Experiments at FCC-ee :
A very large detector for displaced vertices?

Alain Blondel

Main FCC detector constraints

1. **Has to fit in cavern**
2. **Final focus elements are inside the detector and magnetic field volume. They have to be shielded against it.**
3. **Solenoid field has to be compensated to avoid effects on emittance and spin**
4. **Should do all the most important precision measurements**

   ee→ ZH, ee-> Z, ee-> WW, ee-> ttbar

Towards detector design for FCC-ee

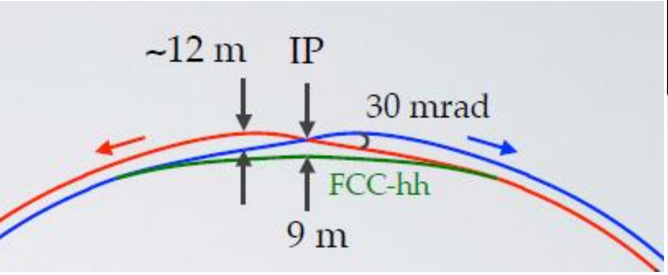
intend to produce (at least) two different designs:

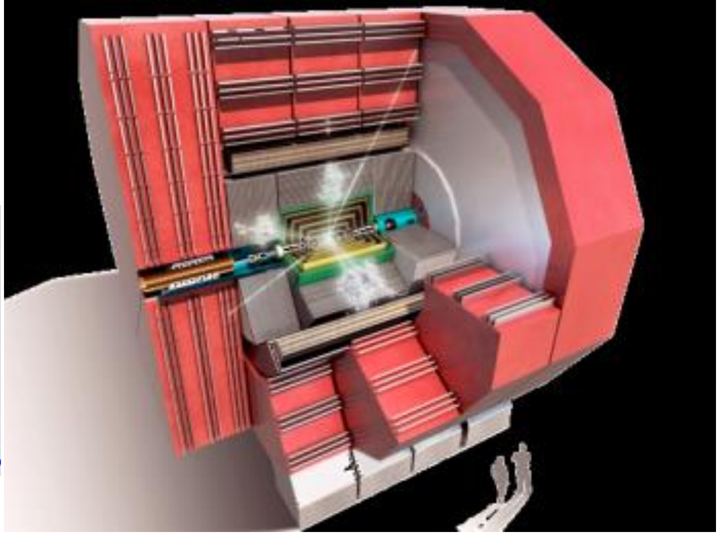
-- design(s) based on an adaption of an ILC or CLIC detector design.

-- a design based on the specific aspects of the FCC-ee, Z factory in particular, aimed and long-lived particles and excellent PID for rare decays. (take advantage as much as possible of large cavern for FCC-hh) This talk

Should keep in mind that the FCC-ee detector design study aims at demonstrating feasibility And give a guideline for cost and performance.
Once the decision is made to build FCC-ee, more intense work and ideas will come from dedicated experimental collaborations.

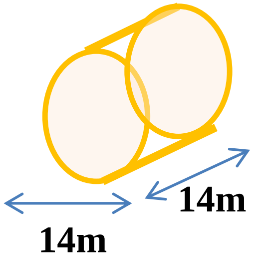
Present baseline is two IPs for FCC-ee.
More if there is a strong and viable demand from the community.

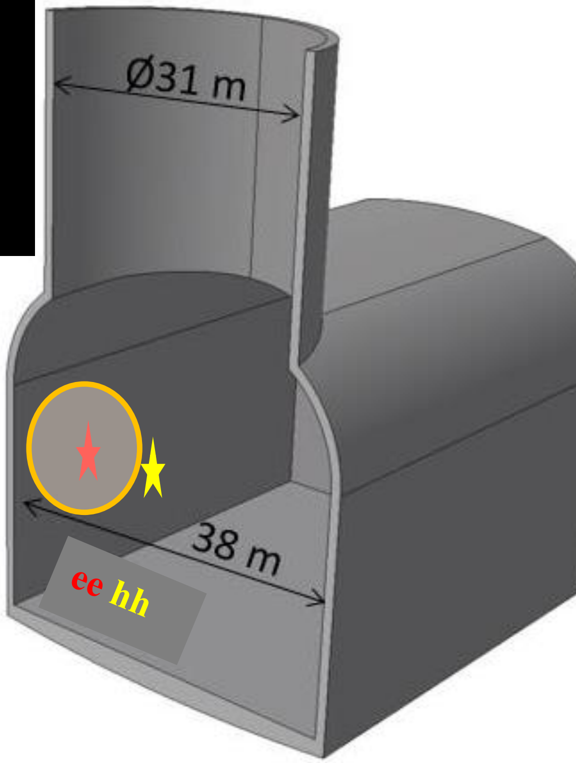




Typical e+e- detector
(ILD, CLIC-SID) is 14m across&long
W. Klempt

Asymmetric IR helps (a lot)
with Synchrotron Radiation
Displaced w.r.t. hh collision point
leaves 10m between IR
and (preliminary) cavern →

