

Search for Higgs decay to invisibles at the LHeC and the FCC-eh

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Tokyo Institute of Technology



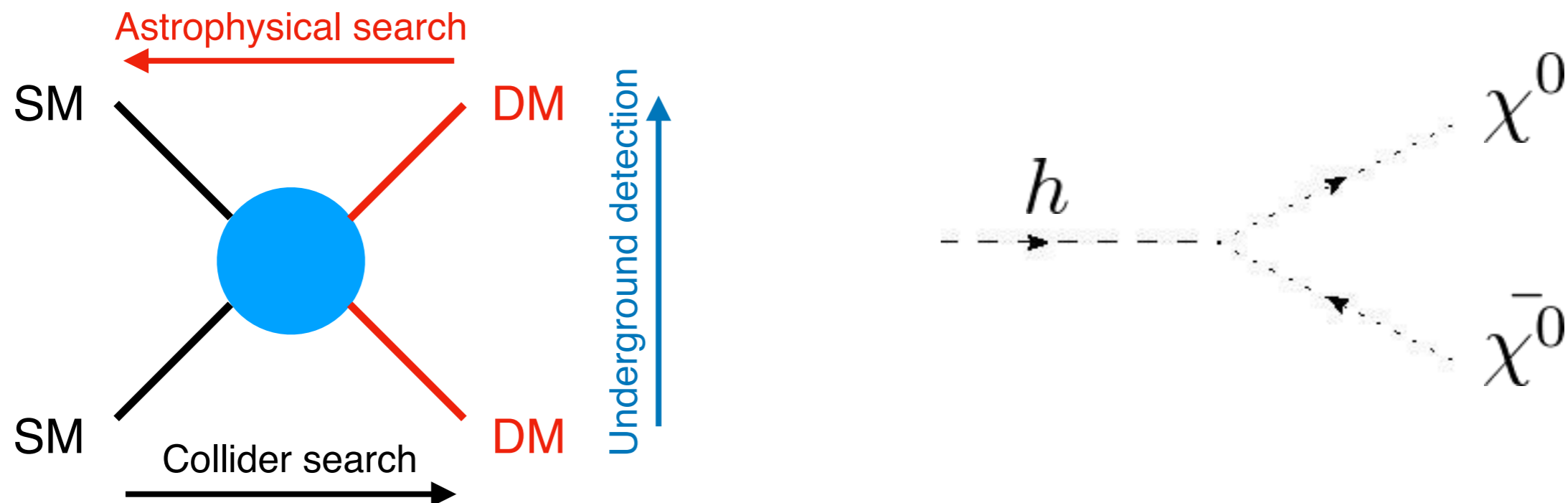
Electrons for the LHC
Orsay, 27 June 2018



130th Anniversary in 2011

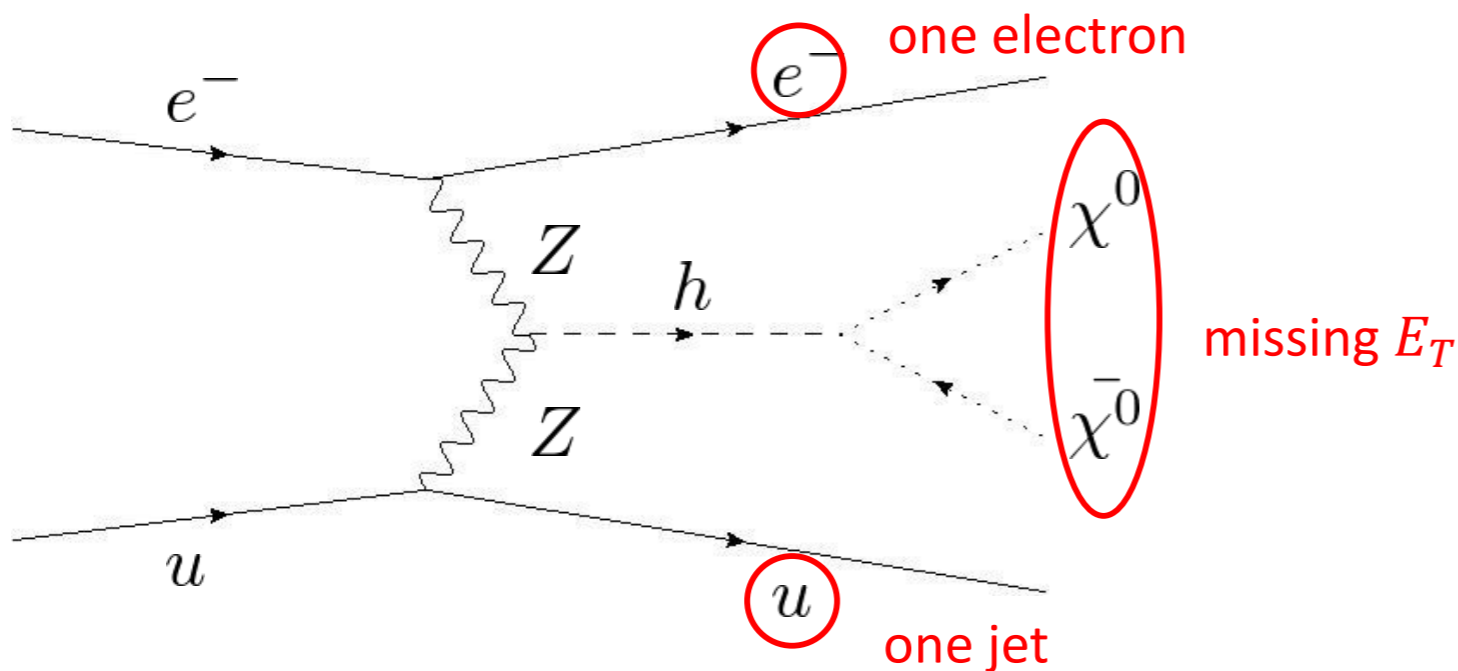
Higgs to invisible decay

- Key to Beyond-SM physics
- Negligible SM B.R. $\sim 0.1\%$ ($H \rightarrow ZZ^* \rightarrow 4\nu$)
- Very interesting connection to **Dark Matter**:
if $m_{\text{DM}} < m_H/2$, anomalous decay BR to DM
- Testable at hh, eh, and ee colliders



Higgs to invisible in ep

- NC ZZ fusion: $eq \rightarrow eqZZ \rightarrow eqH$ (20fb at LHeC)
- CC WW fusion has larger xsec, but the signature is mono-jet \rightarrow hard to separate from SM CC DIS
- Signature: **e+jet+MissE_T**, main background from SM W and Z production ($W \rightarrow l\nu$ / $Z \rightarrow \nu\nu$)



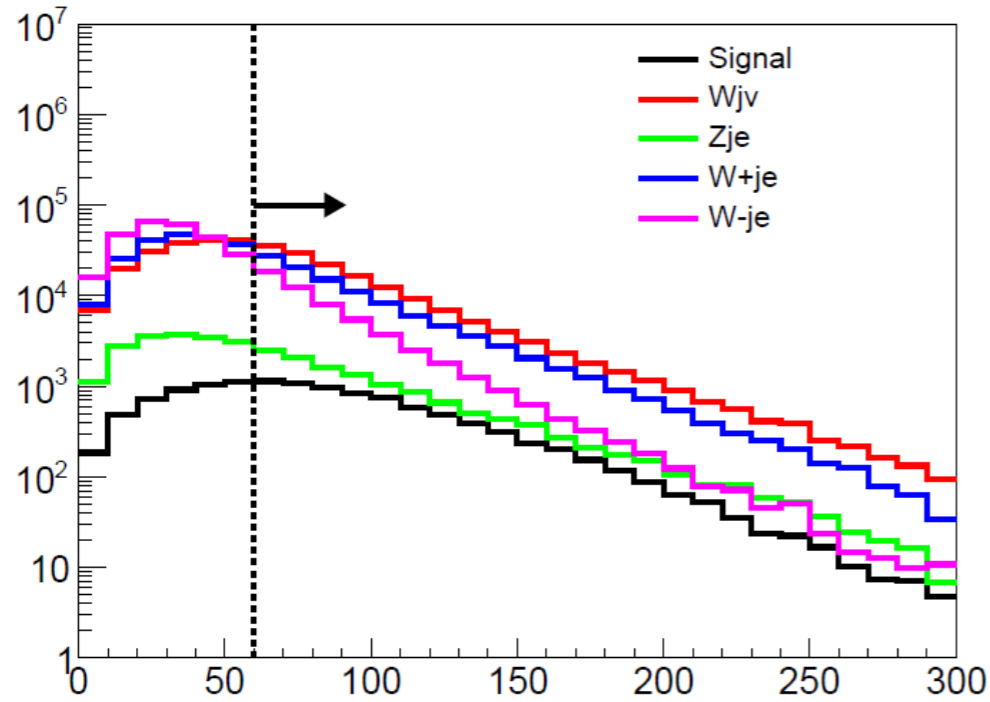
- Unlike ee-collider, 'recoil mass' cannot be reconstructed due to unknown Bjorken-x

