

Plan

La détection au Cern

Comme partout sur la planète

Mesures au LHC

Idée → mesure
traitement des données

Introduction

LHC

Mesures

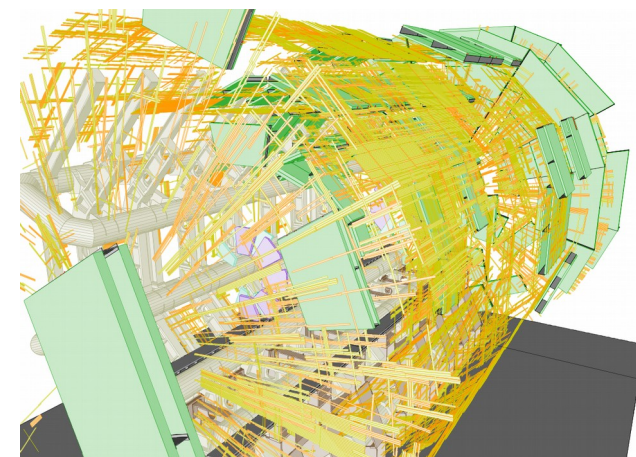
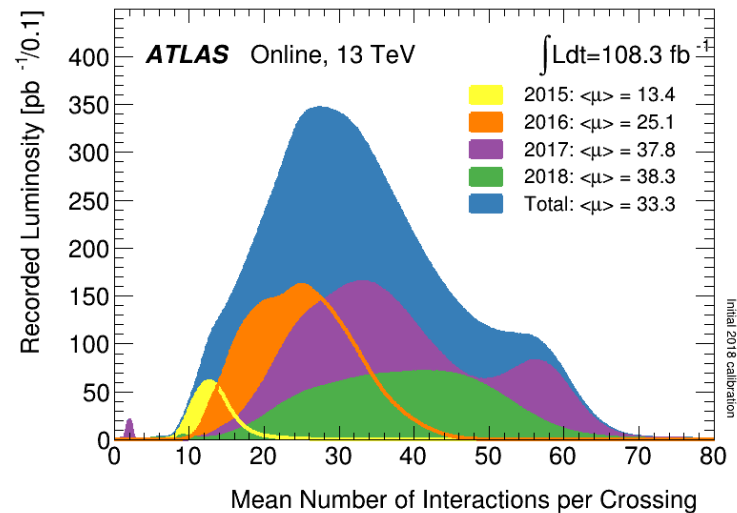
Simulation

Erreurs

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Détecteur

Conclusion



NUMBER 16 PHYSICAL REVIEW LETTERS 19 Octo

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs

Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)



Contents lists available at SciVerse ScienceDirect

Physics Letters B

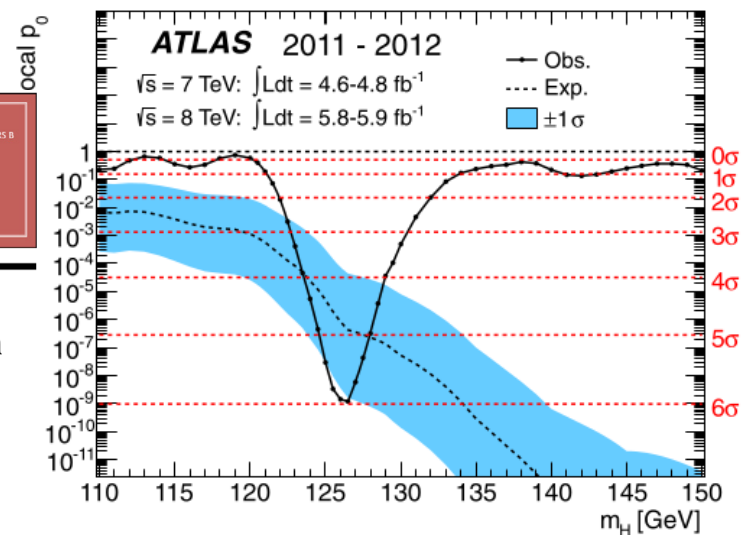
www.elsevier.com/locate/physletb



Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

ATLAS Collaboration *

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.



Remarques liminaires

Le Diable est dans les détails



Vocabulaire !

« Une rupture du continuum espace-temps a produit une nouvelle séquence chrono événementielle entraînant l'émergence de cette réalité alternative »
(Retour vers le futur II, version française)

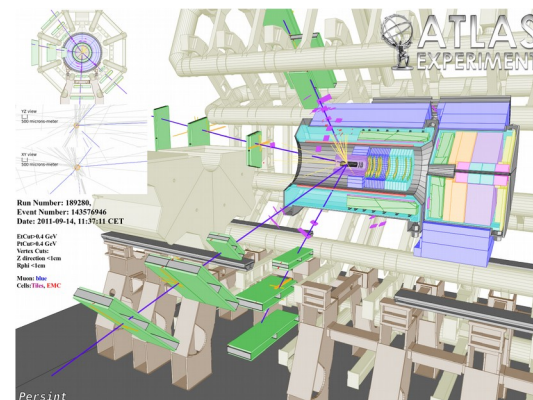
Observable (beobachtbar)

Observer:

regarder et garder

Détection → détecteur:

œil + appareil photographique



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Remarques liminaires

Observables : $X|\psi\rangle = x|\psi\rangle$

presque directement accessible par le détecteur

R : position (vertex)

P : impulsion

E : énergie

V : vitesse

Q : charge

m, L, S, M très indirect

On ne détermine ces informations qu'après un processus d'analyse partant des signaux enregistrés par le détecteur.

simulation

trigger (déclenchement)

étalonnage → détermination des résolutions :

spatiales, en impulsion, en énergie...

Remarques liminaires

Observable \rightarrow Traces + Analyse

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Le Large Hadron Collider

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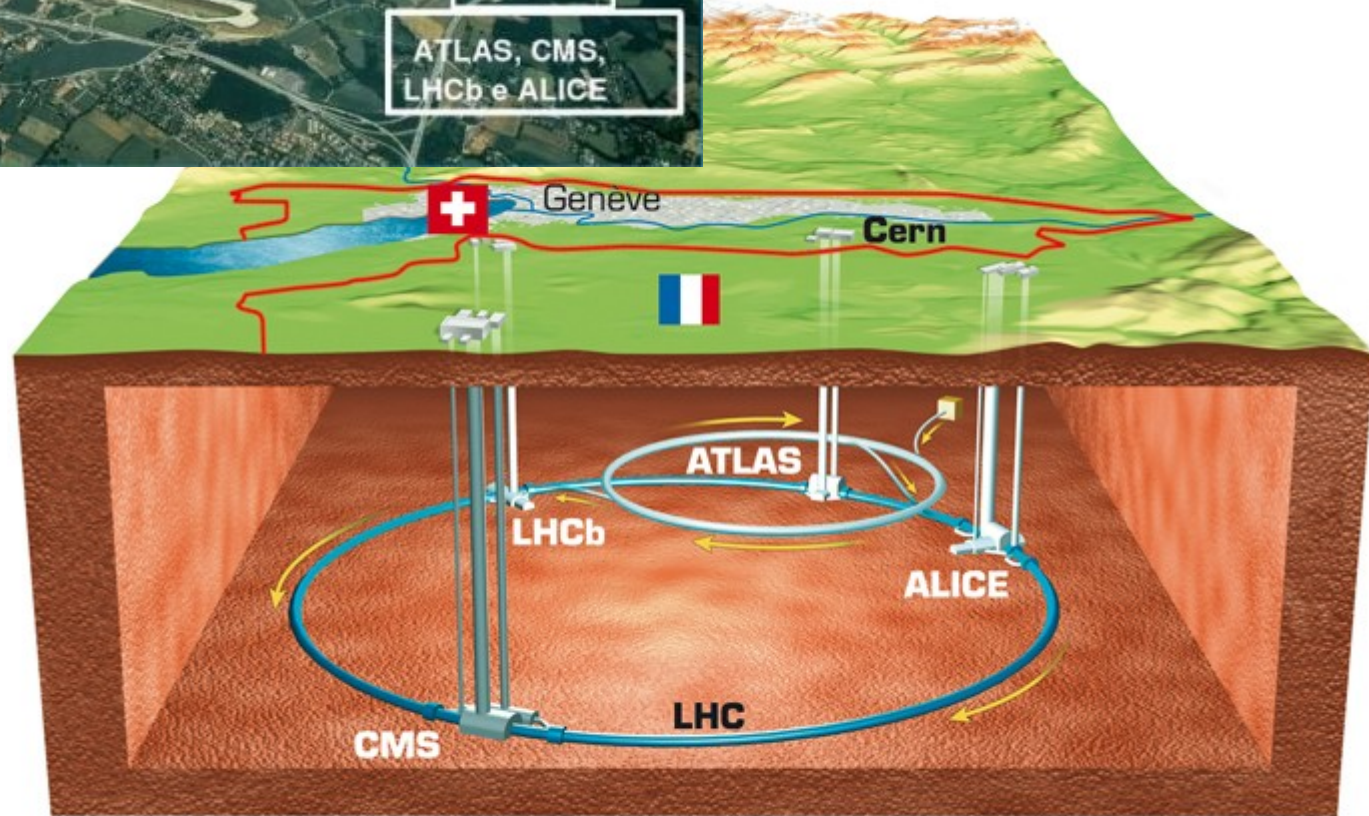
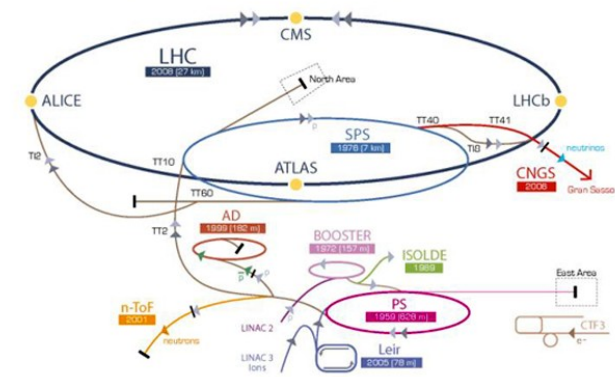
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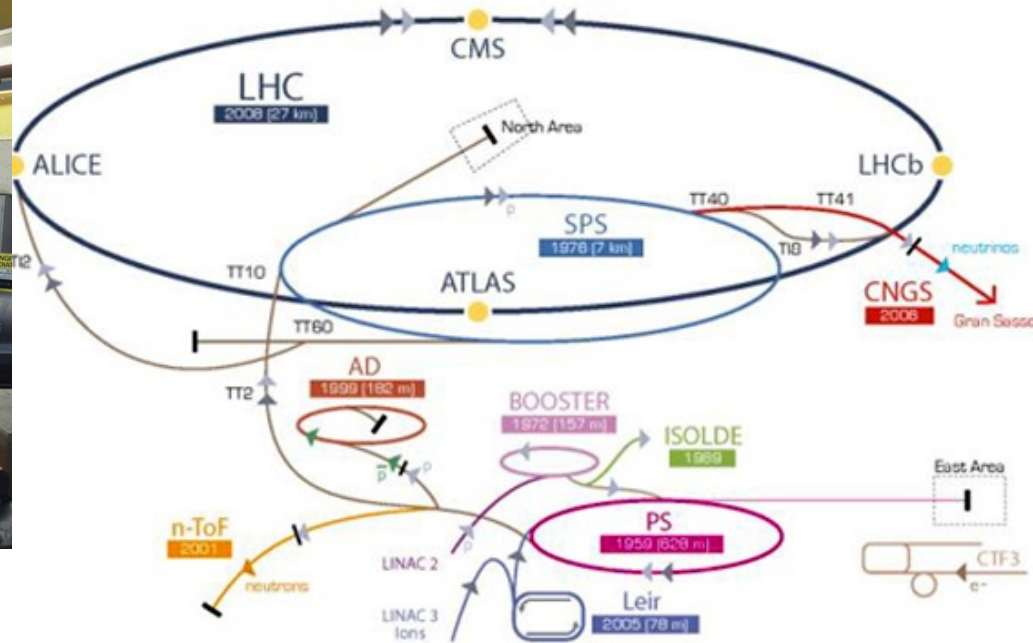
Complexe des accélérateurs du CERN



Le Large Hadron Collider

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$

Complexe des accélérateurs du CERN



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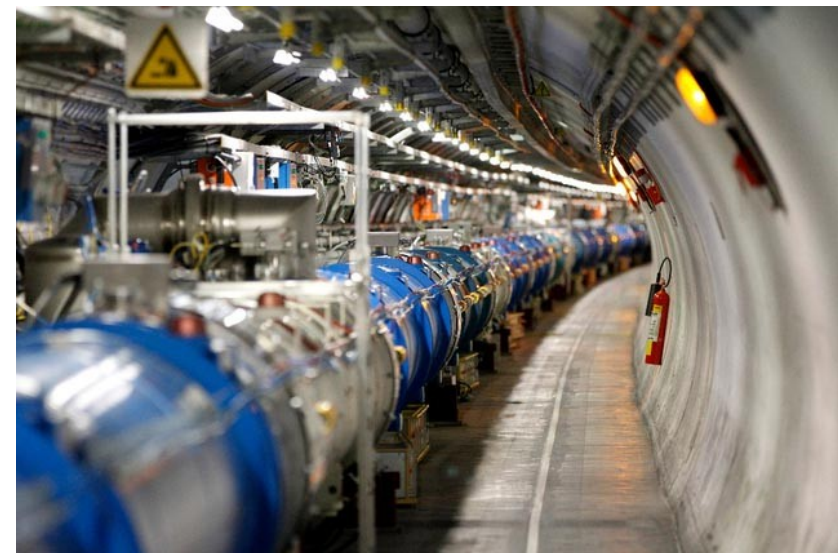
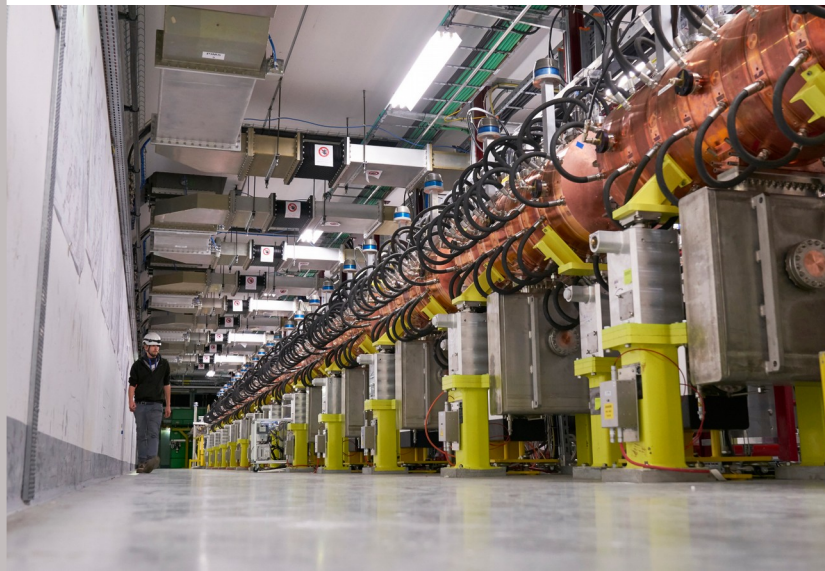
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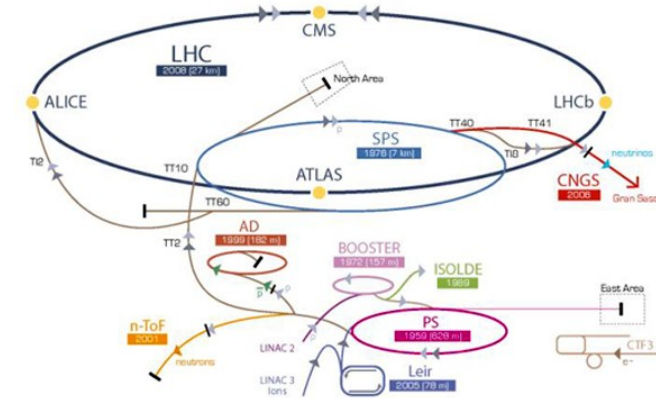
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Le Large Hadron Collider



Introduction

25ns \rightarrow 40 MHz \rightarrow 100Hz
 1 Mbytes (10^6 octets)
 10^7 s

LHC

Par expérience LHC

$\rightarrow 10^2 \times 10^6 \times 10^7 = 10^{15}$ octets = 1PBytes/an

Mesures

dictionnaire usuel ~ 60000 mots $\sim 10^5$ octets

$\rightarrow 1$ PB ~ 1 milliards de dictionnaires/an

$\rightarrow 1$ million de DVD par an

Erreurs

Statistique

Solution

\rightarrow calculs délocalisés

\rightarrow Tier 0,1,2

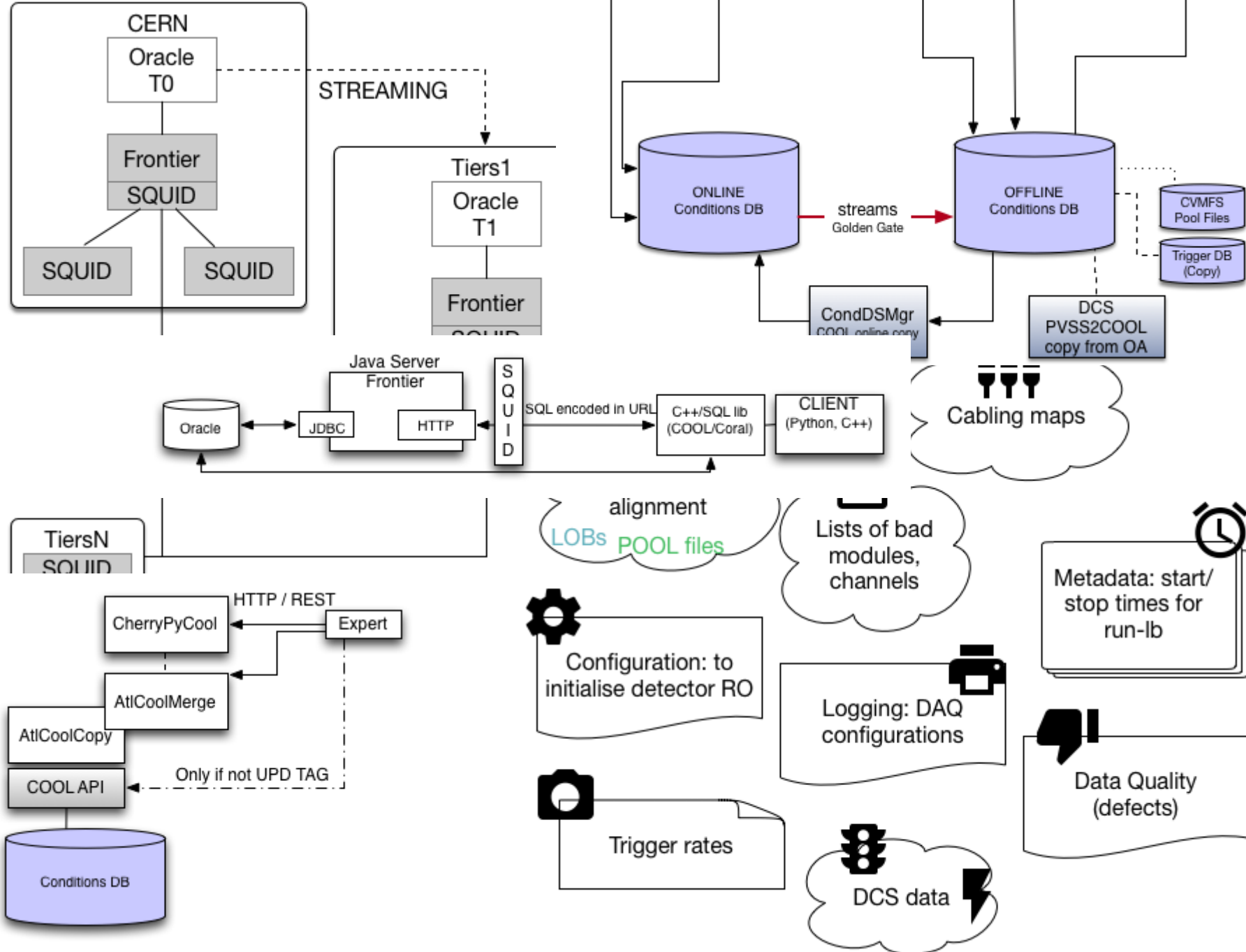
\rightarrow simulation... $\rightarrow \sim 10^{16}$ B/an

Détecteur

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Mesures au LHC

gestion des données



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Ordre de grandeur de ce qu'on cherche

