Cross-talk between experiments and LSS losses at FCC-hh

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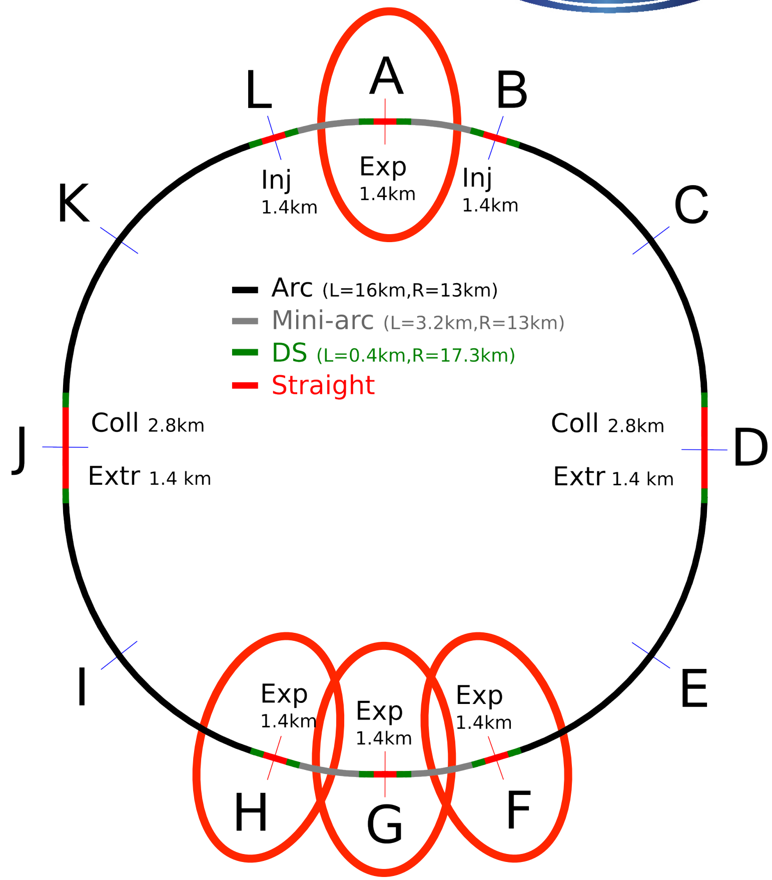
FCC workshop, Rome
12th April 2016

Many thanks to Roman, Francesco, Andrei, Daniel

MDI activities

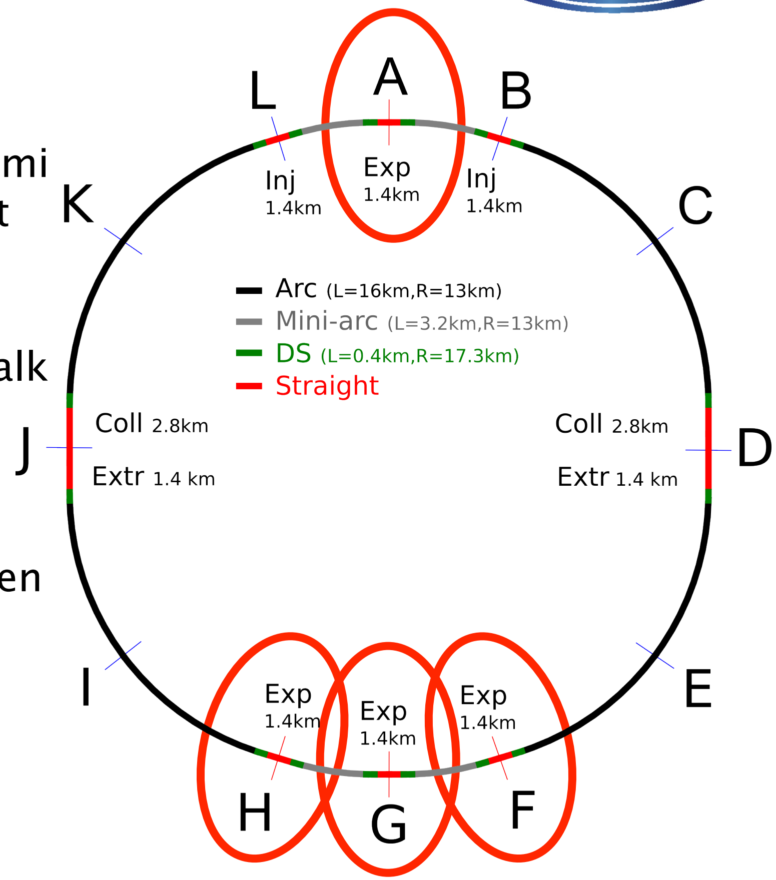
- Experimental Interaction Region
  - **One of critical areas defining FCC-hh performance**

- Design tasks of EuroCirCol IR Work Package
  - **Coordination**
    - JAI/Oxford (lead), CERN, task 3.1
  - **Development of the interaction region lattice**
    - JAI/Oxford (lead), CERN, task 3.2
  - **Design of machine detector interface**
    - CI/Manchester (lead), INFN, CERN, task 3.3
  - **Study of beam-beam interaction**
    - EPFL (lead), CERN, task 3.4



Cross-talk between IRs

- Given the 50 TeV on 50 TeV protons collisions at a lumi of 5E34, experimental cross-talk is a possible issue at FCC-hh.
- Here we use the DPMJETIII generator in its upgraded form, valid at this energy, to look at potential cross-talk contributions.
- We take IPA to IPB as a representative high lumi to other experiment, with ~5k of straight and arc between them.
  - (We use IPA to IPB for ease…same results as IPG->IPH)
- This first study looks at
  - Inelastic protons through beam pipe vacuum (i.e. optics)
  - Elastic protons through beam pipe vacuum (i.e. optics)
  - Muons travelling through rock from IPA to IPB.
  - (Muons through beam pipe vacuum automatically)
- But need to extend to showers, bouncing muons etc
- Interesting implications for experiments, and collimator structure in LSS and DS

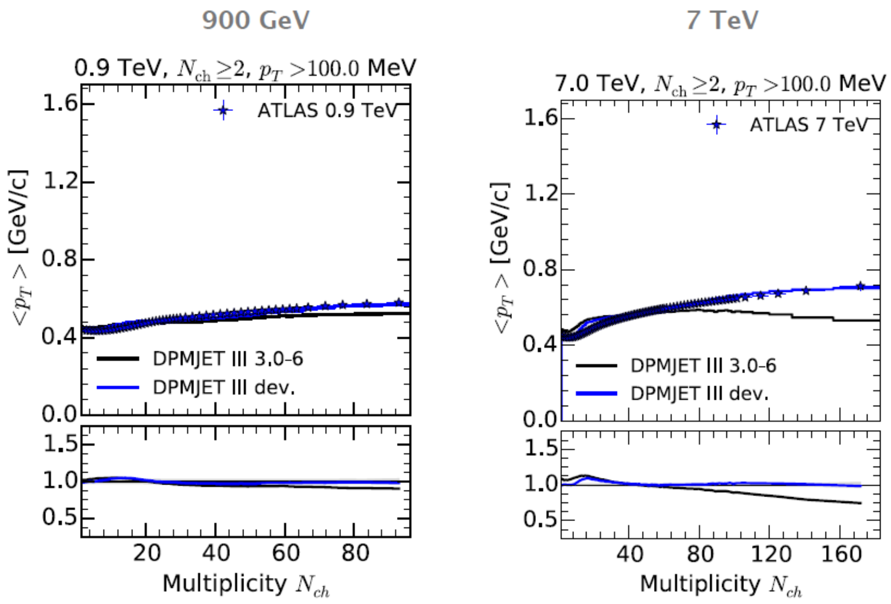


p-p EVENT GENERATOR (DPMJET-III)

