Geant4 developments, Forward options

by **Helmut Burkhardt** (CERN)

few short, not directly related points; FYI and feedback

1. **Using and if required improving GEANT4 in the context of FCC**
   1. **very high energy -- 100 TeV**
   2. **synchrotron radiation, keV X-ray photons**

2. **Forward physics options**

GEANT4 in the context of FCC

http://geant4.web.cern.ch **toolkit for the simulation of the passage of particles through matter**
large international collaboration, many outside CERN (spokesperson Makoto Asai / KEK)
applied, tested, validated in very broad range of applications (HEP, medicine, space, underground)
and energies eV .. PeV; multi-threaded, OpenGL visualization
detailed documentation, examples and source code (C++) available wikipedia.org/wiki/Geant4

open for contribution / feedback
have contributed to process codes, examples and documentation (SR, γ --> $\mu+\mu-$, e+e- --> $\mu+\mu-$, TestEm6, TestEm16)

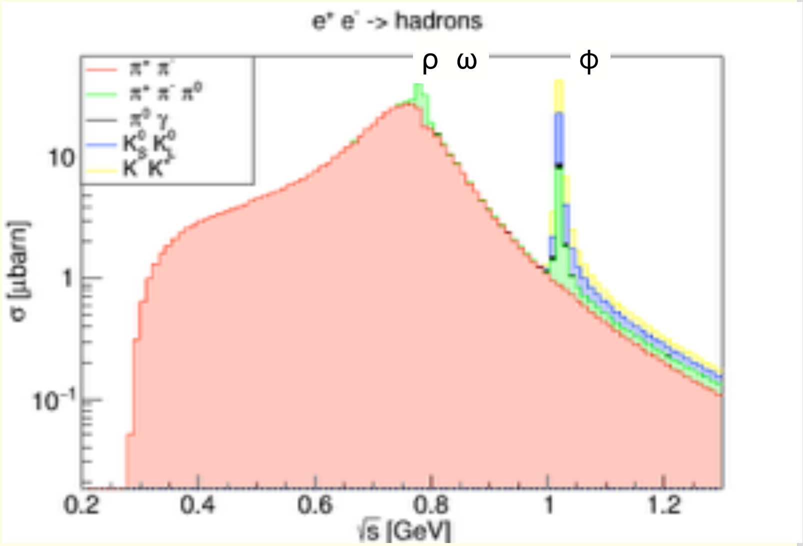
Future planning :
EM plan2016.txt **FCC included**
recent G4 EM meeting 15 Feb.
with my presentation on **Needs for FCC machine background simulation**
and discussion on
Very high energy : validation / improvements to 100 TeV
e+e- --> had --> muon production, muon multiple scattering and energy loss

G4, very high energy

What is the minimum distance and angle needed between IRs H, G, F ?
Needs detailed simulation of muon production, energy loss and scattering up to maximum FCC energy

Muon background and shielding was studied for CLIC using Geant4/BDSIM
3 TeV c.ms., Eb = 1.5 TeV $\sqrt{s} = \sqrt{(2\, m_e\, Eb)} = 1.24$ GeV; Belgin Pilicer (PhD), H.B. IPAC'15

G4 already pretty good for 100 TeV and beyond
Few known restrictions, to be removed for FCC :
high energy e+, e- at rest
e+e- --> hadrons `G4eeToHadrons Emax = 10 TeV ok for CLIC`
50 TeV for FCC **$\sqrt{s}$ = 7.15 GeV**
above charm threshold, Ψ's; many more channels



Review validation / improvements of G4
including muon multiple scattering and energy loss
to 100 TeV as relevant for FCC planned

Synchrotron radiation

Ref. : H.B., CERN-OPEN-2007-018, Geant4 physics-manual Implemented as process G4SynchrotronRadiation

Recently generalized to all long live charged particles including ions in Geant4 10.1 released 5/12/2014 and now `geant4-10-02-ref-01`