Studies for ep colliders

- Y.Tang, C.Zhang, C.Zhu [Phys. Rev. D94 \(2015\) 011702](#)
 - Parton-level study at LHeC (60GeV+7TeV), pol=-0.9
 - Following background processes considered
 - NC W (Wje), CC W (Wj ν), NC Z (Zje)
 - 2σ (~95%CL) upper limit BR < 6% for 1ab⁻¹ (10 years)
- Studies by Tokyo Tech students (this talk) pol=-0.8
 - Standard ‘LHeC WG tools’: MadGraph+Pythia+Delphes
 - Also following b.g. MC considered
 - Single top, NC multi-jets, W photo-production
 - Turns out to be negligible (but included)

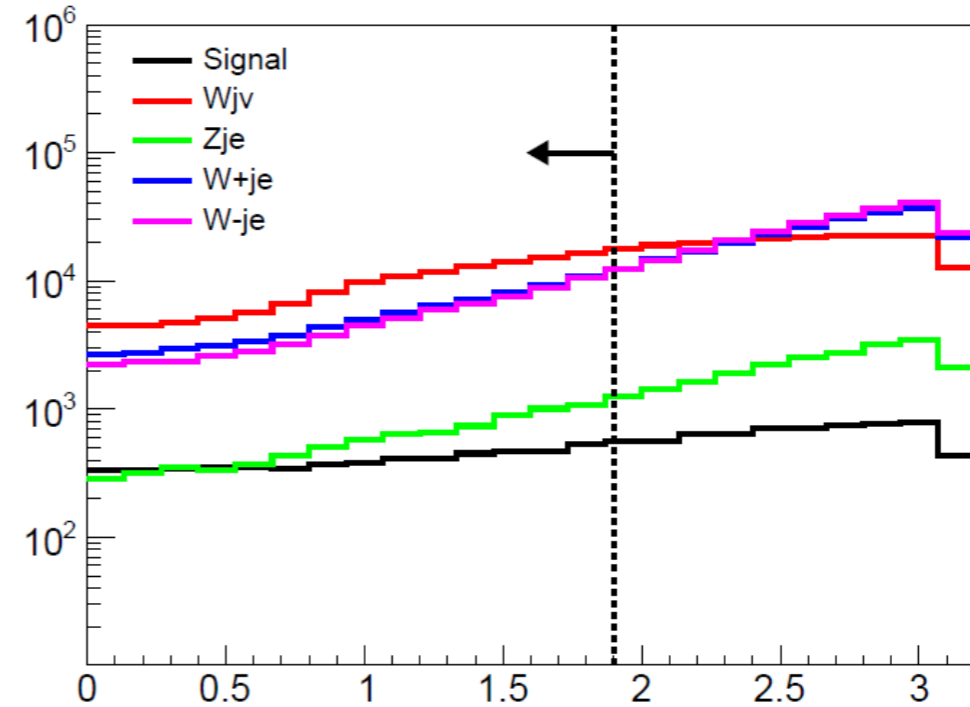
Selection variables (1)

Events/1ab⁻¹



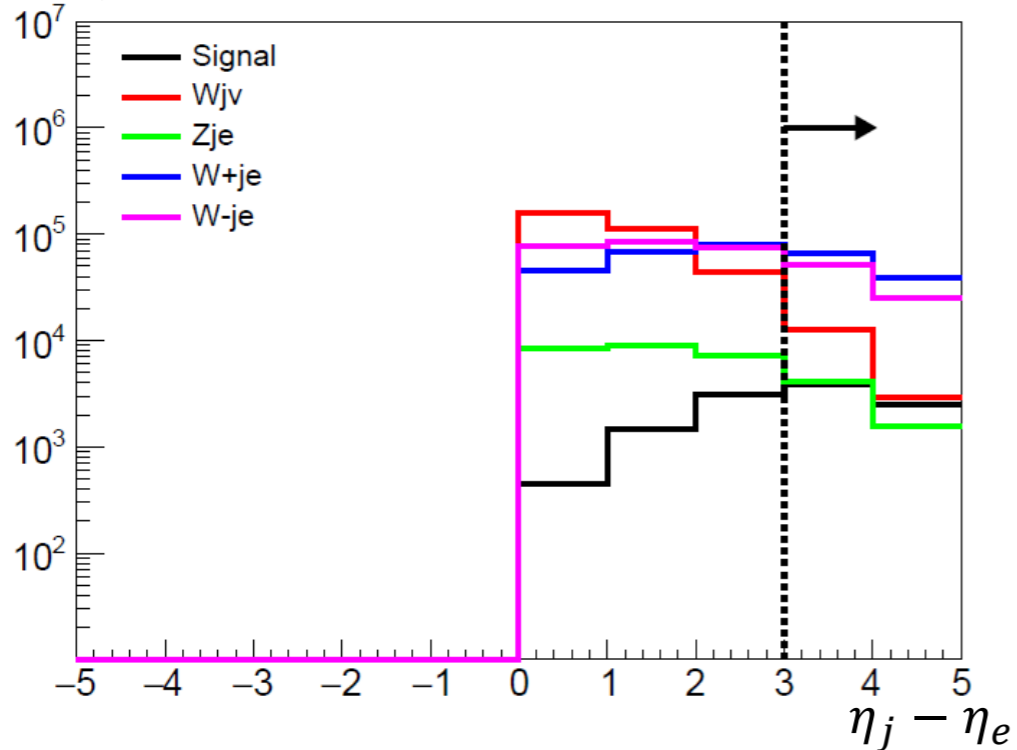
missing E_T (GeV)