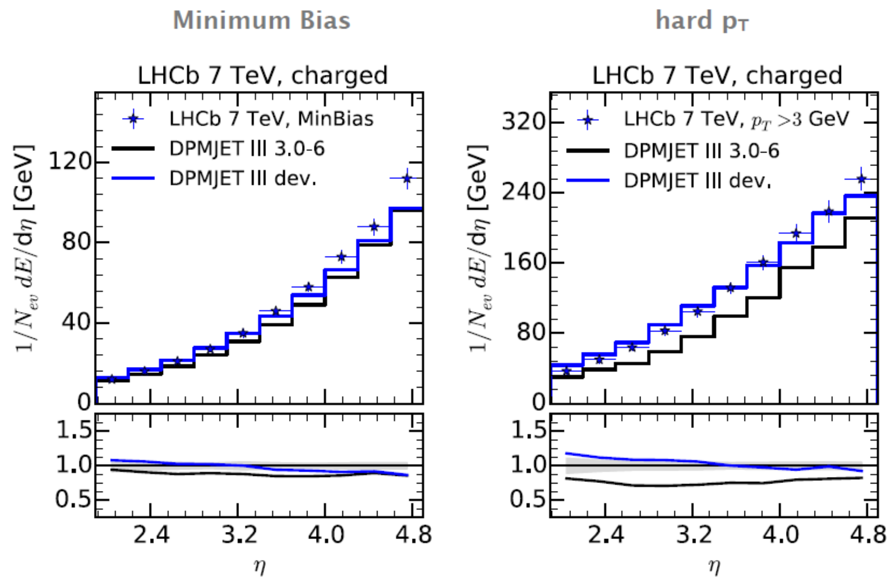
PhD thesis of A. Fedynitch
supervisors R. Engel (KIT) and A. Ferrari

- implementation of *new parton distributions functions and improved hard scatter*
- all Regge parameters re-fitted to match cross-sections from low energy up to LHC as good as possible
- Exists inside development version of FLUKA
- **Crucial for loads on the inner triplet (CERN) and experiment cross-talk (Manchester)**

ATLAS average p_T



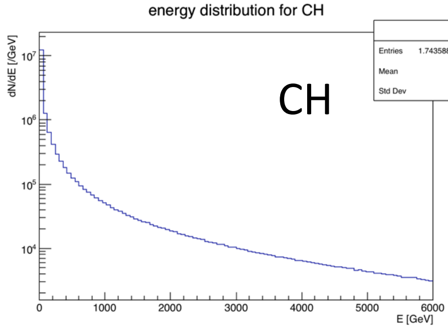
LHCb forward energy flow

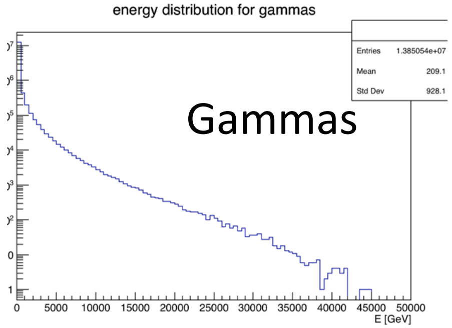


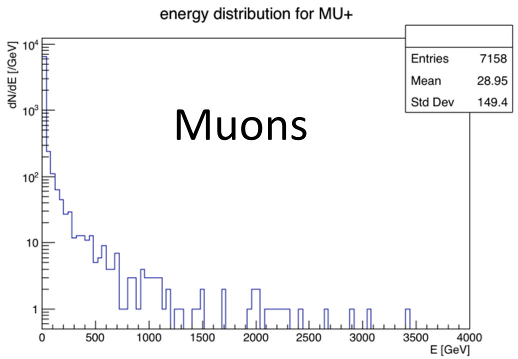
50 TeV-50 TeV pp collision particle content (prompt)

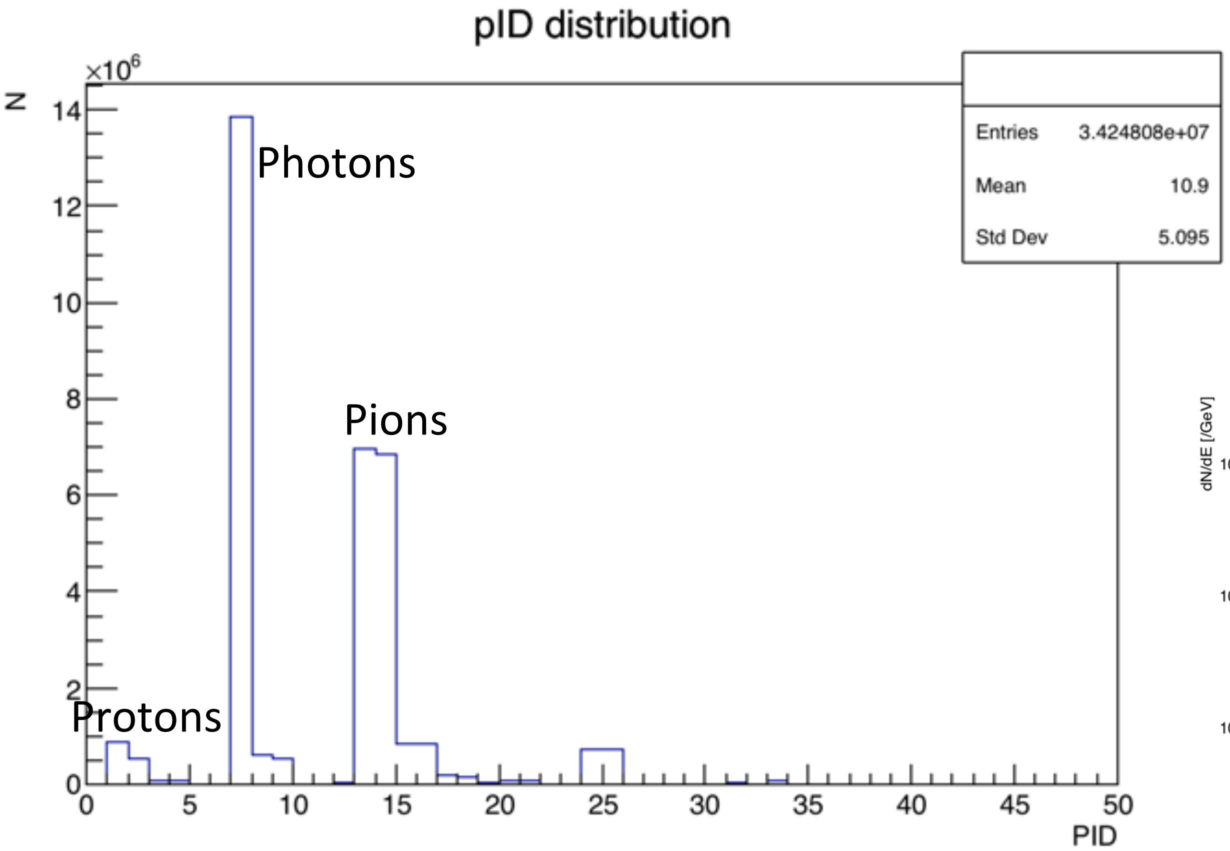
[Rates are for prompt particles (just after IP), with E > 1 GeV 1M collisons]

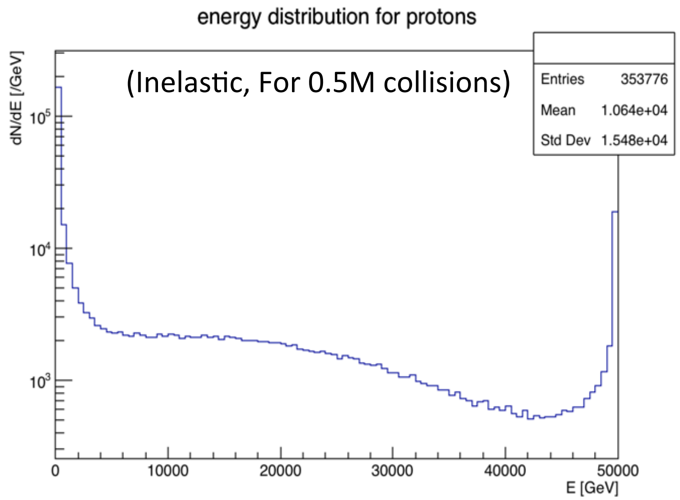
Mean protons per primary 0.89
Mean energy of protons 14757 GeV
Mean mu- per primary 0.007
Mean energy of mu- 34 GeV
Mean CH per primary 17.4
Mean energy of CH 373 GeV
Mean gammas per primary 13.8
Mean energy of gammas 209 GeV







