# Exercise 1 : Hunting the chargino !

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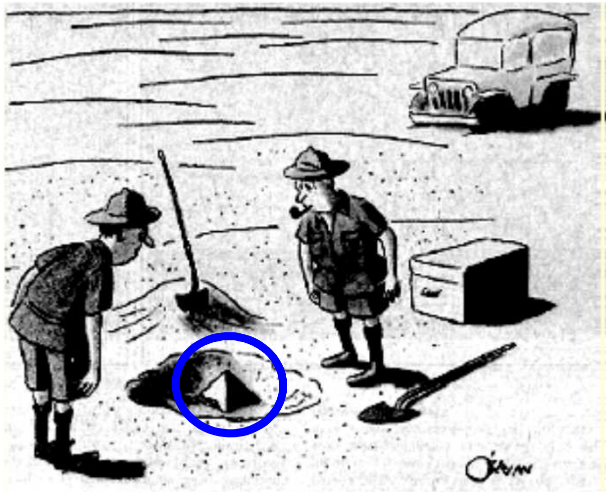
**Lectures at Niels Bohr Institute**



*"This could be the discovery of the century. Depending, of course, on how far down it goes"*

**Part II (3 lectures + 2 exercises)**
Direct SUSY searches at LHC

| W 30-Oct | Th 31-Oct | Fr 01-Nov |
|---|---|---|
| -- | Lecture IIA<br>**Exercise 1** | Lecture IIC<br>**Exercise 2** |
| Lecture IA<br>Lecture IB | **Exercise 1**<br>Lecture IIB | **Exercise 2**<br>Lecture III |

# Exercise 1

## ❑ General Question : can we discover the chargino at LHC ?

- We know it's hard but we will try to be quantitative !

## ❑ Organisation:

- 15' : Put in context: what we should know about EWKino sector for this exercise
- 30' : Background : how to reduce them, which one dominates ? [WIDE DISCUSSION]
- Form groups of 2 people
- 1h : Signal Region definition : what discriminating variables ? [USE OF ROOT MACRO]

------------------------------ BREAK -----------------------------------------------------------------------

- 1h : Signal Region definition : SR design and sensitivity expected [USE OF ROOT MACRO]
- 30' : Compare with the published results …
- 15' : Impact of this study and left-over ?

## ❑ Root Macro: 557 MB (!) → Check that the macro works on your laptop before the exercise !!

- http://www.cern.ch/pralavop/SUSYAnalyzer.tar.gz [Final version have files dated 15-Oct]
- When downloaded: tar -xzvf SUSYAnalyzer.tar.gz; cd SUSYAnalyzer and follow README
- Originally setup for ROOT 5.34.05. Works for 5.28/00 onwards.

# Context (0)

$R_P$=-1

| Names | Spin | $P_R$ | Gauge Eigenstates | Mass Eigenstates |
|---|---|---|---|---|
| Higgs bosons | 0 | +1 | $H_u^0\ H_d^0\ H_u^+\ H_d^-$ | $h^0\ H^0\ A^0\ H^\pm$ |
| squarks | 0 | −1 | $\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ | (same) |
| | | | $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ | (same) |
| | | | $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$ | $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$ |
| sleptons | 0 | −1 | $\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ | (same) |
| | | | $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ | (same) |
| | | | $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$ | $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$ |
| neutralinos | 1/2 | −1 | $\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$ | $\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$ |
| charginos | 1/2 | −1 | $\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$ | $\tilde{C}_1^\pm\ \tilde{C}_2^\pm$ |
| gluino | 1/2 | −1 | $\tilde{g}$ | (same) |
| goldstino (gravitino) | 1/2 (3/2) | −1 | $\tilde{G}$ | (same) |

**2- SUSY**: Each **gauge** field has a partner with S-1/2 in the vector multiplet

$c_W = \cos\theta_W$
$s_W = \sin\theta_W$
$c_\beta = \cos\beta$
$s_\beta = \sin\beta$

$$\begin{pmatrix} M_1 & 0 & -c_\beta\, s_W\, m_Z & s_\beta\, s_W\, m_Z \\ 0 & M_2 & c_\beta\, c_W\, m_Z & -s_\beta\, c_W\, m_Z \\ -c_\beta\, s_W\, m_Z & c_\beta\, c_W\, m_Z & 0 & -\mu \\ s_\beta\, s_W\, m_Z & -s_\beta\, c_W\, m_Z & -\mu & 0 \end{pmatrix}$$

