Future ee Colliders and the study of Colour Reconnection effects

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Outlook

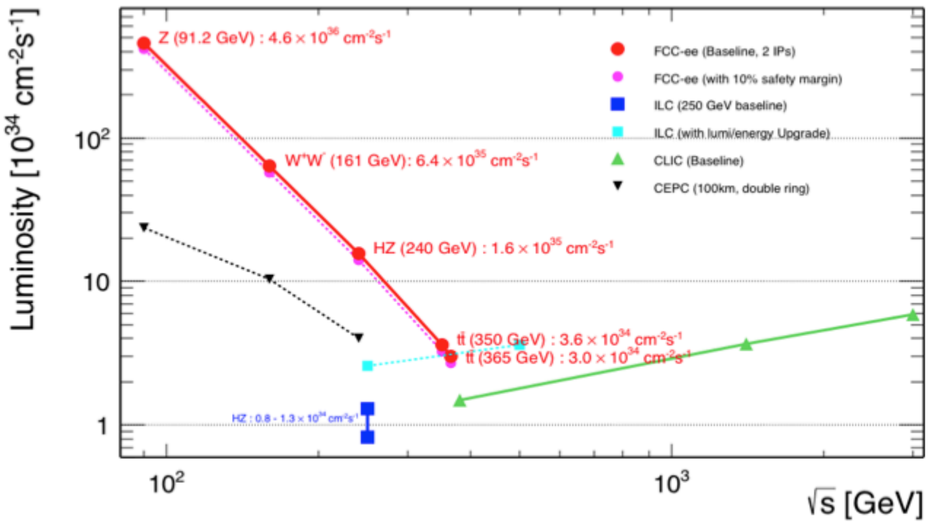
- Future ee Colliders
- The effects of Colour Reconnection
- Results of study the effects of CR
- New models for study of CR effects
- CR at Future ee Colliders

Future ee Colliders

Linear or Circular?

Linear: ILC, CLIC

Circular: FCC-ee, CERP



- With linear colliders are achievable a high center-of-mass energies due the absence of synchrotron radiation
- While a clear advantage of a future circular ee mashines is absolute luminosity

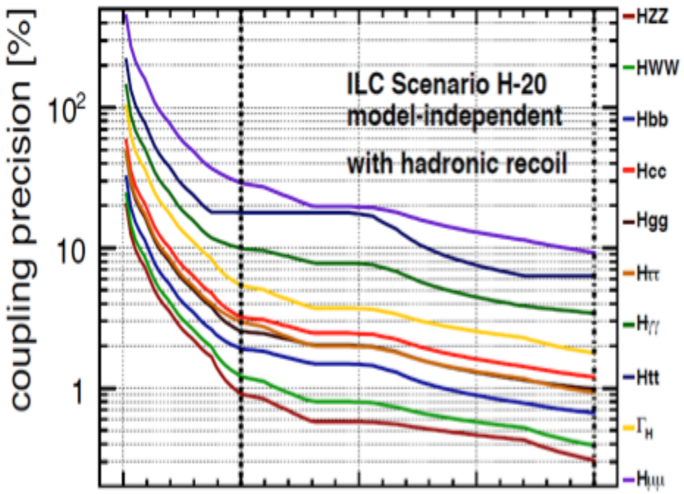
Future ee Colliders

The **FCC-ee** - ***Future Circular Collider*** – will be a unique for searches new physics via high-precision studies of the W, Z, H bosons and top quark with uncertainties at the permil level or below, with huge luminosities (1-100) ab^1 with 4 interaction points, beam energy 90-350 GeV
10^8 jets from Z and W bosons decays
10^5 gluon jets from Higgs boson decays

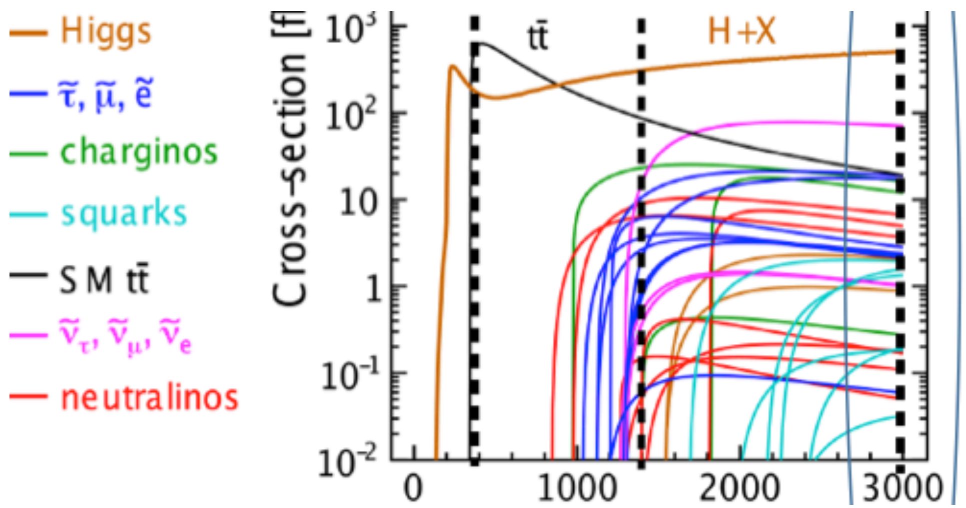
$\sqrt{s}$ (GeV):	90 (Z)	125 (eeH)	160 (WW)	240 (HZ)	350 ($t\bar{t}$)	350 (WW→H)
$\mathscr{L}$/IP (cm^{-2} s^{-1})	$2.2\cdot10^{36}$	$1.1\cdot10^{36}$	$3.8\cdot10^{35}$	$8.7\cdot10^{34}$	$2.1\cdot10^{34}$	$2.1\cdot10^{34}$
$\mathscr{L}_{int}$ (ab^{-1}/yr/IP)	22	11	3.8	0.87	0.21	0.21
Events/year (4 IPs)	$3.7\cdot10^{12}$	$1.2\cdot10^{4}$	$6.1\cdot10^{7}$	$7.0\cdot10^{5}$	$4.2\cdot10^{5}$	$2.5\cdot10^{4}$
Years needed (4 IPs)	2.5	1.5	1	3	0.5	3

Future ee Colliders

ILC 250 GeV

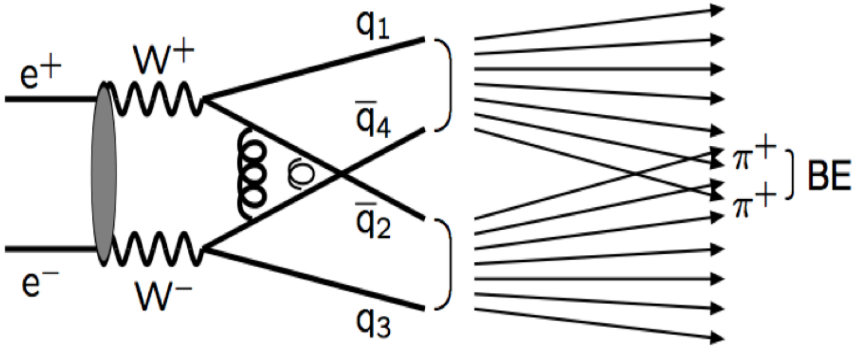


CLIC



Colour reconnection effects

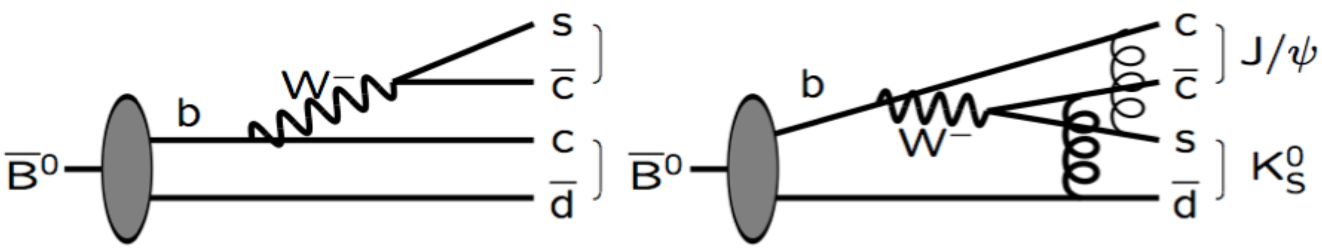
- Color reconnection is an *ad hoc* mechanism aiming to describe the interactions that can occur between chromoelectric fields during the hadronization transition.
- CR : top quark, Z, W bosons have widths around 2 GeV and cτ= 0.1fm
- which is smaller than the hadronization times
- which means inside all the hadronization colour fields, in the evolution of the parton sh ronic systems by exchanging colo



