LHeC Potential for BSM and Higgs Physics

- Leptoquarks
- Contact Interactions
- Light SM Higgs
- Probing New Physics at HWW Vertex

With some text inserted to help her replacement..

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on behalf of the LHeC BSM Study Group

UNIVERSITY OF LIVERPOOL

LHeC

DIS2011, Newport News, April 14^{th}, 2011

http://cern.ch/lhec

The Challenge

- **LHC** is challenging the Standard Model in unchartered territory and has been built to ***discover New Physics*** and *the **Higgs** boson*.

- **LHeC**, an future electron-proton collider, may be built to ***map the gluon field*** at low x to ***unprecedented precision*** using 50-140 GeV electrons/positrons scattering off 7 TeV LHC protons.

- LHeC BSM study group aimed for an identification of such processes sensitive to BSM and Higgs physics where an LHeC with c.m.s. energies in the range of 1-2 TeV may add on value.

- Summary of the findings are part of the LHeC CDR, see G. Azuelos talk at DIS2010 for previous and not updated studies.

- **This talk focuses on recently updated and new studies.**

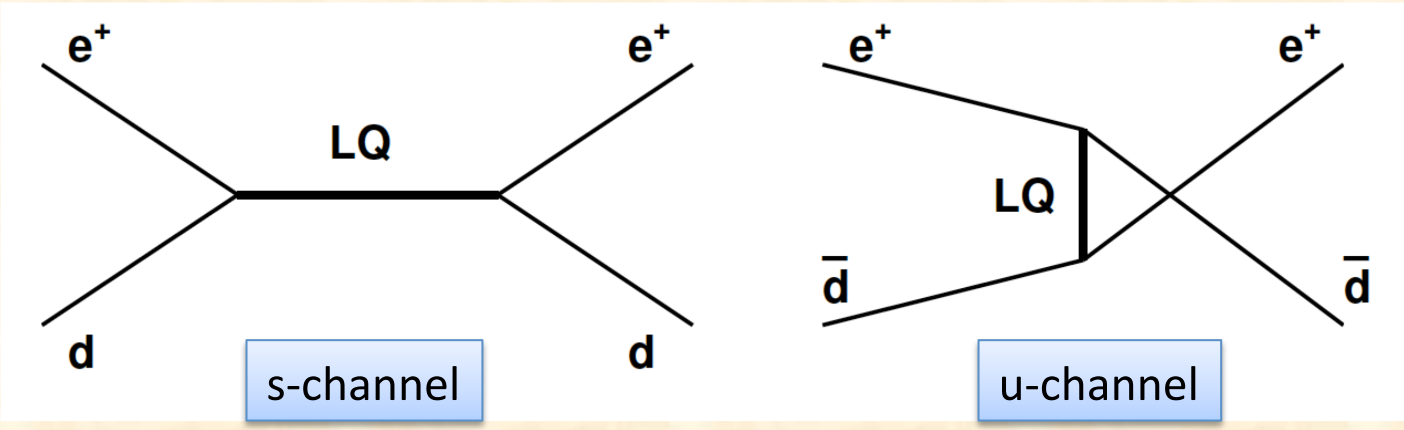
Leptoquark Production

E6 new fields
TC bound states of technifermions
PS l 4th colour of quarks
l,q composite models

LHC : Pair production via gg and qg production may probe M_{LQ} of 1.5-2 TeV mainly independent of the couplings λ, but hard to determine the quantum numbers → needs single LQ production

LHeC : Cross section of resonant single LQ production $\sim\lambda^2 q(x)$

- LQ with fermion number F=0 (exchange quarks for $|F|$=2)



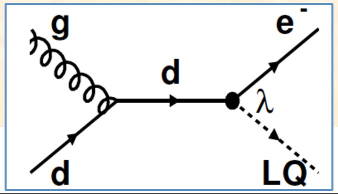
- Analysis strategy : search for peak in the invariant mass FS of high Q^2 DIS event, i.e. final state lepton should show Jacobian peak at $M_{LQ}/2$ where $M_{LQ} \leq \sqrt{sx}$

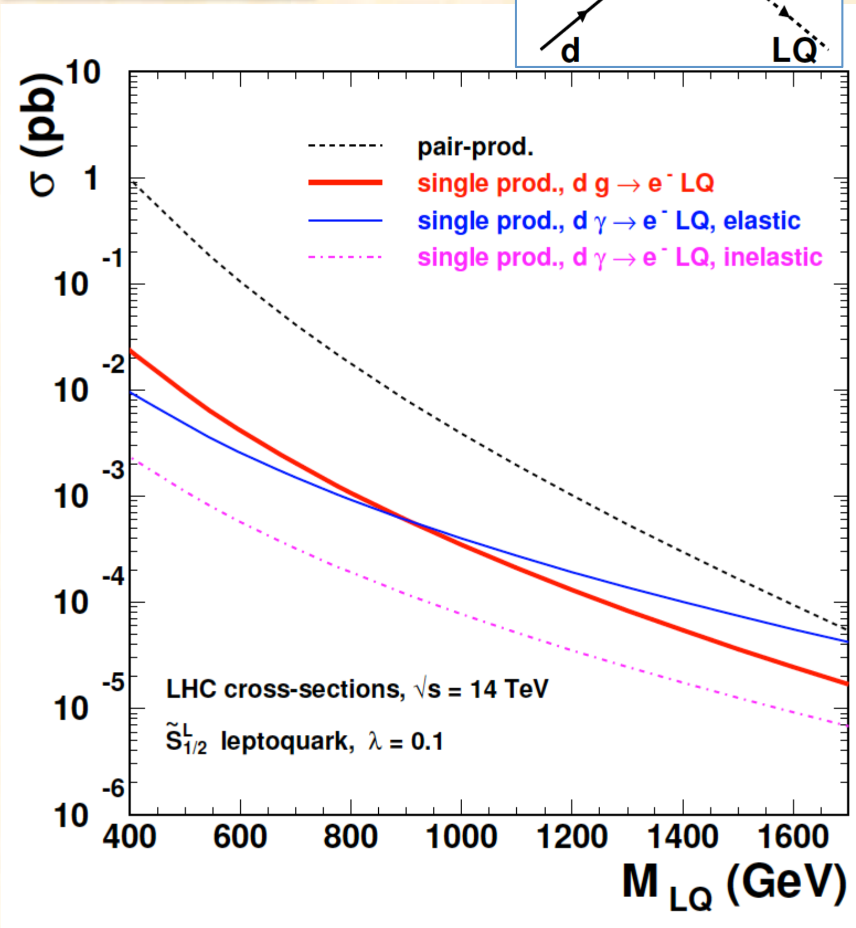
→ H1 and ZEUS constrained λ<0.3 for M_{LQ}<300 GeV, D0 excluded full first LQ generation range of M_{LQ}<300 GeV for $\beta(LQ \rightarrow eq)=1$

Single LQ Production

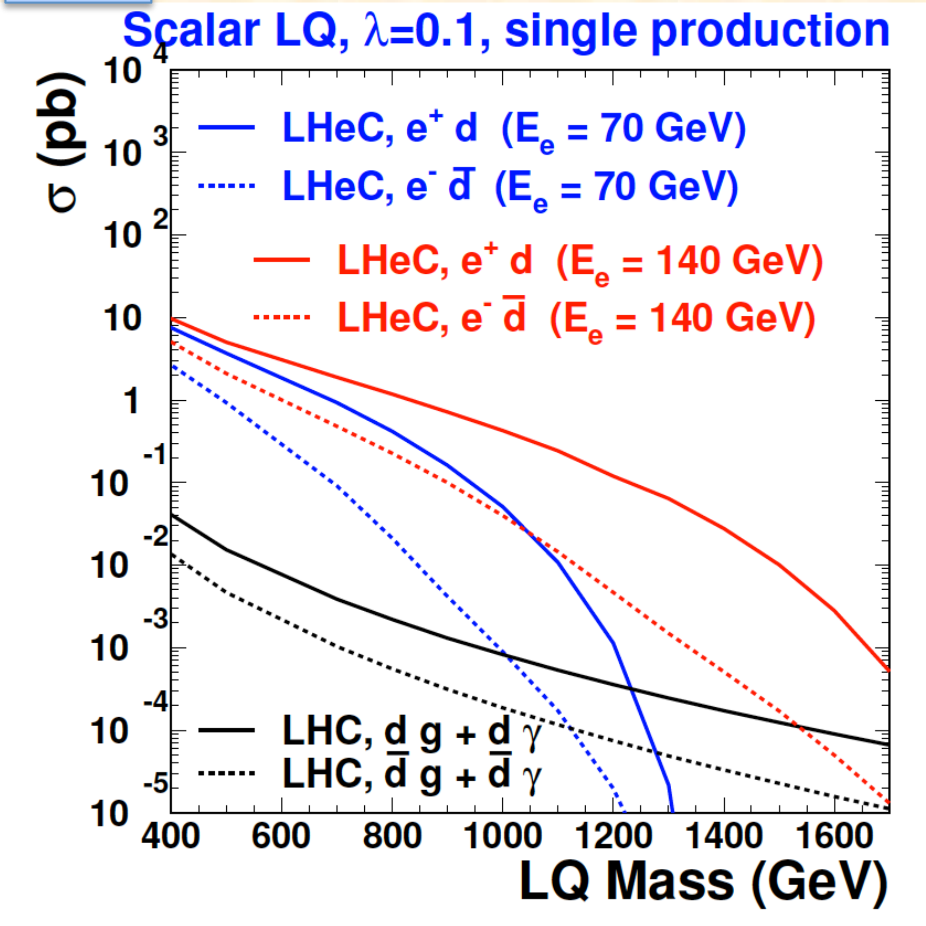
New for CDR: photons from p and q at LHC