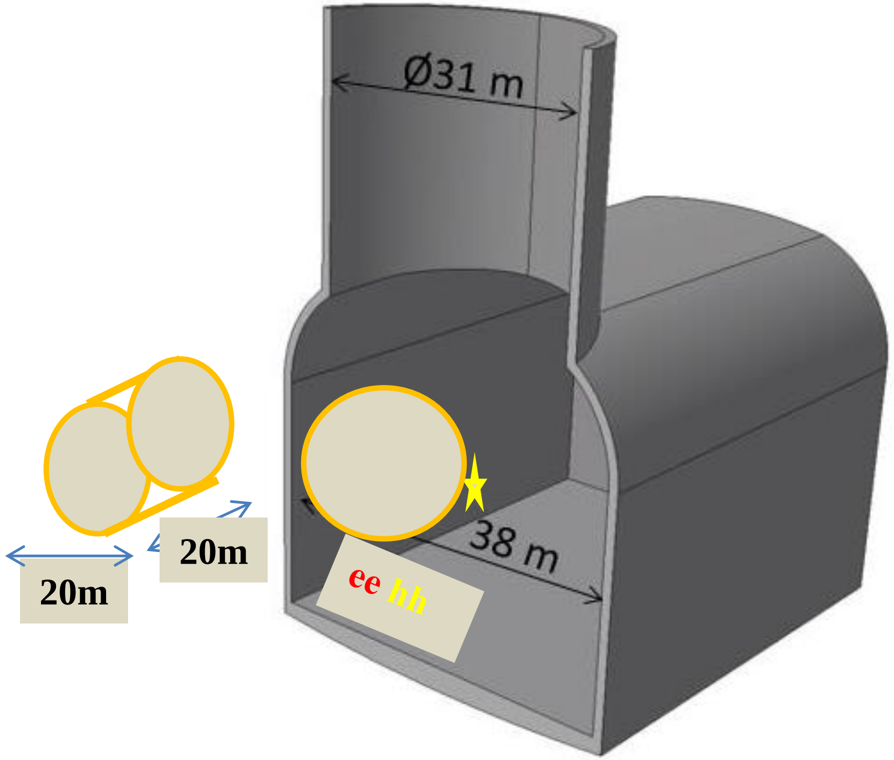




Constraints on detector:

- small L* ~ O(2m)
- 30mrad crossing leads to transverse field on the beam
  => need solenoid compensation
- two beam pipes entering detector + small L* lead to delicate design of lumi monitor
- wrt LC detectors: probably need to reduce magnetic field (2T?), increase tracking length
  → overall size might be wider.
- first studies of beam induced backgrounds taking place.

**Fitting a 14m-wide detector in a 18m-wide space is 'just'
and will become 'very just'
if FCC-hh detector shrinks
and its cavern with it!
And what if we would like it bigger?**



Well maybe if the FCC-hh detector shrinks down to say 10m .. We can have 20+ m for ourselves.

Example of application: long lived particle, the right handed neutrinos.

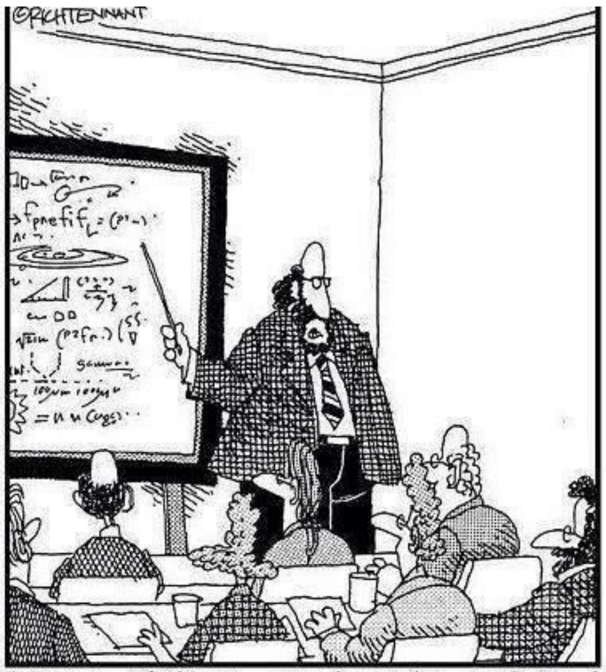
Electroweak eigenstates

$\begin{pmatrix} e \\ \nu_e \end{pmatrix}_L \quad \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_L \quad \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}_L$	$(e)_R \quad (\mu)_R \quad (\tau)_R$	Q= -1
	$(\nu_e)_R \quad (\nu_\mu)_R \quad (\nu_\tau)_R$	Q= 0
I = 1/2	I = 0	

Right handed neutrinos are singlets
no weak interaction
no EM interaction
no strong interaction

can't produce them
can't detect them
-- so why bother? –

Also called 'sterile'



"Along with 'Antimatter,' and 'Dark Matter,' we've recently discovered the existence of 'Doesn't Matter,' which appears to have no effect on the universe whatsoever."