Reconnection exists

$B \to J/\psi \to \mu^+\mu^-$ good way to find B mesons:
H. Fritzsch, Phys. Lett. **B86** (1979) 164, 343

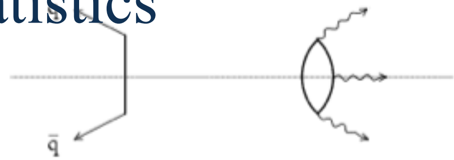
$g^* \to c\bar{c} \to J/\psi$ production mechanism in pp (“colour octet”)
H. Fritzsch, Phys. Lett. **B67** (1977) 217

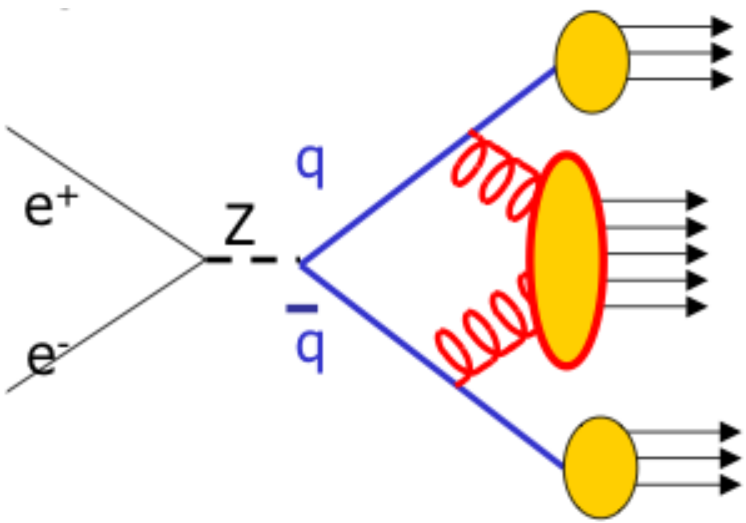


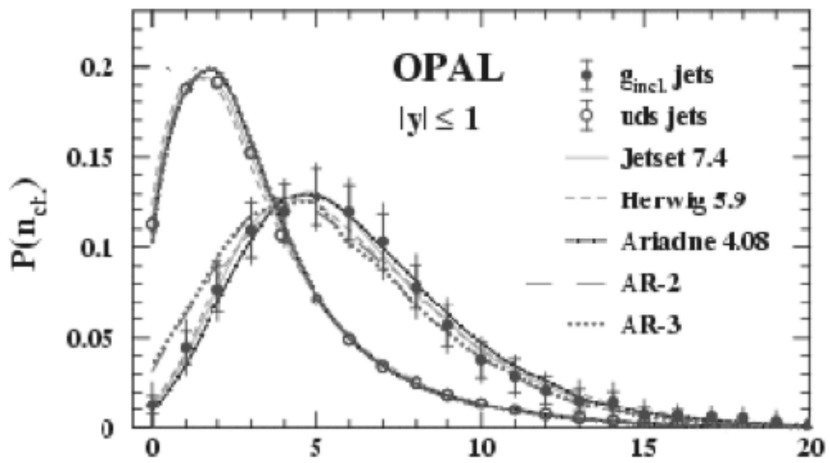
Looking on LEP1 data

Z->qqgg form a “glue ring” (Friberg et al. 97)

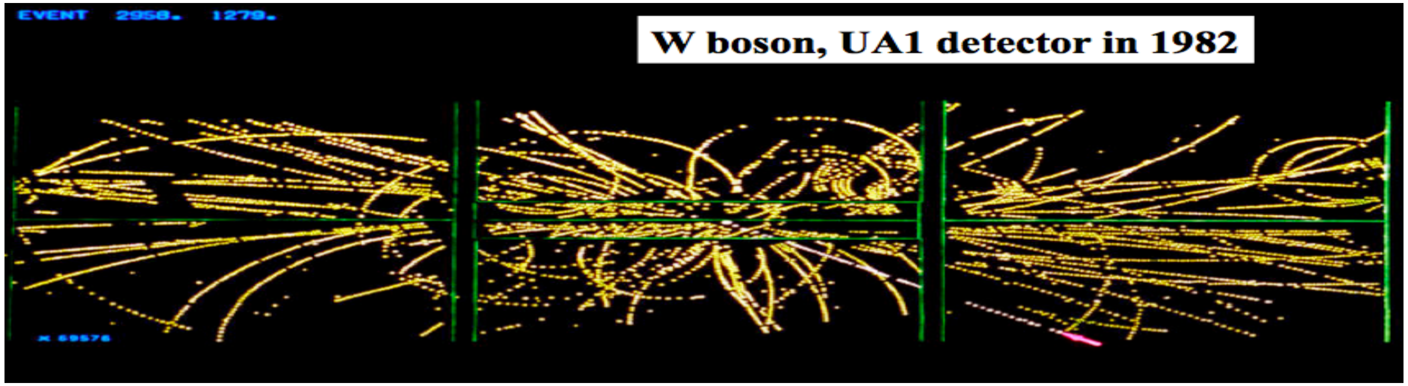
OPAL: 439 events in the full LEP1 statistics







W boson



$$W^- \to e^- \overline{\nu}_e \qquad W^- \to d\overline{u} \;\; \times 3|V_{ud}|^2 \qquad W^- \to d\overline{c} \;\; \times 3|V_{cd}|^2$$

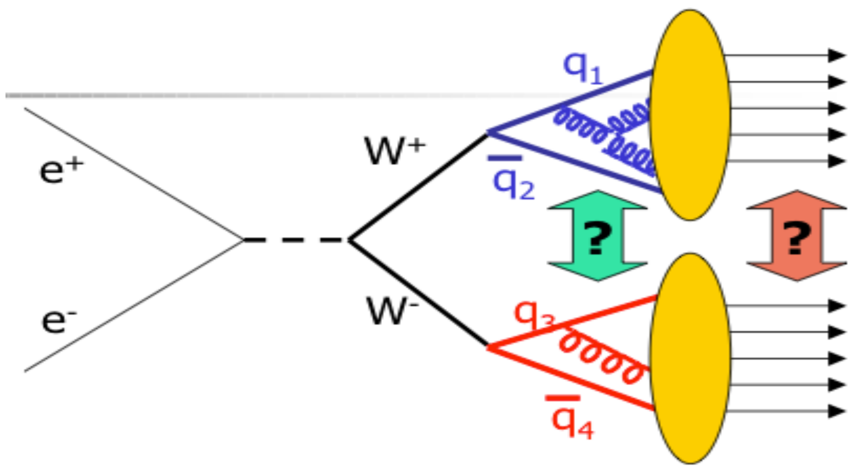
$$W^- \to \mu^- \overline{\nu}_\mu \qquad W^- \to s\overline{u} \;\; \times 3|V_{us}|^2 \qquad W^- \to s\overline{c} \;\; \times 3|V_{cs}|^2$$

$$W^- \to \tau^- \overline{\nu}_\tau \qquad W^- \to b\overline{u} \;\; \times 3|V_{ub}|^2 \qquad W^- \to b\overline{c} \;\; \times 3|V_{cb}|^2$$

$$\Gamma_W = 9\Gamma_{W\to e\nu} = \frac{3g_W^2 m_W}{16\pi} = 2.07\,\text{GeV}$$

CR effects in WW events

- In the absence of colour reconnection, from the fragmentation of two colour singlet strings each of which is stretched between the two quarks from a W boson.
- However, interactions may occur between the decay products of the two W bosons.
- This "cross-talk" is due relatively short distance separating the decay of the W bosons (in order of 0.1 fm)