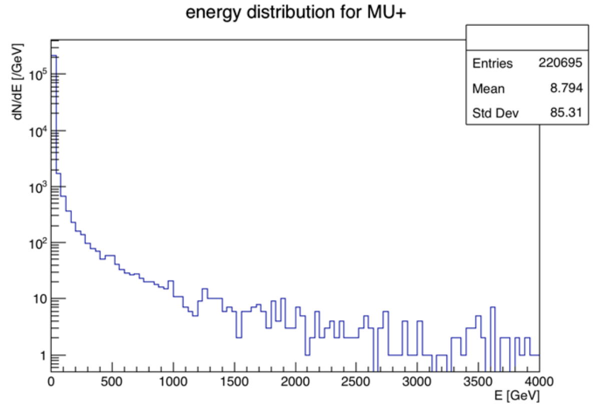


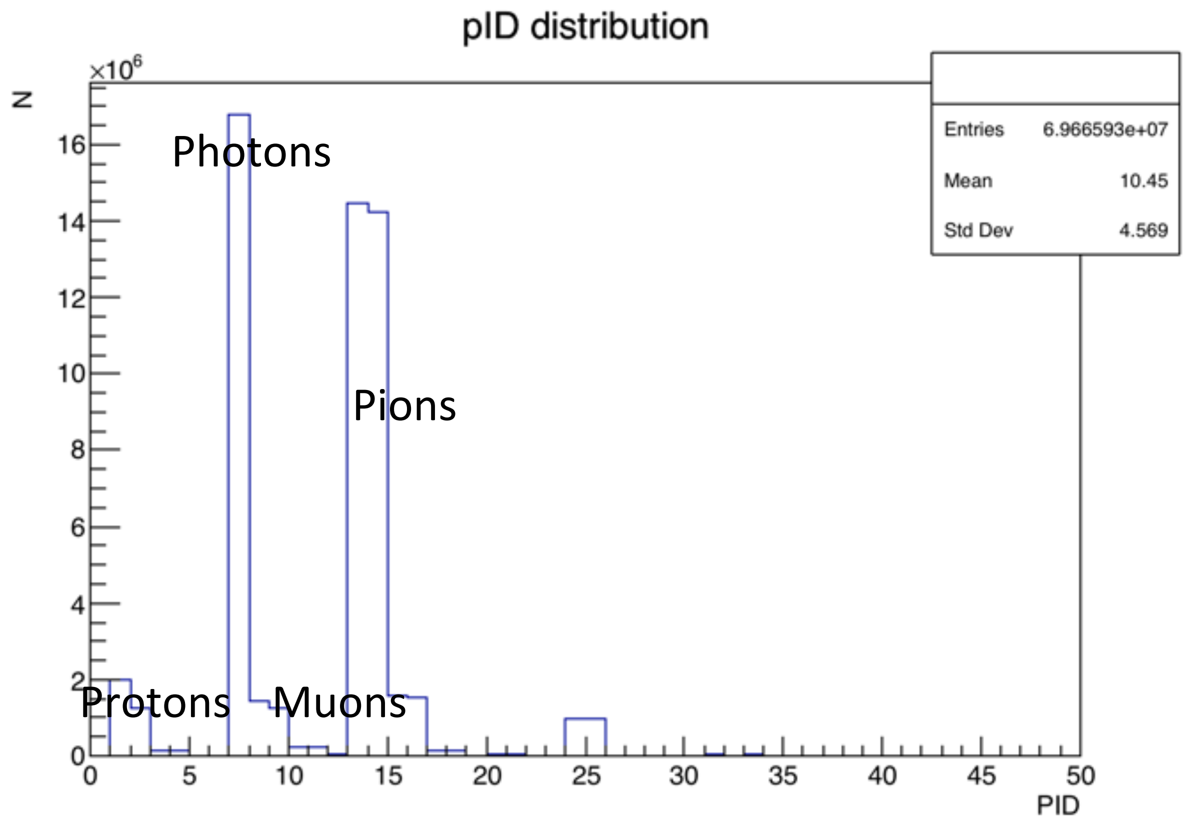


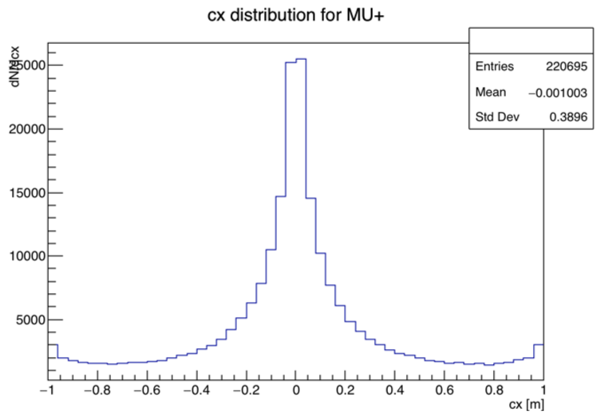
50 TeV-50 TeV pp collision particle content (prompt+decay)

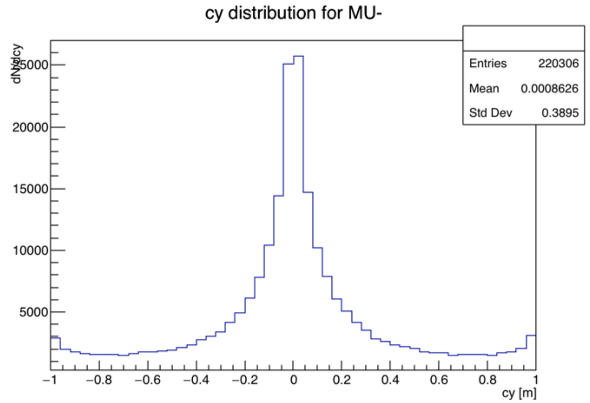
[Rates are for prompt +decayed particles (3m after IP), with E > 1 GeV
1M collisions]

Mean protons per primary 1.98
Mean energy of protons 13308.
Mean mu- per primary 0.22
Mean energy of mu- 11.8
Mean ch per primary 34.1
Mean energy of ch 381.7
Mean gammas per primary 28.7
Mean energy of gammas 205









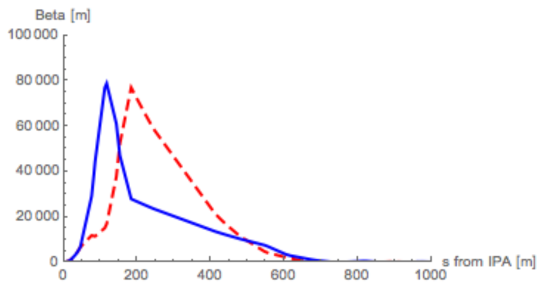
The simulation framework

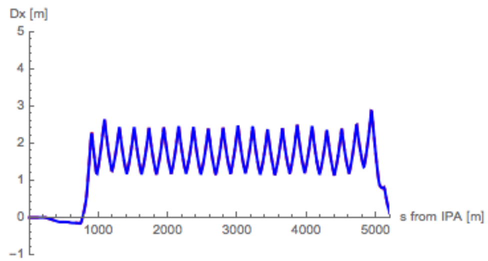
Approach gives accurate tracking and loss rates, and allows TCL-like jaw setting calculations, but excludes showers (-> FLUKA, BDSIM)

[Energy loss models (muons)]

DPMJETIII → **MADX-PTC** → **Aperture model (Python)** → **Post-processing (Python/ Mathematica)**

- **DPMJETIII**: Generate 50 TeV on 50 TeV collision products using DPMJETIII inside FLUKA
- **MADX-PTC**: Track through the FCC-hh latttice, matched with IR, l*=45m, beta*=0.3m. Store tracks to next IR ~5k away
- **Aperture model (Python)**: Apply aperture model as post-processor, to compute particle transmission and loss rates
- **Post-processing (Python/ Mathematica)**: Compute loss rates and IR cross-talk, plus loads on TAS.