Mixing

Bino, Wino, Higgsino → Neutralinos

| Names | Spin | $P_R$ | Gauge Eigenstates | Mass Eigenstates |
|---|---|---|---|---|
| neutralinos | 1/2 | −1 | $\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$ | $\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$ |
| charginos | 1/2 | −1 | $\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$ | $\tilde{C}_1^\pm\ \tilde{C}_2^\pm$ |

Charginos

$$\begin{pmatrix} M_2 & \sqrt{2} s_\beta\, m_W \\ \sqrt{2} c_\beta\, m_W & \mu \end{pmatrix}$$

Masses of Gauge Eigenstates

Bino Wino Higgsino

**4 param.** M1, M2, μ, tanβ

Ratio of SUSY Higgses vevs

# Context (1)

## ❑ All what you need to know about the chargino

- Linear combination of charged Wino and Higgsino.
  - ✓ J=1/2
  - ✓ Naturalness (10%) → m ~ 200-400 GeV
- Theory Unknowns:

| |
|---|
| 1- **SUSY Breaking** (SUGRA, GMSB, AMSB) |
| 2- **RPC** vs **RPV** |
| 3- **Open** or **compressed** spectra |

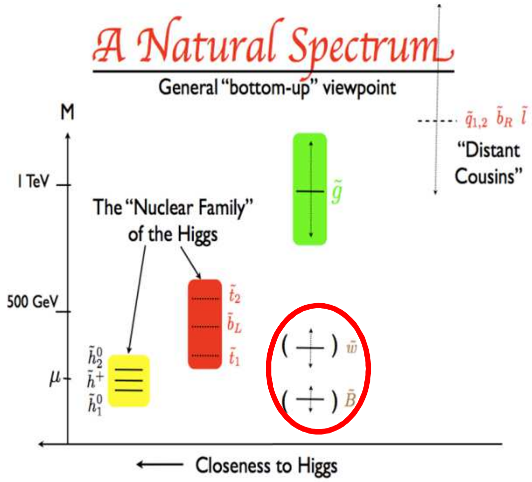
Assumptions for the exercise:

1. **SUGRA-like (N1=LSP)**: N1 Bino / C1 Wino**, i.e. n**ot natural but highest cross-section
2. Rparity conserved: pair produced, decay to LSP
3. **Open** spectra: ΔM(C1-N1) > M(W) →BR(C1→WN1)=100%

→ **Only 2 new particles beyond SM: C1 and N1**

✓ All other particles decoupled (conservative) !

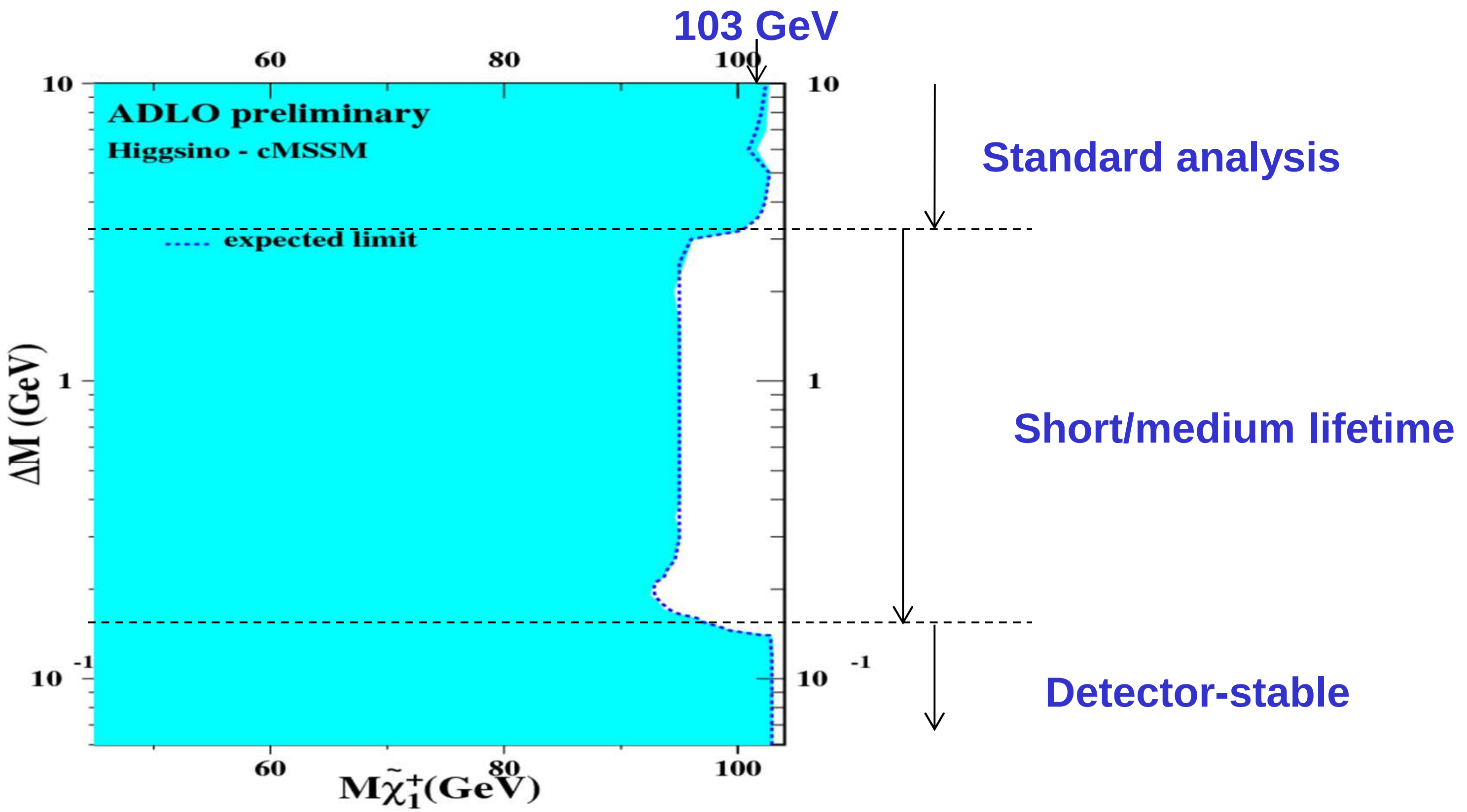
→ **Considerable hole in the natural searches** *(N. Craig, 1309.3568)*




