# ***Physics at Very High Luminosity Collider***

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# Post-LHC pp colliders

- *VHLC/SLHC:*
  **(ATLAS-PHYS-2001-002)**
  - *$L = 5x10^{34} – 10^{35}$ cm$^{-2}$s$^{-1}$*
  - *Ös=14 ® 28 TeV*

*Pro's & Con's*

- *civil engineering done*
- *detectors ready (?)*
  - *radiation damage*
  - *pile-up at >>$10^{34}$ cm$^{-2}$s$^{-1}$*
- *B=17 T (do not exist yet)*

- *VLHC:*
  **(Fermilab-TM-2149)**
  - *Stage I: Ös=40 TeV, $L = 10^{34}$ cm$^{-2}$s$^{-1}$*
  - *Stage II (post-LHC/NLC):*

| Ös (TeV) | 125 | 150 | 175 | 200 |
|---|---|---|---|---|
| $L$ x$10^{-34}$ (cm$^{-2}$s$^{-1}$) | 5.1 | 3.6 | 2.7 | 2.1 |

*Pro's & Con's*

- *new machine*
- *40 TeV ® B=2 T*

# General Remarks

- For processes where $n_{obs}$ µ $L/(Ös)^2$
  (ie. W' production) Ös xN « L $xN^2$
- To explore scales beyond 1 TeV an increase in Ös is better (mandatory) than an increase in L
- Available "full-simulation" studies (ATLAS) on:
  - $L = 10^{34}\ cm^{-2}s^{-1}$ Ös=14 TeV
  - $L = 10^{35}\ cm^{-2}s^{-1}$* Ös=14 TeV
  - $L = 10^{34}\ cm^{-2}s^{-1}$ Ös=28 TeV*
  - $L = 10^{35}\ cm^{-2}s^{-1}$* Ös=28 TeV*

* 12.5 ns bunch spacing

* "speculative"