Optics:
L*=45m optics with matched IRA
TAS at 50mm, length 750m
Beta*=0.3m
NO crossing angle (hence this dispersion)
Norm emit 2.2E-6 m
L=5E34, sigma-ie=108mb

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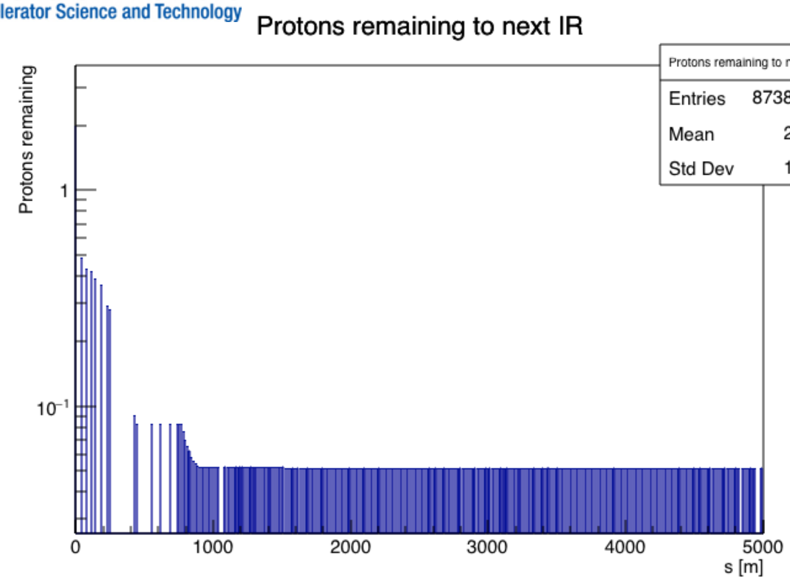
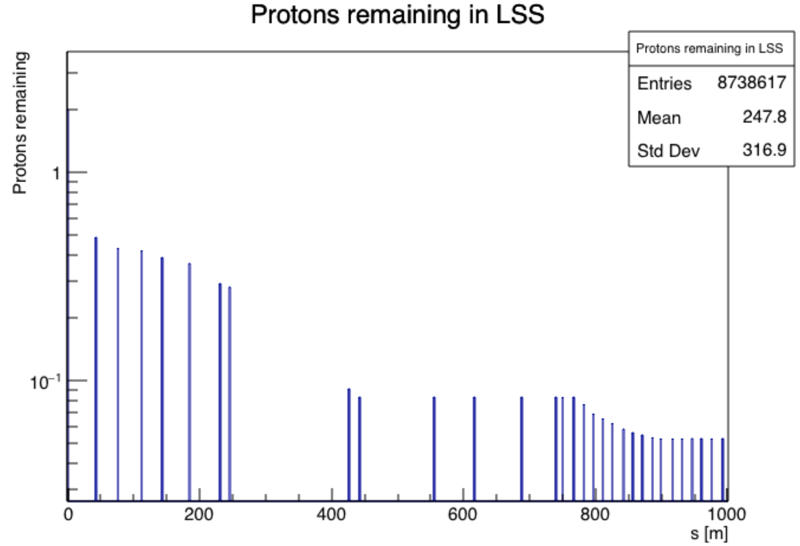
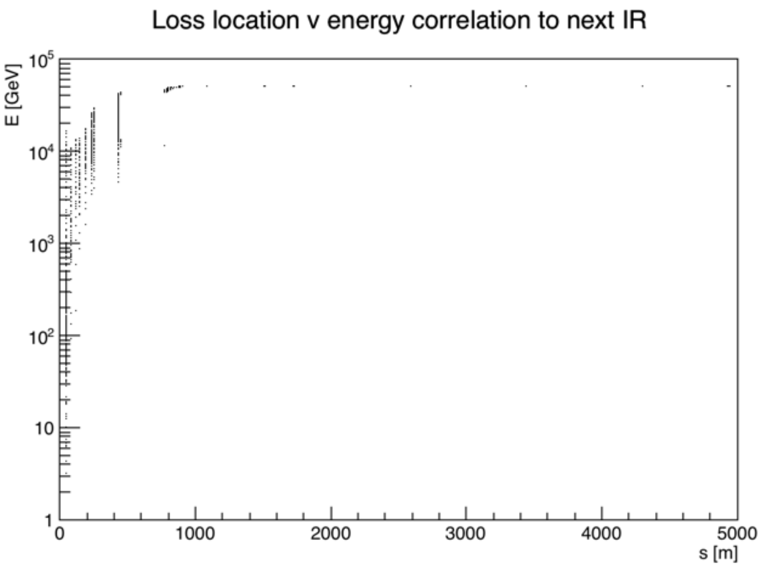
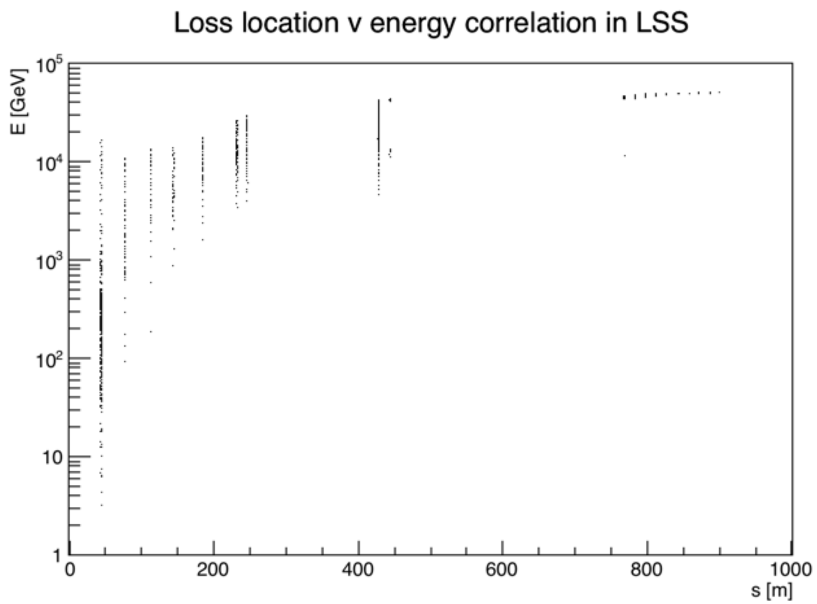
Inelastic protons : loss patterns

L*=45m optics with matched IRA
Beta*=0.3m, NO crossing angle
Losses assume L=5E34, sigma-ie=108mb









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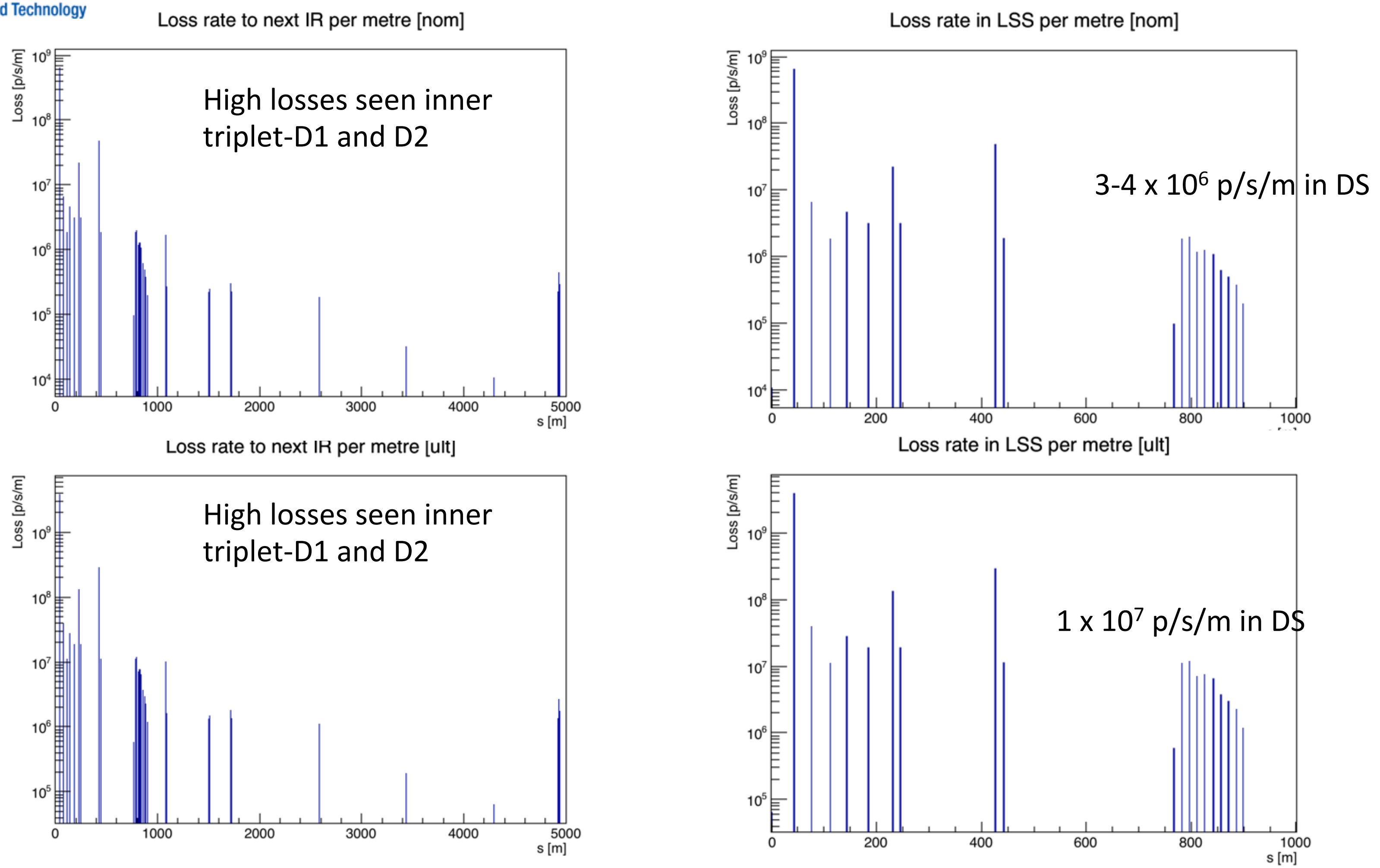
Inelastic protons : loss rates p/s/m