~SUGRA
**Bino-Wino case**
Open Spectra

# Context (2)

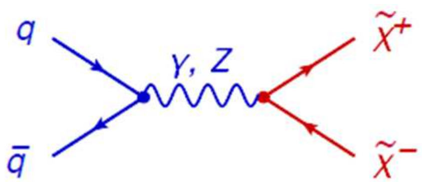
- **All what you need to know about the chargino**
  - Main limit come from LEP2 (RPC or RPV):




Still far from the natural mass of the chargino …

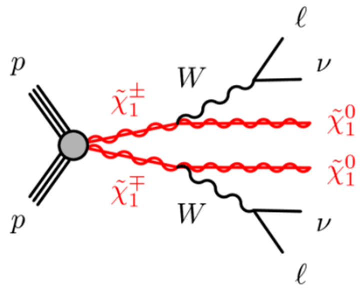
# Context (3)

## ❑ Cross-section and final state



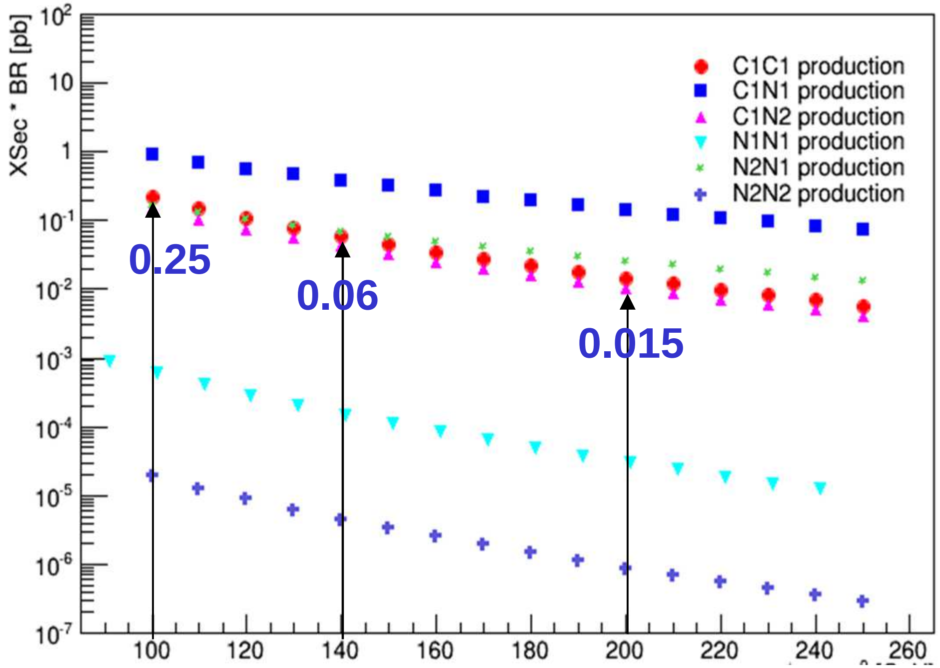

J=1/2

J=1/2



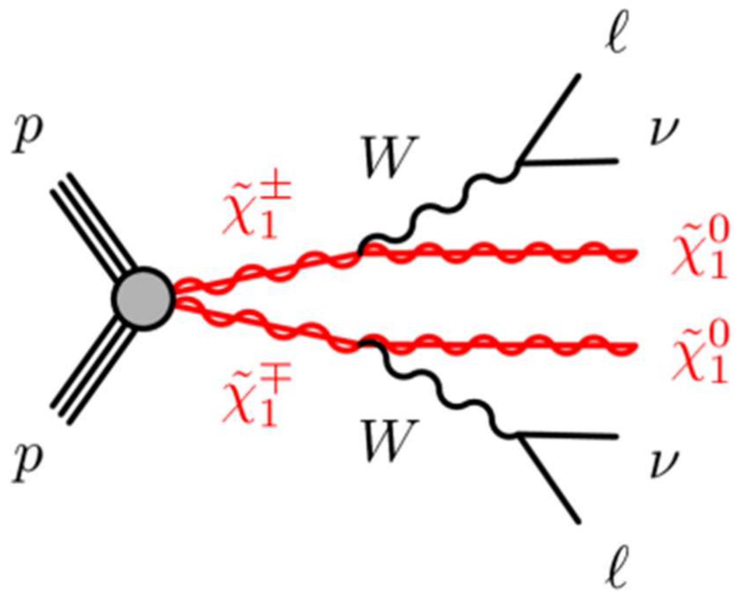

Final state: 2l + MET

BR stands for
W→lν (l=e/μ)
**BR=0.21²~0.05**



# Background

**Final state: 2l (e,mu)+ MET**

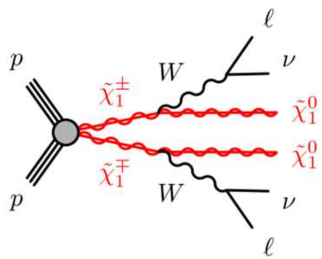



Other final states (1l+2j, 0l+4j) more complicated a priori …

# Background

## ❑ Main Questions

Final state: 2l + MET




