background (eg. revert the cuts above)

Background extrapolation...

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Reference selection :

- like signal, but
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- no lepton pair cuts
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Background extrapolation...

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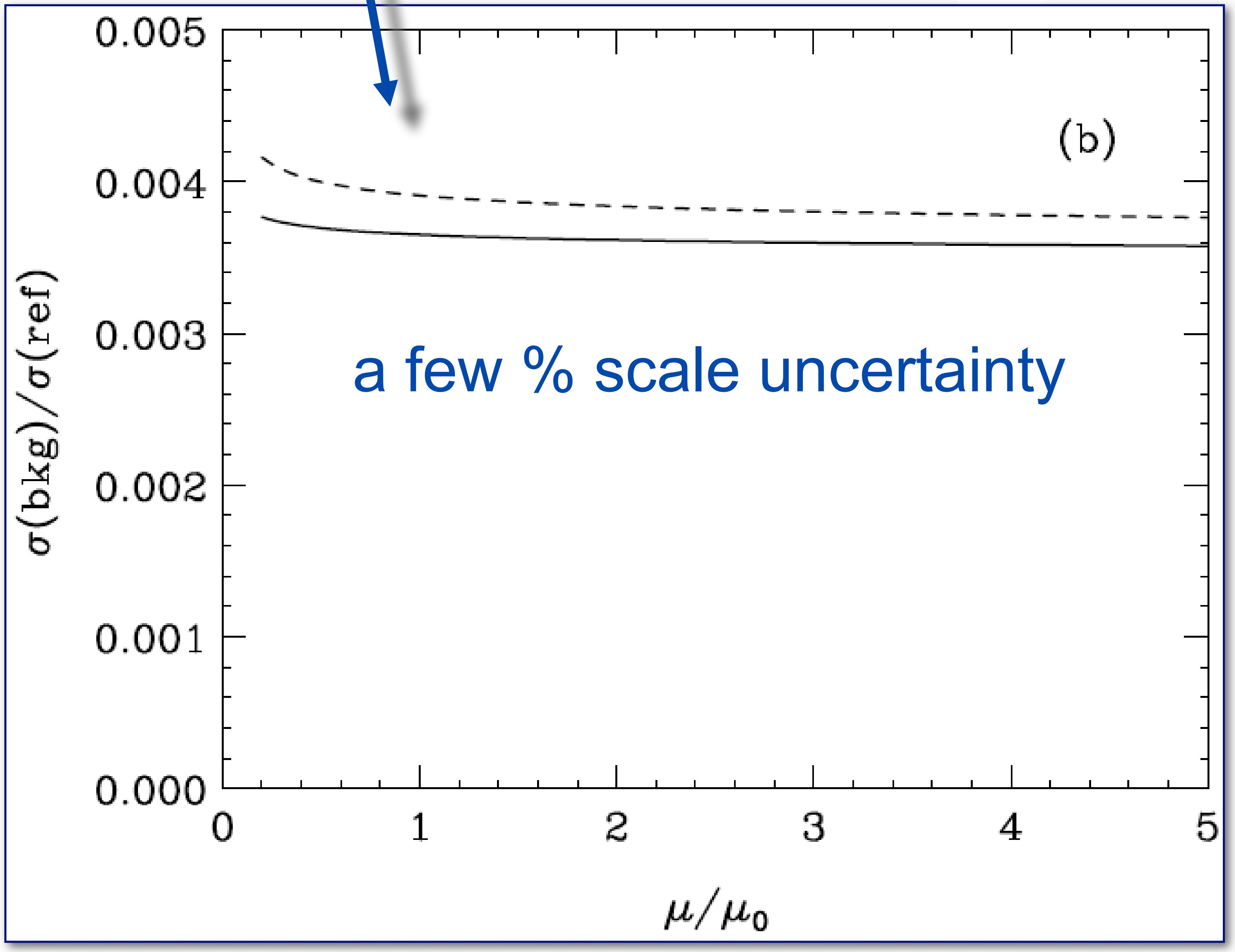

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The CMS study

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$$N_{signal_{reg}} = \frac{N^{MC}_{signal_{reg}}}{N^{MC}_{control_{reg}}} N_{control_{reg}} = \frac{\sigma^{MC}_{signal_{reg}}}{\sigma^{MC}_{control_{reg}}} \frac{\varepsilon^{MC}_{signal_{reg}}}{\varepsilon^{MC}_{control_{reg}}} N_{control_{reg}}$$

