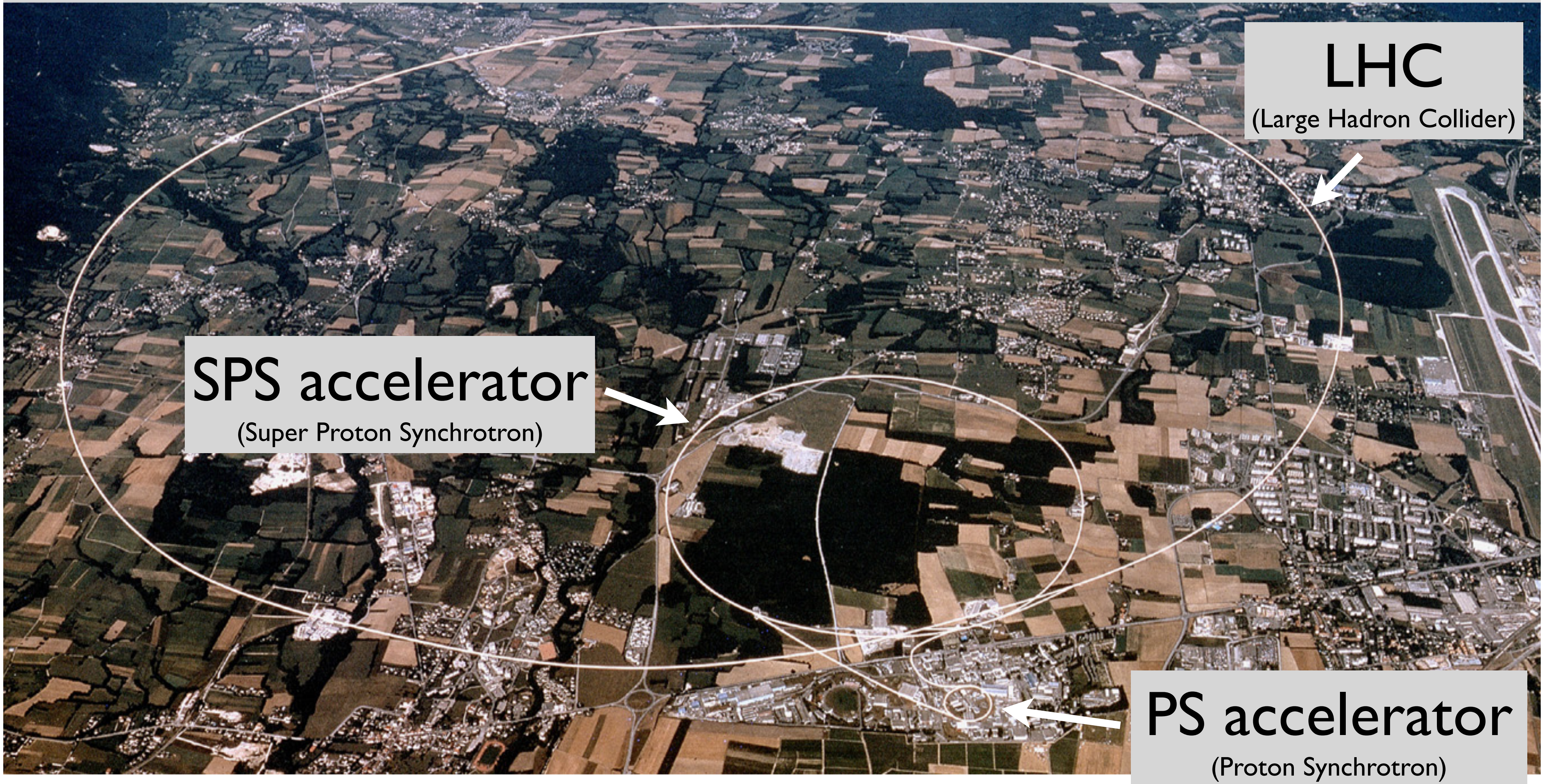
The Physics Experiments at CERN's Injector Accelerators

CERN, 27 October 2015

Christoph Rembser (CERN)

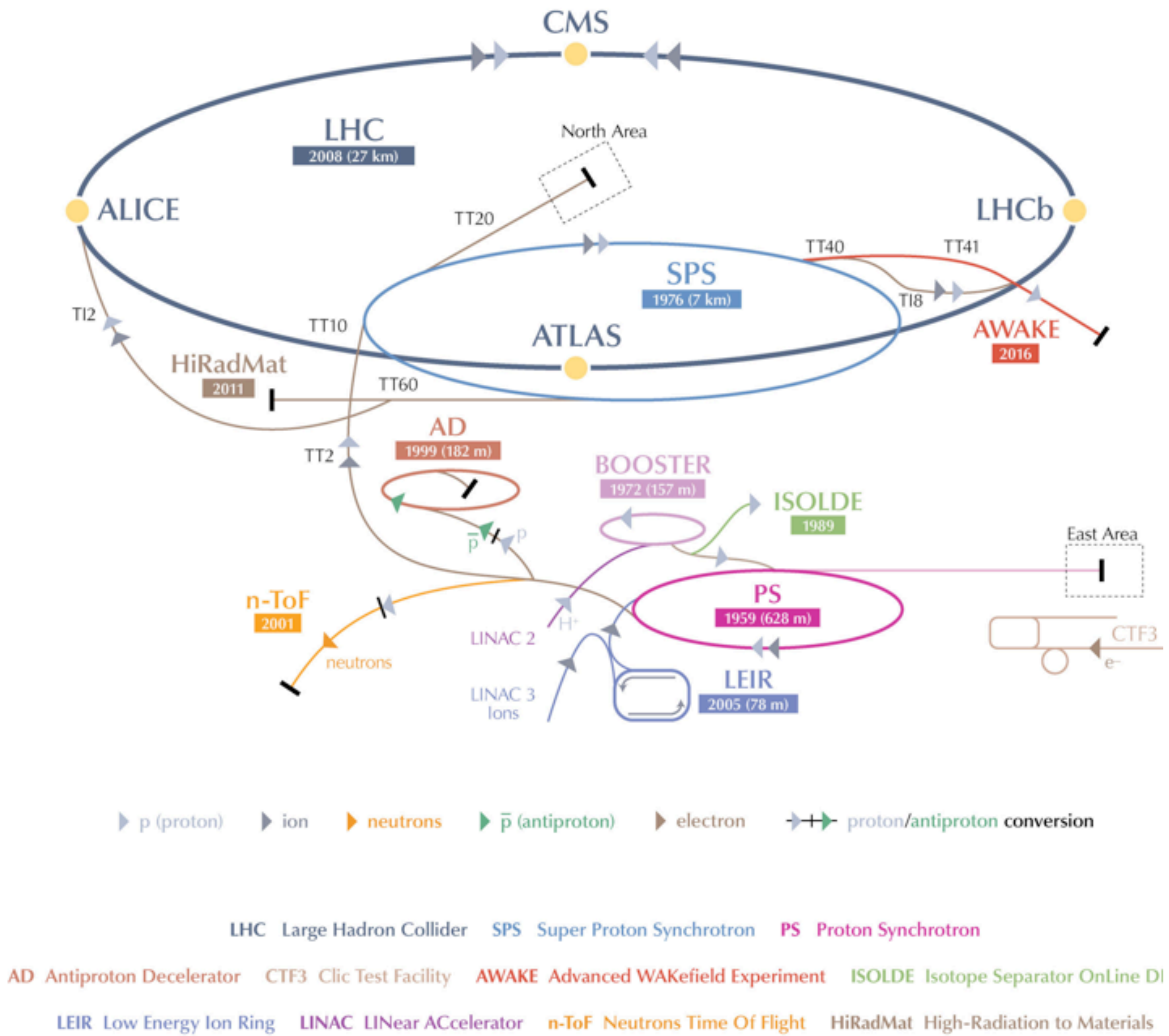
Searching for answers at the CERN accelerators



CERN: in total >11000 users, representing >500 universities & institutes, more than 90 nationalities; most working at CERN's flagship: the Large Hadron Collider **LHC**…

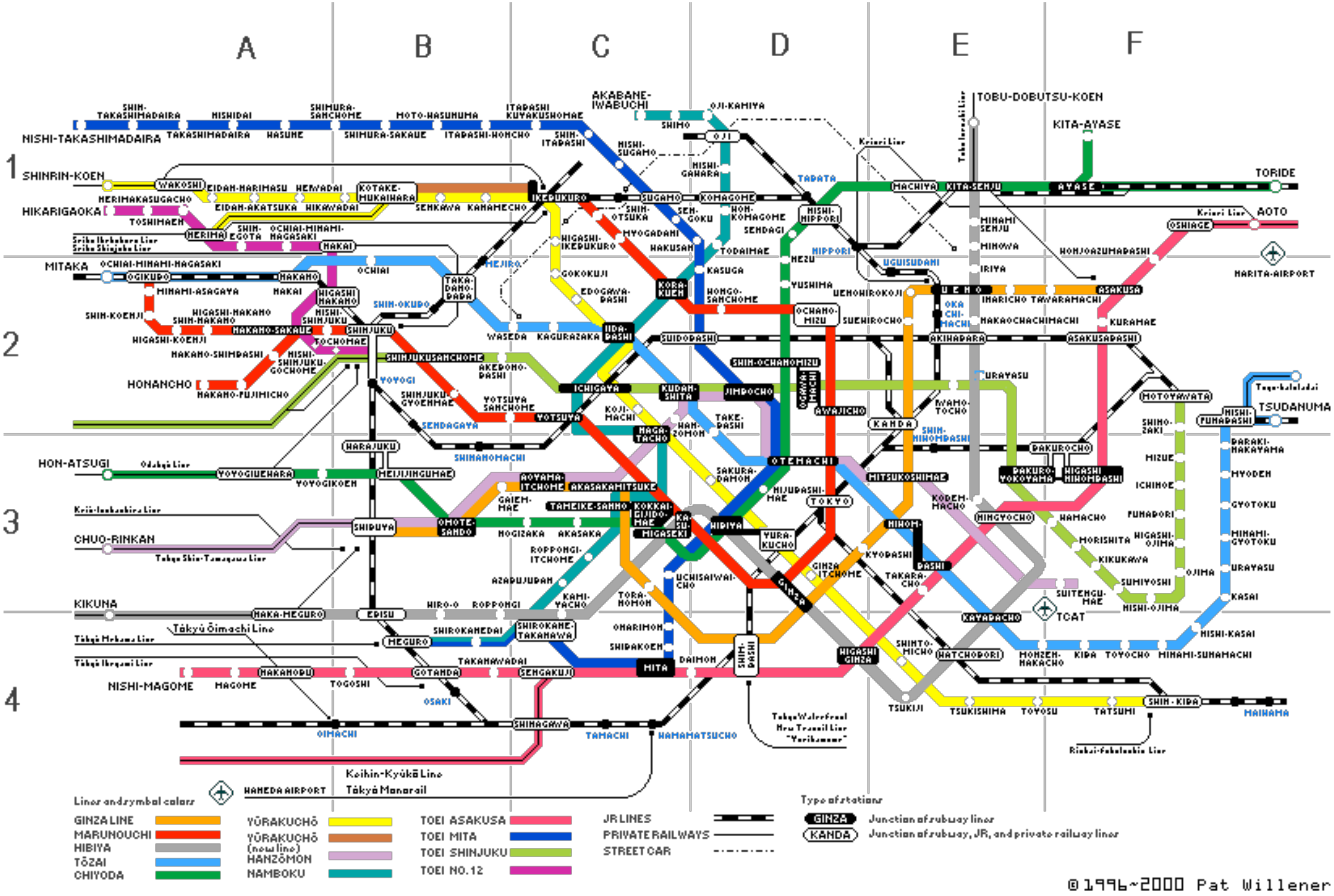
…but also ~3000 physicists perform >**50 experiments and beam tests** at the Proton Synchrotron **PS** and Super-Proton Synchrotron **SPS.**

The CERN accelerators

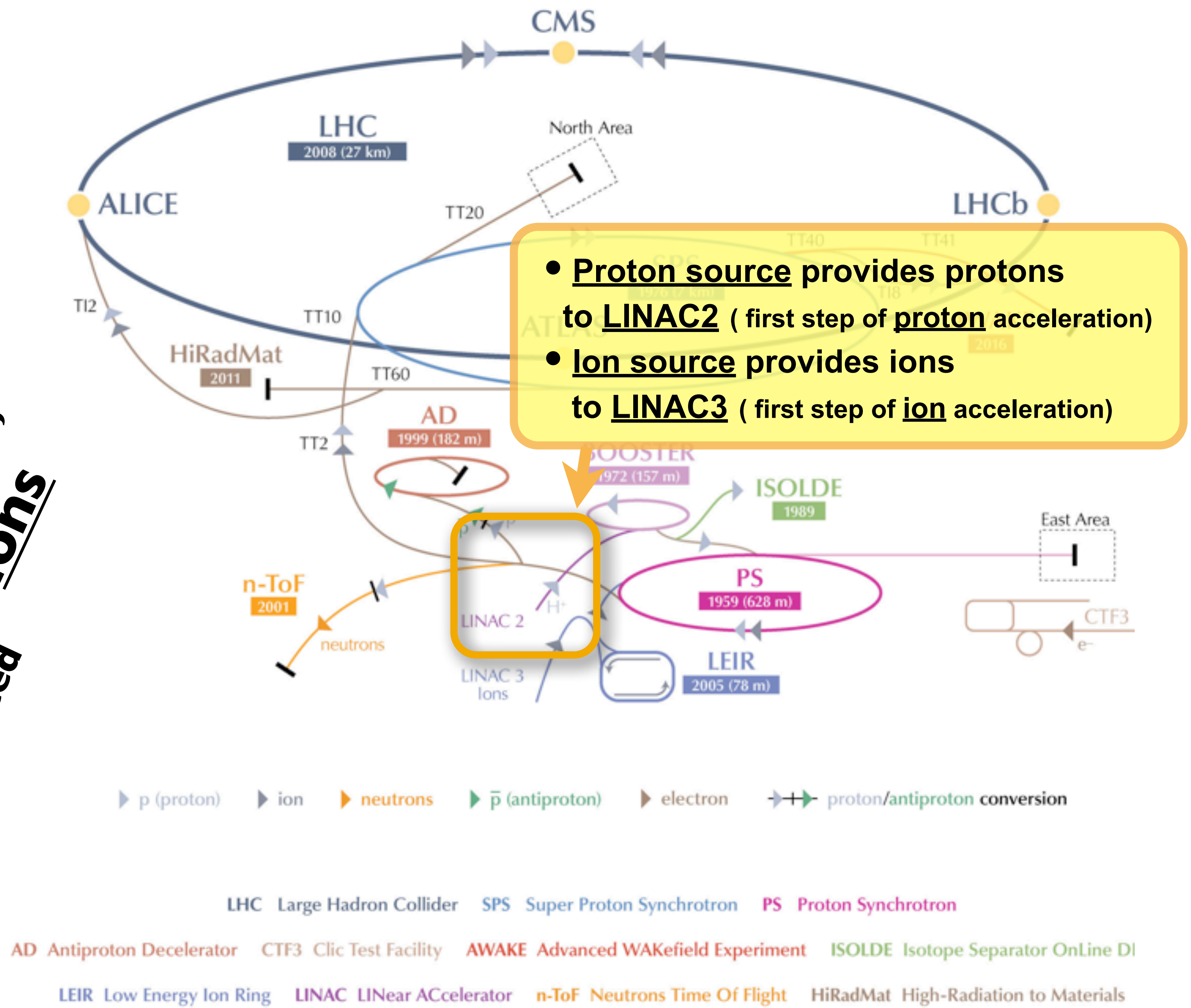


The CERN accelerators

...don't worry - not as complicated as the the Tokyo subway...



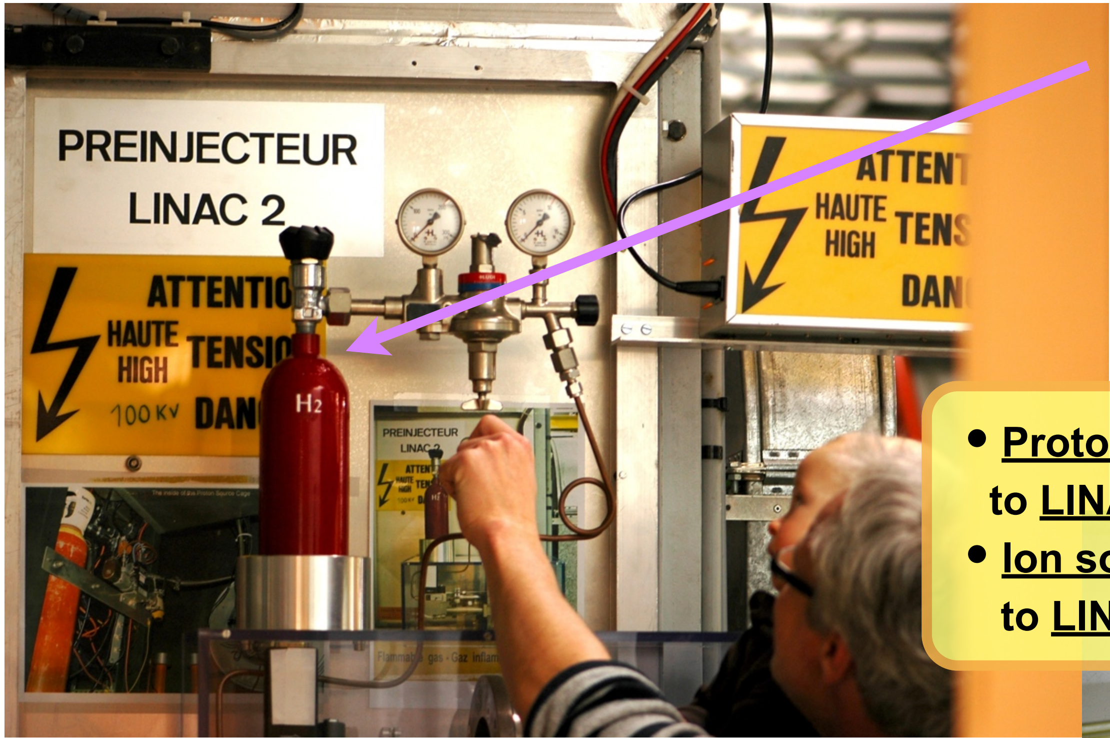
The CERN accelerators



- **Proton source** provides protons to **LINAC2** (first step of **proton** acceleration)
- **Ion source** provides ions to **LINAC3** (first step of **ion** acceleration)

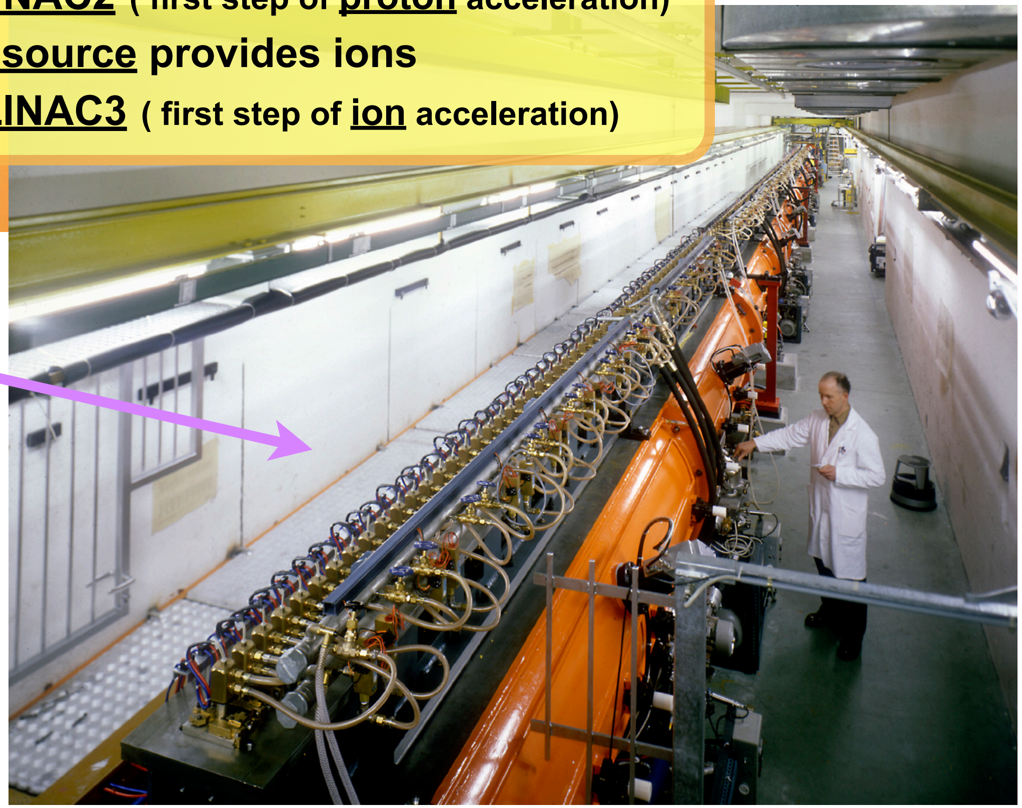
In the CERN accelerators, protons and ions are accelerated

The CERN accelerators



The CERN Proton source:
Bottle with Hydrogen gas;
electrons striped off, protons (H^+) extracted with energy of **92keV** (**250 - 320mA**).
Before injection into **LINAC2**, Radio Frequency Quadrupole accelerates the protons to **750keV**

- **Proton source provides protons to LINAC2** (first step of proton acceleration)
- **Ion source provides ions to LINAC3** (first step of ion acceleration)

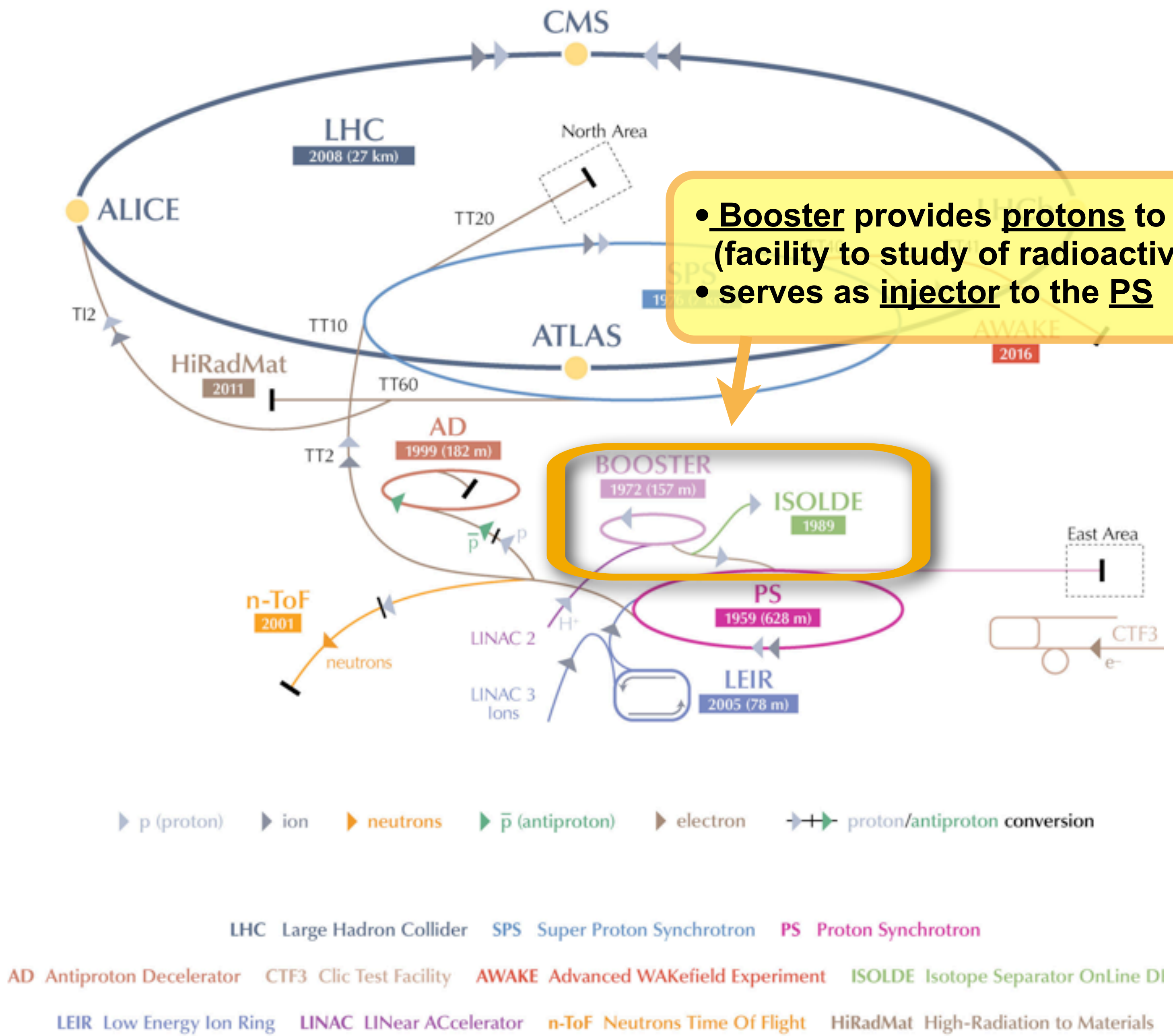


The CERN Proton LINAC2 (1978):
Protons are accelerated to **50MeV**;
typical intensities for LHC: **150mA - 180mA**

N.B.: a new LINAC (LINAC4) is currently in preparation, start of operation in after LS2.
*N.b.: the new LINAC is an **H⁻** LINAC!!!*

The CERN accelerators

- **Booster** provides **protons** to **ISOLDE** (facility to study of radioactive ion beams)
- serves as **injector** to the **PS**



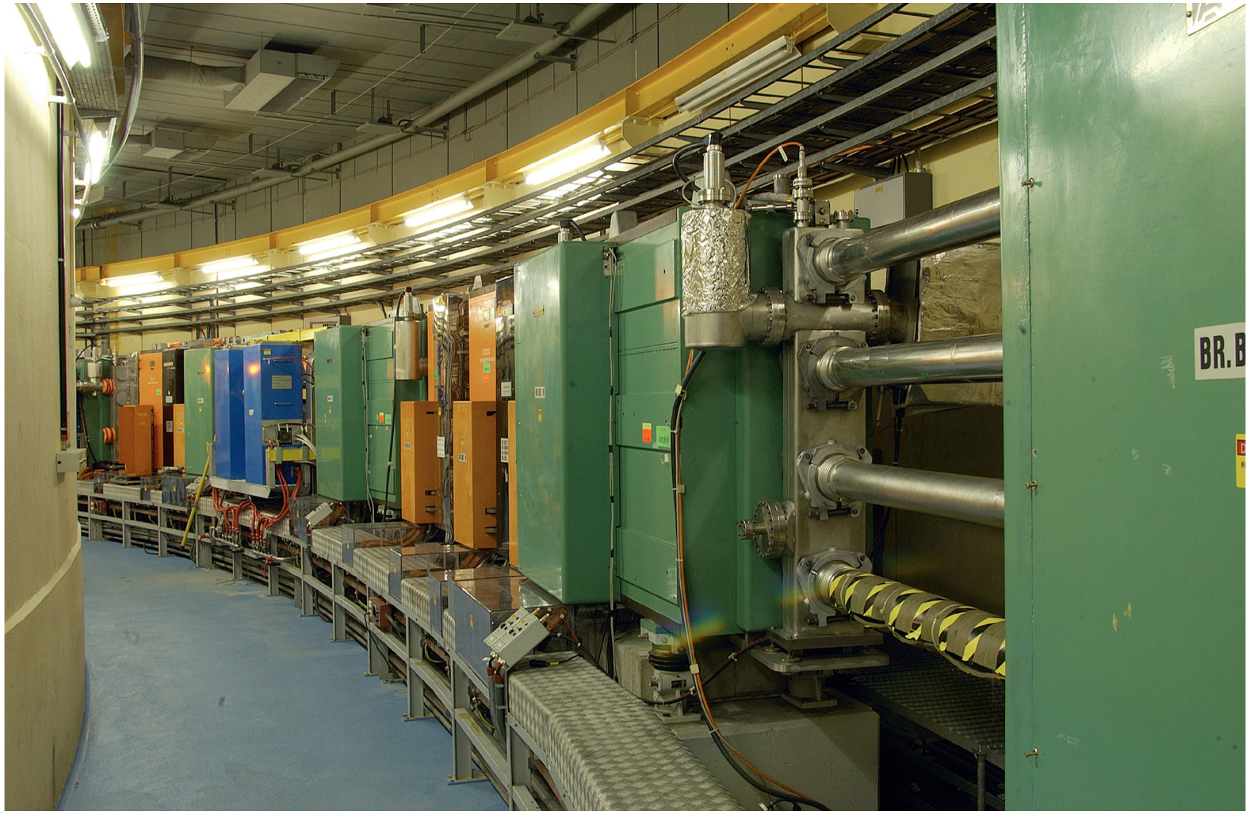
The CERN accelerators

ISOLDE (since1992 at PS Booster):

production of huge variety of radioactive ion beams for nuclear and atomic physics, solid-state physics, life sciences and material science.
Radioactive nuclides are produced via proton beams in thick high-temperature targets. Until now more than 600 isotopes of more than 60 elements have been produced.

C.R. not an expert on the ISOLDE physics programme...