Events/1ab⁻¹



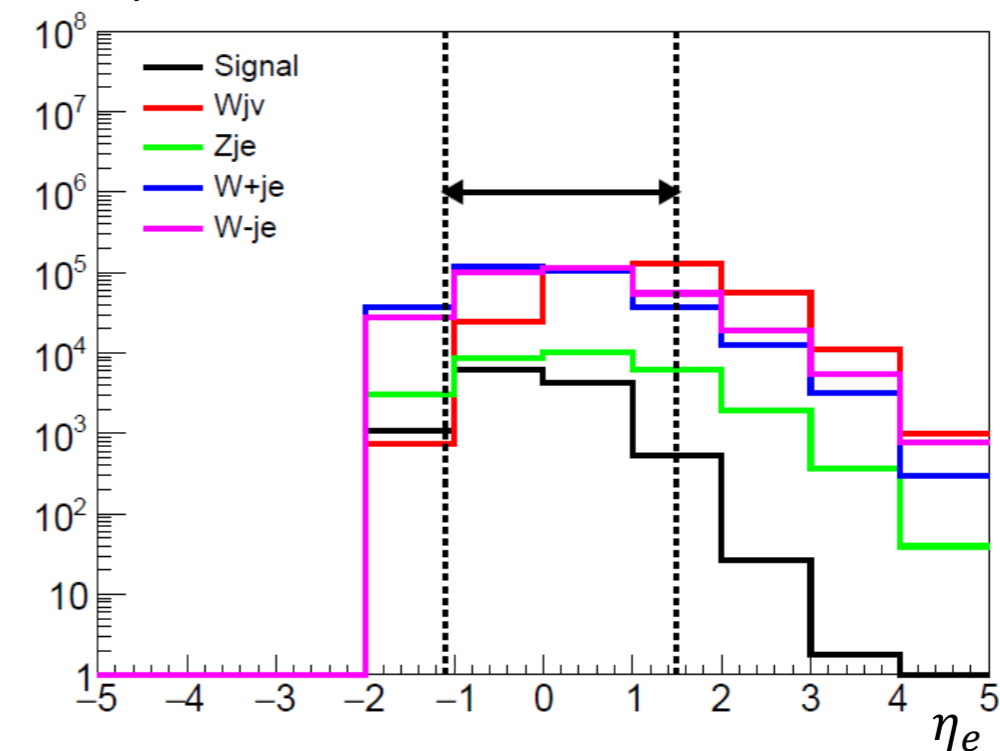
$|\phi_j - \phi_e|$ (rad)

Events/1ab⁻¹



$\eta_j - \eta_e$

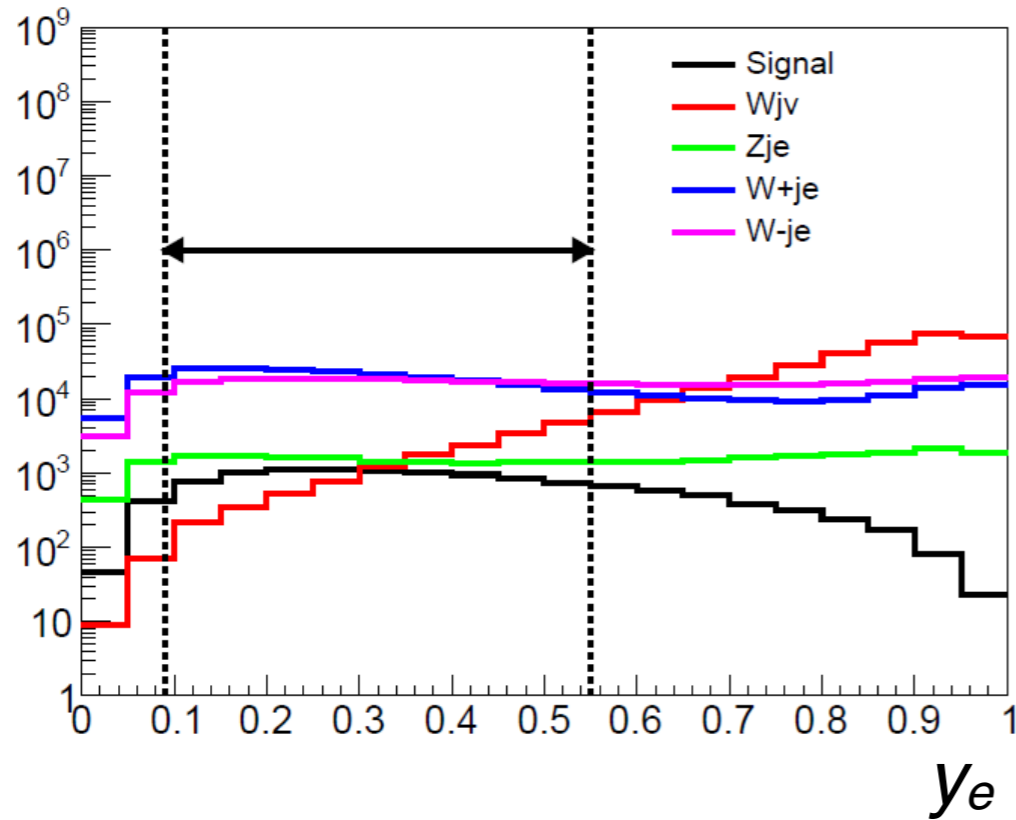
Events/1ab⁻¹



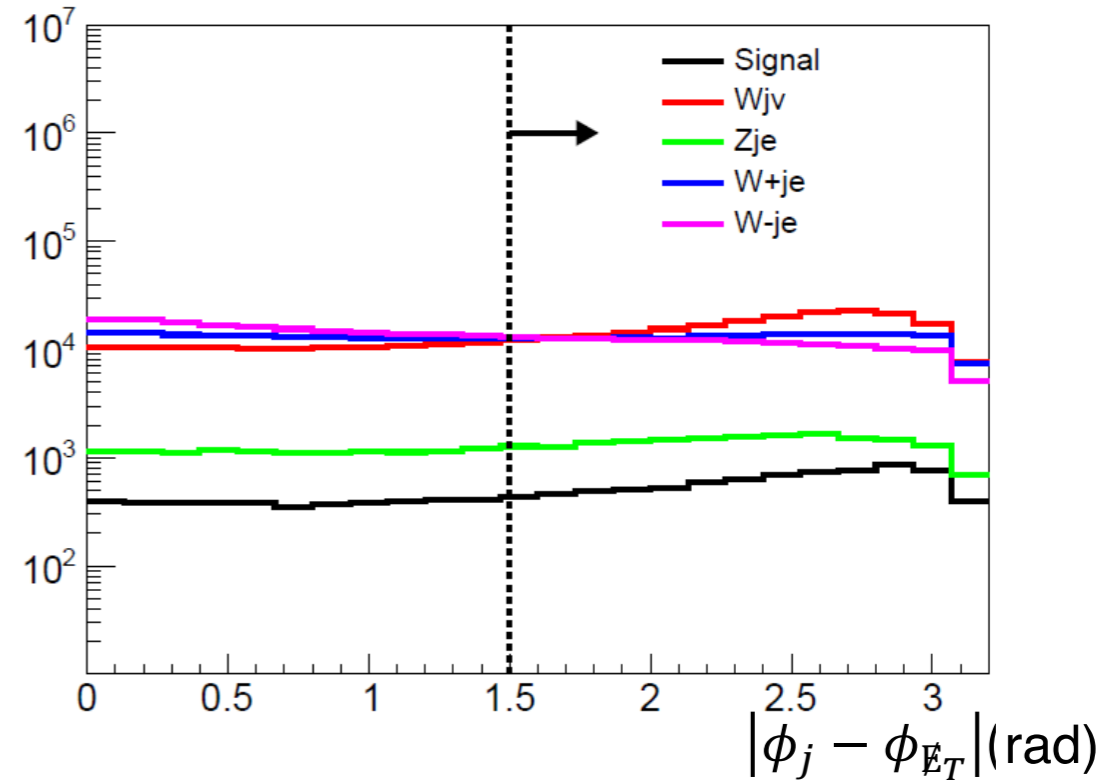
η_e

Selection variables (2)

