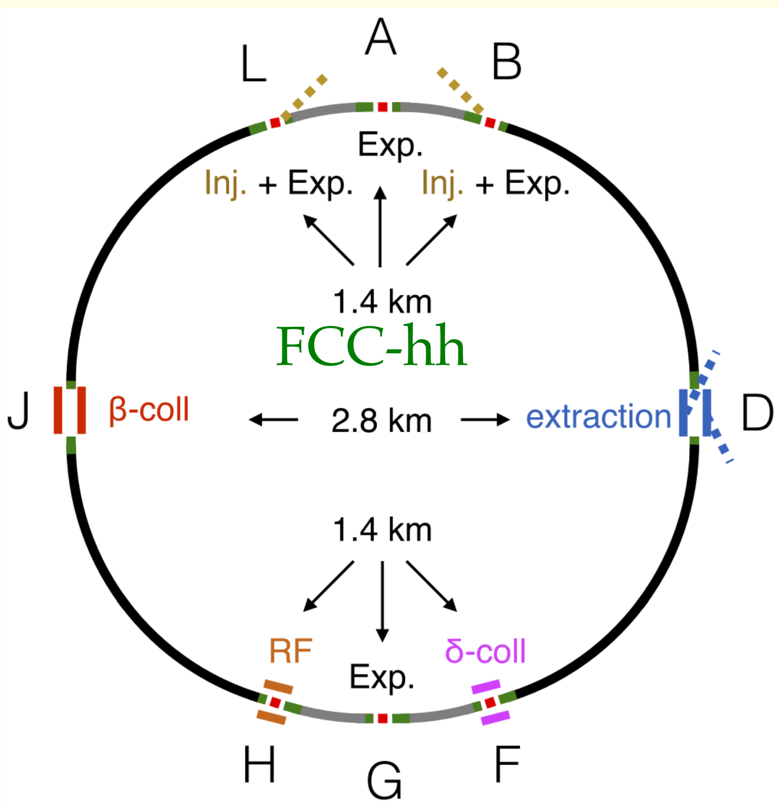
Needs and plans for **F**uture **C**ircular **C**ollider

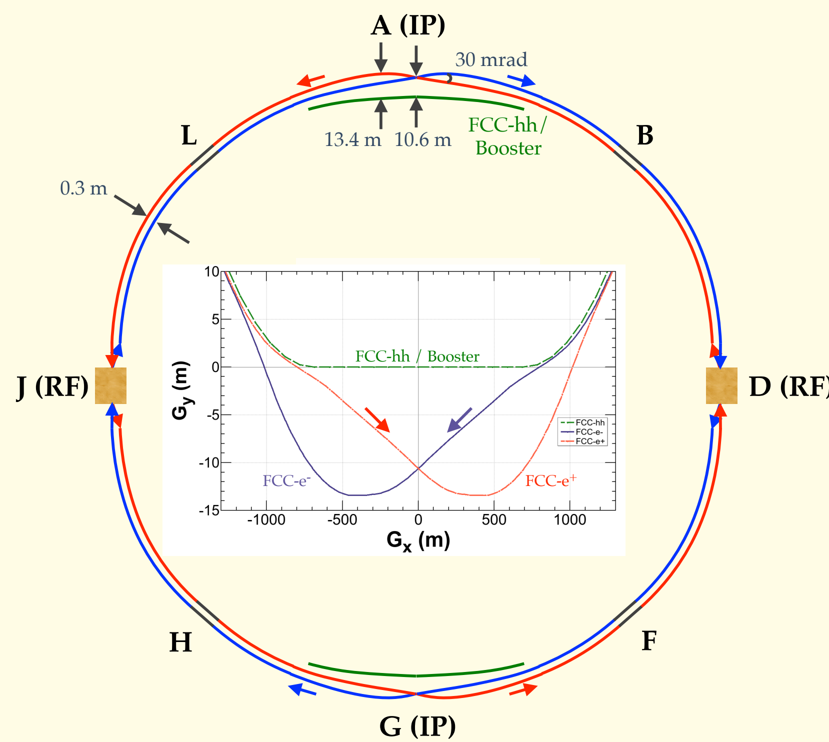
by Helmut Burkhardt (CERN)

and (if time left) more generally future accelerators also proposed in context of European strategy

