DARKNESS

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Darkness = propety of gravitational vacuum, with scale (in empty space) $\sim 10^{-13}$ cm.

Its relevance depends upon choice of GR descriptive language.

Metric (EH) Gravity

$$\mathcal{L} = M_P^2 \sqrt{g}\, R(g) \qquad g = \left(\begin{array}{cccc} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{array}\right)$$

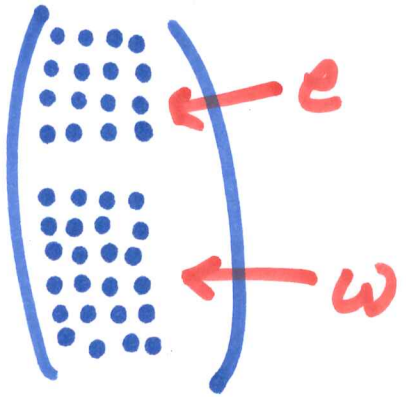
First order (gauge) gravity (EC):

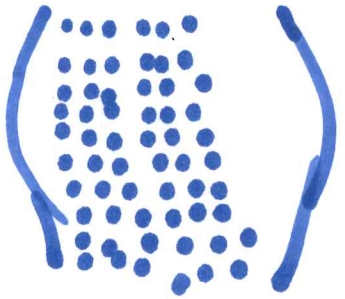
$$\mathcal{L} = M_P^2\, e\, e\, R \qquad e = \left(\begin{array}{cccc} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{array}\right)$$

$$R = \left(\begin{array}{cccc} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{array}\right) \qquad A = \left(\begin{array}{cccc} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{array}\right) = \omega$$

Mac-Dowell Mansouri Extension of EC:

$$\mathcal{L} = \frac{M_{Pl}^2}{\Lambda} F F$$

$A =$ 

$F =$ 

Decomposition of MM to EC:

$$\mathcal{L} = \frac{M_{Pl}^2}{\Lambda}\left[RR + \Lambda eeR + \Lambda^2 eeee \right]$$

Important Features of MM:

- It is a gauge theory like QED, QCD, EW
- $\mathcal{L}$ is quadratic in F
- But it is $E \cdot B$-like (NOT $E^2 - B^2$-like)
- Leading term is topological:

$$\int d^4x \left(\frac{M_{Pl}^2}{\Lambda^2} R\tilde{R}\right) = \int dt \left(2\pi \frac{dN}{dt}\right)$$

← DARKNESS

How Darkness Behaves:

In FRW expanding universe:

$$N(t) \sim \frac{M_{pl}^2}{\Lambda}\int (\dot{a}^3)\, d^3x = \frac{M_{pl}^2}{\Lambda} V(t) \left(\frac{\dot{a}}{a}\right)^3$$

