How to reduce Neutrino hazard

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Neutrino Hazard

- How is it possible??
- First of all, we are dealing with low doses: Limit is given by limit to population → STAY AT 1/10 →below 0.1mSv/y

Definition	Limits
Effective dose whole body	1 mSv/an
Equivalent dose for crystalline lens	15 mSv/an
Equivalent dose for the skin	50 mSv/an

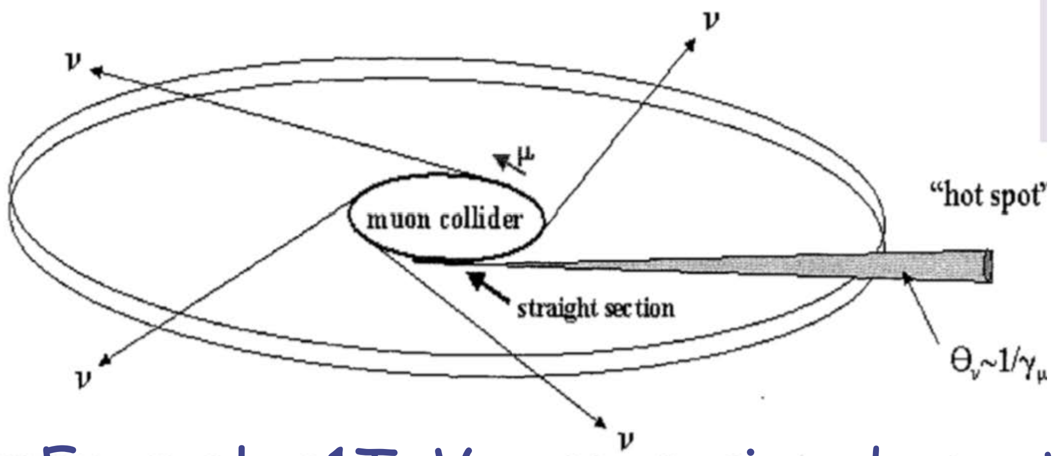
Annual exposure limits beyond medicine and natural radioactivity
These annual limits for exposure of the population are those of the public health code. These limits apply to the total effective dose or equivalent received outside of natural radioactivity and medicine, including those resulting from nuclear activities. The maximum permissible dose of 1 mSv per year represents approximately 40% of natural exposure. (For the skin, it is the average dose per cm2 of skin, regardless of the display surface).

http://www.radioactivity.eu.com/site/pages/Doses_Limits.htm

- Neutrinos from decay of (intense) muon beams are extremely well collimated: Neutrino beam size roughly given by muon $1/\gamma$. At 1 TeV, $1/\gamma \approx 10^{-4}$
- Number of muon decays ~3 10^{13} /s/beam ➔ 6$10^{20}$ /year/beam (these are not p.o.t!)
- Dose comes from energy released by neutrino interaction products
- Collider is underground: no problem until beam reaches surface

Neutrino Hazard

- Number of muon decays ~3 10^{13} /s/beam ➔ $6 10^{20}$ /year/beam (2 $10^{12}\mu$/bunch)
- (Assuming proton driver. Electron driver has 300 times lower current!)



"Ring" dose and "straight section" dose

$\frac{D}{\gamma}$ = 5m !

- Example: 1TeV muons, ring dose at D=50 km:
- $\Phi_\nu = 2 * \frac{1.2 \cdot 10^{21}}{2\pi D * \frac{D}{\gamma}} \approx 1.5 \cdot 10^{11} \nu/cm^2 y$ $\quad < \sigma_\nu > \approx 0.5 * 1000 * 10^{-38} cm^2$.

TeV

Interactions/kg/y =$\Phi \sigma N_A * 1000 \approx 400$.