Events/1ab⁻¹



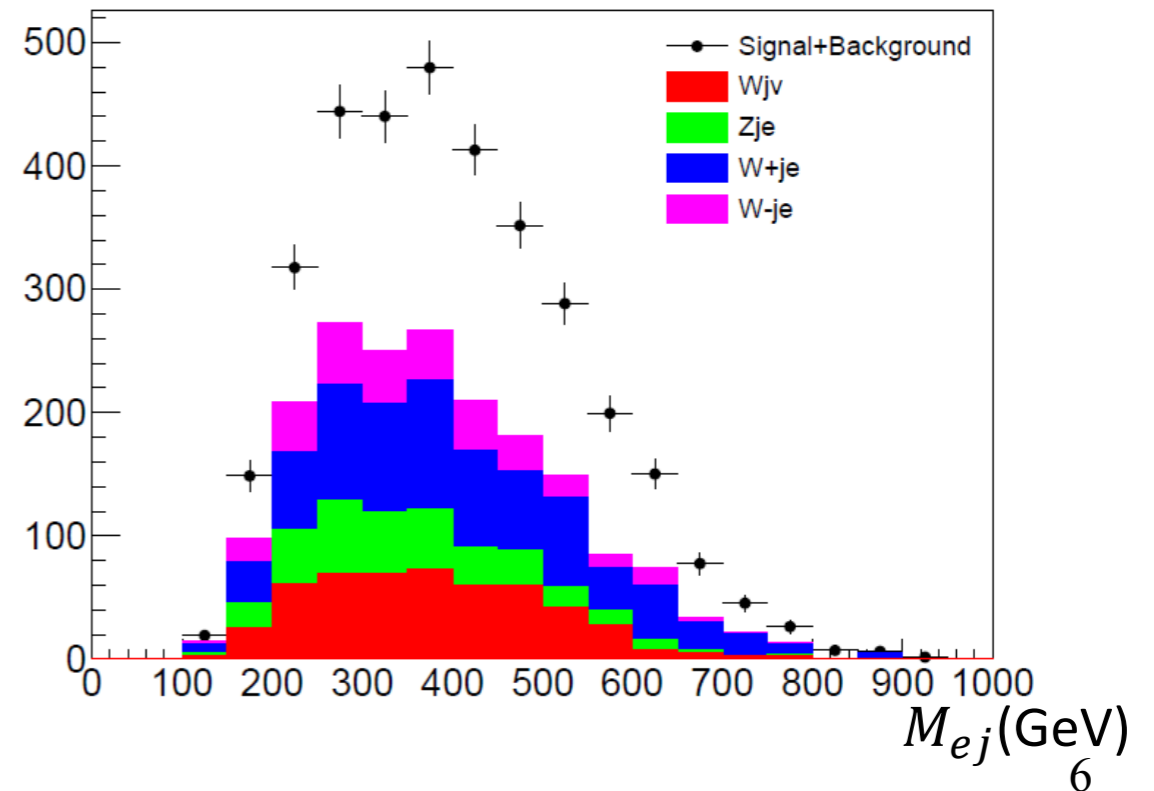
Events/1ab⁻¹



- $|\phi_j - \phi_{\cancel{E}T}| > 1.5$
- $\cancel{E}T > 60\text{GeV}$
- $\eta_j - \eta_e > 3.0$
- $|\phi_j - \phi_e| < 1.9$
- $-1.1 < \eta_e < 1.5$
- $0.09 < y_e < 0.55$
- $N_e = 1$
- $N_\mu = 0$
- $N_\tau = 0$
- $N_j = 1$

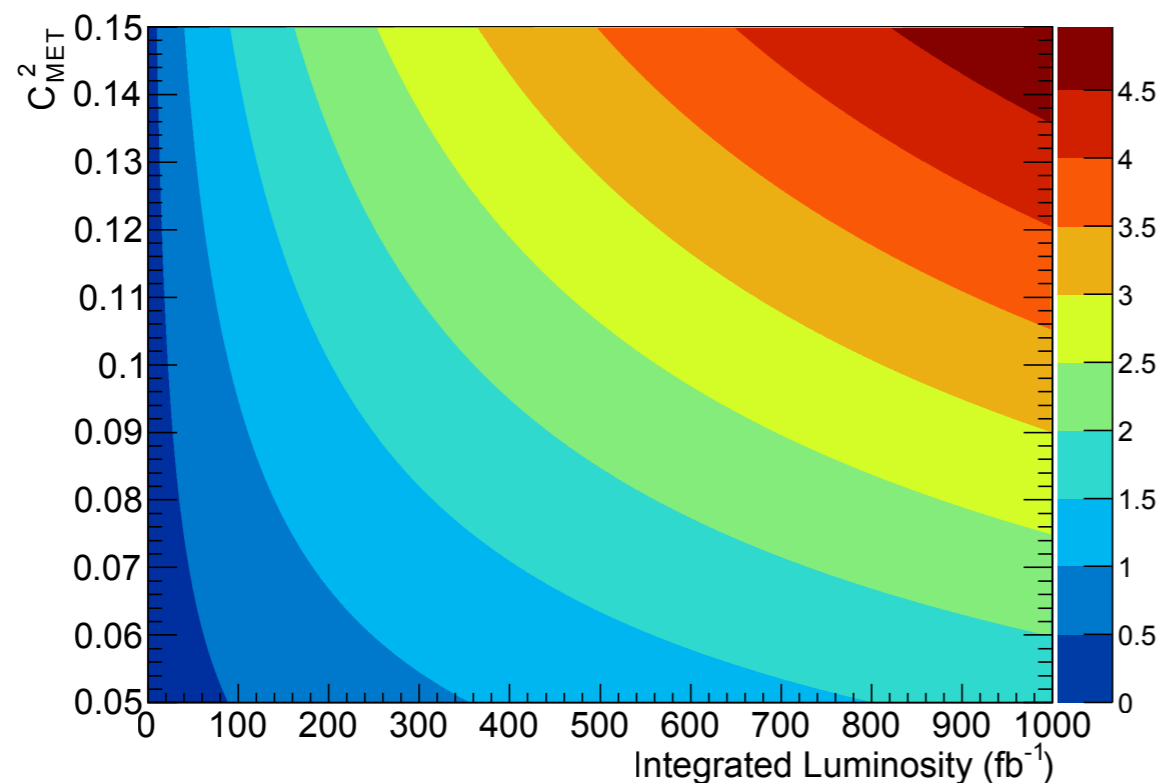
Events/1ab⁻¹

After all cuts (signal BR=100%)



