Phase space analysis of secondary beams generated in hadron-photon collisions

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High Brightness Beams, Havana, Cuba

Conceptual study to generate
TeV low emittance muon beams
in highly Lorentz boosted frame
by colliding TeV protons (LHC/FCC) and
high brilliance keV photon beams (FEL)

OUTLINE

- Introduction to Hadron-Photon Collider

- Kinematics of relavant reactions and description of event-generator code to simulate the secondary beams

- Phase space and luminosity analysis in various scenarios

Advantages of HPC scheme:

INTRODUCTION

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· TeV protons keV photons: very asymmetrical collision

$$\gamma_{CM} = \frac{E_{tot}^{lab}}{E_{CM}} \simeq \frac{E_p + h\nu}{\sqrt{4E_p h\nu + M_p^2}}$$

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· energy of photons in protons rest frame
much higher than in laboratory $\rightarrow$
maximum efficiency above threshold
even at keV photon energies

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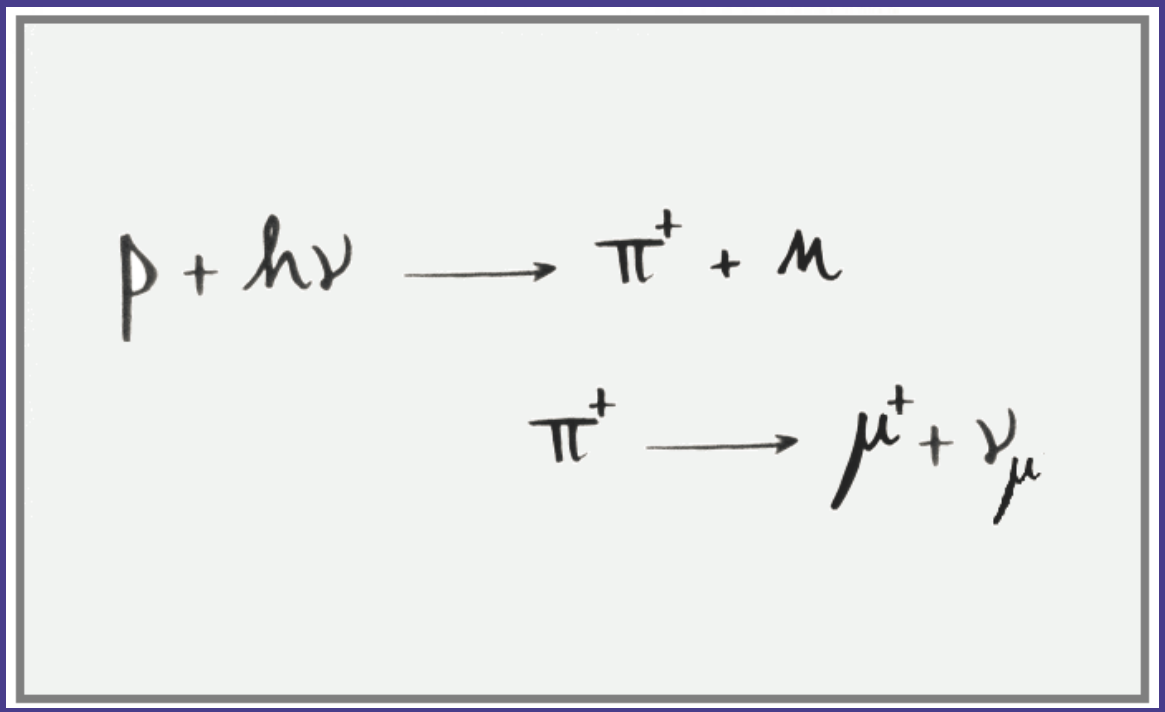
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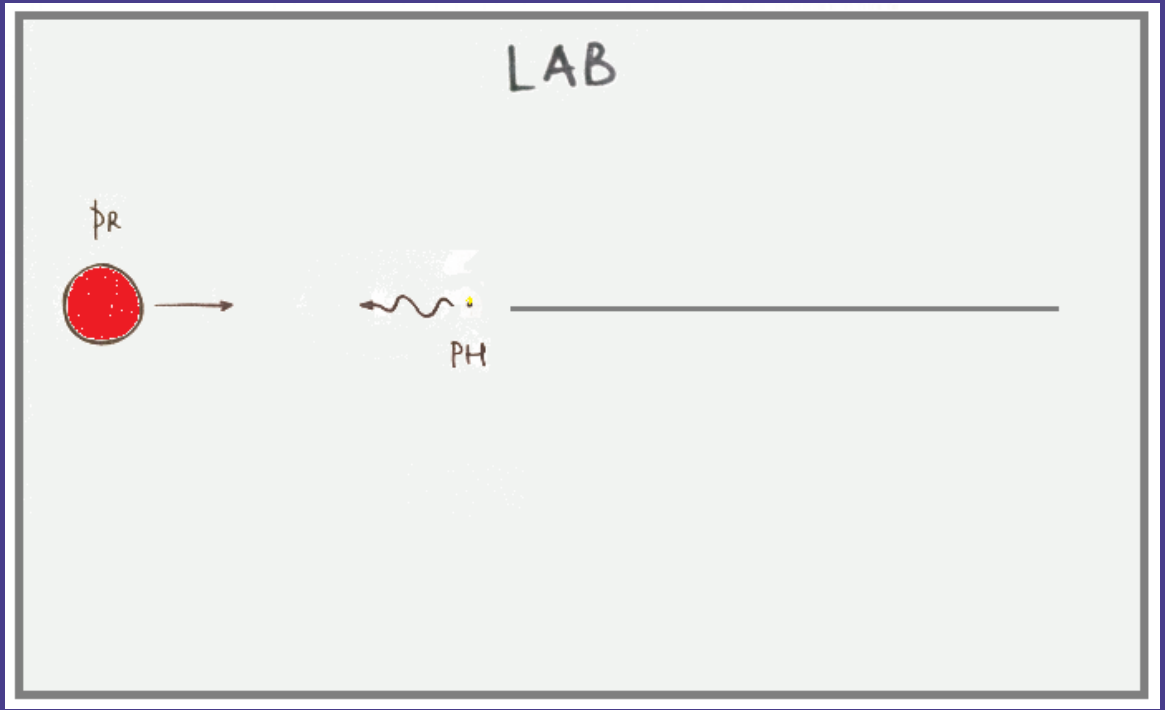
$p + h\nu \rightarrow \pi^+ + n$ AND $\pi^+ \rightarrow \mu^+ + \nu_\mu$



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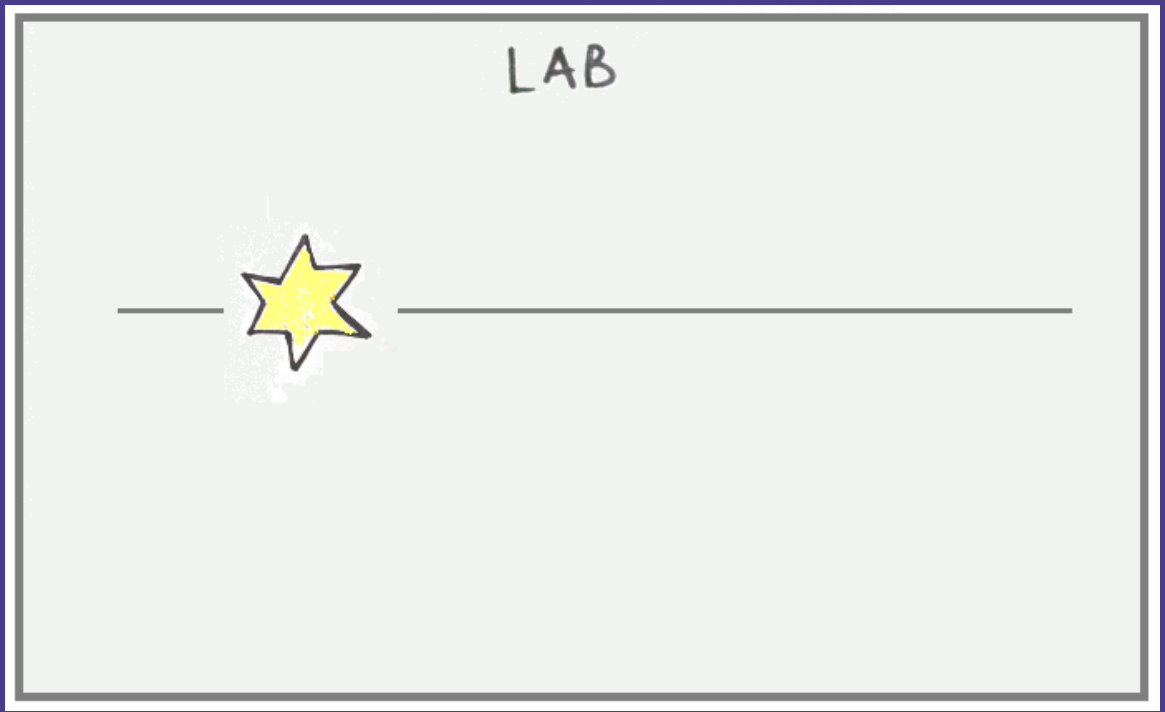