A few REFERENCES

B. Kayser, the physics of massive neutrinos (1989)

PHYSICAL REVIEW D VOLUME 29, NUMBER 11 1 JUNE 1984

Extending limits on neutral heavy leptons

Michael Gronau*

Department of Physics, Syracuse University, Syracuse, New York 132

JHEP — Published for SISSA by Springer

Received: September 23, 2013 Accepted: December 25, 2013 Published: January 29, 2014

First look at the physics case of TLEP

arxiv:1308.6176

The TLEP Design Study Working Group

M. Bicer,[a] H. Duran Yildiz,[b] I. Yildiz,[c] G. Coignet,[d] M. Delmastro,[d] T. Alexopoulos,[e] C. Grojean,[f] S. Antusch,[g] T. Sen,[h] H.-J. He,[i] K. Potamianos,[j] S. Haug,[k] A. Moreno,[l] A. Heister,[m] V. Sanz,[n] G. Gomez-Ceballos,[o] M. Klute,[o] M. Zanetti,[o] L.-T. Wang,[p] M. Dam,[q] C. Boehm,[r] N. Glover,[r] F. Krauss,[r] A. Lenz,[r] M. Syphers,[s]

FLAVOUR(267104)-ERC-23 TUM-HEP 850/12 SISSA 25/2012/EP CFTP/12-013

arxiv:1208.3654

Higgs Decays in the Low Scale Type I See-Saw Model

C. Garcia Cely[a)], A. Iba

theories of the el

and mixings with

Search for Heavy Right Handed Neutrinos at the FCC-ee

A. Blondel (presenter)[a], E. Graverini[b], N. Serra[b], M. Shaposhnikov[c]

arXiv:1411.5230v2

CERN–PPE/96–195

18 December 1996

Neutral Heavy Leptons ...uced in Z Decays

DELPHI Collaboration

The Role of Sterile Neutrinos in Cosmology and Astrophysics

Alexey Boyarsky, Oleg Ruchayskiy and Mikhail Shaposhnikov

FCC design study and FCC-ee http://cern.ch/fcc-ee
and presentations at *FCC-ee physics workshops*
http://indico.cern.ch/category/5684/

The νMSM, Dark Matter and Neutrino Masses

Takehiko Asaka, Steve Blanchet, and Mikhail Shaposhnikov

, Switzerland

Phys.Lett.B631:151-156,2005
arXiv:hep-ph/0503065

Preprint typeset in JHEP style - HYPER VERSION

FERMILAB-PUB-08-086-T, NSF-KITP-08-54, MADPH–06–1466, DCPT/07/198, IPPP/07/99

The Search for Heavy Majorana Neutrinos

Anupama Atre[1,2], Tao Han[2,3,4], Silvia Pascoli[5], Bin Zhang[4*]

Testable Baryogenesis in Seesaw Models

21 June! arXiv:1606.06719v1

P. Hernández,[a] M. Kekic,[a] J. López-Pavón,[b] J. Racker,[a] J. Salvado.[a]

Mass eigenstates

See-saw type I :

$$\mathcal{L} = \frac{1}{2}(\bar{\nu}_L,\, \bar{N}^c_R) \begin{pmatrix} 0 & m_D \\ m_D^T & M_R \end{pmatrix} \begin{pmatrix} \nu^c_L \\ N_R \end{pmatrix}$$

$M_R \neq 0$
$m_D \neq 0$
Dirac + Majorana mass terms

$$\tan 2\theta = \frac{2\, m_D}{M_R - 0} \qquad \ll 1$$

$$m_\nu = \tfrac{1}{2}\left[(0 + M_R) - \sqrt{(0 - M_R)^2 + 4\, m_D^2}\right] \qquad \simeq -m_D^2/M_R$$

$$M = \tfrac{1}{2}\left[(0 + M_R) + \sqrt{(0 - M_R)^2 + 4\, m_D^2}\right] \qquad \simeq M_R$$

general formula — if $m_D \ll M_R$

$M_R = 0$
$m_D \neq 0$
Dirac only, (like e- vs e+):

m ↑

	ν_L	ν_R	$\bar{\nu}_L$	$\bar{\nu}_R$
I_{weak}=	½	0	½	0

4 states of equal masses

Some have I=1/2 (active)
Some have I=0 (sterile)