Cut-based selection result

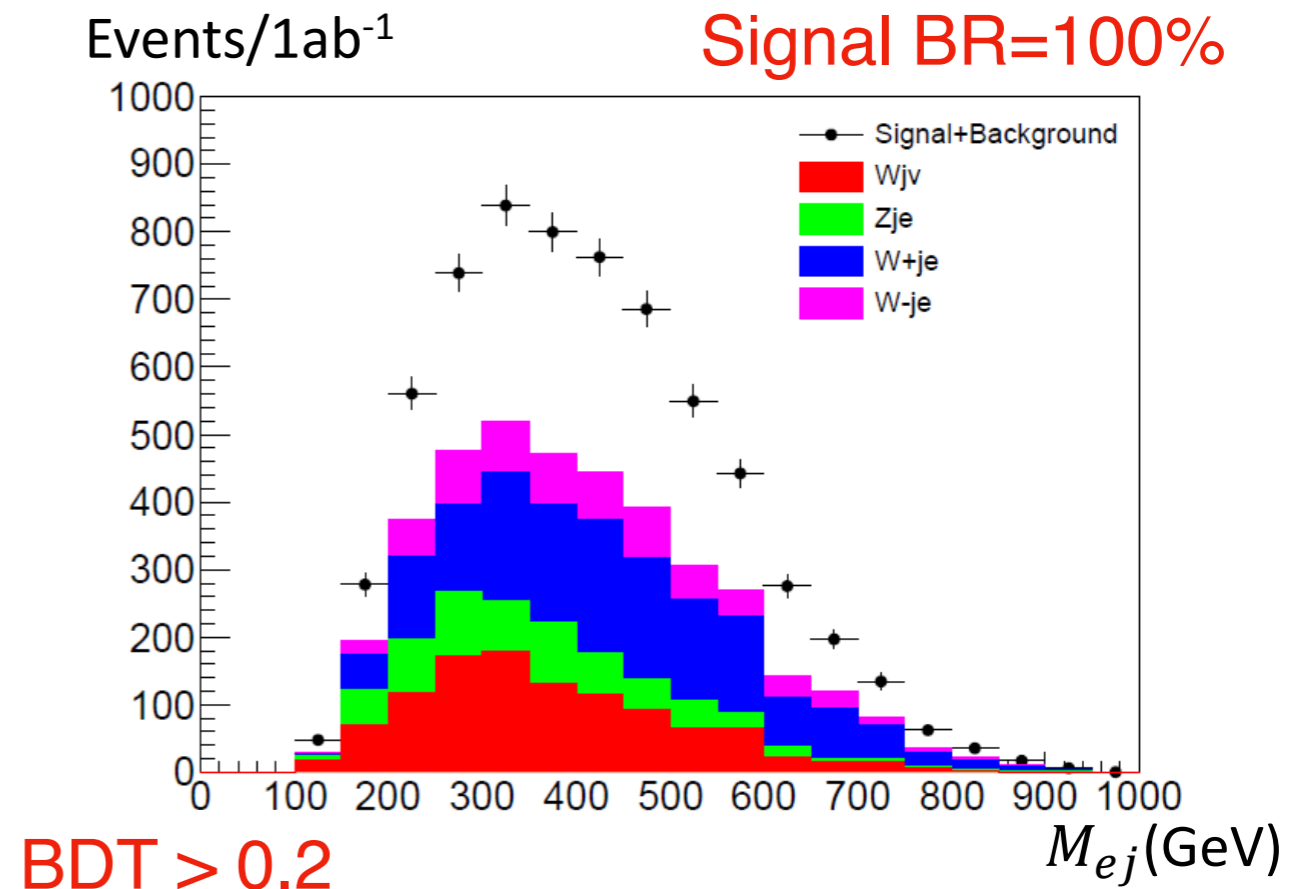
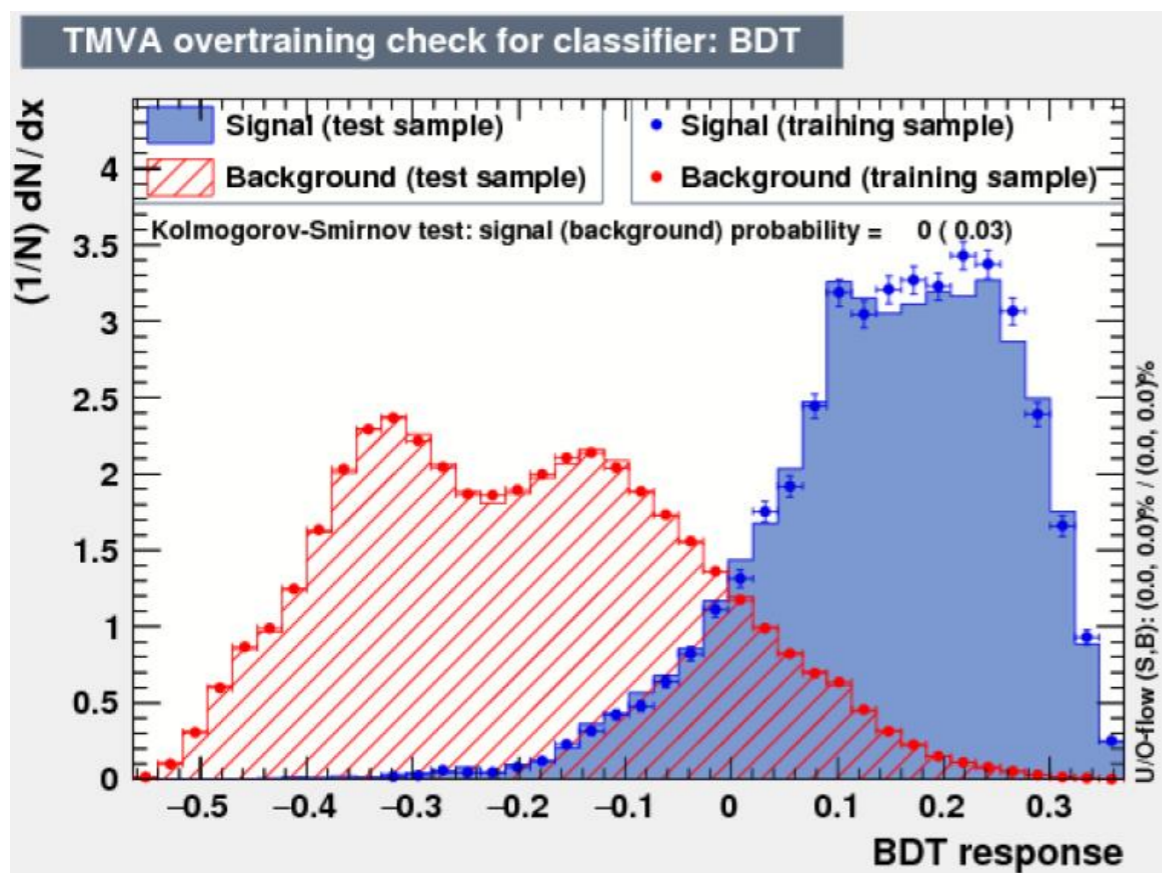
- $S \sim 1500$ (for $BR=100\%$), $B \sim 1900$ events
- 2σ upper limit on $BR \sim 6\%$ (stat. error only)
- Syst. on b.g. should be controllable from other W and Z decay channels ($\mu\nu$, $\mu\mu$, etc.)



Significance as a function of
luminosity and BR
(from Phys. Rev. D94, 011072)