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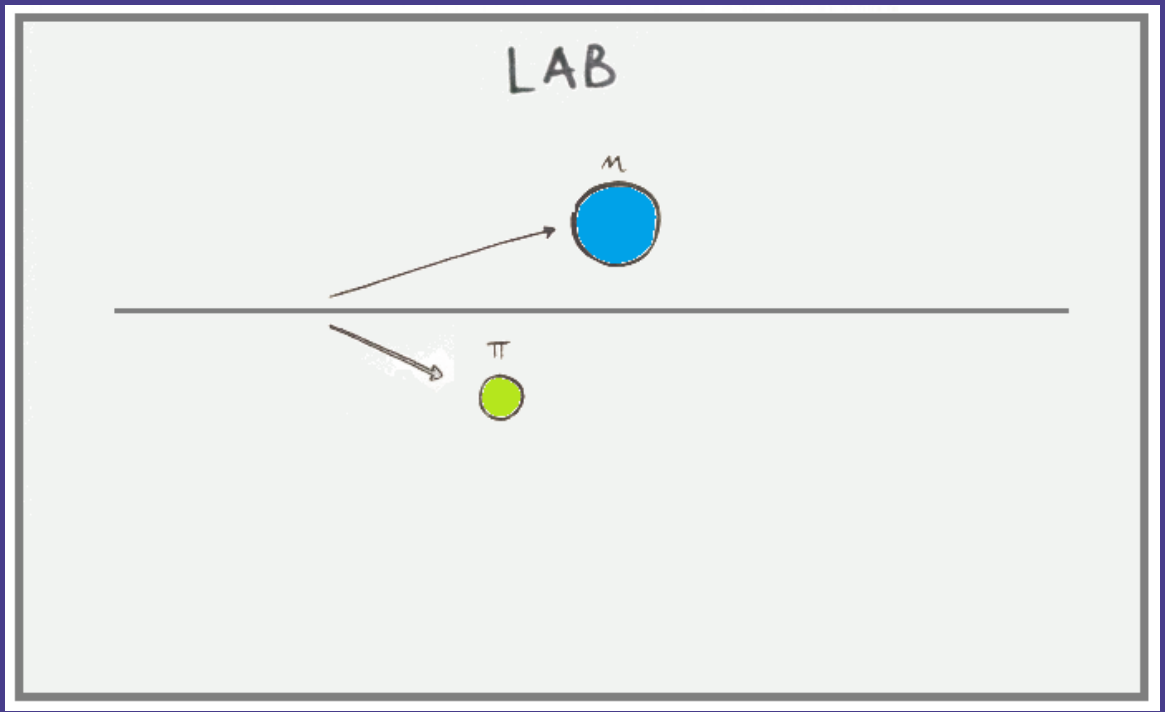

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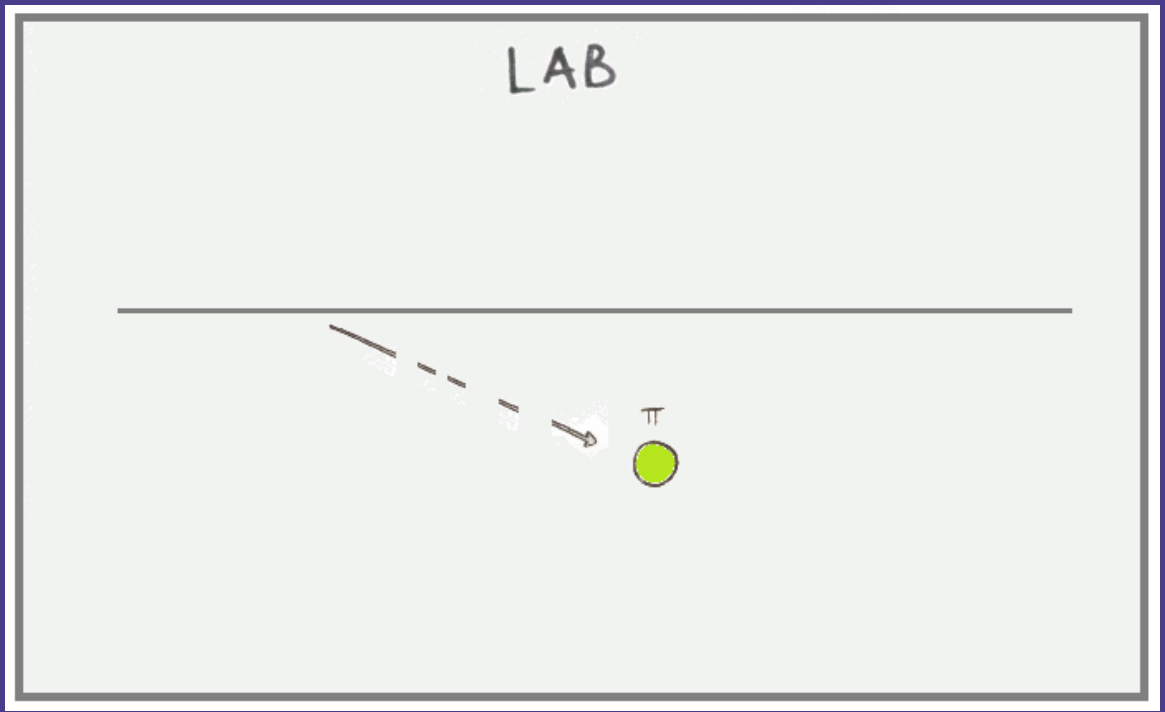

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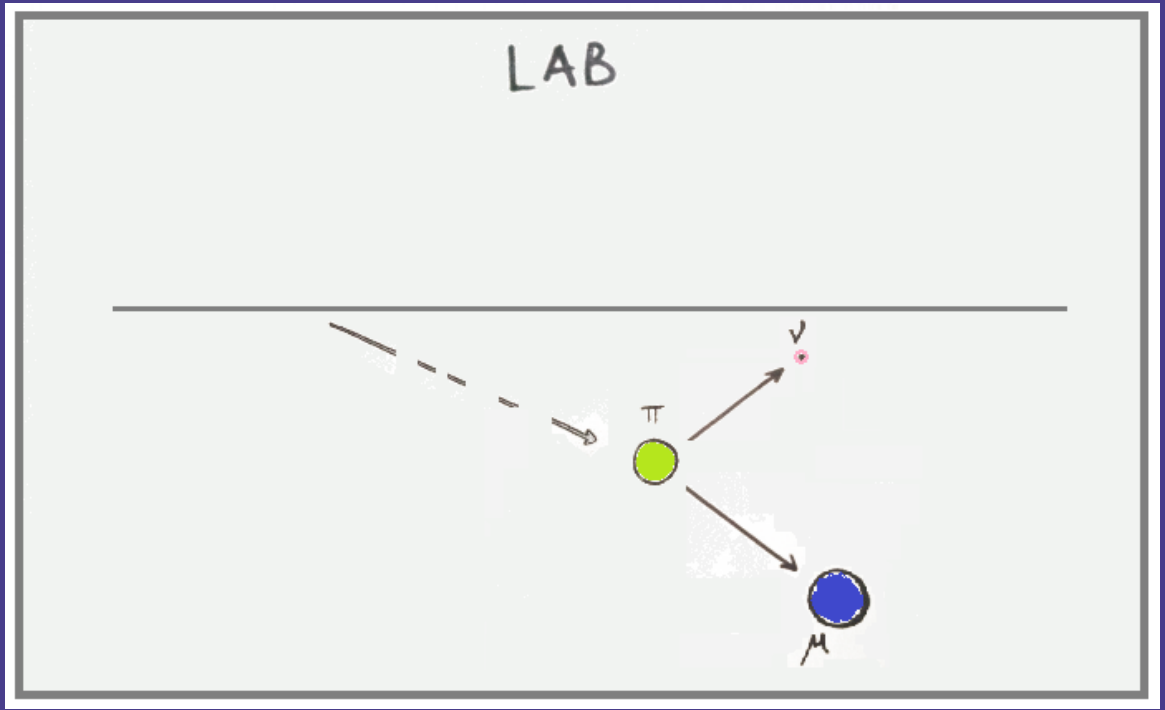

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PR source	E_p [TeV]	N_p	σ_0 [μm]	PH source	$h\nu$ [keV]	N_{ph}
LHC	7	$2 \cdot 10^{11}$	7	FEL	20	10^{13}
FCC	50	10^{11}	1.6	FEL	3	10^{14}

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why FEL?