$M_R \neq 0$
$m_D = 0$
Majorana only

m ↑

	ν_L	$\bar{\nu}_R$
I_{weak}=	½	½

2 states of equal masses

All have I=1/2 (active)

$M_R > m_D \neq 0$ — **see-saw**

Dirac + Majorana

m ↑

dominantly:

	ν	N	$\bar{\nu}$	$\bar{N}$
I_{weak}=	½	0	½	0

4 states , 2 mass levels

m_1 have ~I=1/2 (~active)
m_2 have ~I=0 (~sterile)

Manifestations of right handed neutrinos

one family see-saw :
$\theta \approx (m_D/M)$
$m_\nu \approx \frac{m_D^2}{M}$
$m_N \approx M$
$|U|^2 \propto \theta^2 \approx m_\nu / m_N$

$$\nu = \nu_L \cos\theta - N^c{}_R \sin\theta$$

$$N = N_R \cos\theta + \nu_L{}^c \sin\theta$$

what is produced in W, Z decays is:

$$\nu_L = \nu \cos\theta + N \sin\theta$$

ν = light mass eigenstate
N = heavy mass eigenstate
$\neq \nu_L$, active neutrino which couples to weak inter.
and $\neq N_R$, which does'nt.

m_ν = 50 meV & m_N = 50 GeV
➔ $|U|^2 \approx \theta^2 \approx O(10^{-12})$

-- mixing with active neutrinos leads to various observable consequences
  -- if very light (eV) , possible effect on neutrino oscillations (see talks later today)
  -- if in keV region (dark matter), monochromatic photons from galaxies with $E=m_N/2$
-- possibly measurable effects at High Energy
  If N is heavy it will decay in the detector (not invisible)
  ➔ PMNS matrix unitarity violation and deficit in Z «invisible» width
  ➔ Higgs, Z, W visible exotic decays $H \rightarrow \nu_i \bar{N}_i$ and $Z \rightarrow \nu_i \bar{N}_i$, $W \rightarrow l_i \bar{N}_i$
  ➔ also in K, charm and b decays via $W^* \rightarrow l_i^{\pm} \bar{N}$, $N \rightarrow l_j^{\pm}$
    with any of six sign and lepton flavour combination
  ➔ violation of unitarity and lepton universality in Z, W or τ decays
  -- etc... etc...
-- Couplings are very small (m_ν / m_N) *(but who knows?)* and generally seem out of reach at high energy colliders.

RHASnu's production in Z decays

Production:

$$BR\left(Z^0 \to \nu_m \overline{\nu}\right) = BR\left(Z^0 \to \nu\bar{\nu}\right)|U|^2 \left(1 - \frac{m_{\nu_m}^2}{m_{Z^0}{}^2}\right)^2 \left(1 + \frac{1}{2}\frac{m_{\nu_m}^2}{m_{Z^0}{}^2}\right)$$

multiply by 2 for antineutrino and add contributions of 3 neutrino species (with different |U

Decay

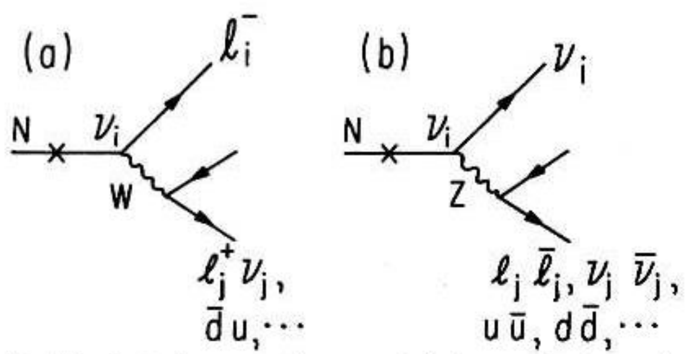


FIG. 2. Typical decays of a neutral heavy lepton via (a) charged current and (b) neutral current. Here the lepton l_i denotes e, μ, or τ.