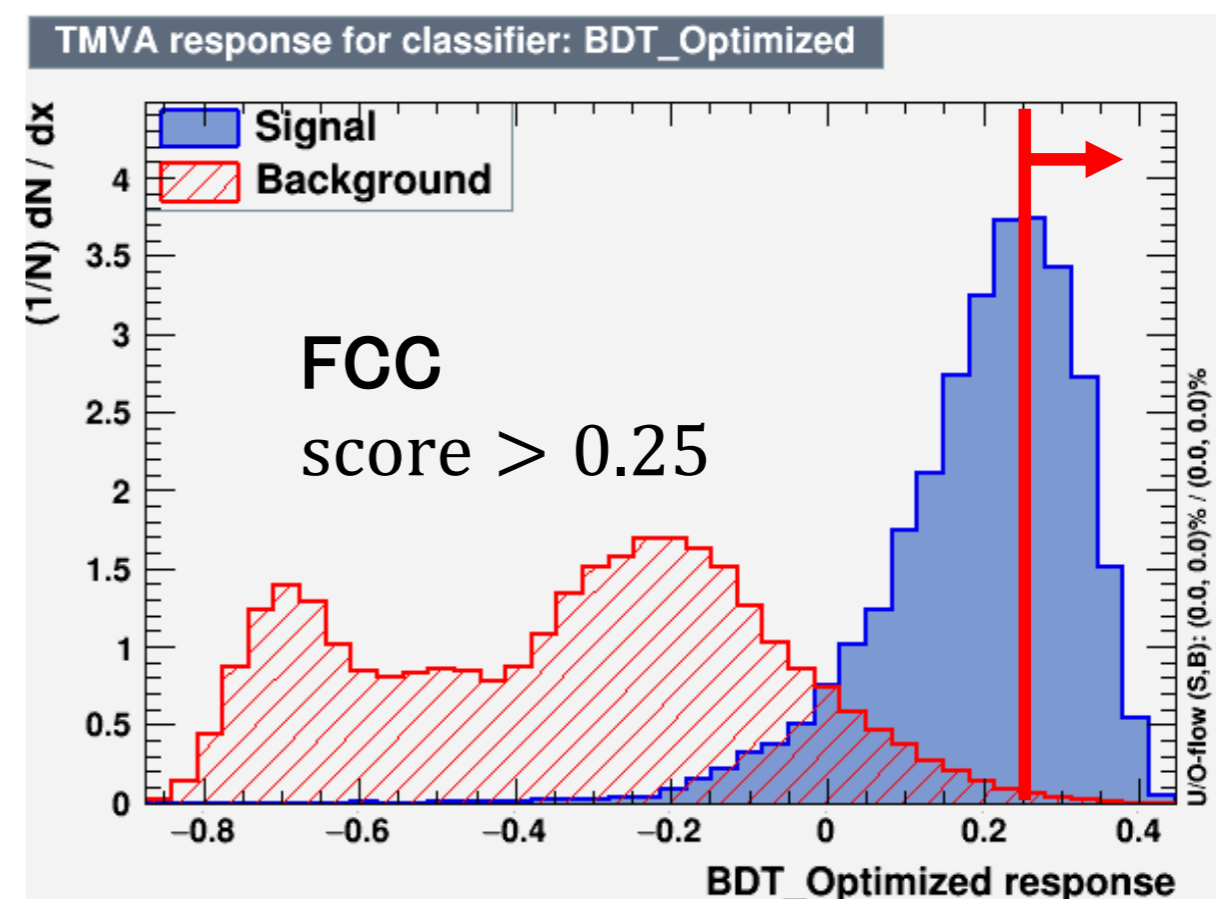
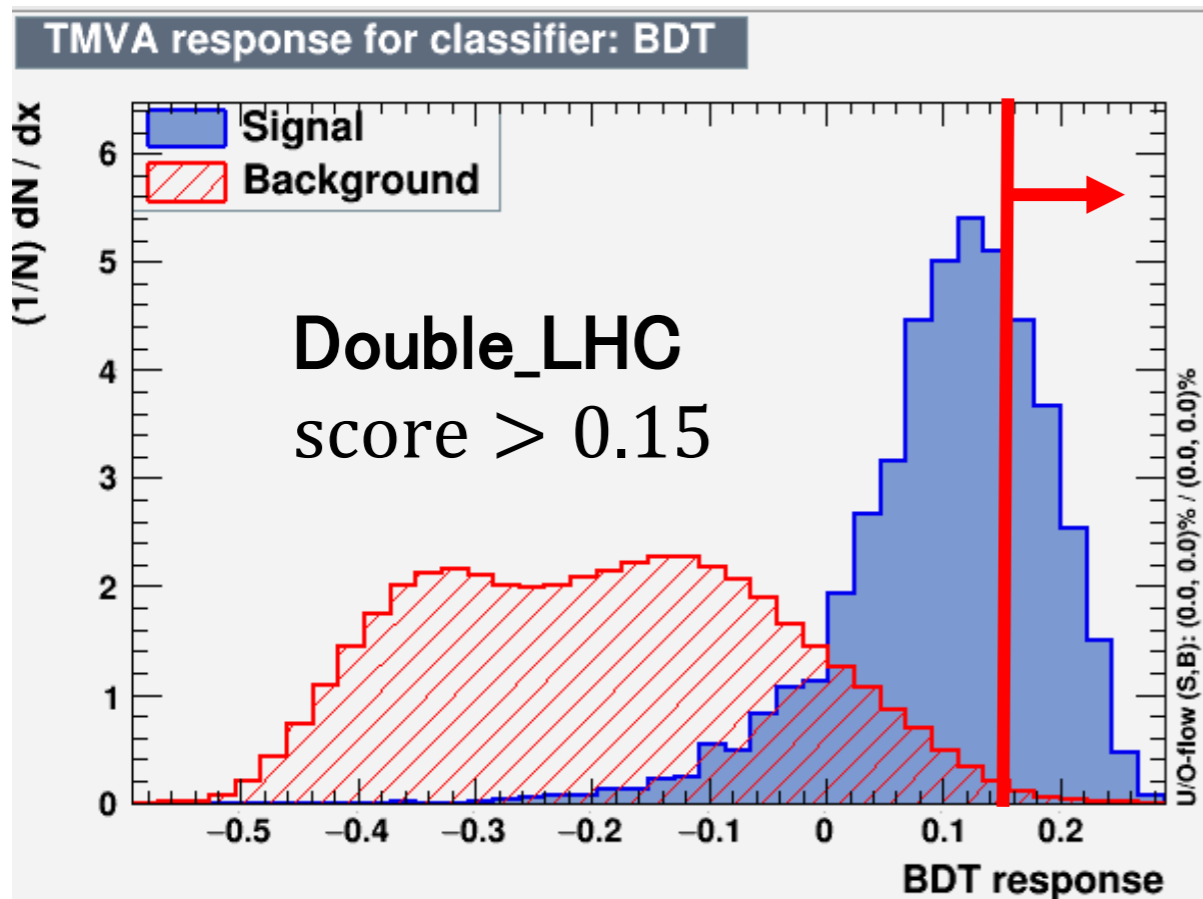
BDT selection (TMVA)

- Same set of input variables used
- $S \sim 2800$ (BR=100%) $B \sim 5900$ for 1ab^{-1}
- 2σ upper limit on BR $\sim 5.5\%$
- Optimization of BDT config. also tried



Higher proton beam energy

- LHeC (7TeV) $\sigma \sim 20\text{fb}$, BR < 5.5% (BDT)
- DLHC (14TeV) $\sigma \sim 45\text{fb}$. BR < 3.4% (BDT)
- FCC-eh (50TeV) $\sigma \sim 120\text{fb}$, BR < 1.7% (BDT)



Comparison w/ other colliders

- Current LHC limit $\sim 25\%$ (95% CL)