HIGH BRIGHTNESS
HIGH TUNABILITY

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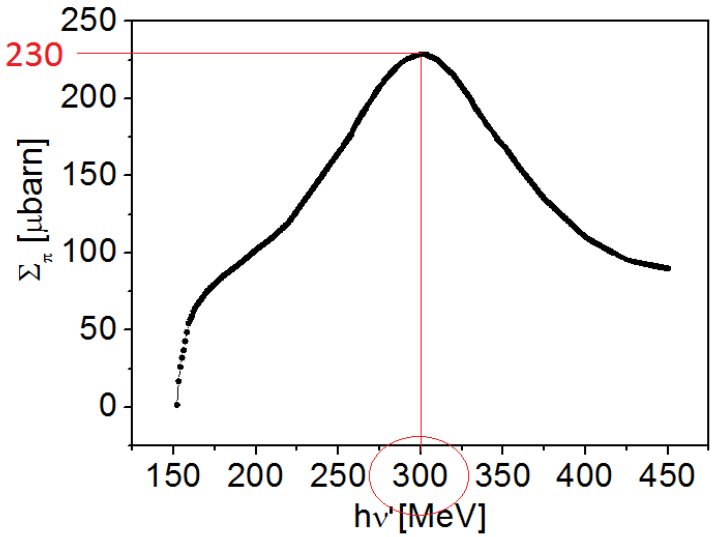
hν chosen to maximize Lorentz invariant total cross section of pion photo-production on protons



J. Phys. G: Nucl. Part. Phys. 18 (1992) 449–497.
Dieter Drechsel and Lothar Tiator

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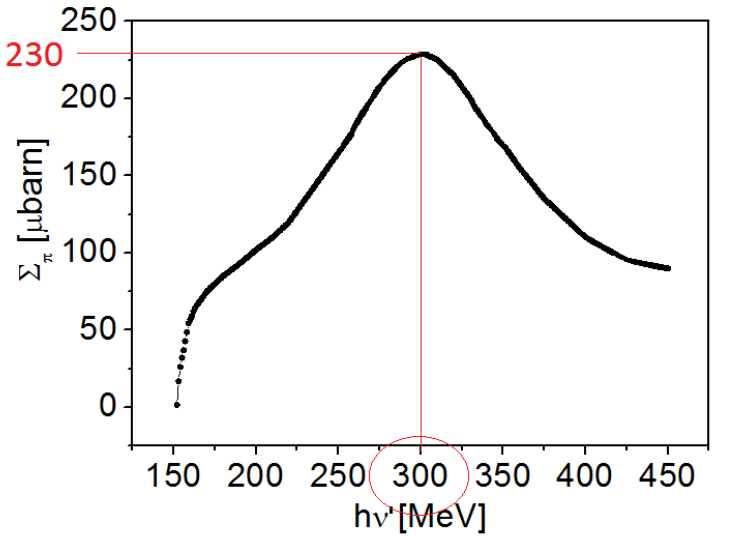
photon energy seen by the proton:

$$h\nu' = h\nu\gamma(1 - \underline{\beta} \cdot \underline{e}_k)$$

- $h\nu$: photon energy in lab
- γ: proton gamma
- $\underline{\beta}$: proton velocity
- $\underline{e}_k$: photon direction



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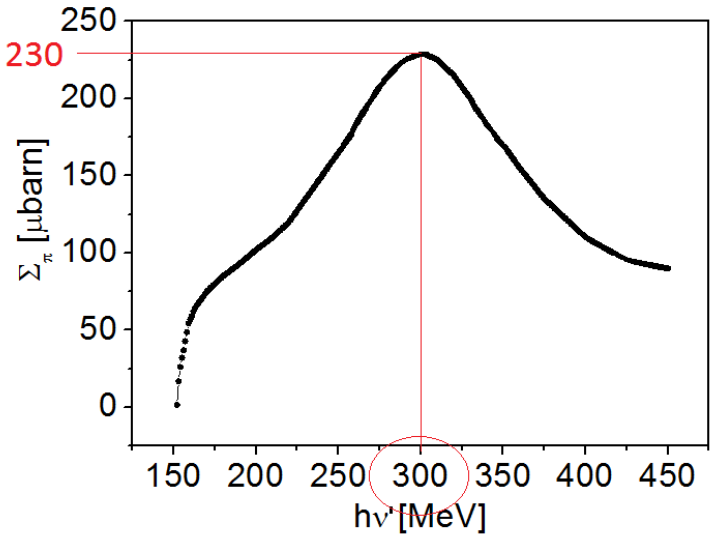
photon energy seen by the proton:

$$h\nu' \simeq 2h\nu\gamma$$

for head-on collision
of ultra-relativistic
proton vs keV photon



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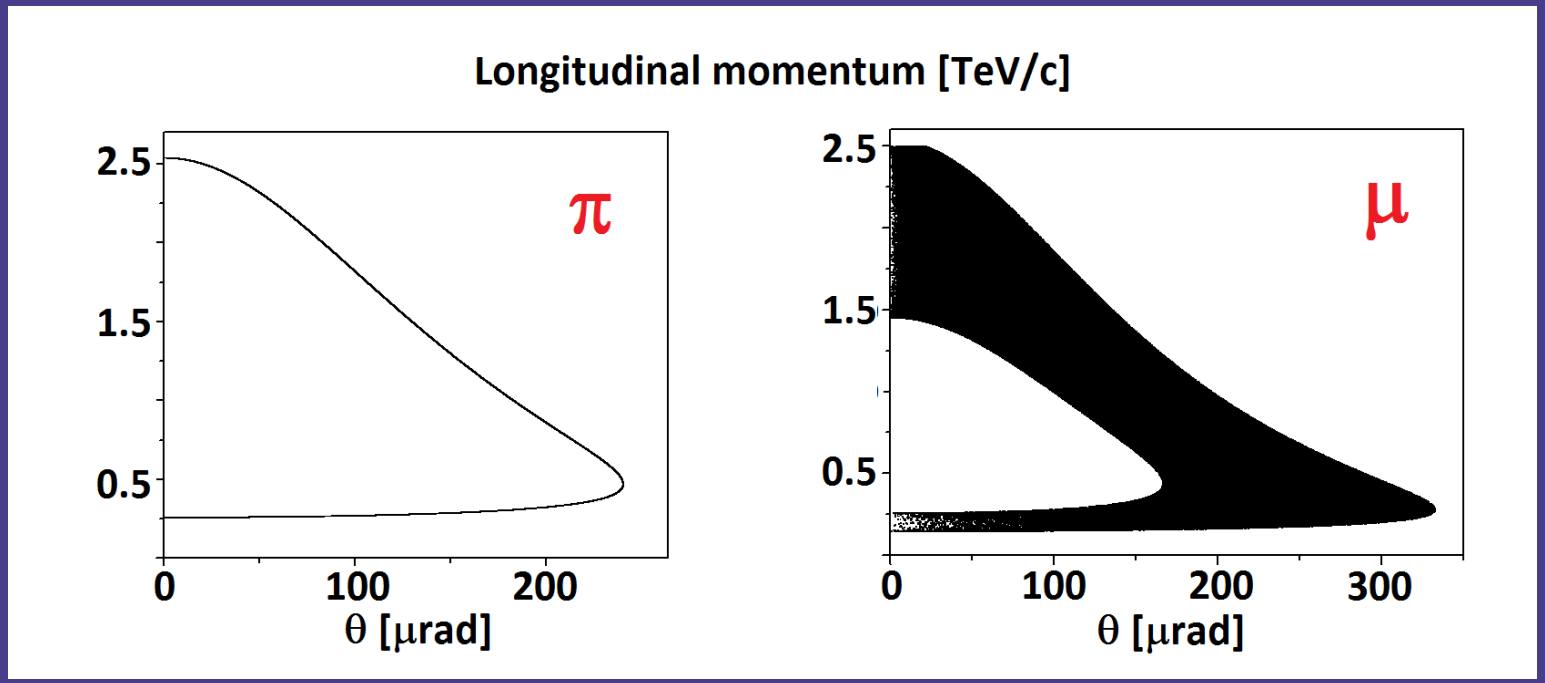
Event-generator code: results for $E_p = 7$ TeV and $h\nu = 20$ keV, no proton beam emittance.