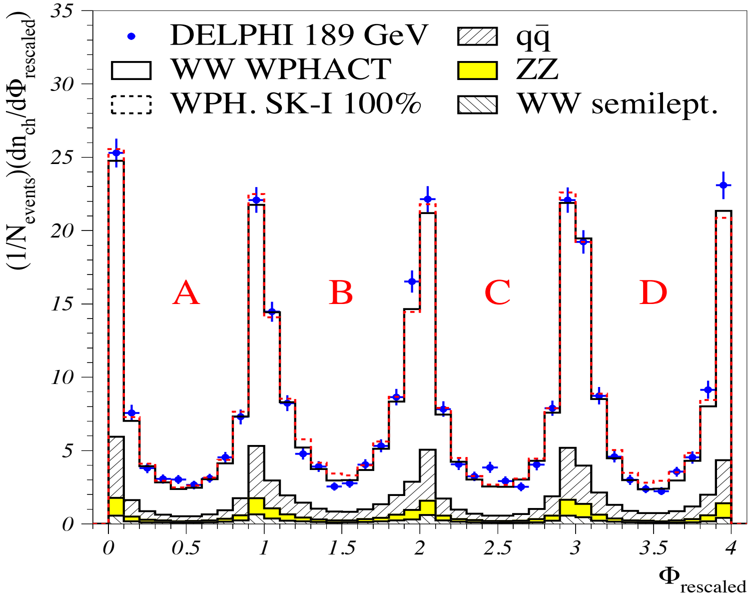


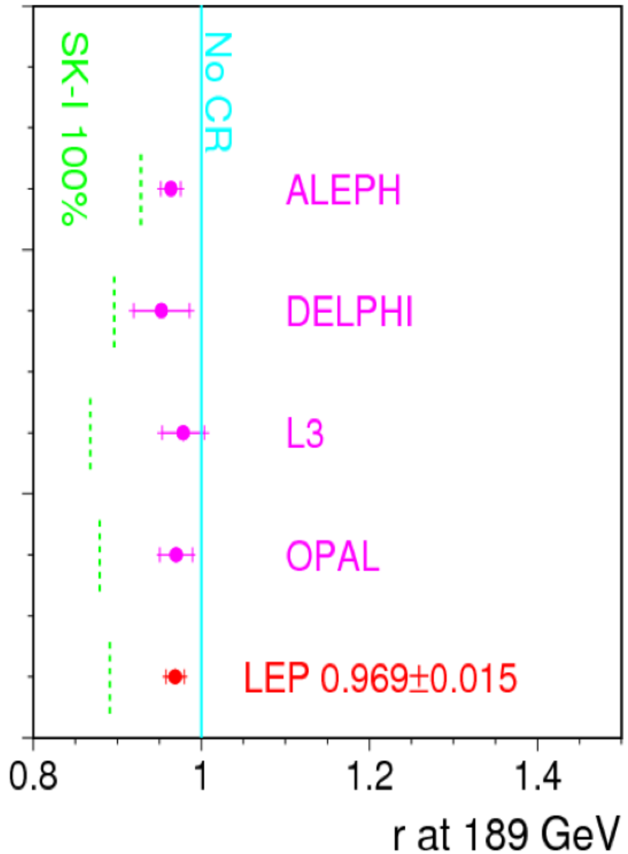
Systematics of WW at LEP2

Source	qqlv	qqqq	combined
Hadronisation	13	19	14
QED(ISR/FSR)	8	5	7
Detector	10	8	10
Colour Reconnection	0	35	9
Bose-Einstein Correlation	0	7	2
LEP Beam Energy	9	9	10
Other	3	11	4
Total Systematics	21	44	22
Statistical	30	40	25
Total	36	59	33

The conclusion of the LEP2

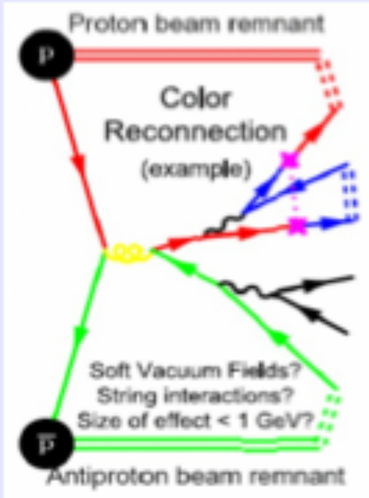
- Best LEP2 fit (topology + mass): 51% of 189 GeV events reconnected in SKI model.
- No-CR excluded at 99.5% CL





Tevatron results

- Study withthe Perugiao tune, which gives 1.3 GeV



to the top mass systematics of order

CR(sys)≈ 0.5 GeV

generator : $\Delta(m_t)$ = 0.25 GeV (HERWIG-PYTHIA)

ISR/FSR : $\Delta(m_t)$ = 0.15 GeV

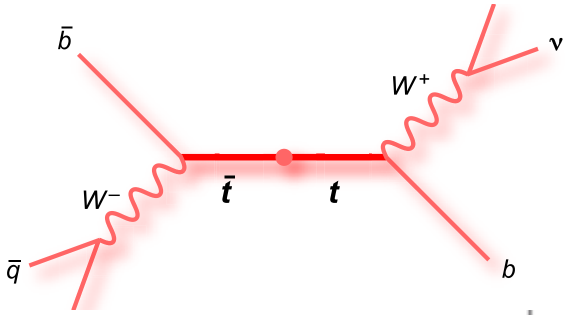
Jets (OOC+JES) : $\Delta(m_t)$ = 0.43 GeV