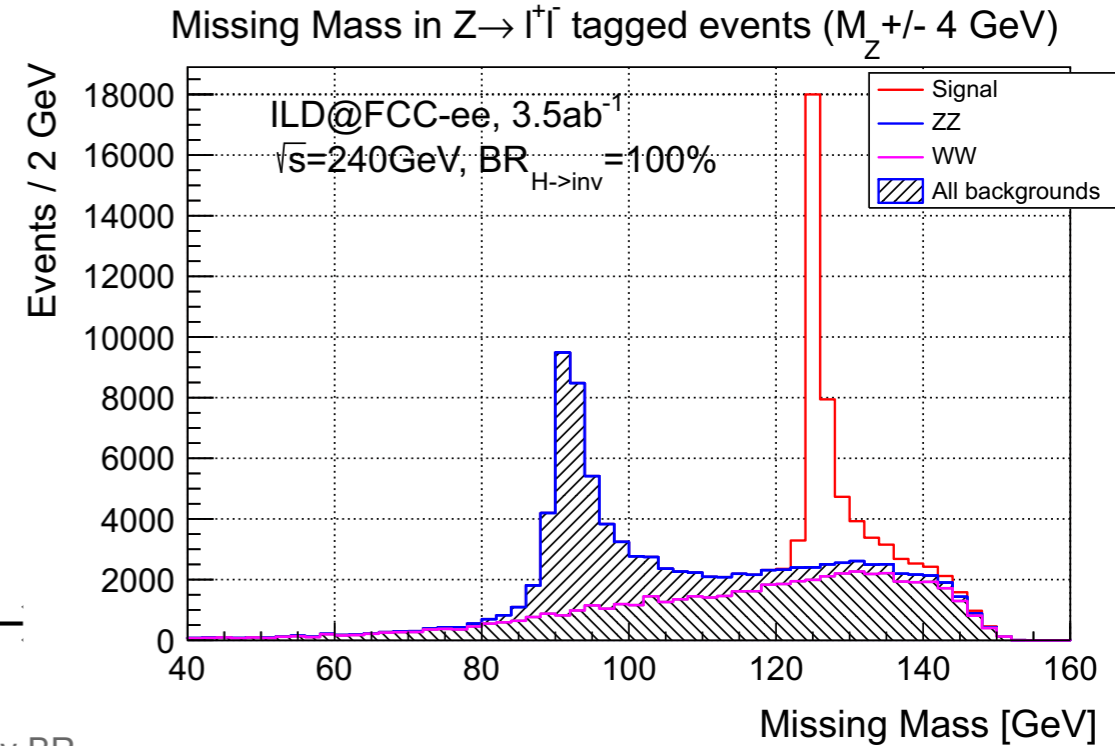
ATLAS: JHEP 11 (2015) 206

- Prospect at HL-LHC $\sim 3.5\%$

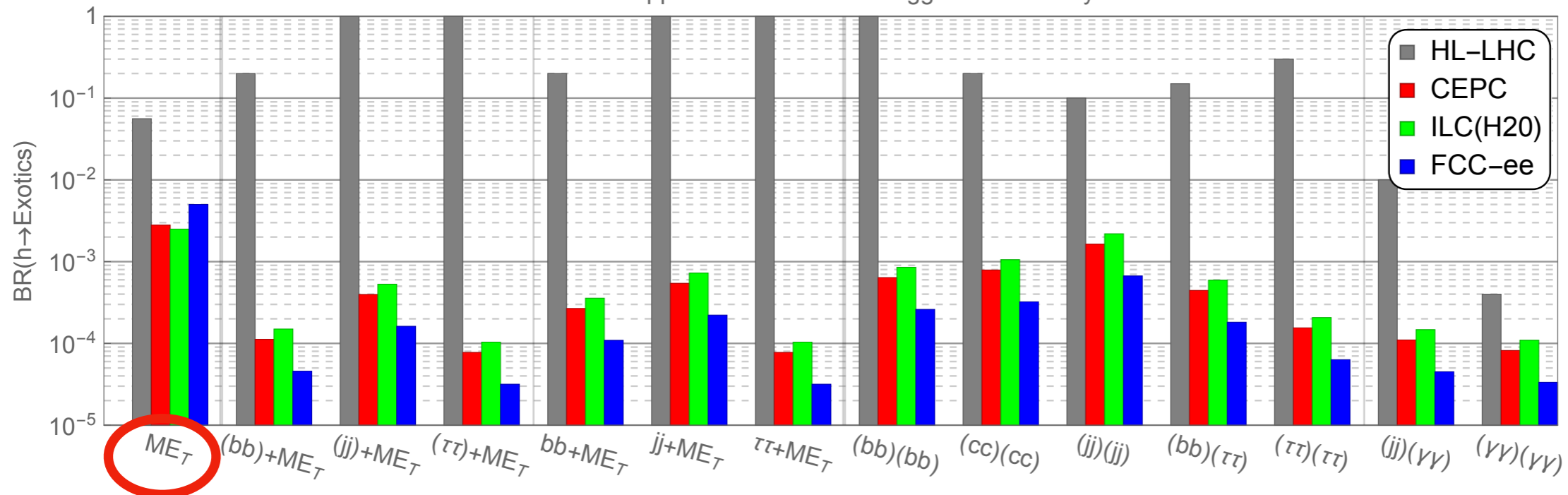
C. Bernaciak et al.,
Phys. Rev. D91 (2015) 035024

- Prospect at FCC-ee $\sim 0.63\%$

O. Cerri et al., EPJC77 (2017) 116

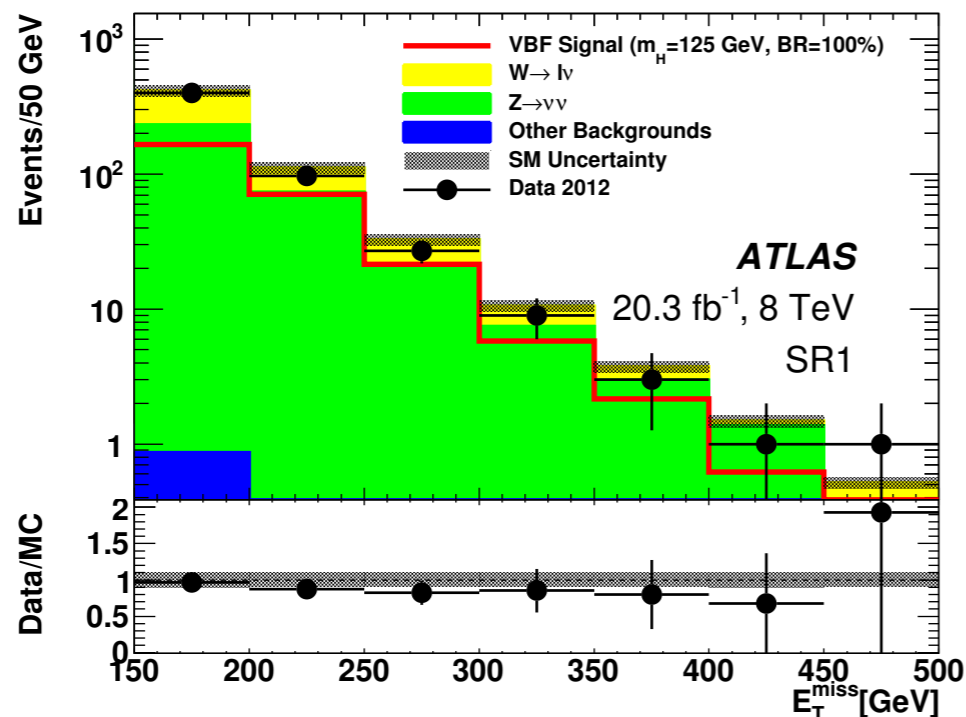
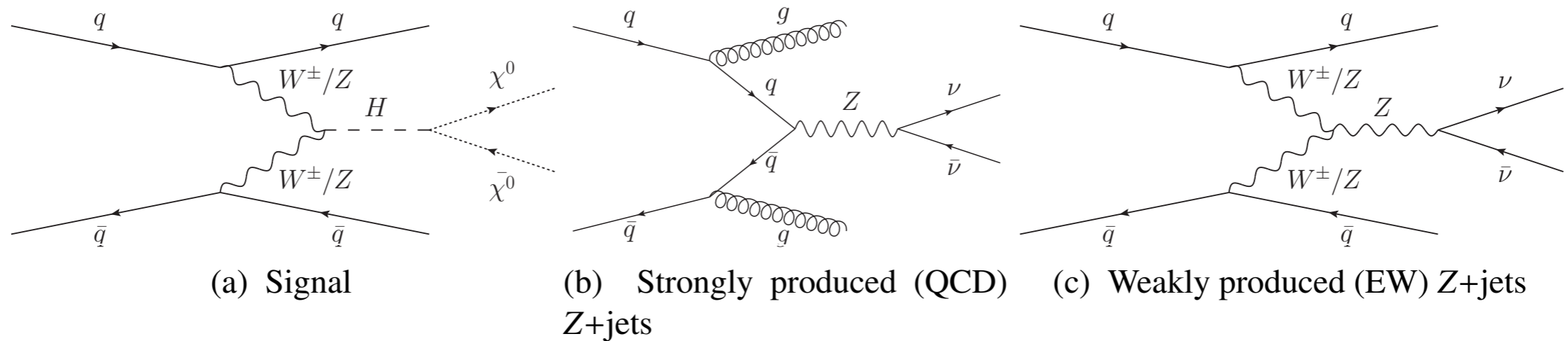


95% C.L. upper limit on selected Higgs Exotic Decay BR

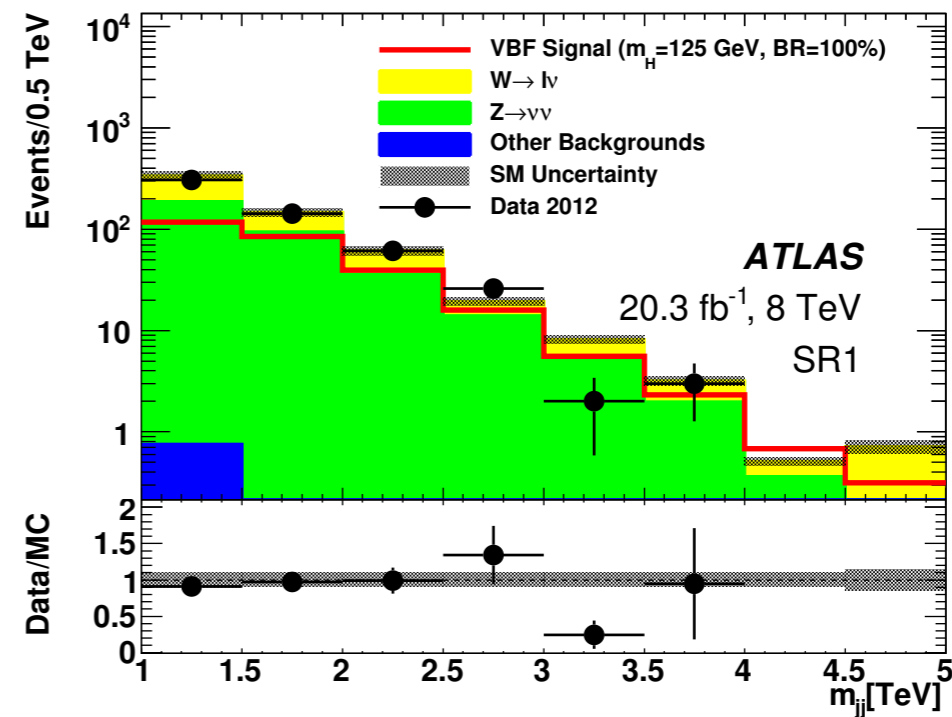


How does LHC do (now)?