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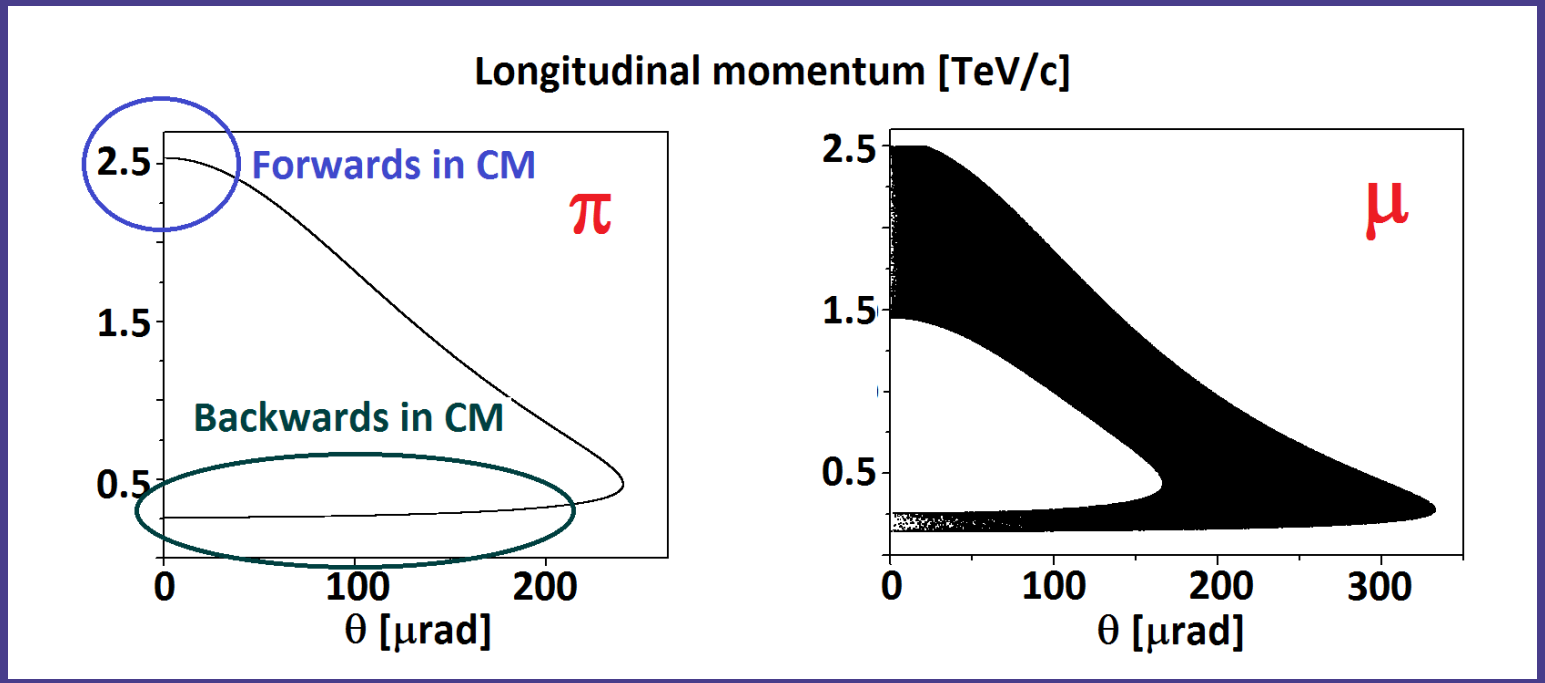

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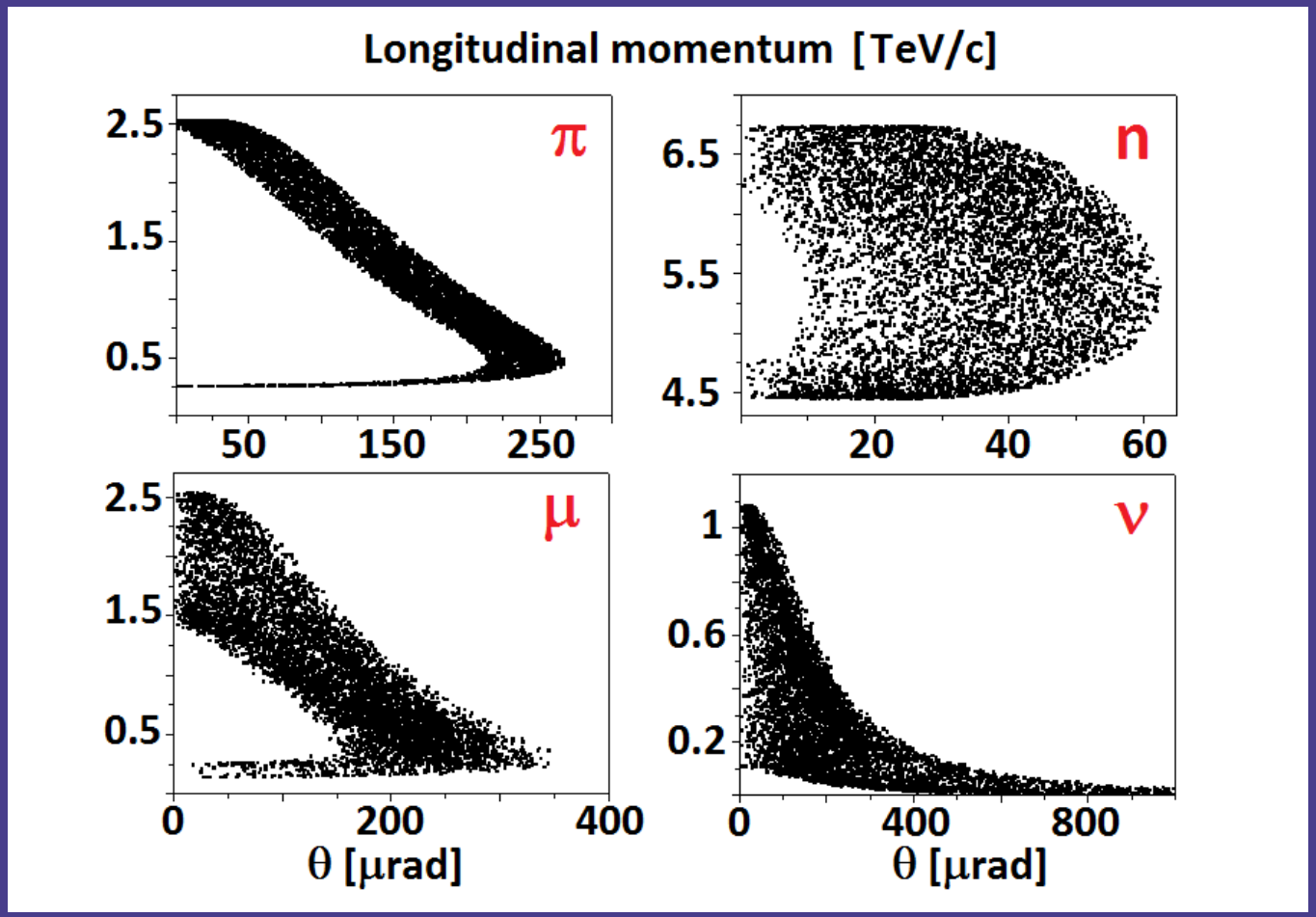
With proton emittance: increase of angular spread and dispersion in momentum for all particles



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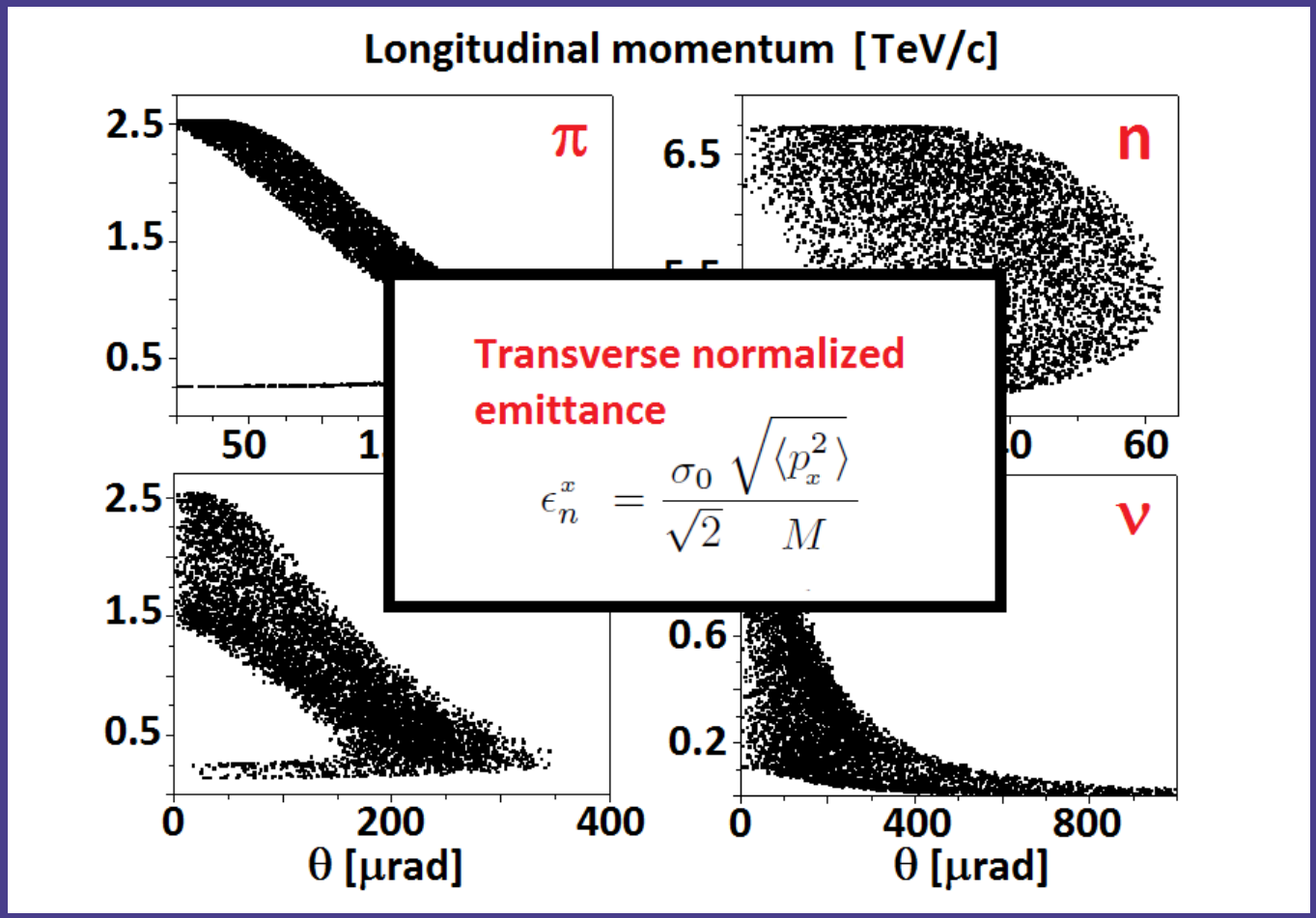