FCC ~ 100 km (baseline for CDR 97.75 km) hh, ee, ion collisions and eHad options

FCC hh pp √s = 100 TeV **FCC ee up to √s = 365 GeV**



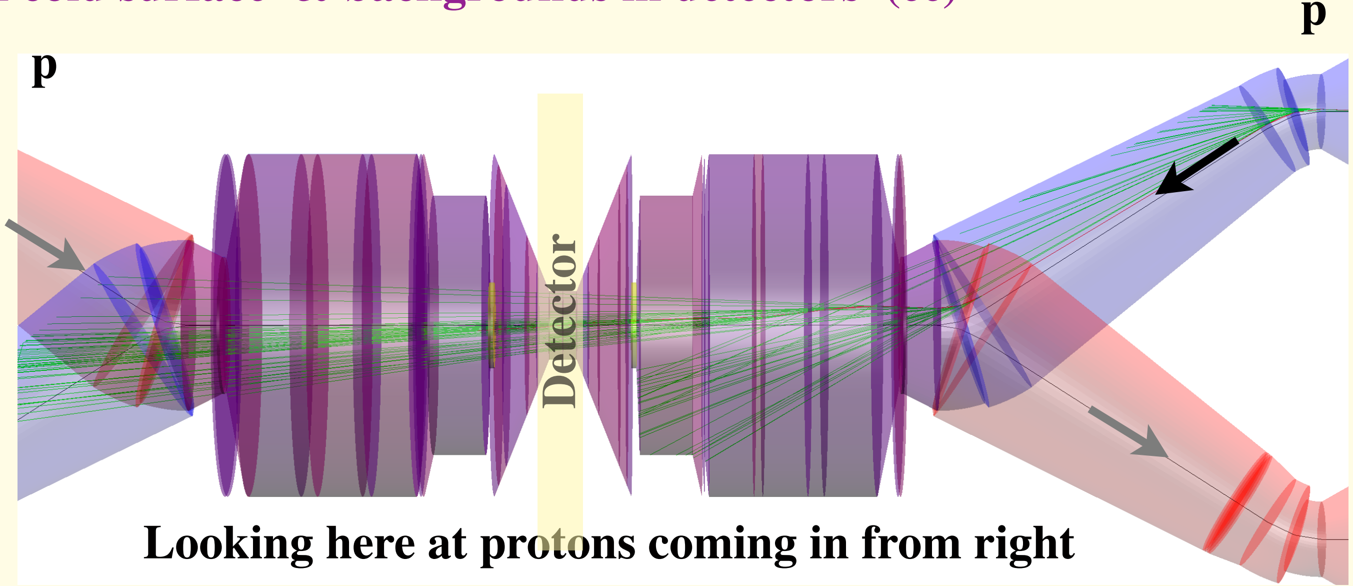


Conceptual studies including detailed simulations are in progress and CDR writing has started as input for strategy discussion in 2019 and the planned European strategy update in early 2020

Synchrotron radiation, FCC-hh

SR (synchrotron radiation) as major constraint both hh and ee

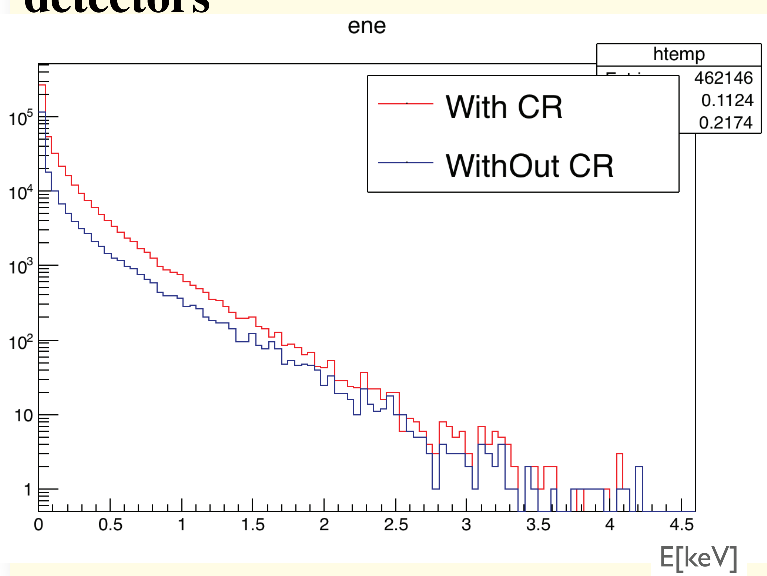
100 MW ee, 5 MW in pp -- on cold surface & backgrounds in detectors (ee)



Example of use of G4 upgraded for FCC

SR of protons and high precision um over km tracking to predict the rate and spectrum of photons into detectors

Looking here at protons coming in from right tracked over 700 m to IP and beyond generating SR photons shown in green transverse scale × 1000