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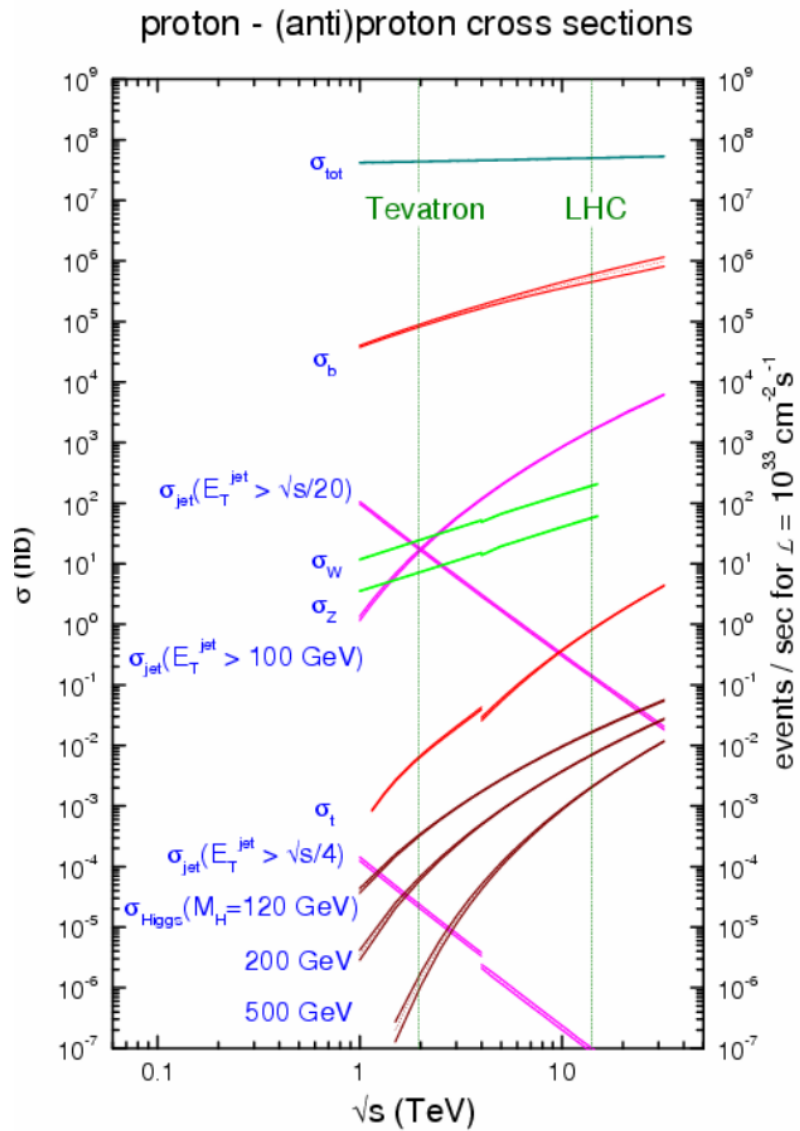
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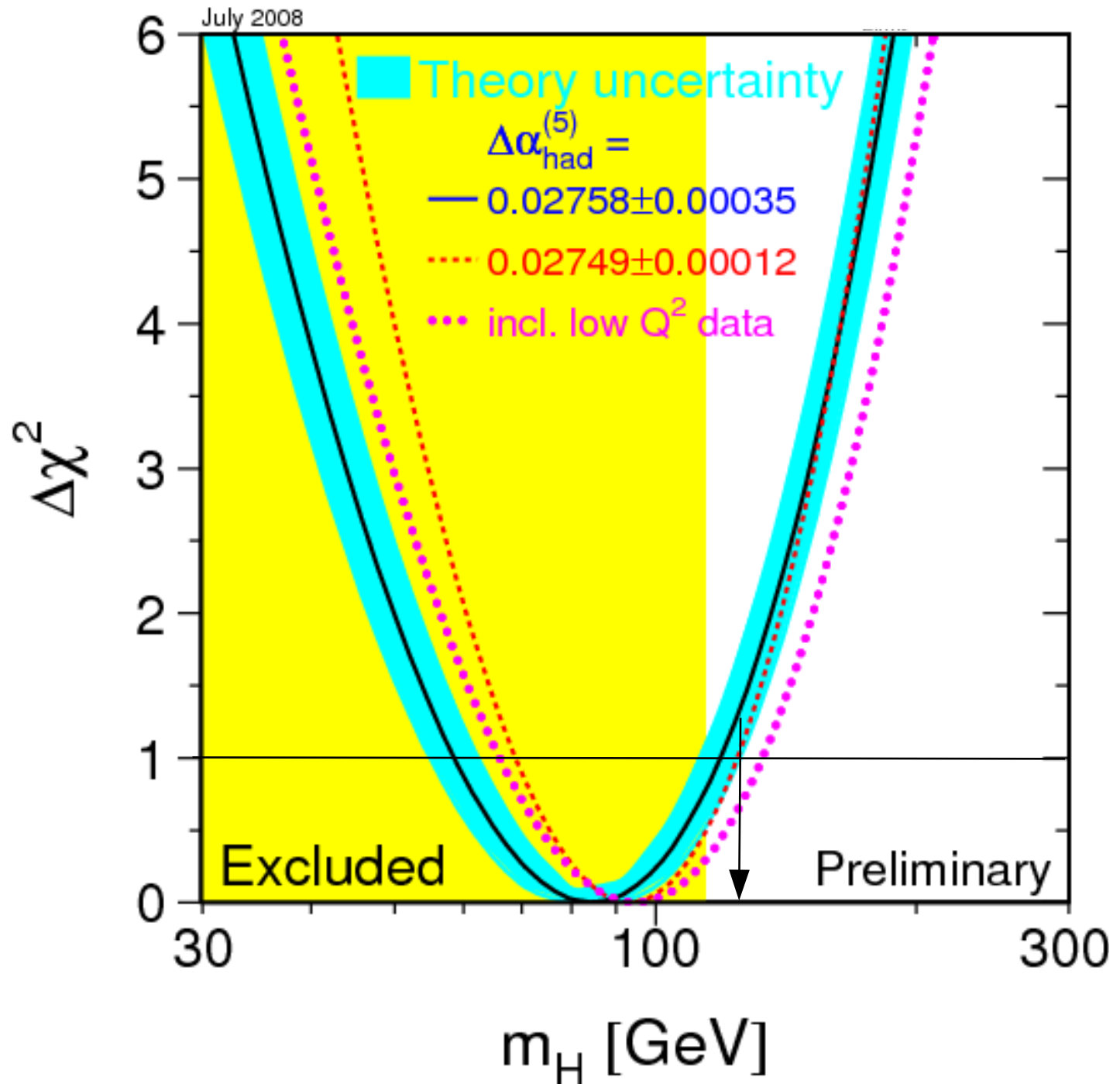


$\rightarrow \sim 10^{11}$

$\rightarrow \sim 10^8$

Conclusion

Mesures au LHC : contraintes précédentes → LEP



Mesures au LHC

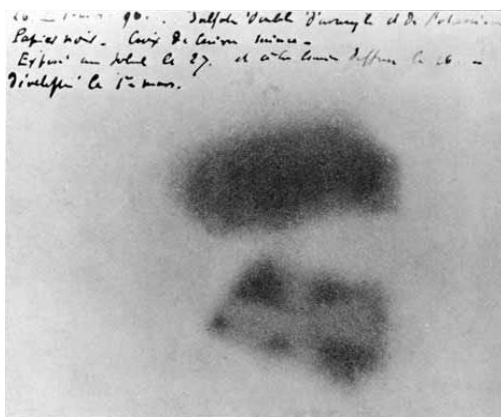
Introduction

« Rayon uranique » et croix en cuivre

LHC



Mesures



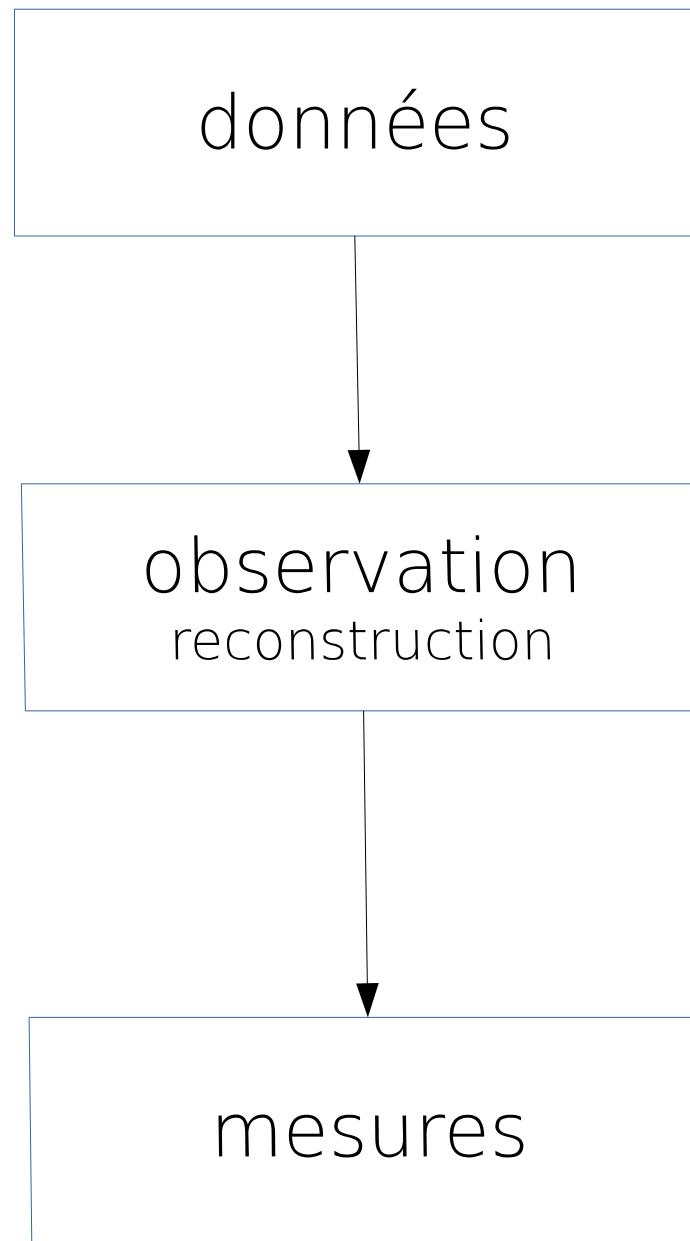
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Mesures au LHC

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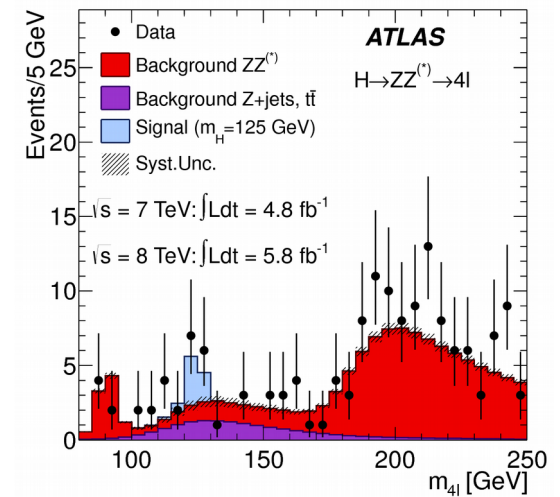
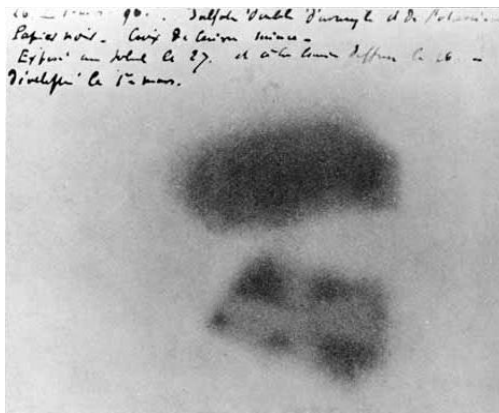
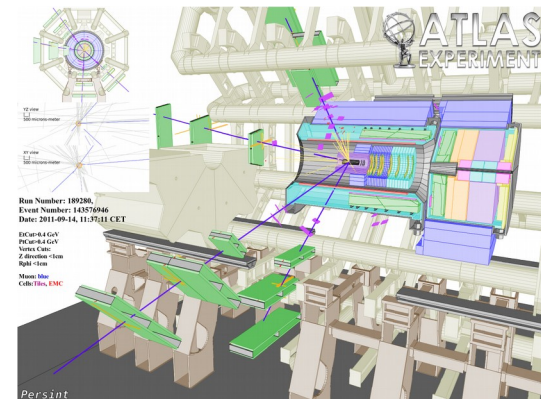
Conclusion

simulation

données

reconstruction

mesures



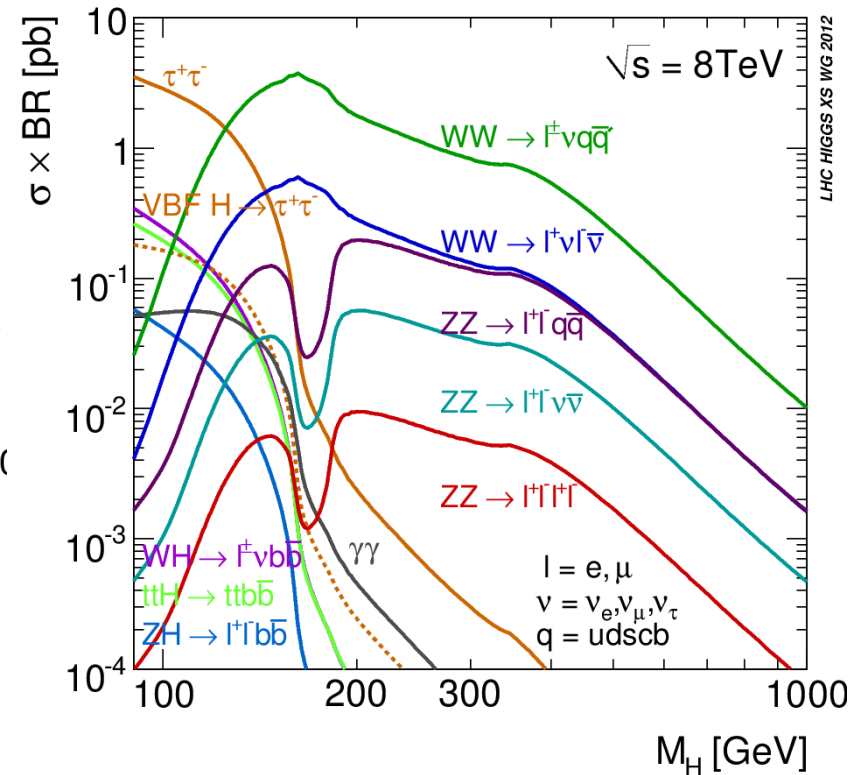
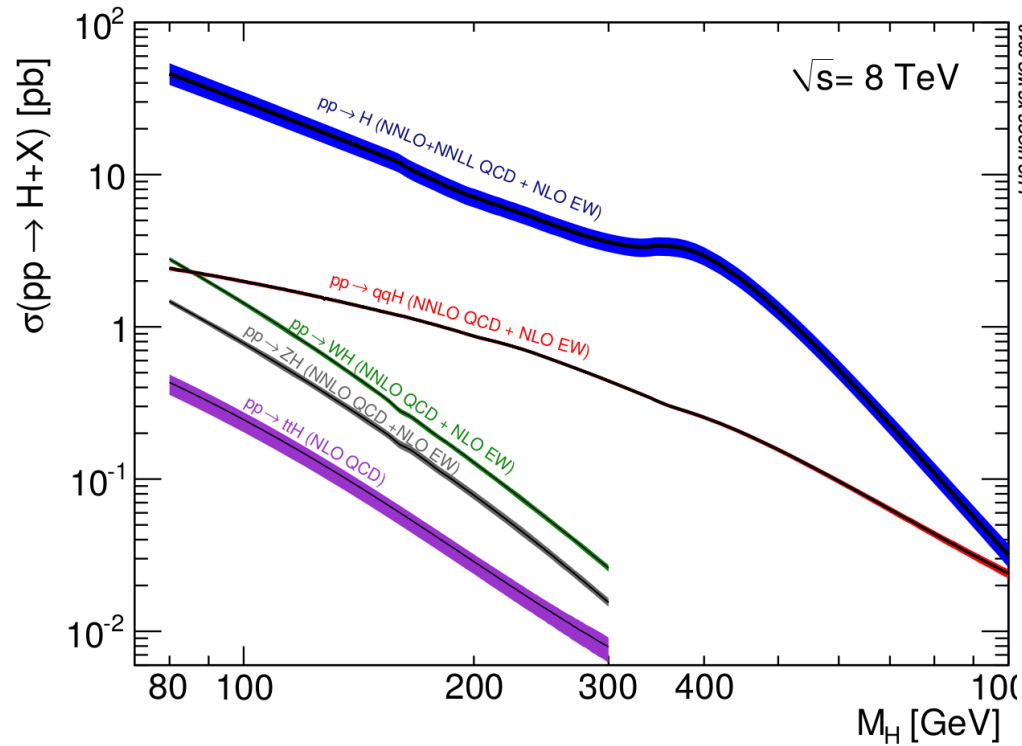
Mesures au LHC

Théories et modèles → Simulation

performances du LHC

dessins expériences

estimations des mesures potentielles



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Mesures au LHC

Simulation

générateur

hard process

parton distribution function

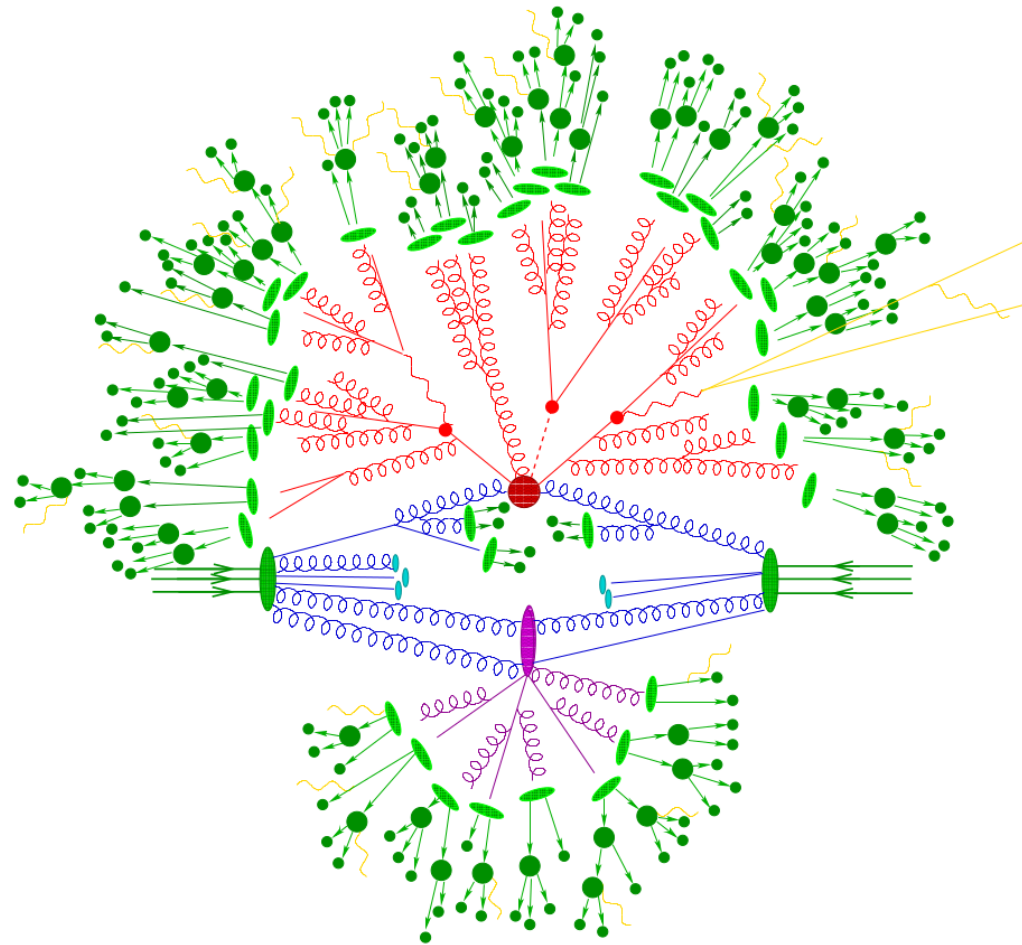
underlying event

parton shower

hadronisation

pile-up

détecteur



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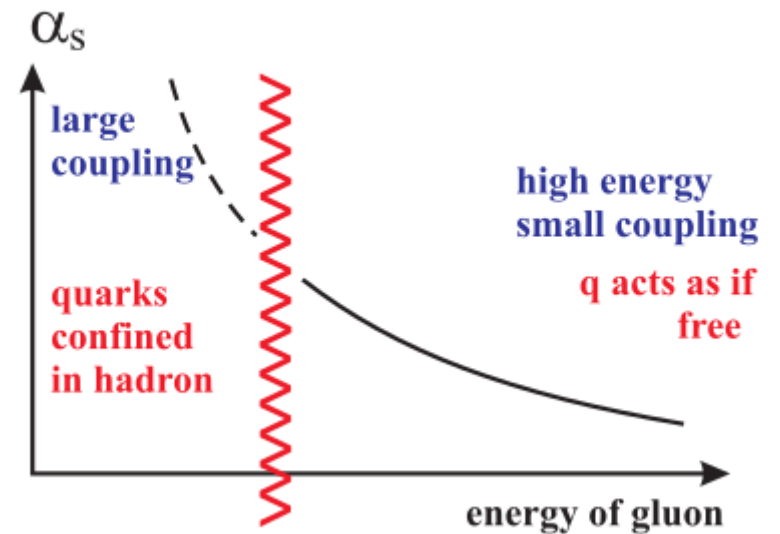
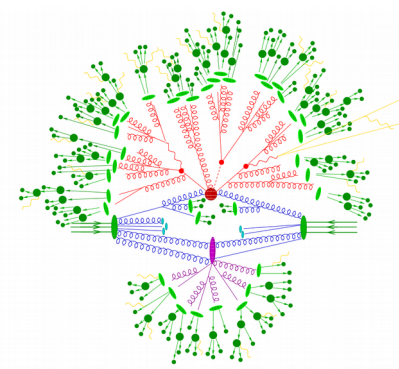
Mesures au LHC