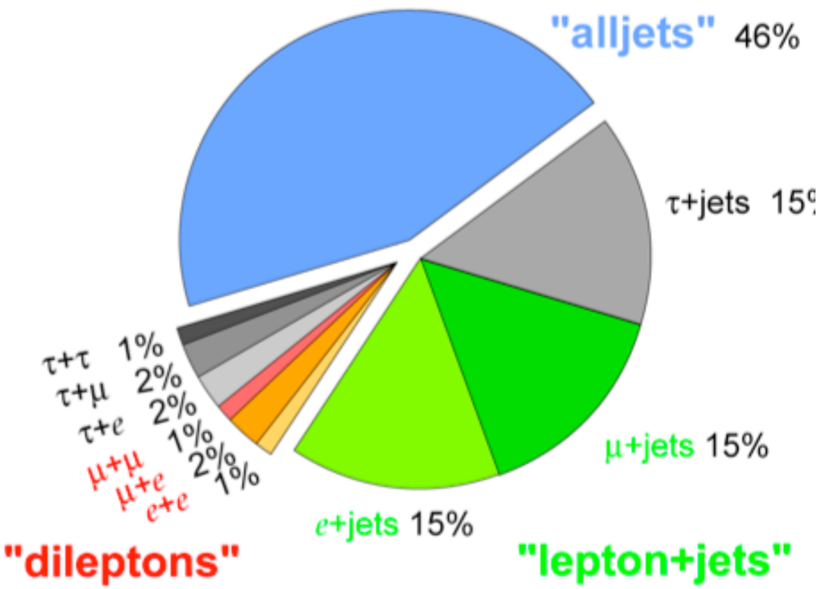
b-jets : $\Delta(m_t)$ = 0.16 GeV

Color reconnection: $\Delta(m_t)$ = 0.37 GeV

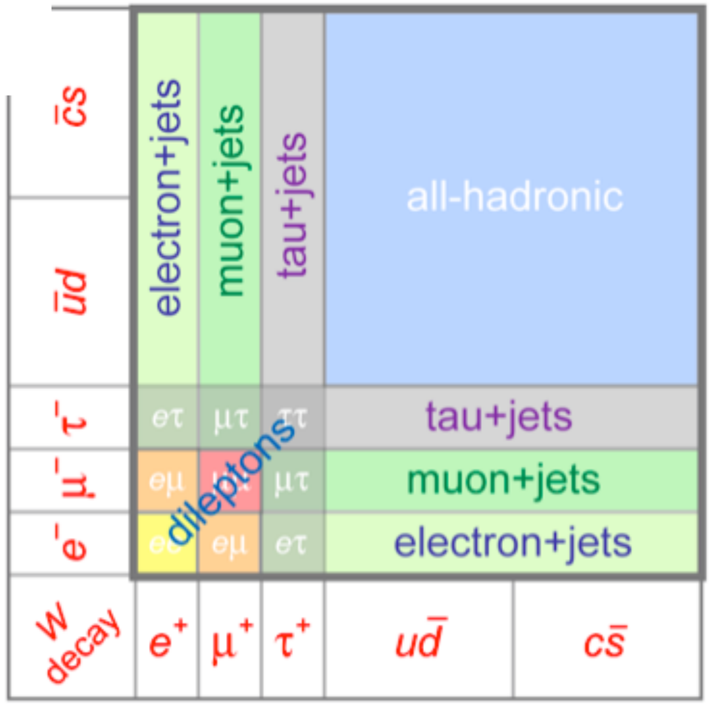
Top BR and Decays

BR



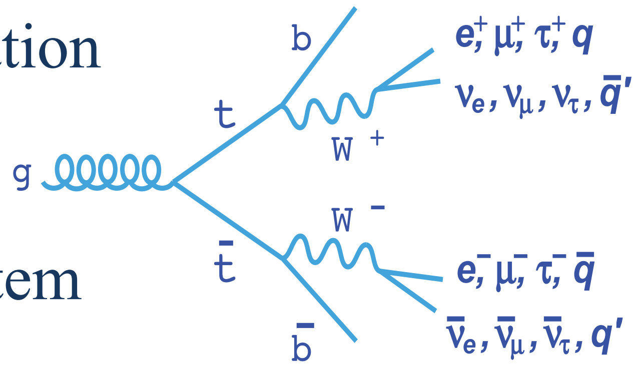


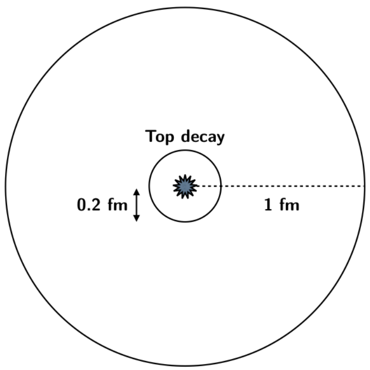
Decays

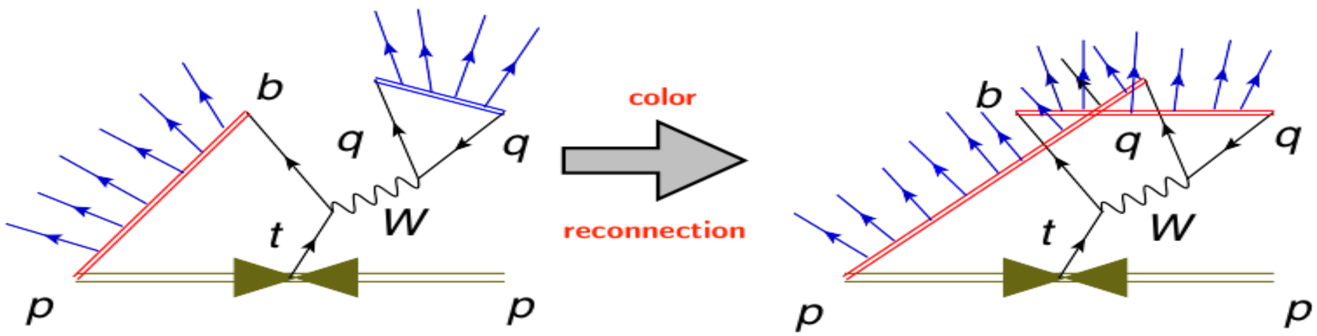


CR at Top decays

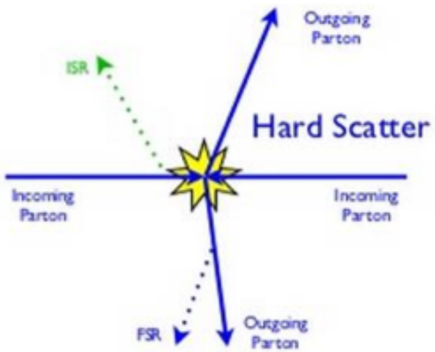
- Interactions and interference between the top decay products during the hadronization
- Important effect for the top mass measurements
- CR affects the reconstruction of top system

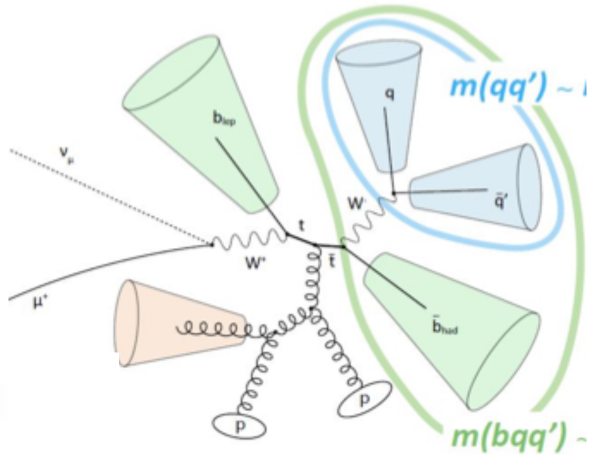


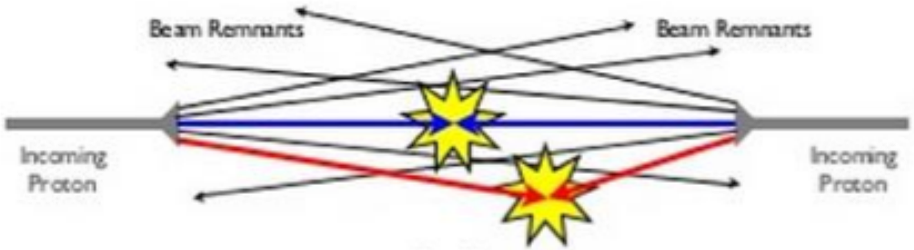


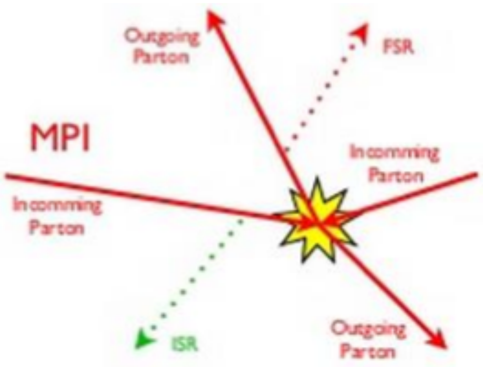


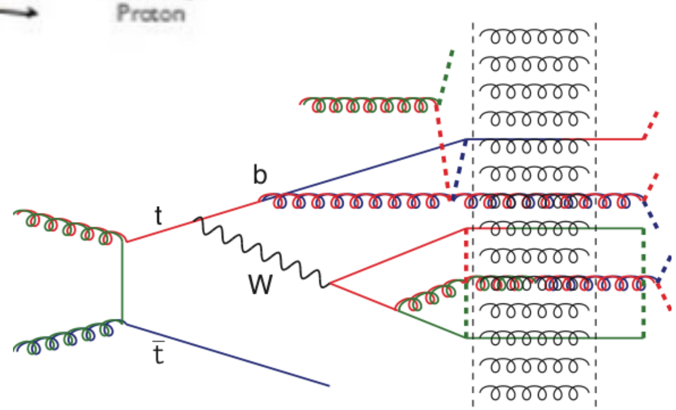
Top decay in pp events











Atlas results:

Model with "no-CR" - unphysical

New (toy models)

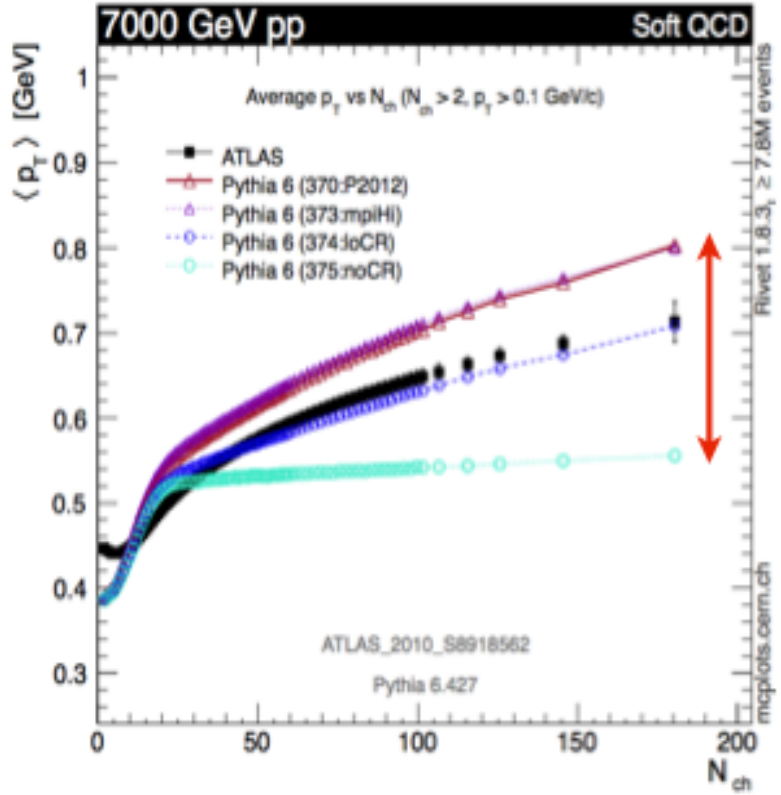
- forced random
- forced nearest
- forced farthest
- forced smallest Δλ
- smallest Δλ

only top events
default CR afterburner

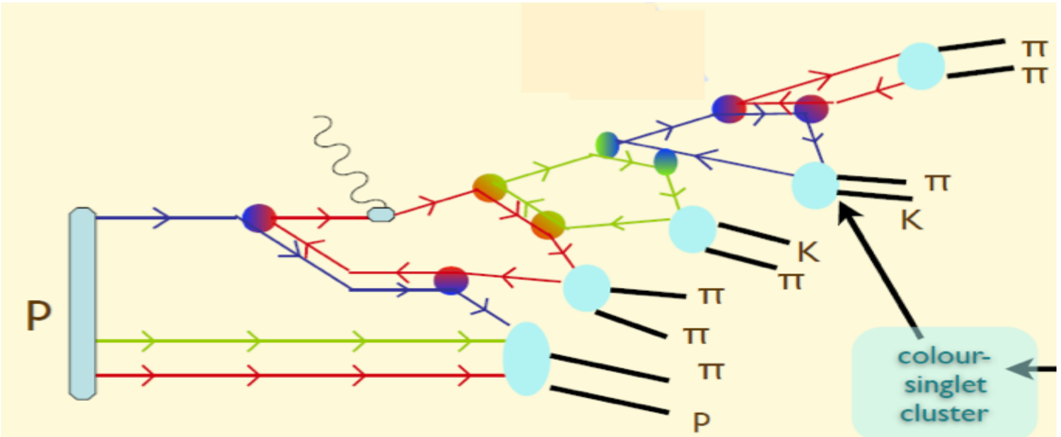
New (more sophisticated)

- swap
- move
- swap + flip
- move + flip

all events



Colour reconnection pp



sub-leading color effects in the perturbative part of the calculation

Interaction between colour fields during the hadronization

Parameter	Definition
MPI Parameters	
`MultipartonInteractions:pT0Ref`	p_T regularisation parameter
`MultipartonInteractions:expPow`	Exponent of matter overlap function
MPI based CR model (CR0)	
`ColourReconnection:range`	CR strength
QCD-based model (CR1)	
`ColourReconnection:m0`	Mass parameter of order λ_{QCD} used in the string length measure
`ColourReconnection:junctionCorrection`	Multiplicative correction to string length above
Gluon-move scheme (CR2)	
`ColourReconnection:m2Lambda`	Equivalent to m0 for QCD-based model
`ColourReconnection:fracGluon`	Average fraction of gluons that undergo a colour reconnection
`ColourReconnection:dLambdaCut`	Minimal value for decrease in string length

Table 1: Tuning parameters and their definitions. The `MultipartonInteractions:expPow` can only be used with an exponential MPI matter overlap function (`MultipartonInteractions:bProfile = 3`). The parameters specific to a CR model are stated together. CR1 model was used was used with `ColourReconnection:allowDoubleJunRem = off` setting, as recommended by the authors.