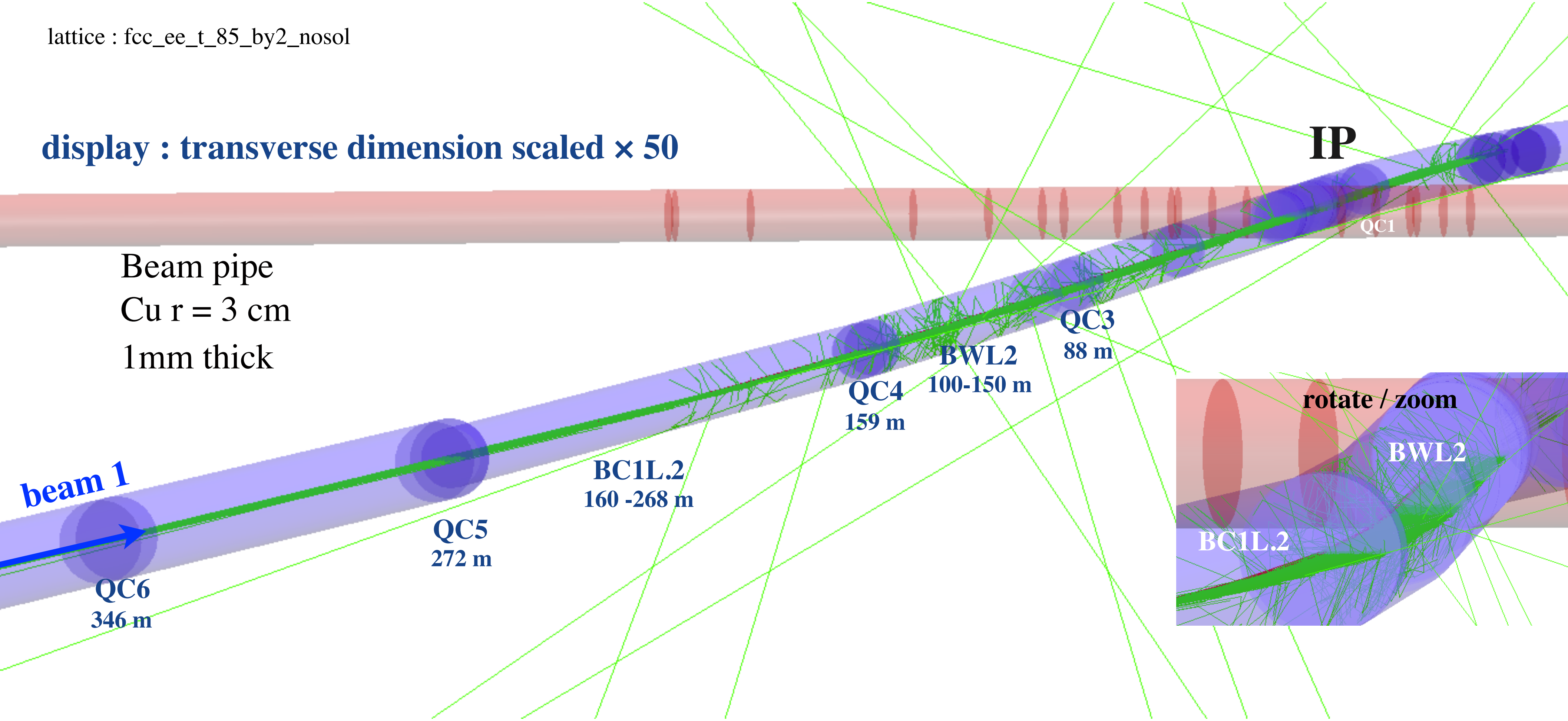


SR photon spectrum coming into detector region depending on crossing angle

Ref :
Synchrotron Radiation Backgrounds for the FCC-hh Experiments, IPAC2017 paper and F. Collamati / INFN-Rom presentation 10/2017

SR FCC-ee

lattice : fcc_ee_t_85_by2_nosol



(Gaussian) beam 1, 5000 e+ 175 GeV

tracked 510 m to IP (just after BC3 to Q2)

with SR and standard G4 em processes eIoni, eBrem, annihil, phot, compt, conv, Rayl

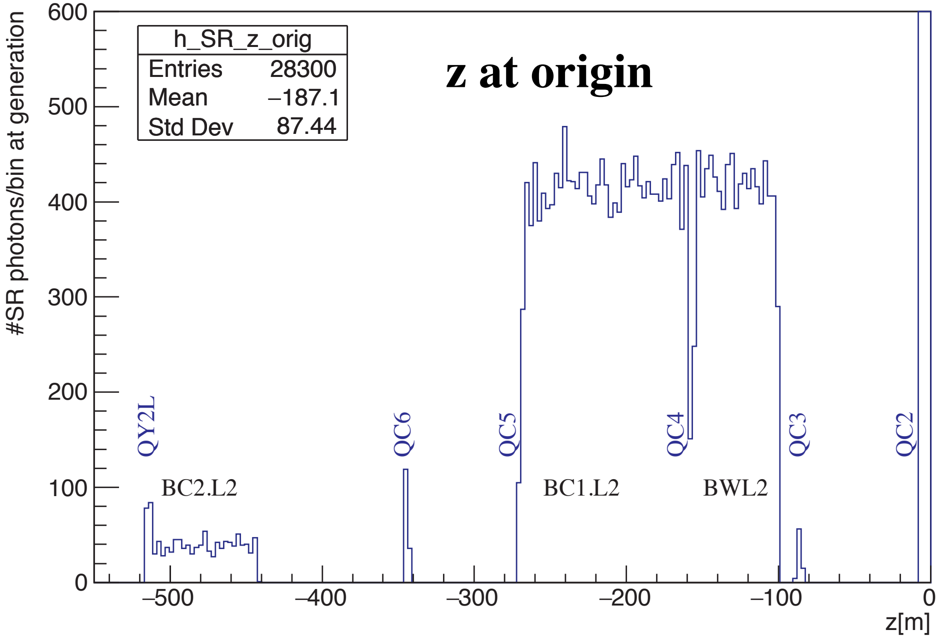
28300 SR γ's generated, first 1000 γ's shown here