Simulation générateur

hard process
parton distribution function
underlying event
parton shower
hadronisation
pile-up

} factorisation

détecteur



$$\sigma_{1,2} = \int f_1(x_1, \mu_f) dx_1 f_2(x_2, \mu_f) dx_2 d\tilde{\sigma}_{1,2 \rightarrow X}(\mu_f, \mu_r)$$

$$\sigma = \sum_{1,2} \sigma_{1,2} \quad 16$$

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Simulation générateur

hard process

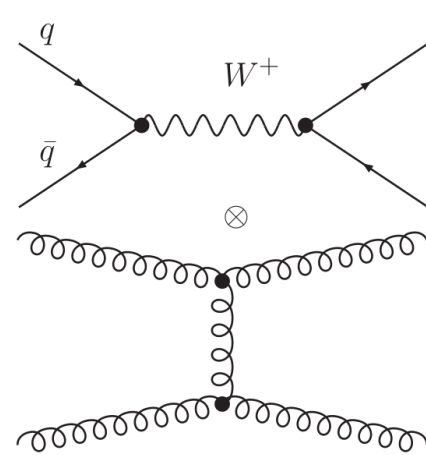
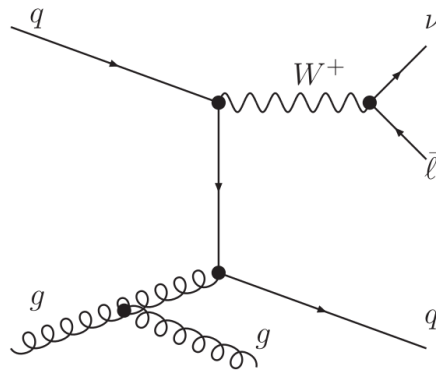
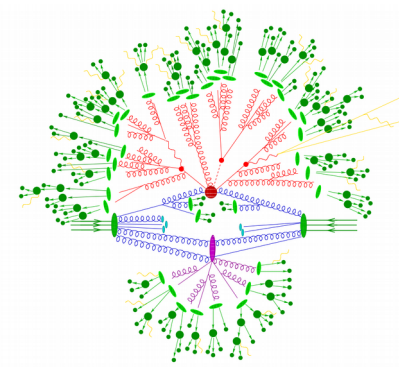
parton distribution function

factorisation

$$\sigma_{1,2} = \int f_1(x_1, \mu_f) dx_1 f_2(x_2, \mu_f) dx_2 \underbrace{d\tilde{\sigma}_{1,2 \rightarrow X}(\mu_f, \mu_r)}_{\text{Calculable}}$$

Calculable

→ diagrammes de Feynman



Mesures au LHC

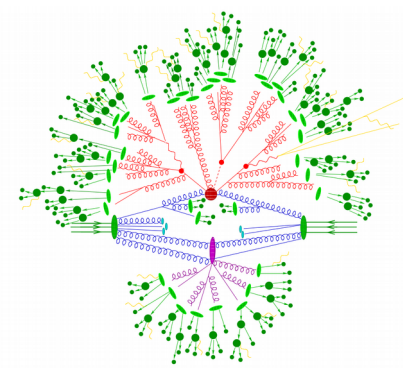
Simulation générateur

hard process

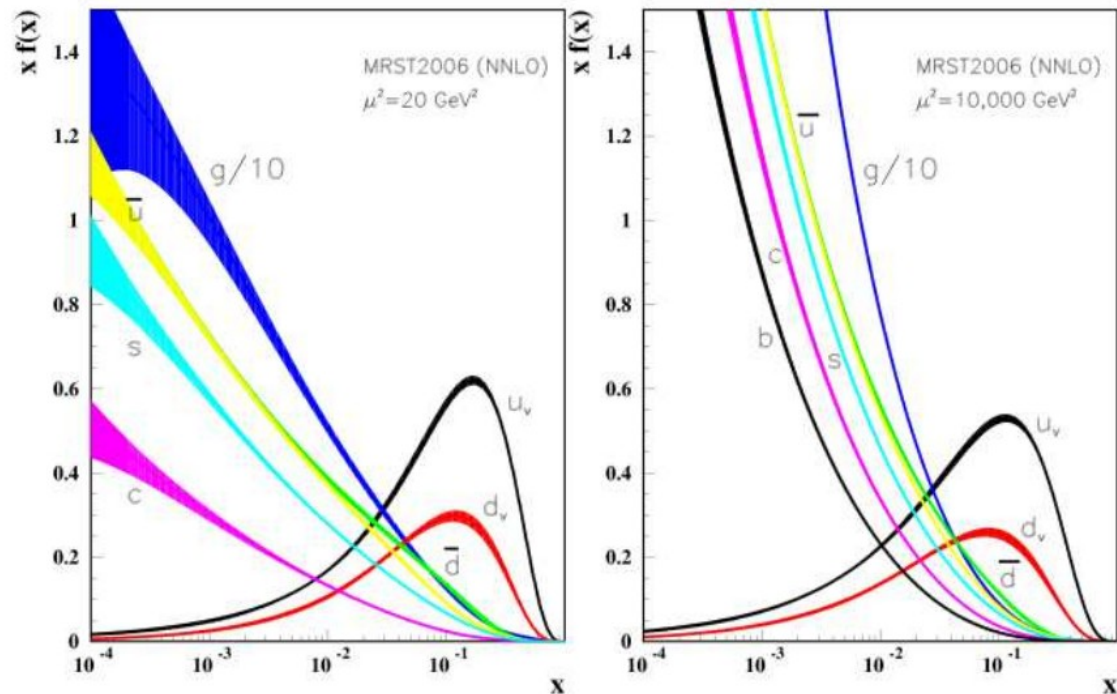
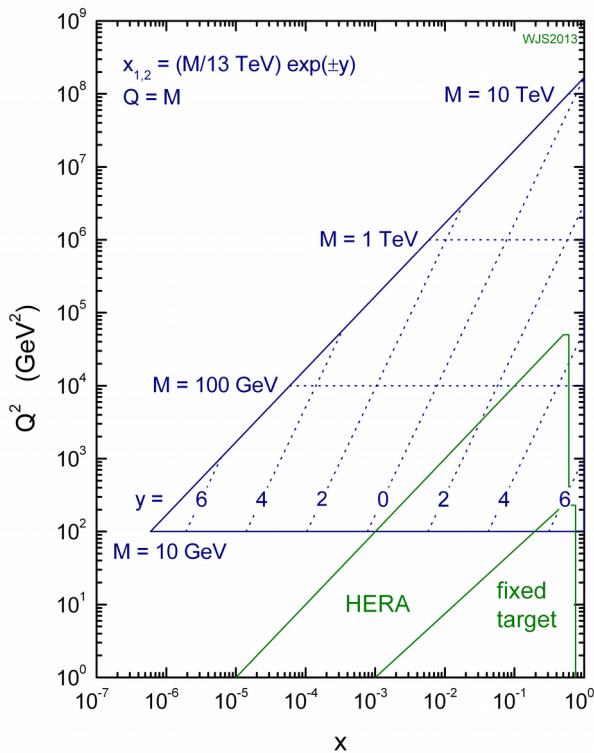
parton distribution function

} factorisation

$$\sigma_{1,2} = \int f_1(x_1, \mu_f) dx_1 f_2(x_2, \mu_f) dx_2 d\tilde{\sigma}_{1,2 \rightarrow X}(\mu_f, \mu_r)$$



13 TeV LHC parton kinematics



DGLAP : Dokshitzer-Gribov-Lipatov-Altarelli-Parisi Equations

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Simulation générateur

hard process

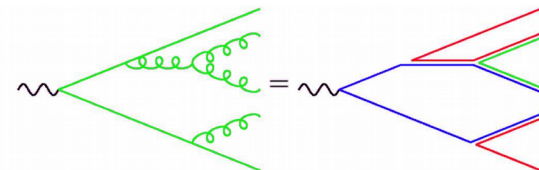
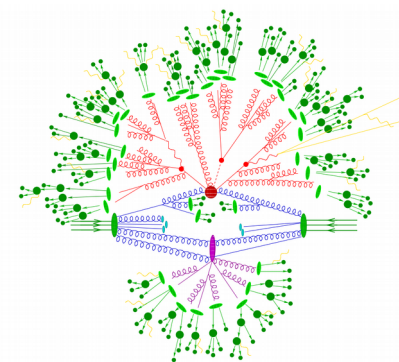
parton distribution function

underlying event

parton shower → resummation

hadronisation → modèles phénoménologique

pile-up



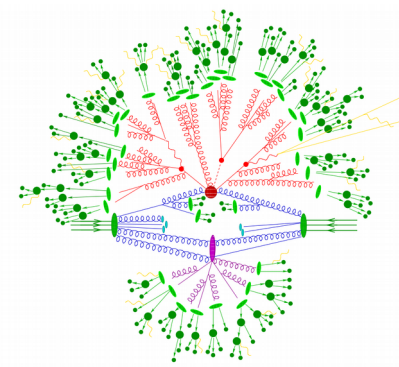
$$f_q(x,t) \begin{array}{c} q \\ \nearrow \\ \circ \\ \searrow \\ \text{---} \end{array} = \int_x^1 \frac{dz}{z} \frac{\alpha_s}{2\pi} \begin{array}{c} P_{qq}(z) \\ q \\ \nearrow \\ \circ \\ \searrow \\ \text{---} \end{array} f_q(x/z,t) + \int_x^1 \frac{dz}{z} \frac{\alpha_s}{2\pi} \begin{array}{c} P_{gq}(z) \\ q \\ \nearrow \\ \circ \\ \searrow \\ \text{---} \end{array} f_g(x/z,t)$$

$$f_g(x,t) \begin{array}{c} g \\ \nearrow \\ \circ \\ \searrow \\ \text{---} \end{array} = \sum_{i=1}^{2n_f} \int_x^1 \frac{dz}{z} \frac{\alpha_s}{2\pi} \begin{array}{c} P_{qg}(z) \\ g \\ \nearrow \\ \circ \\ \searrow \\ \text{---} \end{array} f_q(x/z,t) + \int_x^1 \frac{dz}{z} \frac{\alpha_s}{2\pi} \begin{array}{c} P_{gg}(z) \\ g \\ \nearrow \\ \circ \\ \searrow \\ \text{---} \end{array} f_g(x/z,t)$$

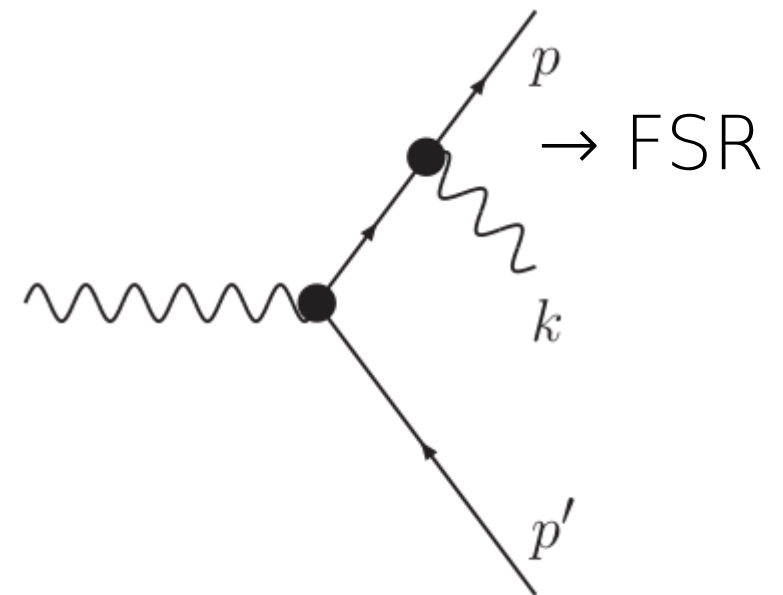
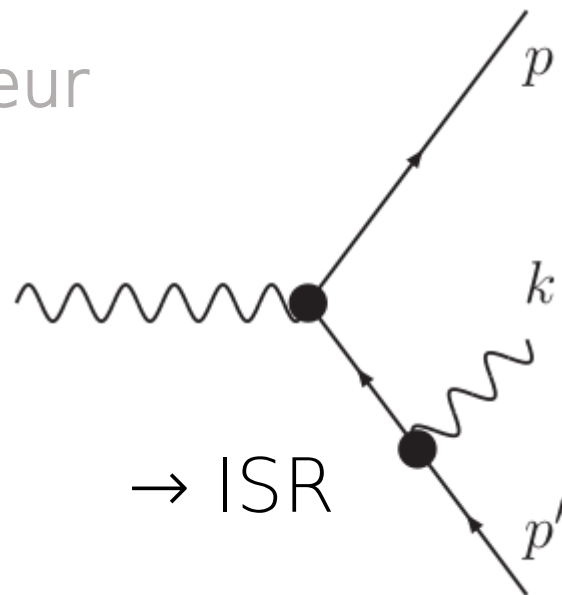
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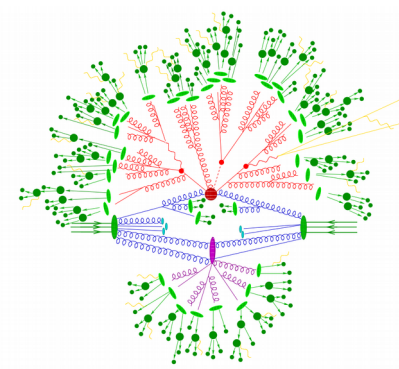
détecteur



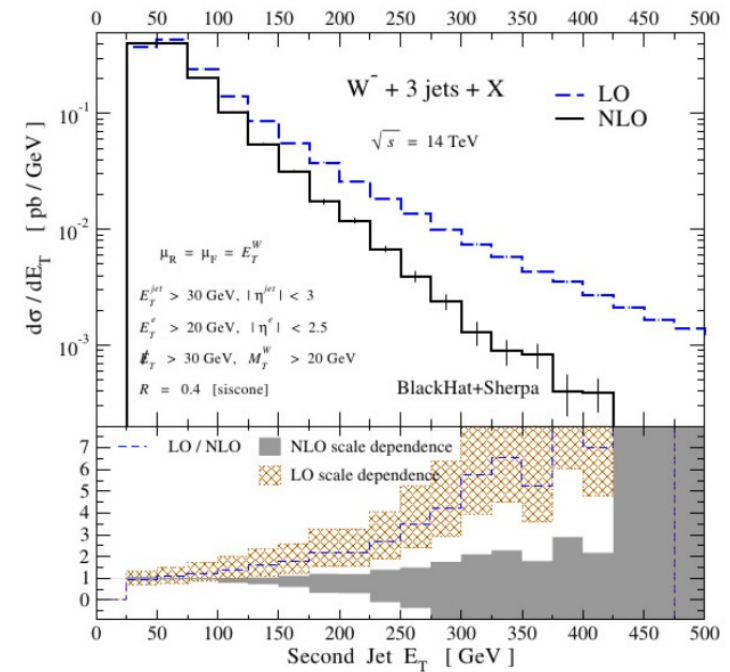
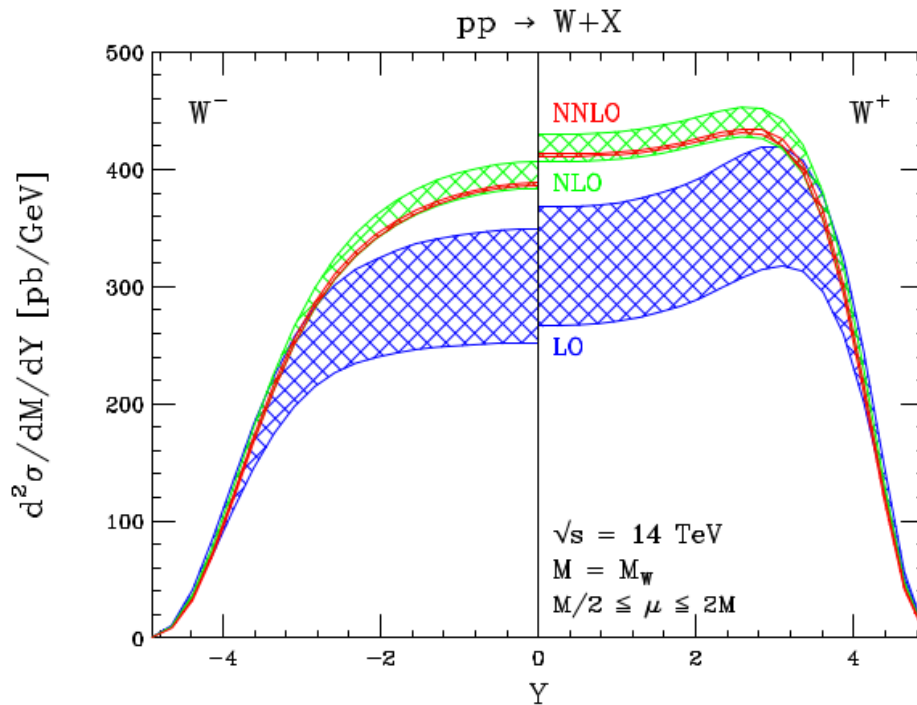
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LO, NLO, NNLO...



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Scenario of a hadron-hadron collision

Slides stolen from Torbjorn Sjostrand

Introduction

Warning: schematic only, everything simplified, nothing to scale, ...