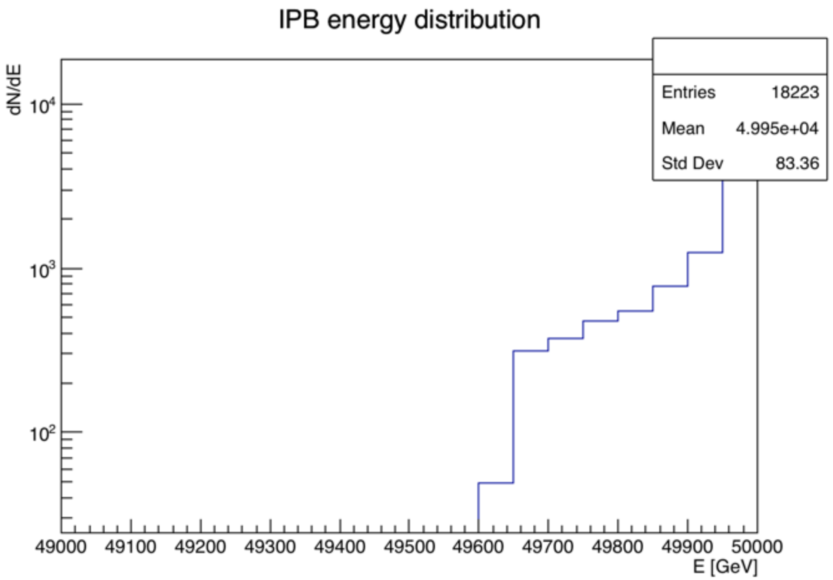
L*=45m optics with matched IRA
Beta*=0.3m, NO crossing angle
Losses assume L=5E34, sigma-ie=108mb

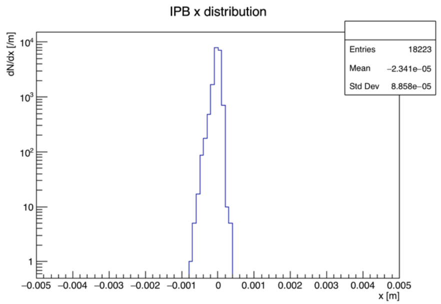


Note - losses are per element, i.e. the high p/s/m on Q1 are distributed along the magnet length

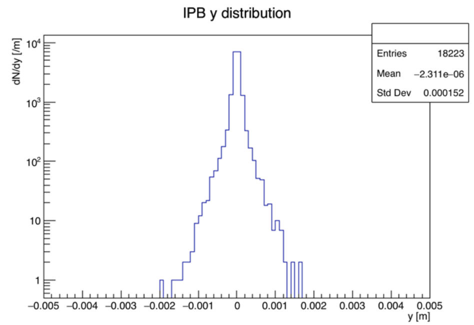
- losses consistent with estimation from FLUKA group
- losses are exceed by pion loss, which will be shielded by liner
- losses will be reduced by crossing angle and impact of detector dipole
- losses will create local showers – to be studied

Inelastic protons : IPA->IPB

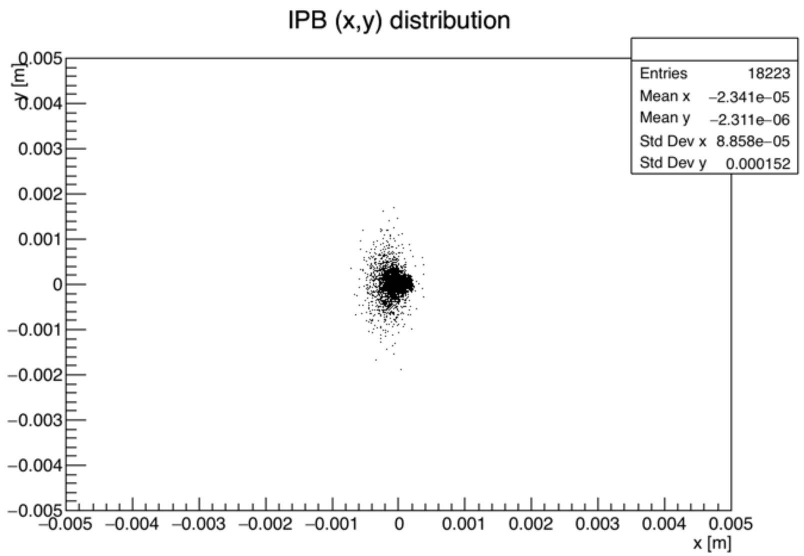




L*=45m optics with matched IRA
Beta*=0.3m, NO crossing angle
Losses assume L=5E34, sigma-ie=108mb



Particles at IPB PER BX [nom]: 6.2
Particles at IPB PER BX [ult]: 37.4
Particles at IPB PER SEC [nom]: 311613300
Particles at IPB PER SEC [ult]: 11218078800
Power [W] at IPB [nom]: 1575
Power [W] at IPB [ult]: 9451
Mean energy of protons at IPB [GeV]: 49962
0.1%



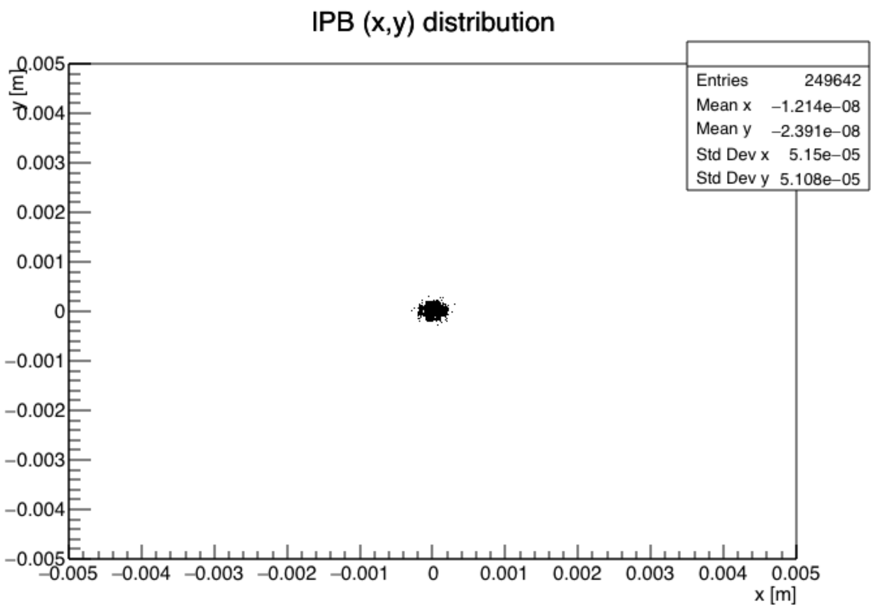
X-STDDEV=Around 100 um

Elastic protons

Particles at IPB PER BX [nom]: 85
Particles at IPB PER BX [ult]: 512
Particles at IPB PER SEC [nom]: 4268878200
Particles at IPB PER SEC [ult]: 1.536796152e+11
Power [W] at IPB [nom]:
Power [W] at IPB [ult]:
Mean energy of protons at IPB [GeV]: 50000.0