↑ comoving volume

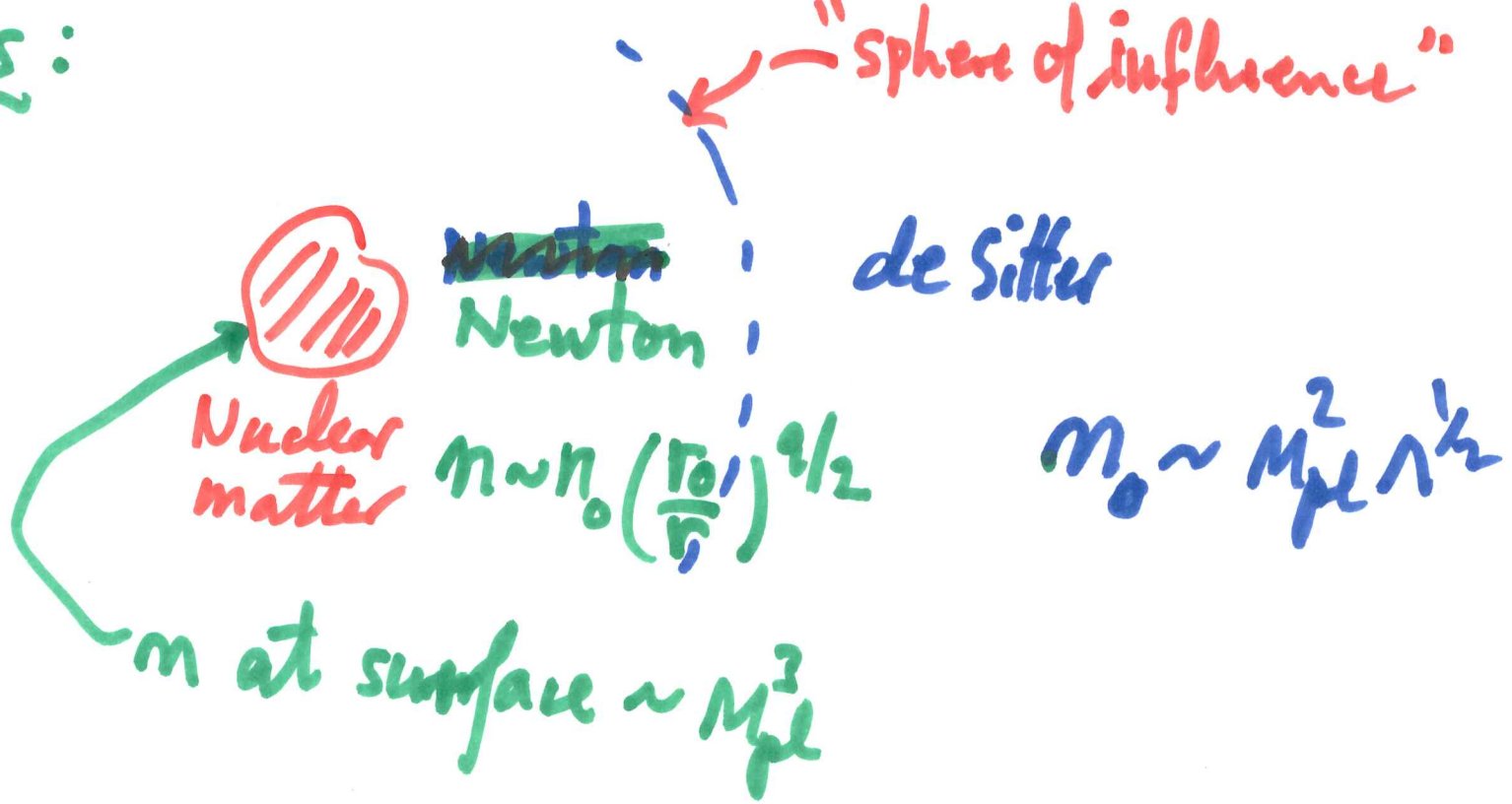
Nowadays (& in the future) $\left(\frac{\dot{a}}{a}\right)^2 \sim \Lambda \Rightarrow n \approx (M_{pl}^2 \Lambda^{1/2}) \sim 10^{39}\, cm^{-3}$

In the past, $n(t)$ was much larger

When $T \sim 50$ MeV $\quad n(t) \sim M_{pl}^3$

"QCD" scale
Zeldovich
$\Leftrightarrow$ limit of validity of MN description

Sources :



Note:

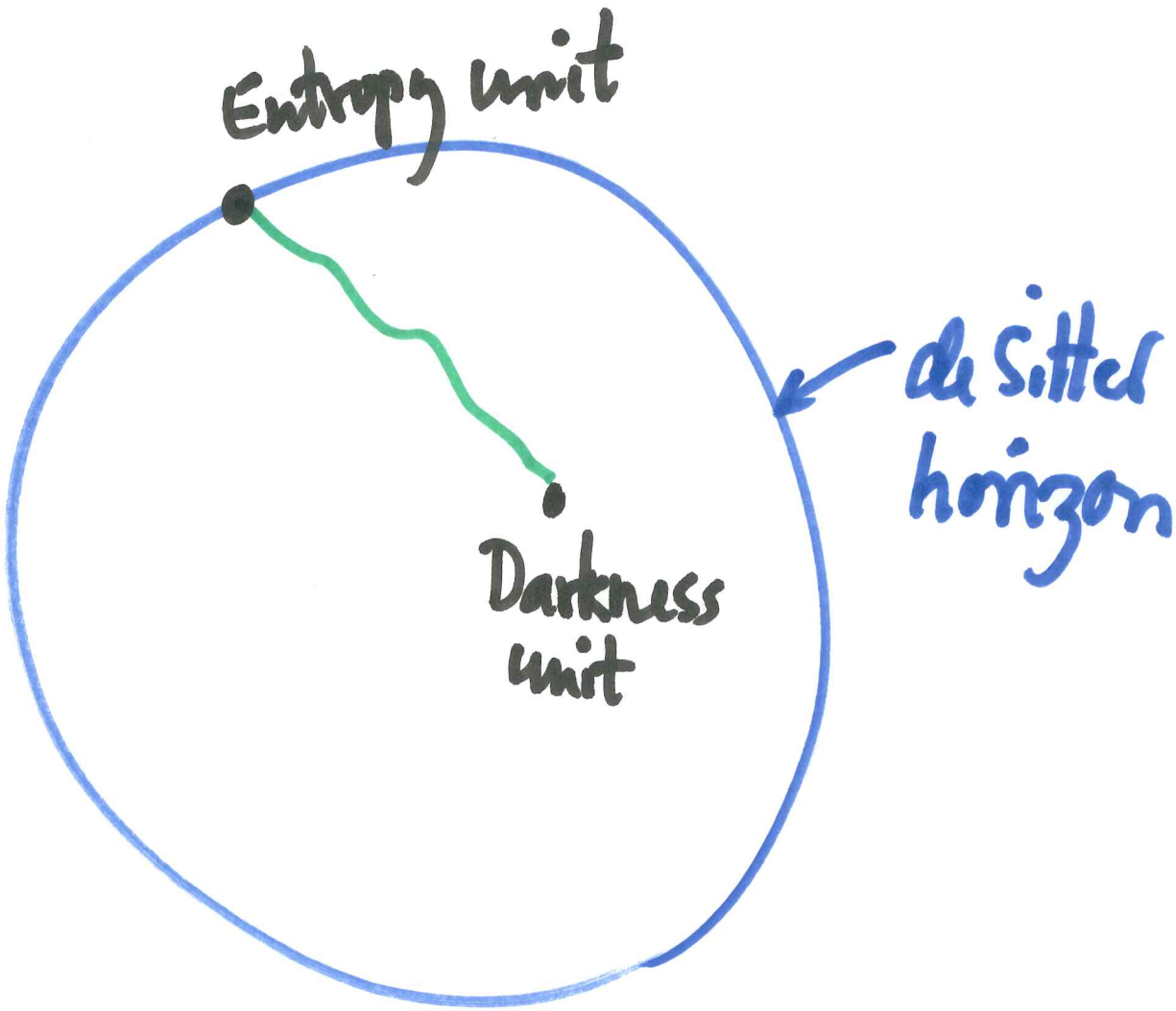
Total amount of darkness in universe dominated by matter:

$$\left.\begin{array}{l} \text{Baryon}^{\#} \sim 10^{80} \\ \text{Darkness/nucleon} \sim 10^{60} \end{array}\right\} \Rightarrow 10^{140}$$