LHC



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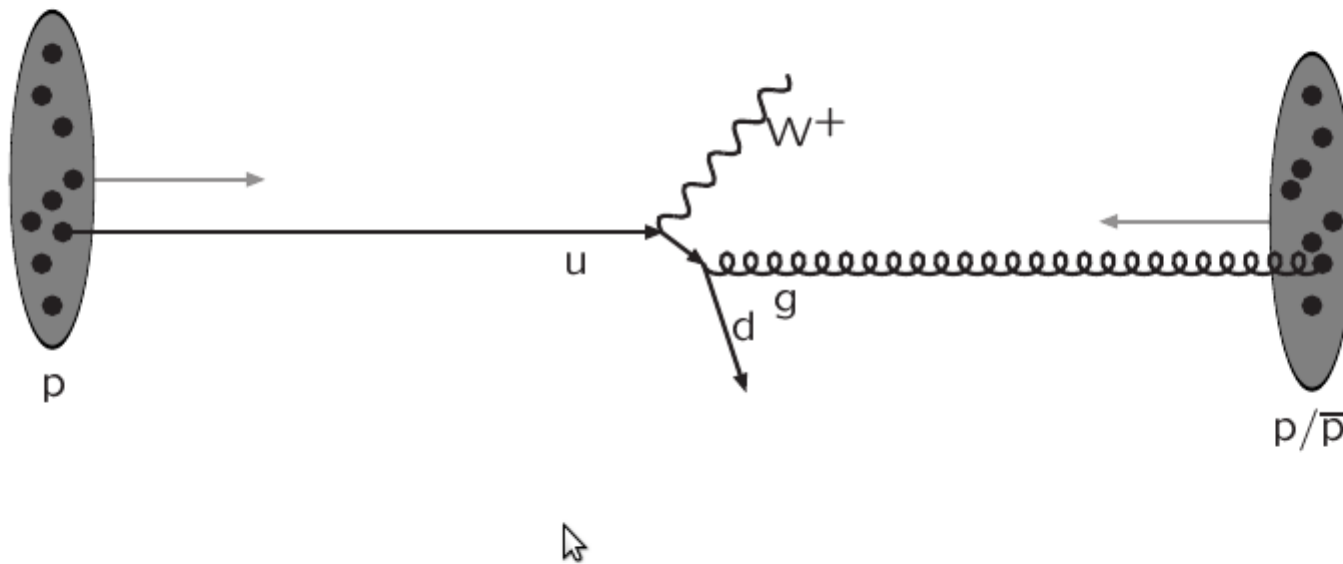
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Incoming beams: parton densities

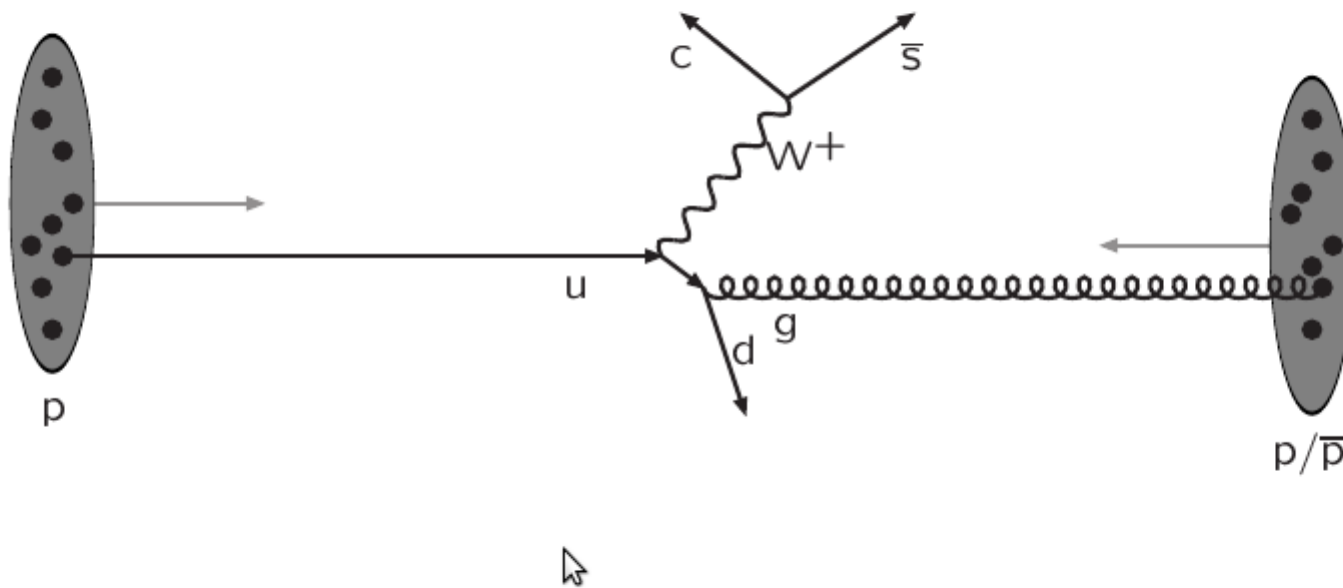
Conclusion

Théorie : diagramme Feynman



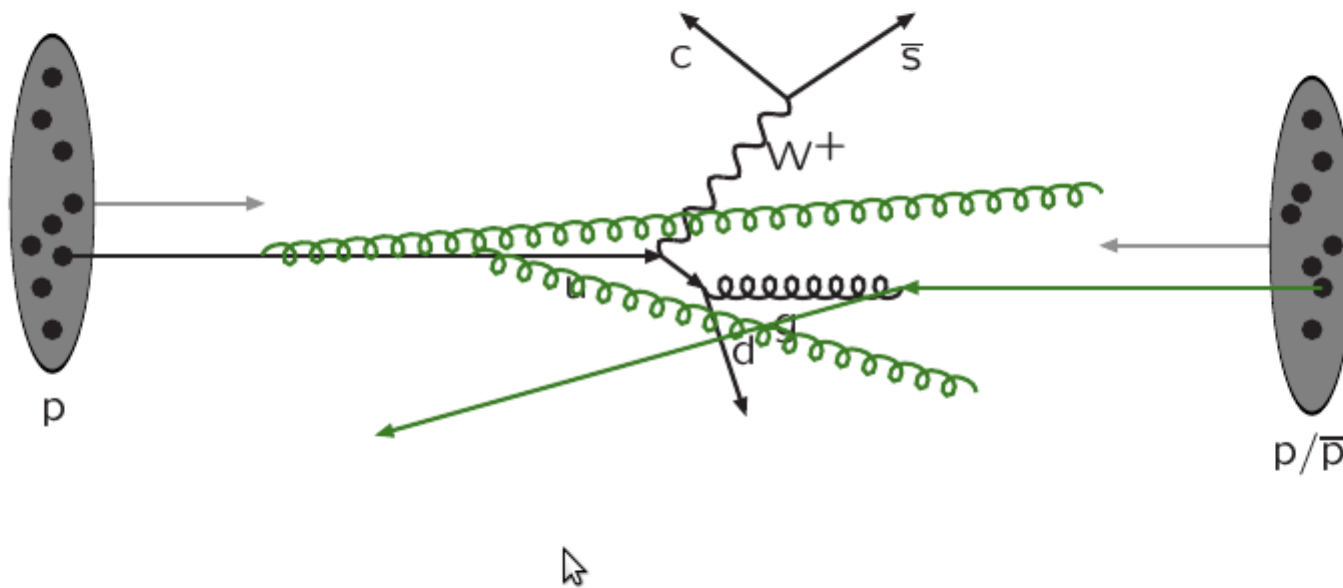
Hard subprocess: described by matrix elements

Théorie : diagramme Feynman



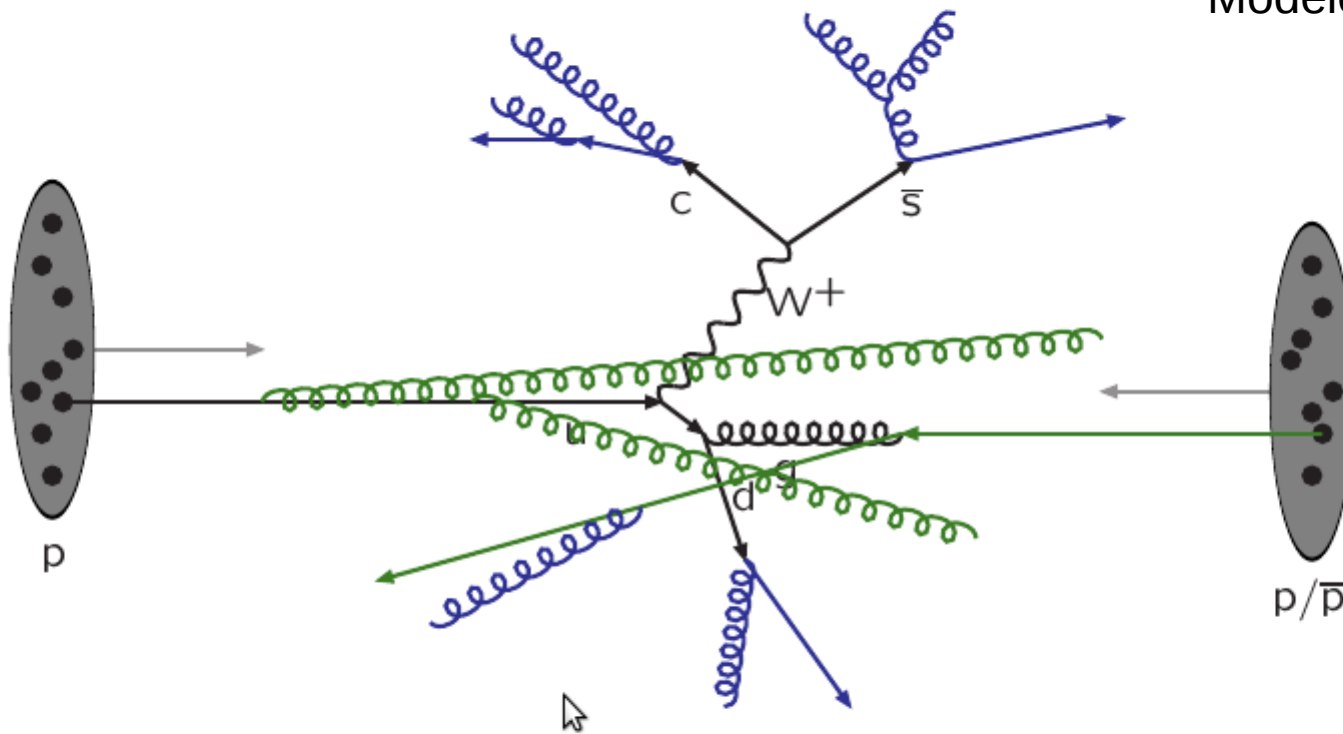
Resonance decays: correlated with hard subprocess

Modèle : hadronisation

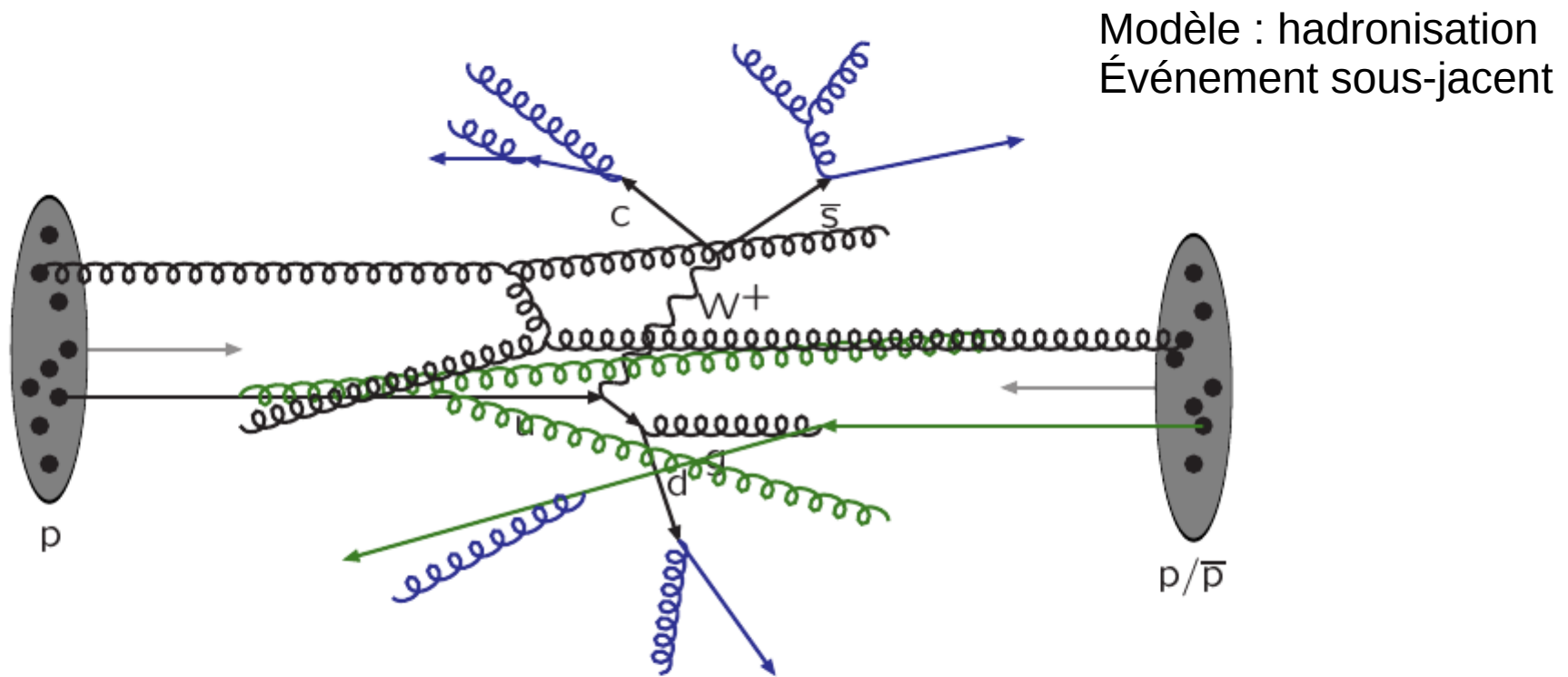


Initial-state radiation: spacelike parton showers

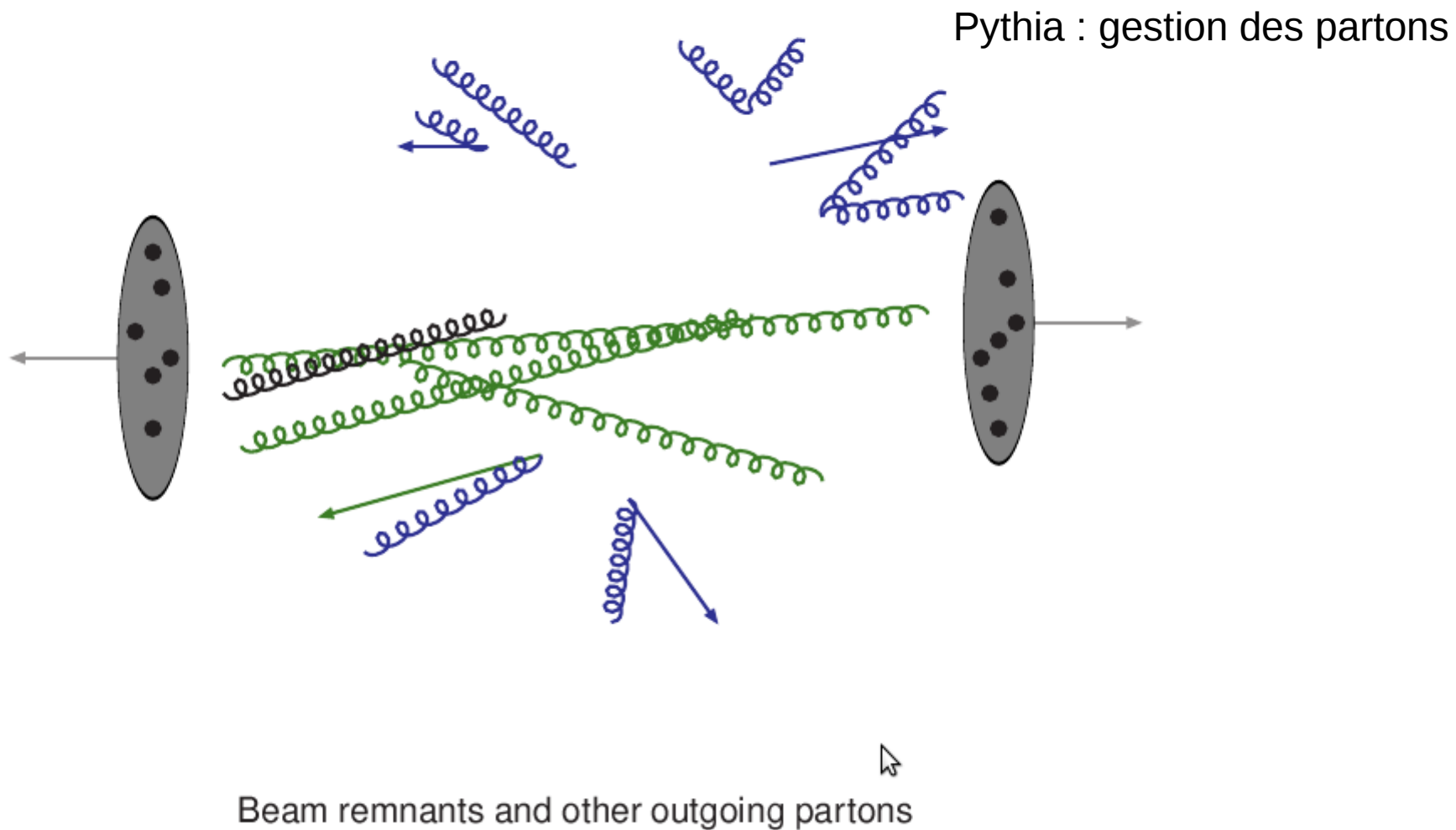
Modèle : hadronisation



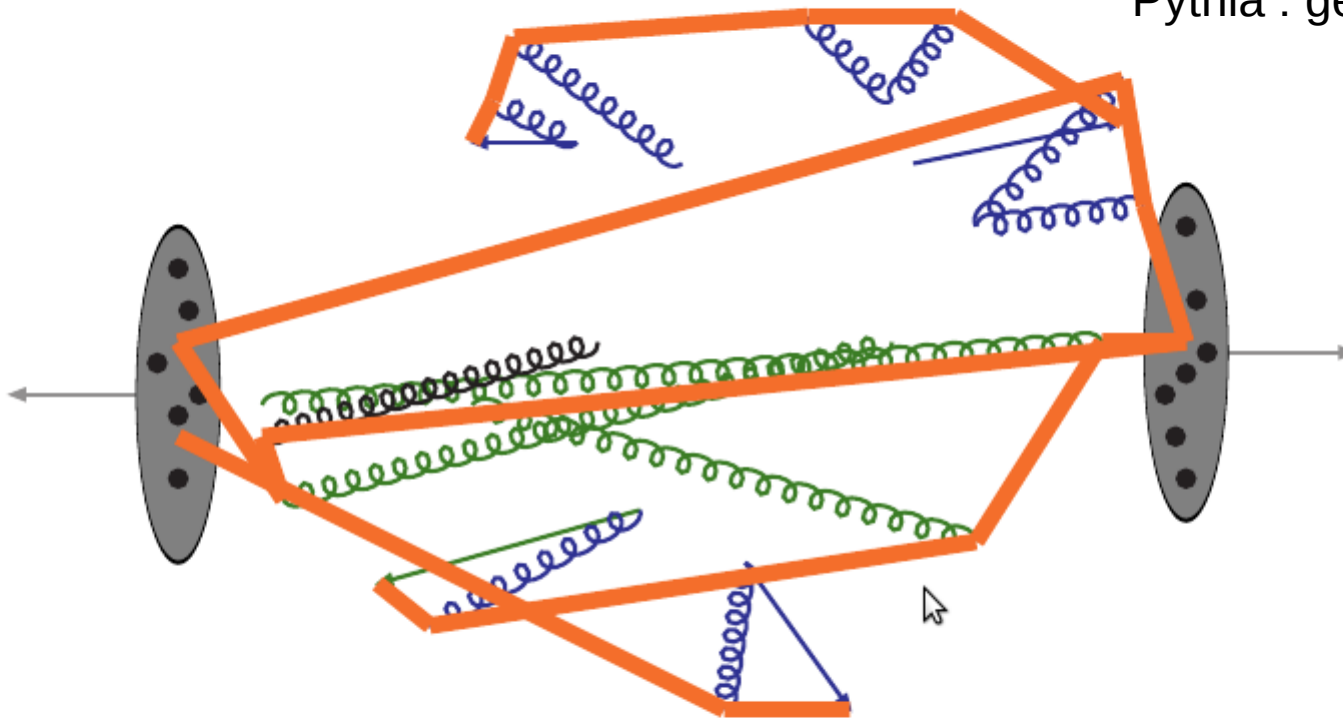
Final-state radiation: timelike parton showers



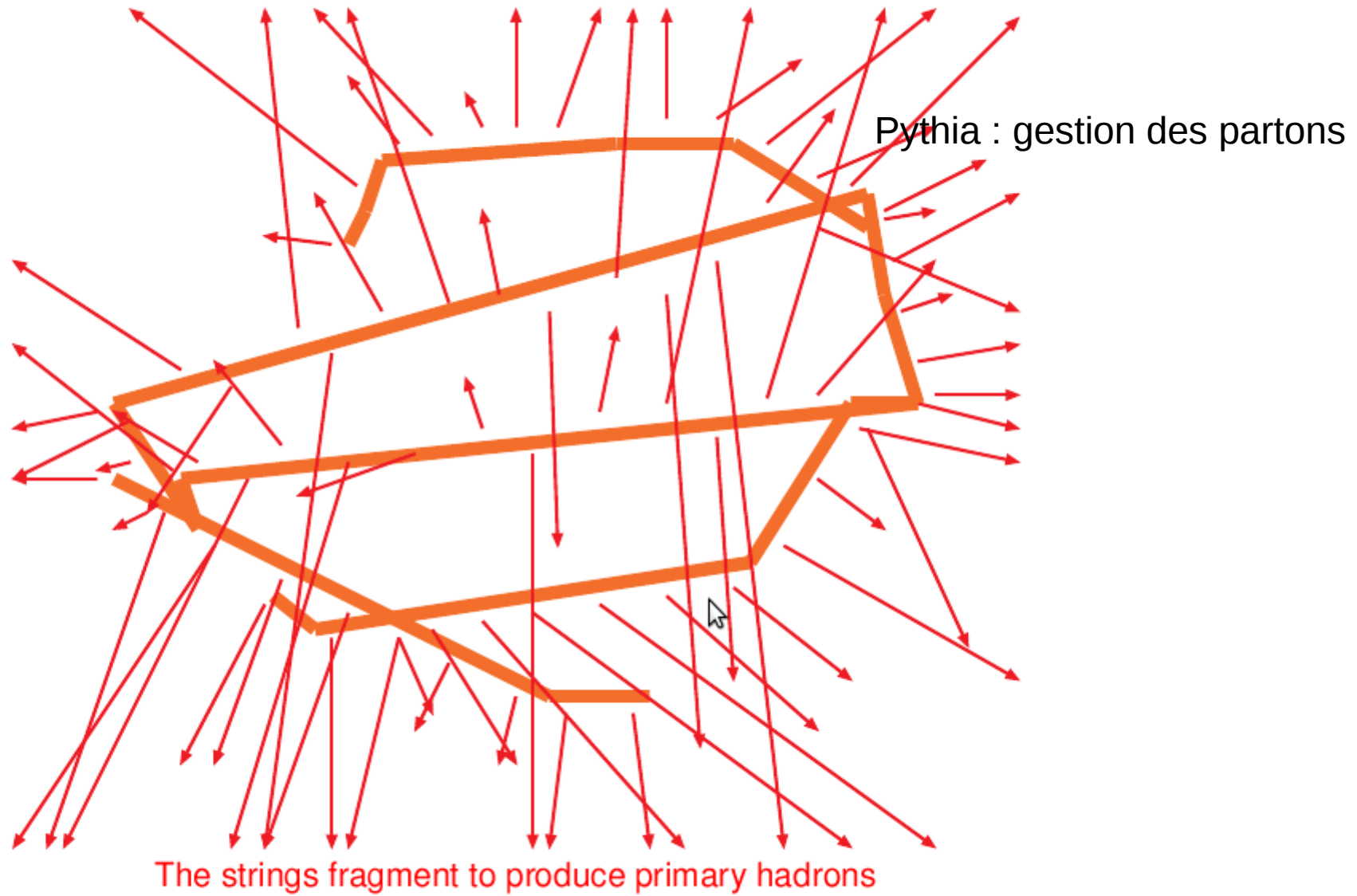
Multiple parton-parton interactions ...