- To compete with VLHC:
  Ös=28 TeV and $L = 10^{35}\ cm^{-2}s^{-1}$

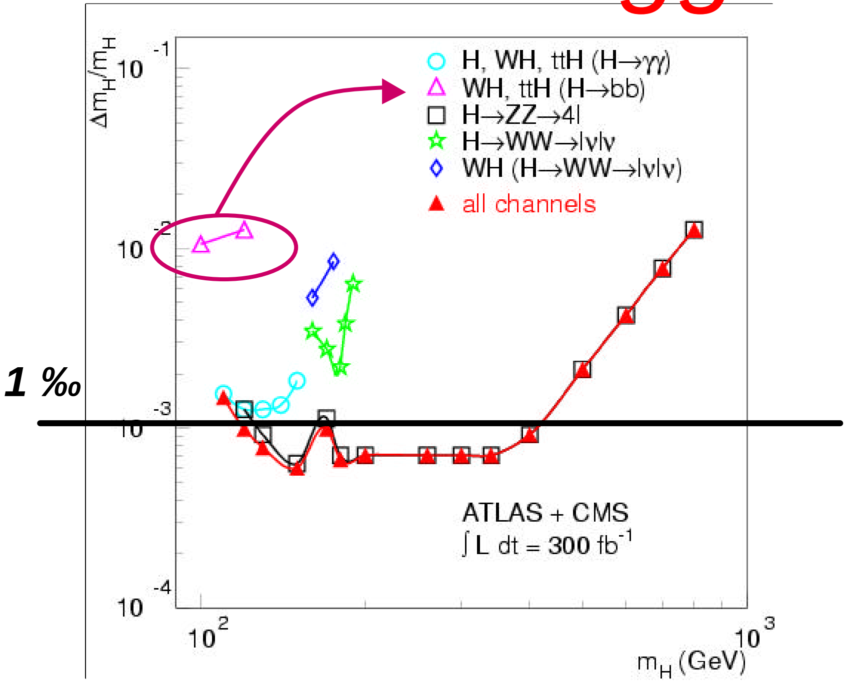
# *Rest of the talk*

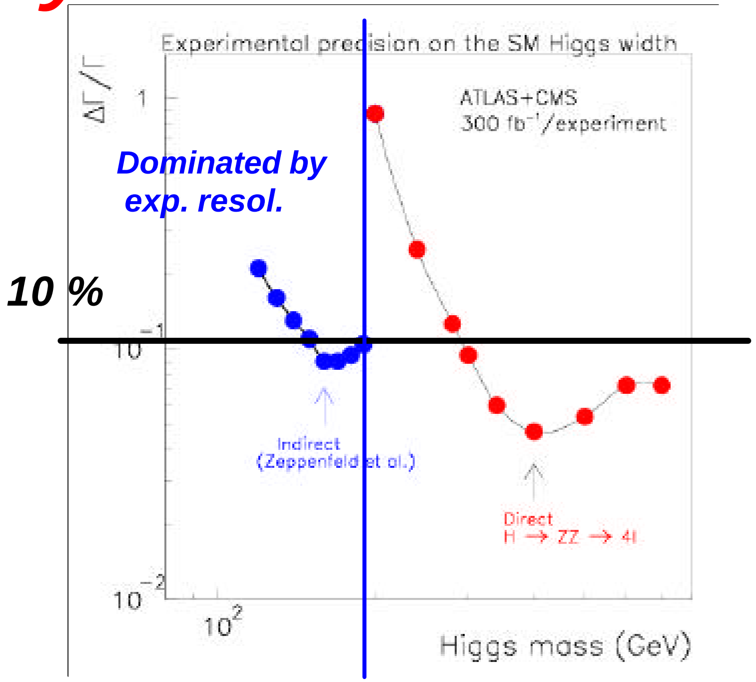
- *Review physics opportunities of post-LHC pp colliders*
- *Compare energy vs/ lumi upgrade options*
- *Detector requirements*
- *Tracking*

# *Physics at VHLC/SLHC*

- *Higgs physics*
- *strong EWSB*
- *compositeness*
- *Supersymmetry*
- *new gauge bosons*
- *extra dimensions*

# Higgs Physics

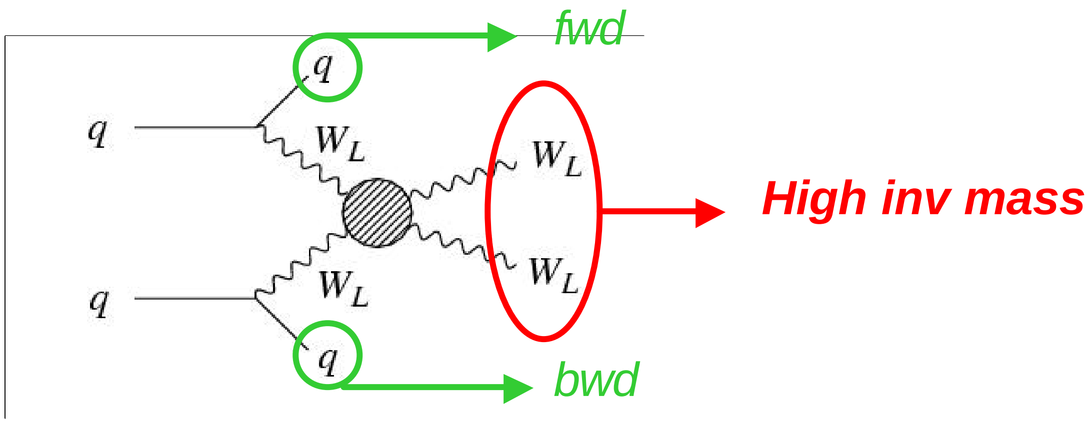



- *SM Higgs discovered in the entire mass range $m_H$<1 TeV before any upgrade*
- *Dm$_H$/m$_H$ £ 1 ‰ ,DG$_H$/G$_H$ £ 10 %*
- *Ratios of WWH, ZZH, ttH, bbH couplings at 10-20 % statistically limited*
- *Non-Standard Higgs $m_{H}$ =400-800 GeV:*
  *($y_t$,x$y_W$) L x10 ®dx/3, Ös x2 ®dx/2*