LHC for λ=0.1





LHeC

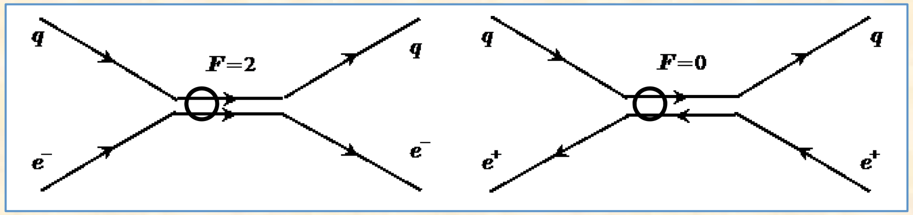


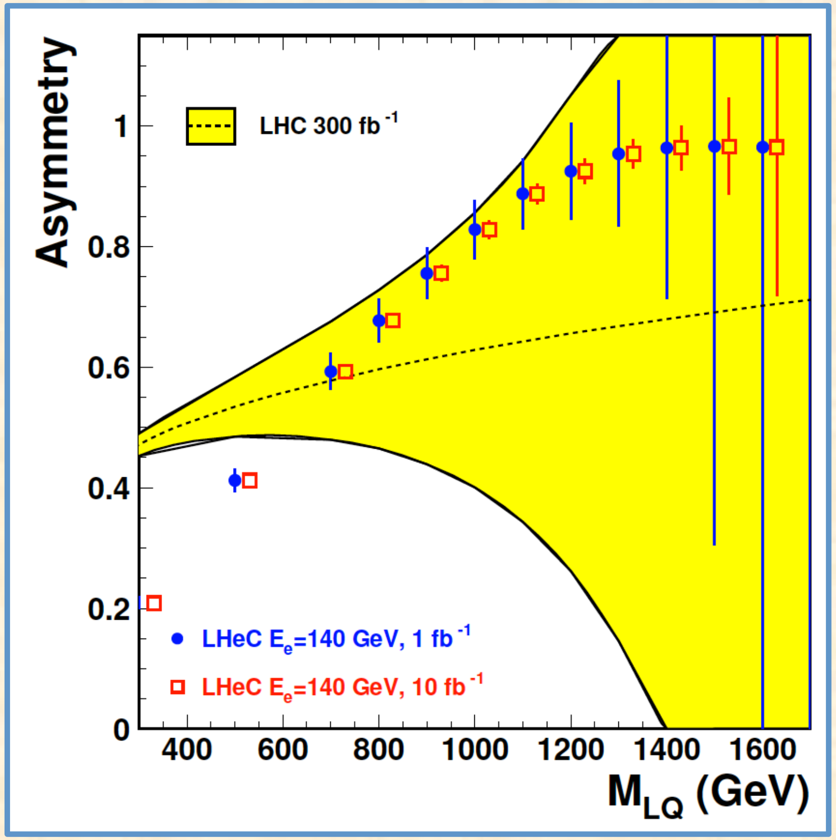
- Considering same couplings and mass ranges, single LQ would be more abundantly produced in ep collisions.

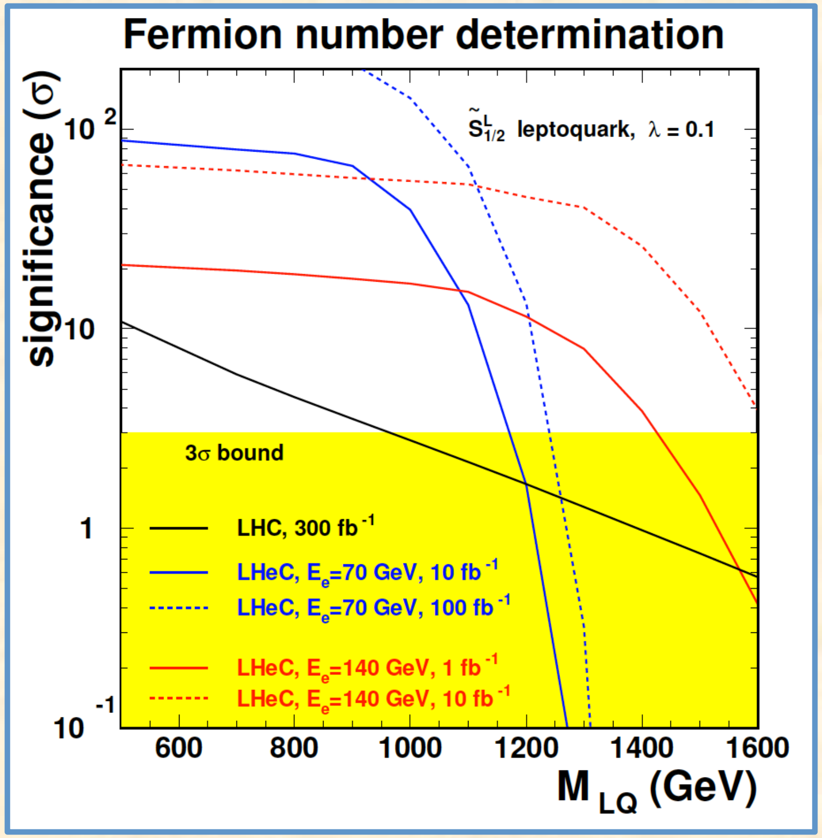
LQ Quantum Numbers and Couplings

- Fermion number *F* from asymmetry in e+/e-p cross sections
- Much cleaner accessible in DIS

$$A = \frac{\sigma_{e^-} - \sigma_{e^+}}{\sigma_{e^-} + \sigma_{e^+}} \begin{cases} >0 \text{ for } F=2 \\ <0 \text{ for } F=0 \end{cases}$$





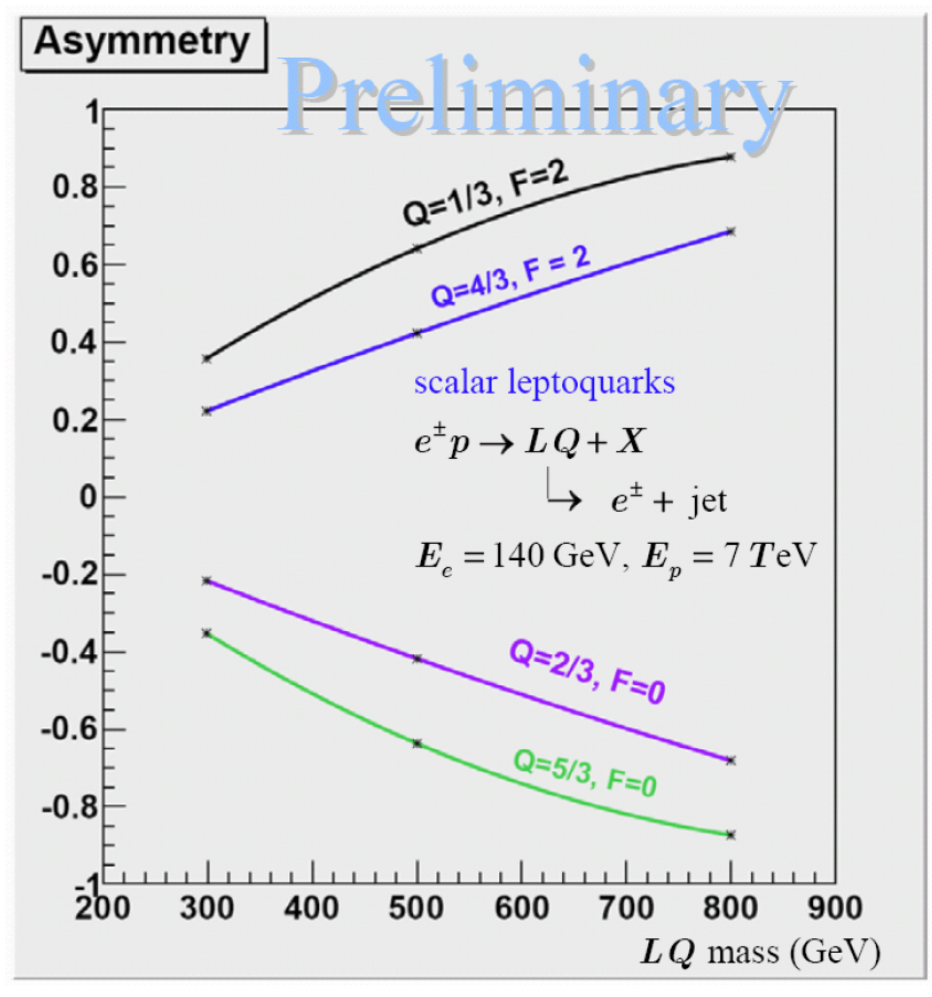


Studies for “low`` lumi assumptions for pp and ep

Flavour Structure of LQ Coupling

- Using the charge asymmetry and the PDF sensitivity of the interacting quark, the flavour structure of the LQ coupling can be probed