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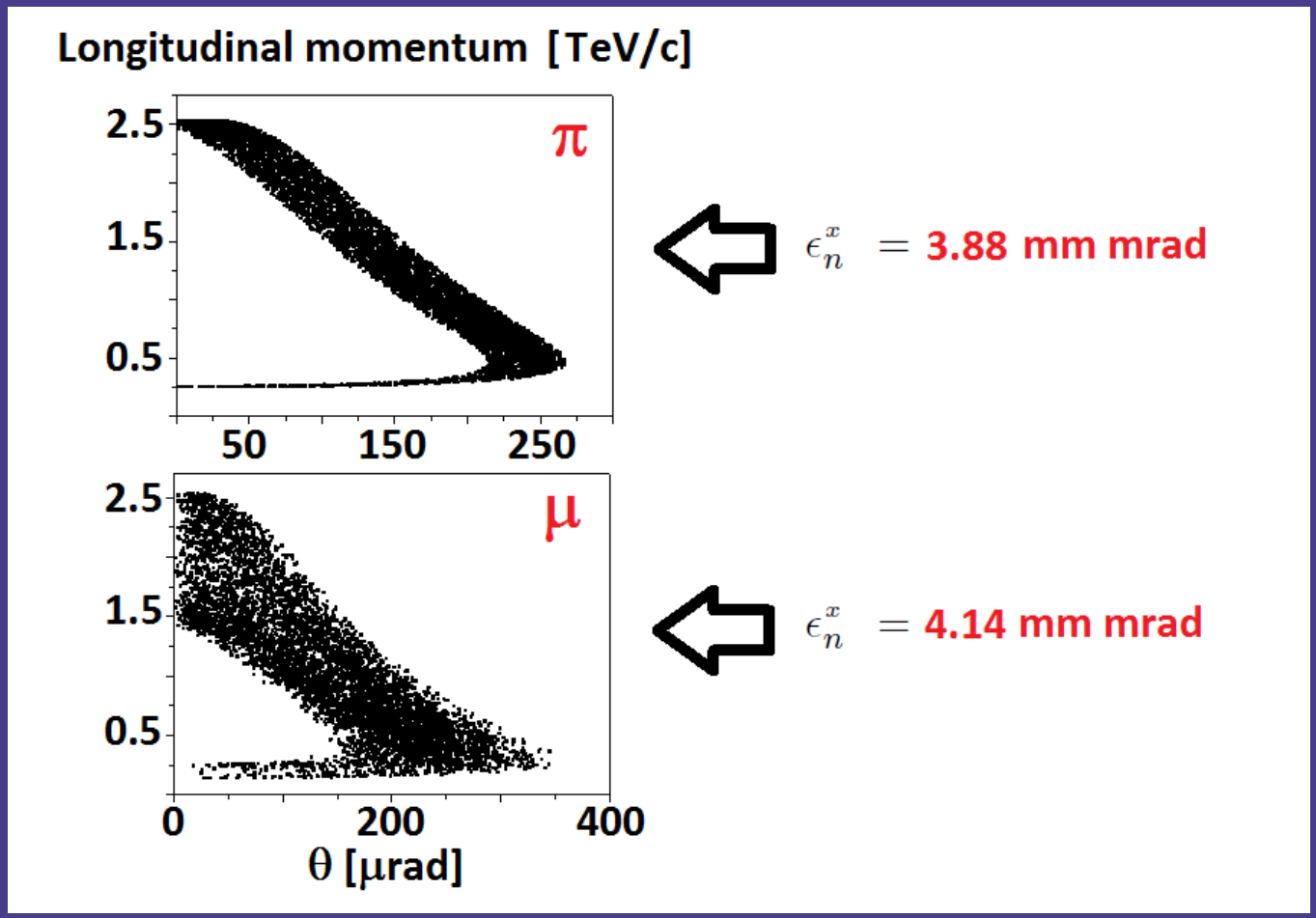
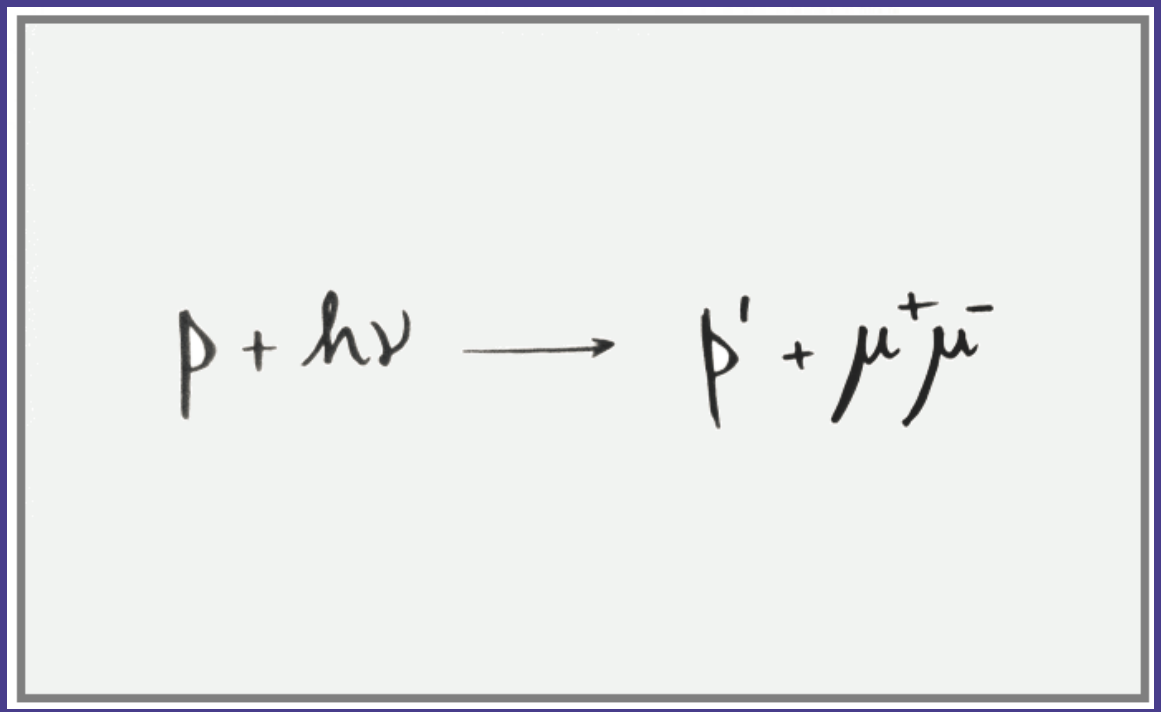
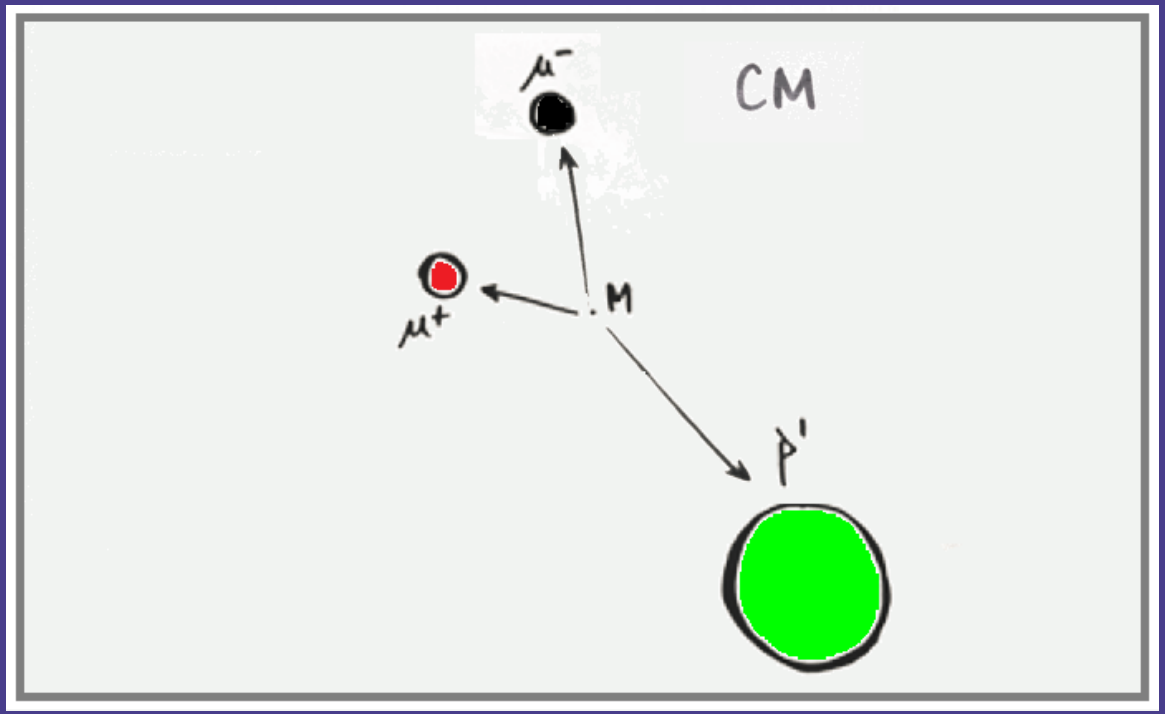