`from Jan. 2016, has` "FCC-hh" as example in standard GEANT4 distribution

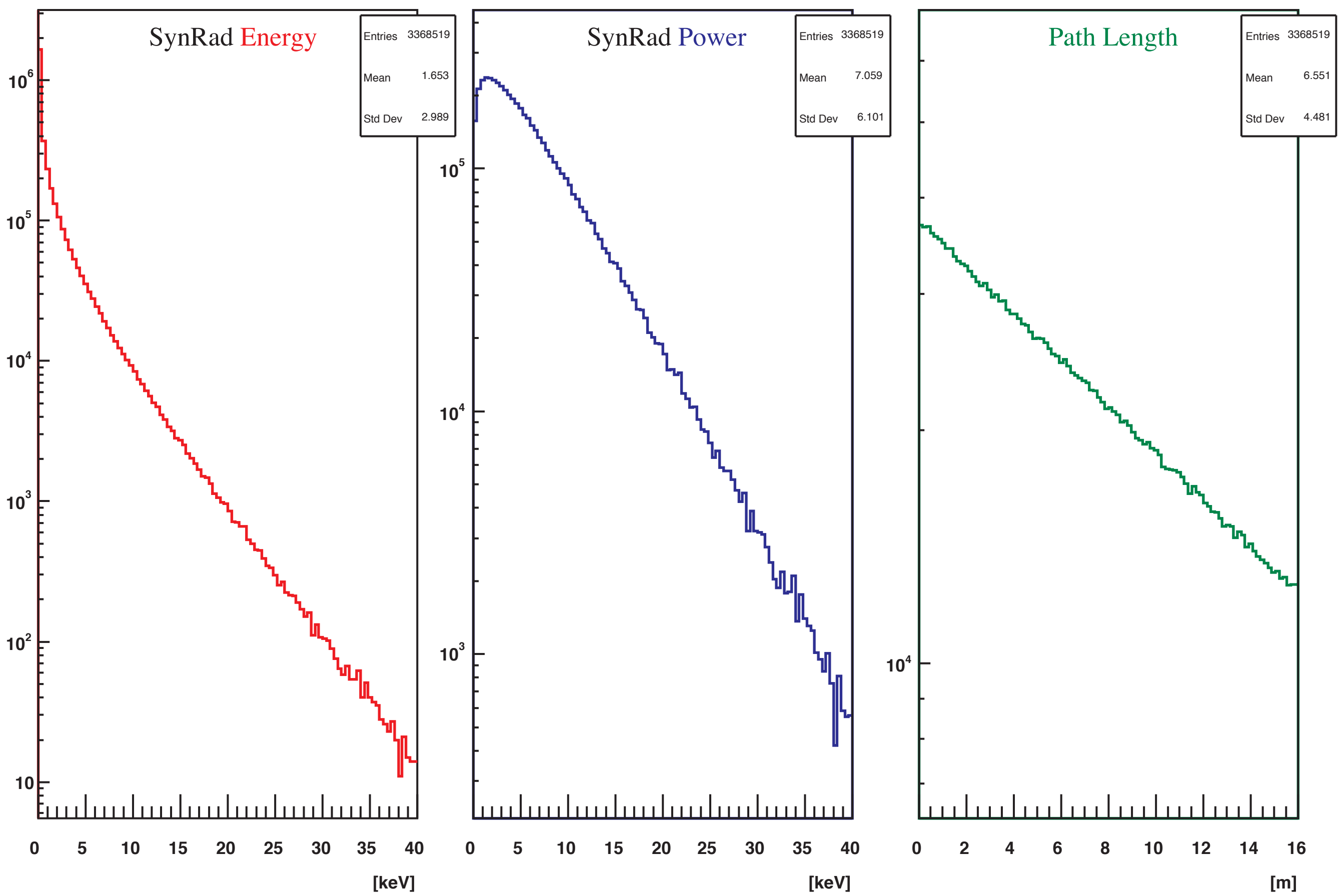
in run01_prot.mac provided $G4INSTALL/examples/extended/electromagnetic/TestEm16

```
# fcc-hh example
/globalField/setValue 0 0 20 tesla
# proton
/gun/particle proton
/gun/energy 50 TeV
#
/run/beamOn 100000
```

```
G4SynchrotronRadiation  Init :
  Ecr   = 5.372 keV
  Emean = 1.654 keV
  E_rms = 3.003 keV

Run Summary
  Number of events processed : 100000
  User=37.5s Real=4.84s Sys=0.07s
Summary for synchrotron radiation :
  Number of photons = 3368519
  Emean             = 1.655 +/- 0.0016 keV
  E_rms             = 3.005 keV
  Energy Max / Mean = 40.09
  MeanFreePath      = 14.41 m
```