Decay length:

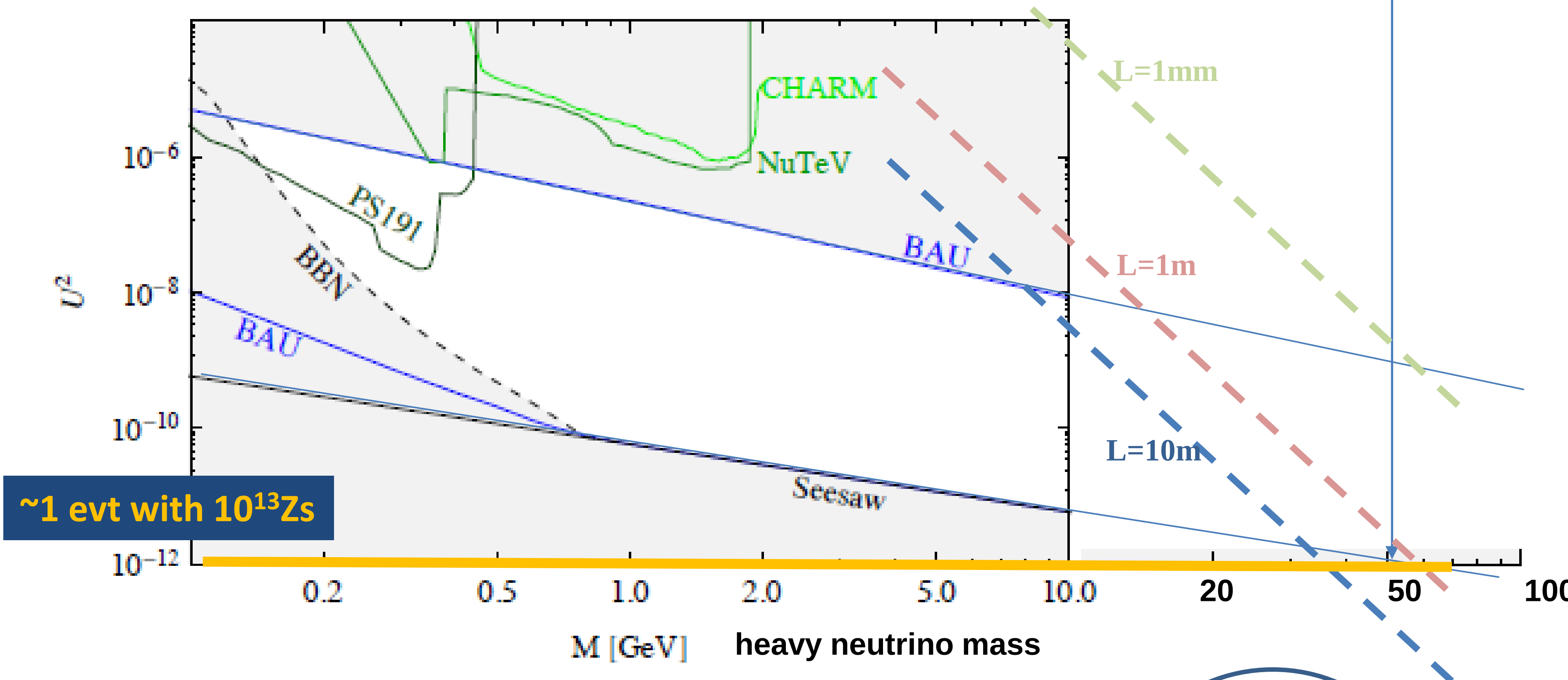
$$L \approx \frac{3 \text{ cm}}{|U|^2 \left(m_{\nu_m}(\mathrm{GeV}/c^2)\right)^6}$$

NB CC decay always leads to ≥ 2 charged tracks

Backgrounds : four fermion: e+e- → W*+ W*- e+e- → Z*(vv) + (Z/γ)*

Decay length

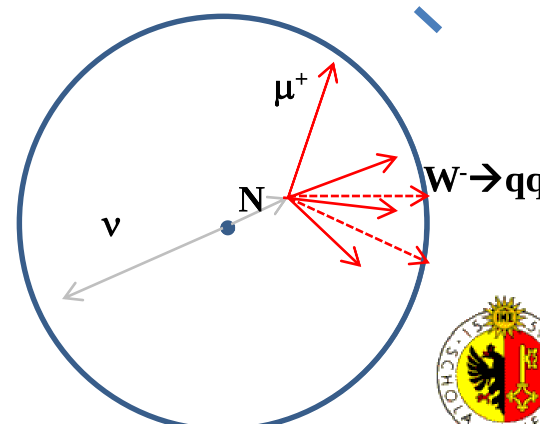
Interesting region
$|U|^2 \sim 10^{-9}$ to 10^{-12} @ 50 GeV