1. What are the potential Backgrounds ?

2. How to remove most of them ?

3. What is the hardly reducible Background ?

4. What will be the dominant systematics (Exp or theory) ?

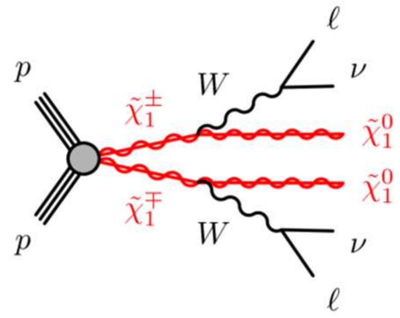
5. How to control this dominant background ?

# Background (6)

l=e/μ

## ❑ Recap

- Deduce sensitivity (Zn) assuming a relative error on background (x)
  - ✓ Zn ~ ***S/(√B+(x*B)^2)*** **→ *5 can discover !, =2 can exclude @95%***
  - ✓ Do it for x=0.00001 - 10 – 20 %




| W→lν, l = e/μ | N(Sig) | N(WW) | N(H→WW) |
|---|---|---|---|
| Initial | 5000 | 52000 | 3600 |
| After pre-selection | 750 | 7800 | 1100 |
| Z(x~0) | ~8 | | |
| Z(x=0.1) | ~0.8 | | |
| Z(x=0.2) | ~0.4 | | |