`Geant4 version Name: geant4-10-02-ref-01 [MT]   (31-January-2016)   << in Multi-threaded mode >>`



X-rays, GEANT4

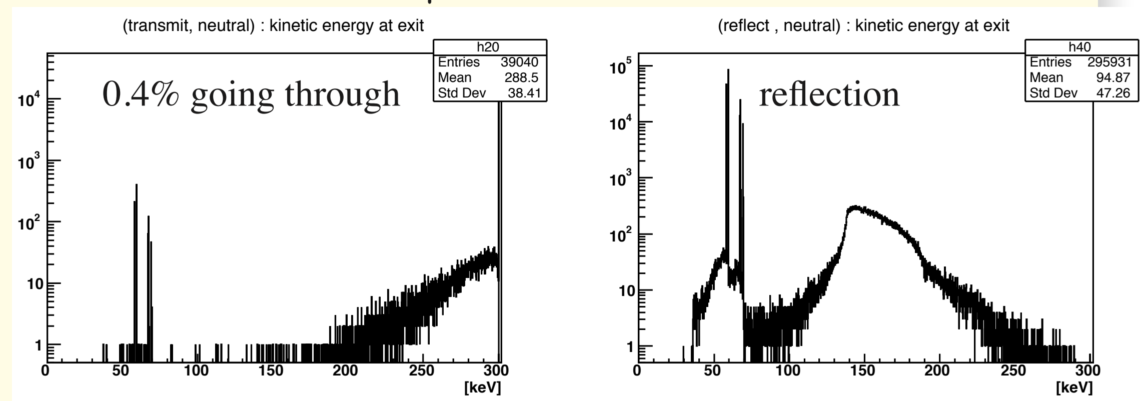
Relevant absorption process and secondary e,γ emission,   in standard G4