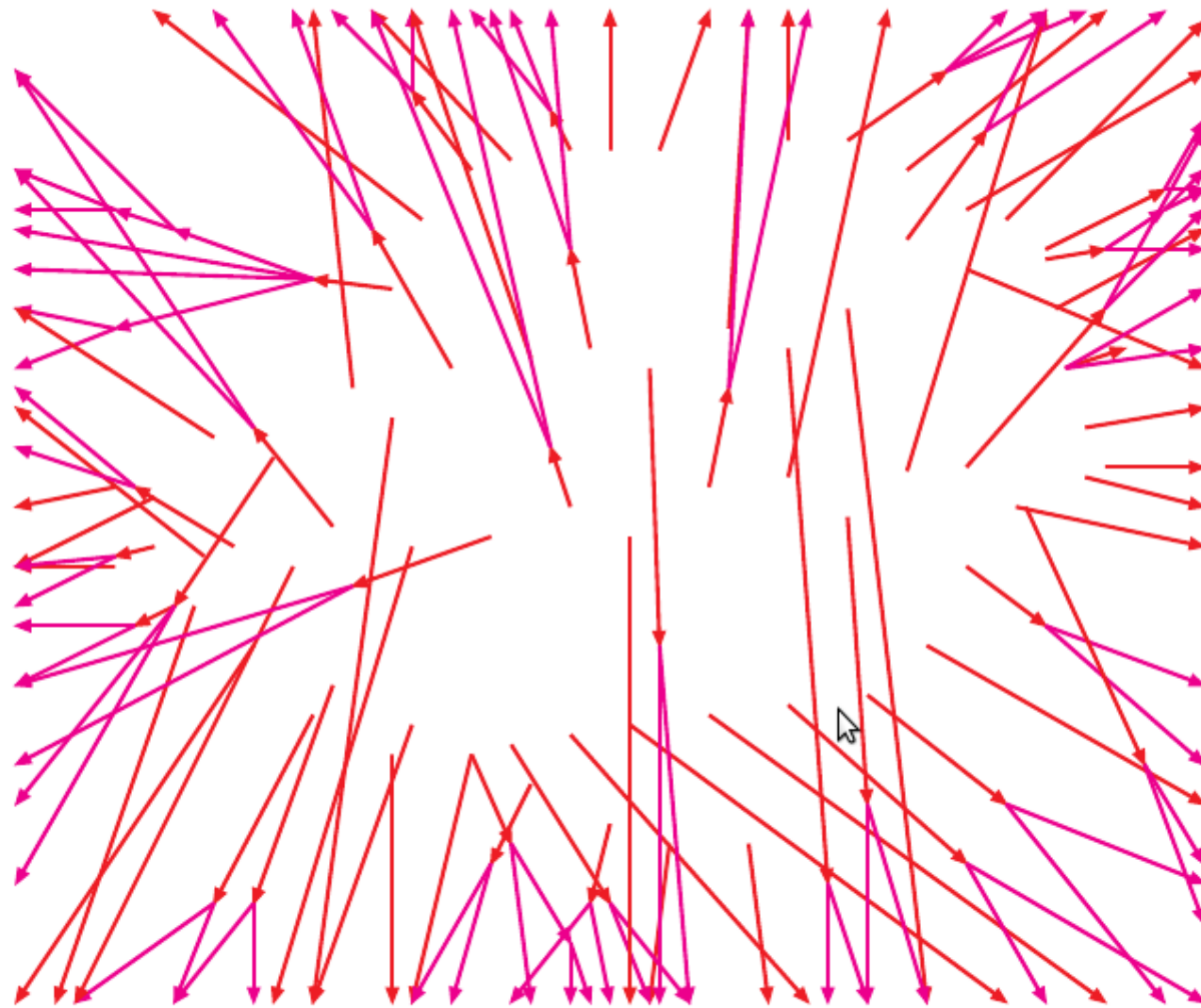
Pythia : gestion des partons



Everything is connected by colour confinement strings
Recall! Not to scale: strings are of hadronic widths



Quadri-vecteur envoyé à G4



Many hadrons are unstable and decay further

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Proton-proton interaction

Introduction

The “hard process” (e.g, W or Z resonance production) is accompanied by much other, mostly decorrelated activity that also leave signals in the detector

LHC

Colliding protons are not like protons at rest. When 2 protons move towards each other, the quarks on each side start interacting

Emitting gluons : $q \rightarrow q g$

can split into new quarks $g \rightarrow q qbar$

Mesures

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Resulting in a complex “soup” of gluons and quarks of all flavours!

Conclusion

Mesures au LHC

Estimation des erreurs statistiques systématiques

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

ATLAS Collaboration ☆

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

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ABSTRACT

A search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7 \text{ TeV}$ in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$ in 2012. Individual searches in the channels $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$, $H \rightarrow \gamma\gamma$ and $H \rightarrow WW^{(*)} \rightarrow e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \rightarrow ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of $126.0 \pm 0.4 \text{ (stat)} \pm 0.4 \text{ (sys) GeV}$ is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9} , is compatible with the production and decay of the Standard Model Higgs boson.

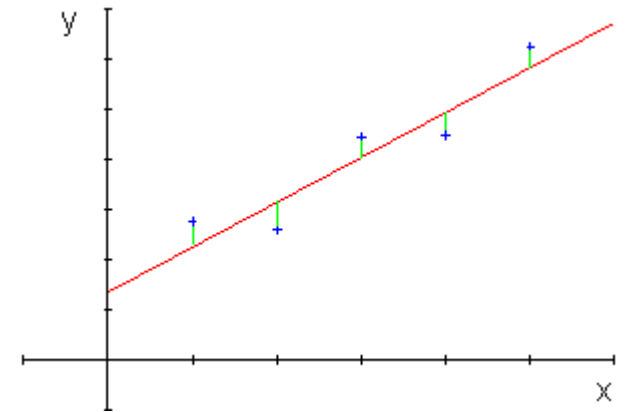
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Mesures au LHC

données + simulation + erreurs → outils statistiques
minimisation de χ^2
maximisation du log Likelihood

Minimisation →
$$\chi^2 = \sum_i \frac{(y_i - \bar{y})^2}{\sigma_i^2}$$

→ $y = ax + b$



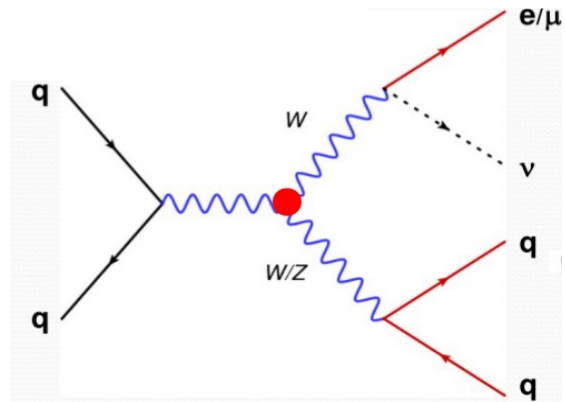
paramètres de nuisances : L

$$\chi^2 = \sum_i \frac{((1 + \delta L)y_i - \bar{y})^2}{\sigma_i^2 + y_i^2 \sigma_L^2} + \left(\frac{\delta L}{\sigma_L}\right)^2$$

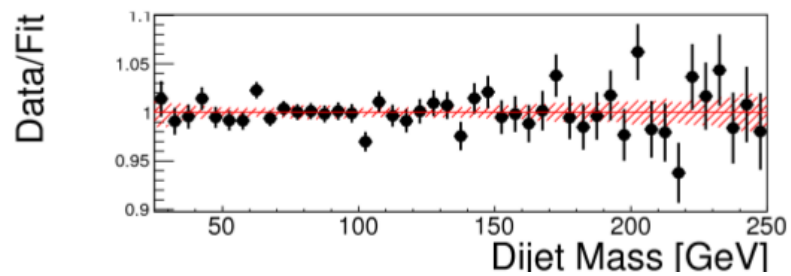
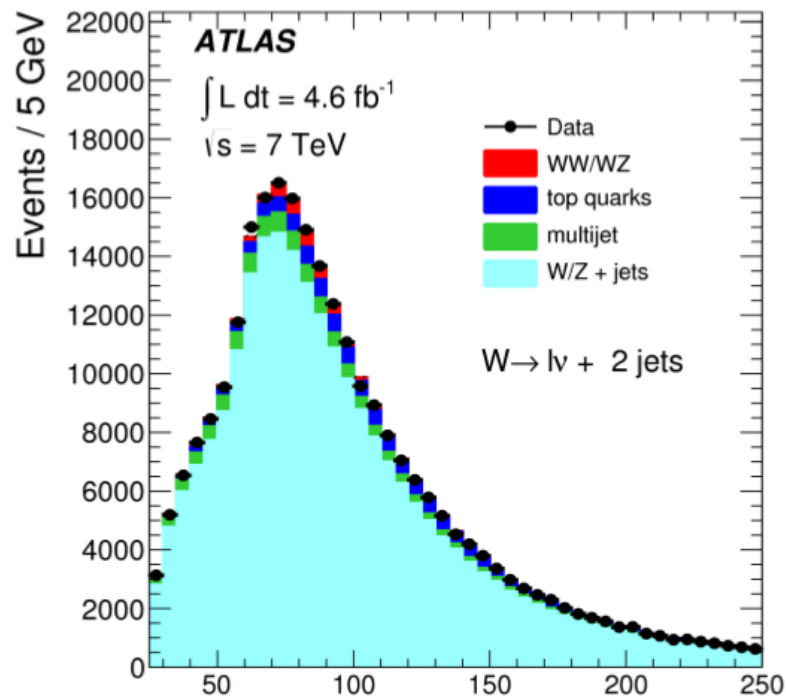
Reconstruction de traces

→ $p = (\theta, \phi, a_0, z_0, \frac{q}{p})$ & $\sigma_p(\text{MC})$
$$\chi^2 = \sum_i \frac{(p - \bar{p})^2}{\sigma_p^2}$$

Mesures au LHC

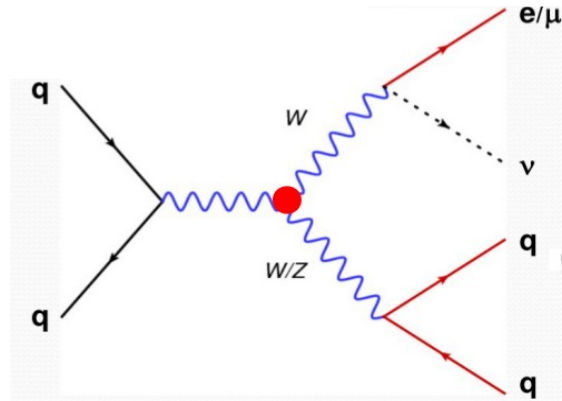


Simulation
Estimation des erreurs



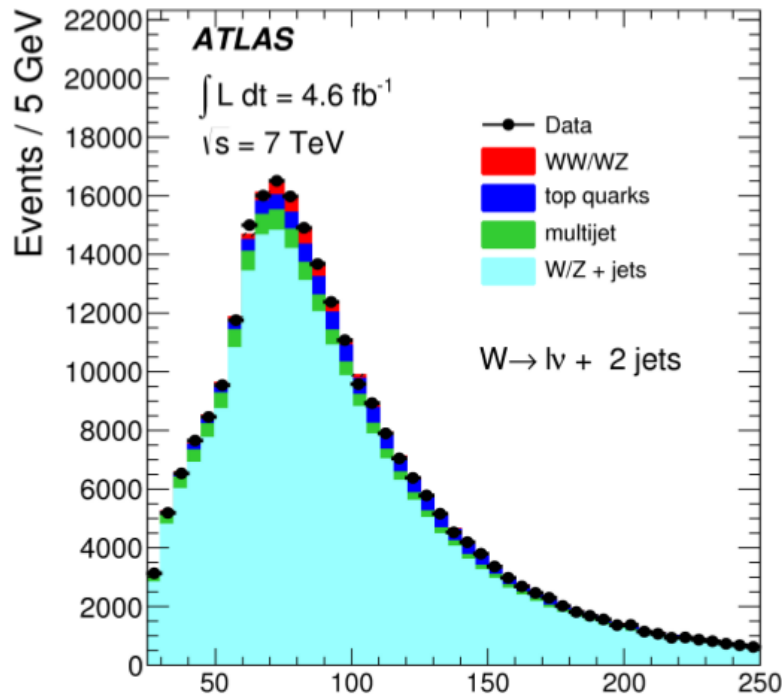
Mesures au LHC

Introduction



- 1/ Simulation
- 2/ Estimation des erreurs

LHC



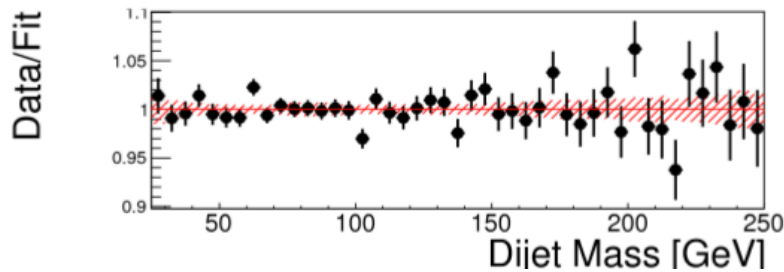
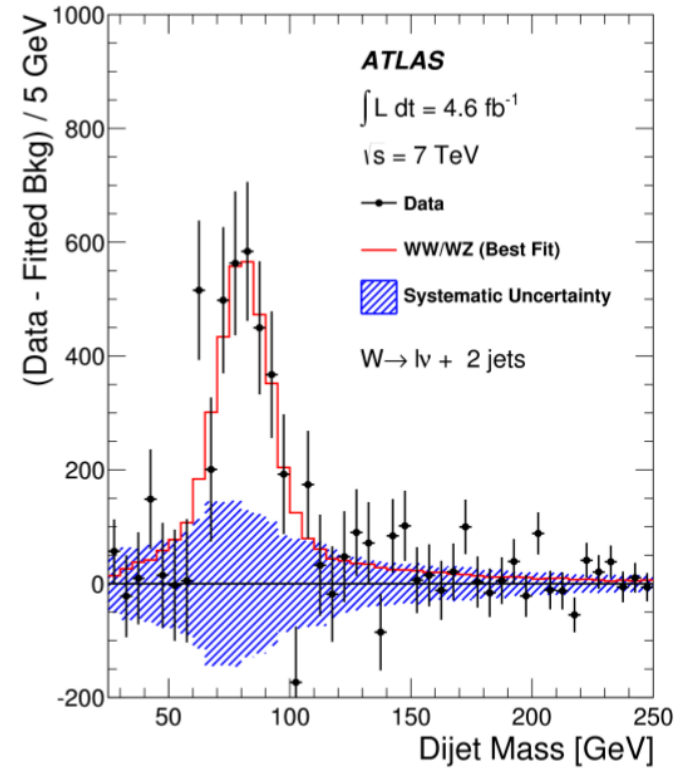
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Erreurs

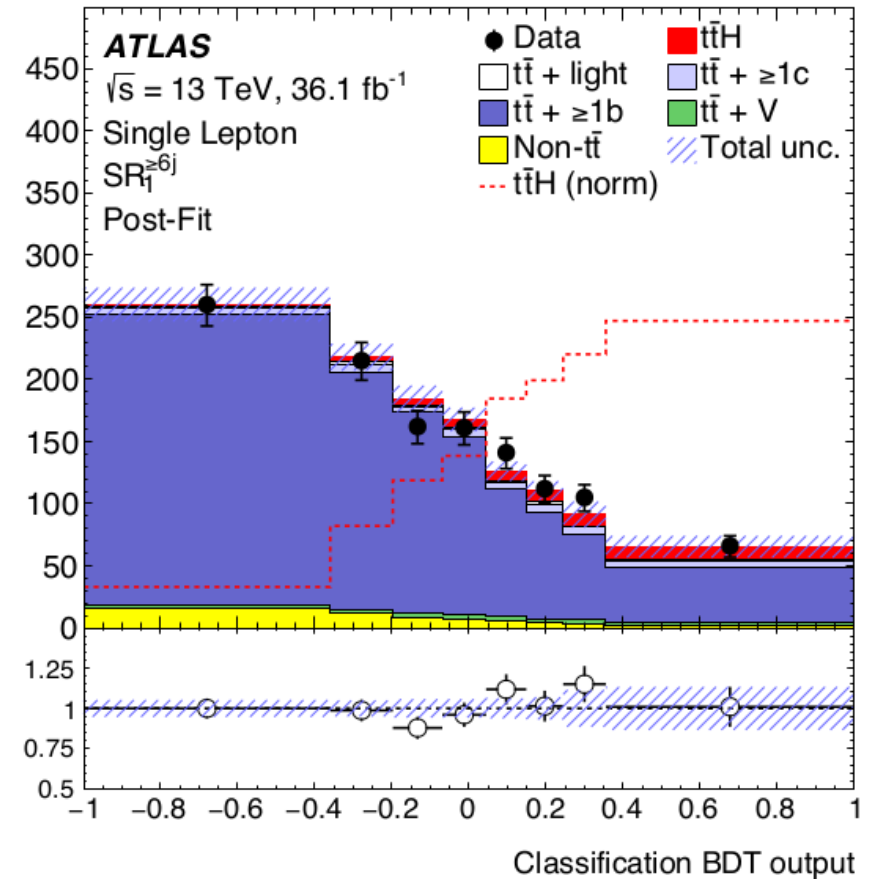
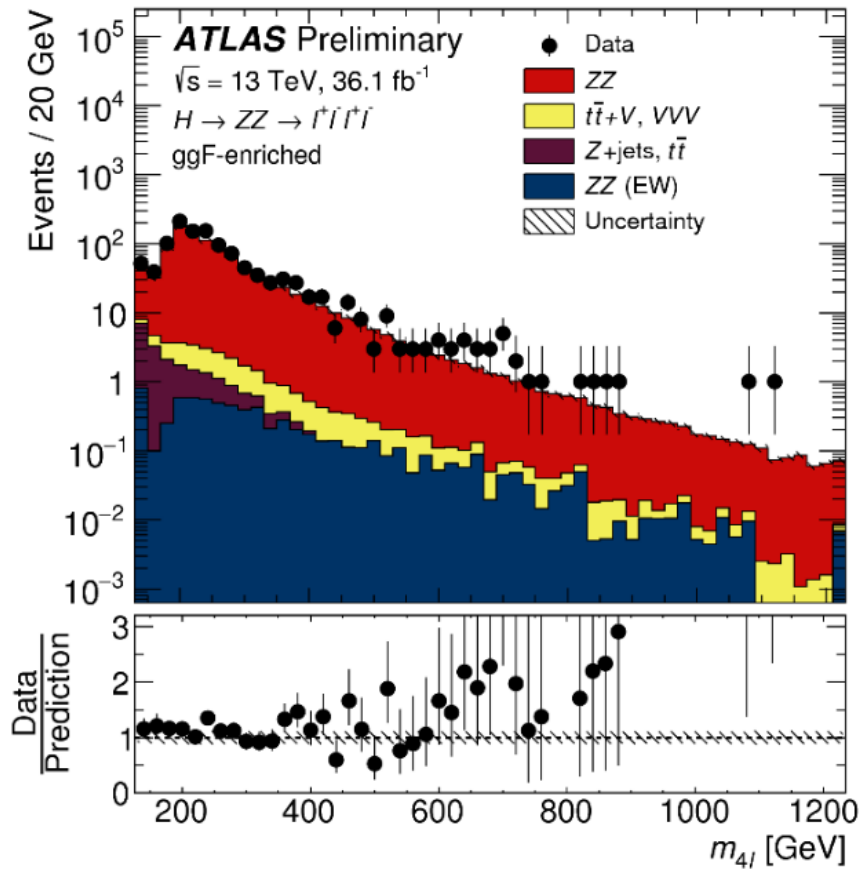
Statistique