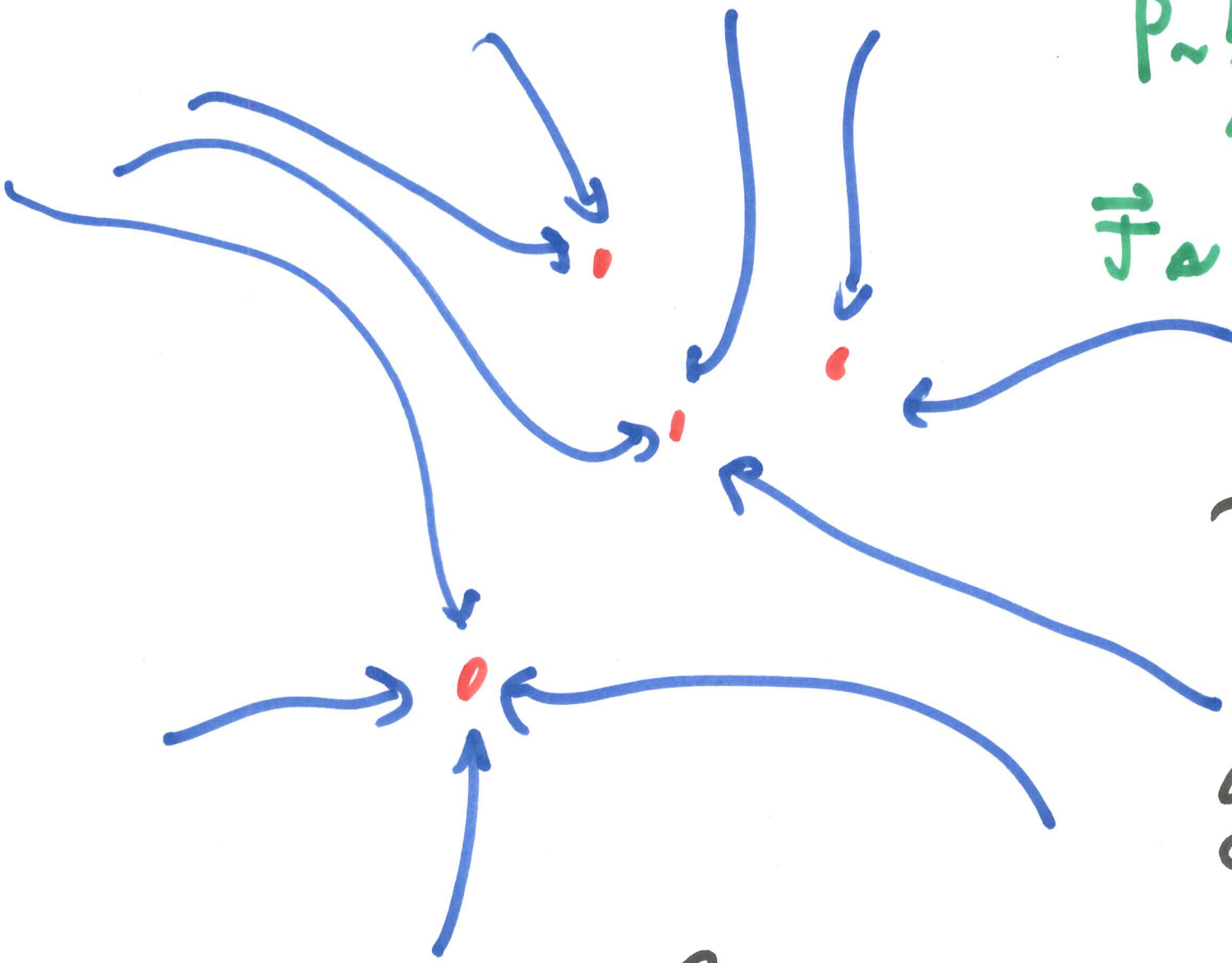
De Sitter density × Volume of universe (inside the horizon)

$$\sim (10^{-29}\,\text{cm}^{-3}) \times (10^{28}\,\text{cm})^3 \sim 10^{123}$$

Is Darkness = Horizon Entropy?



Newtonian Darkness Flow



$$P \sim \frac{M_{Pl}^2}{\Lambda} \sqrt{\det T}$$

$$\vec{f} \sim \frac{M_{Pl}^2}{\Lambda} \vec{\nabla} |g|^2$$

$$T_{ij} = \nabla_i \nabla_j \phi$$

$$g_i = \nabla_i \phi$$

Comments:

- Is the darkness scale related to
  - Λ_{QCD} ?
  - g/l mass scale?
  - Dark-matter mass-scale?

- QCD/EW/Higg vacuua vs grav. vacuum.