p + hν ⟶ p' + μ⁺μ⁻

$$p + h\nu \rightarrow p' + \mu^- \mu^+$$



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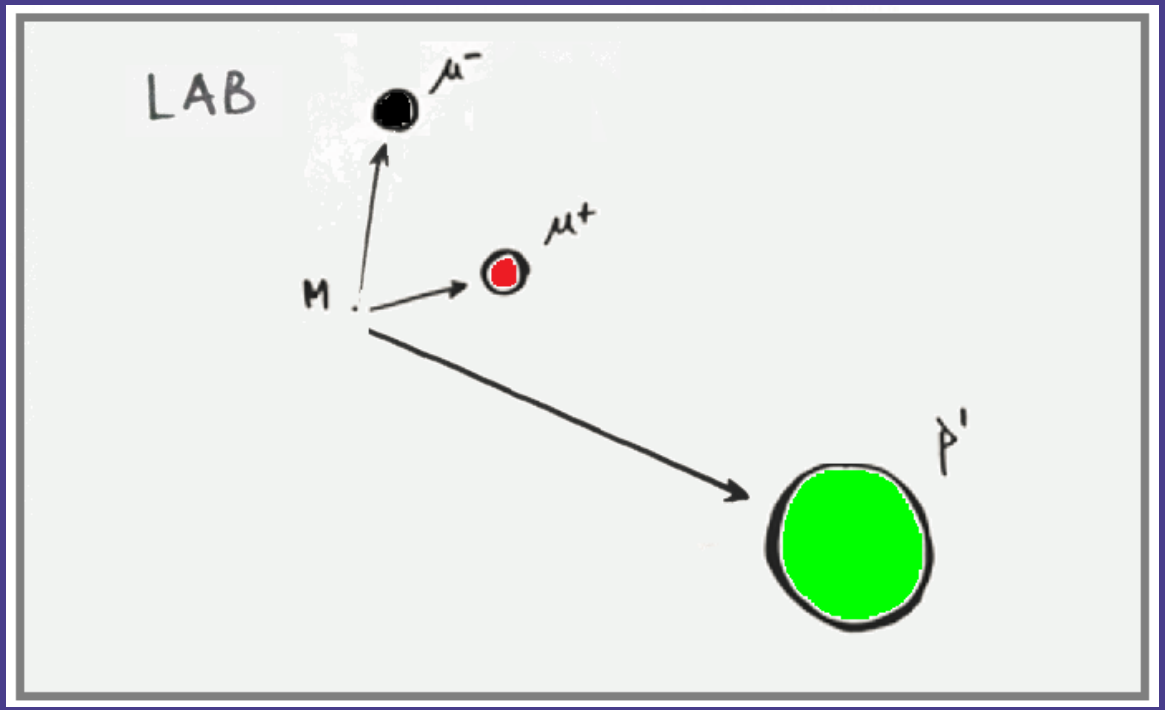

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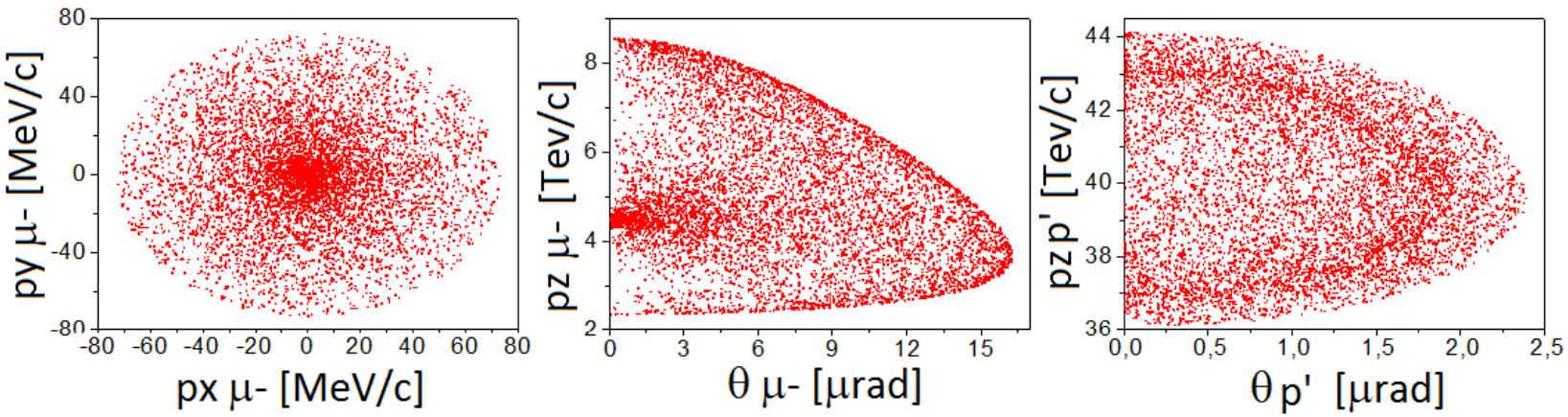
E_p =50 TeV hν=2.5 KeV



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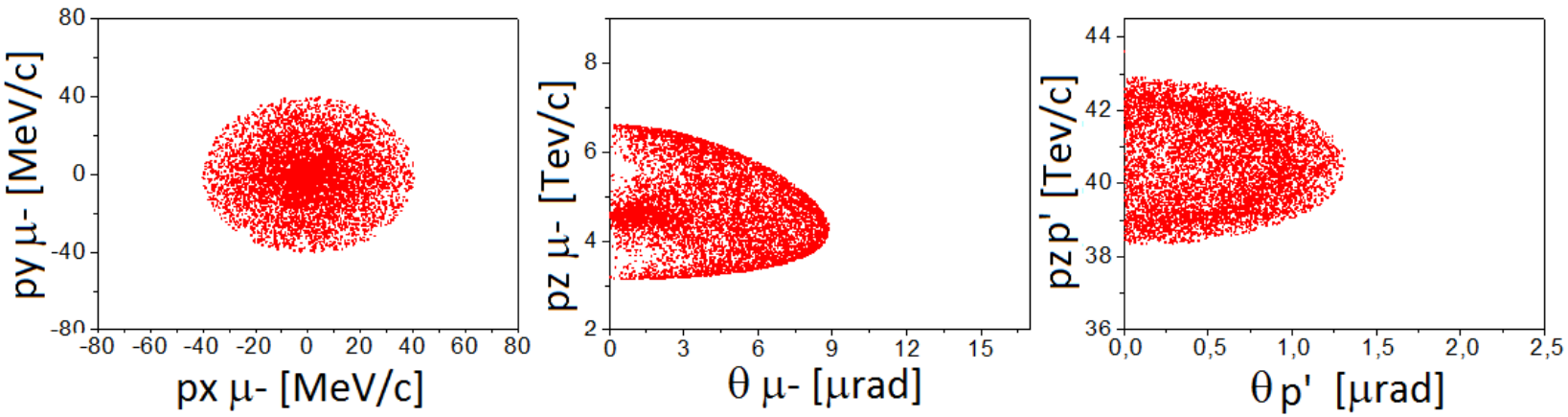
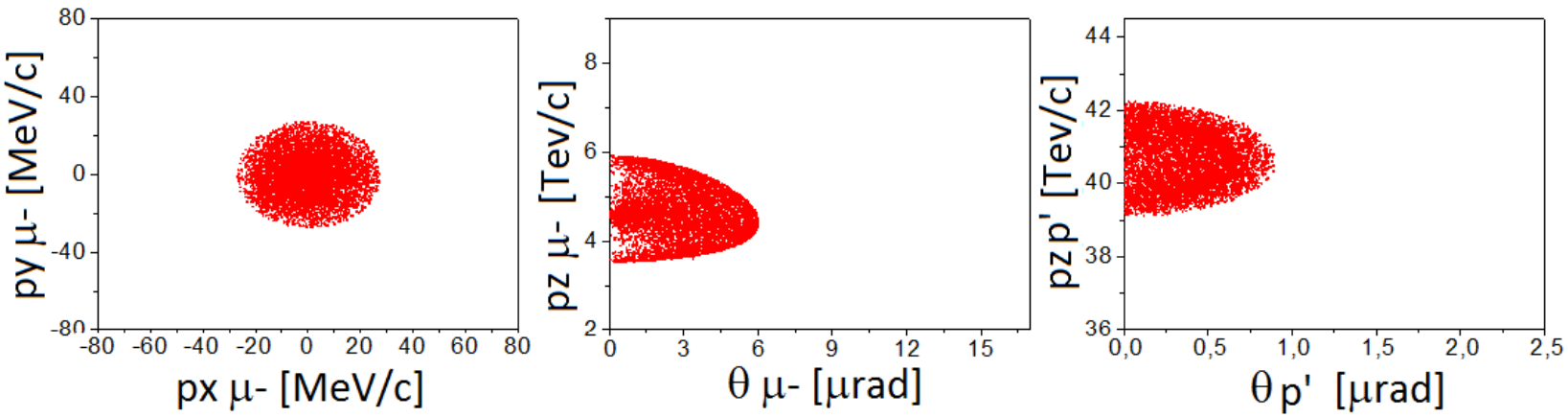
E_p =50 TeV hν=2.3 KeV