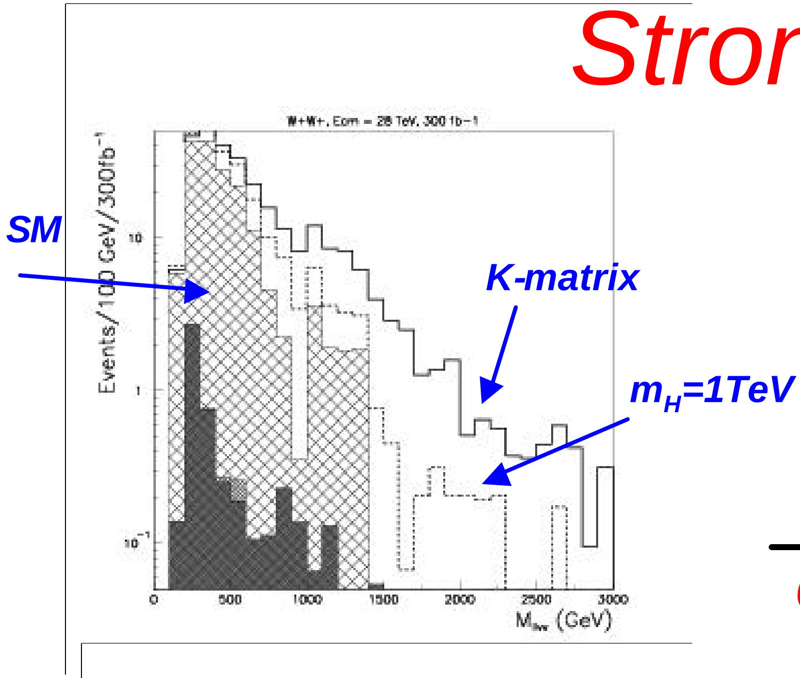
# Strong EWSB

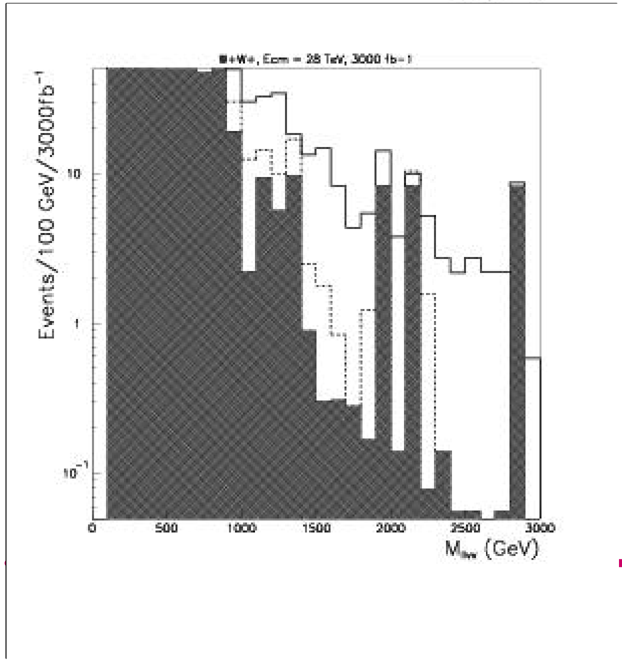
- *No Higgs exists: strong interaction in longitudinal vector boson scattering $V_L V_L \rightarrow V_L V_L$ at $\sqrt{s}$ >1 TeV*




- *compare $m_H$=1 TeV with “K-matrix unitarization” (extension of partial wave analysis)*

# Strong EWSB




- *$WW \rightarrow \ell^+\nu\, \ell^+\nu$: excess at high $m(\ell\ell E_{T,miss})$ "bgd" has the same spectrum $\rightarrow$ high statistics required*

| $\sqrt{s}$ (TeV) | L ($fb^{-1}$) | S/$\sqrt{(S+B)}$ | |
|---|---|---|---|
| | | K-matrix | $m_H$=1TeV |
| *14* | *300* | *2.9* | *1.7* |
| *14* | *3000* | *2.8* | *1.5* |
| *28* | *300* | *7.8* | *3.9* |
| *28* | *3000* | *13.5* | *5.3* |

# Compositeness (I)

- *quarks/leptons composite objects with constituents bound by an interaction at scale L*