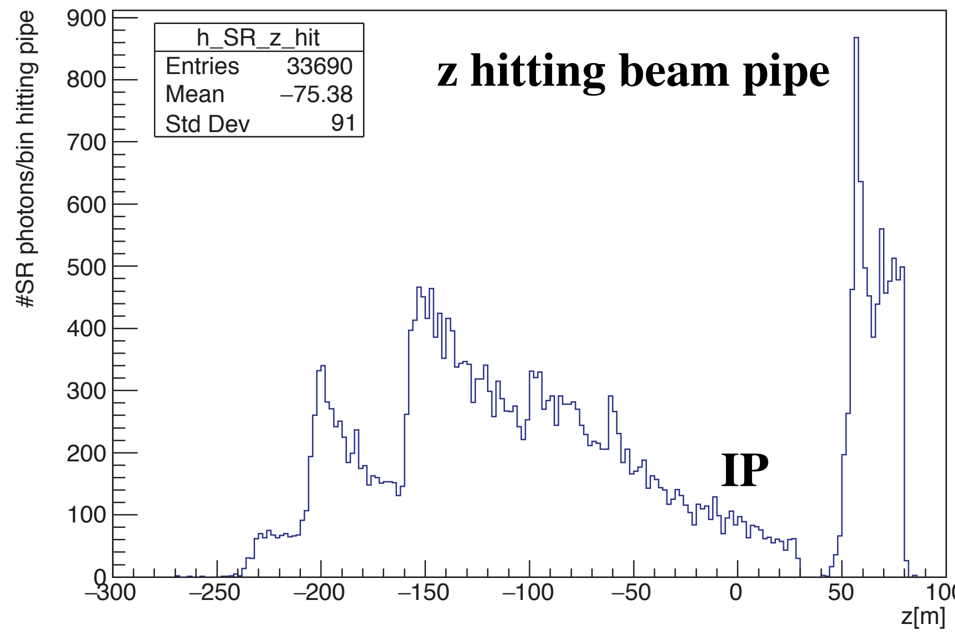
rather fast, < 1 min (MacMini i7)

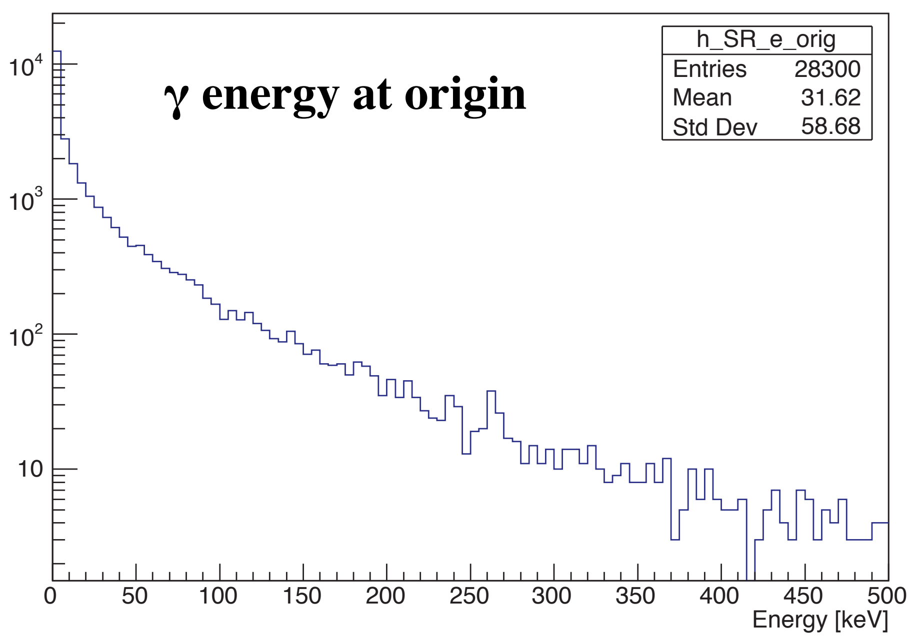
multiply with
2.3e+11/5000 = 4.6e7
to get statistics of 1 bunch
1.3e12 SR γ's

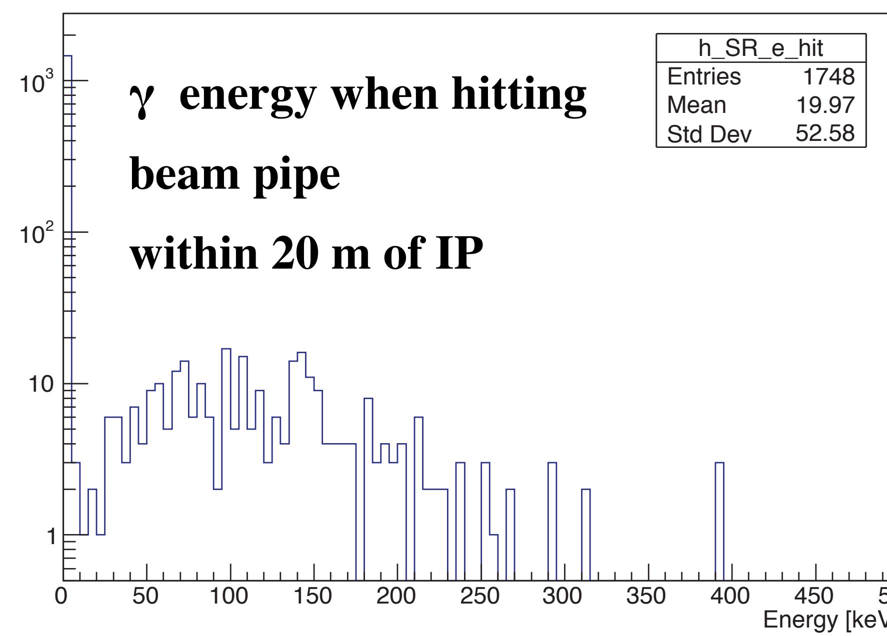
Detailed study by PhD student Marian Lückhof + myself