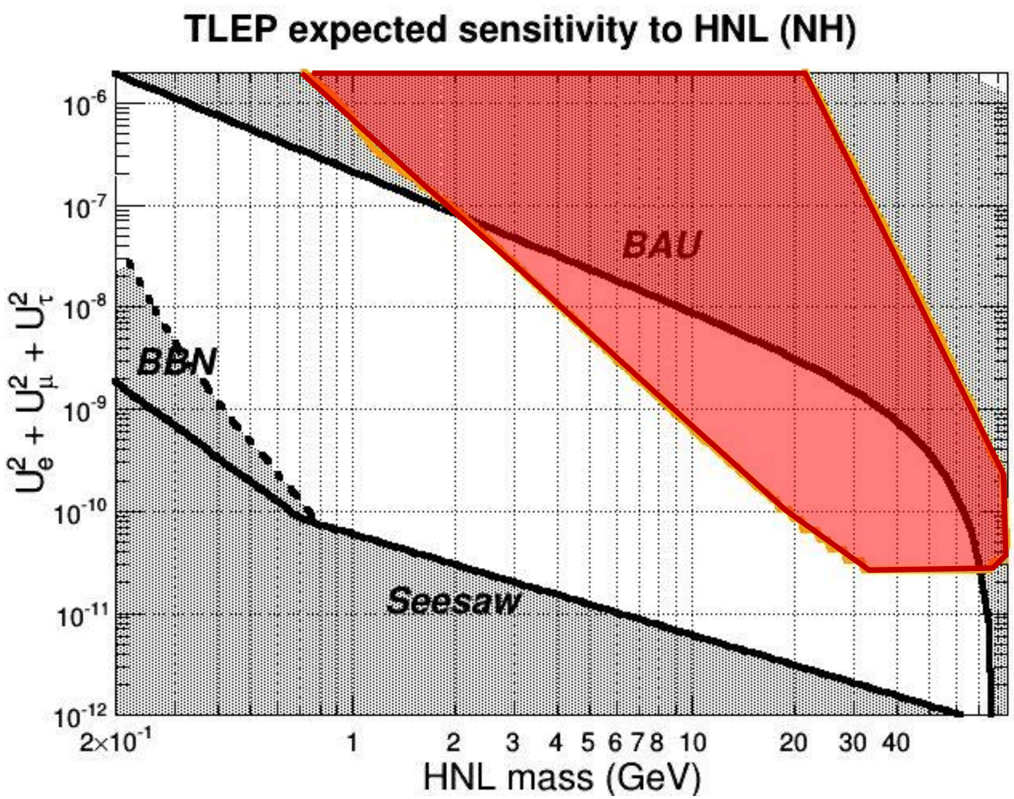


a large part of the interesting region will lead to detached vertices

… ➔very strong reduction of background!

Exact reach domain will depend on detector size and details of displaced vertex efficiency & background