Détecteur

Conclusion

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Estimation des erreurs



Mesures au LHC

Simulation

générateur

hard process

parton distribution function

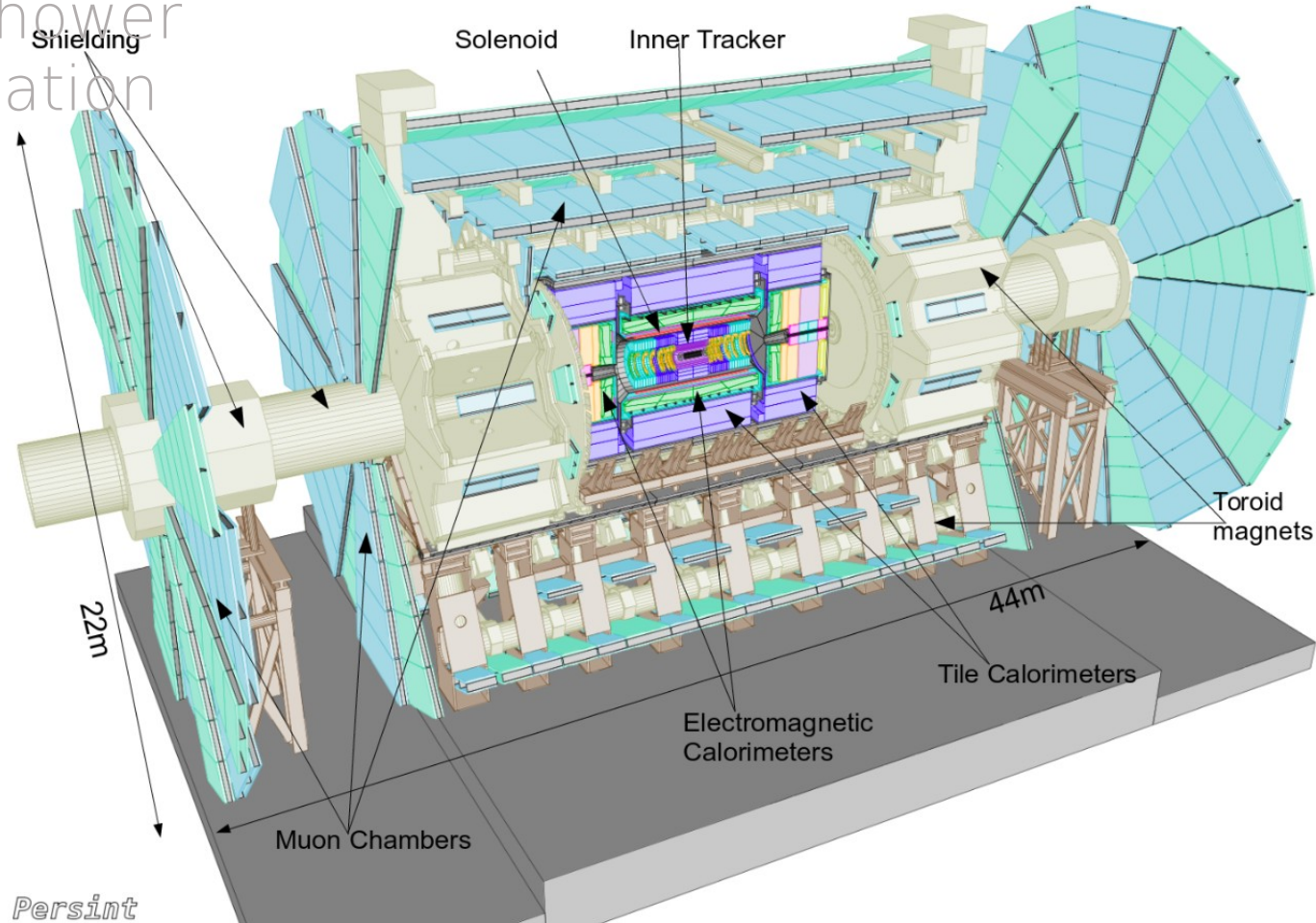
underlying event

parton shower

hadronisation

pile-up

détecteur



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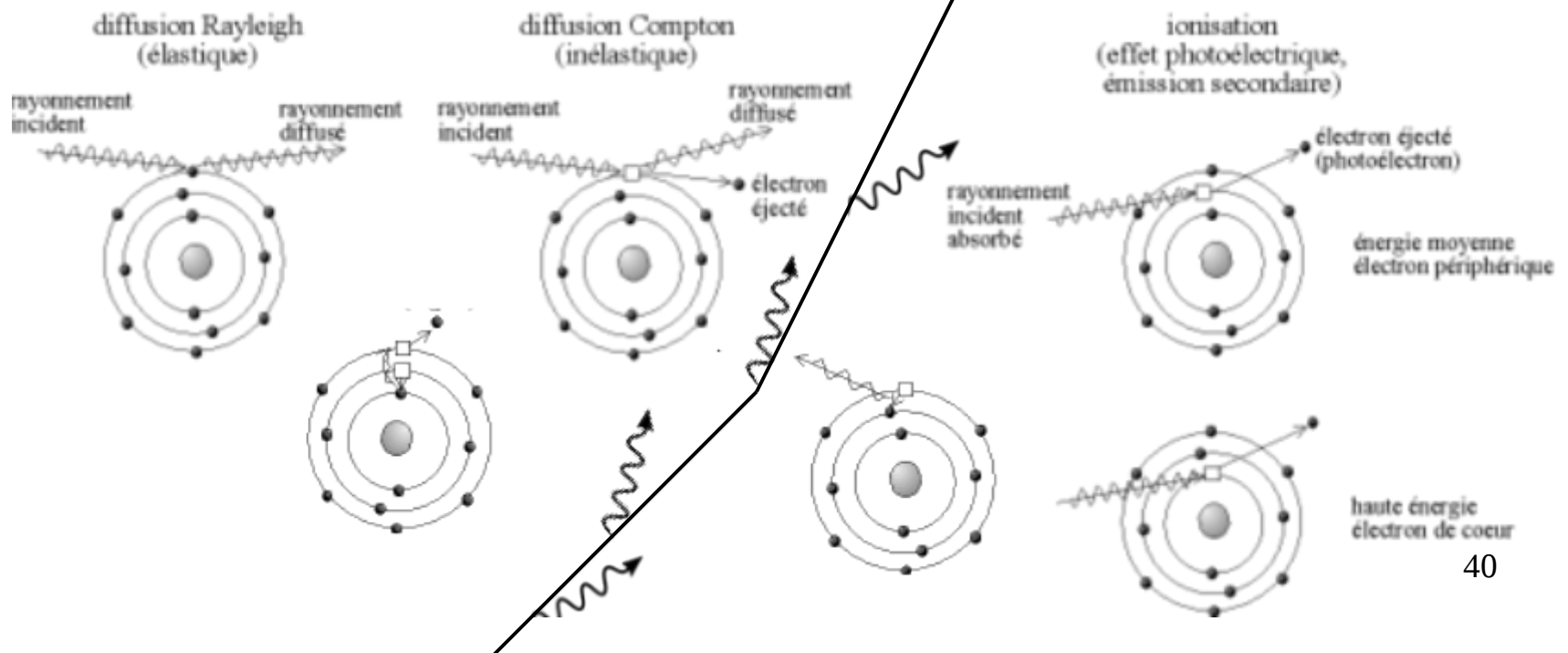
Conclusion

Mesures au LHC

Détecteur

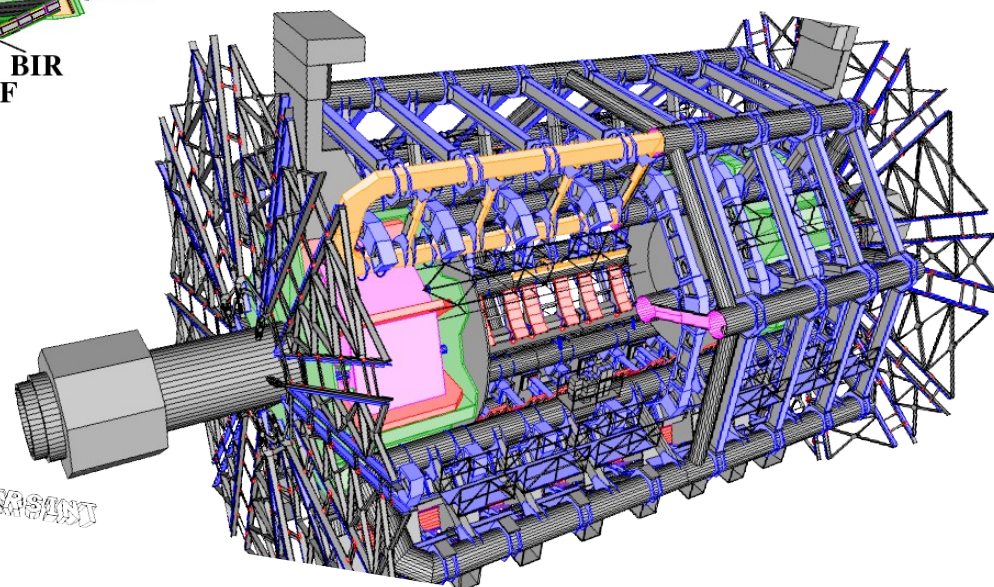
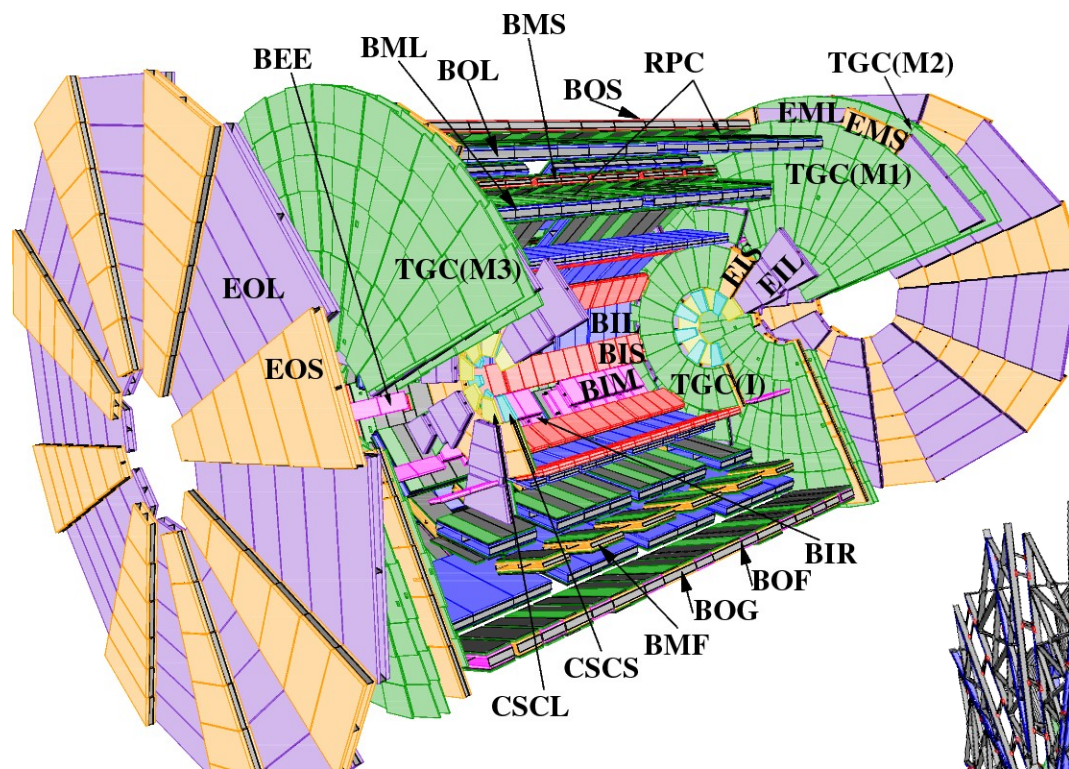
Ionisation (dE/dx)
Bremsstrahlung
Effet Čerenkov
Rayonnement de Transition

Fluctuations de Landau
Diffusion multiple
Création de paires (e^+/e^-)



Mesures au LHC

Détecteur description



Mesures au LHC

Détecteur

temps de mesures
résolution spatiale & en énergie

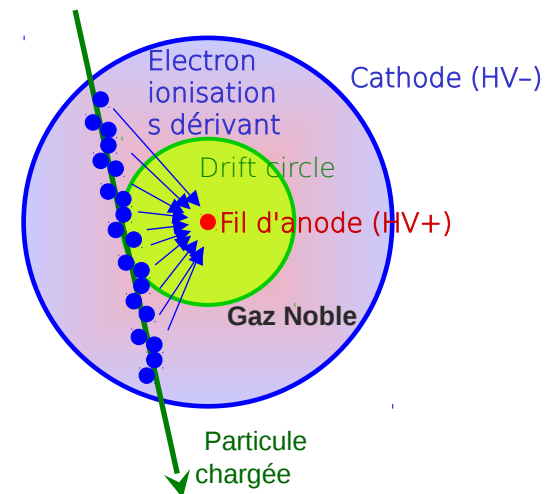
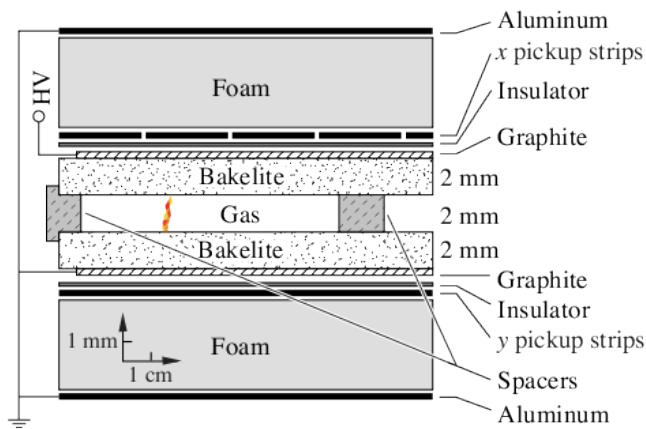
deux types de détecteurs

trigger :

rapide \sim ns résolution spatiale \sim mm

mesures :

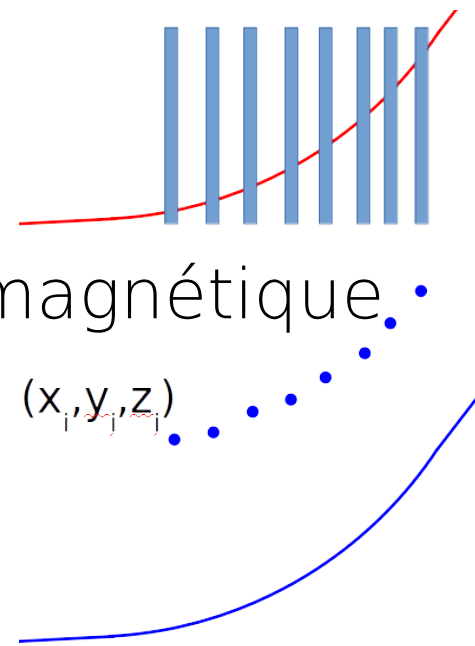
lent \sim μ s résolution spatiale \sim 10 μ m \rightarrow 100 μ m



Mesures au LHC

Détecteur

→ échantillonnage dans un champ magnétique



→ mesures (presque) directes

Q : charge

→ tracker + B

E : énergie

→ calorimètres

P : impulsion

→ tracker + B

V : vitesse

→ ionisation

R : position (vertex)

→ reconstruction all tracks

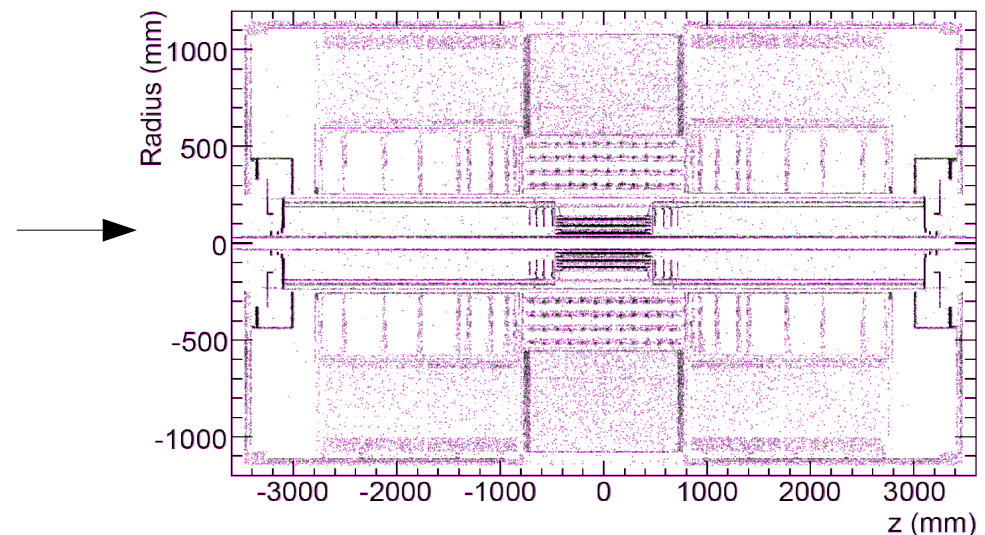
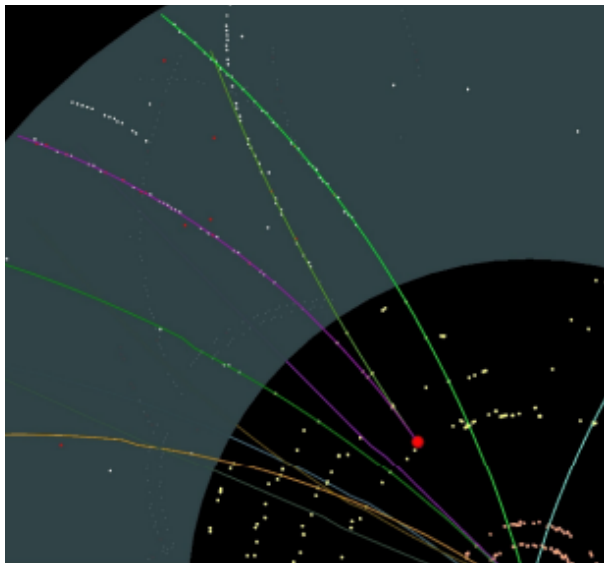
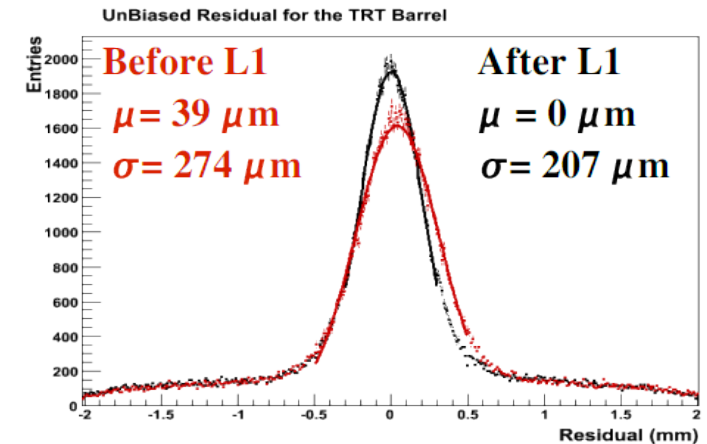
→ Photons, électrons, muons

→ Hadrons (jets ← $k, \pi, p, n, \Lambda, \dots$)

Mesures au LHC

Détecteur → simulation
→ estimation des performances
→ construction

Détecteur → données
→ étalonnage →
en faisceau test
cosmiques
résonances
mécanisme physique connu



Mesures au LHC

Détecteur

- mesures (presque) directes
 - Photons, électrons, muons
 - Hadrons (jets ← $k, \pi, p, n, \Lambda \dots$)

- mesures indirectes

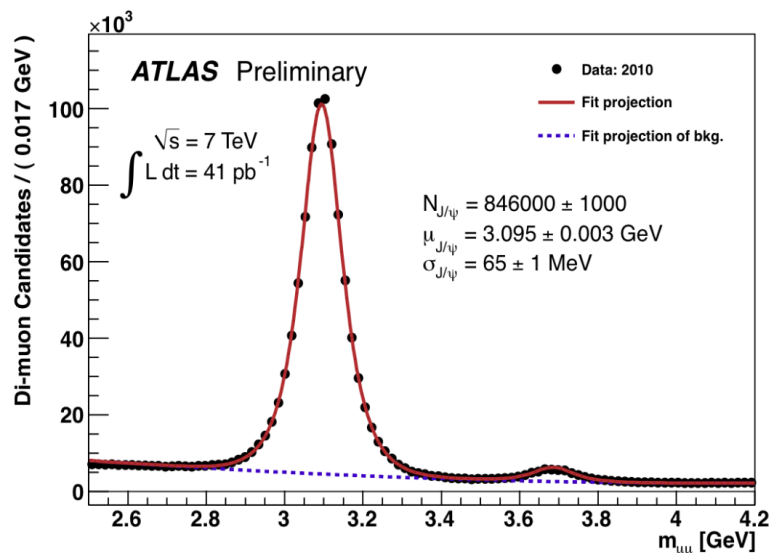
- jets

- énergie manquante

comprendre le détecteur : neutrino + NP ?