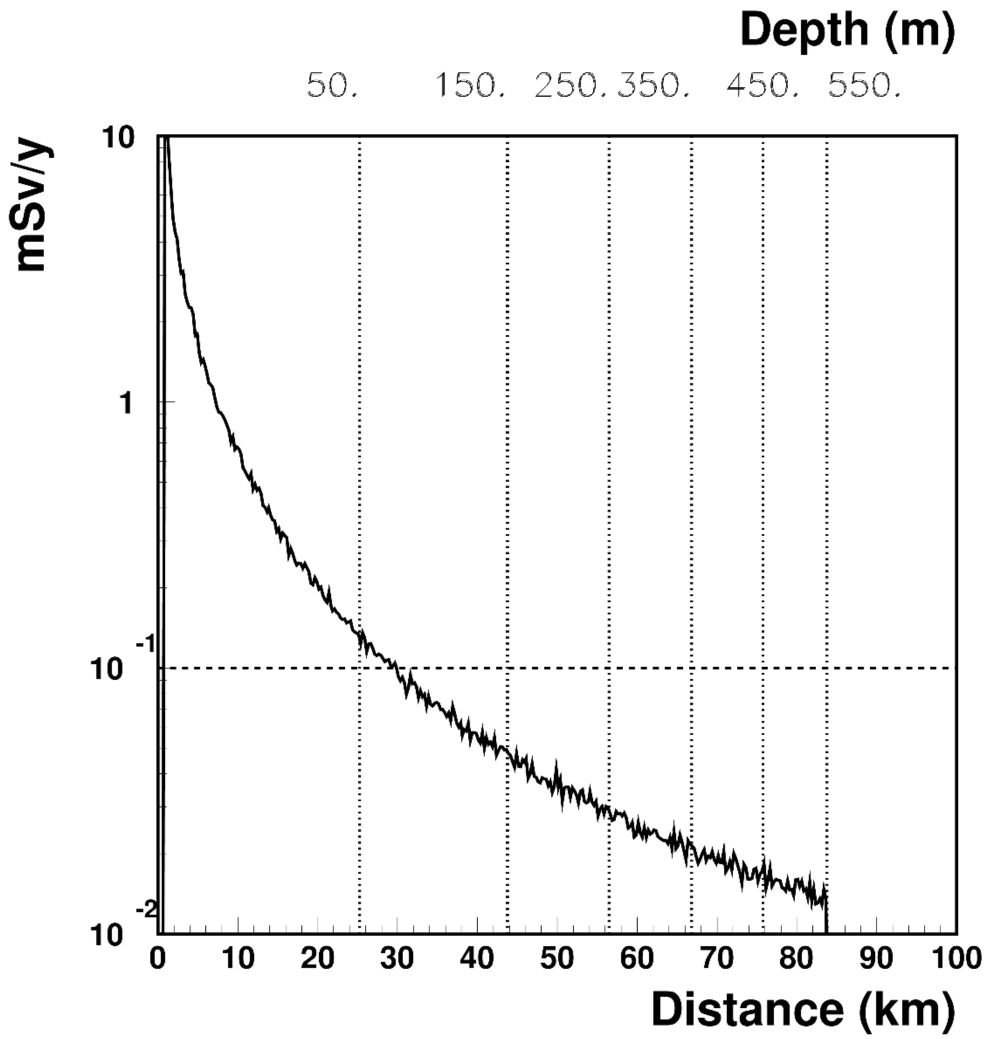
At equilibrium, deposited energy=Interactions*energy. Convert TeV to J:

Gy/y $= 4 \cdot 10^2 * 1.6 10^{-7} \approx 6 \cdot 10^{-5}$. ➔ approx 0.06 mSv/y

Neutrino Hazard

- Importance of radiation hazard due to highly collimated intense neutrino beams known since many years
- Already studied in analytical way and with MARS simulations: see for instance
  - Nikolai Mokhov & Andreas Van Ginneken *Neutrino Radiation at Muon Colliders and Storage Rings*, J. of Nuclear Science and Technology, 37:sup1, (2000) 172
  - R. B. Palmer *Muon Colliders* RAST 7 (2014) 137
  - B. J. King *Neutrino Radiation Challenges and Proposed Solutions for Many-TeV Muon Colliders* arXiv:hep-ex/0005006 (2000)