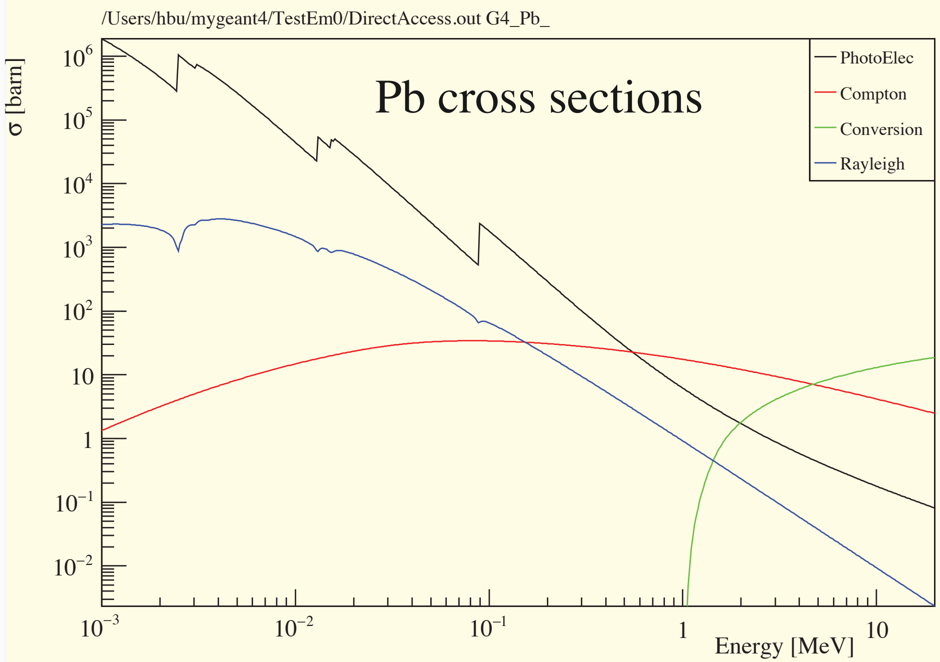
Compton, Rayleigh, pair production ✔

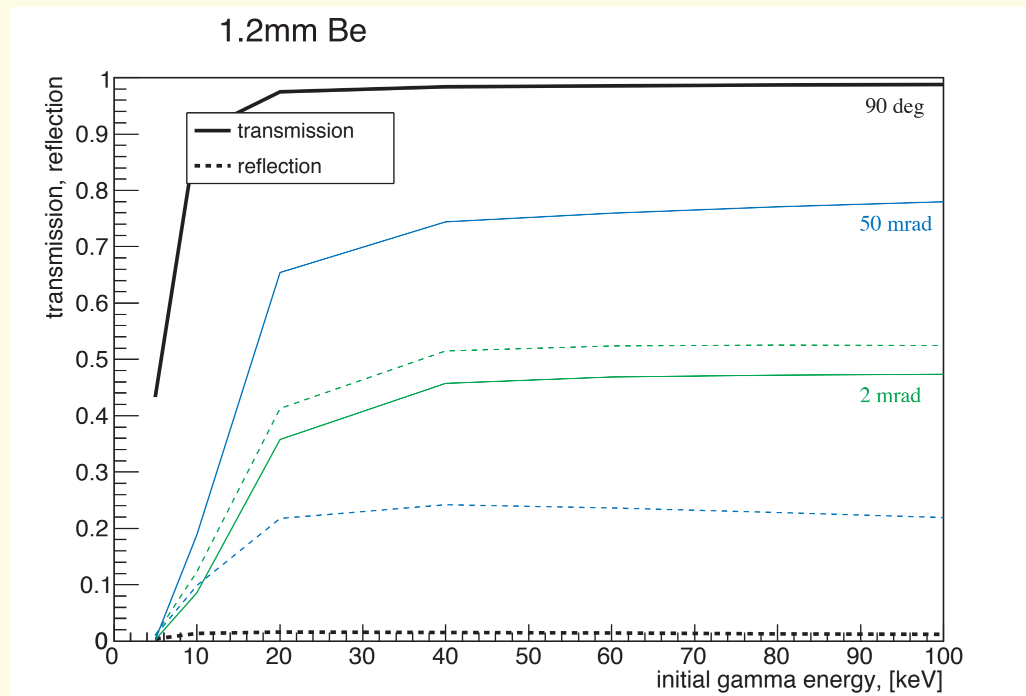
Photo effect + Fluorescence ✔

(multiple) Auger (✔)

1.e7 γ 300 keV on 10 mm W :







Next :   further validation, grazing angles

checking / extension on **specular reflection, X-ray mirror**

ideas for benchmarking with light sources

Quick look with MDISim

Serious issue for FCC-ee MDI

Here few keV which should be easy to absorb - however easily reflected and going through Be pipe

```
fcc_ring_v4_baseline.madx
ex=0.041284 ey=0.041284 nm  geometrical emittances, normalized exN=2.2e-06 eyN=2.2e-06 m
RFHV=   1000 MV Harm=201000
 Qs=0 sige=0.000227676 sigz=      0 fm sigb=0
frev=3.08065 kHz fRF=619.211 MHz
ibun=49.3575 muA ibeam= 523.19 mA
SR Power / beam =2.42997 MW
```