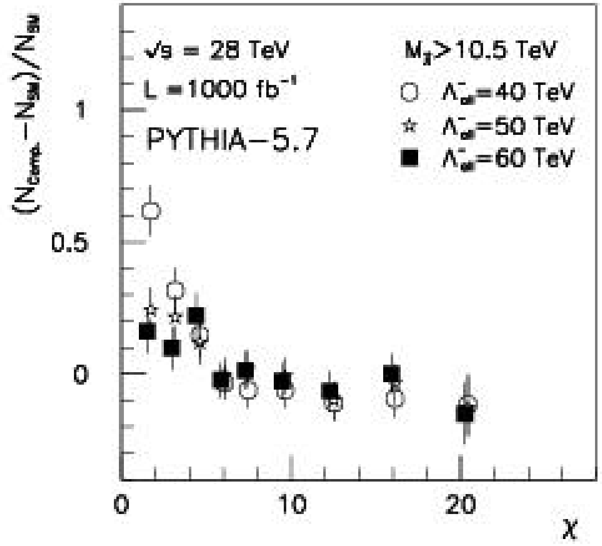
*Ös << L ® contact interactions*

*signature:*

*– excess of high $E_T$ centrally produced jets*

*– di-jet angular distribution*

| Ös (TeV) | L (fb$^{-1}$) | L (TeV) |
|---|---|---|
| 14 | 300 | 40 |
| 14 | 3000 | 60 |
| 28 | 300 | 60 |
| 28 | 3000 | 85 |
| 40 | 300 | 75 |




**(1+|cosq|)/(1-|cosq|)**

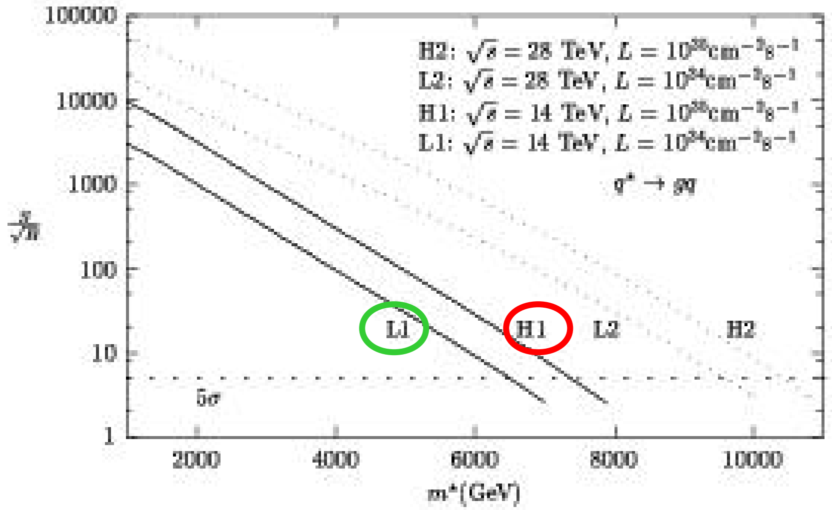
# Compositeness (II)