Has been studied in detail in CMS
Davatz, Giolo-Nicollerat, Zanetti

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	Theor. Error	Detector systematics			Stat. Error	Total Error
		JES	α crit.	b-tagging		
(L = 1 fb^{-1})	10 %	10 %	4 %	11 %	24 %	30 %
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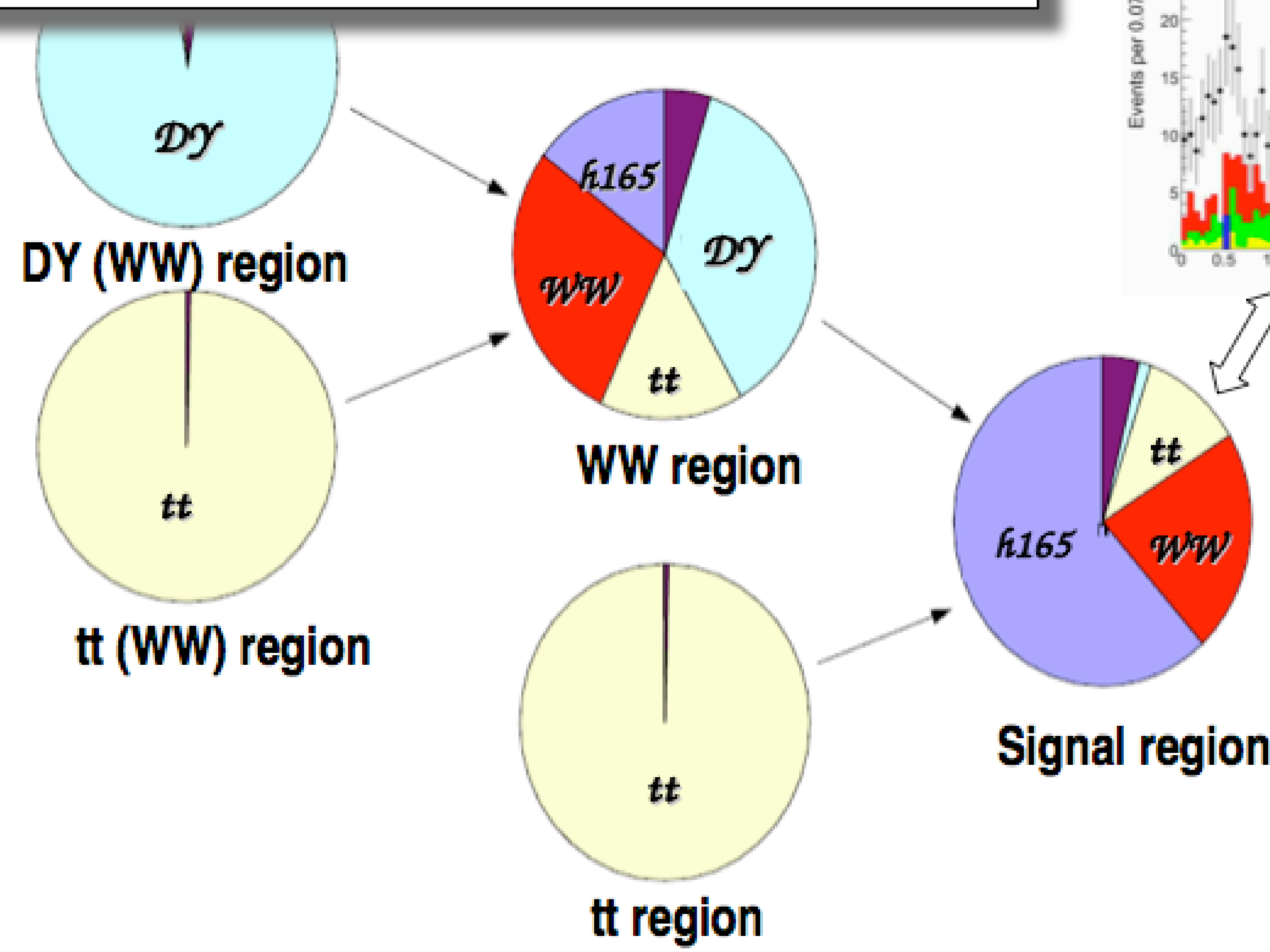