- **Booster provides protons to ISOLDE (facility to study of radioactive ion beams)**
- **serves as injector to the PS**



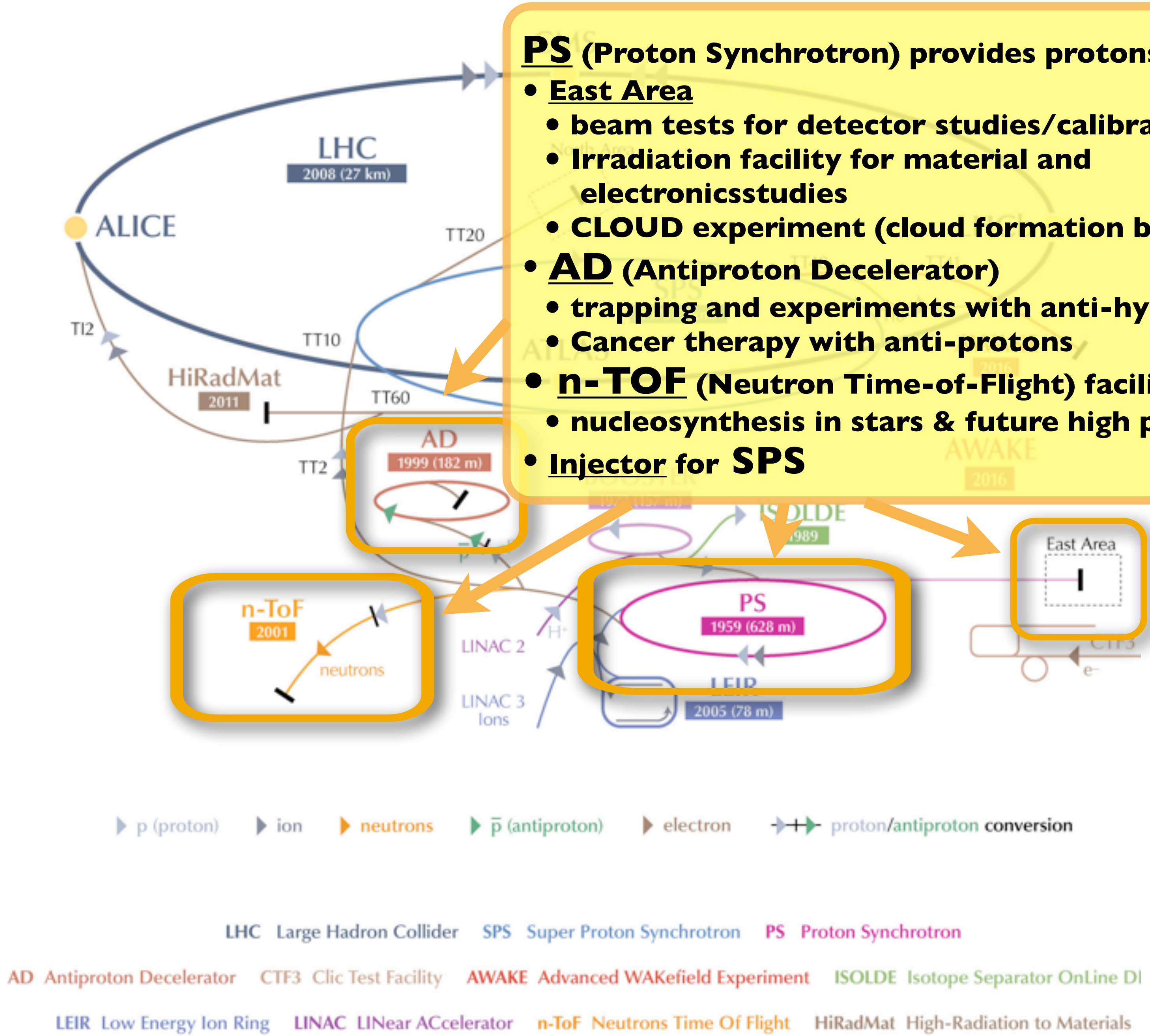
PS Booster (1972):

4 superimposed rings accelerate 4 bunches of 1.05×10^{12} protons each from 50 MeV up to **1.4 GeV**.
A Booster cycle lasts **1.2 s** (defines the **heartbeat** of the CERN accelerator complex)

The CERN accelerators

PS (Proton Synchrotron) provides protons to

- **East Area**
  - beam tests for detector studies/calibration
  - Irradiation facility for material and electronicsstudies
  - CLOUD experiment (cloud formation by cosmic rays)
- **AD** (Antiproton Decelerator)
  - trapping and experiments with anti-hydrogen
  - Cancer therapy with anti-protons
- **n-TOF** (Neutron Time-of-Flight) facility
  - nucleosynthesis in stars & future high power targets
- **Injector** for **SPS**



The CERN accelerators

The CERN Proton Synchrotron (<u>PS, 1959</u>):
filled by 2 batches from Booster, ramping protons up to **26GeV**, maximum 1.4x10^{13} protons per pulse.

<u>PS</u> (Proton Synchrotron) provides protons to
- **<u>East Area</u>**
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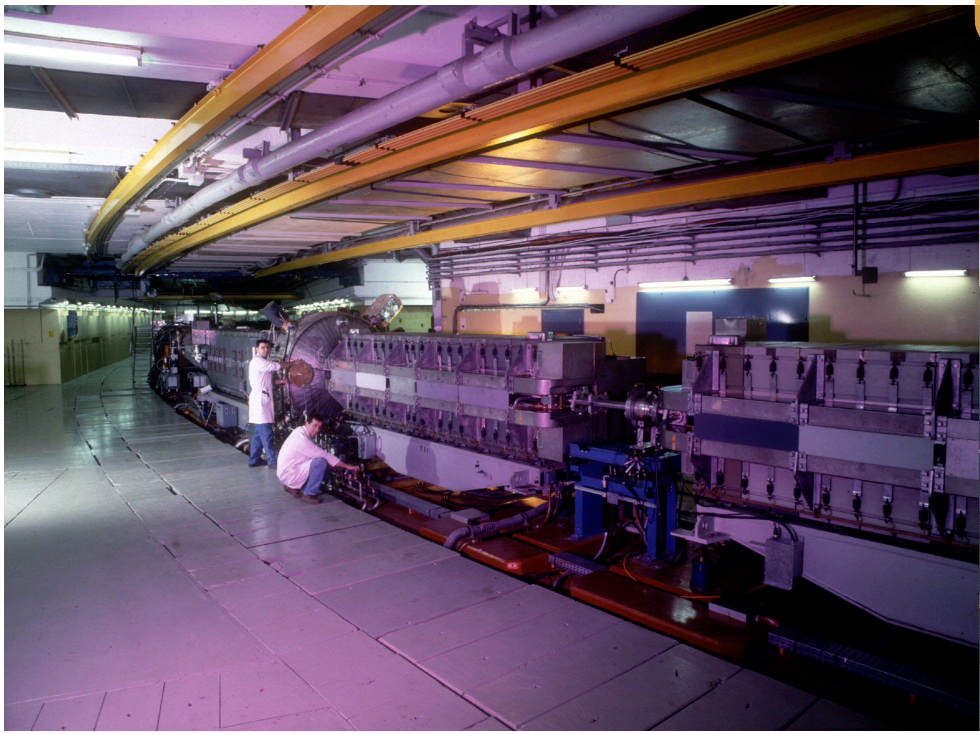
  - **Irradiation facility for material and electronicsstudies**
  - **CLOUD experiment (cloud formation by cosmic rays)**
- **<u>AD</u> (Antiproton Decelerator)**
  - **trapping and experiments with anti-hydrogen**
  - **Cancer therapy with anti-protons**
- **<u>n-TOF</u> (Neutron Time-of-Flight) facility**
  - **nucleosynthesis in stars & future high power targets**
- **<u>Injector</u> for SPS**

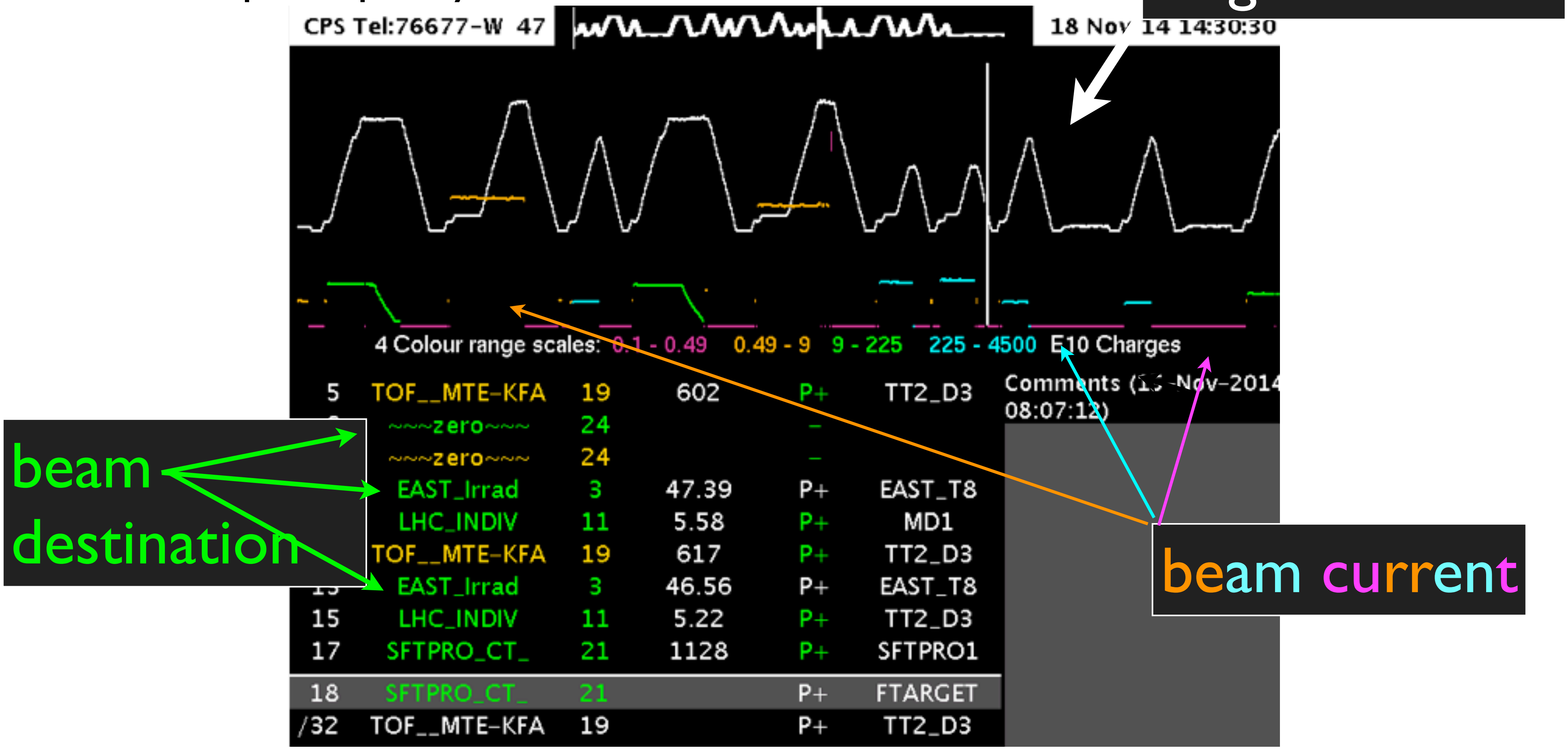
View into the PS tunnel



The PS magnets' power supply: a rotor generator

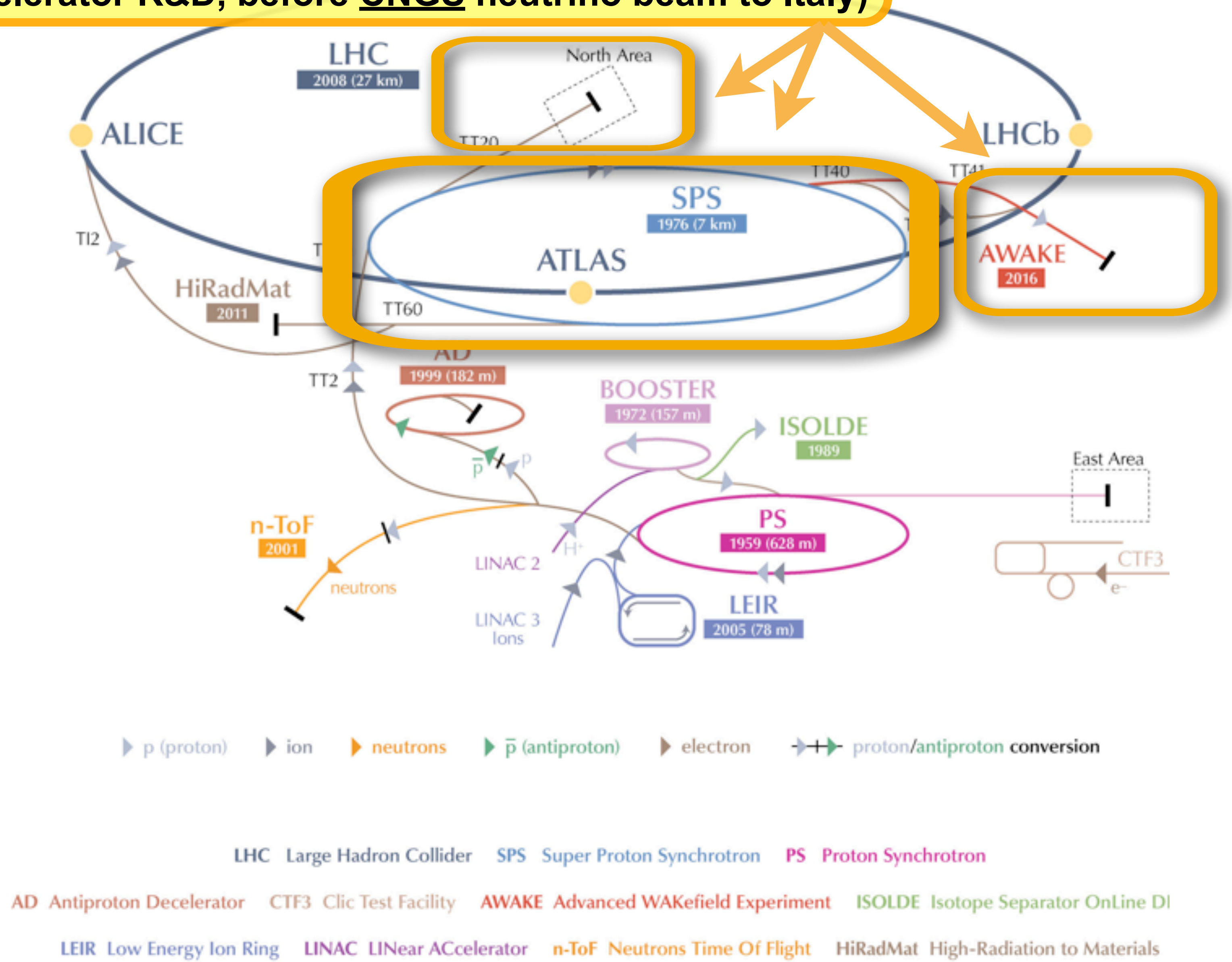
A complicated ballet: beam to the various users

- A **super-cycle** defines the sequence of beam distribution to the users which repeats itself after 30 - 90 seconds.
  - ➡ Example: super-cycle in the PS, November 2014:



The CERN accelerators

SPS (Super Proton Synchrotron) provides protons to
- **North Area**
  - **beam tests for detector studies/calibration, material studies**
  - **COMPASS experiment (hadron spectroscopy)**
  - **NA62 experiment to study rare kaon decays, NA61, NA63**
- **AWAKE (accelerator R&D, before CNGS neutrino beam to Italy)**



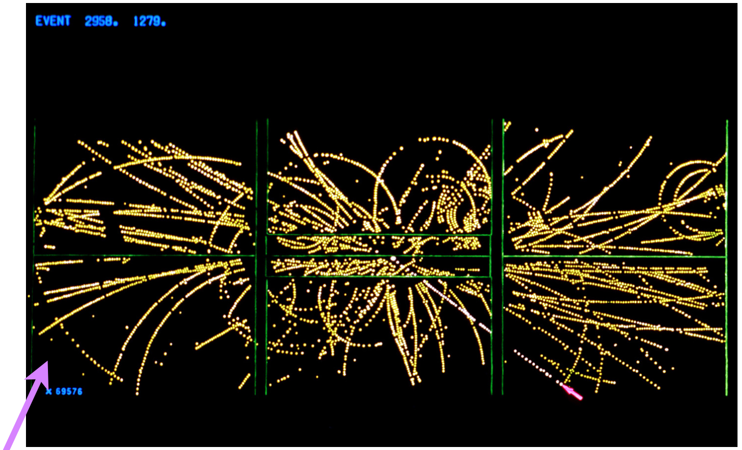
The CERN accelerators

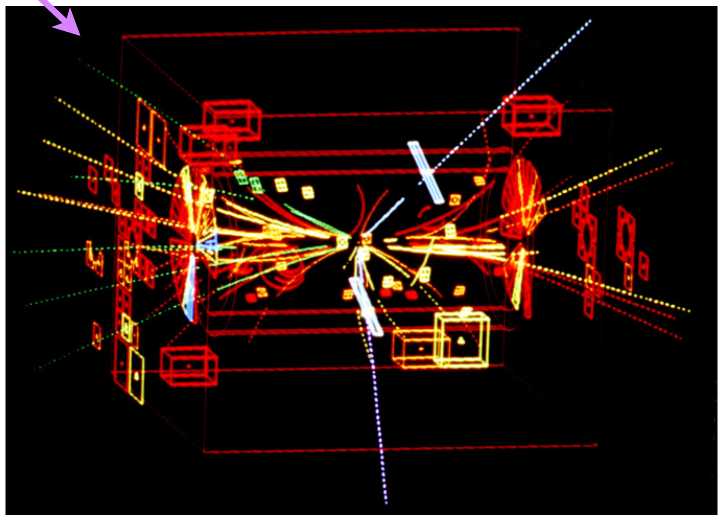
<u>SPS</u> (Super Proton Synchrotron) provides protons to
- **<u>North Area</u>**
  - **beam tests for detector studies/calibration, material studies**
  - **COMPASS experiment (hadron spectroscopy)**
  - **NA62 experiment to study rare kaon decays, NA61, NA63**
- **<u>AWAKE</u> (accelerator R&D) & <u>CNGS</u> (neutrino beam to the Italy)**

The CERN <u>SPS</u> (1976) accelerates protons up to **450GeV** with intensities up to 10^{11} protons per bunch.
In 1981 upgraded to a proton-antiproton collider (SPP^{bar}S) using stochastic cooling

View into the SPS tunnel

Observations of $W^{+/-}$ (1982) and Z^0 event (1983) with the UA1 detector



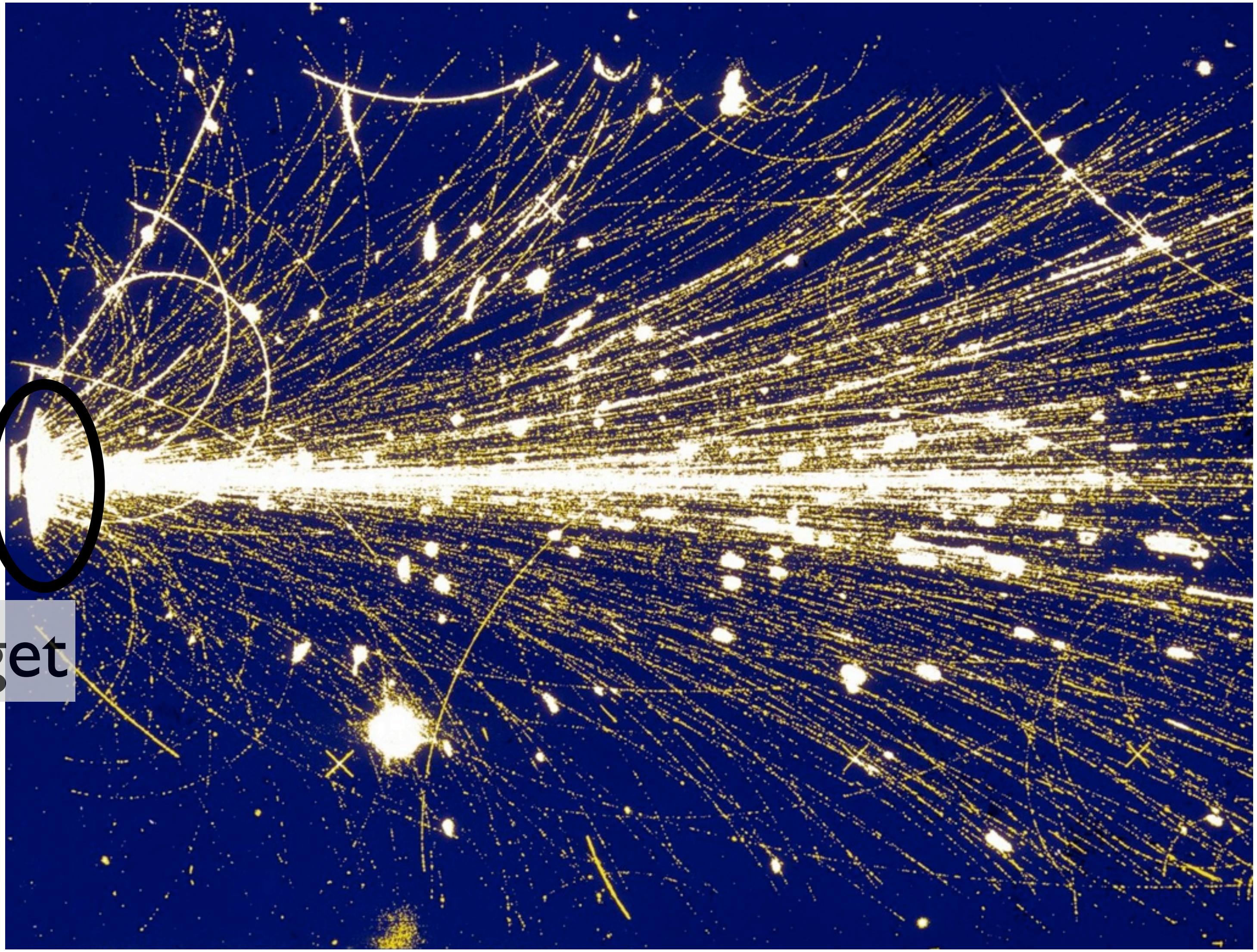


Experiments at the PS/SPS are called"fixed-target experiments"

Protons from the accelerator hit a target

beam

target



Spray of secondary, tertiary particles get out of the target. Particles (electrons, muons, pions, antiprotons...) are selected using magnets and/or absorption foils

Picture: a collision of a sulphur ion onto a gold target, recorded by the NA35 experiment at the SPS in 1991

The CERN accelerators

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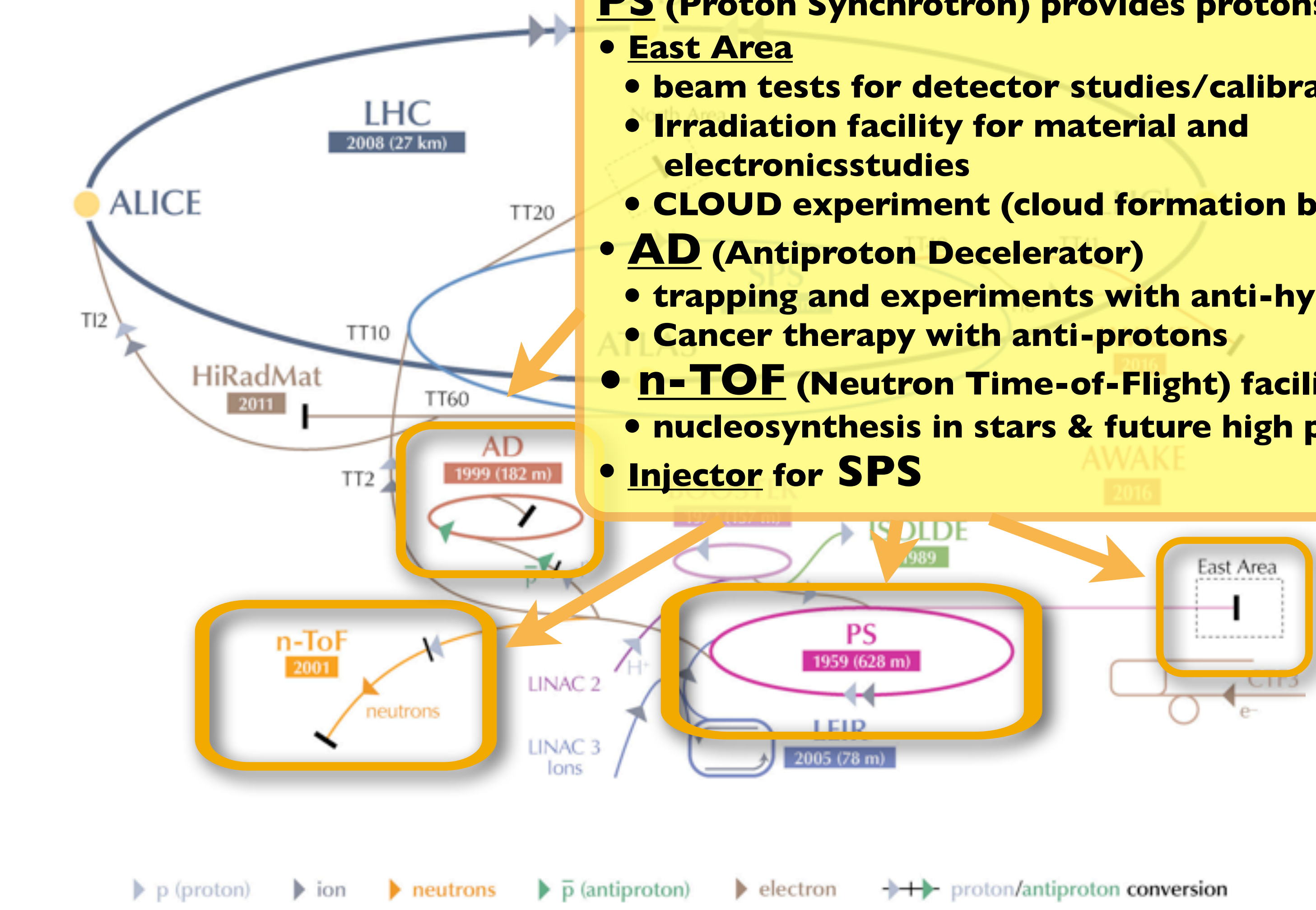
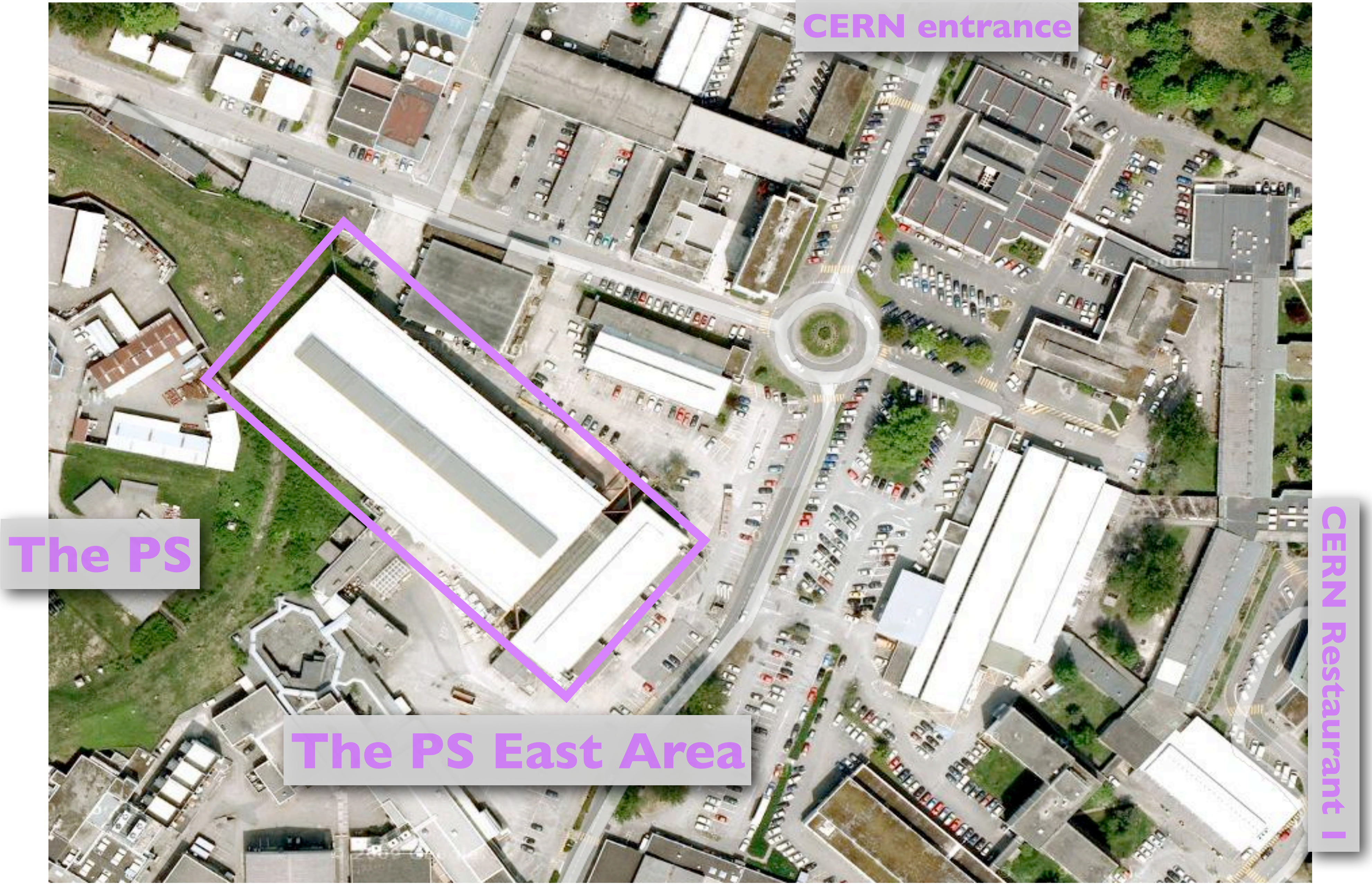


LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

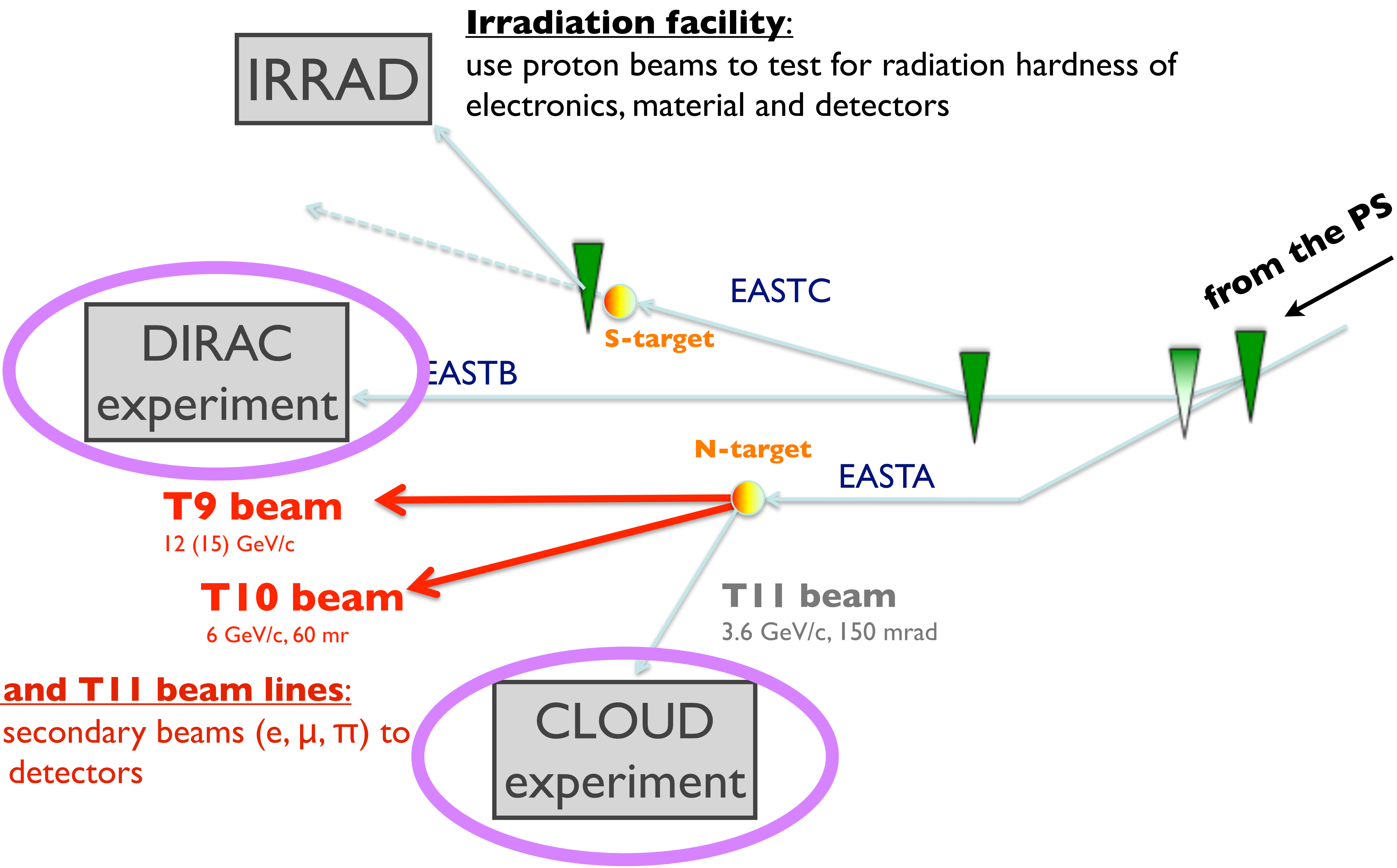
AD Antiproton Decelerator CTF3 Clic Test Facility AWAKE Advanced WAKefield Experiment ISOLDE Isotope Separator OnLine DI

LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight HiRadMat High-Radiation to Materials

The PS East Area



East Area beams - a schematic view

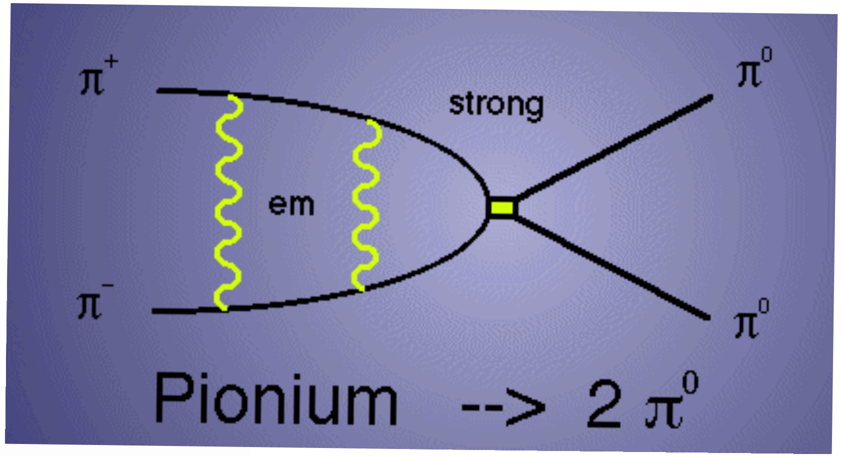


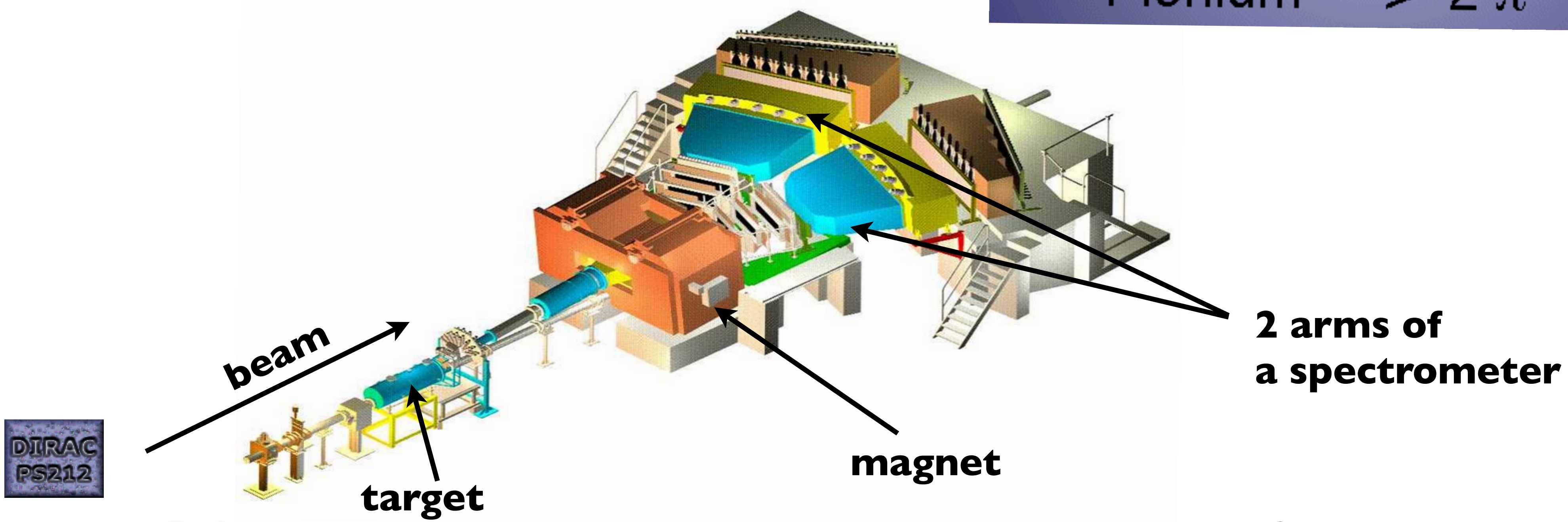
T9 and T11 beam lines:
use secondary beams (e, μ, π) to test detectors

DIRAC: do we understand the strong force?

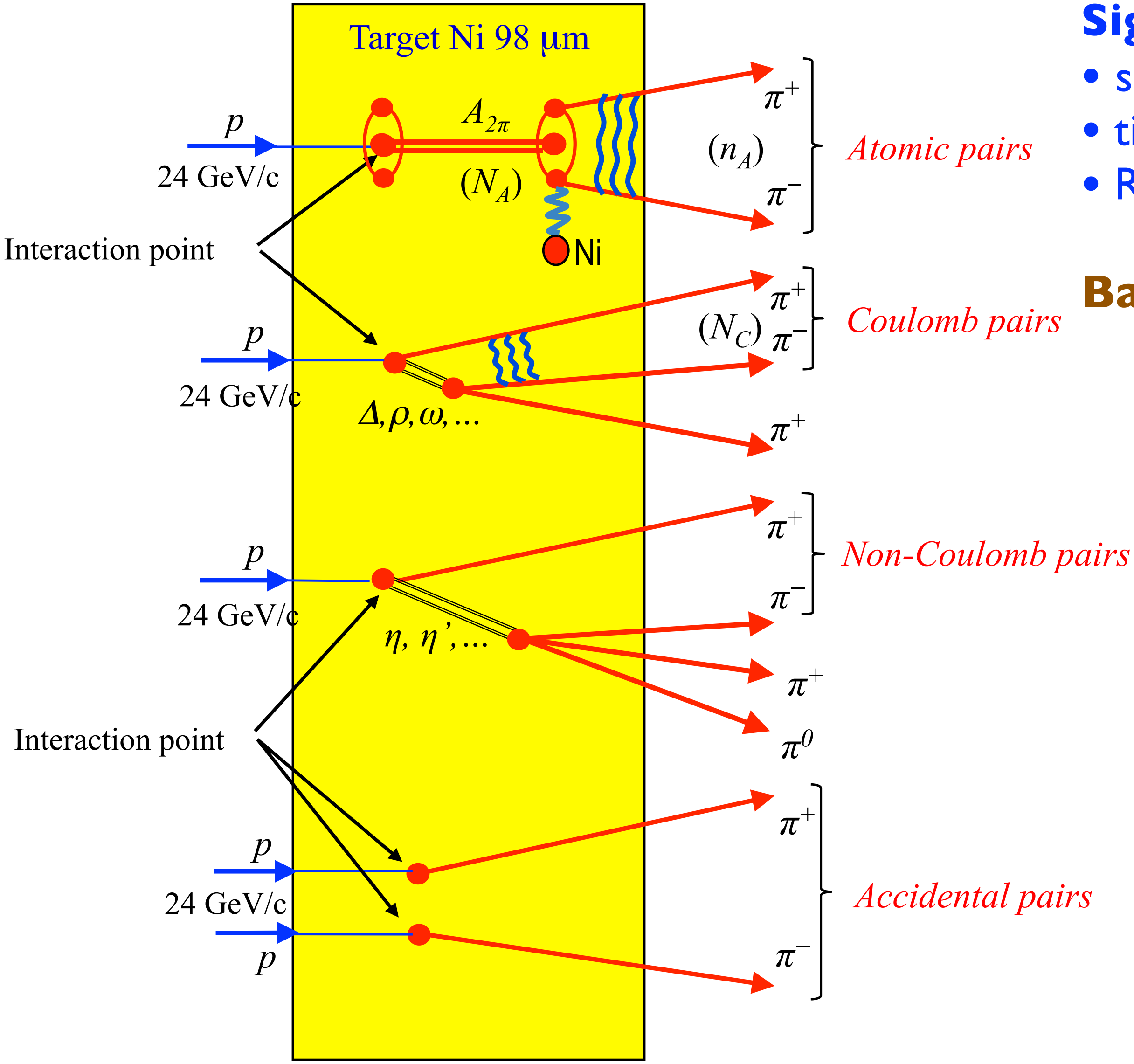
- Quantum Chromo Dynamics (**QCD**): theory to describe strong interaction
- QCD is quite advanced, e.g. precise prediction of lifetime of $\pi^+\pi^-$ atoms
- need **experimental tests** → DIRAC
- $\pi^+\pi^-$ (pionium) atoms: formed by interaction of proton beam in target, Coulomb attraction if 2 pions get closer than few fm
- Pionium: decays 99.6% to $\pi^0\pi^0$ (but π^0 can not be seen by detector, decay products in beam direction…)
- **Trick**: pionium ionisation *(=break-up)* probability is proportional to pionium lifetime

→ **Measure $\pi^+\pi^-$ pairs from pionium ionisations**



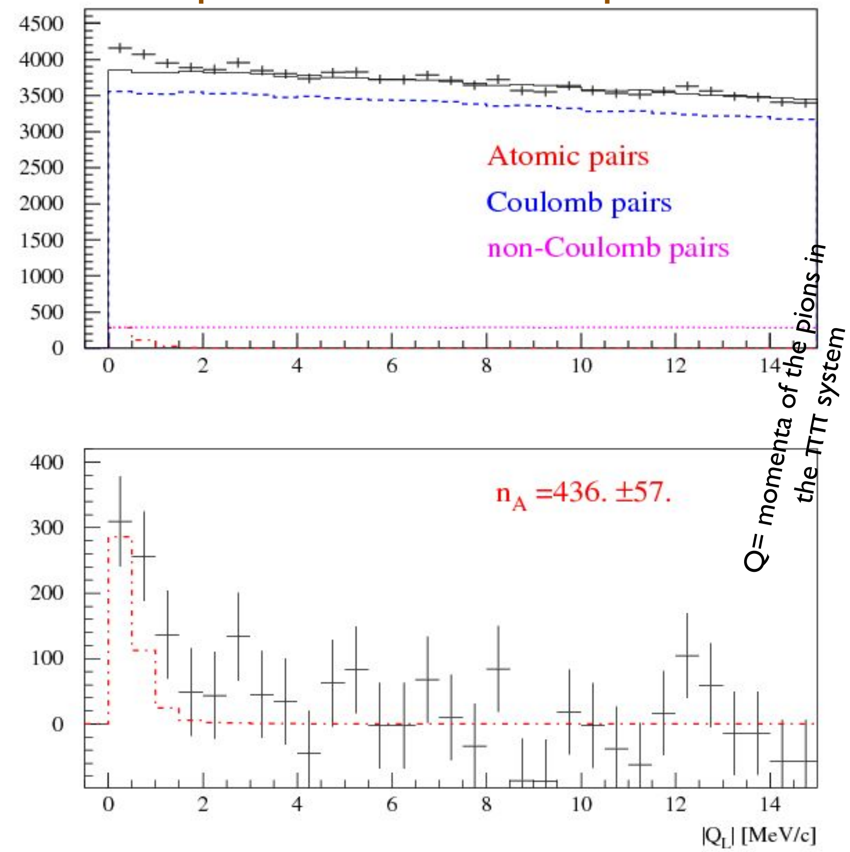


DIRAC: how to measure π⁺π⁻ atoms



Signal: atomic pairs
- small opening angles
- time correlated pions
- Relatively small pair momenta <3GeV

Background: free pairs from hadron production from Coulomb pairs, non-Coulomb pairs and accidental pairs



τ= 2.91 fs (predicted: 2.9 fs)

... error ~20%....

DIRAC finished data taking...

...and dismantling has started.

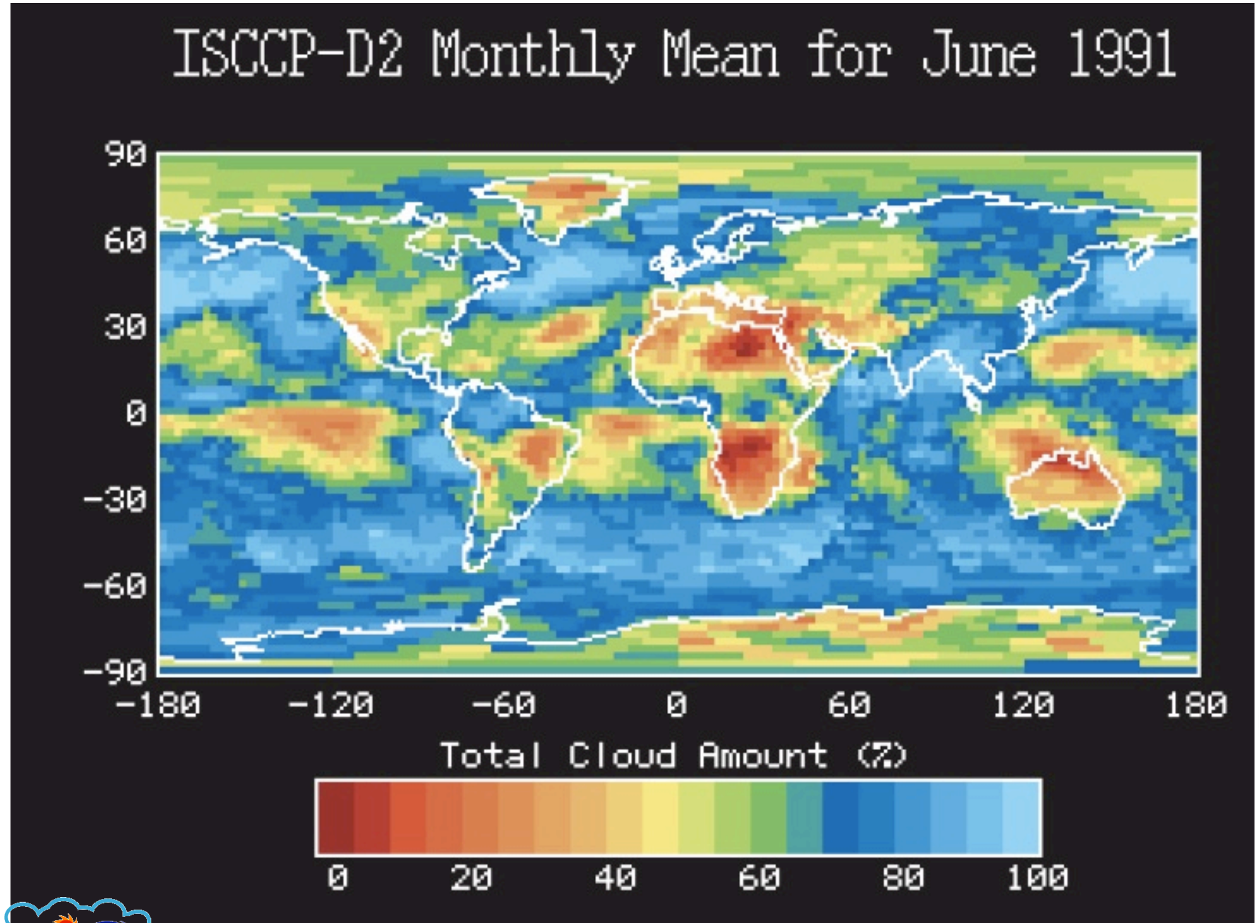
February 2013

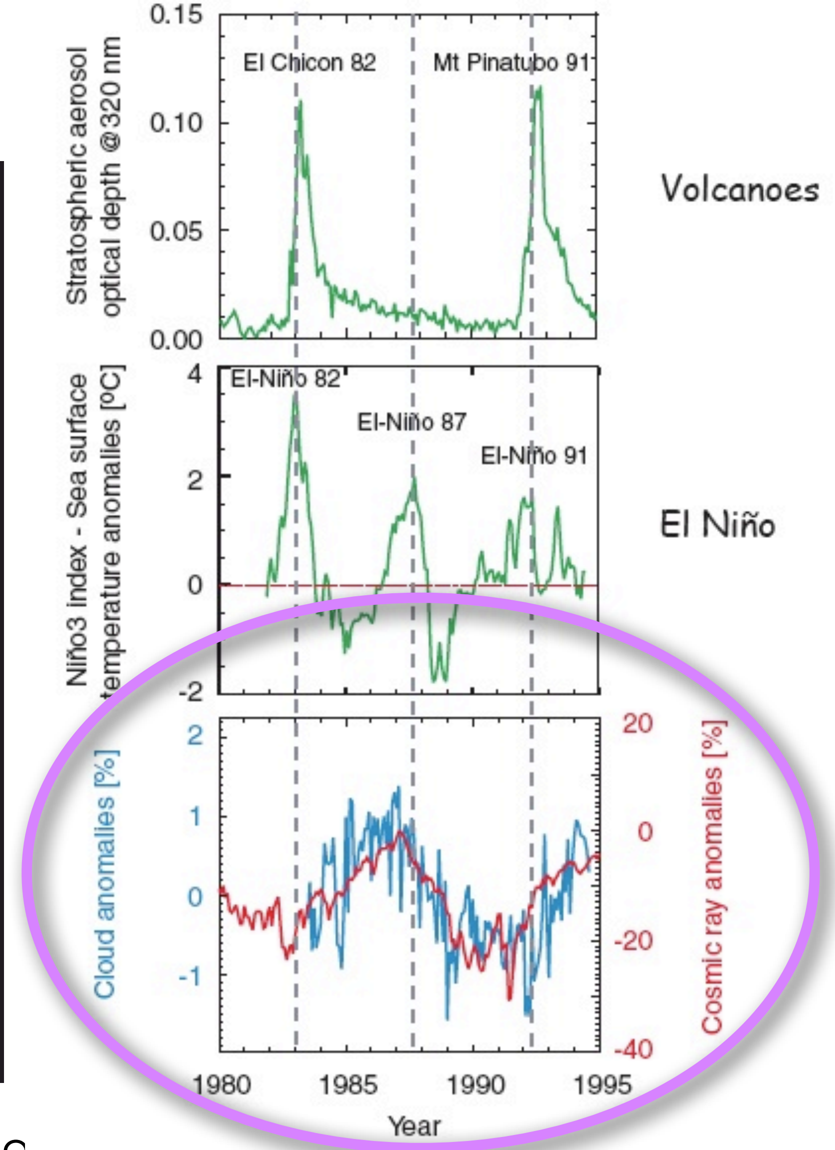
March 2013

How are clouds formed?

- Observations of density of clouds by satellites and measurement of cosmic rays suggest a **correlation between cosmic rays and our weather**

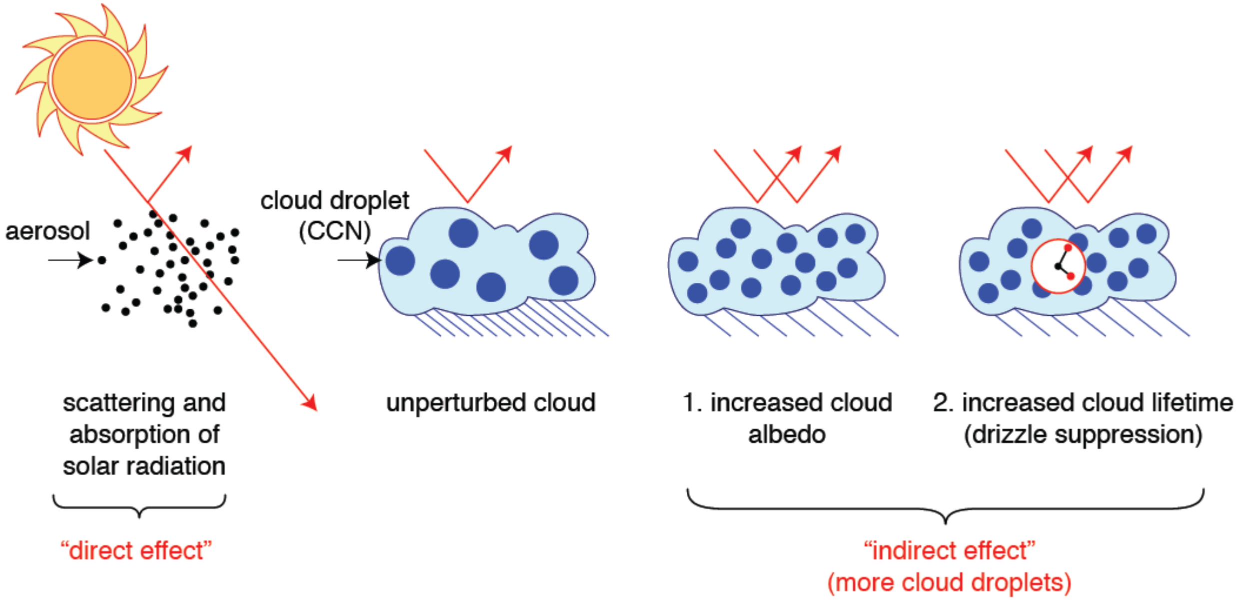
Data from satelite observation

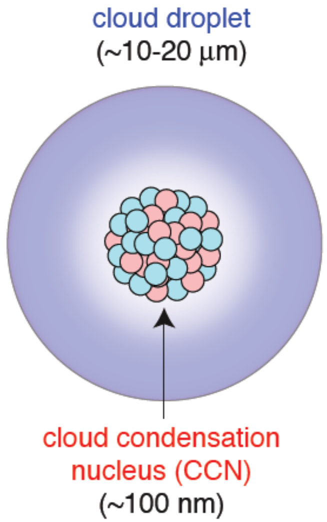




Cloud droplets form on aerosol seeds

...thus aerosols are important for our climate!



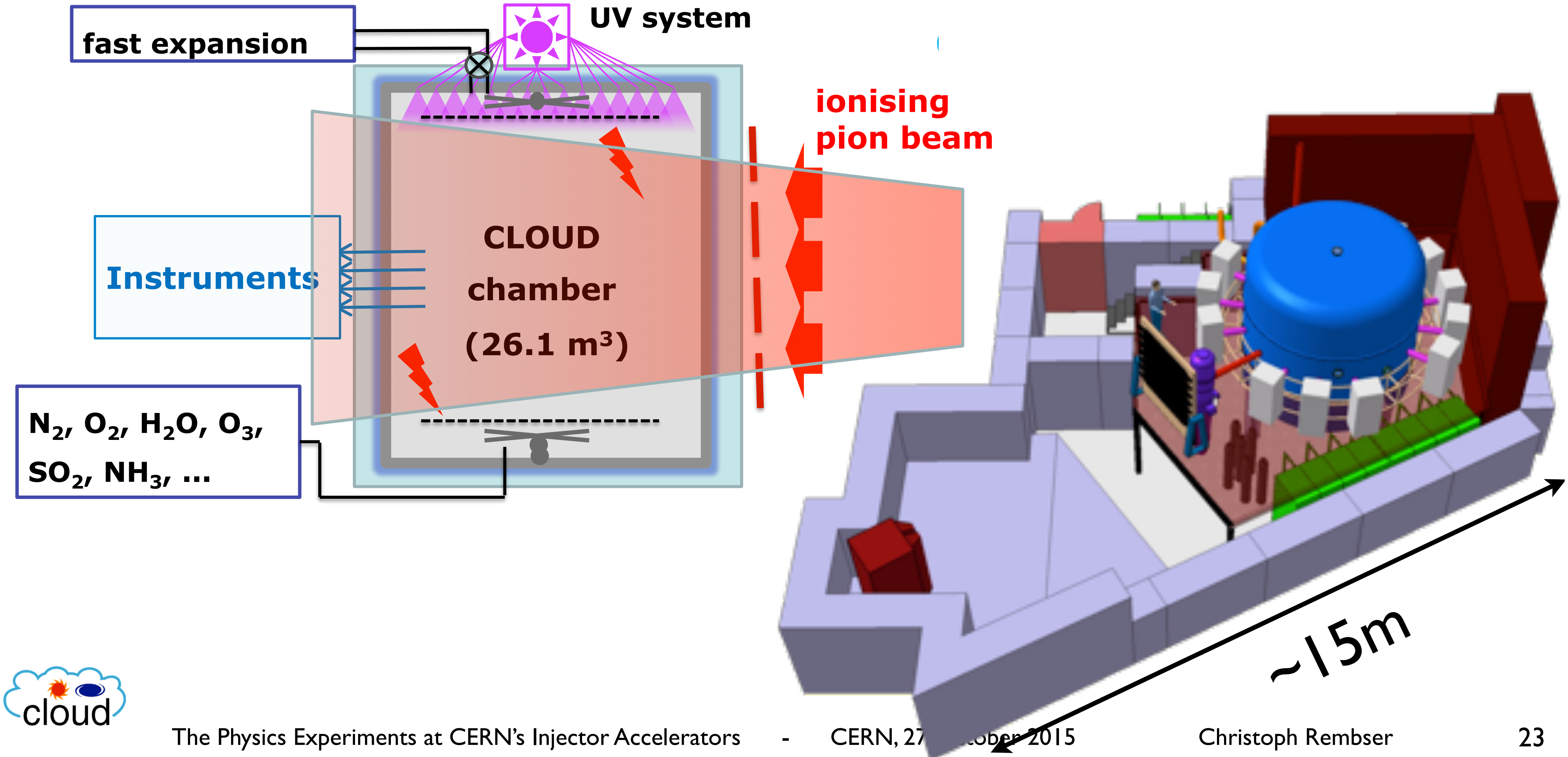


- All cloud droplets form on aerosol "seeds" known as cloud condensation nuclei - CCN
- Cloud properties are sensitive to number of droplets
- More aerosols/CCN:
  - brighter clouds, with longer lifetimes
- Sources of atmospheric aerosols:
  - direct (dust, sea salt, fires)

...but how do aerosols form clouds?

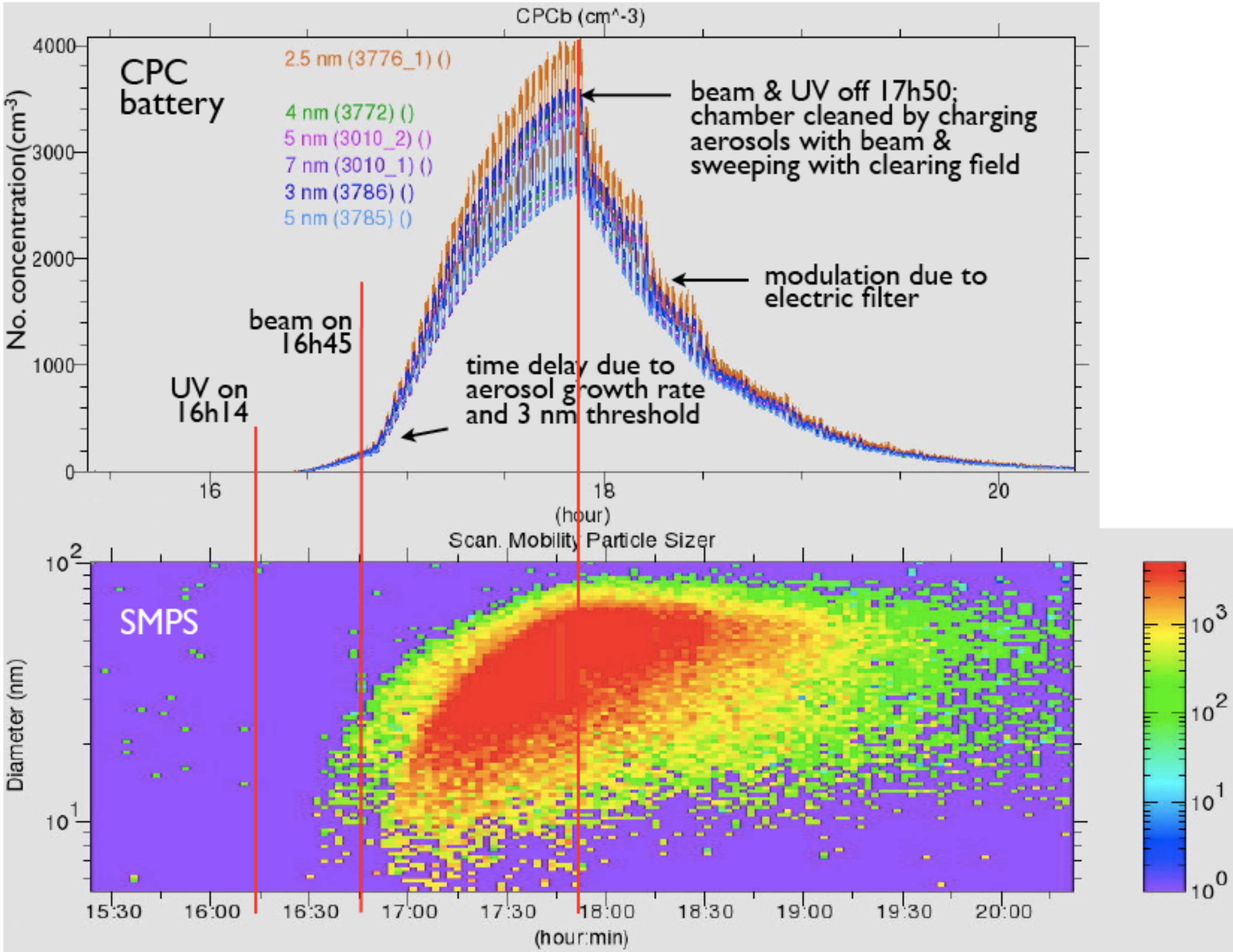
CLOUDs at CERN

- Simulate atmosphere in a cloud chamber (incl. gas composition, temperature, pressure...)
- use 3.6 GeV pions from the PS, spread over 1.8x1.8m, 1-100kHz rate, to simulate cosmic rays.