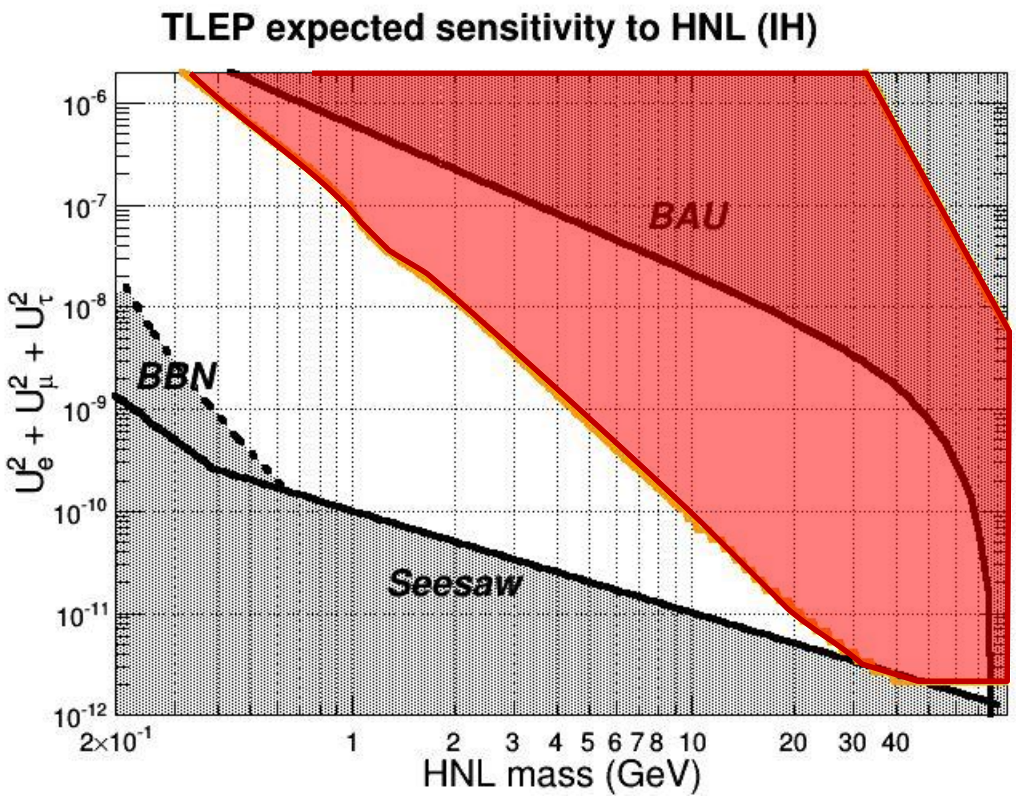
$N_Z = 10^{12}$ 1mm<L<1m

region of interest

FCC-ee sensitivity

A.B, Elena Graverini, Nicola Serra, Misha Shaposhnikov

arXiv:1411.5230v2



$N_Z = 10^{13}$ $100\mu m$ <L<5m

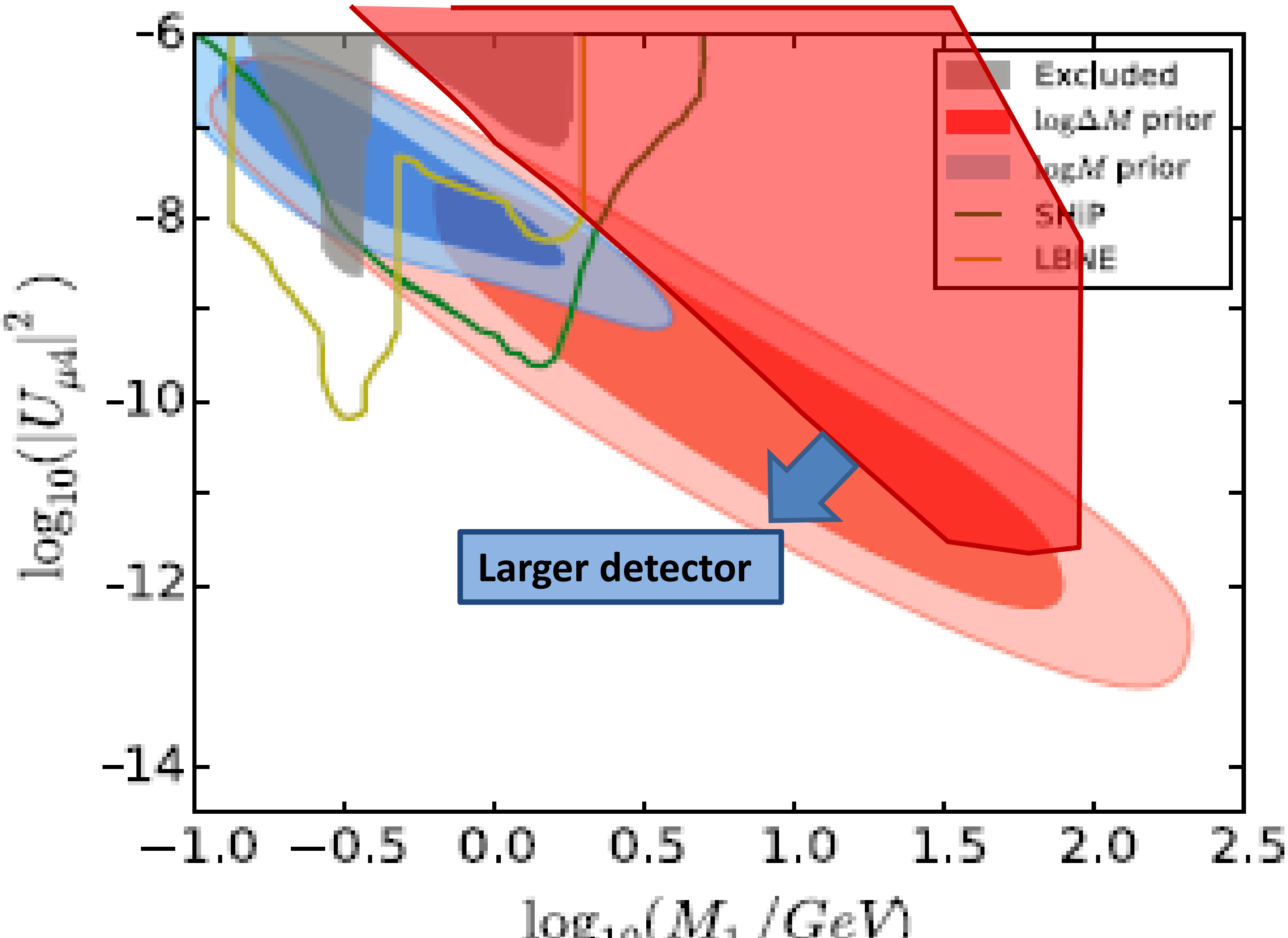
region of interest

FCC-ee sensitivity

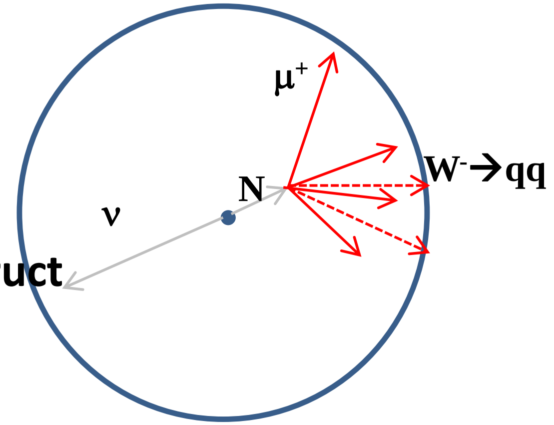
region of interest

FCC-ee sensitivity

$N_Z = 10^{13}$ 100μm <L<5m



Detector considerations.



One possibility is to have very large tracking volume with reduced magnetic field.

Still wants to maintain EM and hadron calorimeter, to reconstruct invariant mass, direction (pointing to vertex) and lepton ID (presence of lepton is signature of leptonic nature of particle)

Also wants to separate e/mu/taus, and measure charge. Space may allow more detailed PID. Also great for K^0 and Λ decays.

To be studied:

-- scaling law for B field vs tracking radius. Does it scale like B.L or B.L^2 ?
-- presuma bly will end up with quite low field (0.2 T for R=8.5m and BL^2 scaling)
-- this will make compensation and sceening much easier.
-- this may mean that one can build it in front of calorimeters.
-- what kind of tracking detector can be extended to >5 or even up to 15 meters radius?
-- usefulness of time-of-flight?
-- precise timing may be very interesting but does it work with very high rate buch Xing ? (3ns-7.5ns between bunches!)

Table 1: FCC-ee baseline parameters.

	Z	Z	W	H	tt
Circumference [km]	100				
Bending radius [km]	11				
Beam energy [GeV]	45.6		80	120	175
Beam current [mA]	1450		152	30	6.6
Bunches / beam	30180	91500	5260	780	81
Bunch spacing [ns]	7.5	2.5	50	400	4000
Bunch population [10^{11}]	1.0	0.33	0.6	0.8	1.7