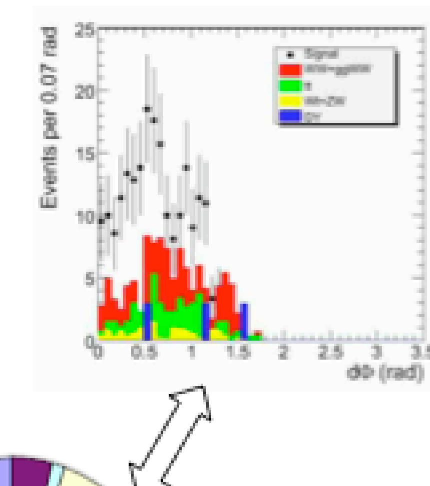

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Getting things from data

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- **Calibrations**
  - **Electromagnetic calorimetry**
    - $Z \rightarrow ee$, $W \rightarrow e\nu$, Minimum-bias
  - **Hadronic calorimetry and jets**
    - Di-jet balance, $Z (\rightarrow ll) +1j$, $W \rightarrow jj$ in tt events, photon + jet
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    - $Z (\rightarrow ll)$ +jets, then remove leptonic information
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- **Important kinematic properties**
  - W + n jets, p_t of W : take Z ($\rightarrow$ ll) + n jets
  - Use bbZ ($\rightarrow$ ll) as benchmark for bbA

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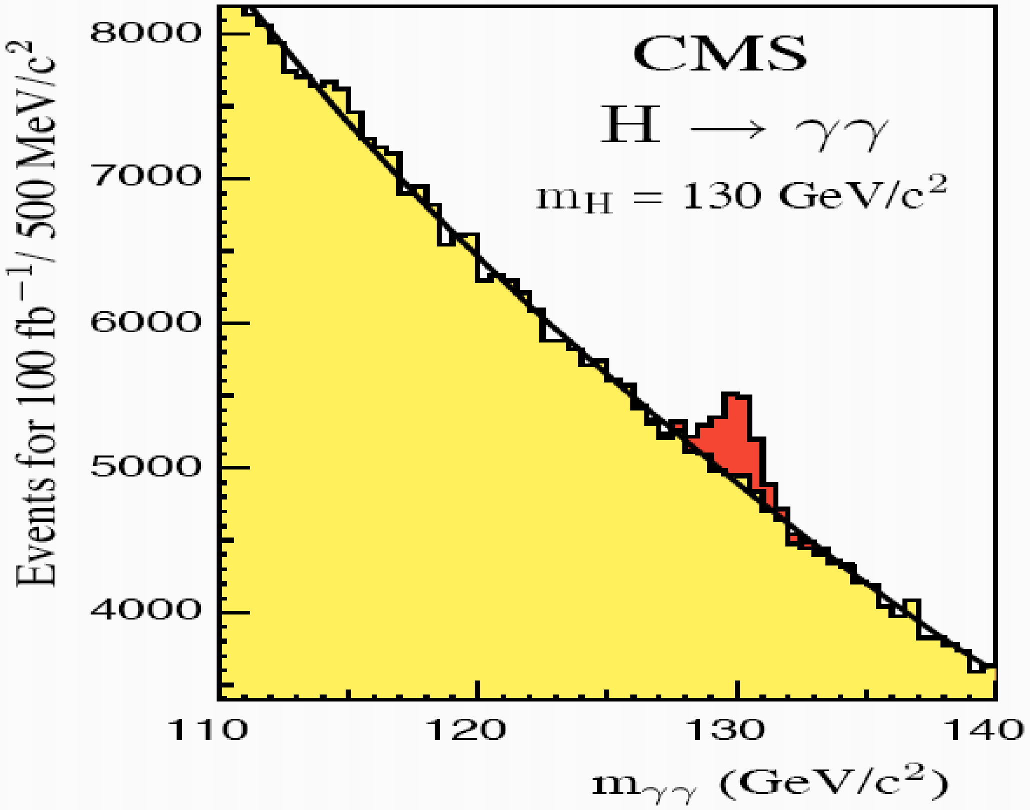
    - b-tag : use ttbar events to commission



- **Important kinematic properties**
  - W + n jets, p_t of W : take Z ($\rightarrow$ ll) + n jets
  - Use bbZ ($\rightarrow$ ll) as benchmark for bbA
- **Backgrounds**
  - Sidebands, or
  - normalize background via background-enhancing selection, use theory to extrapolate to signal-enhancing selection

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  - Resummation important, e.g. in context with jet vetos
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  - NNLO, fully differential
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- Other interesting processes
  - Jet + photon/Z : gluon pdf
  - Excellent understanding of incl. jet and di-jet prod.

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ETH Institute for Particle Physics

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Thanks for the invitation!