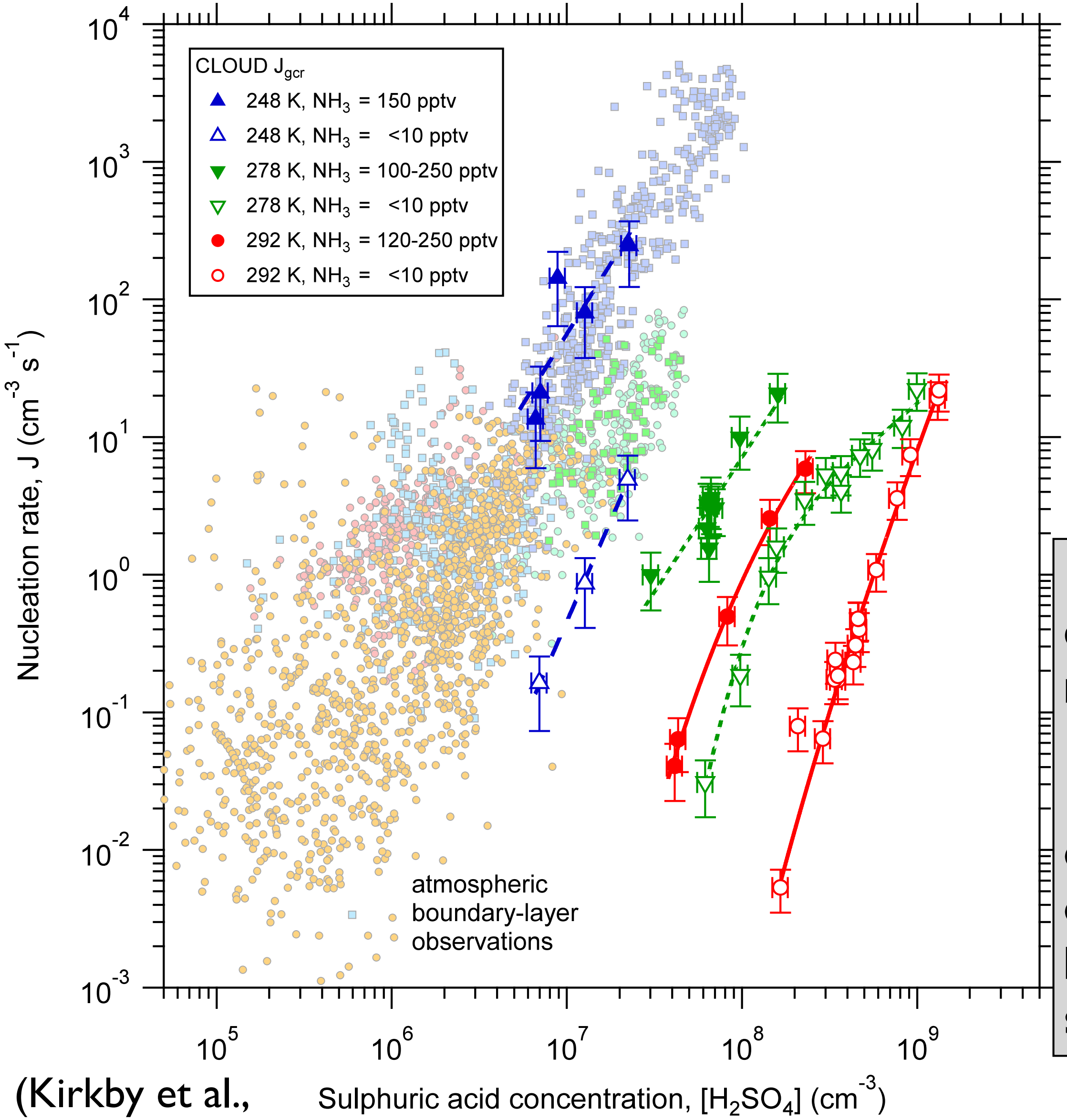


The CLOUD experiment in T11

A typical CLOUD run



CLOUD nucleation rate



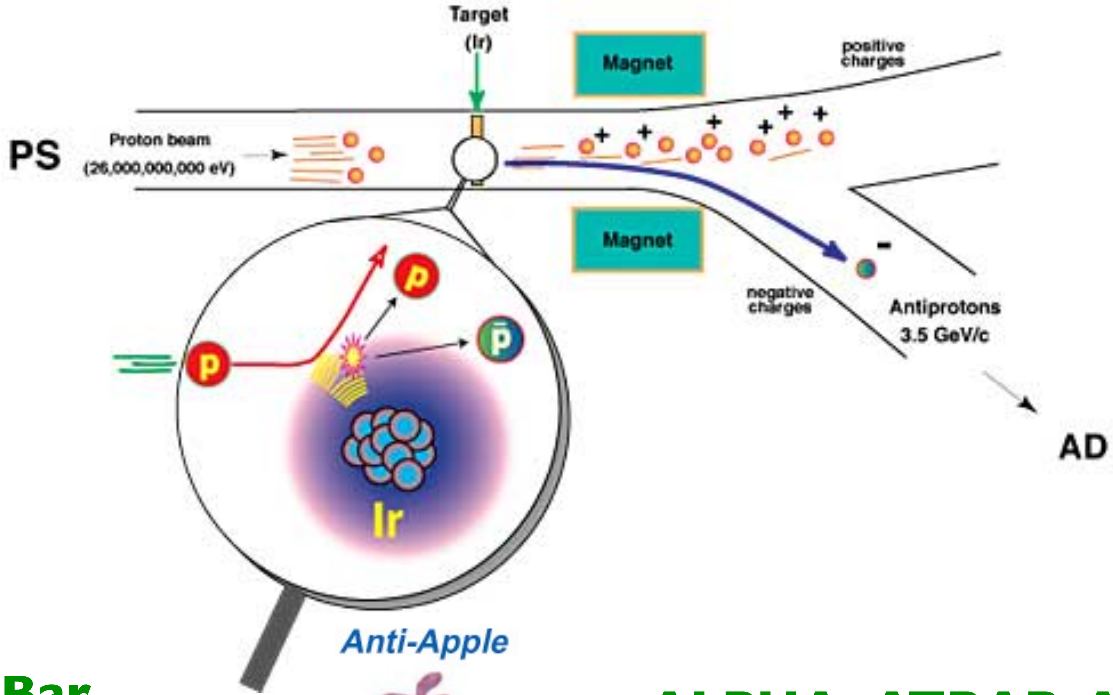
(Kirkby et al., Nature, 476, 2011)

➡ boundary layer nucleation cannot be explained by H_2SO_4 + NH_3 + ions (factor 10-1000 too slow)

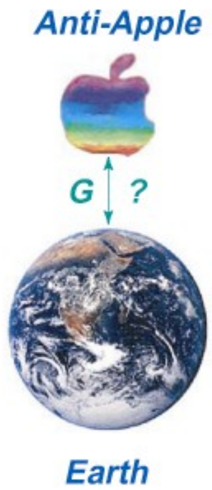
Results up to now cannot explain the observed atmospheric nucleation rates!

More measurement needed, more chemical compounds which contribute to nucleation rate need to be identified, more results to come... stay tuned!

Difference Matter-Antimatter: the AD experiments



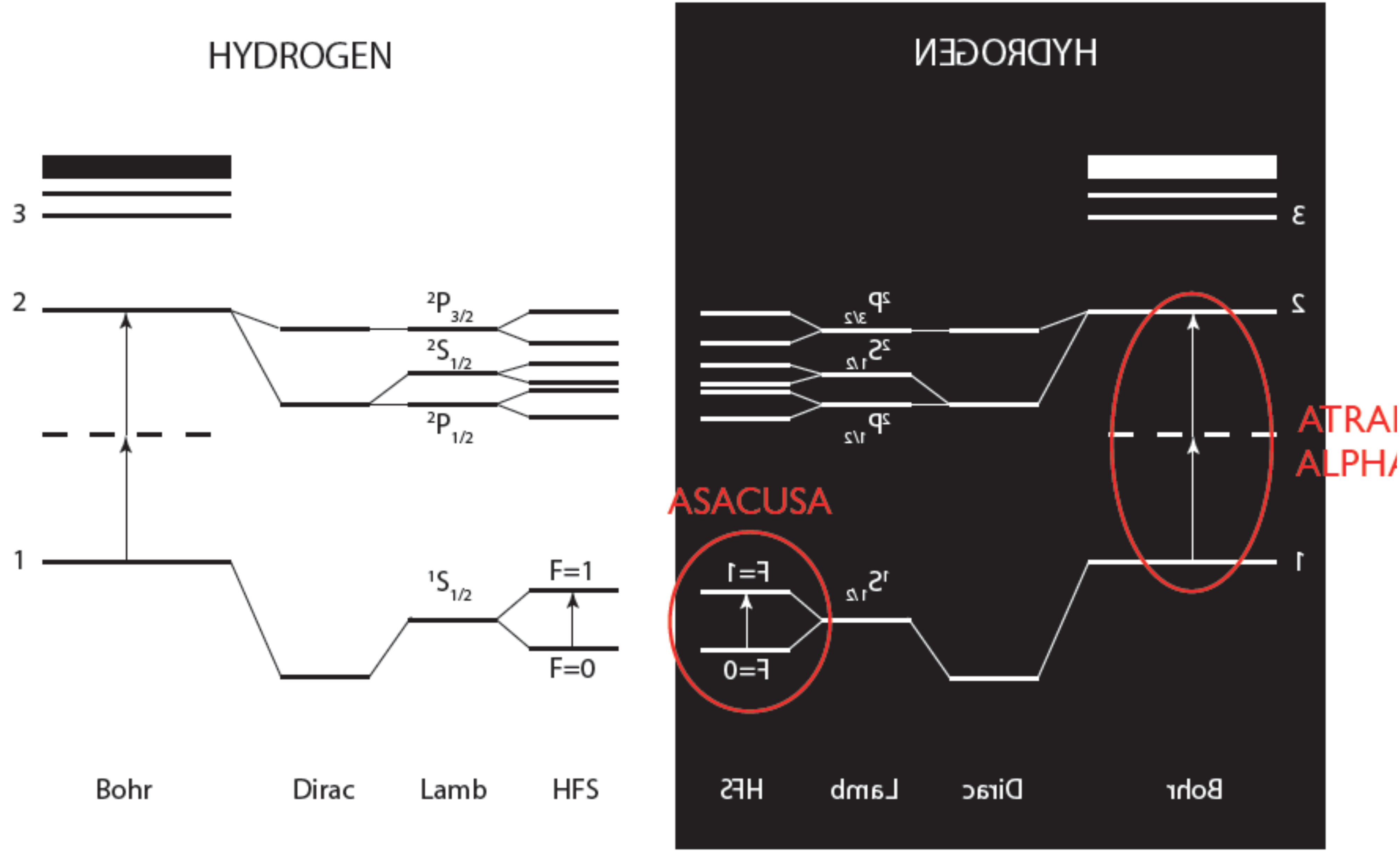
AEGIS and **GBar** **experiments:**
Comparing the behaviour of hydrogen
and anti-hydrogen in the earths **gravitational field**



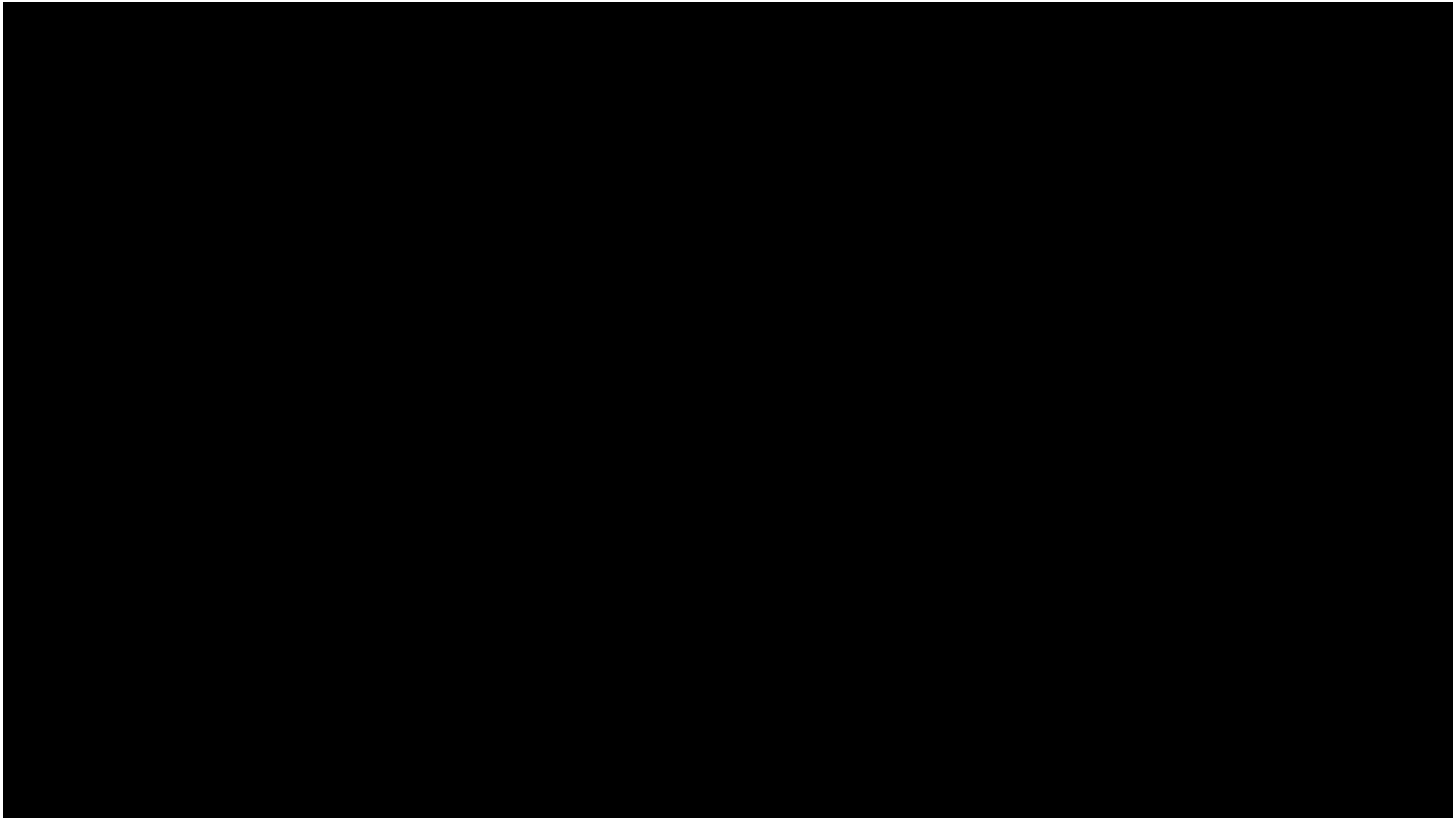
ALPHA, **ATRAP**, **ASACUSA** **experiments:**
Looking for differences between hydrogen and anti-hydrogen using **spectroscopy**
(well established technique, Gustav Robert Kirchhoff, Robert Wilhelm Bunsen 1859)

...and the **BASE** **experiment** is measuring the **magnetic moment of the anti-proton**

Spectroscopy - very precise

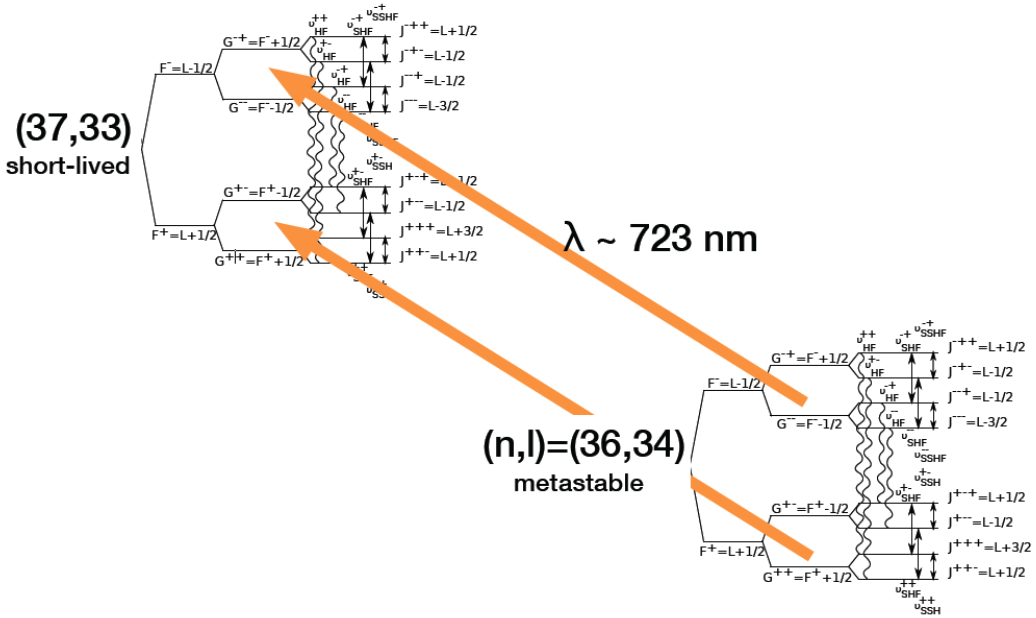


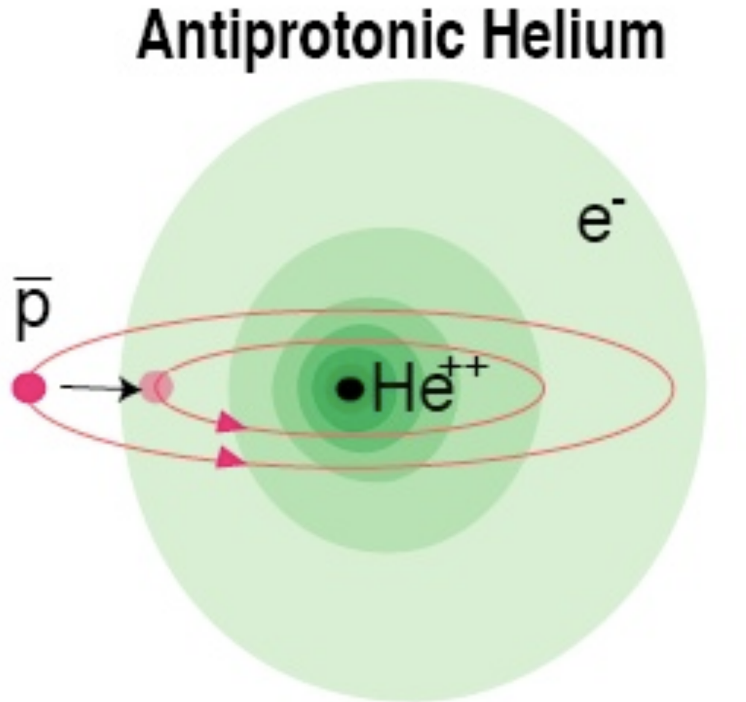
How it really works

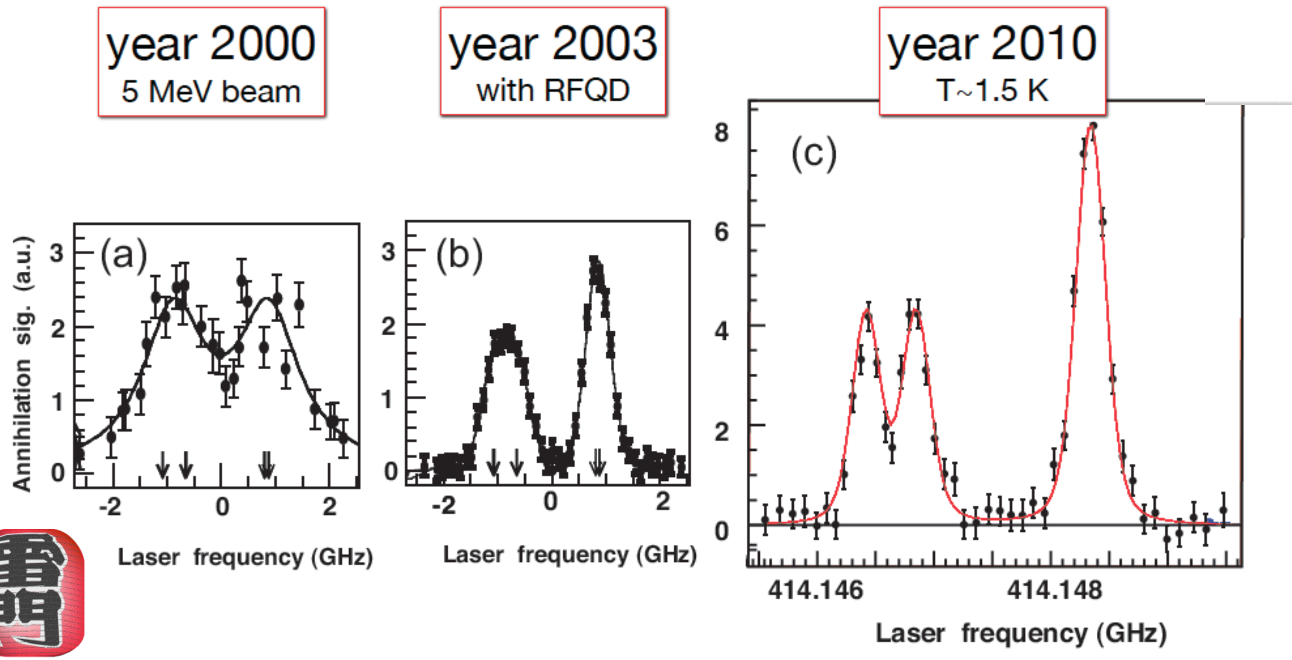


Video: ALPHA Collaboration

Spectroscopy, first steps: investigate antiprotonic Helium (ASACUSA)

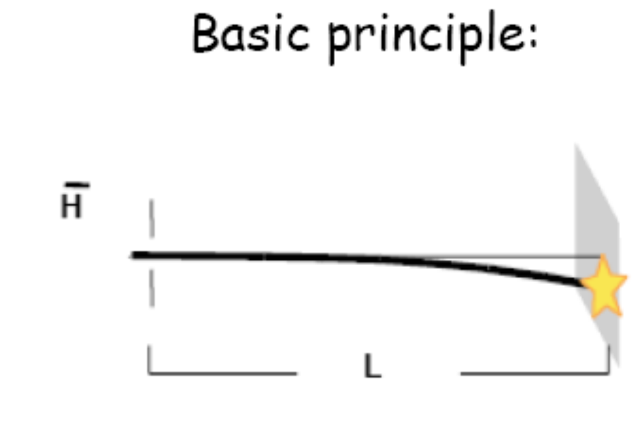






Very high accuracy reached!

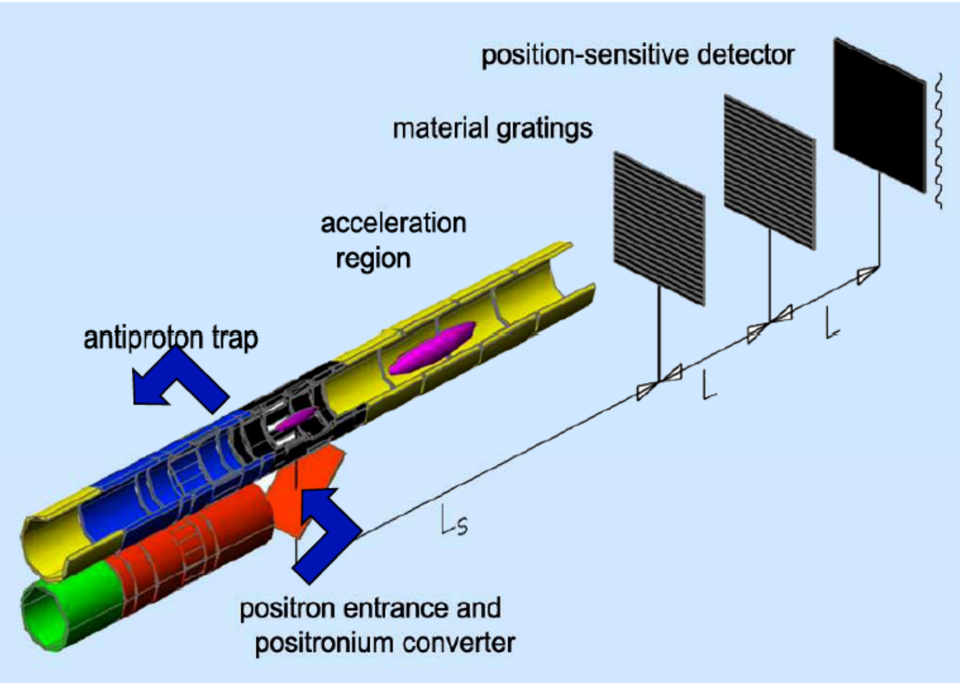
Measuring influence of gravity: AEGIS



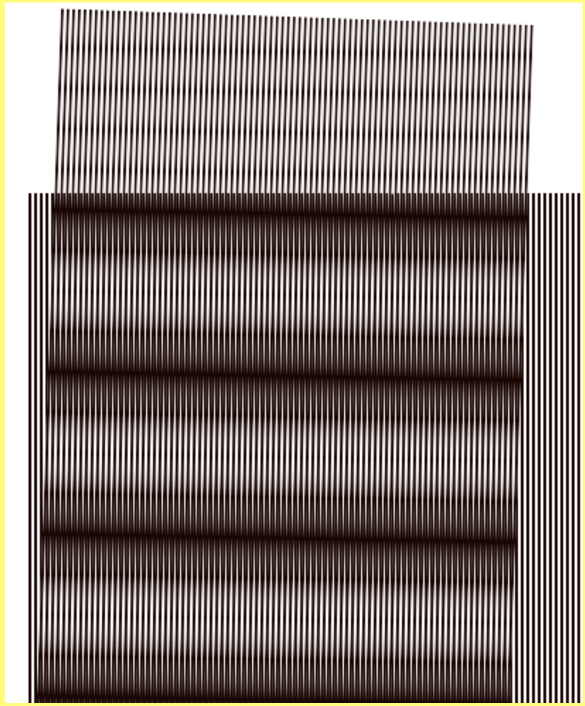
$$h = \frac{g}{2} \bullet \left(\frac{L}{v_h}\right)^2$$

Principle:

- Produce Anti-Hydrogen **beam…**
- …flying for 1m at a few 100m/s…
- …expect a deflection by gravity of about 20µm…
- …use **Moiré-Interferometer** to check deflection

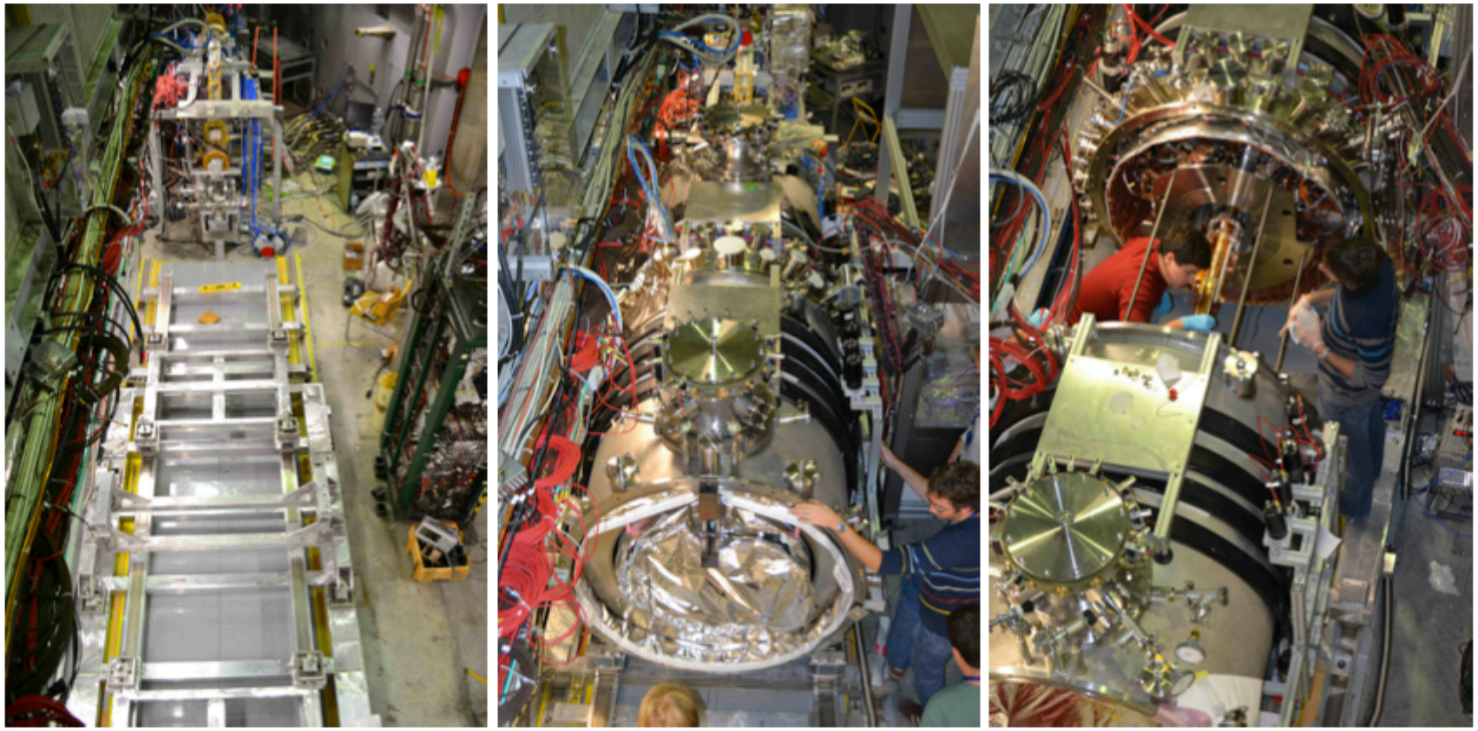


A ntimatter
E xperiment:
G ravity
I nterferometry
S pectroscopy

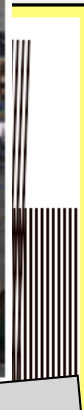


"A Moiré pattern, formed by two sets of parallel lines, one set inclined at an angle of 5° to the other"

Measuring influence of gravity: AEGIS



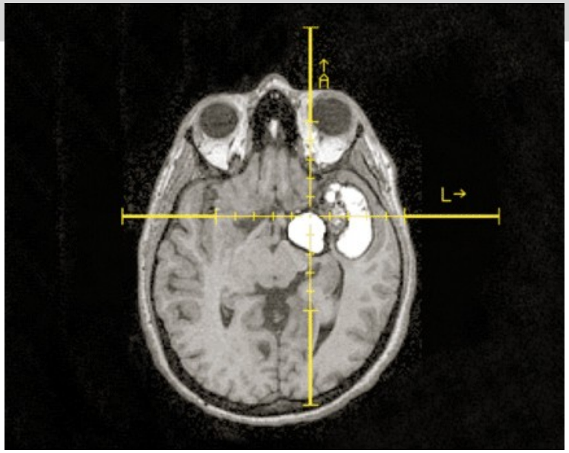
t 20μm…
ıeck deflection



Experiment is installed, commissioning with beam has started in 2012;
In 2013/2014: continuing commissioning with protons (source currently installed);
Start data taking end 2014.