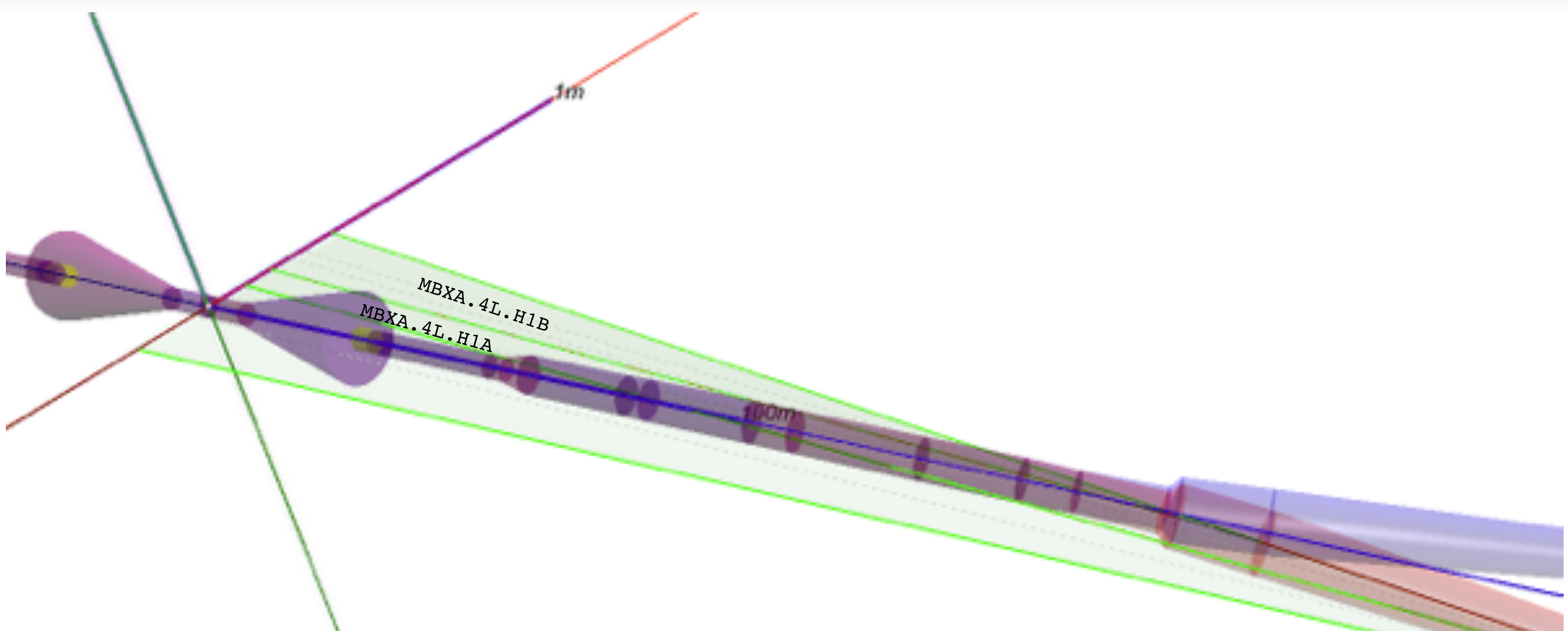
iele	NAME	KEYWORD	S	L	Angle	Ecrit	ngamBend	rho	B	BETX	SIGX	divx	Power	frac>10MeV	ngam*npart	Egamtot	Emean
			m	m		keV		m	T	m	mm	mrad	kW			GeV	keV
21	MBXA.4L.H1A	SBEND	164.7	12.5	0.0008982	3.219	0.5042	13916.7	11.984	13833.6372	0.7557	0.0008	0.2614	0	5.04e+10	5e+04	0.991
23	MBXA.4L.H1B	SBEND	178.7	12.5	0.0008982	3.219	0.5042	13916.7	11.984	13425.3289	0.7445	0.0008	0.2614	0	5.04e+10	5e+04	0.991
25	MBRD.4L.H1A	SBEND	248.2	15	-0.0008982	2.682	0.5042	16700.0	-9.987	11487.9335	0.6887	0.0008	0.2178	0	5.04e+10	4.16e+04	0.826
27	MBRD.4L.H1B	SBEND	264.7	15	-0.0008982	2.682	0.5042	16700.0	-9.987	11050.5392	0.6754	0.0008	0.2178	0	5.04e+10	4.16e+04	0.826
45	MBDS.A8LA.H1	SBEND	551.5	13.47	0.001284	4.27	0.7207	10490.0	15.8992	39.0139	0.0401	0.0010	0.4958	0	7.21e+10	9.48e+04	1.31
47	MBDS.B8LA.H1	SBEND	566.3	13.47	0.001284	4.27	0.7207	10490.0	15.8992	44.1130	0.0427	0.0010	0.4958	0	7.21e+10	9.48e+04	1.31