Atlas study of CR

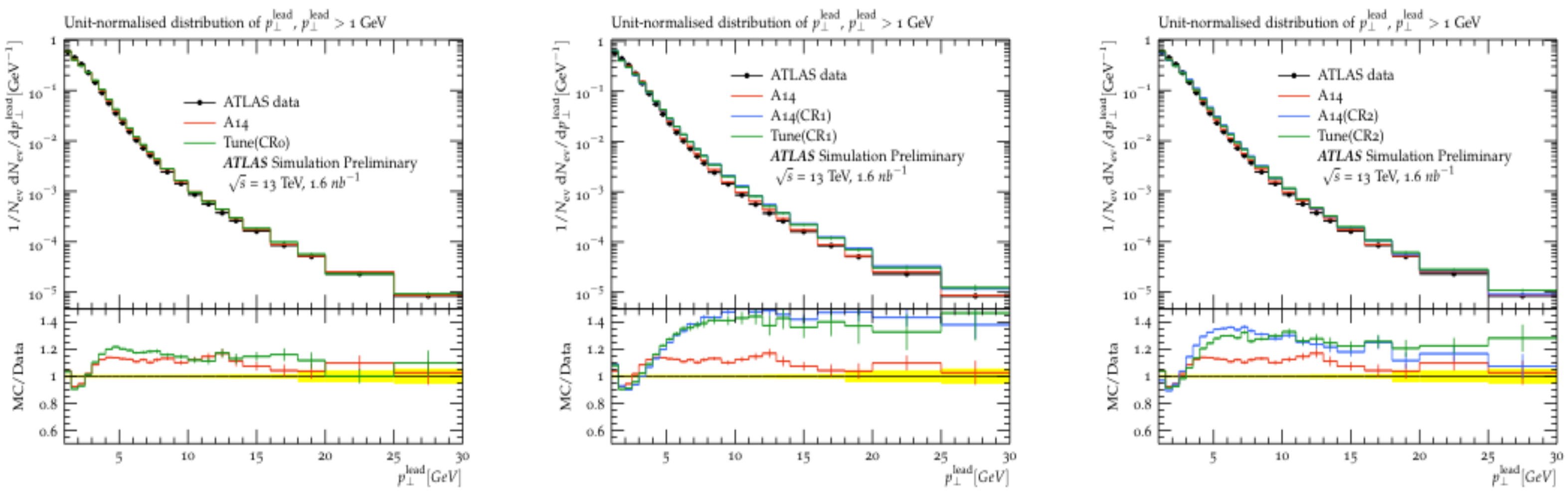
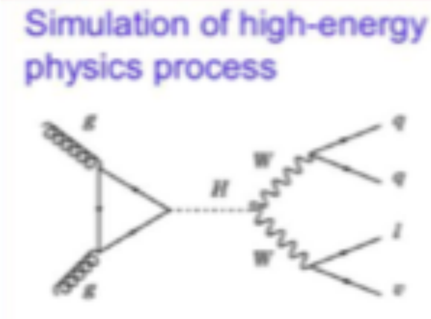
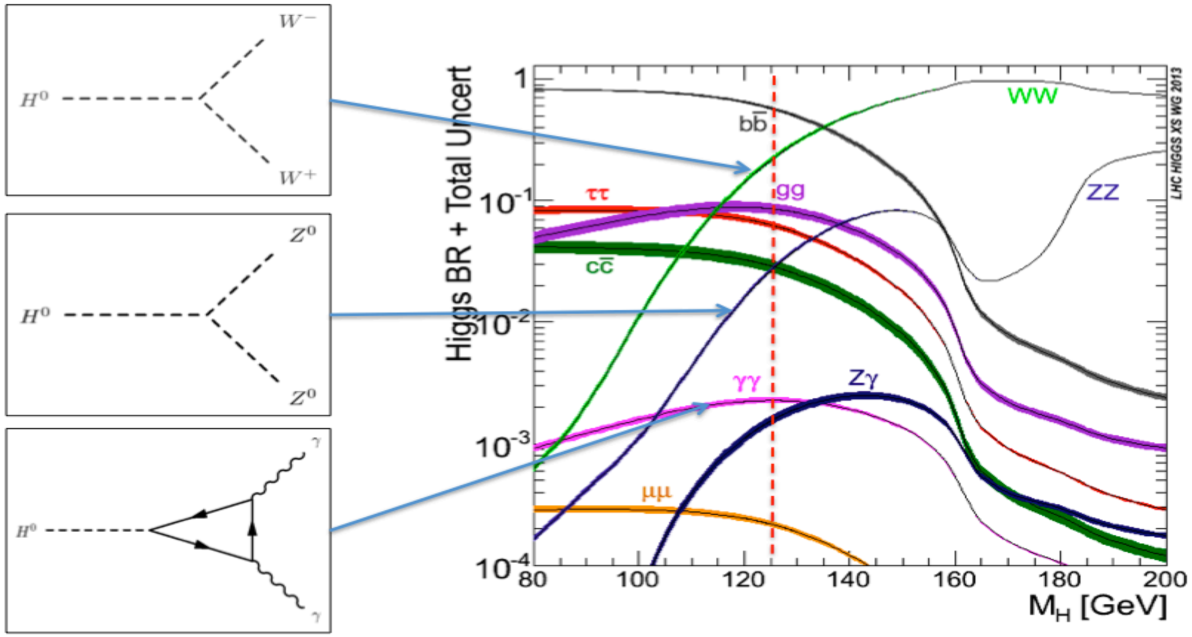


Figure 4: Predictions using the A14 tuned parameter settings (red), A14 tuned parameter settings with only CR model changed (blue), and a new set of tuned parameters with the new CR model (green) for CR0, CR1 and CR2 settings (left to right) are compared with leading charged particle p_T distribution with ATLAS data from Run 2 [7]. The yellow shaded areas at the ratio plot in the bottom represent the uncertainty on the data.

Higgs decays

BR H->WW 21%



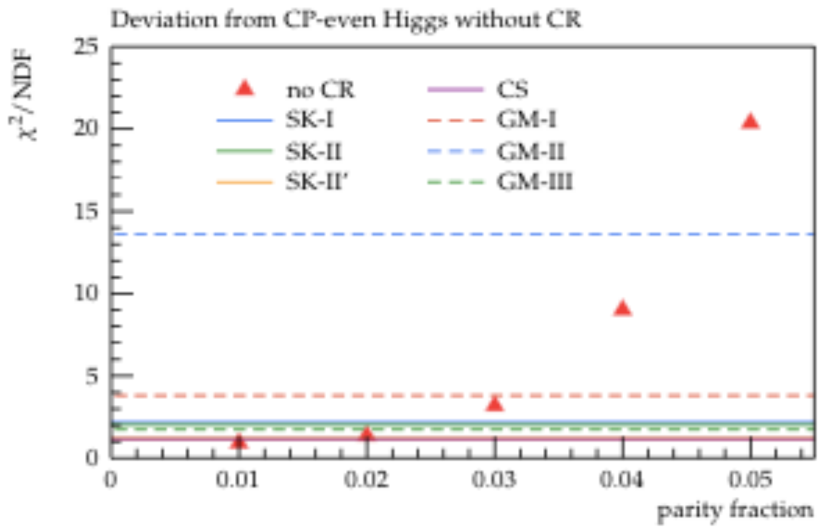


CR in H->WW

- CR includes the big uncertainty
- CR can shift jet directions – necessary CR well understood
- Results of Higgs Parity

  measurement

  in WW->qqqq



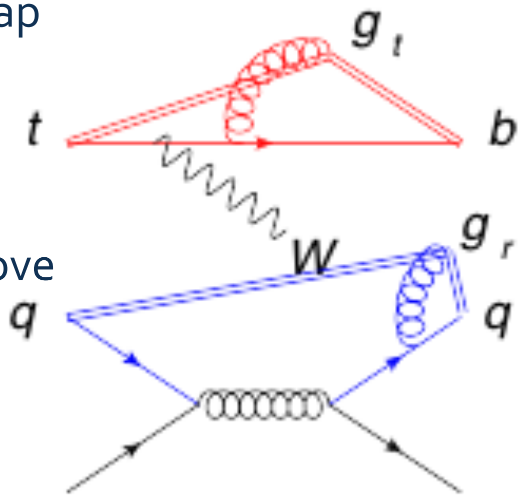
CR models

The CR effects were search firstly at LEP2 in ee->WW->qqqq events, a number of models were developed:

- main in the PYTHIA – SKI, SKII
- in HERWIG – Plain CR considers all quark ends of clusters and reconnects clusters – probability p_reco and Statistical CR
- for HERA – new models in terms of CR from the Uppsala group which described DIS and rapidity gaps
- MPI – multiparton intersction model in PYTHIA for hadronic collisions, which explain the increasing transverse momentum p_t with increasing charged multiplicity n_ch
- “gluon move” model – GM in PYTHIA 8
- a new QCD-based CR model – CS – Y-shaped topology
- Rope Hadronization model – with effects on flavour composition, can explain QGP-like features in systems as small as pp