- *Leptogluons* are not widely discussed in literature, but similar measurements than for the leptoquarks can be performed for them as well



LG's predicted in all models with coloured preons. Result: e.g.:
For scale Λ of 10 TeV have mass reach of 1.1 TeV in M_{e8}. L ~ 1/2Λ …

Leptogluons..

IASSNS-HEP-96/104

REVISED April, 1997

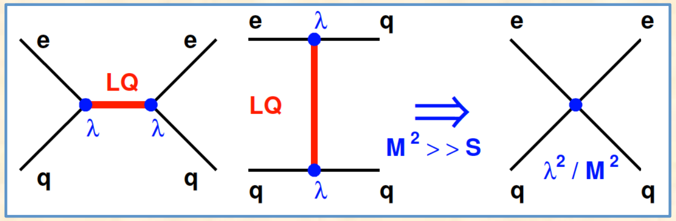
Frustrated SU(4) as the Preonic Precursor of the Standard Model

Stephen L. Adler

In summary, we suggest that the production and decay of the excess HERA events, interpreted as leptogluons, could be accounted for in our model when augmented by either the assumption that the Z_6 condensate that breaks $SU(4)$ to color $SU(3)$ contains a small component that further breaks color $SU(3)$ to glow $SO(3)$, or by the assumption that color symmetry remains exact but that color neutralization is incomplete in hard processes. On the other hand, a leptoquark interpretation of the HERA events is not apparent in our model; composite vector leptoquarks would be expected to have masses near Λ_H, since

Theorists are certainly more inventive once something appears in experiment..

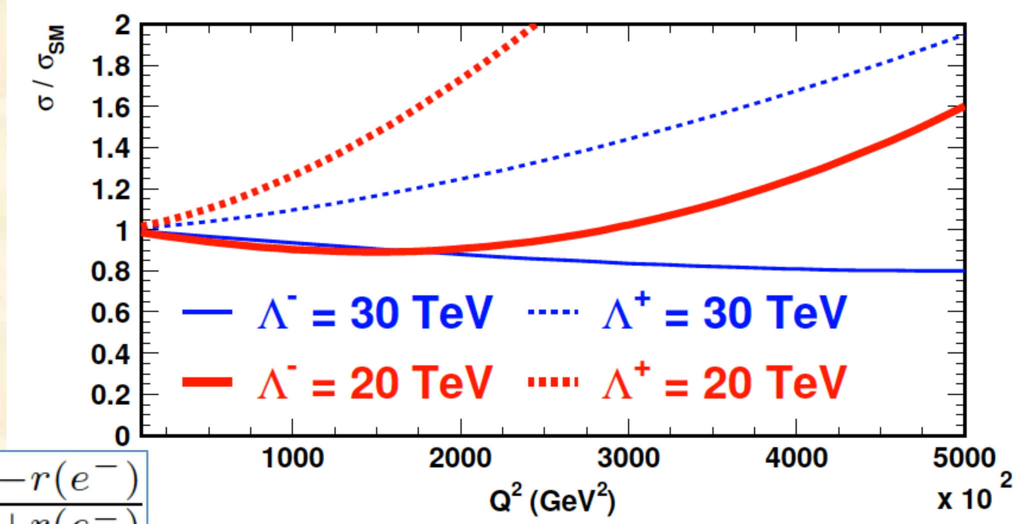
Contact Interactions



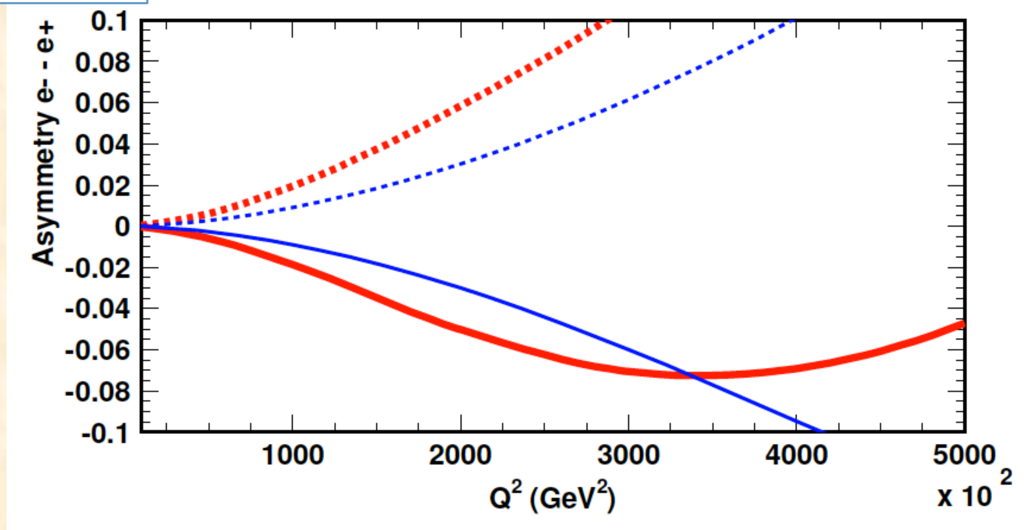
Effective 4 fermion interaction to access scales beyond s. Substructure but as well KK gravitons: could study ED for different charge polarisation and quark flavour

- Probe deviations in the SM DIS cross section for ***eeqq*** contact interactions
- LHeC could test scales between 20-45 TeV
- *Polarised* lepton beam would help to establish the chiral structure of a new interaction ➔ very likely that a **combination of *pp* and *ep data*** will be needed to underpin the chiral structure of the new interaction