...

in quads at offset of nsig=1 sigma emit=0.000993nm   -- careful with offsets and crossing angle

iele	Element	s	L	betx	sigx	divx	K1L	k0	x	Angle	Ecrit	ngam	Power
		m	m	m	mm	mrad	m-2	m-1	mm		keV		kW
7	MQXC.1L	56	20	1.53e+04	0.1231	8.063e-06	-0.02627	3.235e-06	0	6.47e-05	0.1449	0.03631	0.0008476
12	MQXD.A2L	80.6	17.5	3.89e+04	0.1965	5.052e-06	0.01976	3.883e-06	0	6.795e-05	0.1739	0.03814	0.001069

...

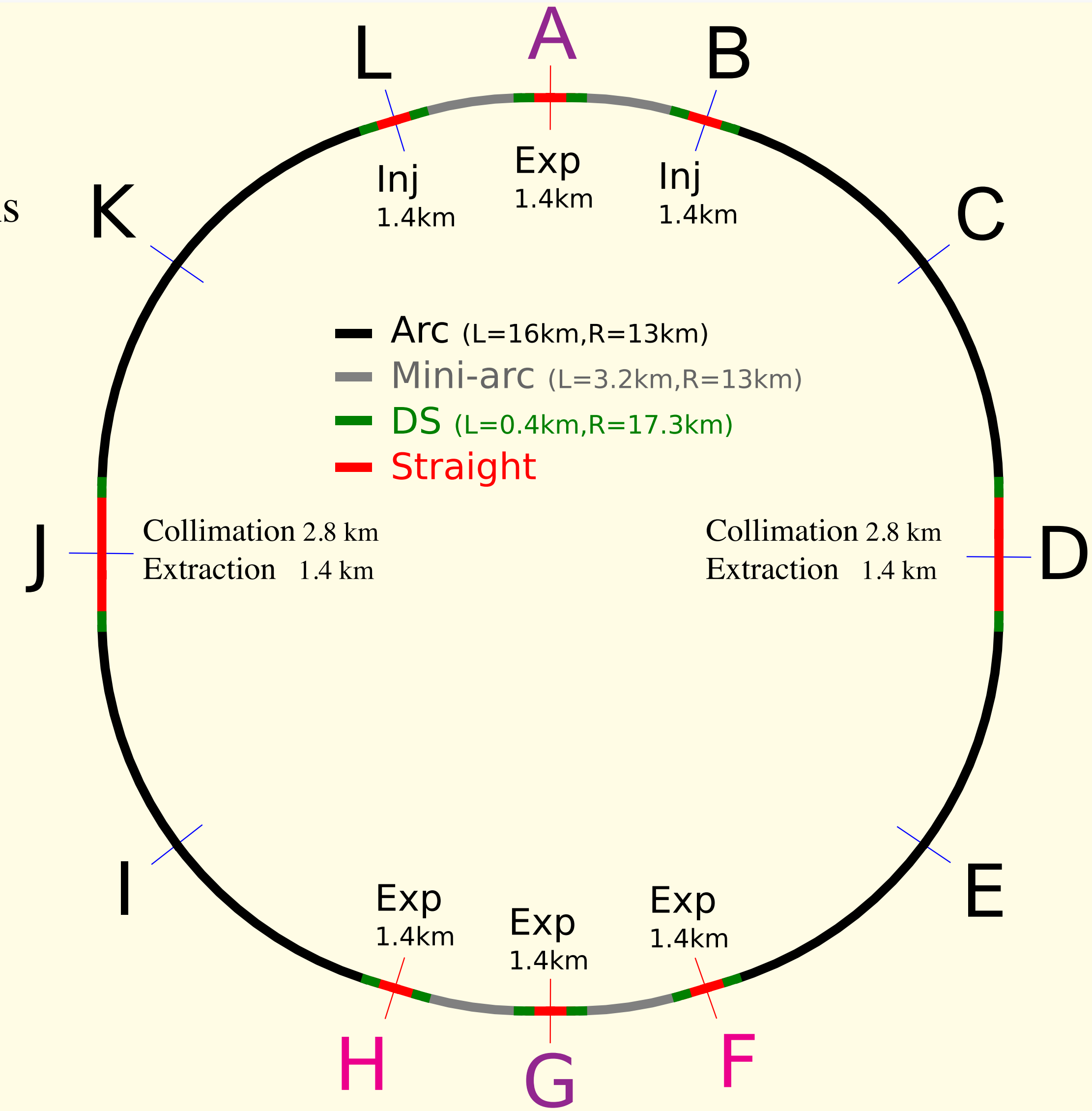


Extra IRs

FCC baseline has 4 IRs like LHC
where layout & optics of extra IR2/8
are very (too ?) similar to high luminosity IRs

in LHC we have
Forward spectrometers in ALICE, LHCb
and very forward
TOTEM - roman pots, alone and with CMS
ATLAS/ALFA + AFP, LHCf
operated at higher β* and lower pile-up
complementing the physics reach
for elastic and diffractive physics

Can we do better for FCC ? yes :
-- more space
-- not restricted by injection
-- not competing in running time if going to
extra IRs H, F



Schematic collider layout. The straight insertions are shown in red and the arcs in black; the anticipated space for the dispersion suppressors is indicated in green.

Forward physics options, scenarios

LHC Working Group on Forward Physics and Diffraction -- all experiments + theory

first presentation (by me, Xavier also present) and discussion in meeting on 27/10/2015