SR FCC-ee , distributions of these photons







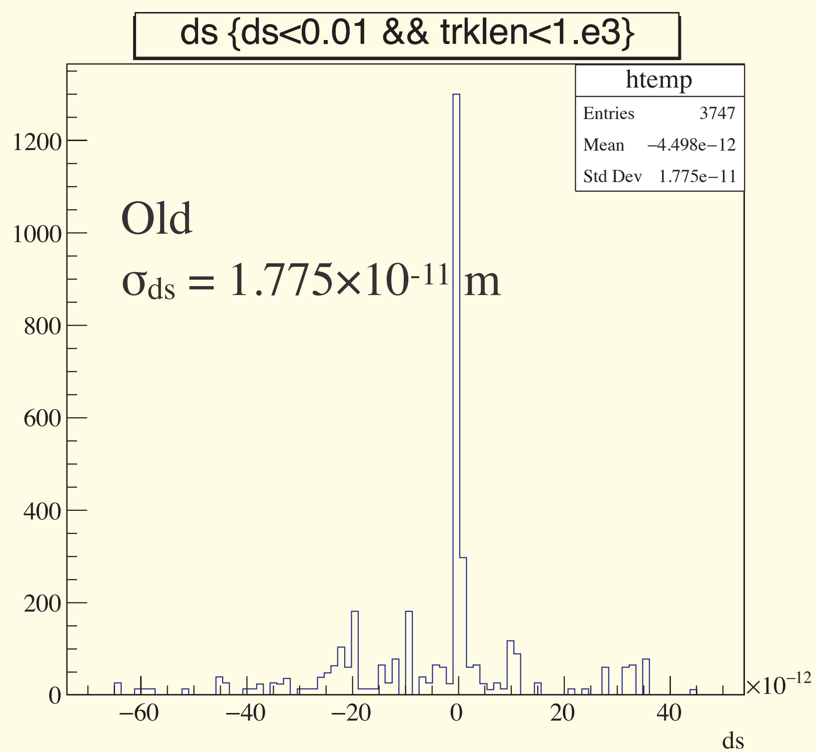


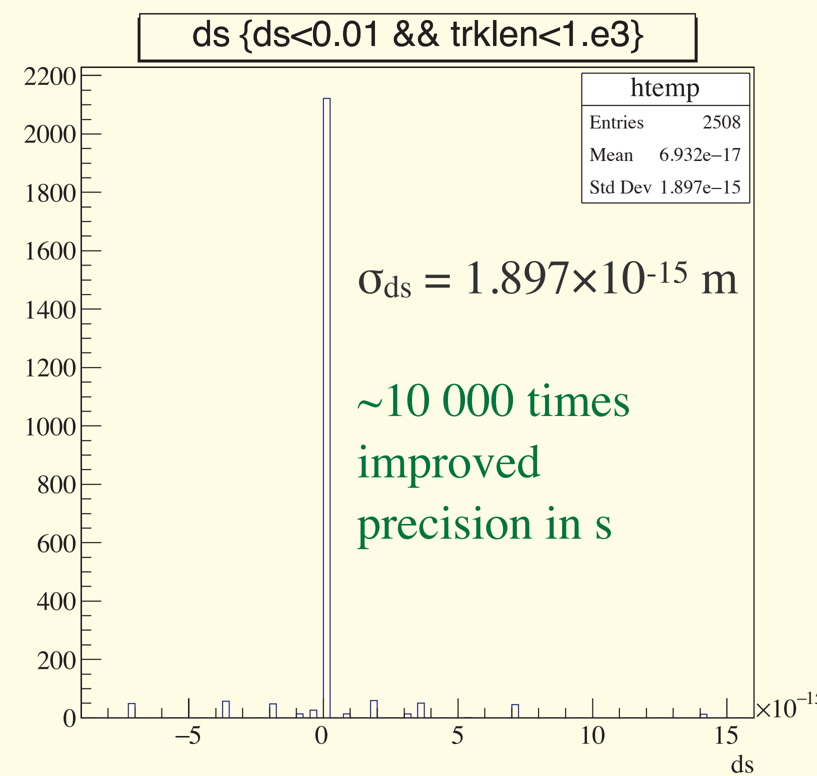
Tracking precision, GDML ROOT --> G4

Root exports geometries in various formats root, C, xml, gdml

```
Example
18.067141635485662 "true" value printed to 17 digits to avoid any loss in precision
18.0671416355       GDML export, used as input to GEANT4
18.067142           C export
1.806714e+01        XML export
```

Reported as [Root issue on 21/06/2017]() with proposed fix change "%.12g" to "%.17g" in TGDMLWrite.cxx
running since then with "my own" improved root module for geometry generation





difference between GEANT4 and MAD-X track position for LEIR

G4 tracking checked with 78 m machine LEIR

Using the **improved ROOT GDML export**, angle off by 1.227×10^{-9} after 1st bend in LEIR

GEANT4 magnetic field tracking accuracy adjusted :