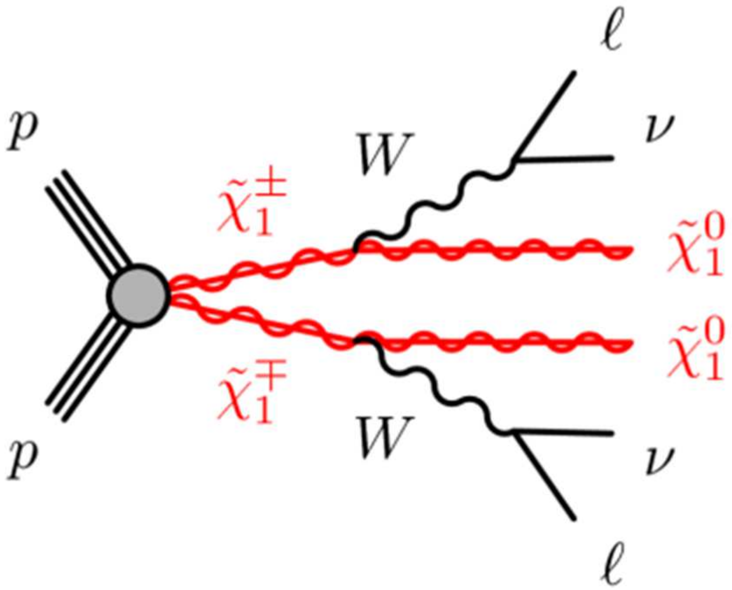
***√B~95***

No sensitivity with the highest possible cross-section (mC1=100 GeV) (applies to Z(x=0.1) and Z(x=0.2))

Need to increase sensitivity !!!

# Signal Region

**Final state: 2l (emu)+ MET**



# Signal Region (1)

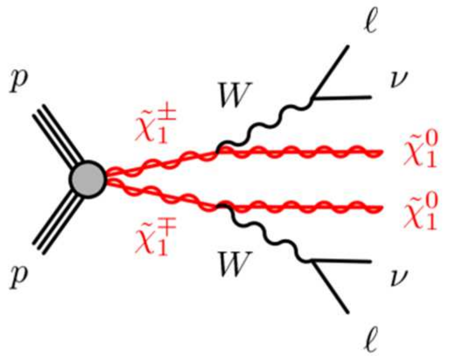
## ❑ Design Signal Region to enhance sensitivity

- Now we know what is the dominant background to kill (WW, HWW)

  1- What variables do you have at hand ?

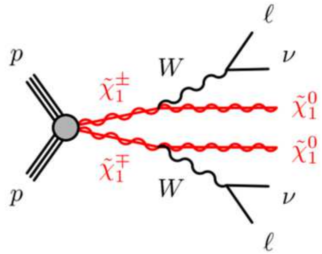
  2- What discriminant variable to choose (if any) ?

**Final state: 2l + MET**



# Signal Region (3)

## ❑ Design Signal Region to enhance sensitivity




- Now we know what is the dominant background to kill (**WW, HWW**)

  1- What variables to you have at hand ?

  2- What discriminant variable to choose ?

- Macro: Truth level (can not give you ATLAS data, not public !), include the main background, automatically compute Zn, …

- Run with default configuration

------------ QUESTIONS -------------------------

- **Change the cuts as you wish to increase signal sensitivity:**

  →3 signal points: C1,N1=(100,0) ; (140,0) ; (200,0)

  → Find the best signal region for each point !!!

  → Will then compare to ATLAS results (optimize with reconstructed events not truth)

# Signal Region (4)

l=e/μ/τ

## ❑ Key numbers without any cuts

- isOS&&n_signal_L20jets==0&&n_signal_F30jets==0&&n_signal_B20jets==0&&isemu

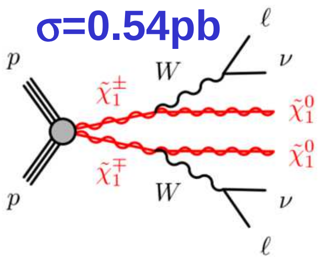
*Cut Efficiency ε(S)~ 11 % , ε(B1)~10%, ε(B2)~12.5%*

**L = 20300pb$^{-1}$**

| W→lν, l = e/μ/τ | N(Sig) | N(WW) | N(H→WW) |
|---|---|---|---|
| Initial | 10860 | 125860 | 6900 |
| After pre-selection | 1180 | 12500 | 860 |
| Z(dB~0) | ~10 | | |
| Z(dB=0.1) | ~0.8 | | |
| Z(dB=0.2) | ~0.3 | | |