Ös ³ L ® *excited quarks q* and leptons l**

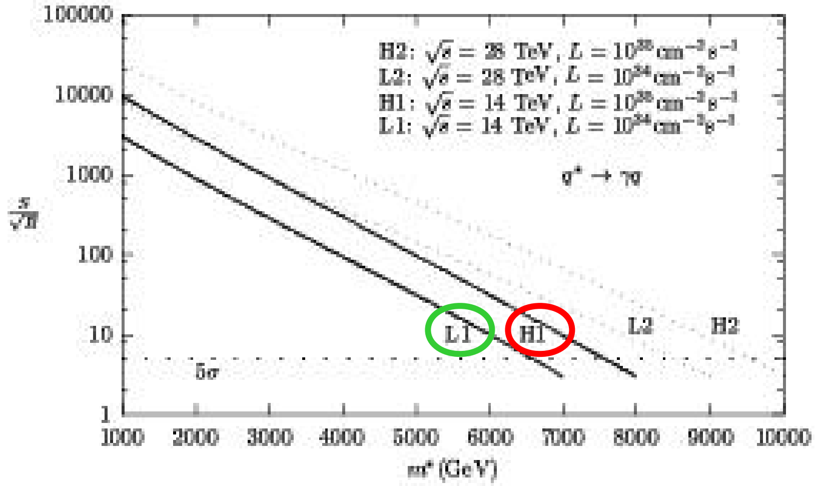
*signature:*

*– qg ® q*® qg/qg/qV*

*di-jet*




*prompt isolated g*



# Supersymmetry

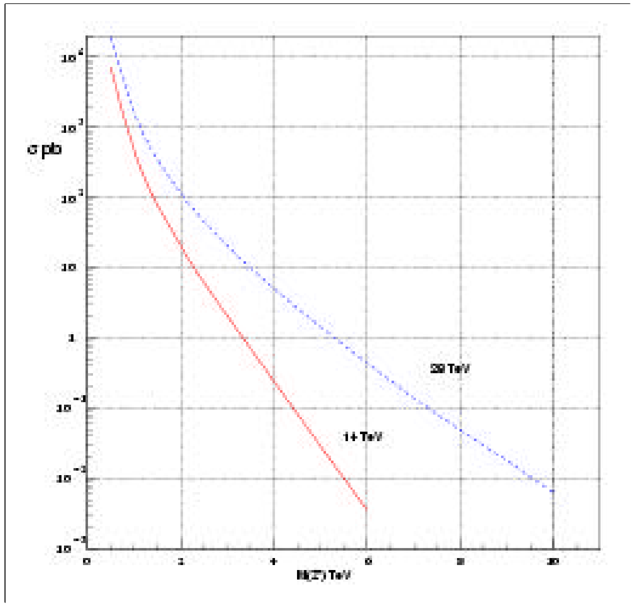
| $\sqrt{s}$ (TeV) | L (fb$^{-1}$) | $\tilde{q},\tilde{g}$ (TeV) |
|---|---|---|
| 14 | 100 | 2 |
| 14 | 1000 | 2.5 |
| 28 | 100 | 3-4 |
| 28 | 1000 | 4-4.5 |
| 40 | 100 | 4-5.5 |

– *If SUSY exists (at the weak scale) it will be discovered by LHC*

– *signatures: large $E_{T,miss}(\tilde{\chi}^0_1)$ / n-jets/n-$l$* (SUGRA)
*prompt $\gamma$ ($\tilde{\chi}^0_1 \rightarrow \tilde{G}\gamma$) /stable $\tilde{l}$ ($\tilde{\tau} \rightarrow \tilde{G}\tau$)* (GMSB)
*large n-jets ($\tilde{\chi}^0_1 \rightarrow qqq$)/n-$l$ ($\tilde{\chi}^0_1 \rightarrow l\, l\, \nu$)* (R –viol.)

# New gauge bosons

- W',Z' predicted by GUT




*benchmark:*
*Z' ® mm (with Z couplings)*

- *1000 fb$^{-1}$ @ 28 TeV equivalent 100 fb$^{-1}$ @ 40 TeV*

- *L x10 ® $M_{Z'}$ x1.2*

# Extra dimensions

- *Gravitons emitted during collisions ® $E_{T,miss}$ events*
- *Gravitons exchanged between SM particles ® modification of cross-sections*

| Ös (TeV) | L ($fb^{-1}$) | $M_D$ (TeV) | |
|---|---|---|---|
| | | n=2 | n=4 |
| 14 | 100 | 9 | 6 |
| 14 | 1000 | 12 | 7 |
| 28 | 100 | 15 | 10 |
| 28 | 1000 | 19 | 12 |