$r = \sigma/\sigma_{SM}$ e^-p DIS



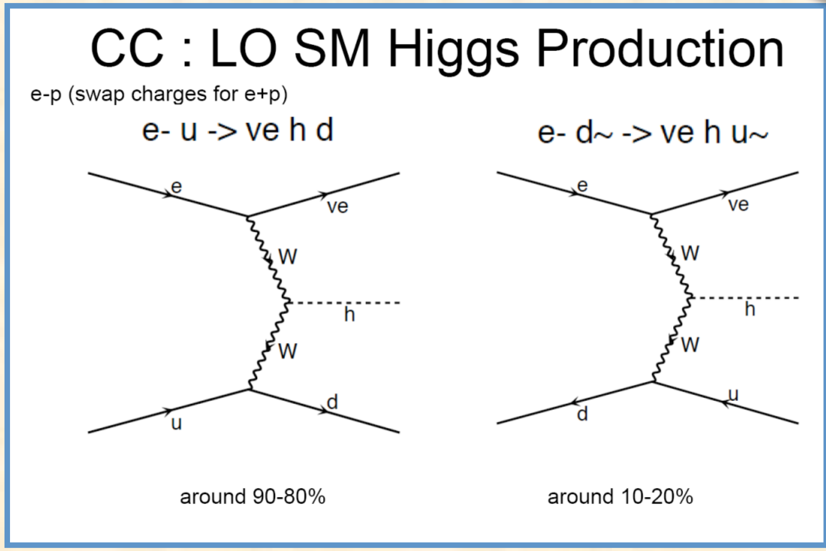
$\frac{r(e^+)-r(e^-)}{r(e^+)+r(e^-)}$



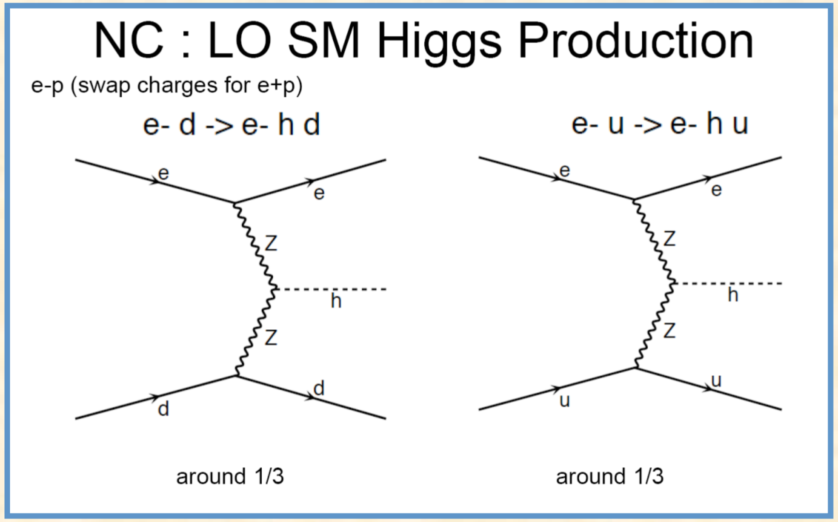
Search for a Light SM Higgs

√s=1 – 2 TeV

- σ~ 200 fb
- Light SM Higgs boson with M_H < 140 GeV decays predominantly into bb pair



- σ~ 50 fb (Z heavier than W and couplings to fermions smaller)



ATLAS and CMS will settle the SM Higgs question by next year, LHC permitting..

Case Study SM Higgs M_H=120 GeV

- Parameters for $\sqrt{s}$ = 2.05 TeV using 7 TeV x 150 GeV
  Luminosity L=10 fb^{-1}

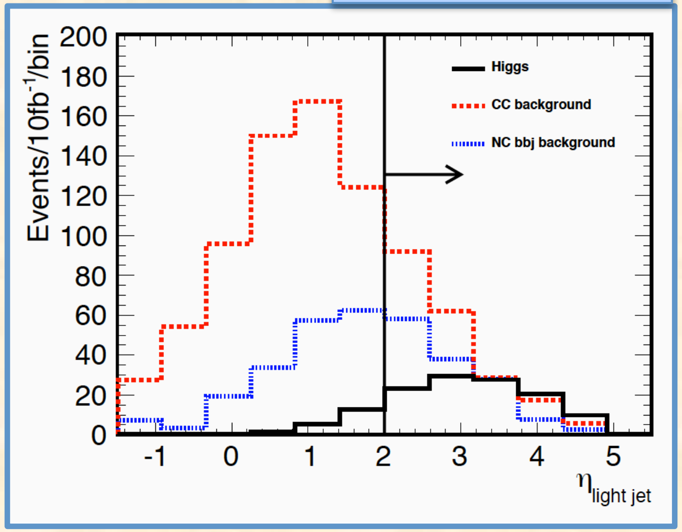
- new : use (more recent) Madgraph version 4.4.44 & modified Pythia-Pgs interface for DIS

→ new : Higgs decay into bbar via Madgraph package DECAY
  PDF : CTEQ6L1 (LO PDF and LO α_S=0.13)

→ 'Detector-level' Higgs search requiring CAL coverage up to $|\eta|<5$ and flat b-tagging efficiencies of 60% for $|\eta|<3$
  (mistag 10% c, 1% light quarks)

- ***New* studies**
  - improved CC background control via forward jet tagging and single top and W rejection
  - extended NC background studies

Forward jet η



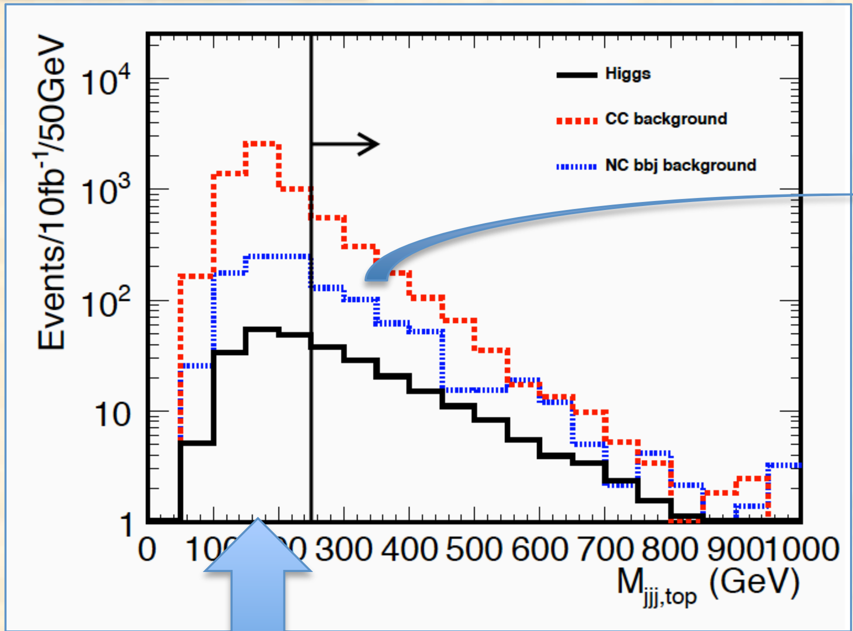
Single Top and Rejection

- Cut on tri-jet (H candidate and 3rd jet) invariant mass M_{jjj}> 250 GeV
- Contribution of NC background estimated in two ways:
  1) bbar from fragmentation (dedicated NC ep bbj sample)
  2) bbar from fragmentation and parton shower ('standard' NC sample)

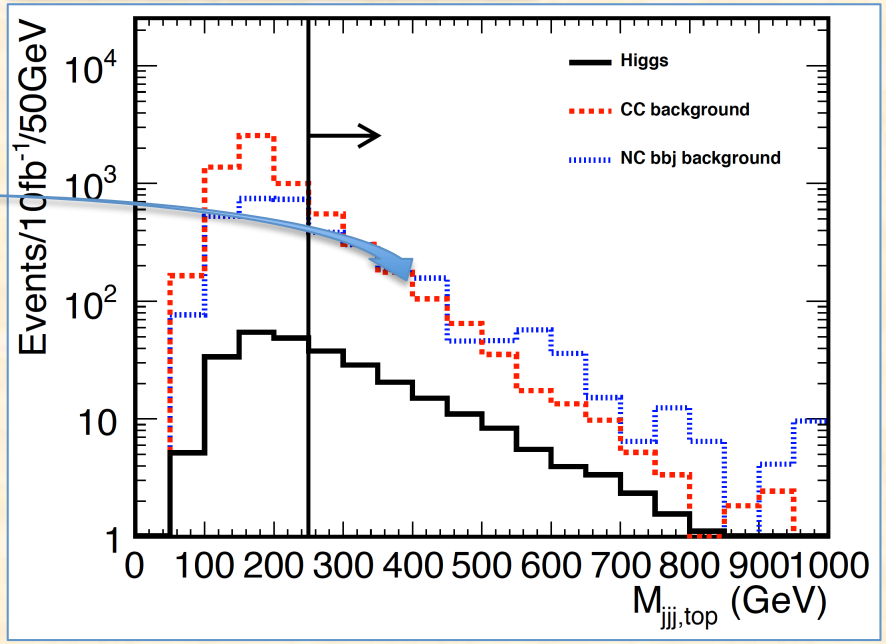
→ low remaining FS b tagged jets and high scaling factors for 2nd sample