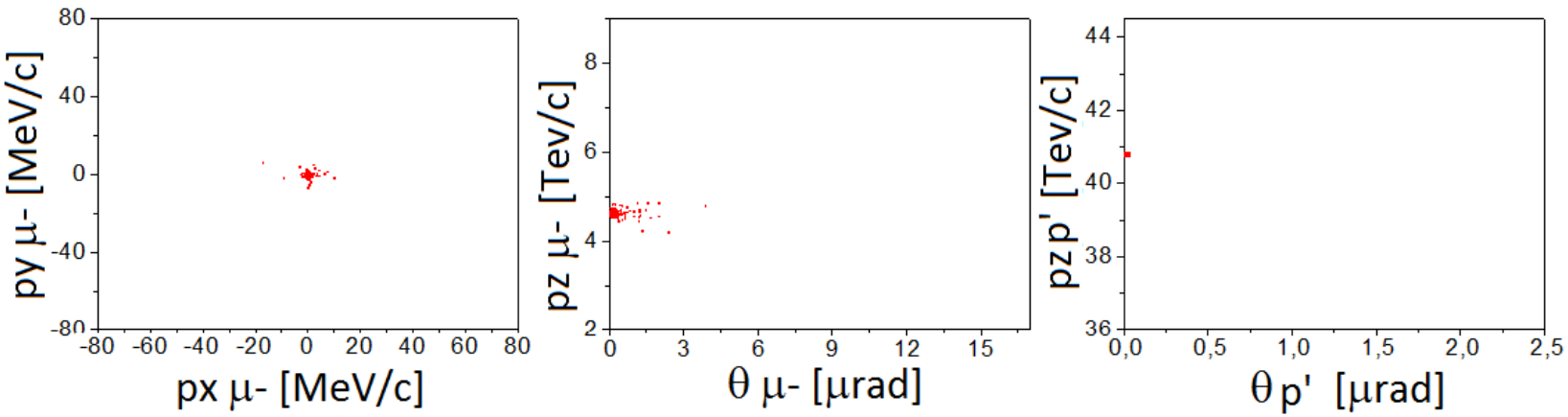
$$p + h\nu \rightarrow p' + \mu^- \mu^+$$

E_p =50 TeV hν=2.25 KeV



$$p + h\nu \rightarrow p' + \mu^- \mu^+$$

E_p =50 TeV hν=2.2053 KeV



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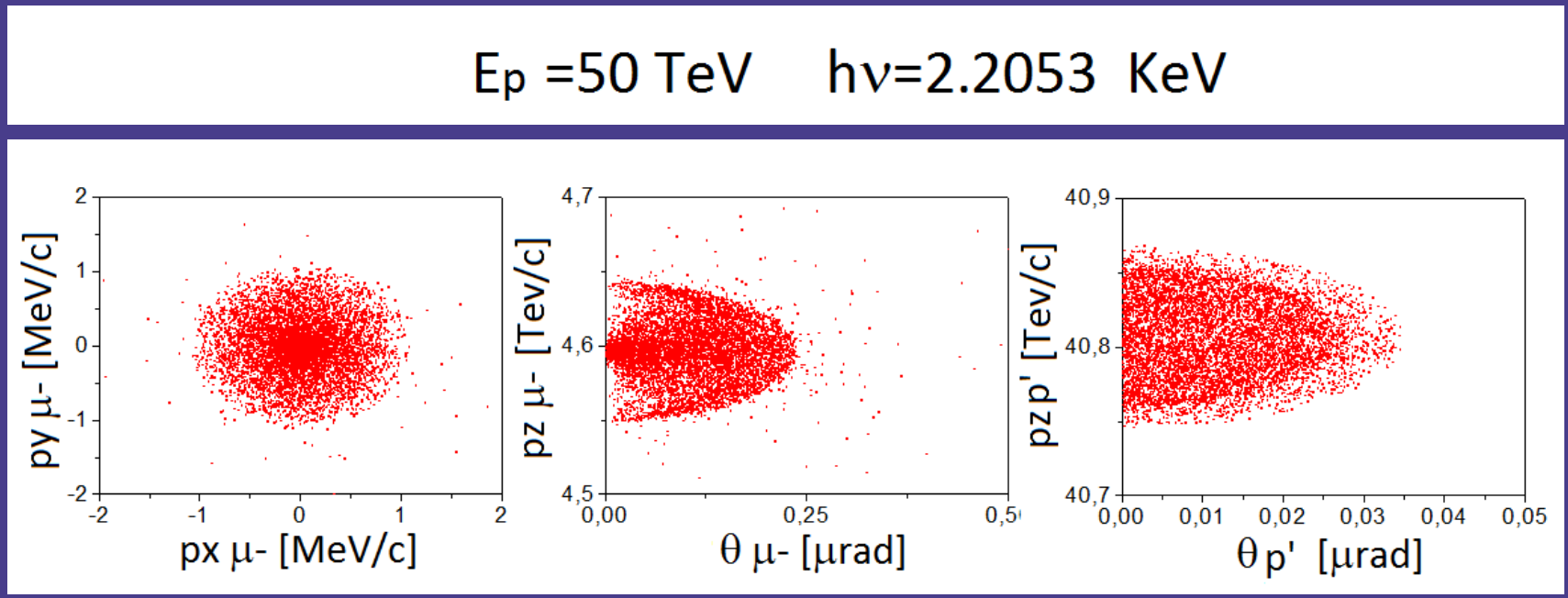


Threshold photon energy in proton rest frame for pair production:

$$h\nu'^{th} = \frac{(2M_\mu + M_p)^2 - M_p^2}{2M_p} = 235\text{MeV}$$

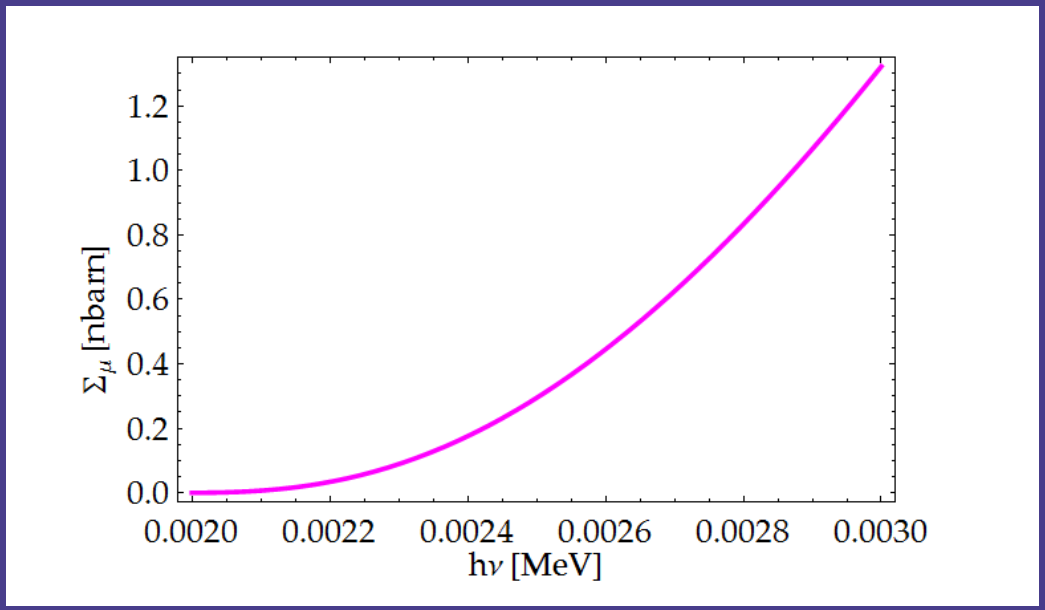
Ex: $E_p = 50$ TeV $\Rightarrow h\nu = h\nu'^{th}/(2\gamma) = 2.2053$ keV

$p + h\nu \rightarrow p' + \mu^- \mu^+$

Total cross section: Racah formula if close to muon pair threshold

$$\sigma \simeq \alpha Z^2 r_0^2 \frac{2\pi}{3} \left(\frac{k-2}{k}\right)^3 \left(1 + \frac{\epsilon}{2}\right)$$

where $k = h\nu'/M_\mu$, $\epsilon = (k-2)/(k+2)$,
$r_0 = r_e(M_e/M_\mu) = 2.82 \cdot 10^{-15}(0.511/105.65)$ m, $\alpha = 1/137$ and $Z = 1$.