Parasitic running in standard physics next to high luminosity IP, with tens of kilowatts of collision debris will be difficult. Rather assume more dedicated lower luminosity IP.

Two scenarios sufficient ?

1. **Dedicated very high β^* operation for cross section measurements**
   Few bunches, no crossing angle. Few dedicated runs.
   Roman pots very close (few sigma).
   Minimize beam-beam (no collisions in other IPs, moderated bunch intensities) :
   Profit from SR/RF radiation damping : **$\varepsilon_N = 2.2\ \mu m \times \exp(-t/\tau)$**
   where $\tau = 1$ h. After ~ 4 hours at reduced equilibrium emittance, maybe as low as ~ 0.05 μm
   β^* ~ few km could be sufficient, very high $\beta^* > 10$ km may not be needed
   at reduced bunch intensities, more bunches compatible with no crossing angle to get sufficient luminosity
   to be checked and optimized : damping partition, beam-beam, bunch schemes, IBS
2. **Moderately high β^* ~ 100 m operation for forward / diffractive physics**
   (and minimum bias, proton vs / ion calibration ..) with kind of "ALICE+TOTEM" IR and detectors
   Design IP such that enough corrector strength and aperture available for sufficient crossing angle and parallel separation to operate with full number of bunches with 25 ns spacing
   Aim : **compatible with standard physics** --- no need for limited special runs
   Roman pots at ~ 10 sigma ? (after some h in physics)

---- to be followed up, next WG meeting 15-16 March, expect ideas/requests from experiments