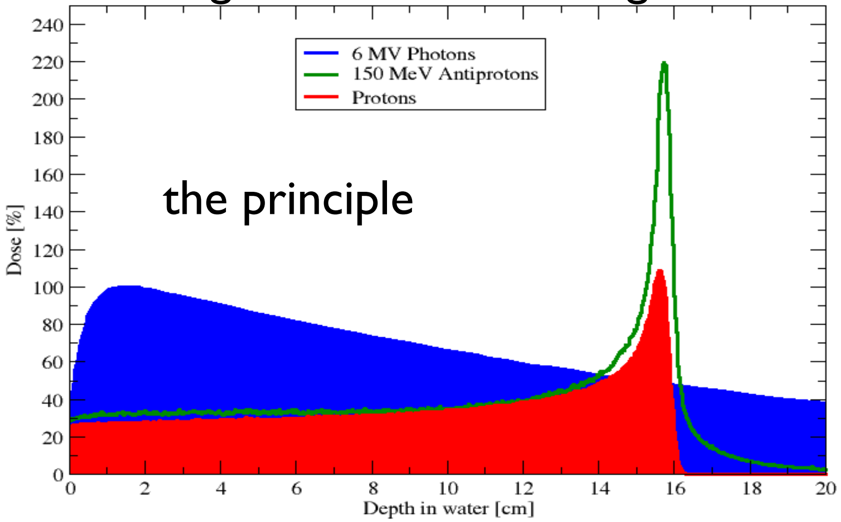
one set inclined at an angle of 5° to the other”

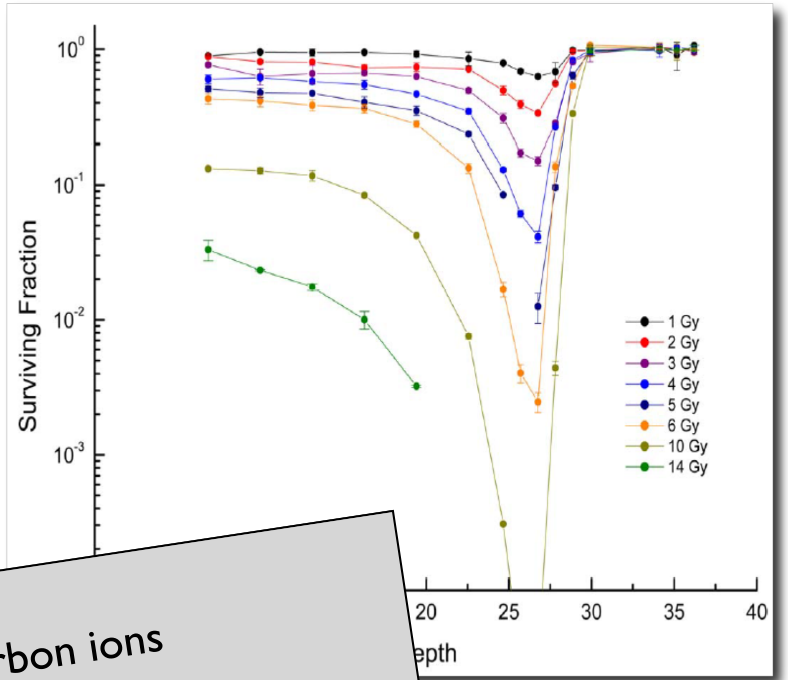
ACE experiment: Cancer therapy with antiprotons

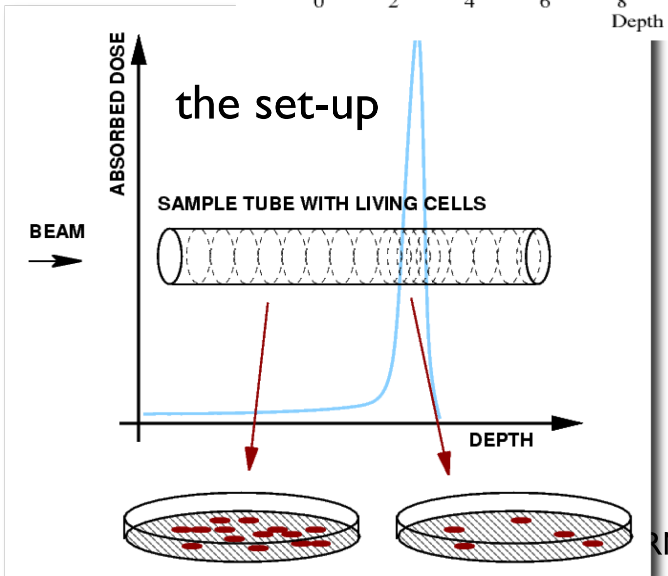


The challenge: hit the tumor, save surrounding tissue
The method: use antiproton annihilation

- Energy = 2 x mp ~1.88GeV
- Most of energy carried away by π,
- Recoiling nuclei do the damage ~ 30MeV



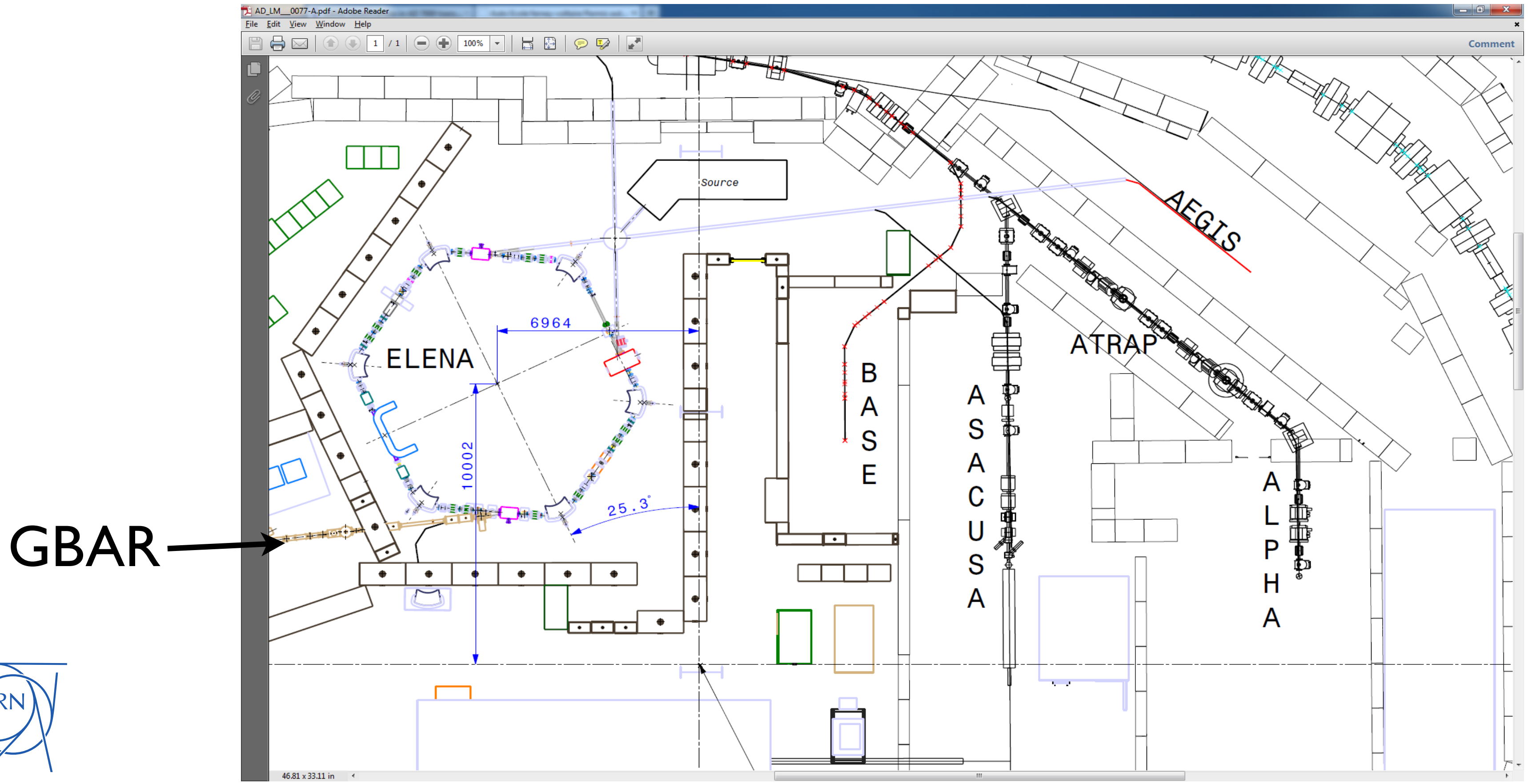




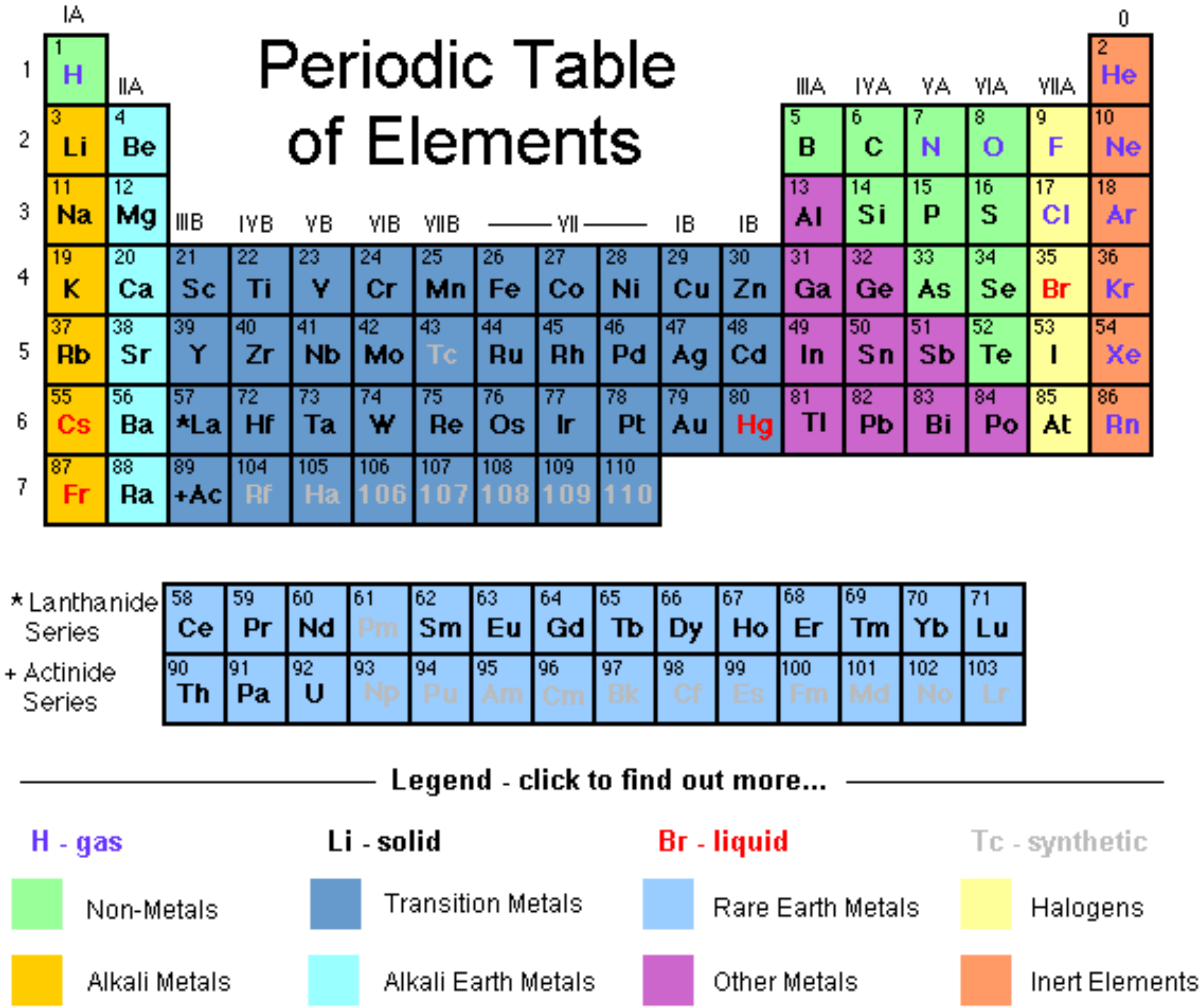
→ Still some way to go!
→ Need cross-check with carbon ions
→ Need better dose measurements…
→ Finale paper January 2016?

Very active programme at the AD

- even more experiments: GBAR (gravity) and BASE (antiproton magnetic moment);
- To provide sufficient number of antiprotons: "antiproton accumulator" ELENA (10-100 times more antiprotons for experiments), commissioning 2016, operation 2017.



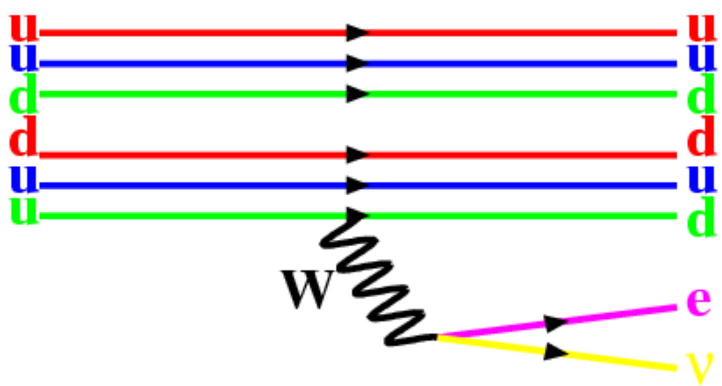
n-TOF: from particles to atoms and elements

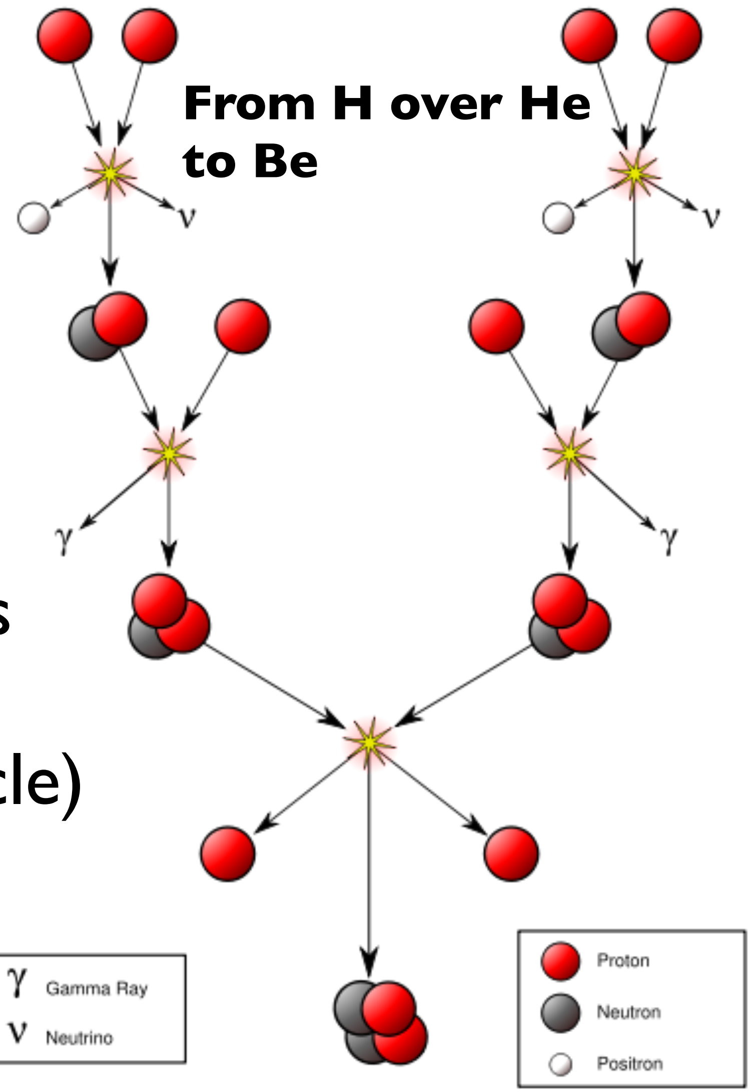


Elements in the universe

Elements up to iron are produced in stars by fusion
➙ fundamental process:

β+ decay of a proton to a neutron

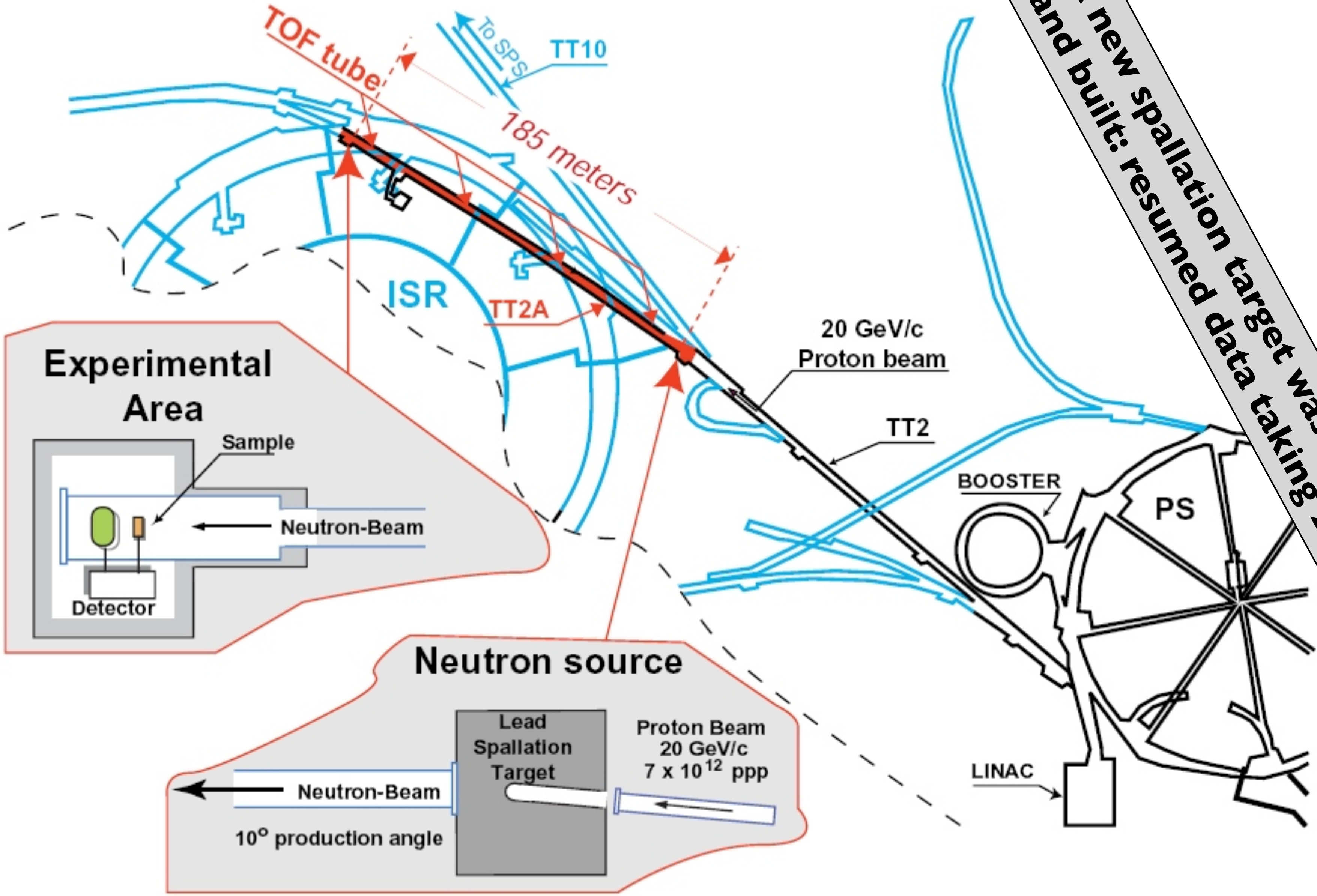




For elements bigger than Fe(26 protons, 30 neutrons) this process stops
➙ difficult for a proton (=charged particle) to enter the atom and reach nucleus

Where and how are heavy elements produced?

The n-TOF facility

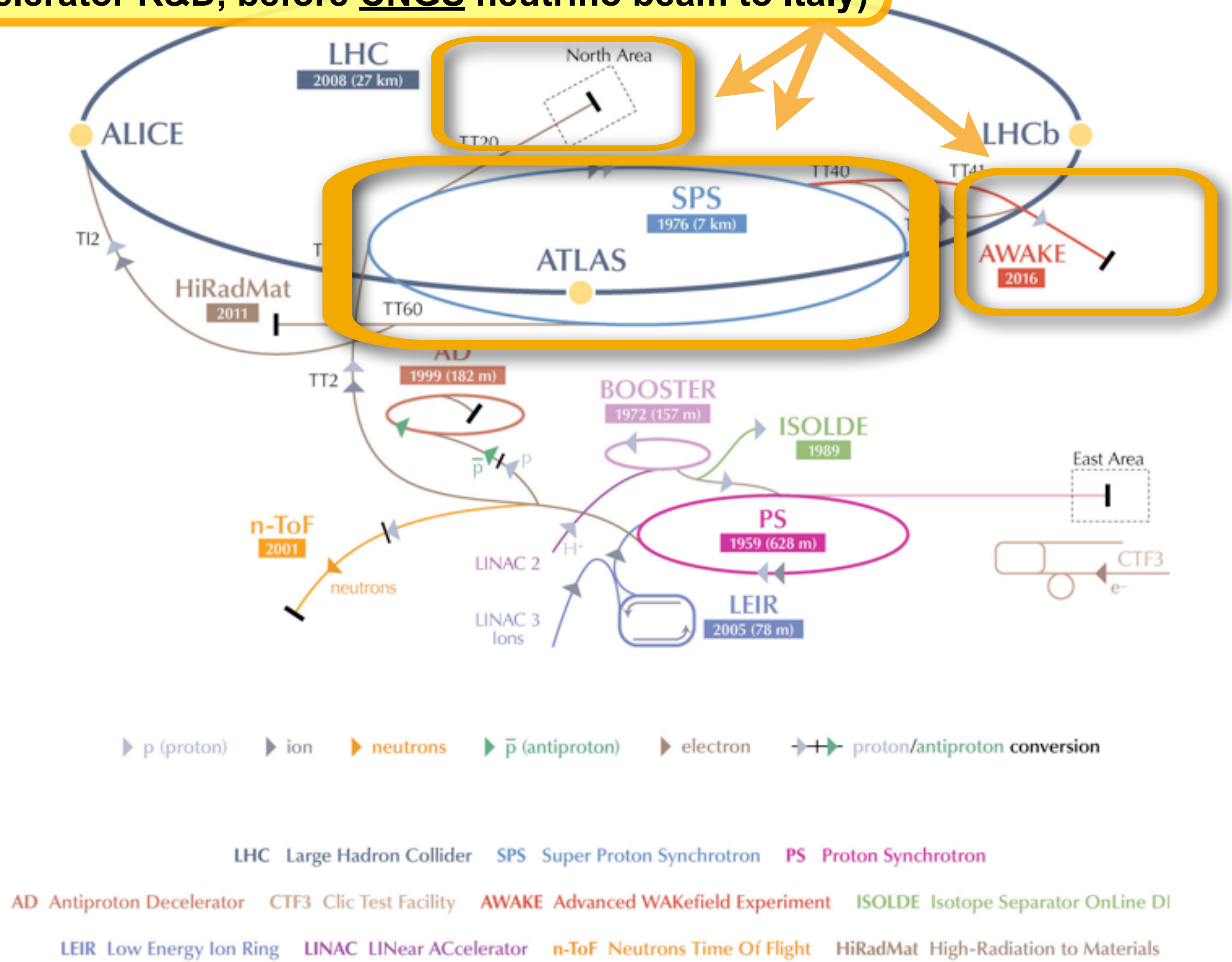


A new spallation target was needed and built: resumed data taking 2009

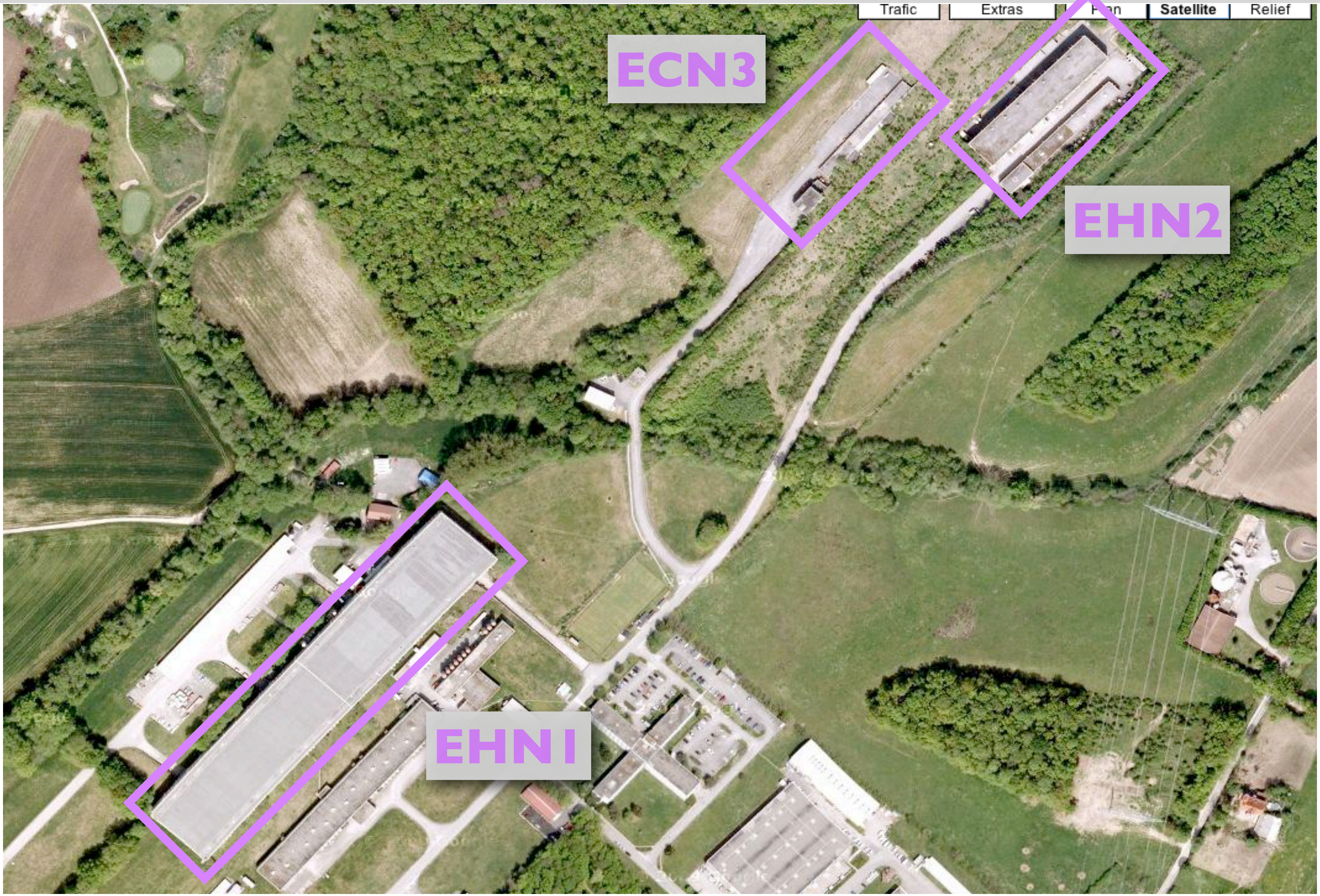
The CERN accelerators

<u>SPS</u> (Super Proton Synchrotron) provides protons to

- **<u>North Area</u>**
  - **beam tests for detector studies/calibration, material studies**
  - **COMPASS experiment (hadron spectroscopy)**
  - **NA62 experiment to study rare kaon decays, NA61, NA63**
- **<u>AWAKE</u> (accelerator R&D, before <u>CNGS</u> neutrino beam to Italy)**