Conclusion : elastics stay well within beampipe and TAS (as LHC)

-> Emittance growth (as LHC)



Muons through rock : theory

Muon stopping power for high energy muons can be described by

$$\left\langle -\frac{dE}{dx} \right\rangle = a(E) + b(E)E$$

Where E is the energy, a(E) models electronic stopping power (ionization and excitation) and b(E) is due to radiative processes, such that

$$b = b_{brems} + b_{pair} + b_{nucl}$$

Note b(E) is << a(E) for most materials, when E <= 100 GeV.
The range in the continuous slowing down approximation is given by

$$R(E) = \int_{E_0}^{E} (a(E') + b(E')E')^{-1} \, dE'$$

Which is what we use for FCC. However we can do the integral at high energy, when a(E) and b(E) are constant to get

$$R(E) \sim \frac{1}{b} \ln(1 + \frac{E}{E_c})$$

Where the electronic and radiative losses are equal at the 'critical energy'

$$a(E_c) = E_c b(E_c)$$

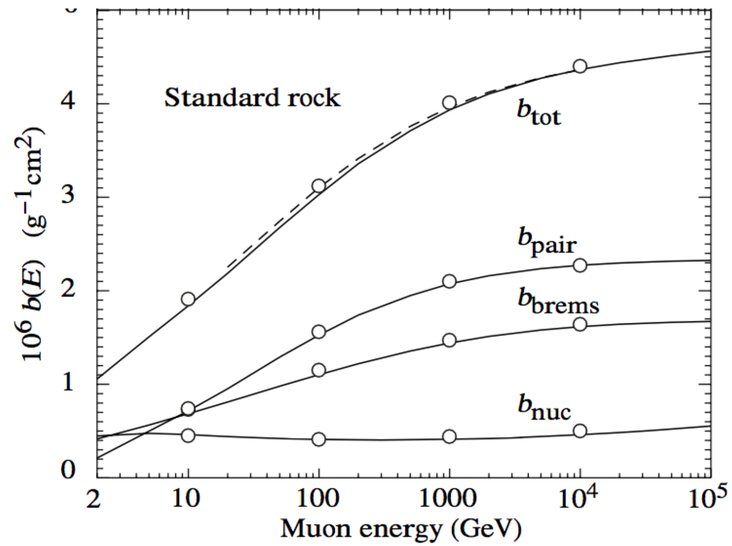
Muons through rock : *a* and *b*

http://pdg.lbl.gov/2015/AtomicNuclearProperties/HTML/standard_rock.html

T	p	Ionization	brems	pair	photonuc	Radloss	dE/dx	CSDA Range	delta	beta	dE/dx_R
[MeV]	[MeV/c]	-----------------------[MeV cm^2/g]					-----------------------	[g/cm^2]		[MeV cm^2/g]	
1.000E+00	1.457E+01	2.643E+00	0.000E+00	0.000E+00	4.771E-05	4.771E-05	5.286E+00	2.311E-03	0.0000	0.13661	4.060E+01
1.200E+00	1.597E+01	3.517E+01	0.000E+00	0.000E+00	4.780E-05	4.780E-05	3.517E+01	7.619E-03	0.0000	0.14944	3.517E+01
1.400E+00	1.726E+01	3.112E+01	0.000E+00	0.000E+00	4.789E-05	4.789E-05	3.112E+01	1.368E-02	0.0000	0.16119	3.112E+01
1.700E+00	1.903E+01	2.667E+01	0.000E+00	0.000E+00	4.802E-05	4.802E-05	2.667E+01	2.413E-02	0.0000	0.17725	2.667E+01
2.000E+00	2.066E+01	2.342E+01	0.000E+00	0.000E+00	4.816E-05	4.816E-05	2.342E+01	3.616E-02	0.0000	0.19186	2.342E+01
2.500E+00	2.312E+01	1.960E+01	0.000E+00	0.000E+00	4.838E-05	4.838E-05	1.960E+01	5.961E-02	0.0000	0.21376	1.960E+01
3.000E+00	2.536E+01	1.694E+01	0.000E+00	0.000E+00	4.860E-05	4.860E-05	1.694E+01	8.713E-02	0.0000	0.23336	1.673E+01
3.500E+00	2.742E+01	1.498E+01	0.000E+00	0.000E+00	4.883E-05	4.883E-05	1.498E+01	1.186E-01	0.0000	0.25120	1.462E+01
4.000E+00	2.935E+01	1.347E+01	0.000E+00	0.000E+00	4.905E-05	4.905E-05	1.347E+01	1.539E-01	0.0000	0.26763	1.302E+01
4.500E+00	3.116E+01	1.227E+01	0.000E+00	0.000E+00	4.927E-05	4.927E-05	1.227E+01	1.928E-01	0.0000	0.28290	1.176E+01
5.000E+00	3.289E+01	1.129E+01	0.000E+00	0.000E+00	4.950E-05	4.950E-05	1.129E+01	2.353E-01	0.0000	0.29720	1.074E+01
5.500E+00	3.453E+01	1.047E+01	0.000E+00	0.000E+00	4.972E-05	4.972E-05	1.047E+01	2.814E-01	0.0000	0.31066	9.902E+00

Standard rock data:

Quantity	Value
<Z/A>	0.50000
Specific gravity	2.650 g cm-3
Critical energy	49.13 MeV (for e-), 47.74 MeV (for e+)
Muon critical energy	693. GeV



Muon range through rock (prompt+decay)

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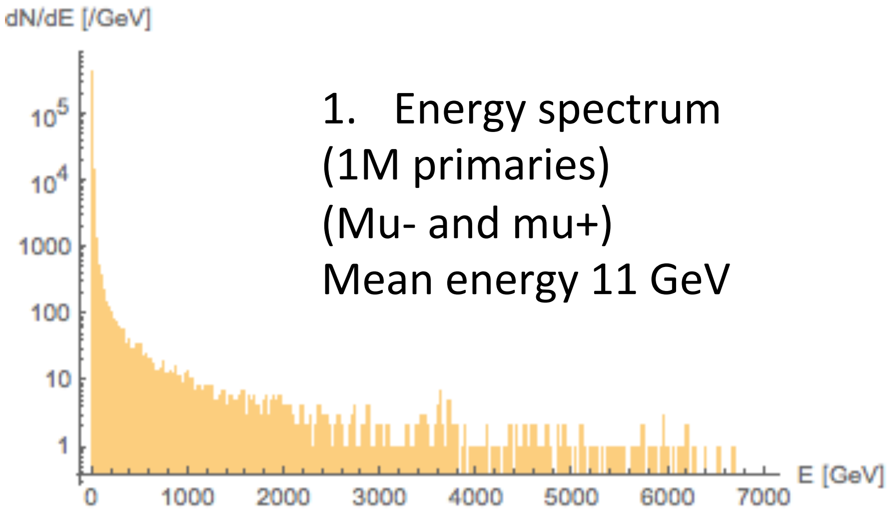
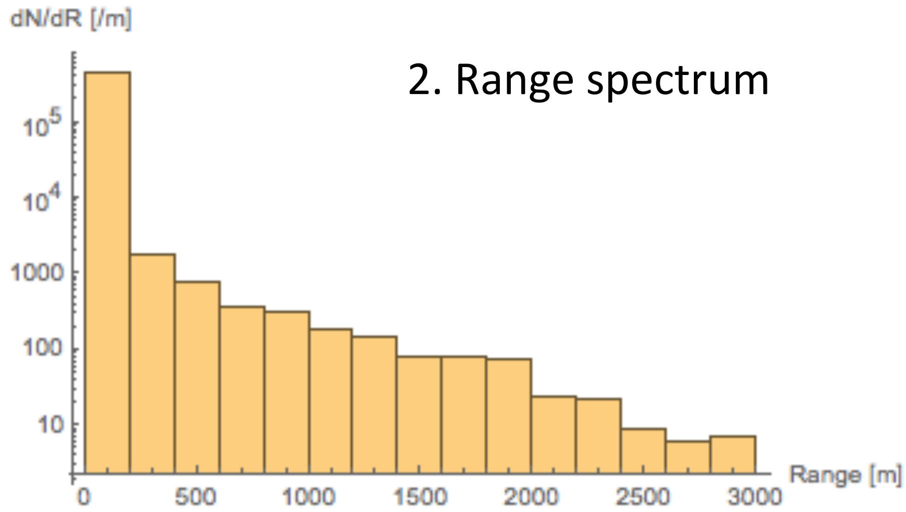