Let's start at 1+1 TeV : ring dose



plot stops at 550m==position of ring in MC geo

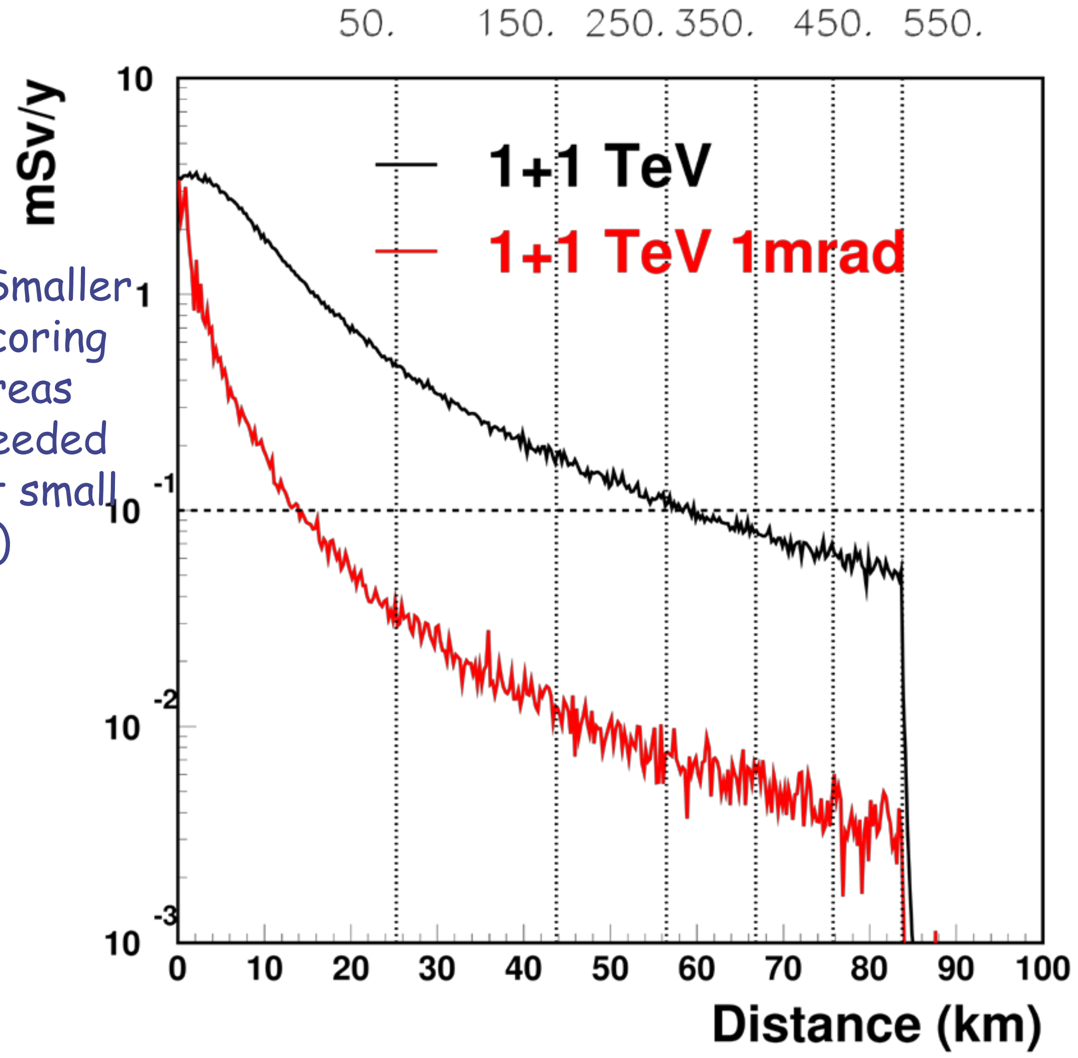
FLUKA results for ambient dose equivalent (H*(10)) as a function of distance from ring, or (top axis), depth of the ring. Averaged over 1m in the vertical plane. Assuming **1.2 10^{21}** decays/y (2.10^{12} μ/bunch, 15 Hz, 200 days)

Muon beams with Zero emittance

Warning here : distance/depth relation from spherical earth surface, no mountains

No problem !!

Let's start at 1+1 TeV : straight sections



(Smaller scoring areas needed at small D)

Same as prevous slide, for a straight section

whose length is 1/10000 of the ring circumference. Which is small, means **that optics must be well studied**.