→ *very conservative* approach : scale up bbj background by factor 3

NC bbj sample



Scaled NC bbj sample



Single top in CC

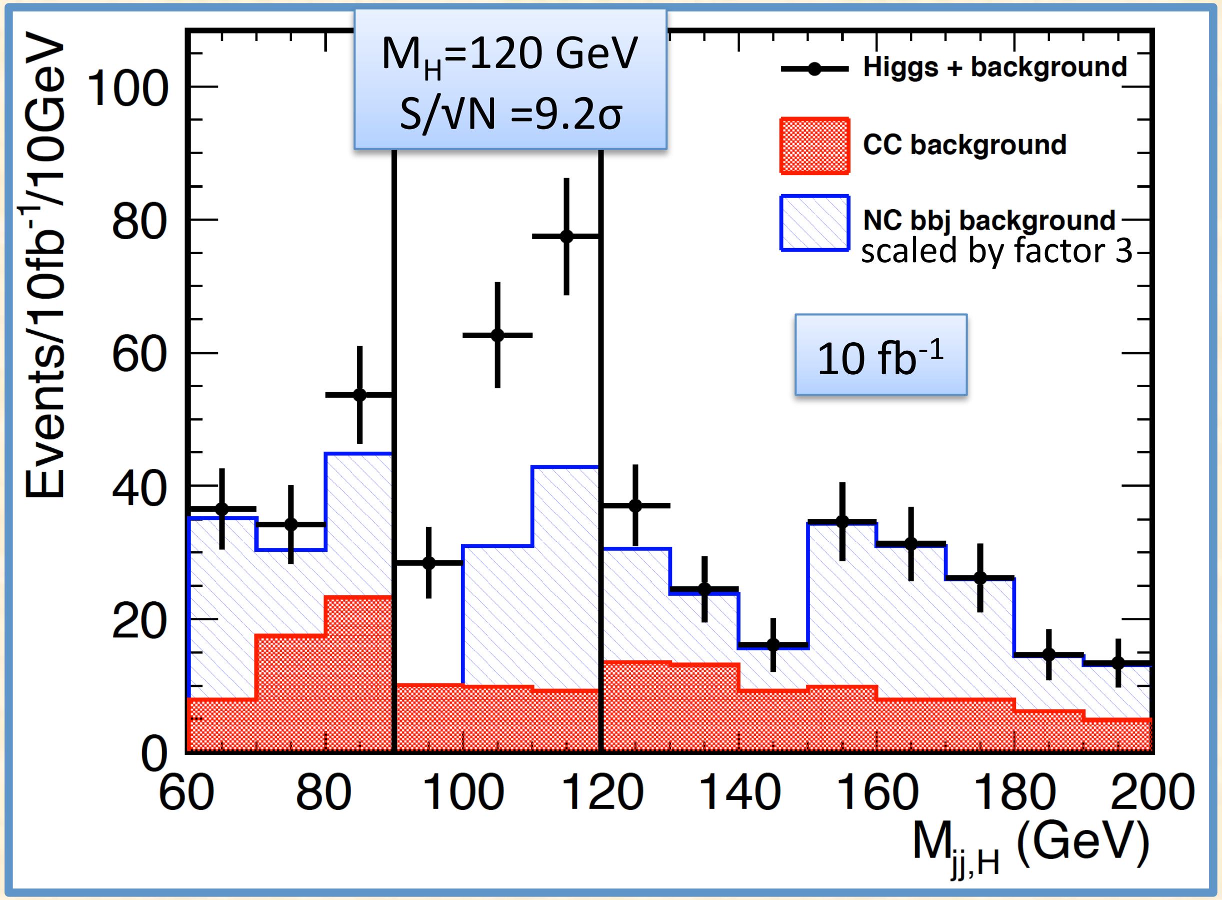
Higgs Signal Candidates

- $Q^2>400$ GeV^2, $E_{T,miss}>20$ GeV, $y_{JB}<0.9$, 2 b jets, top and W vetos
- Expectation of 84.6 H→bb candidates and CC background of 29.1 events while NC background is in the range of 18 to 55 events
- S/N in the range of 1.8 to 1 and **S/√N = 13σ to 9.2σ**

More cases

- For 150 GeV Higgs and 10 fb^{-1} :
  24.7 H→bb
  S/N = 0.353
  S/√N = 3

- For 60 GeV beam and 50 fb^{-1} :
  124 H→bb
  S/N = 0.522
  S/√N = 8



Sets scales for luminosity and detector resolution of the LHeC

CP Properties of a SM Higgs and NP

- In SM, the only fundamental neutral scalar is a $J^{PC} = 0^{++}$.

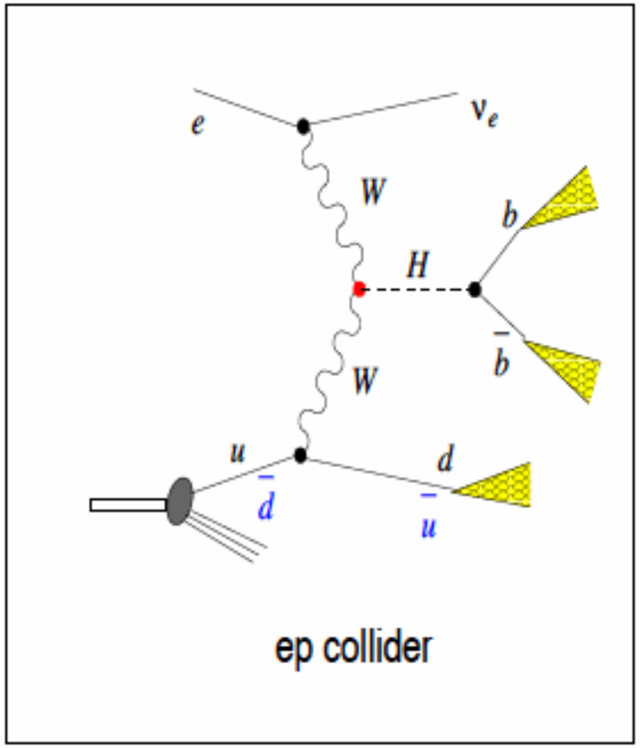
- Various extensions of the SM can have several Higgs bosons with different CP properties : e.g. MSSM has two CP-even and one CP-odd states.

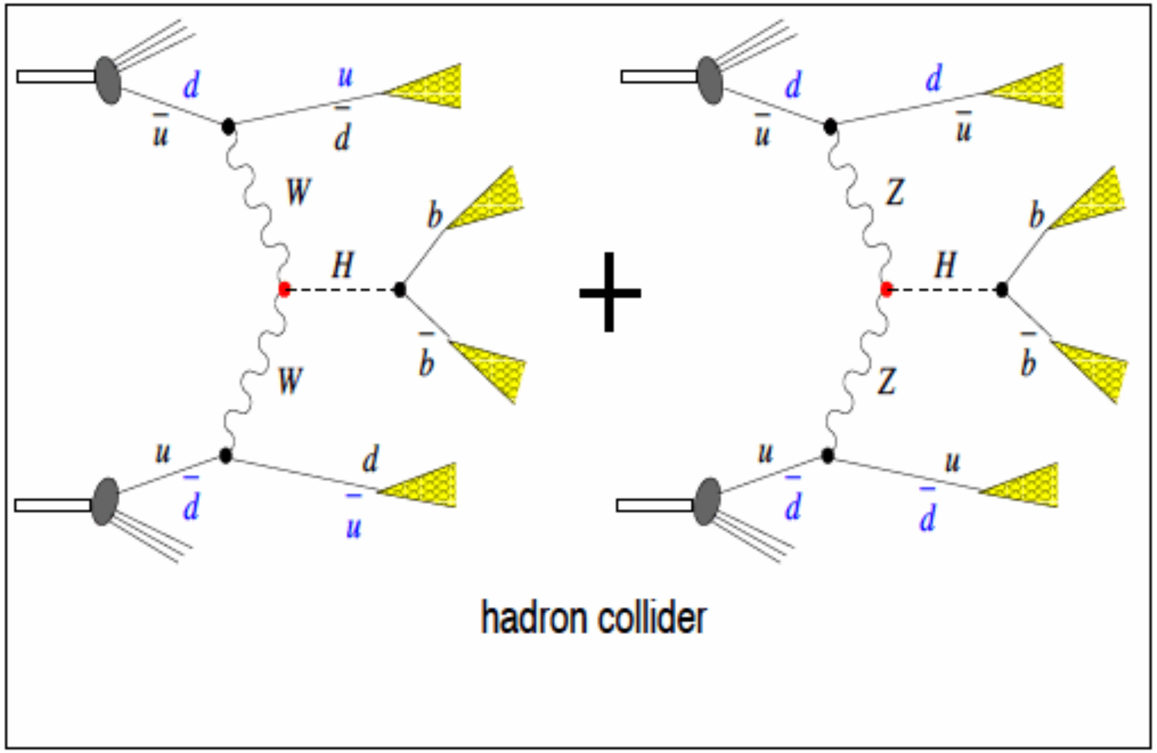
- Therefore, should a neutral spin-0 particle be detected, a study of its CP-properties would be essential to establish it as *the* SM Higgs boson.

- To study the effects beyond SM, we need to establish the CP eigenvalues for the Higgs states if CP is conserved, and measure the mixing between CP-even and CP-odd states if it is not.

Probing New Physics at HWW Vertex

higgs + 2jets: VBF (LHC), higgs + jet + missing E_T (LHeC)





ep process uniquely addresses the HWW vertex.