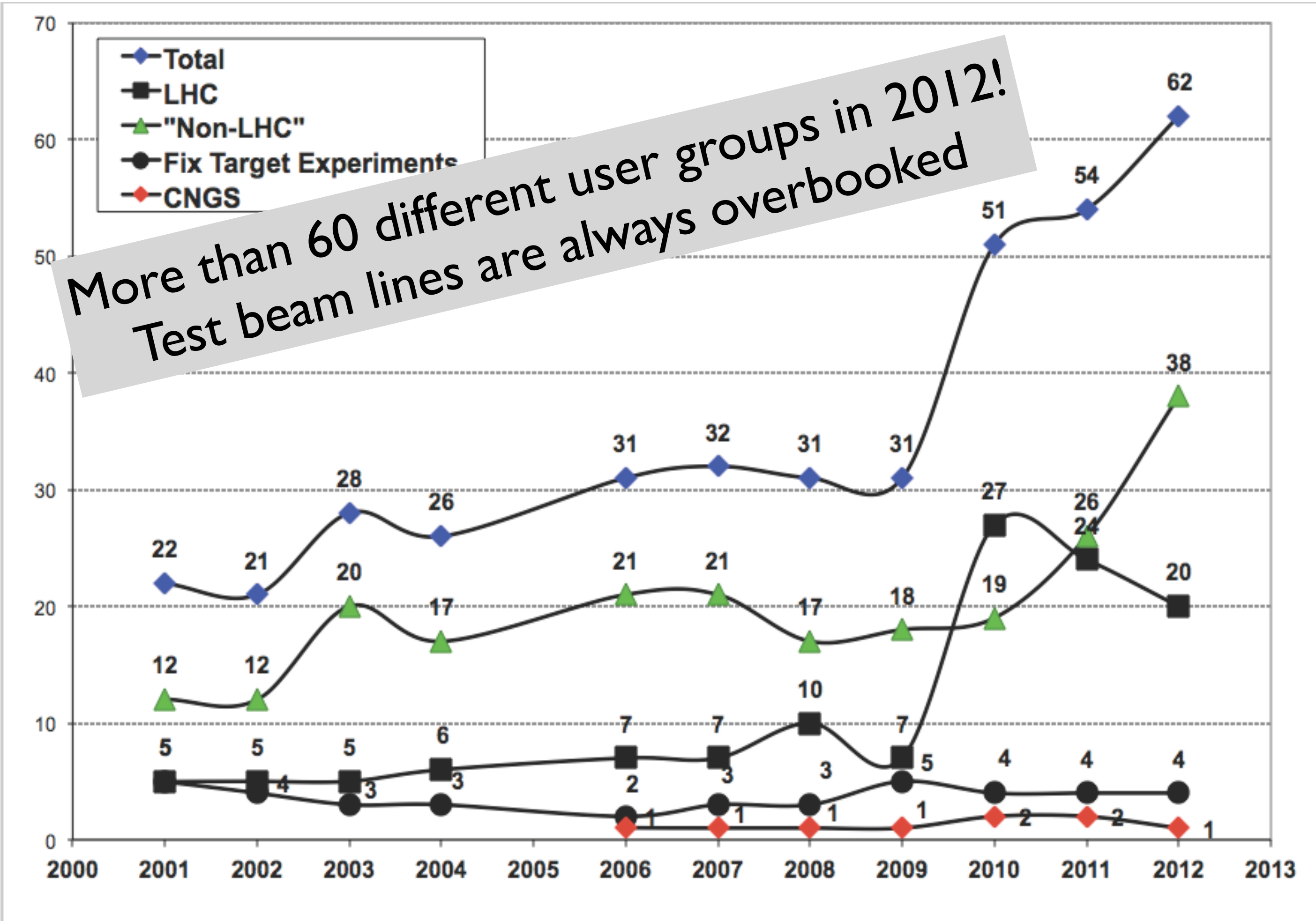
The SPS North Area



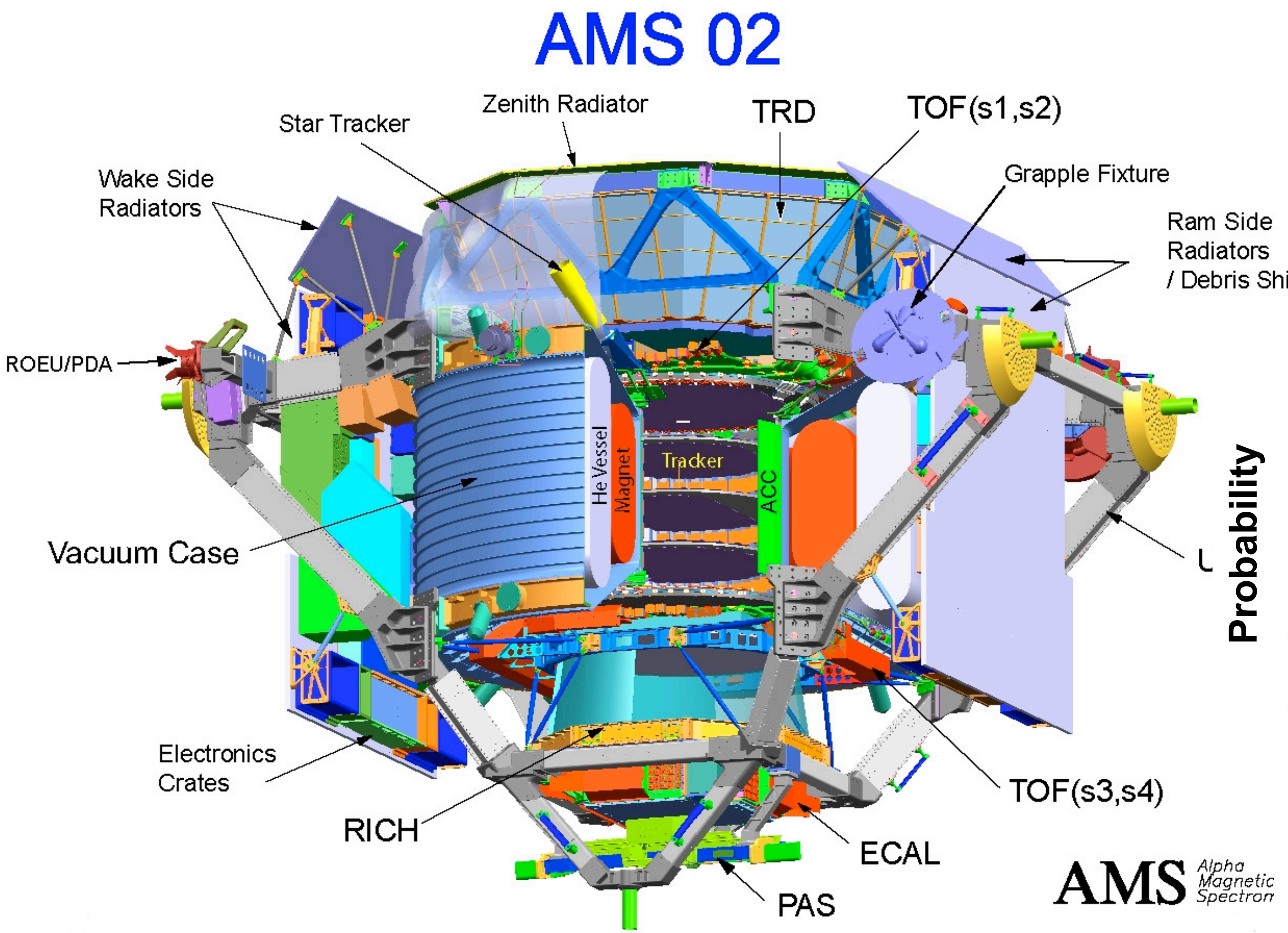
Inside the EHN1 experimental area

Number of test beam users is increasing

PS and SPS test beams provide world-wide unique opportunities to develop novel technologies, to test and calibrate particle detectors!

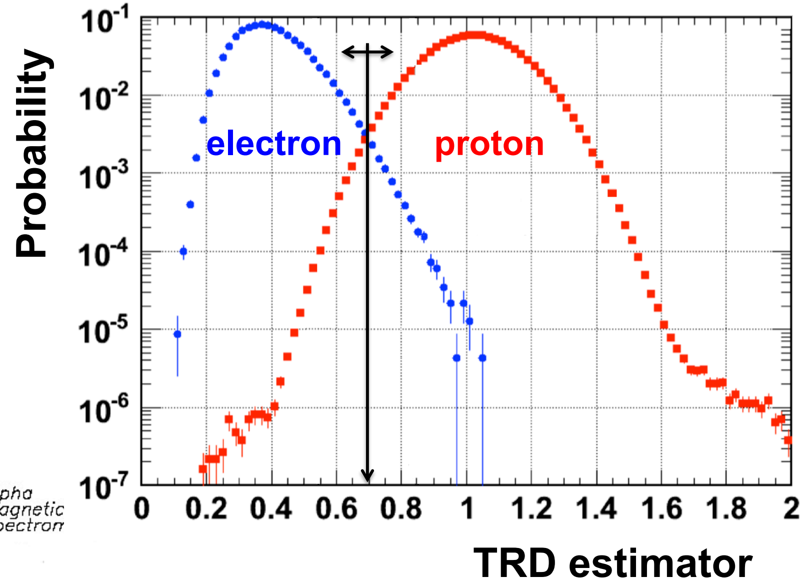


AMS: search for antimatter in space...



Example:
excellent particle identification in TRD - only achieved because of excellent calibration in SPS test beams:

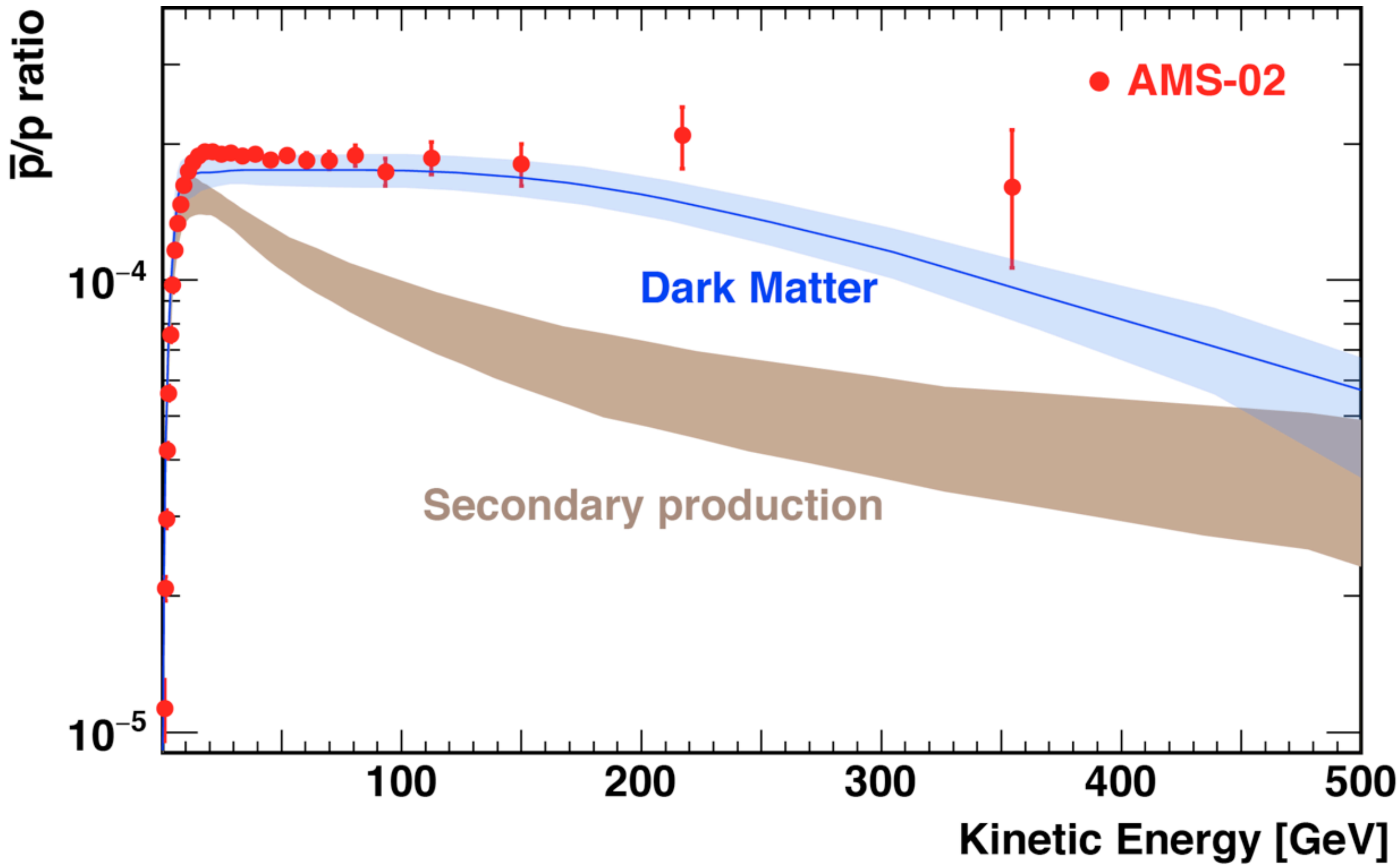
TRD estimator = $-\ln(P_e/(P_e+P_p))$



...needs down to earth calibration

AMS - very interesting results!

- see talk by A. Kounine, 15. April 2015 at the AMS days (https://indico.cern.ch/event/381134/timetable/#20150415)



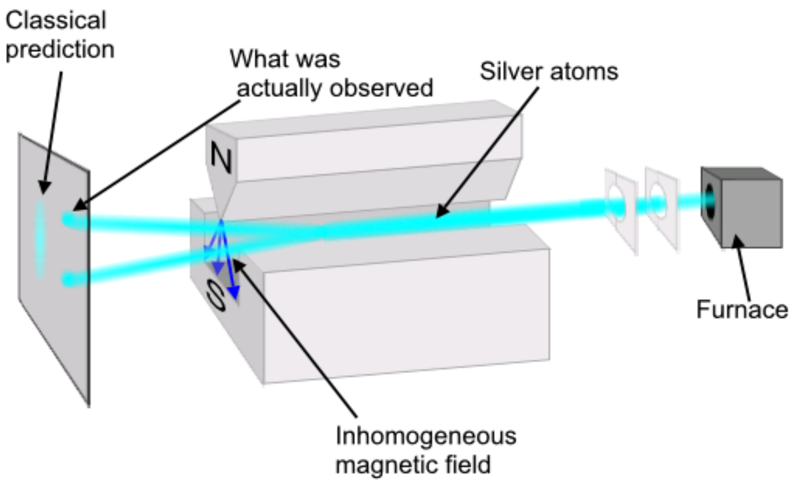
Number of antiprotons w.r.t. number of protons larger than expected. Hint for dark matter annihilation?

→ AMS will continue to operate for many years.

Important property of particles: the spin

Spin is an intrinsic property of a particle, like its charge, its mass.
Quantum Mechanics: angular momentum of particle is quantised
magnitude S can only take values of s, $S = \hbar\sqrt{s(s+1)},$

First observation by Stern & Gerlach 1922:



A beam of electrically neutral particles is influenced by magnetic field!!!

Silver atoms exist in two states!!! (spin 1/2 & spin -1/2)

Spin is a fundamental property of particles (Pauli Principle).

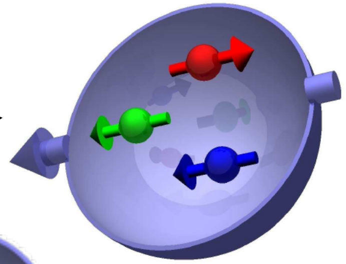
Do we understand the spin of compound objects,
e.g. **proton spin (=1/2)**???

The spin of the nucleon

Contributions to the spin of the proton

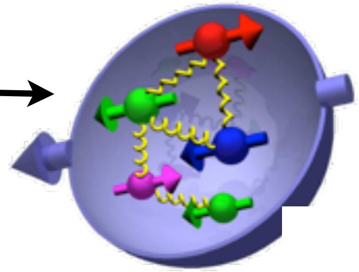
- naive QPM: only valence quarks Δq_v

  QPM = Quark Parton Model

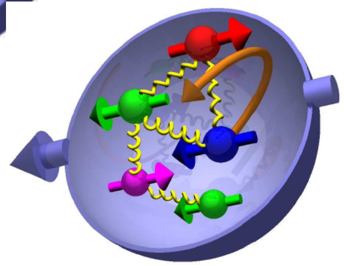


- QCD: sea quarks and gluons Δq_s, ΔG

  QCD = Quantum Chromo Dynamic



- orbital angular momentum L_q, L_g



Spin of proton = 1/2

- naive QPM: 1/2 = 1/2 - 1/2 + 1/2
- otherwise, with $\Delta\Sigma = \Delta u + \Delta d + \Delta s$

$$1/2 = 1/2 \cdot \Delta\Sigma + 1 \cdot \Delta G + \langle L_z \rangle$$

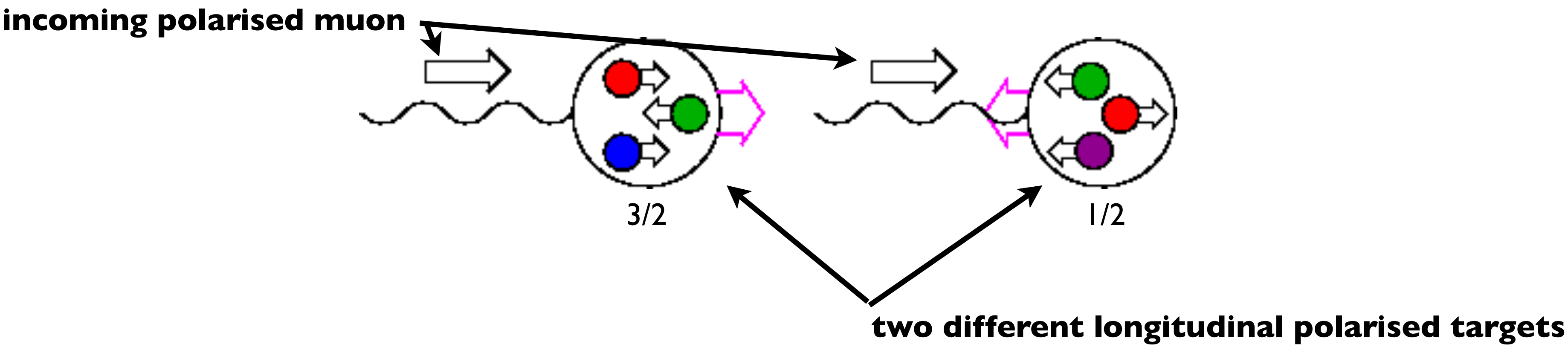
contribution from quarks... ...from gluons... ...and angular momentum

The Common Muon and Proton Apparatus for Structure and Spectroscopy: COMPASS

View from the crane into the COMPASS experimental facility

How to measure $\Delta\Sigma$?

Incoming (polarised) muon radiates (polarised) photon (photoabsorption)



- only quarks with opposite helicity can absorb the polarised photon via spin-flip
- Measure "deflected" muon, count interactions with target 1 or 2

→ Number of quarks in polarisation direction of nucleon: $\frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$

Asymmetry measurement (a / sum)
no systematics, e.g. particle flux

Result: $\Delta\Sigma \sim 0.25$

(=fraction of contribution to proton spin by quarks)

...what else contributes???

What else contributes?

$$1/2 = 1/2\cdot\Delta\Sigma + 1\cdot\Delta G + \langle L_z \rangle$$

small — unknown challenge! — unknown^2

some theories predict VERY high contributions, but shielded and canceled by higher sea quark contributions

Instead of photoabsorption by quarks, measure absorption by gluons
Difficulty: how to distinguish absorption by quark and gluon???

- → photon interaction with gluons sometimes produces heavy quarks (c, …)
- → look for **particle jets containing c quarks**…
  (and repeat asymmetry measurement, see previous slide)

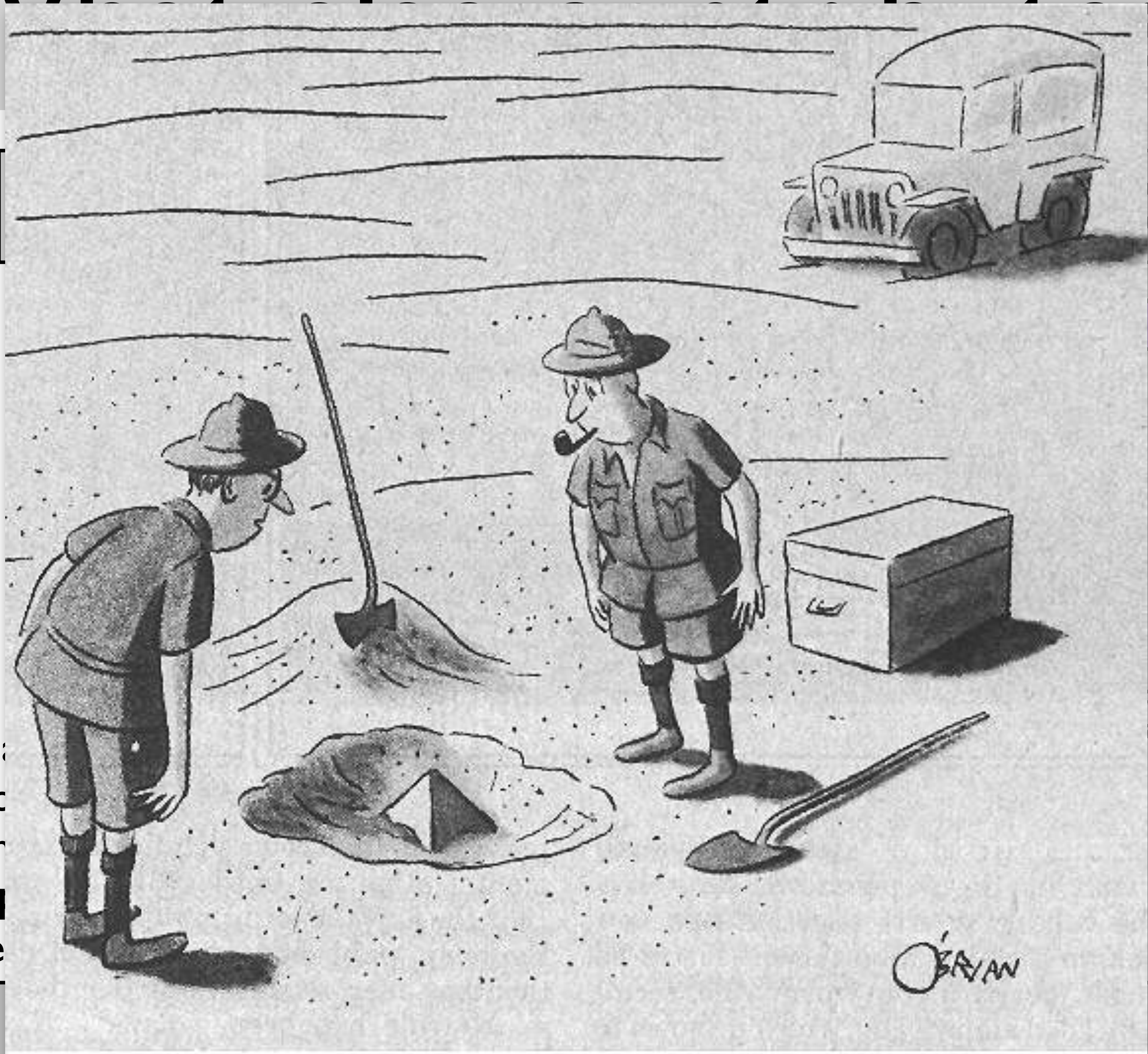
COMPASS result: ΔG ~ 0.06
VERY SMALL!!!
Search for the spin contribution be continued…

Wh… s?

…wn^2

…ict VERY high
…hielded and canceled
contributions

Instead of photo…
Difficulty: how to…
→ photon in…
→ look for …
(and repe…



“This could be the discovery of the century. Depending, of course, on how far down it goes.”

Search… …nued…

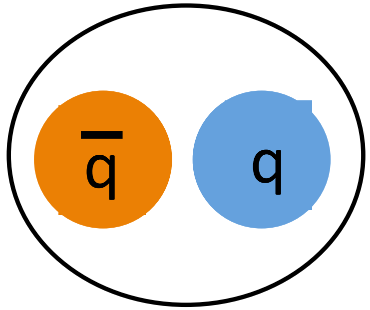
COMPASS

Understanding compound states...

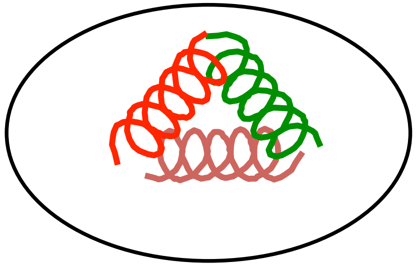
...requires to measure and to understand how quarks and gluons interact (QCD).

- Light mesons, quarks and gluons:

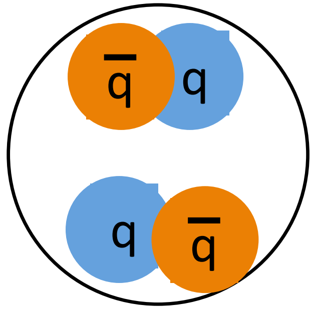
Quark model mesons (u, d, s quarks) →



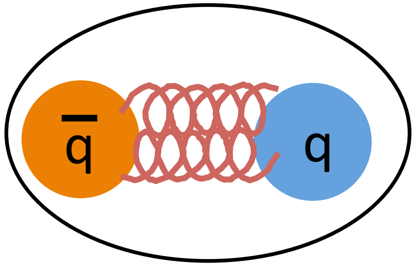
Glueballs (gluons and no valence quarks) →



Multiquarks (quark-antiquark pairs) →



Hybrids (quarks and gluonic excitation, which contribute to static properties) →

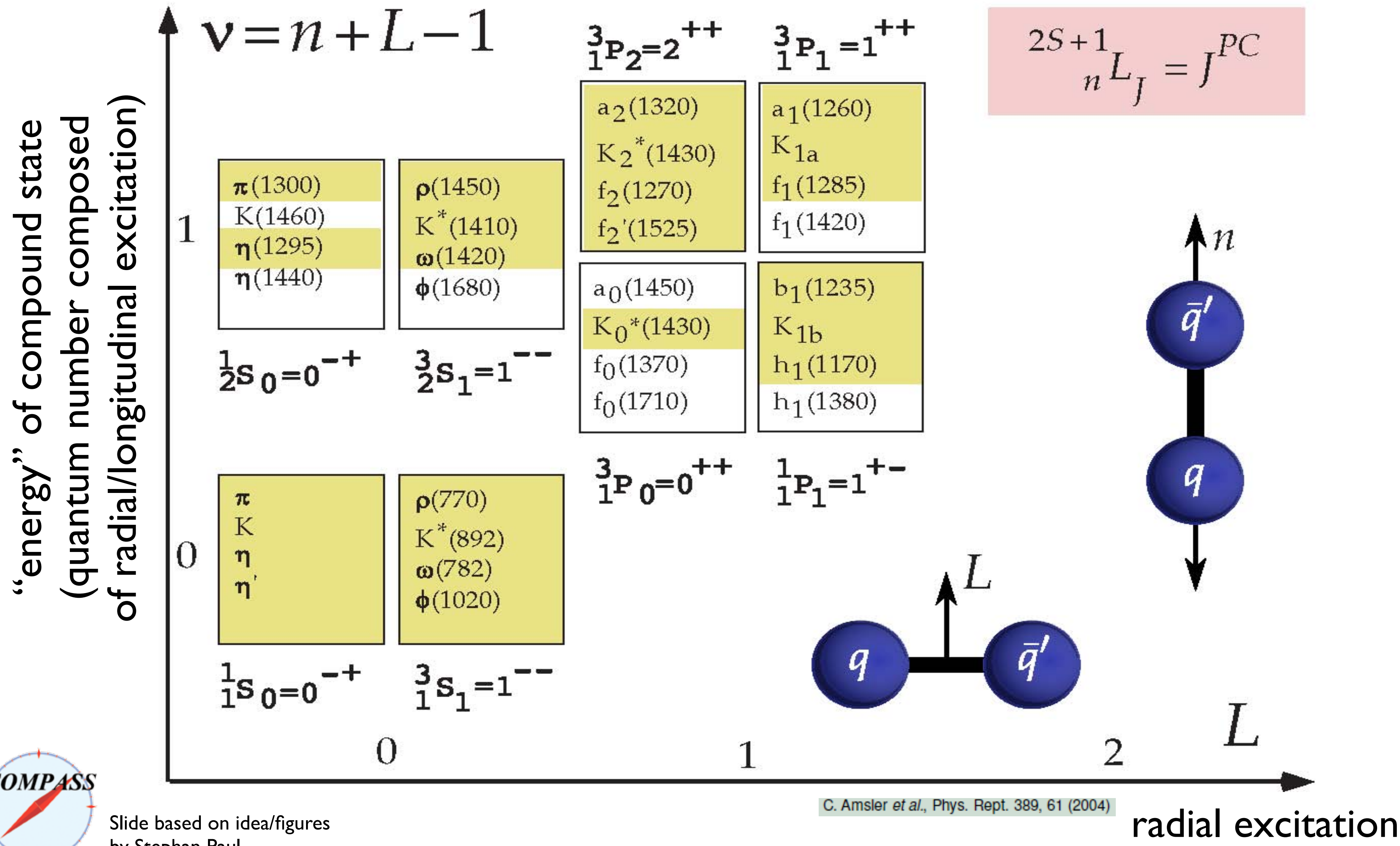


COMPASS

Slide based on idea/figures by Stephan Paul

COMPASS Meson Spectroscopy

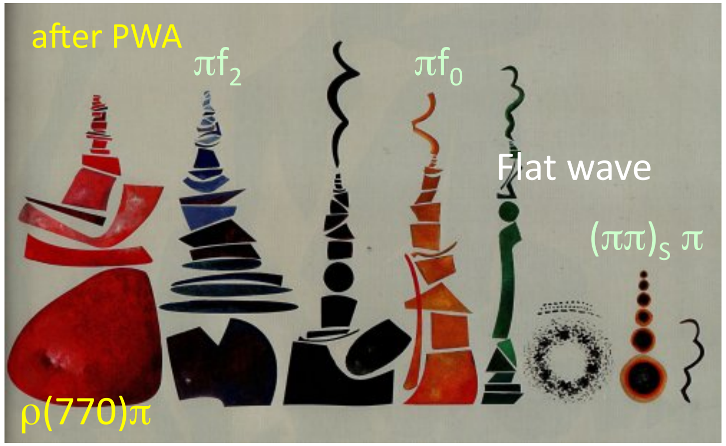
What is the hierarchy or spectrum of particles that quarks and gluons can form?