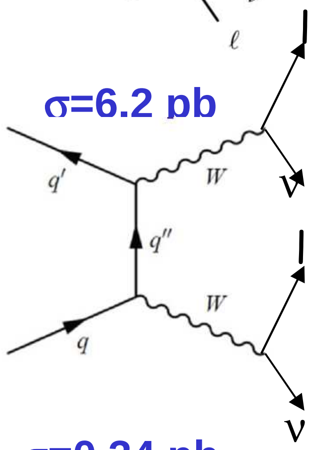
**M=100 GeV**
**σ=0.54pb**

S



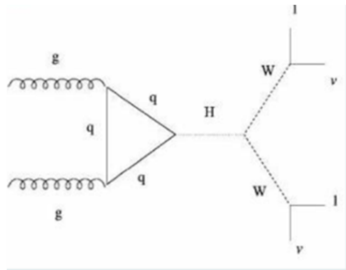

**σ=6.2 pb**

B1



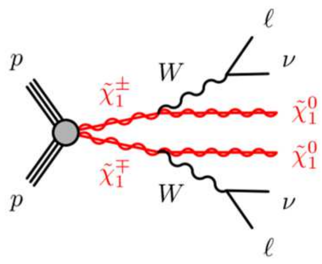

**σ=0.34 pb**

B2



# Impact of the study

- Can we increase sensitivity to this signal with 20 fb-1 ?



- WW Cross-section has one sigma excess. Hint of SUSY ?

# Exercise 1: Homework (1)

## 1. Redo sensitivity studies for ee and mumu. What do we gain ?

- Assume WW still dominant since Z+X background can be killed by a Zveto
- Compute Zn(**ee**) and Zn(**mumu**)
- Add all Zn in quadrature to obtain the new sensitivity
  - → Does it help to exclude the signal ??

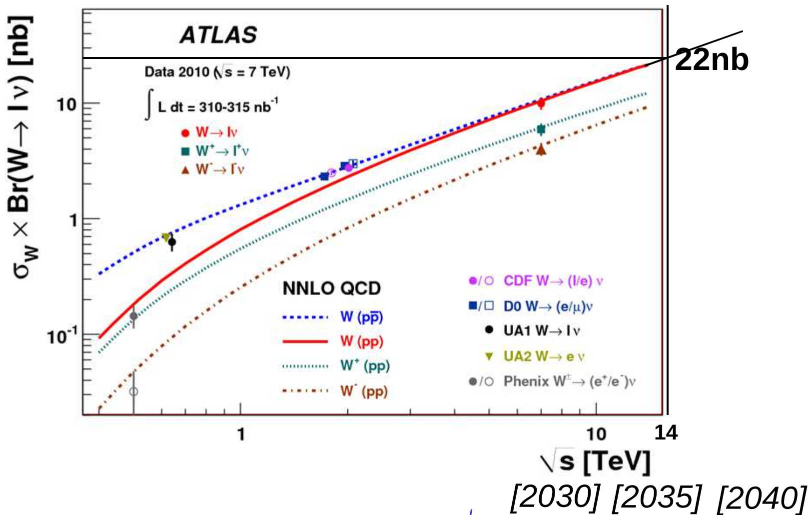
## 2. Can you discover the Higgs boson (H→WW) ?

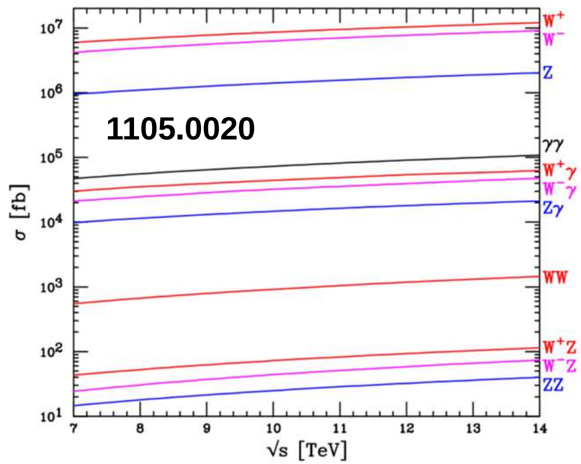
- Focus on the **emu** channel
- Assume same preselection and that **WW** is still the dominant background
- How to modify the cuts to enhance Higgs signal ? Consider new discriminant variable ?

# Exercise 1: Homework (2)

## 3. The chargino in the next decades

- Up to what mass can we go with higher luminosity ?
  - ✓ Rerun the macro with an increased luminosity L = 300 *[2022]* / 3000 $fb^{-1}$ *[2030]*
  - ✓ Rescale also cross-section by a factor ~ 2 for S and B:  8 → 14 TeV
  - ✓ And assume B(reco)=B(true)/1.5[1] for SRWWa[b,c]




- Competition between ILC (√s=250, 500, 1000 GeV) and LHC14 ?
  - ✓ Assume that reachable mass at ILC is M(C1)=√s/2
  - ✓ Who wins in 2030 ? 2035 ? and 2040 ?