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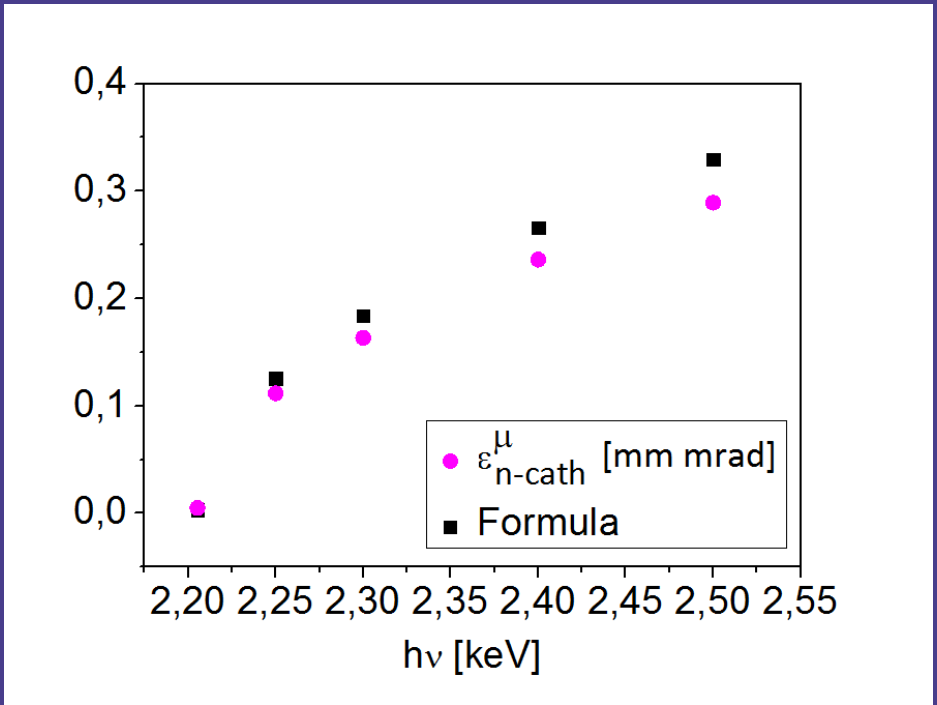
$E_p = 50$ TeV, no proton beam emittance, $\Delta_p = 4h\nu\gamma/M_p$

$$\epsilon^{\mu}_{n-cath} \leq \frac{1}{\sqrt{3}} \frac{\sigma_0}{\sqrt{2}} \sqrt{\frac{M_p^2}{4M_\mu^2} \left(\sqrt{1+\Delta_p} - 1\right)^2 - 1}$$



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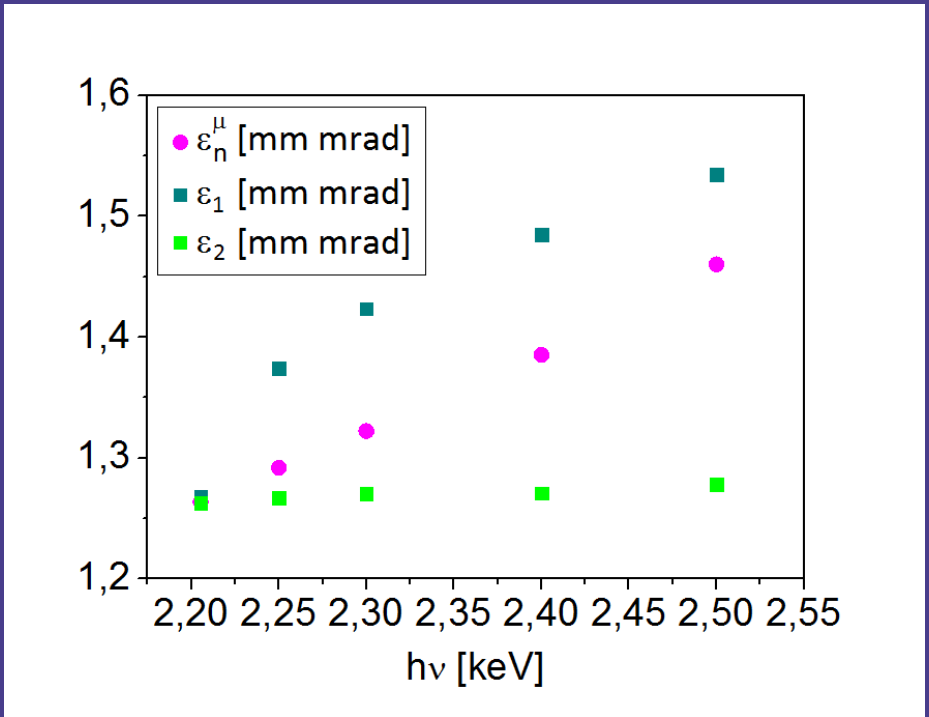
$E_p = 50$ TeV, with incoming proton beam emittance

$$\epsilon_2 = \epsilon^{\mu}_{n-cath} + \epsilon^{p'}_{n} < \epsilon^{\mu}_{n} < \epsilon_1 = \sqrt{(\epsilon^{\mu}_{n-cath})^2 + (\epsilon^{p'}_{n})^2}$$



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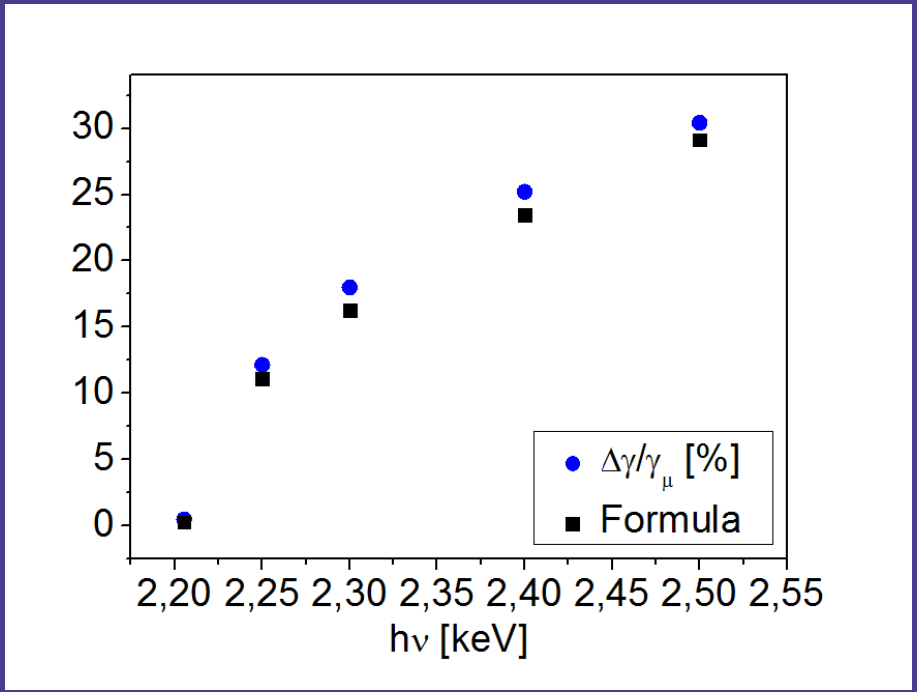
$$\frac{\Delta\gamma}{\gamma}_{\mu} = \frac{1}{\sqrt{3}} \sqrt{\frac{M_p^2}{4M_\mu^2} \left(\sqrt{1+\Delta_p} - 1\right)^2 - 1}$$



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50	1.43 (π^{th})	$1.86 \cdot 10^9$	0	$4.5 \cdot 10^{11}$
50	2.2053 (μ^{th})	$3.72 \cdot 10^9$	$1.25 \cdot 10^3$	$5 \cdot 10^{11}$
50	2.5	$4.65 \cdot 10^9$	$9.3 \cdot 10^3$	$5.1 \cdot 10^{11}$
50	3	$6.5 \cdot 10^9$	$4 \cdot 10^4$	$5.4 \cdot 10^{11}$

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· Direct muon pair production
using lead ions: gain factor ~ 670

Thank you for your attention!

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- J. W. Motz, H. A. Olsen and H. W. Koch, *Pair production by photons*, Rev. Mod. Phys. 41 (1969)
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