DeltaOneStep = 1.e-05 default, with 1.e-9 angle off by 6.864×10^{-9}, 18× better

Excellent results with :

minEpsilonStep= 5e-08 m maxEpsilonStep= 1e-06 m DeltaOneStep= 9e-11 m

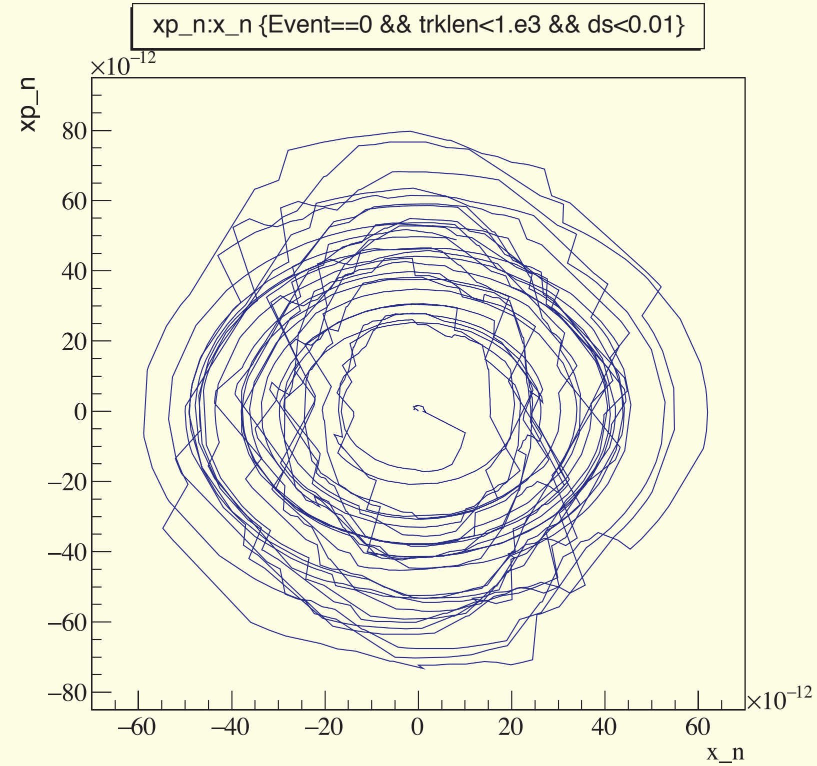
DeltaIntersection=3.6e-11 m.

LEIR normalized x vs x'

tracked over 10 km

or 127 turns

numerical noise < 10^{-10}



Needs, Plans

General (hadron)

- **Check / update processes to 100 TeV,** anything missing ?

  pp cross sections including diffractive, elastic ..

  adapt parametrisations (COMPETE..) to new precise measurements, TOTEM CERN EP-2017-335

EM

- **X-ray mirror, specular reflection for keV photons, depends on surface, roughness.**

  expected to significantly increase backgrounds into detectors for FCC-ee
- benchmarking with light source studies for FCC and comparison with SynRad by R. Kersevan
- **γ (MeV) - nuclear, giant-dipole/quadruple resonance (started ?)**
- **improve SR angular distribution**
- **improve AnnihiToMuPair threshold**

known to be missing (but rather small) --- "just clone" **AnnihiToMuPair ?**

- **e+e- --> τ+τ- production AnnihiToTauPair, relevant for Ee+ > 12.4 TeV**

  may be easy ? " clone" AnnihiToMuPair ?

AnnihiToMuPair

Threshold for annihilation of e+ with atomic e- (at rest)

to produce muon pair $E_{\rm th} = 2m_\mu^2/m_e - m_e \approx 43.69~\rm GeV$

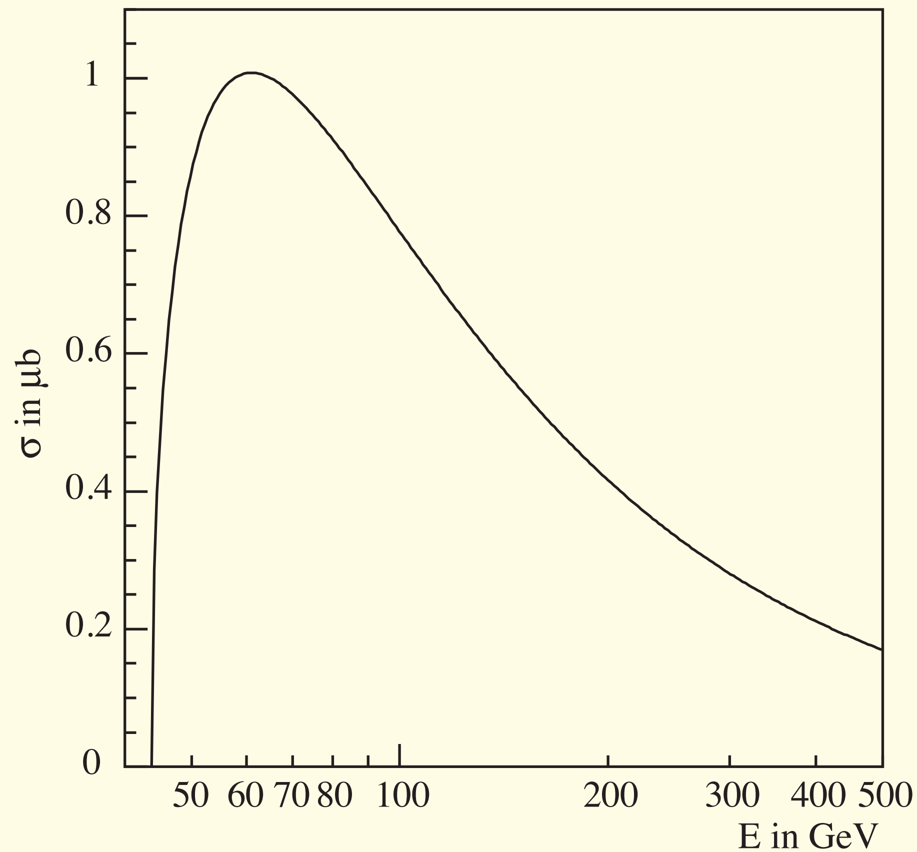
and 12.4 TeV to produce tau pair, **within the energy range of FCC-hh**