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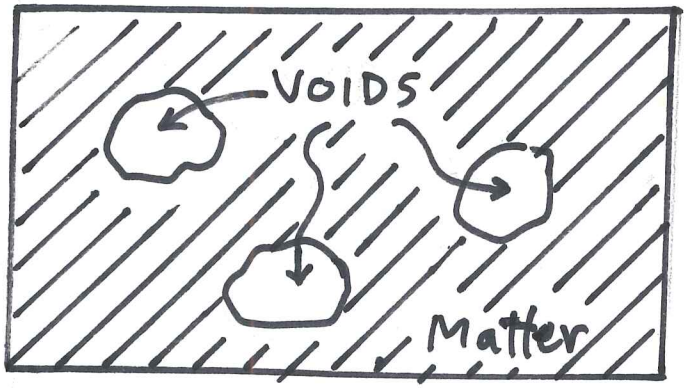
VOIDS

The Usual Definition:

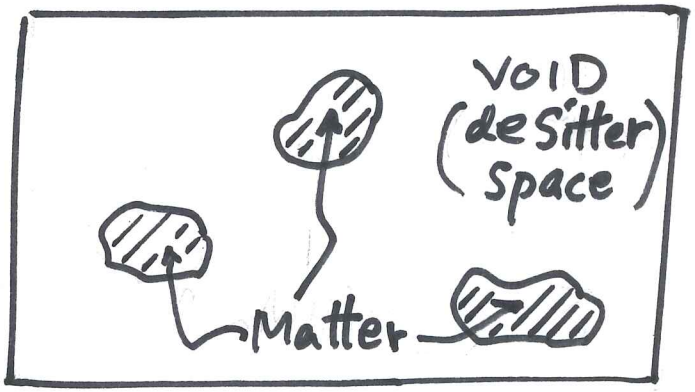
DENSITY CONTRAST



BEFORE ($a(t) \ll 1$)

The Suggested Definition

RIEMANN CURVATURE



AFTER ($a(t) \gg 1$)

RIEMANN CURVATURE

$$R^{\alpha\beta}_{\mu\nu} \sim \frac{GM}{r^3}\begin{pmatrix} 2 & & & & & \\ & -1 & & & & \\ & & -1 & & & \\ & & & 2 & & \\ & & & & -1 & \\ & & & & & -1 \end{pmatrix}$$

tr tθ tφ θφ rθ rφ

Schwarzschild

$$R^{\alpha\beta}_{\mu\nu} \sim \Lambda\begin{pmatrix} 1 & & & & & \\ & 1 & & & & \\ & & 1 & & & \\ & & & 1 & & \\ & & & & 1 & \\ & & & & & 1 \end{pmatrix}$$

de Sitter

THE NEWTONIAN LIMIT

Tidal tensor: $T_{ij} = \nabla_i \nabla_j \phi$ ← Newtonian potential

If $\mathrm{Tr}\, T^2 \gg \Lambda$, Matter

If $\mathrm{Tr}\, T^2 \ll \Lambda$, de Sitter Void

THE SUGGESTION

- Locate the boundary surface in LSS simulations
- Learn by doing
- Is evolution of boundary surface sensitive to quintessence models?
- Study motion of "test particles" in voids
- Apply what is learned to real life (much harder)