C. Amsler et al., Phys. Rept. 389, 61 (2004)

Slide based on idea/figures by Stephan Paul

COMPASS: Partial Wave analysis

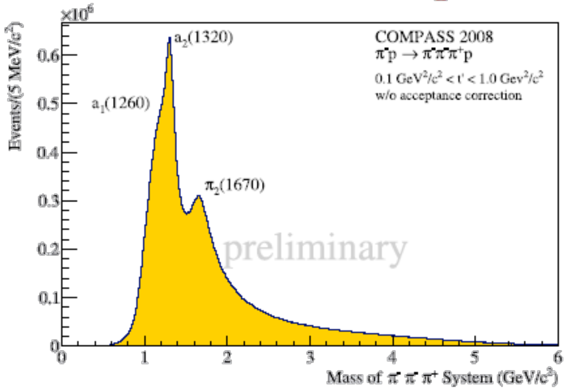


Art taken from Urs Wehrli:
"Kunst aufgeräumt"
Idea: Stephan Paul

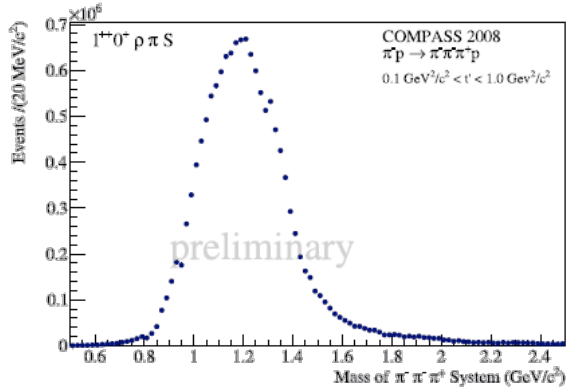
2013: new state observed, see https://indico.cern.ch/conferenceDisplay.py?confId=286069
$a_1(1420)$, $M_{a1(1420)}$ = 1412-1422 MeV/c^2 , $\Gamma_{a1(1420)}$ = 130-150 MeV/c^2

Major waves used for fit (examples):

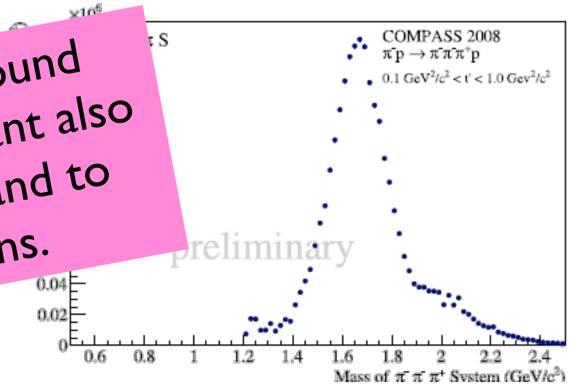
$\pi^-\pi^+\pi^-$ invariant mass spectrum



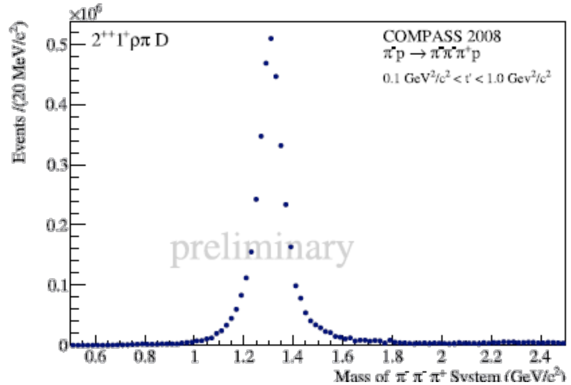
$1^{++}0^+ [\rho\pi]S : a_1(1260)$



$2^{-+}0^+ [f_2\pi]S : \pi_2(1670)$



$2^{++}1^+ [\rho\pi]D : a_2(1320)$

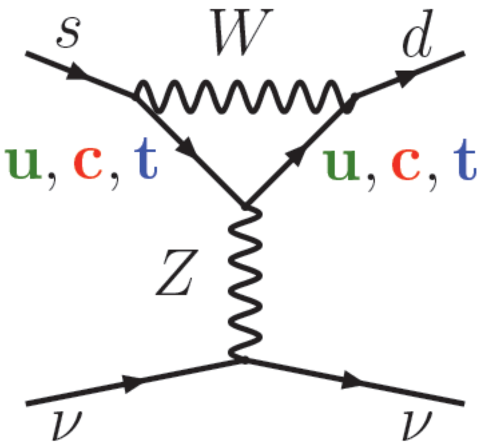


CR Comment: Knowledge of compound states of quarks and gluons is important also for the LHC to better understand and to simulate proton proton collisions.

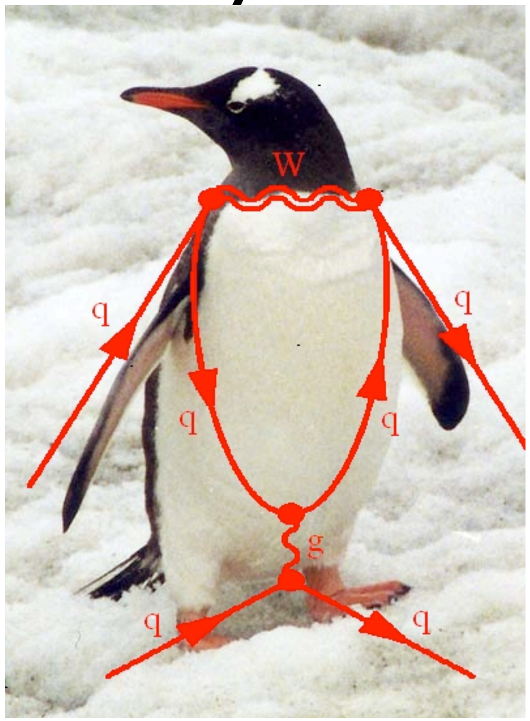
Probing the Standard Model

- NA62 is searching for ultra-rare kaon decays

$K \rightarrow \pi \nu \bar{\nu}$

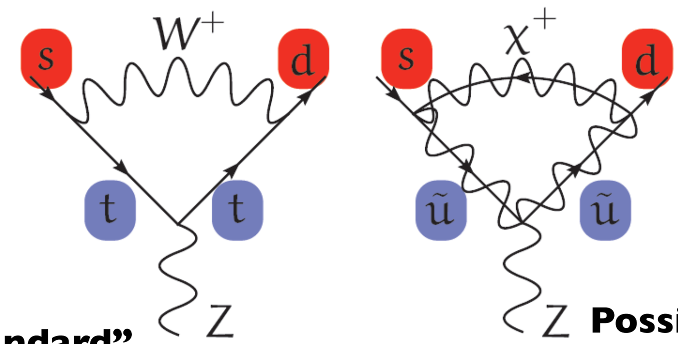


...so-called "penguin graph"



The contribution to these processes due to the Standard Model is **strongly suppressed (<10^{-10})** and **calculable with excellent precision (~%)**

They are very sensitive to possible contributions from **New Physics**



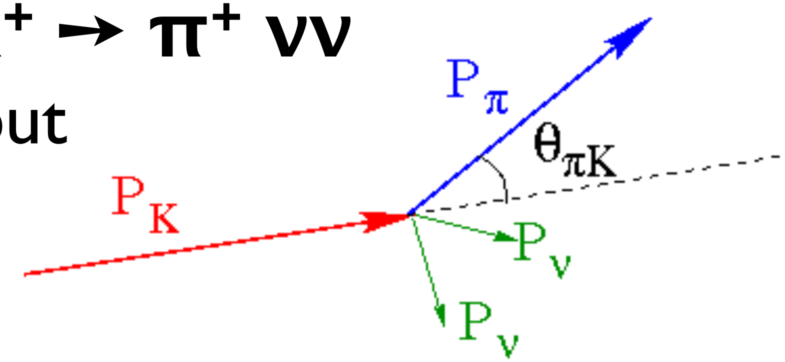
"Standard" Penguin

Possible "Super-Symmetric" Penguin

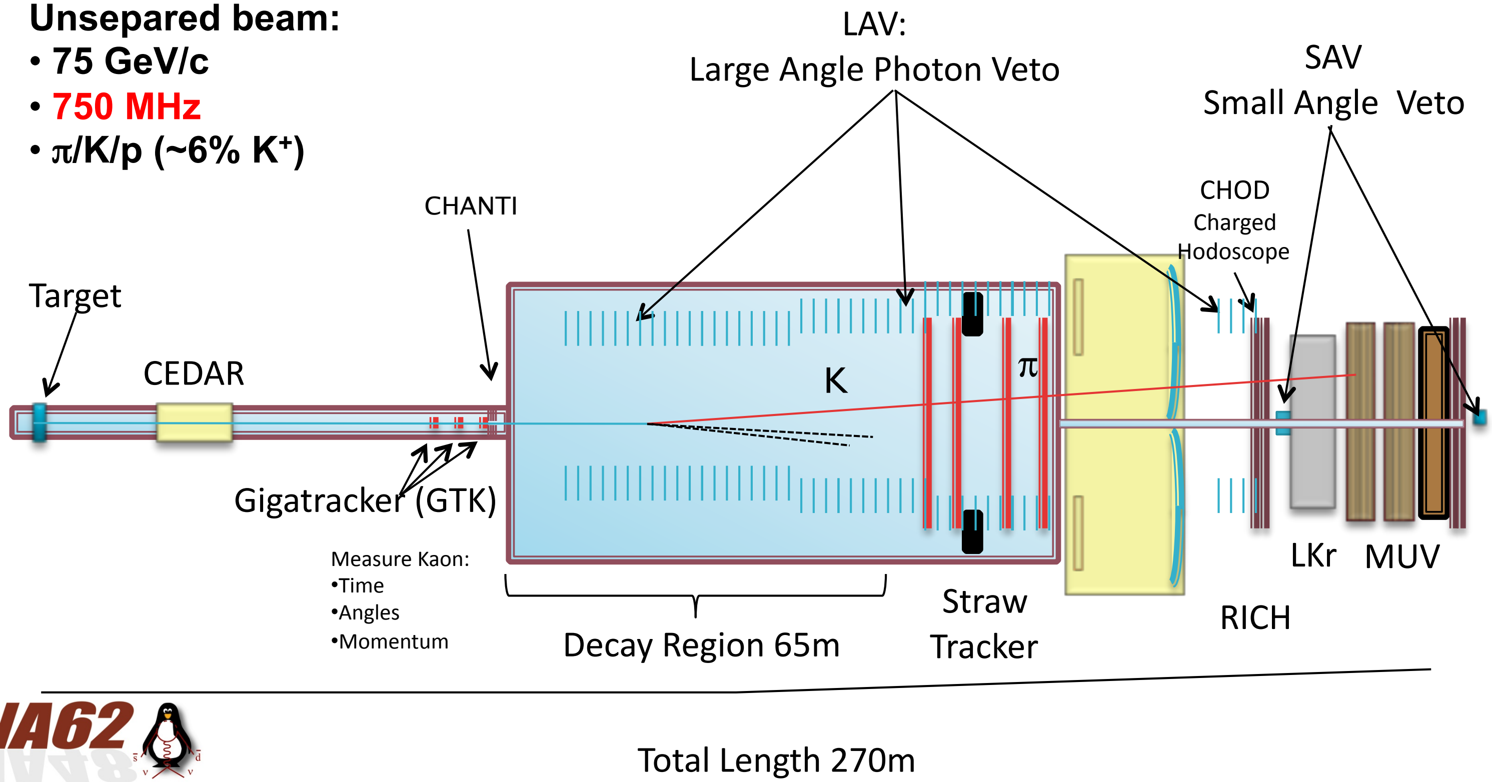
N62: experiment to measure rare kaon decays

Goal of the experiment:
Measure rate of rare kaon decay $\mathbf{K^+ \rightarrow \pi^+ \nu\nu}$
Rate in Standard Model: ~O(10^{-6}) but much enhanced when there is physics beyond the SM

Main background
$\mathbf{K^+ \rightarrow \pi^+ \pi^0}$



SPS primary p: 400 GeV/c
Unsepared beam:
- **75 GeV/c**
- **750 MHz**
- **π/K/p (~6% K⁺)**



Beam line:
- •CEDAR: K ID
- •Gigatracker: beam particle ID
- •CHANTI: Charged particle veto

Detector region:
- •pion tracks: straws
- •particle ID: LKr, RICH
- •muon rejection: MUV
- •photon rejection: LKr, LAV, SAV

•K+ rate: 11 kHz

NA62 - work ongoing, start in 2014

NA62 - work ongoing, start in 2014

NA62 high intensity will allow searches for lepton flavour violation

- 4.5x1012 K decays/year will allow improvements in many possible processes:

Mode	UL at 90% CL	Experiment	Reference
$K^+ \to \pi^+\mu^+e^-$	1.3×10^{-11}	E777/E865	PRD 72 (2005) 012005
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}		
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10}	E865	PRL 85 (2000) 2877
$K^+ \to \pi^-e^+e^+$	6.4×10^{-10}		
$K^+ \to \pi^-\mu^+\mu^+$	1.1×10^{-9}	NA48/2	PLB 697 (2011) 107
$K^+ \to \mu^-\nu e^+e^+$	2.0×10^{-8}	Geneva-Saclay	PL 62B (1976) 485
$K^+ \to e^-\nu\mu^+\mu^+$	no data		
$\pi^0 \to \mu^+e^-$	3.6×10^{-10}	KTeV	PRL 100 (2008) 131803
$\pi^0 \to \mu^-e^+$	3.6×10^{-10}		

from T. Spadaro, talk at BLV2013 in Heidelberg

- First studies indicate that sensitivities down to 10^{-12} are possible.
- Also option to measure decays from π^0 are currently studied as e.g. decays into eμ are forbidden by SM.
- More studies for future measurements at NA62: study of very rare $K^0_L \to \pi^+ \nu\nu$

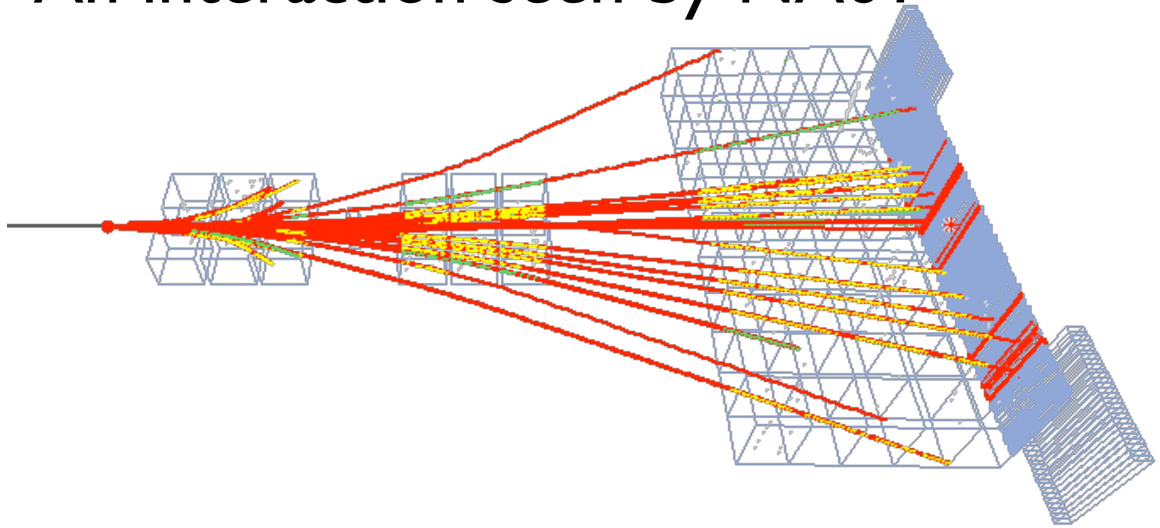
Searches, Predictions, Spectra - the NA61 experiment

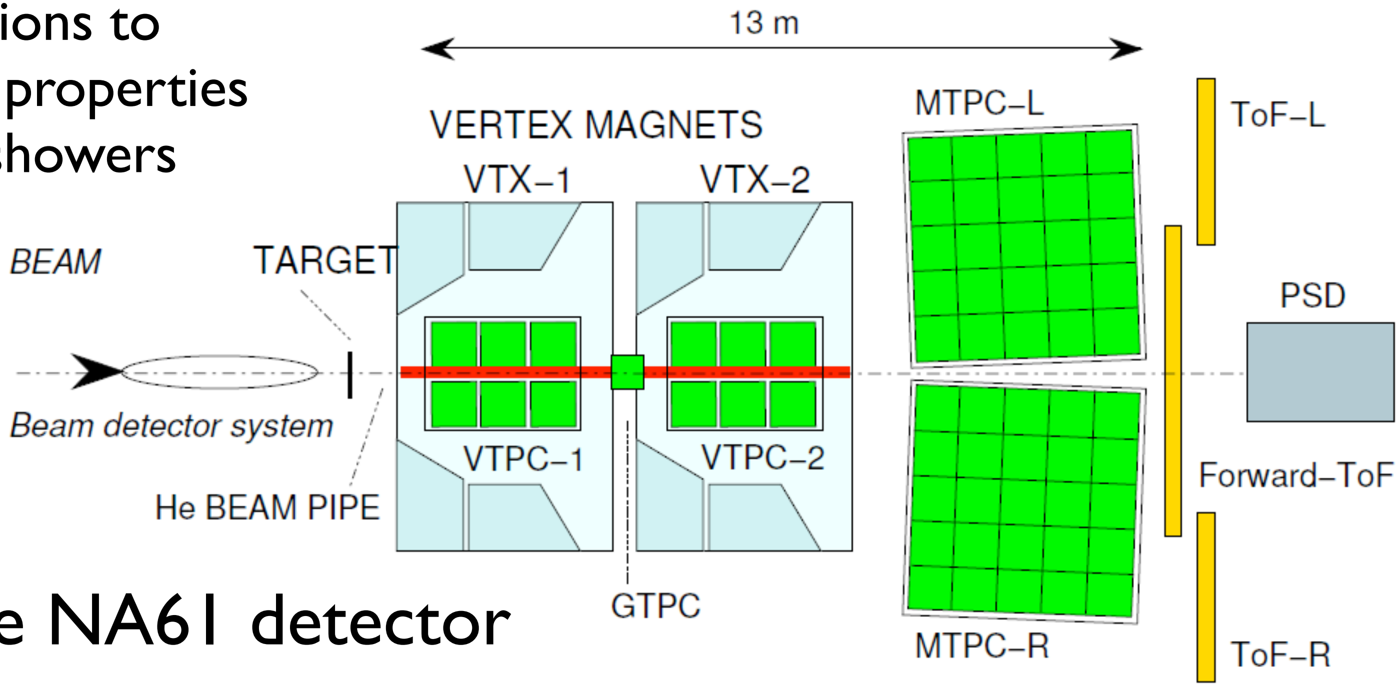
NA61 measures the production of hadrons in different types of collisions:

- Nucleus-nucleus (heavy-ion) collisions to investigate properties of the transition line between quark-gluon plasma and hadron gas (deconfinement);
- Hadron-nucleus interactions to determine neutrino beam properties and to model cosmic ray showers

NA61/Shine
Data taking since 2007
120 physicists, 31 institutes, 15 countries

An interaction seen by NA61

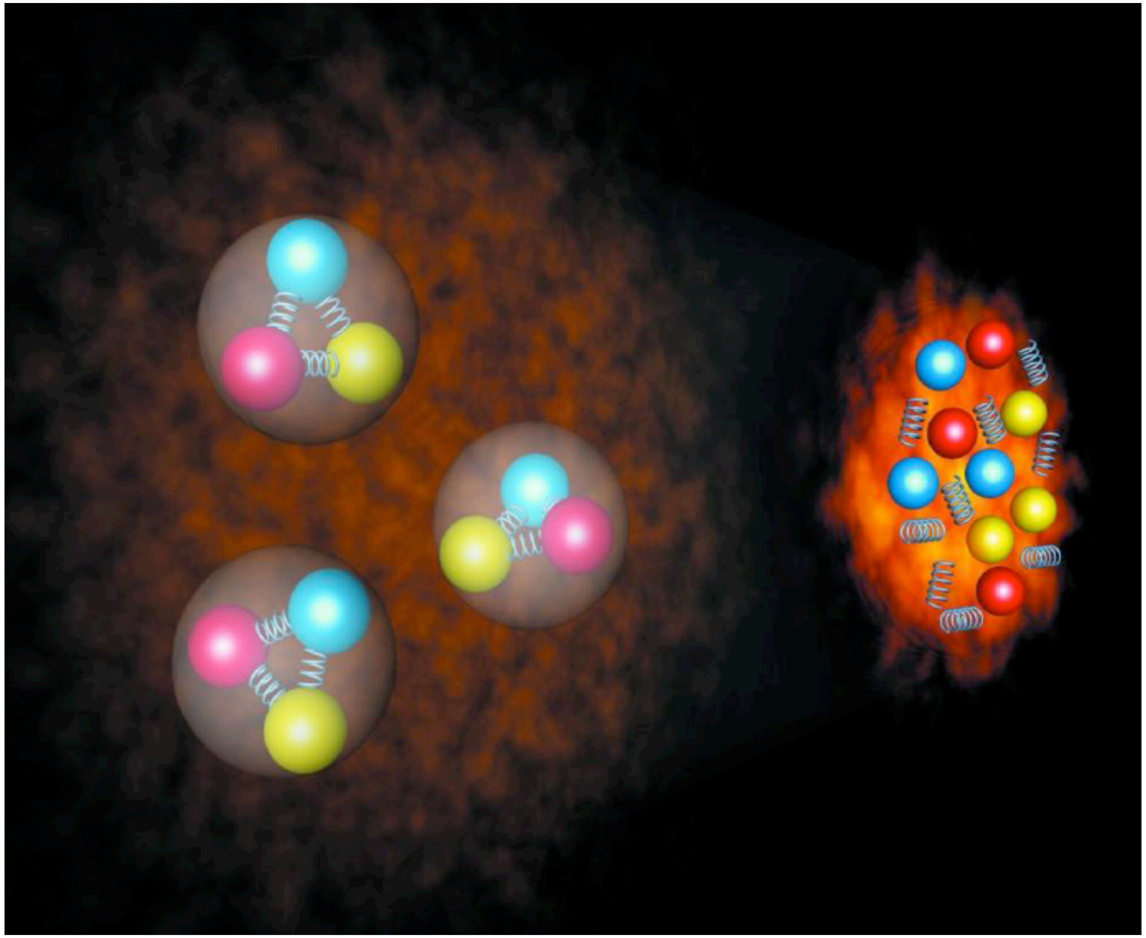




The NA61 detector

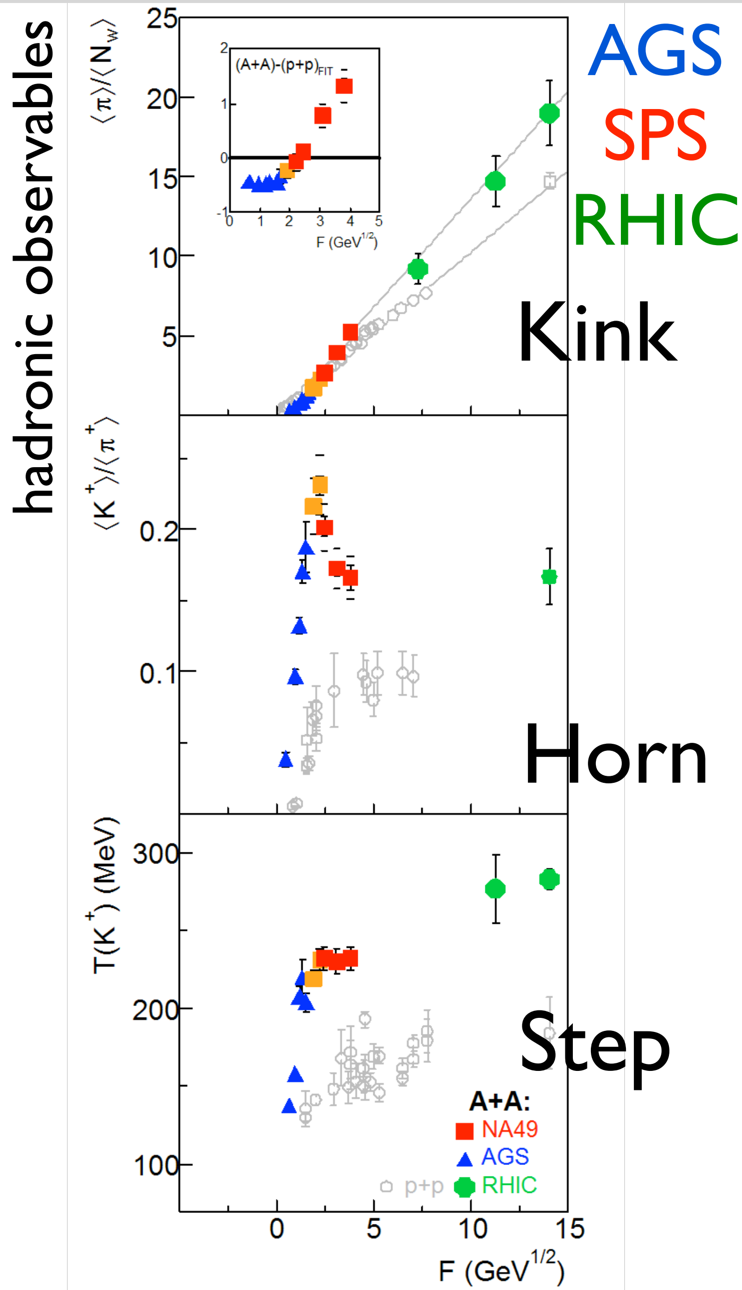
Signals of deconfinement

Hadrons Mixed



AGS SPS RHIC

collision energy

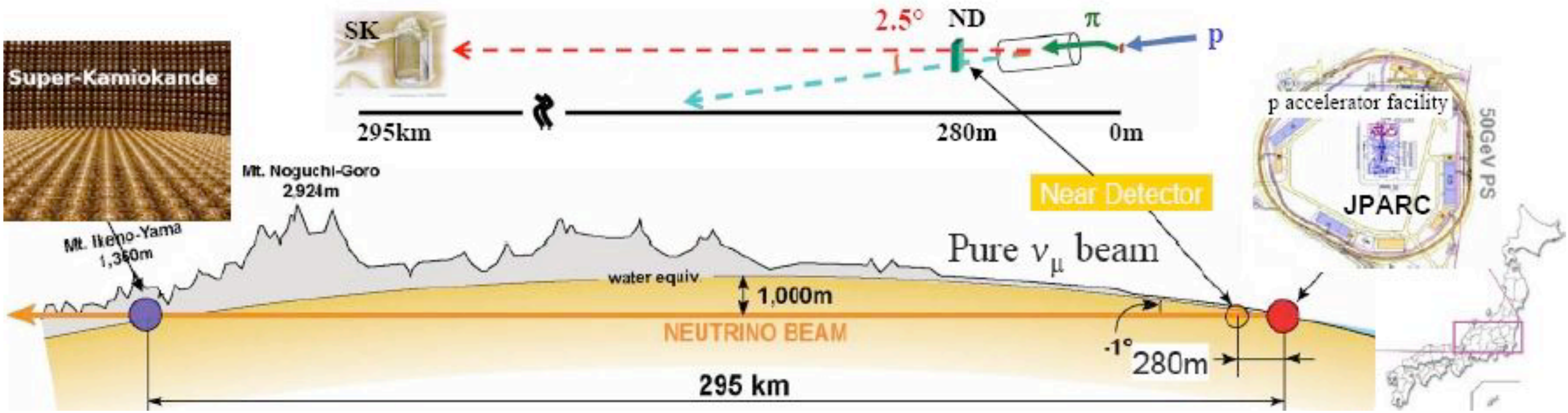


collision energy

Slide based on idea by
Gerd Mallot

Hadron production data for neutrino experiments

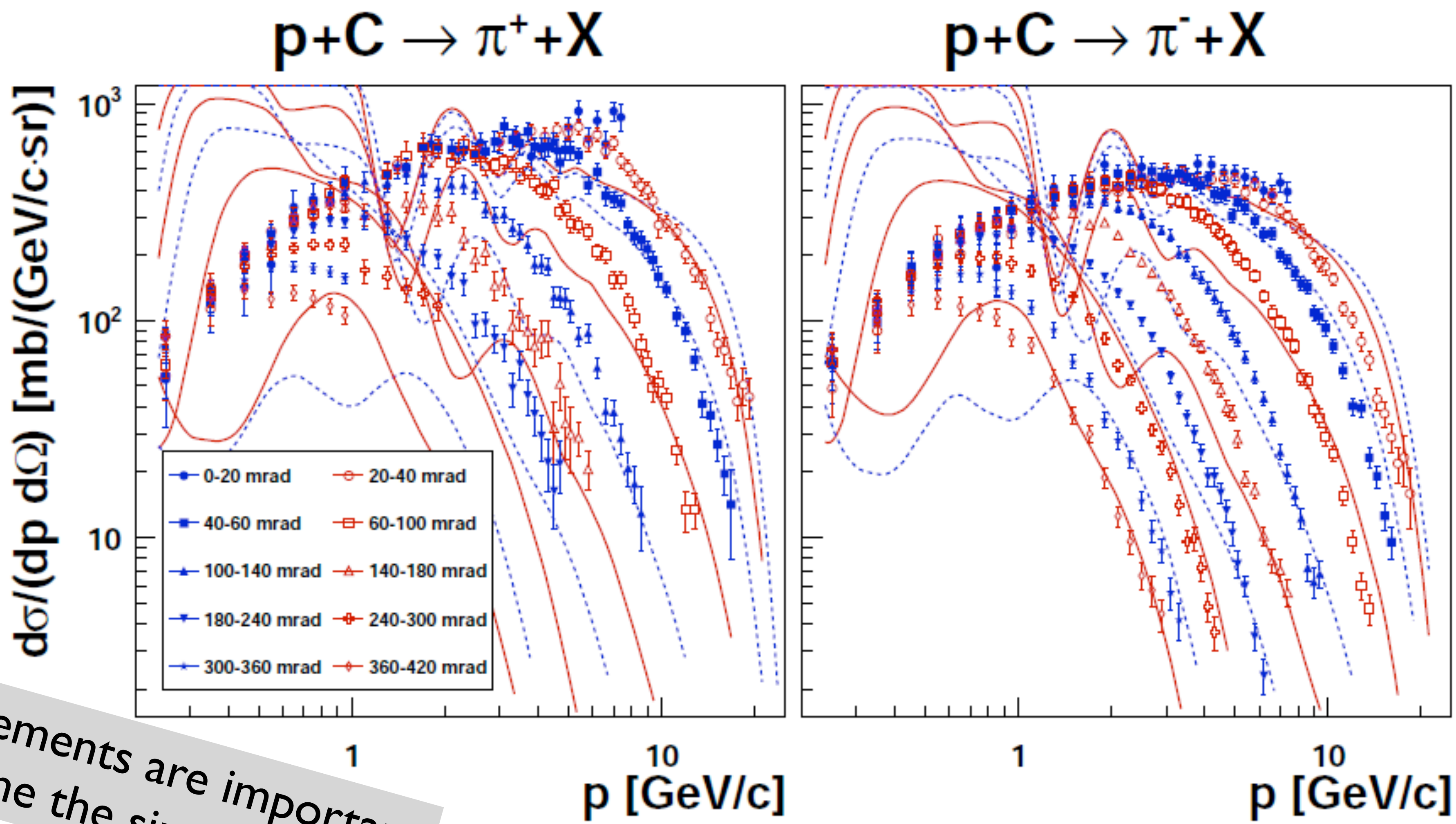
e.g. for T2K:



- Precision data on kaon and pion production on the target is needed to get the initial neutrino flux

Precise data for neutrino experiments

Inclusive π^+ spectra in p+C at 31 GeV/c



Measurements are important to tune the simulation!

comparison to Gheisha2002

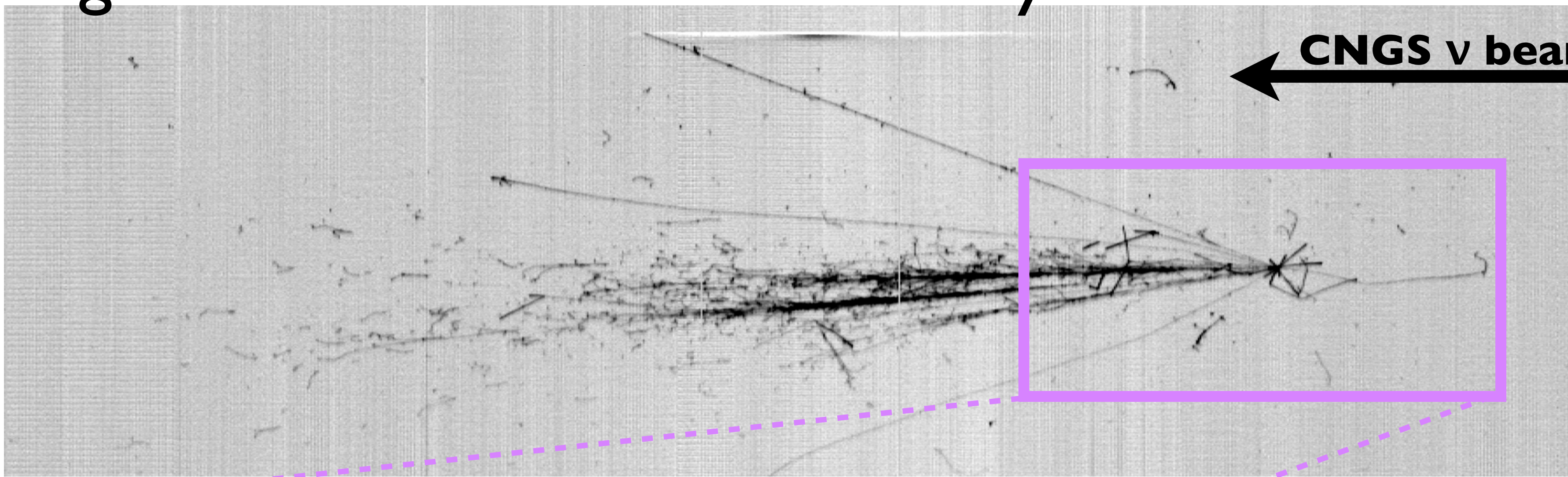
Open questions in neutrino physics

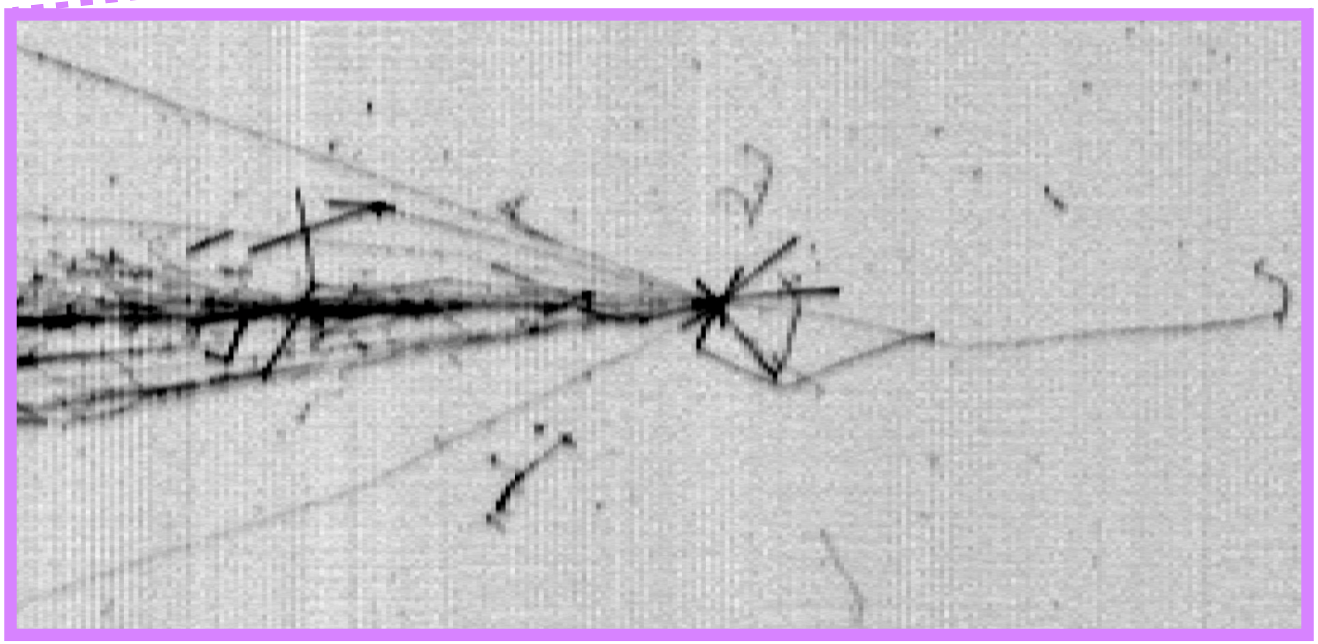
- **Mass hierarchy of neutrinos**
  - ➡ Hierarchy can be seen investigating interference effects when neutrinos cross matter.
    - For beam neutrinos effect increases linear with length of baseline ➙ to solve the riddle: **long baseline experiments**.
    - For atmospheric neutrinos effect is happening when crossing core of the earth. Experiments need excellent energy and angular resolution!
    - number of proposals, only 2 (GLACIER, LENA) can see mass hierarchy in entire phase space with at least 3σ.

- **Sterile neutrinos?**
  - ➡ there are anomalies (experiments with ν beams, ν from reactor) with ~3σ significance (theorists expect similar anomalies for solar neutrinos, but not observed).
  - ➡ need number of experiments with different neutrino sources
  - ➡ high energy beam neutrinos probably cleanest way to solve anomalies because of least systematic effects ➙ **short baseline experiments**.

Huge LAr TPCs: the detectors for neutrinos

E.g. neutrino interactions seen by ICARUS





CERN Neutrino Platform

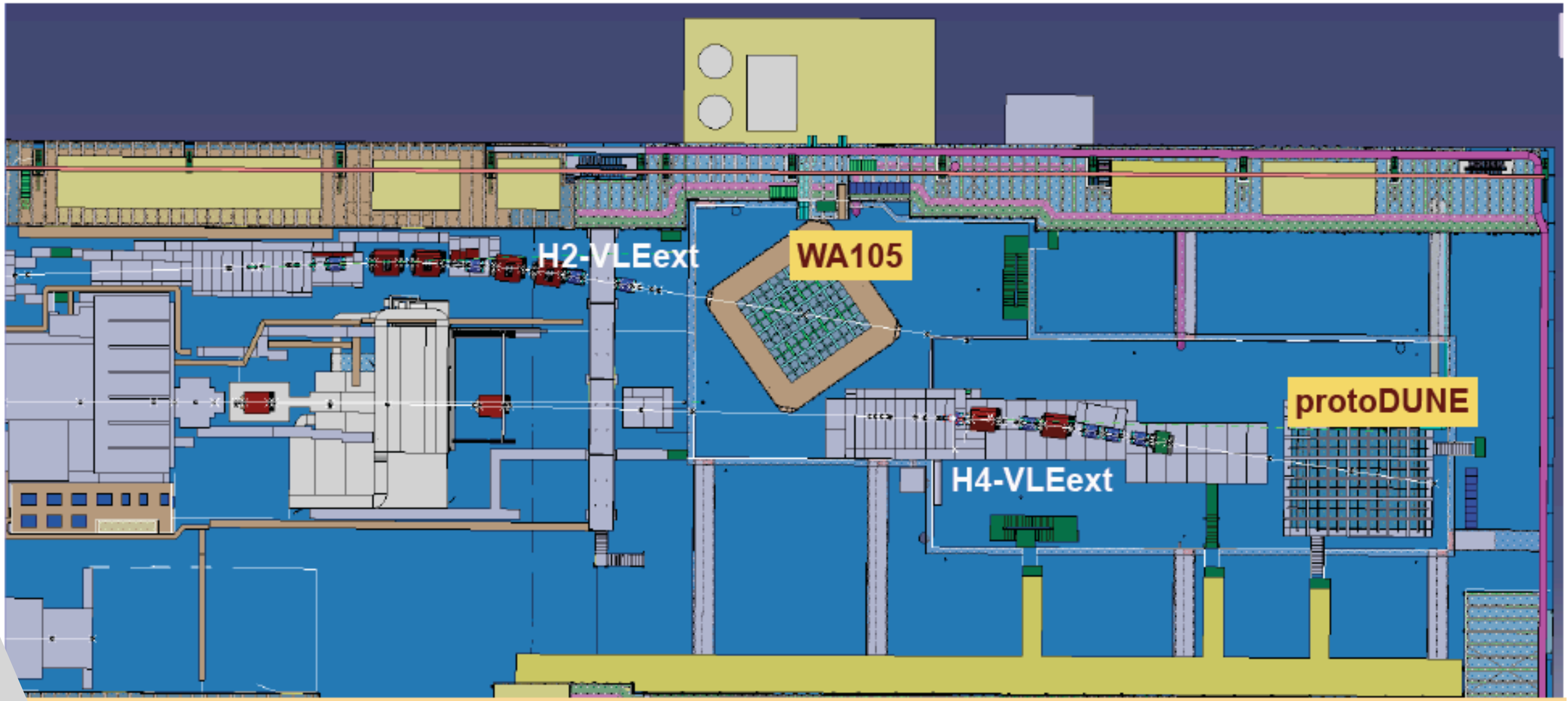
Framework for EU groups to a possible future neutrino LBL programme in the US

- Possibility to carry out neutrino detector R&D (2014 - 2018) with charged particle beams;
- Requires EHN1 (North Area extension).

➡WA105: R&D on 2-phases LAr TPC prototpes (1x1x3 proto, 6x6x6 demonstrator)

➡MIND: R&D on muon tracking detectors (Baby MIND)

➡DUNE-PT: R&D on single-phase LAr

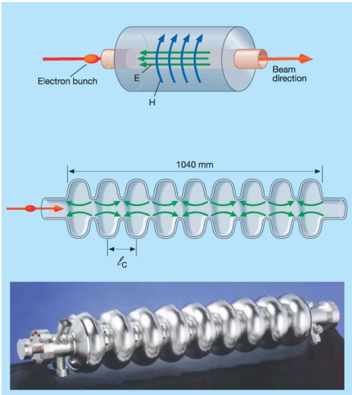


- H2 extension to **WA105** cryostat: 1(0.5) ÷ 12 GeV tertiary beam
- H4 extension to **DUNE** cryostat: 1(0.2) ÷ 7(10) GeV tertiary beram
- Beam characteristics:
  - Use secondary beam of 80 Gev (π/p, or e) to produce the tertiary low-energy beams on a secondary target
  - VLE beams : mixed **hadrons** ($\pi^{\pm}$, $\mu^{\pm}$, $K^{\pm}$, p), ~pure **electron** ($e^{\pm}$) beams

~60m per beam line
[30m high-energy + 30m VLE]

Beam expected second half 2017

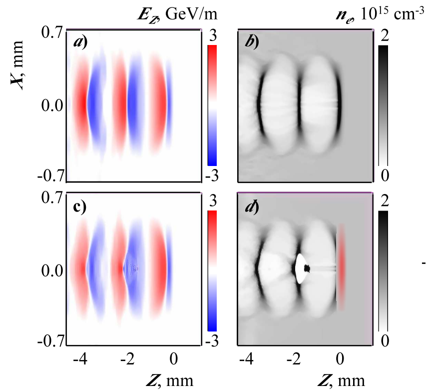
The AWAKE experiment at CERN



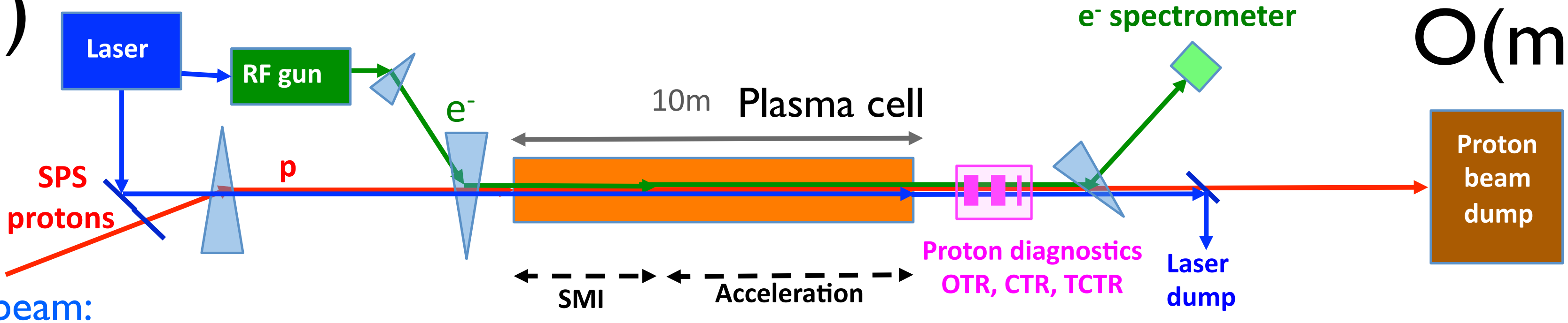
Accelerating field of today's RF cavities or microwaves technology is limited to **<100MV/m**: high energy (linear) accelerators need to be long!

O(m)

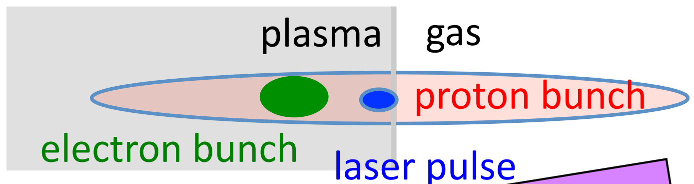
Plasma can sustain up to three orders of magnitude much higher gradient. e.g. at SLAC (2007): electron energy doubled from 42GeV to 85 GeV over 0.8 m ➙ **52GV/m gradient**



O(mm)



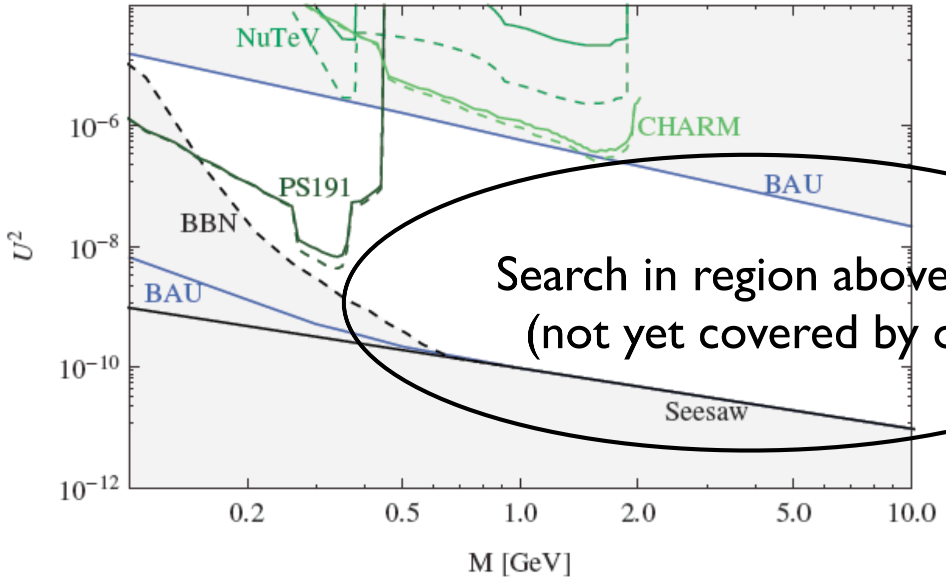
- Laser beam:
  - ➡ ionizes the plasma + seeds the self-modulation instability of the proton beam;
  - ➡ 4.5TW laser, 100fs
- Proton beam:
  - ➡ drives the plasma wakefield + undergoes self-modulation instability.
  - ➡ LHC-type proton beam, 400 GeV/c, 3E11 protons/bunch, 400ps long
- Electron beam:
  - ➡ witness beam to 'surf' on the wakefield and get accelerated
  - ➡ 16 MeV/c, 1.2E9 electrons/bunch, 4ps long



R&D for future accelerators

One of the ideas for future experiments

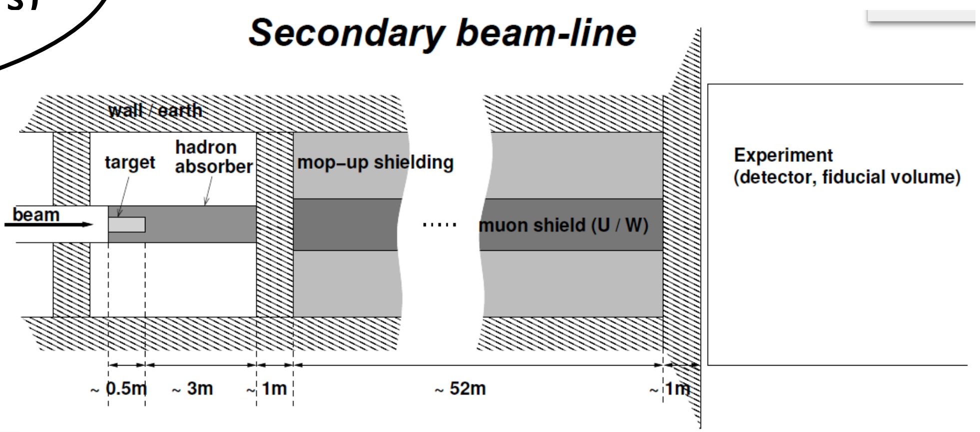
- Expression of interest to search for heavy neutral leptons (νMSM: T.Asaka, M.Shaposhnikov PL B620 (2005) 17)

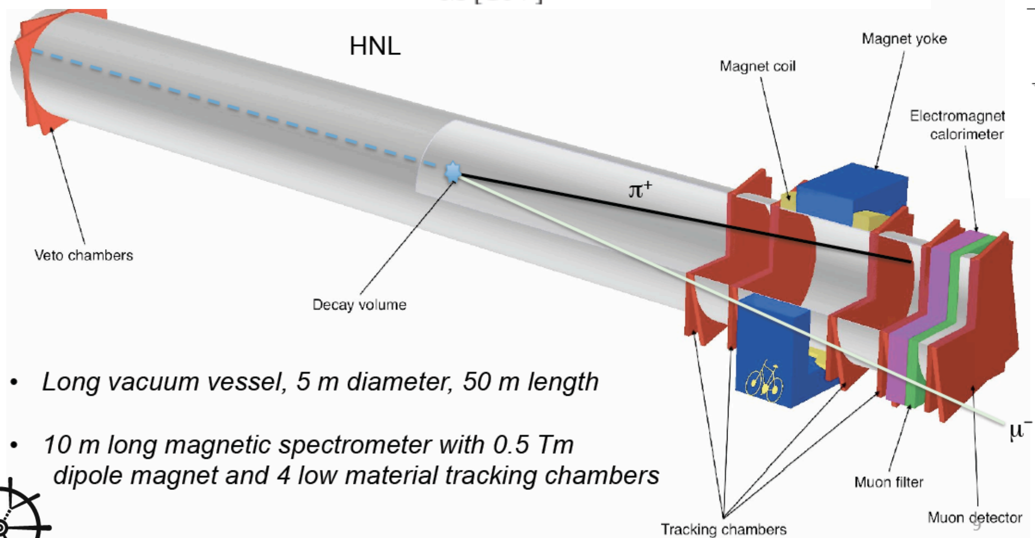


Search in region above K mass
(not yet covered by others)

If LHC finds nothing in the next years...
...maybe SHIP will do?

Experimentally challenging!



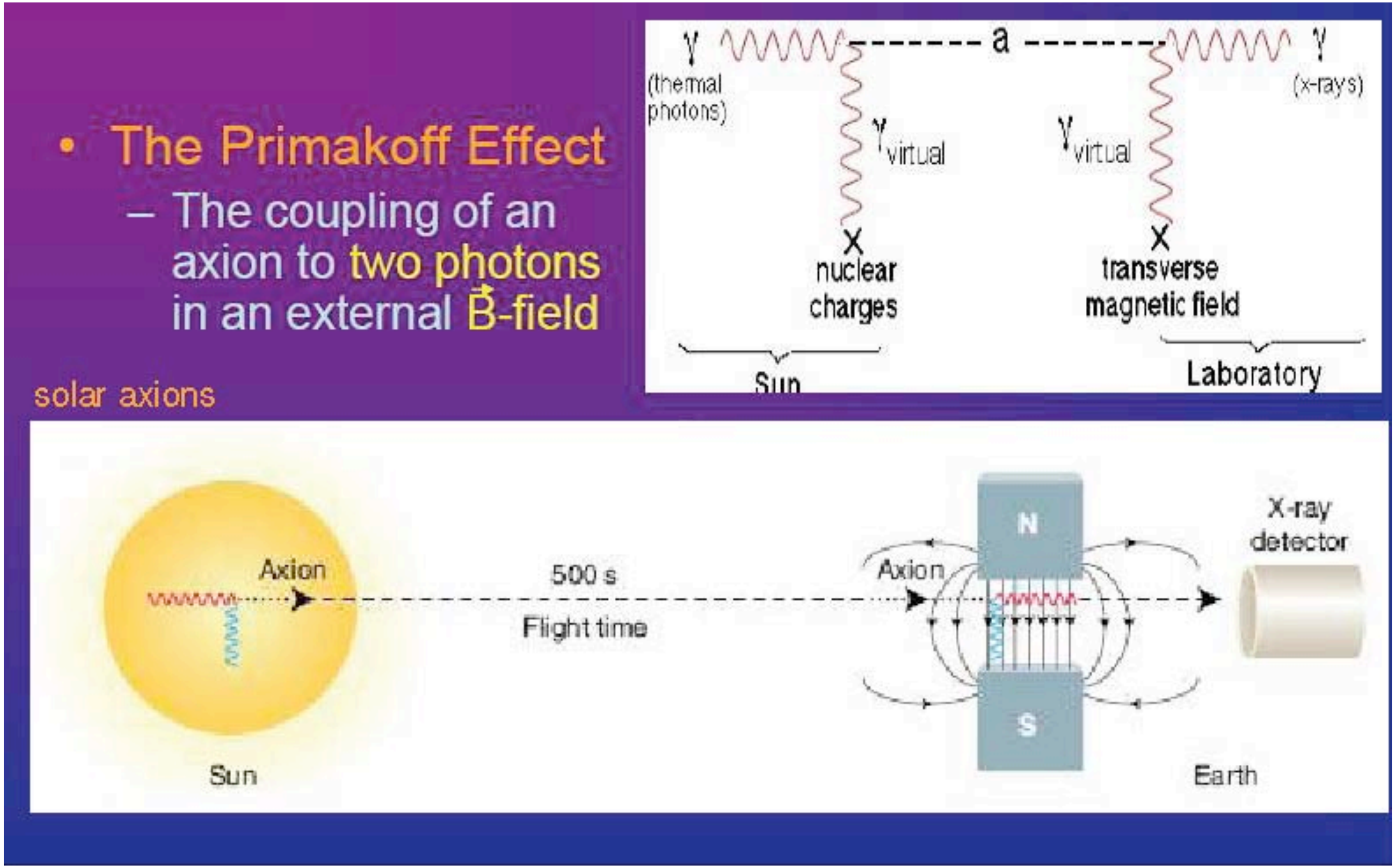


Technical Design to CERN SPSC (April 2014),
SHIP (Search for HIden Particles)
see http://ship.web.cern.ch/ship/
(experiment contact **Andrey Golutvin)**

Non-accelerator experiments*

*which nevertheless use accelerator technologies

- The Axion Solar Telescope (CAST) and the OSQAR experiment are searching for new physics, e.g. axions (dark matter?)

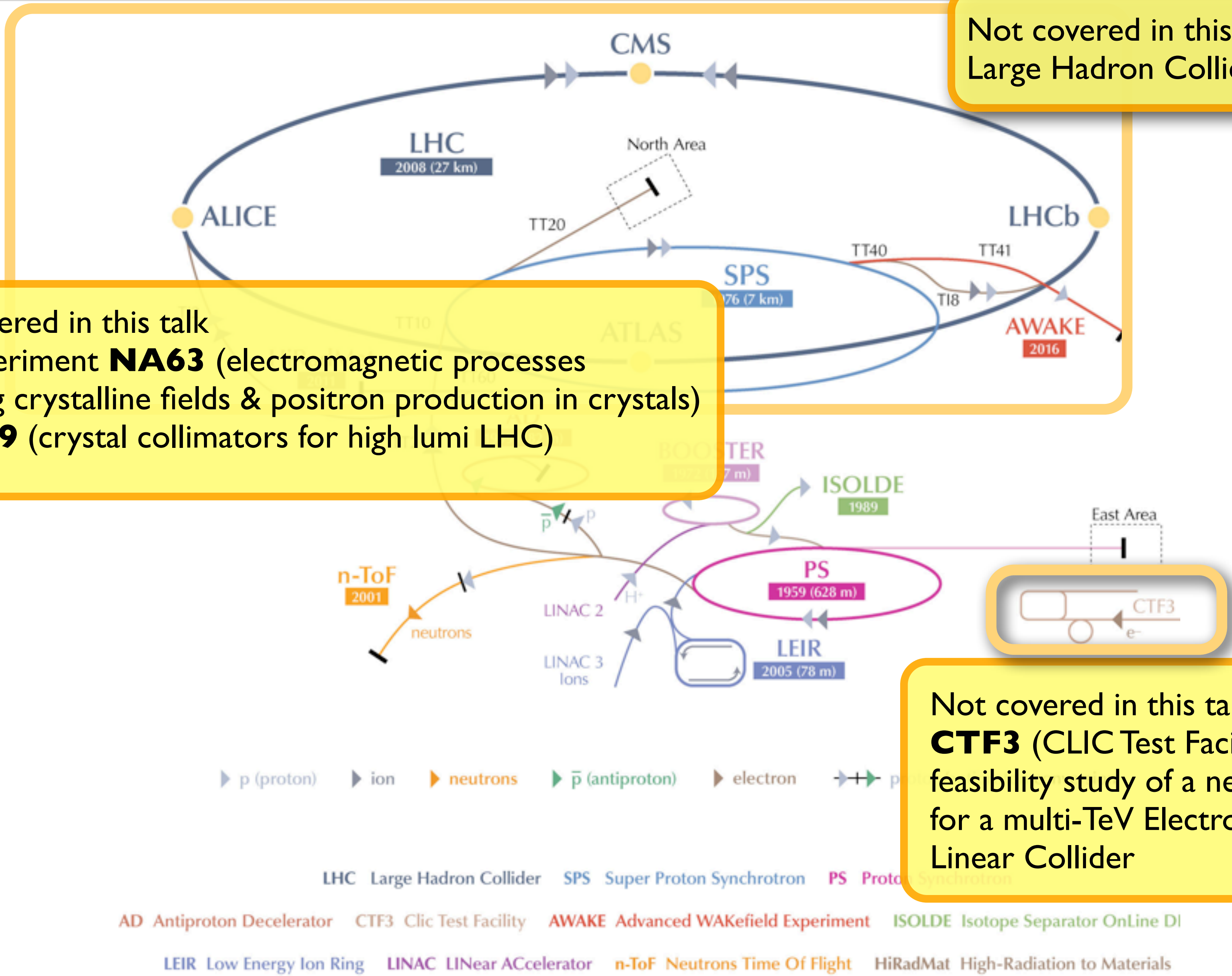


CAST

recycling:
magnet = prototype for LHC
cryogenics = LEP + DELPHI @ -140m
CAST too large: installed on surface
cold box (4.5 K) brought up from u/g
⇒ cosmogenics
the CAST magnet
CAST
pressure <10^-6 mbar, 1.8 K, 13 330 A
sept 2002: 1st commissioning + cooldown
test quench recovery, training quench
nov 2002: 1st DAQ with TPC
CAST: 95 T m
~ 100 x better than
Tokyo (9.2 T m)

The CERN accelerators

Not covered in this talk:
Large Hadron Collider **LHC**



Not covered in this talk
SPS experiment **NA63** (electromagnetic processes in strong crystalline fields & positron production in crystals) and **UA9** (crystal collimators for high lumi LHC)

Not covered in this talk
CTF3 (CLIC Test Facility): feasibility study of a new scheme for a multi-TeV Electron-Positron Linear Collider

Summary

- **There is a rich physics programme** at the CERN **PS** and **SPS** accelerators:
  - ➡ using unique experimental facilities
- Non-collider experiments vital part of physics landscape: exploration and understanding of
  - ➡ of novel phenomena
  - ➡ using high statistics
  - ➡ investigating rare processes
  - ➡ and investigating structure and property of matter (antimatter)

➡ The experiments at the CERN injector accelerators are and will remain an important part of the international particle physics landscape.