Total cross section

$$\frac{4\pi\alpha^2}{3\,s}\,\beta_\mu\left(\frac{3-\beta_\mu^2}{2}\right)$$

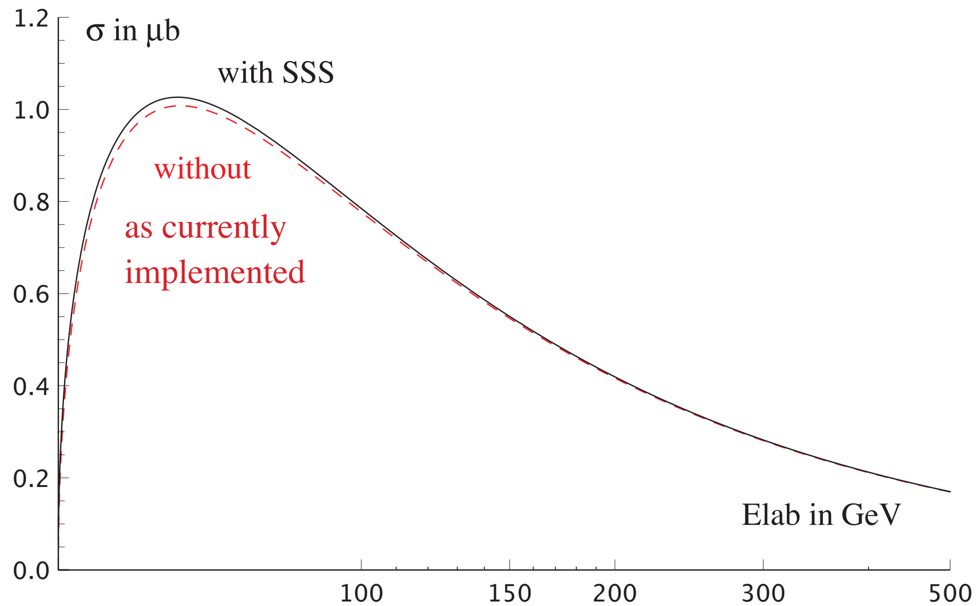
implemented in slightly approximated form (ok to 10 ppm) :

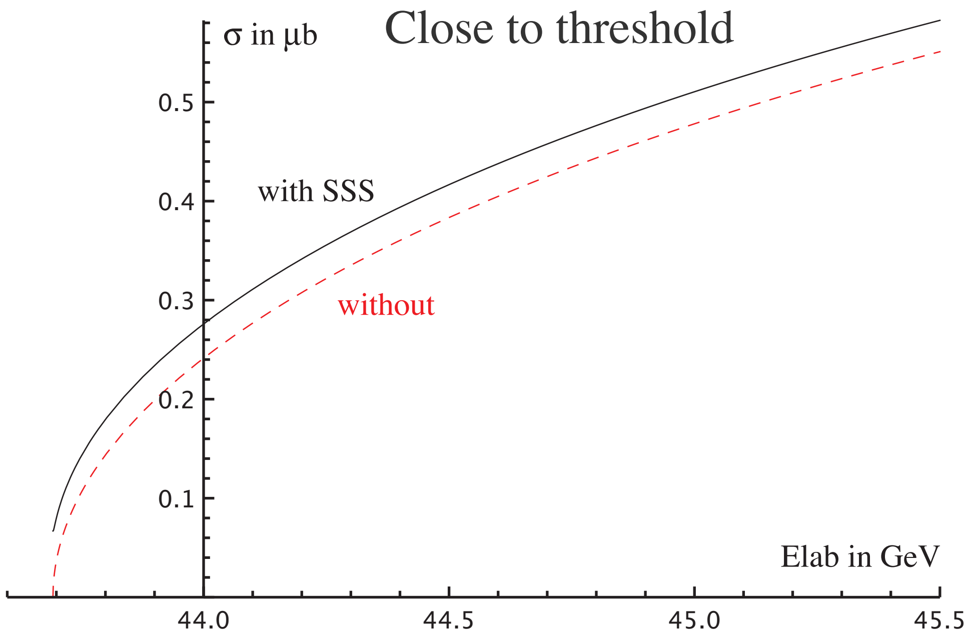
$$\sigma = \frac{\pi\, r_\mu^2}{3}\,\xi\left(1+\frac{\xi}{2}\right)\sqrt{1-\xi}$$