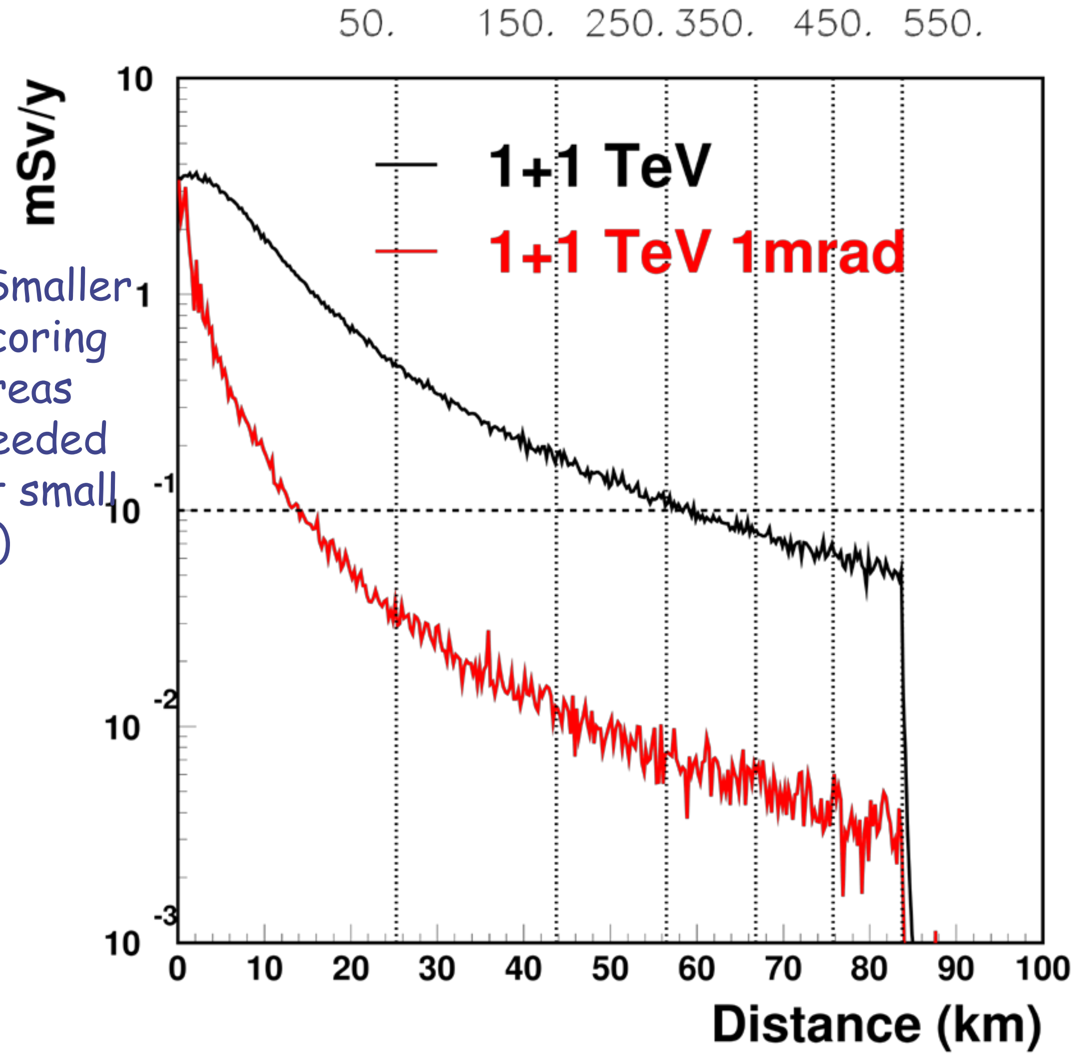
Red: added divergence=1mrad (10 times $1/\gamma$)

Also here no big problem, need care

Need to design new ring with suitable orientations

Let's start at 1+1 TeV : interaction point

(Smaller scoring areas needed at small D)



Plot is the same. But the interaction point will not fit in ~1m..