- identification statistique

- identification decays → résonances $h, Z, W, J/\psi \dots$



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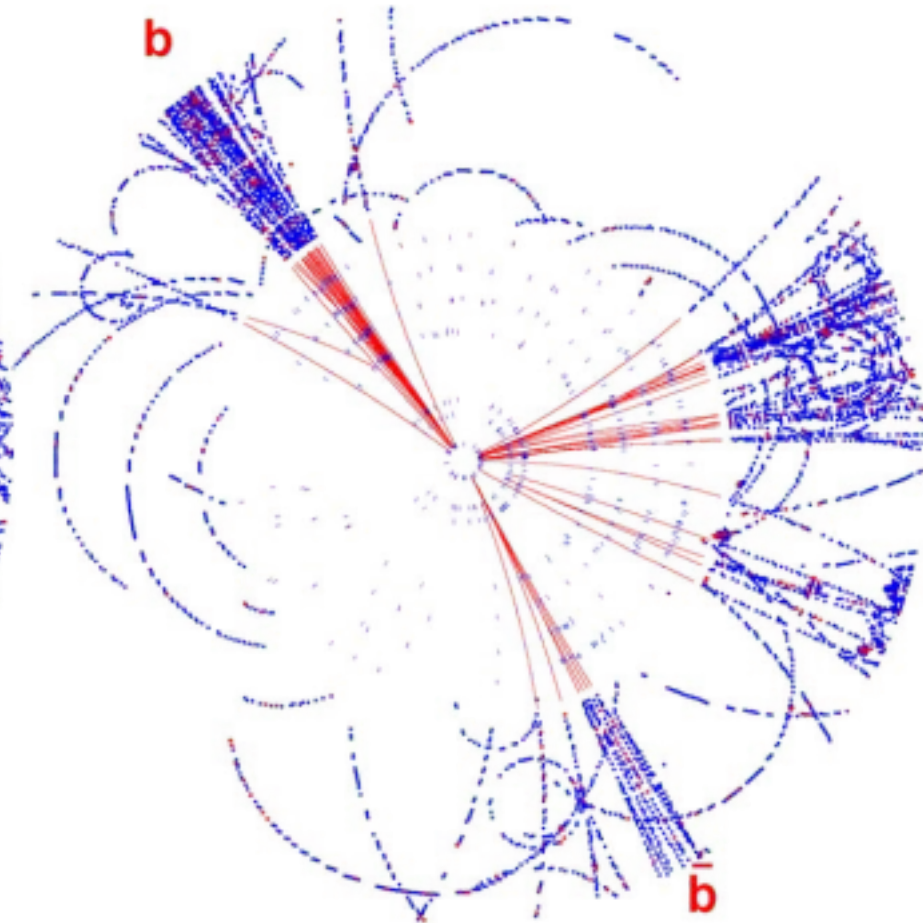
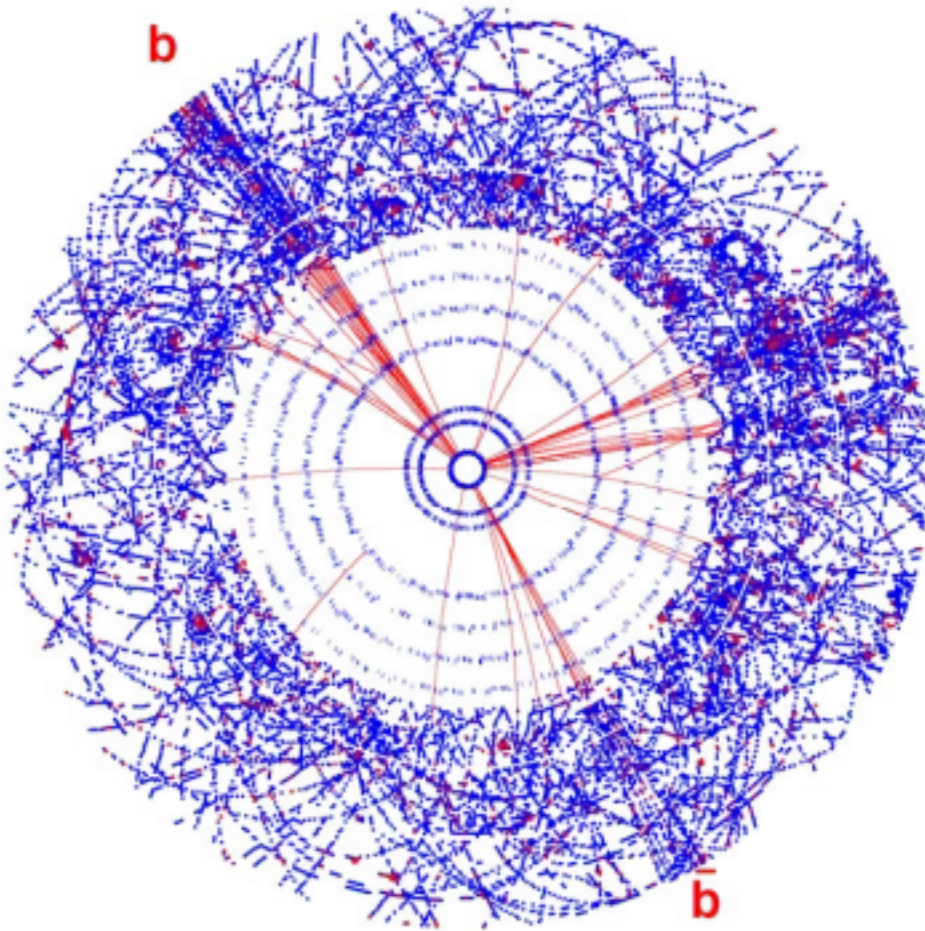
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Mesures au LHC

Détecteur → données + simulation
 → remesurer les processus connus

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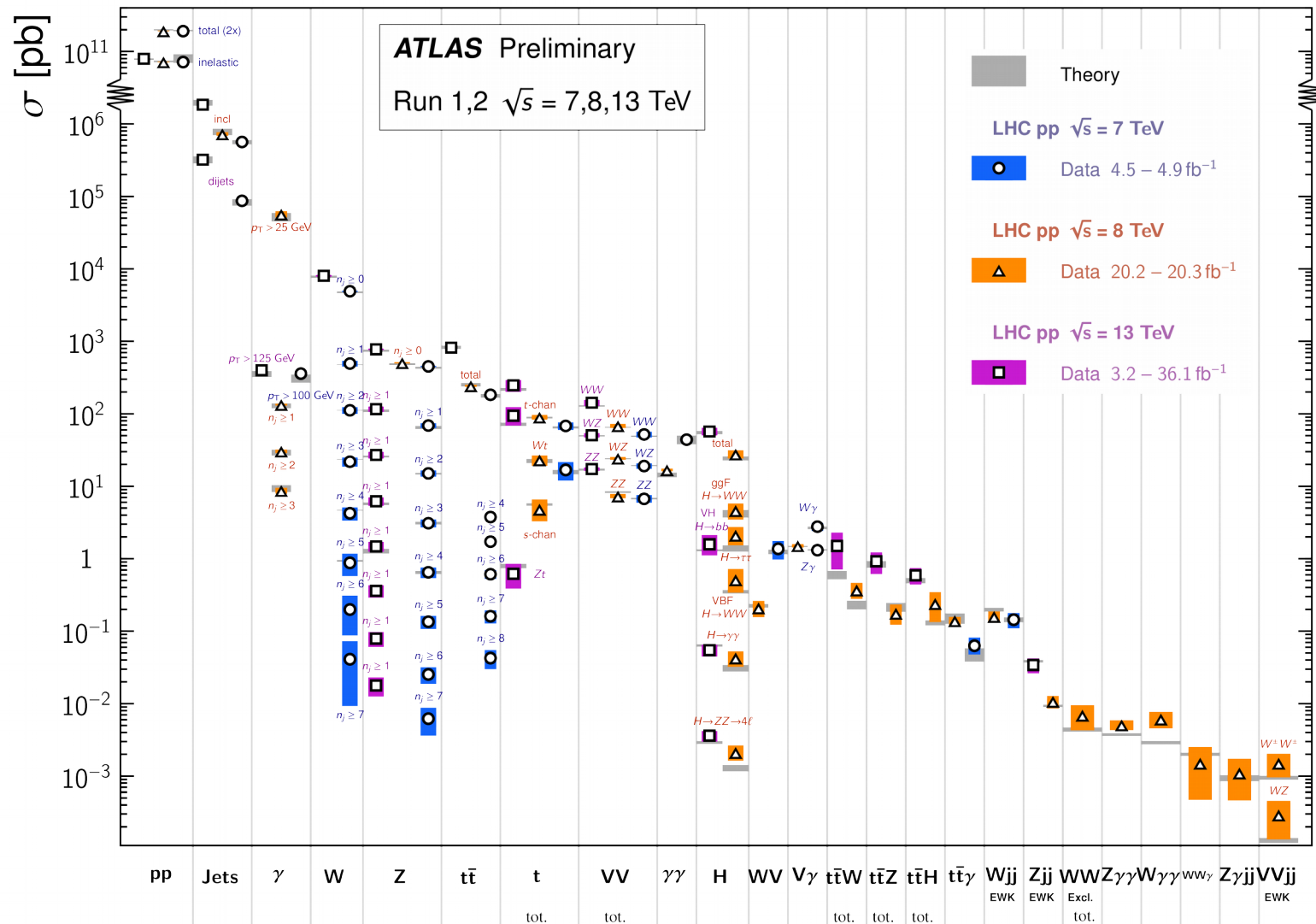
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Standard Model Production Cross Section Measurements

Status: March 2018



Mesures au LHC

DéTECTEUR : masse du W

Measurement of the W -boson mass in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

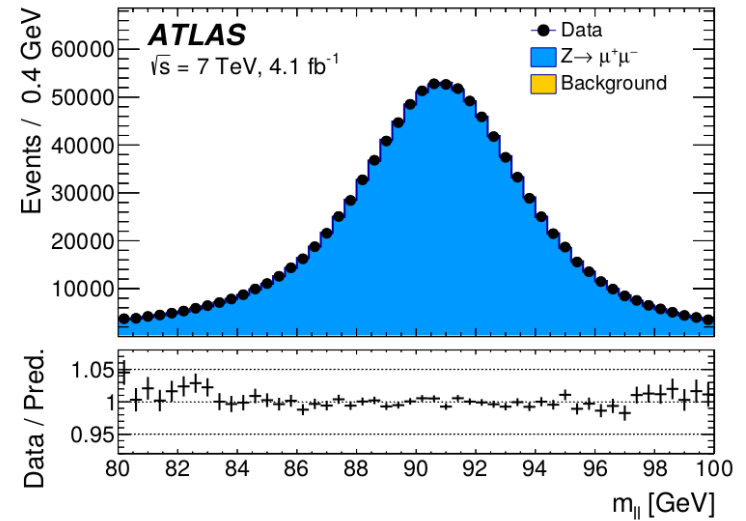
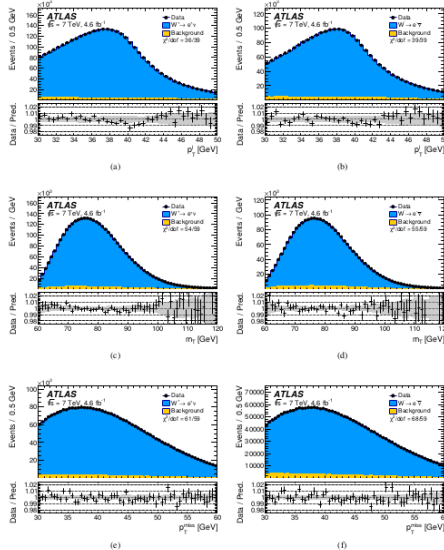
The ATLAS Collaboration

A measurement of the mass of the W boson is presented based on proton-proton collision data recorded in 2011 at a centre-of-mass energy of 7 TeV with the ATLAS detector at the LHC, and corresponding to 4.6 fb^{-1} of integrated luminosity. The selected data sample consists of 7.8×10^6 candidates in the $W \rightarrow \mu\nu$ channel and 5.9×10^6 candidates in the $W \rightarrow e\nu$ channel. The W -boson mass is obtained from template fits to the reconstructed distributions of the charged lepton transverse momentum and of the W boson transverse mass in the electron and muon decay channels, yielding

$$m_W = 80370 \pm 7 \text{ (stat.)} \pm 11 \text{ (exp. syst.)} \pm 14 \text{ (mod. syst.) MeV}$$

$$= 80370 \pm 19 \text{ MeV,}$$

where the first uncertainty is statistical, the second corresponds to the experimental systematic uncertainties, and the third to the physics-modelling systematic uncertainty. A measurement of the W^+ and W^- bosons yields $m_{W^+} - m_{W^-} =$



Channel	m_W m_T -Fit [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.
$W^+ \rightarrow \mu\nu, \eta < 0.8$	80371.3	29.2	12.4	0.0	15.2	8.1	9.9	3.4	28.4	47.1
$W^+ \rightarrow \mu\nu, 0.8 < \eta < 1.4$	80354.1	32.1	19.3	0.0	13.0	6.8	9.6	3.4	23.3	47.6
$W^+ \rightarrow \mu\nu, 1.4 < \eta < 2.0$	80426.3	30.2	35.1	0.0	14.3	7.2	9.3	3.4	27.2	56.9
$W^+ \rightarrow \mu\nu, 2.0 < \eta < 2.4$	80334.6	40.9	112.4	0.0	14.4	9.0	8.4	3.4	32.8	125.5
$W^- \rightarrow \mu\nu, \eta < 0.8$	80375.5	30.6	11.6	0.0	13.1	8.5	9.5	3.4	30.6	48.5
$W^- \rightarrow \mu\nu, 0.8 < \eta < 1.4$	80417.5	36.4	18.5	0.0	12.2	7.7	9.7	3.4	22.2	49.7
$W^- \rightarrow \mu\nu, 1.4 < \eta < 2.0$	80379.4	35.6	33.9	0.0	10.5	8.1	9.7	3.4	23.1	56.9
$W^- \rightarrow \mu\nu, 2.0 < \eta < 2.4$	80334.2	52.4	123.7	0.0	11.6	10.2	9.9	3.4	34.1	139.9
$W^+ \rightarrow e\nu, \eta < 0.6$	80352.9	29.4	0.0	19.5	13.1	15.3	9.9	3.4	28.5	50.8
$W^+ \rightarrow e\nu, 0.6 < \eta < 1.2$	80381.5	30.4	0.0	21.4	15.1	13.2	9.6	3.4	23.5	49.4
$W^+ \rightarrow e\nu, 1.8 < \eta < 2.4$	80352.4	32.4	0.0	26.6	16.4	32.8	8.4	3.4	27.3	62.6
$W^- \rightarrow e\nu, \eta < 0.6$	80415.8	31.3	0.0	16.4	11.8	15.5	9.5	3.4	31.3	52.1
$W^- \rightarrow e\nu, 0.6 < \eta < 1.2$	80297.5	33.0	0.0	18.7	11.2	12.8	9.7	3.4	23.9	49.0
$W^- \rightarrow e\nu, 1.8 < \eta < 2.4$	80423.8	42.8	0.0	33.2	12.8	35.1	9.9	3.4	28.1	72.3
p_T-Fit										
$W^+ \rightarrow \mu\nu, \eta < 0.8$	80327.7	22.1	12.2	0.0	2.6	5.1	9.0	6.0	24.7	37.3
$W^+ \rightarrow \mu\nu, 0.8 < \eta < 1.4$	80357.3	25.1	19.1	0.0	2.5	4.7	8.9	6.0	20.6	39.5
$W^+ \rightarrow \mu\nu, 1.4 < \eta < 2.0$	80446.9	23.9	33.1	0.0	2.5	4.9	8.2	6.0	25.2	49.3
$W^+ \rightarrow \mu\nu, 2.0 < \eta < 2.4$	80334.1	34.5	110.1	0.0	2.5	6.4	6.7	6.0	31.8	120.2
$W^- \rightarrow \mu\nu, \eta < 0.8$	80427.8	23.3	11.6	0.0	2.6	5.8	8.1	6.0	26.4	39.0
$W^- \rightarrow \mu\nu, 0.8 < \eta < 1.4$	80395.6	27.9	18.3	0.0	2.5	5.6	8.0	6.0	19.8	40.5
$W^- \rightarrow \mu\nu, 1.4 < \eta < 2.0$	80380.6	28.1	35.2	0.0	2.6	5.6	8.0	6.0	20.6	50.9
$W^- \rightarrow \mu\nu, 2.0 < \eta < 2.4$	80315.2	45.5	116.1	0.0	2.6	7.6	8.3	6.0	32.7	129.6
$W^+ \rightarrow e\nu, \eta < 0.6$	80336.5	22.2	0.0	20.1	2.5	6.4	9.0	5.3	24.5	40.7
$W^+ \rightarrow e\nu, 0.6 < \eta < 1.2$	80345.8	22.8	0.0	21.4	2.6	6.7	8.9	5.3	20.5	39.4
$W^+ \rightarrow e\nu, 1.8 < \eta < 2.4$	80344.7	24.0	0.0	30.8	2.6	11.9	6.7	5.3	24.1	48.2
$W^- \rightarrow e\nu, \eta < 0.6$	80351.0	23.1	0.0	19.8	2.6	7.2	8.1	5.3	26.6	42.2
$W^- \rightarrow e\nu, 0.6 < \eta < 1.2$	80309.8	24.9	0.0	19.7	2.7	7.3	8.0	5.3	20.9	39.9
$W^- \rightarrow e\nu, 1.8 < \eta < 2.4$	80413.4	30.1	0.0	30.7	2.7	11.5	8.3	5.3	22.7	51.0

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Conclusion

Mesures dépend de nombreux paramètres

- théories et modèles
- des mesures précédentes
- simulations
- détecteur
- statistique
- estimation des erreurs
- millions de lignes de code
- stockages + accès aux données
- millions d'heures de réunions
- autres....