Higgs CP-odd and CP-even states

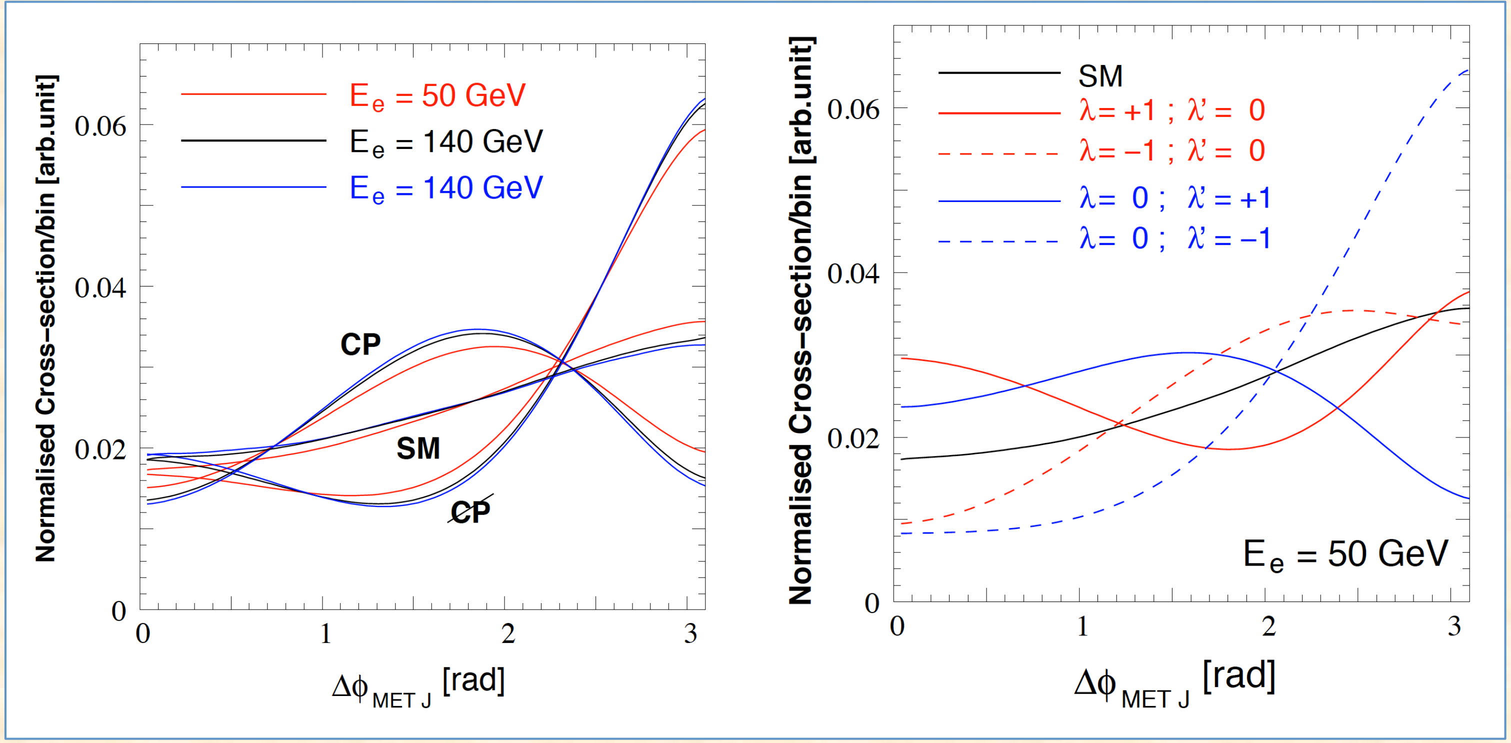
$$V_{HVV}^{\mu\nu} = -ig\left[f_1\, g_{\mu\nu} + f_2\,(g_{\mu\nu}k1.k2 - k1_\nu k2_\mu) + f_3\, i\epsilon_{\mu\nu\alpha\beta}\, k_1^\alpha k_2^\beta\right]$$

- Probe the HWW vertex itself
- CP-odd Higgs: branching fraction *largest* for bbar decay
- Study ***shape changes*** in DIS normalised CC Higgs→ bb cross section versus the azimuthal angle between $E_{T,miss}$ and leading jet, $\Delta\phi_{MET,J}$
- Only very mild dependence of the predictions on lepton beam energy
- NP (λ, λ') will modify CP-odd and CP-even states differently

$f1 = mW/2m_H$

$f2 = \lambda/m_W$

$f3 = \lambda'/m_W$

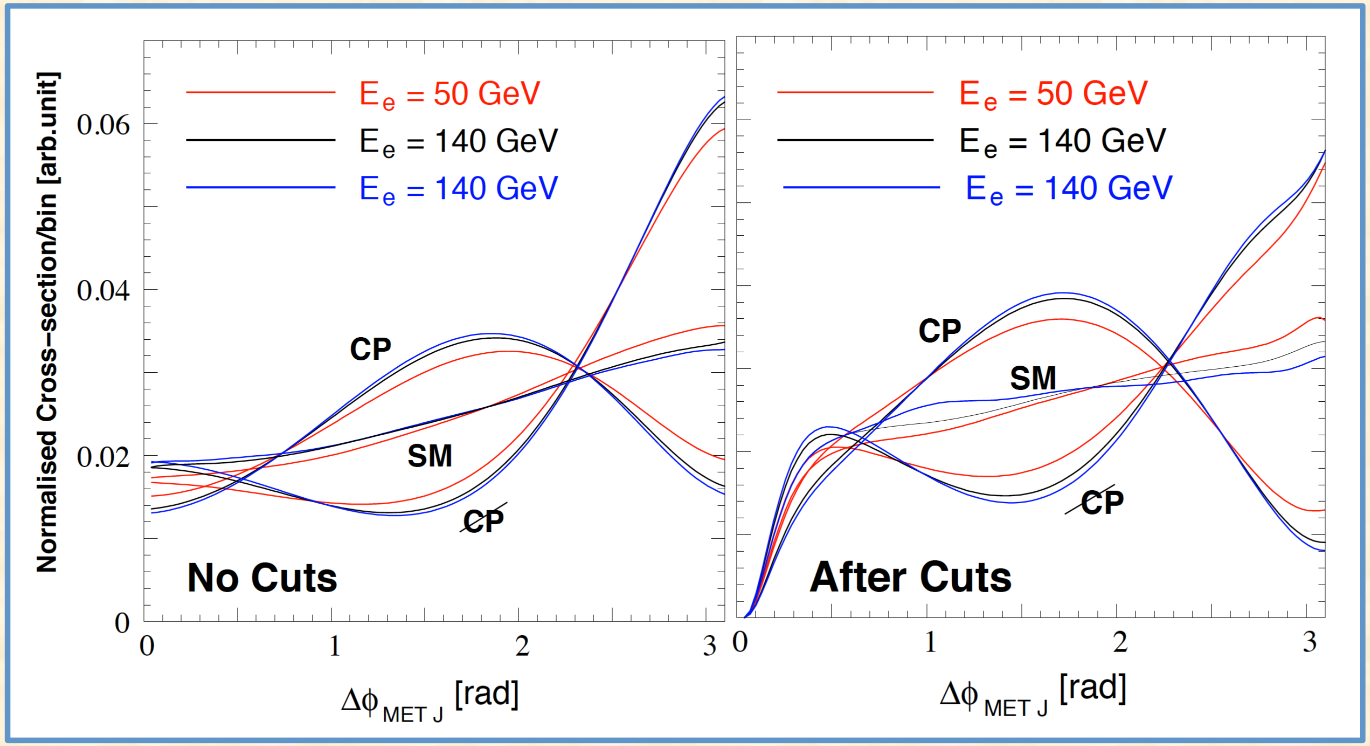


Effect of Cuts

Experimental cuts will not change the basic picture of the $\Delta\varphi_{MET,J}$ dependence of normalised DIS CC Higgs cross section

Cuts

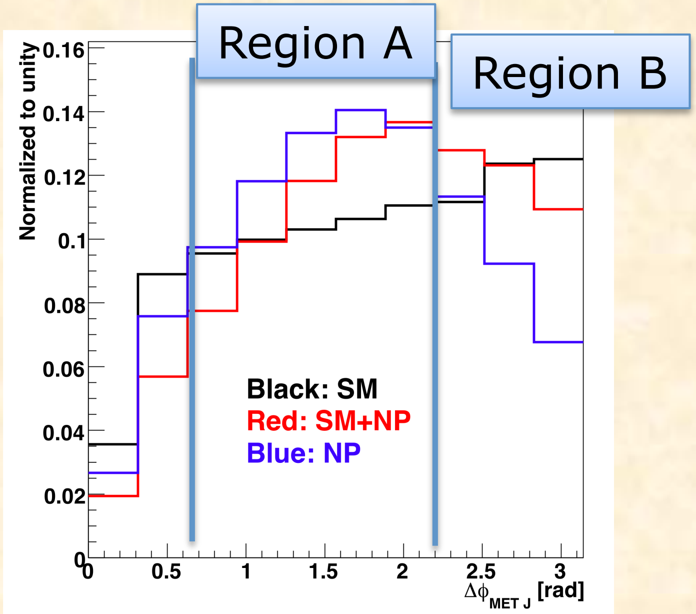
1. All 3 jets have $p_T > 30$ GeV.
2. b-tagged jets must have $|\eta| < 2.5$
3. remaining jet must have $1 < |\eta| < 5$
4. inv. mass of remaining jet and reconstructed Higgs > 250 GeV (at parton level, just the 3-jet invariant mass)
5. MET > 25 GeV
6. $\Delta\phi$ between reconstructed MET and each jets > 0.2.