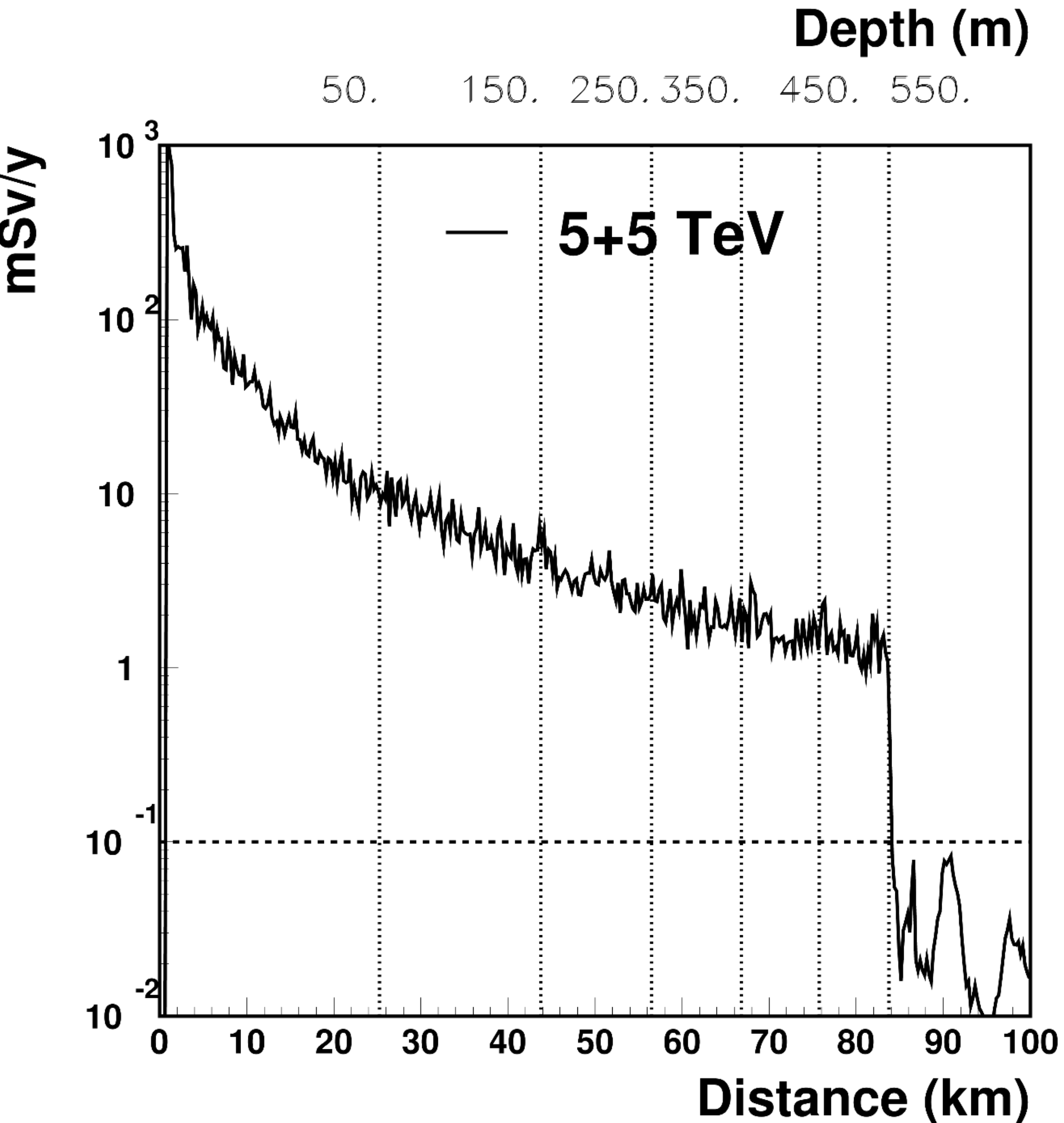
Dose scales linearly with section length (fraction of the beam that decays there)

Emittance can help, especially in vertical direction (Earth's curvature)

Orography can help: from preliminary investigations based on LHC straight sections (Youri,last workshop) , exit points as far as >200 km exist.