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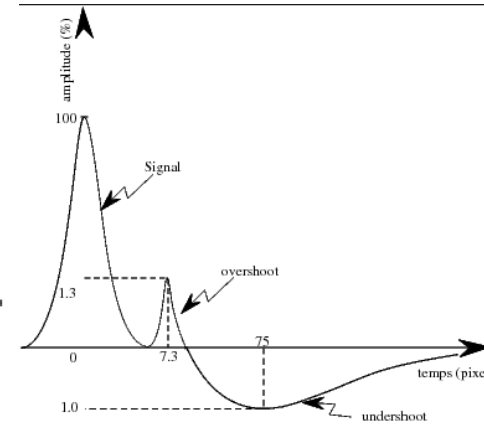
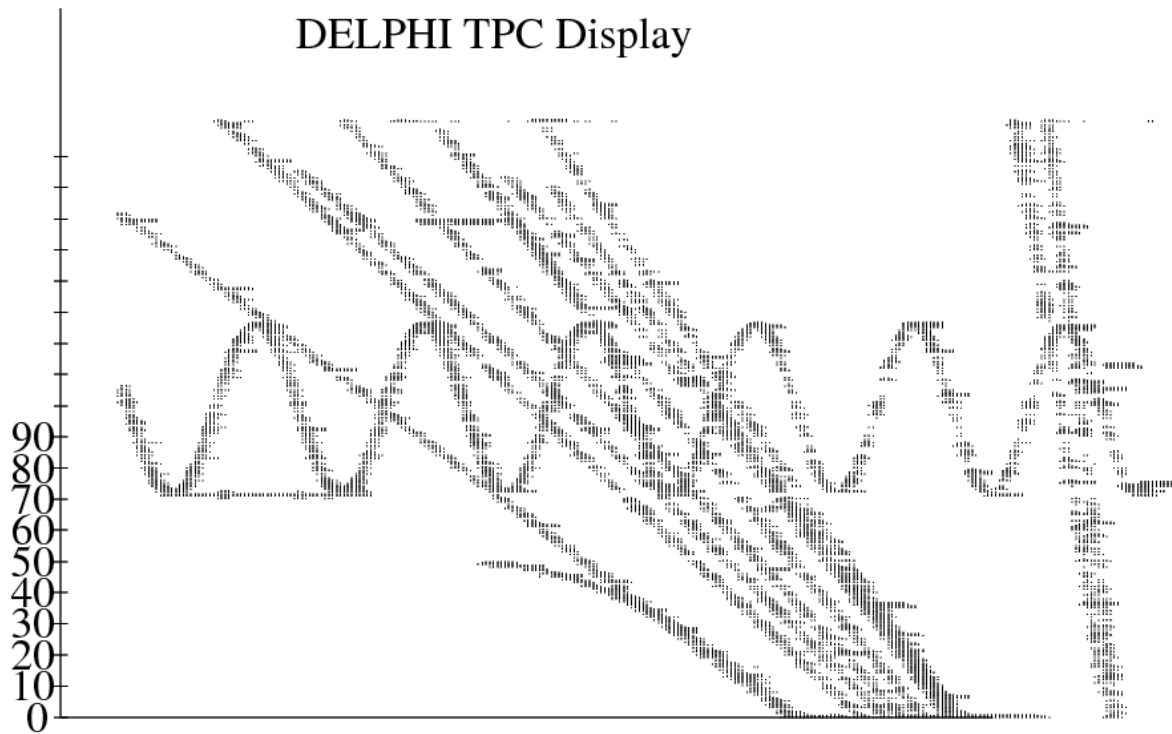
Erreurs

Statistique

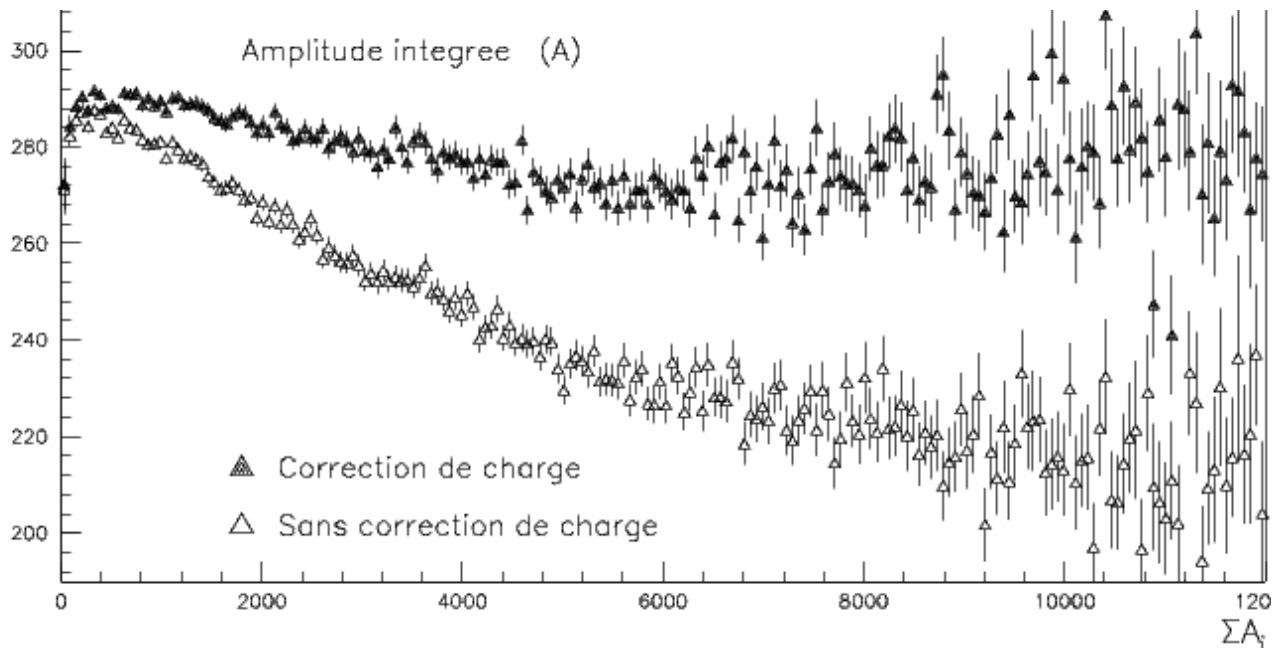
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DELPHI TPC Display



run = 22679 Sector number 4



ATLAS

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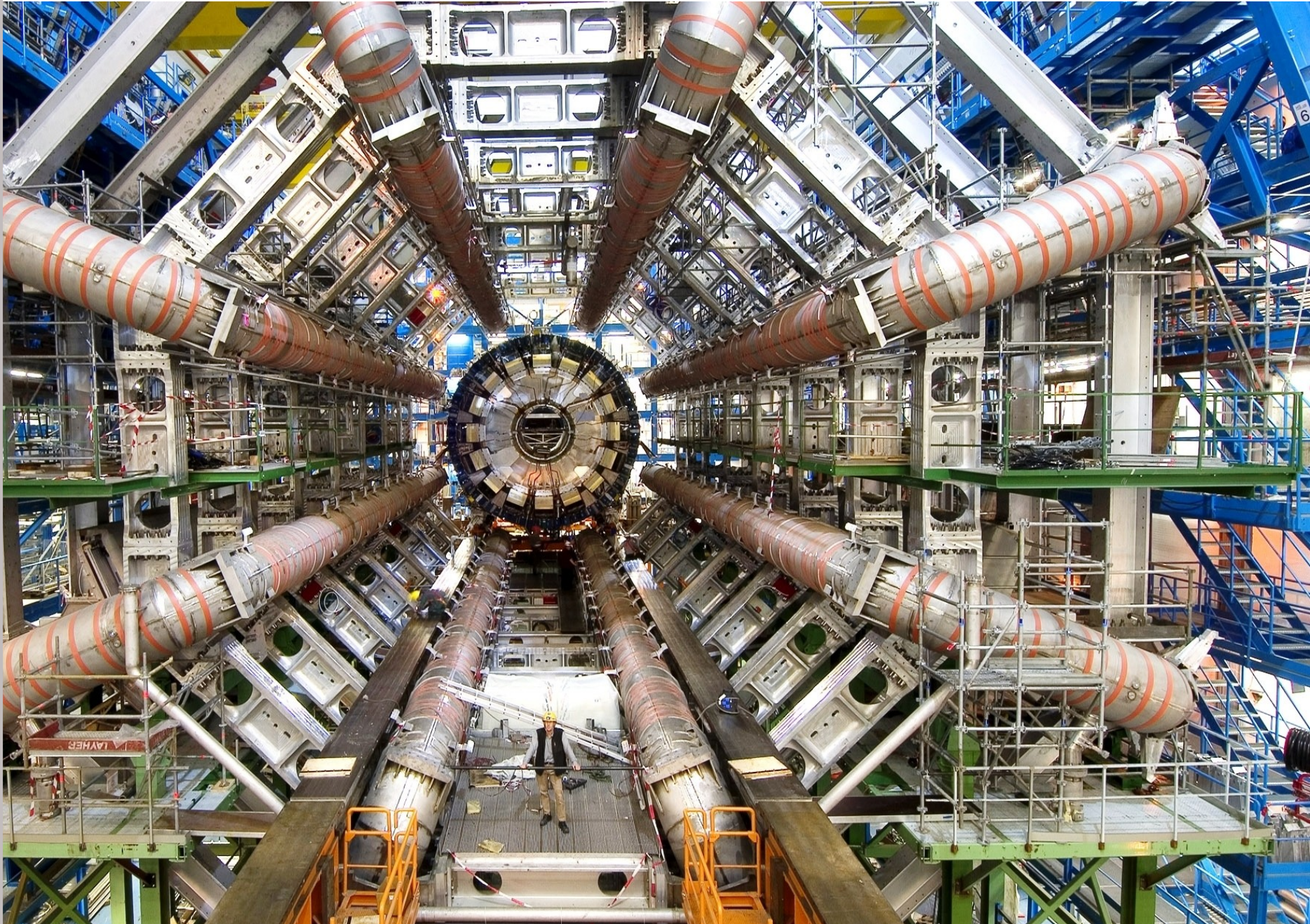
Simulation

Erreurs

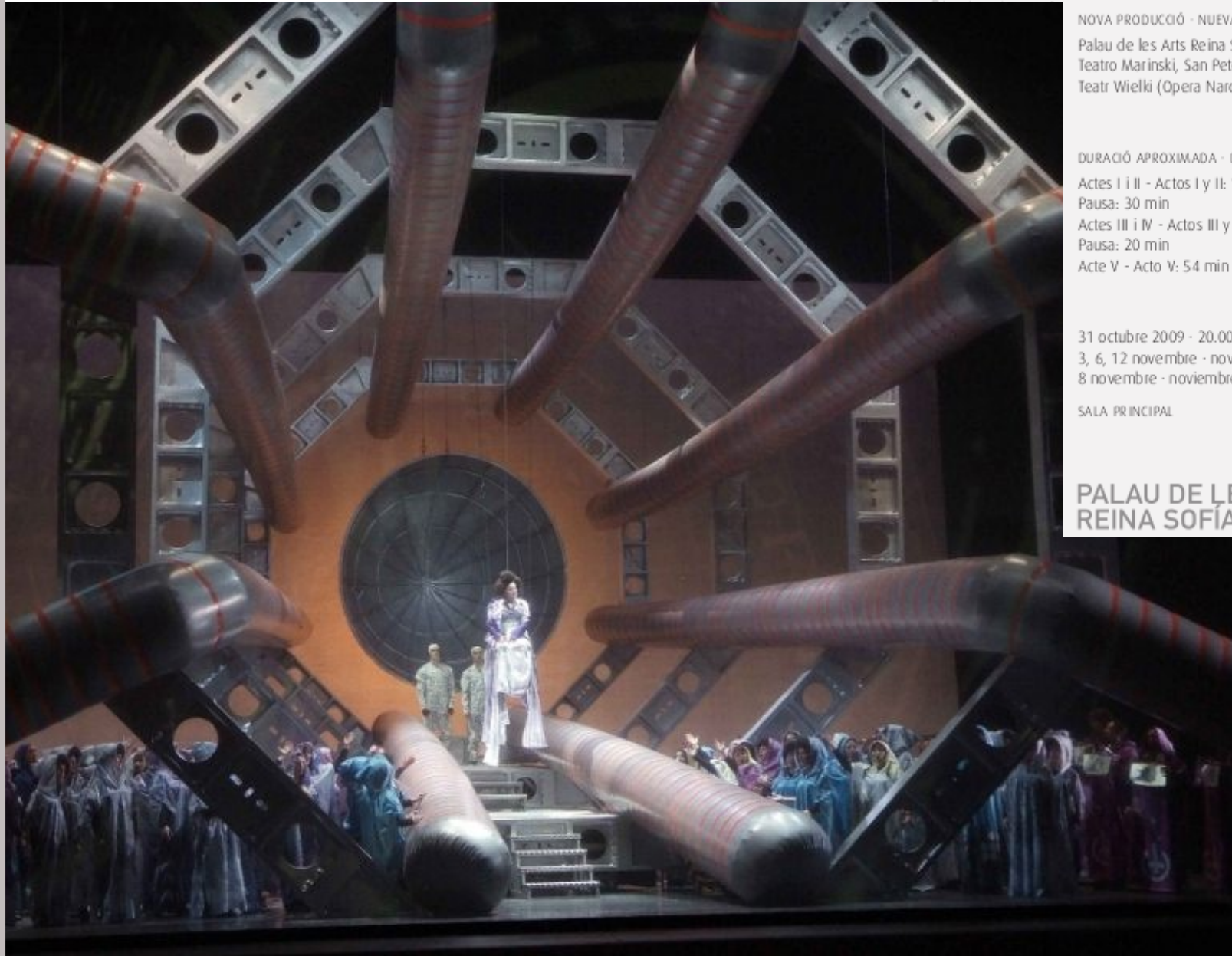
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HECTOR BERLIOZ Les Troyens



NOVA PRODUCCIÓN · NUEVA PRODUCCIÓN
Palau de les Arts Reina Sofía
Teatro Marinski, San Petersburgo
Teatr Wielki (Opera Narodowa), Varsovia

DURACIÓ APROXIMADA · DURACIÓN APROXIMADA
Actes I i II - Actos I y II: 1 h 21 min
Pausa: 30 min
Actes III i IV - Actos III y IV: 1 h 42 min
Pausa: 20 min
Acte V - Acto V: 54 min

31 octubre 2009 - 20.00 h
3, 6, 12 novembre - noviembre 2009 - 20.00 h
8 novembre - noviembre 2009 - 19.00 h

SALA PRINCIPAL

**PALAU DE LES ARTS
REINA SOFÍA** Temporada 20

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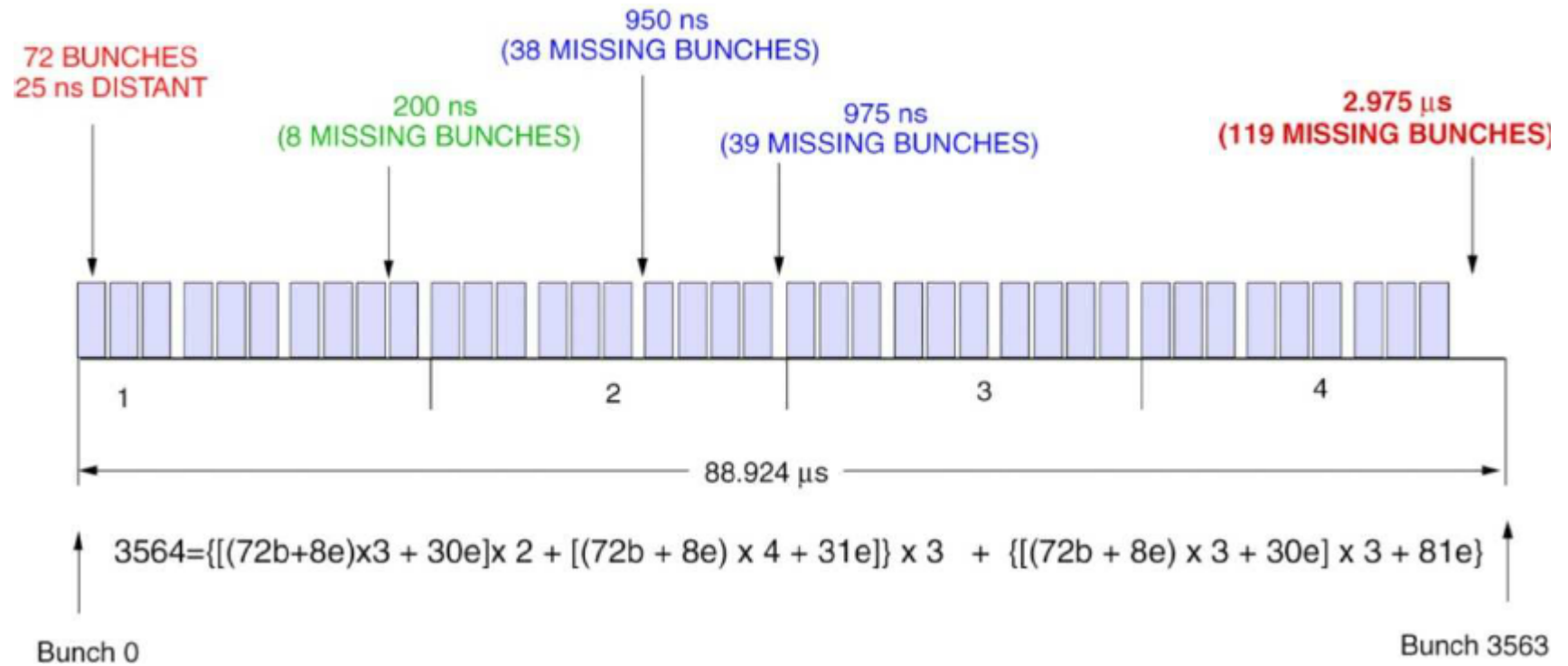
Conclusion

Les devises Shadok



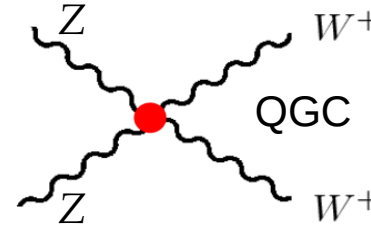
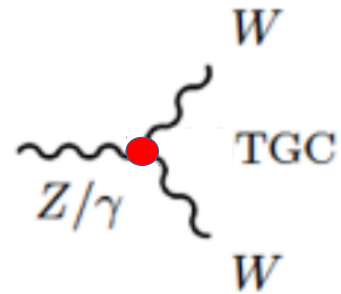
S'IL N'Y A PAS DE SOLUTION
C'EST QU'IL N'Y A PAS DE PROBLÈME.

LHC bunch structure

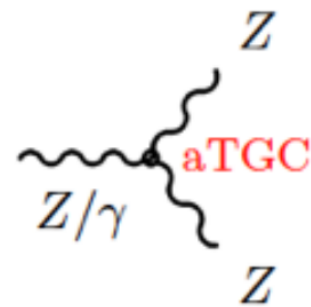
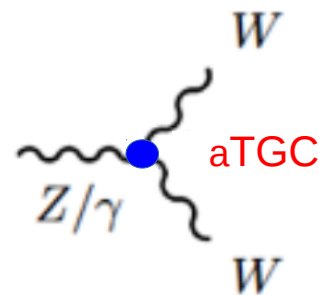


SM

Non-Abelian structure of $SU(2)_L \times U(1)_Y$
 allow TGC(charged only) & QGC (charged only)



aTGC



coupling	aTGC parameters (All = 0 in SM)	channel
$WW\gamma$	$\lambda_\gamma, \Delta\kappa_\gamma$	$WW, W\gamma$
WWZ	$\lambda_Z, \Delta\kappa_Z, \Delta g_1^Z$	WW, WZ
$ZZ\gamma$	h_3^Z, h_4^Z	$Z\gamma$
$Z\gamma\gamma$	h_3^γ, h_4^γ	$Z\gamma$
$Z\gamma Z$	$f_{40}^\gamma, f_{50}^\gamma$	ZZ
ZZZ	f_{40}^Z, f_{50}^Z	ZZ

EFT

Λ : scale of new physics

$\mathcal{O}_i^{(d)}$: new operators of higher dimensions (d)

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_d \sum_i \frac{c_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

=> Modify differential and total cross sections