$r_\mu = r_e\, m_e/m_\mu$ is the classical muon radius, $\xi = E_{\rm th}/E$

SSS modified threshold





Cross-section increased by Sommerfeld-Schwinger-Sakharov factor

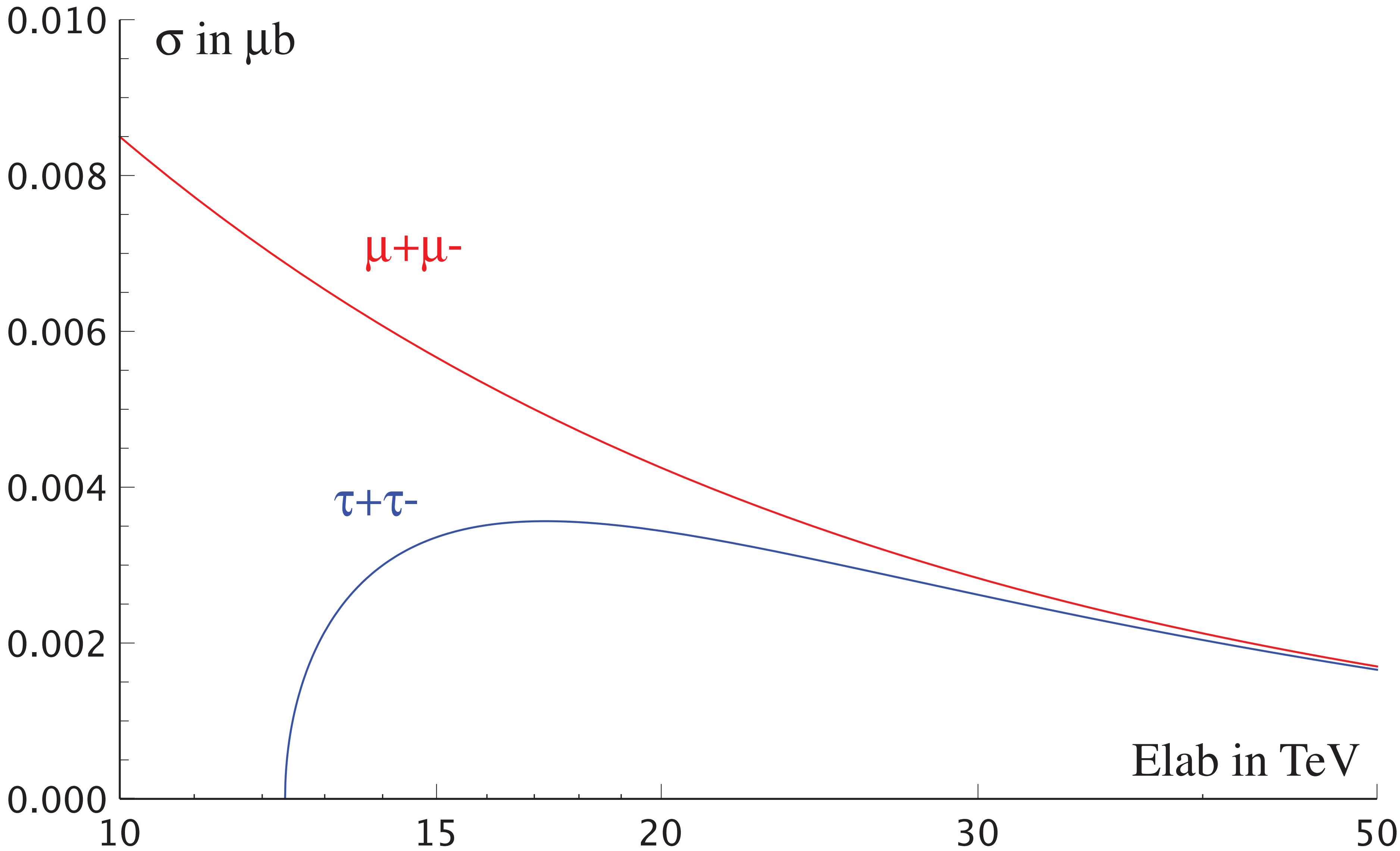
Stanley J. Brodsky and Richard F. Lebed, PRL 102, 213401, 5/2009

$$S(\beta) = \frac{X(\beta)}{1 - e^{-X(\beta)}} \qquad \text{where} \qquad X(\beta) = \pi\alpha\sqrt{1-\beta^2}/\beta$$

$$\sigma_{\rm SSS} = \frac{2\pi\alpha^2\beta_\mu}{s}\left(1 - \frac{\beta_\mu^2}{3}\right) S(\beta_\mu) = \frac{4\pi\alpha^2}{3\,s}\,\beta_\mu \left(\frac{3-\beta_\mu^2}{2}\right) S(\beta_\mu)$$

Plan : could be implemented soon (working on fast numerically stable approximation, goal ≲ 1%)

e+e- annihilation to MuPair and TauPair at FCC-hh energies



Backup

muons for physics rather than background

The implementation of EM muon production, Bethe Heitler and e+e- annihilation was originally motivated by studies to minimize muon backgrounds generated in beam halo collimation in linear colliders

Also relevant for FCC but not expected to be a major issue since halo collimation can be done very far from the experiments

More recently, there appears to be renewed interest in EM muon production close to threshold as source of low emittance muon beams for muon colliders without need for muon cooling

HIGS intense high energy γ from not fully stripped ion beams, W. Krasny et al. with (polarized) muon production by Bethe Heitler

LEMMA low emittance muon beam production from ~ 45 GeV positrons on target

Ref: Mario Antonelli et al.

IPAC2016 tupmu001, IPAC2017 weoba3

benchmarking in test beam on SPS

interested in improved AnnihiToMuPair