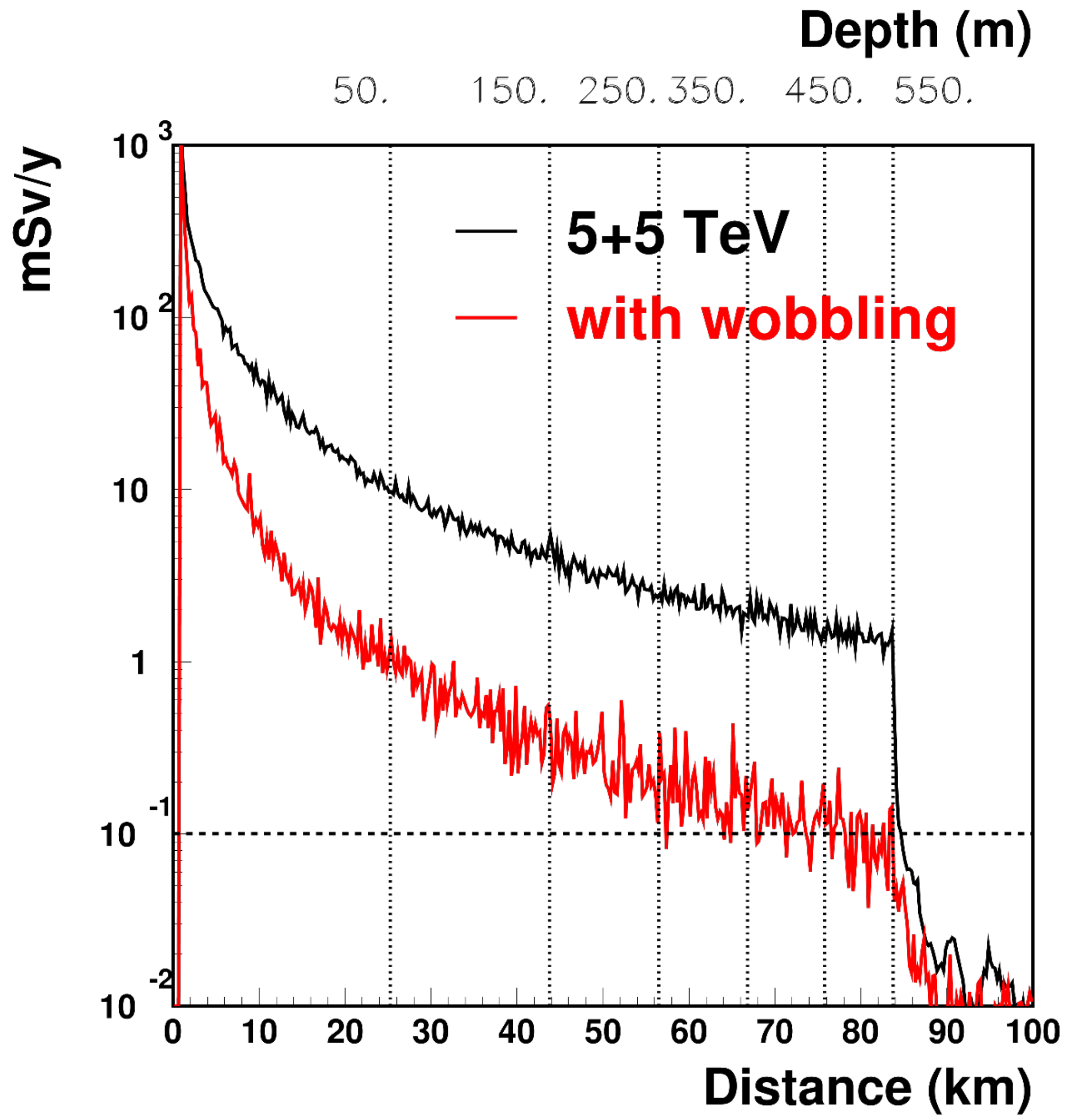
And, on one hot spot, we can build a super neutrino detector…

Can we go up?