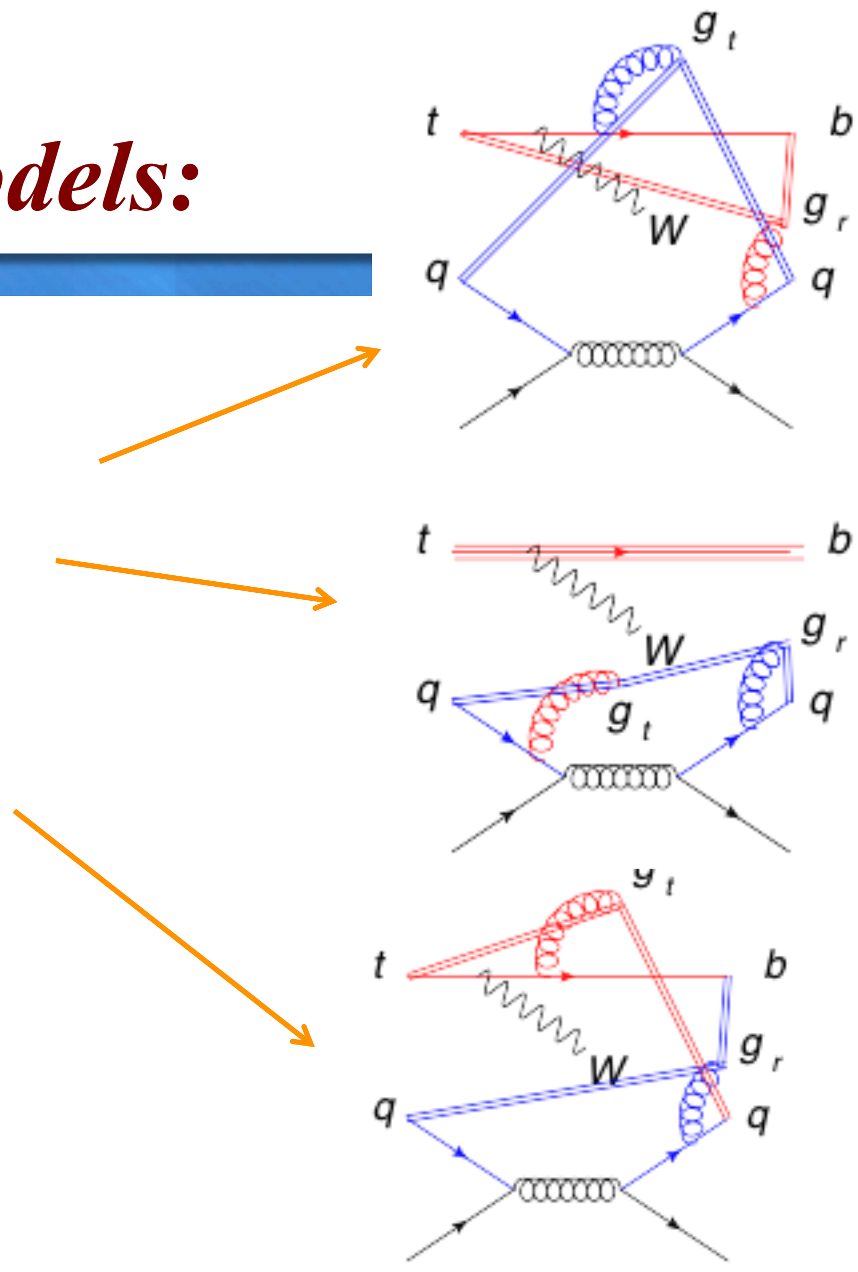
How looks CR models:

Color Swap



Gluon Move

Color Flip

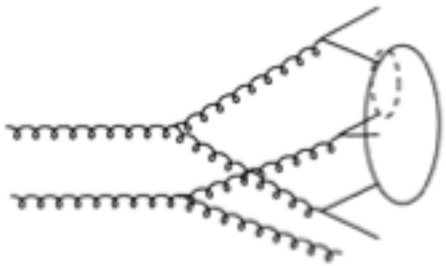


Model	$\Delta m_{top}^{rescaled}$ [GeV]
default	+0.239
forced random (min)	-0.524
move	+0.239
swap (max)	+0.273

CR in models

Herwig:

- based on space-time structure of event at the end of parton shower
- perform a reconnection (ij)(kl) ->(ik)(jl)
- accept with probability 1/9

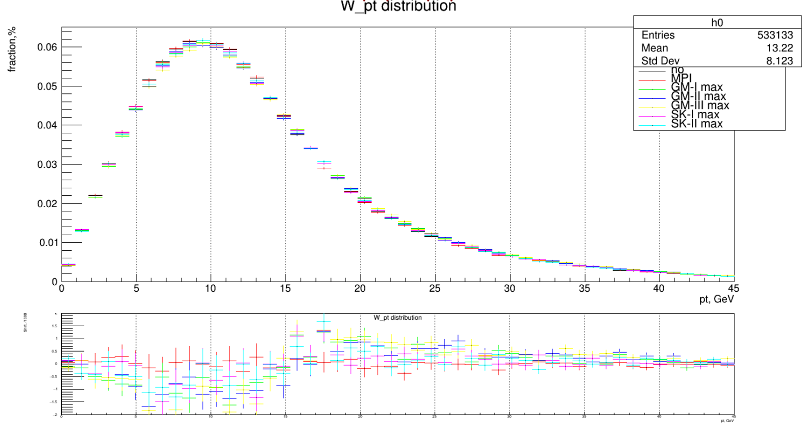


Sherpa:

- Model 1: reconnections that minimize “color length”
- Model 2: random assigment of parton into color singlets

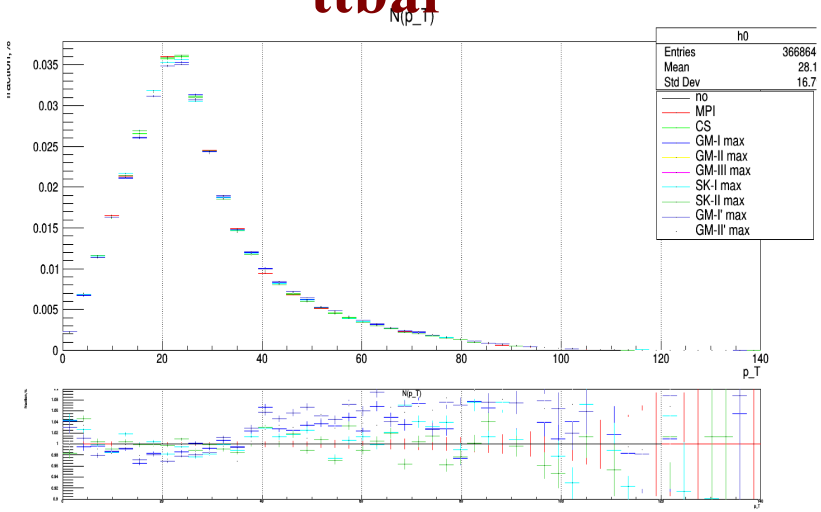
Results of simulations - Pythia8

WW



SKI dMw = 24 MeV, dN_ch = 0.6
SKII dMw = 6 MeV dN_ch = 0.2
CS dMw = 6 MeV dN_ch = 0.5
GMI dMw = 31 MeV dN_ch = 1.2
GMII dMw = 41 MeV dN_ch = 0.5
GMIII dMw = 43 MeV dN_ch = 2.0

ttbar



SKI dMtop =-160 MeV, dN_ch = 0.2
SKII dMtop = 20 MeV dN_ch = 0.1
CS dMtop = -30 MeV dN_ch = 0.9
GMI dMtop = 100 MeV dN_ch = 2.3
GMII dMtop = 200 MeV dN_ch = 0.4
GMIII dMtop = 180 MeV dN_ch = 3.1

CR at FCC-ee

- The CR issues will reappear at FCC-ee for W boson mass
- top quark study
- The CR understanding is interesting itself
- In SM M(H)=125GeV is a pure CP-even state, but in can be an CP-odd admixture, then it is important to set stringent limits
- Possible to study angular correlations in H->WW->qqqq decays – CR can shift jet directions – necessary CR well understood