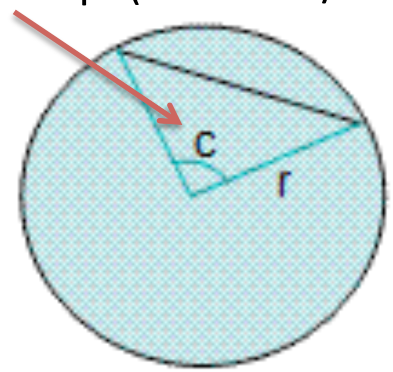
1. Energy spectrum
(1M primaries)
(Mu- and mu+)
Mean energy 11 GeV



2. Range spectrum

3. Chord through FCC-hh ring

circum=100 km. r=15.9 km.
C=2.pi.(5.964 km/100 km) = 0.37 rad



Chord=2.r.Sin(c/2)
= 5.92 km

Max energy is 22 TeV
Max range is ~3 km

So do not expect many muons through rock

Needs checking with Monte Carlo to include fluctuations and straggling
-> FLUKA
And check muons bouncing down tunnel, along with local losses close to next IP.

Summary

- **Inelastic protons through beam pipe vacuum** give a rate of protons per BX at the IPB of 6 for nominal parameters and 37 for ultimate parameters, with a spot rms of 100 um.
  - May cause some background due to position spread…to be checked
  - Proton losses in the LSS are high but expected… protection from TAS and TAN and liner (but not highest contribution, which is pions). We get 1E7 p/m/s at start of arc (ultimate)
    - Tentative FCC-hh loss limit (agreed with magnet and FLUKA teams) 0.5E6 p/s/m
  - DS absorbers further down would be useful for protection (and maybe TCLs?)

- **Elastic protons through beam pipe vacuum** give rise to a rate of protons per BX at the IPB of 85 for nominal parameters and 512 for ultimate parameters, with a spot comparable to the nominal beam size. This will lead to emittance growth.

- **Muons travelling through rock** from IPA to IPB will only have the range in extreme cases to give a meaningful cross-talk flux

- **Muons, due to energy, will not last for long in the optics**, if produced heading in the forward region

- Both calculations would benefit from shower codes, in the proton case to check local effects of high proton loss and in the muon case to properly include range straggling and fluctuations.
  - E.g**. potential muon background from inelastic losses close to IPB**
  - **or bouncing muons**

- Need to check
  - Impact of crossing angle (expect to increase cross-talk and LSS losses)
  - Detector spectrometer and compensator magnets)

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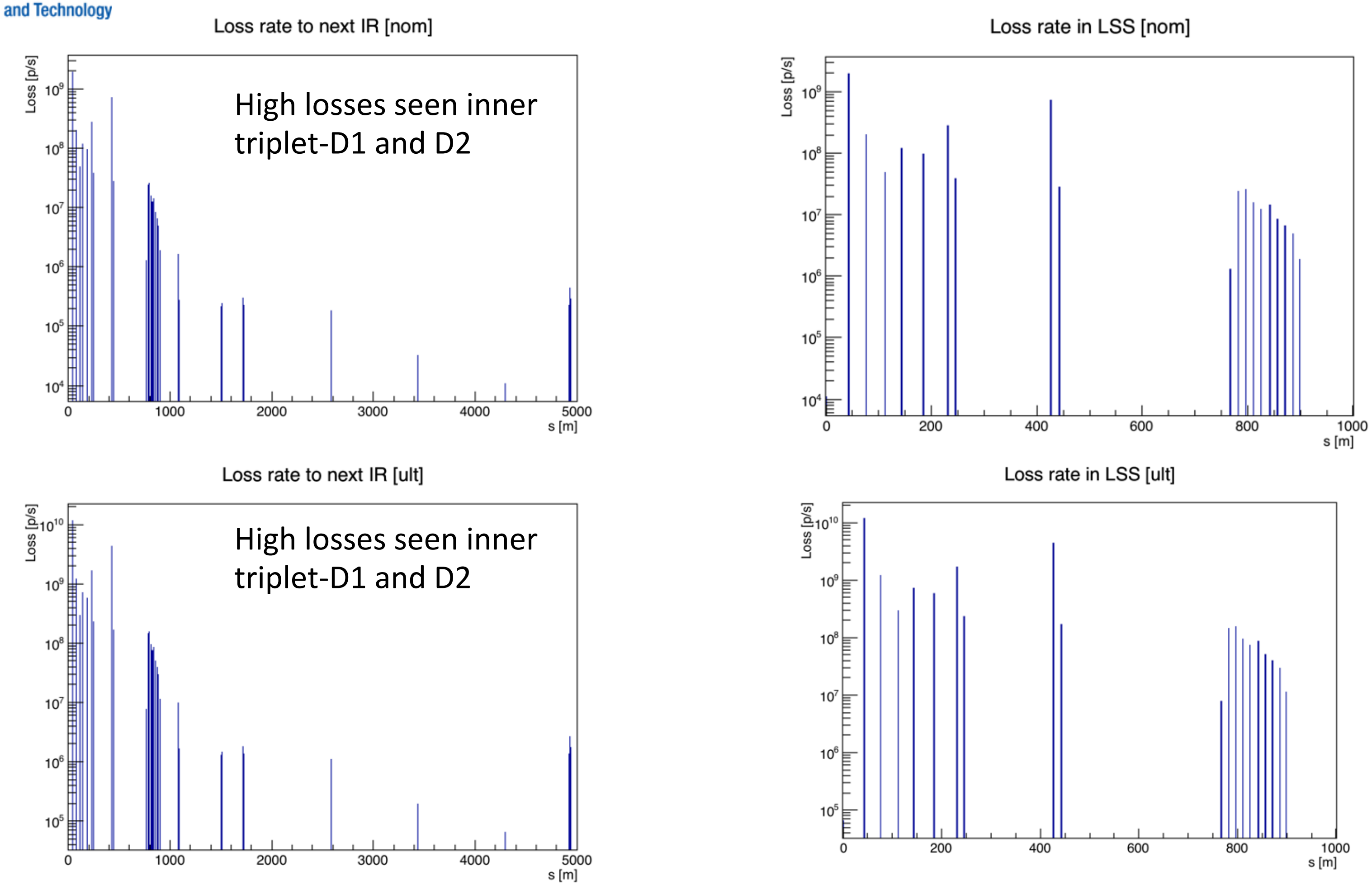
Inelastic protons : loss rates p/s

L*=45m optics with matched IRA
Beta*=0.3m, NO crossing angle
Losses assume L=5E34, sigma-ie=108mb



Note - losses are per element, i.e. the high p/s on Q1 are distributed along the magnet length

- losses consistent with estimation from FLUKA group (~5E8 p/s with crossing angle)
- losses are exceed by pion loss, which will be shielded by liner
- losses will be reduced by crossing angle and impact of detector dipole
- losses will create local showers – to be studied