Horizontal emittance ε [nm] Vertical emittance ε [pm]	0.2 1	0.09 1	0.26 1	0.61 1.2	1.3 2.5
Momentum comp. [10^{-5}]	0.7	0.7	0.7	0.7	0.7
Betatron function at IP - Horizontal β^* [m] - Vertical β^* [mm]	 0.5 1	 1 2	 1 2	 1 2	 1 2
Horizontal beam size at IP σ^* [μm] Vertical beam size at IP σ^* [nm]	10 32	9.5 45	16 45	25 49	36 70
Crossing angle at IP [mrad]	30				
Energy spread [%] - Synchrotron radiation - Total (including BS)	 0.04 0.22	 0.04 0.09	 0.07 0.10	 0.10 0.12	 0.14 0.17
Bunch length [mm] - Synchrotron radiation - Total	 1.2 6.7	 1.6 3.8	 2.0 3.1	 2.0 2.4	 2.1 2.5
Energy loss / turn [GeV]	0.03		0.33	1.67	7.55
SR power / beam [MW]	50				
Total RF voltage [GV]	0.4	0.2	0.8	3	10
RF frequency [MHz]	400				
Longitudinal damping time [turns]	1320		243	72	23
Energy acceptance RF [%]	7.2	4.7	5.5	7.0	6.7
Synchrotron tune Q_s	0.036	0.025	0.037	0.056	0.075
Polarization time τ_p [min]	11200		672	89	13
Interaction region length L_i [mm]	0.66	0.62	1.02	1.35	1.74
Hourglass factor H (L_i)	0.92	0.98	0.95	0.92	0.88
Luminosity/IP for 2IPs [10^{34} $cm^{-2}s^{-1}$]	207	90	19.1	5.1	1.3
Beam-beam parameter - Horizontal - Vertical	 0.025 0.16	 0.05 0.13	 0.07 0.16	 0.08 0.14	 0.08 0.12
Luminosity lifetime [min]	94	185	90	67	57
Beamstrahlung critical	No/Yes	No	No	No	Yes

Conclusions for today

-- with the availability of the very large caverns eventually needed for FCC-hh detectors We may have an opportunity to consider a very large detector, presumably with low field

-- different tracker and calorimeter techniques.
-- different scaling laws
-- easier for machine
-- cost saling is far from obvious
-- naively expect cost to rise with size.

People interested please signal!