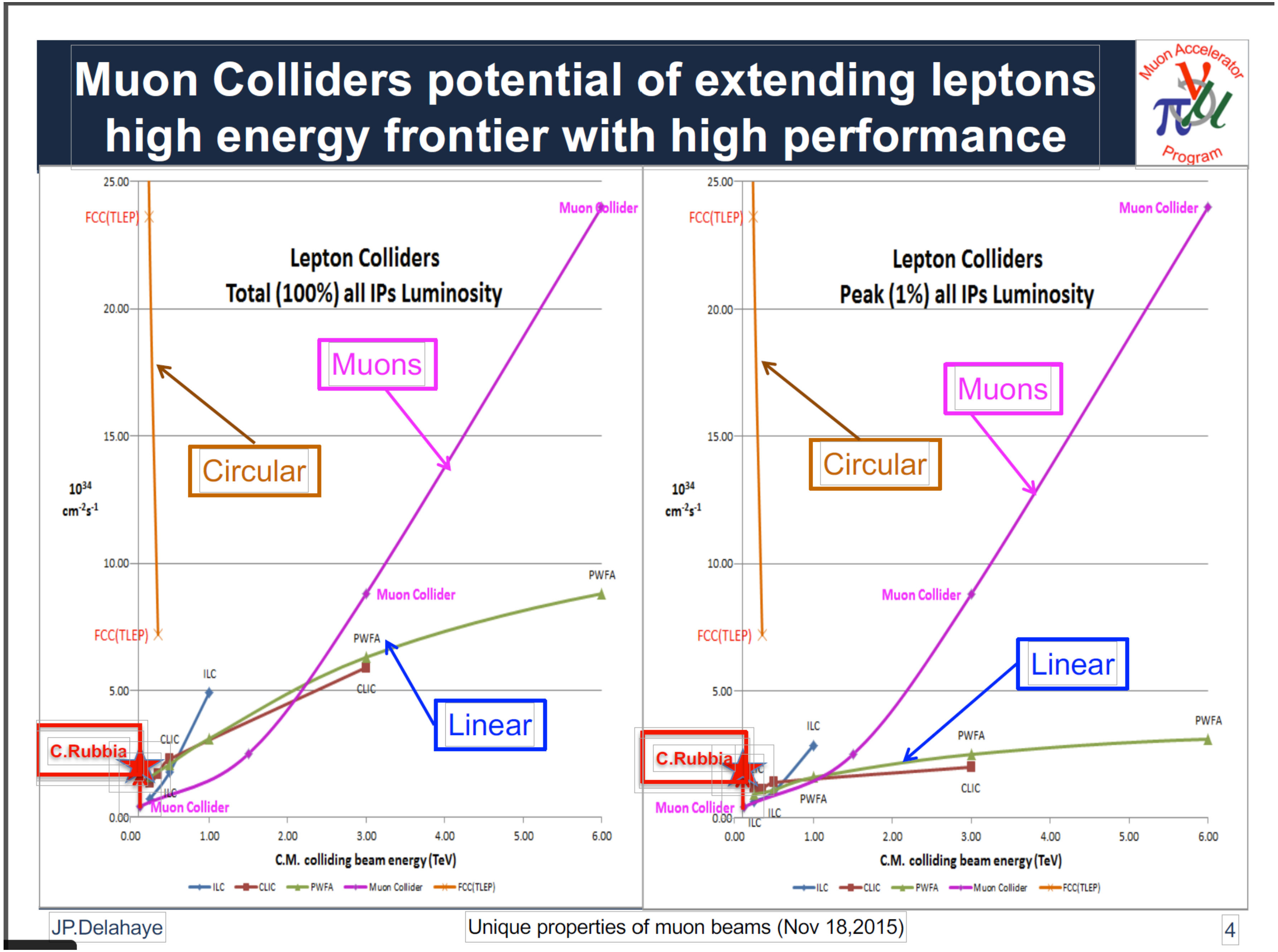


- Roughly, ring dose scales with E^3 : from $1/\gamma$, from available energy, from neutrino cross section (this last no longer linear above fev TeV)
- Indeed, preliminary results at 5+5 TeV indicate slower growth
- Here: 5+5 TeV, ring dose