E_{cm}	$\langle \delta \overline{m}_W \rangle$ (MeV)						
(GeV)	I	II	II′	GM-I	GM-II	GM-III	CS
170	+18	−14	−6	−41	+49	+2	+7
240	+95	+29	+25	−74	+400	+104	+9
350	+72	+18	+16	−50	+369	+60	+4

Future ee Colliders

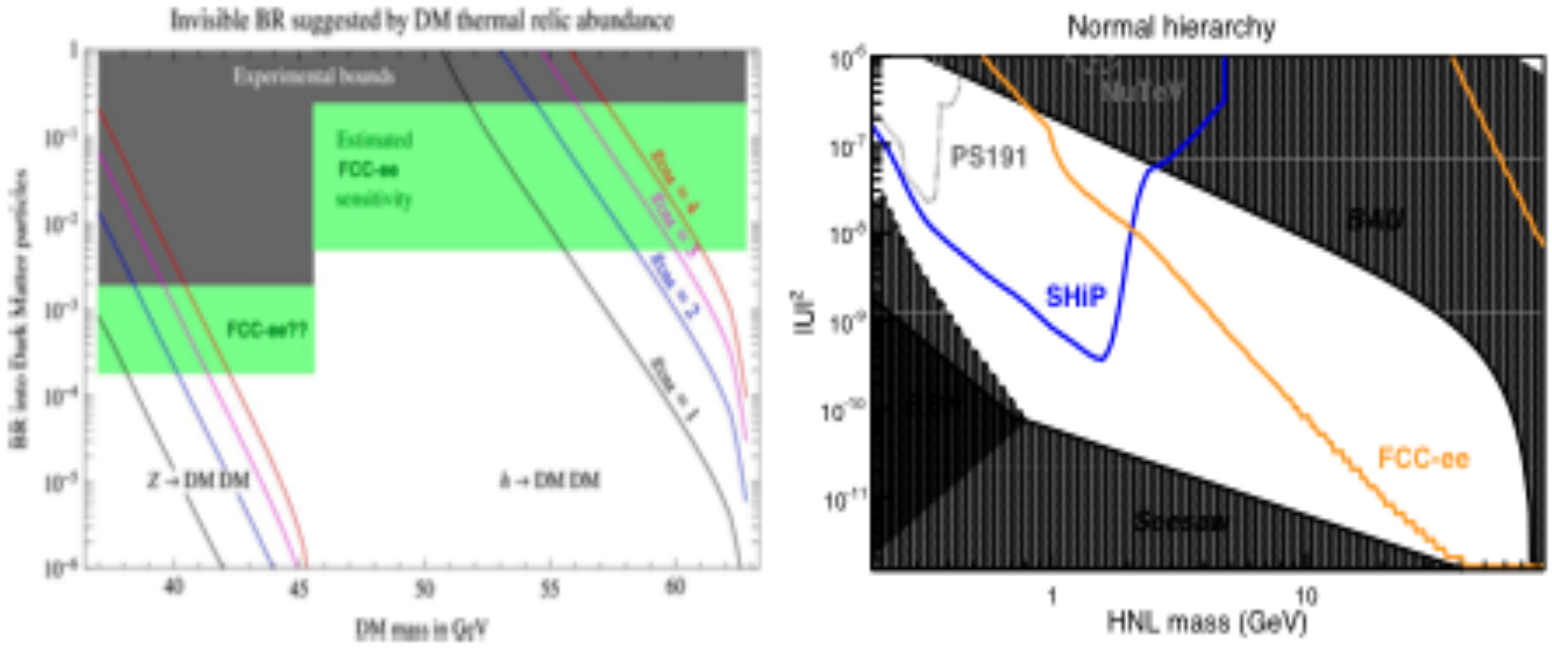
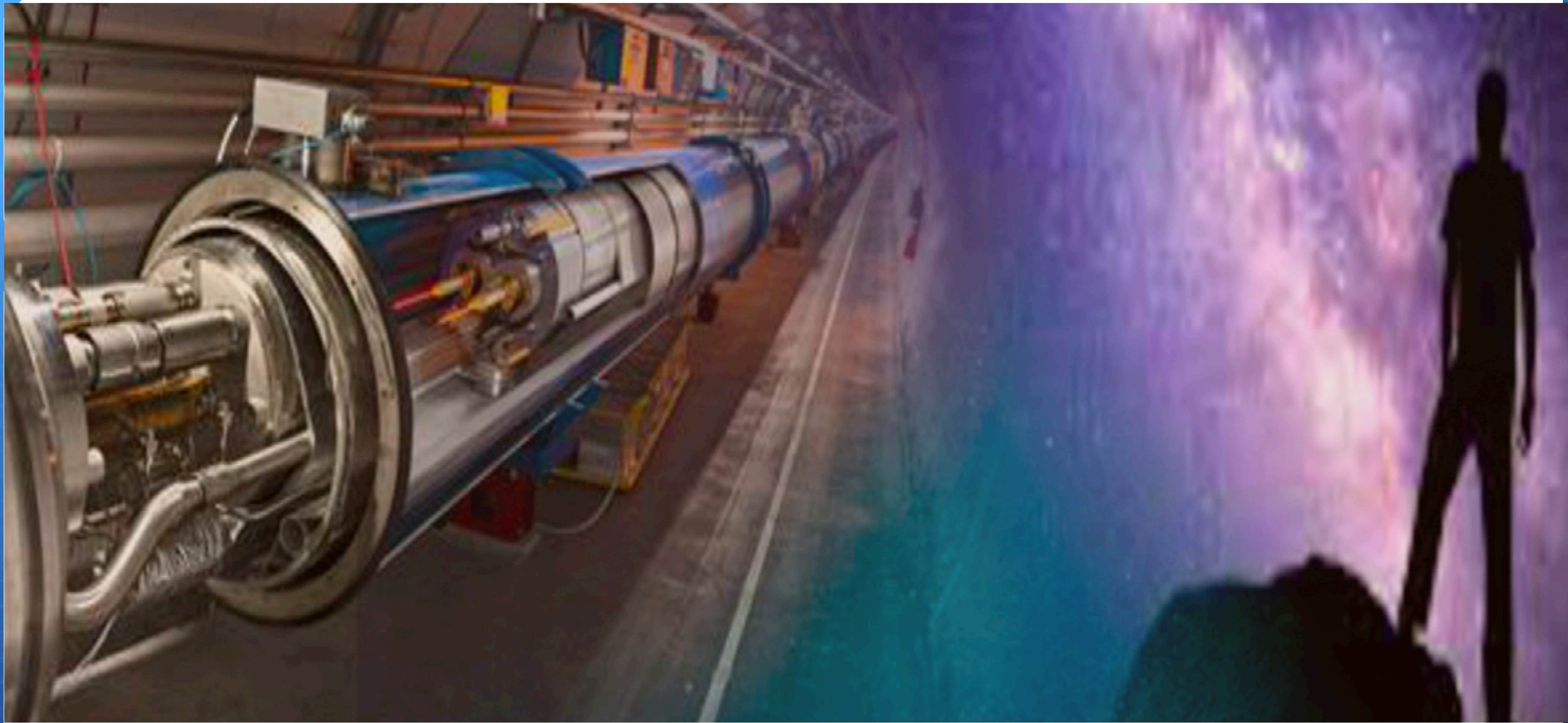


Figure 5: Regions of FCC-ee sensitivity for: (i) Rare Z and H decays into DM pairs in the $BR_{Z,H\to DM\,DM}$ vs. m_{DM} plane (left) [21], and (ii) sterile neutrinos as a function of their mass and mixing to light neutrinos (normal hierarchy) for 10^{13} Z decays (right) [22].



Thanks for attentions