**25%**

**60%**

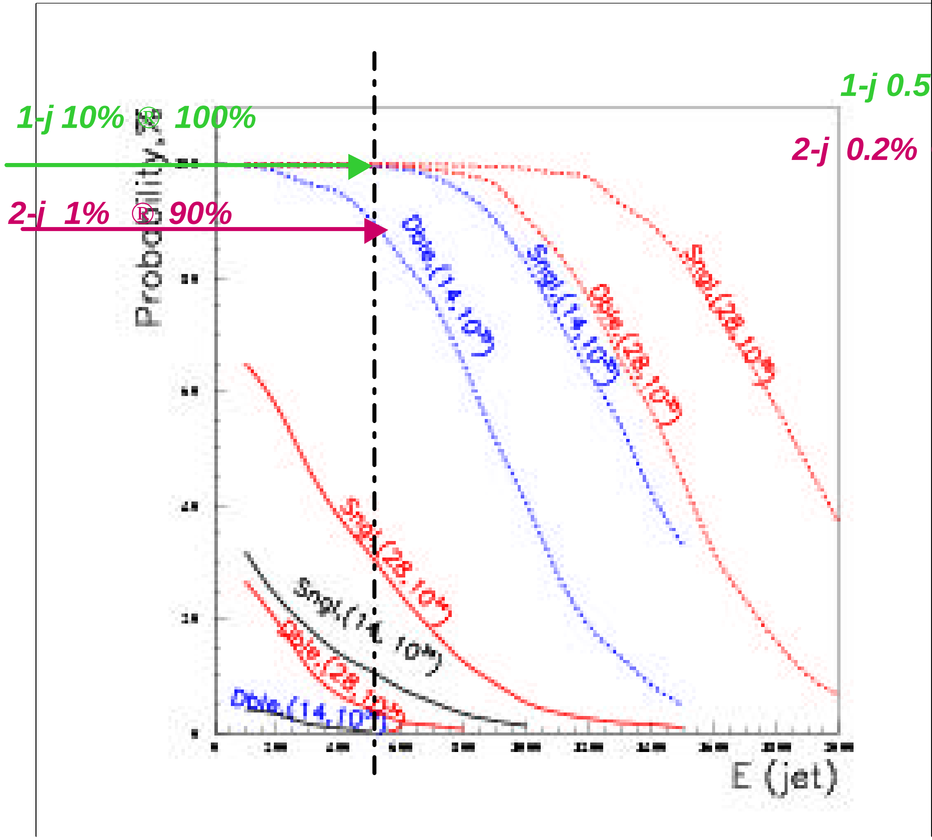
# Detector issues

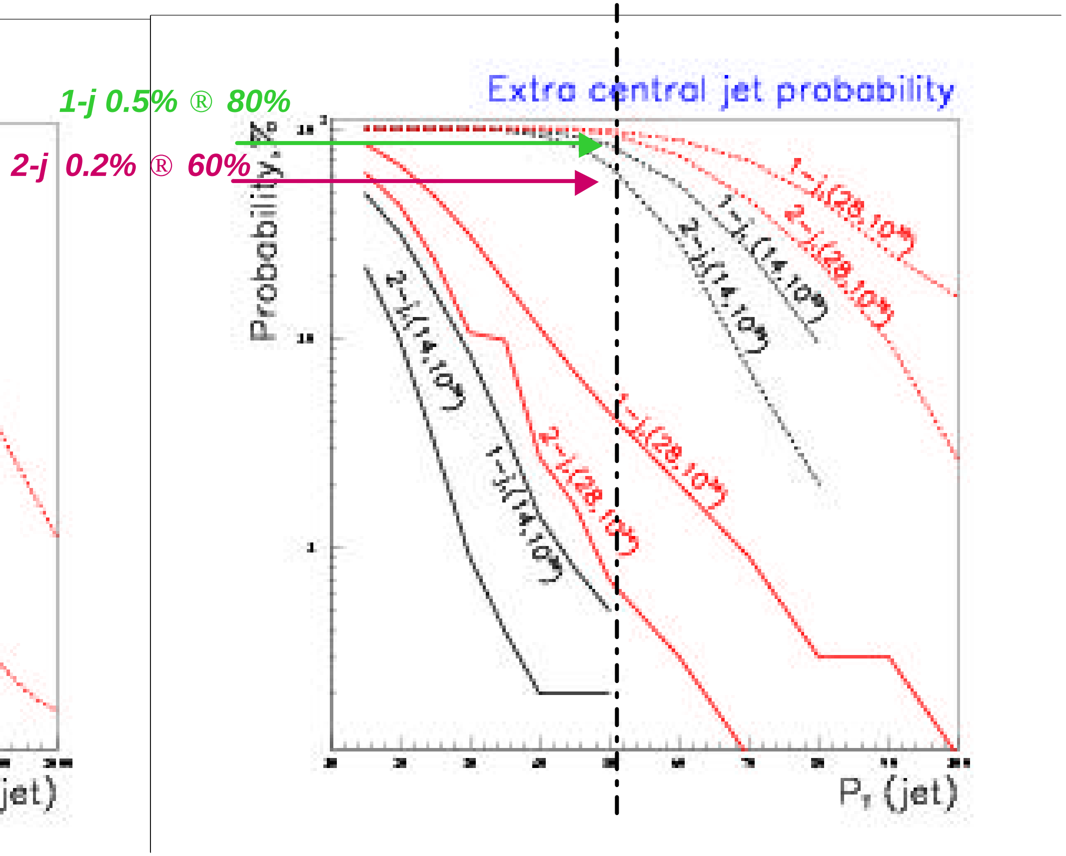
| Channel | calorimeter | lepton reconstruction |
|---|---|---|
| Higgs | jet fwd tag | W/Z tag, $m_{H,}$ $G_H$ reconstruction |
| Strong EWSB | jet fwd tag, $E_{T,miss}$ | W tag |
| Compositeness (I) Contact int. | $E_T$, $q_{jet}$ | |
| Compositeness (II) q* | $q_{jet,,}$ $g$ | |
| SUSY | $E_{T,miss}$ ,n-jets | n-$l$ |
| W',Z' | | W'/Z' tag |
| Extra dimensions | $E_{T,miss}$ | |