Can we go up? Ring solutions



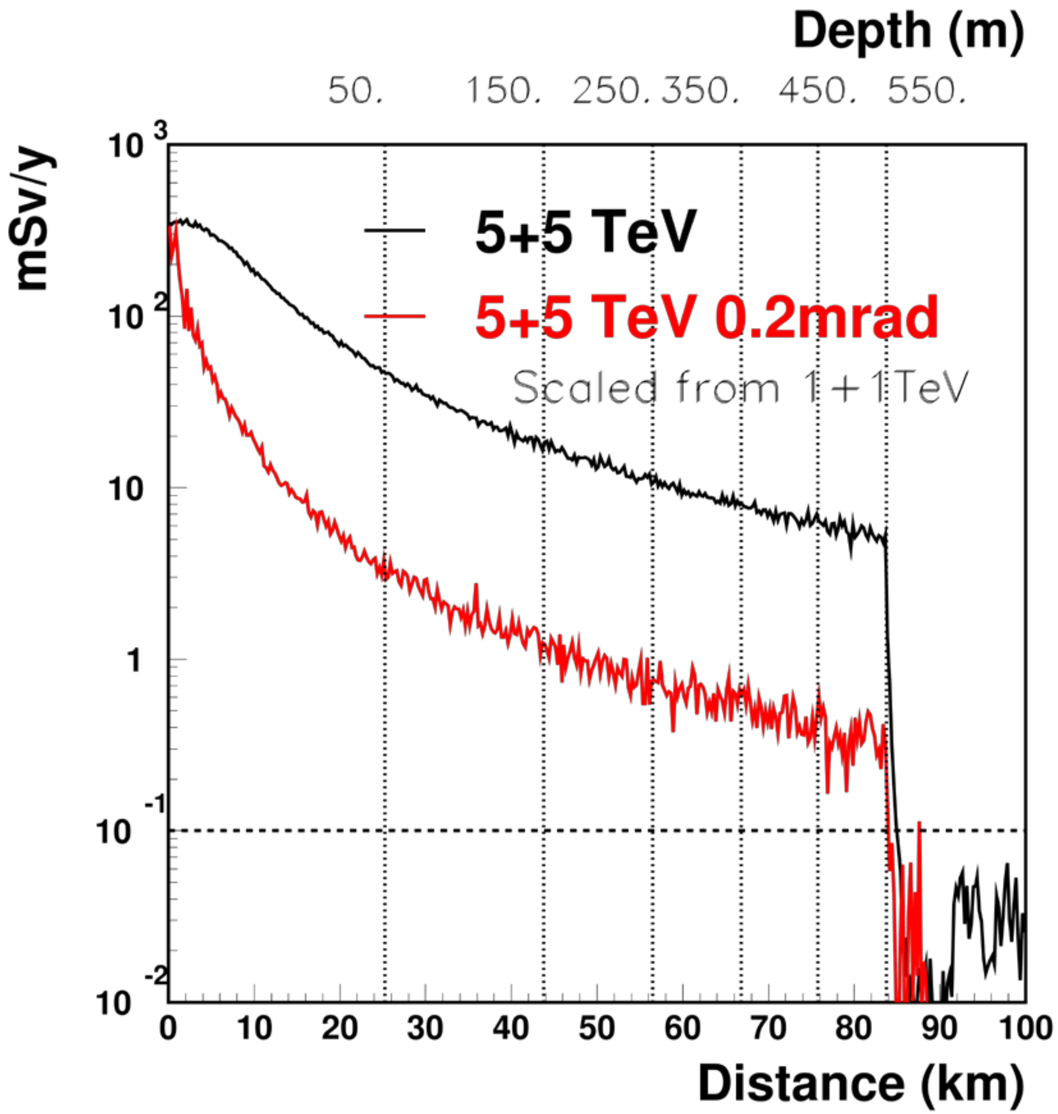
- Wobbling: Vertical periodic deflection of muon beams in the ring (achievable with small tilt of the magnets). Here example with a 200μrad kick: almost OK
- Periodic "bumps", slowly changing during the year
- Emittance: possibility 20 times more vertical than horizontal
- Luminosity?? Do we need the same beam intensity at all energies?



Luminosity

- MuonC design luminosities FAR EXCEED the ones considered for electron-positron colliders.
- Thus there could be room to sacrifice some of the MC luminosity to help deal with the radiation issue
- As already considered by the MAP collaboration

Can we go up? Straight sections



- Again: try to keep them as small as possible
- Play with emittance
- Reduce intensity to acceptable level
- Play with exit points
- For one of the exit points ..build a superb neutrino detector

Conclusions

- Neutrino hazard exists, should and can be managed
- With ease at 1+1 TeV
- With more thinking at higher energies
- All this for a proton driver.
- Positron driver would reduce the issue by ~factor 300 (scaling with beam current)

wikipedia

Average annual human exposure to ionizing radiation in millisieverts (mSv) per year

Radiation source	World[2]	US[3]	Japan[4]	Remark
Inhalation of air	1.26	2.28	0.40	mainly from radon, depends on indoor accumulation
Ingestion of food & water	0.29	0.28	0.40	(K-40, C-14, etc.)
Terrestrial radiation from ground	0.48	0.21	0.40	depends on soil and building material
Cosmic radiation from space	0.39	0.33	0.30	depends on altitude
sub total (natural)	2.40	3.10	1.50	sizeable population groups receive 10–20 mSv
Medical	0.60	3.00	2.30	worldwide figure excludes radiotherapy; US figure is mostly CT scans and nuclear medicine.
Consumer items	–	0.13		cigarettes, air travel, building materials, etc.
Atmospheric nuclear testing	0.005	–	0.01	peak of 0.11 mSv in 1963 and declining since; higher near sites
Occupational exposure	0.005	0.005	0.01	worldwide average to workers only is 0.7 mSv, mostly due to radon in mines;[2] US is mostly due to medical and aviation workers.[3]
Chernobyl accident	0.002	–	0.01	peak of 0.04 mSv in 1986 and declining since; higher near site
Nuclear fuel cycle	0.0002		0.001	up to 0.02 mSv near sites; excludes occupational exposure
Other	–	0.003		Industrial, security, medical, educational, and research
sub total (artificial)	0.61	3.14	2.33	
Total	3.01	6.24	3.83	**millisieverts per year**