Case Study for M_H=120 GeV

- Measure deviation of the Higgs production with respect to the SM using the absolute rate of events
- The ratio of the number of events in region B to that of region A in the $\Delta\varphi_{MET,J}$ spectrum

CP-odd case

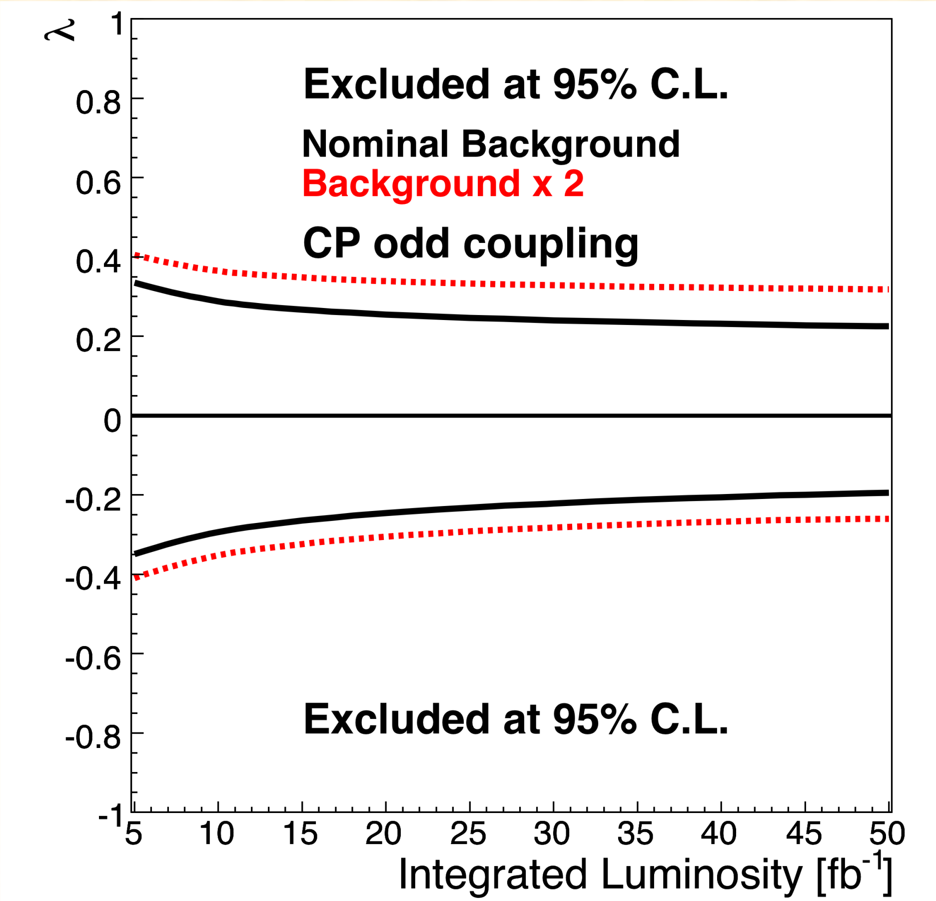


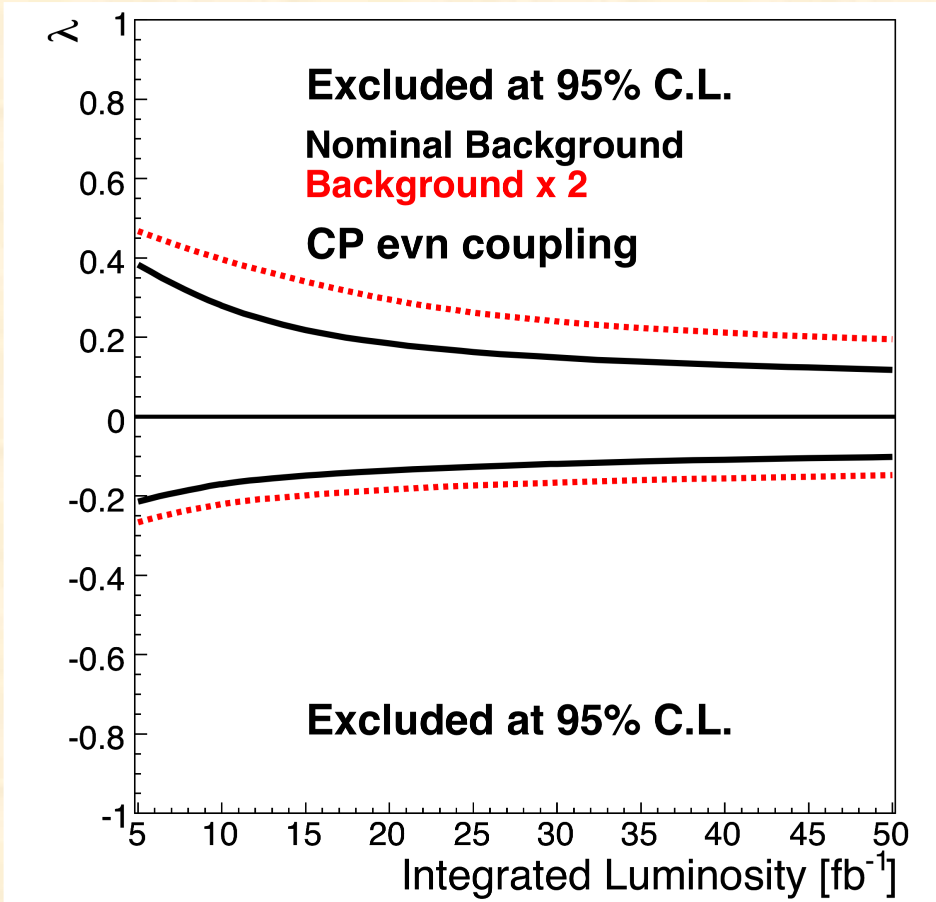
- Assume Gaussian errors and the following systematics:
  - 10% on the background rate
  - 5% on the shape of the $\Delta\varphi_{MET,J}$ in background
  - 5% on the rate of the SM Higgs
  - Evaluating theoretical error on $\Delta\varphi_{MET,J}$ shape

Higgs CP Couplings and NP

$$\frac{\sigma}{\sigma_{SM}} = 1 + \lambda^2 R_1 + \lambda R_2$$
$$R_1 = \sigma_{NPonly}/\sigma_{SM}$$
$$R_2 = \sigma_{Int}/\sigma_{SM}$$

- Based on background estimates for light SM Higgs search study ➔ background is *further enlarged* by factor 2
- Limits on CP-even and CP-odd couplings are correlated
- At LHeC, with 5-10 fb^{-1}, $|\lambda|$ values up to 0.4 can be uniquely probed for both the CP-odd and CP-even states of a light SM Higgs