# Jets

- *exploring higher energy scale/heavy objects trigger: fwd jets + veto on central jet*

- *Probability of fake rate in fwd (| h|>2.5)*
- *Probability of extra central (| h|<2) jet*



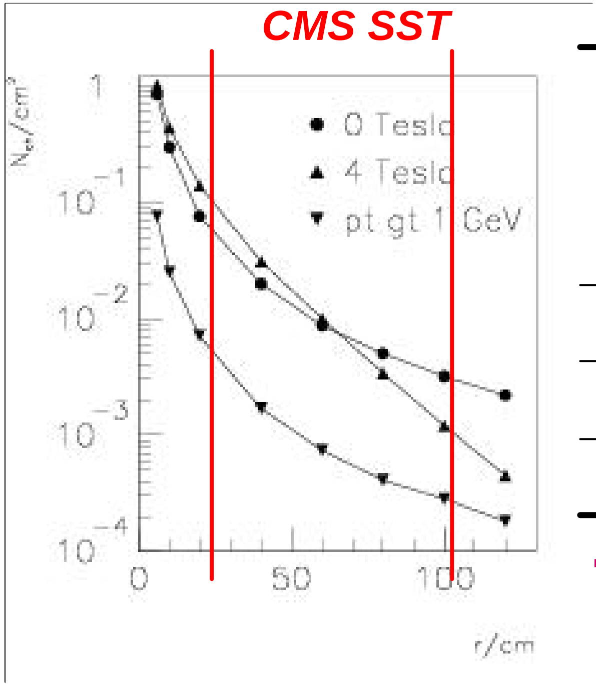
# Tracking at $10^{35}$ cm$^{-2}$s$^{-1}$

**Use of Tracking ® e-identification**

Consequences of $10^{34}$ ® $10^{35}$ cm$^{-2}$s$^{-1}$ with Dt=25 ® 12.5 ns

1. faster R/O
2. higher doses (x10)
3. occupancy (<1%): L=A/Dt  Lx10 = Ax5/(Dt/2 )

20 ® 100 int/bco @ 14 TeV




| r(cm) | p(mm) | l(cm) | L= $10^{34}$ | | L= $10^{35}$ (x5) |
|---|---|---|---|---|---|
| | | | $f_{ch}$(cm$^{-2}$) | Occ.($10^{-2}$) | |
| 25 | 80 | 12 | $10^{-1}$ | 0.96 | |
| 60 | 120 | 12 | $10^{-2}$ | 0.144 | ok |
| 100 | 180 | 19 | $10^{-3}$ | 0.034 | ok |

# $dp_T$ VHLC vs VLHC

- with vtx constraint with B=4T:

  $dp_T/p_T$ » 0.43($p_T$/TeV)(p/100mm)(m/L)$^2$ 1/Ö(N+4)

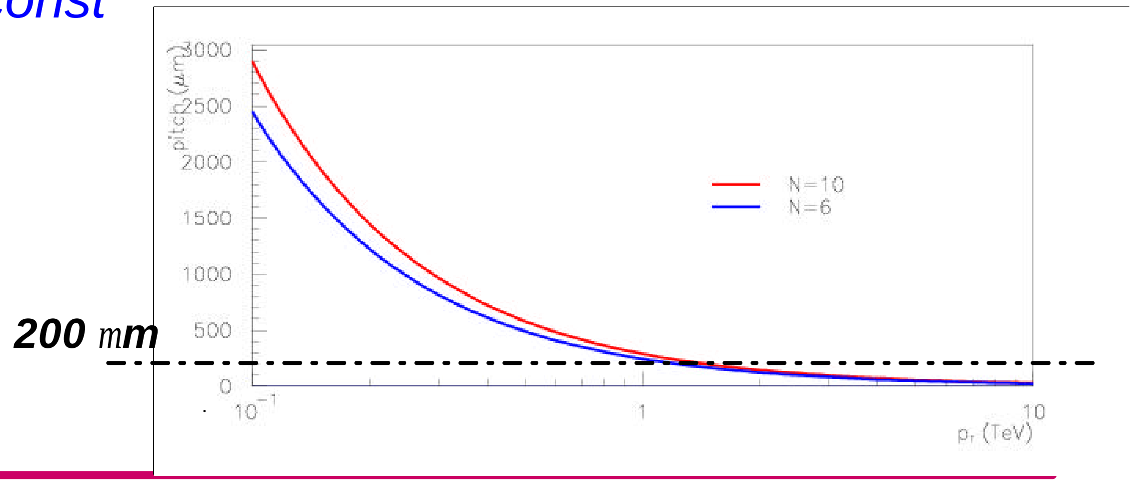
1. VHLC vs LHC:
   - N: 10 ® 6
   - p: 100 ® 180 mm

   $dp_T/p_T$ x1.5

2. VLHC vs LHC:
   – $p_T$/Ös » const

   $dp_T/p_T$ x3

3. Charge mistag
   1.3 ‰ (3s)



# Detector issues

| Channel | calorimeter | lepton reconstruction |
|---|---|---|
| Higgs | jet fwd tag | W/Z tag, ✓ $m_{H,}$ $G_H$ reconstruction |
| Strong EWSB | jet fwd tag, $E_{T,miss}$ | W tag ✓ (x2) |
| Compositeness (I) Contact int. | $E_T$, $q_{jet}$ | |
| Compositeness (II) q* | $q_{jet,,}$ $g$ | |
| SUSY | $E_{T,miss}$ ,n-jets | n-$l$ |
| W',Z' | | W'/Z' tag ✓ (x1.2) |
| Extra dimensions | $E_{T,miss}$ | |

# *Summary*

- *Physics at $\geq$ 1 TeV scale attractive/unknown*
- *It requires*
  - *high luminosity (not only high energy)*
  - *multipurpose detector (as it is unknown)*
  - *fwd jets and leptons crucial for tagging new heavy objects*
  - *tracking mandatory for e-identification*
  - *vertexing/b-tag challenging*

# *VLHC Pocket guide* **(U.Baur Snowmass01/E4)**

| | 14 TeV<br>100 $fb^{-1}$ | 14 TeV<br>1000 $fb^{-1}$ | 28 TeV<br>100 $fb^{-1}$ | 40 TeV<br>100 $fb^{-1}$ | 200 TeV<br>100 $fb^{-1}$ |
|---|---|---|---|---|---|
| q~,g~ | 2 | 2.5 | 4 | 5.5 | 15 |
| W',Z' | 4.5 | 5.4 | 7 | 10 | 30 |
| q* | 7 | 8 | 10 | 16 | 70 |
| L comp | 33 | 50 | 60 | 75 | 130 |
| $M_D$ (n=2) | 9 | 12 | 15 | 20 | 65 |