QCD at the LHC

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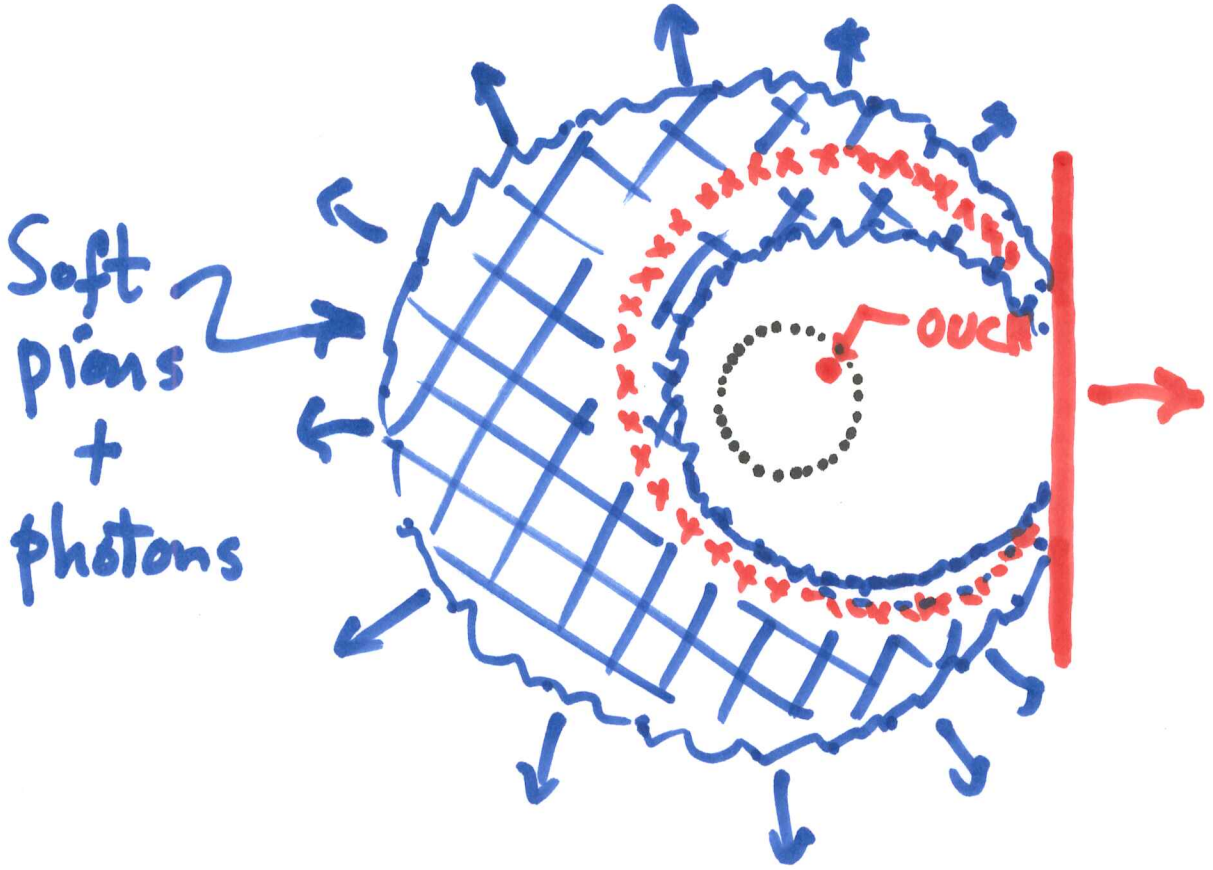
- HEAVY IONS (Pb)
- FIXED TARGET (C, N, Al, Fe)

THE DECAY OF "NOTHING"



Huygen's principle tells the story

- Pulse thickness is ~ nuclear diameter
- The pulse is noisy
- How much energy is emitted?
- What is the multiplicity of emitted quanta?

EM Radiation:

$$\text{Energy} = \int d^3r \left(\frac{E^2}{2}\right) \sim \begin{cases} \frac{Z^2\alpha}{R_{\text{Nucleus}}} & \text{(coherent)} \\ \frac{Z\alpha}{R_{\text{Quark}}} & \text{(incoherent)} \end{cases}$$

$$\text{Momentum} \sim \begin{cases} \frac{1}{R_{\text{Nucleus}}} & \text{coherent} \\ \frac{1}{R_{\text{Quark}}} & \text{incoherent} \end{cases}$$

Pion Radiation in Chiral Limit ($m_\pi = 0$)

$$\text{Energy} \overset{?}{\sim} \begin{cases} \Delta\left(F_\pi^4 \cdot \frac{4}{3}\pi R_{Nuc}^3\right) \sim (\Delta F_\pi)\, A \\ \qquad \text{(coherent)} \\ \sim m_q A \quad \text{incoherent} \\ \qquad \text{("ouches")} \end{cases}$$

$\Delta F_\pi \equiv$ change in vev due to presence of nuclear matter ("bag model")

Real life:

How does $m_\pi \neq 0$ affect the answer?