Summary

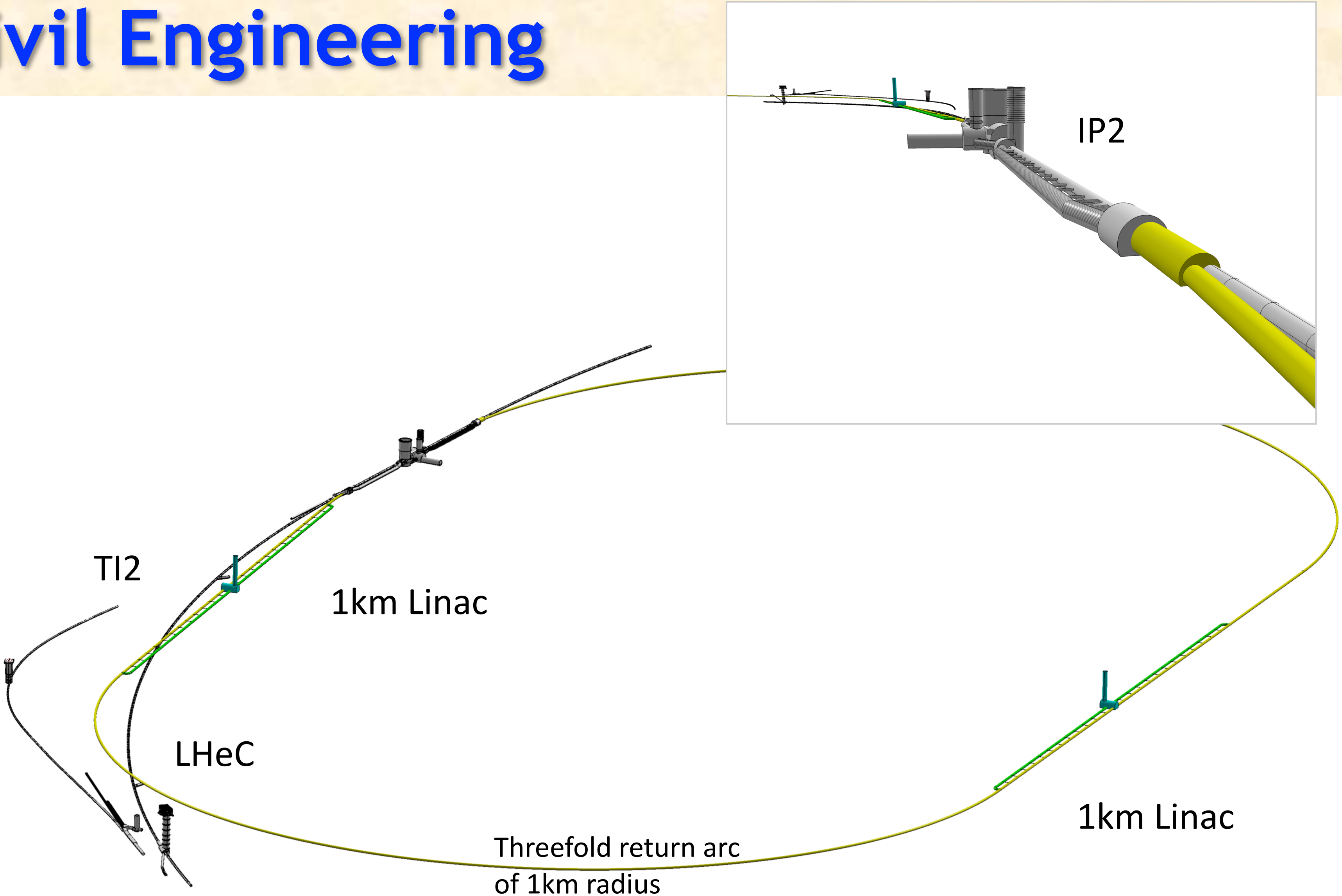
- An TeV ep collider can complement LHC in the understanding of new physics phenomena
- LHeC could deliver more precision and would allow more complete theoretical interpretations of LHC discoveries, in particular for lepton and quark interactions like e.g. leptoquarks, excited fermions, compositeness, contact interactions
- LHeC could deliver unique insights on light SM Higgs and the CP eigenstates of the SM or nonstandard Higgses
- Some restricted parameters spaces (as small couplings in excited leptons) which are unique to ep

LeHC BSM Study Group

E. Perez, G. Azuelos, M. Kuze, K. Kimura, K. Sampei,
M. Ishitsuka, U. Klein, C. Hengler, B. Mellado,
R. Godbole, S. Raychaudhuri

in close collaboration
with P. Kostka, A. Pollini, M. Klein and many other colleagues from the LHeC CDR team ….

Civil Engineering



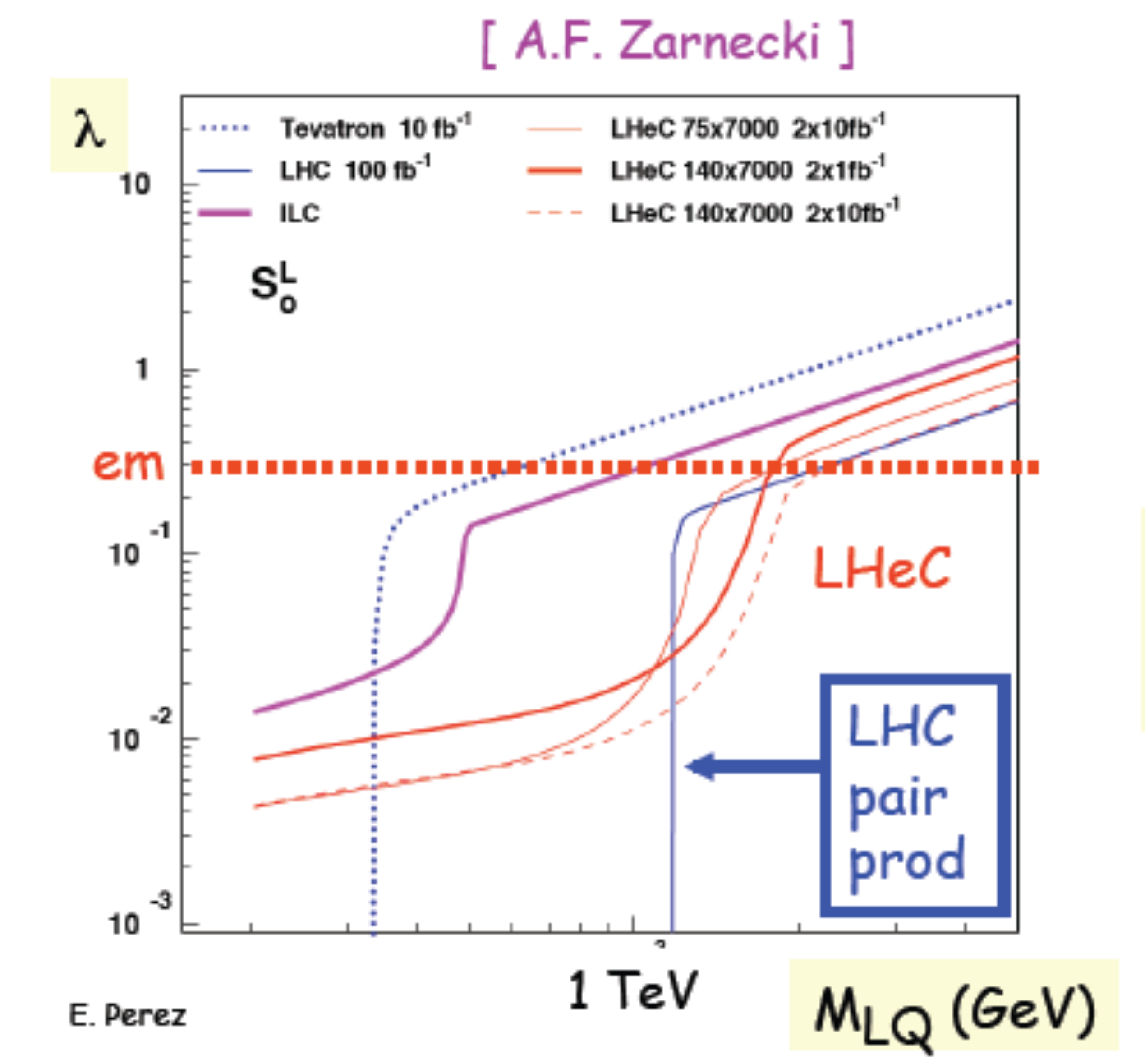
Version of 12.4.11

Or ring or much higher energy Linac

Addendum to first talk at this session

BackUp

Scalar LQ Coupling Limits in $e^- u$



'Detector'

...events passed thru PGS generic LHC detector

LHC	! parameter set name
320	! eta cells in calorimeter
200	! phi cells in calorimeter
0.0314159	! eta width of calorimeter cells |eta| < 5
0.0314159	! phi width of calorimeter cells
0.01	! electromagnetic calorimeter resolution const
0.2	! electromagnetic calorimeter resolution * sqrt(E)
0.8	! hadronic calolrimeter resolution * sqrt(E)
0.2	! MET resolution
0.01	! calorimeter cell edge crack fraction
cone	! jet finding algorithm (cone or ktjet)
5.0	! calorimeter trigger cluster finding seed threshold (GeV)
1.0	! calorimeter trigger cluster finding shoulder threshold (GeV)
0.5	! calorimeter kt cluster finder cone size (delta R)
2.0	! outer radius of tracker (m)
4.0	! magnetic field (T)
0.000013	! sagitta resolution (m)
0.98	! track finding efficiency
1.00	! minimum track pt (GeV/c)
3.0	! tracking eta coverage
3.0	! e/gamma eta coverage
2.4	! muon eta coverage
2.0	! tau eta coverage

20% → 5%

80% → 60%

jets: cone<0.5

Disclaimer :
PGS of LHC detector
+ flat b-tagging
in the full tracking range of
$|\eta|<3.0$
b: 60%, c: 10%, udsg: 1%
CAL coverage until $|\eta|<5.0$