- Current ATLAS limit from VBF $\sim 28\%$ (95% CL)
JHEP 01 (2016) 172



(a) E_T^{miss} distribution



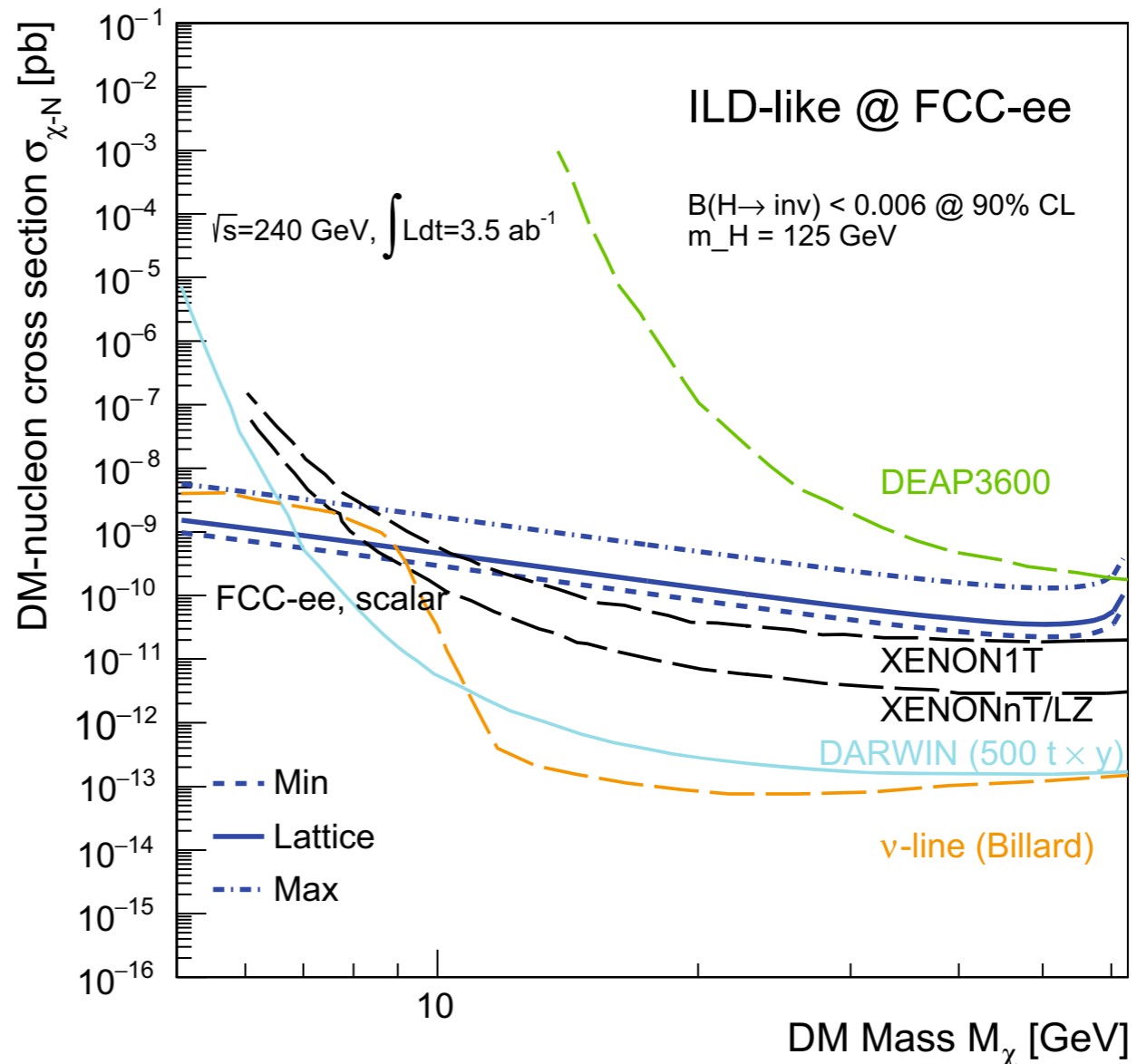
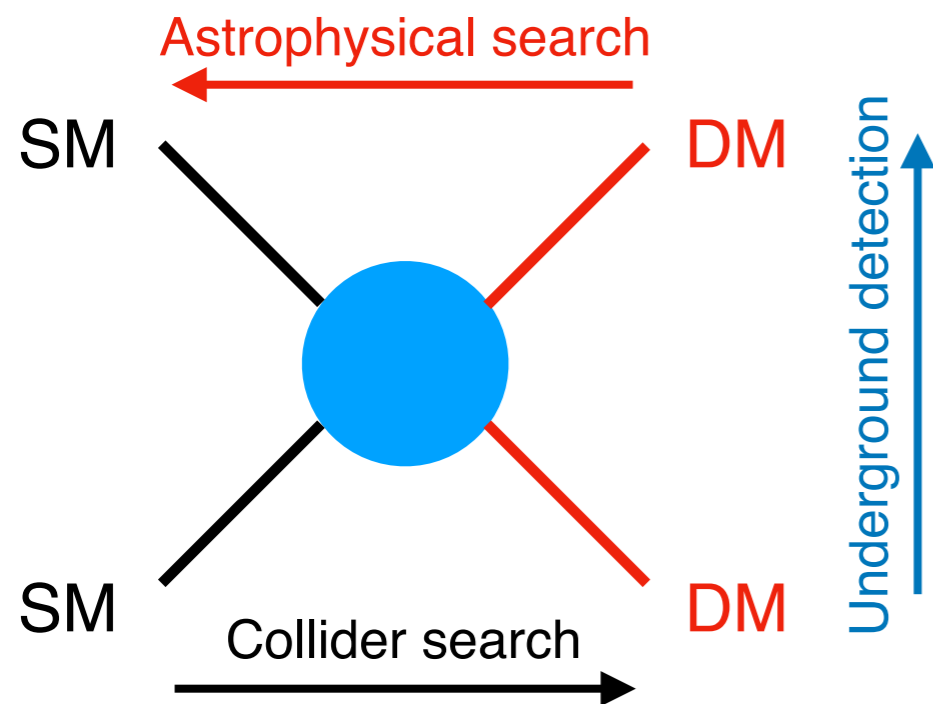
(b) m_{jj} distribution

Connection with DM search

- Example from FCC-ee

O. Cerri et al., EPJC77 (2017) 116

→ complementary to direct searches at low m_{DM}



Conclusions

- **Higgs to invisible** decay is an important key to physics beyond SM, especially with connection to DM
- Negligible SM BR (0.1%)
- Potential in ep colliders investigated in NC ZZ fusion production (**e + jet + missE_T**)
- At LHeC, upper limit **~5%** can be obtained, while **<2%** can be achieved at FCC-eh
- Good complementarity with hadron colliders, with ultimate precision perhaps from ee collider.