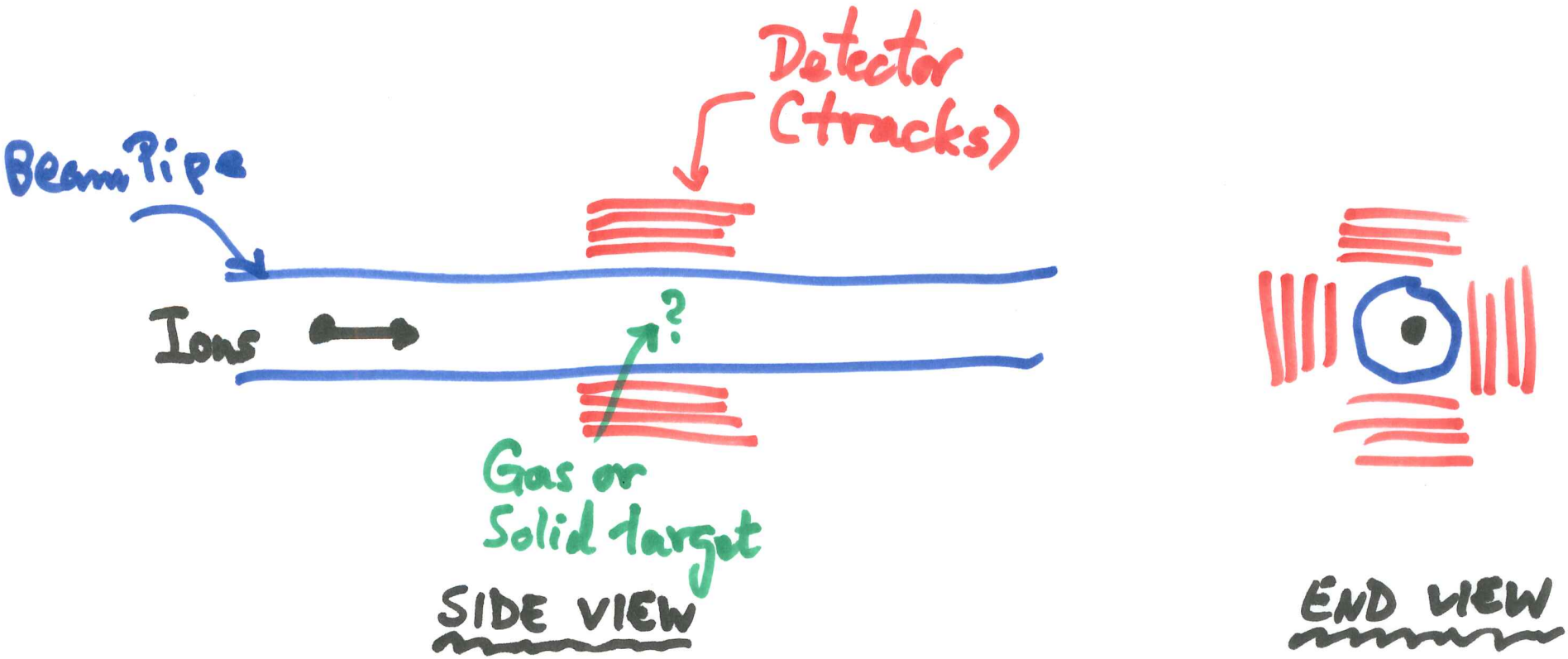
"Coherent" piece is suppressed?

"Ouch" piece is robust?

Best answer:

Do the experiment & find out.

The experiment:



- For every bunch crossing ($\Delta t = 200$ nsec), count tracks.
- Location: Beam abort channel? Halo of circulating beam?

VACUUM ENGINEERING

WHAT DOES ONE LEARN ??

- Nothing of importance ?
- Something about chiral QCD vacuum?
- Link with cosmic-ray 200 events ?

TOOLS :

Multiplicity dist
Momentum spectra

DCC ??
HBT ??

????