Optics and lattice properties

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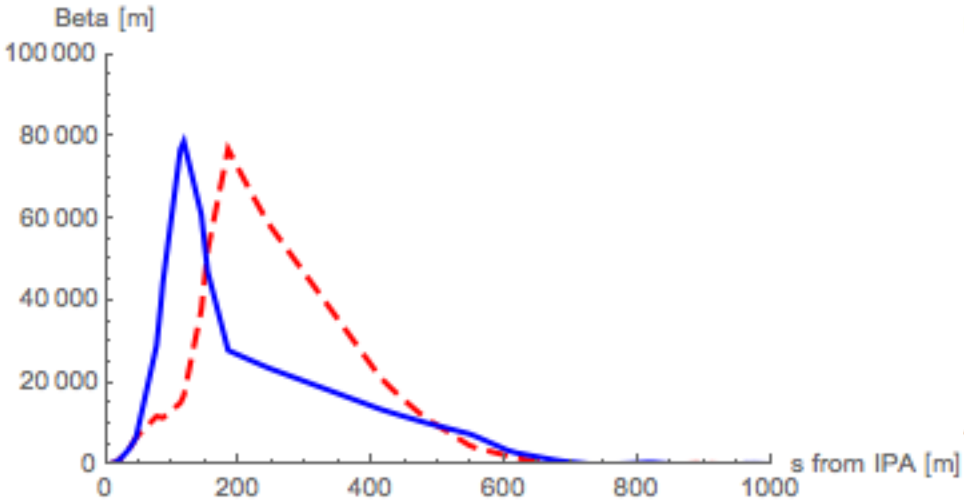

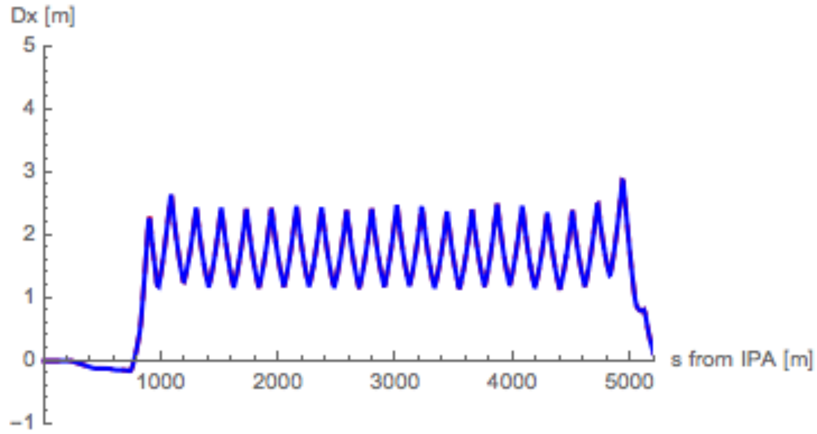

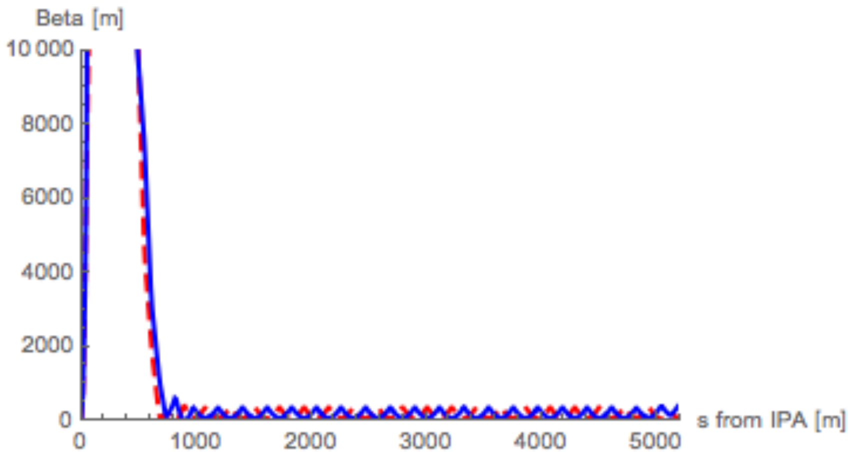

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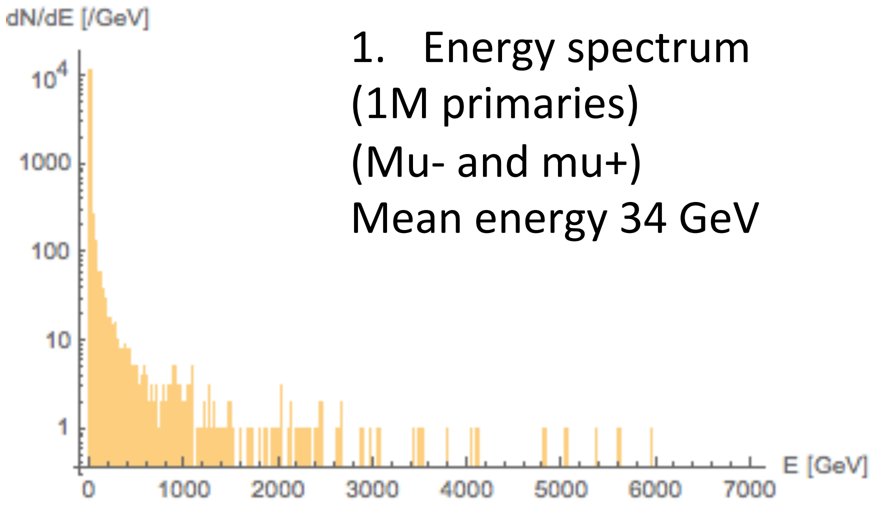
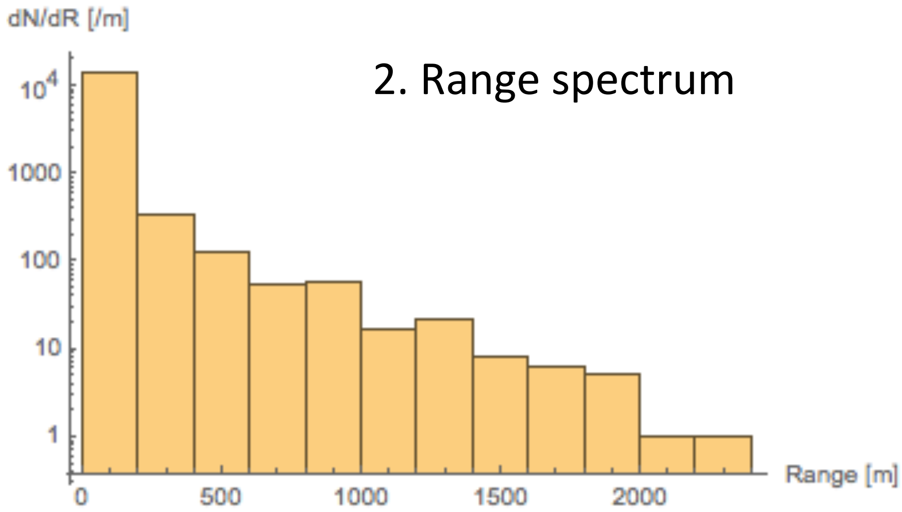
TAS at 50mm, length 750m
Beta*=0.3m
NO crossing angle (hence this dispersion)
Norm emit 2.2E-6 m

L=5E34, sigma-ie=108mb

Muon range through rock (prompt)



1. Energy spectrum
(1M primaries)
(Mu- and mu+)
Mean energy 34 GeV



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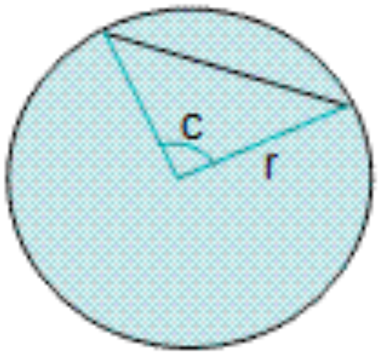

Chord=2.r.Sin(c/2)
= 5.92 km

Max energy is 7.9 TeV
Max range is 2.2 km

Do not expect many muons through rock

Needs checking with Monte Carlo to include fluctuations and straggling
-> FLUKA

Inelastic protons : On TAS

Proton loss rate on TAS [p/s] [nom] = 1958202000.
Proton power rate on TAS [W] [nom] = 61 (due to low energy protons)
Proton loss rate on TAS [p/s] [ult] = 11749212000
Proton power rate on TAS [W] [ult] = 365

Picture will be changed by detector dipole and crossing angle